Measurements of Δg with the PHENIX Detector at RHIC

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for

the PHENIX Collaboration

Outline:

- Motivation
- PHENIX Detector
- π^0 A_{LL} Measurement Method
- π^0 A_{LL} Measurement Result
- Direct Photon Discussion

Proton Spin

- The Proton is a composite particle, and so we expect its properties to arise from the quarks and gluons
- For example:
  - Charge→ +1 = 2/3 + 2/3 -1/3. Only quarks contribute.
  - Momentum→ carried by both quarks and gluons.
  - Spin ?

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$\Delta\Sigma$ = Quark Contribution $\simeq$ 20-30%
Δg = Gluon Contribution—minimally constrained
ΔL = Orbital Angular Momentum Contribution—??

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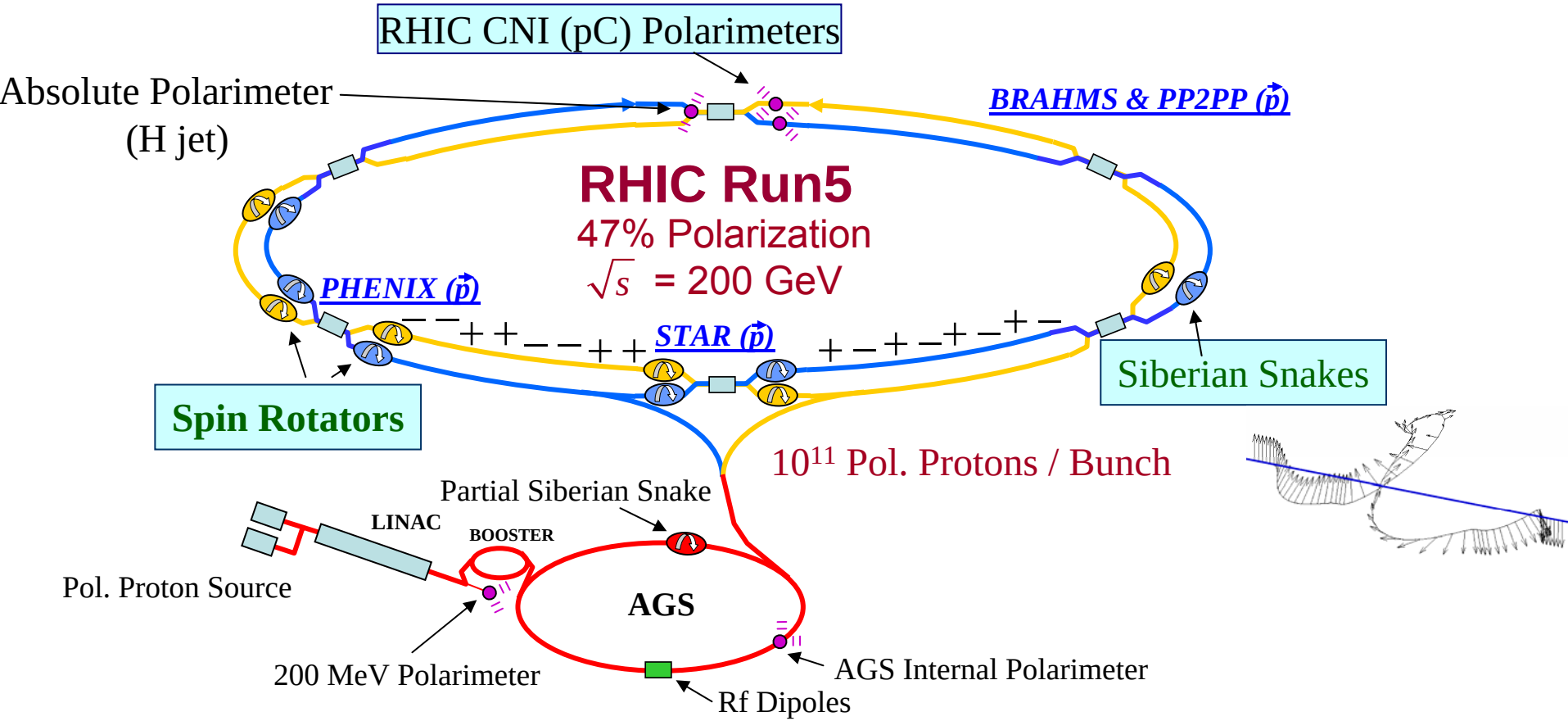
We want to measure gluon contribution, so we look for polarized pp collider.

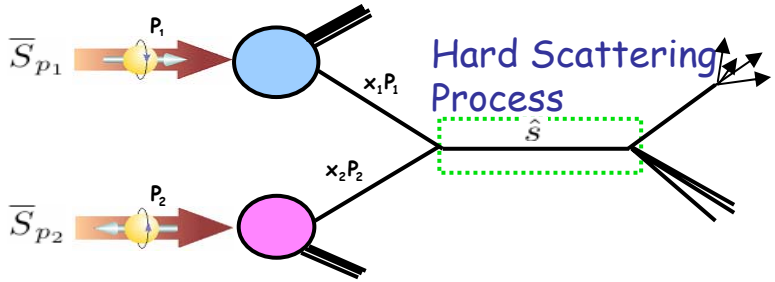
RHIC



RHIC accelerates polarized protons to (presently) 100 GeV per beam

Double Helicity Spin Asymmetry

So we have a polarized pp collider—what do we do?



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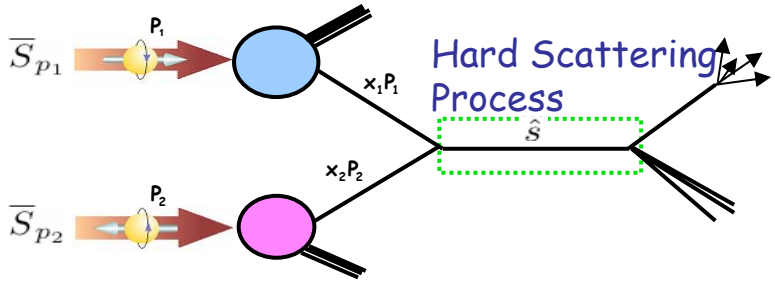


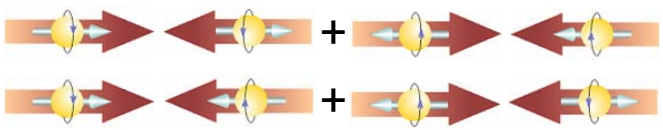
Various channels can be used to probe Δg:

- π^0, π^+, π^-
- direct photon
- jets
- Heavy flavor

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

+- =

++ =



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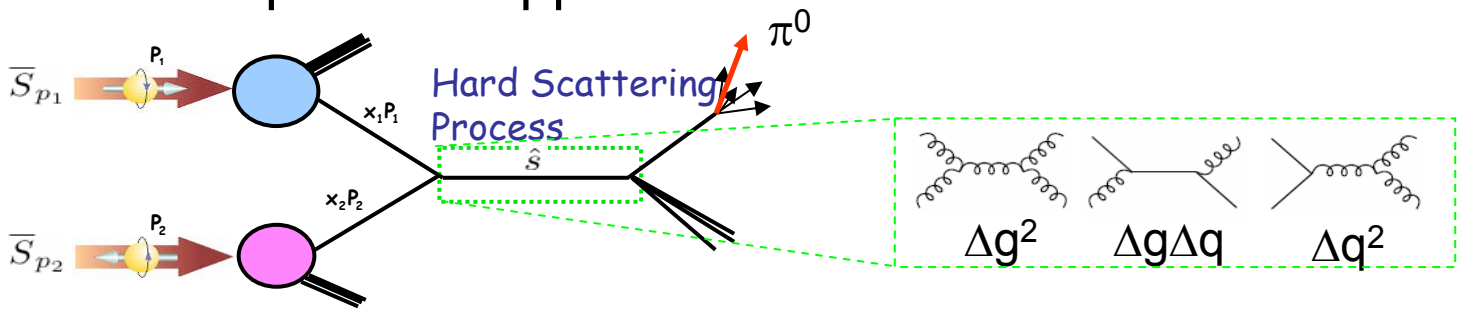

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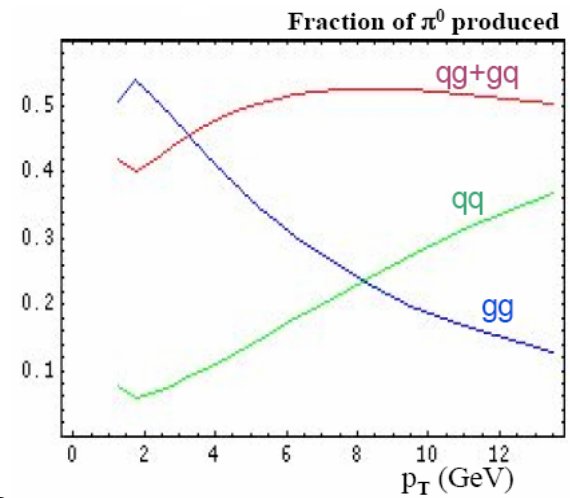
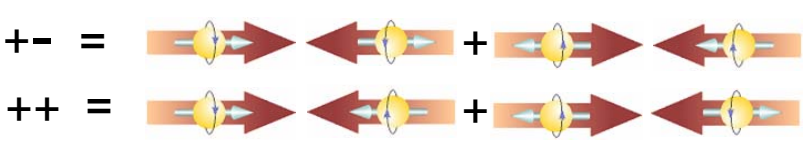


$$A_{LL}^{\pi^0} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = a_{gg} * \Delta g^2 + b_{gq} * \Delta g\, \Delta q + c_{qq}\, \Delta q^2$$



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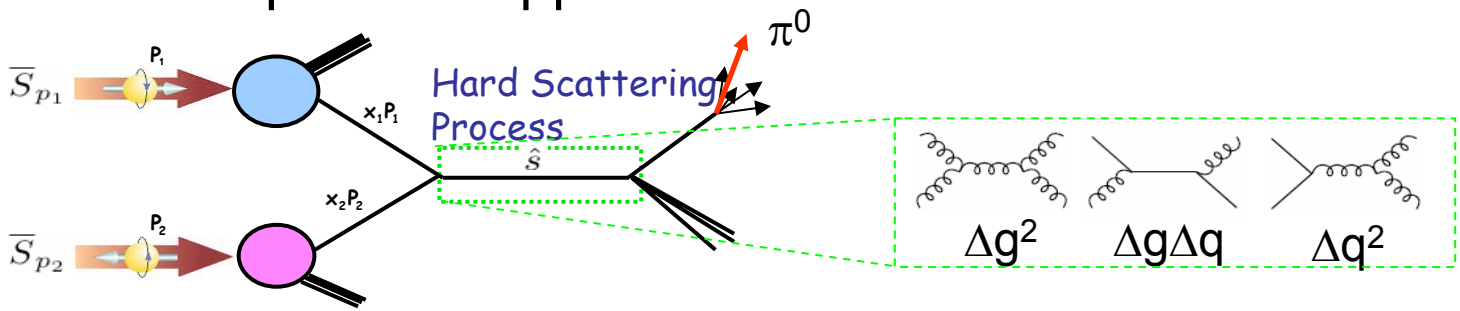

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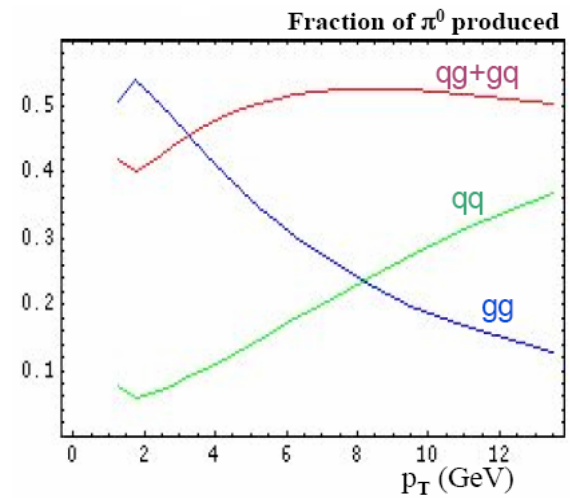
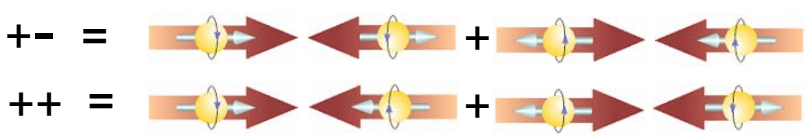
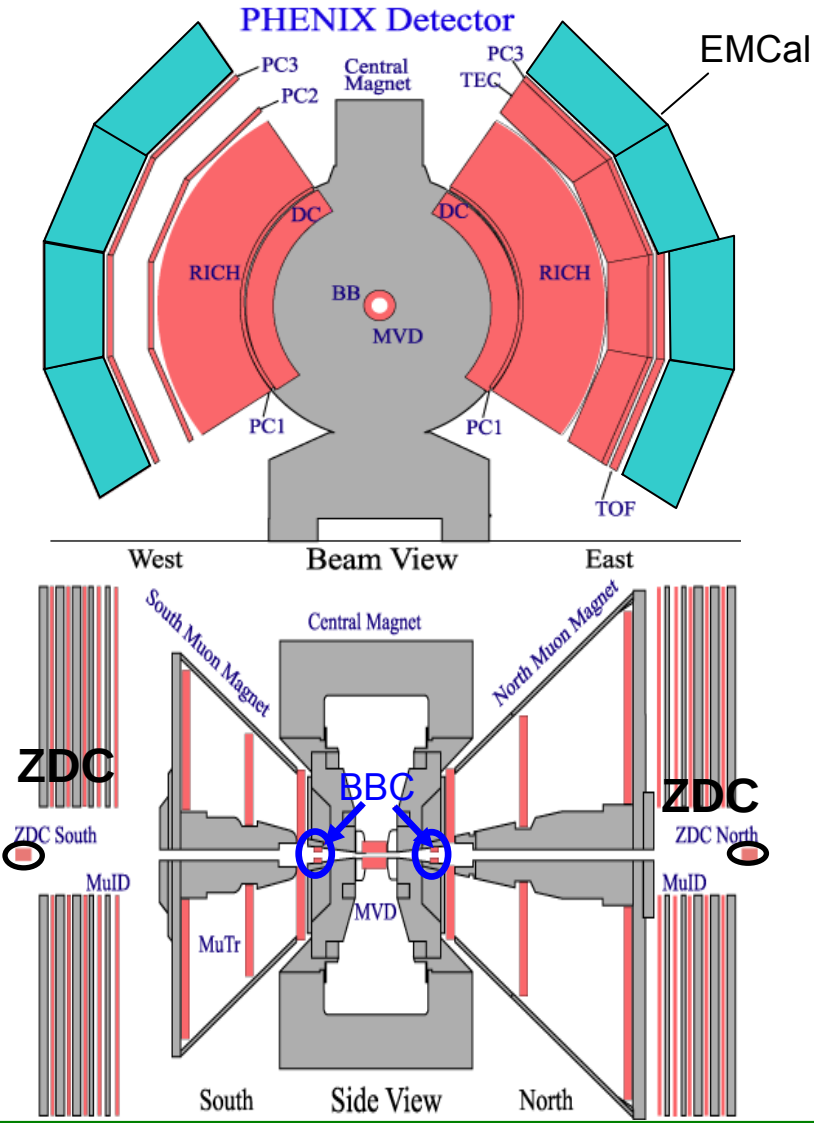


$$A_{LL}^{\pi^0} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P^2}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, \quad R = \frac{L_{++}}{L_{+-}}$$

P=polarization
N = particle yield
L = Luminosity



PHENIX Detector

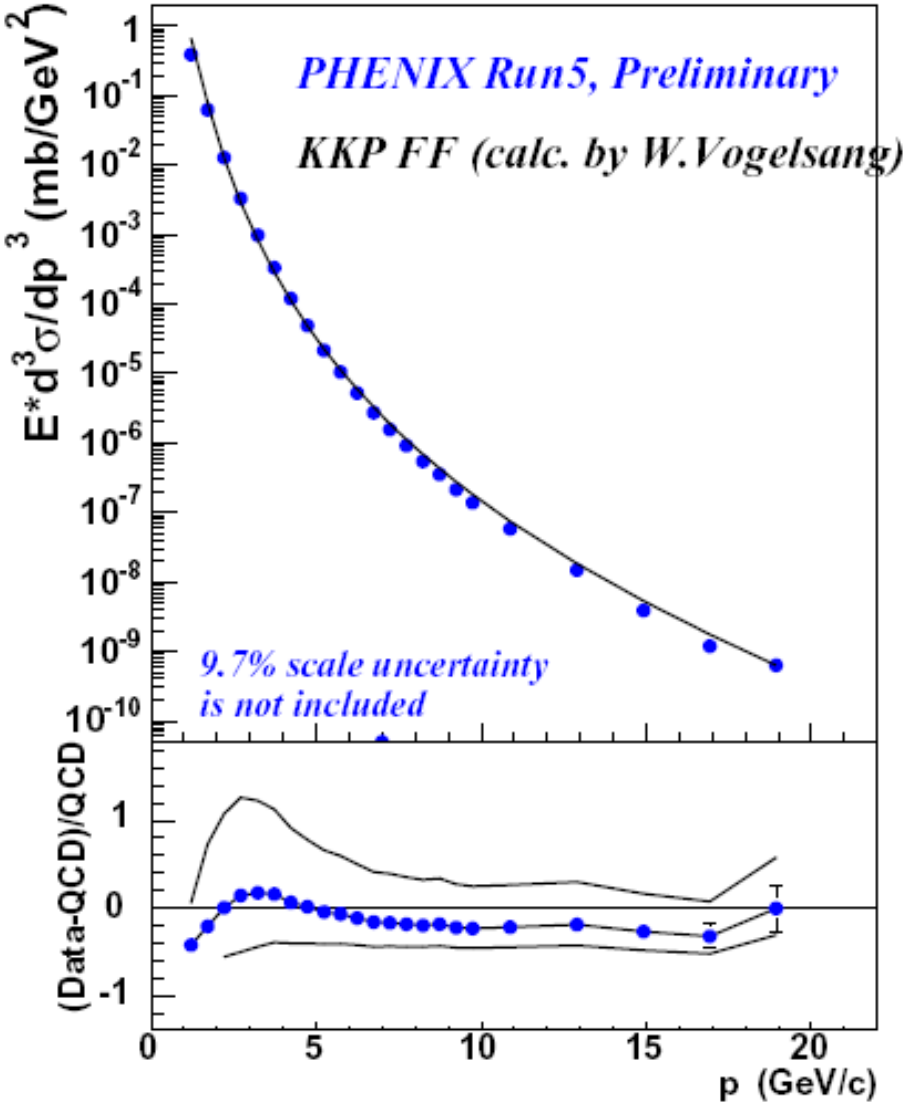


Direct γ, π° detection

- Electromagnetic Calorimeter (EMCal):
  - High p_T photon trigger
  - Acceptance: $\eta<|0.35|$, $\phi = 2 \times \pi/2$
  - High granularity (~10*10mrad2)
- Beam Beam Counter (BBC)
  - Coincidence between two BBCs required for event trigger.
  - Used for Relative Luminosity Normalization.
- Zero Degree Calorimeter (ZDC)
  - Used for Relative Luminosity.
  - Used to monitor beam polarization directions.

Run5 π^0 Cross Section

- Consistent with previous results.
- Extends previous results to p_T of 20 GeV/c.
- NLO pQCD Theory is consistent with data over nine orders of magnitude.



Uncertainty of A_{LL}

$$A_{LL}^{\pi^0} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P^2}\frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

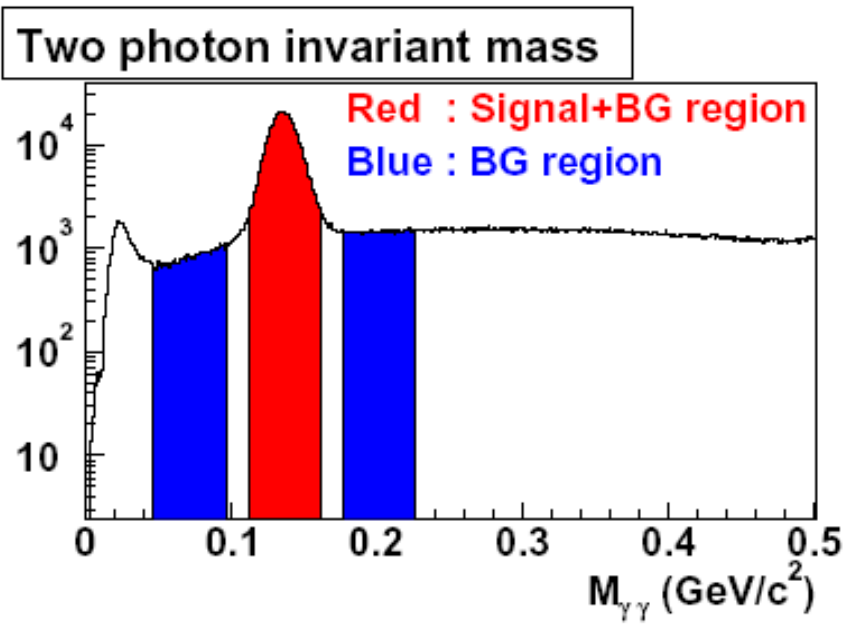
P=polarization
N = particle yield
L = Luminosity

- For A_{LL}, detector efficiencies and acceptance cancel out.
- For RHIC Run5, uncertainty due to Relative Luminosity Normalization was 2.3×10^{-4} which is an order of magnitude lower than our current statistical error.
- By measuring the asymmetry in forward neutron production, we can measure the degree to which the beam polarization is longitudinal. In RHIC Run5, both beams were ~99% longitudinally polarized.

Calculating A_{LL}

1. Calculate $A_{LL}(\pi^\circ+BG)$ and $A_{LL}(BG)$ separately.
2. Get background ratio (w_{BG}) from fit of all data.
3. Subtract $A_{LL}(BG)$ from $A_{LL}(\pi^\circ+BG)$:

$$A_{LL}(\pi^\circ+BG) = w\pi^\circ \cdot \boxed{A_{LL}(\pi^\circ)} + w_{BG} \cdot A_{LL}(BG)$$



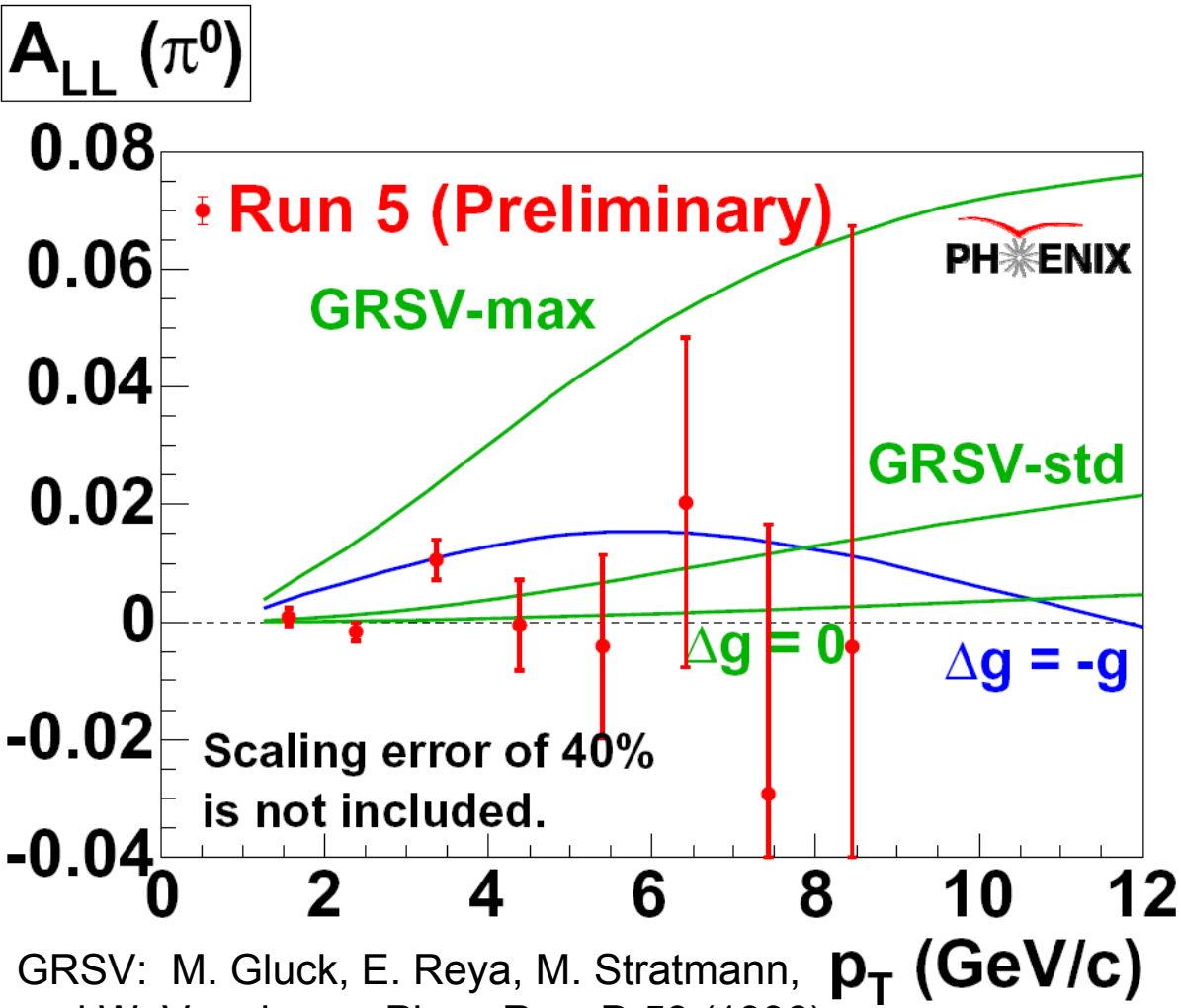
π°+BG region :

±25 MeV around π° peak

BG region :

two 50 MeV regions around peak

Run5 π^0 A_{LL}



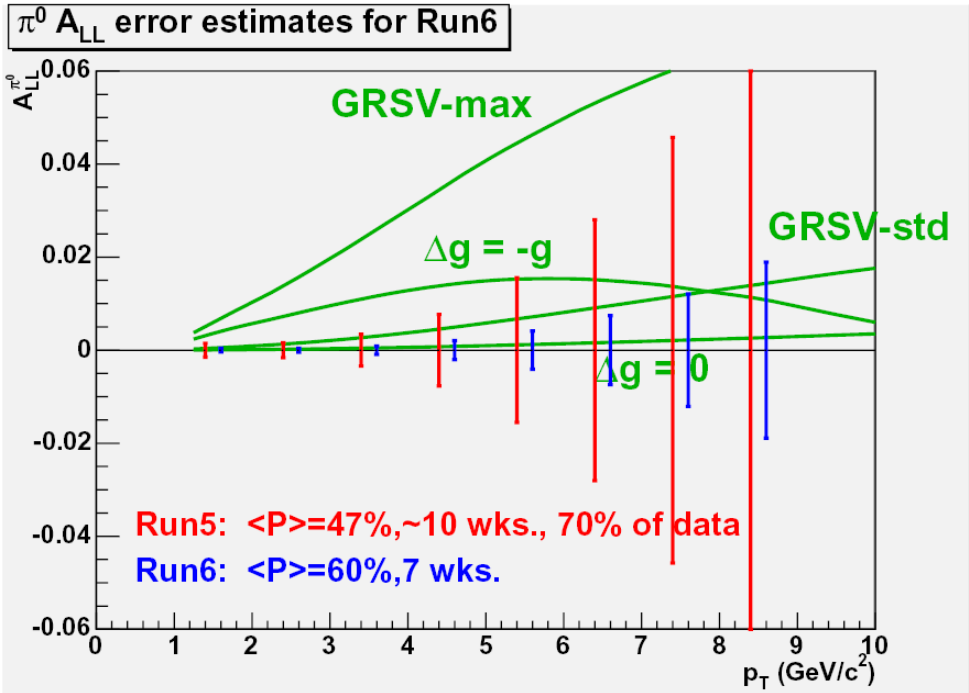
GRSV: M. Gluck, E. Reya, M. Stratmann, and W. Vogelsang, Phys. Rev. D 53 (1996) 4775.

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 = .4 GeV^2

Expectations of RHIC Run6

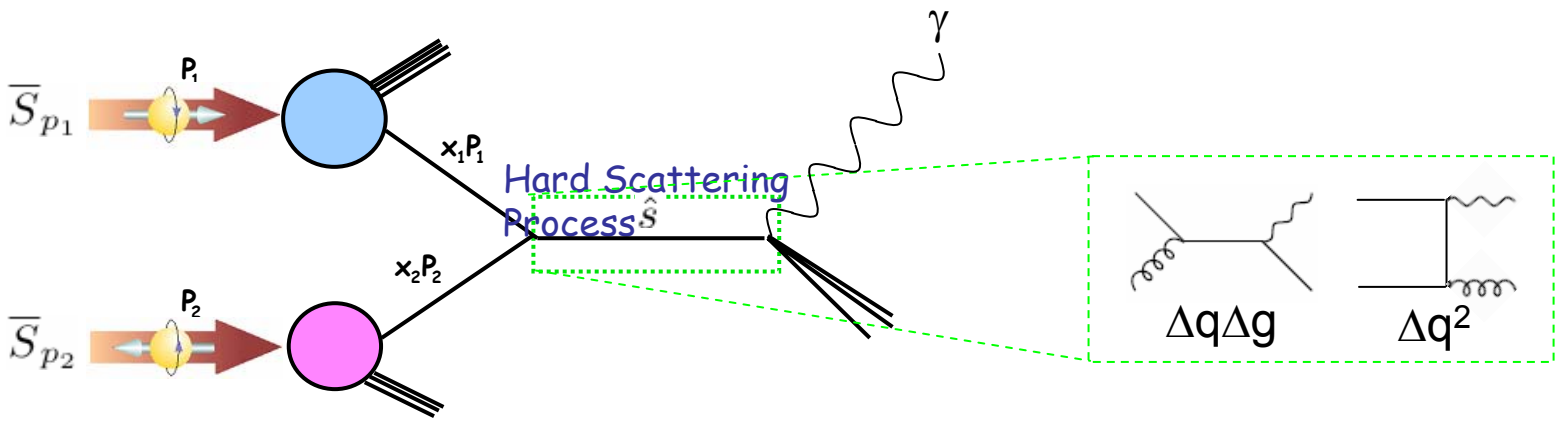
- Run6 is scheduled to begin in ~2 weeks.
- We expect both polarization and luminosity increases
- This will decrease our uncertainty by a factor of ~4 (~3 when all Run5 data is considered).



Run	Int.Lum.	Pol.	Figure of Merit (P^4L)
Run 3 (2003)	220 nb^{-1}	27%	1.17 nb-1
Run 4 (2004)	75 nb^{-1}	40%	1.92 nb^{-1}
Run 5 (2005) [full data set]	1.8 [2.7] pb^{-1}	47%	87.8 [132] nb^{-1}
Run 6 *Expected*	*11.4 pb^{-1}*	*60%*	*1.48 pb^{-1}*

Direct Photon

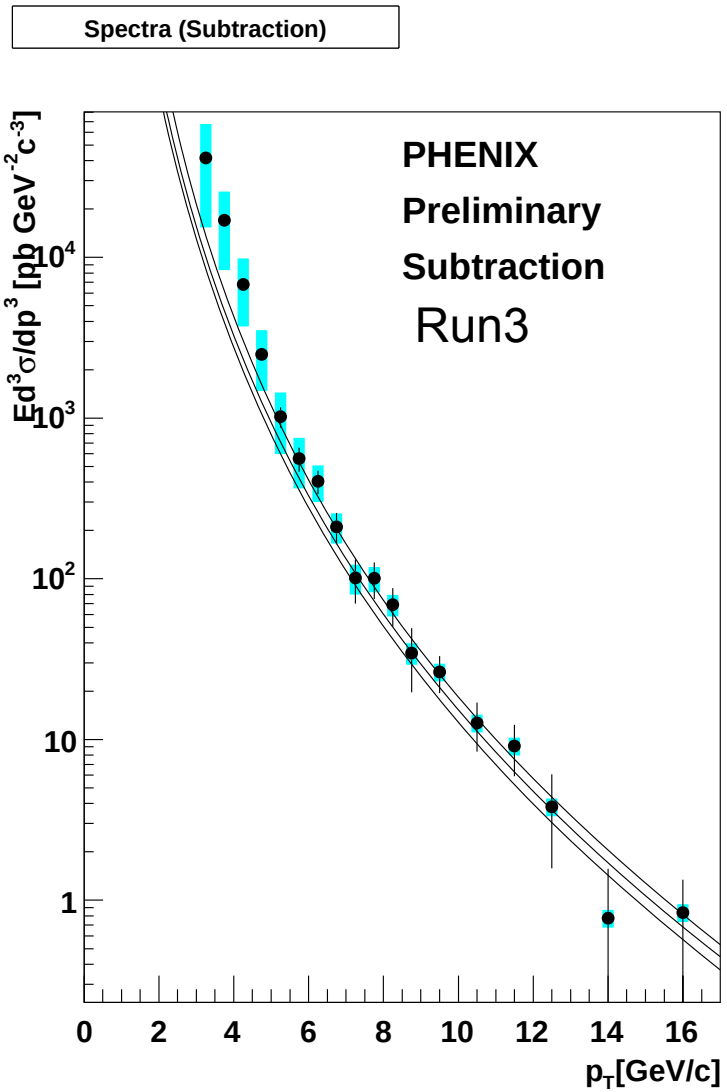
- Measuring A_{LL} of direct photons can give us a cleaner measurement of Δg than we get from π^0, as the cross section is only linear in Δg. This linear term, the Compton process, is dominant (~90%).



$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} \sim a_{gq} * \Delta g\, \Delta q + b_{qq} * \Delta q^2$$

Direct Photon II

- Direct photon cross section has been measured from Run3.
- Run5 cross section analysis is under way.
- Run 6 may give us a first measurement of A_{LL} for direct photon, though it will be a few years before a statistically significant measurement is made.

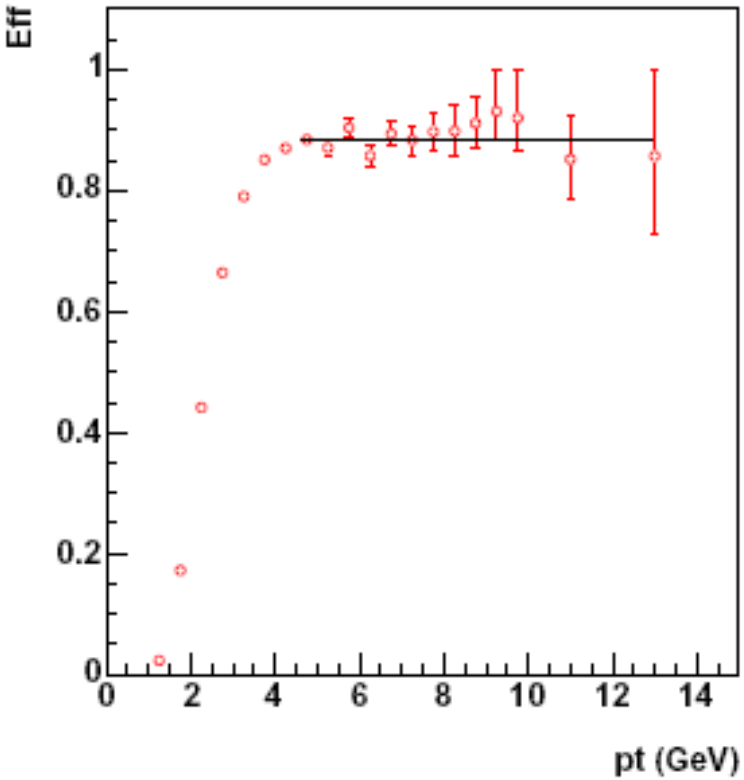


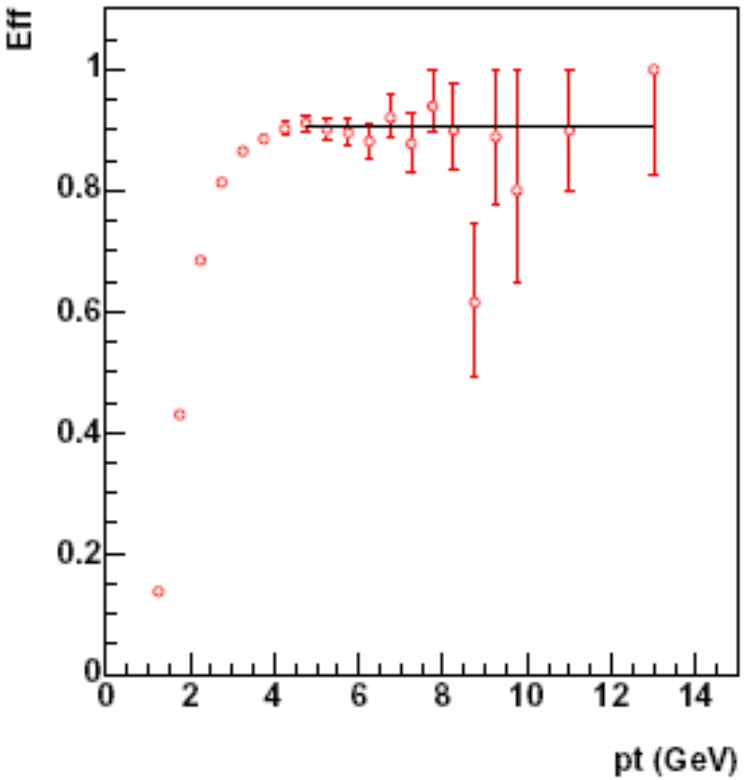
Conclusions

- Measurements at PHENIX with polarized protons allow us to constrain the gluon contribution to the proton's spin.
- Results for π^0 A_{LL} from RHIC Run5 exclude both positive and negative GRSV maximal gluon scenarios.
- RHIC Run6 will increase our figure of merit by a factor of 10 over Run5 and also may give the first measurement of A_{LL} of the direct photon.

Backups

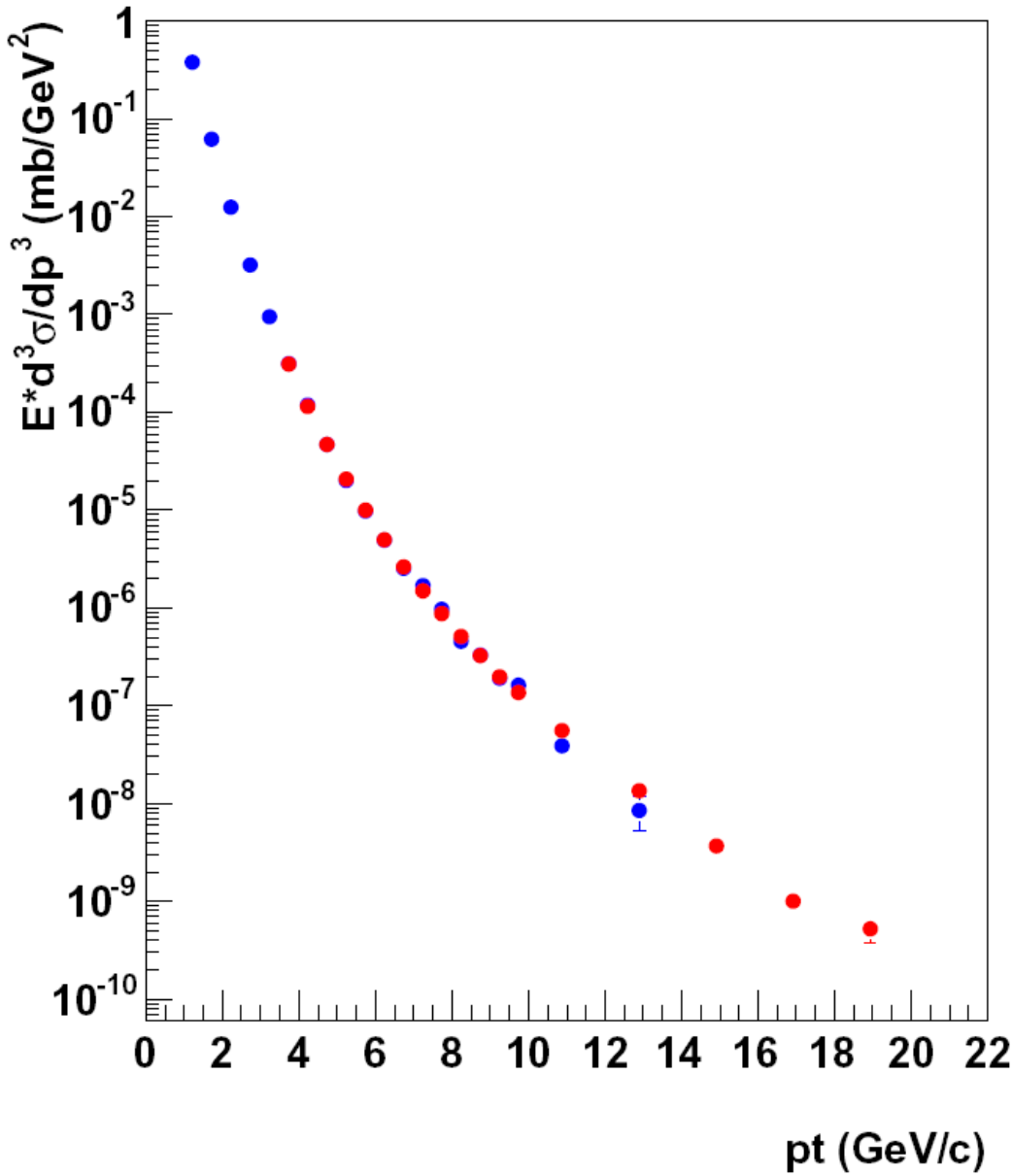
Photon Trigger Efficiency





Detector	1<pT<2 GeV/c	2<pT<3 GeV/c	3<pT<4 GeV/c	pT> 4GeV
PbSc	6%	50%	81%	88%
PbGl	21%	72%	87%	90%

- Minimum Bias (BBC |z|<30)
- Minimum Bias in coincidence with High Energy Photon trigger (Cluster Energy>1.4GeV)



Relative Luminosity

- Number of BBC triggered events used to calculate Relative Luminosity.
- For estimate of Uncertainty, fit

$$r(i) = C[1 + A_{LL} P_B(i) P_Y(i)]$$

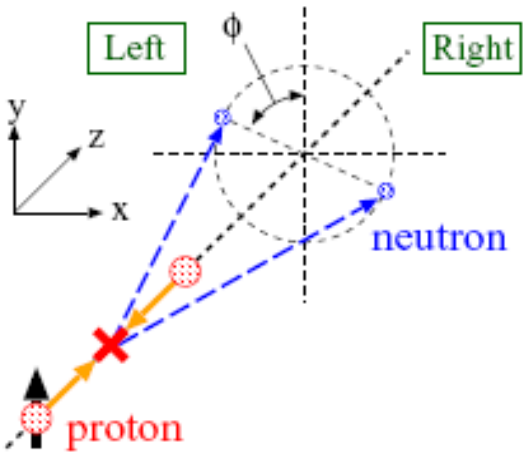
where

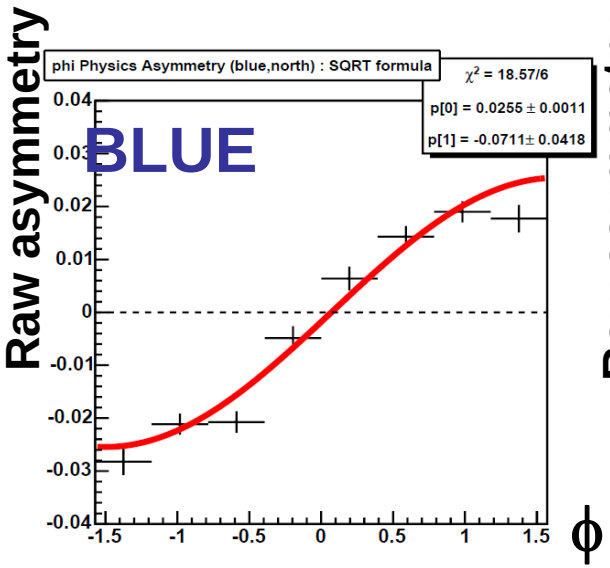
$$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)}$$

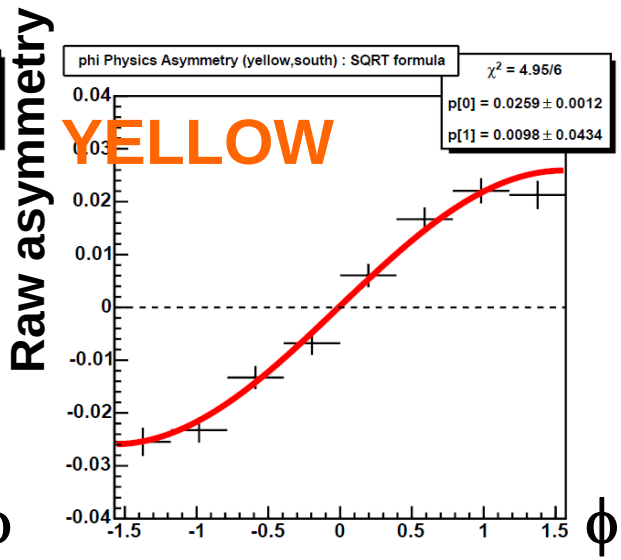
- δR=1.0e-4
- δA_{LL}=2.3e-4
- A_{LL} of BBC to ZDC consistent with zero

Local Polarimetry at PHENIX

- Use Zero Degree Calorimeter (ZDC) to measure a L-R and U-D asymmetry in forward neutrons.
- When transversely polarized, we see clear asymmetry.
- When longitudinally polarized, there should be no asymmetry.

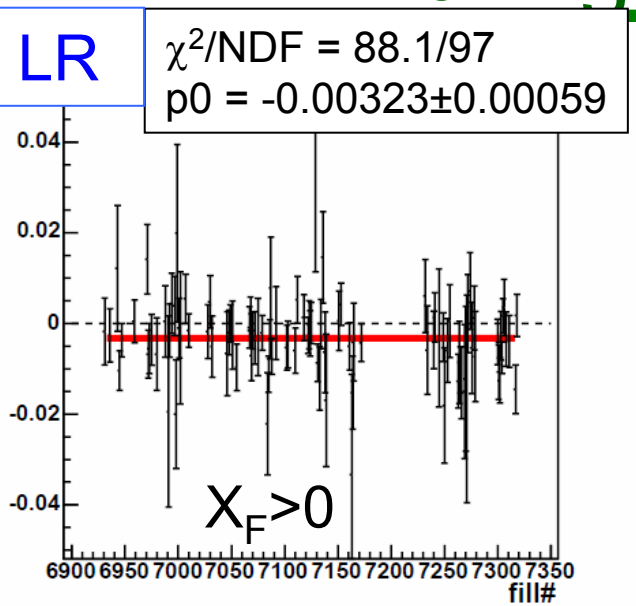


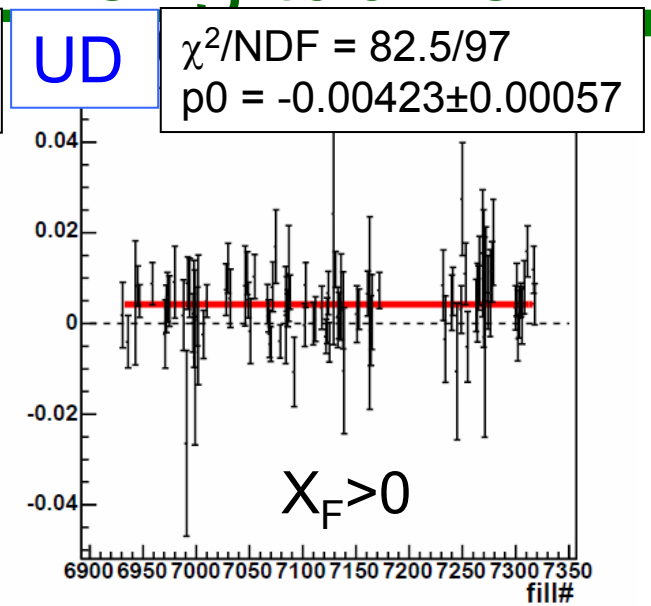


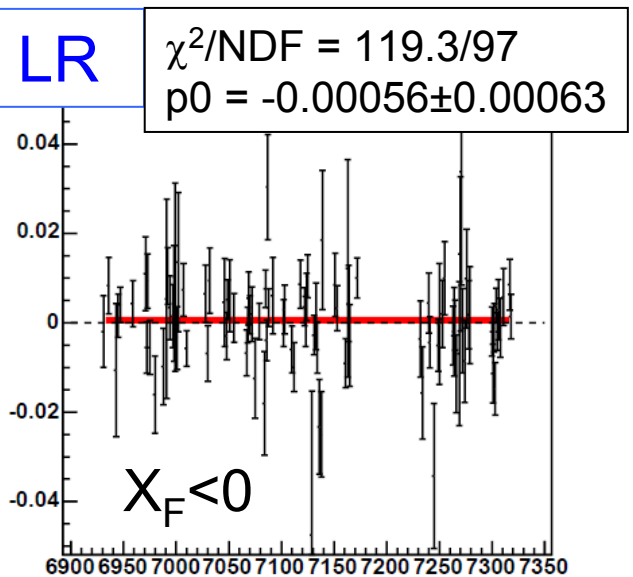


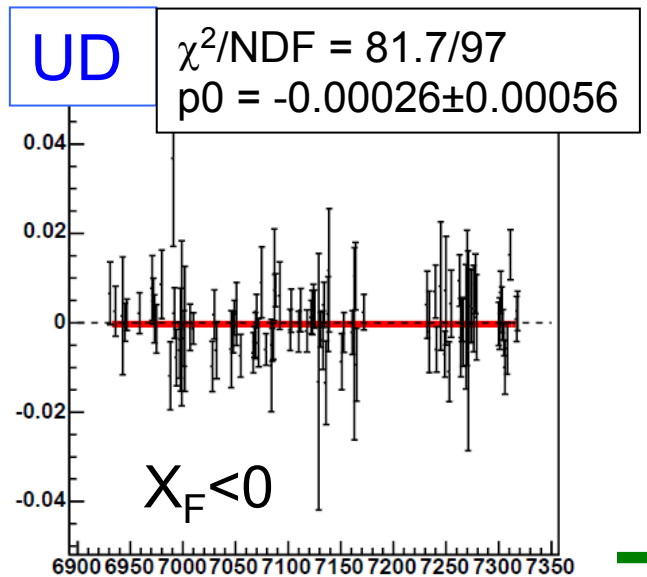
Idea: Use neutron asymmetry to study transversely polarized component.

Measured Asymmetry During Longitudinal Running









Fill Number

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$$S_L = \sqrt{1-S_T^2}$$

$$S_T = \sqrt{S_X^2 + S_Y^2}$$

Blue Beam:
$\langle P_T/P \rangle$= 10.25±2.05(%)
$\langle P_L/P \rangle$ = 99.48±0.12±0.02(%)

Yellow Beam:
$\langle P_T/P \rangle$= 14.47±2.20(%)
$\langle P_L/P \rangle$ = 98.94±0.21±0.04(%)