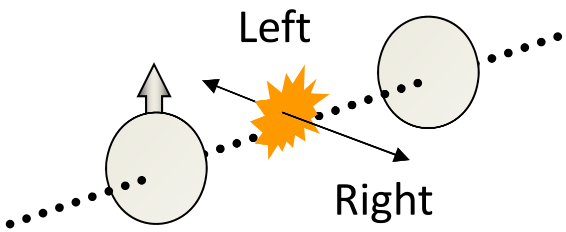
Prompt Photon A_N with the PHENIX MPC-EX Detector

J. Lajoie
Iowa State University
for the PHENIX MPC-EX group

Single Transverse Spin Asymmetries



$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$

A_N difference in cross-section between particles produced to the left and right

Theory Expectation:
Small asymmetries at high energies
(Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

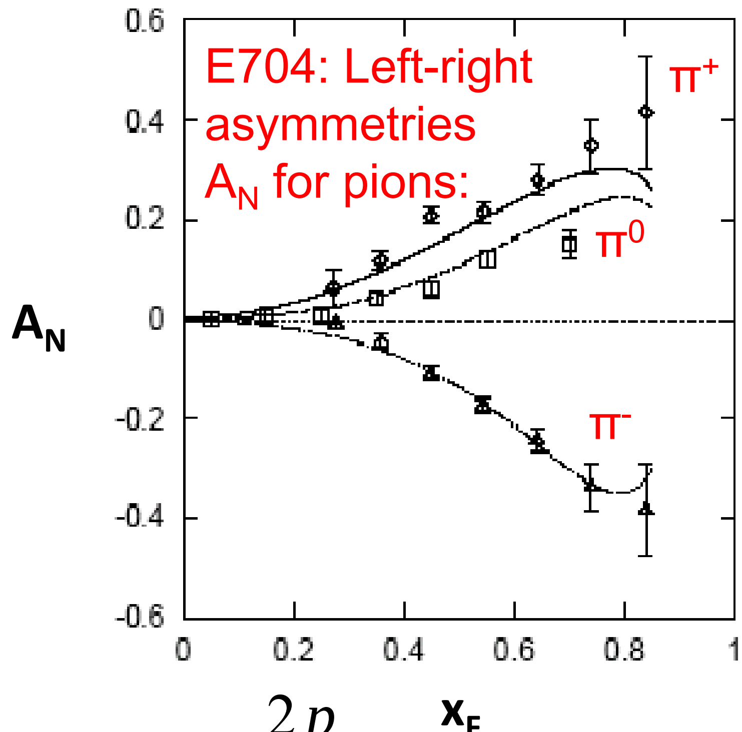
$$A_N \propto \frac{m_q}{\sqrt{s}}$$

A_N O(10^{-4}) Theory

Experiment:
(E704, Fermi National Laboratory, 1991)

$$pp^\uparrow \rightarrow \pi + X$$
$$\sqrt{s} = 20\,\mathrm{GeV}$$

A_N O(10^{-1}) Measured



$$x_F = \frac{2p_L}{\sqrt{s}}$$

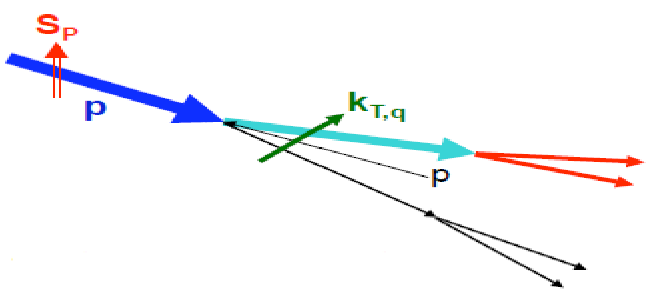
Sources of Transverse SSA's

"Sivers effect"

TMD: Correlation between nucleon spin and parton k_T.

Phys. Rev. D **41**, 83 (1990)
Phys. Rev. D **43**, 261, (1991)

$$d\sigma^{\uparrow} \propto \underbrace{\bar{f}_{1T}^{\perp q}(x,k_{\perp}^{2})}_{\text{Sivers distribution}} \cdot D_{q}^{h}(z)$$



Twist-3: Quark-gluon correlations in polarized hadron

Phys. Rev. D **59**, 014004 (1998)

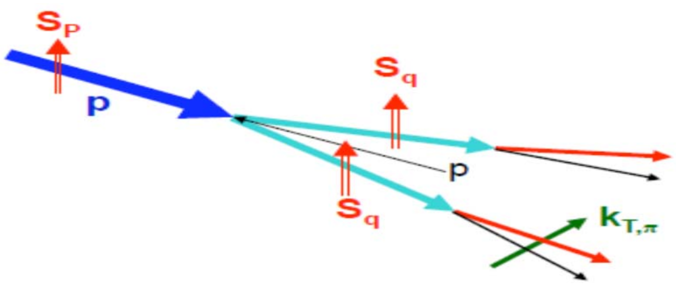
$$gT_{q,F}(x,x) = -\int d^{2}k_{\perp} \frac{|k_{\perp}|^{2}}{M} f_{1T}^{\perp q}(x,k_{\perp}^{2})$$

"Collins effect"

TMD: Transversity distributions + Spin dependent fragmentation functions

Nucl. Phys. B 396, 161 (1993)

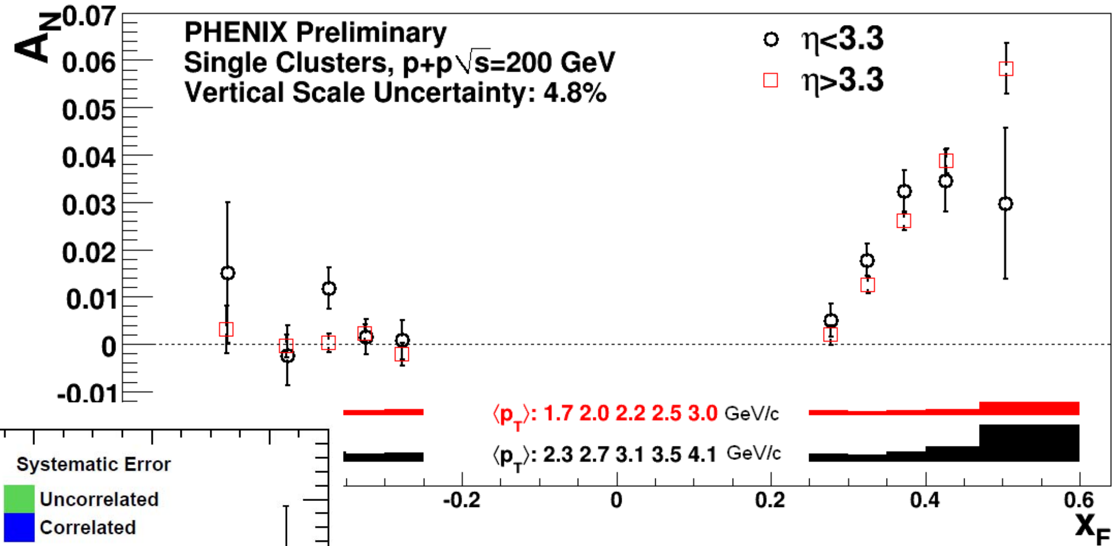
$$d\sigma^{\uparrow} \propto \underbrace{\delta q(x)}_{\text{Transversity}} \cdot \underbrace{H_{1}^{\perp}(z_{2},\bar{k}_{\perp}^{2})}_{\text{Collins FF}}$$

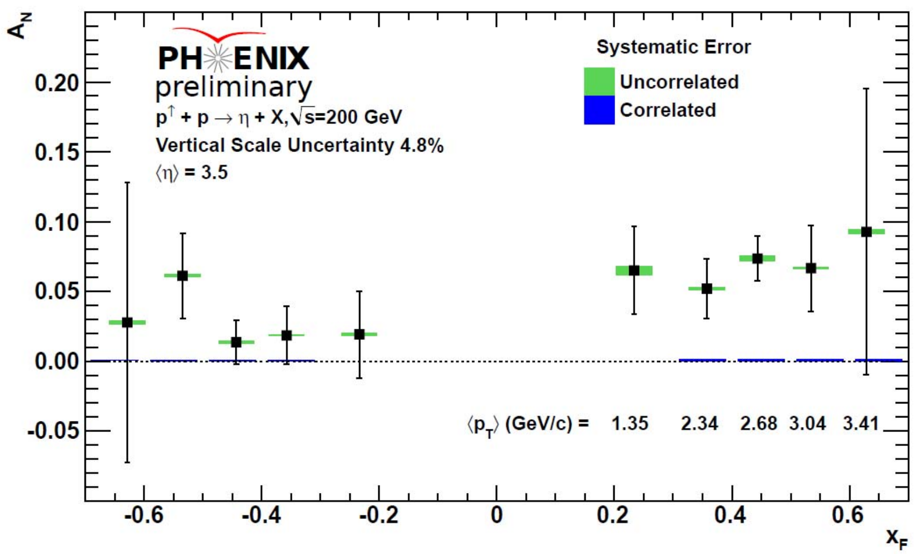


Twist-3: Transversity combined with twist-3 quark-gluon fragmentation function

Single Spin Asymmetries in PHENIX MPC

Neutral Clusters





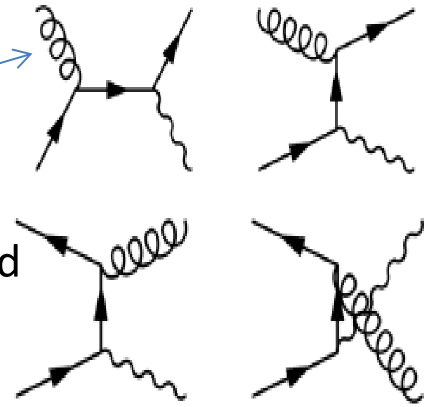
Identified η mesons

- Current measurements cannot address the <u>source</u> of these asymmetries
  - Need more targeted measurements

Prompt Photons at Forward Rapidity

<u>Direct Photons</u>

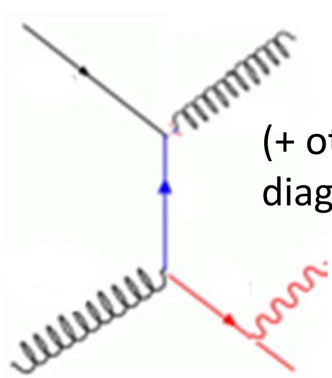
Dominated by gluon Compton at forward rapidites



Same level of production in pythia and NLO calculations (within factor of ~2)

<u>Fragmentation Photons</u>

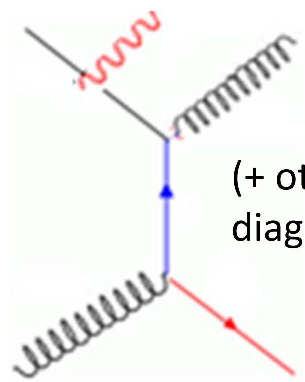
Comparable between pythia and NLO calculations



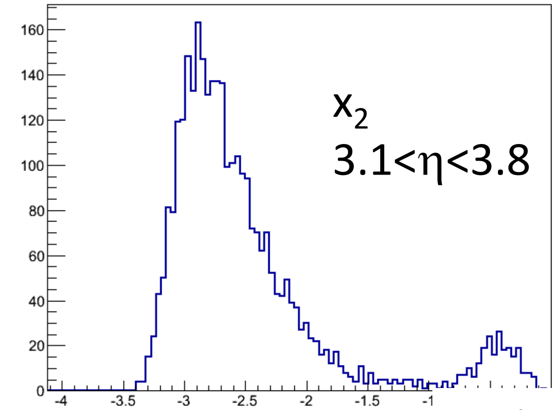
(+ other diagrams)

<u>QED Radiation (initial state)</u>

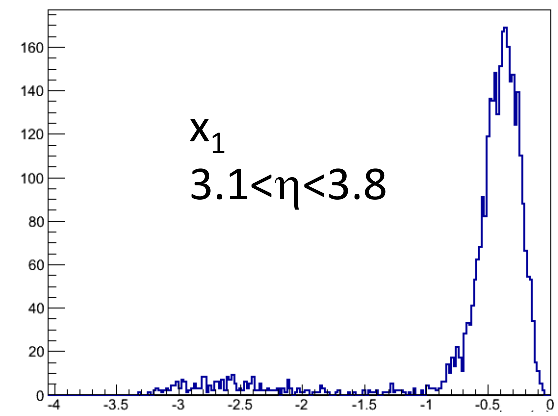
Production <u>over-estimated</u> in Pythia (Included in direct in NLO)



(+ other diagrams)



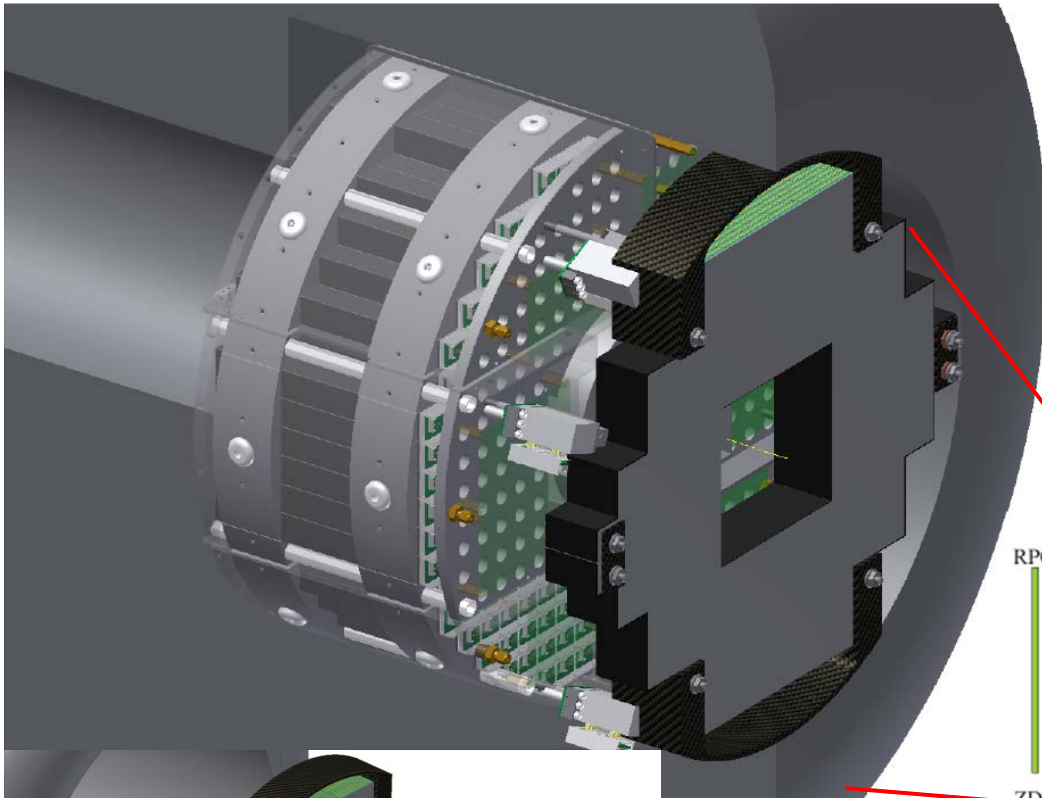
$\log(x_2)$

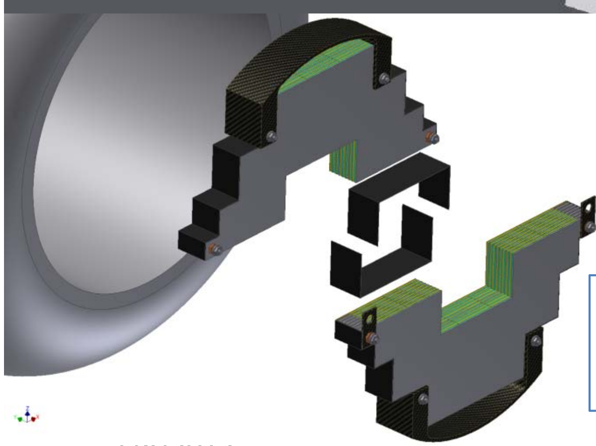


$\log(x_1)$

p↑+p : high-x quarks
p+A : low-x gluons

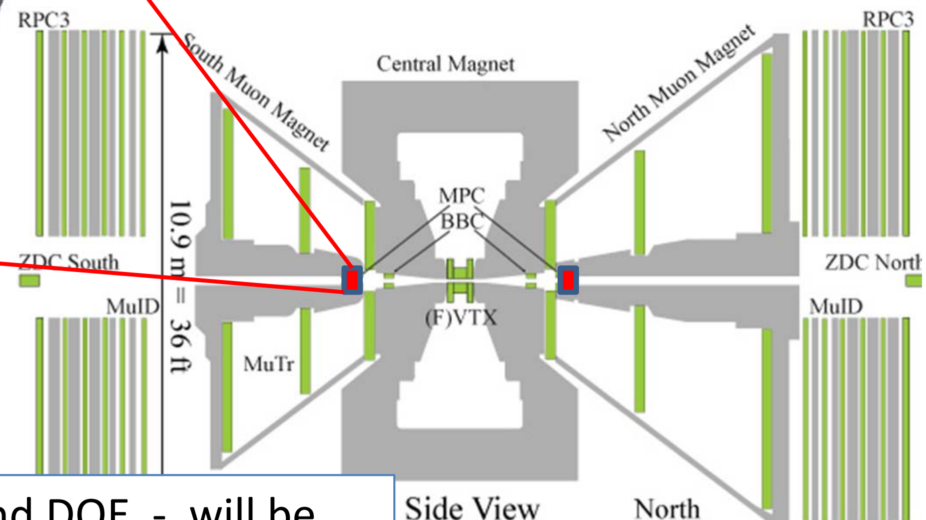
The MPC-EX Detector





A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- π^0 rejection (direct photons)
- π^0 reconstruction out to >80GeV
- Charged track identification



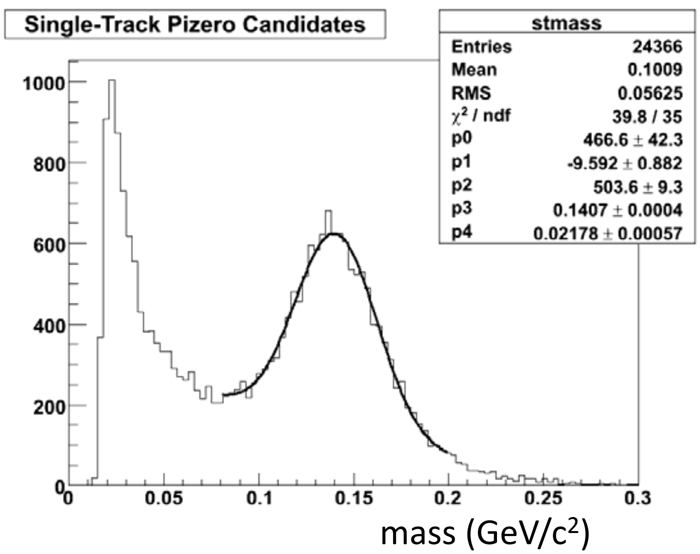
3.1<η<3.8

Approved by BNL and DOE - will be ready for Run-15 (earliest p+Au run)

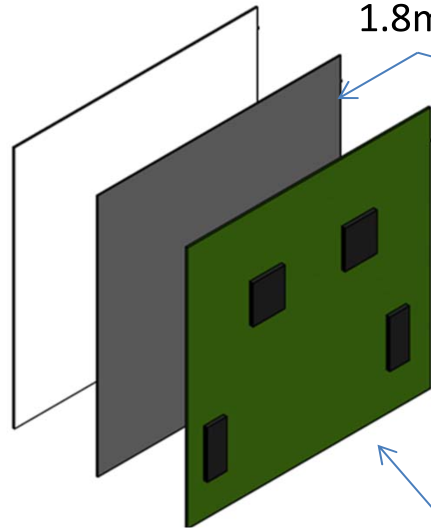
Minipad Sensors

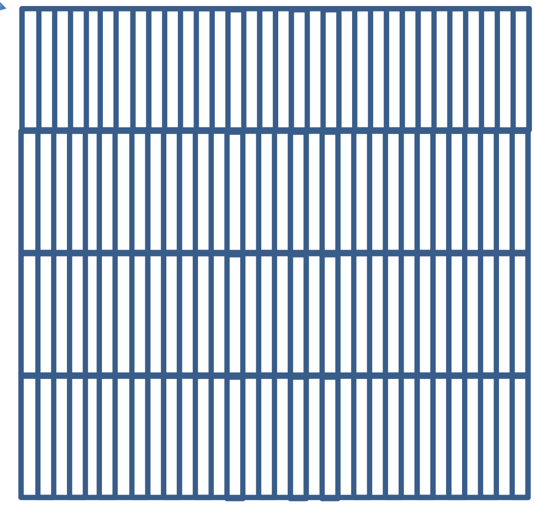
Detector elements are Si "minipad" detectors, one layer per tungsten gap, oriented in X and Y (alternating layers).

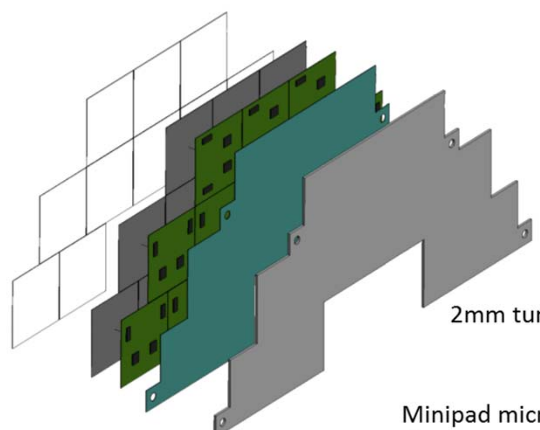
π^0 mesons reconstructed in p+p jet events (E>20GeV)



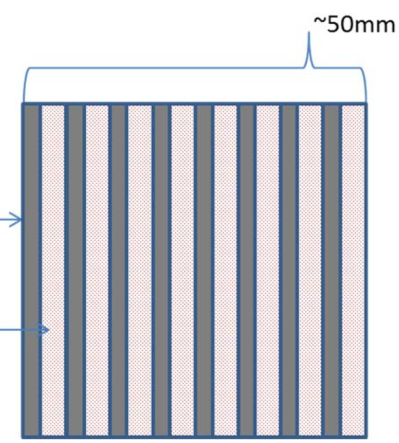
1.8mm x 15mm "minipad" sensor







Cross-Section View:



MPC-EX Event Reconstruction

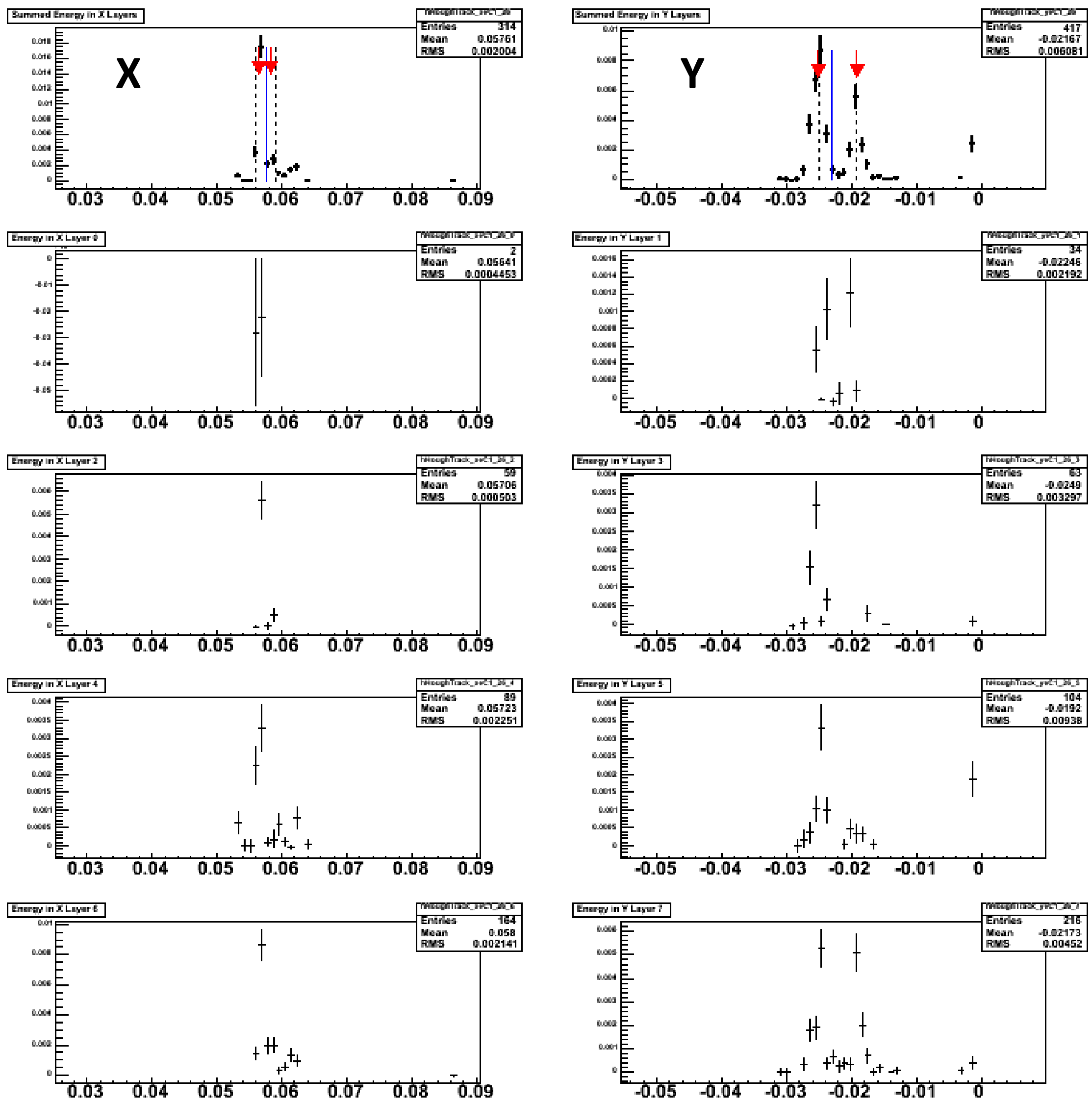
Layer Sum

Layer 1

Layer 2

Layer 3

Layer 4



Event 26

Arm = 1
Energy = 45.60 GeV
Mass = 0.147 GeV
Vertex = 0.40 cm

Hough Slope 1x = 0.05601
Hough Slope 1y = -0.02504
Hough Slope 2x = 0.05892
Hough Slope 2y = -0.01924

E1 = 23.94 GeV
E2 = 21.65 GeV
Asymmetry = 0.050

True Energy = 43.66 GeV
True Asymmetry = 0.197

True Hough Slope 1x = 0.05832
True Hough Slope 1y = -0.01916
True Hough Slope 2x = 0.05644
True Hough Slope 2y = -0.02519

First X Layer = 0
First Y Layer = 1

MIPs in Last Layer = 244.3

radius of hit = 13.42 cm

Exit

The MPC-EX Physics Program

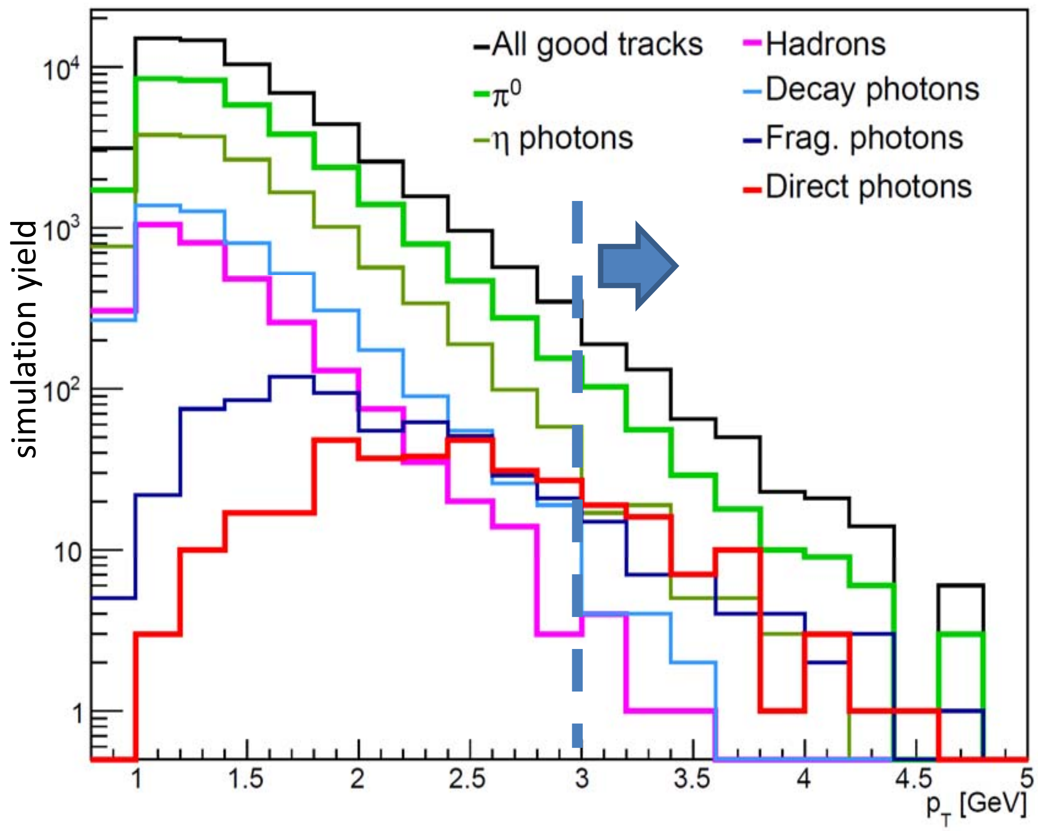
- **The Gluon Distribution in Cold Nuclear Matter at Low-x:**
  - Single π^0 production
  - π^0 pairs
  - **Prompt Photons**

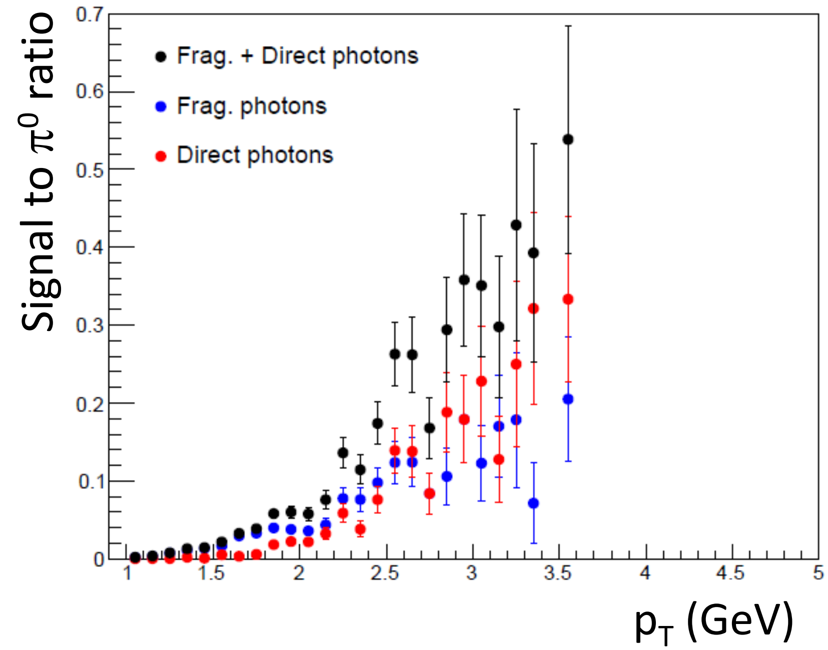
Extended kinematic range for existing measurements (p_T>1 GeV/c, E>20GeV)

- **Source of A_N in p↑+p Collisions:**
  - **Prompt Photon A_N**
  - **π^0 correlations with jet-like clusters**
    - "pioneering" measurement
  - Jet A_N

Prompt Photon Simulations (π^0 cuts)

868M pythia MB+direct photon events (200GeV)





Basic cuts designed to remove π^0, charged hadrons and other backgrounds.

<u>For p_T>3 GeV</u>:

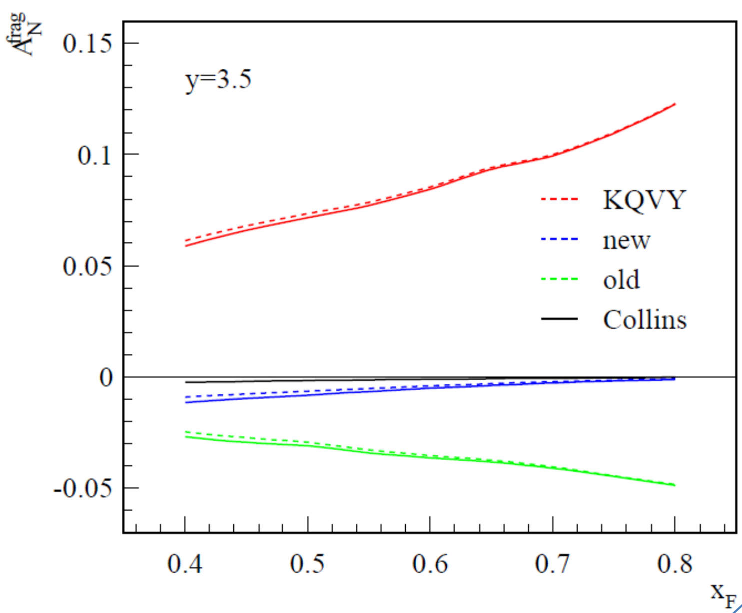
2.9% efficiency for π^0
31.2% efficiency for direct photons

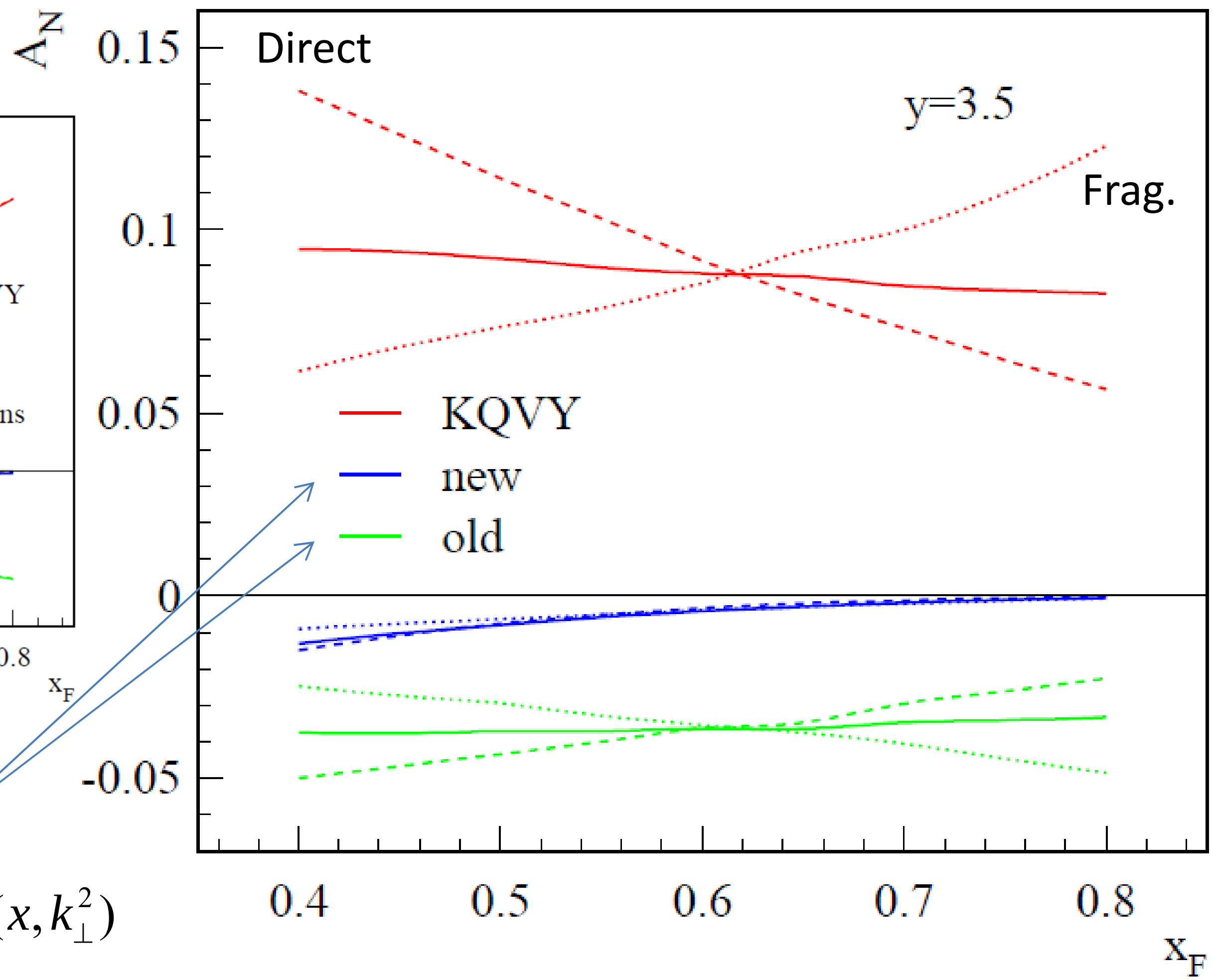
dir/(frag+dir): 57.4%

Direct and Frag. Photon A_N (x_F>0)

Gamberg and Kang, arXiv 1208.1962v1 (2012)

A_N^{Direct} falls with x_F, while
A_N^{Frag} rises with x_F.

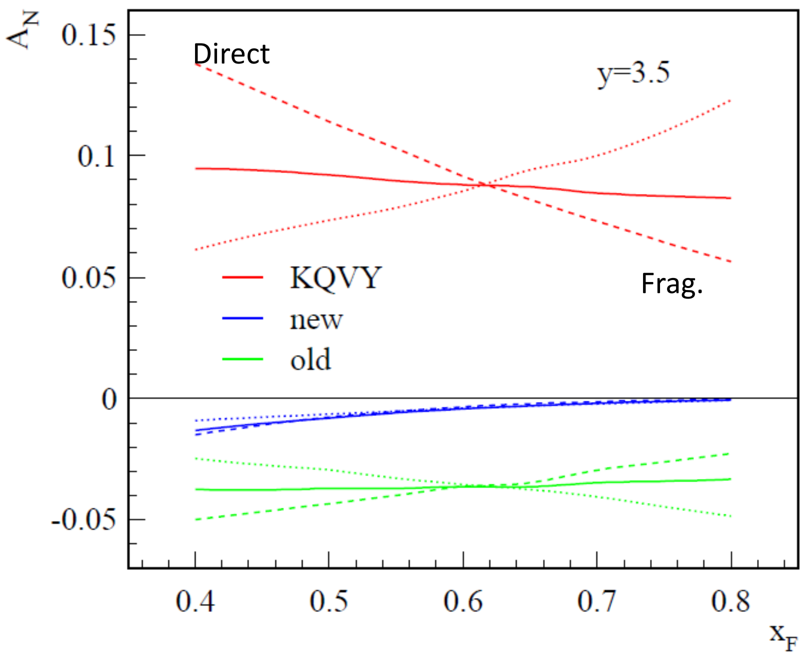




$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x,k_\perp^2)$$

Separating Direct and Frag. Photons

Gamberg and Kang, arXiv 1208.1962v1 (2012)

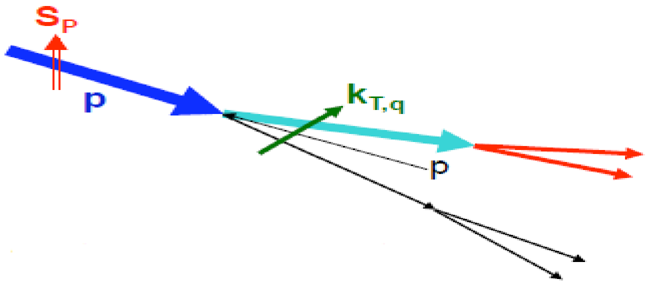


Can control the direct/frag ratio with tightened isolation cuts in the MPC/MPC-EX

Tightening cuts →

	π^0 Cuts	Cuts 1	Cuts 2
Direct-to-signal ratio	57.4%	68.3%	78.6%
R_γ	1.34	1.31	1.31
Signal-to-π^0 ratio	43 ± 5 %	37 ± 7 %	40 ±13 %
Direct photon ϵ	31.2%	15.1%	5.9%
Frag. photon ϵ	24.3%	7.3%	1.7%

Prompt Photon A_N (x_F>0)

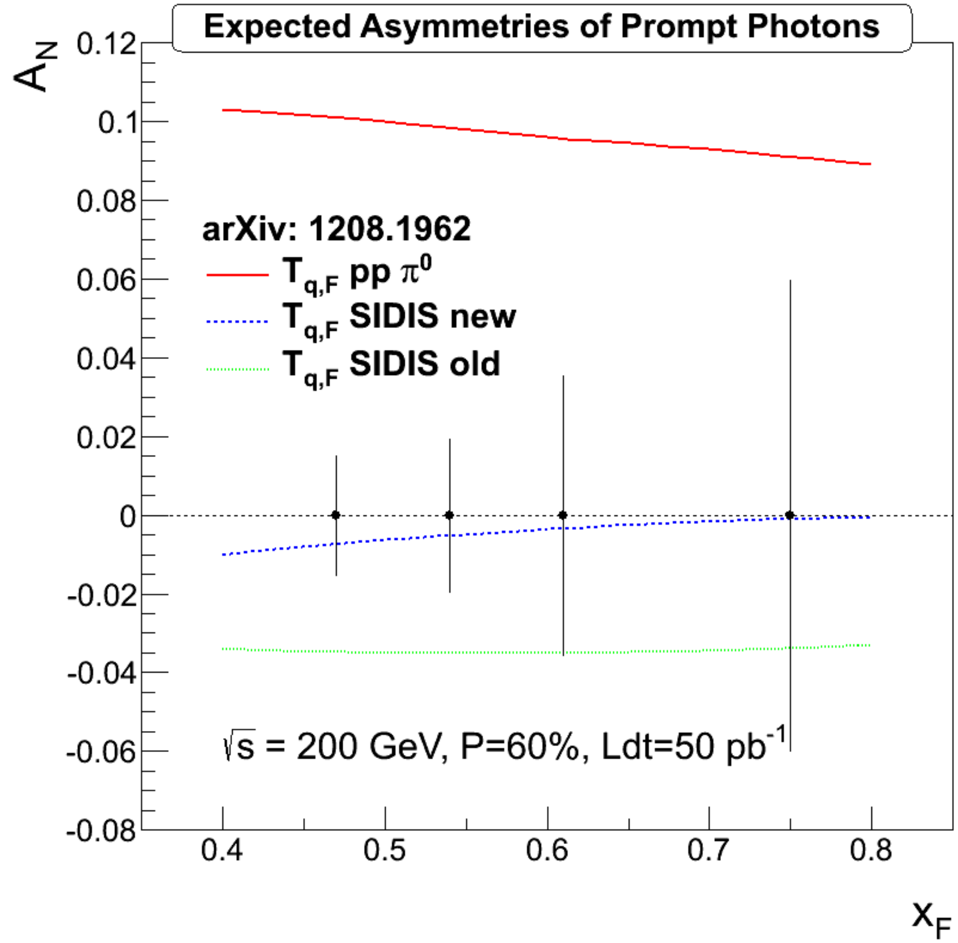


$$A_S = (1+\frac{1}{r})A_{meas} - \frac{1}{r}A_B.$$

r= S/B = 0.34

$$(\delta A_S)^2 = (1+\frac{1}{r})^2(\delta A_{meas})^2 + (\frac{1}{r})^2(\delta A_B)^2.$$

Kang, Qiu, Vogelsang and Yua, Phys Rev. D 83 094001 (2011)
Gamberg and Kang, arXiv 1208.1962v1 (2012)



Prompt Photon A_N

- Projected error bars assume statistical errors, subtraction of π^0 and η photon asymmetry, and 60% polarization
- Test of theoretical frameworks
- Measure of quark Sivers

Prompt photon measurements with MPC-EX will resolve the issue.

Prompt Photon A_N (x_F<0)

x_F<0 samples the gluon distribution in the polarized proton

Two different tri-gluon correlation functions: *O(x)* and *N(x)*

<u>Models:</u>

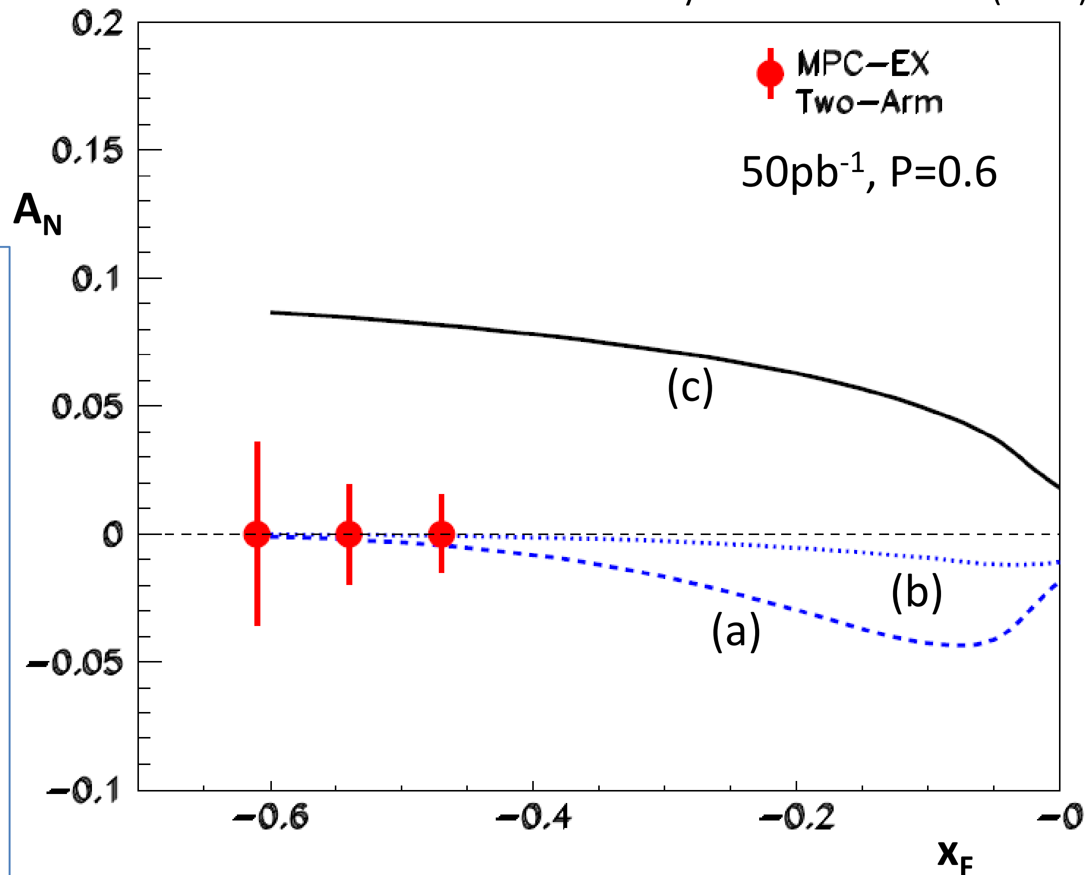
$(a)\ O(x) = K_G xG(x) \qquad N(x) = O(x)$

$(b)\ O(x) = K_G' \sqrt{x} G(x) \qquad N(x) = O(x)$

$(c)\ O(x) = K_G xG(x) \qquad N(x) = -O(x)$

Parameters constrained by open heavy flavor production at RHIC.

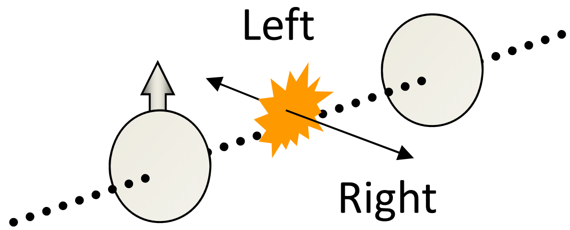
Koike and Yoshida Phys Rev. D 85 034030 (2012)



A_N for x_F<0 carries information about the tri-gluon correlation function.

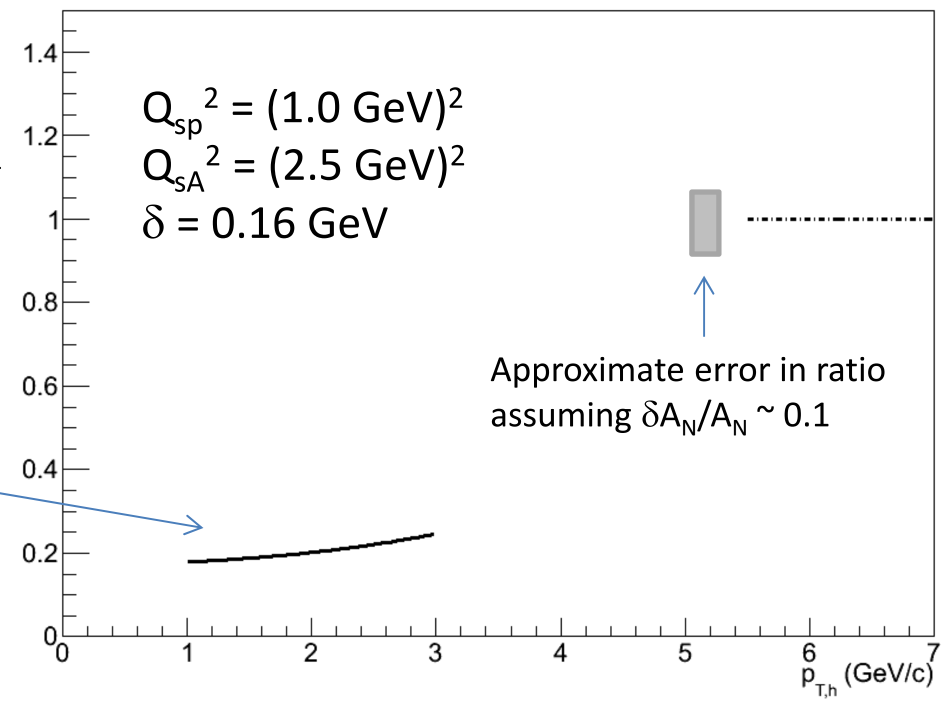
Polarized p+A Collisions

$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$



$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 << Q_{sA}^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{P_{h\perp}^2 \delta^2 / Q_{sp}^2}$$

Kang and Yaun, PRD 84, 034019 (2011)
(asymmetries modeled as Collins)

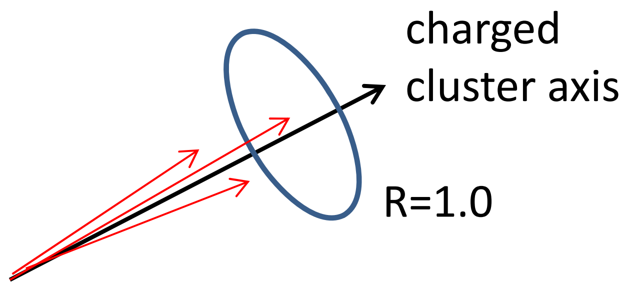


Single spin asymmetries can act as a probe of the saturation scale.

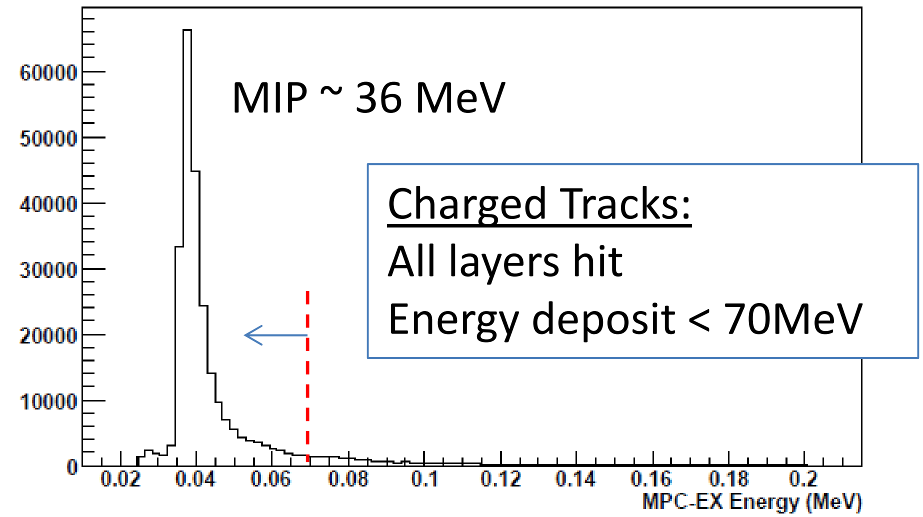
A unique capability of RHIC!

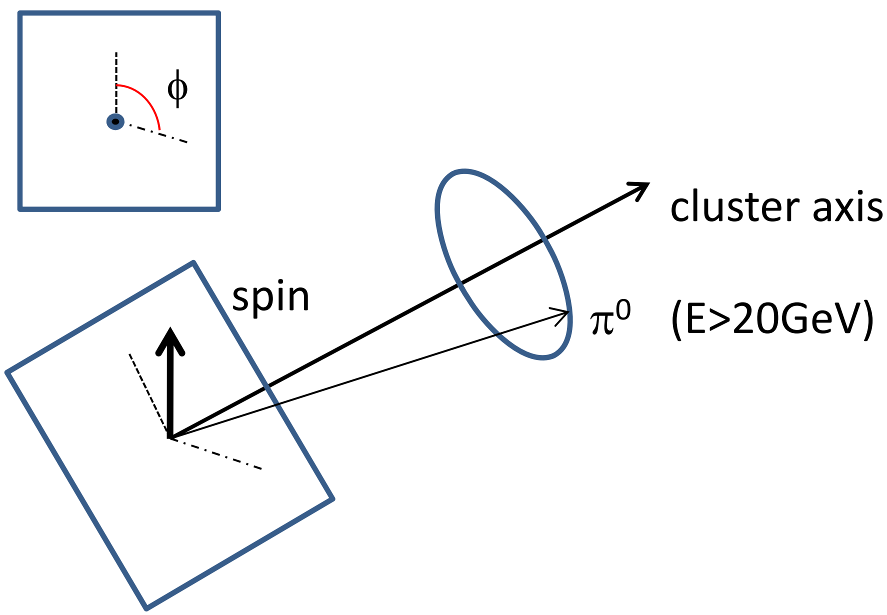
- Dependence of Q_{sA} on A
- Combined with other measurements this can estimate Q_{sp}

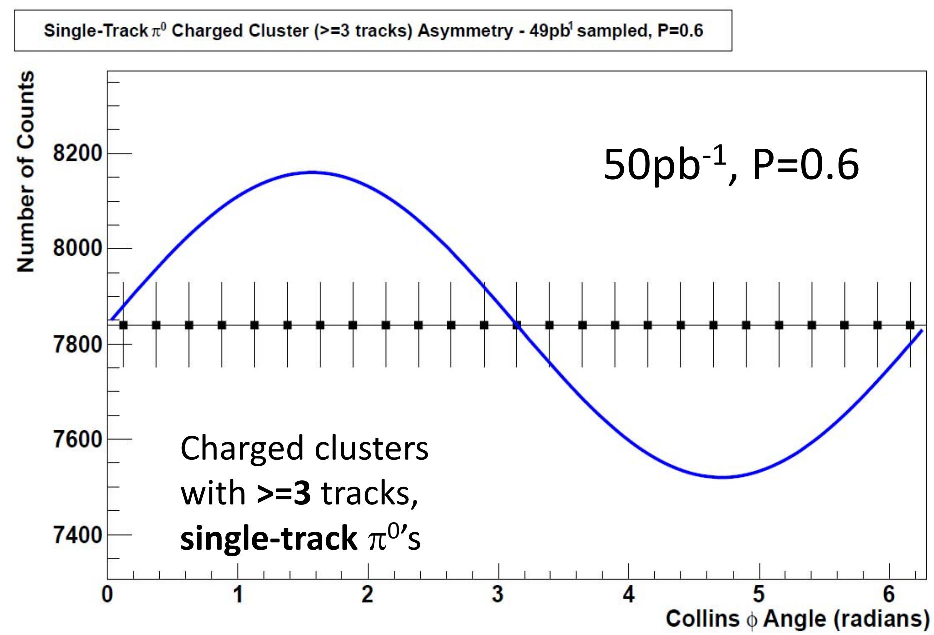
Collins Asymmetry in Jets



- All tracks given equal weight
- Select the cluster with highest number of tracks





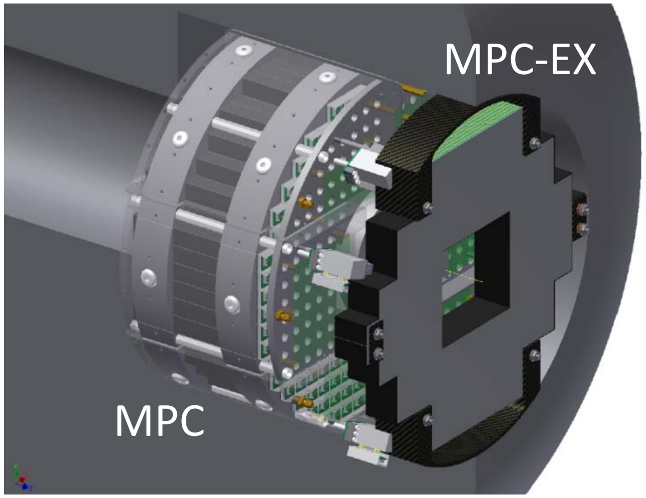


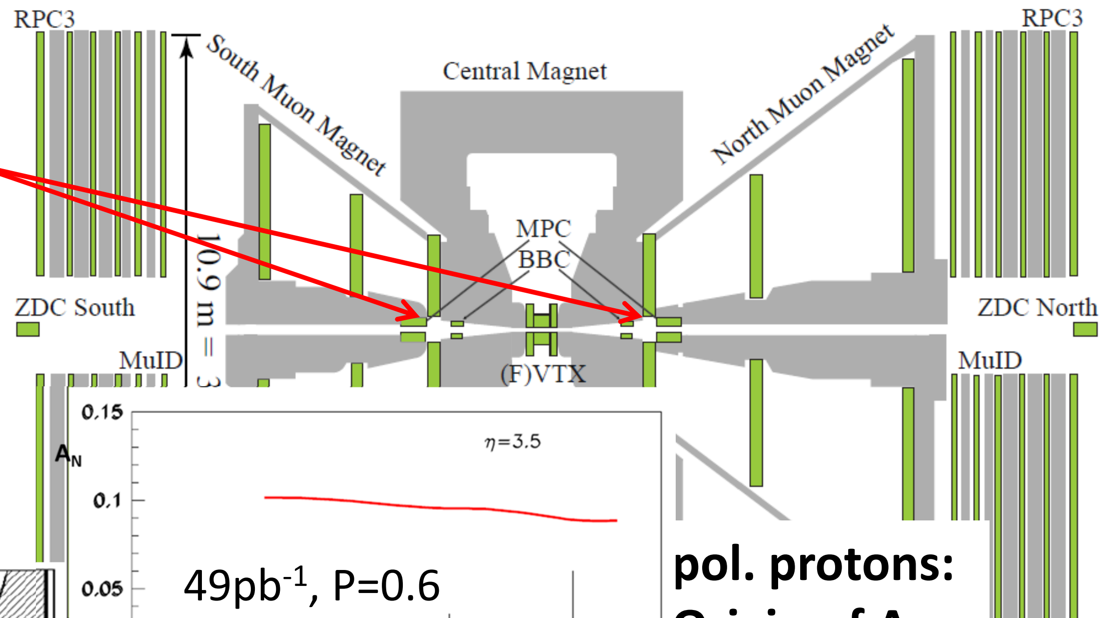
Summary

- **The MPC-EX is a novel detector that offers exciting new physics opportunities:**
  - Separate the sources of SSA's measured in 200GeV transversely polarized p+p collisions
    - Deepen understanding of hadron structure
    - Enable continued progress in the application of fundamental QCD to p+p collisions
  - Measurement of the gluon distribution in cold nuclear matter
    - Further understanding saturation, shadowing, …
    - Set initial conditions for HI collisions at RHIC and LHC

- **Exciting new physics output from RHIC!**

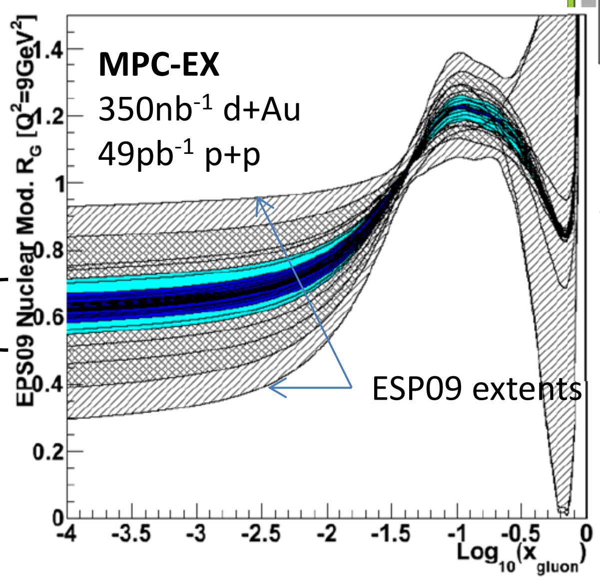
The PHENIX Muon Piston Calorimeter Extension (MPC-EX)

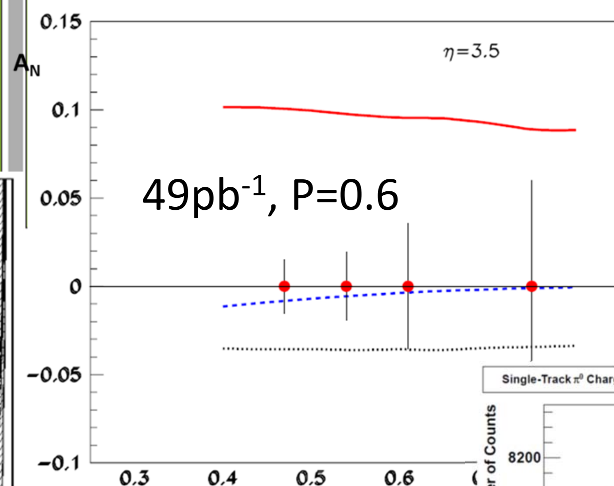




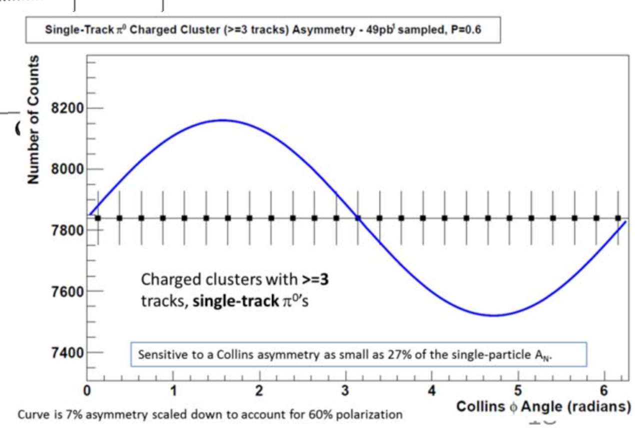
d+Au: Gluons in Nuclei

Colored band = range with MPC-EX direct photon data



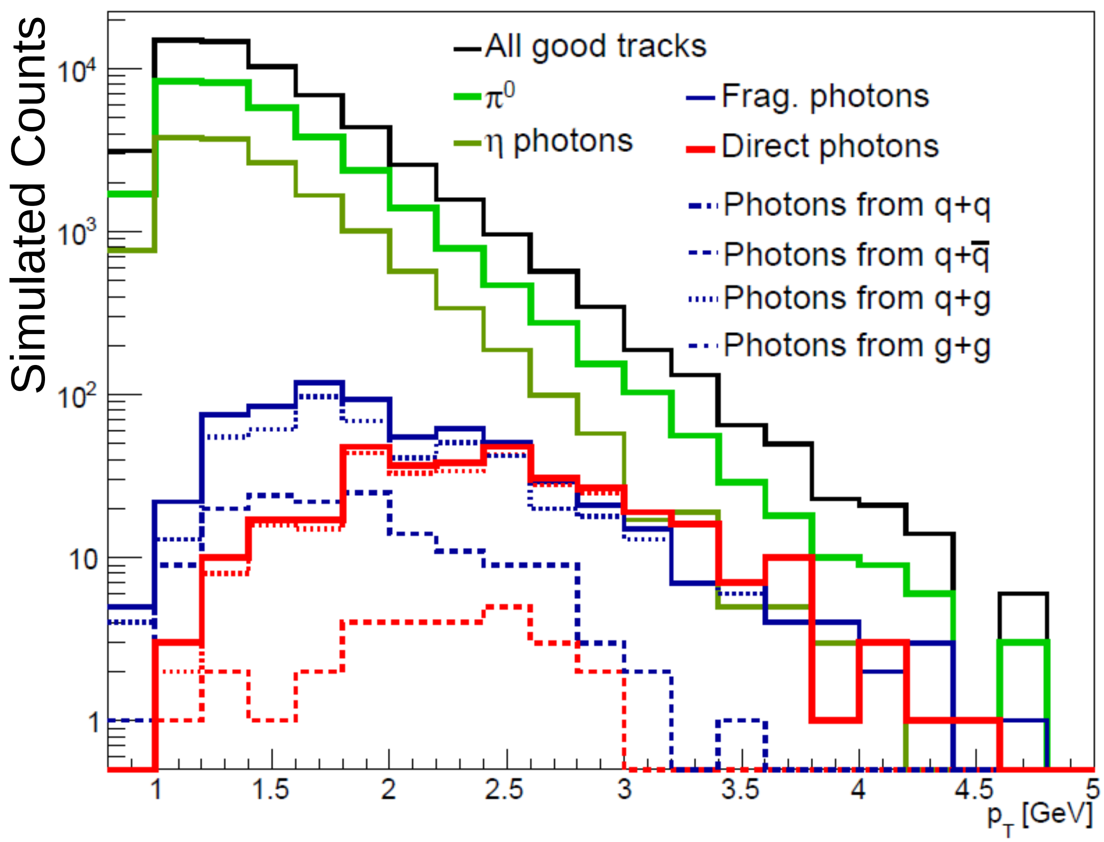


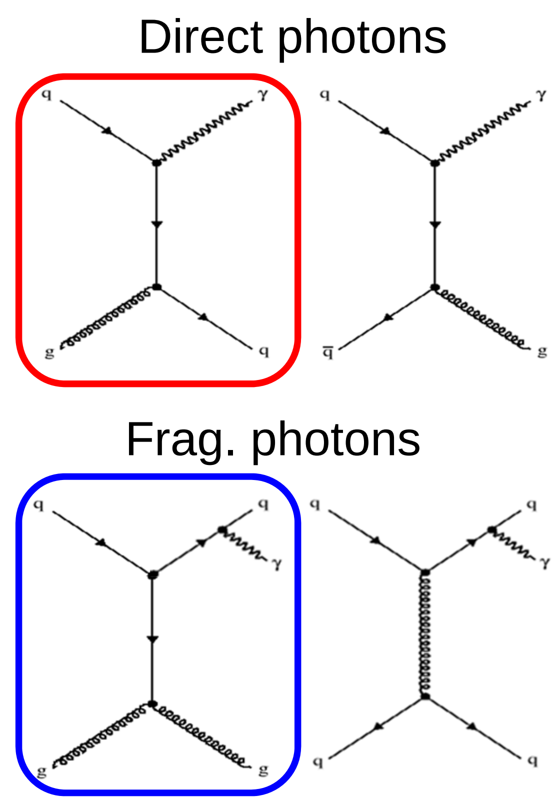
pol. protons: Origin of A_N



BACKUP

Process Breakdown

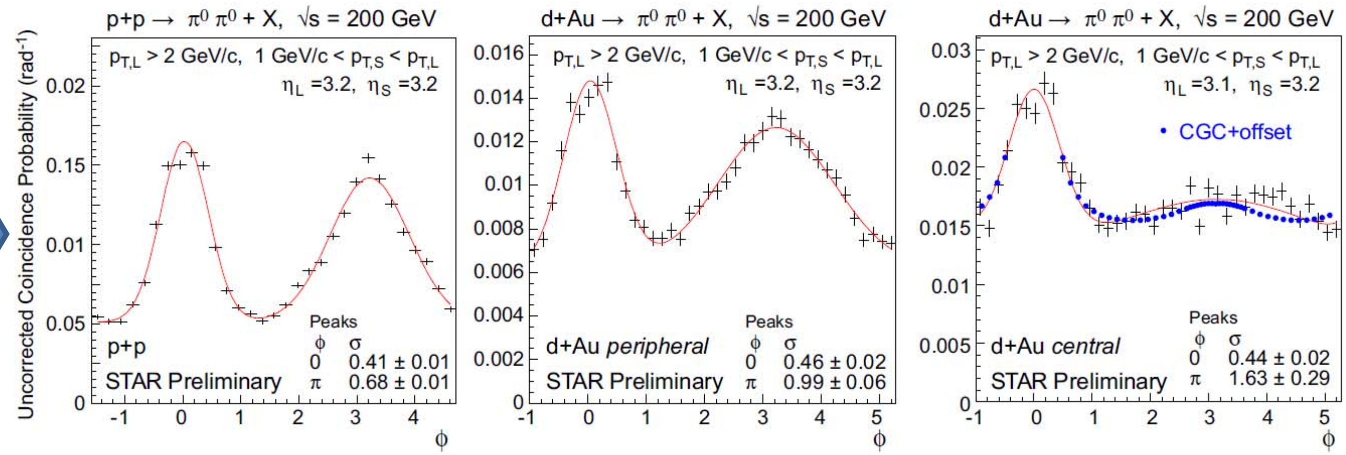


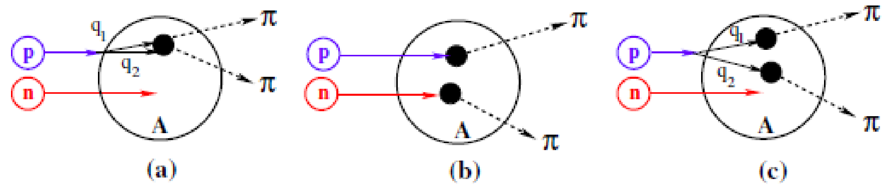


Direct photons 100% ***q+g*** **for p_T>3GeV**
Fragmentation photons 93% ***q+g, 7% q+qbar*** **for p_T>3GeV**

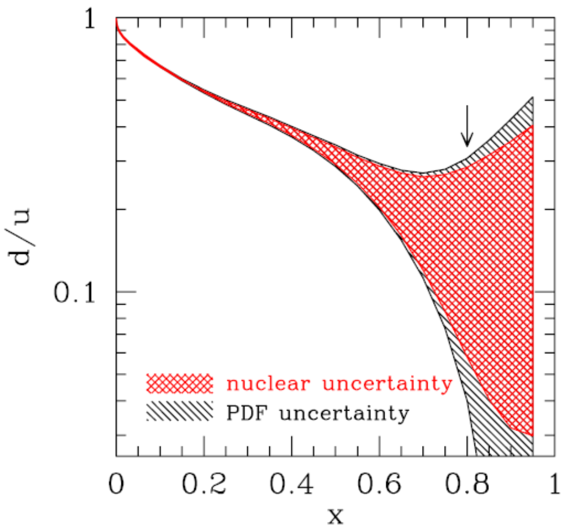
Why p+A instead of d+A?

Multi-parton interactions can contribute to the suppression of the away-side correlation strength.





Phys. Rev. D 84 014008 (2011)



Forward rapidity corresponds to *high-x* in the projectile nucleon (d or p). Nuclear corrections at high-x are large for the deuteron, which may necessitate d+p running for proper comparison.

…and you can't polarize the deuteron at RHIC…

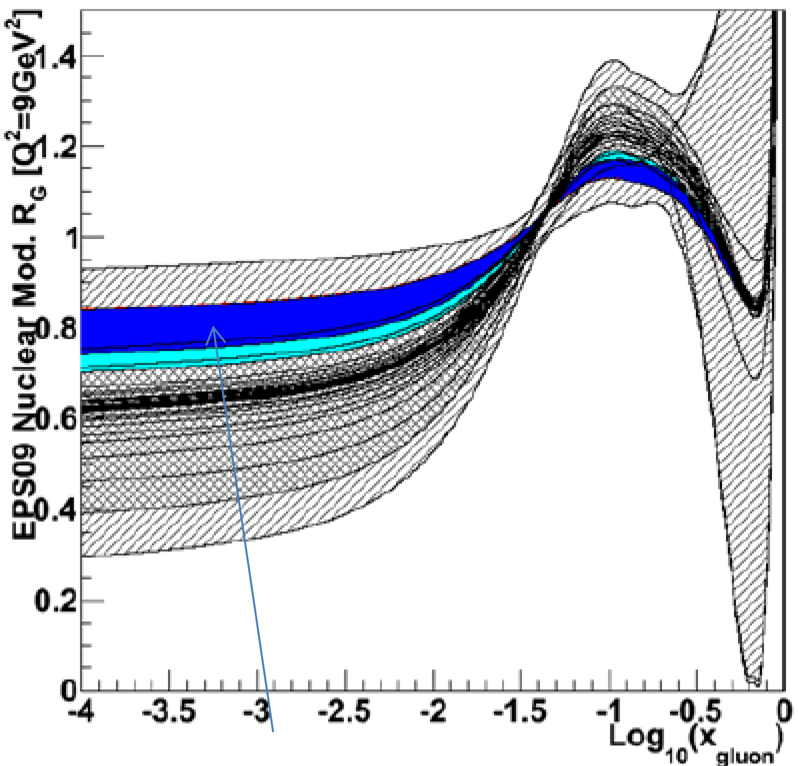
SSA's in polarized p+A Collisions

- Kang and Yuan, PRD 84, 034019

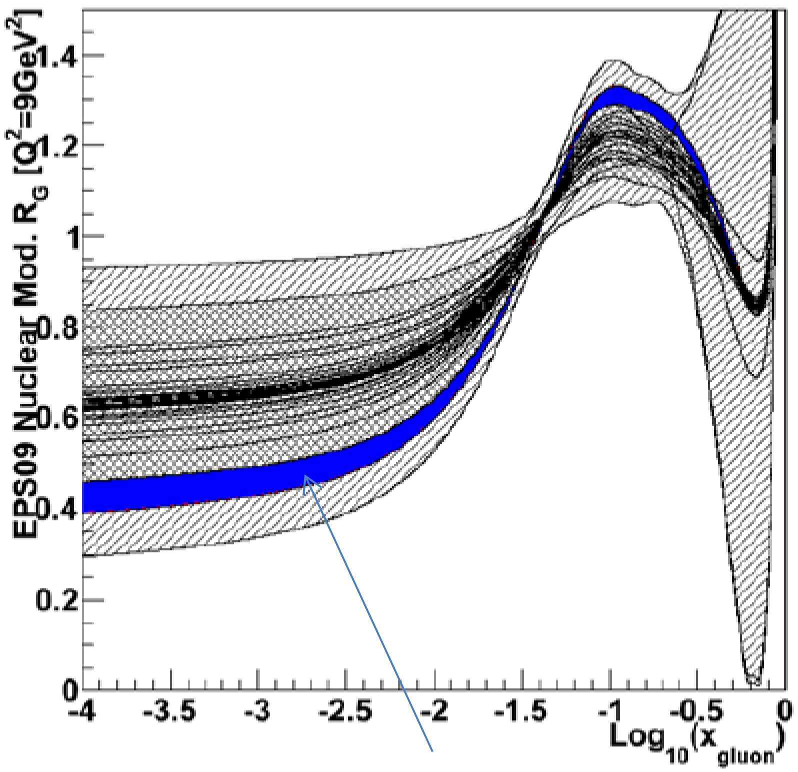
$$\left.\frac{A_N^{p+A\to h}}{A_N^{p+p\to h}}\right|_{P_{h\perp}^2 << Q_s^2} \approx \frac{Q_{s,p}^2}{Q_{s,A}^2}\cdot e^{\frac{P_{h\perp}^2\cdot\delta^2}{Q_{s,p}^4}}, \quad \left.\frac{A_N^{p+A\to h}}{A_N^{p+p\to h}}\right|_{P_{h\perp}^2 >> Q_s^2} \approx 1$$

A systematic study of SSA's in spin-polarized p+A collisions would allow us to study the gluon saturation scale.

EPS09 Limits from Direct Photons



assuming EPS09 upper curve

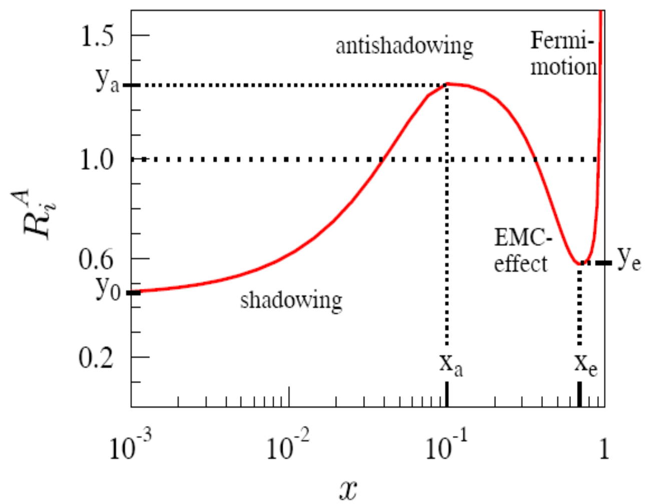


assuming EPS09 lower curve

Ultimate sensitivity depends on the measurement and a full NLO fit.

Gluons in Nuclei

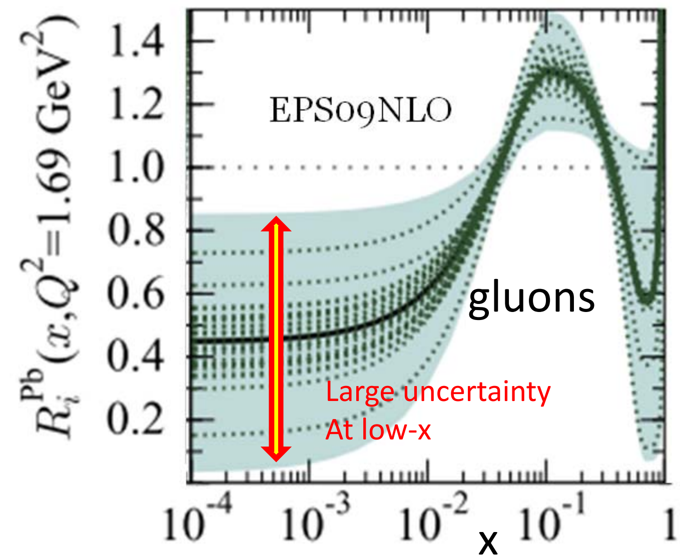
shadowing/saturation in nuclei



Fit data on nuclei:
SLAC, NMC, EMC
DIS+DY+PHENIX
midrapidty π^0

Lack of data
⇨large uncertainly
in gluon pdf
at low-x

$$R_G^{Pb}(x,Q^2) = \frac{xG_A(x,Q^2)}{AxG_p(x,Q^2)}$$



Eskola , Paukkunen, Salgado, JHP04 (2009)065

Large uncertainties in low-x gluons in nuclei!

Important for fundamental understand of partonic processes in nuclei, as well as for the initial conditions at RHIC and the LHC.

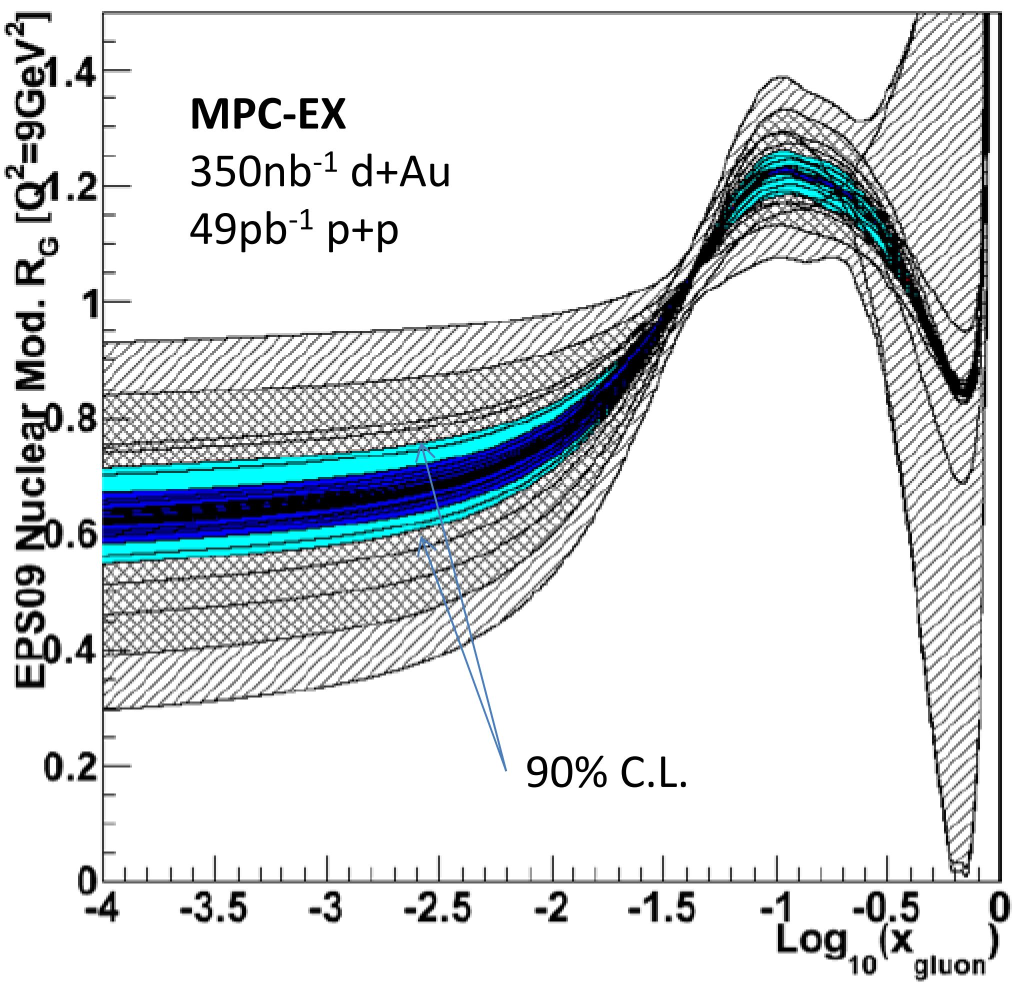
Use EPS09 as a baseline for comparison.

The MPC-EX measurement will directly address any model of low-x gluons.

EPS09 Limits from Prompt Photons

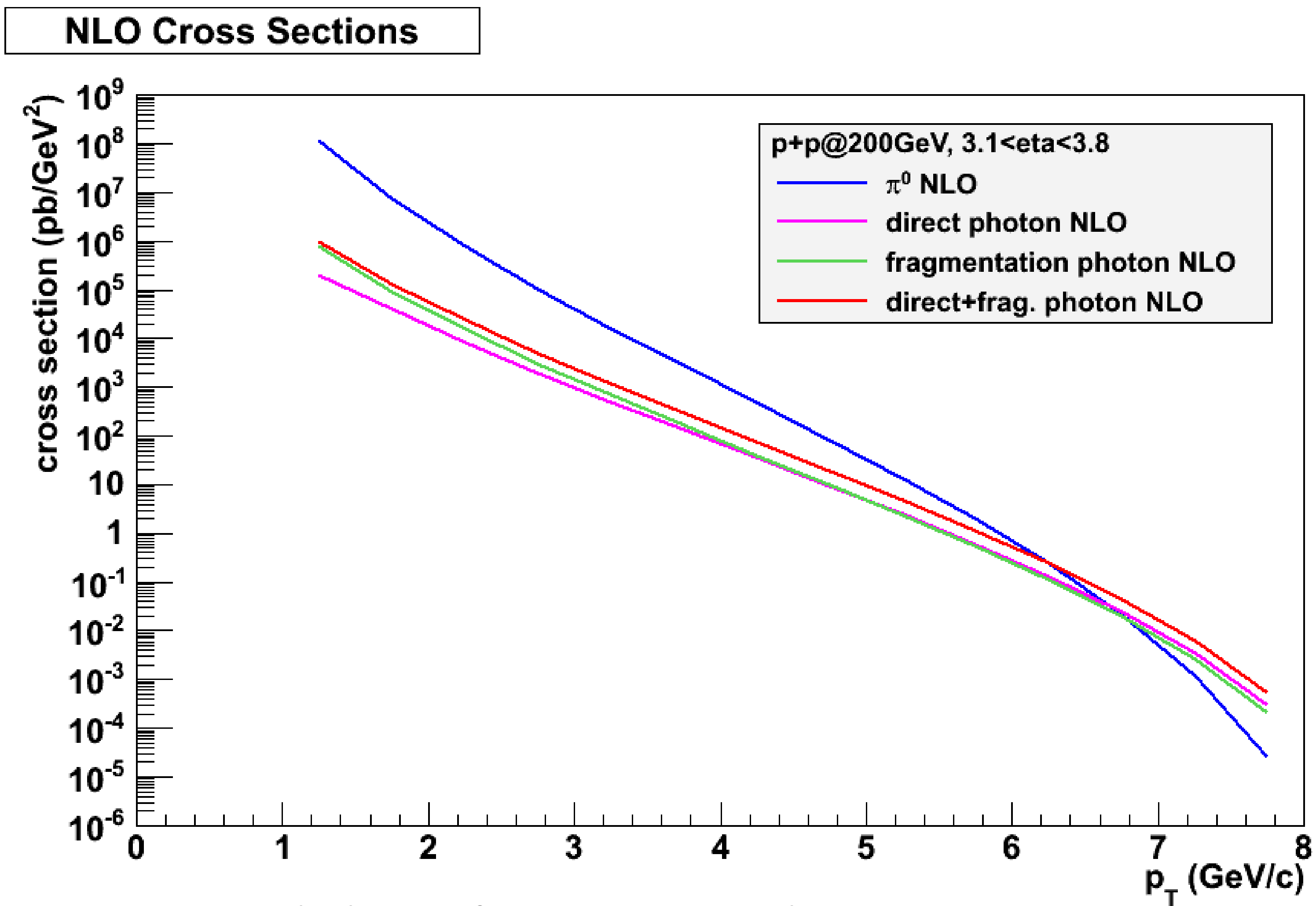
– Weight events in x,Q^2 according to EPS09 to generate R_{dAu} for each curve
– Assume the R_{dAu} value we measure corresponds to the EPS09 baseline
– Vary R^{pp}_{γ}, R^{dAu}_{γ}, γ^{dAu}_{incl} and γ^{pp}_{incl} within 3-sigma systematic errors

– Evaluate EPS09 curves to see which are consistent within 90% C.L.



Prompt photons in MPC-EX -> Precise Measurement of Gluons at Low-x

Direct Photon NLO Cross Sections



NLO calculations from Werner Vogelsang

Direct Photons in Pythia