BNL-71900-2004
FORMAL REPORT

Proceedings of RIKEN BNL Research Center Workshop Volume 58

RHIC Spin Collaboration Meeting XX

November 18, 2003

Organizer:

Les Bland

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-eight 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

RHIC Working Point

Wolfram Fischer
and
Rogelio Tomas

BROOKHAVEN
NATIONAL LABORATORY

RHIC Spin Collaboration Meeting 2003
17 November 2003

- Working Point
  = choice of transverse oscillation frequencies
  → **Need to minimize effect of resonances**
- Resonances are driven by
  - Non-linear magnetic fields in triplets
    (single beam, independent of intensity)
  - Beam-beam interaction
    (two beams, dependent of intensity)
- Collider should run dominated by beam-beam
  - Can correct triplet errors
  - Cannot compensate beam-beam

  → **Need to correct triplet errors first**
  (IR Correction Task Force)

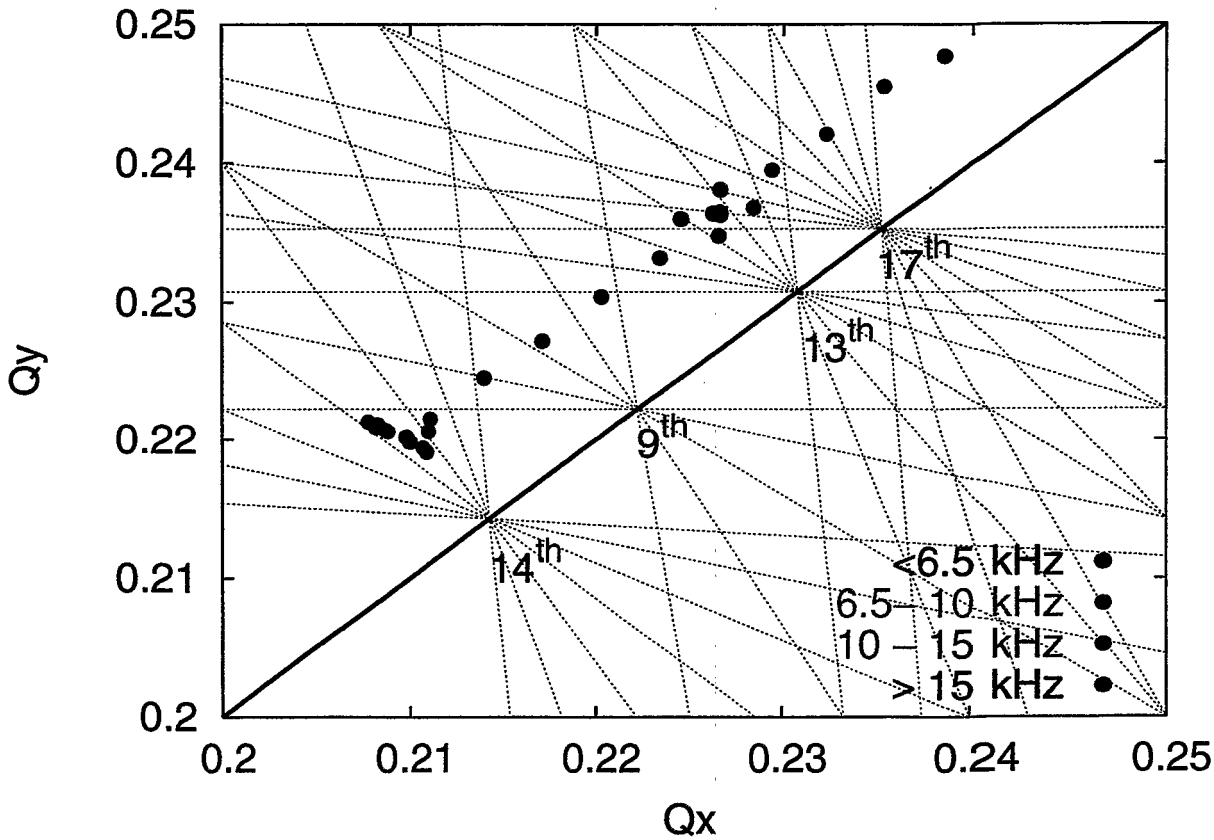
- Triplet error correction
  - Low order errors (octupole and sextupole) can be corrected with beam measurements
    → Technique commissioned last Run (F. Pilat), work not yet finished
  - High order errors (12-poles) correction better based on magnet measurements
    → Robust correction being develop (Y. Luo)
  - Need better machine model for corrector calculation
    → Being developed (R. Tomas), DX, D0, splits, end effects, data base driven
- Goal: Finish IR correction by end of Run-4

Contents

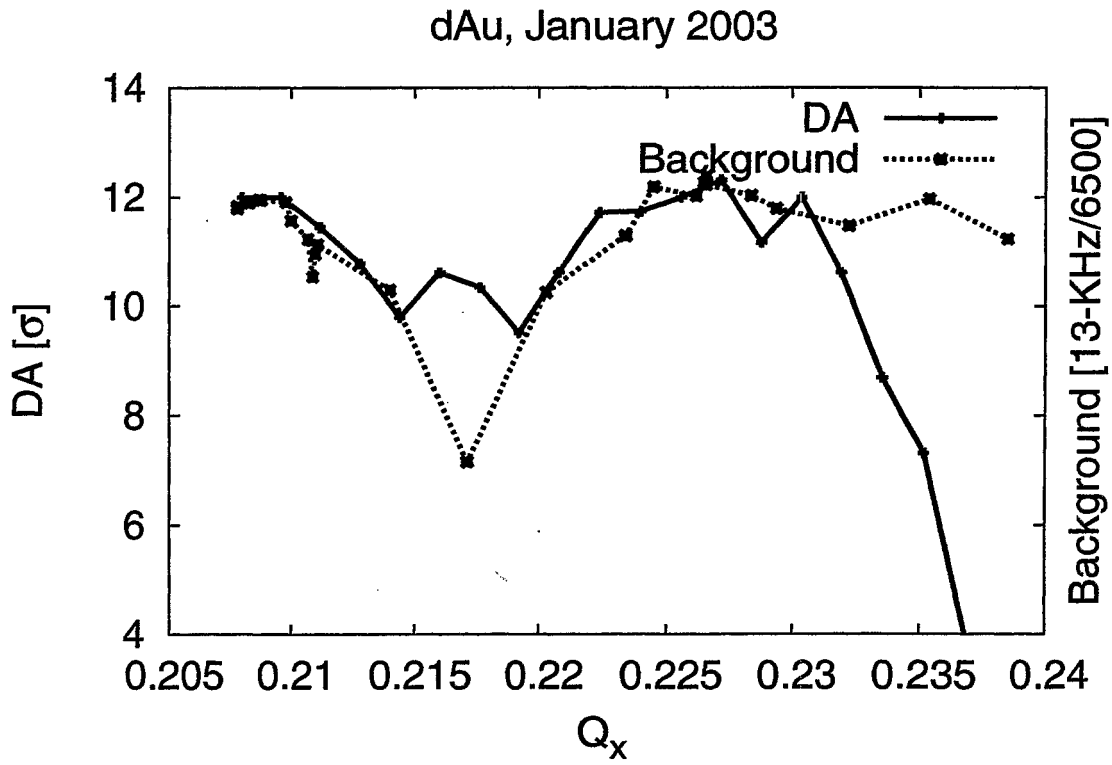
- Background measurements vs. Dynamic Aperture
- Beam Beam effect on Dynamic Aperture
- Possible working points
- IR Task Force preliminary study

Background measurements

dAu, January 2003

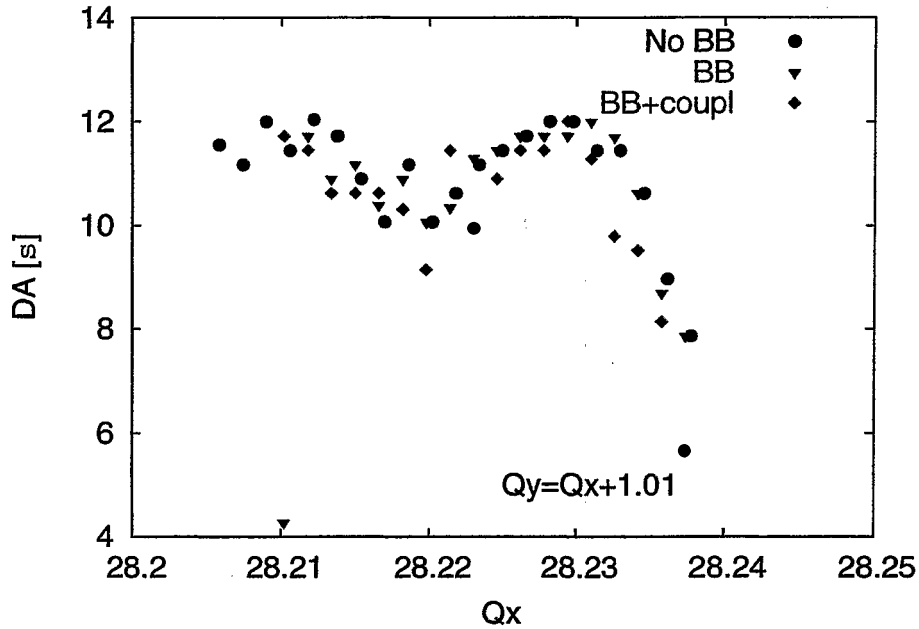


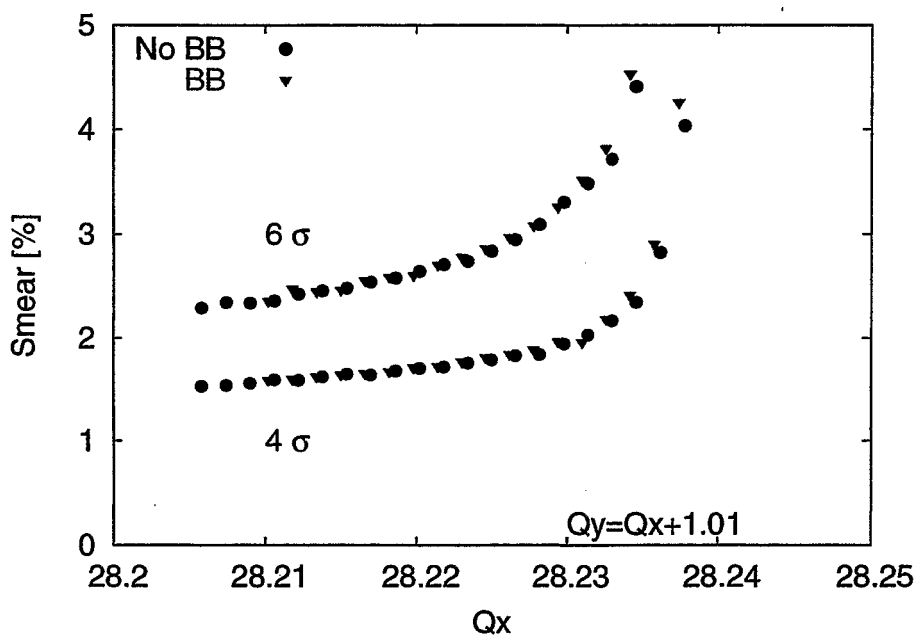
Background measurements vs. DA



The model contains beam-beam, triplet errors, 5% σ low frequency orbit modulation, and power supply ripples (no correctors).

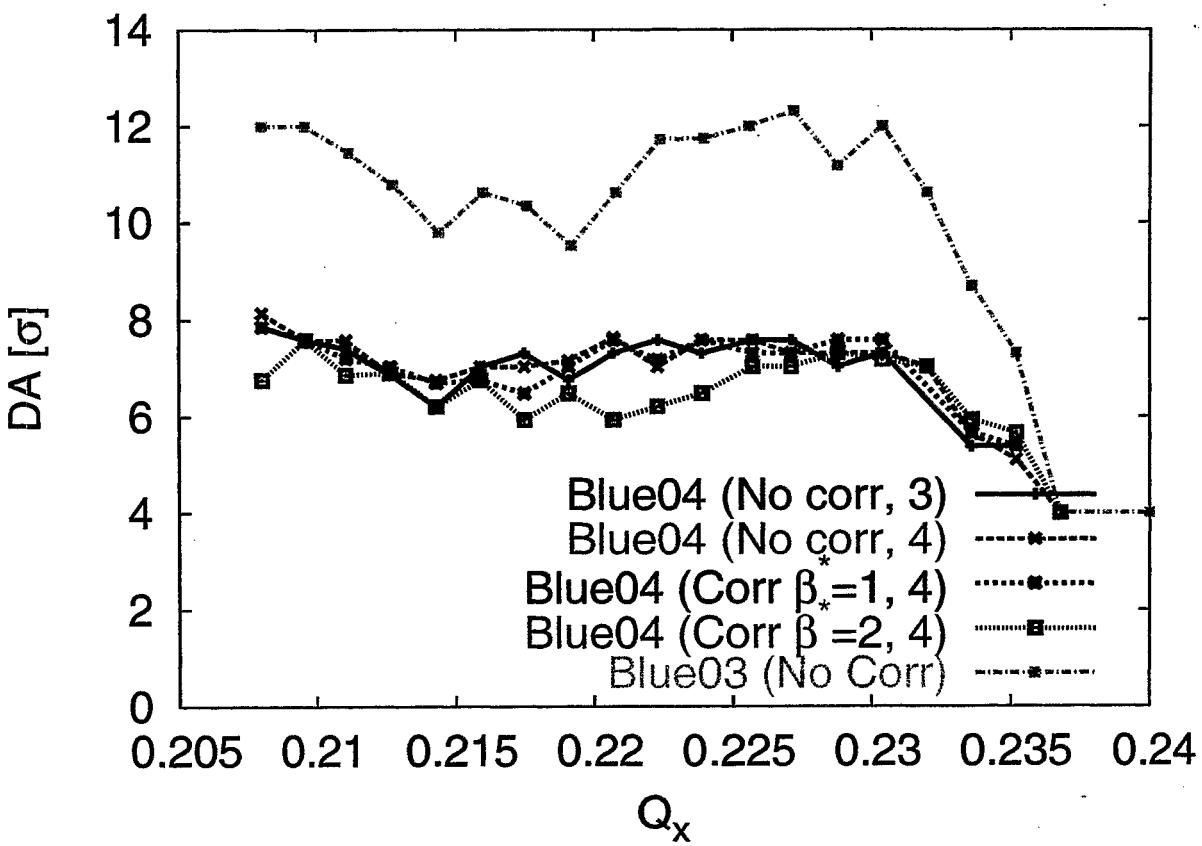
Problem: Beam-Beam does not dominate





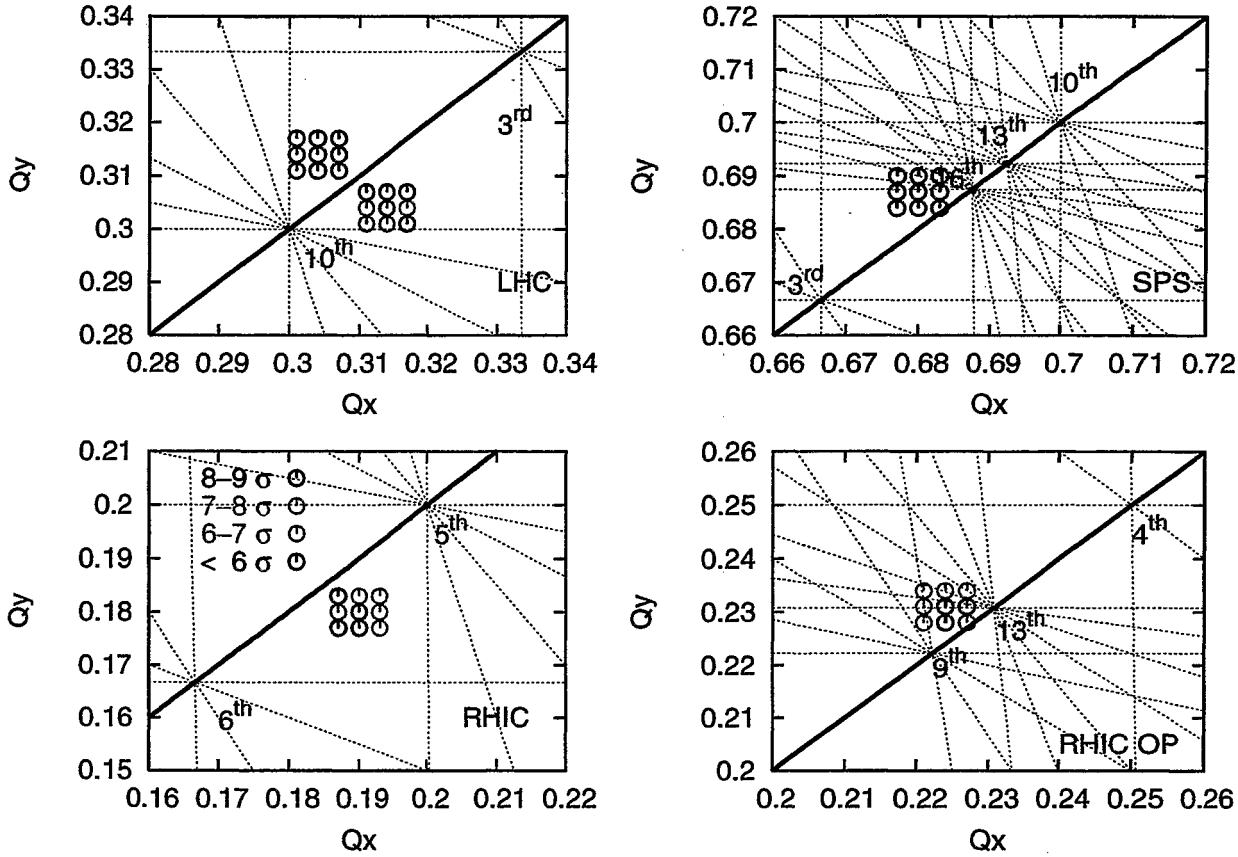
Next year lattice - DA

β^*'s = 1 1 4 5 3 5 and 1 1 3 5 3 5



⇒IR non-linear correction is needed

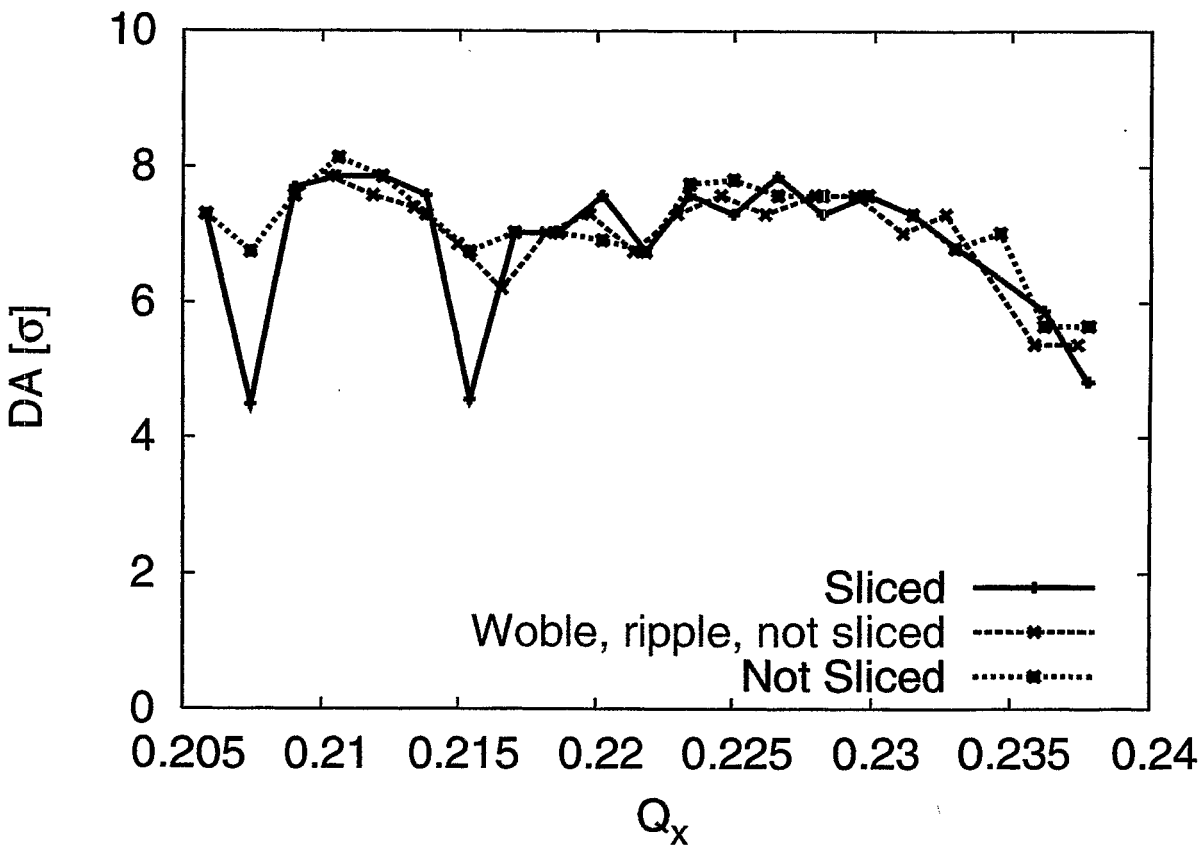
Possible working points - 113535



⇒ SPS working point seems a good candidate (ISR w.p.≈ 0.95 will be considered too)

IR Task Force preliminary study

Improvement of the model by a simple slicing of the triplet quadrupoles leads to changes:



⇒ A more refined model of the IR non-linearities is needed and is presently under construction.

Summary

- Simulations and observations show limited agreement

- Beam Beam does not dominate in simulations

$\Rightarrow$ Improved model under construction

- DA could be enlarged in two ways:
  - by non-linear correction in the IRs
  - by changing the tunes to SPS ones, ≈ 0.68. (ISR tunes, ≈ 0.95, need further consideration too).

Helical Dipole Partial Snake for AGS

Junpei Takano / TITech
Masahiro Okamura / RIKEN
Koji Takano / Takano Original Magnet CO. LTD.

- Design study
- Optimization
- Fabrication
- Future plan

RIKEN

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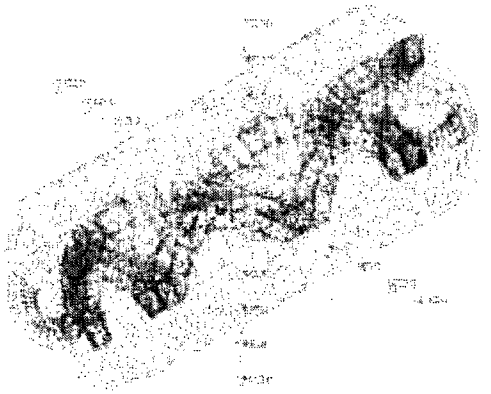
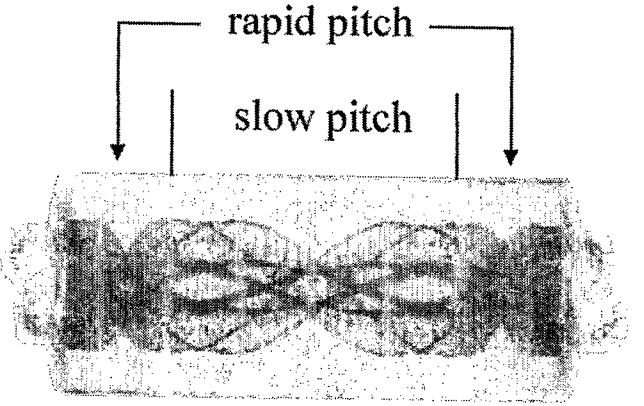
Takano Original Magnet

Design study





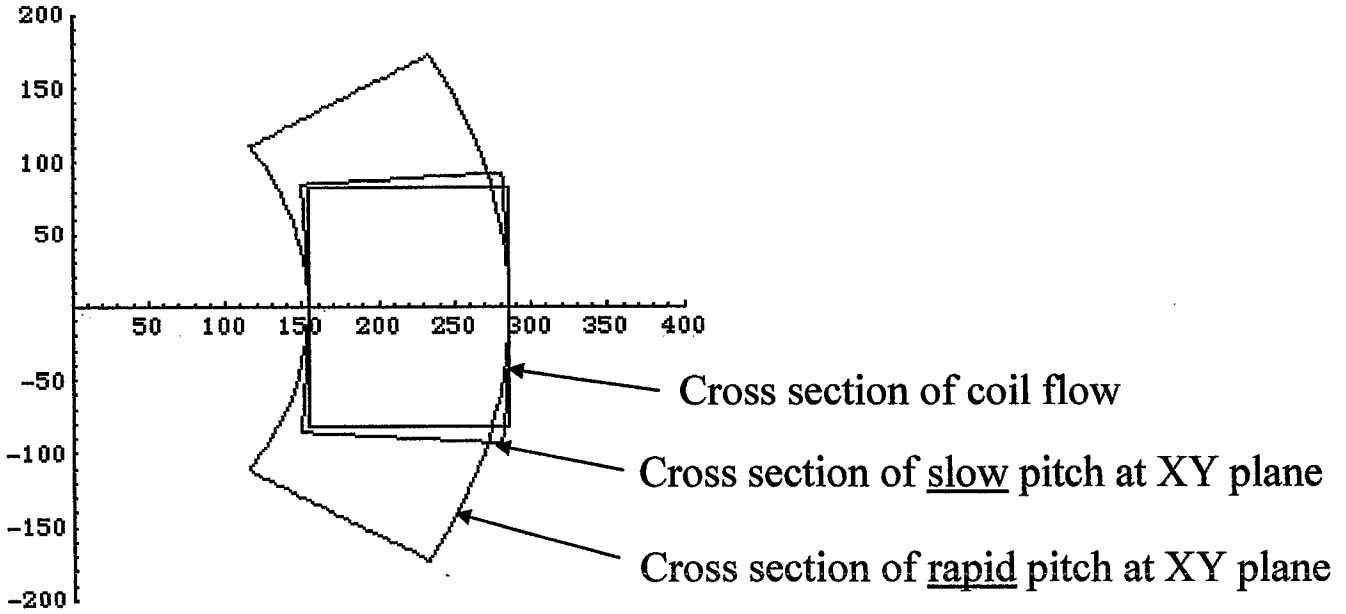
Double pitch structure

- spin rotation is 5% (9degree)
- Max B = 1.5 T
- Beam offset and diffraction angle = 0

Double helical pitch structure is very reasonable in space and cost.

Design study

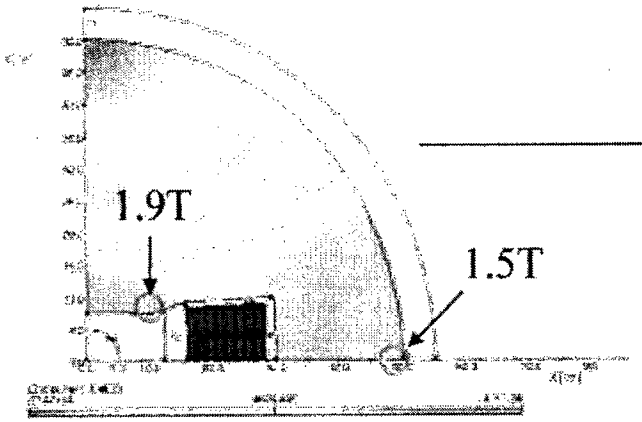
Cross section of helical coil



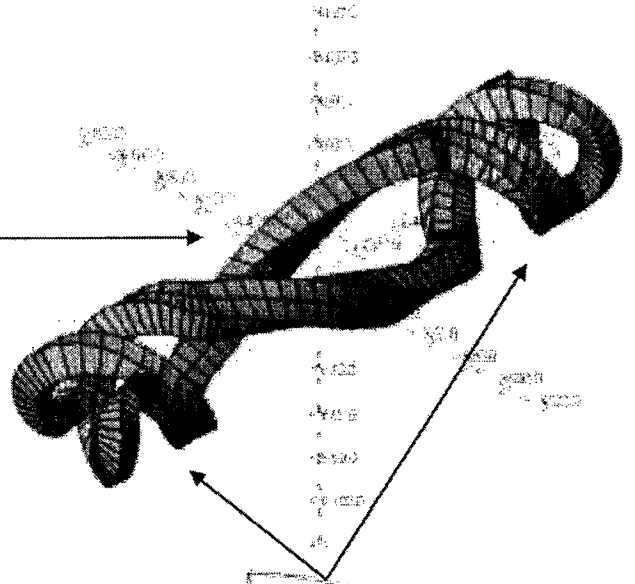
Shape of helical coil is larger than normal window frame type coil.

Design study

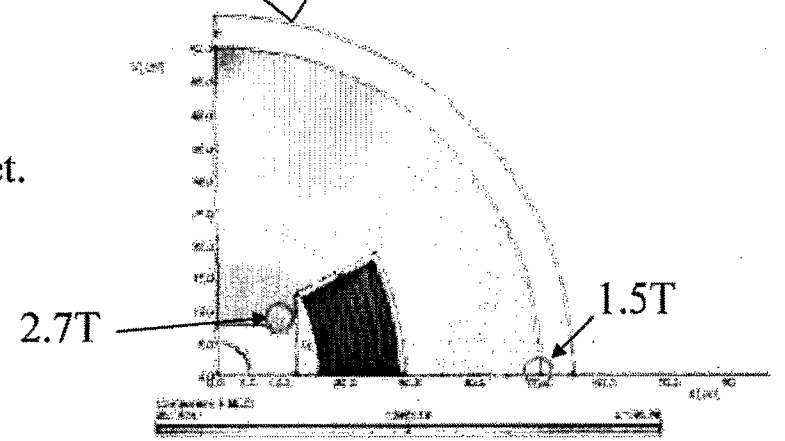
Cross section of helical magnet



Slow pitch region



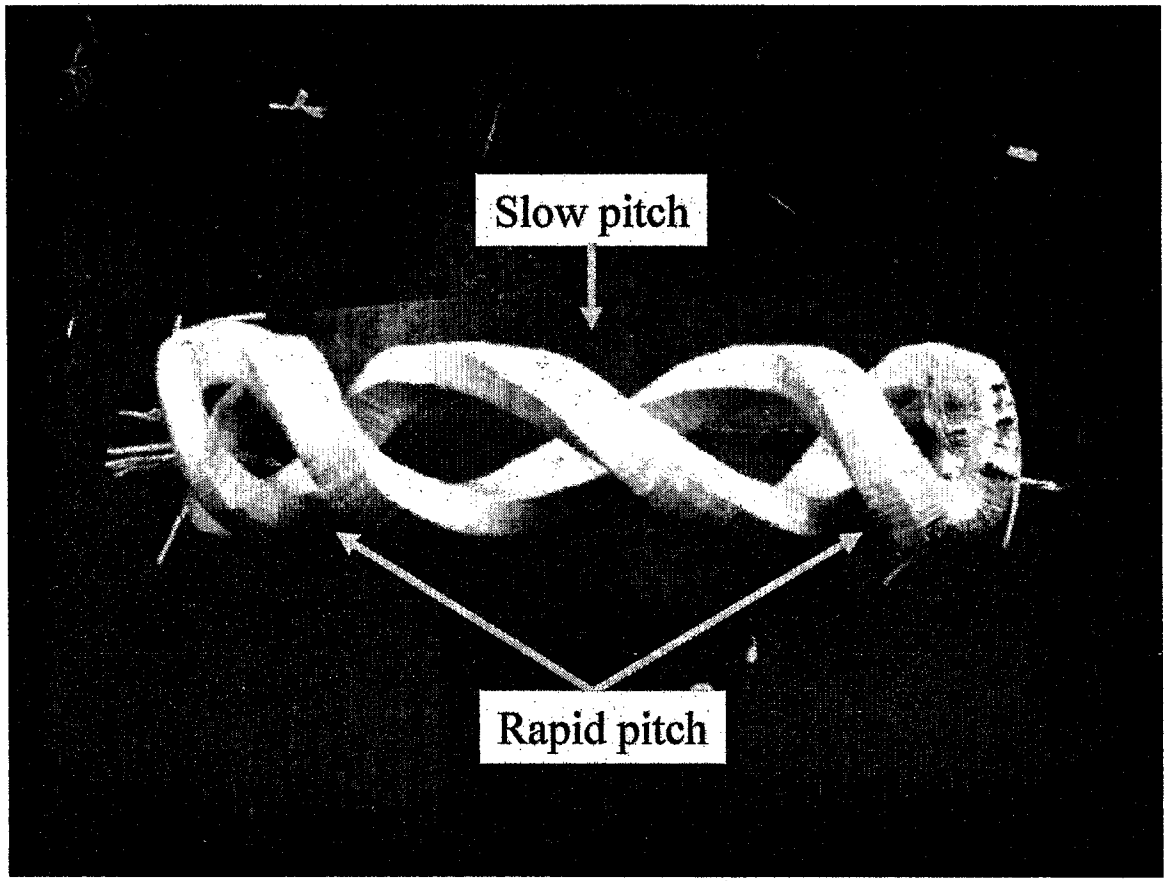
Coil position is window frame type.
The yoke has pole piece like H type magnet.



Rapid pitch region

Design study

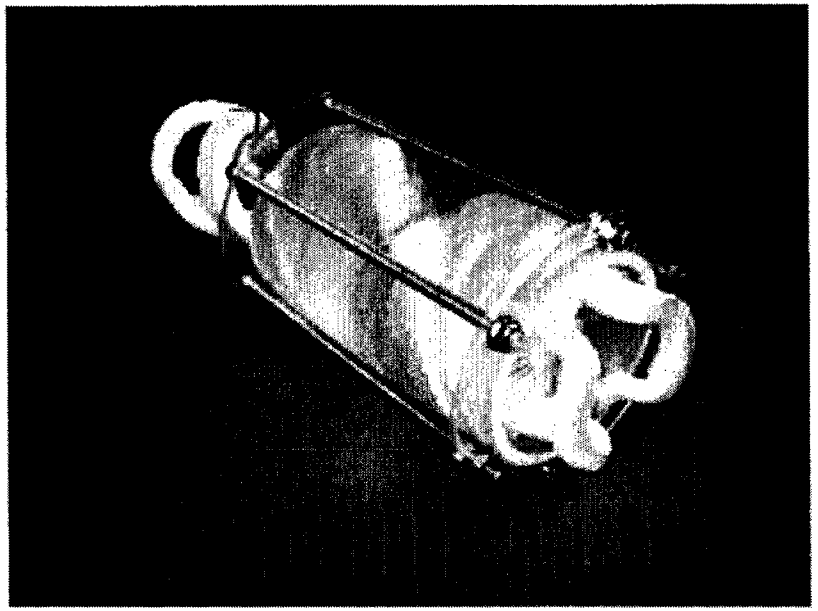
1/5 model of the helical coil

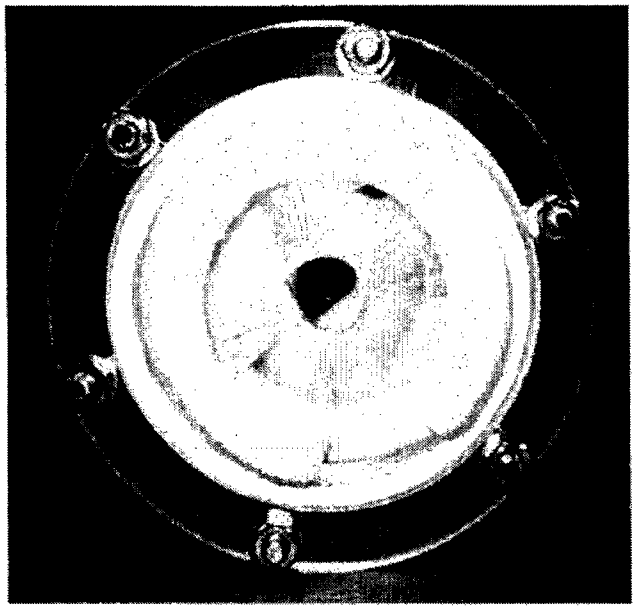


This model is constructed to verify processes of assembling the magnet.

Design study

1/5 model of the helical magnet





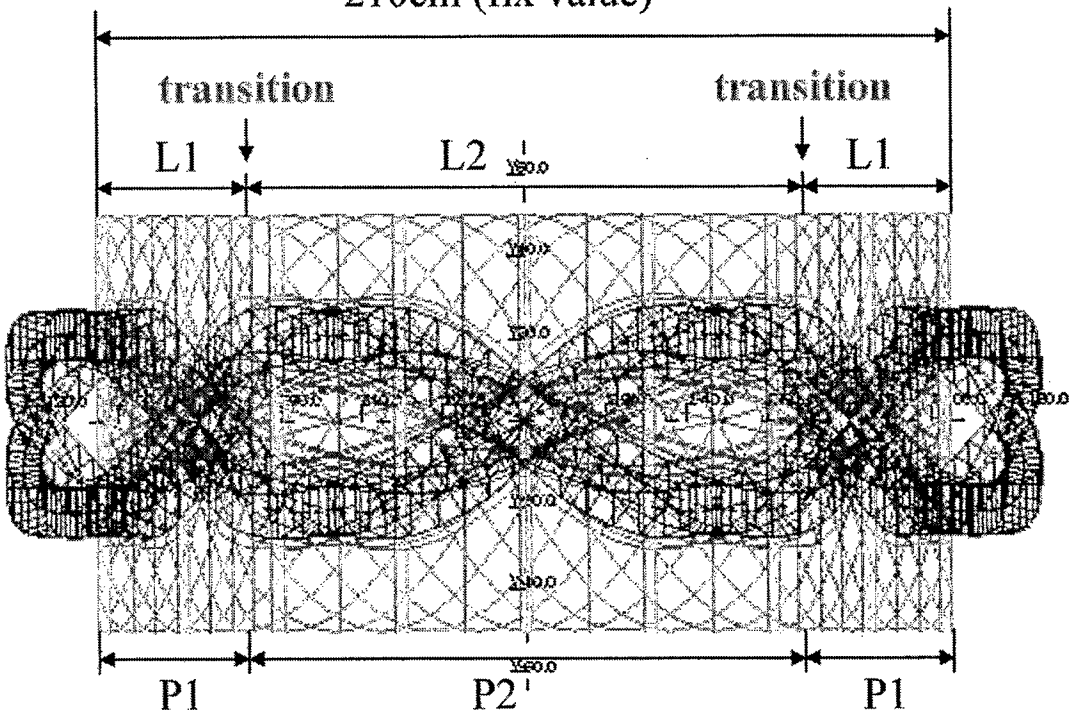
This model is constructed to verify processes of assembling the magnet.

Design study

Property of the helical magnet

	Required property	Designed property
Water pressure	200-250 [PSI]	213.5 [PSI] (=15kg/cm2)
Temperature rise	17 [degree C]	14.97 [degree C]
Current	3000 [A]	2671.429 [A]
Voltage	300 [V]	237.44 [V]
Power	900 [kW]	634.3 [kW]
Ramp rate	0.5 [sec]	0.5 [sec]
Duty factor	100 [%]	100 [%]
Weight	18000 [kg]	15000 [kg]

Optimization of helical pitch

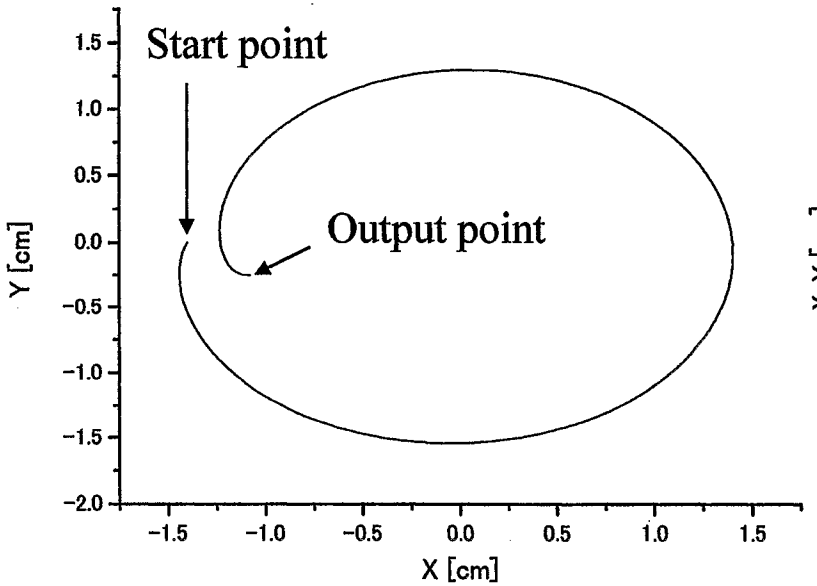


(fix value)
90 [cm/rev]

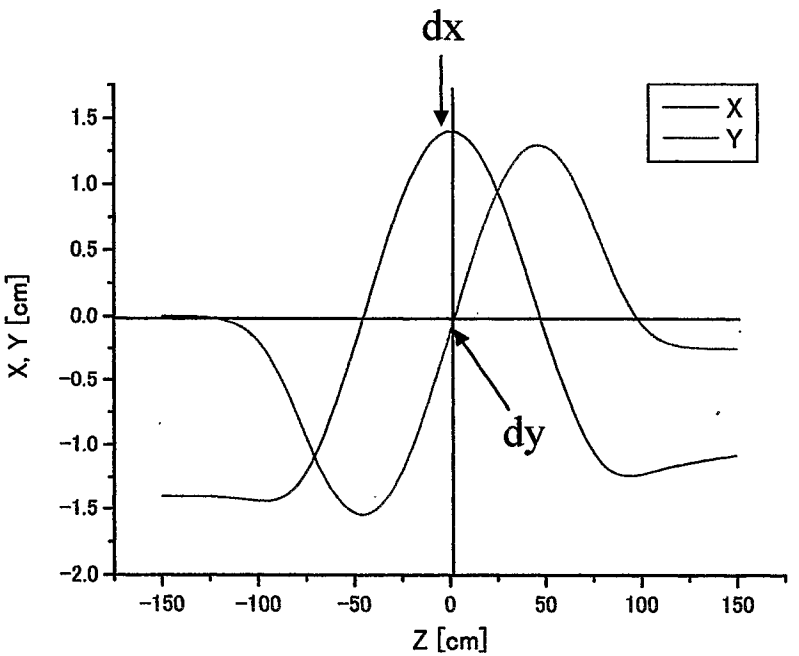
L2, P2 : parameter

Optimization of helical pitch

Example of beam trajectory



beam trajectory of x vs. y



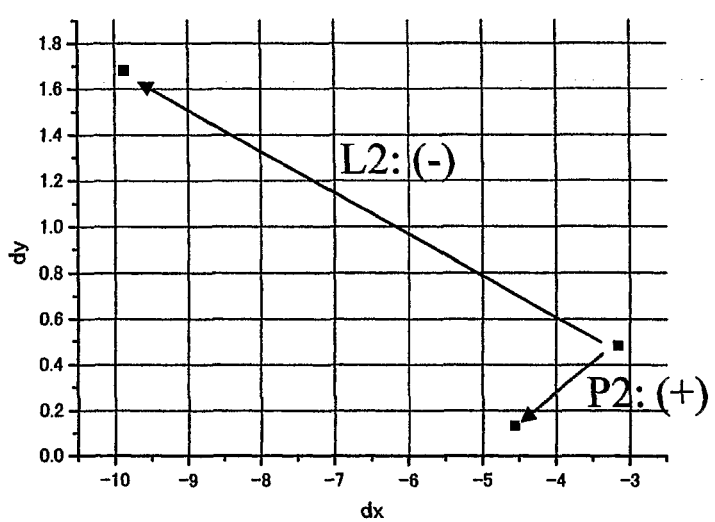
beam trajectory of z vs. x; y

If dx and dy = 0 then the beam trajectory will be closed.

Optimization of helical pitch

The table of dx and dy when changing the parameter (L2, P2)

	L2	P2	dx	dy
pattern1(ref.)	130	200	-3.158	0.481
pattern2	130	240	-9.881 (-)	1.682 (+)
pattern3	125	200	-4.564 (-)	0.133 (-)



Matrix for dx, dy = 0

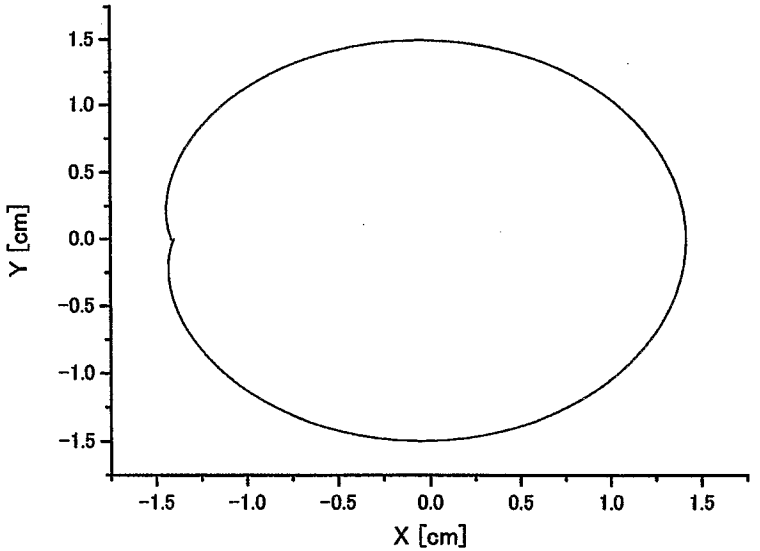
$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} \Delta L2 \\ \Delta P2 \end{pmatrix} = \begin{pmatrix} \Delta dx \\ \Delta dy \end{pmatrix}$$

Solving this matrix,
L2 = 131.8371575
P2 = 183.7732405

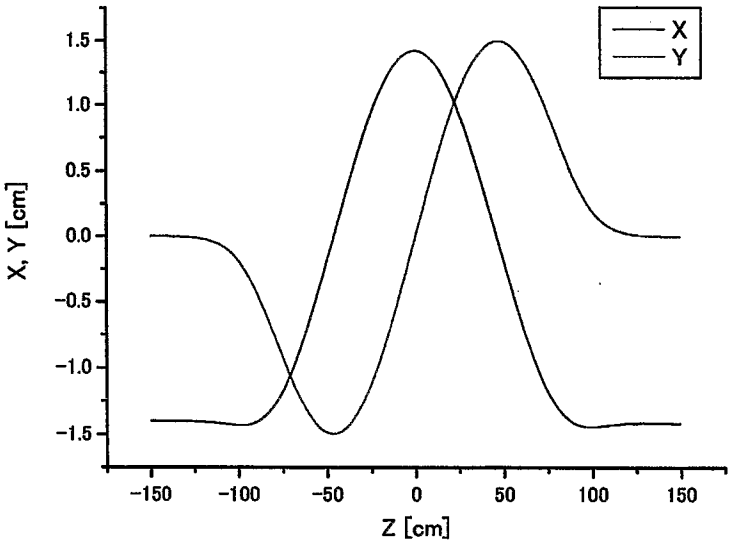
Optimization of helical pitch

Beam trajectory with optimized parameter

L1 = 39.08142125[cm] , L2 = 131.8371575[cm]
P1 = 90[cm/rev] , P2 = 183.7732405[cm/rev]



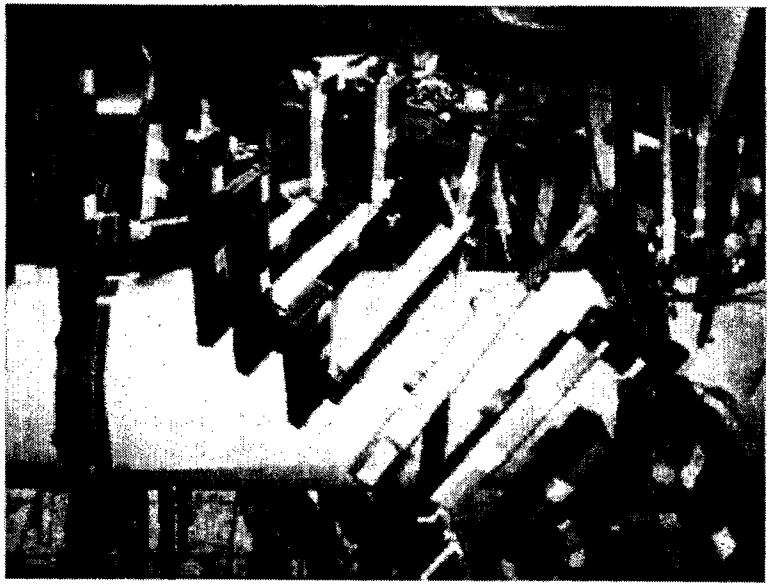
Beam trajectory is closed.



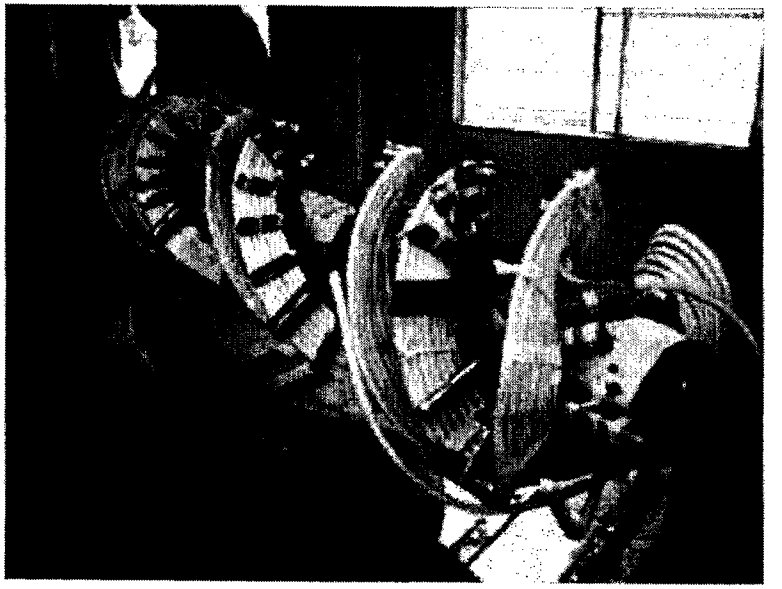
Offset and diffraction angle = 0.

Fabrication

Winding helical snake coil



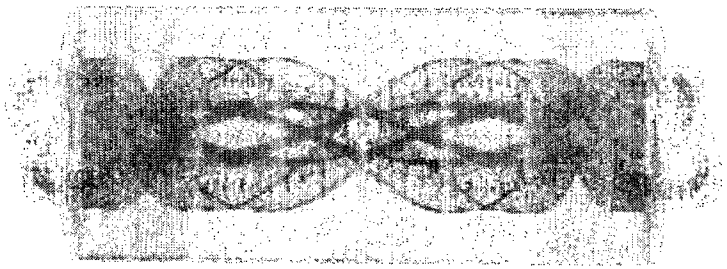
Winding frame



1st layer is wound

Fabrication

Winding helical snake coil

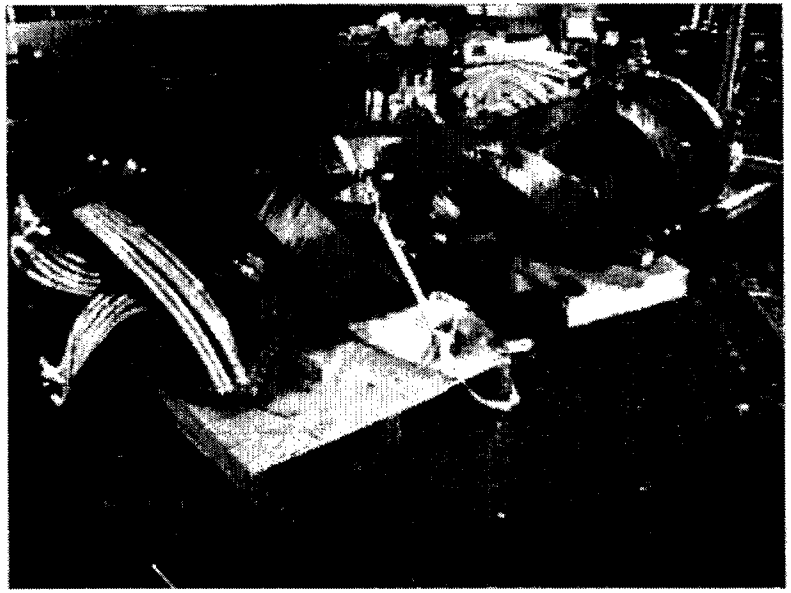


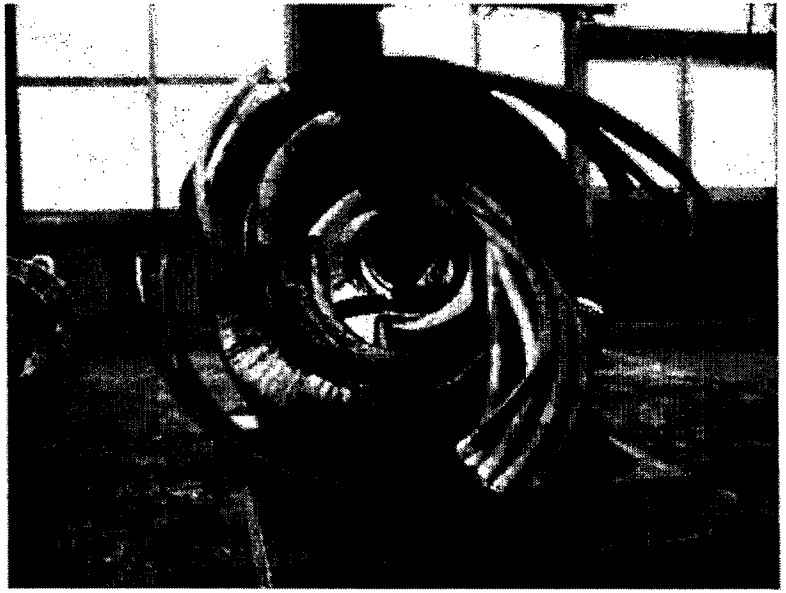
Simulation 3D model

Completed winding

Fabrication

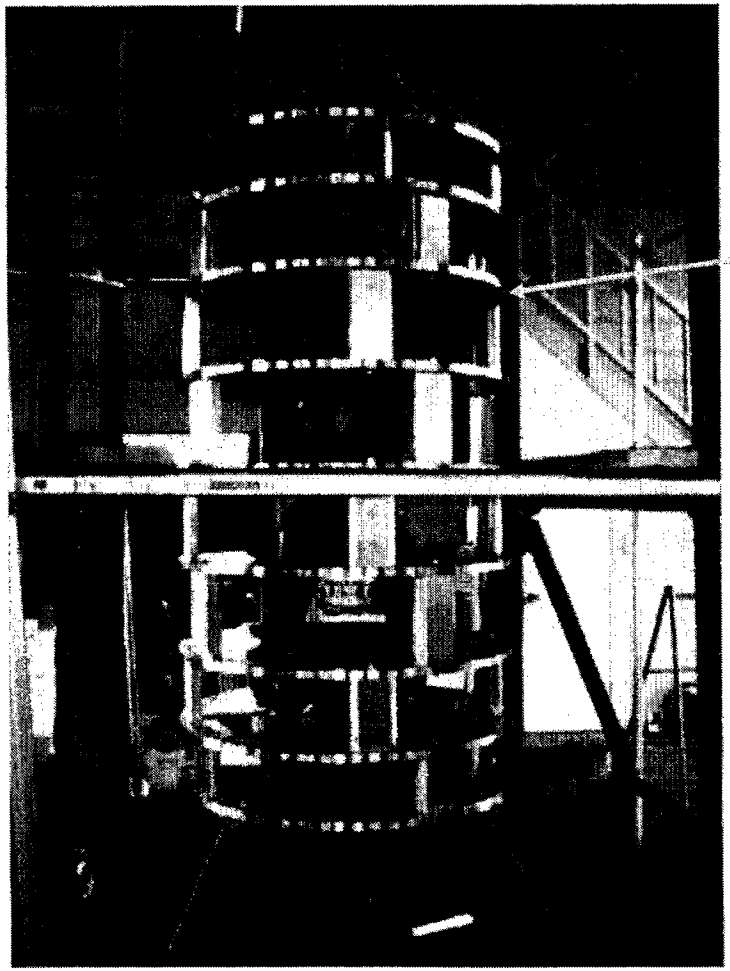
Helical snake coil

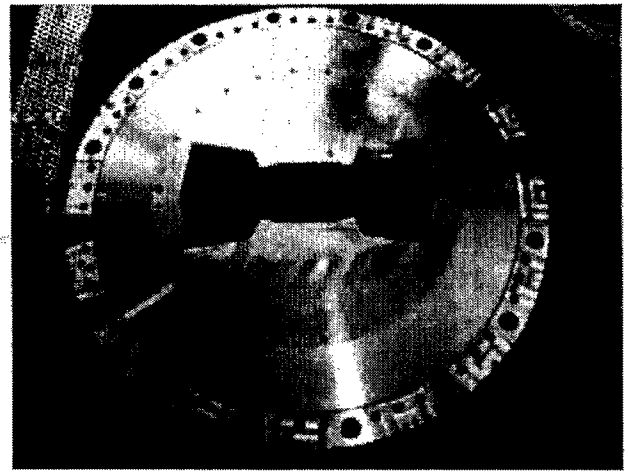




Fabrication

Alimentation of coil position



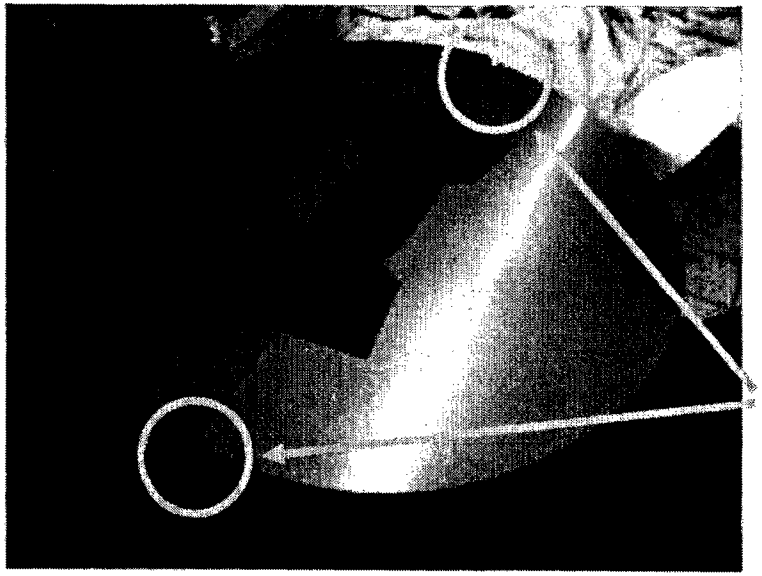


Reference plate is for alimentation of coil and pressing lamination steels.

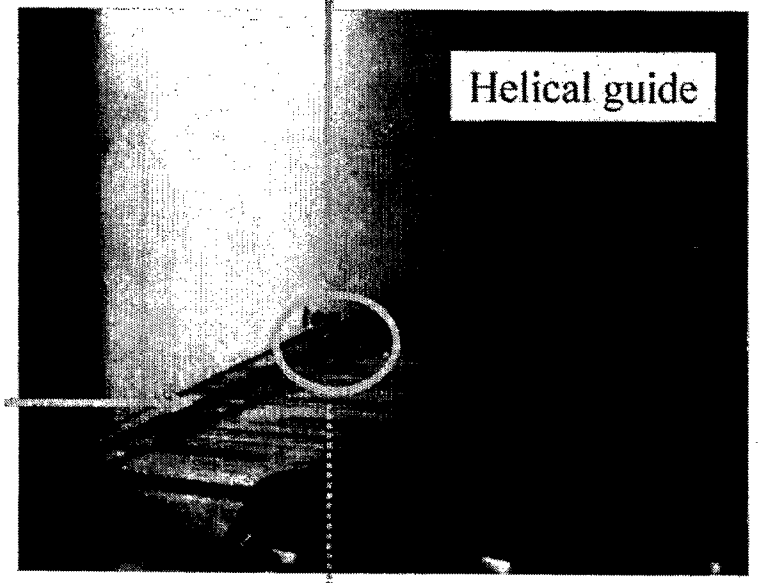
captured snake in the yoke

Fabrication

Lamination steels



Notch

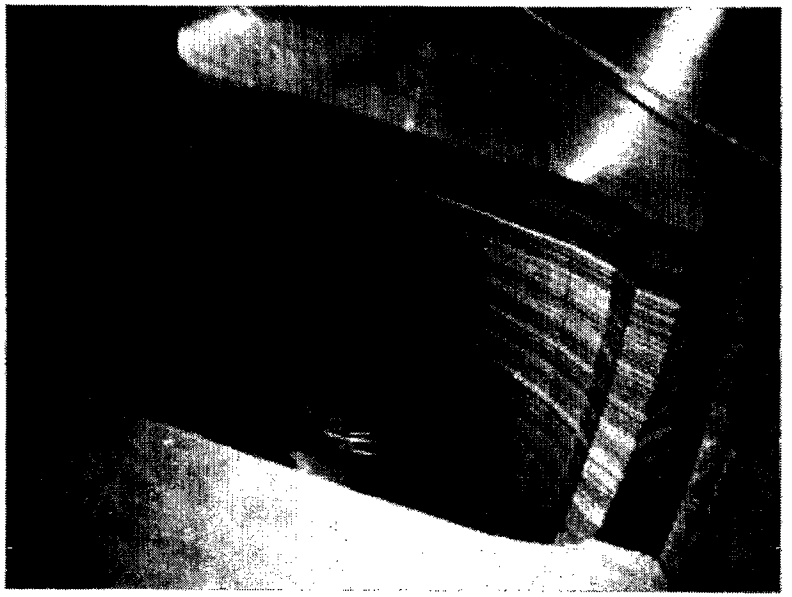


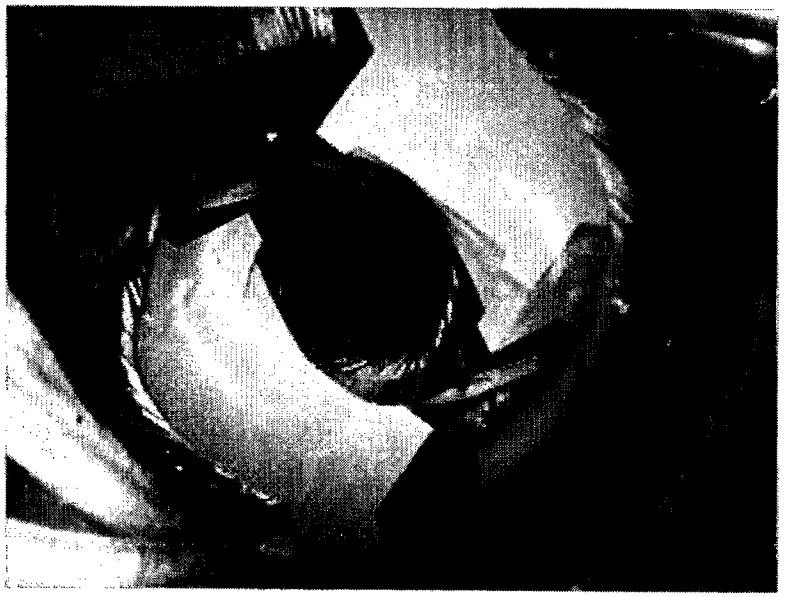
Transition point

Slow ⟷ Rapid

Fabrication

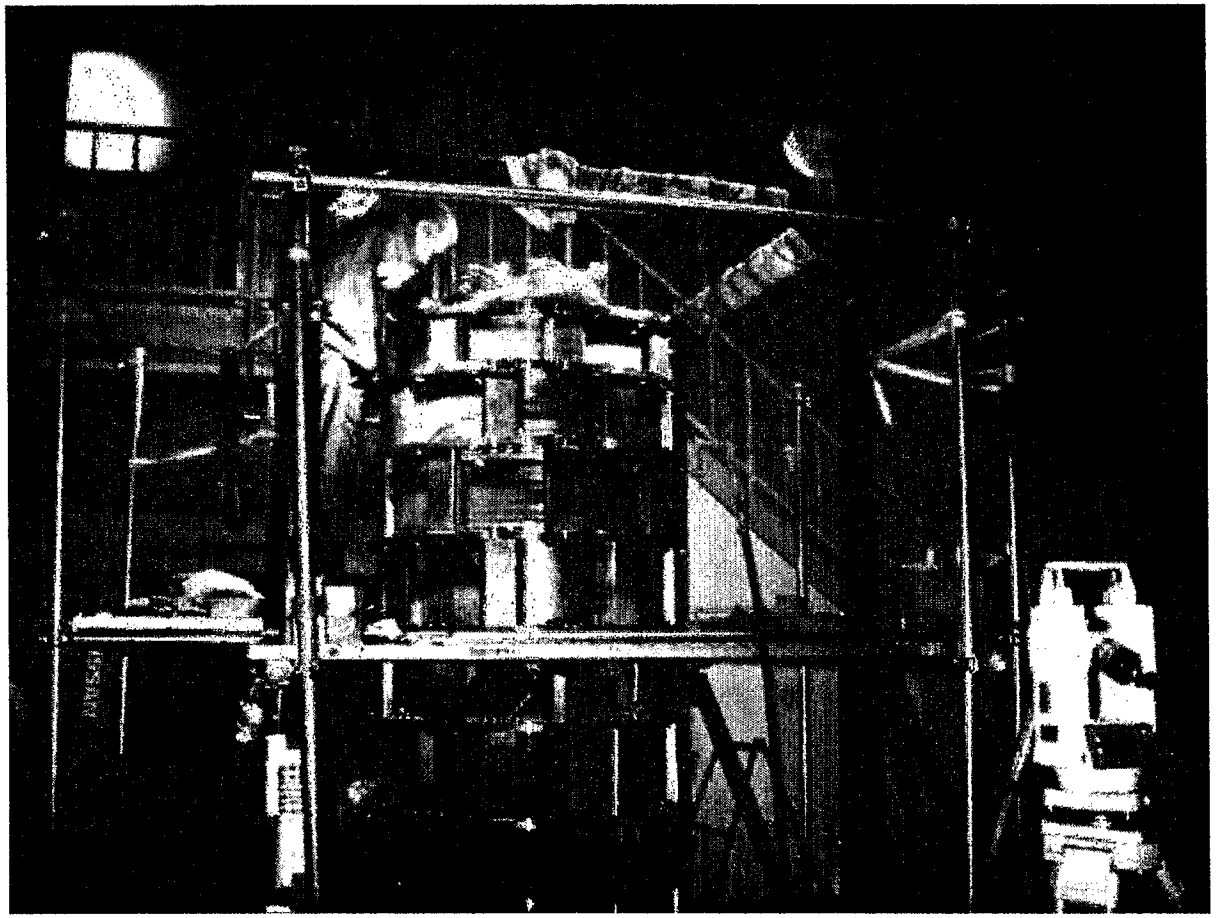
Helical pole face





Fabrication

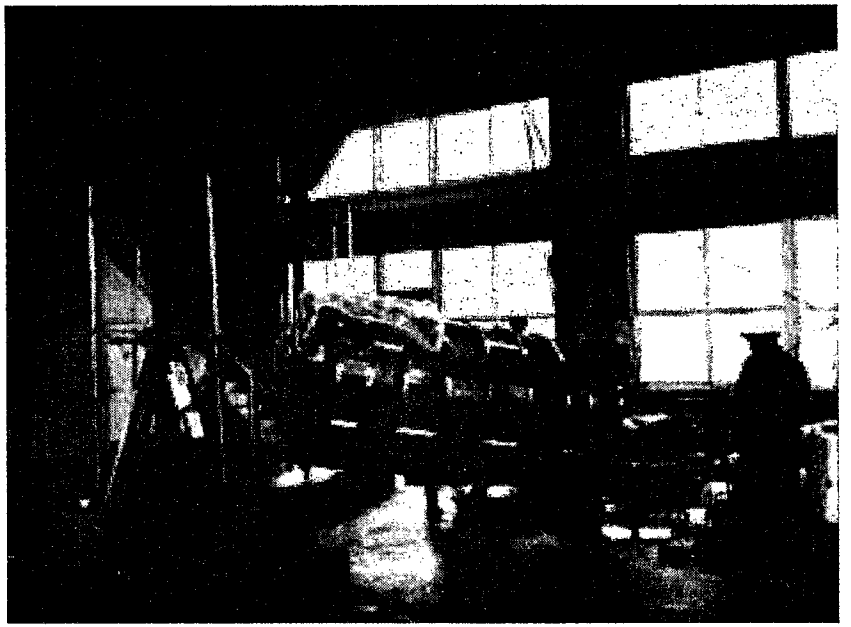
Under construction

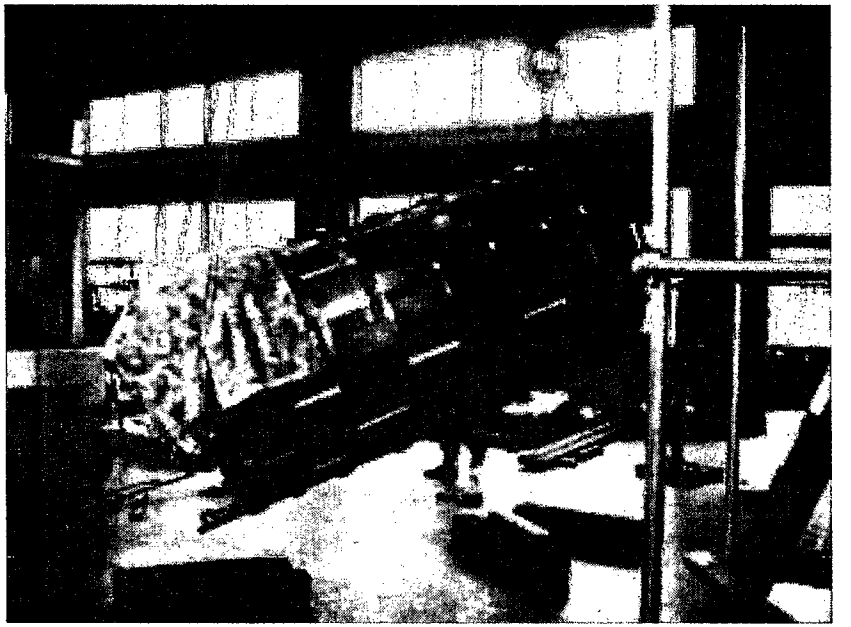


Upper side lamination is complete

Fabrication

Upside down

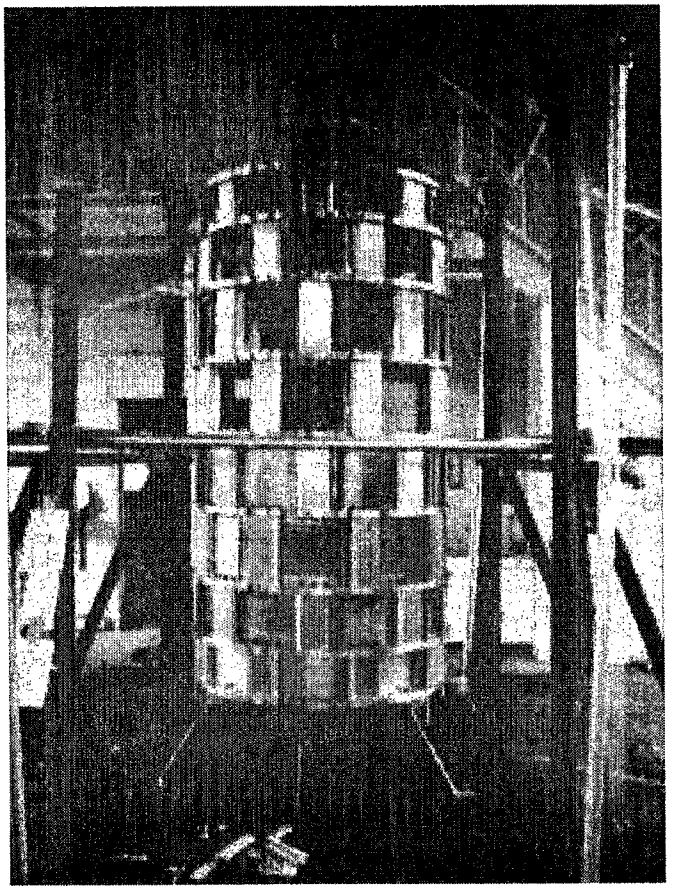




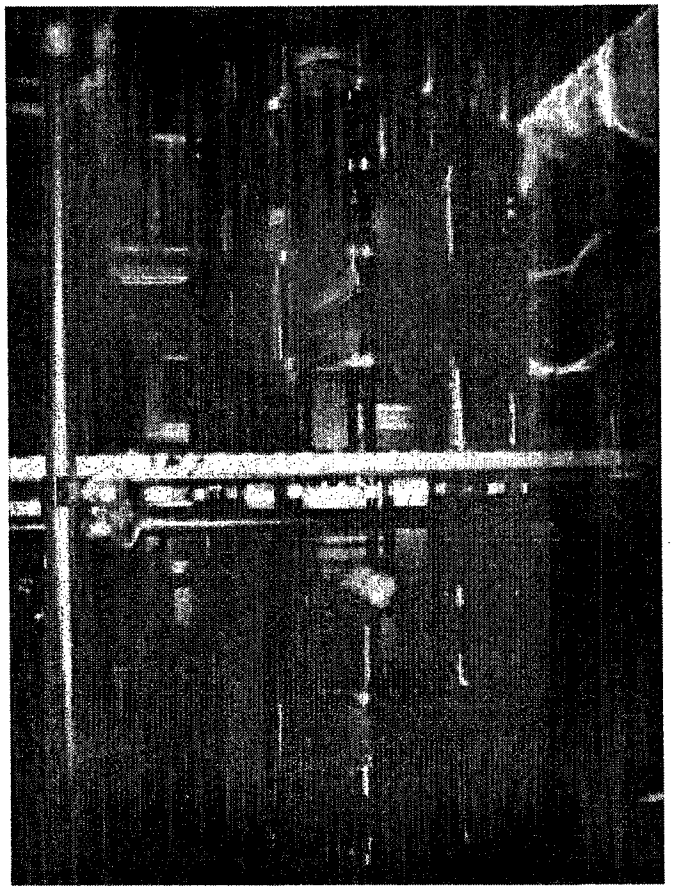
Crane track's work

Fabrication

50% and 100% lamination



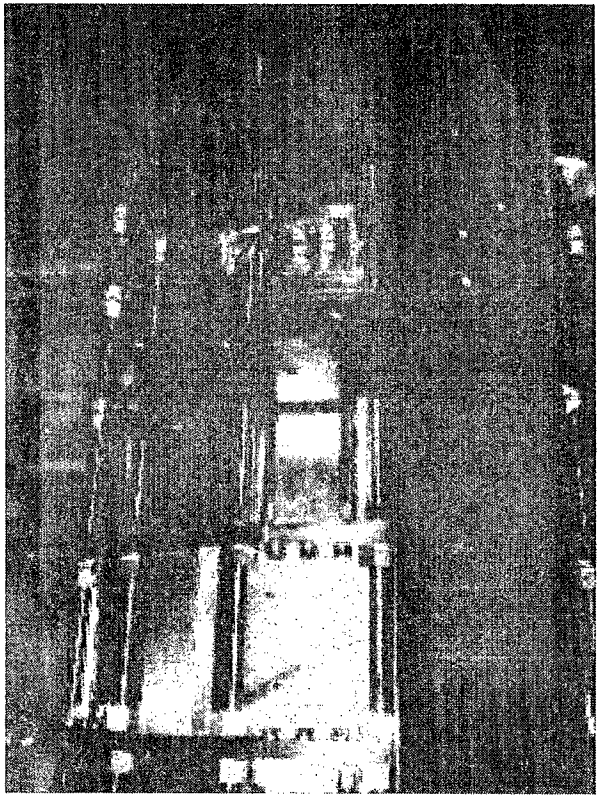
After upside down (50% laminated)

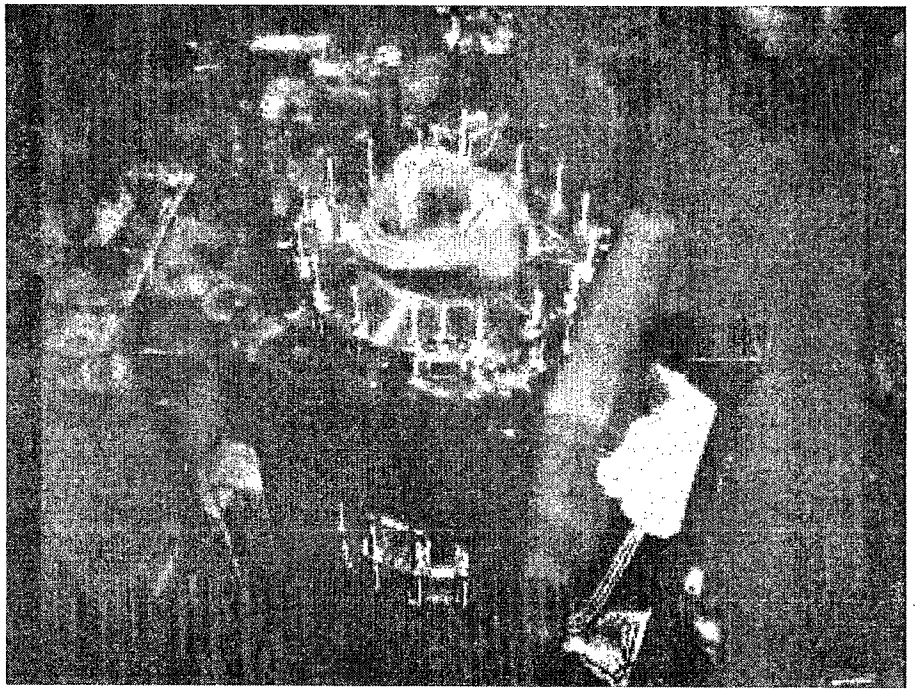


Lamination is completed

Fabrication

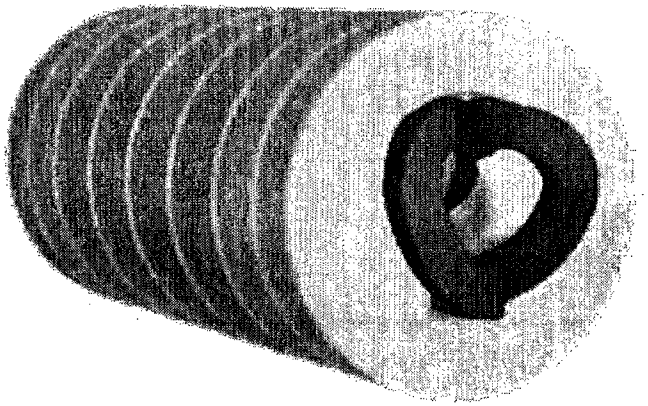
Outer base frame

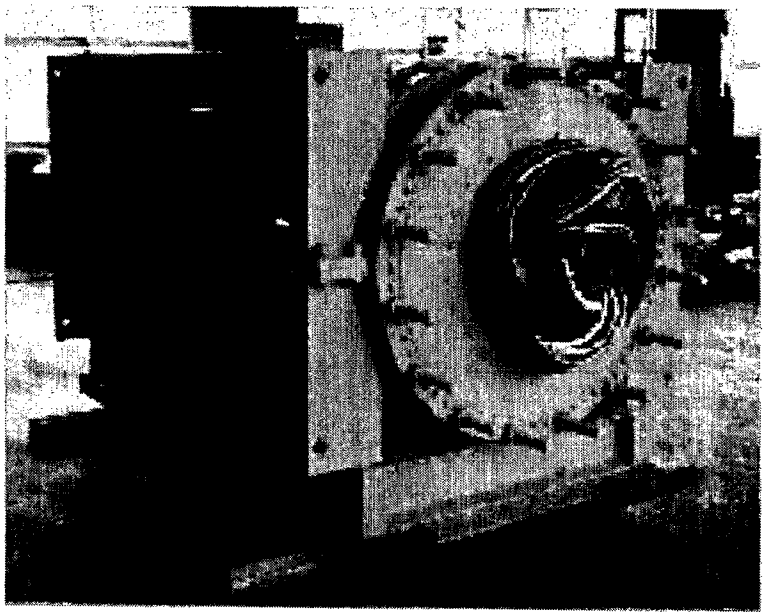




Fabrication

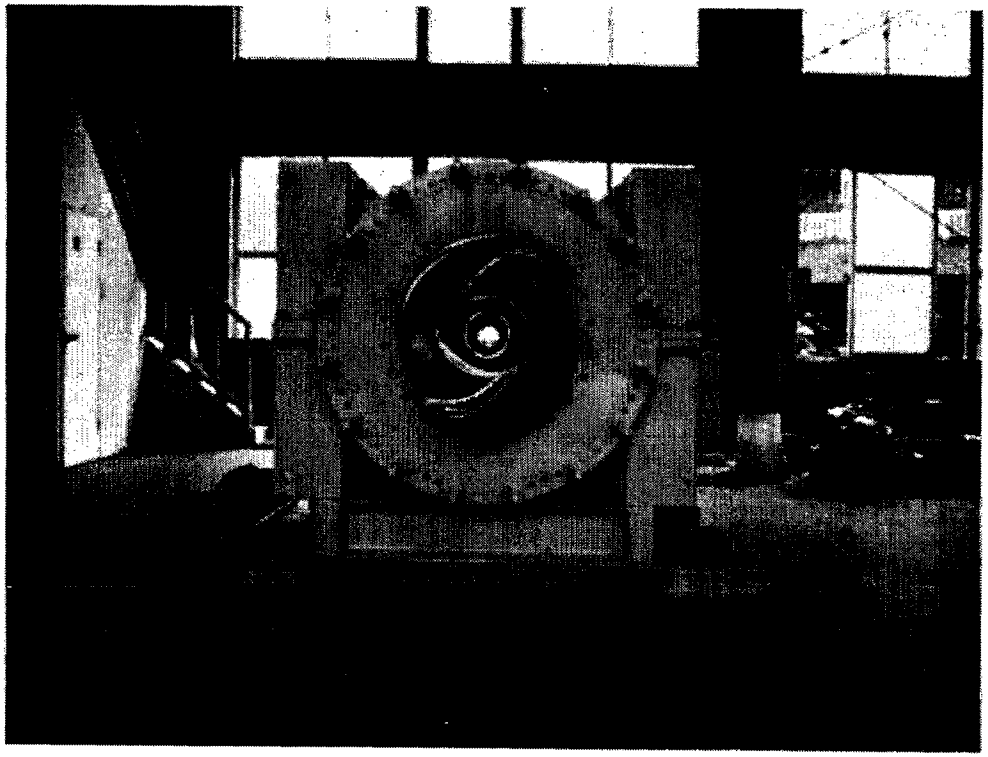
Complete the helical magnet





Fabrication

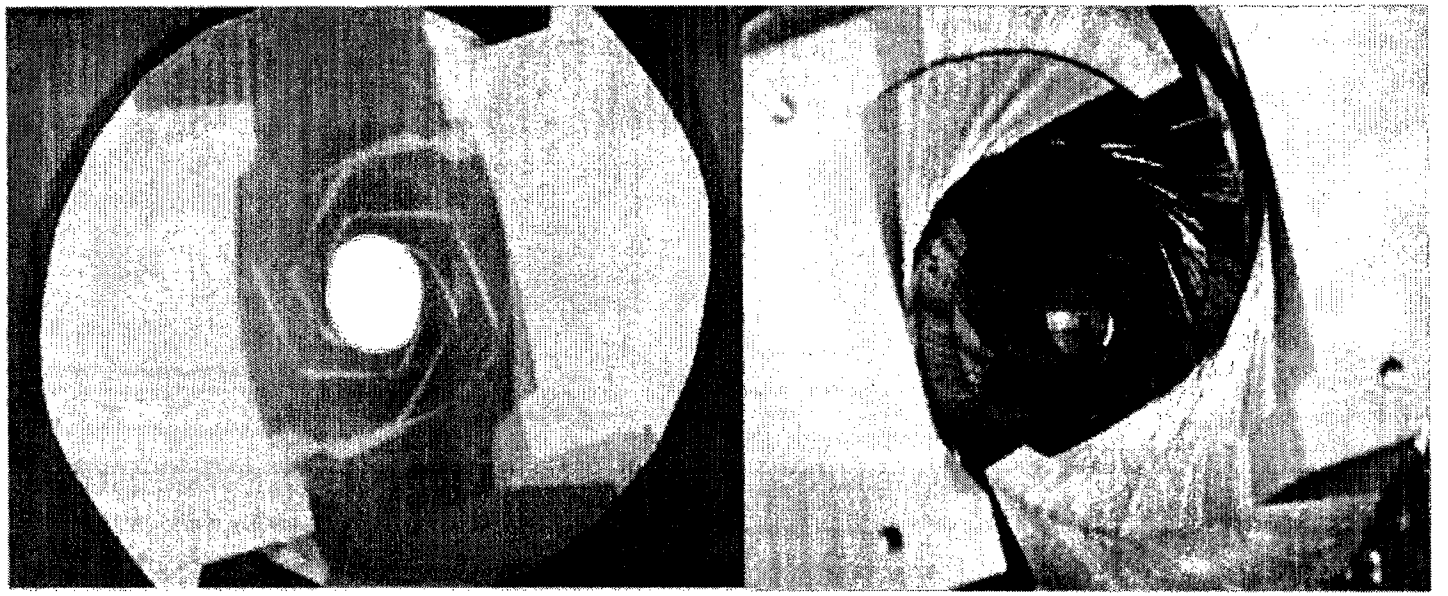
Helical magnet with pipe



148mm diameter pipe is installed.
The designed pole gap is 150mm.

Fabrication

Zoom up the helical pole face



Future plan

High order magnetic field measurement of this helical magnet will be done at magnet division.

↓

Cross checking the simulation and measurement data.

↓

Adjusting the magnetic field based on the measurement data before install to beam line.

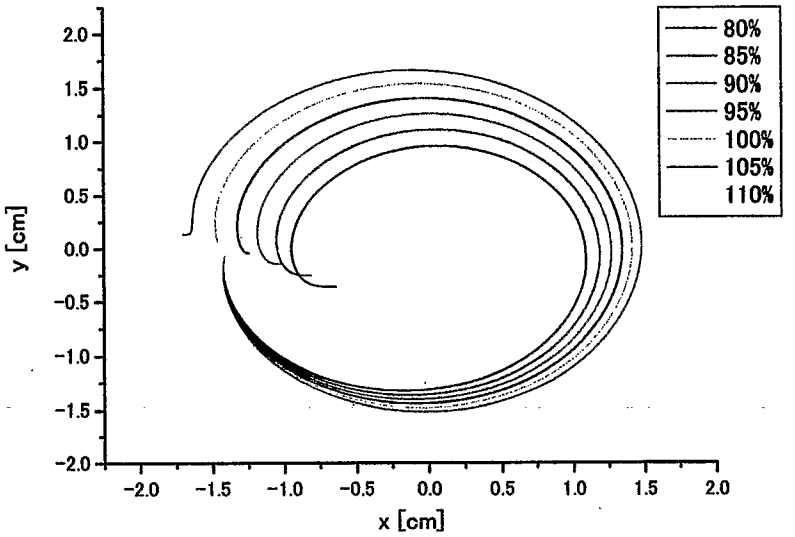
↓

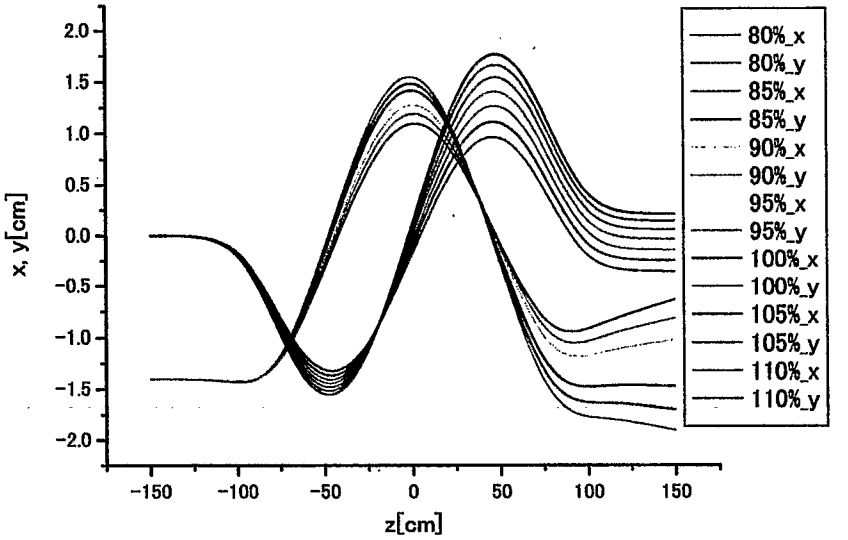
After installation, the experiment for the effect of this helical magnet will be done.

Future plan

Adjusting

Current = 80% to 110%





We can find out the good operation current point.

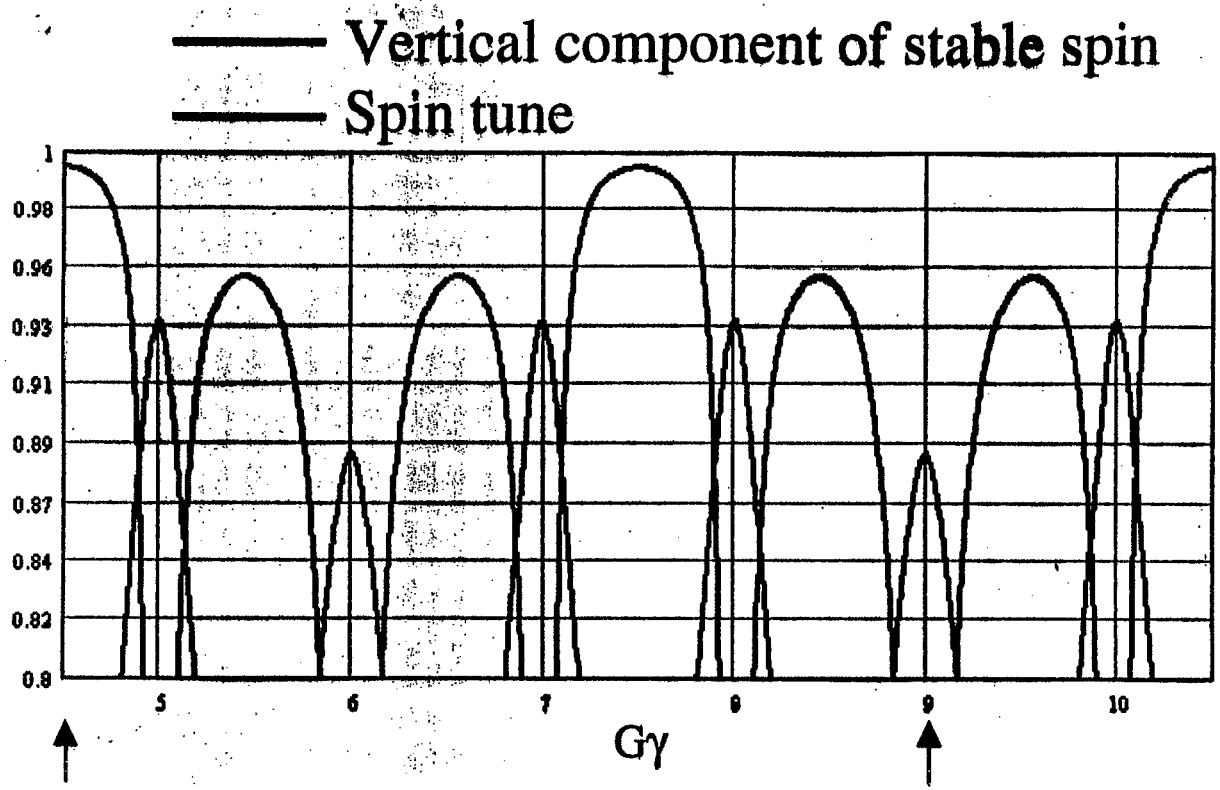
Future plan

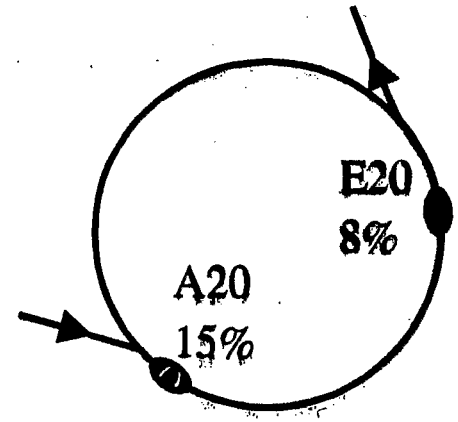
Operation pattern

Red snake	Blue snake	
On	Off	normal operation before installing the blue snake
Off	On	new operation after blue snake is set up
On	On	the pattern we can run before removing the red snake

After super conductor partial snake is completed,
we can have more combination operating pattern.

2 Partial Siberian Snakes in AGS





BROOKHAVEN
NATIONAL LABORATORY

From T. Roser

Waldo MacKay

RHIC Spin Tune Measurement & Polarization Reversal

RHIC Spin Collaboration Meeting, Nov. 18, 2003

Mei Bai, BNL, Upton, NY 11973

□ Spin tune measurement

- In resonance rotating frame, the vertical and horizontal projections of the polarization are given by

$$P_y = P\frac{\circ}{\acute{A}} \qquad P_x = P\frac{»}{\acute{A}}$$

$$\circ = \frac{(f_{drive} \square f_{spin})}{f_{rev}} \qquad » = \frac{(1 f G^1)}{4Æ}\frac{B_d L}{BÇ} \qquad \acute{A} = \sqrt{\circ^2 f »^2}$$

- Method 1: map Py as a function of the spin flipper frequency

  spin precession frequency =

  spin flipper frequency at which Py vanishes

  - This requires no new development
  - However, this is rather time consuming and is not practical for beam at store

□ Spin tune measurement

- Method 2: measure the amplitude of the coherent precession of the horizontal component. The spin tune is then given by

  - This requires a modification of the existing polarimeter so that one can measure the turn by turn horizontal component. In principle, this is achivable using CNI as well as STAR polarimeter, according to Gerry and Les.
  - However, the accuracy of this measurement highly depends on how close the driving frequency is to the intrinsic spin precession frequency. To achive an accuracy of 0.001, a ~ 1.0% error bar on Px is required assuming the total polarization is about 50% and delta is about 0.01.
  - According to Gerry and HH, a 200 sec will yield a 2% Px measurement provided the total polarization is 50%.
- Method 3: measure Py while sweeping the spin flipper frequency.

□ Polarization reversal

- F-S formula

$$P_f = P_i(2e^{\square Æ|»|^2 / 2} \square 1)$$

- Assume total n times spin flipping are performed, let η be the effciency of each spin flipping. The polarization at the end of the nth spin flipping is then $P_f = P_i \eta^n$. To achieve $P_f > 0.90$

$$½ \ldots \sqrt[n]{0.90}$$

- Say n=20, η > 0.995, with ε. $= 4.6 \times 10^{-4}$, one needs to sweep the spin flipper tune in

  0.02 in 57379 revolution turns.

□ Polarization reversal commissioning

. ***Three sets of measurements:***

- a) measure the spin flipping efficiency vs. flipper strength. The flipper
- frequency sweep range as well as the spin tune remain constant.
- b) measure the spin flipping efficiency vs. flipper frequency sweep range
- with fixed flipper strength as well as the spin tune.
- c) repeat b) with different spin tune.
- with the current snake power supplies, we are able to move the spin tune
- to 0.45 the outer current of one snake should be 94Amps and the inner
- current should be 294.54Amps. The nominal current setting for the snake
- is (inner,outer)=(326.23,100). It takes about 2 minutes to ramp the snake
- current from 326.23 to 294.54.

Status of PLL

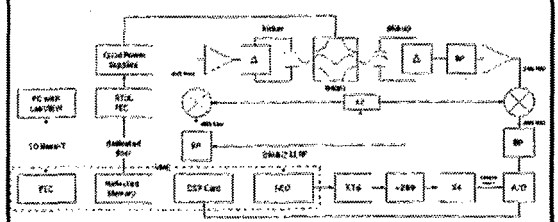
P. Cameron, BNL

for
RHIC Spin Collaboration Meeting XX
November 18, 2003
RIKEN BNL Research Center

PLL/TF Lessons Learned – in order?

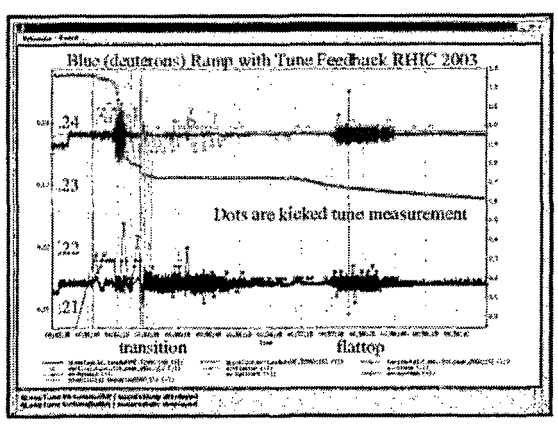
- Humility
- ***Stability and Loop Tuning - modeling***
- Signal to Noise, Dynamic Range
- Anomalous phase shifts
- Coupling
- Chromaticity control (not)

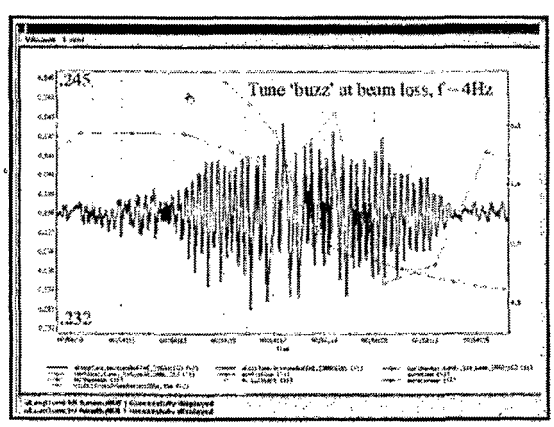
PLL/Tune Feedback Block Diagram

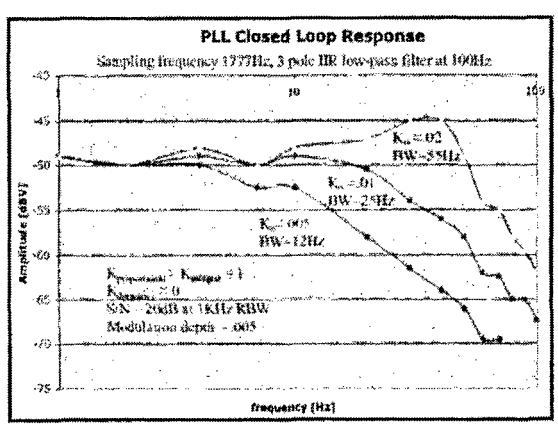


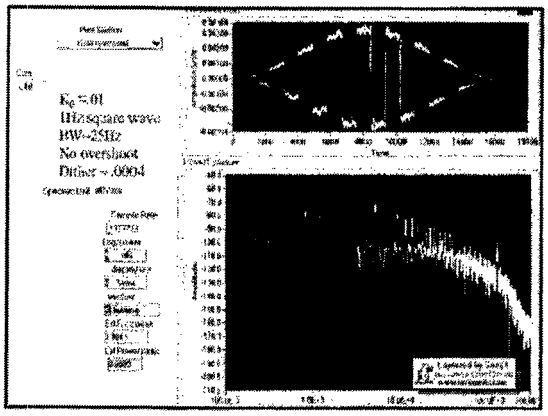
Stability

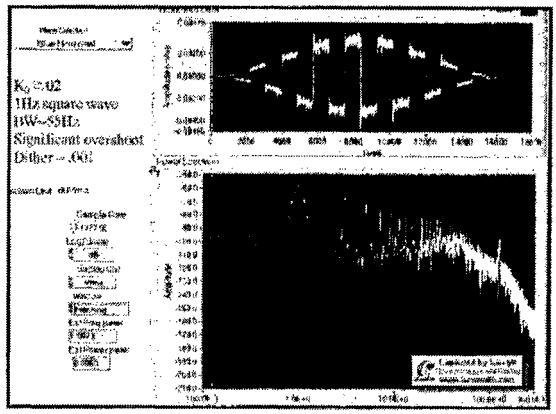
- Minimize phase shifts – two sources
  - Sampling delay – RHIC 2003 was 4 degrees/Hz with 90Hz update rate
  - BW limiting filter – RHIC 2003 was 40Hz IIR, lots of phase shift (100 degrees at 20Hz)
  - Result was loop was twitchy, always close to instability, efforts went into derivative, auto loop gain,…
- For RHIC 2004 (many thanks to Carl Schultheiss)
  - Increasing sampling rate to ~ 1777Hz
  - Move filter to ~100Hz, switchable digital filters
  - Result is ~x10 improvement in loop bandwith, gain margin,…

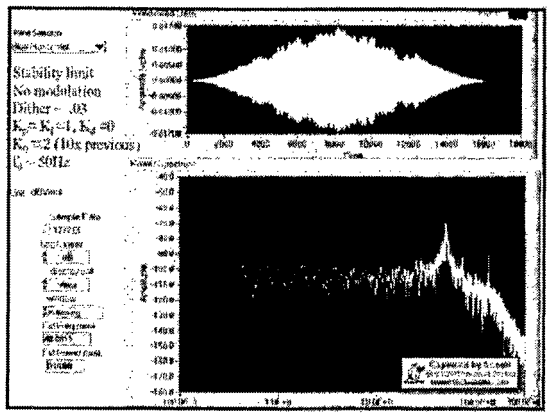




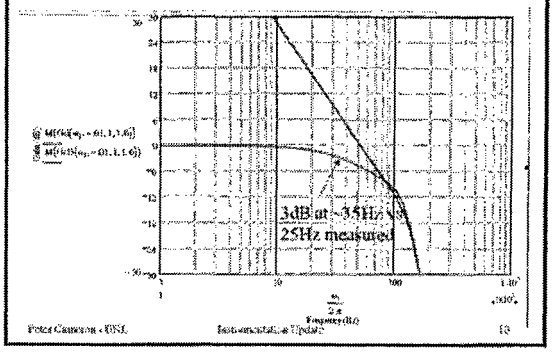






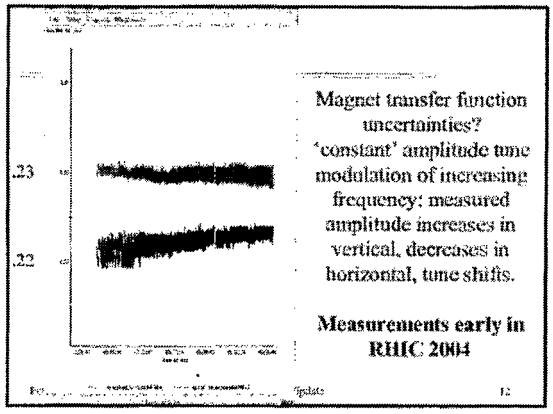


Magnitude of open and closed loop gains



Loop tuning with beam 1

- Simple tuning algorithm (if FFT not available) – apply square wave at 10% of desired BW
  - Adjust $K_{proportional}$ for ~10% overshoot
  - Raise $K_{derivative}$ until critically damped
  - Raise $K_{integral}$ for ~15% overshoot
- **But**
  - max dither of ~.001 limits gains to regime of no overshoot?
  - Magnet system BW not sufficient?
  - Questions remain about matrix?



Magnet transfer function uncertainties?
'constant' amplitude tune modulation of increasing frequency: measured amplitude increases in vertical, decreases in horizontal, tune shifts.

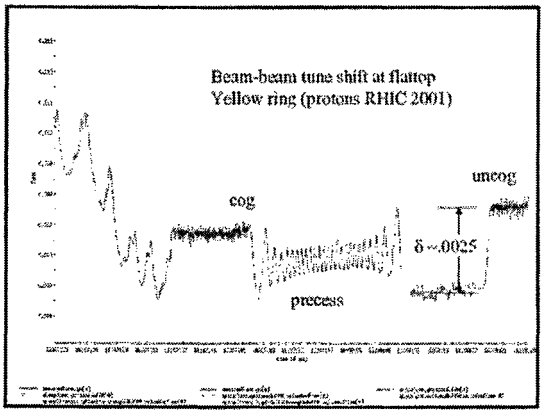
Measurements early in RHIC 2004

Loop tuning with beam 2

- We do have FFT! Apply modified Zeigler-Nichols tuning (Rasmussen - www.control.auc.dk/~hr/ad.ipt/auto.pdf)
  - Adjust $K_{proportional}$ for oscillation, measure frequency
  - Calculate $K_{derivative}$ and $K_{integral}$ from oscillation period
- **But**
  - max dither of ~.001 imposed by machine requirements again limits gains to regime of no oscillation?
  - Dither at oscillation often sufficient to cause excursions outside beam resonance (is this a problem?)
  - Experimental results are questionable

Almost random thoughts on loop tuning

- Loop BW is not an explicit function of S/N
  - Loop BW is a function of loop gain
  - Maximum loop gain is a function of phase and gain margins
  - Phase and gain margins are a function of S/N
- BTF portion of loop gain varies considerably during ramp
  - We can (and do) control signal amplitude with kicker power feedback – hopefully this corrects BTF variation of loop gain
- What's left? Tune and 'noise' fluctuations. We require sufficient gain and phase margin to accommodate tune and noise fluctuations during ramping.
- Beam has memory
  - increases effective loop gain? How do we model this?
- Magnet BW sufficient for tuning? Use beam-beam?

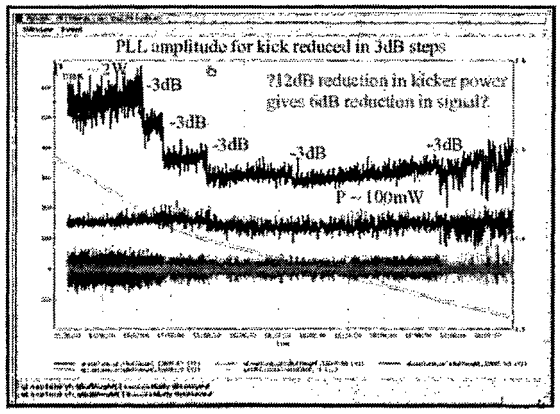


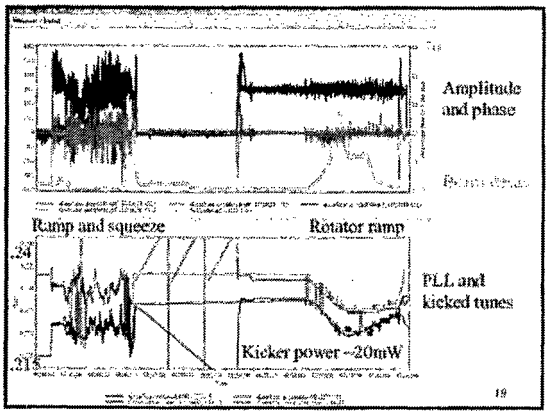
PLL Lessons Learned – in order?

- Humility
- Stability and Loop Tuning - modeling
- ***Signal to Noise***
- Anomalous phase shifts
- Coupling
- Chromaticity control (not)

Signal to Noise (need ~20dB minimum)

- Loop bandwidth (and filtering)
  - As low as possible to maximize S/N
  - As high as possible to minimize phase shift, maximize loop stability
  - minimum ~ x10 magnet system BW
- Revolution line - saturation and dynamic range
  - Moveable BPM, feedback to keep it centered
  - Better mixers
- Kick strength and emittance growth
  - Kicker power <100mW
  - Sensitive to linewidth
  - Feedback on kicker power essential





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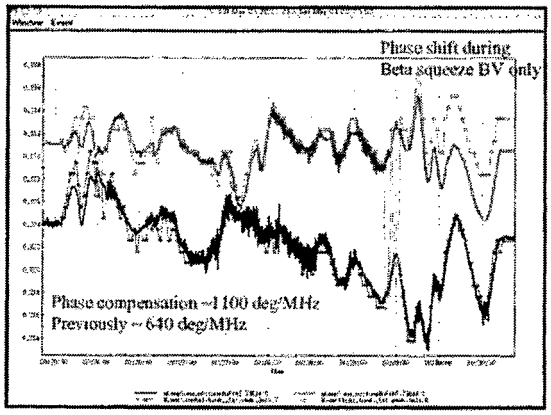

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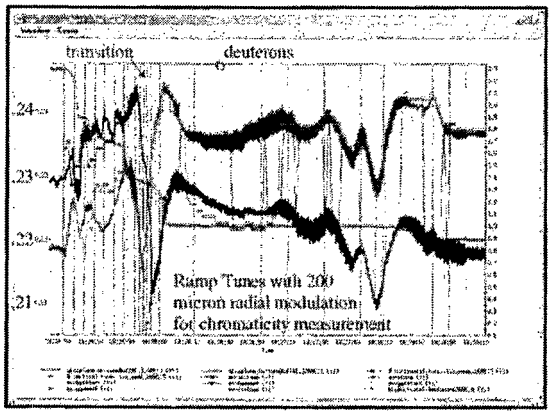
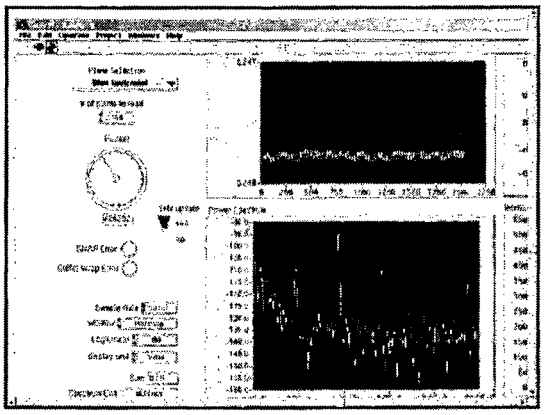
- Anomalous phase shifts
- ***Coupling***
- Chromaticity control (not)



Coupling correction on the ramp

- During tune meter kicks
- Schottky - passive
  - Far free from LFS, more difficult from HFS
  - Need GPM, include in Schottky
  - Motion control, Improved S/N
- PLL – skew quad modulation (Roser)
  - First efforts during last run's Beam Experiments
  - Small (~10-4) tune modulations give good signal
  - Supplement to Artus/BPM method when beam is kicked
  - Gives coupling when beam is not kicked



PLL Lessons Learned – in order?

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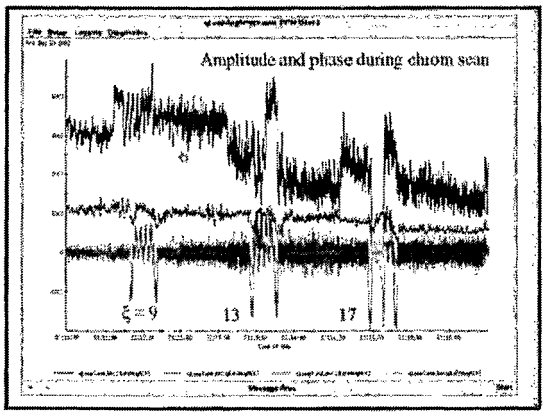
- Stability and Loop Tuning - modeling
- Signal to Noise
- Anomalous phase shifts
- Coupling
- ***Chromaticity control (not)***



Chromaticity Effect on PLL

- Conclusion from the chromaticity study is that PLL tune measurement can cope with a large range of chromaticity
- Chromaticity control is not a primary issue for PLL tune measurement and tune feedback
- Chromaticity control is an issue primarily in the usual operational sense

Conclusions

- Not obvious that much more can be done to improve S/N with the present approach (superconducting pickup?)
- Remaining improvements will be in loop tuning
- Testing on resonator
  - refine PID
  - improve model (include beam memory? How?)
  - open-loop measurements
- Startup - single ring, single bunch; then six bunches
  - tune PID (on background first, then modulate magnets) – one and six bunches
  - close magnet loop and modulate – six bunches
- Startup - both rings, six bunches
  - Use beam-beam for fast efficient tuning?
- Warm and Fuzzy? Not yet; still in a new realm
- Feedforward?

AGS Polarization
Comments from the 2003 Run

L. Ahrens, BNL

for
RHIC Spin Collaboration Meeting XX
November 18, 2003
RIKEN BNL Research Center

AGS Polarization – Comments from the 2003 Run
18Nov03 Ahrens

1) The "Gauss Clock" timing framework seems adequate.

AC dipole timing scans give polarization dependence close to expections.

Magnetic "flat tops" at correct Gγ. No tuning of the intermediate porches necessary. If Woody's sharp polarization loss spikes are at (.3 and .7) on 46.5 porch then our position is nearly perfect. Fig 1

However calibration measurements no so robust during the run. (gold work)

2) Intensity dependence of measured polarization in AGS (?) and the poor polarization over the last shift of the run – effects not yet cleanly understood.

Plot of some (Pol vs Int) from the last two weeks of the run. Fig 2

3) AC Dipole behavior and associated beam behavior.

Deterioration (over the run) of the beam coherent motion during the dipole pulse. That this structure was getting "worse" was not particularly obvious and does not particularly correlate with polarization loss. But it may be important. We need to quantify the structure and pay attention to it. Figs 3 & 4

The (magnet-power supply) system for the AC dipole was not healthy. Will be better next time.

4) Up-the-Ramp measurement clearly showed no polarization loss as the beam passed through the Gγ=48-νy resonance region, where a 10 % loss is expected. Mystery!

The measurement looks good. Can our machine and model differ enough to explain this? Fig 5

Maybe we can make some measurements of the AGS beta function around the machine using the response of the beam position monitors to dipole orbit distortions.

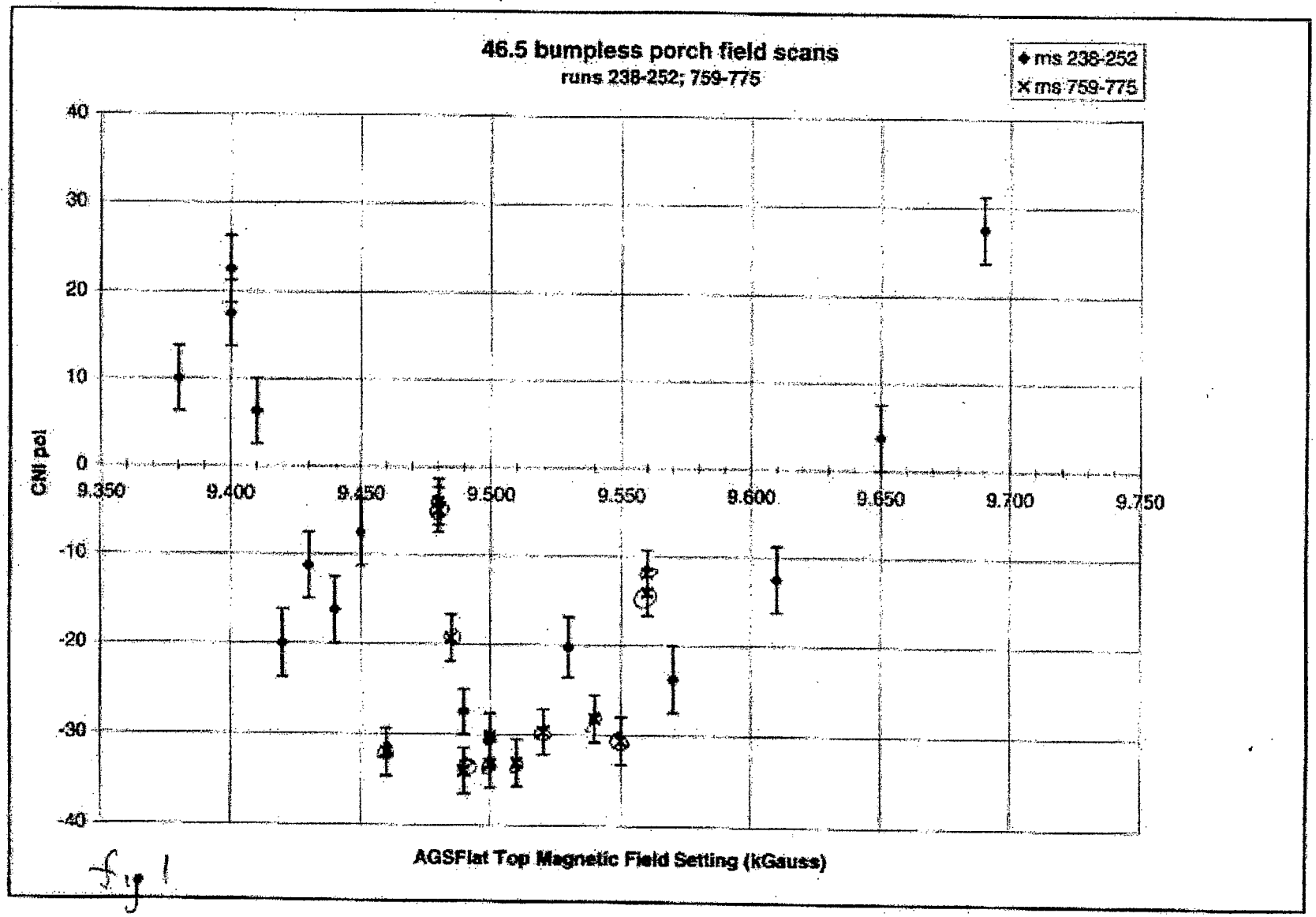

46.5 bumpless porch field scans
runs 238-252; 759-775
ms 238-252
ms 759-775
CNI pol
40
30
20
10
0
-10
-20
-30
-40
9.350
9.400
9.450
9.500
9.550
9.600
9.650
9.700
9.750
AGSFlat Top Magnetic Field Setting (kGauss)

fig 1

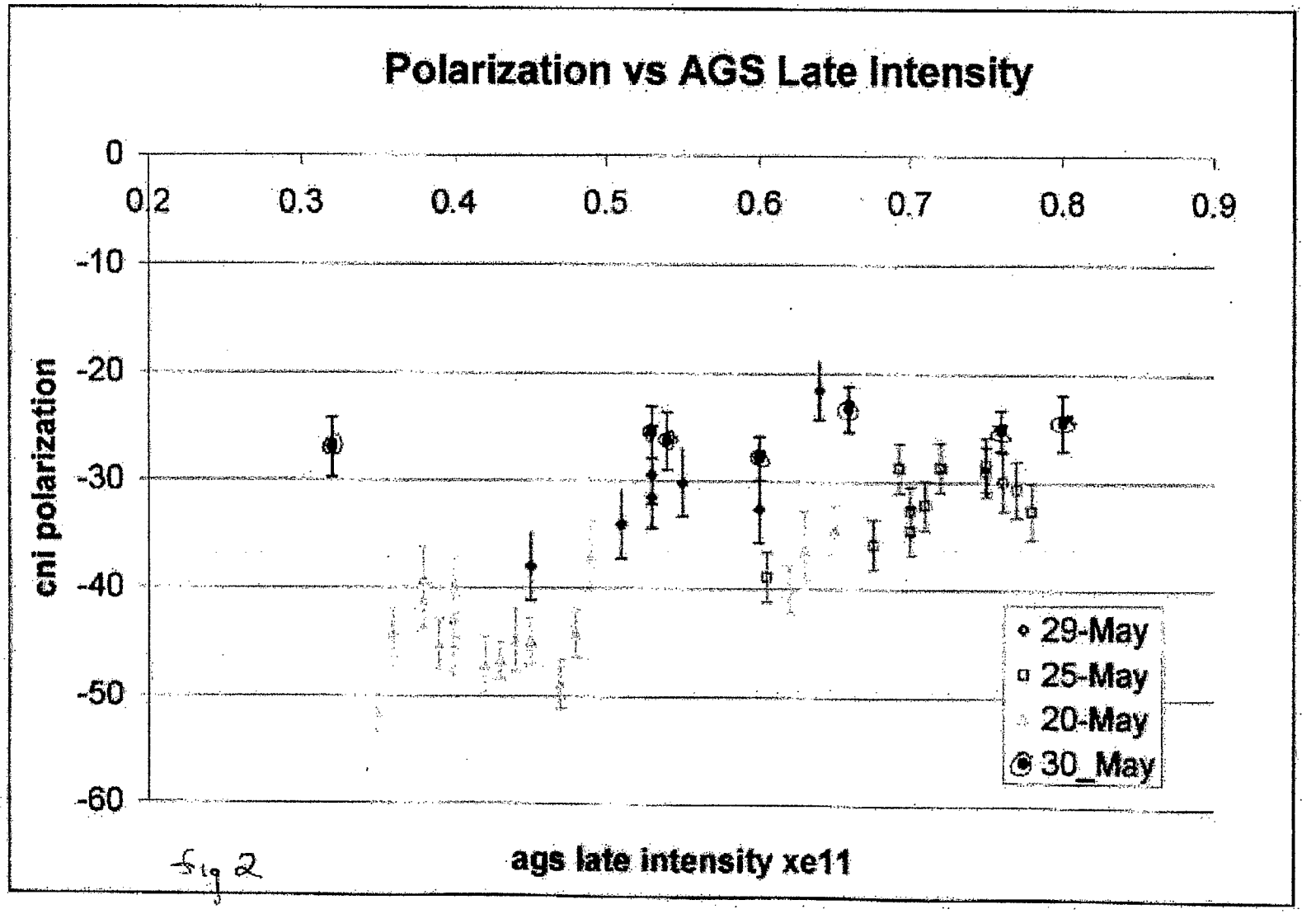

Polarization vs AGS Late Intensity
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
-10
-20
-30
-40
-50
-60
cni polarization
ags late intensity xe11
29-May
25-May
20-May
30_May

Fig 2

21 March 03

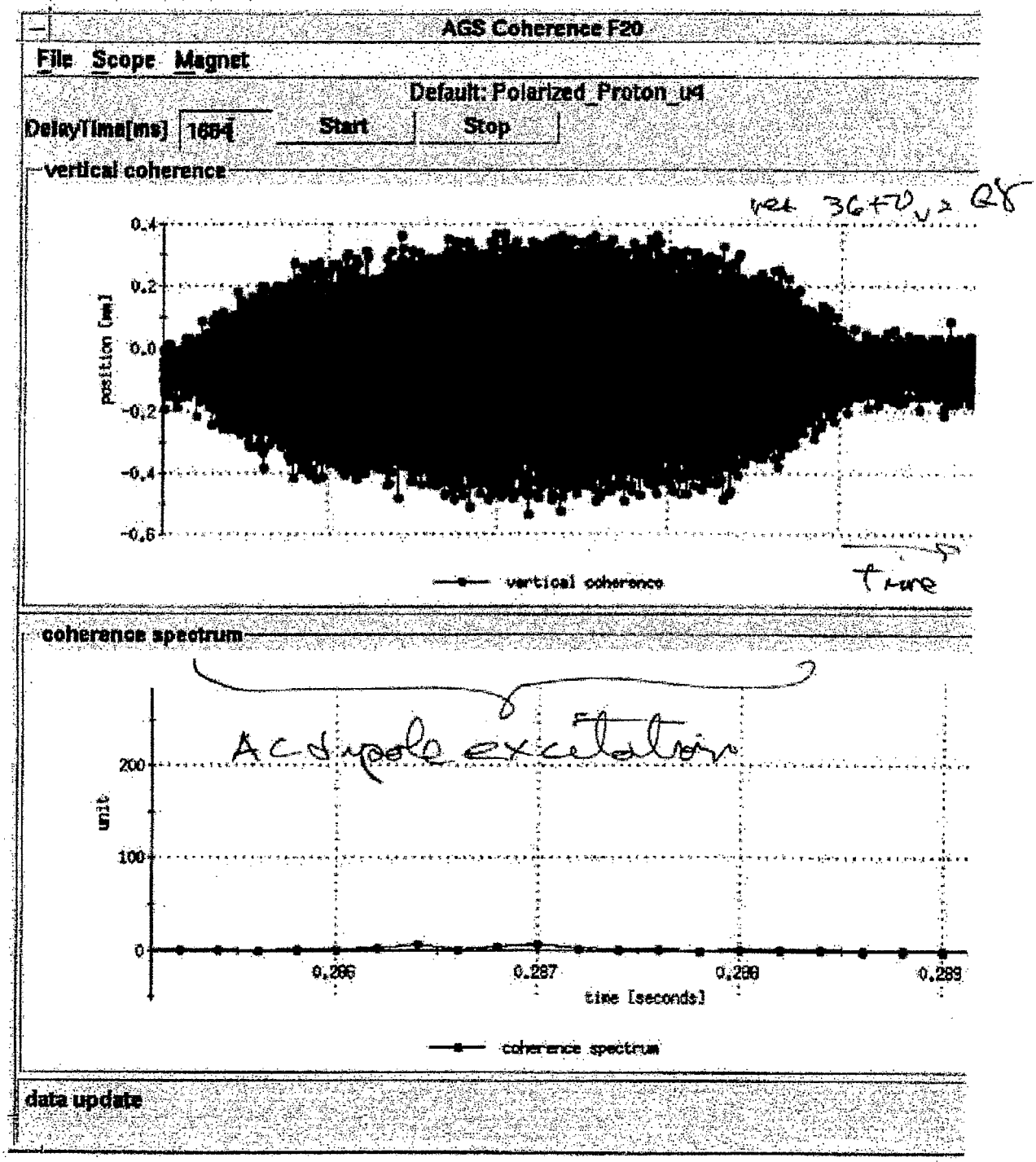
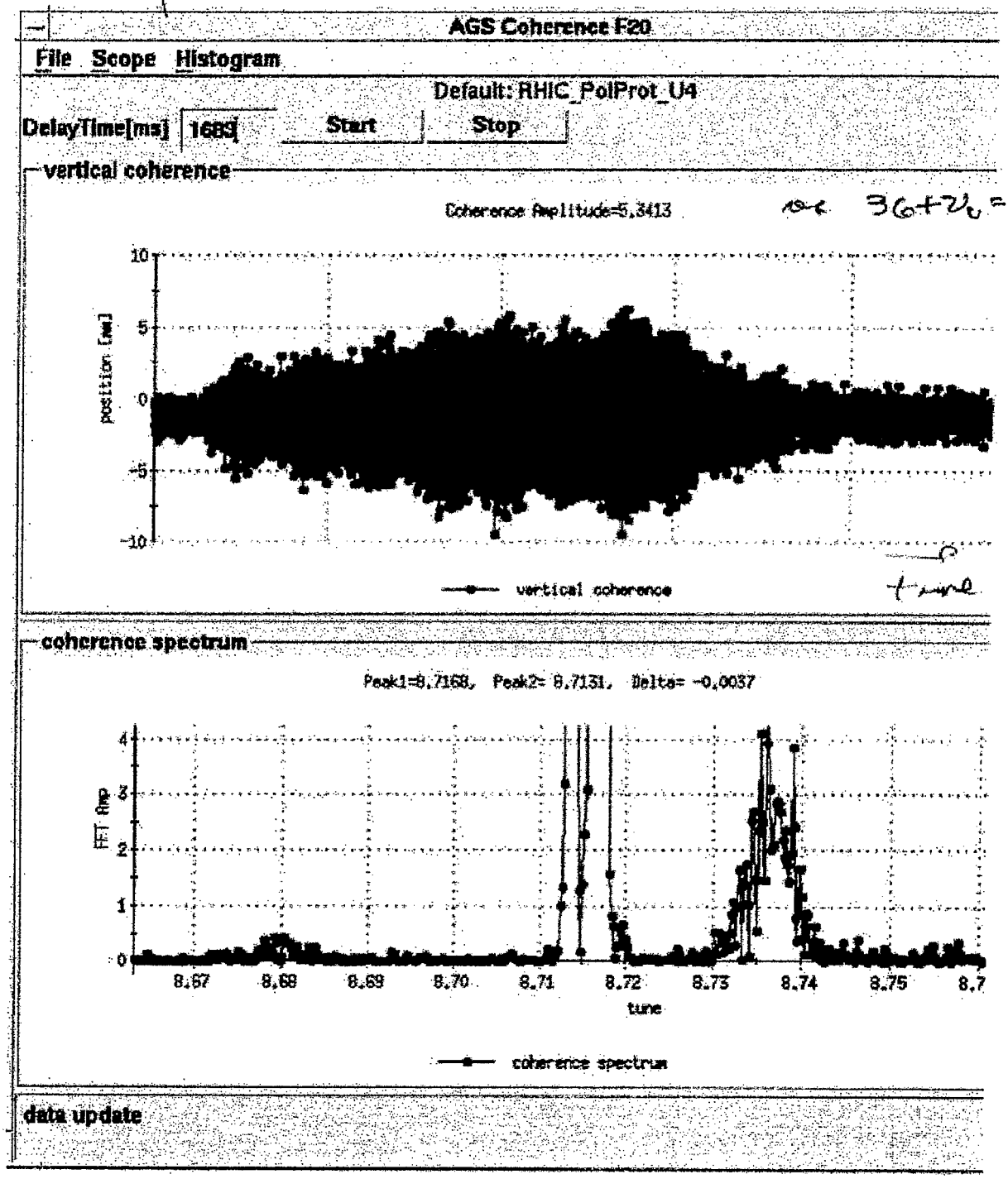


fig 3 (early)

mid-May '03



$3\sigma + 2\nu_c = \sigma\delta$

time

figure 4 (late in run)

http://www.cadops.bnl.gov/cgi-bin/machlog.pl?nb=rhic_pp_fy03&action=view&page=-6909 11/17/03

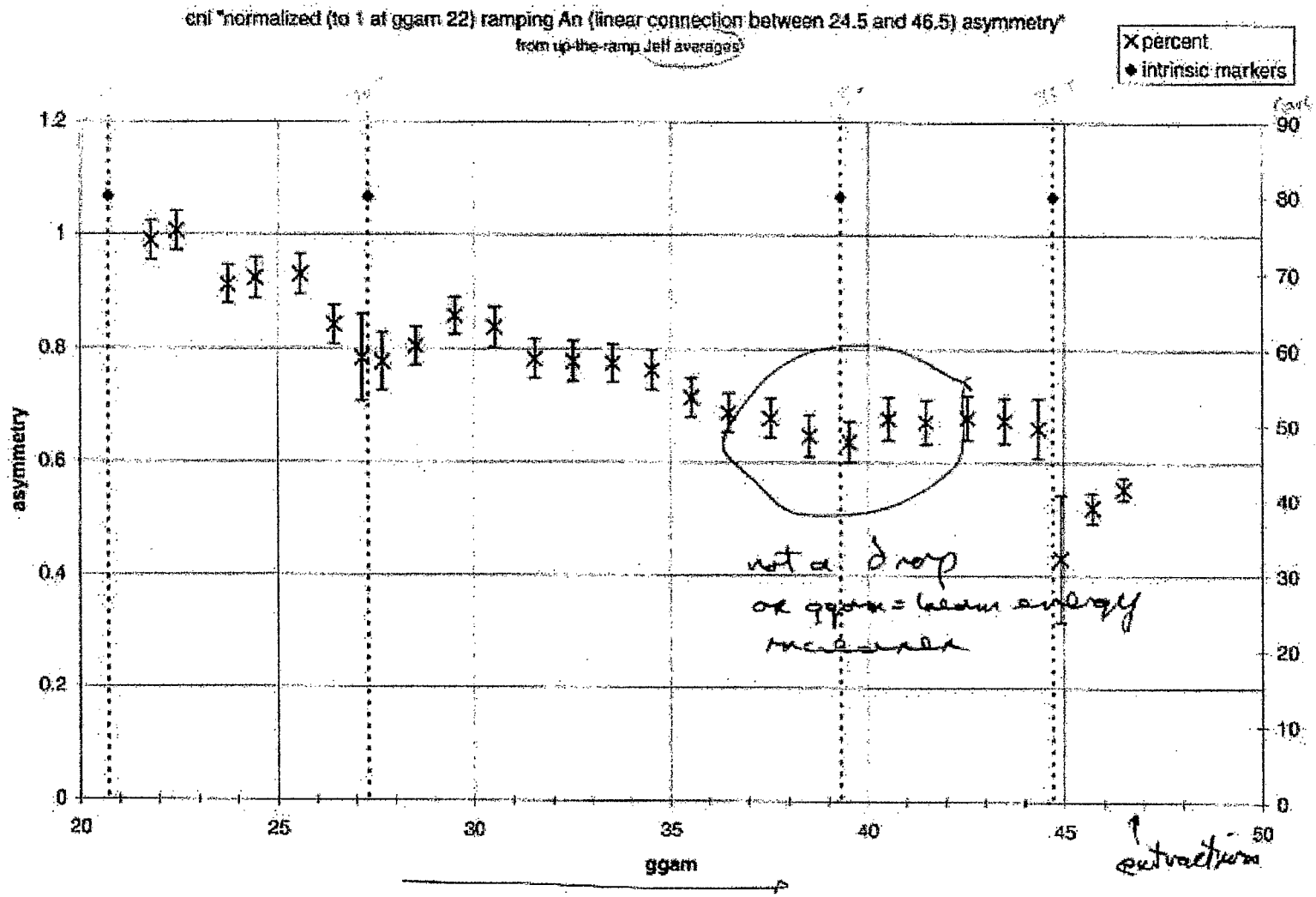


Fig 5

up the ramp

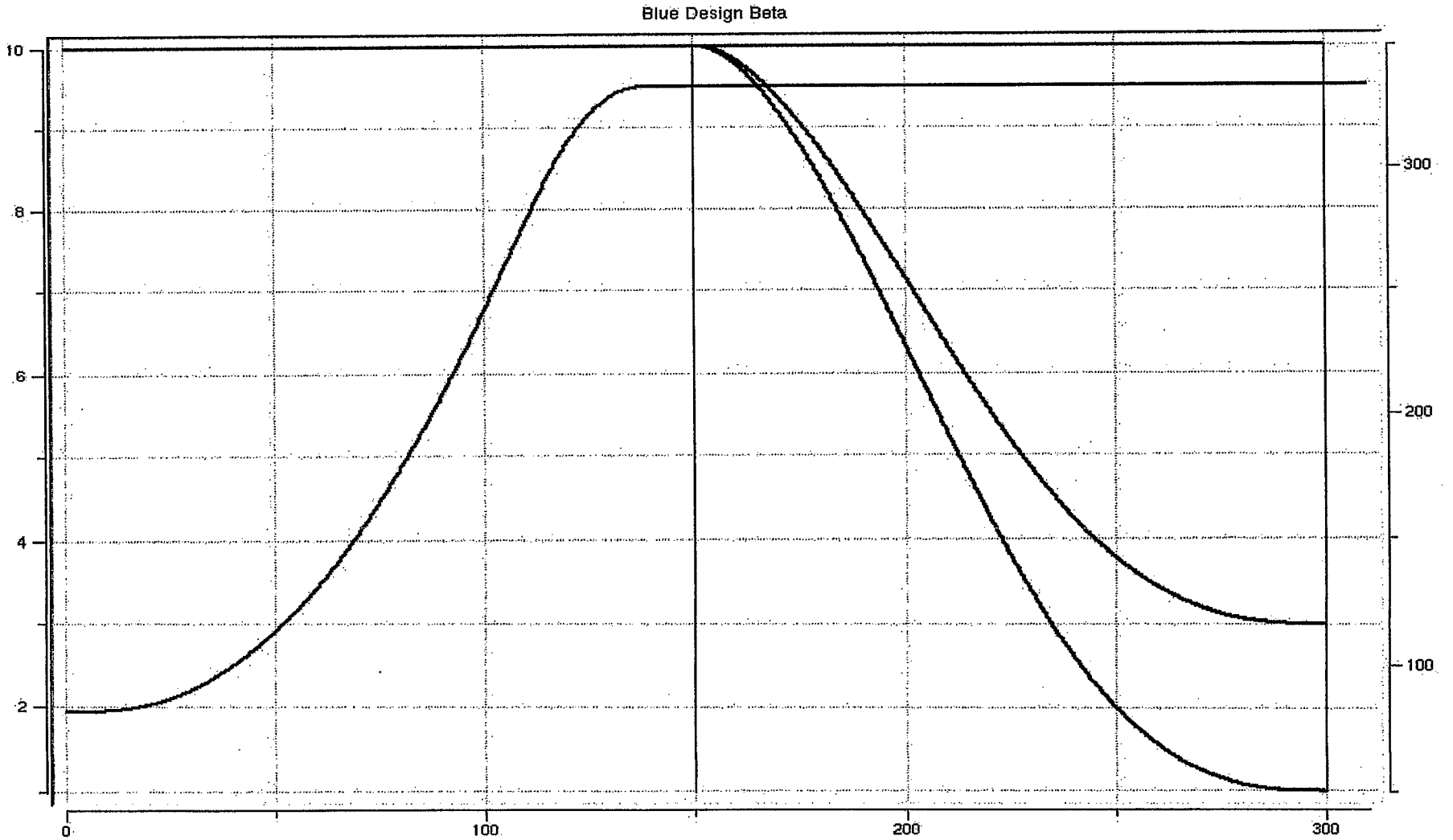
Polarized Proton Ramps

Johannes van Zeijts
CAD/AP

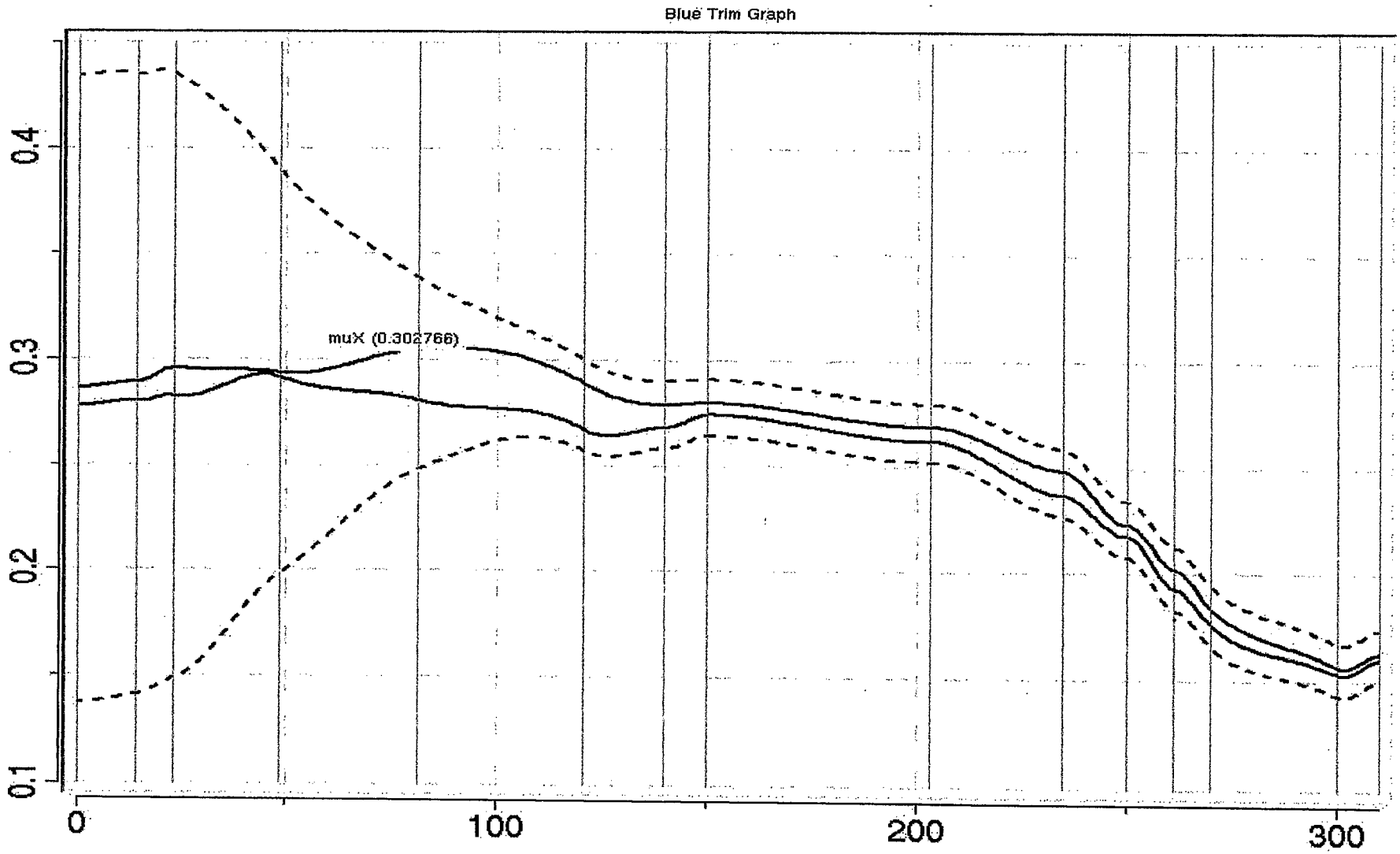
Outline

- FY03 ramp as designed
- FY03 ramp optics analyzed
- FY04 proton ramp issues

FY03 Ramp Design



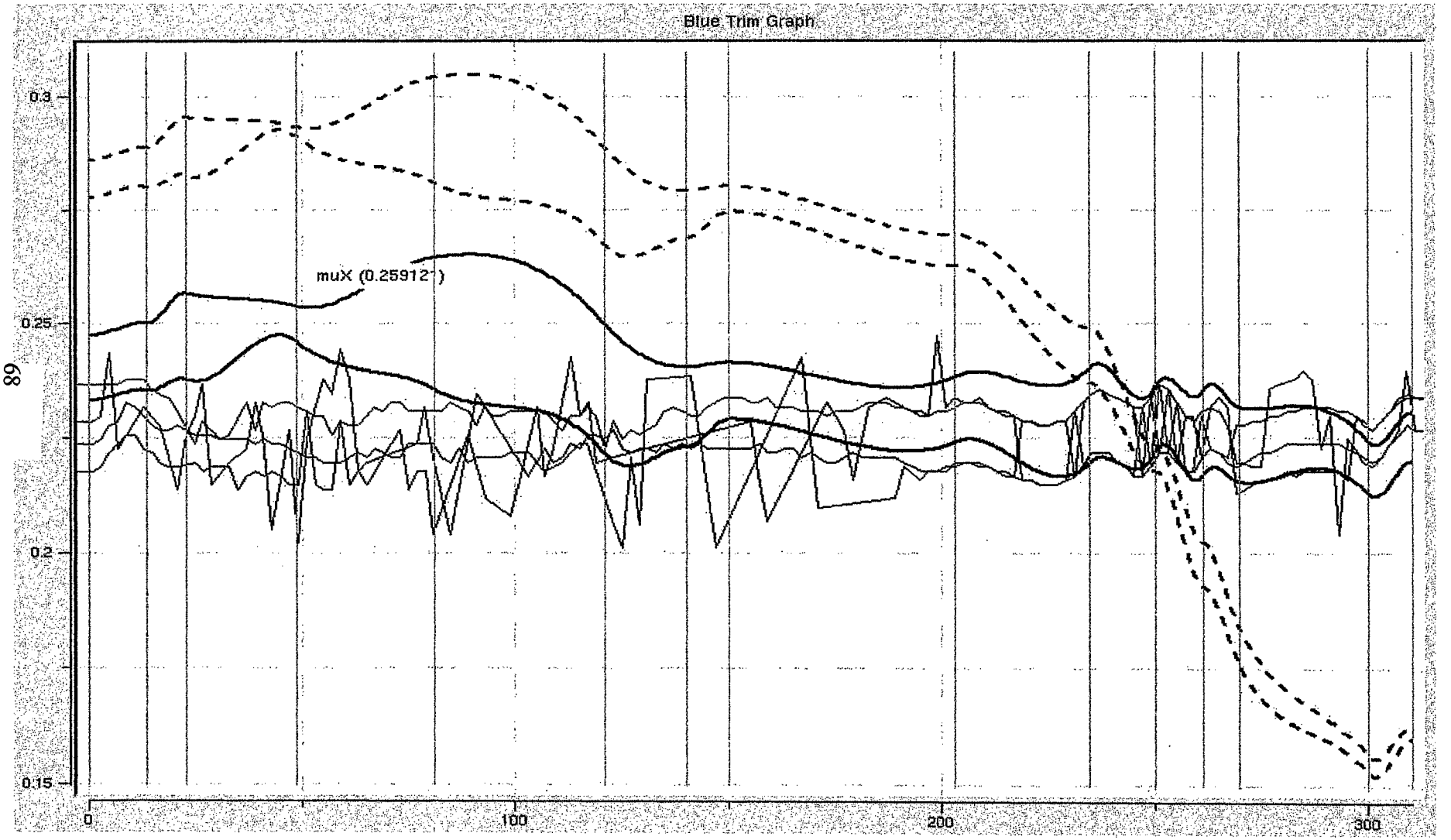
FY03 model tunes- part I



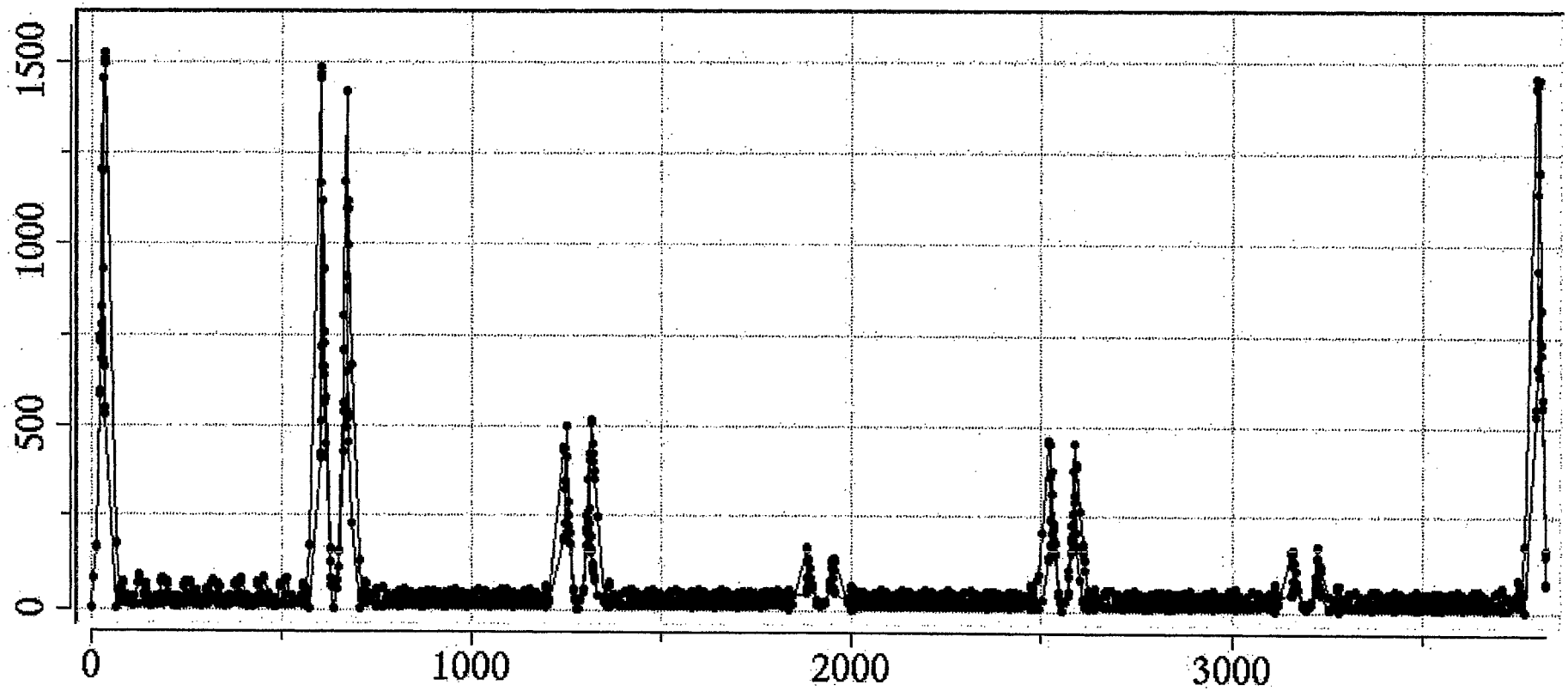
Quadrupole Transfer Functions

- 13cm quadrupoles: Q 1/2/3
  - dT/T = 0.0028
- 8cm quadrupoles
  - dT/T = -0.0026

FY03 model tunes – part B



Lattice Functions at Store



Beta* at Store

- Not quite as designed:
  - STAR 1m -> 0.93/0.86 (B) , 1.23/0.91 (Y)
  - Phenix 1m -> 1.22/0.89 (B), 1.41/0.91 (Y)
  - Phobos 3m -> 2.96/2.51 (B), 2.30/2.51 (Y)
  - Brahms 3m-> 2.81/3,33 (B), 3.06/3.62 (Y)
- Effect on Luminosity
  - 6/8 = 1.12, observed ratio = 1.14
  - 8/10 = 2.36, observed ratio = 2.3

Proton Ramp Issues

- 'Regular' ramp issues
  - Minus transition
- Add path length changes from snake/rotaters
- With new TF knowledge (to be confirmed..)
  - Can just squeeze on ramp
- How do we want to handle the rotators?
  - Too much time wasted (20 min.) at store
  - Always on at full field?

Conclusion

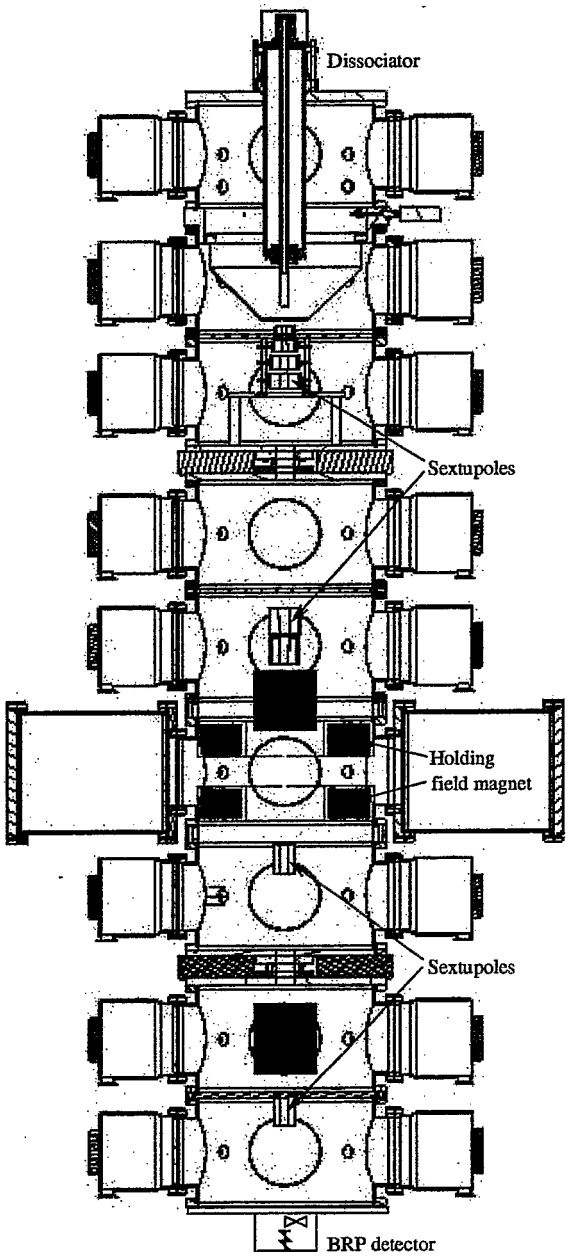
- FY03 pp ramp very useful for AP analysis

Update on the H-Jet

1. High frequency transitions installed and tested.
2. Holding field magnet powered up.
3. Running under PLC control.
4. Modifications to the IR completed.
5. Moved the jet to the IR.
6. Water cooling system completed.
7. Jet systems running in the IR.
8. Started to monitor the jet through the VME crate.
9. Results of the Safety Review.
10. Next steps.

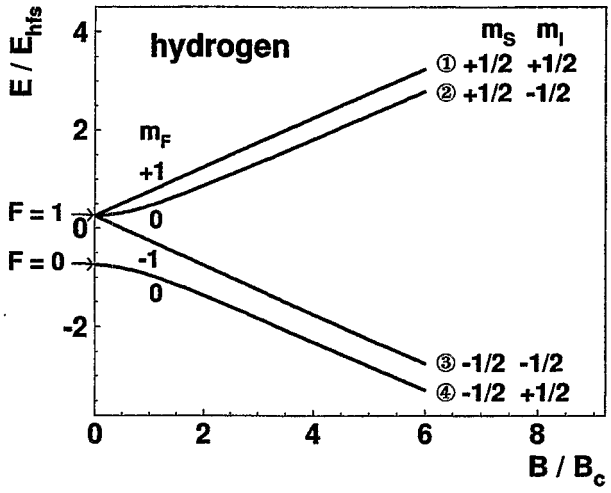
Alexander Nass, Brookhaven National Laboratory 17. November 2003

The Jet


Dissociator
Sextupoles
Holding
field magnet
Sextupoles
BRP detector

Achieving polarized atoms in the Jet

Hyperfine structure of hydrogen in an external magnetic field.



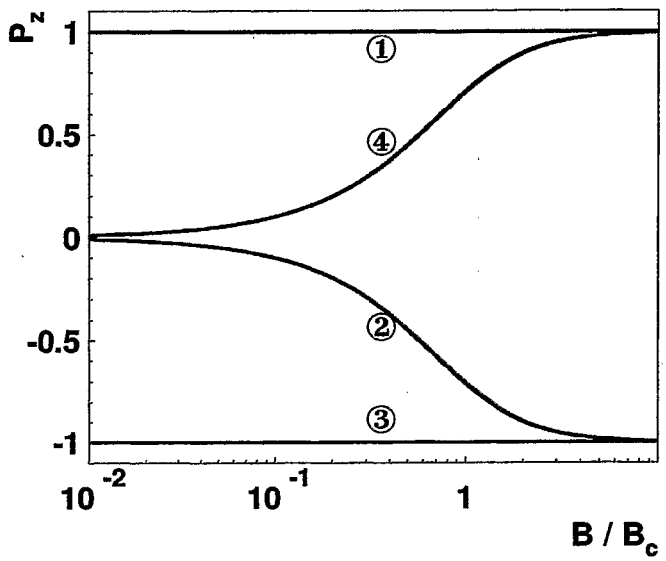
$$
\begin{aligned}
|1\rangle &= |+\frac{1}{2},+\frac{1}{2}\rangle \\
|2\rangle &= \cos\theta|+\frac{1}{2},-\frac{1}{2}\rangle \\
&+ \sin\theta|-\frac{1}{2},+\frac{1}{2}\rangle \\
|3\rangle &= |-\frac{1}{2},-\frac{1}{2}\rangle \\
|4\rangle &= \cos\theta|-\frac{1}{2},+\frac{1}{2}\rangle \\
&- \sin\theta|+\frac{1}{2},-\frac{1}{2}\rangle
\end{aligned}
$$

with $\theta = \frac{1}{2}\arctan\frac{B_c}{B}$

$B_c = 0.507$ kGauss

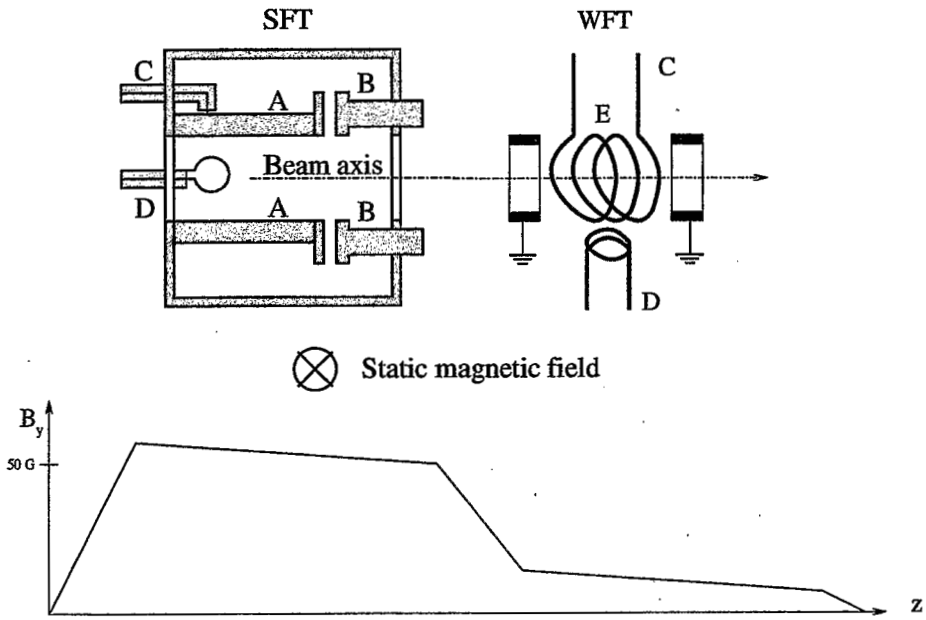
Achieving polarized atoms in the Jet

Calculation of the nuclear polarization:
$P_z = n_1 - n_3 + (n_4 - n_2)\cos 2\theta$



- Focussing atoms with electron spin $+\frac{1}{2}$ into the target region while defocussing atoms with electron spin $-\frac{1}{2}$ by 2 sets of sextupole magnets using the Stern-Gerlach effect
- Exchange of occupation numbers of states $|1\rangle$ and $|3\rangle$ ($|2\rangle$ and $|4\rangle$) with the WFT (SFT) to obtain a negative (positive) nuclear polarization.
- $\Rightarrow$ 95% (96%) maximal polarization at 1kGauss (1.2 kGauss) holding field.

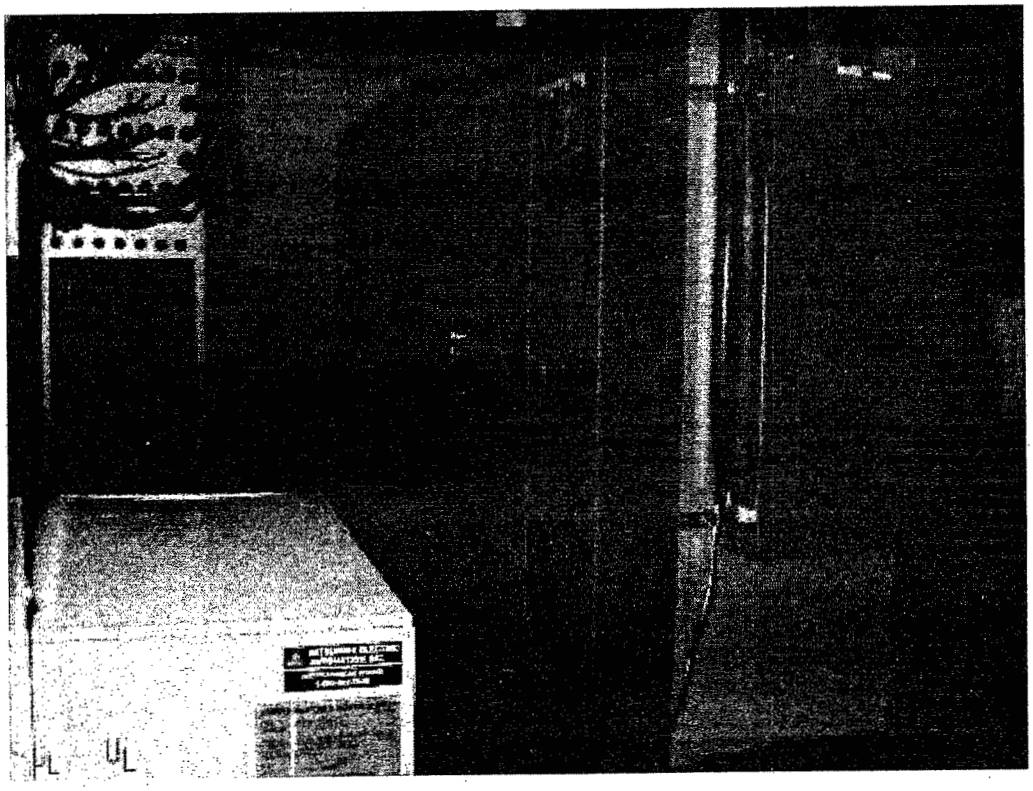
High frequency transitions and holding field magnet



- High frequency transitions installed in a shielding box to reduce z-field in the transition region.
- Installed water cooling to remove the heat from the coils.
- Measured efficiencies of all transitions to be $> 99.5\%$.
- Installed 2 beam blockers to remove states $|3\rangle$ and $|4\rangle$ and molecules completely from the BRP beam.
- Main holding field magnet powered up without problems. No polarization losses due to non adiabatic conditions of the field.
- $\Rightarrow > 94.5\,\%$ ($95.5\,\%$) polarization at 1kGauss (1.2 kGauss) field.

PLC control

- Setup of a PLC system to completely interlock the Jet.
- Hardware now protected in case of failures (power, water, comp. air ...).
- PLC can be monitored and controlled by a PC.
- Additional interlocks for power supplies of holding field magnet, HFT coils and HFT RF (temperature, cooling water, vacuum).
- Readout of vacuum gauges, water flow meters, valve and forpump status via ADC of PLC.



Modifications and moving to the IR

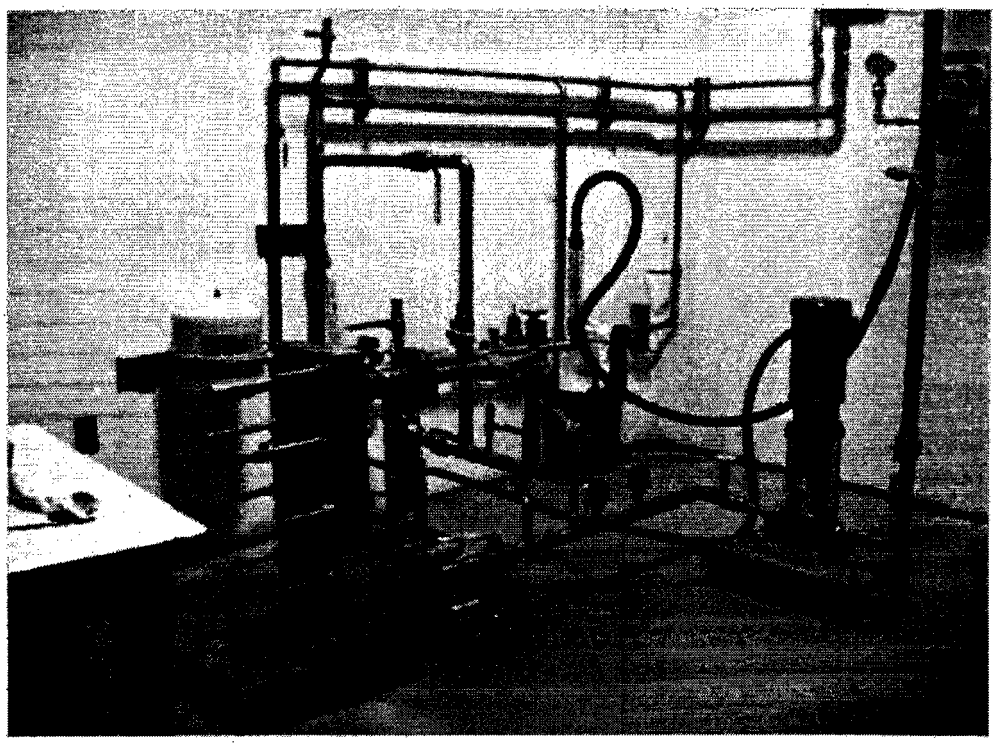
- Crane installed and tested in the IR.
- Rails mounted on the floor.
- Cable trays installed from the service building to the IR.
- Cables pulled and terminated for the whole system.

- Moving started October 9th by splitting the jet in 3 parts:
  1. ABS stage (3 upper chambers)
  2. RHIC and BRP stage (6 chambers)
  3. Racks
- Riggers moved all 3 parts out of Bldg. 930 to Bldg. 1012.
- Items 1 and 2 $\Rightarrow$ IR, 3 $\Rightarrow$ service building.
- Moved part 1 ontop of the rails with the crane.
- Moved part 2 ontop of 1 using a forklift (only this time, modifications on the crane in progress).
- Beamline not in place.
- Connected cables between Jet and racks.

- $\Rightarrow$ whole moving will need 1 day of RHIC down.
  + an additional day for leak checking.

Water cooling system

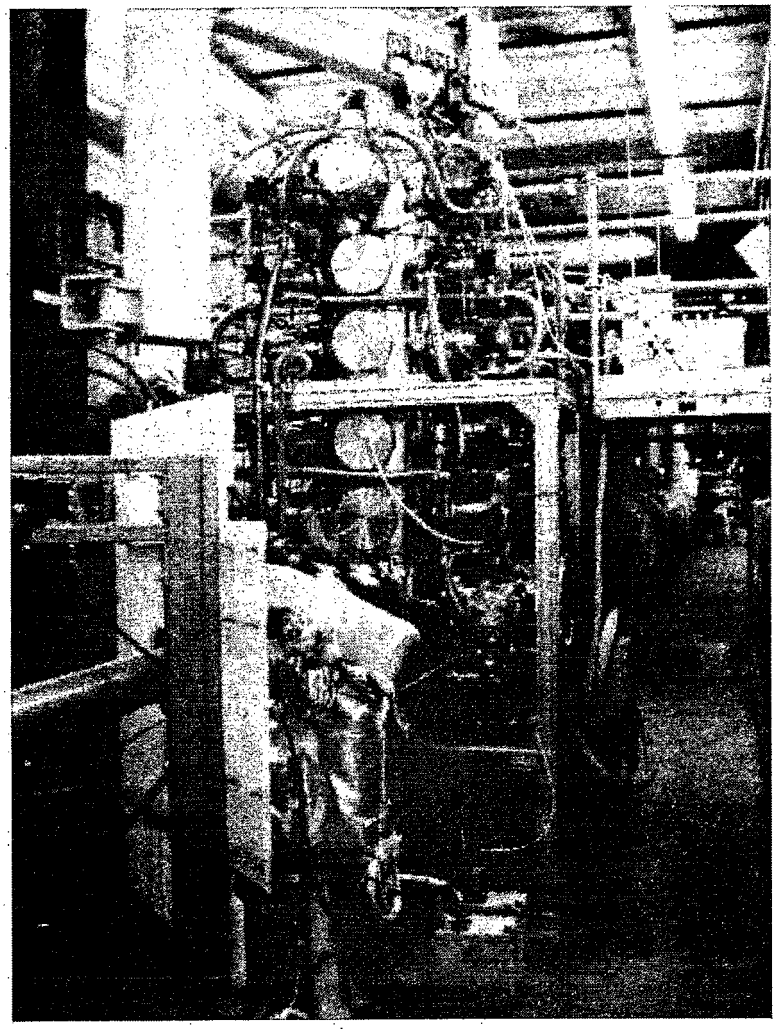
- Heat exchange system located in the service building.
- Water lines running to the IR as well as to the racks.
- Cooling needed for the holding field magnet, the turbo pumps, the RF-coils, the nozzle cold head compressor and the RF-amplifier for the dissociator.
- Additional chiller in the IR for the dissociator tube cooling.
- Closed cycle system using tap water for heat exchange at the moment.
- Filters installed to clean up the system to prevent blocking of the small conductance holding field magnet lines.
- Decision to use cooling tower or chiller for heat exchange will follow.



Jet running in the IR

- After fixing some leaks start of all pumps. Pressures achieved $\approx 10^{-8}$ Torr without hydrogen beam (chamber in RHIC vacuum $7 \cdot 10^{-9}$ Torr without RHIC pumps running).
- Dissociator was running but intensity droped after some hours running.
- Exchange of the glass tube (2 mm thickness $\Rightarrow$ 1mm thickness) $\Rightarrow$ stable operation at a high intensity level.
- Running the high frequency transitions without any big problems. Stable operation and high polarization.
- Holding field magnet powered up and running without problems (up to 1.2 kGauss).
- No problems found when running all devices with the 50 m cables instead of the short cables before.
- Replaced (50 m) BRP gauge cable with shielded one and improved power supply to increase the signal to noise ratio.

- Now testing for long term stability.
- Started to monitor the jet via VME crate.
- Using 'pet' pages and archiving to monitor the different parameters.
- Cabling on the way to fully monitor and digitally control the jet.



Next Steps

- When vacuum established in the beam lines adjoining the jet, ⇒ open the vacuum valves and measure the true jet beam gas load.
- Control the power supplies through the VME crate and PET control.
- Some minor things to fix after Safety Review Committee review and initial walkthrough.
- Move out of the IR on November 20th with beamline in place.
- Move back to Bldg. 930 and continue long term stability tests as well as controll and measurement of the polarization via VME.
- Focus on preparations to install the silicon detectors on the jet (flanges, collimators, etc.).
- Developing and constructing the H_2 (H_1, H_2O) monitor
- Check alignment of the whole system.

RHIC Polarimeter Status

H. Huang, BNL

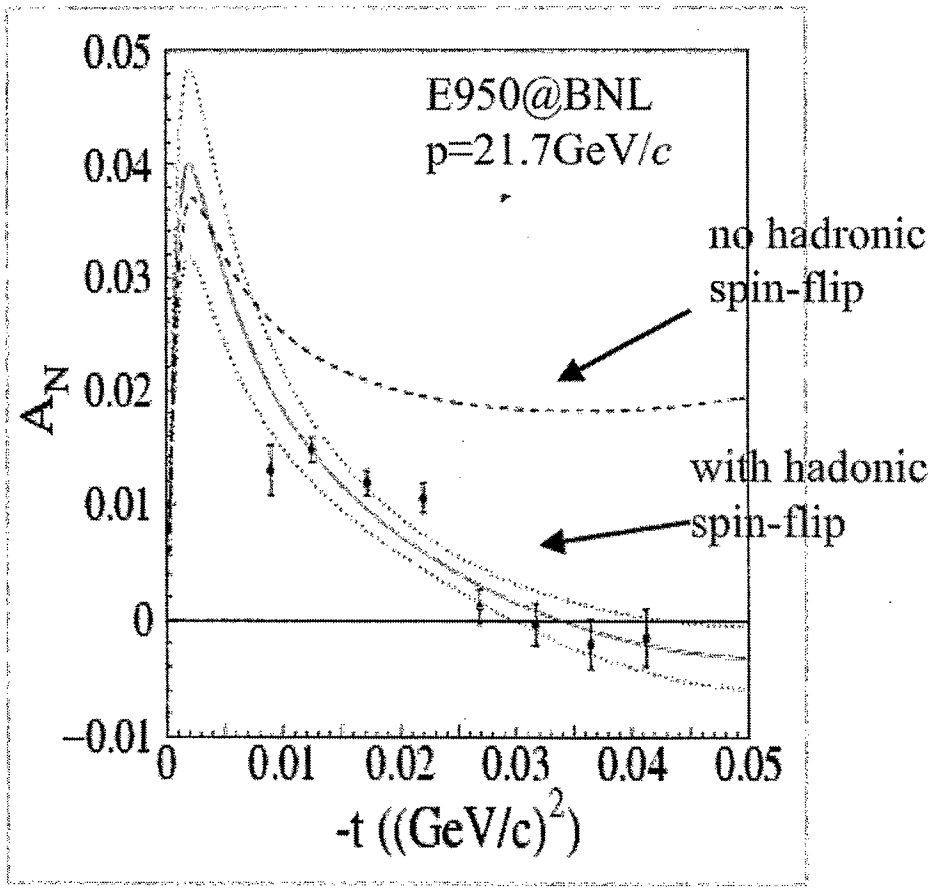
for
RHIC Spin Collaboration Meeting XX
November 18, 2003
RIKEN BNL Research Center

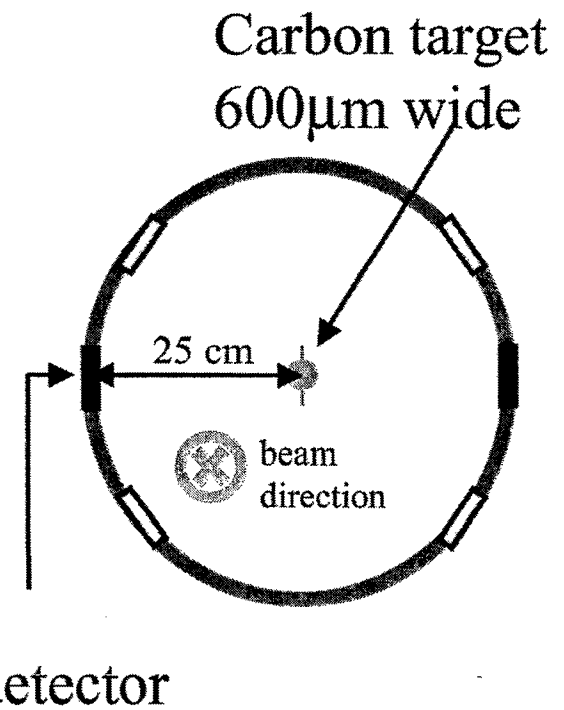
RHIC Polarimeter Status

- All targets and Si detectors have been installed at the end of October. The targets survived the vacuum pump down. All Si detectors show reasonable signals from the Am source.
- The 90 degree Si detectors are in parallel with beam direction now: no angle information available anymore and distribute the events originally at central strip.
- All electronics boards are out to test the oscillation problem. They will be put back before pp run.
- All electronics will be moved into the jet target control hut to share electronics with jet target and convenient for control purpose.
- Need a fast turn around time for the coming run. We estimate that a 12 hours dedicated time (spread over days) is needed for polarimeter commissioning. Expect the polarimeter to be ready within the first week.

AGS CNI Polarimeter

pC Analyzing Power





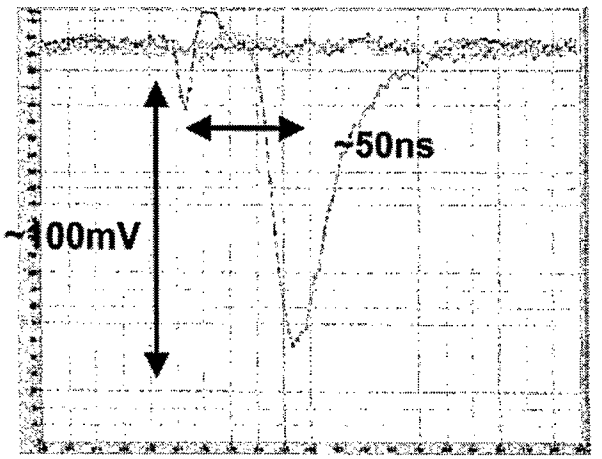
FY03 AGS Polarimeter Performance

About 10 min measurement to give 2.6% errorbar for $6*10^{10}$

In the long run, the polarimeter is required to handle ~$2*10^{11}$/bunch intensity

Two limitations in last run: oscillation in electronics induced by bunch passing (proportional to beam intensity) and data processing speed

- DAQ can only handle 600K/spill ($1.3*10^{11}$/spill for 2 sec.) with 5 sec. rep. rate. This was a limitation in multiple bunch running mode.
- Narrower targets below 200 μm broke before testing with beam.
- Si detectors are dying near the end of run.



AGS Polarimeter Modification

If don't care of measuring time, we can always reduce the target-in time to meet the DAQ constraint. For the oscillation problem, we can raise the t value (with lower A_N).

- Reduce target width by a factor 2. 250-300 μm target. Delivery schedule is under discussion.
- Increase distance by 1.3. Add spacer to increase distance between target and Si detector from 25 cm to 33 cm.
- Put two Si detectors in one flange. Flange design is almost done.
- New shaper board is in design stage and should be ready by Feb.
- Install peltier cooler to extend lifetime of the detector.
- Faster DAQ using USB 2.0 CAMAC controller (increase speed by about 4 times).
- Continue testing narrower target while modify motor running profile to smooth out target motion as much as we can.

AGS Polarimeter Modification (2)

- Acceptance increase by 2(# of Si detectors)/1.3(distance increase)=1.6
- Target width reduces by ½.
- Increase bunch intensity by $(2*10^{11}/0.6*10^{11})=3.3$.
- The event rate will be higher than last year by about 2.5 times and reduce measurement time from 10 min. to 4 minutes. This will be within the new DAQ system capability.
- For 6 bunch running mode, the event rate will be higher and may require further upgrade on DAQ system.

CNI polarimetry status

Osamu Jinnouchi (RIKEN BNL Research Center)
/ Sandro Bravar (BNL)

RHIC-Spin-Collaboration Meeting

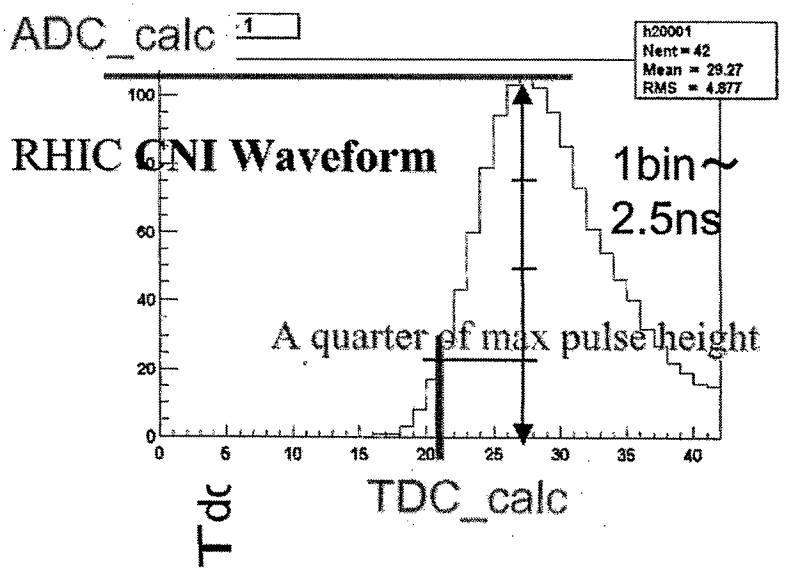
November 18, 2003

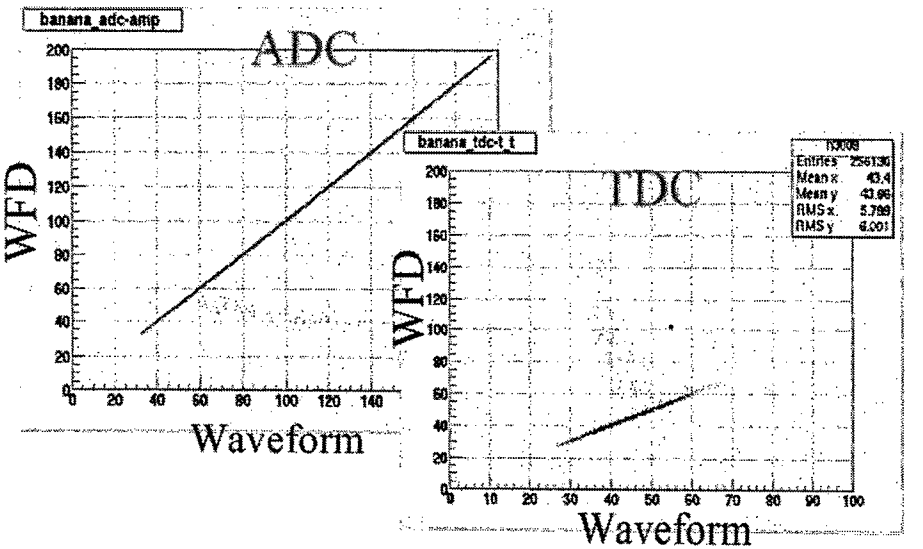
Update of RHIC polarization status

- During the run, polarization from the scaler numbers was distributed to the experiments. The number depends on,
  - $T_{1/4}$, ADC_{max} determined by WFD algorithm
  - WFD look-up-table banana cut
- This online results were defined as tentative "official polarization" for run-03
- The calibration and correction were done at some level at the online stage, and the recoil Carbon energy is one of the most important value which determine the A_N
- Energy calibration (Correction)
  - Scale – 241 Am source
    - Stable within a few % throughout the run (c.f. 20% in RUN-02)
  - Scale and shift –Energy loss in SSD dead layer
    - Estimated by kinetic fit to E-T banana curve
    - Would generate 50-80keV shift in detection energy

Comparison WFD algorithm vs. Waveform

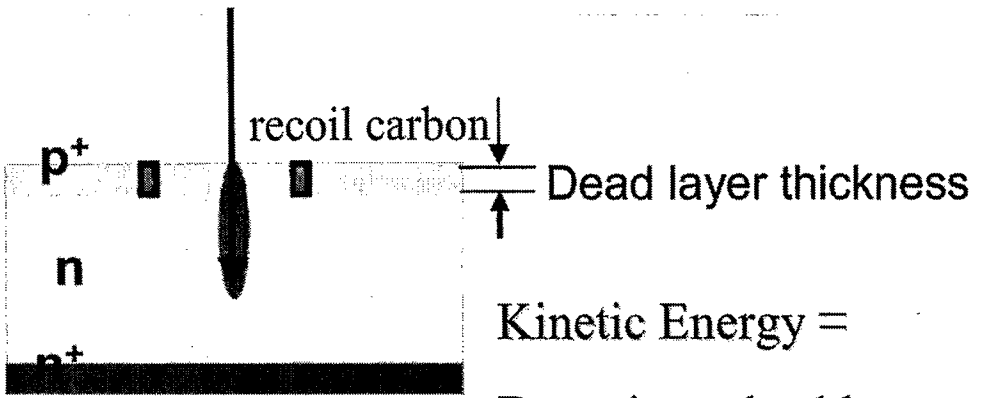
- (A, T) values from the WFD FPGA algorithm were compared with the result from waveform data samples
- Clear correspondence in each event
- The Event mode data and scaler mode data were confirmed to be correct for the first time
- Storing the timing info at the maximum pulse height will be also useful





SSD dead layer estimation

- Ambiguity about dead layer width is one of the systematic error source in A_N → polarization error
- The width could be different in each Si detector, and each strip
- It can be roughly (and indirectly) estimated by kinetic fit for banana distribution
- Direct measurement using the test beam was done during the last three weeks at Tandem in Kyoto (Basic data sets were collected for 3 SSDs) The run was very successful !!
- It is desirable to perform this test for all the detectors, each year – Since this is time consuming, we need to develop test bench system in Lab space

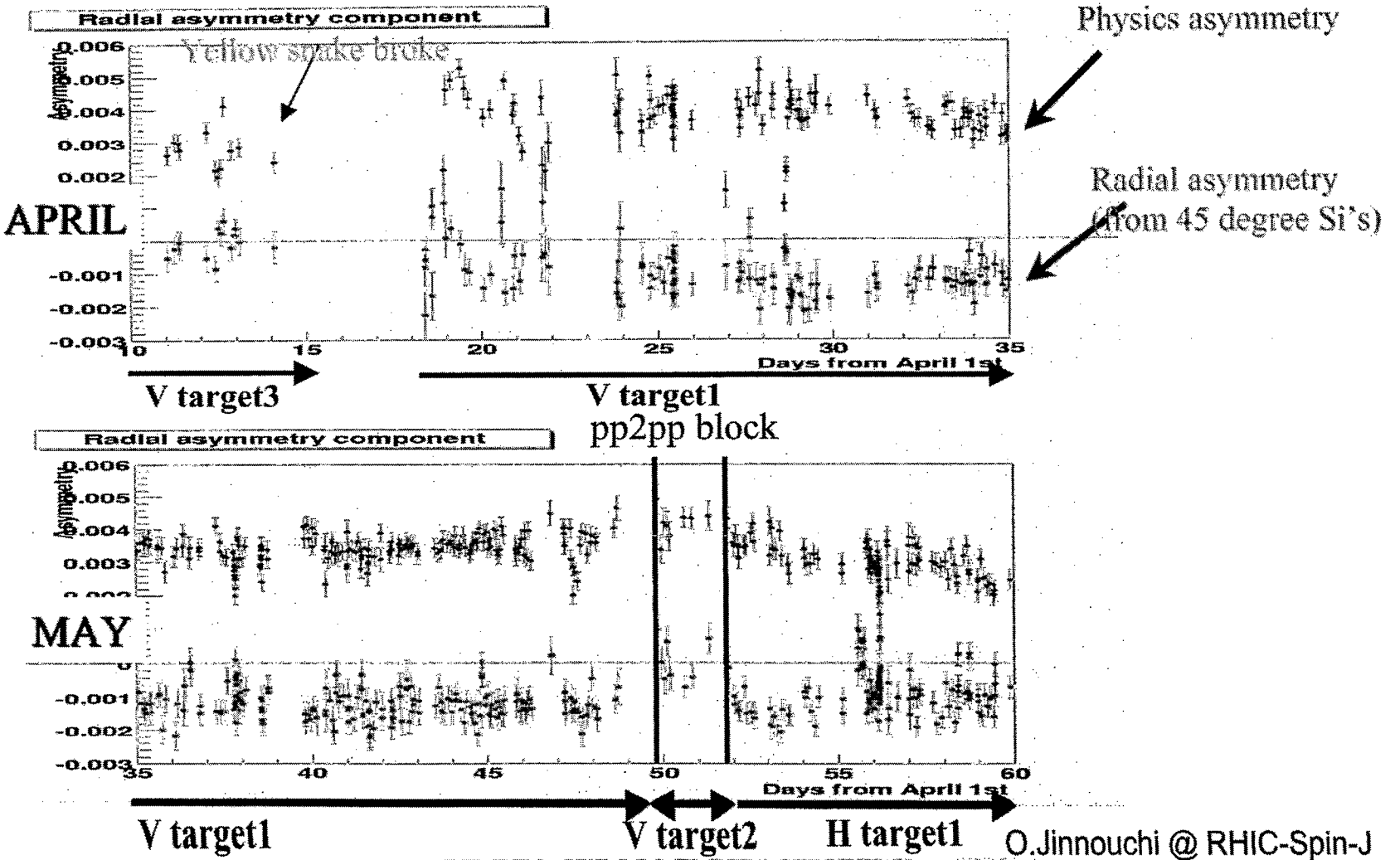


Kinetic Energy =

Deposit on dead layer + deposit on Si

The radial component (at BLUE Flattop)

False asymmetry (radial component) had been seen throughout the Run-03
The effect was significant and there are many possible candidates for the source



Limitation of the square root formula

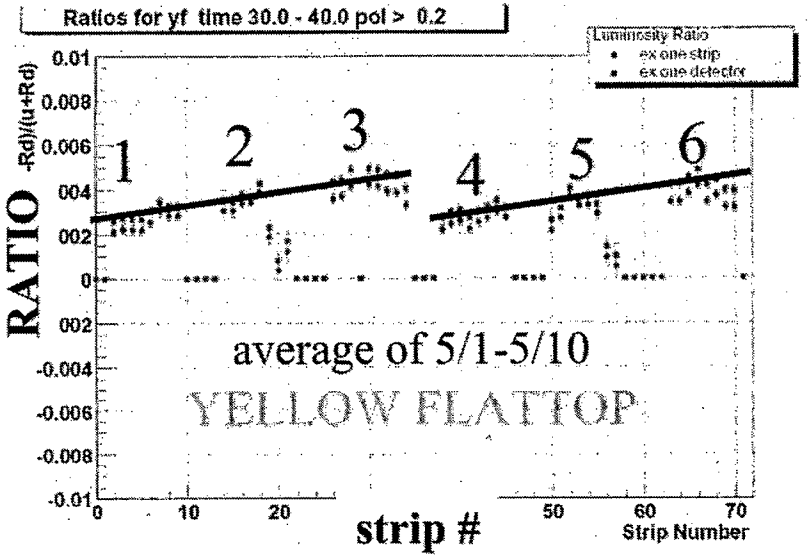
- Square root formula (actually any other formula) can generate false asymmetry with 45 degree SSDs, when A_N of each detector is different
- Also it is possible to generate false asymmetry by just eliminating the suspicious Si strip channels
- A_N for each strip would be the useful parameter to look at so that we can visually understand the anomalous behavior of asymmetries

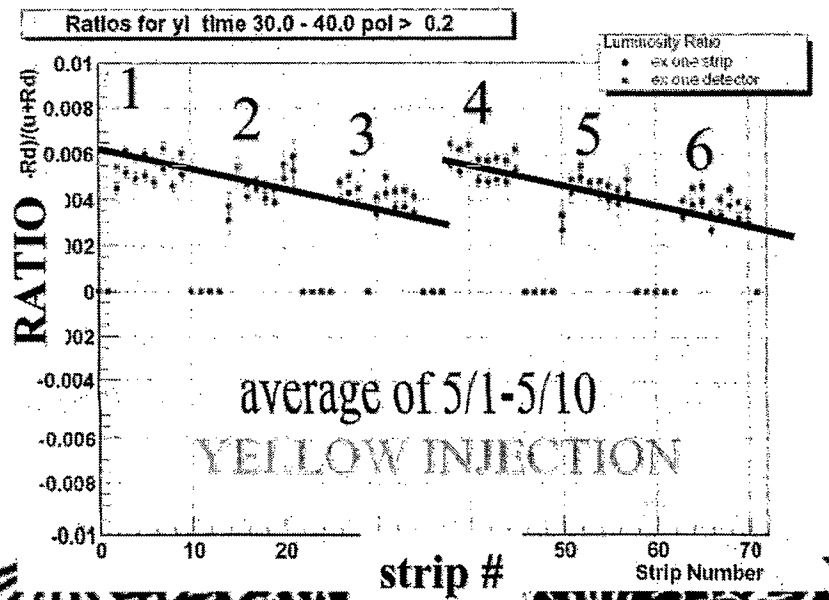
The Ratio(i) = $(U_i - RD_i)/(U_i + RD_i)$

U_i : Spin Up counts for i-th strip
D_i : Spin Down counts for i-th strip
R : luminosity ratio Lu/Ld

represents A_N for each strip

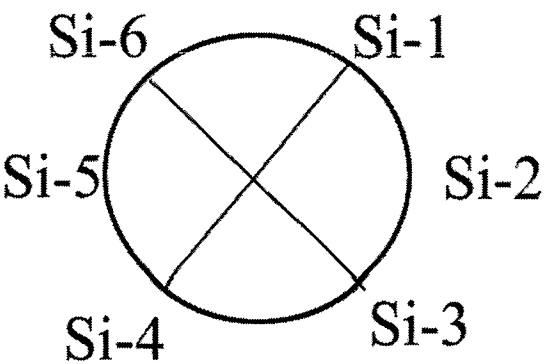
A_N for each strip (in YELLOW)



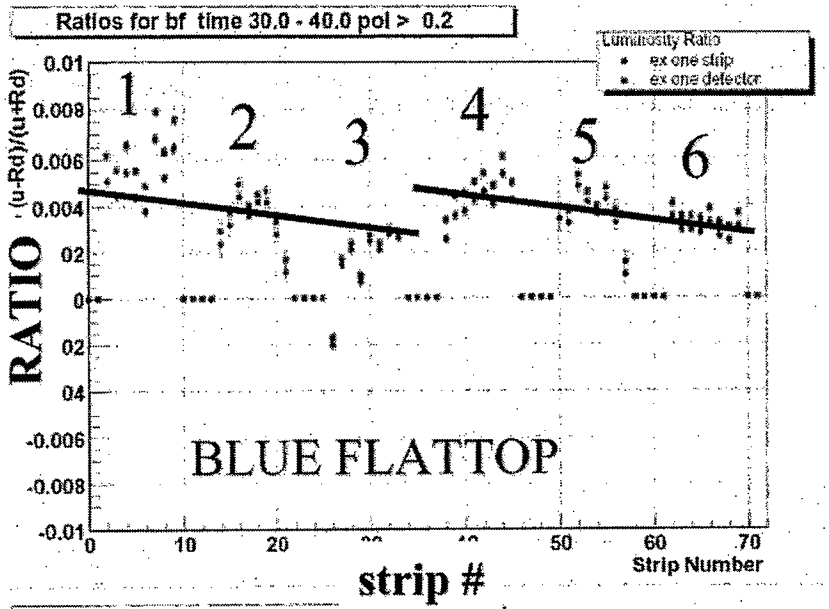


Ratio (A_N) is corrected with the sign (1-3 for plus and 4-6 for minus) and factor $\sqrt{2}$ for 45 degree SSDs

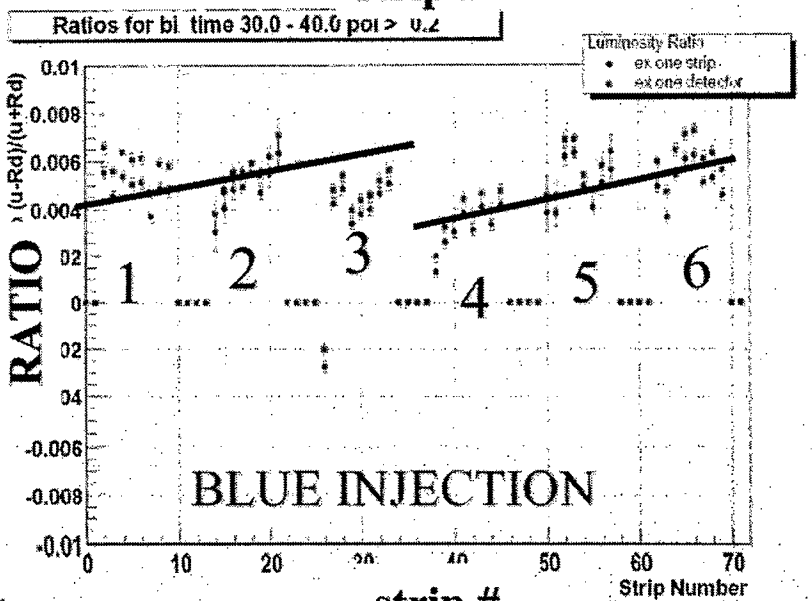
- Both energies in yellow can indicate the tilted spin from vertical
- Opposite direction btw injection and flattop
- Other things look to be normal



A_N for each strip (in BLUE)



strip #



strip #

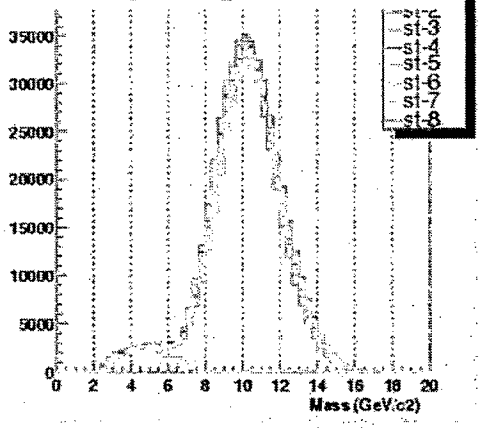
- A_N for BLUE Si-3 is extremely small and this has created the large asymmetry in radial direction
- The reduction cannot be explained by,
  - Wrong dead layer estimation
  - Wrong energy scale
  - Banana cut is not right

  because the size is too significant

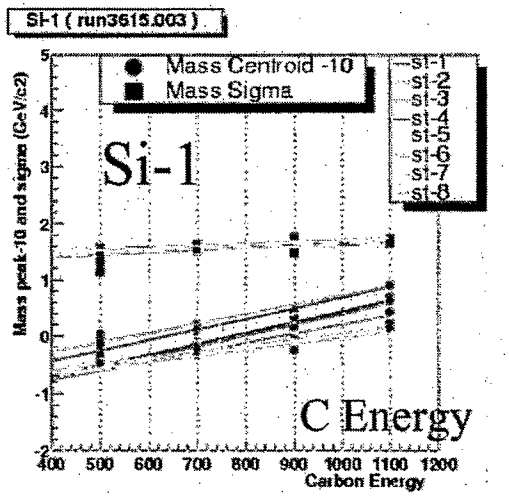
Mass distribution

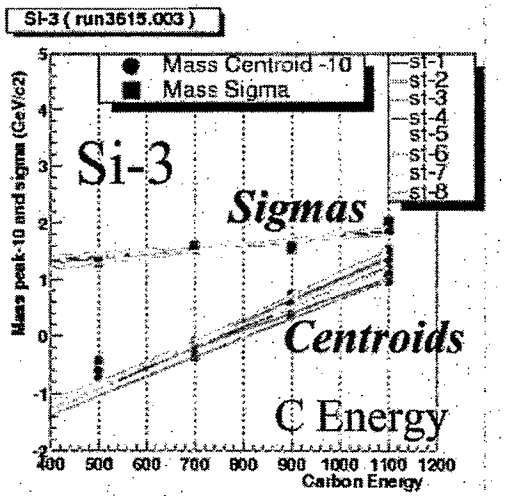
- One way to check the consistency in kinematics is to see the mass distribution
- The width has similar behavior, but centroid has different slope only in Si-3

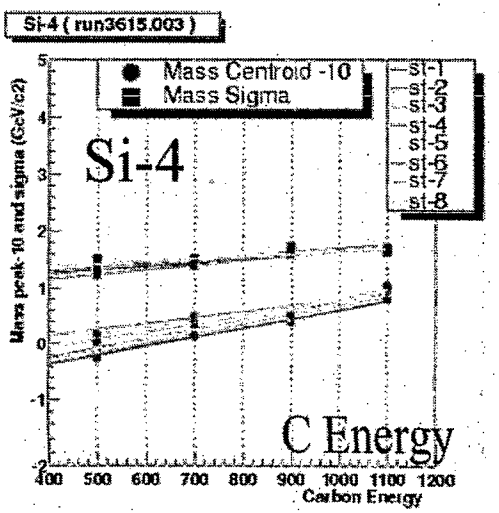
Mass distribution for Every strips in Si-3

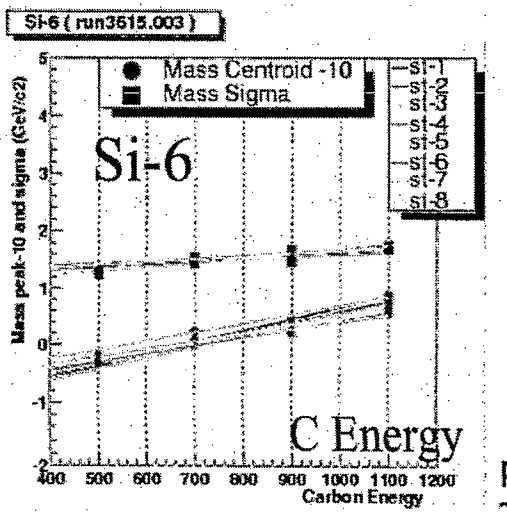


Mass vs. C Energy









Beam position was off-centered

- The data from BPM and survey group indicates the target (and beam) was not centered w.r.t. polarimeter chamber
- The effective angle for each 45 degree detector (= effective A_N) was changed ($\cos 45 = 1./\sqrt{2} \rightarrow ??$)
- The size of this effect can even become ±10% according to the geometrical displacement
- Only Si-3 could be largely affected while the others get small effects

Summary

- Algorithm of WFD has been studies with waveform analysis
- SSD dead layer measurement in Kyoto successfully finished
- To understand the anomaly in Blue flattop is the top priority
- The mechanism has been understood, then we need to find out the source and how to avoid it in the run-04

New theory studies for pp scattering

Werner Vogelsang

RIKEN-BNL Research Center / BNL Nuclear Theory

RSC meeting, BNL, November 18, 2003

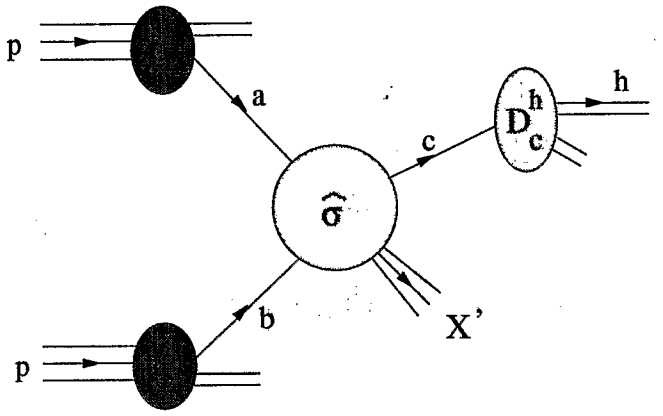
Outline :

- Near-term prospects for measuring Δg at RHIC
  - high-p_T jet / hadron production
  - sign of Δg ?
- Single transverse-spin asymmetries

Near-term prospects for measuring Δg

– High-p_T jets and hadrons –

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

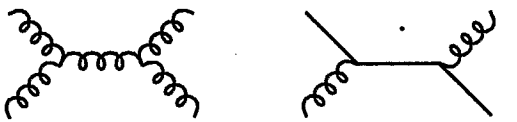


$$\left. \right|^2 + \mathcal{O}\left(\frac{\lambda}{p_T}\right)^n$$

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

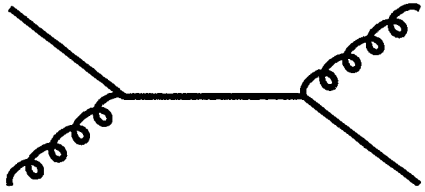
$$\Delta\hat{\sigma}^{(0)} + \alpha_s \Delta\hat{\sigma}^{(1)} + \ldots \text{ pert.}$$

LO NLO

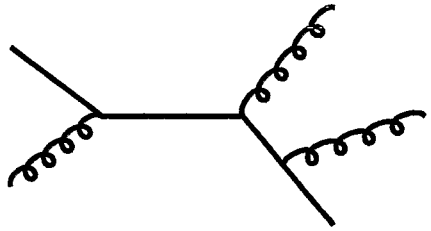


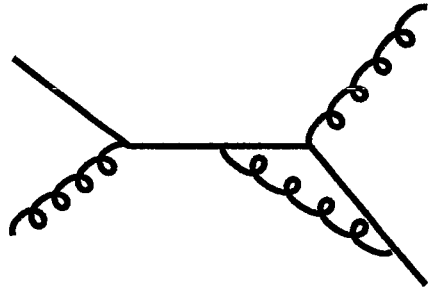
- nucleon spin structure $\Delta f_{a,b}$
- for hadrons : fragmentation functions D_c^h $\rightsquigarrow$ e^+e^- annihilation

- NLO = state of the art



LO





NLO

- lowest order : good for qualitative descriptions
- however, precise predictions afford higher-order NLO calculations :
  - may be sizeable, in particular in polarized case
  - reduction in scale dependence

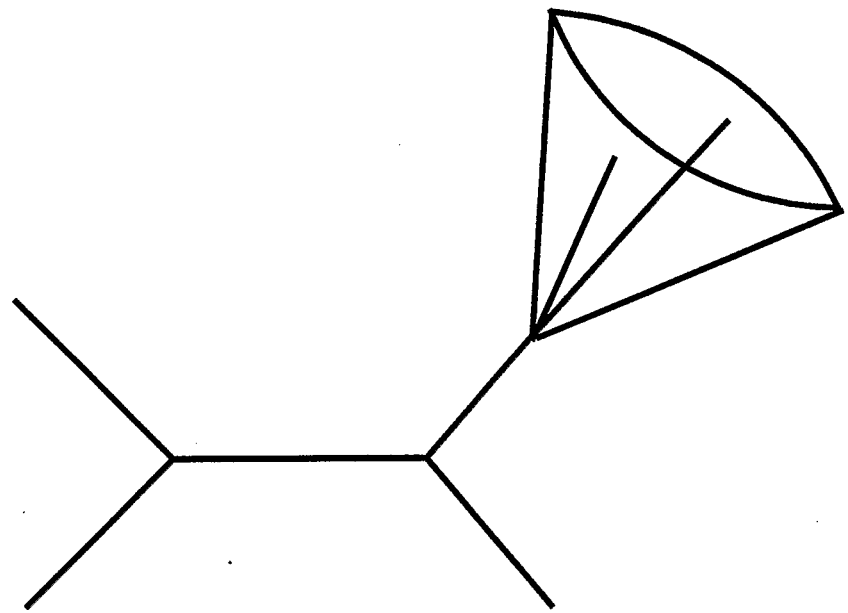
$$\mu \frac{\mathrm{d}}{\mathrm{d}\mu} d\sigma_{\text{phys}} = 0$$

$$\neq 0 \quad \text{in truncated perturbation theory}$$

- NLO corrections now known for all relevant reactions

  Gordon,WV; Contogouris et al.; de Florian,Frixione, Signer,WV; Stratmann,Bojak; de Florian; Jäger,Schäfer,Stratmann,WV; . . .

- jet and hadron caclulations share many features
- however :



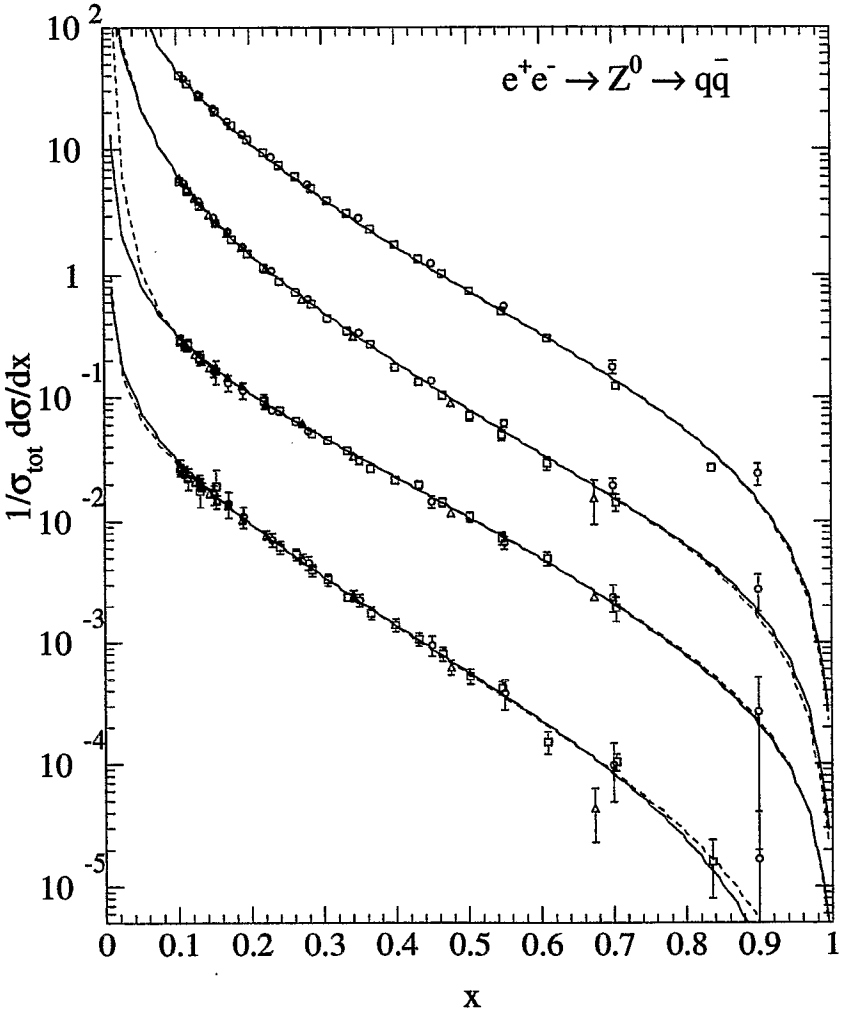
- final-state singularities . . .

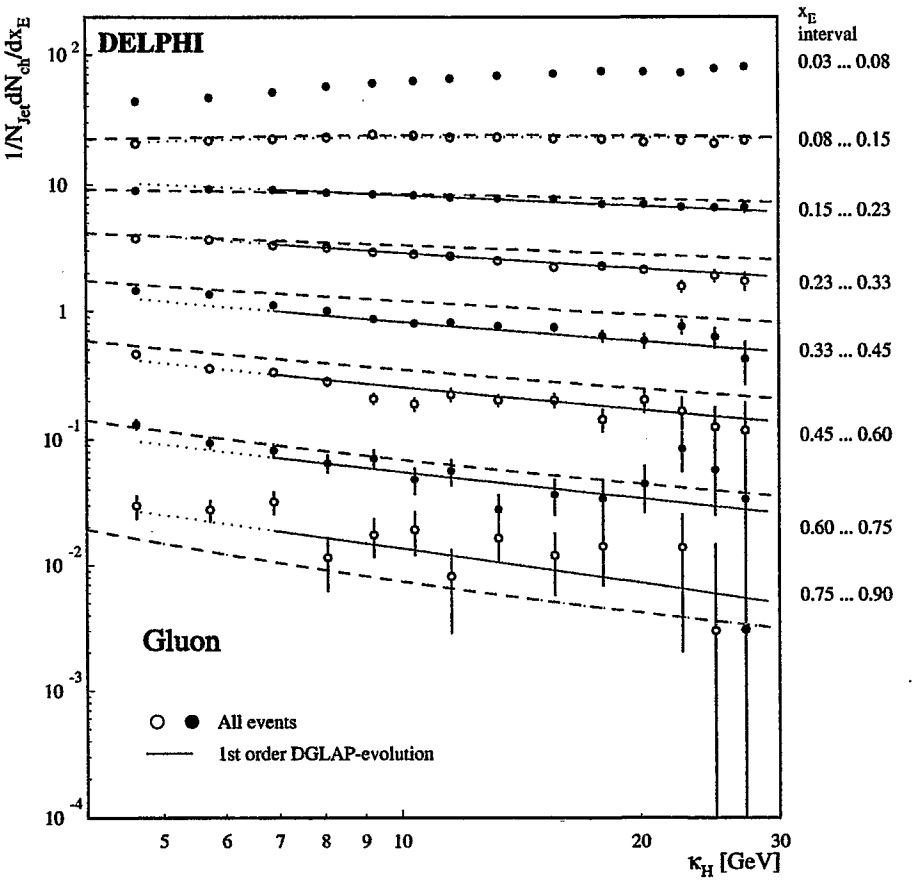
  . . . cancel for jets

  . . . imply additional non-perturbative input for incl. hadrons

  $\longrightarrow$ fragmentation functions

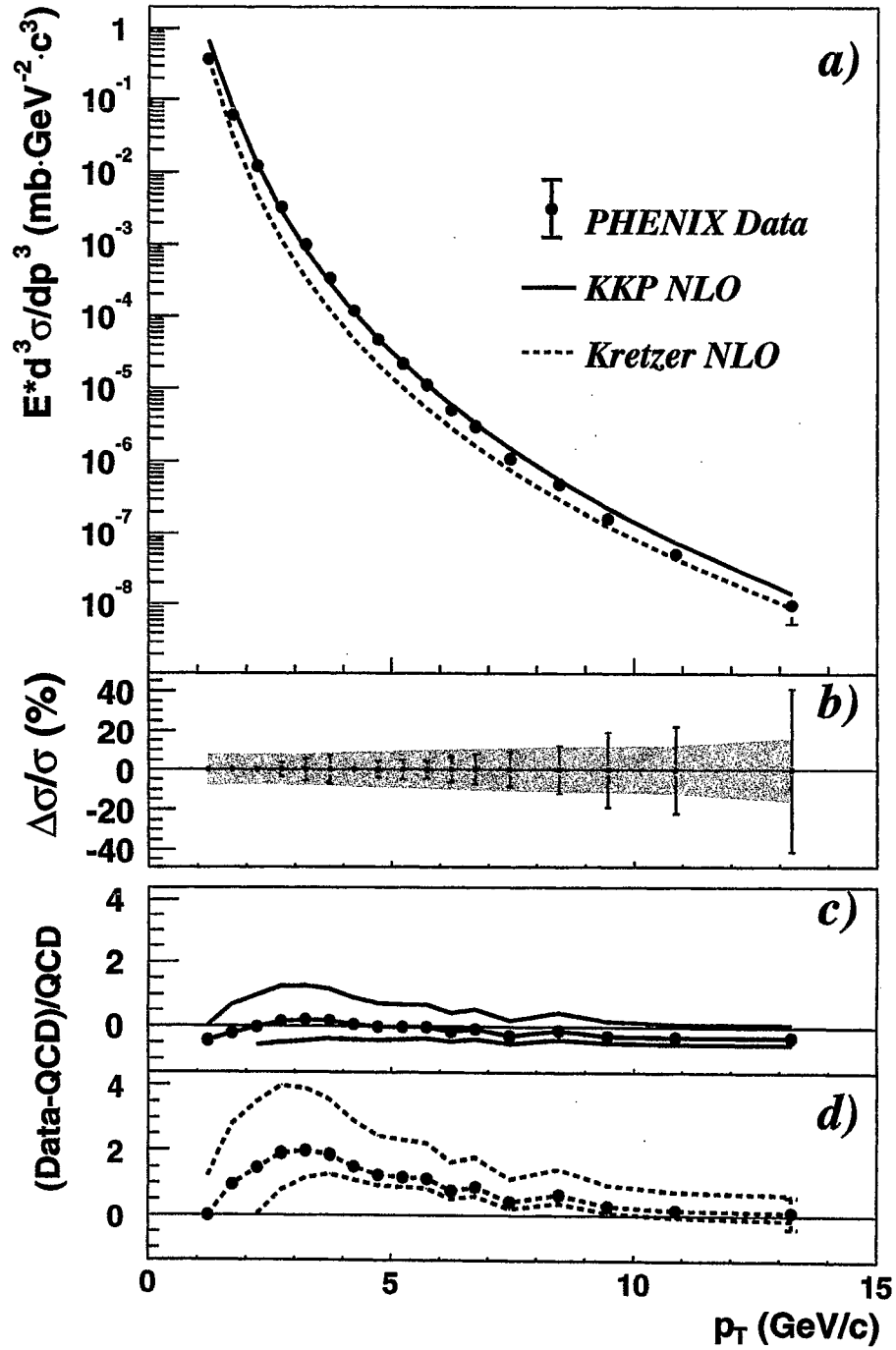
- fragm. fct. analyses : Kniehl,Kramer,Pötter and Kretzer



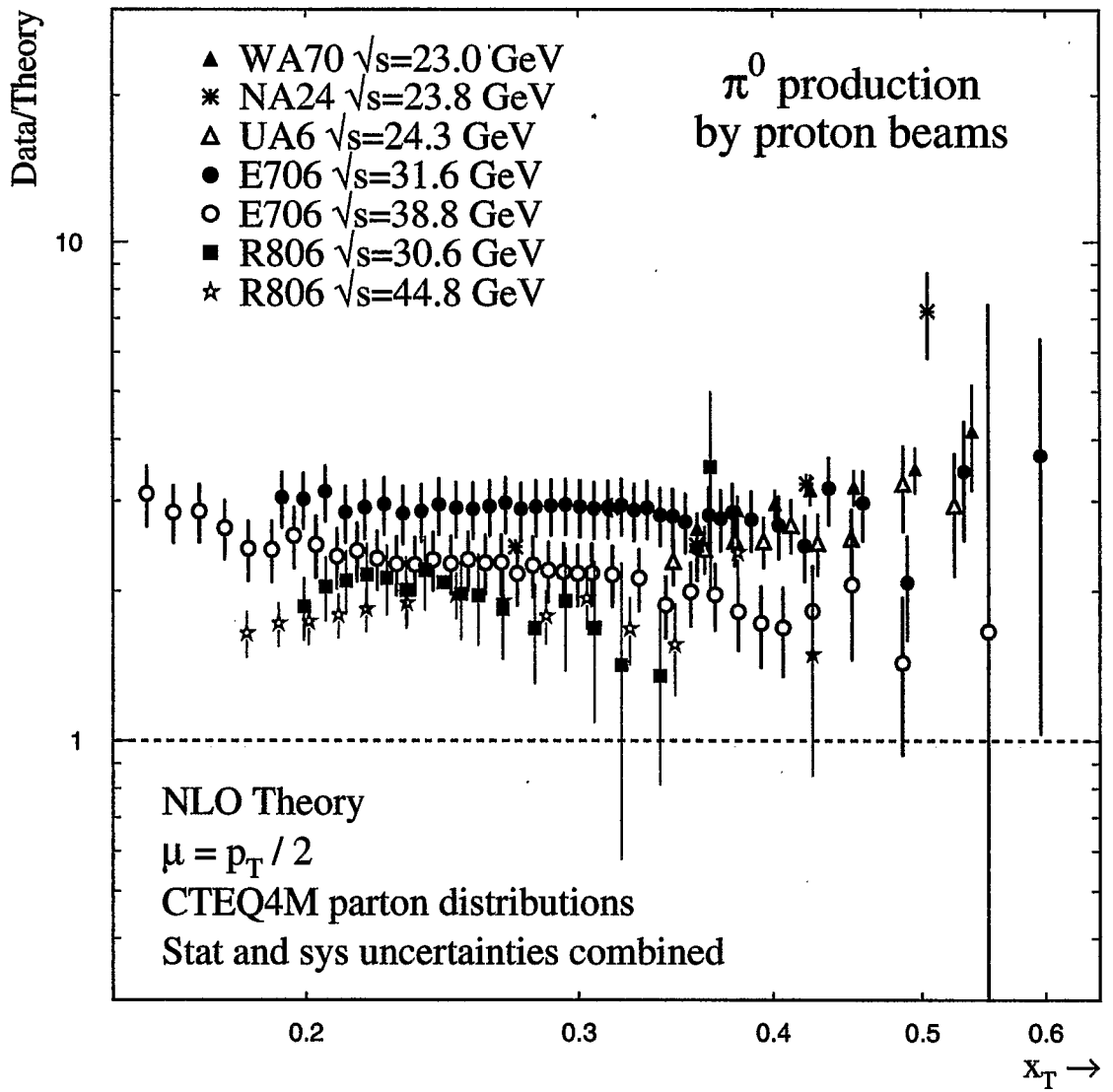


Unpolarized cross section

$pp \to \pi^0 X$ **by**
PHENIX

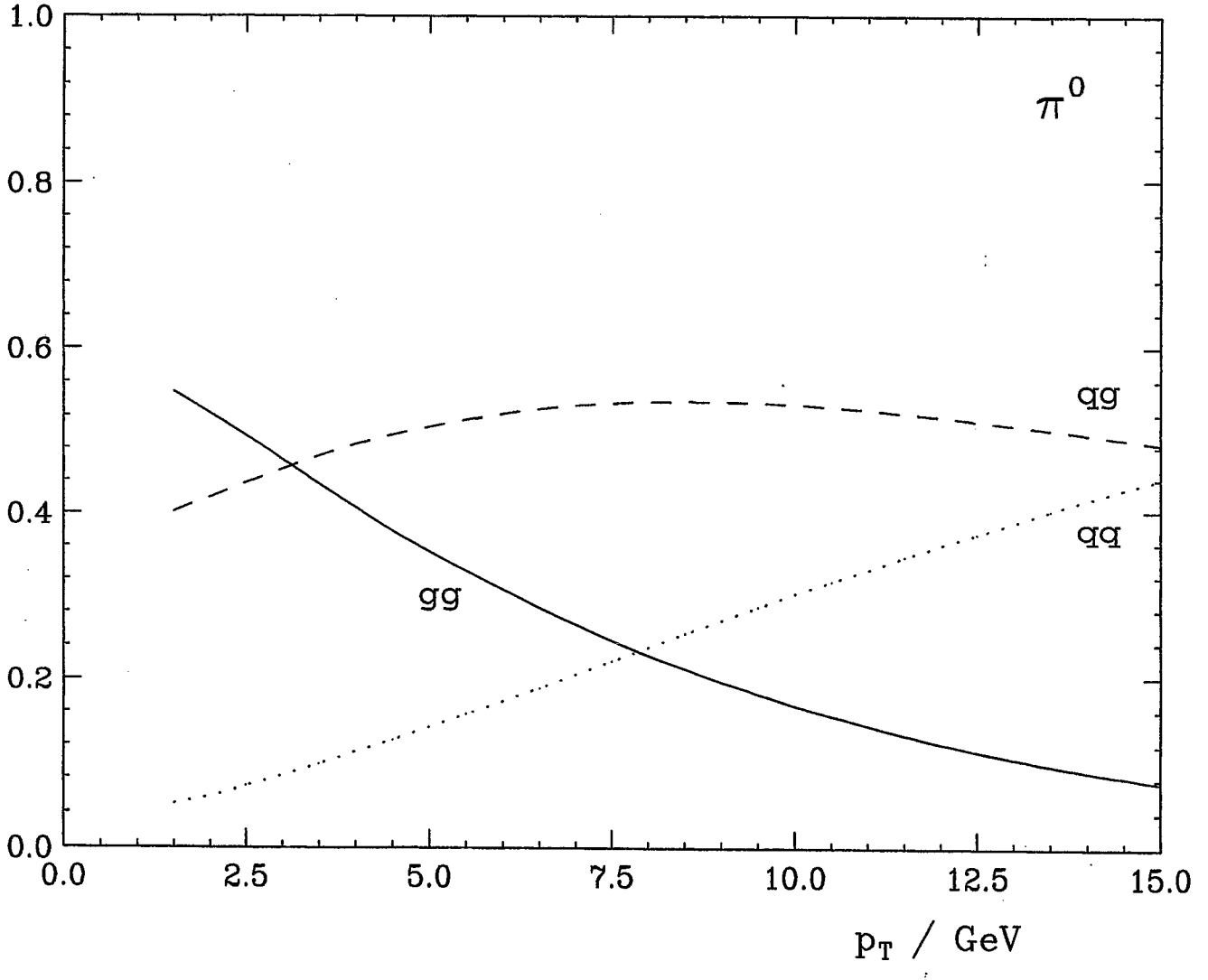


(Why so good . . . ?)

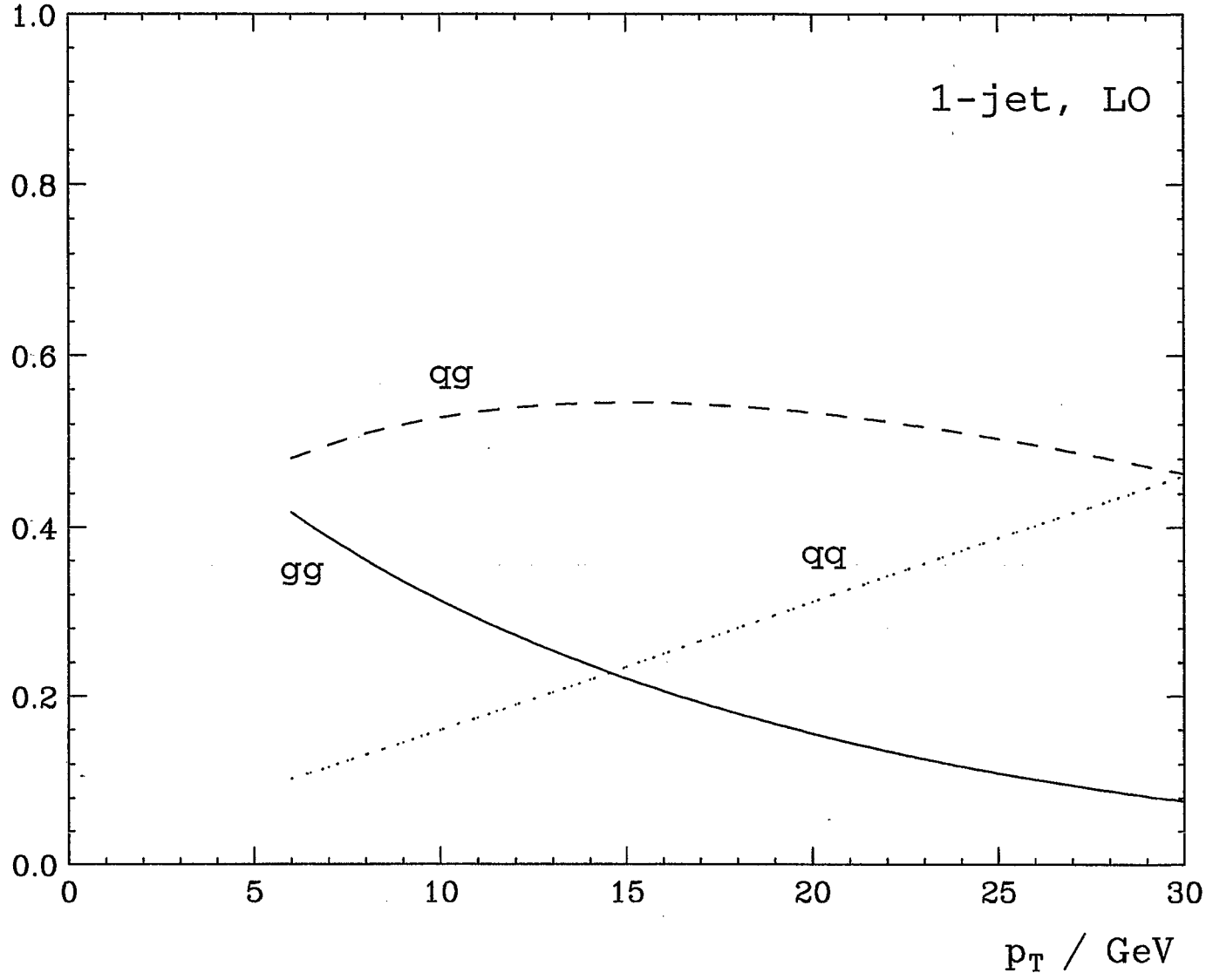


Apanasevich et al. (see also : Aurenche et al.)

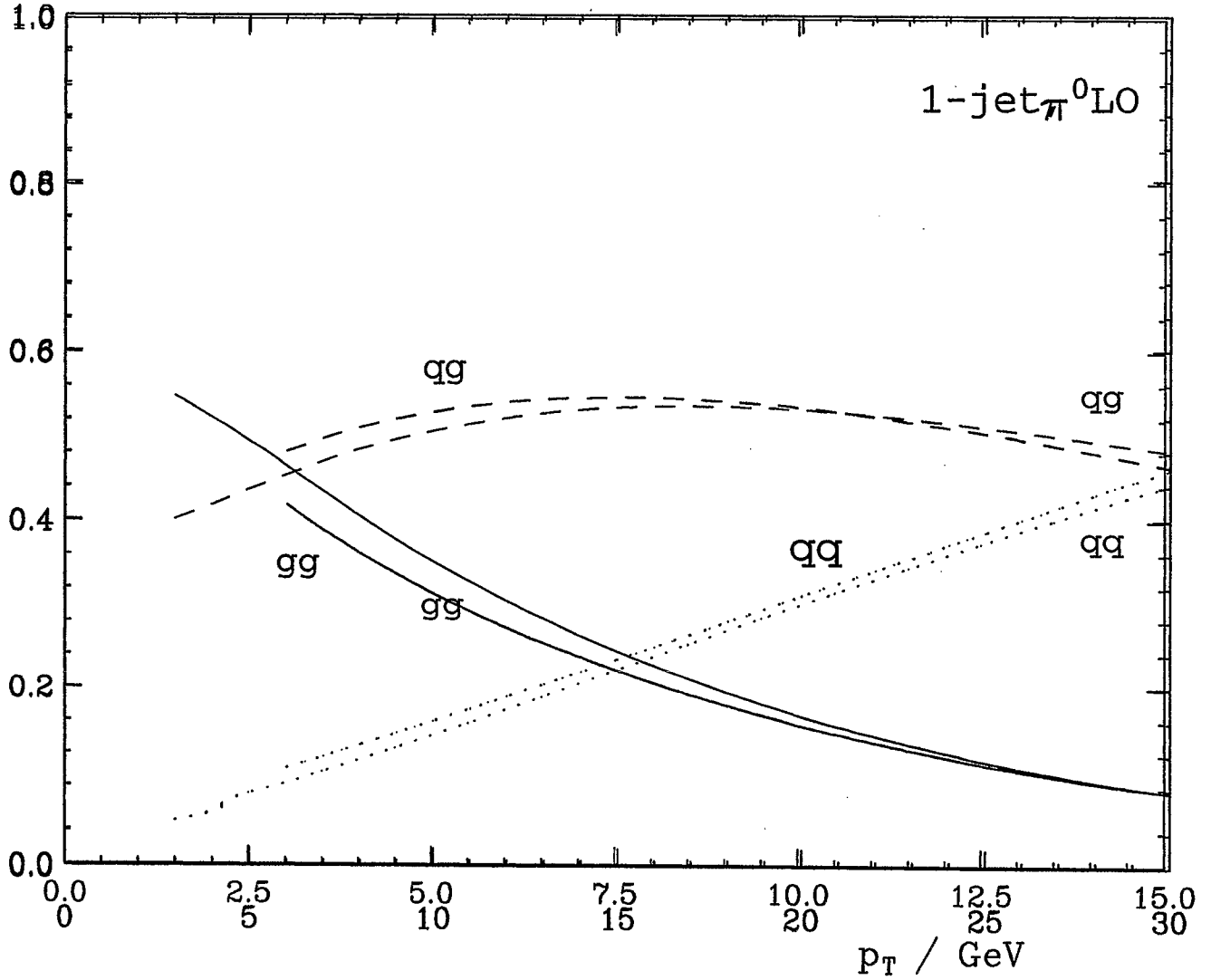
- contributions by partonic scatterings : pions



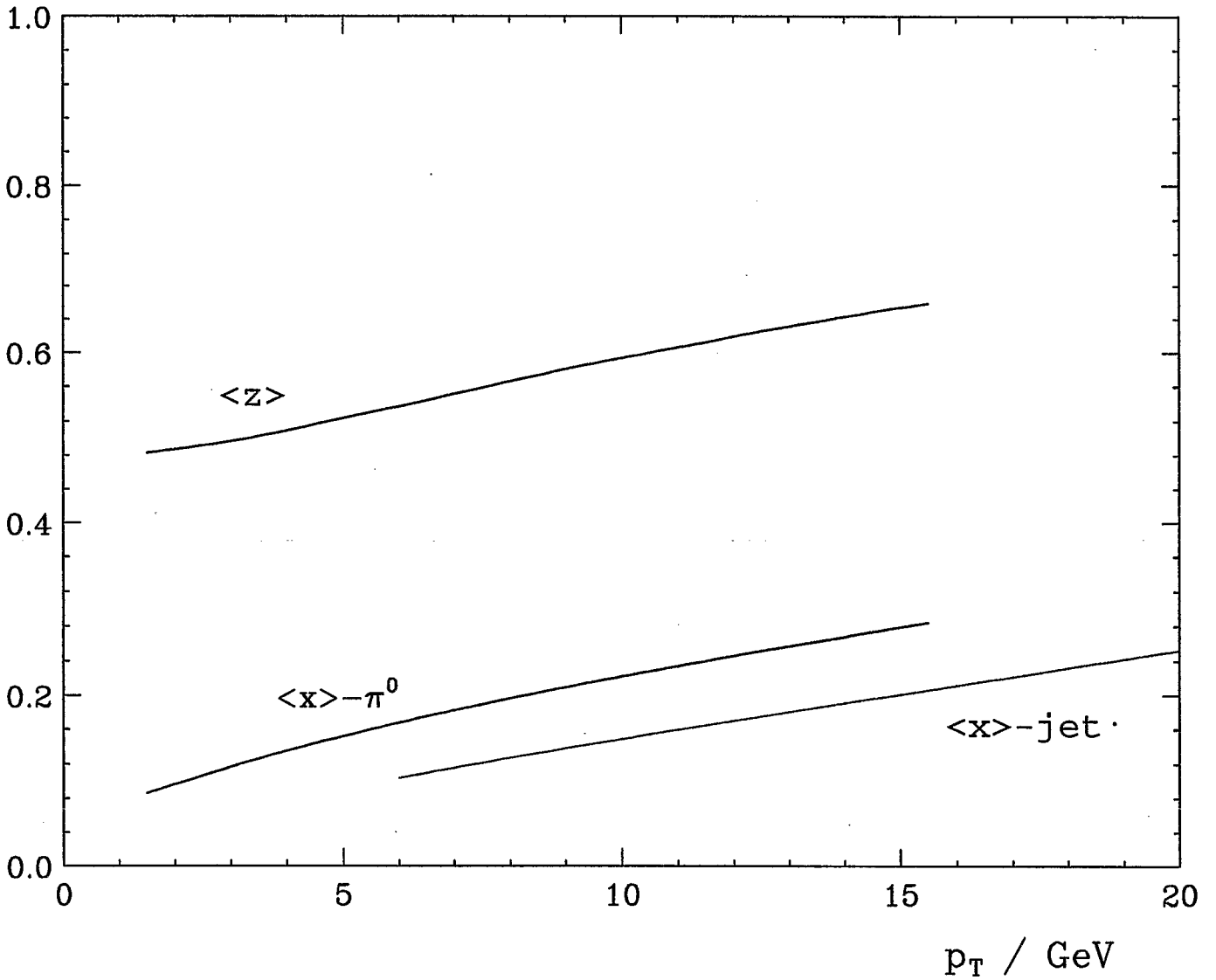
- contributions by partonic scatterings : jets

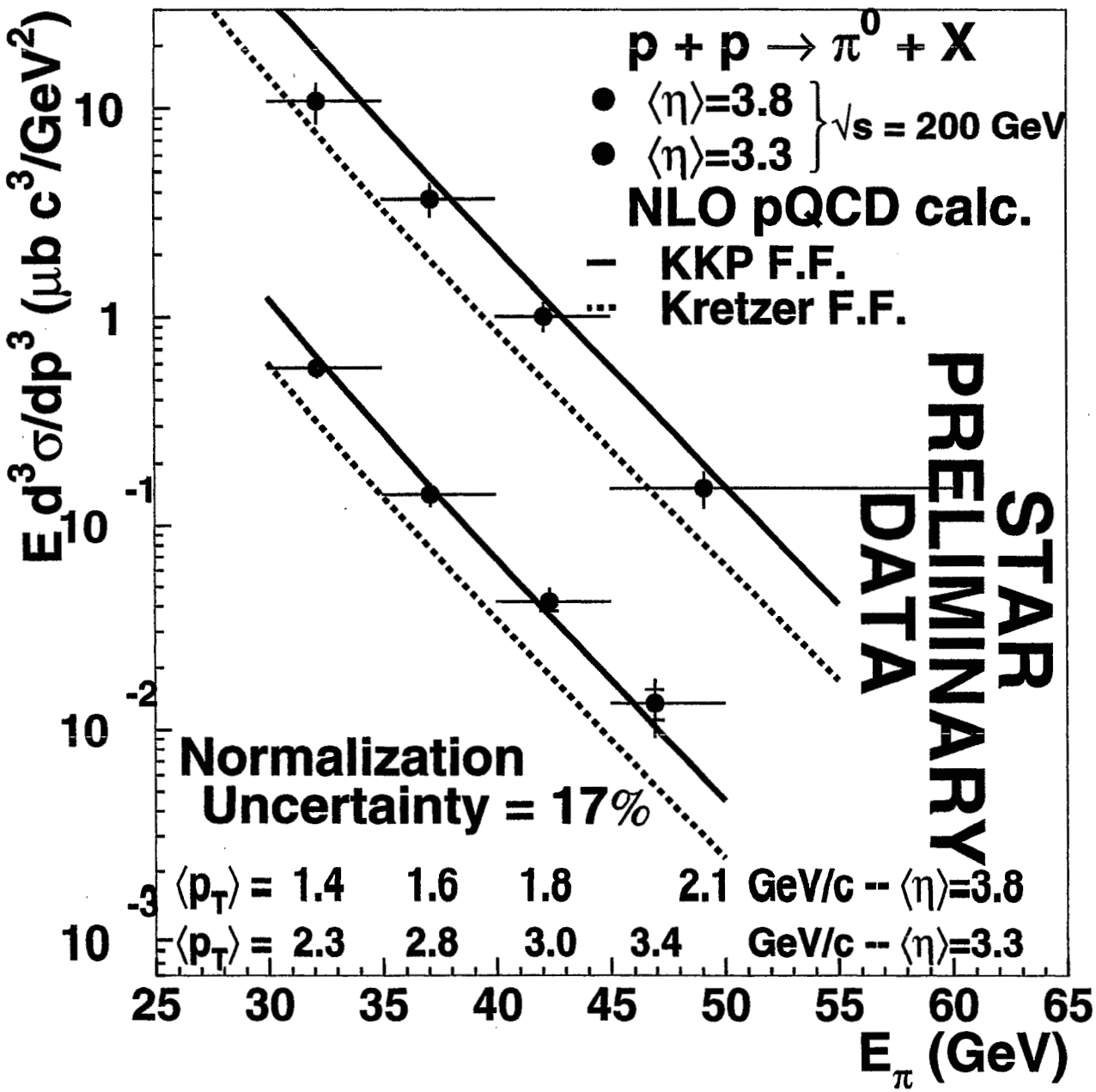


- contributions by partonic scatterings :



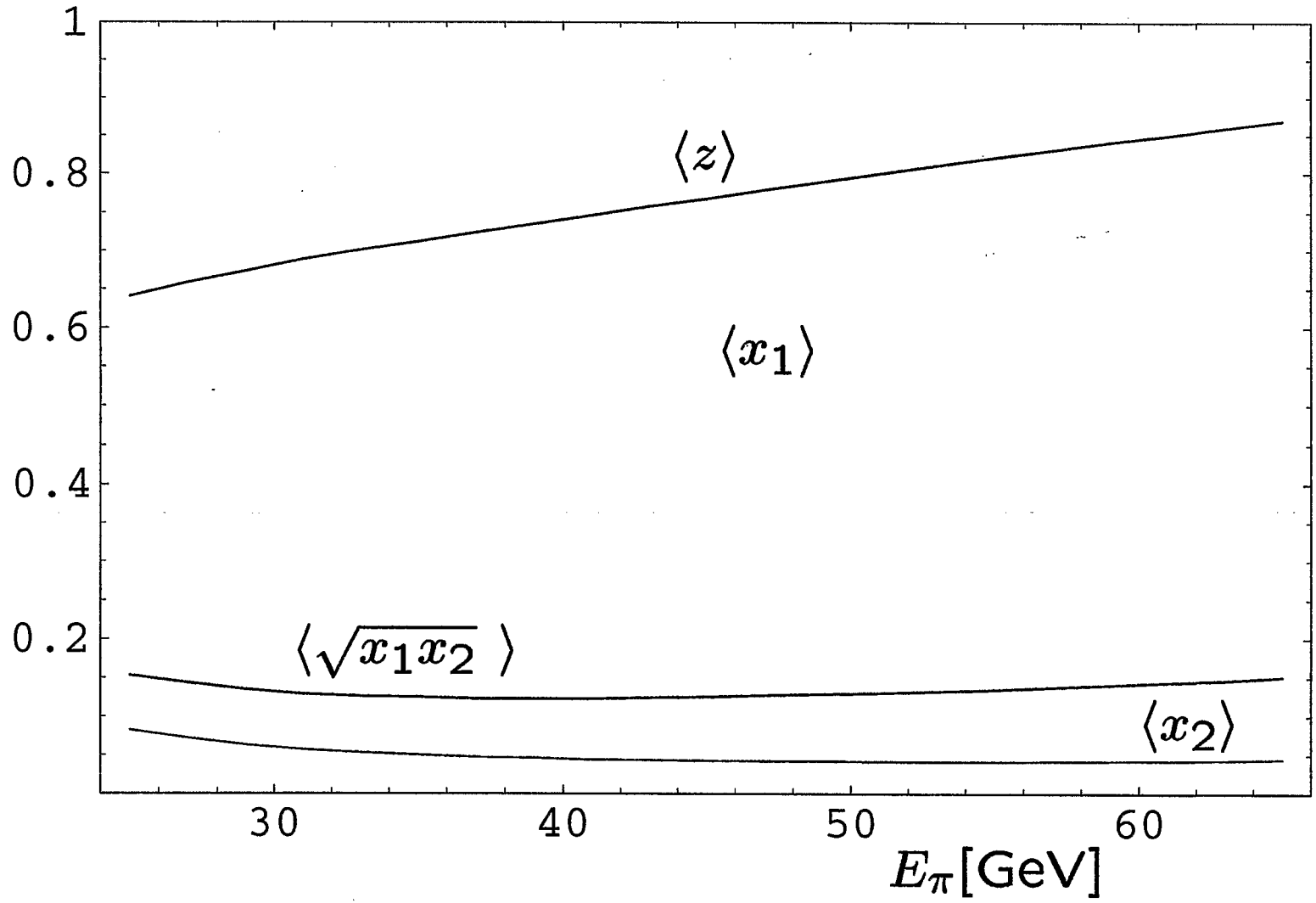
- average x and z :



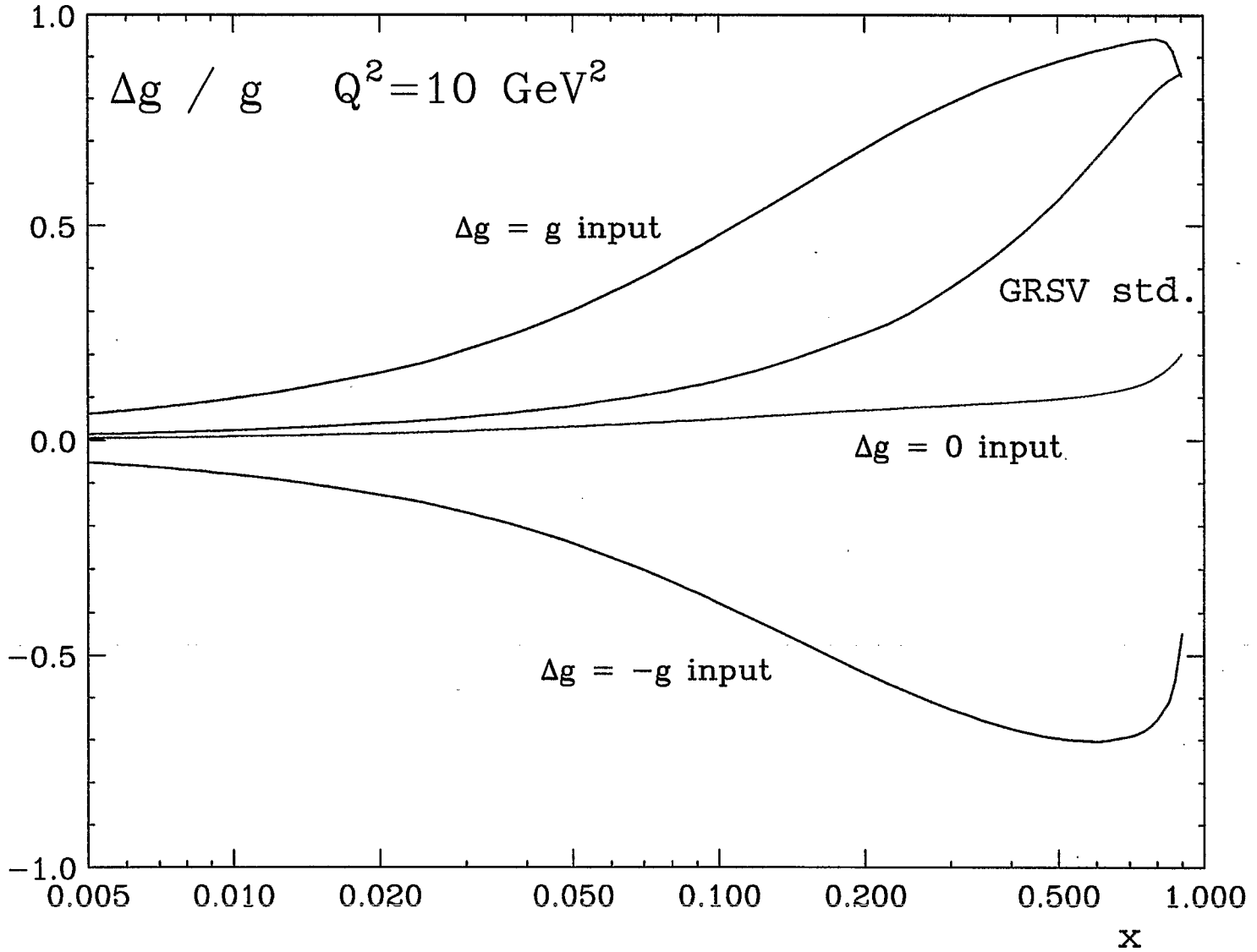

p + p → π0 + X
⟨η⟩=3.8
⟨η⟩=3.3
√s = 200 GeV
NLO pQCD calc.
KKP F.F.
Kretzer F.F.
STAR
PRELIMINARY
DATA
Normalization
Uncertainty = 17%
⟨pT⟩ = 1.4 1.6 1.8 2.1 GeV/c -- ⟨η⟩=3.8
⟨pT⟩ = 2.3 2.8 3.0 3.4 GeV/c -- ⟨η⟩=3.3
E d3σ/dp3 (μb c3/GeV2)
Eπ (GeV)

- average x and z in forward region :

Kretzer



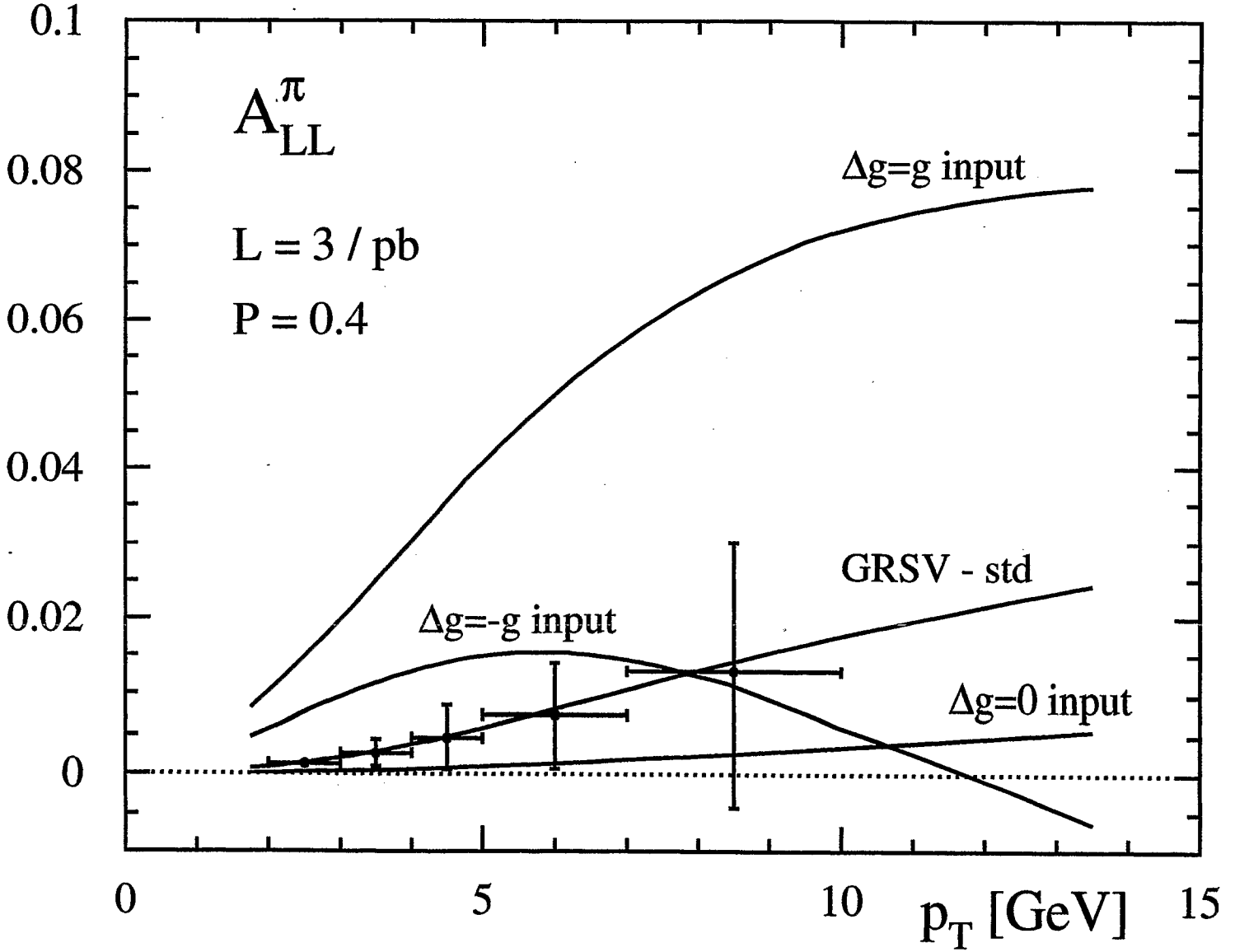
Spin asymmetry



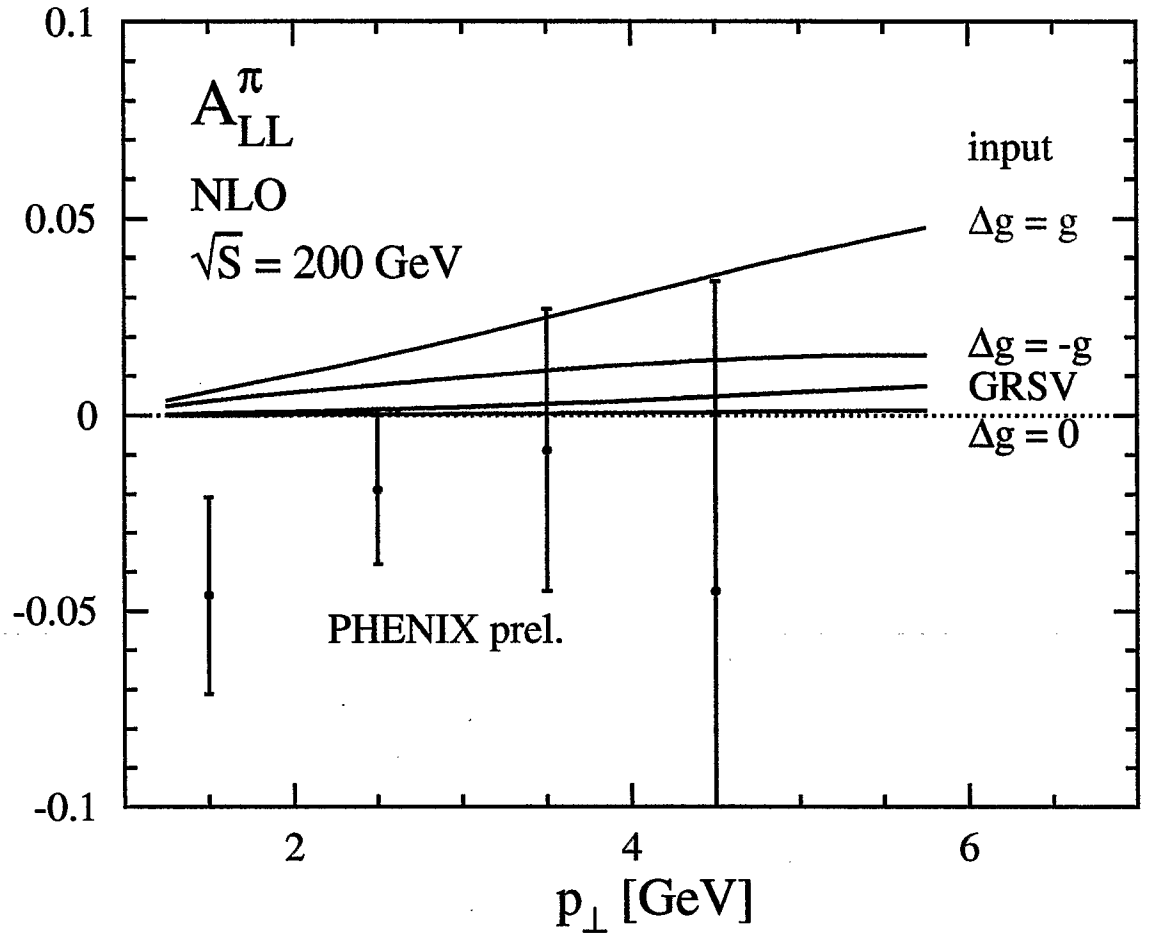
Polarized gluon densities : Glück,Reya,Stratmann,WV

$pp \to \pi^0 X, \ \sqrt{S} = 200\,\mathrm{GeV}\,, \ |\eta| \leq 0.38$

Jäger,Schäfer,Stratmann,WV

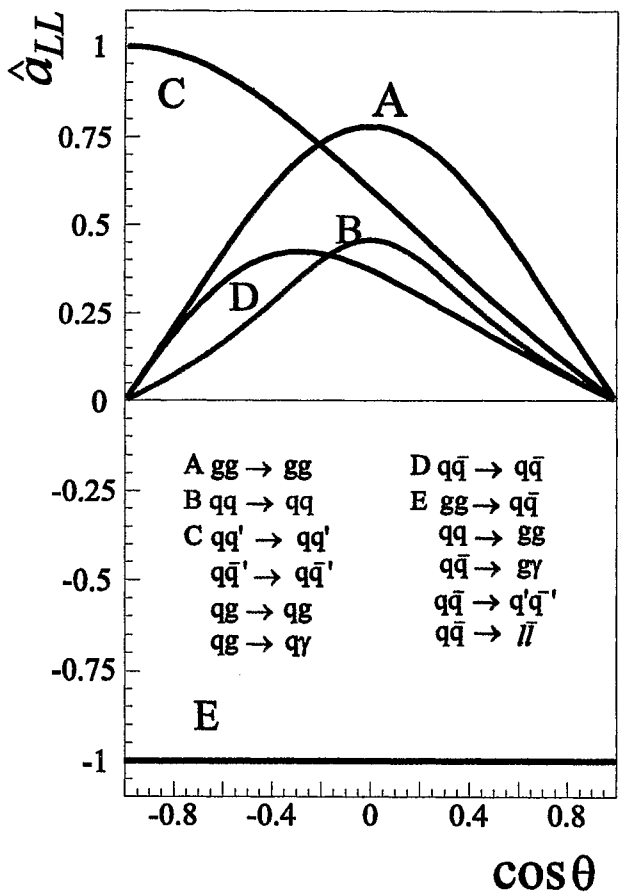


- latest development : first preliminary data from PHENIX !



- $\Rightarrow$ can A_{LL}^{π} be negative ? How negative can it be ?

- partonic subprocess asymmetries $\hat{a}_{\rm LL} \equiv \frac{\hat{\sigma}_{++} - \hat{\sigma}_{+-}}{\hat{\sigma}_{++} + \hat{\sigma}_{+-}}$



- $gg \to q\bar{q}$ has negative $\hat{a}_{\rm LL}$

- however, $\hat{\sigma}_{gg\to gg} \approx 160 \times \hat{\sigma}_{gg\to q\bar{q}}$ (at $\hat{\eta} = 0$)

A lower bound on A_{LL}^{π}

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 Δg :

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

$\mathcal{A}^N$: gg scatt.

$\mathcal{B}^N$: qg

$\mathcal{C}^N$: $qq,\ qq',\ q\bar{q},\ \ldots$

- 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 :

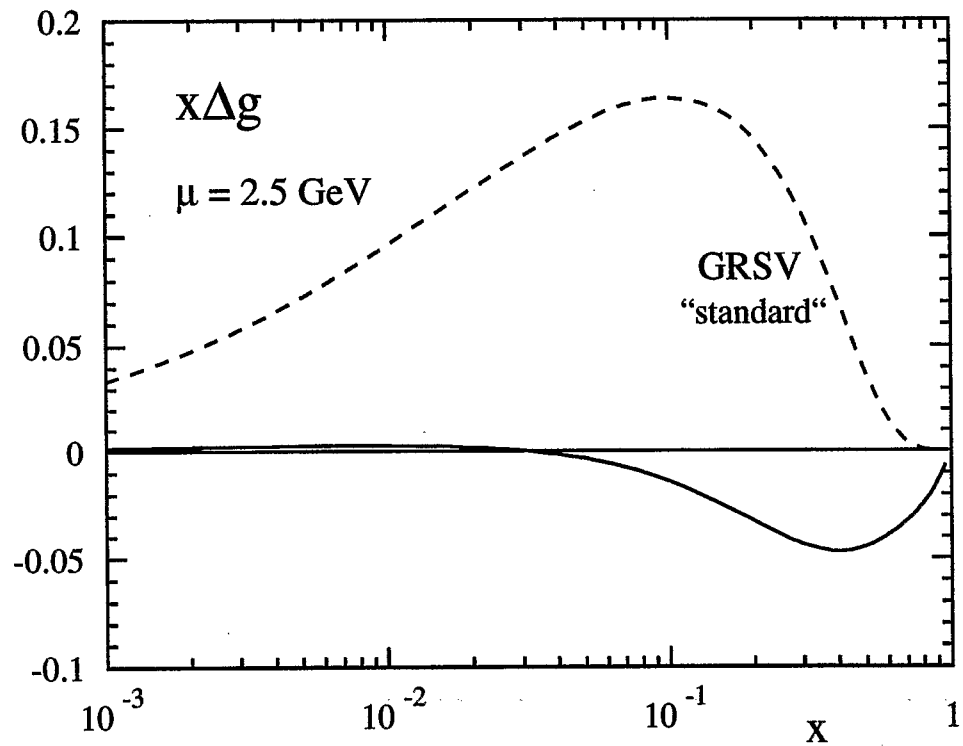
$$\frac{p_\perp^3 \, d\Delta\sigma^\pi}{dp_\perp}\Bigg|_{\min} \; = \; \frac{1}{2\pi i}\int_\Gamma dN \, \left(x_T^2\right)^{-N} \, \Delta\sigma^\pi(N)\Big|_{\min}$$

- resulting asymmetry : negative, but tiny

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

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

- the polarized gluon that minimizes $A_{\rm LL}^{\pi}$:



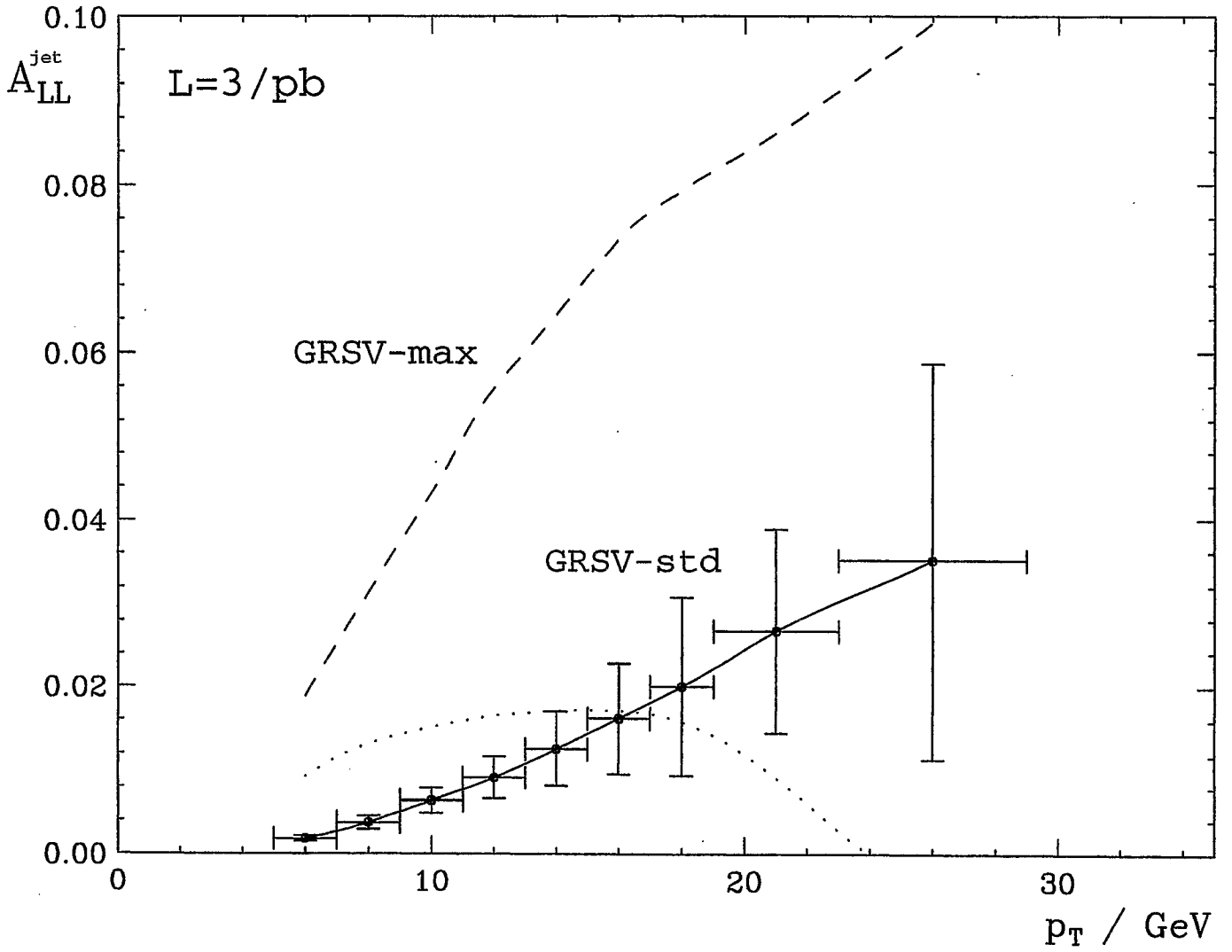
- a node – helps by allowing $\Delta g(x_a) \times \Delta g(x_b) < 0$

- a full "global analysis" confirms :

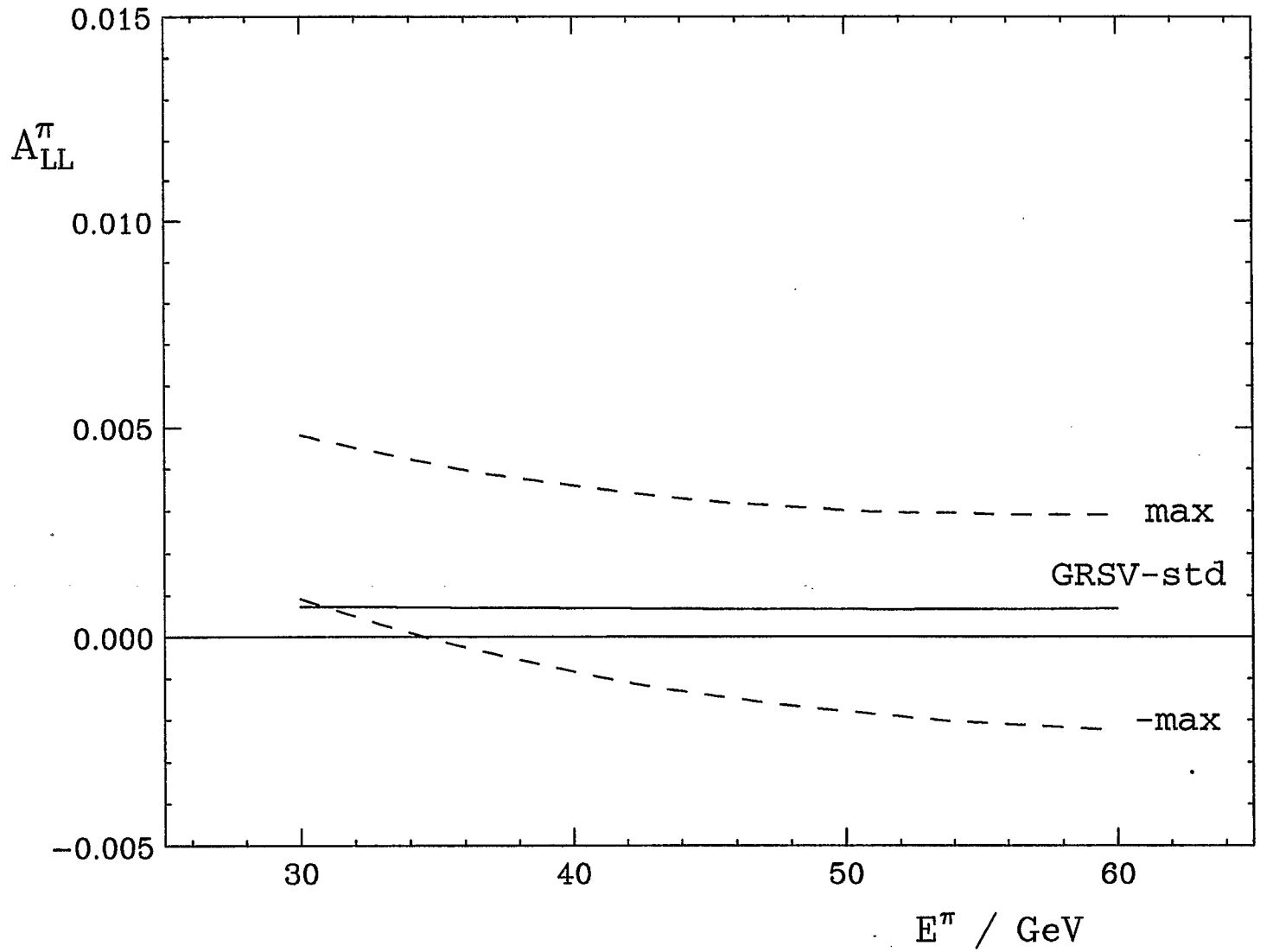
  pQCD at leading power predicts that a negative $A_{\rm LL}^{\pi}$ is small

$pp \to \mathrm{jet}X, \ \sqrt{S} = 200\,\mathrm{GeV}\,,\ 0 \le \eta \le 1$

de Florian,Frixione,Signer,WV



$pp \to \pi^0 X, \ \sqrt{S} = 200\,\mathrm{GeV}\,, \ \eta \ = \ 3.3$

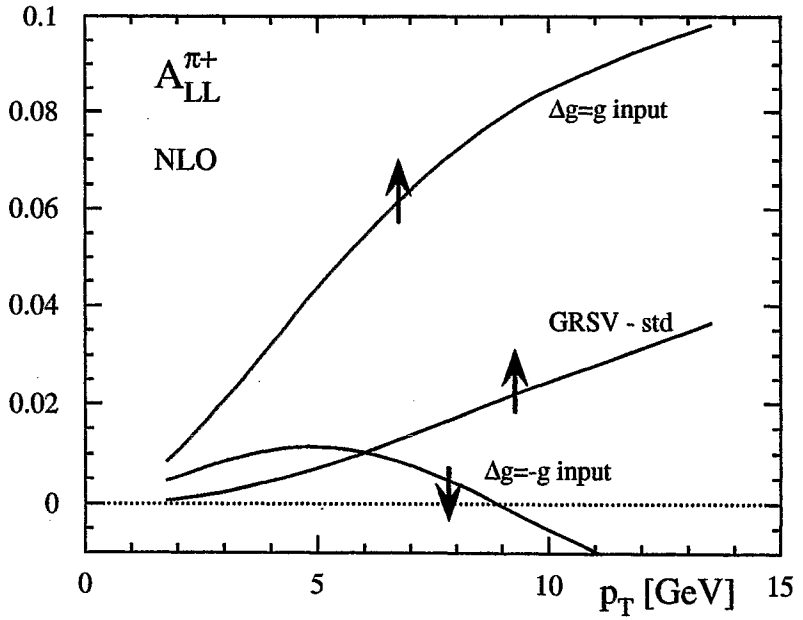


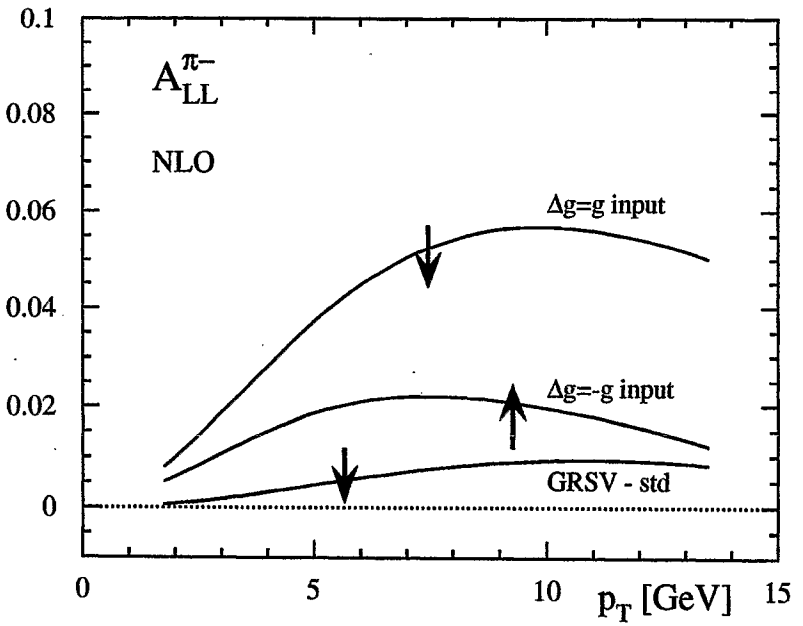
- dominance of $qg \to qg$ sets in

π^+ and π^-

positive Δg: $A_{LL}^{\pi^+} > A_{LL}^{\pi^0}$
negative Δg: $A_{LL}^{\pi^+} < A_{LL}^{\pi^0}$

positive Δg: $A_{LL}^{\pi^-} < A_{LL}^{\pi^0}$
negative Δg: $A_{LL}^{\pi^-} > A_{LL}^{\pi^0}$





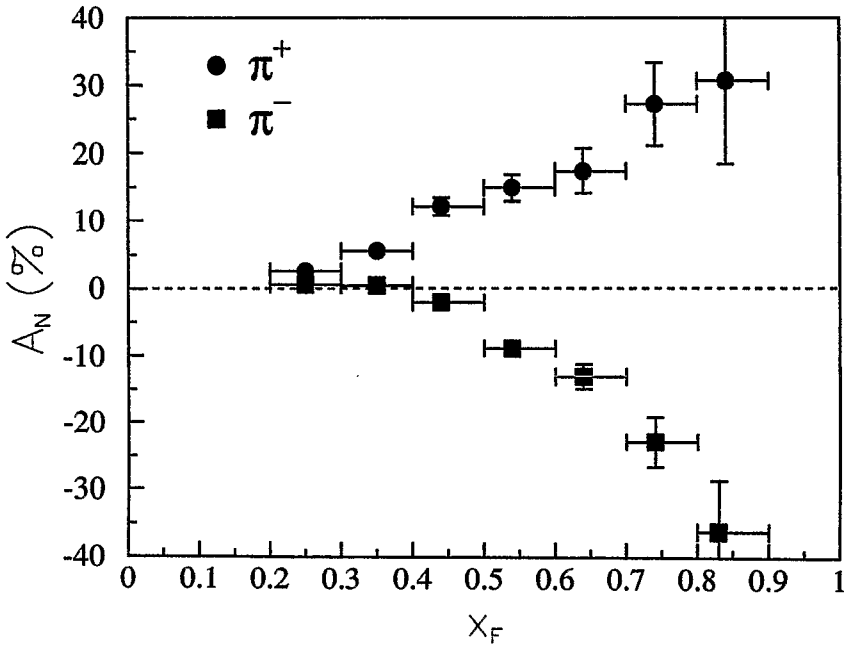
...only at $p_T > 5$ GeV, good statistics required

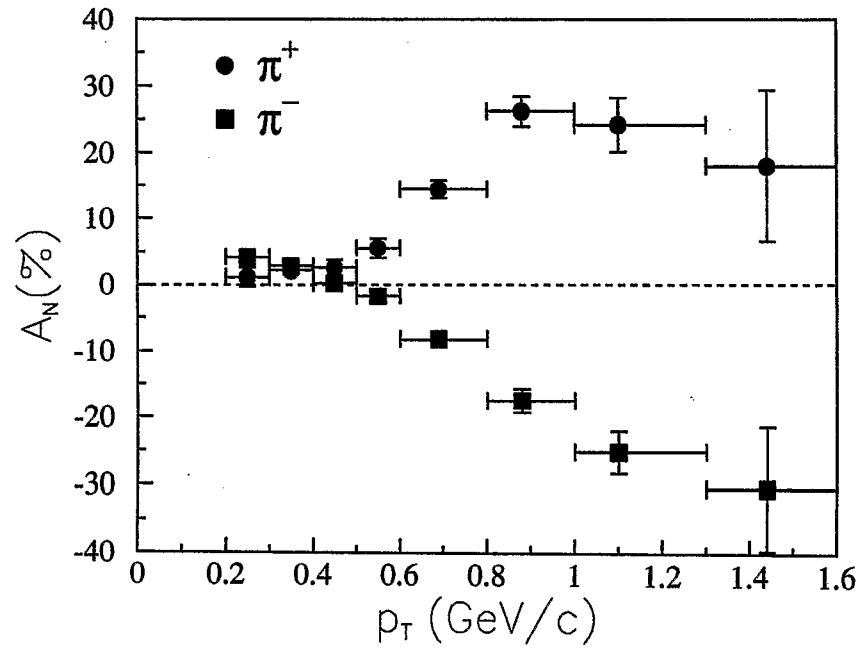
Single-transverse spin asymmetry A_{N}

- correlation $\sim i\,\vec{s}_T \cdot (\vec{p}_{\rm beam} \times \vec{l}_\pi)$

  * large $A_{\rm N}$ seen in fixed-target experiments at BNL,ANL,Fermilab,Serpukhov

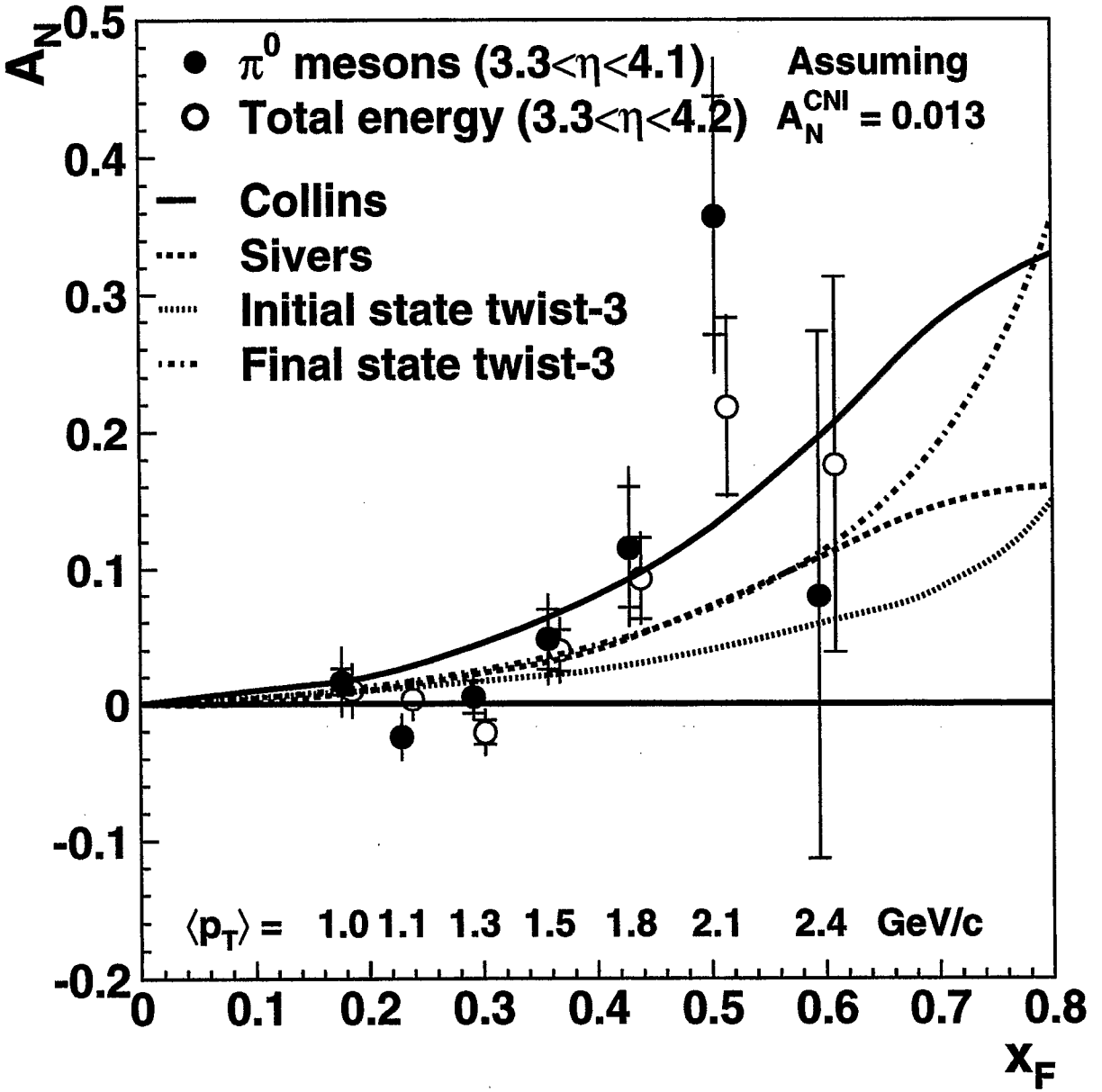
  * E704 ('96) :





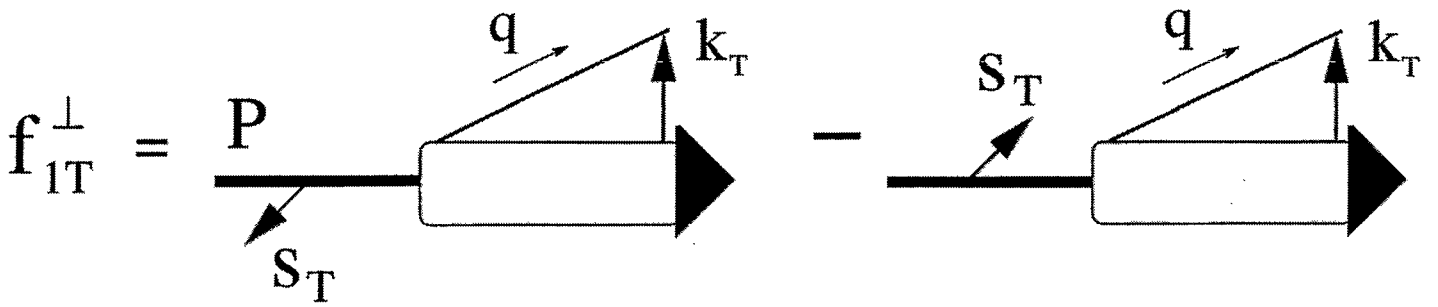
- $A_{\rm N}$ is power-suppressed as $1/p_T$ . . .

STAR



∗ higher p_T : see expected $1/p_T$ behavior ?

- Sivers '90 :



asymmetry $\boxed{q_{p\uparrow}(x, \vec{k}_T) \neq q_{p\uparrow}(x, -\vec{k}_T)}$

- mechanism is

$$A_{\rm N} \propto f_{1T}^{\perp}(x_a, k_\perp)\, q(x_b)\, \hat{\sigma}^{qq\to qq}(k_\perp)\, D(z)$$

- however Collins '93 : for distribution functions correlation $\vec{S}_T \cdot (\vec{P} \times \vec{k}_T)$ ruled out by T invariance of QCD

- recent development : gauge links that make pdfs *gauge invariant* allow the "T-odd" structure

(Brodsky,Hwang,Schmidt; Collins; Belitsky,Ji,Yuan; Boer,Mulders,Pijlman)

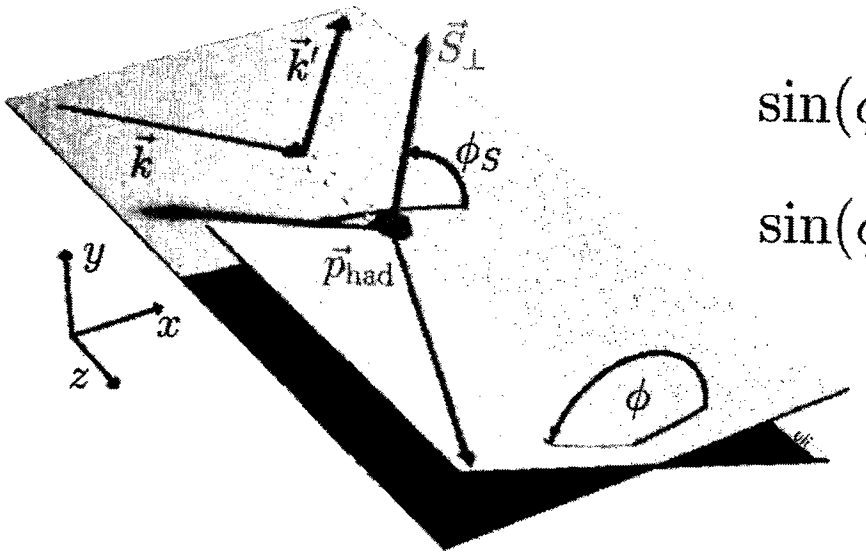
- $A_{\rm N}$ for a single-inclusive observable :
  - interpretation complicated : Sivers vs Collins vs Qiu/Sterman,Koike
  - $p^{\uparrow}p \to \gamma X,\ p^{\uparrow}p \to \mu^+\mu^- X,\ p^{\uparrow}p \to \text{jet}\, X\ \ldots$
  - factorization with $k_\perp$ an *assumption*

- there is a class of observables that depend directly on a measured k_T :
  - azimuthal asymmetries in $ep^{\uparrow} \to e'\pi X$
  - azimuthal asymmetries in $e^+e^- \to \pi\pi X$
  - $p^{\uparrow}p$ scattering ?

- for these, $k_\perp$ effects are not power-suppressed,
  and more experience with factorization is available

- example : $ep^{\uparrow} \to e\pi X$

Collins



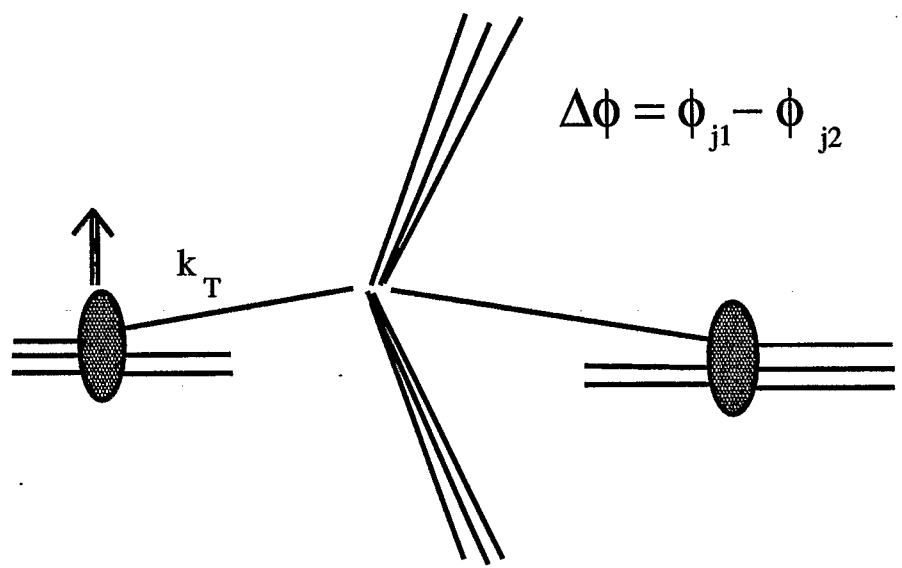
$$\sin(\phi + \phi_S) \sum_q e_q^2 \, \delta q(x) \, H_1^{\perp,q}(z)$$

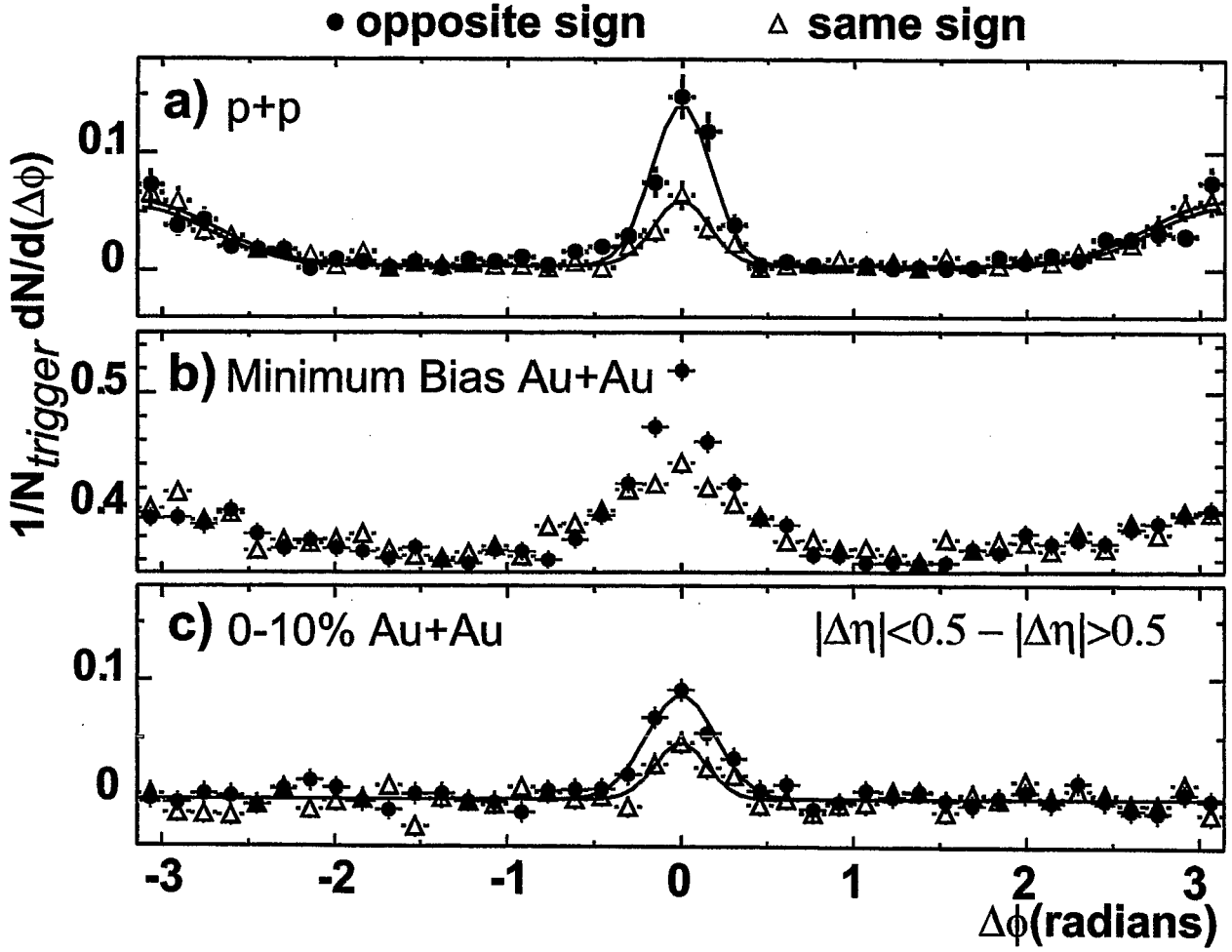
$$\sin(\phi - \phi_S) \sum_q e_q^2 \, f_{1T}^{\perp,q}(x) \, D_q(z)$$

- HERMES
- only moderate Q^2

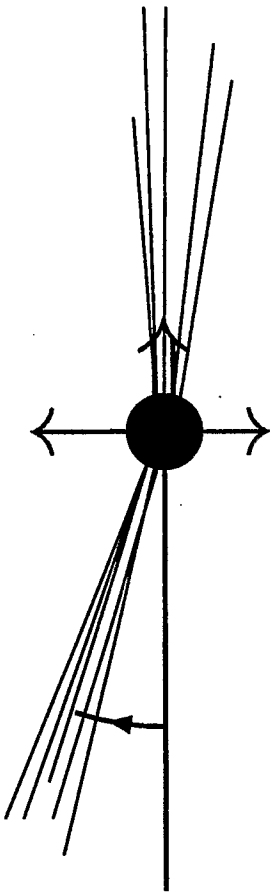
What's a similar observable in pp ?

- example : near back-to-back jets in $p^{\uparrow}p \longrightarrow$ jet jet X Boer,WV




• opposite sign
▵ same sign
a) p+p
b) Minimum Bias Au+Au
c) 0-10% Au+Au
|Δη|<0.5 – |Δη|>0.5
1/N_trigger dN/d(Δφ)
0.1
0
0.5
0.4
-3
-2
-1
0
1
2
3
Δφ(radians)

STAR



$$\phi_1 = 0$$

$$\phi_2 - \phi_1 = \pi + \Delta\phi$$

- A simple estimate : Boer,WV

- Gaussian $k_\perp$ distribution for partons in unpolarized proton :

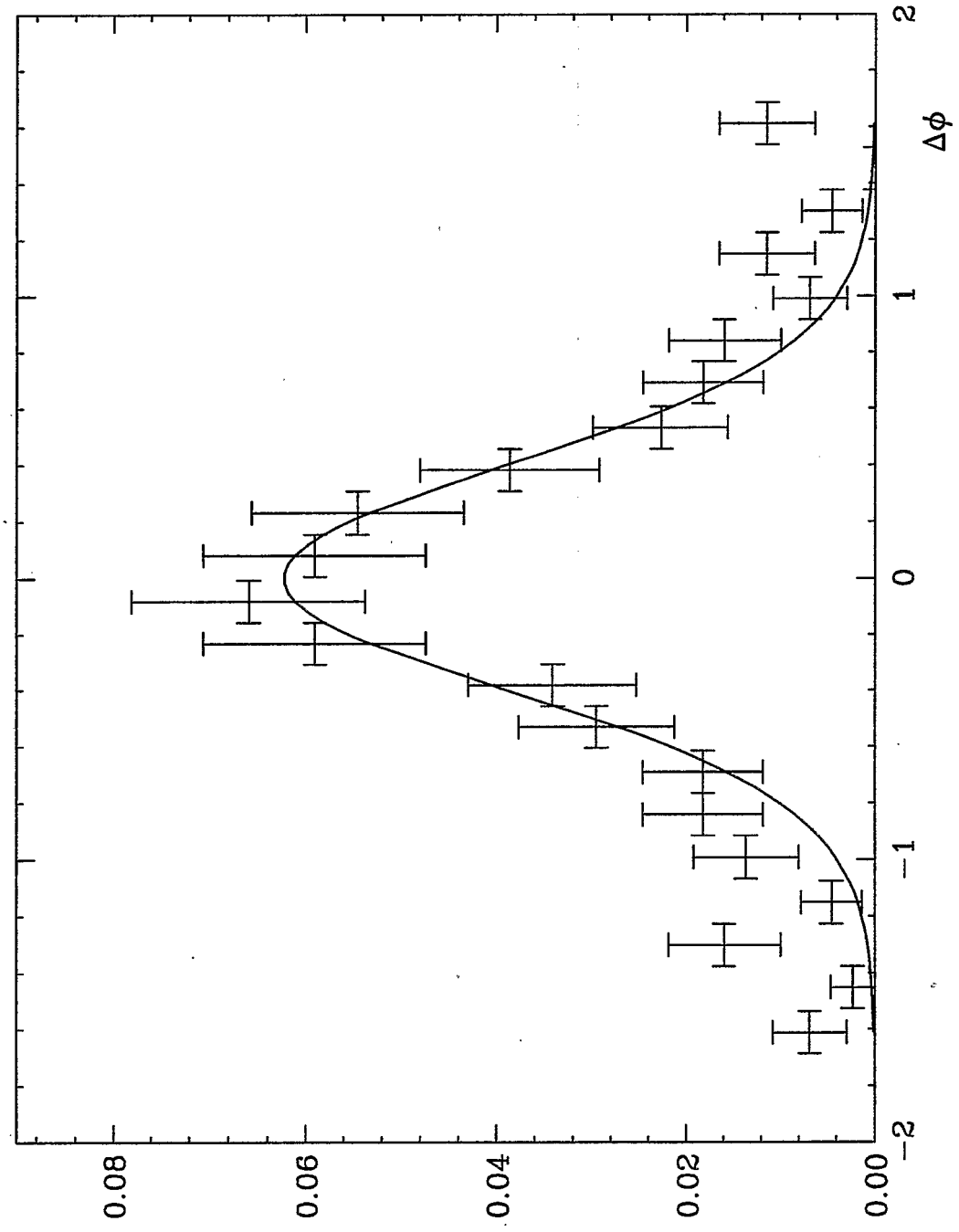
$$f(k_\perp) = \frac{\mathrm{e}^{-(k_\perp)^2/\langle k_\perp^2\rangle}}{\pi\langle k_\perp^2\rangle} \qquad \text{(mostly gluons)}$$

- leads to distribution

$$\propto \ \mathrm{e}^{-a\,(1-\cos(\Delta\phi))}$$

- fit to STAR back-to-back data :

$$\sqrt{\langle k_\perp^2\rangle} \ \approx \ 1.3 \text{ GeV}$$


0.08
0.06
0.04
0.02
0.00
−2
−1
0
1
2
Δφ

- Sivers type correlation :

$$f_{1T}^{\perp}(k_\perp) \propto k_\perp \, \mathrm{e}^{-(k_\perp)^2/\langle r_\perp^2 \rangle}$$

- leads to spin asymmetry

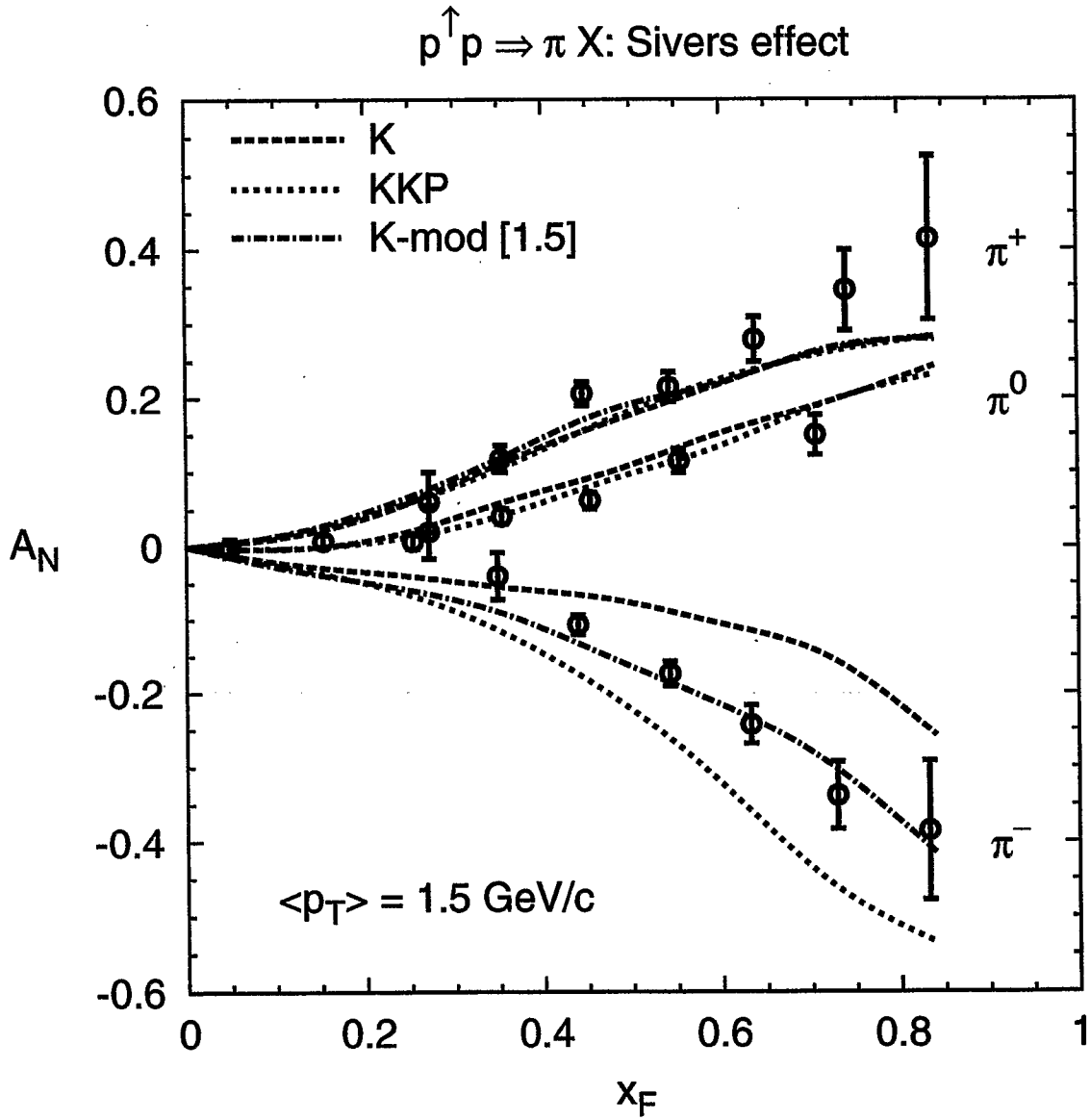
$$A_{\mathrm{N}} \propto \left(|\vec{P}_c^{\perp}| \sin\phi_c + |\vec{P}_d^{\perp}| \sin\phi_d \right) \frac{2\langle r_\perp^2 \rangle}{\left(\langle r_\perp^2 \rangle + \langle k_\perp^2 \rangle\right)^2} \, e^{-\left[\vec{P}_c^{\perp} + \vec{P}_d^{\perp}\right]^2 / \left(\langle r_\perp^2 \rangle + \langle k_\perp^2 \rangle\right)}$$

- for $\vec{P}_c^{\perp} \parallel \vec{S}_\perp$

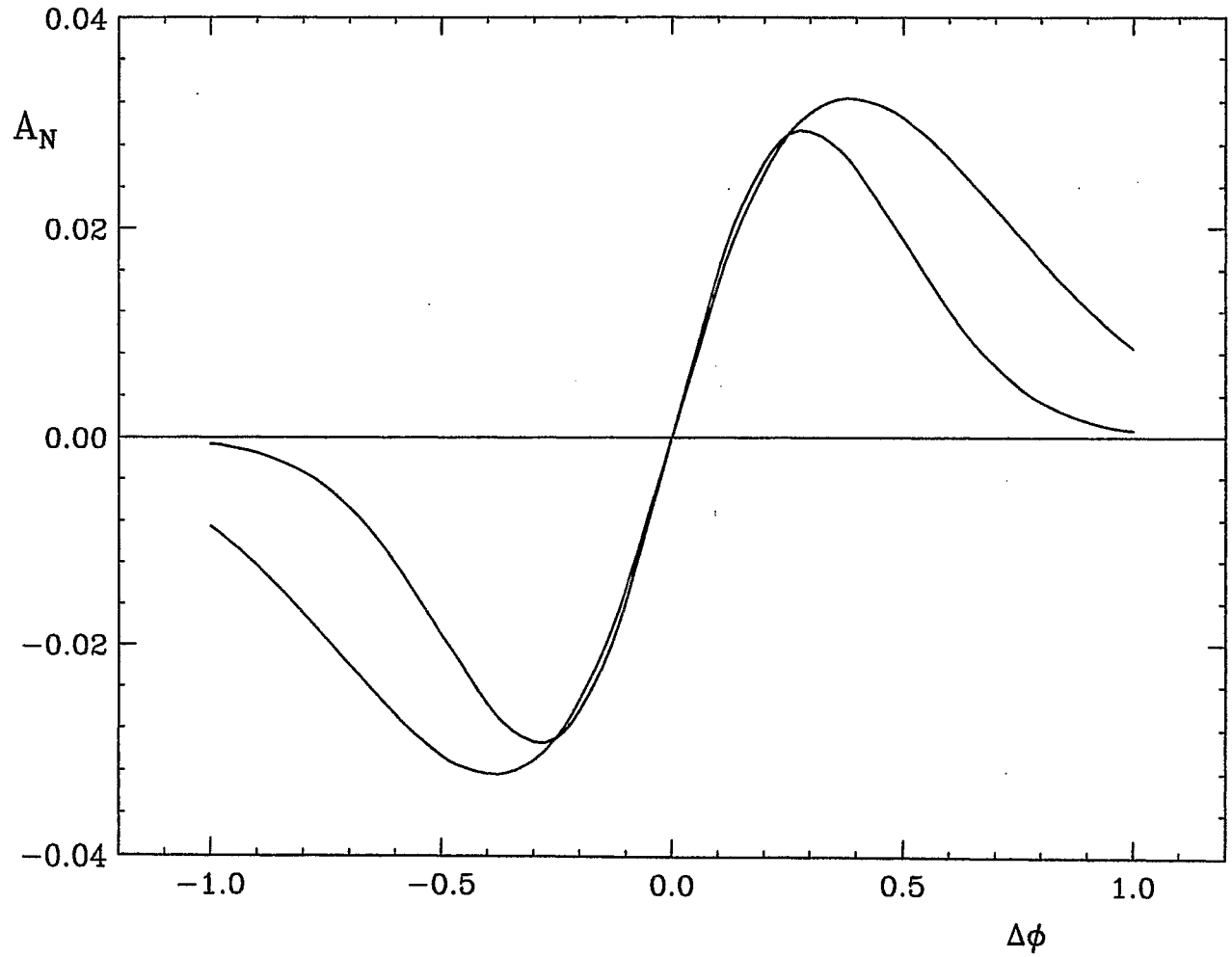
$$\propto \sin(\Delta\phi) \, \mathrm{e}^{-a\,(1-\cos(\Delta\phi))}$$

- use parameters of Anselmino,D'Alesio,Murgia
- very sensitive to gluon Sivers function
- future : perturbative tail, Sudakov effects

- d'Alesio,Murgia



$\sqrt{S} = 200\,\mathrm{GeV},\ 8 \leq p_{T_{1,2}} \leq 12\ \mathrm{GeV},\ -1 \leq \eta_{1,2} \leq 1$ Boer,WV



Conclusions :

Δg

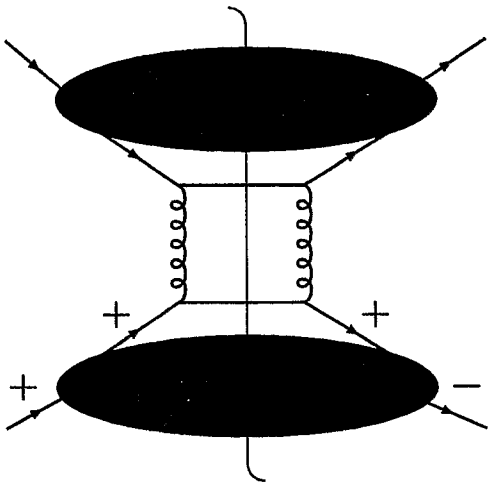
- a lot can be learned from jets and hadrons
- sign of Δg from forward region ?
- most theoretical tools in place – some challenges remain

A_{N}

- look for $1/p_T$ behavior of $p^{\uparrow}p \to \pi X$
- large potential for back-to-back observables

- physics importance of Sivers function :

  * interference of $J_z = +\frac{1}{2}$ and $J_z = -\frac{1}{2}$ amplitudes
    $\longrightarrow$ orbital angular momentum



  * Burkardt : connection $q(x, \vec{k}_T) \leftrightarrow q(x, \vec{b}_T) \leftrightarrow H\,,\ E$ "GPD's"

  * universality ?

$$f_{1T}^{\perp}|_{\rm DY} = -f_{1T}^{\perp}|_{\rm DIS}$$

Collins; Brodsky,Hwang,Schmidt;

Belitsky,Ji,Yuan; Boer,Mulders,Pijlman; Anselmino,D'Alesio,Murgia

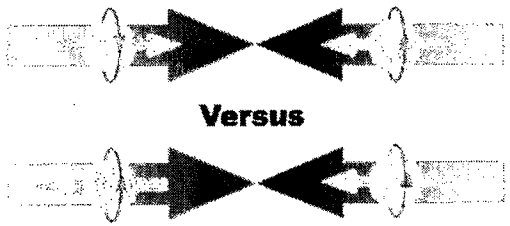
π^0 A_{LL} analysis in PHENIX

K. Tanida (RIKEN/RBRC)
RSC meeting 11/18/03

Outline

- Relative luminosity
  - estimation of systematic error
  - A_{LL} in ZDC/BBC
- LocalPol
- Counting number of π^0's
- Result

A_{LL}



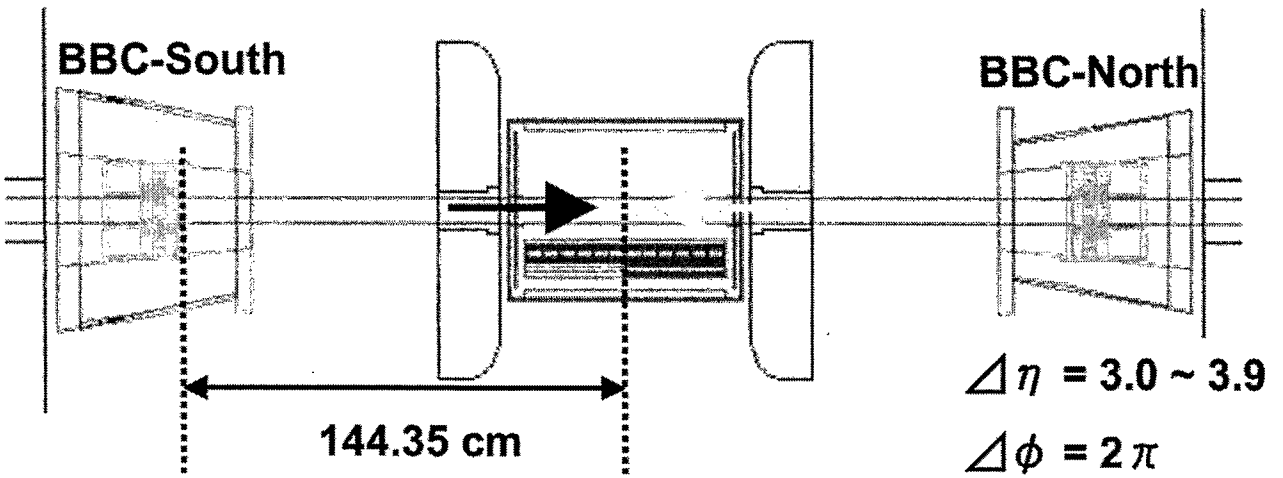
$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{|P_B P_Y|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

++ same helicity
+– opposite helicity

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

How to get relative luminosity?

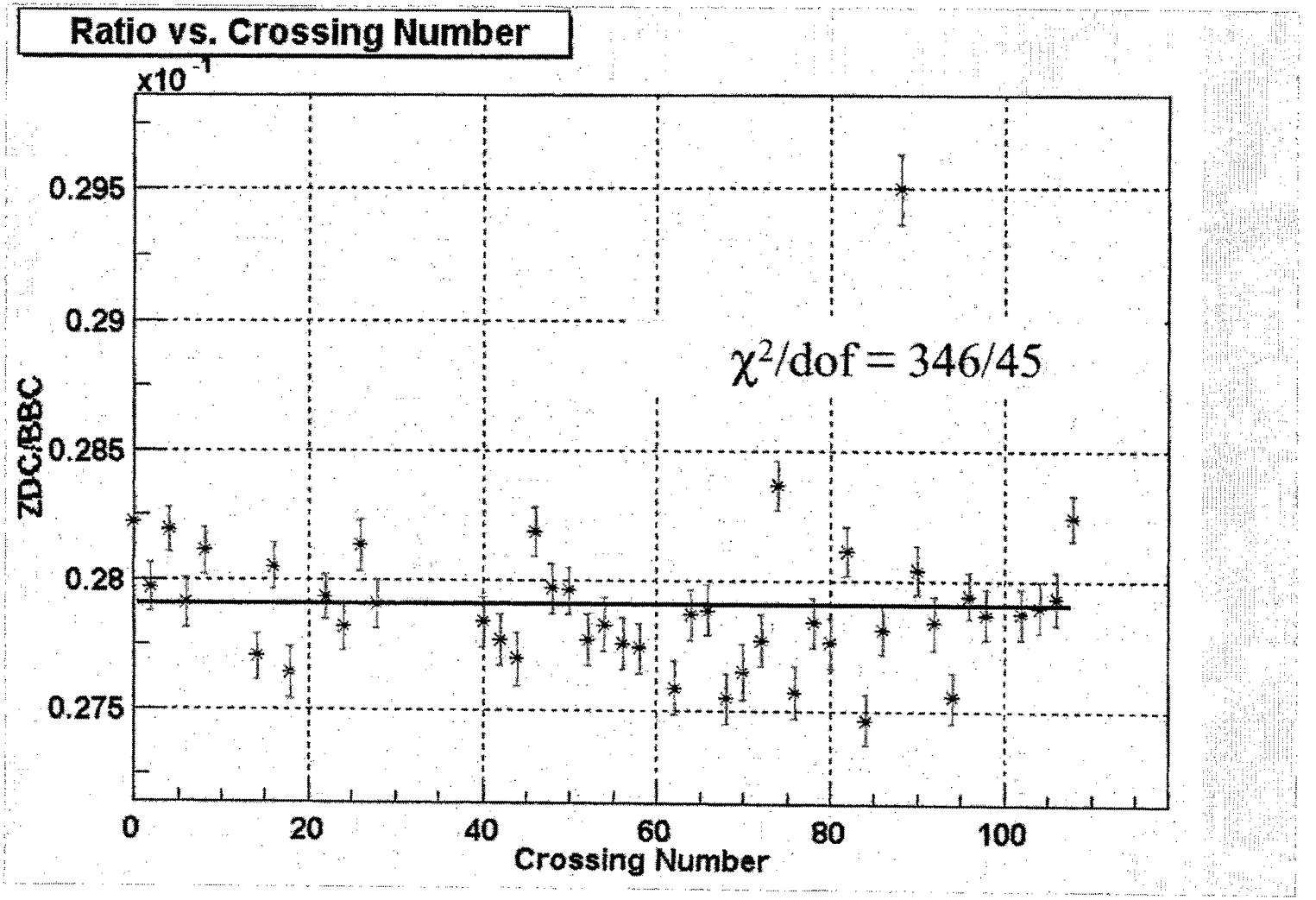
- Principle: $R=N_{++}/N_{+-}$ -- from any counter (trigger)
- BBCLL1 trigger
  - coincidence of two Beam-Beam Counters
  - small background ($\sim 10^{-4}$)
  - high statistics (detects ~ 1/2 of all collisions)
  - A_{LL}^{BBC}: expected to be small, need confirmation



Method of accuracy estimation

- Cross-check by ZDCLL1 trigger
  (Zero Degree Calorimeter)
  - low background (~ 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 crossing
- Required accuracy: constant to 10^{-3} level for each fill.

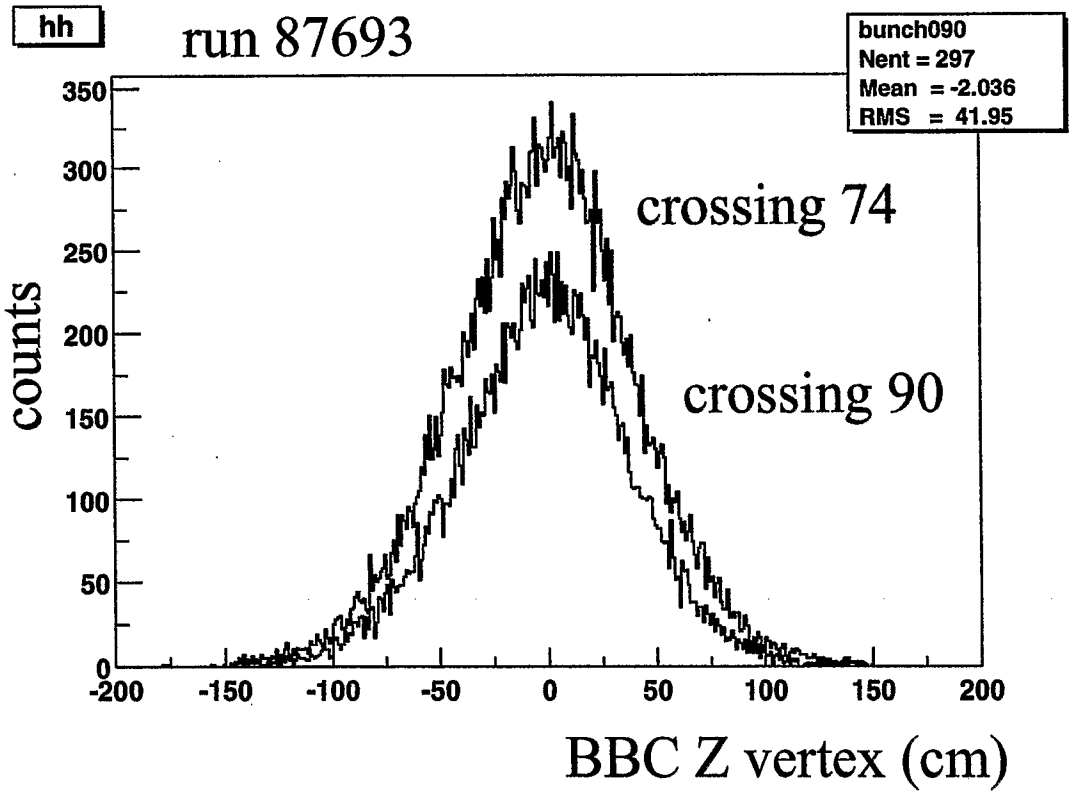
crossing-by-crossing ratio



Significant deviation from constant. Why?

Possible explanation – detector acceptance

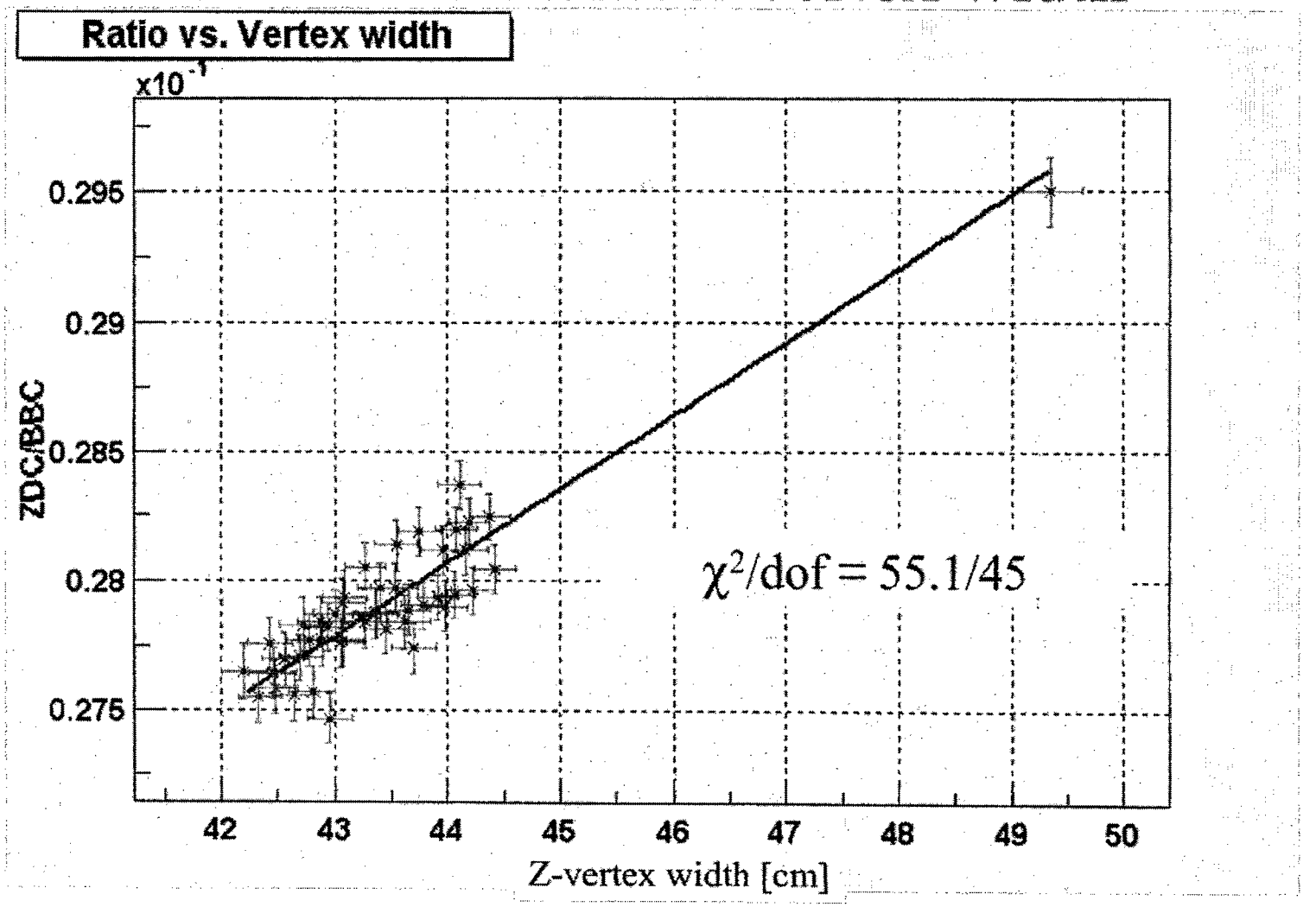
- Extreme cases
  - Flat acceptance
    → N: area
  - Narrow acceptance
    → N: height



- ZDCLL1: Z-vertex resolution ~ 20 cm (wider acceptance)
- BBCLL1: ~ 5 cm (narrower)

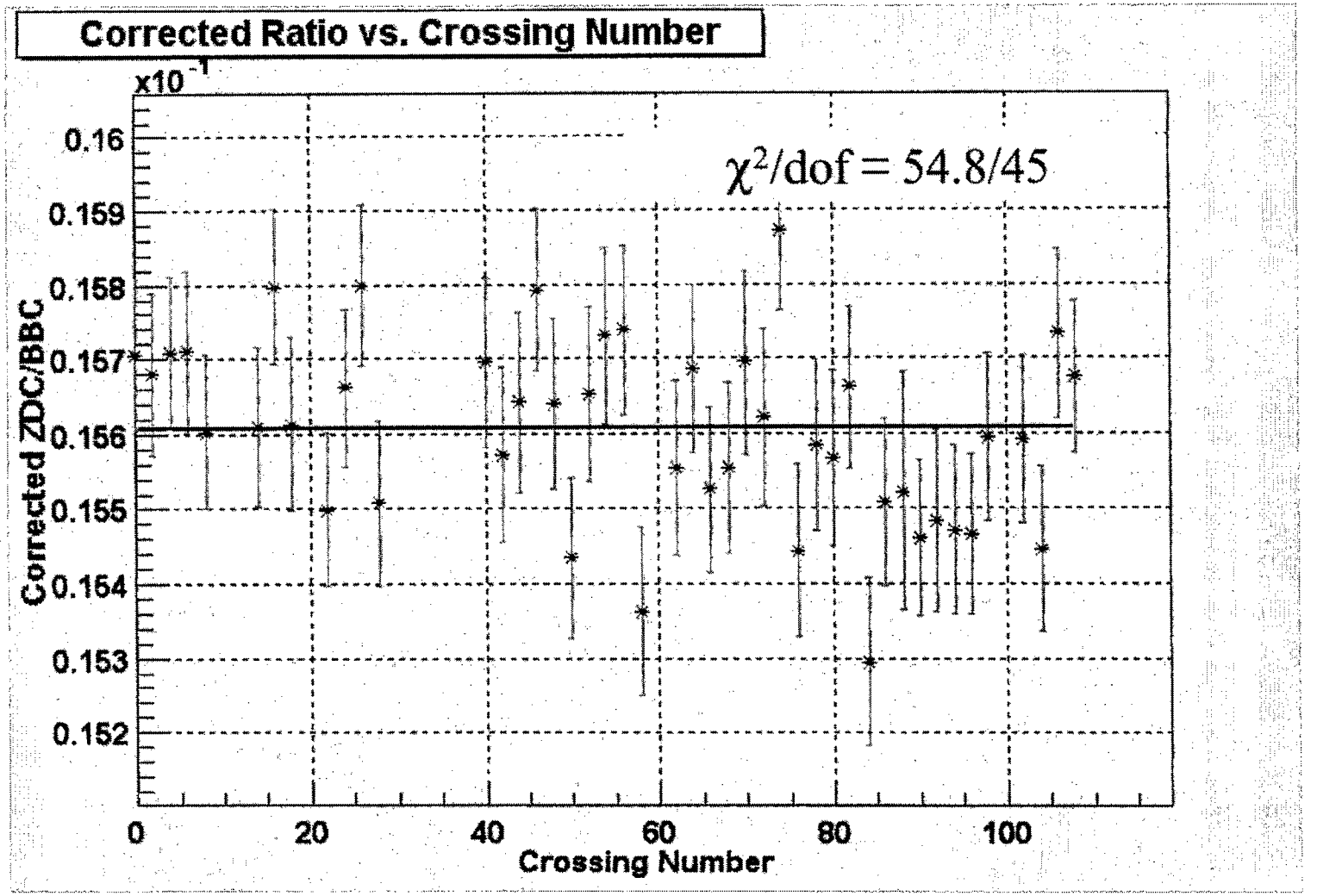
  (both have Z-vertex cut at ±30 cm)

Correlation with Z-vertex width



We understand the reason now → correction

After correction



Relative luminosity accuracy < 0.09% (stat. limited)

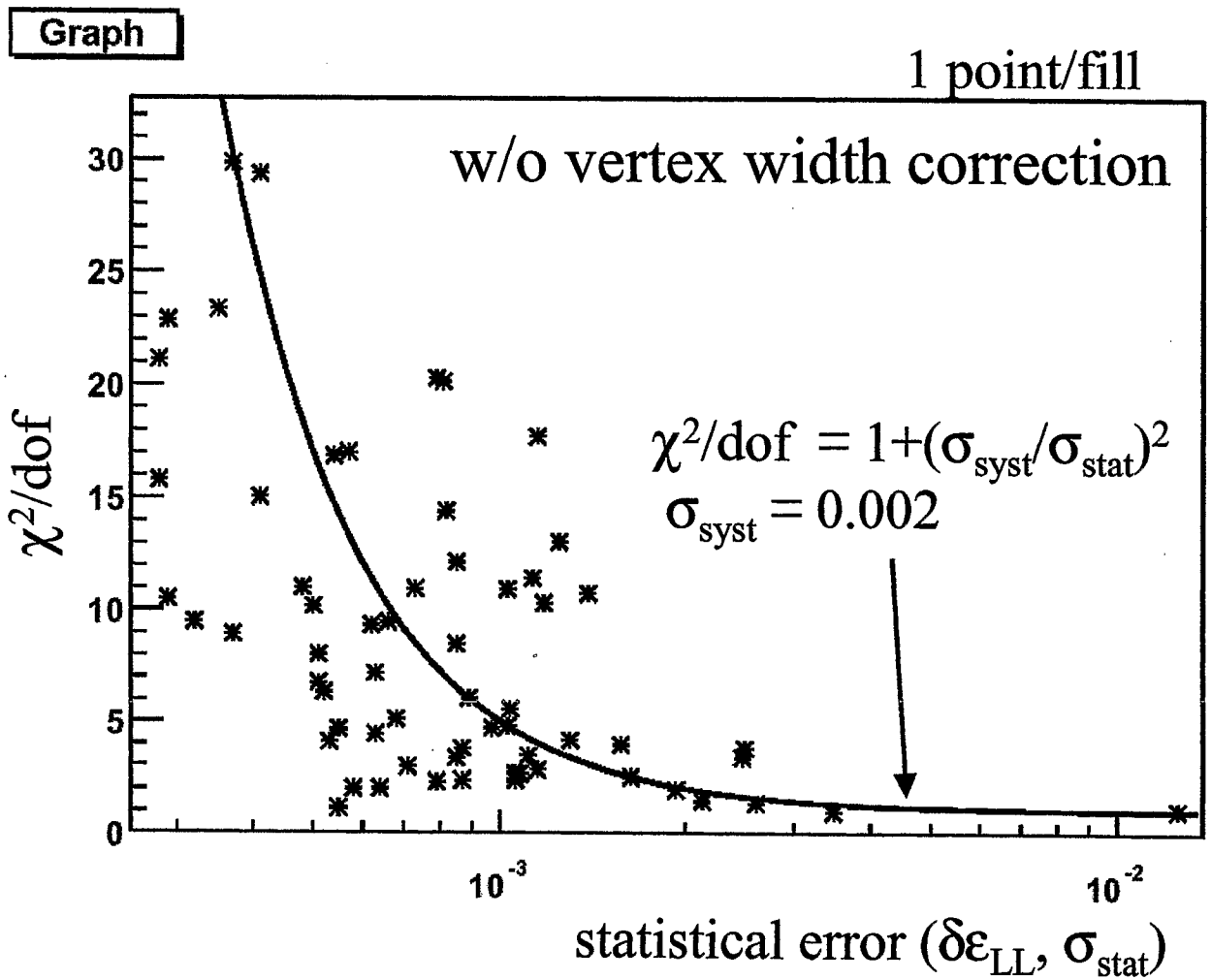
Alternative correction

- Actual vertex width is not yet available in most runs (will come soon)
- Alternative width estimation
  → use ZDCout/ZDCin ratio
    - ZDCin: ZDCLL1 counts with Z-vertex cut of 30 cm
    - ZDCout: ZDCLL1 outside of ZDCin.
      (both are counted crossing-by-crossing)
  → wider vertex distribution ⇔ larger ratio

Actual accuracy estimation -- Bunch fitting

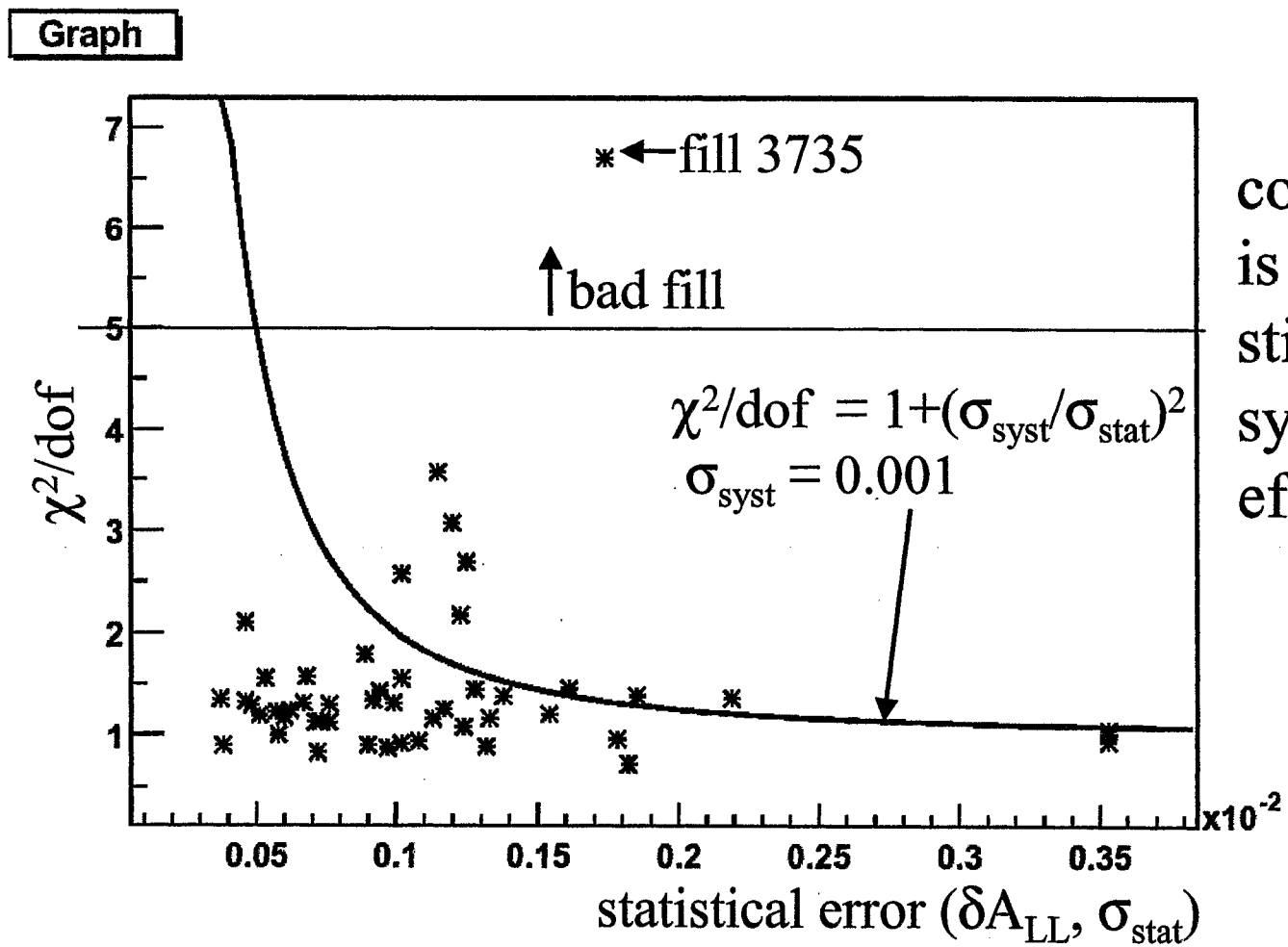
- Crossing-by-crossing analysis, taking care of possible effect of A_{LL} in BBC and ZDC
- For i-th crossing, calculate
  $r(i) = N_{ZDCLL1}(i)/N_{BBCLL1}(i)$
  corrected for vertex width
- Fit r(i) by
  $r(i) = C[1+A_{LL}^{BBC/ZDC}P_B(i)P_Y(i)]$
  fit parameter: C, $A_{LL}^{BBC/ZDC}$
- You will get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

χ^2 vs stat. error – before correction



correlating
→ $\sigma_{syst} \sim 0.002$

χ^2 vs stat. error – after correction



correlation is weak, but still some systematic effect remains

Result & BBC/ZDC A_{LL}

- Systematic error seen → χ^2 correction required
- If χ^2/dof is larger than 1, then enlarge statistical error by sqrt(χ^2/dof) – conservative correction
- Averaged result: $A_{LL}^{BBC/ZDC} = (1.8 \pm 1.8) \times 10^{-3}$
  (without vertex width correction, δA_{LL} is ~2 larger)
- 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 $A_{LL} = 0$

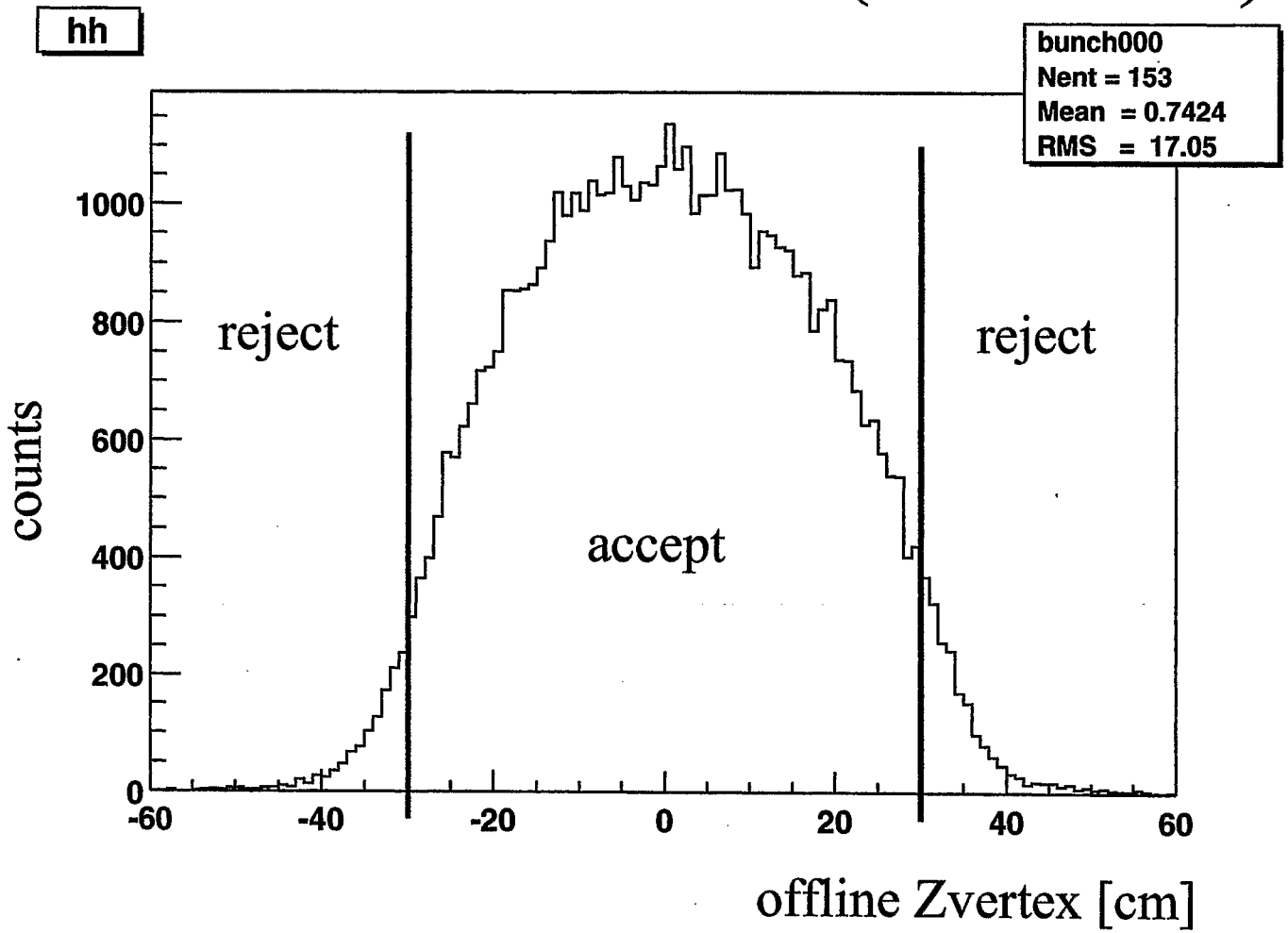
Some notes

- We reached $\delta A_{LL}^{BBC/ZDC}=1.8 \times 10^{-3}$
  - this is dominated by statistics of ZDC, so it's rather conservative estimation
  - actual relative luminosity is given by BBC
- In π^0 analysis, vertex position dependence of acceptance is the same as BBCLL1 because
  - BBC hits are required in the analysis
  - PHENIX central arm acceptance is almost flat for π^0 within the region we are using ($\pm$30 cm)

Remaining tasks for rel. luminosity

- Apply offline Z-vertex cut
  - better resolution: ~ 5 cm → ~ 2 cm
    (effect is found to be small)
- Full accuracy estimation using real vertex distribution.
  - correction for other than vertex width?
- Study effect of multiple collisions
  - negligible in Run3, significant for higher luminosity.
- Z-vertex dependence of acceptance (efficiency) for BBCLL1, π^0 and other reaction channels.
  - reaction channel specific relative luminosity.
  - BBCLL1 itself is almost perfect for π^0 case, but may be not for other channels.

Vertex distribution (BBCLL1)

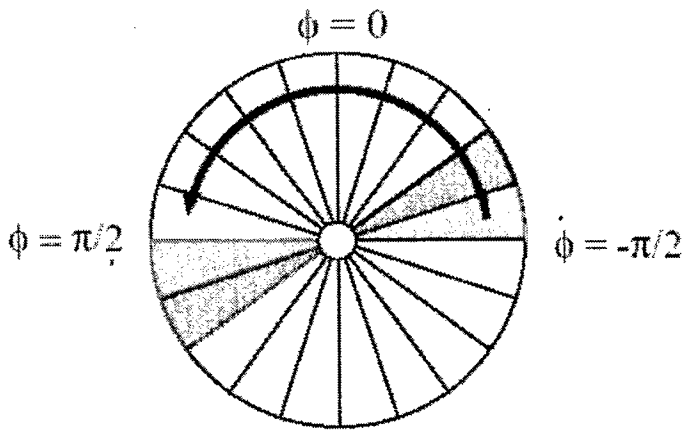


changes rel. lumi. by < 0.04% per fill (negligible)

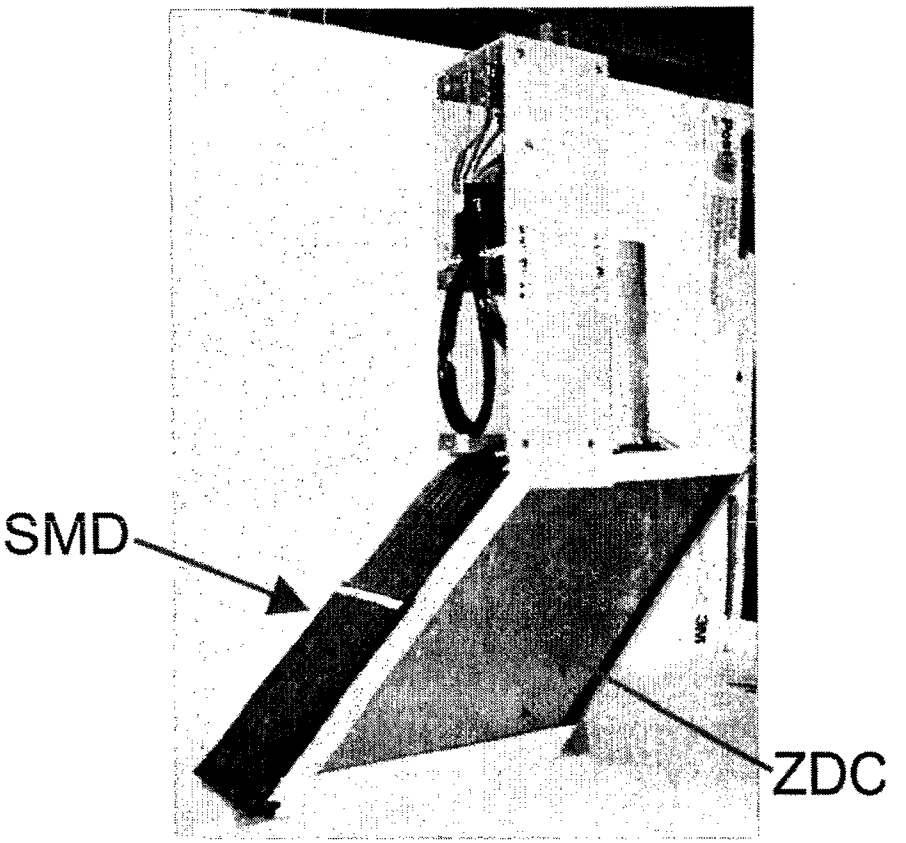
PHENIX Local Polarimeter

- ✓ Forward neutron transverse asymmetry (A_N) measurements
- ✓ SMD (position) + ZDC (energy)

ϕ distribution



Vertical → $\phi \sim \pm\pi/2$
Radial → $\phi \sim 0$
Longitudinal → no asymmetry



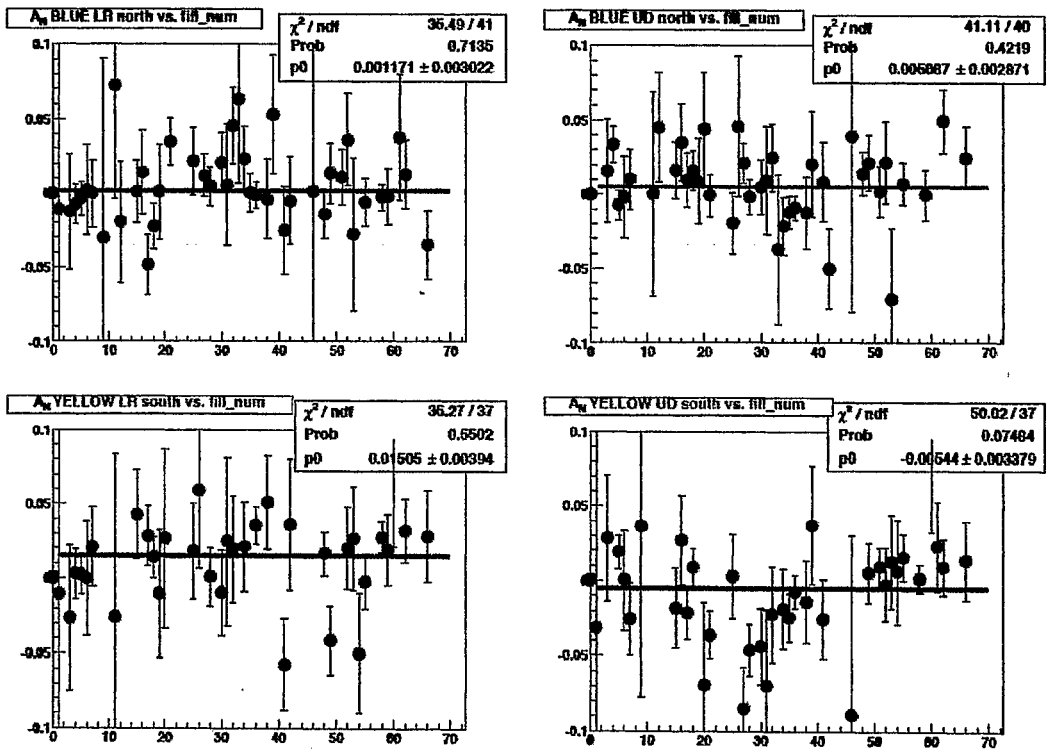
Spin Longitudinal Component

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

S_T is measured with PHENIX Local Polarimeter

Left-Right asymmetry

Up-Down asymmetry



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

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

π^0 counting

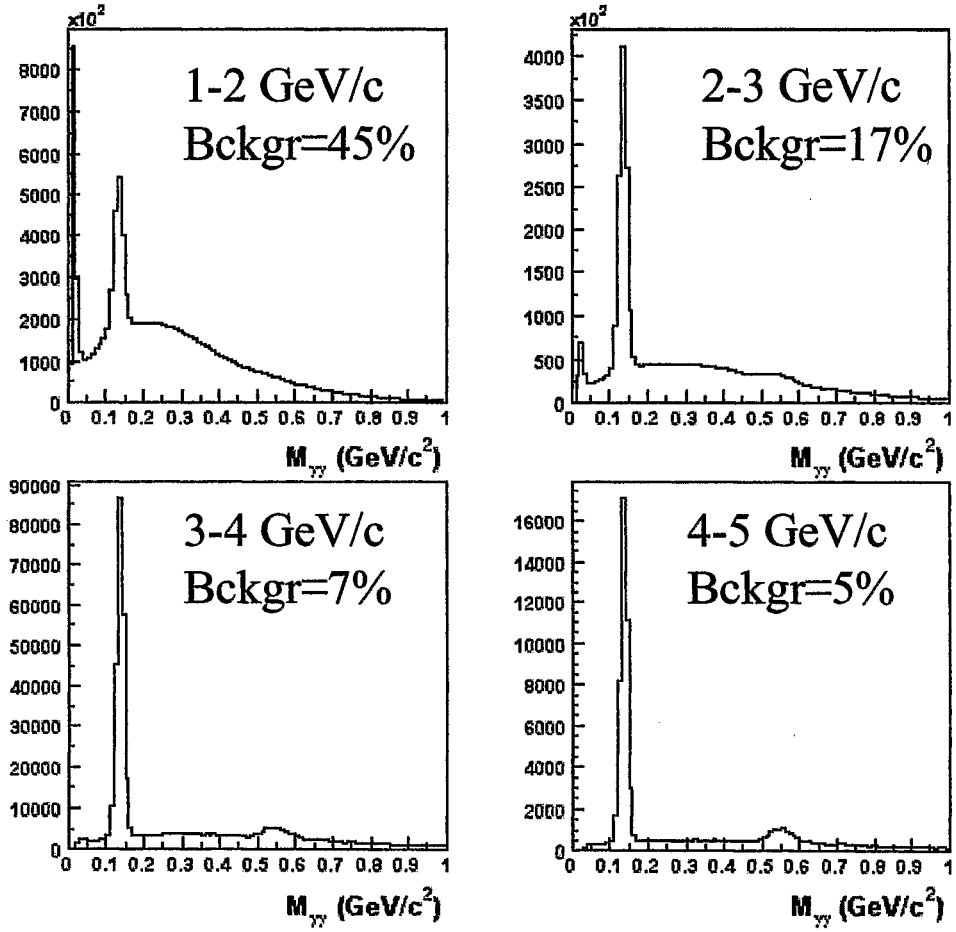
Data collected with high p_T photon trigger

- 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" $\pi 0$ cross section at low p_T
- For high p_T photon trigger efficiency study

π^0 reconstruction for A_{LL}

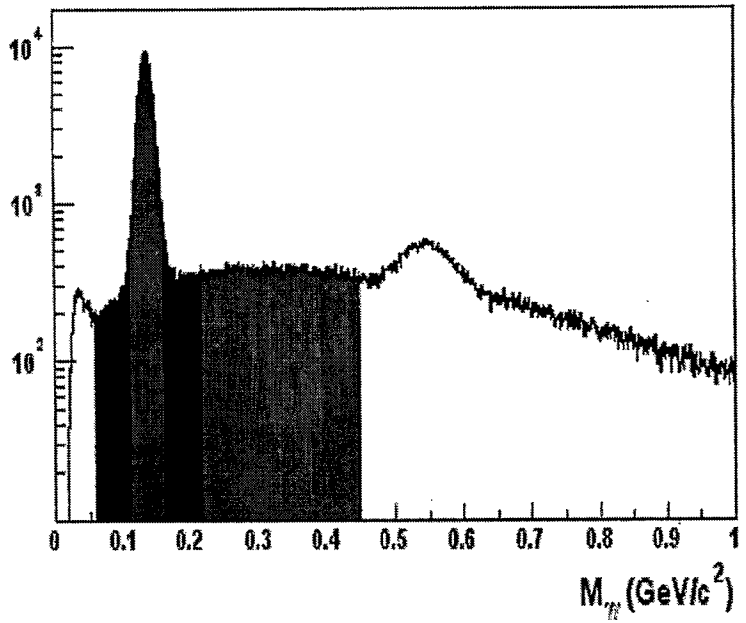


Results obtained for four pt bins from 1 to 5 GeV/c

Pi0 peak width varies from 12 to 9.5 MeV/c^2 from lowest to highest pt bins

Background contribution under pi0 peak for ±25 MeV/c^2 mass cut varies from 45% to 5% from lowest to highest pt bins

π^0 counting for A_{LL}



$N_{\pi 0}$:
±25 MeV/c^2 around $\pi 0$ peak (and also ±15 and ±35 MeV/c^2 for cross checks)

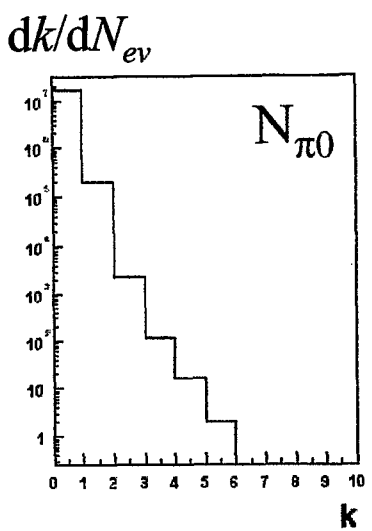
N_{bck1}:
Two 50 MeV/c^2 wide areas adjacent to $\pi 0$ peak

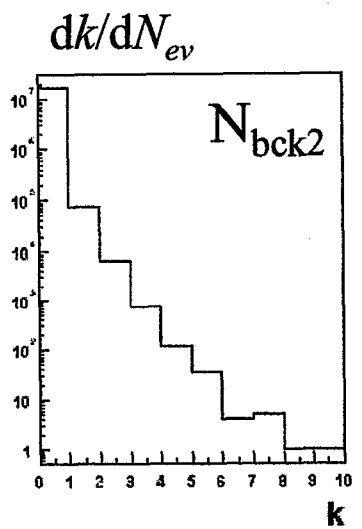
N_{bck2}:
250 MeV/c^2 wide area between $\pi 0$ and η peaks

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

pt GeV/c	$N_{\pi 0}$ 15 MeV/c^2	$N_{\pi 0}$ 25 MeV/c^2	$N_{\pi 0}$ 35 MeV/c^2	N_{bck1}	N_{bck2}
1-2	1278k	1777k	2129k	1470k	3478k
2-3	874k	1059k	1146k	335k	989k
3-4	176k	201k	208k	27k	83k
4-5	34k	38k	39k	3.9k	12k

$N_{\pi 0}$ statistical error estimation





In multi-π^0 events:

$$\sigma^2_{N_{\pi 0}} = \sigma^2_k N_{ev} + \langle k \rangle^2 \quad \sigma^2_{N_{ev}} = \langle k^2 \rangle N_{ev}$$

Comparison to naïve approach: $\sigma^2_{N_{\pi 0}} = N_{\pi 0}$

$$(k^{enhance})^2 = \frac{\langle k^2 \rangle N_{ev}}{N_{\pi 0}} = \frac{\langle k^2 \rangle}{\langle k \rangle}$$

Fluctuation enhancement (squared) due to multi-particle events

pt GeV/c	$N_{\pi 0}$ 15 MeV/c^2	$N_{\pi 0}$ 25 MeV/c^2	$N_{\pi 0}$ 35 MeV/c^2	N_{bck1}	N_{bck2}
1-2	1.134	1.220	1.302	1.360	1.708
2-3	1.047	1.081	1.114	1.178	1.406
3-4	1.015	1.026	1.037	1.101	1.222
4-5	1.008	1.015	1.021	1.059	1.162

A_{LL} measurements

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

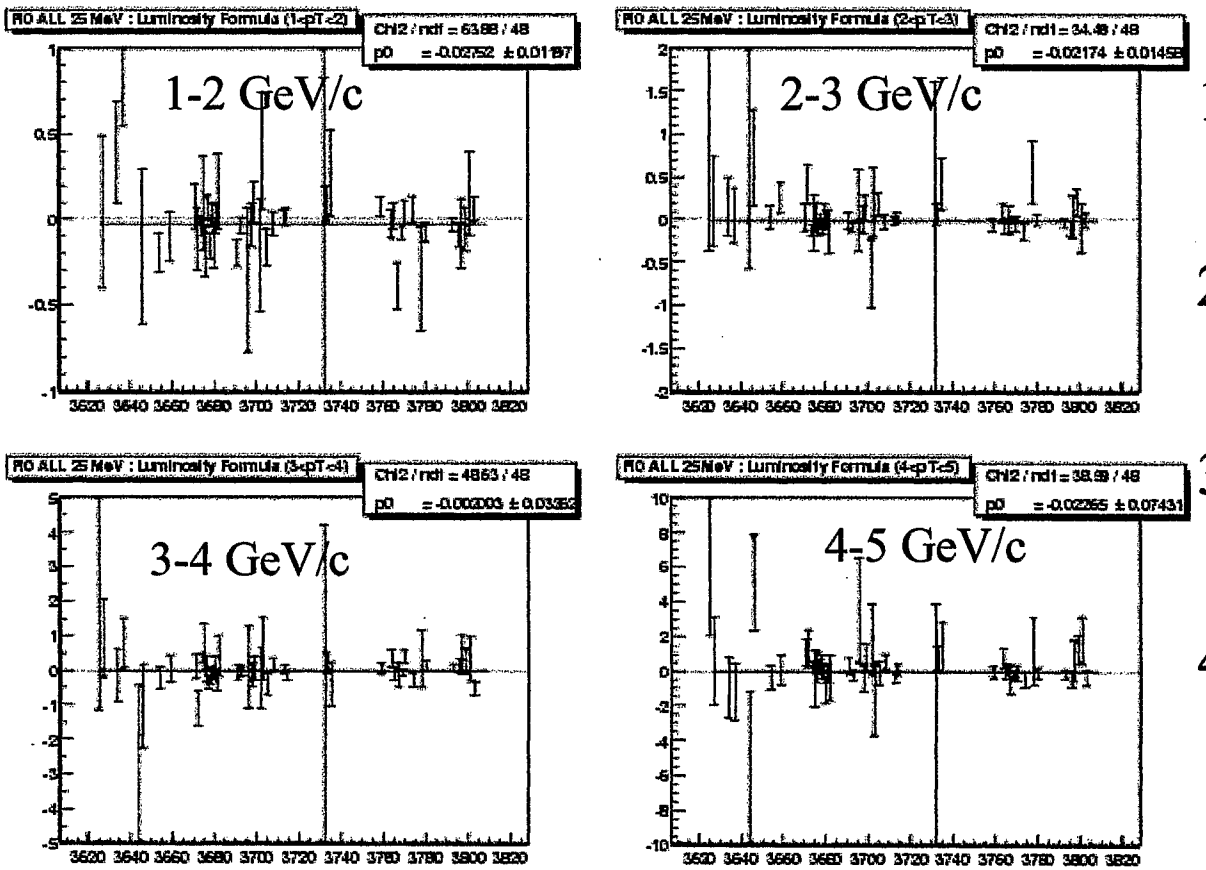
++ same helicity
+– opposite helicity

Procedure

1. Collect N and L for ++ and +– configurations (sum over all crossings) and calculate A_{LL} for each fill
2. Average A_{LL} over fills; use χ^2/NDF to control fit quality; use "bunch shuffling" to check syst. errors

A_{LL} Calculations

A_{LL} averaged over fills



1-2 GeV/c

A_{LL}= -2.8%±1.2%

χ^2/ndf = 64/48

2-3 GeV/c

A_{LL}= -2.2%±1.5%

χ^2/ndf = 34/48

3-4 GeV/c

A_{LL}= -0.2%±3.3%

χ^2/ndf = 49/48

4-5 GeV/c

A_{LL}= -2.3%±7.4%

χ^2/ndf = 39/48

A_L check for "yellow" beam

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = -\frac{1}{|P|}\frac{N_+/L_+ - N_-/L_-}{N_+/L_+ + N_-/L_-}$$

pt GeV/c	$A_L^{\pi 0+bck}$ 15 MeV/c²	$A_L^{\pi 0+bck}$ 25 MeV/c²	$A_L^{\pi 0+bck}$ 35 MeV/c²	A_L^{bck1}	A_L^{bck2}
1-2	0.001±0.004	0.000±0.003	0.000±0.003	0.002±0.004	0.000±0.003
2-3	0.001±0.004	0.000±0.004	0.000±0.004	0.002±0.007	0.002±0.005
3-4	0.007±0.009	0.011±0.009	0.008±0.009	-0.033±0.025	-0.010±0.015
4-5	-0.001±0.021	0.004±0.020	0.008±0.020	0.020±0.064	0.050±0.039

All are zeros within 1.5σ

A_L check for "blue" beam

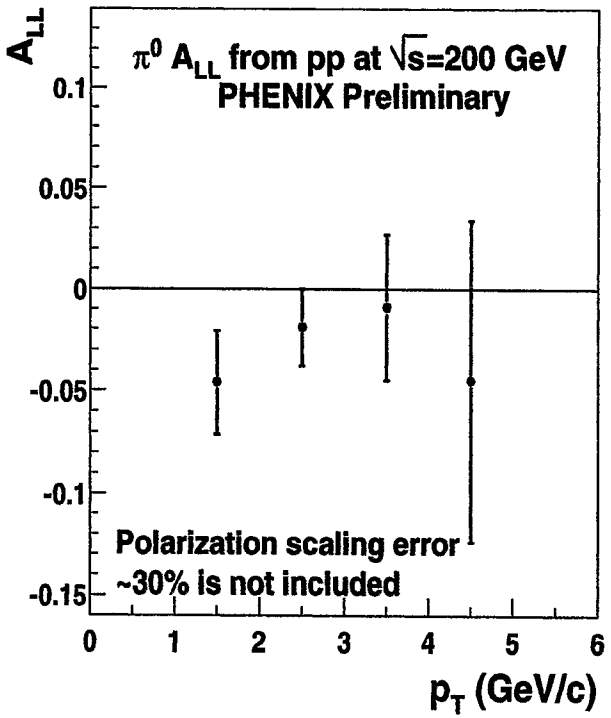
$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = -\frac{1}{|P|}\frac{N_+/L_+ - N_-/L_-}{N_+/L_+ + N_-/L_-}$$

pt GeV/c	$A_L^{\pi 0+bck}$ 15 MeV/c^2	$A_L^{\pi 0+bck}$ 25 MeV/c^2	$A_L^{\pi 0+bck}$ 35 MeV/c^2	A_L^{bck1}	A_L^{bck2}
1-2	-0.001±0.004	0.001±0.003	0.000±0.003	-0.002±0.004	-0.000±0.003
2-3	0.001±0.004	0.000±0.004	0.002±0.004	0.009±0.007	0.000±0.005
3-4	0.004±0.009	0.006±0.009	0.006±0.008	-0.004±0.024	-0.036±0.015
4-5	-0.024±0.021	-0.016±0.020	-0.016±0.019	-0.011±0.062	0.013±0.038

All are zeros within 1.5σ, except

π^0 A_{LL} result

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 (17%)	-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 δP ~30%: is not included

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

p_T smearing correction is not included

Summary

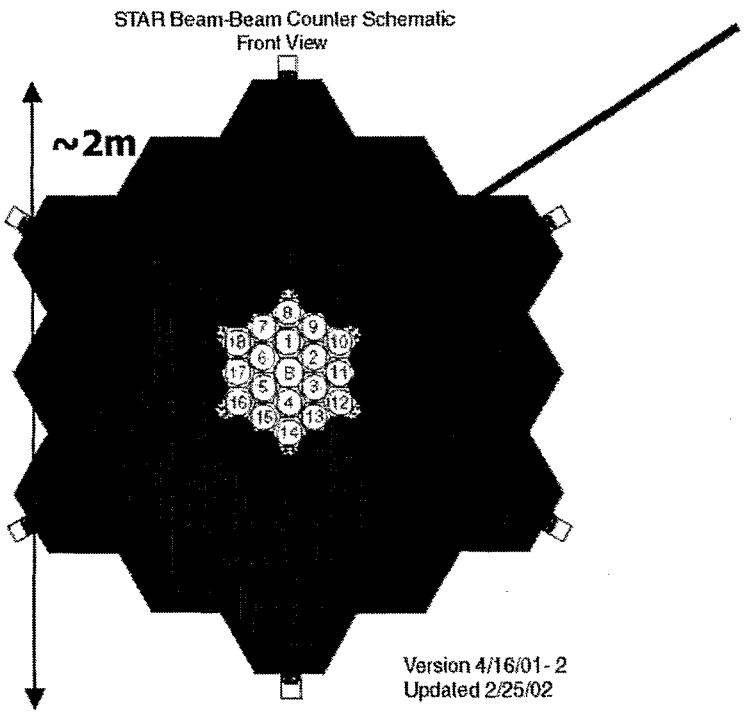
- Relative luminosity – systematics is mostly due to crossing by crossing variation of Z-vertex width and acceptance difference
  → correction applied
- Relative luminosity accuracy
  $\delta A_{LL} = 1.8 \times 10^{-3}$ achieved
- Relative luminosity is reaction channel dependent
  - For π^0 analysis, BBCLL1 is good enough.
- Preliminary result for π^0 A_{LL} obtained
- Various null tests – all OK
  statistical and systematic errors are well studied.

STAR Spin Analysis Update

Stephen Trentalange

Beam-Beam Counters

- **scintillator annulus** installed around the beam pipe, on the east and west poletips of STAR magnet at ±3.74m from IR for detection of charged particles in forward region $2 < |\eta| < 5$

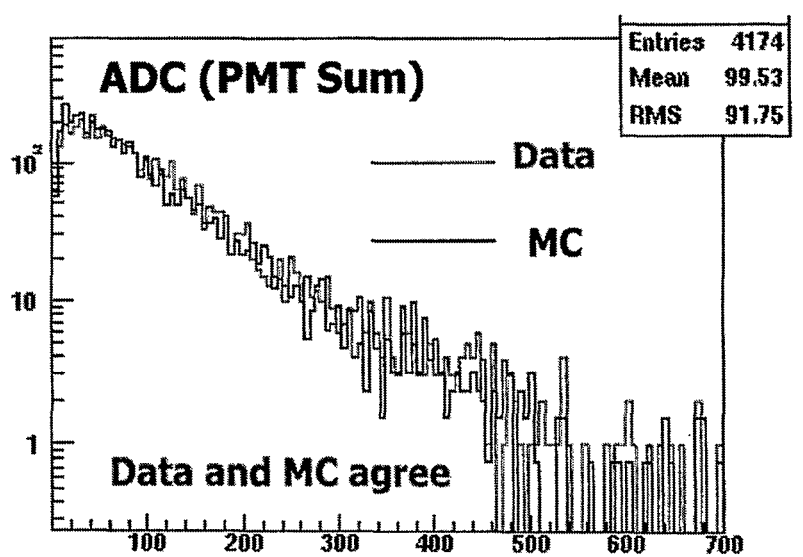


Small hexagonal annulus:

18 pixels (16 PMT) covering **$3.3<|\eta|<5.0$ and $0<\varphi<2\pi$**
- **azimuthal segmentation !**

A coincidence condition between BBC East and West - suppresses beam-gas background and used for:

- **triggering in pp (minimum bias, jet triggers),**
- **(relative) luminosity measurements**
- **local polarimetery**



BBC cross section:

σ(**BBC**) ~ **50% of** σ_{tot} **(pp) = 26 mb Large!**

- Van der Meer scans at RHIC (Run2 and Run3 data) are consistent with Geant simulations for STAR

Transverse Single Spin Asymmetries

Asymmetries measured for p+p -> A + X, where A – hit(s) in the BBC (small tiles, 3.3<|η|< 5.0)

$$\varepsilon_{LR} = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}} \approx P_{beam}^{vert} \times \underline{A_N(BBC)}$$

RHIC CNI polarimeter $\left(\varepsilon_{CNI} = P_{beam} \times A_N(CNI) \right)$

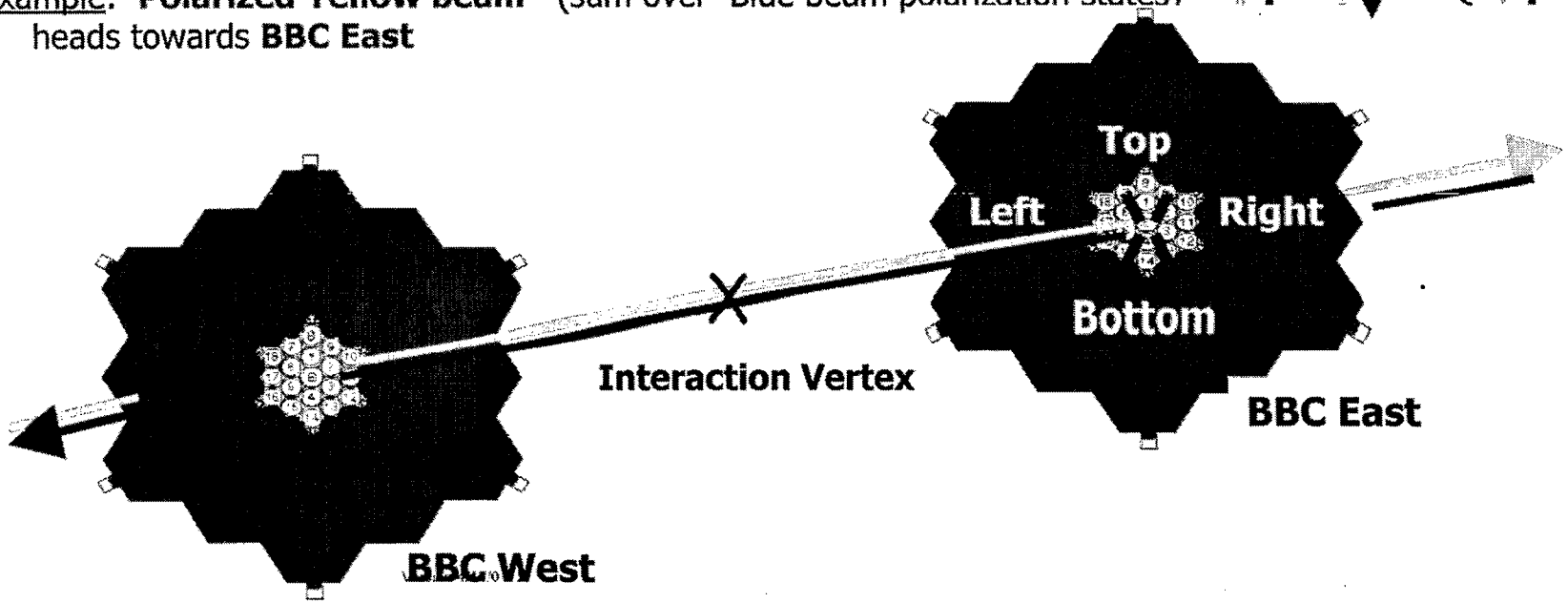
$$\varepsilon_{TB} = \frac{\sqrt{N_T^{\uparrow} N_B^{\downarrow}} - \sqrt{N_T^{\downarrow} N_B^{\uparrow}}}{\sqrt{N_T^{\uparrow} N_B^{\downarrow}} + \sqrt{N_T^{\downarrow} N_B^{\uparrow}}} \approx P_{beam}^{rad} \times A_N(BBC)$$

Zero at RHIC (Vertical pol)

$N_{L(R,T,B)}$ -nr of counts from BBC East or West in Left, Right, Top, Bottom part counted every bunch crossing by scaler system]

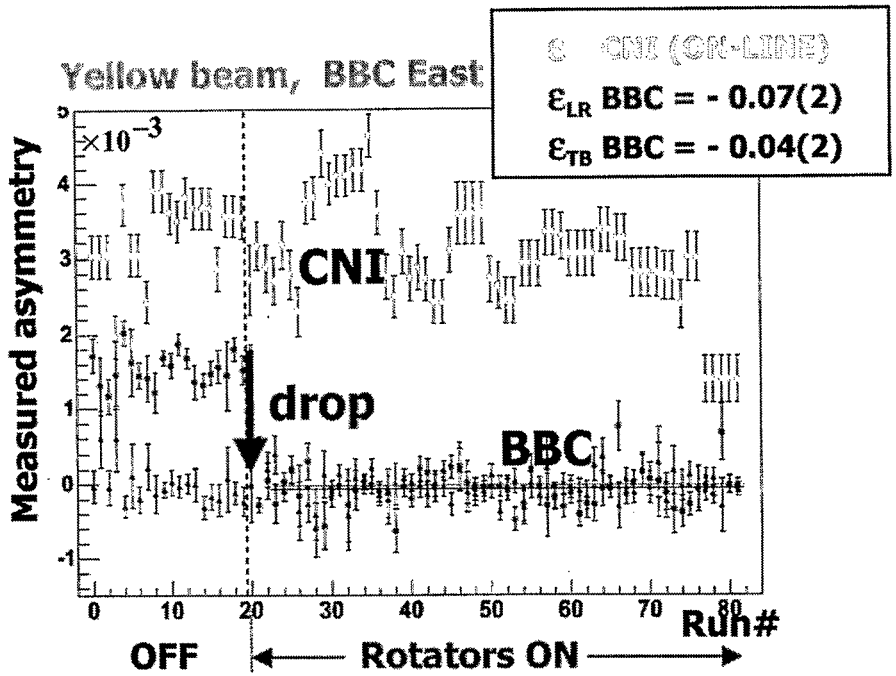
Number of counts from the BBC (L,R,T,B) sorted by beam polarization states

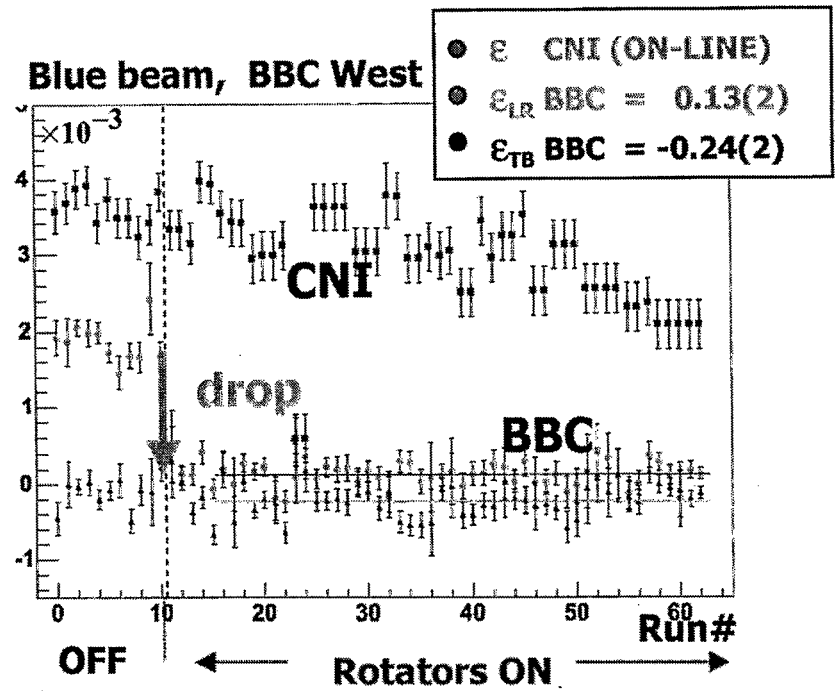
<u>Example</u>: **Polarized Yellow beam** (sum over Blue beam polarization states) heads towards **BBC East**



Local Polarimetry

Rotators		OFF	ON
CNI polarimeter		non-zero	non-zero
BBC Left-Right	(vertical)	NON_ZERO →	ZERO
BBC Top-Bottom	(radial)	zero	zero





Spin rotators worked as designed and stable,
BBC worked very well as a local polarimeter
- vertical and radial polarization components smaller than 3%

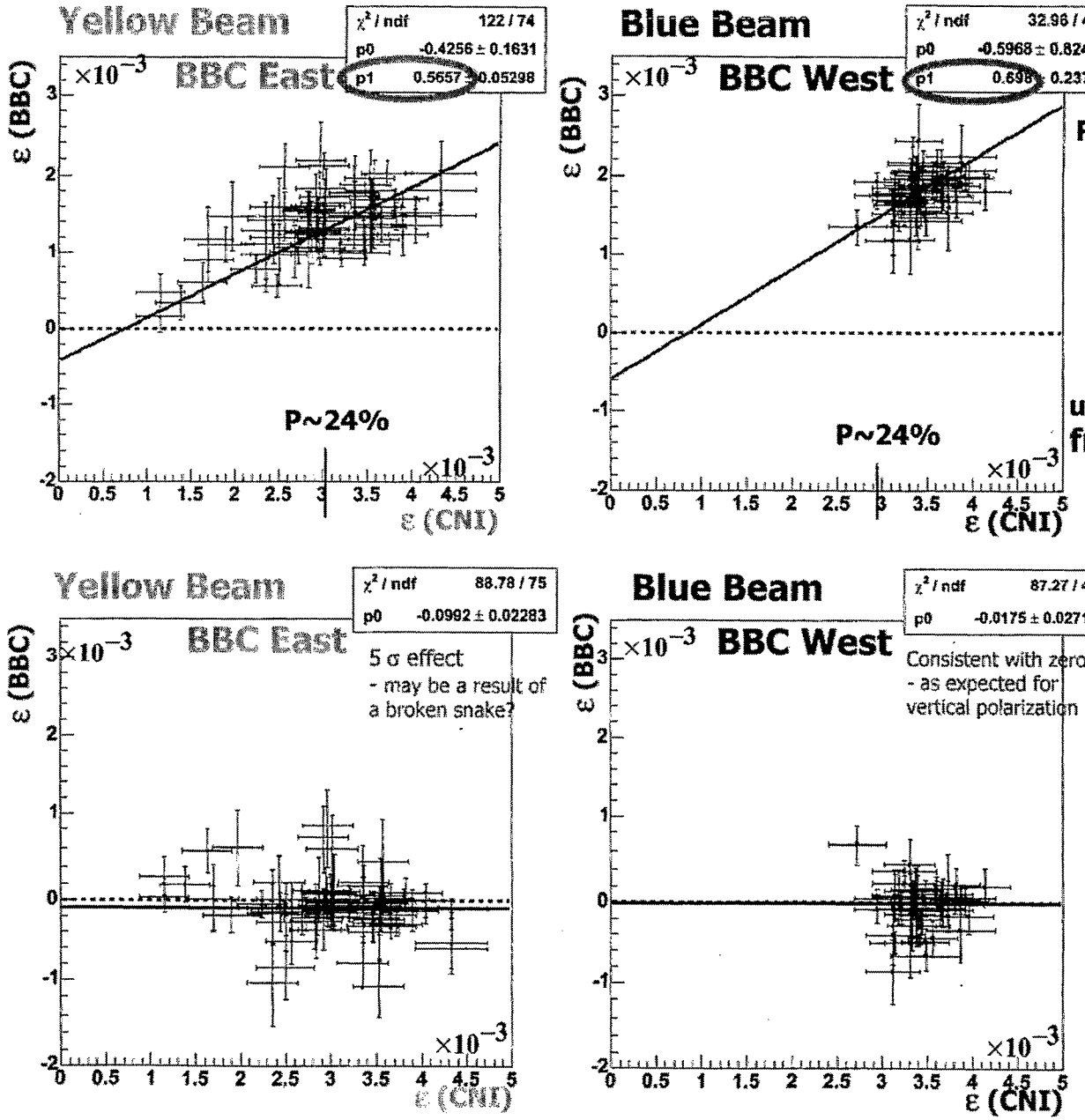
Longitudinal polarization for the first time!

Joanna Kiryluk

Transverse Single Spin Asymmetries – Preliminary Results

Left-Right BBC asymmetry (Vertical P_{beam} component)

Top-Bottom BBC asymmetry (Radial P_{beam} component)



Ratio: ε (BBC East)/ε (CNI) consistent with ε (BBC West)/ε (CNI)

We get:

A_N(BBC)=0.0066(8)

Stat. error only!

using: A_N(CNI) = 0.0118 (10) from CNI online analysis

Joanna Kiryluk

Relative Luminosity - Motivation

Double spin longitudinal asymmetry (e.g. p+p -> jet + X) is defined as:

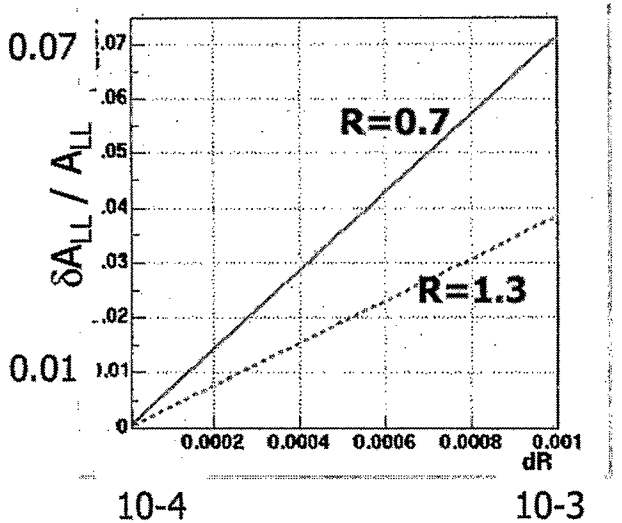
$$A_{LL} = \frac{1}{P_1 P_2} \times \frac{N_{++} - R \times N_{+-}}{N_{++} + R \times N_{+-}}$$

$P_{1,2}$ – beam polarization, from CNI polarimeter at RHIC

N_i where i=++, +- are spin dependent yields

$R = \frac{L_{++}}{L_{+-}}$ - relative luminosity of bunch crossings with different spin directions

Assumption: $A_{LL} = 0.01$

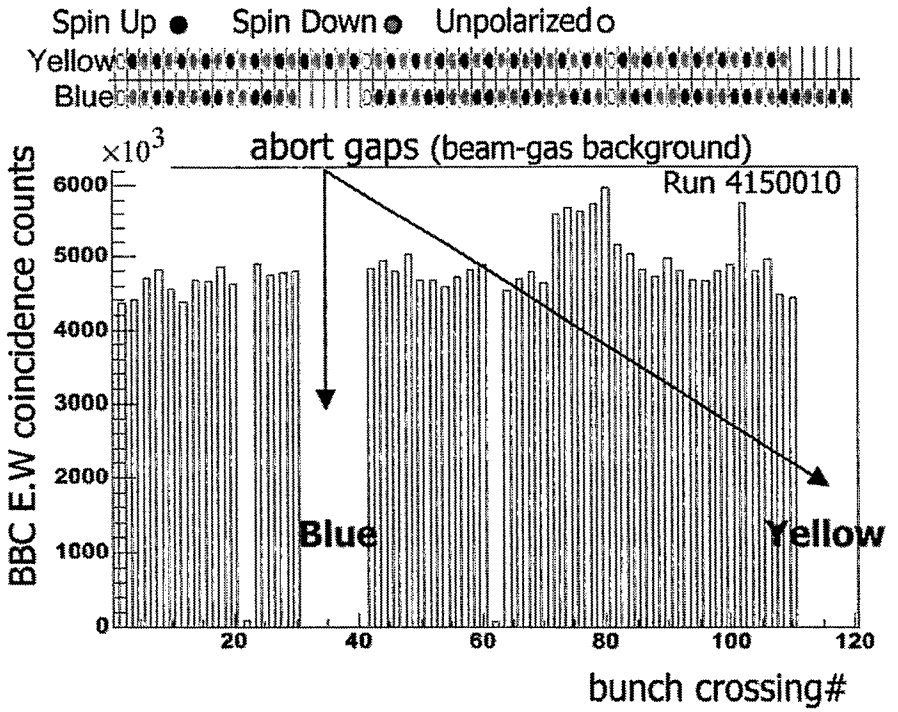


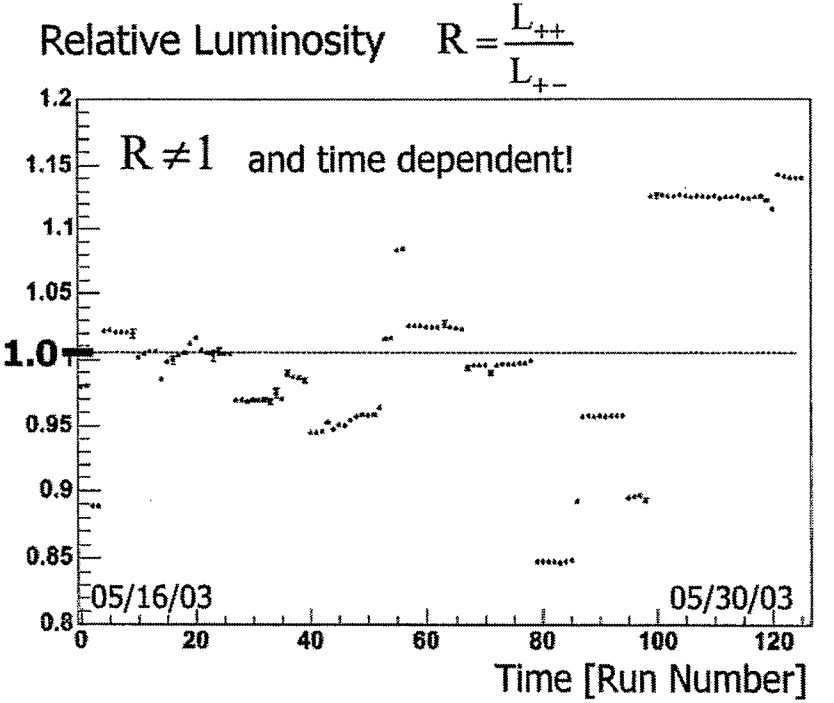
Relative luminosity - one of the dominant systematic errors in A_{LL} measurement It must be known at (least) 10^{-3} level

Requirements for a luminosity process/detector:
- high rates
- small background
- no (or small) spin dependence $\delta R << P_1 P_2 \times A_{LL}$

Relative Luminosity - Measurement

- RHIC filled with 55 - transversly polarized - proton bunches,
- spin orientation related to the bunch crossing number 1-120, **polarization pattern at STAR**:





- integrated luminosity (number of BBC E.W counts) recorded every 5 minutes - scaler board system
- relative luminosities calculated for each STAR run, which typically lasts from a few minutes to ~ hour
- statistical uncertainty $\delta R_{stat} \sim 10^{-4} - 10^{-3}$

Joanna Kiryluk

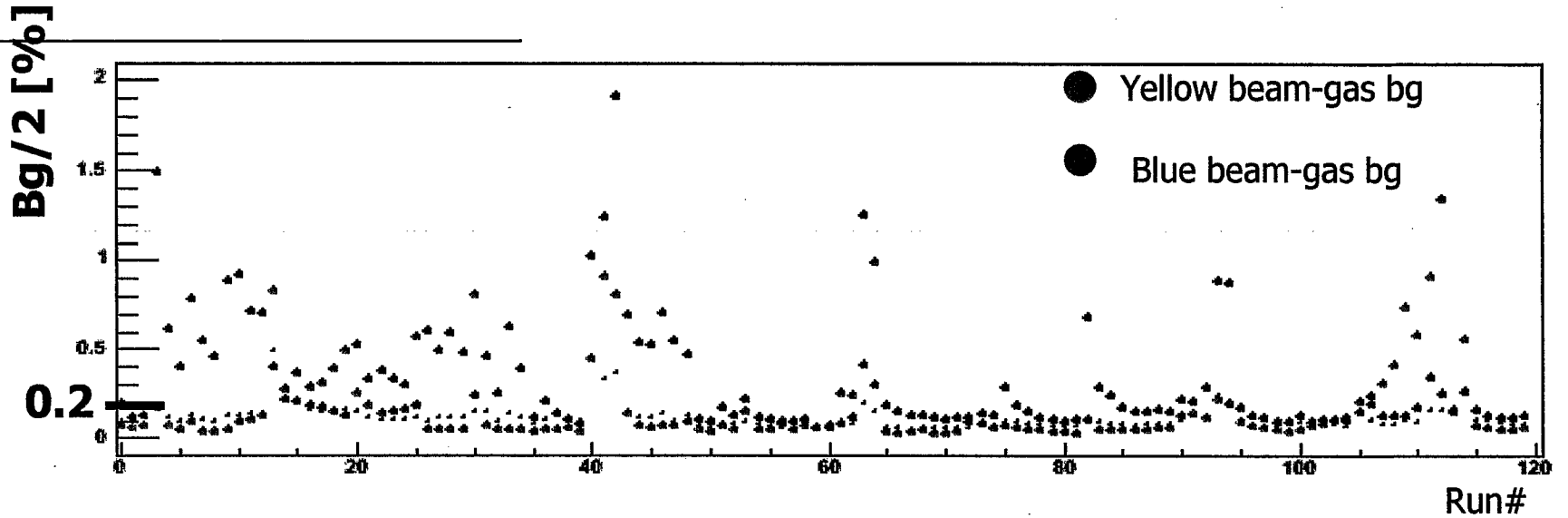
Relative Luminosity – Systematics

Beam-Gas Background Contribution

$$R(BBC) - R(true) = Bg \times [1 - R(true)]$$

if $R(true) = 1$ then $R(BBC) = R(true)$

$$R(BBC) = \frac{N_{++}^{BBC}}{N_{+-}^{BBC}} \cong \frac{L_{++} + N_{bg}}{L_{+-} + N_{bg}} = \Lambda\Lambda \text{ simple math } \Lambda\Lambda = \frac{L_{++}}{L_{+-}} + Bg \times \left(1 - \frac{L_{++}}{L_{+-}}\right)$$



Contribution to systematic uncertainty on R δ R(sys) ~ 0.004 x 0.2 ~ 8 x 10-4

- **must correct for background**

Joanna Kiryluk

Summary

1. **Single transverse spin asymmetry measured with the Beam Beam Counters** in 2003 were found to be **A_N(BBC)=0.0066(8)** using A_N(CNI)=0.0118(10) from CNI online analysis. Systematic studies in progress.

2. The BBC was used to tune spin rotators needed to get longitudinally polarized beams at STAR IP and to monitor on-line transverse and radial beam polarization components. They are found to be small: $P_{rad(vert)} < 3\%$.

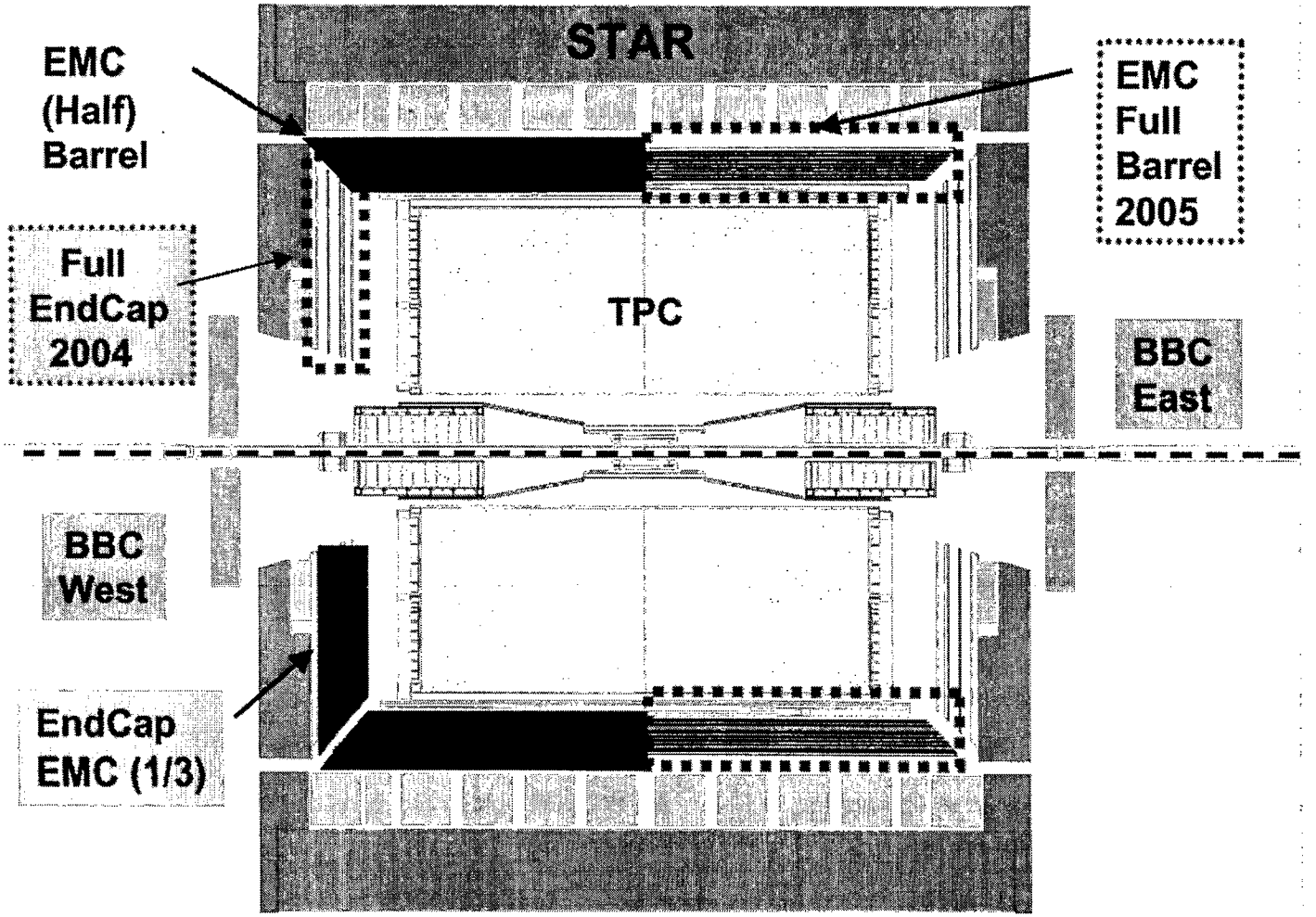
3. The BBC in STAR is a good luminosity monitoring detector. **The relative luminosity is known at the level of ~ 3 x10^{-3}**

   - statistical uncertainty: 10^{-4} – 10^{-3}
   - (conservative) systematic uncertainty (BBC and ZDC comparison) ~ 3 x 10^{-3}

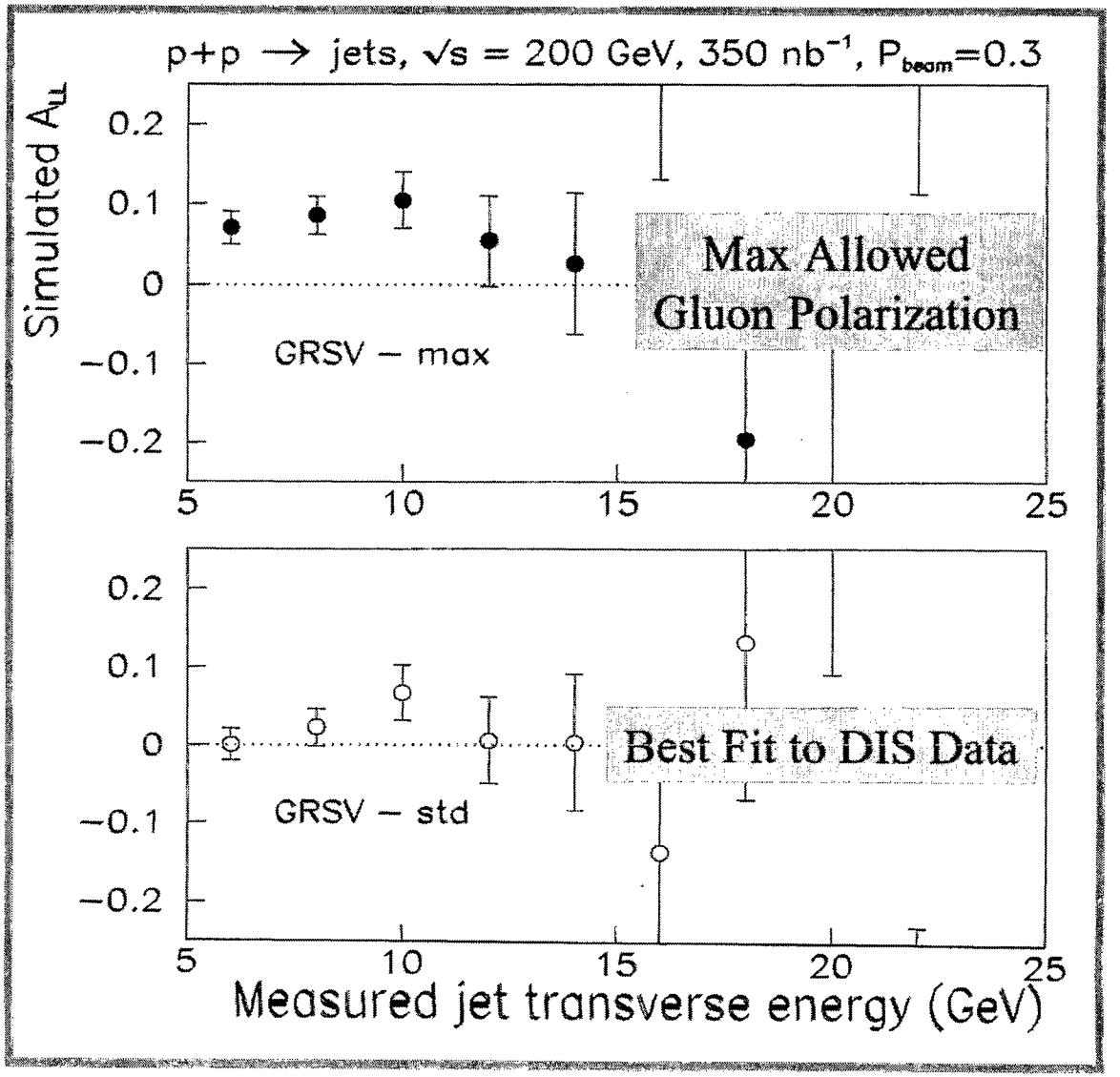
   This needs further studies (background contribution)

Joanna Kiryluk

2003 Detector Configuration



Leading Jet Asymmetries are Sensitive to Gluon



- Simulation based on Pythia
- Use Fast TPC and EMC Simulators
- EMC+TPC Jets Reconstructed using Cone Algorithm
- Includes Jet-Patch Trigger ($E_T > 5$) covering the Full Half Barrel Calorimeter
- A_{LL} includes all jet processes (not a direct measure of delta G)

Simulations by Les Bland

pp Longitudinal Data Set

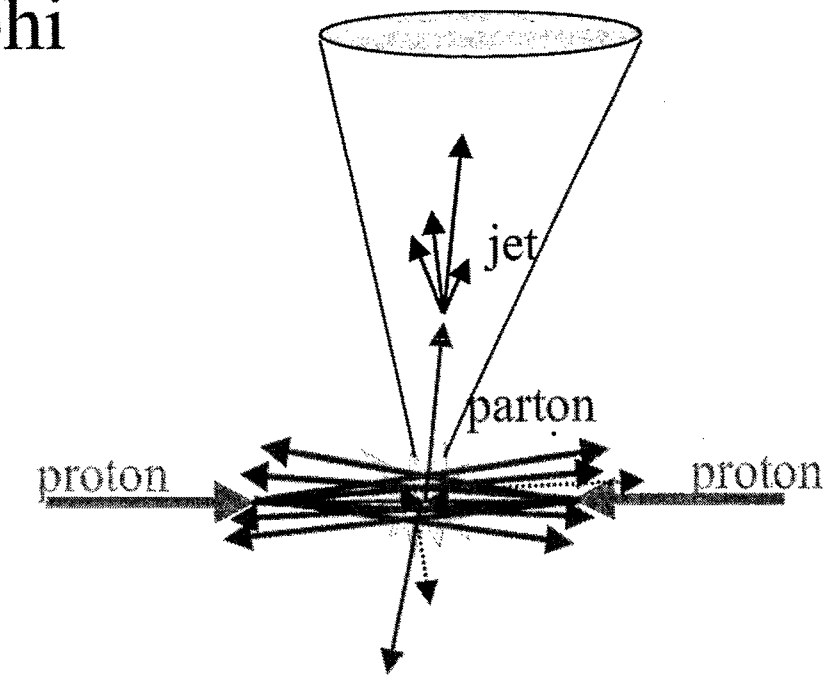
- May 16- May 30 2003
- Ave Polarization / Beam ~0.25
- RHIC Delivered Integrated Luminosity ~ 420 nb^{-1}
- Full STAR Detectors Sampled ~ 330 nb^{-1}
- Recorded Luminosity ~ 180 nb^{-1}
- Barrel EMC Covers

  0-1 in Eta and the Full Azimuth
- High Tower Trigger
  - Requires Single Tower ADC>287 (E_T ~ > 2.4 GeV)
- Jet Patch Trigger
  - Requires Patch of 1x1 (η ,ϕ) E_T > 5 GeV

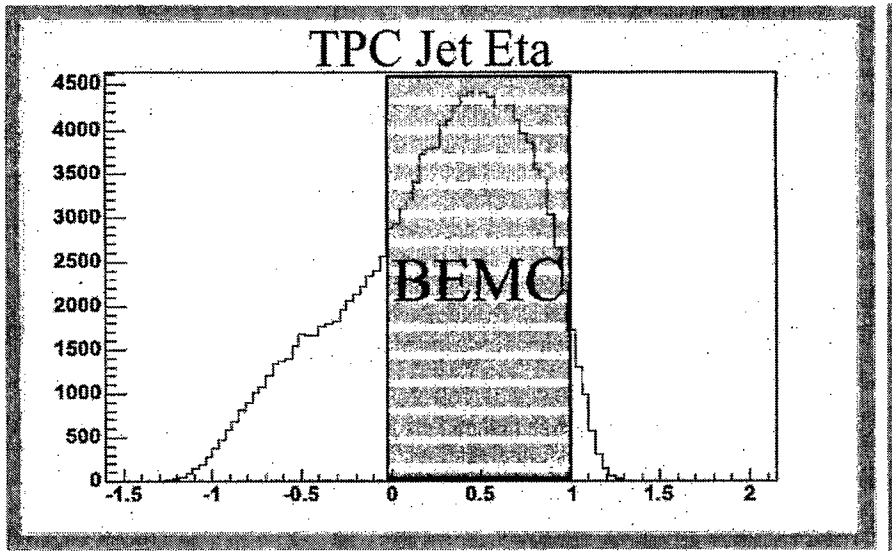
Jet Finder (Mike Miller/Thomas Henry)

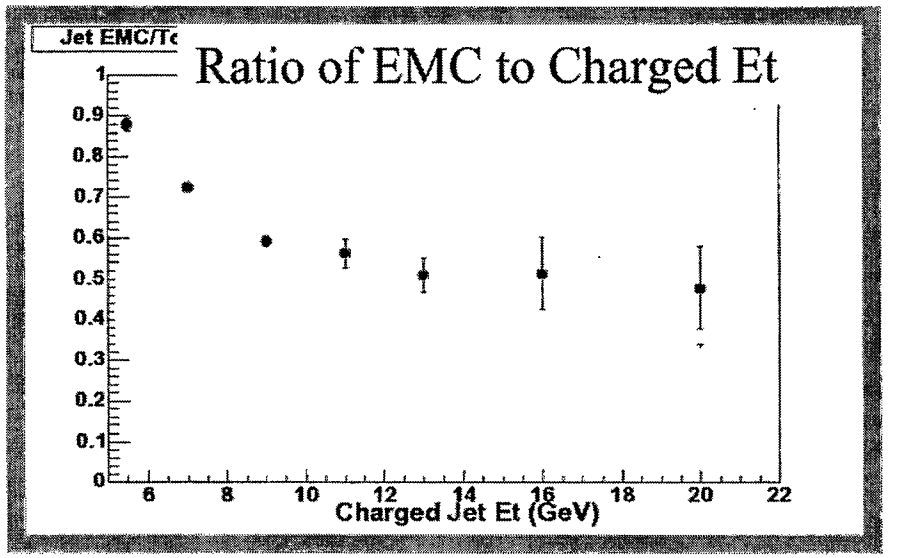
For this Analysis, Jets are defined as a grouping of one or more (charged) Tracks measured in the TPC and satisfying the following requirements…

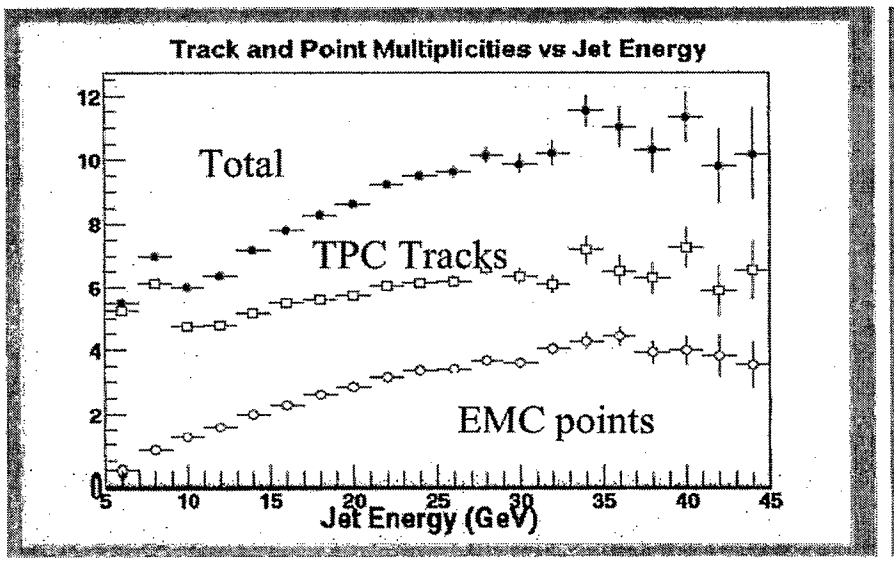
- Using an Iterative, Midpoint, Cone Algorithm
- Cone Angle = 0.7 in eta-phi
- Seed Energy = 0.5 GeV
- pT Track > 0.1 GeV
- Track Range = +/- 1.6
- pT Jet > 5 GeV
- Z = +/- 75 cm

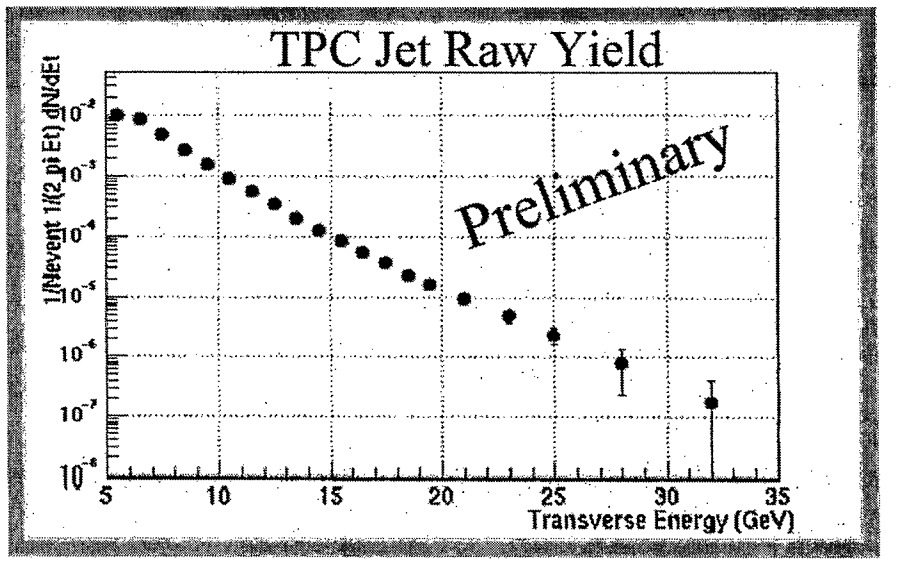


TPC Jet Characteristics – EMC Trigger









- Strong Trigger Bias at low E_T
- Goal: Measured E_T --> Parton E_T

Longitudinal Spin Asymmetries

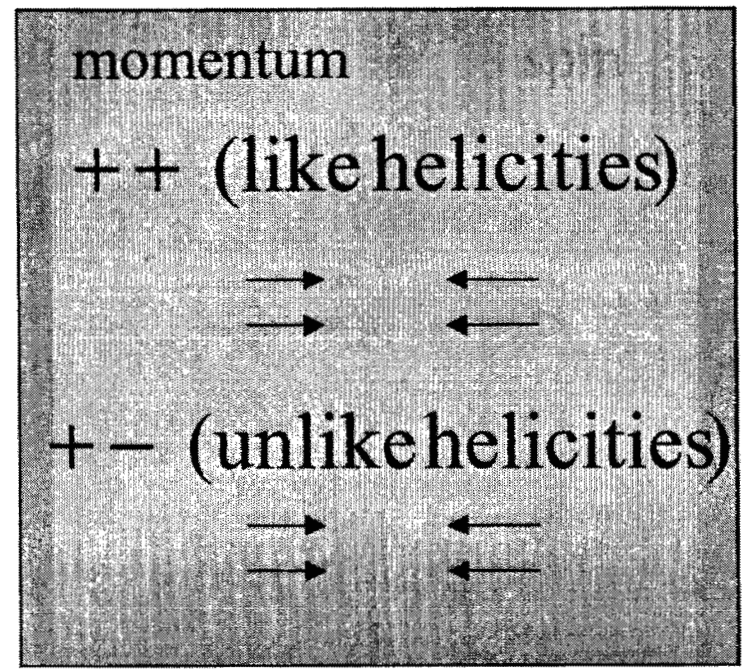
$$\varepsilon_{LL} = P_A P_B \cdot A_{LL} = \frac{N^{++} - R_2 * N^{+-}}{N^{++} + R_2 * N^{+-}}$$

Does Not Violate Parity

$$\varepsilon_L = P_A \cdot A_L = \frac{N^{+} - R_1 * N^{-}}{N^{+} + R_1 * N^{-}}$$

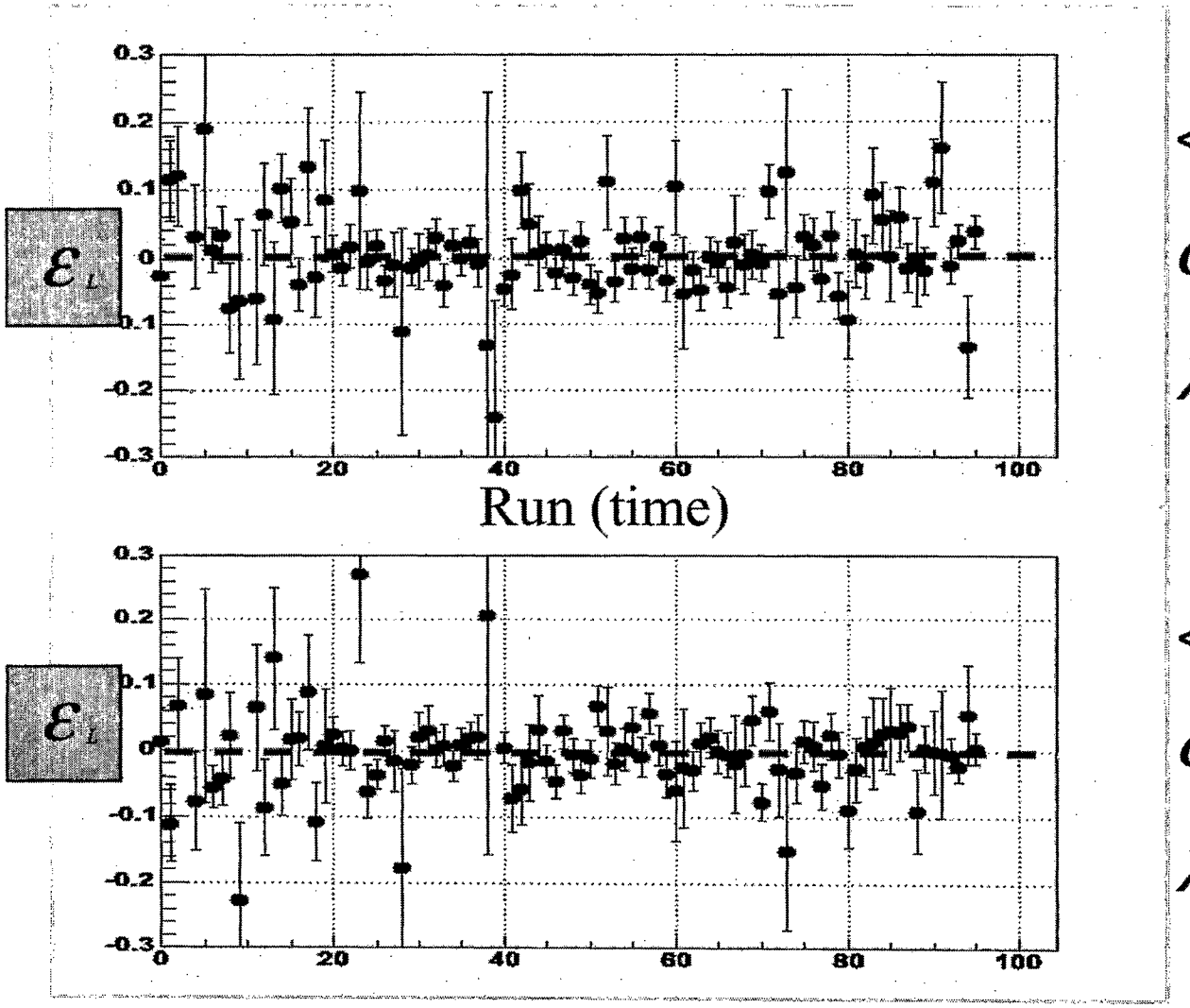
Violates Parity

$$R_1 = L^{+} / L^{-} \qquad R_2 = L^{++} / L^{+-}$$



REQUIRES luminosity ratios to be measured much more accurately than desired asymmetry

TPC-Jet, Single-Spin Asymmetries



Blue Beam

$$< \varepsilon >= 0.00016$$

$$\delta(\varepsilon) = 0.0038$$

$$\chi^2 / dof = 106/95$$

Yellow Beam

$$< \varepsilon >= -0.005$$

$$\delta(\varepsilon) = +0.0038$$

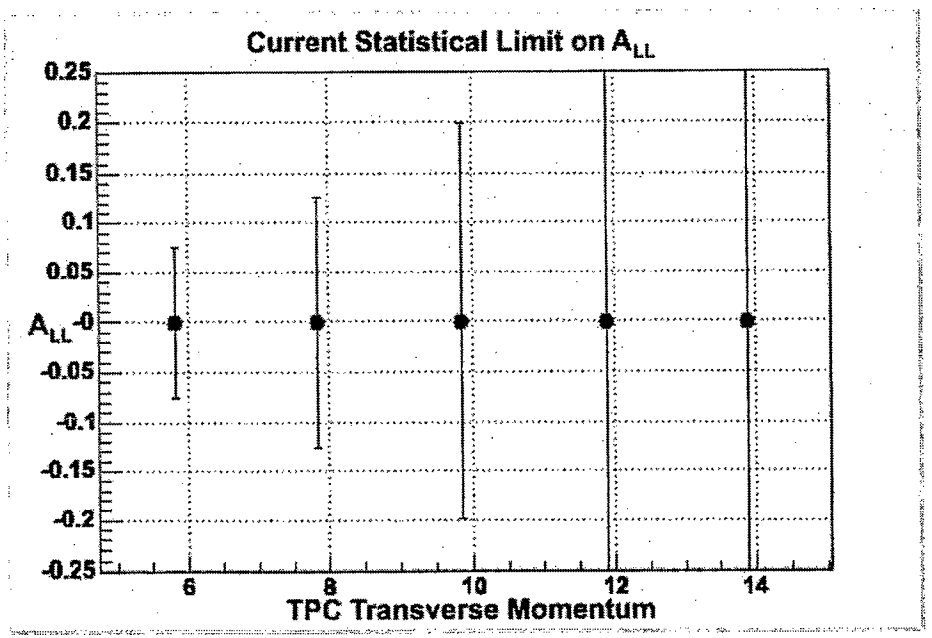
$$\chi^2 / dof = 99/96$$

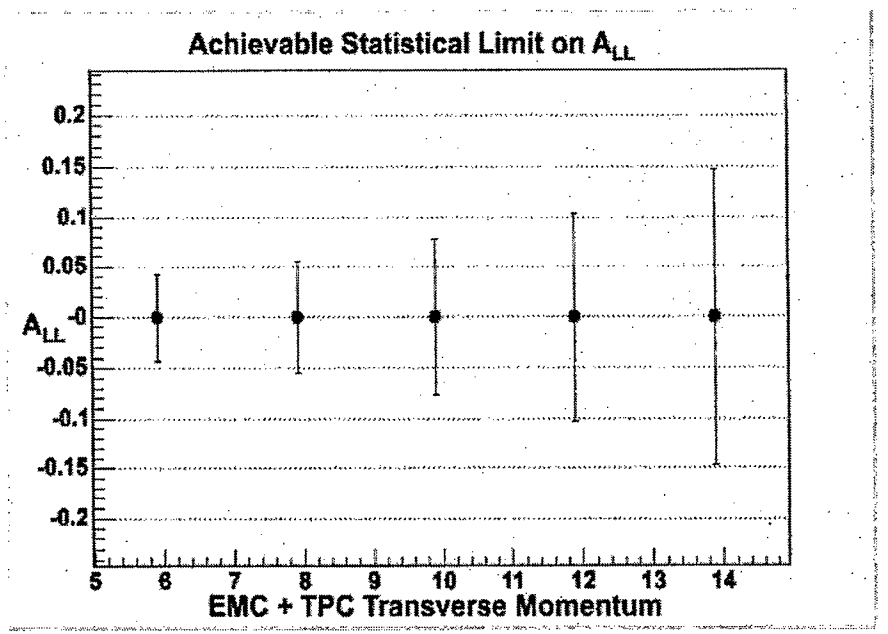
Parity-Violating Asymmetries are Consistent with Zero

Dylan Thein

2003 Outlook

Data	Statistical Precision on A_{LL}
TPC Jets	+/- 0.057
EMC+TPC Jets	+/- 0.030





RHIC Spin Collaboration Meeting XX
November 18, 2003
RIKEN BNL Research Center

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RIKEN BNL Research Center

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RHIC Spin Collaboration Meeting XX
November 18, 2003
RIKEN BNL Research Center

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RIKEN BNL Research Center
RHIC Spin Collaboration Meeting XX
November 18, 2003
Bldg. 1005, Third Floor Conference Room
Brookhaven National Laboratory

*******AGENDA*******

Accelerator topics

9:00 - 9:30 RHIC working point.....Rojelio Tomas and Wolfram Fischer
9:30-10:00 AGS warm-bore helical dipole.....Jun Takano and Waldo MacKay
10:00-10:20 RHIC spin-tune measurement and polarization reversal.....Mei Bai
10:20-10:40 Status of PLL..... Peter Cameron
10:40-11:10 Coffee Break
11:10-11:30 AGS polarized proton commissioning..... Leif Ahrens
11:30-12:00 Run - 4 PP ramp.....Johannes van Zejts

12:00 - 1:15 Lunch

Polarimetry

1:15 - 1:35 Status of polarized gas jet target.....Alexander Nass
1:35 - 1:55 Polarimeter Status.....Haixin Huang
1:55 - 2:15 CNI polarimetry status.....Osamu Jinnouchi and Sandro Bravar

Future...

2:15 - 2:45 Discussion: Physics opportunities in runs-4, 5
2:45 - 3:15 Discussion: Summary of spin-strategy meeting and plans..S. Vigdor (TBC)
3:15 - 3:45 Coffee Break

Status of Run-3 analyses

3:45 - 4:15 New theoretical studies of pp interactions.....W. Vogelsang
4:15 - 4:45 PHENIX.....Kiyoshi Tanida
4:45 - 5:15 STAR.....Stephen Trentalange

Additional RIKEN BNL Research Center Proceedings:

Volume 58 – RHIC Spin Collaboration Meeting XX – BNL-
Volume 57 – High pt Physics at RHIC, December 2-6, 2003 – BNL-
Volume 56 – RBRC Scientific Review Committee Meeting – BNL-
Volume 55 – Collective Flow and QGP Properties – BNL -
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

Additional RIKEN BNL Research Center Proceedings:

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

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Volume 5 – Color Superconductivity, Instantons and Parity (Non?)-Conservation at High Baryon Density – BNL-65105

Volume 4 – Inauguration Ceremony, September 22 and Non -Equilibrium Many Body Dynamics – BNL-64912

Volume 3 – Hadron Spin-Flip at RHIC Energies – BNL-64724

Volume 2 – Perturbative QCD as a Probe of Hadron Structure – BNL-64723

Volume 1 – Open Standards for Cascade Models for RHIC – BNL-64722

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RIKEN BNL RESEARCH CENTER

RHIC Spin Collaboration Meeting XX

November 18, 2003

Li Keran

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

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Speakers:

L. Ahrens
M. Bai
S. Bravar
P. Cameron
W. Fischer
H. Huang
O. Jinnouchi
W. MacKay
A. Nass
J. Takano
K. Tanida
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Organizer: L. Bland