Spin Results

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Stonybrook/RBRC

Mini Workshop on RHIC Spin 1
AGS-RHIC User's Meeting
May 10, 2004

Plan of this talk....

PHENIX

- Brief history of spin

- PHENIX detector Run (2000/1) I to Run (2002/3) III
- PHENIX Results
  - Single Spin asymmetry Measurements
    - π^0 and $h^{+/-}$ production
  - Double Spin asymmetry Measurements π^0 production
    - Longitudinal beams at PHENIX (single spin asymmetry)
    - Relative luminosity issues
    - Background estimate and asymmetry of the background
    - Systematic checks
    - *Result and discussion in the context of pQCD*

- Summary & outlook

Past experiments & results

PHENIX

- Past experiments: Deep Inelastic Scattering (DIS)
  Fixed target experiments, probe nucleon structure using virtual photons
  - **EMC, SMC at CERN:**
    -- polarized muon beams (~190 GeV/c)
    → on polarized solid state targets
  - **SLAC(E80,E130,E142,E143,E154,E155,X)**
    -- polarized electron beams (~10→49 GeV/c)
    → on polarized solid/gaseous targets

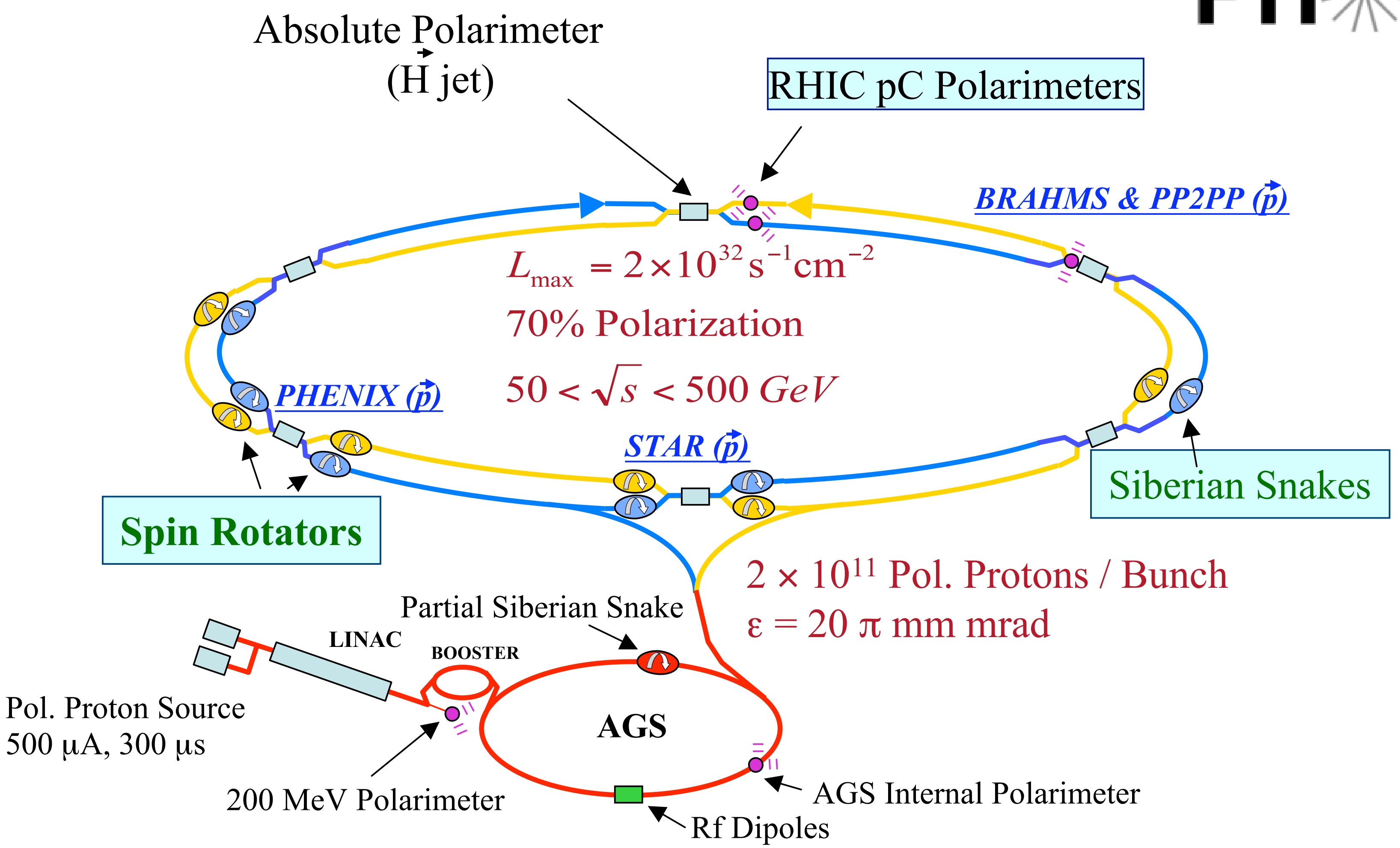
  } Spin crisis
  E-J, Bj Sum rules

  - **HERMES at DESY**
    -- polarized electron/positron beam (~27 GeV/c)
    → on polarized gas/jet targets

  } Semi-inclusive

- Where is the nucleon spin? → Gluons?
- Virtual photons are weak probes of gluons….

Relativistic Heavy Ion Collider



RHIC accelerates heavy ions to 100 GeV/A
and polarized protons to 250 GeV

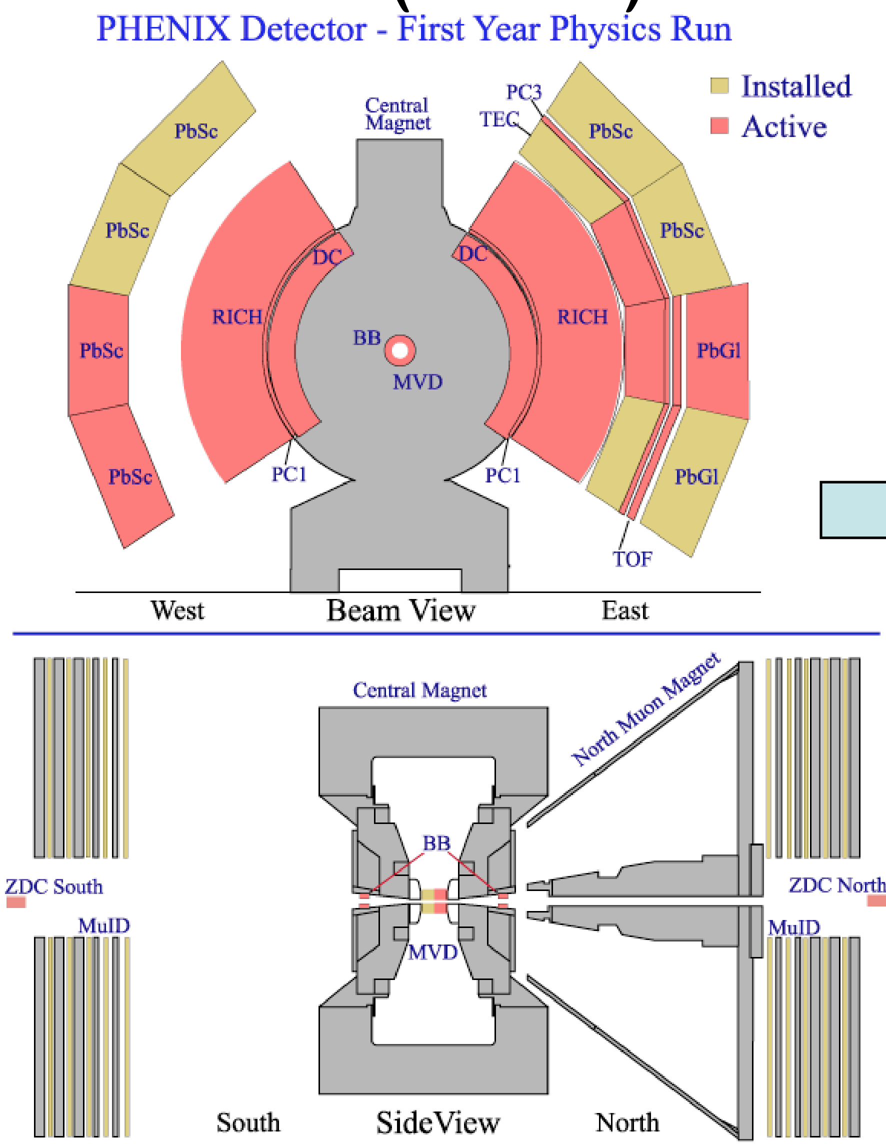
Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	University of Tokyo, Bunkyo-ku, Tokyo
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
S. Korea	Cyclotron Application Laboratory, KAERI, Seoul
	Kangnung National University, Kangnung
	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
Russia	Institute of High Energy Physics, Protovino
	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
	St. Petersburg State Technical University, St. Petersburg
Sweden	Lund University, Lund

12 Countries; 57 Institutions; 460 Participants

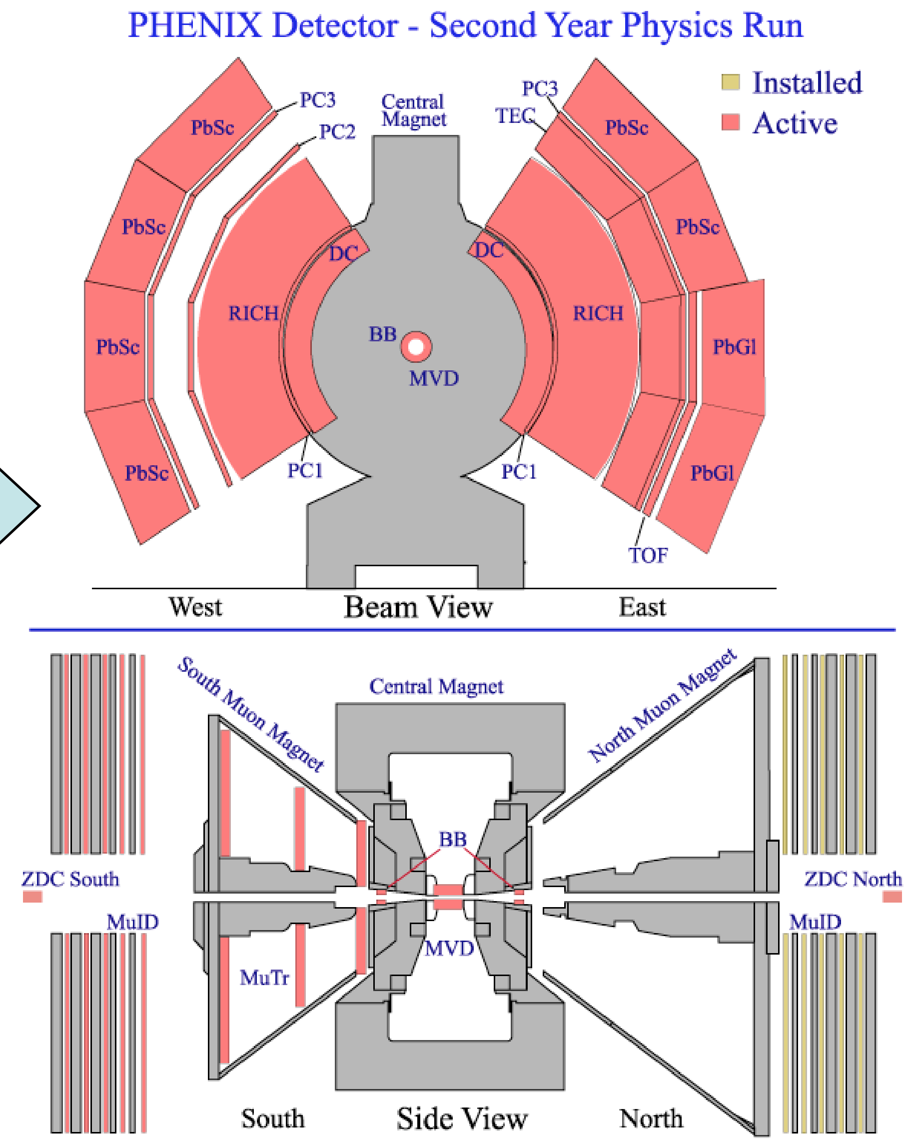
USA	Abilene Christian University, Abilene, TX
	Brookhaven National Laboratory, Upton, NY
	University of California - Riverside, Riverside, CA
	University of Colorado, Boulder, CO
	Columbia University, Nevis Laboratories, Irvington, NY
	Florida State University, Tallahassee, FL
	Georgia State University, Atlanta, GA
	University of Illinois Urbana Champaign, IL
	Iowa State University and Ames Laboratory, Ames, IA
	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
	University of New Mexico, Albuquerque, NM
	New Mexico State University, Las Cruces, NM
	Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
	Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
	Oak Ridge National Laboratory, Oak Ridge, TN
	University of Tennessee, Knoxville, TN
	Vanderbilt University, Nashville, TN

The Detector: Run 1 → Run 2

Run-1 (2000-1)



Run-2 (2001-2)



Run 3 Configuration

Central Arm Tracking
- Drift Chamber
- Pad Chambers
- Time Expansion Chamber

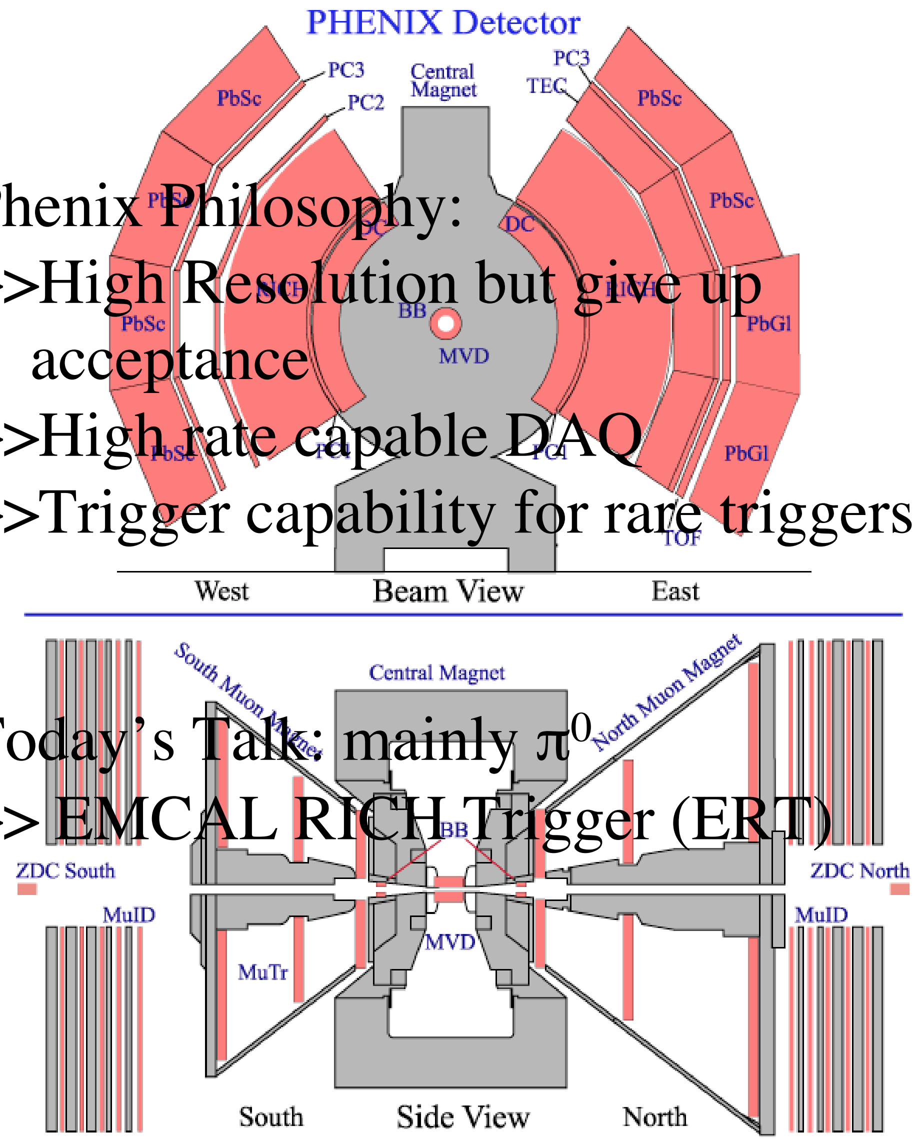
Muon Arm Tracking
- Muon Tracker: **North Muon Tracker**

Calorimetry
- PbGl
- PbSc

Particle Id
- Muon Identifier: **North Muon Identifier**
- RICH
- TOF
- TEC

Global Detectors
- BBC
- ZDC/SMD **Local Polarimeter**
  - **Forward Hadron Calorimeters**
- NTC
- MVD

Online Calibration and Production



Phenix Philosophy:
- >>High Resolution but give up acceptance
- >>High rate capable DAQ
- >>Trigger capability for rare triggers

Today's Talk: mainly π^0
- >> EMCAL RICH Trigger (ERT)

RHIC Spin Physics Program

PHENIX

Gluon Polarization

ΔG

$\pi^{0,+,-}$ Production

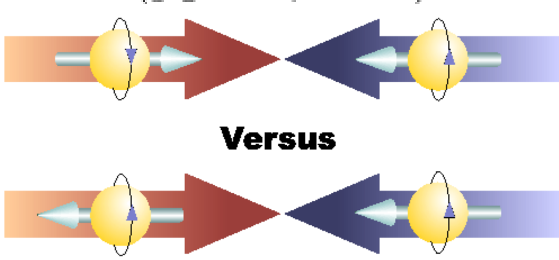
$A_{LL}(gg, gq \rightarrow \pi^{0,\pm} + X)$

Heavy Flavors

$A_{LL}(gg \rightarrow c\bar{c}, b\bar{b} + X)$

Prompt Photon

$A_{LL}(gq \rightarrow \gamma + X)$



Flavor Decompsition

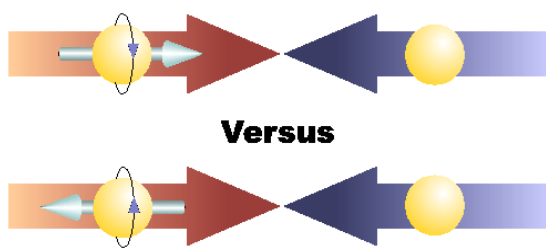
$\frac{\Delta u}{u}, \frac{\Delta \bar{u}}{\bar{u}}, \frac{\Delta d}{d}, \frac{\Delta \bar{d}}{\bar{d}}$

W physics

$A_L(u + \bar{d} \rightarrow W^+ \rightarrow l^+ + \nu_l)$

$A_L(\bar{u} + d \rightarrow W^- \rightarrow l^- + \overline{\nu_l})$

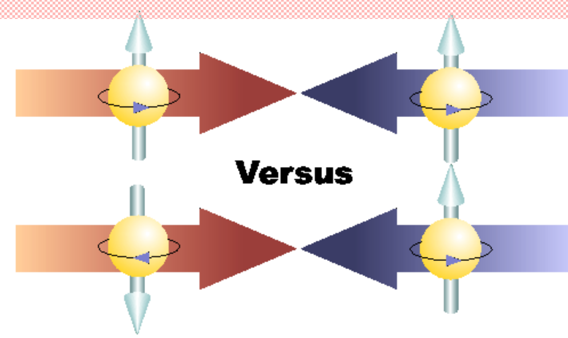
Longitudinal single spin physics



Transverse single/double spin physics

Transversity:
Sivers vs. Collins effects
& physics of higher twists;
Pion interf. Fragmentation

Transverse single spin physics
Phenix-Local Polarimetry

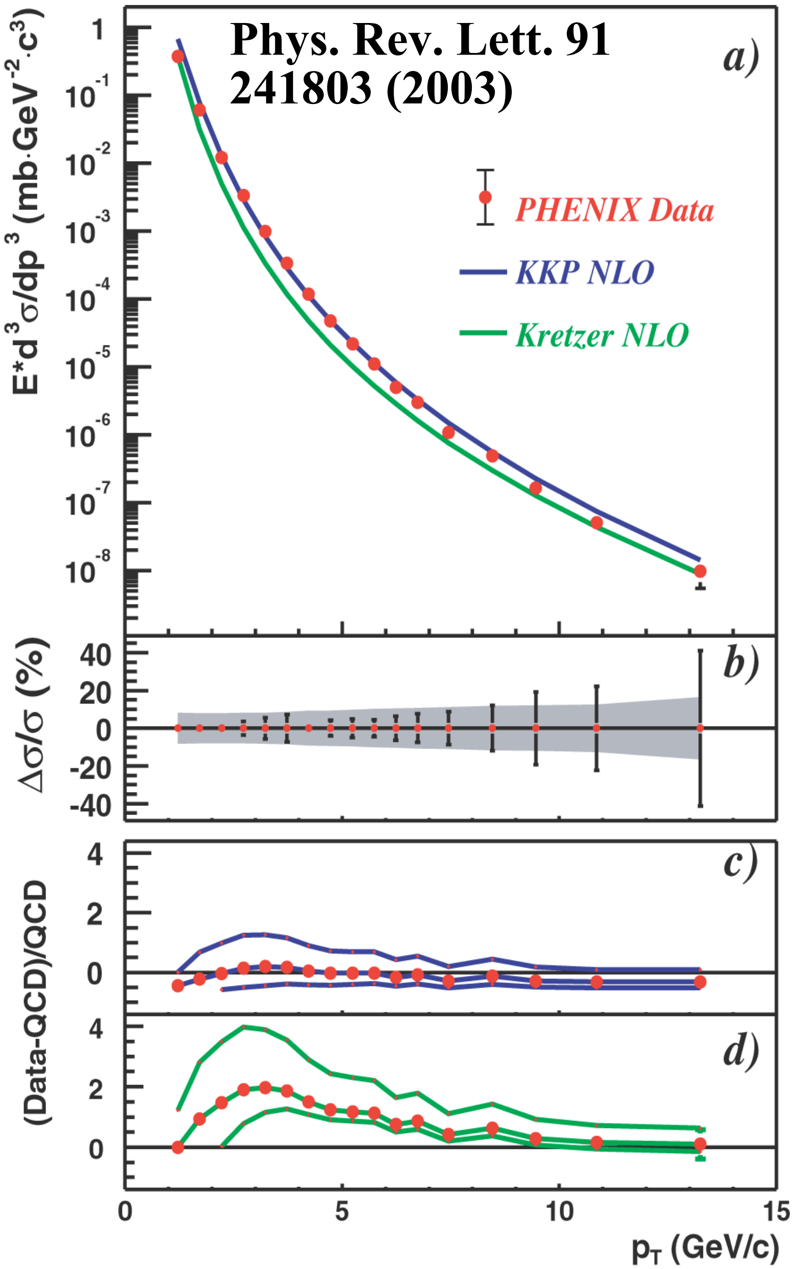


Data

- 2001-2 (Run 2)
  - *Transversely* polarized p+p collisions (NO Spin Rotators Magnets)
  - Average polarization of ~15%
  - Integrated luminosity 0.15 pb^{-1}
- 2002-3 (Run 3)
  - *Longitudinally* polarized p+p collisions achieved
  - Average polarization of ~27%
  - Integrated luminosity 0.35 pb^{-1}
- 2003-4 (Run 4)
  - 5 weeks polarized p+p commissioning
    - Started April 2nd
    - Specifically to work on spin tune and AGS polarization
    - Commission hydrogen jet polarimeter
- **2005**
  - **Long spin run planned!**

π^0 cross section (2002 Run2)

PHENIX



- Results consistent with pQCD calculation
- Favors a larger gluon-to-pion FF (Kniehl Kramer Potter)
- Important confirmation of theoretical foundations for spin program
- Run3 results reproduce Run2 results
  - ✓ Confirm the Run-3 data reliability and consistency
  - ✓ Run3 data reaches even higher p_Ts; results will be finalized soon

Why measure A_N at PHENIX?

Unpolarized cross section for pp->π^0X agrees well with pQCD at NLO

Single spin effects are associated with either genuine transverse spin effects in the nucleon OR they can be manifestations of final state effects after the partonic collision OR a combination of both

– Depending on their nature: "Sivers" or "Collins" effects

- STAR measured a significant single spin asymmetry in π^0 production in forward region: at the partonic level this is dominated by $x_{quark} > 0.6$ (J. Kiryluk, following talk)
- PHENIX acceptance, central rapidity, probes the quark's role in this result ($x_{quark} \sim 0.1$), since gluons do not contribute to transverse spin effects
- Charged (unidentified) hadrons also available for measuring this effect

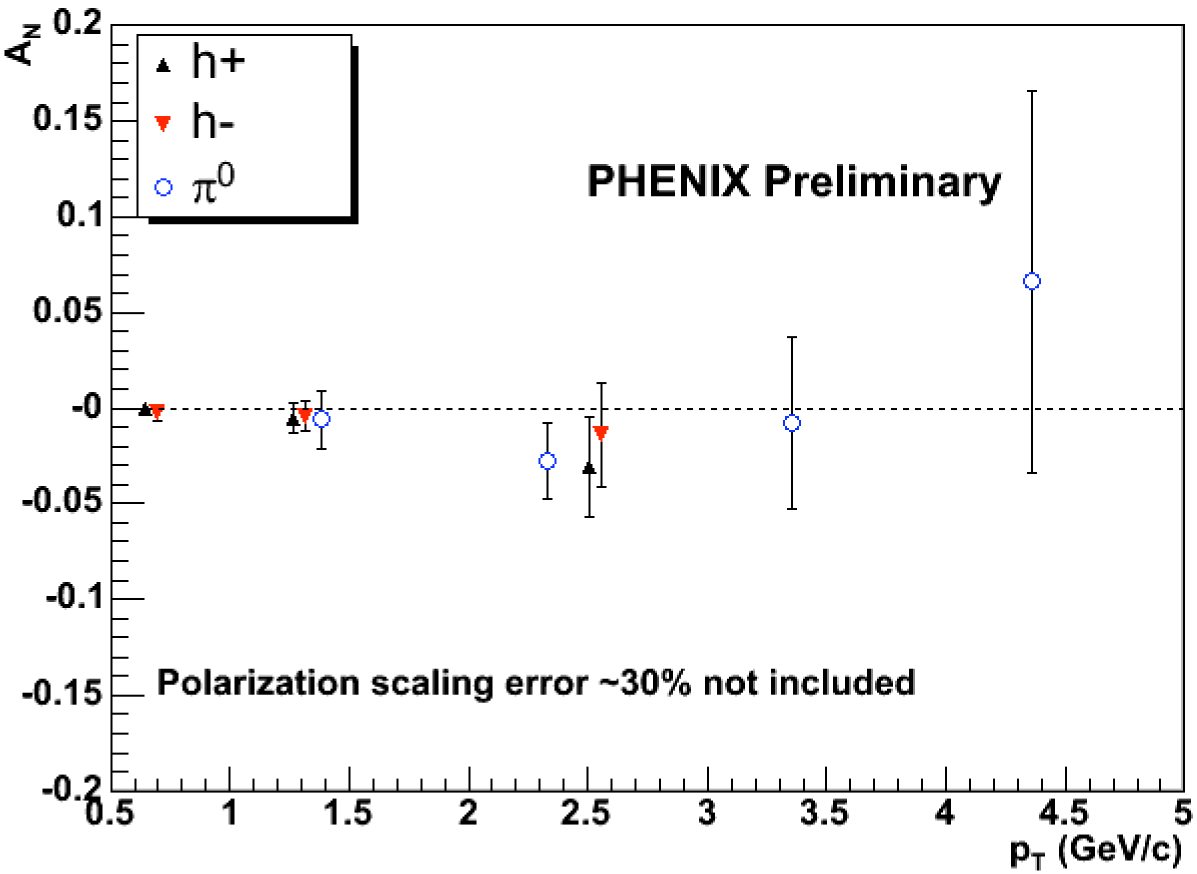
A_N of π^0 and $h^{+/-}$

- **Independently measured for the two beams**
- **Two methods tried and confirm identical results**
  - **Sqrt formula:** $A_N^{beam} = \frac{1}{p^{beam}} \frac{\sqrt{N_{left}^{beam+} N_{right}^{beam-}} - \sqrt{N_{right}^{beam+} N_{left}^{beam-}}}{\sqrt{N_{left}^{beam+} N_{right}^{beam-}} + \sqrt{N_{right}^{beam+} N_{left}^{beam-}}}$
  - **Luminosity formula** $R = \frac{L^{beam+}}{L^{beam-}}$

$$A_N^{beam,left} = \frac{1}{p^{beam}} \frac{(N^{beam+,left} - RN^{beam-,left})}{(N^{beam+,left} + RN^{beam-,left})}$$

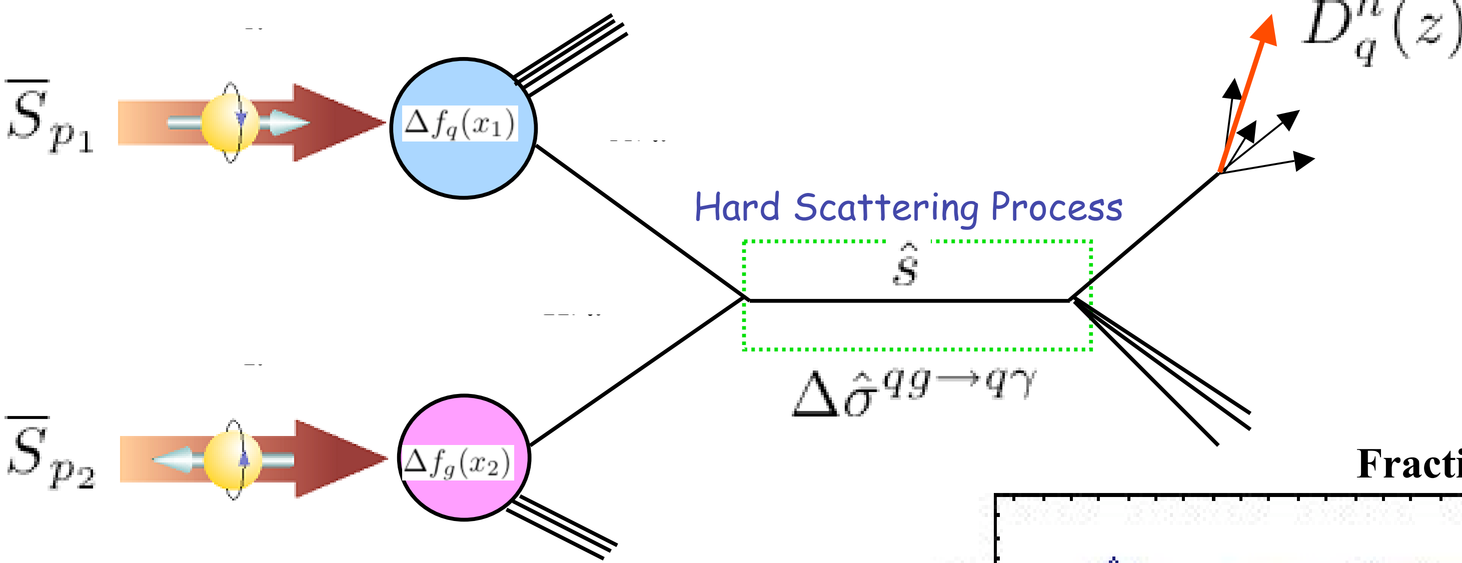
- **Independent results for two diferent detectors (east,west EM cal)**
- **Check store-by-store stabilty**

A_N Results



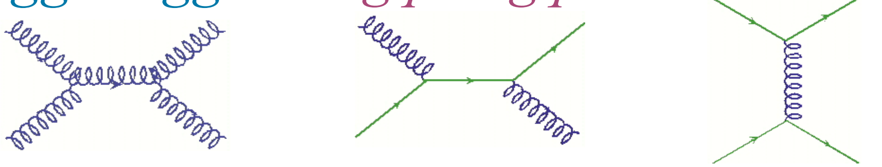
A_N for both charged hadrons and neutral pions consistent with zero.

Double Spin: Leading hadrons

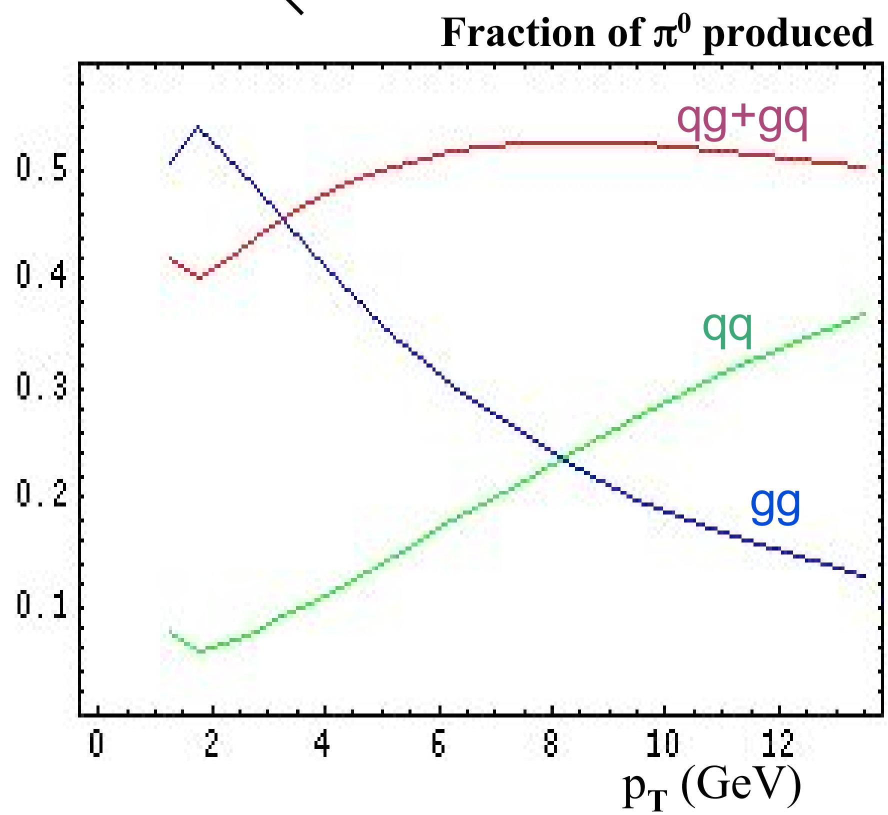


$h = \pi^0$

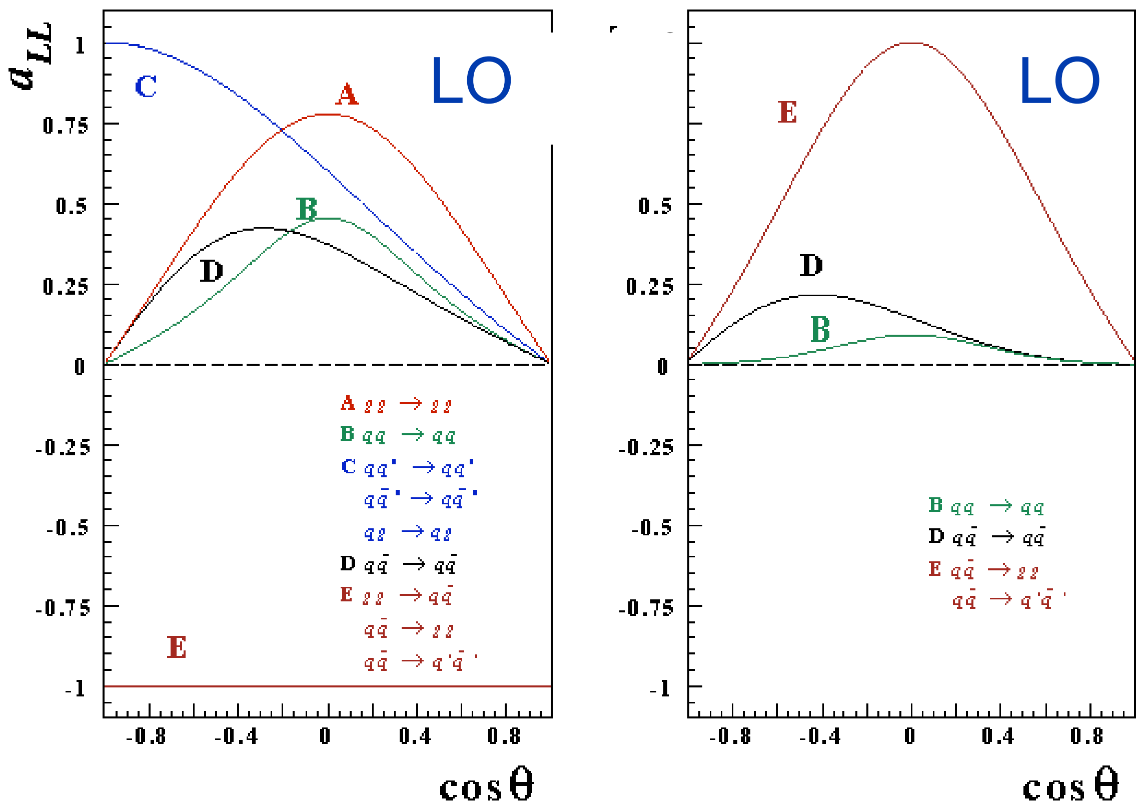
$gg \to gg$ $\quad$ $gq \to gq$ $\quad$ $qq \to qq$



$\propto \frac{\Delta G}{G}\frac{\Delta G}{G}$ $\quad$ $\propto \frac{\Delta q}{q}\frac{\Delta G}{G}$ $\quad$ $\propto \frac{\Delta q}{q}\frac{\Delta q}{q}$



Analyzing powers



- NLO corrections are now known for all relevant reactions

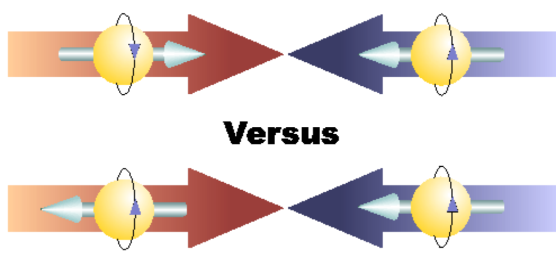
$$A_{LL} \propto \frac{\Delta q}{q} \frac{\Delta G}{G} a_{ll}(qg \to qg)$$

Double spin asymmetry π^0production

PHENIX

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

++ same helicity
+– opposite helicity



(P) Polarization -- absolute scale and "longitudinal"ness
(L) Relative Luminosity -- bunch to bunch variation
(N) Number of π^0 s -- triggers and efficiencies etc.

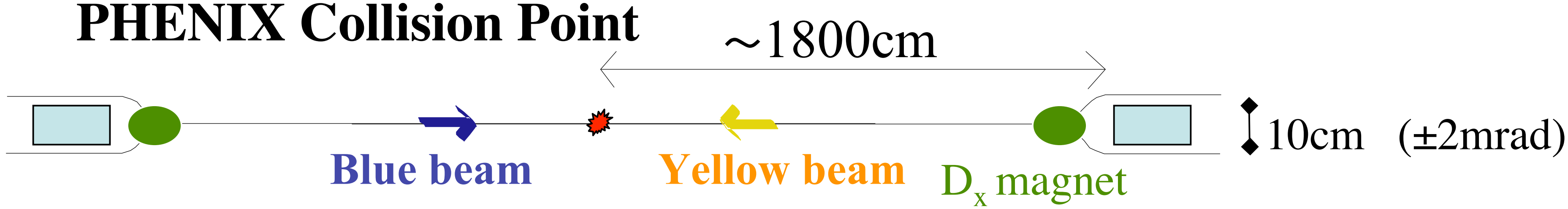
Beam polarization in PHENIX

PHENIX

- Absolute polarization scale
  - With RHIC CNI polarimeter
  - Uncertainty estimated from AGS-E950 experiment performed with 22 GeV p beam, to be ~30%
  - Using the same uncertainty at 100 GeV involves another ~10% coming from the energy dependence of the analyzing power
  - Total UNCERTAINTY: 32% per beam in polarization
  - Hep-ph/0404027 for summary
  - This error does not change the significance of A_{LL}, because it scales both value and error in the same way
- Spin direction confirmation
  - With Spin Rotators commissioning
  - Confirmed with PHENIX local polarimeter
- Long. component of the spin direction monitor
  - PHENIX local polarimeter

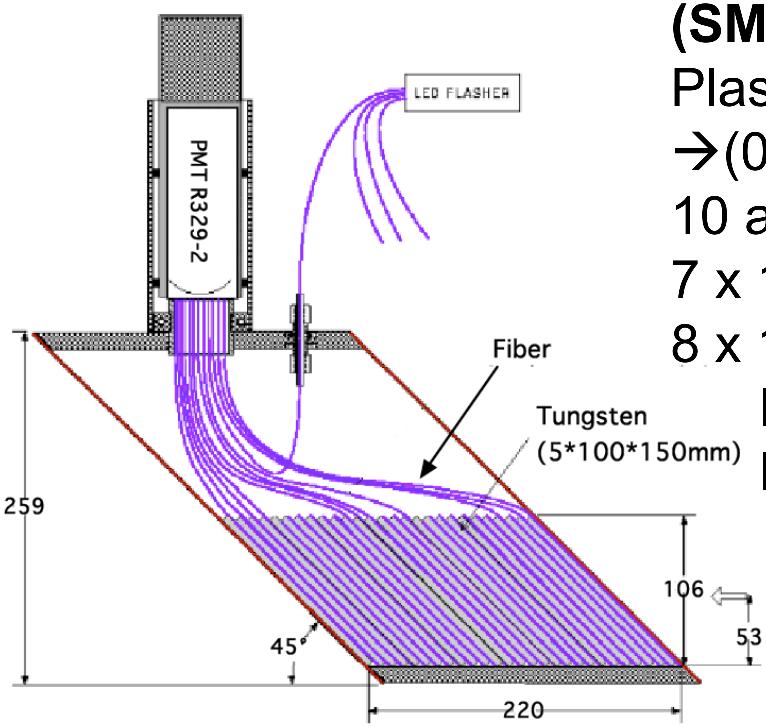
PHENIX Local Polarimeter 2003

PHENIX Collision Point



Zero Degree Calorimeter (ZDC)
Tungsten-Fiber Sandwich
5.1 λ_T, 149 X_0 → 3 ZDCs each side

Shower Max Detector (SMD)
Plastic Scint. strips
→(0.5cm x 3)
10 and 15 cm long
7 x 1.5cm columns
8 x 1.5cm rows
Read by
Hamamatsu M16

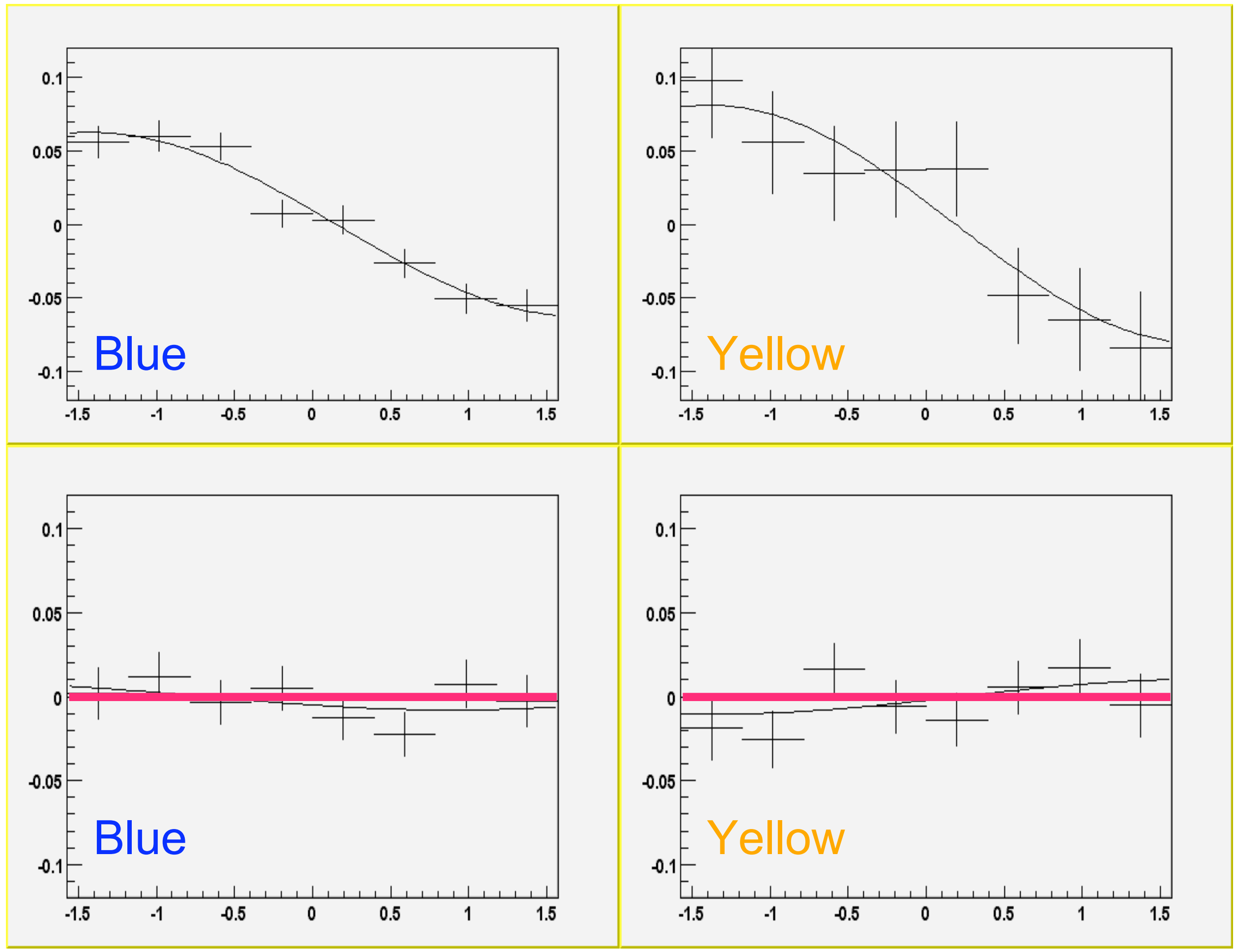


beam

Longitudinal Polarization

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Correct Current !
Longitudinal polarization!

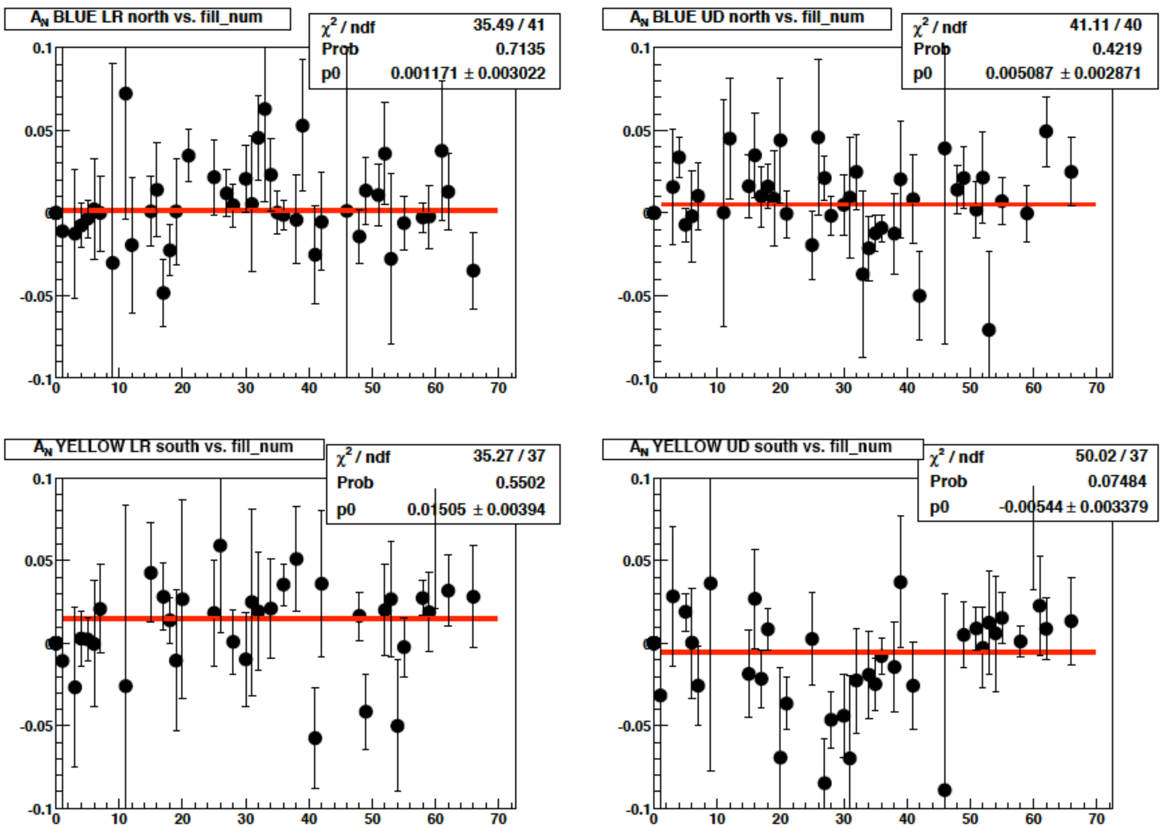


Longitudinal component of spin

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

S_T is measured with PHENIX Local Polarimeter

Left-Right asymmetry   Up-Down asymmetry



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

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

Relative luminosity: Result

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- Beam-Beam-Counter (BBC) used as Relative Luminosity Monitor
  - Low background
  - High statistics
- Zero Degree Calorimeter (ZDC) used as a cross check
  - Different kinematics & acceptances
- Bunch-by-bunch comparison of ratio of no. of hits in BBC vs. ZDC

- Achieved relative luminosity precision $\delta R = 2.5 \cdot 10^{-4}$
  - Pessimistic estimation limited by ZDC statistics (30 times less than BBC statistics used in Rel. Lum. measurements)
- Rel. Lum. contribution for π^0 A_{LL} less than 0.2%
  - For average beam polarizations of 27%
- A_{LL} of BBC relative to ZDC consistent with 0 (<0.2%)
  - Strong indication that both A_{LL}s are zero (very different kinematical regions, different physics signals)

Data set: selection criteria

PHENIX

Photon ID

Shower profile requirement, time of flight & charge veto

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 (~0.22 pb^{-1})**

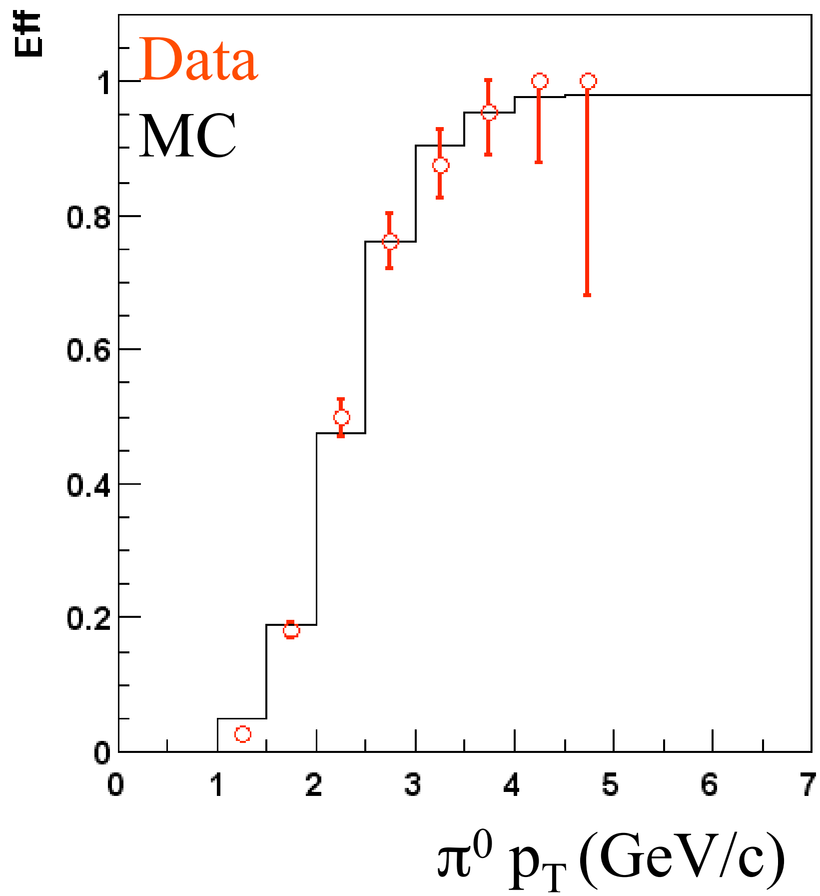
sqrt(<$P_b P_y$>)~27%

Minimum Bias data

To obtain "unbiased" π0 cross section at low p_T

For high p_T photon trigger efficiency study

γ trigger efficiency for π^0



- π^0 efficiency plateaus for p_T>4 GeV/c
- Limited efficiency at p_T<4 GeV/c:
  - 1-2 GeV/c: 6%
  - 2-3 GeV/c: 60%
  - 3-4 GeV/c: 90%
  - 4-5 GeV/c: 95%
- Monte Carlo reproduces Data well

π^0 reconstruction for A_{LL}

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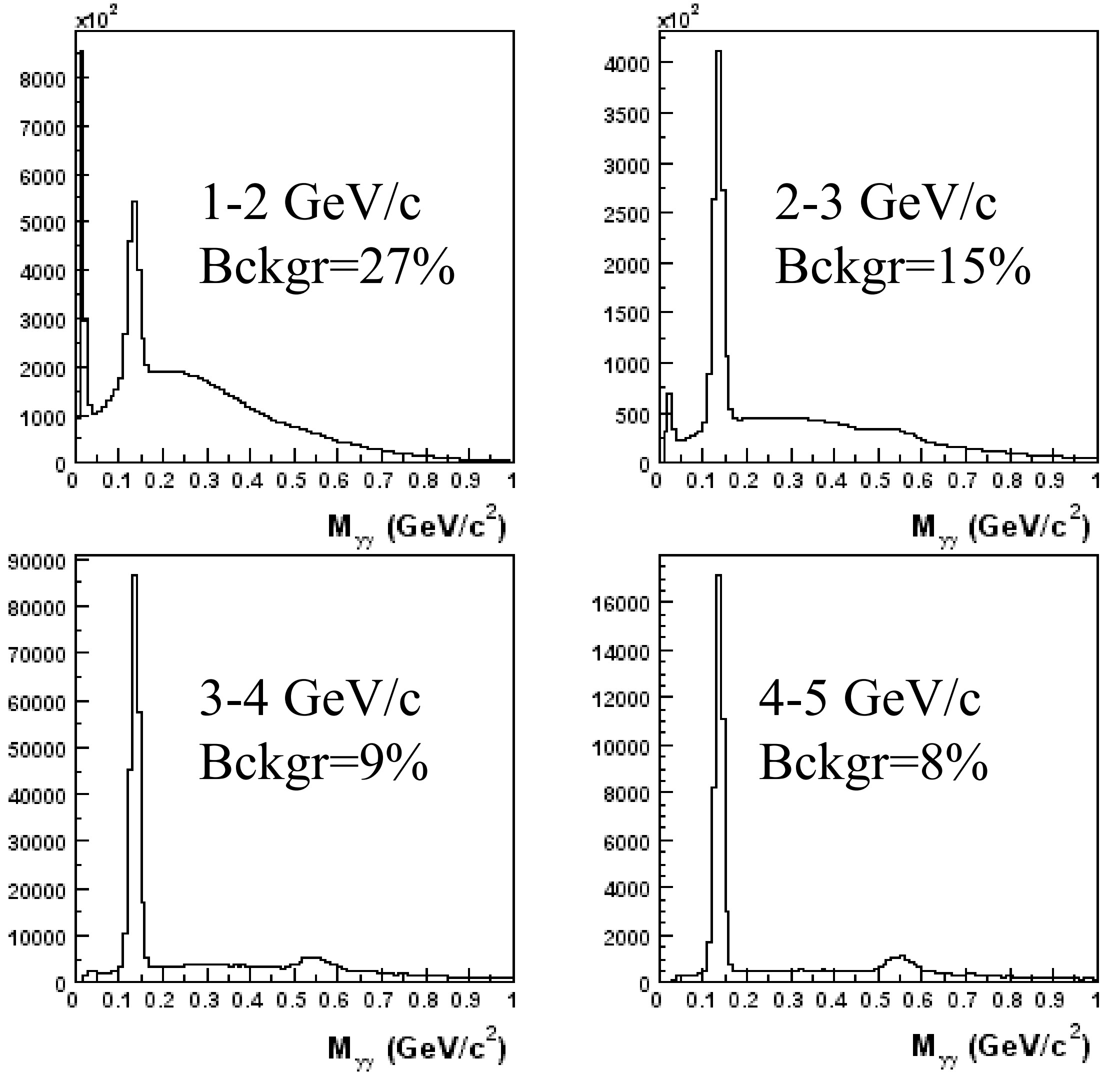


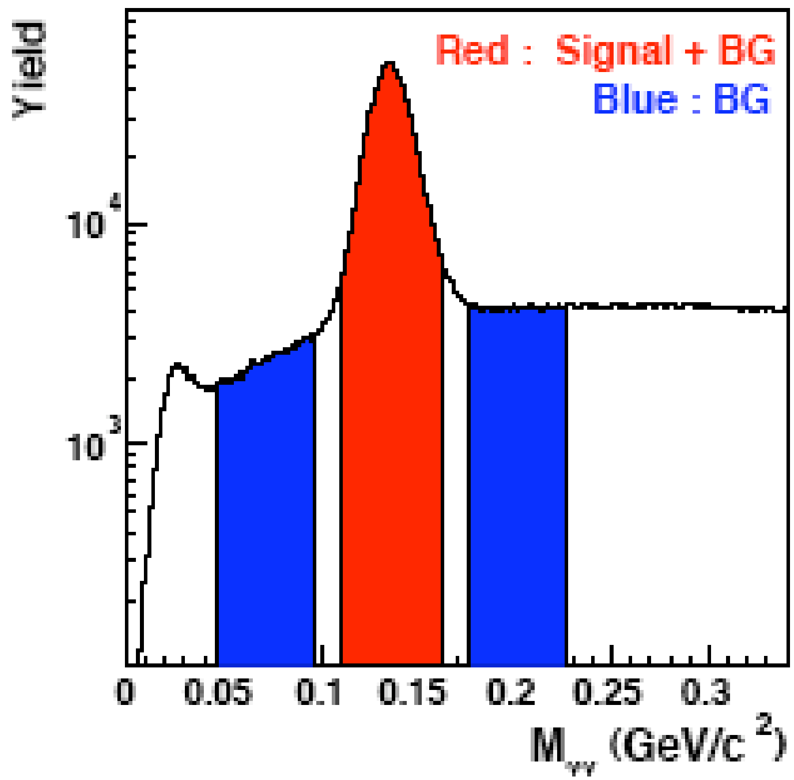
Results obtained for four p_T bins from 1 to 5 GeV/c

π^0 peak width varies from 12 to 9.5 MeV/c^2 from lowest to highest pt bins

Background contribution under π^0 peak for ±25 MeV/c^2 mass cut varies from 27% to 8% from lowest to highest p_T bins

π^0 reconstruction efficiency varies from 84% to 93% from lowest to highest p_T bin

π^0 counting & background



$N_{\pi 0}$: ±25 MeV/c^2 around π^0 signal

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

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

pt GeV/c	$N_{\pi 0}$ 25 MeV/c^2	N_{bck1}
1-2	1777k	1470k
2-3	1059k	335k
3-4	201k	27k
4-5	38k	3.9k

$$A_{LL}^{\pi^0} = \frac{A_{LL}^{raw} - rA_{LL}^{BG}}{1-r} \qquad \sigma_{A_{LL}^{\pi^0}} = \frac{\sqrt{\sigma^2_{A_{LL}^{raw}} + r^2\sigma^2_{A_{LL}^{BG}}}}{1-r}$$

r = normalized counts of background [(red)/(blue)]

A_{LL} & Systematic studies

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

++ 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**
3. **Variation of photon identification**
4. **Mass window around signal varied both for signal and background**
5. **Possible single spin parity violating asymmetry:** $A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$

Systematic check: bunch shuffling

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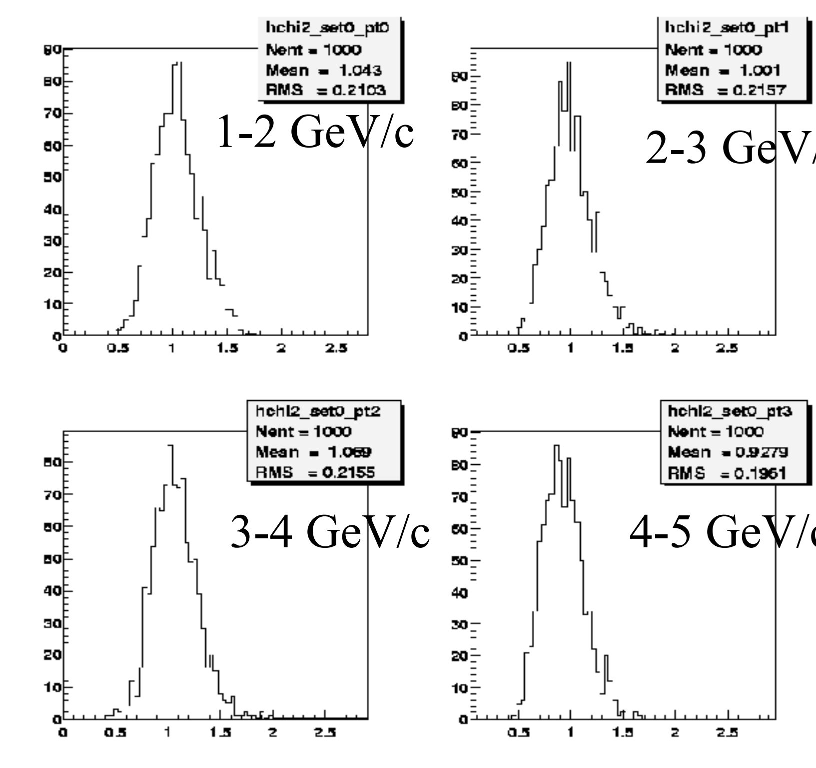
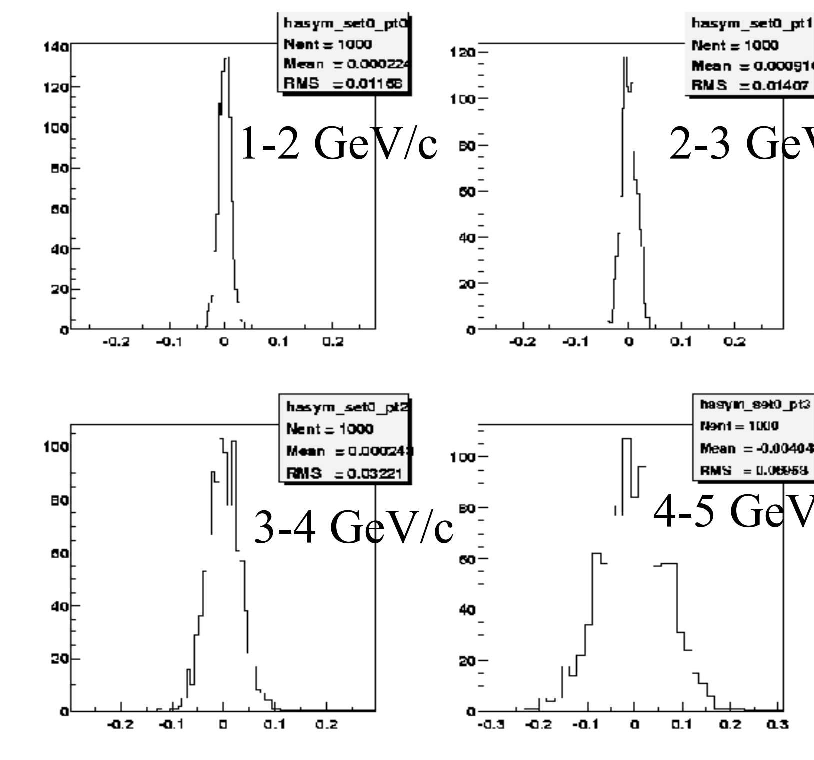
Bunch shuffling = Randomly assigns helicity for each crossing

χ^2/NDF



All <χ^2/NDF> are ~1

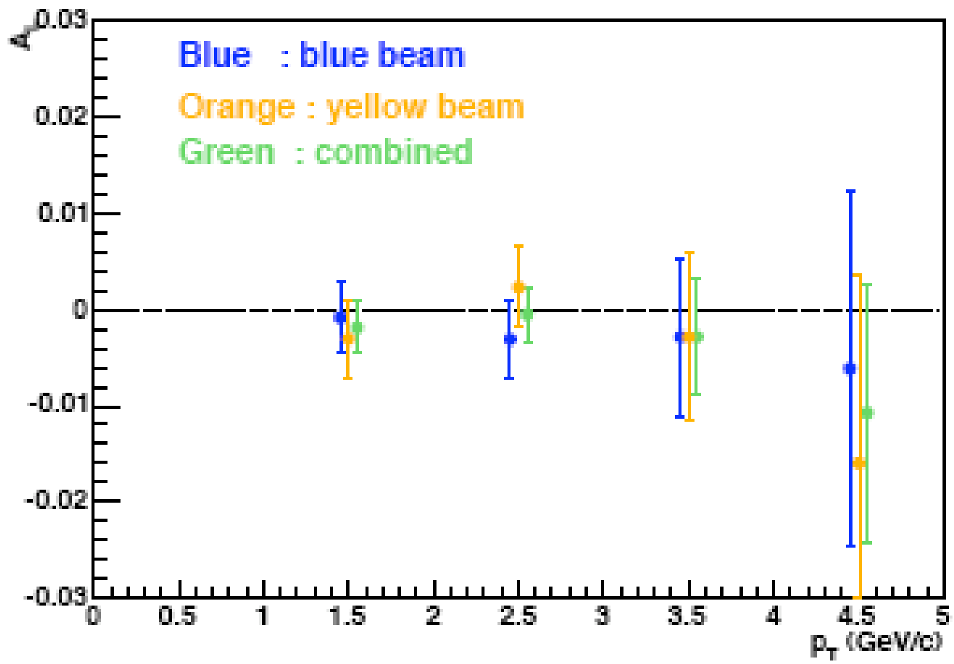
A_{LL}



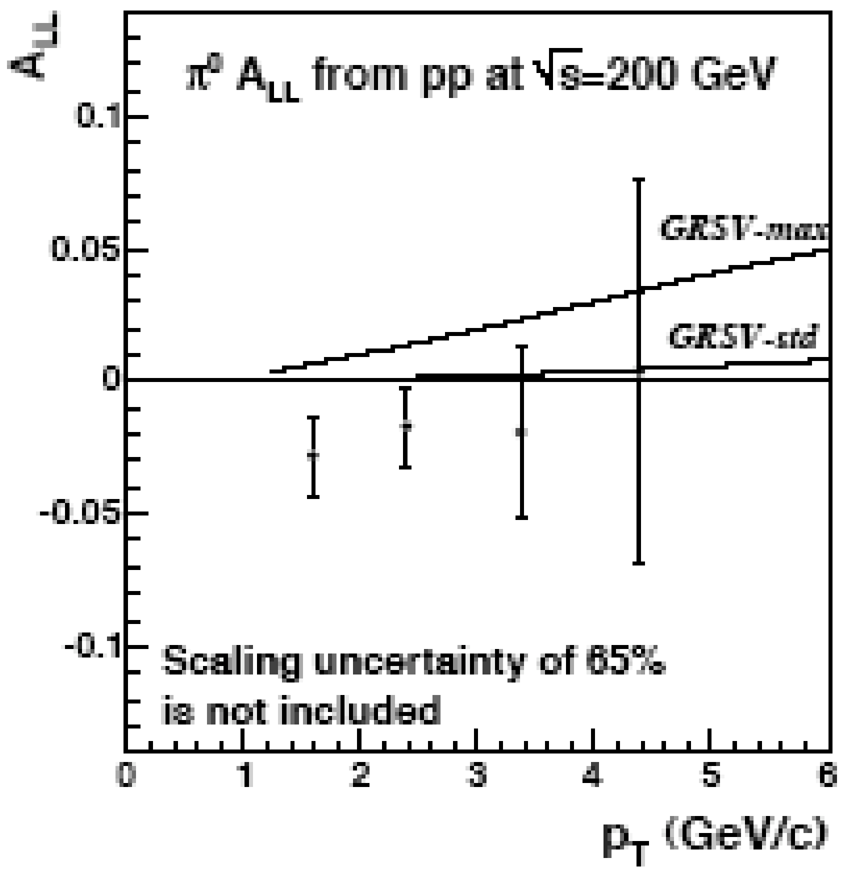
Widths are consistent with obtained errors $\delta(A_{LL})$

PV single spin asymmetry

Parity violating single spin asymmetries were measuered
-- Possible contribution to A_{LL}
-- Physics results by themselves
>> Asymmetries calculated with (++) vs. (--)
Asymmetries calculated with (+-) vs. (-+) bunch-crossings



Result and Discussion



- GRSV Curves from B.Jaeger et al., PRD67, 054005 (2003)
  - >input scale Q^2=0.6 GeV^2
  - >both curves positive
- B. Jaeger et al. Hep/ph-0310197 argue: Negative A_{LL} difficult to accommodate

- Not including theory uncertainty
  GRSV-std CL: 16-20%
  GRVS-max CL: 0.02-5%

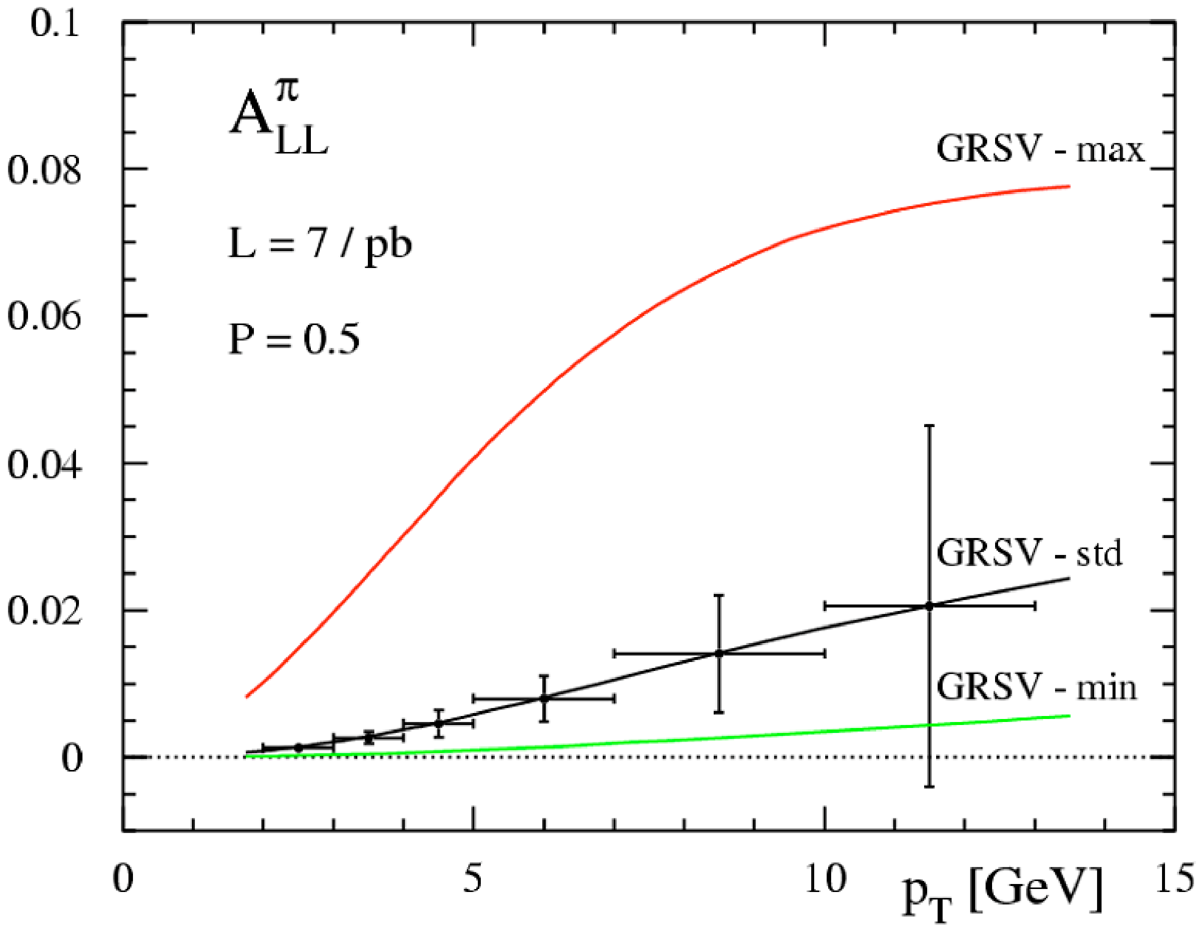
$p_T(GeV/c)$	Bckg. contr.	$A_{LL}^{\pi^0+bckg}$	A_{LL}^{bckg}	$A_{LL}^{\pi^0}$
1-2	27%	-0.015 $\pm$ 0.010	-0.018 $\pm$ 0.016	-0.028 $\pm$ 0.015
2-3	15%	-0.019 $\pm$ 0.013	-0.031 $\pm$ 0.028	-0.017 $\pm$ 0.015
3-4	9%	-0.018 $\pm$ 0.029	-0.008 $\pm$ 0.079	-0.019 $\pm$ 0.032
4-5	8%	0.025 $\pm$ 0.066	0.26 $\pm$ 0.20	0.004 $\pm$ 0.072

Summary

- PHENIX is ready and taking data:
  - Presented A_N and A_{LL} data in spite of moderate polarizations and luminosities of Runs 2 and 3
- Figure of Merit: Sqrt($P_1^2 * P_2^2 * L$) so
  - improvements are expected fast…. *A modest increase in polarization and luminosity will make a world of difference!*
- **Annual beam time for polarization and luminosity development crucial…**
- **Future of Spin at PHENIX looks very bright!**
  - **PHENIX Spin: other paths to ΔG, quark/anti-quark distributions, transversity**
  - **Ample opportunities for new groups to collaborate on new detector ideas and concepts being considered…**

π^0 Production and ΔG

- π^0 can be used to determine ΔG with limited L & P



Run 5???

Jager, Schafer, Stratmann, Vogelsang

Upgrades & Physics Opportunities

PHENIX

- **PHENIX Physics Plans for near and long term future:**
  - Discovery and study of QGP using A-A collisions
  - Study of nucleon spin structure using polarized pp collisions
  - Gluon disrtibutions in nuclei using p-A collisions

- **Detector Upgrade plans & Opportunities for new groups**
  - Aerogel & time-of-flight system to provide π/K/p separation
  - A vertex tracker to detect displaced vertices for c,b phyiscs
  - A hadron blind detector to detect electrons near the vertex
  - A mini-TPC to enhance PHENIX's tracking in azimuth & pseudorapidity
  - A forward detector upgrade for improved muon trigger
  - A forward calorimeter for photoh+jet studies over wide kinematic range