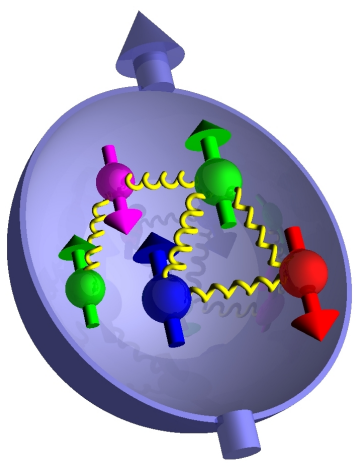
Spin Physics Opportunities with the NCC

What makes up the nucleon spin?

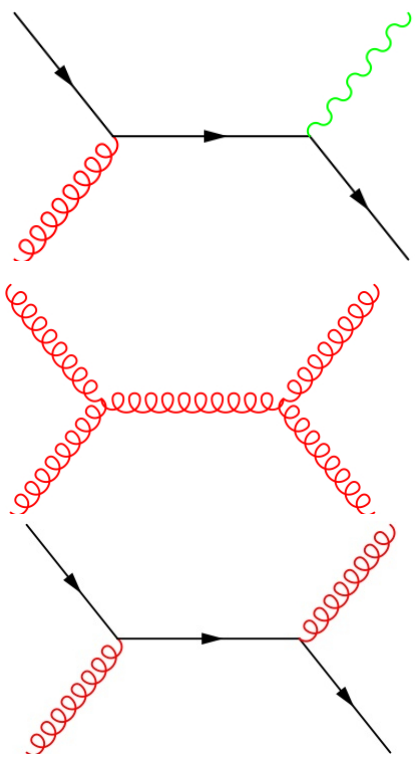


$$\frac{1}{2}\hbar = S_{quark} + L_{quark} + S_{glue} + L_{glue}$$
$$= \frac{1}{2}\Delta\Sigma + L_{quark} + \Delta G + L_{glue}$$

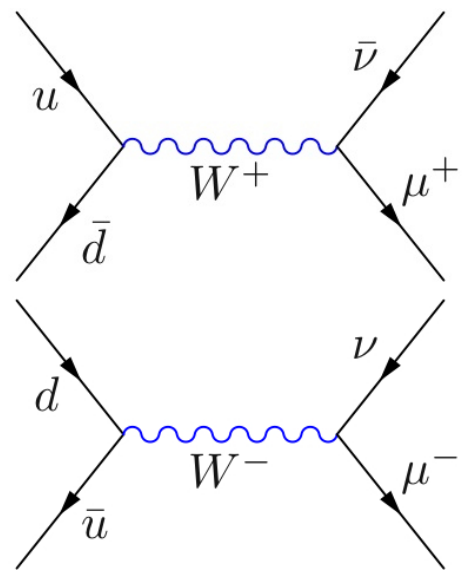
- Polarized partonic structure determined over a small range in *x* and Q^2
  - ✓ *Quark spins account for 30% of proton spin*
  - ✓ *Gluon contribution unconstrained from deep inelastic scattering*
  - ✓ *Role of Orbital angular momentum unclear*
  - ✓ *Existing (fixed target) Direct DIS determination of gluon and virtual sea contributions complicated by understanding of fragmentation*

RHIC with Polarized Protons

- Collisions of Longitudinally Polarized Protons
  - ✓ Gluon spin contribution ΔG to proton spin directly accessible
  - ✓ Different final states give different sensitivities
  - ✓ Direct photon is theoretically cleanest for gluon spin contribution
  - ✓ Use $W^{\pm}$ reaction to determine virtual sea contribution



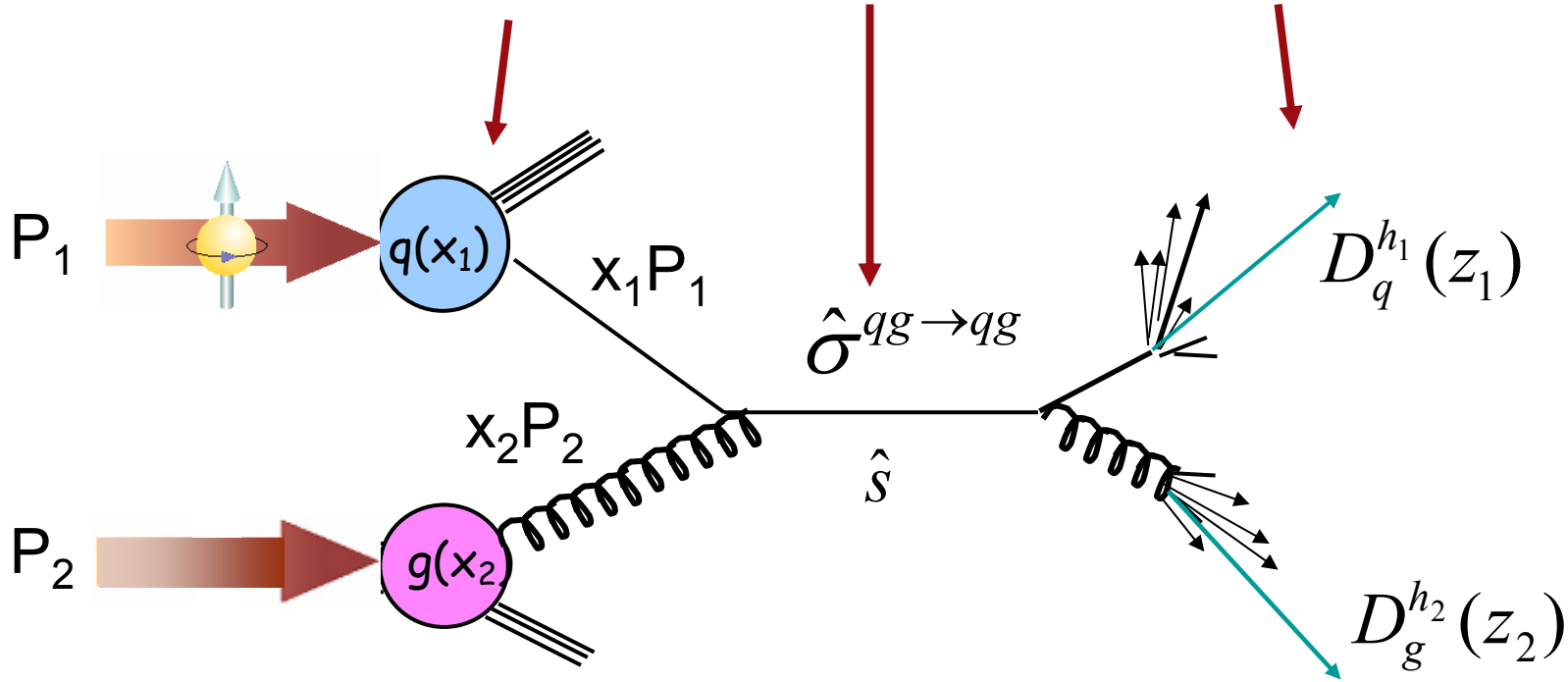
$$\frac{\Delta g}{g}$$



$$\frac{\Delta \bar{q}}{\bar{q}}$$

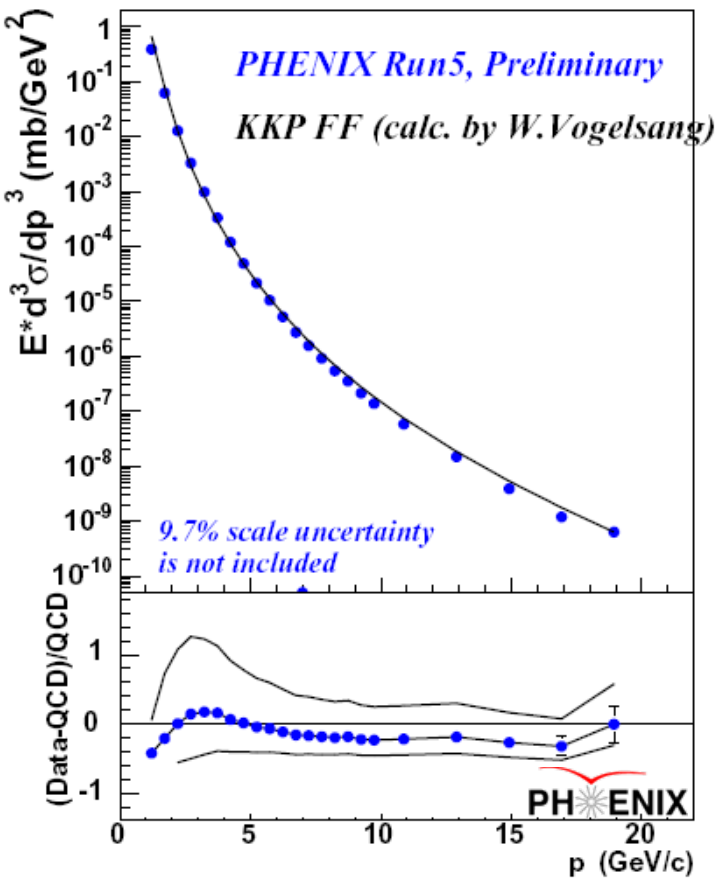
Hard Partonic Reactions in *pp* Collisions

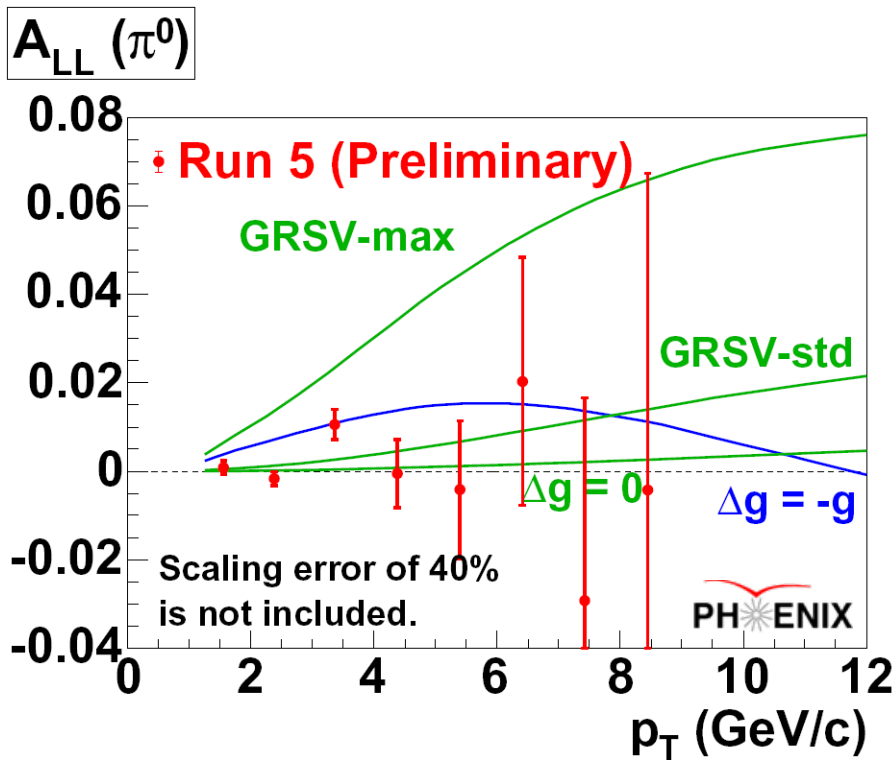
$$d\sigma_{pp} \propto q(x_1)g(x_2)\ \hat{\sigma}^{qg\to qg}(\hat{s})\ D_q^{h_1}(z_1)D_g^{h_2}(z_2)$$



PHENIX Inclusive π^0 Results

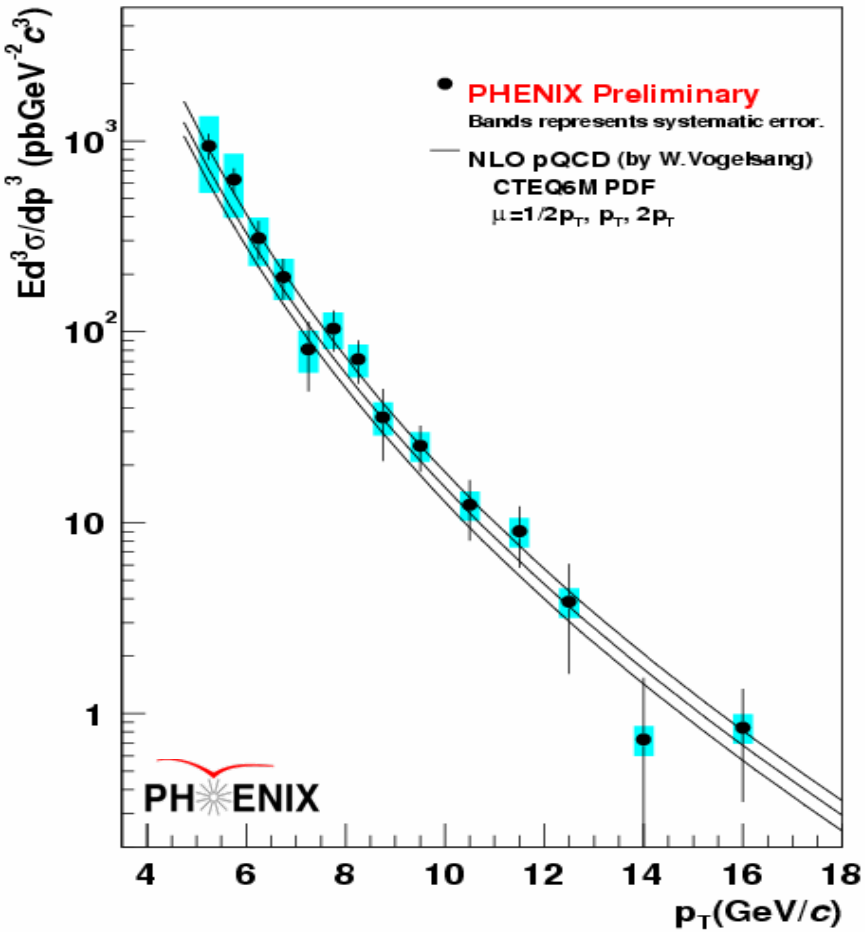
Detect π^0 in Central Arm detectors

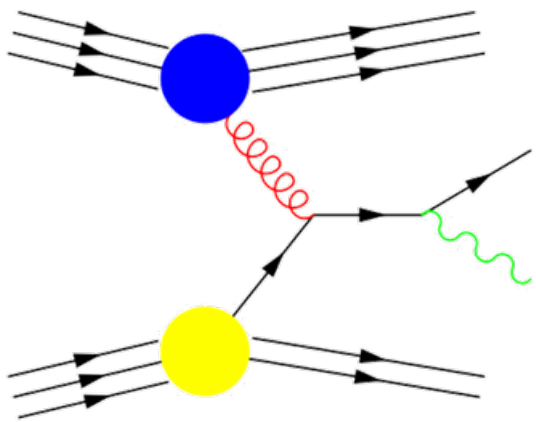




Perturbative QCD works at RHIC !

PHENIX Direct Photon Results





Earlier theoretical issues with fixed target data are understood

Determining $\Delta g(x)$

Theoretical analysis of inclusive spectra requires convolution over all partonic kinematics leading to a particle at (η, p_T)

If one adds information on the "recoiling" parton kinematics, the kinematics of the parton-parton collision can be unfolded

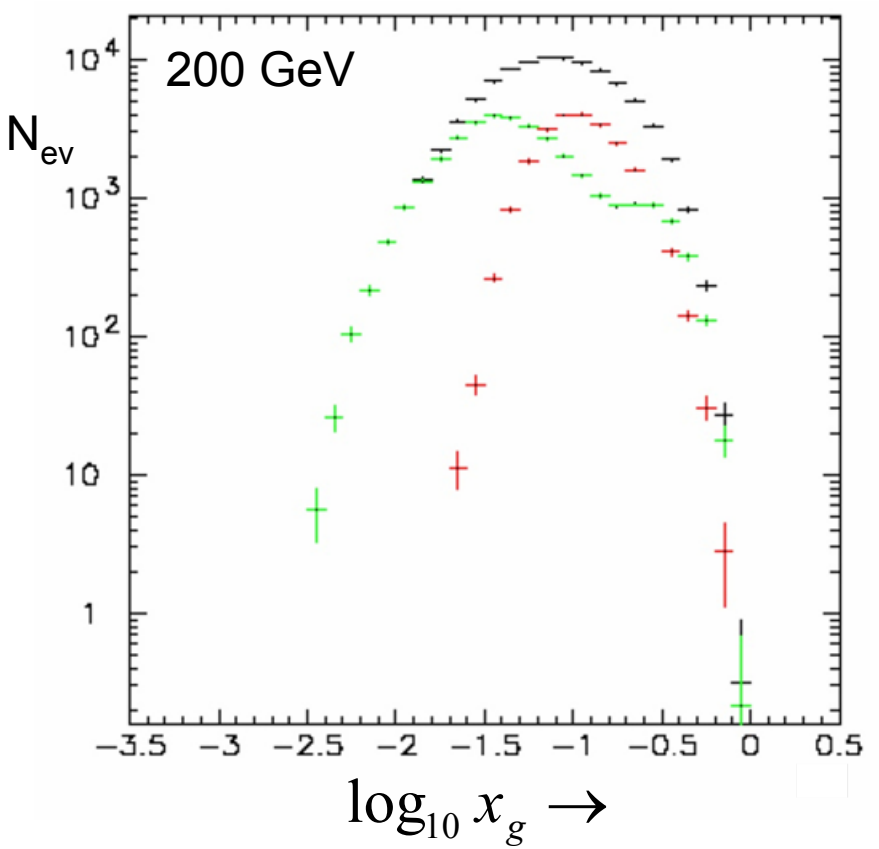
$$x_q = \frac{p_{T\gamma}}{\sqrt{s}}(e^{+\eta_\gamma} + e^{+\eta_{jet}})$$

$$x_g = \frac{p_{T\gamma}}{\sqrt{s}}(e^{-\eta_\gamma} + e^{-\eta_{jet}})$$

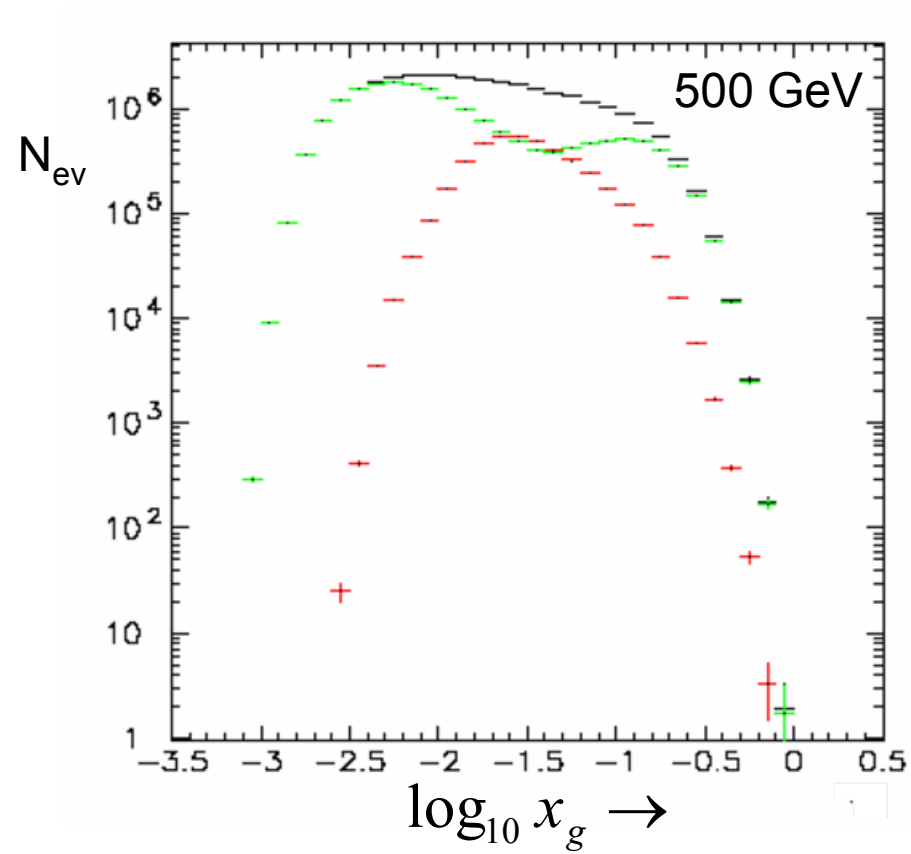
X dependence of structure functions can be directly constrained

PHENIX Bjorken *x* Sensitivity

g(x) is large at low x → need to measure the gluon polarization at low x!



Central arms alone: 0.03-0.5
Central arms + NCC: 0.01-0.5



Central arms alone: 0.01-0.5
Central arms + NCC: 0.002-0.5

Transverse Physics

We are just starting to fully explore the true 3-dimensional nature of the nucleon's partonic structure

- Experiments indicate presence of intrinsic k_T, but difficult to obtain a clean measurement.

- Intrinsic transverse momenta of the partons typically inserted by hand in phenomenology. New theoretical advances are able to generate the transverse momenta through NLO QCD processes.

Transverse Spin Physics

Long standing puzzles in polarized *pp* reactions:

- Large Λ polarization
- Large asymmetry in π production
  - $\rightarrow$ Naïve pQCD gives ~0
  - $\rightarrow$ Soft interactions?

New Observations!

- Large asymmetry in forward π production at STAR
- Large azimuthal asymmetries of mesons from polarized electron-polarized proton scattering at HERMES
- Breakthrough in understanding treatment of gauge links in theory

Transverse Partons

At lowest order, we have 3 pieces to determine:

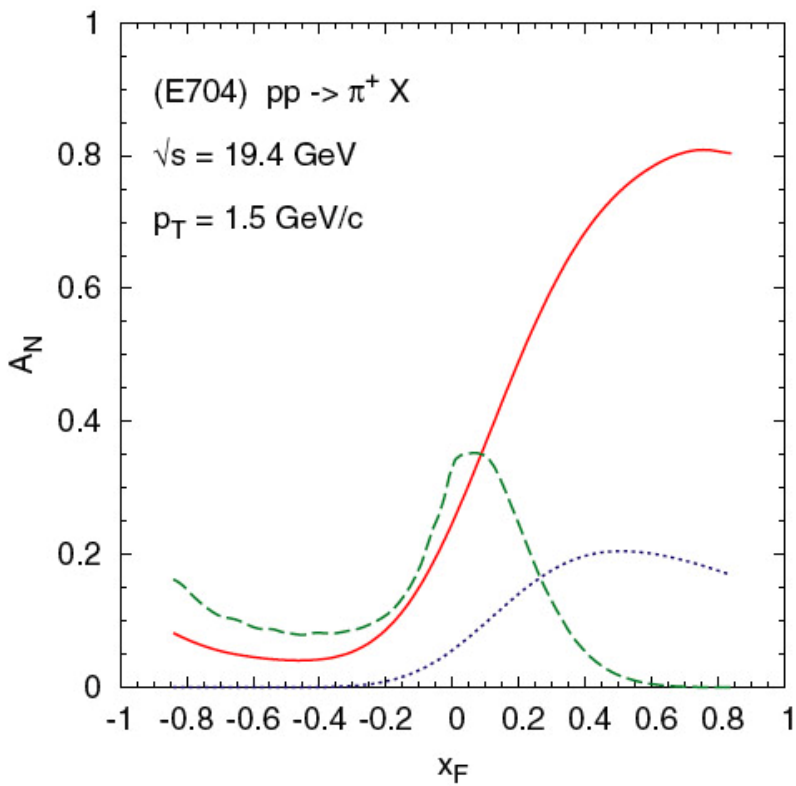
1. Sivers Distribution - describes correlation between nucleon spin and k_T , e.g., as might arise from orbital motion

2. Transversity Distribution - describes alignment of quark spins parallel to the spin of the nucleon *in the case that the nucleon is transversely polarized.* Detectable via Collins fragmentation function.
   - ✓ Collins correlates target spin & fragment p_T

3. Higher twist components to the basic known distributions

Role of NCC

- Allows measurement of forward hadron asymmetries
  - → With MPC and Central Arms we have much larger acceptance from 0 to 4 in η, *especially for "jet-jet" correlations*
  - → We can also use different kinematic dependences to help separate different contributions, e.g., in single spin asymmetry A_N



Predictions by *Anselmino et al.* for E704 show clear kinematic trends

quark Sivers contribution

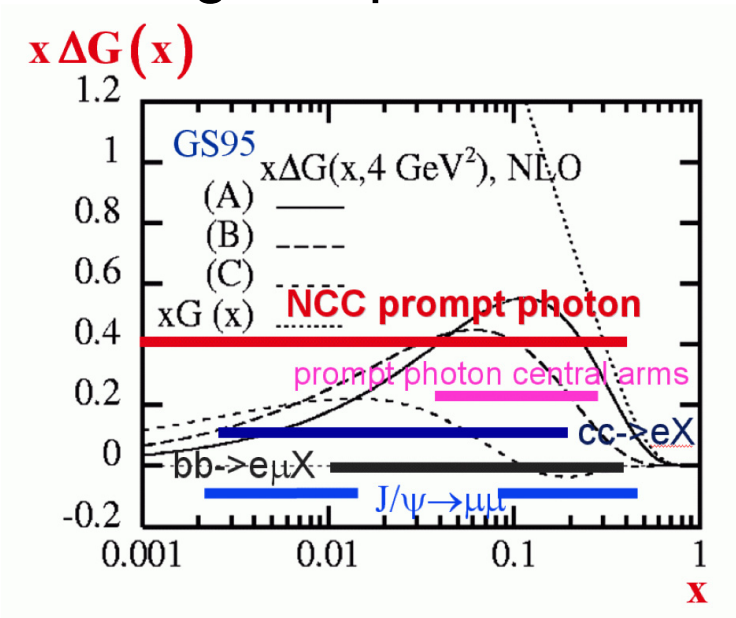
gluon Sivers contribution

Collins contribution

Note, there is little dependence on $\sqrt{s}$

Summary

- NCC greatly expands reach of PHENIX in low *x* for determination of gluon polarization



- Detection of photon + "jet" gives direct information on the *x* dependence of the gluon polarization
- Detection of hadrons in NCC rapidity expands the means to study transverse spin physics at PHENIX