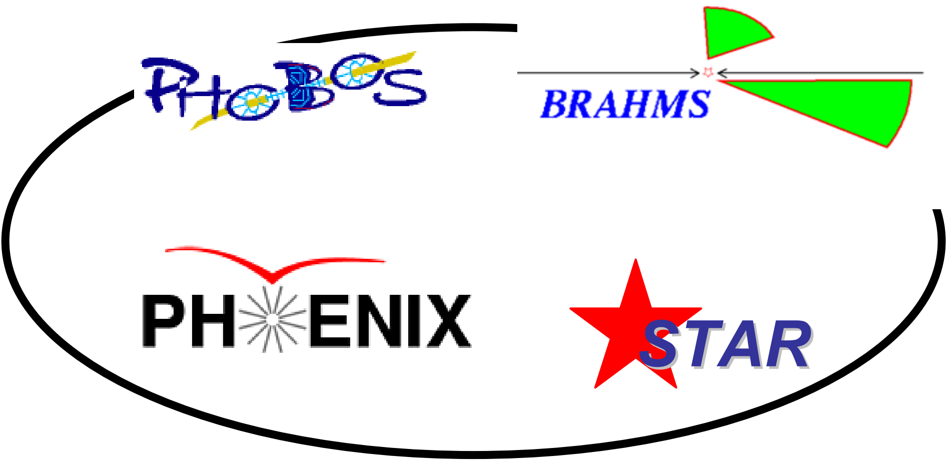
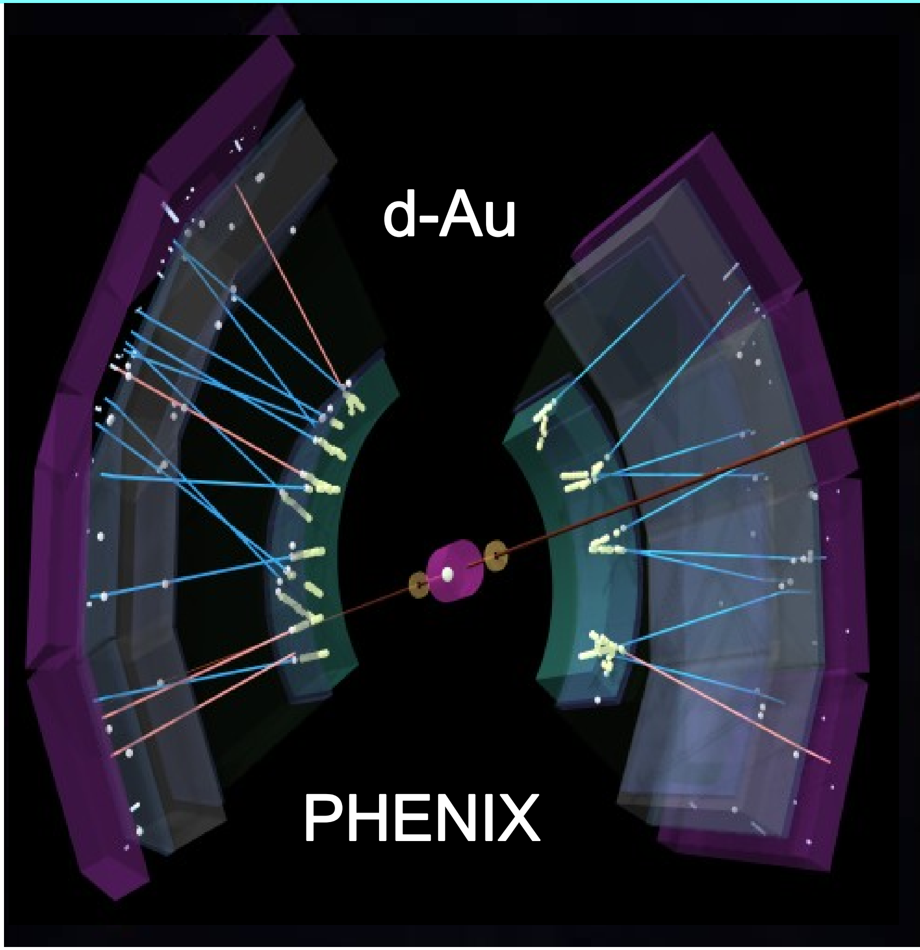
Nuclear Effects in d-Au Collisions with PHENIX at RHIC

M. Grosse Perdekamp -- UIUC





Electromagnetic Interactions with Nucleons and Nuclei

8th European Research Conference,

Milos September 27th – October 2nd 2009

------------ Outline ------------

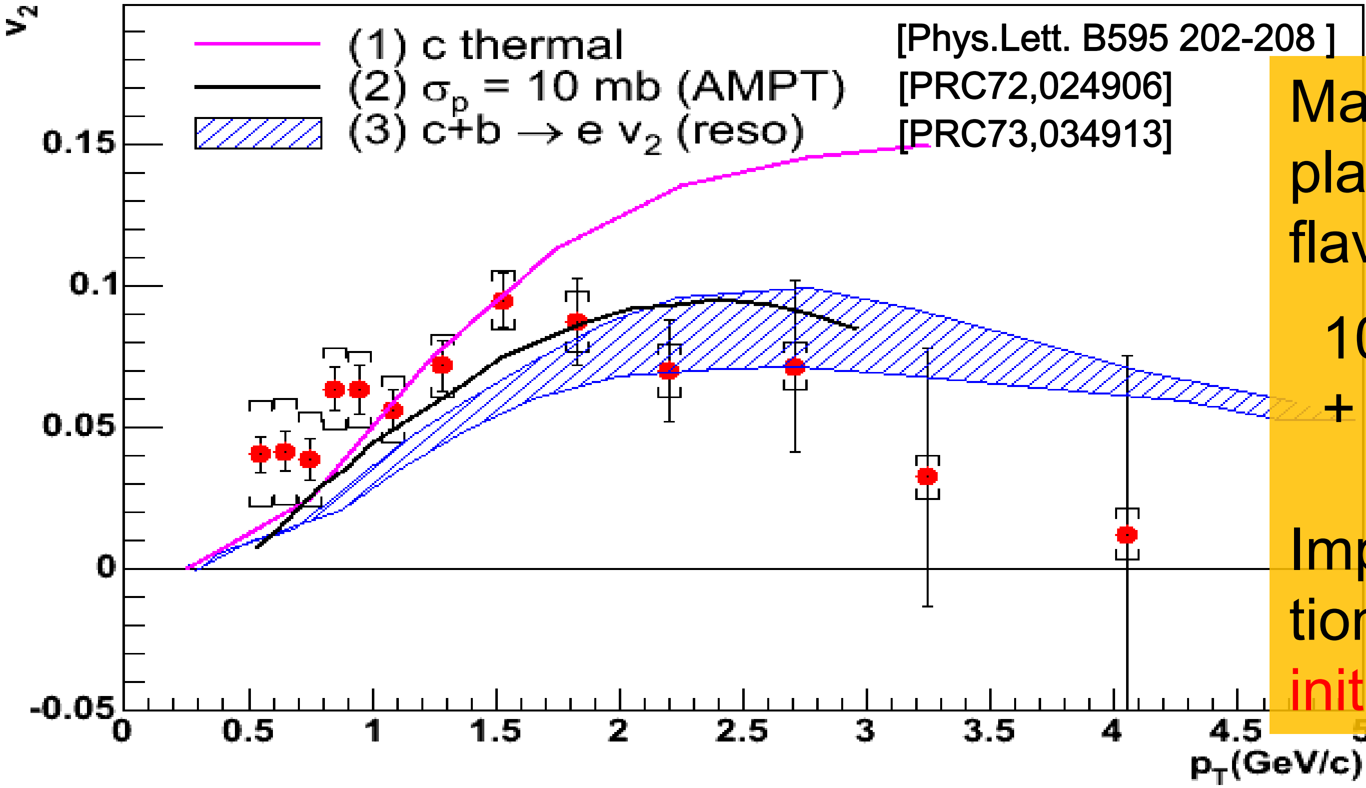
- Nuclear effects in nucleon structure: can we determine the initial state in heavy ion collisions at RHIC ?
- Cross sections at forward rapidity:

  Experimental observables and results.
- Di-hadron correlations (separated in rapidity):

  Idea + forward detector upgrades

  First results
- Outlook: Analysis plan for the 2008 d-Au data sample.

Elliptic Flow v_2 for Charm: Indicates Quark Level Thermalization & Strong Coupling



Major upgrades planned for heavy flavor channels:

10 x RHIC Lumi.
+ vertex detectors

Improve hydro calculations + knowledge of initial state!

Connection between experimental observable and theory through hydrodynamic models:

Initial state often from Color Glass Condensate or event generators !

Nucleon Structure in Nuclei Using d-Au Collisions at RHIC

- Motivation:

  Characterize initial state in heavy ion collisions.

  Probe gluon distributions at low x and high parton densities (in nuclei).

- How exactly $G(x)$ saturates at low x and high parton densities is subject of active theoretical studies (see previous talk!)

- Signatures of saturation include suppressions of cross sections in d-Au collisisions compared to pp at forward rapidity:

  $R_{dA}(p_T)$, $R_{cp}(p_T)$, and suppression of di-hadron yields $I_{dA}(p_T)$

Suppression of Cross Sections
in Forward Direction:

Sufficient Evidence for Saturation Effects in the Gluon Field in the Initial State of d-Au Collinsion at RHIC?

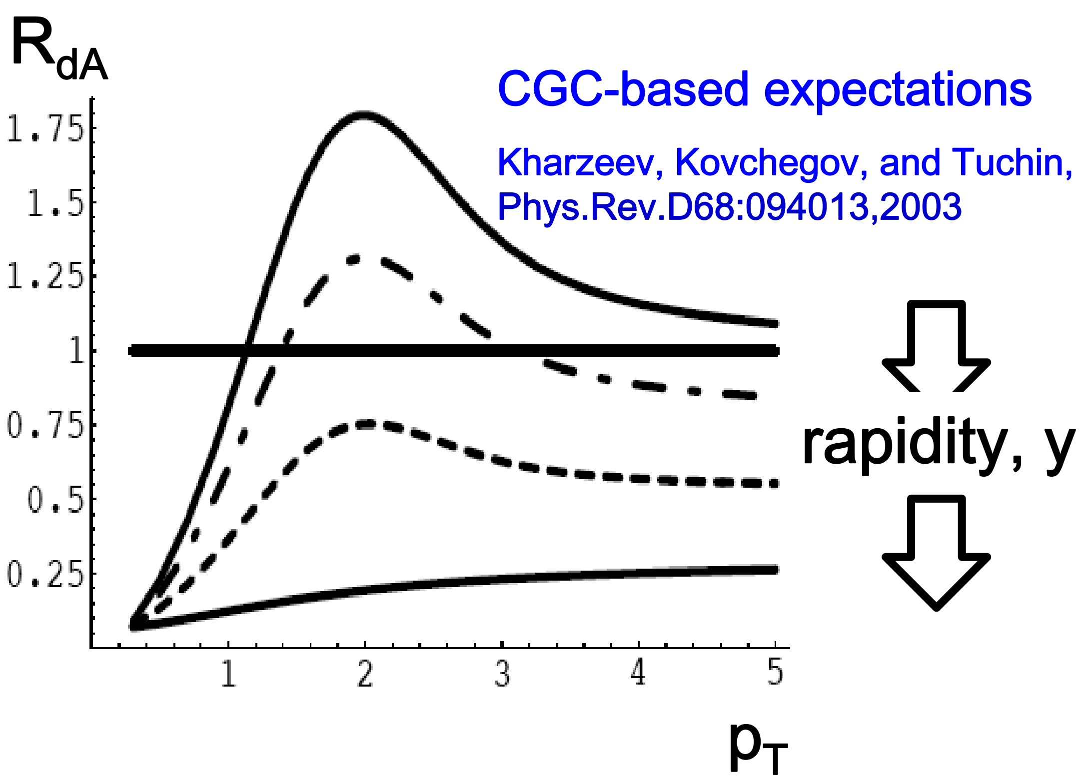
Quantify Nuclear Modification of Hadron Spectra in d-Au Collisions

Nuclear Modification Factor:

$$R_{dA}(p_T) = \frac{d^2N^{dA} / dp_T d\eta}{T_{dA} d^2\sigma^{pp} / dp_T d\eta}$$

nucleon-nucleon cross section

$\langle N_{binary}\rangle / \sigma_{inel}^{p+p}$

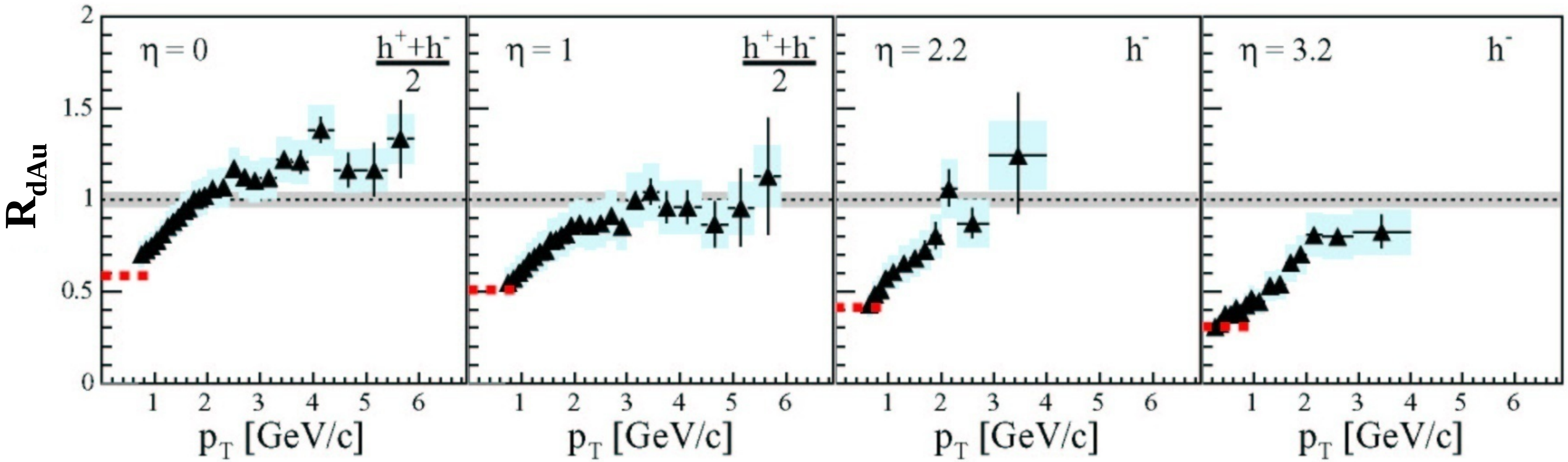


CGC-based expectations

Kharzeev, Kovchegov, and Tuchin, Phys.Rev.D68:094013,2003

BRAHMS d+Au Cross Sections Decrease with Increasing Rapidity and Centrality

BRAHMS, PRL 93, 242303

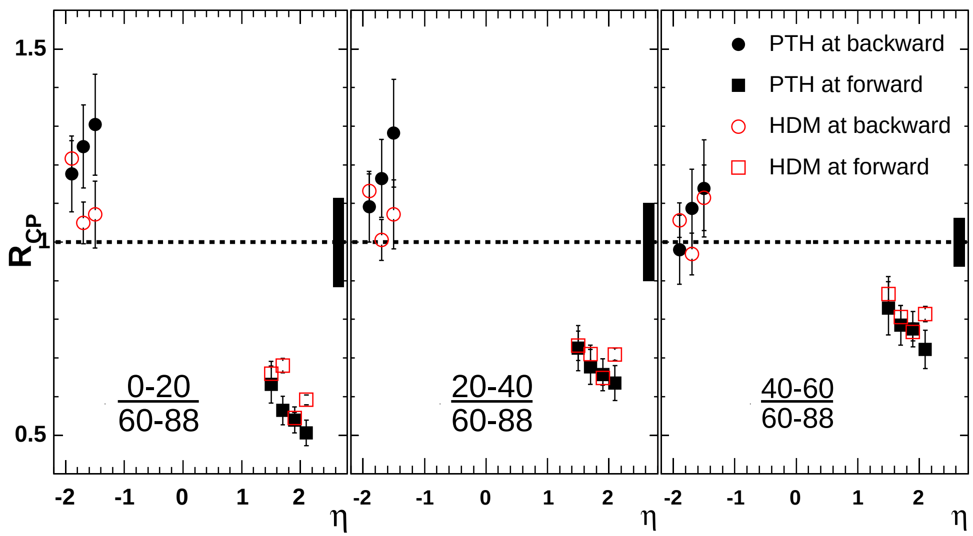


Hadron production is suppressed at large rapidity consistent with saturation effects at low x in the Au gluon densities → CGC

Similar Results from STAR, PHENIX and PHOBOS

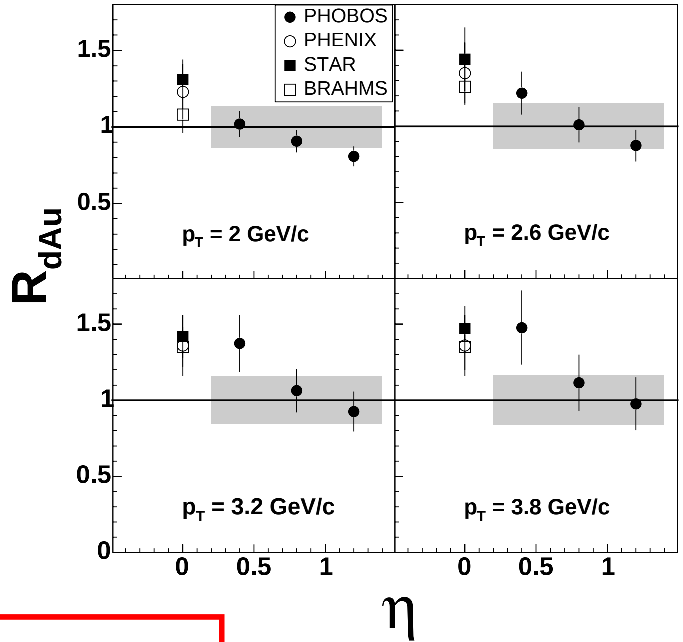
PRL 94, 082302

PHENIX



PRC 70, 061901(R)

PHOBOS



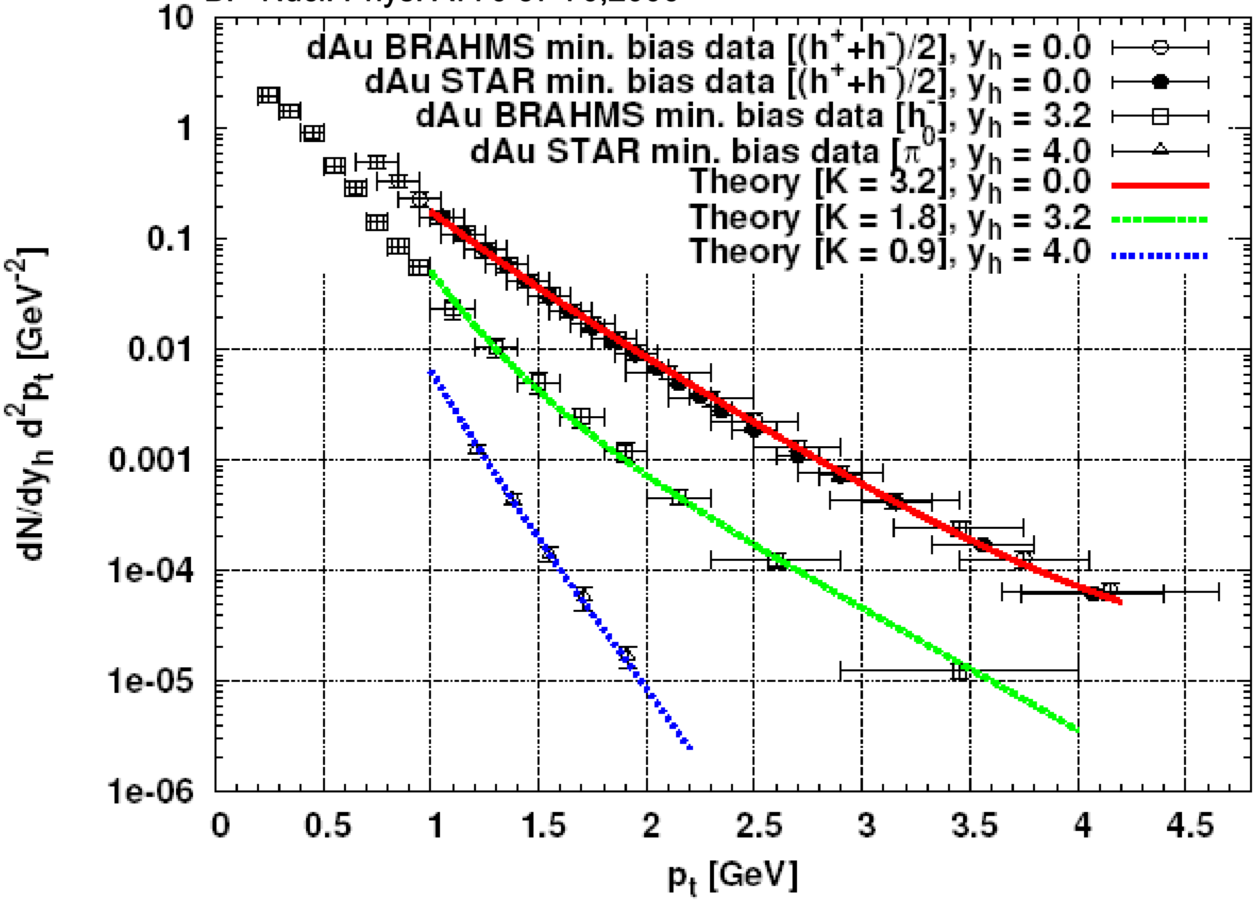
Suppression in the d direction and enhancement in the Au fragmentation region

D → x_1 → ← Au → x_2

$x_1 \gg x_2$ for forward particle, $x_g = x_2 \to 0$

Theory vs Data ➔ CGC Inspired

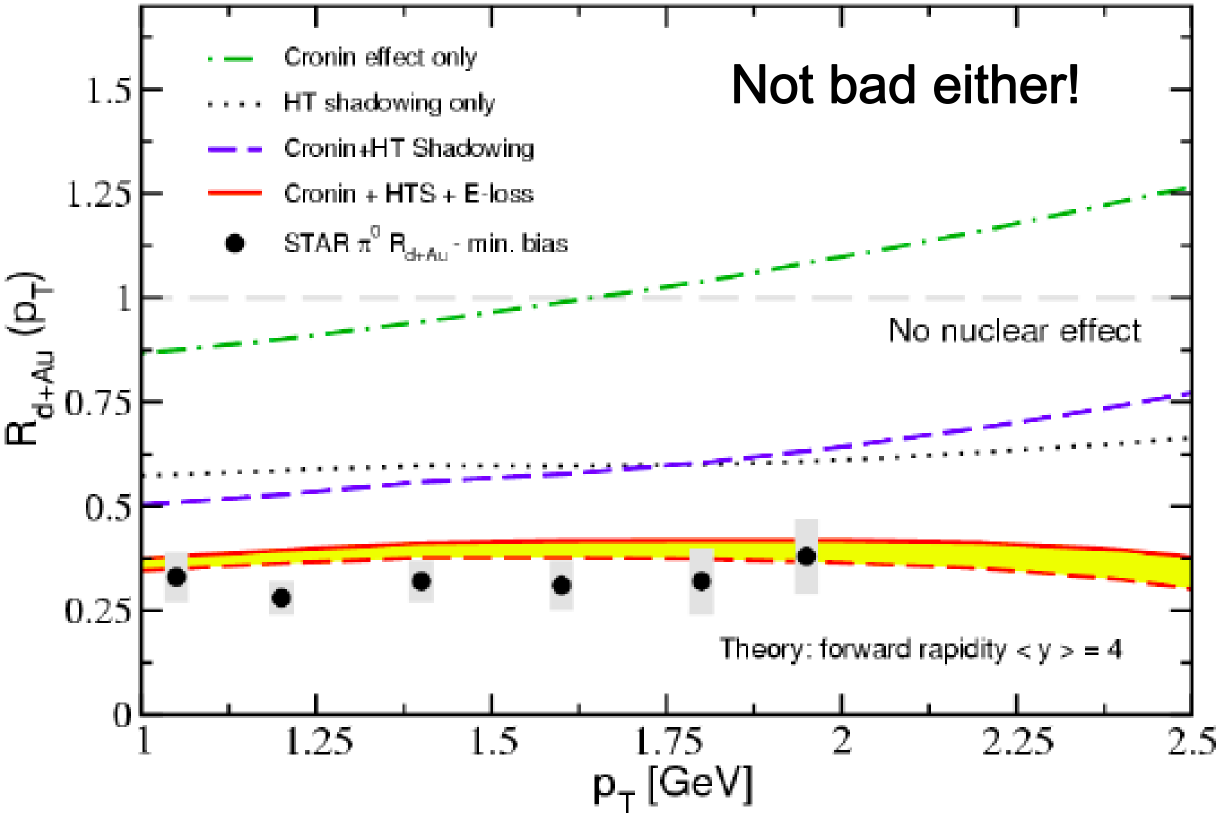
A. Dumitriu, A. Hayashigaki, J. Jalilian-Marian
B. Nucl. Phys. A770 57-70,2006



Not bad! However, large K factors, rapidity dependent.

Theory vs Data ➔ Cronin + Shadowing + E-loss

I.Vitev, T. Goldman, M.B. Johnson, J W. Qiu, Phys. Rev. D74 (2006) and I. Vitev , in preparation.



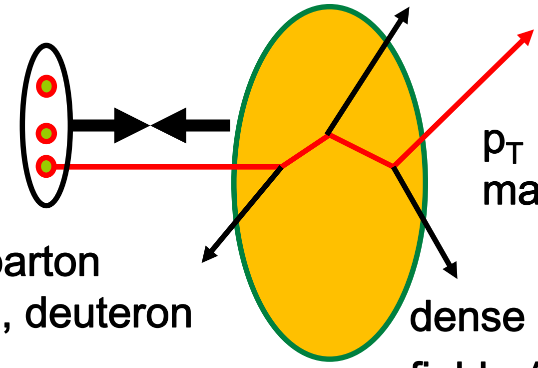
➔ R_{dA} results alone do not demonstrate gluon saturation. More data & different observables will be needed !

Rapidity Separated di-Hadron Correlations:

Idea + Forward Upgrades

First Results

Rapidity-Separated Hadron Correlations in d+Au



Idea:

Presence of dense gluon field in the Au nucleus leads to multiple scatterings and parton can distribute its energy to many scattering centers ➔ "Mono-jet signature". D. Kharzeev, E. Levin, L. McLerran, Nucl.Phys.A748:627-640,2005

Experimental signature:

Observe azimuthal correlation between hadrons in opposing hemisphere separated in rapidity

➔ widening of correlation width of d-Au compared to pp?

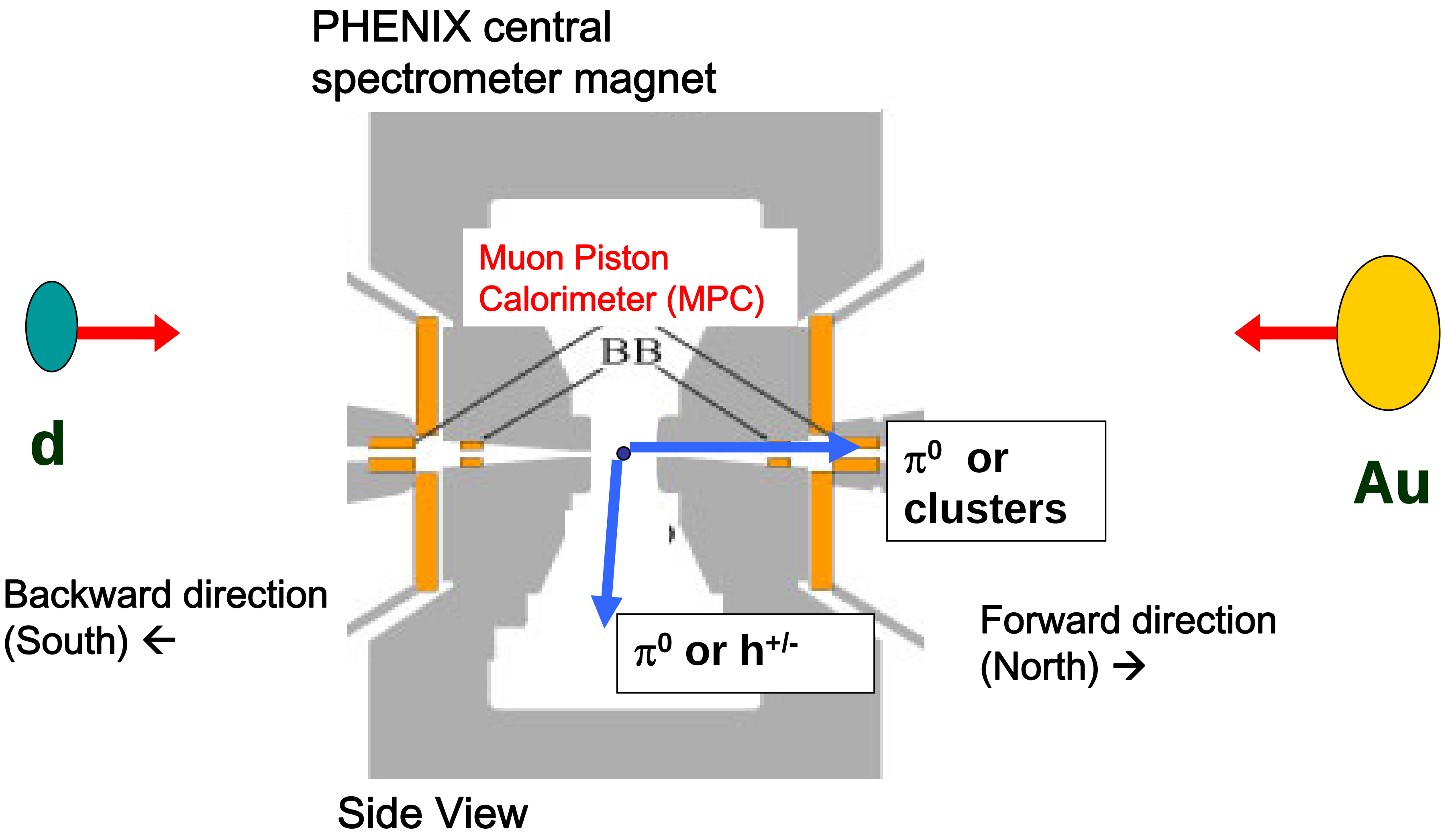
➔ reduction in associated yield of hadrons on the away site

➔ Upgrades

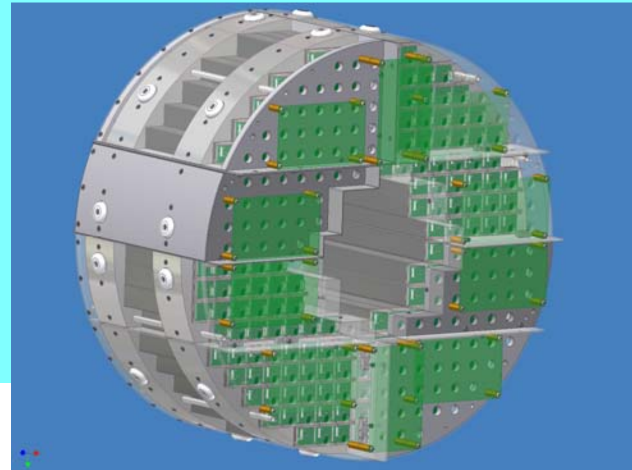
Electromagnetic forward calorimeters added to STAR (FMS) and PHENIX (MPC) for 2008 d-Au run.

+ large acceptance forward calori-meter upgrade (FOCAL) planned in PHENIX.

New PHENIX Forward Calorimeters (MPC) for the Measurement of di-Hadron Correlations



PHENIX Muon Piston Calorimeter



Technology → ALICE(PHOS)

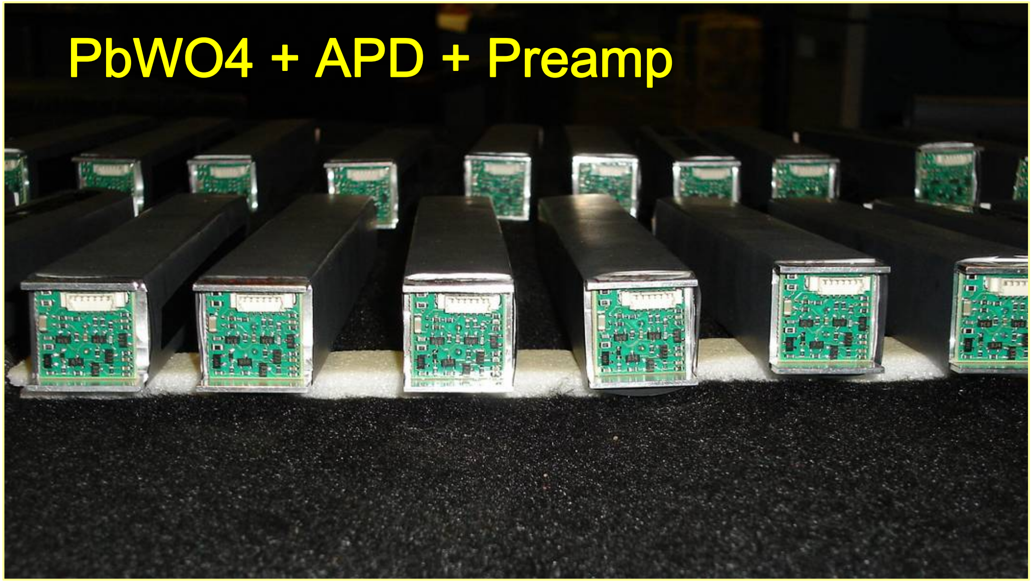
- $PbWO_4$
- avalanche photo diode readout

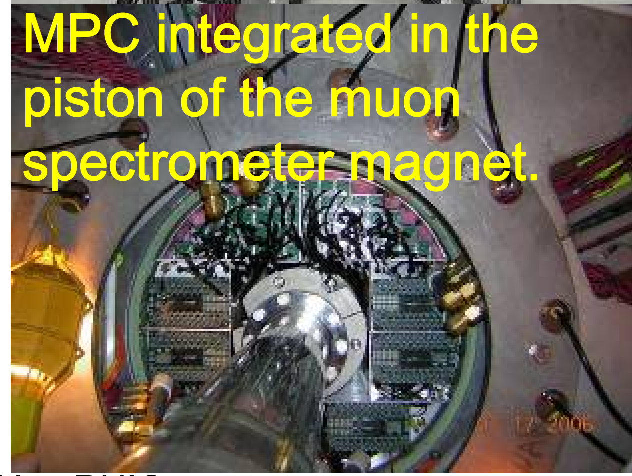
Acceptance:

$$3.1 < \eta < 3.9, \quad 0 < \varphi < 2\pi$$
$$-3.7 < \eta < -3.1, \quad 0 < \varphi < 2\pi$$

d-Au data sampled:

Both detector were fully installed in PHENIX and commissioned for the d-Au run 2008 at RHIC.





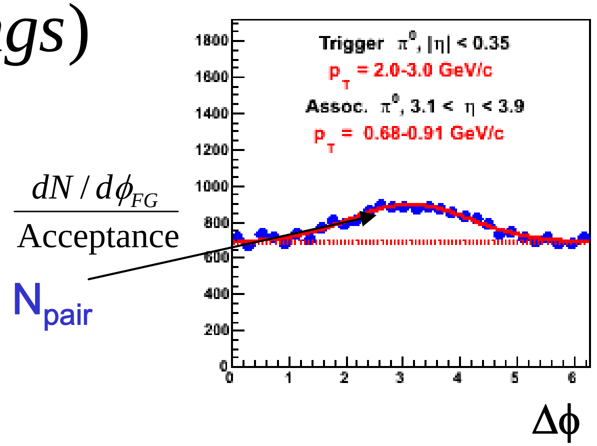
The Correlation Measurements

- $\sqrt{s_{NN}} = 200$ GeV d-Au, pp collisions from 2008 at RHIC (30 x run 2003 !)
- Trigger particles are (π^0, $h^{+/-}$) with $|\eta| < 0.35$
- Associate particles are π^0, clusters with $3.1 < \eta < 3.9$
- One possible method to quantify the correlation:

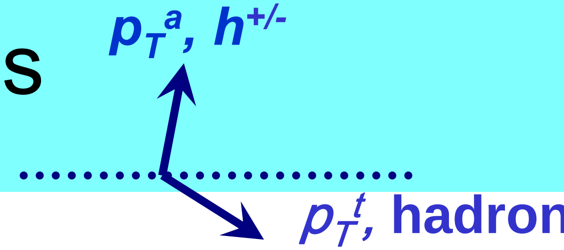
$$N_{pair} = \frac{dN / d\varphi_{FG}}{\text{Acceptance}} - Background(wings)$$

$$CY = \frac{N_{pair}}{N_{trig}\,\varepsilon_{assoc}} \qquad I_{dA} = \frac{CY_{dA}}{CY_{pp}}$$

Peripheral d-Au
Correlation Function



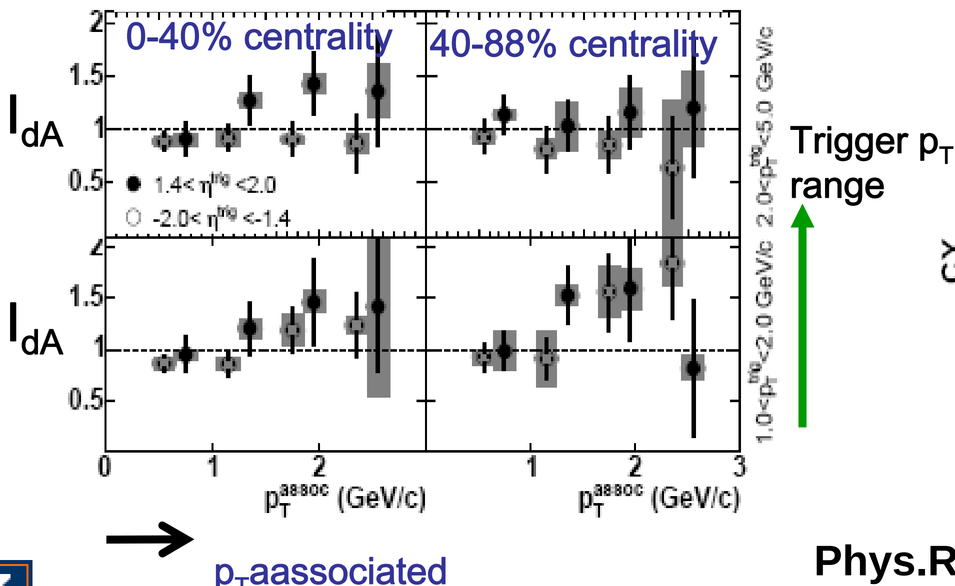
I_{dAu} from the PHENIX Muon Arms

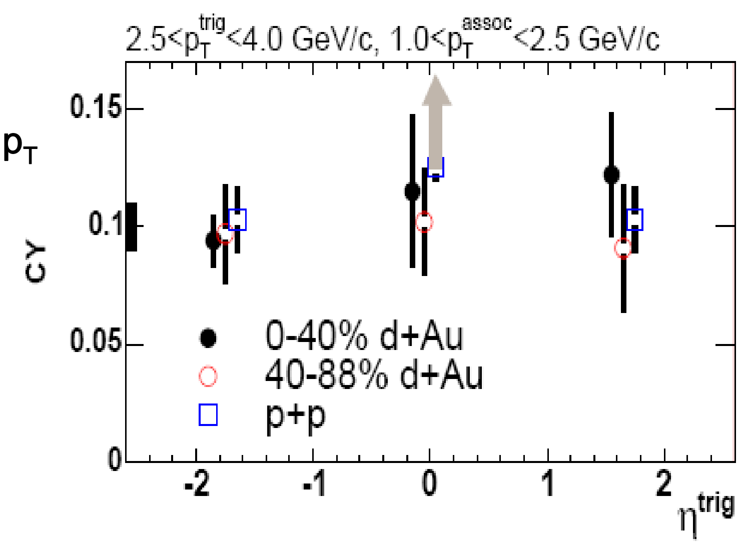


Observations at PHENIX using the 2003 d-Au sample:

- Left: I_{dA} for hadrons $1.4 < |\eta| < 2.0$, PHENIX muon arms.
  correlated with $h^{+/-}$ in $|\eta| < 0.35$, *central arms.*
- Right: Comparison of conditional yields with different trigger particle pseudo-rapidities and different collision centralities

➔ No significant suppression or widening seen!



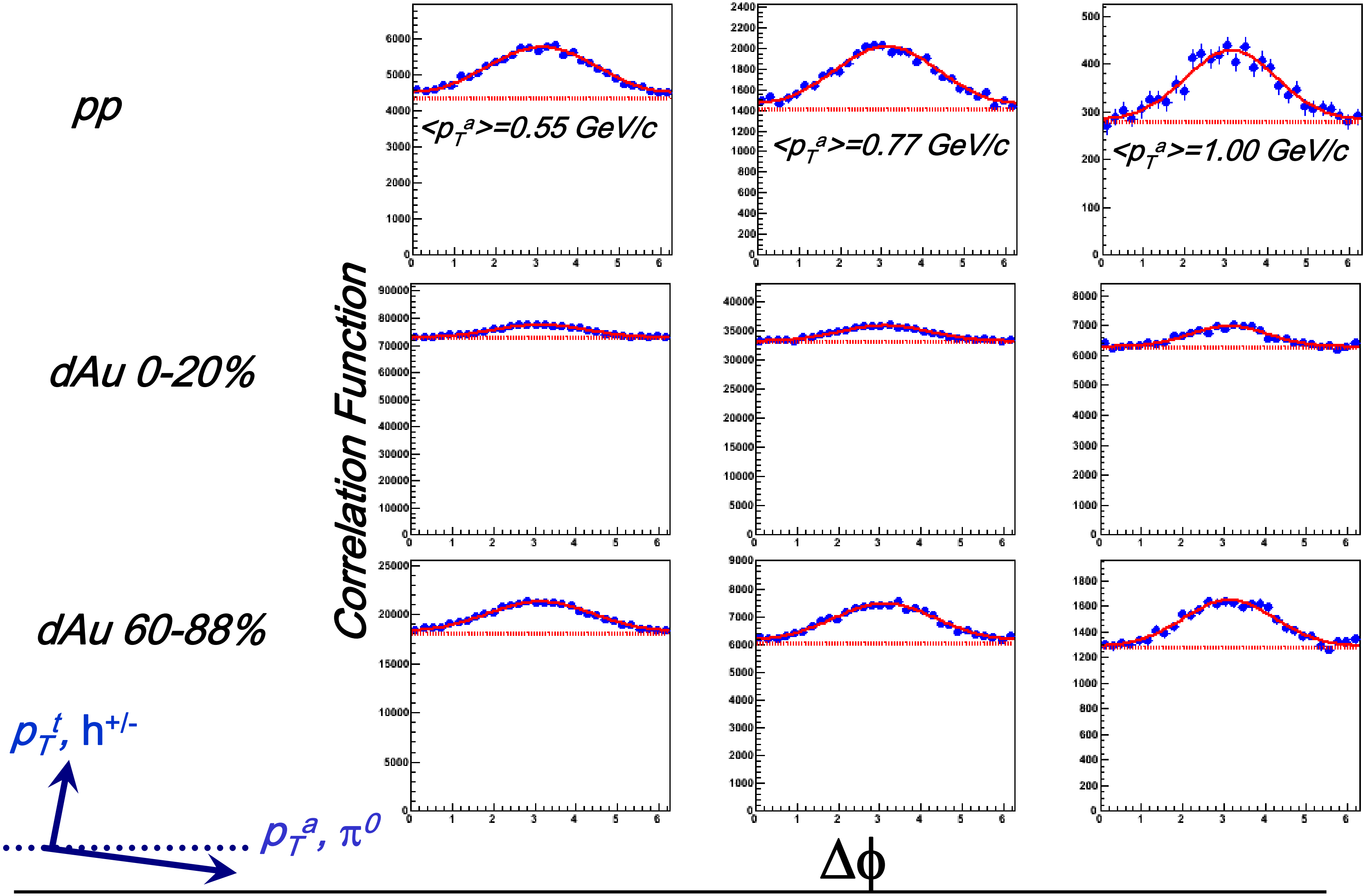


Phys.Rev.Lett. 96 (2006) 222301

Correlation Functions from Run 9
Central arm trigger vs MPC

$h^{+/-}$ (trigger,central)/π^0 (associate,forward)

1.0 < p_T^t < 2.0 GeV/c for all plots



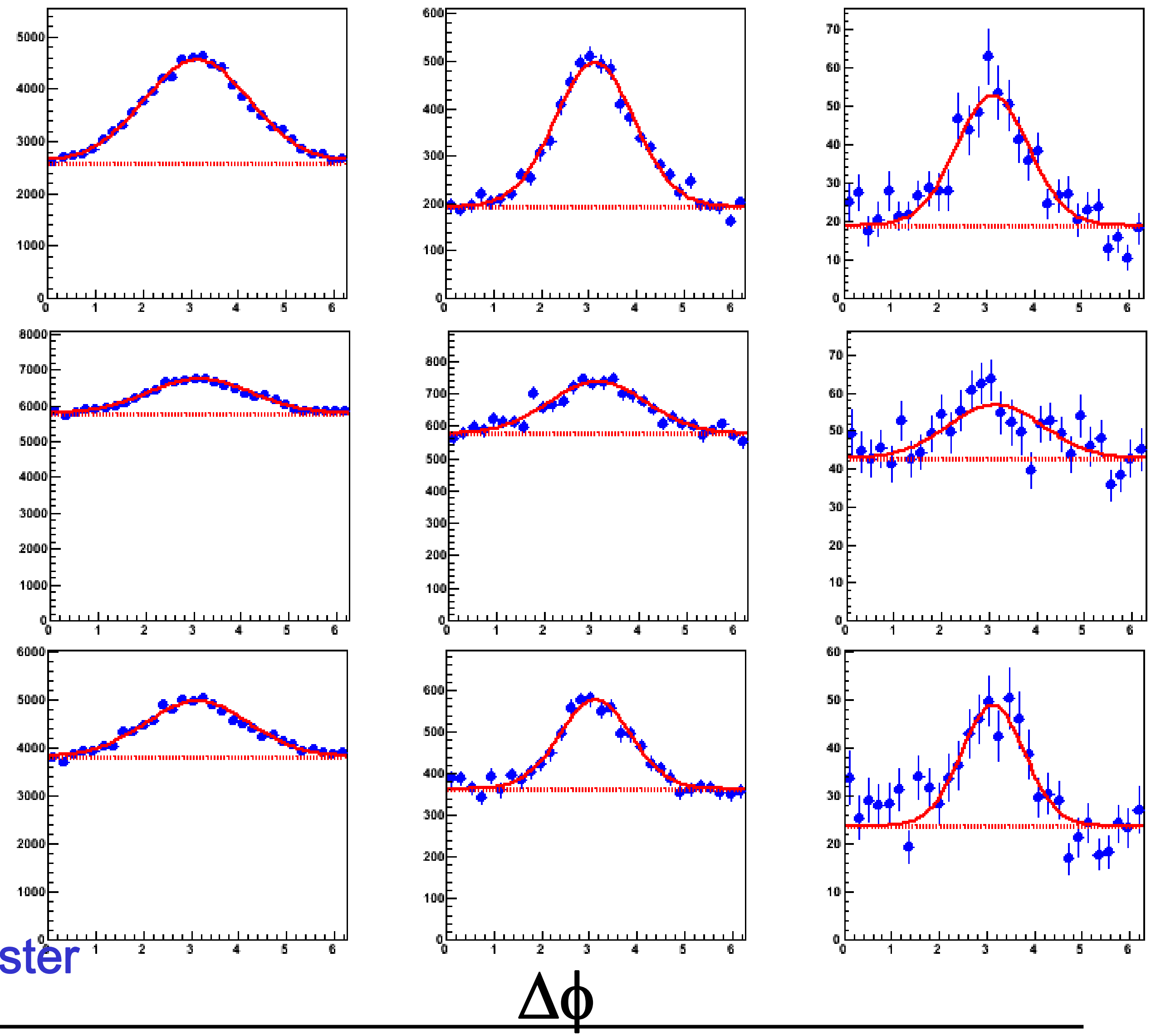
π^0 (trigger,central)/cluster (associate,forward)

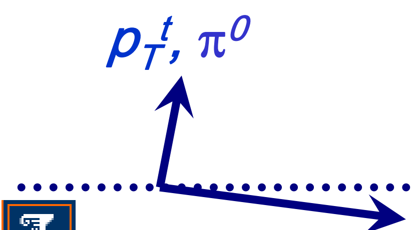
3.0 < p_T^t < 5.0 GeV/c for all plots

pp

dAu 0-20%

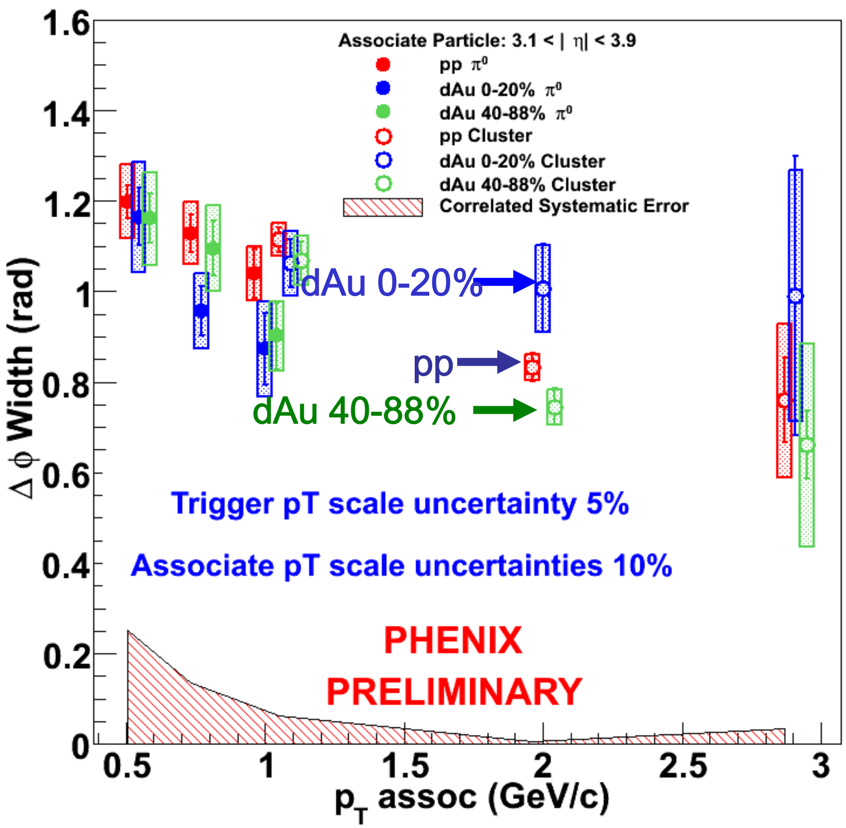
dAu 60-88%



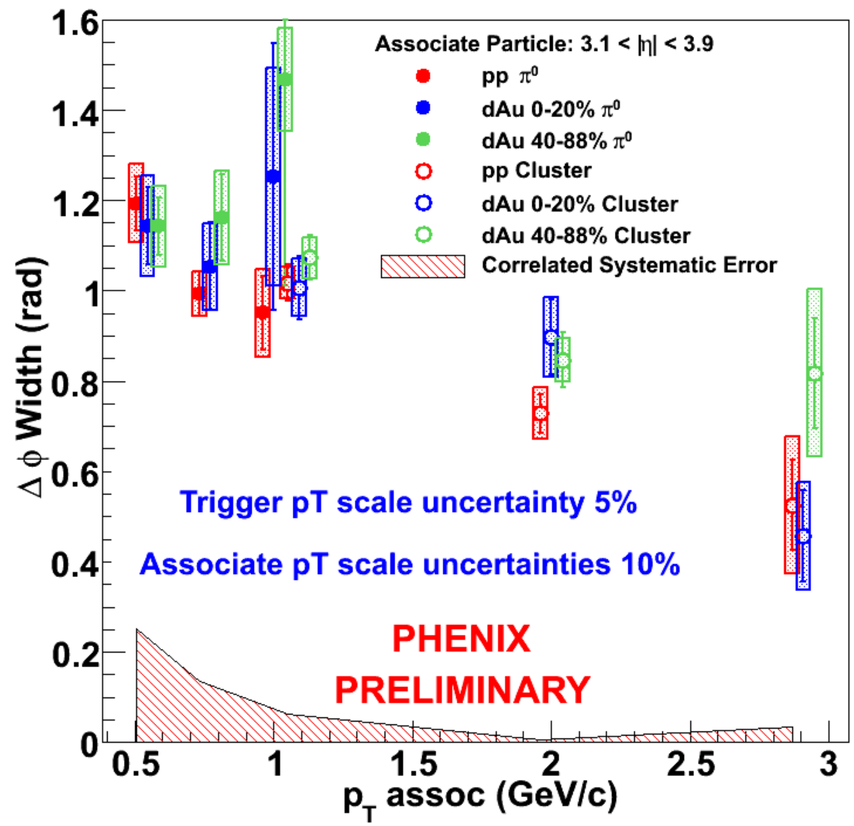


Forward/Central Correlation Widths

Trigger π^0: $|\eta| < 0.35$, $2.0 < p_T < 3.0$ GeV/c



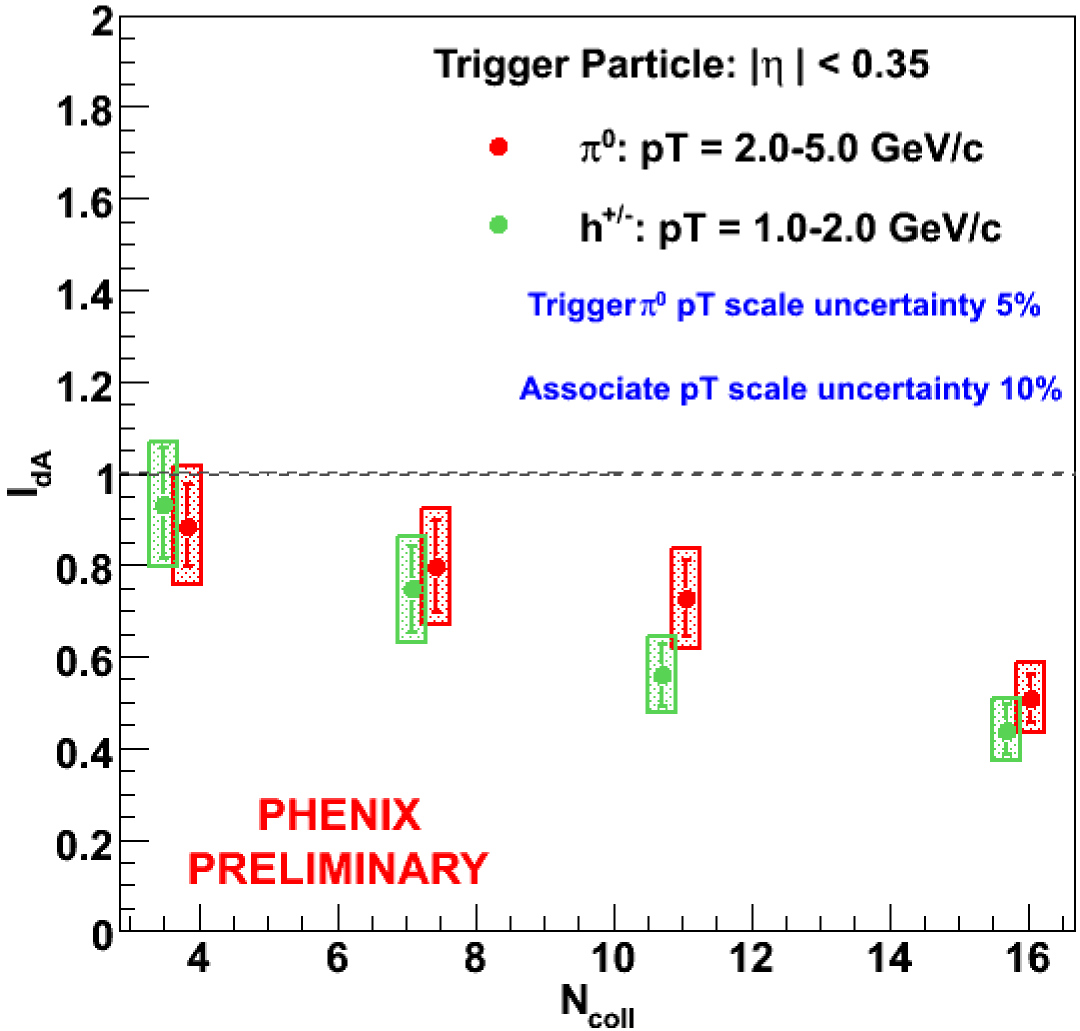
Trigger π^0: $|\eta| < 0.35$, $3.0 < p_T < 5.0$ GeV/c



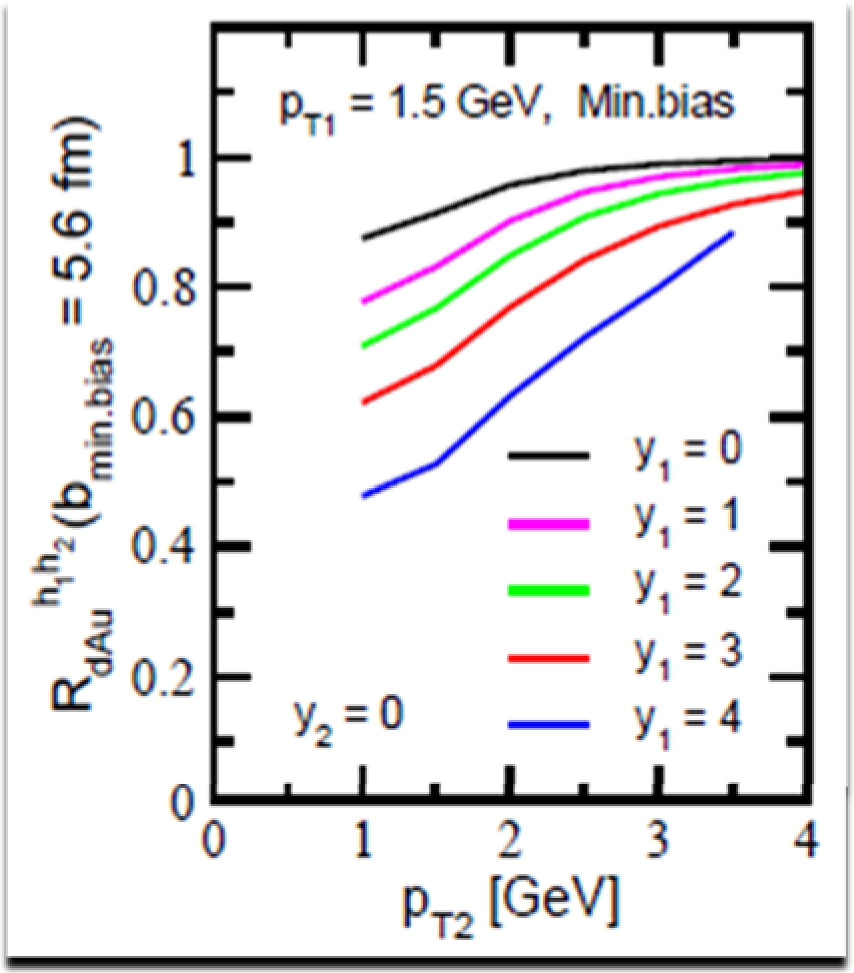
Forward/Central I_{dA} vs N_{coll}

- Increasing suppression of I_{dA} reaches a factor 2 for central events
- Model calculations are needed to distinguish between different models
  - Saturation (Color Glass Condensate)
  - Shadowing
  - Cronin
  - Others?

Associate π^0: $3.1 < \eta < 3.9$, $0.45 < p_T < 1.6$ GeV/c



Alternative Explanation of Rapidity-Separated di-Hadron correlations in d+Au



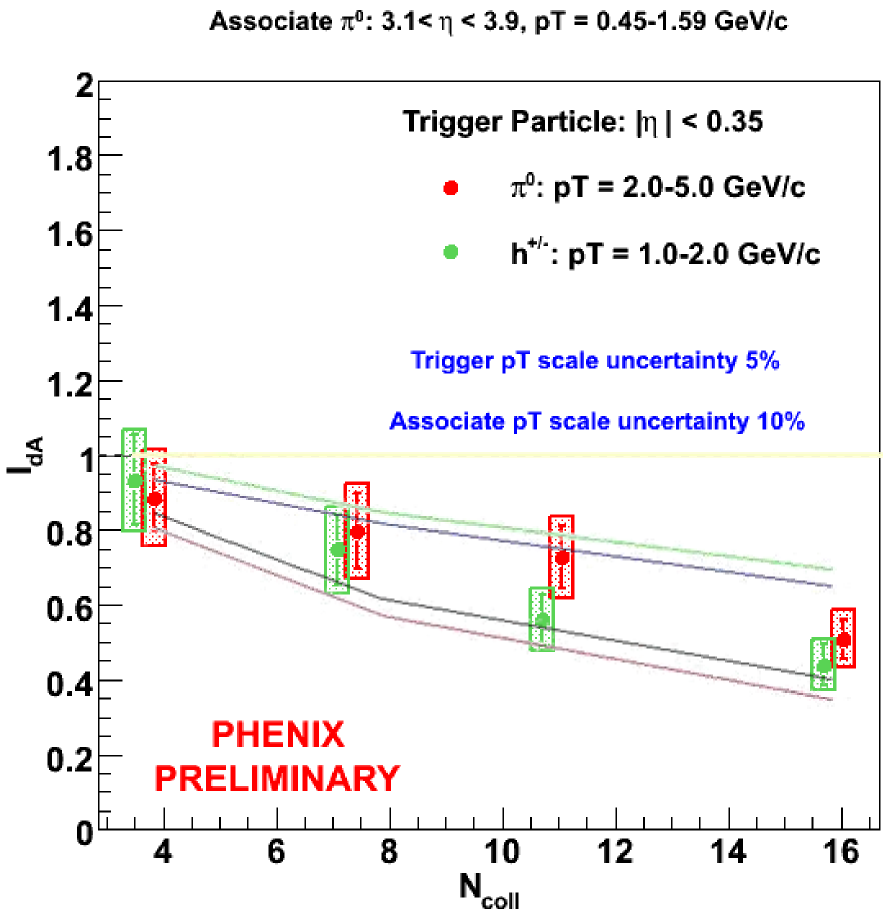
Complete (coherent + multiple elastic scattering) treatment of multiple parton scattering gives suppression of pairs with respect to singles for mid-rapidity tag!

However, small for forward trigger particle!

J. Qiu, I. Vitev, Phys.Lett.B632:507-511,2006

➔ *Expand analysis to backward MPC and forward + backward triggers. Update muon arm analysis from run 8.*

Update from Ivan Vitev after QM 2009 !!



➔ Expand analysis to backward MPC and forward + backward triggers. Update muon arm analysis from run 3!

Analysis Plan with 30 x $\int Ldt$ and the MPC

- **I_{dA} and R_{dA} with Forward Calorimeters $3.1 < |\eta| < 3.9$ + High Statistics from 2008 d+Au Run. Update earlier muon arm measurement!**

	South MPC	South Muon Arm	Central Arm	North Muon Arm	North MPC
Particle Detection	π^0	$h^{+/-}$	Identified hadrons	$h^{+/-}$	π^0
η_{min} η_{max}	-3.7 -3.1	-2.0 -1.4	-0.35 +0.35	1.4 2.0	3.1 3.9
Phys.Rev.Lett. 96 (2006) 222301					
Phys.Rev.Lett. 96 (2006) 222301					
Backward/Central					
Forward/Central					
Forward/Backward					

Conclusions

- First results from azimuthal angle correlations for rapidity separated di-hadrons with new forward MPCs:
  - The widths do not show appreciable variation for central/peripheral dAu vs pp within experimental precision.
  - Suppression of I_{dA} is observed for central collisions.
  - Model calculations needed to differentiate possible explanations:
    - Saturation effects or shadowing
      - are we at low enough x to see this?
    - Cronin, other physics?
- Use 2008 d-Au sample + upgrade to evaluate R_{dA} and I_{dA} for different rapidity (gaps).

Backup Slides

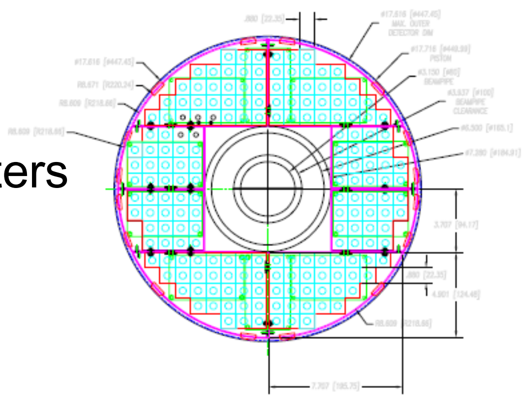
MPC Pion/Cluster Identification

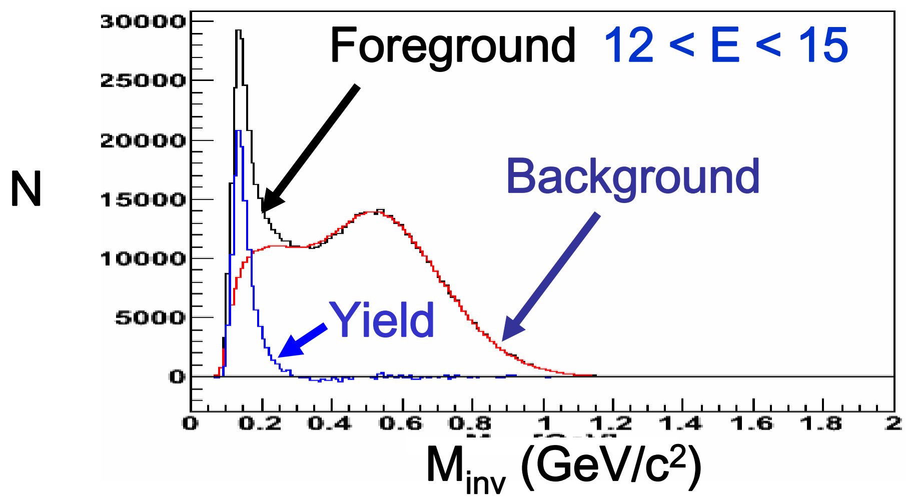
- The MPC can reliably detect pions (via $\pi^0 \rightarrow \gamma\,\gamma$) up to E = *17* GeV
- To go to higher p_T, use single clusters in the calorimeter
  - Use π^0s for *7* GeV < *E* < *17* GeV
  - Use clusters for *20* GeV < *E* < *50* GeV
- Correlation measurements are performed using π^0s, clusters
- Use event mixing to identify pions:

  foreground → photons from same event

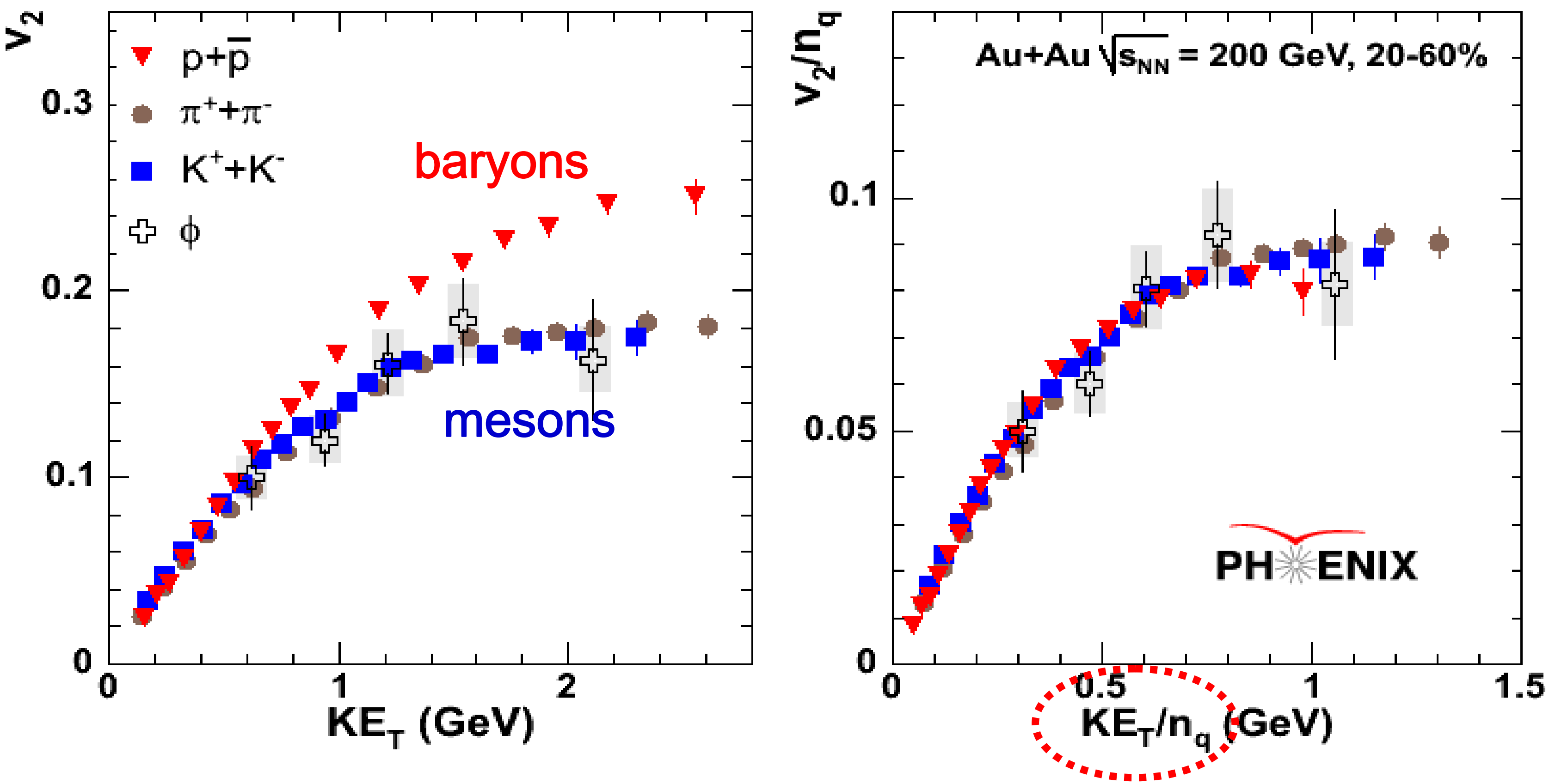
  background → photons from different events

South MPC





Elliptic Flow v_2: Among Key Evidence for Formation of Partonic Matter at RHIC

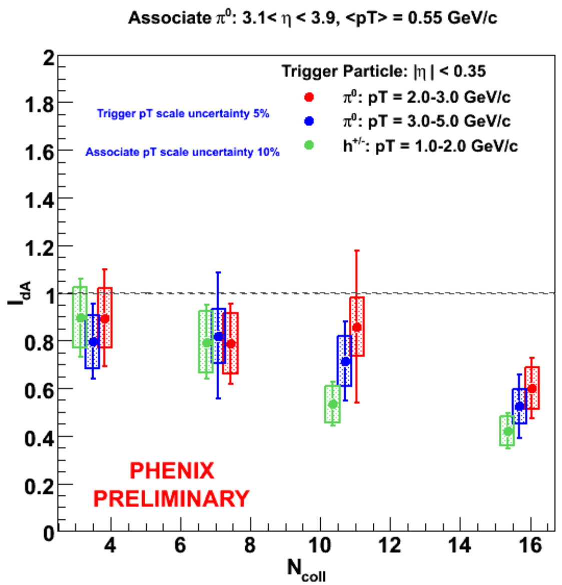


- ➔Early thermalization
- ➔Strongly interacting
- ➔Quark dofs, v_2/n_q scales

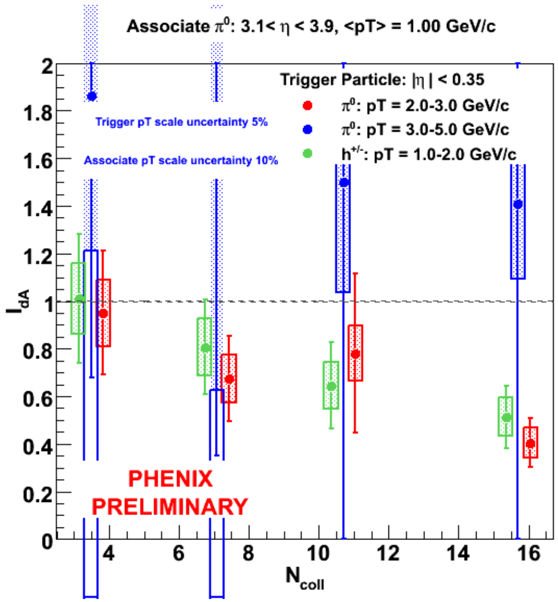
➔ Heavy quarks ?

I_{dA} vs p_T^a

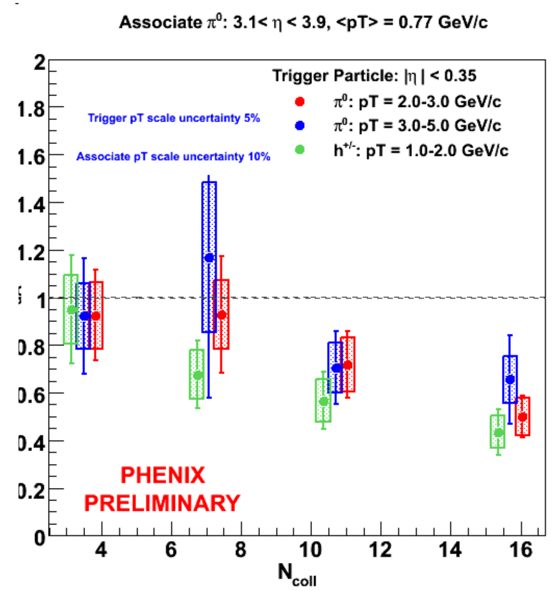
$\langle p_T^a \rangle$=0.55 GeV/c



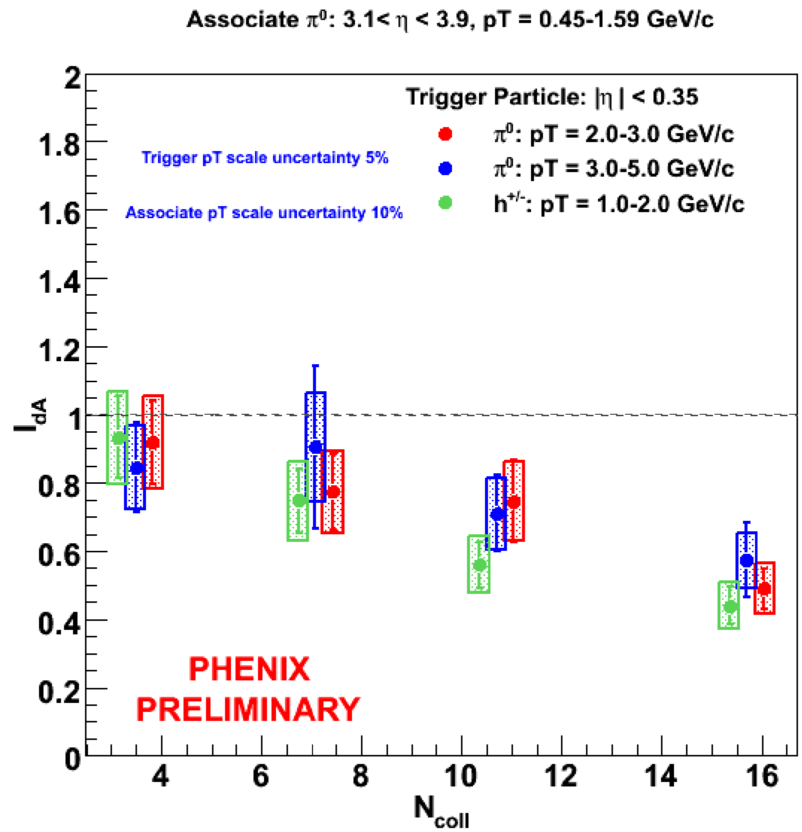
$\langle p_T^a \rangle$=0.77 GeV/c



$\langle p_T^a \rangle$=1.00 GeV/c

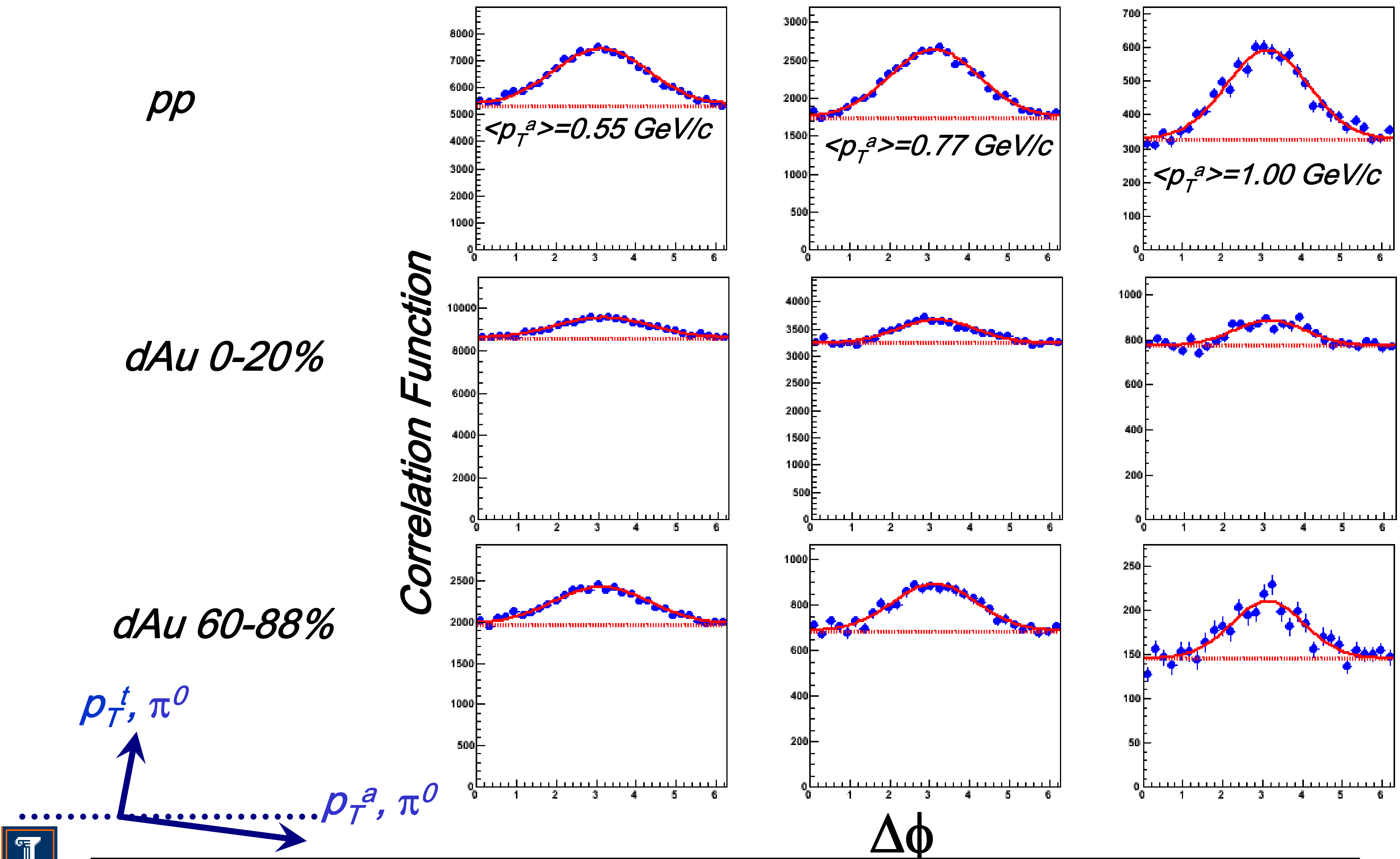


I_{dA} with 3 Trigger Particle Bins



π^0 (trigger,central)/π^0 (associate,forward)

$2.0 < p_T^t < 3.0$ GeV/c for all plots



π^0 (trigger,central)/π^0 (associate,forward)

$3.0 < p_T^t < 5.0$ GeV/c

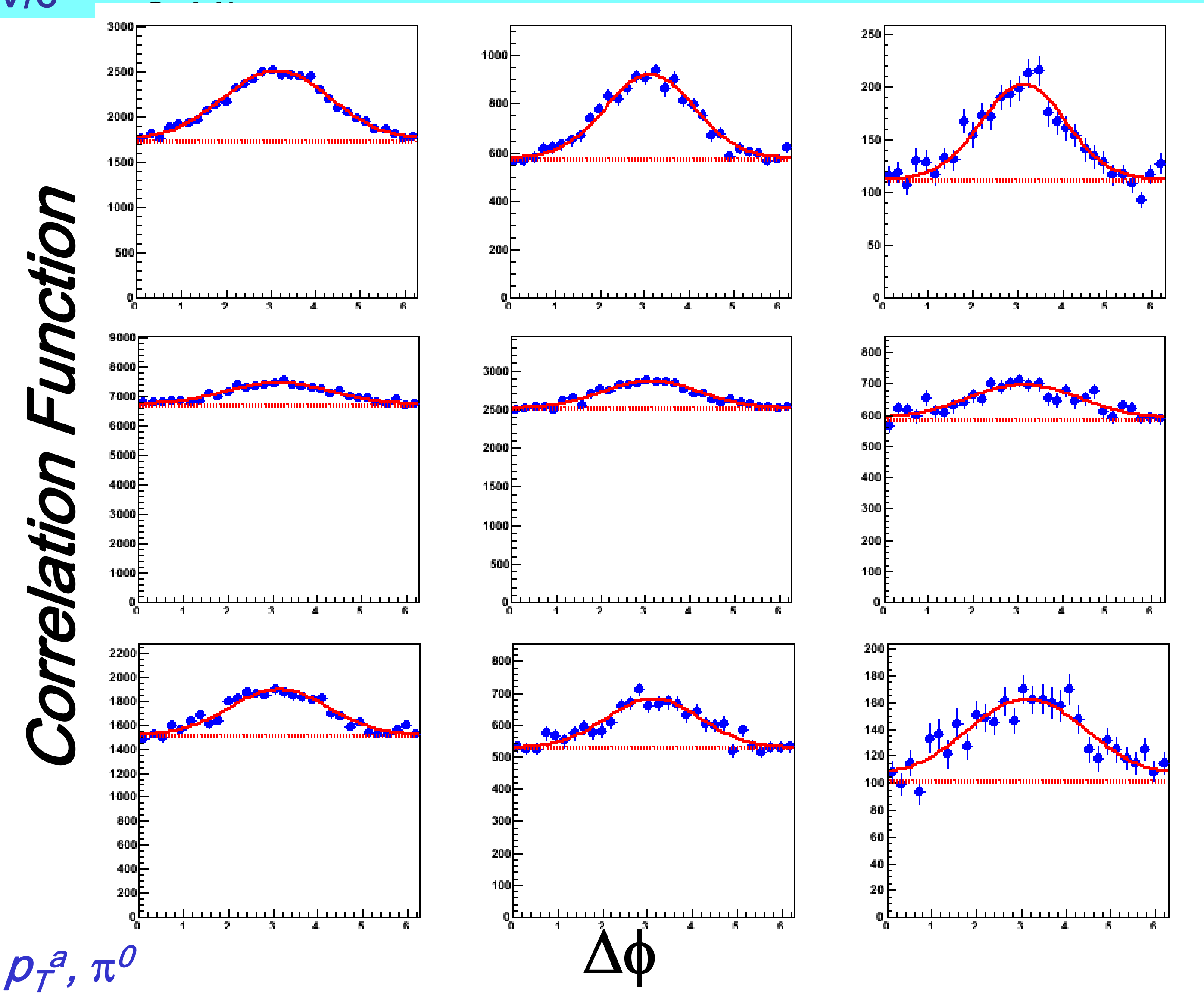
for all plots

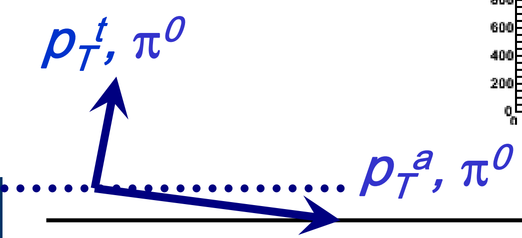
$<p_T^a>=0.55$ $<p_T^a>=0.77$ $<p_T^a>=1.00$

pp

dAu 0-20%

dAu 60-88%

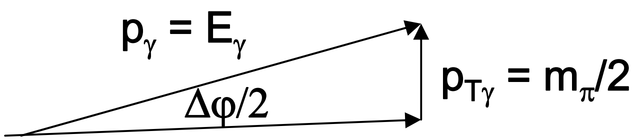




Clusters vs π^0s

- MPC crystals are ~ 2.2 cm, and the detector sits Δz=220 cm from z = 0
- From previous page, Δr min for two photons is 3.5 cm
- What is max pion energy we can detect?
  - For α=0, $E_{\gamma 1,max} = E_{\gamma 2,max}$
  - $E_{\gamma,max} = p_{T,\gamma} / \sin(\Delta\varphi/2) = m_\pi \Delta z / \Delta r_{min}$
  - $E_{\pi,max} = 2 m_\pi \Delta z / \Delta r_{min}$ = 17 GeV

γ kinematics, π_0 decay



- Able to identify pions up to 17 GeV for α = 0
- Beyond this we need better cluster splitting
  - As of now, single clusters above this energy are likely to be π^0s, direct γs, or background
- Use high energy clusters as well for correlations, R_{cp}, R_{dA}

MPC Pion Selection

- Cuts
  - Cluster Cuts
    - Cluster ecore > 1.0 (redundant w/ pion assym and energy cuts)
  - Pi0 pair
    - E > 6 GeV
    - Asym < 0.6
    - Separation cuts to match fg/bg mass distribution
    - Max(dispx, dispy) < 2.5

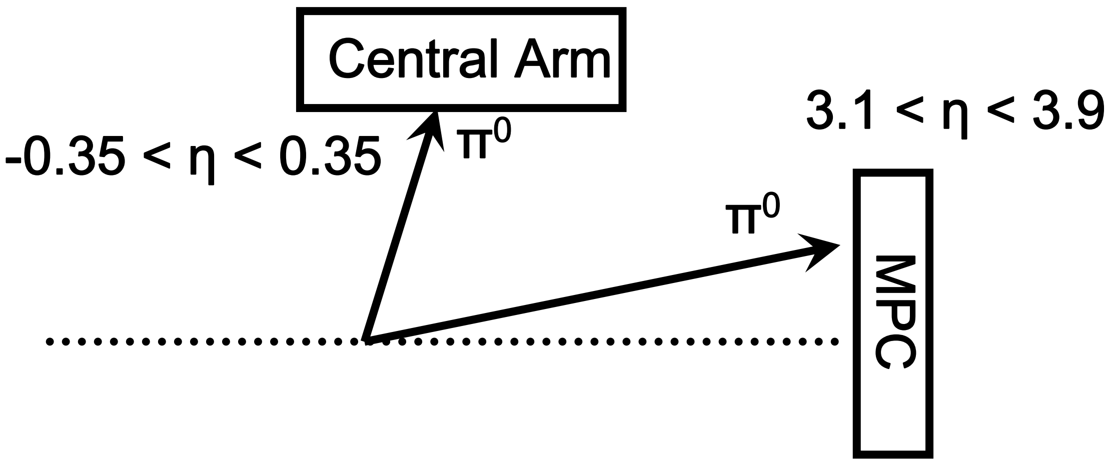
$$dr \equiv \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} > 3.5cm$$
$$\sqrt{(ix_1 - ix_2)^2 + (iy_1 - iy_2)^2} > 1.5$$

- Use mixed events to extract yields
  - Normalize from 0.25-0.4 presently

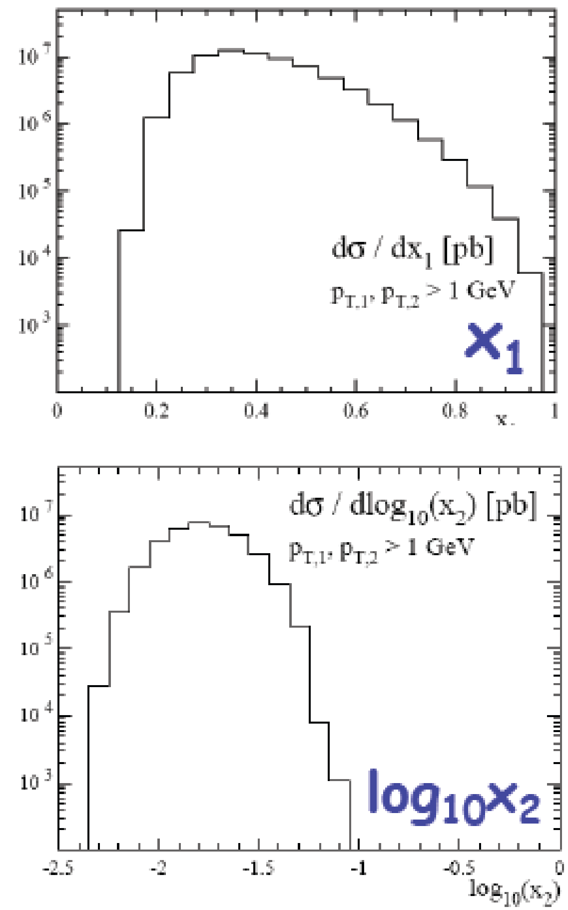
MPC/CA Cuts

- MPC pi0 ID
  - Mass window of 0.1-0.2 GeV + previously shown cuts
  - 7 – 17 GeV energy range
  - Max(dispx,dispy) <= 2.5
- Charged Hadron ID Track Quality == 31 or 63
  - n_0 <0 Rich cut
  - p_T < 4.7 GeV
  - pc3 sdz and sdphi matching < 3
  - -70 < zed < 70
- EMC pi0
  - Alpha < 0.8
  - PbGl min E = 0.1, PbSc min E = 0.2
  - Chi2 cut of 3, prob cut of 0.02
  - Sector matching
  - Mass window 0.1-0.18
  - Trigger bit check

x_1 and x_2 in Central Arm – MPC correlations



X_2-range: $0.006 < x < 0.1$



Marco Stratman pQCD calculations for pp

$x_1 > x_2$