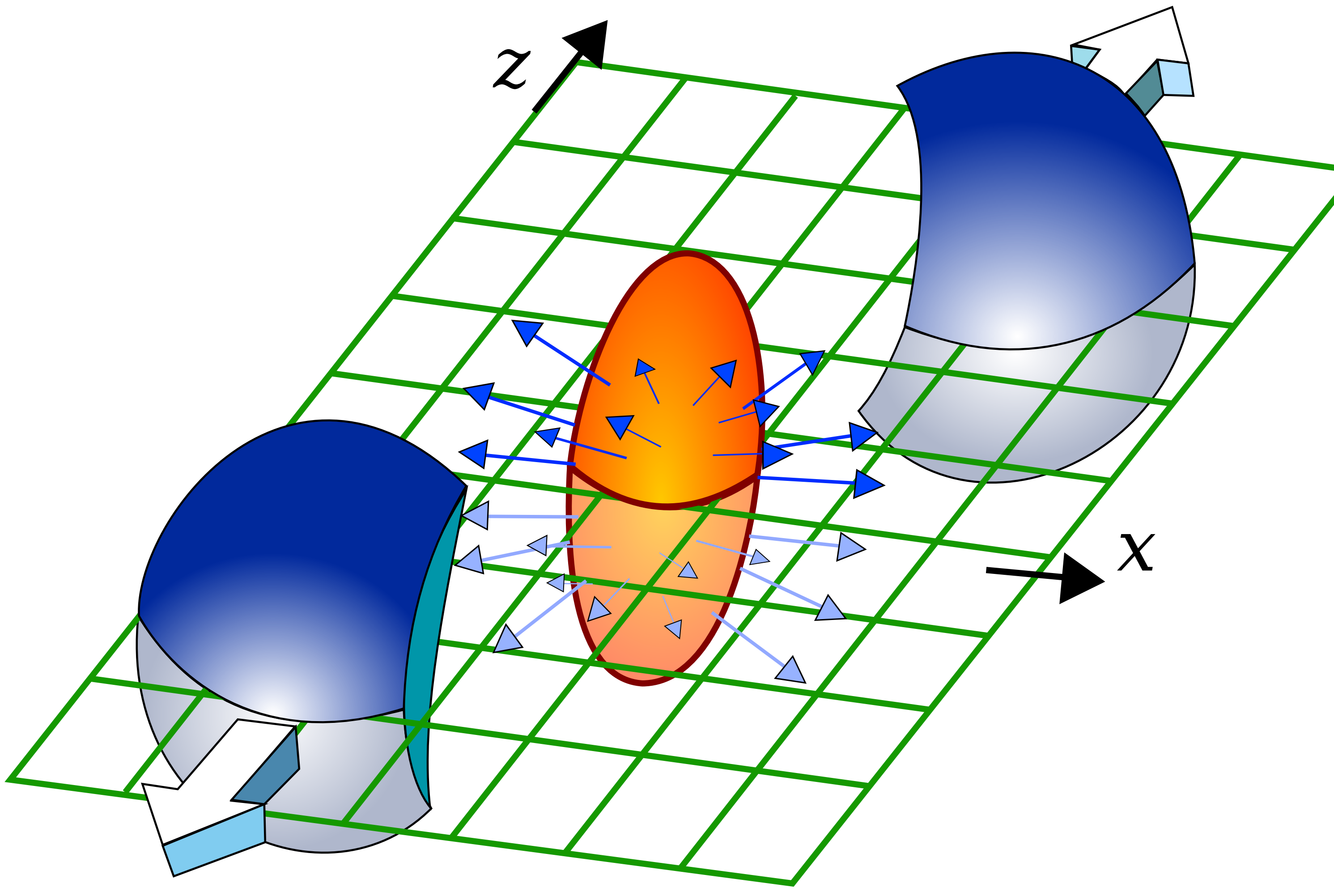
Big Questions from Small Systems: dAu at RHIC

Anne M. Sickles
Brookhaven

DNP Newport News 2013

hydrodynamics in heavy ions



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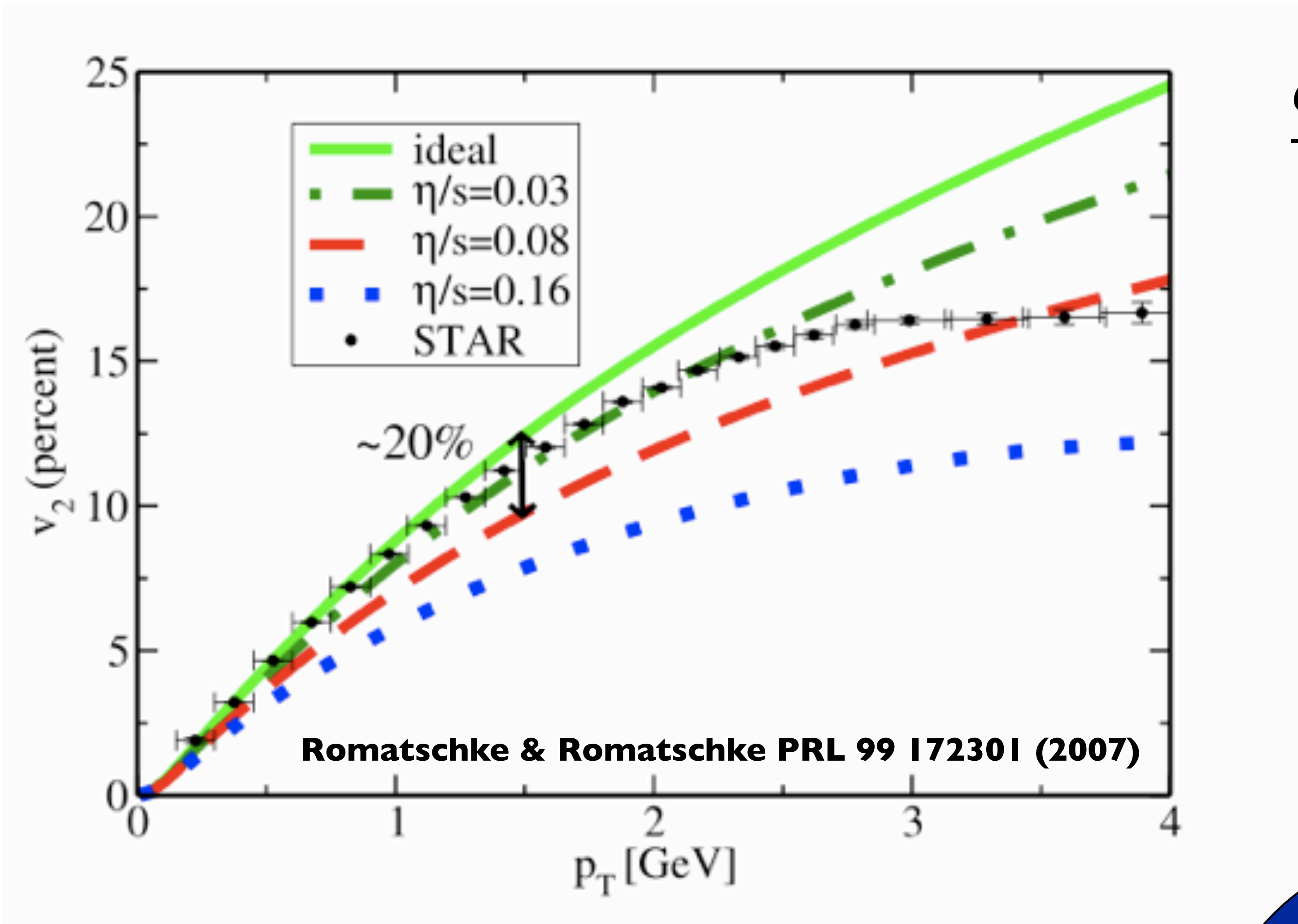
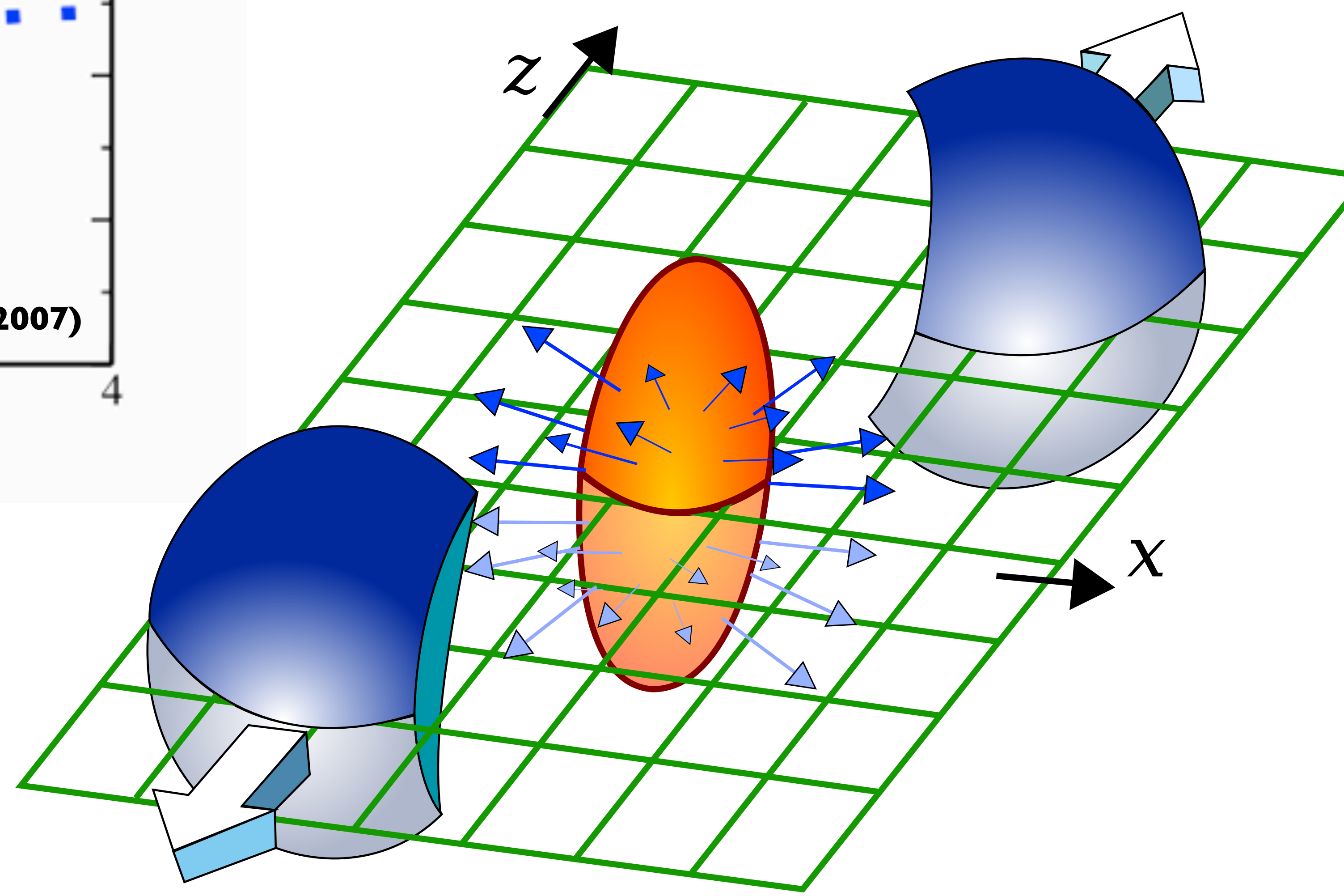
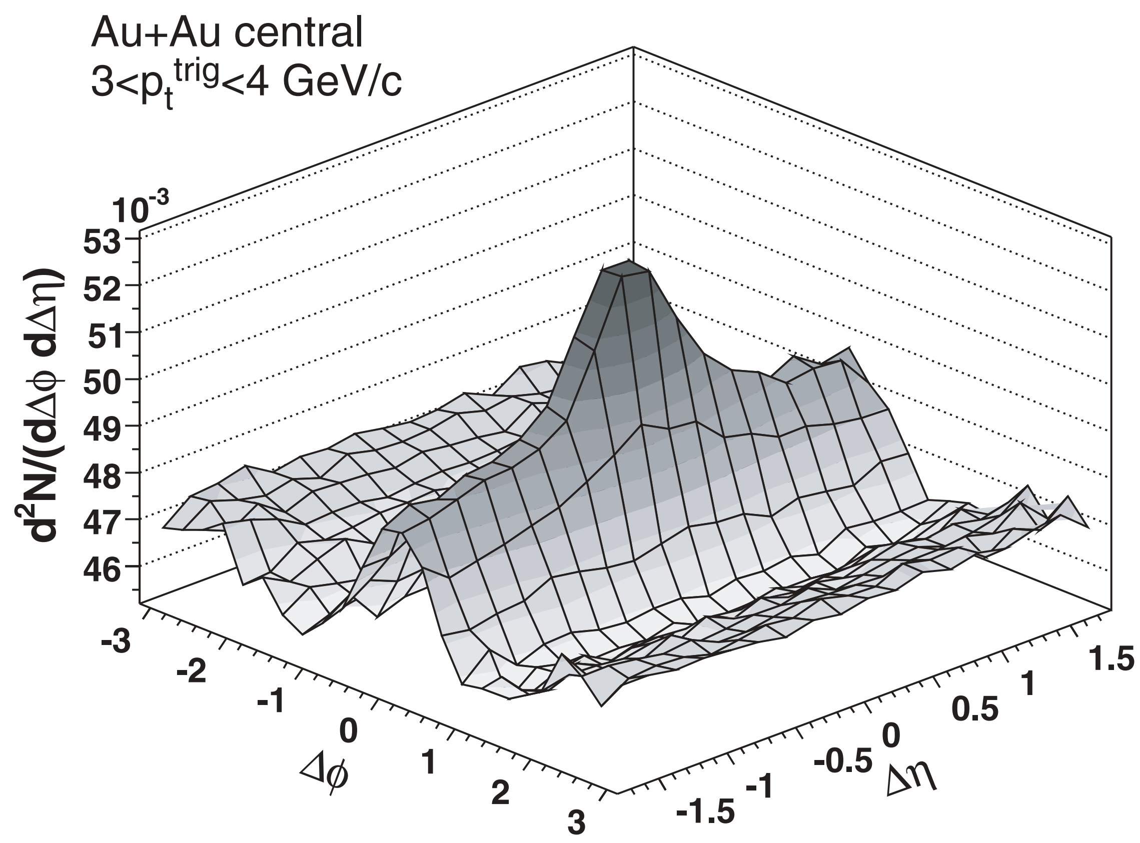


$$\frac{dN}{d\phi} \propto 1 + 2 v_2 \cos 2(\phi - \Phi_{RP})$$



the ridge in heavy ion collisions

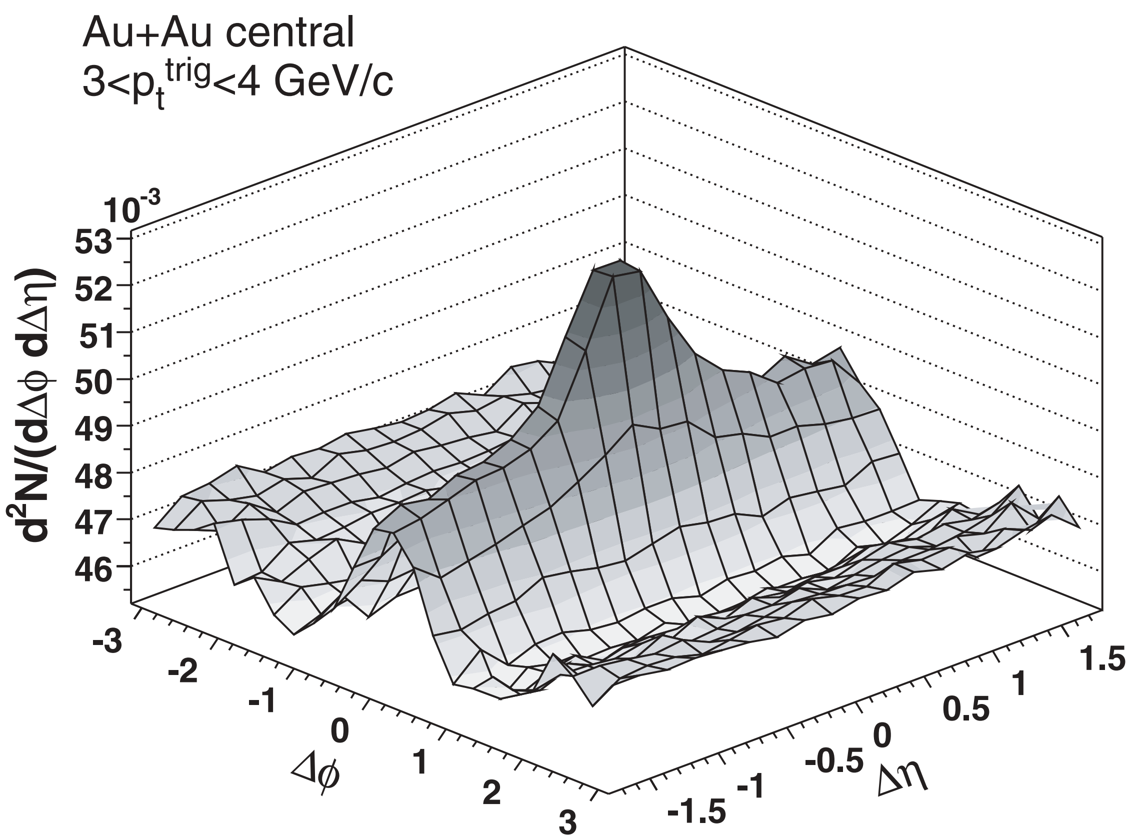


the ridge: long range $\Delta\eta$ correlation in heavy ion collisions

many theoretical explanations proposed...

STAR PRC80 064912
ALICE PLB708 249
Alver & Roland PRC81 054905

the ridge in heavy ion collisions



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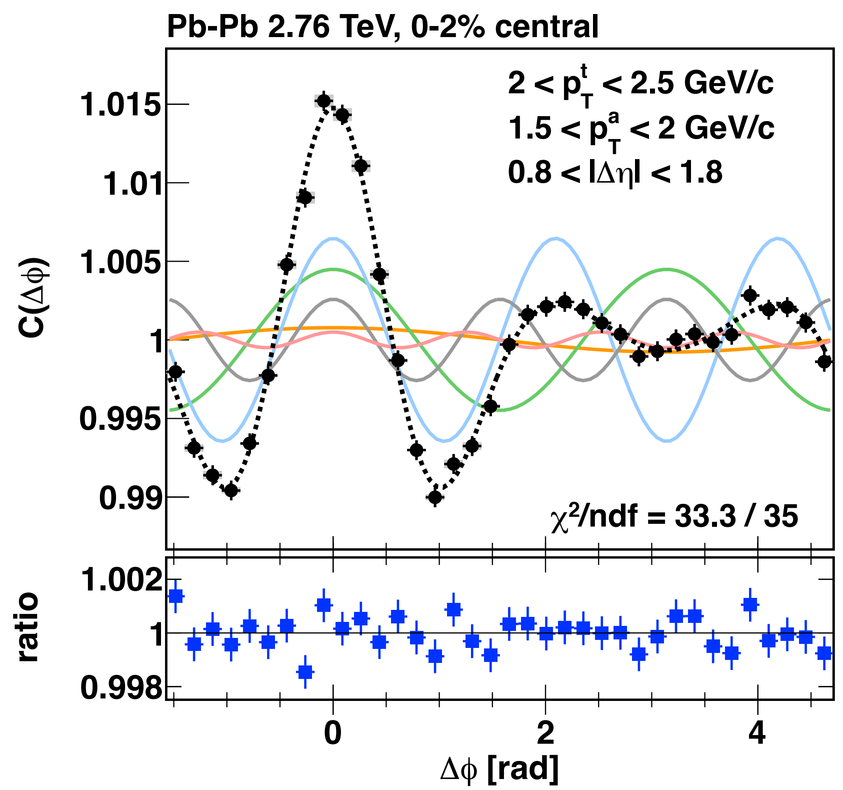

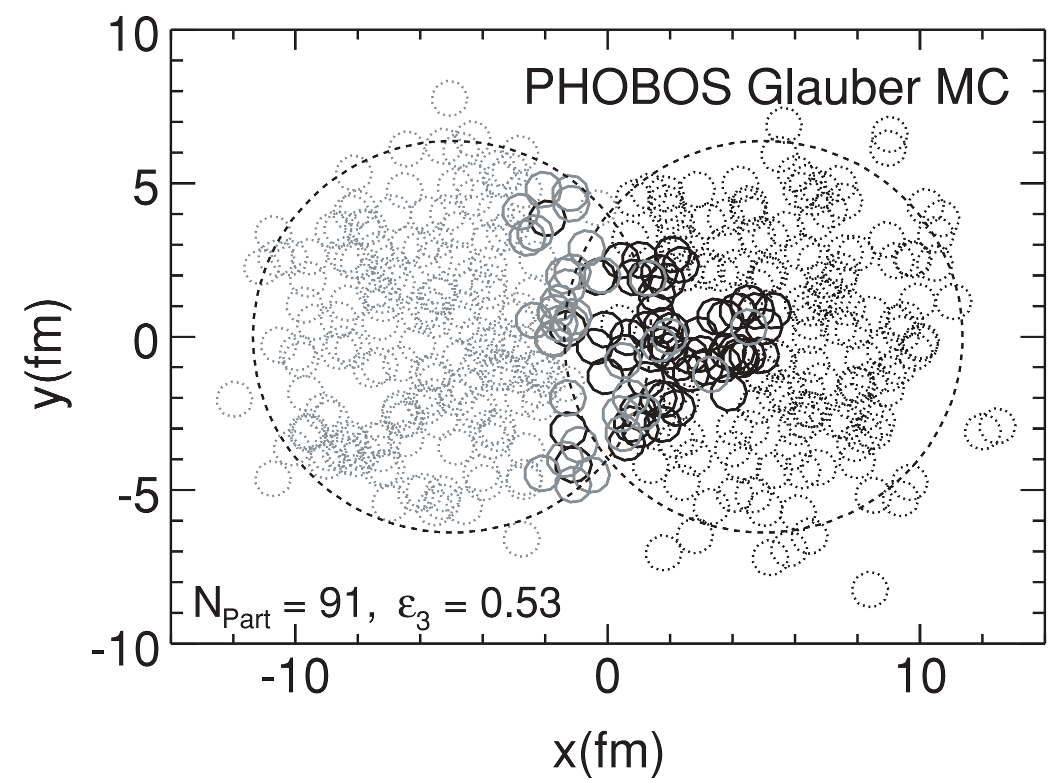

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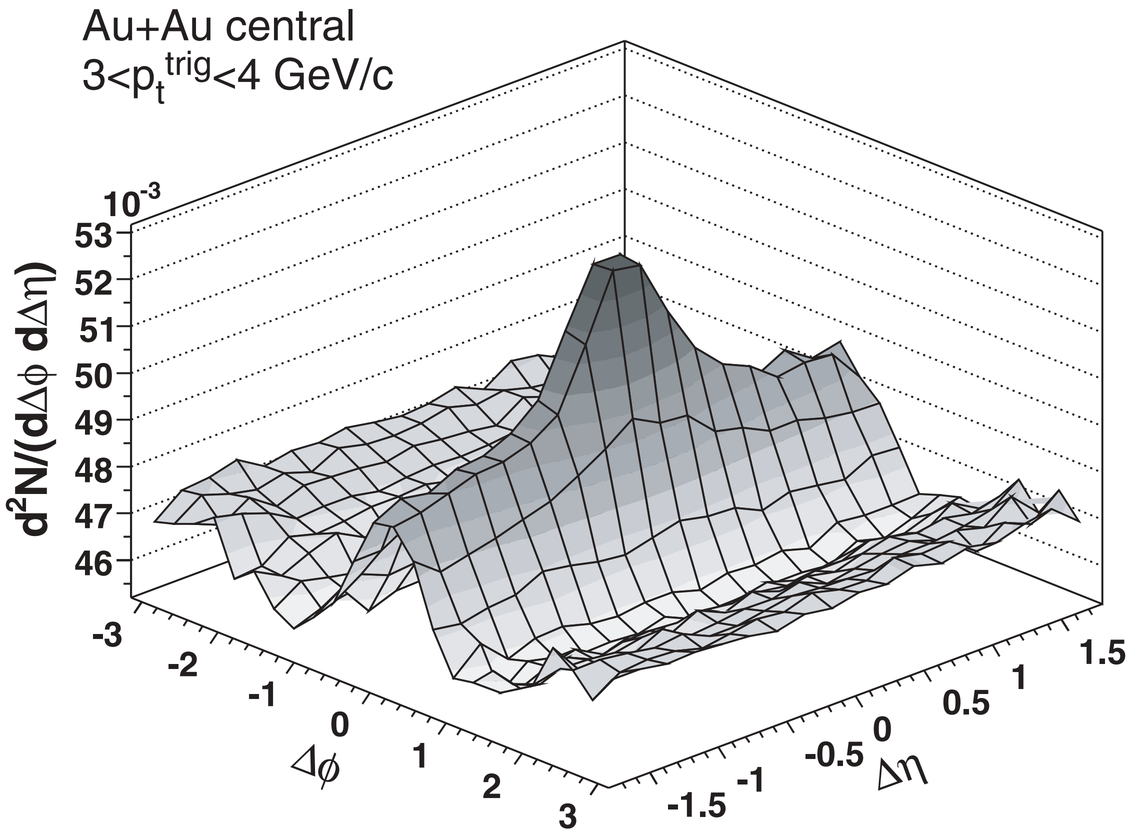
the ridge in heavy ion collisions



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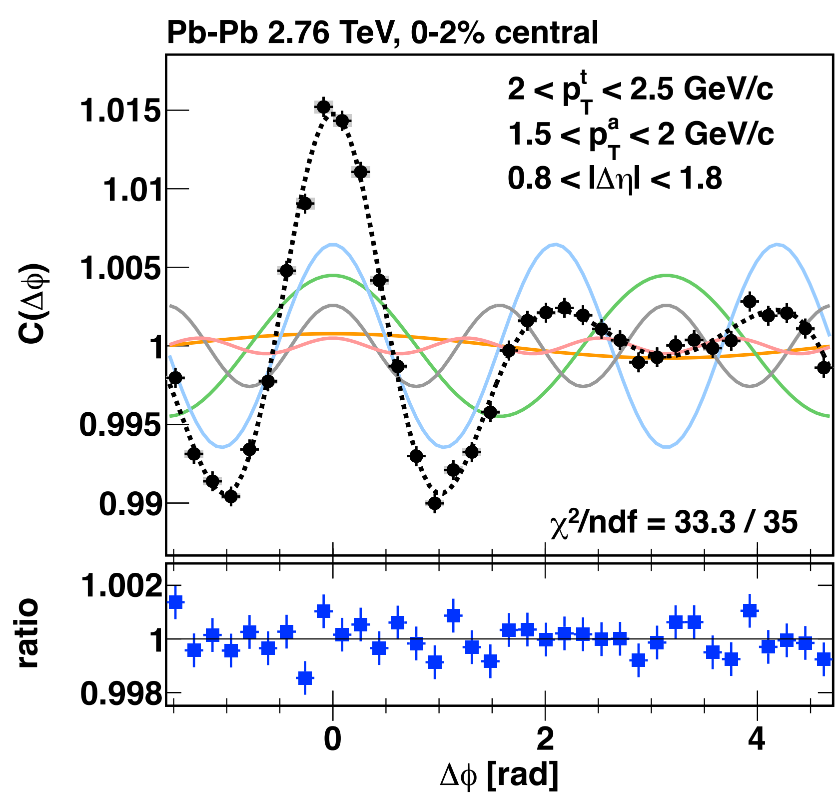

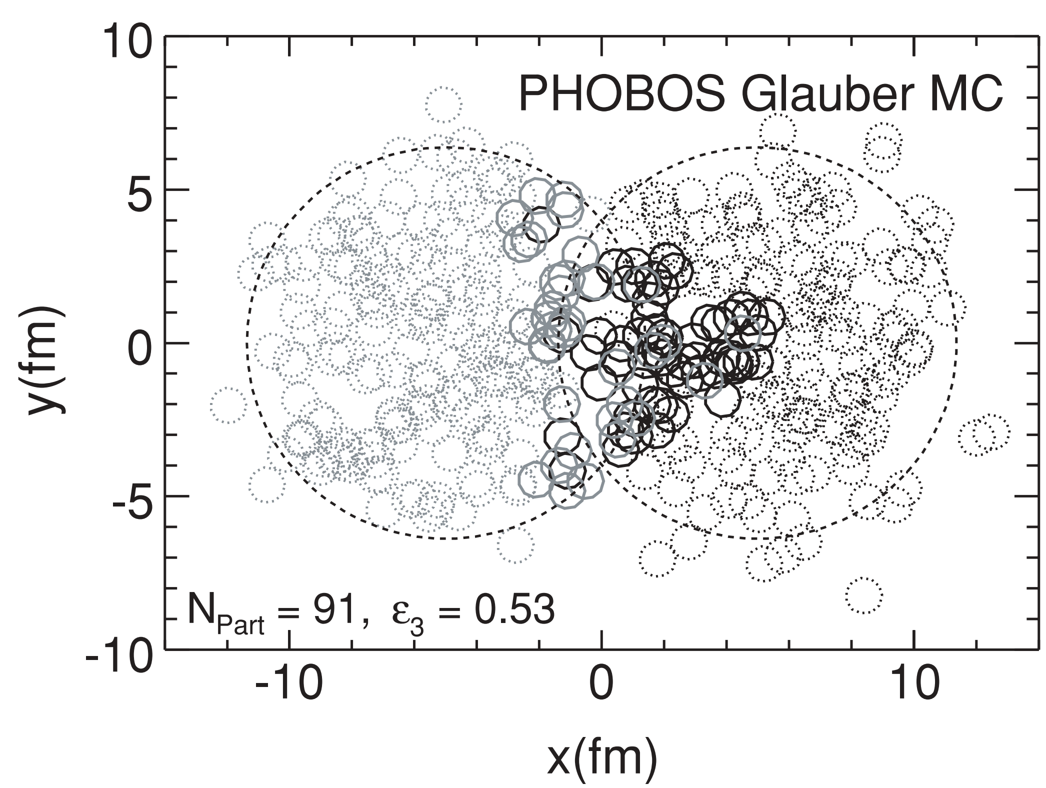

ridge: geometry + hydrodynamic evolution

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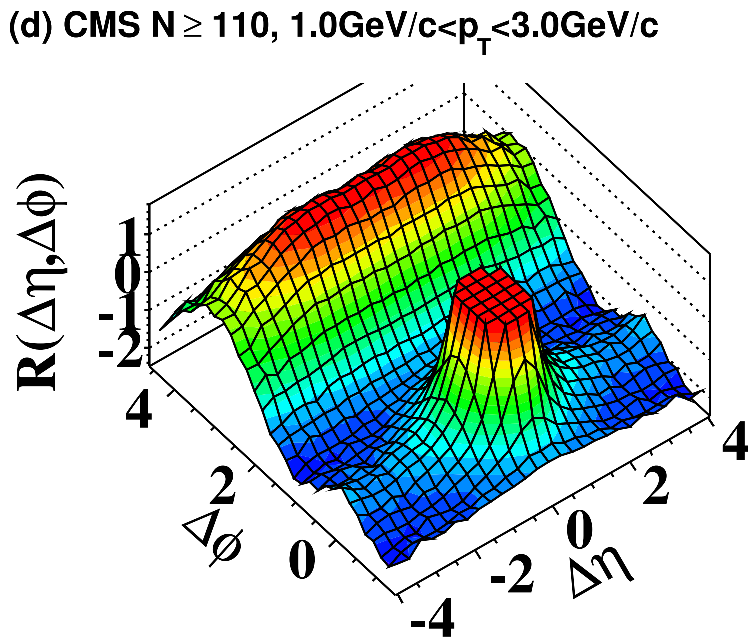
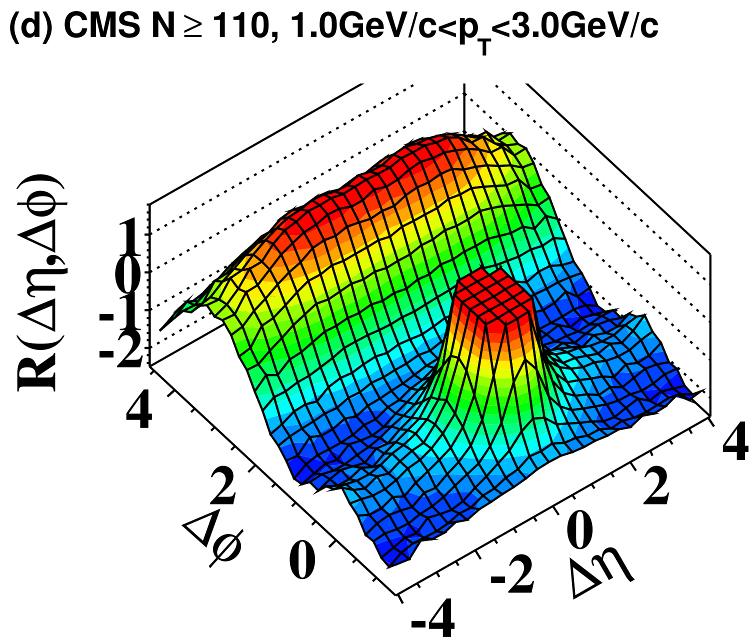
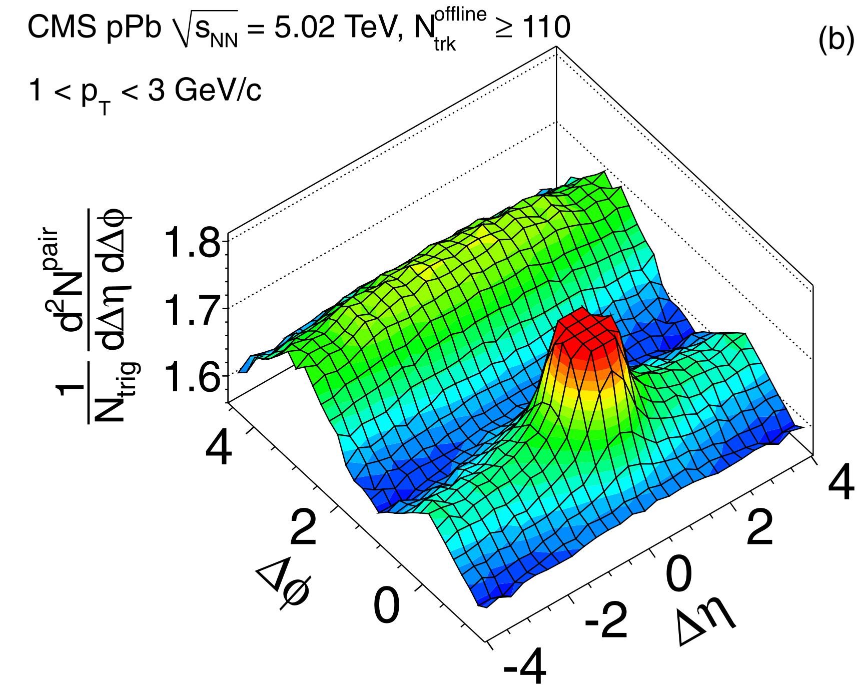
pp & pPb ridges



CMS PLB 718 795 (2013)
ALICE PLB 719 29
ATLAS PRL 110 182302

pp & pPb ridges





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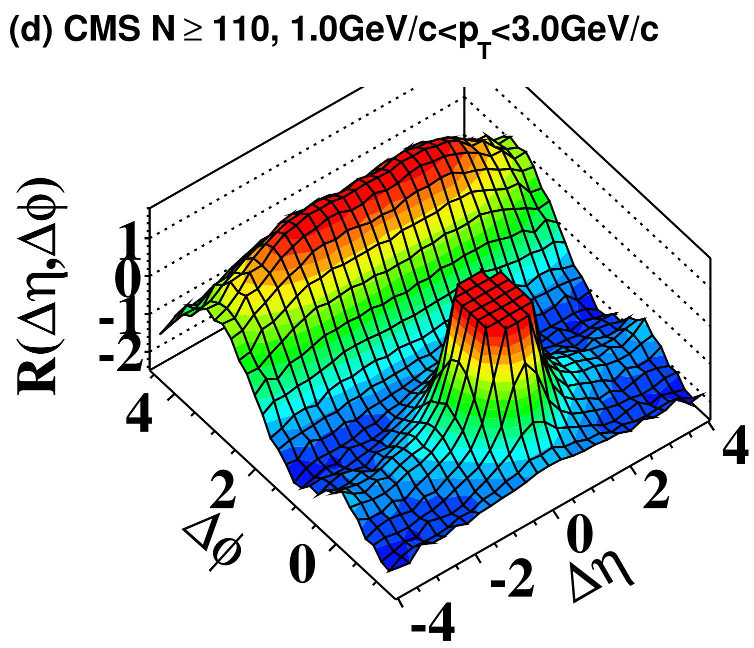

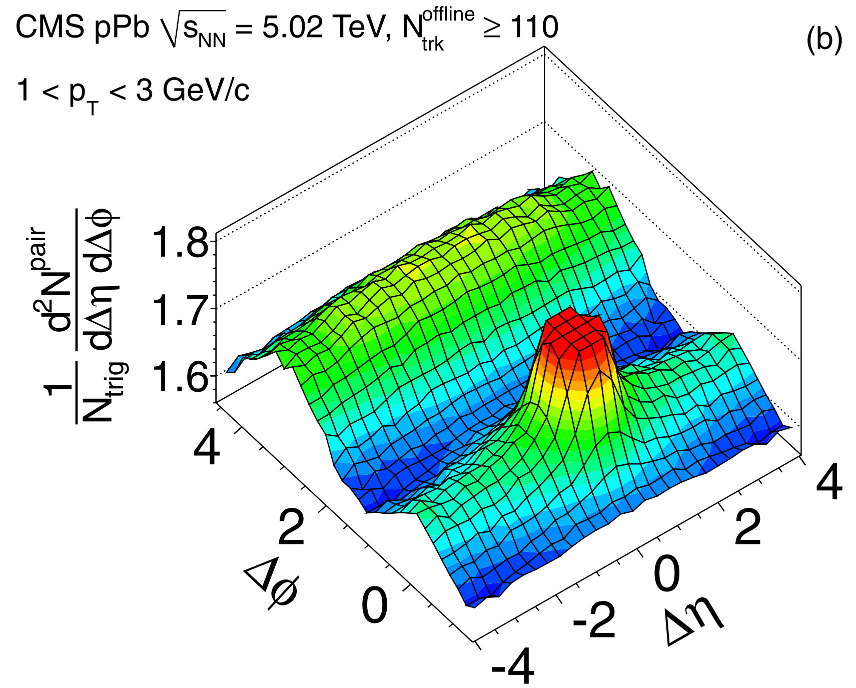

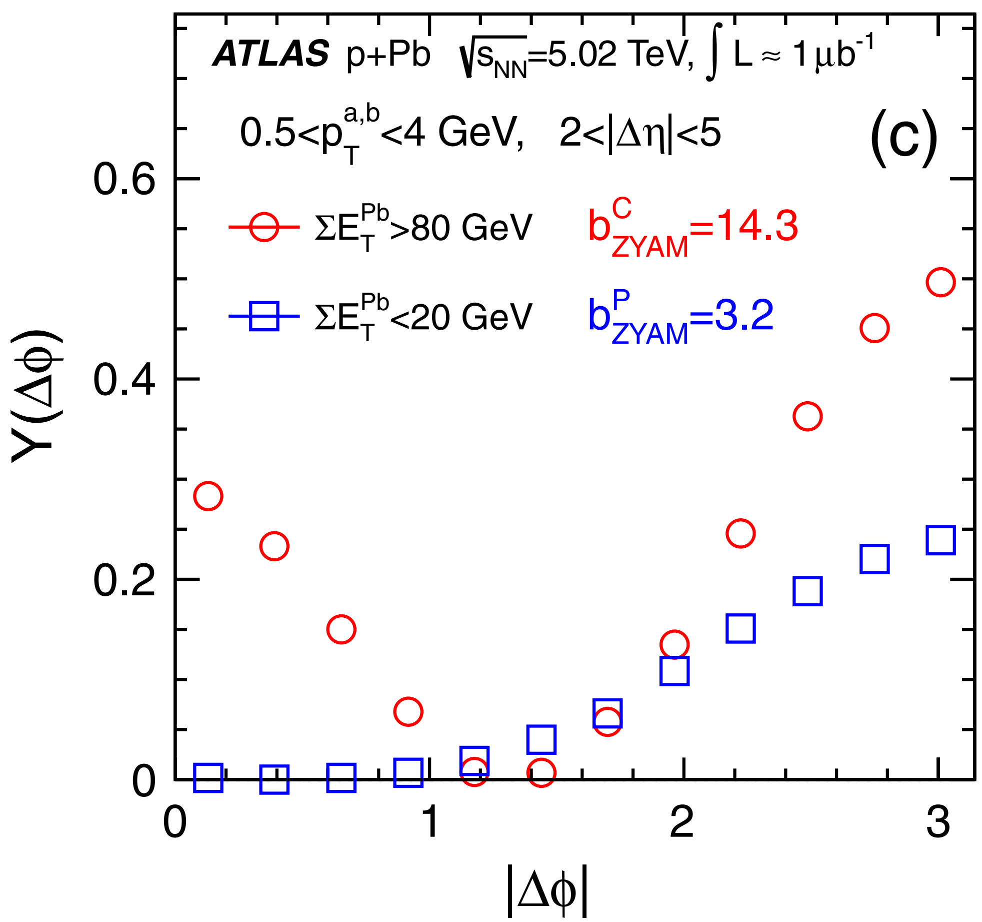

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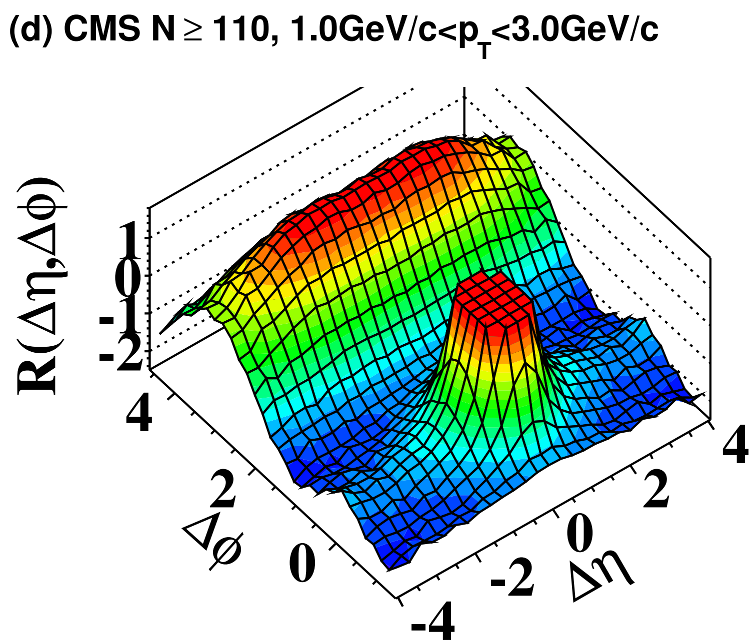

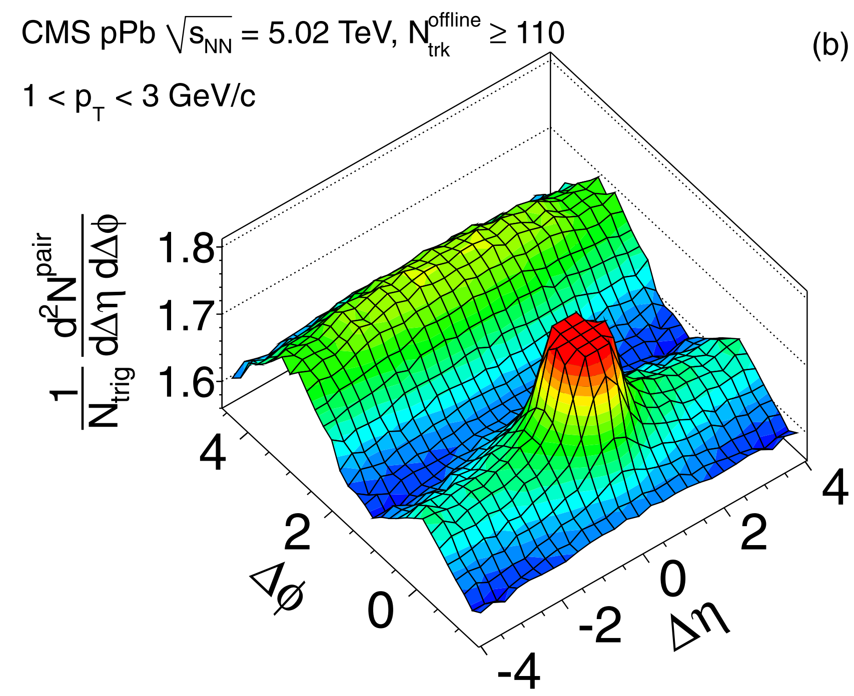

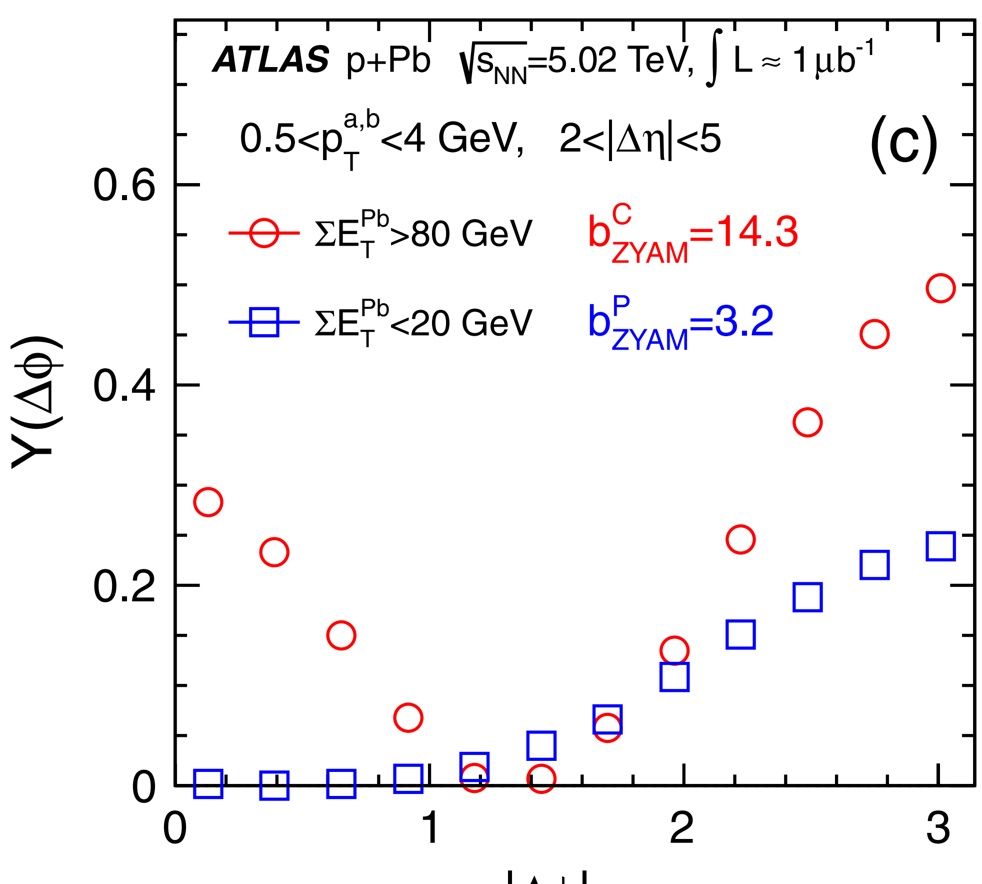

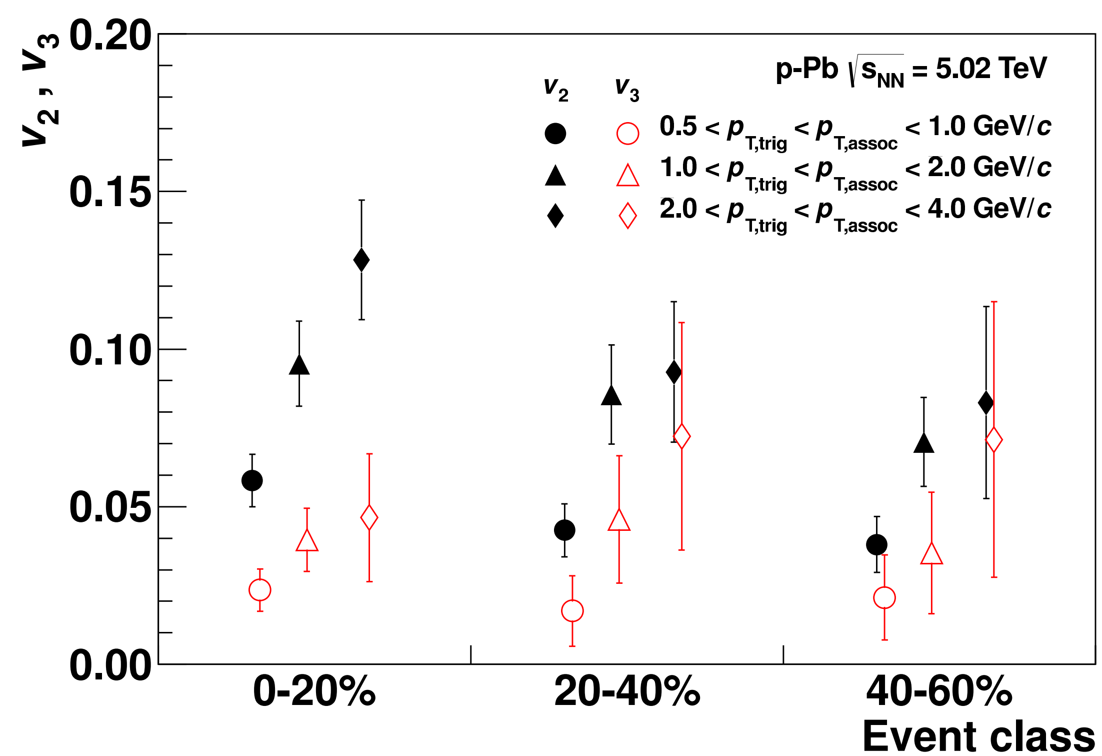

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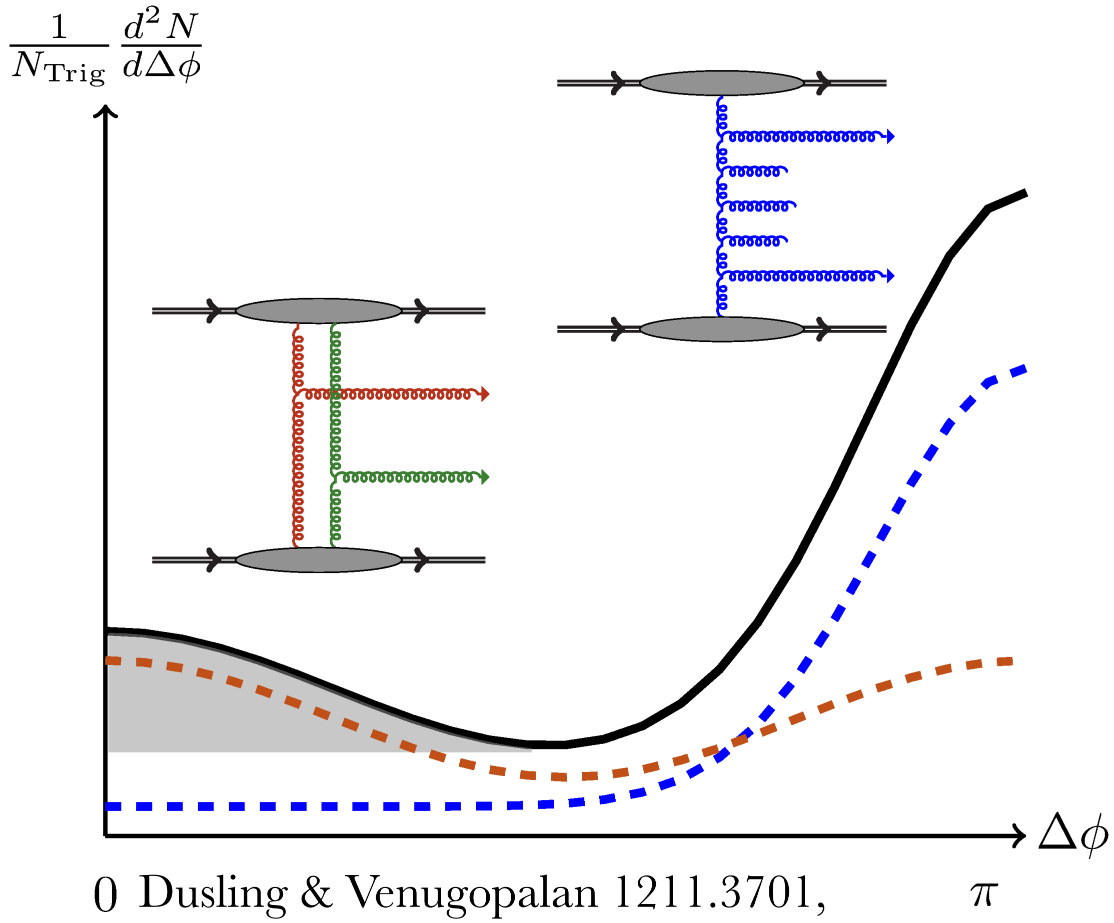
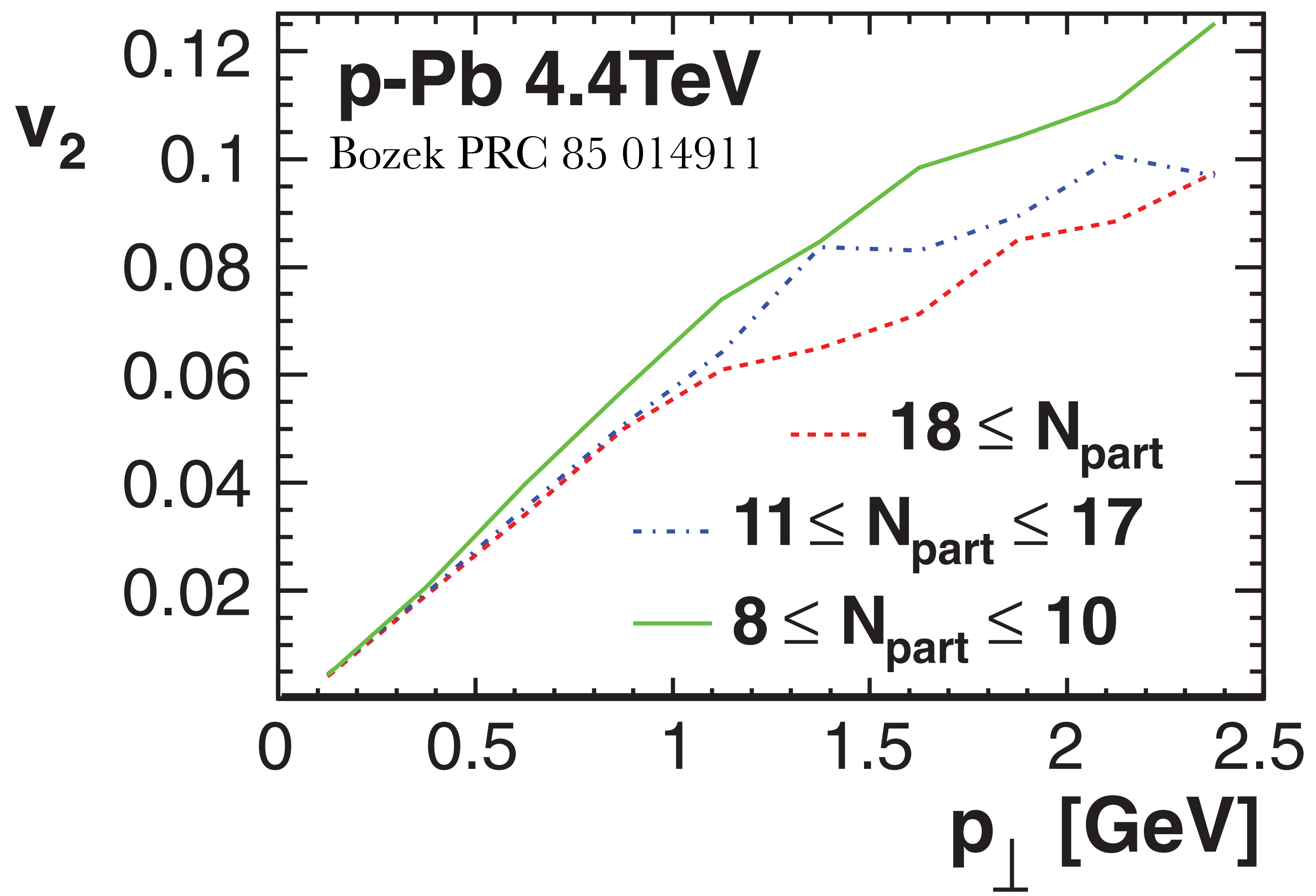
ridge in small systems



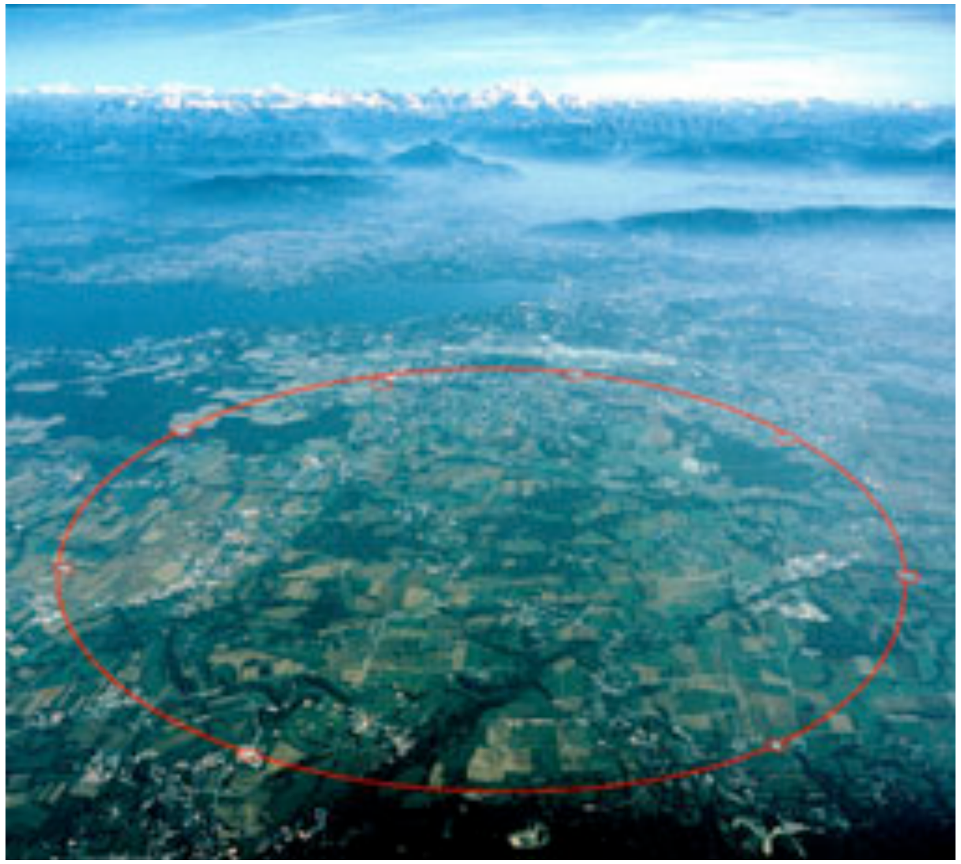
Dusling & Venugopalan 1211.3701, 1302.7018



Color Glass Condensate

hydrodynamics

RHIC & LHC

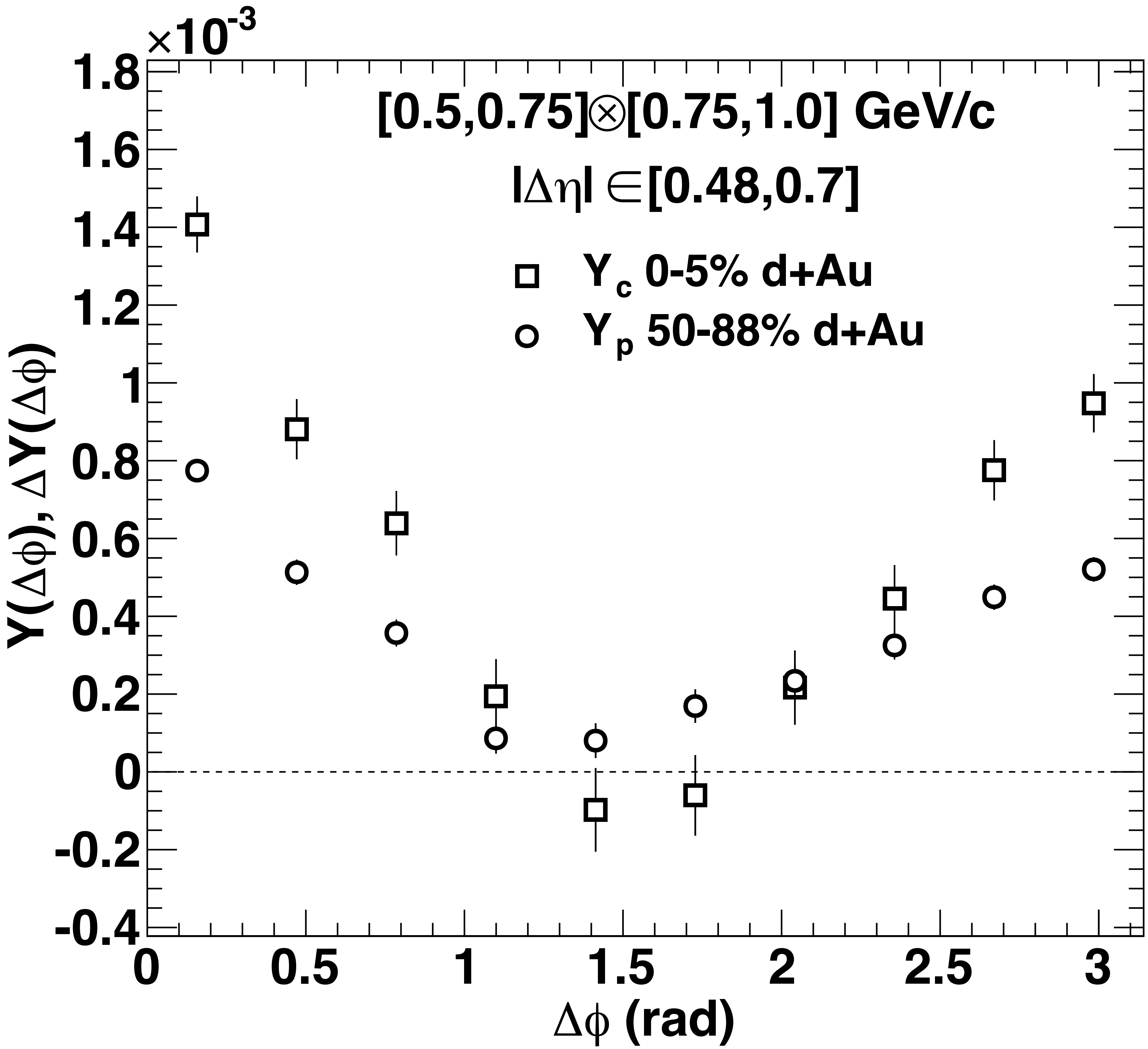


5.02TeV pPb

200GeV dAu

25x difference in collision energy
d-A vs p-A
large data sample already on tape

centrality dependence



central

peripheral

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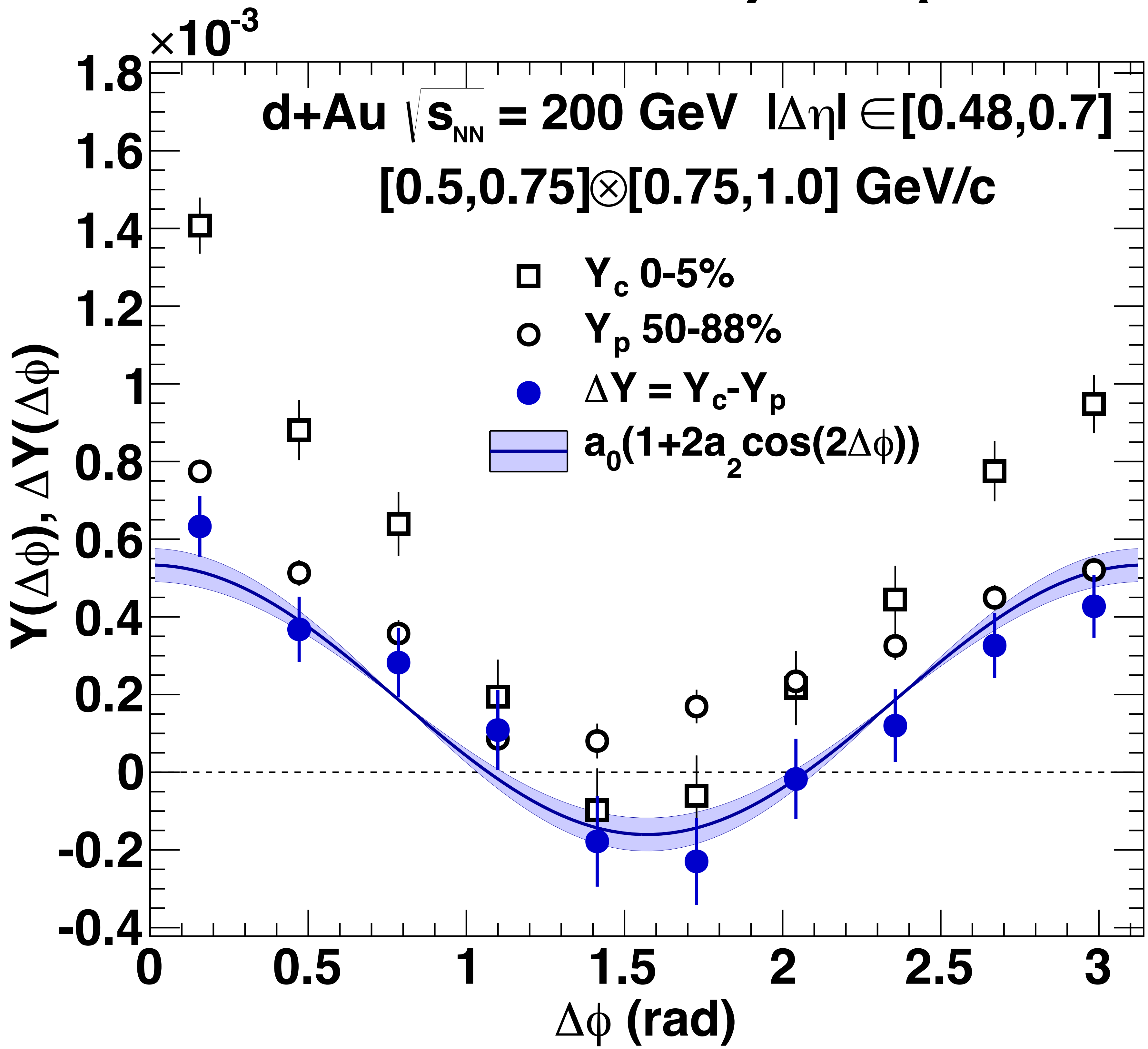
centrality dependence



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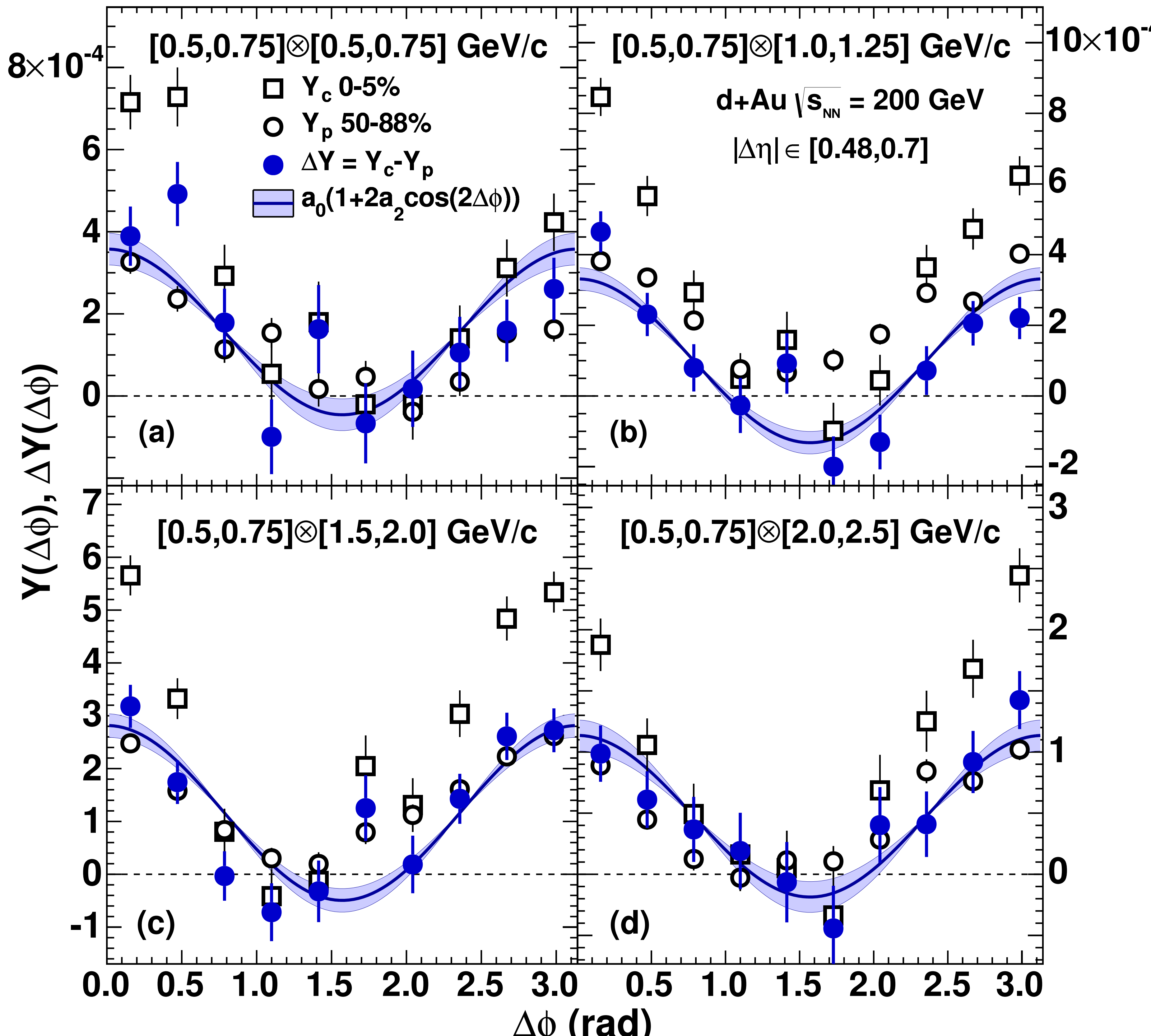
centrality dependence consistently described by cos2Δφ shape evidence for double ridge



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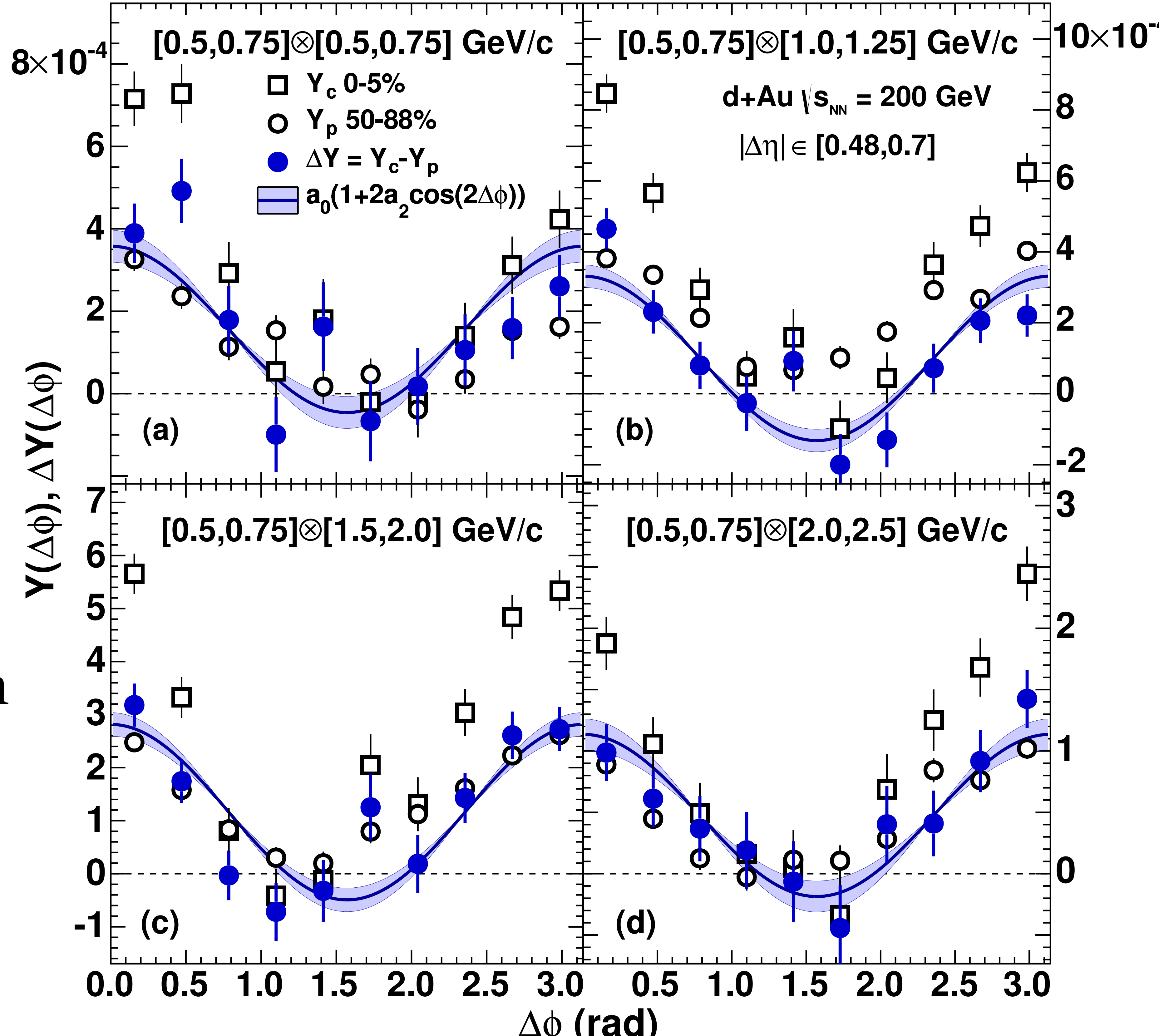
centrality dependence consistently described by cos2Δφ shape evidence for double ridge

but is this just an artifact of the small |Δη| acceptance?



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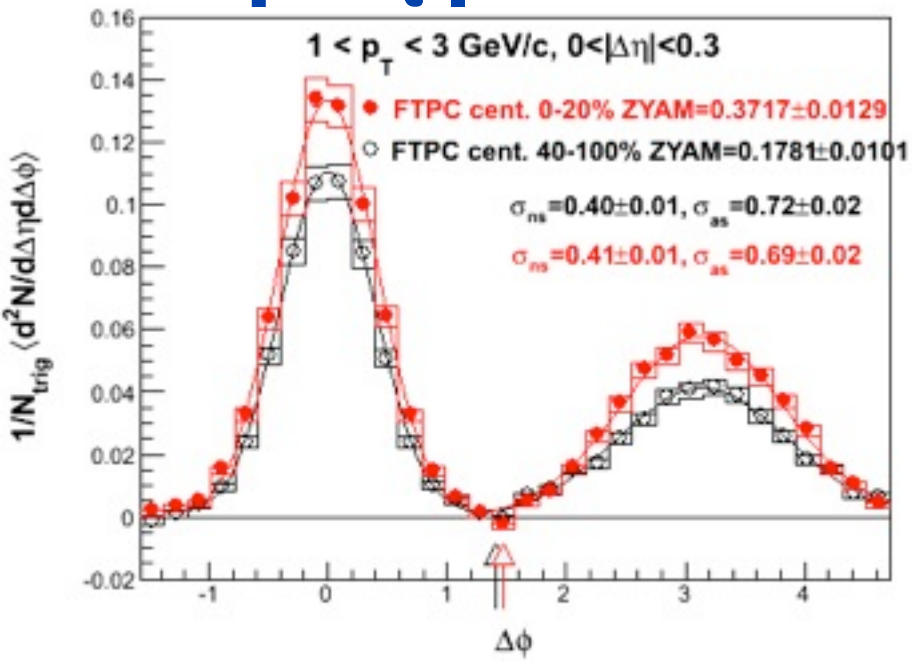
results from STAR

$|\Delta\eta|<0.3$



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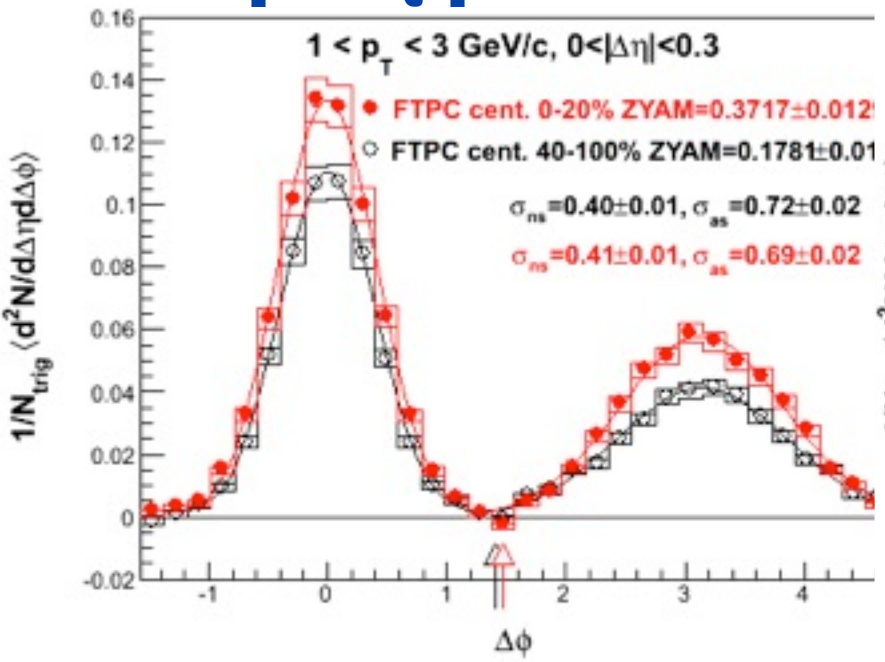
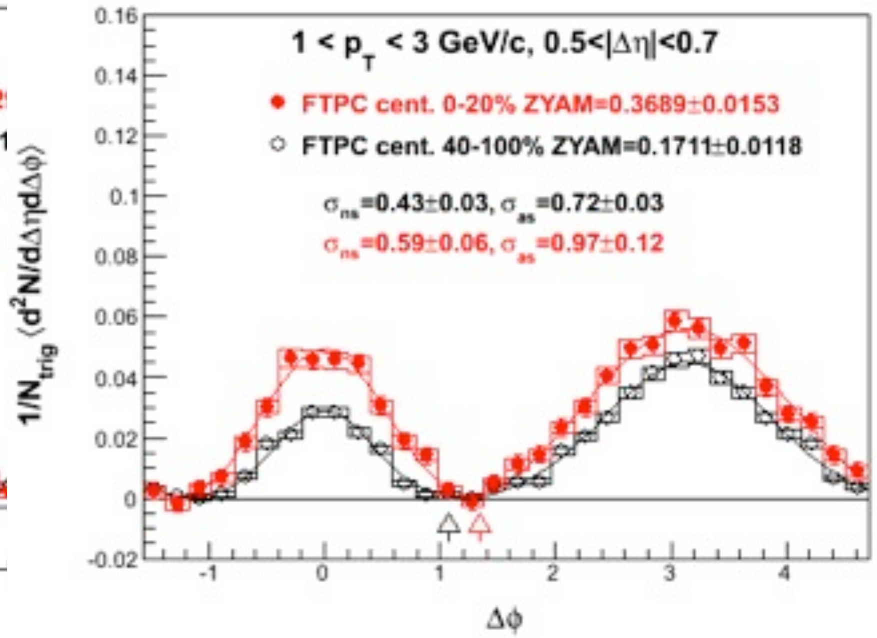
results from STAR

|Δη|<0.3



0.5<|Δη|<0.7



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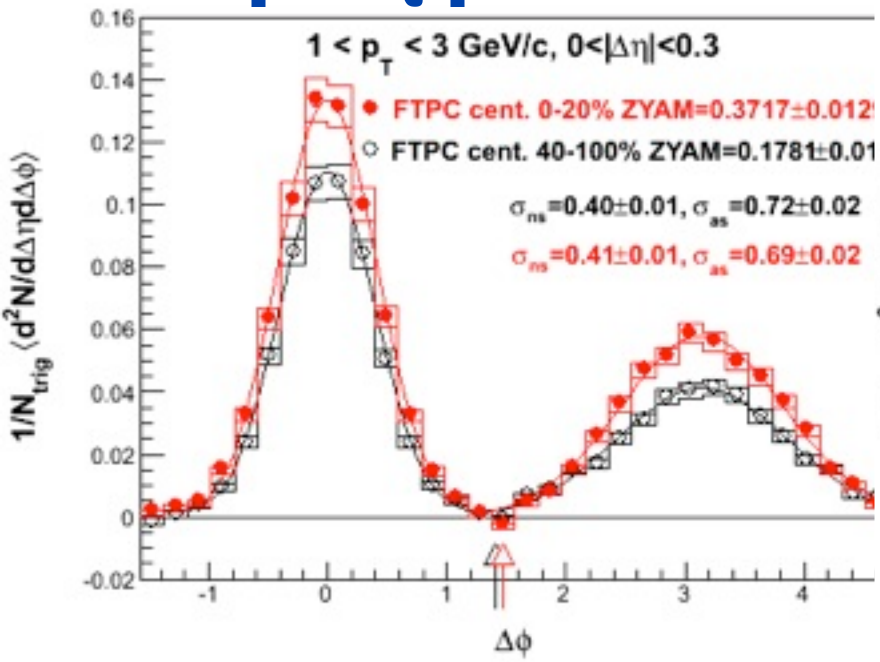
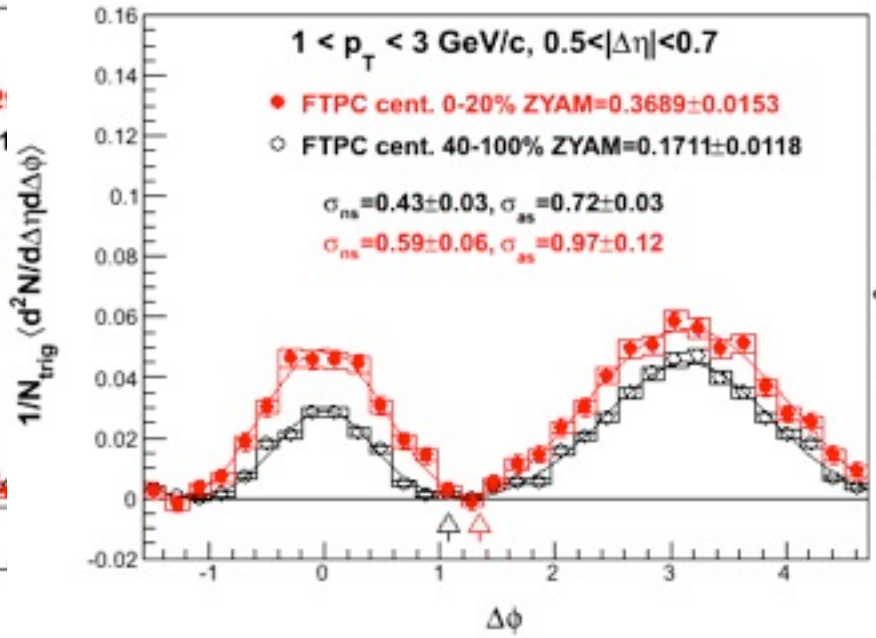
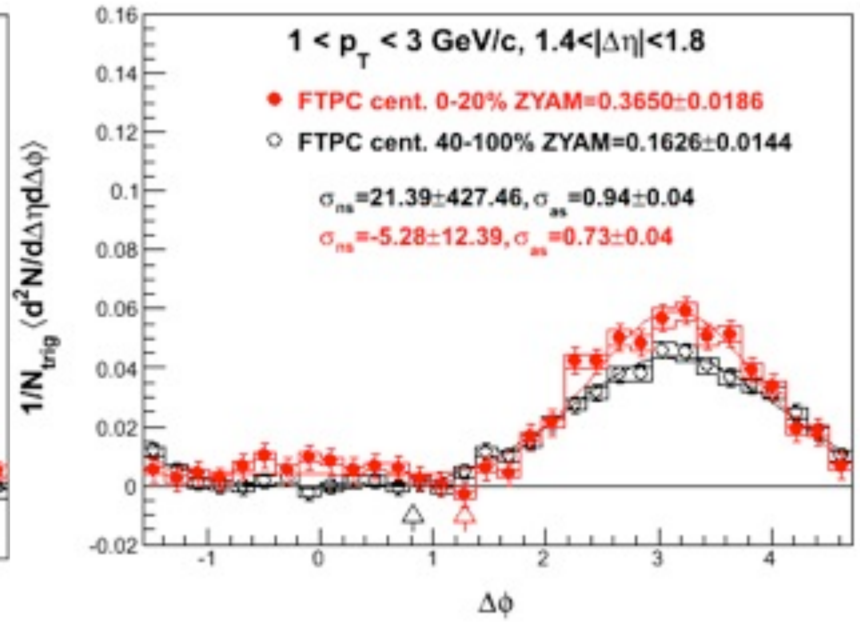
results from STAR

|Δη|<0.3   0.5<|Δη|<0.7   1.4<|Δη|<1.8







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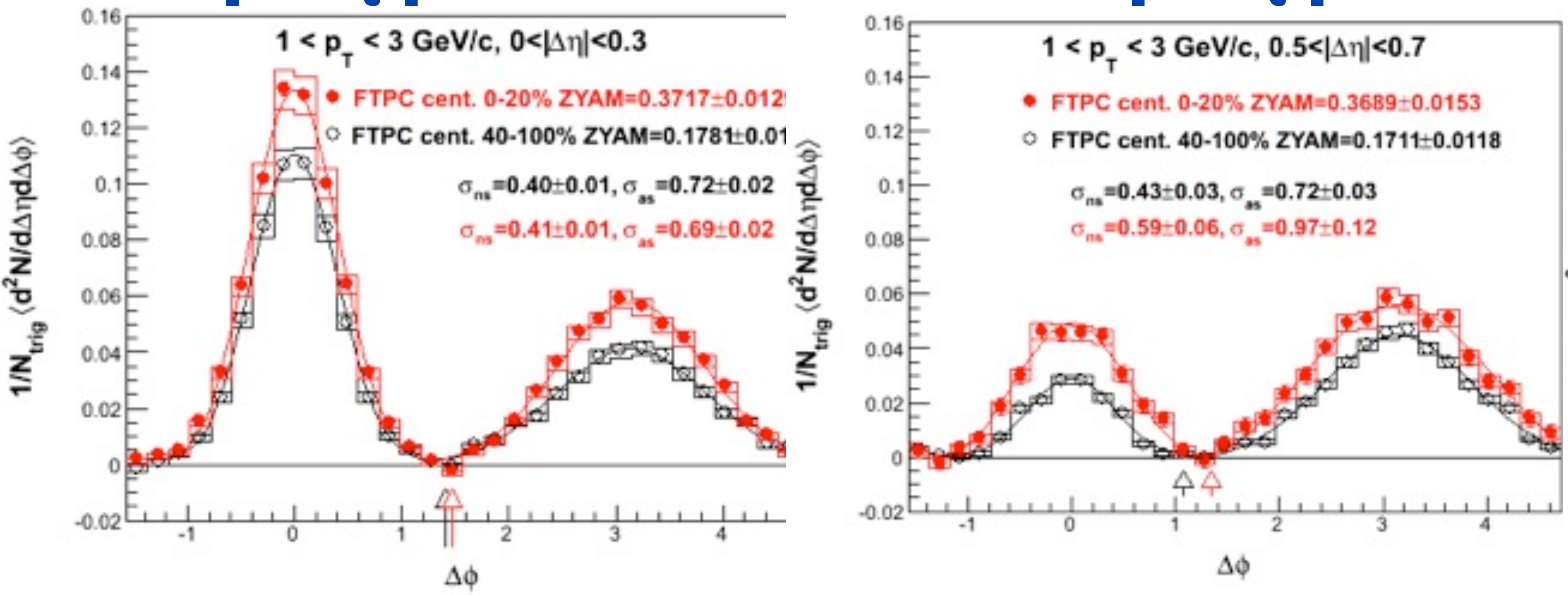
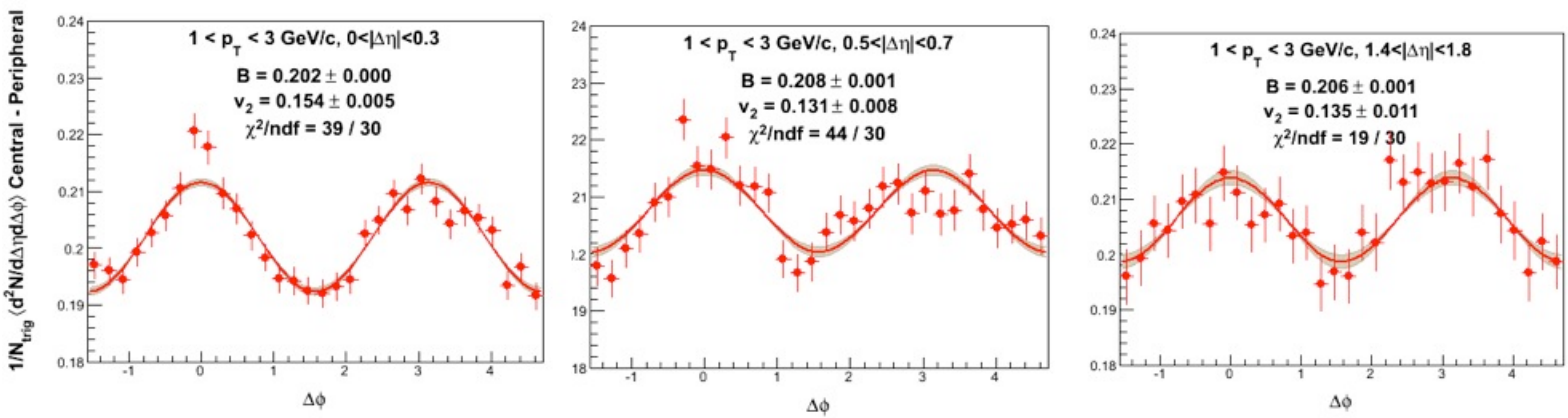
results from STAR

$|\Delta\eta|<0.3$ $\quad$ $0.5<|\Delta\eta|<0.7$ $\quad$ $1.4<|\Delta\eta|<1.8$



central - peripheral



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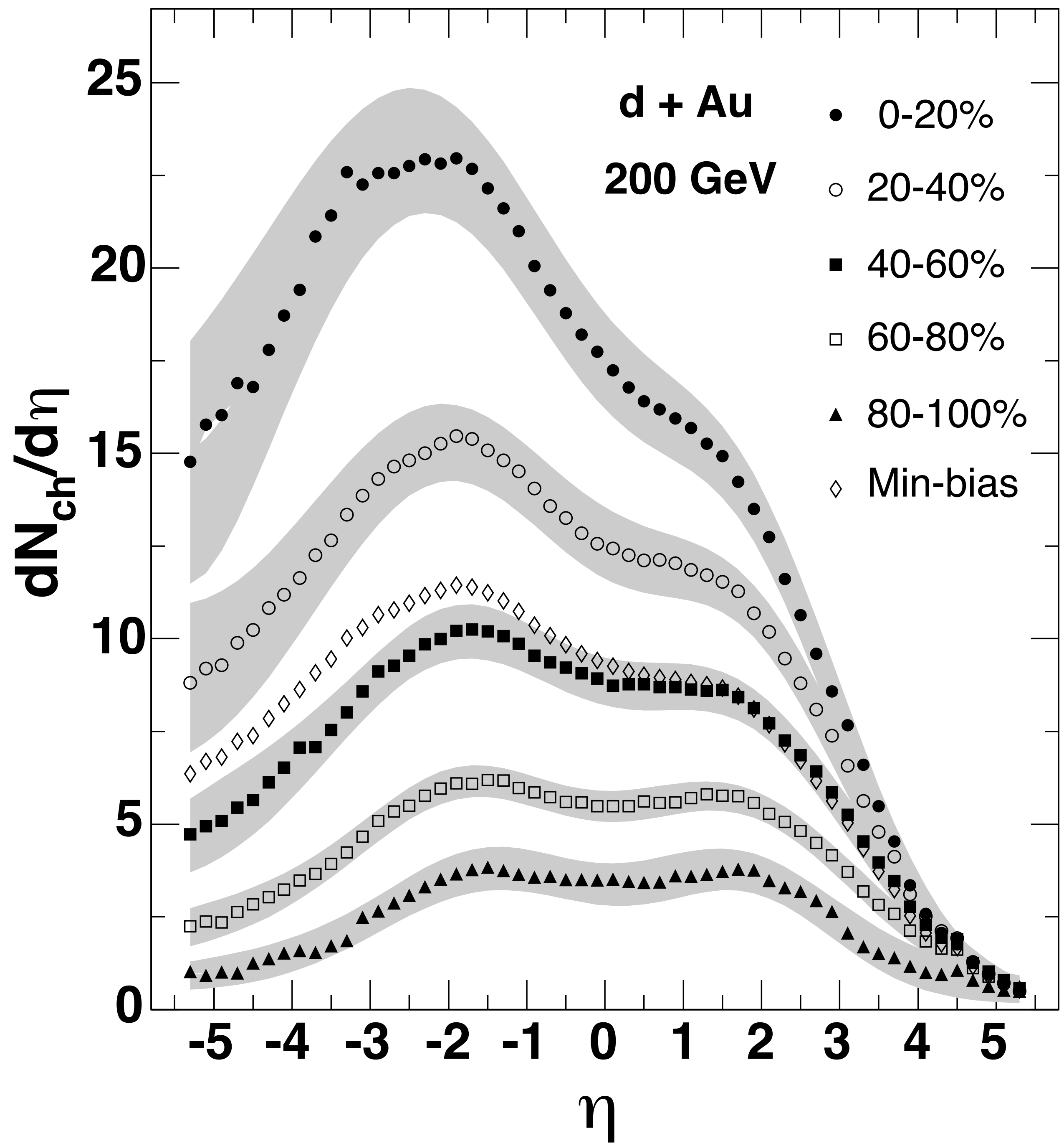
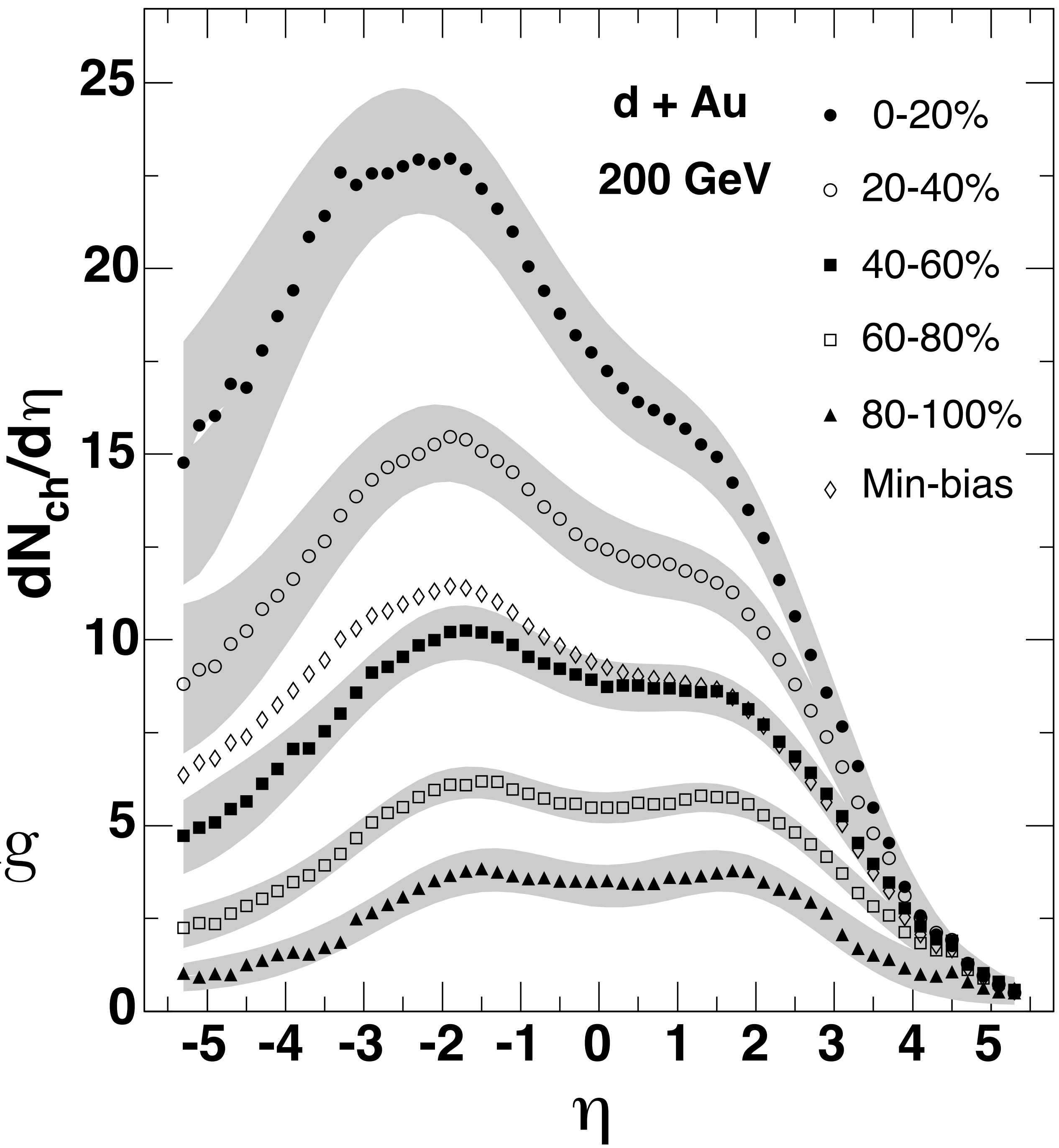
even larger |Δη|

PHOBOS PRC72 031901



PHOBOS PRC72 031901



- Muon Piston Calorimeter
  - correlate with central arm: long range: $3 < |\Delta\eta| < 4$
- separate d-going and Au-going phenomena

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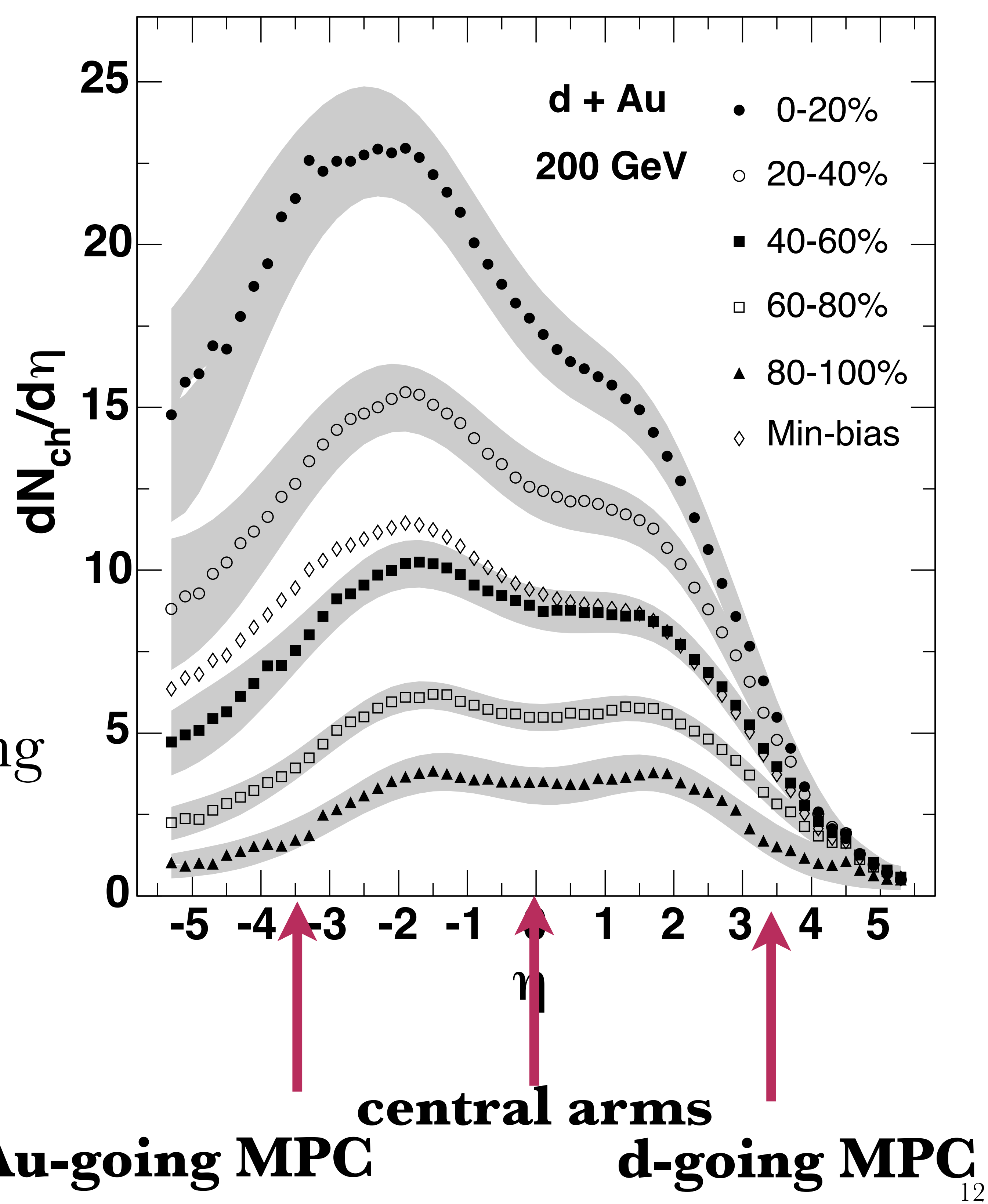
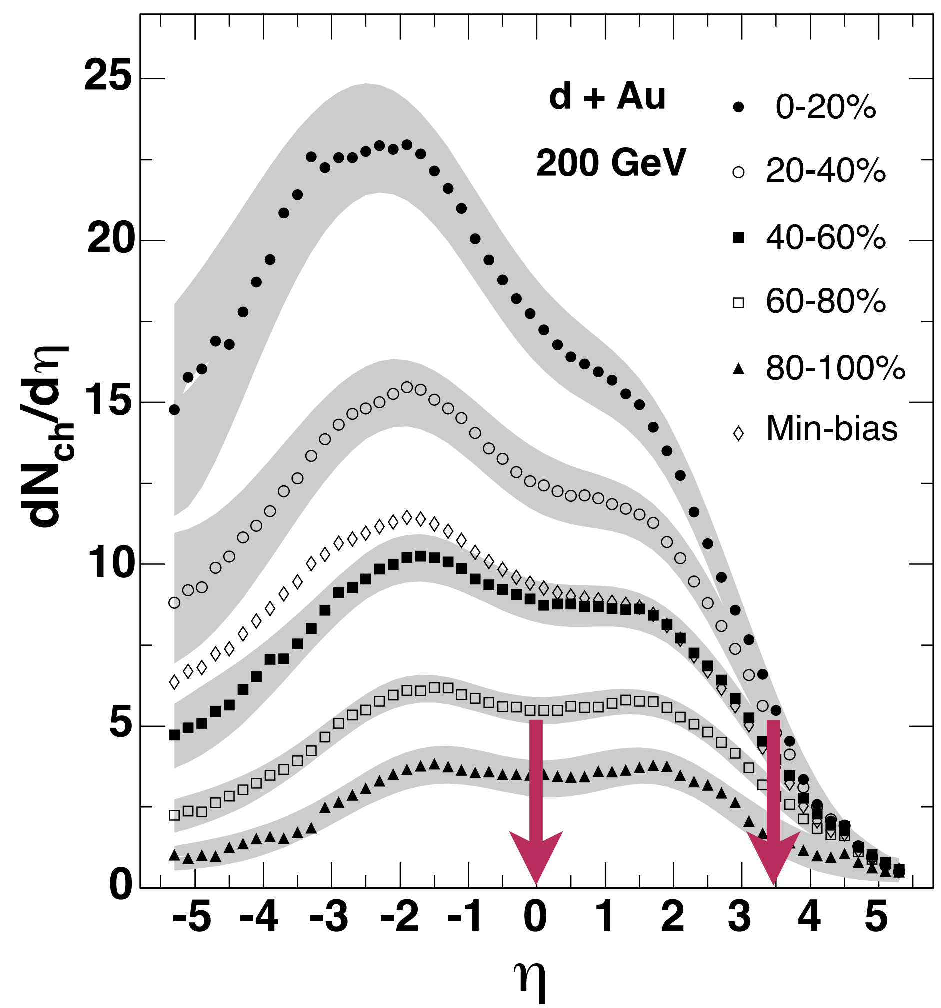
  - correlate with central arm: long range: $3 < |\Delta\eta| < 4$
- separate d-going and Au-going phenomena

PHOBOS PRC72 031901



mid/d-going correlations

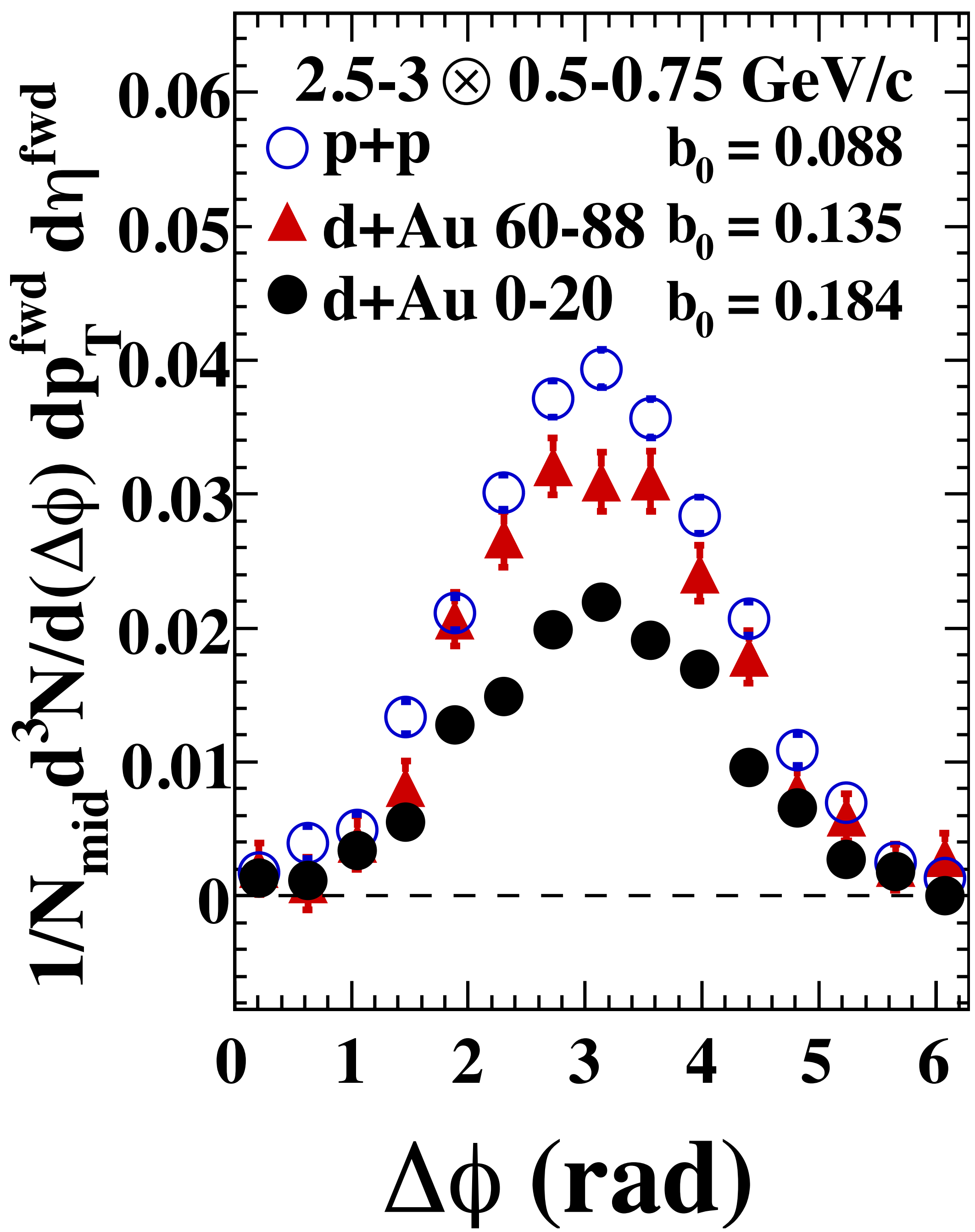
PHOBOS PRC72 031901



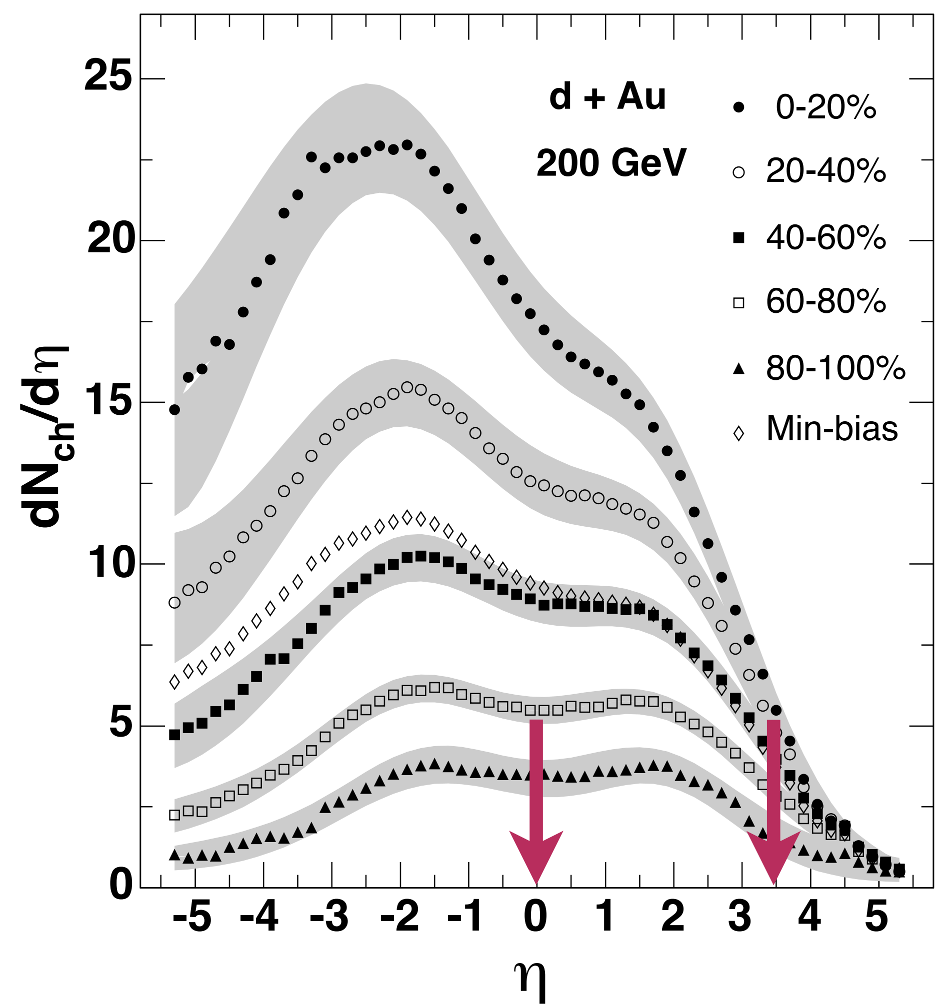
mid/d-going correlations

PRL **107,** 172301 (2011) PHYSICAL REVIEW LETTERS week ending 21 OCTOBER 2011

Suppression of Back-to-Back Hadron Pairs at Forward Rapidity in d + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

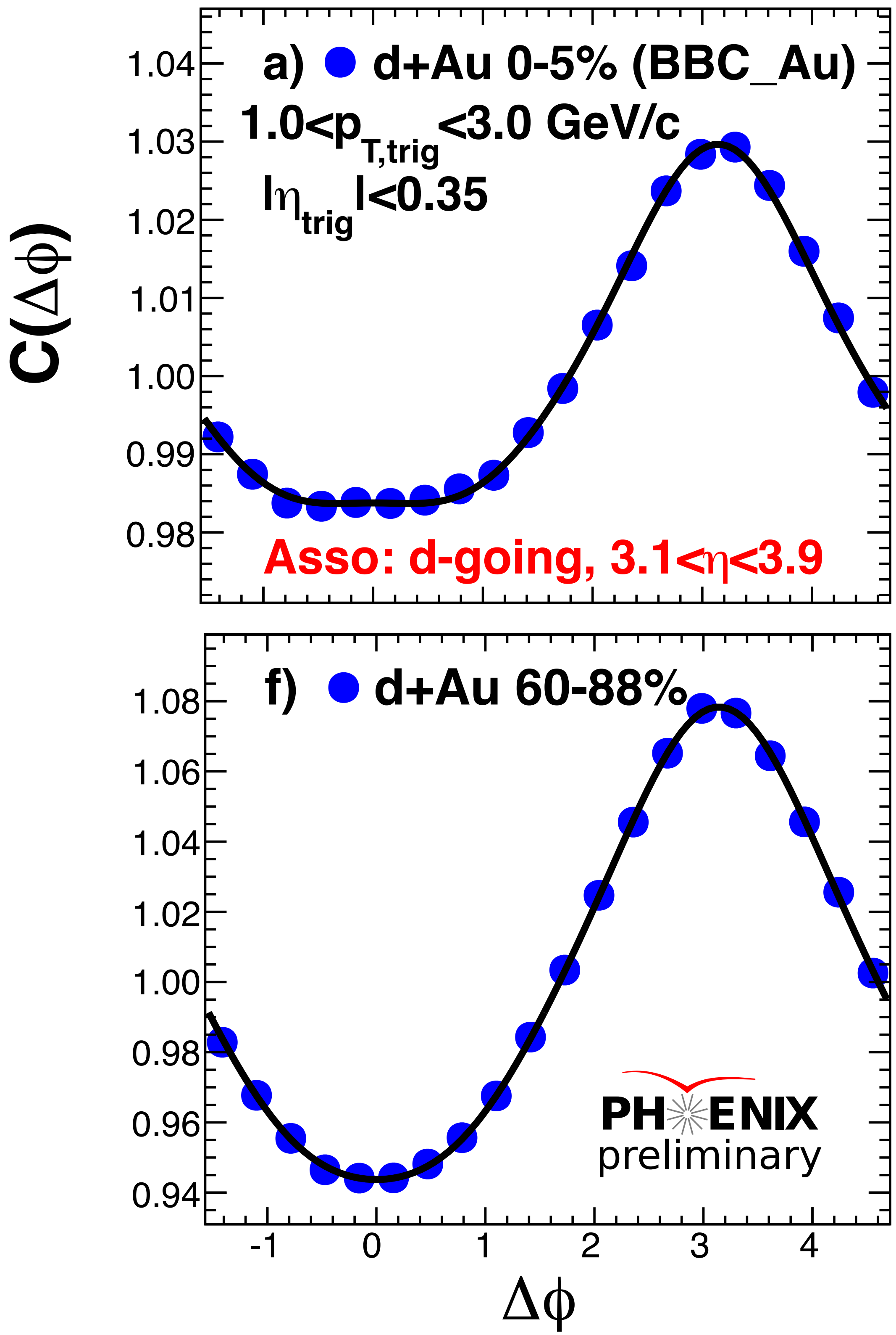


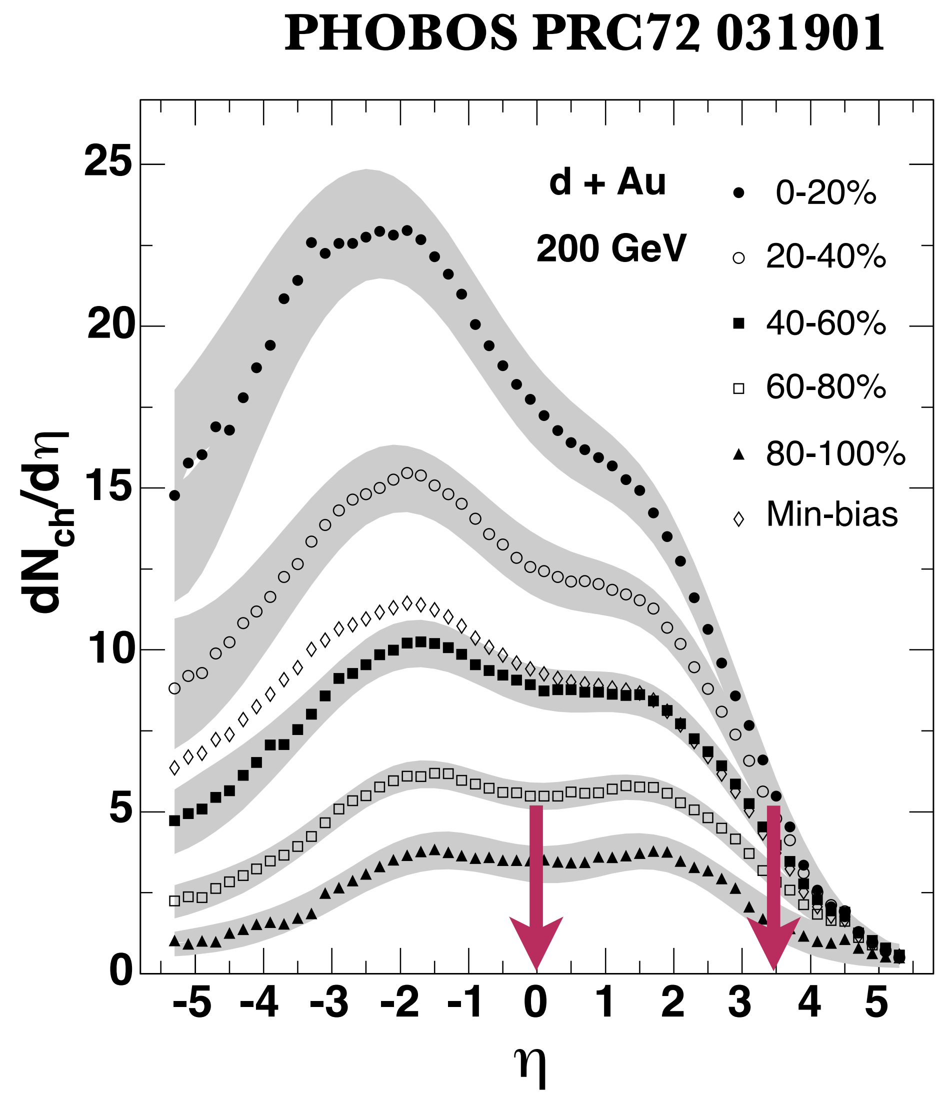
PHOBOS PRC72 031901



no evidence for long range correlation at Δφ~0

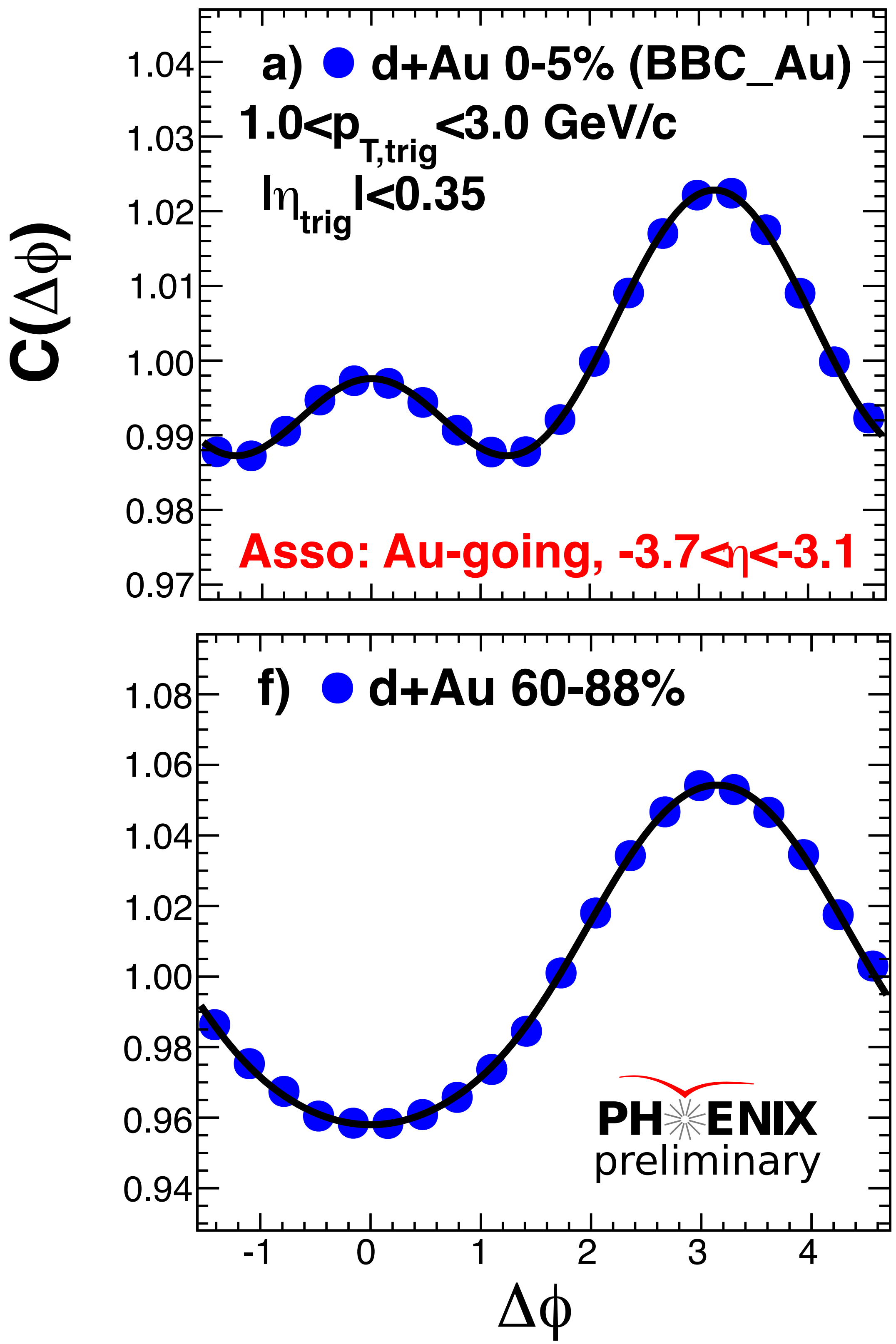
mid/d-going correlations





no small Δφ bump, some shape change with centrality

mid/Au-going correlations



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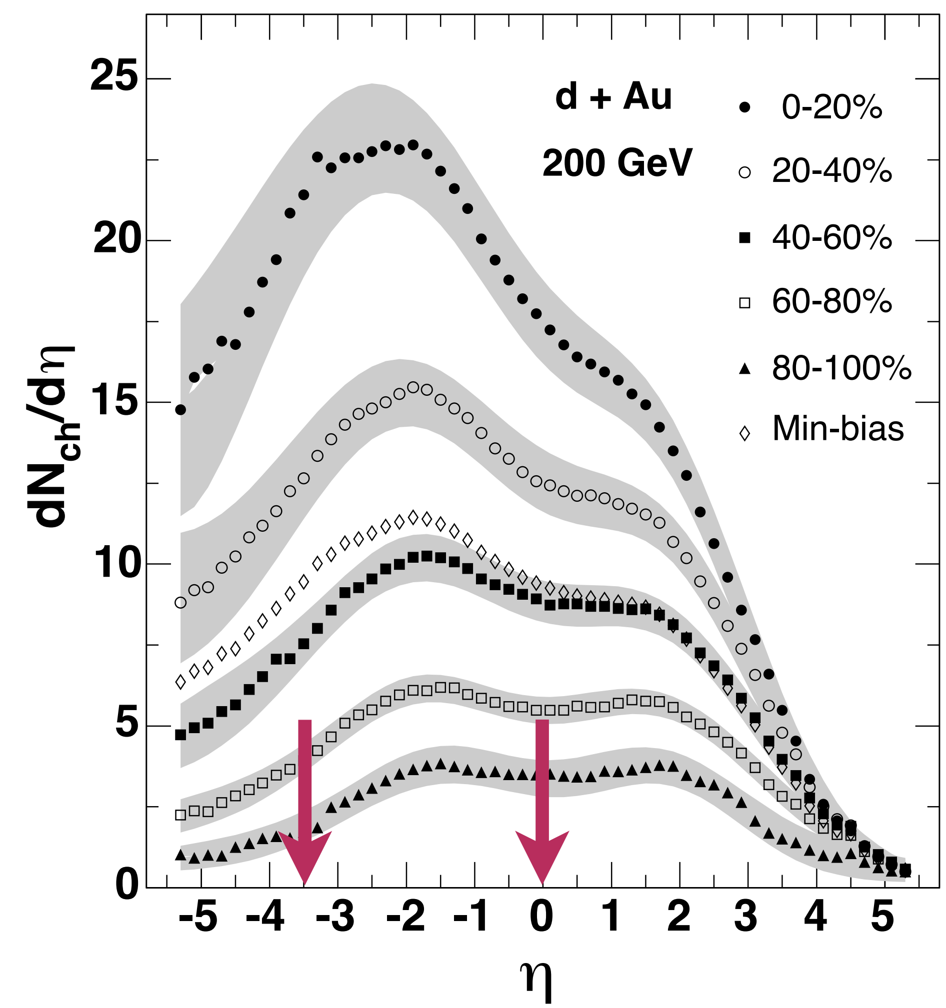
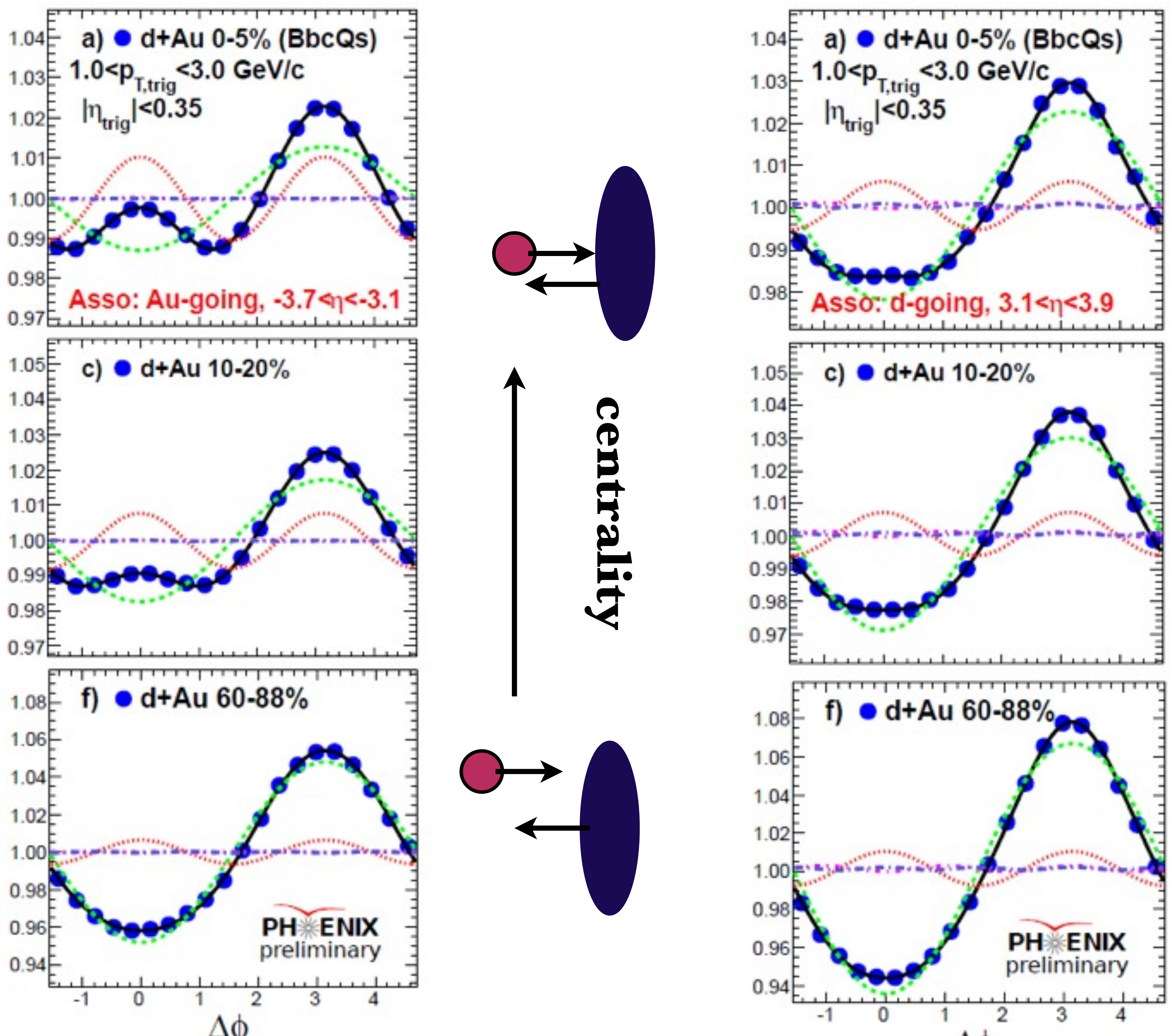


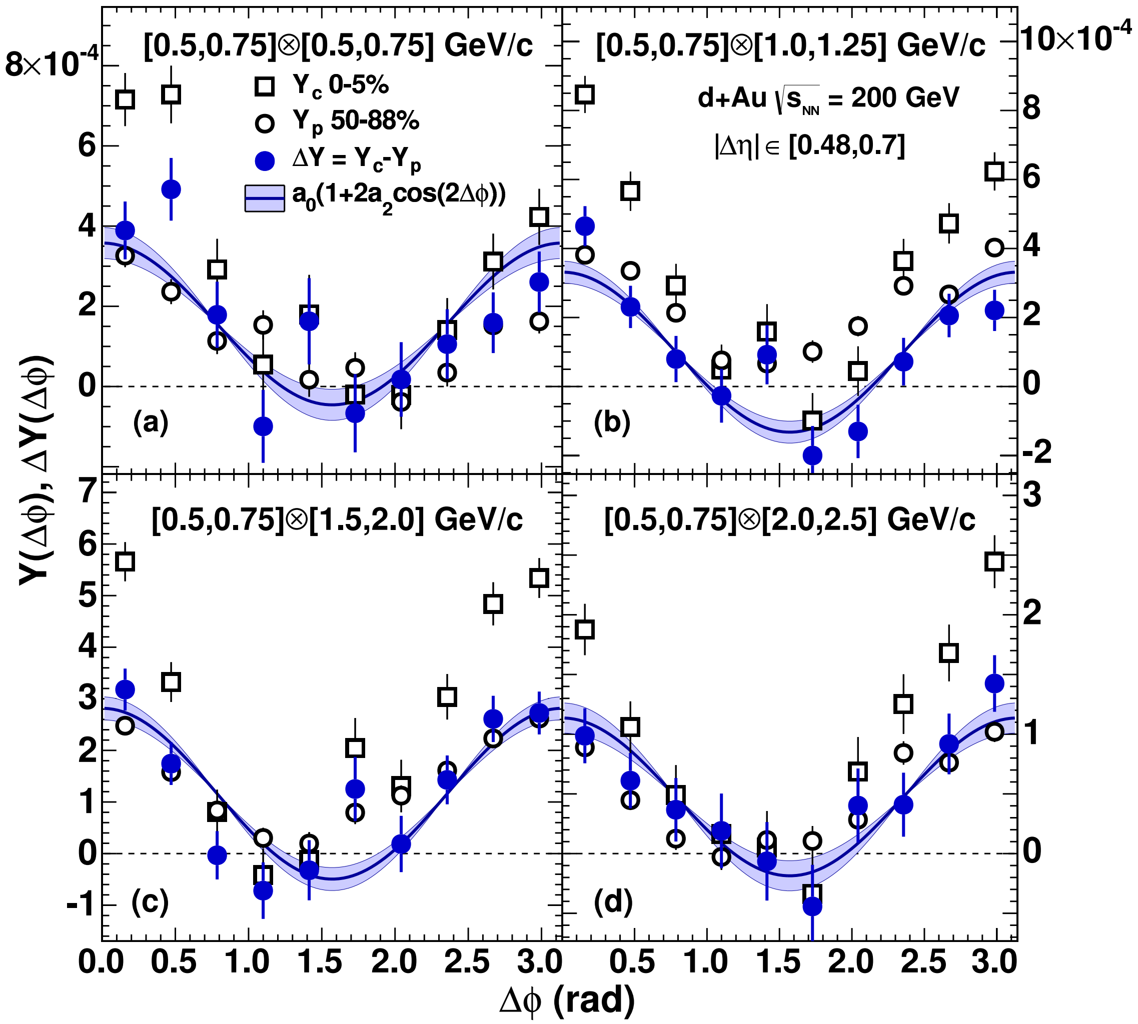
near side ridge observed at large Δη in central dAu collisions

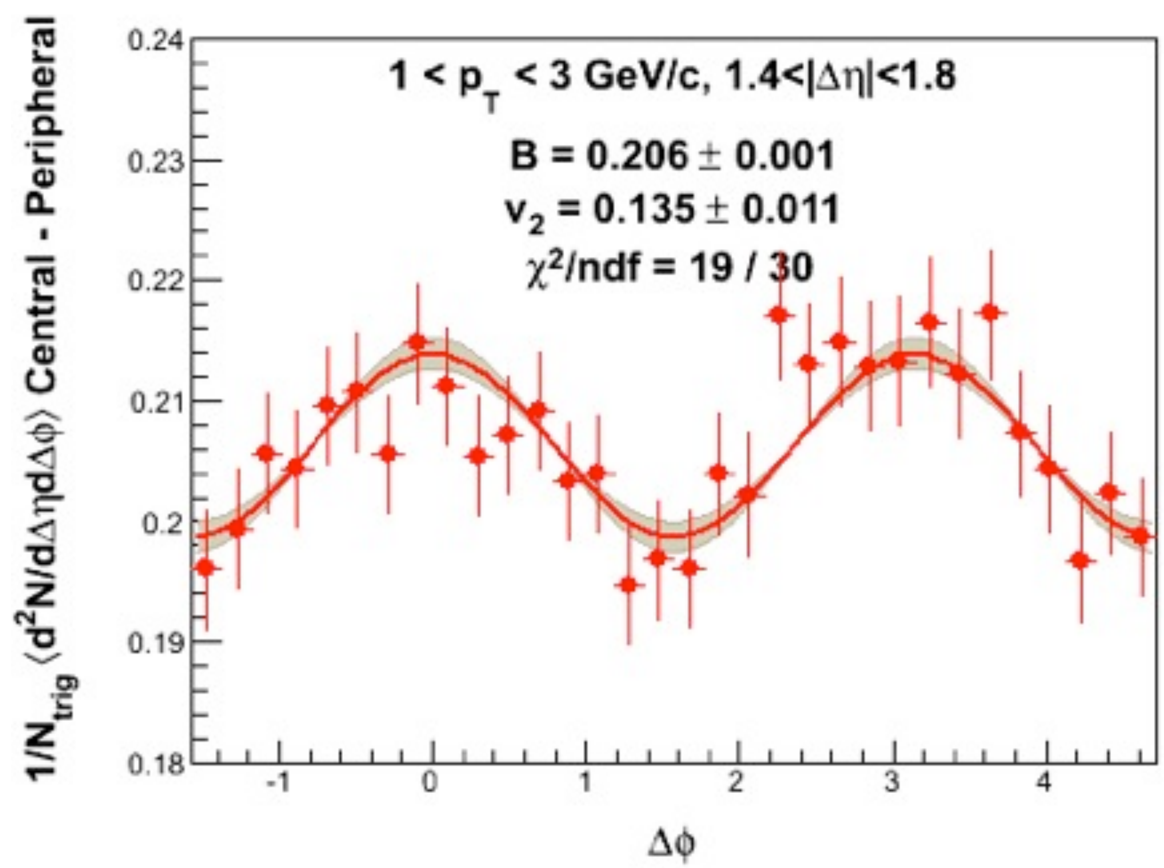
η dependence

Au-going   d-going



back to mid-rapidity





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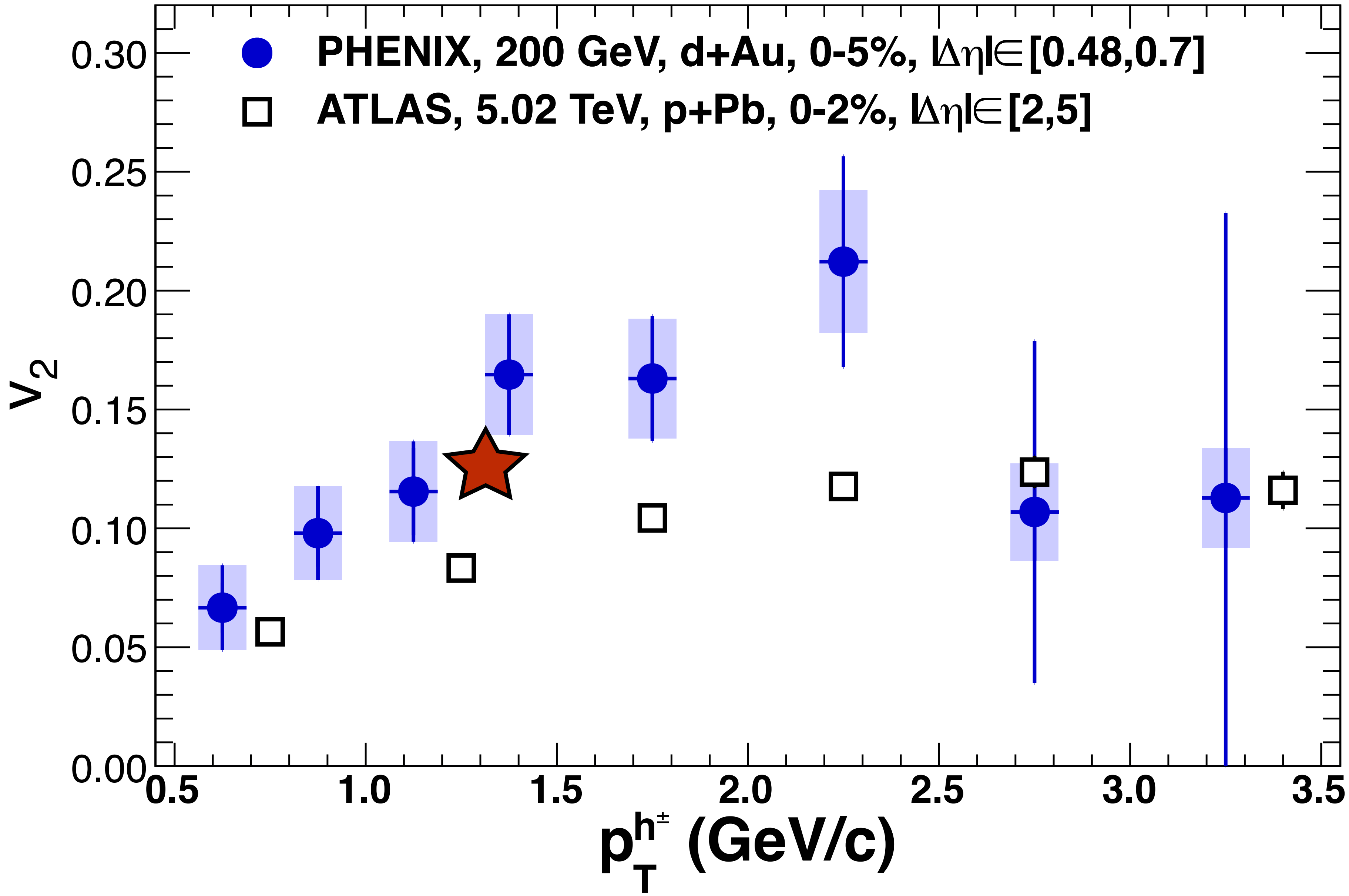
RHIC comparisons



STAR v_2: ~13±1% $1<p_T<3$GeV/c

good consistency at RHIC!

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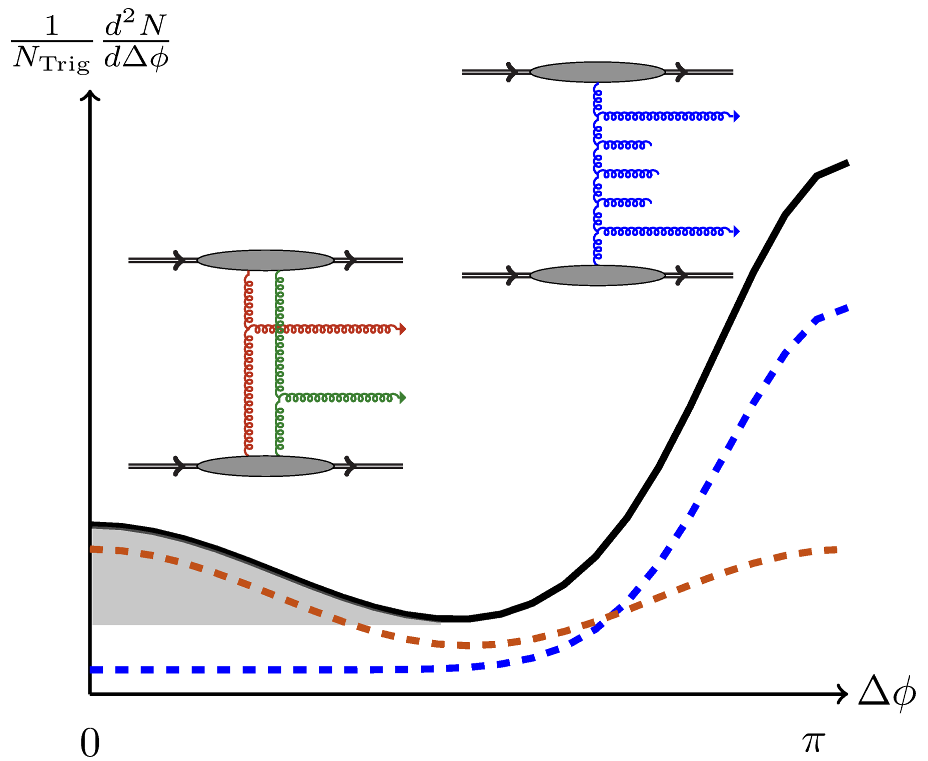
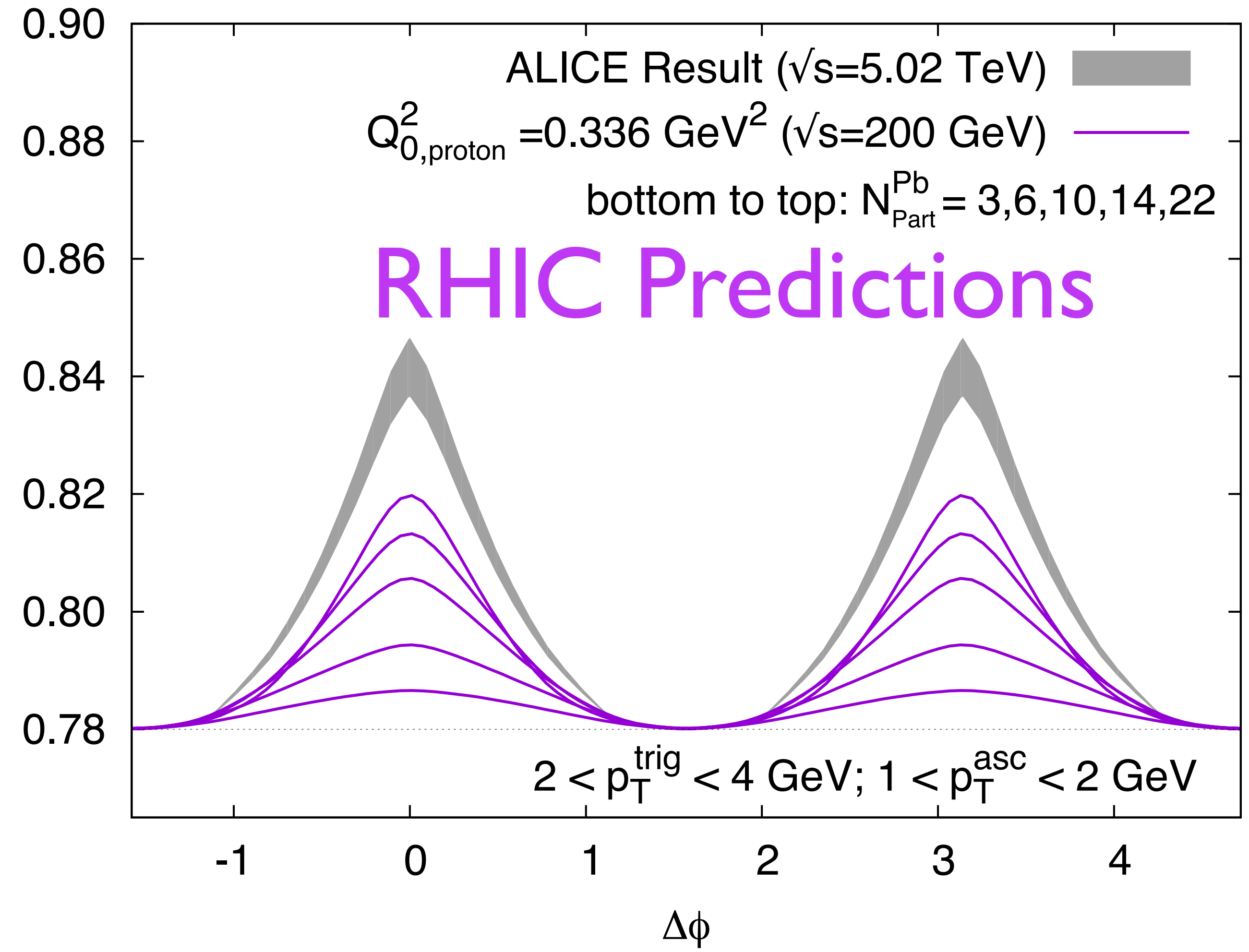
what about the CGC?

significant signal expected at RHIC!

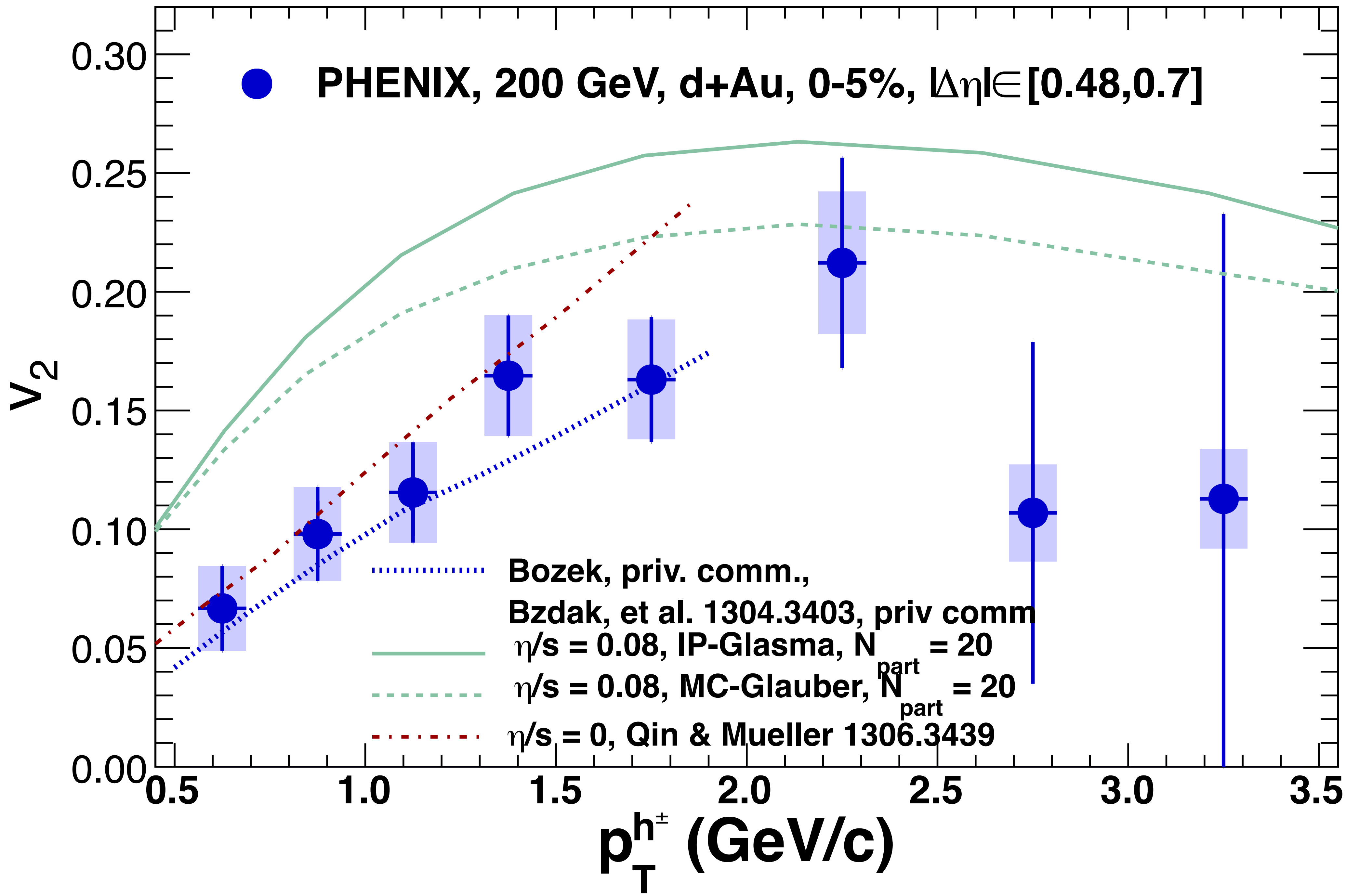




- smaller yield expected at RHIC compared to LHC
- Fourier coefficients aren't calculated for this model--working to compare to data

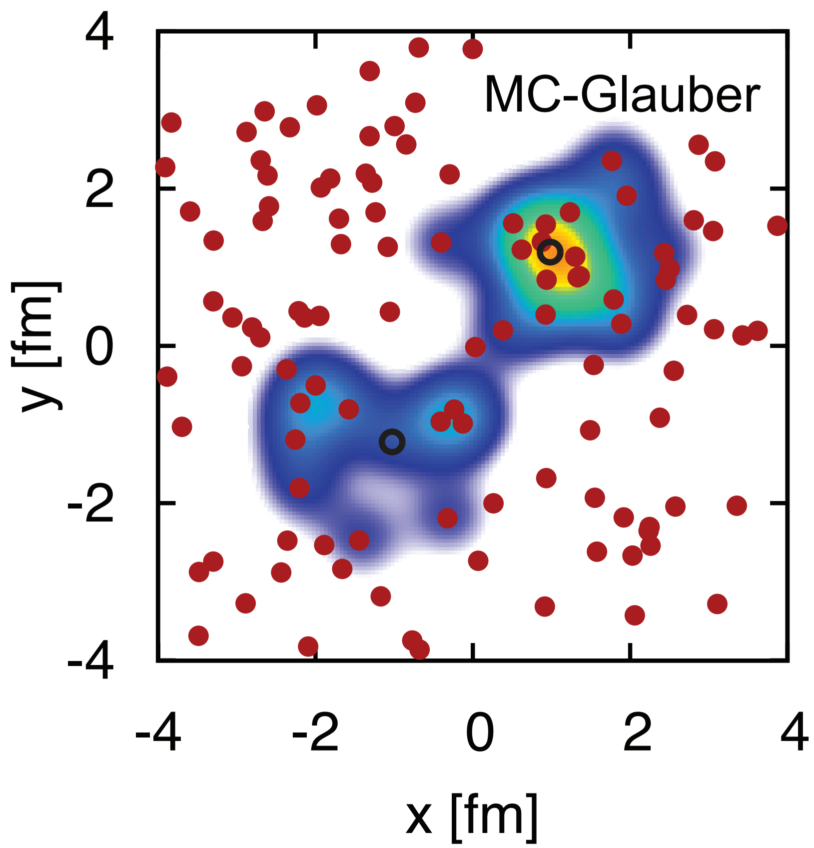
Dusling & Venugopalan 1211.3701, 1302.7018 & private comm.

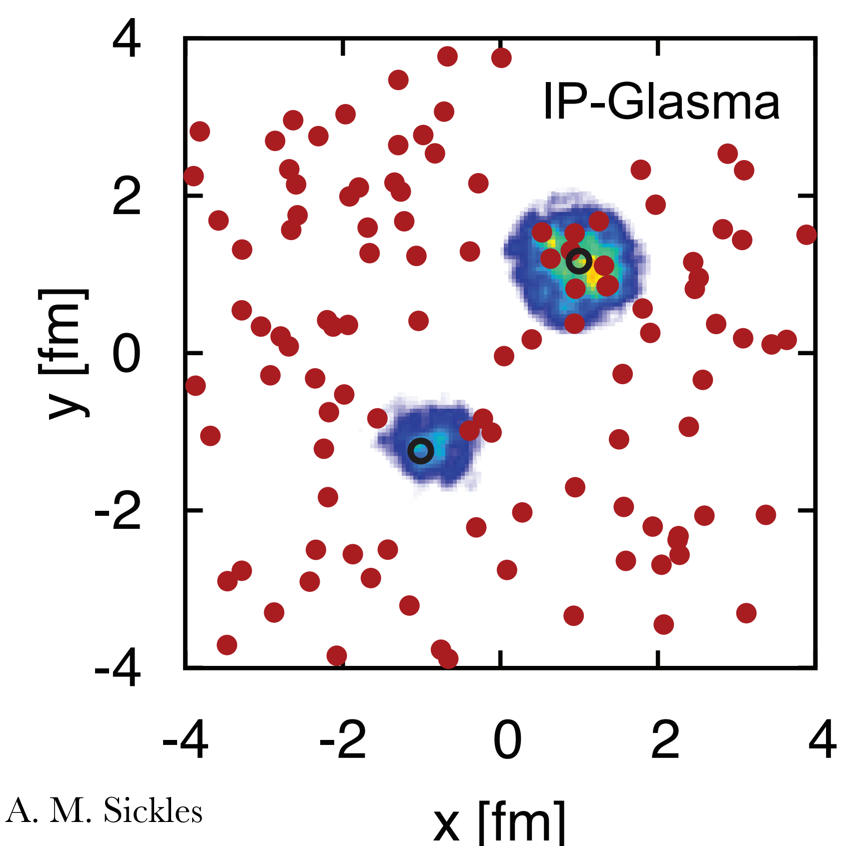
comparison to hydro calculations

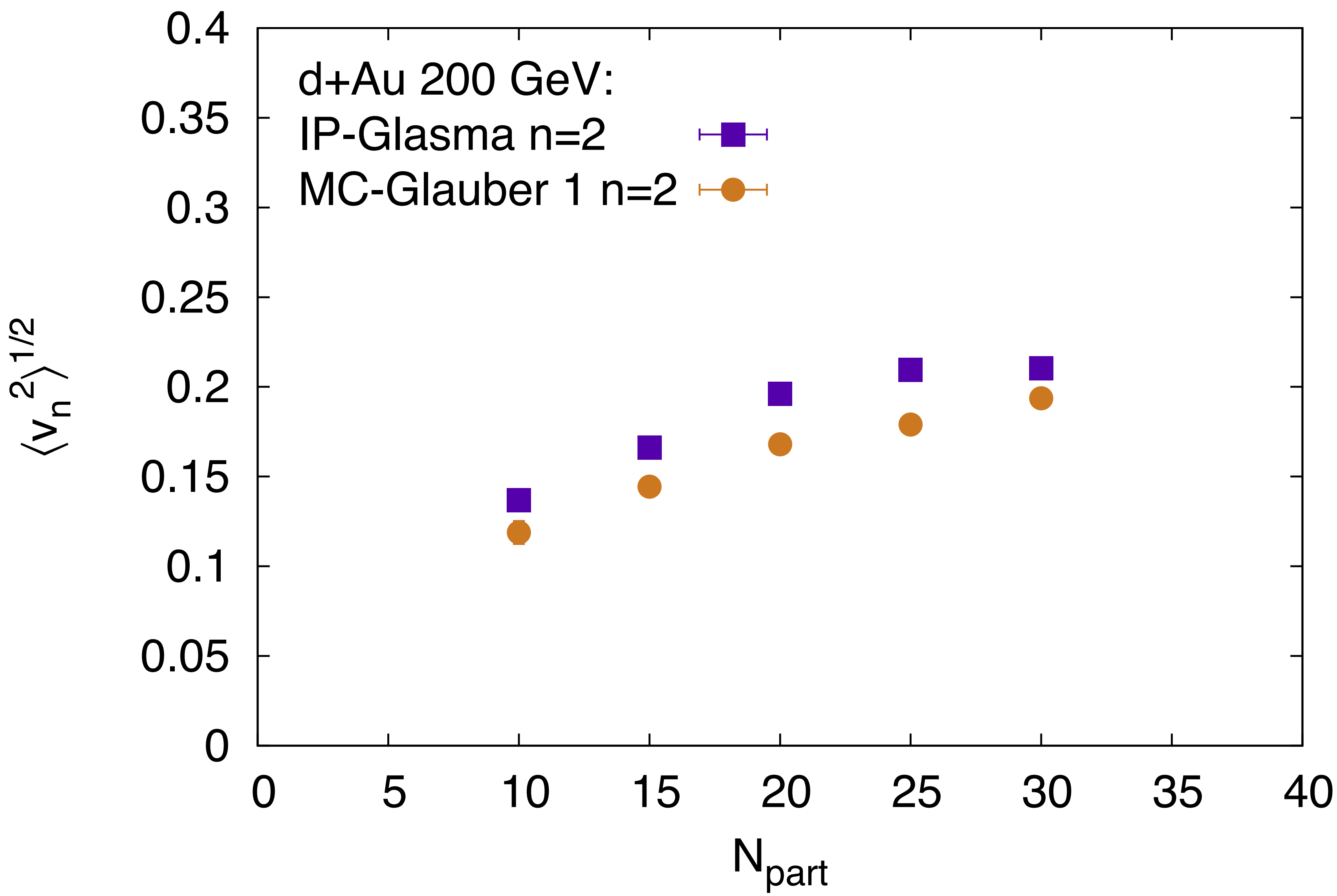


qualitative agreement with hydro calculations with $\eta/s \leq 0.08$

the shape of the initial state





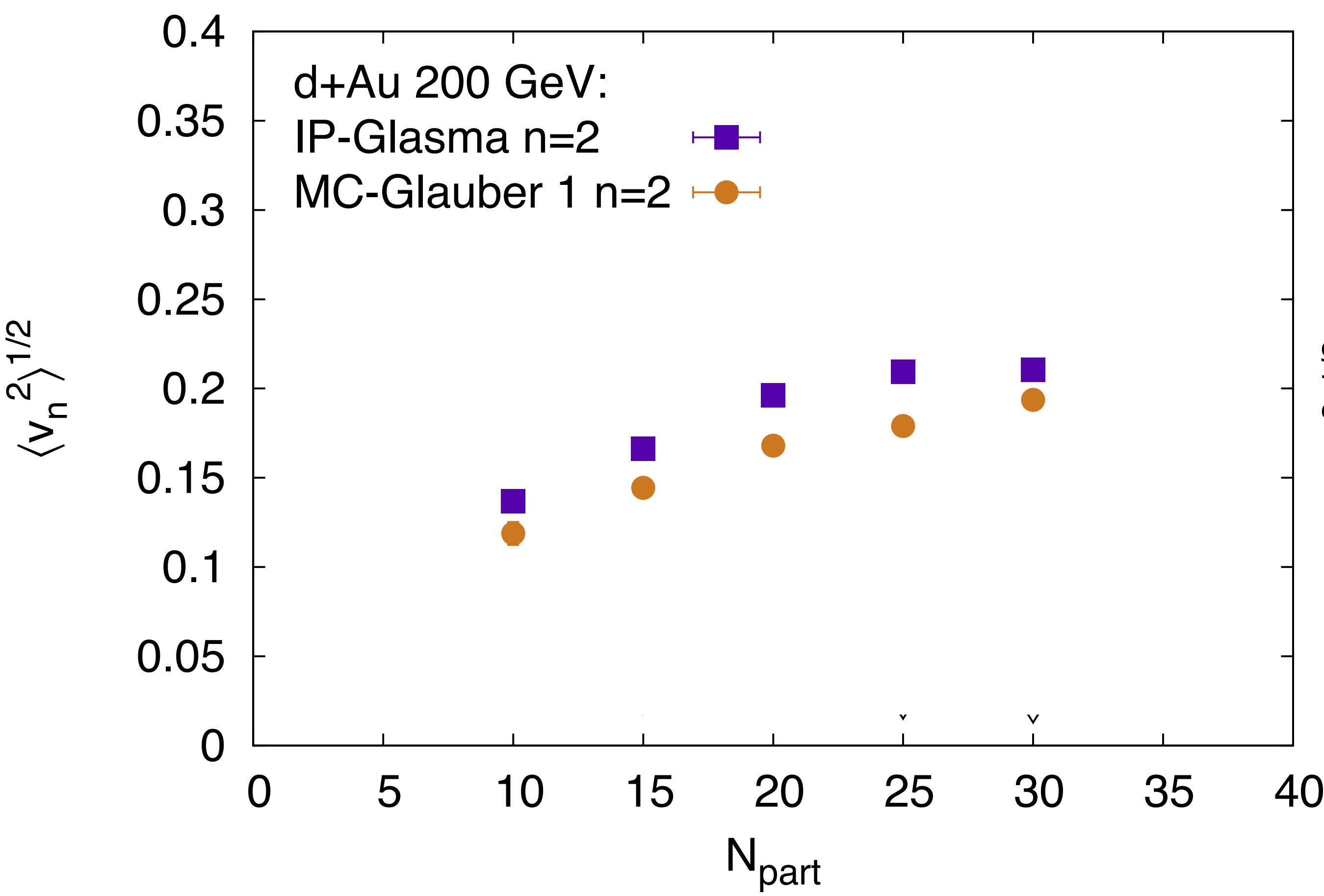


- **v2 naturally enhanced in dAu**
- **little dependence on initial state description--Glauber vs IP-Glasma**

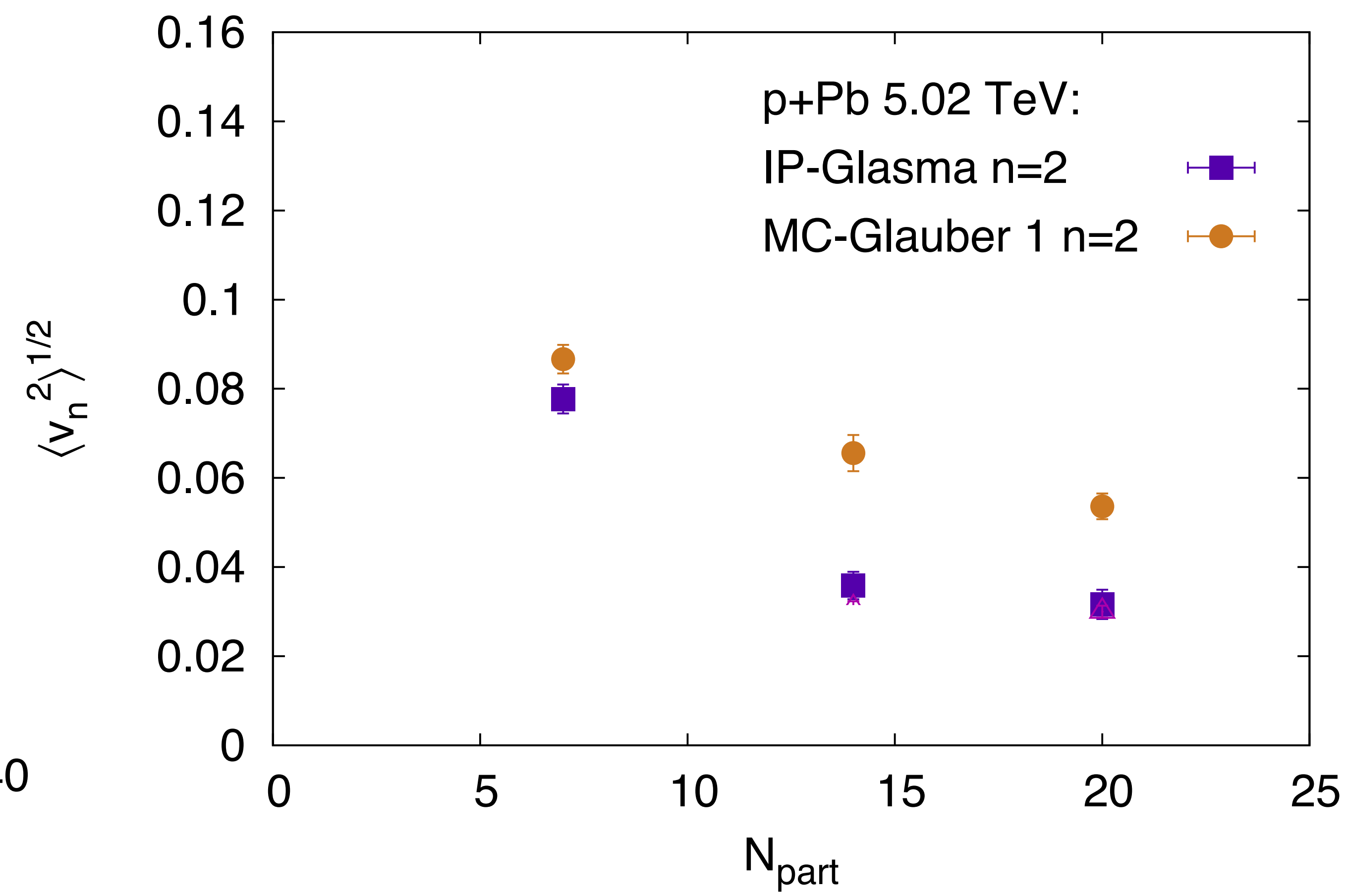
Bzdak et al: 1304.3403

d+Au compared to p+Pb

d+Au



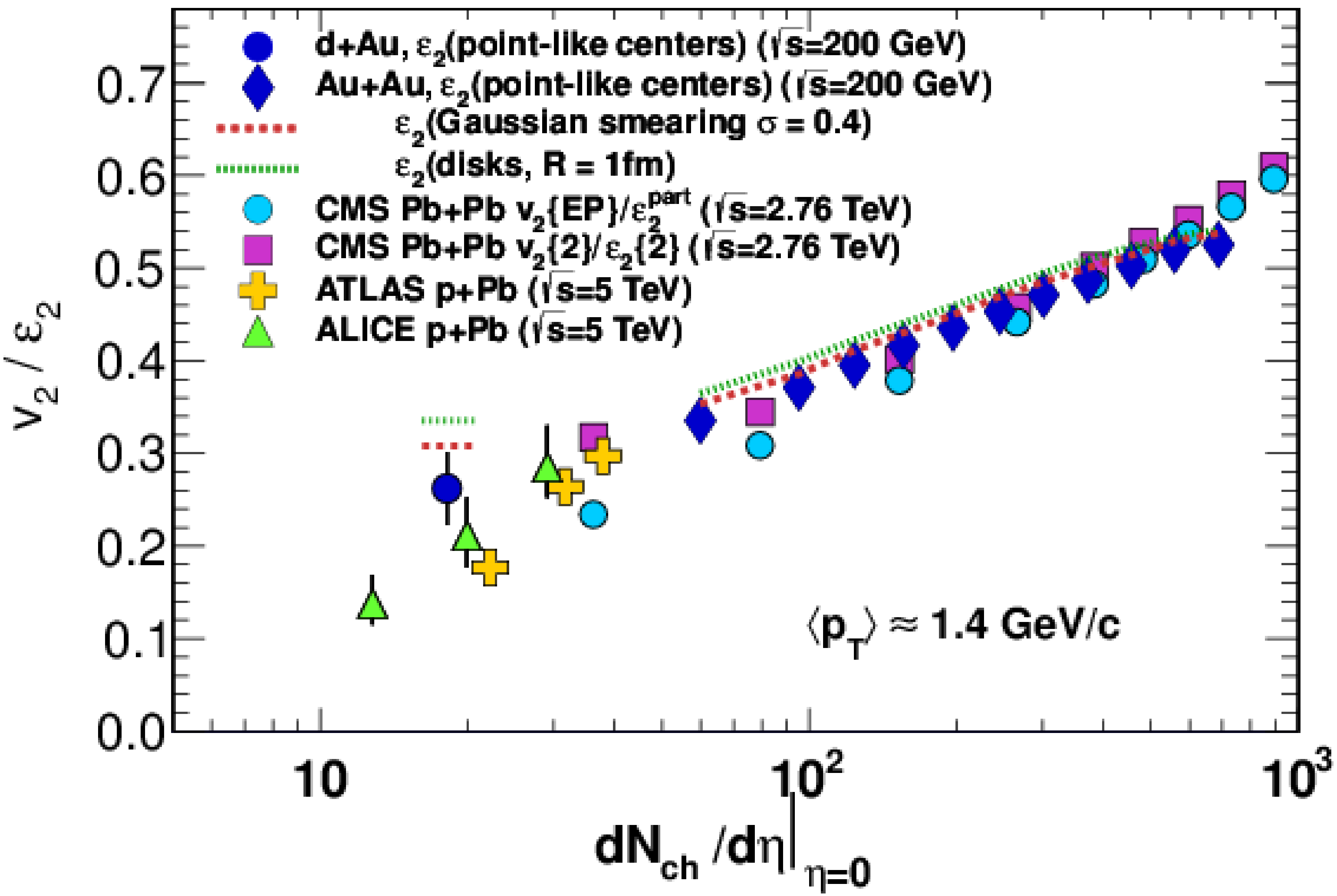
p+Pb



- d+Au:
  - larger v_2
  - smaller dependence on initial state description

Bzdak et al: 1304.3403

v_2/ε_2 vs multiplicity



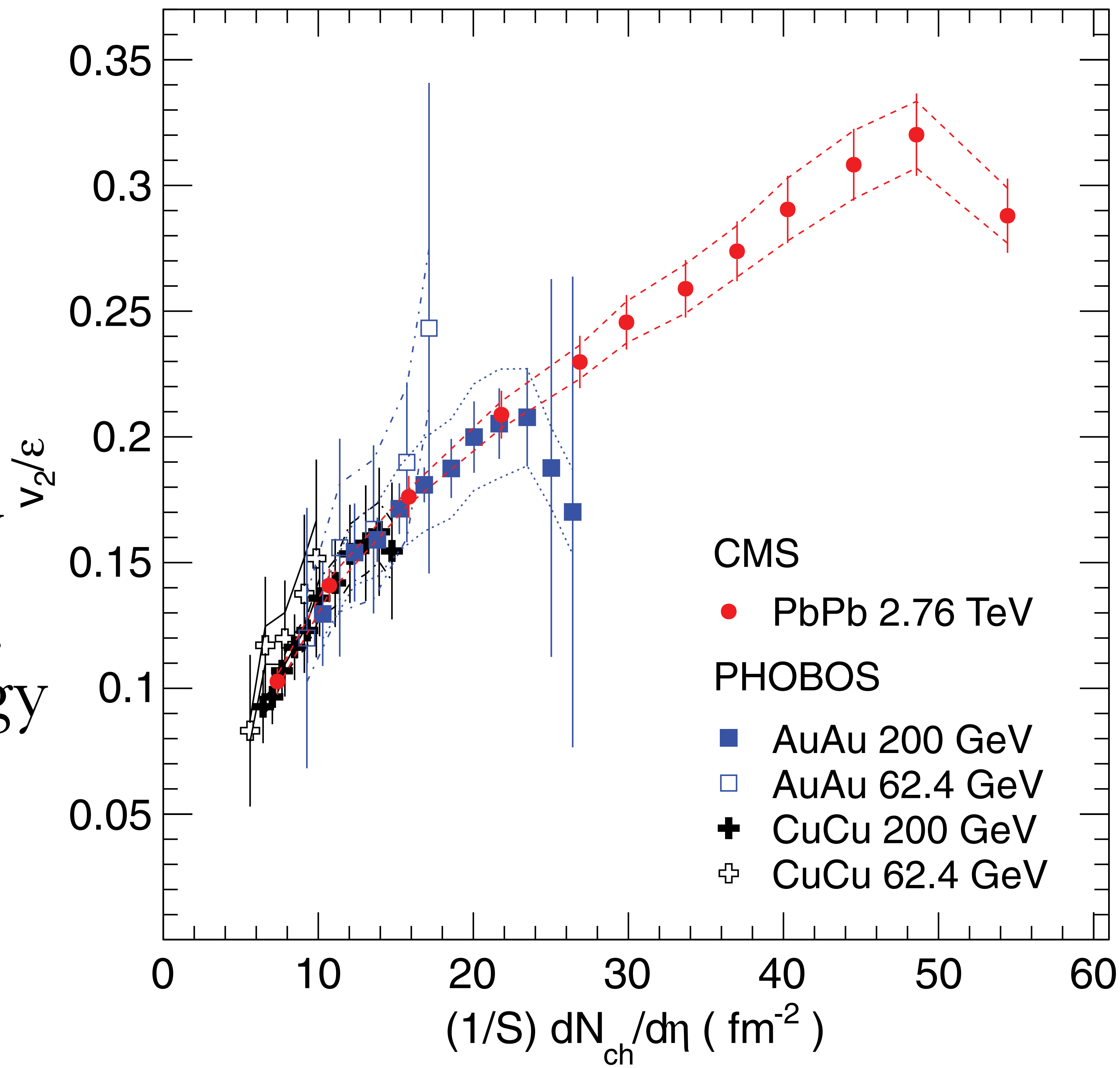
- Glauber MC & pointlike centers to calculate ε_2
- $\rightarrow$ approximate scaling of v_2/ε_2 with dN/dη

a common relationship between geometry and v_2?

scaling with overlap area?

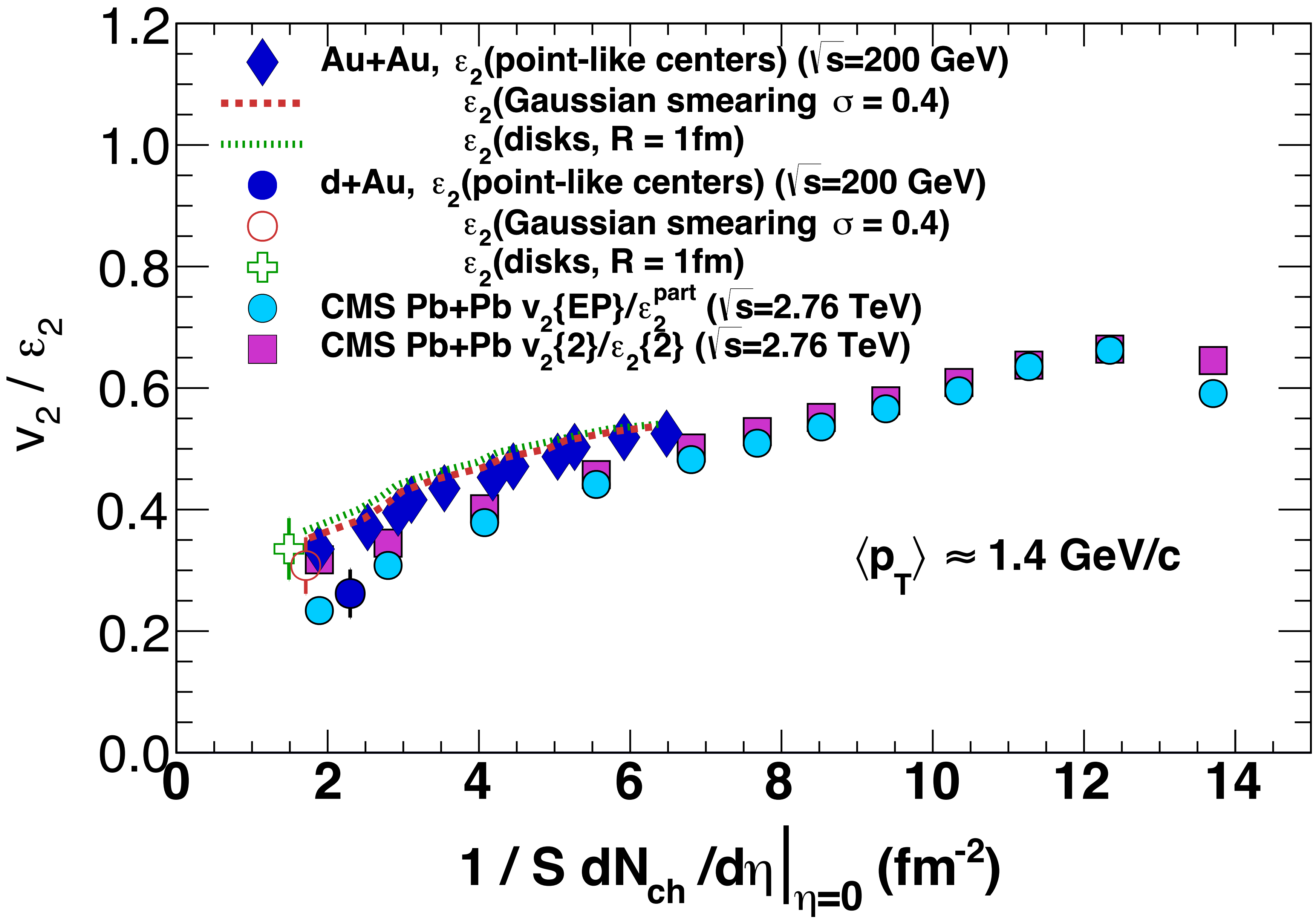
$S = 4\pi\sqrt{\sigma_x^2\sigma_y^2 - \sigma_{xy}^2}$

p_T integrated v_2 data found to scale in heavy ions with $1/S\ dN_{ch}/d\eta$ over wide collision energy



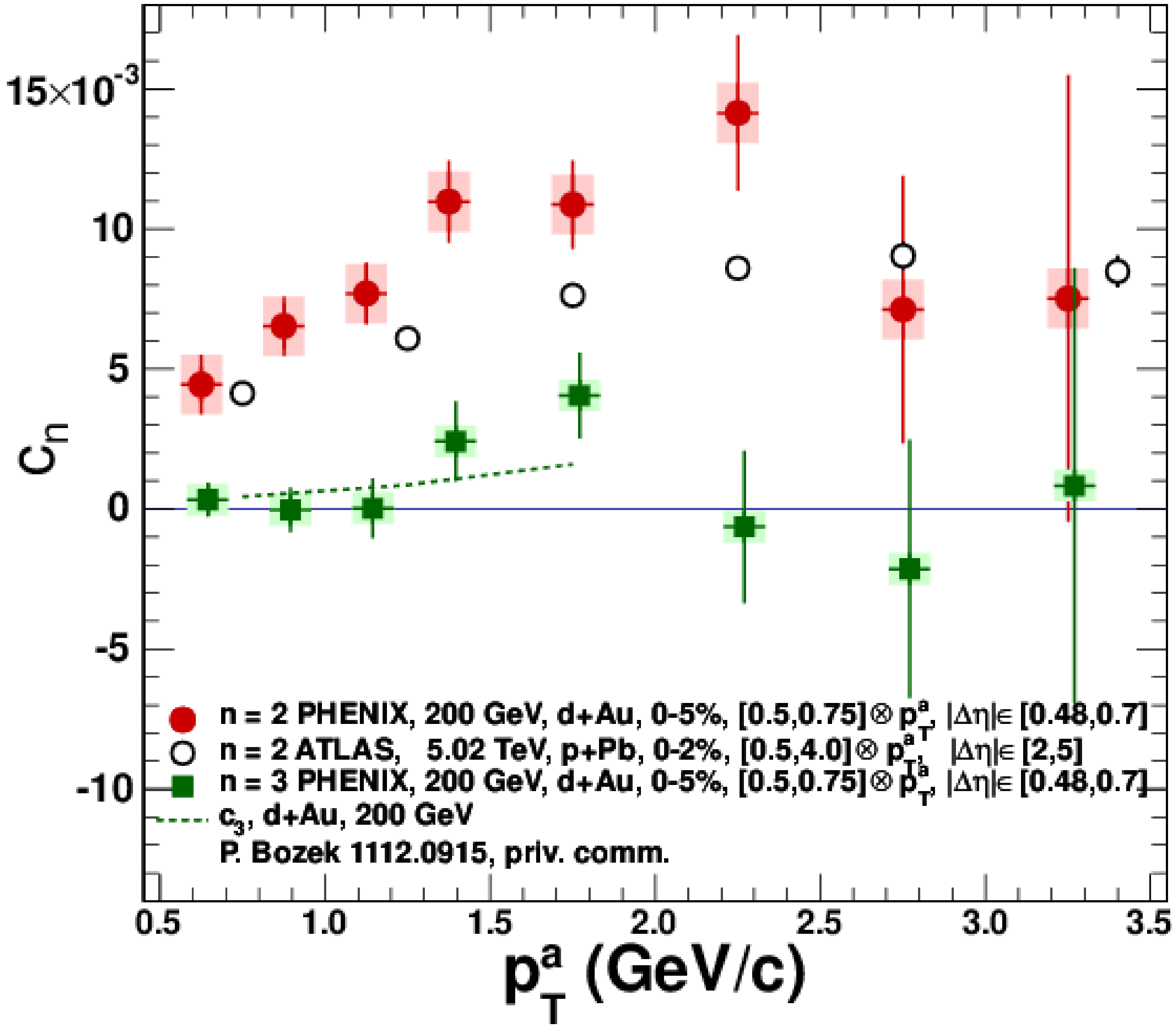
CMS PRC 87 014902

scaling with overlap area?



- approximate scaling with $1/S\ dN_{ch}/d\eta$
  - significant uncertainties due to nucleon representations in d+Au
  - n.b. not directly comparable to other 1/S plots, here v_2 at fixed p_T!

v_3 at RHIC?



no evidence for significant v3, consistent with hydro expectations

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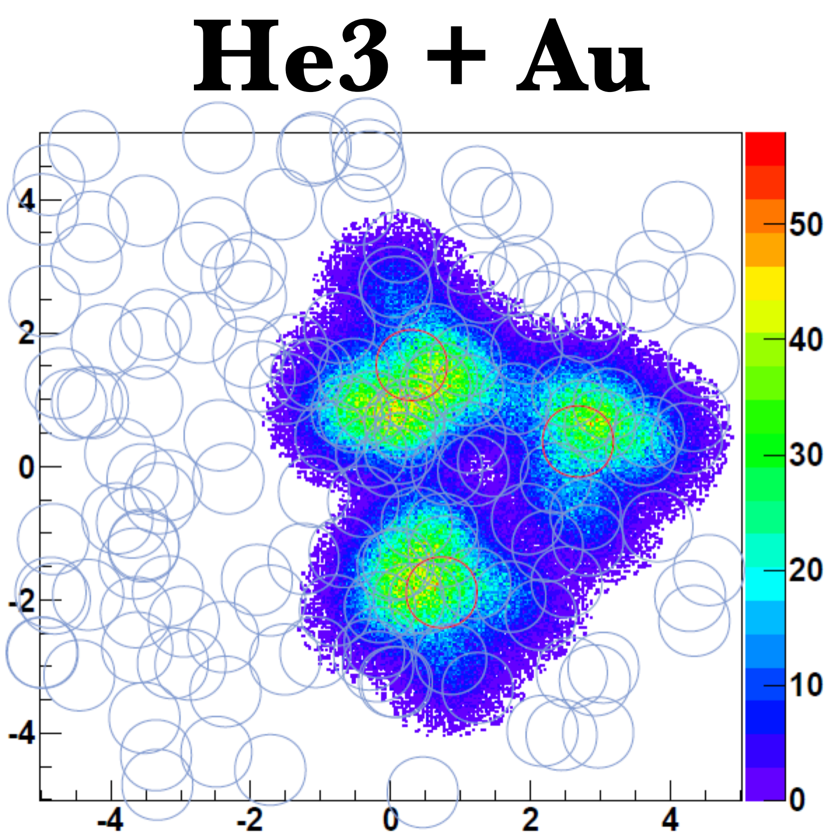
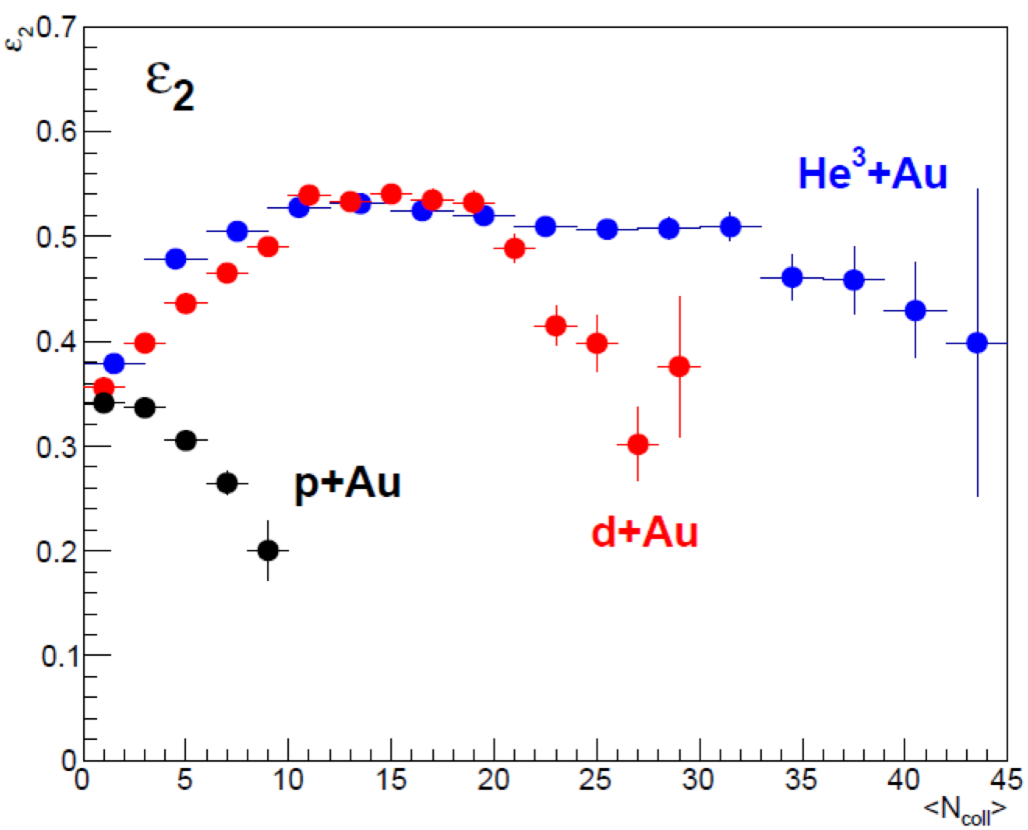
determine the role of geometry

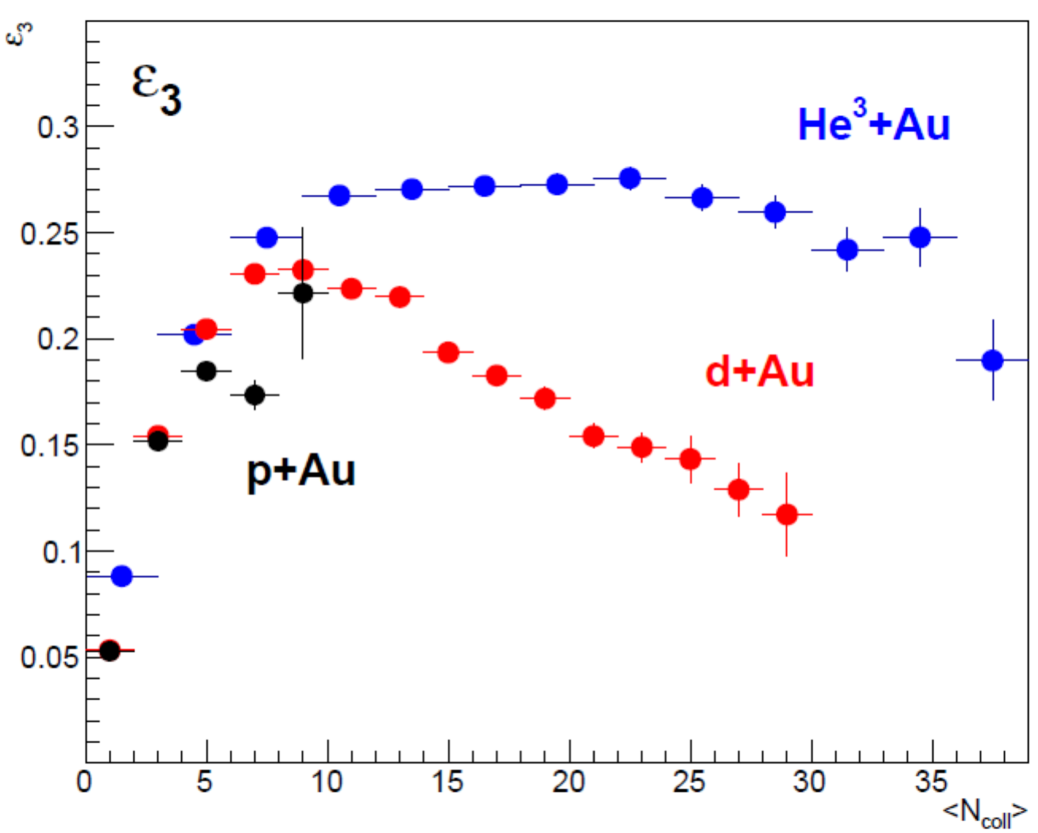
determine the role of geometry



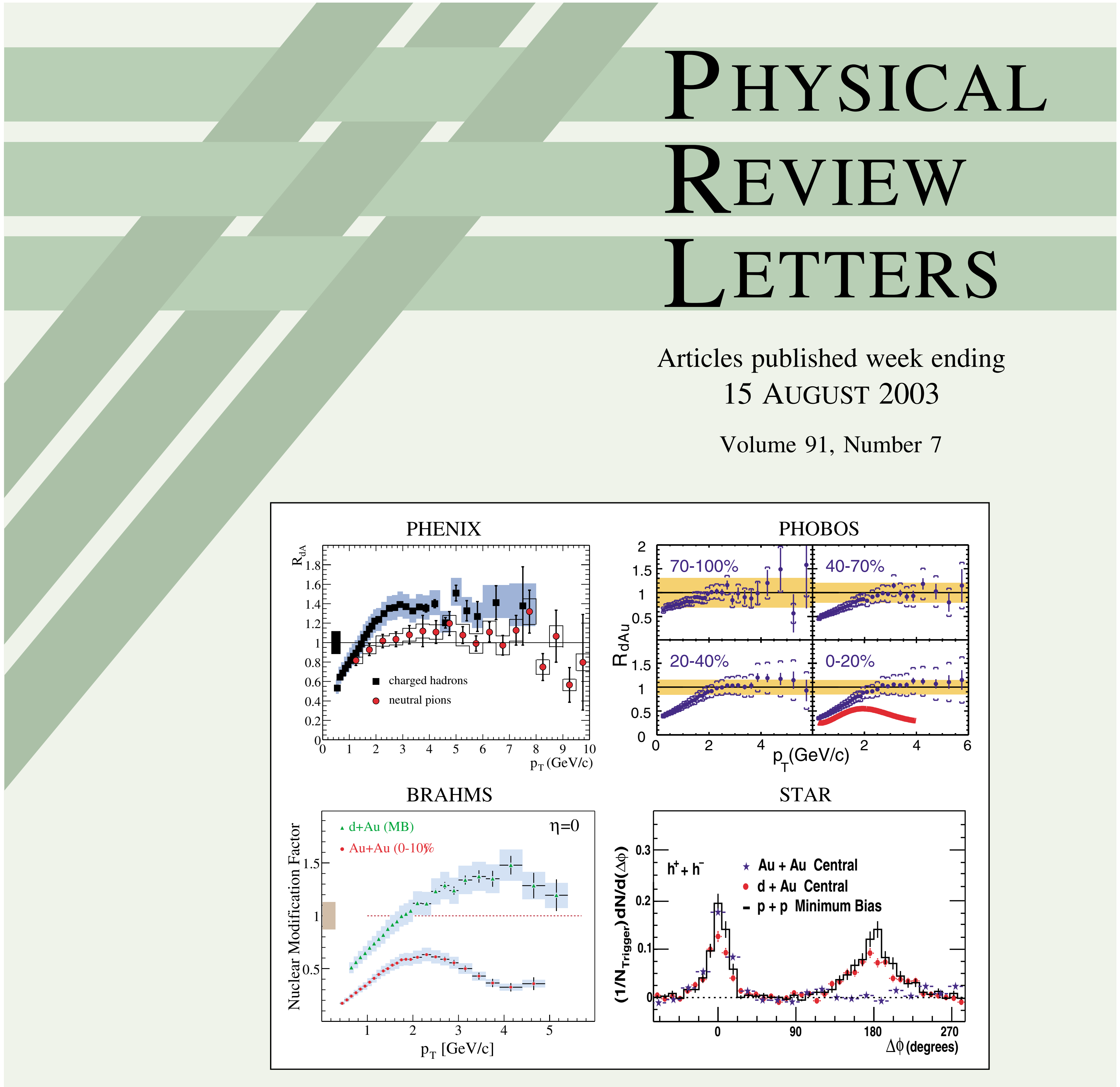
increase the triangularity of the initial state! what happens to v_3?

geometry running planned for 2015 running PHENIX: increased acceptance relative to previous d+Au running (VTX/FVTX)





exploit the versatility of RHIC!



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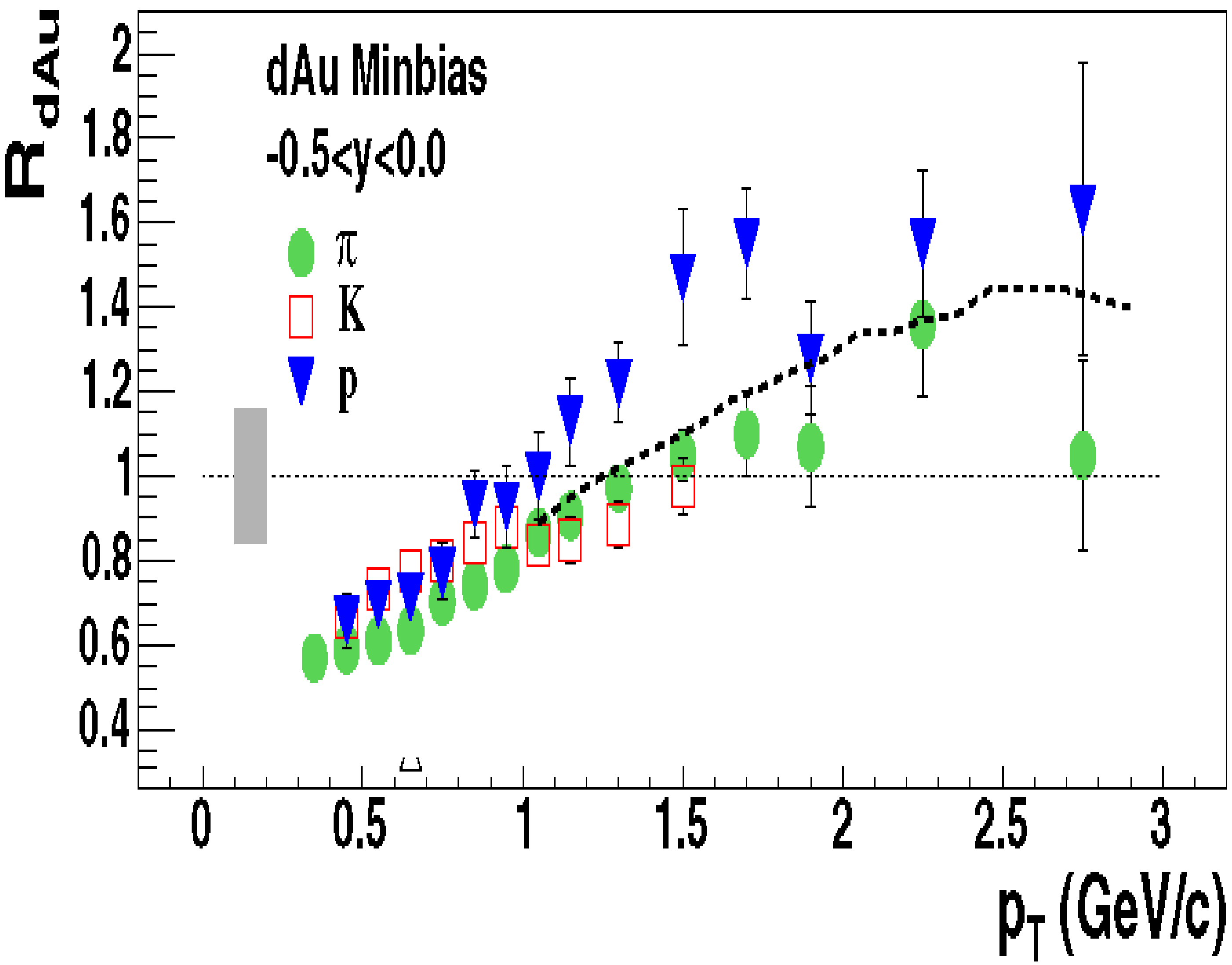
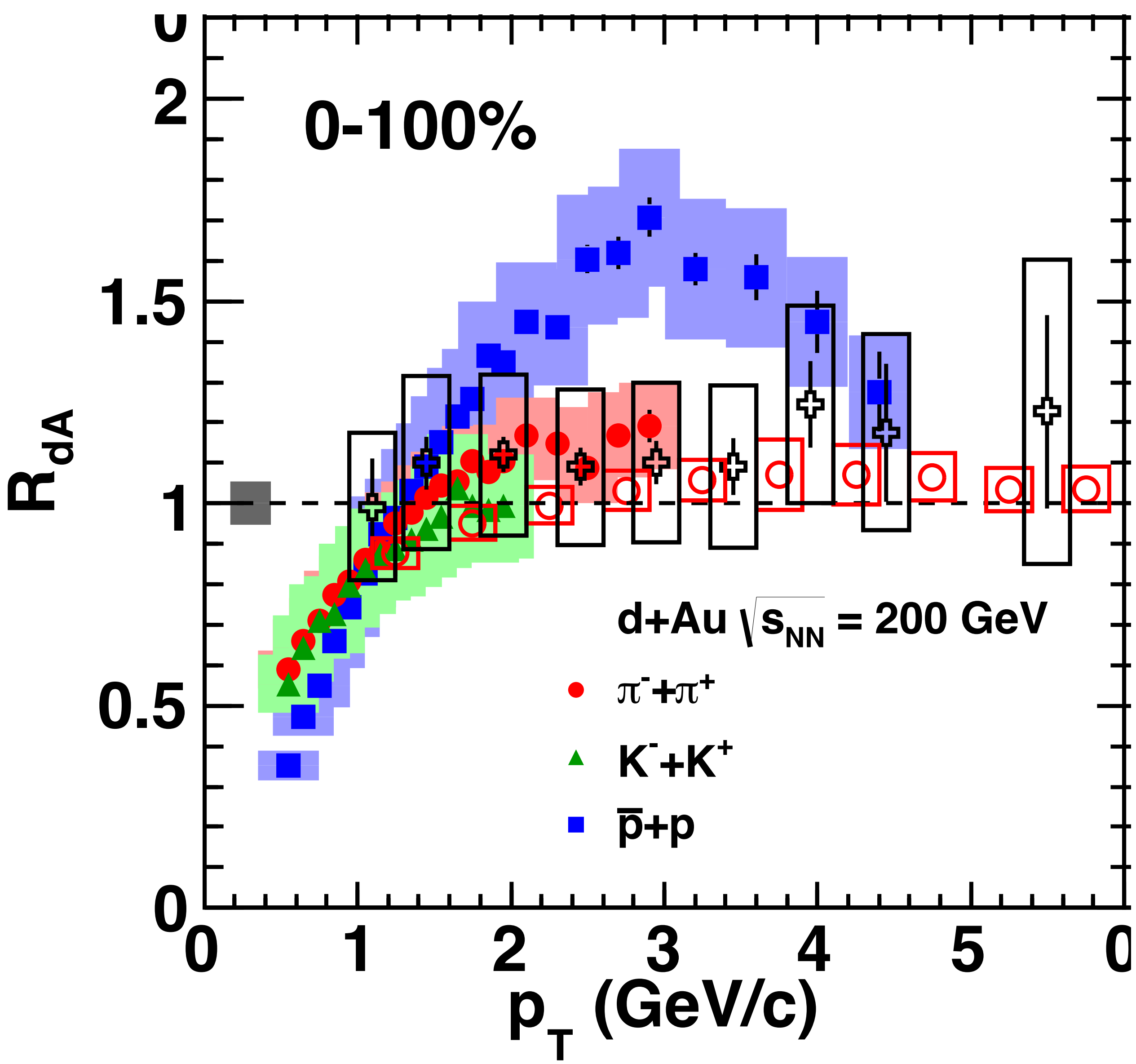
particle species dependence



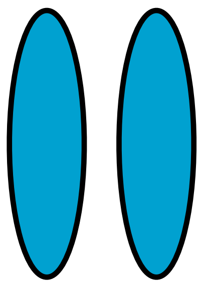


larger Cronin effect for p than π

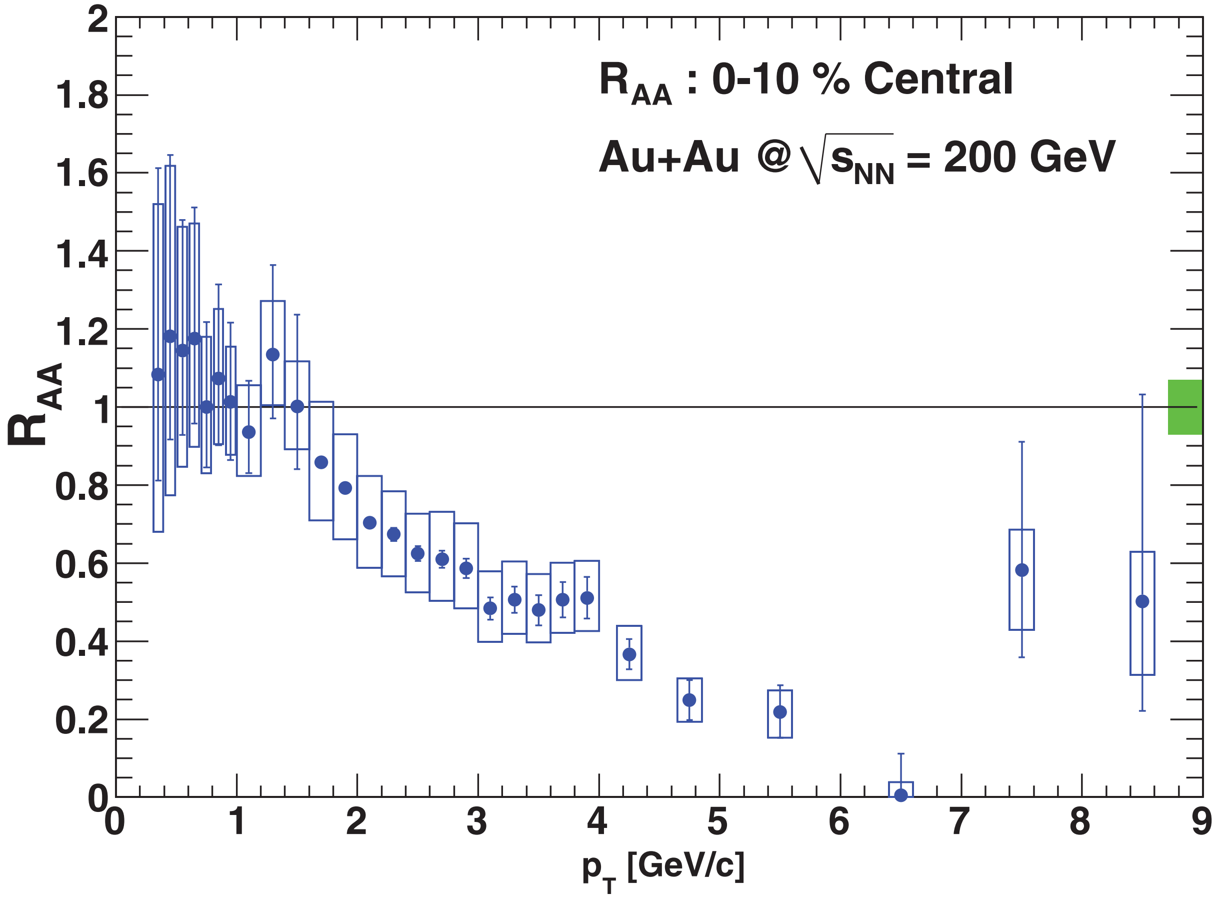
STAR PLB 616 8
PHENIX PRC 88 024906

...and heavy flavor

electrons from heavy flavor decays

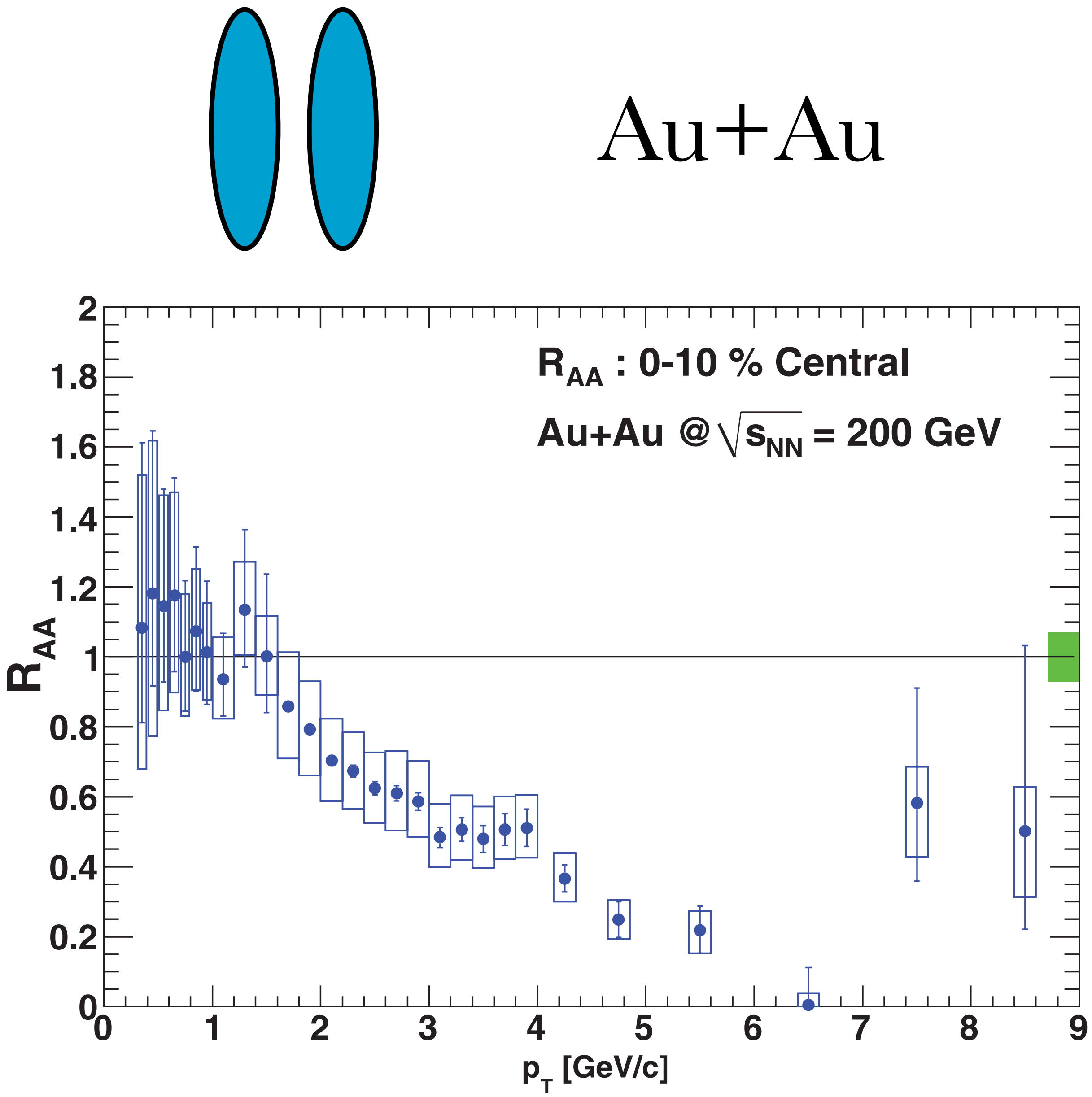


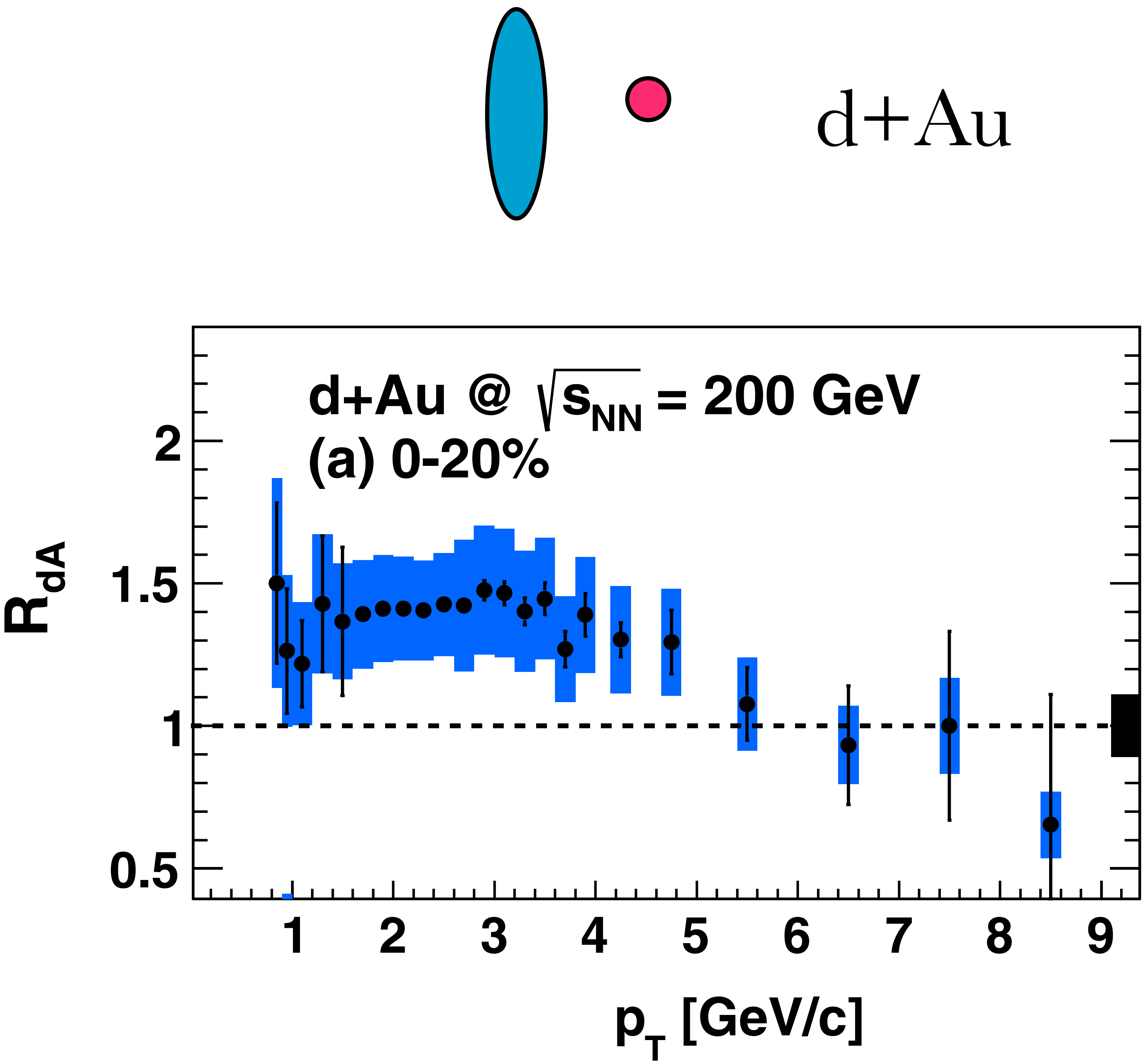
Au+Au



PHENIX PRL 109 242301
PHENIX PRC 84 044905

electrons from heavy flavor decays





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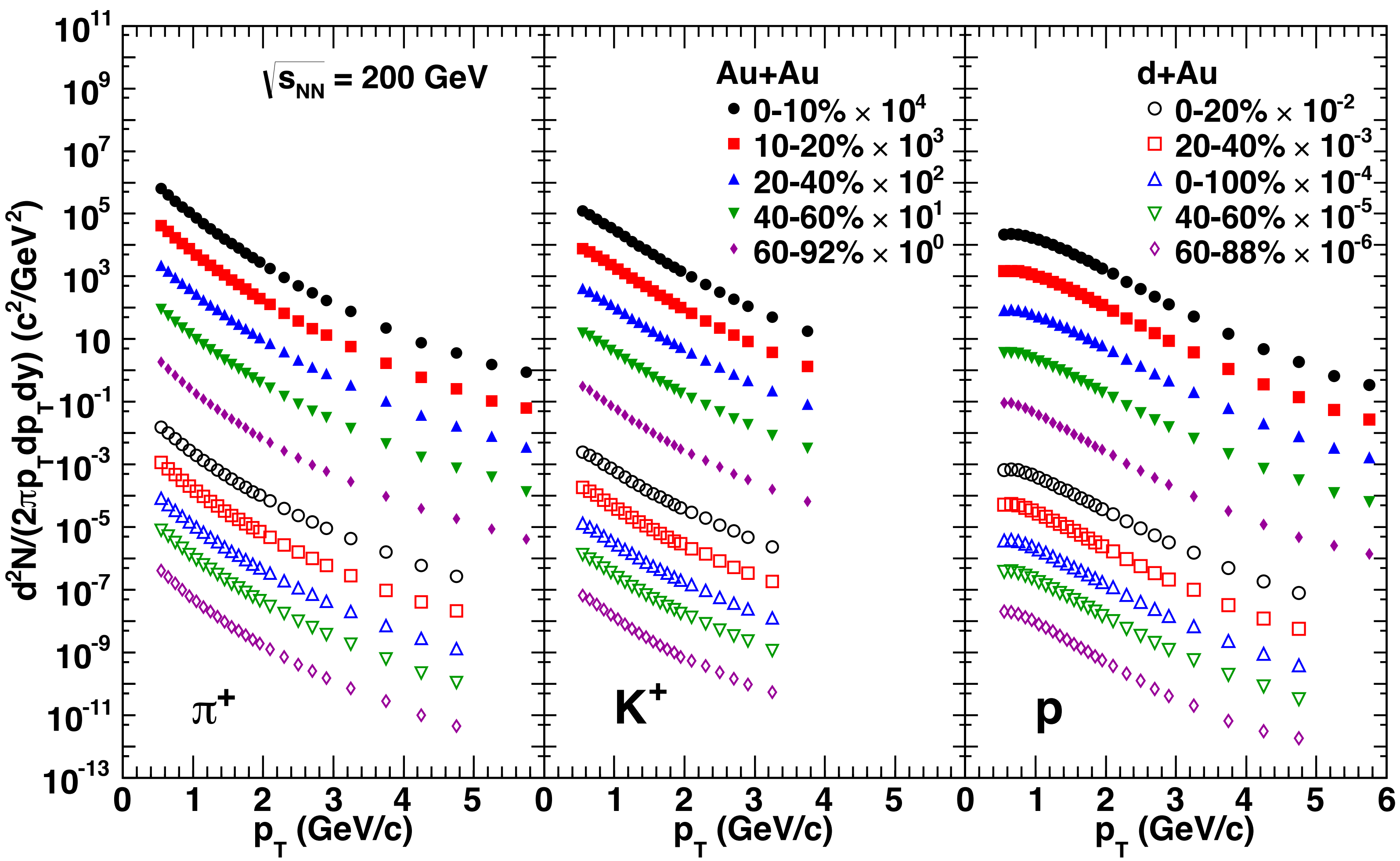
what about radial flow?

- Shuryak & Zahed (1301.4470 & WWND2013)
  - pA systems especially sensitive to radial flow...

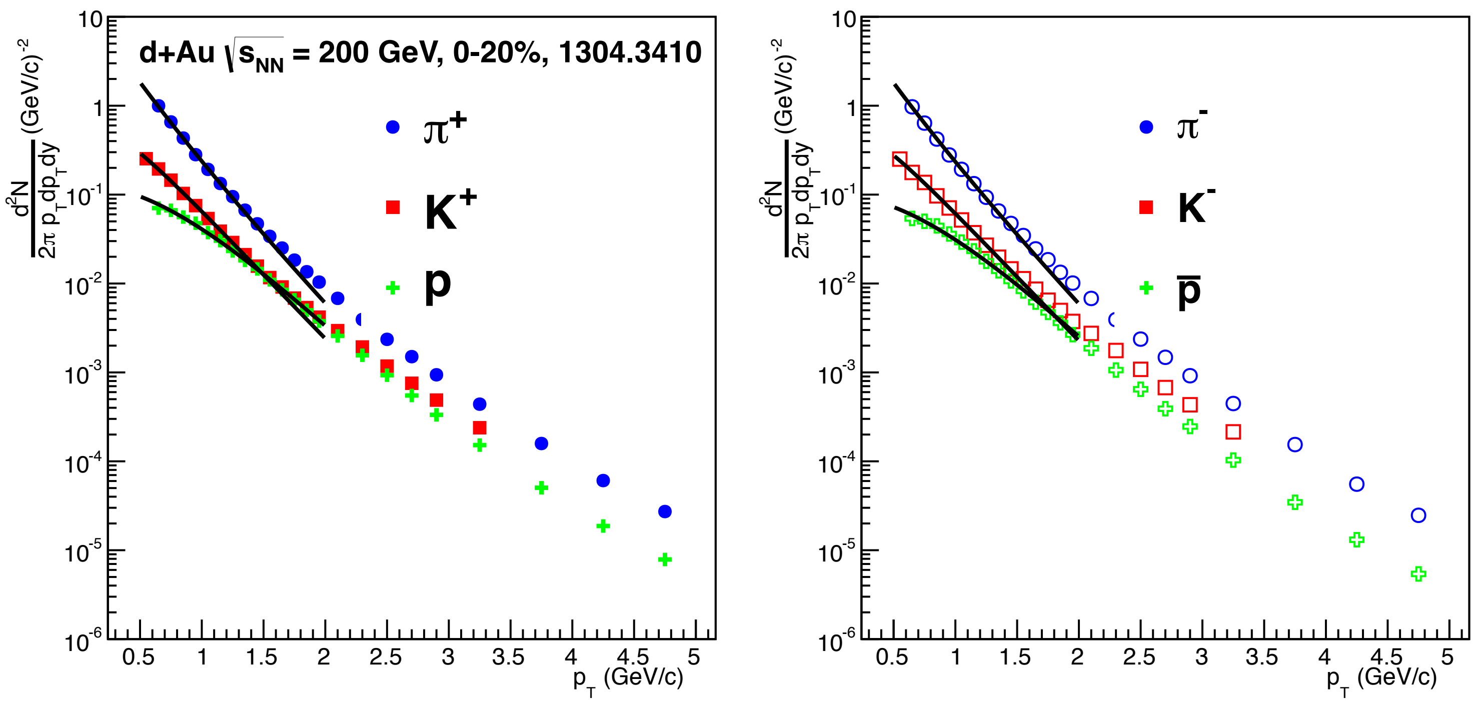
the Blast-Wave

$$\frac{1}{p_T}\frac{dN}{dp_T} \propto \int_0^R r\,dr\,m_T\,I_0\left(\frac{p_T \sinh\rho}{T_{fo}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{fo}}\right) \qquad \rho = \tanh^{-1}\left(\beta_{max}\left(r/R\right)^n\right)$$



PHENIX PRC 88 024906

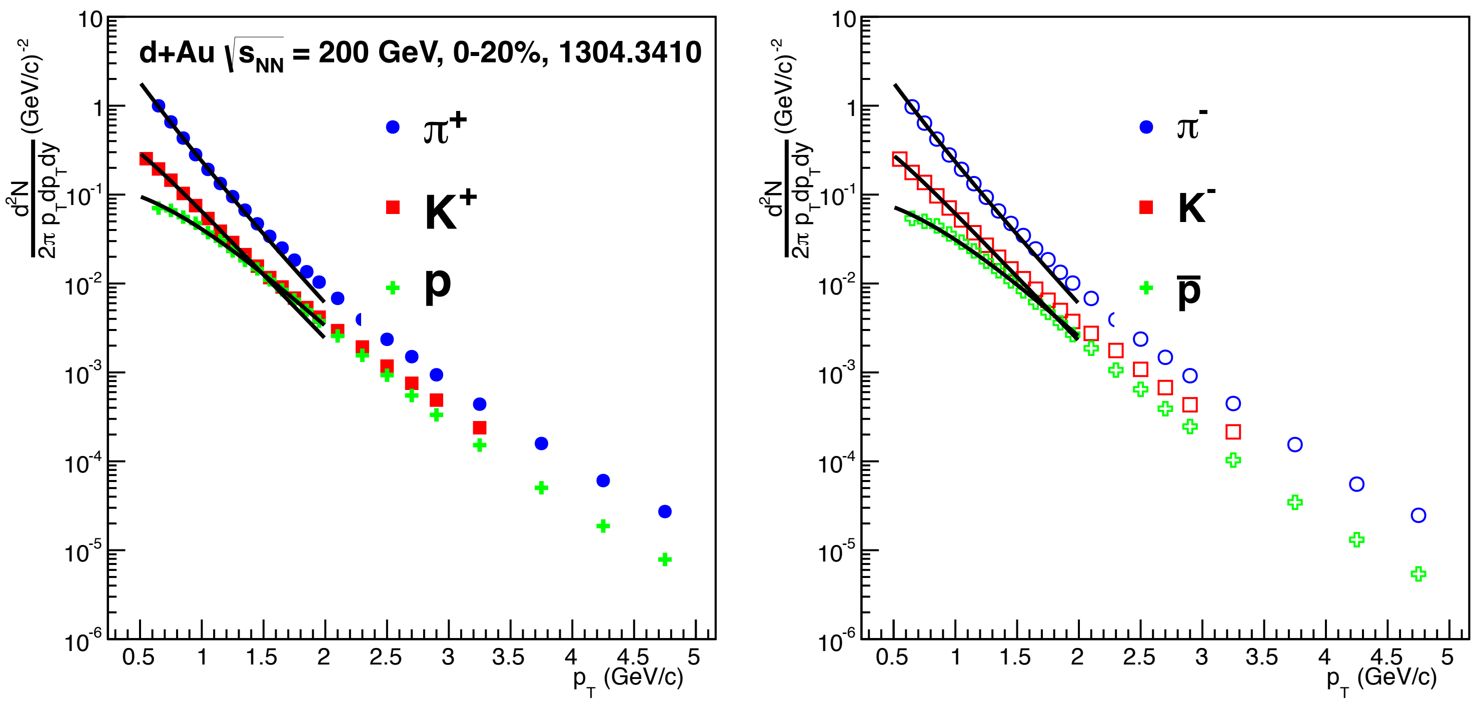
blast-wave fit to dAu data



0-20% d+Au
$\beta_{max} = 0.70$
$T_{fo} = 139$MeV

data: PHENIX PRC 88 024906
AMS: 1309.6924

blast-wave fit to dAu data



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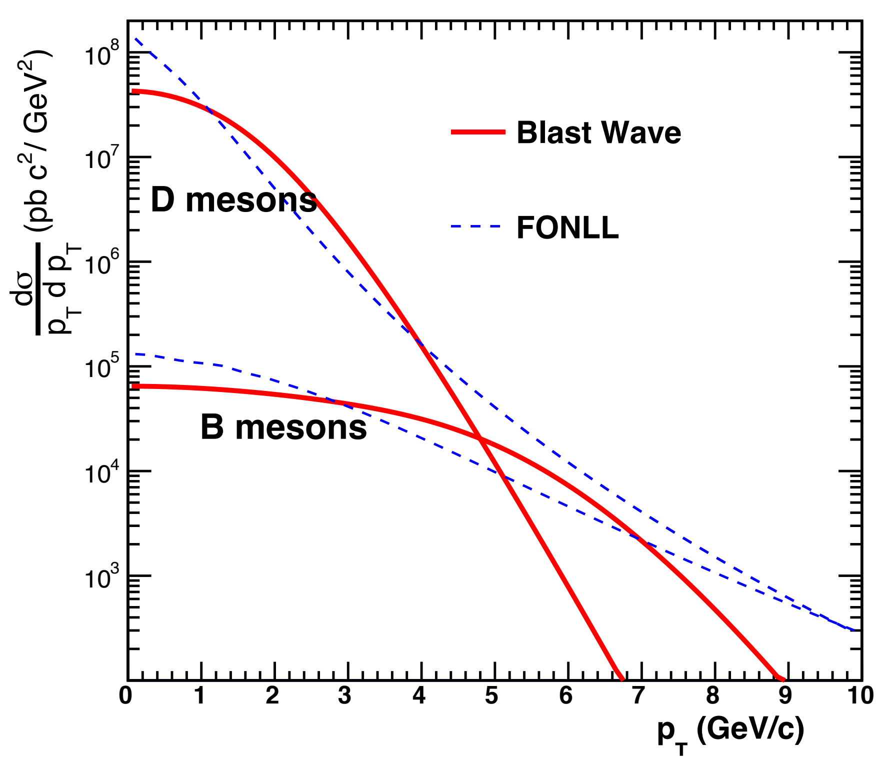

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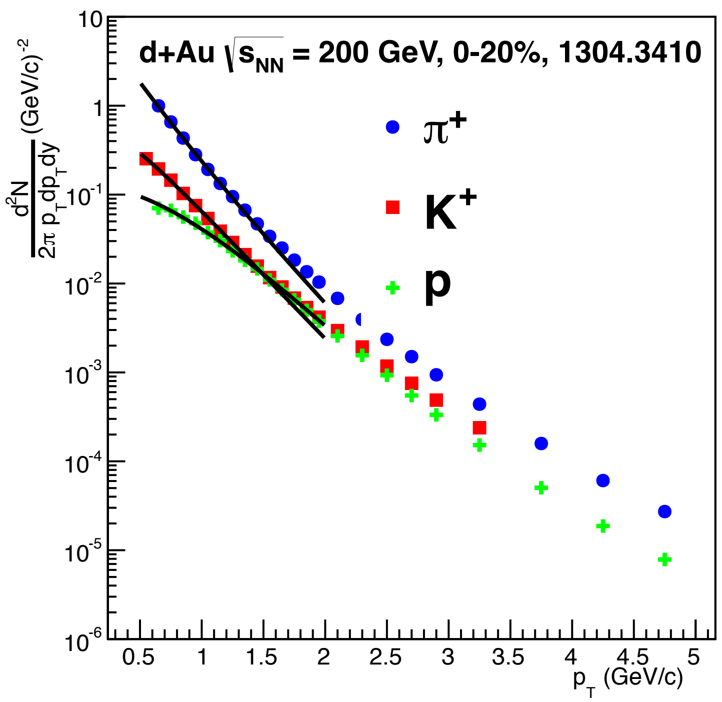
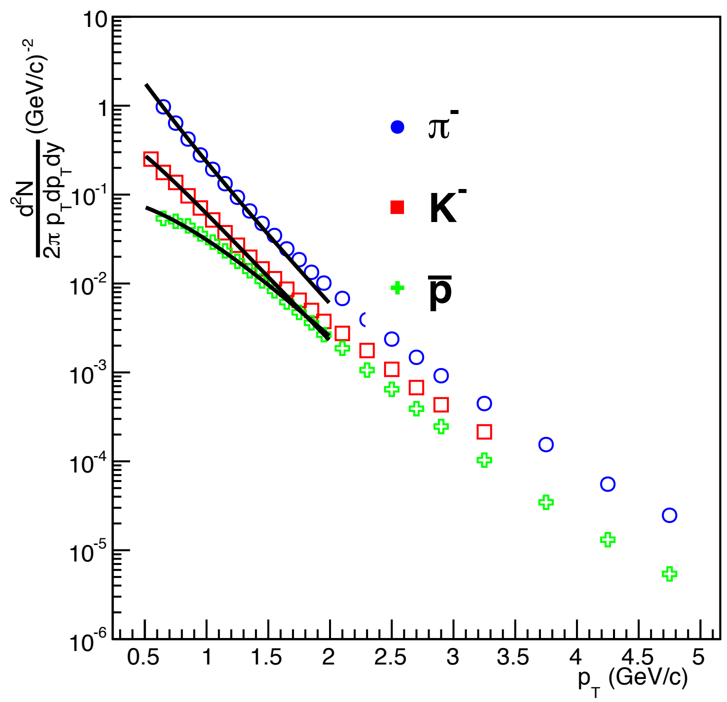
blast-wave fit to dAu data





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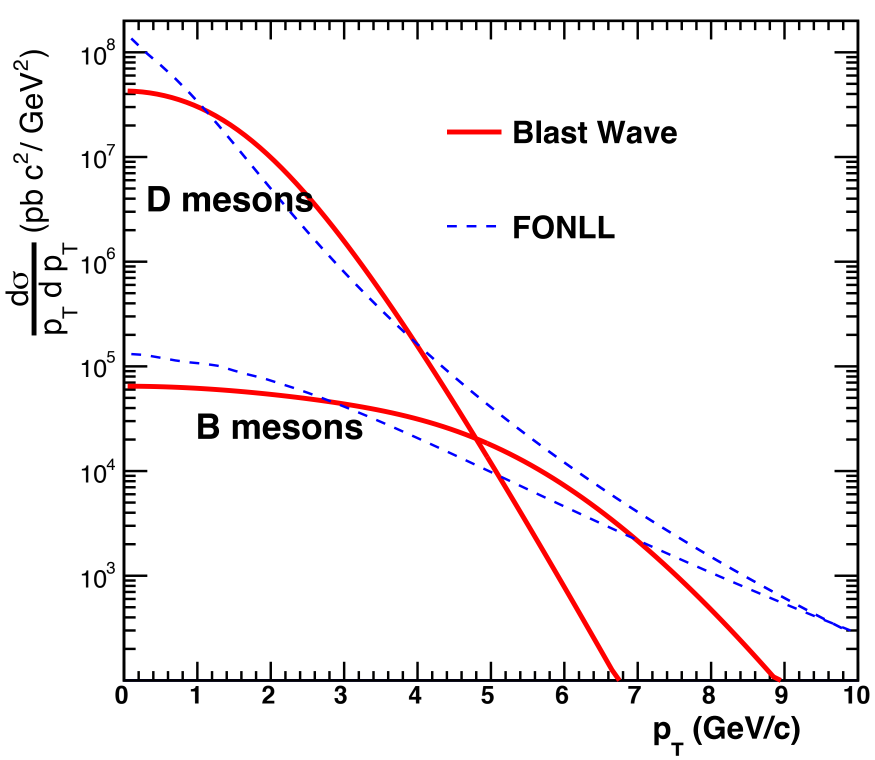
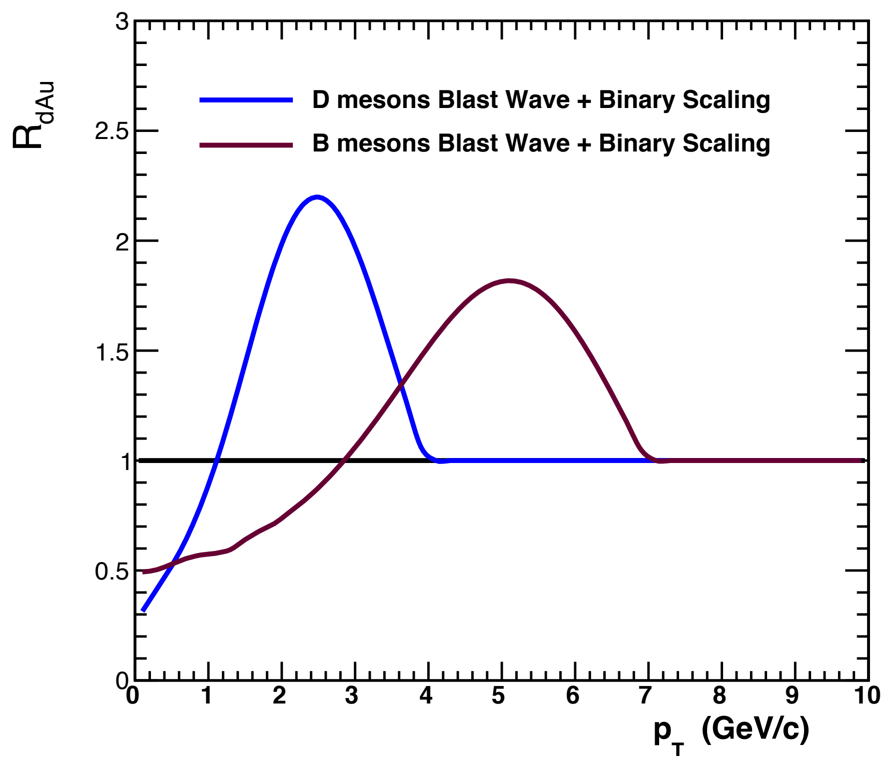
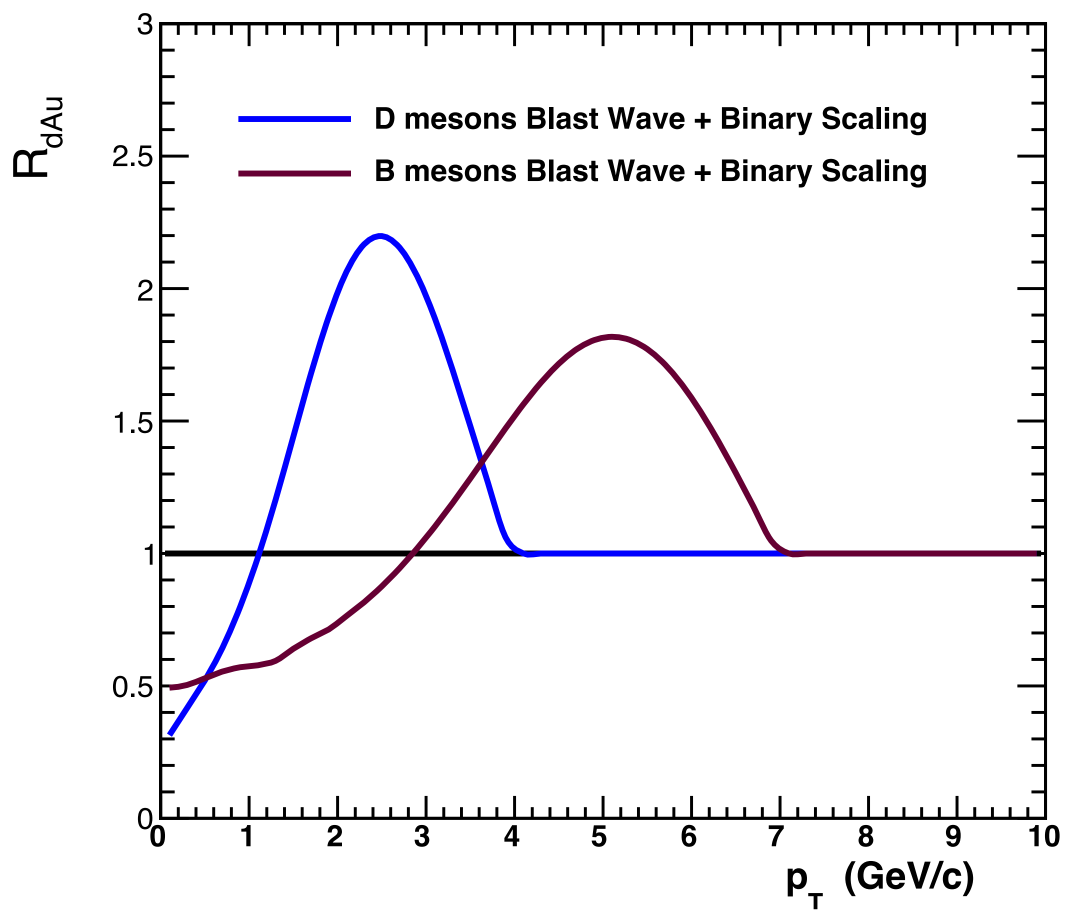


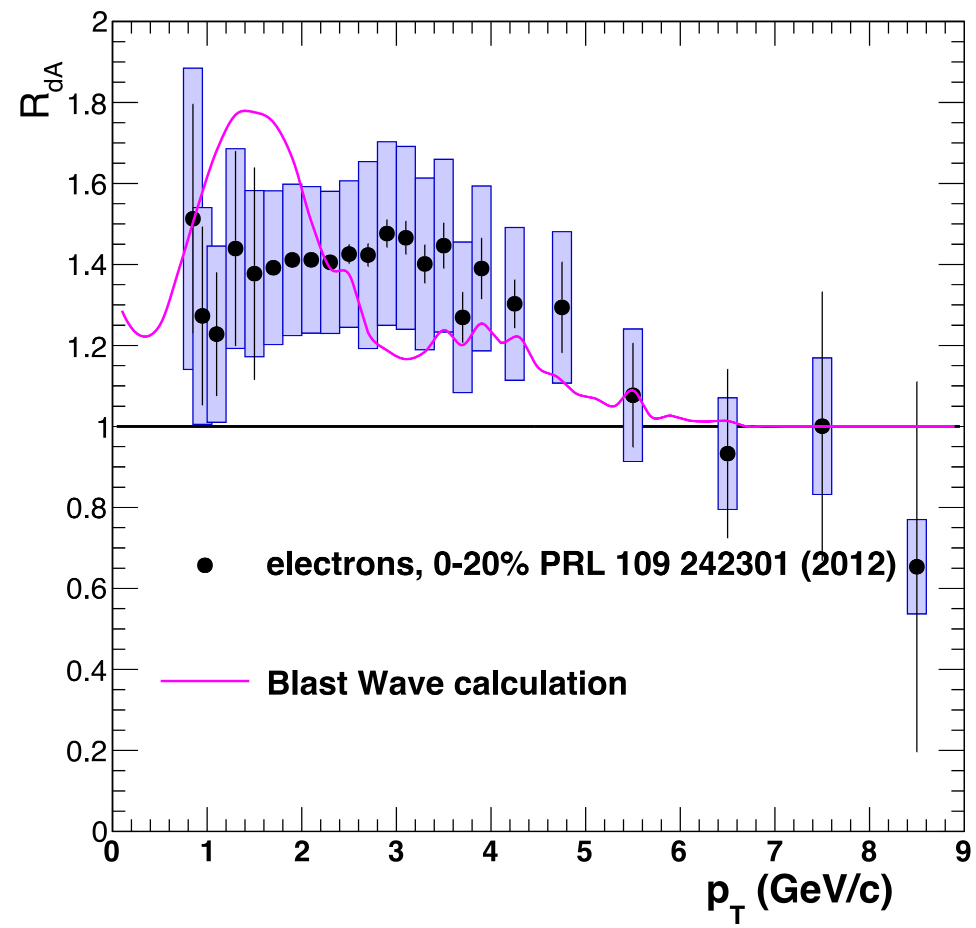


could lead to large enhancement of heavy mesons!

data: PHENIX PRC 88 024906
AMS: 1309.6924

and for the electrons?



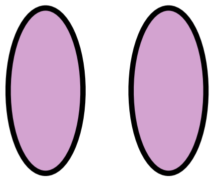


are we really looking at cold nuclear matter effects?

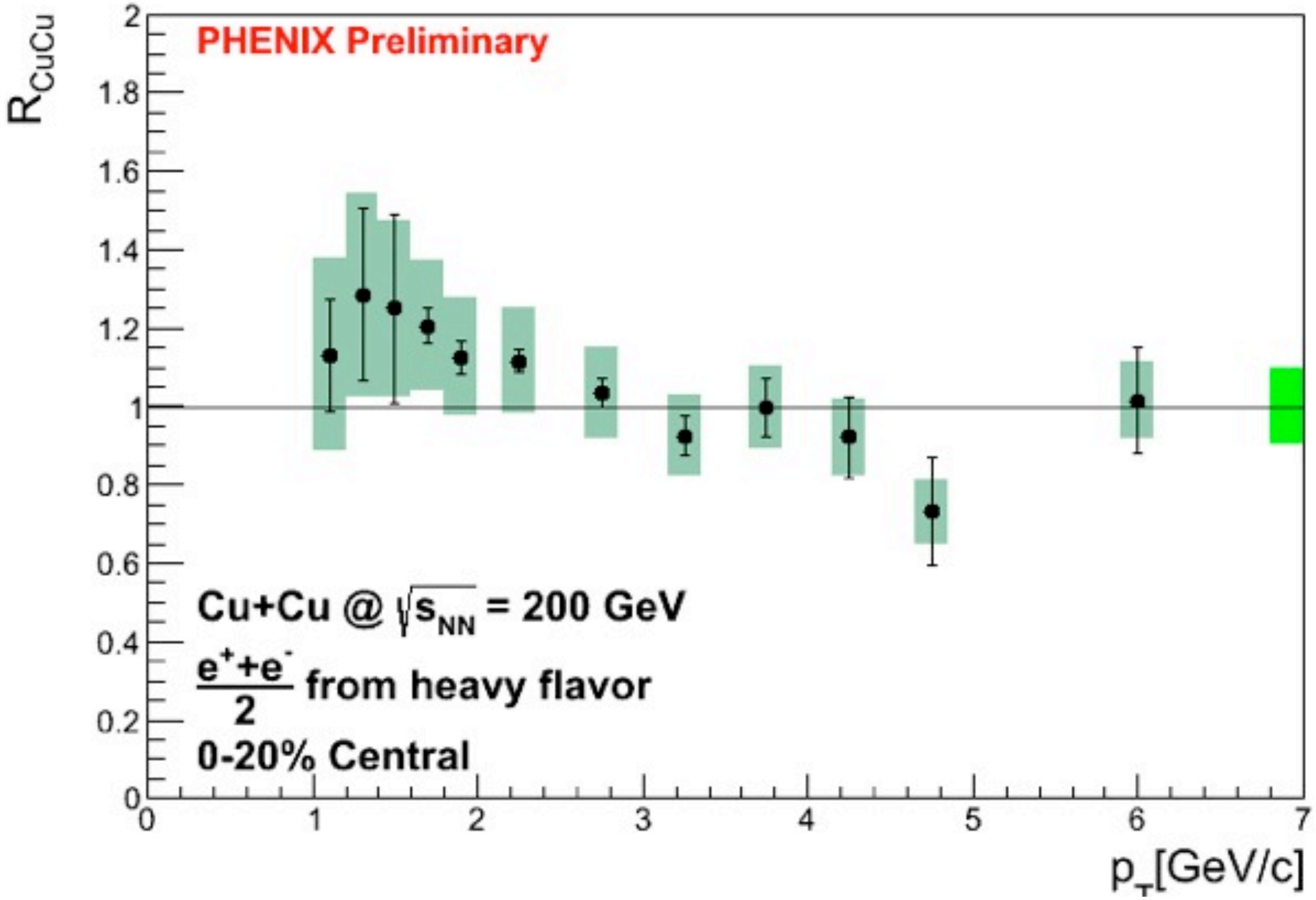
reconstructed D RdAu measurements at RHIC would be very telling

data: PHENIX PRL 109 242301
AMS: 1309.6924

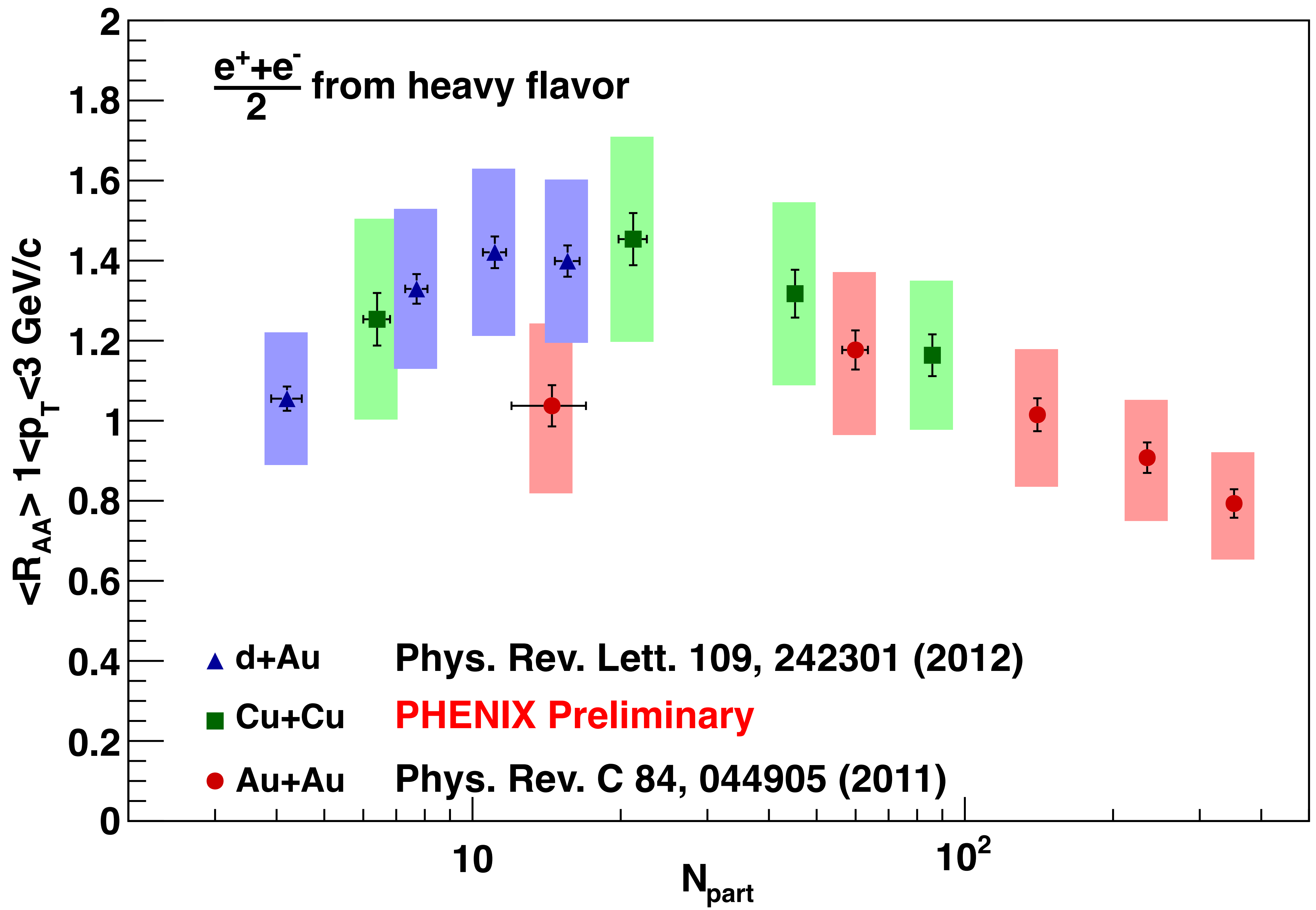
evolution with system size



Cu+Cu collisions



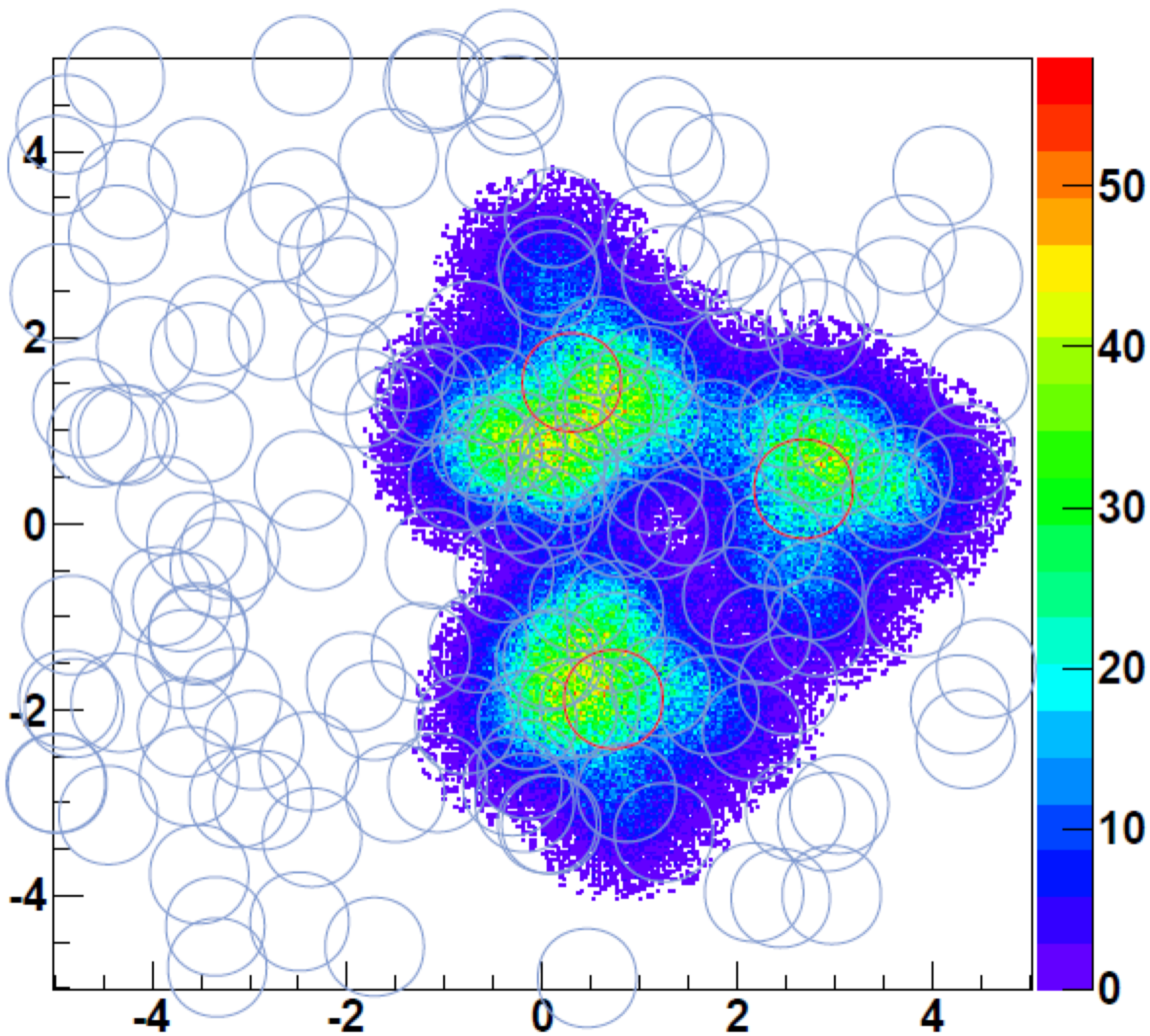
evolution with system size



comparison of system size and geometry is key to understanding relationship between big and small systems

conclusions

- exciting effects seen in d+Au collisions which challenge the distinction between "hot" and "cold" nuclear matter
- upcoming geometry runs promise new understanding
  - smaller HI systems already helping to connect dA to AA
    - other observables: HBT (Ajitanand FG.00007, balance functions 1005.2307...)



compelling illustration of the complementarity between RHIC & LHC and the power of varying the collision system

backups

remaining jet effects?

issue: short range effects from centrality dependent jet modifications could modify near side correlations within small $|\Delta\eta|$

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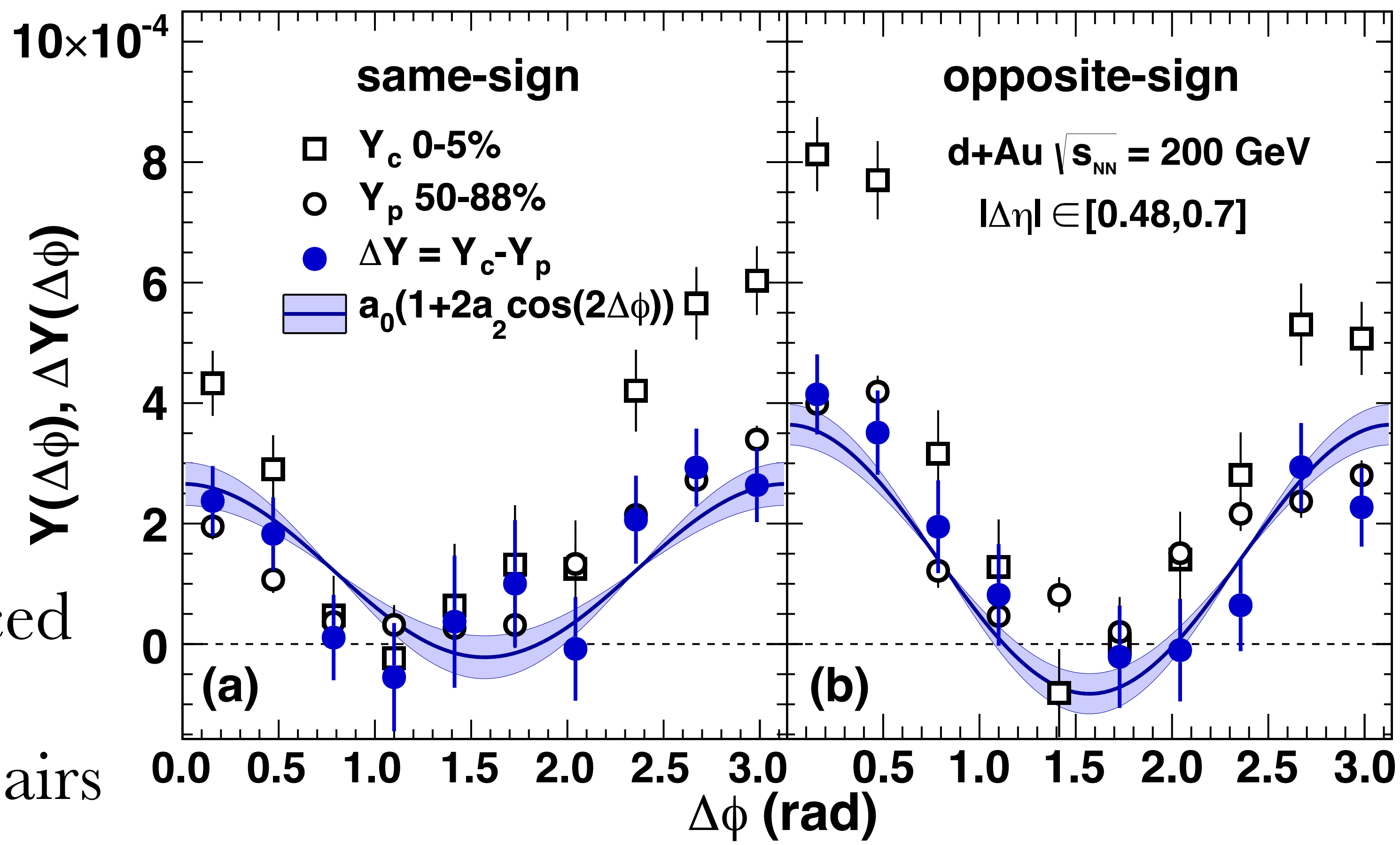
- vary the minimum $|\Delta\eta|$ cut from 0.36 to 0.60
- look at the charge sign dependence:
  - jet correlations are enhanced for opposite sign pairs and suppressed for same sign pairs
- further studying with event generators
- look for long range correlations

remaining jet effects?

issue: short range effects from centrality dependent jet modifications could modify near side correlations within small $|\Delta\eta|$

PHENIX: 1303.1794



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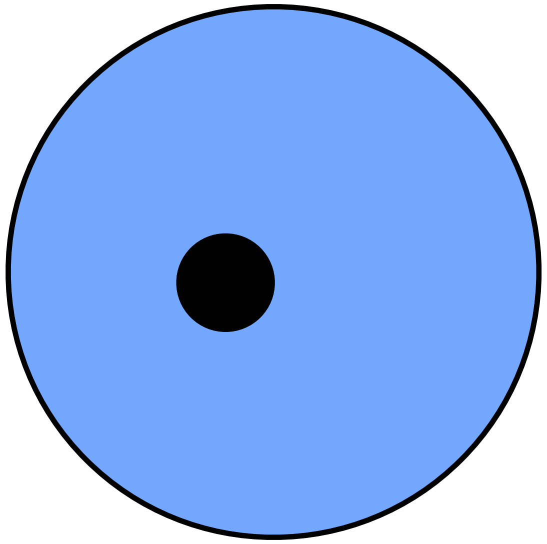
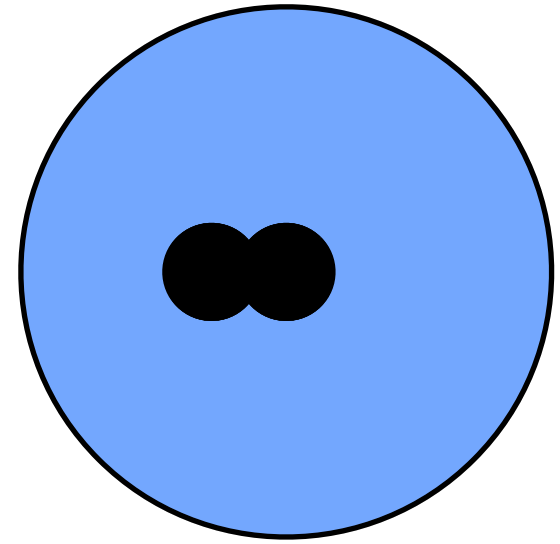
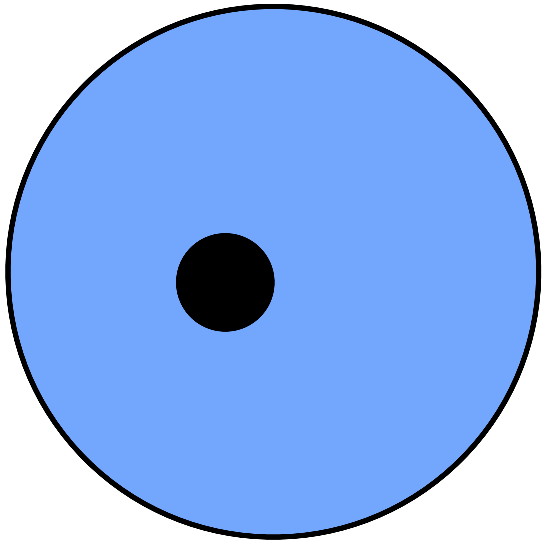
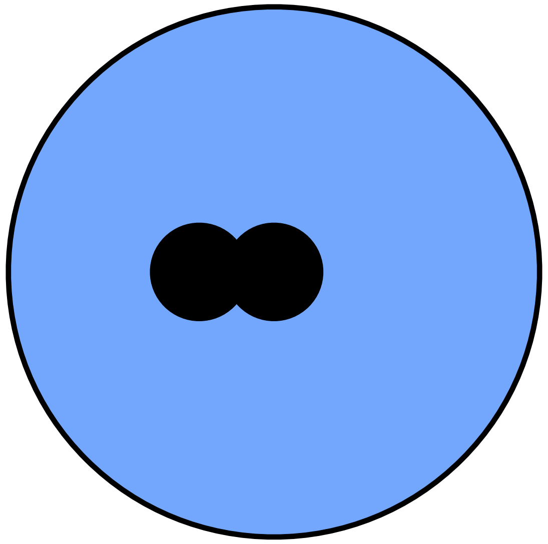
pPb vs dAu

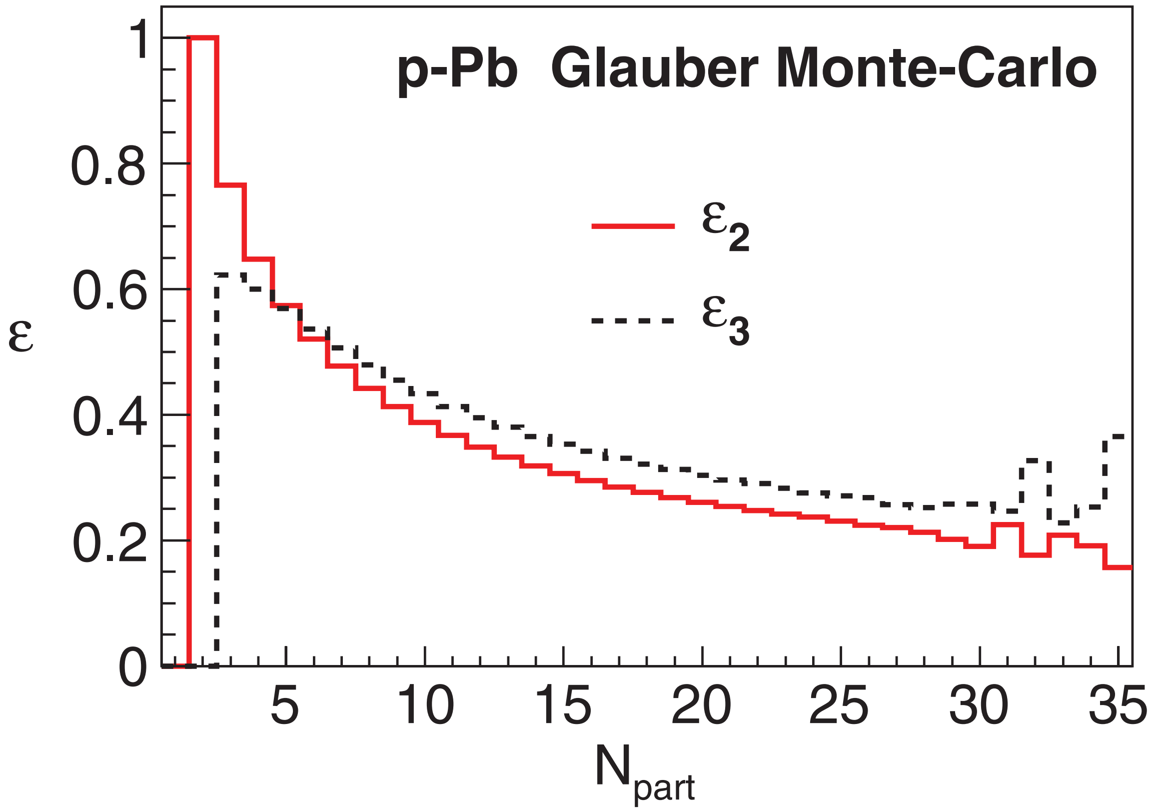


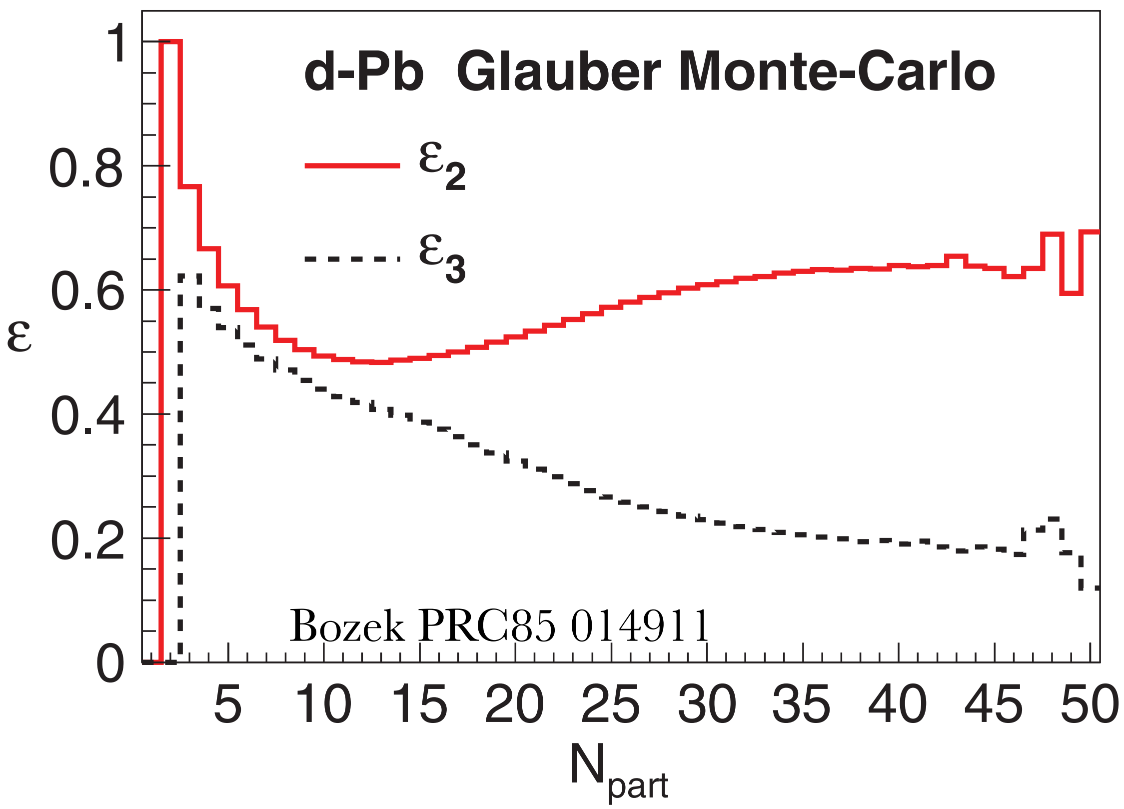


pPb vs dAu

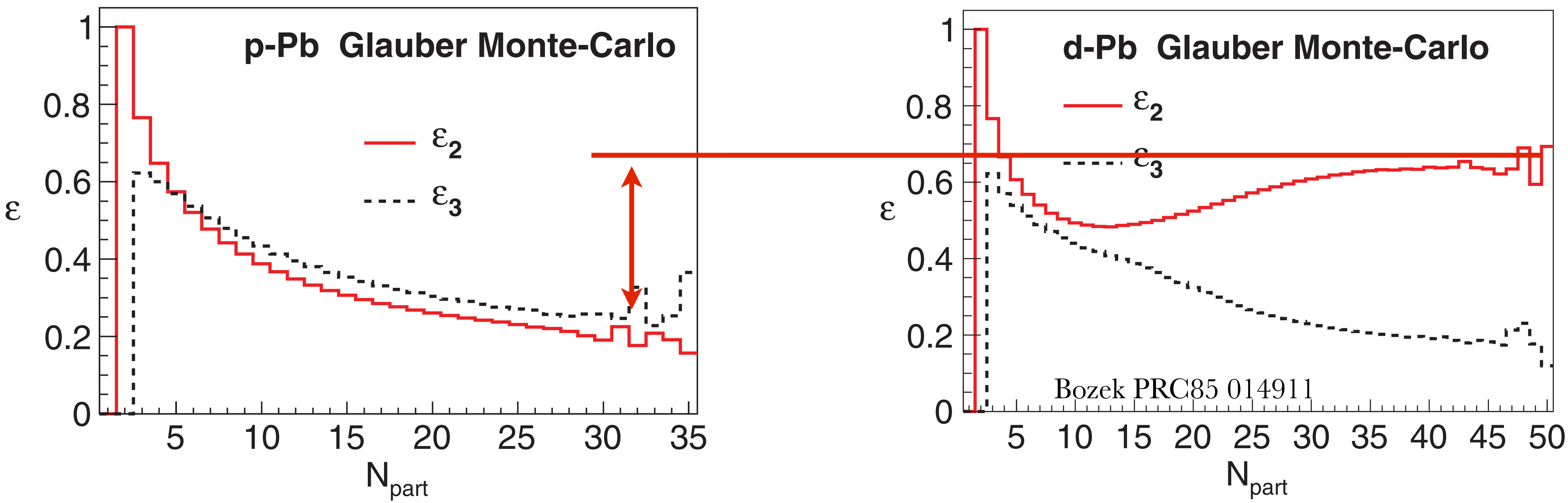





p-Pb Glauber Monte-Carlo
ε
ε_2
ε_3
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
N_{part}

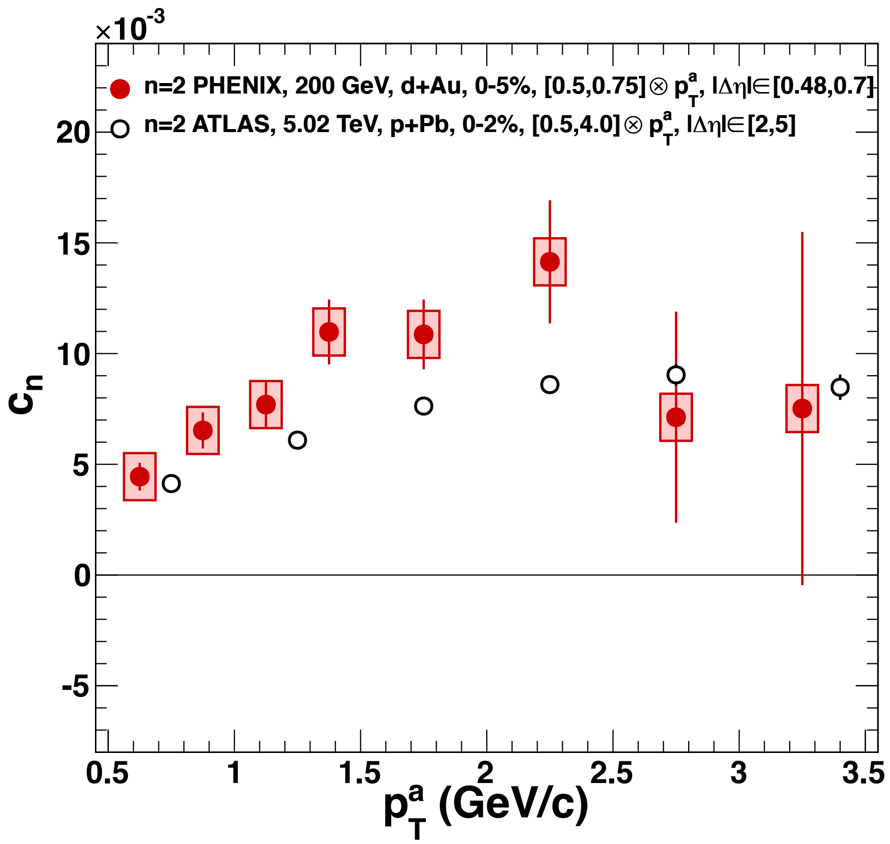

d-Pb Glauber Monte-Carlo
ε
ε_2
ε_3
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
40
45
50
N_{part}
Bozek PRC85 014911

pPb vs dAu



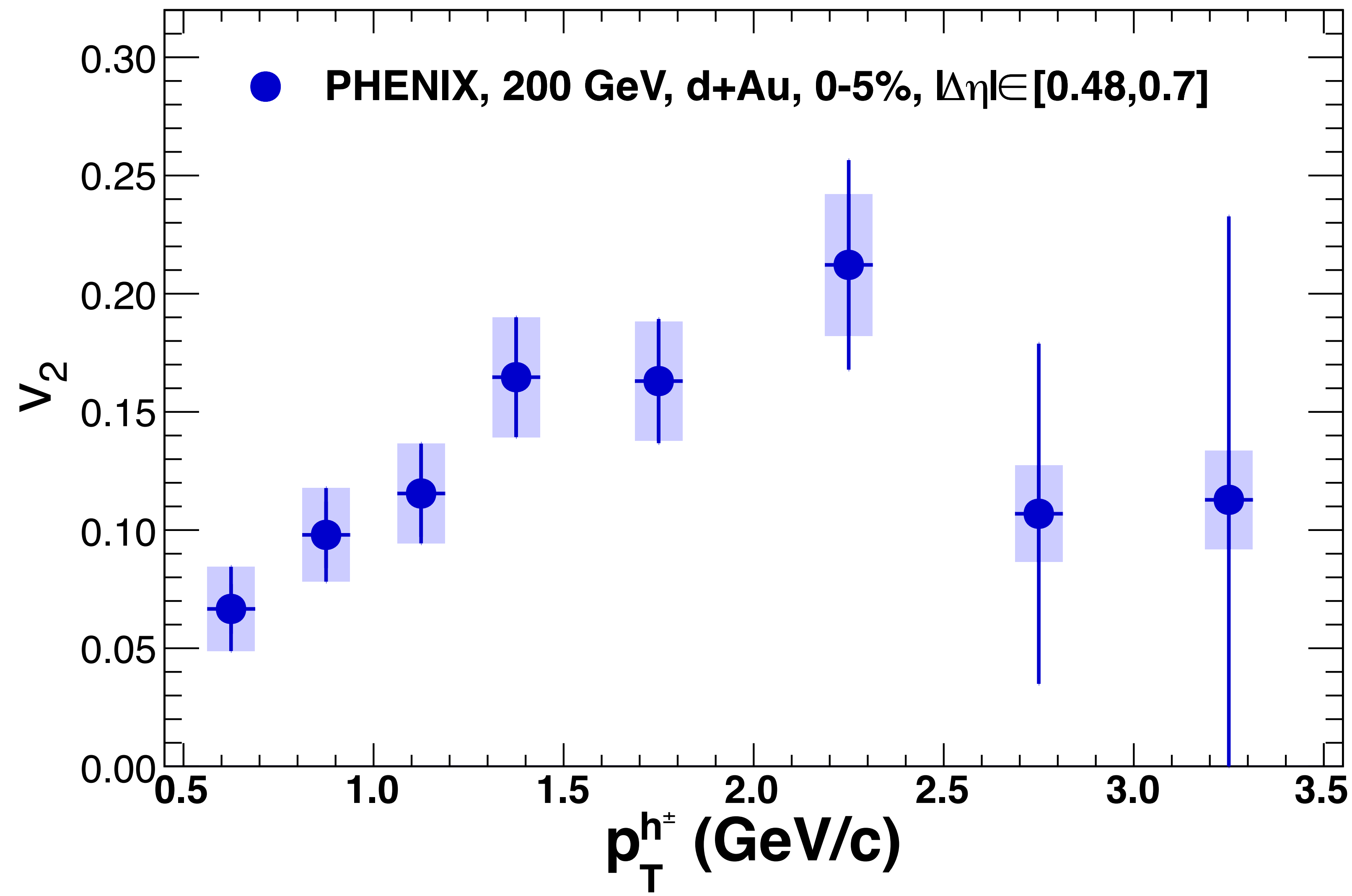
d+A central collisions have much larger ε_2 than p+A

extract v_2 via factorization



$$c2(p_{T,a},p_{T,b}) = v2(p_{T,a})v2(p_{T,b})$$

→factorization assumption: two particle modulation is the product of the single particle anisotropies, no inconsistencies with this assumption found



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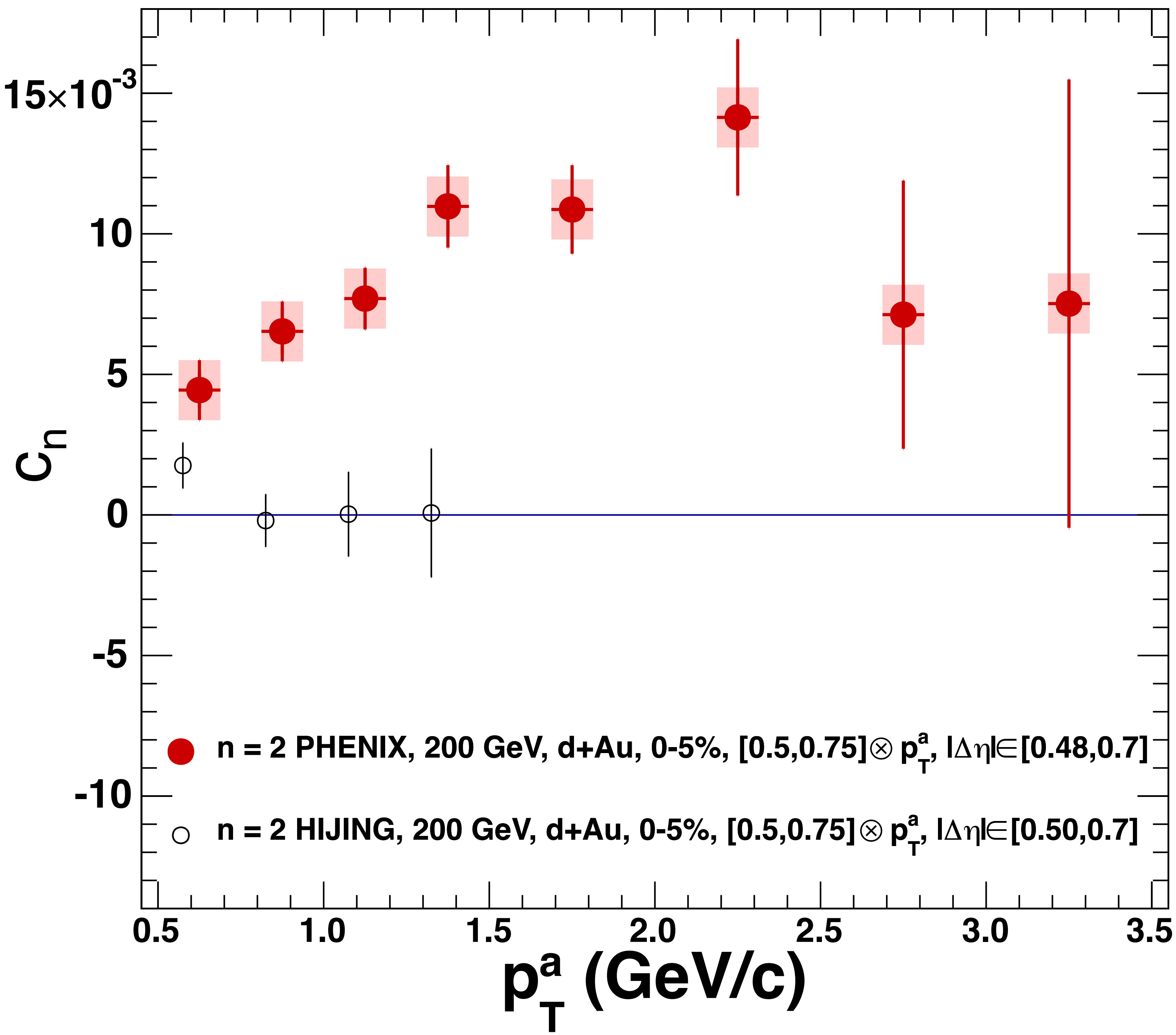
Hijing expectations?

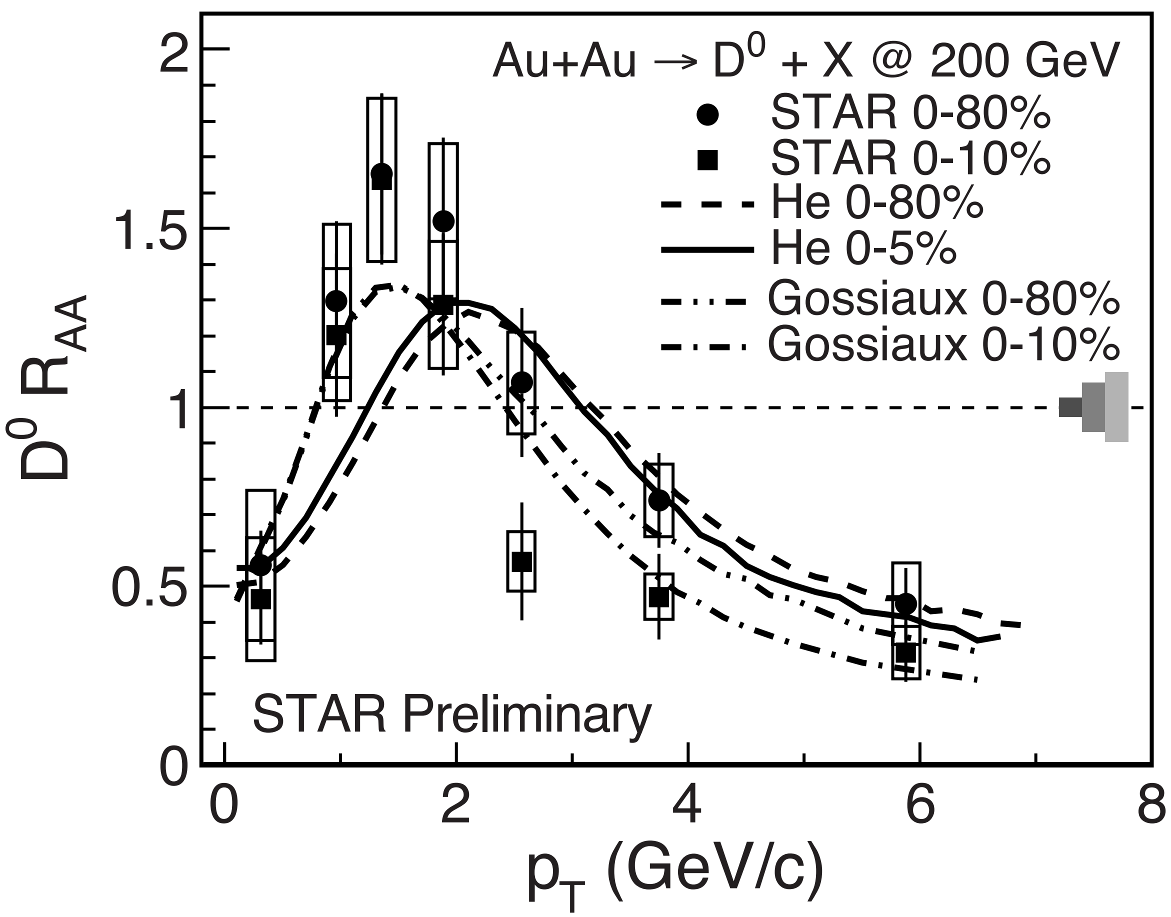
- HIJING has no flow, no CGC
- perform the same study with HIJING as in the data

HIJING c_2 consistent with 0, much smaller than in data



D results at RHIC

Au+Au preliminary, QM12

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Open Charm Yields in d + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV