Forward Physics Results at STAR

Akio Ogawa

BROOKHAVEN NATIONAL LABORATORY

For STAR

RHIC AGS Users Meeting
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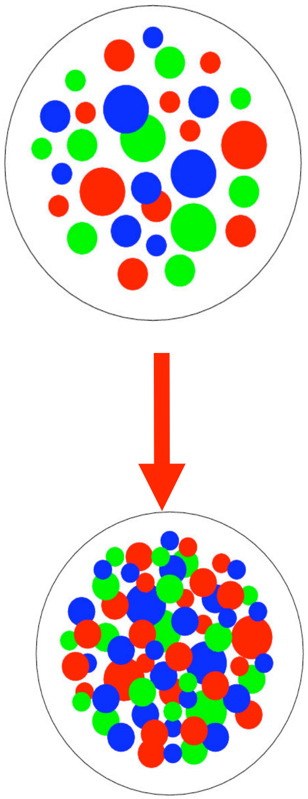
BNL

Gluon density at low x

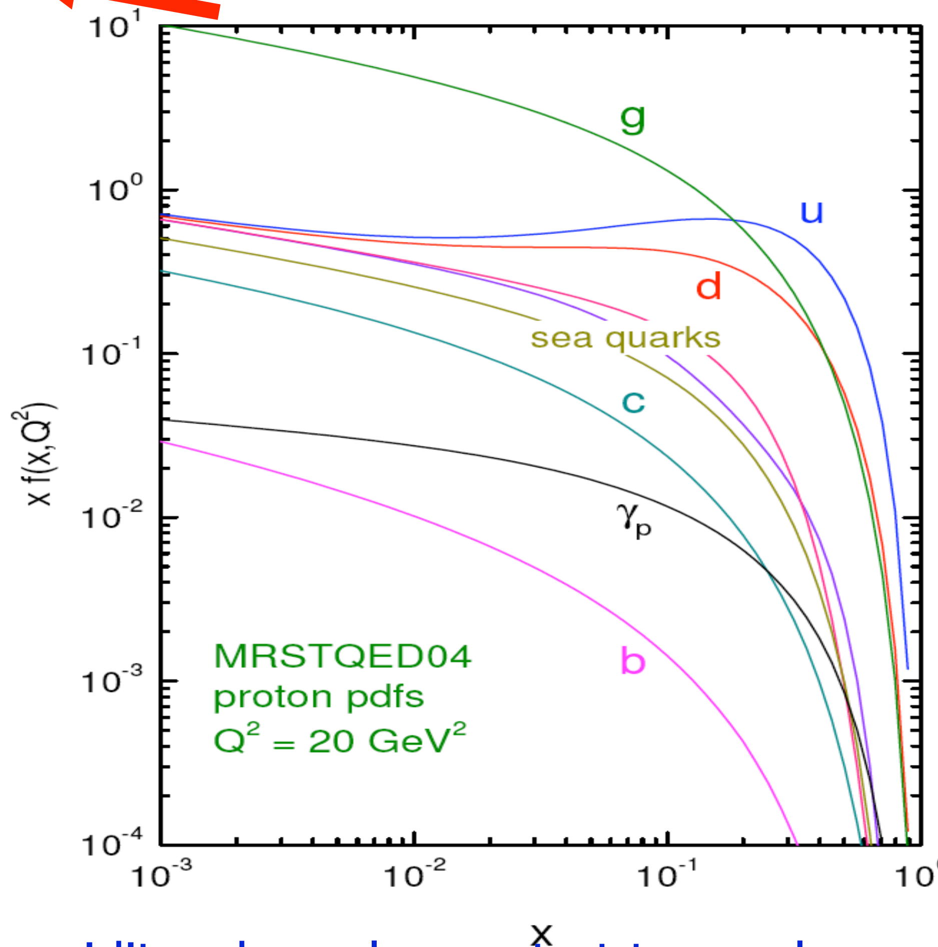
Gluon density can't grow forever.



Mid Rapidity

$$x \sim \frac{2p_T}{\sqrt{s}} e^{-y}$$

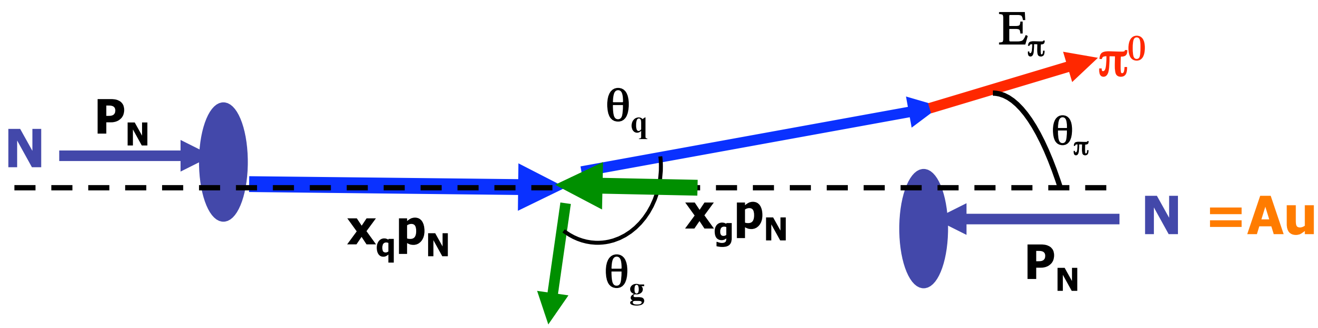
Forward Rapidity



Saturation must set in at forward rapidity when gluons start to overlap and recombination becomes important

Can RHIC see gluon saturation? (or at LHC/eRHIC?)

Why forward rapidity @ hadron collider?



- Forward scattering probes asymmetric partonic collisions
- Mostly scattering of

high-x valence quarks (with known & large polarization)

$0.25 < x_q < 0.7$

on

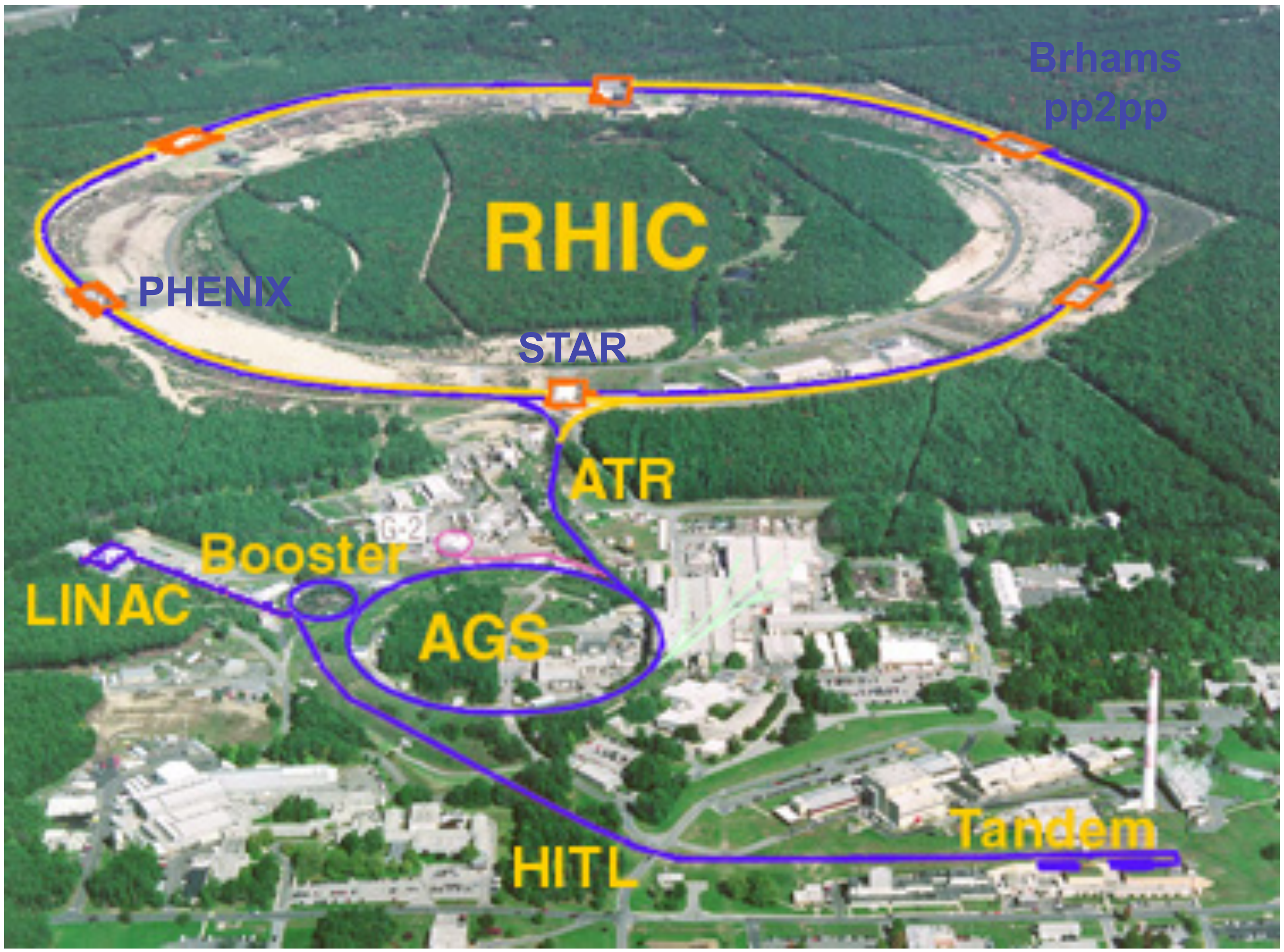
low-x gluons

$0.001 < x_g < 0.1$

With heavy nucleus target,
gluon density would be even bigger

In CGC picture, x_g ~ few 10^{-4}

The Relativistic Heavy Ion Collider



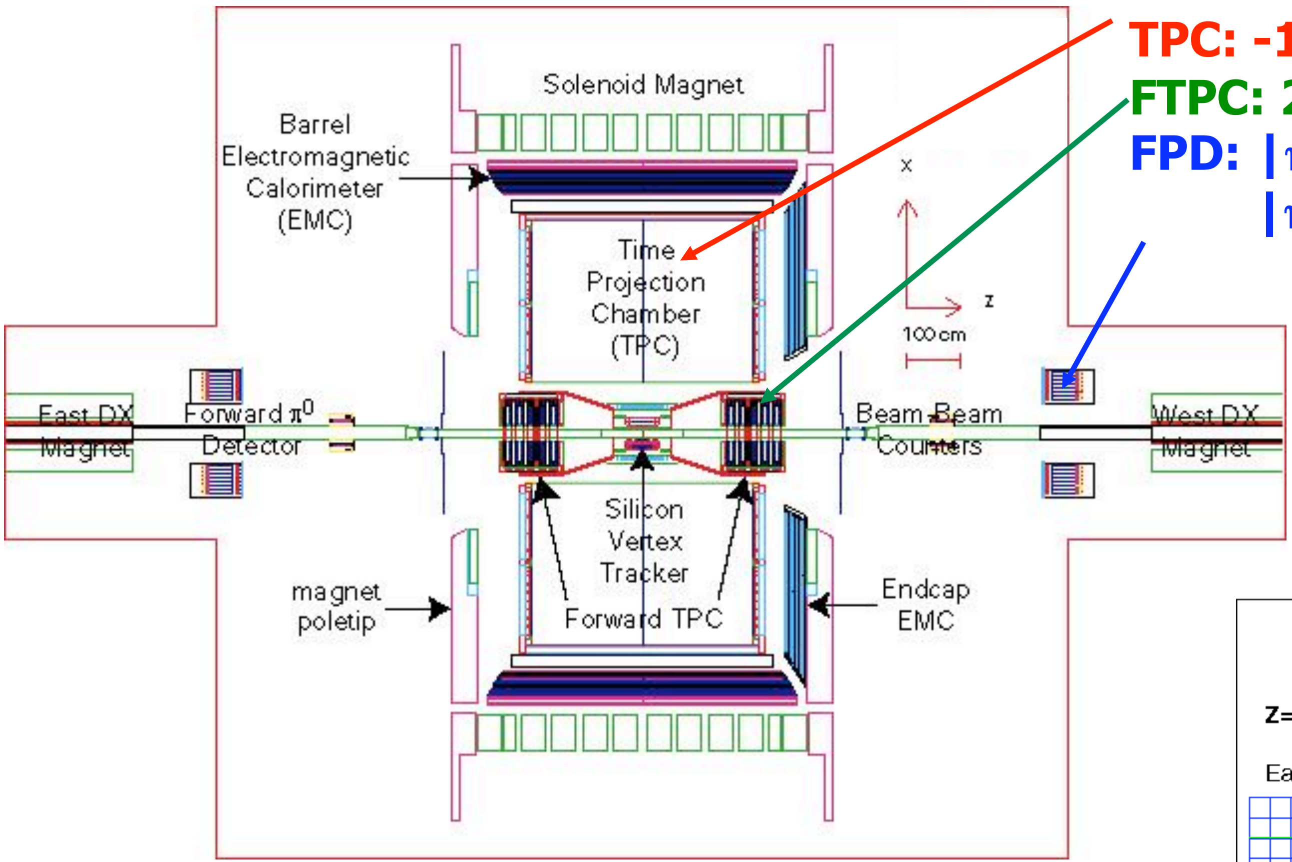
Au+Au

Polarized p+p

d+Au

RHIC is a QCD lab

The STAR Detector (run3)

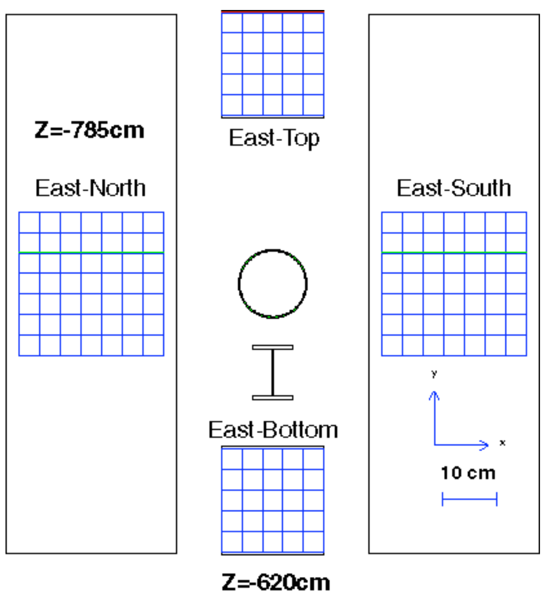


TPC: $-1.0 < \eta < 1.0$

FTPC: $2.8 < |\eta| < 3.8$

FPD: $|\eta| \sim 3.8$ (p+p)

$|\eta| \sim 4.0$ (p+p, d+Au)

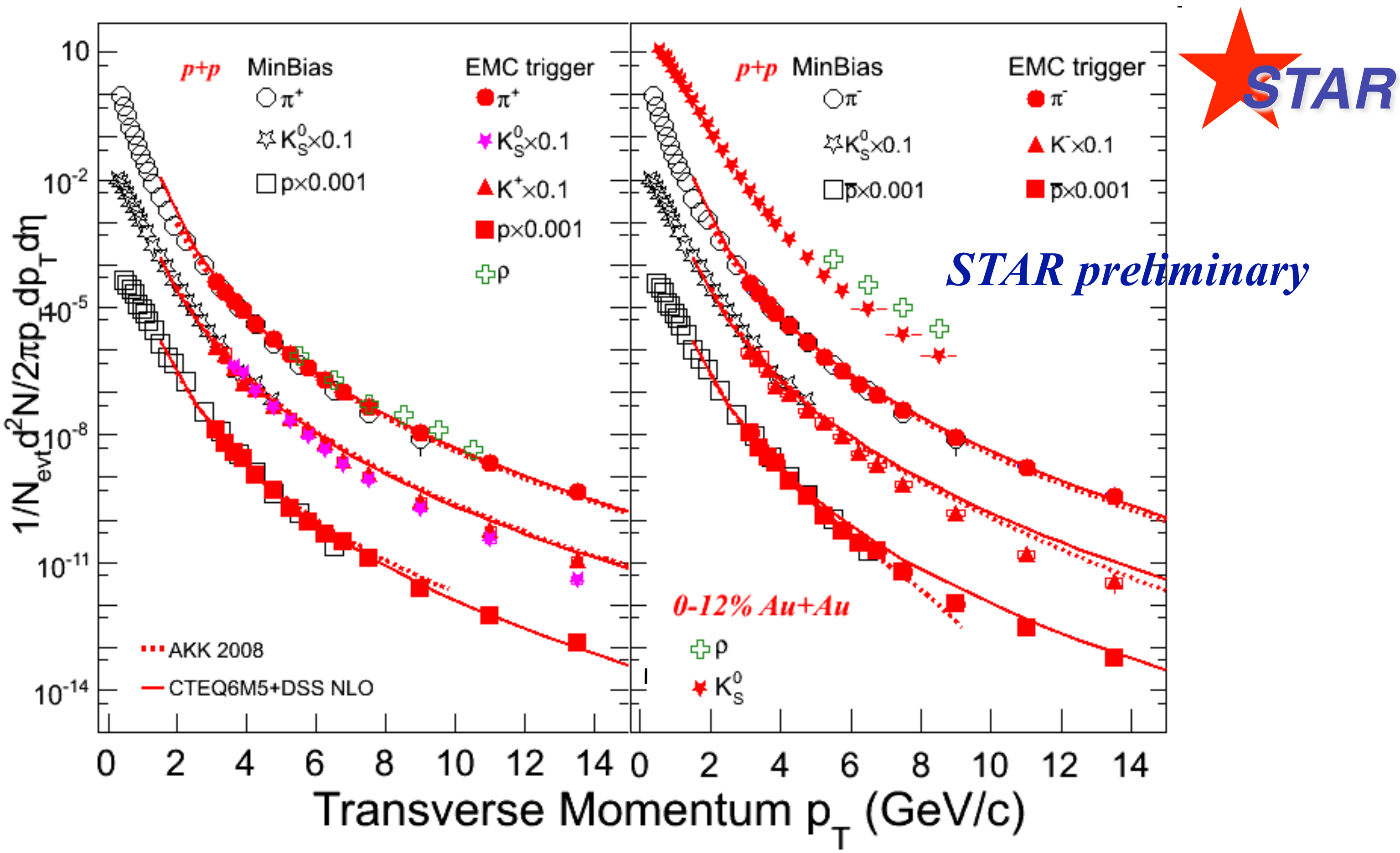


Forward π^0 Detector (FPD)

- **Pb-glass EM calorimeter**
- **Shower-Maximum Detector (SMD)**
- **Preshower**

Mid-rapidity p+p

Identified particle spectra in p+p

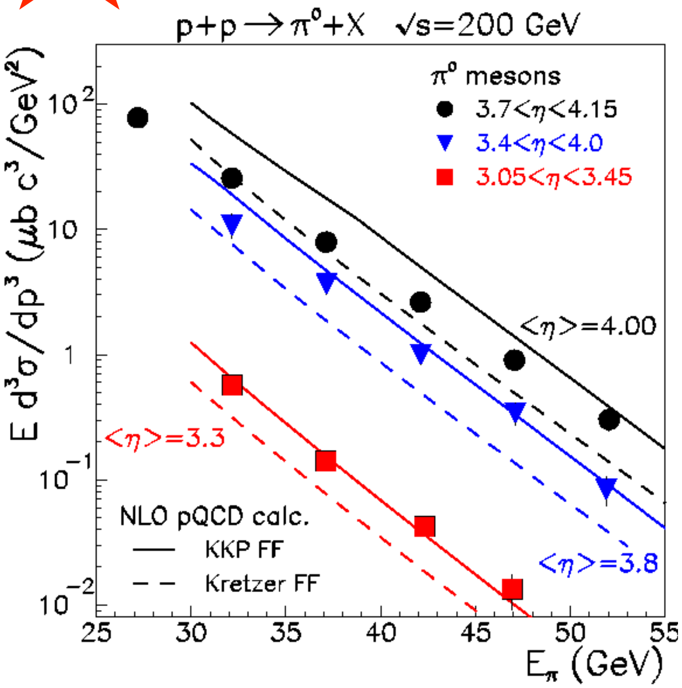


MinBias p+p data
Phys. Lett. B. 637 (2006) 161
Higher pT data
Xu Y. QM09

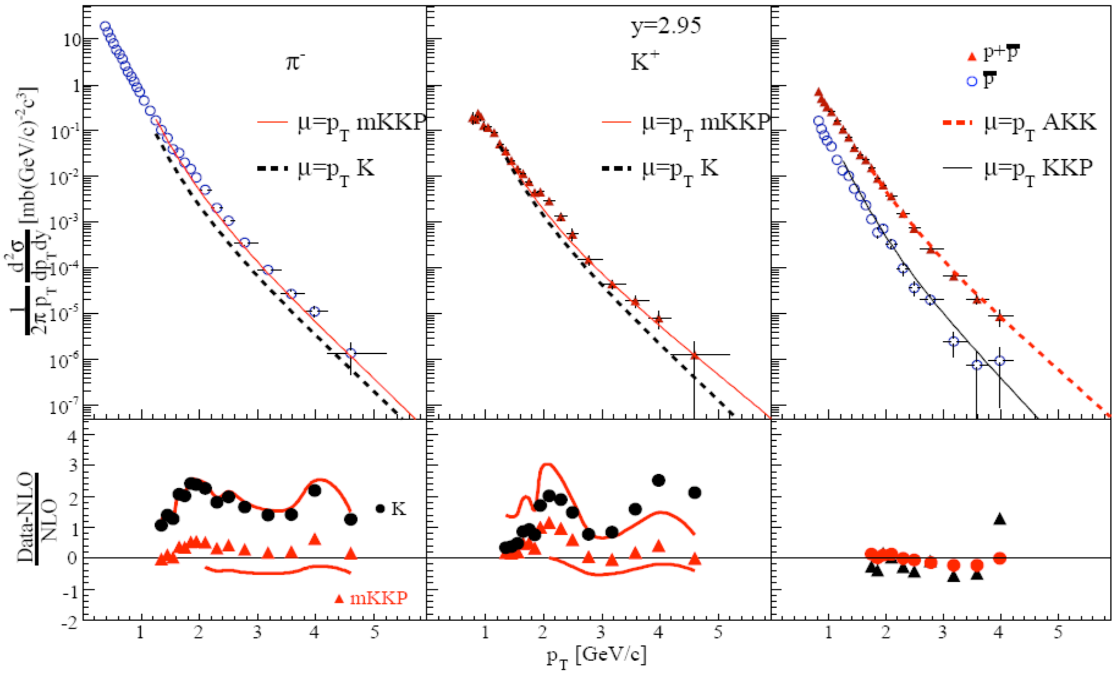
p+p at 200 GeV, pQCD does a very good job describing mid-rapidity hadron yields

Forward rapidity p+p

STAR PRL 97, 152302



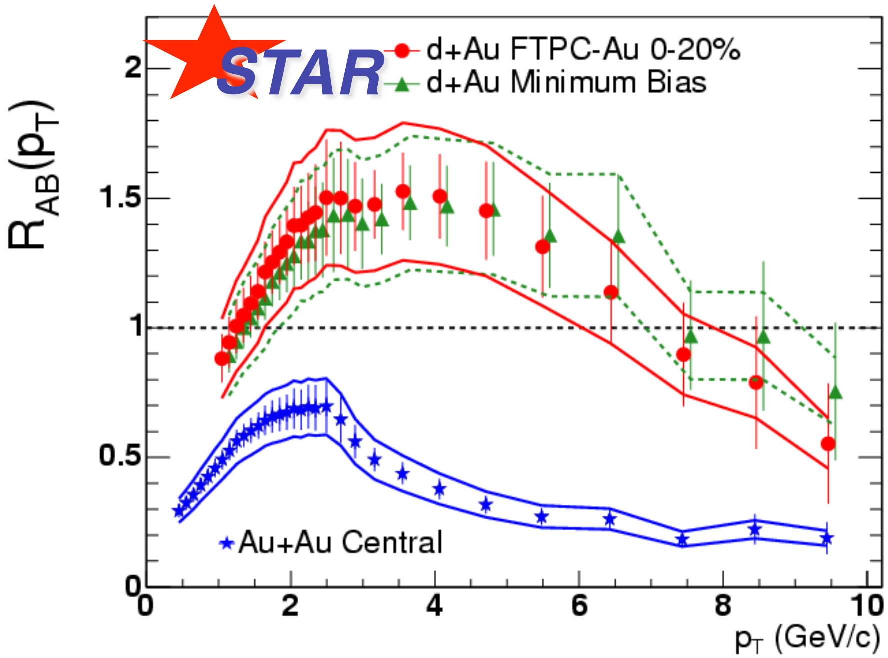
BRAHMS PRL 98, 252001



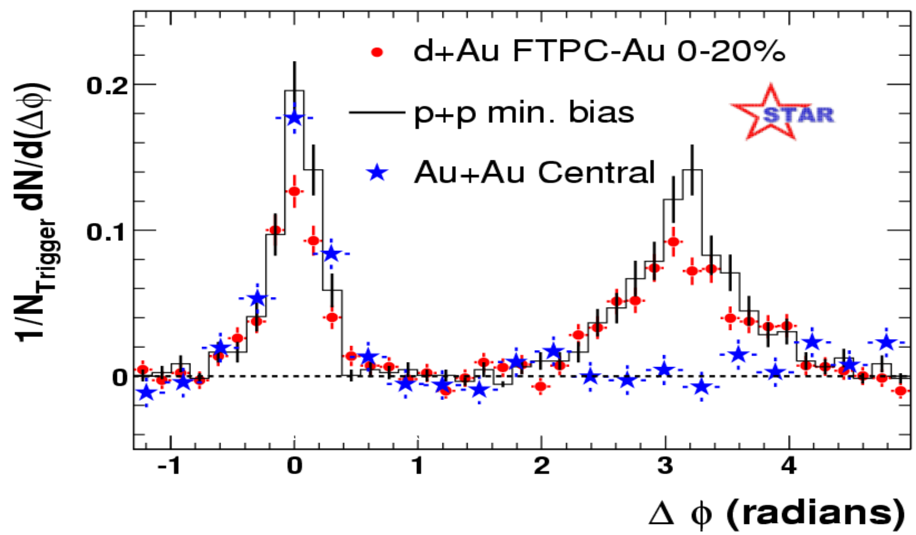
p+p at 200 GeV, pQCD does a very good job describing ~~mid-rapidity~~ hadron yields

both mid and forward rapidity (0<|η|<4)

Mid-rapidity d+Au (and Au+Au)



PRL 91, 072304



p+p and d+Au similar in

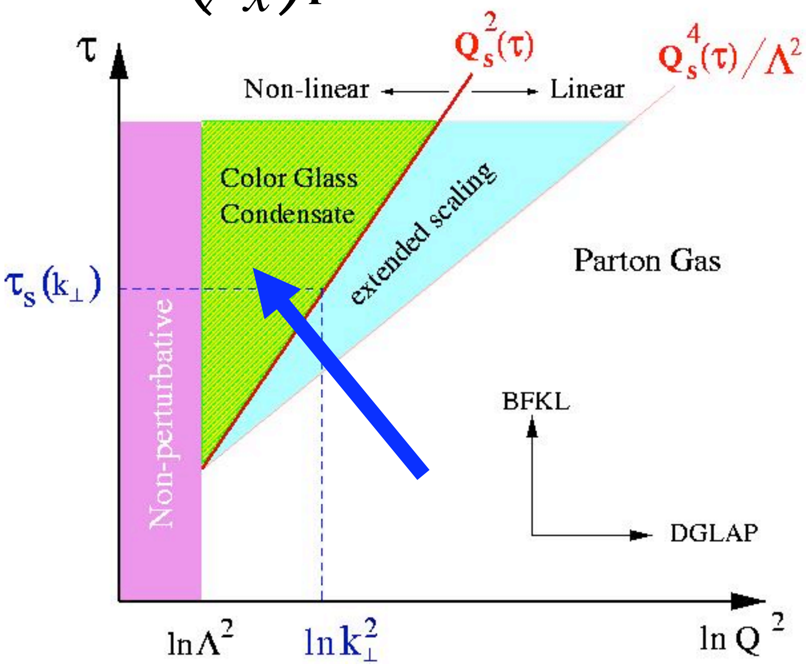
inclusive yields (~1.5 enchancements at mid-p_T)
back-to-back di-hadron correlations

In contrast, Au+Au collisions are very different from p+p and d+Au

Forward rapidity d+Au?

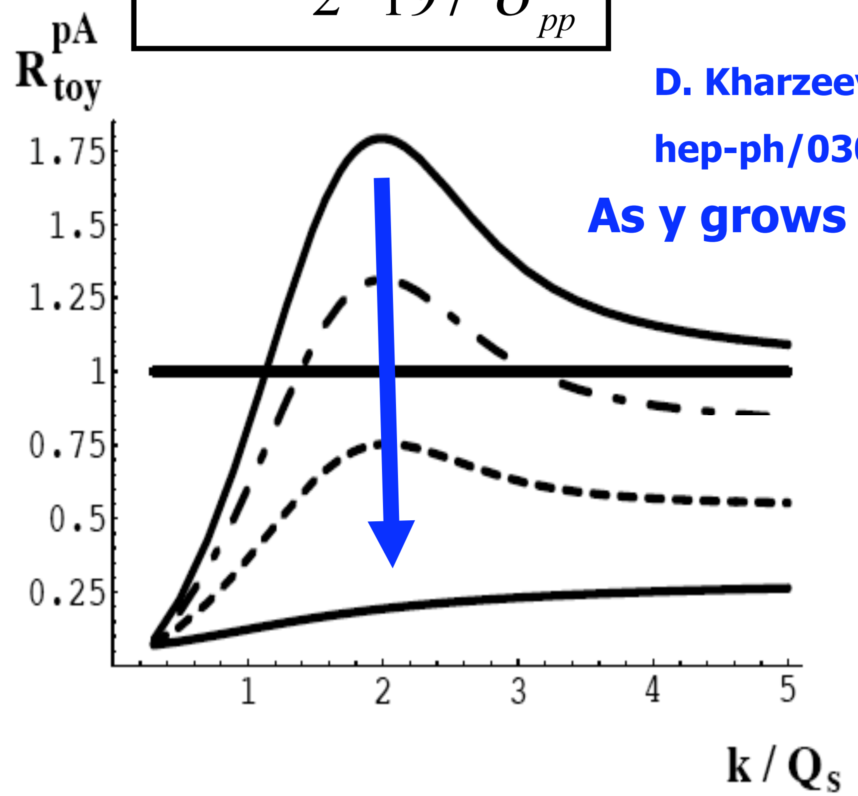
Expectations from Color Glass Condensate

$\tau = \ln\left(\frac{1}{x}\right)$ τ related to rapidity of produced hadrons.



Iancu and Venugopalan, hep-ph/0303204

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



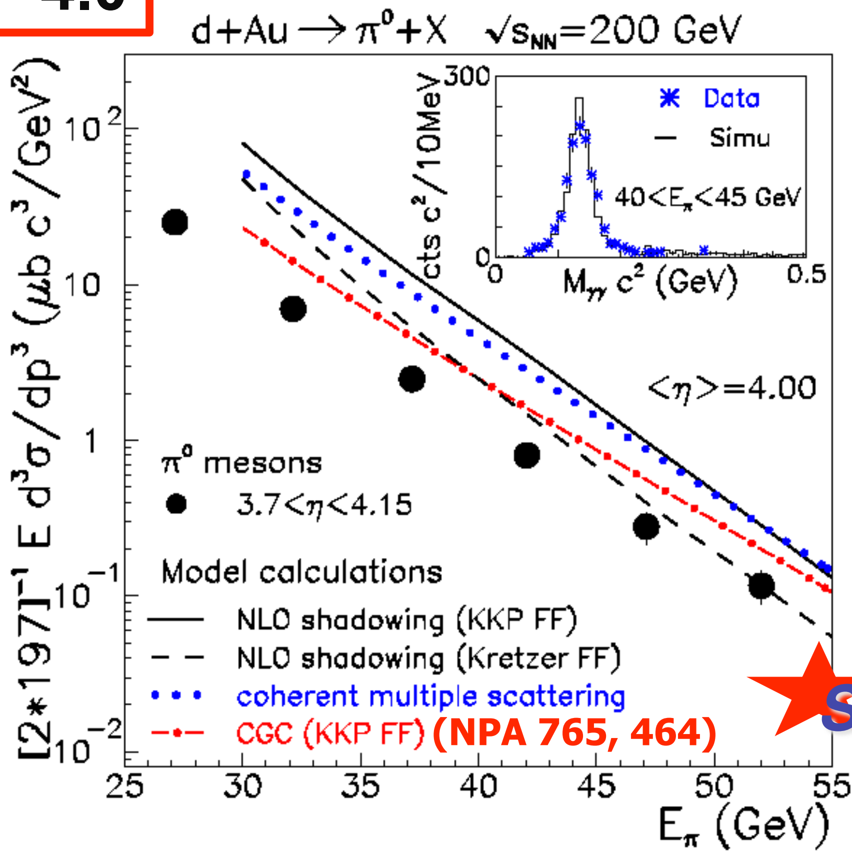
D. Kharzeev
hep-ph/0307037

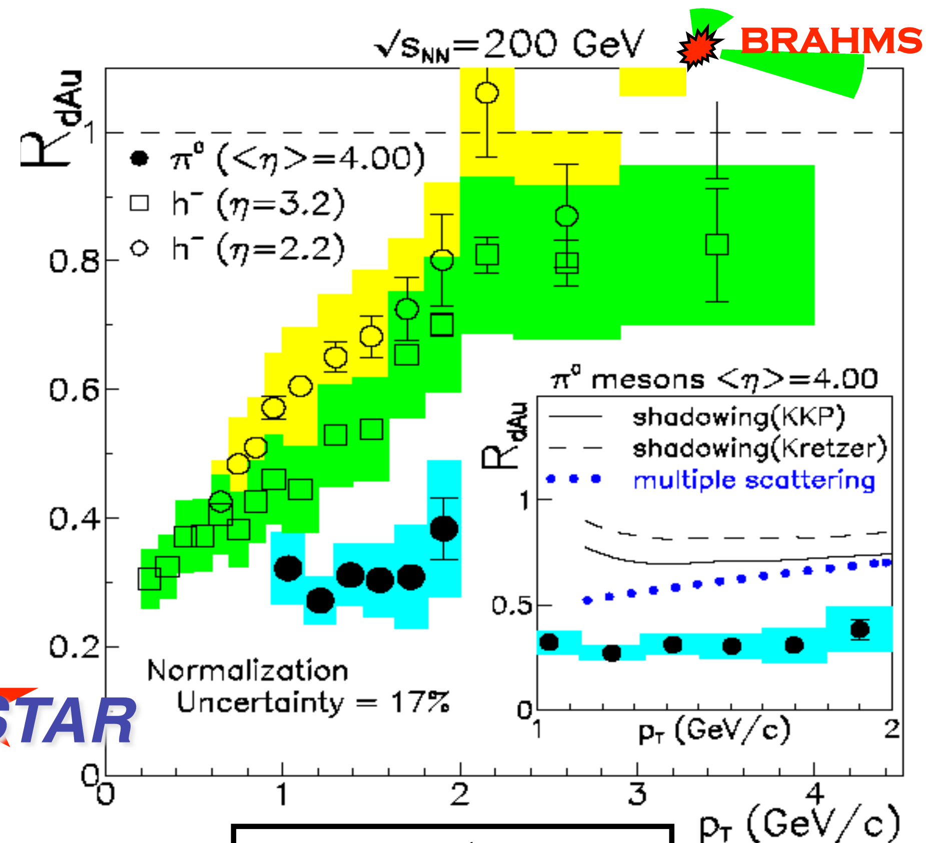
CGC expects suppression of forward hadron production

STAR d+Au forward π^0

η = 4.0

PRL 97, 152302





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

Sizable suppression

pQCD+Shadowing expects suppression, but not enough

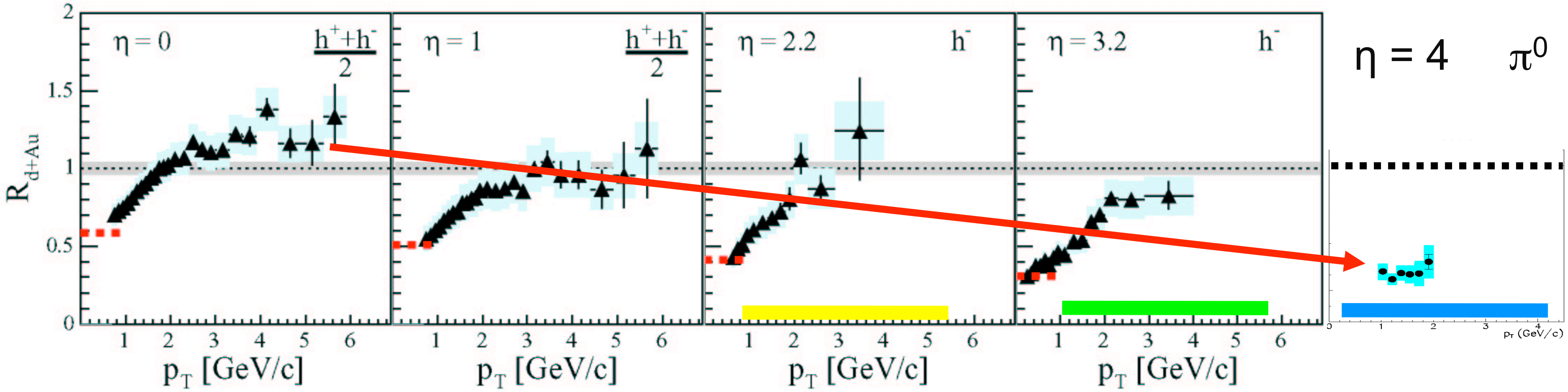
CGC gives best description on p_T dependence

R_{dAu} rapidity dependence

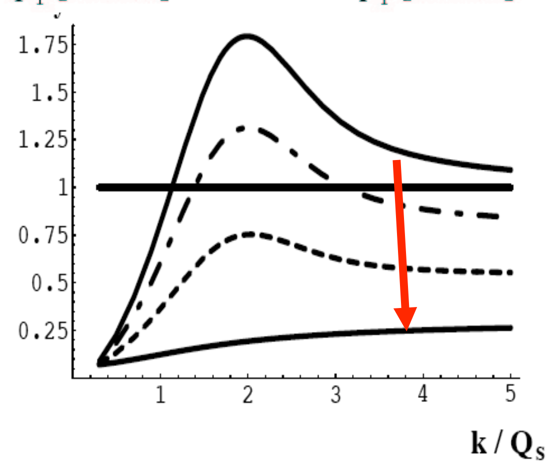
η = 0➔4

BRAHMS PRL 93, 242303

STAR PRL 97, 152302



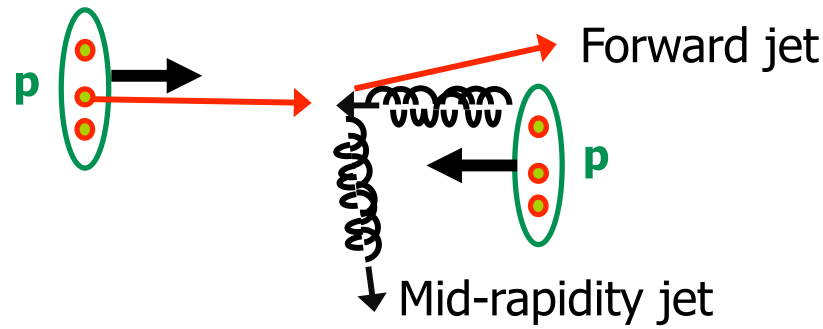
$$R_{dAu} = \frac{1}{2*197} \frac{\sigma_{dAu}}{\sigma_{pp}}$$



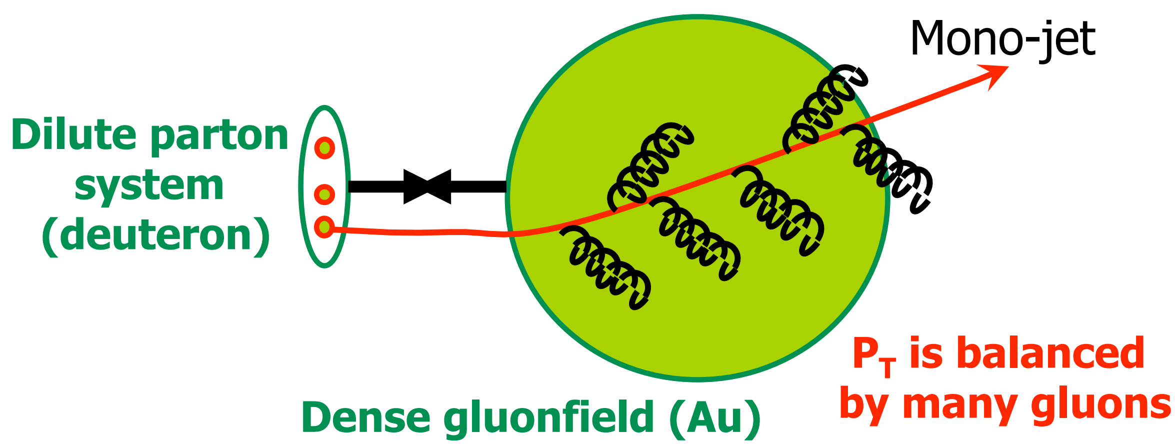
Observe significant rapidity dependence similar to expectations from the CGC framework

Back-to-back Angular Correlations

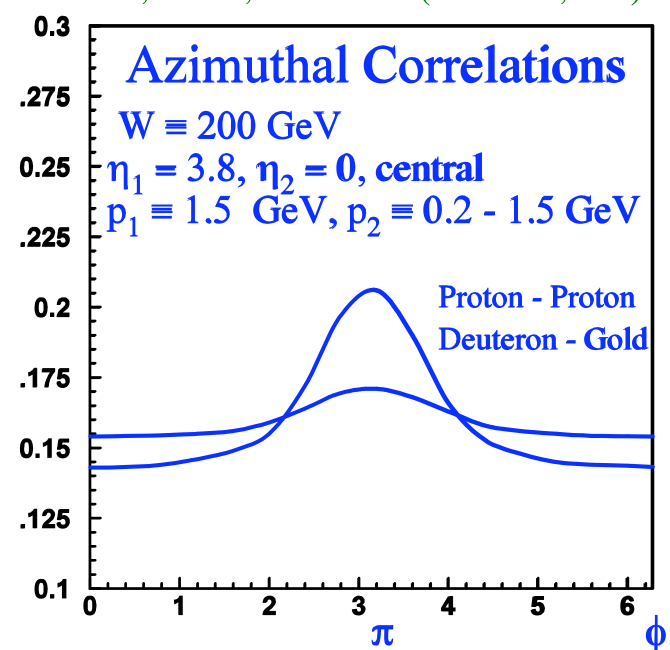
pQCD 2➔2 process =back-to-back di-jet (Works well for p+p)



With high gluon density
2➔1 (or 2➔many) process = Mono-jet ?

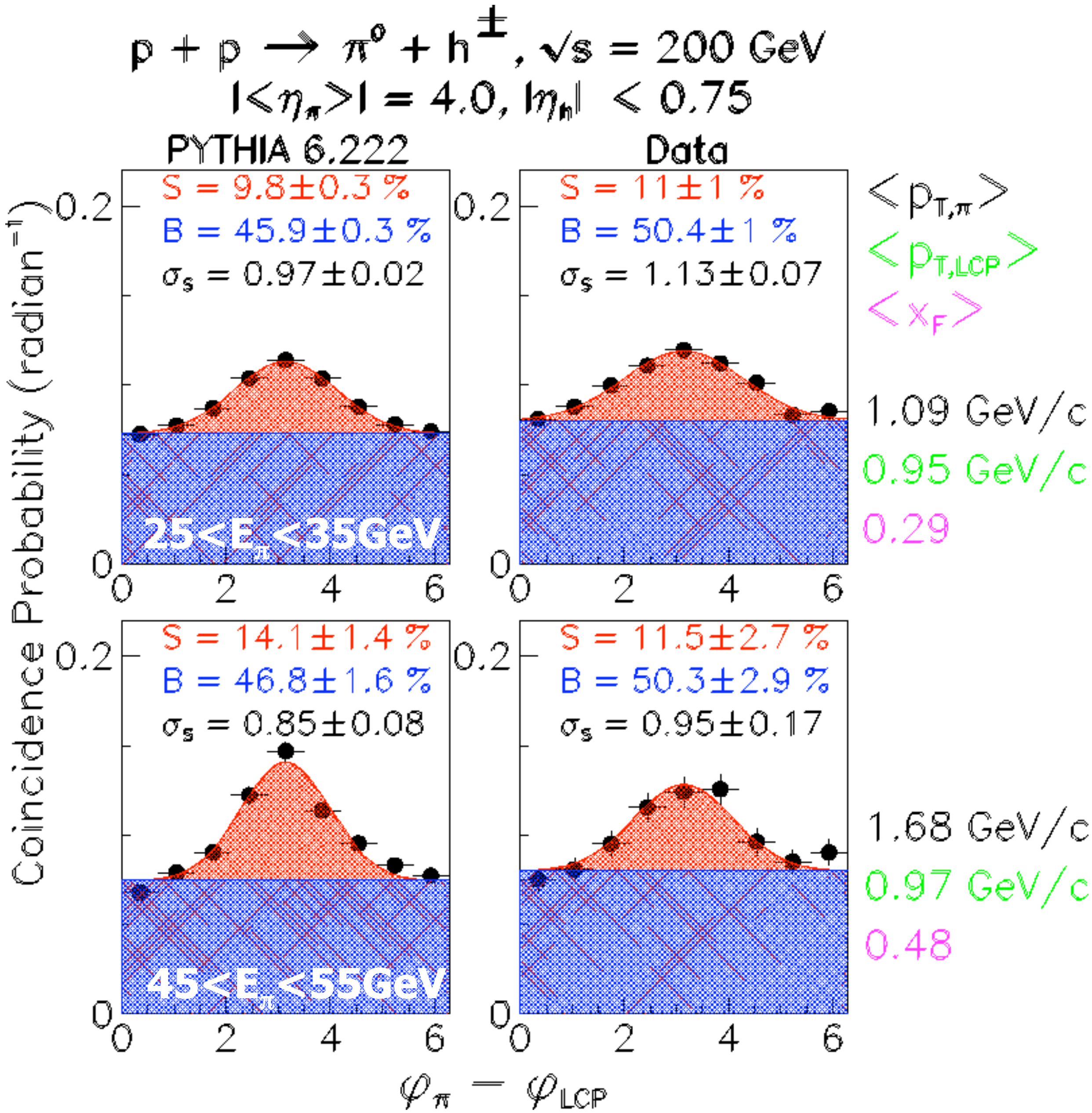


Kharzeev, Levin, McLerran (NPA748, 627)



CGC predicts suppression of back-to-back correlation

p+p Forward-Midrapidity Correlations



Forward pi0 (FPD)
+
Mid-rapidity
Leading Charged Particle
(TPC)

PYTHIA + detector predict

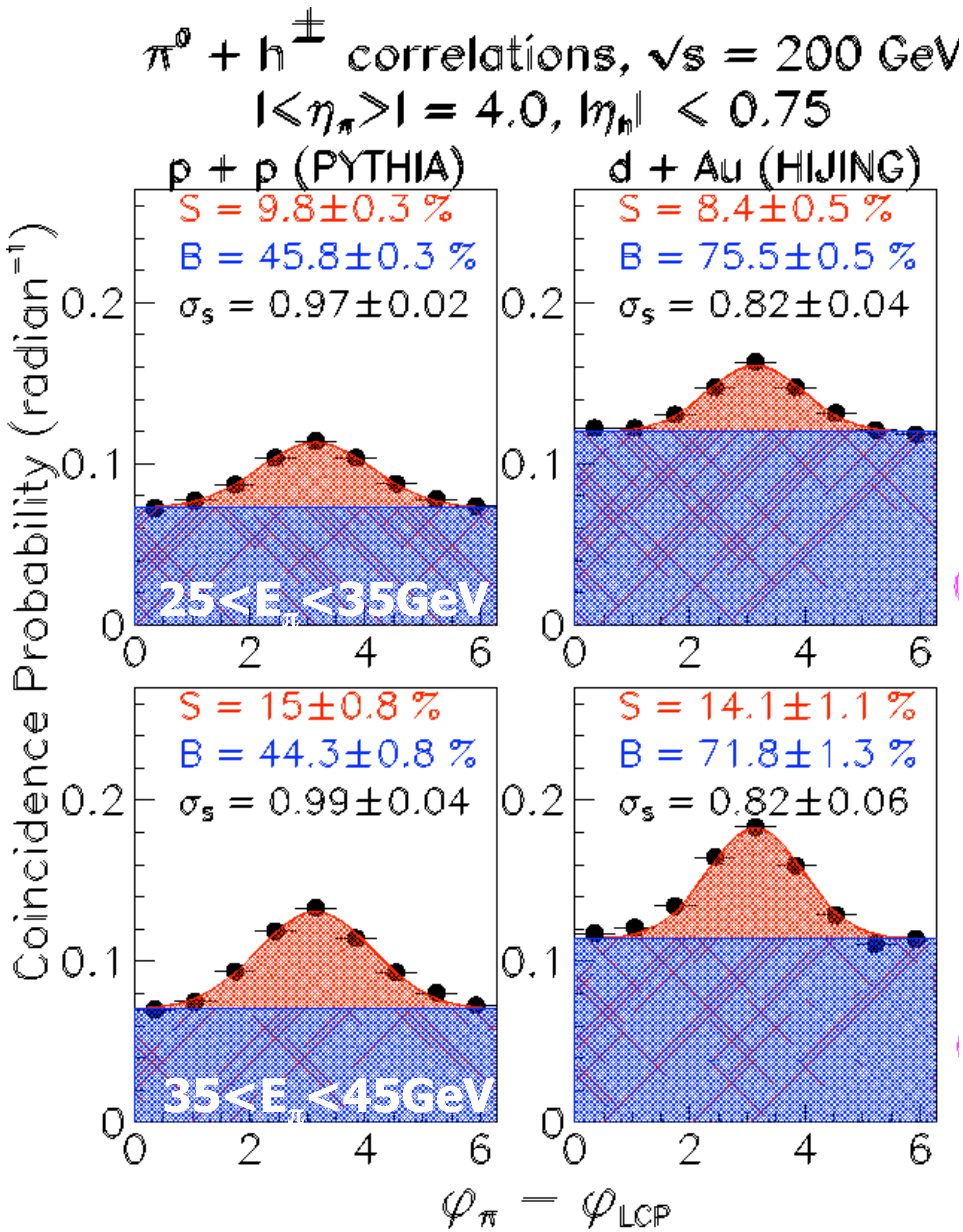
As $\langle x_F \rangle$ and $\langle p_{T,\pi} \rangle$ grows

- **"S" grows with**
- **"σ_s" decrease**

PYTHIA prediction agrees with data

$\eta^{trig} = 4.0$
$\eta^{asso} = 0.0$

PYTHIA (p+p) vs HIJING (d+Au)

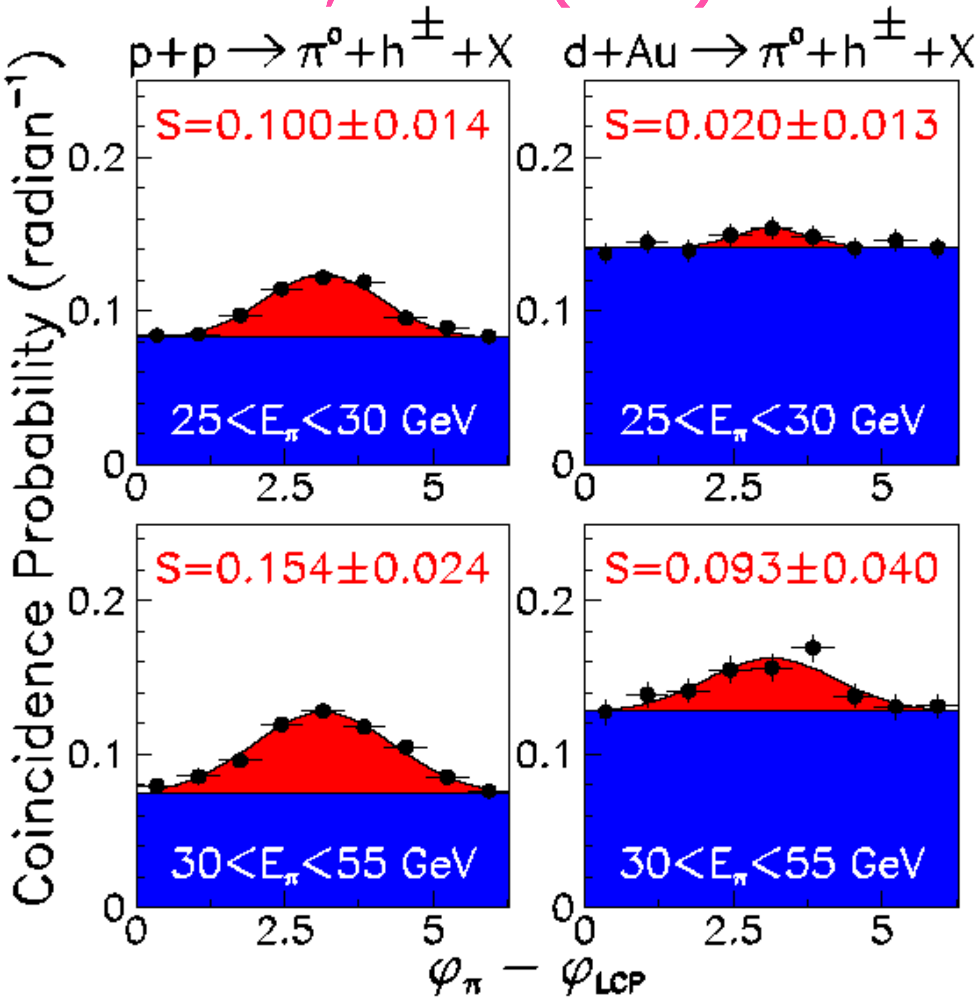


- **HIJING predicts similar correlations in d+Au as PYTHIA predicts for p+p.**
- **Only significant difference is combinatorial background level**

η^{trig} = 4.0
η^{asso} = 0.0

An initial glimpse: correlations in d+Au (Run3)

PRL 97, 152302 (2006)



π^0: $|\langle\eta\rangle| = 4.0$

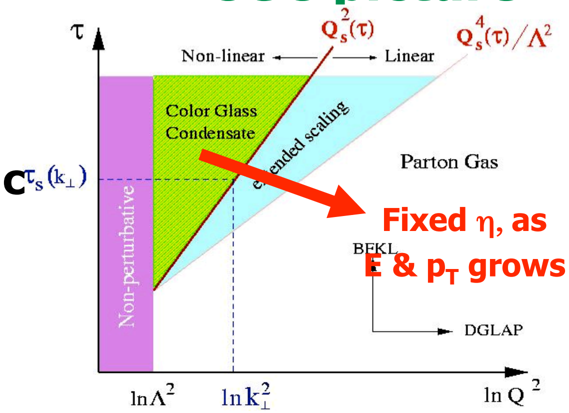
$h^\pm$: $|\eta| < 0.75$; $p_T > 0.5$ GeV/c

$\langle p_{T,\pi}\rangle \sim$ 1.0 GeV/c

$\langle p_{T,\pi}\rangle \sim$ 1.3 GeV/c

suppressed at small $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$

consistent with CGC picture



- **are similar in d+Au and p+p at larger $\langle x_F\rangle$ and $\langle p_{T,\pi}\rangle$**

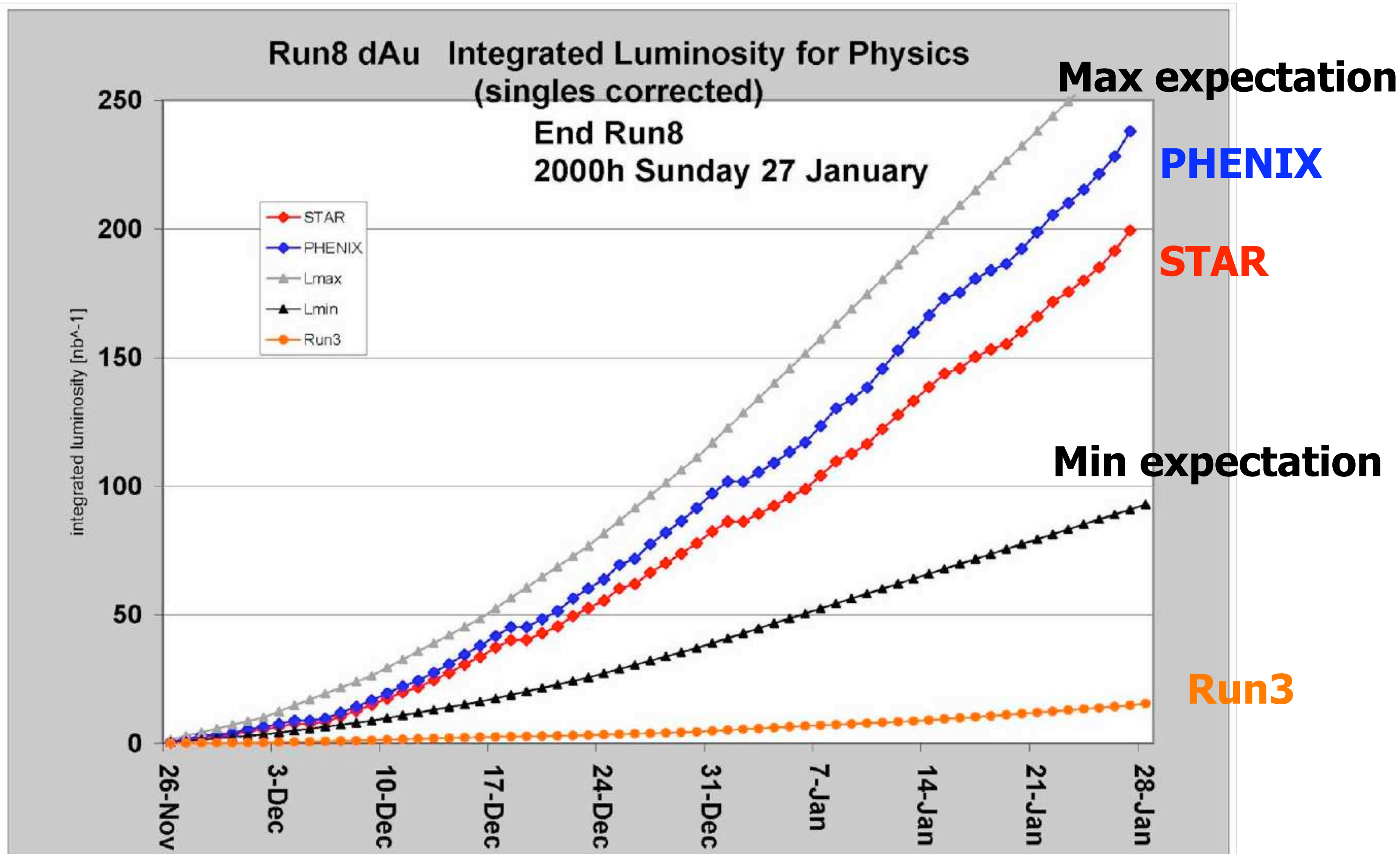
as expected by HIJING

$\eta^{trig} = 4.0$
$\eta^{asso} = 0.0$

$x_g \sim 0.006$
$\Delta\eta \sim 4.0$

Relativistic Heavy Ion Collider

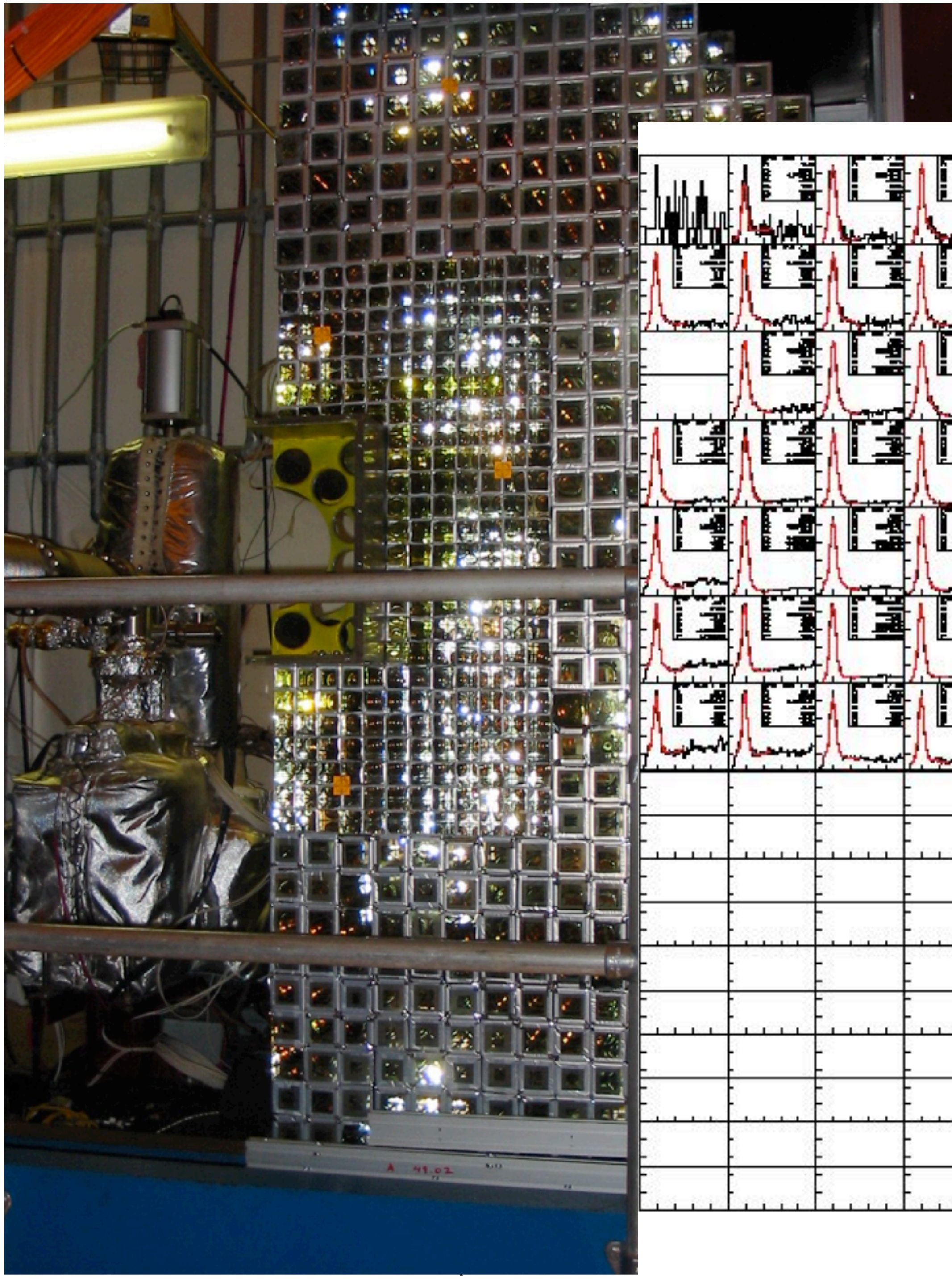
Run8 d+Au @ 200GeV

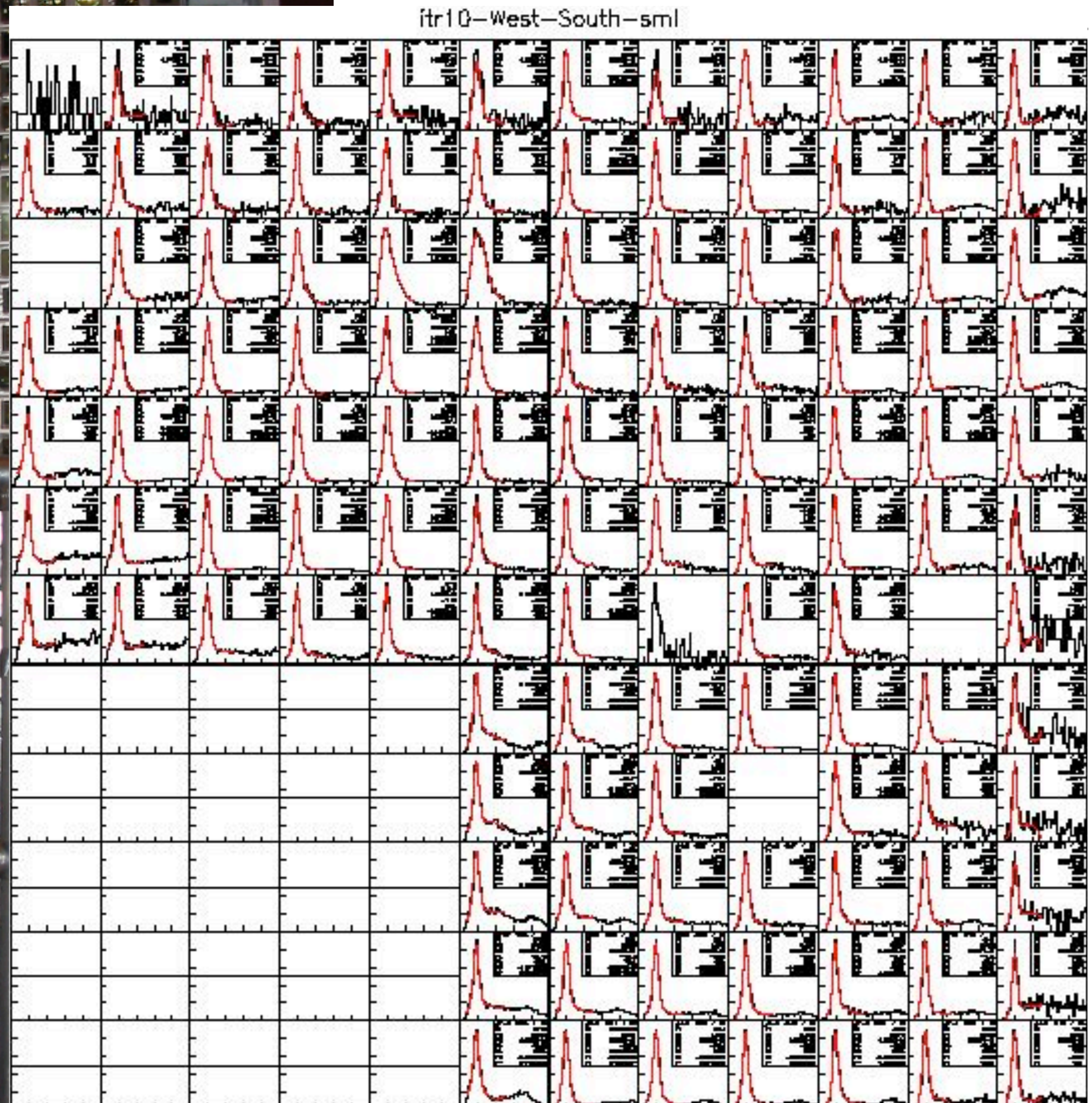


~x30 luminosity (from run3) Great success!

+(polarizaed) pp run ➔ reference data

ctrometer for Run8

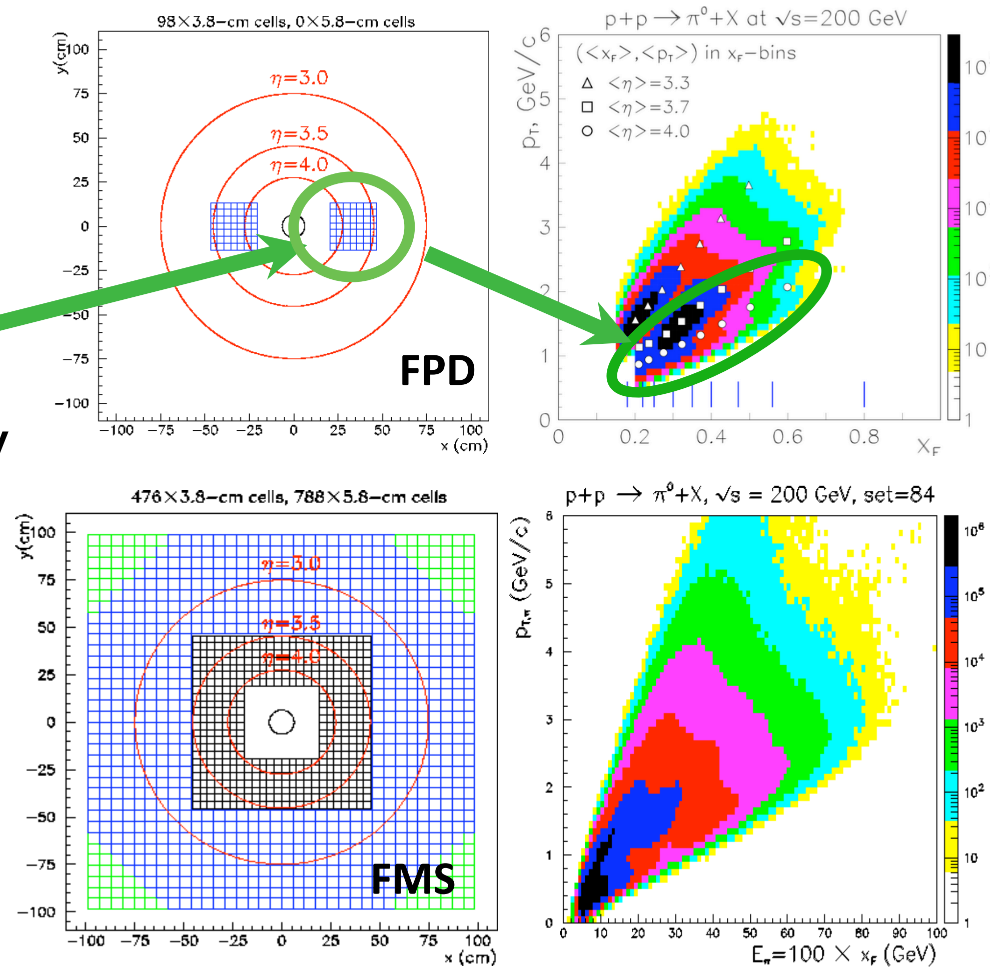




FPD to FMS

- In d+Au, FPD/FMS faced d beam to see neutral pions produced by large-x partons with low-x nuclear gluons
- Exploratory run-3 measurements: West-South FPD module only
- Run-8 measurements: first FMS run (50x bigger acceptance)
- $L_{run-8}=10*L_{run-3}$

Phys. Rev. Lett. 97 (2006) 152302



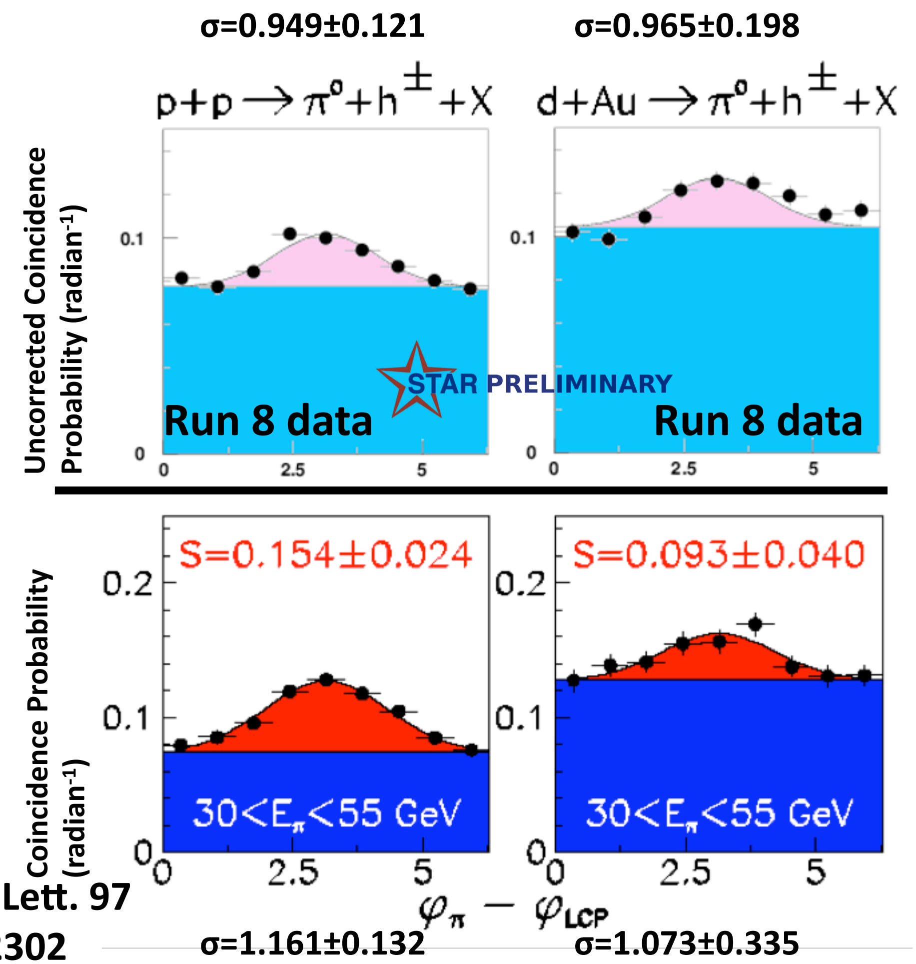
FPD – FMS comparison

$\eta^{trig} = 4.0$
$\eta^{asso} = 0.0$

- Emulate FPD from run-8 FMS:
  - FMS photons: x > 0cm;
  - $|\eta_{TPC}| < 0.75$; $3.8 < \eta_{FMS} < 4.1$;
  - $0.5GeV < p_T^{(TPC)}$
  - $|\alpha_{FMS}| = |E_1 - E_2|/(E_1 + E_2) < 0.7$;
  - $30 < E_{FMS} < 55$ GeV
  - leading (in p_T) particles considered

- Reproduce gaussian width and many similarities

- Normalization requires more systematic studies:
  - pile-up correction
  - vertex efficiency
  - run-3/run-8 trigger



Phys. Rev. Lett. 97 (2006) 152302

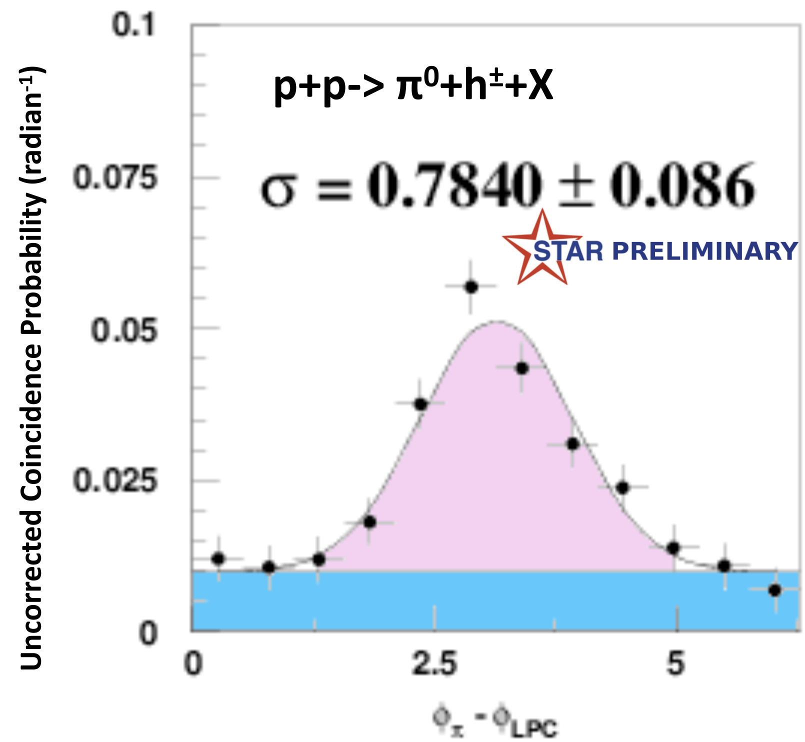
FMS results : π^0+$h^\pm$ correlations

- Correlate forward π^0 with a mid-rapidity charged track (TPC)

pQCD inspired “GSV cuts”
(Guzey, Strikman and Vogelsang, hep-ph/0407201):

- $|\eta_{TPC}| < 0.9$; $2.8 < \eta_{FMS} < 3.8$
- $2.5GeV < p_T^{(FMS)}$
- $1.5GeV < p_T^{(TPC)} < p_T^{(FMS)}$
- $|\alpha_{FMS}| < 0.7$
- $0.07 < M_{\gamma\gamma} < 0.30$ GeV
- only leading particle considered
- corrected for pile-up
- (as proposed in hep-ex/0502040)

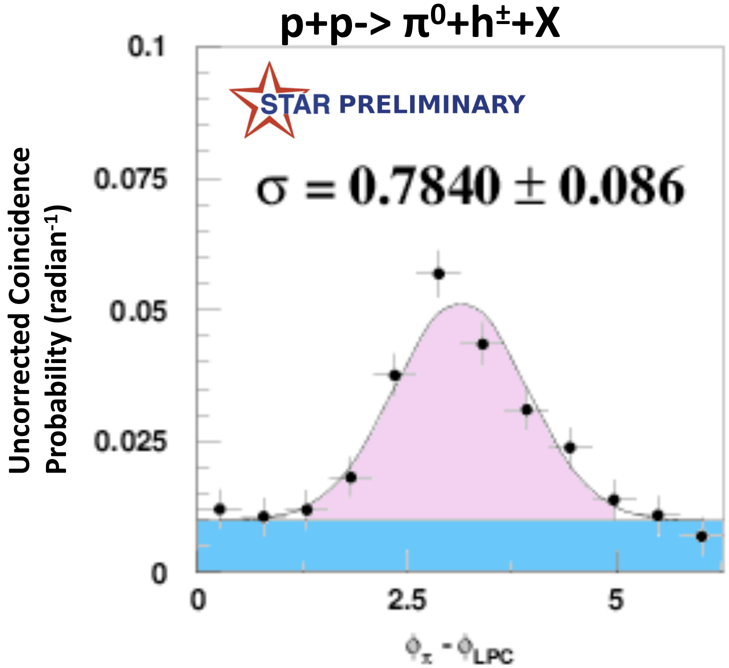
•Normalization requires more systematic studies

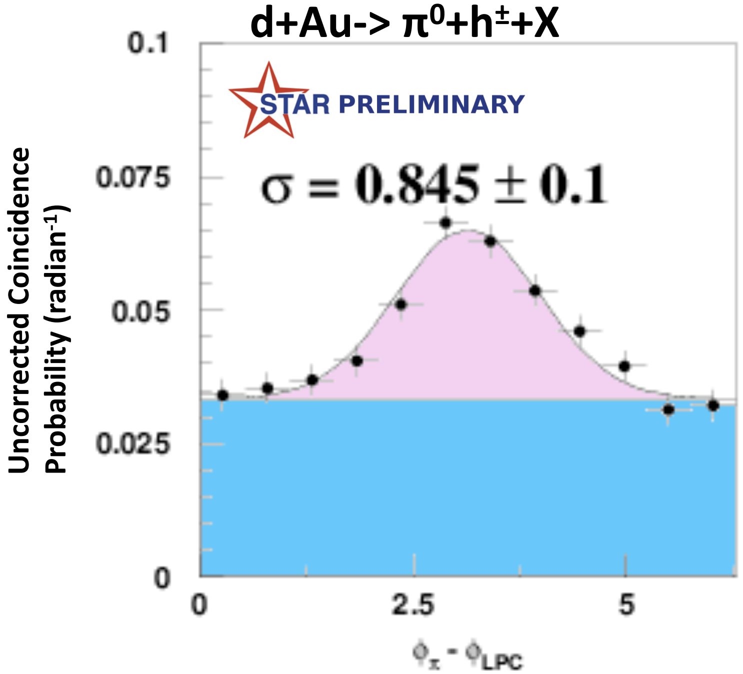


FMS results : π^0+$h^\pm$ correlations

comparison p+p & d+Au

- Same conditions ("GSV cut") were applied in d+Au

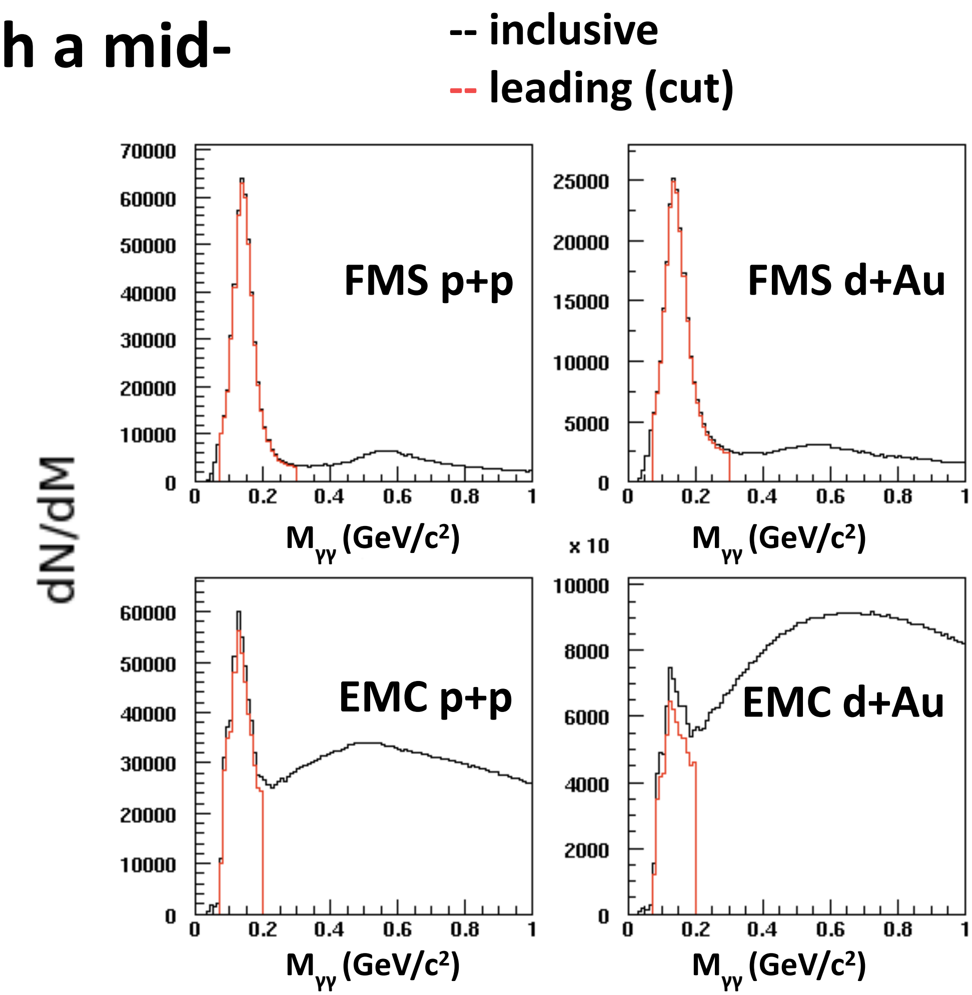




- **Back to back peaks are evident**

FMS results: $\pi^0+\pi^0$ correlations

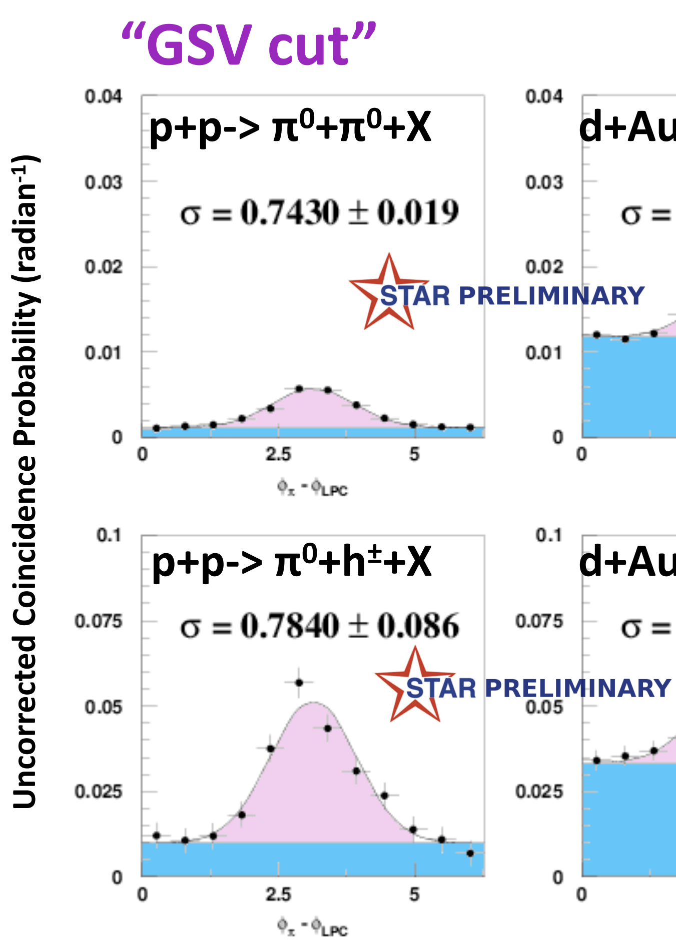
- Correlate forward π^0 with a mid-rapidity π^0 (bEMC)



- $|\eta_{EMC}| < 0.9$;
- $2.8 < \eta_{EMC} < 3.8$;
- $2.5\text{GeV} < p_T^{(FMS)}$;
- $1.5\text{GeV} < p_T^{(EMC)} < p_T^{(FMS)}$;
- $|\alpha_{FMS/EMC}|<0.7$;
- $0.07 < M_{\gamma\gamma}^{(FMS)} < 0.30$ GeV
- $0.07 < M_{\gamma\gamma}^{(EMC)} < 0.20$ GeV
- Only EMC towers used (no SMD)
- only leading particles considered

FMS results: $\pi^0+h^\pm$ & $\pi^0+\pi^0$ comparison

"GSV cut"



2.5GeV < $p_T^{(FMS)}$

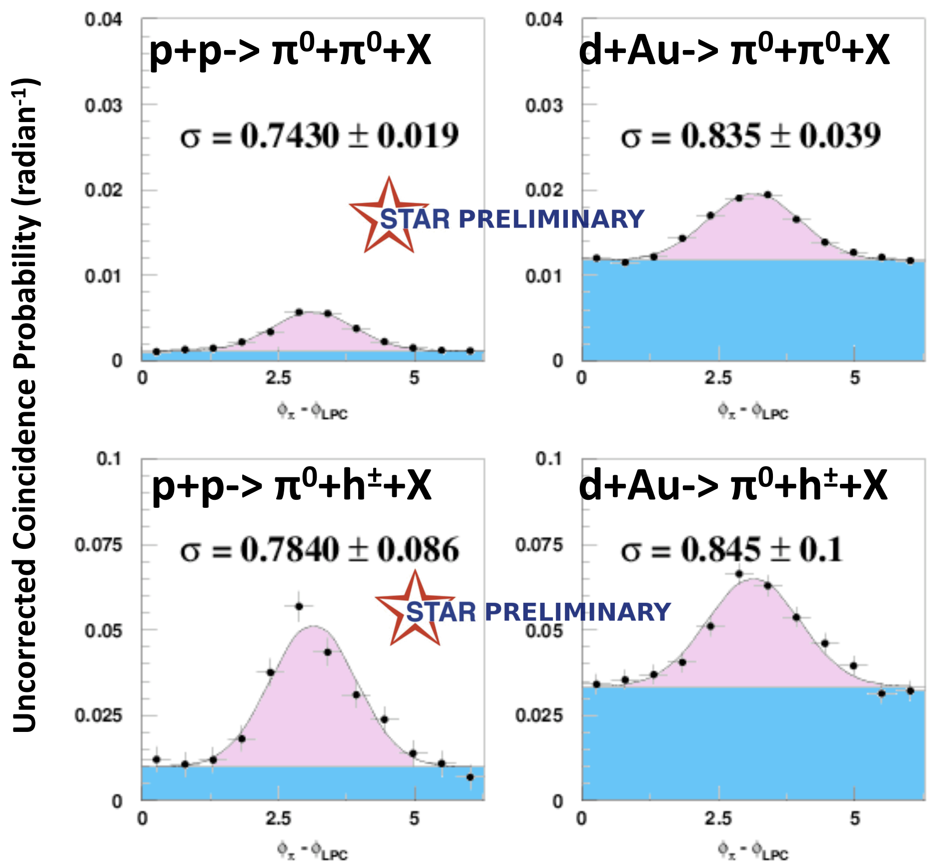
1.5GeV < $p_T^{(EMC)}$ < $p_T^{(FMS)}$

$\sigma_{dAu} - \sigma_{pp} = 0.09 \pm 0.04$

- Correlation in $\pi^0+\pi^0$ shows broadening in signal width from p+p to d+Au
- Correlation in $\pi^0+h^\pm$ shows signal width consistent with $\pi^0+\pi^0$

FMS results: π^0+h$^\pm$ & π^0+π^0 comparison

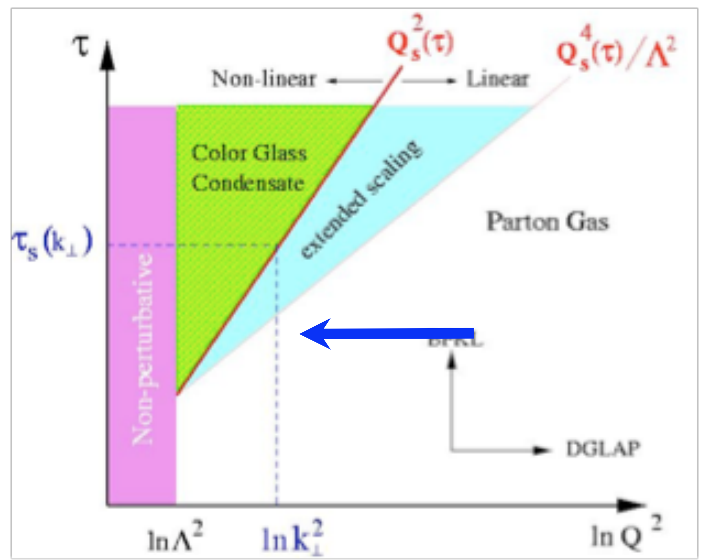
"GSV cut"



$2.5\text{GeV} < p_T^{(FMS)}$

$1.5\text{GeV} < p_T^{(EMC)} < p_T^{(FMS)}$

$$\sigma_{dAu} - \sigma_{pp} = 0.09 \pm 0.04$$



FMS results: $\pi^0+h^\pm$ & $\pi^0+\pi^0$ comparison

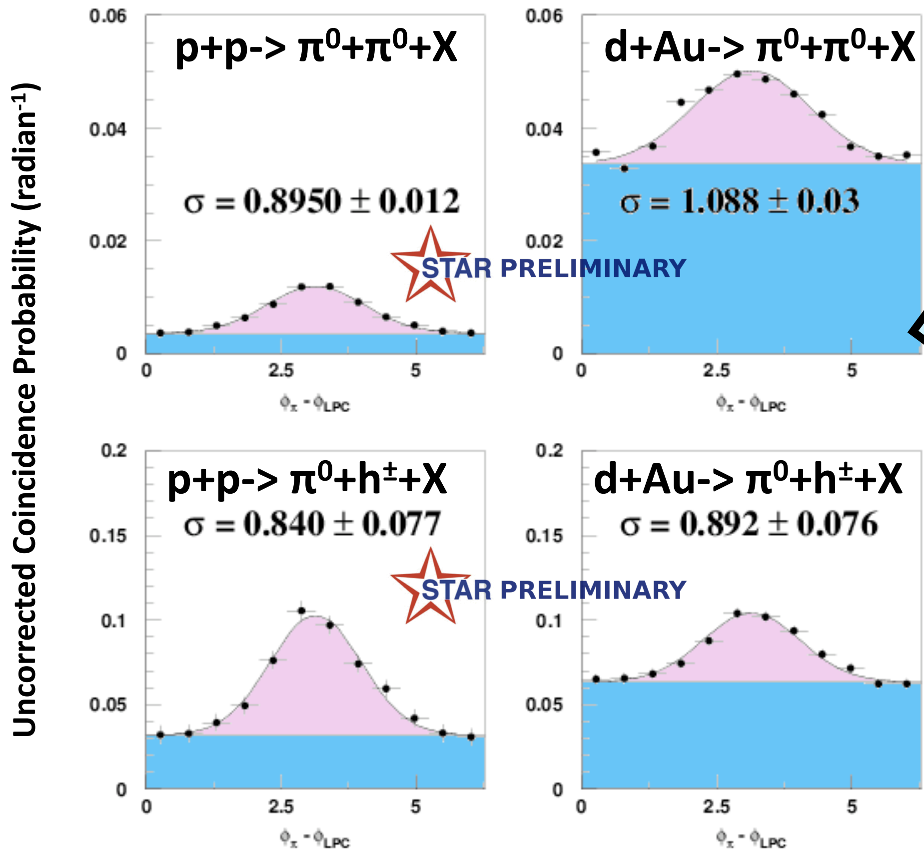
"GSV cut"

$2.5\text{GeV} < p_T^{(FMS)}$

$1.5\text{GeV} < p_T^{(EMC)} < p_T^{(FMS)}$

$\sigma_{dAu} - \sigma_{pp} = 0.09 \pm 0.04$

lower-p_T cut



lower-p_T cut

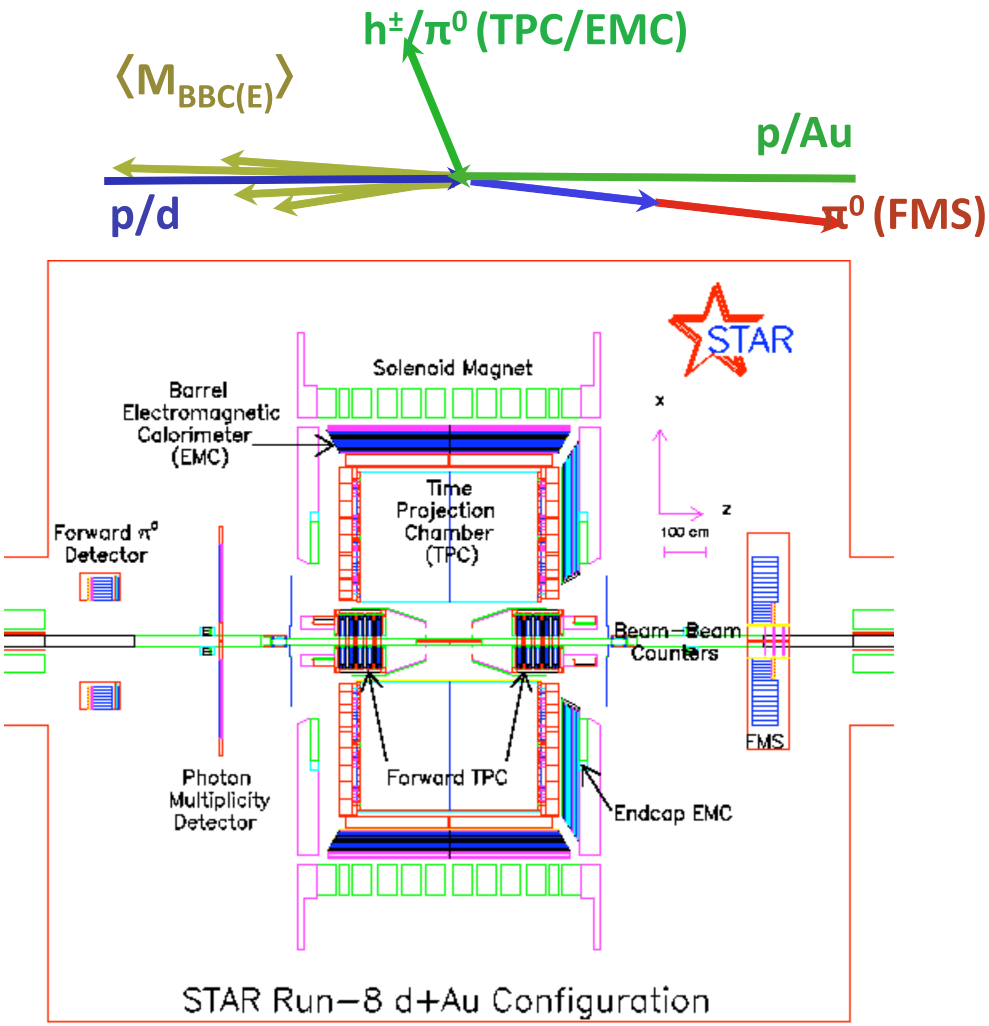
$2.0\text{GeV} < p_T^{(FMS)}$;

$1.0\text{GeV} < p_T^{(EMC)} < p_T^{(FMS)}$)

$\sigma_{dAu} - \sigma_{pp} = 0.19 \pm 0.03$

- p_T dependent azimuthal signal broadening

Gold-side multiplicity dependence



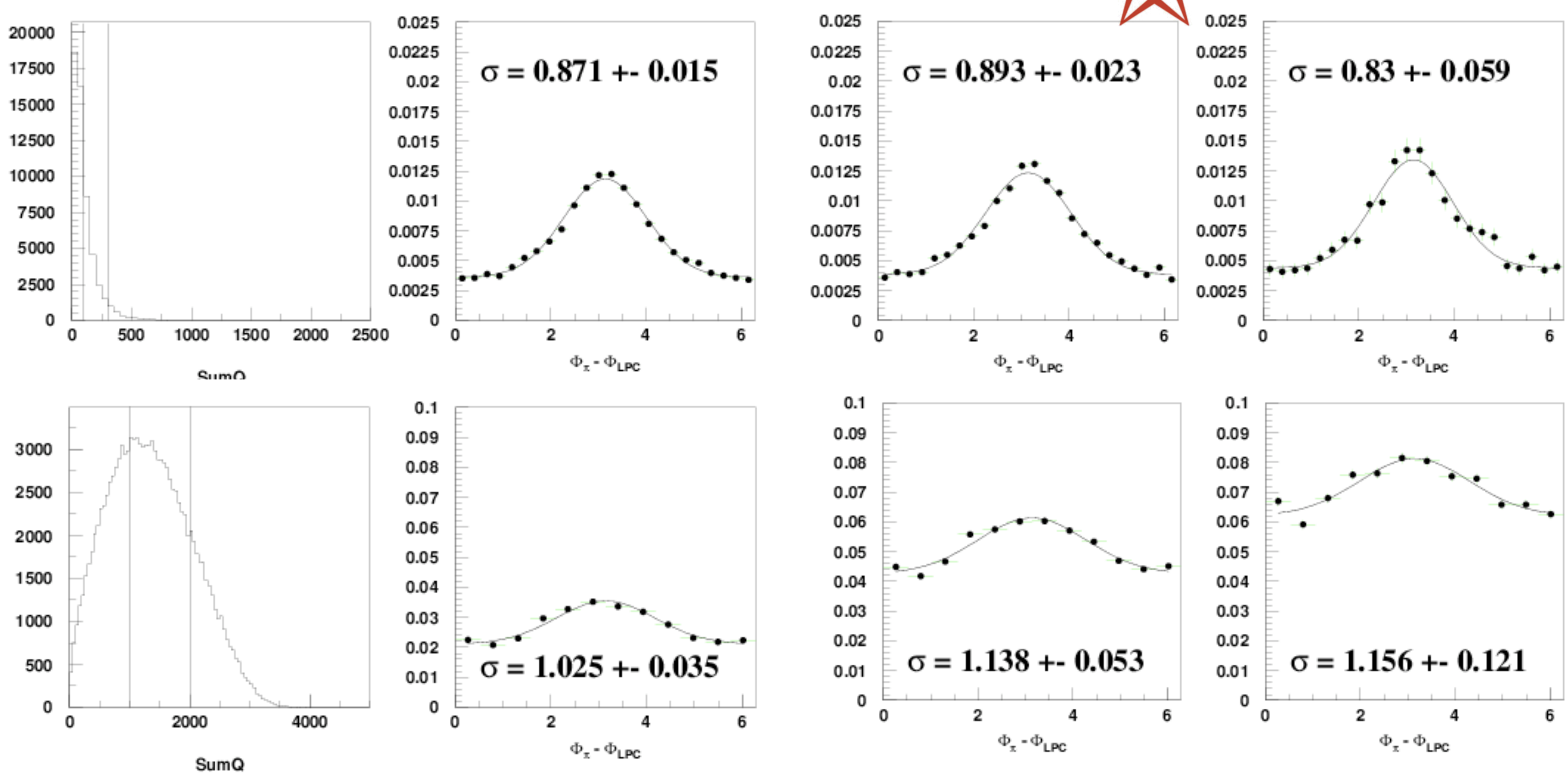
- **Selection: charge sum from east (Au side: $-5.0 < \eta_{BBC} < -3.4$) BBC phototubes (18 counts ~ 1MIP)**

Gold-side multiplicity dependence

- Modification in background level in d+Au $\pi^0+\pi^0$ correlations

low-p_T cut (2.0GeV < $p_T^{(FMS)}$; 1.0GeV < $p_T^{(EMC)}$ < $p_T^{(FMS)}$)

STAR PRELIMINARY



- **Modification in d+Au $\pi^0+\pi^0$ (FMS-EMC) correlations**

Is saturation really the explanation?

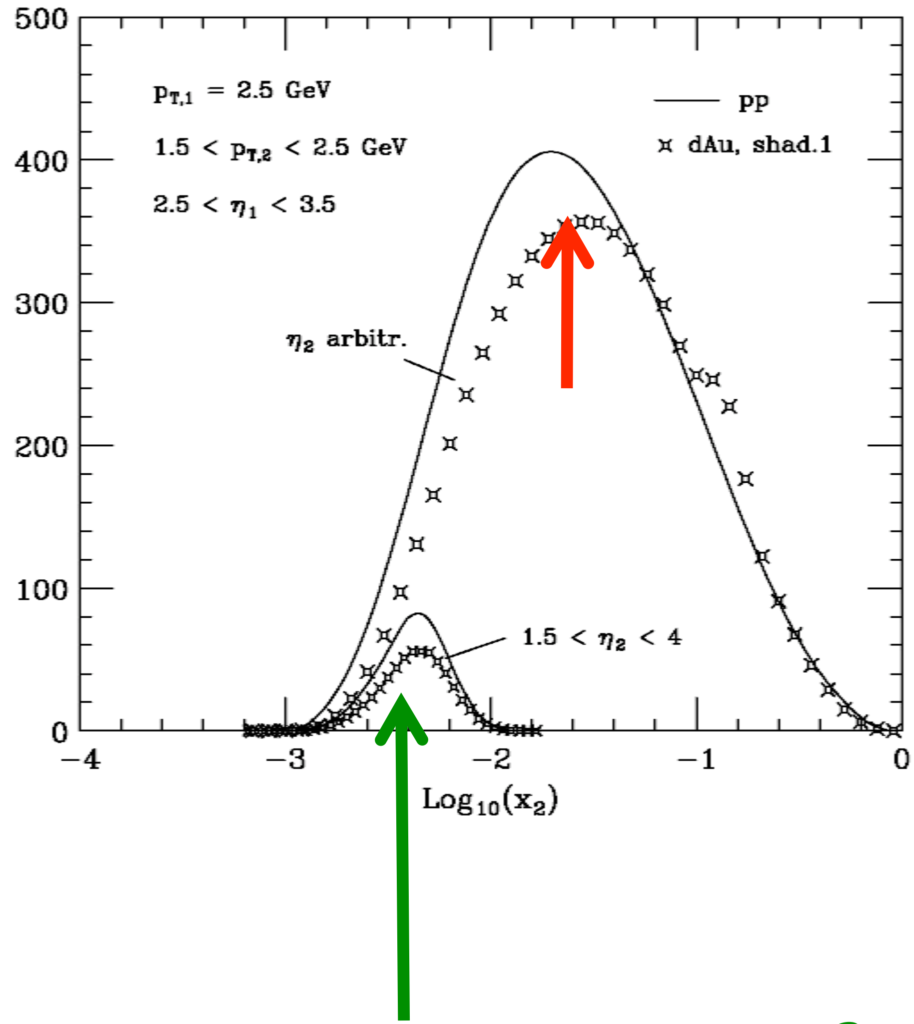
NLO pQCD calculations

$<x_g> \sim 0.02$ is not that small

(Guzey, Strikman, Vogelsang, PL B603, 173)

In contrast, $<x_g> <\sim 0.001$ in CGC calculations

(Dumitru, Hayashigaki, Jalilian-Marian, NP A765, 464)



Basic difference:

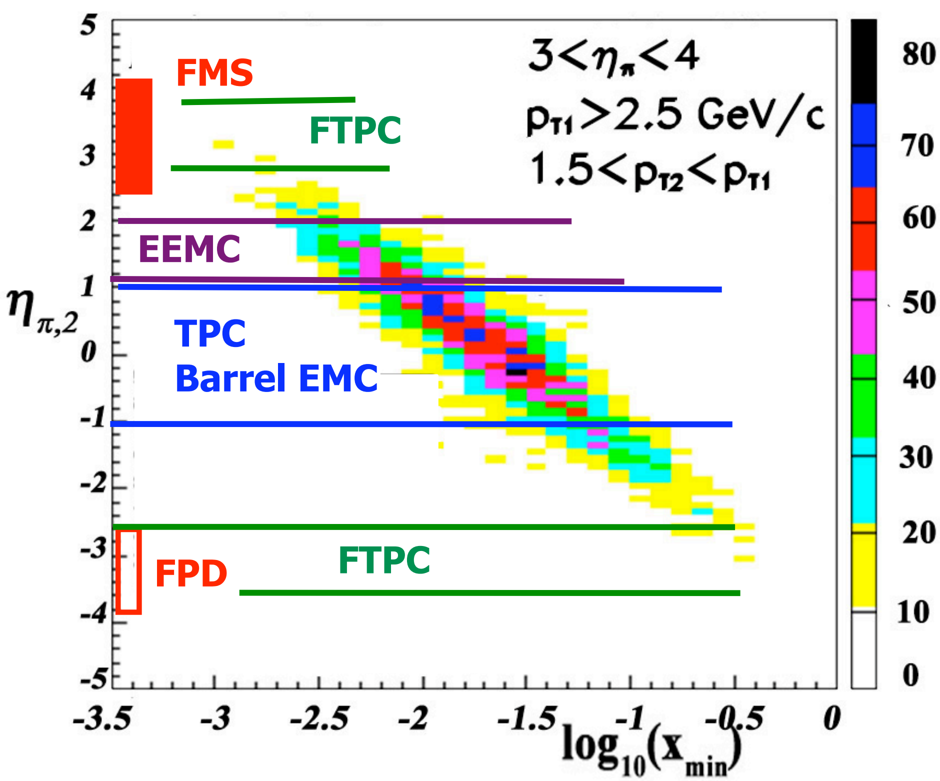
pQCD: 2 → 2

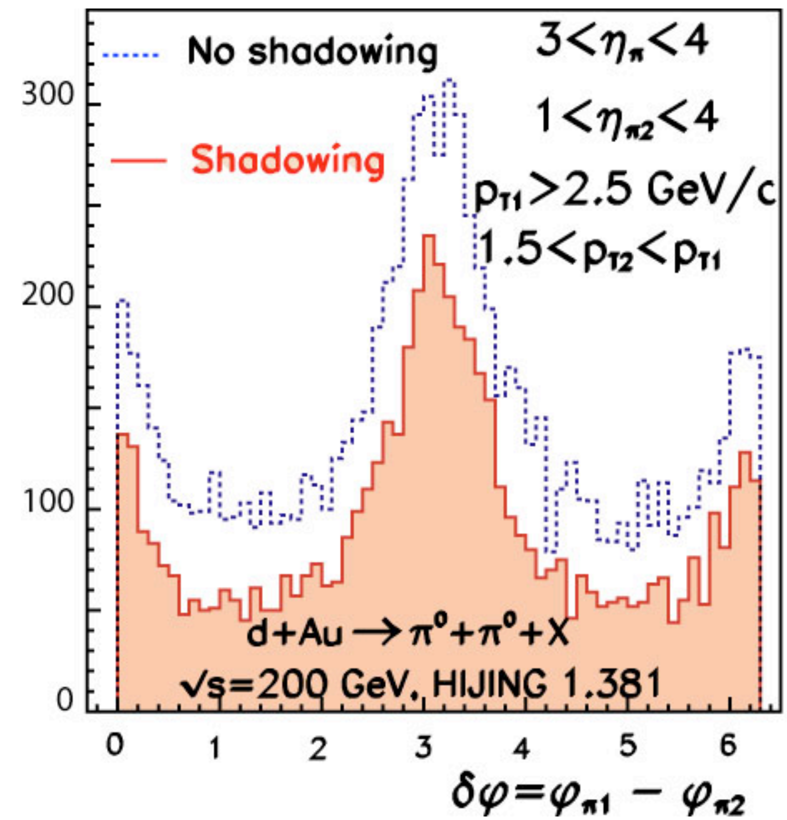
CGC: 2 → 1

Forward-forward di-hadron correlation : $<x_g>\sim10^{-3}$

with CGC : $<x_g>\sim10^{-4}$

$\pi^0+\pi^0$(or h) correlations with forward π^0





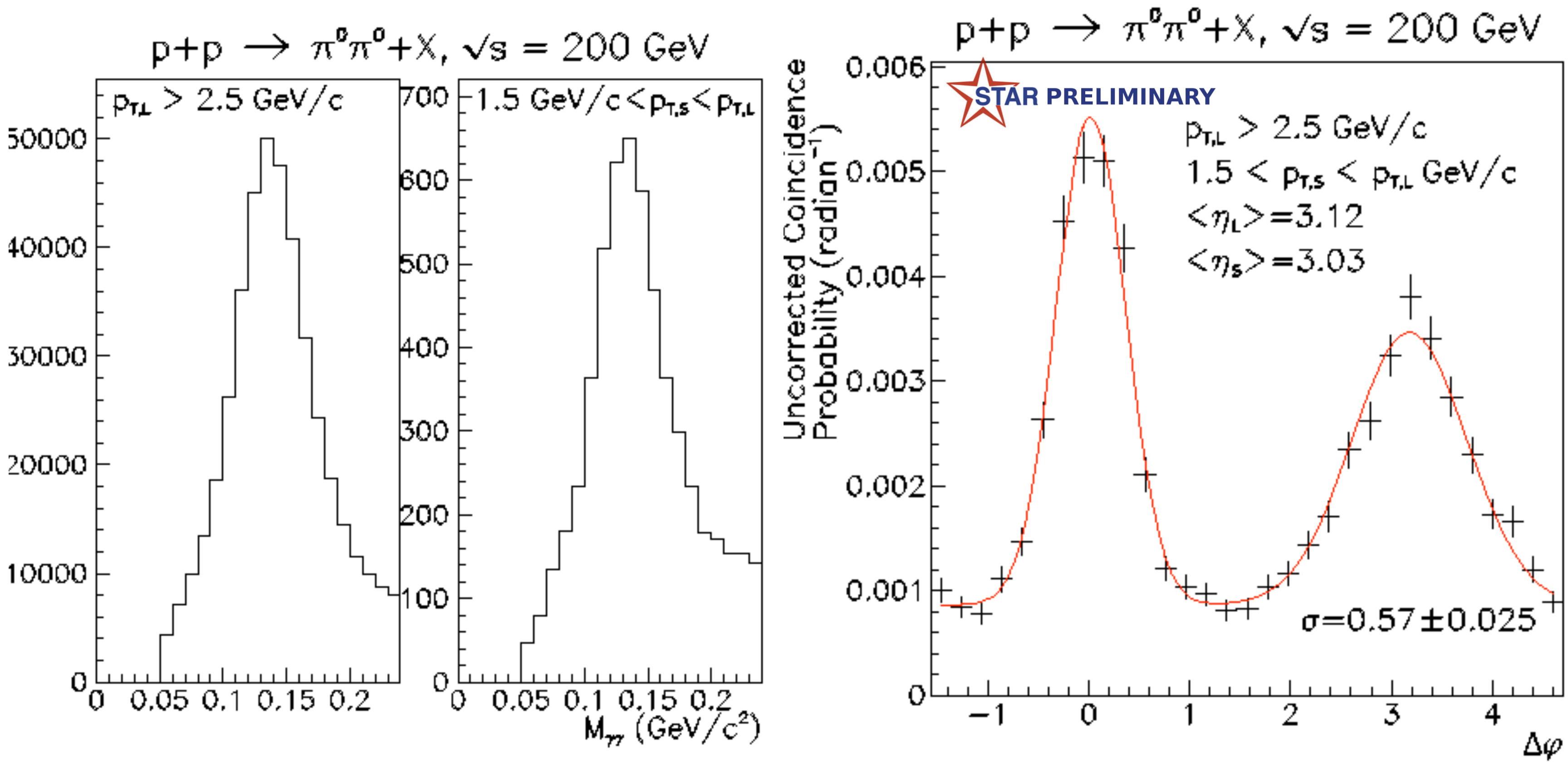
η^{asso} scan gives handle on x_{gluon}

Forward-forward di-hadron correlation to reach lowest x

Conventional shadowing changes yield, but not angular correlation

CGC expects changes in yield and the angular correlation

Forward pi0 (FMS) – Forward pi0(FMS) Azimuthal Correlations



- **Possible spin measurements**
- **Low-x / gluon saturation study – accessing lowest x_{Bj}^{gluon}**

H^{trig} = 3.0
H^{asso} = 3.0

Summary

- Forward rapidity at RHIC access to low-x physics
- pp mid-rapidity, pp forward and dAu mid-rapidity under control

- Run3 dAu
  - Hadron production
    - No suppression at backward
    - Suppression in forward hadron production
  - Di-hadron back-to-back correlation
    - No suppression at $\eta<2.2$
    - Suppression at $\eta=4$ & low x_F/p_T

- Run8 dAu
  - ~x30 more integrated luminosity
  - STAR FMS (~ x50 acceptance) commissioned and took data
  - FMS reproduces Run-3 FPD gaussian widths
  - Comparison of $\Delta\Phi_{\pi0(FMS)+\pi0(EMC)}$ for pp and dAu indicates azimuthal broadening in dAu

Data are qualitatively consistent with a p_T dependent picture of gluon saturation of the gold nucleus.

Outlook

- d+Au for forward π^0- forward π^0
- Scanning the p_T (from GSV down to run-3)
- Normalization and systematic studies

- Yield with scanning $\Delta\ \eta$

  x dependence of nuclear parton density
- Clustering: towards π^0+jet or jet+jet