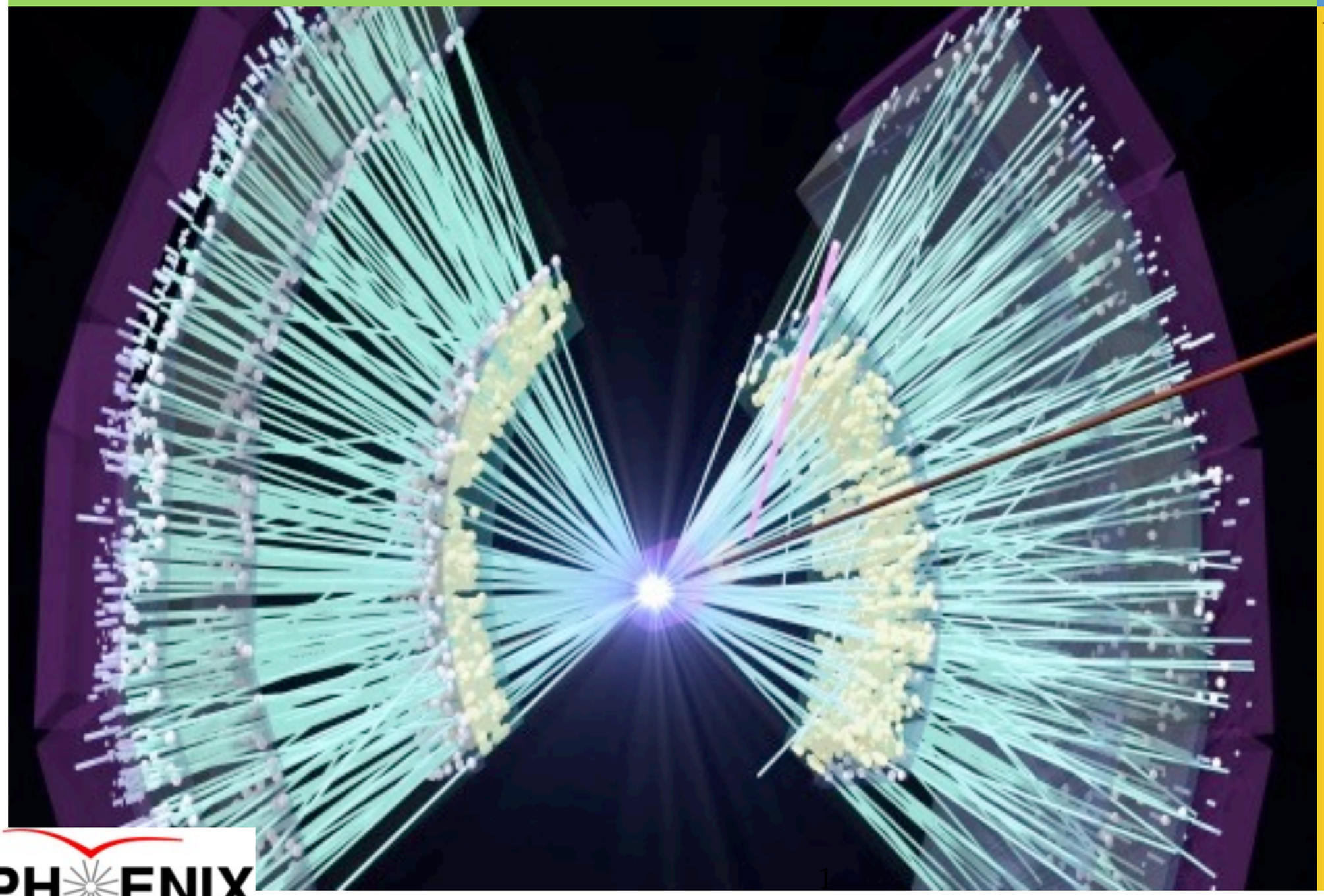
Spin measurements at PHENIX and future plans

RBRC Workshop on Forward Physics at RHIC, BNL, July 2012

Francesca Giordano
for the PHENIX collaboration



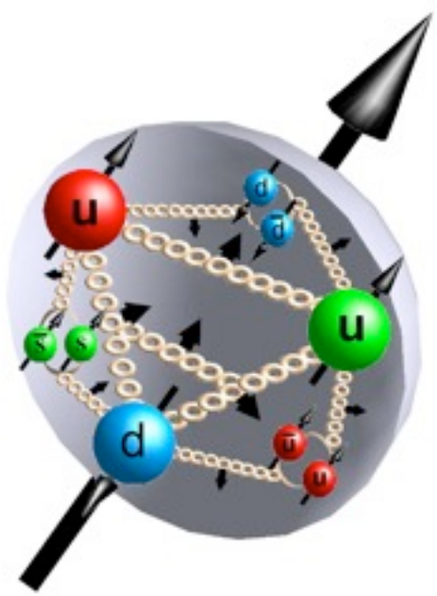
PHENIX

You think you understand something? Now add spin....

R. Jaffe

The proton structure:

where does the proton spin come from ?

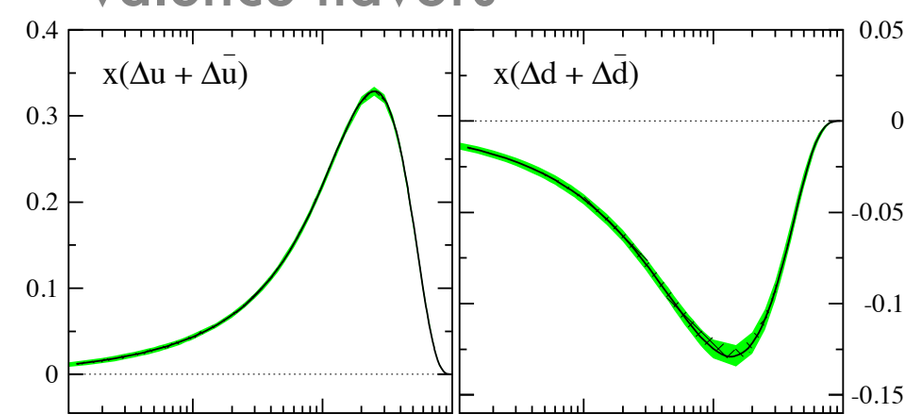


$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z$$

quark spins — gluon spins — quark&gluon orbital motion

Δu_v Δd_v Δq_{sea}

valence flavors



First *spin crisis:*

quarks only provide ≈ 30% of the proton spin

Where is the rest of the proton spin?

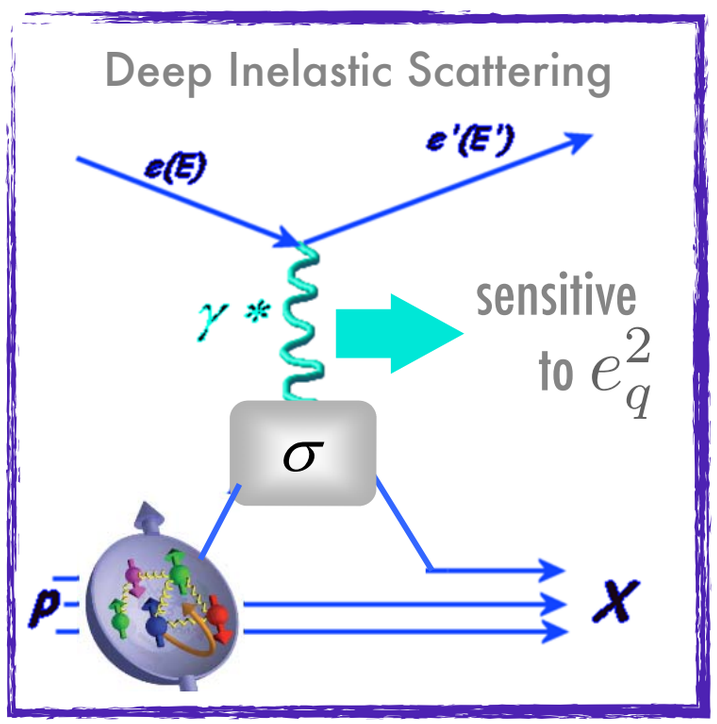
Gluon spin? Orbital motion?

The proton structure:

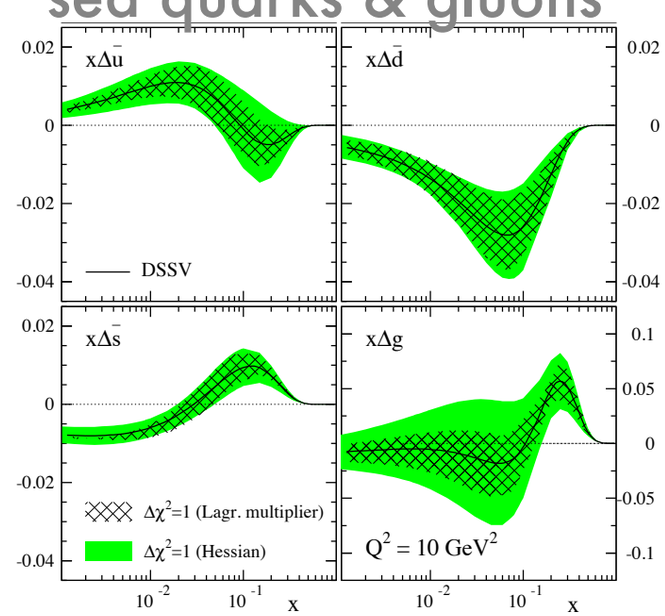
where does the proton spin come from ?

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

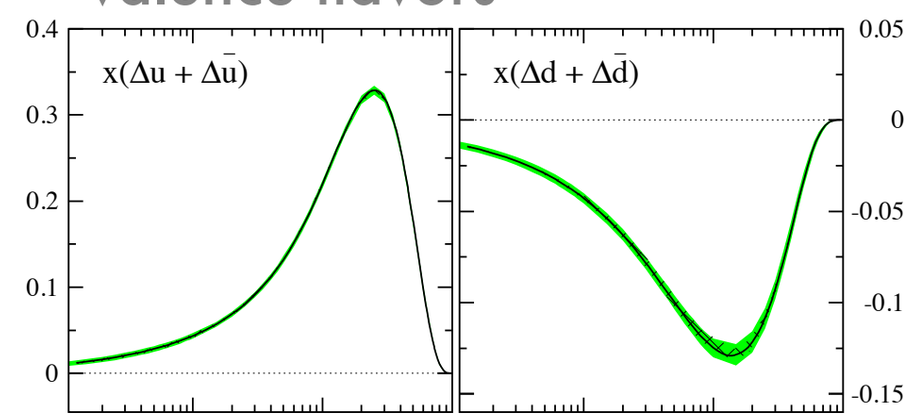
quark spins — gluon spins — quark&gluon orbital motion



sea quarks & gluons

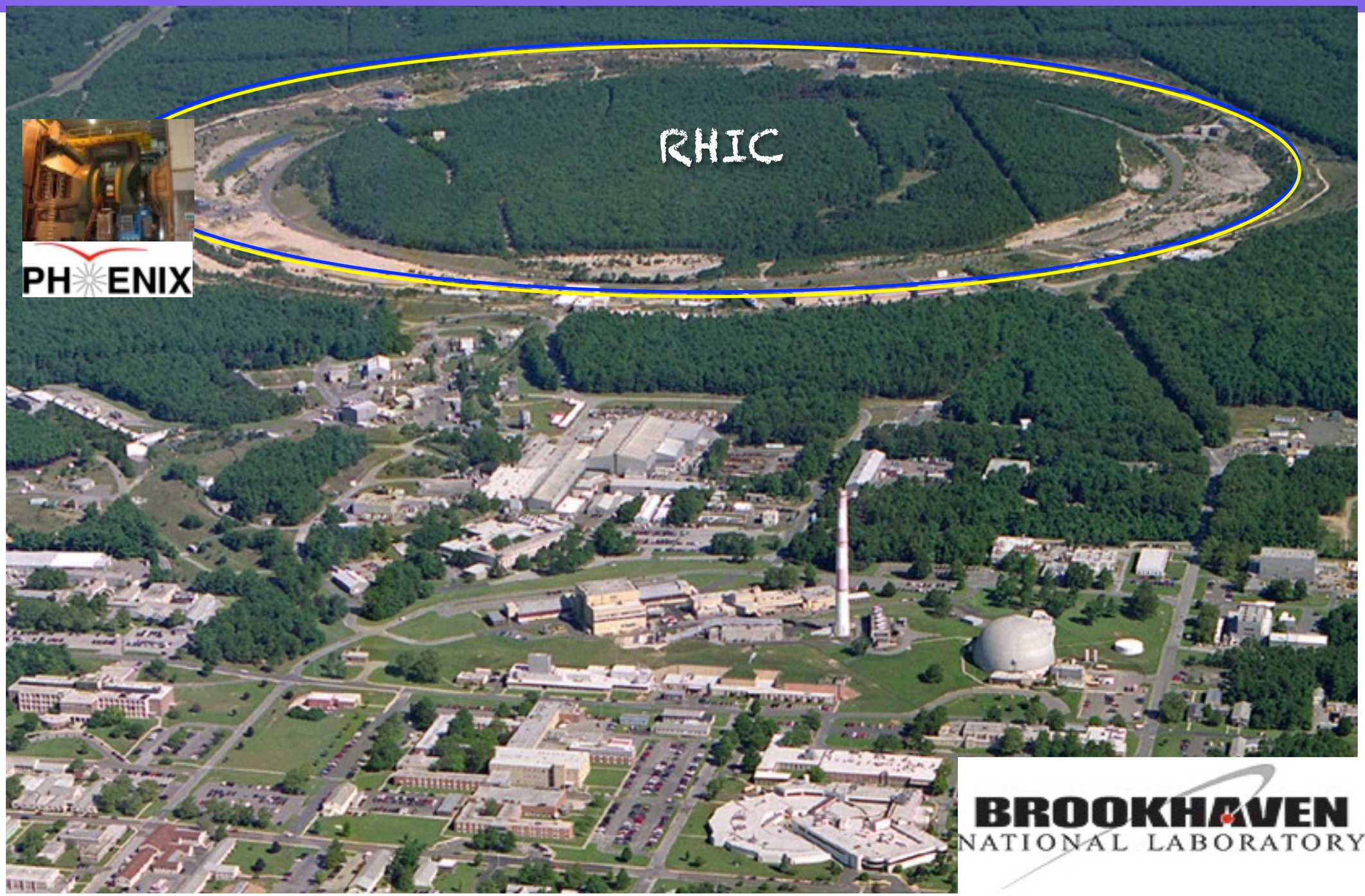


valence flavors



Most helicity results from Deep Inelastic scattering, but DIS can access gluons only indirectly, and sea quark distribution extractions are model-dependent

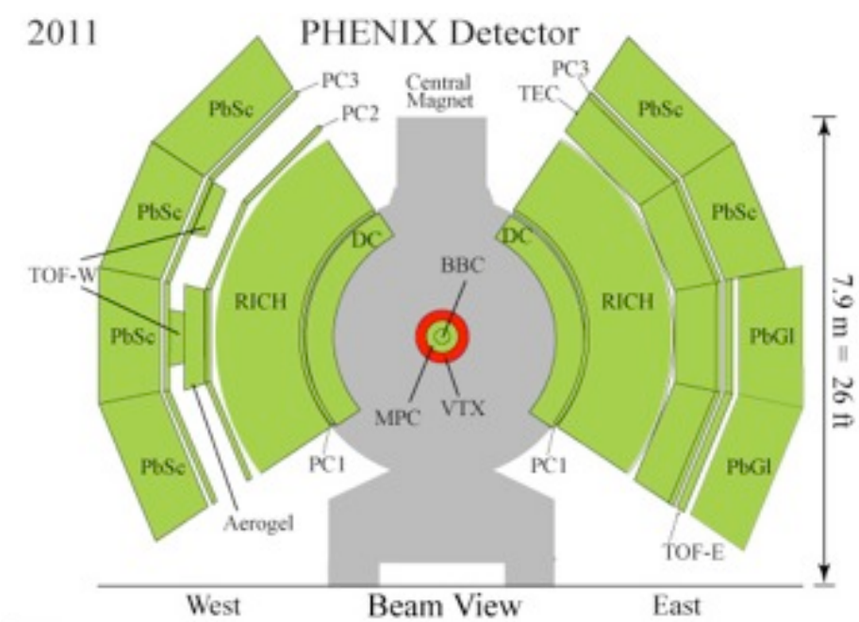
Polarized proton-proton collider



PHENIX

Central Arms:

$$|\eta| < 0.35$$



Tracking, Momentum and PID for:

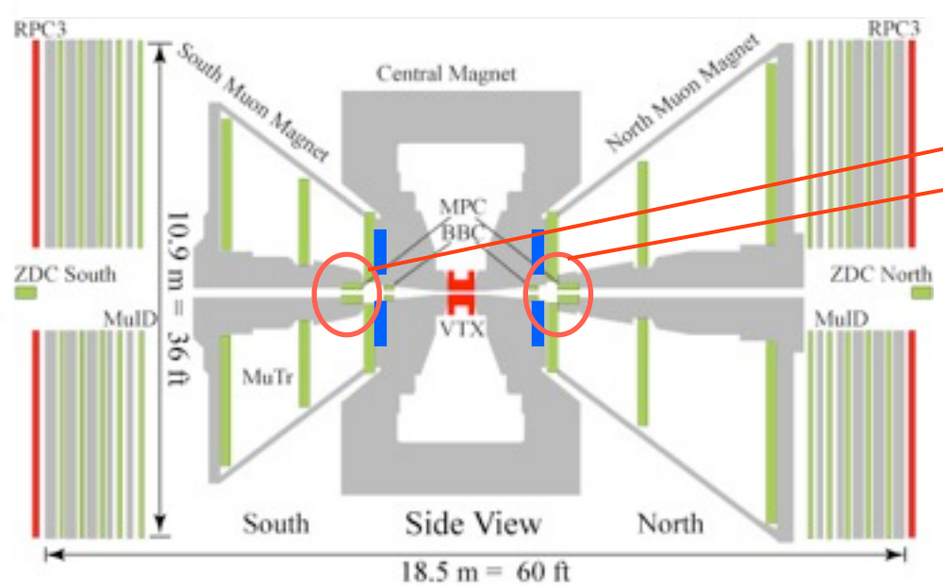
- ☆charged and neutral hadrons
- ☆direct photons
- ☆e+e-

Forward Arms:

$$1.2 < |\eta| < 2.4$$

Tracking and Momentum for:

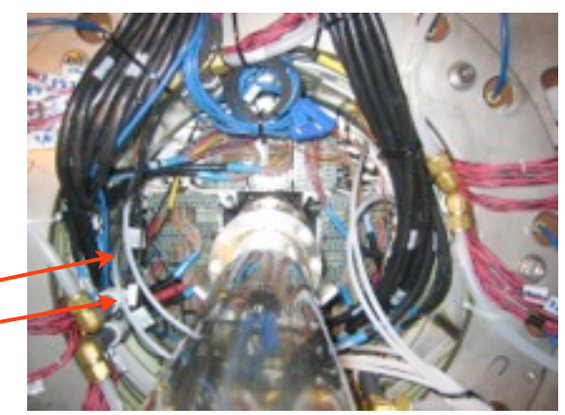
- ☆ $\mu^{\pm}$



Even more forward: MPC

$$3.1 < |\eta| < 3.9$$

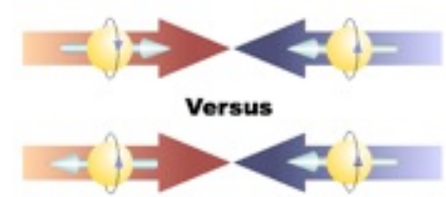
$$\pi^0 \to \gamma\gamma$$

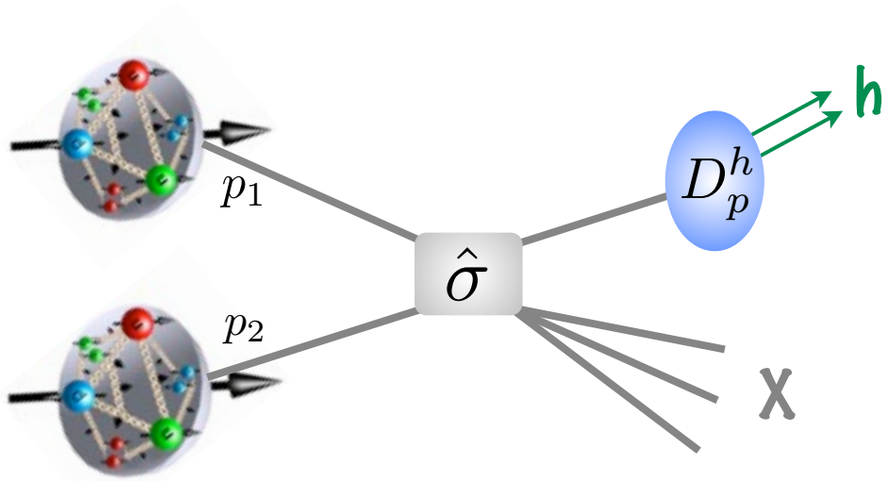


Gluon Helicity

Gluon polarization

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



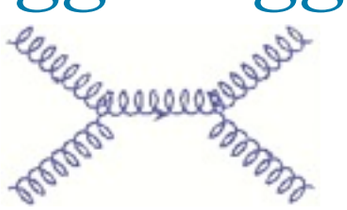


$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

$$\approx \frac{\Delta p_1 \times \Delta p_2 \times \hat{\sigma} \times D_p^h}{p_1 \times p_2 \times \hat{\sigma} \times D_p^h}$$

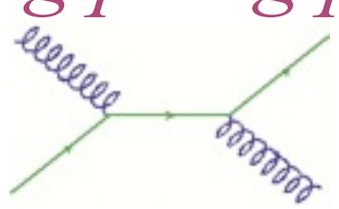
$$p_1,\, p_2 = q/g$$

$gg \to gg$



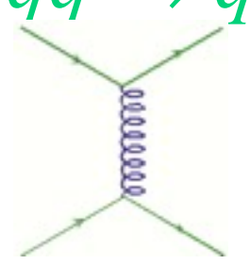
$$\propto \frac{\Delta g}{g}\frac{\Delta g}{g}$$

$gq \to gq$

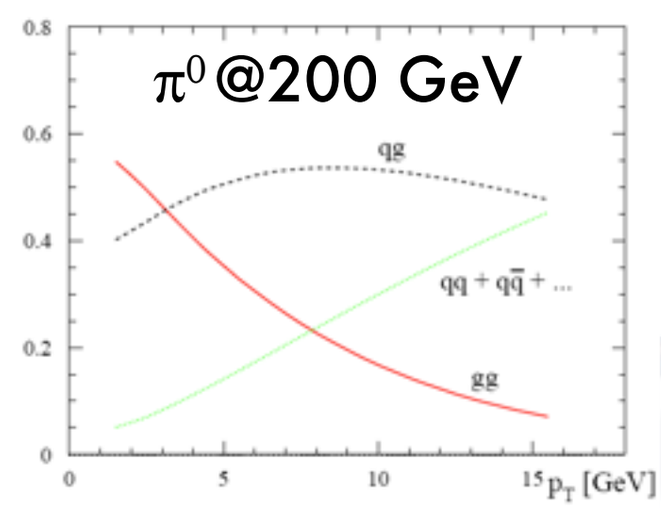


$$\propto \frac{\Delta q}{q}\frac{\Delta g}{g}$$

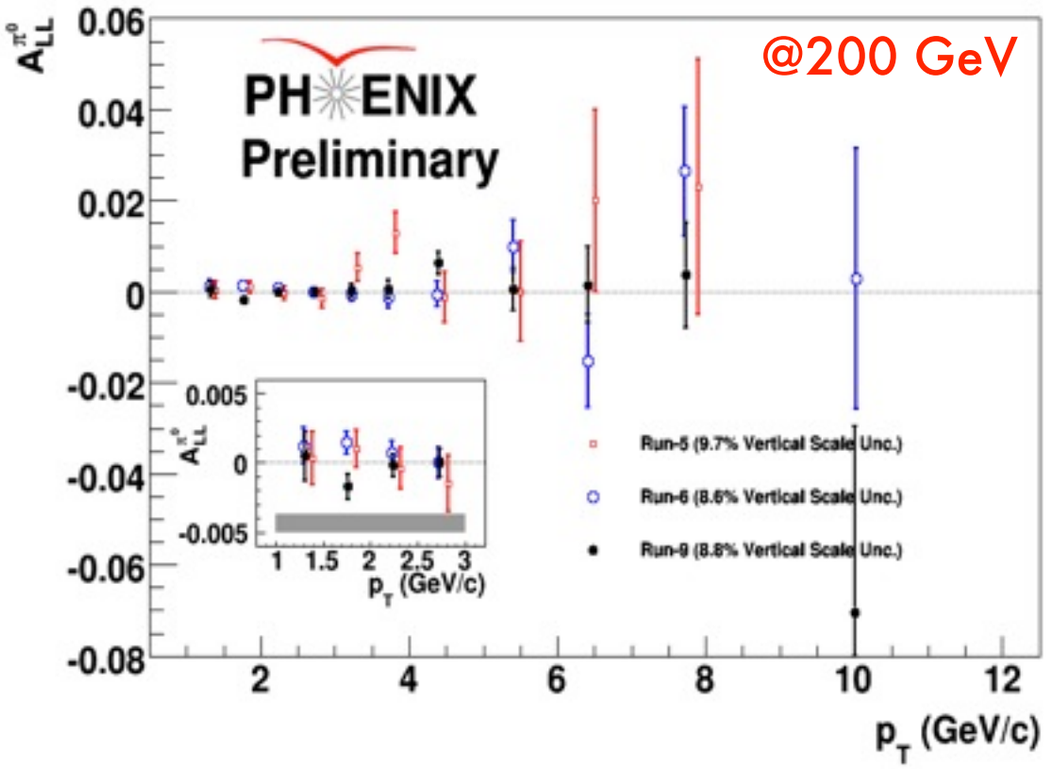
$qq \to qq$

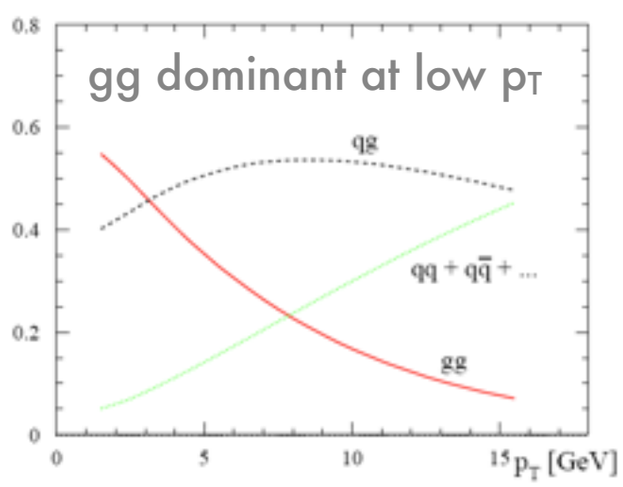


$$\propto \frac{\Delta q}{q}\frac{\Delta q}{q}$$

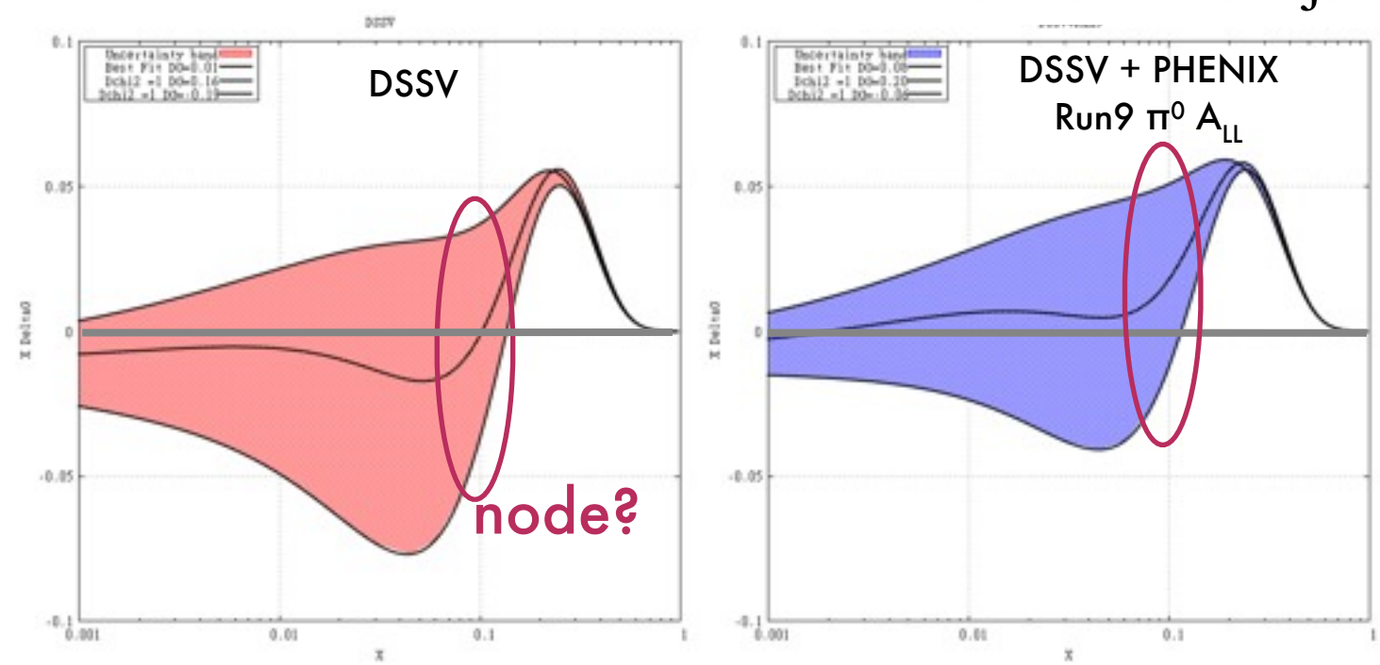


$\pi^0 A_{LL}$



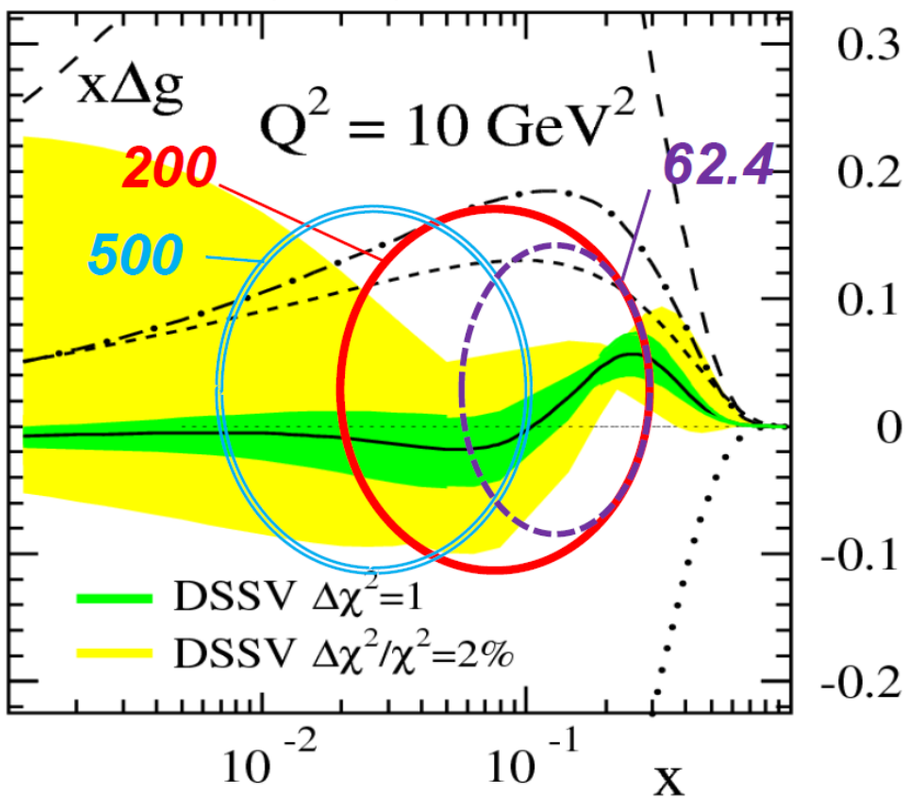


Swadhin Taneja

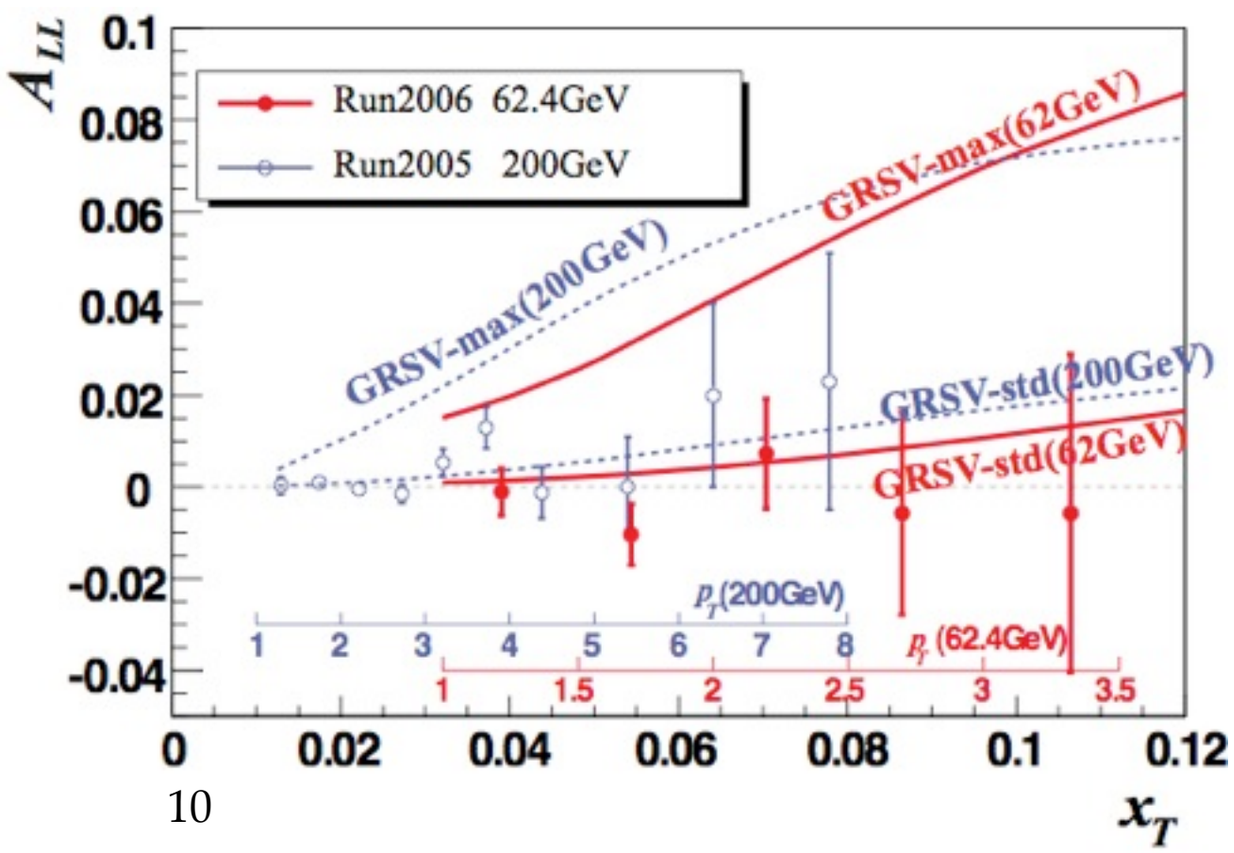


Mapping vs. x

PRL 101, (2008)072001 DSSV 08

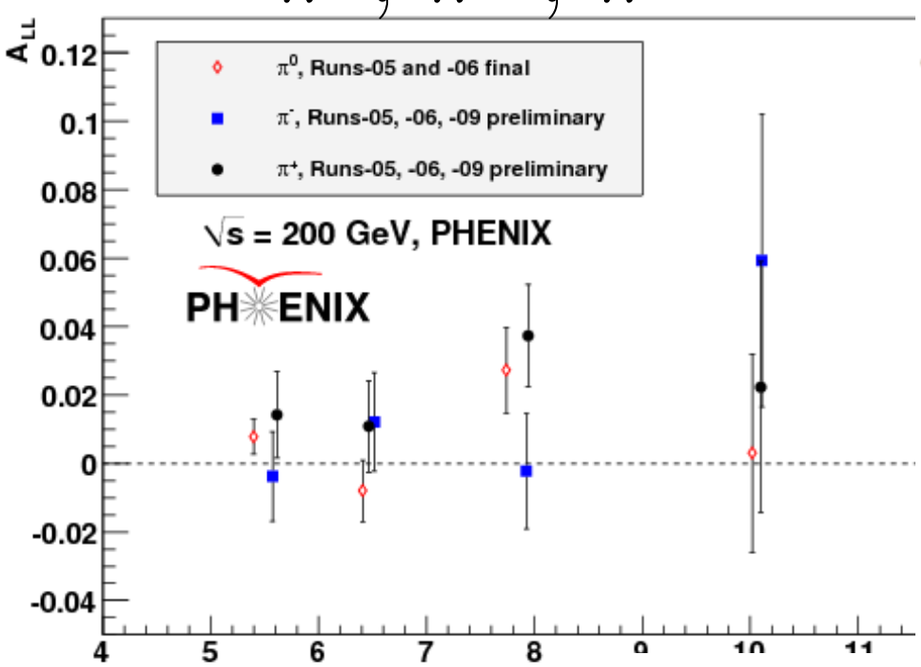


Different energy => different x

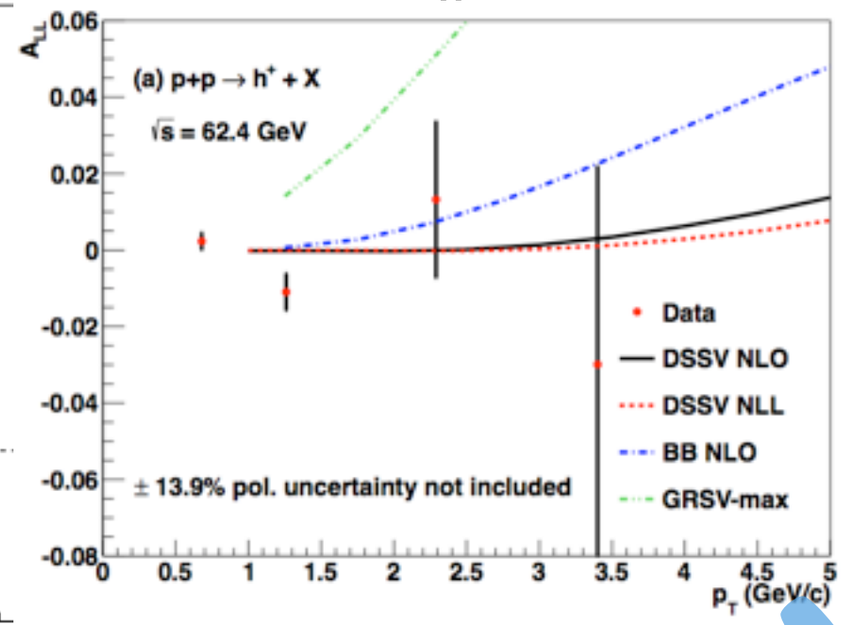


More probes @ midrapidity

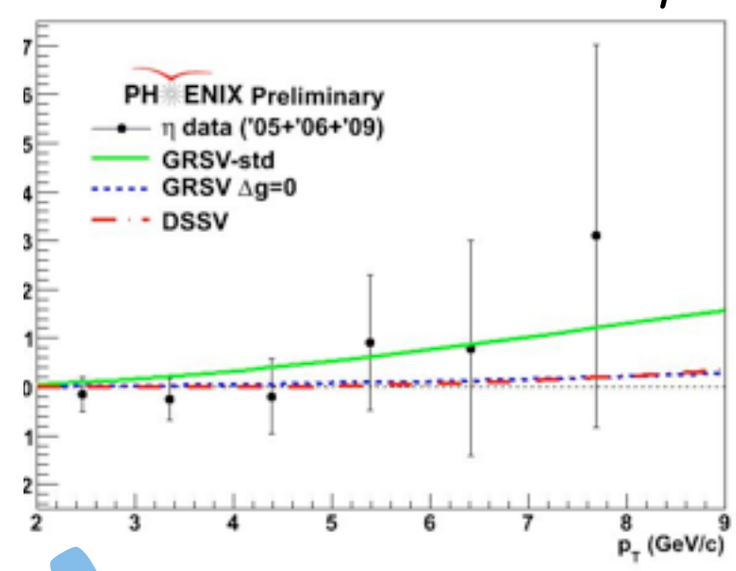
π^0, π^+, π^-



h^+

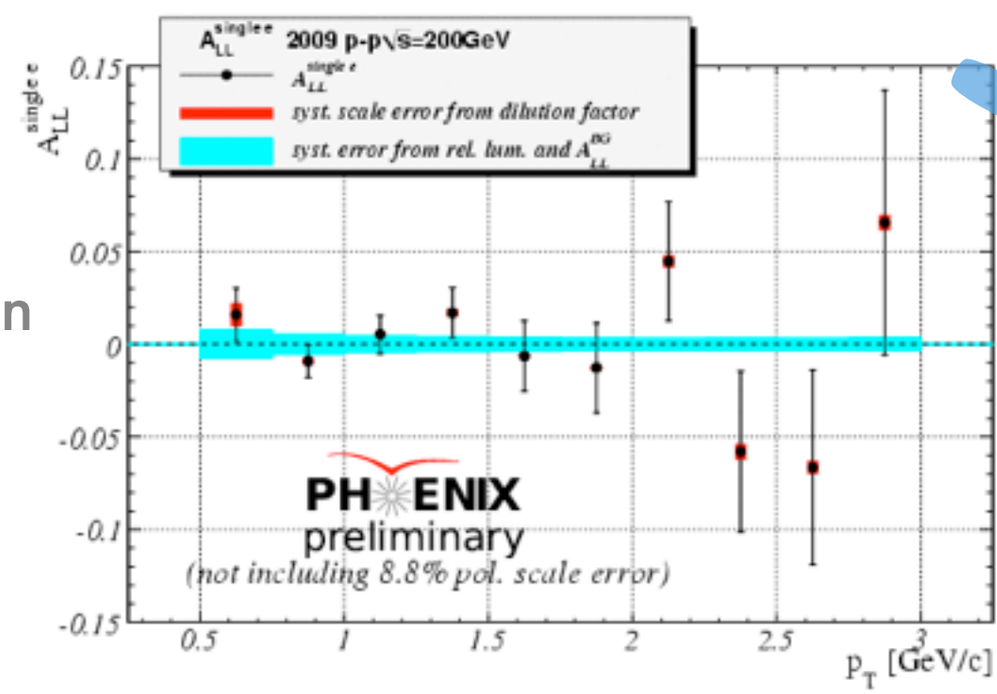


η



single electron

$D^+ \to \bar{K}^0 \nu_e e^+$
$D^0 \to \bar{K}^- \nu_e e^+$

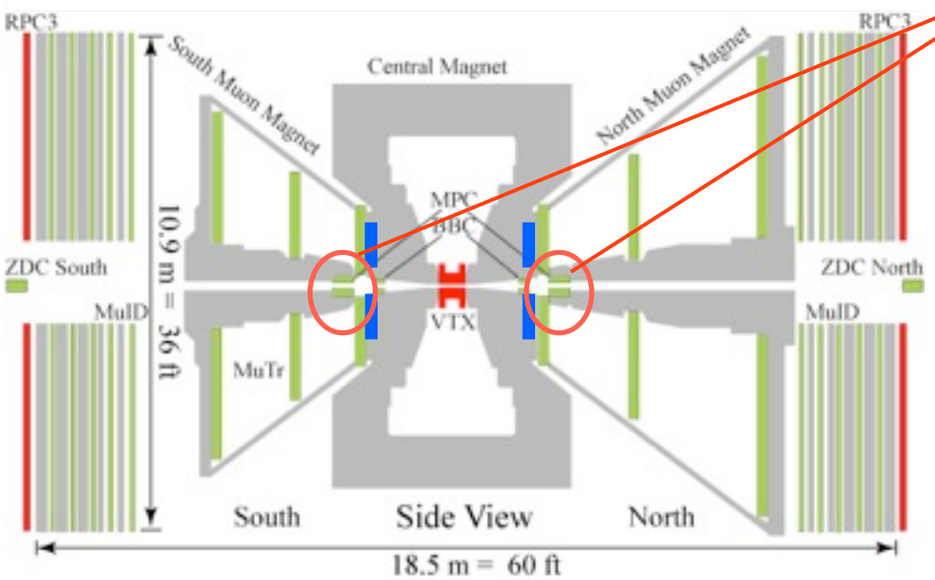


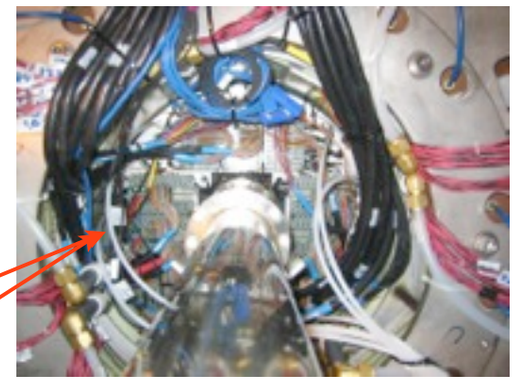
small gluon helicity
@ midrapidity

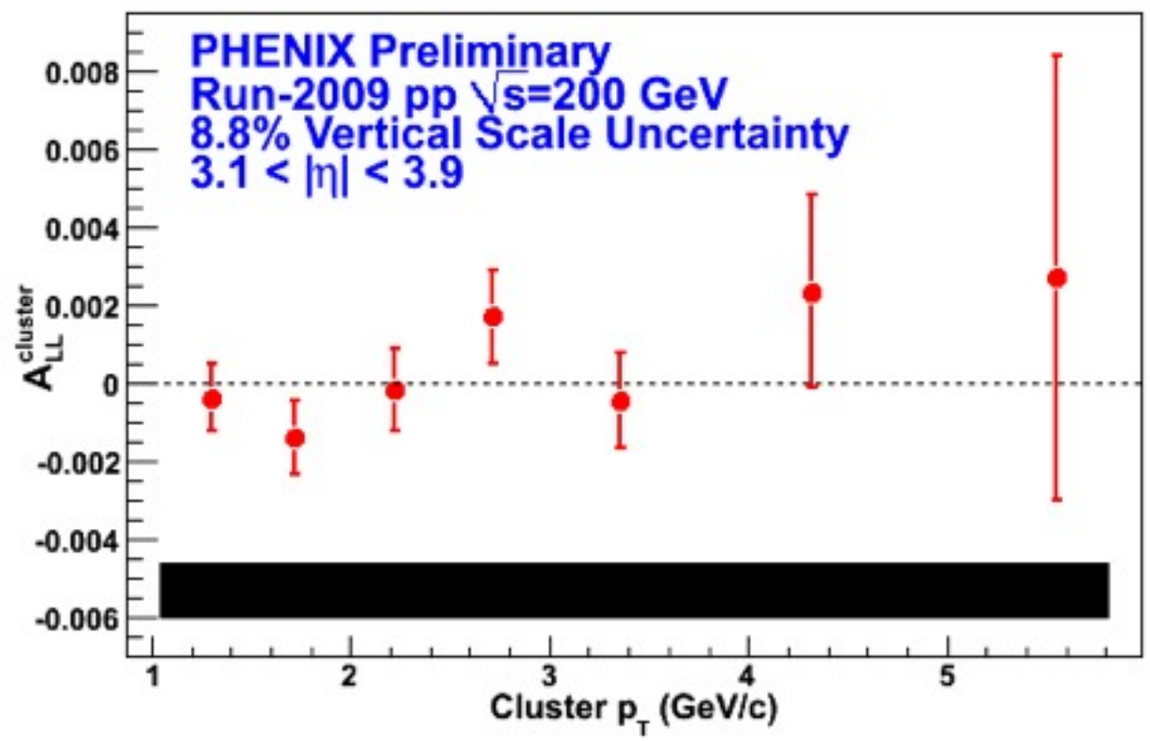
MPC: forward A_{LL}

Muon Piston Calorimeter:

$3.1 < |\eta| < 3.9$





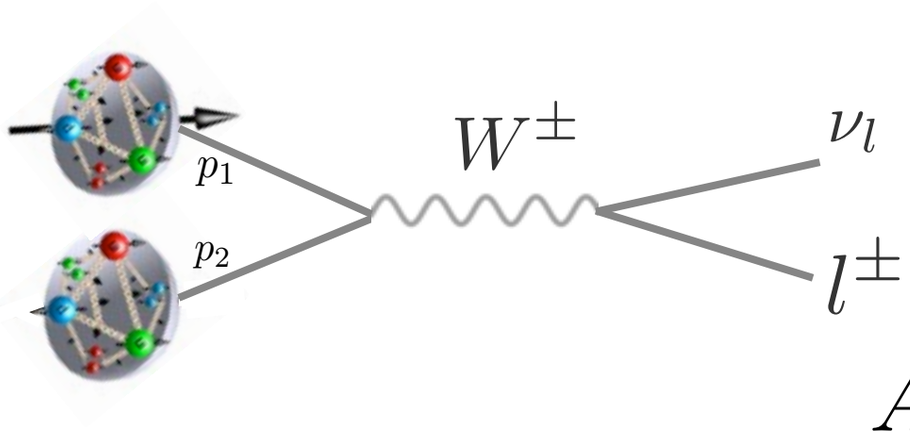


more data at 500 GeV in preparation...

Sea Quark Helicity

Sea quark helicity

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

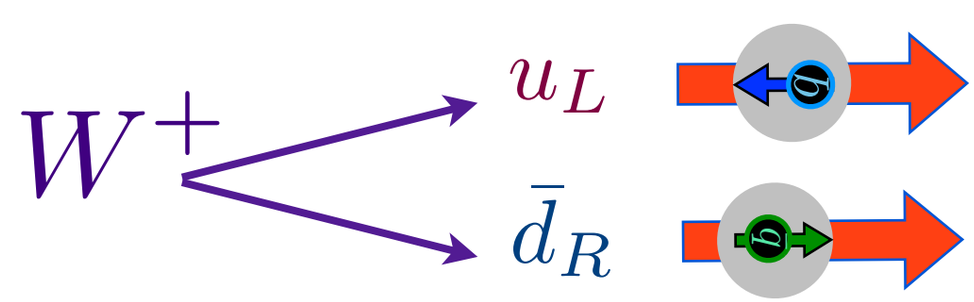


$$A_L = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

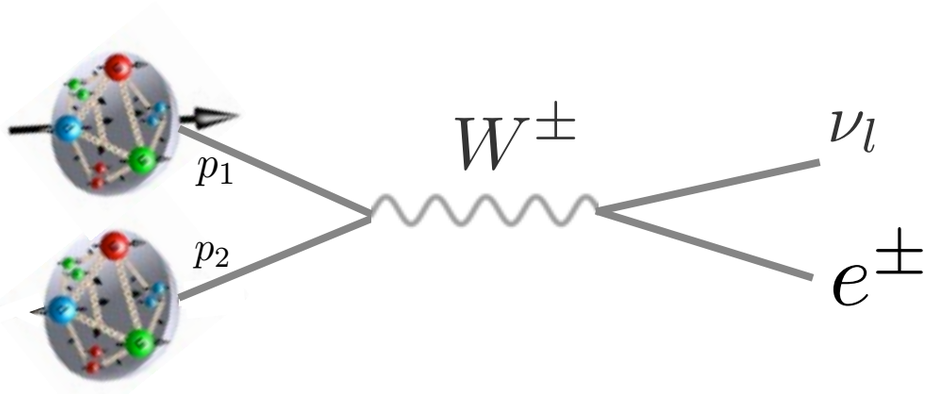
$$\propto \Delta u_L \times \bar{d}_R + \Delta \bar{d}_R \times u_L$$

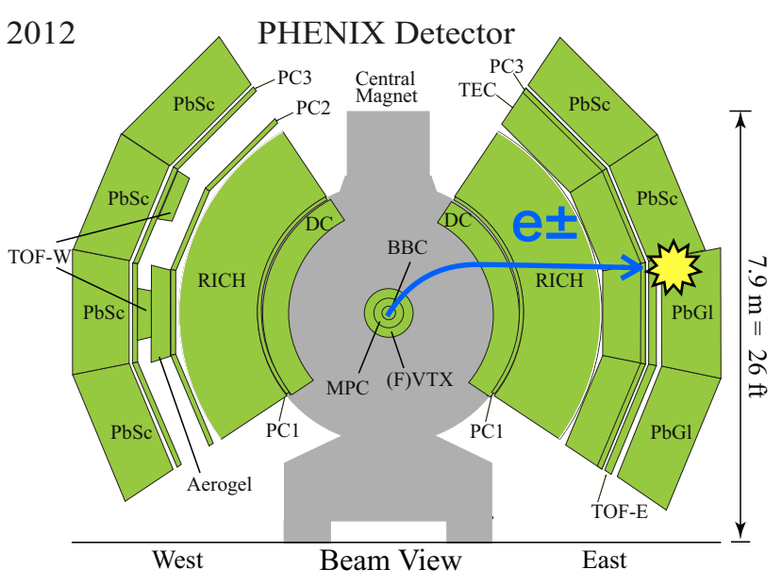
Accessing $W^{\pm}$

to "know" the quark (anti-quark) polarization state!

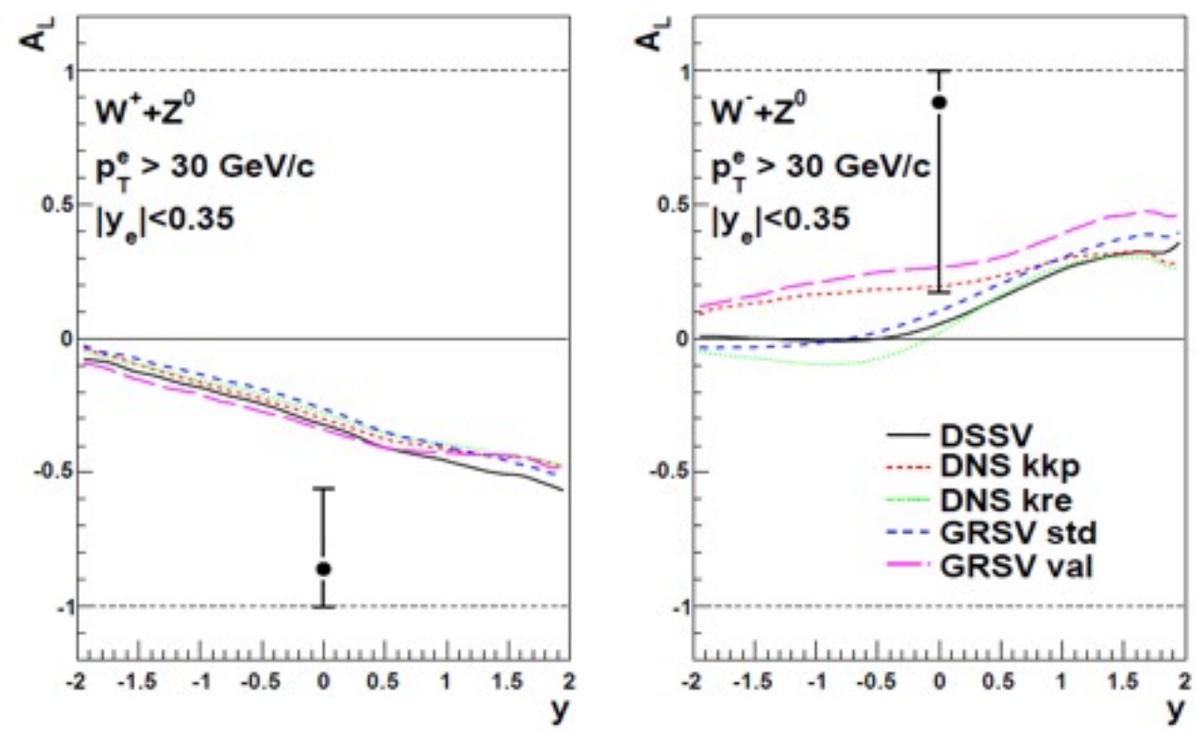


W central



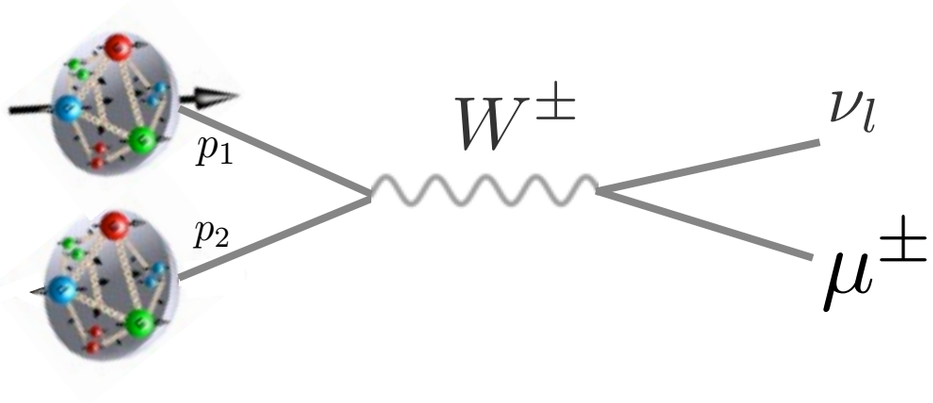


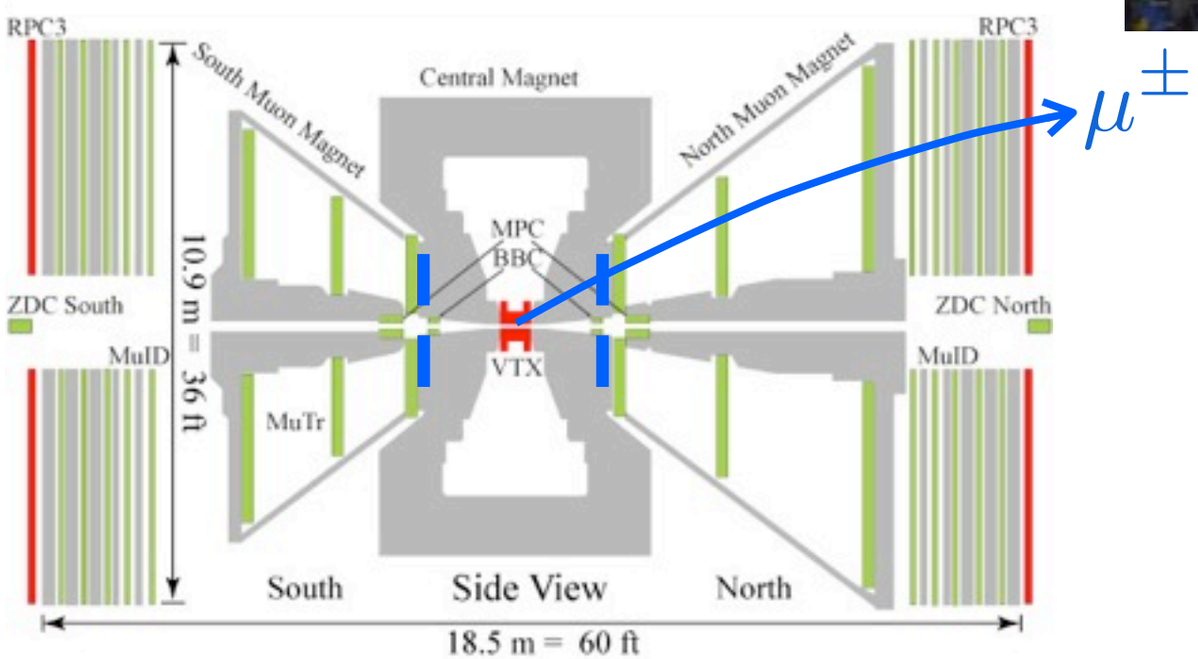
Non-zero asymmetry!

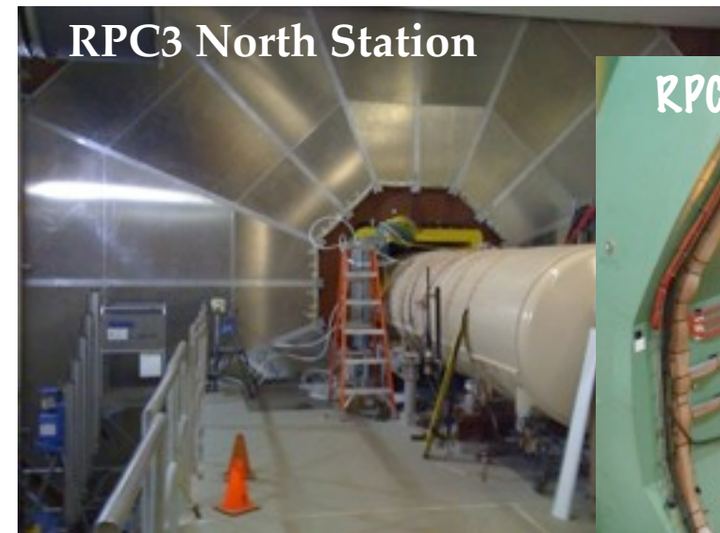


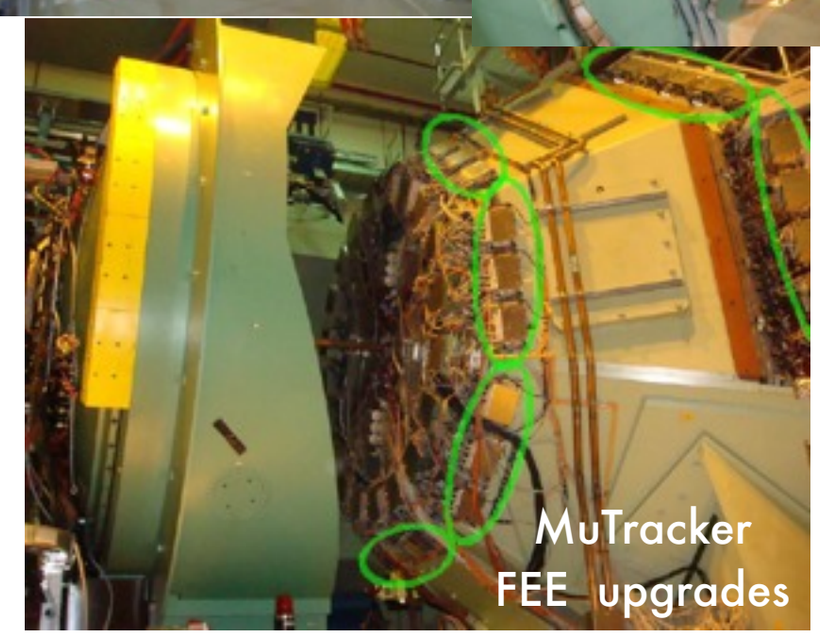
More data in progress...

W forward



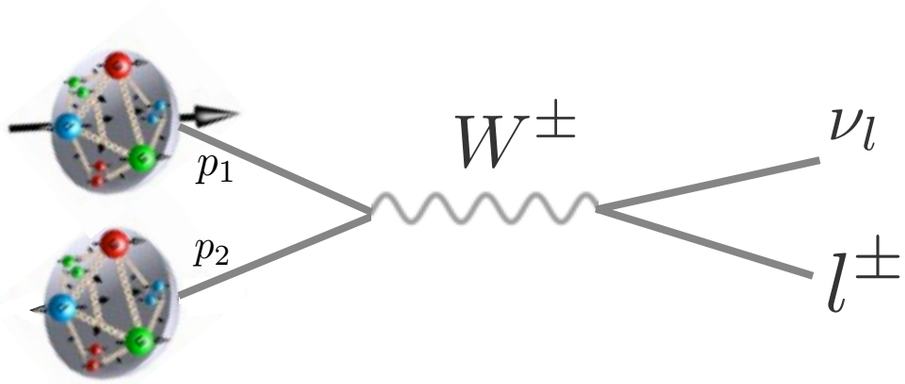


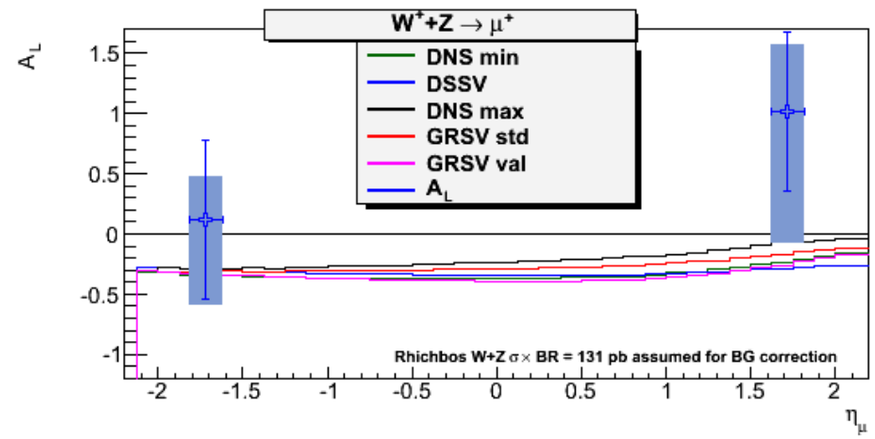


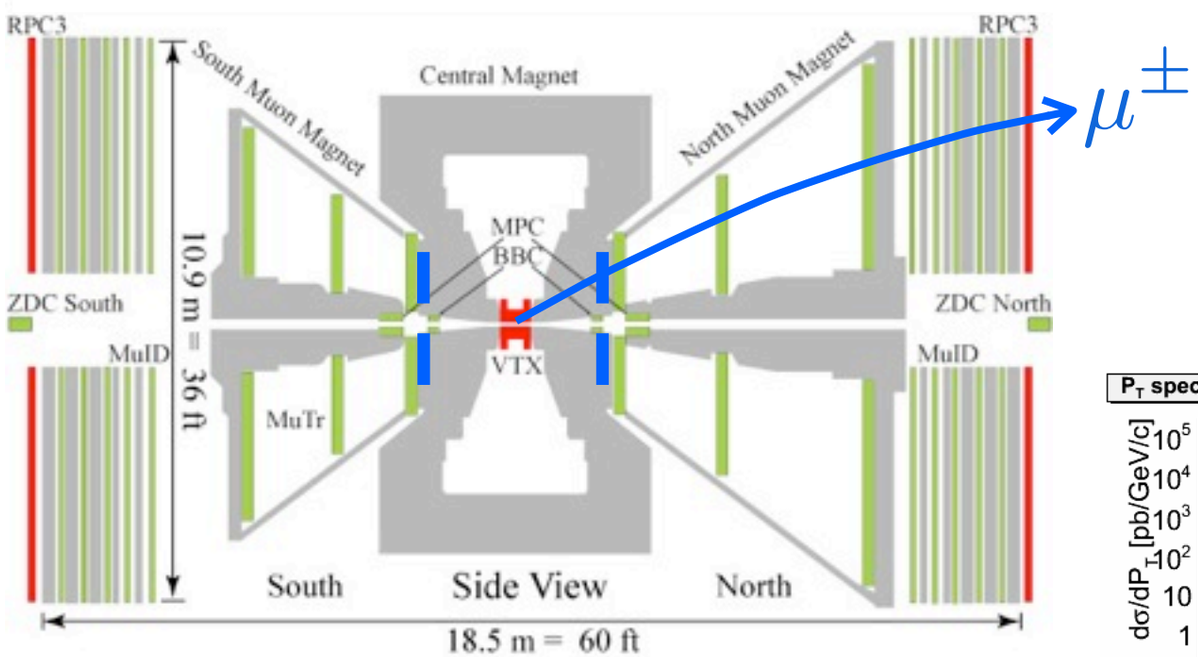


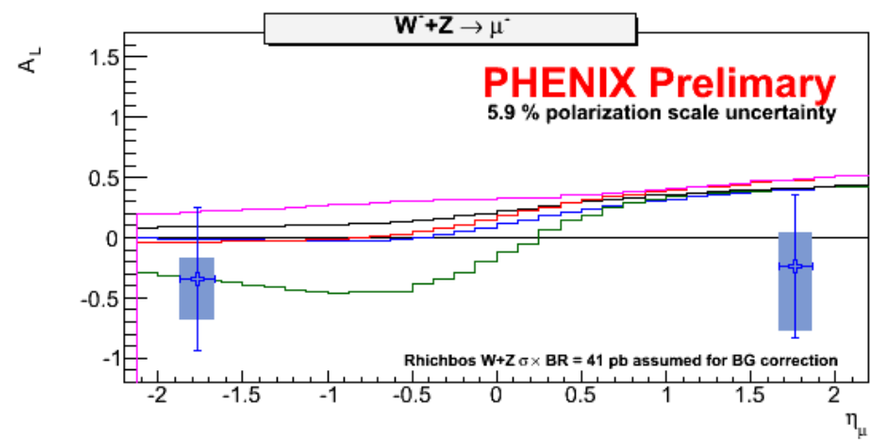
2012: Complete Forward Trigger upgrade

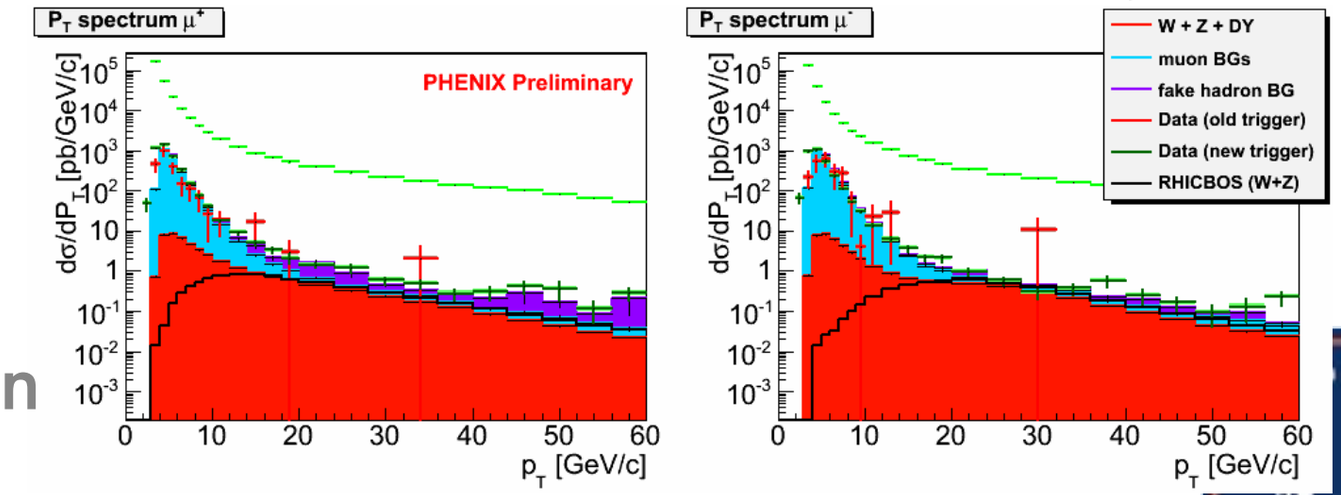
W forward









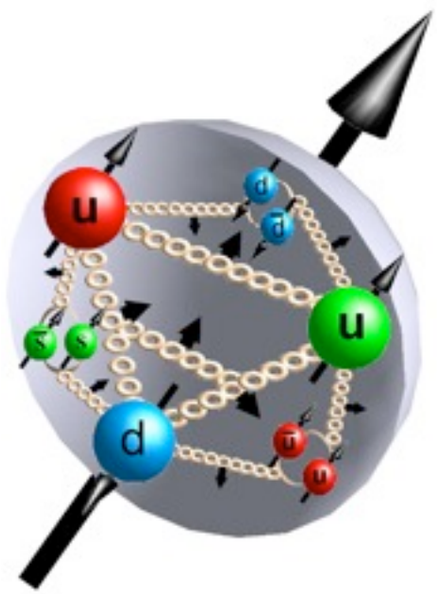


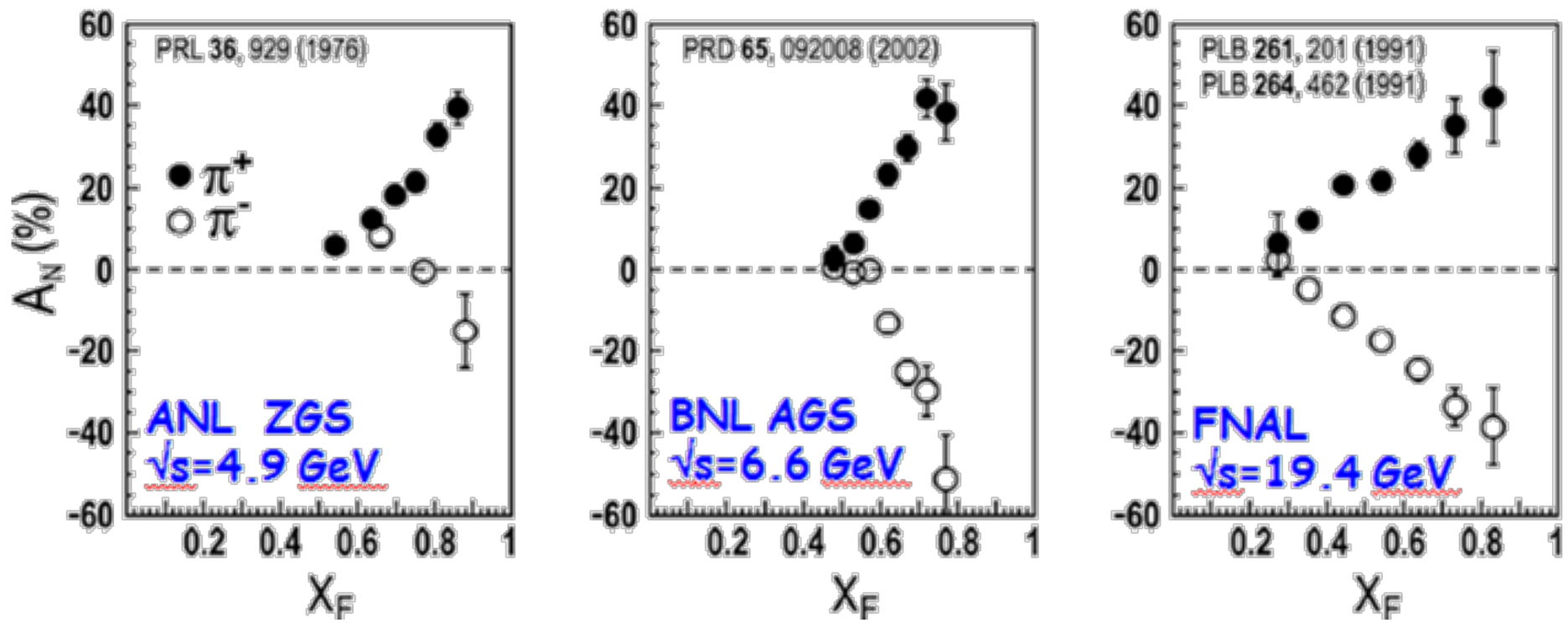
Additional background reduction with FVTX and RPC1

Transverse Spin

The proton structure:

where does the proton spin come from ?

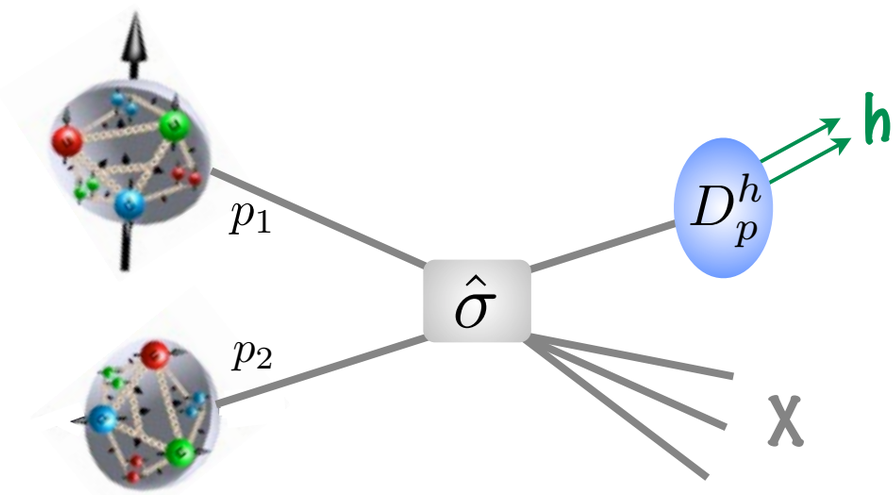




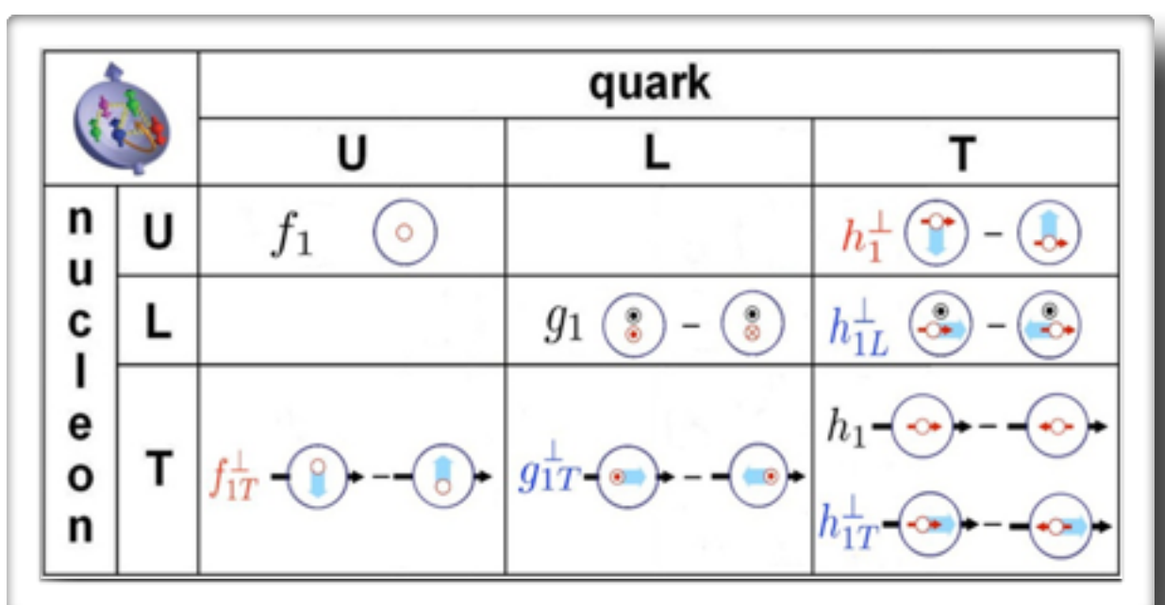
Second *spin crisis:*

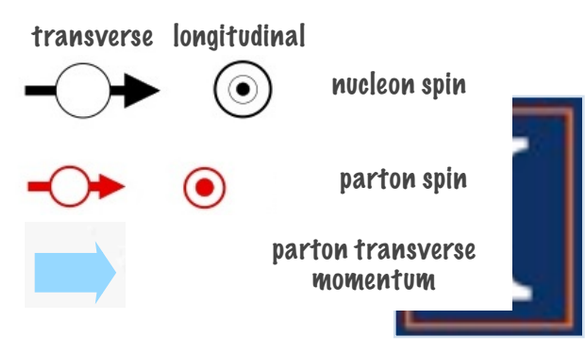
transverse effect not small!

TMD Factorization

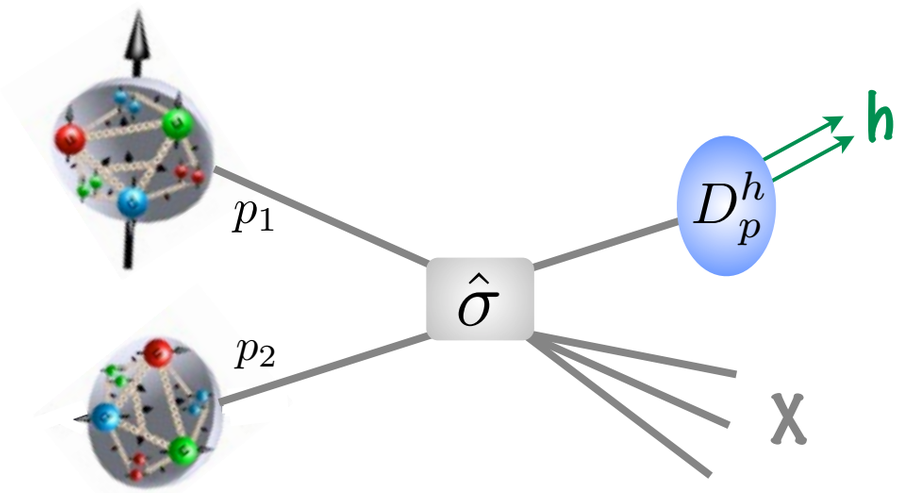


$$\sigma(pp \to hX) \propto DF \times DF \times \hat{\sigma}(qq \to qq) \times FF$$



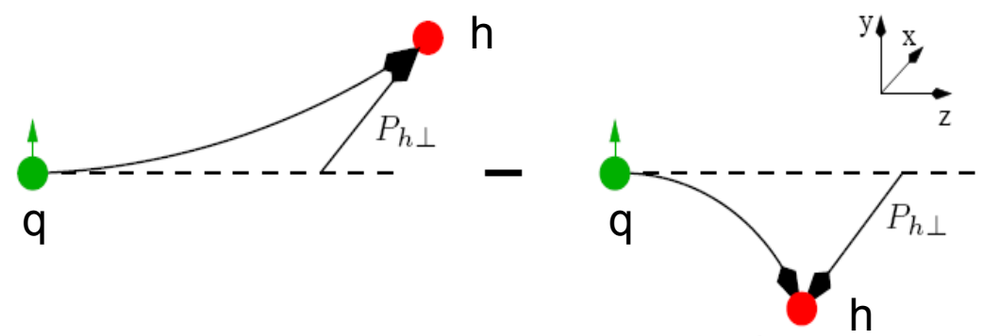


Transversity

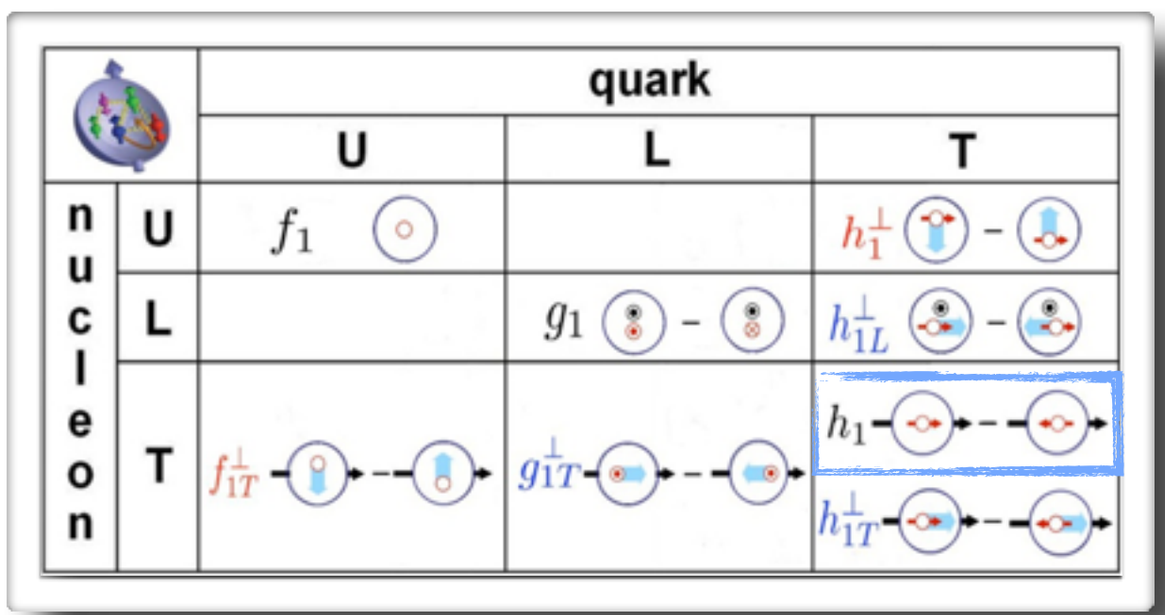


Accessible via the Collins mechanism:

left-right asymmetry from correlations between quark transverse spin and outgoing hadron direction



$$A_N \propto h_1 \times H_1^{\perp}$$

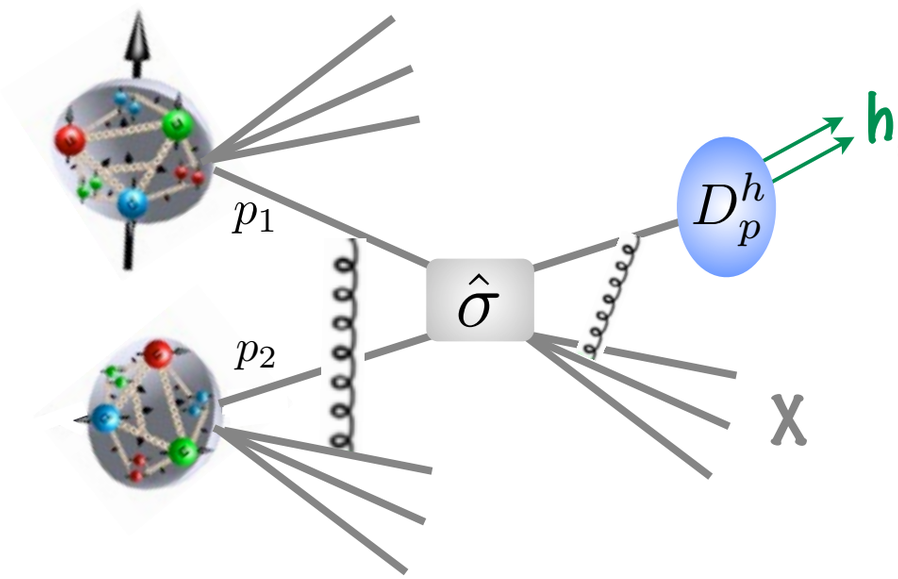


BUT!!

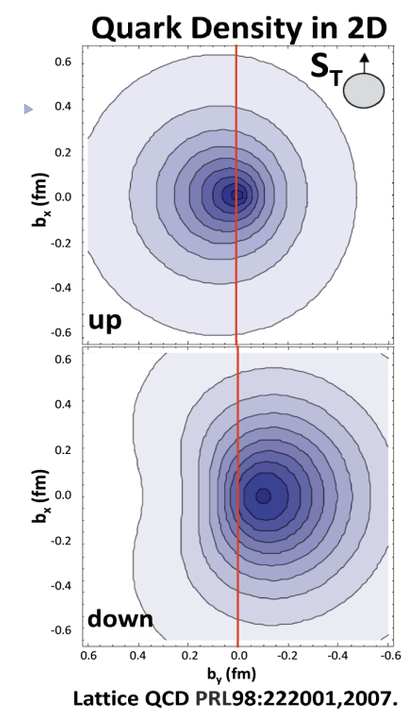
TMD factorization not valid in pp => hadron reaction!

A_N also generated by other effects:
- Higher twist effects
- Sivers effect

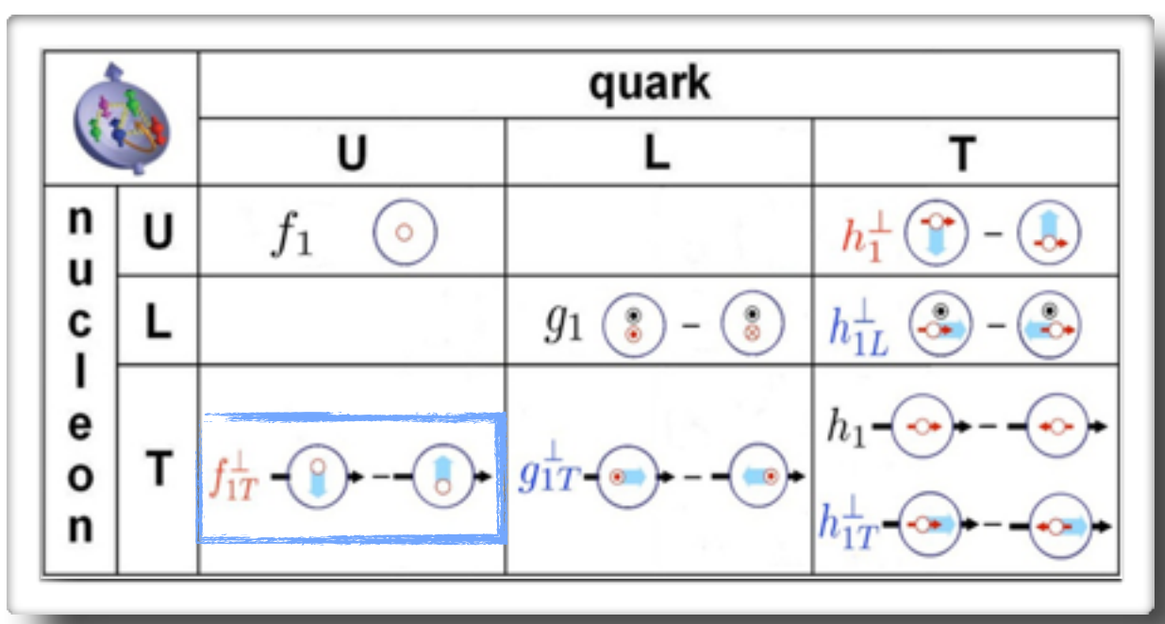
Sivers mechanism



Azimuthal asymmetry generated by correlations between quark transverse momentum and the proton transverse spin

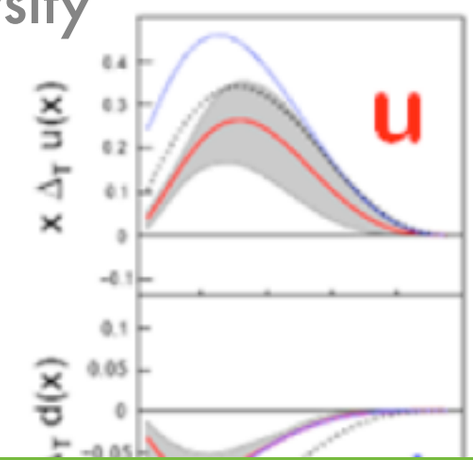


Spatial deformation due to spin-orbit correlations:
=> non zero Orbital Angular Momentum!

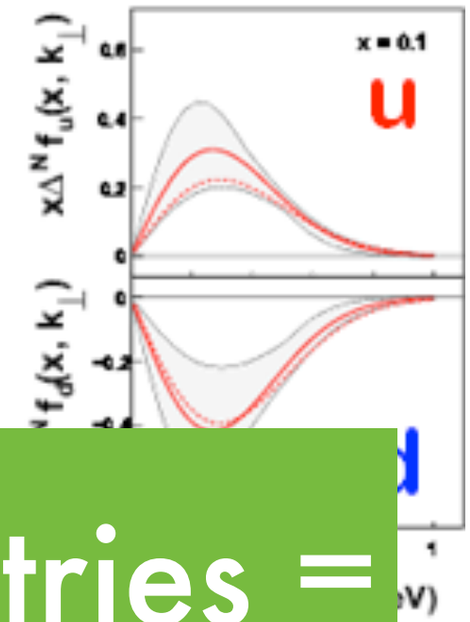


Which effect?

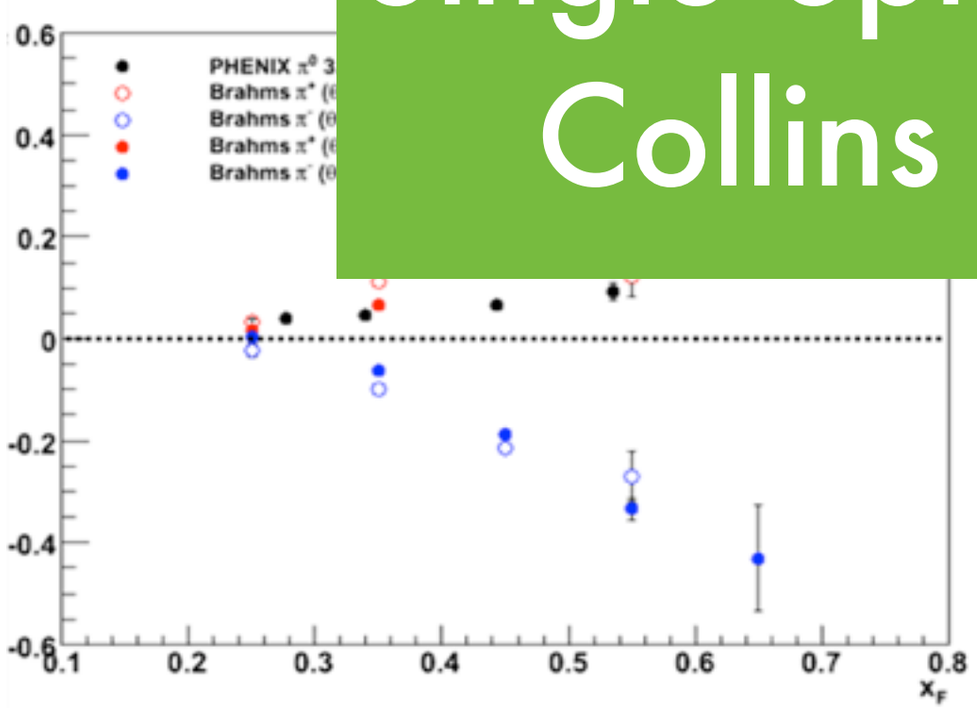
transversity



Sivers



Single Spin Asymmetries = Collins + Sivers + ...

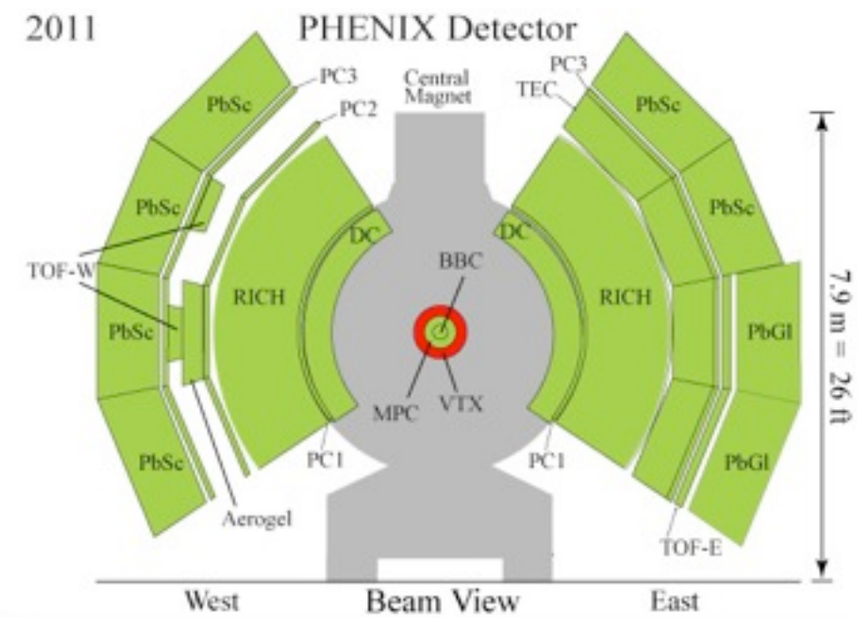


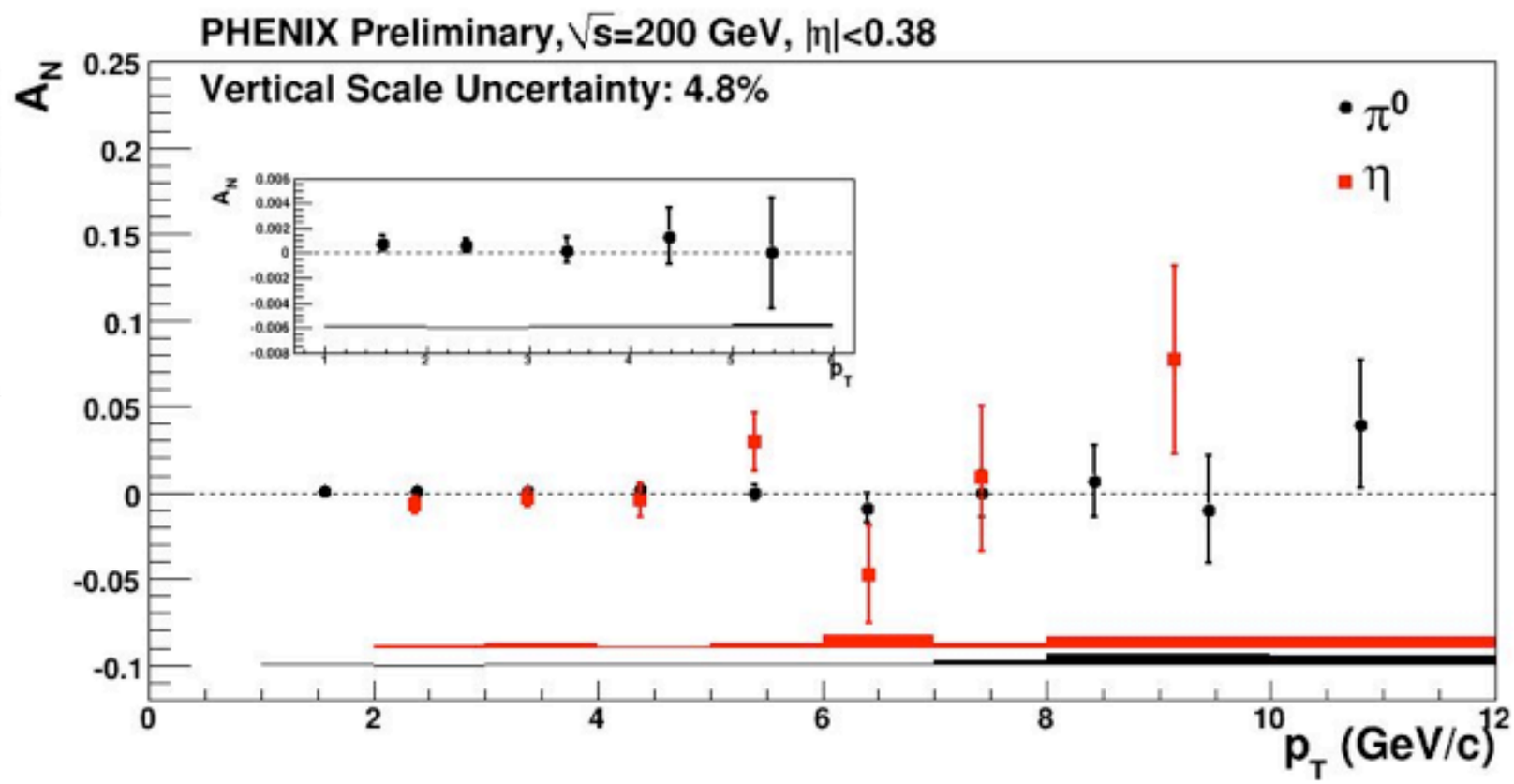
$1:0$

$\pi^0\,(u\bar{u}+d\bar{d})$ $\quad u:d\to\pi^0$ $\quad 2:1$

$\pi^-\,(\bar{u}d)$ $\quad u:d\to\pi^-$ $\quad 1:1$

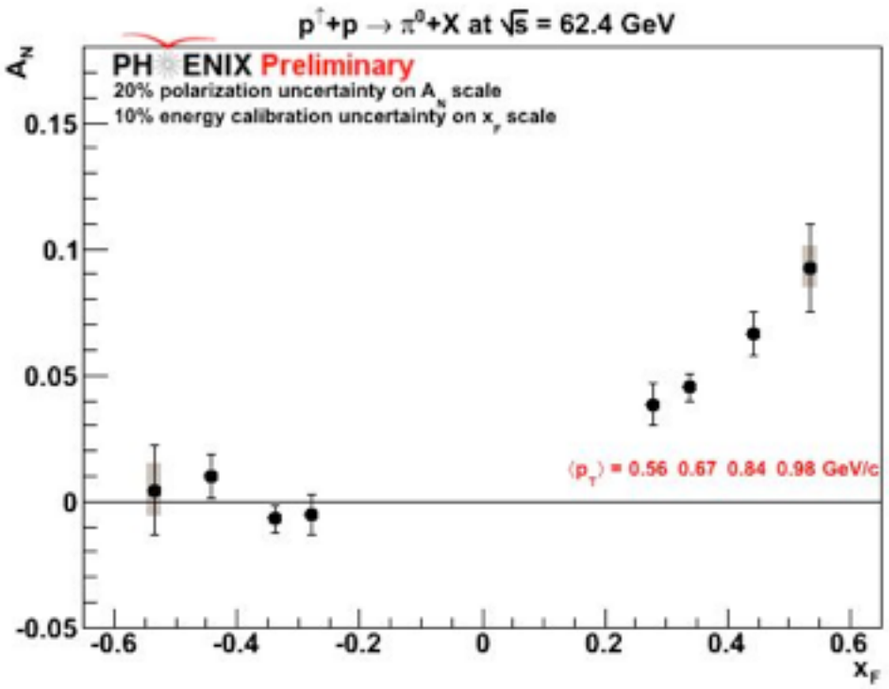
A_N for π^0 @ midrapidity

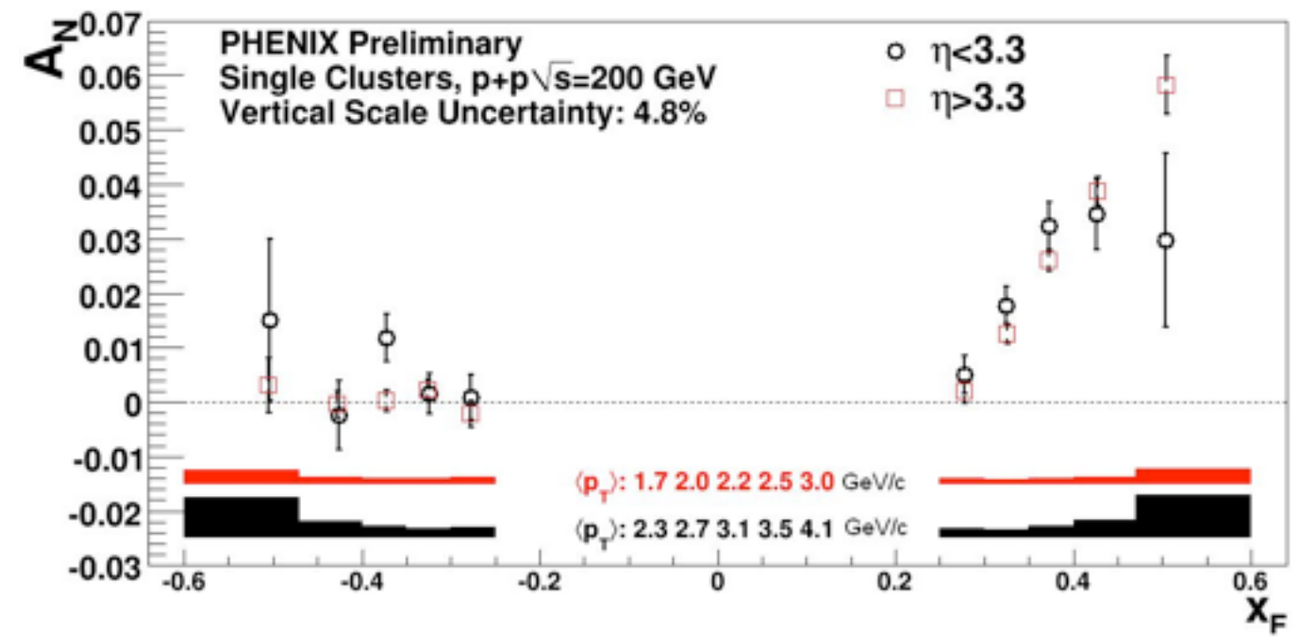




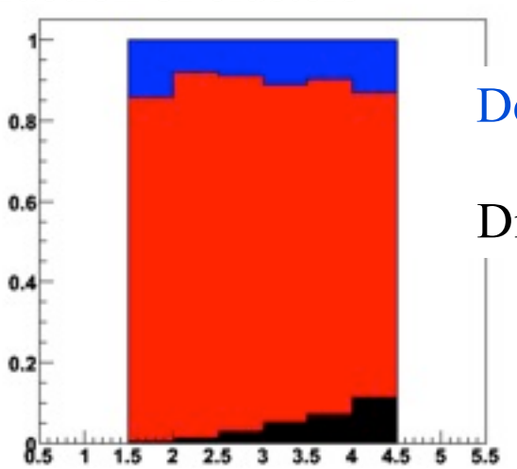
$A_N \approx 0$

A_N for π^0 forward





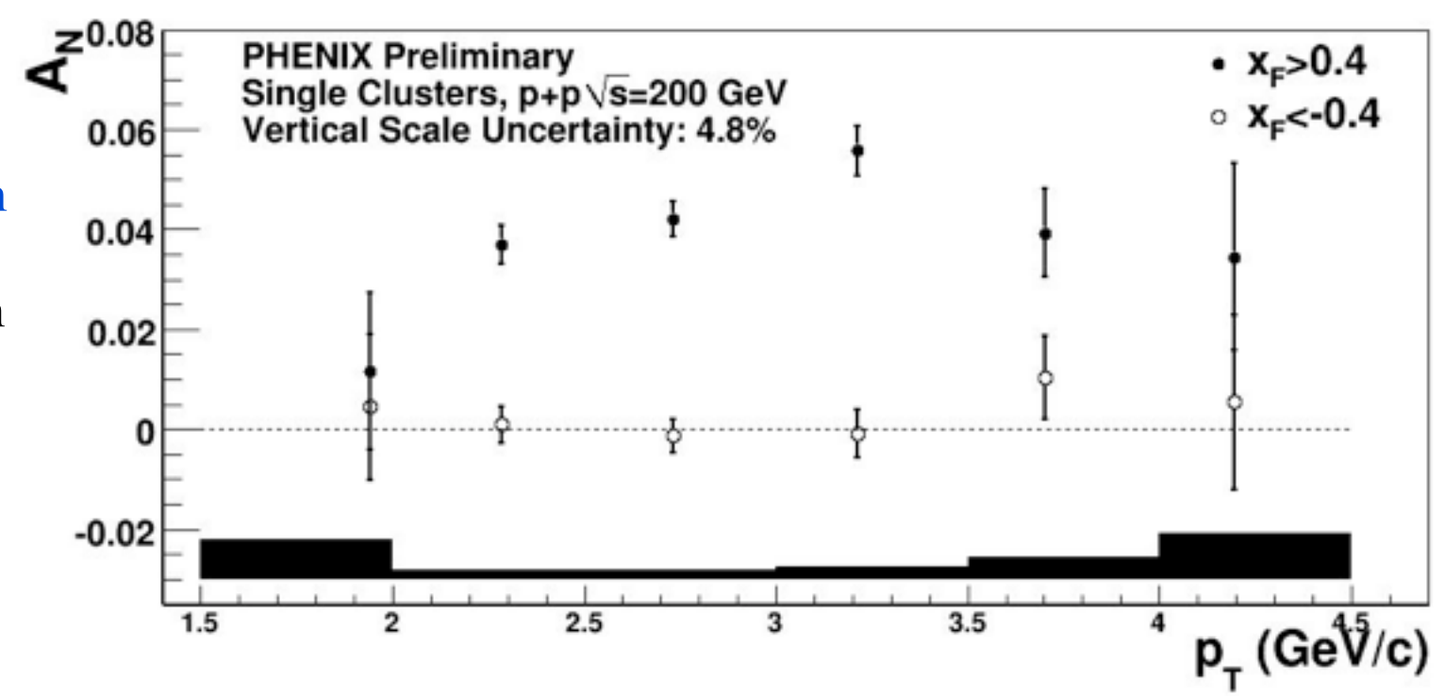
Fraction of clusters



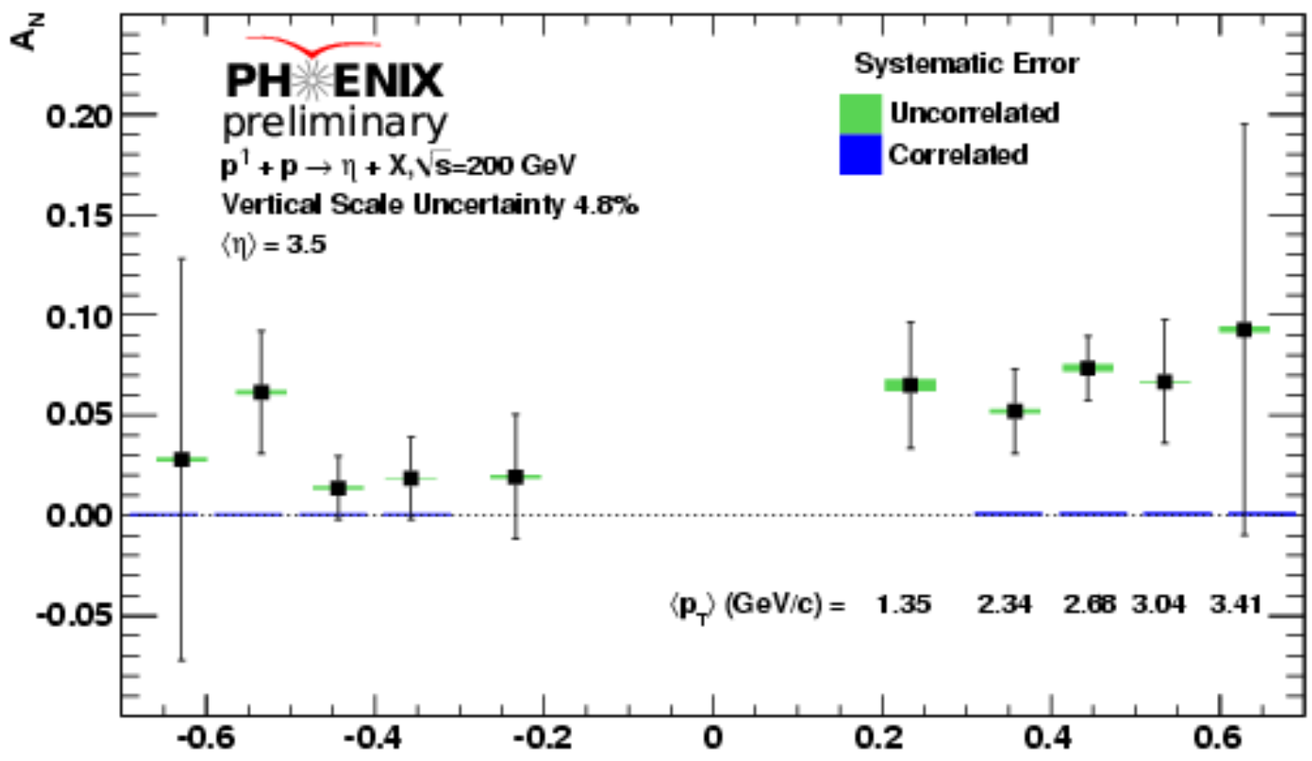
Decay photon

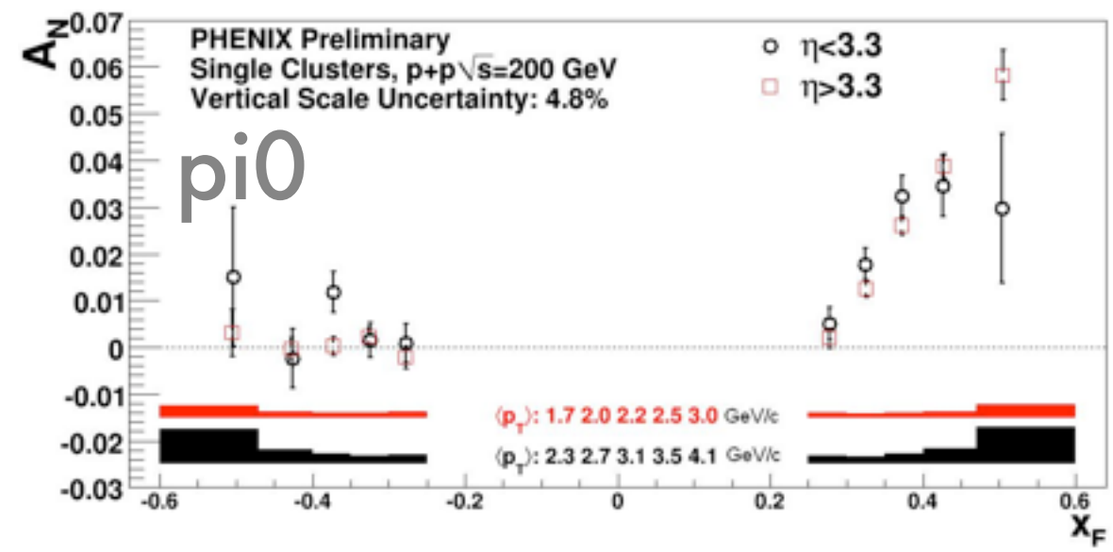
π^0

Direct photon



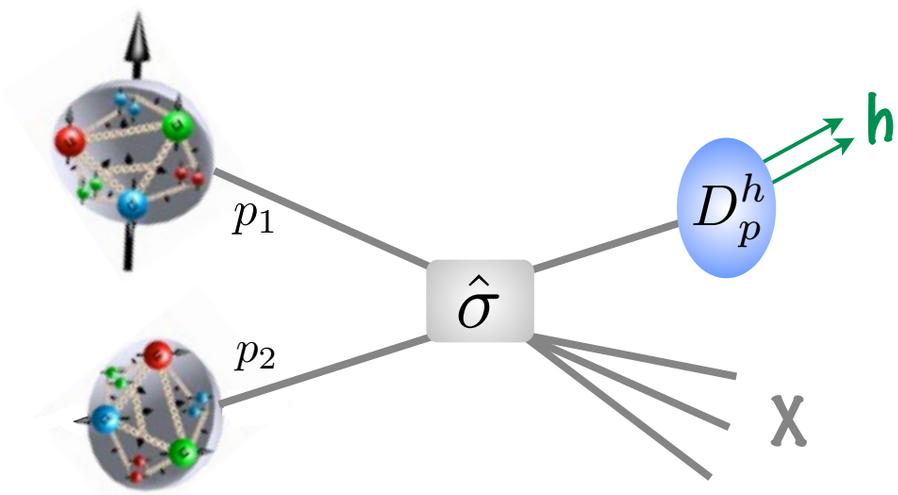
A_N η forward





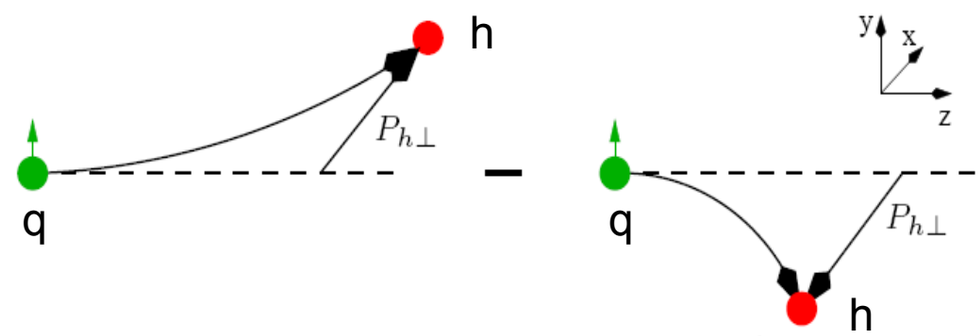
Larger asymmetry : strange contribution?

Transversity

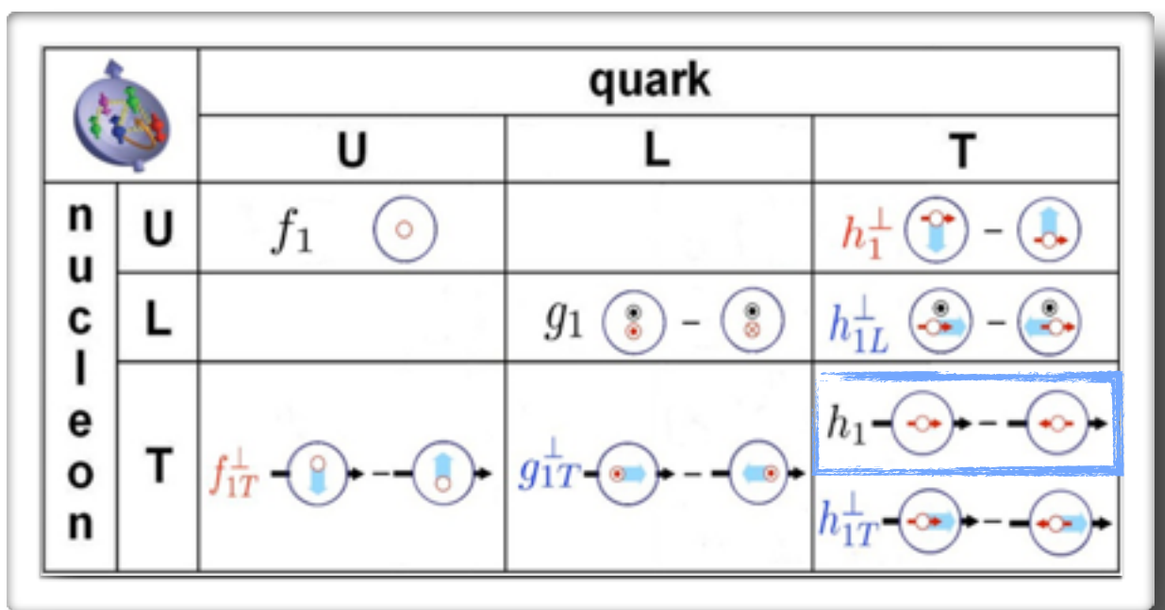


Accessible via the Collins mechanism:

left-right asymmetry from correlations between quark transverse spin and outgoing hadron direction



$$A_N \propto h_1 \times H_1^{\perp}$$



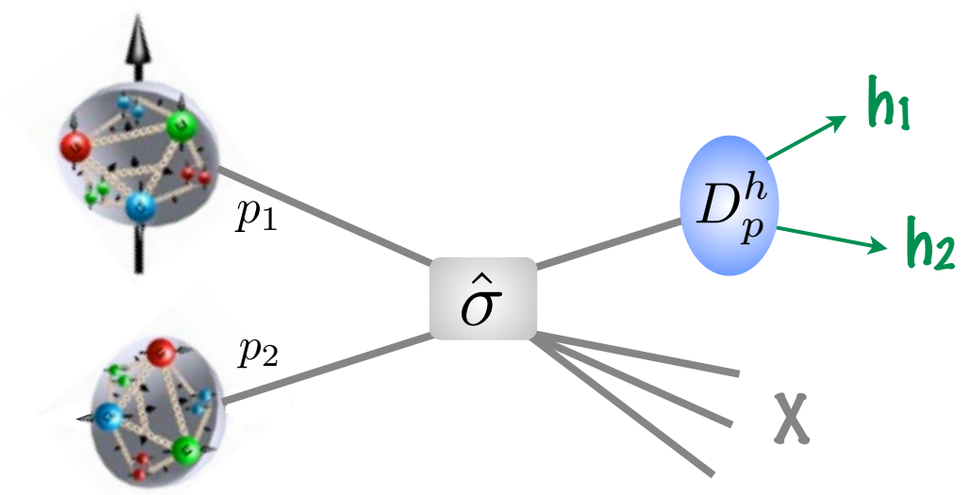
BUT!!

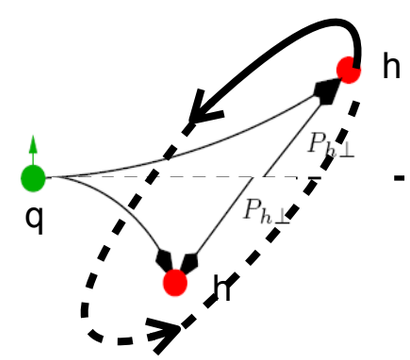
TMD factorization not valid in pp => hadron reaction!

A_N also generated by other effects:
- Higher twist effects
- Sivers effect

Transversity x IFF

Interference Fragmentation:
left-right asymmetry from correlations between quark transverse spin and relative orbital angular momentum of the hadron pair





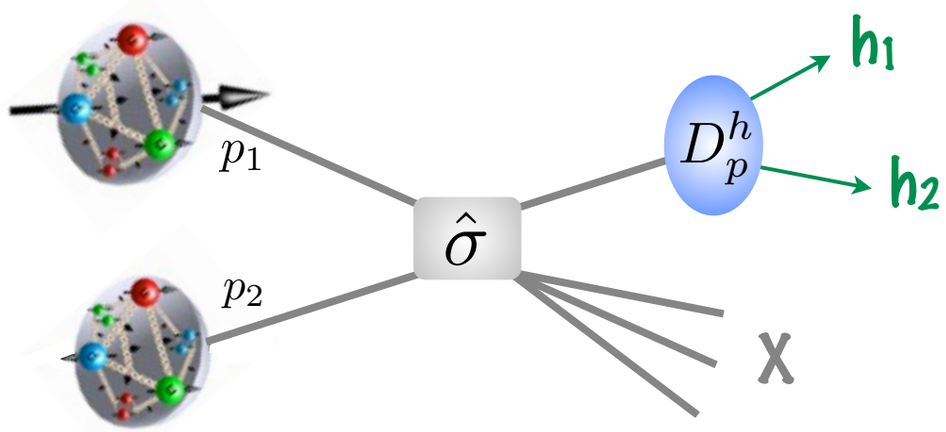
Collinear, no TMD!

Collinear factorization

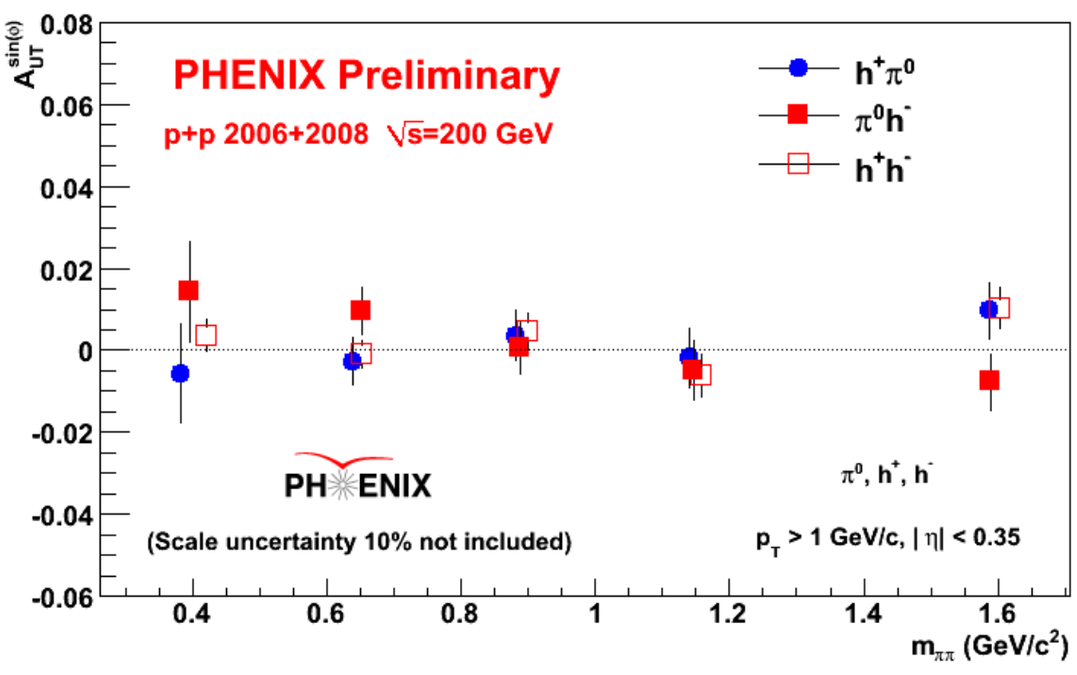
Independent access to transversity

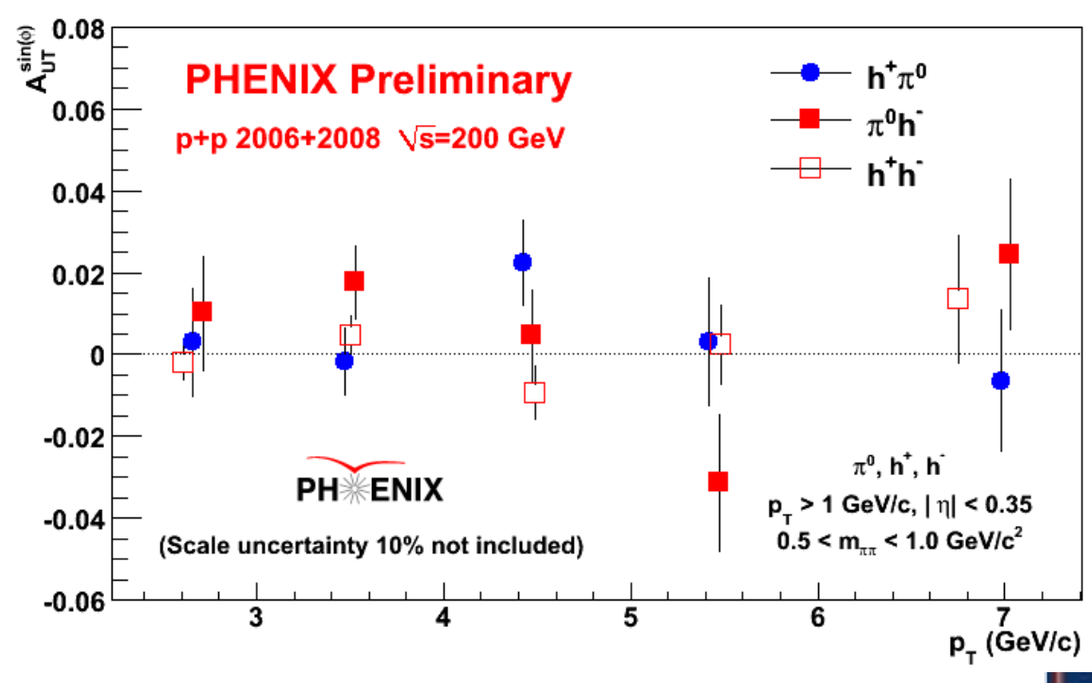
Measure of TMD factorization breaking in pp => hadrons reaction

Transversity x IFF @ midrapidity



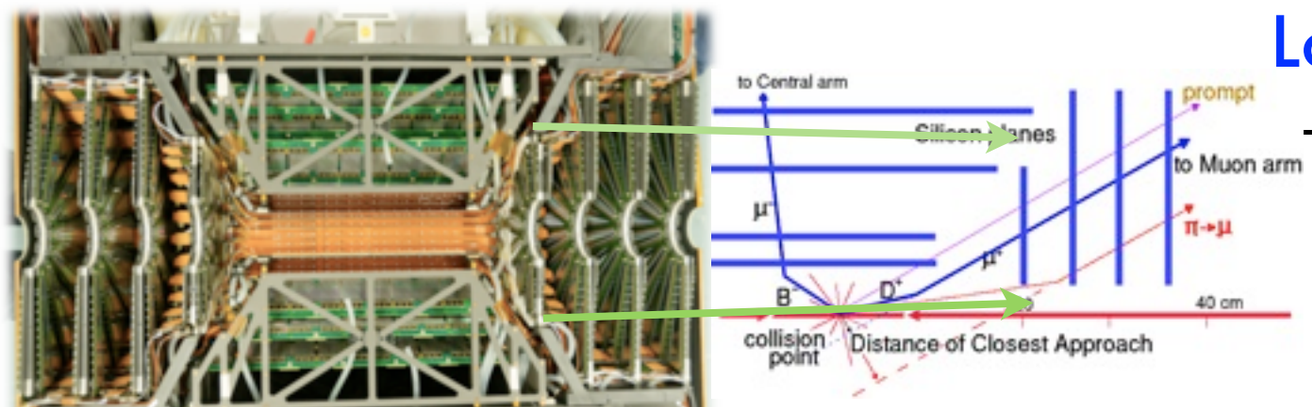
$$A_N \propto h_1 \times H_1^{\angle}$$

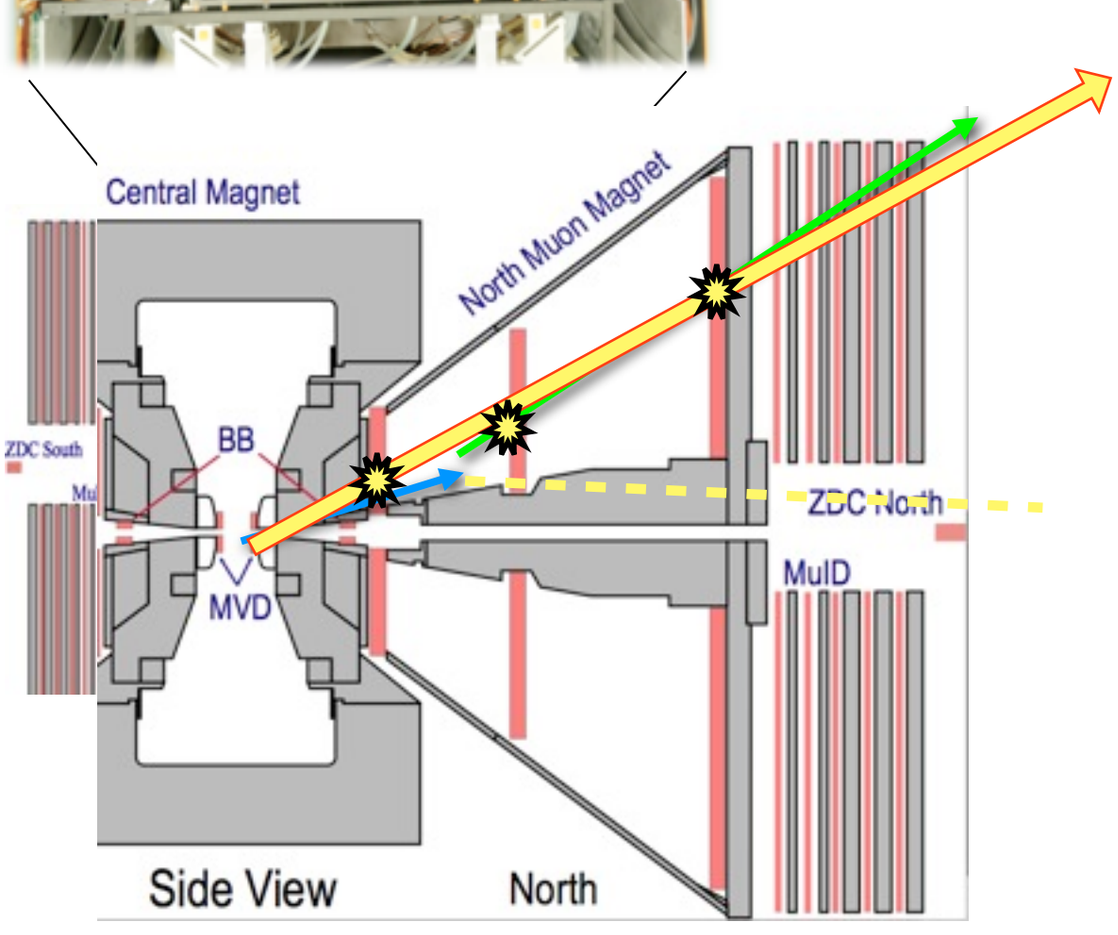




Near Future measurements

FVTX

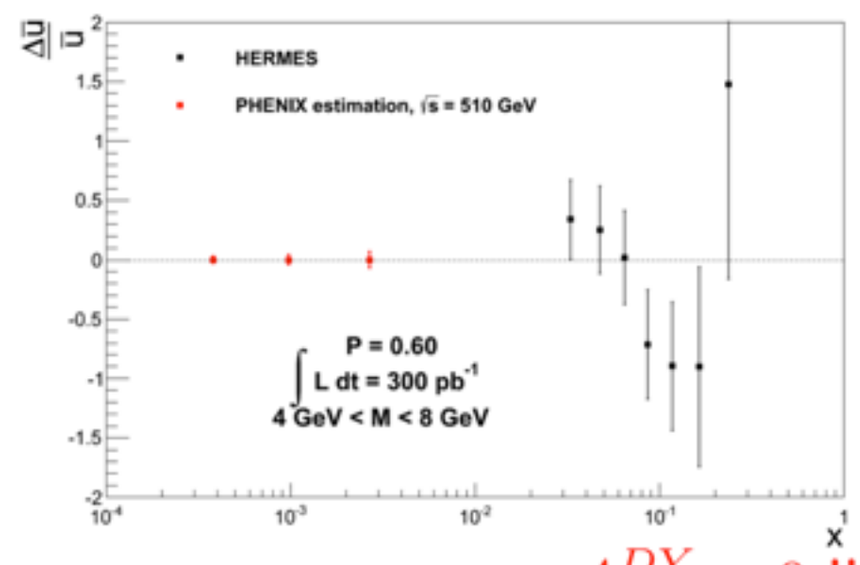




Longitudinal Spin program:

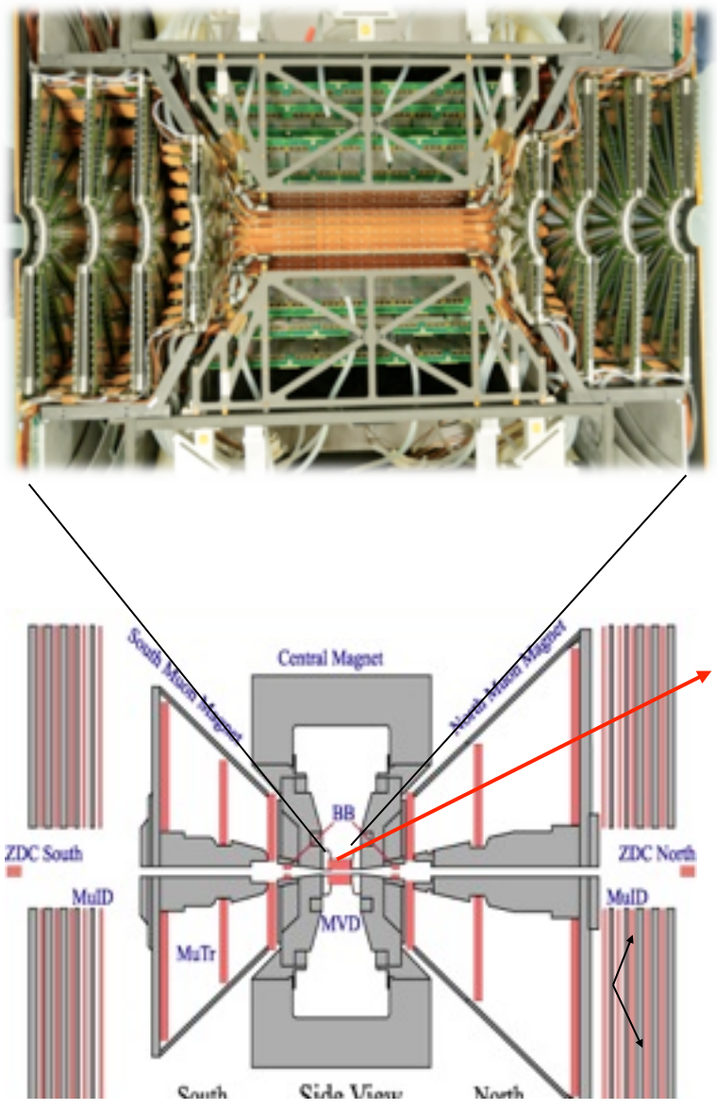
- Flavor dependent sea quark polarization:
  - S/B study for W - > muon
  - Drell-Yan for anti-u-quark polarization

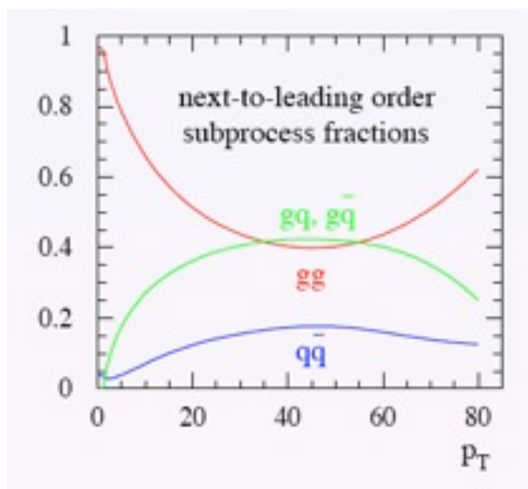
$\Delta\bar{u}/\bar{u}$ (L = 300 pb^{-1}) $\delta(A_{LL})\approx 1\%$



if anti-quarks carry no spin ➔ $A_{LL}^{DY} \equiv 0$!!!

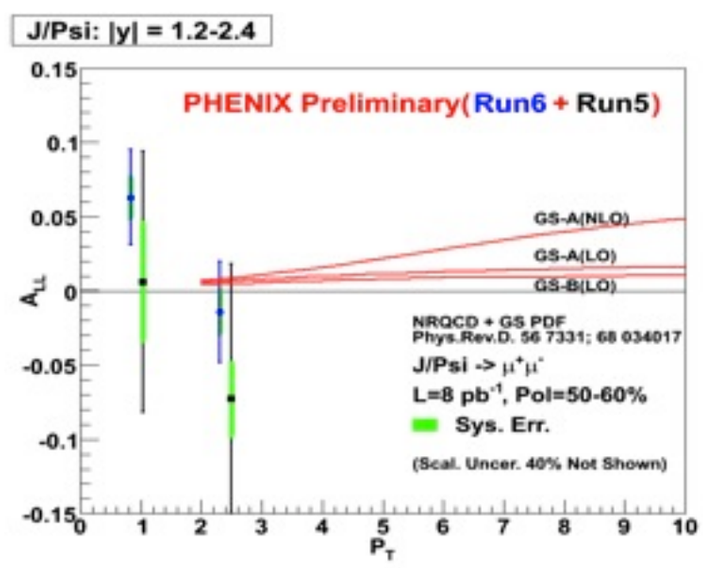
FVTX

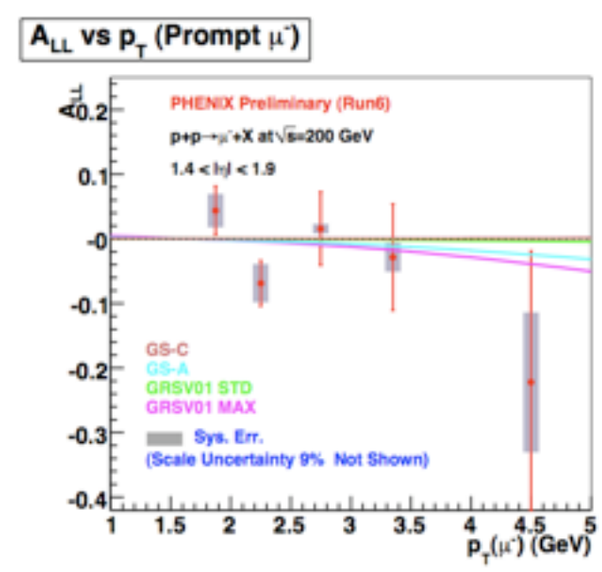




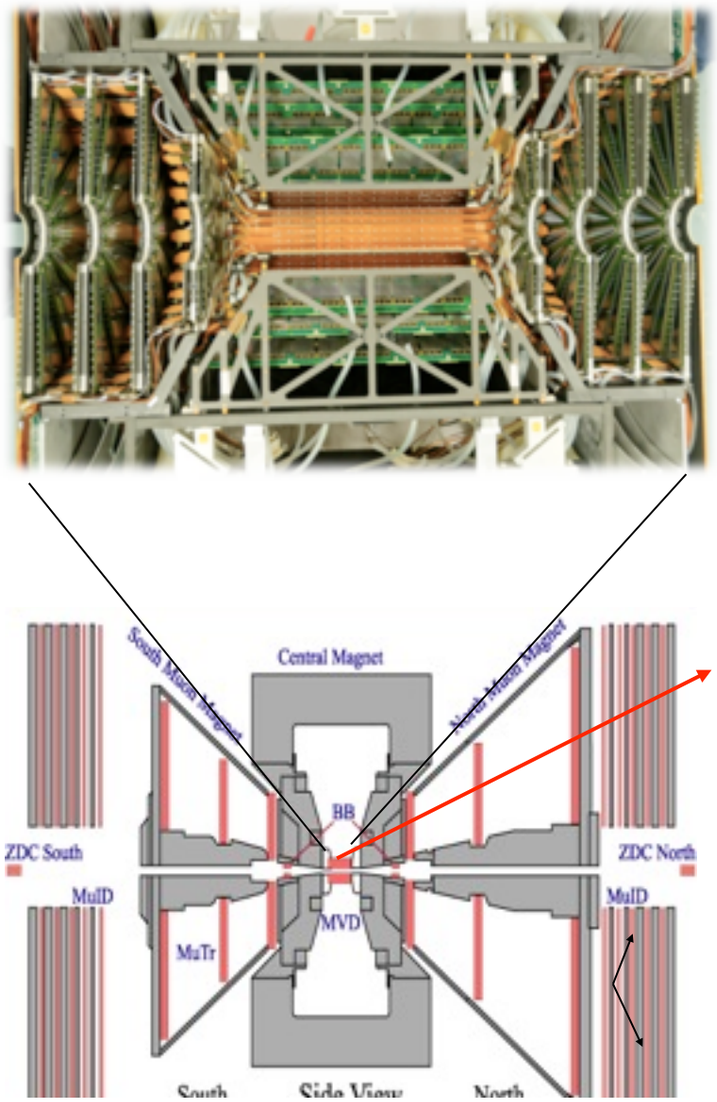
Longitudinal Spin program:

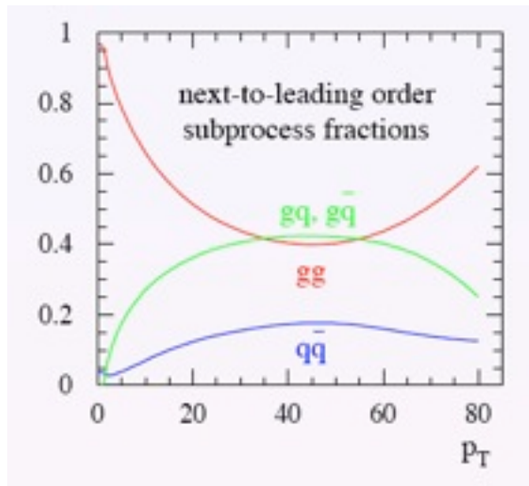
- Flavor dependent sea quark polarization:
  - S/B study for W - > muon
  - Drell-Yan for anti-u-quark polarization
- Gluon polarization at small-x (10^-3-10^-2):
  - Single high pT muon
  - Charm & Beauty measurements

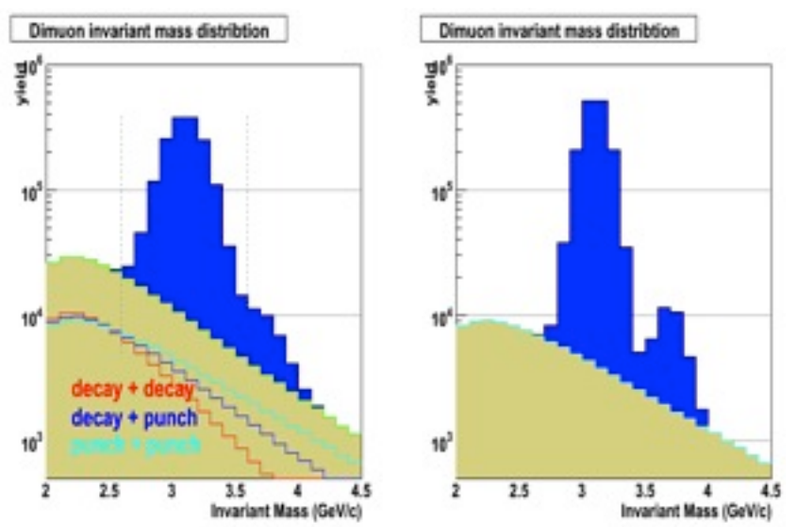




FVTX

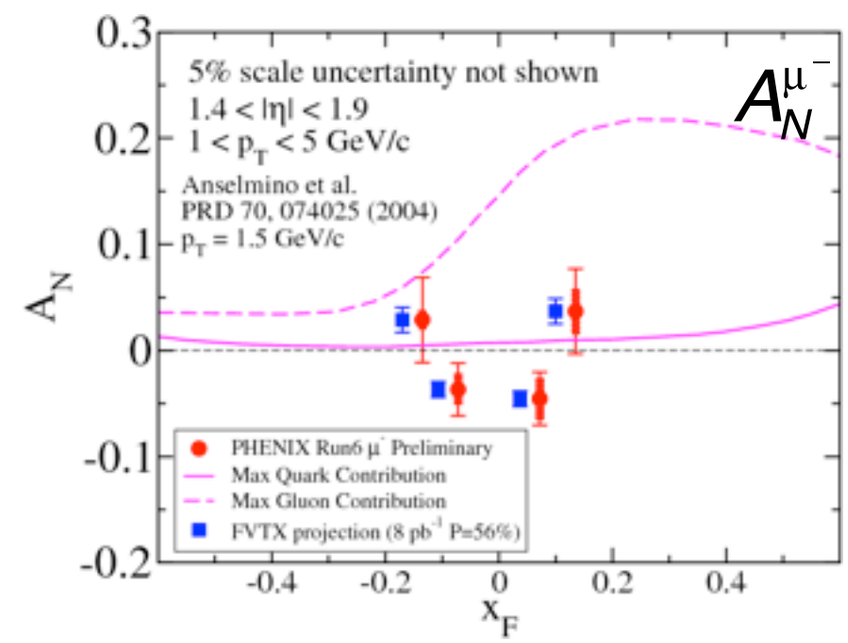




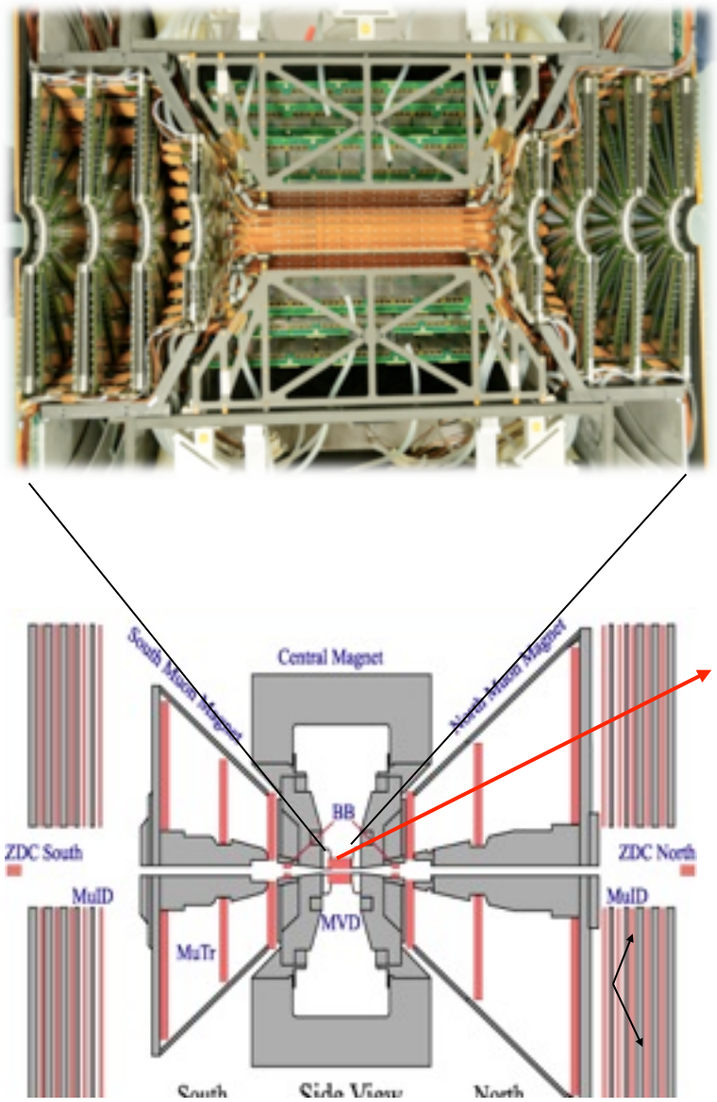


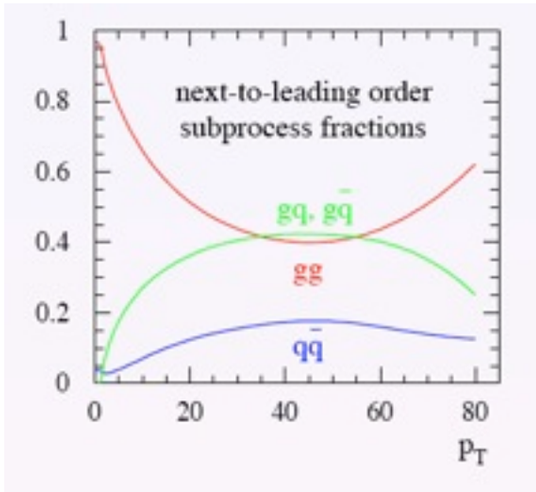
Transverse Spin program:

- Heavy flavors Transverse SSA
  - sensitive to gluon Sivers



FVTX

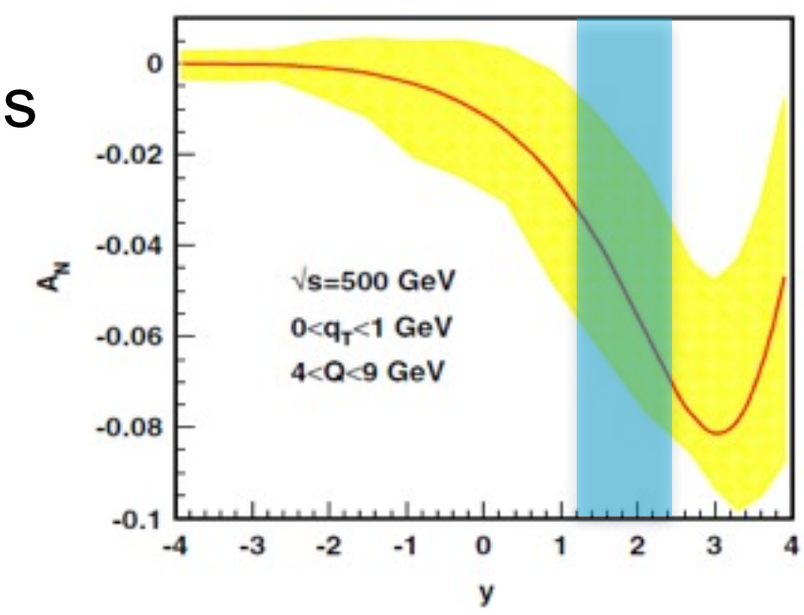




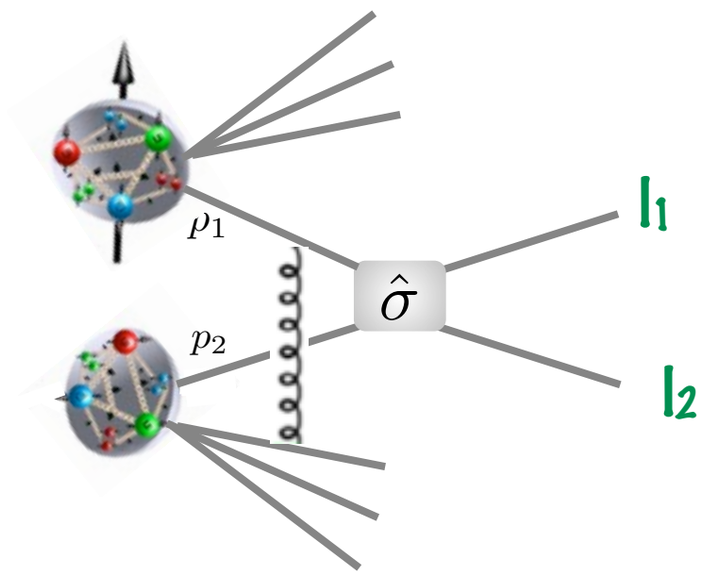
Transverse Spin program:

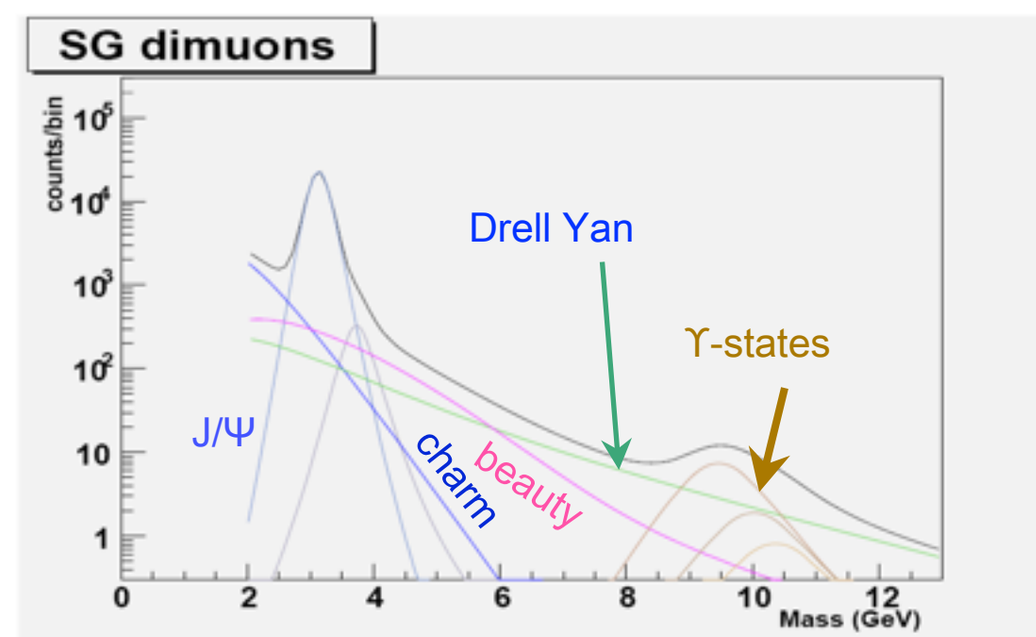
- Heavy flavors Transverse SSA
  - sensitive to gluon Sivers
- Drell-Yan Transverse SSA
  - sensitive to quark Sivers

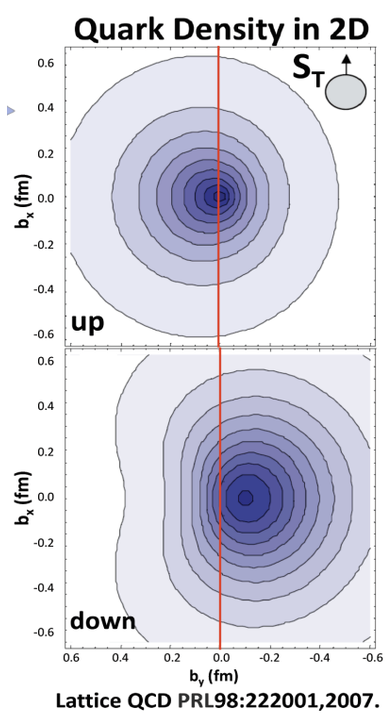
PHENIX muon arms



Sivers in Drell-Yan





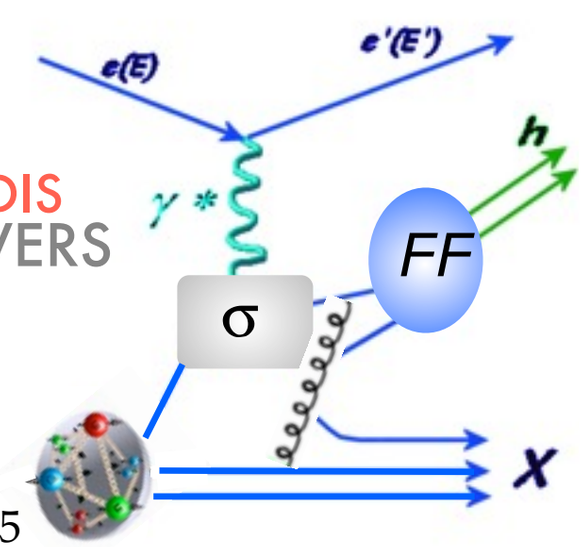


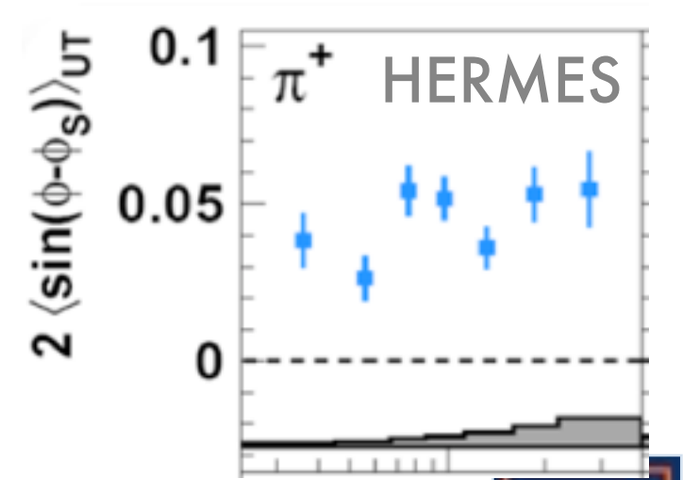
Lattice QCD PRL98:222001,2007.

Sivers effect gives access to the spatial quark distribution

$$TSSA^{DY}_{SIVERS} = - TSSA^{SIDIS}_{SIVERS}$$

SIDIS





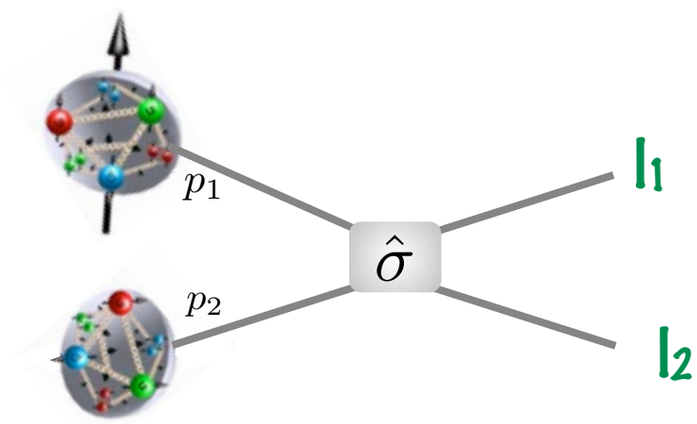
Forward

PHENIX

Physics program

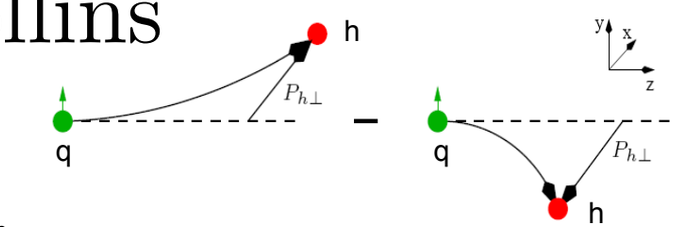
Drell-Yan

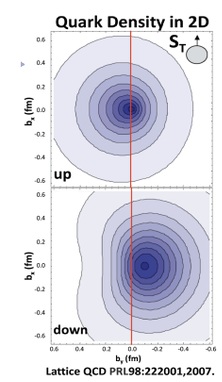
Sivers Gluon Sivers



$pp \to$ jets

Collins



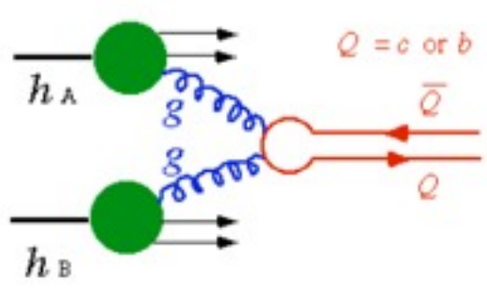


Sivers

Transversity $\times$ IFF

Heavy Flavors

e^+e^-, $\mu^+\mu^-$, $e\mu$, eX, μX



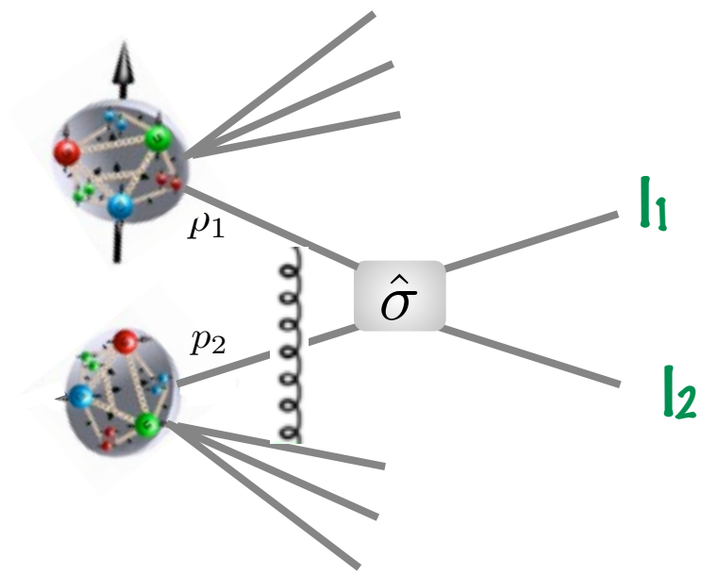
. . .

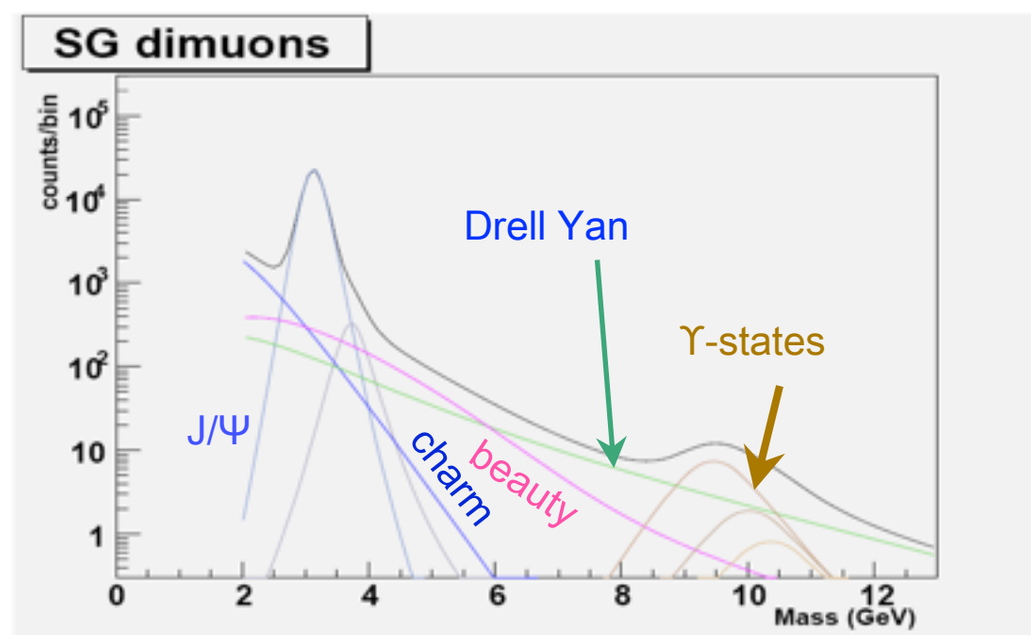
Boer-Mulders

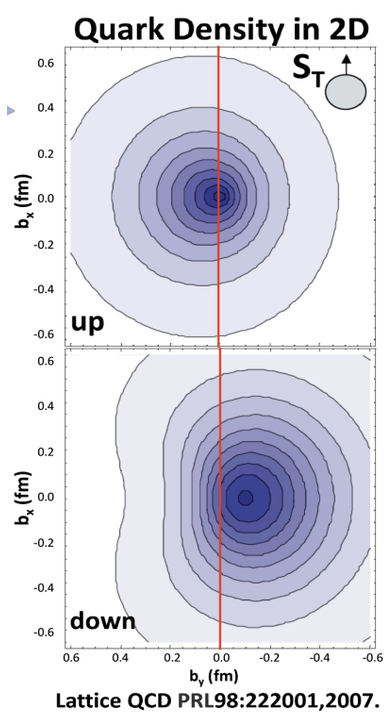
Sea Transversity

$\bar{u}$ Helicity

Sivers in Drell-Yan







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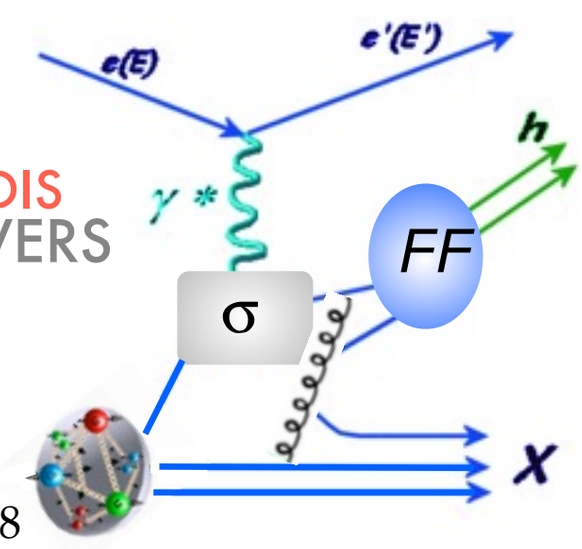
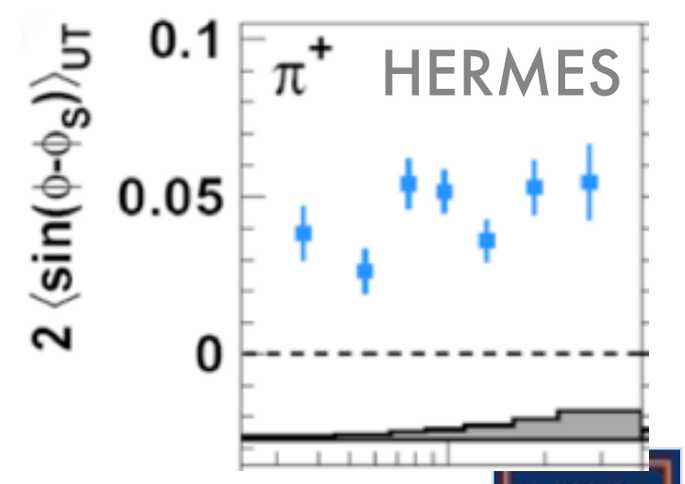
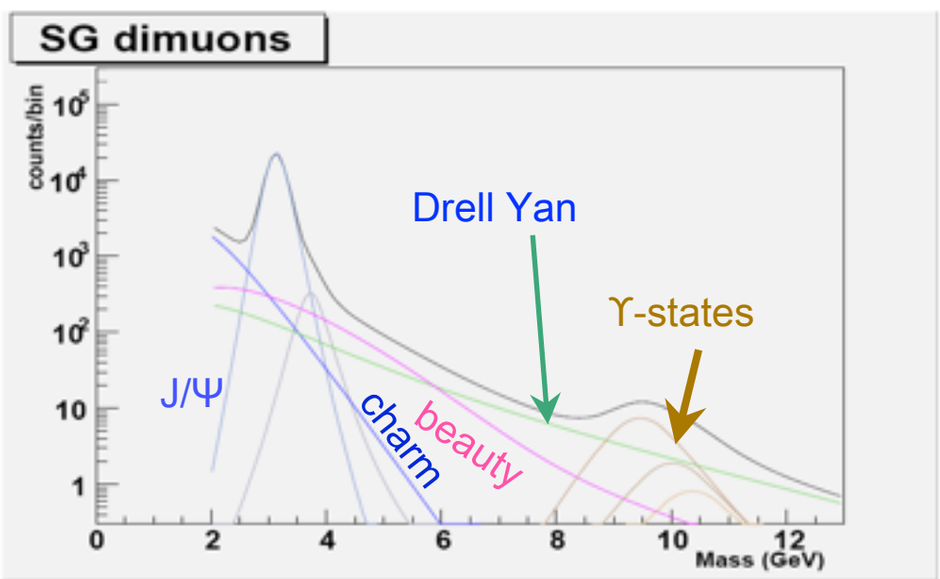
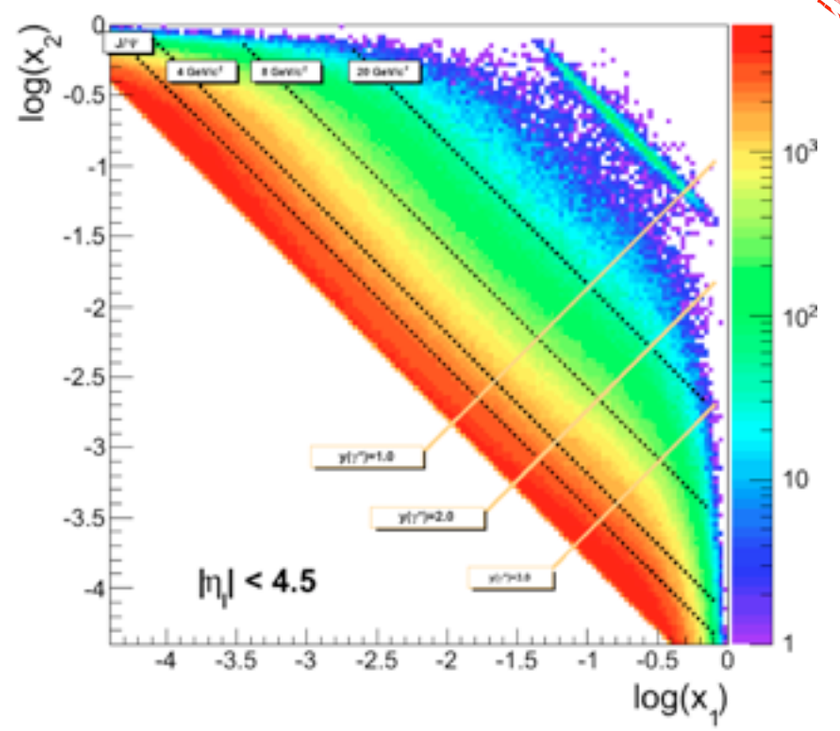
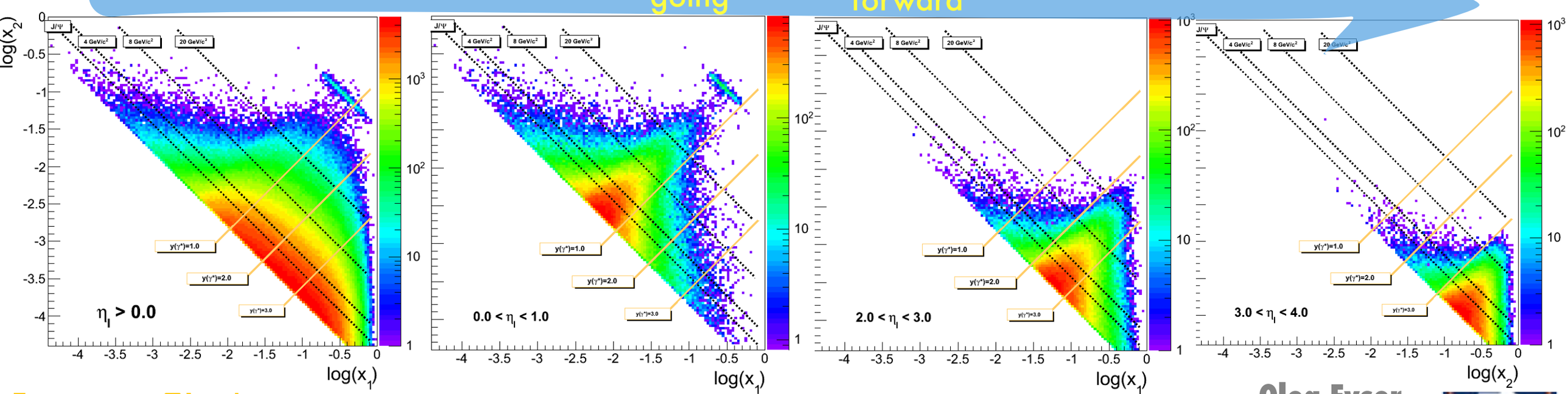




Mapping the Sivers mechanism



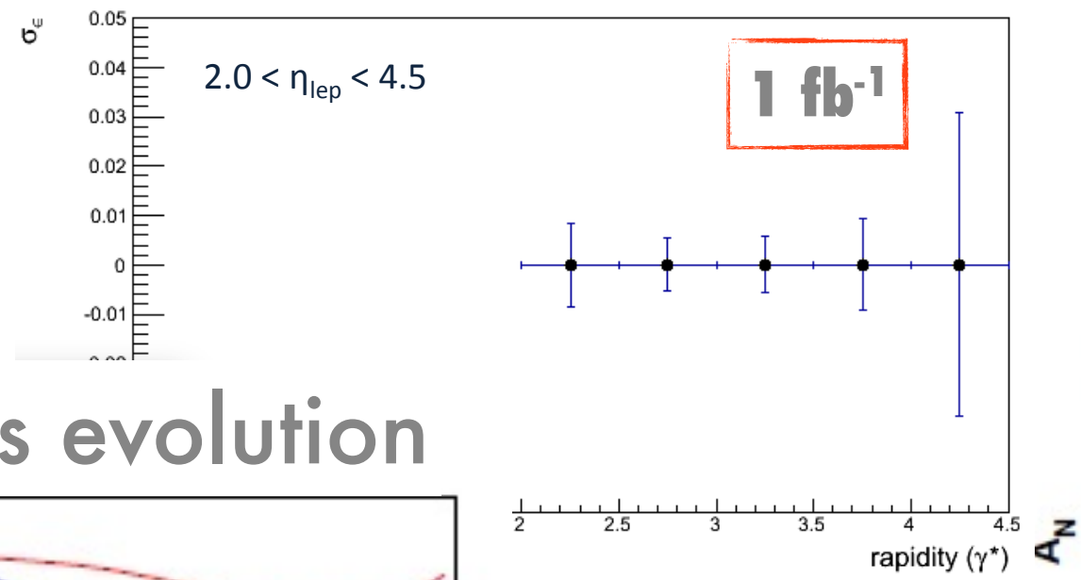


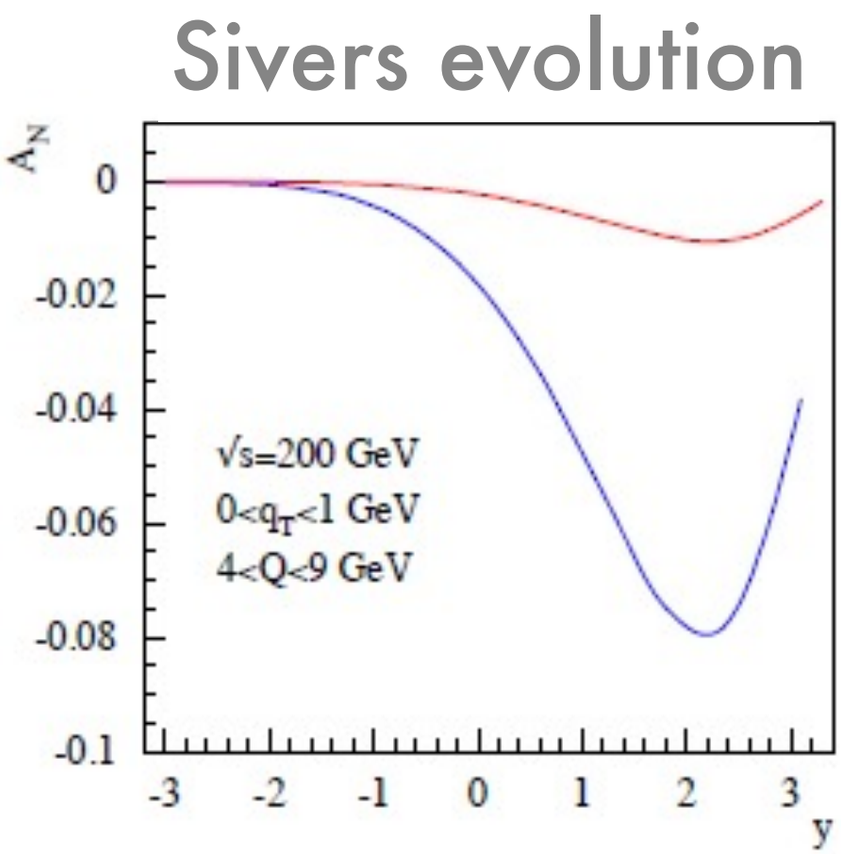


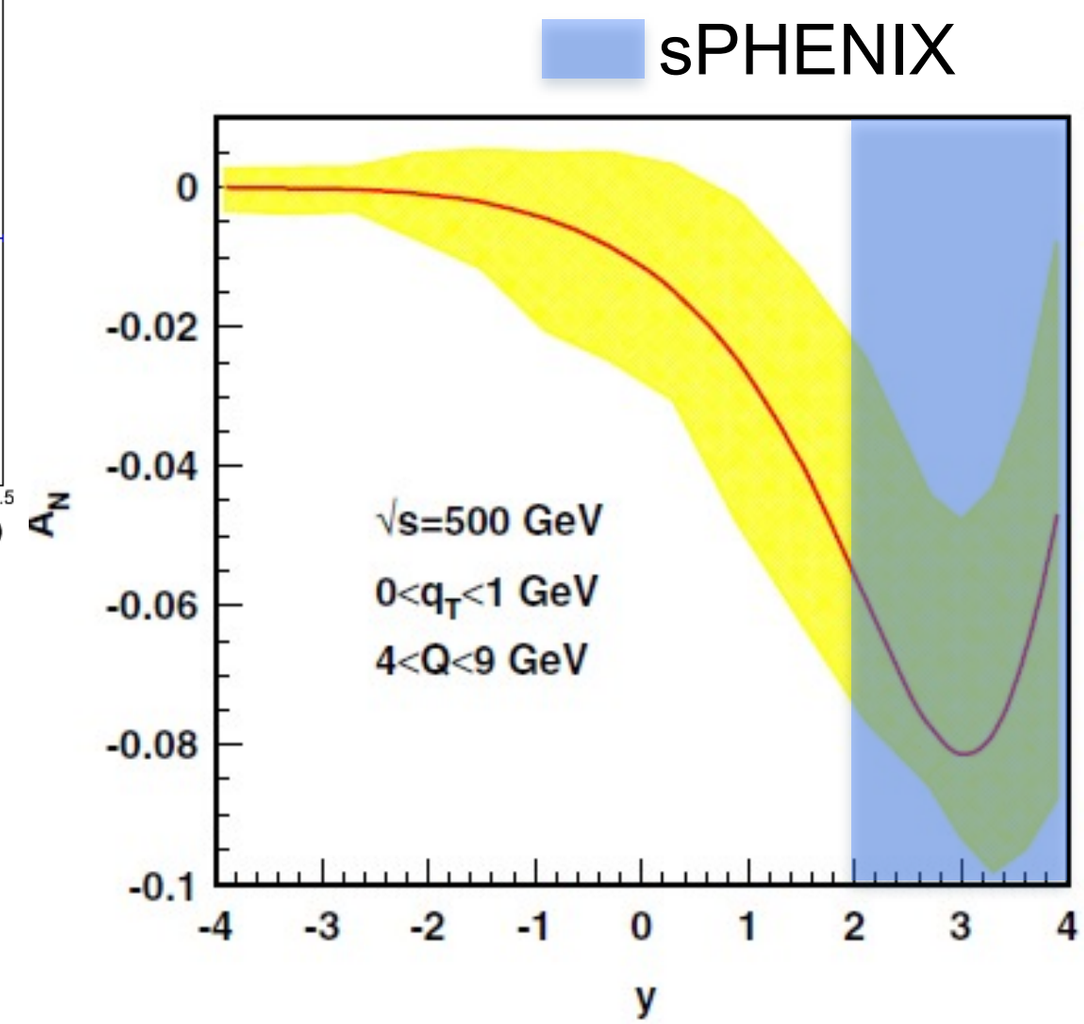
Francesca Giordano

Oleg Eyser

Sivers in Drell-Yan

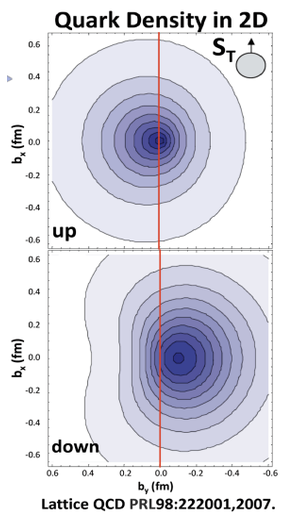




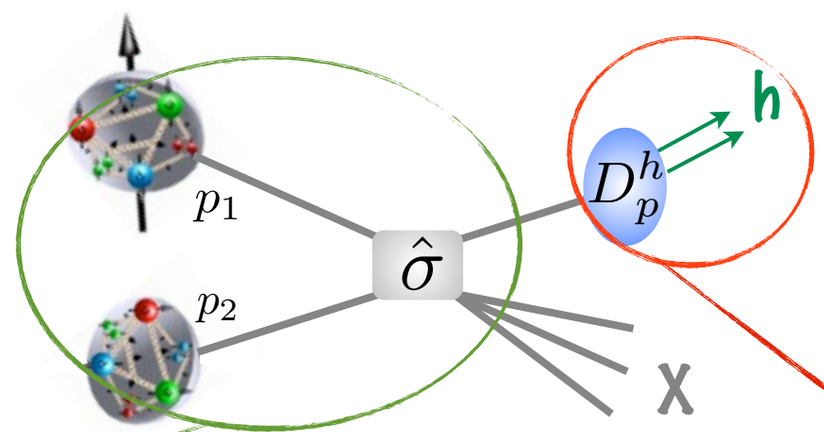


Sivers vs. Collins

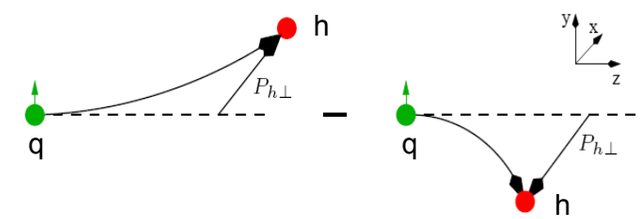
Sivers mechanism



+ FSI + ISI

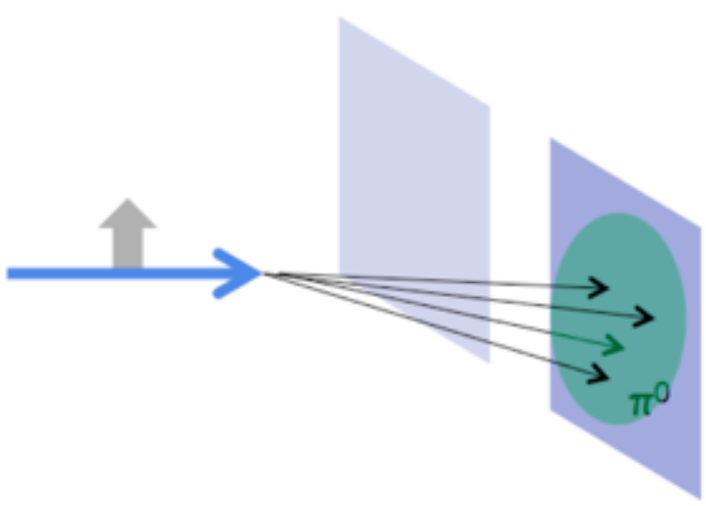


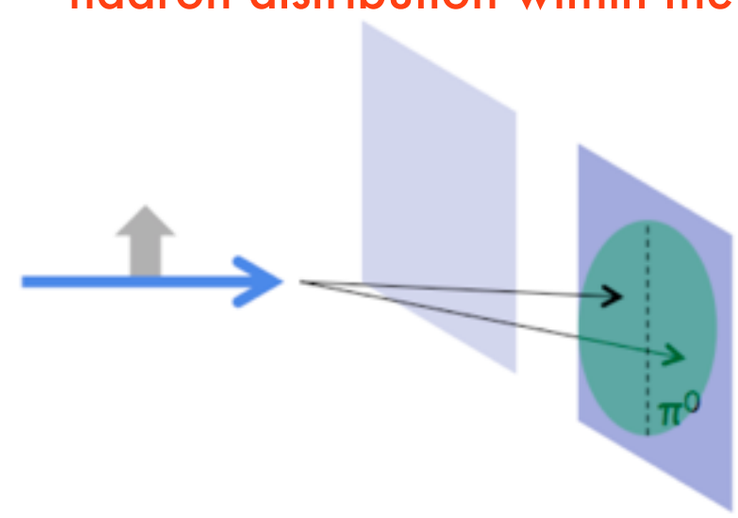
Collins mechanism



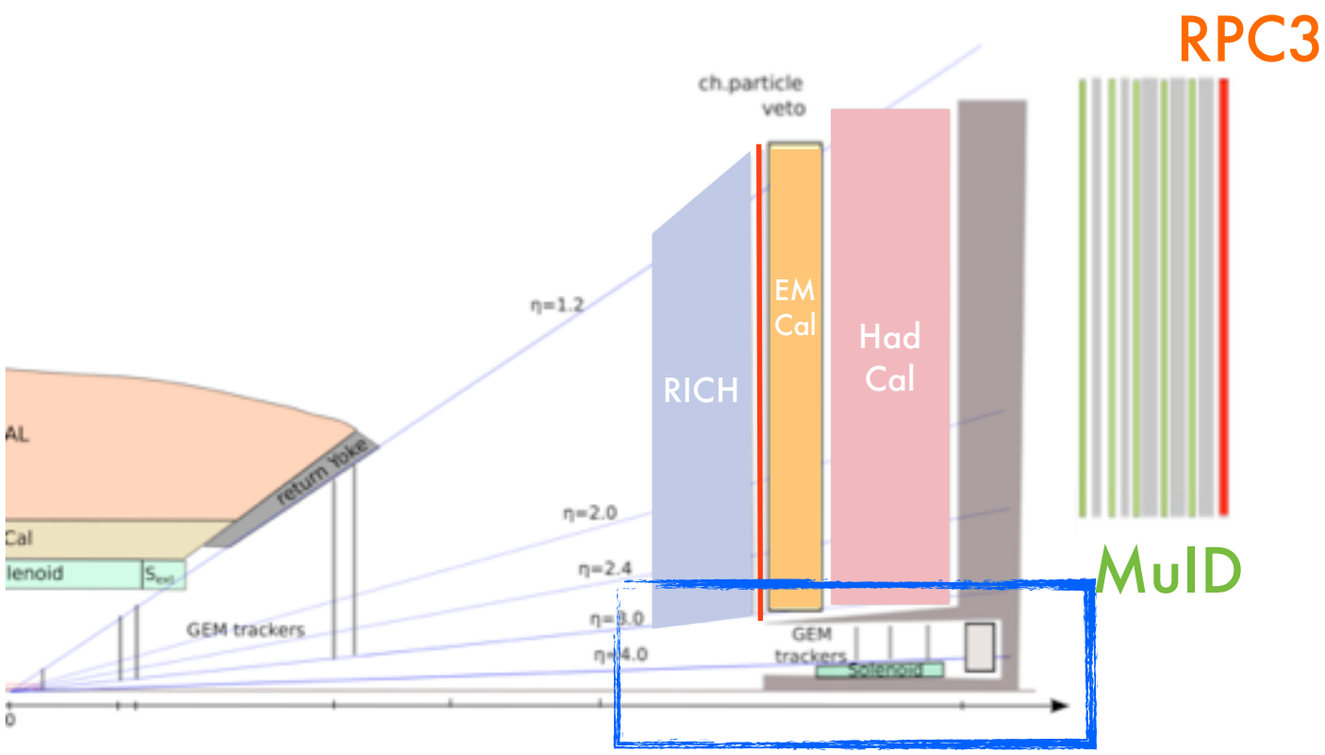
determines the
direction of the outgoing quark
>> the direction of the jet

determines the
hadron distribution within the jet





What's needed?



Good Tracking

Los Alamos, RBRC

Tracking chambers

Magnetic field

Los Alamos, RBRC, UCR

Good jet reconstruction

UIUC

Hadronic calorimeter

Lepton Identification

EM calorimeter + Preshower

RBRC, ISU

Hadron Identification

Ring Imaging Cherenkov

Stony Brook

Detector simulation in progress...

Summary

Broad spin program @ PHENIX

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

Gluon polarization

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

Flavor dependent quark polarization

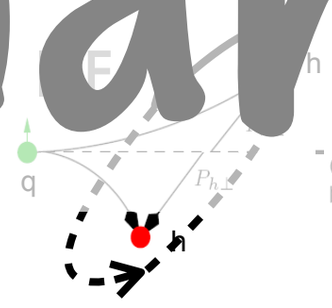
A_N Sivers + Collins

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

Forward

Boer-Mulders

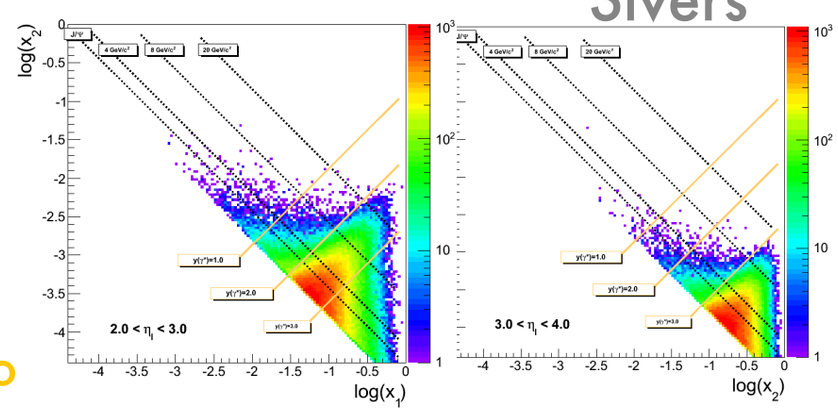
Sea Transversity



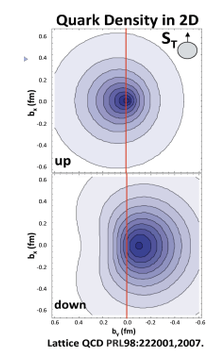
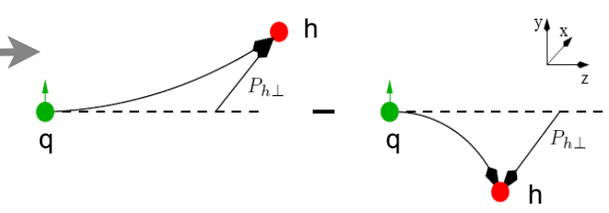
Thank you!

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

Sivers



Sivers



Collins