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PHENIX Spinfest School 2009 at BNL

July 01 – July 31, 2009

Organizers:

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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 Memorandum of Understanding between RIKEN and BNL, initiated in 1997, has been renewed in 2002 and again in 2007. 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.

The RBRC has both a theory and experimental component. The RBRC Theory Group and the RBRC Experimental Group consists of a total of 25-30 researchers. Positions include the following: full time RBRC Fellow, half-time RHIC Physics Fellow, and full-time, post-doctoral Research Associate. The RHIC Physics Fellows hold joint appointments with RBRC and other institutions and have tenure track positions at their respective universities or BNL. To date, RBRC has ~50 graduates of which 14 theorists and 6 experimenters have attained tenure positions at major institutions worldwide.

Beginning in 2001 a new RIKEN Spin Program (RSP) category was implemented at RBRC. These appointments are joint positions of RBRC and RIKEN and include the following positions in theory and experiment: RSP Researchers, RSP Research Associates, and Young Researchers, who are mentored by senior RBRC Scientists. A number of RIKEN Jr. Research Associates and Visiting Scientists also contribute to the physics program at the Center.

RBRC has an active workshop program on strong interaction physics with each workshop focused on a specific physics problem. In most cases all the talks are made available on the RBRC website. In addition, highlights to each speaker's presentation are collected to form proceedings which can therefore be made available within a short time after the workshop. To date there are ninety- two proceeding volumes available.

A 10 teraflops RBRC QCDOC computer funded by RIKEN, Japan, was unveiled at a dedication ceremony at BNL on May 26, 2005. This supercomputer was designed and built by individuals from Columbia University, IBM, BNL, RBRC, and the University of Edinburgh, with the U.S. D.O.E. Office of Science providing infrastructure support at BNL. Physics results were reported at the RBRC QCDOC Symposium following the dedication. QCDSP, a 0.6 teraflops parallel processor, dedicated to lattice QCD, was begun at the Center on February 19, 1998, was completed on August 28, 1998, and was decommissioned in 2006. It was awarded the Gordon Bell Prize for price performance in 1998.

N. P. Samios, Director
June 2009

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

CONTENTS

INTRODUCTION

Fifth Annual PHENIX Spinfest and School

Since 2005, the PHENIX Spin Physics Working Group has set aside several weeks each summer for the purposes of training and integrating recent members of the working group as well as coordinating and making rapid progress on support tasks and data analysis. One week is dedicated to more formal didactic lectures by outside speakers. The location has so far alternated between BNL and the RIKEN campus in Wako, Japan, with support provided by RBRC and LANL. Originally this year's Spinfest School was slated to take place in Japan, however, due to the H1N1 virus; this year's PHENIX Spinfest School 2009 will take place July 01 – 31, 2009 at BNL.
The mornings of July 7, 8, 9, and 13th lectures will take place in Bldg. 510 Small Seminar Room, Physics bldg. 510. The mornings of July, 27 -31, Bldg 510 Small Seminar room, the invited speaker will be Dr. Markus Diehl, DESY. All are welcome.

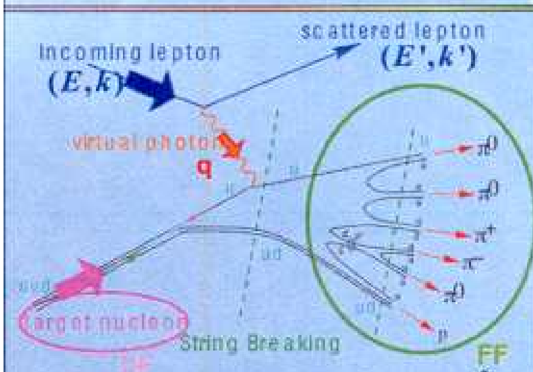
The Organizers
July 2009

Abstract

Deep Inelastic Scattering
or
A clean way to access the partonic structure of nucleons

The question after the individual parton (quarks and gluons) contributions to the spin of the nucleon is even after 20 years of experimental efforts not yet solved. After several very precise measurements in polarized deep inelastic scattering it is clear, that the spin of the nucleon can not be explained by the contribution of the quarks alone. This is affirmed by the newest results from COMPASS, HERMES and JLAB on the inclusive spin structure function g1 and on the individual contributions from the different quark flavors from semi-inclusive deep inelastic scattering data.
Recently COMPASS and HERMES have started to measure the gluon polarization by isolating the photon gluon fusion process in semi-inclusive deep inelastic scattering; latest results on the contribution of the gluons to the nucleon spin from these measurements and RHIC will be discussed.
The clear experimental evidence of exclusive reactions, especially DVCS, allows in the formalism of generalised parton distributions the study of an other component of the nucleon spin the orbital angular momentum.
The most recent results (H1, Zeus, Hermes and JLab) on indications of the size of the orbital angular momentum of quarks will be presented.
The newest data from HERMES and COMPASS constraining the fast developing field of transverse momentum distributions, like transversity and the Sivers fct will be also presented.

Deep Inelastic Scattering



Important kinematic variables:

Collider / fixed target:

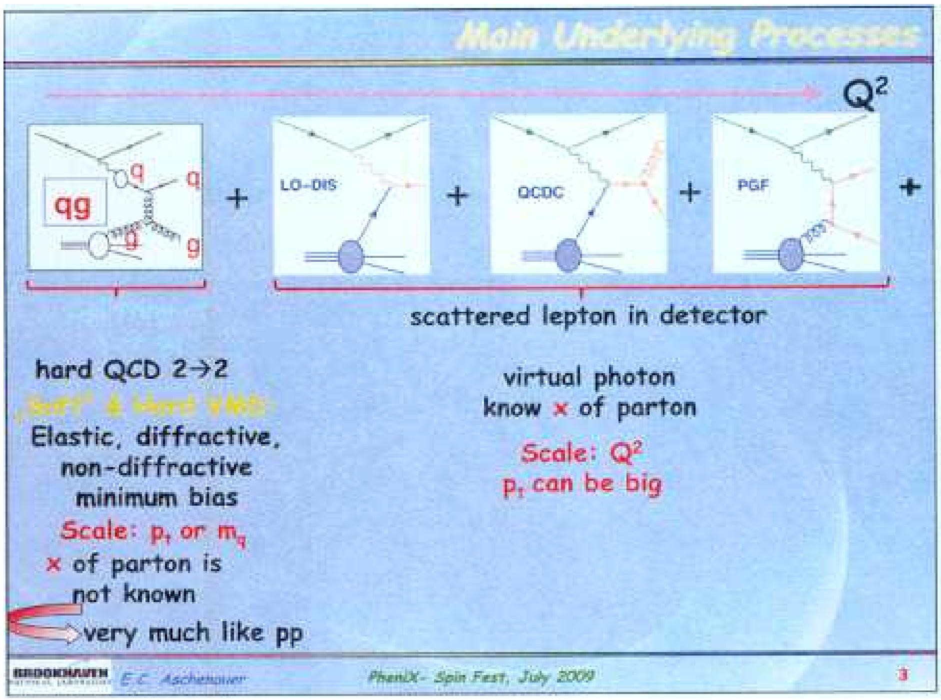
Photon:
$Q^2 = -q^2 = -(k-k')^2 \approx 4EE'\sin^2\frac{\Theta}{2}$
$\nu = E - E'$

Quark: $x = \frac{Q^2}{2M\nu}$

Hadron: $z = \frac{E_h}{\nu} \quad p_t^2$

cross section: $\frac{d^2\sigma}{d\Omega dE'} \sim L_{\mu\nu}W^{\mu\nu}$

$$W^{\mu\nu} = -g^{\mu\nu}F_1 - \frac{p^\mu p^\nu}{\nu}F_2 + \frac{i}{\nu}\varepsilon^{\mu\nu\lambda\sigma}q^\lambda s^\sigma g_1 + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma}q^\lambda(p\cdot q s^\sigma - s\cdot q p^\sigma)g_2$$
$$\underbrace{-r_{\mu\nu}b_1 + \frac{1}{6}(s_{\mu\nu}+t_{\mu\nu}+u_{\mu\nu})b_2 + \frac{1}{2}(s_{\mu\nu}-u_{\mu\nu})b_3 + \frac{1}{2}(s_{\mu\nu}-t_{\mu\nu})b_4}_{\text{Spin 1}}$$


Main Underlying Processes
Q²
qg
q
q
g
g
+
LO-DIS
+
QCDC
+
PGF
+
scattered lepton in detector
hard QCD 2→2
Elastic, diffractive,
non-diffractive
minimum bias
Scale: pt or mq
x of parton is
not known
very much like pp
virtual photon
know x of parton
Scale: Q²
pt can be big
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E.C. Aschenauer
PheniX- Spin Fest, July 2009
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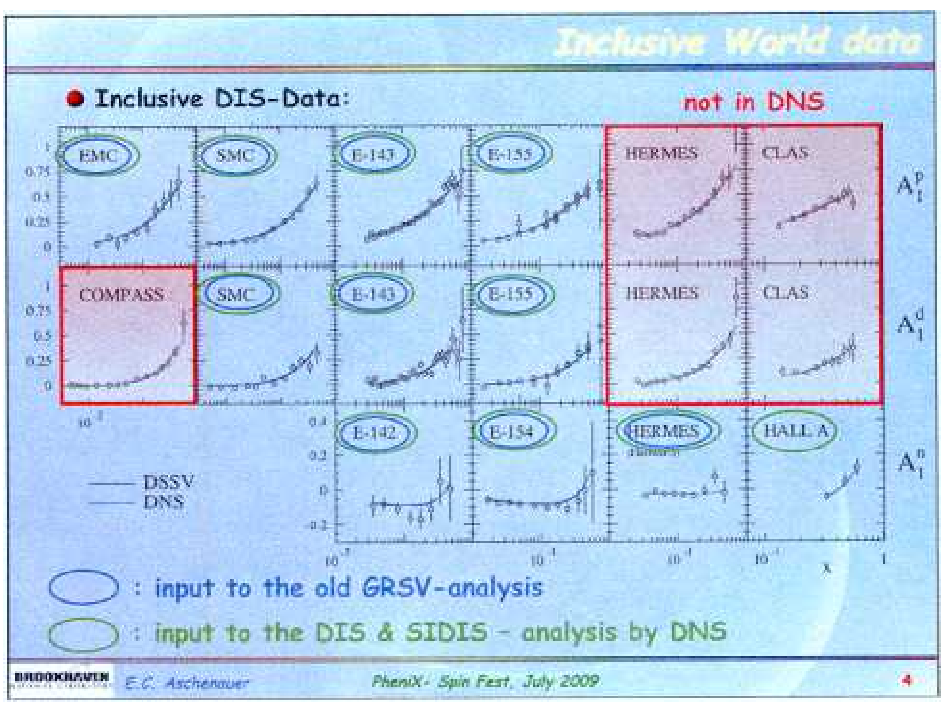
Inclusive World data
Inclusive DIS-Data:
not in DNS
EMC
SMC
E-143
E-155
HERMES
CLAS
COMPASS
SMC
E-143
E-155
HERMES
CLAS
E-142
E-154
HERMES
HALL A
DSSV
DNS
x
: input to the old GRSV-analysis
: input to the DIS & SIDIS - analysis by DNS
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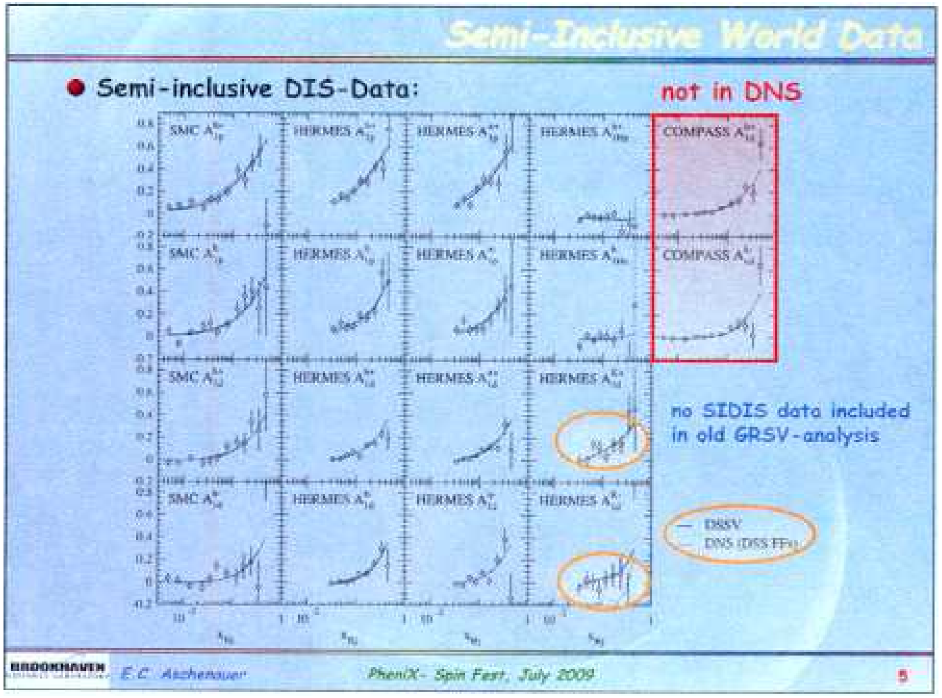
Semi-Inclusive World Data
Semi-inclusive DIS-Data:
not in DNS
SMC
HERMES
COMPASS
no SIDIS data included in old GRSV-analysis
DSSV
DNS (DSS FFs)
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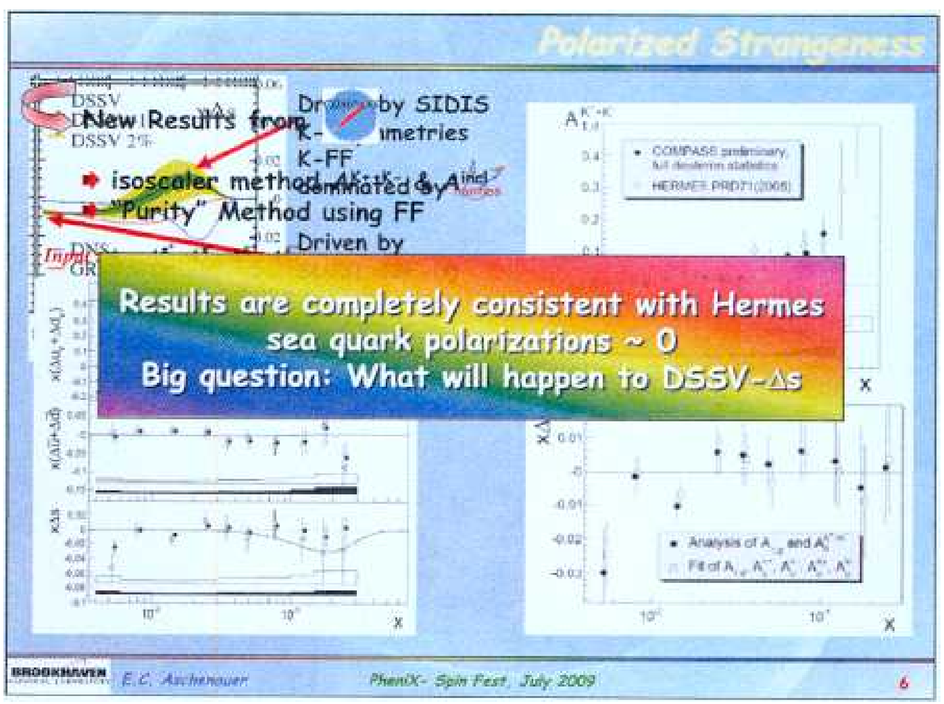
Polarized Strangeness
New Results from
"Purity" Method using FF
K-FF
Driven by
COMPASS preliminary, full deuteron statistics
HERMES PRD71(2005)
Results are completely consistent with Hermes
sea quark polarizations ~ 0
Big question: What will happen to DSSV-Δs
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How to access GPDs?

$$\frac{1}{2} = J_q^z + J_g^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z + J_g^z$$

$$J_q^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z$$

$$J_q^z = \frac{1}{2}\left(\int_{-1}^{1} x\,dx\left(H^q + E^q\right)\right)_{t\to 0}$$

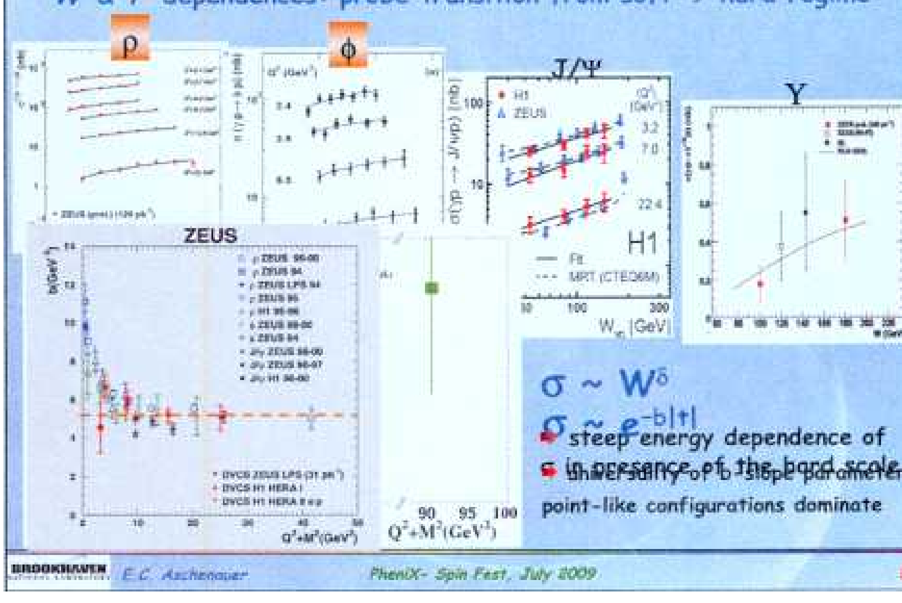
quantum number of final state selects different GPDs:

- theoretically very clean DVCS (γ): H, E, $\tilde{H}$, $\tilde{E}$
- VM (ρ, ω, ϕ): H E
- info on quark flavors PS mesons (π, η): $\tilde{H}$ $\tilde{E}$

π^0	$2\Delta u+\Delta d$
η	$2\Delta u-\Delta d$
ρ^0	2u+d, 9g/4
ω	2u−d, 3g/4
ϕ	s, g
ρ^+	u−d
J/ψ	g

VM production @ small x

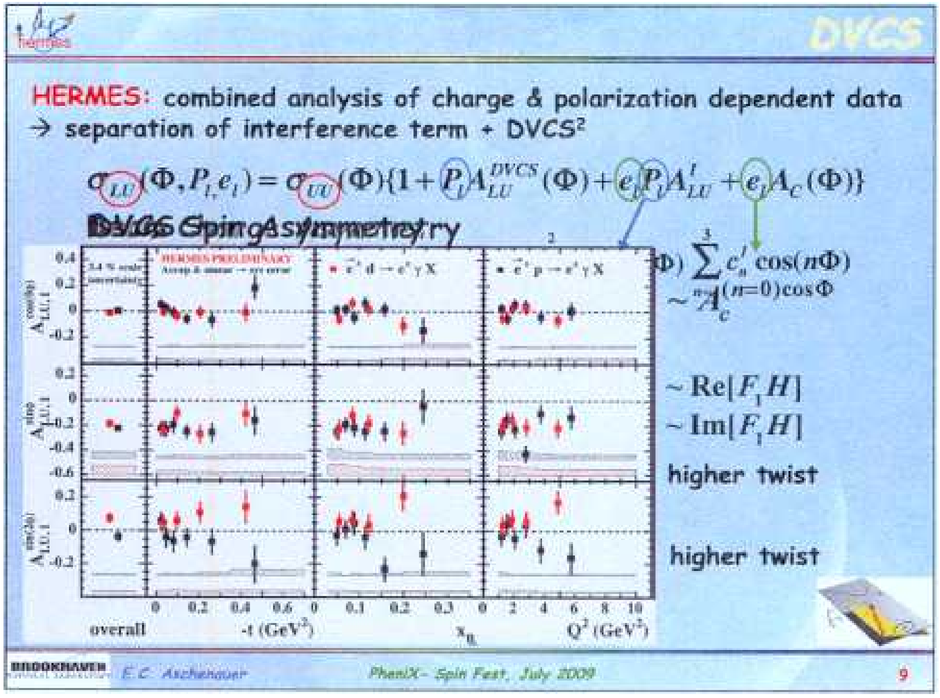
W & *t* dependences: probe transition from soft → hard regime



$\sigma \sim W^{\delta}$

$\sigma \sim e^{-b|t|}$

- steep energy dependence of σ in presence of the hard scale
- universality of b slope parameter: point-like configurations dominate



DVCS
HERMES: combined analysis of charge & polarization dependent data
→ separation of interference term + DVCS²
$\sigma_{LU}(\Phi, P_l, e_l) = \sigma_{UU}(\Phi)\{1 + P_l A_{LU}^{DVCS}(\Phi) + e_l P_l A_{LU}^{I} + e_l A_C(\Phi)\}$
DVCS Spin Asymmetry
HERMES PRELIMINARY
$\sum c_n^I \cos(n\Phi)$
$\sim A_c^{(n=0)\cos\Phi}$
~ Re[F₁H]
~ Im[F₁H]
higher twist
higher twist
overall
-t (GeV²)
x_B
Q² (GeV²)
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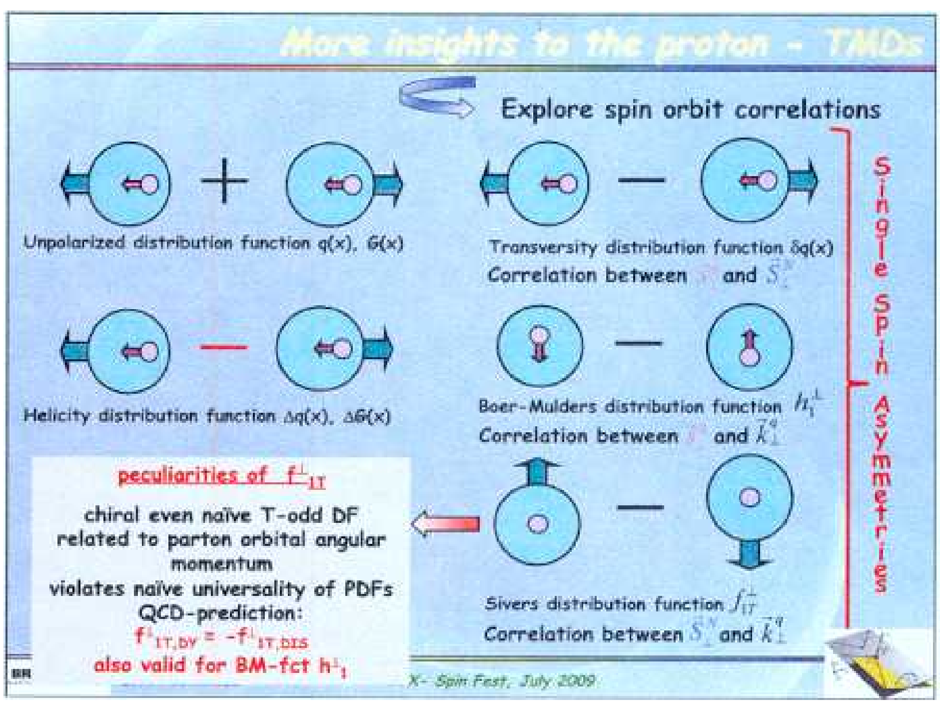
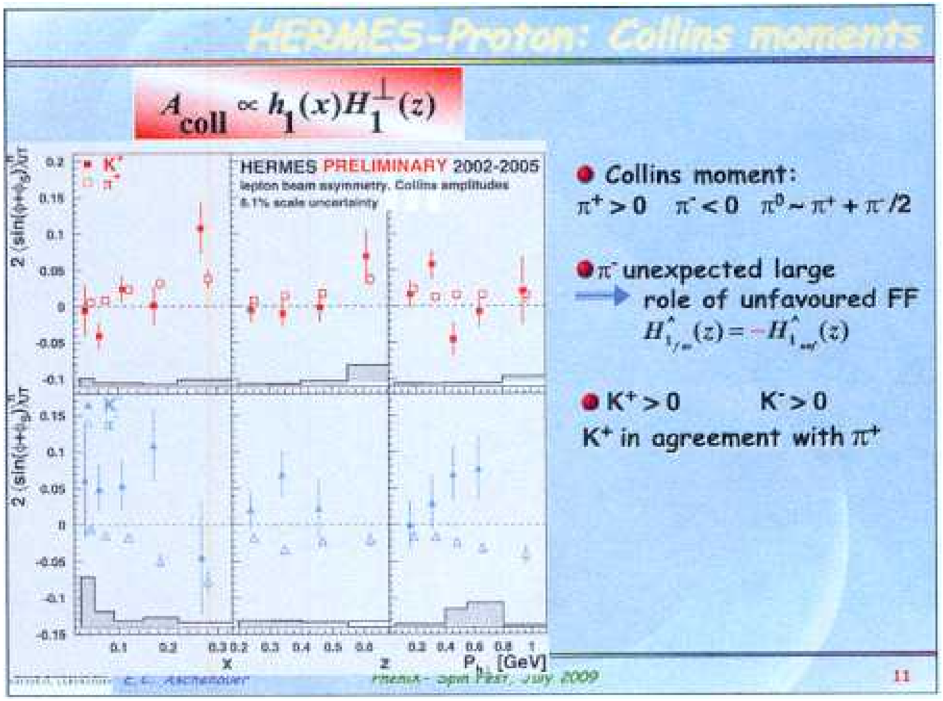


More insights to the proton - TMDs
Explore spin orbit correlations
Unpolarized distribution function q(x), G(x)
Helicity distribution function Δq(x), ΔG(x)
Transversity distribution function δq(x)
Correlation between and $\vec{S}_\perp^N$
Boer-Mulders distribution function $h_1^\perp$
Correlation between and $\vec{k}_\perp^q$
Sivers distribution function $f_{1T}^\perp$
Correlation between $\vec{S}_\perp^N$ and $\vec{k}_\perp^q$
Single Spin Asymmetries
peculiarities of $f^\perp_{1T}$
chiral even naïve T-odd DF
related to parton orbital angular momentum
violates naïve universality of PDFs
QCD-prediction:
$f^\perp_{1T,DY} = -f^\perp_{1T,DIS}$
also valid for BM-fct $h^\perp_1$
X- Spin Fest, July 2009


HERMES-Proton: Collins moments
$A_{coll} \propto h_1(x)H_1^{\perp}(z)$
HERMES PRELIMINARY 2002-2005
lepton beam asymmetry, Collins amplitudes
8.1% scale uncertainty
x
z
$P_{h\perp}$ [GeV]
Collins moment:
$\pi^+ > 0$ $\pi^- < 0$ $\pi^0 \sim \pi^+ + \pi^-/2$
π^- unexpected large
role of unfavoured FF
$H^{\wedge}_{1,fav}(z) = -H^{\wedge}_{1,unf}(z)$
$K^+ > 0$ $K^- > 0$
K^+ in agreement with π^+
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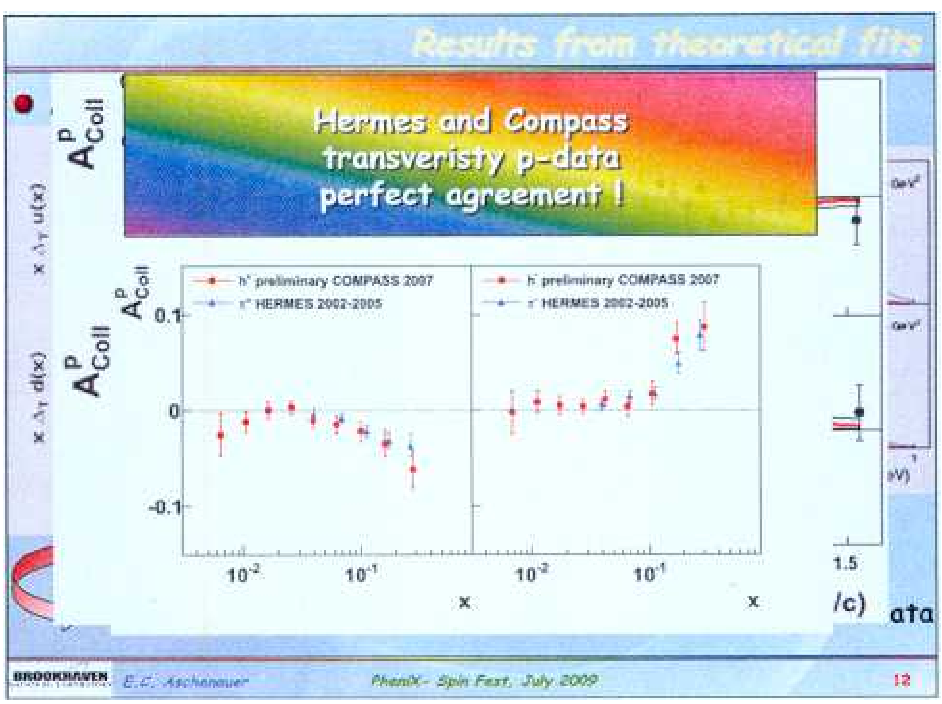
Results from theoretical fits
Hermes and Compass
transveristy p-data
perfect agreement !
A^p_{Coll}
h^+ preliminary COMPASS 2007
π^+ HERMES 2002-2005
h^- preliminary COMPASS 2007
π^- HERMES 2002-2005
x
x
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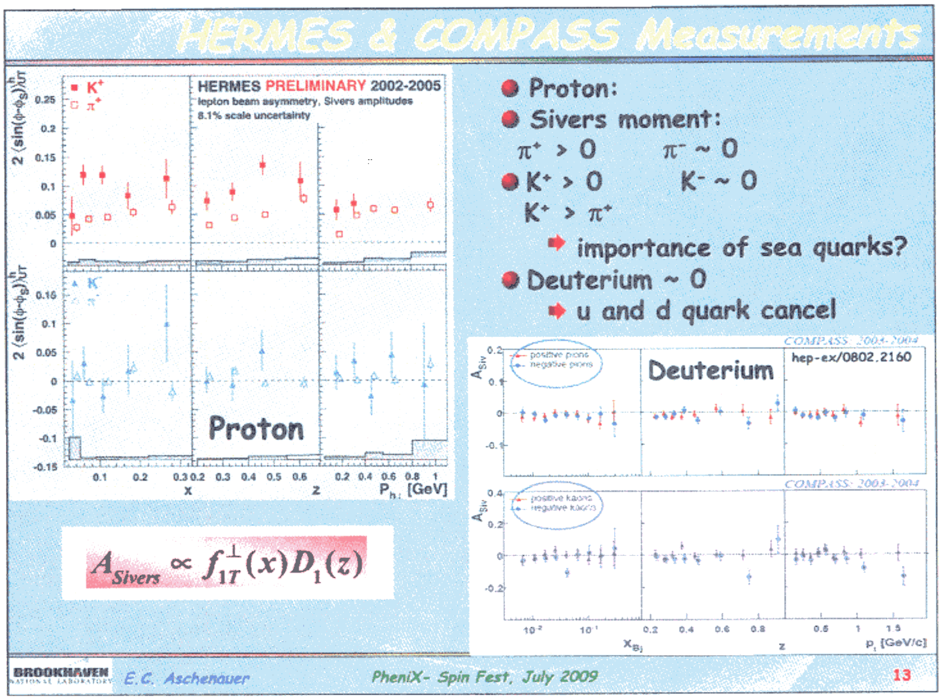
HERMES & COMPASS Measurements
HERMES PRELIMINARY 2002-2005
lepton beam asymmetry, Sivers amplitudes
8.1% scale uncertainty
Proton
Proton:
Sivers moment:
π+ > 0 π- ~ 0
K+ > 0 K- ~ 0
K+ > π+
importance of sea quarks?
Deuterium ~ 0
u and d quark cancel
Deuterium
hep-ex/0802.2160
$A_{Sivers} \propto f_{1T}^{\perp}(x) D_1(z)$
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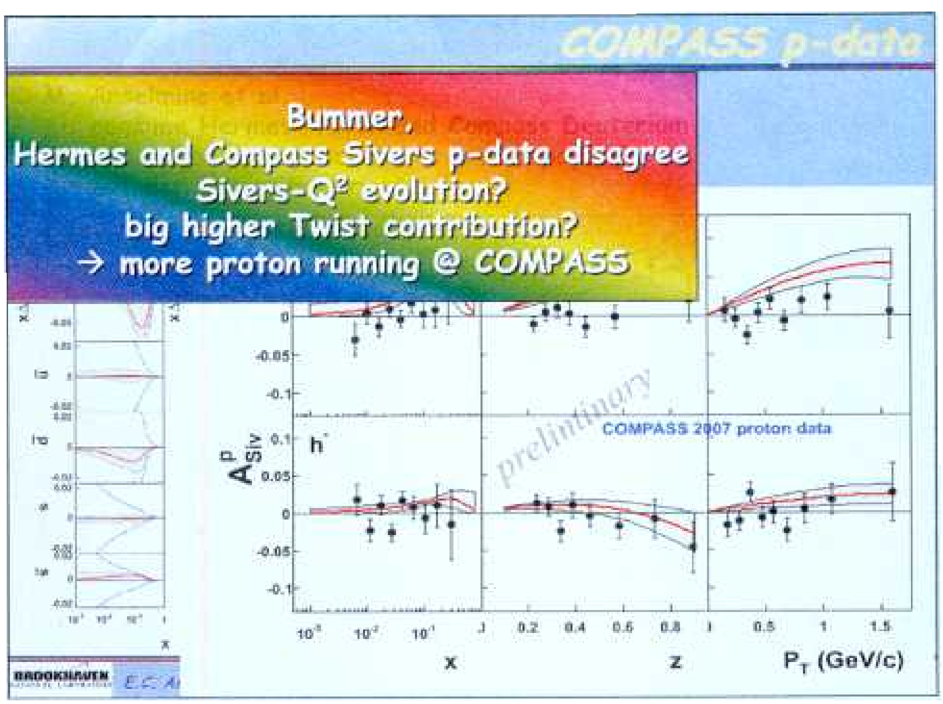

COMPASS p-data
Bummer,
Hermes and Compass Sivers p-data disagree
Sivers-Q² evolution?
big higher Twist contribution?
→ more proton running @ COMPASS
COMPASS 2007 proton data
preliminary
x
z
P_T (GeV/c)
BROOKHAVEN

Proton Spin Structure from Polarized Proton-Proton Collisions and Related Measurements in e^+e^-

PHENIX Spin Fest

Brookhaven National Laboratory

July 8th, 2009

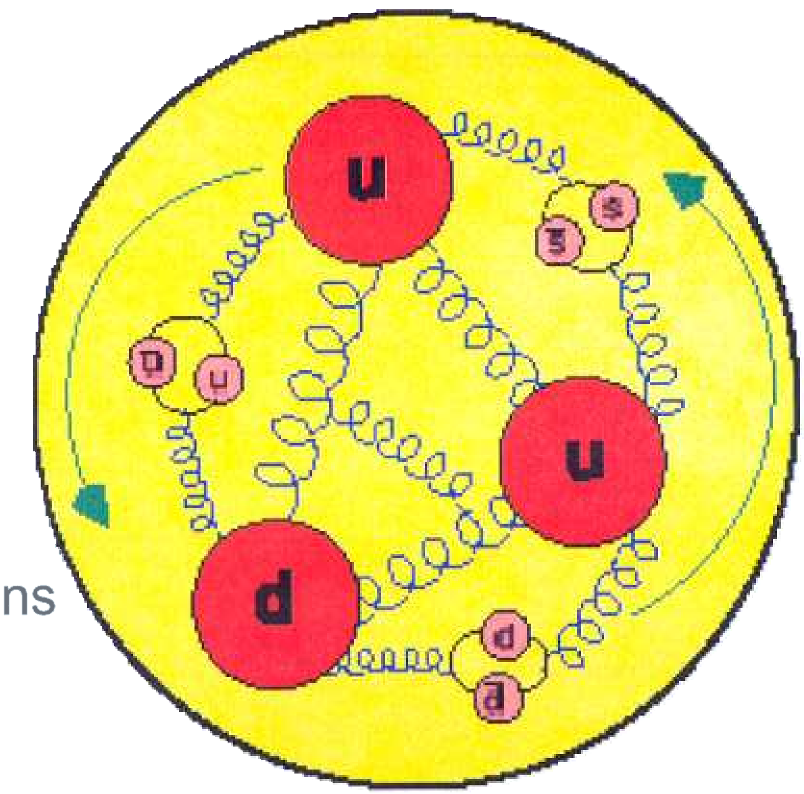
M. Grosse Perdekamp, UIUC

Overview

- **Motivation and some History**
- **p-p Scattering**
  - Kinematics and sub-processes
  - Results & Global Analysis
- **Gluon Spin**
  - Experimental results from RHIC and their global analysis
  - Fragmentation functions (from e+e-)
  - Future steps
- **Physics with W-bosons (need extra talk …)**
- **Transverse Spin**
  - Definitions + Names
  - Transversity
  - Sivers
  - Collins in e^+e^-

The Nucleon as QCD Laboratory → Synthesis of Nuclear Matter from Quarks and Gluons

The proton is the fundamental bound state of QCD - quarks and gluons are the constituents:



Can we understand the wave function of the nucleon from first principles QCD ?

Present (modest) status:

Description of proton in hard scattering processes with parton distribution functions (often model dependent!).

Two (of many) open questions:

Origin of the spin and mass of the proton ?

The Rabi School of Physics → Structure of Atomic Matter

N. F. Ramsey, Eur. J. Phys. 11 (1990) 137
J. Rigden, Physics World, Nov. 1999

Rabi maintained molecular beam laboratory at Columbia University with strong emphasize on the development of new experimental technology.

Rabi, Nobel Prize 1944

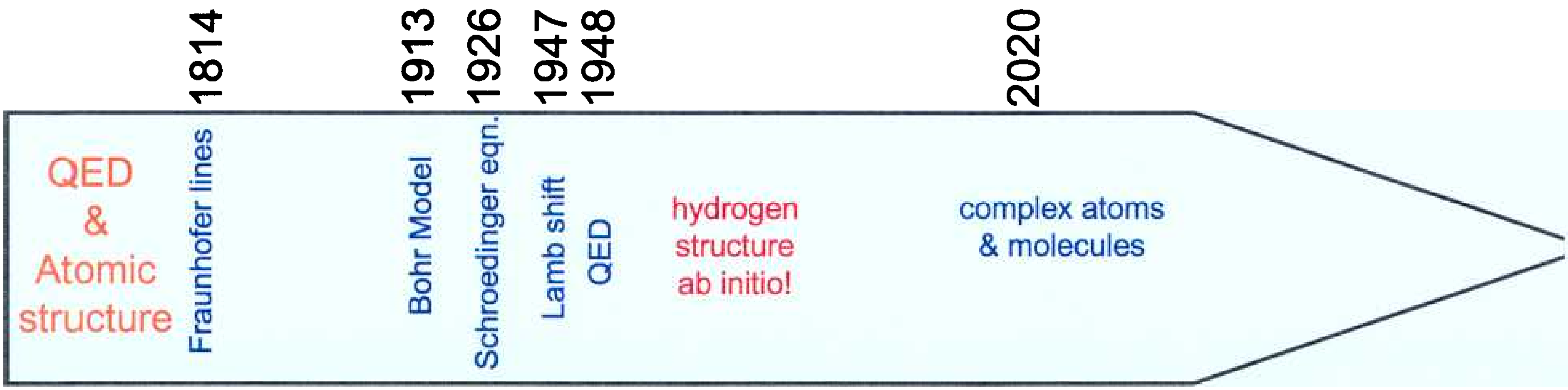
Idea → Field new, precise instrumentation to study fundamental questions of physics.

Example: Precision Measurements of "Hydrogen Spin Structure"

g-2 of the electron, P. Kusch
Lamb shift, W. E. Lamb
} Nobel Prize 1955

Dirac Theory → QED
Tomonaga, Schwinger, Feynman
} Nobel Prize 1965

Rabi School of Physics and QED



observation & models

precision measurements & fundamental theory

application

SLAC: Quark Structure of the Proton

New instrumental method & fundamental physics !

Experiment:
Deep inelastic electron nucleon scattering

Friedman, Kendall, Taylor
Nobel Prize 1990

Nucleon ⟺ **Quantum Chromo Dynamics**

Theory:
quark structure of hadrons, QCD

Gell Mann
Nobel Prize 1969

also Nakano, Nishijima

Polarized Deep Inelastic Scattering

a contribution from the Rabi School of Physics !

(I) Molecular beam technology as starting point for the development of polarized electron beams at Yale starting 1959.

(II) Physics:

- (a) Proton spin structure
- (b) Test the Bjorken sum rule as fundamental QCD prediction

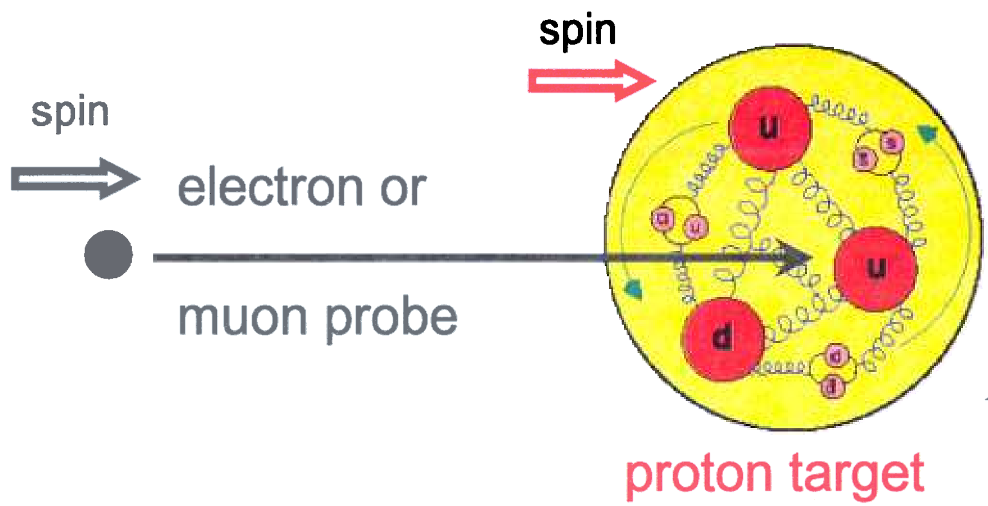
Experiments E80+E130 at SLAC

Bielefeld – CUNY – SLAC – Nagoya – Tsukuba – Yale
(Coward, Kondo, Hughes)

EMC experiment at CERN
(Gabathuler, Sloan, Hughes)

Vernon W. Hughes

Proton Spin Structure from Inclusive Deep Inelastic Lepton-Nucleon Scattering



Large Q^2: measure photon-quark absorption cross section double spin asymmetry

$$A_{LL}^{\gamma q} \equiv A_1 = \frac{\sigma_{\gamma q}^{\uparrow\downarrow} - \sigma_{\gamma q}^{\uparrow\uparrow}}{\sigma_{\gamma q}^{\uparrow\downarrow} + \sigma_{\gamma q}^{\uparrow\uparrow}} \propto g_1(x,Q^2)$$

Extract spin dependent quark distribution functions from the spin structure function $g_1(x,Q^2)$ (later SIDIS & exclusive processes)

$$g_1(x,Q^2) \rightarrow \Delta q(x) = q^{\uparrow\uparrow}(x) - q^{\uparrow\downarrow}(x)$$

$$\Delta\Sigma = \sum_{q,\bar{q}} \int_0^1 \Delta q(x)dx \quad \text{at } Q_0^2$$

Triggering in Particle Physics Experiments

J. Lajoie, Iowa State University

The role of a trigger in a particle physics experiment is to efficiently select rare physics events while suppressing background events. The degree to which this must be accomplished is determined by the requirements of the experiments data acquisition system (DAQ) and the ability to archive data to permanent storage. The trigger system must ultimately reduce in the input, or physics event rate, to the rate at data acquisition rate. These two rates can often differ by many orders of magnitude, and the challenge for the experimenter is to achieve this reduction while simultaneously maintaining a high efficiency for physics events of interest.

Experimental constraints determine the optimal approach in designing a triggers system. Cosmic rays experiments have no fixed timing structure, while accelerator experiments can take advantage of the accelerator RF structure to provide fixed time references. Fixed target experiments typically deal with an extracted beam cycle of order Hz, with microstructure within the extracted beam that may have Mhz components. At collider experiments, bunch spacing determines the relevant timescale for a trigger decision. Electron-positron colliders typically have physics event rates of a few hundred Hz, but are dominated by beam backgrounds. Hadron colliders have many soft QCD processes providing backgrounds to the trigger, while the desired events are relatively rare. In addition, high luminosities at hadron colliders mean that multiple interactions per bunch crossing must also be dealt with.

A given trigger system can be characterized by its efficiency for the events of interest, and it deadtime. Deadtime is defined as the fraction of the time the detector is unavailable to capture a physics event, and if determined by the trigger decision time and the readout time of the DAQ. Minimizing deadtime is a critical parameter in modern particle physics experiments, as a reduction in deadtime translates directly into more events per unit time (or dollar of running time spent). Modern trigger systems use pipelining of the trigger and front-end electronics to provide an essentially "deadtimeless" first level trigger for the experiment.

Often the required rate reduction cannot be accomplished in a single trigger step, with the limited information available at an early stage in the trigger process. This has led to the evolution of the multilevel trigger system, in which the trigger decision is refined at higher levels as the input rate to each level is reduced. This approach permits increasingly sophisticated trigger decisions at higher levels which make use of the full detector data in the trigger decision.

The development of trigger systems for particle physics experiments has been driven by increasing commercial availability of commodity hardware (FPGA's, PC's, networking, high-speed communication links, etc.) This trend will likely continue in the future, with only part of the first-level trigger system continuing to be designed in custom hardware, and full detector readout occurring at earlier stages in the trigger process.

Triggering in Particle Physics Experiments

- Why Trigger?
  - Early Experiments
- Experimental Constraints
  - Cross Sections and Luminosity
  - Electron+positron, hadron machines
  - Multiple Interactions
- Efficiency and Deadtime
  - Minimizing deadtime
  - Queuing Theory

Material drawn heavily from IEEE NSS
2002 Workshop by Peter J. Wilson

- Signatures in Detectors
- Multilevel Trigger Systems
- Pipelined Trigger Systems
- Components of Modern Trigger Systems
  - Hardware Implementation
- The PHENIX Trigger System
- The (Near) Future
  - Trigger/DAQ at LHC
- "Non-Traditional" Expts.

Experimental Constraints

Different experiments have very different trigger requirements due to different operating environments

Timing structure of beam

Rate of producing physics signals of interest

Rate of producing backgrounds

- **Cosmic Ray Expts** – no periodic timing structure, background/calibration source for many other experiments.
- **Fixed Target Expts** – close spacing between bunches in train which comes at low rep rate (~Hz)
  - Backgrounds from undesirable spray from target

    Cosmics are particularly a background for neutrino beams
- **e^+e^- collider** – very close bunch spacing (few nsec), beam gas and beam wall collisions
- **ep collider** – short bunch spacing (96ns), beam gas backgrounds
- **pp/ppbar collider** – modest bunch spacing (25-400ns), soft QCD

Efficiency and Deadtime I

The goal of trigger and DAQ is to maximize the amount data sent to storage (for later analysis) for a desired process with minimal cost:

$$\varepsilon = \varepsilon_{operations} * \varepsilon_{trigger} * (1\text{-deadtime})$$

•Relevant efficiency is for events that will be useful for later analysis:

$$\varepsilon_{trigger} = N_{good}(\text{accepted})/N_{good}(\text{produced})$$

•For low rate process (e.g. e+e- to hadrons, Higgs production at Tevatron or LHC) try to accept all signal in trigger □ **Maximize efficiency**

•Deadtime is due to fluctuations when the rate into a stage of the trigger (or readout) approaches the rate it can handle (busy). Simple case of no buffering:

$$\text{deadtime} = (\text{Input Rate}) * (\text{Execution Time})$$

•Buffering incoming data reduces dead time, more buffering less dead time

- If <Incoming Rate> > 1/<Execution Time>, dead no matter what!

•Minimizing dead-time helps all processes (and all budgets!)

- 1% of machine time * 1 year = $$$$$

Multi-Level Trigger Systems

High Efficiency ⟺ Large Rejection

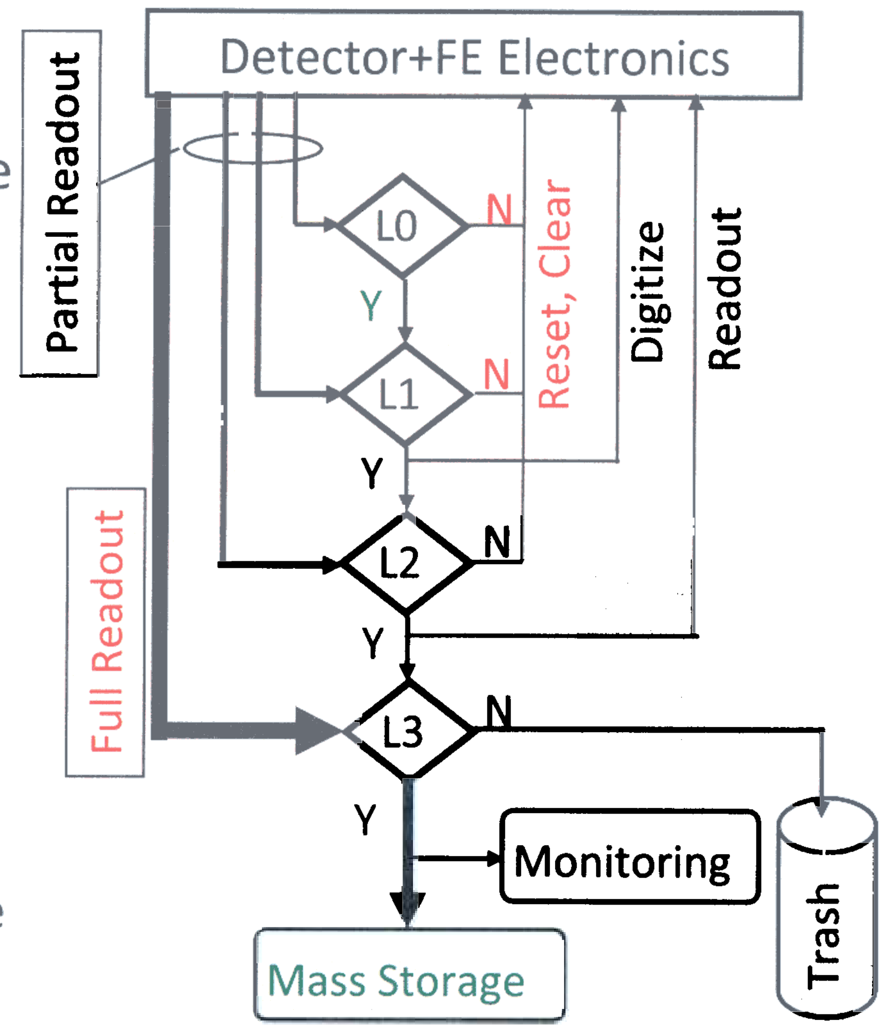
- Often can't achieve necessary rejection in a single triggering stage
- Reject in steps with successively more complete information

L0 – very fast (<~bunch x-ing), very simple, usually scint. (TOF or Luminosity Counters)
(Few expts use a L0 anymore)

L1 – fast (~few μs) with limited information, hardware

L2 – moderately fast (~10s of μs), hardware and sometimes software

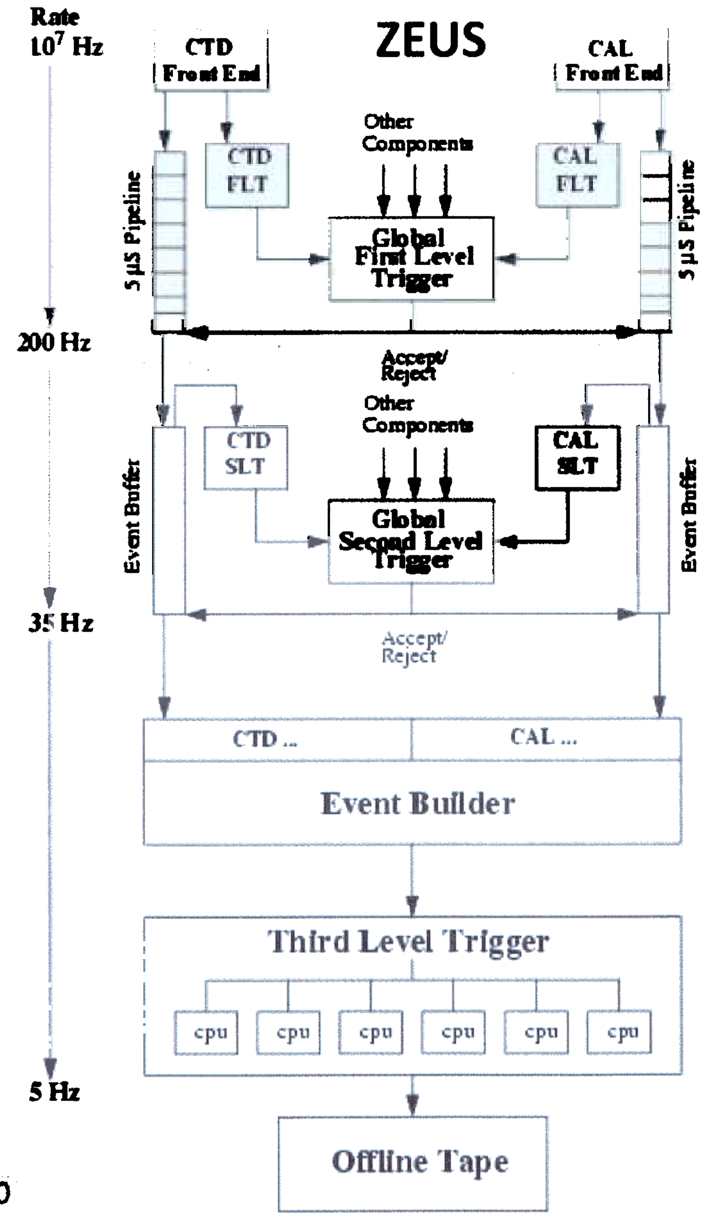
L3 – Commercial processor(s)



Trigger and FEE Pipelining : ZEUS, H1

Poor vacuum due to synchrotron radiation.
Large proton-beam background : $\sigma_{pp} >> \sigma_{ep}$
Beam-gas rate ~100kHz (10μs)

Bunch crossing rate 10.41MHz (96ns)
Can't make the decision in one step!
Solution is to pipeline the FEE and trigger.



Three-Level Trigger

- **L1 (FLT):** Hardware triggers
  starts readout (digitization)
- **L2 (SLT):** Software trigger with distributed processors
  starts event building
- **L3 (TLT):** Software trigger in a single processor
  starts data storage

PYTHIA at RHIC – Helen Caines, Yale University, July 13th 2009

PYTHIA is based on the Lund Model of hadronization via strings, which was started by the Lund Theory Group in 1978. The Lund model assumes that all final state hadrons stem from the force between partons and not the partons themselves. Due to the self-interaction of gluons (the force carriers) the field lines between partons form narrow colored tubes, or strings. These strings that fragment causing a spray of particles between separating partons – i.e. a jet. PYTHIA models the whole of a p-p event by splitting the event into several distinct parts

Hard sub-processes, which are described via matrix elements.
Resonance decays (such as the W), which are associated with the hard sub-process.
Initial State Radiation (ISR), via space like parton showers.
- Final State Radiation (FSR) ,via time like parton showers.
- Multiple Parton Interactions (MPI) with their ISR and FSR.
- Beam-Beam remnants.
- Reconnection of all objects via color confinement strings.

Hadronization and decay of unstable particles.

The jet properties are well modeled at RHIC despite there being significant gluons scattering at these energies and gluon FF not being well measured. The intrinsic k_T of the proton used in PYTHIA was extracted from CDF 1.8 TeV data on the Z boson, a value of 2.1 GeV/c is used. This seems low compared to values extracted from di-hadron correlations by PHENIX which is $<k_T^2>2.68\pm0.04$ GeV/c.

By studying the underlying event it appears that there is very little large angle ISR/FSR at RHIC. This is in stark contrast to the significant contributions measured at the Tevatron. To describe all the details of the underlying event, including the multiplicity dependence, MPI are required. The probability of MPI is best simulated when the proton is assumed to have double-Gaussian hard core matter distribution. More "central" events have harder scattering and more MPI leading to a rising mean p_T with increased multiplicity in the event. RHIC data is helping constrain the collision energy dependence of MPI. The activity in the RHIC underlying events shows that the old default scaling value in PYTHIA of $\varepsilon=0.16$ is incorrect and $\varepsilon=0.25$ should be used instead. The new value results in increased activity at RHIC but a significant decrease of 26% at the LHC.

The strange baryons and heavy flavor production are currently not well modeled by PYTHIA. A different K-factor (a simple scaling factor used to take into account the fact that PYTHIA is only a LO calculation) is required to reproduce the measured p_T spectra resulting in the inability to simulate the light-flavor hadrons at the same time as the particles containing heavier (s,c,b).

For details on the latest and greatest tune please take a look at arXiv:0905.3418 and the PYTHIA manual available from their webpage.

PYTHIA at RHIC

Helen Caines - Yale University

PHENIX Spinfest School BNL
12th July 2009

Outline

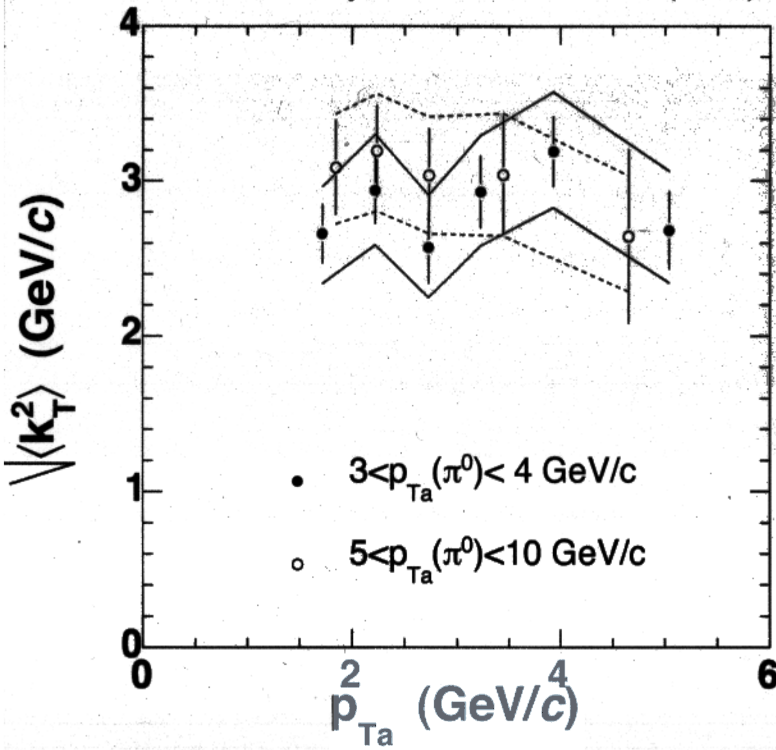
- Why study p+p
- How PID is done
- Min-bias distributions
- Jets
- Summary

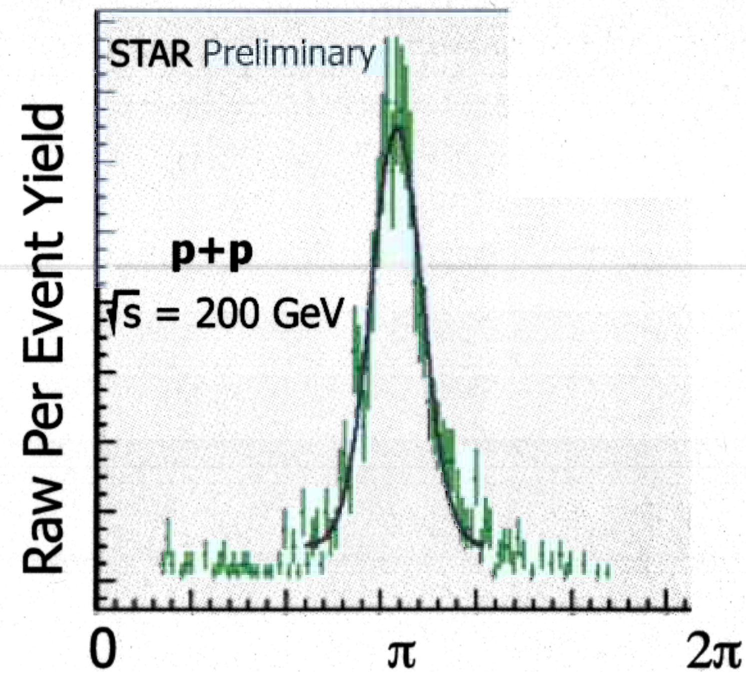
Intrinsic k_T at RHIC

- STAR di-jet reconstruction

$\langle k_T^2 \rangle = 2.3 \pm 0.4 \pm ^{0.67}_{1.11}$ GeV/c

PHENIX - Phys. Rev. D 74, 072002 (2006)





- PHENIX di-hadron correlations
  p-p 200 GeV

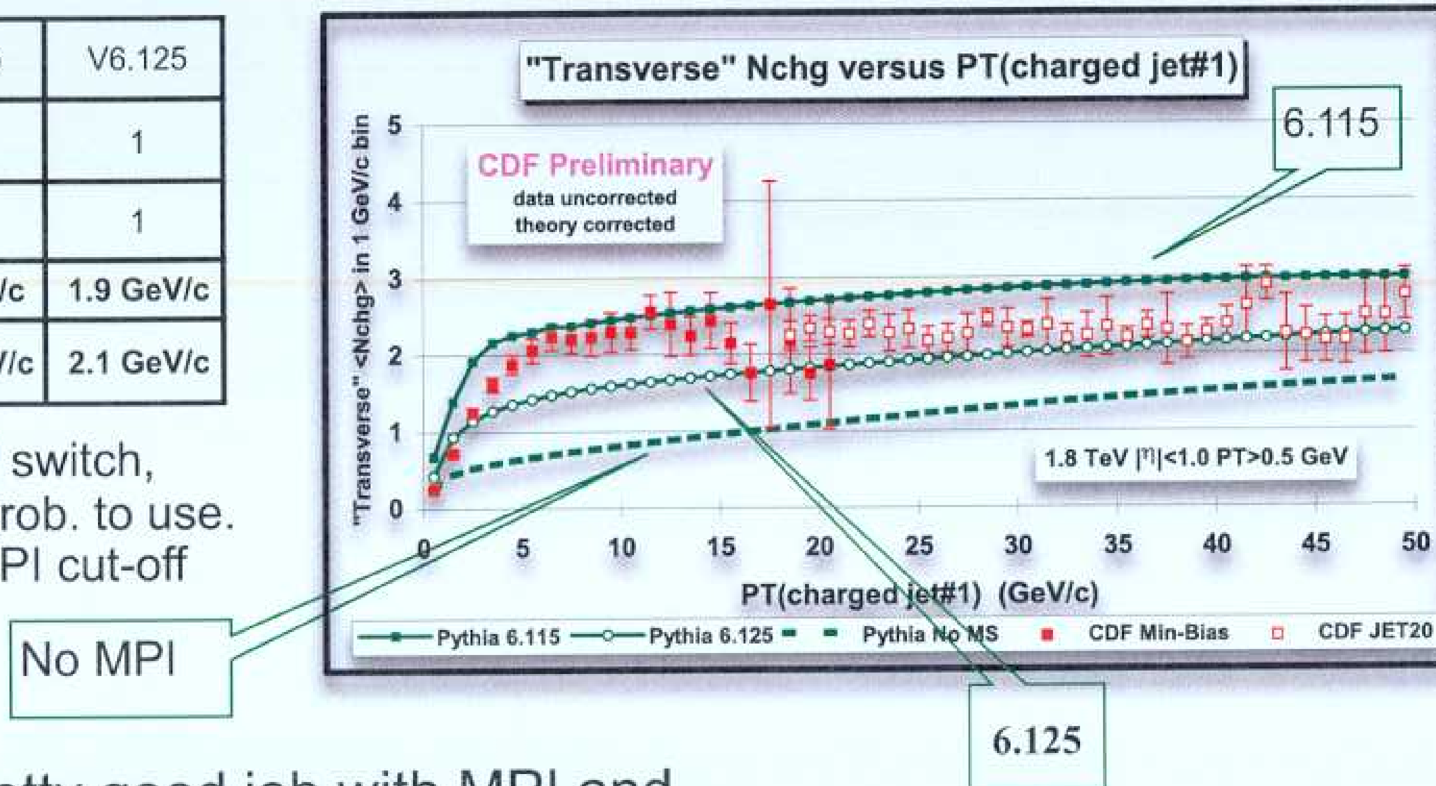
$\langle k_T^2 \rangle = 2.68 \pm 0.04$ GeV/c

Data suggest k_T higher than PYTHIA default (2.1)

Determining MPI Parameters

Parameter	V6.115	V6.125
MSTP(81)	1	1
MSTP(82)	1	1
PARP(81)	1.4 GeV/c	1.9 GeV/c
PARP(82)	1.55 GeV/c	2.1 GeV/c

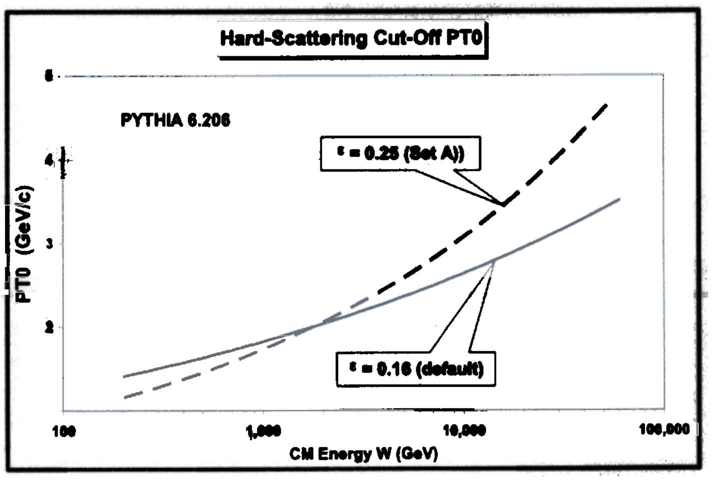
MSTP(81) - MPI switch,
what scattering prob. to use.
PARP(81/82) - MPI cut-off



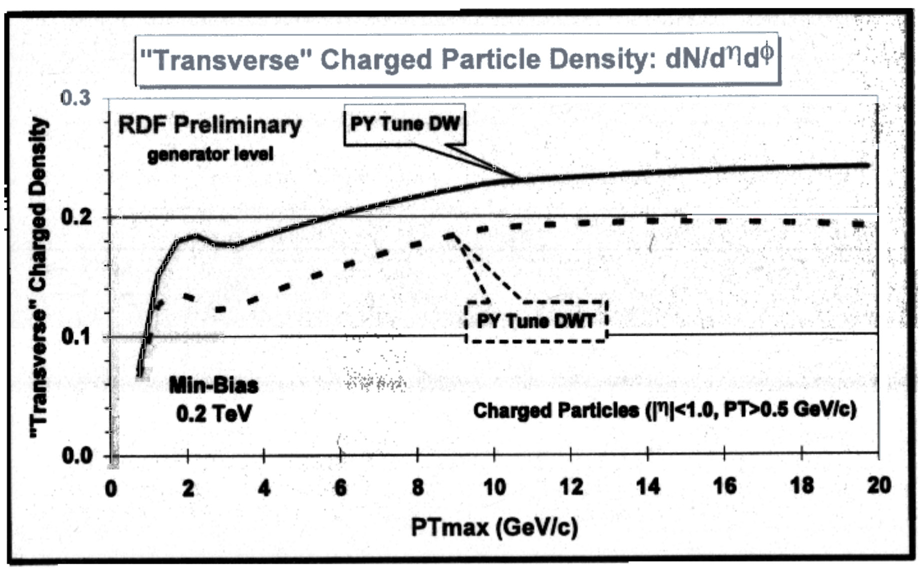
- Could do a pretty good job with MPI and const. scattering probability
- But do better with hard core and variable impact parameter
- Note strong dependence on PDFs - need to pick before tuning

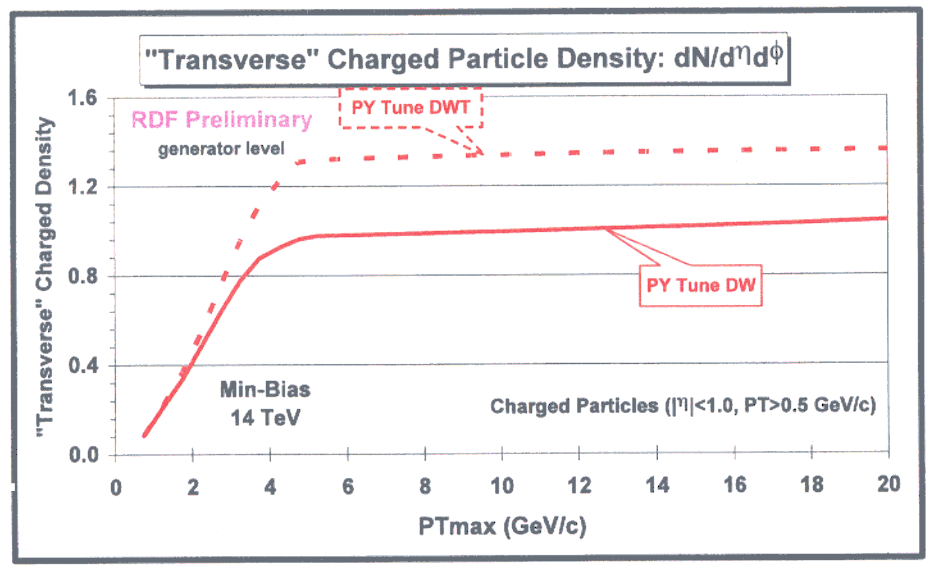
p: double Gaus hard core → collisions have impact parameter dependence

Effect of hard scattering cut-off scaling



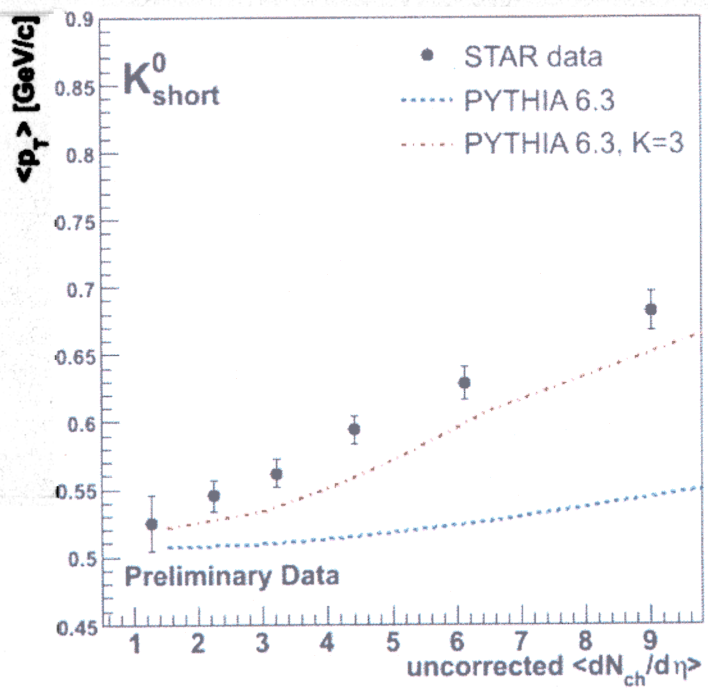
- Increasing ε creates smaller energy dependence for UE
- remember pivot point at 1.9 TeV
- ε = 0.16 (DWT) → 0.25 (DW) (suggested by 630 GeV Tevatron) → 35% more RHIC, 26% less LHC

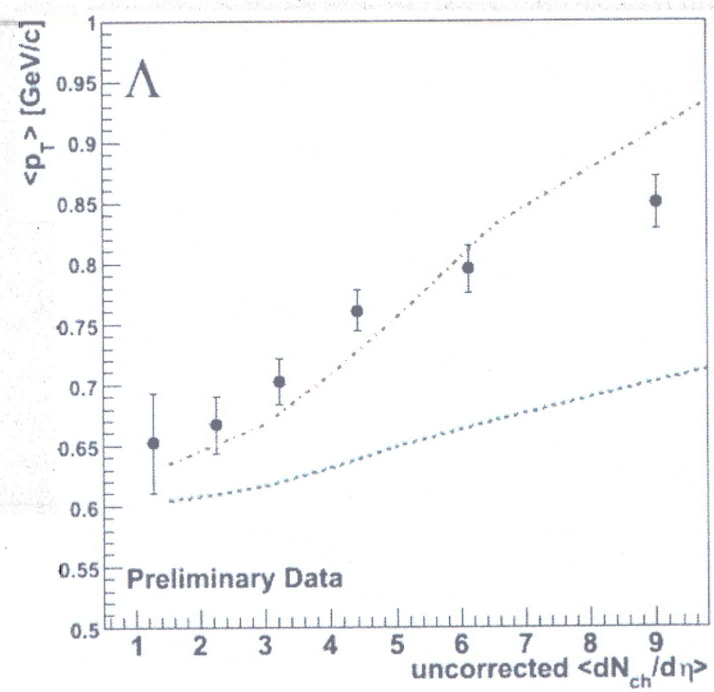




PYTHIA $\langle p_T \rangle$ vs N_{ch}

- **More sensitive observable to compare models to (mini-jet and/or multiple interaction implementations in models)**
- K-factor accounts for increase of $\langle p_T \rangle$ with charged multiplicity





K factor tuned PYTHIA seems to do OK job for strange hadrons

- Light hadrons and HF need different values

Perugia Tunes

- The major changes to PYTHIA for Perugia tunes
- arXiv:0905.3418

Parameter	Type	S0A-Pro	P-0	P-HARD	P-SOFT	P-3	P-NOCR	P-X	P-6
MSTP(51)	PDF	7	7	7	7	7	7	20650	10042
MSTP(52)	PDF	1	1	1	1	1	1	2	2
MSTP(64)	**ISR**	2	3	3	2	3	3	3	3
PARP(64)	**ISR**	1.0	1.0	0.25	2.0	1.0	1.0	2.0	1.0
MSTP(67)	**ISR**	2	2	2	2	2	2	2	2
PARP(67)	**ISR**	4.0	1.0	4.0	0.5	1.0	1.0	1.0	1.0
MSTP(70)	**ISR**	2	2	0	1	0	2	2	2
PARP(62)	**ISR**	-	-	1.25	-	1.25	-	-	-
PARP(81)	**ISR**	-	-	-	1.5	-	-	-	-
MSTP(72)	**ISR**	0	1	1	0	2	1	1	1
PARP(71)	FSR	4.0	2.0	4.0	1.0	2.0	2.0	2.0	2.0
PARJ(81)	FSR	0.257	0.257	0.3	0.2	0.257	0.257	0.257	0.257
PARJ(82)	FSR	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MSTP(81)	UE	21	21	21	21	21	21	21	21
PARP(82)	UE	1.85	2.0	2.3	1.9	2.2	1.95	2.2	1.95
PARP(89)	UE	1800	1800	1800	1800	1800	1800	1800	1800
PARP(90)	UE	0.25	0.26	0.30	0.24	0.32	0.24	0.23	0.22
MSTP(82)	UE	5	5	5	5	5	5	5	5
PARP(83)	UE	1.6	1.7	1.7	1.5	1.7	1.8	1.7	1.7
MSTP(88)	**BR**	0	0	0	0	0	0	0	0
PARP(79)	**BR**	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
PARP(80)	**BR**	0.01	0.05	0.01	0.05	0.03	0.01	0.05	0.05
MSTP(91)	**BR**	1	1	1	1	1	1	1	1
PARP(91)	**BR**	2.0	2.0	1.0	2.0	1.5	2.0	2.0	2.0
PARP(93)	**BR**	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
MSTP(95)	CR	6	6	6	6	6	6	6	6
PARP(78)	CR	0.2	0.33	0.37	0.15	0.35	0.0	0.33	0.33
PARP(77)	CR	0.0	0.9	0.4	0.5	0.6	0.0	0.9	0.9
MSTJ(11)	**HAD**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
PARJ(21)	**HAD**	**0.313**	**0.313**	**0.34**	**0.28**	**0.313**	**0.313**	**0.313**	**0.313**
PARJ(41)	**HAD**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**	**0.49**
PARJ(42)	**HAD**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
PARJ(46)	**HAD**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
PARJ(47)	**HAD**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

QCD and Spin Physics

M. Diehl

Deutsches Elektronen-Synchroton DESY, 22603 Hamburg, Germany

In these lectures I review some of the basic concepts of QCD that underly the interpretation of high-energy scattering experiments.

After a brief general introduction, the first lecture recalls the necessity of ultraviolet renormalization and then discusses some of its practical consequences. The connection between the renormalization scale dependence of perturbative results and the estimate of higher-order corrections is presented in some detail.

In the second lecture, I take the example of e^+e^- annihilation into hadrons to discuss a characteristic feature of QCD perturbation theory: the occurrence of soft and collinear divergences and their cancellation in suitable observables. I then recapitulate the optical theorem and discuss its practical value and some of its physical implications. Finally, I recall the notation of chirality and present a set of useful properties of Dirac spinors.

The third lecture reviews in broad lines the logic of collinear factorization, a cornerstone for the application of perturbative methods to lepton-hadron and hadron-hadron scattering. As a by-product, definitions and some properties of parton densities in QCD will be obtained. In the fourth lecture, I discuss the need to introduce a factorization scale and the corresponding scale dependence of parton densities. I give a brief account of the peculiarities of the evolution for polarized quark and gluon densities.

A different version of factorization is presented in the fifth lecture, where transverse-momentum dependent parton densities and fragmentation functions are introduced. I highlight the special role of Wilson lines in this context and show how they are related with time-reversal odd observables like the Sivers or Boer-Mulders asymmetries. Differences and similarities between collinear and k_T factorization will be discussed, as well as their complementarity in the description of final states with moderately large p_T.

Throughout the lectures, emphasis is put on the physics underlying the theoretical methods on one hand, and on simple calculations illustrating their technical implementation on the other hand.

Summary of lecture 1

Renormalization

- beyond all technicalities reflects physical idea:
  eliminate details of physics at scales $\gg$ scale μ of problem
- dependence of observable on μ governed by RGE
  reflects (and estimates) particular higher-order corrections
  . . . but not all
- prescriptions for scale choice = educated guesses

Summary of lecture 2

- perturbative calculations beyond tree level
  only for quantities that are IR and collinear safe
  ⇝ dominated by large virtualities
  - simplest examples: total cross sections/decay rates for colorless initial states
  - for jets in final state suitable (and unsuitable) observables exist
- opt. theorem:
  - can trade inclusive quantities ↔ forward amplitudes
  - generalization to non-forward amplitudes
    with important consequences for asymmetries
  - valid for individual Feynman graphs → cutting rules

Summary of lecture 3

Factorization

- implements ideas of parton model in QCD
  - inclusion of perturbative corrections (NLO, NNLO, ...)
  - field theoretical def. of parton densities and fragmentation fcts.
    ⇝ bridge to non-perturbative QCD
- valid for specified observables in specified kinematics
  - important results from general principles (power counting, ...)
  - soft spectator interactions complicate analysis
    for > 1 observed hadron (SIDIS, hadron-hadron coll., ...)
  - factorization proofs rather rare
- is an approximation scheme for large scales $(Q, p_T, \dots)$
  - certain asymmetries zero in large-scale limit, progress in calculating $\frac{1}{Q}$ suppressed (= twist three) observables
  - higher power corrections ($\frac{1}{Q^2}$ etc.) in general not calculable

Summary of lecture 4

Evolution

- for consistency must in collinear factorization
  - remove collinear kinematic region in hard scattering
  - remove hard kinematic region in parton densities
    $\leftrightarrow$ UV renormalization

  procedure introduces factorization scale μ
  - separates "collinear" from "hard", "object" from "probe"
- scale dependence of parton densities (and hard scattering) given by evolution equations
  - for moments of parton densities get usual RGE
- special situation for first moments $\Delta\Sigma$ and Δg
  - due to axial anomaly
  - scheme choice exhibits limits of parton-model interpretation in full-fledged quantum field theory

Summary of lecture 5

- transverse-momentum dependent factorization for measured small transv. mom. (or small transv. mom. differences)
- more structure in parton densities and fragm. fcts.
  - k_T dependence
  - correlations between k_T and spin of parton and/or hadron
- factorization more complicated
  - soft factor
  - Sudakov logarithms (but in turn no DGLAP evolution)
- nontrivial dynamics (including T odd effects) from rescattering
  - incorporated into Wilson lines
  - best understood for e^+e^-, SIDIS, Drell-Yan
- k_T factorization related with collinear factorization for high p_T

PHENIX Spinfest 2009 at BNL

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PHENIX Spinfest 2009 at BNL

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PHENIX SPINFEST SCHOOL 2009 AT BNL

Physics Bldg. 510 RBRC Conference Room 2-220, 2nd Floor and Small Conference room 1st floor

Agenda July 01 – 31, 2009

Wednesday, July 01 – 03 **RBRC Conference Room 2-220** **Bldg. 510**	**Chair – Ralf Seidl** Open discussion
Monday, July 6 **RBRC Conference Room 2-220** **Bldg. 510**	**Chair – Ralf Seidl** Open discussion
Tuesday Morning, July 07 **Small Conference Room** 09:30 - 12:00	**Chair – Ralf Seidl** **Speaker: Elke Aschenauer, BNL** eP scattering
Wednesday Morning, July 08 **Small Conference Room** 09:30 - 12:00	**Chair – Ralf Seidl** **Speaker: Matthias Grosse-Perdekamp, UIUC** PP scattering, (and e+e)
Thursday Morning, July 09 **Small Conference Room** 09:30 - 12:00	**Chair – Ralf Seidl** **Speaker: John Lajoie, ISU** Triggering in High Energy Experiments
Friday July 10 **RBRC Conference Room** 09:30 – 12:00	**Chair – Ralf Seidl** **Open discussion**
Monday Morning, July 13 **Small Conference Room** 9:30 – 12:00	**Chair – Ralf Seidl** **Speaker: Helen Caines, Yale** Pythia and the Lund Fragmentation Model
Tuesday July 14 – Friday July 24th **RBRC Conference Room 2-220** **Bldg. 510**	**Chair – Ralf Seidl** Open discussion
Monday – Friday, July 27 – 31 **Small Conference Room** 9:30 – 12:00	**Chair – Ralf Seidl** **Speaker: Dr. Markus Diehl, DESY** QCD Theory Lecture


NASA

RBRC Workshop Proceedings

Volume 92 - PKU-RBRC Workshop on Transverse Spin Physics. June 30 - July 04, 2008. BNL-81685-2008
Volume 91 - RBRC Scientific Review Committee Meeting. Nov. 17 & 18, 2008. BNL-81556-2008
Volume 90 - PHENIX Spinfest School 2008 at BNL, August 4-8, 2008. BNL-81478-2008
Volume 89 - Understanding QGP through Spectral Functions and Euclidean Correlators, April 23-25, 2008 - BNL-81318-2008
Volume 88 - Hydrodynamics in Heavy Ion Collisions and QCD Equation of State, April 21-22, 2008 - BNL-81307-2008
Volume 87 - RBRC Scientific Review Committee Meeting - BNL-79570-2007
Volume 86 - Global Analysis of Polarized Parton Distributions in the RHIC Era, October 8, 2007 - BNL-79457-2007
Volume 85 - Parity Violating Spin Asymmetries at RHIC-BNL, April 26-27, 2007 - BNL - 79146-2007
Volume 84 - Domain Wall Fermions at Ten Years, March 15-17, 2007 - BNL-77857-2007
Volume 83 - QCD in Extreme Conditions, July 31-August 2, 2006 - BNL-76933-2006
Volume 82 - RHIC Physics in the Context of the Standard Model, June 18-23, 2006 - BNL-76863-2006
Volume 81 - Parton Orbital Angular Momentum (Joint RBRC/University of New Mexico Workshop) February 24-26, 2006 - BNL-75937-2006
Volume 80 - Can We Discover the QCD Critical Point at RHIC?, March 9-10, 2006 - BNL 75692-2006
Volume 79 - Strangeness in Collisions, February 16-17, 2006 - BNL-79763-2008
Volume 78 - Heavy Flavor Productions and Hot/Dense Quark Matter, December 12-14, 2005 - BNL-76915-2006
Volume 77 - RBRC Scientific Review Committee Meeting, October 10-12, 2005 - BNL- 52649-2005
Volume 76 - Odderon Searches at RHIC, September 27-29, 2005 - BNL-75092-2005
Volume 75 - Single Spin Asymmetries, June 1-3, 2005 - BNL-74717-2005
Volume 74 - RBRC QCDPC Computer Dedication and Symposium on RBRC QCDOC, May 26, 2005 - BNL-74813-2005
Volume 73 - Jet Correlations at RHIC, March 10-11, 2005 - BNL-73910-2005
Volume 72 - RHIC Spin Collaboration Meetings XXXI (January 14, 2005), XXXII (February 10, 2005), XXXIII (March 11, 2005) - BNL-73866-2005
Volume 71 - Classical and Quantum Aspects of the Color Glass Condensate - BNL-73793-2005
Volume 70 - Stongly Coupled Plasmas: Electromagnetic, Nuclear & Atomic - BNL-73867-2005
Volume 69 - RBRC Scientific Review Committee Meeting - BNL-73546-2004
Volume 68 - Workshop on the Physics Programme of the RBRC and UKQCD QCDOC Machines - BNL-73604-2004
Volume 67 - High Performance Computing with BlueGene/L and QCDOC Architectures - BNL-
Volume 66 - RHIC Spin Collaboration Meeting XXIX, October 8-9, 2004, Torino, Italy - BNL-73534-2004
Volume 65 - RHIC Spin Collaboration Meetings XXVII (July 22, 2004), XXVIII (September 2, 2004) - BNL-73506-2004
Volume 64 - Theory Summer Program on RHIC Physics - BNL-73263-2004
Volume 63 - RHIC Spin Collaboration Meetings XXIV (05/21/04), XXV (05/27/04), XXVI (06/01/04) - BNL-72397-2004
Volume 62 - New Discoveries at RHIC, May 14-15, 2004 - BNL-72391-2004
Volume 61 - RIKEN-TODAI Mini Workshop on "Topics in Hadron Physics at RHIC", March 23-24, 2004 - BNL-72336-2004
Volume 60 - Lattice QCD at Finite Temperature and Density - BNL-72083-2004
Volume 59 - RHIC Spin Collaboration Meeting XXI, XXII, XXIII - BNL-72382-2004
Volume 58 - RHIC Spin Collaboration Meeting XX - BNL-71900-2004
Volume 57 - High pt Physics at RHIC, December 2-6, 2003 - BNL-72069-2004
Volume 56 - RBRC Scientific Review Committee Meeting - BNL-71899-2003
Volume 55 - Collective Flow and QGP Properties - BNL-71898-2003
Volume 54 - RHIC Spin Collaboration Meetings XVII, XVIII, XIX - BNL-71751-2003
Volume 53 - Theory Studies for Polarized *pp* Scattering - BNL-71747-2003
Volume 52 - RIKEN School on QCD, "Topics on the Proton" - BNL-71694-2003
Volume 51 - RHIC Spin Collaboration Meetings XV, XVI - BNL-71539-2003
Volume 50 - High Performance Computing with QCDOC and BlueGene - BNL-71147-2003
Volume 49 - RBRC Scientific Review Committee Meeting - BNL-52679
Volume 48 - RHIC Spin Collaboration Meeting XIV - BNL-71300-2003
Volume 47 - RHIC Spin Collaboration Meetings XII, XIII - BNL-71118-2003
Volume 46 - Large-Scale Computations in Nuclear Physics using the QCDOC - BNL-52678
Volume 45 - Summer Program: Current and Future Directions at RHIC - BNL-71035

Volume 44 – RHIC Spin Collaboration Meetings VIII, IX, X, XI – BNL-71117-2003
Volume 43 – RIKEN Winter School – Quark-Gluon Structure of the Nucleon and QCD – BNL-52672
Volume 42 – Baryon Dynamics at RHIC – BNL-52669
Volume 41 – Hadron Structure from Lattice QCD – BNL-52674
Volume 40 – Theory Studies for RHIC-Spin – BNL-52662
Volume 39 – RHIC Spin Collaboration Meeting VII – BNL-52659
Volume 38 – RBRC Scientific Review Committee Meeting – BNL-52649
Volume 37 – RHIC Spin Collaboration Meeting VI (Part 2) – BNL-52660
Volume 36 – RHIC Spin Collaboration Meeting VI – BNL-52642
Volume 35 – RIKEN Winter School – Quarks, Hadrons and Nuclei – QCD Hard Processes and the Nucleon Spin – BNL-52643
Volume 34 – High Energy QCD: Beyond the Pomeron – BNL-52641
Volume 33 – Spin Physics at RHIC in Year-1 and Beyond – BNL-52635
Volume 32 – RHIC Spin Physics V – BNL-52628
Volume 31 – RHIC Spin Physics III & IV Polarized Partons at High Q^2 Region – BNL 52617
Volume 30 – RBRC Scientific Review Committee Meeting – BNL-52603
Volume 29 – Future Transversity Measurements – BNL-52612
Volume 28 – Equilibrium & Non-Equilibrium Aspects of Hot, Dense QCD – BNL-52613
Volume 27 – Predictions and Uncertainties for RHIC Spin Physics & Event Generator for RHIC Spin Physics III – Towards Precision Spin Physics at RHIC – BNL-52596
Volume 26 – Circum-Pan-Pacific RIKEN Symposium on High Energy Spin Physics – BNL-52588
Volume 25 – RHIC Spin – BNL-52581
Volume 24 – Physics Society of Japan Biannual Meeting Symposium on QCD Physics at RIKEN BNL Research Center – BNL-52578
Volume 23 – Coulomb and Pion-Asymmetry Polarimetry and Hadronic Spin Dependence at RHIC Energies – BNL-52589
Volume 22 – OSCAR II: Predictions for RHIC – BNL-52591
Volume 21 – RBRC Scientific Review Committee Meeting – BNL-52568
Volume 20 – Gauge-Invariant Variables in Gauge Theories – BNL-52590
Volume 19 – Numerical Algorithms at Non-Zero Chemical Potential – BNL-52573
Volume 18 – Event Generator for RHIC Spin Physics – BNL-52571
Volume 17 – Hard Parton Physics in High-Energy Nuclear Collisions – BNL-52574
Volume 16 – RIKEN Winter School - Structure of Hadrons - Introduction to QCD Hard Processes – BNL-52569
Volume 15 – QCD Phase Transitions – BNL-52561
Volume 14 – Quantum Fields In and Out of Equilibrium – BNL-52560
Volume 13 – Physics of the 1 Teraflop RIKEN-BNL-Columbia QCD Project First Anniversary Celebration – BNL-66299
Volume 12 – Quarkonium Production in Relativistic Nuclear Collisions – BNL-52559
Volume 11 – Event Generator for RHIC Spin Physics – BNL-66116
Volume 10 – Physics of Polarimetry at RHIC – BNL-65926
Volume 9 – High Density Matter in AGS, SPS and RHIC Collisions – BNL-65762
Volume 8 – Fermion Frontiers in Vector Lattice Gauge Theories – BNL-65634
Volume 7 – RHIC Spin Physics – BNL-65615
Volume 6 – Quarks and Gluons in the Nucleon – BNL-65234
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Volume 4 – Inauguration Ceremony, September 22 and Non -Equilibrium Many Body Dynamics – BNL-64912
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Volume 2 – Perturbative QCD as a Probe of Hadron Structure – BNL-64723
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Information on RBRC (RIKEN BNL Research Center):

RIKEN Home page: http://www.bnl.gov/riken/
RHIC Spin Group: http://www.phy.bnl.gov/rhicspin/
Spin Collaboration: http://spin.riken.bnl.gov/

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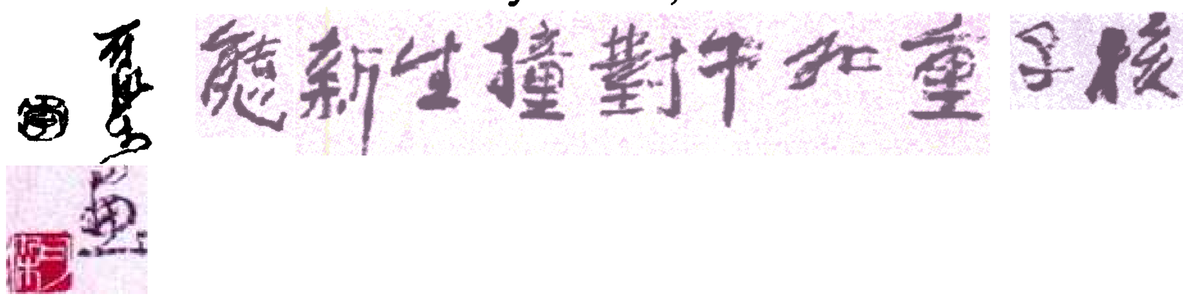

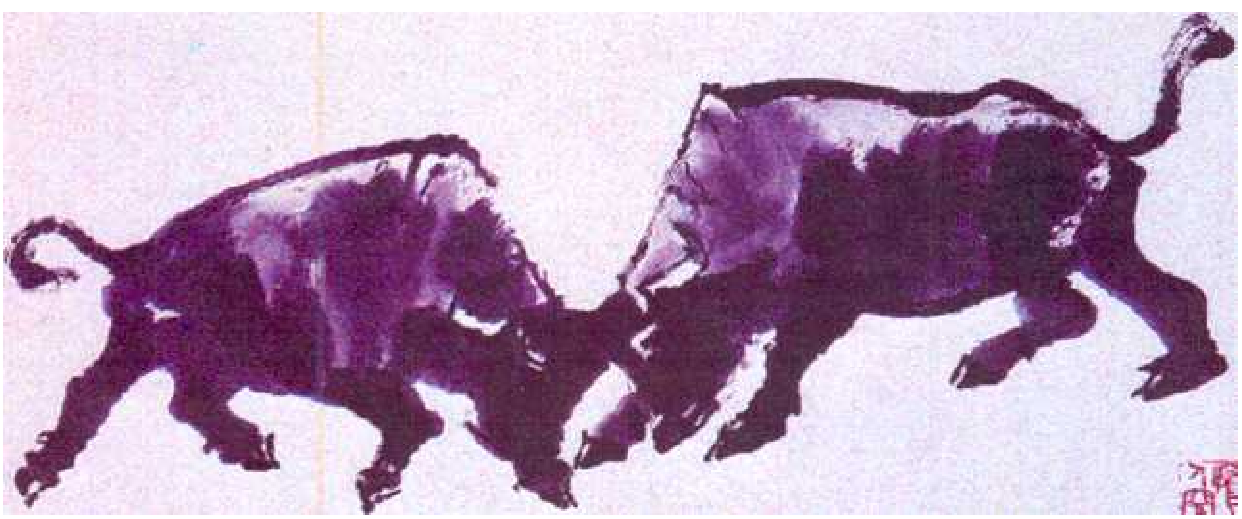

Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T.D. Lee

Speakers:

Elke Aschenauer (BNL

Helen Caines (Yale)

Matthias Grosse-Perdekamp (UIUC)

John Lajoie (ISU

Markus Diehl (DESY)

Organizers: Ralf Seidl (BNL/RBRC); Yuji Goto (RIKEN/RBRC); Kensuke Okada (BNL/RBRC)