PHENIX results on centrality dependence of yields and correlations in d+Au collisions at $\sqrt{s_{NN}}$=200GeV

~Expectations, and beyond~

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QUARK MATTER 2015
The XXVth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

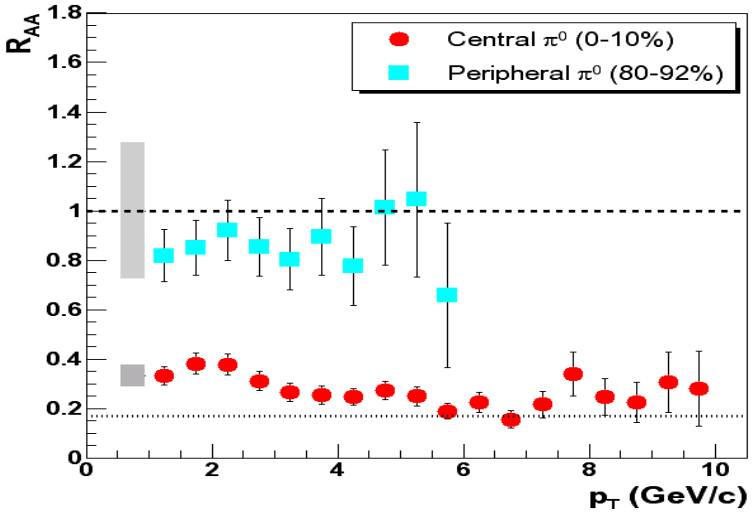
Why *were* we interested in d+Au collisions?

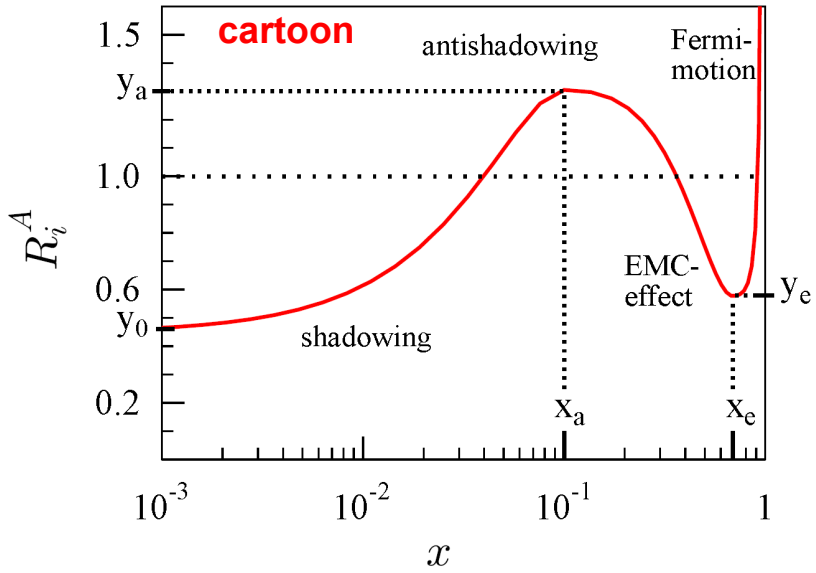
- In order to confirm the high p_T hadron suppression is due to final state effects, and not cold nuclear matter (CNM) effects
  - Need system without additional effects from a hot medium.

- CNM effects include:
  - k_T-broadening (Cronin enhancement at moderate p_T)
  - Shadowing of parton distributions
  - Cold nuclear matter energy loss
  - And possibly more…

- d+Au is more favorable for RHIC operation
  - Better rigidity match
  - p+Au becomes feasible now

PHENIX, Phys. Rev. Lett. 91, 072301 (2003)

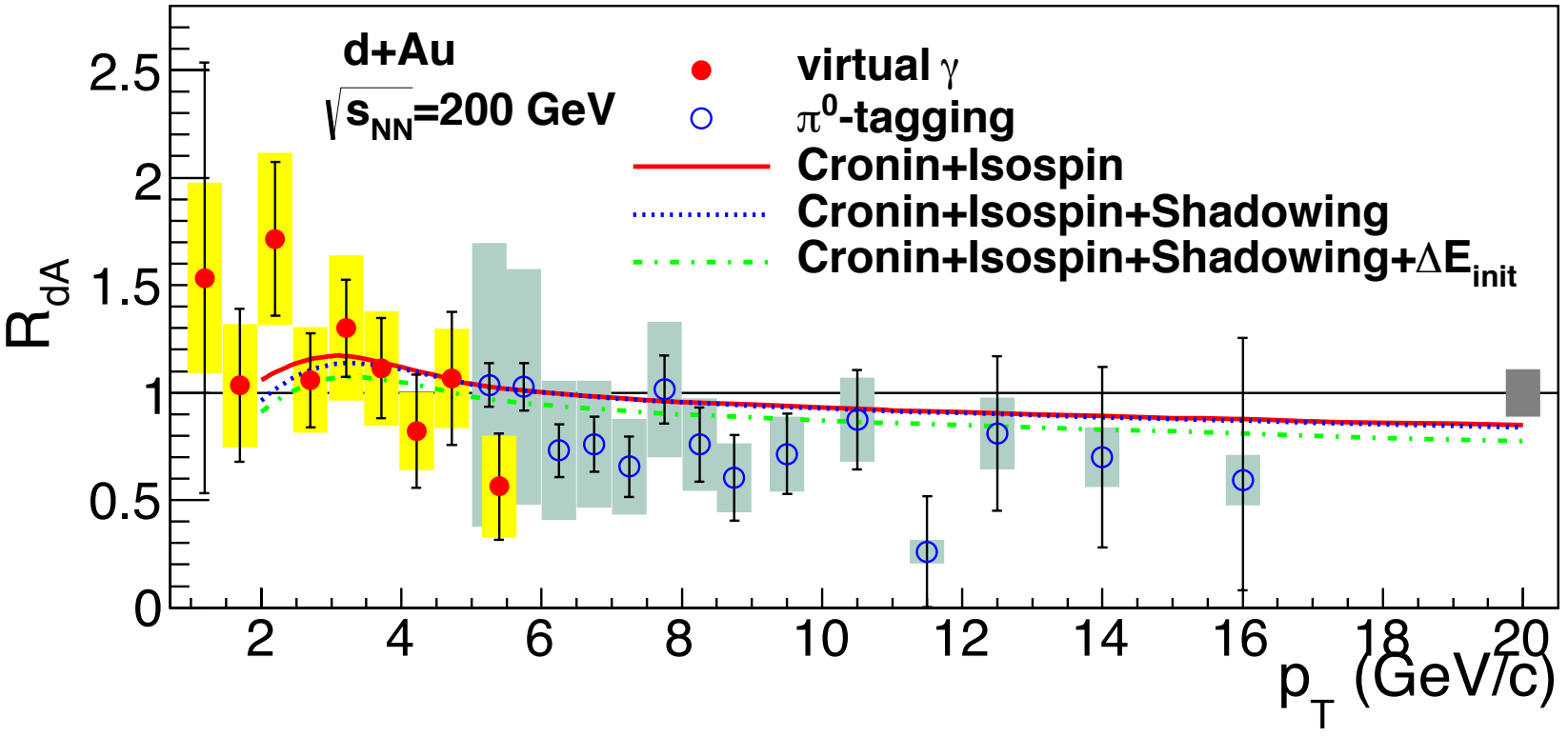




Direct photons – as expected

- No modification in initial hard scattering and PDF compared to p+p at mid-rapidity

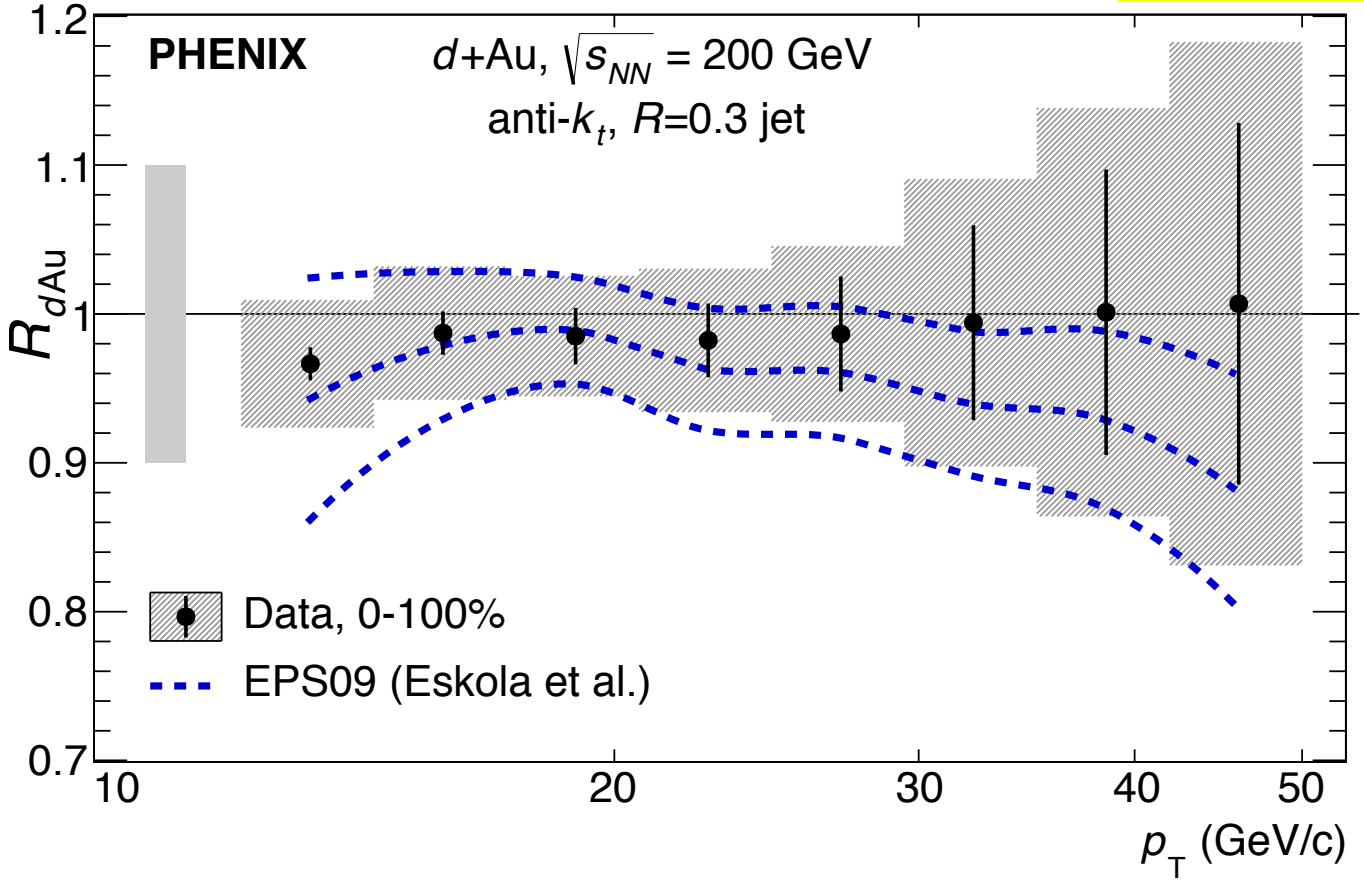
PRC87, 054907 (2013)



Jets – as expected in MinBias

- R_{dA} is consistent with unity up to 50GeV/c within the quoted uncertainty
  - As expected from parton distribution function (EPS09).

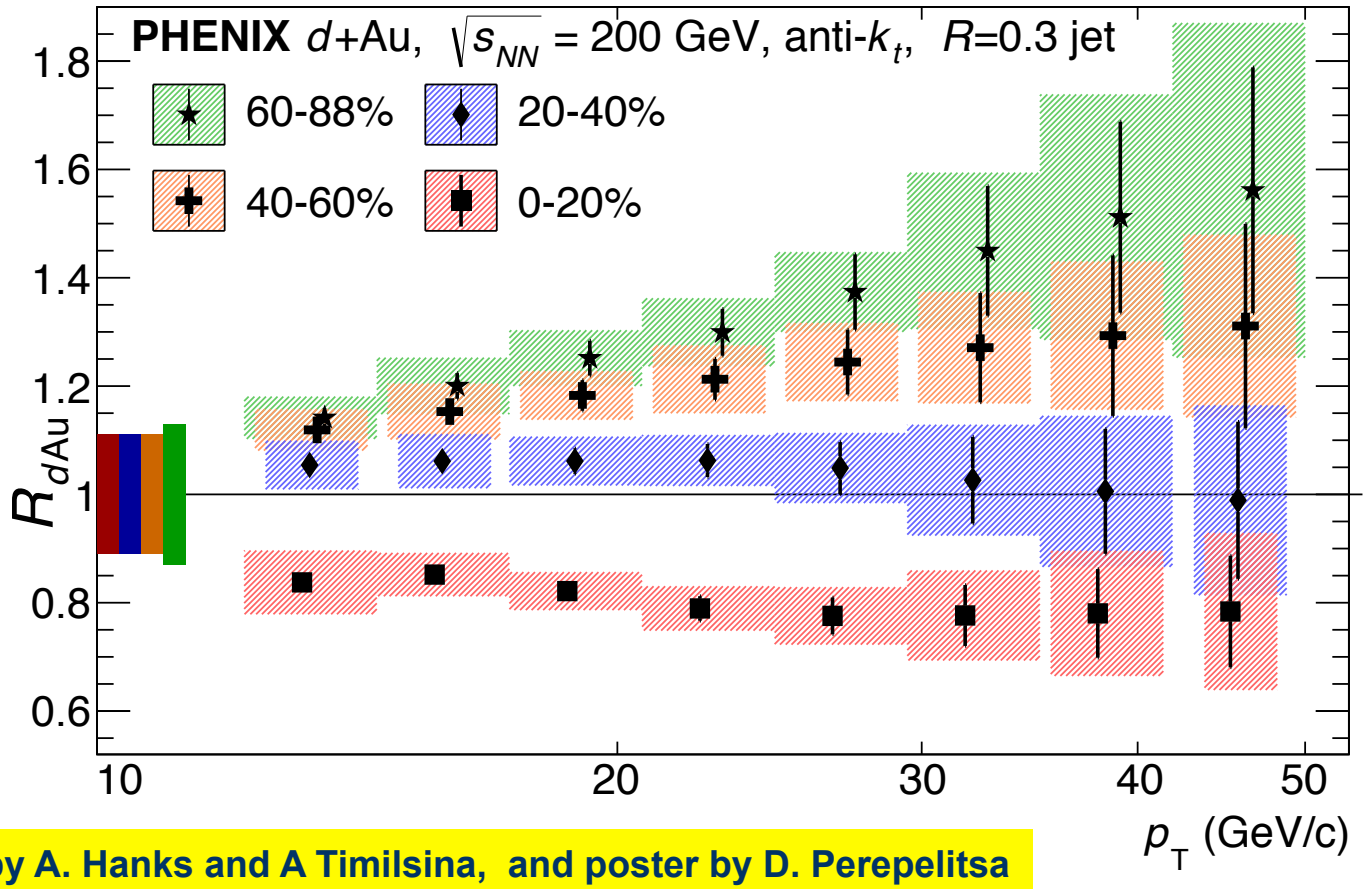
arXiv:1509.04657



Jets with centrality – beyond expectations?

R_{dA} shows strong centrality dependence

arXiv:1509.04657

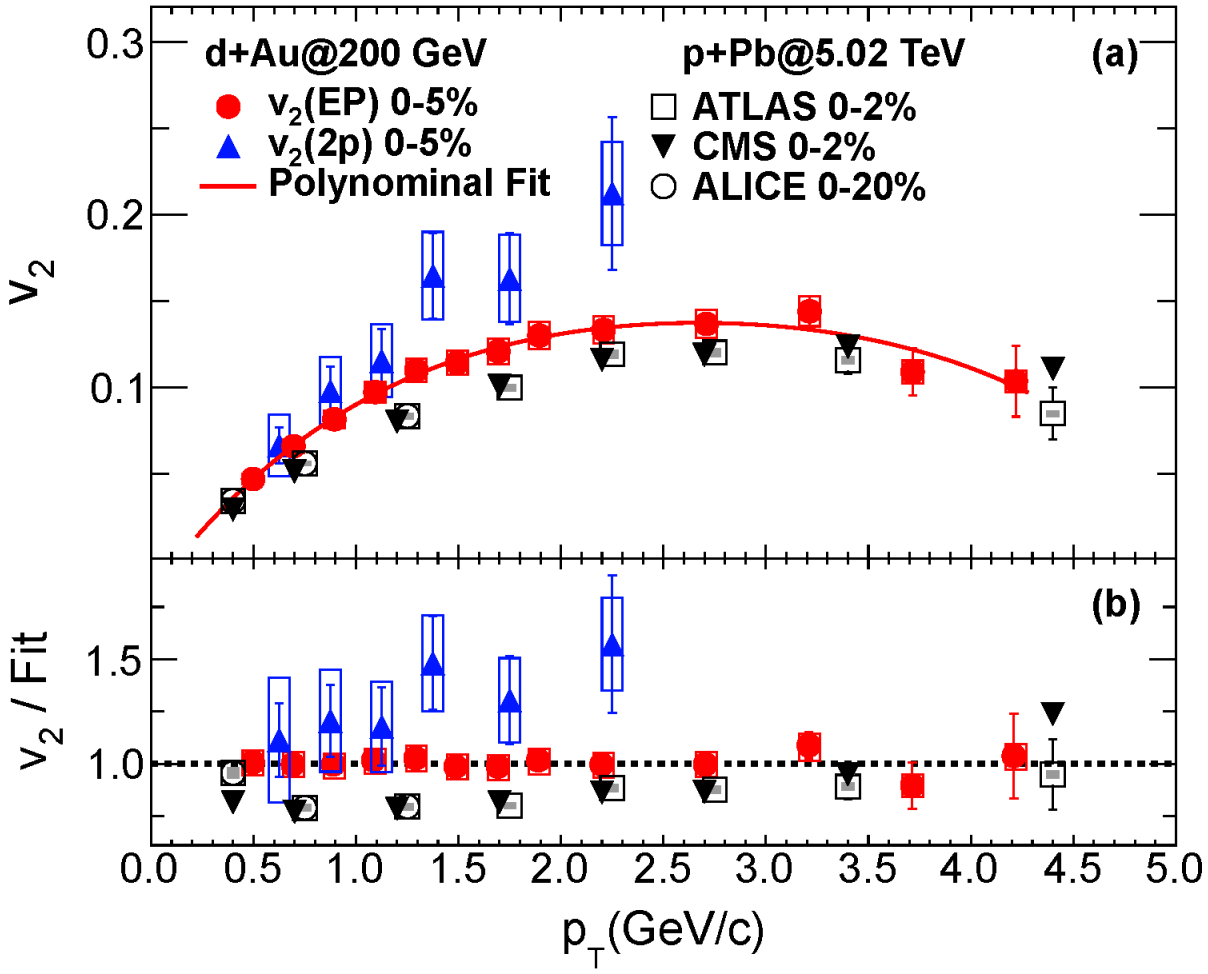


See talks by A. Hanks and A Timilsina, and poster by D. Perepelitsa

Collective flow – beyond expectations

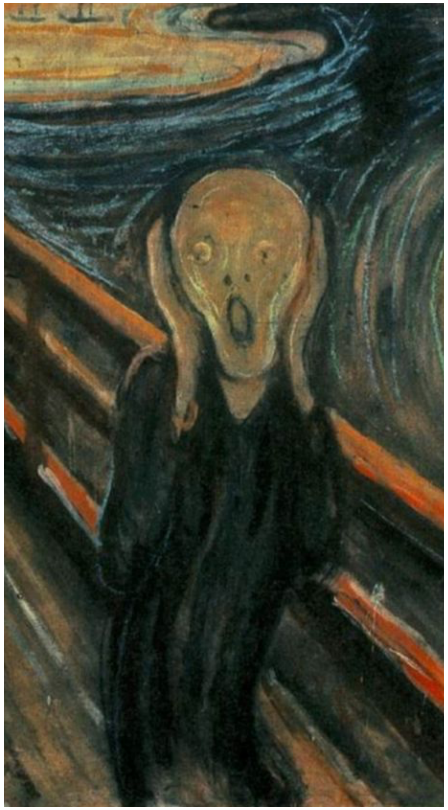
We didn't anticipate "flow" in a small system like d+Au

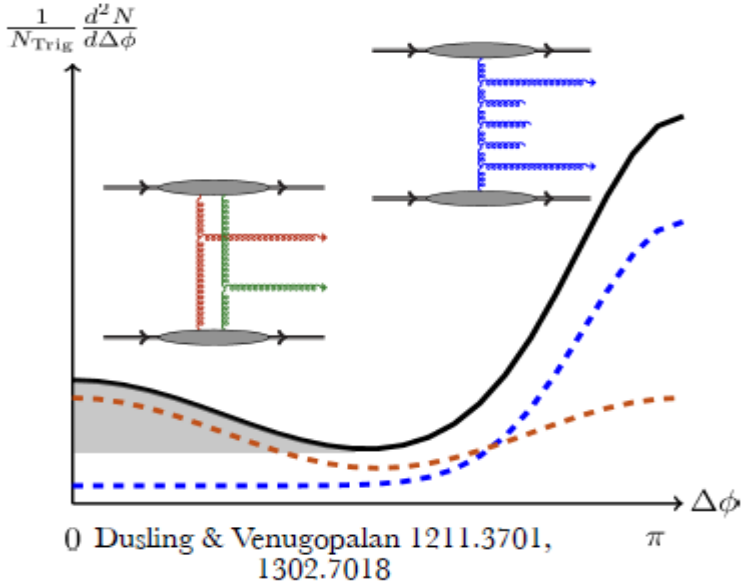
PHENIX, PRL114, 192301 (2015)



d+Au is no longer a baseline or a simple system…

- Mini-QGP production?
  - Initial state effects, e.g. CGC, will affect to the angular correlation of particles
  - Final state effects, e.g. hydrodynamics will produce flow-like structure





Dusling & Venugopalan 1211.3701, 1302.7018

d+Au is no longer a baseline or a simple system…

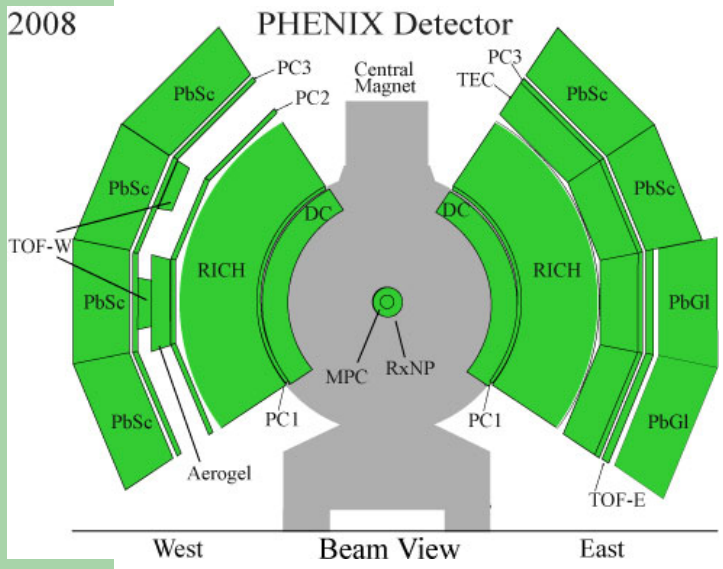
- Mini-QGP production?
  - Initial state effects, e.g. CGC, will affect to the angular correlation of particles
  - Final state effects, e.g. hydrodynamics will produce flow-like structure
- Through Fourier analysis of long-range particle correlations, we look for similar phenomena as in A+A collisions
  - i.e. flow, ridge and differential energy loss
- New opportunity for discovery!

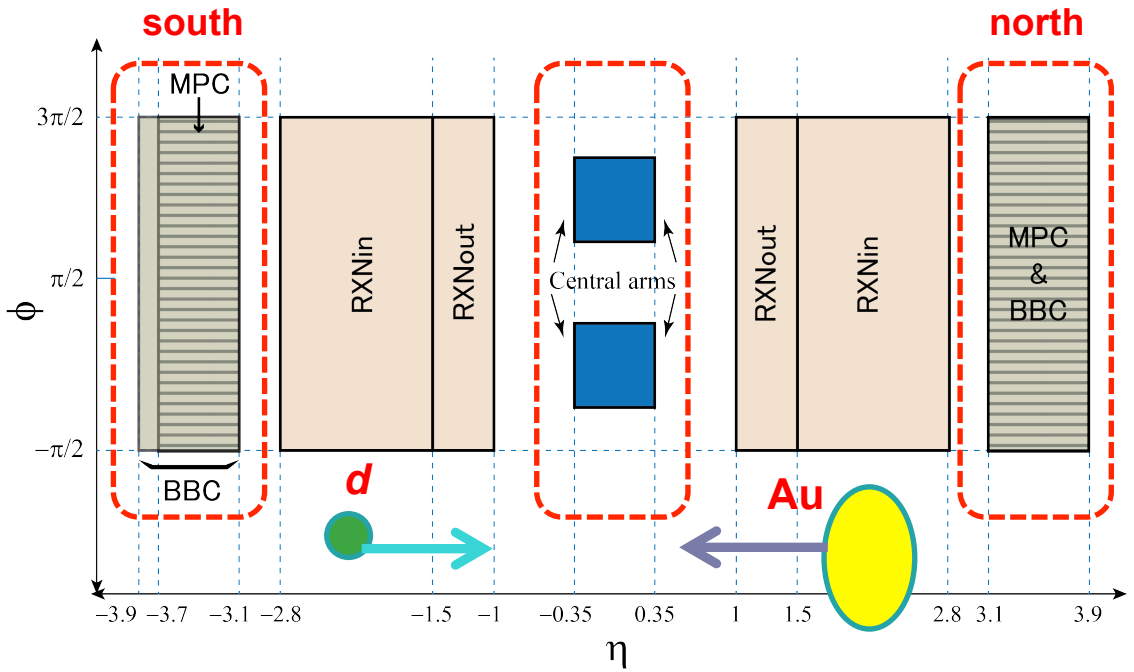
Measurement strategy

- Make pairs of charged hadrons ($h^{+/-}$) or π^0's measured in the central arm ($|\eta|<0.35$) with tower hits in MPC south ($-3.7<\eta<-3.1$) or north ($3.1<\eta<3.9$)
  - South is Au-going (more multiplicity), and North is d-going.
  - Long range: $|\Delta\eta| = \eta_{MPC}-\eta_{cent} = \sim 3.4$
- Fit correlation functions with Fourier series

$$\frac{dN}{d\Delta\varphi} = N_0\left\{1+2c_1\cos(\Delta\varphi)+2c_2\cos(2\Delta\varphi)+2c_3\cos(3\Delta\varphi)+2c_4\cos(4\Delta\varphi)\right\}$$

$$c_n = v_n(MPC)\times v_n(Central)$$

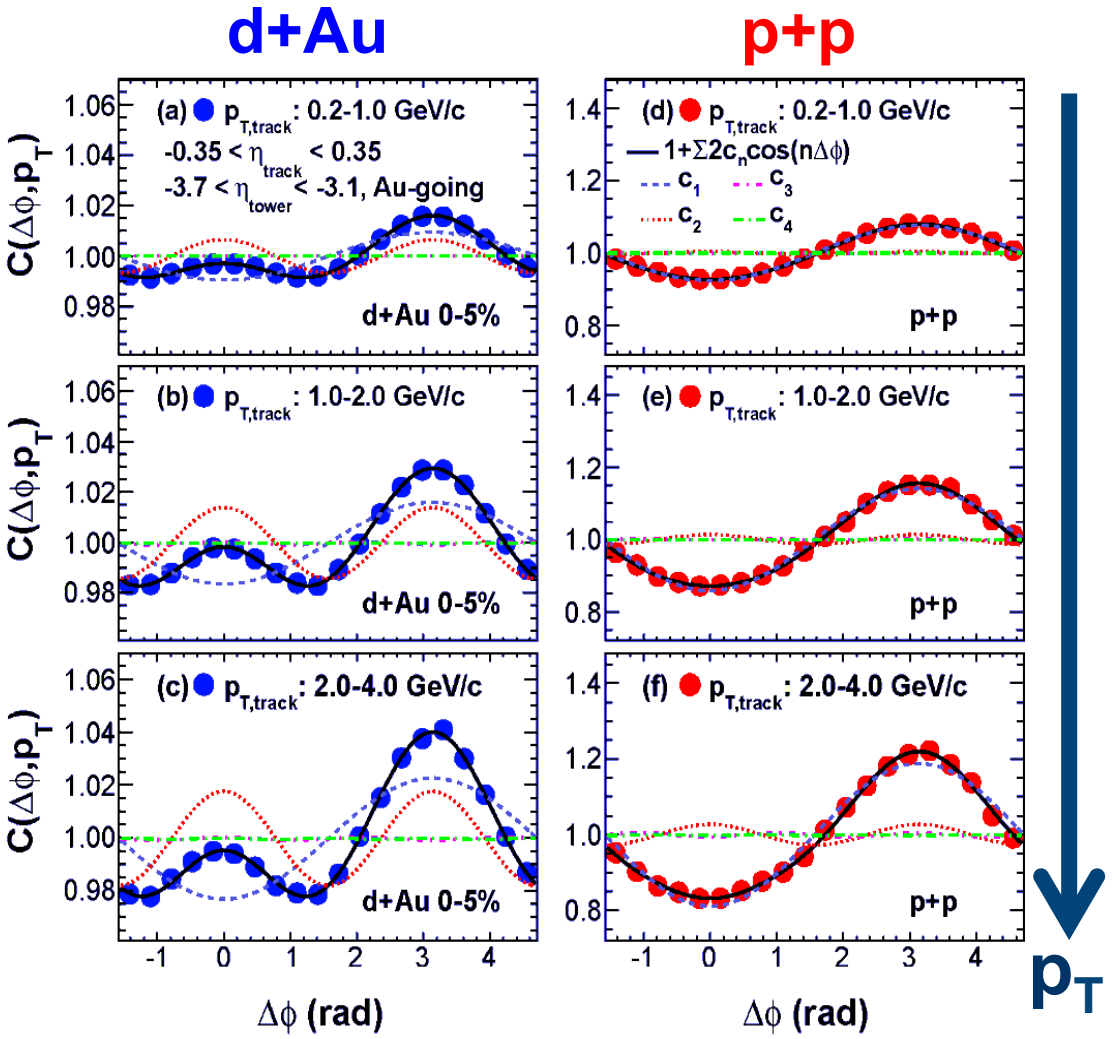




Ridge-like structure is observed in d+Au

PHENIX, PRL114, 192301 (2015)

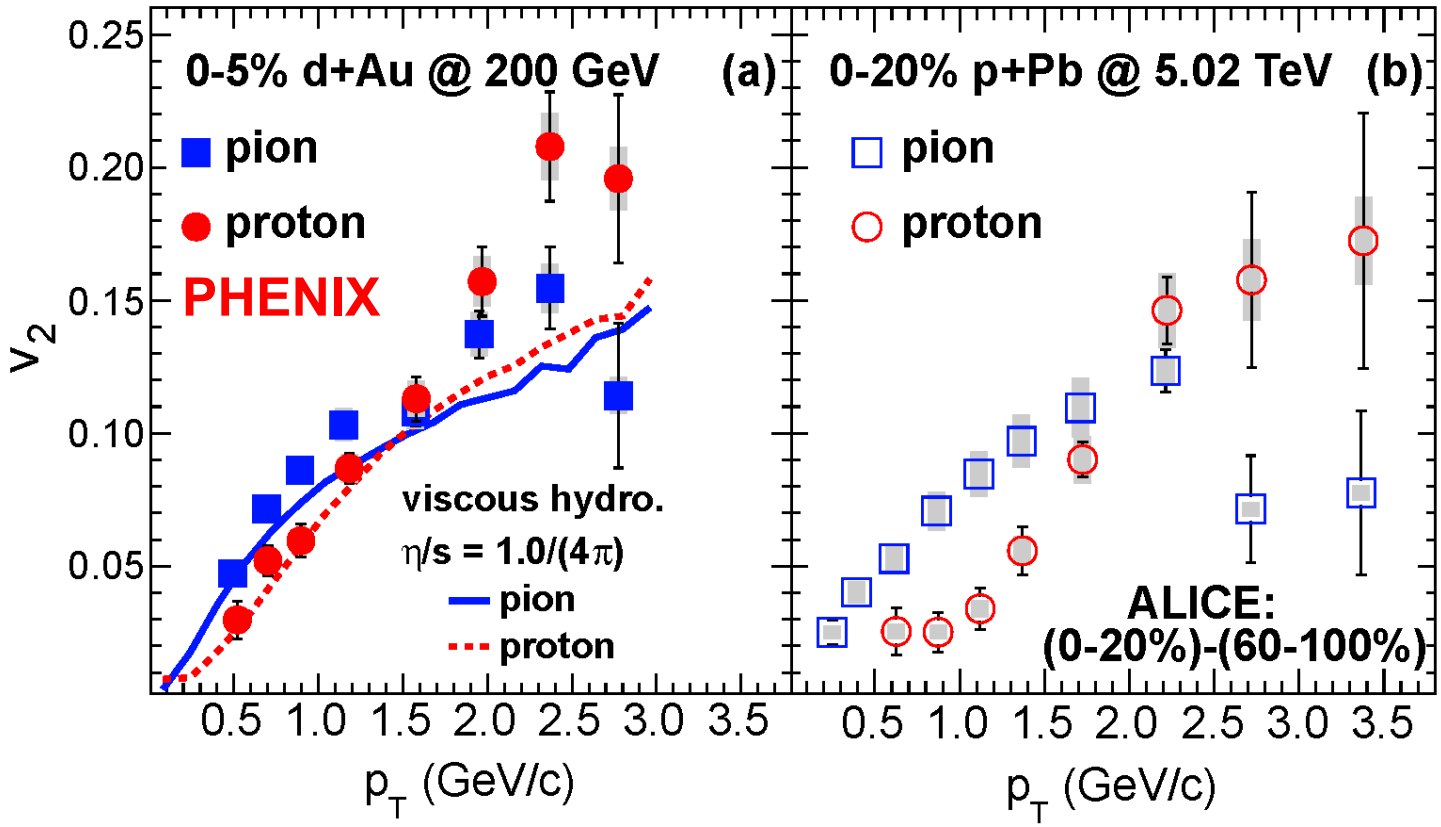
- $h^{+/-}$ - MPC south correlation functions in central d+Au and minbias p+p collisions
  - Au-going direction
- Near-side peak clearly seen in d+Au but not in p+p
- Analyze correlation functions with Fourier fits
- 2nd order component (c_2) increases as p_T becomes larger
- Similar correlation but the smaller strength is seen in $h^{+/-}$ - MPC north correlation



Measured v_2 in central d+Au at low p_T

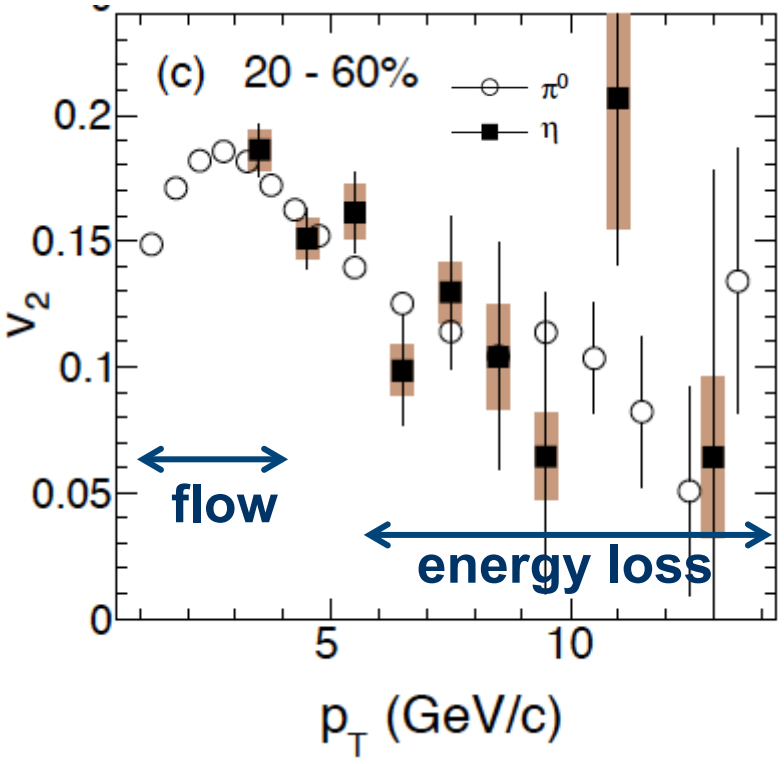
- Using event-plane method, v_2 was measured for 0-5% d+Au collisions
- Mass ordering is similar to what we have seen in Au+Au

PHENIX, PRL114, 192301 (2015)

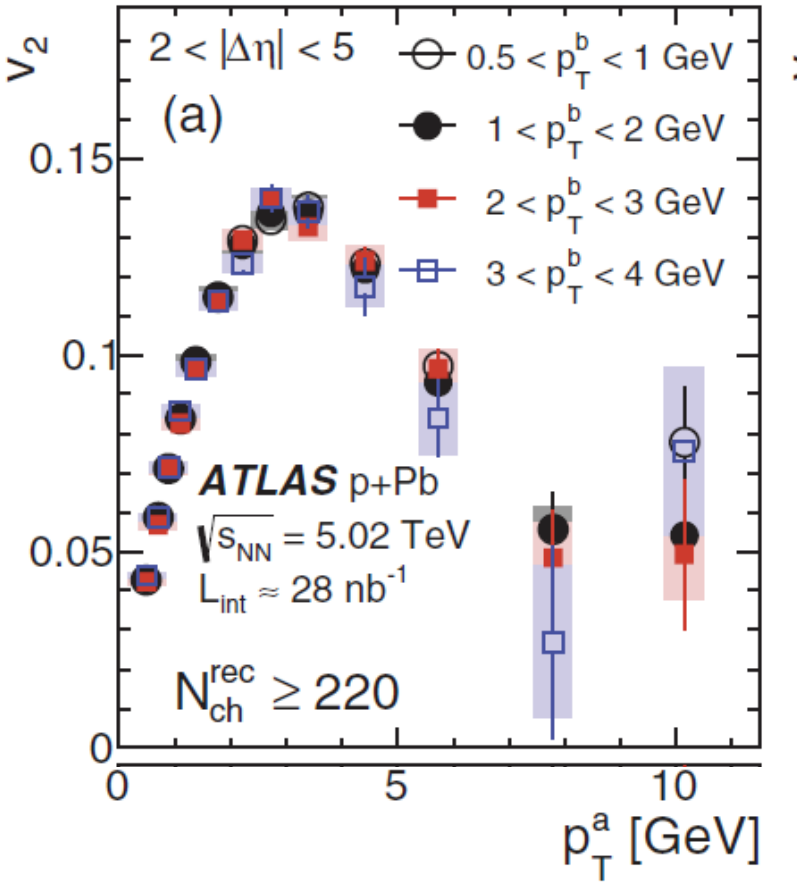


Anisotropy continues to high p_T

PHENIX Au+Au 200GeV, π^0 / η
PRC88, 064910 (2013)



ATLAS p+Pb 5.02TeV, $h^{+/-}$
PRC90, 044906 (2014)

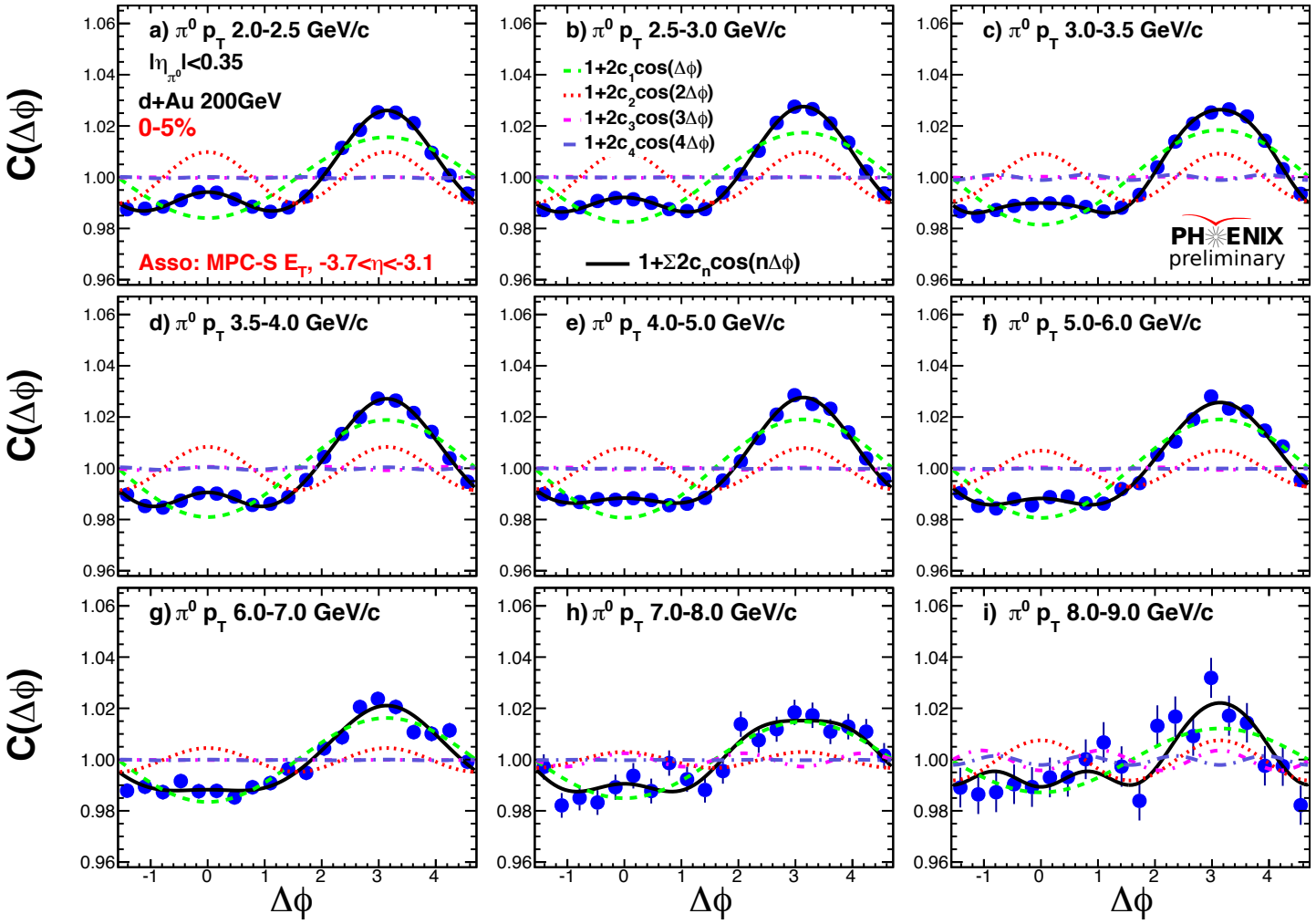


Let's look at PHENIX d+Au!

We use π^0 to get to high p_T

Ridge structure up to high p_T in d+Au

- π^0-MPC south correlation functions



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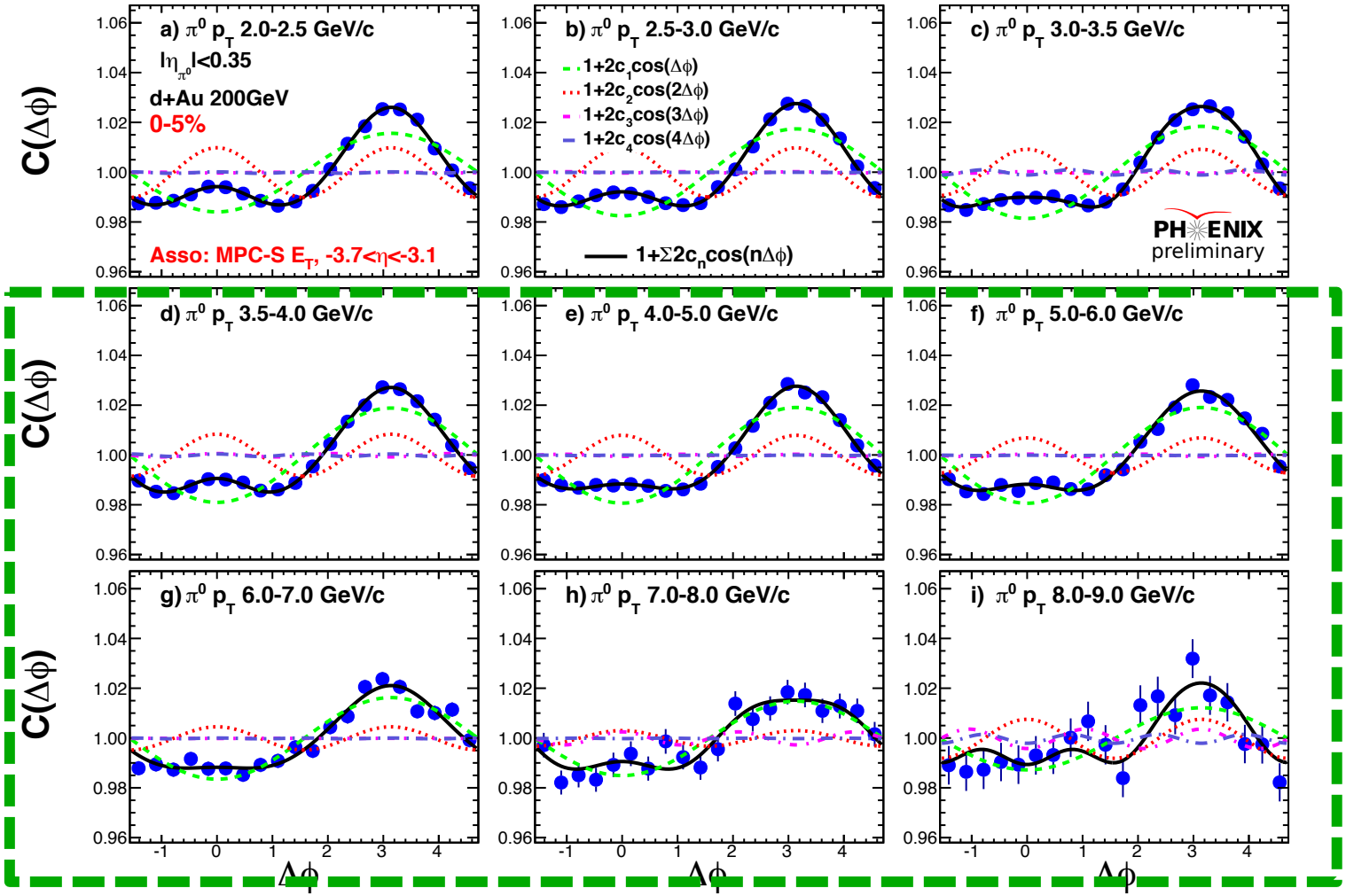
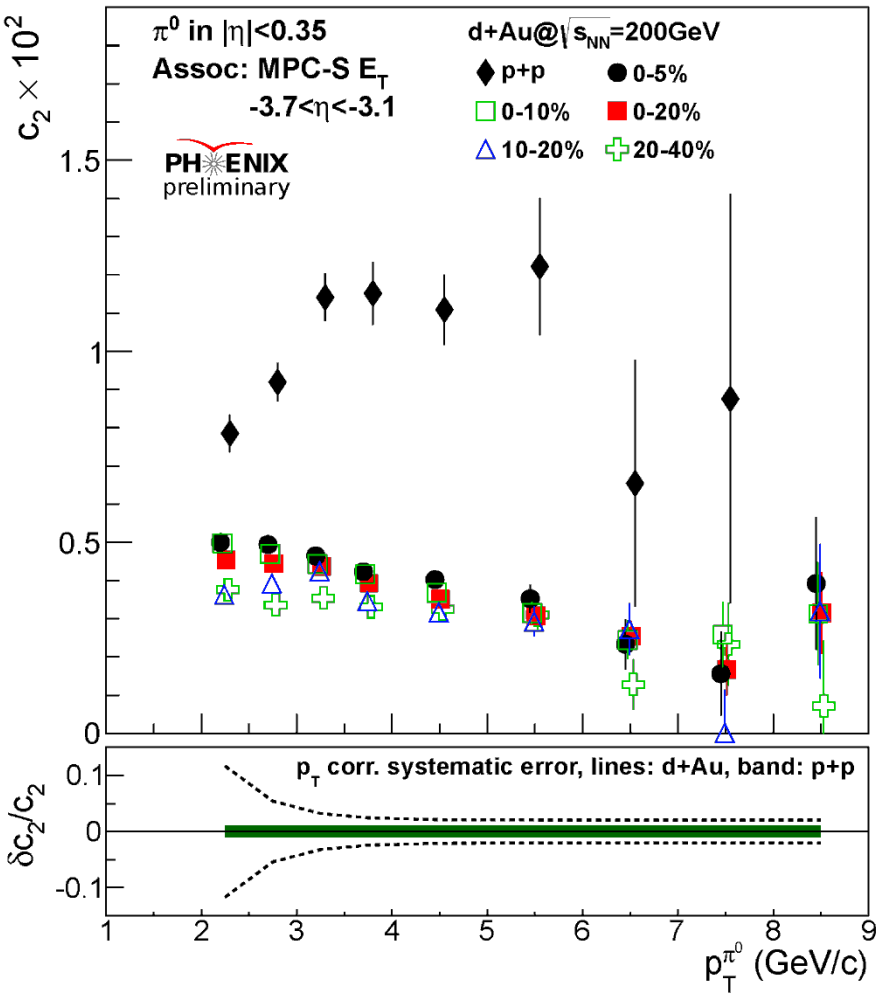


Extended p_T range by using π^0s

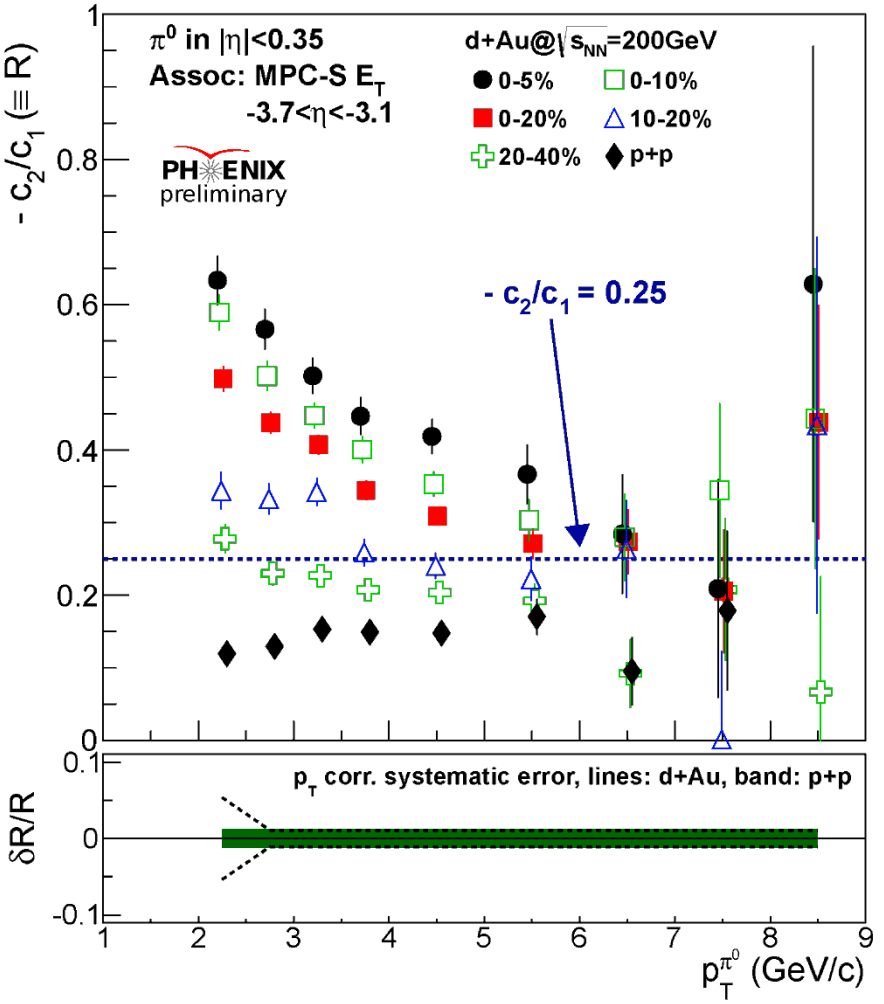
Fourier coefficients over centrality and p_T

- c_2 from π^0 - MPC south correlations
  - Au-going direction
- c_2 is decreasing above ~ 3GeV/c
  - visible up to ~8GeV/c
- Look for shape changes by comparing c_2 to c_1



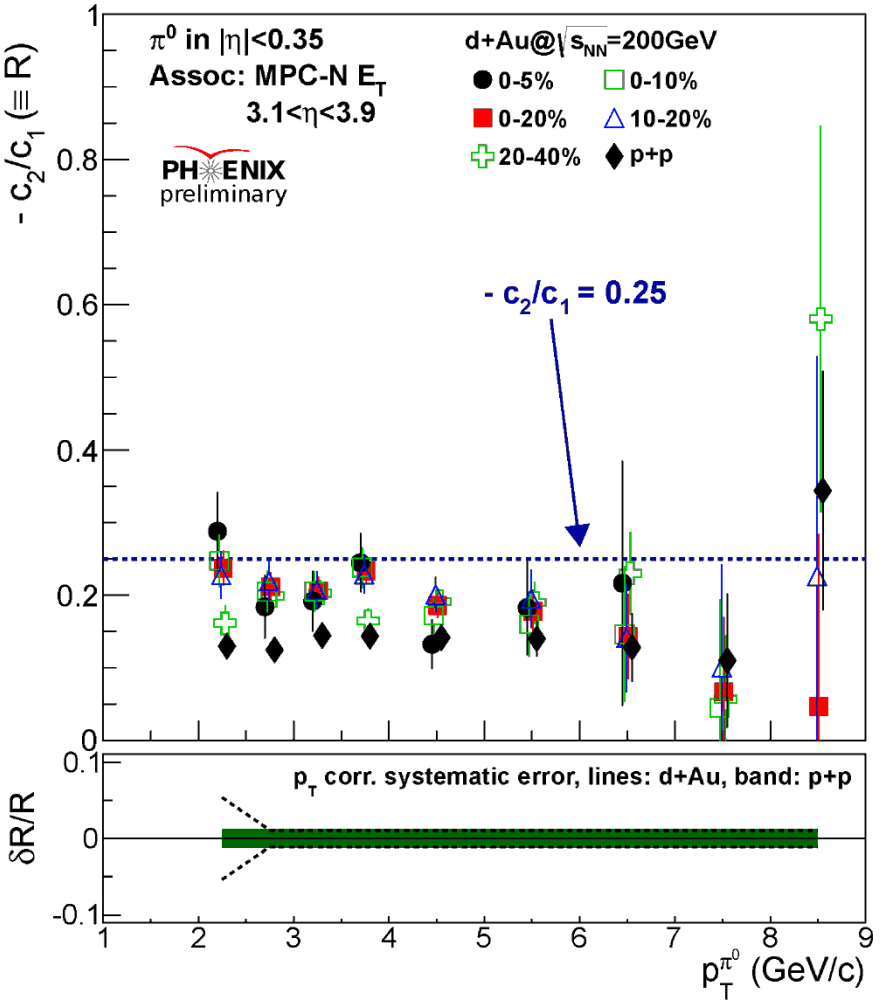
Ridge evolution in π^0-MPC south / Au-going…

- $-c_2/c_1$ from π^0 - MPC south correlations
  - Au-going direction
  - Assuming c_1 is a proxy of jets or global momentum conservation
- Measure shape evolution by relative magnitude of 2nd order component
- $-c_2/c_1 > 0.25$ corresponds to near-side local maximum (if $c_3 = c_4 = 0$)



… and for the north / *d*-going

- $-c_2/c_1$ from π^0 - MPC north correlations
  - *d*-going direction
- Very different behavior
  - $-c_2/c_1$ is much lower than in π^0-MPC south correlations
  - Much less centrality evolution, closer to p+p values
- Ridge is asymmetric in rapidity



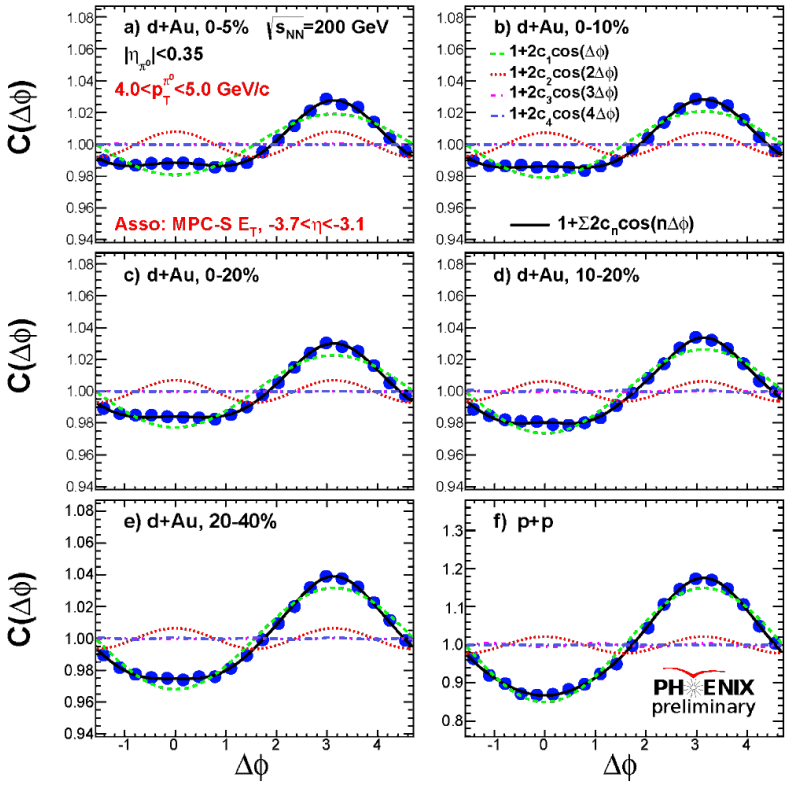
Summary

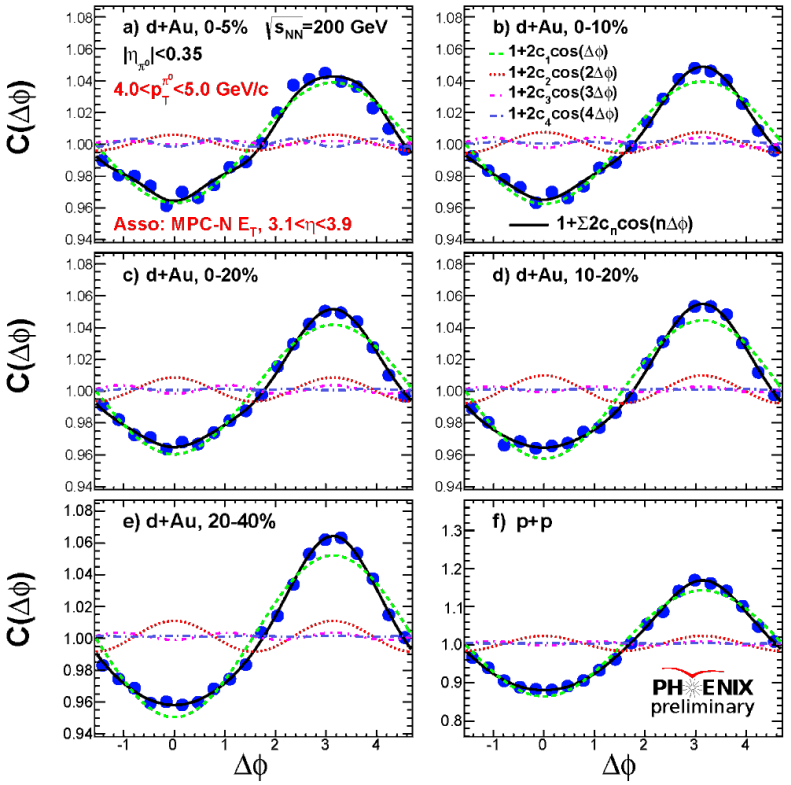
- d+Au collisions are no longer a simple system
- Anomalous centrality dependence of jet production has been observed in d+Au collisions
  - Enhancement of R_{dA} in peripheral and suppression in central
  - Minbias R_{dA} is consistent with unity
- Ridge (flow)-like structure is observed in long-range two-particle correlations
  - $h^{+/-}$ - MPC south in Au-going direction
  - p_T and mass dependence is similar to what was observed in A+A
- Use π^0 correlations to extend the range in p_T
- Ridge (flow)-like structure visible up to ~8GeV/c in π^0 - MPC south (Au-going direction) correlations, analyzed with $-c_2/c_1$
- $-c_2/c_1$ is weaker for π^0 - MPC north correlations (*d*-going direction)

Backup

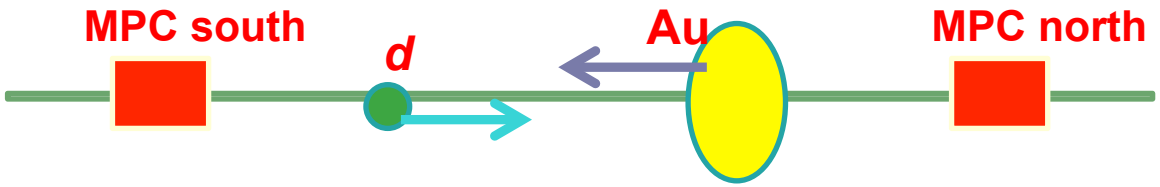
Ridge structure up to high p_T?

- Going to more central, the ridge-like structure become more prominent
  - As was the case for low pT
- Stronger correlation seen for CNT-MPCS

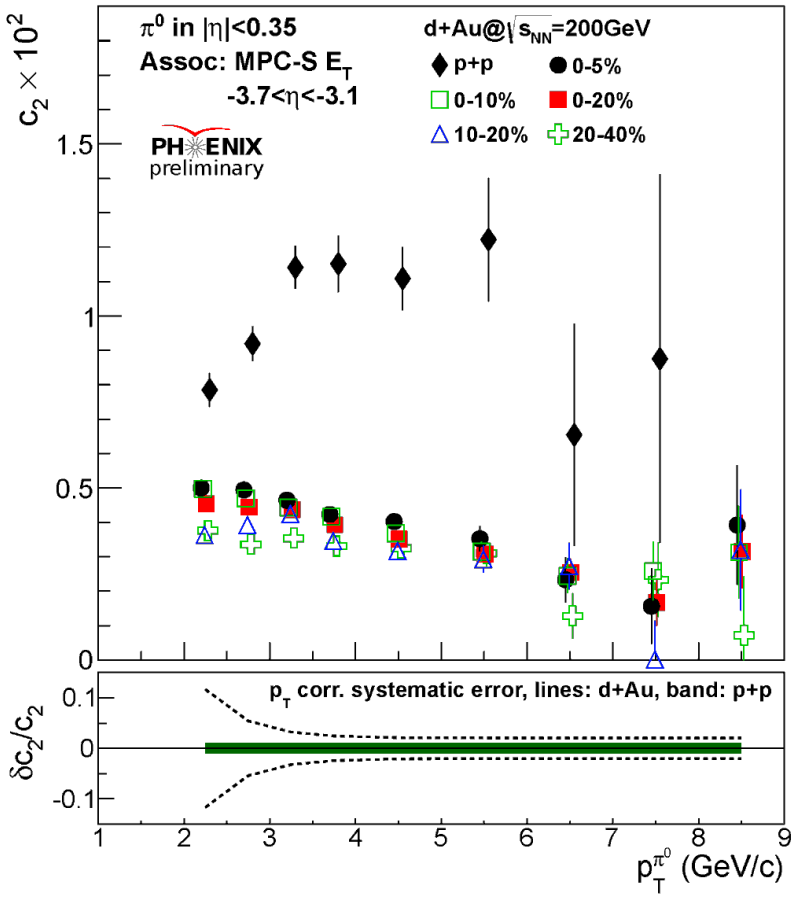


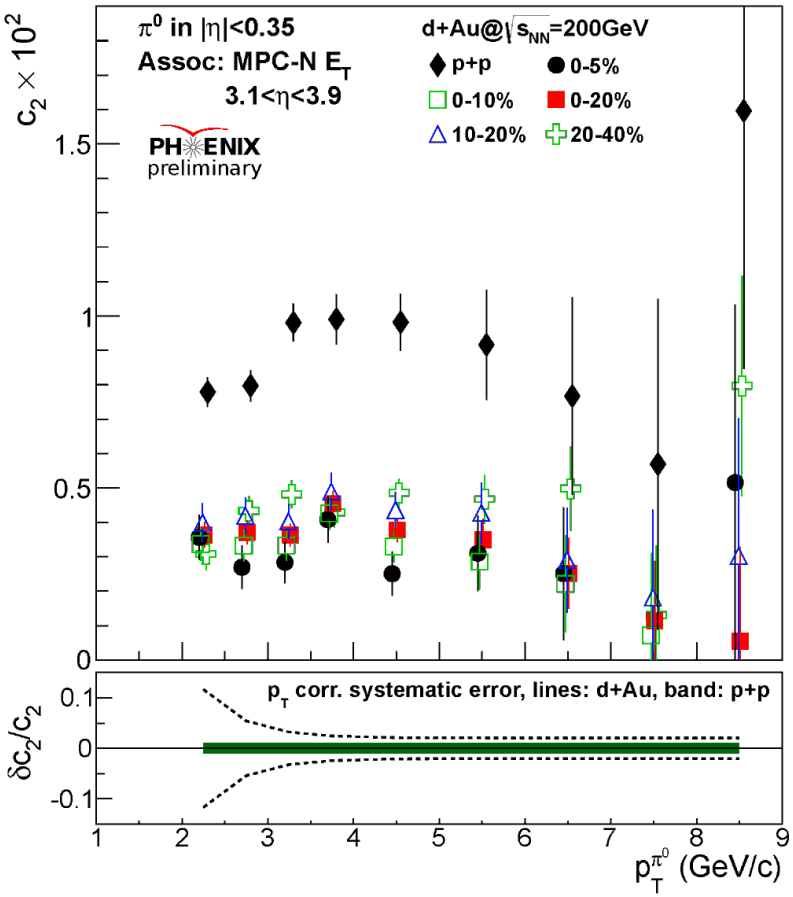


Ridge structure upto high pT?



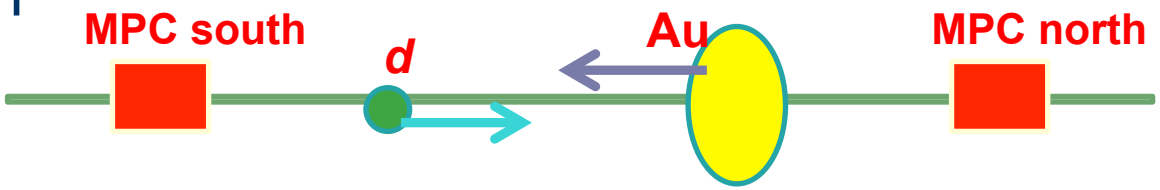
- c2

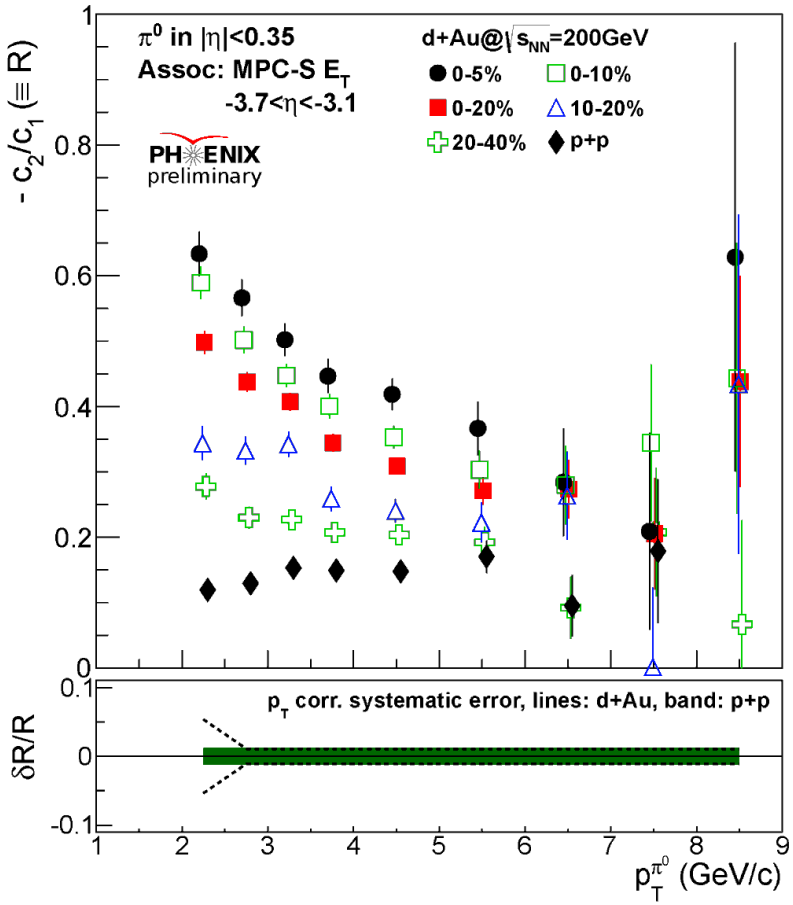


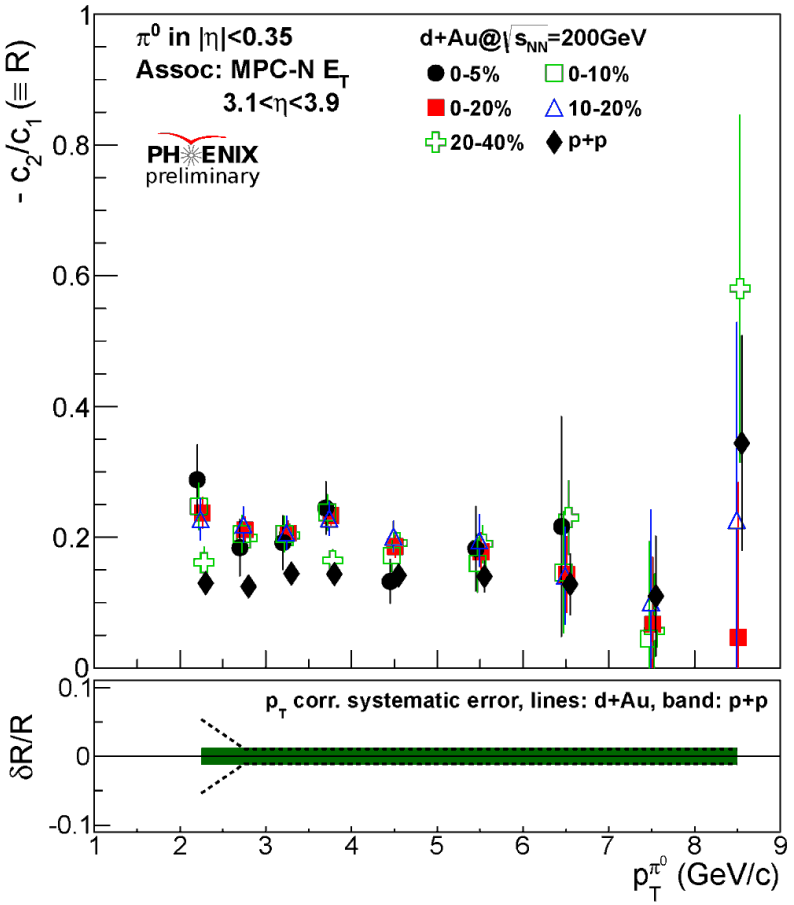


Ridge structure upto high pT?

- -c2/c1

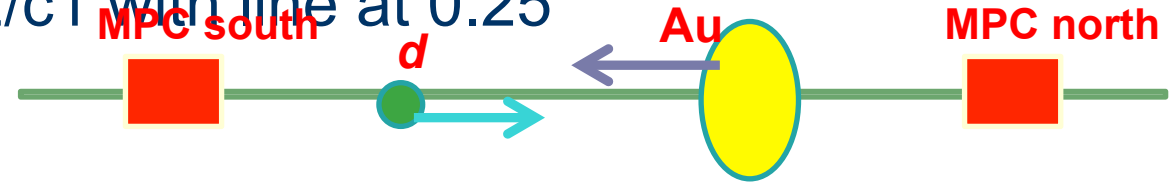


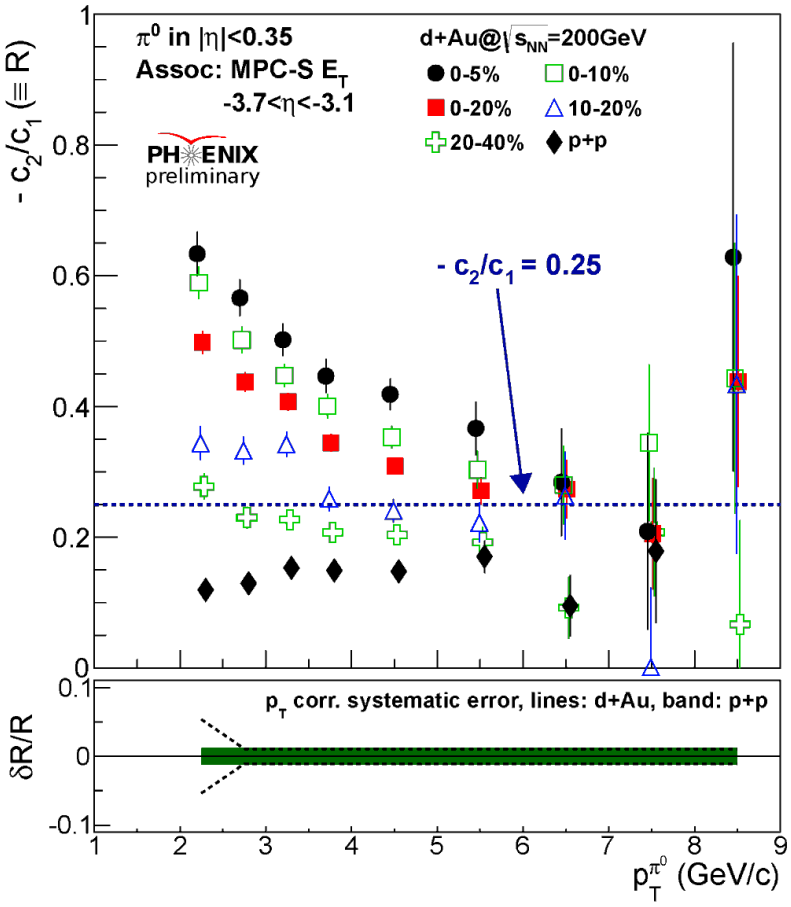


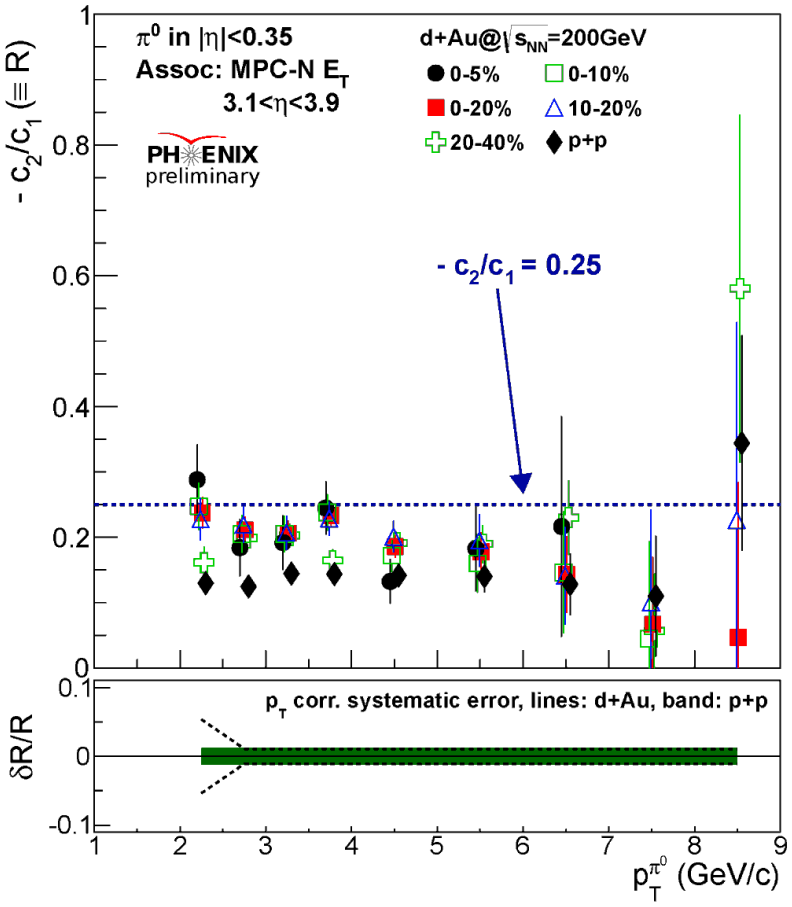


d+Au is suppressing

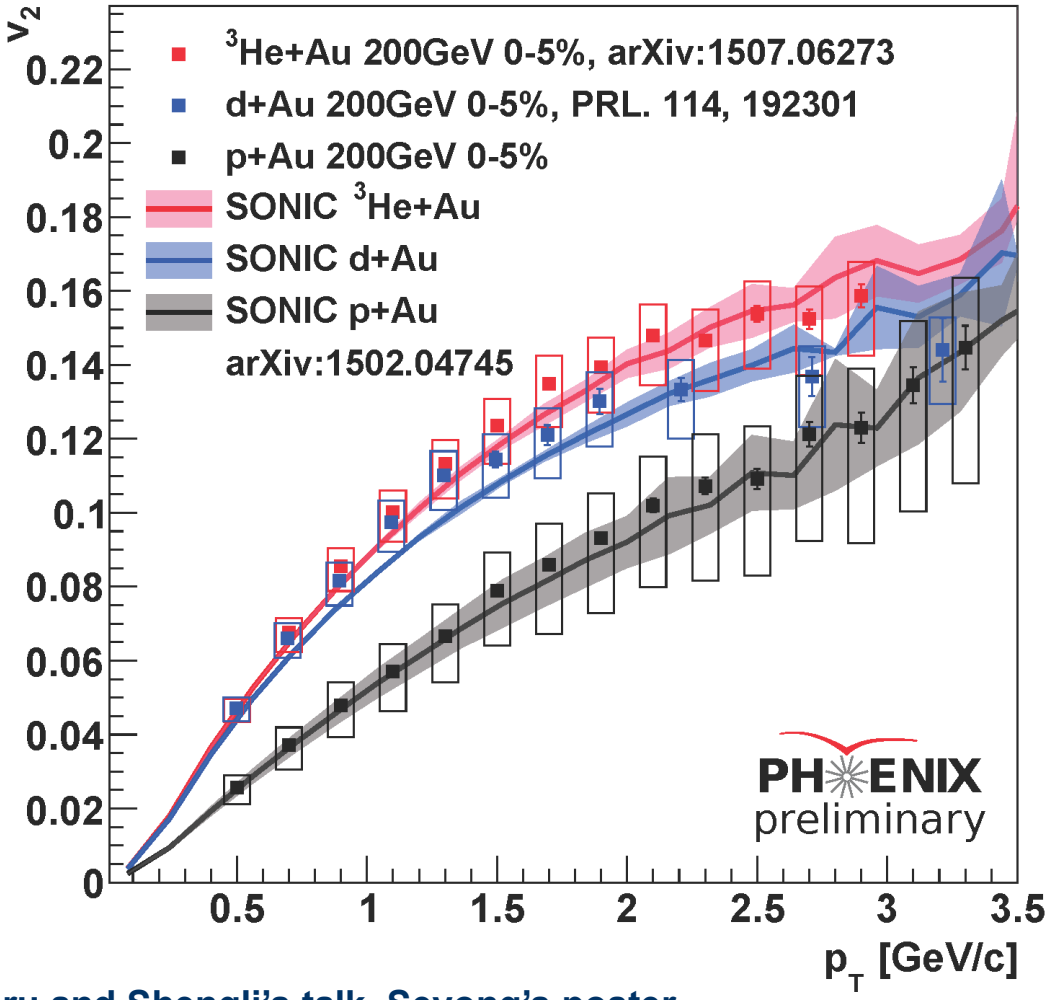
- -c2/c1 with line at 0.25





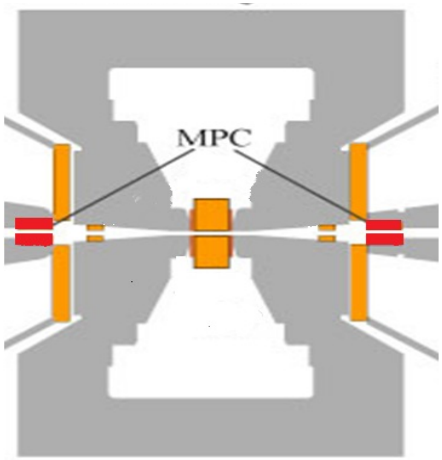


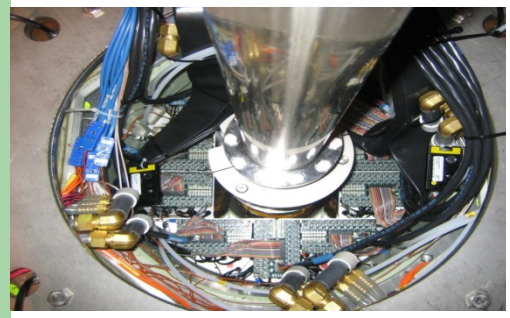
Comparing with new collision systems

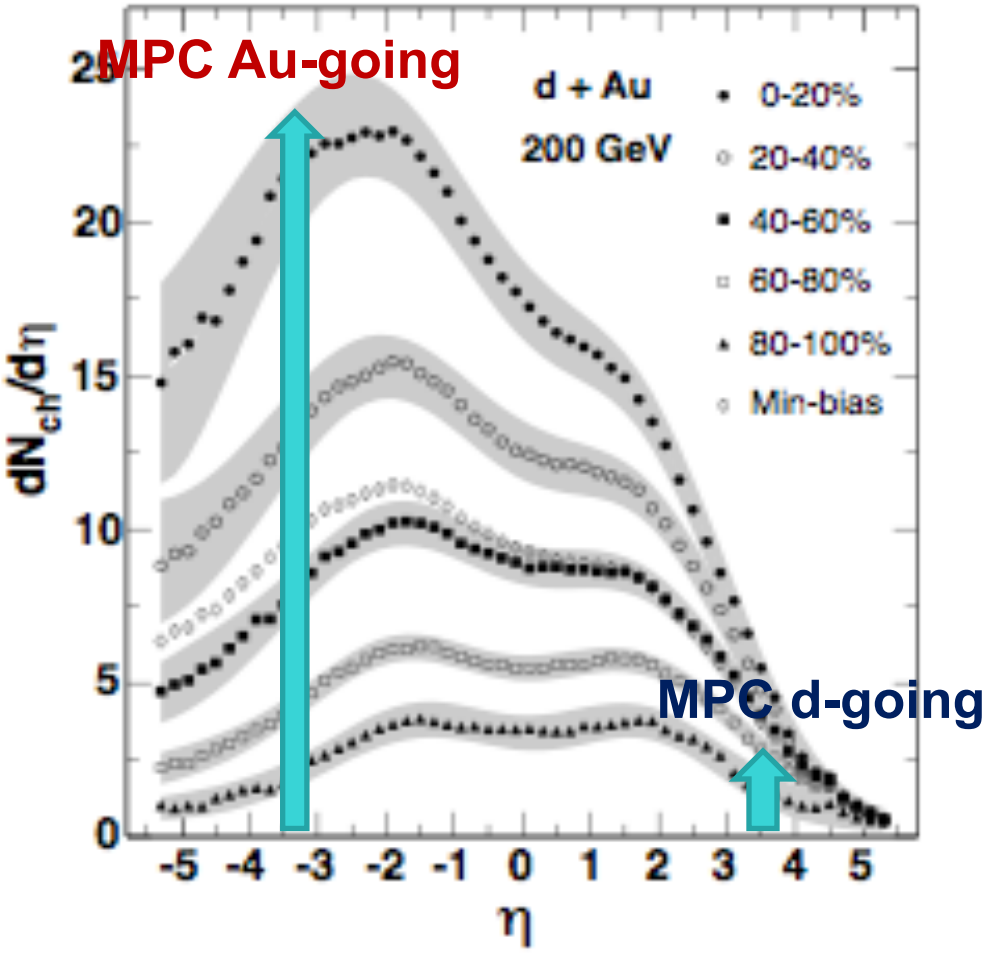


Pointer to Itaru and Shengli's talk, Seyong's poster

Extend the rapidity range





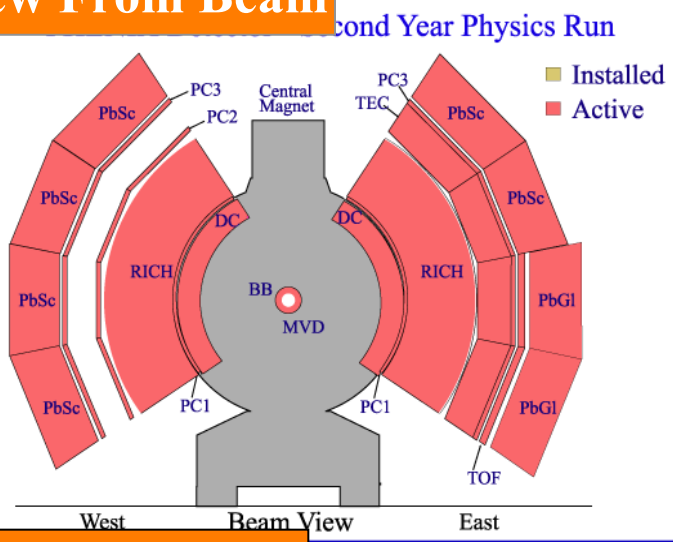


- Muon Piston Calorimeter
  Forward/backward-rapidity $3<|\eta|<4$
- Extend the rapidity range by measuring the correlation between Tracks ($<|\eta|<0.35$) and MPC towers: $|\Delta\eta|>2.75$!

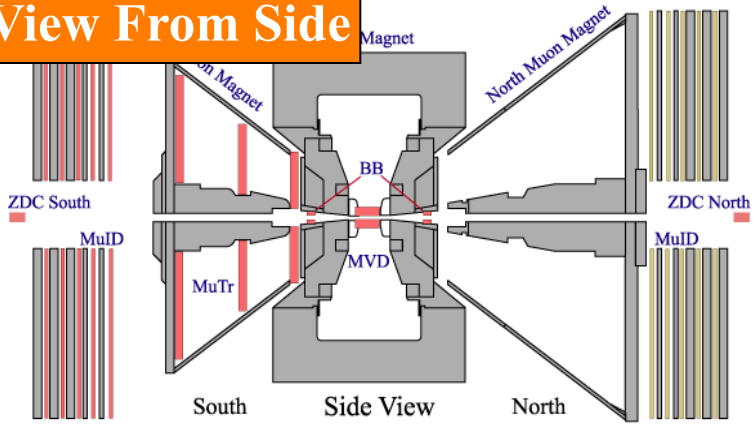
PHOBOS Phys. Rev. C72, 031901

PHENIX Detector and analysis

View From Beam



View From Side



- Photon measurement
  - EMCal(PbSc, PbGl): Energy measurement and identification of real photons
  - Tracking(DC, PC): Complement Veto to Charged particles
- Charge particle measurement
  - RICH: Identify electrons
  - Tracking(DC, PC): Momentum measurement of electrons
  - EMCal(PbSc, PbGl): Complement information on identifying electrons

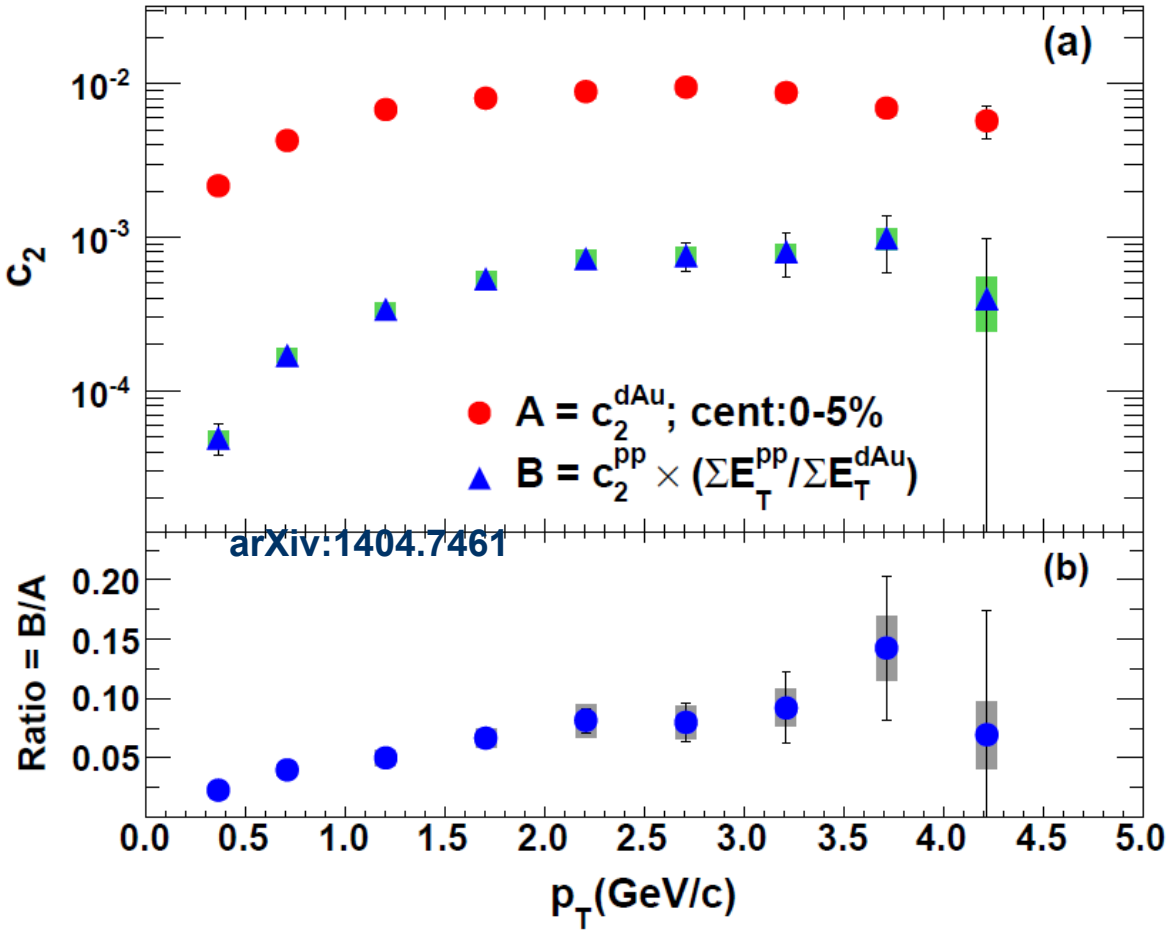
$$\frac{\sigma_E}{E} = \frac{8.1\%}{\sqrt{E}} \oplus 2.1\%. \quad \textbf{(PbSc)}$$

$$\frac{\sigma_E}{E} = \frac{5.9\%}{\sqrt{E}} \oplus 0.76\%. \quad \textbf{(PbGl)}$$

- Event triggered by BBC and ZDC
  - Select Minimum bias events
  - And, event plane detectors..

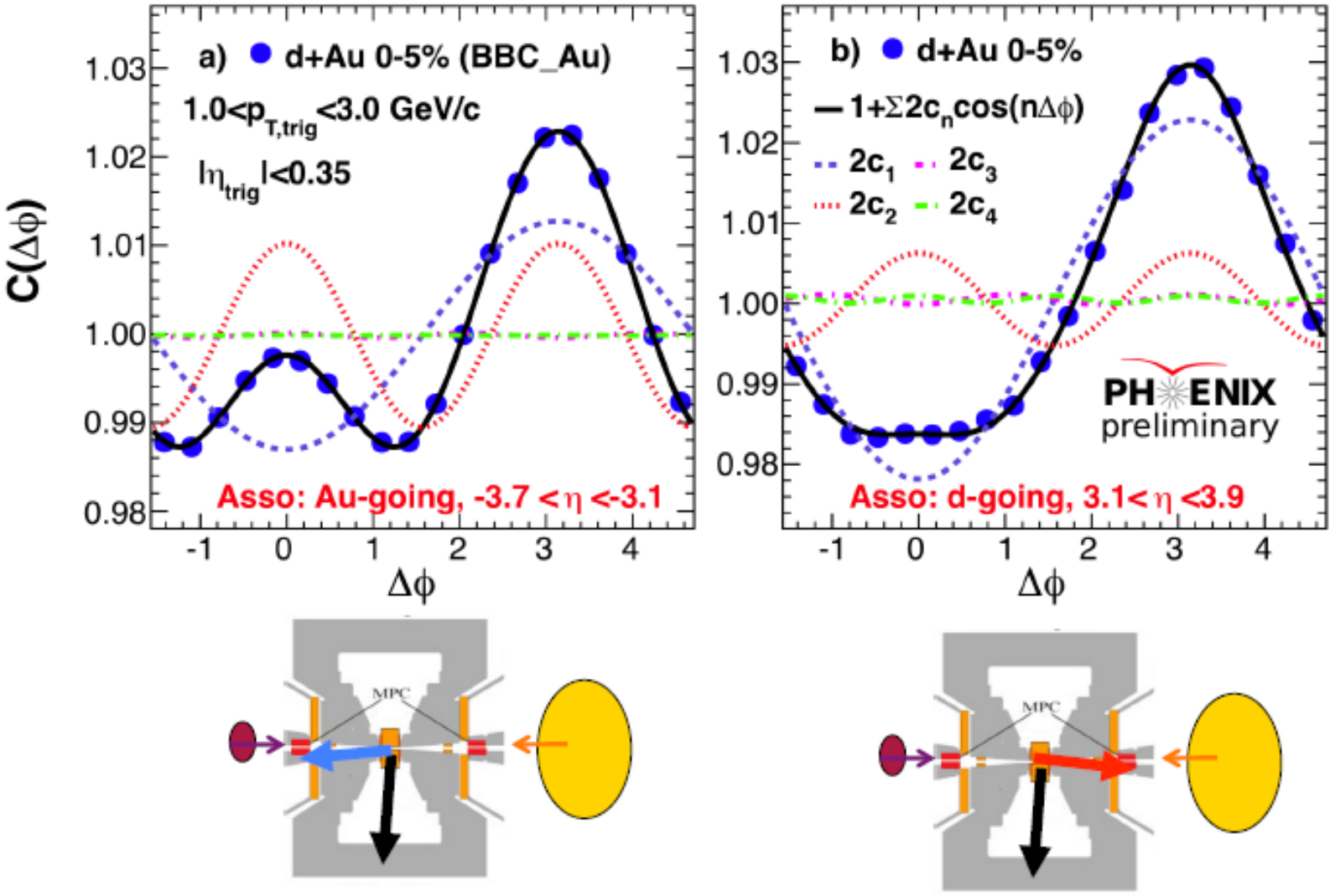
PHENIX recorded d+Au events of 80 nb^{-1} in 2008 (2.74 nb^{-1} in 2003)

Compare c_2 from d+Au and p+p

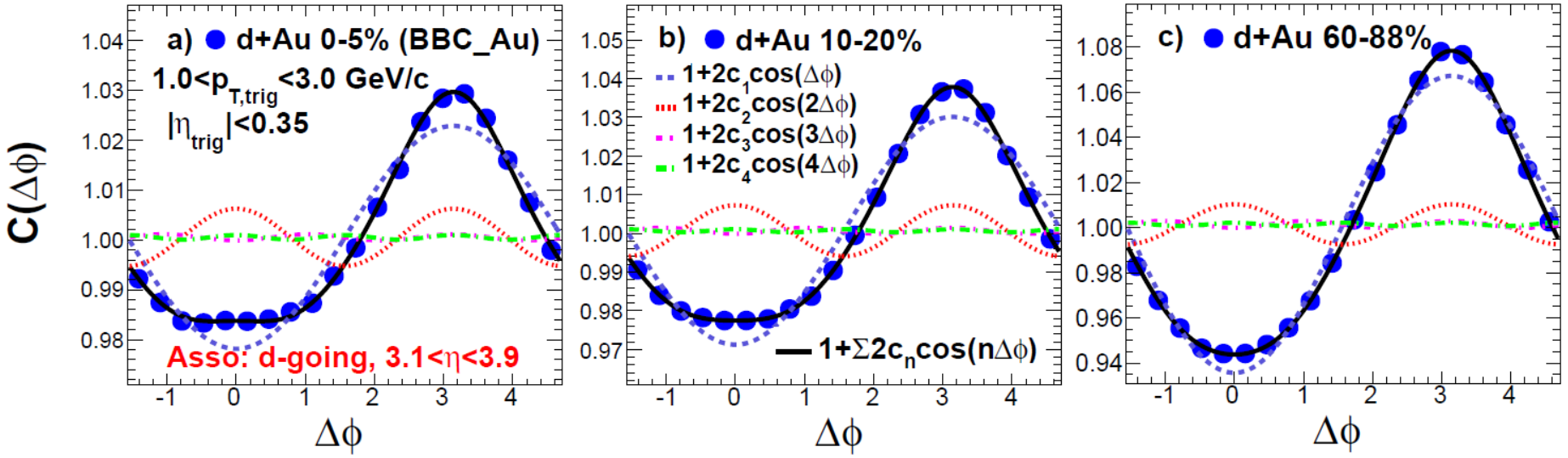


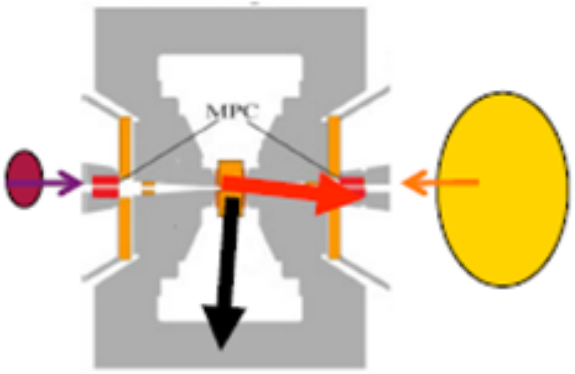
The difference indicates that the contribution from di-jet, resonance decay … is less than 10% for

"Au-going" vs "d-going"



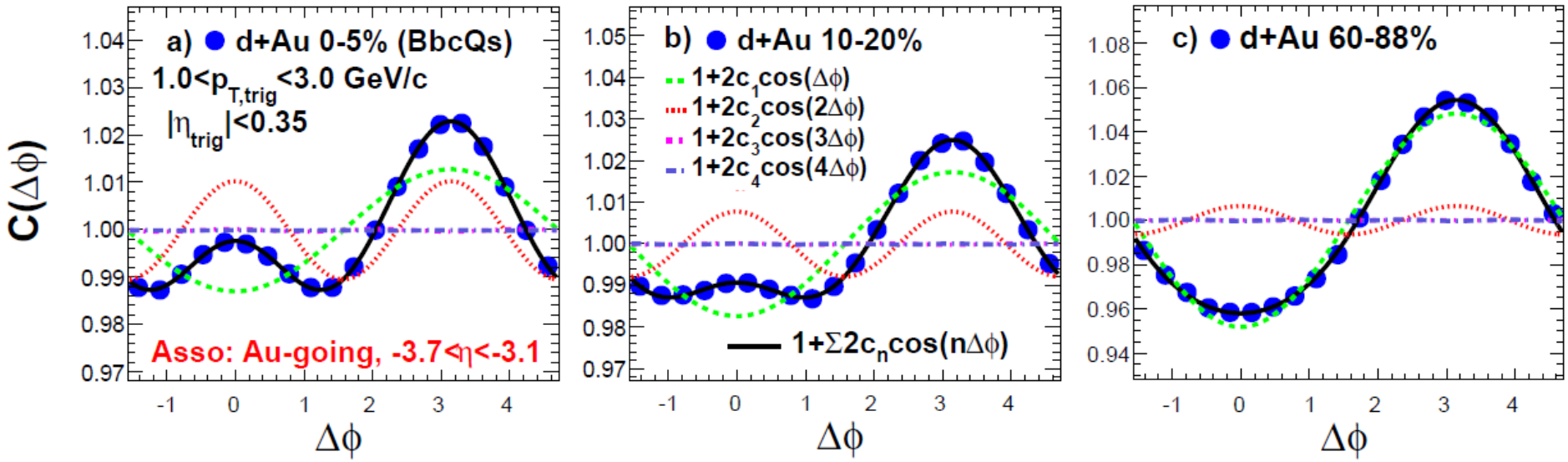
mid-forward(d-going) correlation

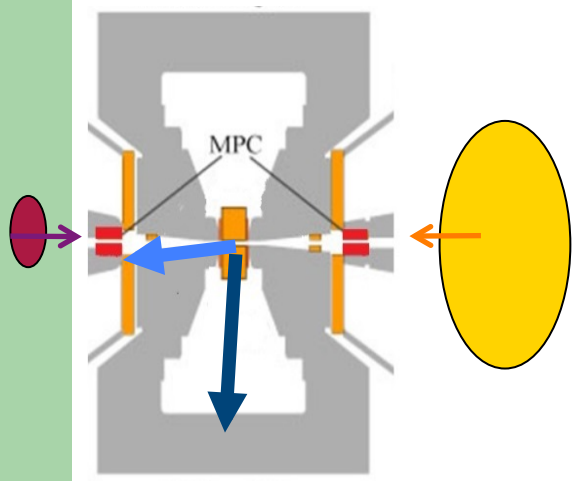




- The mid-forward rapidity correlation in central d+Au is different from that in peripheral, even though there is no near-side peak

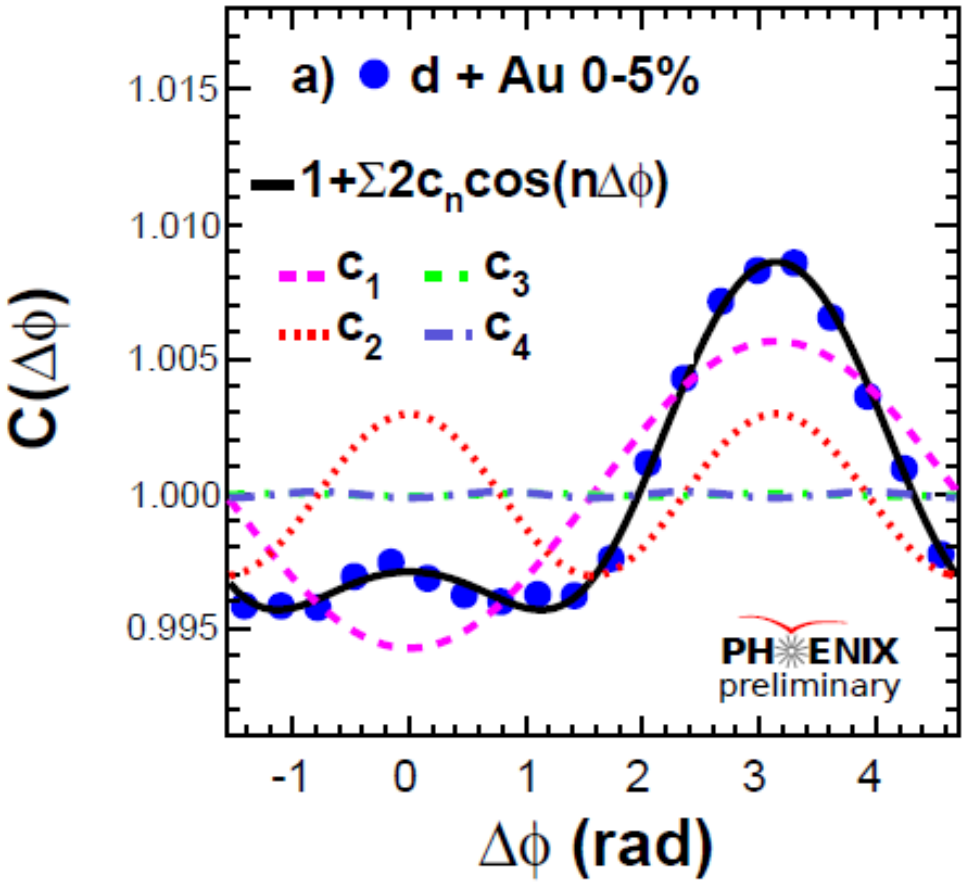
Mid-backward(Au-going) correlation

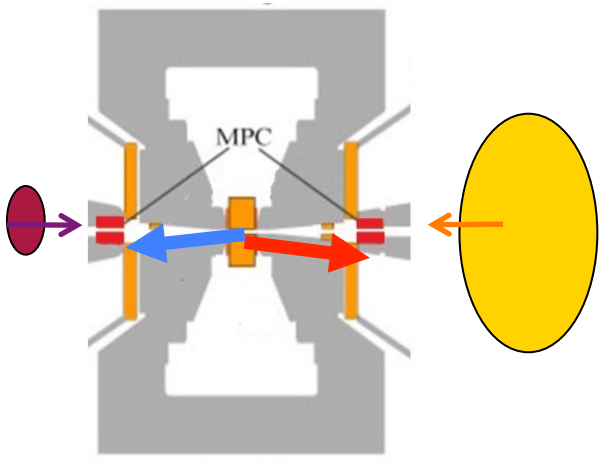




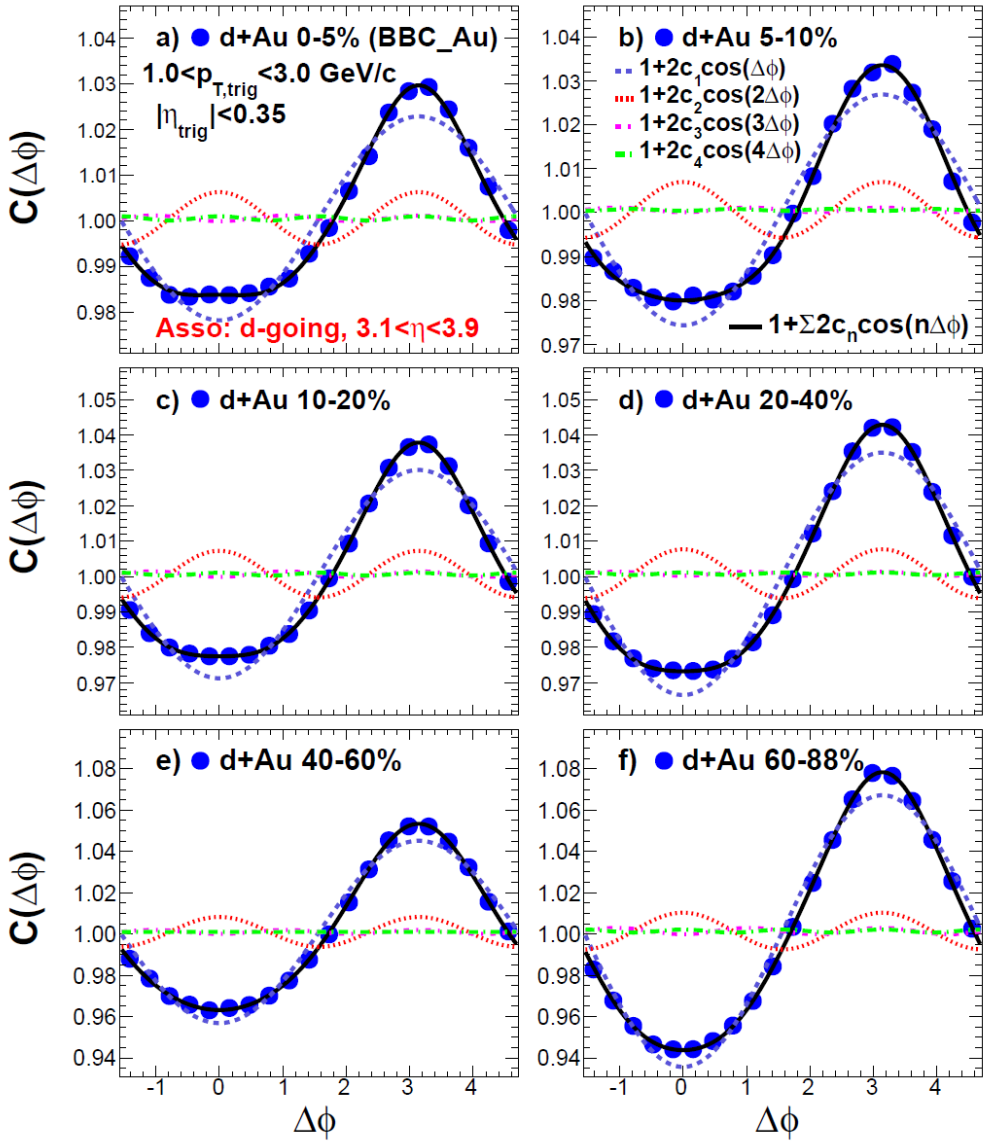
- The near-side peak is visible until 10-20% centrality
- In peripheral collisions, the Au-going correlation is similar to the d-going correlation

A ridge is observed with| Δη |>6.0





- Correlation between Au-going and d-going MPC towers


a) d+Au 0-5% (BBC_Au)
1.0<p_T,trig<3.0 GeV/c
|η_trig|<0.35
Asso: d-going, 3.1<η<3.9
b) d+Au 5-10%
1+2c_1cos(Δφ)
1+2c_2cos(2Δφ)
1+2c_3cos(3Δφ)
1+2c_4cos(4Δφ)
1+Σ2c_ncos(nΔφ)
c) d+Au 10-20%
d) d+Au 20-40%
e) d+Au 40-60%
f) d+Au 60-88%
C(Δφ)
Δφ