# *Spin Physics Results at PHENIX*

Advanced Studies Institute on
Symmetries and Spin in Prague

July 25, 2006

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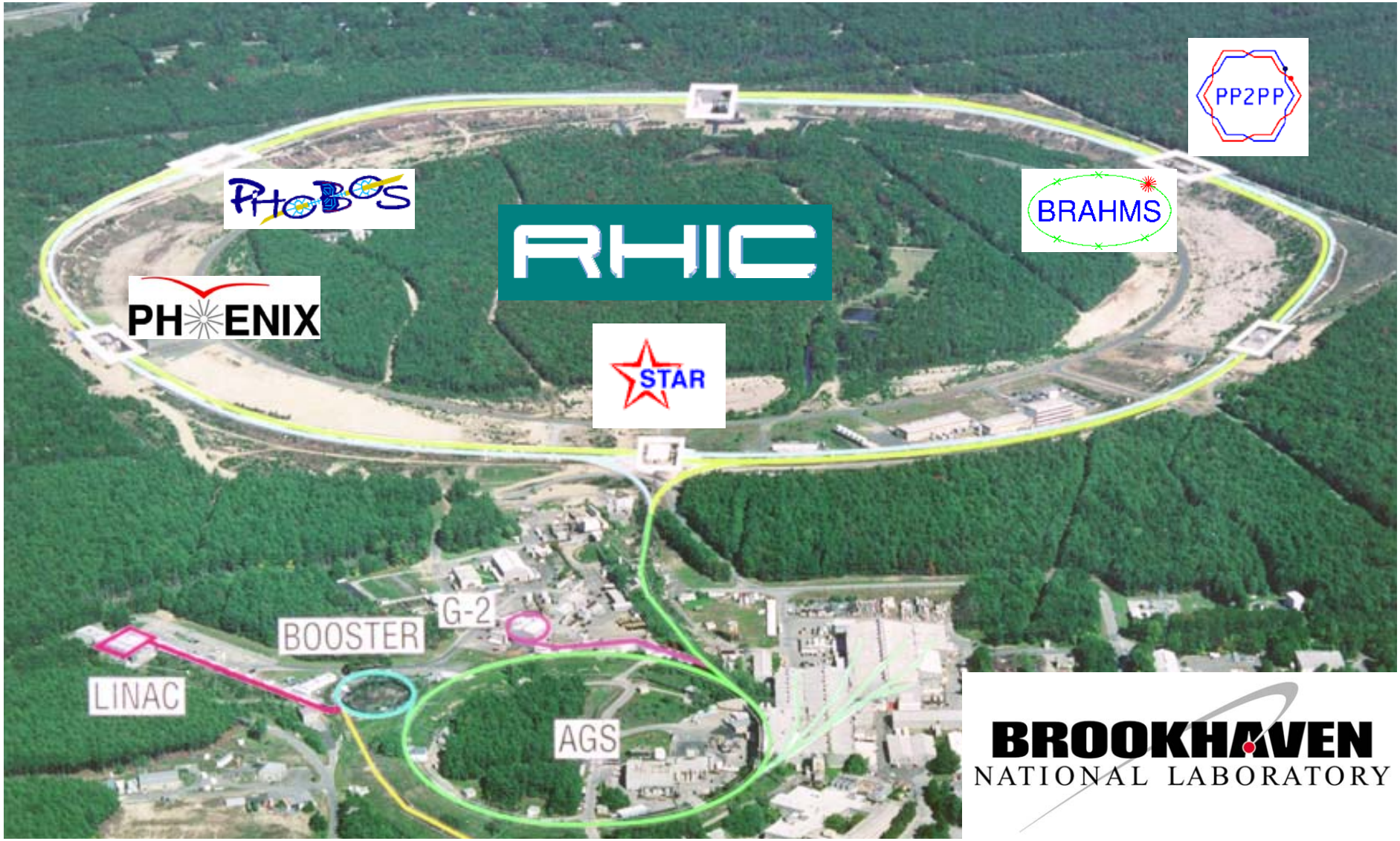
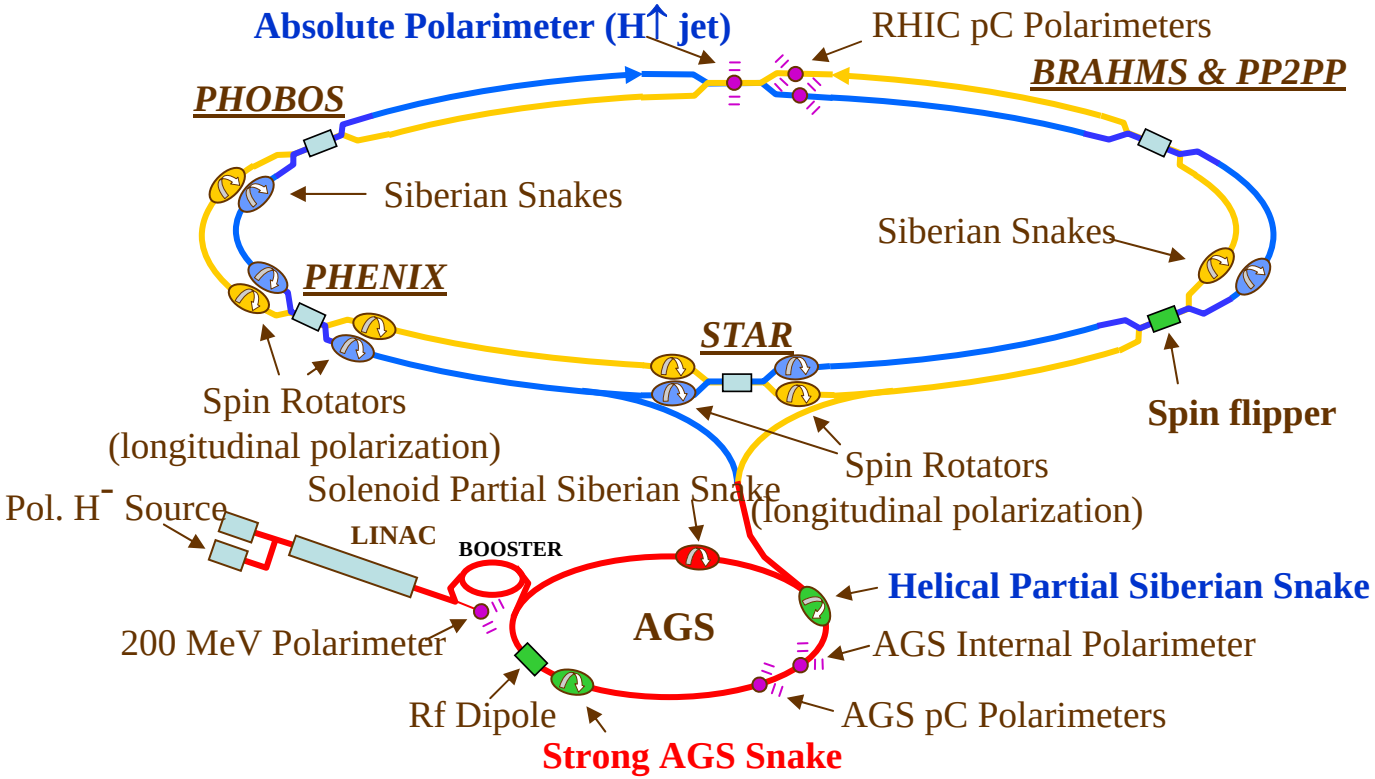
for the PHENIX collaboration


# RHIC – QCD collider



# RHIC polarized-proton collision

- Luminosity $3\times10^{31}$ cm$^{-2}$sec$^{-1}$ at $\sqrt{s}$ = 200 GeV achieved
  - $6\times10^{31}$ cm$^{-2}$sec$^{-1}$ at 200 GeV and $1.5\times10^{32}$ cm$^{-2}$sec$^{-1}$ at 500 GeV in the future
- Polarization 65% achieved – 70% in the future




- installed and commissioned in 2004 run
- installed in 2005 and commissioned in 2006
- to be commissioned

# PHENIX collaboration

## 13 Countries; 62 Institutions; 550 Participants*

- University of São Paulo, São Paulo, Brazil
- Academia Sinica, Taipei 11529, China
- China Institute of Atomic Energy (CIAE), Beijing, P. R. China
- Peking University, Beijing, P. R. China
- Charles University, Faculty of Mathematics and Physics, Ke Karlovu 3, 12116 Prague, Czech Republic
- Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering, Brehova 7, 11519 Prague, Czech Republic
- Institute of Physics, Academy of Sciences of the Czech Republic, Na Slovance 2, 182 21 Prague, Czech Republic
- Laboratoire de Physique Corpusculaire (LPC), Universite de Clermont-Ferrand, 63 170 Aubiere, Clermont-Ferrand, France
- Dapnia, CEA Saclay, Bat. 703, F-91191 Gif-sur-Yvette, France
- IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, BP1, F-91406 Orsay, France
- Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS-IN2P3, Route de Saclay, F-91128 Palaiseau, France
- SUBATECH, Ecòle des Mines at Nantes, F-44307 Nantes France
- University of Muenster, Muenster, Germany
- KFKI Research Institute for Particle and Nuclear Physics at the Hungarian Academy of Sciences (MTA KFKI RMKI), Budapest, Hungary
- Debrecen University, Debrecen, Hungary
- Eövös Loránd University (ELTE), Budapest, Hungary
- Banaras Hindu University, Banaras, India
- Bhabha Atomic Research Centre (BARC), Bombay, India
- Weizmann Institute, Rehovot, 76100, Israel
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- Nagasaki Institute of Applied Science, Nagasaki-shi, Nagasaki, Japan
- RIKEN, The Institute of Physical and Chemical Research, Wako, Saitama 35 0198, Japan
- RIKEN – BNL Research Center, Japan, located at BNL
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- Tokyo Institute of Technology, Oh-okayama, Meguro, Tokyo 152-8551, Japa
- University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi Ibaraki-ken 305-8577, Japan
- Waseda University, Tokyo, Japan
- Cyclotron Application Laboratory, KAERI, Seoul, South Korea
- Kangnung National University, Kangnung 210-702, South Korea
- Korea University, Seoul, 136-701, Korea
- Myong Ji University, Yongin City 449-728, Korea
- System Electronics Laboratory, Seoul National University, Seoul, South Korea
- Yonsei University, Seoul 120-749, Korea
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- Joint Institute for Nuclear Research (JINR-Dubna), Dubna, Russia
- Kurchatov Institute, Moscow, Russia
- PNPI, Petersburg Nuclear Physics Institute, Gatchina, Leningrad region, 188300, Russia
- Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Vorob'evy Gory, Moscow 119992, Russia
- Saint-Petersburg State Polytechnical Univiversity, Politechnicheskayastr, 2 St. Petersburg, 195251, Russia
- Lund University, Lund, Sweden
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- Brookhaven National Laboratory (BNL), Upton, NY 11973, USA
- University of California - Riverside (UCR), Riverside, CA 92521, USA
- University of Colorado, Boulder, CO, USA
- Columbia University, Nevis Laboratories, Irvington, NY 10533, USA
- Florida Institute of Technology, Melbourne, FL 32901, USA
- Florida State University (FSU), Tallahassee, FL 32306, USA
- Georgia State University (GSU), Atlanta, GA, 30303, USA
- University of Illinois Urbana-Champaign, Urbana-Champaign, IL, USA
- Iowa State University (ISU) and Ames Laboratory, Ames, IA 50011, USA
- Los Alamos National Laboratory (LANL), Los Alamos, NM 87545, USA
- Lawrence Livermore National Laboratory (LLNL), Livermore, CA 94550, USA
- University of New Mexico, Albuquerque, New Mexico, USA
- New Mexico State University, Las Cruces, New Mexico, USA
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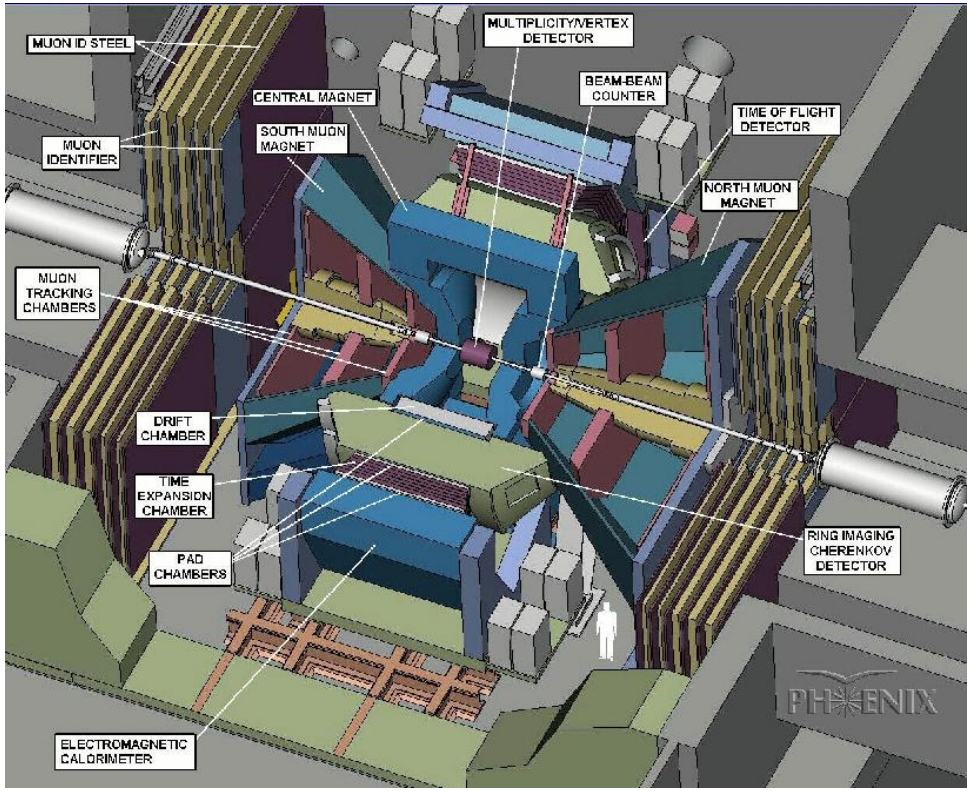
- Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831, USA
- University of Tennessee (UT), Knoxville, TN 37996, USA
- Vanderbilt University, Nashville, TN 37235, USA

# PHENIX detector

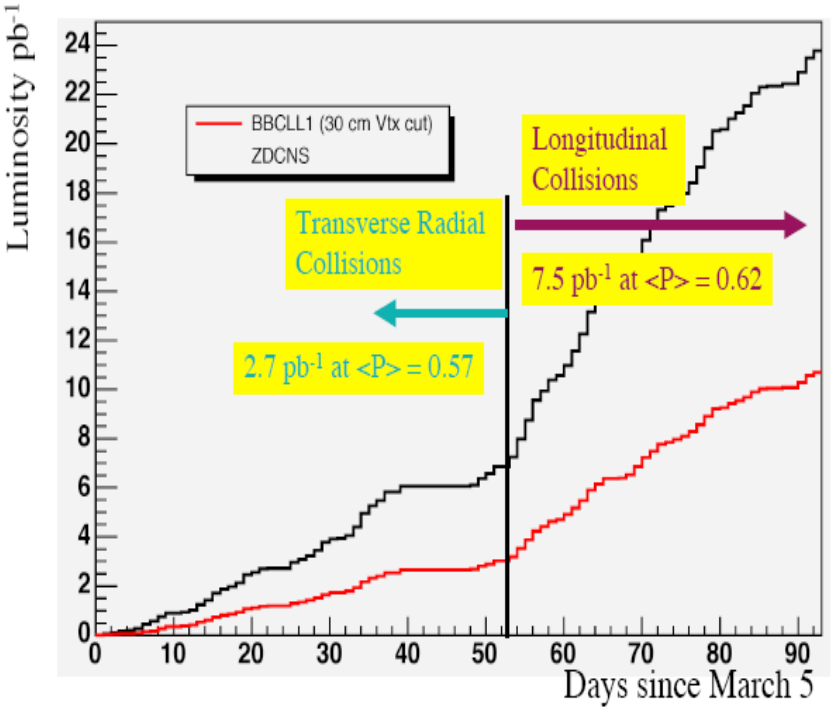


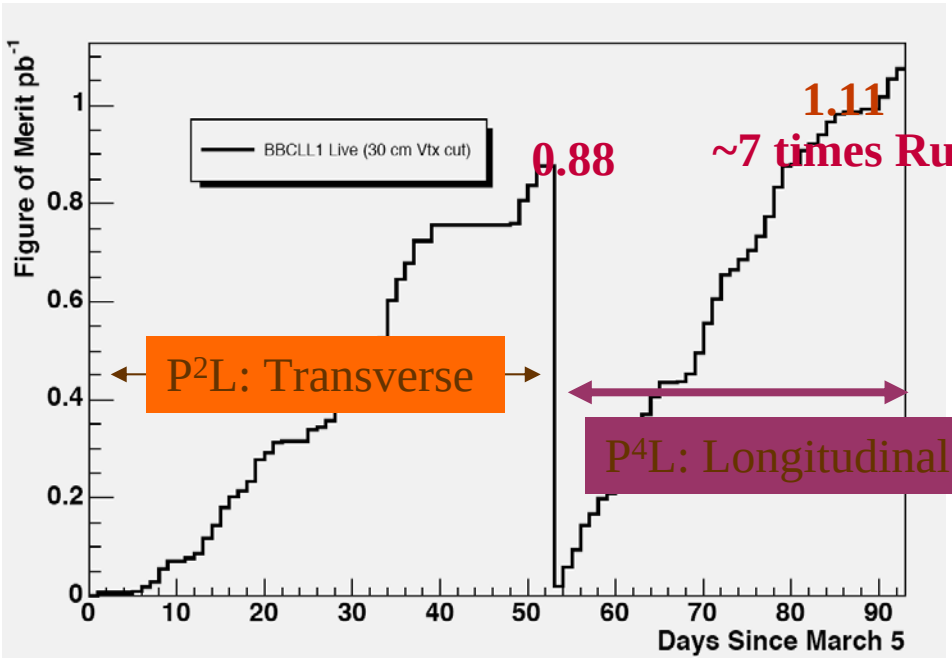

- Philosophy
  - high resolution at the cost of acceptance
  - high rate capable DAQ
  - excellent trigger capability for rare events
- Central tracking
  - pad chamber (PC), drift chamber (DC), time expansion chamber (TEC)
- Forward tracking
  - muon tracker (MuTr)
- Central arm EM calorimetry
  - EMCal
- Particle ID
  - muon ID (MuID), RICH, TOF, TEC

- Global detectors
  - beam-beam counter (BBC), zero-degree calorimeter (ZDC)

# 2006 run

- 200 GeV transverse (radial) spin
  - 2.7 $pb^{-1}$ with ⟨57%⟩ polarization
- 200 GeV longitudinal spin
  - 7.5 $pb^{-1}$ with ⟨62%⟩ polarization



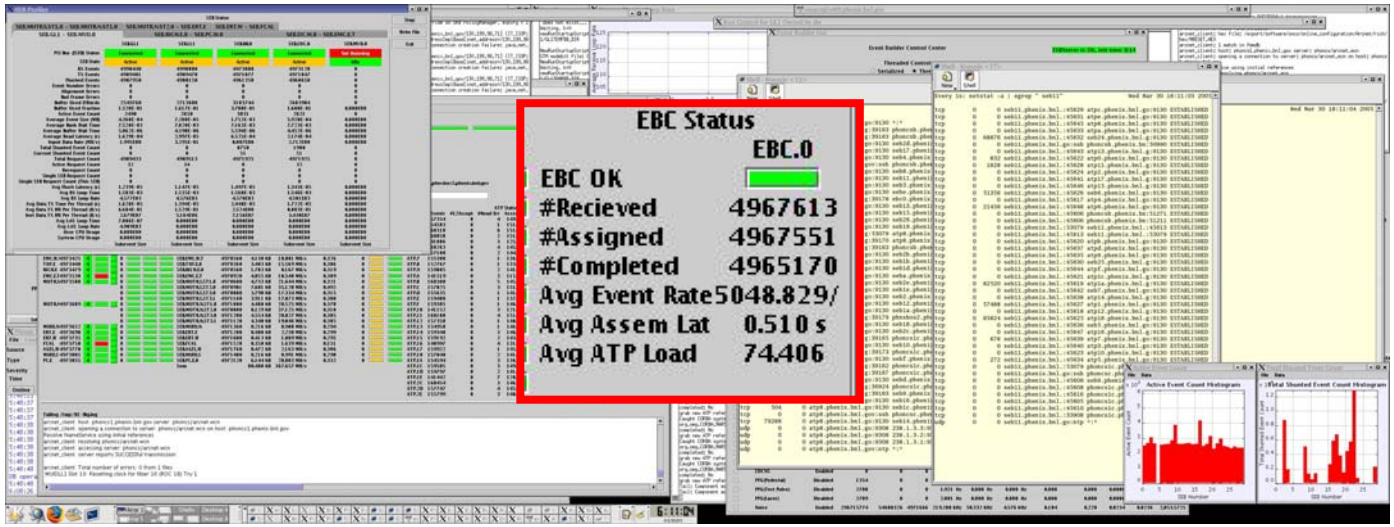

- 22 GeV test
- 62.4 GeV transverse and longitudinal physics run
- 500 GeV machine study

# RHIC/PHENIX polarized-proton runs

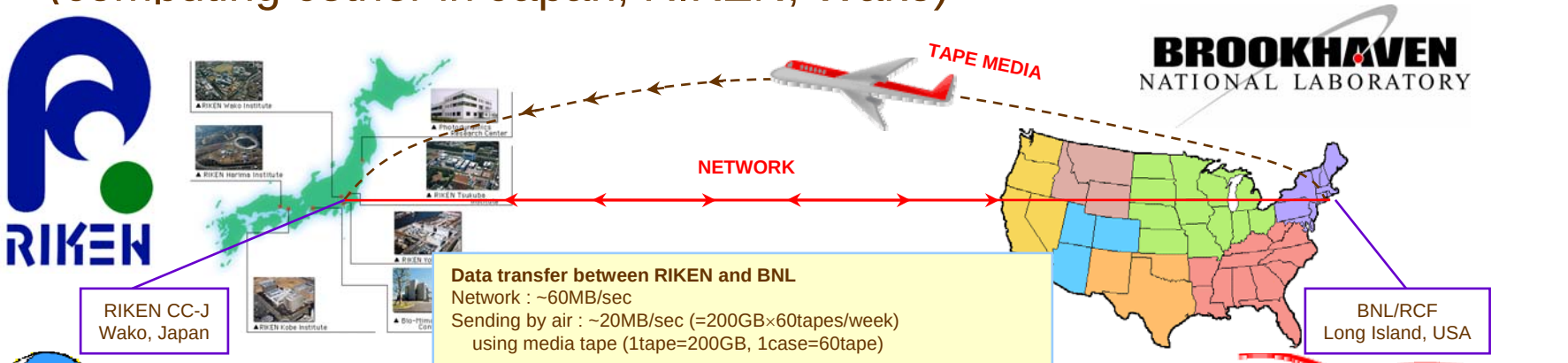
| | P | recorded L | $LP^2/LP^4$ | data volume |
|---|---|---|---|---|
| 2001-2002 $\sqrt{s}$ = 200 GeV transverse/vertical-spin run | | | | |
| | 15% | 0.15 $pb^{-1}$ | 3.4 $nb^{-1}$ | 20 TB |
| first polarized proton collisions | | | | |
| 2003 $\sqrt{s}$ = 200 GeV longitudinal-spin run | | | | |
| | 27% | 0.35 $pb^{-1}$ | 1.5 $nb^{-1}$ | 35 TB |
| spin rotators commissioned, AGS p-C CNI polarimeter | | | | |
| 2004 commissioning run ($\sqrt{s}$ = 200 GeV longitudinal spin) | | | | |
| | 40% | 0.12 $pb^{-1}$ | 3.3 $nb^{-1}$ | 35 TB |
| AGS warm snake operated, gas-jet absolute polarimeter | | | | |
| 2005 $\sqrt{s}$ = 200 GeV longitudinal-spin run | | | | |
| | 49.5/44.5% | 3.8 $pb^{-1}$ | 205 $nb^{-1}$ | 260 TB |
| AGS cold snake installed | | | | |
| 2006 $\sqrt{s}$ = 200 GeV transverse/radial-spin run | | | | |
| | 57% | 2.7 $pb^{-1}$ | 880 $nb^{-1}$ | 100 TB |
| $\sqrt{s}$ = 200 GeV longitudinal-spin run | | | | |
| | 60% | 7.5 $pb^{-1}$ | 1100 $nb^{-1}$ | 160 TB |
| $\sqrt{s}$ = 62.4 GeV transverse and longitudinal run | | | | |
| | 60% | 0.1 $pb^{-1}$ | | 50 TB |
| AGS cold snake operated | | | | |

# DAQ and WAN data transfer

- DAQ rate more than 5 kHz



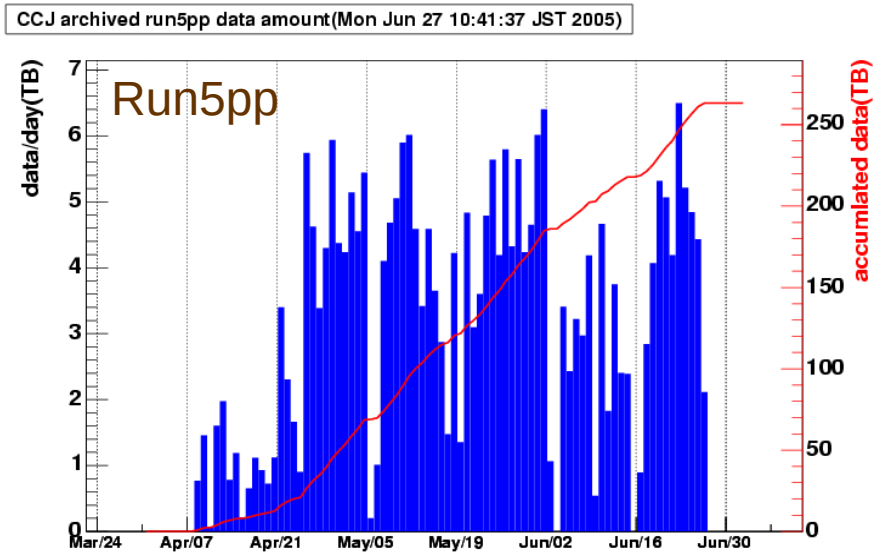

- WAN data transfer and data reconstruction/production at CC-J (computing cetner in Japan, RIKEN, Wako)



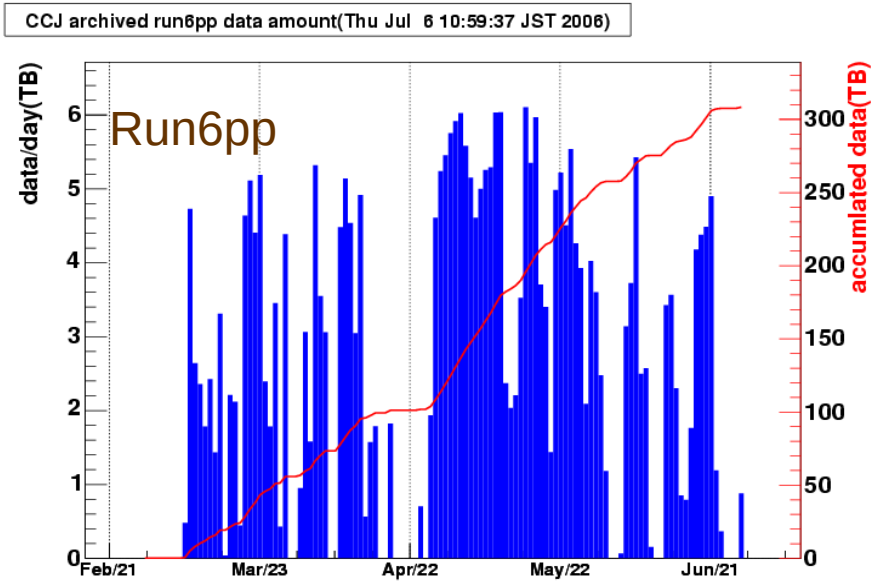

60 MB/s sustained rate

# Data transfer

- 6 TB/day = 70 MB/sec max
- Run5pp: 260 TB transferred
- Run6pp: 310 TB transferred
  - 200 GeV transverse/radial 100 TB
  - 200 GeV longitudinal 160 TB
  - 62.4 GeV 50 TB




2005




2006

# $A_{LL}$ Results

RIKEN

PHENIX

# Gluon contribution

- scaling violation in polarized DIS
  - spanning a limited range of $Q^2$

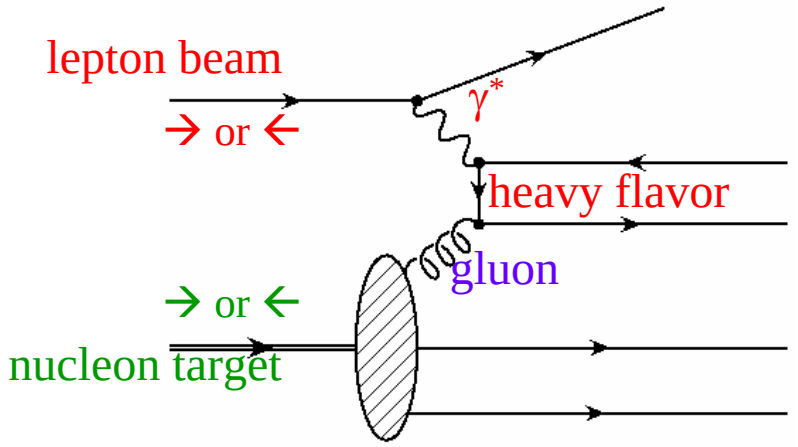
$$\mathrm{SMC}:\ \Delta g(Q^2 = 1\,\mathrm{GeV}^2) = 0.99^{+1.17}_{-0.31}(\mathrm{stat})^{+0.42}_{-0.22}(\mathrm{syst})^{+1.43}_{-0.45}(\mathrm{th})$$

B. Adeba et al., PRD 58, 112002 (1998).

$$\mathrm{E155}:\ \Delta g(Q^2 = 5\,\mathrm{GeV}^2) = 1.6 \pm 0.8(\mathrm{stat}) \pm 1.1(\mathrm{syst})$$

P.L. Anthony et al., PLB 493, 19 (2000).

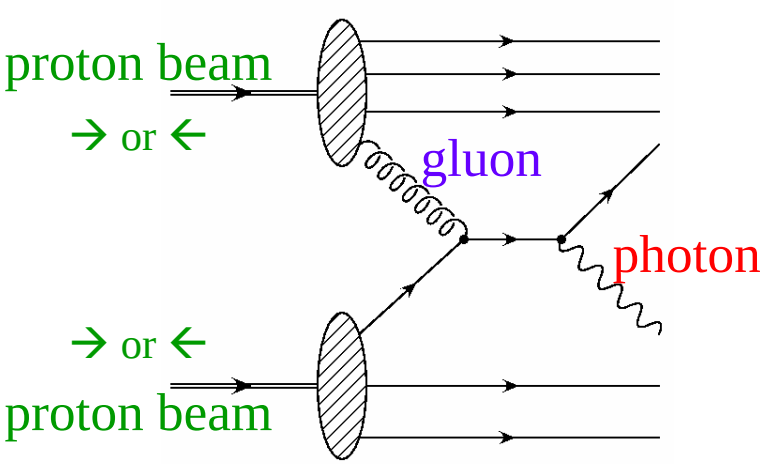
- semi-inclusive DIS
  - high-$p_T$ hadron pairs
  - open charm production



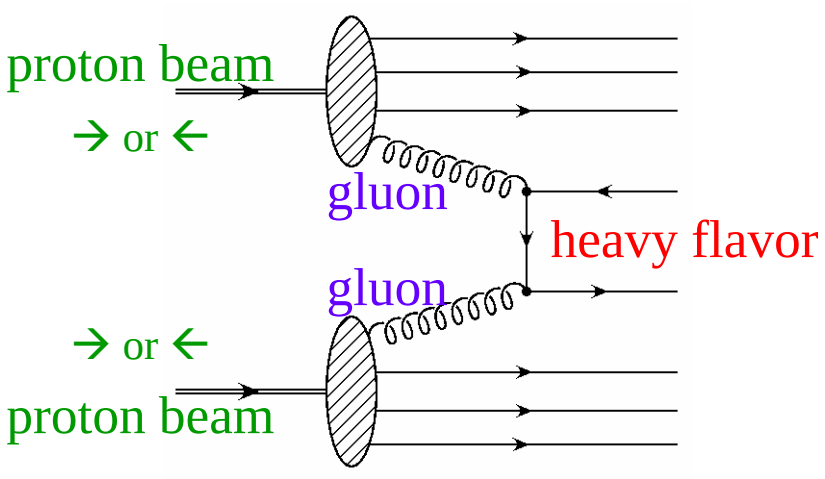
# Gluon polarization measurement

- Polarized hadron collision
  - leading-order gluon measurement

direct photon production




heavy-flavor production




- $A_{LL}$ measurement
  - $P$: polarization
  - $N$: yield
  - $R$: relative luminosity

$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}$$

$$= \frac{1}{P_1 \cdot P_2} \cdot \frac{N_{++} - R \cdot N_{+-}}{N_{++} + R \cdot N_{+-}} \qquad R = \frac{L_{+-}}{L_{++}}$$

# *Relative luminosity*

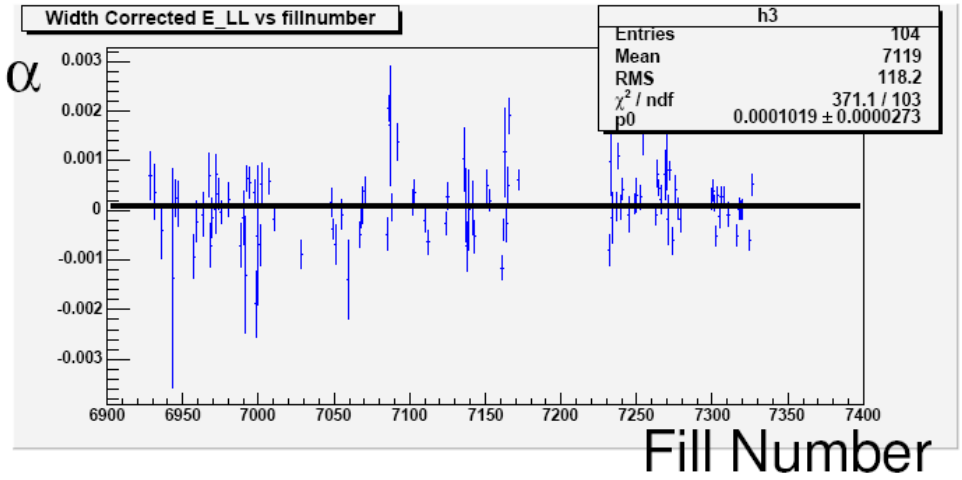
- Beam-Beam Counter (BBC) used as relative luminosity monitor
  - $3.0 < |\eta| < 3.9$
  - low background
  - high statistics
- Zero-Degree Calorimeter (ZDC) used as a cross check
  - $6 < |\eta|$
  - different kinematics and acceptance
- Bunch-by-bunch comparison of ratio of scalar counts in BBC and ZDC

$r(i) = N_{ZDC}(i)/N_{BBC}(i)$ is fitted by expected polarization pattern:

$C[1+A_{LL}P_1(i)P_2(i)]$

C: constant

$A_{LL}$: $A_{LL}$ of BBC relative to ZDC after vertex-width correction



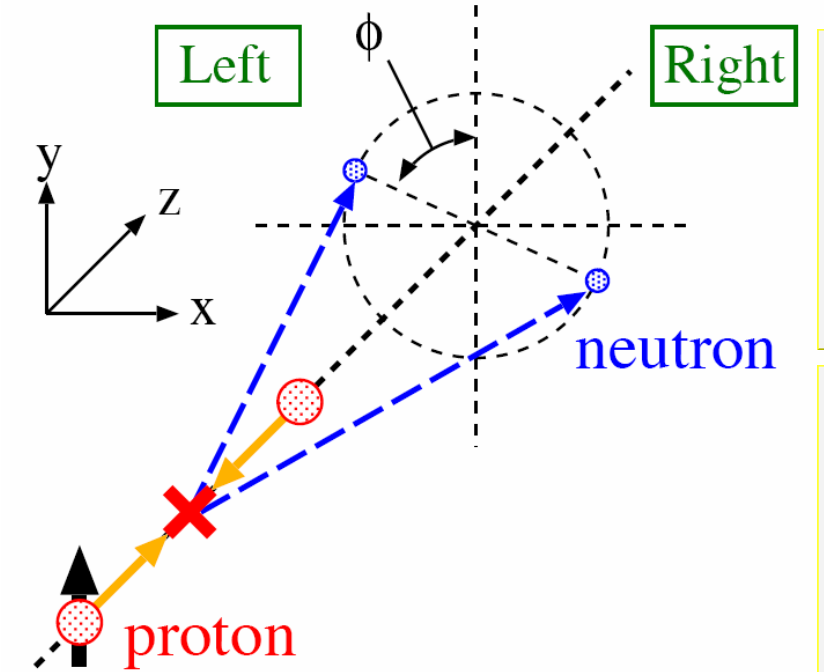

very constant zero-consistent value is obtained: it shows a precision of the relative luminosity

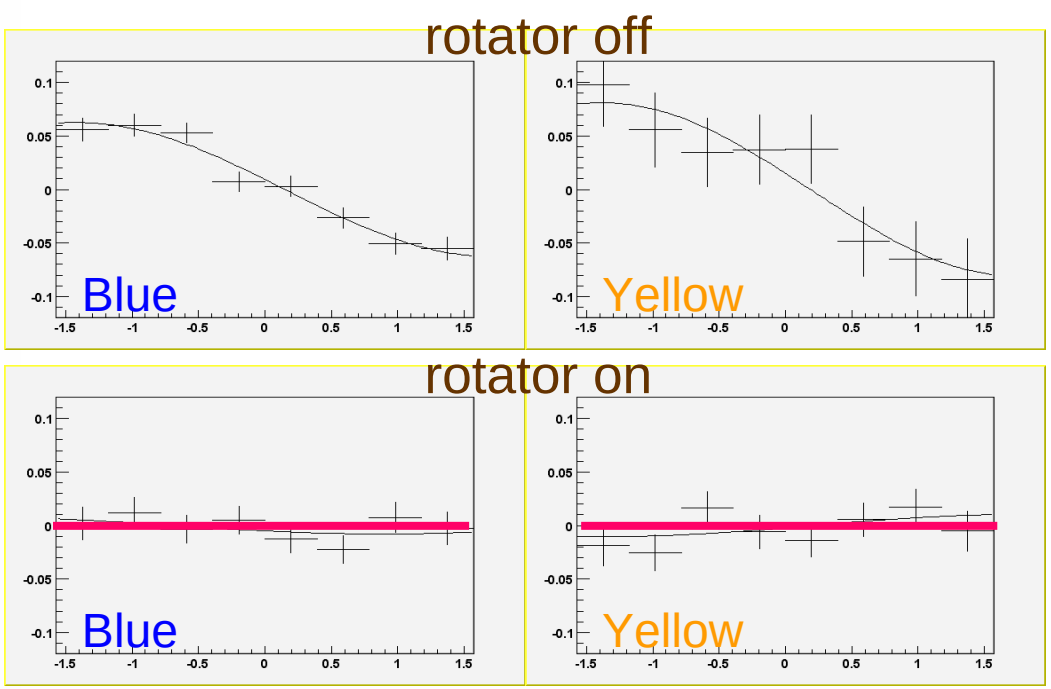
# *Relative luminosity*

- 2005 run
  - achieved relative luminosity precision $\delta R = \delta(L_{++}/L_{+-})$ smaller than $1.0 \times 10^{-4}$
  - relative luminosity contribution to $A_{LL}(\pi^0)$ smaller than 0.023% (47% beam polarization)
  - $A_{LL}$ of BBC relative to ZDC consistent with zero (smaller than 0.02%)
    - strongly indicates that both double spin asymmetries are zero

# Local polarimeter

- Spin rotator magnets enable longitudinal collisions
- PHENIX discovered at low $p_T$ and high $x_F$ an analyzing power of neutron production in pp collisions at $\sqrt{s}$ = 200 GeV
- ZDC + Shower Max Detector



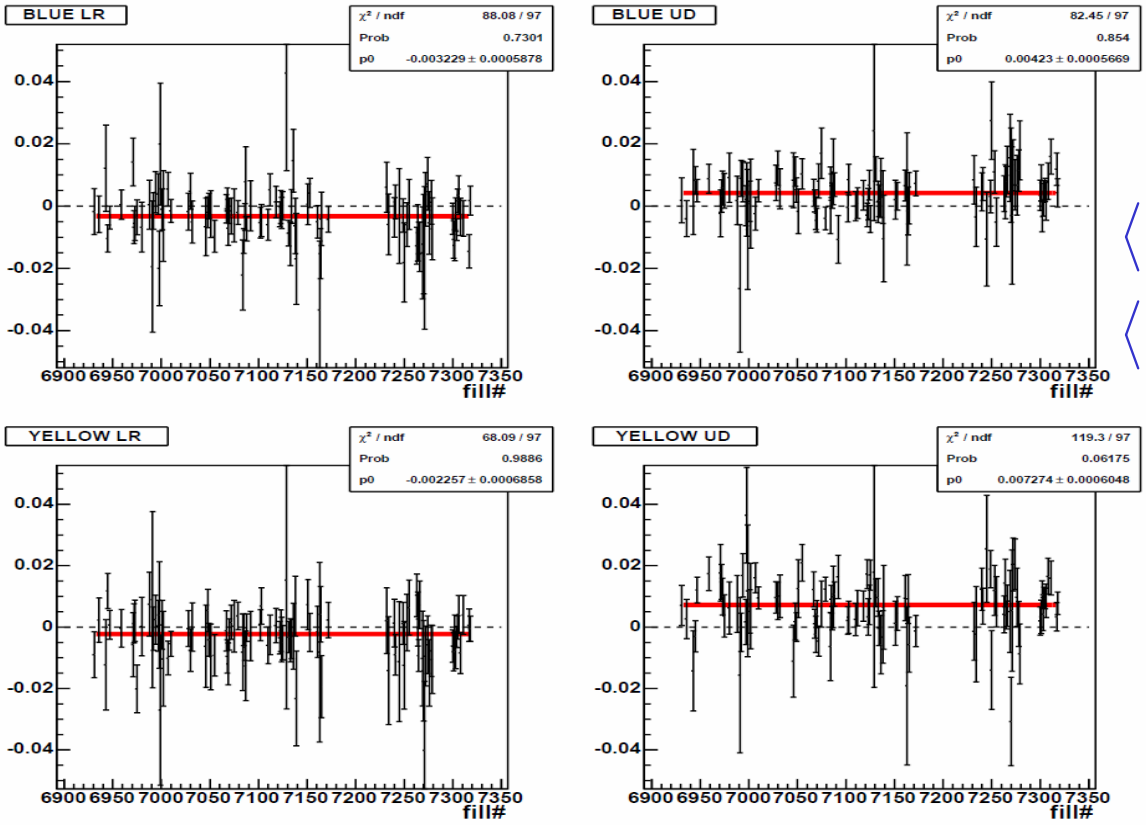



# Local polarimeter

- Longitudinal component measurement

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

  - $S_T$ is measured with the local polarimeter




2005 run

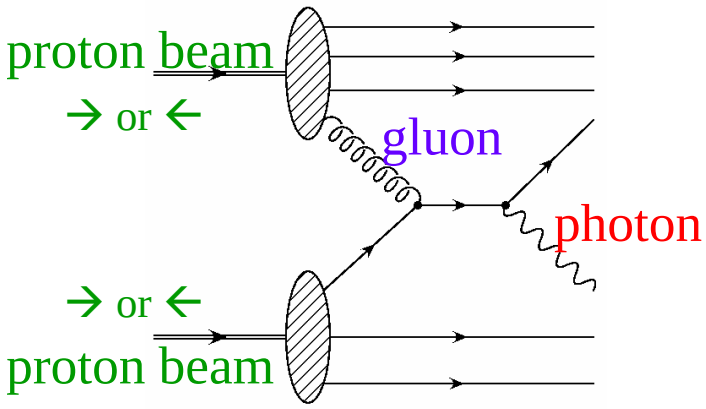
$$\langle p_L / p \rangle_{Blue} = 99.48 \pm 0.12 \pm 0.02\%$$

$$\langle p_L / p \rangle_{Yellow} = 98.94 \pm 0.21 \pm 0.04\%$$

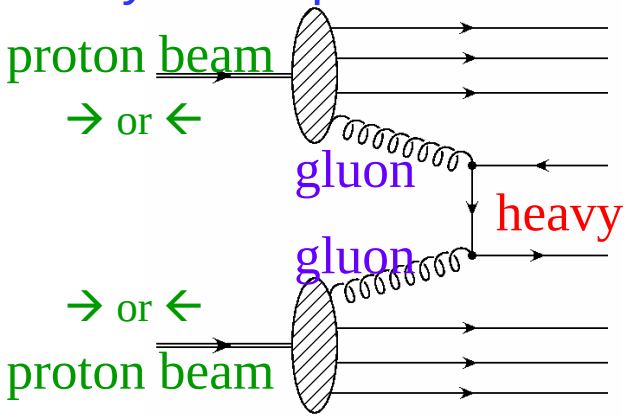
# Gluon contribution ?

- Polarized hadron collision
  - leading-order gluon measurement

direct photon production



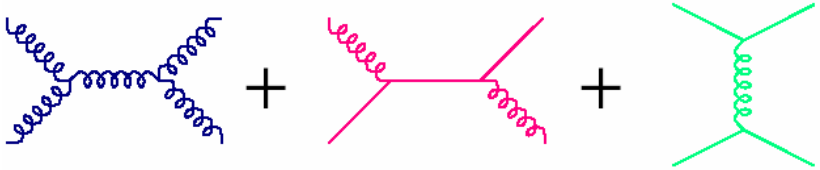

heavy-flavor production

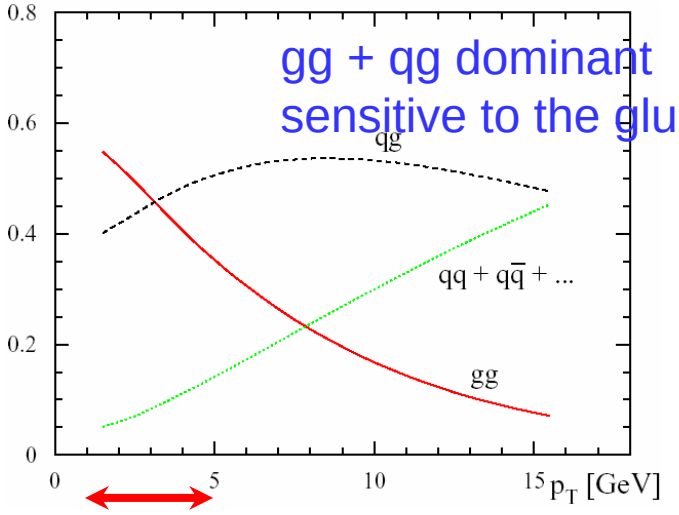



- $A_{LL}$ of $\pi^0$

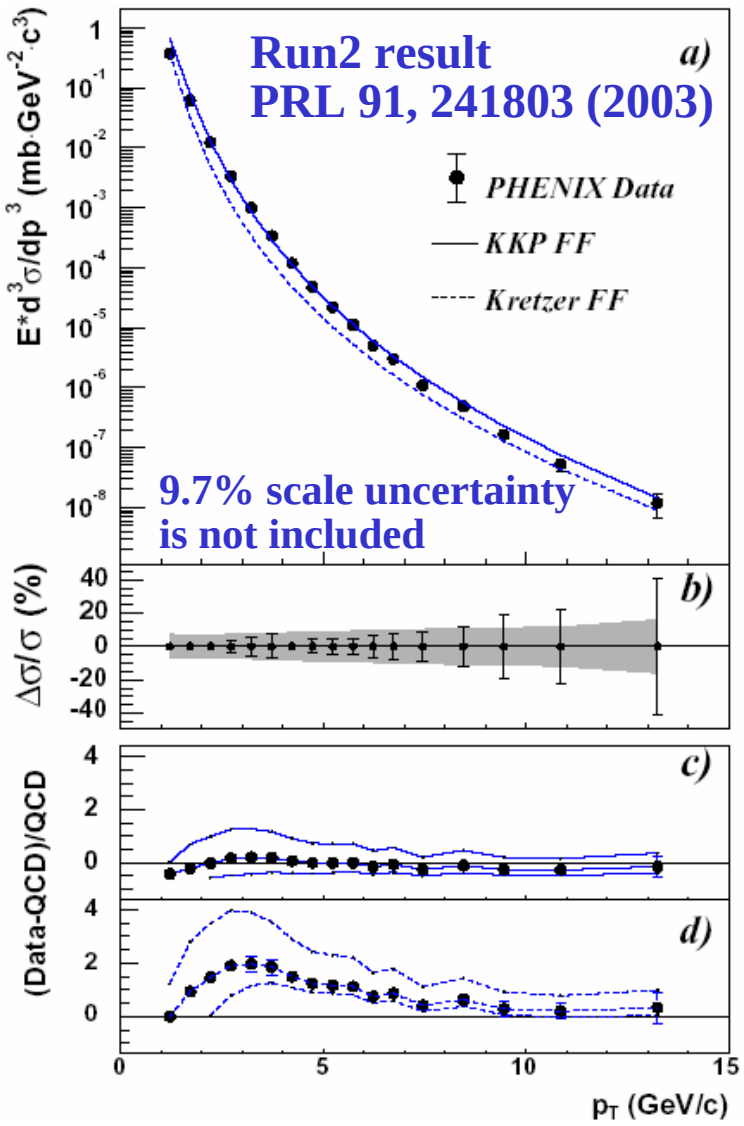
$$A_{LL} = \frac{d\sigma_{++} - d\sigma_{+-}}{d\sigma_{++} + d\sigma_{+-}}$$

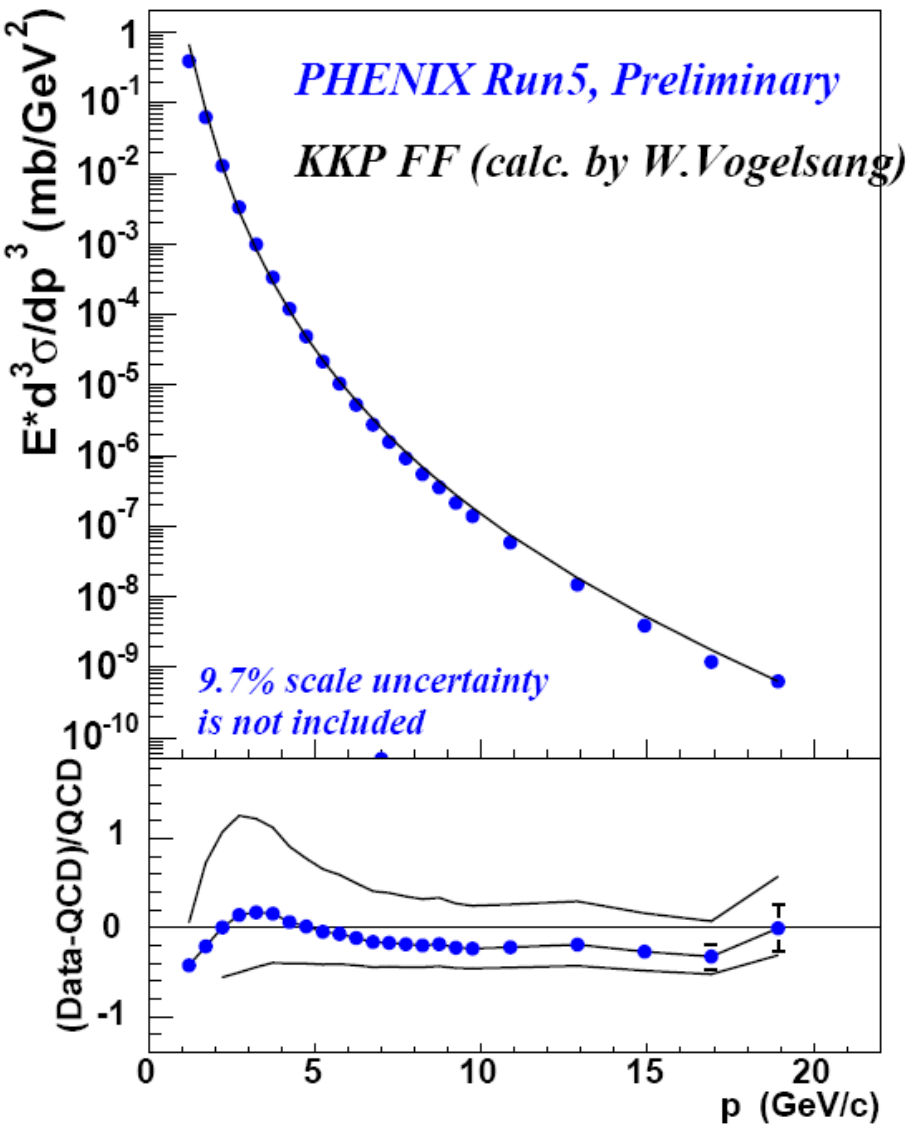
$$= [\omega_{gg}]\Delta g \Delta g + [\omega_{gq}\Delta q]\Delta g + [\omega_{qq}\Delta q \Delta q]$$





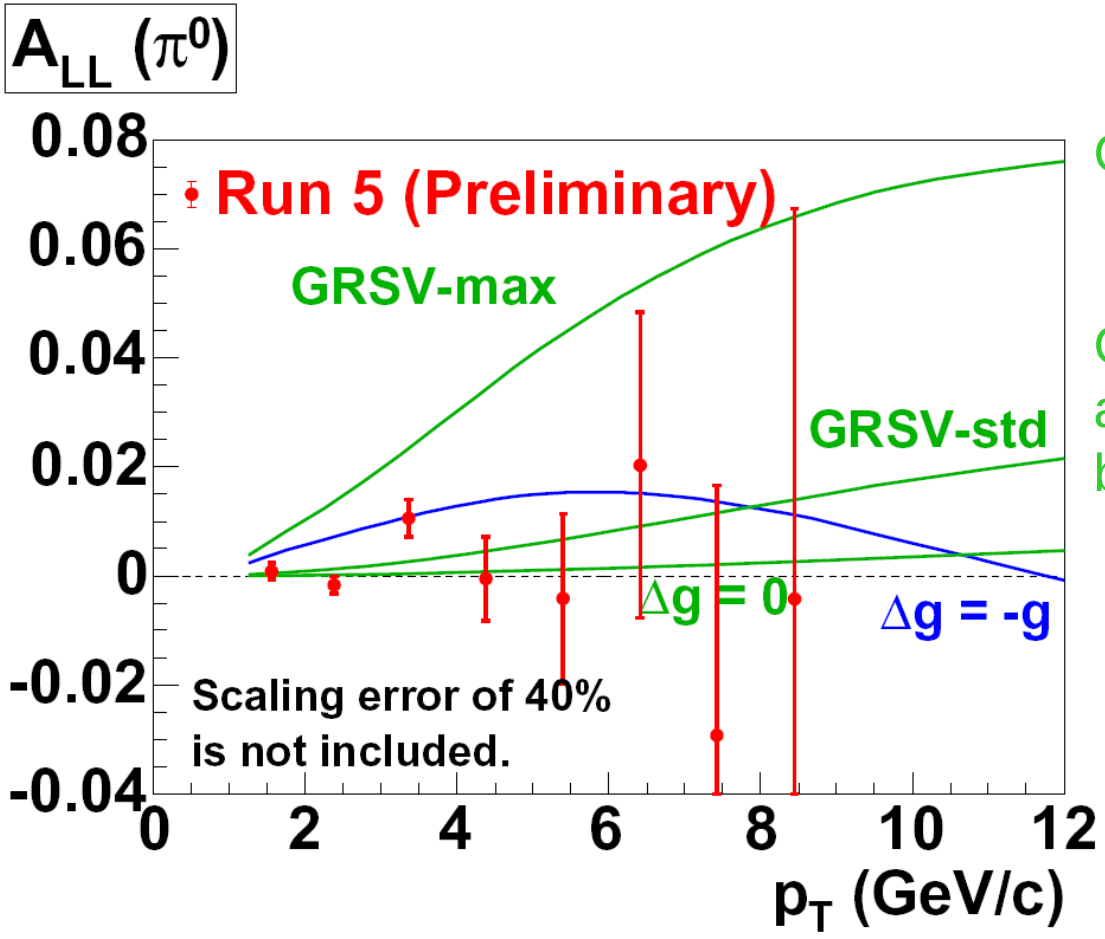
# $\pi^0$ cross section




agreement of cross section between data and NLO pQCD calculations is excellent at RHIC

# PHENIX $A_{LL}$ of $\pi^0$




GRSV-max: Δg = 1.84

GRSV-std: Δg = 0.42
at $Q^2$=1(GeV/$c$)$^2$
best fit to DIS data

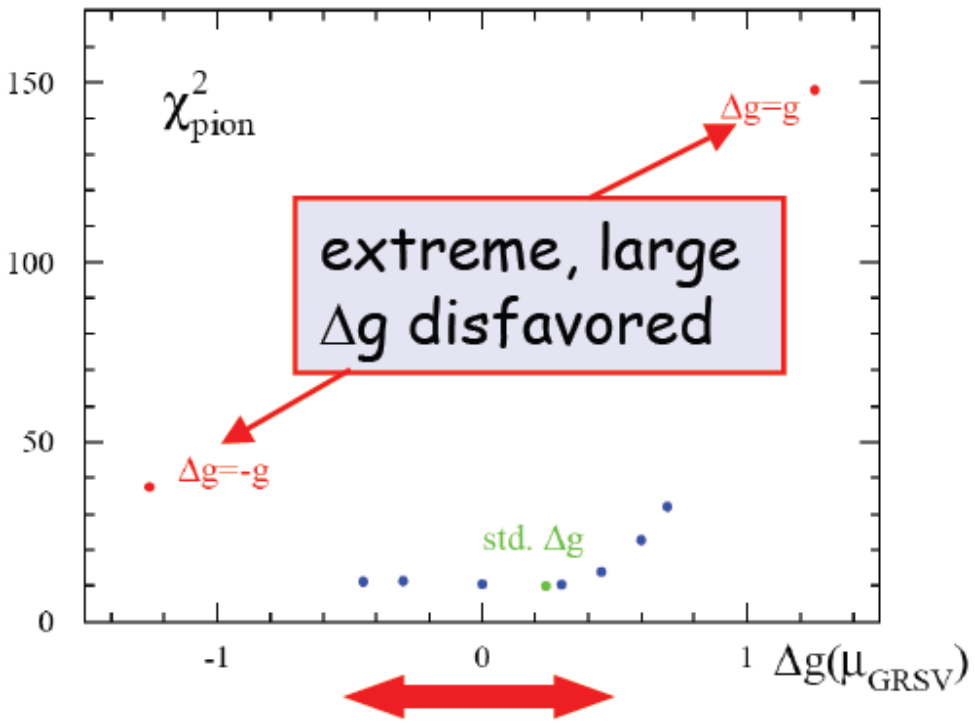
| Theory model | C.L. (%) |
|---|---|
| GRSV-std | 17.1-21.7 |
| *GRSV-max (Δg=g) | 0.0-0.0 |
| *GRSV Δg=0 | 16.7-18.4 |
| *GRSV Δg=−g | 0.0-0.7 |

* at input scale $Q^2$ = 0.4 GeV

- Run5 conclusively excludes GRSV maximal scenarios.
- Data consistent with GRSV standard and GRSV ΔG = 0.

# $A_{LL}$ of $\pi^0$

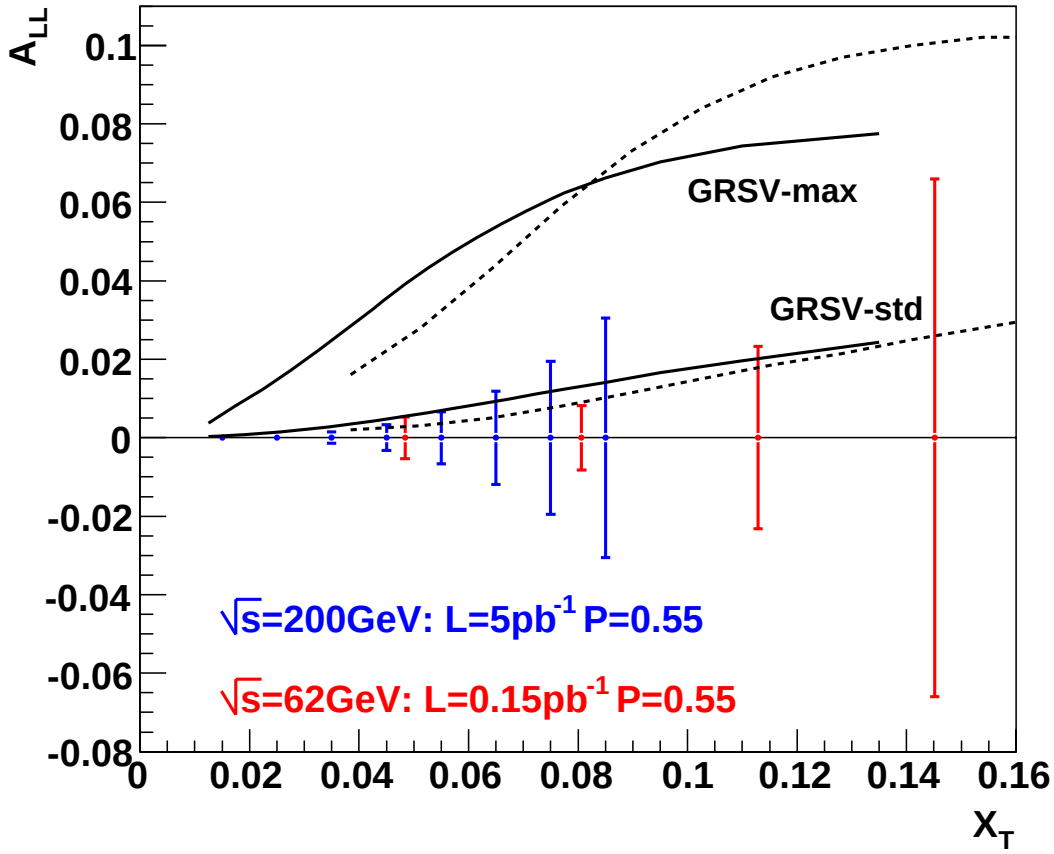
– $\chi^2$ analysis by M. Stratmann and W. Vogelsang



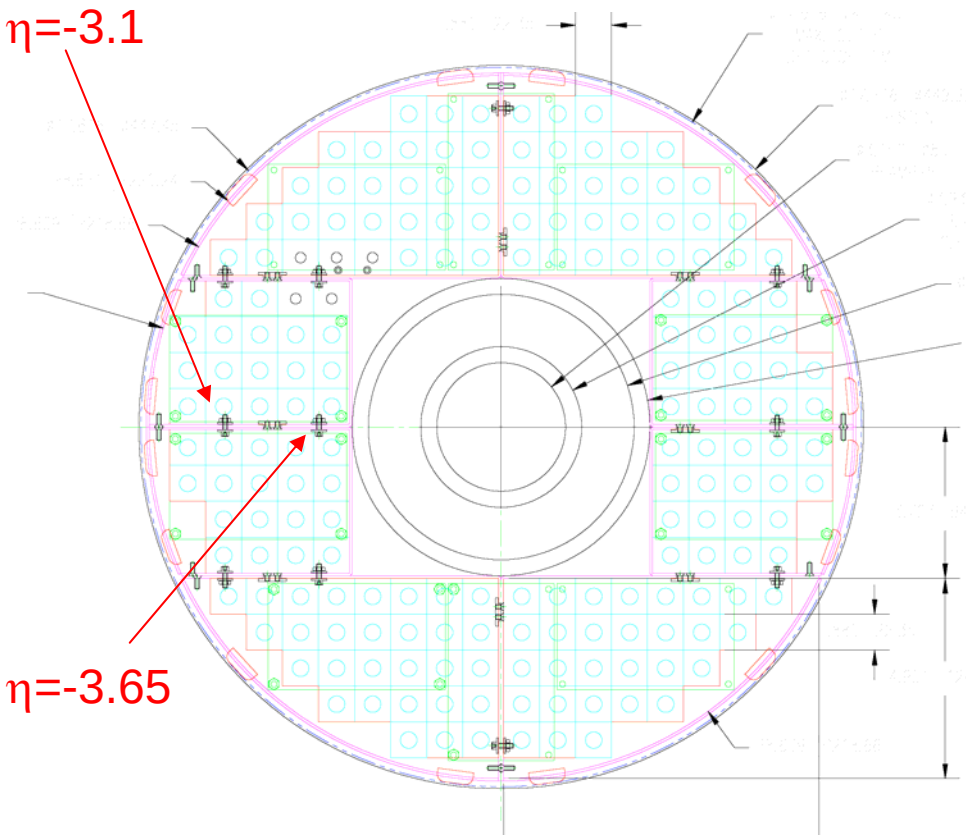

very flat $\chi^2$ distr.
around zero

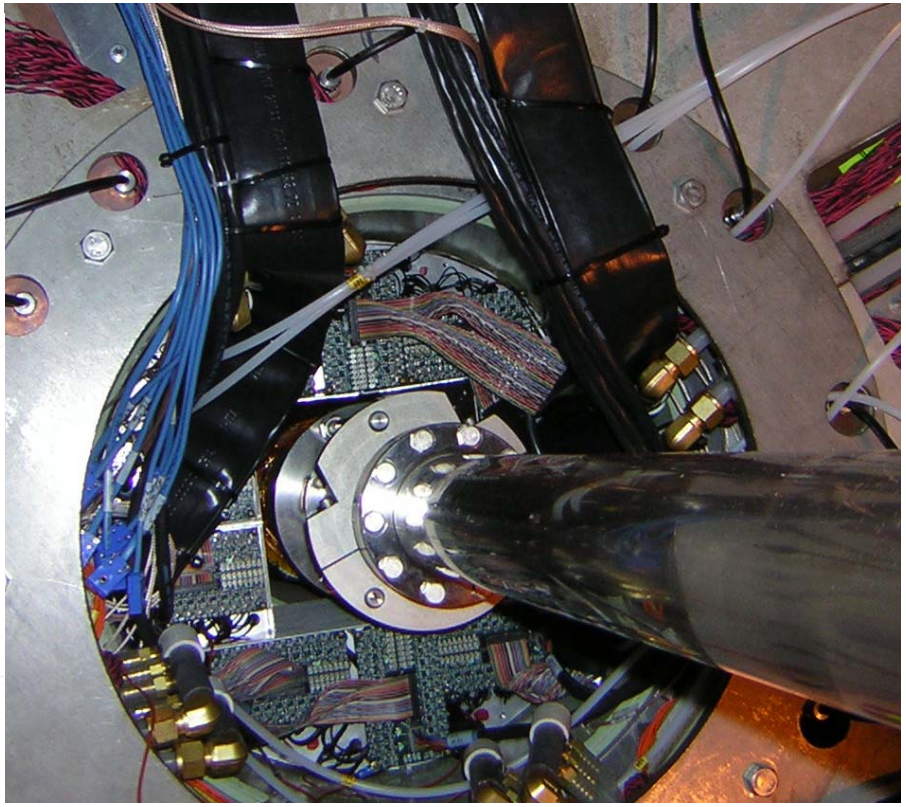
# 62.4 GeV run

- $A_{LL}$ of $\pi^0$
  - low FoM but good high-*x* coverage



# Muon Piston Calorimeter

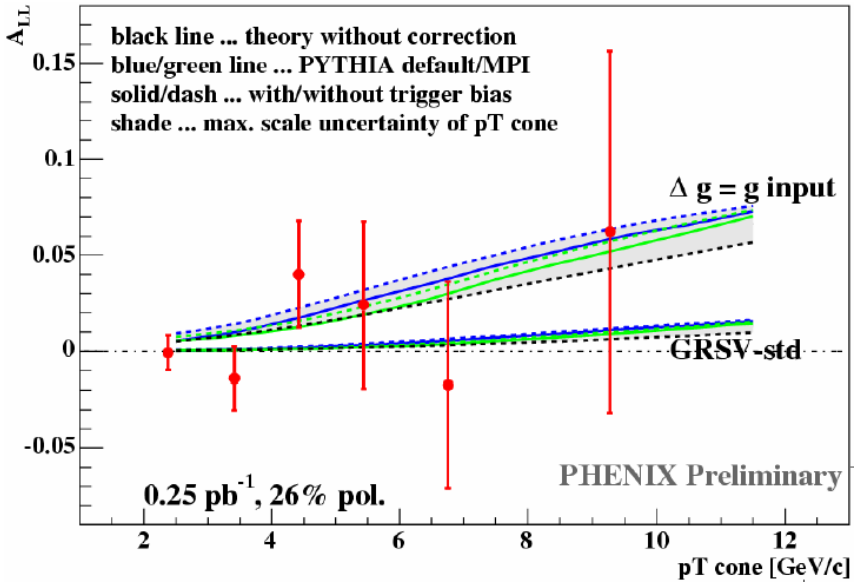


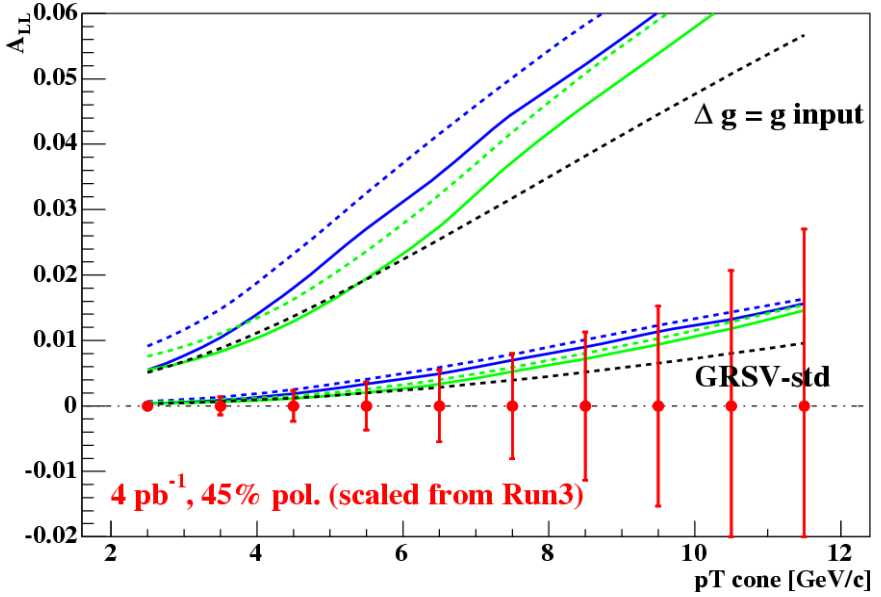
- $3.1 < |\eta| < 3.65$
- 192  2.2x2.2x18 $cm^3$ PWO crystals, 220 cm from vertex (behind Beam-Beam counter)
- Energy Resolution:  13%/√E??  from beam test

# $A_{LL}$ of jet-like cluster

- "jet" detection: tag one high energy photon and sum energy of nearby photons and charged particles
- definition of $p_T$ cone: sum of $p_T$ measured by EMCal and tracker with $R = \sqrt{(|\phi|^2+|\eta|^2)}$
- real $p_T$ of jet is evaluated by tuned PYTHIA




Run3 result

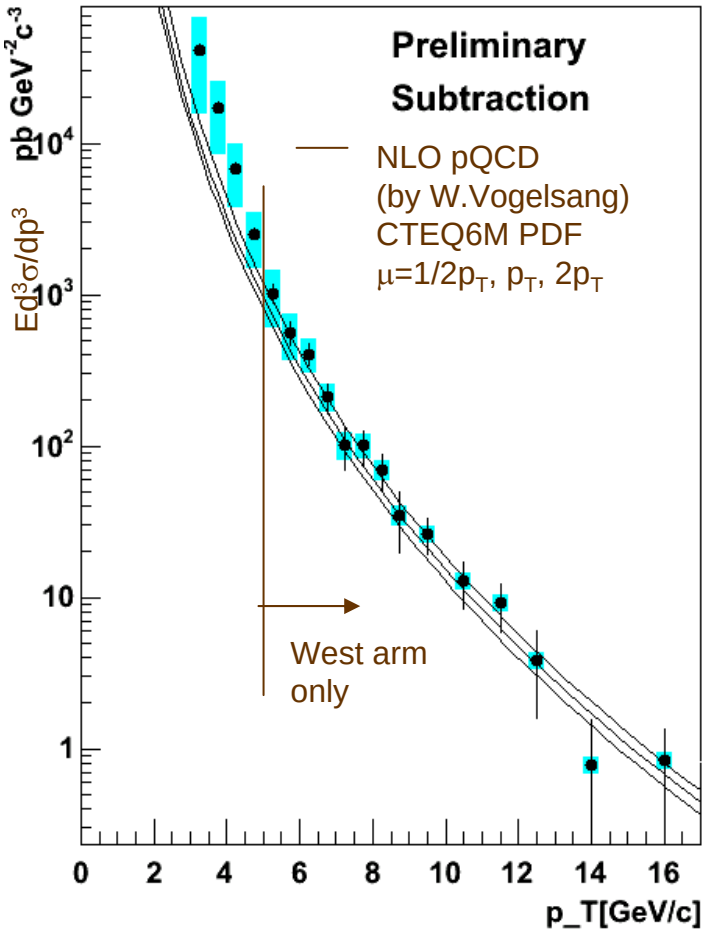



Run5 projection

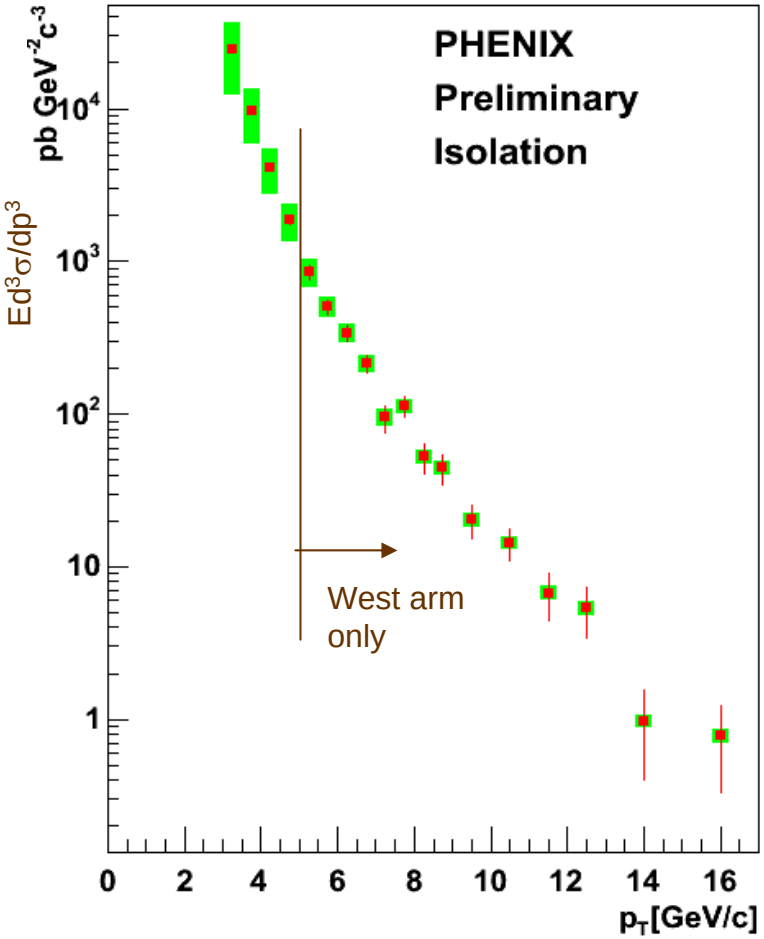
# *Direct photon*

## Run3 preliminary results

### subtraction method



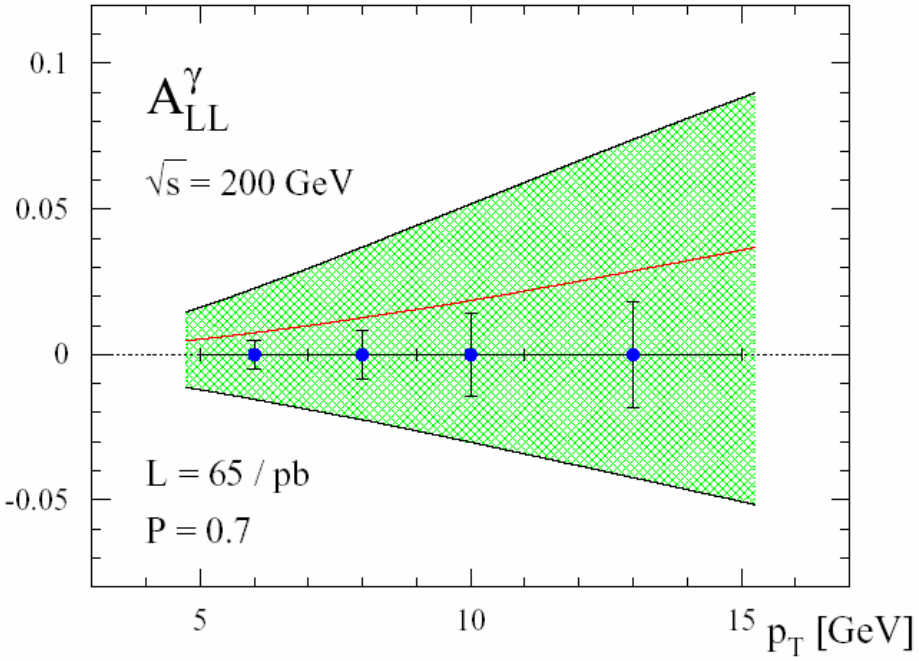

### isolation method



# Future outlook

- We have been accumulating data
  - $A_{LL}$ of direct photon
    - gluon Compton (gq→qγ) dominant
    - clean Δg measurement including sign of Δg

$$A_{LL}(p_T) = \frac{\Delta g(x_g)}{g(x_g)} \cdot A_1^{\,p}(x_q) \cdot \hat{a}_{LL}$$

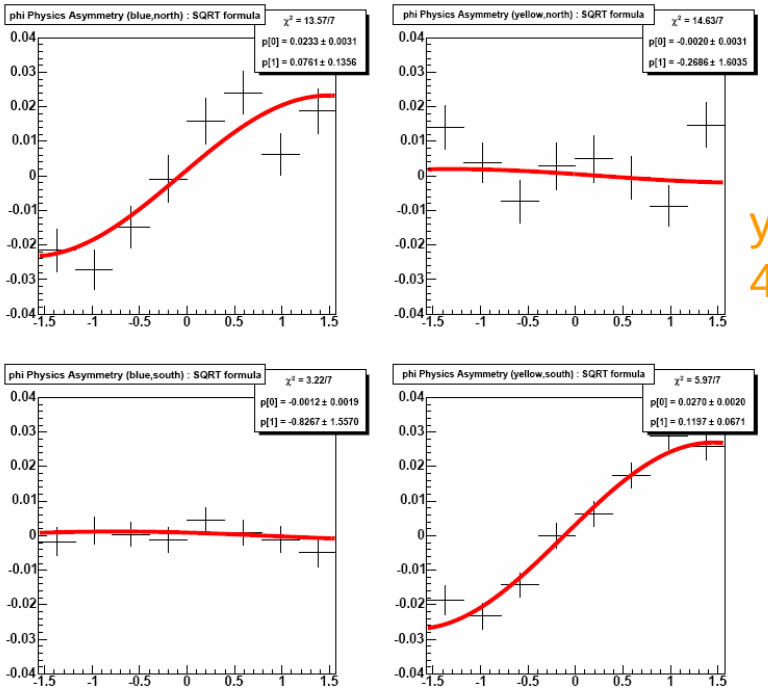



  - $\sqrt{s}$ = 200 GeV run until 2009
  - $\sqrt{s}$ = 500 GeV run from 2009 (and developments until then)

# *Towards the 500 GeV run*

- 410 GeV run in 2005
  - accelerator study towards the 500 GeV run
    - RHIC is capable of accelerating to higher $\sqrt{s}$ without losing all polarization

blue:
33% pol.




yellow:
49% pol.

analyzing power of local polarimeter roughly the same despite doubling of energy

- 500 GeV commissioning in 2006

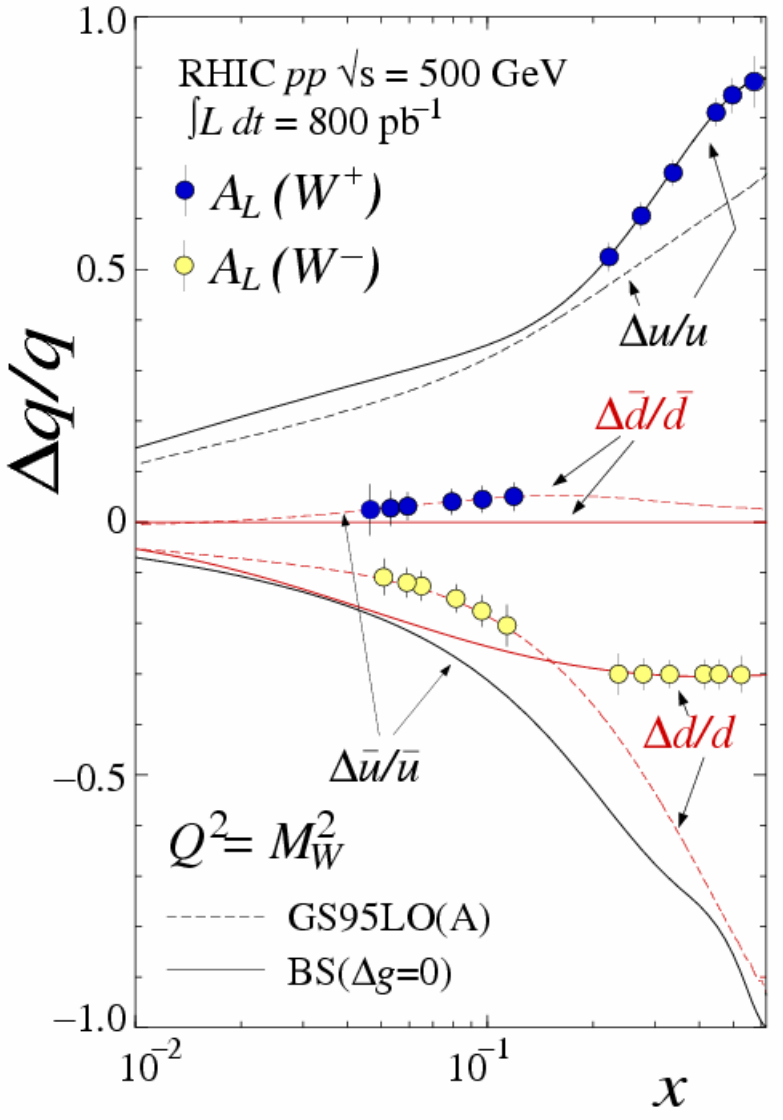
# Flavor-identified quark polarization

- Weak boson measuremen
  - at $\sqrt{s}$ = 500 GeV
- parity-violating $A_L$ measurement

$$A_L^{W^+} = \frac{\Delta u(x_a)\bar{d}(x_b) - \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

$$A_L^{W^-} = \frac{\Delta d(x_a)\bar{u}(x_b) - \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)}$$

  - no fragmentation ambiguity
  - important to limit the gluon polarization, too



# $A_N$ Results

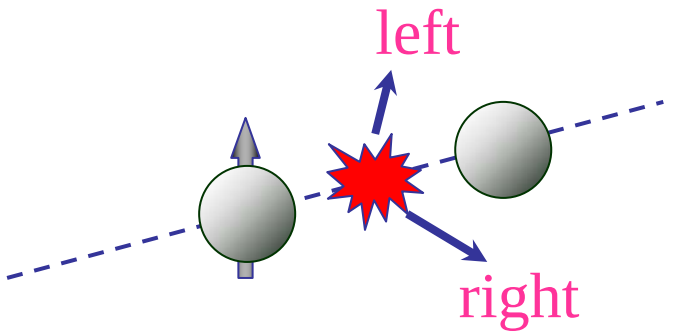
RIKEN

PHENIX

# *Single transverse-spin asymmetry ($A_N$)*

- Left-right asymmetry

$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

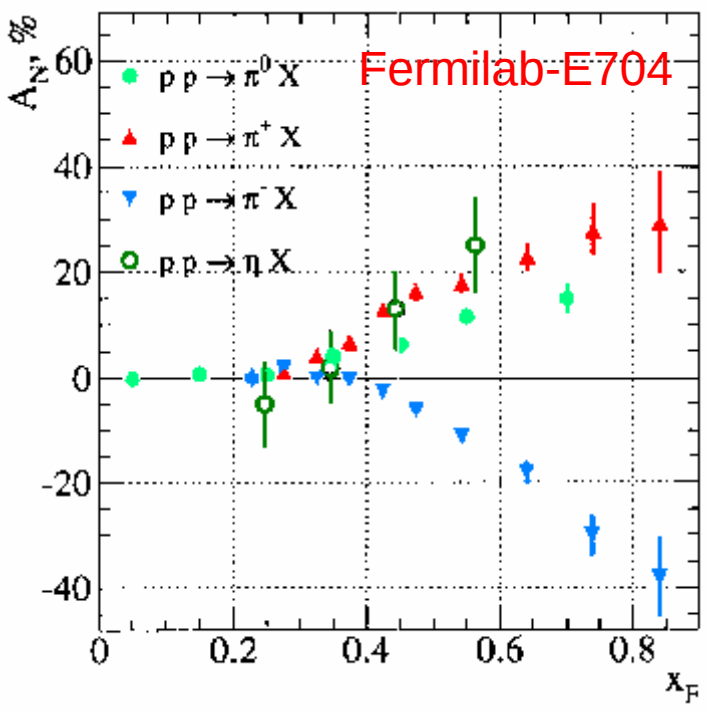



- Forward-rapidity
  - Fermilab-E704
    - fixed-target experiment at $\sqrt{s}$ = 19.4 GeV
  - RHIC-STAR
    - $\sqrt{s}$ = 200 GeV
    - large asymmetry at $x_F > 0.3$
  - and more fixed-target data at lower energies

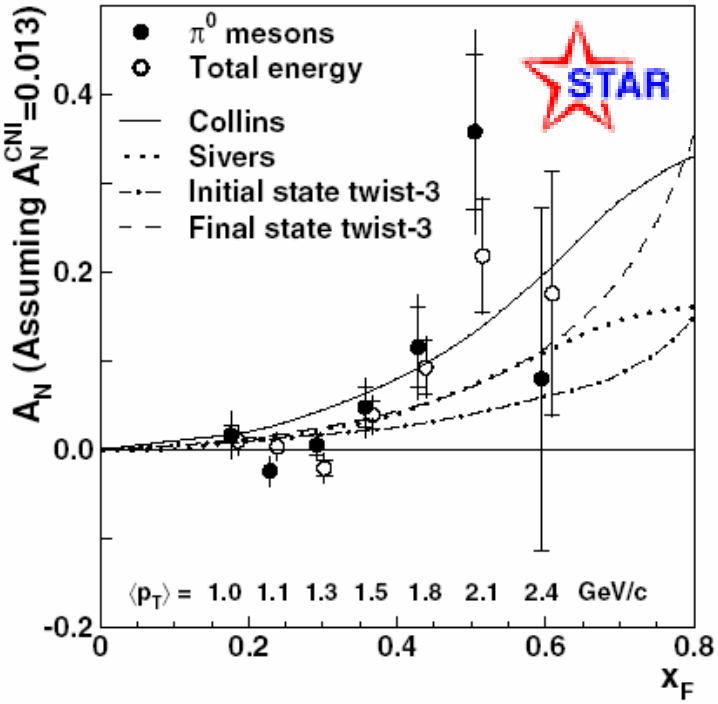
# *Single transverse-spin asymmetry ($A_N$)*

- Forward-rapidity
  - ~ 20% asymmetry
  - many QCD-based theories developed

$\sqrt{s}$ = 19.4 GeV




$\sqrt{s}$ = 200 GeV




Phys.Rev.Lett. 92 (2004) 171801

# *Quark distribution functions and fragmentation functions*

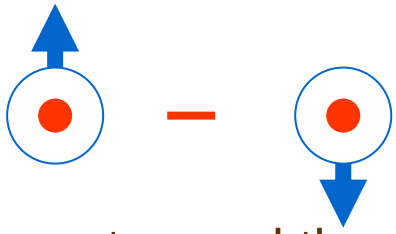
- transversity distribution function

$$\delta q(x) = h_{1T}(x)$$

  - distribution of the transverse-spin of a parton inside the transversely polarized proton

- Sivers distribution function

$$f_{1T}^{\perp}(x, p_T^2)$$



  - correlation between the transverse-spin of the proton and the transverse-momentum of an unpolarized parton inside the proton ($p_T^2$)

- Collins fragmentation function

$$H_1^{\perp}(z, k_T^2)$$

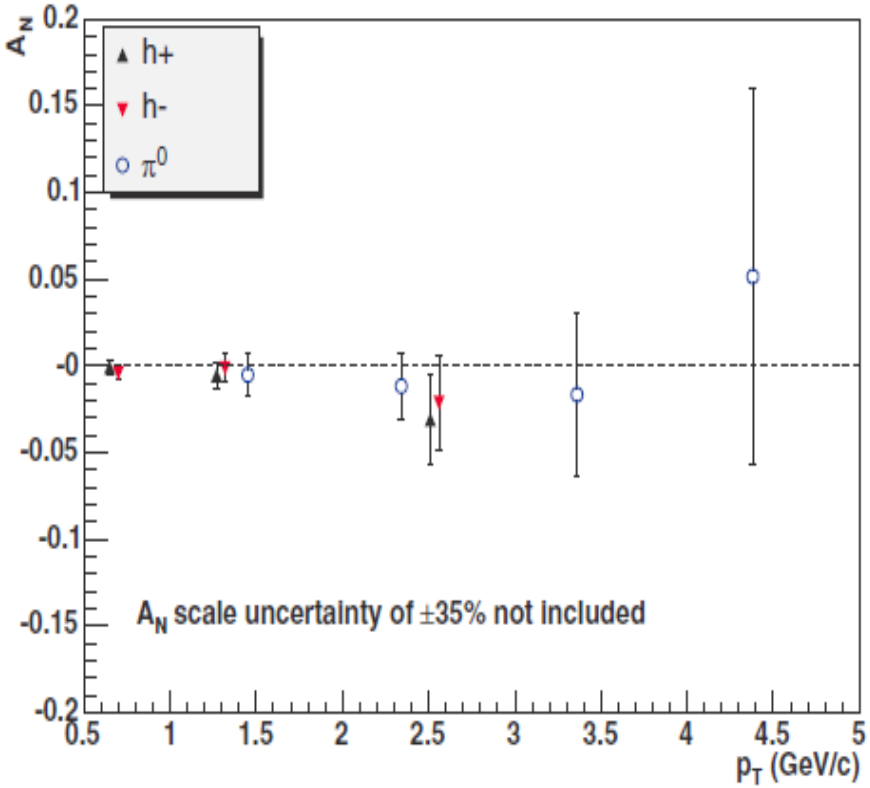
  - correlation between the transverse spin of a fragmenting quark and the transverse momentum of the outgoing hadron relative to the quark ($k_T^2$)

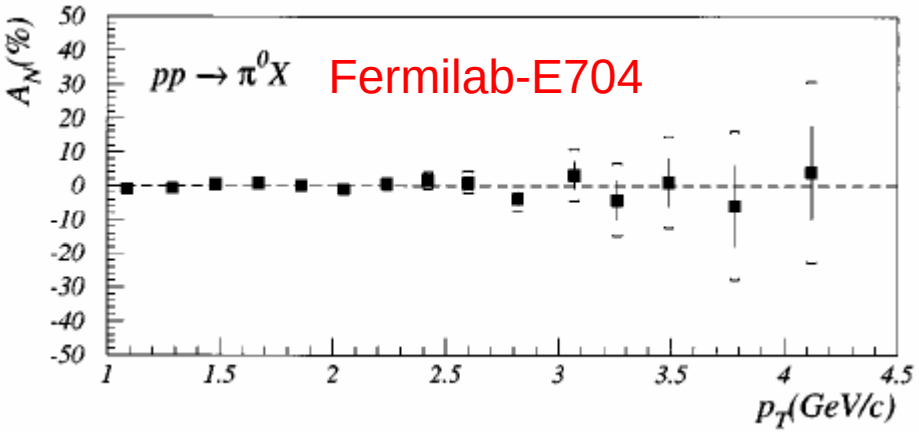
# *Mid-rapidity at PHENIX*

- Different kinematic region
  - forward-rapidity at STAR ($x_F > 0.3$)
    - quark-gluon reaction dominant
    - large contribution from x ~ 0.6 quark polarization/transversity
  - mid-rapidity at PHENIX ($x_F \sim 0$)
    - contribution from both gluon-gluon and quark-gluon reactions
    - x = 0.03 – 0.1
    - small quark polarization/transversity
    - no gluon transversity in leading twist
    - negligible transversity & Collins effect contribution

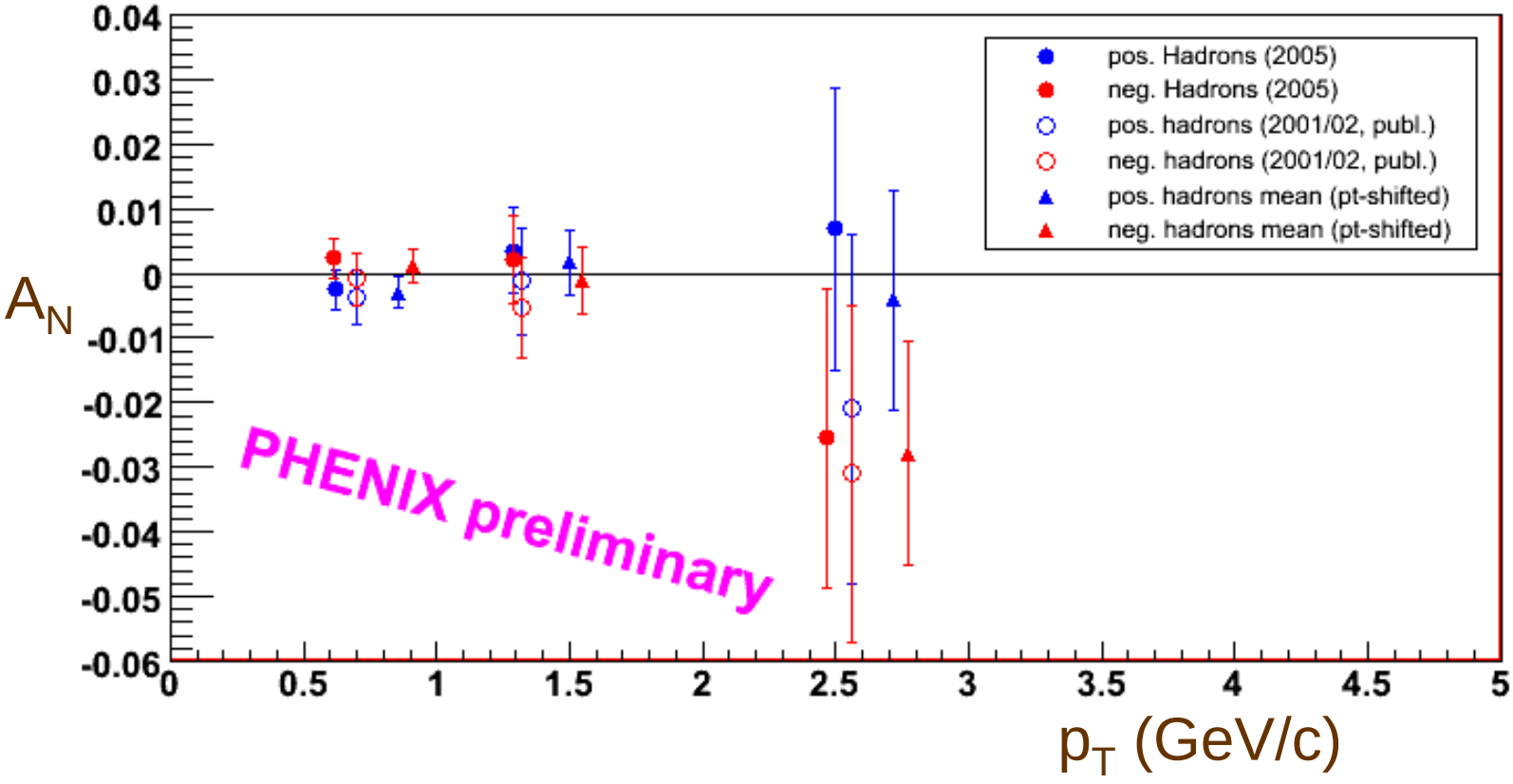
# *Mid-rapidity at PHENIX*

- Run2 results
  - $A_N$ for both $\pi^0$ and charged hadrons consistent with zero at mid-rapidity
  - ~5 times smaller asymmetry than STAR forward-rapidity data (~10%)
  - comparable data with Fermilab-E704 for $\pi^0$ and charged hadrons



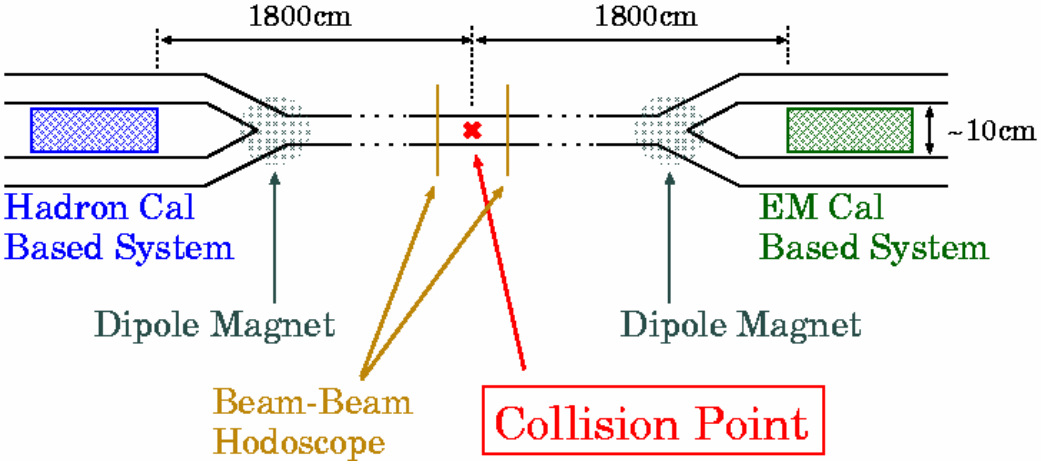
# *Update on charged pions*

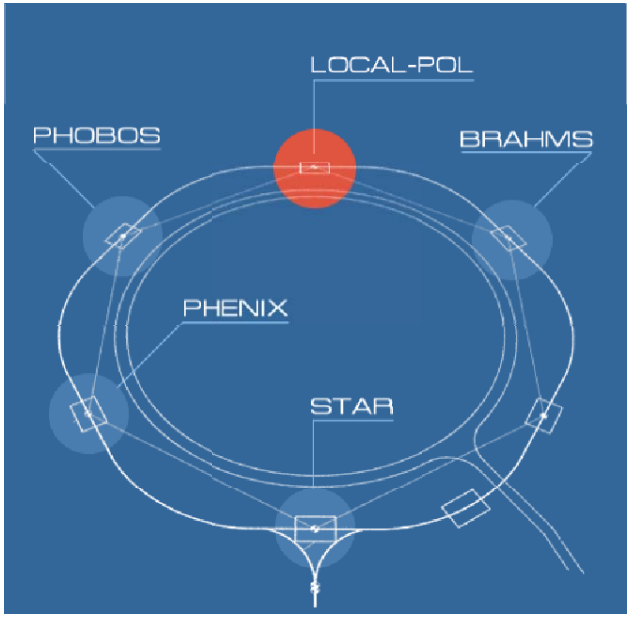


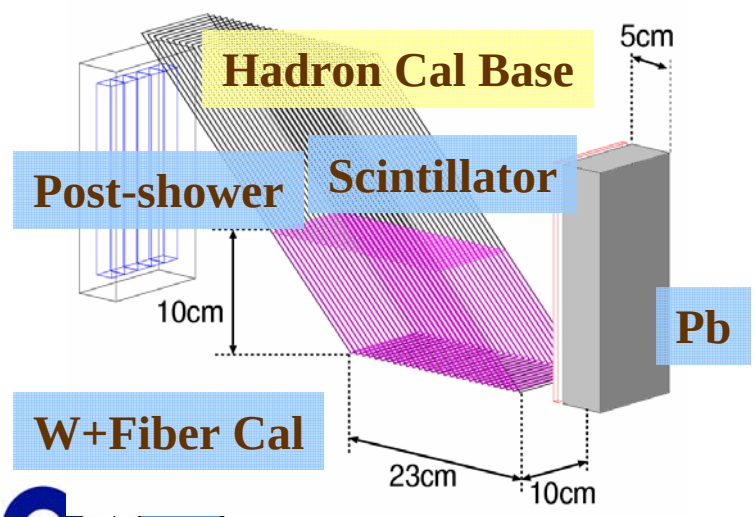

- Improved polarization: P=15% in 2001/02, P=47% in 2005 while statistics is smaller.
- $A_N$ is 0 within 1% → interesting contrast with forward $\pi$

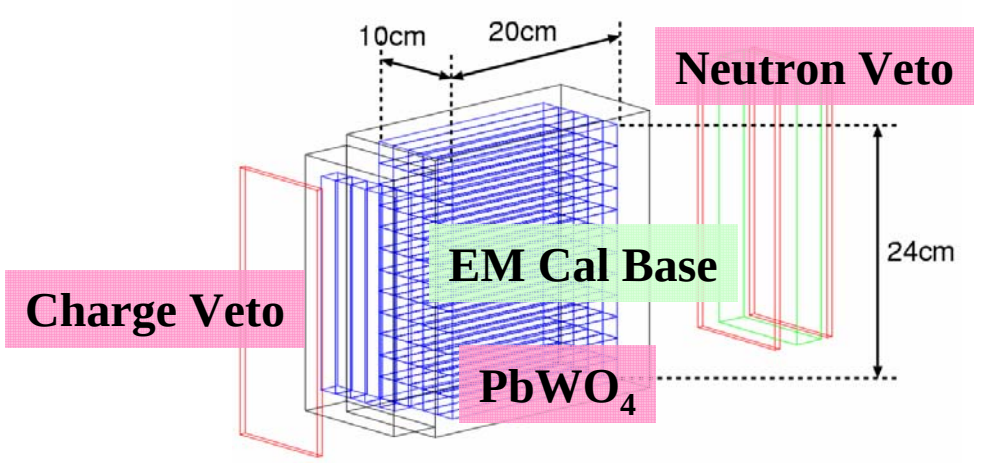
# Forward neutron asymmetry

- PHENIX local polarimeter R&D at IP12

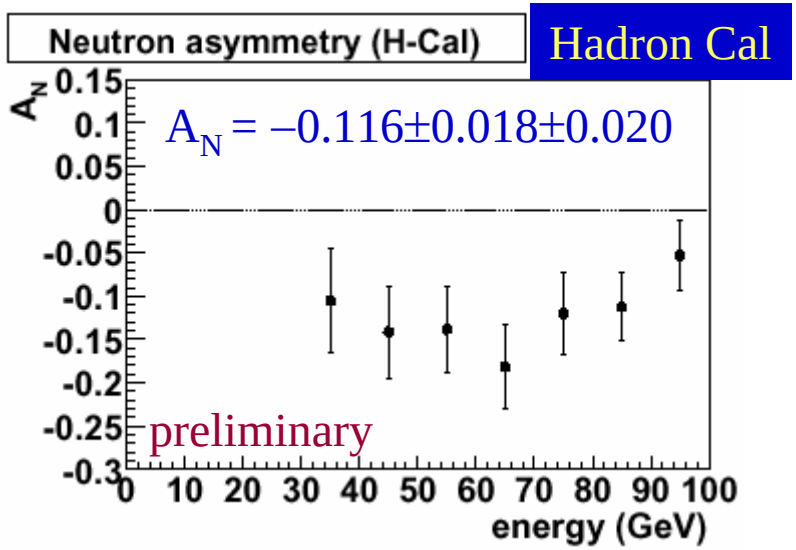


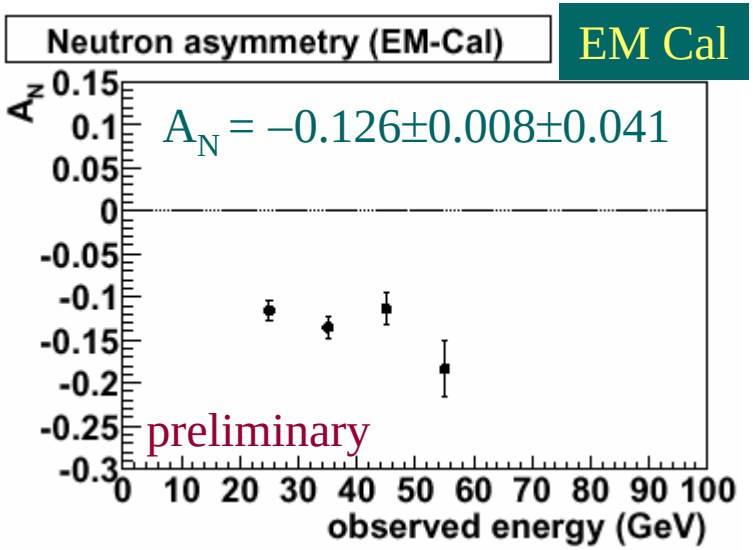



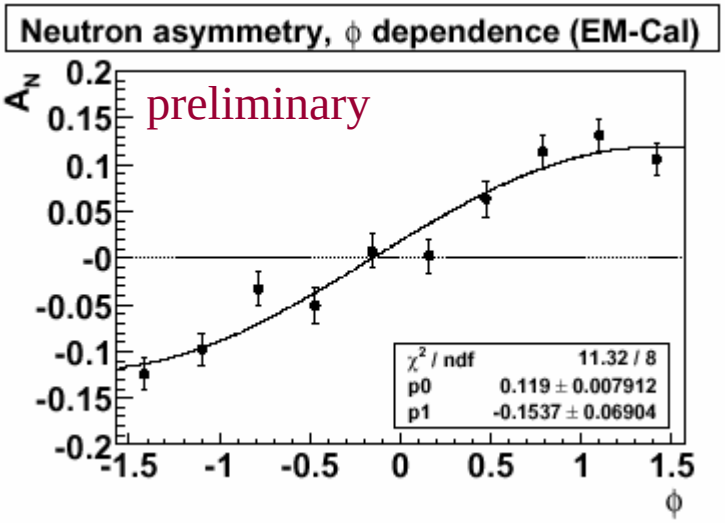



# Forward neutron asymmetry




very forward neutron
$A_N$ ~ -12%
$x_F > 0.2$
$p_T < 0.3$ GeV/$c$



# *PHENIX local polarimeter*

- ZDC + SMD
  - ZDC: Zero-Degree Calorimeter
    - hadron calorimeters at the most forward location (~18m from IP)
  - SMD: Shower-Maximum Detector
    - plastic scintillator array
    - X: 7 array, Y: 8 array

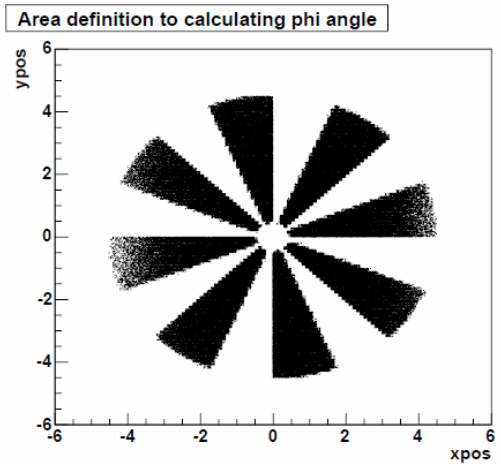
# Forward neutron asymmetry

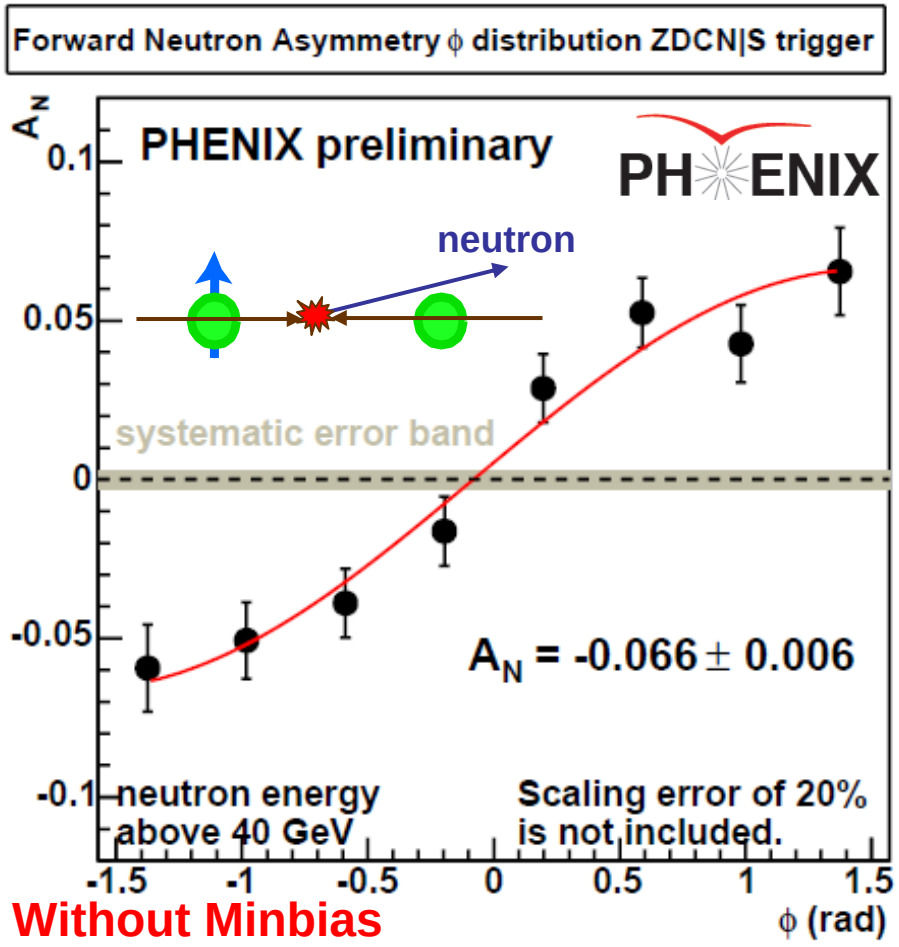
- Square-root formula

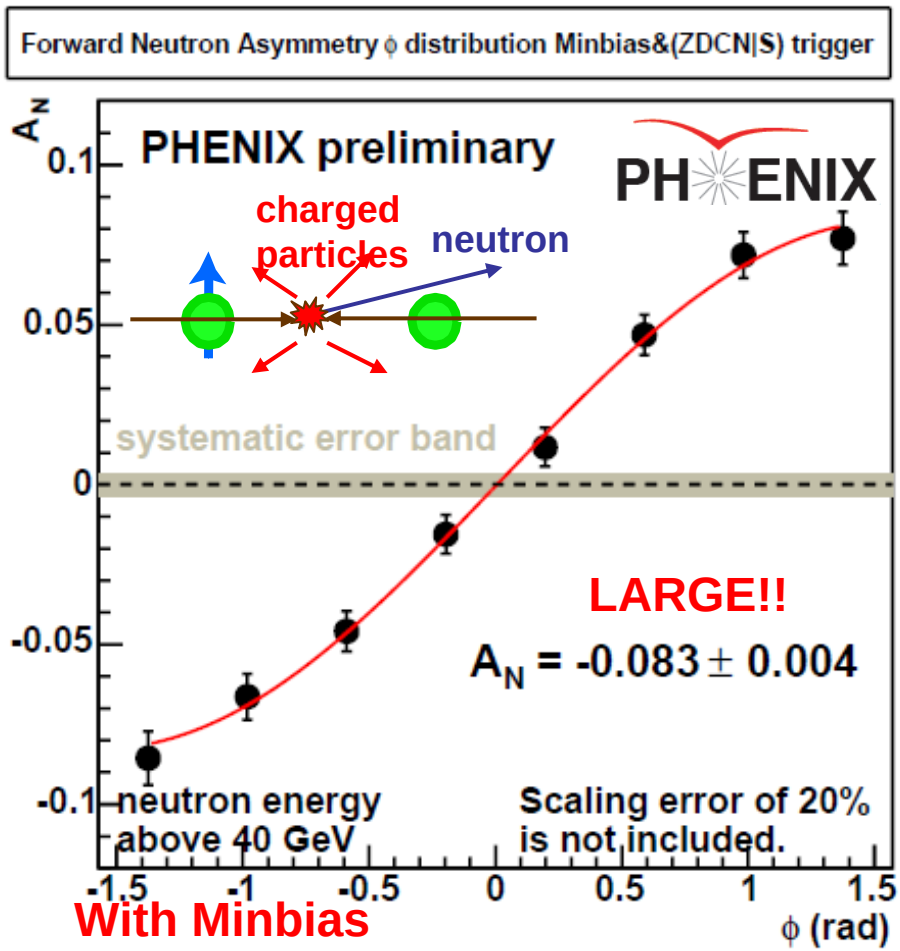
$$A_N \equiv \frac{1}{P}\frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \approx \frac{1}{P}\frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}}$$

- Smearing effect -- simulation

**P~48%**



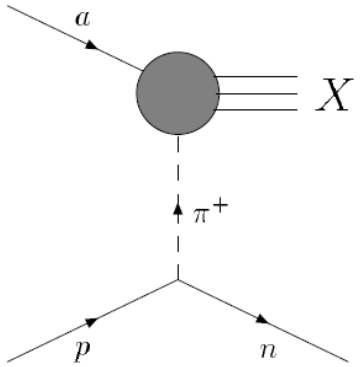



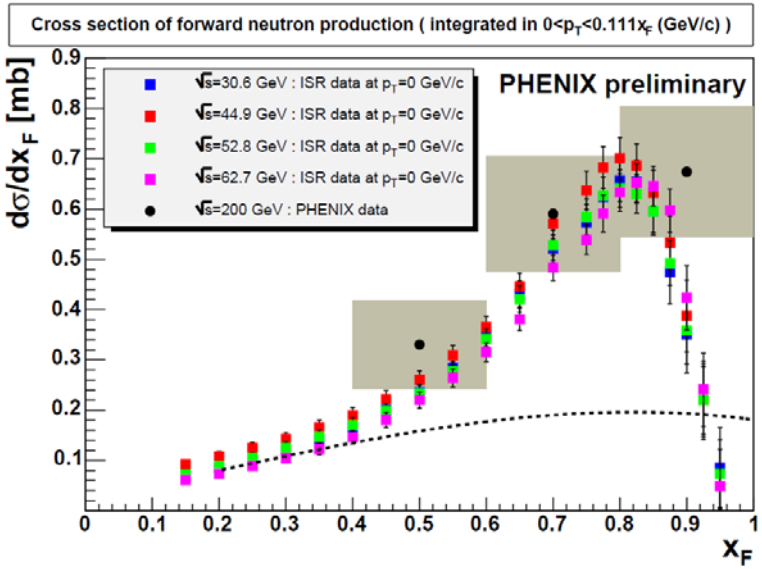
# Forward neutron asymmetry

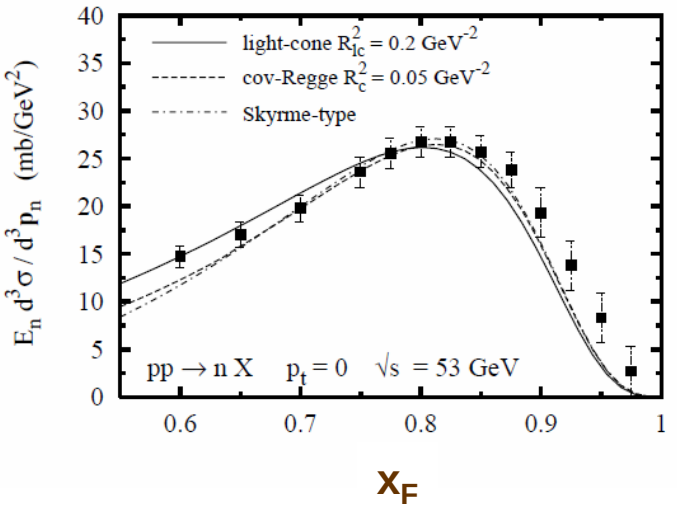
- $A_N$ is produced via interferance of spin non-flip and spin-flip amplitudes
- In Regge theory
  - Pomeron gives no spin-flip amplitude
  - We need spin-flip amplitude
- One pion exchange model may explain the result
  - Cross-section at ISR is OK
  - $x_F$-scaling at different sqrt(s)
  - → Need more data

    e.g., $p_T$ dependence of $A_N$, coincident particles

**Eur.Phys.J.A7:109-119,2000**

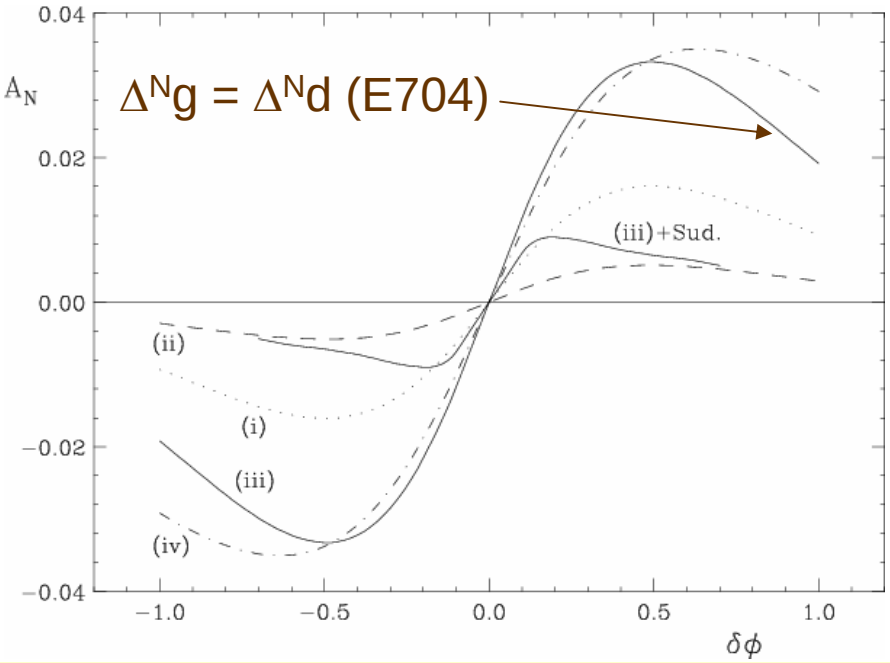


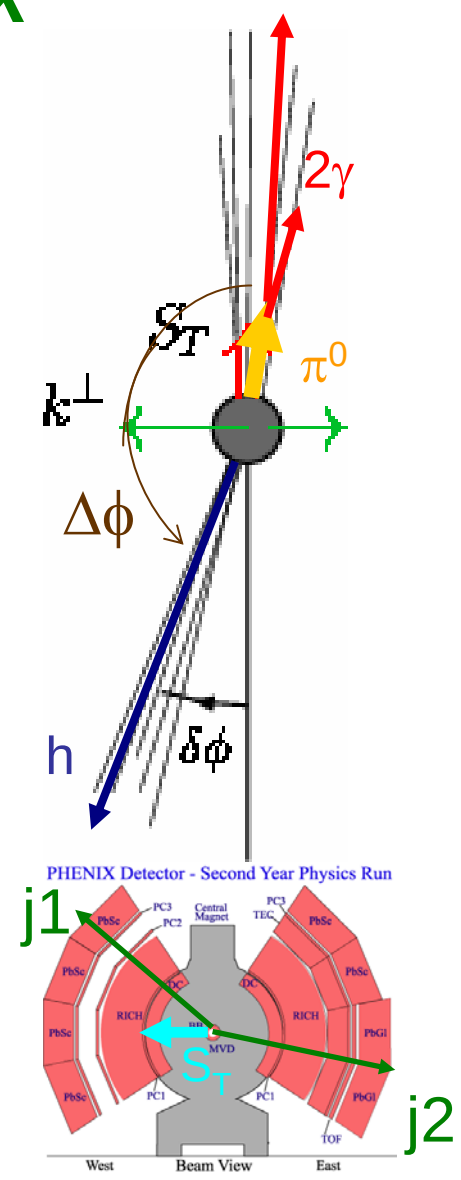



# Back-to-back jet at PHENIX

- Boer and Vogelsang find that this parton asymmetry will lead to an asymmetry in the $\delta\phi$ distribution of back-to-back jets
- Should also be able to see this effect with fragments of jets, and not just with fully reconstructed jets

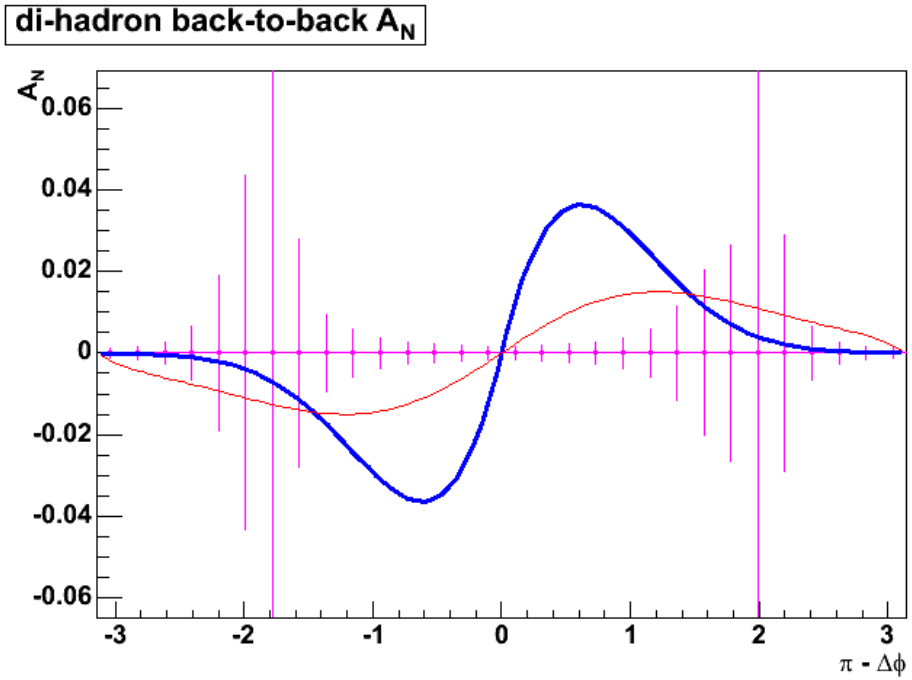



**Boer and Vogelsang, Phys.Rev.D69:094025,2004**



# *Back-to-back jet at PHENIX*

- Measurement of the gluon Sivers function via $A_N$ for di-hadron angular correlations
  - Sivers distribution is a transverse parton momentum distribution correlated with the nucleon's spin axis, which could arise from orbital angular momentum
  - Error bars: Expected sensitivity with P=60% and 7 $pb^{-1}$



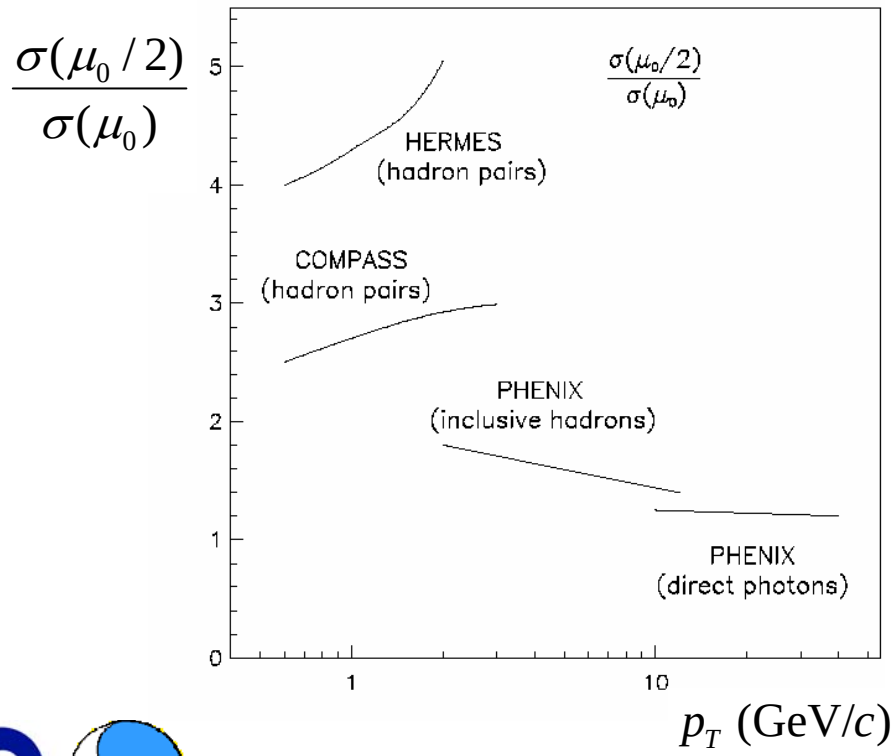
# Summary

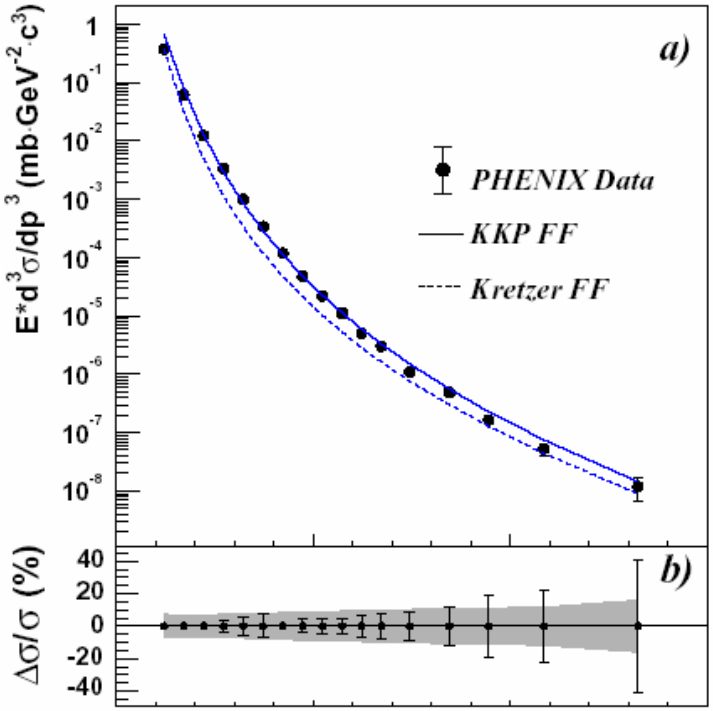
- We have been accumulating and presenting data for both $A_{LL}$ and $A_N$ physics
  - $\sqrt{s}$ = 200 GeV run until 2009
  - $\sqrt{s}$ = 500 GeV run from 2009
- $A_{LL}$ physics
  - Gluon polarization measurement
  - 2005 $A_{LL}(\pi^0)$ data distinguished between GRSV-max and GRSV-std
  - more data: 2006 $A_{LL}(\pi^0)$ data 200 GeV & 62.4 GeV, forward $\pi^0$, "jet", direct photon, …
  - Towards the future: flavor-identified quark polarization measurement with $W^{\pm}$
- $A_N$ physics
  - mid-rapidity: $\pi^0$, charged hadrons, back-to-back jet, …
  - forward: neutron, $\pi^0$, …

# *Backup Slides*


# Advantage-1

- High $\sqrt{s}$ and $p_T$ make the NLO pQCD analysis reliable
  - dependence of the calculated cross section on $\mu$ represents an uncertainty in the theoretical predictions
  - comparison of $\pi^0$ cross section between data and NLO pQCD calculations
    - PHENIX mid-rapidity data
    - excellent agreement even down to $p_T$ ~ 1 GeV/*c*

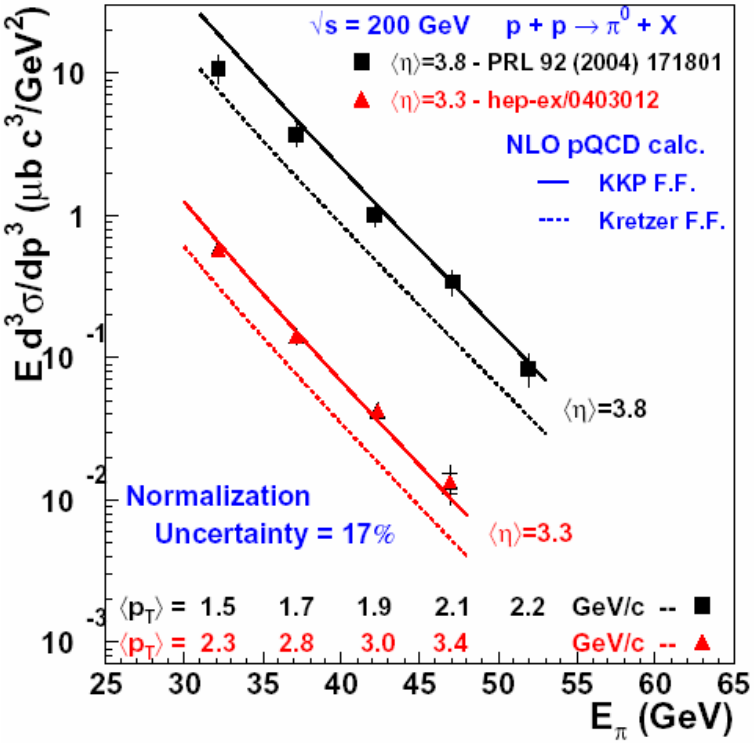


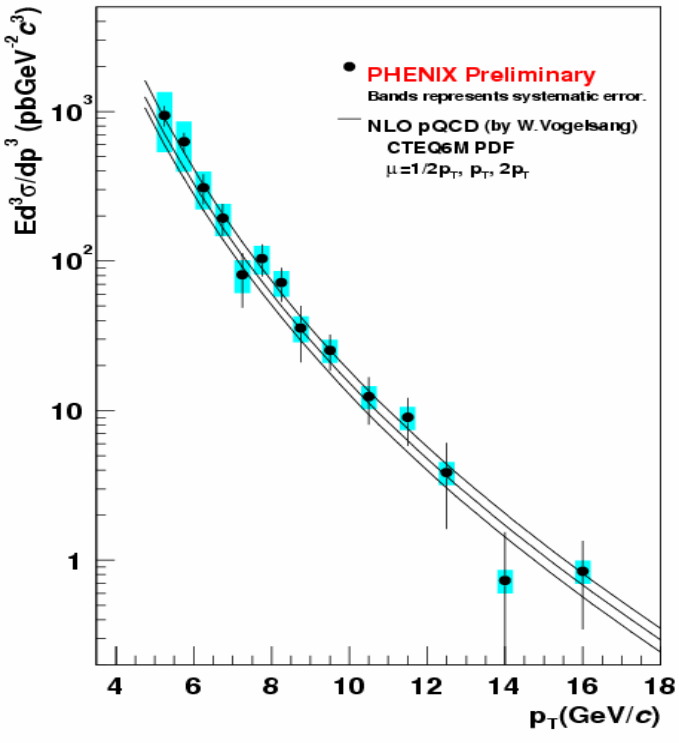

M. Stratmann and W. Vogelsang

# Advantage-1

– STAR forward-rapidity $\pi^0$ cross section



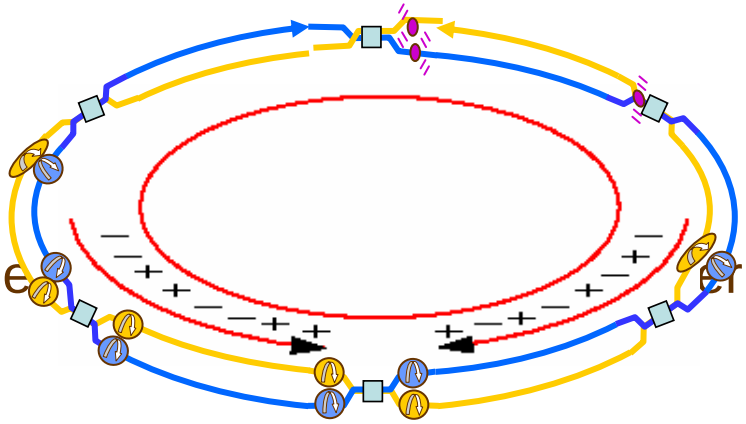

– PHENIX mid-rapidity direct photon cross section



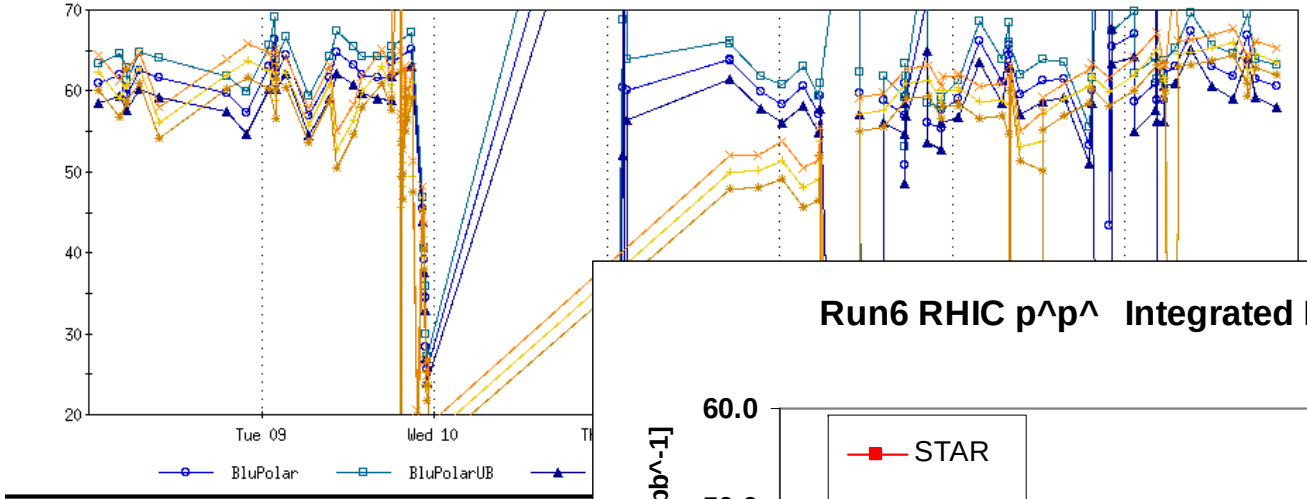

agreement of cross section between data and NLO pQCD calculations is excellent at RHIC

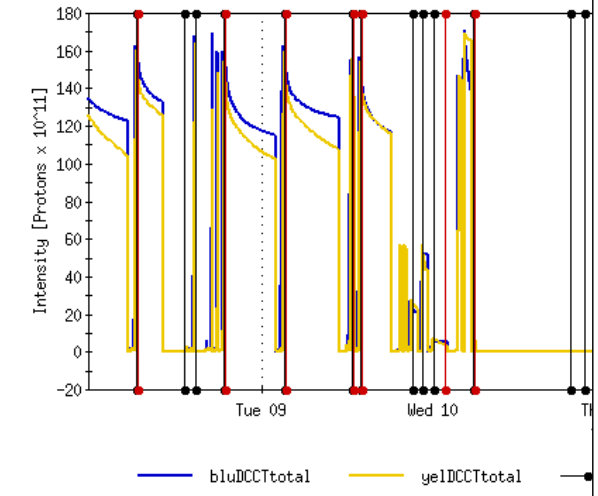
# *Advantage-2*

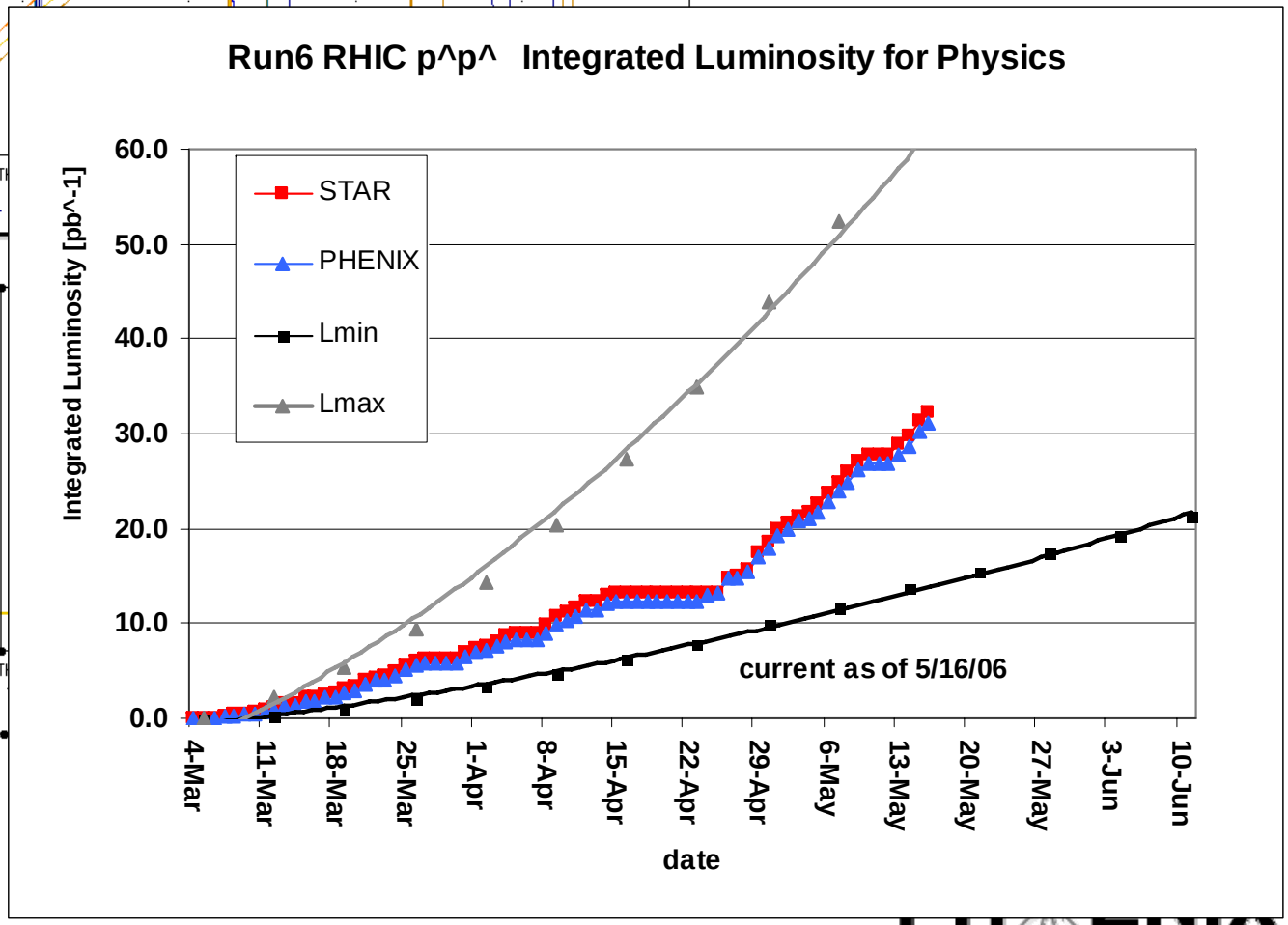
- Multi-bunch collisions to cancel systematics
  - 56 crossings in 2001-2004, 106 crossings in 2005
  - different spin combination every crossings
  - time-dependent correction not necessary for the asymmetry calculation
  - bunch-by-bunch characteristics can be investigated and have small enough difference to cancel out systematic uncertainties so far
  - spin flip in the



# 2006 run


70
60
50
40
30
20
Tue 09
Wed 10
BluPolar
BluPolarUB


Intensity [Protons x 10^11]
180
160
140
120
100
80
60
40
20
0
-20
Tue 09
Wed 10
bluDCCTtotal
yelDCCTtotal


Run6 RHIC p^p^ Integrated Luminosity for Physics
Integrated Luminosity [pb^-1]
60.0
50.0
40.0
30.0
20.0
10.0
0.0
STAR
PHENIX
Lmin
Lmax
current as of 5/16/06
4-Mar
11-Mar
18-Mar
25-Mar
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
6-May
13-May
20-May
27-May
3-Jun
10-Jun
date

# 2005 data transfer

- WAN data transfer between RCF (BNL) and CC-J (computing center in Japan, RIKEN, Wako)
  - data sample 270 TB
  - rate 60 MB/sec
  - duration ~11 weeks

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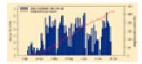
Computing News and Features

**PHENIX experiment uses Grid to transfer 270 TB of data to Japan**

During the polarized proton-proton run that ended in June at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven, Grid tools were used by the PHENIX experiment to send recently acquired data to a regional computing centre for the experiment in Japan. Brookhaven National Laboratory, on Long Island, New York, is home to the RHIC/ATLAS Computing Facility (RCF/ACF), which is the main computing centre for experiments at RHIC and a Tier-1 computing centre for ATLAS. The PHENIX regional computing centre in Japan (CCJ) is at the RIKEN research centre on its Wako campus close to Tokyo.

Going into the polarized proton-proton run, PHENIX faced the challenge that the RCF would be busy reconstructing and analysing gold-gold and copper-copper data recorded in 2004 and 2005. The enormous polarized proton-proton data set was transferred to Japan to make use of the substantial computing resources at CCJ, which is comparable to the PHENIX portion of the RCF.



Data transfer

The PHENIX data acquisition can sustain a peak data rate of up to 600 MB/s, and runs at a typical rate of 250 MB/s while beam is stored in RHIC. The data were buffered at the experimental site before being transferred and archived in the RCF tape library. A 35 TB disk-storage system (about 60 h at typical data rates) allowed PHENIX to archive and transfer data at a lower steady rate, taking advantage of various breaks in the flood of data. A transfer rate of 60 MB/s sustained steadily around the clock was able to keep up with the incoming data stream.

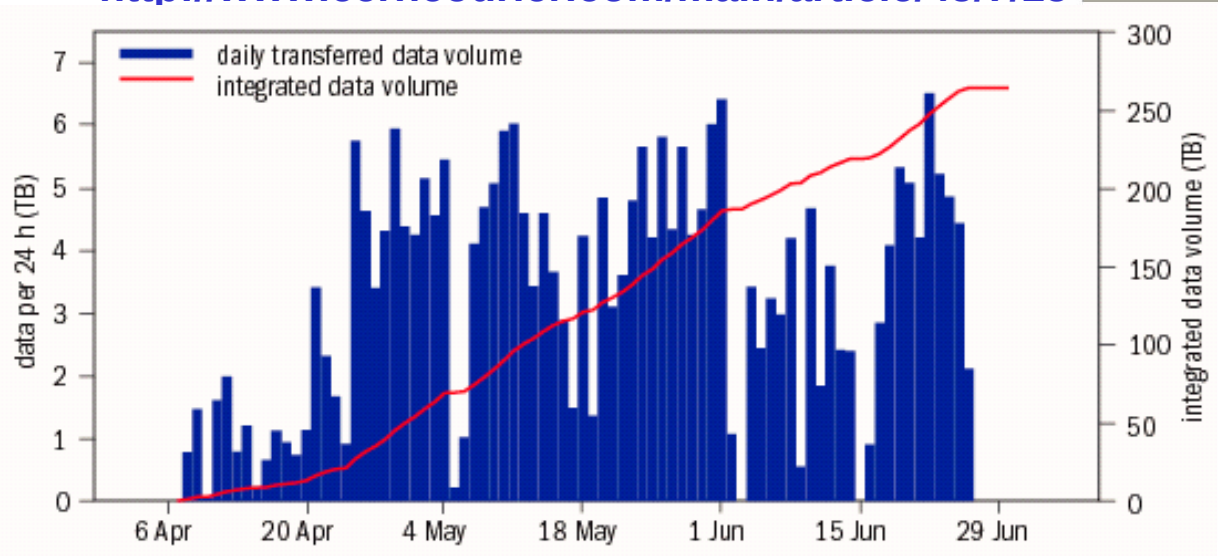
Initially, PHENIX had planned to transfer the polarized proton-proton data by physically transporting tape cartridges to CCJ. During the early part of the run, however, it was found that network transfer rates of 700-750 Mbits/s could be achieved. A dedicated network path was established from the PHENIX counting house to the BNL perimeter network, and the tape option became a fall-back solution. In the end, not a single tape was shipped.

The principal tool used for the transfer was GridFtp, which proved to be very stable. Brookhaven has a high-speed connection (OC48) to ESNET, which is connected to a transpacific line (10 Gbit/s) served by SINET in Japan. Apart from two half-day outages of ESNET, the transfers continued around the clock for the entire 11 week run.

Approximately 270 TB of data (representing 6.8 billion polarized proton-proton collisions) were transferred to CCJ. After a few days of fine-tuning the transfer parameters, the transfers became part of the regular data-handling operation of the PHENIX shift crews, requiring experts to intervene only occasionally.

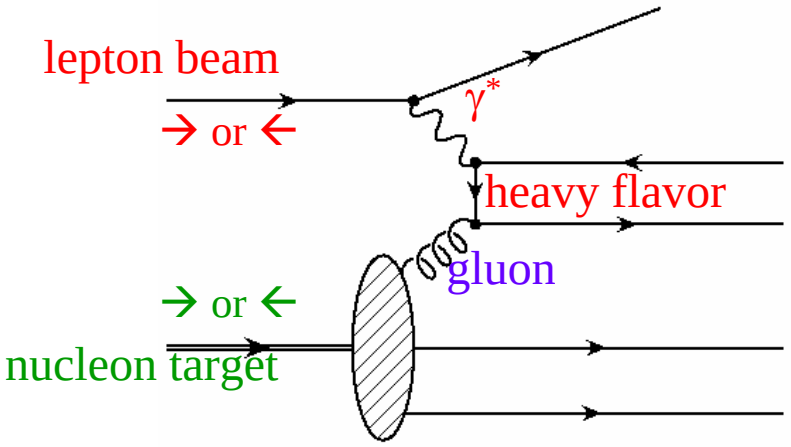
This seems to be the first time that a data transfer of such magnitude was sustained over many weeks in actual production, and was handled as part of routine operation by non-experts. The successful completion of this large-scale transfer project demonstrates both the maturity of today's Grid tools and the real feasibility of integrating remote resources into the data-handling and processing chain of large experiments.

**http://www.cerncourier.com/main/article/45/7/15**

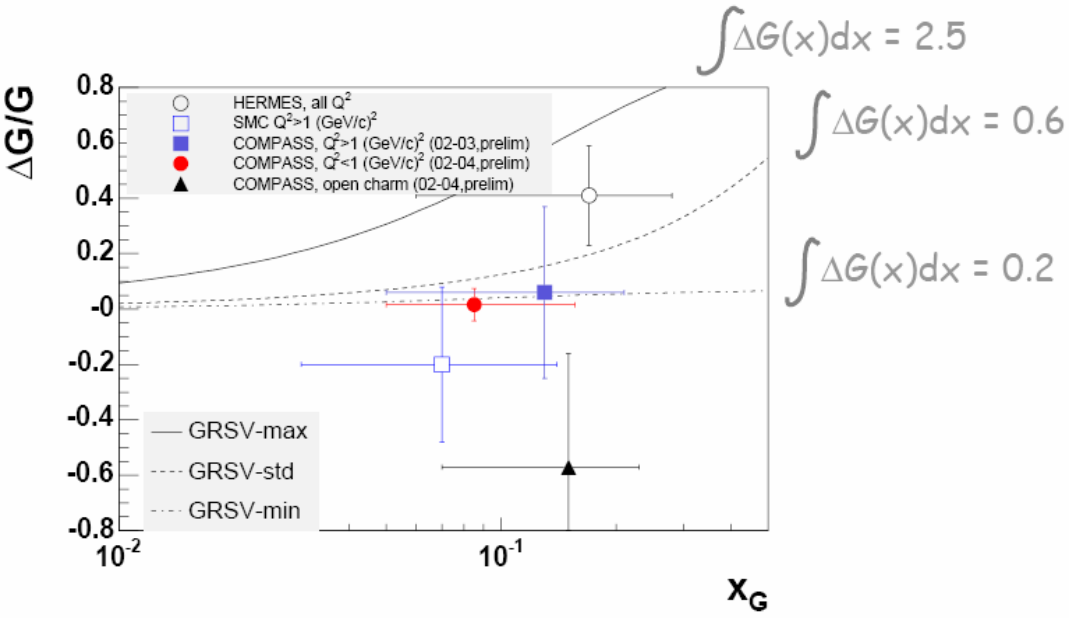


# Gluon polarization

- semi-inclusive DIS
  - HERMES @ DESY
    - high-$p_T$ hadron pairs
  - SMC @ CERN
    - high-$p_T$ hadron pairs
  - COMPASS @ CERN
    - high-$p_T$ hadron pairs
    - open charm (projection)




New COMPASS 2002-2004 data, $Q^2<1$




$\int \Delta G(x)dx$ small, or $\Delta G(x)$ has a node at $x \sim 0.1$

Consistent also with RHIC $A_{LL}$ ($\pi^0$ channel) measurements

# *Where is the proton spin ?*

- Origin of the nucleon spin 1/2
  - polarized DIS experiments showed the quark contribution is only 10-30%
  - gluon contribution ?
- Scaling violation in polarized DIS

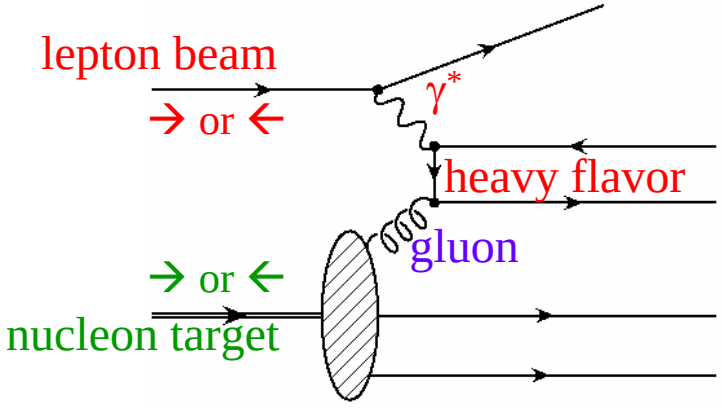
$$\mathrm{SMC}: \Delta g(Q^2 = 1\,\mathrm{GeV}^2) = 0.99^{+1.17}_{-0.31}(\mathrm{stat})^{+0.42}_{-0.22}(\mathrm{syst})^{+1.43}_{-0.45}(\mathrm{th})$$

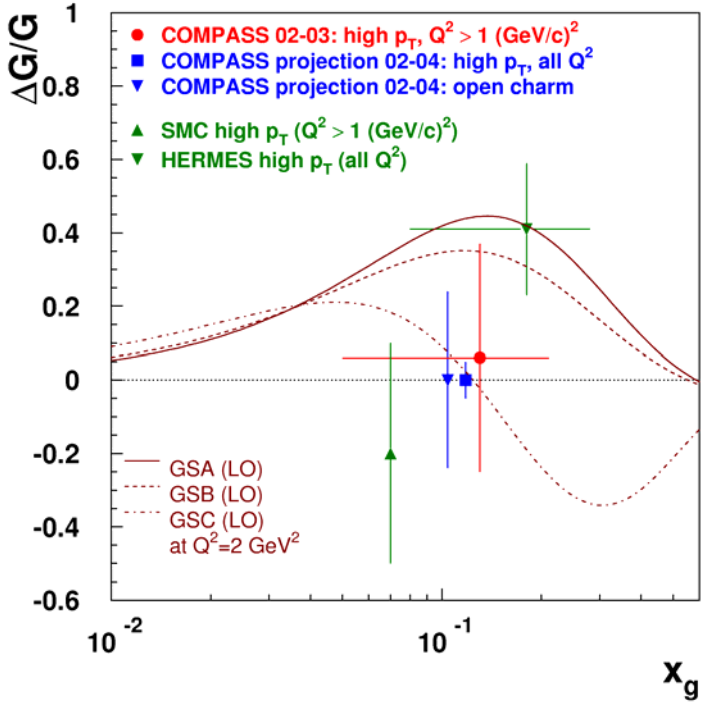
B. Adeva et al., PRD 58, 112002 (1998).

$$\mathrm{E155}: \Delta g(Q^2 = 5\,\mathrm{GeV}^2) = 1.6 \pm 0.8(\mathrm{stat}) \pm 1.1(\mathrm{syst})$$

P.L. Anthony et al., PLB 493, 19 (2000).

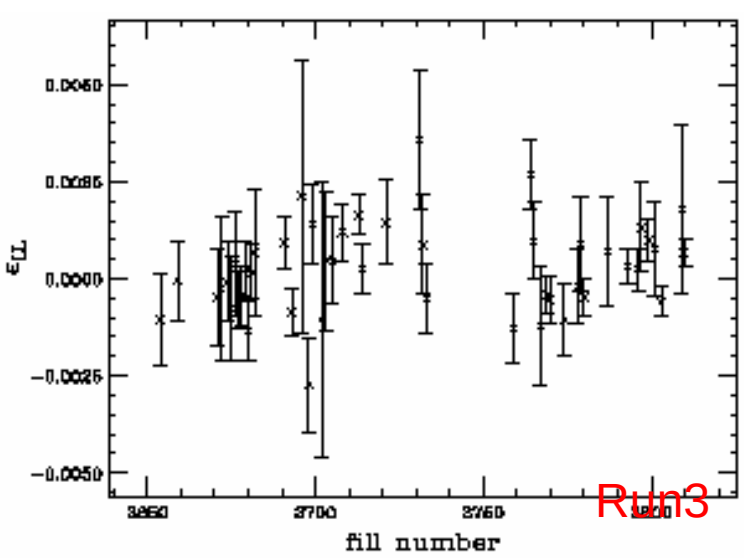
- Semi-inclusive DIS
  - high-$p_T$ hadron pairs
  - open charm production

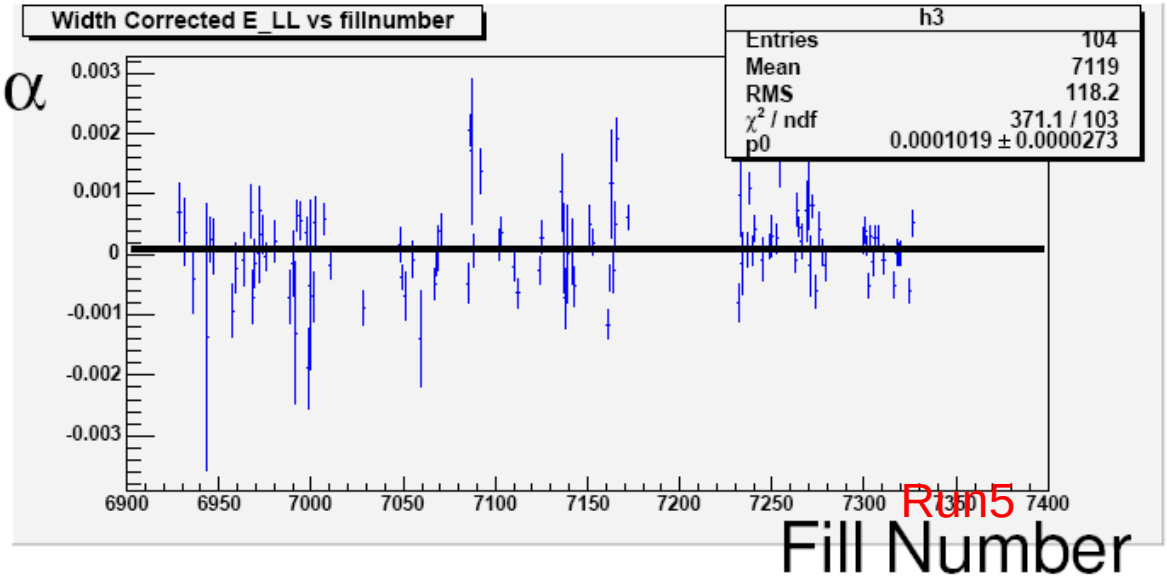


# Relative luminosity

– systematic error of the $A_{LL}$ measurements




Run3

$\delta R = 2.5\times10^{-4} \rightarrow \delta A_{LL} = 0.2\%$

Run4

$\delta R = 5.8\times10^{-4} \rightarrow \delta A_{LL} = 0.2\%$

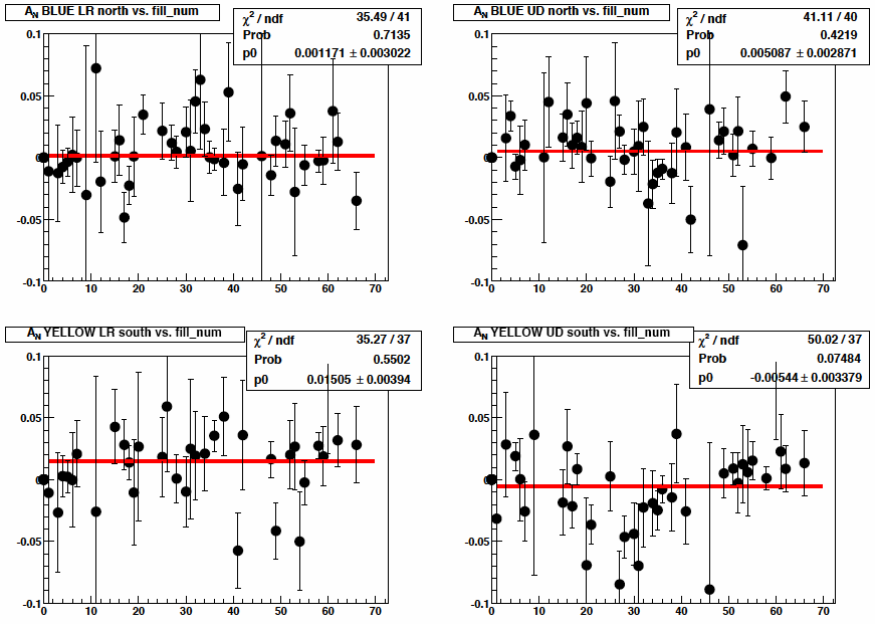
Run5

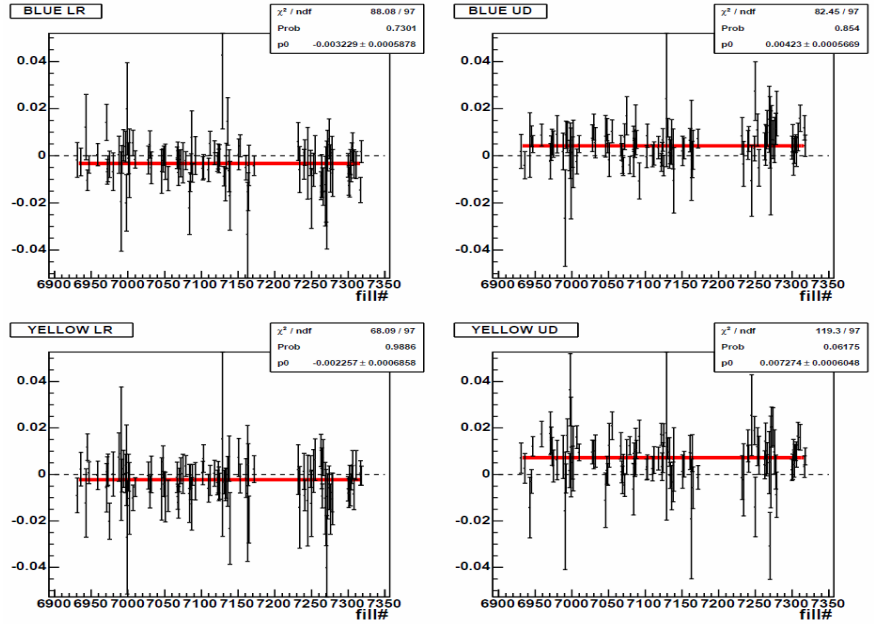
$\delta R = 1.0\times10^{-4} \rightarrow \delta A_{LL} = 0.023\%$

– multi-collision study with new scaler board in Run5

# Local polarimeter

- longitudinal component of the proton polarization at PHENIX IP
  - better statistics due to better DAQ rate
  - backward asymmetry consistent with zero




Run3 $\langle p_L / p \rangle_{Blue} = 99.3^{+0.5+0.0}_{-1.4-0.9}\%$

$\langle p_L / p \rangle_{Yellow} = 97.4^{+1.3+0.1}_{-3.2-0.9}\%$

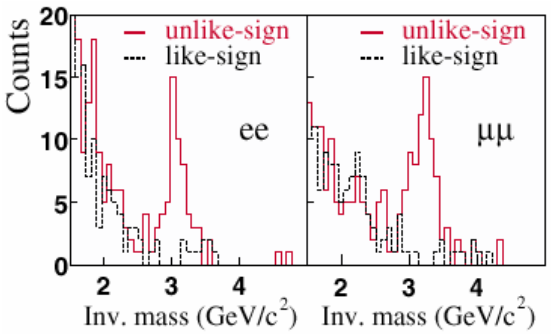
Run5 $\langle p_L / p \rangle_{Blue} = 99.48 \pm 0.12 \pm 0.02\%$

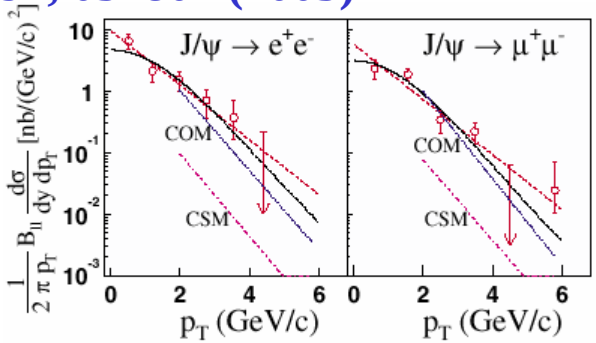
$\langle p_L / p \rangle_{Yellow} = 98.94 \pm 0.21 \pm 0.04\%$

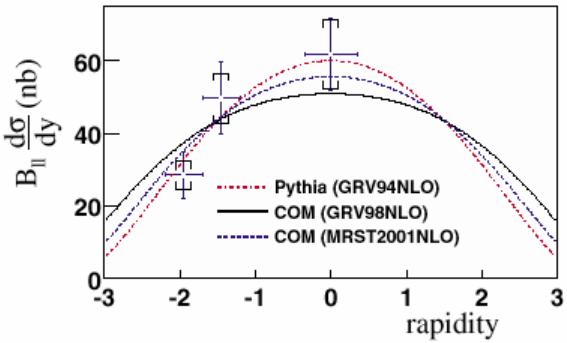
# $A_{LL}$ of J/ψ

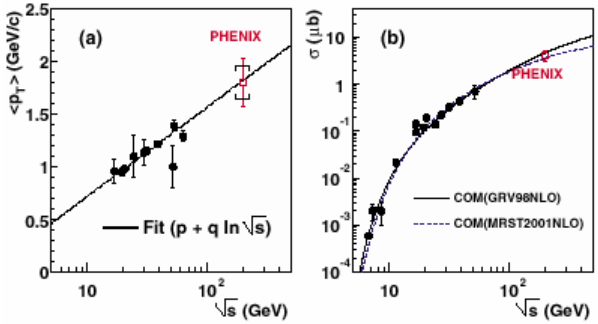
- Muon arm results

**Run2 results, PRL 92, 051802 (2003)**

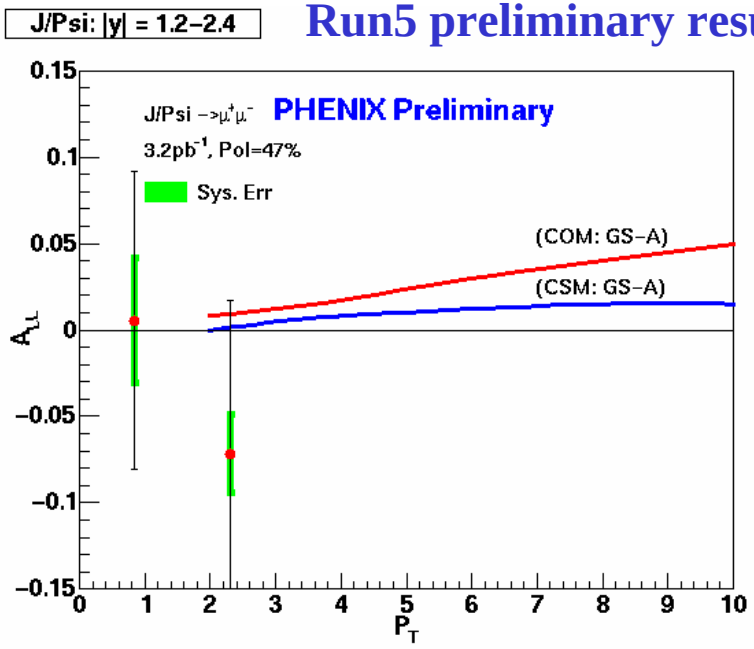



**Run5 preliminary result**

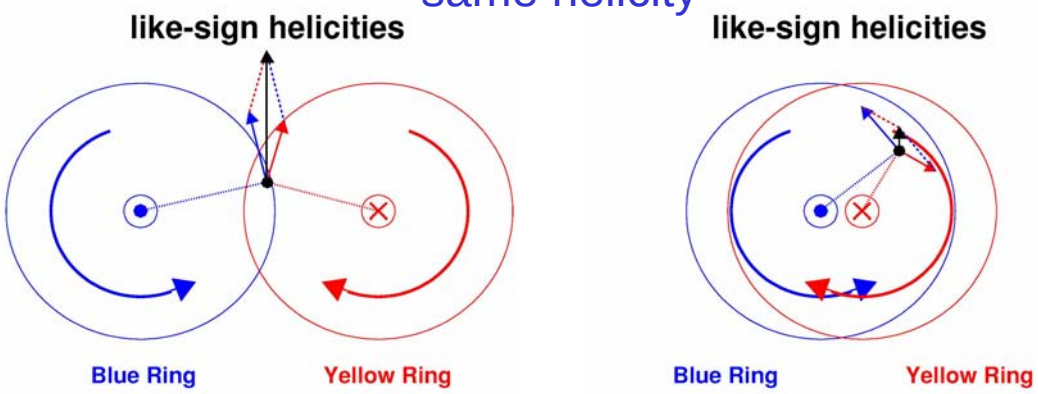


# *Spin dependence of $k_T$ of jets*

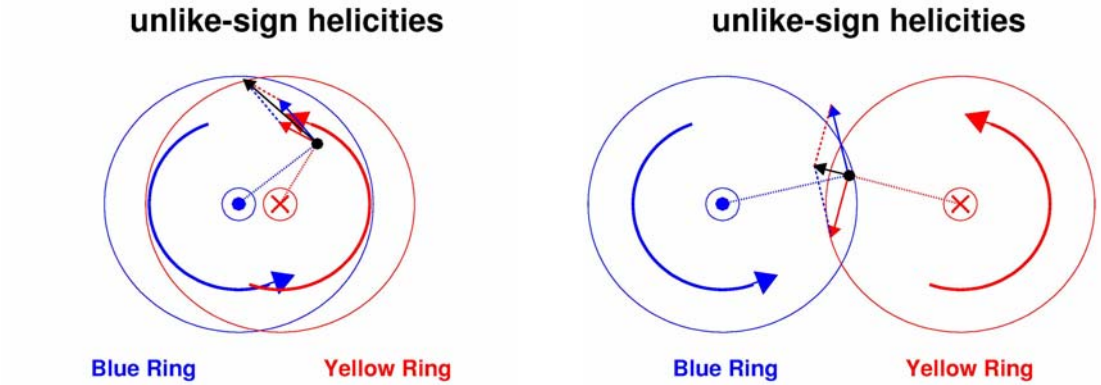
– possible helicity effect

- We may observe net effect (after averaging over impact factor)

same helicity



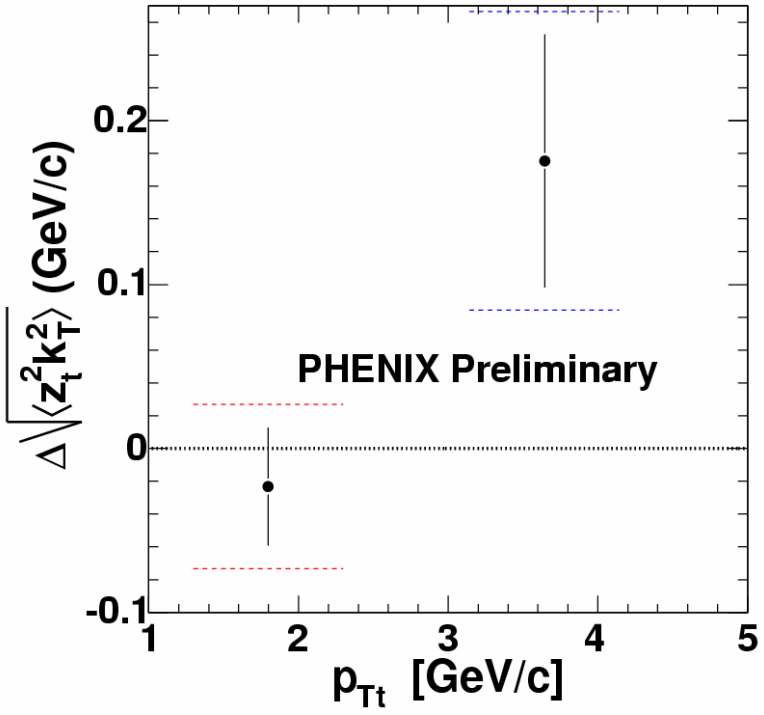

opposite helicity




Run3 result

hint of helicity dependence ?

not yet sure

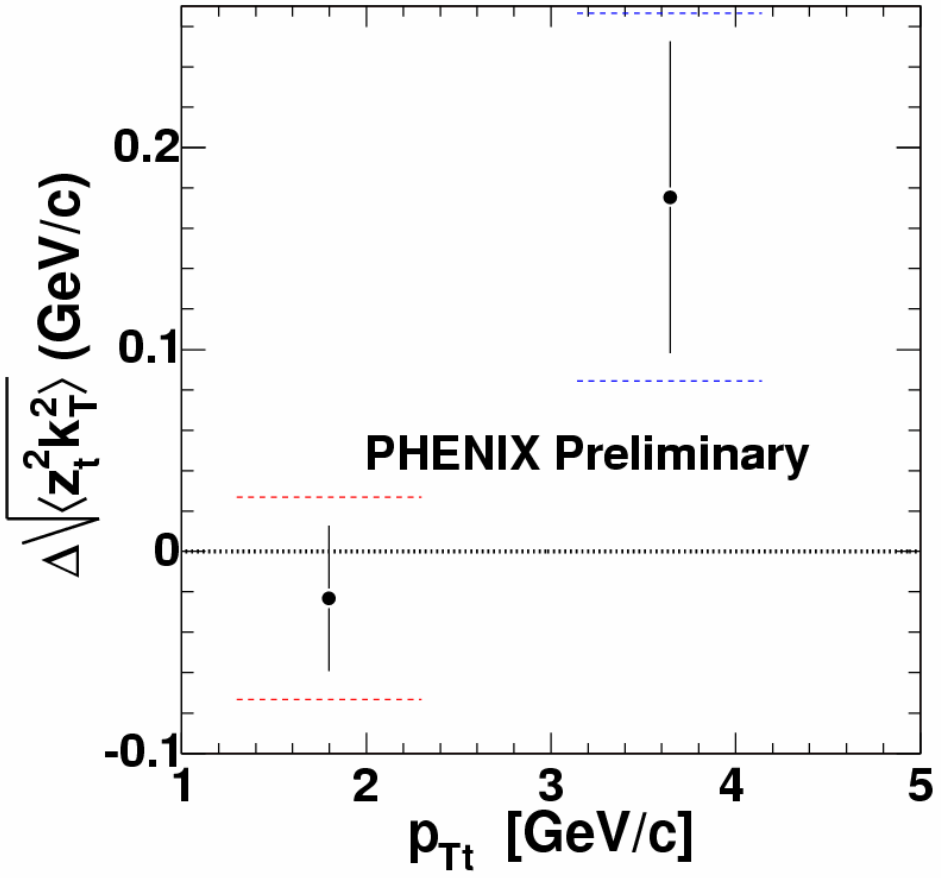


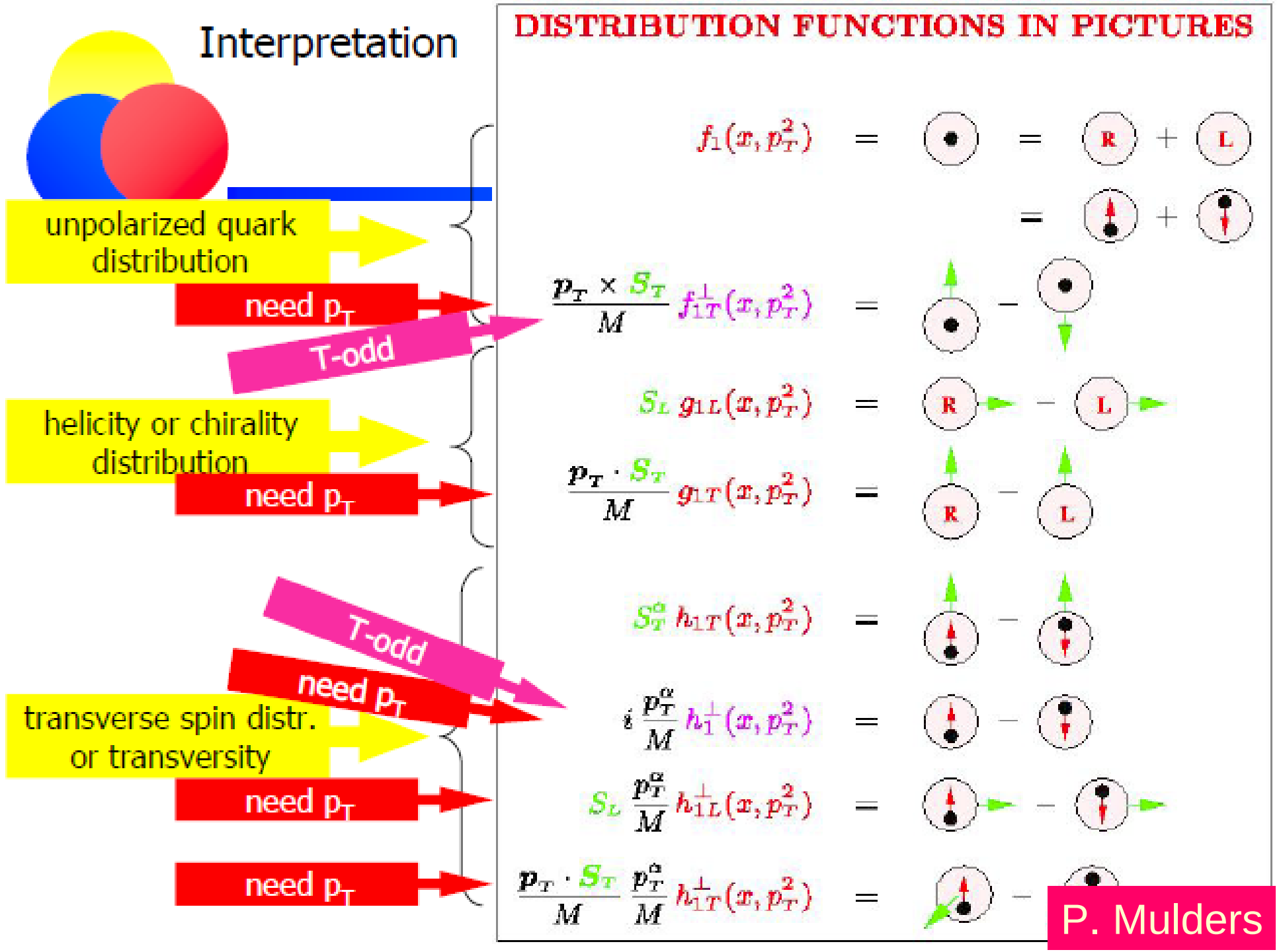

Run5 data

yield a definite answer ?

# *Spin dependence of $k_T$ of jets*

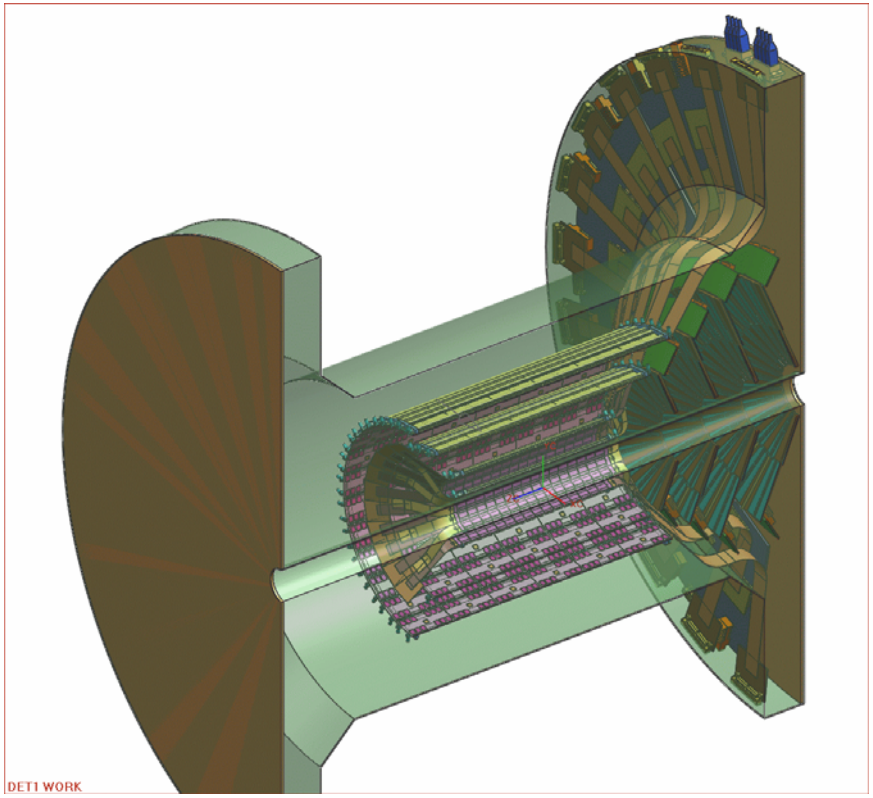
- Run3 result: hint of helicity dependence ?
  - not yet sure
- Run5 data should yield a definite answer.




Interpretation
DISTRIBUTION FUNCTIONS IN PICTURES
unpolarized quark distribution
need $p_T$
T-odd
helicity or chirality distribution
need $p_T$
T-odd
need $p_T$
transverse spin distr. or transversity
need $p_T$
need $p_T$
$f_1(x, p_T^2)$
$\frac{p_T \times S_T}{M} f_{1T}^{\perp}(x, p_T^2)$
$S_L\, g_{1L}(x, p_T^2)$
$\frac{p_T \cdot S_T}{M} g_{1T}(x, p_T^2)$
$S_T^{\alpha} h_{1T}(x, p_T^2)$
$i \frac{p_T^{\alpha}}{M} h_1^{\perp}(x, p_T^2)$
$S_L \frac{p_T^{\alpha}}{M} h_{1L}^{\perp}(x, p_T^2)$
$\frac{p_T \cdot S_T}{M} \frac{p_T^{\alpha}}{M} h_{1T}^{\perp}(x, p_T^2)$
R
L
P. Mulders

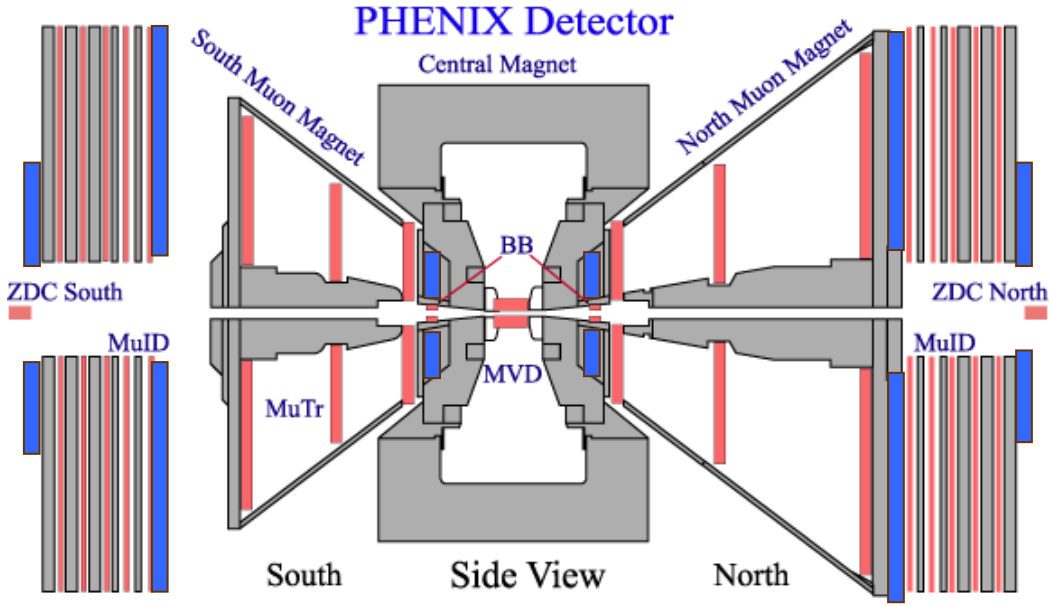
# *Silicon-vertex upgrade*

- Barrel silicon vertex tracker
  - 2 pixel layer + 2 strip layer
  - jet axis measurement and isolation cut by charged particle detection with wider acceptance
  - displaced vertex measurement for heavy flavor tagging
- Schedule
  - completion and installation in 2008 summer
  - commissioning and data taking from 2009 run



# *Muon-trigger upgrade*

- Requirement towards the $\sqrt{s}$ = 500 GeV run
- Resistive Plate Chamber technology chosen by PHENIX
  - cheap – wide coverage possible
  - can leverage existing RPC R&D from CMS
  - timing information
  - 3-dim space point for enhanced pattern recognition
- Two small prototypes successfully tested in 2005 run
- Approved NSF-MRI – 1st Arm in 2008,  2nd Arm in 2009




Trigger RPC Locations