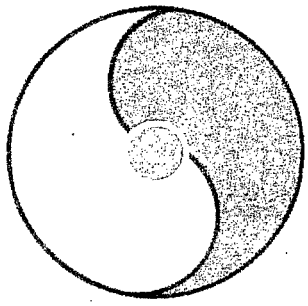
BNL-71899-2003
FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 56

# RBRC Scientific Review Committee Meeting

November 20-21, 2003



Organizers:

N. P. Samios and T. D. Lee

RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

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## Preface to the Series

The RIKEN BNL Research Center (RBRC) was established in April 1997 at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkyusho" (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD, and RHIC physics through the nurturing of a new generation of young physicists.

During the first year, the Center had only a Theory Group. In the second year, an Experimental Group was also established at the Center. At present, there are three Fellows and seven Research Associates in these two groups. During the third year, we started a new Tenure Track Strong Interaction Theory RHIC Physics Fellow Program, with six positions in the first academic year, 1999-2000. This program had increased to include ten theorists and one experimentalist in academic year, 2001-2002. With five fellows having already graduated, the program presently has ten theorists and two experimentalists. Five of the ten RHIC Physics Fellows have been awarded/offered tenured positions, and this will be their final year in the program.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC, presently comprising six RSP Researchers, and six RSP Research Associates. In addition, RBRC has four RIKEN Jr. Research Associates and one RBRC Young Researcher. A number of Visiting Scientists also contribute to the physics program at the Center.

RBRC also has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form proceedings, which can therefore be available within a short time. To date there are fifty-five proceeding volumes available.

The construction of a 0.6 teraflops parallel processor, dedicated to lattice QCD, begun at the Center on February 19, 1998, was completed on August 28, 1998. A 10 teraflops QCDOC computer in under development and expected to be completed in JFY 2004.

N. P. Samios, Director
November 2003

*Work performed under the auspices of U.S.D.O.E. Contract No. DE-AC02-98CH10886.

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Contact Information

# RBRC Scientific Review Committee Meeting

## November 20-21, 2003
## Brookhaven National Laboratory, Upton, NY 11973

The sixth evaluation of the RIKEN BNL Research Center (RBRC) took place on November 20-21, 2003, at Brookhaven National Laboratory. The present members of the Scientific Review Committee are Dr. Jean-Paul Blaizot, Professor Makoto Kobayashi, Dr. Akira Masaike, Professor Charles Young Prescott (absent), Professor Stephen Sharpe, and Professor Jack Sandweiss, Committee Chair. In order to illustrate the breadth and scope of the program, each member of the Center made a presentation on his research efforts. In addition, a special presentation was given jointly by our collaborators, Professors Norman Christ and Robert Mawhinney of Columbia University, on the progress and status of the RBRC QCDSP/QCDOC Supercomputer program. A demonstration of a 64-node (64 Gflops peak speed) QCDOC machine in action followed. Although the main purpose of this review is a report to RIKEN Management (Dr. Ryoji Noyori, RIKEN President) on the health, scientific value, management and future prospects of the Center, the RBRC management felt that a compendium of the scientific presentations are of sufficient quality and interest that they warrant a wider distribution. Therefore we have made this compilation and present it to the community for its information and enlightenment.

Thanks to Brookhaven National Laboratory and to the U. S. Department of Energy for providing the facilities to hold this meeting.

N. P. Samios & T. D. Lee

# RIKEN BNL Research Center

Building 510A, Brookhaven National Laboratory, Upton, NY 11973 USA

**11/12/03**

**RBRC Scientific Review Committee (SRC) Meeting**
**Brookhaven National Laboratory, Upton, NY**
**Physics Department, Building 510, Open Sessions – Large Seminar Room**
**November 20-21, 2003**
**Draft Agenda**

Committee Members: Jean-Paul Blaizot, Makoto Kobayashi, Akira Masaike, Charles Prescott (Absent), Stephen Sharpe, and Jack Sandweiss, Chair

**Thursday, November 20, 2003**

**8:00 AM to 9:00 AM** *Open Executive Session & Working Breakfast - (Room 2-160)*
*(Presentations by RBRC Administration)*

**Large Seminar Room**

**9:00 AM to 10:15 AM EXPERIMENTAL PRESENTATIONS –GERRY BUNCE, CHAIR**

| | | |
|---|---|---|
| 9:00 | CCJ—The Computer Center in Japan | Yasushi Watanabe |
| 9:15 | Polarimetry (AGS, RHIC, Jet) | Osamu Jinnouchi |
| 9:30 | Forward Neutron Asymmetry and Longitudinal Polarization at PHENIX | Abhay Deshpande |
| 9:45 | Central Arm Triggering for 2003 for PHENIX | Kensuke Okada |
| 10:00 | Relative Luminosity for $A_{LL}$ Measurements | Kiyoshi Tanida |
| 10:15 AM | Break | |

**10:45 AM to 12:15 PM EXPERIMENTAL PRESENTATIONS—HIDETO EN'YO, CHAIR**

| | | |
|---|---|---|
| 10:45 | $A_{LL}$ For $\pi^0$ | Alexander Bazilevsky |
| 11:00 | Belle Fragmentation Functions | Matthias Grosse Perdekamp |
| 11:15 | J/Psi for pp and d-gold Collisions | Douglas Fields |
| 11:30 | $\pi^0$ Azimuthal Anisotropy in $\sqrt{s_{NN}}$ = 200 GeV Au + Au Collisions | Masashi Kaneta |
| 11:45 | Electrons and Direct Photons | Yasuyuki Akiba |
| 12:00 | Vertex Detector for PHENIX | Yuji Goto |

12:15 to 1:30 PM *SRC Executive Session (Committee Members) - Working Lunch (Room 2-160)*

**Friday, November 21, 2003**

| | |
|---|---|
| 8:00 AM to 8:30 AM | *SRC Executive Session (Committee Members) and Continental Breakfast (Room 2-160)* |

**Large Seminar Room**

| | |
|---|---|
| 8:30 AM to 9:30 AM | QCDSP/QCDOC: Physics Results and Prospects/Project Status<br>Norman H. Christ and Robert Mawhinney |
| 9:30 AM to 10:00 AM | Demonstration of QCDOC |
| 10:00 AM to 12:30 PM | Meetings with Individual RBRC Staff<br>Theorists (Room 2-160)<br>Experimentalists (Room 2-78)<br><br>(Possible Tours) |
| 12:30 PM to 1:30 PM | *SRC Executive Session (Committee Members) and Working Lunch – (Room 2-160)* |
| 1:30 PM to 3:00 PM | Meetings with Individual RBRC Staff (Continued)<br>Theorists (Room 2-160)<br>Experimentalists (Room 2-78) |
| 3:00 PM to 4:00 PM | *SRC Executive Session (Committee Members) - (Room 2-160)* |
| 4:00 PM to 5:00 PM | Meeting with RBRC Administration - (Room 2-160) |
| 5:00 PM | Adjourn |

## RBRC Scientific Review Committee Membership 2003

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# RBRC ADMINISTRATION PRESENTATIONS

# RIKEN BNL Research Center (RBRC)

Nicholas P. Samios

RBRC

1997 – 2003 In existence for 6 years
Director: T. D. Lee
Three Components: Theory, Experiment, Computing

High Energy Density Nuclear Matter (RHIC)
Spin Component of Proton
Lattice QCD

RHIC Great Year (if not spectacular)
Previous Au x Au, p x p running
d x Au Run. Technical feat – asymmetric operation
Exciting results:

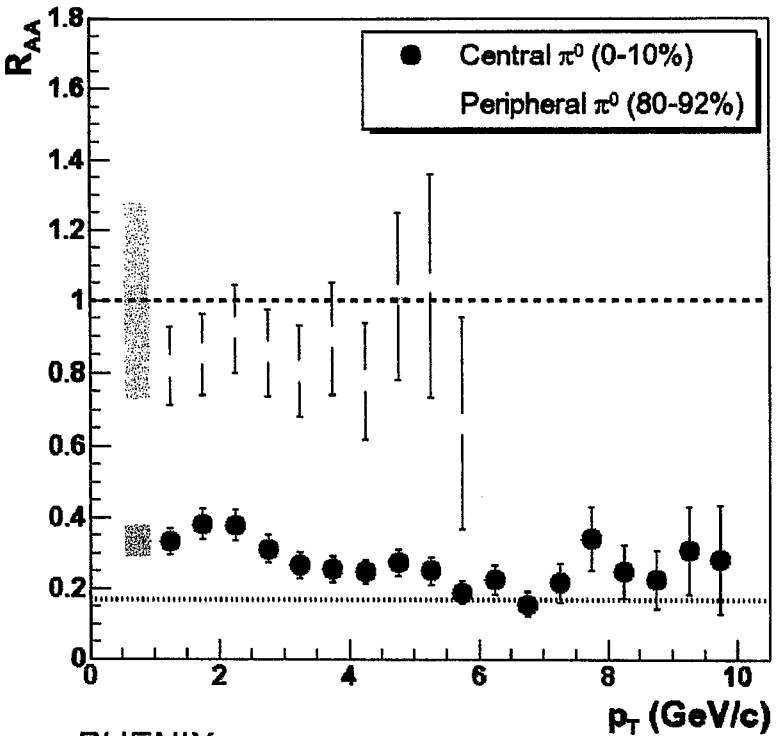
| | |
|---|---|
| Multiplicities | New Phenomena |
| Radial & Elliptic Flow | |
| HBT size measurements | Hot, dense nuclear matter |
| $R_{AA}$ = Factor of 5 decrease | |
| Jets | Color glass condensate |
| High y, small x effects | |

Next run: Au x Au

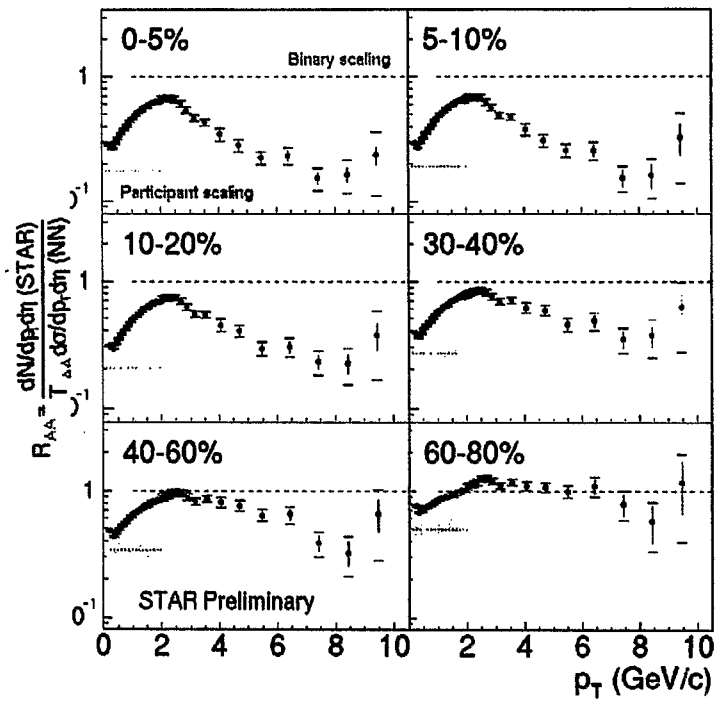
# Suppression of leading hadrons in RHIC data

$\sqrt{S_{nn}}$=200: Au+Au

$$R_{AA}(p_T) = \frac{d^2N^{AA} / dp_T d\eta}{T_{AA} d^2\sigma^{NN} / dp_T d\eta}$$

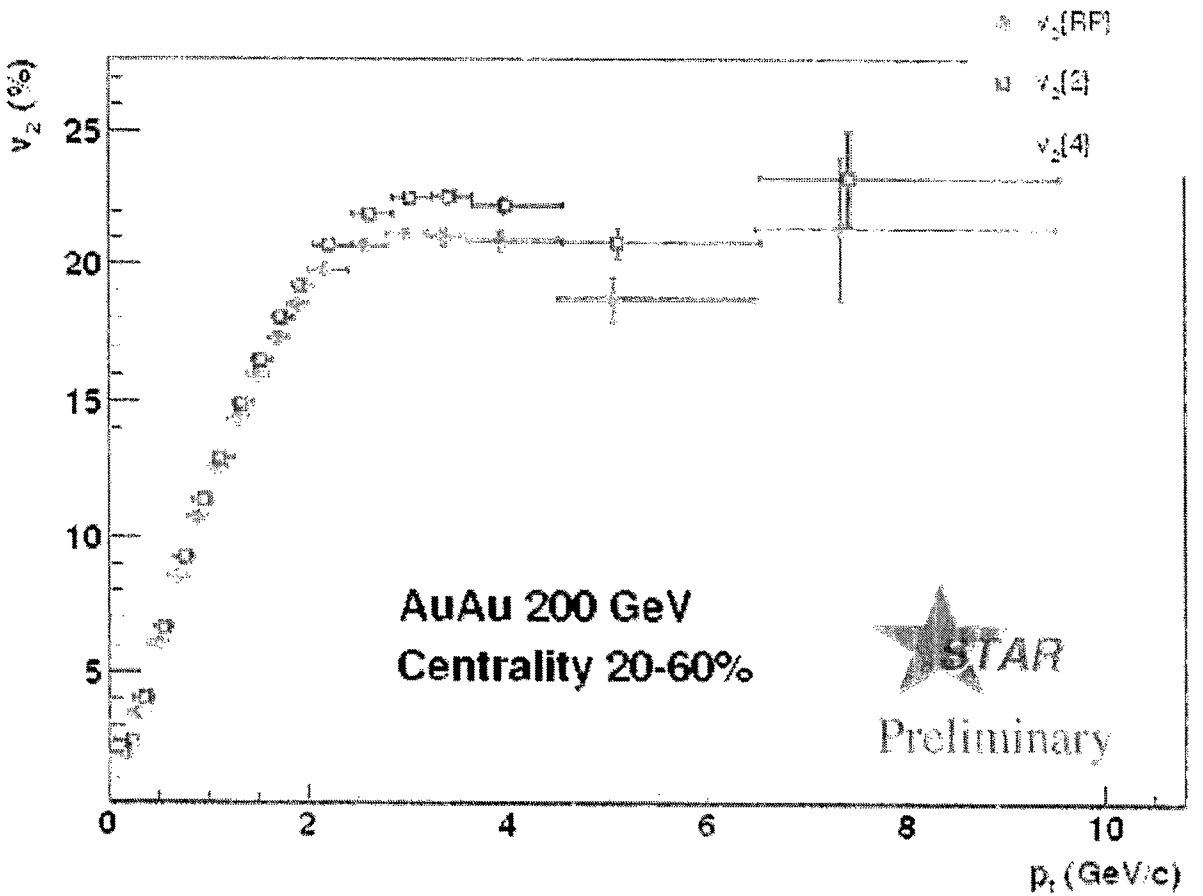



PHENIX:
Inclusive $\pi^0$ in central & peripheral collisions




STAR Charged hadrons:
Dependence on centrality

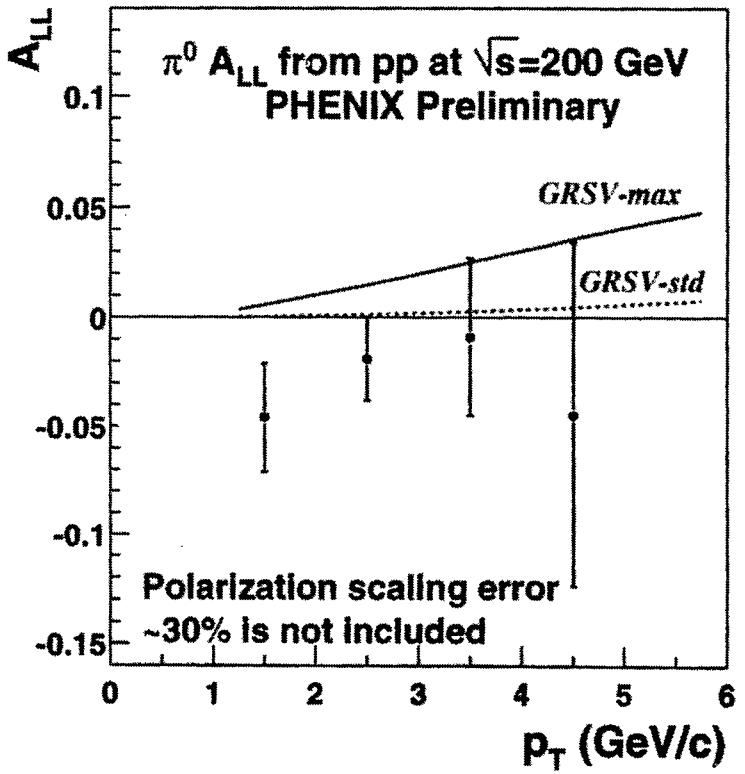
# Anisotropy vs. $p_T$ at 200 GeV




Significant anisotropy in Au+Au up to 7 GeV/c

# $A_{LL}$: PHENIX vs theory

B.Jäger e al., PRD67, 054005 (2003)




PHENIX

RBRC

Director Emeritus: T. D. Lee
Director: N. P. Samios
Associate Director: H. En'yo

Theory Group Leader (Designee): L. McLerran
Deputy Group Leader: A. Baltz

Experimental Group Leader: H. En'yo
Deputy Group Leader: G. Bunce

Theory Advisory Committee:

T. D. Lee
L. McLerran
A. Baltz
M. Creutz
M. Gyulassy
R. Pisarski (T. L. Trueman)

Experimental Advisory Committee:

A. Masaike
J. Sandweiss
S. Nagamiya

Workshops: 8
Publications: 95 Theory/33 Experiment
Seminars: 6/week
Other Articles: 2/8

| | |
|---|---|
| Volume 53 | Theory Studies for Polarized pp Scattering (BNL- )*<br>August – September 2003<br>Organizers: S. Kretzer and W. Vogelsang |
| Volume 54 | RHIC Spin Collaboration Meetings XVII, XVIII, XIX (BNL- )<br>June 20, 2003, June 30, 2003, and August 18, 2003<br>Organizer: Brendan Fox |
| Volume 55 | Collective Flow and QGP Properties (In preparation)<br>November 17-19, 2003<br>Organizers: Nu Xu, E. Shuryak, P. Kolb, U. Heinz, S. Esumi, and S. Bass |

*In press

# THEORY PUBLICATION LIST

## November 2002 to November 2003

RBRC-294 Konstantinos Orginos, (For the RBC Collaboration: Y. Aoki, T. Blum, N. Christ, M. Creutz, C. Dawson, T. Izubuchi, L. Levkova, X. Liao, G. Liu, R. Mawhinney, Y. Nemoto, J. Noaki, S. Ohta, K. Orginos, S. Prelovsek, S. Sasaki, and A. Soni, "Spin on the Lattice," to appear in the *Proc. of the International Spin Physics Symposium, SPIN 2002*, Upton, NY, USA, September 9-14, 2002.

. . . . . .

RBRC-388 M. Hasenbusch, K. Jansen, D. Pleiter, H. Stüben, P. Wegner, T. Wettig, and H. Wittig, "Benchmarking Computer Platforms for Lattice QCD Applications," [hep-lat/0309149], to appear in Nucl. Phys. B (Proc. Suppl.)

PROSPECTS OF THE GLUON POLARIZATION MEASUREMENT AT PHENIX, Y. Goto for the PHENIX Collaboration, SPIN 2002, AIP Conf. Proc. 675 (2003) 493-503.

FIRST POLARIZED PROTON COLLISIONS AT PHENIX, Y. Goto for the PHENIX Collaboration, DIS 2002, Acta Phys. Polon. B33 (2002) 3767-3771.

THE QUEST FOR NUCLEON SPIN, VERNON W. HUGHES; THE LAST DECADE: 1993-2003, A. Deshpande, Proceedings of "Symmetries and Spin 2003", Prague, to be published by World Scientific.

eRHIC: THE ELECTRON ION COLLIDER AT BNL, A. Deshpande, European Journal of Physics A, to be published in the Proceedings of International Meeting on Perspectives on Hadronic Physics, ICTP, Trieste, Italy, May 2003.

SPIN PHYSICS AT RHIC: PRESENT & FUTURE, A. Deshpande, to be published in PRAMANA Journal of Physics, Indian Academy of Sciences, Proceedings of QCD2002 Conference, IIT Kanpur, October 2002.

COMMISSIONING OF RHIC POLARIMETERS, A. Bravar, et al., BNL-Report-68976

TESTING OF QCD THROUGH SPIN OBSERVABLES IN NUCLEAR TARGETS, Workshop Summary of Experimental Talks, A. Deshpande, University of Virginia, April 20, 2003, World Scientific, Editors: D. Crabb, D. Day, J. Chen

MULTISTRANGE BARYON PRODUCTION IN AU-AU COLLISIONS AT S(NN)**1/2=130 GEV, Submitted to Phys. Rev. Lett, e-Print Archive: nucl-ex/0307024.

PHENIX DETECTOR OVERVIEW, PHENIX Collaboration (K. Adcox et al.), Nucl. Instrum. Meth. A499 (2003) 469-479.

PHENIX Magnet System, PHENIX Collaboration (S. H. Aronson et al.), Nucl. Instrum. Meth. A499 (2003) 480-488.

PHENIX Central Arm Particle ID Detectors, PHENIX Collaboration (M. Aizawa et al.), Nucl. Instrum. Meth. A499 (2003) 508-520.

PHENIX CALORIMETER, PHENIX Collaboration (L. Aphecetche et al.), Nucl. Instrum. Meth. A499 (2003) 521-536.

PHENIX Muon Arms, PHENIX Collaboration (H. Akikawa et al.), Nucl. Instrum. Meth. A499 (2003) 537-548.

PHENIX Inner Detectors, PHENIX Collaboration (M. Allen et al.), Nucl. Instrum. Meth. A499 (2003) 549-559.

# Weekly Seminars

| | | |
|---|---|---|
| Spin Physics<br>*(Theory & Exp)* | Tuesdays<br>(10:00 a.m.) | Organized by Y. Goto<br>W. Vogelsang<br>A. Deshpande |
| Nuclear Physics | Tuesdays<br>(11:00 a.m.) | Organized jointly by<br>W. Vogelsang<br>P. Petreczky<br>with BNL Staff |
| High Energy-RIKEN Theory | Wednesdays<br>( 1:30 p.m.) | Organized jointly by<br>S. Ohta with<br>BNL Theorists |
| QCD and RHIC Physics<br>*(Theory & Exp)* | Thursdays<br>(12:30 p.m.) | Organized by<br>W. Vogelsang |
| High Energy Theory<br>Lunch Talks | Fridays<br>(12:00 Noon) | Organized by S. Dawson |
| Nuclear Physics-RIKEN Theory | Fridays<br>( 2:00 p.m.) | Organized jointly by<br>S. Kretzer, C. Dawson<br>with BNL Staff |

The Outstanding Junior Investigator Award in Nuclear Theory was established by DOE in 2000. Since Then, five RBRC members have received the OJI Awards:

| | |
|---|---|
| Son, D. T. | (2000) |
| Stephanov, M. | (2001) |
| van Kolck, U. | (2001) |
| Schaefer, T. | (2002) |
| Bass, S. | (2003) |

| RHIC Physics Fellow Present Program | RBRC Dates | Position | New Position | Present Institution |
|---|---|---|---|---|
| van Kolck, Ubirajara | 08/2000 - 08/2003 (Tenure) | RHIC Physics Fellow; U. of Arizona/Asst. Prof. | Tenured Associate Professor | RBRC/U. of Arizona |
| Vogelsang, Werner | 4/1/2000 to 9/30/2003<br>10/1/2003 - | RIKEN BNL Fellow<br>RHIC Physics Fellow<br>BNL/Associate Physicist | | RBRC/BNL |
| Wettig, Tilo | 10/1999 - | RHIC Physics Fellow, Yale/Asst. Prof. | Associate Professor (2003) | RBRC/Yale |
| Experimentalists | | | | |
| Fields, Douglas | 09/2001 | RHIC Physics Fellow, U. of New Mexico/Asst. Professor | | RBRC/U. of New Mexico |
| Grosse Perdekamp, Matthias | 01/1999 to 8/31/02<br>09/01/2002 - | RIKEN BNL Fellow<br>RHIC Physics Fellow, U. of Illinois, Urbana Champaign/Asst. Prof. | | RBRC/U. of Illinois Urbana Champaign |

| Name | Dates at RBRC | RBRC Position | New Position Title | New Position Institution |
|---|---|---|---|---|
| Saito, Naohito | [04/1995 to 03/1996]<br><br>04/1996 to 03/2001<br>04/2001 to 03/2002<br>03/2002 - present | [RIKEN Special Postdoc. Fellow]<br>RIKEN/RBRC Res.<br>RIKEN Spin Prog. Res<br>RSP Visiting Scientist. | Associate Professor | Kyoto U., Japan |
| Sasaki, Shoichi | 09/1998 to 09/2000 | Research Associate | Assistant Professor | U. of Tokyo, Japan |
| Schaffner-Bielich, Jürgen | 09/1998 to 10/2001 | Research Associate | Research Associate | Columbia University<br>University of Frankfurt |
| Son, Dam Thanh | 10/1999 to 03/2002 | RHIC Physics Fellow, Columbia U. | Associate Professor, Tenured | U. of Wash, Seattle, Natl. Inst. for Nucl. Th |
| Venugopalan, Rajagopal | 10/1/2000 to 6/30/2003 | RHIC Physics Fellow, BNL | Physicist with Tenure 6/1/02 | BNL |
| Vogelsang, Werner | 4/1/2000 to 9/30/2003<br>10/01/2003 | RIKEN BNL Fellow | RHIC Physics Fellow/Associate Physicist | RBRC/BNL |
| Wingate, Matthew | 09/1997 to 09/2000 | Research Associate | Assistant Professor | Ohio State U., Columbus |
| Yasui, Yoshiaki | 09/1997 to 09/2000 | Research Associate | Postdoc<br>Postdoctoral Fellow | Radiation Lab, RIKEN, KEK, Theory Group, Japan |

N. P. Samios, RBRC Director
T. D. Lee, RBRC Director Emeritus
Hideto En'yo, RBRC Associate Director
* * * *

RBRC Research Scientists (2002 – 2003)
Experimental Group
Hideto En'yo, Group Leader
Gerry Bunce, Deputy Group Leader

Research Associates
Jinnouchi, O.
Kaneta, M.
Okada, K.
Fellows
Bazilevsky, A. (4/1/03)*
Deshpande, A.
Fox, B. (10/15/03)*
Messer, F. (4/1/03)*

Tenure Track/RHIC Fellow
Fields, D. (UNM)
Grosse-Perdekamp, M. (UIUC)

RIKEN Spin Program (RSP) Researchers
Akiba, Y.
Goto, Y.
Ichihara, T.
Taketani, A.
Tanida, K.
Watanabe, Y.
RIKEN Spin Program (RSP) Research Associates
Kobayashi, H. (9/30/03)*
Yokkaichi, S.
Tabaru, T.
Torii, H.
RIKEN Spin Program/ Visiting Scientists
Kurita, K.
Lange, J. S.
Li, Zheng
Ogawa, A.
Saito, N.

Advisory Committee
Experiment
Masaike, A.
Nagamiya, S.
Sandweiss, J.

Consultants
Jaffe, R.
Roser, T.
Makdisi, Y.
Tannenbaum, M.

RBRC Young Researchers
Siegle, V. (3/31/03)

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Fukao, Y.
Hachiya, T.
Horaguchi, T.
Visiting Res. Assoc.
Kiyomichi, A.
Sato, H.
Tojo, J.
RIKEN Researchers
Okamura, A.
RIKEN Young Res.
Kamihara, N.
Okada, H.
Togawa, M.

Technical Collaborator
Hiejima, H. (UIUC)

# RBRC Theory Group

## Larry McLerran

# Theoretical Physics at RIKEN–BNL Center

## Strong Interactions and QCD

How are strongly interacting particles made from fundamental constituents?

How do the fundamental interactions of QCD produce quark confinement and mass?

What is the behaviour of strongly interacting matter in bulk?
Nuclear Matter $\rightarrow$ Quark Gluon Plasma

What is the physics beyond the standard model?
Tests of CKM matrix.

All issues intertwined!

Require understanding and computation

# Current Interests in RIKEN–BNL Center

## Lattice Gauge Theory

Masses and matrix elements of hadrons
CKM matrix
Properties of QGP and hadronic matter

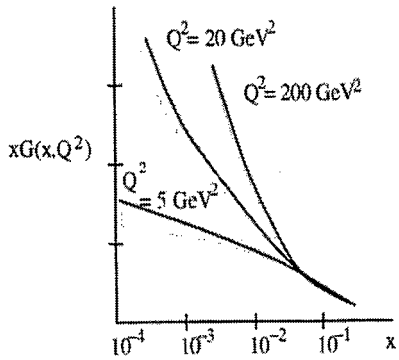
## Color Glass Condensate and Quark Gluon Plasma

RHIC Phenomenology
Everything for $x \leq 10^{-2}$

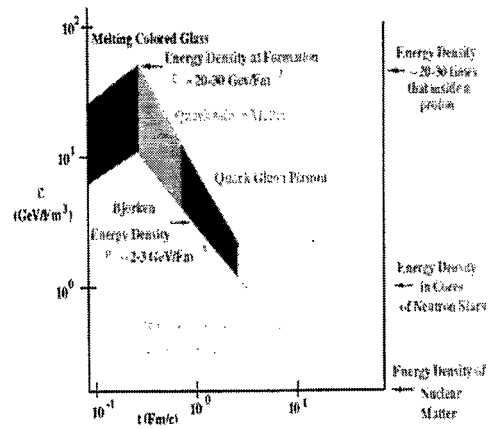
## Structure of Hadrons

Origin of spin
Quark and gluon distribution functions
Perturbative QCD: RHIC and LHC

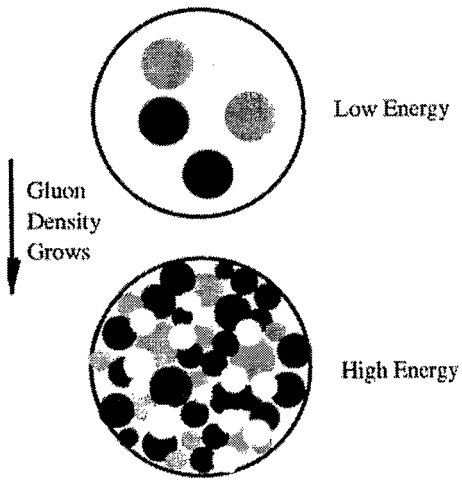
# Matter at High Density



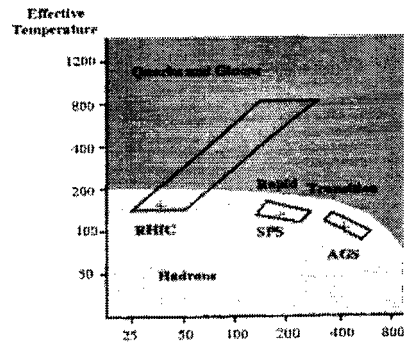

High Energy –> High Gluon Density




Energy densities high
Matter strongly interacts




High Density →
Short Dstances




Probes interesting
phase space

# RIKEN–BNL Physics Fellows

## Graduates

D. Bodeker Tenured C-4 Bielefeld
D. Kharzeev Tenured BNL
D. Rischke Tenured C-4 Frankfurt
D. Son Tenured U of Washington
R. Venugopalan Tenured BNL
T. Wettig Tenured C-3 Regensburg

## Current Fellows

S. Bass Duke
T. Izubuchi Kanazawa
S. Jeon McGill
A. Kusenko UCLA (Tenure in process.)
T. Schaefer N. Carolina (Tenure in process)
M. Stephanov U of Ill. Chicago (Tenure in process)
U. van Kolck U of Arizona (Tenure in process)
T. Blum U of Connecticut
W. Vogelang BNL
P. Petreczky BNL

All at good research universities.

Sense of Community!

All succesful.

# Overview RBRC Experimental Group

Hideto En'yo

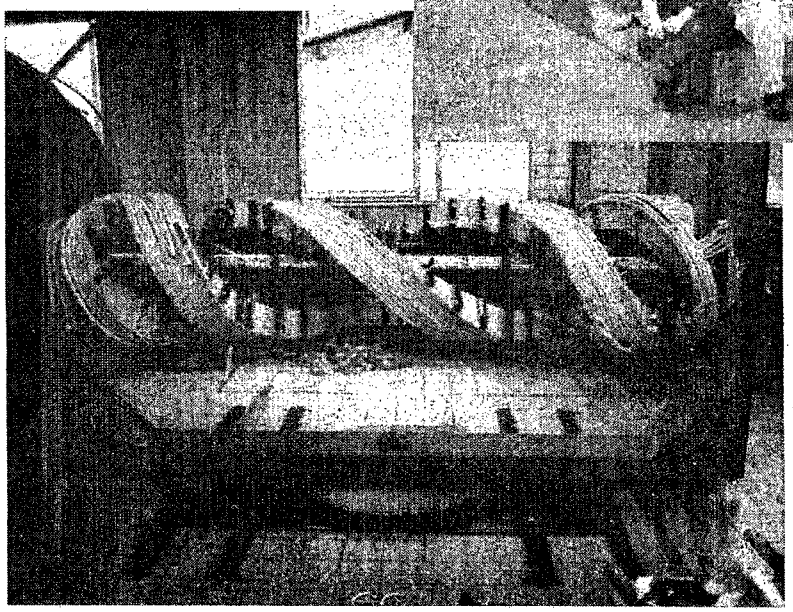
# Overview

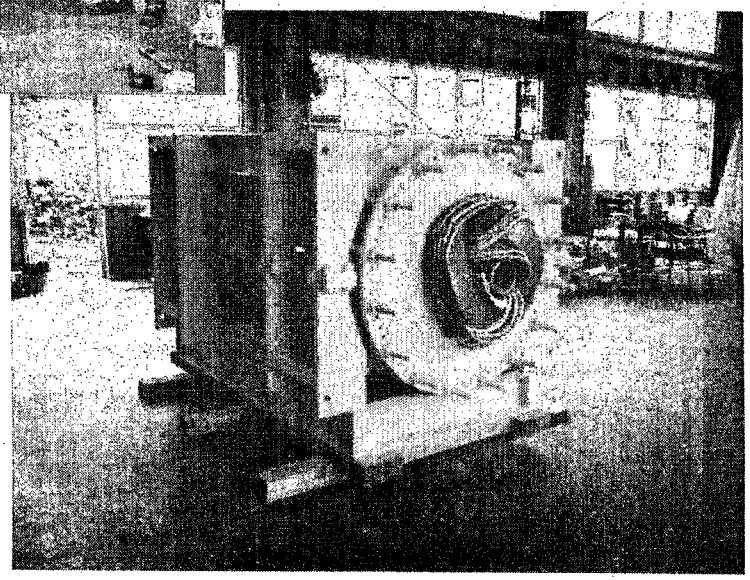
# RBRC Experimental Group

RBRC Review, 2003

Hideto Enyo

# AGS warm snake, made in Japan





# Experiment G. Organization JFY03

***UPGRADE@CERN***
Hiroaki Ohnishi
Johann Hauser
Hiroyuki Kano

**RIKEN@RBRC**
Yasuyuki Akiba
Yuji Goto
Hideyuki Kobayashi
Takahiro Kawabata
Tsuguchika Tabaru

***RBRC STUDENTS***
Hiroki Sato
Viktor Siegel
Nobuyuki Kamihara
Takuma Horaguchi
Manabu Togawa
Yoshi Fukao
Hiromi Okada
Takashi Hachiya

***RBRC***
Hideto Enyo
Gerry Bunce
Matthias Grosse Perdekamp
Abhay L Deshpande
Douglas E. Field
Brendan Fox
Federica Messor
Alexander Bazilevsky
Kensuke Okada
Osamu Jin-nouchi
Masashi Kaneta
Naohito Saito (Visitor)

**~40 active member**
**+~3 active visitors**

**BELLE**
Soeren Lange (Visitor)
Akio Ogawa (Visitor)
Kazumi Hasuko

***RIKEN/Wako***

***Masahiro Okamura***
Kiyoshi Tanida
Atsushi Taketani
Rykov Vladimir
Junji. Tojo
Hisa Torii
Tetsuya Chujo

***WAKO/CCJ***
Takashi Ichihara
Yasushi Watanabe
Satoshi Yokkaichi
Akio Kiyomichi

# Students in 2003 (Students!)

- Longtime issue: RIKEN could support students only when they were Junior Research Associate or JSPS fellow.
- Hiroki Sato, now phD, AGS-RHIC Thesis Award, JSPS Fellow

- Established the RBRC Young Researcher
- (Many Thanks to Review Committee)
  - Viktor Siegle (Heiderberg) =>Finishing his diploma at home
  - Yoshi Fukao (Kyoto-U, RBRC-YR =>JRA from April 03)
  - Takuma Horaguchi (TITech, RBRC-YR=>JRA from April 03)
  - Manabu Togawa (Kyoto-U JRA from April 02)
  - Hiromi Okada (Kyoto-U, became JRA2 from April 03)
  - Takashi Hachiya (Hiroshima-U, became JRA2 from April 03)
  - Kazuya Aoki ( Kyoto-U, will be this year's candidate)
  - Theory JRA ( Hatta (Kyoto) from 02, Yokoya(Hiroshima) 03)

# Special Thanks to Administrative Staffs in BNL and Wako

Especially to M.Yokota

# EXPERIMENTAL PRESENTATIONS

# CCJ—The Computer Center in Japan

Yasushi Watanabe

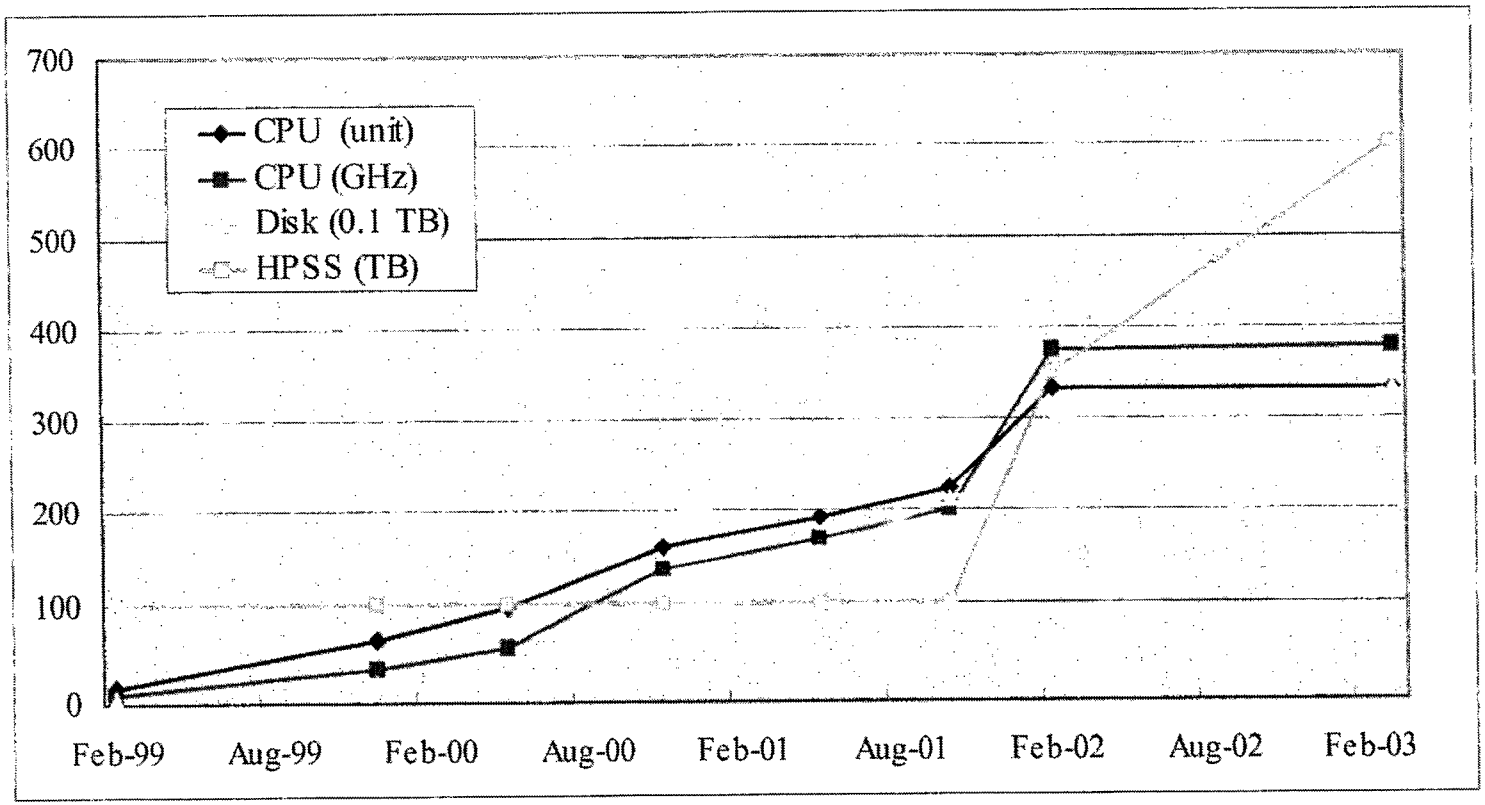
# atus

## ing Center in Japan for spin physics at RHIC

Y. Watanabe, T. Ichihara, S. Yokkaichi, A. Kiyomichi,
O. Jinnouchi, H. En'yo, Y.Goto , H. Hamagaki[1]
RIKEN, RBRC, CNS[1]

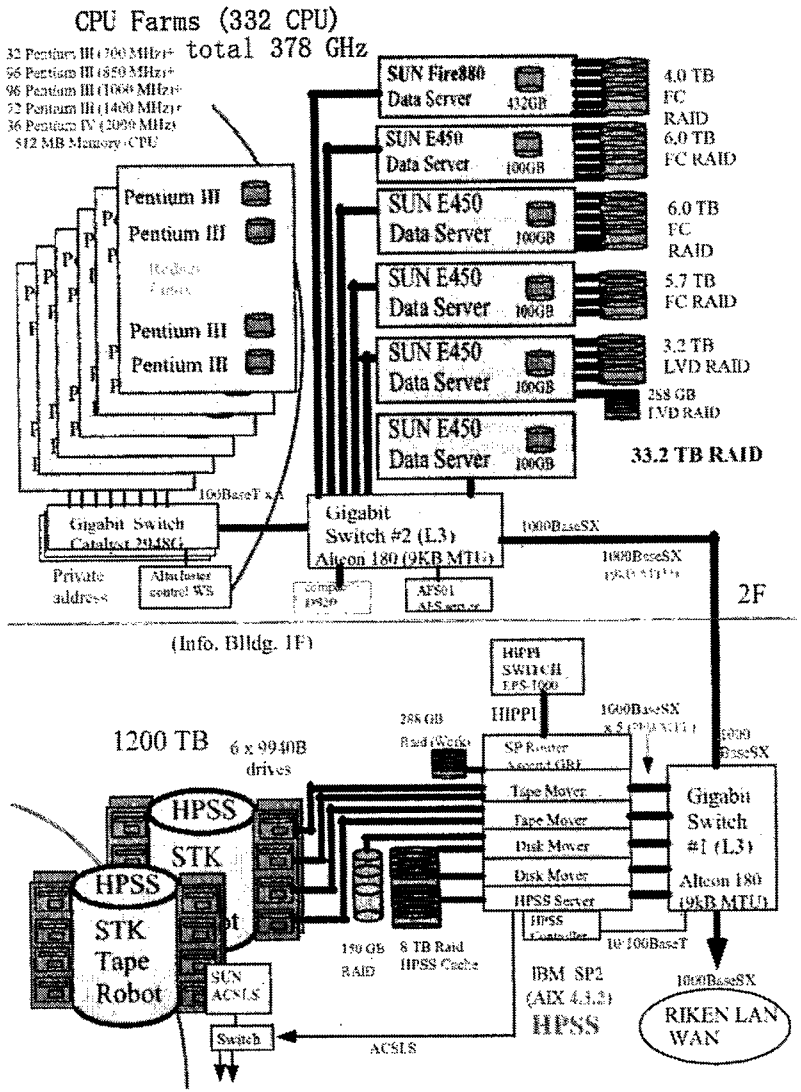
Presented on 20th November 2003 at RBRC Review at BNL

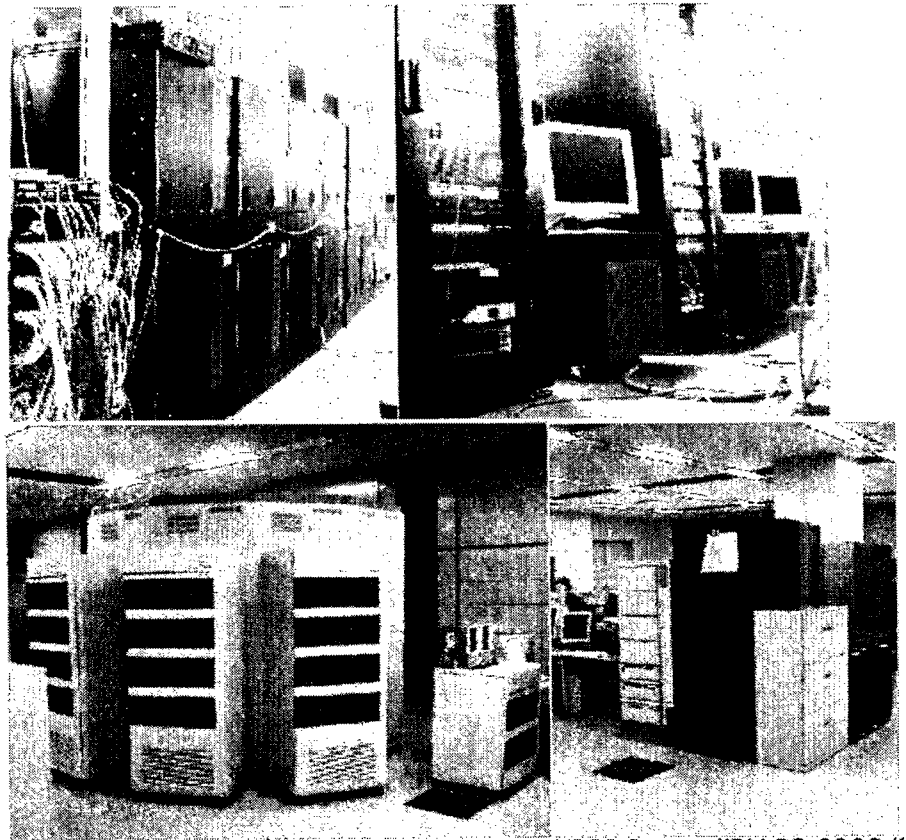
# CCJ growing history




| | Feb-99 | Dec-99 | May-00 | Nov-00 | May-01 | Oct-01 | Feb-02 | Mar-03 |
|---|---|---|---|---|---|---|---|---|
| CPU (unit) | 16 | 64 | 96 | 160 | 192 | 224 | 332 | 332 |
| CPU (GHz) | 8 | 34 | 56 | 136 | 168 | 200 | 374 | 378 |
| Disk (0.1 TB) | 3 | 19 | 35 | 92 | 152 | 212 | 252 | 332 |
| HPSS (TB) | 100 | 100 | 100 | 100 | 100 | 100 | 350 | 600 |

# Current configuration of CCJ



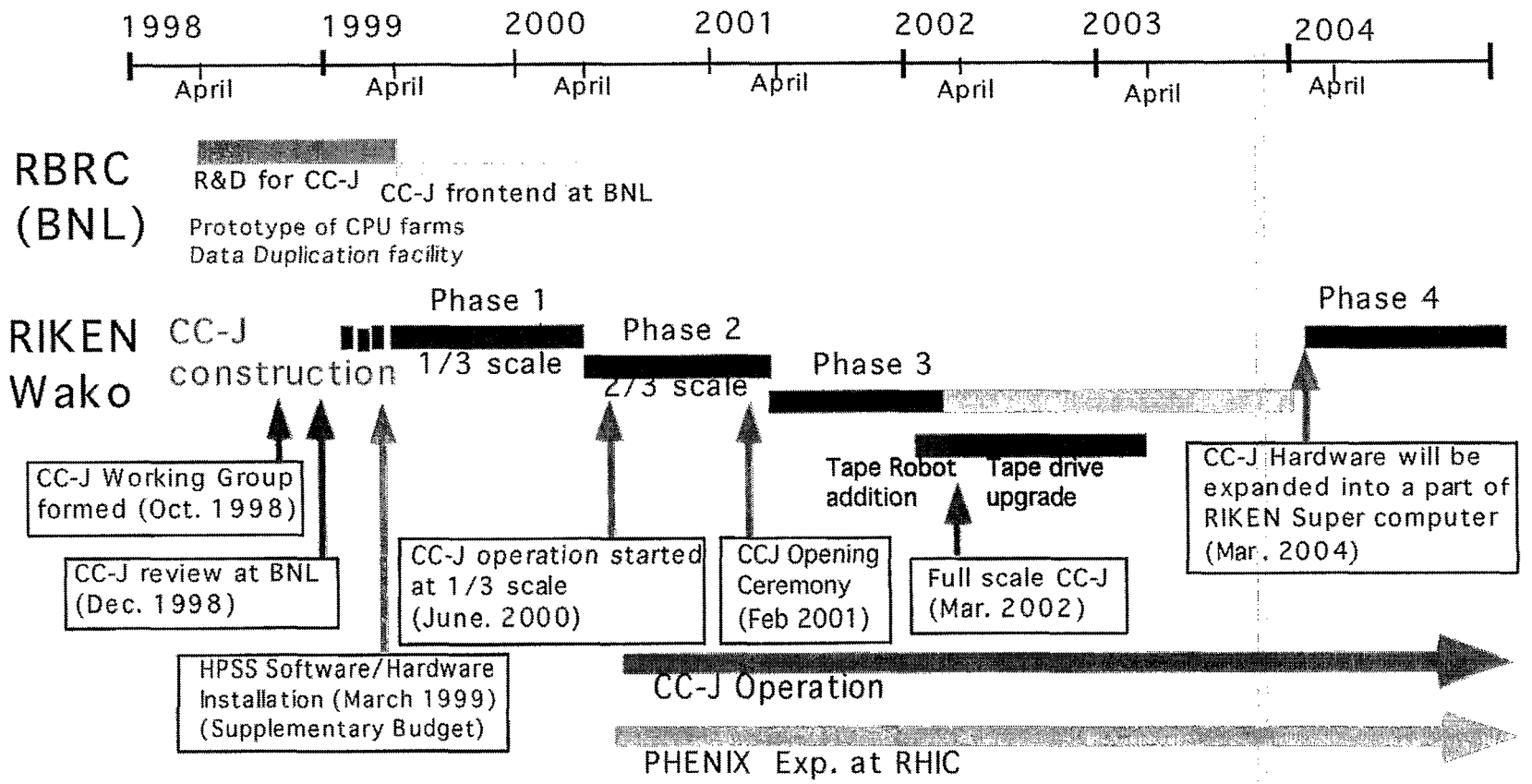
StorageTek Tape Robot
Capacity: >1000TB
Installed 3000 tapes (600TB)

HPSS Server (IBM RS-6000/

# Analysis for the PHENIX experiment with CCJ

- Official productions and simulations
  - Study of the conversion and Albedo stuffs in the pp->pi0 analysis
  - Run2pp DST production
  - Run3pp filtered data fast analysis
  - run3pp data refiltering + spin-nanoDST + gamma3 process
  - PbGl data analysis for the pi0 asymmetry fast analysis
  - Run2-pp pi0 A_N analysis
- Major analysis projects
  - Analysis for silicon strip detector in PHENIX Upgrades - J. Tojo
  - Searching for Non-hadronic sources of photons in Au+Au Collisions at $\sqrt{s_{NN}}$=200GeV at RHIC-PHENIX - T. Sakaguchi
  - Identified Hadron Spectra and Yields at 200 GeV AuAu Collisions from the PHENIX experiment at RHIC - T. Chujo
  - Reproduction of SpinLumi root files for analysis of BBC single spin asymmetry with ZDC coincidence - K. Tanida
  - Pico DST production for pi0 anisotropy analysis from micro DST of 200 GeV Au+Au data - M. Kaneta
  - Single particle MC simulation for hadron spectra(run2 pp) - S. Kaminaga
  - 2nd scan of pi0 anisotropy analysis - M. Kaneta
  - Monte-Carlo event generation for the study of dimuon production at CERN-SPS - H. Ohnishi
  - Run#91720 MUIDS1D triggered events production - K. Aoki
  - Direct photon mesurement in RHIC-PHENIX - T. Horaguchi
  - Simulation study for the Aerogel Cherenkov Counter - S. Takagi
  - Belle simulation - K. Hasuko, A. Ogawa, M. G. Perdekamp

# Plan and Current Status of RIKEN CCJ



# Polarimetry (AGS, RHIC, Jet)

Osamu Jinnouchi

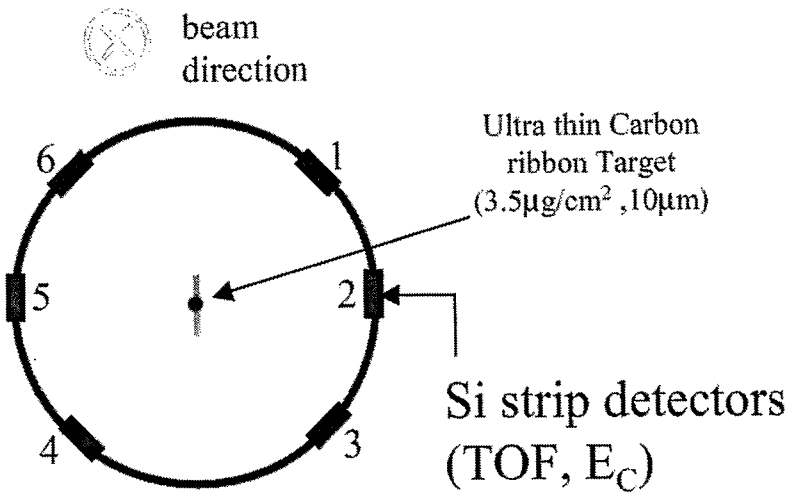
# Polarimetry in RHIC, AGS and $\vec{H}$ Jet

Osamu Jinnouchi
(RIKEN BNL Research Center)

Outline

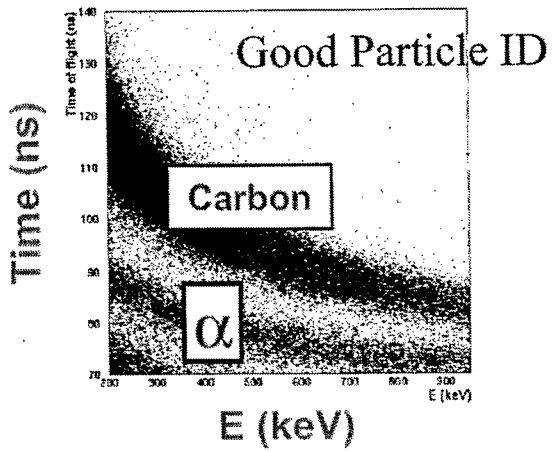
- Brief Introduction
- Outcomes from Run-03, RHIC & AGS
- Towards the next run

# *Detector/Target and Event selection*




non-relativistic kinematics

$$tof = \sqrt{\frac{M_C}{2T_{kin}}}L$$




**RHIC SSDs = ▮ + ▮**

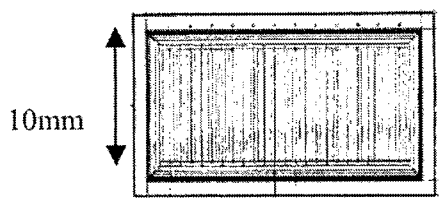
**6-Detectors : sensitive to X,Y**

**15cm radius**

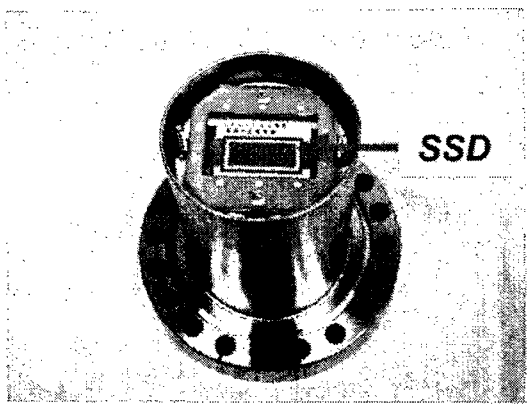
**AGS SSDs = ▮**

**2-detectors**

**25cm radius**




2mm pitch
12 strips



# *AGS Polarization in Run-03*

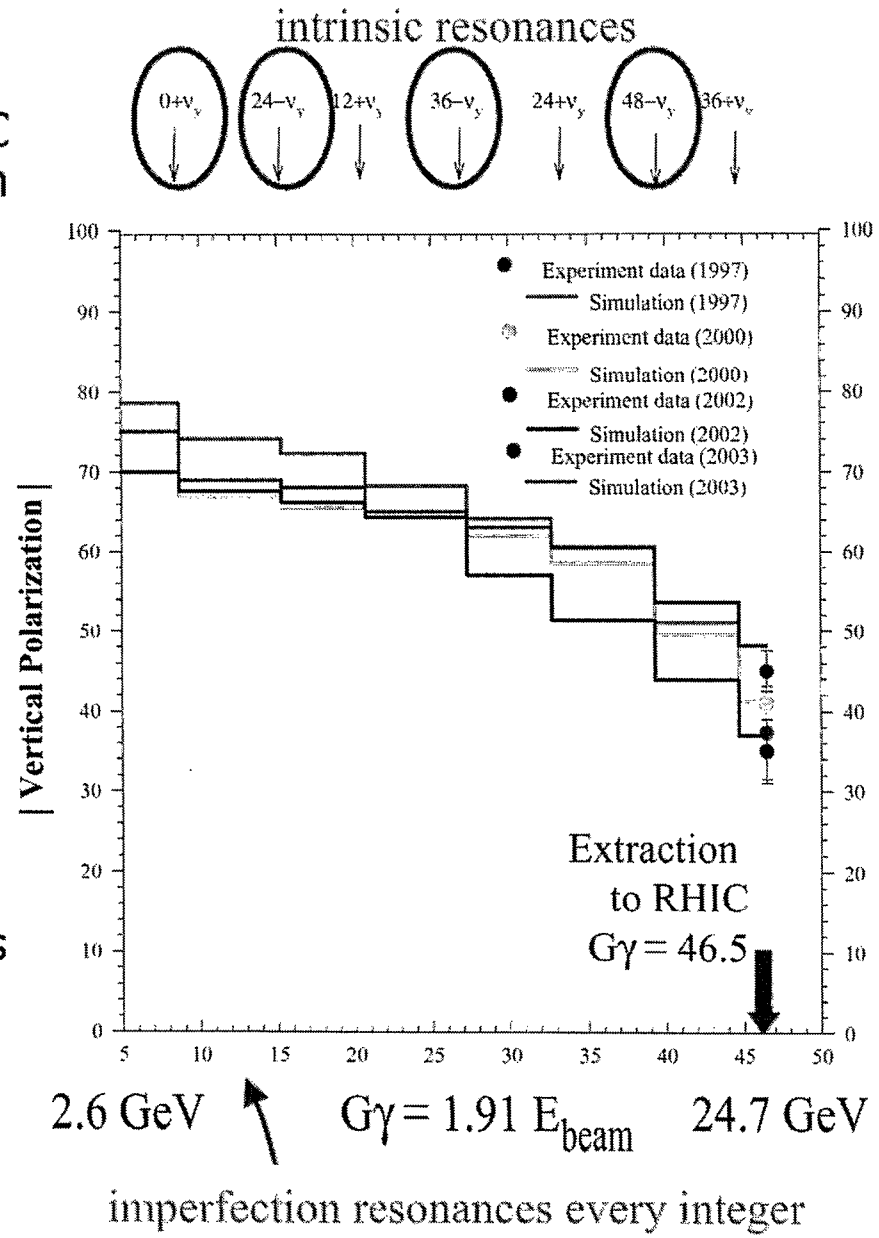
Main source of low polarization in RHIC Run-02 was due to large depolarization in AGS acceleration

Extremely important to know the polarization during the ramp to understand depolarization mechanism

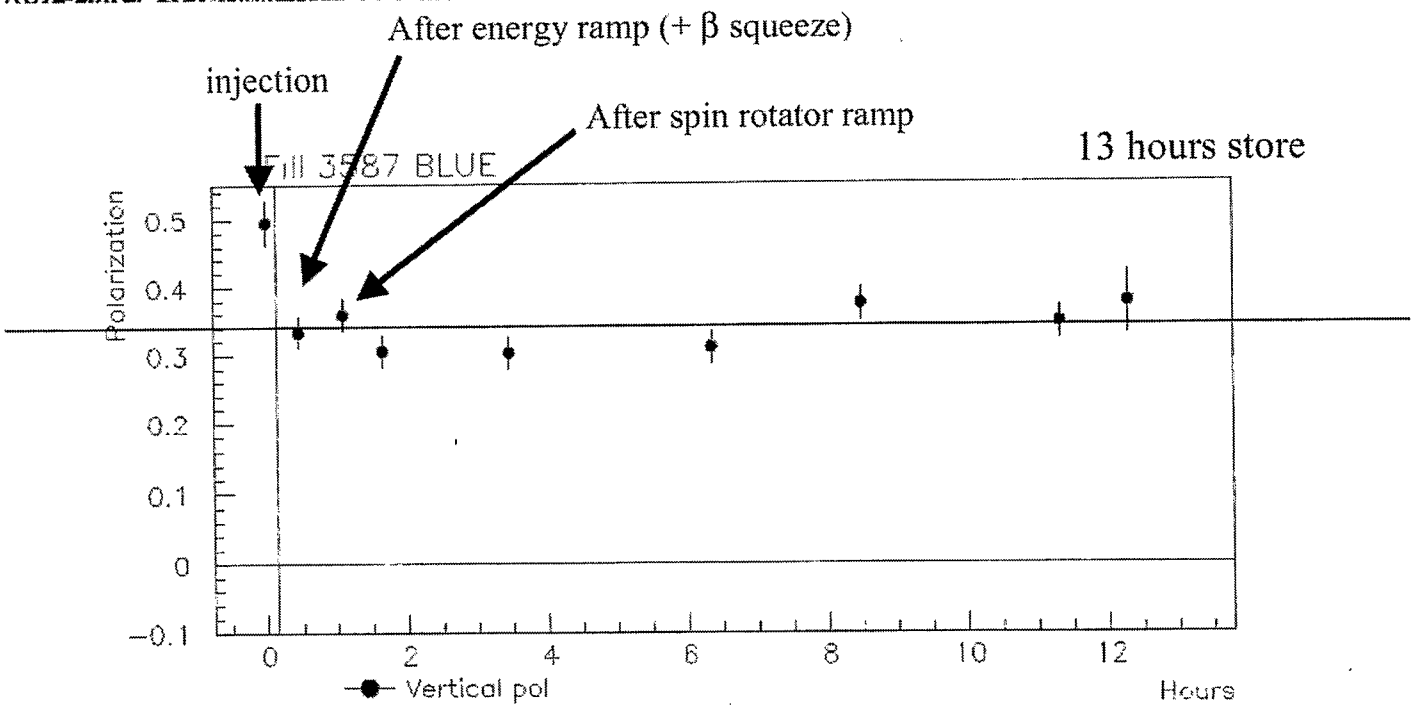
Full spin flip at all imperfection resonances using a solenoidal partial Siberian snake

Full spin flip at strong intrinsic resonances using an rf AC dipole (spin flipper)

Remaining polarization losses are from coupling and weak intrinsic resonances



# *RHIC : Polarization measurements in typical fill*

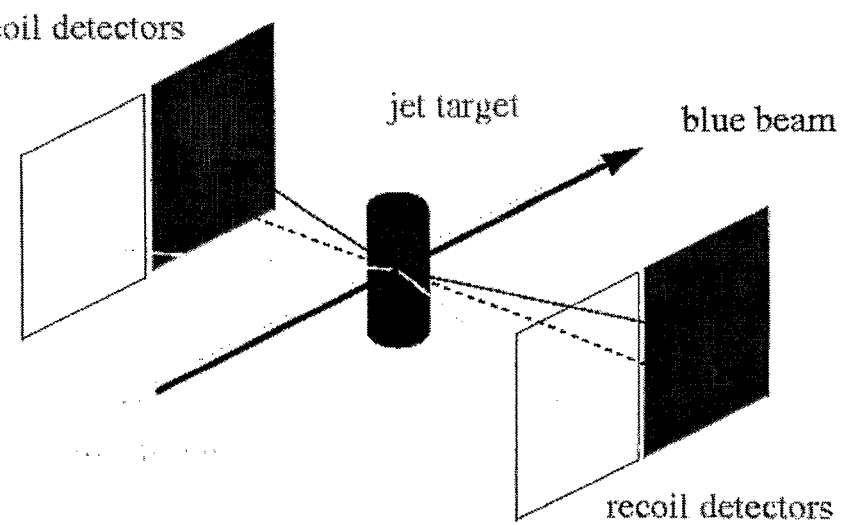



- Measurements for every 2 hours (24GeV,100GeVs)
- Long beam lifetime, stable polarization
- Spin rotators keep the polarization
- Polarization in store energy was up from run02
  - BLUE 29% YELLOW 25% in average

# Summary & Outlook for Run04

- First successful result from ramp measurement in AGS with using the CNI polarimeter as in RHIC
- Successful commissioning of Spin-rotator is confirmed
- Improved polarization in RHIC

- Add a 5% warm helical snake (run '04)
- To avoid all depolarization build a strong (20%) super-conducting helical Siberian snake snake (2005-2006)
- Commissioning of H jet target in 2004



# Forward Neutron Asymmetry and Longitudinal Polarization at PHENIX

Abhay Deshpande

PHENIX

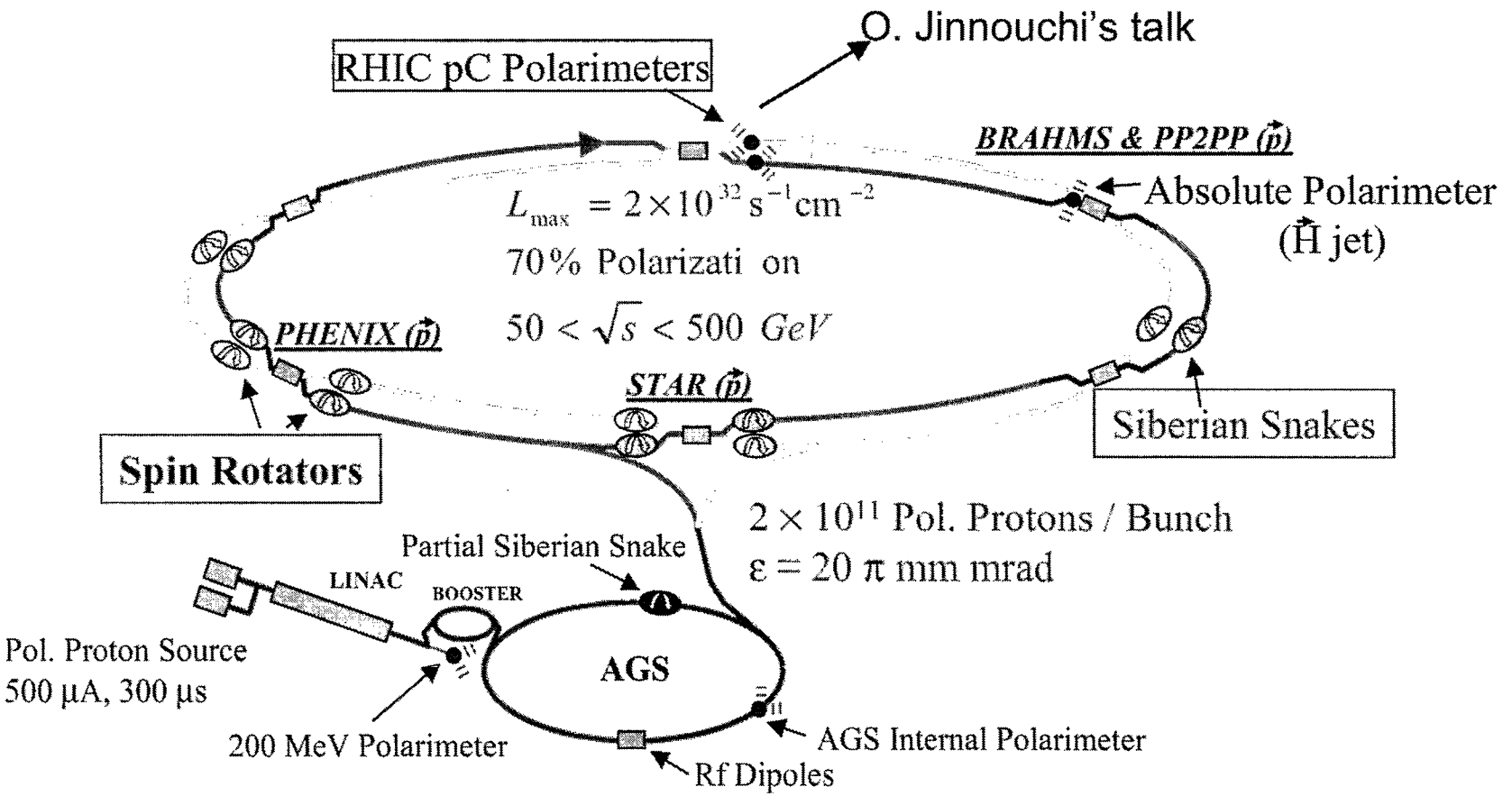
# Measurement of single transverse spin asymmetry $A_N$ in forward neutron production at PHENIX

# (Experimental confirmation of longitudinally polarized proton beams at PHENIX)

**Abhay Deshpande**
**RIKEN BNL Research Center**

# Relativistic Heavy Ion Collider

PHENIX



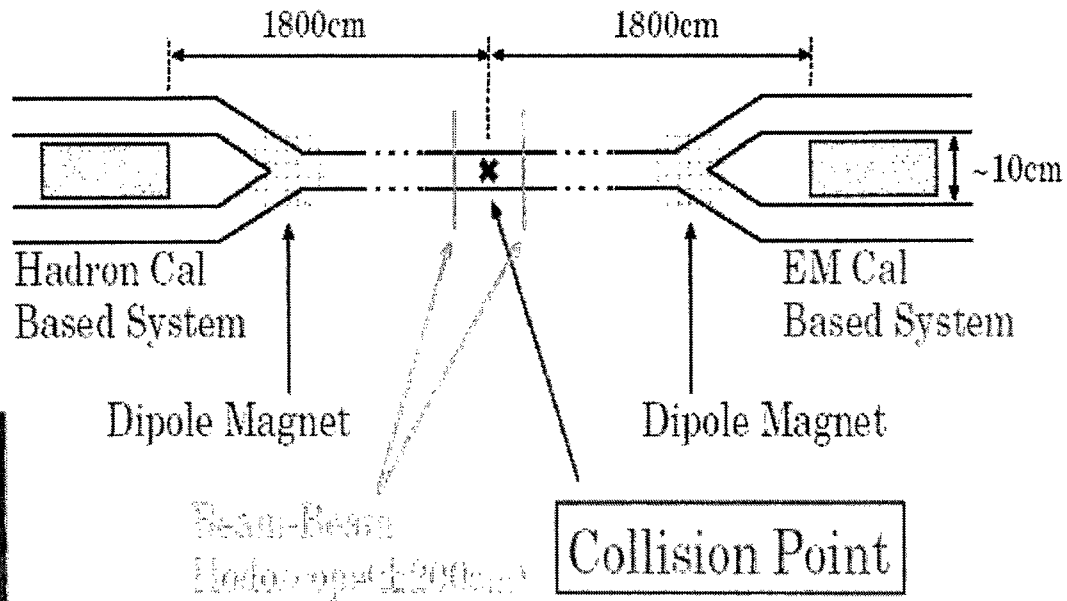

RHIC accelerates heavy ions to 100 GeV/A
and polarized protons to 100 GeV (250 GeV in future)

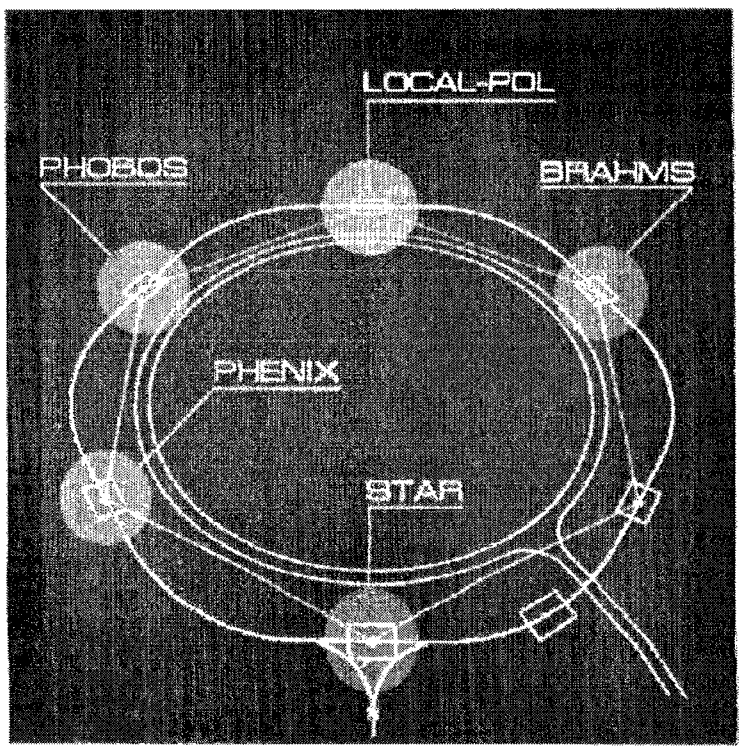
Abhay Deshpande
RBRC Review 2003

# Local Polarimeter at IP12 2001/2

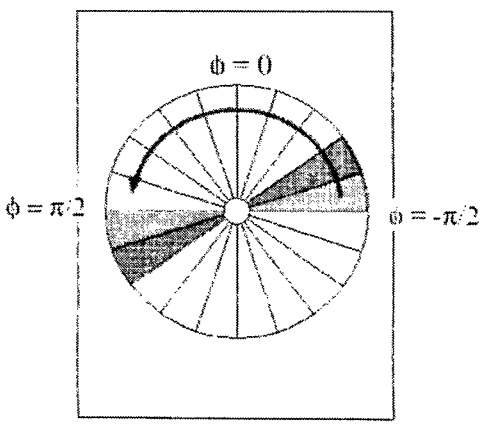
PHENIX

- *RUN-2: Neutron asymmetry observed in IP12 while testing a local polarimeter designed to look for $\pi^0$, $\gamma$ asymmetries:*




- *"Left-Right" asymmetry measured for different slices in $\Phi$:*

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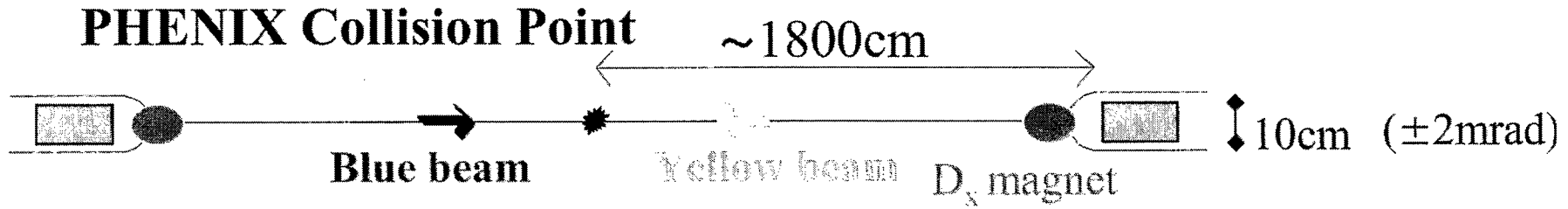
RBRC Review 2003

# PHENIX Local Polarimeter 2003

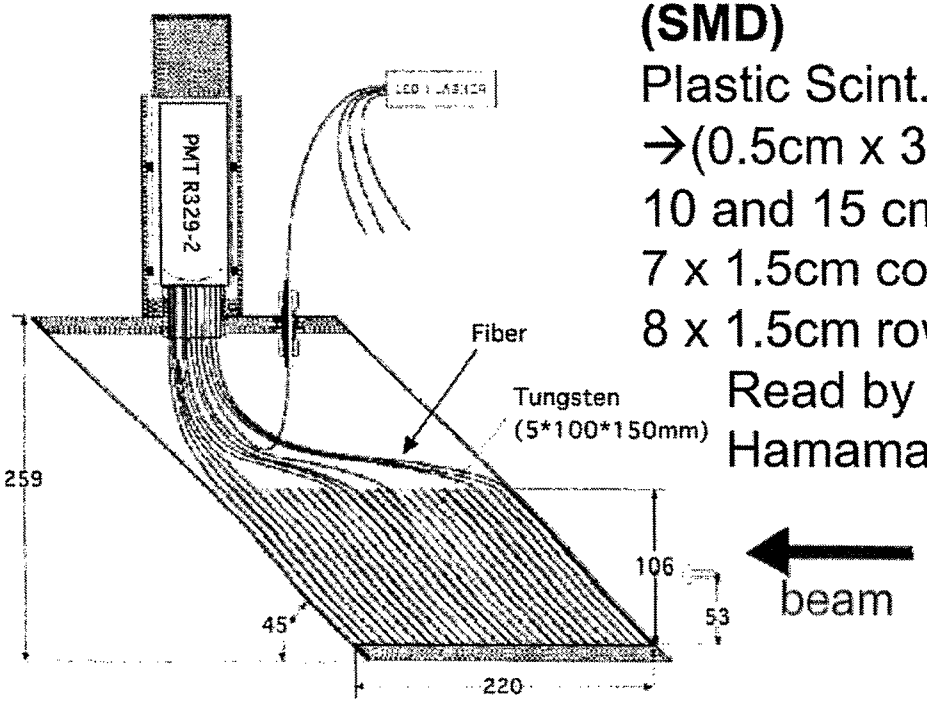
PHENIX




**Zero Degree Calorimeter (ZDC)**

Tungsten-Fiber Sandwich

5.1 $\lambda_T$, 149 $X_0$ → 3 ZDCs each side




**Shower Max Detector (SMD)**

Plastic Scint. strips

→(0.5cm x 3)

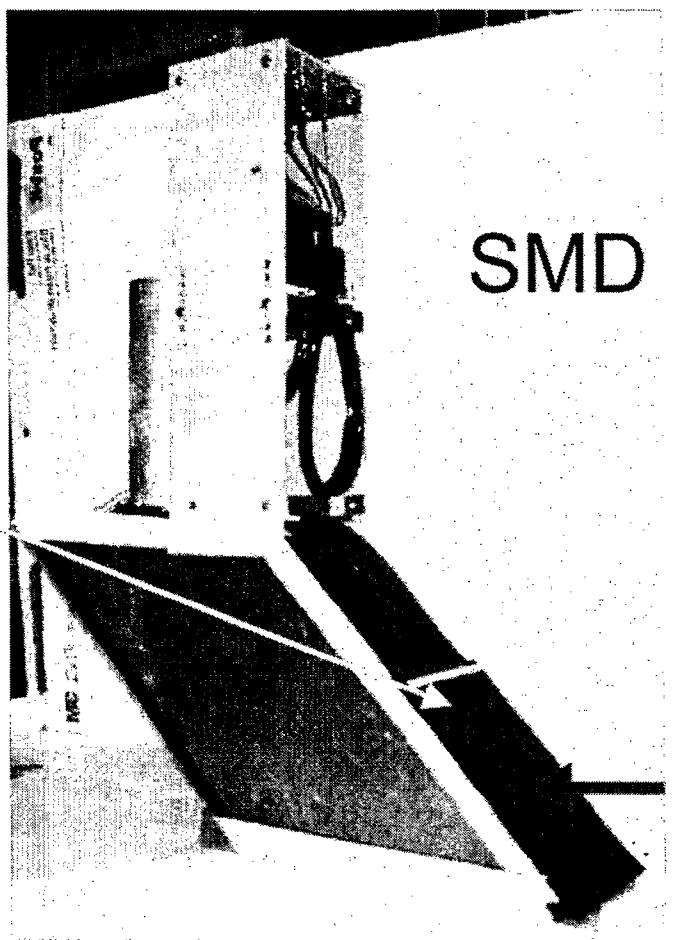
10 and 15 cm long

7 x 1.5cm columns

8 x 1.5cm rows

Read by

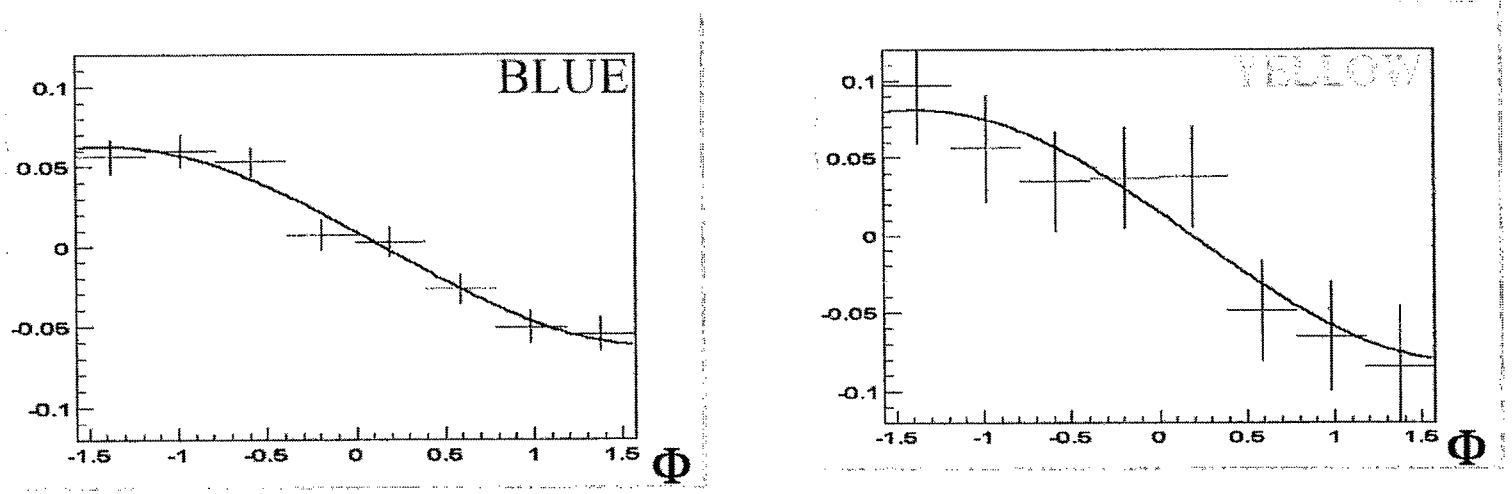
Hamamatsu M16



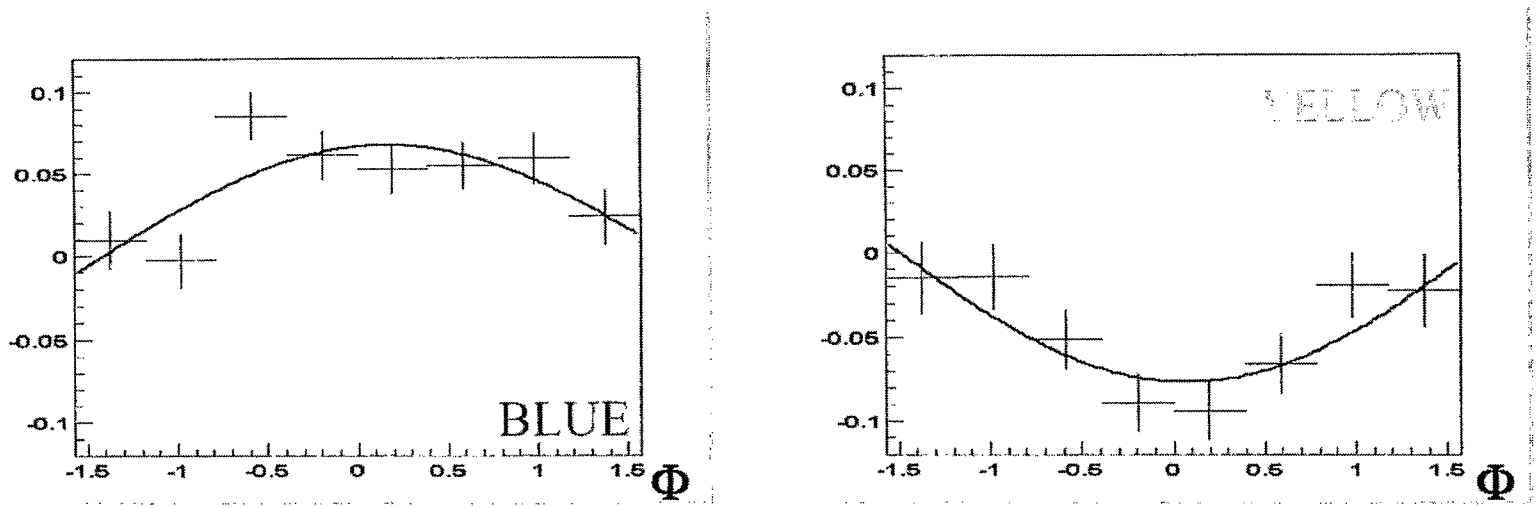
# Spin Rotator Commissioning (I)

PHENIX

Max at $\Phi$ = +/- $\pi/2$ ➔ Transverse




Max at $\Phi$ = 0 ➔ Transverse Radial ! Spin Rot PS wired wrong!




(Raw Asymmetry) / (beam pol.)



Abhay Deshpande
RBRC Review 2003

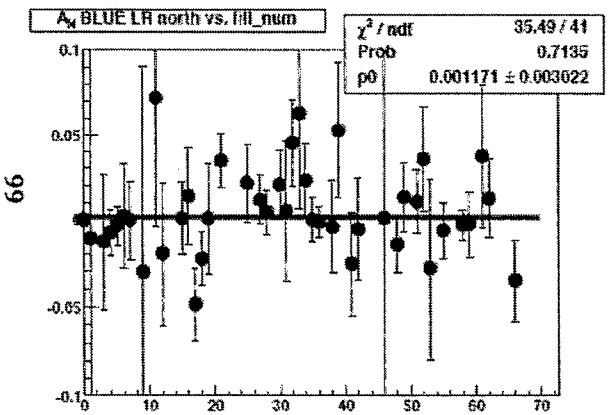
# How longitudinal were the beams?

PHENIX

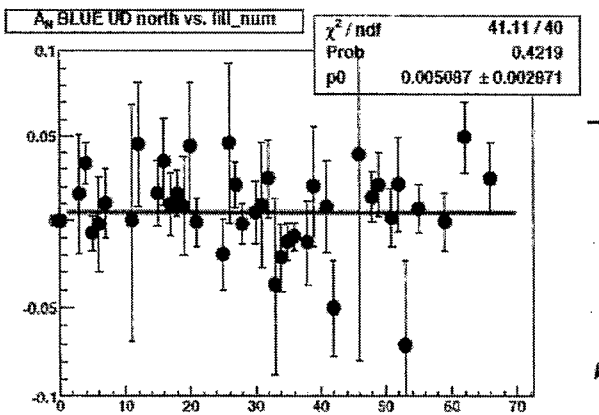
$$S_L = \sqrt{1 - S_T^2}, \qquad S_T = \sqrt{S_{T-vertical}^2 + S_{T-radial}^2}$$

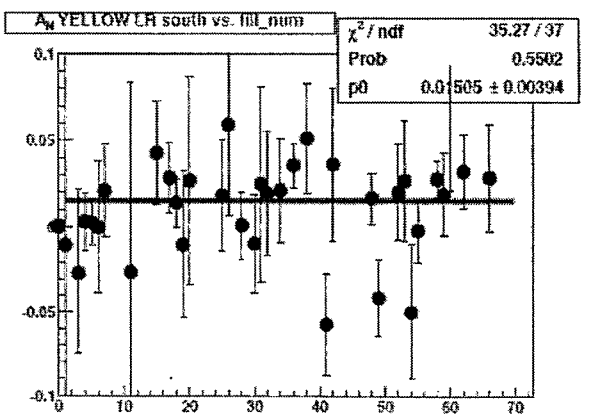
PHENIX Local Polarimeter measures $S_T$

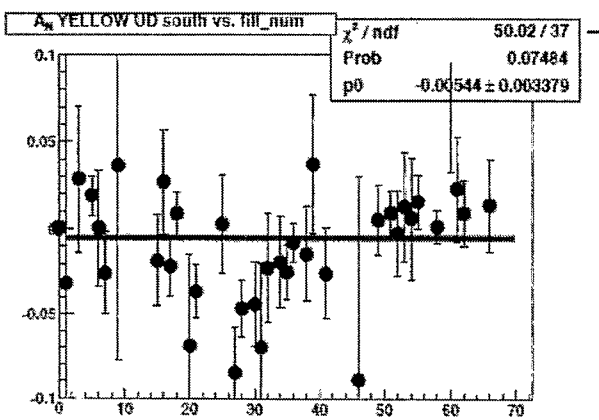
Left-Right vs. Fill No.




Up-Down vs. Fill No.




$$S_L(blue) = 99.3^{+0.5}_{-1.4}{}^{+0.0}_{-0.9}$$

$$S_L(yellow) = 97.4^{+1.3}_{-3.2}{}^{+0.1}_{-0.9}$$

Abhay Deshpande
RBRC Review 2003

# Central Arm Triggering for 2003 for PHENIX

Kensuke Okada

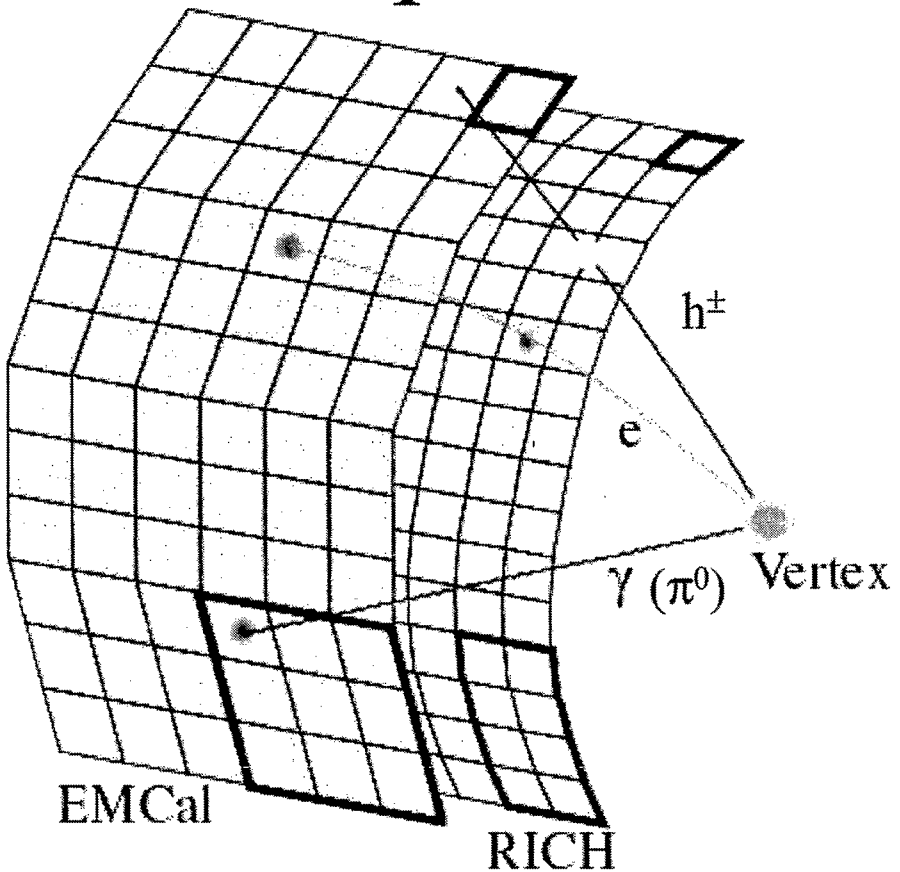
# PHENIX Central Arm Trigger in RUN3

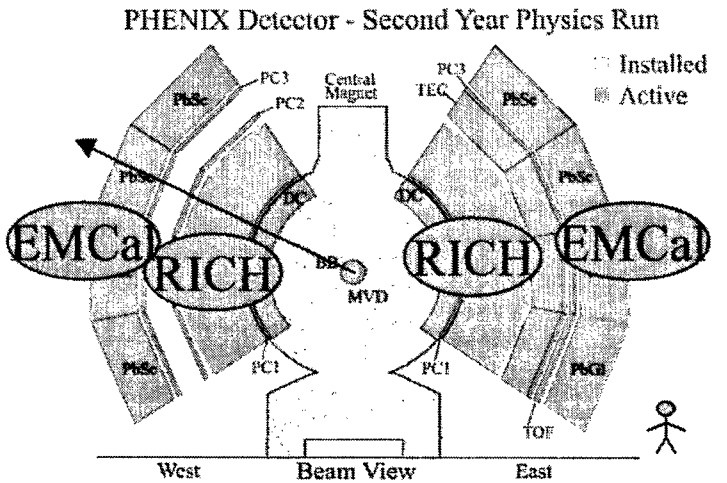
Kensuke Okada

RBRC review

2003

# Concept of EMCal-RICH trigger




PHENIX central arm
2 types of EMCal (PbSc, PbGl)

$\gamma(\pi^0)$ : EMCal
Electron : EMCal and RICH
$h^{\pm}$ : EMCal and RICH (through hadronic interactions)

# Run2 → Run3 (The second year of ERT)

Live area :

EMCal from 75% to 90~95%

We improved it with 2 steps

A) Replacement of bad FEM boards (Nov, Dec 2002)

B) Mask bad tiles instead of whole SM. (Apr 2003)

RICH from 15% to 70%

(In pair analysis for J/ψ, the efficiency is 90%.)

4x4 overlapping between super modules

4x4 turn-on width improvement

# Trigger Circuit "variation"

The first assumption was it came from the deviation of the pedestal.

→ The pedestal scan was performed to check electrical zero level.

(It was independent to HV on/off)

Threshold setting was adjusted for each trigger tile.

(~ ±1.5 for 4x4, ~±2 for 2x2, FWHM)

Rejection power improvement

| Trigger | Old RF | New RF |
|---|---|---|
| 2x2 (800 MeV) | 29.5 | 35 |
| 4x4a (2.8 GeV) | 863 | 1989 |
| 4x4b (3.5 GeV) | 3762 | 5197 |
| 4x4c (2.1 GeV) | 190 | 606 |
| e (2x2⊗RICH) | 977 | 1077 |

RF of 4x4 triggers improved for more than 2 times.

**Table 1:** *Rejection factors with old and new threshold settings.*

# Physics Results using ERT

## Run2

$\pi^0$

"Midrapidity Neutral Pion Production in Proton-Proton Collisions at sqrt(s) = 200 GeV"
S.S. Adler et al, accepted for publication in PRL on 19 September 2003
Preprint

$J/\psi$

"J/psi production from proton-proton collisions at sqrt(s) = 200 GeV"
S.S. Adler et al., submitted to Physical Review Letters July 8 2003
Preprint

## Run3

$\pi^0$

"Absence of Suppression in Particle Production at Large Transverse Momentum in sqrt(s_NN) = 200 GeV d+Au Collisions"
S.S. Adler et al.,
Was

# How to evaluate the threshold value?

<u>If the time variation scale is a week or so</u>.

Perform a calibration scan once a week.

Feed back to the new setting,

or

Record them for the offline-analysis.

| Method | Time (hour) /tile | Comment |
|---|---|---|
| Pedestal scan | 0.3 (Arcnet download) | Wide pitch, far from real threshold |
| Laser scan | ~1 (rate, polarizer) | Only for PbSc 4x4 |
| HV scan with LED for PbGl | ~1 (HV setting time) | LED light length? |
| CALDAC scan | ~1 (Arcnet download) | Good for PbGl, PbSc |

It has to be multiplied by 36 to scan all.

Anyway it needs a speed-up for a regular calibration.

# Relative Luminosity for $A_{LL}$ Measurements

Kiyoshi Tanida

# Relative luminosity for $A_{LL}$ measurements – in PHENIX run3

K. Tanida (RIKEN/RBRC)

11/20/03 RBRC review

Outline

- What is relative luminosity? Why?
- How to get relative luminosity?
- Method of accuracy estimation
- Results and ZDC/BBC $\Delta A_{LL}$
- Summary and outlook

# Our goal in PHENIX run3

- $\delta A_{LL} \sim \delta R/(2P_B P_Y) < 3 \times 10^{-3}$
  (c.f. expected $A_{LL}$ for pions)
- Beam polarization ~ 27%

⬇

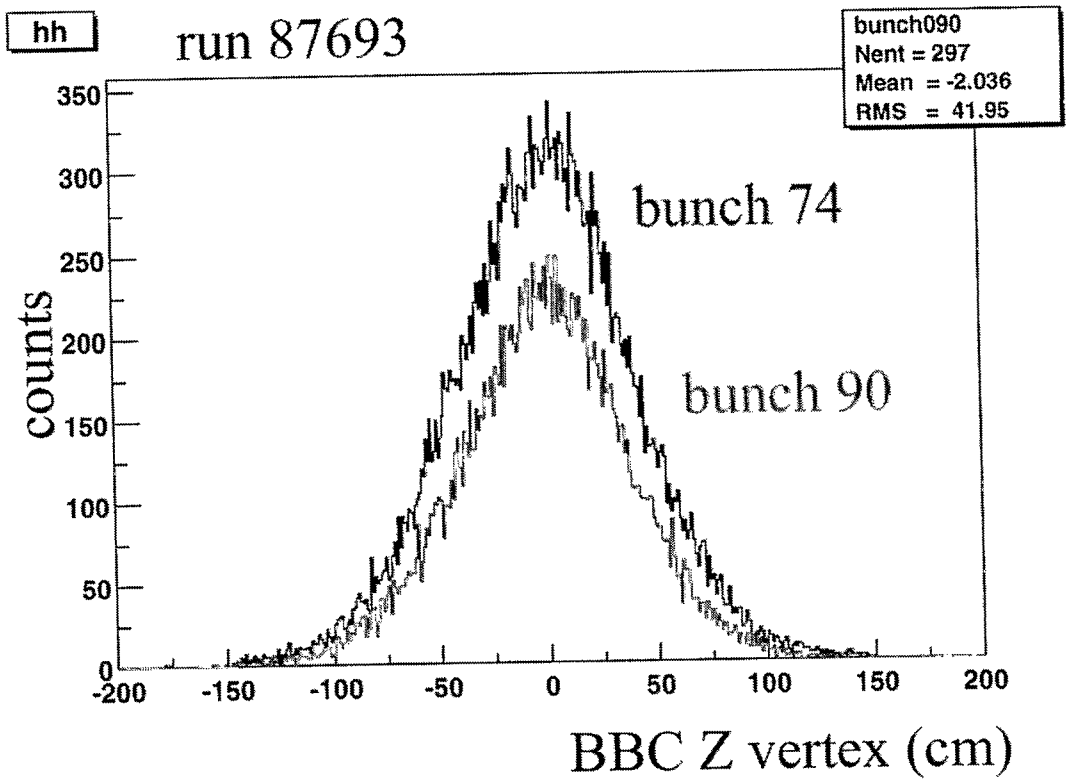
- Relative luminosity accuracy:
  $\delta R < 4 \times 10^{-4}$

# Method of accuracy estimation

- Cross-check by ZDCLL1 trigger
  (Zero Degree Calorimeter)
  - low backbround (~ $10^{-4}$)
  - statistics: moderate (~ 3% of BBCLL1)
- N(ZDCLL1)/N(BBCLL1) must be constant
- Crossing-by-crossing, fill-by-fill ratio calculation
  Blue: + − + − + − + −....
  Yellow: + − + − + − + −....
  → We have all spin combinations in each fill
- GL1p scaler counts both BBCLL1 and ZDCLL1 for each bunch
- Required accuracy: constant to $10^{-3}$ level for each fill.

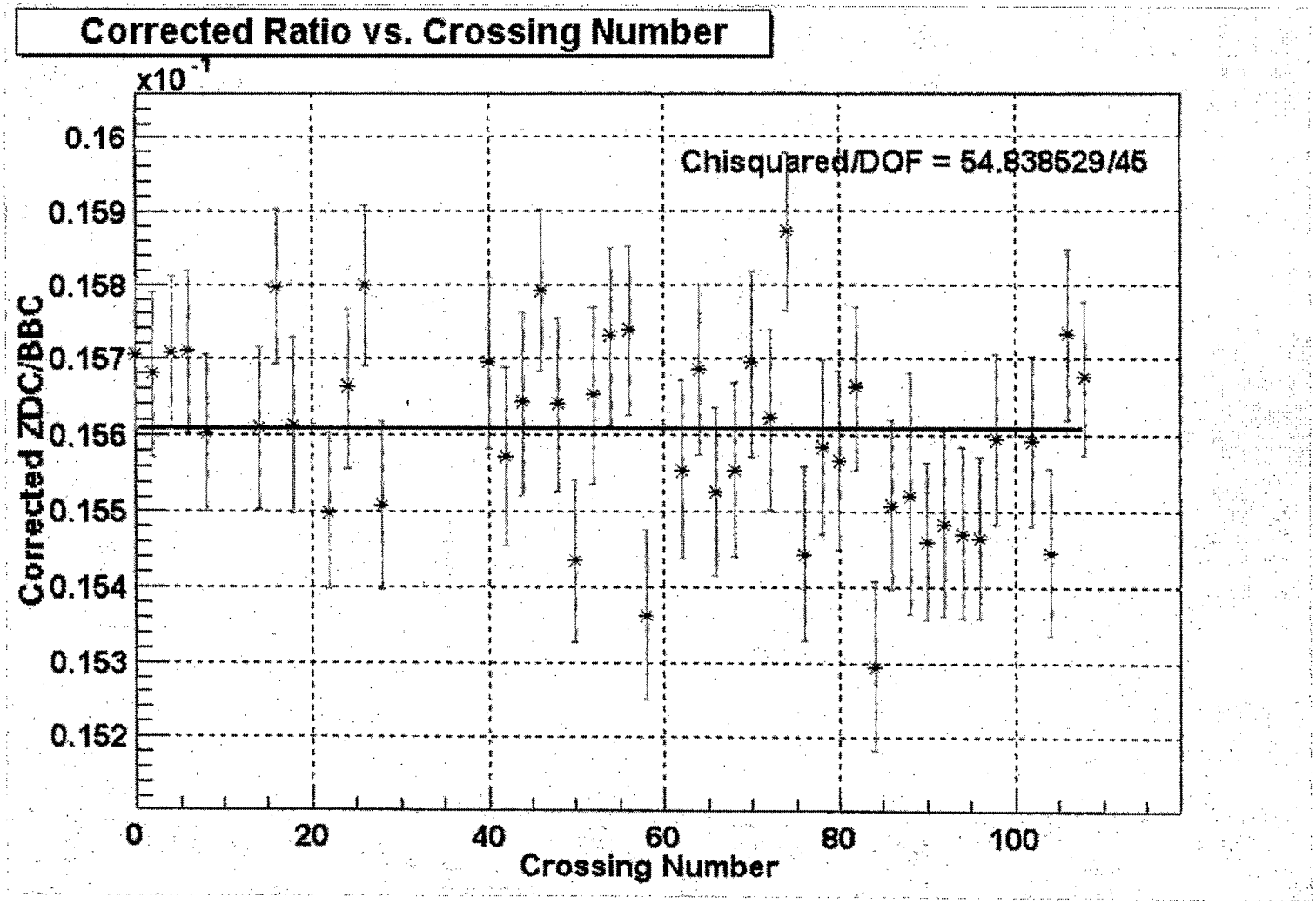
# Possible explanation – detector acceptance

- Extreme cases
  - Flat acceptance
    → N ∞ area
  - Narrow acceptance
    → N ∞ height




- ZDCLL1 has flat acceptance, while BBCLL1 has slightly center-peaked acceptance distribution

# After correction




Relative luminosity accuracy < 0.09% (stat. limited)

# Actual accuracy estimation -- Bunch fitting

- Crossing-by-crossing analysis, taking care of possible $A_{LL}$ effect
- For i-th crossing, calculate
  $r(i) = N_{ZDCLL1}(i)/N_{BBCLL1}(i)$
  corrected for vertex width
- Fit r(i) by
  $r(i) = C[1+A_{LL}P_B(i)P_Y(i)]$
  fit parameter: C, $A_{LL}$
- You will get C, $A_{LL}$, their errors, and $\chi^2$
  - accuracy is obtained as $\delta A_{LL}$ (x $P_B P_Y$)
  - $\chi^2$ gives a good check for systematic errors.

# Result & BBC/ZDC $A_{LL}$

- Systematic error seen → $\chi^2$ correction required
- If $\chi^2$/dof is larger than 1, then enlarge statistical error by sqrt($\chi^2$/dof) – conservative correction
- Averaged result: $A_{LL} = (2.3 +- 1.6) \times 10^{-3}$
- This corresponds to relative luminosity accuracy of $\delta R = 2.5 \times 10^{-4}$
  → Achieved the goal
- ZDC-BBC $A_{LL}$ is 0 consistent
  → we can use both for reference of $A_{LL} = 0$

# Summary and outlook

- Relative luminosity was calculated by using BBCLL1 trigger counts and were checked using ZDCLL1 trigger.
- Accuracy: $2.5 \times 10^{-4}$ achieved ($\delta A_{LL} = 1.6 \times 10^{-3}$) after vertex width correction.
  - error is dominated by ZDC statistics

- Outlook:
  - full accuracy estimation using real vertex distribution
  - different relative luminosity necessary for different reaction channels (acceptance correction).
  - study of multiple collision effect for future high-luminosity runs

# $A_{LL}$ for $\pi^o$

Alexander Bazilevsky

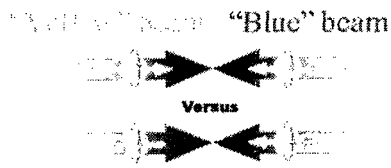
# First $\pi 0$ $A_{LL}$ results from PHENIX

RBRC Scientific Review Committee Meeting
BNL, November 20, 2003

A.Bazilevsky

PHENIX

# $A_{LL}$




$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

++ same helicity
+– opposite helicity

(P) Polarization
(L) Relative Luminosity
(N) Number of pi0s

PHENIX

# Relative Luminosity: Results

See talk by K.Tanida

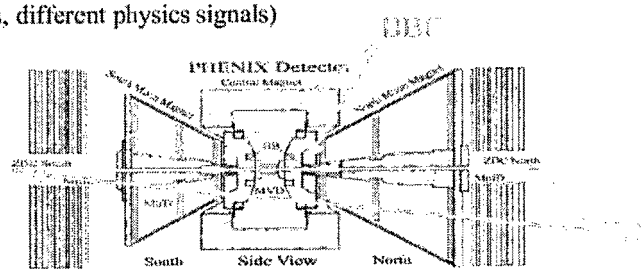
Beam Beam Counter (BBC) used
Zero Degree Calorimeter (ZDC) as a cross check

Achieved relative luminosity precision $\delta R = 2.5 \cdot 10^{-4}$

Pessimistic estimation limited by ZDC statistics (30 times less than BBC statistics used in Rel. Lum. measurements)

$A_{LL}$ of BBC relative to ZDC consistent with 0 (<0.2%)

Strong indication that both $A_{LL}$s are zero (very different kinematical regions, different physics signals)




PHENIX

# π0 Data Set

See talk by K.Okada

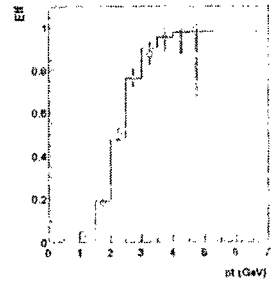
$\sqrt{s}$=200 GeV data collected with high $p_T$ photon trigger

- Based on EMCal; Threshold ~1.4 GeV/c
- Rejection factor ~110
- Analyzed data sample:
  - 42.7M events (~0.215 pb$^{-1}$)
  - sqrt(<$P_b P_y$>)~26%

Minimum Bias data

- To obtain "unbiased" π0 cross section at low $p_T$
- For high $p_T$ photon trigger efficiency study

Trigger efficiency for pi0s




- ✓ Pi0 efficiency plateaus for $p_T$>4 GeV/c
- ✓ Limited efficiency at $p_T$<4 GeV/c
  - 1-2 GeV/c: 6%
  - 2-3 GeV/c: 60%
  - 3-4 GeV/c: 90%
  - 4-5 GeV/c: 95%
- ✓ Monte Carlo reproduces Data well

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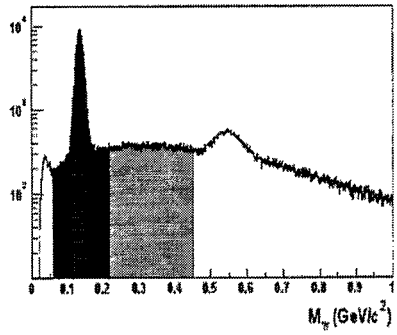
# Pi0 counting for $A_{LL}$




$N_{\pi 0}$:
±25 MeV/c² around $\pi 0$ peak (and also ±15 and ±35 MeV/c² for cross checks)

$N_{bck1}$:
Two 50 MeV/c² wide areas adjacent to $\pi 0$ peak

$N_{bck2}$:
250 MeV/c² wide area between $\pi 0$ and $\eta$ peaks

$N_{\pi 0}$ and $N_{bck}$ accumulated statistics

| pt GeV/c | $N_{\pi 0}$ 15 MeV/c² | $N_{\pi 0}$ 25 MeV/c² | $N_{\pi 0}$ 35 MeV/c² | $N_{bck1}$ | $N_{bck2}$ |
|---|---|---|---|---|---|
| 1-2 | 1278k | 1777k | 2129k | 1470k | 3478k |
| 2-3 | 874k | 1089k | 1146k | 335k | 989k |
| 3-4 | 176k | 201k | 208k | 27k | 83k |
| 4-5 | 34k | 38k | 39k | 3.9k | 12k |

PHENIX

# $A_{LL}$ measurements

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}, \quad \delta_{A_{LL}} \approx \frac{1}{|P_B P_Y|} \frac{1}{\sqrt{N_{++} + N_{+-}}}$$

++ same helicity
+– opposite helicity

Procedure

1. Collect $N$ and $L$ for ++ and +– configurations (sum over all crossings) and calculate $A_{LL}$ for each fill (a few hours of running, constant beam polarization)
2. $\delta(A_{LL})$ is based only on $N_{\pi 0}$ stat. error
3. Average $A_{LL}$ over fills; use $\chi^2$/NDF to control fit quality; use "bunch shuffling" to check syst. errors

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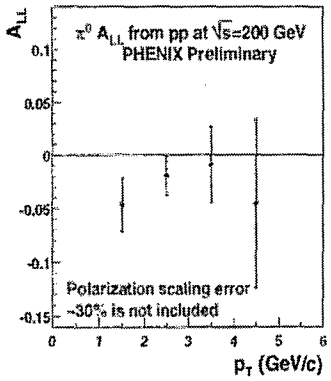
# Cross Checks

- Different mass window cut for $N_{\pi^0}$
  15, 25 and 35 MeV/c² cuts
  All results are consitent
- Different photon PID
  All results are consitent
- Parity violating $A_{LL}$'s
  ++ vs — and +– vs –+
  All are consistent with 0 within 1.5σ (as expected)
- Parity violating single spin asymmetries $A_L$
  All are consistent with 0 within 1.5σ (as expected)

PHENIX

# $\pi^0$ $A_{LL}$ from pp at 200 GeV

| $p_T$ GeV/c | $A_{LL}^{\pi^0+bck}$ ($r_{bck}$) | $A_{LL}^{bck}$ | $A_{LL}^{\pi^0}$ (Background subtracted) |
|---|---|---|---|
| 1-2 | -0.028±0.012 (45%) | -0.006±0.014 | -0.046±0.025 |
| 2-3 | -0.022±0.015 (67%) | -0.035±0.027 | -0.019±0.019 |
| 3-4 | -0.002±0.033 (7%) | 0.094±0.092 | -0.009±0.036 |
| 4-5 | -0.023±0.074 (5%) | 0.38±0.24 | -0.045±0.079 |




Polarization scaling error $\delta P$ ~30%: is not included

- ✓ Enters the $A_{LL}$ quadratically
- ✓ Analyzing power $A_N$(100 GeV) ~ $A_N$(22GeV) is assumed
- ✓ $\delta P$~30%: combined stat. and syst. error for $A_N$(22GeV) (AGS E950)

Relative luminosity contribution to $\pi^0$ $A_{LL}$ error is <0.2%

$p_T$ smearing correction is not included

# Belle Fragmentation Functions

Matthias Grosse Perdekamp

# Prospects of Spin Dependent Fragmentation Function Measurements at Belle

## RBRC Review

**RIKEN BNL Research Center, Upton, New York, November 20-21, 2003**

**M. Grosse Perdekamp (UIUC and RBRC)**
**K. Hasuko (RIKEN/RBRC)**
**S. Lange (Frankfurt/RBRC)**
**A. Ogawa (BNL/RBRC) and V. Siegle (RBRC)**
**for the Belle Collaboration**

# Motivation: Transversity at RHIC I

## Physics Channels

$\int Ldt = 320\text{pb}^{-1}, \sqrt{s} = 200\text{GeV}$

STAR

PHENIX

- Collins Effect in Jets:

$$A_T(pp_\perp \to \pi + Jet + X)$$

J.C. Collins, Nucl. Phys. B396, 161(1993)

- $\pi^+, \pi^-$ Interference Fragmentation:

$$A_T(p_\perp p \to (\pi^+, \pi^-) + X)$$

J. Collins, S. Heppelmann, G. Ladinsky, Nucl.Phys. B420 (1994)565

R. Jaffe, X.Jin, J. Tang Phys. Rev. D57 (1999)5920

- Inclusive jet production

$$5 \cdot 10^{-4} \le A_{TT} \le 3 \cdot 10^{-3}$$

W. Vogelsang and M. Stratmann, RBRC Workshp on Transversity (2000)

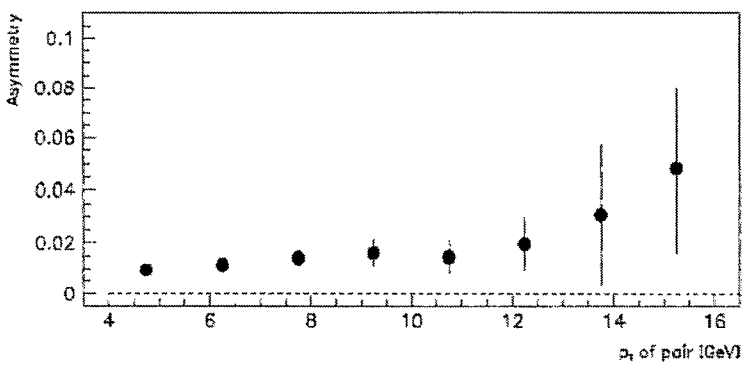
Observables $\propto \delta q \cdot H$

( O $\propto$ distribution - func. $\times$ fragmentation func.)

**Example: Interference Fragmentation in PHENIX**

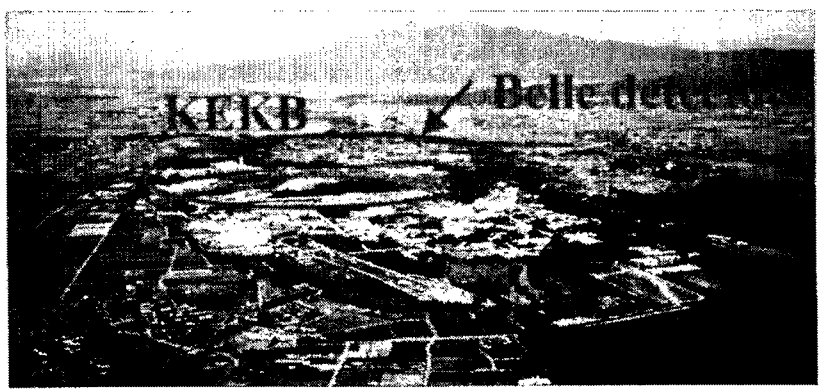
$A_T(p_\perp \to \pi^+\pi^- + X)$ vs $p_T^{pair}$

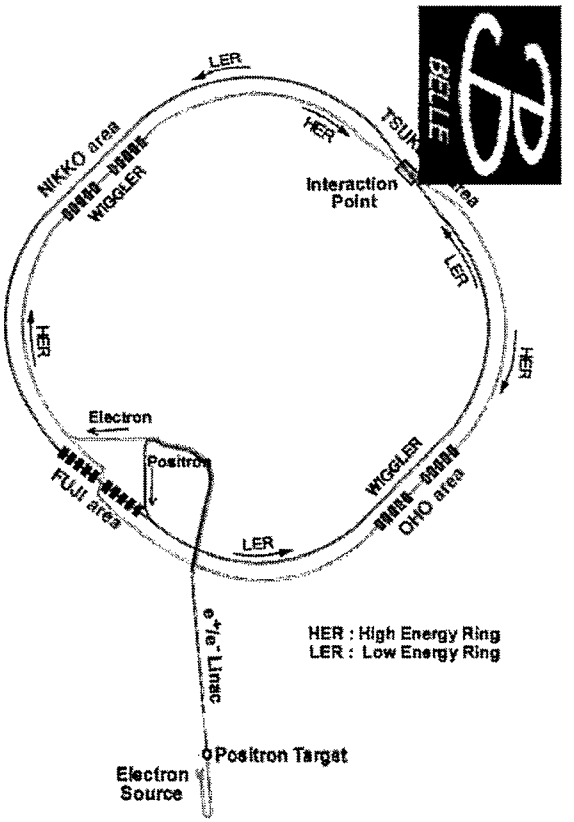
Statistical sensitivity for 32pb$^{-1}$ (1 week of running)



# KEKB and the Belle Experiment

- KEKB
  - Asymmetric collider
  - 8GeV $e^-$ + 3.5GeV $e^+$
  - $\sqrt{s}$ = 10.58GeV (Y(4S))
  - Beam size: 100 $\mu m(\sigma_x)$ x 3 $\mu m(\sigma_y)$
  - Crossing angle: 11mrad

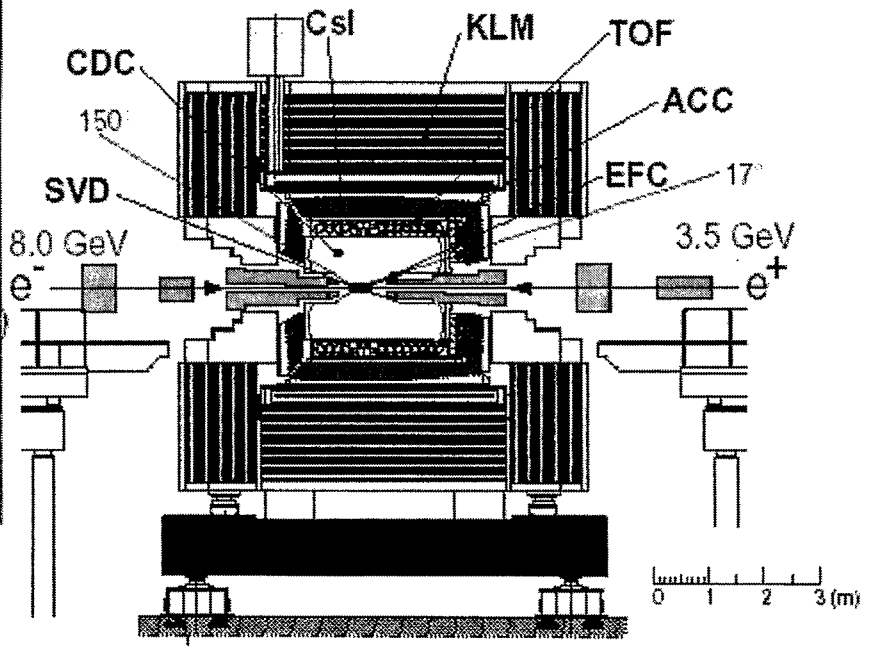


# Belle Detector Performance

Tracking part :

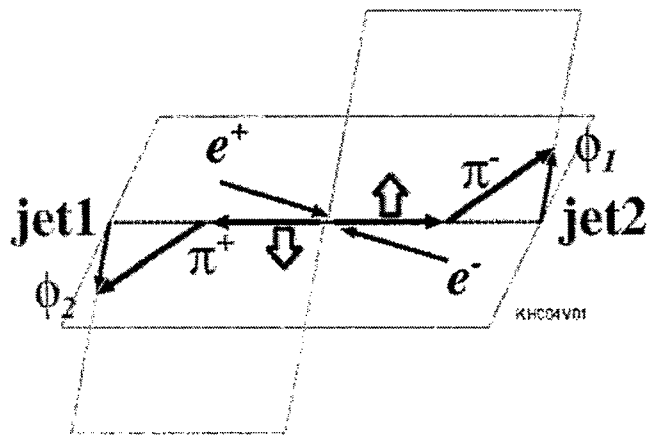
Central Drift Chamber(CDC)
(50 layers)
$\sigma_{p_t/p_t} \sim 0.35\%$ @ 1 GeV/c
Silicon Vertex Detector(SVD)
(3 silicon layers/double sided)
$\sigma \sim 55\mu m$ for 1GeV/c @ 90°



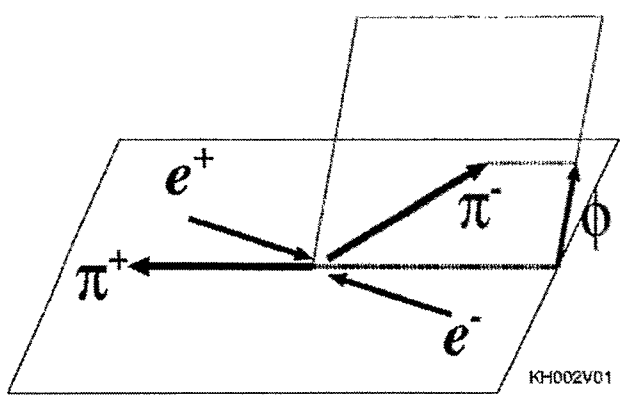

Particle identification ($K^{\pm}$ id up to 3.5 GeV/c)
Aerogel Cherenkov Counter(ACC) : n = 1.01 ~ 1.03
Time of Flight (TOF) $\sigma \sim 95$ ps
CDC (dE/dx) $\sigma_{dE/dx} \sim 7\%$
Electromagnetic Calorimeter(CsI(Tl) crystals) $\sigma_E/E_\gamma \sim 1.8\%$ @ 1 GeV
$K_L$ and Muon detector (KLM = 14 layers) $\mu$ : $\varepsilon > 90\%$ and fake rate ~2%

# Collins Fragmentation Function

- $e^+e^- \rightarrow \pi^+_{jet1}\pi^-_{jet2}X$
- Reaction plane defined with beam (z-axis) and jet axis
- Product ($\pi$) plane defined with $\pi$ and jet axis
- $\phi$: angle between the planes
- $A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(\phi_1+\phi_2)$




- Can analyze with/without using jet axis
  $A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(2\phi)$

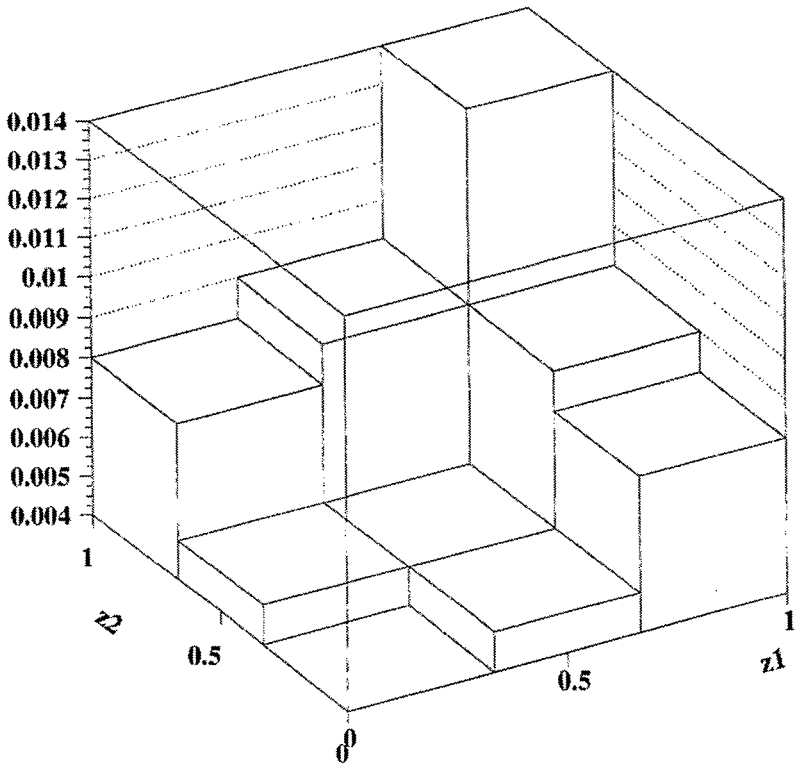


# Analysis Method

- Reproduce spin-averaged FF from data
  - To estimate error sizes
  - Precision input to NLO pQCD FF-analysis
- Use off-resonance data (also can use on-resonance data)
- Select light-quark events
  - Event-shape cuts
  - charm tag: vertexing, mass, etc.
  - bottom tag: in on-resonance; easy
- Require two-jet events
  - Define fragmentation functions inclusively
- Study azimuthal distribution as functions of $z$, $k_T$
  - Ratio between different analyzing powers
    Data/(MC w/o spin-dependent FF), unlike-sign/like-sign, etc.
  - Use $\tau$ productions for cross checks

# Available Statistics (off-resonance)

- #events ~ 27M (off-resonance data)
- Event selection
  - Thrust > 0.85
  - $\pi^+\pi^-$ in different hemispheres (for Collins function)
  - 8 bins in $2\phi$ ($\phi_1+\phi_2$)
- $\delta A = \delta(H_1^{\perp}H_1^{\perp})\cos(\phi_1+\phi_2)$
  = 1.4% of statistical error for high z-bin (> 0.5)
- More data available on-resonance



# J/Psi for pp and d-gold Collisions

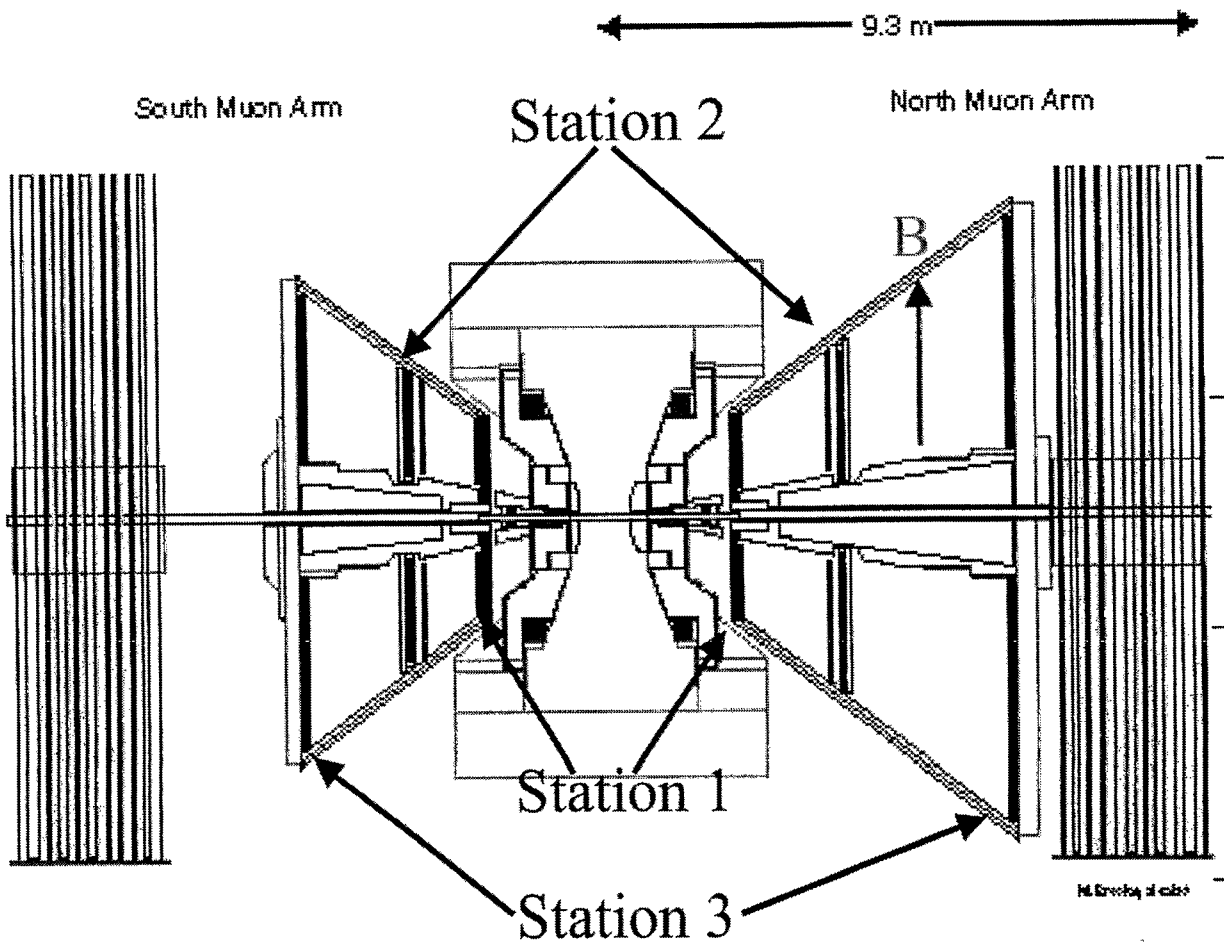
Douglas Fields

# $J/\Psi \rightarrow \mu\mu$ in $\sqrt{s} = 200$ GeV p-p and d-Au Collisions

Douglas E. Fields

University of New Mexico/RIKEN-BNL Research Center

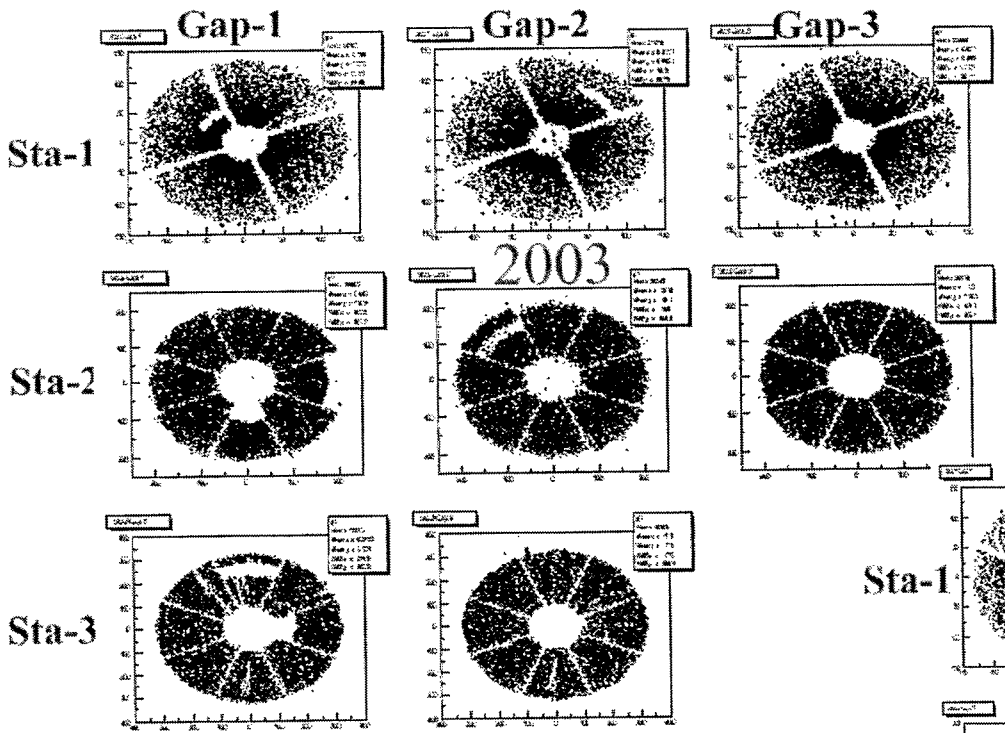
# Detector Overview




Central magnet Acts as pion absorber

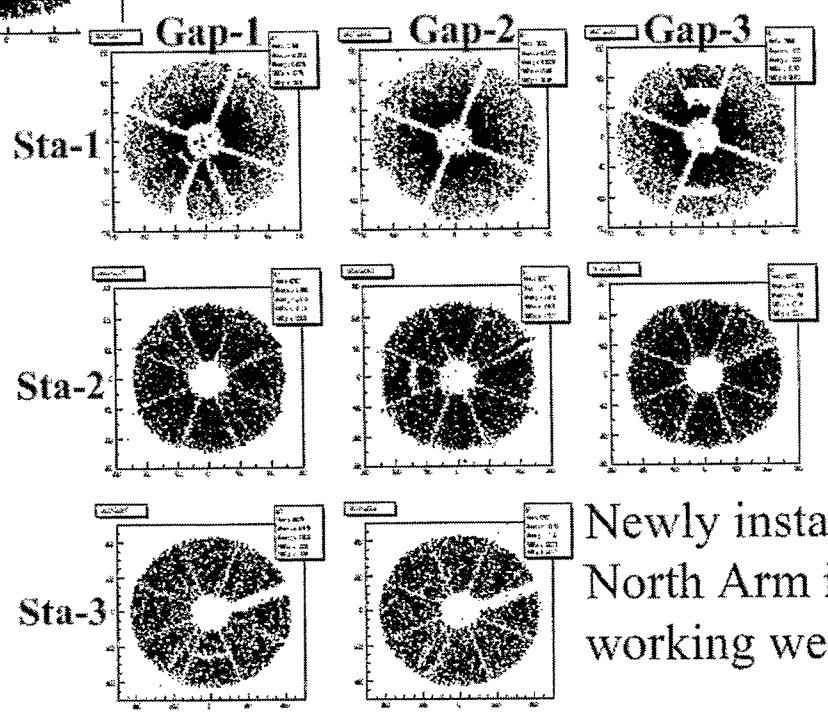
$\pi$/K rejection factor ~ $2.5 \times 10^{-4}$

Chamber resolution ~ 100 μm/plane




Radiographs of active area for South arm in run-II. (Three stations with 3 or 2 gaps each)

Vast improvement for present (run-III) after extensive repairs to electronics and HV during shutdown




Newly installed North Arm is working well

# Preliminary Run3 Results

## Luminosities in this analysis (so far)

| Run | Arm | Trig | nDst Trigs | RC Trigs (for runs used) | BBCLL 1 ($x10^9$) | BBCLL1 Eff ($x10^9$) | Lum ($nb^{-1}$) |
|---|---|---|---|---|---|---|---|
| dAu | N | 2D | 1088671 (96%) | 1139145 | 1.816 | 1.736 | 0.873 |
| | | 1D1S | 3350008 (91%) | 3696734 | 2.313 | 2.096 | 1.054 |
| | S | 2D | 3462112 (94%) | 3685783 | 1.786 | 1.678 | 0.844 |
| | | 1D1S | 0 | 0 | 0 | 0 | Soon: ~1 |
| pp | N | 1D1S | 2902091 (90%) | 3210357 | 3.103 | 2.797 | 125 |
| | S | 1D1S | 938597 (98%) | 953267 | 3.418 | 3.365 | 151 |

Nominal Run3 Luminosities:

- dAu – 2.74 $nb^{-1}$
- pp – 352 $nb^{-1}$

~ 20 to 40% More expected

67$nb^{-1}$ in Run2

# Summary

- Both North and South Arms installed and performing well.
- Problems in previous runs with MuID trigger should be better this run with tunnel shielding and new LL1.
- Run3 analysis of J/Ψ approaching completion for both pp and d-Au runs.
- Challenge for Au-Au.
- More luminosity for pp - spin physics with muon arms!

# $\pi^0$ Azimuthal Anisotropy in $\sqrt{s_{NN}}$ = 200 GeV Au + Au Collisions

Masashi Kaneta

# $\pi^0$ $v_2$ study in $\sqrt{s_{NN}}$ = 200GeV Au+Au collisions

KANETA, Masashi

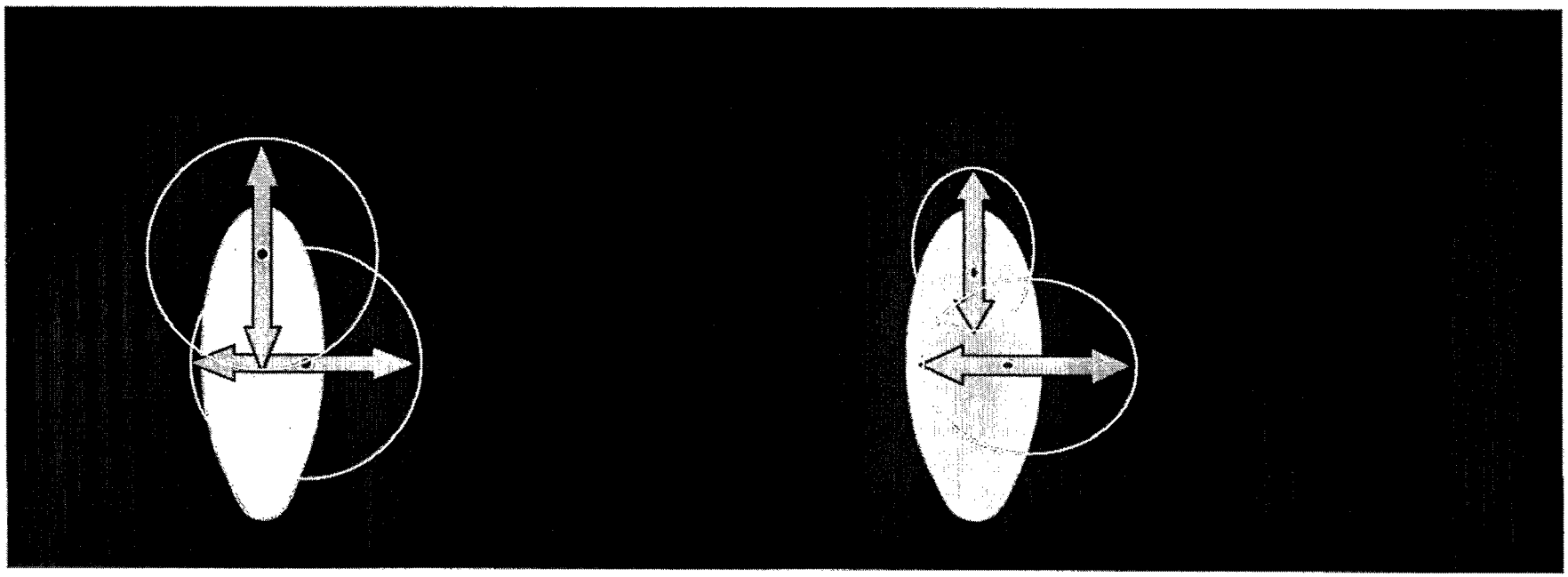
金田雅司

*for the PHENIX Collaboration*

*RIKEN-BNL Research Center*

# Event anisotropy in high $p_T$

- Hadron production in high $p_T$ come from jet production
  - jet itself has NO event anisotropy for azimuthal direction
- Jet quench will make an event anisotropy due to different energy loss in different direction
  - for example M.Gyullasy, I.Vitev, X.N.Wong, PRL86 (2001) 2537



# Method of $\pi^0$ $v_2$ Measurement

- Define reaction plane by charged multiplicity on Beam-Beam Counters
- $\pi^0$ reconstruction from gamma measured by Electro-Magnetic Calorimeter (EMC)
  - For each $p_T$, azimuthal angle, centrality
- Combine both information
  - Counting number of $\pi^0$ as a function of

$$E\frac{dN^3}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T\,dp_T\,dy}\left(1+\sum_{n=1}^{\infty} 2\,\underline{v_n^{measured}}\cos[n(\underline{\phi}-\underline{\Psi_r})]\right) \text{ where } n=1,2,3,....$$

event anisotropy parameter measured

azimuthal angle of the particle

reaction plane angle

$$v_n^{real} = v_n^{measured} / (\text{reaction plane resolution})_n$$

Note: the detail of reaction plane definition will be found in **nucl-ex/0305013**

# $\pi^0$ Identification

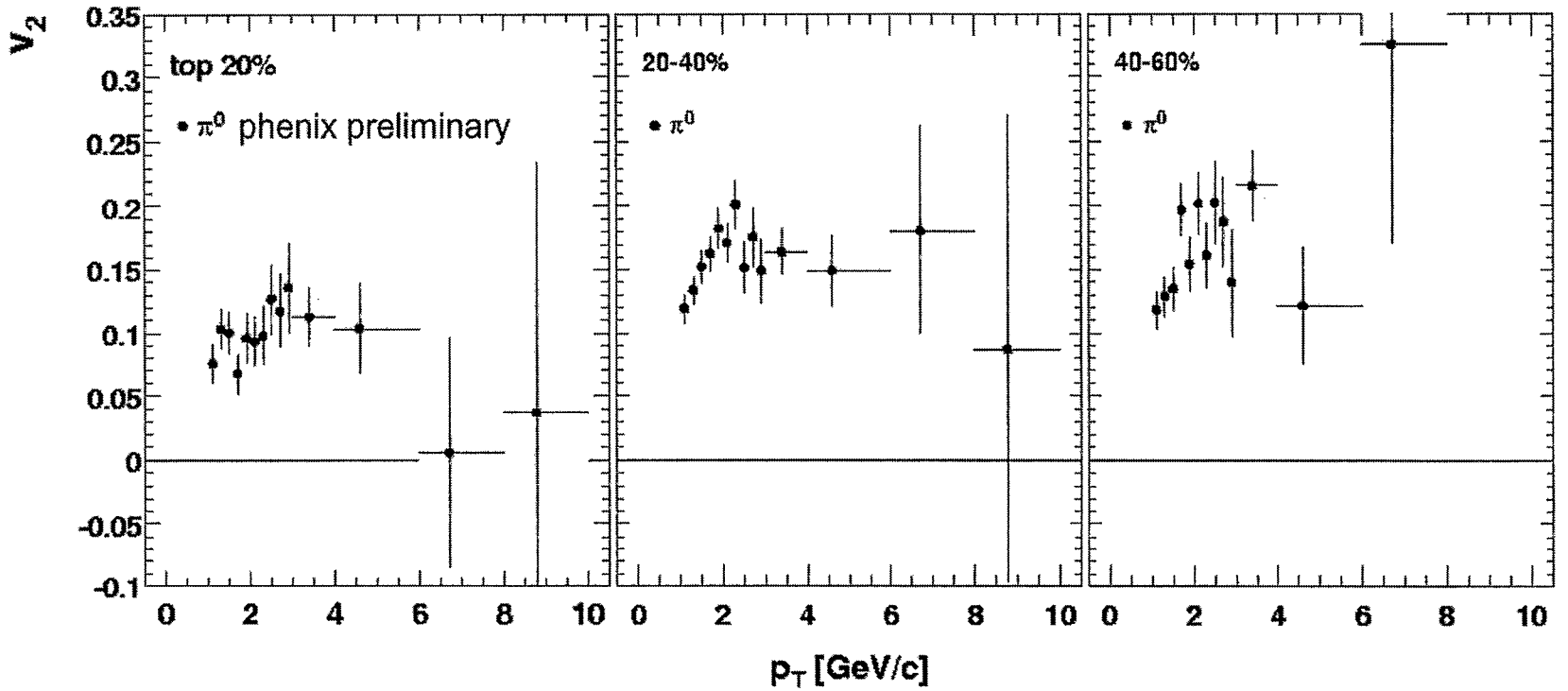
- Requirement for photon
  - Dead and noisy EMC towers are removed for the analysis
  - Energy of shower on EMC>0.040 [GeV]
  - PID cuts: $\chi^2<3$ for photon probability
  - |TOF|<1.2 [ns]
  - Note: those cut are loser than single $p_T$ distribution analysis
- For $\pi^0$
  - Asymmetry cut: $|E_1-E_2| / (E_1+E_2) < 0.8$
  - Combinatorial background is estimated by event mixing
    - Classes categorized for event mixing
      - centrality : every 10%
      - BBC Z Vertex : every 10cm in ±30cm
      - reaction plane direction in PHENIX detector : 24 bins in $\pm\pi$

# One of difficulties (?) is..

- The analysis of $\pi^0$ $v_2$
  - Counting number of $\pi^0$ as a function of centrality, $p_T$ and $\phi$-$\Phi_R$
  - The analyses (fitting of combinatorial background, its subtraction, counting $\pi^0$ and so on) are done by macro automatically
  - However, we need to think it is not perfect, that is, it may fail sometime
- Therefore, ....

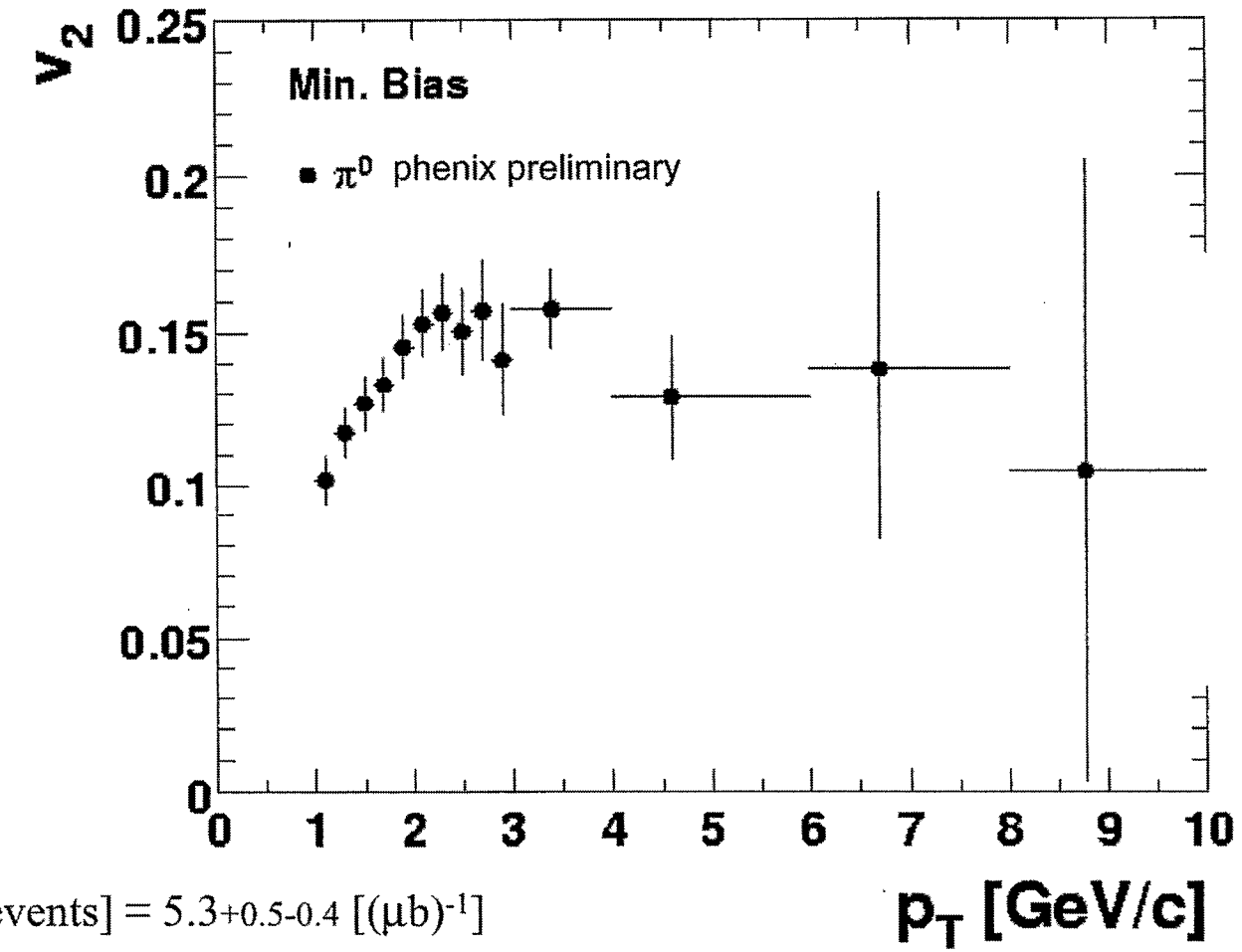
# $v_2$ vs. $p_T$ vs. Centrality from 200GeV Au+Au

Statistical error is shown by error bar
Systematic error from $\pi^0$ count method and reaction plane determination is shown by gray box



# $v_2$ vs. $p_T$ (Minimum Bias) from 200GeV Au+Au

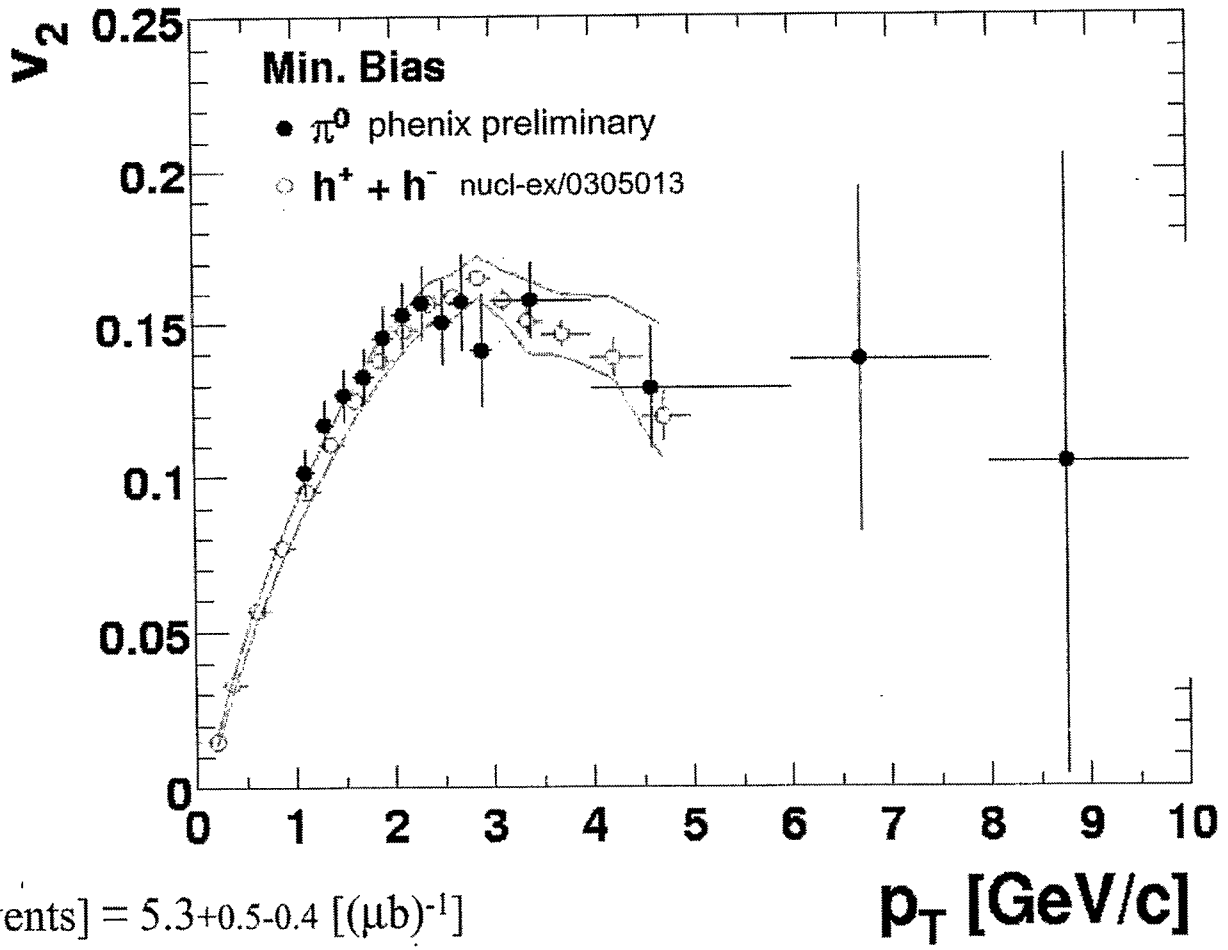
- Identified particle $v_2$ up to $p_T$=10GeV/c




$36.3\times10^6$ [events] = $5.3^{+0.5}_{-0.4}$ [$(\mu b)^{-1}$]

# $v_2$ vs. $p_T$ (Minimum Bias) from 200GeV Au+Au

- Identified particle $v_2$ up to $p_T$=10GeV/c



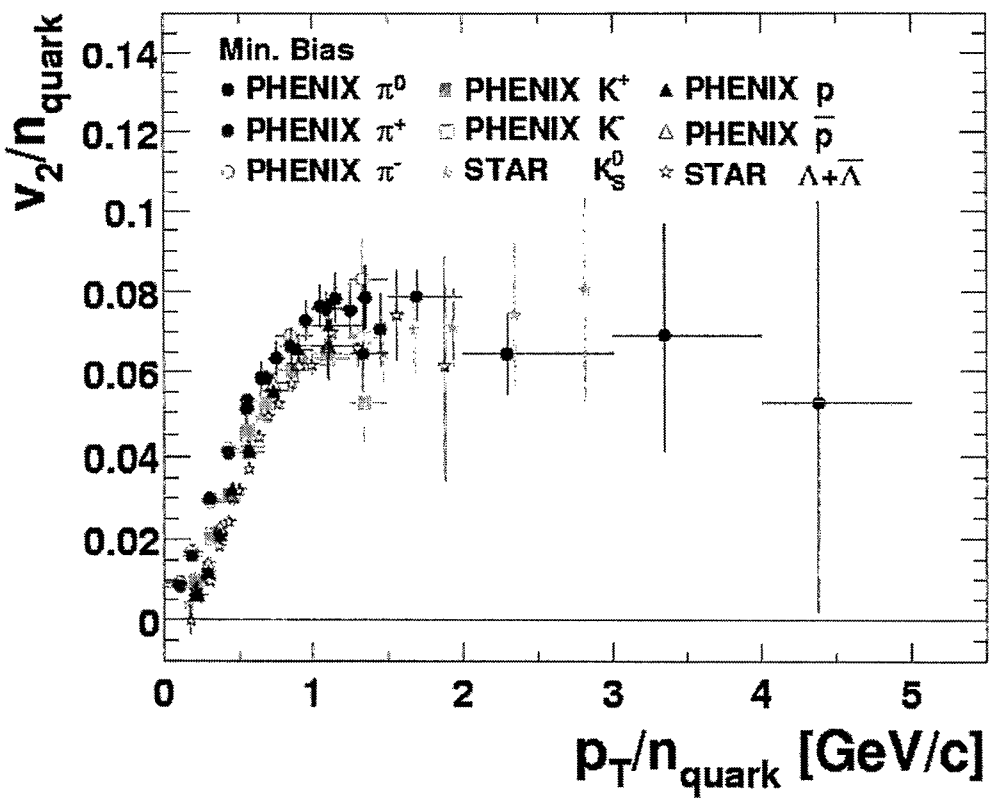

$36.3\times10^6$ [events] = $5.3^{+0.5}_{-0.4}$ [$(\mu b)^{-1}$]

# Quark Coalescence

- Phys. Rev. Lett. 91 (2003) 092301, D.Molnar and S.A. Voloshin
- $q\bar{q} \rightarrow$ meson, $qqq(\bar{q}\bar{q}\bar{q}) \rightarrow$ Baryon

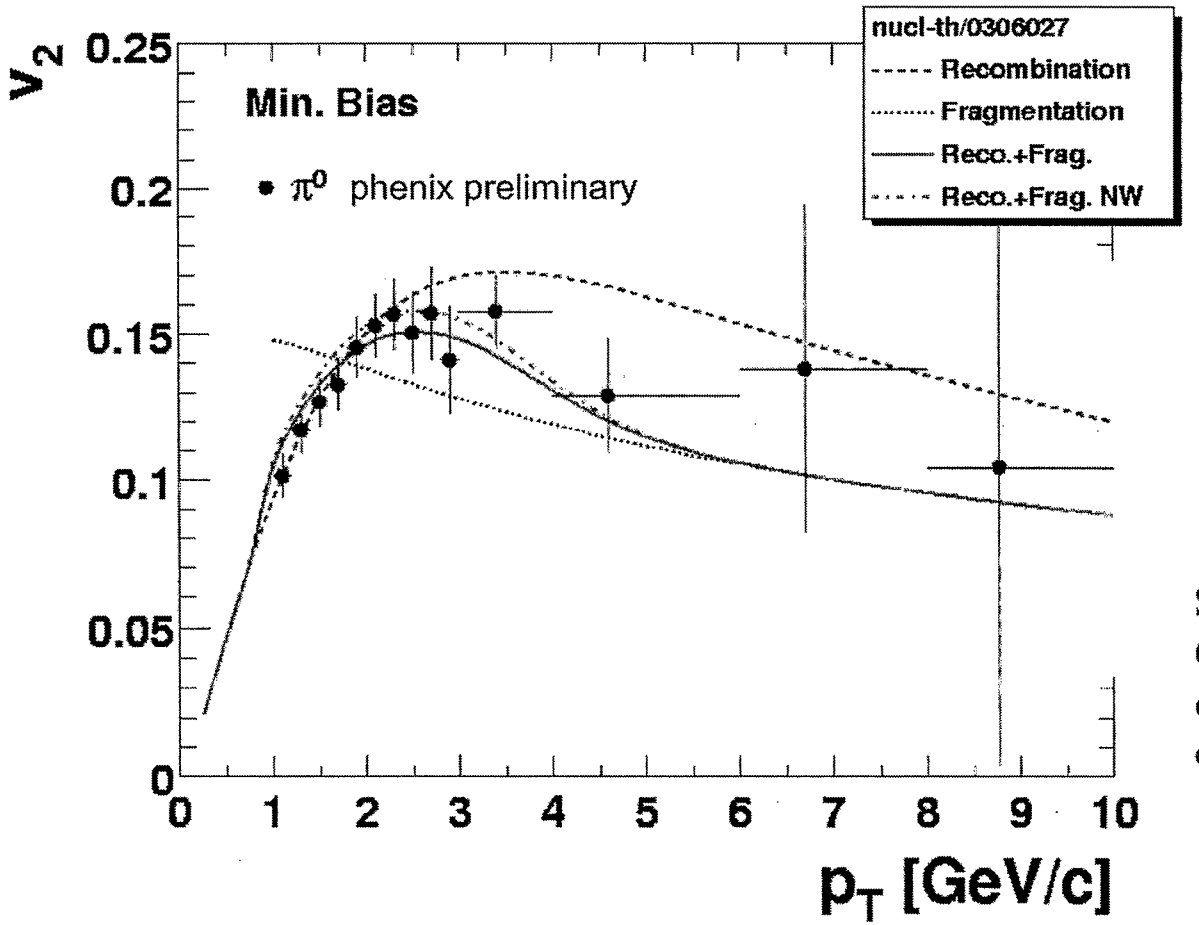
$$v_{2,M}(p_\perp) \approx 2v_{2,q}\left(\frac{p_\perp}{2}\right), \qquad v_{2,B}(p_\perp) \approx 3v_{2,q}\left(\frac{p_\perp}{3}\right),$$

- How data looks like?




- Non-strange and strange meson and baryon seems to be merged around $p_T/n_{quark} \approx$1-3GeV/c
- But we need more statistics to conclude it

# Comparison with a model




Special thanks to
C. Nonaka (one of authors)
of nucl-th/0306027 for
data of model calculation

Comparison with a model which is described in nucl-th/0306027. Here we don't want to discuss which model can describe the data. To conclude which model can describe the data, we need much more statistics in high $p_T$ region.

# Outlook

- Feature plan of analysis
  - Using high $p_T$ gamma trigger in run2 Au+Au data
    - We will have about twice statistics in high $p_T$
    - need to study trigger bias
      - therefore, present analysis results are from minimum bias trigger events
  - $\eta$ $v_2$ is also available by same method
  - PHENIX has photon $v_2$ also (STAR also, but not opened yet)
  - photon $v_2$, especially low $p_T$!
- RHIC run4 Au+Au, it will be
  - Much more statistics
    - Detail study of $v_2$ shape around $p_T$=2-4GeV/c
  - Much higher $p_T$
    - We want to know where is the end of finite $v_2$ in very high $p_T$

# Electrons and Direct Photons

Yasuyuki Akiba

# Single electron production and direct photon production at RHIC

Y. Akiba

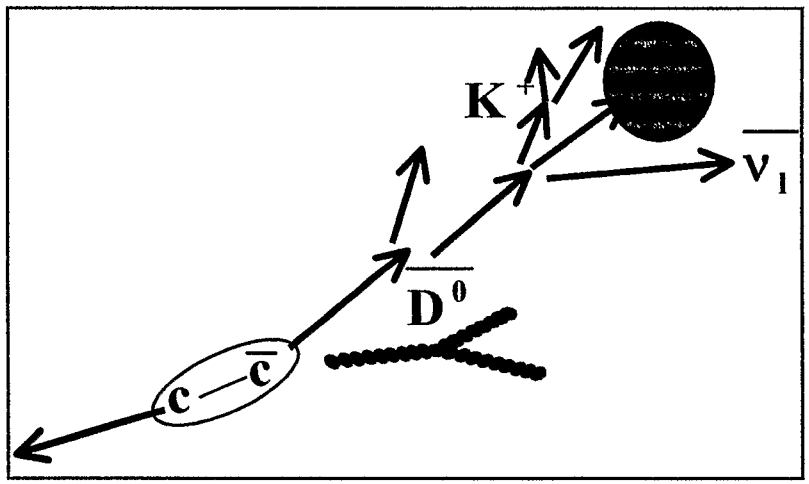
# Au+Au →e : motivation

- From single electron momentum distribution, charm production in Au+Au collision can be extracted.
- This method was used in RUN1 of RHIC.

$$\sigma_{c\bar{c}}^{0-10\%} = 380 \pm 60 \pm 200\mu b$$

$$\sigma_{c\bar{c}}^{0-92\%} = 420 \pm 33 \pm 250\mu b$$

- From charm production we can probe the earliest stage of Au+Au collision at RHIC
  - Gluone density
  - Energy loss of c-quark in dense matter
  - Reference to J/Ψ production

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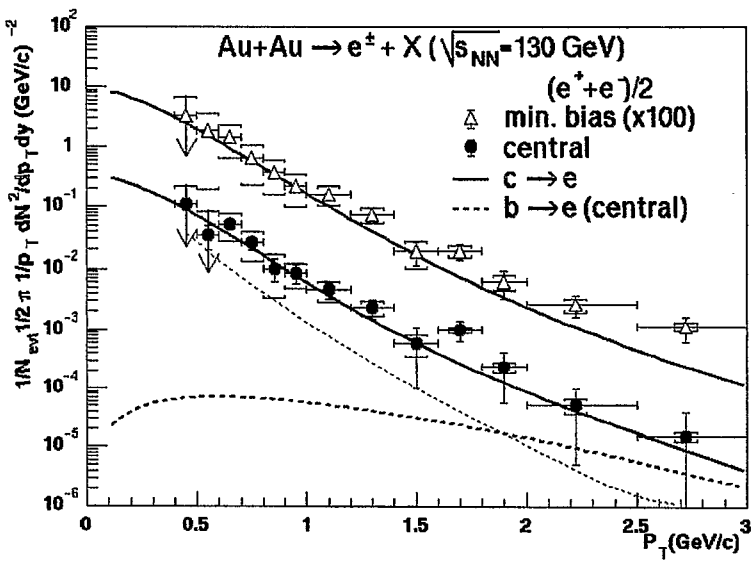
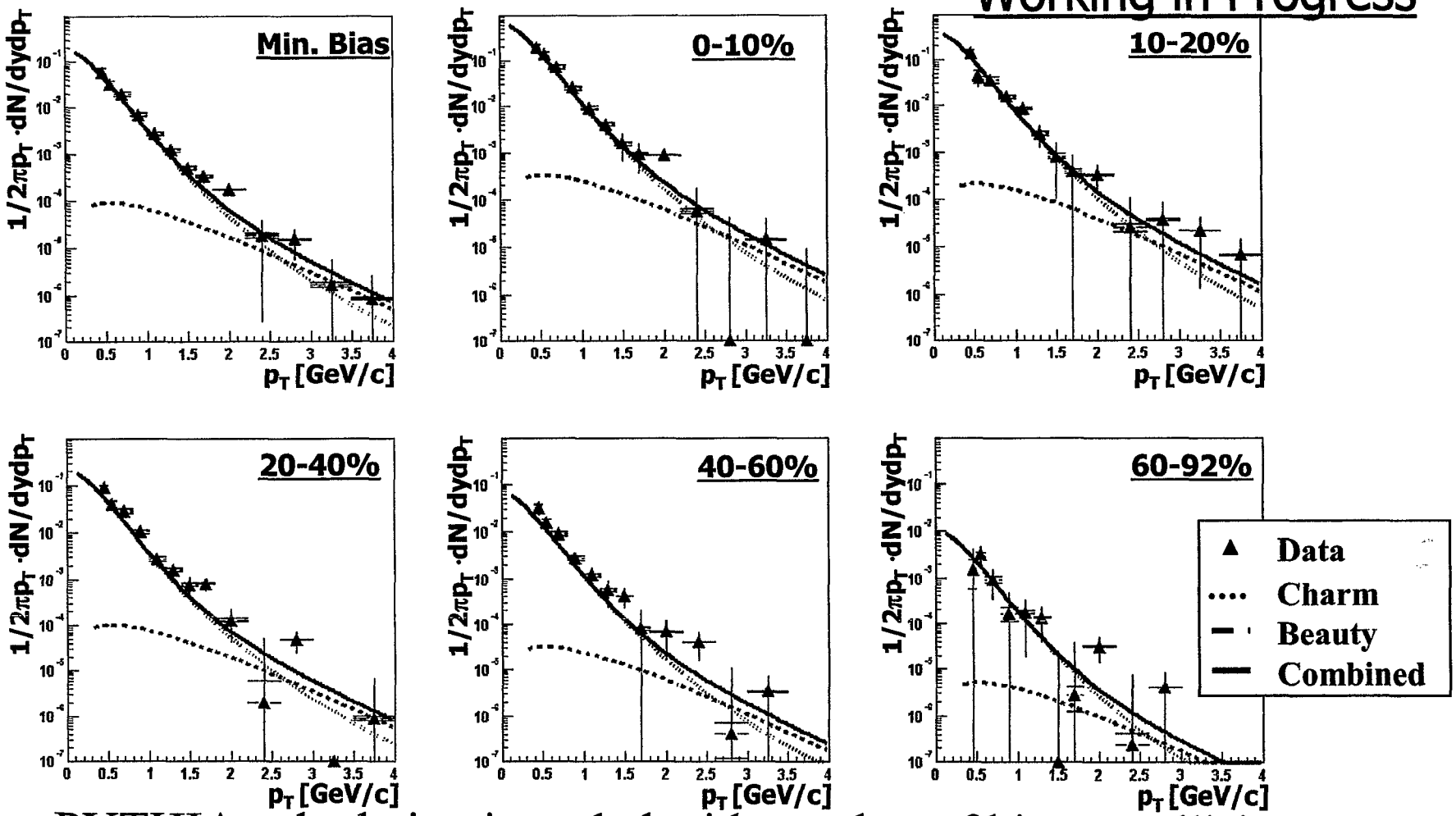


# Centrality Dependence of Non-Photonic Electrons

Working in Progress



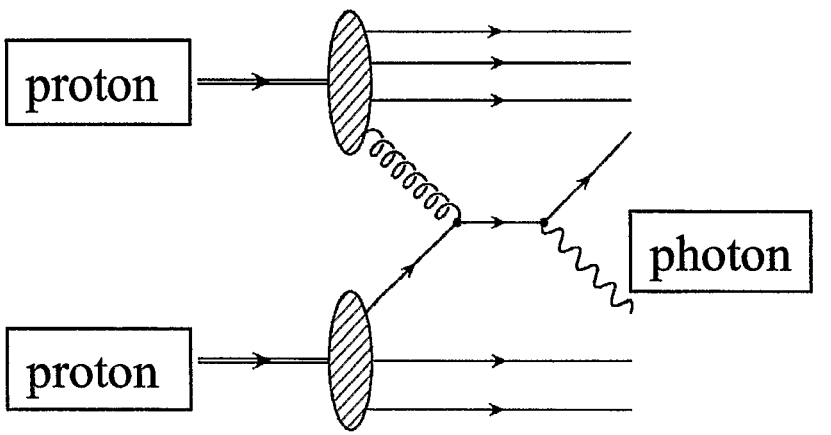

- PYTHIA calculation is scaled with number of binary collisions.
- Well described for all centralities.

Presented in JPS

# Direct photon in pp

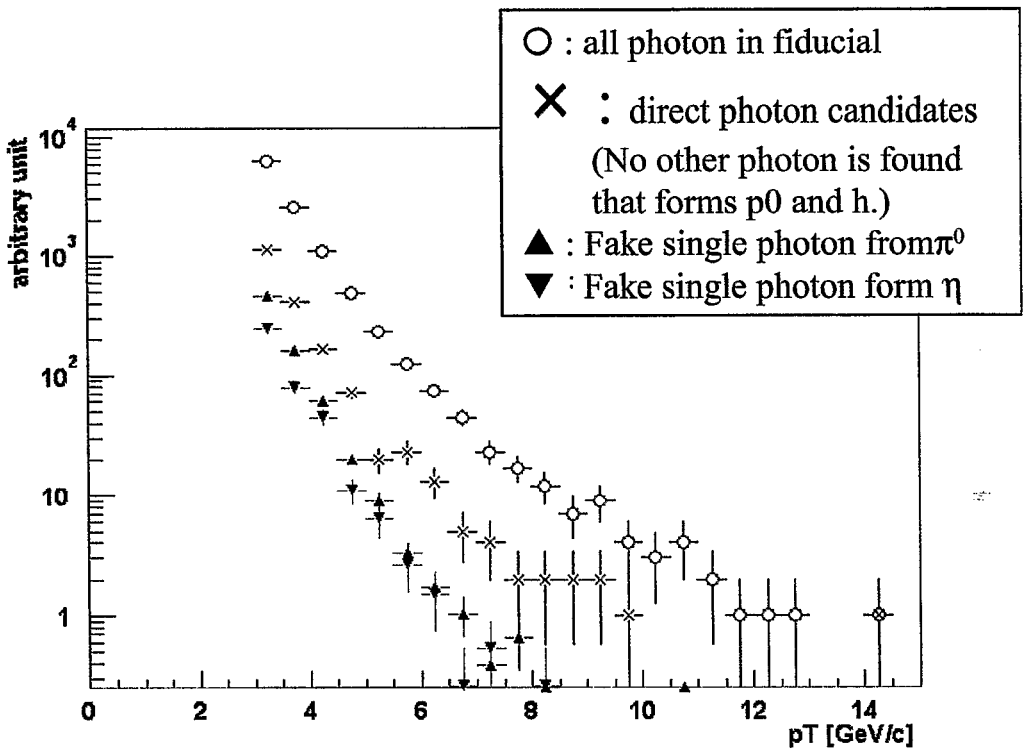
- High Pt direct photon measurement in pp
  - Test of pQCD
  - Measurement of G(x)
  - Measurement of $\Delta G(x)$
- Backgrounds of direct photon are photons from light hadron decays
  - $\pi 0 \rightarrow \gamma\gamma$
  - $\eta \rightarrow \gamma\gamma$
- Expected S/B is small
  - $\gamma/\pi^0 \sim$ a few % at $p_T$=4 GeV/c

**Quark-Gluon Compton Scattering**



# Present status

- T. Horaguchi (Tokyo Inst. Tech, JRA2) is working on the analysis.
- Analysis seems to indicate the presence of direct photon signal that is consistent with pQCD calculation.
- Other groups in PHENIX are also looking for direct photon signal in pp.
- Recently, pre-PPG has been formed.
- RUN3 pp data can be added to the analysis
- Present goal is to present "PHENIX preliminary" data of direct photon in QM2004 conference in January.




Plot shown in the fall JPS meeting by T. Horaguchi

# Vertex Detector for PHENIX

Yuji Goto

# *Vertex Detector for PHENIX*

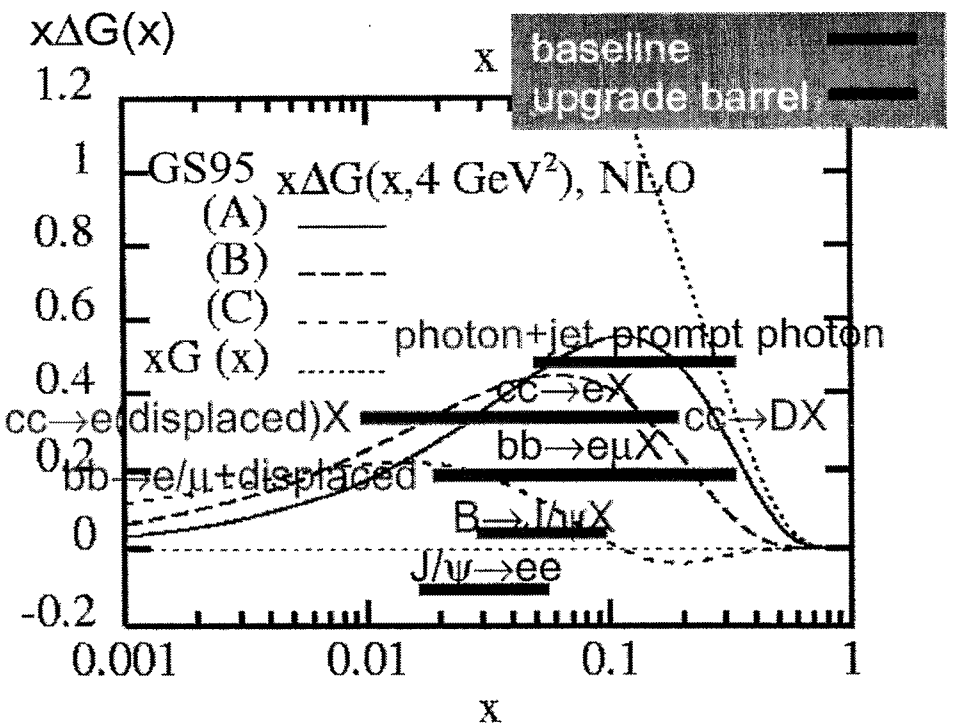
RBRC Review

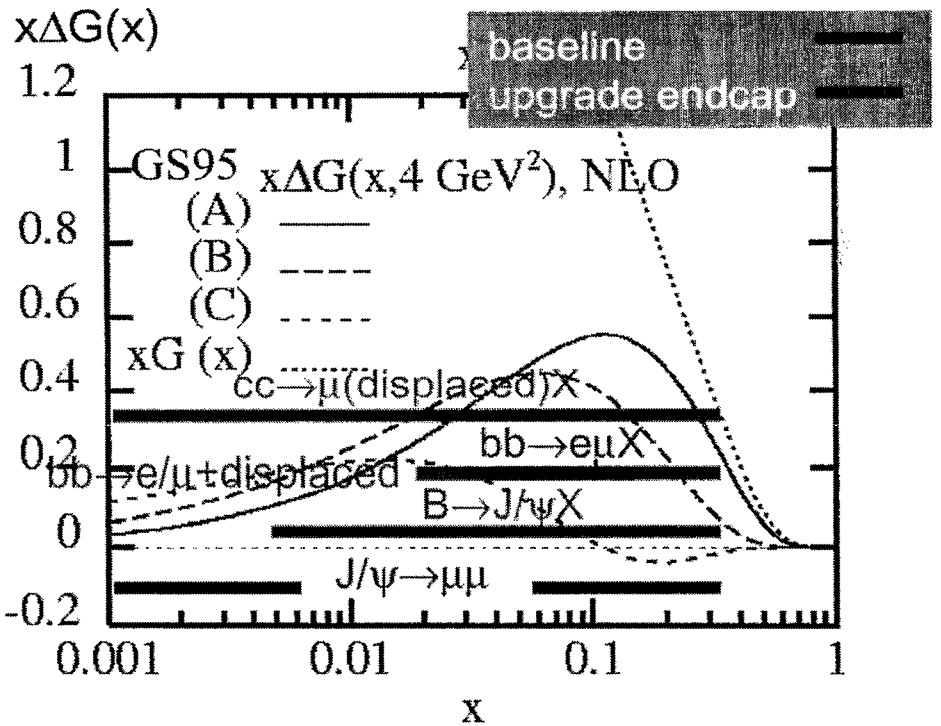
November 20, 2003

Yuji Goto

# *Spin physics with VTX*

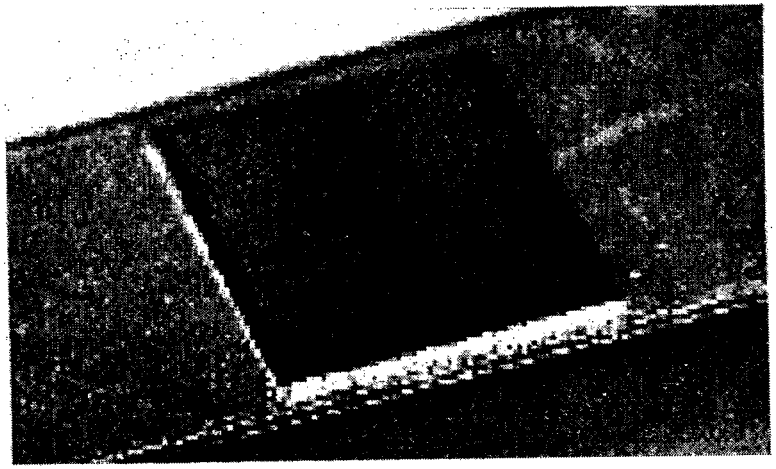
- Gluon polarization measurement
  - covering $x_{gluon}$ coverage
  - photon+jet and heavy-flavor production

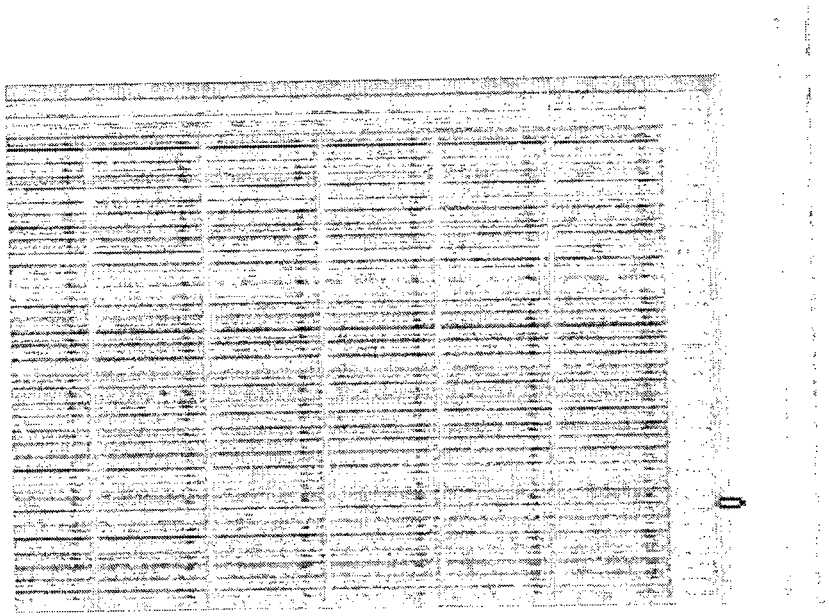


# *Silicon pixel detector*

- ALICE1 pixel hybrid
  - CERN test beam this month …
  - ALICE production will start soon ???
  - It will include PHENIX chip (CERN-RIKEN contract)



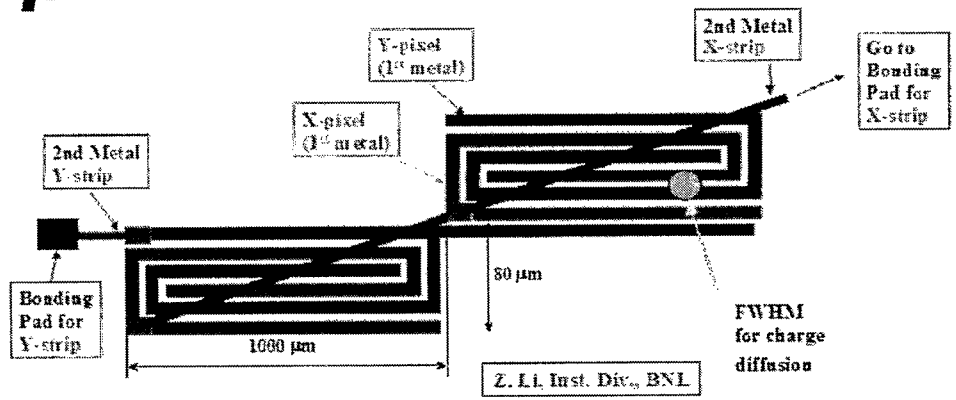


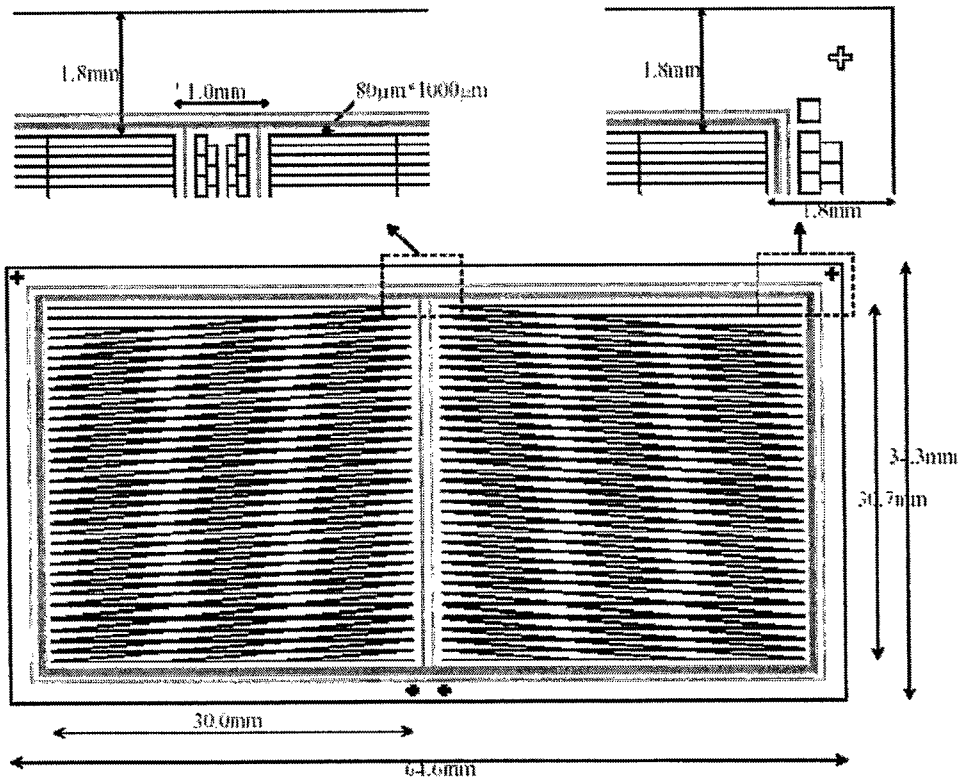
# *Silicon pixel detector*

- Pilot chip & bus
  - at CERN
    - ALICE pixel bus R&D
      - Cu (5 layers): tested
      - Cu+Al (7 layers): will be available, and used for test beam
      - Al (5 layers): will be available soon …
        - » common power/ground lines for digital and analog parts
    - pilot chip
      - minor-modified version for PHENIX will be made: zero suppression study
      - parallelization study will be done next …
        - » with bus study
  - In Japan
    - test production of pixel MCM board and bus will be done …

# Silicon strip detector

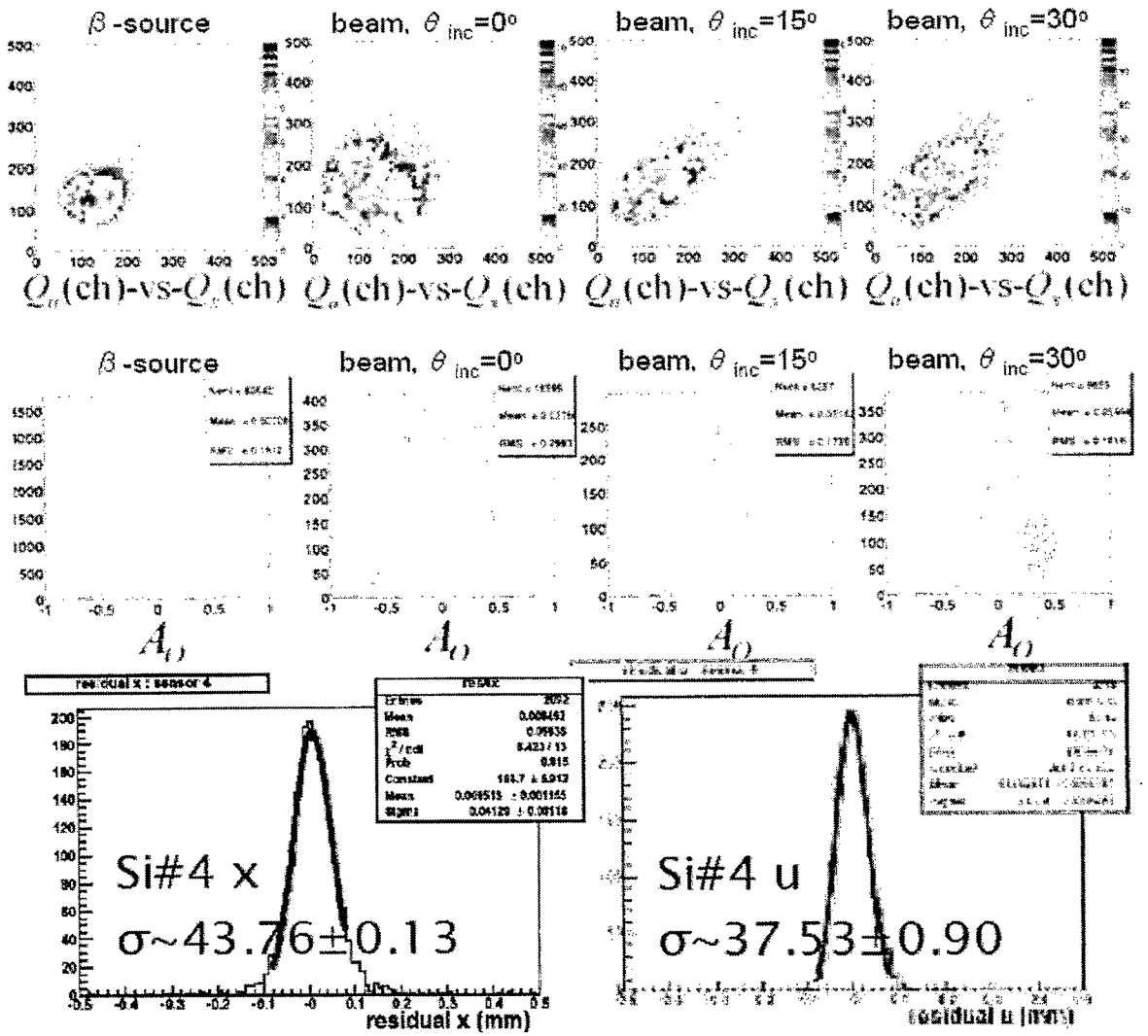
- Prototype v.1
  - single-sided
  - two-dimensional projection



# *Silicon strip detector*

- Test results
  - β-source
  - KEK test beam
  - prototype v.1
    - position resolution
      - 23-26μm (23μm expected)
    - efficiency
      - ~97% for good sensors
    - charge division
      - need finer lines



# THEORY PRESENTATIONS

# Matrix Models and Lattice Data for the QCD Dirac Operator with Chemical Potential

Tilo Wettig

# Matrix models and lattice data for the QCD Dirac operator with chemical potential

Tilo Wettig (Yale and RBRC)

work done with Gernot Akemann (Saclay), hep-th/0308003 $\longrightarrow$ PRL



Outline:

1. Motivation
2. Matrix models and the domains of weak and strong non-hermiticity
3. Comparison with lattice data

## Matrix models at $\mu > 0$

Stephanov (1996): matrix model for Dirac operator

$$Z(\mu) = \int_{\mathbb{C}^{(N+\nu)\times N}} dW\, e^{-N \text{ tr } WW^\dagger} \prod_{f=1}^{N_f} \det \begin{pmatrix} m_f & iW+\mu \\ iW^\dagger + \mu & m_f \end{pmatrix}$$

- explains failure of quenched approximation at $\mu > 0$
- difficult to compute eigenvalue correlations on the scale of the mean level spacing

Akemann (2002): complex eigenvalue model (with $1 - \tau^2 \mathrel{\widehat{=}} \mu^2$)

$$Z(\tau) = \int_{\mathbb{C}} \prod_{j=1}^{N} dz_j dz_j^* \; |z_j|^{2\nu+1} \prod_{f=1}^{N_f} (z_j^2 + m_f^2) e^{-\frac{N}{1-\tau^2}\left[|z_j|^2 - \frac{\tau}{2}(z_j^2 + z_j^{*\,2})\right]} \Delta^2(z^2)$$

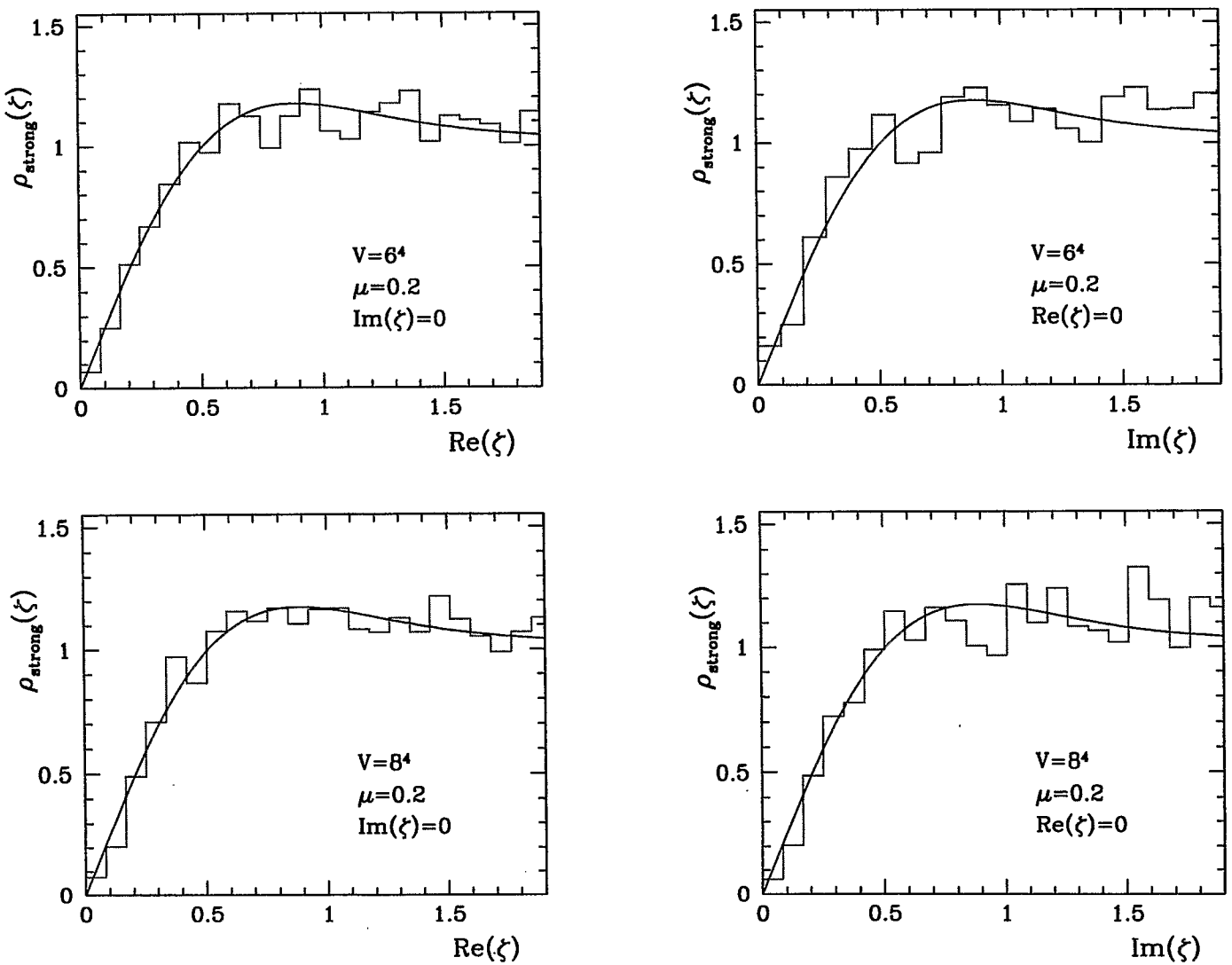
- complex extension of the chiral Gaussian Unitary Ensemble
- spectral correlations computed for $N_f = 0$ and for $N_f > 0$ "phase-quenched" massless flavors

- lattice simulations with staggered Dirac operator (Wilson has complex eigenvalues even at $\mu = 0$, Neuberger and DW too expensive)
- need high statistics (20,000 configurations for each parameter set)
- $\beta = 5.0$ strong coupling (can be justified for this particular purpose)
- $\nu = 0$ because of zero-mode shift (Smit-Vink 1985)
- <u>no free parameter</u>: scale is set via mean level spacing

$$d_{\text{weak}} = \frac{\pi}{\sqrt{2}N} \qquad d_{\text{strong}} = c\sqrt{\frac{1-\tau^2}{2N}} \text{ with } c = 1.1429$$

- gauge fields generated in quenched approximation
  $N_f \to 0$ limit is subtle at $\mu > 0$
  - analytical results from $N_f \to 0$ limit of "phase-quenched" theory
    $\longrightarrow$ corresponds to theory with quarks and conjugate quarks
    $\longrightarrow$ should agree with quenched lattice data
  - results computed at $N_f > 0$ should describe unquenched lattice data (future work)

# Comparison with lattice data: strong nonhermiticity



# Dynamical Domain Wall Fermions

Christopher Dawson

# Dynamical Domain Wall Fermions

Chris Dawson, RIKEN/BNL Research Center

[RBC Collaboration]

# Details

- Dynamical simulations cost $\approx$ 100 times more than a quenched simulations.

- We are using several improvements to the HMC algorithm

  1. Improved fermion force term
  2. Chronological inverter
  3. Multiple gauge-step leapfrog.

  that give a factor of $\approx$ 3 speed-up.

- Total number of "trajectories" collected so far:

  - $am_f = 0.02$ - 4716 trajectories (7 months on 200GF)
  - $am_f = 0.03$ - 4785 trajectories
  - $am_f = 0.04$ - 3445 trajectories

  and we take one "independent" configuration every 50 trajectories.

## Summary

- Modifications to the standard algorithms have provided approximately a factor of 2-3 in simulation speed.

- With the DBW2 action, dynamical DWF seem to be practical for lattice spacings around $a^{-1} \approx 2\text{GeV}$. Although the chiral symmetry breaking is larger than for a quenched calculation at a similar scale.

Future/Now

- In the progress of gathering more statistics while calculating
  - Spectrum ( $\eta'$ )
  - Weak Matrix Elements ( $B_K$, $\epsilon'/\epsilon$ )
  - Structure Functions
  - ....

# Pion Electromagnetic Form-factor with Domain Wall Fermions in Lattice QCD

Yukio Nemoto

# Pion electromagnetic form-factor with domain wall fermions in Lattice QCD

Yukio Nemoto for RBC collaboration

RIKEN-BNL Research Center

# Simulation parameters

- **Fermion action:**
  **Domain wall fermion**$(L_S = 12, M_5 = 1.8)$
  $m_{\rm f}a = 0.02, 0.04, 0.06, 0.08$ ($m_\pi = 390 \sim 760$ **MeV)**

- **Gauge action:**
  **DBW2 (quench)** T.Takaishi, PRD54,1050(1996)

$$S_G = -\frac{\beta}{3}\left((1-8c_1)\sum P[U] + c1\sum R[U]\right)$$

$P$: **plaquette,** $R$: $1\times 2$ **rectangle,** $c_1 = -0.14069$

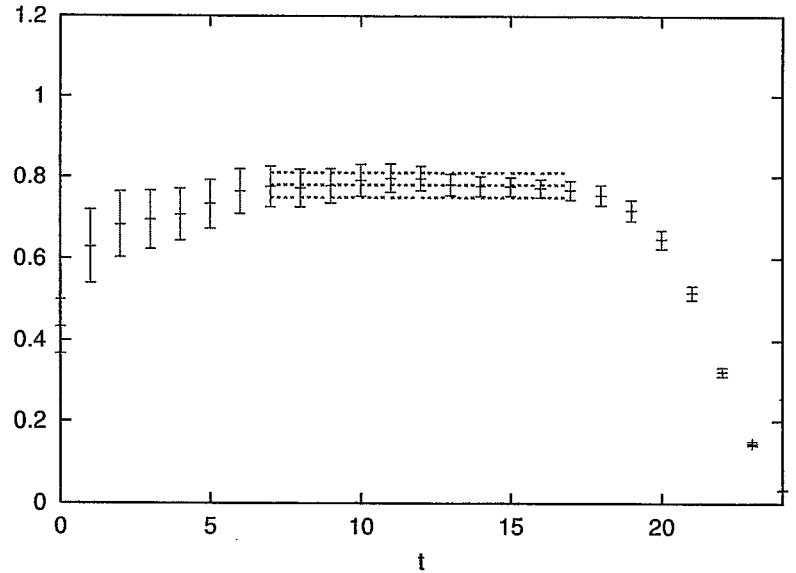
$\beta = 0.87, (a^{-1} = 1.31(4)$ **GeV)**

- **Lattice:**
  **Size:** $16^3 \times 32$, **Volume**$\sim (2.4\,\mathrm{fm})^3$
  **All the quark propagators are averaged over periodic and anti-periodic b.c. in time.** $\longrightarrow$ **Effective temporal size is doubled, 32** $\rightarrow$ **64.**

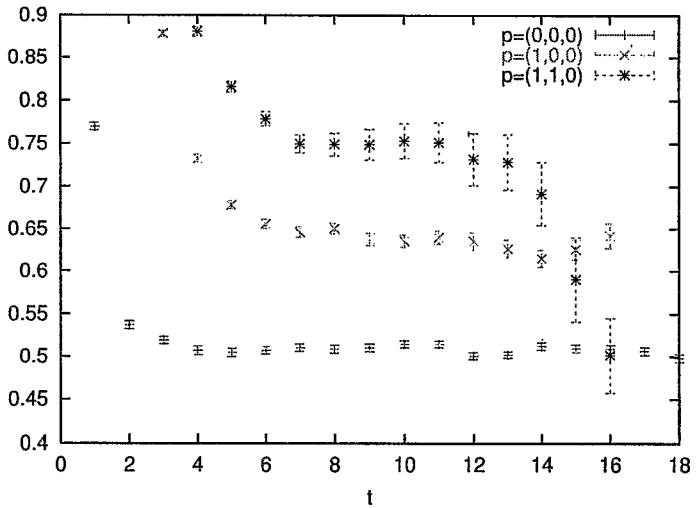
- **Computer: QCDSP (RIKEN-BNL-Columbia)**

$$m_\pi \sim 660 \text{ MeV } (m_f = 0.06)$$

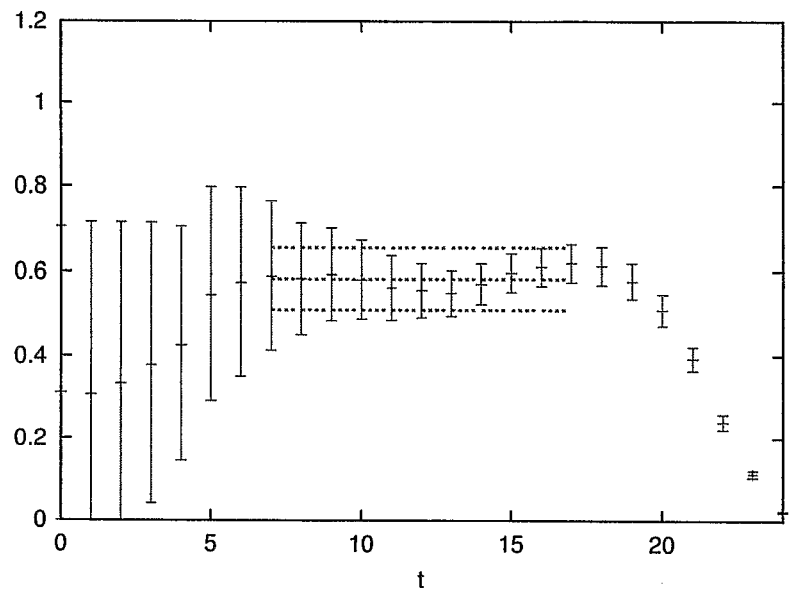
$$F_\pi(Q^2 = 0.26 \textbf{ GeV}^2) \Rightarrow$$




**Effective masses for PS mesons**




$$F_\pi(Q^2 = 0.53 \textbf{ GeV}^2) \Rightarrow$$



# Summary & Outlook

**The pion EM form-factor in DWF + DBW2 gauge action**

- $F_\pi(Q^2 = 0) = 1$ **is well satisfied.**
- **small** $m_{\mathrm{f}}$ **and linear dependence?**

**Future:**

- **More statistics**
- **Higher momenta**
  **functional form of** $F_\pi(Q^2)$**, comparison with VMD, charge radius...**
  **Another way to measure the 3-point function is needed. (on-going)**
- **Related quantities**
  **transition form-factor of the vector meson**

# Application of DWF to Massive Quarks

Norikazu Yamada

# On-shell improvement of Massive DWF

Norikazu Yamada

RIKEN BNL Research Center

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RBRC Scientific Review Committee Meeting
November 20, 2003

# Heavy quark on the lattice

## Obstacles to 5% determination

- (quenched approximation)
- finite volume effect
- chiral extrapolation, $\cdots$
- **heavy quark on the lattice**

Heavy quarks could cause a large discretization error.

e.g.) free quark propagator

$$S_q(p) \quad \rightarrow \quad \frac{i\not{p} + m}{p^2 + m^2}$$

$$+O((am)^2, (a^2 m\vec{p}), (a\vec{p})^2)$$

($a$ : lattice spacing)

smaller $a \leftrightarrow$ larger cost

Presently $am_c \gtrsim 0.3$, $am_b \gtrsim 1.2$

$\Downarrow$

$O((am)^n)$ and $O((a\vec{p})(am)^n)$ errors $> 5\%$

**must be removed!**

## On-shell improvement

Symanzik, Lüscher, Weisz

Improving the lattice action only on mass shell is enough for masses, WME, $\cdots$.

e.g.) free quark propagator

$$S_q(p)|_{\text{on-shell}} \quad \sim \quad \frac{-\gamma_0 E + i\gamma_i p_i + m_1}{-E^2 + \vec{p}^{\,2} + m_1^2}$$

$$+O((a\vec{p})^2).$$

El-Khadra, Kronfeld, Mackenzie carried out this improvement to the Wilson heavy quark

- no $O((am)^n)$ and $O((a\vec{p})(am)^n)$
- only $a\vec{p} \ll 1$ is required. (possible)

**What happen if it is applied DWF?**

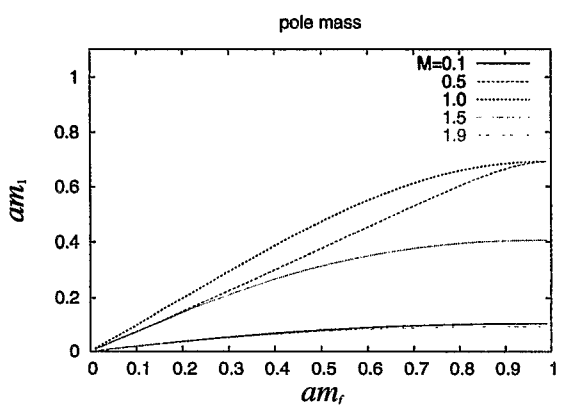
# Results

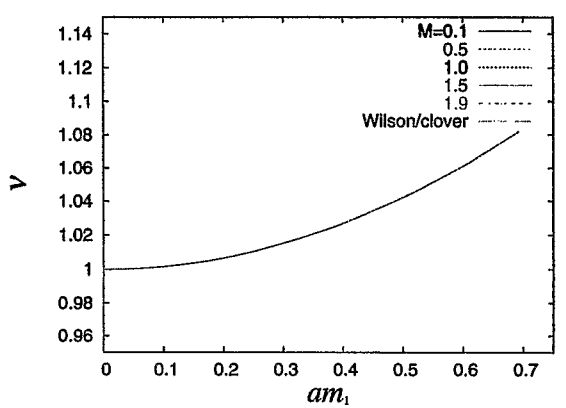
We found that the improvement is realized by replacing $D_{\rm wilson}(x,y)$ with

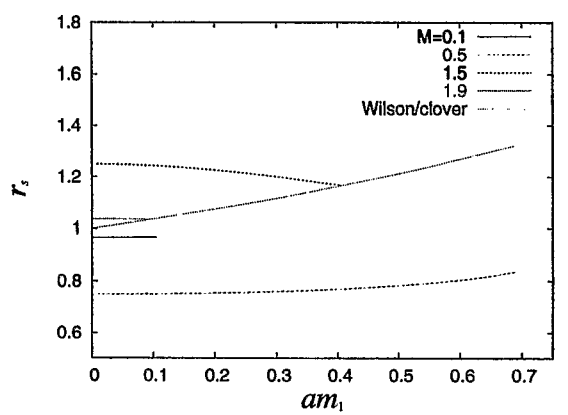
$$D_{\rm imp}(x,y) = \left(\gamma_0\Delta_0 + \nu \sum_i \gamma_i\Delta_i\right) - \left(\frac{r_t}{2}\Delta_0^2 + \frac{r_s}{2}\sum_i \Delta_i^2\right) - \left(c_E\,\frac{ig}{2}\sum_i \sigma_{0i}F_{0i} + c_B\,\frac{ig}{4}\sum_{i,j}\sigma_{ij}F_{ij}\right),$$

and get the parameters proper values.






$c_E{=}\nu$ and $c_B{=}r_s$.

# Vector and Chiral Gauge Theories on the Lattice

Takanori Sugihara

# Vector and chiral gauge theories on the lattice

Takanori Sugihara

RIKEN BNL Research Center

Brookhaven National Laboratory

hep-lat/0310061



## Chiral anomaly

Continuum theory

- $\mathrm{tr}\gamma_5 \neq 0$ (Fujikawa's method)
- Infinite degrees of freedom

Lattice theory

- $\mathrm{tr}\gamma_5 = 0$
- Finite degrees of freedom

Wilson terms reproduce chiral anomaly.

# This work

- Derivative as a Fourier trans of momentum
- Finite lattice
- Antiperiodic boundary conditions
- Lanczos factor (TS, PRD 68, 034502)
- Modification of chiral transformation

Main results

- Chiral anomaly on the finite lattice
- A single Weyl fermion on the lattice



# Doubler-free ultralocal derivative

Discrete Fourier transform with $\nabla_{n+N} = -\nabla_n$

$$\nabla_n = \frac{1}{N} \sum_{l=-N/2+1}^{N/2} i p_l e^{i2\pi \tilde{l} n/N}$$

Inverse transform

$$p_l = \sum_{n=1}^{N_c} F_n \nabla_n \left[ (\delta_{n,\frac{N}{2}} - 1) 2 \sin\left(\frac{2\pi \tilde{l} n}{N}\right) + \delta_{n,\frac{N}{2}} (-1)^l \right]$$

where $F_n$ is the Lanczos factor.

# Vector gauge theory

Modified chiral transformation

$$\begin{aligned}\psi'_m &= \textstyle\sum_n (1+i\theta_n\hat{\gamma}_5)_{m,n}\,\psi_n \\ \bar{\psi}'_m &= \textstyle\sum_n \bar{\psi}_n\,(1+i\theta_n\hat{\gamma}_5)_{n,m}\end{aligned}$$

where

$$(\hat{\gamma}_5)_{m,n} \equiv \gamma_5\left(1-\frac{1}{2}aG\right)_{m,n}$$

$G$ satisfies GW relation $\gamma_5 G + G\gamma_5 = aG\gamma_5 G$.

Correct chiral anomaly $\mathrm{tr}\hat{\gamma}_5 \neq 0$ is reproduced.



# Chiral gauge theory

Gauge transformation

$$\begin{aligned}\psi'_n &= (1+i\theta^a_n T_a P_+)\psi_n \\ \bar{\psi}'_n &= \bar{\psi}_n(1-i\theta^a_n T_a P_-)\end{aligned}$$

Fermion measure is trivially invariant because

$$\mathrm{tr}\gamma_5 = 0$$

A single Weyl fermion can exist on the lattice without violating gauge symmetry.

# Kaon Matrix Elements in Domain-Wall QCD with DBW2 Gauge Action

Jun-Ichi Noaki

RIKEN Review, Nov. 20, 2003

# Kaon Matrix Elements in Domain-Wall QCD with DBW2 Gauge Action

**Jun Noaki** for RBC Collaboration

RIKEN BNL Reserch Center

# Numerical Simulation

- **Quenched Simulation** lat/0309026
  - **size:** $24^3 \times 48$
  - $\beta = 1.22$
  - $L_s = 10,\ M_5 = 1.65$
  - **5 light quark masses**
    $m_f a = 0.008 - 0.040,\ m_s a/2 \simeq 0.0155$
  - **7 charm quark masses**
    $m_f a = 0.08 - 0.50,\ m_c a \simeq 0.45$
  - **#Config.**

| | |
|---|---|
| NPR | 23 |
| $B_K$ | 89 |
| $m_\pi,\ m_\rho,\ K \to \pi$ ME | 62 |

  - **Basic values**

    **Lattice scale** ($m_\rho = 770$ MeV)

    $a^{-1} = 2.88(9)$ GeV

    **Phys. volume** $\simeq 1.8$ fm

    **Chiral symm. breaking**

    $m_{\rm res} \simeq 0.28$ MeV

- **Dynamical Simulation**
  - **size:** $16^3 \times 32$
  - $\beta = 0.80$
  - $L_s = 12,\ M_5 = 1.8$
  - **3 sea quark masses** $m_{\rm sea} a = 0.02, 0.03, 0.04$
  - **5 valence quark masses**
    $m_{\rm valence} a = 0.01 - 0.05$
  - **#Config.** **(all MEs & spectrums)**

| | |
|---|---|
| $m_{\rm sea} a = 0.02$ | 82 |
| 0.03 | 84 |
| 0.04 | 58 |

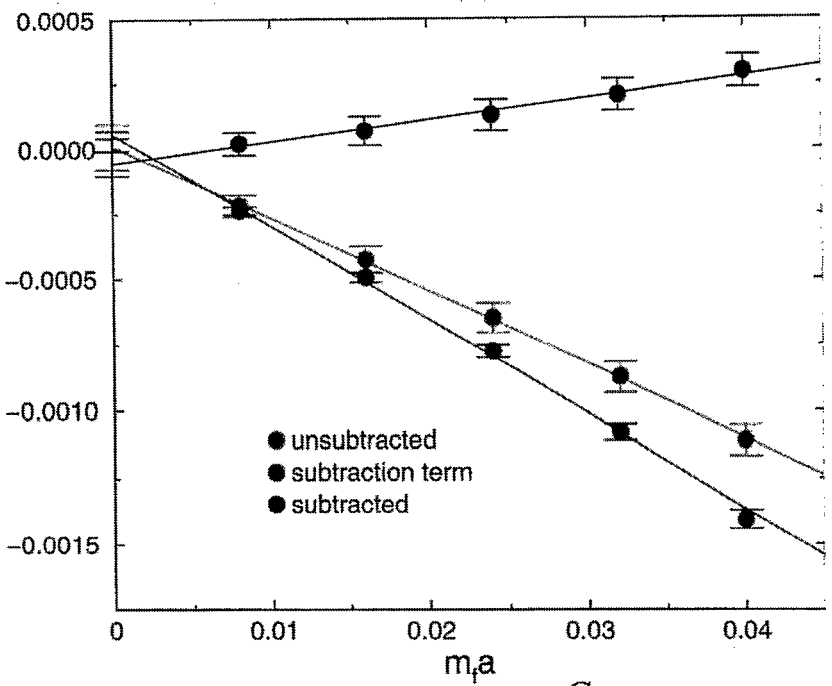
**See C. Dawson's talk for the details**

## $K \to \pi\pi$ matrix elements from $K \to \pi$ ($\Delta I = 1/2$ rule & $\varepsilon'/\varepsilon$)

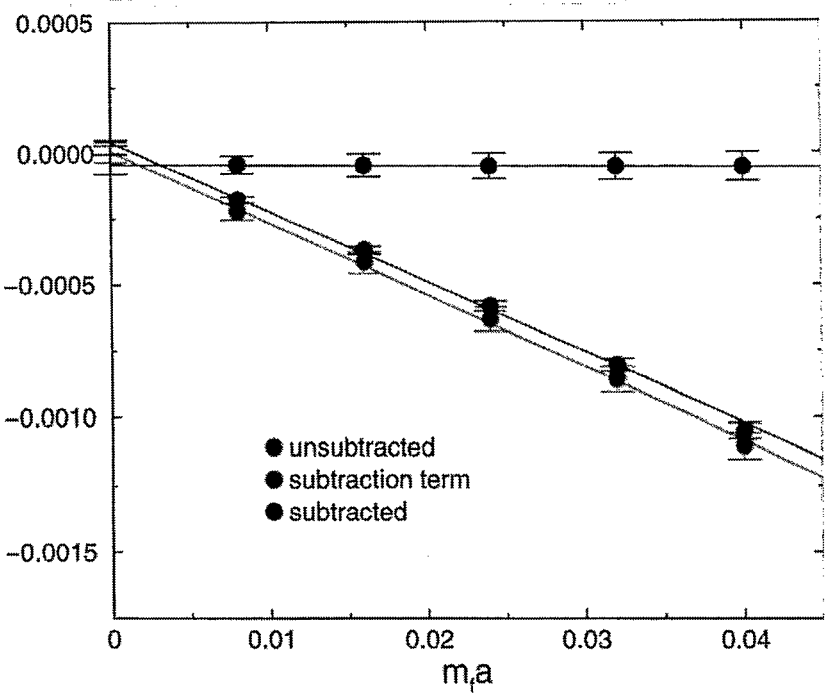
**subtraction for $\Delta I = 1/2$:** $\langle \pi | Q_i - \alpha_i Q_{\rm subt} | K \rangle / m_f a \propto \langle \pi\pi | Q_i | K \rangle$ Bernard *et al.*, 1986

- **Contribution of charmed quark to $\Delta I = 1/2$ rule ?**

$Q_2 = (\bar{s}u)_L(\bar{u}d)_L$ , $\Delta I = 1/2$




$Q_{2c} = (\bar{s}c)_L(\bar{c}d)_L$ , $m_c a = 0.40$




$$A_0 \approx \frac{G_F}{\sqrt{2}} V_{\rm us}^* V_{\rm ud} z_2 \langle (\pi\pi)_{I=0} | (Q_2 - Q_{2c}) | K \rangle$$

**Charmed quark tends to make minor contribution.**

- **Calculation of $\varepsilon'/\varepsilon$ : Large error ($\sim$200%) with current statistics.**

**We need a few times larger statistics to finalize this work.**

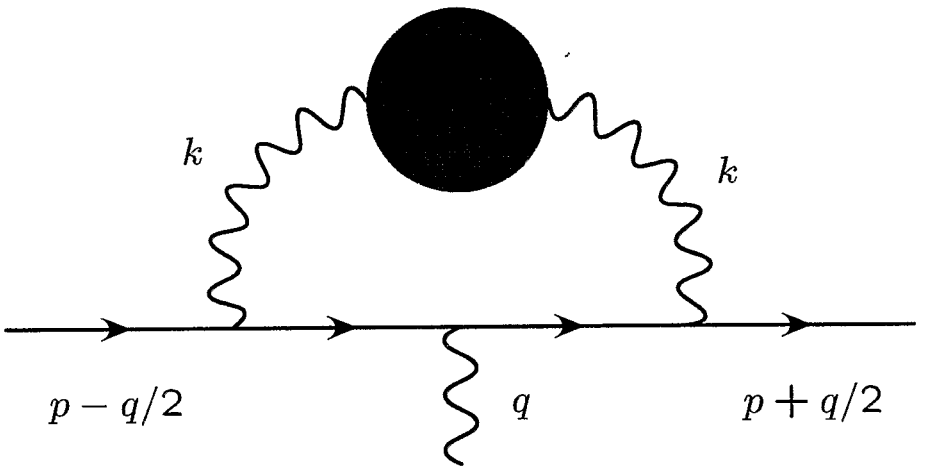
# The Hadronic Vacuum Polarization with 2+1 Flavors of Improved Kogut-Susskind Fermions

Thomas Blum

# The Hadronic Vacuum Polarization in 2+1 flavor QCD with Improved Kogut-Susskind Fermions

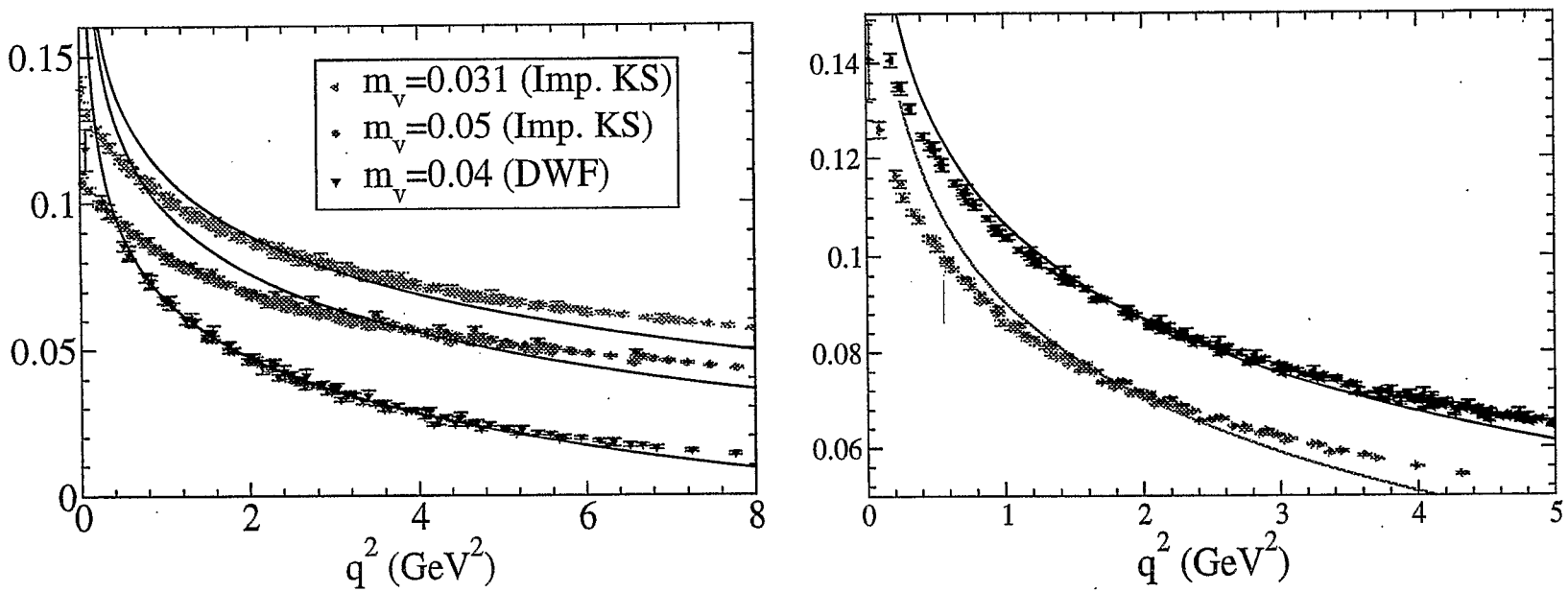
*Tom Blum, RIKEN BNL Research Center*

RBRC Review, BNL, November 20, 2003




[Phys. Rev. Lett. 91 (2003) 052001; hep-lat/0310064]

Comparison with 3-loop continuum perturbation theory




Improved Kogut-Susskind: significant scaling violations.

Better as $m_v \to 0$ (?)

# Summary

- Hadronic vacuum polarization is an interesting quantity for lattice calculations
- Important for muon g-2 (*c.f.* BNL-E821, Standard Model, ...)
- Investigate the structure of QCD, perturbative *vs.* non-pert, ...
- Important test for dynamical lattice calculations
- Encouraging lattice results for quenched and dynamical $\Pi(q^2)$, g-2

# Outlook

- Need to understand lattice artifacts in Kogut-Susskind simulations
- Need to understand quark mass behavior (KS and DWF)
- Need better fit function and/or statistics
- Need dynamical DWF results (2+1 flavors: RBRC QCDOC)
- Bigger (and better) lattices for Kogut-Susskind becoming available (MILC)(SciDAC QCDOC(?))

# High Density Effective Field Theory

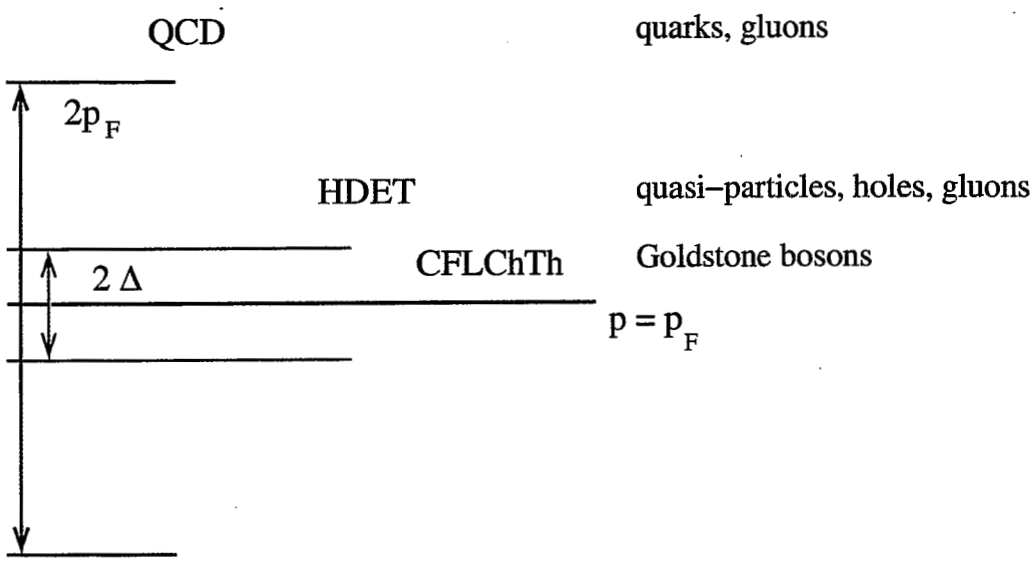
Thomas Schaefer

# High Density Effective Theory in QCD

*Thomas Schaefer*

*North Carolina State University*

*and Riken BNL Research Center*



# Higher Order Terms

- power corrections: $1/\mu$ terms

$$\mathcal{L} = -\frac{1}{2\mu}\sum_v \psi_v^\dagger \left\{ D_\perp^2 - \frac{ag}{2}\sigma^{\mu\nu}G_{\mu\nu}^\perp - MM^\dagger \right\} \psi_v$$

higher order terms: $\frac{c_n}{\mu^n}\psi_v^\dagger D_\perp^{2n_1}(\bar{v}\cdot D)^{n_2}\psi_v, \ldots$

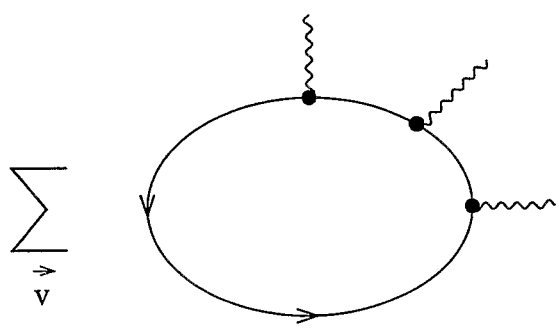
four fermion operators: $\frac{1}{\mu^2}c^{\Gamma\Gamma'}(\vec{v}_i)(\psi_{v_1}\Gamma\psi_{v_2})(\psi_{v_3}^\dagger\Gamma'\psi_{v_4}^\dagger)\delta_{\sum v_i}$

- power counting trivial? amplitude $\sim l^\delta$

$$\boxed{\delta = 4 + \sum_i N_i(d_i - 4)}$$

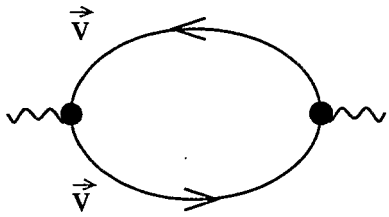
graphs with higher order vertices suppressed

- problem: "hard" loops



# Hard Loops: Gluon Self Energy

- gluon self energy: sum over patches




$$\sum_{\vec{v}} \int \frac{d^4k}{(2\pi)^4} \frac{v_\mu v_\nu}{(k_0 - l_k)(k_0 + p_0 - l_{k+p})}$$

- use

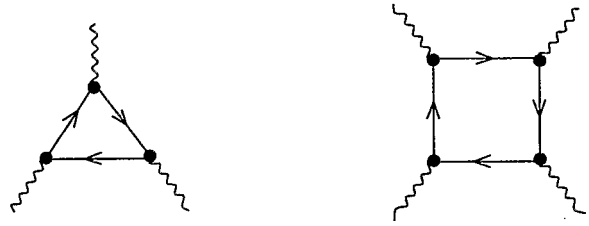
$$\frac{1}{2\pi} \sum_{\vec{v}} \int \frac{d^2 l_\perp}{(2\pi)^2} = \frac{\mu^2}{2\pi^2} \int \frac{d\Omega}{4\pi}.$$

- HDL polarization function

$$\Pi^{ab}_{\mu\nu}(p) = 2m^2 \delta^{ab} \int \frac{d\Omega}{4\pi} v_\mu v_\nu \left\{ 1 - \frac{p_0}{p_0 - l_p} \right\}$$

- need counter term $m^2 A_\perp^2$
- hard loops modify power counting
- have to resum for $E \sim g\mu$

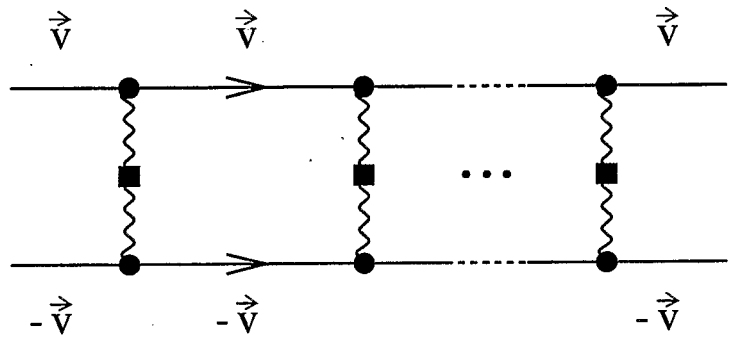
leading order
hard loop diagrams



...

# Superconductivity

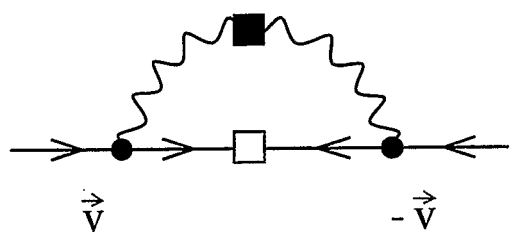
- $E \sim \mu \exp(-1/g)$: BCS ladder diagrams IR divergent




introduce gap term

$$\mathcal{L} = \Delta\, R_l^{\Gamma}(\vec{v} \cdot \hat{\Delta}) \psi_{-v} \sigma_2 \Gamma \psi_v + h.c.$$

- gap equation: only two patches (v,-v)




$$\Delta(p_4) = \frac{g^2}{18\pi^2} \int_0^{\Lambda_\parallel} dq_4 \frac{\Delta(q_4)}{\sqrt{q_4^2 + \Delta(q_4)^2}} \log\left(\frac{\Lambda_\perp}{|p_4^2 - q_4^2|^{1/2}}\right).$$

- solution (can set $\Lambda_\parallel = \Lambda_\perp$ at this order)

$$\Delta_0 = 2\Lambda \exp(-3\pi^2/(\sqrt{2}g))$$

## Summary: High Density Effective Theories

- Effective theories provide useful tools for systematic calculations in the regime $\Lambda < \Delta < \mu$.
- naive power counting modified by "hard loops"
- important questions: renormalization of four-fermion operators, counting and resumming logs

# Hadronizaton at RHIC: Interplay of Recombination and Fragmentation

Steffen Bass

# Hadronization @ RHIC: Interplay of Fragmentation and Recombination

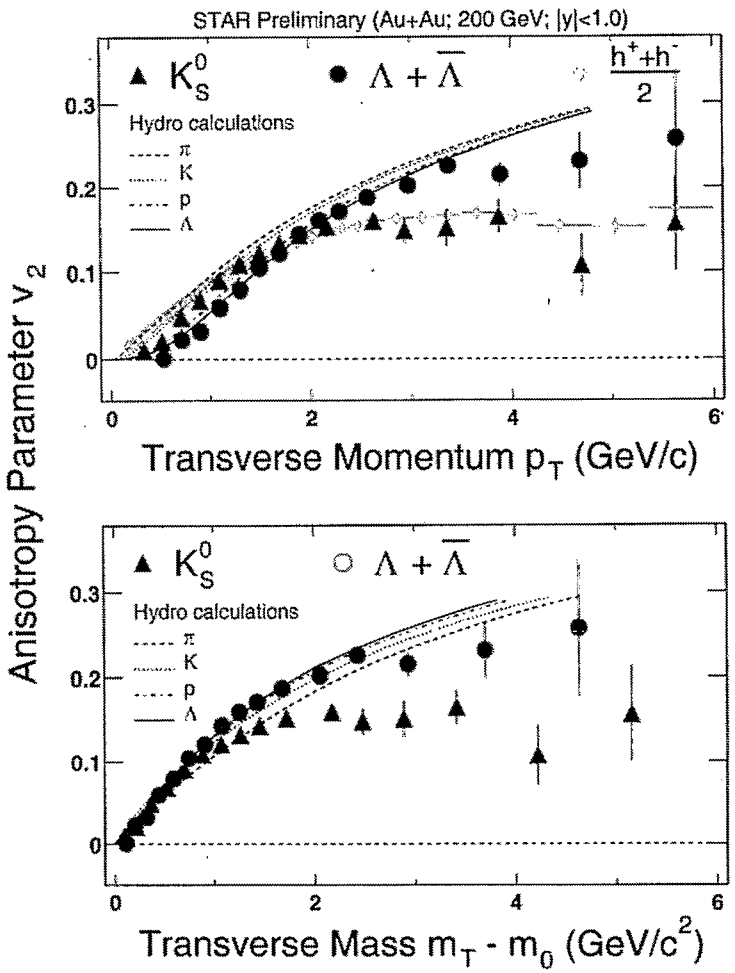
**Steffen A. Bass**

Duke University
& RIKEN-BNL Research Center

- The proton puzzle at RHIC
- Recombination + Fragmentation Model
- Results and Predictions

- R.J. Fries, C. Nonaka, B. Mueller & S.A. Bass, PRL 90 202303 (2003)
- R.J. Fries, C. Nonaka, B. Mueller & S.A. Bass, PRC 68 044902 (2003)

# Species dependent saturation of elliptic flow




- hyperon $v_2$ saturates later and higher than kaon $v_2$.
- same effect observed for protons and pions.
- the phenomenology seems better described in $m_T - m_0$ than $p_T$; why (kinetic energy)?
- what drives the different $p_T$ scales for $K_S$ and $\Lambda$ $v_2$?

➢ novel mechanism of baryon formation?

# Recombination: new life for an old idea

High Energy Physics Phenomenology:

- K.P. Das & R.C. Hwa, Phys. Lett. B68, 459 (1977)

  *Quark-Antiquark Recombination in the Fragmentation Region*

➢ description of leading particle effect

- T. Ochiai, Prog. Theo. Phys. 75, 1184 (1986)
- E. Braaten, Y. Jia & T. Mehen, Phys. Rev. Lett. 89, 122002 (2002)
- R. Rapp & E.V. Shuryak, Phys. Rev. D67, 074036 (2003)

Heavy-Ion Phenomenology:

- T. S. Biro, P. Levai & J. Zimanyi, Phys. Lett. B347, 6 (1995)

  *ALCOR: a dynamical model for hadronization*

➢ yields and ratios via counting of constituent quarks

- R.C. Hwa & C.B. Yang, Phys. Rev. C66, 025205 (2002)
- R. Fries, B. Mueller, C. Nonaka & S.A. Bass, Phys. Rev. Lett. 90
- V. Greco, C.M. Ko and P. Levai, Phys. Rev. Lett. 90

Anisotropic flow:

- S. Voloshin, QM2002, nucl-ex/020014
- Z.W. Lin & C.M. Ko, Phys. Rev. Lett 89, 202302 (2002)
- D. Molnar & S. Voloshin, nucl-th/0302014

# Input and Model Parameters

Input for the model is the momentum distributions of constituent quarks and anti-quarks at the time of hadronization

- the quark distribution is assumed to have a low $p_t$ thermal component and a high $p_t$ pQCD mini-jet component
- the thermal component is parameterized as:

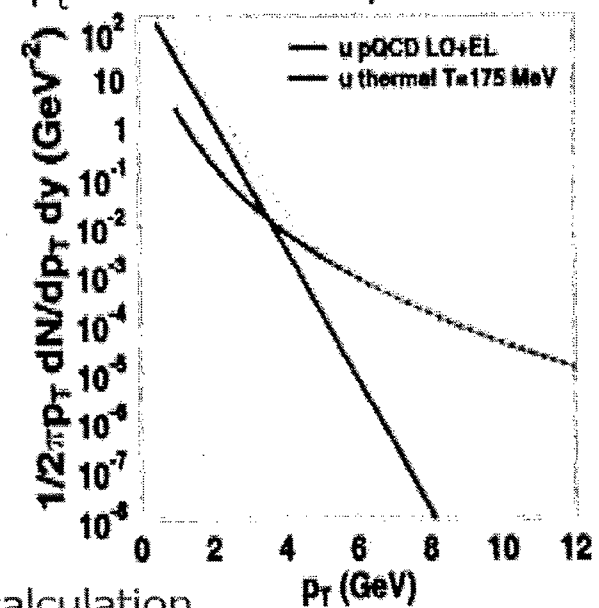
$$w_a(\sigma, p) = g_a e^{-p\cdot v(\sigma)/T}\, e^{-\eta^2/2\Delta^2} f(\rho, \phi)$$

with a flavor dependent fugacity $g_a$, temperature T, rapidity width $\Delta$ and transverse distribution $f(\rho,\phi)$

- the pQCD component is parameterized as:

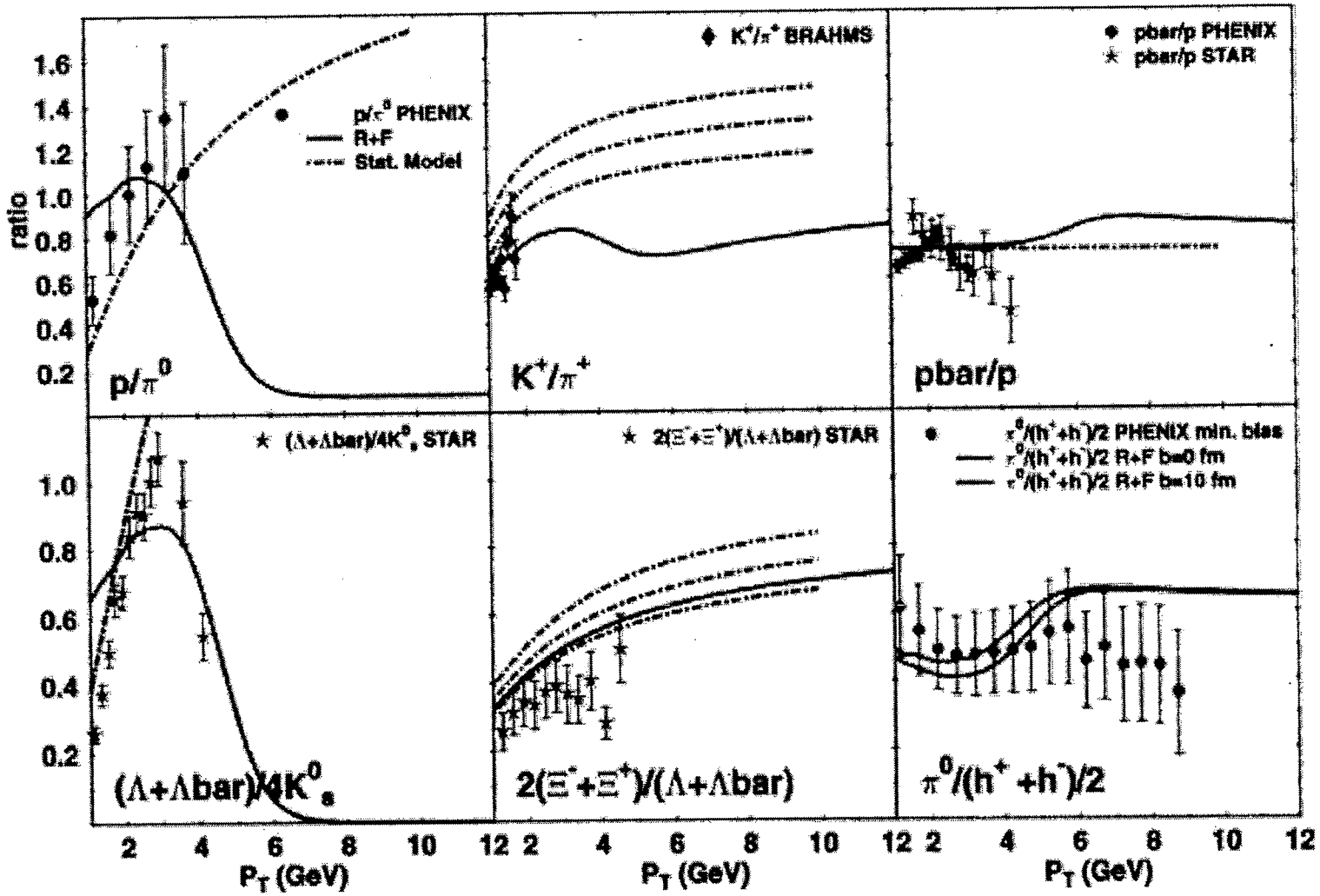
$$\left.\frac{dN_a}{p_t dp_t dy}\right|_{y=0} = K \frac{C}{(1+p_t/B)^{\beta}}$$

with parameters C, B and $\beta$ taken from a lo pQCD calculation




- parton energy loss is treated in the pQCD component (currently utilizing the BDMPS approach)

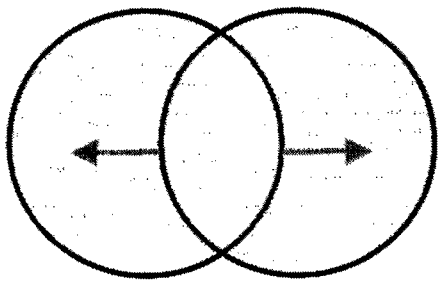
# Hadron Ratios vs. $p_t$



# Elliptic Flow

- anisotropic or "elliptic" flow is sensitive to initial geometry

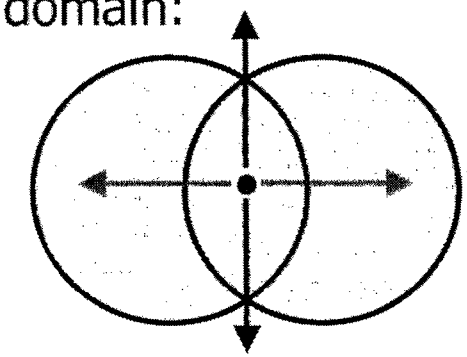
low $p_t$ domain:



$$Force = -\nabla P$$

more flow in collision plane than perpendicular to it

high $p_t$ domain:



$$\Delta E \sim L$$

less absorption in collision plane than perpendicular to it

- total elliptic flow is the sum of both contributions:

$$v_2(p_t) = r(p_t)\, v_2^{\text{recomb}}(p_t) + \left(1 - r(p_t)\right) v_2^{\text{frag}}(p_t)$$

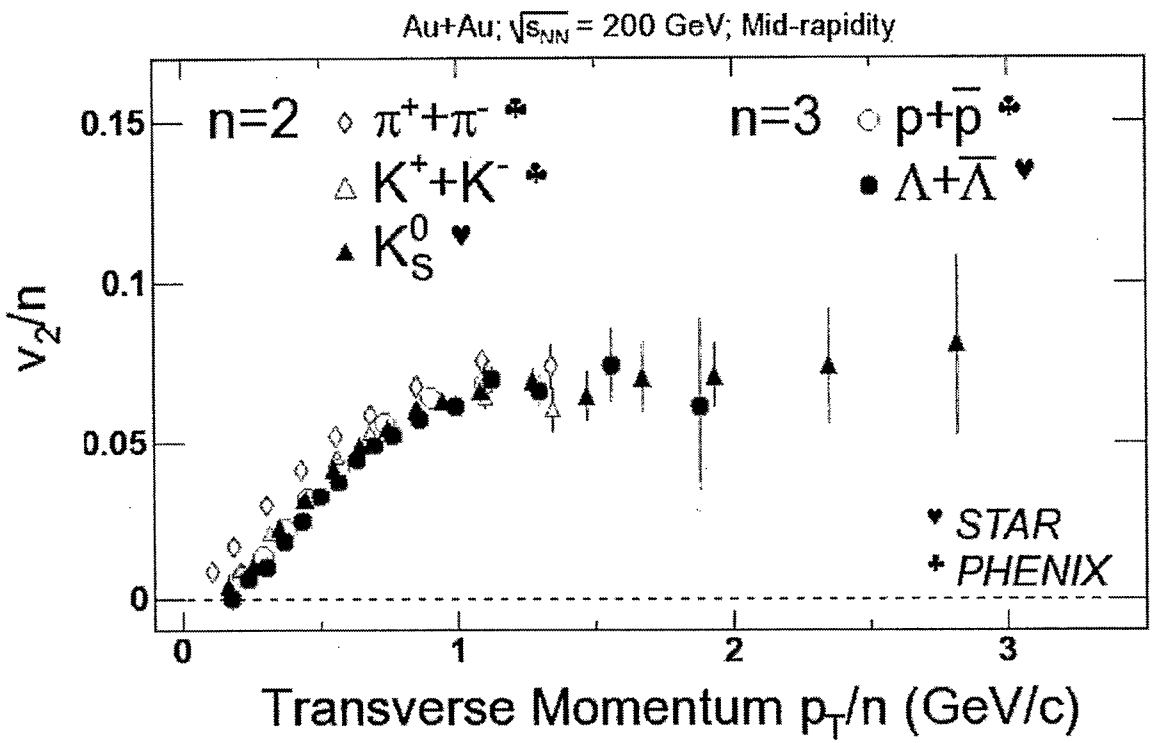
$r(p_t)$: relative weight of the fragmentation contribution in spectra

# Parton Number Scaling of $v_2$

- in leading order of $v_2$, recombination predicts:

$$v_2^M(p_t) = 2v_2^p\left(\frac{p_t}{2}\right)$$

$$v_2^B(p_t) = 3v_2^p\left(\frac{p_t}{3}\right)$$




- smoking gun for recombination
- measurement of partonic $v_2$ !

# Summary & Outlook

The Recombination + Fragmentation Model:

- provides a natural solution to the baryon puzzle at RHIC
- describes the intermediate and high $p_t$ range of
  - hadron ratios & spectra
  - jet-quenching phenomena
  - elliptic flow
- provides a microscopic basis for the Statistical Model

issues to be addressed in the future:

- entropy production
- treatment of gluons
- realistic space-time dynamics of parton source
- need improved data of identified hadrons at high $p_t$

# Interplay Between Soft and Hard Hadronic Components at RHIC

Tetsufumi Hirano

# Interplay Between Soft and Hard Hadronic Components at RHIC

Tetsufumi Hirano

*RIKEN BNL Research Center*

Collaboration with Yasushi Nara (Arizona)

*OUTLINE*

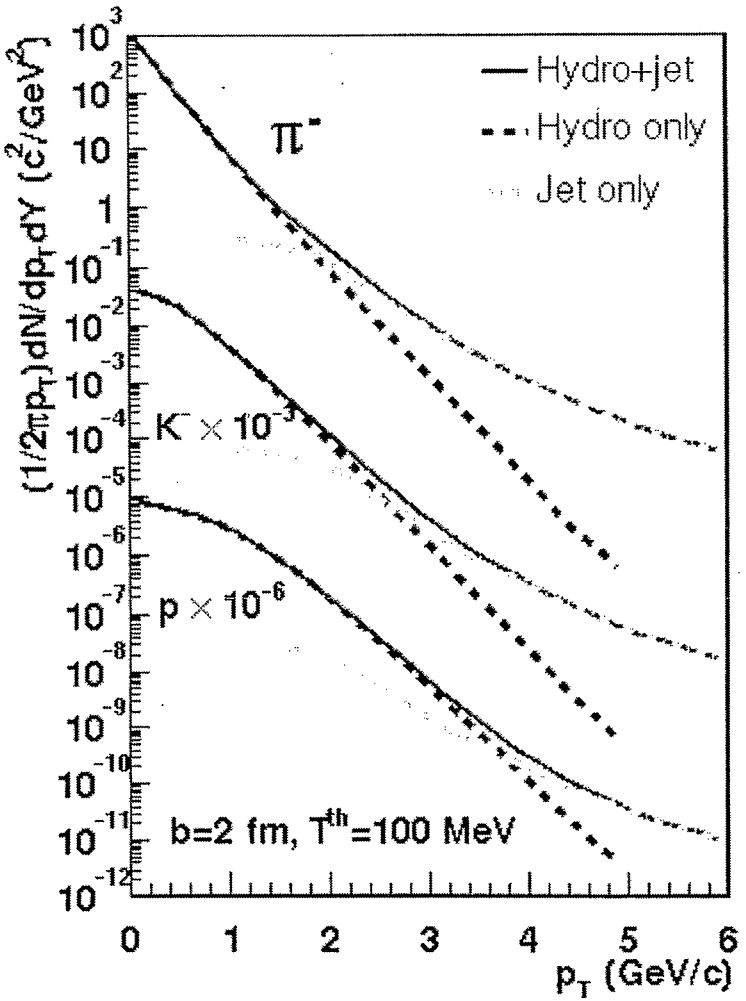
- Introduction
- Hydro+jet model
- $p_T$ spectra for $\pi$, K, p
- Jet quenching at $\eta \sim 2$
- Summary

*References*

T.H. and Y.Nara,
Phys.Rev. C**66**, 041901(2002);
Phys.Rev.Lett. **91**, 82301(2003);
nucl-th/0307015;
nucl-th/0307087.

RBRC Scientific Review Committee Meeting, Nov. 20-21, 2003

# $p_T$ Spectra for Identified Hadrons




$p_{T,\mathrm{cross}}$ depends on particle species!

$p_{T,\mathrm{cross}} \sim$ 1.8 GeV/$c$ for $\pi$
2.7 GeV/$c$ for $K$
3.7 GeV/$c$ for $p$

c.f.) $p_{T,\mathrm{cross}} \sim$ inflection point for kaons and protons

# *Summary*

## QGP in Au+Au collisions at RHIC ?

→Final state effects are consistent with intermediate ~ high $p_T$ data ($R_{AA}$, b-to-b, ...).

→Strongly encouraged by recent $d$+Au data.

- *Dynamical model* (hydro+jet) for heavy-ion physics
- Hadron species dependent transverse dynamics

→Interplay between radial flow and jet quenching

- How large dense matter in longitudinal direction?

←Jet quenching in forward rapidity region ($\eta$~2)

# Calculations of Spin Asymmetries in pp Scattering

Werner Vogelsang

# Calculations of spin asymmetries in pp scattering

Werner Vogelsang

(RBRC Scientific Review, Nov. 20/21 2003)

Today's example :

- High-$p_T$ pion production

  with S. Kretzer, Jäger, Stratmann

Other work :

- Soft-gluon resummation for heavy flavor production

  with H. Yokoya

- Transverse-spin asymmetries at RHIC

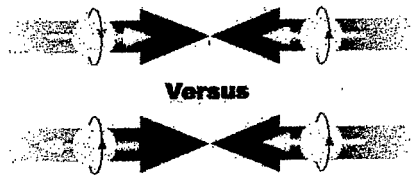
  with Mukherjee,Stratmann

- Higgs production at LHC

  with Kulesza,Sterman

*Spin theory group is growing ! From Nov.'03 : Y. Koike, T. Kucs

# Polarized pp collisions at RHIC :



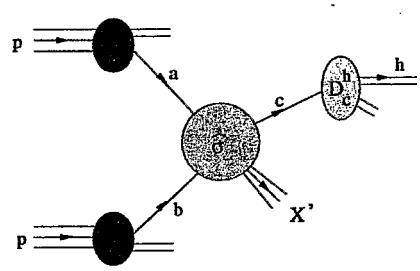

- spin asymmetry

$$\boxed{A_{\rm LL} \equiv \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \equiv \frac{\Delta\sigma}{\sigma}}$$

- consider high-$p_T$ reactions :

$$\vec{p}\vec{p} \to \text{jet}X,\ \vec{p}\vec{p} \to \gamma X,\ \vec{p}\vec{p} \to \pi X,\ \ldots$$

$$p_T^3 \frac{d\Delta\sigma}{dp_T\, d\eta} = \Bigg|$$

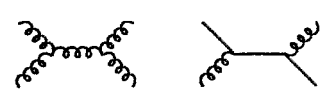



$$\Bigg|^2 + \mathcal{O}\left(\frac{\lambda}{p_T}\right)^n$$

$$\boxed{d\Delta\sigma^{pp\to\pi X} = \sum_{abc} \Delta f_a \otimes \Delta f_b \otimes d\Delta\hat{\sigma}^{ab\to cX'} \otimes D_c^\pi + \text{P.C.}}$$

$$\Delta\hat{\sigma}^{(0)} + \alpha_s \Delta\hat{\sigma}^{(1)} + \ldots \text{ pert.}$$

Jäger,Schäfer,Stratmann,WV



- nucleon spin structure $\Delta f_{a,b}$
- fragmentation functions $D_c^\pi$ $\rightsquigarrow$ $e^+e^-$ annihilation

# A lower bound on $A_{LL}^{\pi}$

Jäger, Kretzer, Stratmann, WV

- integrate LO cross section over all rapidities $|\eta| \leq \cosh^{-1}(x_T)$, and take mellin moments in $x_T^2 \equiv 4p_\perp^2/S$ :

$$\Delta\sigma^\pi(N) \equiv \int_0^1 dx_T^2 \left(x_T^2\right)^{N-1} \frac{p_\perp^3 d\Delta\sigma^\pi}{dp_\perp}$$

- obtain

$$\Delta\sigma^\pi(N) = \sum_{a,b,c} \Delta f_a^{N+1} \Delta f_b^{N+1} \Delta\hat{\sigma}_{ab}^{c,N} D_c^{\pi,2N+3}$$

- in terms of moments of $\Delta g$ :

$$\Delta\sigma^\pi(N) = \left(\Delta g^{N+1}\right)^2 \mathcal{A}^N + 2\,\Delta g^{N+1} \mathcal{B}^N + \mathcal{C}^N$$

$\mathcal{A}^N$: $gg$ scatt. $\quad$ $\mathcal{B}^N$: $qg$ $\quad$ $\mathcal{C}^N$: $qq,\ qq',\ q\bar{q},\ \ldots$

- a parabola – with a minimum given by

$$\mathcal{A}^N \Delta g^{N+1} = -\mathcal{B}^N$$

$$\Delta\sigma^\pi(N)\Big|_{\min} = -\frac{\left(\mathcal{B}^N\right)^2}{\mathcal{A}^N} + \mathcal{C}^N$$

- Mellin inverse :

$$\frac{p_\perp^3 d\Delta\sigma^\pi}{dp_\perp}\Bigg|_{\min} = \frac{1}{2\pi i}\int_\Gamma dN \left(x_T^2\right)^{-N} \Delta\sigma^\pi(N)\Big|_{\min}$$

- resulting asymmetry : negative, but tiny

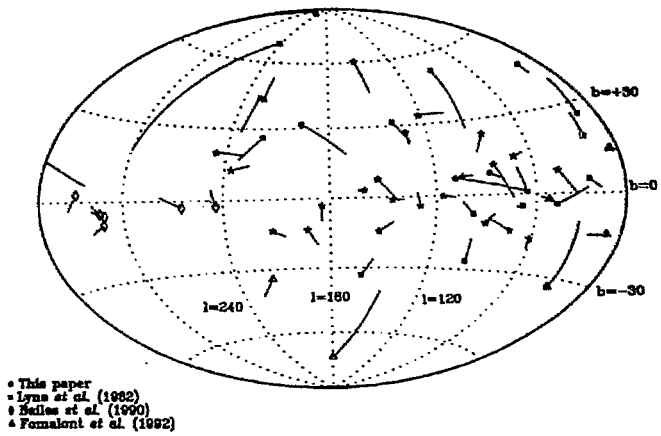
$p_\perp = 1.5$ GeV : $\boxed{A_{LL}^{\pi} \approx -10^{-4}}$

$p_\perp = 4.5$ GeV : $\boxed{A_{LL}^{\pi} \approx -10^{-3}}$

# Dark Matter and Pulsar Kicks from a Sterile Neutrino

Alexander Kusenko

## Pulsar velocities








## Pulsar kicks and dark matter from sterile neutrinos

- Pulsar kicks and possible explanations
- Sterile neutrinos: the missing dark matter particle?
- Pulsar kicks from active to sterile neutrino conversions

## Pulsar kicks from neutrino emission?

Pulsar with $v \sim 500$ km/s has momentum

$$M_{\odot} v \sim 10^{41} \text{ g cm/s}$$

SN energy released: $10^{53}$ erg $\Rightarrow$ in neutrinos. Thus, the total neutrino momentum is

$$P_{\nu;\,\text{total}} \sim 10^{43} \text{ g cm/s}$$

a **1% asymmetry** in the distribution of **neutrinos**

is sufficient to explain the pulsar kick velocities

But what can cause the asymmetry??





## Supernova neutrinos

Nuclear reactions in stars lead to a formation of a heavy iron core. When it reaches $M \approx 1.4 M_{\odot}$, the pressure can no longer support gravity. $\Rightarrow$ collapse.

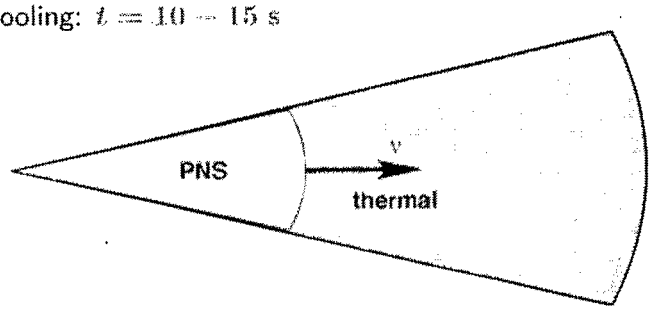
Energy released:

$$\Delta E \sim \frac{G_N M^2_{\text{Fe core}}}{R} \sim 10^{53} \text{erg}$$

99% of this energy is emitted in neutrinos

## Core collapse supernova

Thermal cooling: $t = 10 - 15$ s



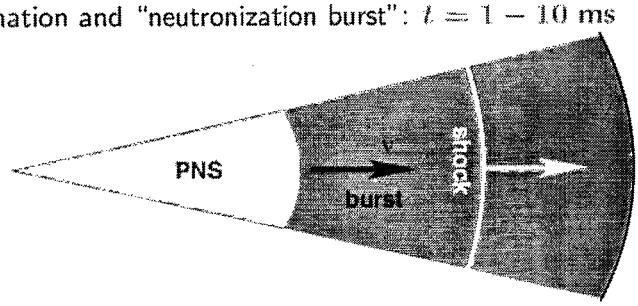

Most of the neutrinos emitted during the cooling stage.





## Core collapse supernova

Shock formation and "neutronization burst": $t = 1 - 10$ ms




Protoneutron star formed. Neutrinos are trapped. The shock wave breaks up nuclei, and the initial neutrino come out (a few %).

## Can the weak interactions asymmetry cause an anisotropy in the flux of neutrinos due to a large magnetic field?

## No

Rescattering washes out the asymmetry [Vilenkin; AK,Segre, Vilenkin].

In approximate thermal equilibrium the asymmetries in scattering amplitudes do not lead to an anisotropic emission. Only the outer regions, near neutrinospheres, contribute (a negligible amount).

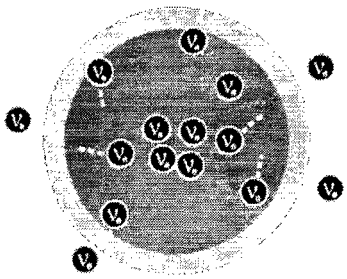
However, if a weaker-interacting sterile neutrino was produced in these processes, the asymmetry would, indeed, result in a pulsar kick!



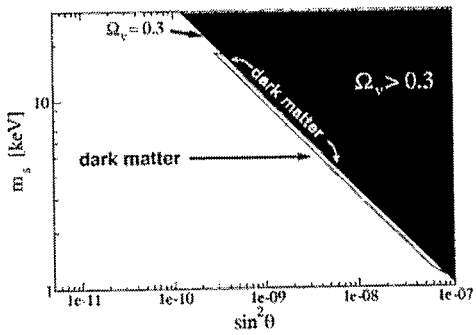
Alexander Kusenko (RIKEN/UCLA) BNL, 2003

## Can the weak interactions asymmetry cause an anisotropy in the flux of neutrinos due to a large magnetic field?

## No



Neutrinos are trapped at high density.




A sterile neutrino in this range, consistent with dark matter, can also explain the observed velocities of pulsars though $\nu_e \to \nu_s$ oscillations in a supernova.





## Sterile neutrinos in cosmology: dark matter

Sterile neutrinos are produced in primordial plasma through oscillations.

The resulting density of relic sterile neutrinos:

$$\Omega_{\nu_2} \sim 0.3 \left(\frac{\sin^2 2\theta}{10^{-8}}\right) \left(\frac{m_s}{\mathrm{keV}}\right)^2$$

[Dodelson, Widrow; Dolgov, Hansen; Fuller, Shi; Abazajian, Fuller, Patel]

$$\begin{cases} |\nu_1\rangle = \cos\theta_m|\nu_e\rangle - \sin\theta_m|\nu_s\rangle \\ |\nu_2\rangle = \sin\theta_m|\nu_e\rangle + \cos\theta_m|\nu_s\rangle \end{cases} \quad (6)$$

The coupling of $\nu_2$ to weak currents is also suppressed, and $\sigma \propto \sin^2\theta$.

The probability of $\nu_e \to \nu_s$ conversion in presence of matter is

$$\langle P_m \rangle = \frac{1}{2}\left[1 + \left(\frac{\lambda_{osc}}{2\lambda_s}\right)^2\right]^{-1} \sin^2 2\theta_m. \quad (7)$$

where $\lambda_{osc}$ is the oscillatino length, and $\lambda_s$ is the scattering length.





Mixing angle in matter is different from vacuum:

$$\sin^2 2\theta_m = \frac{(\Delta m^2/2p)^2 \sin^2 2\theta}{(\Delta m^2/2p)^2 \sin^2 2\theta + (\Delta m^2/2p \cos 2\theta - V_m)^2}. \quad (3)$$

$$V_m = \frac{G_F \rho}{\sqrt{2} m_n}(3Y_e - 1 + 4Y_{\nu_e} + 2Y_{\nu_\mu} + 2Y_{\nu_\tau}) \quad (4)$$

$$\simeq (-0.2... + 0.5)V_0, \quad (5)$$

where $V_0 = G_F\rho/\sqrt{2}m_n \simeq 3.8\text{eV}(\rho/10^{14}\text{gcm}^{-3})$

Mixing is suppressed when $V_m \gg (\Delta m^2/2k)$.

If the fraction of energy emitted in sterile neutrinos is

$$r_{\mathcal{E}} = \left(\frac{\mathcal{E}_s}{\mathcal{E}_{tot}}\right) \sim 0.05 - 0.7, \tag{9}$$

(as it can easily be), then the resulting momentum asymmetry is

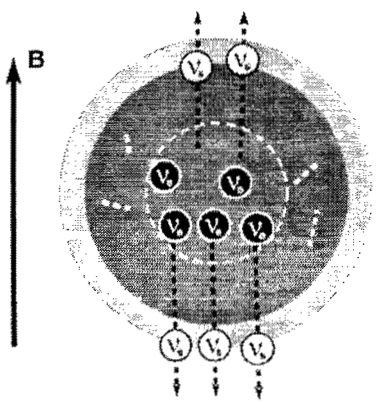
$$\epsilon \sim 0.02 \left(\frac{k_0}{0.3}\right) \left(\frac{r_{\mathcal{E}}}{0.5}\right), \tag{10}$$

which is sufficient to explain the pulsar kick velocities.





Sterile neutrinos leave the star without scattering. Hence, they give the pulsar a kick.



## Resonant active-sterile neutrino conversions in matter

Matter potential:

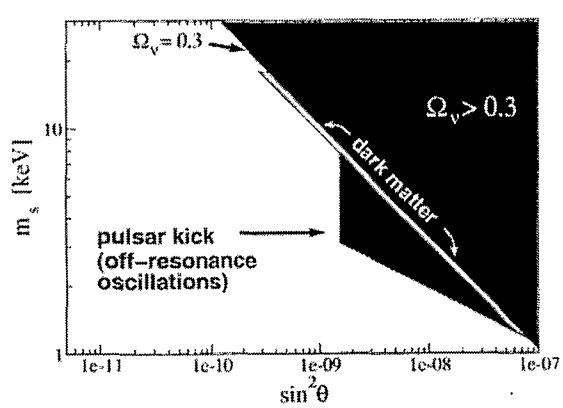
$$
\begin{aligned}
V(\nu_s) &= 0 \\
V(\nu_e) &= -V(\bar{\nu}_e) = \frac{G_F \rho}{\sqrt{2} m_n}(3\,Y_e - 1 + 4\,Y_{\nu_e}) \\
V(\nu_{\mu,\tau}) &= -V(\bar{\nu}_{\mu,\tau}) = \frac{G_F \rho}{\sqrt{2} m_n}(Y_e - 1 + 2\,Y_{\nu_e}) \; + \; c_L^z \, \frac{\vec{k} \cdot \vec{B}}{k}
\end{aligned}
$$

$$
c_L^z = \frac{e G_F}{\sqrt{2}} \left( \frac{3 N_c}{\pi^4} \right)^{1/3}
$$





Allowed range of parameters (time scales, fraction of total energy emitted):




[Fuller, **AK**, Mocioiu, Pascoli, astro-ph/0307267]

## A crude estimate of the kick

The mean energy of emitted sterile neutrinos is proportional to the temperature at the point of production. The point of resonant conversion depends on direction:

$$r(\phi) = r_0 + \delta \cos\phi, \tag{12}$$

where $\cos\phi = (\vec{k}\cdot\vec{B})/k$ and $\delta$ is determined by the equation:

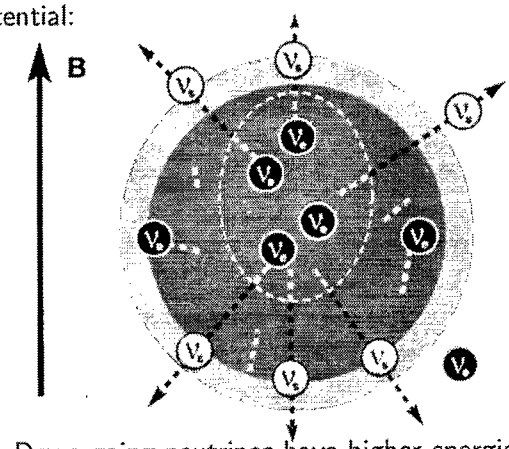
$$2\frac{dN_n(r)}{dr}\delta \approx e\left(\frac{3N_e}{\pi^4}\right)^{1/3} B. \tag{13}$$

This yields



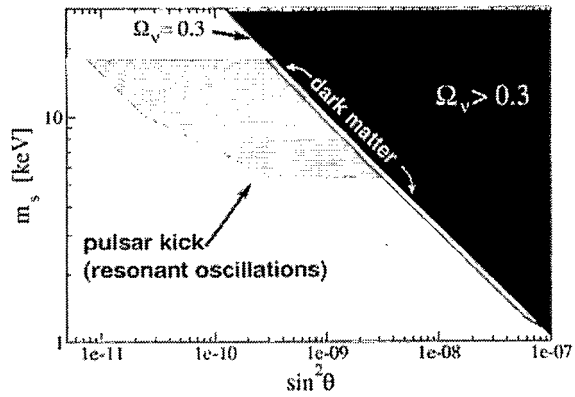


The magnetic field shifts the position of the resonance because of the $\frac{\vec{k}\cdot\vec{B}}{k}$ term in the potential:




Down going neutrinos have higher energies

The range of parameters [**AK**, Segrè; Fuller, **AK**, Mocioiu, Pascoli]:








The core density $\rho \sim 10^{14}$ g/cm$^3$ determines the

$$\Delta m^2 \sim (10\,\mathrm{keV})^2$$

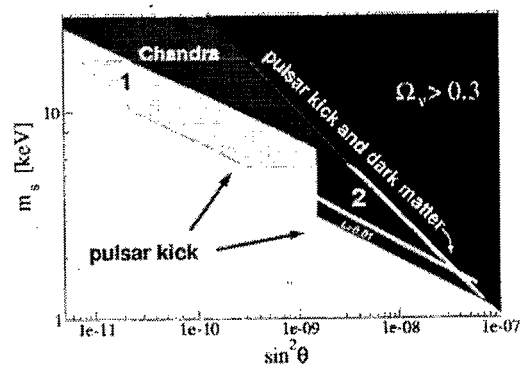
Adiabaticity: the oscillation length

$$\lambda_{\rm osc} \approx \left(\frac{1}{2\pi}\,\frac{\Delta m^2}{2k}\,\sin 2\theta\right)^{-1} \sim \frac{1\,\mathrm{mm}}{\sin 2\theta}.$$

must be smaller than (1) the scale height of density (2) the mean free path of neutrinos. $\Rightarrow$

$$\sin^2\theta \lesssim 10^{-10}$$

## Chandra non-observation of photons from $\nu_s \longrightarrow \nu_e \gamma$

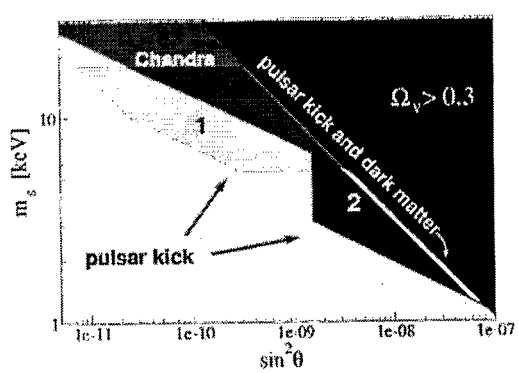



non-zero lepton asymmetry changes the dark matter range



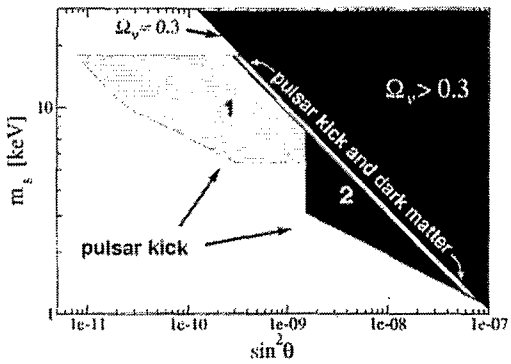


## Chandra non-observation of photons from $\nu_s \longrightarrow \nu_e \gamma$




[Abazajian, Fuller, Tucker]

## Resonant (1) & off-resonant (2) emissions combined:




[Fuller, **AK**, Mocioiu, Pascoli, Phys. Rv. **D**, in press; astro-ph/0307267]





## Conclusions

- Sterile neutrinos in the 1-20 keV range can explain the observed pulsar kicks
- The same neutrino could be the dark matter
- One may be able to confirm this mechanism through observations of gravity waves in the event of a nearby supernova.

# Charge Symmetry Breaking in Few-Nucleon Systems

Ubirajara van Kolck

RBRC Review, Nov. 20-21, 2003

# Charge Symmetry Breaking in Few-Nucleon Systems

**Bira van Kolck**

*University of Arizona*
and
*RIKEN–BNL Research Center*

- ◇ What and why
- ◇ Chiral Symmetry
- ◇ $np \to d\pi^0$
- ◇ $dd \to \alpha\pi^0$
- ◇ $NN \to NN$
- ◇ Summary

Supported in part by the US DOE and by the Sloan Foundation

# Why

- $A$ eventually to be calculated in lattice QCD

  ▷ extract $m_d - m_u$

- $B$ estimated in models, *e.g.*

| | | |
|---|---|---|
| $\bar{\delta} m_N = -(0.76 \pm 0.30)\,\mathrm{MeV}$ | Cottingham sum rule | Gasser + Leutwyler '82 |
| $\bar{\delta} m_N = -\frac{\alpha}{R_N} \simeq -1.5\,\mathrm{MeV}$ | quark models | Miller, Nefkens + Šlaus '90 |

  ▷ test models

- BBN depends sensitively on $\Delta m_N$, *e.g.*

$$\text{if } \Delta m_N \lesssim \left\{ \begin{array}{ll} m_e: & \text{hydrogen} \\ -m_e: & \text{proton} \end{array} \right\} \text{ unstable under } \left\{ \begin{array}{l} \text{electron capture} \\ \beta \text{ decay} \end{array} \right.$$

→ BBN produces essentially $^4$He + free neutrons

(→ no water ...)

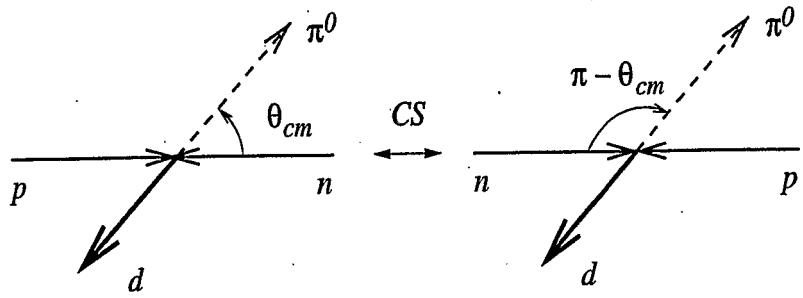
  ▷ constrain variations of parameters with time

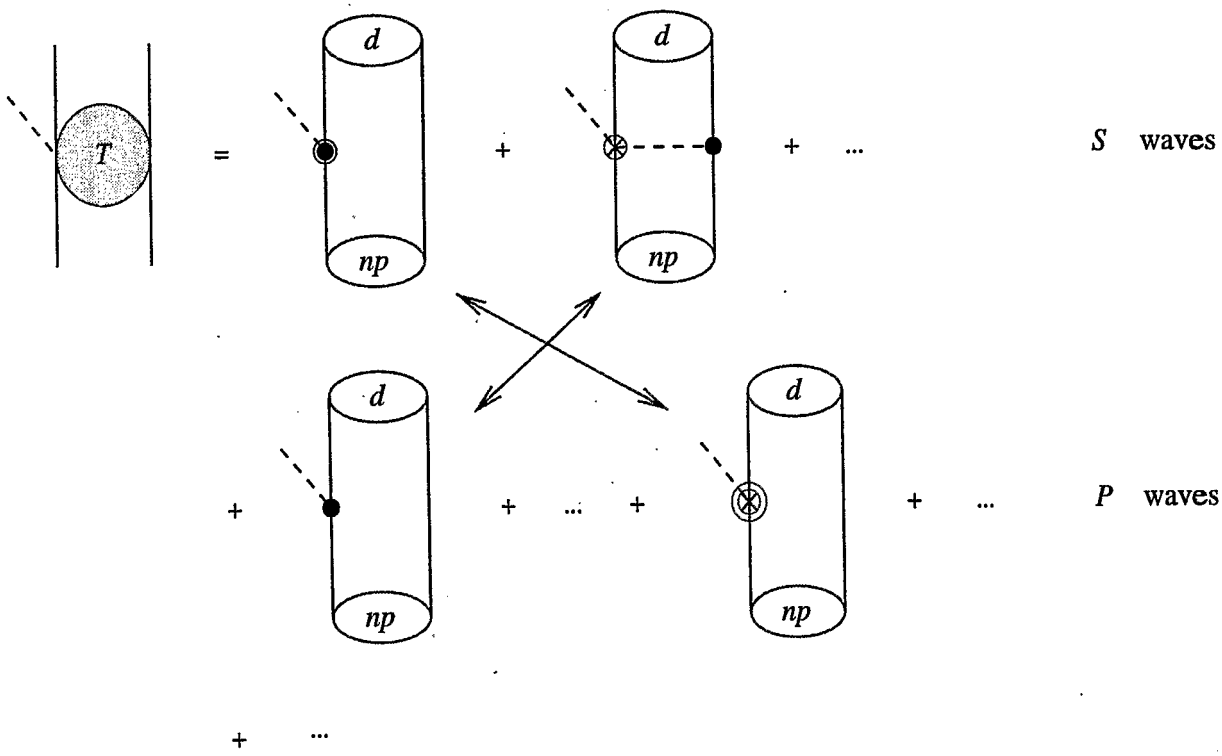
Kolb, Perry + Walker '86

...

# $np \to d\pi^0$

Miller, Niskanen + v.K., '00

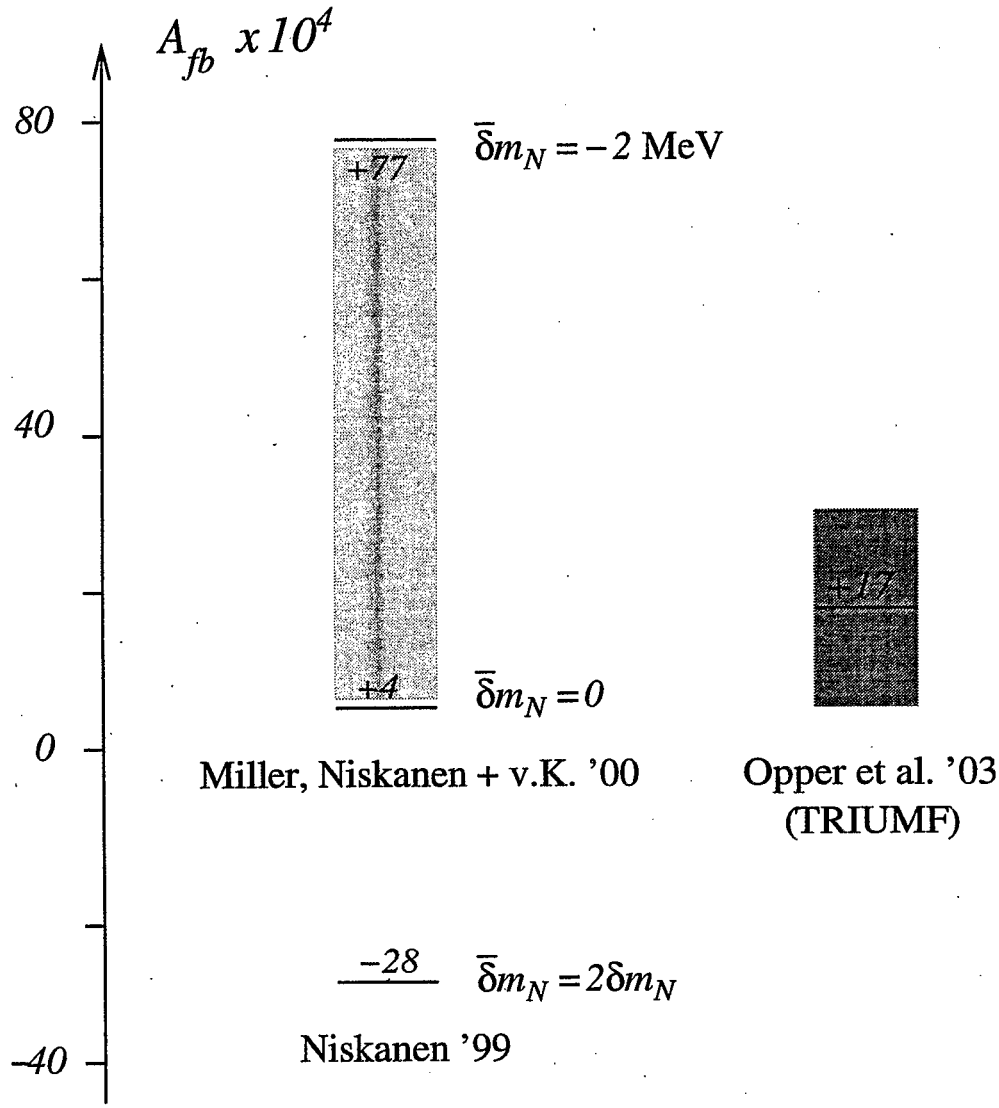



$$A_{fb} = \frac{\int_0^{\pi/2} d\Omega\,(\sigma(\theta) - \sigma(\pi-\theta))}{\int_0^{\pi/2} d\Omega\,(\sigma(\theta) + \sigma(\pi-\theta))}$$
$$= 24.4 \cdot 10^{-4} \left\{ \frac{\delta m_N - \bar{\delta} m_N/2}{\text{MeV}} - 1.15 \frac{g_{\eta NN}}{\sqrt{4\pi \cdot 3.68}} \frac{\langle \pi^0 | H_{QCD} | \eta \rangle}{(-0.0059\ \text{GeV}^2)} + \dots \right\}$$

at $q_\pi/m_\pi = 0.17$.

For $g^2_{\eta NN}/4\pi = 3.68$ and $\langle \pi^0 | H_{QCD} | \eta \rangle = -0.0059\ \mathrm{GeV}^2$,




$$\rightsquigarrow \begin{cases} \delta m_N = 1.66 \pm 0.27 \pm ?_{th}\ \mathrm{MeV} \\ \bar{\delta} m_N = -0.36 \pm 0.27 \pm ?_{th}\ \mathrm{MeV} \end{cases}$$

# Observation of the Charge Symmetry Breaking $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ Reaction Near Threshold

E. J. Stephenson,[1] A. D. Bacher,[1,2] C. E. Allgower,[1] A. Gårdestig,[3] C. M. Lavelle,[1] G. A. Miller,[4] H. Nann,[1,2] J. Olmsted,[1] P. V. Pancella,[5] M. A. Pickar,[6] J. Rapaport,[7] T. Rinckel,[1] A. Smith,[8] H. M. Spinka,[9] and U. van Kolck[10,11]

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(Received 9 May 2003; published 2 October 2003)

We report the first observation of the charge symmetry breaking $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ reaction near threshold. Measurements using a magnetic channel (gated by two photons) of the ${}^4$He scattering angle and momentum (from time of flight) permitted reconstruction of the $\pi^0$ "missing mass," the quantity used to separate ${}^4\mathrm{He} + \pi^0$ events from the continuum of double radiative capture ${}^4\mathrm{He} + \gamma + \gamma$ events. We measured total cross sections for neutral pion production of $12.7 \pm 2.2$ pb at 228.5 MeV and $15.1 \pm 3.1$ pb at 231.8 MeV. The uncertainty is dominated by statistical errors. These cross sections arise fundamentally from the down-up quark mass difference and quark electromagnetic effects that contribute in part through meson mixing (e.g., $\pi^0 - \eta$) mechanisms.

DOI: 10.1103/PhysRevLett.91.142302 PACS numbers: 24.80.+y, 24.85.+p, 25.10.+s, 25.45.–z

Charge symmetry is the symmetry of the quantum chromodynamic Lagrangian under the interchange of equal-mass up and down quarks [1,2]. This symmetry is broken by the different masses of the down and up quarks ($m_d > m_u$) and by their electromagnetic interactions. The combination of these two mechanisms leads, for example, to the neutron being heavier than the proton. Within the framework of chiral effective field theory [3,4], additional experimental information on the relative contributions of these two mechanisms to charge symmetry breaking (CSB) must, in leading order, come from pion-nucleon scattering. Direct experimental evidence is restricted to elastic scattering and charge exchange experiments with low-energy charged pions where the interpretation is complicated by corrections for the neutron-proton mass difference and electromagnetic interactions between the pions and nucleons [5,6]. Reactions in which a $\pi^0$ is emitted after being created by one nucleon and rescattered by a second are particularly clean. One example of such a CSB process is the measurement of a forward-backward asymmetry in the cross section for the $n + p \rightarrow d + \pi^0$ reaction [7].

The $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ reaction violates the conservation of isospin because the pion has isospin one while both the deuteron and ${}^4$He have isospin zero. More specifically, it violates charge symmetry, which is a rotation by $\pi/2$ about the $y$ axis in charge space that interchanges up and down quarks. (Isospin conservation is invariance under any rotation.) The $\pi^0$, whose wave function is odd under the interchange of down and up quarks, should not be produced from an initial state with charge symmetry even (in this case self-conjugate). The amplitude for CSB is weaker than a similar charge symmetry conserving amplitude by about 1/300, roughly the ratio of the quark mass difference to the nucleon mass. This suggests a $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ total cross section, which depends only on a CSB amplitude, that is as small as tens of picobarns.

Several searches for the $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ reaction have produced only upper limits [8]. A positive report at a deuteron energy of 1.1 GeV [9] has been questioned because the experiment did not clearly distinguish the photons from $\pi^0$ decay from photons that could have been produced by the double radiative capture $d + d \rightarrow {}^4\mathrm{He} + \gamma + \gamma$ process. This isospin-allowed process was calculated to be of the same order as the reported cross section [10]. A further search that could clearly distinguish between these two reactions was therefore warranted.

We chose to look for the $d + d \rightarrow {}^4\mathrm{He} + \pi^0$ reaction just above its threshold at 225.5 MeV to avoid other pion producing channels and to take advantage of the clean experimental conditions afforded by the Indiana University Cyclotron Facility's electron-cooled storage ring. A 6° bend located in one section of the ring provided a site where ${}^4$He nuclei, produced in a narrow forward cone just above threshold, could be separated from the circulating deuteron beam. By placing a gas jet target sufficiently upstream of the 6° magnet, it became possible to

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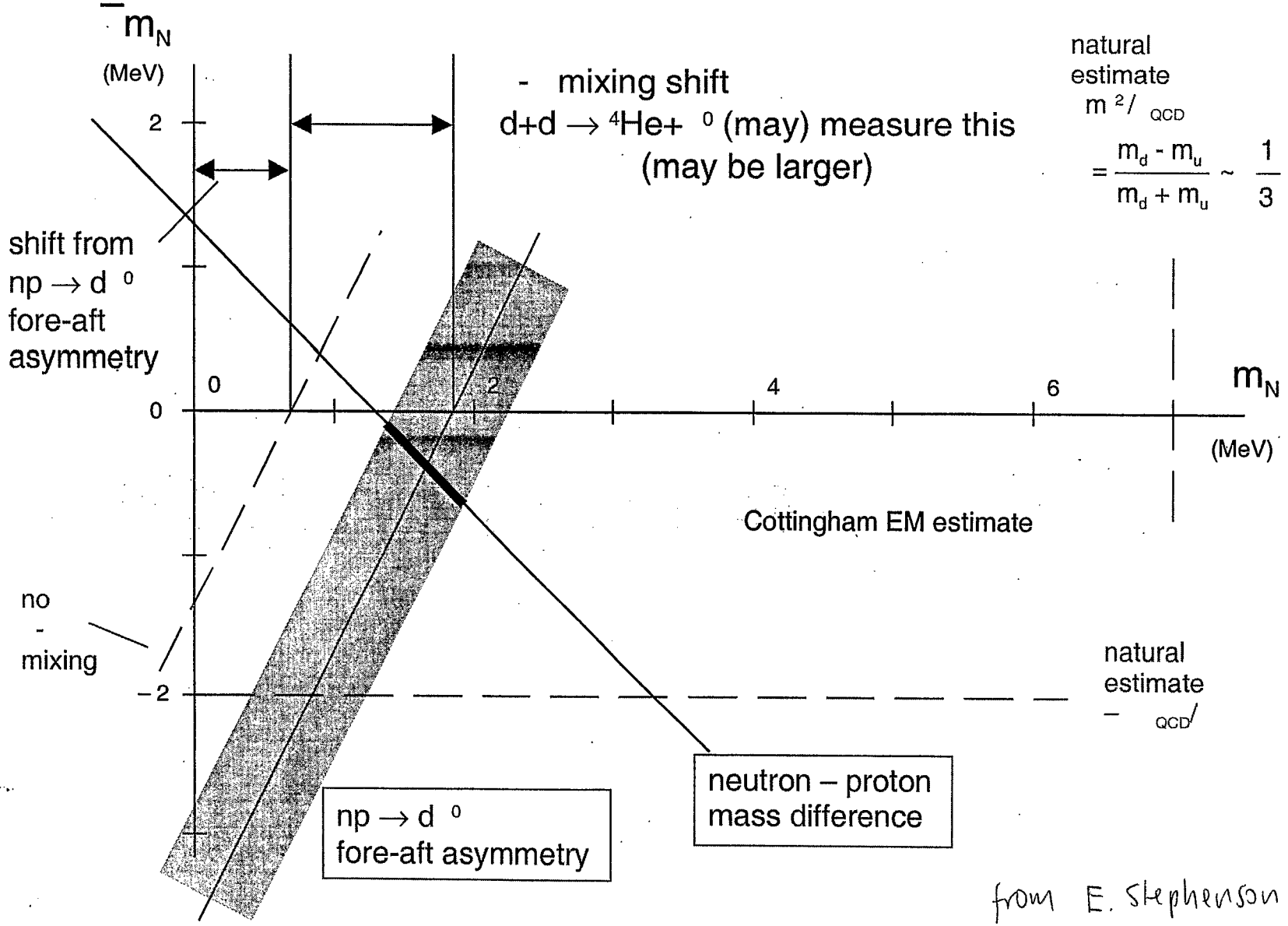
# SUMMARY – a glimpse of what it might look like




from E. Stephenson

# Estimates

Niskanen '02

Friar, Payne, Coon + v.K. '03

| Mechanism | $a_{pp} - a_{nn}$ (fm) | $B_{^3\mathrm{H}} - B_{^3\mathrm{He}}$ (keV) |
|---|---|---|
| short range | 0.7 | 45 |
| $\pi NN$ coupling; OPE | $0 \pm 0.8$ | $0 \pm 50$ |
| kinetic energy | 0.2 | 14 |
| $\delta m_N, \bar{\delta} m_N$; TPE | $< 0.3$ | $< 20$ |
| ... | ... | ... |
| "expt" (soft-EM subtracted) | $1.5 \pm 0.5$ | 87 |

# QCD and Dimensional Deconstruction

Mikhail Stephanov

# QCD and Dimensional Deconstruction

M. Stephanov

*U. of Illinois at Chicago and RIKEN-BNL*

Reference: D.T. Son, M.S., hep-ph/0304182

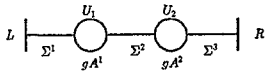


# Introduction/Motivation

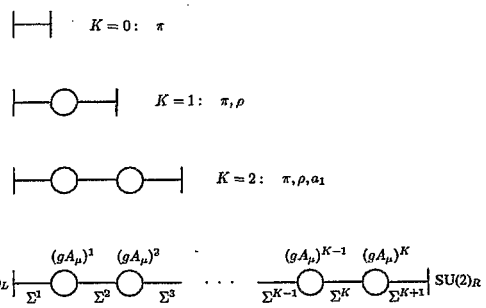
- QCD is largerly unsolved theory.
- Quark/gluon interactions are known and fixed by a principle of local gauge invariance. But ...
- Observable degrees of freedom are hadrons. What principles govern their interactions? Some can be derived from QCD, some not (e.g., VMD).
- Idea of dual description. Large $N_c$ ('t Hooft, Witten) – dual theory weakly coupled?

# $a_1$, etc

- 2 hidden local symmetries: $\pi$, $\rho$, $a_1$ (Bando, *et al*)
- The diagram:

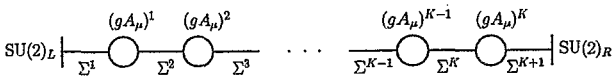



- More mesons (PDG): $\rho(770)$, $a_1(1260)$, $\rho(1450)$, $a_1(1640)$, $\rho(1700)$, ...
  Large $N_c$ – infinite tower of vector/axial mesons.
- Motivation to consider theories of arbitrary number $K$ of hidden local symmetries.






# Open "moose"




$$\mathcal{L} = \sum_{k=1}^{K+1} f_k^2 \mathrm{Tr}|D_\mu \Sigma^k|^2 - \sum_{k=1}^{K} \frac{1}{2} \mathrm{Tr}\left(F_{\mu\nu}^k\right)^2 .$$

Similar to the closed "moose" theory (Arkani-Hamed, Cohen, Georgi).
$f_k$ and $g_k$ – parameters.

Physical observables:

$$\frac{4}{{f_\pi}^2} = \sum_{k=1}^{K+1} \frac{1}{f_k^2} .$$

Meson masses: solutions of normal mode eqs ("springs" $f_k$, "weights" $1/g_k$)

$$(M^2)_{kk'} b_n^{k'} = {m_n}^2 b_n^k .$$

Even/odd $b_n$ alternate $\rightarrow$ $\rho$ and $a_1$ alternate.

# $4+1$d and dimensional deconstruction

$$\Sigma^k \approx 1 + iaA_5(u), \quad \text{(5th link variable)}$$

$$S = -\mathrm{Tr}\int du\, d^4x \left(-f^2(u)F_{5\mu}^2 + \frac{1}{2g^2(u)}F_{\mu\nu}^2\right).$$

or

$$S = -\frac{1}{2g_0^2}\mathrm{Tr}\int d^5x\,\sqrt{|g|}\,e^{-2\phi}F_{\hat{\mu}\hat{\nu}}F^{\hat{\mu}\hat{\nu}},$$

Background metric:

$$ds^2 = -du^2 + f^2 g^2 \eta_{\mu\nu} dx^\mu dx^\nu.$$

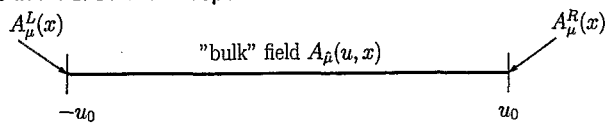
($f^2g^2$ – warp factor), and dilaton field (varying gauge coupling)

$$g_0^2 e^{2\phi} = g^2(u).$$



# AdS/CFT connection

In the continuum limit the procedure of calculating current-current correlators is the same as in AdS/CFT correspondence.




Introduce auxiliary vector fields $A_\mu^L$ and $A_\mu^R$. In the continuum limit $\equiv$ to setting b.c. on the 5d (bulk) field $A_\mu$ on 2 boundaries:

$$A_\mu(-u_0) = A_\mu^L \quad \text{and} \quad A_\mu(+u_0) = A_\mu^R.$$

The classical action $S_{\rm cl}$ is a functional of the b.c. Calculate the 2nd derivative of the action with respect to the boundary fields, e.g.,

$$\langle \mathscr{L}_\mu(x)\mathscr{L}_\nu(y)\rangle = \frac{\delta^2 S_{\rm cl}[A_\mu^{\rm cl}]}{\delta A_\mu^L(x)\delta A_\nu^L(y)}.$$

Unlike AdS/CFT there are 2 boundaries. Moose can be folded, if needed.

# Current correlator and matching to QCD

$$g_{nV,A} = \sqrt{2n(n+1)(2n+1)}\,\frac{\Lambda^2}{g_5}\,.$$

$$\Pi_V(Q^2) = \sum_{n=1}^{K} \frac{g_{nV}^2}{m_n^2(Q^2+m_n^2)} = \frac{2\Lambda^2}{g_5^2}\sum_{n\,\mathrm{odd}} \frac{2n+1}{Q^2+n(n+1)\Lambda^2}\,.$$

For large $Q^2$:

$$\Pi_V(Q^2) \to -\frac{1}{g_5^2}\ln(Q^2), \qquad (Q^2 \gg \Lambda^2).$$

Matching with QCD: $\Pi_V(Q^2) \to -\frac{N_c}{24\pi^2}\ln(Q^2)$, one finds:

$$\frac{1}{g_5^2} = \frac{N_c}{24\pi^2}\,.$$

which gives, for example,

$$f_\pi^2 = \frac{N_c}{24\pi^2} m_\rho^2\,. \qquad \text{(SVZ)}$$



# VMD in 'Cosh' background

Pion e.m. formfactor is saturated by a single $\rho$ pole:

$$g_{n\pi\pi} = \frac{f_\pi^2}{4}\int_{-u_0}^{+u_0}\frac{du}{f^2(u)}\,g(u)b_n(u) = -\frac{c_n}{2}g_5\int_{-1}^{1}d\xi\,\sqrt{1-\xi^2}\,P_n^1(\xi),$$

vanishes unless $n=1$.

More generally, contribution of higher resonances is supressed due to smaller overlap of oscillating $b_n(u)$ with pion "wave-function" $1/f^2(u)$.

# Kinetic Equation for $\phi^4$ Theory with Generalized Kadanoff-Baym Ansatz

**Takashi Ikeda**

# Kinetic equation for $\Phi^4$ Theory with generalized Kadanoff-Baym ansatz

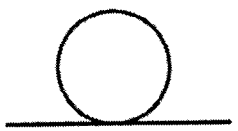
Takashi Ikeda

RIKEN BNL Research Center

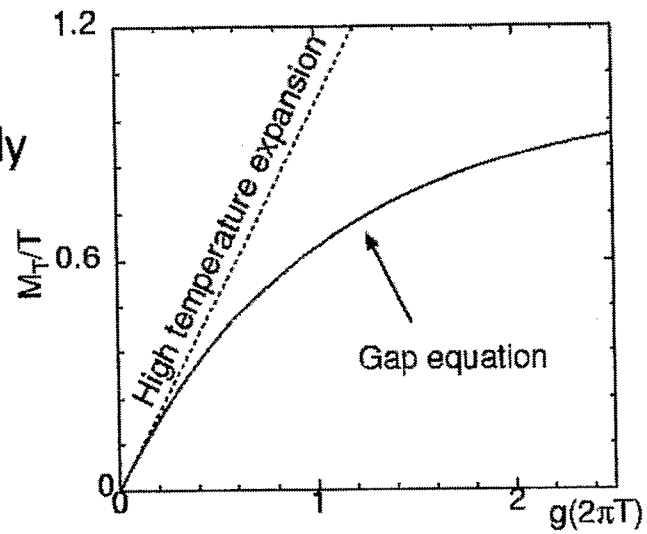
RIKEN Review, Nov., 2003

# Scalar $\Phi^4$ theory & Gap equation

- Self-interacting scalar $\Phi^4$ theory : $\mathcal{L} = \frac{1}{2}(\partial_\mu \Phi)^2 - \frac{1}{2} m^2 \Phi^2 - \frac{\lambda}{4!}\Phi^4$
  (3+1 dimensions,spatially homegeneous)
  - Focusing on decay of single particle excitation
    (Taking selfenergies as in thermal equilibrium and
    using quasiparticle approximation: $\rho(\mathbf{p},p_0) = 2\pi\varepsilon(p_0)\delta(p_0^2 - \mathbf{p}^2 - M_T^2)$ )

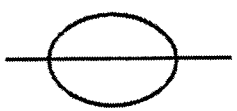
- Self-energies
  -  ..... generating thermal mass $M_T$ by solving gap eq. selfconsistently

$$M_T^2 = \frac{\lambda}{2}\int \frac{d^3\mathbf{k}}{(2\pi)^3}\frac{N_{eq}(E_k)}{E_k} + \frac{\lambda M_T^2}{32\pi^2}\left(\log\frac{M_T^2}{\mu^2} - 1\right) \longrightarrow$$




$(\lambda \equiv 24g^2)$

[ m=0 and renormalization by modified MS scheme
Results agree with PRD**63** 065003 by J.-P.Blaizot et al. ]

  -  $= \Sigma^{\gtrless}$ ..... Scattering processes leading to damping of single particle excitation

# Numerical results for **p**=0 & Conclusions

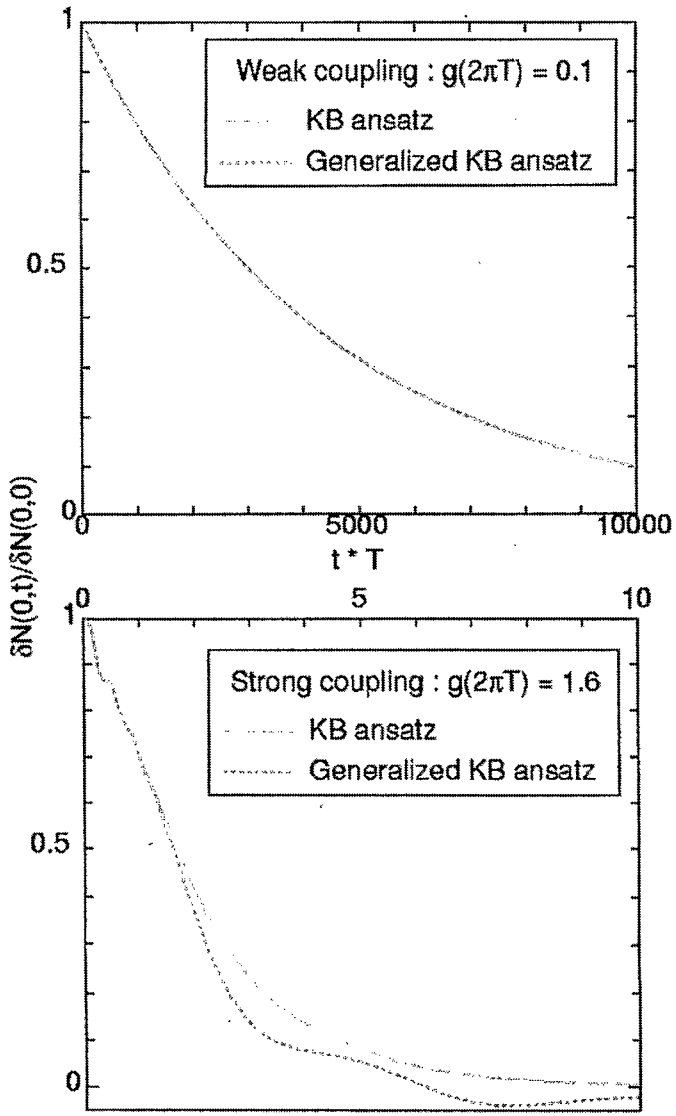
- Weak coupling (g =0.1) :
  Results with KB and generalized KB ansatz are in good agreement ; No memory effect.

Separation of sacle : $1/\gamma(0,t=\infty) \gg t_{osci}$
(at which oscillation of $\gamma(t)$ ends.)

$$\delta N(t) \sim \exp(-2\gamma(t=\infty)\,t)\,\delta N(0)$$

- Strong coupling (g = 1.6) :
  $(1/\gamma(0,t=\infty) \sim t_{osci})$
  - KB ansatz ..... exponential damping
  - **GKB ansatz** ..... non-exponential damping, oscillation

**Memory effect influences relaxation**



# QCDSP/QCDOC: Physics Results And Prospects/Project Status

Norman Christ and Robert Mawhinney

# QCDOC Project and Physics Overview

## 2003 RBRC REVIEW

*November 21, 2003*

Norman H. Christ
Robert D. Mawhinney

# QCDOC PROJECT

- Physics: QCD is a complete, fundamental theory. For many important problems the only significant errors are numerical: Immediate scientific reward from increased computer capability.

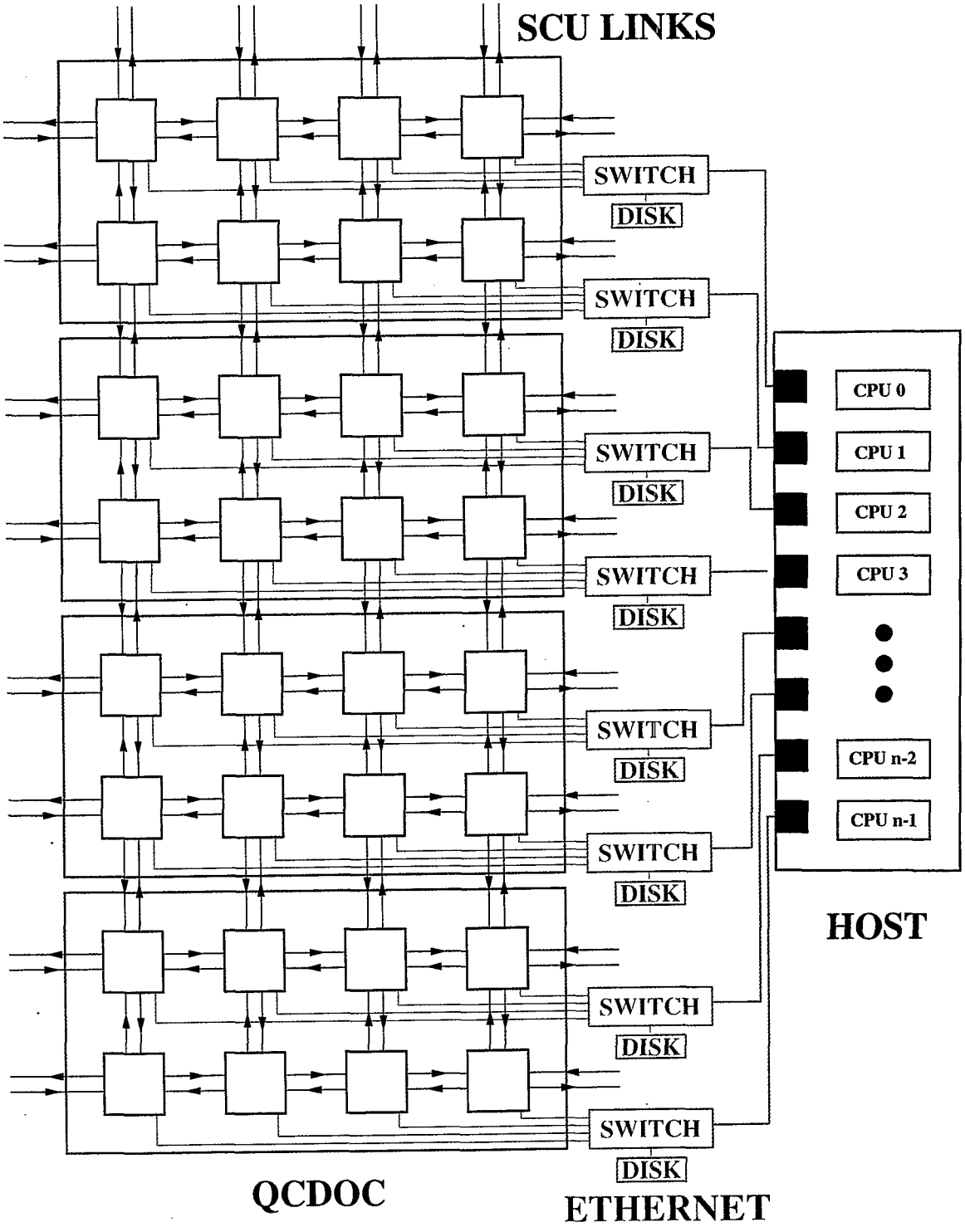
- Architecture: Large gains possible from optimized design.
  - Space-time homogeneity supports easy parallelization and a mesh network.
  - System-on-a-chip technology permits a highly scalable and cost-effective design:
    - Entire node (including interconnect logic) on a single chip.
    - The only extra components:
      Serial nearest-neighbor wires.
      Commercial Ethernet tree for booting, diagnostics and I/O.
  - Low power, compact design.

- Goal: 10 Teraflops QCDOC machine offers 20× boost to RBRC physics.

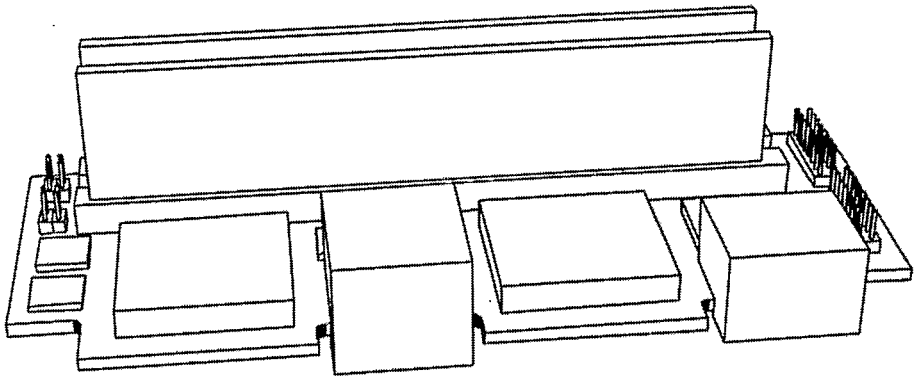
# DESIGN

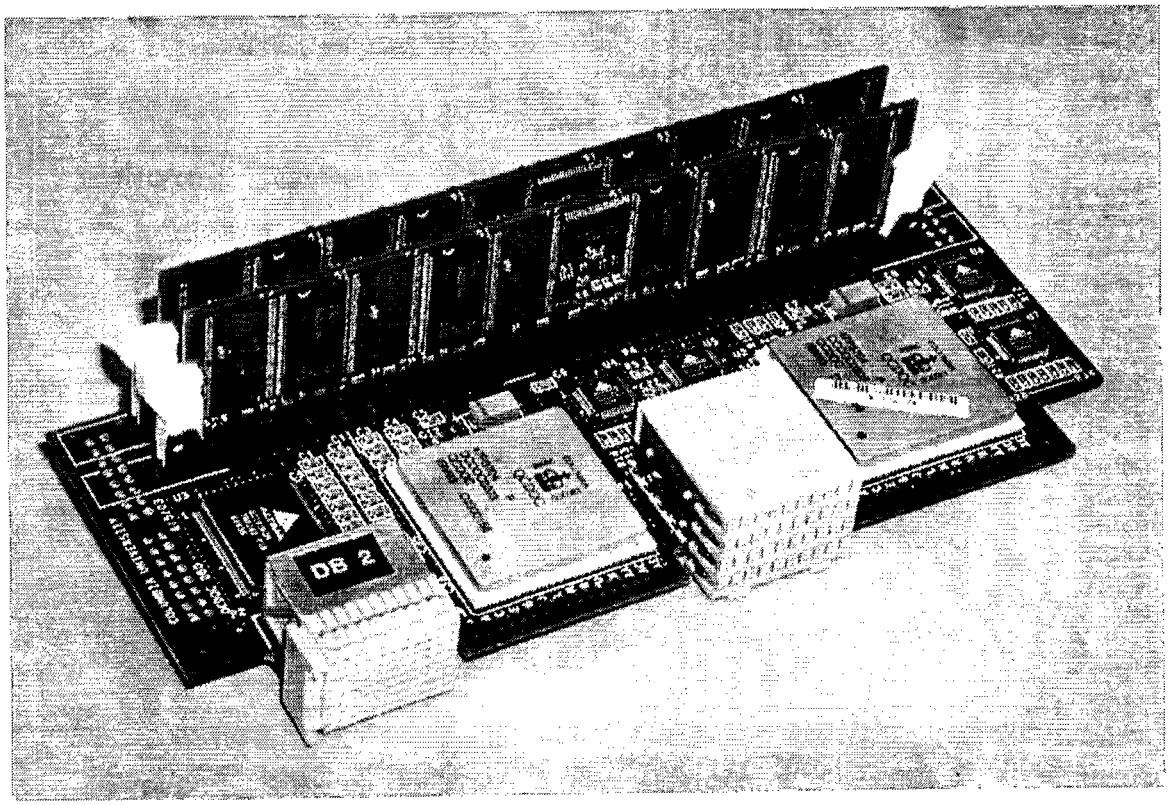
- IBM-fabricated, single-chip node.
  [50 million transistors, 3-4 Watt, 1.3cm×1.3cm die]
- PowerPC 32-bit processor
  - 1 Gflops, 64-bit IEEE FPU.
  - Memory management.
  - GNU and XLC compilers.
- 4 Mbyte on-chip memory and up to 2.0 Gbyte/node on DIMM card.
- 6-dim communications network:
  - Efficient for small packet sizes, $\approx$ 200ns latency.
  - Global sum/broadcast functionality.
  - Minimal processor overhead.
  - Lower dimensional machine partitions.
- 100 Mbit/sec, Fast Ethernet
  - JTAG/Ethernet boot hardware.
  - Host-node OS communication.
  - Disk I/O.
  - RISCWatch debugger.
- $\approx 5$ Watt, 10 in$^3$ per node.

# MACHINE OVERVIEW

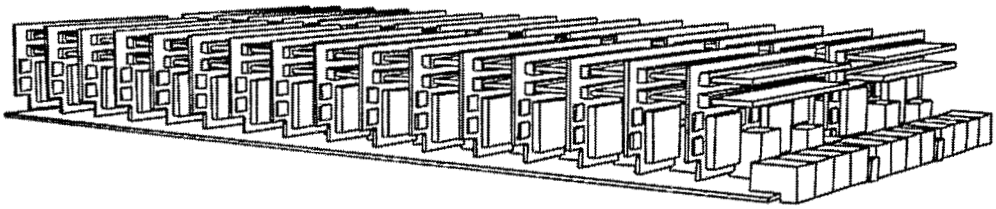


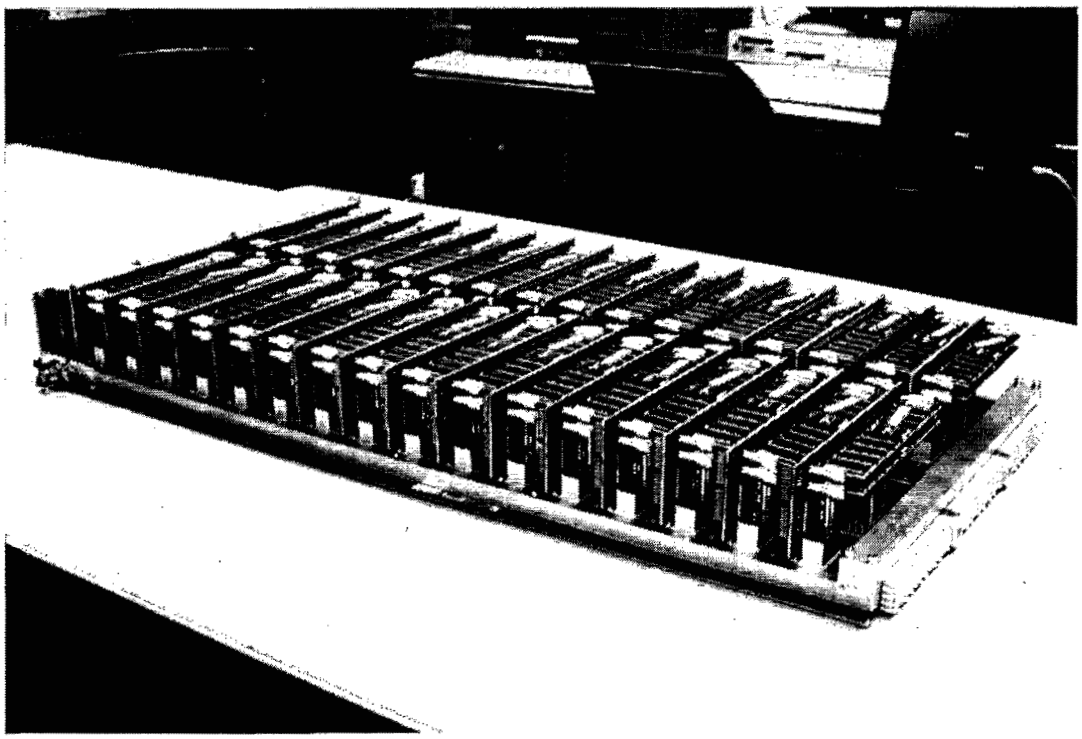
# DAUGHTER BOARDS





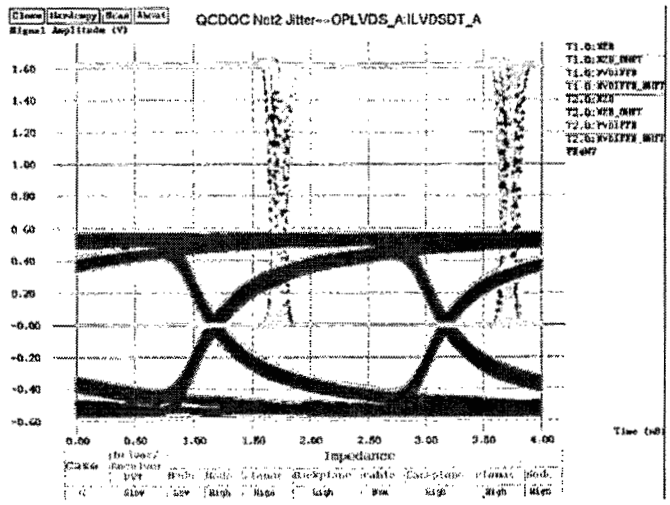
# MOTHER BOARDS



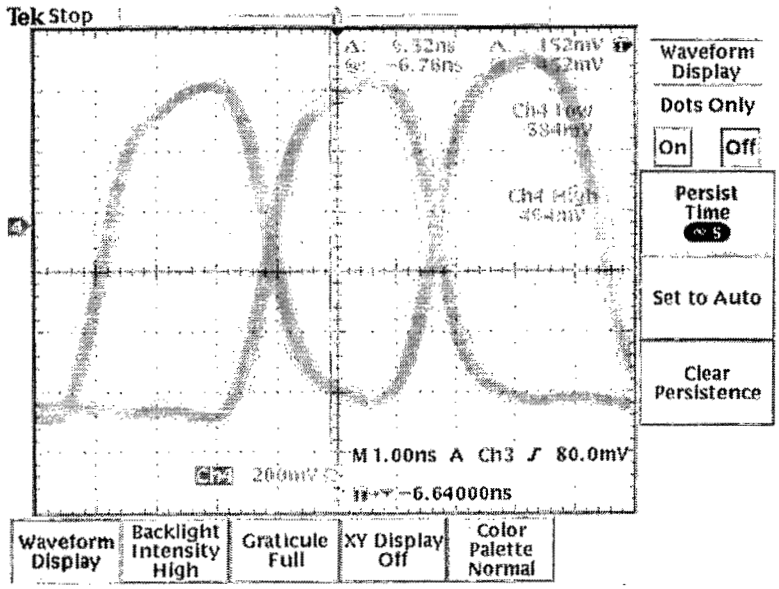


- Serial communications simulated and tested.

  - Simulation:




  - Real 6 meter cable:



# PERFORMANCE†

| Operation | Local Vol. | Mflops/node |
|---|---|---|
| **Optimized assembly code :** | | |
| SU3-SU3 | - | 800 |
| SU3-2spinor | - | 780 |
| DAXPY | - | 190 |
| ZAXPY | - | 450 |
| DAXPY-Norm | - | 350 |
| Wilson $D_{eo}$ | $2^4$ | 470 |
| Wilson $D_{eo}$ | $4^4$ | 535 |
| Clover $D_{eo}$ | $2^4$ | 560 |
| Clover $D_{eo}$ | $4^4$ | 590 |
| Staggered $D_{eo}$ | $2^4$ | 370 |
| Staggered $D_{eo}$ | $2^2.4^2$ | 430 |
| Asqtad $D_{eo}$ | $4^4$ | 440 |
| **Comparison with compiled code :** | | |
| CloverTerm/asm | - | 790 |
| CloverTerm/gcc, no dcbt | - | 150 |
| CloverTerm/xlc, no dcbt | - | 300 |
| **Generic (MILC) C code with QMP :** | | |
| Staggered $D_{eo}$ | $2^4$ | 171 |
| Staggered $D_{eo}$ | $4^4$ | 207 |
| Asqtad $D_{eo}$ | $4^4$ | 157 |
| Asqtad Force | $2^4$ | 140 |
| Asqtad Force | $4^4$ | 200 |

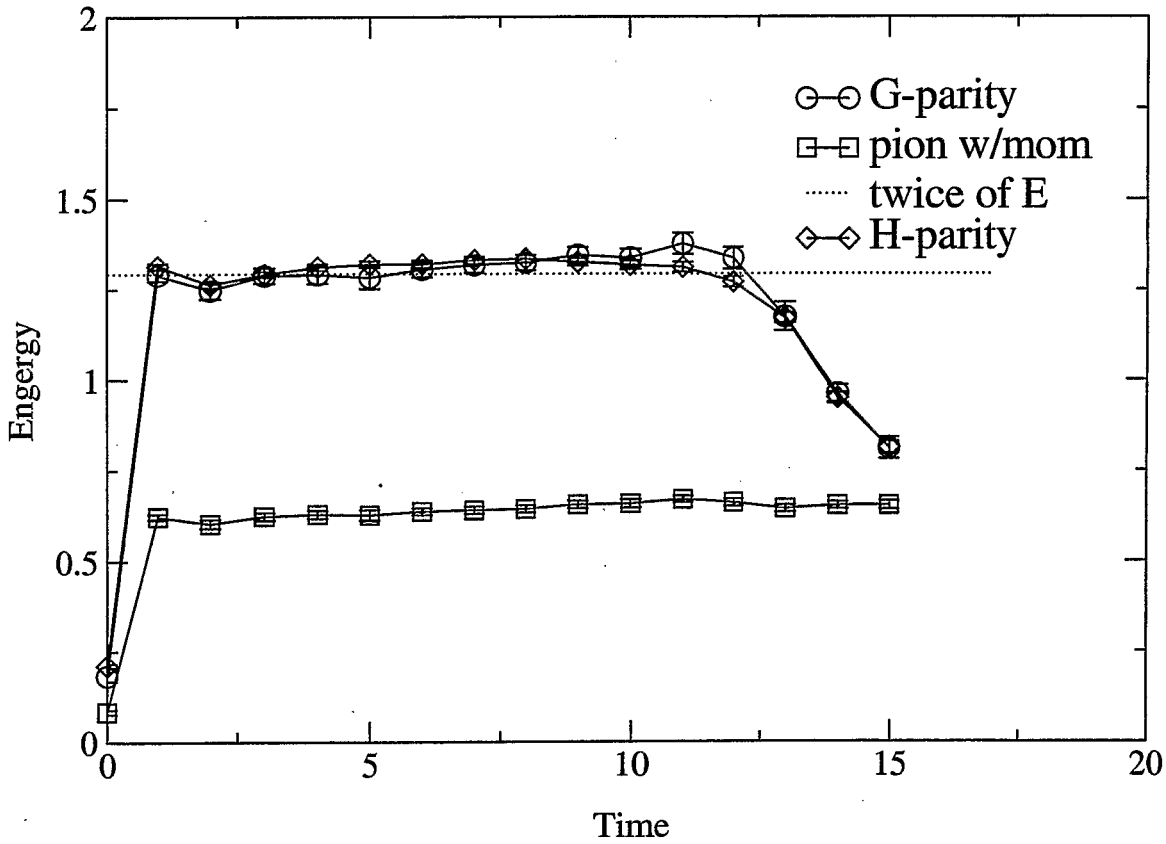
From gate-level simulation of ASIC at "nominal" 500MHz speed. Communication, cache flush overhead and 20 ns pin-pin wire delay included.

† [Boyle, Jung, Wettig http://arXiv.org/abs/hep-lat/0306023]

# OUTLOOK

- 2.0 Tflops (sustained) development machines February 2003.
- Production machines July 2004:
  - 5 Tflops (sustained) RBRC.
  - 5 Tflops (sustained) UKQCD.
  - 10 Tflops (sustained) US/SciDAC ?
- Price/performance of $1/(sustained) Mflops for QCD.

# $\pi - \pi$ Effective Mass — $8^2 \times 16 \times 32$ volume




$1/a =$ **0.978(14)GeV**, $\beta =$**5.7**
$8^2 \times 16 \times 32$ **and** $\times 48$, $L_s$**=10**
**Wilson gauge action, domain wall fermions.**

# QCDSP/QCDOC: Physics Results and Prospects

Robert D. Mawhinney

# QCDSP/QCDOC: Physics Results and Prospects

Robert D. Mawhinney
Columbia University
RIKEN-BNL Research Center

RBRC Review
Brookhaven National Laboratory
November 21, 2003

1. Actions, statistics, errors and warnings in lattice QCD
2. Features of domain wall fermions
3. Summary of QCDSP physics calculations
4. $B_K$: an example of actions, statistics, errors and warnings
5. 2+1 flavor dynamical domain wall fermion simulations with QCDOC

# Basics of Lattice QCD

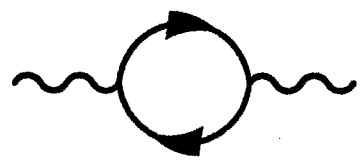
- Sample phase space for Feynman path integral for QCD using importance sampling

$$Z = \int [dU]\,[d\psi]\,[d\bar{\psi}]\,\exp\left\{\sum_n \left[-\beta S_g + \bar{\psi}(\not{D}+m)\psi\right]\right\} = \int [dU]\,\det(\not{D}+m)\exp\left\{\sum_n(-\beta S_g)\right\}$$

- Importance sampling: need solution to $(\not{D}+m)h = k$ for source $k$, not $\det(\not{D}+m)$,
- Numerically evaluate $n$-point functions for QCD. Example is 2-point pion correlator:

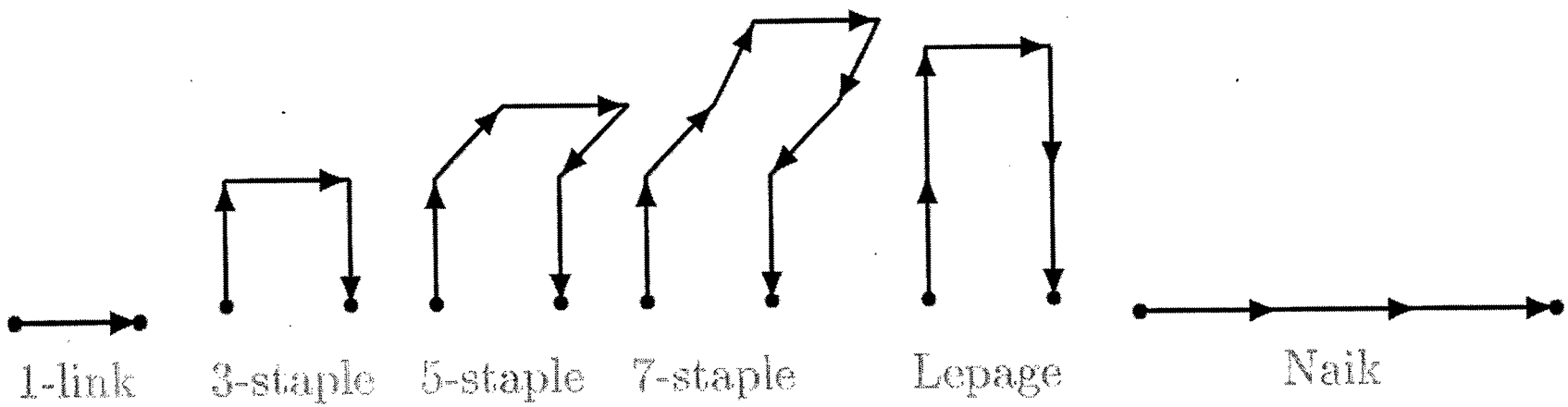
$$\langle(\overline{\psi}\gamma_5\tau^a\psi)_x\,(\overline{\psi}\gamma_5\tau^b\psi)_y\rangle$$

$$= \frac{1}{Z}\int [dU]\,\underbrace{\det(\not{D}+m)}_{m_{\rm dyn}}\exp\left\{\sum_n(-\beta S_g)\right\}\mathrm{Tr}\left[\gamma_5\tau^a\underbrace{((\not{D}+m)^{-1}_{x,y}}_{m_{\rm val}}\gamma_5\tau^b\underbrace{(\not{D}+m)^{-1}_{y,x}}_{m_{\rm val}}\right]$$

- For $n$-point functions, need $h$ from $(\not{D}+m)h = k$ for point, box or volume source $k$
- Solving $(\not{D}+m)h = k$ dominates calculation, $\sim 10^8 \times 10^8$ matrix, $\sim 1000$ $\not{D}$ multiplies
- Leaving out $\det(\not{D}+m)$ is quenching, which removes 

# ASQTAD Fermion Action

- Improve discretization to reduce flavor breaking at finite lattice spacing
- Simple $\overline{\psi}(x+\hat{u})\,U_u(x)\psi(x)$ changed to include other parallel transport paths
- Parallel transport well supported by grid-based computers.



# Residual Chiral Symmetry Breaking for DWF

- Consider introducing in action a $SU(N_f)$ matrix $\Omega$ through term at $l \equiv L_s/2$

$$-\sum_x \left\{\overline{\Psi}_{x,l-1} P_L \left(\Omega^\dagger - 1\right) \Psi_{x,l} + \overline{\Psi}_{x,l} P_R \left(\Omega - 1\right) \Psi_{x,l-1}\right\} \qquad \Omega \to U_R \, \Omega \, U_L^\dagger$$

- QCD chiral Lagrangian, with $\Sigma \equiv \exp\left[2i\phi^a t^a / f\right]$ and quark mass matrix $M$ is:

$$\begin{aligned} \mathcal{L}^{(2)}_{\mathrm{QCD}} &= \frac{f^2}{8} \mathrm{Tr}\left(\partial_\mu \Sigma \partial^\mu \Sigma^\dagger\right) + v \, \mathrm{Tr}\left[M\Sigma + (M\Sigma)^\dagger\right] \\ &+ v' \, \mathrm{Tr}\left[\Omega\Sigma + (\Omega\Sigma)^\dagger\right] + v'' \, \mathrm{Tr}\left[\Omega M^\dagger + \Omega^\dagger M\right] \end{aligned}$$

- For modes bound to walls of fifth dimension, $\Omega$ enters Green's functions as

$$\Omega e^{-\alpha L_s}$$

- Chiral condensate found by differentiating w.r.t. mass

$$-\langle \overline{q} q \rangle (m_f, L_s) \sim v + v''(\Omega + \Omega^\dagger)$$

# Operator Mixing and Chiral Symmetry

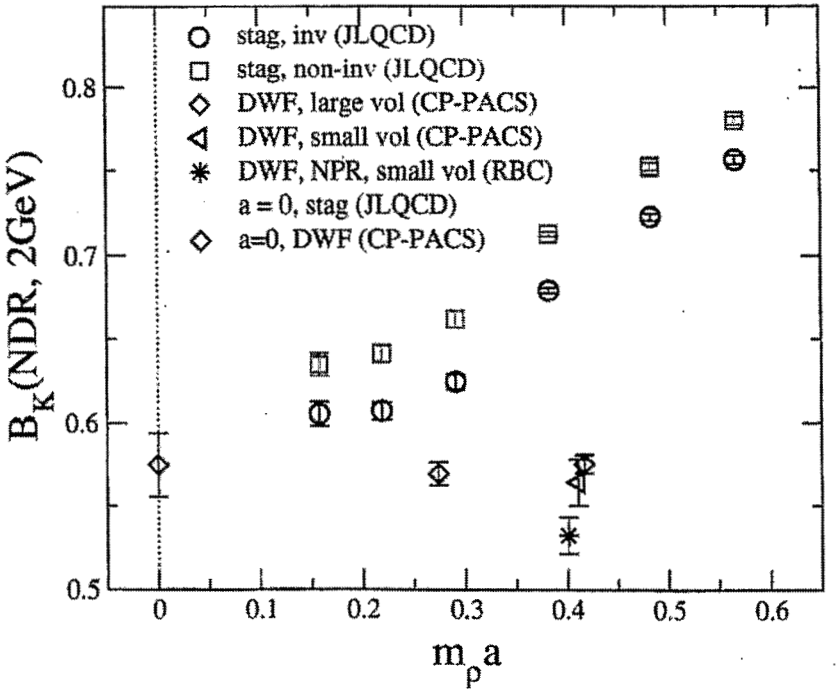
- Presence of lattice chiral symmetry markedly helps operator mixing
- Consider $Q^{(\Delta S=2)}$ as an example

$$\begin{aligned}
\bar{s}^{\rm lat}\gamma_\mu(1-\gamma_5)d^{\rm lat}\ \bar{s}^{\rm lat}\gamma_\mu(1-\gamma_5)d^{\rm lat} &\equiv (\bar{s}^{\rm lat}d^{\rm lat})_{V-A}\ (\bar{s}^{\rm lat}d^{\rm lat})_{V-A} \\
&= Z_1(\mu a)(\bar{s}d)_{V-A}\ (\bar{s}d)_{V-A} \\
&+ Z_2(\mu a)(\bar{s}d)_{V+A}\ (\bar{s}d)_{V+A} \\
&+ Z_3(\mu a)(\bar{s}d)_{P-S}\ (\bar{s}d)_{P-S} \\
&+ Z_4(\mu a)(\bar{s}d)_{P+S}\ (\bar{s}d)_{P+S} \\
&+ Z_5(\mu a)(\bar{s}d)_{T}\ (\bar{s}d)_{T}
\end{aligned}$$

- For DWF, $Z_2, Z_3, Z_4, Z_5$ are $\mathcal{O}(m_{\rm res}^2)$, so small

# The Kaon $B$ Parameter, $B_K$

- RBC Collaboration: using NPR and DWF, $a^{-1} = 1.922(40)$ GeV, $16^3 \times 32 \times 16$ lattice, Wilson gauge action. $B_K(2\text{ GeV}) = 0.532(11)$
- CP-PACS Collaboration: using pert. th. and DWF, $a^{-1} = 1.875(56)$ GeV, $16^3 \times 40 \times 16$ lattice, RG-improved gauge action. $B_K(2\text{ GeV}) = 0.564(14)$
- CP-PACS Collaboration: for $a \to 0$, they quote 0.5746(61)(191), (stat) (scaling)

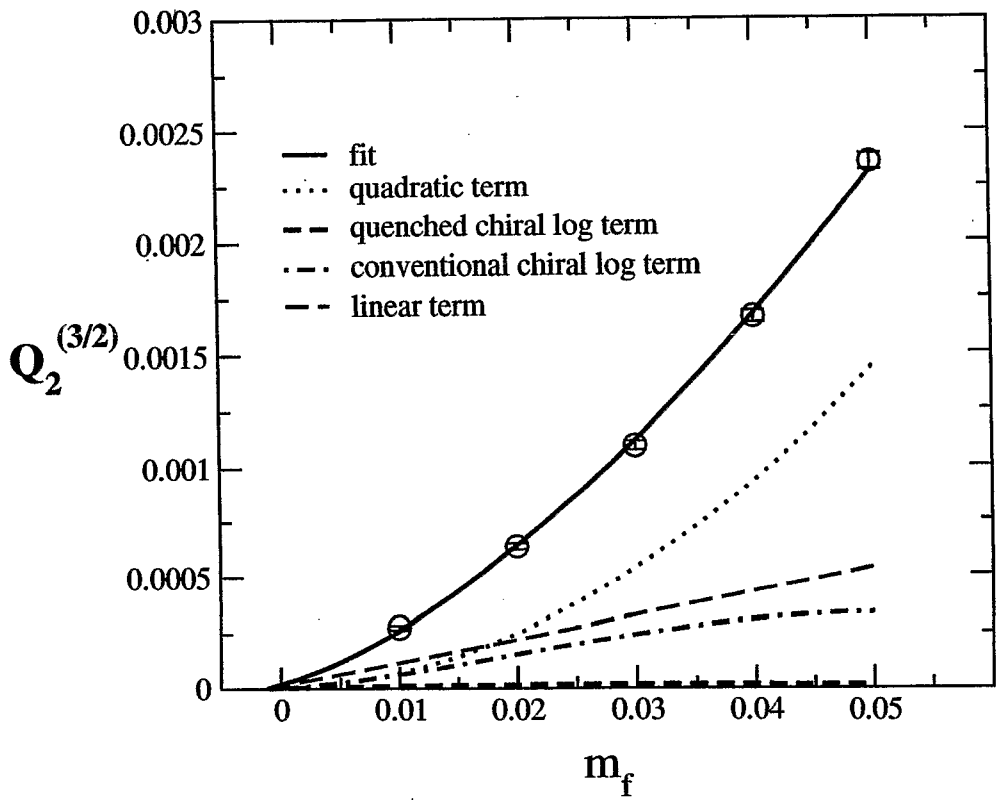


# Results for Real $A_2$

- Lattice determination from $K^+ \to \pi^+$
- Uses known chiral logarithm in quenched theory

$$1 - \frac{6m_M^2}{(4\pi f)^2} \ln(m_M^2/\Lambda^2)$$

- Fit gives coefficients of $m_M^4$ terms



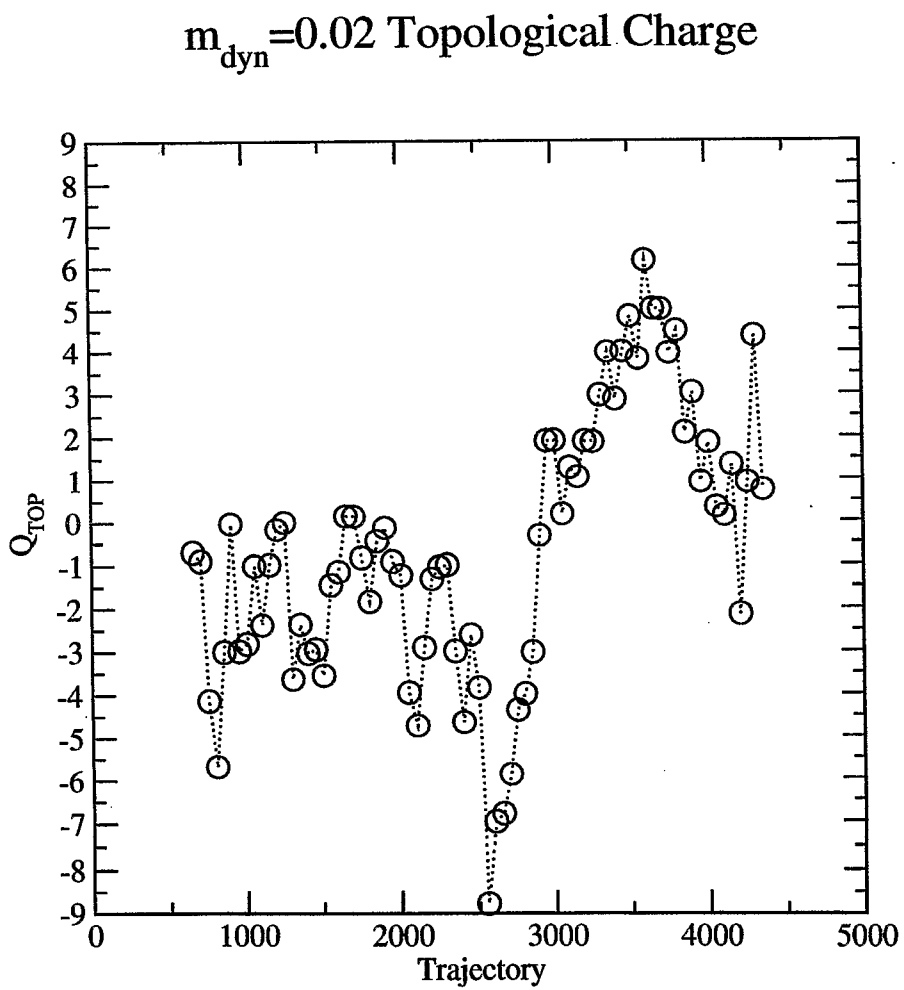
# Major Physics Projects on QCDSP

- Both quenched and full QCD simulations with DBW2 action
- A wide variety of observables being measured.
- Full QCD lattices being analyzed on remaining machines
- Full QCD simulations have been sped up by $\approx 3\times$

| Machines | $a^{-1}$ (GeV) | $L$ (fm) | $N_f$ | $m_f$ | $L_s$ | $m_{\rm res}$ |
|---|---|---|---|---|---|---|
| 300 Gflops RBRC $225 + 3 \times 25$ | 2.9 | 1.6 | 0 | | 10 | $\approx m_s/300$ |
| 200 Gflops CU | 1.7 | 1.9 | 2 | $\approx m_s/2$ | 12 | $\approx m_s/10$ |
| 100 Gflops RBRC | 1.7 | 1.9 | 2 | $\approx 3m_s/4$ | 12 | $\approx m_s/10$ |
| 100 Gflops RBRC | 1.7 | 1.9 | 2 | $\approx m_s$ | 12 | $\approx m_s/10$ |
| 100 Gflops RBRC | 1.3 | 2.5 | 2 | $\approx m_s/2$ | 12 | ? |

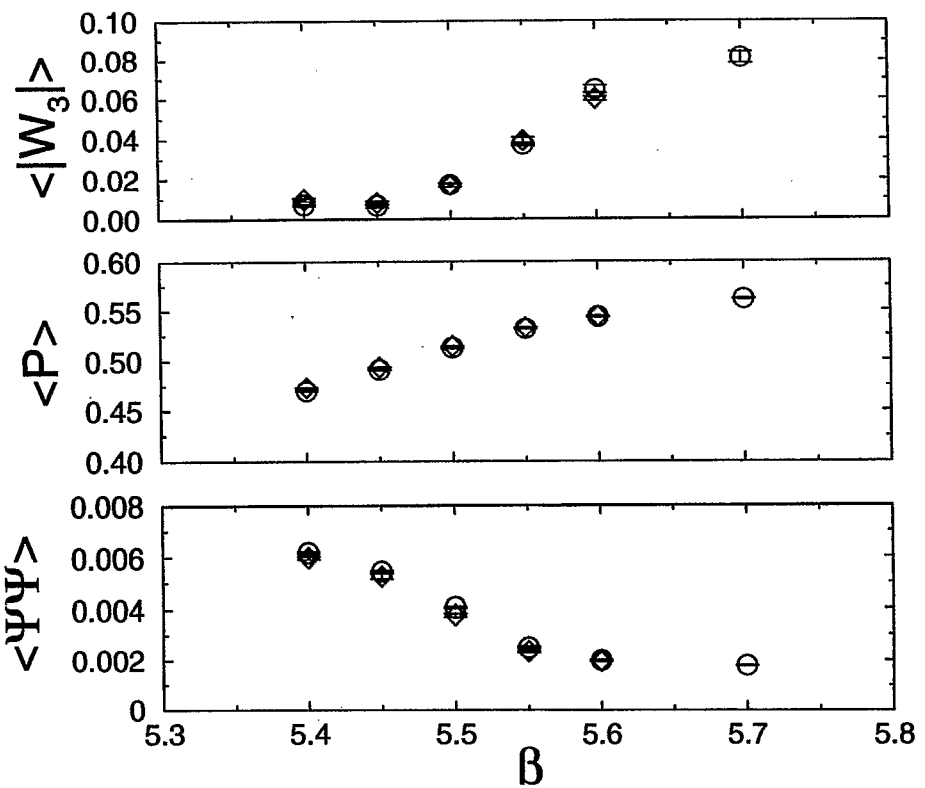
# The Topological Charge

- Define by "smearing" gauge field
- Should preserve topological features beyond lattice scale



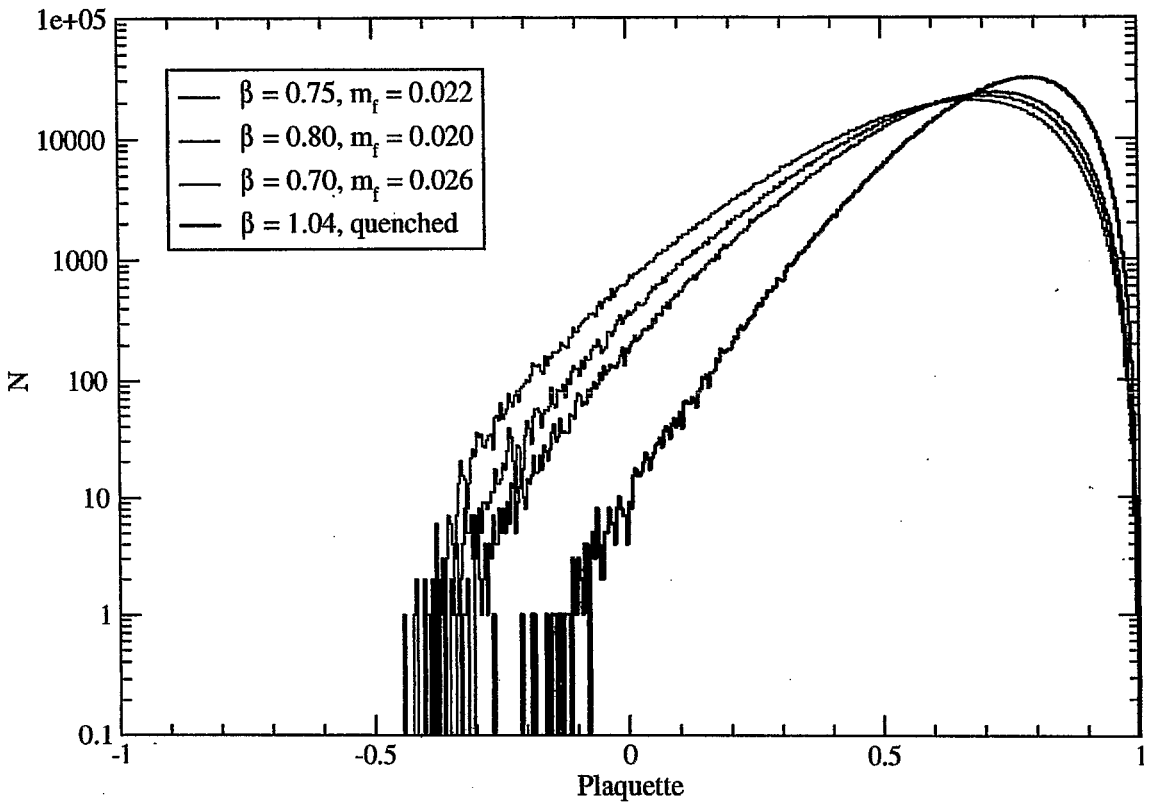
# Dynamical DWF at finite $T$

- $16^3 \times 6$ lattice with $L_s = 32$ and $m_f = 0.022$
- Large residual mass
- Pions still as light as other actions, except special Goldstone of staggered.
- See topology change in evolution



# Plaquette distributions for dynamical DWF+DBW2

- Fermion determinant changes running of coupling
- Makes gauge coupling at lattice scale stronger Stronger coupling gives more lattice dislocations



# RESEARCH SUMMARY - THEORY

# Research Summary

# Taku Izubuchi

Taku Izubuchi
*Institute of Theoretical Physics, Kanazawa University, Ishikawa 920-1192, Japan*
*RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973-5000, USA*

We report preliminary results from an ongoing calculation of $B_K$ for $N_f = 2$ dynamical QCD with domain wall fermions. Simulations have been done with three dynamical quark masses on $16^3 \times 32$ volumes with $L_s = 12$, where the lattice spacing is $a^{-1} = 1.81(6)$ GeV. Using measurements on $\sim 70$ lattices for each dynamical mass and extrapolating $m_{\rm dyn} = m_{\rm val}$ to the kaon point, we find $B_K^{\overline{\rm MS}}(\mu = 2{\rm GeV}) = 0.503(20)$ and in the range of 0.50 to 0.55 from various way analysis.

## I. INTRODUCTION

After two years of collaborative efforts of the Riken-BNL-Columbia collaboration addressing for the full QCD calculation, we are starting to produce important results for phenomenology this year. Here I report our preliminary results relevant for *Cabibbo-Kobayashi-Maskawa matrix.* Other interesting results including quark masses[5] and other Kaon matrix elements[6] would be reported by other members of RBC collaboration.

The uniqueness of our joint work is characterized by the use of the chirally improved fermion, domain wall fermions (DWF), as two flavor *dynamical* quarks on lattice. Using dynamical DWF we could investigate hadron physics on lattice under one of the most ideal conditions :

1. reduced quenching errors, $N_F = 0 \to N_F = 2$
2. small scaling violation, $O(a^2)$,
3. almost negligible unphysical (chirally disallowed) mixings between operators,
4. precise renormalization factors owing to the non-perturbative renormalization.

The kaon B parameter, $B_K$, is an essential bridge between $K_0 - \overline{K_0}$ mixing experiments and the CKM matrix. Using DWF, quenched calculations of $B_K$ have been done [1–3], where operator mixing and $O(a)$ errors are small because of the good chiral properties of DWF. Including dynamical fermions is an obvious way to improve these calculations.

Using an improved HMC algorithm for DWF [4, 5], we have generated three ensembles of lattices of size $16^3 \times 32$ for $N_f = 2$ QCD with degenerate dynamical masses of $m_{\rm dyn} = 0.02, 0.03, 0.04$. Our fermion action is the standard DWF action with $L_s = 12$ and $M_5 = 1.8$ and our gauge action is DBW2 with $\beta = 0.80$. Extrapolating the rho mass in $m_{\rm dyn}$ to the chiral limit, we find a lattice spacing of $a^{-1} = 1.81(6)$ and a residual mass $m_{\rm res} = 0.00136(5)$. We measure on lattices separated by 50 trajectories and have 78, 84, 57 lattices for $m_{\rm dyn} = 0.02$, 0.03 and 0.04, respectively[10]. For more details see [5] and for results with $\Delta S = 1$ matrix elements see [6].

## II. CALCULATION OF $B_K$

$B_K$ is defined by

$$B_K \equiv \frac{\langle \overline{K}^0 | O_{LL} | K^0 \rangle}{\frac{8}{3} \langle \overline{K}^0 | A_\mu | 0 \rangle \langle 0 | A^\mu | K^0 \rangle} \quad , \tag{1}$$

where $A_\mu = \bar{s}\gamma_\mu\gamma_5 d$ and $O_{LL}$ is the $\Delta S = 2$ four-quark operator $(\bar{s}d)_{V-A}\,(\bar{s}d)_{V-A}$. For a general value of the mass of the pseudoscalars entering (1), we will use the symbol $B_{\rm PS}$, reserving $B_K$ for the case where the pseudoscalars have the kaon mass.

We first evaluate this by the conventional method, where the ratio of a three-point Green's function and two pseudoscalar–axial-vector correlators is taken:

$$R(t) = \frac{\langle J_5^a(t_0) O_{LL}(t) J_5^a(t_1) \rangle}{\frac{8}{3} \langle J_5^a(t_0) A_4^a(t) \rangle \langle A_4^a(t) J_5^a(t_1) \rangle} \quad . \tag{2}$$

(no sum on $a$). We use Coulomb gauge fixed wall sources at $t_0 = 4$ and $t_1 = 28$ for valence masses, $m_{\rm val}$, equal to 0.01, 0.02, 0.03, 0.04 and 0.05. Propagators are found with both periodic and anti-periodic temporal boundary conditions and averaged to double the temporal length as sketched in Figure 1.

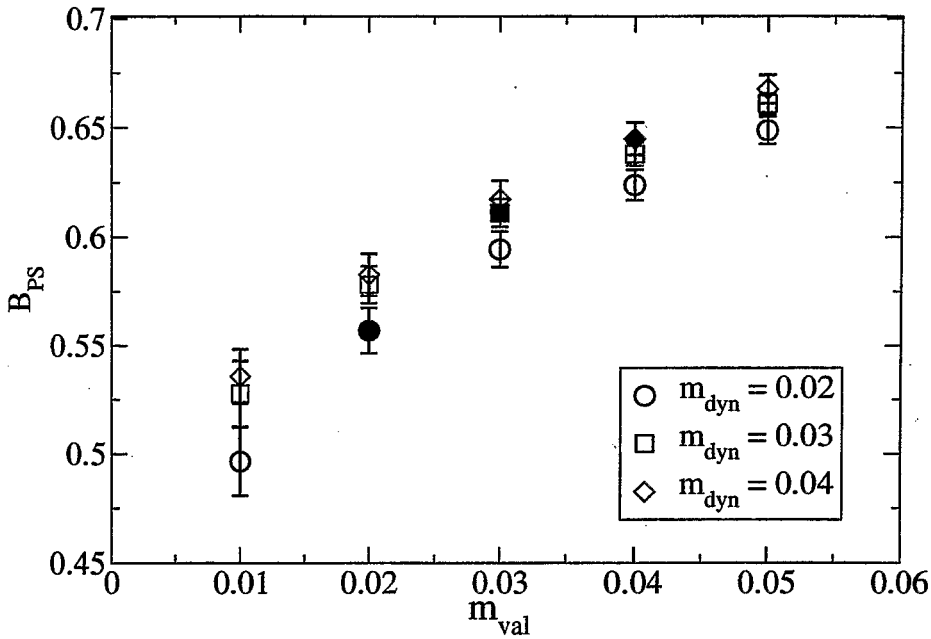



FIG. 3: $B_{\rm PS}^{\rm lat}$ for different valence and dynamical masses. The filled symbols have $m_{\rm val} = m_{\rm dyn}$.

partially quenched formula [7]

$$B_{\rm PS}(m) = b_0 \left(1 - \frac{6}{(4\pi f)^2}\left(M_{\rm PS}^2 \log \frac{M_{\rm PS}^2}{\Lambda_{\chi\rm PT}^2}\right)\right) + b_1 M_{\rm PS}^2 \ , \tag{3}$$

fitting the three points with $m_{\rm val} = m_{\rm dyn}$ to determine $b_0$ and $b_1$. We find $b_0 = 0.267(12)$, $b_1 = 1.256(79)$ and $B_K^{\rm lat} = 0.541(9)$ (statistical error only), with a small $\chi^2$/d.o.f. Note that we are using the known coefficient of the chiral logarithm, $M_{\rm PS}^2 = 4.06 \times (m_f + m_{res})$, $f = 0.0786$ and $\Lambda_{\chi\rm PT} = 1$ GeV. The statistical error in the lattice spacing gives an additional 2% systematic error in the value of $B_K^{\rm lat}$, due to the uncertainty in the strange quark mass.

While our data makes extrapolation to $m_f = \overline{m_s}/2$ quite robust, the value of $b_0$ is much less solid. A small value in the chiral limit has also been seen in the quenched calculations, but more control over the extrapolation is needed.

We have also fit the dependence of $B_{\rm PS}$ on $m_{\rm val}$ to (3) for each fixed $m_{\rm dyn}$, using the five values for $m_{\rm val}$. The interpolated values for $B_K^{\rm lat}(m_{\rm val} = \overline{m_s}/2, m_{\rm dyn})$ are 0.537(11), 0.557(9) and 0.568(10) for $m_{\rm dyn} = 0.02$, 0.03 and 0.04 respectively. We reduce the fitting range to exclude the heaviest two points and see the results stay same within error.

An alternative method of extracting $B_K$ is to divide the three-point function in the numerator of (1) by a wall-wall pseudoscalar correlator [1]. This removes some zero mode effects in the quenched approximation, while giving larger statistical errors. However here we see no difference in the central values for results calculated using these two methods.

## III. RENORMALIZATION AND MIXING

To get to $B_K^{\overline{\rm MS}}$ we need to renormalize $B_K^{\rm lat}$ and control mixing with other dimension six, chirally disallowed operators. Using NPR [8] in the quenched theory we have seen that mixing coefficients with chirally disallowed operators are small. Preliminary NPR calculations on our $\sim 40$ dynamical DWF lattices also show that the mixing coefficients are small (less than a few percent).

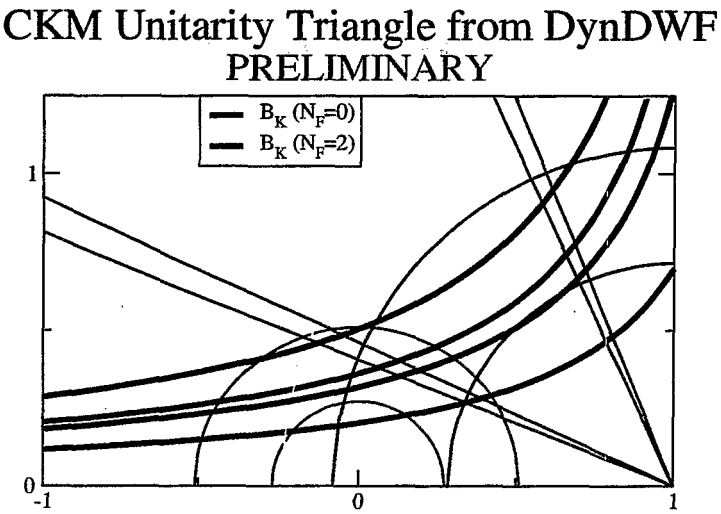



FIG. 4: Preliminary results of CKM unitarity triangle. The allowed region is shown from this work ($N_F = 2$) and that of quenched calculations ($N_F = 0$).

quark masses. So the direct simulation at the light quark masses would be another interesting candidate for future projects on QCDOC.

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[1] T. Blum *et. al.* (2001), hep-lat/0110075.
[2] A.Ali Khan *et. al.* (2001) Phys. Rev. D64 114506.
[3] J. Noaki (RBC), to appear in NPB (Proc. Suppl.).
[4] T. Izubuchi (RBC) NPB (PS) 119 (2002) 813.
[5] C. Dawson (RBC), to appear in NPB (Proc. Suppl.).
[6] R. Mawhinney (RBC), to appear in NPB (Proc. Suppl.).
[7] S. R. Sharpe, Phys. Rev. D46 (1992) 3146, M. F. L. Golterman and K.-C. Leung, Phys. Rev. D56 (1997) 2950.
[8] C. Dawson, NPB (PS) 94 (2001) 613.
[9] S. Aoki *et. al.* Phys. Rev. D67 (2003) 094502.
[10] This includes some data generated after the conference.


[11] The author thanks Dr. N. Yamada for providing the program to draw this figure.

# Research Summary

## Sangyong Jeon

# Energy Loss of Leading Partons in QGP

Sangyong Jeon

McGill University

Riken-BNL Research Center

Work done with G. Moore (McGill)

# Energy Loss Mechanism

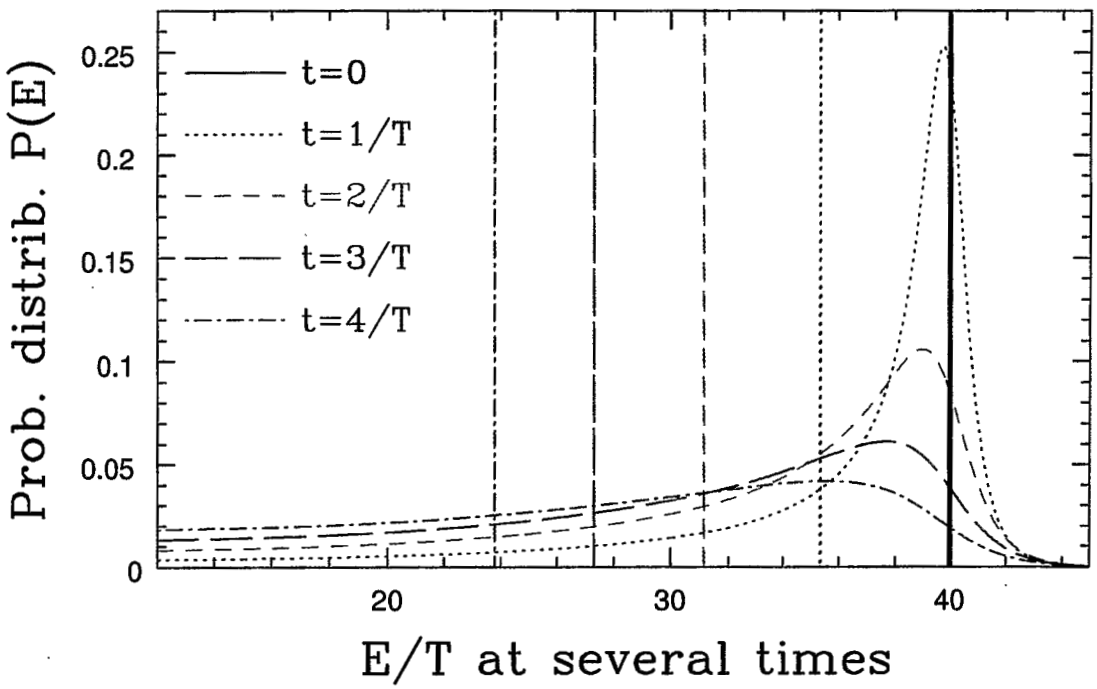
- Medium induced gluon Bremsstrahlung
- Must take into account coherence effect
  - * Original study by Landau, Pomeranchuck and Migdal (LPM)
  - * QCD applications by Xin-Nian Wang and Miklos Gyulassy and also Baier, Dokshitzer, Mueller, Peign and Schiff (BDMPS)
  - * We use recent resummation method by Arnold, Moore and Yaffe (AMY) – Full leading order result in high $T$ QCD
  - * Lesson: For asymptotically high energy partons

$$\Delta E \propto \sqrt{E}$$

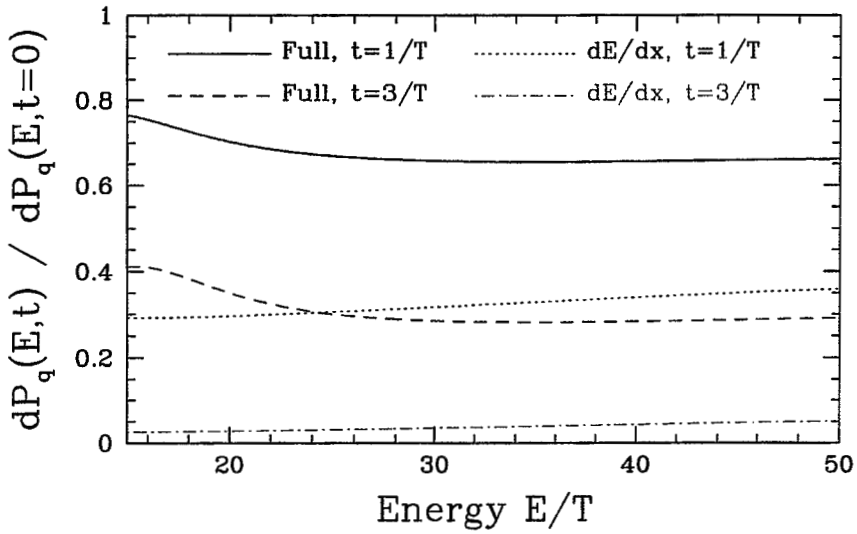
instead of $\Delta E \propto E$ (Bethe-Heitler limit)

# Unwarranted approximations? – I

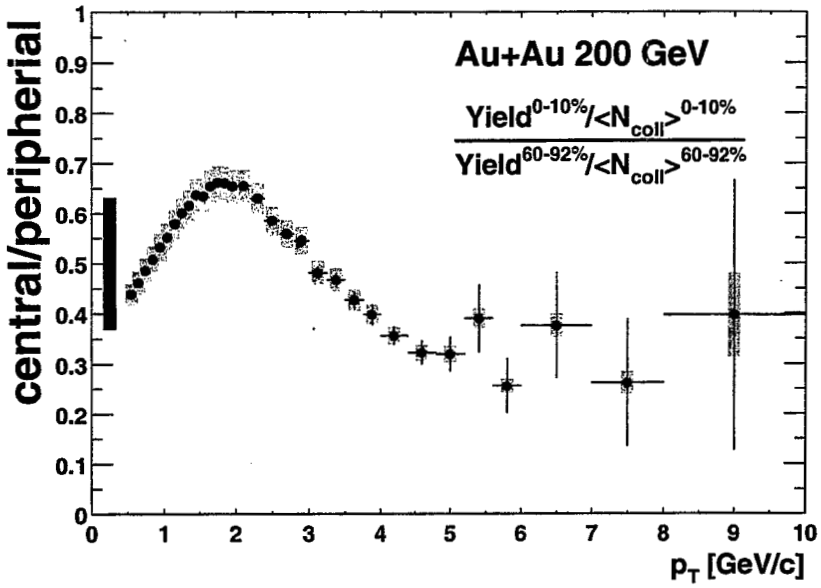
- Approximating the whole passage by the average $dE/dx$ is bad – The energy spectrum shifts as well as broadens




Vertical lines: Energy distribution shifted by $\int dt\,(dE/dt)$ at various times.
Curves: Actual energy distributions at various times.
Energy in unit of temperature.




Full calculation versus $dE/dx$ approximation at various times. Energy in unit of temperature.




Experimental result from PHENIX (nucl-ex/0308006)

# CURRICULA VITAE

## CURRICULA VITAE - SUMMARY
## RBRC FELLOWS/RESEARCH ASSOCIATES/RESEARCHERS

**Yasuyuki Akiba** **Birthplace:** Tokyo, Japan **DOB:** October 20, 1959
**D.S.** 1988, University of Tokyo
**Experience** Research Associate, Institute for Nuclear Study, University of Tokyo, March 1988 – March 1997;
Research Associate, High Energy Accelerator Research Organization (KEK), April 1997 – March 2003;
Senior Research Scientist, RIKEN, April 2003 – July 2003;
Senior Researcher, RIKEN, August 2003 – present;
RIKEN Spin Program Researcher, November 2003 – present

**Yasumichi Aoki** **Birthplace:** Gunma, Japan **DOB:** January 7, 1968
**Ph.D.** 1996, University of Tsukuba, Japan
**Experience:** COE Research Fellow at the Center for Computational Physics University of Tsukuba;
Assistant (3 year research position) at the Center for Computational Physics, University of Tsukuba
Research Associate, RIKEN BNL Research Center, May 1, 2000 – April 30, 2003.
RBRC Visiting Scientist, with Columbia University, May 1 to July 31, 2003.

**Steffen A. Bass** **Birthplace:** Frankfurt, Germany **DOB:** May 17, 1968
**Ph.D.** 1997, J. W. Goethe Universität Frankfurt, Germany
**Experience:** Feodor Lynen Fellow and Research Associate, Duke University, 1998-99
Visiting Assistant Professor, Michigan State University, 1999
•RHIC Physics Fellow/Assistant Professor--RBRC/Duke, September 1, 2000 – present
**Awards and Honors:** W. E. -Heraeus-Award, W.E.-Heraeus Foundation, Germany, 1993
Feodor-Lynen Fellow, A. v. Humboldt Foundation, Germany, 1997
U.S. Department of Energy division of Nuclear Physics Outstanding Junior Investigator Award, 2003.

**Alexander V. Bazilevsky** **Birthplace:** Yaroslavl, Russia **DOB:** May 10, 1968
**Ph.D.** 1999, Institute for High Energy Physics, Protvino, Russia
**Experience:** Scientific Researcher, IHEP, Protvino, Russia
Research Collaborator, BNL PHENIX
Research Associate, BNL, RIKEN BNL Research Center, March 10, 1999 – March 9, 2002;
RIKEN BNL Fellow, March 10, 2002 – April 1, 2003.
**Awards and Honors:** Soros Scholarship, 1996.

**Yuji Goto** **Birthplace**: Shizuoka, Japan **DOB**: November 25, 1965
**Ph.D** 1996, Kyoto University, Kyoto, Japan
**Experience**: Research Fellow of the Japan Society for the Promotion of Science, 1994-1996
Postdoctoral Fellow, RIKEN, Japan, 1996-1999
RIKEN BNL Fellow, November 1999 – March 31, 2002
Scientist, RIKEN, April 2002 to March 2003;
Senior Research Scientist, RIKEN, April 2003 – present.
RIKEN Spin Program Researcher, RBRC, April 1, 2002 – present.

**Matthias Grosse-Perdekamp**
**Birthplace**: Schwenningen, Germany **DOB**: December 1, 1963
**Ph.D.** 1995, University of California at Los Angeles
**Experience**: Associate Research Scientist, Yale University 1995-1998
Research Scientist, Mainz University, 1998-1999
RIKEN BNL Fellow, January 1999 – August 31, 2002.
Member of the PHENIX and BELLE Collaborations;
•RHIC Physics Fellow/Assistant Professor—RBRC-E; University of Illinois, Urbana Champaign, September 1, 2002 – present.
**Awards and Honors**: Foreign Scholar Award, UCLA, 1990; Gustav Mie Preis, Freiburg University, 1991.

**Yoshitaka Hatta** **Birthplace**: Kyoto, Japan **DOB**: August 5, 1976
**Master Degree**
Graduate School: 1999, Kyoto University, Department of Physics
**Experience**: RBRC Young Researcher, Theory Group, RBRC, Spring 2002 – 2003.
RIKEN Junior Research Associate (Theory), April 1, 2003 – present.

**Tetsufumi Hirano** **Birthplace**: Kanagawa, Japan **DOB**: September 17, 1972
**Ph.D.** 2001, Waseda University, Japan
**Experience**: Research Associate, Waseda University, Japan, April 1999 to March 2001
Postdoctoral Fellow at University of Tokyo, Japan, April 2001 to March 2003.
RIKEN Spin Program Research Associate, RBRC Theory Group, March 24, 2003 – present.
**Awards and Honors**: JPS Theory Award for Distinguished Young Researchers in Nuclear Physics (2002).

**Takuma Horaguchi** **Birthplace**: Iwate, Japan **DOB**: September 29, 1977
Graduate School: Tokyo University of Science, Japan
**Experience**: RBRC Young Researcher, Experimental Group, RBRC, Spring 2002 – 2003.
RIKEN Junior Research Associate (Experiment), April 1, 2003 – present.

**Osamu Jinnouchi** **Birthplace**:Saga, Japan **DOB**: June 13, 1972
**Ph.D.** 2001, University of Tokyo
**Experience:** Research Fellow of the Japan Society for the Promotion of Science, January 1999 to March 2001
Contract Researcher of RIKEN, April 2001-2003.
Research Associate, RBRC Experimental Group, April 1, 2003 – present.

**Masashi Kaneta** **Birthplace**: Hiroshima, Japan **DOB**: November 5, 1971
**Ph.D.** 1999, Hiroshima University, Japan
**Experience:** Member of NA44 Experiment at CERN, 1994-present
Member of Beam-Beam Counter (BBC) Group for PHENIX Experiment, 1994-1999; Member of TOF Detector Group in PHENIX Experiment at RHIC, 1999; Member of STAR Experiment at RHIC, 1999-present;
Postdoctoral Fellow at KEK, 1999; Postdoctoral Fellow Physicist at Lawrence Berkeley National Laboratory, 1999-2002.
Research Associate, BNL, RBRC Experimental Group, Nov. 1, 2002-present.

**Hideyuki Kobayashi** **Birthplace**: Japan **DOB**: January 26, 1971
**Ph.D.** 2000, Tokyo Institute of Technology, Faculty of Science
**Experience:** Cooperate Researcher, RIKEN, CCJ, May 1-Sept. 30, 2000
Special Postdoctoral Researcher, RIKEN, October 1, 2000 – September 30, 2003;
RIKEN Spin Program Research Associate, April 1, 2001 – September 30, 2003.
**Awards and Honors**: Fellowship: Japan Society for Promotion of Science (JSPS), Research Fellow, April 1, 1996 – March 31, 1999.

**Stefan A. Kretzer** **Birthplace**: Dortmund, Germany **DOB**: November 26, 1968
**Ph.D.** 1999, University of Dortmund
**Experience:** Visiting Research Associate at Michigan State University, 2000-2002
Research Associate, Brookhaven National Laboratory, October 2002 –present;
Research Associate, Joint RBRC/Nuclear Theory Group, BNL, April 2003 present.
**Awards and Honors**: Associate of the Graduiertenkolleg: Erzeugung und Zerfälle von Elementarteilchen of the Deutsche Forschungsgemeinschaft (DFG) Scholarship, 1996-2000.

**Kazuyoshi Kurita** **Birthplace**: Tokyo, Japan **DOB**: August 11, 1963
**Ph.D.** 1992, Columbia University, New York
**Experience:** June, 1991 Research Associate, Univ. of Tsukuba
April 1994 Assistant Prof., Univ. of Tsukuba
April 1997 Postdoctoral Researcher, RIKEN
Oct. 1997 Special Postdoctoral Researcher, RIKEN
RIKEN BNL Fellow, April 2000 – March 31, 2002;
Visiting Scientist, Experimental Group, RBRC, with Rikkyo University, Japan, April 2002 - present
**Awards and Honors**: Educational Research Award, Tsukuba Gakuto Foundation, July 1992

**Naohito Saito** **Birthplace**: Aomori, Japan **DOB:** November 28, 1964
**Ph.D.** 1995, Kyoto University, Japan
**Experience:** 1993 July, Research Fellow, Kyoto University, Japan
1995 April, RIKEN Special Post Doctoral Fellow
RIKEN/RBRC Researcher, 1996 April to March 2001
RIKEN Spin Program Researcher, April 1, 2001 – March 31, 2002;
Visiting Scientist, Experimental Group, RBRC, with Kyoto University, Japan, Spring 2002 – present.
**Awards and Honors**: Fellowship: Japan Society for the Promotion of Science, 1993-1995

**Thomas M. Schaefer** **Birthplace**: Hanau, Germany **DOB**: May 18, 1965
**Ph.D.** 1992, University of Regensburg
**Experience:** Postdoctoral Research Associate, State University of New York at Stony Brook
Postdoctoral Research Associate Institute for Nuclear Theory, University of Washington; Member Institute for Advanced Study, Princeton;
• RHIC Physics Fellow/Assistant Professor--RBRC/ SUNY, Stony Brook, January 2000 – December 31, 2002.
•RHIC Physics Fellow/Associate Professor (with Tenure)—RBRC/North Carolina State University January 1, 2003 – present.
**Awards and Honors**: Member, Studienstiftung des deutschen Volkes;
Fellowship, German Academic Exchange Service
Feodor Lynen Fellowship, Alexander v. Humboldt Foundation
U.S. Department of Energy Division of Nuclear Physics Outstanding Junior Investigator Award, 2002.

**Viktor Siegle** **Birthplace**: Karaganda, former Soviet Union **DOB**: April 21, 1976
Graduate School: Heidelberg University
**Experience:** RBRC Young Researcher, Experimental Group, RBRC, Spring 2002 – 2003.

**Mikhail Stephanov** **Birthplace**: Moscow, Russia **DOB**: April 19, 1966
**Ph.D.** 1994, Oxford University, U.K.
**Experience:** Postdoctoral Research Associate, U. of Illinois at Urbana-Champaign
Postdoctoral Research Associate, ITP, SUNY at Stony Brook
•RHIC Physics Fellow/Assistant Professor --RBRC/
University of Illinois at Chicago, October 1, 1999 to present
(2003 Promoted to Associate Professor with tenure).
**Awards and Honors**: Soros Scholarship, Overseas Graduate Scholarship from Jesus College, Oxford; U.S. Department of Energy Division of Nuclear Physics Outstanding Junior Investigator Award, 2001; Alfred P. Sloan Fellowship, 2002.

**Takanori Sugihara** **Birthplace**: Japan **DOB**: April 29, 1969
**Ph.D.** 1997, Kyushu University
**Experience:** Research Associate, RCNP, Osaka University, May 1997 – March 1999;
JSPS Postdoctoral Fellow, Nagoya University, April 1999-March 2002
Research Student, Nagoya University, April 2002 - September 2002;
RIKEN Spin Program (RSP) Research Associate, RIKEN BNL Research Center (Theory Group), October 2002 – present.

**Rajagopal Venugopalan** **Birthplace**: India **DOB**: January 29, 1966
**Ph.D.** 1992, SUNY at Stony Brook
**Experience:** Research Associate, Theoretical Physics Institute, University of Minnesota, September 1992-September 1994
Research Associate, National Institute for Nuclear Theory, University of Washington, September 1994-December 1996
Research Assistant Professor and Danish Research Council Fellow, Niels Bohr Institute, Denmark, January 1997 -October 1998
Assistant Physicist, Physics Department, BNL - October 1998
Associate Physicist, Physics Department, BNL - Nov. 1999 – Oct. 2001
Physicist, Physics Department, BNL – Oct. 2001 – June 1, 2002
Physicist with Tenure, Physics Department, BNL – June 1, 2002 – present.
•RHIC Physics Fellow/ RBRC/BNL - October 1, 2000 – June 30, 2003.
**Awards and Honors**: University of Chicago Undergraduate Scholarship, 1984-1987.

**Werner Vogelsang** **Birthplace**: Dortmund, Germany **DOB**: October 6, 1965
**Ph.D.** 1993, University of Dortmund, Germany
**Experience:** Postdoctoral Researcher in Theoretical Particle Physics, U. of Dortmund, Nov. 1993 - Sept. 1994
Research Associate in Theory Group of the Rutherford Appleton Laboratory, Didcot, England, Oct. 1994-Dec. 1996
Fellow in Theory Division, CERN, Geneva, Switzerland, Jan. 1997-Dec. 1998
Post-doctoral Researcher at the Institute for Theoretical Physics at State University of New York, Stony Brook, January 1999 to March 2000
RIKEN BNL Fellow, April 1, 2000 – September 30, 2003.
•RHIC Physics Fellow/Associate Physicist/RBRC/BNL, October 1, 2003 to present
**Awards and Honors**: Scholar of the "Studienstiftung des Deutschen Volkes, 1984-1990

**Yasushi Watanabe** **Birthplace**: Tokyo, Japan **DOB**: February 12, 1961
**Ph.D.** 1993, University of Tokyo, Japan
**Experience:** Scientific Researcher, RIKEN, 1991
Research Collaborator, PHENIX/RBRC
Scientific Researcher, RIKEN, RBRC, 1998-2001
RIKEN Spin Program Researcher, April 1, 2001 – present

**Tilo Wettig** **Birthplace**: Germany **DOB**: December 12, 1966
**Ph.D.** 1994, State University of New York, Stony Brook
**Experience:** Research Associate, Nuclear Theory Group, SUNY, Stony Brook, 1994;
Research Associate, Max-Planck-Institute for Nuclear Physics, Heidelberg, 1995-1996;
Research Associate, Institute for Theoretical Physics, Technical University of Munich; External Scientific Associate, Max-Planck-Institute for Nuclear Physics, Heidelberg, 1997-1999;
•RHIC Physics Fellow/Assistant Professor--RBRC/ Yale University, October 1999 - present; (2003 Promoted to Associate Professor at Yale)
**Awards and Honors**: 1st Prize, National Physics Olympiad, East Germany
Scholar of the "Studienstiftung des deutschen Volkes"
Heisenberg Fellowship of the German National Science Foundation

# RBRC THEORY GROUP PUBLICATIONS

11/05/03

# RIKEN BNL Research Center
# Theory Group
# Publication List

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1. H. Fujii and H. Shin, "Dilepton Production in Meson Condensed Matter," Prog. Theor. Phys. 98, 1139 (1997).

2. K. Bora, and R. L. Jaffe "The Double Scattering Contribution to $b_1(x, Q^2)$ in the Deuteron,"[hep-ph/97113213]; Phys. Rev. D57, 6906 (1998).

3. R. L. Jaffe, X. Jin and J. Tang, "Interference Fragmentation Functions and Valence Quark Spin Distributions in the Nucleon," [hep-ph/9710561, BNL-66451]; Phys. Rev. D57, 5920 (1998).

4. R. L. Jaffe, "Can Transversity Be Measured"? [hep-ph/9710465] to appear in the *Proceedings of Deep Inelastic Scattering off Polarized Targets: Theory Meets Experiment*, DESY, Zeuthen, September 1997.

5. R. L. Jaffe, X. Jin and J. Tang, "Interference Fragmentation Functions and the Nucleon's Transversity," Phys. Rev. Lett. 80, 1166 (1998).

6. D. Kharzeev, "Charmonium Suppression in Nuclear Collisions," *Proceedings of the Quark-Gluon Plasma School*, Hiroshima, Eds. M. Asakawa, T. Hatsuda, T. Matsui, O. Miyamura and T. Sugitate; Progress of Theoretical Physics Supplement No. 129, 73-81 (1997).

7. D. Kharzeev, "Quarkonium Production in Nuclear Collisions," to appear in the *Proceedings of the Color Transparency Workshop*, Grenoble, France, 1997, p. 45, Eds. J.-F. Mathiot and E. Voutier.

8. D. Kharzeev, "The Charm of Nuclear Physics," in *Proceedings of Non-Equilibrium Many Body Dynamics*, Eds. M. Creutz and M. Gyulassy, RIKEN BNL Research Center, 1997, p. 37.

9. D. Kharzeev, "Theoretical Interpretations of $J/\psi$ Suppression, A Summary," *Proceedings of Quark Matter '97*, Tsukuba, Japan, Nucl. Phys. A638, 279c-290c (1998).

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21. S. Kim and S. Ohta, "Quenched Staggered Light Hadron Spectroscopy from $48^3 \times 64$ at $\beta = 6.5^*$," *Proc. "Lattice '97,"* Edinburgh, UK, 1997, [hep-lat/9712014], Eds. C.T.H. Davies et al; Nuclear Physics B (Proc. Suppl.) 63, 185-187 (1998).

22. T. D. Lee, "Generalization of Soluble Gauge Model with Gribov Copies," *Proceedings of the Conference on Continuous Advances in QCD 1998 [Workshop dedicated to the memory of V. N. Gribov. Minneapolis, April 16-19, 1998]*, xxii-xlvi, Editor: A. V. Smilga, World Scientific, Singapore, 1998.

23. Tom Blum, Amarjit Soni, and Matthew Wingate, "Light Quark Masses Using Domain Wall Fermions," [hep-lat/9809065], *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 201-203 (1999).

24. H. Fujii and D. Kharzeev, "Long-range Interactions of Small Color Dipoles," [hep-ph/9807383]; *Proceedings of the Conference on Continuous Advances in QCD 1998 [Workshop dedicated to the memory of V. N. Gribov. Minneapolis, April 16-19, 1998]*, 167-178, Editor: A. V. Smilga, World Scientific, Singapore, 1998.

25. T. D. Lee, "Locality and Beyond," to appear in *Proc. Sid Drell Symposium*, SLAC, August 1998.

26. C. Bernard, T. DeGrand, C. DeTar, Steven Gottlieb, Urs M. Heller, J. E. Hetrick, N. Ishizuka, C. McNeile, R. Sugar, D. Toussaint, and M. Wingate (MILC Collaboration), "Lattice Determination of Heavy-Light Decay Constants," [hep-ph/9806412], Phys. Rev. Lett. 81, 4812-4815 (1998).

27. T. Blum, "Domain Wall Fermions in Vector Gauge Theories," [hep lat/9810017], *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 167-179 (1999).

36. A. J. Baltz, Alfred Scharff Goldhaber, and Maurice Goldhaber, "The Solar Neutrino Puzzle: An Oscillation Solution with Maximal Neutrino Mixing," Phys. Rev. Lett. 81, 5730 (1998).

37. A. J. Baltz and L. McLerran, "Two Center Light Cone Calculation of Pair Production Induced by Ultrarelativistic Heavy Ions," Phys. Rev. C58, 1679 (1998).

38. E. Farhi, N. Graham, P. Haagensen, R. L. Jaffe, "Finite Quantum Fluctuations About Static Field Configurations," [hep-th/9802015], Phys. Lett. B427, 334-342 (1998).

39. D. Chen, P. Chen, N. Christ, R. Edwards, G. Fleming, A. Gara, S. Hansen, C. Jung, A. Kaehler, A. Kennedy, G. Kilcup, Y. Luo, C. Malureanu, R. Mawhinney, J. Parsons, C. Sui, P. Vranas, Y. Zhestkov, "Status of the QCDSP Project," [hep-lat/9810004]; *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 898-900 (1999).

40. P. Chen, N. Christ, G. Fleming, A. Kaehler, C. Malureanu, R. Mawhinney, G. Siegert, C. Sui, P. Vranas, Y. Zhestkov, "Quenched QCD with Domain Wall Fermions," [CU-TP-915, hep-lat/9811026]; *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 204-206 (1999).

41. P. Chen, N. Christ, G. Fleming, A. Kaehler, C. Malureanu, R. Mawhinney, G. Siegert, C. Sui, P. Vranas, Y. Zhestkov, "The Anomaly and Topology in Quenched, QCD above $T_c$" [CU-TP-913]; *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 405-407 (1999).

42. P. Chen, N. Christ, G. Fleming, A. Kaehler, C. Malureanu, R. Mawhinney, G. Siegert, C. Sui, P. Vranas, Y. Zhestkov, "The Domain Wall Fermion Chiral Condensate in Quenched QCD," [CU-TP-913, hep lat/9811013]; *Proc. of the XVI International Symposium on Lattice Field Theory, Lattice '98*, Boulder, Colorado, July 13-18, 1998, Eds. T. DeGrand, C. DeTar, R. Sugar and D. Toussaint; Nuclear Physics B (Proc. Suppl.) 73, 207-209 (1999).

53. T. Blum, "QCD with Domain Wall Quarks," to appear in *Proceedings YKIS '98*, Kyoto, Japan.

54. D. Boer, "Investigating the Origins of Transverse Spin Asymmetries at RHIC," [hep-ph/9902255], Physical Review D 60, 014012 (1999).

55. R. L. Jaffe and D. Kharzeev, "$X_2$ Production in Polarized pp Collisions at RHIC: Measuring $\Delta G$ and Testing the Color Octet Model," [hep-ph/9903280], March 1999, Phys. Lett. B 455, 306-310 (1999).

56. H. Fujii and D. Kharzeev, "Long-Range Forces of QCD," [hep-ph/9903495], Phys. Rev. D 60 114039 (1999).

57. D. Kharzeev, "Observables in $J/\psi$ Production," to appear in *Proceedings of Quarkonium Production in Relativistic Nuclear Collisions*, Ed. D. Kharzeev, RIKEN BNL Research Center, 1999.

58. R. Pisarski and D. H. Rischke, "Superfluidity in a Model of Massless Fermions Coupled to Scalar Bosons," Phys. Rev. D 60, 094013 (1999).

59. N. K. Glendenning and J. Schaffner-Bielich, "First Order Kaon Condensate," Physical Review C 60, 025803-13 (1999).

60. Daniël Boer, "Intrinsic Transverse Momentum and Transverse Spin Asymmetries," [hep-ph/9905336] *Proceedings of the 7th International Workshop on "Deep Inelastic Scattering and QCD," (DIS99)* DESY-Zeuthen, April 19-23, 1999. Nuclear Physics B (Proc. Suppl.) 79, 638 (1999).

61. Daniël Boer and P. J. Mulders, "Color Gauge Invariance in the Drell-Yan Process," [hep-ph/9906223], Nuclear Physics B 569, 505-26 (2000).

62. Dmitri Kharzeev and Robert D. Pisarski, "Pionic Measures of Parity and CP Violation in High Energy Nuclear Collisions, Phys. Rev. D 61, 111901 (2000).

63. D. Kharzeev, H. Satz, A. Syamtomov, G. Zinovev, "$J/\psi$ Photoproduction and the Gluon structure of the Nucleon," Nucl. Phys. A 661, 568 (1999).

73. R. D. Pisarski, D. H. Rischke, "Color Superconductivity in Weak Coupling,". [nucl-th/9910056], Phys. Rev. D 61, 074017 (2000).

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75. R. D. Pisarski, D. H. Rischke, "Why Color-Flavor Locking is Just Like Chiral Symmetry Breaking," [nucl-th/9907094], *Proc. of the Judah Eisenberg Memorial Symposium, "Nuclear Matter, Hot and Cold,"* Tel Aviv, Israel, April 14-16, 1999.

76. D. M. Elliott, D. H. Rischke, "Chemical Equilibration of Quarks and Gluons at RHIC and LHC Energies," [nucl-th/9908004], Nucl. Phys. A671, 583-608 (2000)

77. M.E. Berbenni-Bitsch, M. Göckeler, H. Hehl, S. Meyer, P.E.L. Rakow, A. Schaefer, and T. Wettig, "Random Matrix Theory, Chiral Perturbation Theory, and Lattice Data," [hep-lat/9907014], Phys. Lett. B 466 293 (1999).

78. M. Schnabel and T. Wettig, "Fake Symmetry Transitions in Lattice Dirac Spectra," [hep-lat/9912057], Phys. Rev. D 62, 34501 (2000).

79. T. Wettig, "QCD and Random Matrices," *Proceedings of ``Dynamics of Complex Systems,"* Eds. Y. Alhassid, B. Mehlig, and M. Wilkinson, Physica E 9 (2001) 443. (Elsevier, Amsterdam)

80. B.A. Berg, H. Markum, R. Pullirsch, and T. Wettig, "Random Matrix Theory and Dirac Spectrum at Nonzero Temperature and Density," [hep-lat/9912055], *Proceedings of ``Lattice Fermions and Structure of the Vacuum,"* Eds. V. Mitrjushkin and G. Schierholz (Kluwer, Dordrecht, 2000) page 357.

89. R. Friedberg, T. D. Lee, and W. Q. Zhao, "A New Method to Derive Low-Lying N-dimensional Quantum Wave Functions by Quadratures Along a Single Trajectory, Annals of Physics 288, 52-102 (2001).

90. Daniël Boer, "Double Transverse Spin Asymmetries in Vector Boson Production," [hep-ph/0004217], Phys. Rev. D 62, 094029 (2000).

91. D. Zschiesche, P. Papazoglou, S. Schramm, Ch. Beckmann, J. Schaffner-Bielich, H. Stöcker, and W. Greiner, "Chiral Symmetries in Nuclear Physics," Springer Tracts in Modern Physics Vol. 163, Symmetries in Intermediate and High Energy Physics, Eds.: Faessler, Kosmas, Leontaris, pp. 129-167, Springer-Verlag Berlin Heidelberg, 2000.

92. Shigemi Ohta and Mathew Wingate, "SU(4) Pure-Gauge Phase Structure and String Tensions," Nuclear Physics B (Proc. Suppl) 83-84, 381-383 (2000).

93. Seyong Kim, Shigemi Ohta, "Light-Hadron Spectrum in Quenched Lattice QCD with Staggered Quarks," Physical Review D 61, #074506, 1-5 (2000).

94. T. Schäfer and E. Shuryak, Comment On "On the Origin of the Ozi Rule in QCD," by N. Isgur and H.B. Thacker [hep-lat/0005025], Internal Report, 5 pp., May 2000.

95. Thomas Schäfer, "Gluino Condensation in an Interacting Instanton Ensemble," [hep-ph/0003290] Phys. Rev. D 62, 035013-1-11 (2000).

96. J. T. Lenaghan, D. H. Rischke, J. Schaffner-Bielich, "Chiral Symmetry Restoration at Nonzero Temperature in the $SU(3)_r \times SU(3)_l$ Linear Sigma Model [nucl-th/0004006], Phys. Rev. D 62, 085008-1-13 (2000).

97. J. Schaffner-Bielich, M. Hanauske, H. Stöcker, and W. Greiner, "Hyperstars: Phase Transition to (Meta)-Stable Hyperonic Matter in Neutron Stars," [astro-ph/0005490] Phys. Rev. Lett. (submitted).

98. J. Schaffner-Bielich, A. Gal, "Properties of Strange Hadronic Matter in Bulk and in Finite Systems," [nucl-th/0005060], Physical Rev. C 62, 034311-1-8 (2000).

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# RBRC Scientific Review Committee Meeting

November 20-21, 2003

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*Nuclei as heavy as bulls*
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Session Chairs: A. Baltz, G. Bunce, H. En'yo, S. Ohta
Organizers: N. P. Samios and T. D. Lee