Double Longitudinal Spin Asymmetry Measurements of Inclusive π^0 and η Production at PHENIX in 200 GeV Polarized p+p Collisions

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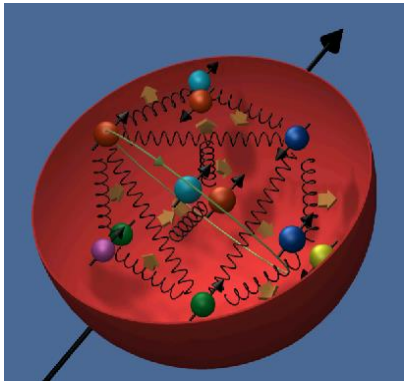
Outline :

- *Introduction*
- *Experimental Equipment and Technique*
- *Results & Impact on ΔG*
- *Conclusions*



Proton Spin Structure

Origin of the proton spin?

All fits show it is small ~ 0.25

Poorly Constrained

Very little is known

$$\langle S_z^p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}$$

Poorly Constrained

- $\vec{p}\vec{p}$ ***at RHIC*** $\Rightarrow$ ***QCD lab: strongly interacting probes***
- ***High*** $\sqrt{s}$ ***make NLO pQCD analysis more reliable***
- ***PHENIX spin program:***
  - ***Longitudinal spin program*** $\Rightarrow$ ***Gluon polarization distribution*** **+** ***Anti-quark sea polarization***
  - ***Transverse spin program*** $\Rightarrow$ ***sensitivity to*** $\langle L_z \rangle$ **+** ***Transversity***

Accessing ΔG in p+p: A_{LL}

➢ ***PHENIX longitudinal spin program ⇒ Gluon polarization distribution***

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_{\pi/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{\pi/c}}$$

From e^+e^- (& SIDIS,pp)

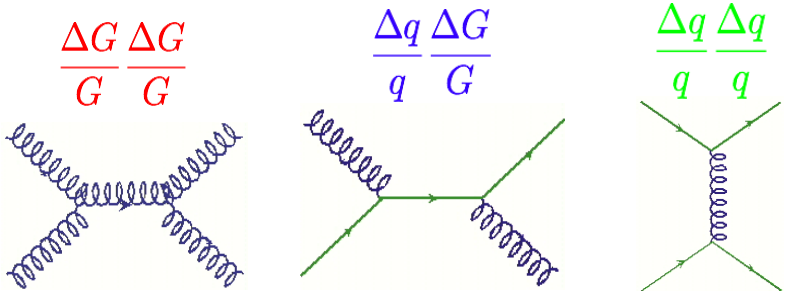
From ep (&pp) (HERA mostly)

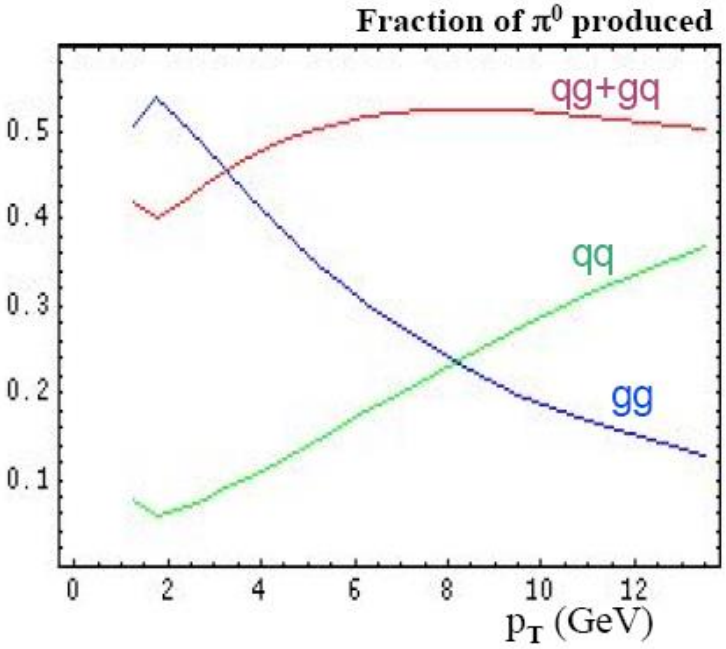
pQCD NLO

- So roughly, we have:

$$A_{LL} \cong a_{gg}\Delta g^2 + b_{gq}\Delta g\Delta q + c_{qq}\Delta q^2$$

where a,b,c depend on kinematics and probe





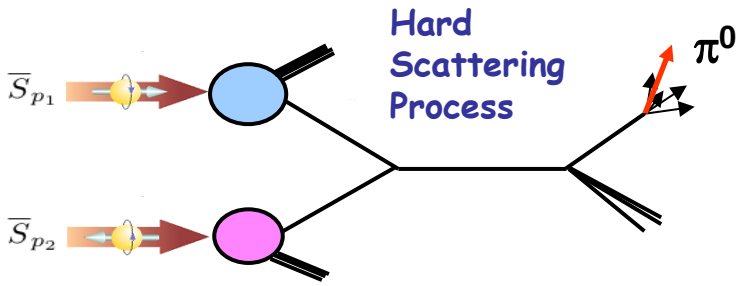
- Δf = Δq, extracted from pDIS

Measuring A_{LL}

PHENIX Analysis Plan

❑ Cross-sections

- *Establish validity of Next to Leading Order perturbative QCD for RHIC kinematics.*
- *Test understanding of detector, measured observable and quality of simulations*



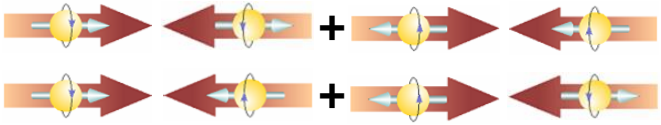
❑ Asymmetries

- *Provide access to polarized parton distributions*

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

+ - = Opposite helicity =

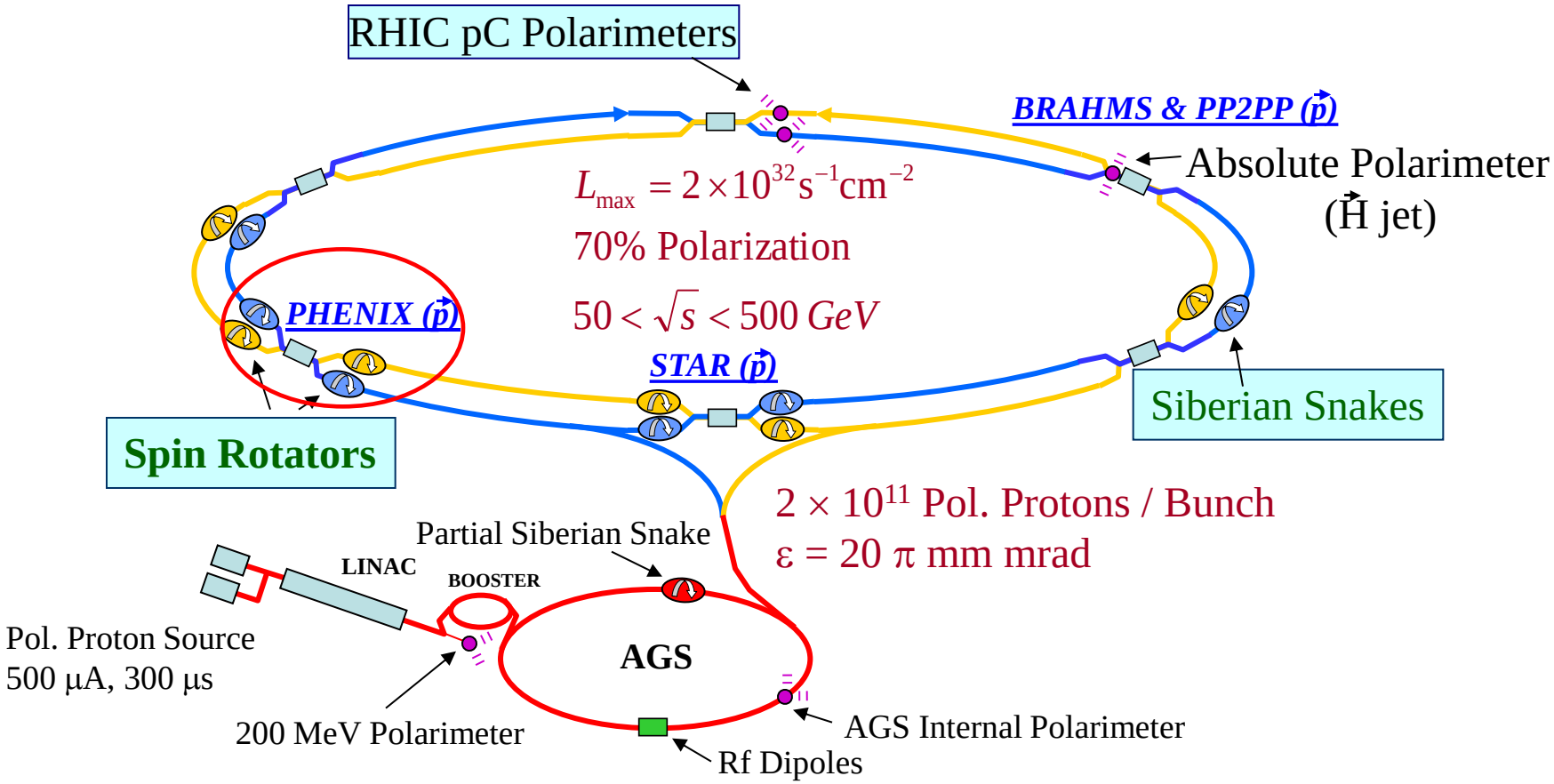
++ = Same helicity =



- Helicity Dependent Particle Yields (N)
  - π^0, π^+, π^-, γ, η, etc
- Beam Polarization (P)
- Relative Luminosity ($R=L_{++}/L_{+-}$)

Relativistic Heavy Ion Collider

…worlds 1st $\vec{p}$ $\vec{p}$ Collider



RHIC accelerates heavy ions up to 100 GeV/A and polarized protons up to 255 GeV

PHENIX Detector Layout

Philosophy (initial design):

- High rate capability & precision
- ➢ Good mass resolution & particle ID
- ○ Sacrifice acceptance

Special interest for spin (π^0,$\eta \rightarrow \gamma\gamma$)

Electromagnetic Calorimeter:

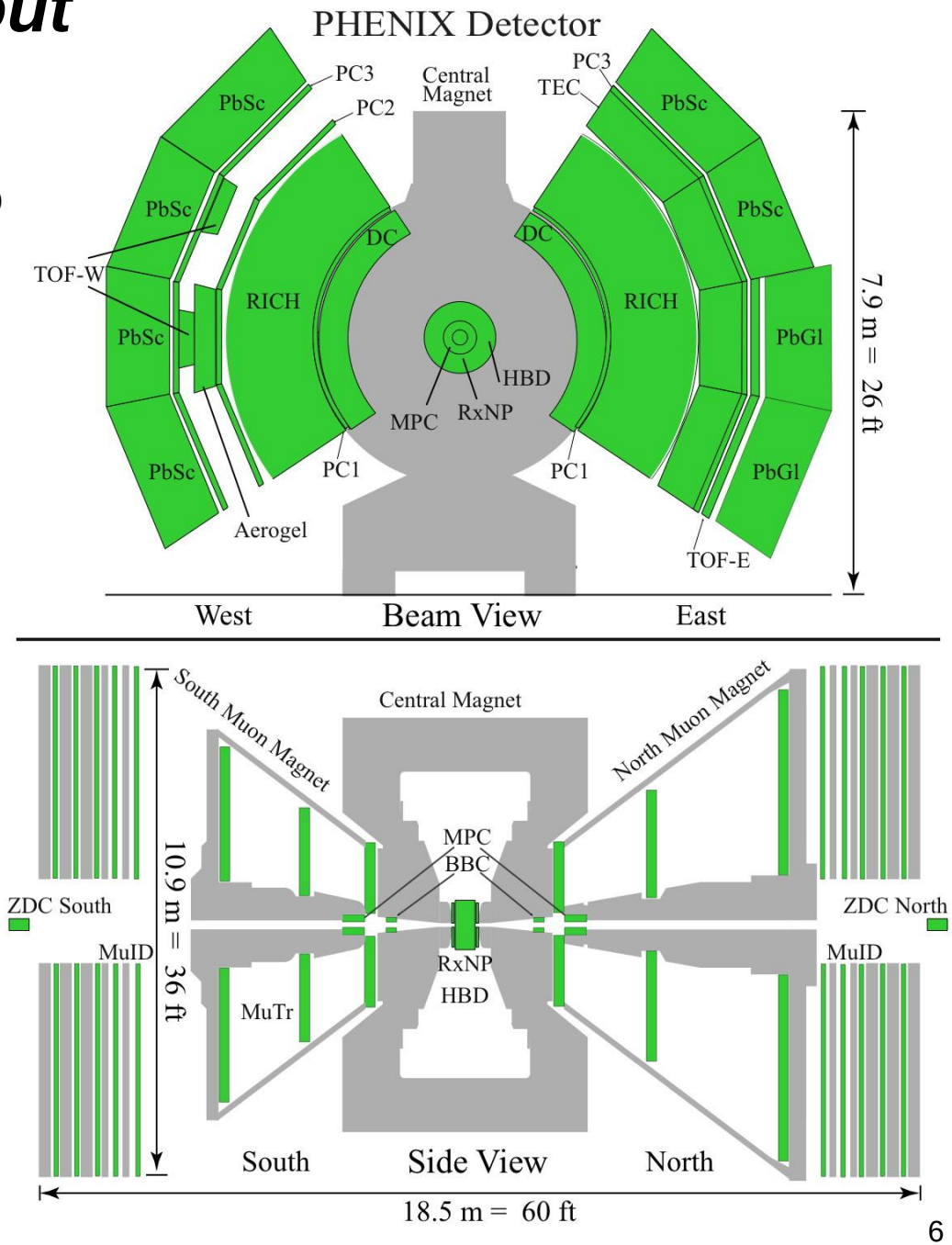
- ➢ 6 sectors PbSc with 64 layers of Pb and scintillator
- ➢ 2 sectors PbGl, used in WA98
- ➢ $\Delta\eta \cdot \Delta\phi \approx 0.01 \cdot 0.01$

Charged Particle Veto

- ➢ Pad chambers directly in front of EMCal

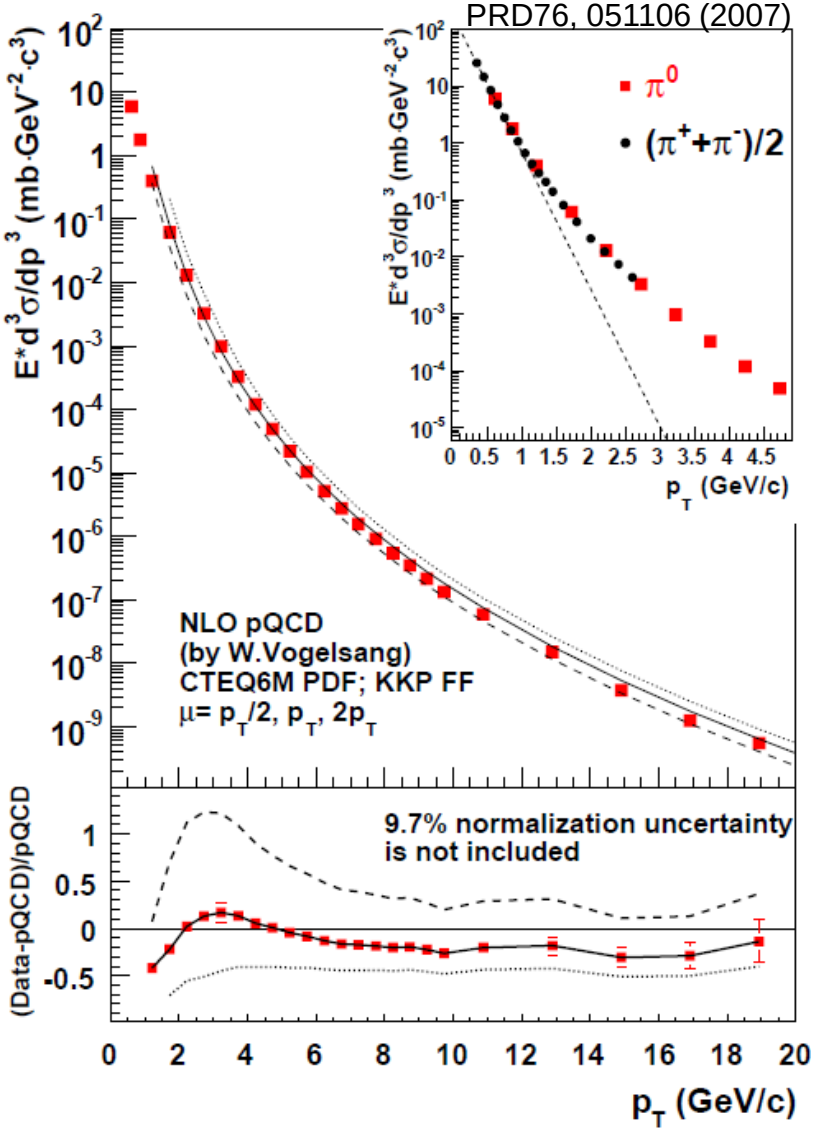
Relative Luminosity

- ➢ Beam Beam Counter (BBC)
  (3.0< η<3.9)
- ➢ Zero Degree Calorimeter (ZDC)

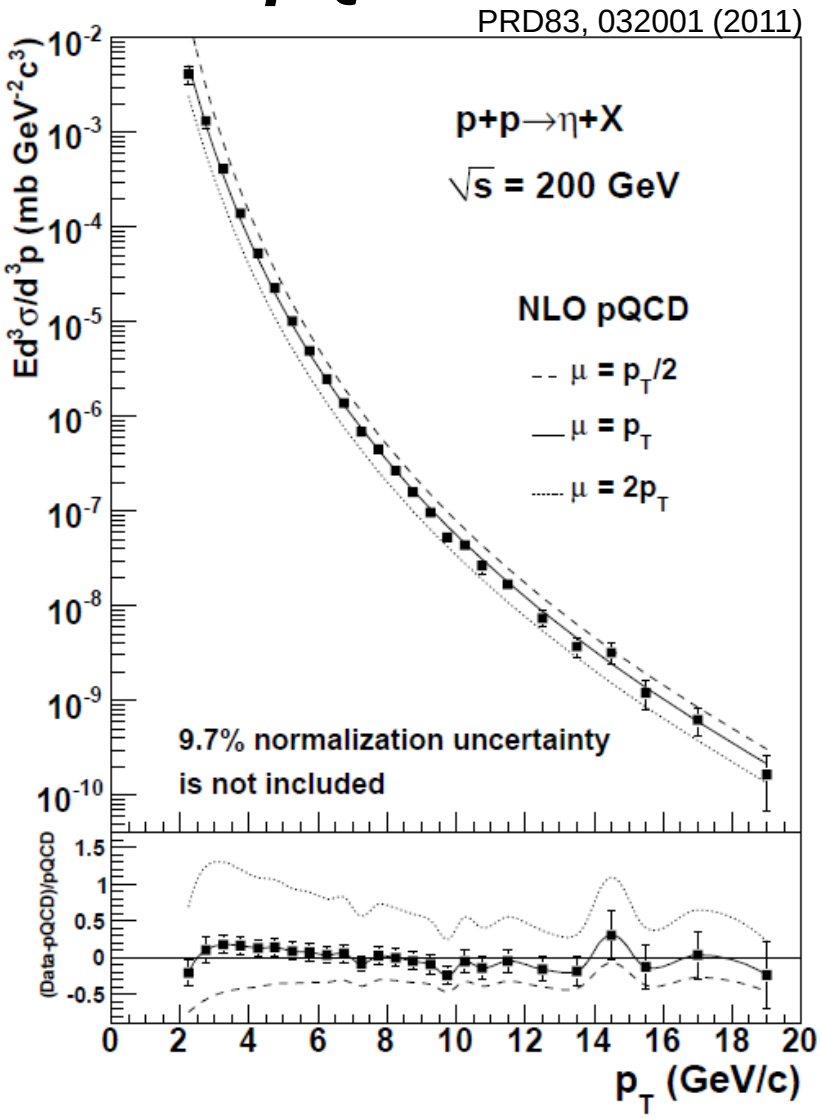


Cross Sections from PHENIX and pQCD

PRD76, 051106 (2007)



PRD83, 032001 (2011)



Consistent with NLO pQCD calculations over several orders of magnitude ⇒

pQCD suitable framework for treating polarization observables in these kinematics

2009 Inclusive $A_{LL}^{\pi^0,\eta}$ Analysis

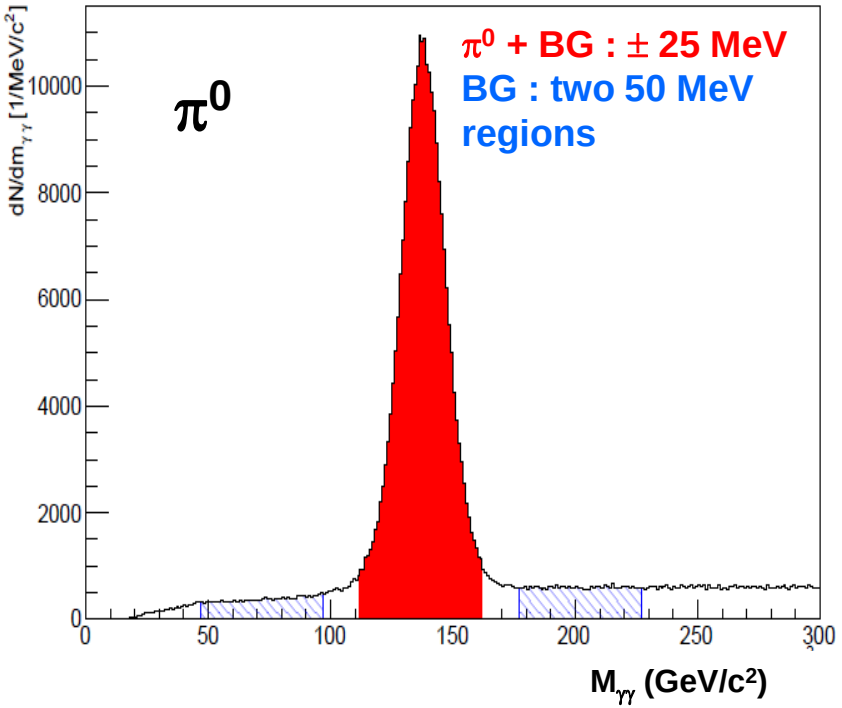
- 4x4 tower triggers at 1.4 and 2.1 GeV threshold
- 14 pb^{-1} @ $\langle P_B P_Y \rangle \sim 0.30$
- Charge veto cut
- -6 ns < TOF < 8 ns
- %2< probability cut of being EM shower
- Energy Asymmetry cut of <0.7 for η only

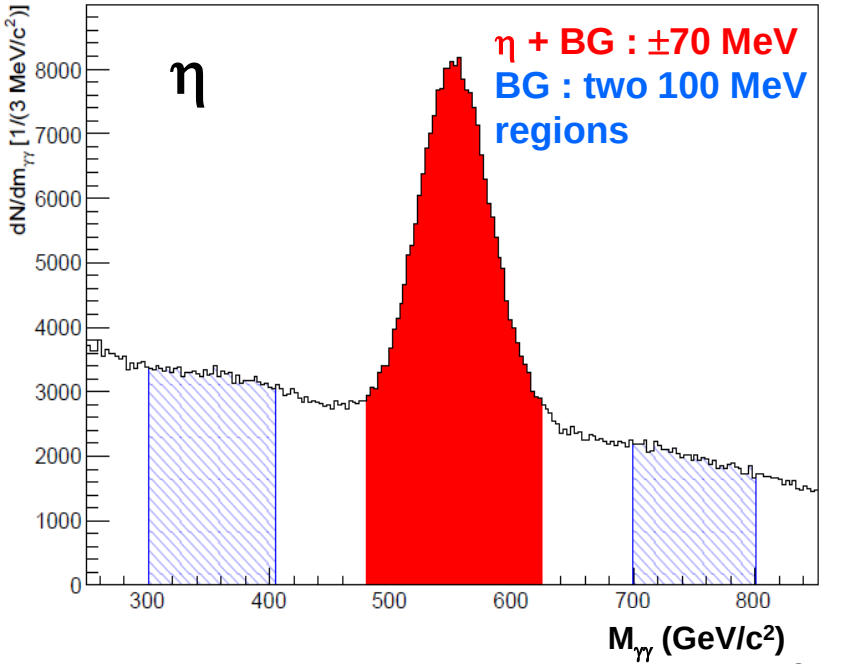
Reconstruction

- Calculate $A_{LL}(\pi^0 + BG)$ and $A_{LL}(BG)$ separately
- Get background ratio (ω_{BG}) from fit of all data.
- Subtract $A_{LL}(BG)$ from $A_{LL}(\pi^0 + BG)$:

$$A_{LL}(\pi^0 + BG) = \omega_{\pi^0} \cdot A_{LL}(\pi^0) + \omega_{BG} \cdot A_{LL}(BG)$$

A_{LL} systematics	Value
Relative luminosity	1.3×10^{-3} "Dominant"
Background Fraction Est.	1% – 2.1% of stats uncer
High vs low mass bkgrd	0.16×10^{-3}
Non-longitudinal Pol.	[-4.2% , +2.6%]





Relative Luminosity Systematic

- Relative luminosity is measured using BBC counters, $R = \frac{N^{BBC}_{++}}{N^{BBC}_{+-}}$
- Systematic Uncertainty, $A_{LL}^{R} \equiv \frac{1}{P_B P_Y} \frac{r_{++} - r_{+-}}{r_{++} + r_{+-}}$, where $r \equiv \frac{N_{ZDC}}{N_{BBC}}$

BBC vs ZDC

- Different geometrical acceptance
- Sample significantly different class of events
  - BBC fires predominantly on charged particles and photons
  - ZDC fires on neutrons and photons (setting behind the accelerator's bending magnets)
- Large transverse single spin asymmetry, A_N, in neutron production is apparent in ZDC triggers $\Rightarrow$ Sensitive detector to spin effects**.**

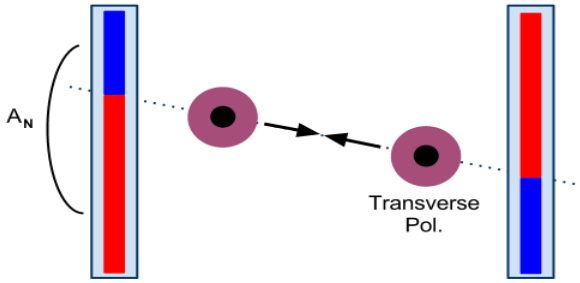
Historically

Run, $\sqrt{s}$	σ_{stat} π^0 A_{LL} smallest uncer. p_T bin	σ_{sys} RL
2005, 200 GeV	13×10^{-4}	2.5×10^{-4}
2006, 200 GeV	8.2×10^{-4}	7.5×10^{-4}
2009, 200 GeV	8.1×10^{-4}	13×10^{-4}

If this is due to a physics asymmetry, it should be constant year to year. Typical uncertainty on this number ~2.5×10^{-4}, and it is not consistent?

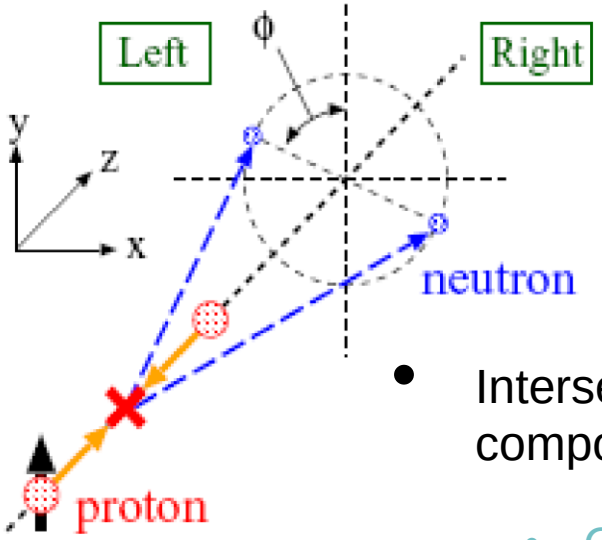
RL Studies:

May be A_N coupled with some geometrical effect could be faking (ZDC - BBC) asymmetries???

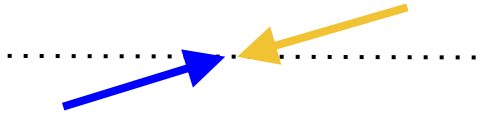


- The longitudinally polarized beams have some small transverse component
- Transverse running in 2012 gave us an opportunity to test a hypothesis ⇒ we angled the beam through the PHENIX IR and calculated our typical BBC/ZDC asymmetries

❖ Ideally, the beams that traverse IRs in "zero" magnetic field region are assumed to be at straight paths and will look like:

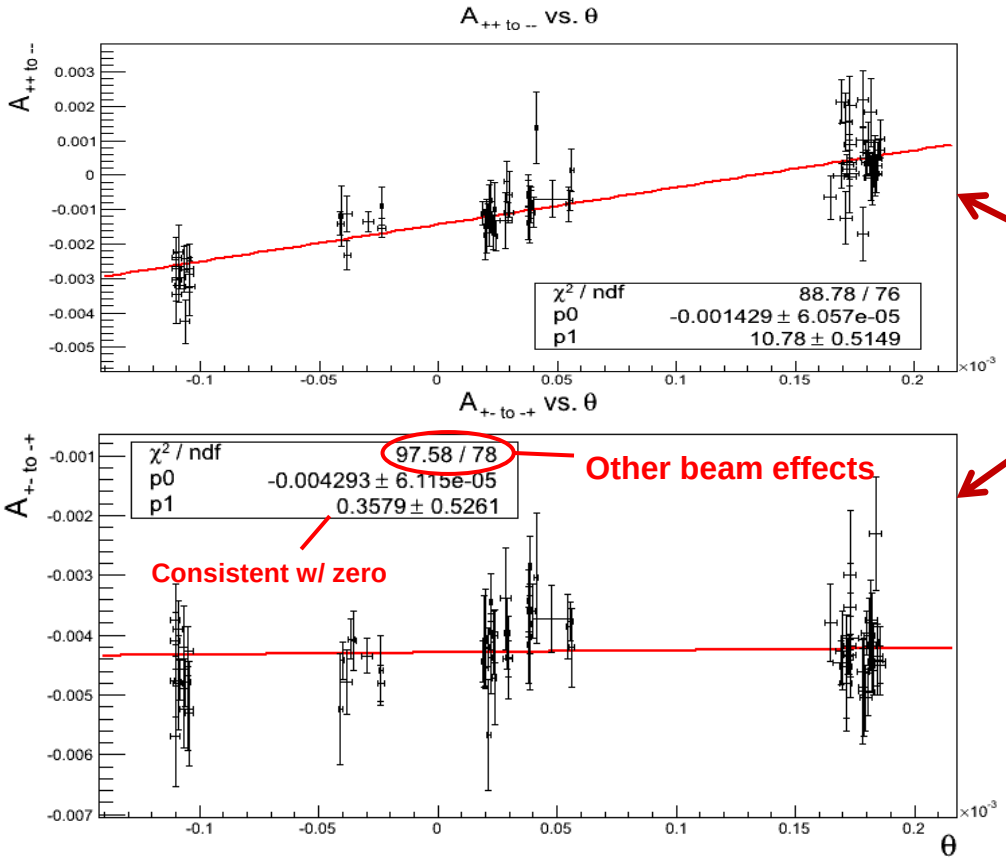


- Intersection geometry of beams can be decomposed into three components (x 2 planes)
  - Collinear Angle
  - Offset
  - Boost



studied in Run12!

Results: 2012 Beam Angle Scan at PHENIX



Predicted behavior from simple considerations, supported by MC:

$$A_{++\ \text{to}\ --} \propto (P_B + P_Y)\theta$$

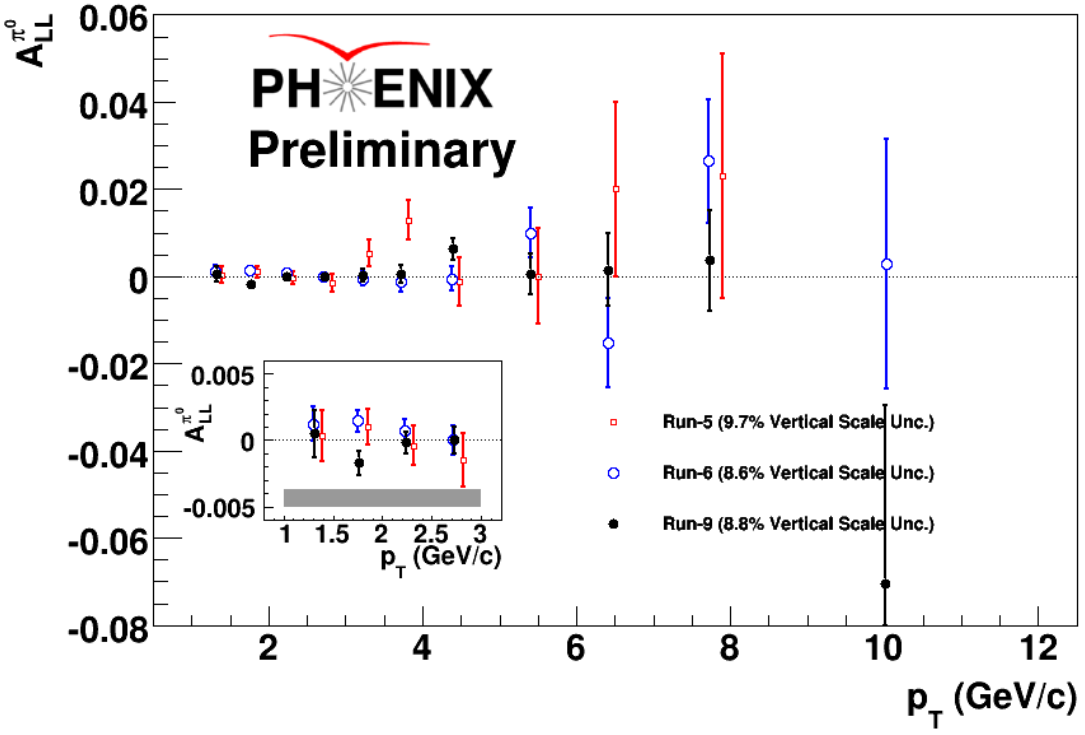
$$\frac{\partial}{\partial\theta} A_{+-\ \text{to}\ -+} = 0$$

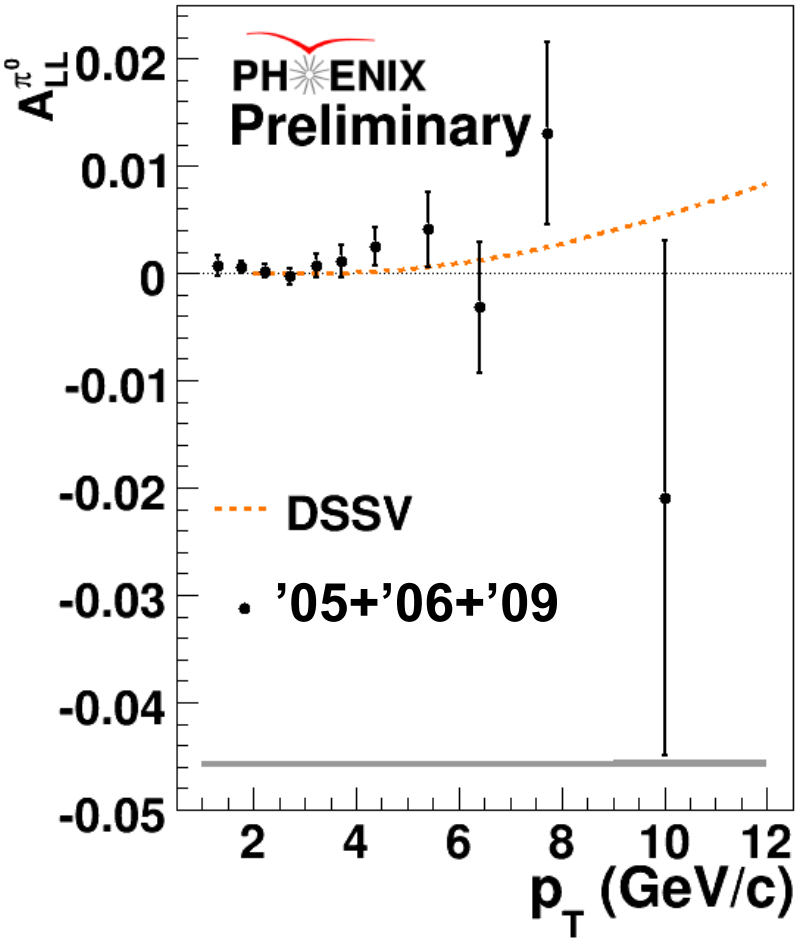
Can seemingly explain non-physical (large parity violating) asymmetries in longitudinal running with a transverse beam component + A_N

This study was limited in scope and could not completely explain our false asymmetries. In 2013, PHENIX commissioned new scaler readout:

- looks at the interaction from different angles and offsets *simultaneously*
- covers the entire running period

2009 π^0 Results

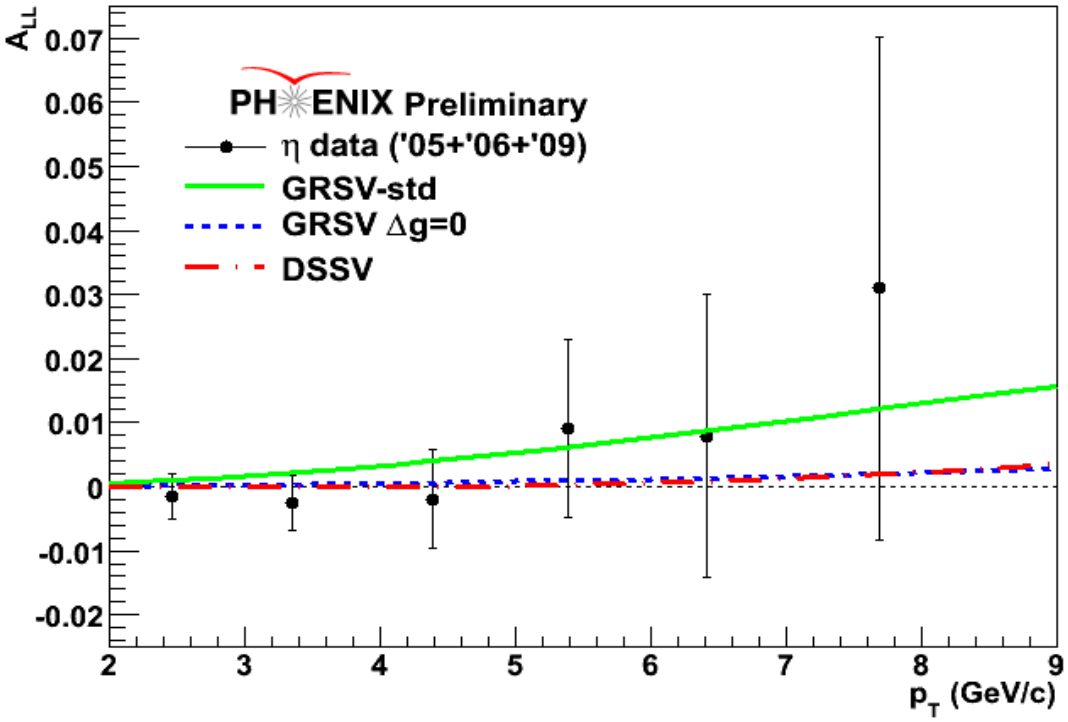


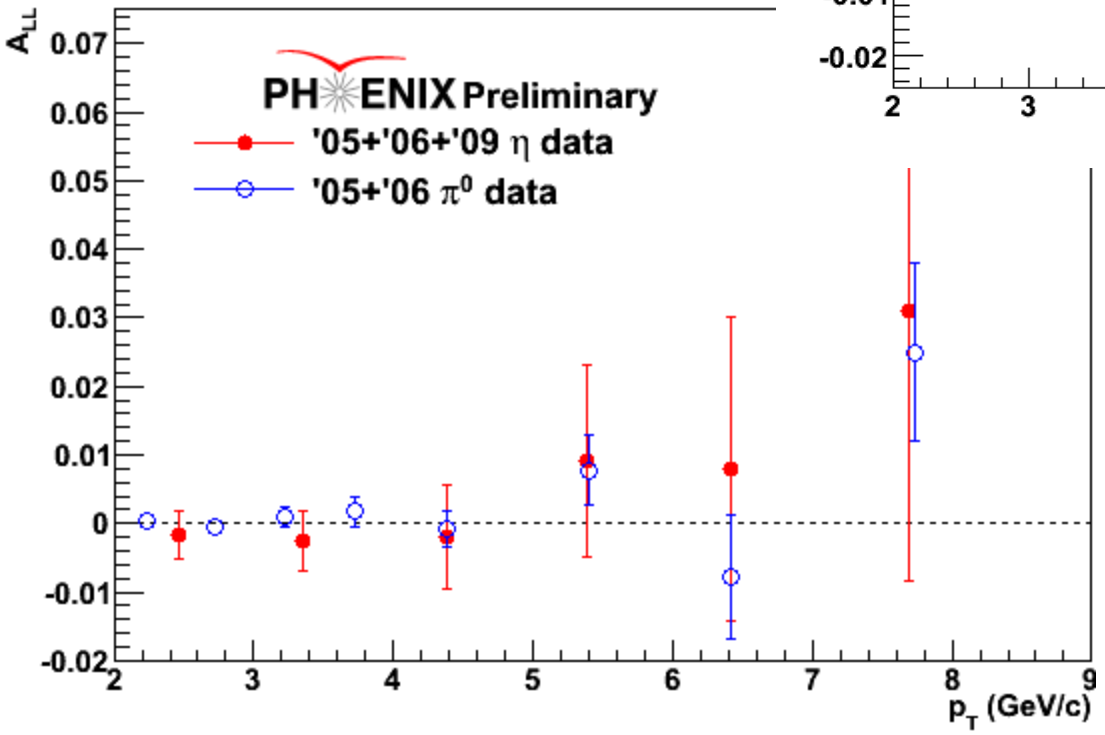


- Data consistent with previous results
- Combined 2005, 2006 and 2009 data favor larger A_{LL} than the DSSV best fit predicts

2009 η Results

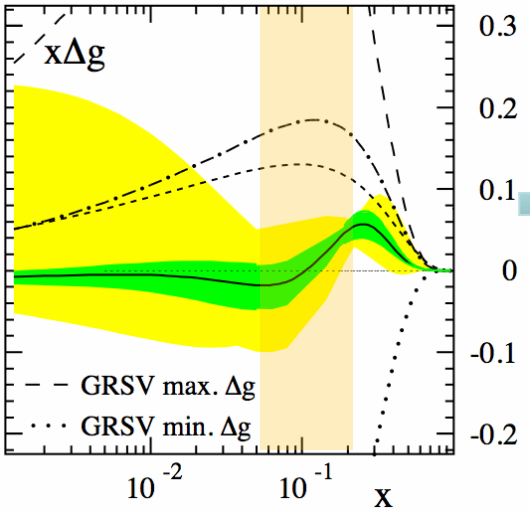
Combined η results from ‘05, ’06, and ’09 ⇒ while statistically limited it is systematically higher than DSSV fit

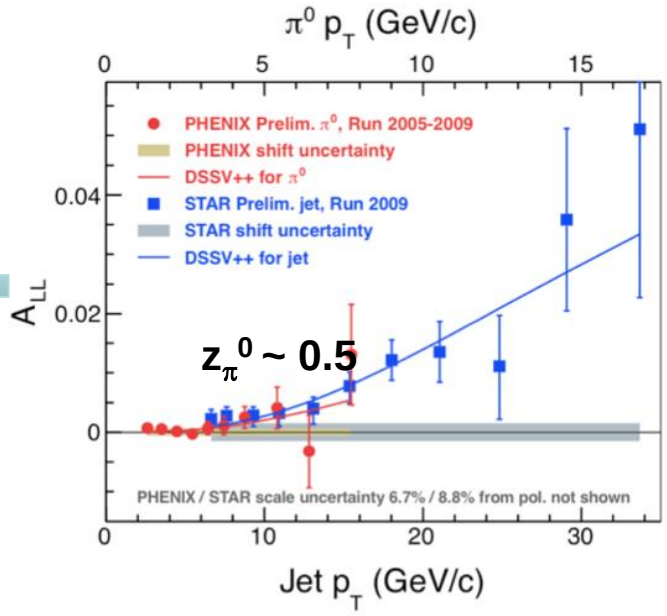


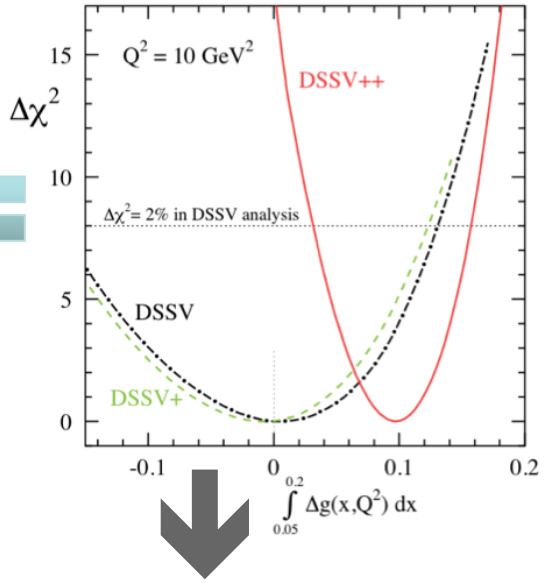


Combined η results from ‘05, ’06, and ’09 are consistent with combined π^0 results from ‘05 and ‘06

Inclusion in Global Analysis





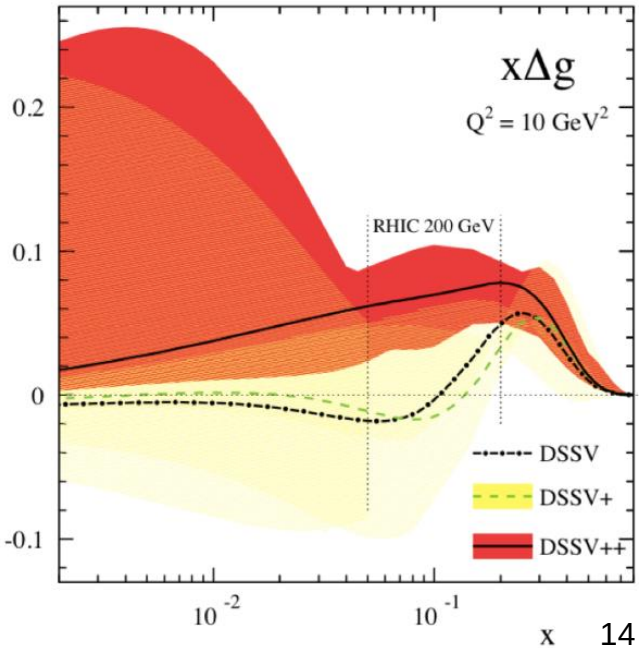


- Stratmann and Sassot recently included 2009 data in DSSV++
- First indications of non-zero ΔG

$$\int_{0.05}^{0.2} \Delta g(x)\,dx = 0.1 \pm^{0.06}_{0.07}$$

compared to DSSV's $0.005^{+0.129}_{-0.164}$

- Good constraint in x-region probed at RHIC
- Preliminary results shown here in RHIC Spin write up arXiv:1304.0079



Conclusions

- PHENIX has measured A_{LL} of π^0 & η production in 2005, 2006. π^0 data was included in global analysis (DSSV)
  - 2005 and 2006 π^0 data significantly constrained ΔG in the accessible kinematic range, $0.02<x<0.3$, as found by DSSV global analysis

- Larger data sample in 2009 included in a new fit (DSSV++). DSSV++ indicates non-zero ΔG

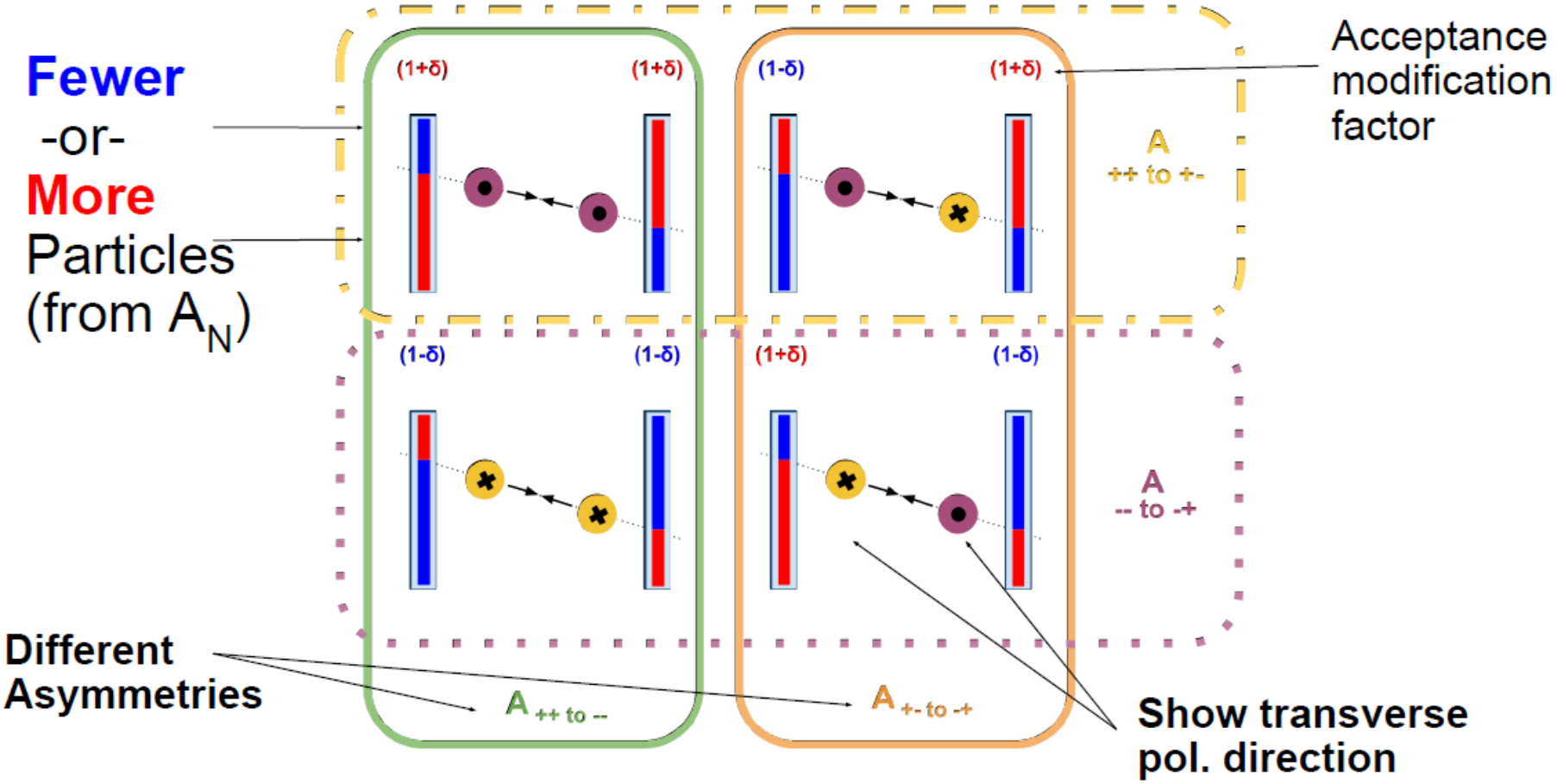
$$\int_{0.05}^{0.2} \Delta g(x)\, dx = 0.1 \pm^{0.06}_{0.07}$$

  - 2009 results appear to favor larger ΔG compared to DSSV
  - Best fit ΔG (0.1) contribution roughly the same size as quark spin contribution ($\frac{1}{2}\Delta\Sigma \approx 0.125$), though uncertainty on ΔG is still large

Thank You

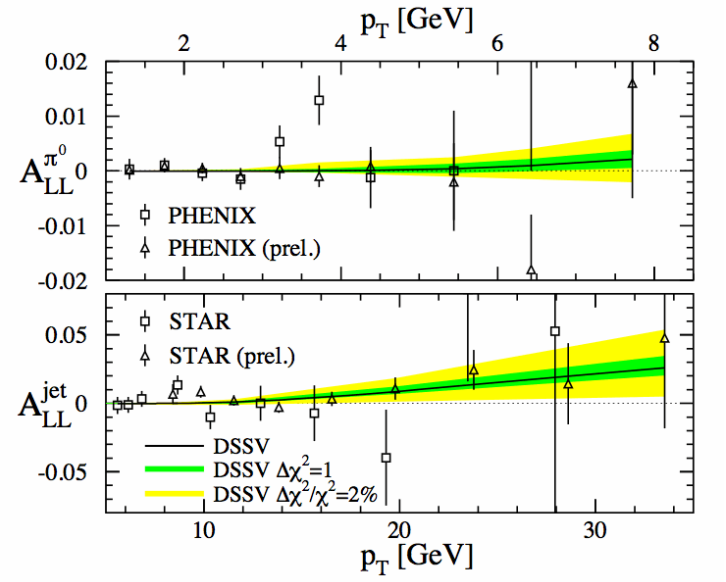
Back up

Model: Case of Collinear Beam Angle



Constraining ΔG

2005 & 2006 RHIC data



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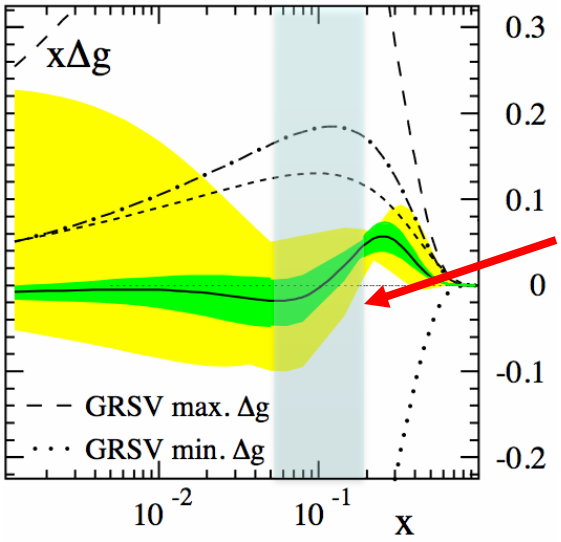

RHIC region

- Results from 2005 & 2006 constrained ΔG.
- DSSV fit world data, including p+p for first time.
  - ***PRL101:072001, 2008***
  - ***PRD 80:034030, 2009***
- RHIC data offer significant constraint at $0.05 < x < 0.2$.

$$\int_{0.05}^{0.2} dx\, \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2) = 0.005^{+0.129}_{-0.164}$$

- Large uncertainty remains below RHIC *x*-range.