Small x and Forward Physics in pp/pA at RHIC

STAR Forward Physics

FMS

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Outline

- Forward Detection in STAR (also PHENIX)
- Sensitivity to small x physics
- STAR dAu results
- Summary of Single Spin Asymmetries
- STAR future Soft Gluon Measurements
- Future RHIC Possibilities (merging soft gluon physics with spin physics)

FPD++ Detector Forward Calorimeter III
FPD Detector Forward Calorimeter II 2006 (RHIC Run 6)
before 2006 (RHIC Run 6)

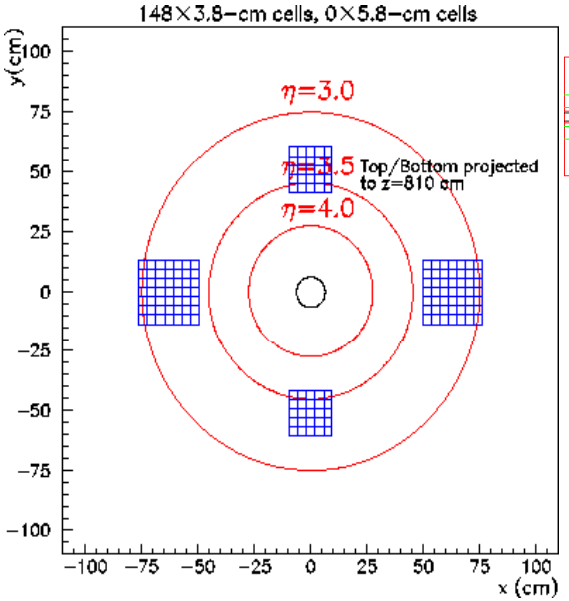
FPD East End

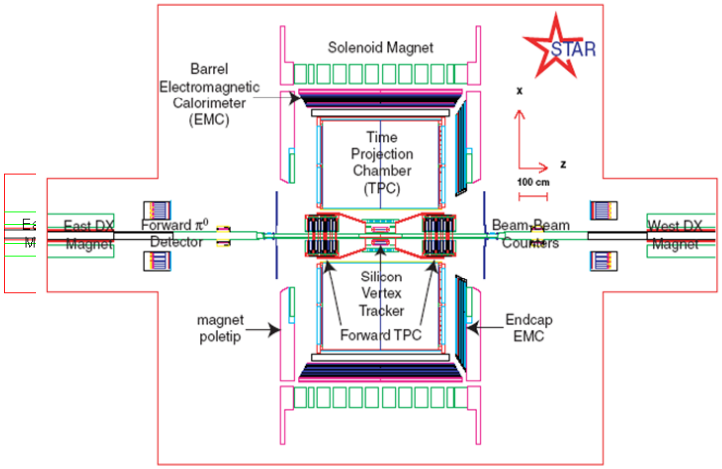
FPD East End

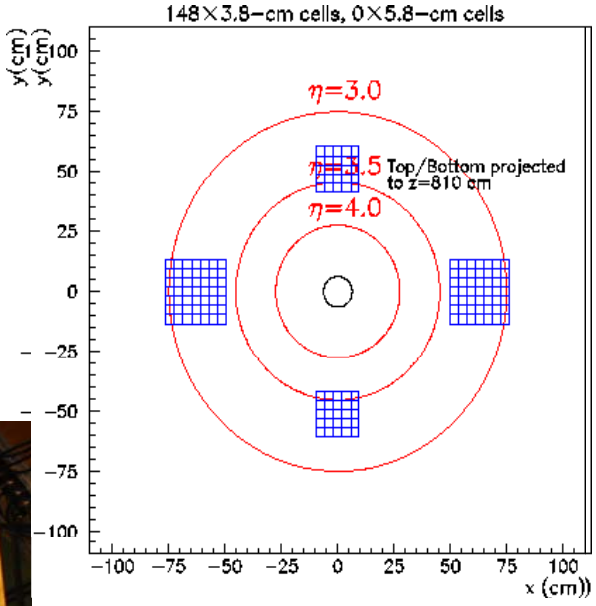
End

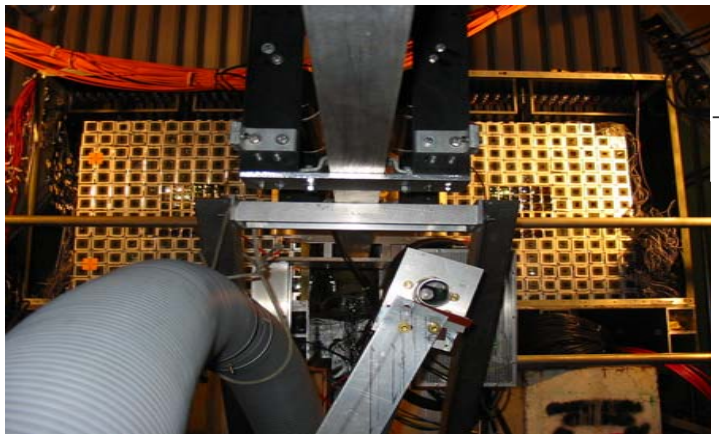
FPD++ West

FPD West End









West end of the ***STAR*** interaction region

This detect[or] FPD: a set of 8 Arrays of Pb Glass Blocks [s]urement with X_F vs P_T de[pendence] This detector used for published forward d Au pion production in STAR.

FMS Detector Forward Calorimeter IV Installed 2007

PHYSICS OBJECTIVES

1. A **d-Au** measurement of the **parton model gluon density distributions x g(x)** in **gold nuclei** for **0.001< x <0.1**. For 0.01<x<.1, this measurement tests the universality of the gluon distribution.

2. Characterization of correlated pion cross sections as a function of Q^2 (p_T^2) to search for the onset of **gluon saturation effects** associated with **macroscopic gluon fields. (again d-Au)**

3. Measurements with **transversely polarized protons** that are expected to **resolve the origin of the large transverse single spin asymmetries** in reactions for **forward π^0 production. (polarized pp)**

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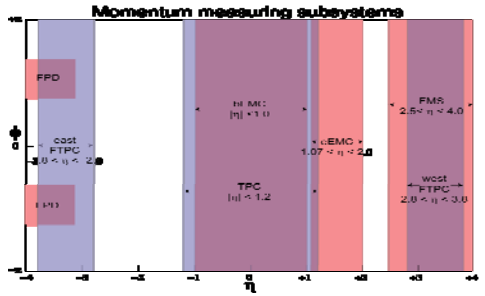
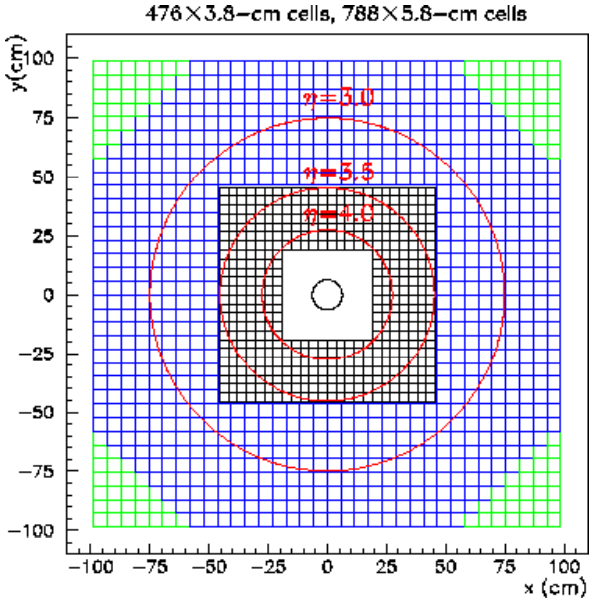




FMS Wall

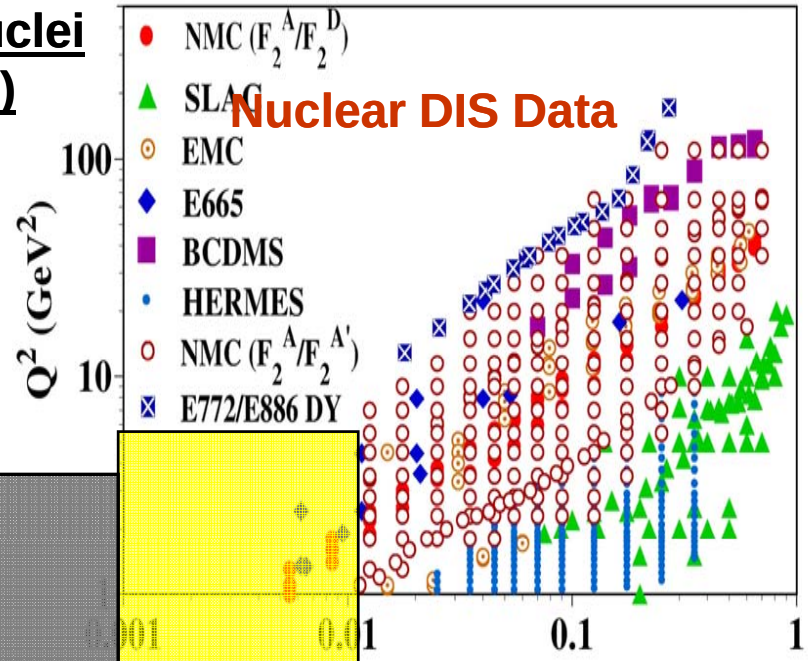
FMS ½ Wall Pb. Glass

Measuring nuclear soft gluon densities in nuclei
d+Au => jet +jet (Forward EM calorimeter)

F_2 measured in Deep Inelastic Scattering of electrons from protons.

$$F_2(x,Q^2) = x\sum_n e_n^2[q_n(x,Q^2)+\bar{q}_n(x,Q^2)]$$

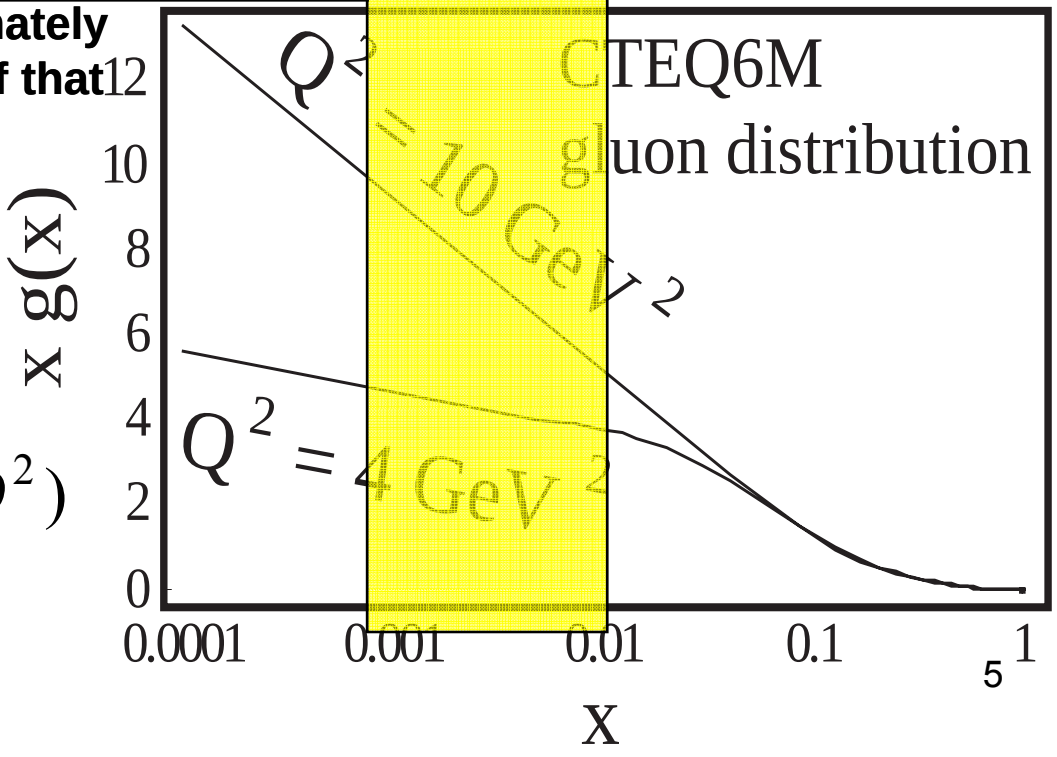
DIS Would Require Electron Heavy Ion Collider To Probe g(x) in the x<.01 Region



Sensitivity to *g*(*x*) in DIS is approximately given by the Q^2 variation of F_2 at half that *x* value,

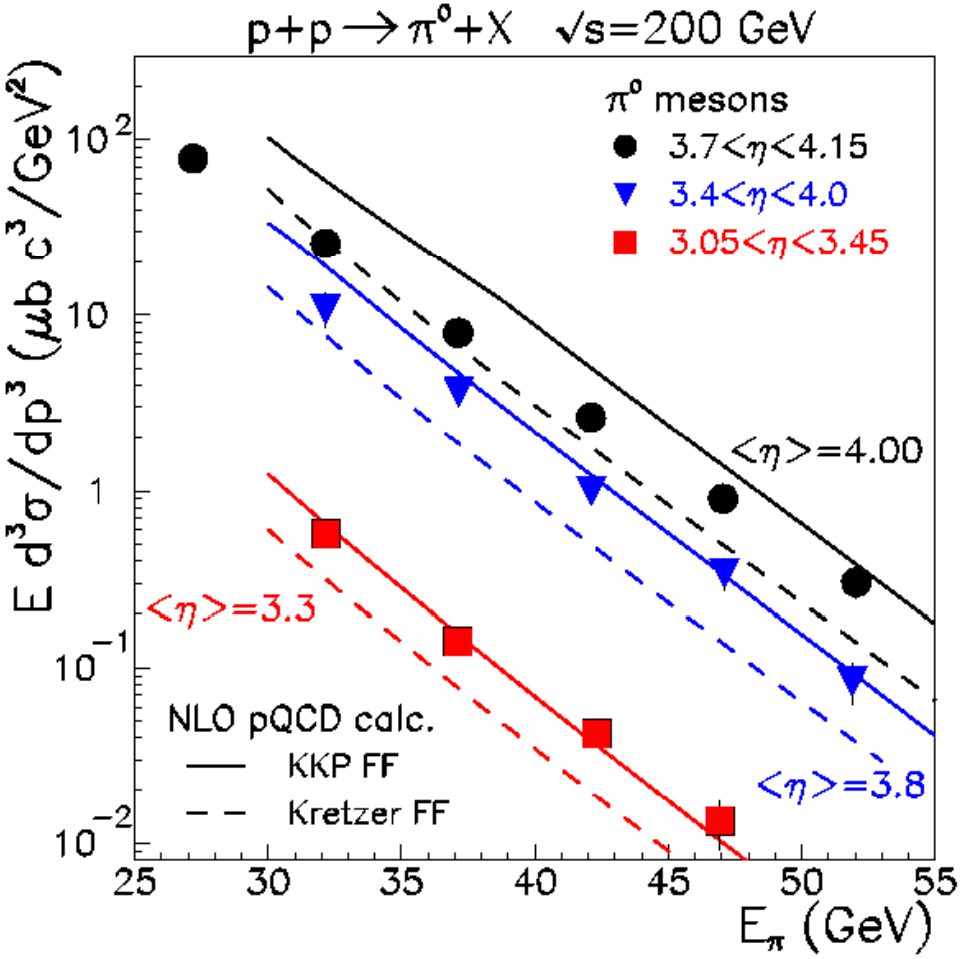
RHIC (STAR) has a window of opportunity to observe low x saturation effects before other facilities come online.

$$g(2x) \propto \partial F_2(x,Q^2)/\partial(\ln Q^2)$$



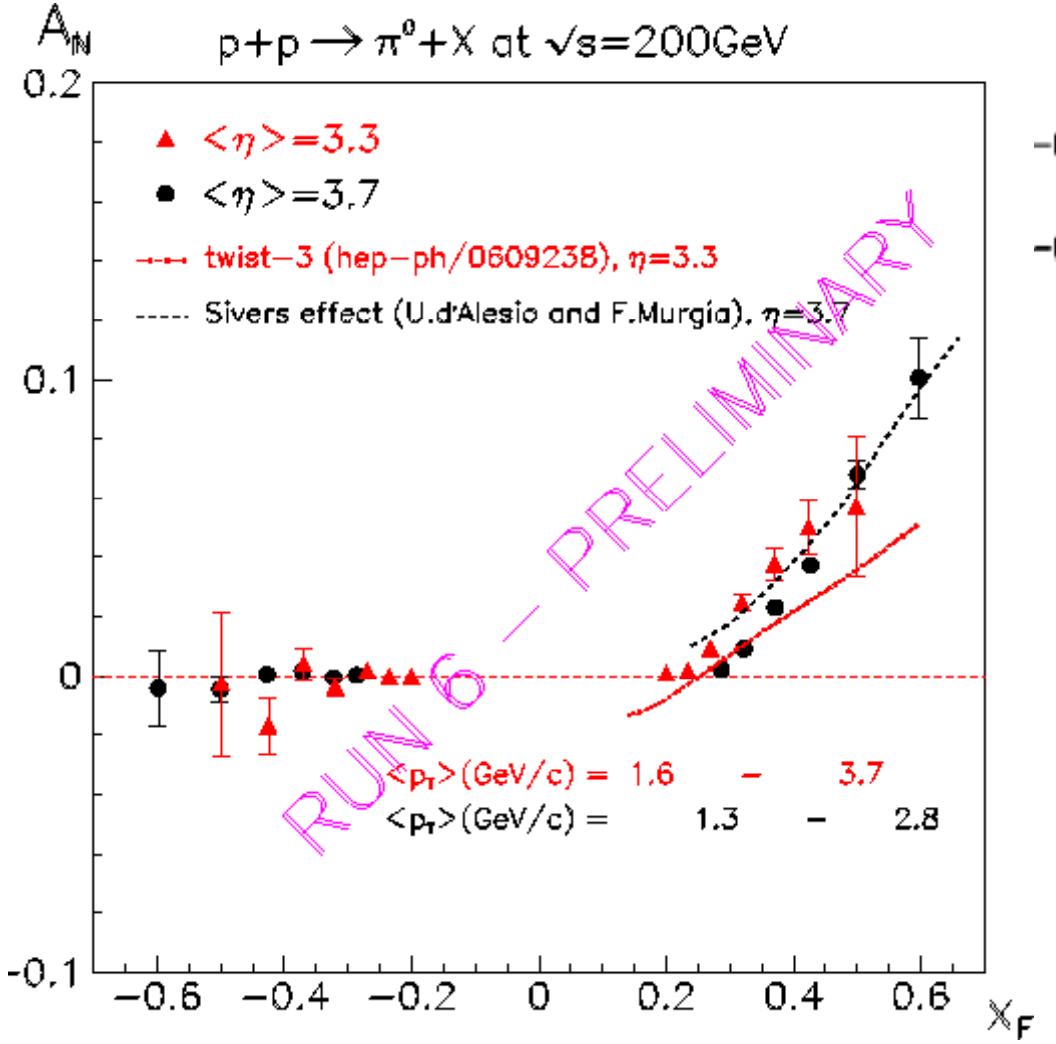
STAR p+p → π^0+X at 200 GeV

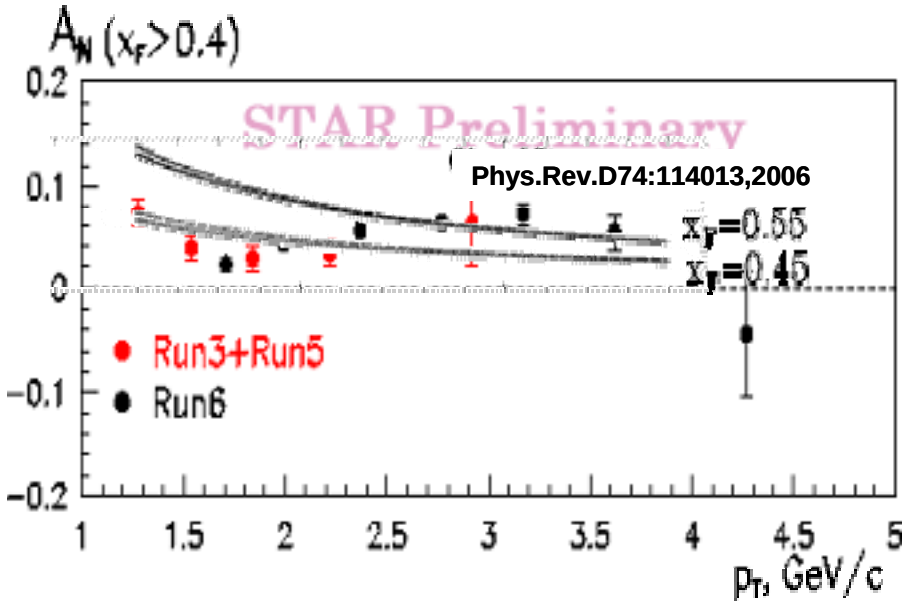
PRL97:152302,2006



- The error bars are statistical plus point-to-point systematic
- Consistent with NLO pQCD calculations at $3.3 < \eta < 4.0$
- Data at low p_T trend from KKP fragmentation functions toward Kretzer. PHENIX observed similar behavior at mid-rapidity.

π^0 A_N at $\sqrt{s}$=200 GeV – x_F-dependence Run 6 (2006)





- Small errors of the data points allow quantitative comparison with theory predictions

Current Theories require A_N to fall with increasing P_T at fixed X_F.

Based upon cross sections (summed over spin) the forward production of pions at RHIC is in good agreement with PQCD

…. where hard quarks in a polarized proton scatter from a soft gluon
Underlying event well understood
Factorization seems ok!!

BUT for unsummed cross sections

- **Large Transverse Asymmetries A_N**
- **Not Falling with P_T in the range $1<P_T<4$ (GeV/c)**

new features needed
Beyond Colinear Factorization
Beyond Leading Twist
But why not falling with P_T?

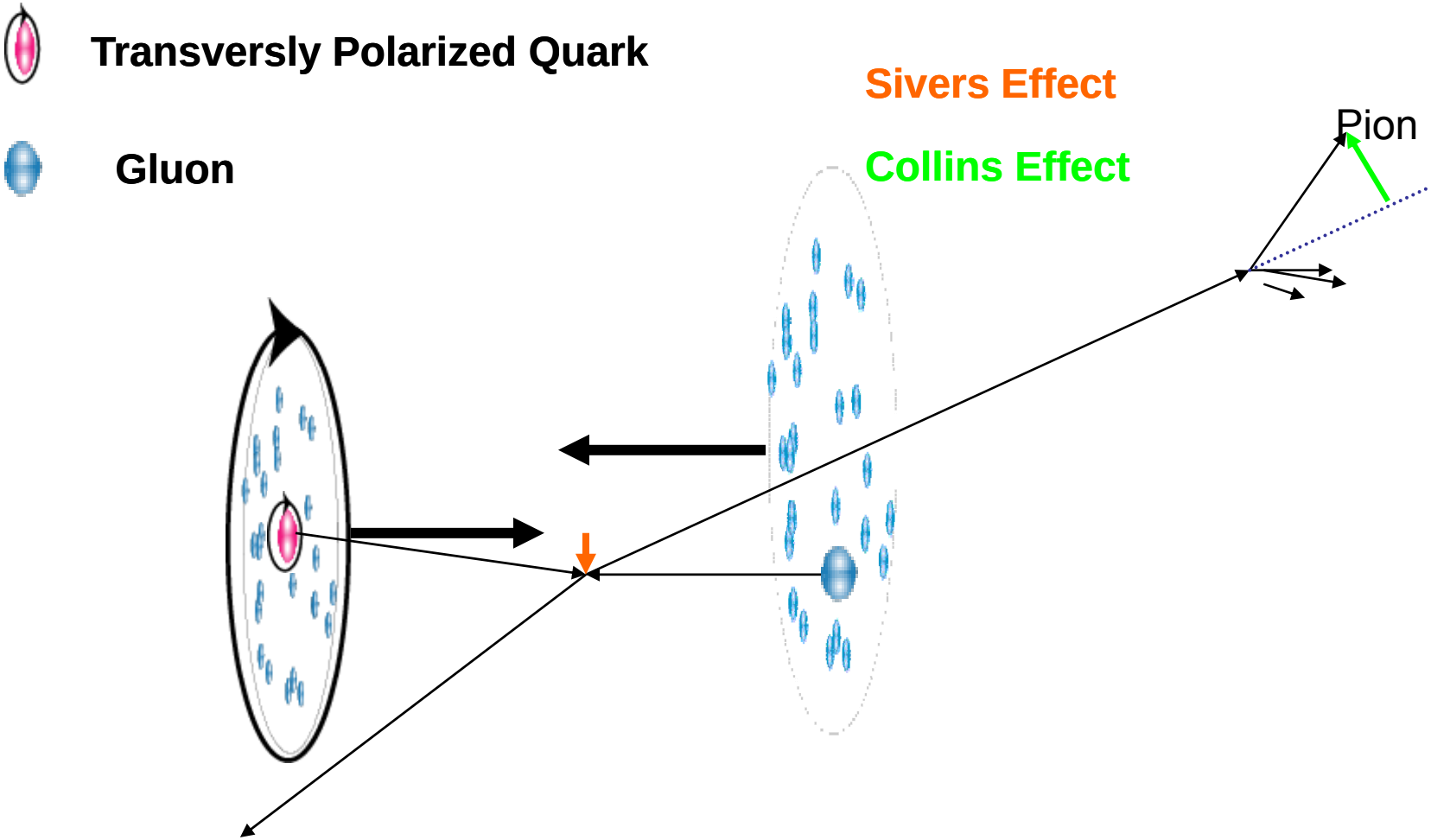
Something New may be Needed! **A_N is sensitive to .. Interference between Real Quark Non-Flip amplitude and Imaginary Quark Flip amplitude. (at large PT)**

Sounds like absorption effects
Sounds like a role for soft gluons
Same kinematic region where we will look for saturation effects.

my view: Related to Physics at the "Factorization Frontier"
An important and most interesting frontier today in QCD.
Perturbative quark and model for glue
(Like Color Glass Condensate effects)
Boer, Dumitru, Hayashigaki

Probabilistic Picture

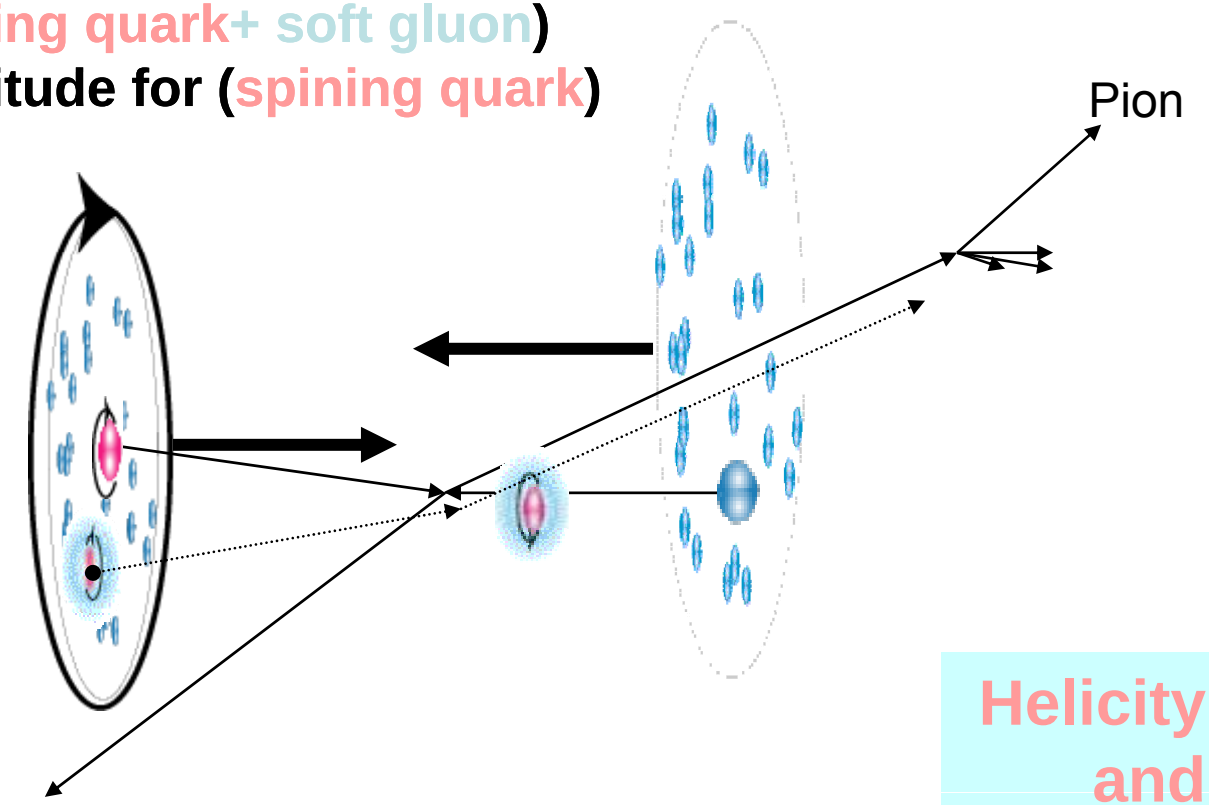
- quark with aligned transverse orbital anglular momentum and/or spin scatters
- preserving transverse spin
- finally fragments into pion



At the helicity “amplitude” level

- amplitude for helicity flip (with phase delay)
- interferes with non flip amplitude

Higher Twist: Qiu and Sterman
Interference between amplitude
for (spinning quark+ soft gluon)
with amplitude for (spining quark)

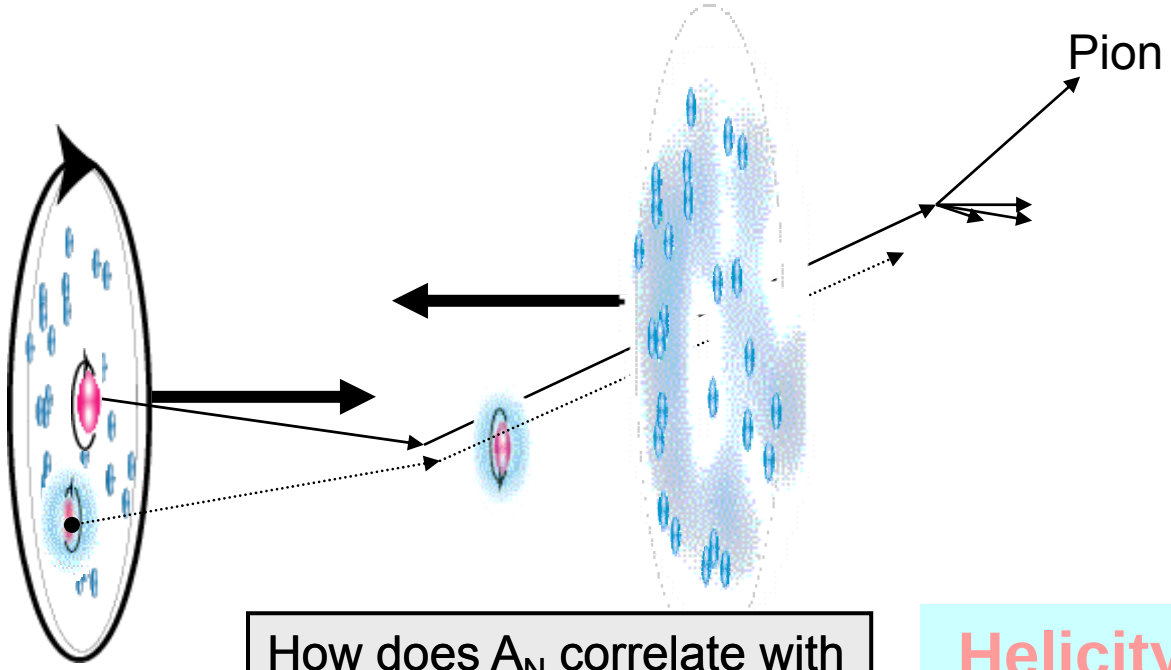


Helicity flip and Phase Delay

Scattering from DGLAP distribution of soft gluons.

Scattering from classical gluon field .

(i.e. **Boer, Dumitru, Hayashigaki: (Color Glass**)



How does A_N correlate with
- Features of away side jet
- Features of near side jet
- Nuclear Target

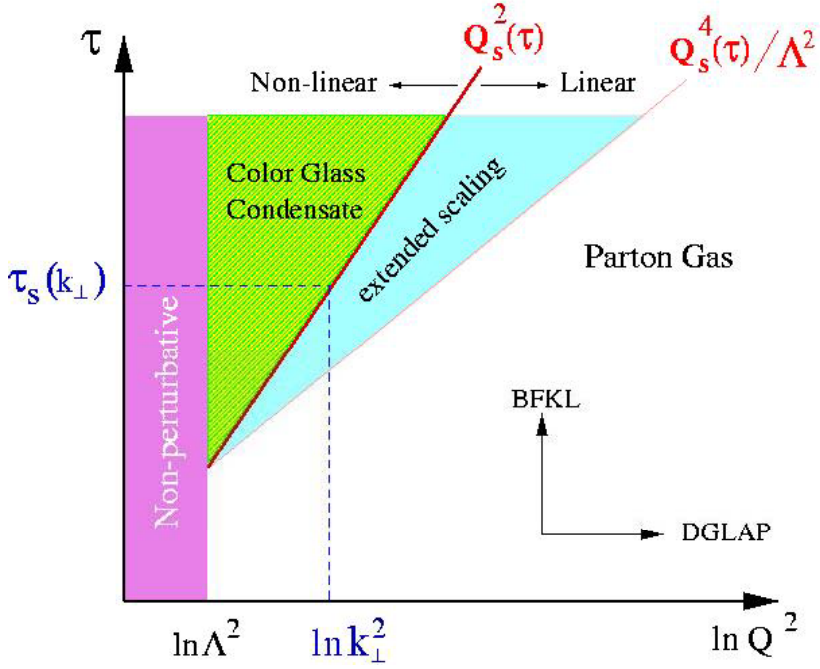
Helicity flip and Phase Delay

No Recoil Jet

Expectations for a color glass condensate

$$\tau = \ln\left(1/x\right)$$

τ related to rapidity of produced hadrons.

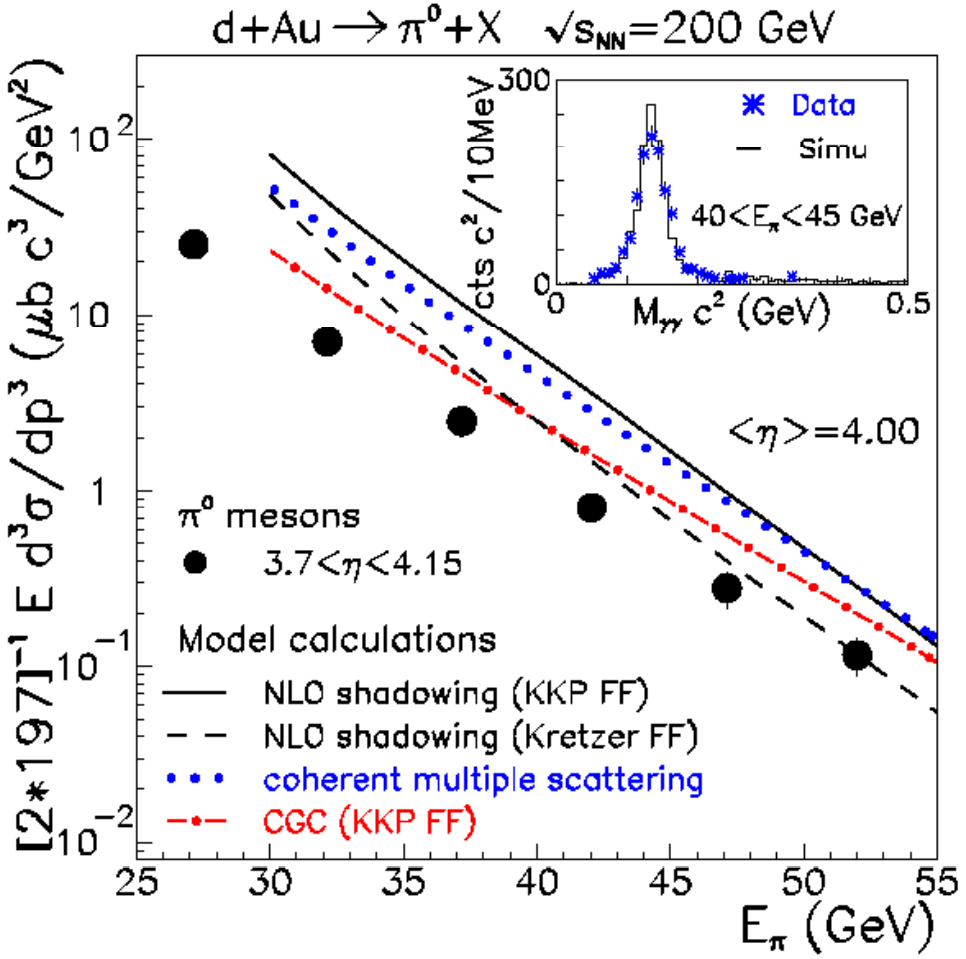


Iancu and Venugopalan, hep-ph/0303204

Are the BRAHMS and STAR data evidence for **gluon saturation at RHIC energies**?

d+Au → π^0+X at 200 GeV

PRL97:152302,2006



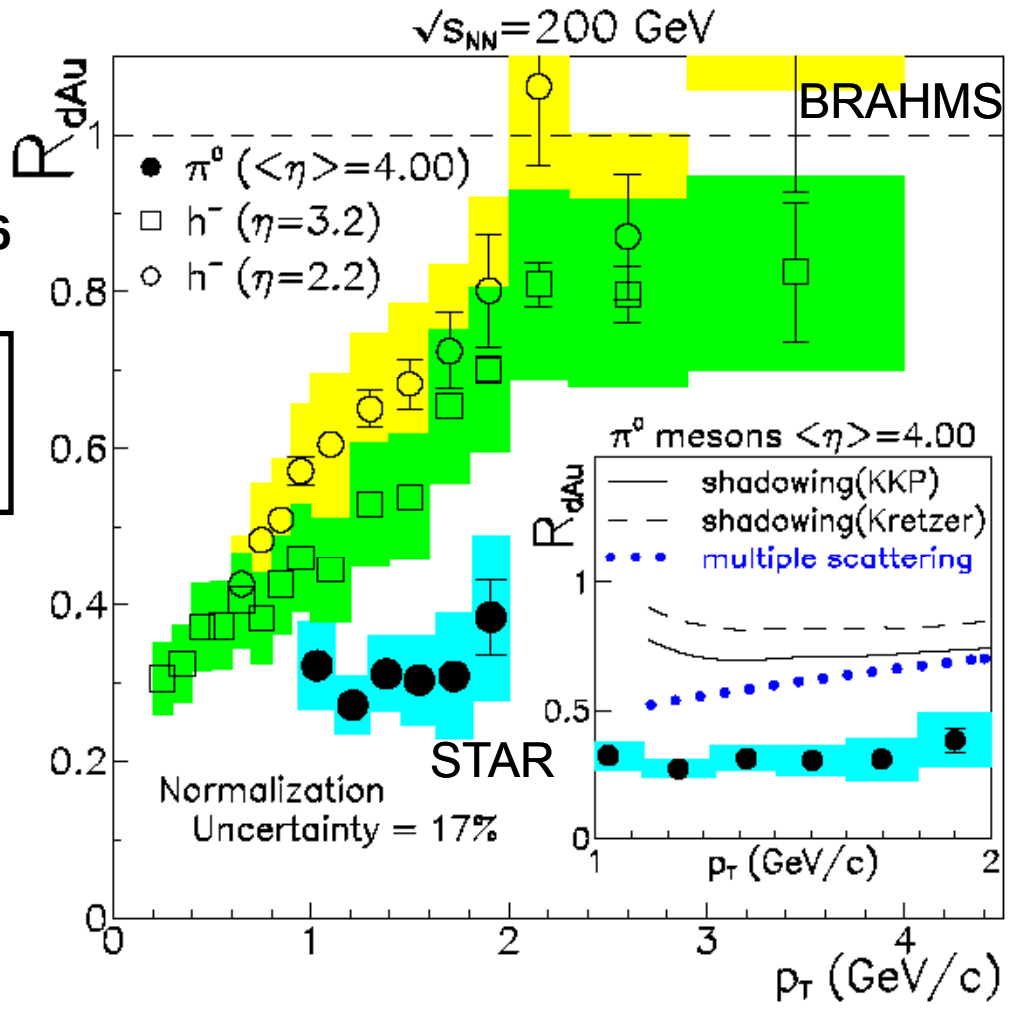
p_T dependence of d+Au π^0 cross section at $\langle\eta\rangle$ = 4.0 is best described by a LO CGC calculation.

(Dumitru, Hayashigaki, and Jalilian-Marian, NPA 765, 464)

η dependence of R_{dAu}

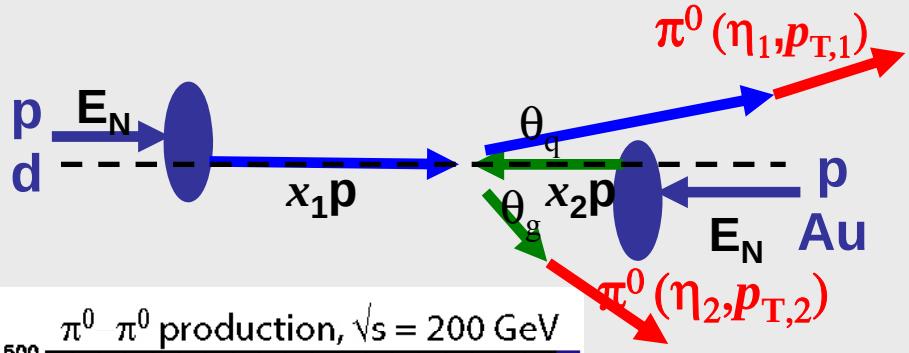
PRL97:152302,2006

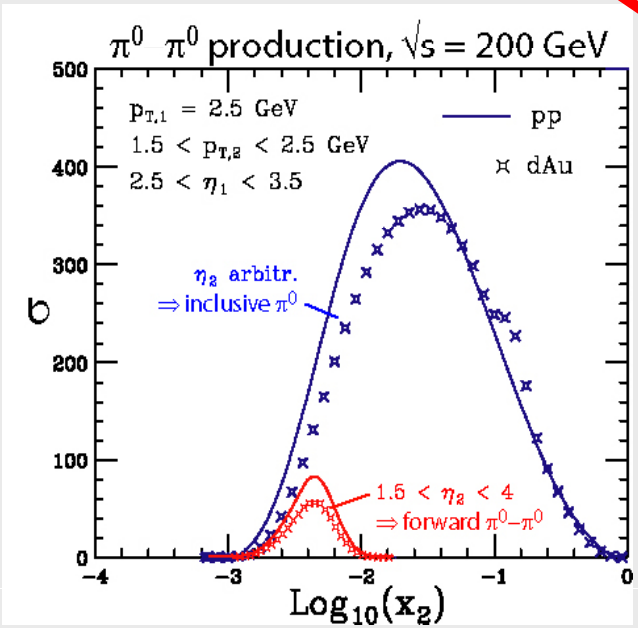
$$R_{dAu} = \frac{1}{2*197}\frac{\sigma_{dAu}}{\sigma_{pp}}$$



- Observe significant rapidity dependence.
- pQCD calculations significantly over predict R_{dAu}.

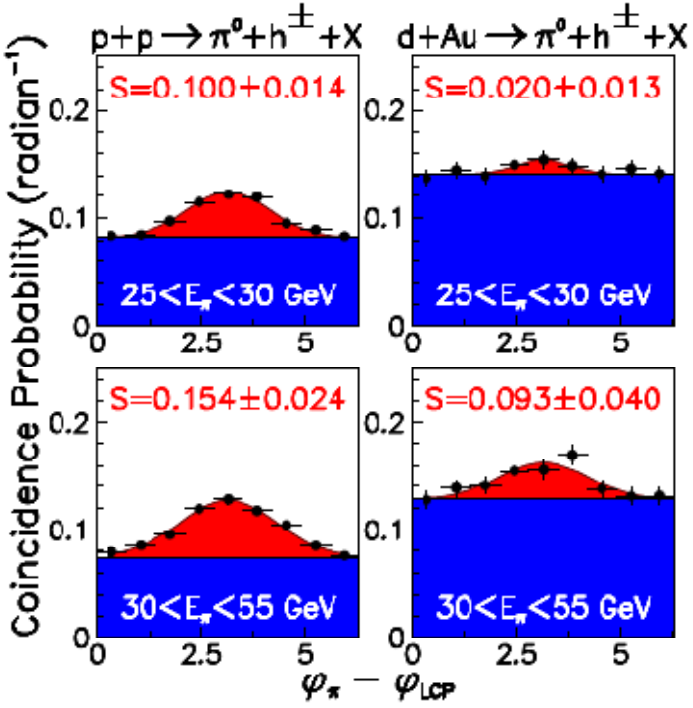
Any difference between p+p and d+Au?





V. Guzey, M. Strikman and W. Vogelsang

PRL97:152302,2006



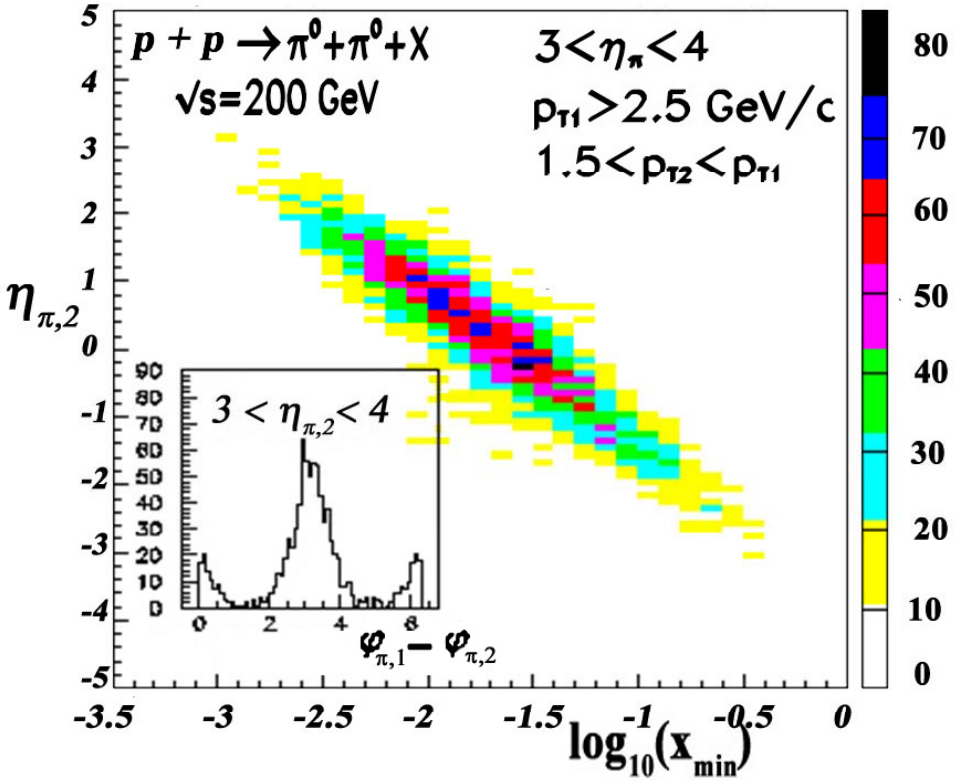
(Phys.Lett.B645:412-421,2007)

Explains our R_{dAu} result with **black center nucleus** (>10% energy loss) and only peripheral events contributing to leading pion production.
Also explain suppression of away jet with sampling arguments.

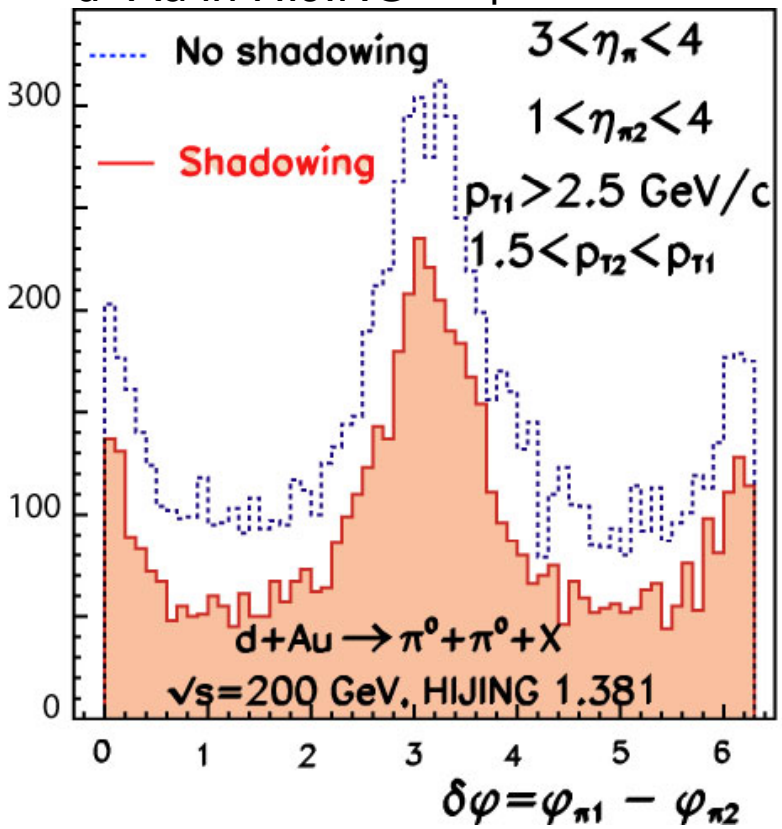
FMS for d-Au saturation physics

p+p and d+Au → π^0+π^0+X correlations with forward π^0

p+p in PYTHIA



d+Au in HIJING hep-ex/0502040



Conventional shadowing will **change yield, but not angular correlation**.
Saturation will **change yield and modify the angular correlation**.

Sensitive down to x_g ~ 10^{-3} **in pQCD** scenario; **few x** 10^{-4} **in CGC** scenario.

Among Future Opportunities in RHIC

- dAu Run (Run 8)
- possibility for (polarized proton)-nucleus collisions
  - $p^{\uparrow}$ Au
  - (asymmetric beams 100GeV/c on 250 GeV/c)
- possibility for polarized Deuteron beam
  - $d^{\uparrow}$ Au
  - $d^{\uparrow}$ $p^{\uparrow}$
  - Forward Neutron detection can distinguish polarized p interactions from polarized neutron interactions.

Merging the two classes of forward physics questions.

•How does transverse asymmetry correlate with gluon saturation effects?

•How does mono-jet vs di-jet topology and suppression correlate with single spin asymmetries?

Summary

- P_T dependence of single spin asymmetry in forward pion production raises the possibility of a connection to gluon saturation physics.

- STAR FMS will measure full mono-jet vs di-jet topology in pp and in dAu collsions. PHENIX also with forward EM calorimetry. This will characterize the topology of forward pion events, with identification of gluon x~.001.

- Additional measurements, including direct photon, di-lepton and heavy meson production are also planned.

- If polarized proton/deuteron beams colliding with heavy ion beams are available in the future, a great number of new directions will become possible.