Recent PHENIX Results in Longitudinally Polarized Proton Collisions

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for the

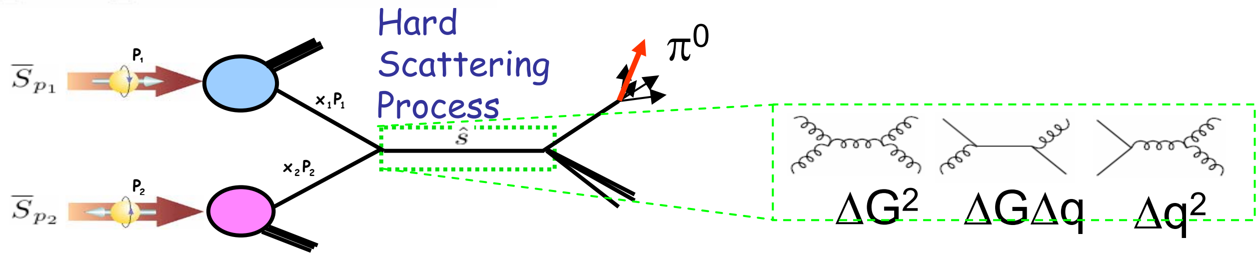
PHENIX Collaboration

Outline:

- Quick Physics overview
- RHIC and PHENIX, and A_{LL}
- Run5 and Run6 new Results

Accessing ΔG in pp scattering

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$ with $\Delta\Sigma$ ~25%, ΔG not well constrained, L?



→ $A_{LL} \sim a_{gg} * \Delta G^2 + b_{gq} * \Delta G\, \Delta q + c_{qq}\, \Delta q^2$

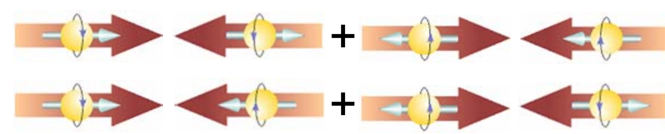
- From Run5 and Run6, we are currently studying an array of probes:
  - π^0 — large statistics, specified trigger
  - π^+, π^- — large statistics, low trigger efficiency, PID only for pT<2.8 and pT>4.7 GeV/c
  - Direct photon — low statistics, no ΔG^2 very clean signal
  - η — need FF
  - multiparticle "cone"
  - J/Ψ

Measuring A_{LL}

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_b P_y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

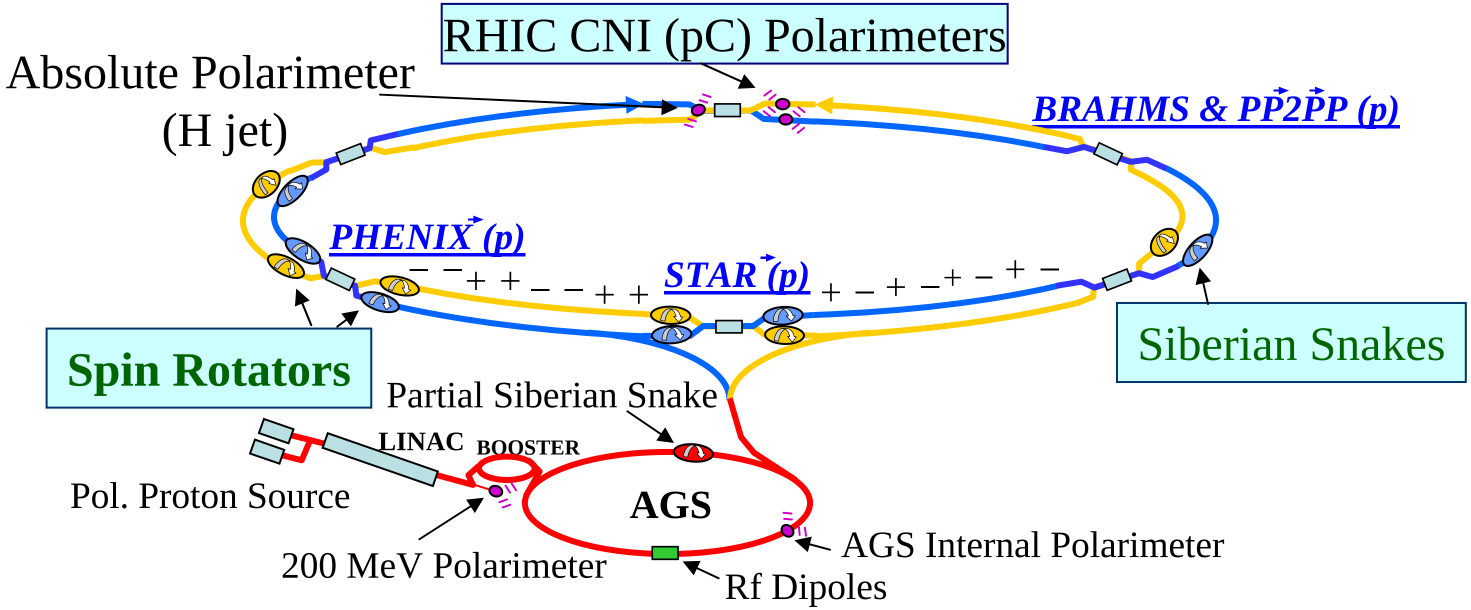
+ - = Opposite helicity =

++ = Same helicity =



- Helicity Dependent Particle Yields
  - π^0, π^+, π^-, γ, η, etc
- (Local) Polarimetry
- Relative Luminosity ($R=L_{++}/L_{+-}$)
- A_{LL}

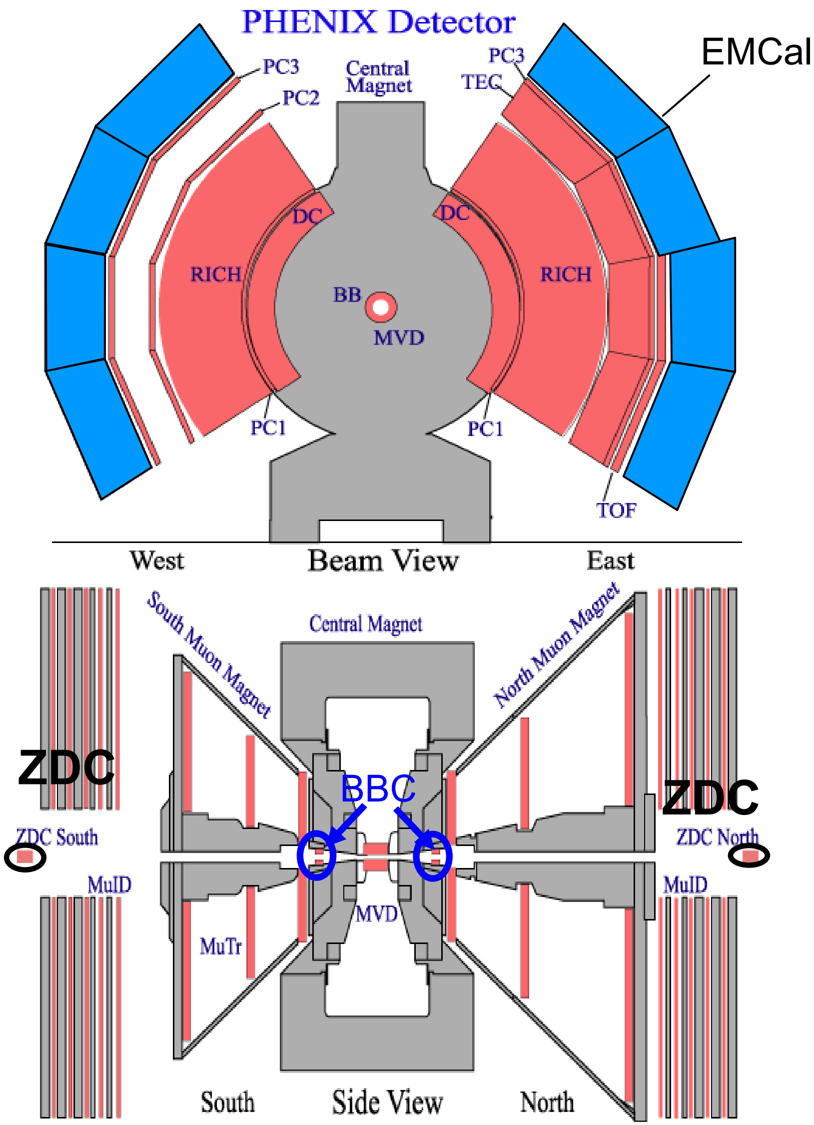
RHIC



Year	$\sqrt{s}$ [GeV]	Luminosity [pb^{-1}] (recorded)	Polarization [%]	Figure of Merit (P^4L)
2003 *	200	0.35	27	0.0019
2004 *	200	0.12	40	0.0031
2005 *	200	3.4	49	0.20
2006 *	200	7.5	62	1.11
2006 *	62.4	0.08	48	0.0042

* Longitudinal

PHENIX Detector



$\pi^0/\gamma/\eta$ detection

- Electromagnetic Calorimeter (PbSc/PbGl):
  - High p_T photon trigger to collect π^0's, η's, γ's
  - Acceptance: $|\eta|<0.35$, $\phi = 2 \times \pi/2$
  - High granularity (~10*10mrad²)

$\pi^+/\ \pi^-$

- Drift Chamber (DC) for Charged Tracks
- Ring Imaging Cherenkov Detector (RICH)
  - High p_T charged pions (p_T>4.7 GeV).

Relative Luminosity

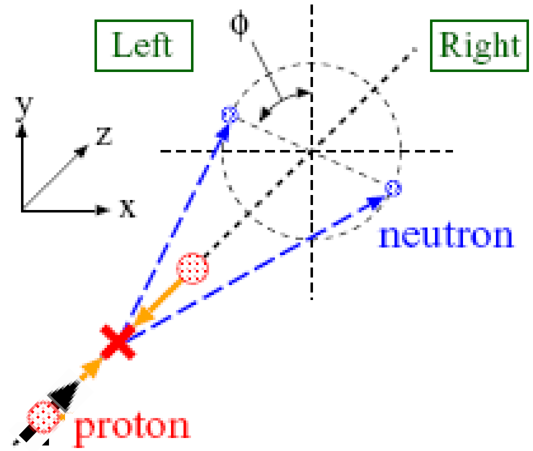
- Beam Beam Counter (BBC)
  - Acceptance: $3.0< \eta<3.9$
- Zero Degree Calorimeter (ZDC)
  - Acceptance: ±2 mrad

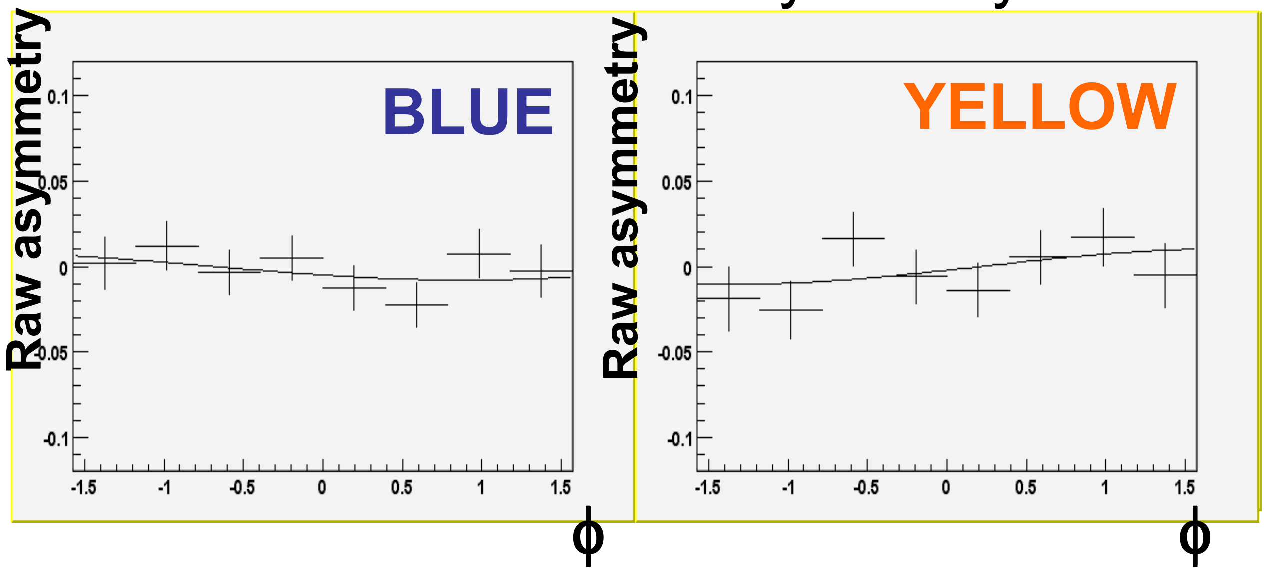
Local Polarimetry

- ZDC
- Shower Maximum Detector (SMD)

Local Polarimetry at PHENIX

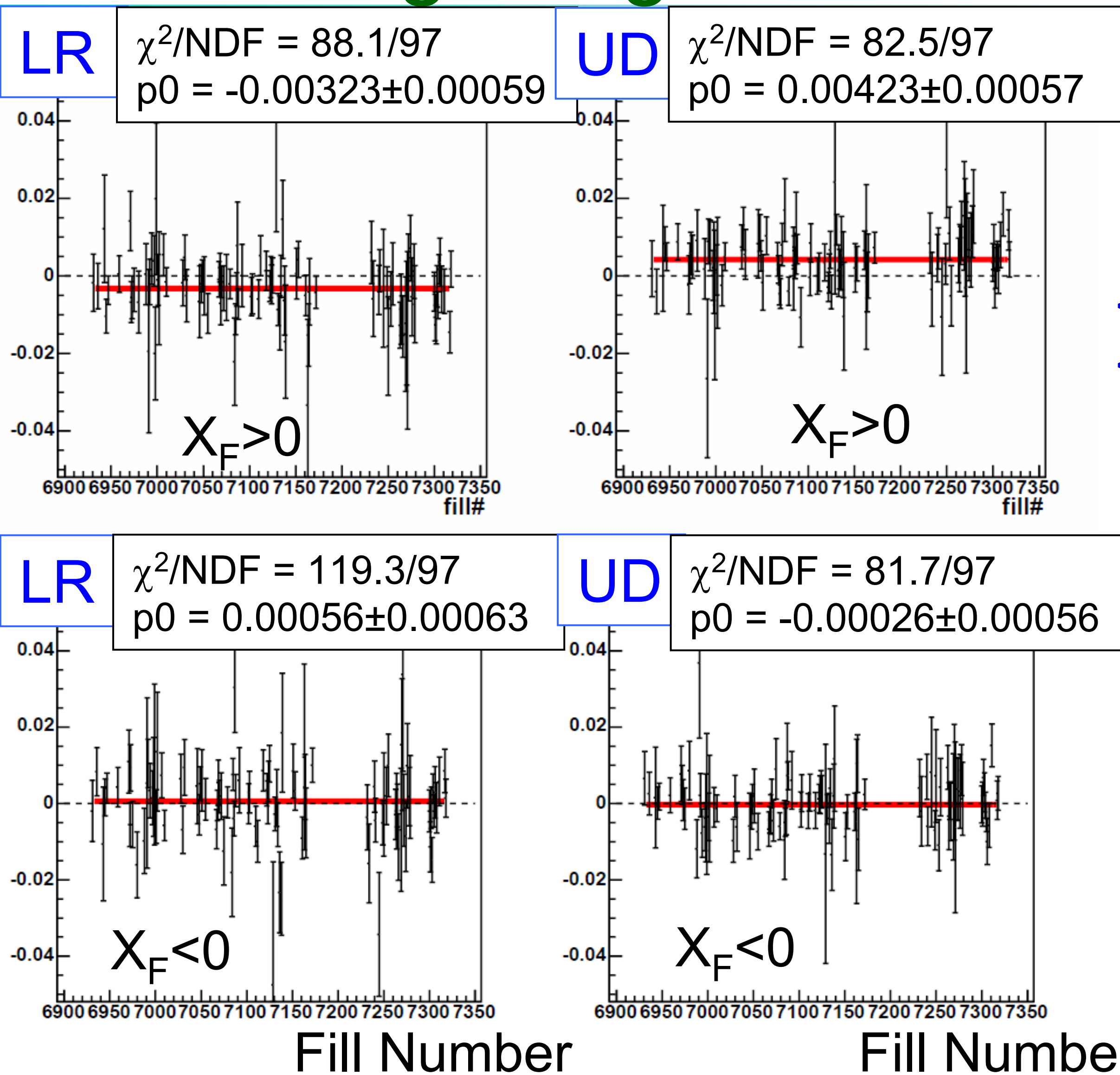
- Use ZDC and SMD to measure a L-R and U-D asymmetry in forward neutrons (Acceptance: ±2 mrad).
- When transversely polarized, we see clear asymmetry.
- When longitudinally polarized, there should be no asymmetry.





Idea: Use neutron asymmetry to study transversely polarized component.

Measured Asymmetry During Longitudinal Running (2005)



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

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

$<P_T/P>$=10±2(%)

$<P_L/P>$ =99.48±0.12±0.02(%)

$<P_T/P>$=14±2(%)

$<P_L/P>$=98.94±0.21±0.04(%)

- Measurement of remaining transverse component → spin pattern is correct

Also confirmed in Run6 analysis

Relative Luminosity

- R = L++/L+- ; L = luminosity.
- Luminosity is given by the number of BBC triggered events (N_{BBC}).
- For estimate of uncertainty, measure A_{LL} in the ratio of our two luminosity detectors

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

Year	[GeV]	δR	δA_{LL}
2005 *	200	1.0e-4	2.3e-4
2006 *	200	3.9e-4	5.4e-4
2006 *	62.4	1.3e-3	2.8e-3

* Longitudinal

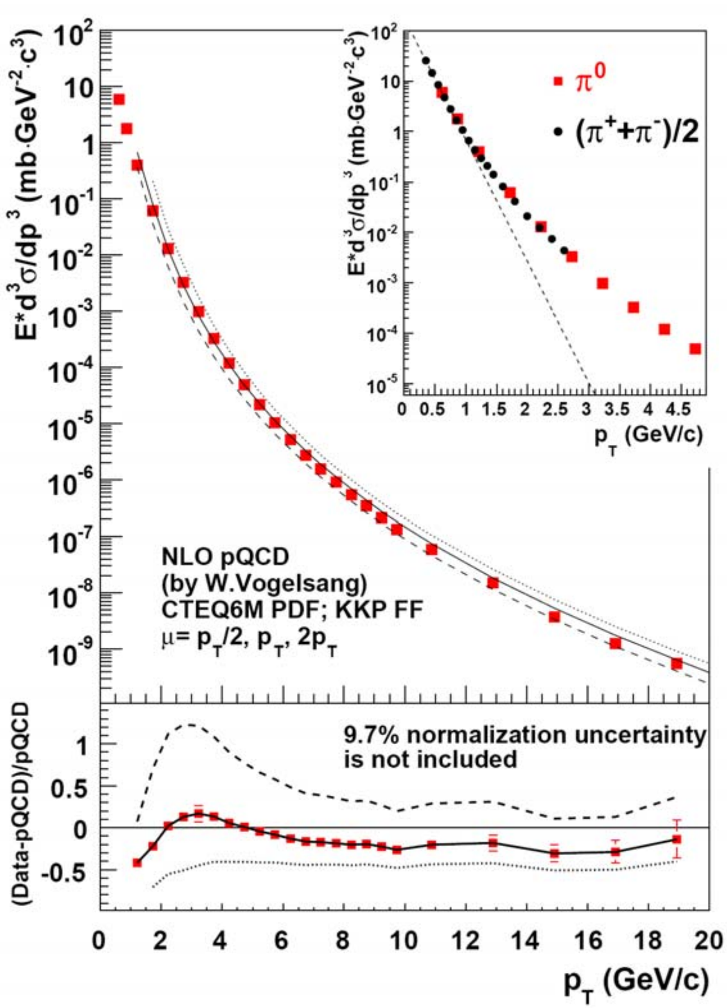
Strategy:

1. Measure Cross Section to confirm that pQCD is applicable to data
2. Measure A_{LL} to extract ΔG

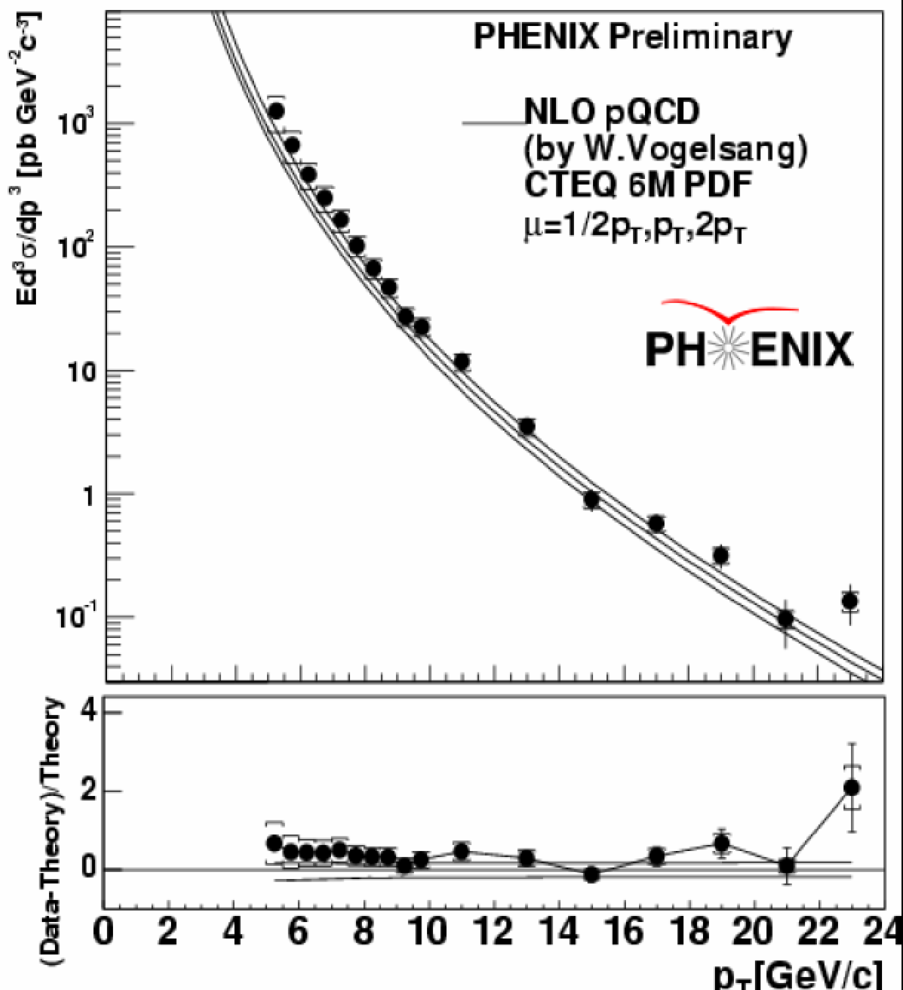
pQCD works

π⁰ @ 200 GeV

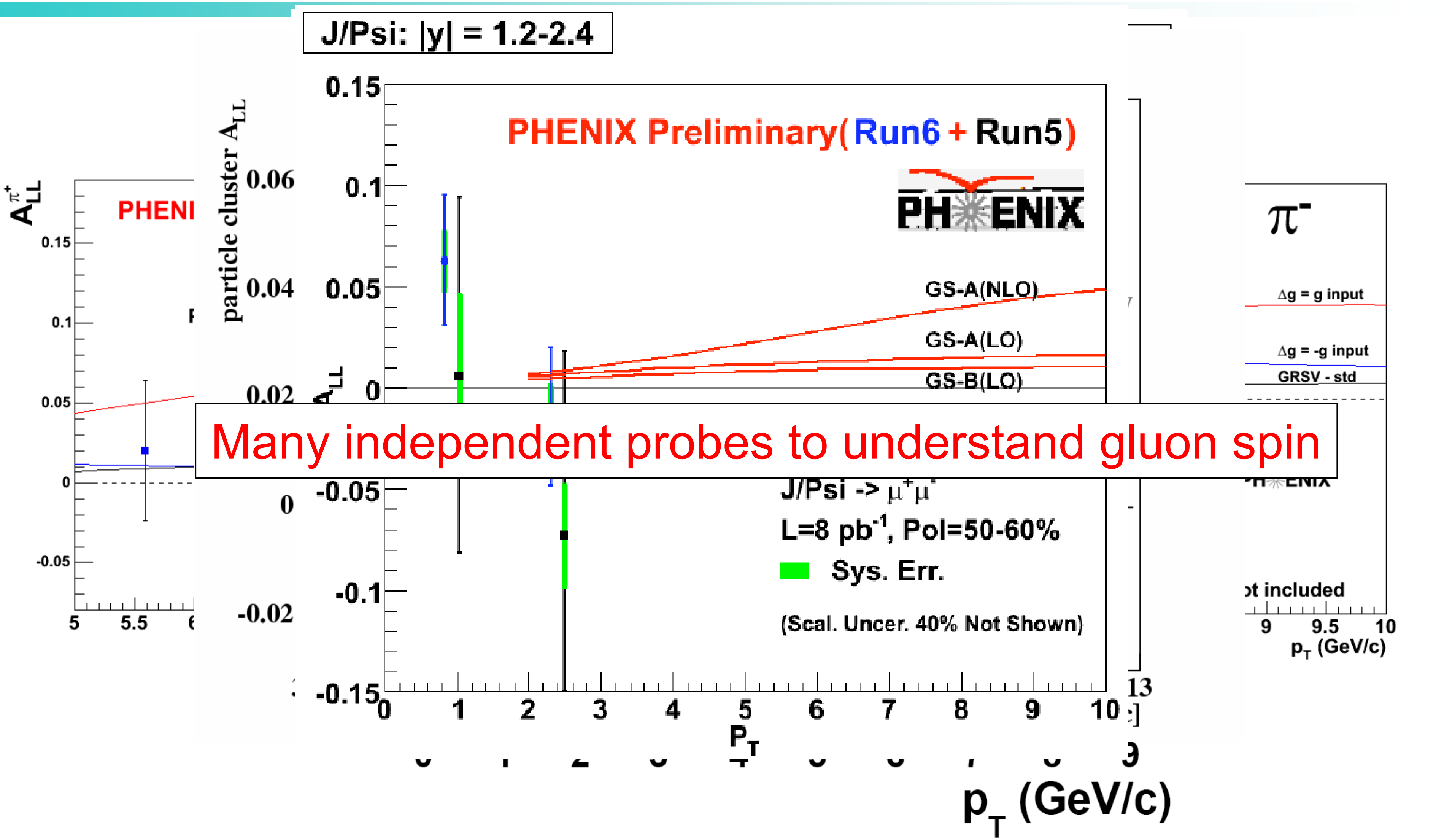
arXiv:0704.3599 [hep-ex]



Direct γ @ 200 GeV



Recent A_{LL} Measurements



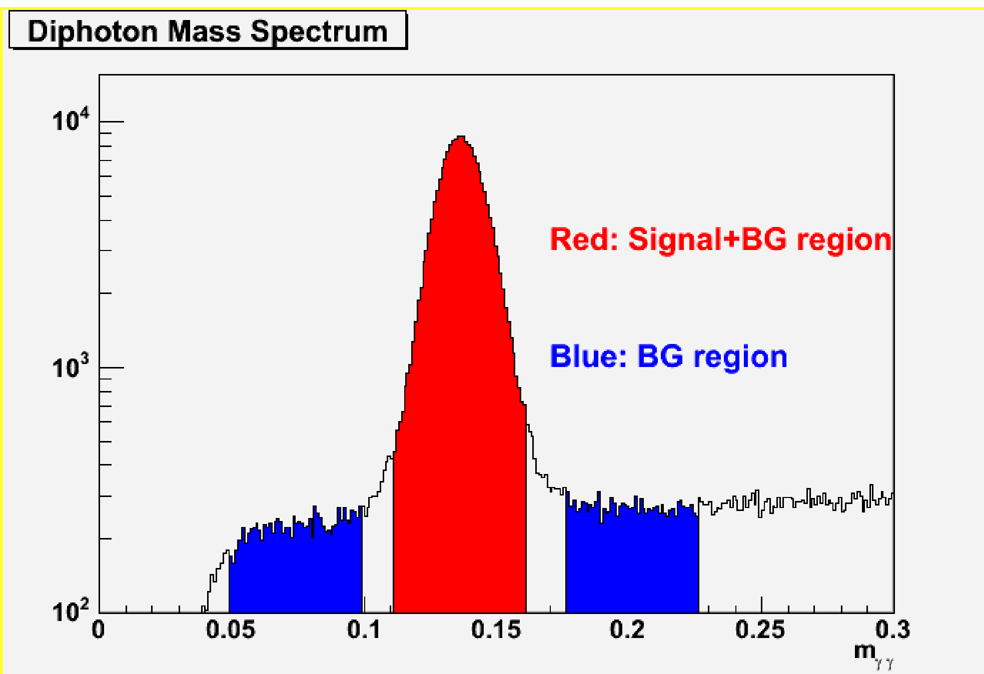
Many independent probes to understand gluon spin

An in depth look at π^0 A_{LL}

Calculating π^0 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 $A_{LL}(\pi^\circ+BG)$:

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



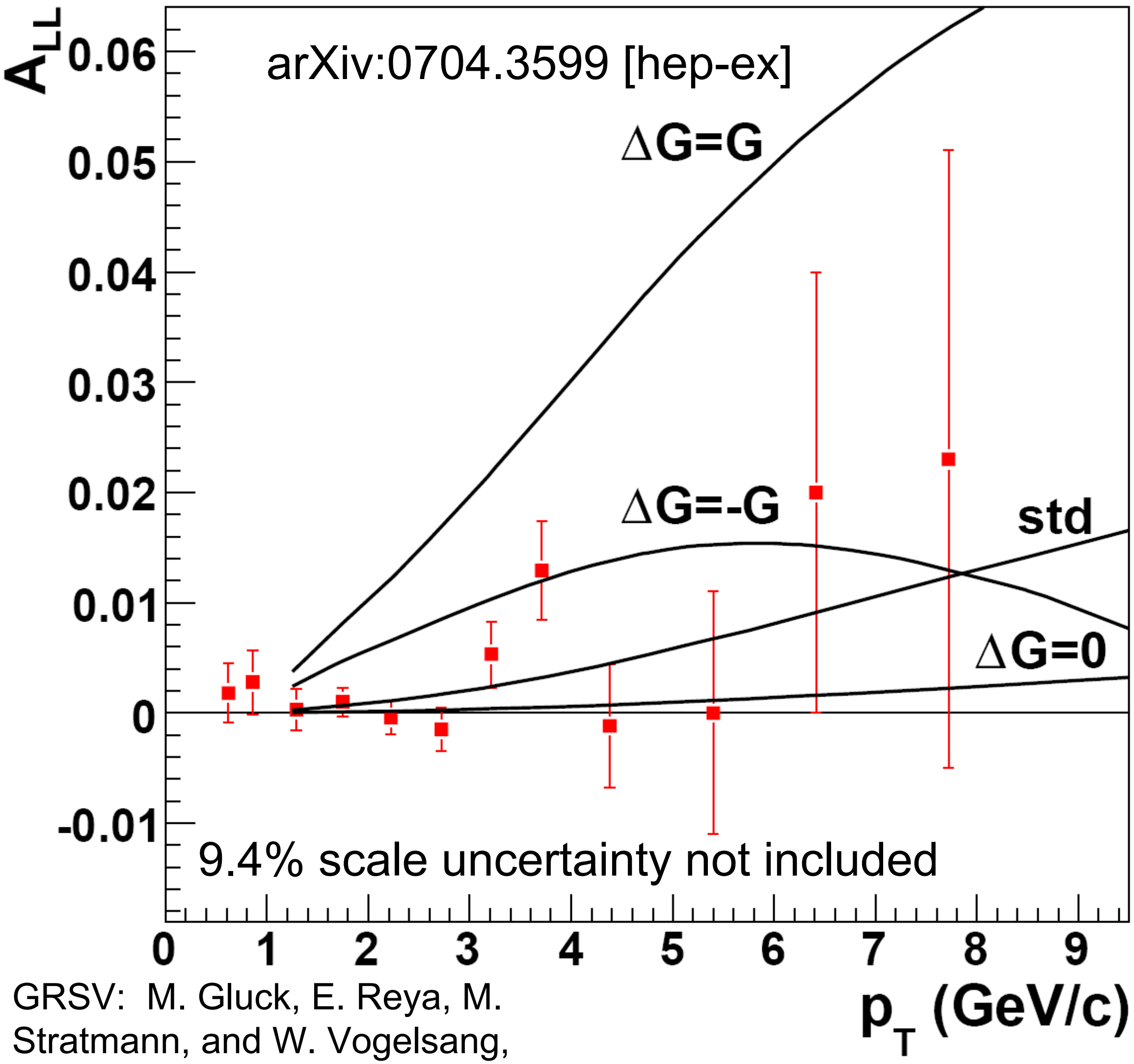
π^0+BG region :

±25 MeV around π^0 peak

BG region :

two 50 MeV regions around peak

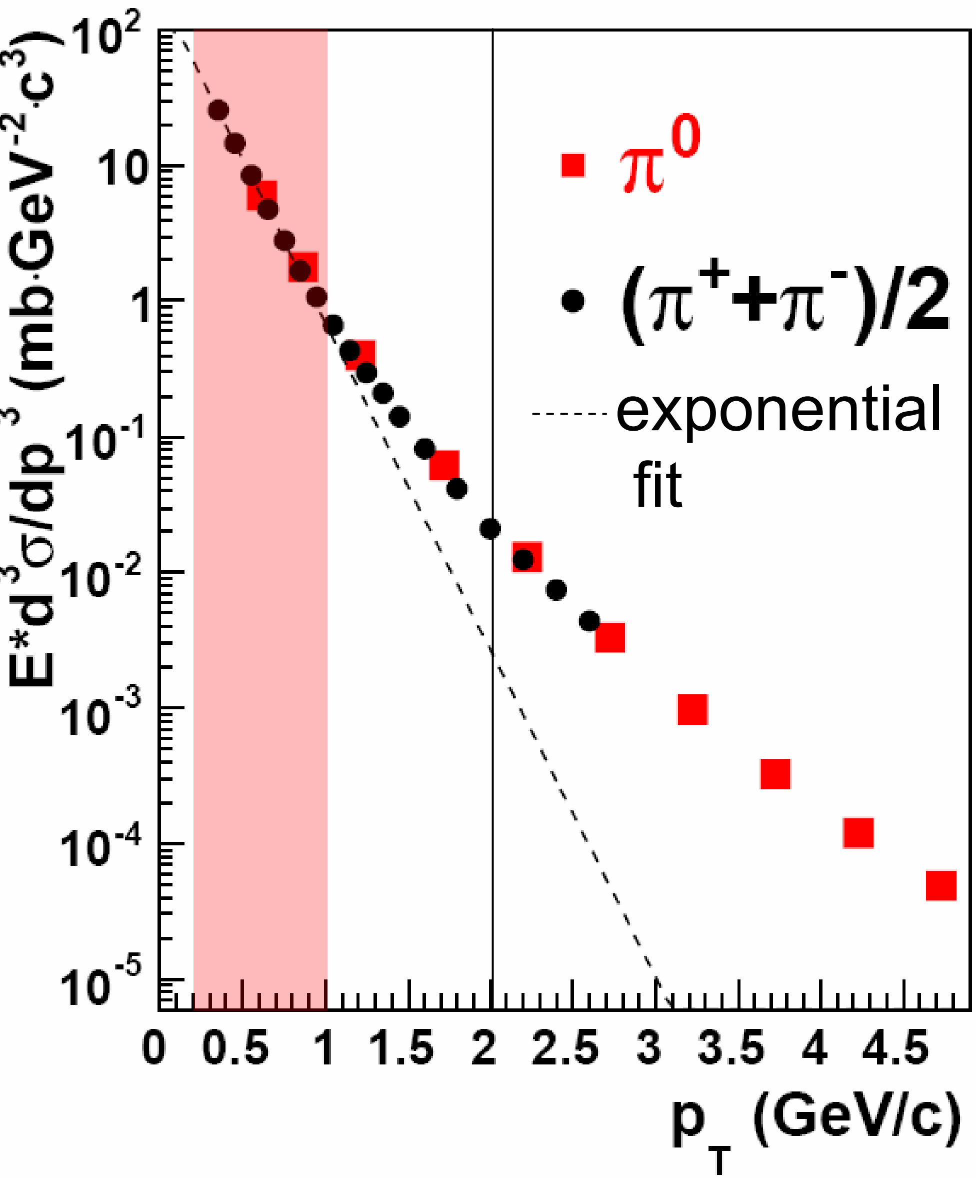
Final Run5 π^0 A_{LL}



GRSV: M. Gluck, E. Reya, M. Stratmann, and W. Vogelsang, Phys. Rev. D 63 (2001) 094005.

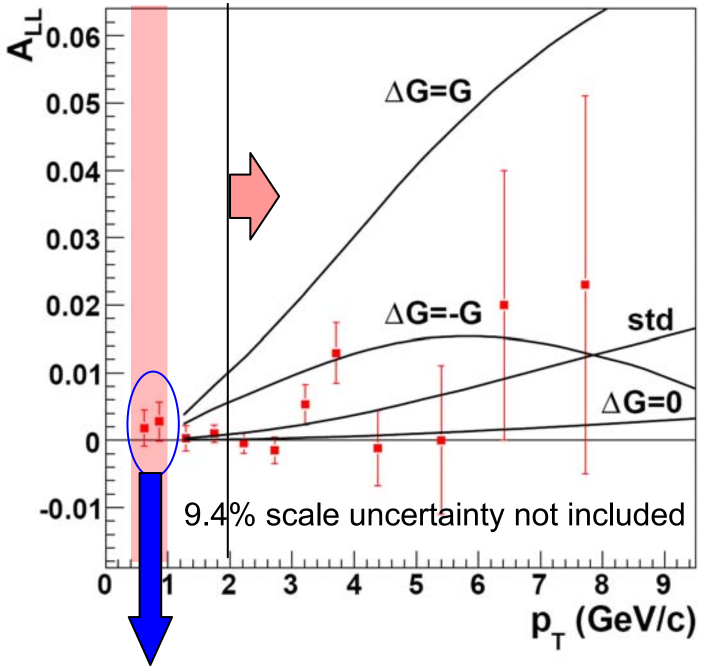
- Data is compared to GRSV model with several input values of ΔG.
- Question: At what p_T does soft physics contribution become small enough to allow comparison to pQCD models

Soft physics

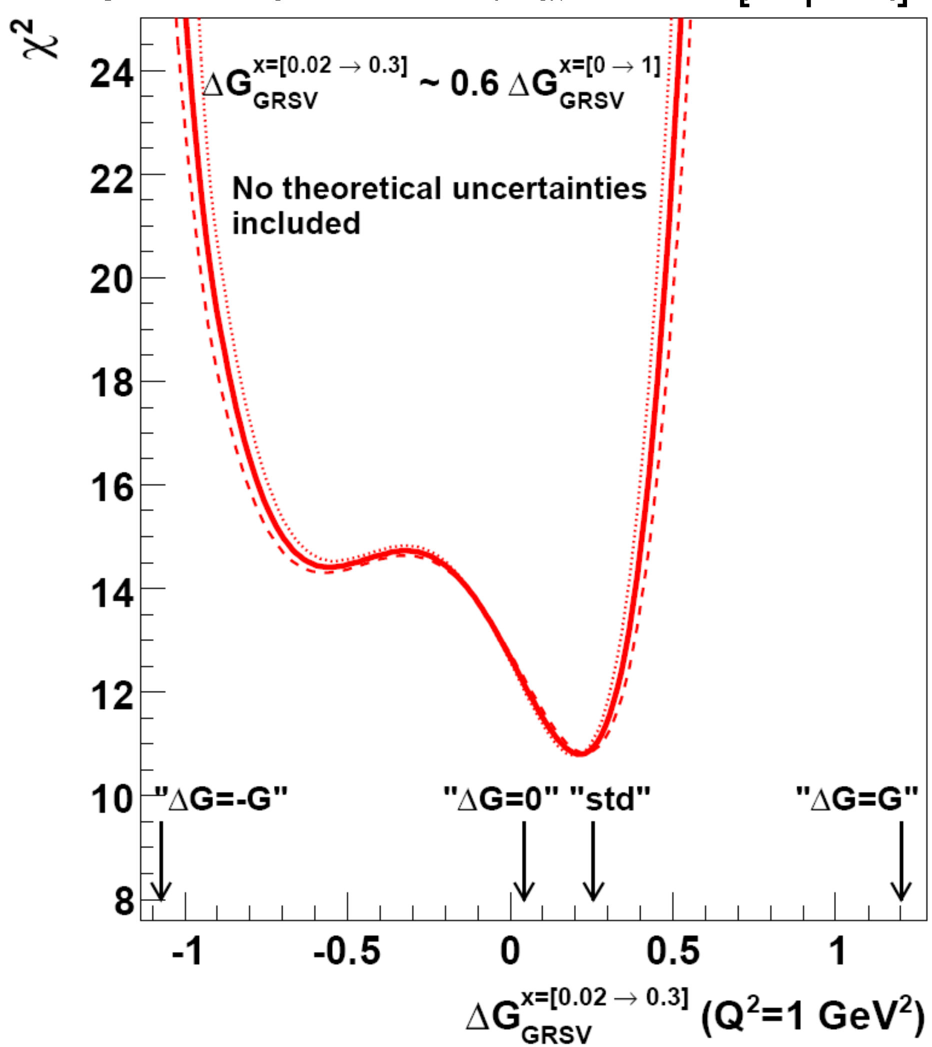


- By comparing p0 data with charged pion data, which has very good statistics at low pT, can estimate soft physics contribution
- Fitting an exponential to the low p_T charged pion data (pT<1 GeV/c) gives an estimate on the soft physics contribution.
- Fit result:
  - α= 5.56±0.02 (GeV/c)$^{-1}$
  - χ^2/NDF = 6.2/3
- From this, we see that for p_T>2 GeV, the soft physics component is down by more than a factor of 10.

Final Run5 π^0 A_{LL}

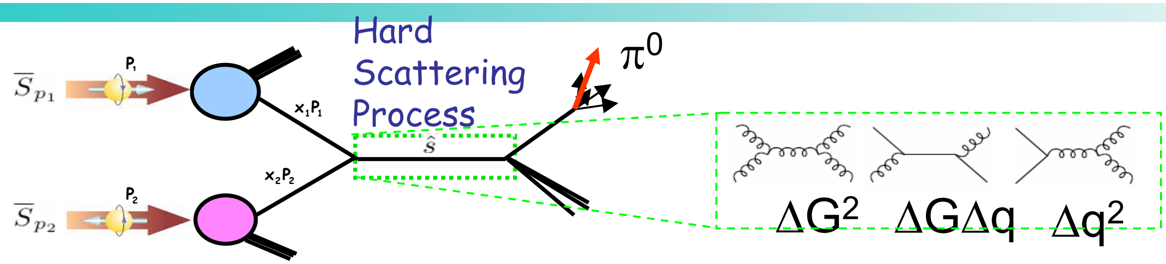


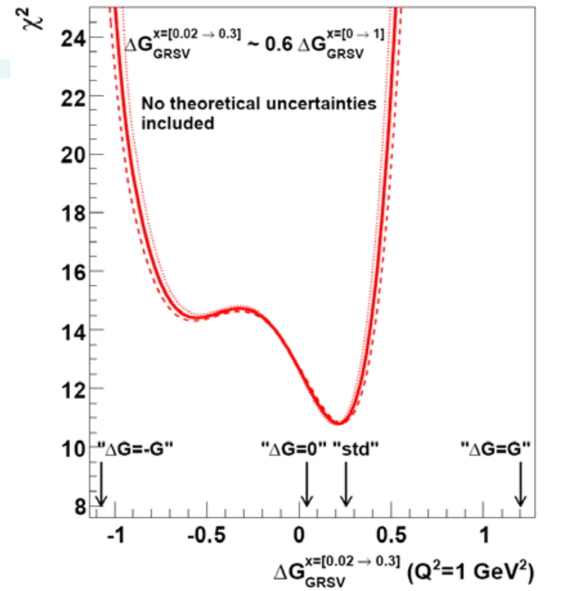
Theory arXiv:0704.3599 [hep-ex] χ^2/NDF CL (%)



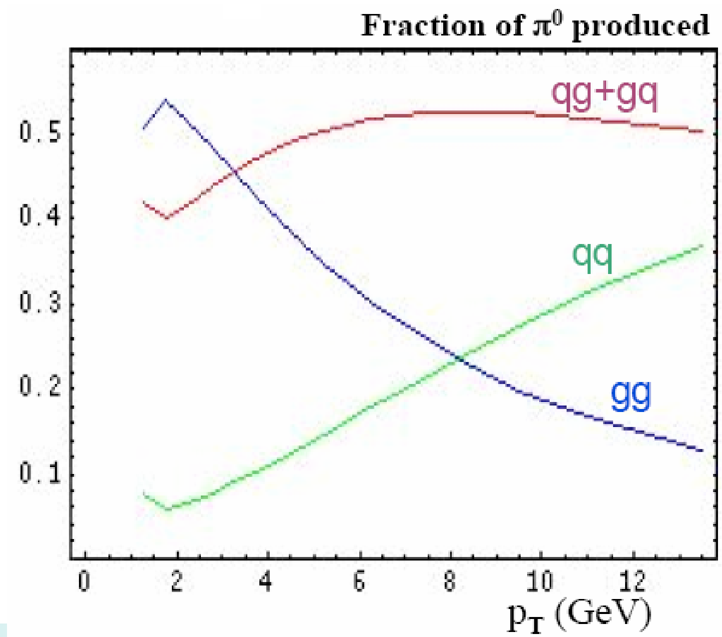
- Measure below 1 GeV (~100% soft physics). A_{LL} = 0.002±0.002.
- Above p_T=2 GeV/c, soft physics contribution estimated to be <10%
- Contamination from soft physics asymmetry is small

Sign Ambiguity





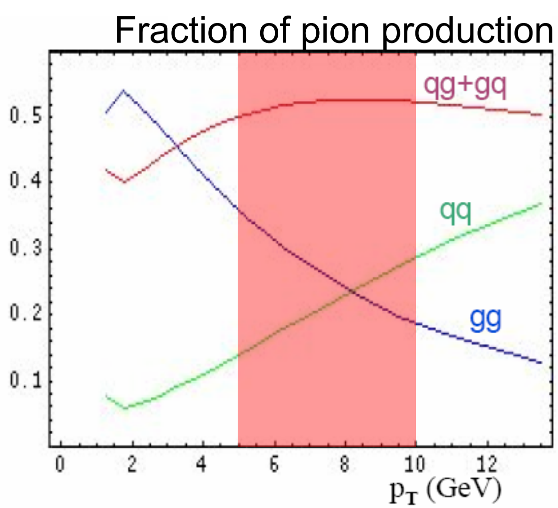
- Dominance of two gluon interaction at low p_T
  ➔ present π^0 A_{LL} data cannot determine sign of ΔG.
- Solution:
  - Higher p_T → higher FOM (P^4L)
  - Look to other probes:
    - Direct Photon (See Y. Goto, later in this session)
    - Charged pions

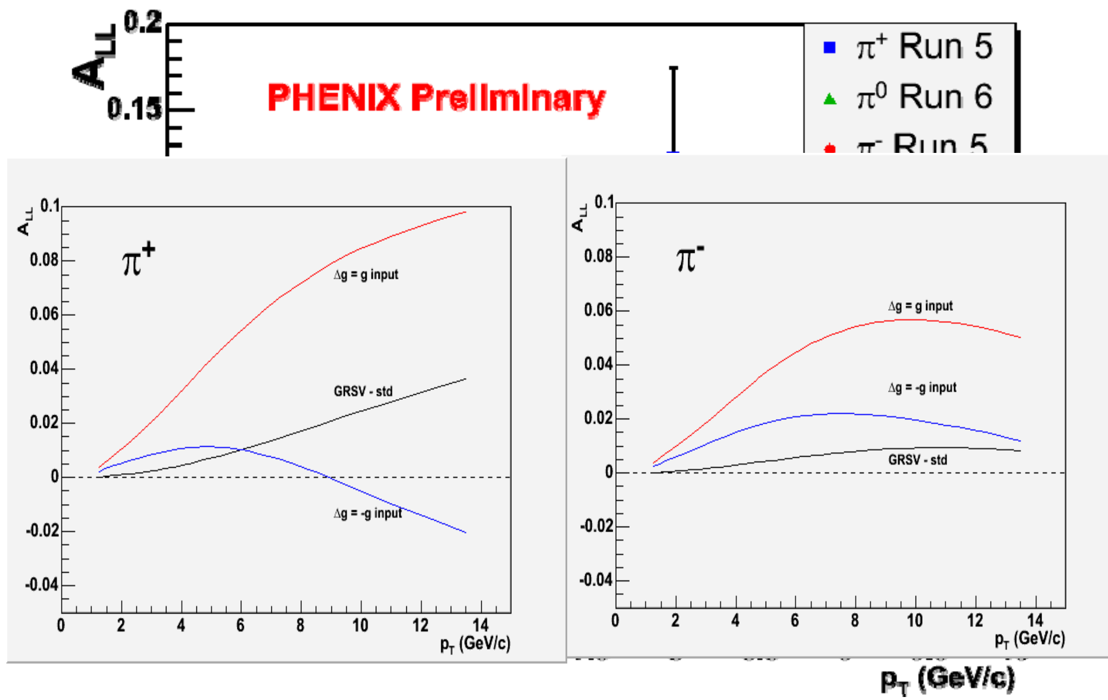


Sign Ambiguity II

- With PHENIX RICH, charged pions above 4.7 GeV can be identified.
- At higher p_T, qg interactions become dominatant and so $\Delta q \Delta g$ term in A_{LL} becomes significant allowing acces to the sign of ΔG
- Expect if $\Delta G > 0$, then:

  $A_{LL}(\pi^+) > A_{LL}(\pi^0) > A_{LL}(\pi^-)$
- Run 6 will help.





Improved FoM→Run6

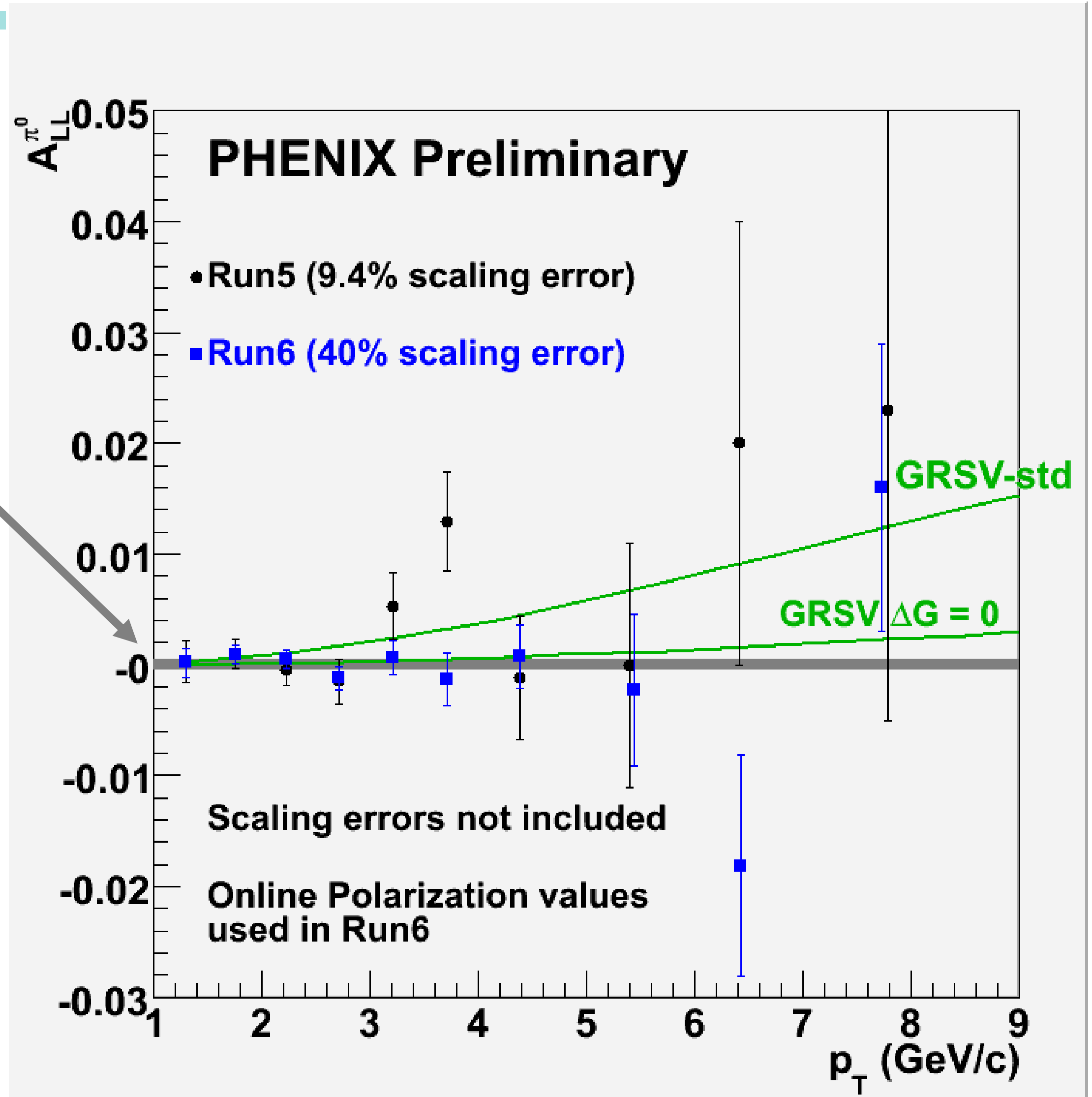
Run:	5→6
Luminosity:	3.4→7.5
Polarization:	49%→62%
FoM (P^4L):	0.20→1.11

Run6 π^0 A_{LL}

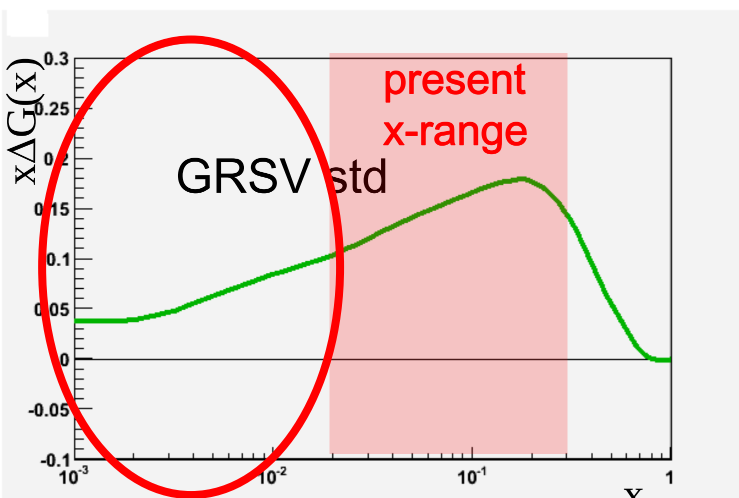
- Run6 scaling error based on online polarization values. Final scaling error expected to be ~10%
- Grey band is systematic uncertainty due to Relative Luminosity, and is p_T independent.
- Run6 Data favor “GRSV ΔG=0” over GRSV-std

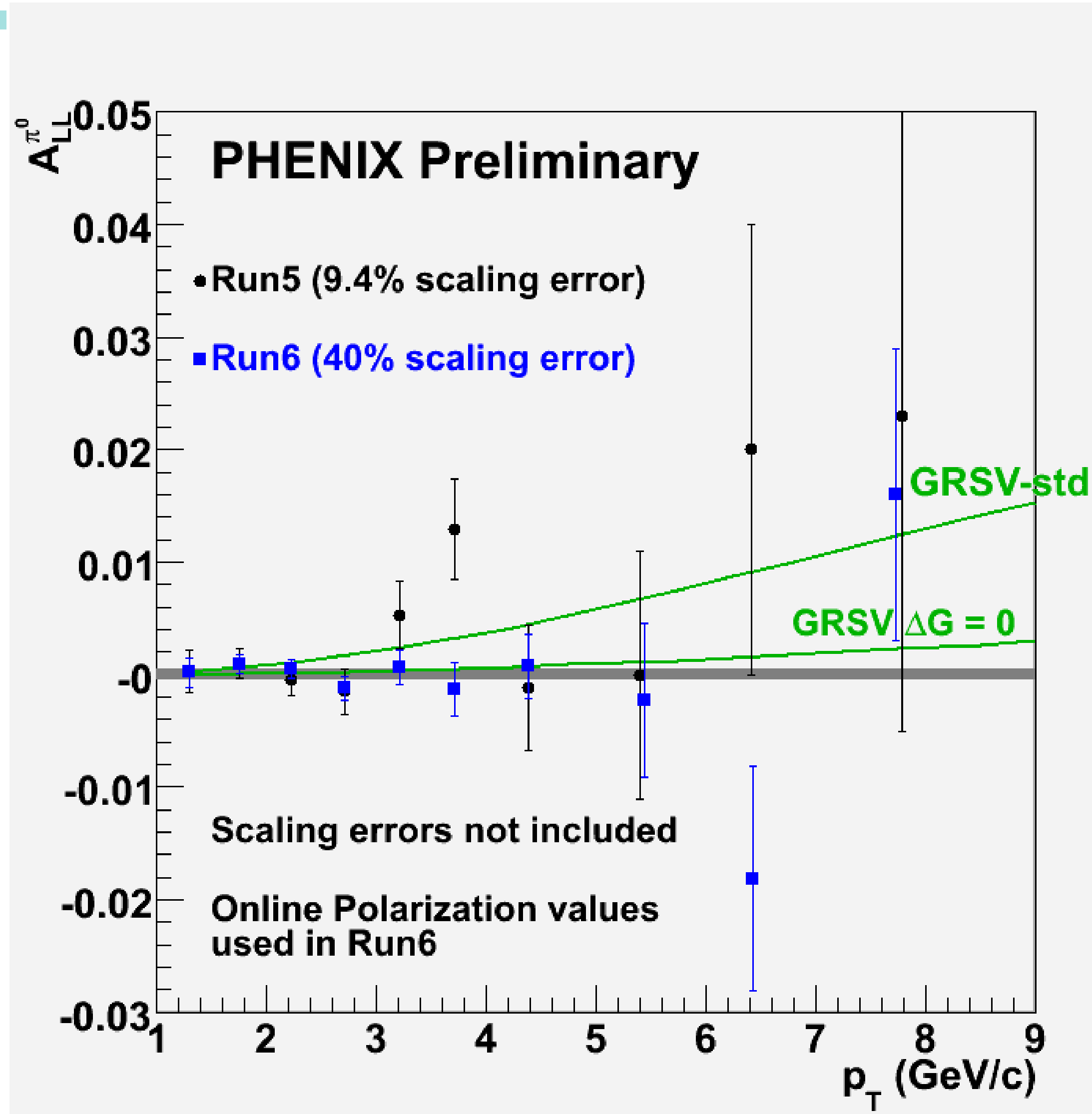
Theory	χ^2/NDF	CL(%)
GRSV-std	23.8/8*	0.25
GRSV ΔG=0	7.9/8*	44

*Theoretical uncertainties not included



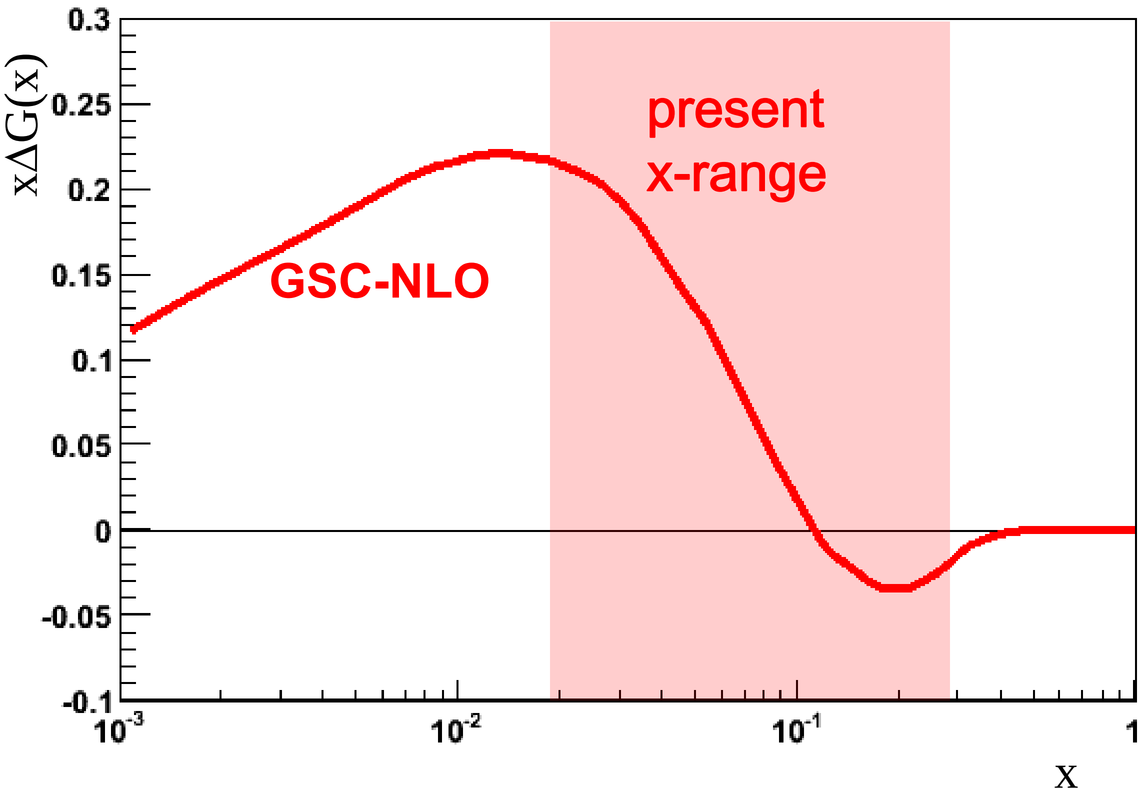
Sensitivity of π^0 A_{LL} to ΔG





ΔG(x) C from Gehrmann Stirling

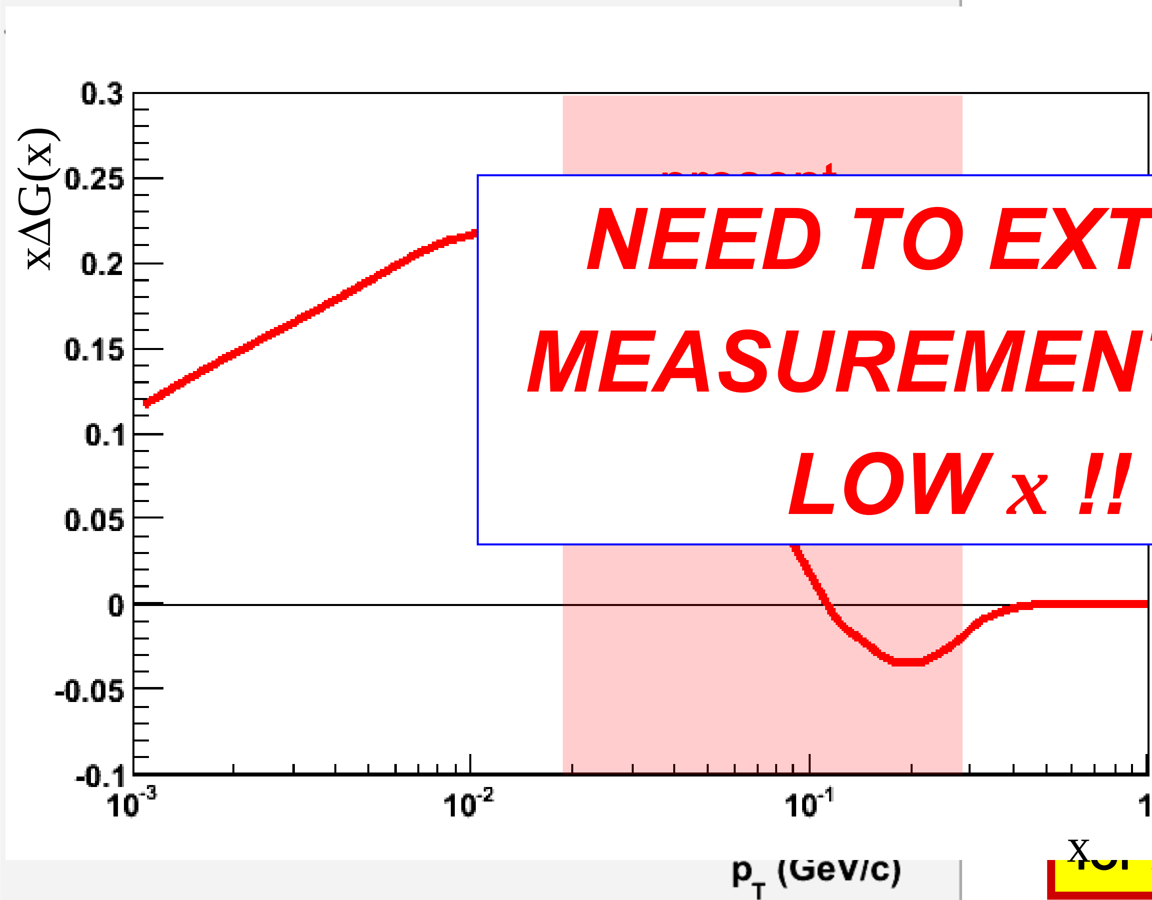
GSC-NLO: $\Delta G = \int \Delta G(x)dx = 1.0$



Much of the first moment $\Delta G = \int \Delta G(x)dx$ might emerge from low x!

GSC-NLO: $\Delta G = \int_{0.02}^{0.3} \Delta G(x)dx \sim small \rightarrow 0$

PHENIX π^0 A_{LL} vs GSC-NLO



NEED TO EXTEND MEASUREMENTS TO LOW x !!

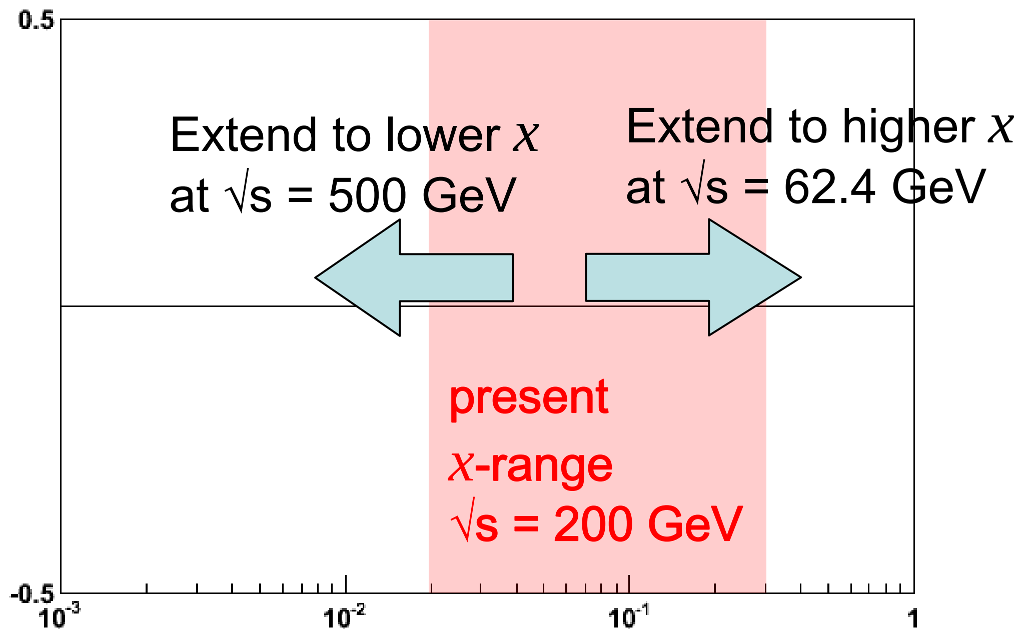
O: $\Delta G = \int \Delta G(x)dx = 1.0$

ncertainties resulting
functional form used
) in the QCD analysis!

GSC-NLO courtesy of Marco Stratmann and Werner Vogelsang

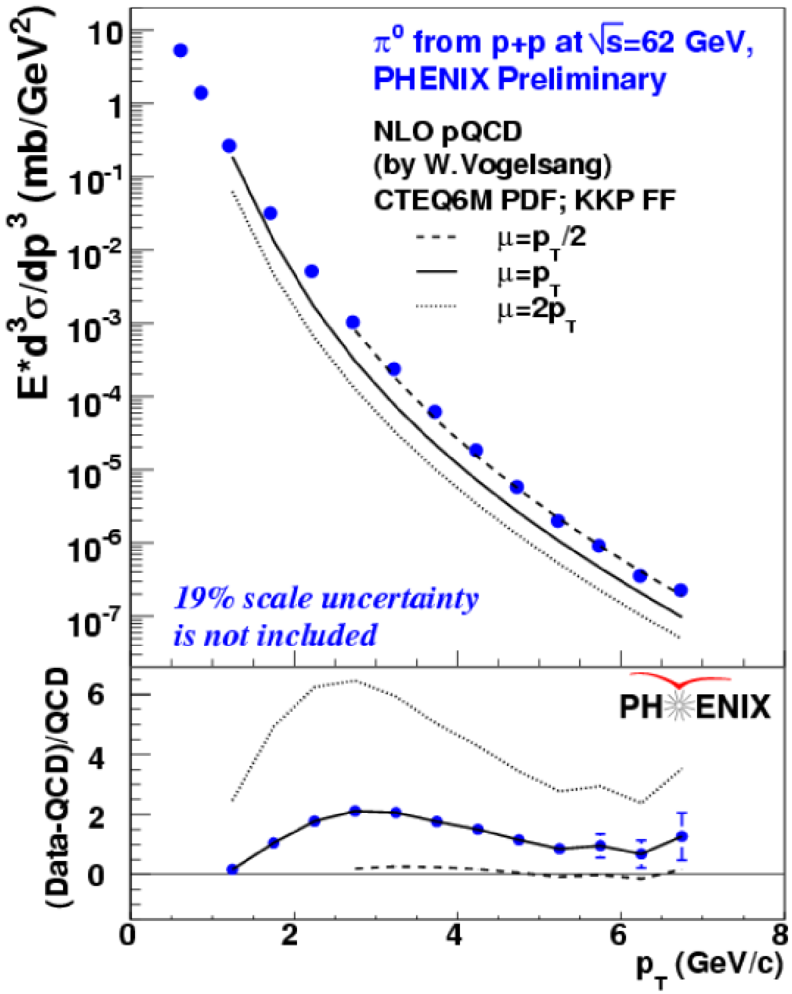
Extend x Range

- To measure ΔG, need as wide an *x* range as possible.
- Planned Upgrades will help (see talk on Wednesday)
- By measuring at different center of mass energies, we can reach different *x* ranges.
- We can extend our *x* coverage towards lower *x* at $\sqrt{s}$ = 500 GeV. Expected to start in 2009.
- We can extend our *x* coverage towards higher *x* at $\sqrt{s}$ = 62.4 GeV. → Run6

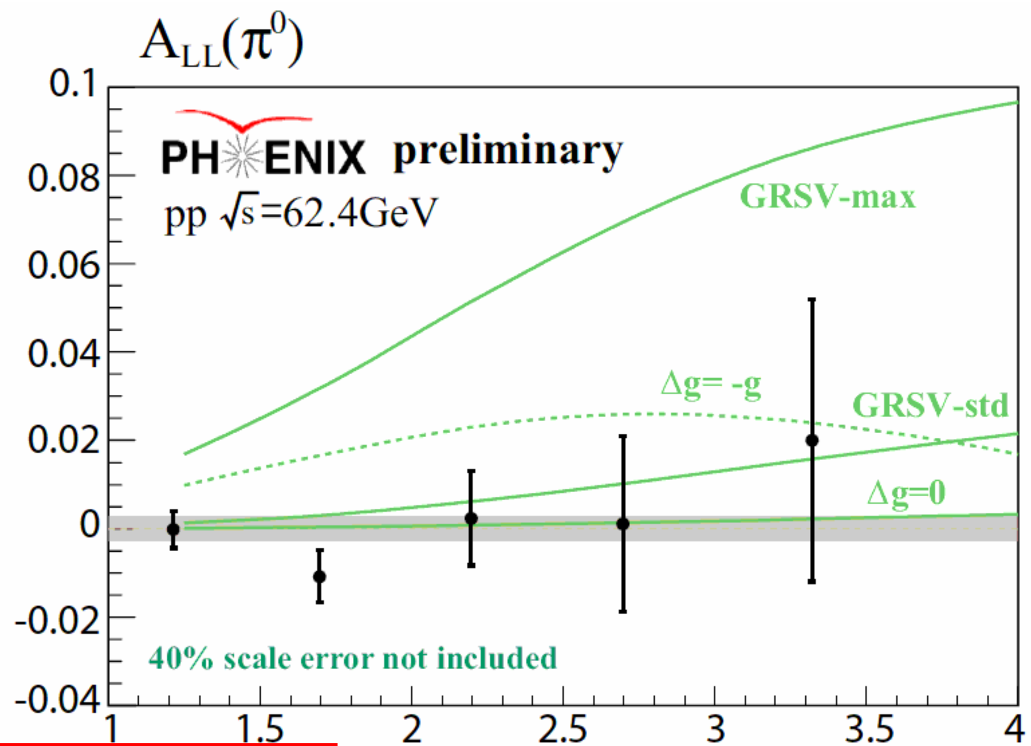


π^0 A_{LL} at $\sqrt{s}$ = 62.4 GeV for high x measurement

π^0 ALL @ $\sqrt{s}$=62.4 GeV



- Short run with longitudinal polarized protons→A_{LL}
- Grey band is systematic uncertainty due to Relative Luminosity



pQCD works →measure A_{LL}

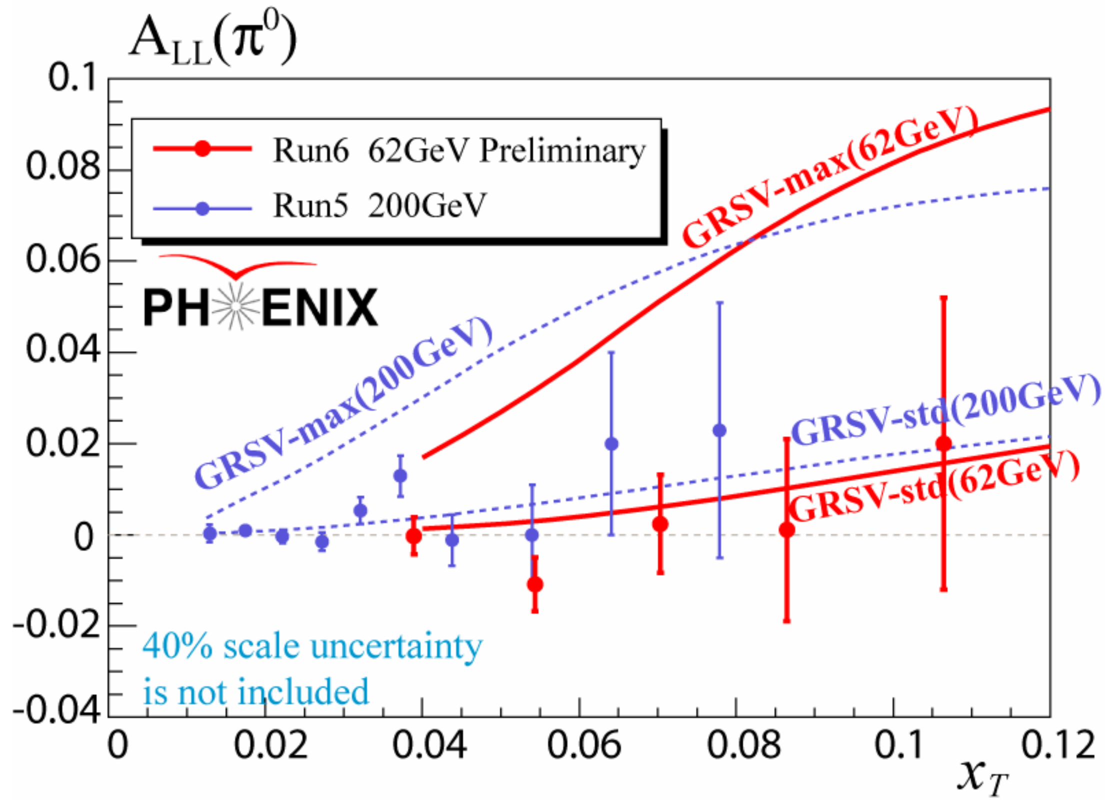
GRSV: M. Gluck, E. Reya, M. Stratmann, and W. Vogelsang, Phys. Rev. D 53 (1996) 4775.

Comparison with 200 GeV

$$x_T = \frac{p_T}{\sqrt{s}/2} \to x$$

- At fixed x_T, π^0 cross section is 2 orders of magnitude higher at 62.4 GeV than at 200 GeV
- Converting to x_T, we can get a better impression of the significance of the $\sqrt{s}$=62.4 GeV data set, when compared with the Run5 final data set.

Run5 200GeV final 2.7pb^{-1} (49%)
Run6 62.4GeV prelm. 0.04 pb^{-1} (48%)



Conclusions

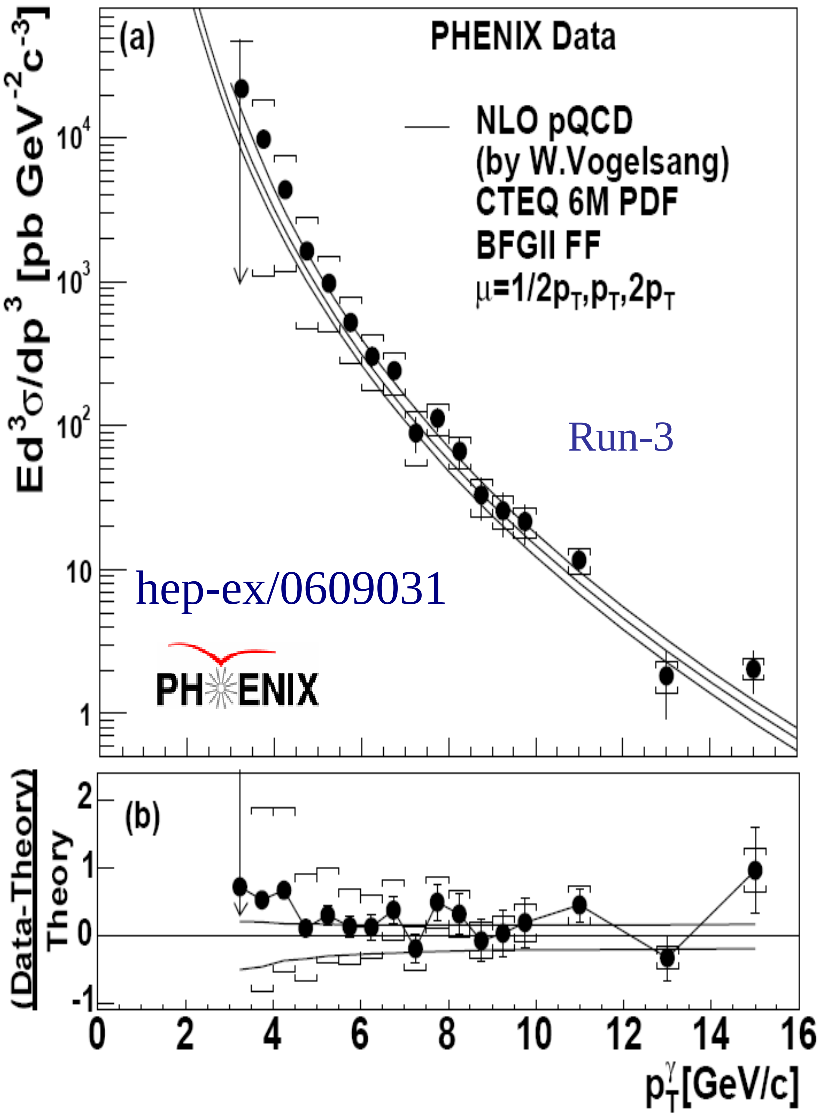
- PHENIX has measured cross sections at $\sqrt{s}$=200 and 62.4 GeV, and found that pQCD describes our data well.
- PHENIX is able to probe the gluon polarization in the proton through many channels.
- Run5 and Run6 π^0 A_{LL} are a significant constraint on the gluon polarization in the proton in the x range [0.02,0.3].
  - More luminosity at 200 GeV will enable us to address the ΔG sign ambiguity with charged pions and direct photons.

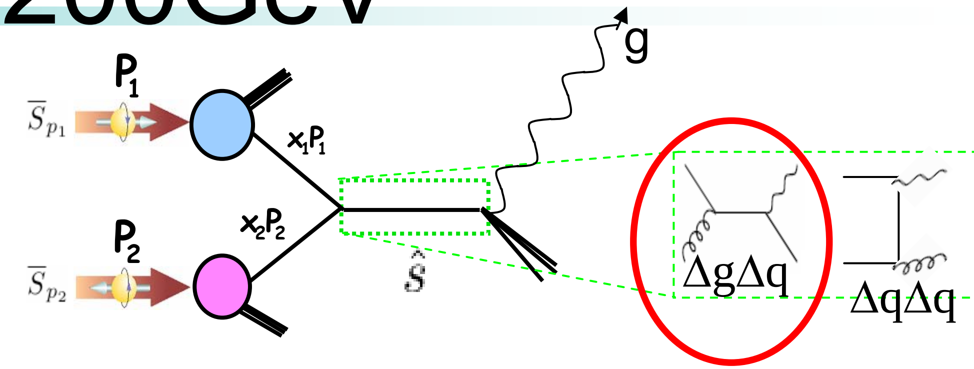
Outlook

- To understand the gluon polarization, we must cover a wide x-range by varying the center of mass energy.
  - PHENIX has begun this by measuring π^0 A_{LL} at $\sqrt{s}$=62.4 GeV.
  - $\sqrt{s}$ = 500 GeV running will also extend the low x reach.
- Detector Upgrades, such as the Silicon VTX, FVTX, and Nose Cone Calorimeter will extend the x reach at low x.
  - heavy quarks and Direct photons (see Y. Goto, later today)
- If we find ΔG is small, we must explore other possibilities, such as Orbital Angular Momentum. PHENIX is working on this:
  - transverse spin effects (see tomorrow's session)
  - k_T effects in longitudinally polarized protons (See D. Fields' talk, later today).

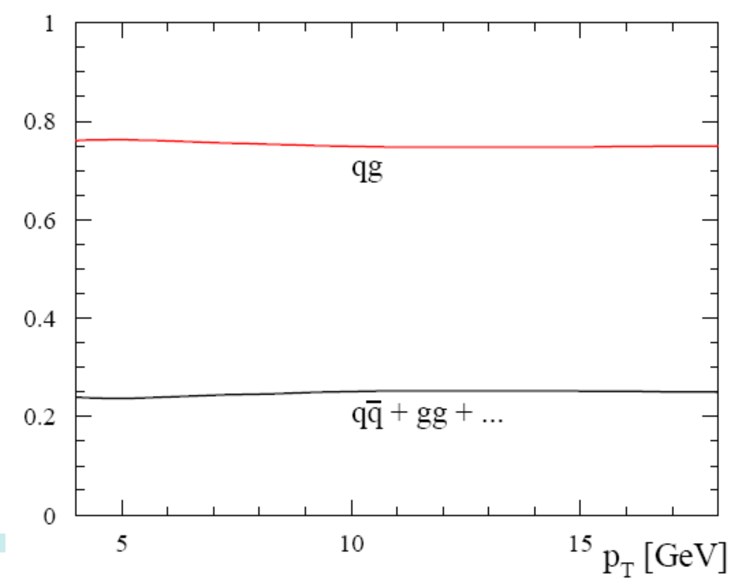
Backups

Prompt γ Production at √s=200GeV



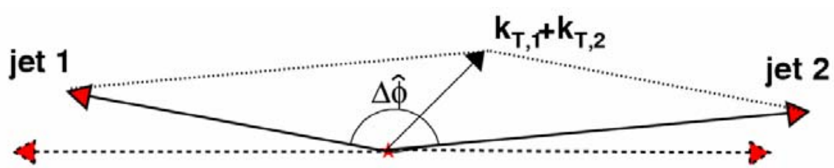


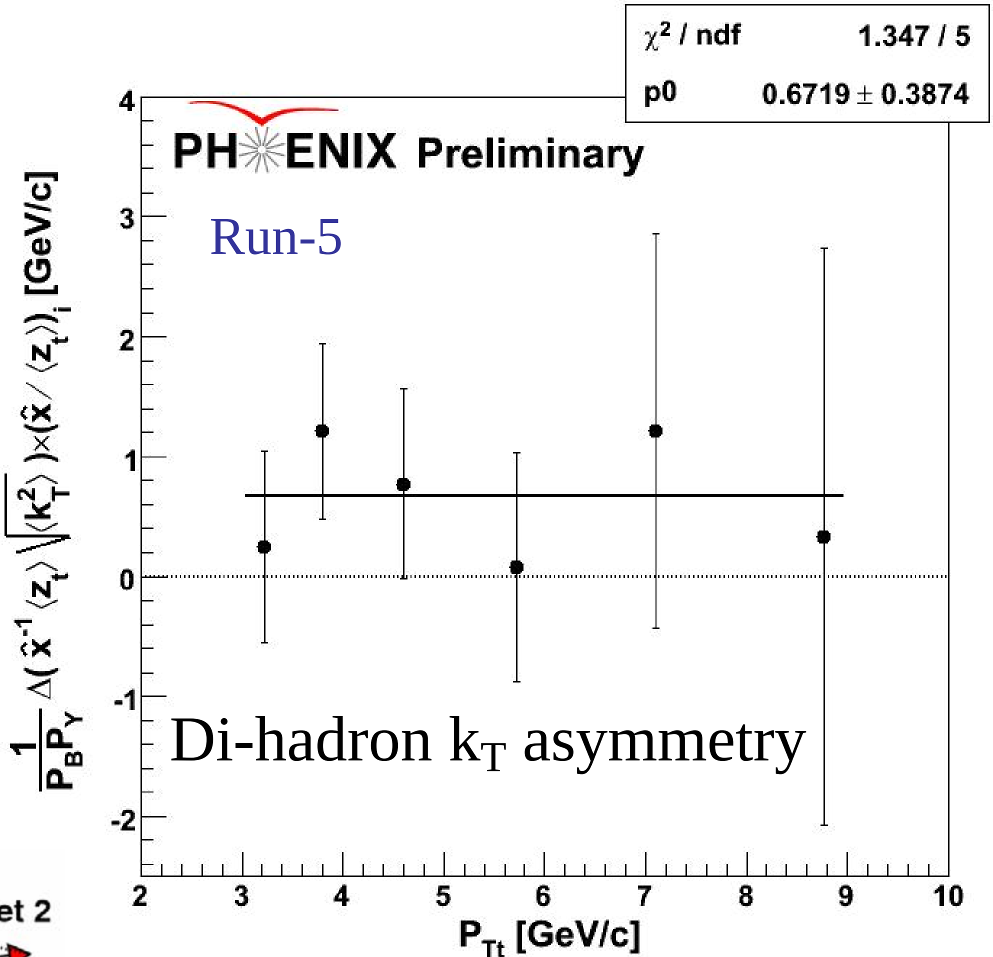
$$A_{LL} \propto \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\Delta q(x_2)}{q(x_2)} \otimes \hat{a}_{LL}(gq \to \gamma q)$$



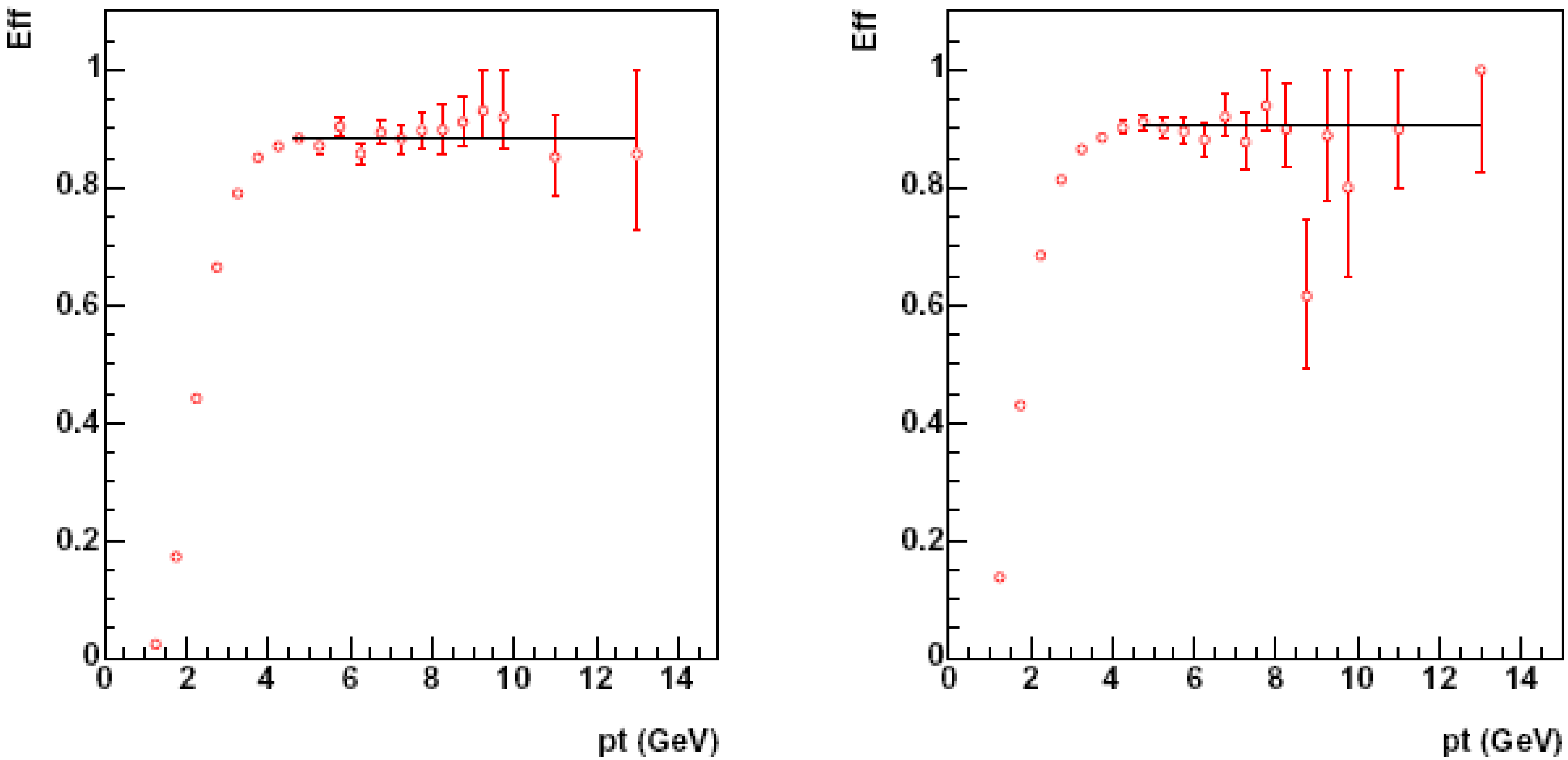
Attempting to Probe k_T from Orbital Motion

- Spin-correlated transverse momentum (orbital angular momentum) may contribute to jet k_T. (Meng Ta-chung et al., Phys. Rev. D40, 1989)
- Possible helicity dependence
- Would depend on (unmeasured) impact parameter, but may observe net effect after averaging over impact parameter





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%