Longitudinal Spin Asymmetry Measurements at PHENIX

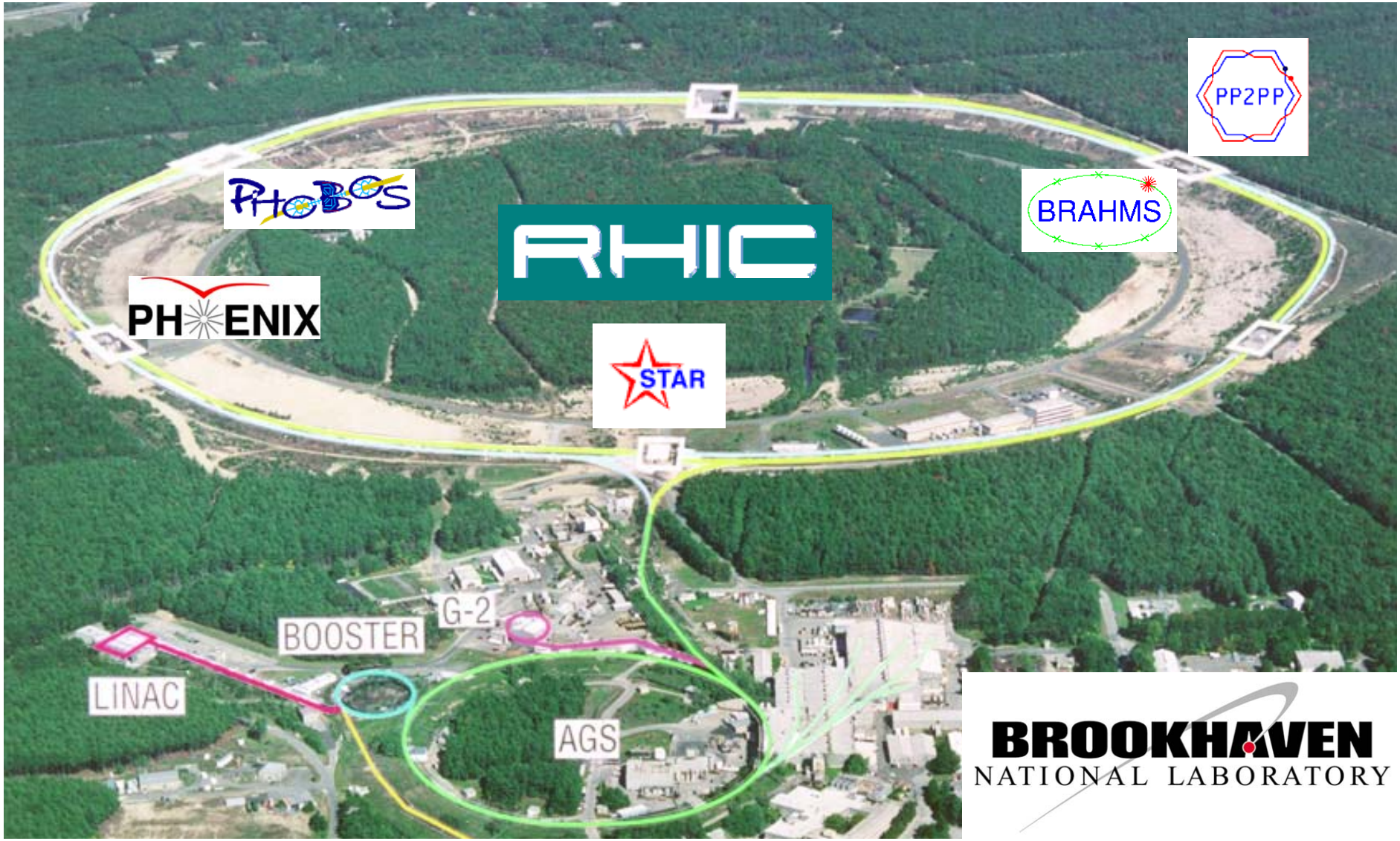
DNP/JPS joint meeting in Hawaii
September 18, 2005

Yuji Goto (RIKEN/RBRC)
for the PHENIX collaboration

Contents of this talk

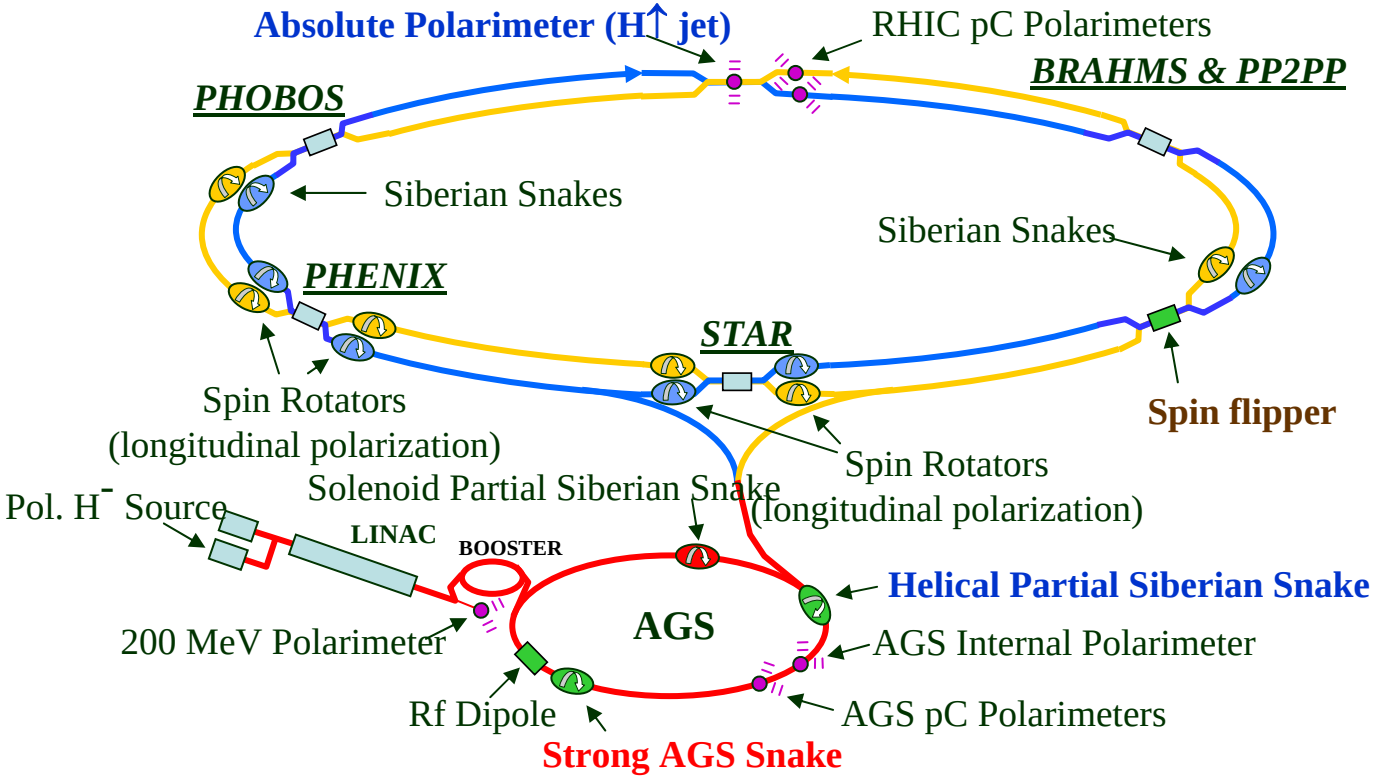
- RHIC – QCD collider
- PHENIX detector
- Longitudinal spin physics
- Achievements in 2003-2004
- 2005 run
- Future outlook

RHIC – QCD collider



RHIC polarized-proton collision

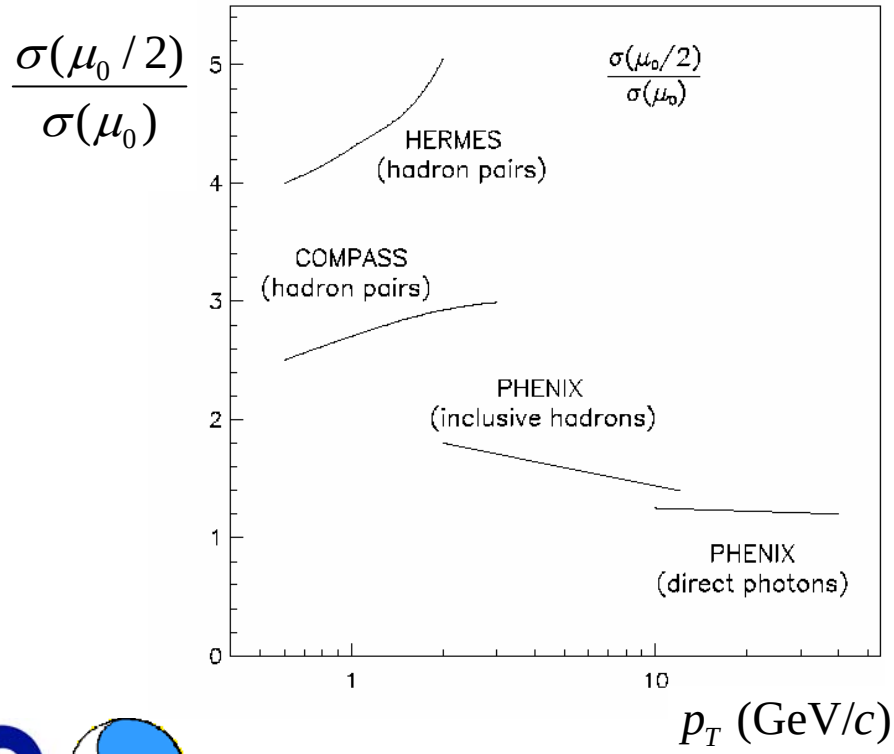
- Luminosity 1×10^{31} cm^{-2}sec^{-1} at $\sqrt{s}$ = 200 GeV achieved
  - 8×10^{31} cm^{-2}sec^{-1} at 200 GeV and 2×10^{32} cm^{-2}sec^{-1} at 500 GeV in the future
- Polarization 50% achieved – 70% in the future



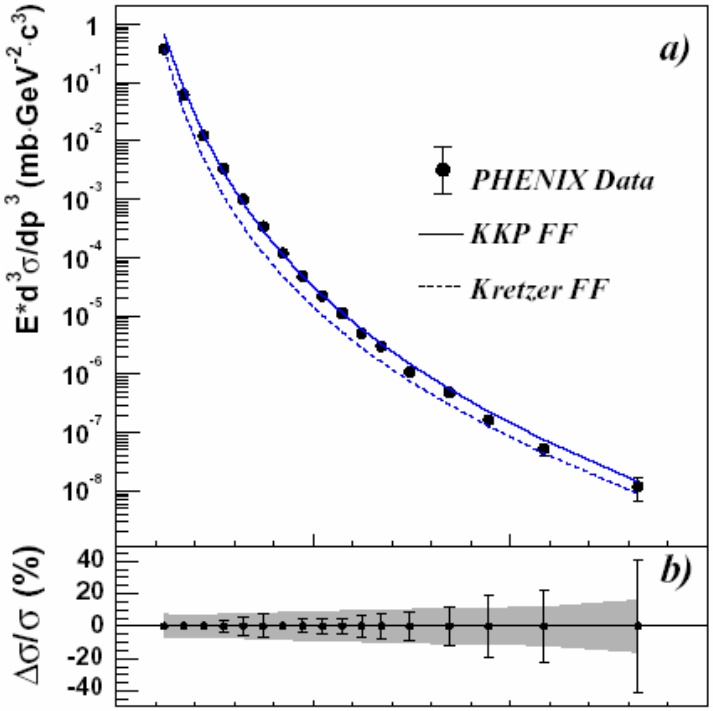
- installed and commissioned during in 2004 run
- installed in 2005 and to be commissioned
- to be commissioned

Advantage-1

- High $\sqrt{s}$ and p_T make the NLO pQCD analysis reliable
  - dependence of the calculated cross section on μ represents an uncertainty in the theoretical predictions



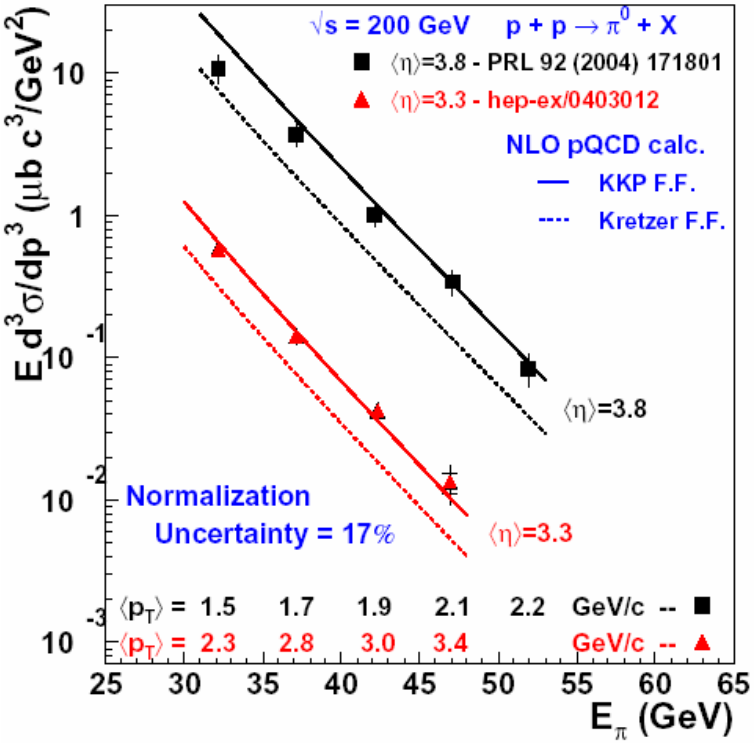
- comparison of π^0 cross section between data and NLO pQCD calculations
  - PHENIX mid-rapidity data
  - excellent agreement even down to p_T ~ 1 GeV/c



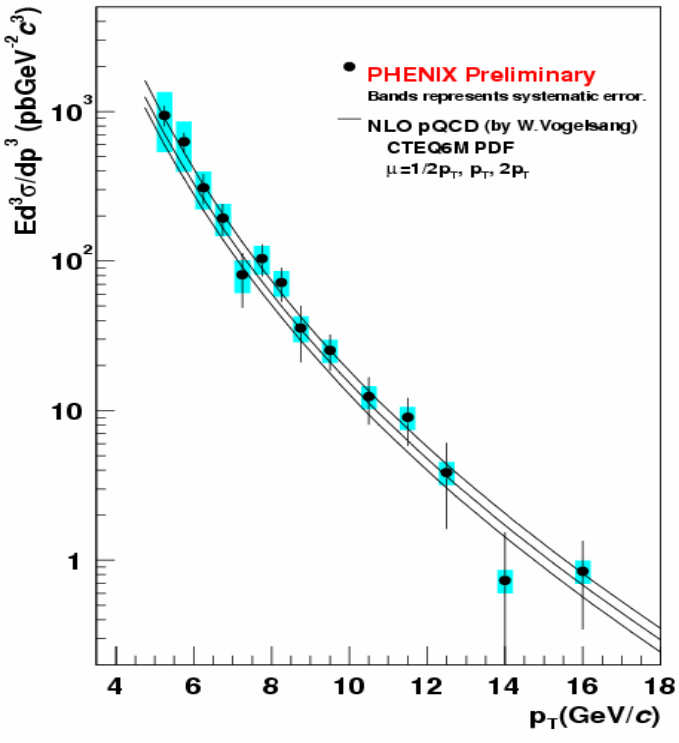
M. Stratmann and W. Vogelsang

Advantage-1

– STAR forward-rapidity π^0 cross section



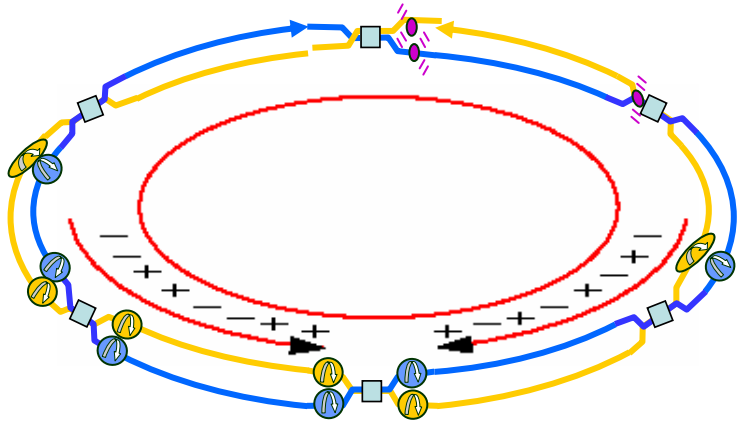
– PHENIX mid-rapidity direct photon cross section



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 future will improve this further

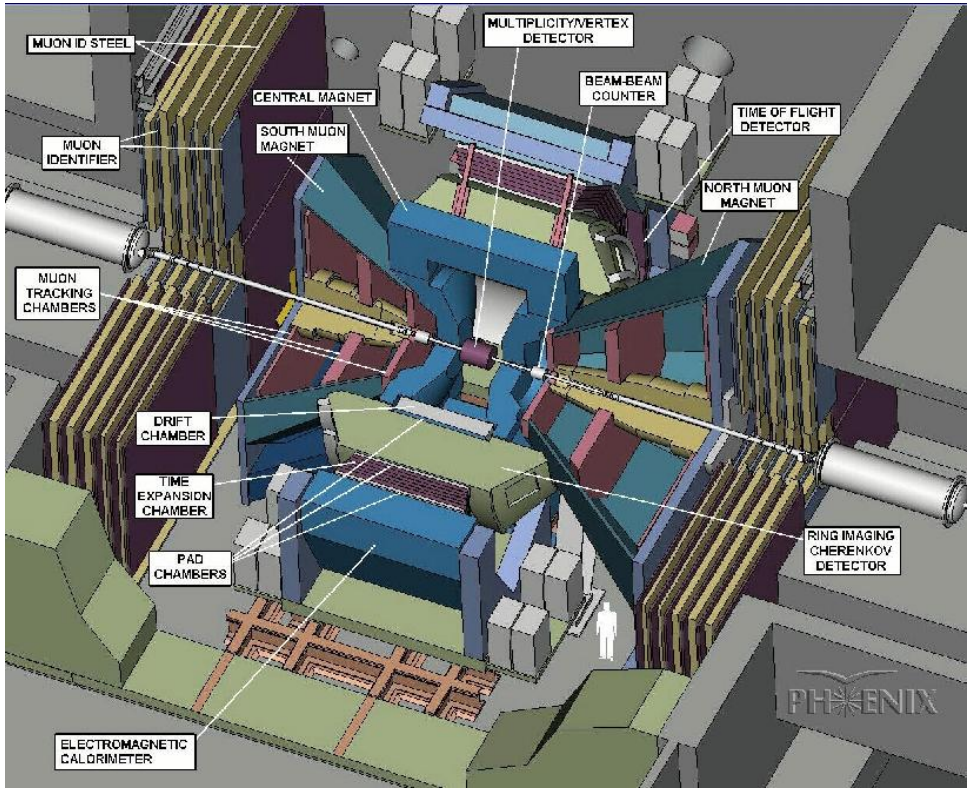
PHENIX collaboration

- 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
- Center for Nuclear Study (CNS-Tokyo), University of Tokyo, Tanashi, Tokyo 188, Japan
- Hiroshima University, Higashi-Hiroshima 739, Japan
- KEK - High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
- Kyoto University, Kyoto, Japan
- 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
- Physics Department, Rikkyo University, 3-34-1 Nishi-Ikebukuro, Toshima, Tokyo 171-8501, Japan
- 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
- IHEP (Protvino), State Research Center of Russian Federation "Institute fo High Energy Physics", Protvino 142281, Russia
- 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

13 Countries; 62 Institutions; 550 Participants*

- Lund University, Lund, Sweden
- Abilene Christian University, Abilene, Texas, USA
- 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
- Department of Chemistry, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- Department of Physics and Astronomy, State University of New York at Stony Brook (USB), Stony Brook, NY 11794, USA
- 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)

RHIC/PHENIX polarized-proton runs

$\sqrt{s}$ = 200 GeV	P	recorded L	recorded LP^4	data volume
2001-2002 transverse-spin run				
	15%	0.15 pb^{-1}		20 TB
first polarized proton collisions				
2003 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 (longitudinal spin)				
	40%	0.12 pb^{-1}	3.3 nb^{-1}	
AGS warm snake commissioned, gas-jet absolute polarimeter				
2005 longitudinal-spin run				
	49.5/44.5%	3.8 pb^{-1}	205 nb^{-1}	262 TB
AGS cold snake installed				

2005 – First long longitudinal-spin polarized-proton run
Figure of merit (LP^4) more than 40 times larger than that of previous runs

Gluon polarization measurement

- 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).

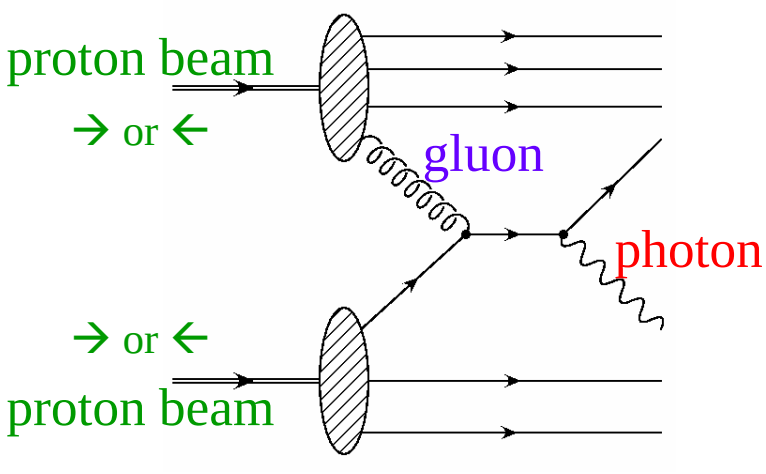
- Semi-inclusive DIS
  - high-p_T hadron pairs
  - open charm production

➔ COMPASS/HERMES/JLAB talks

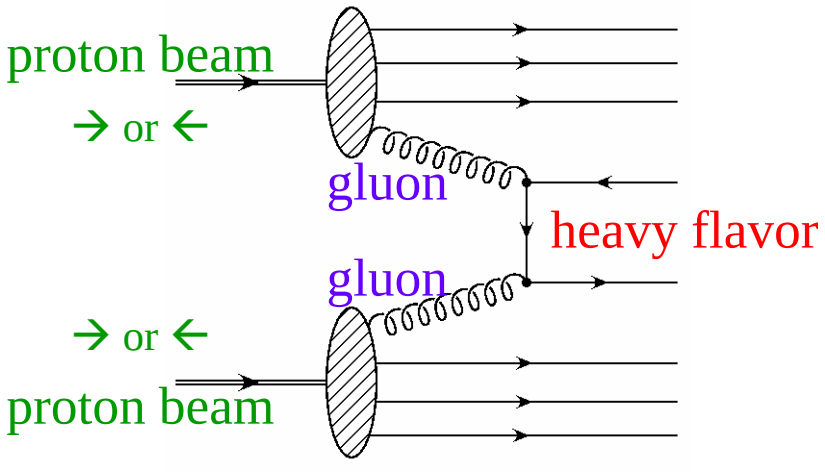
Gluon polarization measurement

- Polarized hadron collision
  - leading-order gluon measurement

direct photon production



heavy-flavor production



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

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

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

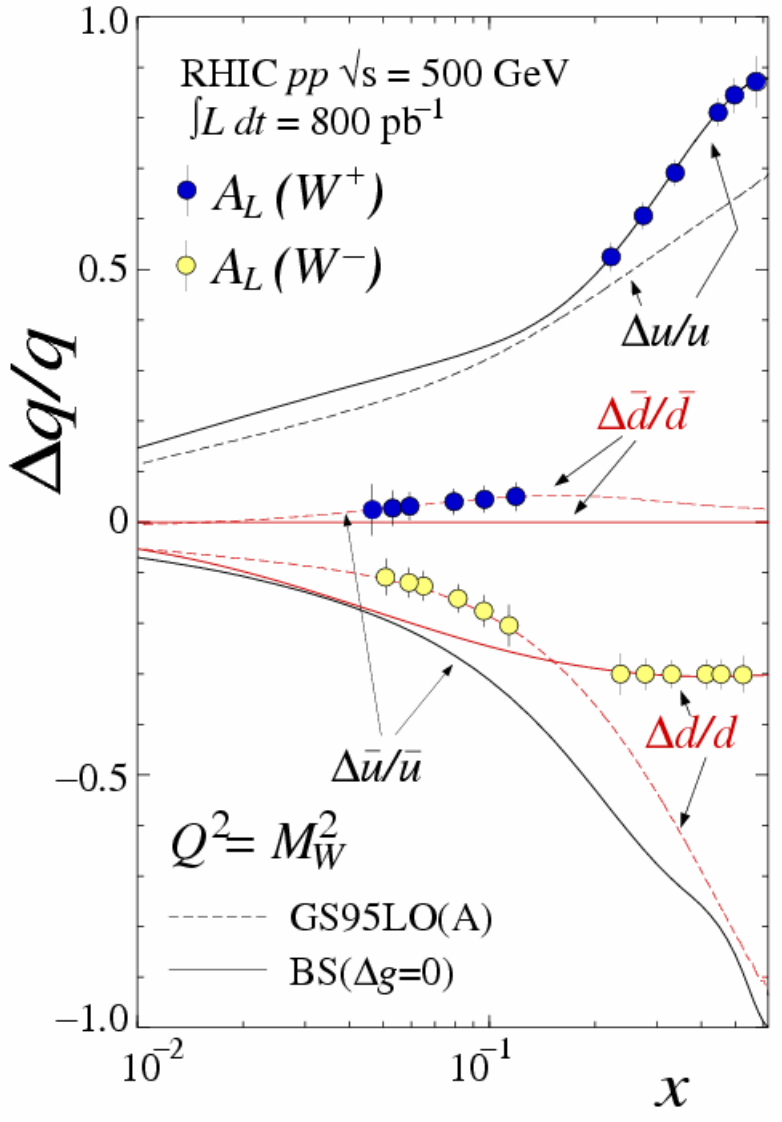
Flavor-identified quark polarization

- 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



Relative luminosity

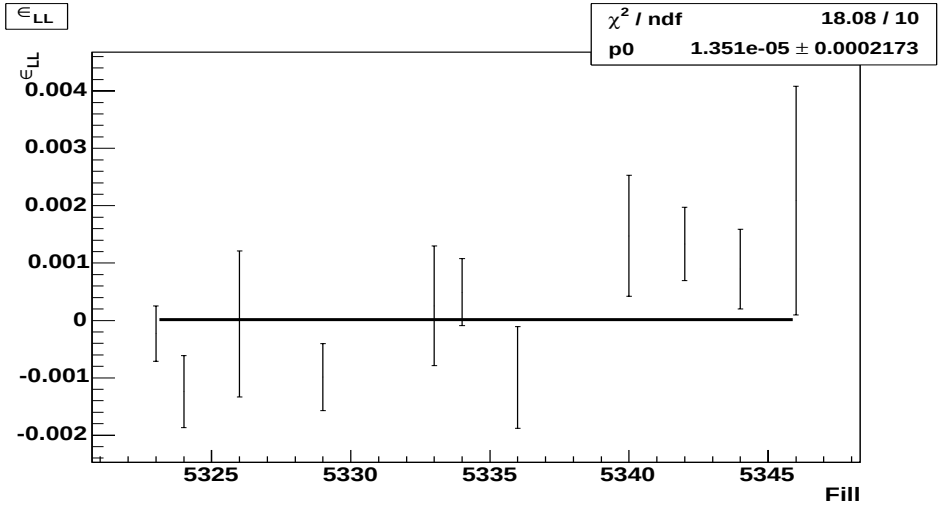
- Beam-Beam Counter (BBC) used as relative luminosity monitor
  - $3.0 < |\eta| < 3.9$
  - low background
  - high statistics
- Zero-Degree Calorimeter (ZDC) used as a cross check
  - $6 < |\eta|$
  - different kinematics and acceptance
- Bunch-by-bunch comparison of ratio of scalar counts in BBC and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

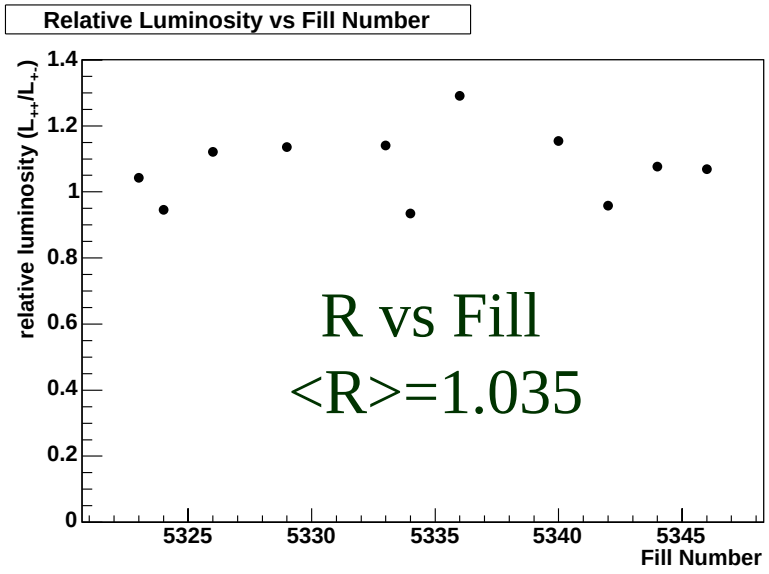
A_{LL}: A_{LL} of BBC relative to ZDC after vertex-width correction



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

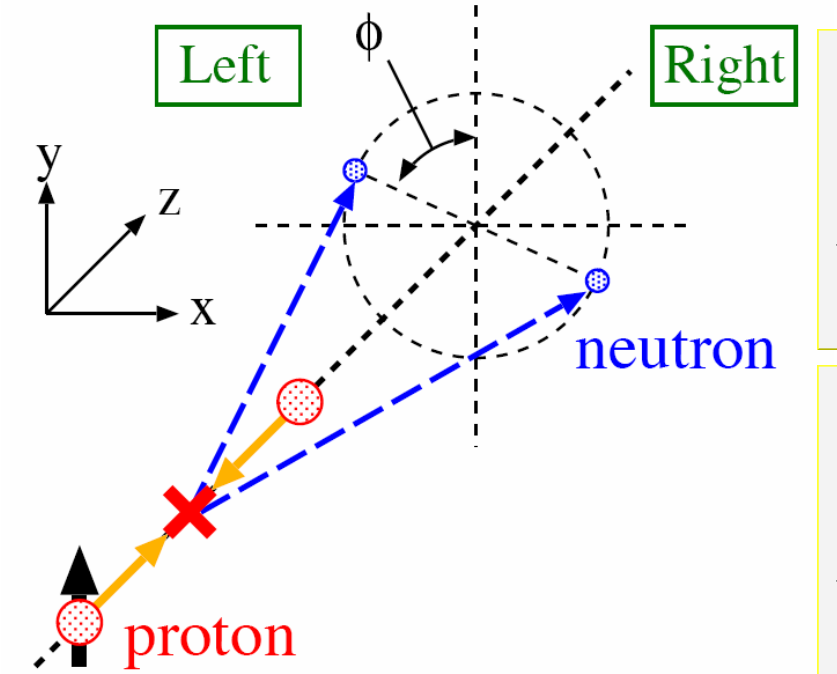
Relative luminosity

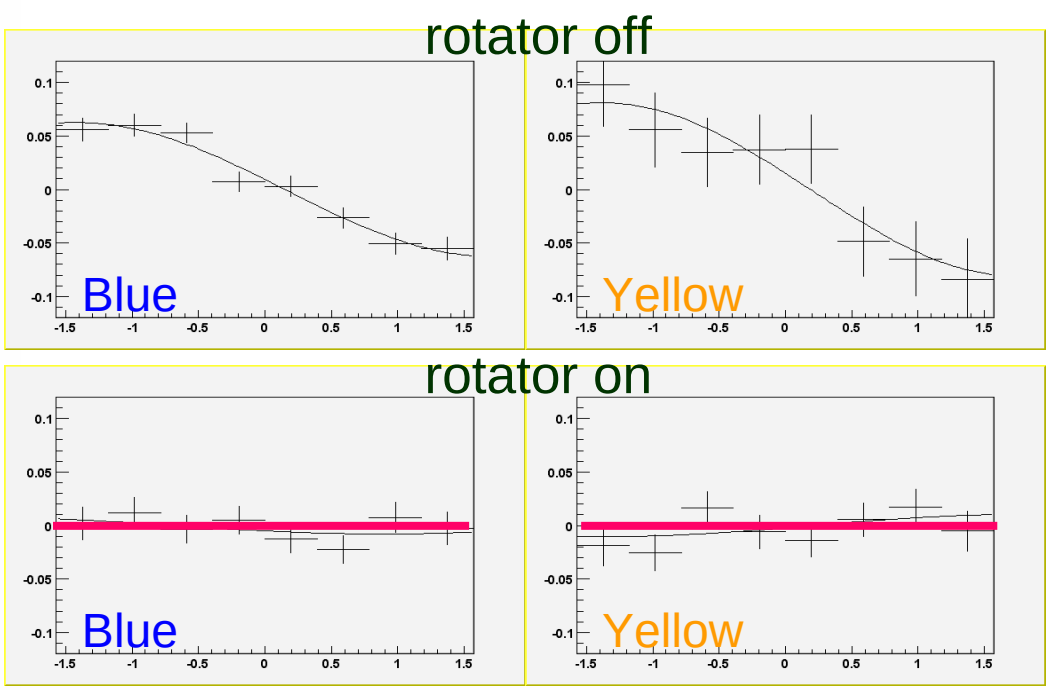
- 2004 run
  - achieved relative luminosity precision $\delta R = \delta(L_{++}/L_{+-})$ smaller than 5.8×10^{-4}
  - relative luminosity contribution to $A_{LL}(\pi^0)$ smaller than 0.2% (40% beam polarization)
  - A_{LL} of BBC relative to ZDC consistent with zero (smaller than 0.2%)
    - strongly 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



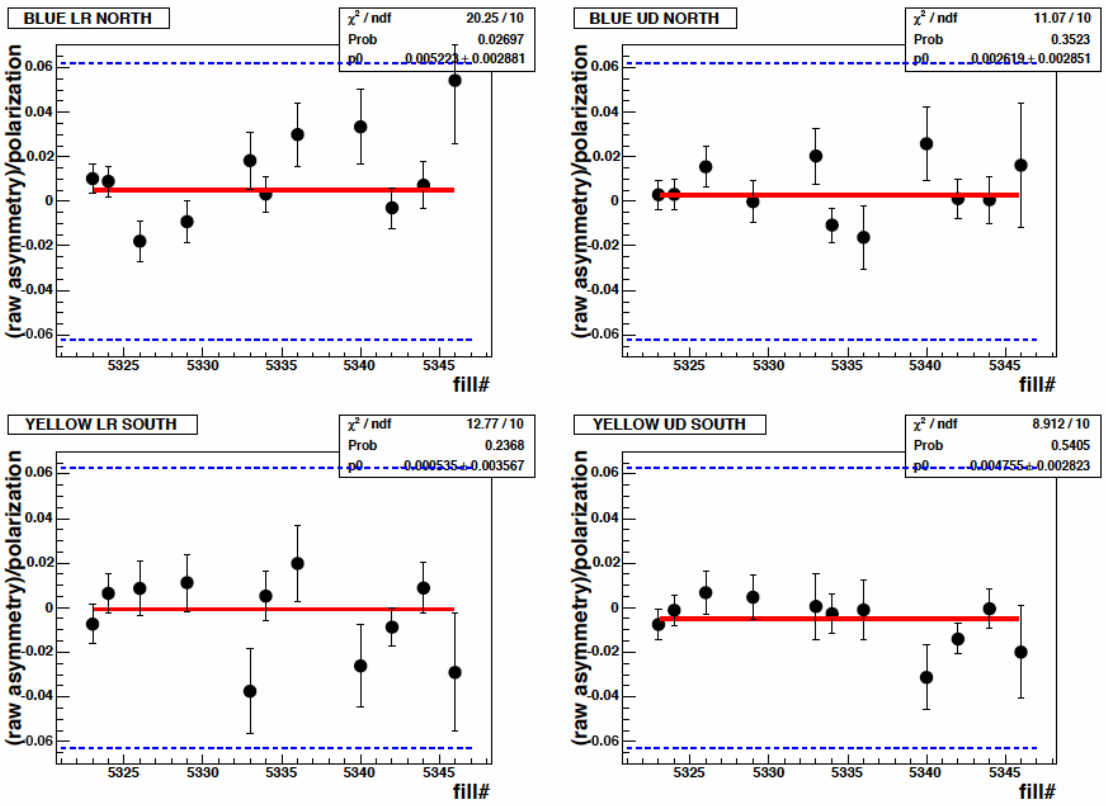


Local polarimeter

- 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



2004 run

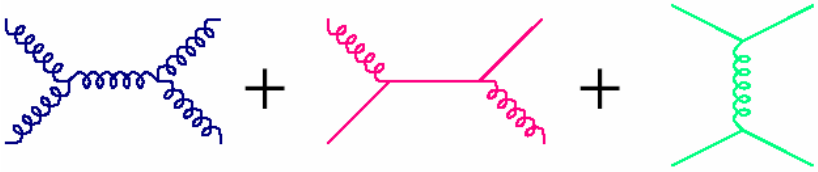
$$S_L(\text{blue}) = 99.7^{+0.3}_{-0.7}\%$$

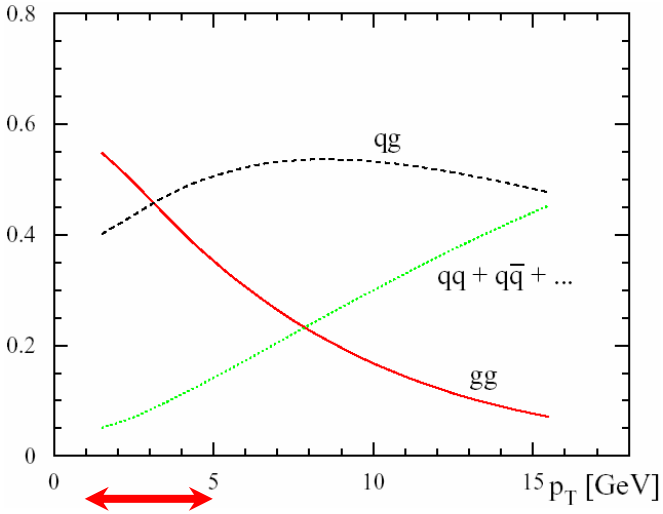
$$S_T(\text{yellow}) = 99.8^{+0.2}_{-0.7}\%$$

Achievements in 2003-2004

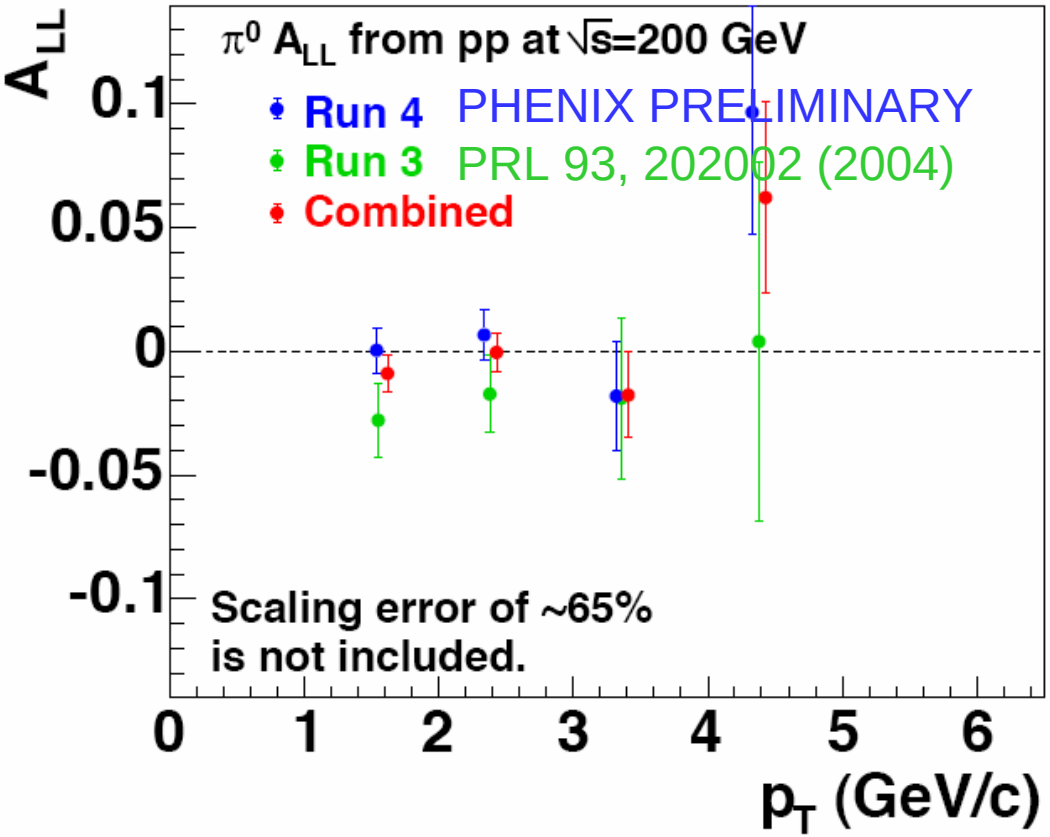
- A_{LL} of π^0

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



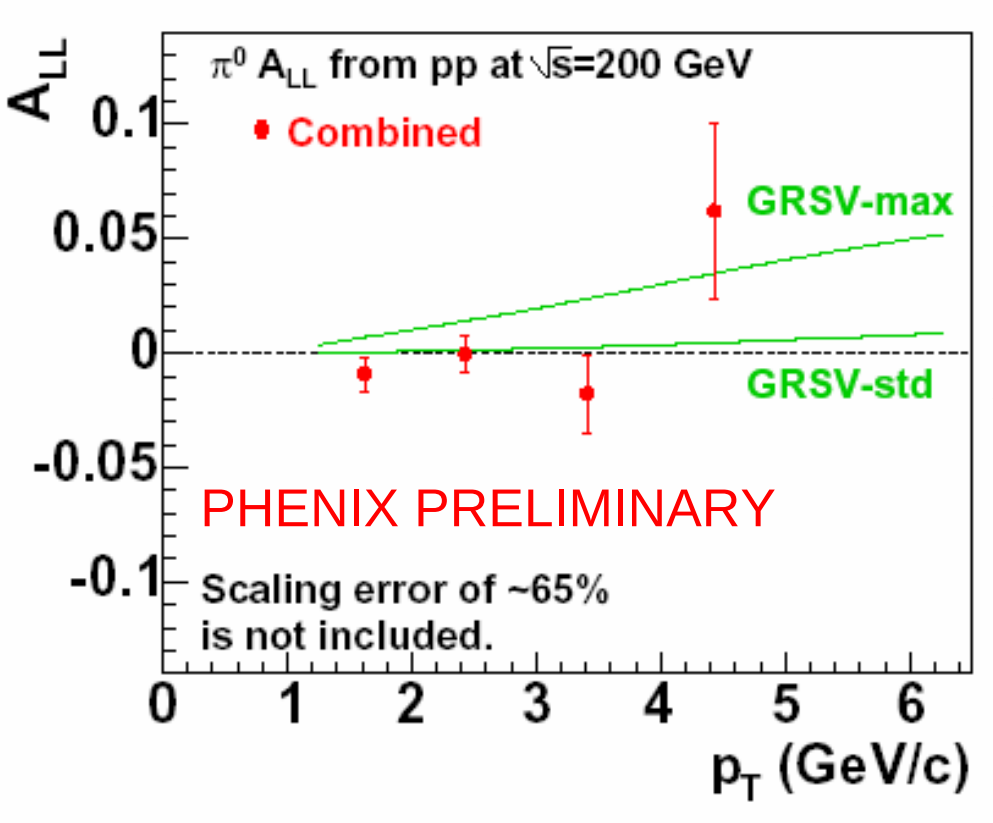


gg + qg dominant
sensitive to the gluon reaction



Achievements in 2003-2004

- A_{LL} of π^0



$\Delta g = 1.84$

$\Delta g = 0.42$
at $Q^2=1(\mathrm{GeV}/c)^2$
best fit to DIS data

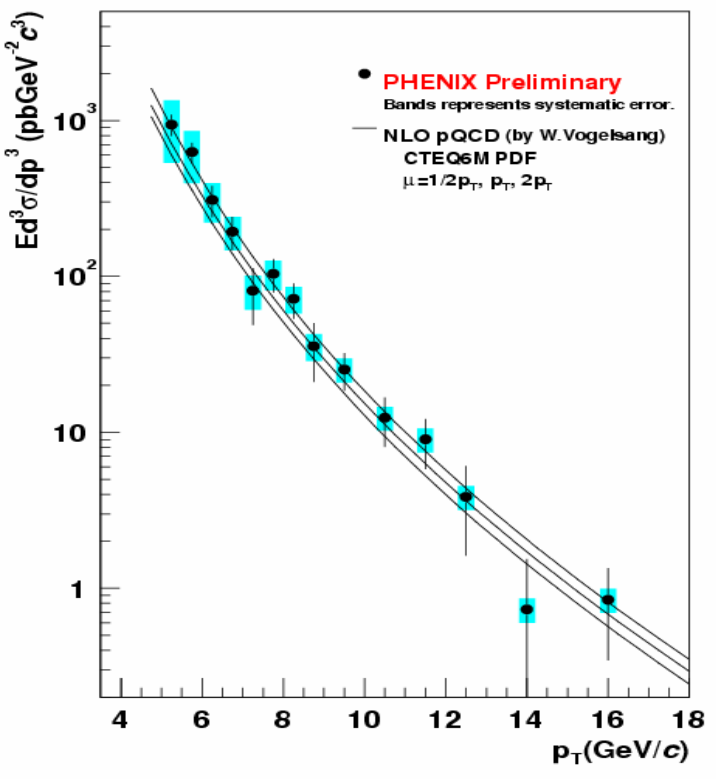
confidence level

	GRSV-std	GRSV-max
4 points (1-5 GeV/c)	21-24%	0.00-6%
3 points (2-5 GeV/c)	27-29%	0.01-13%

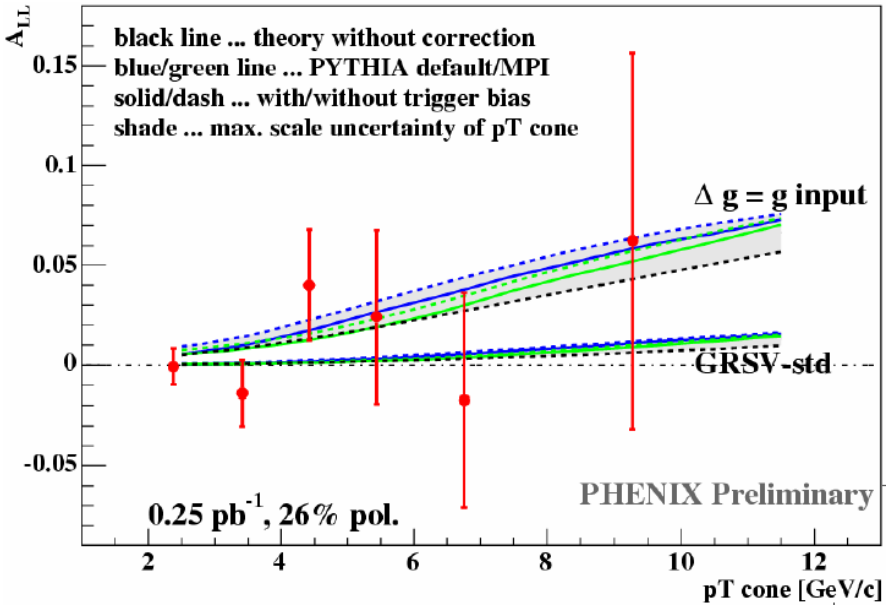
data prefers the GRSV-std curve

Achievements in 2003-2004

- Direct photon cross section
  - Kensuke Okada's talk (Tuesday afternoon)

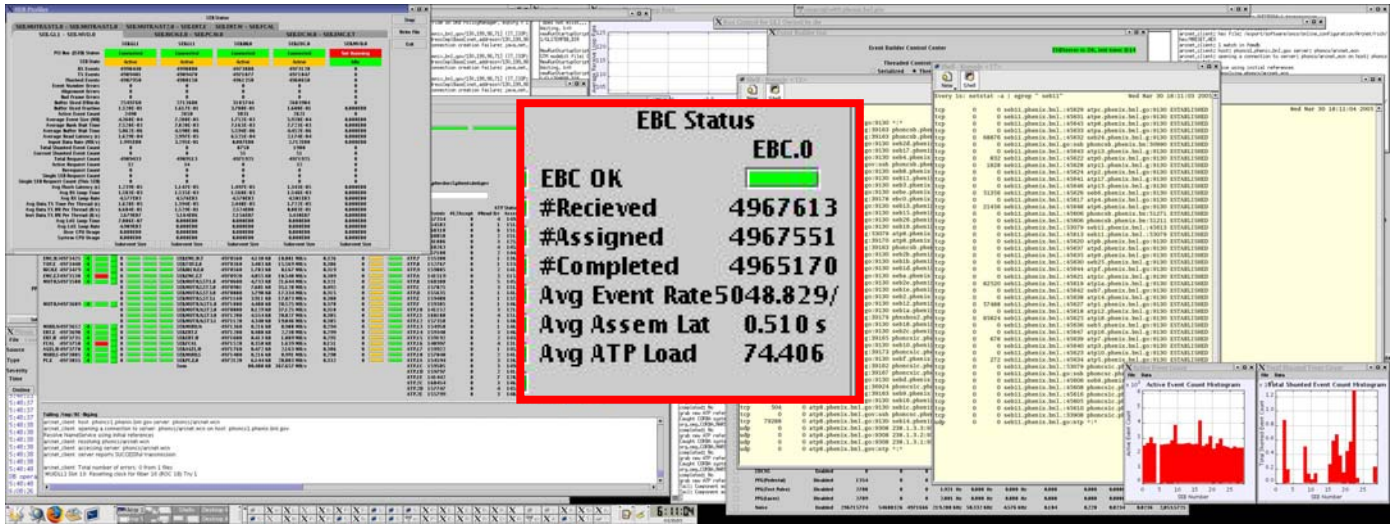


- A_{LL} of jet-like cluster
  - even with a limited acceptance in PHENIX central arm, we can capture most of a jet
    - tag one photon, sum all observed energy/momentum in one arm
  - Kenichi Nakano's talk (Monday evening)

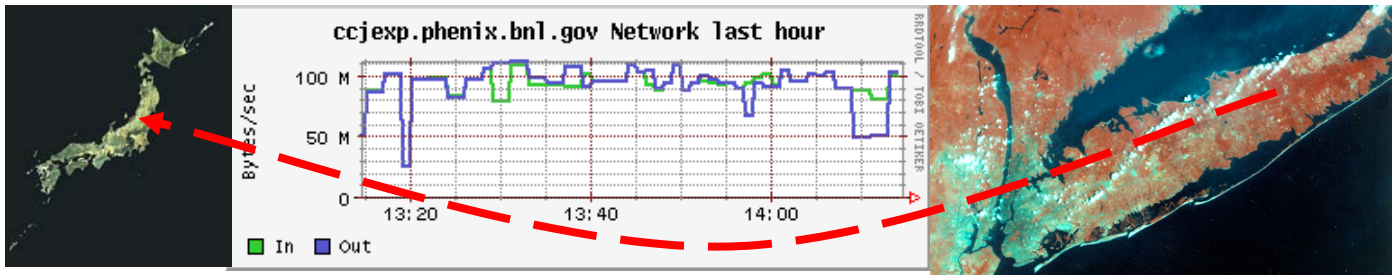


Improvements in 2005 run

- DAQ rate more than 5 kHz (1.4 kHz max. in 2004 run)



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



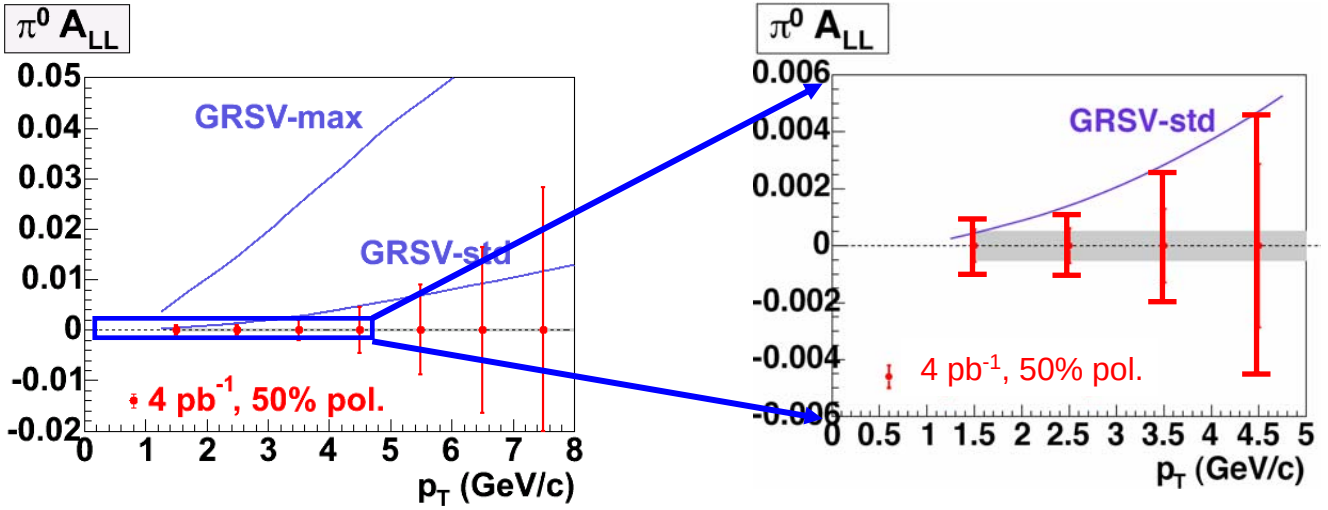
60 MB/s sustained !!

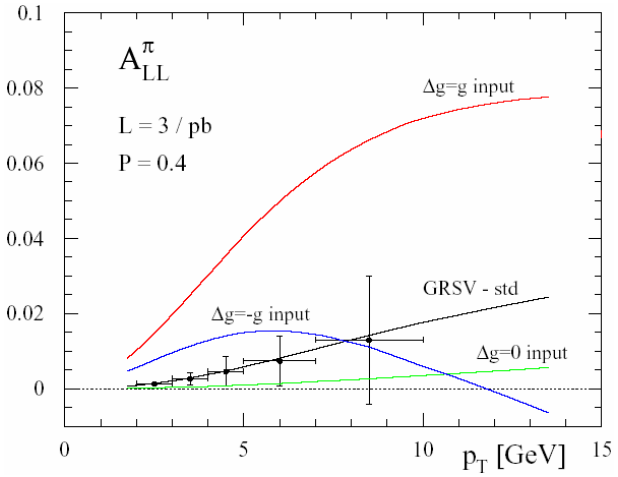
Improvements in 2005 run

- Relative luminosity
  - new scalar board
    - developed by the STAR group
    - better correlation-study capability of many trigger counters
  - multi-collision study
- Local polarimeter
  - better statistics due to better DAQ rate
  - blue: 8% transverse, 99.7% longitudinal
  - yellow: 15% transverse (almost radial), 98.9% longitudinal
  - backward asymmetry consistent with zero
  - Manabu Togawa's talk (Wednesday morning)

Physics expectations in 2005 run

- A_{LL} of π^0
  - 2003-2004 data distinguish between GRSV-max and GRSV-std
  - 2005 data will distinguish GRSV-std from A_{LL} = 0

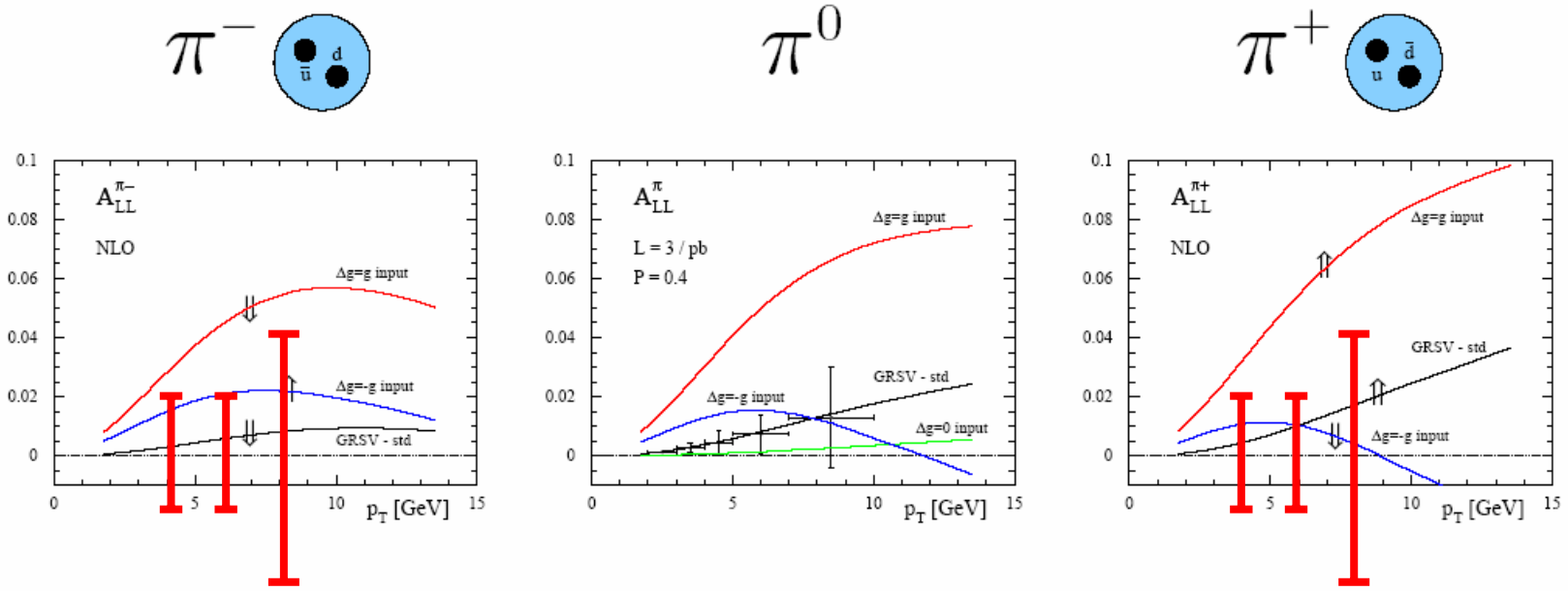




because of gg-process dominance, low p_T region of this channel is not sensitive to sign of Δg …

Physics expectations in 2005 run

- A_{LL} of charged pions
  - 5-15 GeV/c $\pi^{\pm}$ identified by RICH and EMCal hadronic shower



idea: qg starts to dominate for $p_T \gtrsim 5\,\mathrm{GeV}$ and $D_u^{\pi^+} > D_u^{\pi^0} > D_u^{\pi^-}$, $D_g^{\pi^+} = D_g^{\pi^-}$

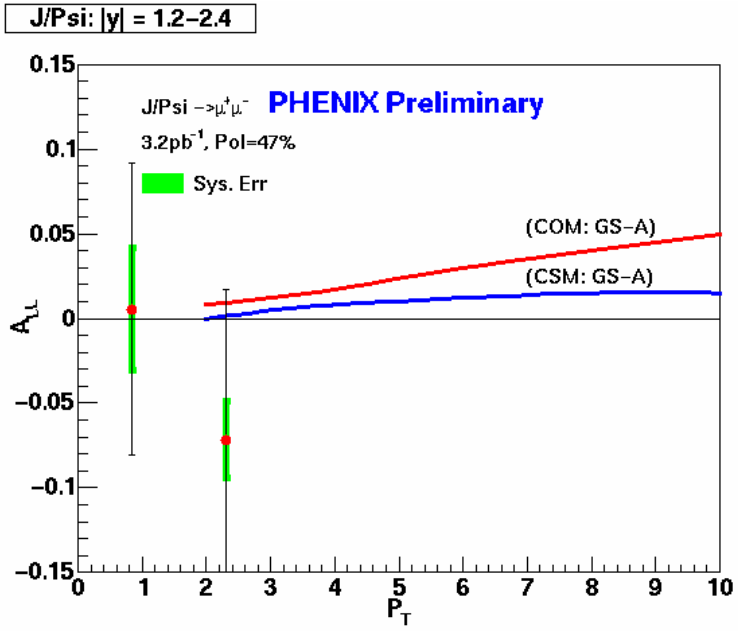
expect: sensitivity to sign of Δg, e.g., positive Δg: $A_{\mathrm{LL}}^{\pi^+} > A_{\mathrm{LL}}^{\pi^0} > A_{\mathrm{LL}}^{\pi^-}$

M. Stratmann et al.

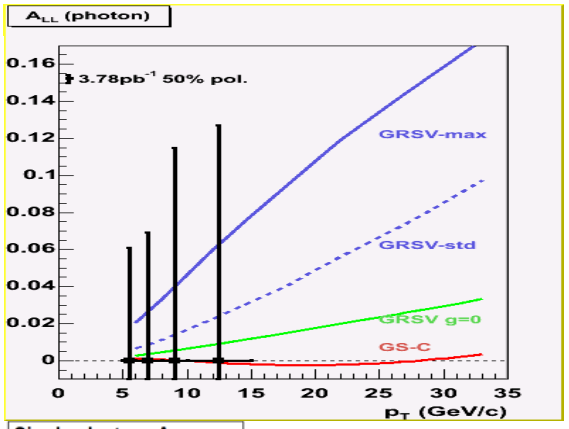
sensitivity to sign of Δg can be expected

Physics expectations in 2005 run

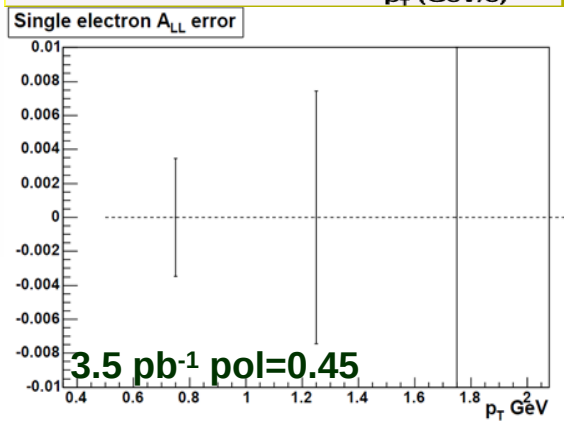
- Many first asymmetry results are coming
  - important to measure a variety of physics channels
    - covering wide and overlapping x-region
    - to reduce experimental and theoretical systematics
  - direct photon, η, "jet", $e^{\pm}$, $\mu^{\pm}$, J/ψ, Λ, …



J/ψ – Imran Younus' talk (Thursday afternoon)



photon projection

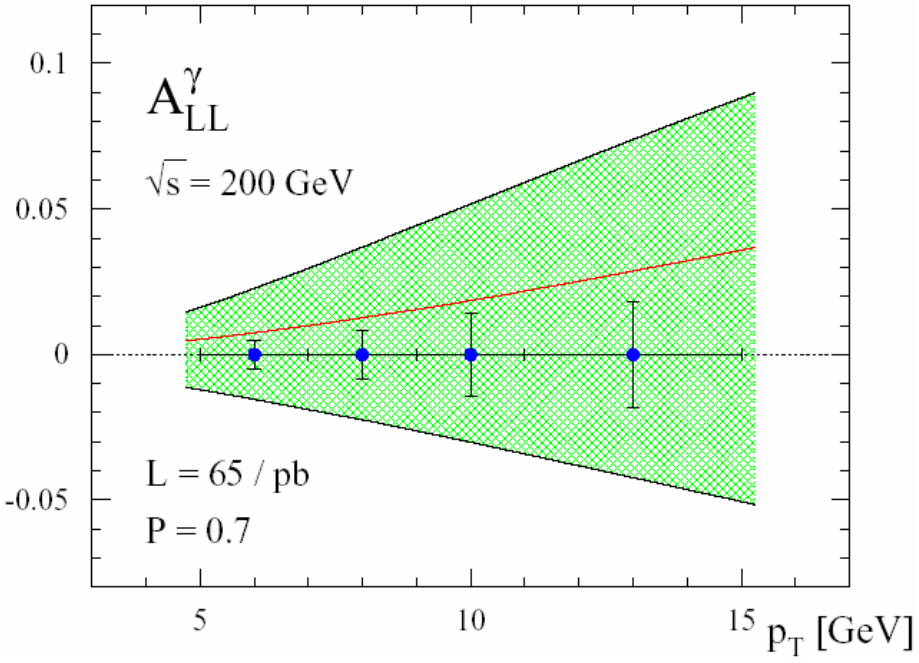


electron projection

Future outlook

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

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

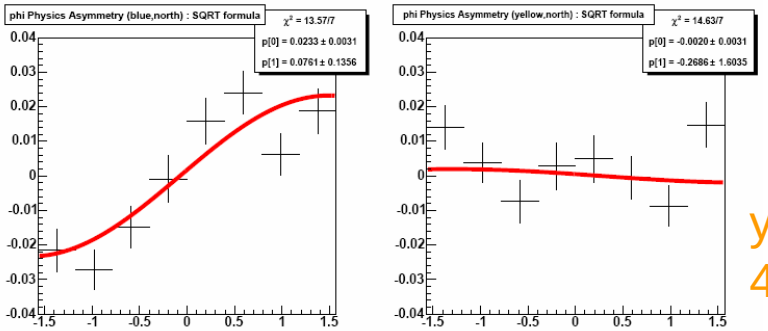


  - $\sqrt{s}$ = 200 GeV run until 2009
  - $\sqrt{s}$ = 500 GeV run from 2009 (and developments until then)

More in 2005 run

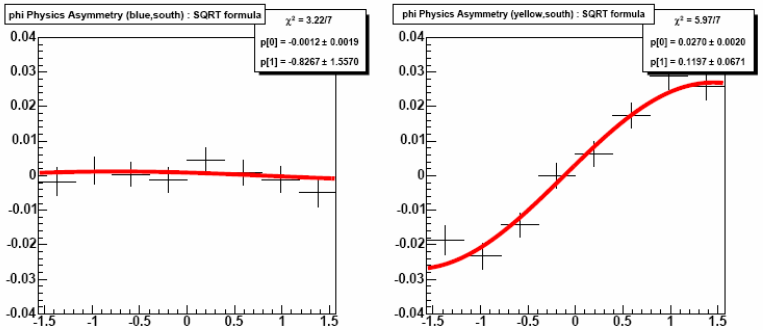
- 410 GeV run
  - accelerator study towards the 500 GeV run
    - RHIC is capable of accelerating to higher $\sqrt{s}$ without losing all polarization

blue:
33% pol.



yellow:
49% pol.

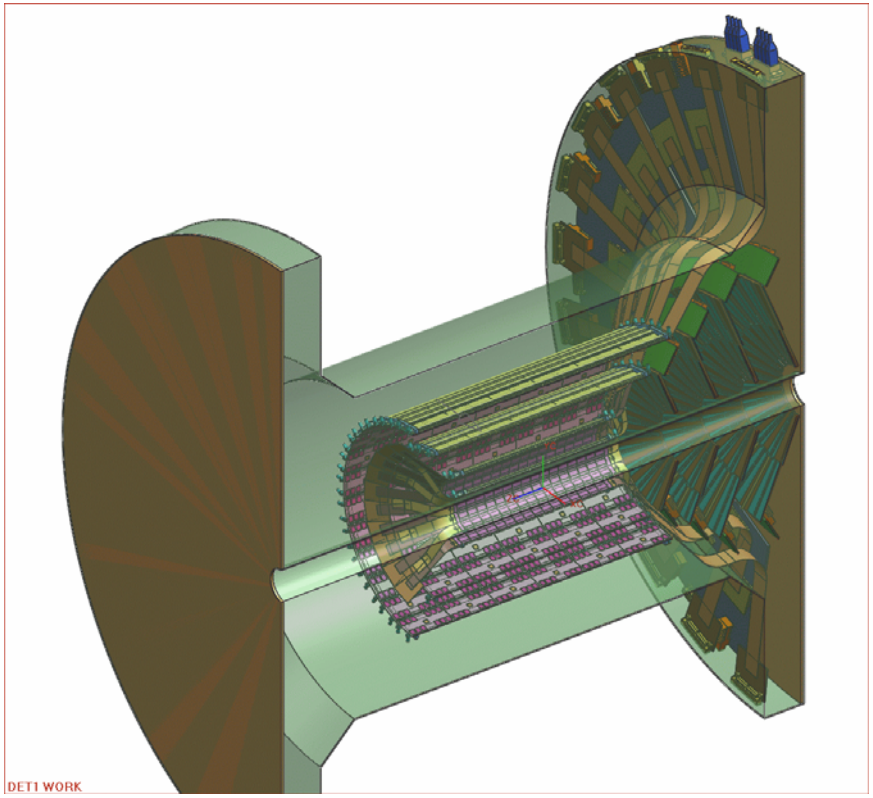
analyzing power of local polarimeter roughly the same despite doubling of energy



- 200 GeV transverse-spin run
  - A_{TT} measurement to limit a systematic uncertainty on A_{LL} from a transverse component

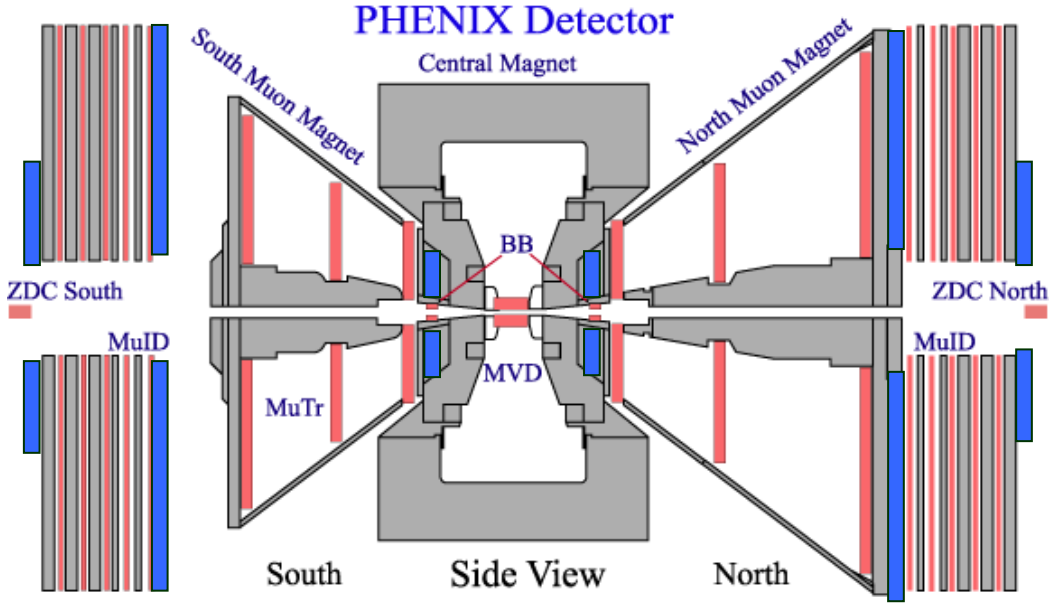
Silicon-vertex upgrade

- 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 2008-2009 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

Summary

- Gluon polarization measurement
  - 2003-2004 $A_{LL}(\pi^0)$ data distinguished between GRSV-max and GRSV-std
- 2005 – first long longitudinal-spin polarized-proton run
  - Figure of merit (LP4) more than 40 times larger than that of previous runs
  - 2005 $A_{LL}(\pi^0)$ data will distinguish GRSV-std from $A_{LL} = 0$
- We have been accumulating data …
  - Many first asymmetry results are coming: A_{LL} of direct photon, …
  - $\sqrt{s}$ = 200 GeV run until 2009
  - $\sqrt{s}$ = 500 GeV run from 2009
- Towards the future: flavor-identified quark polarization measurement with $W^{\pm}$
  - accelerator development for $\sqrt{s}$ = 500 GeV
  - detector upgrades