Proton Spin at PHENIX

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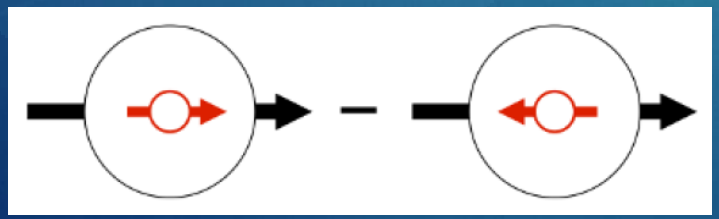
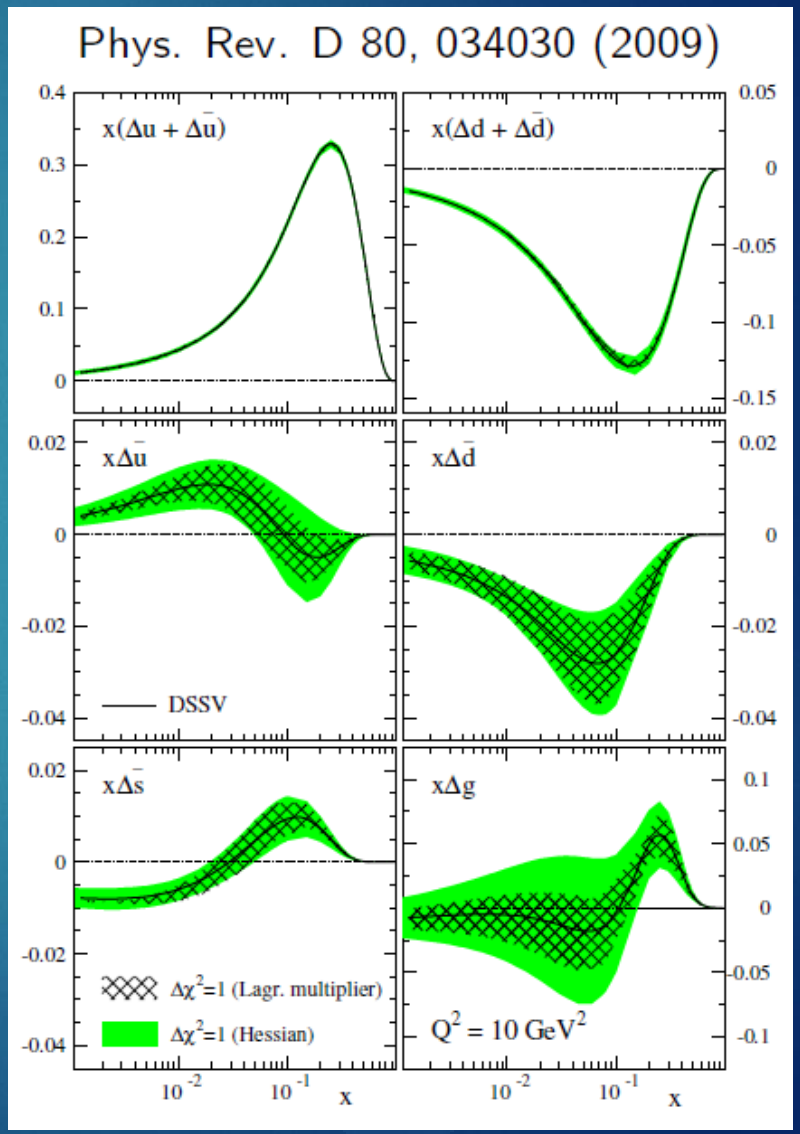
Overview

- Proton Spin
- RHIC Spin Overview
- PHENIX Measurements
  - Transverse spin
  - Gluon polarization
  - Sea quark polarization
- Future Prospects

Proton Spin

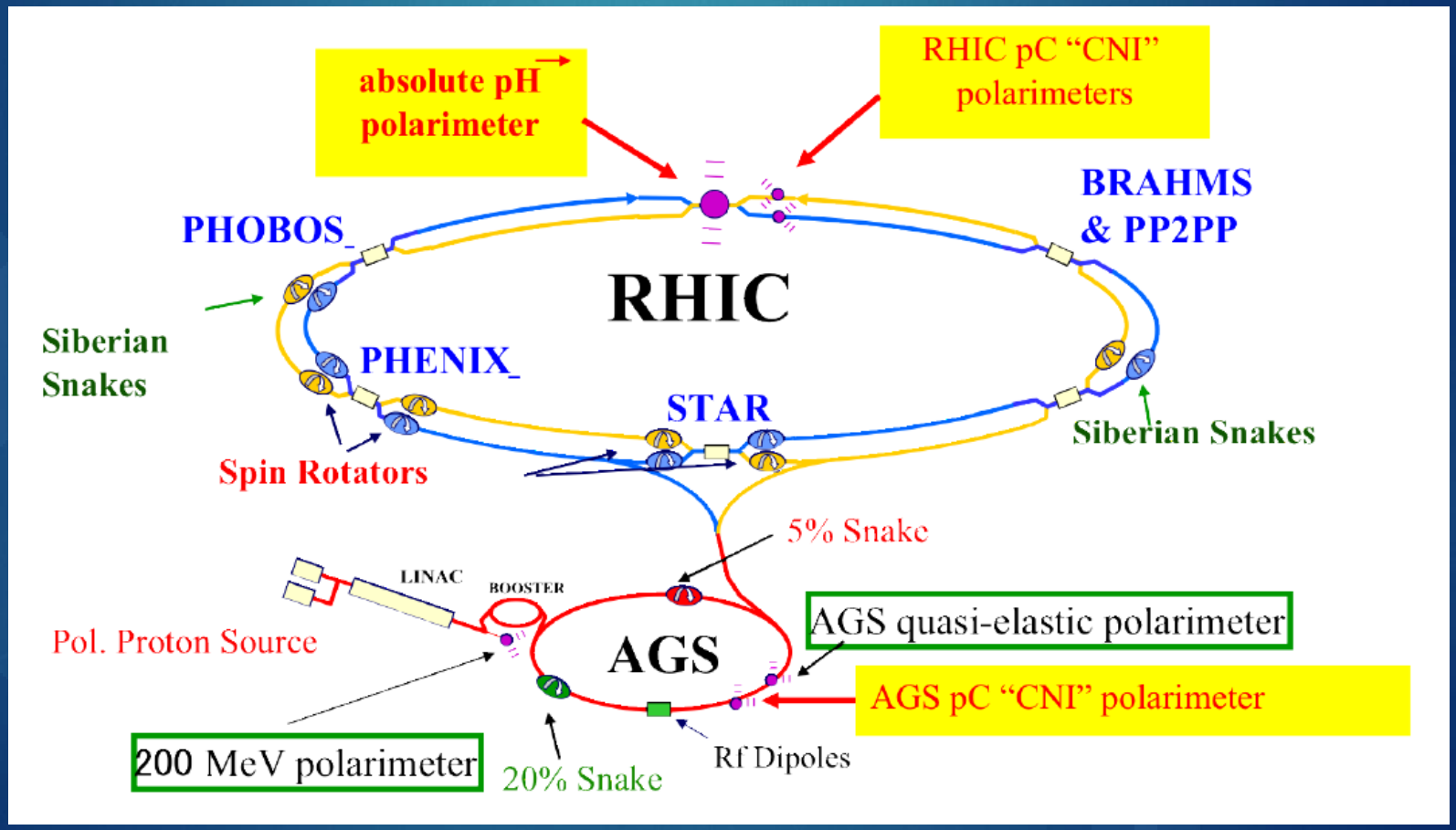
- Proton Spin "crisis"
- Spin Composition of the Proton:
  - $S_p = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_q + \mathcal{L}_g$
    - $\Delta\Sigma$ – Quark and anti quark spins
    - ΔG – Gluon spin
    - $\mathcal{L}_x$ "orbital angular momentum"
- Current Understanding
  - DIS/SIDIS
    - Δq, some $\Delta\bar{q}$
  - RHIC
    - Δg, $\Delta\bar{q}$





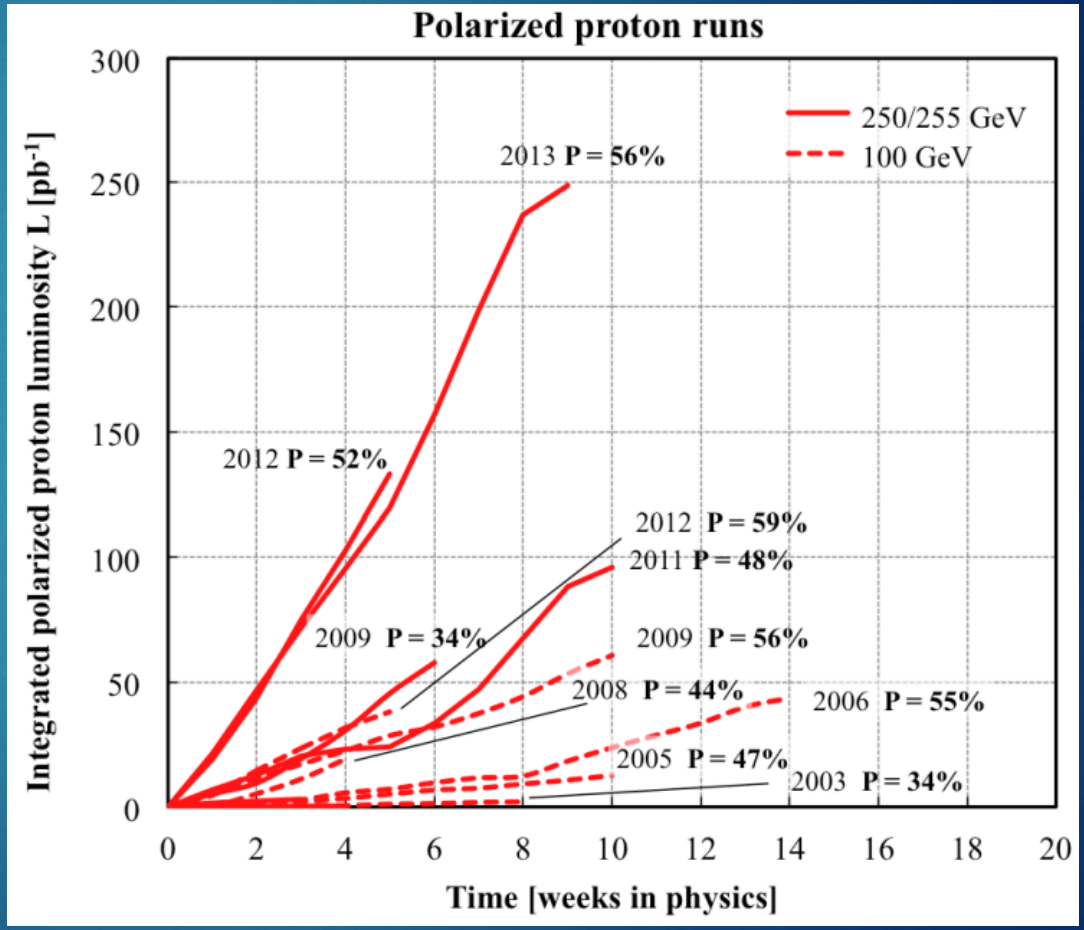
Spin at RHIC

- $\sqrt{s} = 510\ GeV$ at up to 60% polarization
- "Siberian Snake" Spin Rotators



Spin at RHIC

- Up to $\sqrt{s} = 510$ GeV
- High polarization is important for figure of merit
  - $A_{LL}FOM \propto LP^4$
  - $A_L FOM \propto LP^2$

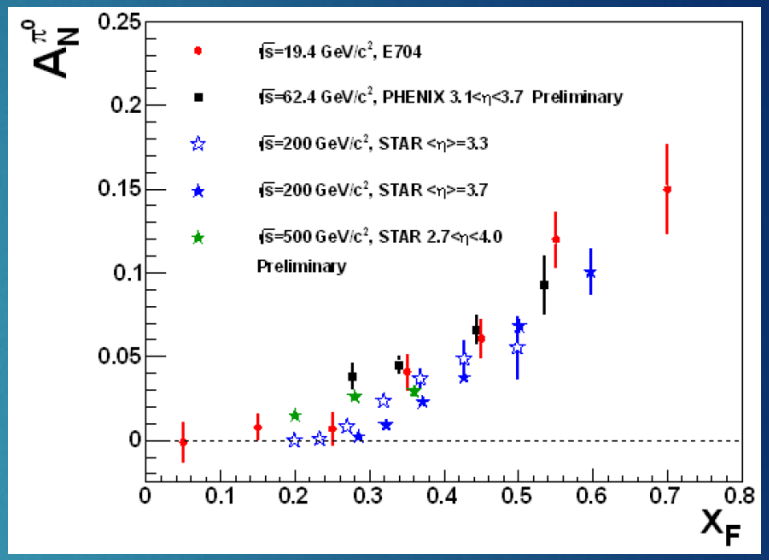


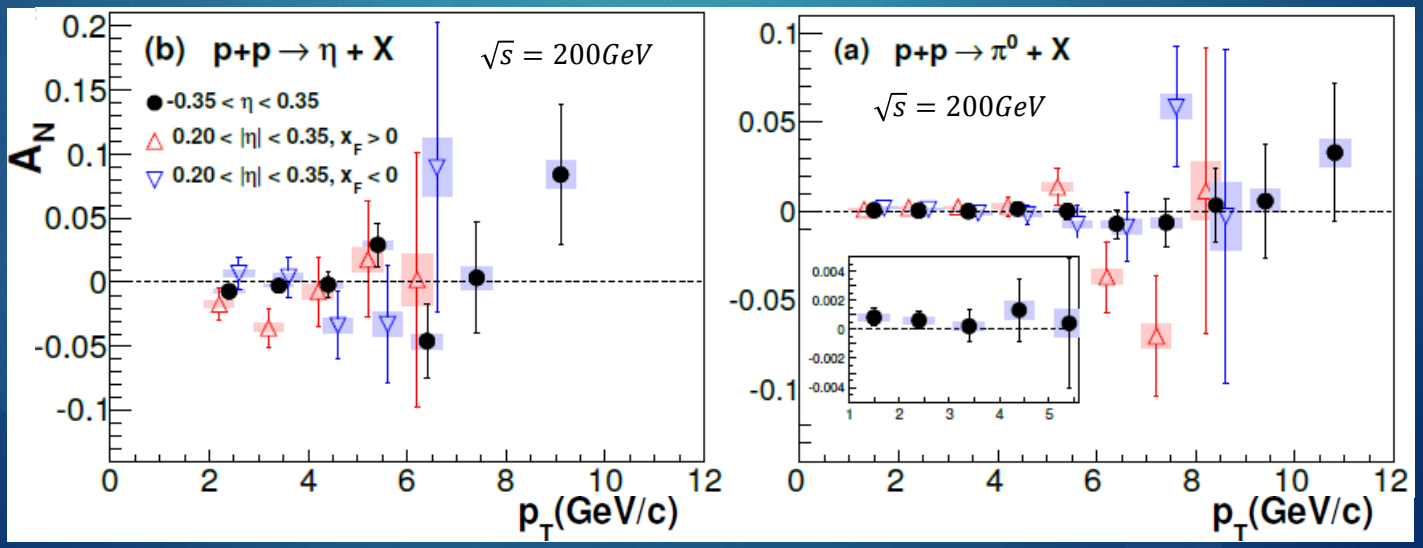
PHENIX Spin Measurements

- Transverse Spin
  - Forward single spin asymmetry A_N
  - Future Measurements
- Gluon Spin (Δg)
  - Various q and g interactions in pp scattering
  - Double spin asymmetry A_{LL}
- Sea Quark Spin
  - $q\bar{q} \rightarrow WX \rightarrow \ell\nu_\ell$
  - Single spin asymmetry A_L

Transverse Spin

- Current measurements:
  - Single spin asymmetry in inclusive hadron production
  - Unexpectedly large asymmetry at forward rapidity
    - QCD predicts $A_N \sim 10^{-4}$
    - RHIC measurements confirm previous observation



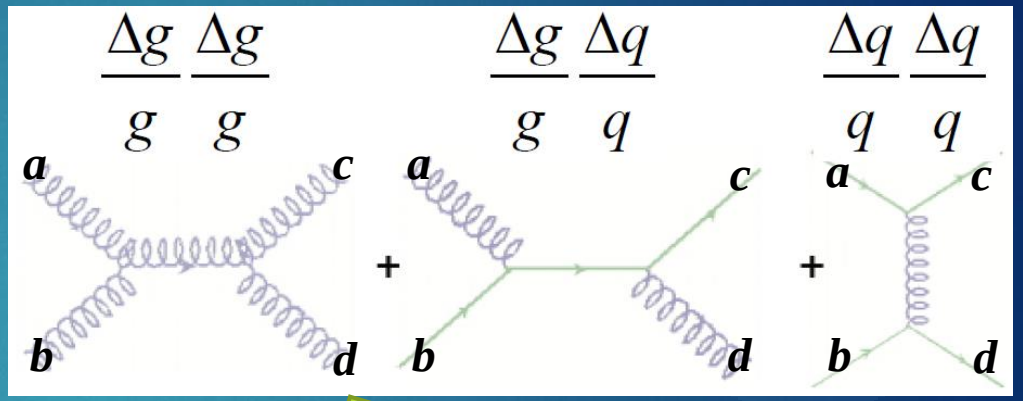


Transverse Spin

- Possible theoretical interpretation
  - correlations between transverse proton spin and intrinsic transverse quark momentum in the initial state (Denis Sivers, 1990).
  - correlations between transverse quark spin and hadron k_T in the finals state jet (John Collins, 1993)
- Further exploration
  - Other channels
    - eg. J/Ψ: heavy flavor sensitive to gluons
  - Forward calorimeter upgrade (MPCEX)
    - γ's offer more direct access to origin of transverse spin
  - fsPHENIX
    - Jet measurements
- BONUS: Tie-in to heavy ion
  - Forward A_N for p collisions with various heavy species:
    - Trend of change in A_N sensitive to gluon saturation

Accessing Gluon Spin

- A_{LL} measurements made for various final states (π^o, $\pi^{\pm}$, η, $e^{\pm}$, jets, di-hadrons, di-jets)
- Sensitivity to Δq, Δg depends on interaction



$$A_{LL}^{\pi^o} = \frac{\Delta\sigma^{p+p\to\pi^o+X}}{\sigma^{p+p\to\pi^o+X}} = \sum_{a,b,c,d=q,\bar{q},g} \frac{\Delta f_a \; \Delta f_b}{f_a \; f_b} \frac{\Delta\hat{\sigma}^{a+b\to c+d}}{\hat{\sigma}^{a+b\to c+d}} \frac{D_{c+d\to\pi^o}}{D_{c+d\to\pi^o}}$$

Quark & gluon PDF's

pQCD calculable hard scattering σ

Fragmentation functions

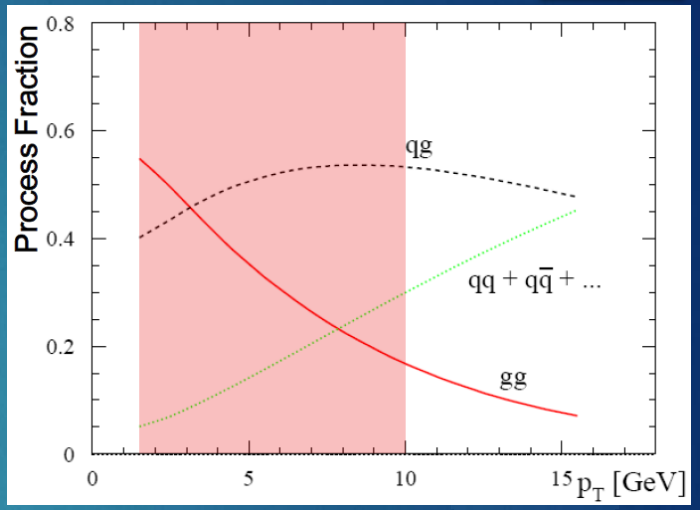
In terms of observables:
- P – beam polarization
- R – Relative luminosity ($R = L_{++}/L_{+-}$)
- N – event yields

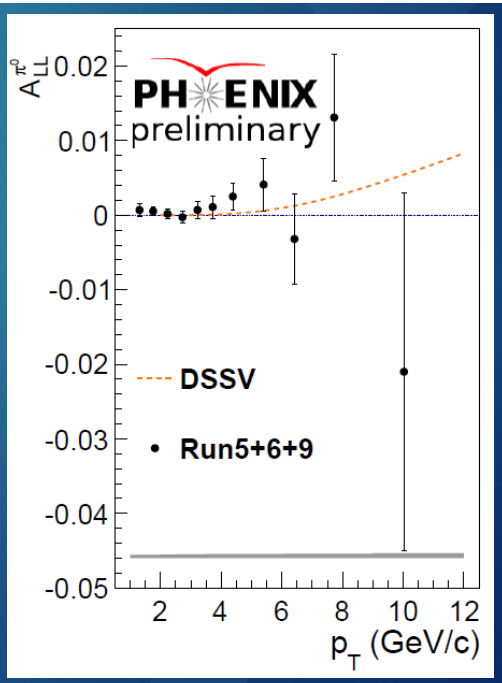
$$A_{\mathrm{LL}} = \frac{1}{P_B P_Y} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}}$$

A_{LL} Measurements

- PHENIX measures A_{LL} at low p_T
  - Large PHENIX DAQ bandwidth and trigger rate → access to lower p_T, lower x
  - Good statistical resolution for magnitude of Δg

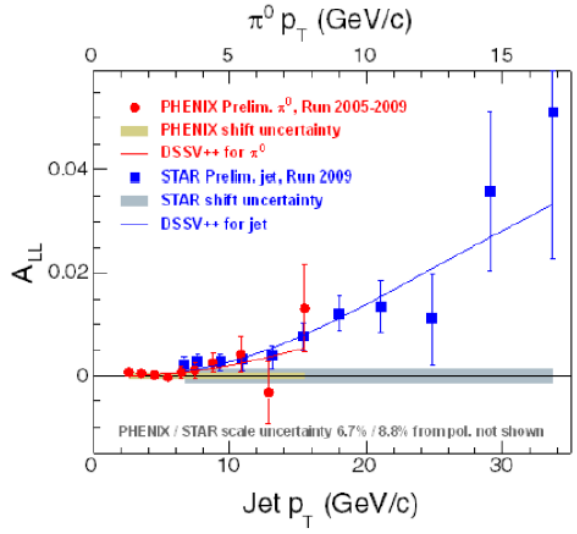
- measurements from 2005,06,09
  - $200\ GeV\ \pi^o$ asymmetry
  - Recently submitted for publication
  - Trends above theory curve

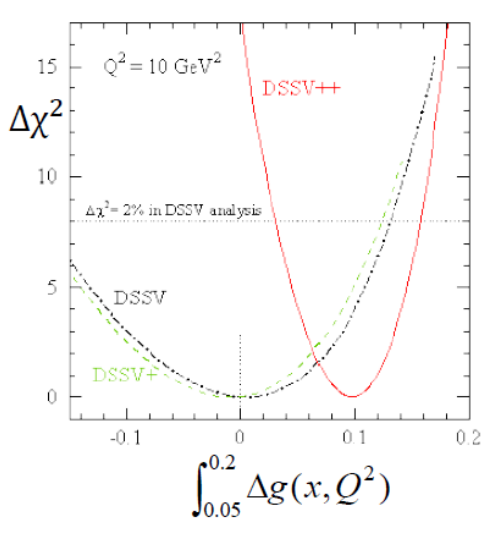




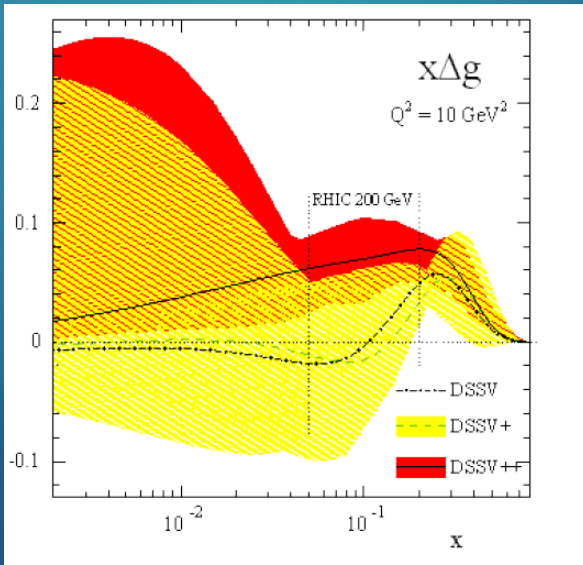
Results and Prospects

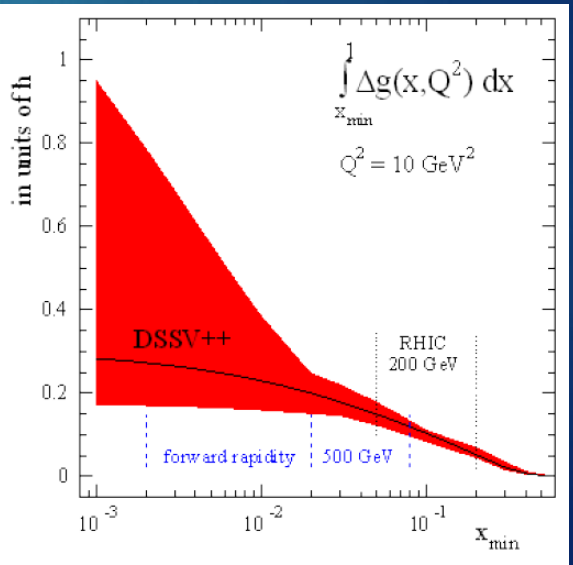
- STAR and PHENIX results for jet and π^o respectively
- First sign of a non-zero Δg





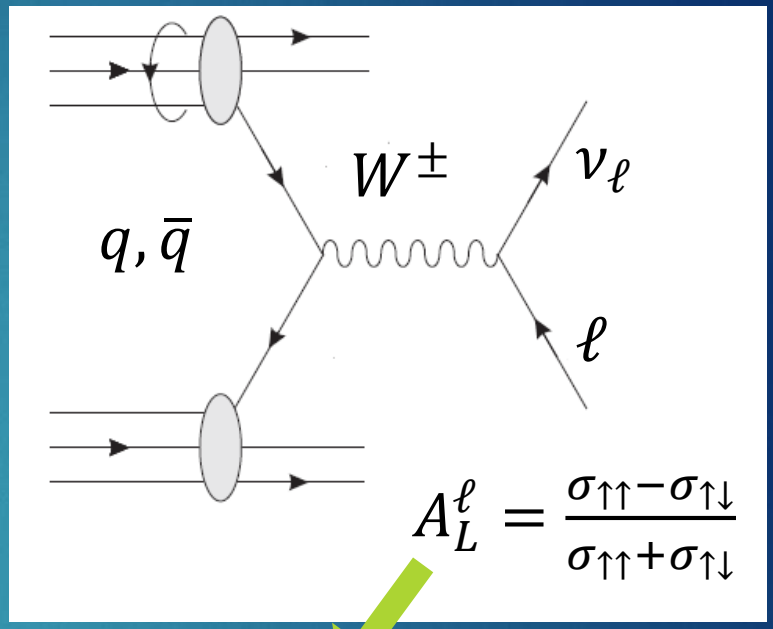
- Projected improvement to DSSV global fit
  - Improvements and further data with forward detectors
    - Forward rapidity sensitive to low x





Accessing Sea Quark Spin

- More clean and direct access with the weak interaction
  - No fragmentation functions
  - High Q^2
- Constraints:
  - Weak parity violation
    - W's couple to left handed q and right handed $\bar{q}$
  - Known q spin distributions
    - u spin tends to be aligned with proton spin, d anti-aligned



$$A_L^{W^+} = \frac{-\Delta u(x_1)\bar{d}(x_2) + \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}$$

$$A_L^{W^-} = \frac{-\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

Flavor Sensitivity at Forward Rapidity

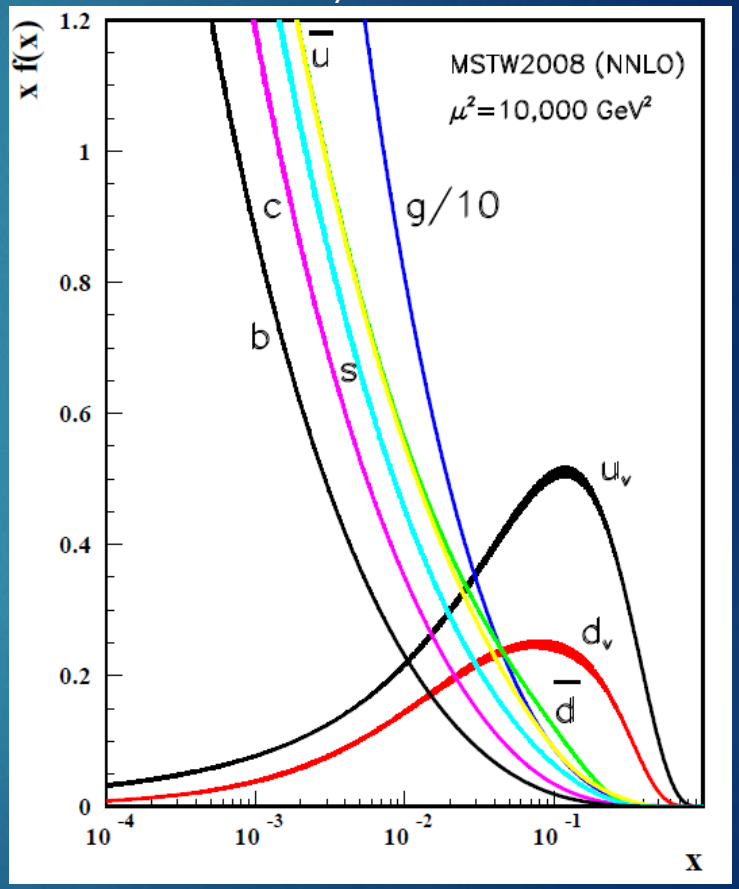
- A first order motivation:
  - At forward rapidity $x_1 \gg x_2$ or $x_1 \ll x_2$
  - A_L equations reduce:

$$A_L^{W^+} \approx \frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)} \quad for \;\; x_1 \gg x_2$$

$$A_L^{W^-} \approx \frac{\Delta\bar{u}(x_1)}{\bar{u}(x_1)} \quad for \;\; x_1 \gg x_2$$

- It's not actually this simple!
  - Extracting $\Delta\bar{q}$ requires NLO pQCD and modern resummation techniques

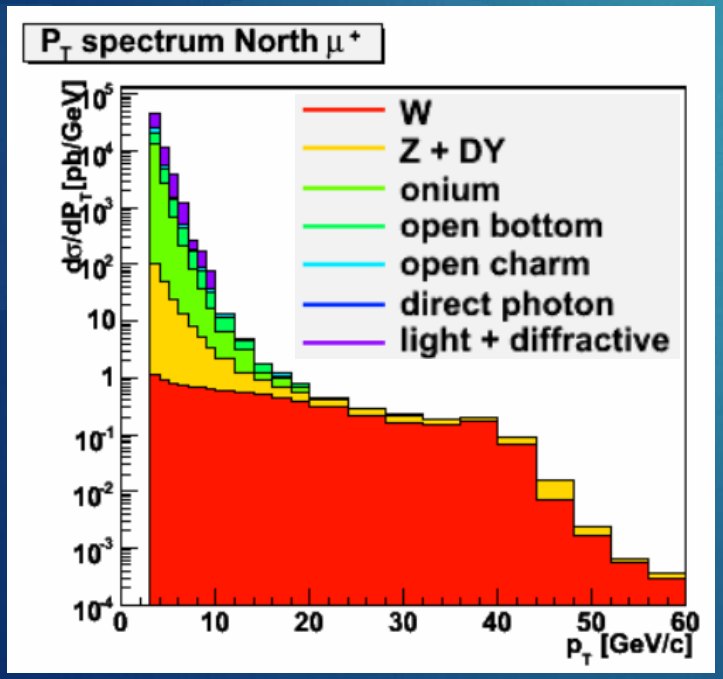
Proton Constituent Probability Distributions



Asymmetry Challenges

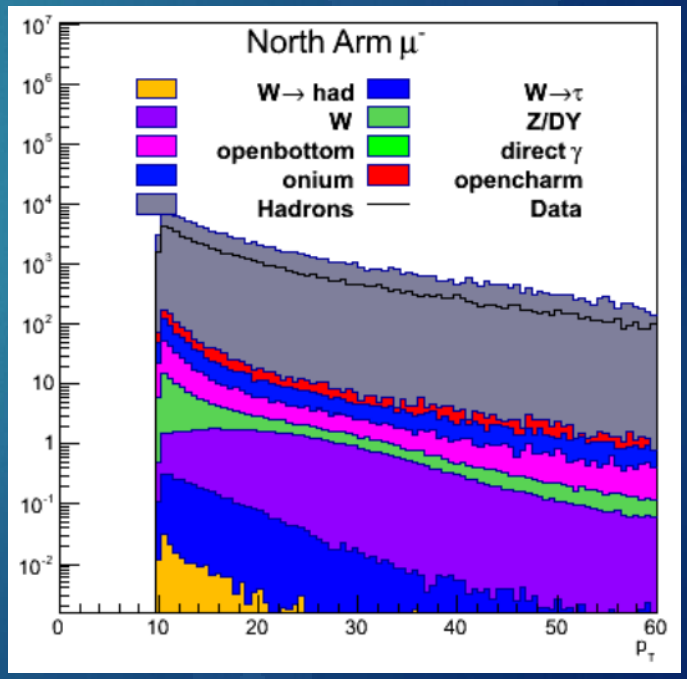
- Signal $W \rightarrow \mu\nu$ events dominated by other processes
  - Other sources of muons, "Fake" muons from hadronic decay
- Made worse by p_T smearing in tracking detectors

Process cross sections vs p_T from simulations



Left: Muon backgrounds and signal only. True distributions – no smearing

Right: Also includes hadronic background with real detector p_t smearing included

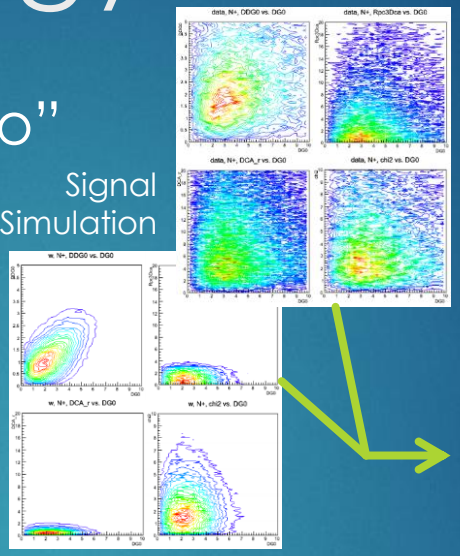


Analysis Strategy

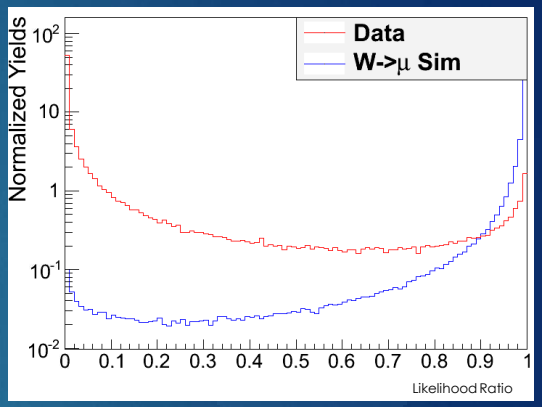
- Construct "likelihood ratio" for **event pre-selection**
- Characterize **signal/background** of resulting data set
- Calculate **Final Asymmetries**

Data (Background)

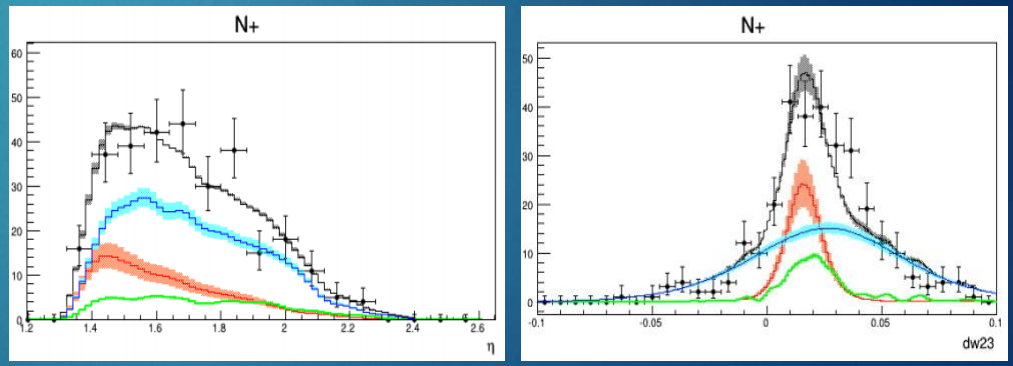
Signal Simulation



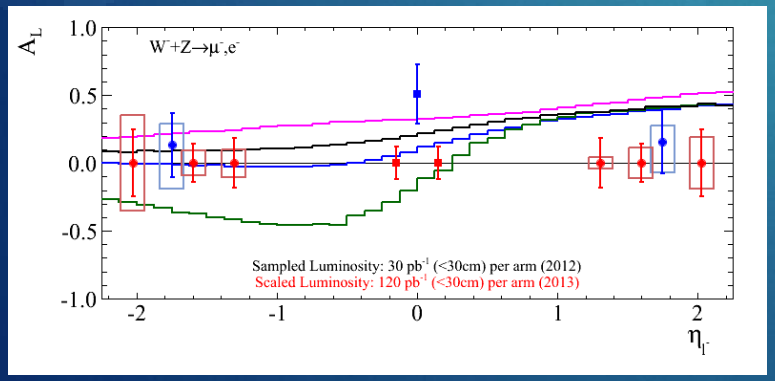
Likelihood Ratio



Results of 2D unbinned maximum likelihood fit

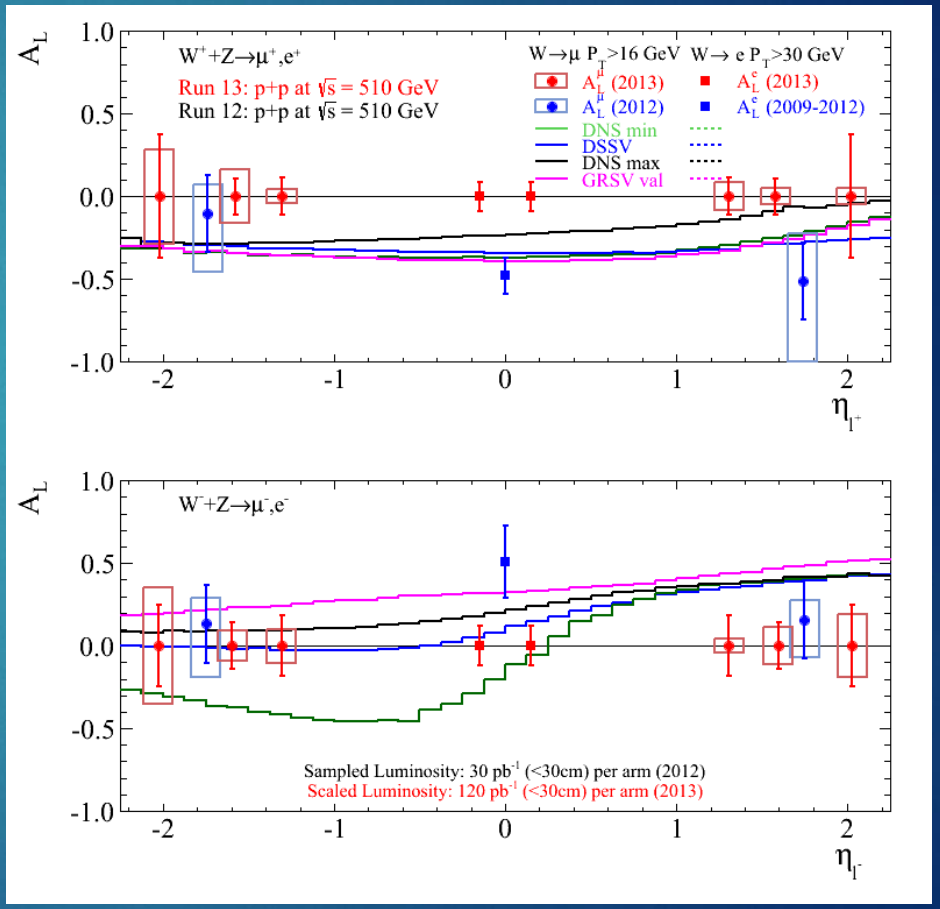


Example Projected Asymmetries



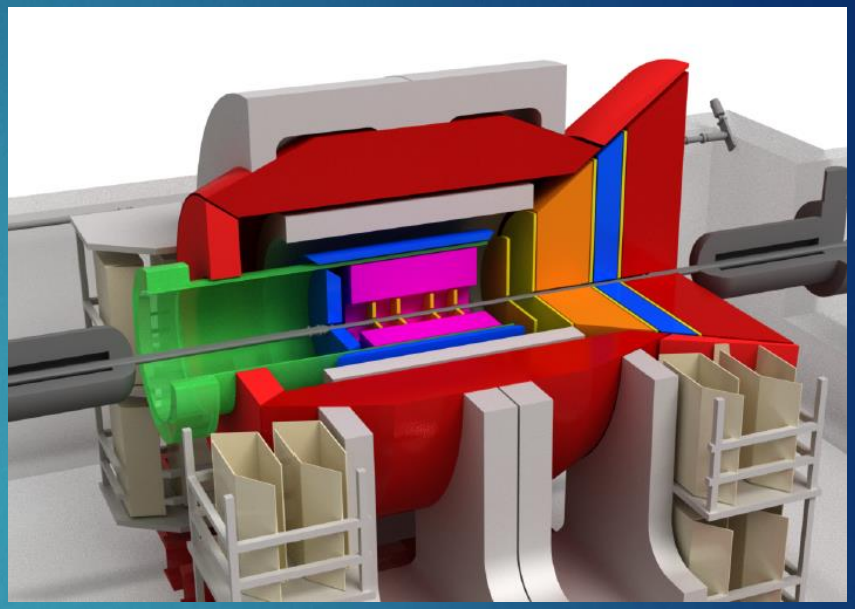
Results and Prospects

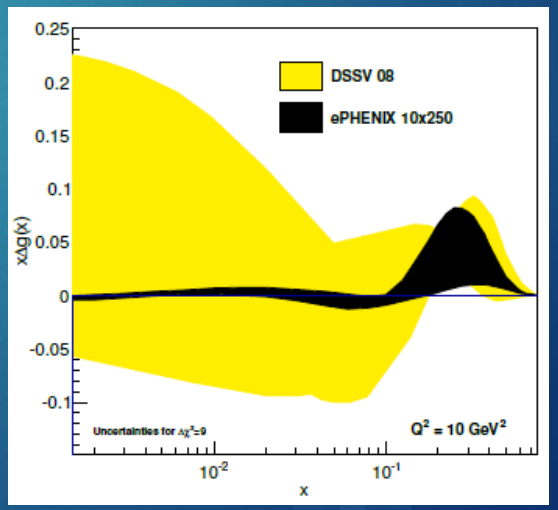
- **2012 preliminary Results**
  - $42\ pb^{-1}$
- **Projected 2013 Results**
  - Projected error for 200 pb^{-1}
  - Actual data taken:
    - 228 pb^{-1}
  - Analysis well underway, preliminary results soon!



Proposed Upgrades

- sPHENIX, ePHENIX
  - Hear more tomorrow evening! (Jin Huang)
- Spin Measurements:
  - ePHENIX – greatly improved Δg
  - Kaon asymmetries for $\Delta \bar{s}$
  - Transverse momentum distributions





Summary

- Various PHENIX measurements aim to constrain least known aspects of proton spin structure
  - Δg with A_{LL} at forward and central rapidity
  - $\Delta \bar{q}$ with W A_L at forward rapiditiy
  - Explore transverse spin with A_N
- Future RHIC Upgrades will provide even further understanding