Recent PHENIX Results on Gluon Polarization

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Proton Spin Structure

Manohar-Jaffe sum rule:

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \Delta L_q + \Delta L_g$$

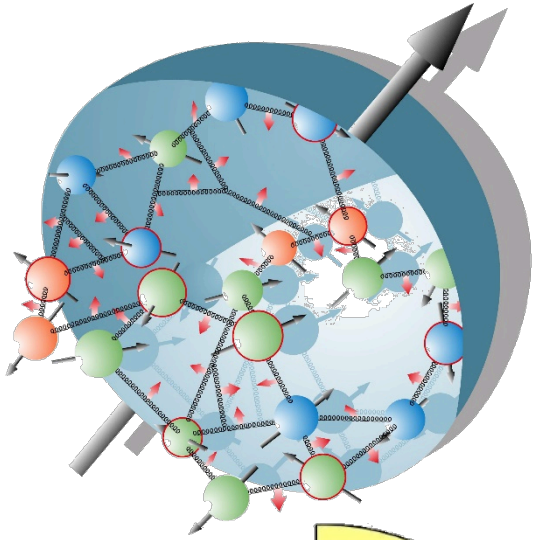
Know very little

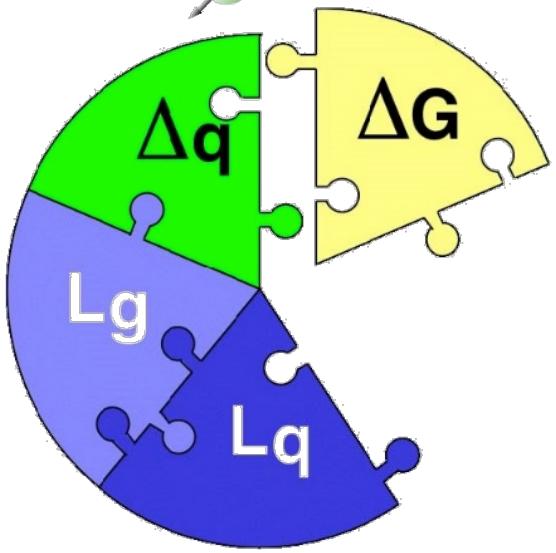
~0.33 (small)

Poorly constrained

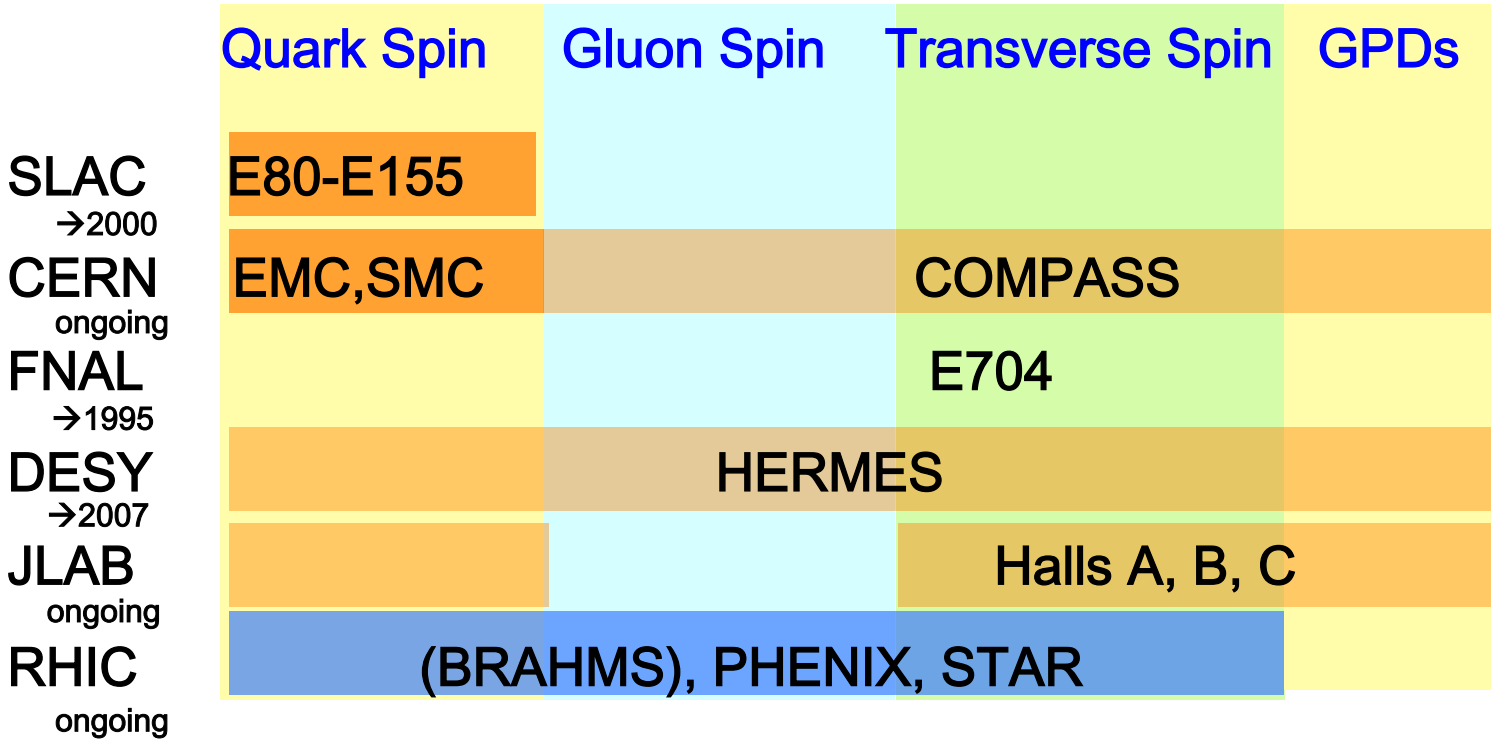
$$\Delta\Sigma = \Delta u + \Delta d + \Delta\bar{u} + \Delta\bar{d} + \ldots$$

Poorly constrained





Nucleon Spin Structure History



major experimental innovations

DIS — semi inclusive + exclusive processes, luminosity

polarized pp — polarized proton beams, polarized proton collider

RHIC Spin Program

Phys. Rev. D 80, 034030 (2009)

From 2009 DSSV global fit

- Quark contribution is well understood by DIS and SIDIS.
- Large uncertainty on sea quark polarization due to the large uncertainty in fragmentation.
- Gluon Polarization is largely unconstrained, especially in the low x region.

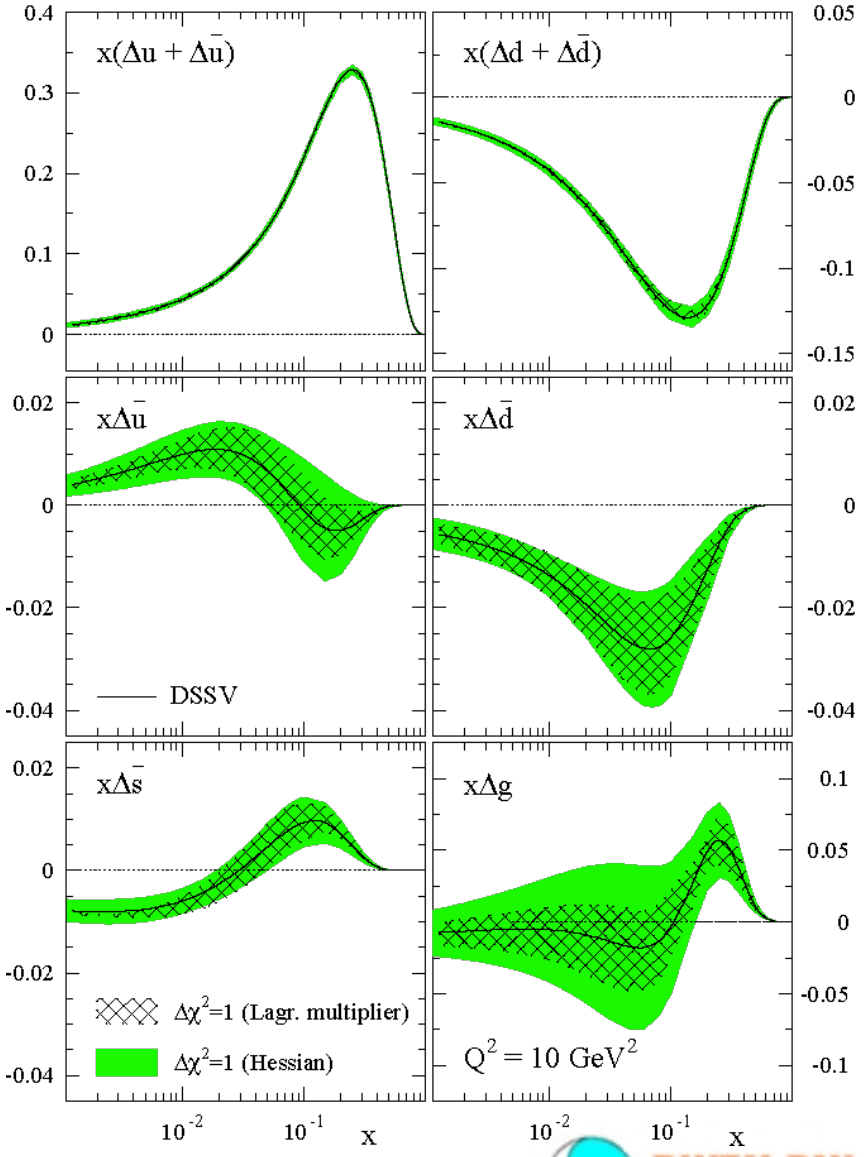
RHIC spin goal:

- Gluon Polarization

PEHNIX and STAR are adding more data points into global fit.

- Sea quark contribution

W measurement in lepton channel



PHENIX Spin Program

Longitudinal spin program

- **Gluon polarization distribution** $\Delta G = \int_0^1 dx \cdot \Delta g(x)$

-- PHENIX has measured π^0, jet, charged π, η, heavy flavor A_{LL} at $\sqrt{s}$ = 62.4 and 200 GeV at mid-rapidity.

-- π^0, A_{LL} at $\sqrt{s}$ = 500 GeV at mid-rapidity

-- J/Ψ, A_{LL} at $\sqrt{s}$ = 500 GeV at forward rapidity

-- π^0, A_{LL} at $\sqrt{s}$ = 500 GeV at forward rapidity, in progress

- **Anti-quark sea polarization:** Talk by Nerangika Bandara (UMass)

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

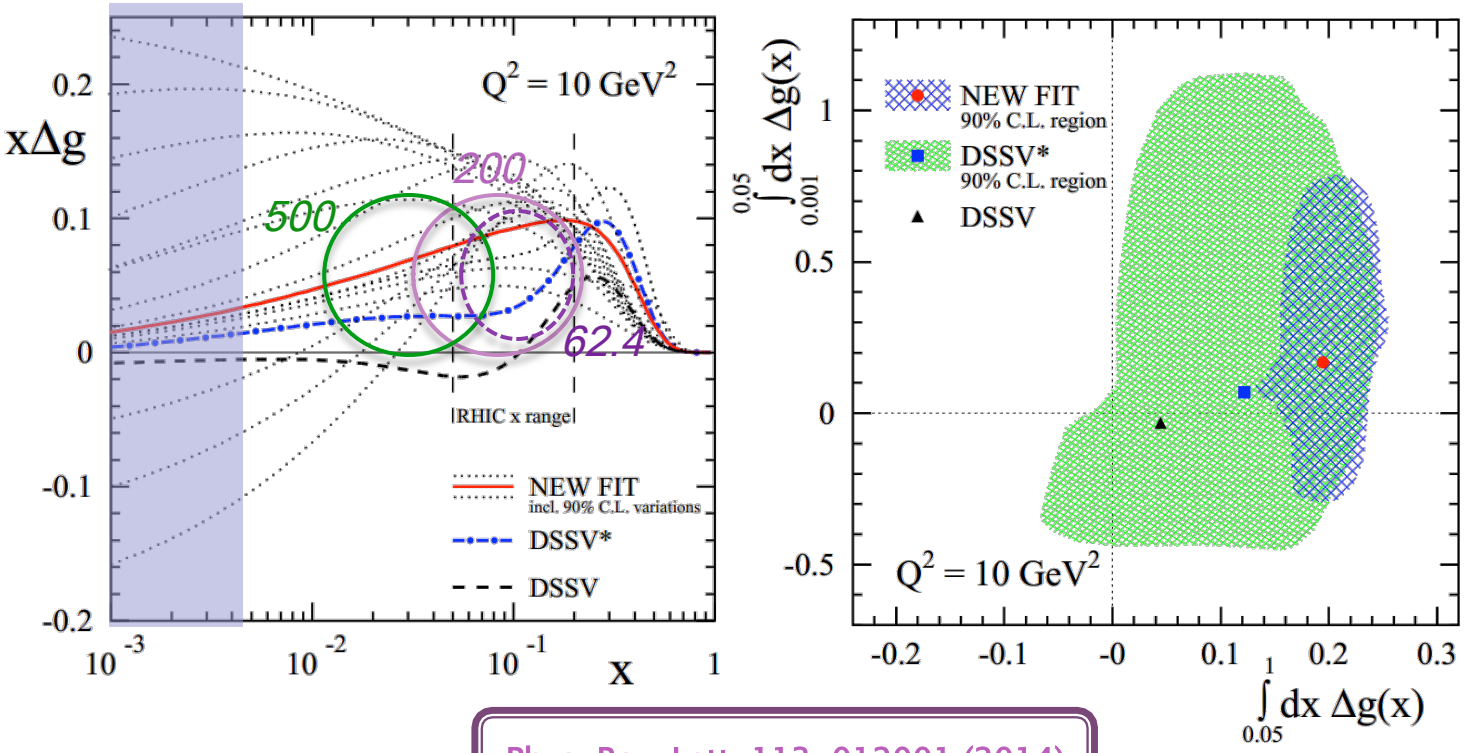
$$A_L(\bar{u} + d \rightarrow W^- \rightarrow l^- + \bar{\nu}_l)$$

Transverse spin program: Talk by Ming Liu (LANL)

-- sensitivity to <Lz> + transversity

Current Understanding of Gluon Polarization 2014 DSSV Global Fit

- Including 2009 RHIC data sets, the 2014 DSSV global fit suggests non zero polarization of gluons in the proton at intermediate x range (0.05 ~ 1).
- At low x region, the errors of DSSV are still poorly constrained.



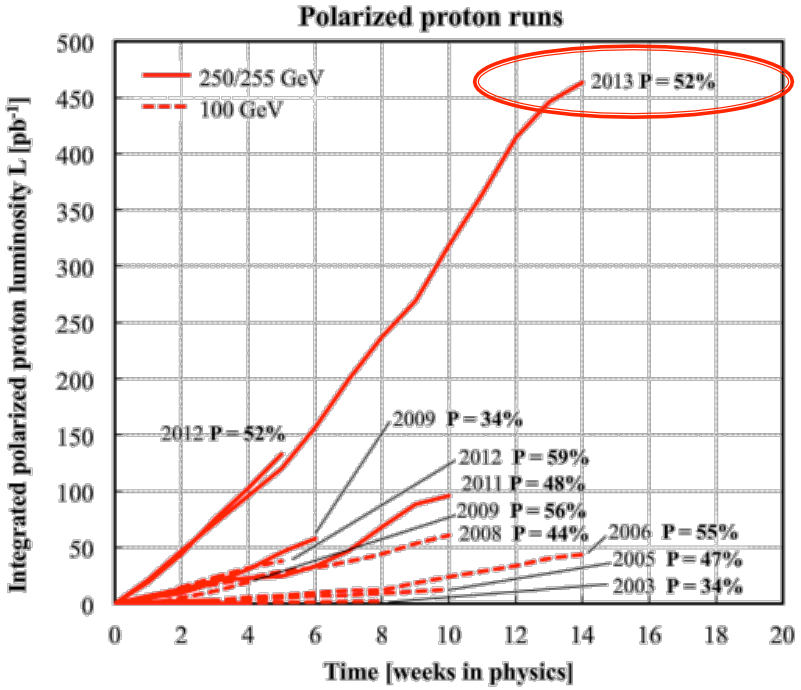
Phys. Rev. Lett. 113, 012001 (2014)

Resent Spin Run at RHIC

Recent Spin Runs

- 2009: First 500 GeV longitudinal
- 2011: 500 GeV longitudinal
- 2012: 200 GeV transverse and 510 GeV longitudinal
- 2013: 510 GeV longitudinal run

Combined data from 2009-2013 longitudinal runs provide a high statistics, high polarization sample for sea quark and gluon polarization studies

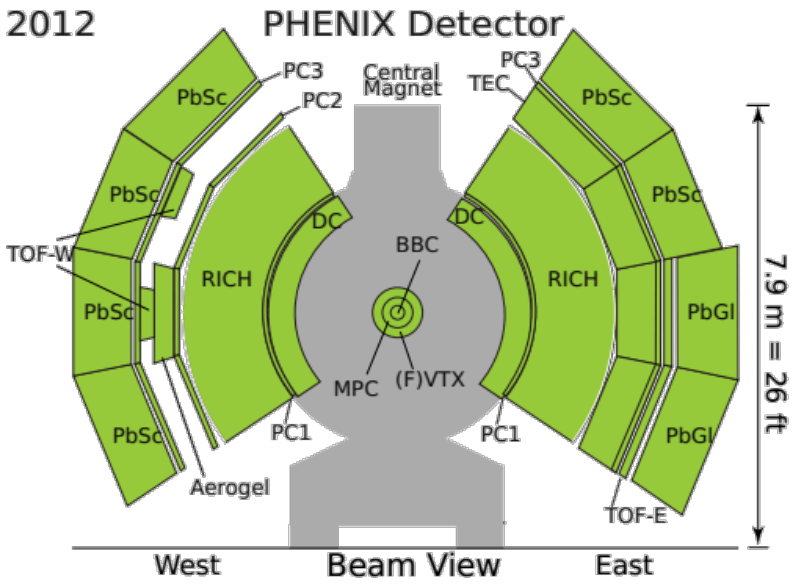


Figures of Merit

- Single Spin Asymmetry FOM: $L\langle P\rangle^2$
- Double Spin Asymmetry FOM: $L\langle P\rangle^4$

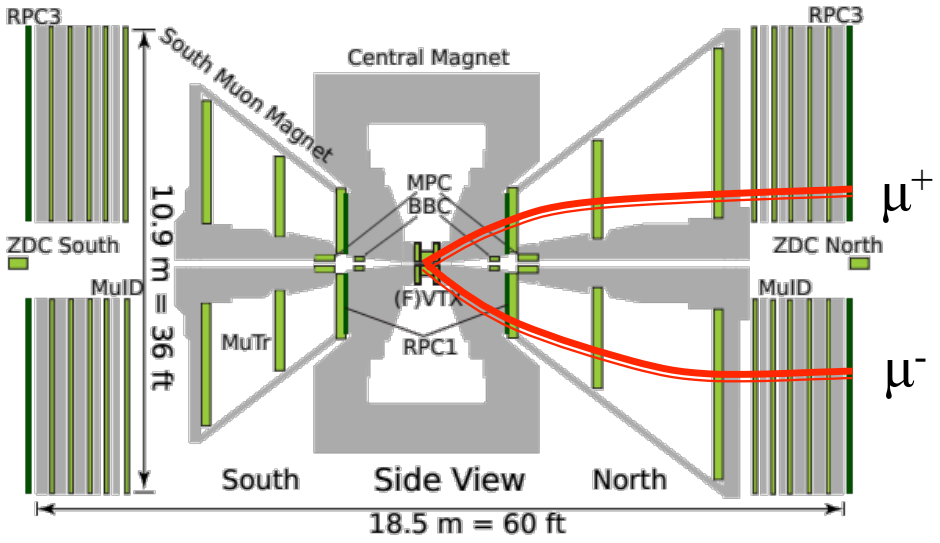
High polarization is essential for an effective measurement of A_{LL}

PHENIX Central Arm



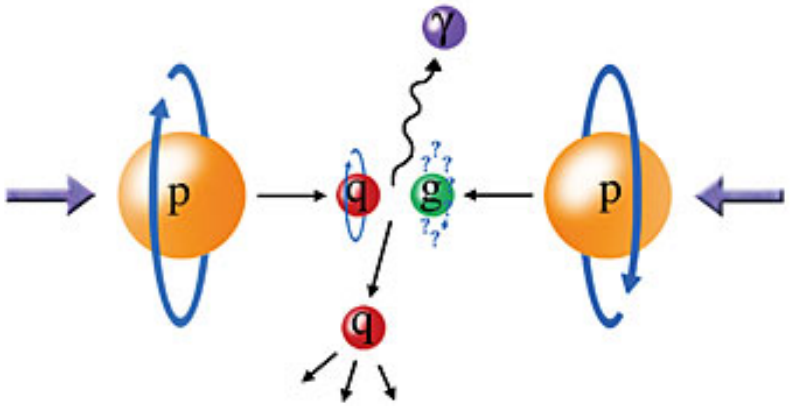
- Energy measured in EM Calorimeter (PbSc + PbGl)
- Momentum/Tracking in Drift Chamber (DC) + Silicon Barrel (VTX)
- PID with Ring Imaging Cherenkov Counter (RICH)
- $|\eta| < 0.35$, $\Delta\phi = 2 \times \frac{\pi}{2}$

PHENIX Muon Arm



- Silicon strip tracking and vertexing (FVTX)
- Momentum measured in cathode strip tracking chambers (MuTr)
- $\mu^{\pm}$ ID from Iarocci tubes interleaved with steel absorbers (MuID)
- $1.2 < |\eta| < 2.2$, $\Delta\phi = 2\pi$

Access Gluon Polarization -- A_{LL}



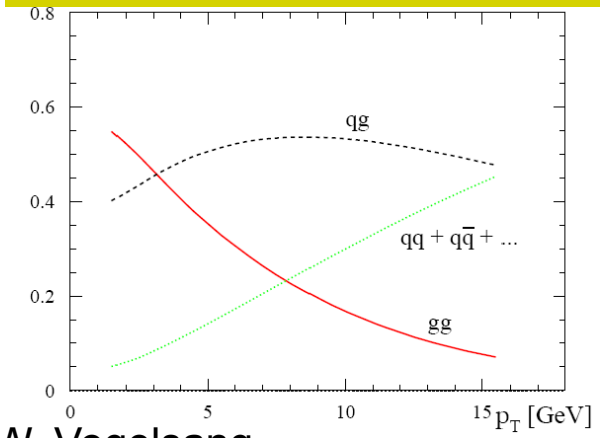
$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

$$A_{LL} = \frac{1}{P_Y P_B} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}, R = \frac{L_{++}}{L_{+-}}$$

$$\Delta\sigma(pp \to \pi^0 X) \approx \Delta q(x_1) \otimes \Delta g(x_2) \otimes \Delta\hat{\sigma}^{qg \to qg}(\hat{s}) \otimes D_q^{\pi^0}(z)...$$

DIS ? pQCD e+e-

NLO sub-process in π production

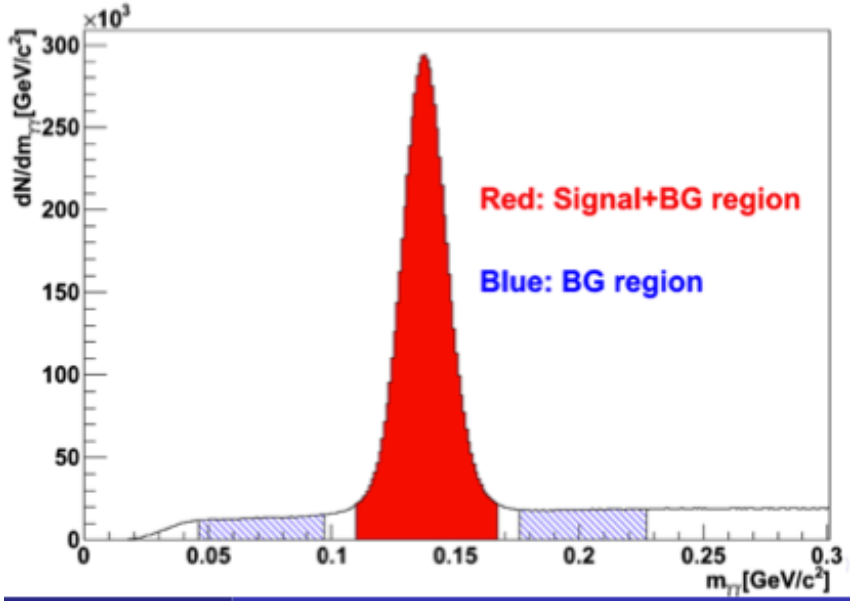


W. Vogelsang

-- Parton distribution functions
-- Partonic hard scattering rates
-- Fragmentation functions

π^0 A_{LL} measurement at PHENIX

- Integrated Luminosity 150 pb^{-1}, polarization ~ 56 % (2013)
- Reconstruct π^0 peak with γ pair in Electromagnetic Calorimeter at PHENIX (PbSc and PbGl)
- Large cross section + finely segmentation EMCal + high p_T photon trigger
- Inclusive asymmetry and side band background asymmetry
- $$A_{LL} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$
- R is the relative luminosity. It is the main source of systematic.



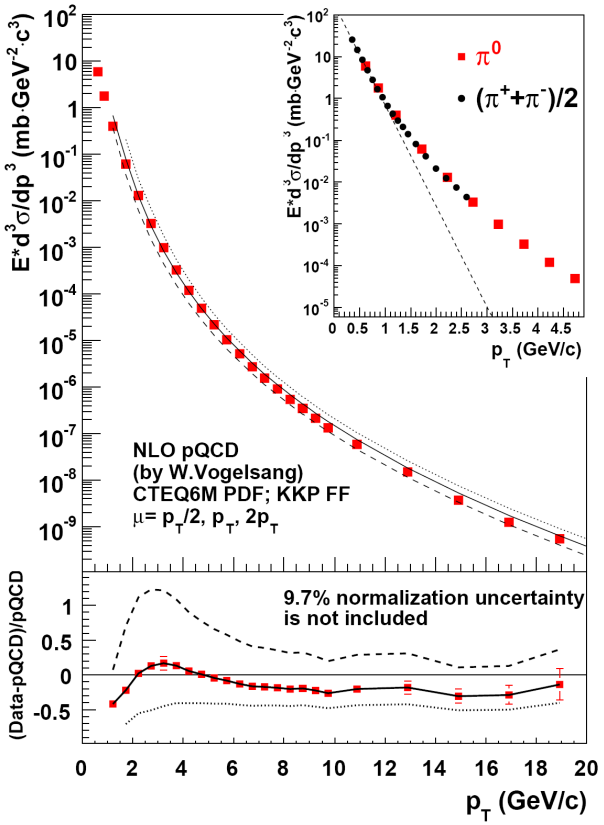
$$A_{LL}^{\pi^0} = \frac{A_{LL}^{(\pi^0+BG)} - rA_{LL}^{BG}}{1-r}$$

Unpolarized Cross Sections at Lower Energies

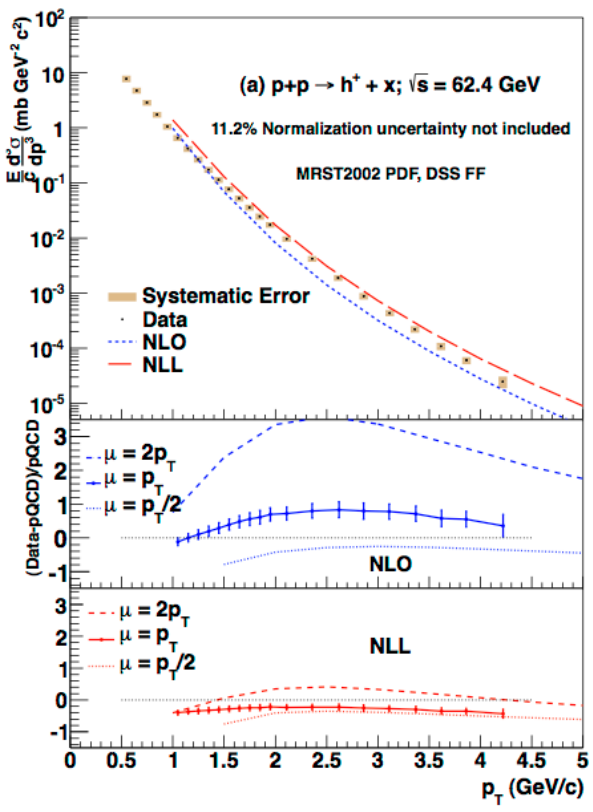
PRD 76, 051106

arXiv:1202.4020

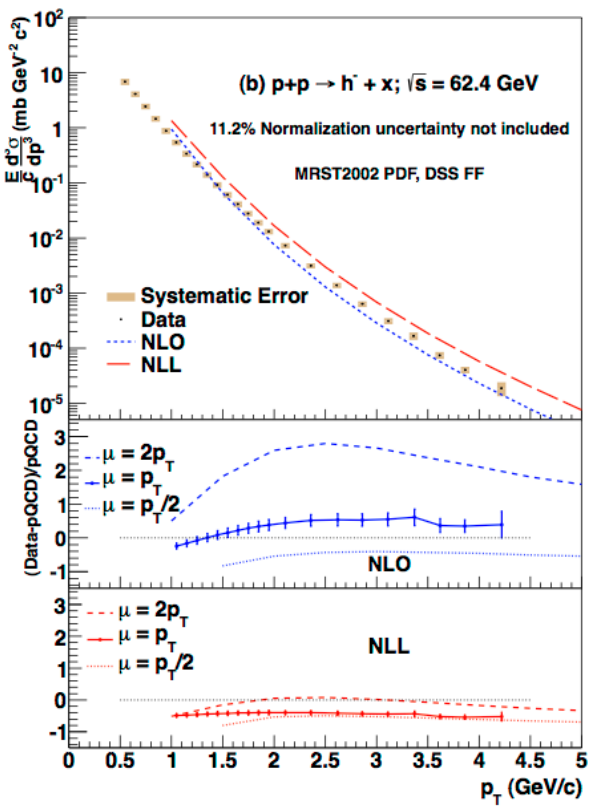
π^0 at 200GeV



h^+ at 62.4GeV

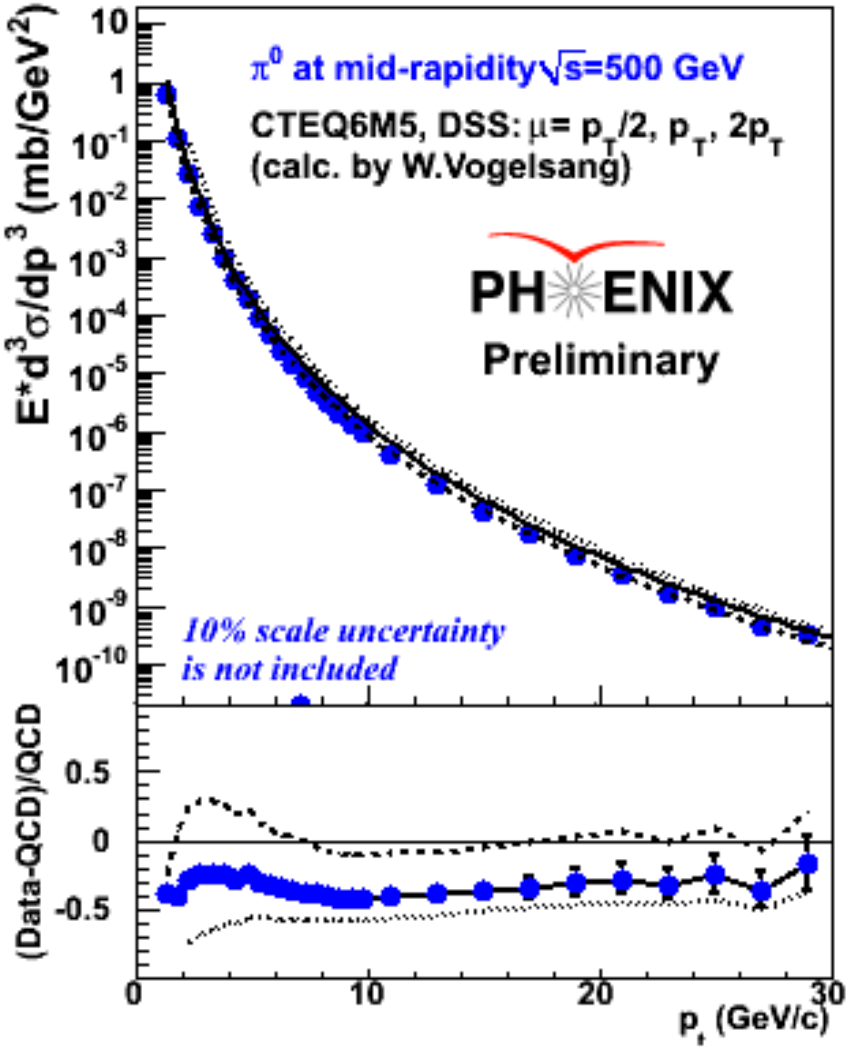


h^- at 62.4GeV



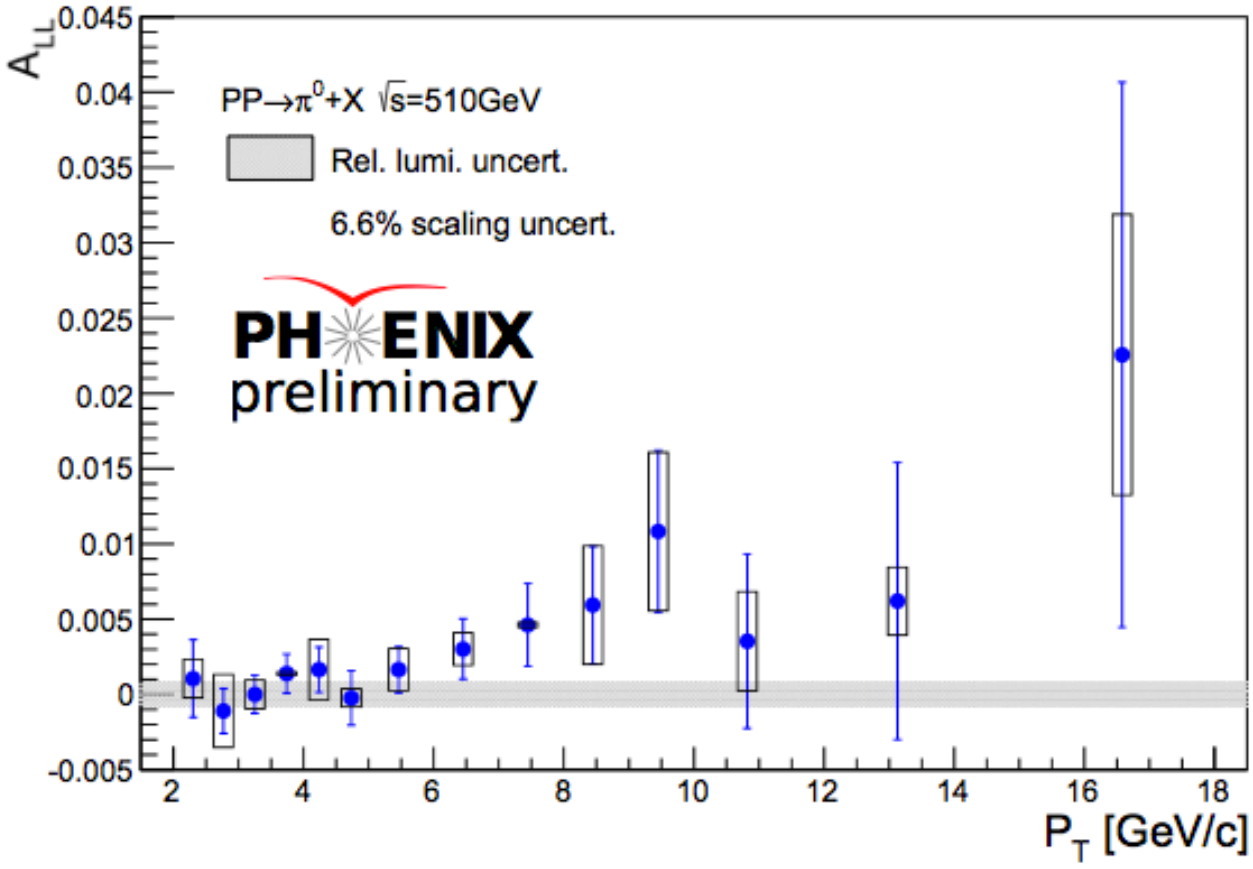
- **NLO QCD Calculation Cross-sections consistent with Data.**
- **pQCD works over a very broad kinematic range at RHIC energies**

π^0 Cross Section at 510 GeV



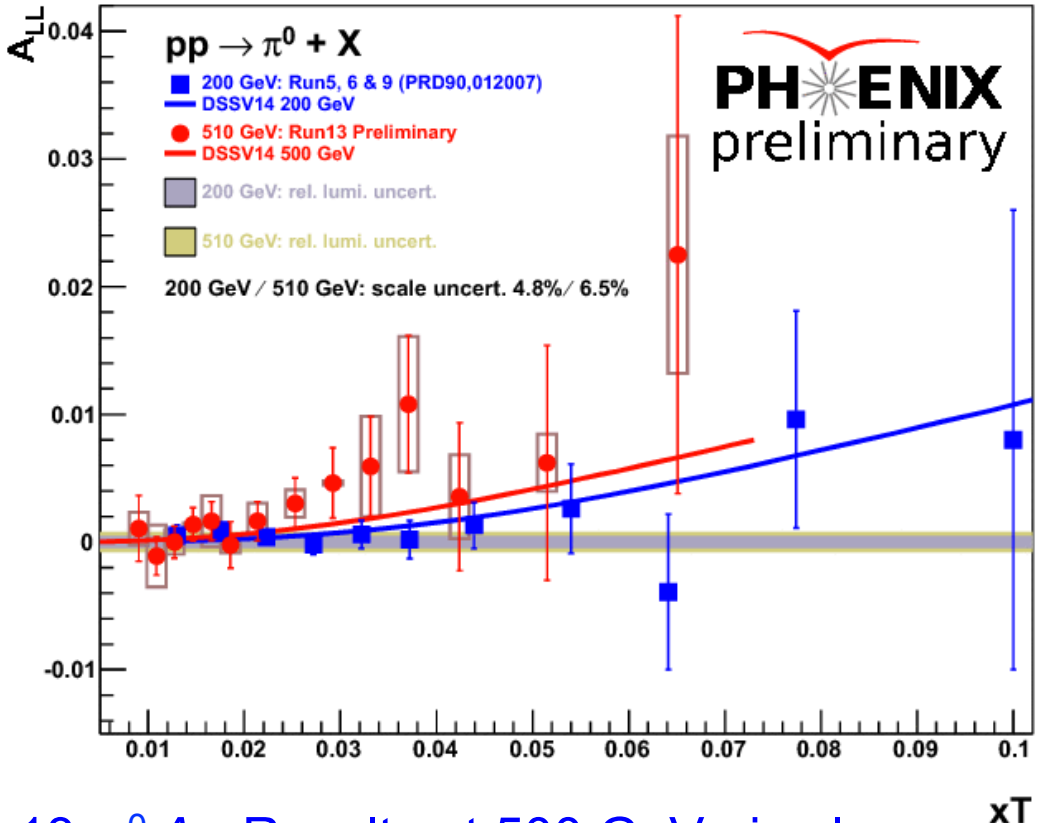
- Cross section results are given for transverse momenta p_T = 0.5 to 30 GeV/c.
- The cross section is described well by NLO perturbative QCD.

π^0 A_{LL} vs p_T Results



Larger asymmetry is observed at √s = 510 GeV.

π^0 A_{LL} vs x_T Results

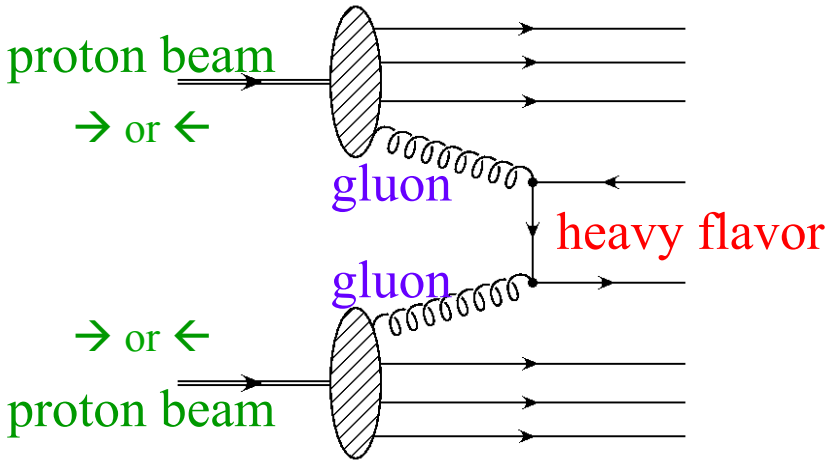


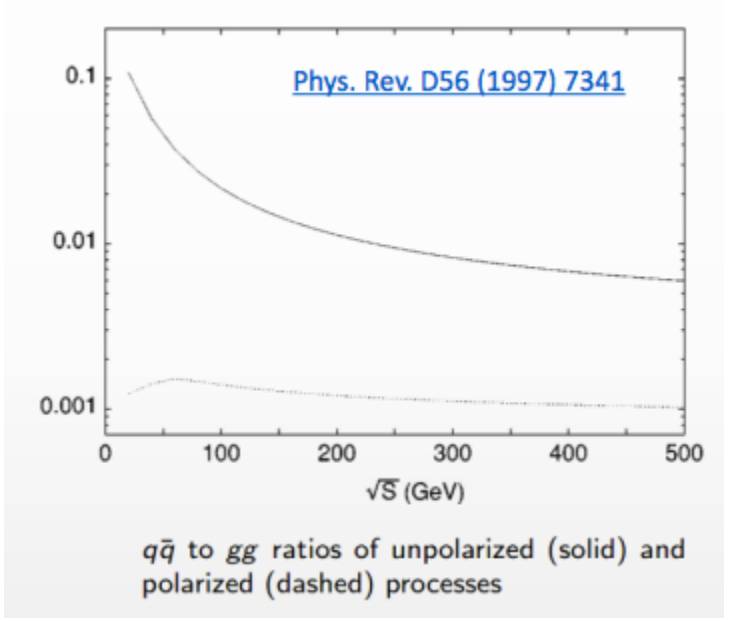
$$x_T = 2\frac{p_T}{\sqrt{s}}$$

- Run13 π^0 A_{LL} Results at 500 GeV give larger asymmetry compare with previous results at 200 GeV.
- Measured asymmetry is consistent with DSSV theory curve within uncertainties. Data favor larger A_{LL} than DSSV best fits.
- Data will add constrain in low-x region.

J/Ψ A_{LL} at PHENIX

- Heavy-flavor production is leading-order gluon interactions





- At RHIC energies J/Ψ production is dominated by gluon-gluon fusion. The J/Ψ A_{LL} can be written at LO

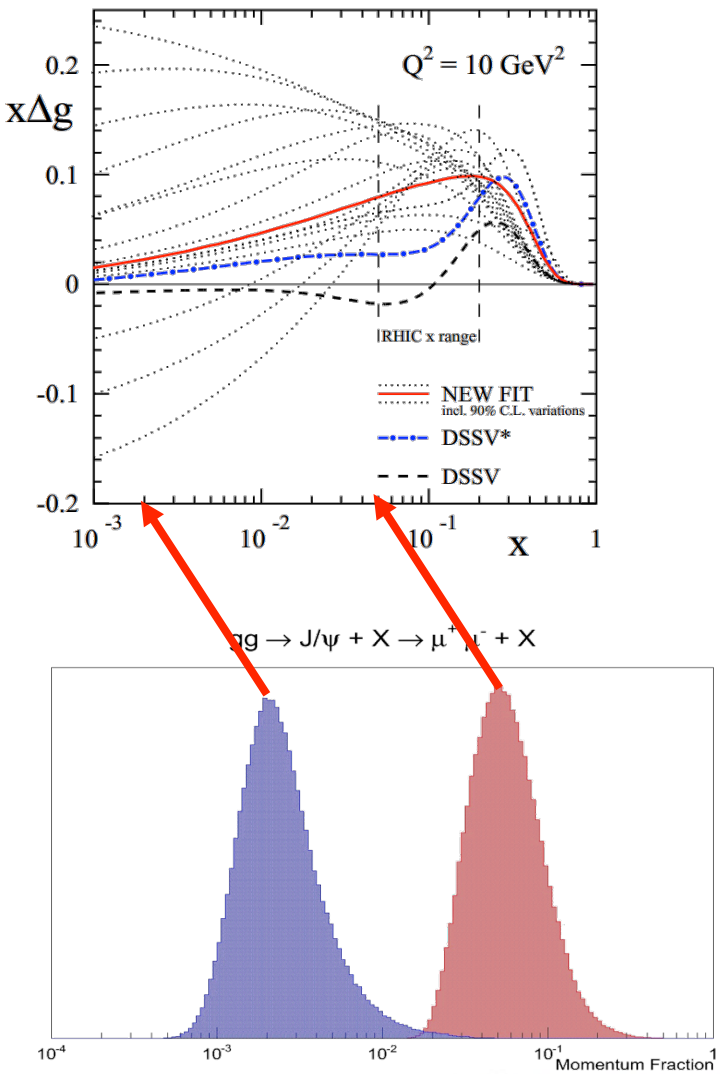
$$A_{LL} = \frac{\Delta\sigma}{\sigma} \propto \frac{\Delta g(x_1)}{g(x_1)} \frac{\Delta g(x_2)}{g(x_2)}$$

J/Ψ A_{LL} at Forward Rapidity

- At forward rapidity the x distribution of the two gluons are at very different region.
- PHENIX muon arms probing

$$\frac{\Delta g(x_1)}{g(x_1)}\frac{\Delta g(x_2)}{g(x_2)}$$

- The forward J/Ψ->μ+ μ- A_{LL} give sensitivity to possible sign change in xΔg.
- And it will accesses to low x range down to about 2×10^{-3}



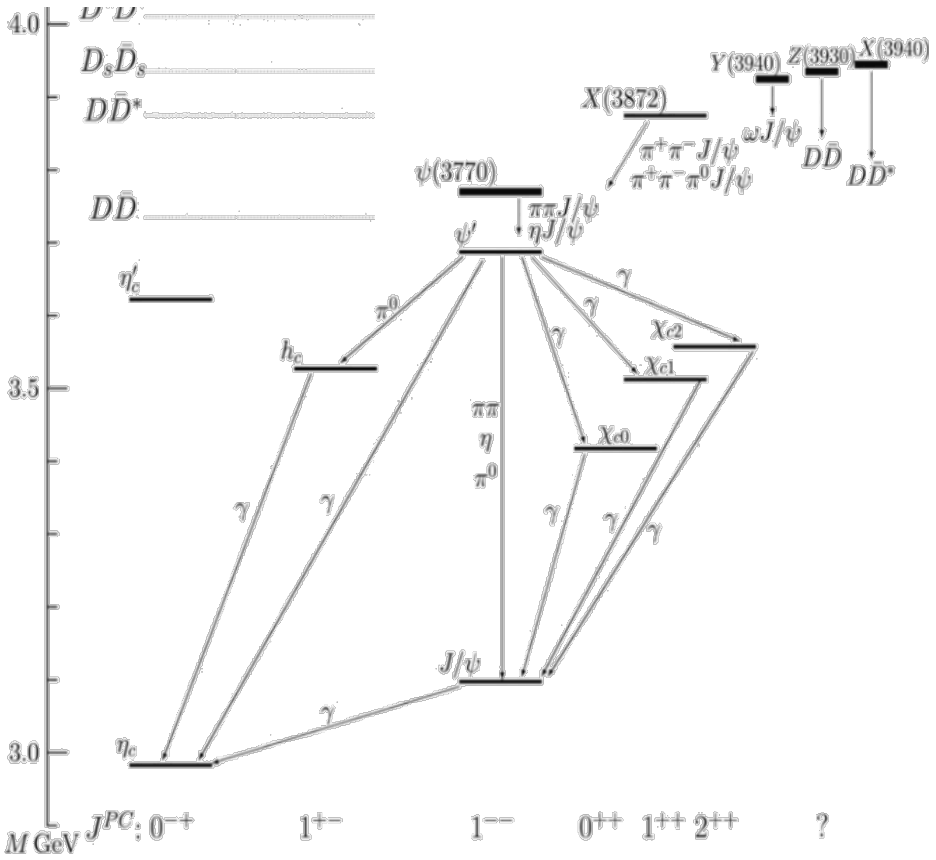
Charmonium A_{LL}

- Excited charmonium states are also generated in RHIC.
- Sizeable feed down (>40%) contribution from χ_C and ψ' .

  Phys. Rev. D85, 092004 (2012)
- Due to the PHENIX muon arm resolution, ψ's overlap with J/Ψ.
- Excited charmonium states might give different gluon polarization.

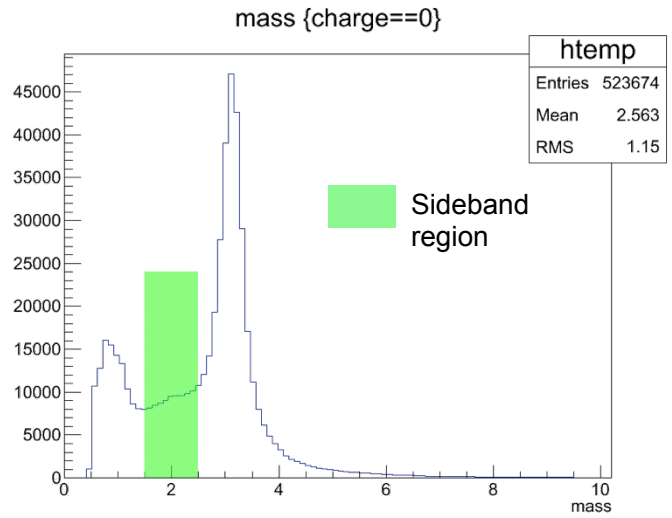
  Phys. Rev. D56, 7341(1997)
- Need more theoretical input to understand Δg through J/Ψ A_{LL}

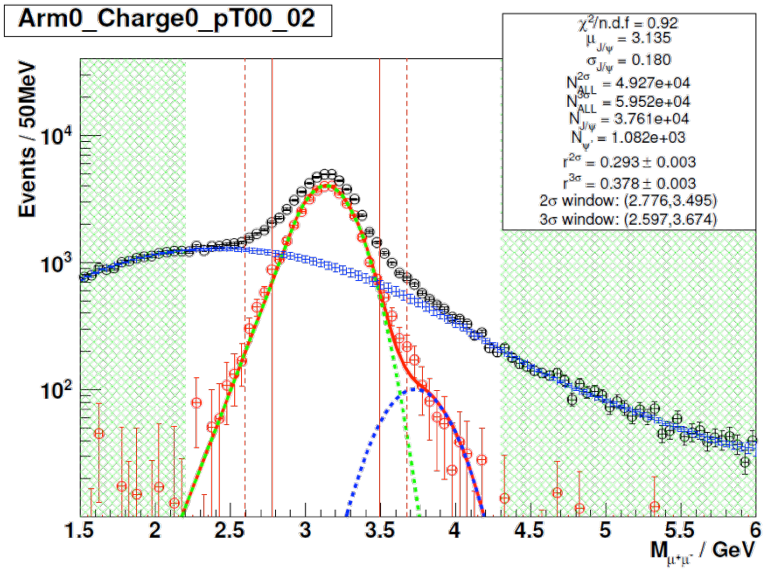
  J/Ψ production mechanism is involved!



J/Ψ A_{LL} measurement at PHENIX

- Analyze south and north arm separately, and divide data for each arm into 3 p_T bins.
- Fit each subsets for 2σ J/ψ mass window and background fraction "r".
  - Cristal ball shape for J/ψ, Gaussian for ψ'
  - Gaussian Process Regression (GPR) for background shape
- Sideband region is defined as $M_{\mu\mu} \in$ [1.5 GeV, 2.5 GeV]
- Calculate inclusive A_{LL} in the 2σ J/ψ mass window
- Estimate the background asymmetry from a sideband

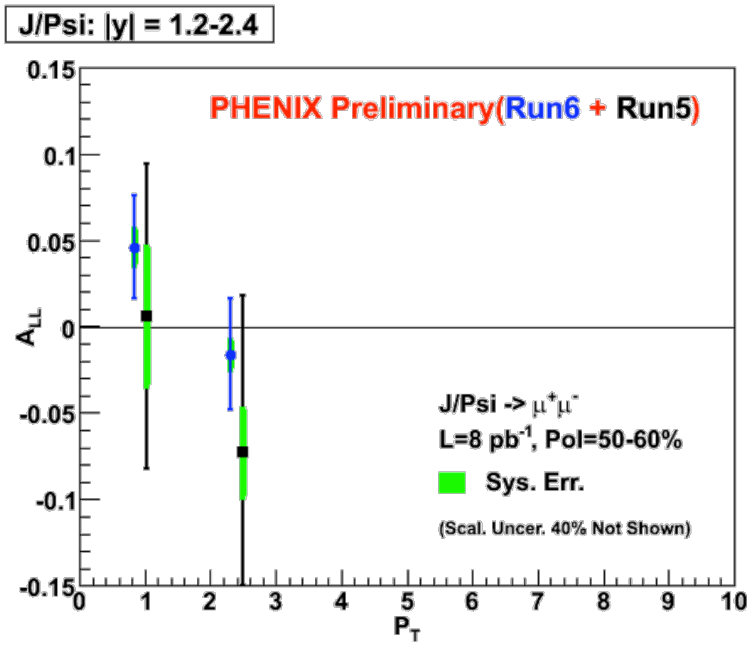


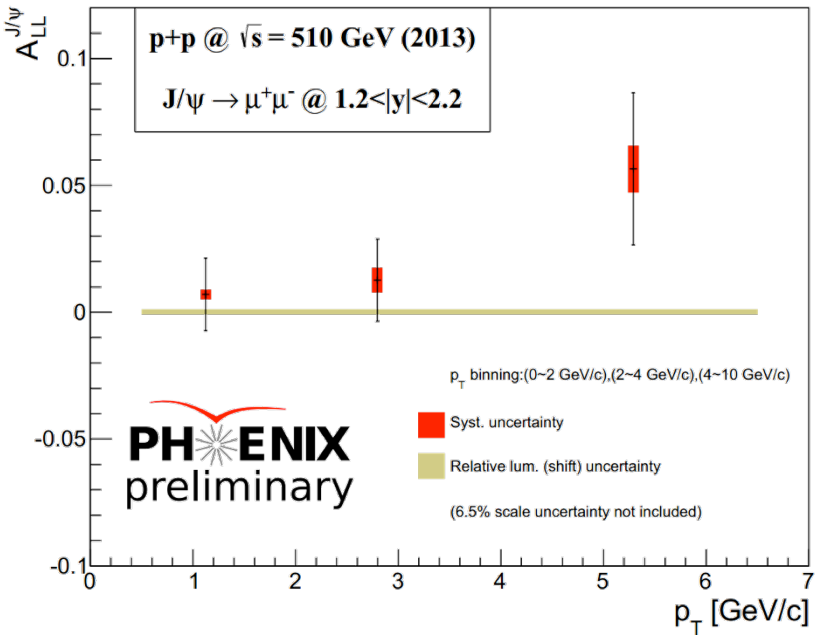


J/Ψ A_{LL} Results at Forward Rapidity

$$pp \rightarrow J/\psi + X \rightarrow \mu^+ + \mu^- + X \quad @ \sqrt{s} = 200GeV$$

$$pp \rightarrow J/\psi + X \rightarrow \mu^+ + \mu^- + X \quad @ \sqrt{s} = 510GeV$$





There is no theoretical calculation! J/Ψ production mechanism is not well understood?
Is it possible we could add data points into the global fit?

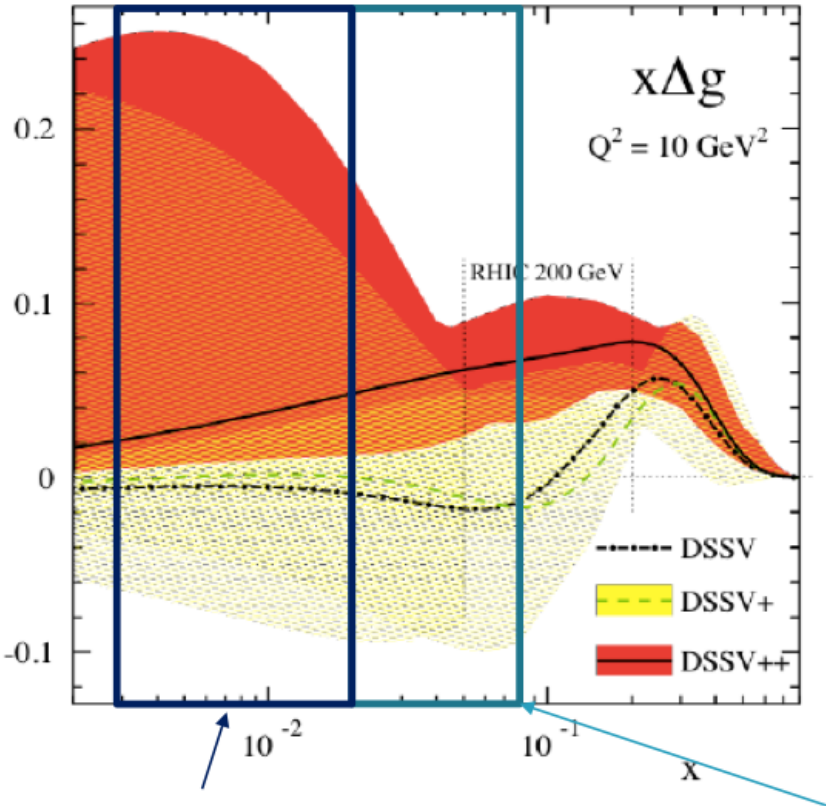
Summary

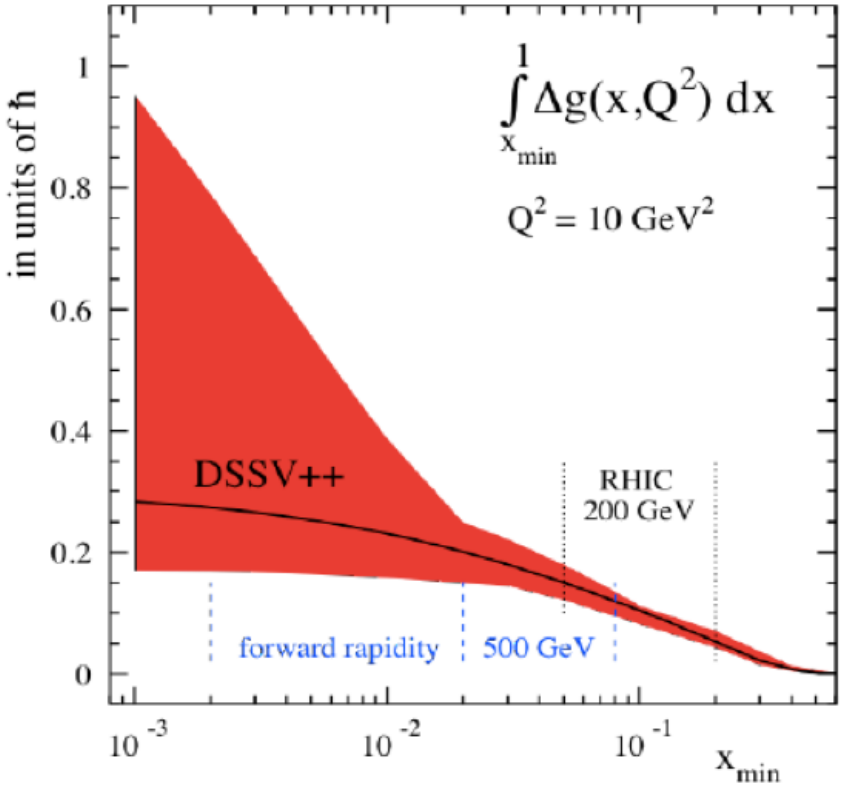
- Run13 pp 510GeV data has been taken and analyzed. Integrated Luminosity 150 pb^{-1}, Pol ~ 56%
- PHENIX measured the π^0 cross section A_{LL} in the middle rapidity. Larger asymmetry was observed compare with Run09 π^0 A_{LL} at 200 GeV
- PHENIX also measured the J/Ψ A_{LL} at Forward Rapidity. The statistical and systematic errors are significant improved compare with earlier run5 + run6 results.
- We encourage theory community to include those data into global analysis. We hope the data will help to constrain Δg at low x region.

- Final results toward to publications for central π^0 A_{LL} and J/Ψ A_{LL} at forward rapidity are underway.
- J/Ψ cross section analysis effort at 500 GeV is ongoing.

Outlook – Near Future

PHENIX π^0 A_{LL} measurement at 500 GeV at forward rapidity will come soon.





Forward π^0 A_{LL} analysis with PHENIX MPC (Run11 and Run13)

510 GeV Region

Experimental Probes for Nucleon Structure

- **Electromagnetic (E&M) probes: (γ*)**
  - Drell-Yan
  - Charged lepton scattering (DIS, SIDIS)

- **Strong interaction probes:**
  - Parton-parton scattering in hadron-hadron collisions

  Provide unique opportunities to study gluon properties in proton

- **Weak interaction probes:**
  - exchange W* or Z* during lepton nucleon scattering
  - W or Z production in h-h collisions

  W provide complementary information on the flavor decomposition.