Jets in dAu/pPb at RHIC and LHC

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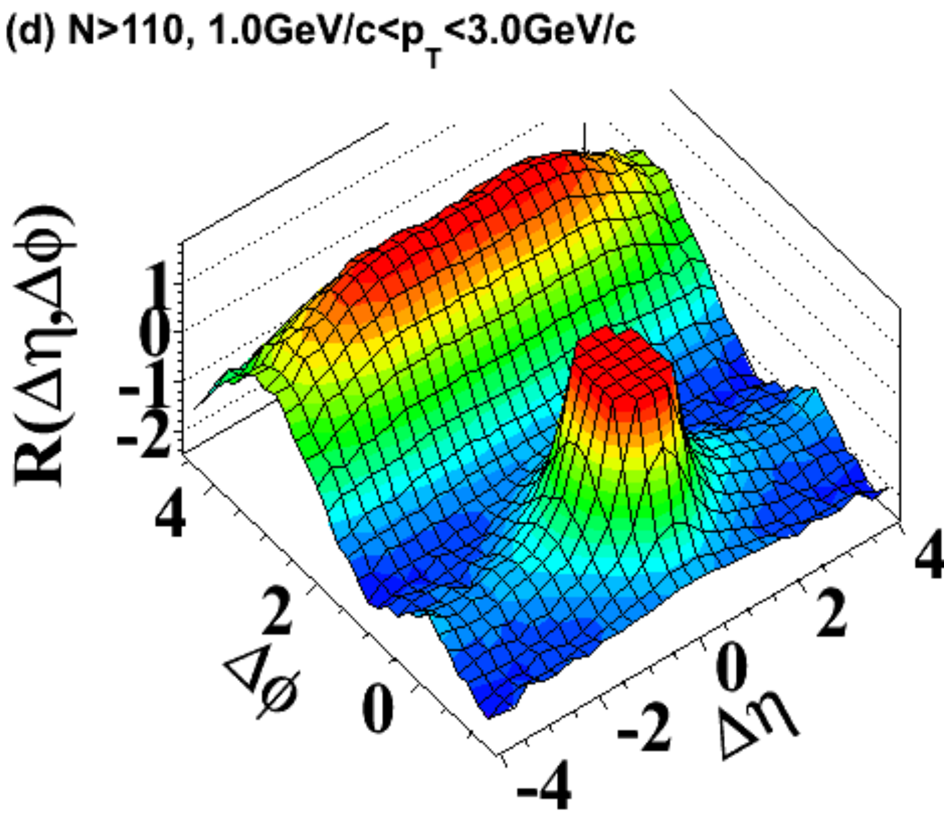
RHI Physics Paradigm

- p+p: baseline
- p(d)+A: baseline + CNM
- A+A: baseline + CNM + Hot Nuclear Matter

Has the time come for a `paradigm shift'?

(T. Kuhn, `The Structure of Scientific Revolutions', 1962)

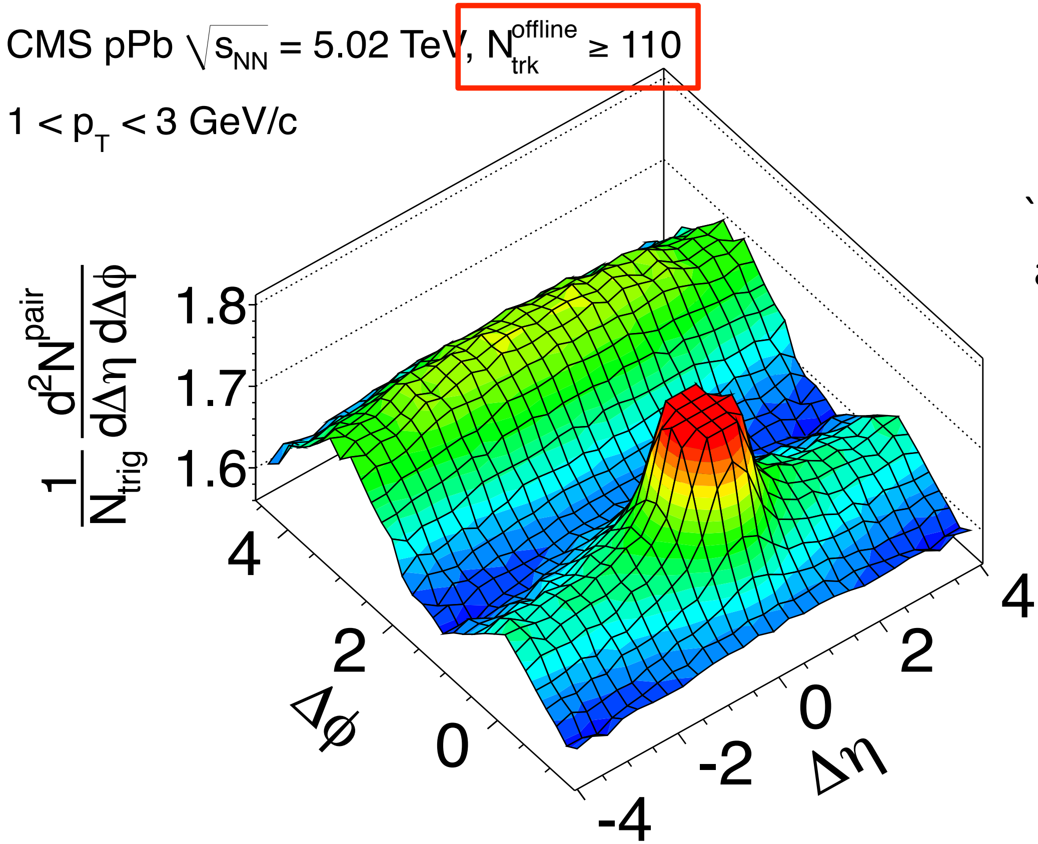
Ridge in p+p



`Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC',
CMS,
J. High Energy Phys. 09 (2010) 091,
arXiv:1009.4122.

Very high multiplicity events

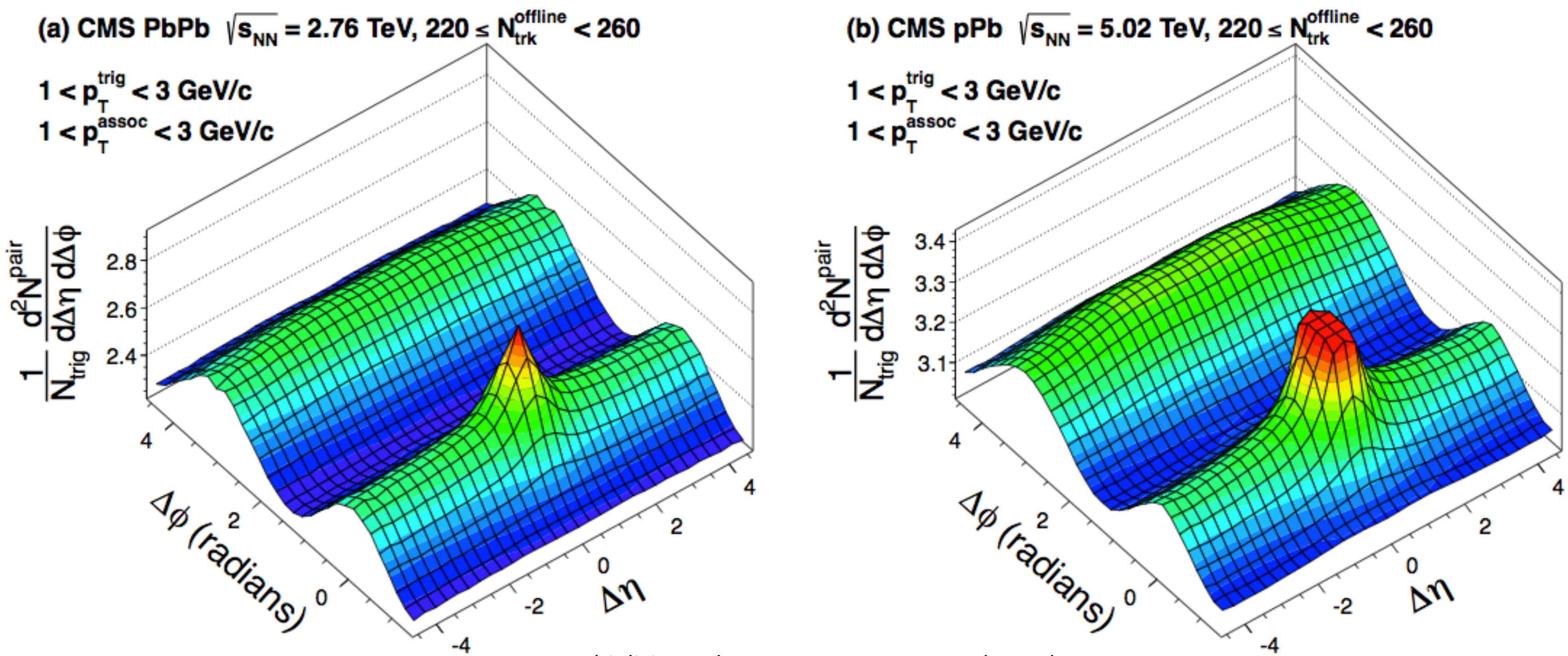
Ridge in p+Pb



`Observation of long-range, near-side angular correlations in pPb collisions at the LHC',
CMS, 2012 data
Phys. Lett. B 718 (2013) 795-814,
arXiv:1210.5482.

High multiplicity events

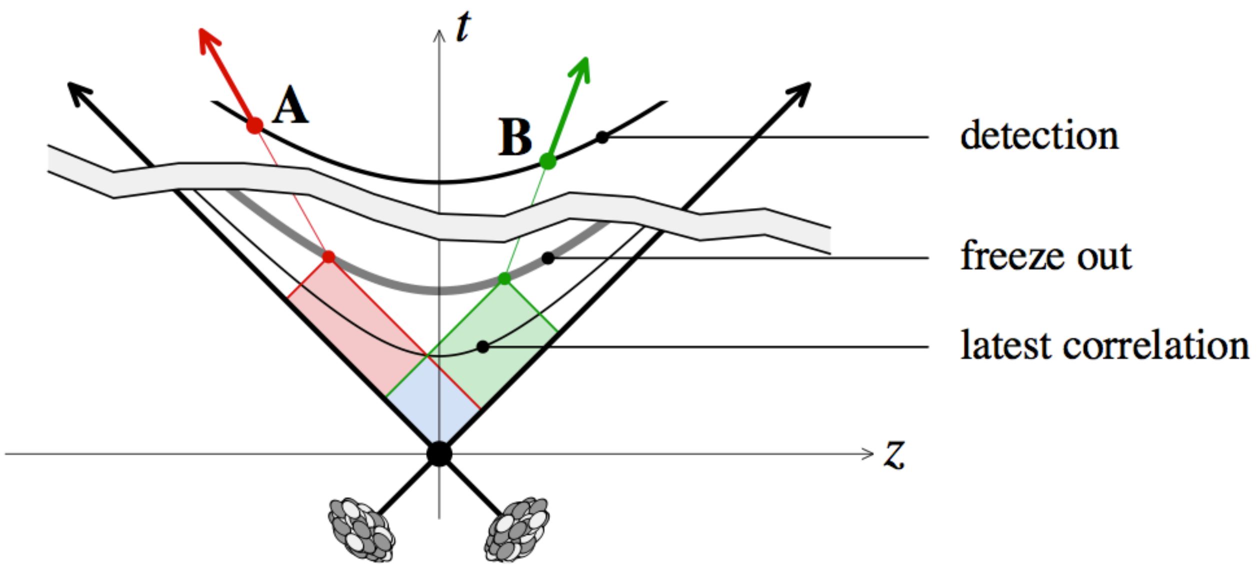
Ridge in Pb+Pb



Multiplicity and transverse-momentum dependence
of two- and four-particle correlations in pPb and
PbPb collisions,
CMS, 2013 data,
Phys.Lett. B724 (2013) 213-240,
1305.0609.

Semi-central events

Ridge Causality Constraint



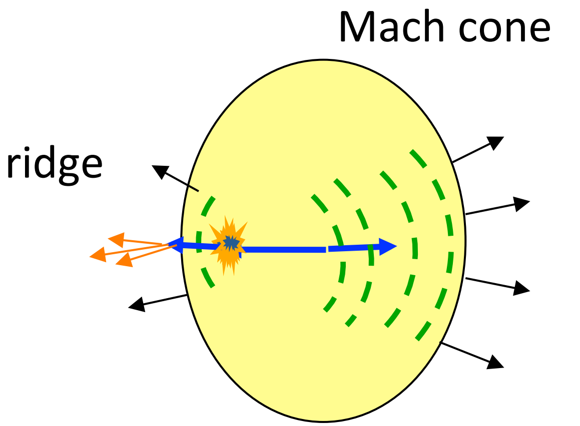
A. Dumitru et al.,
Nucl. Phys. A810, 91 (2008)

$$\tau_{\text{init.}} = \tau_{\text{freeze-out}} \exp\left(-\frac{1}{2}|\Delta y|\right)$$

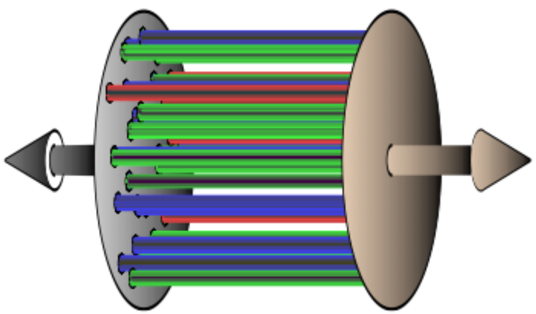
Causality constraint:
Large $\Delta\eta$ correlation has to be
Established shortly after collision occurs

Information on:
Initial-state structure of proton wave function
Quantum fluctuations of primordial color field

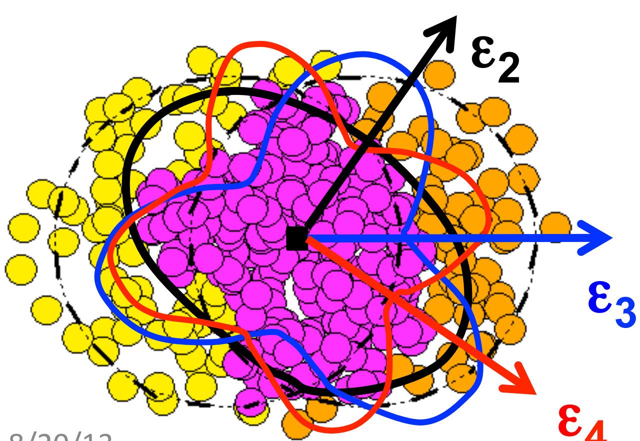
A+A ridge: alternative explanations



- Jet-induced



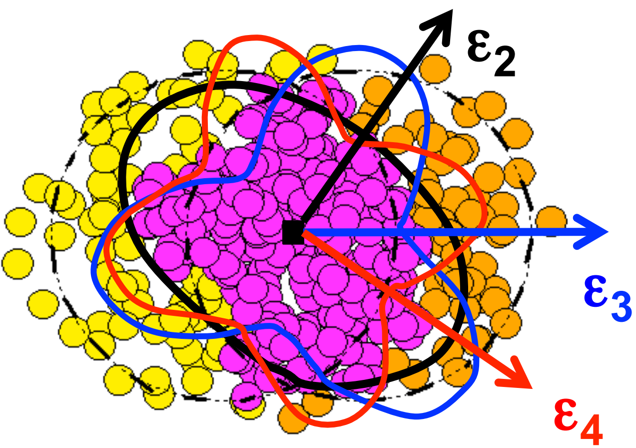
- Glasma flux tubes (boosted by radial flow)

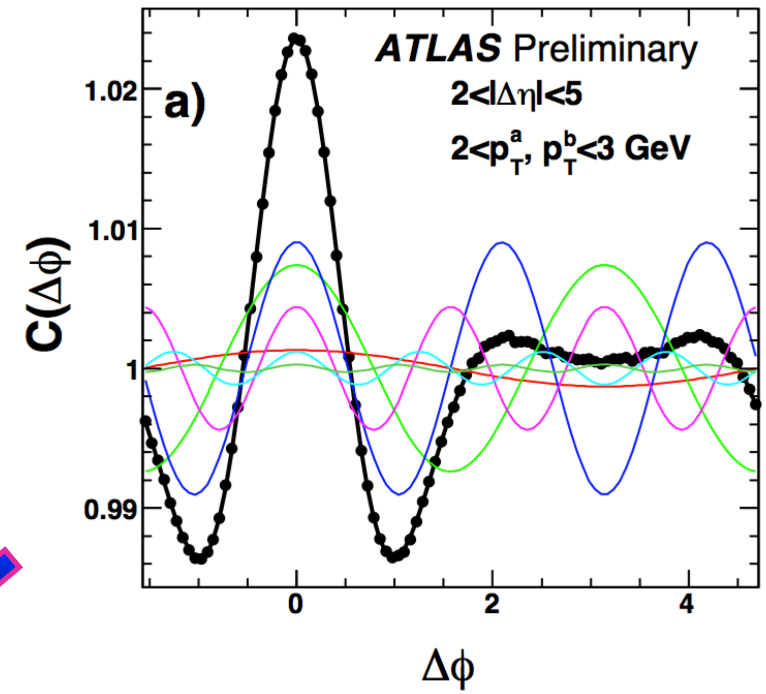


- Eccentricity of initial state energy-density profile of overlapping nucleus-nucleus system resulting in hydrodynamic flow

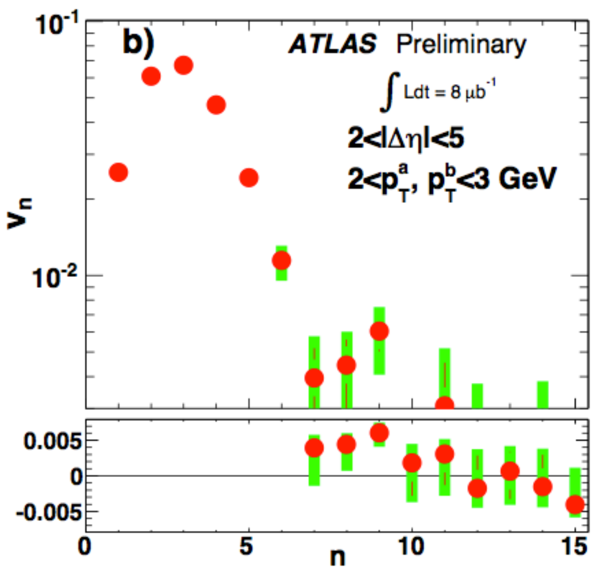
Ridge in A+A: triangular flow

Alver, Roland, Luzum, Sorensen, etc



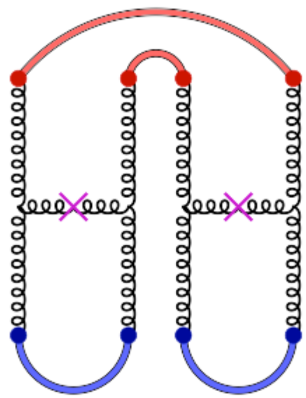


J. Jia for ATLAS
2011 J. Phys. G: Nucl. Part. Phys. 38 124012

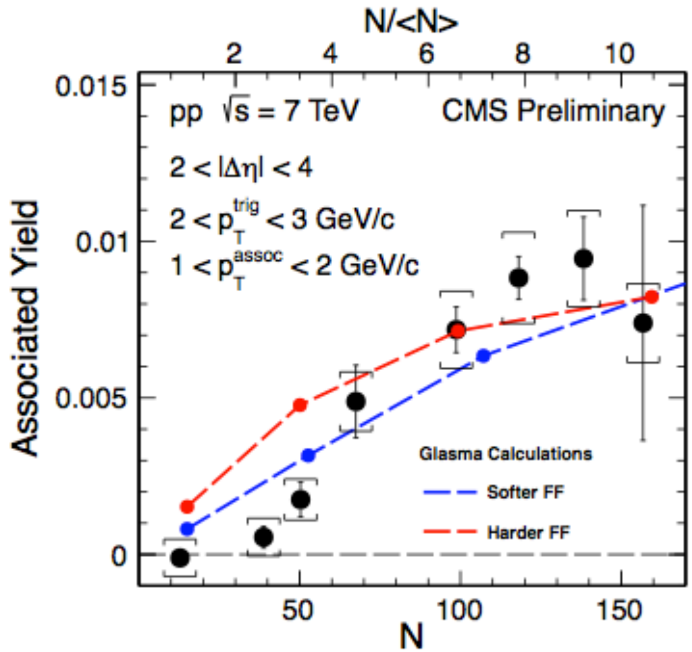


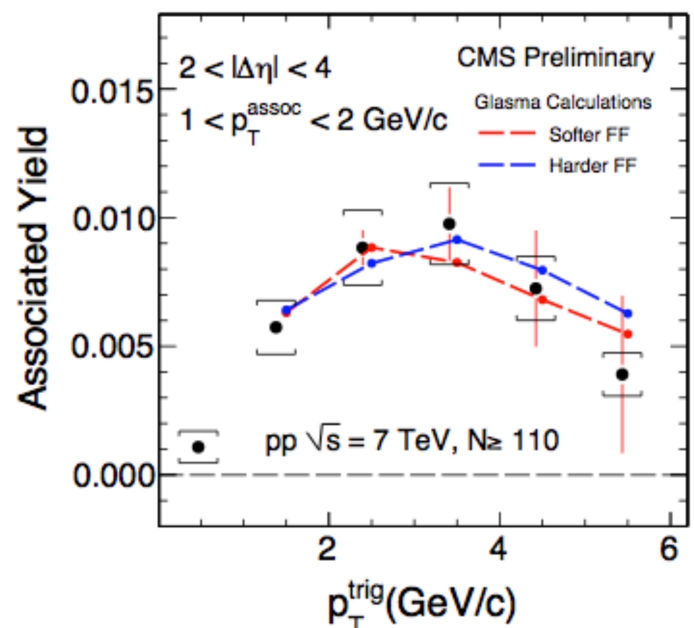
paradigm shift

Ridge in p+p: Glasma Graphs?



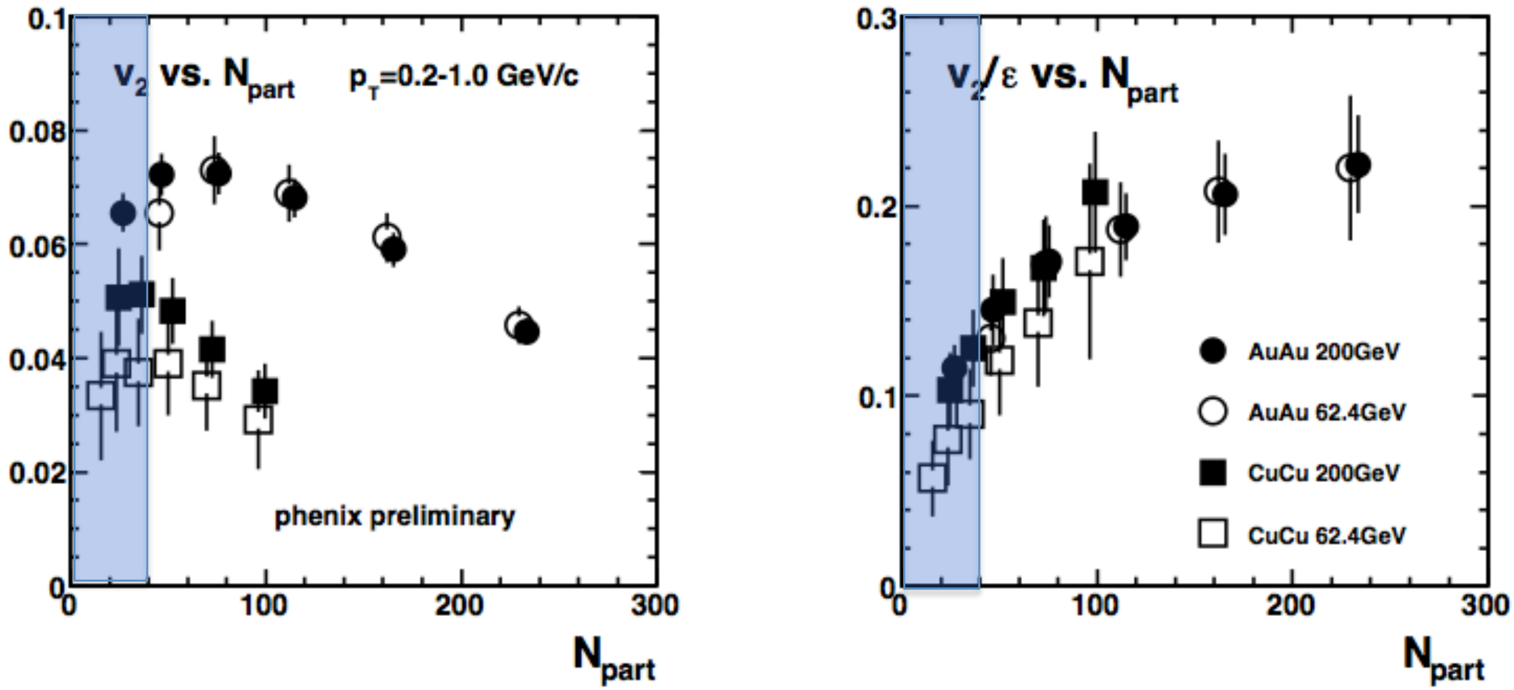
K. Dusling and R. Venugopalan, Phys.Rev.Lett. 108 (2012) 262001, arXiv:1201.2658 [hep-ph].





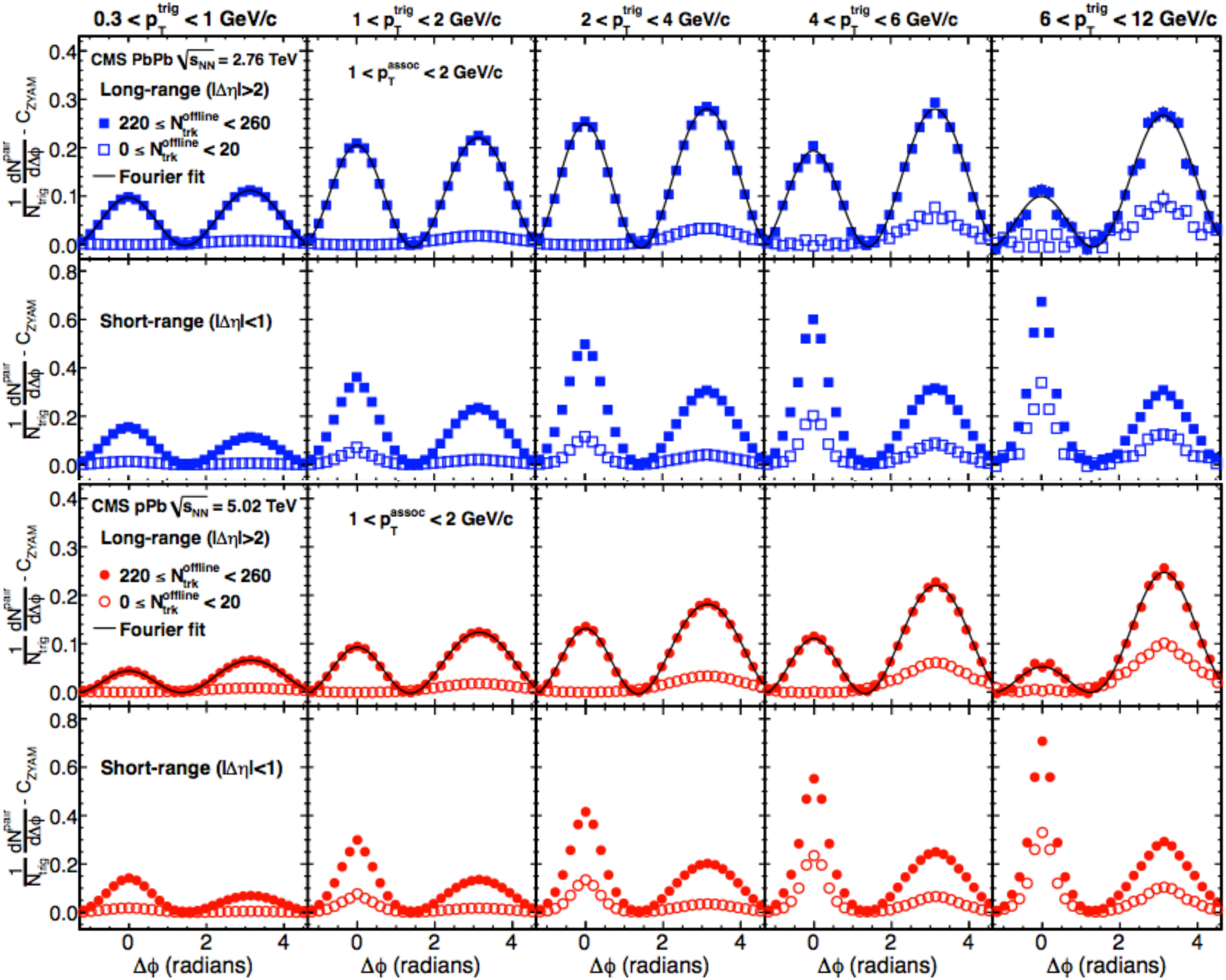
Ridge in p+Pb: ?

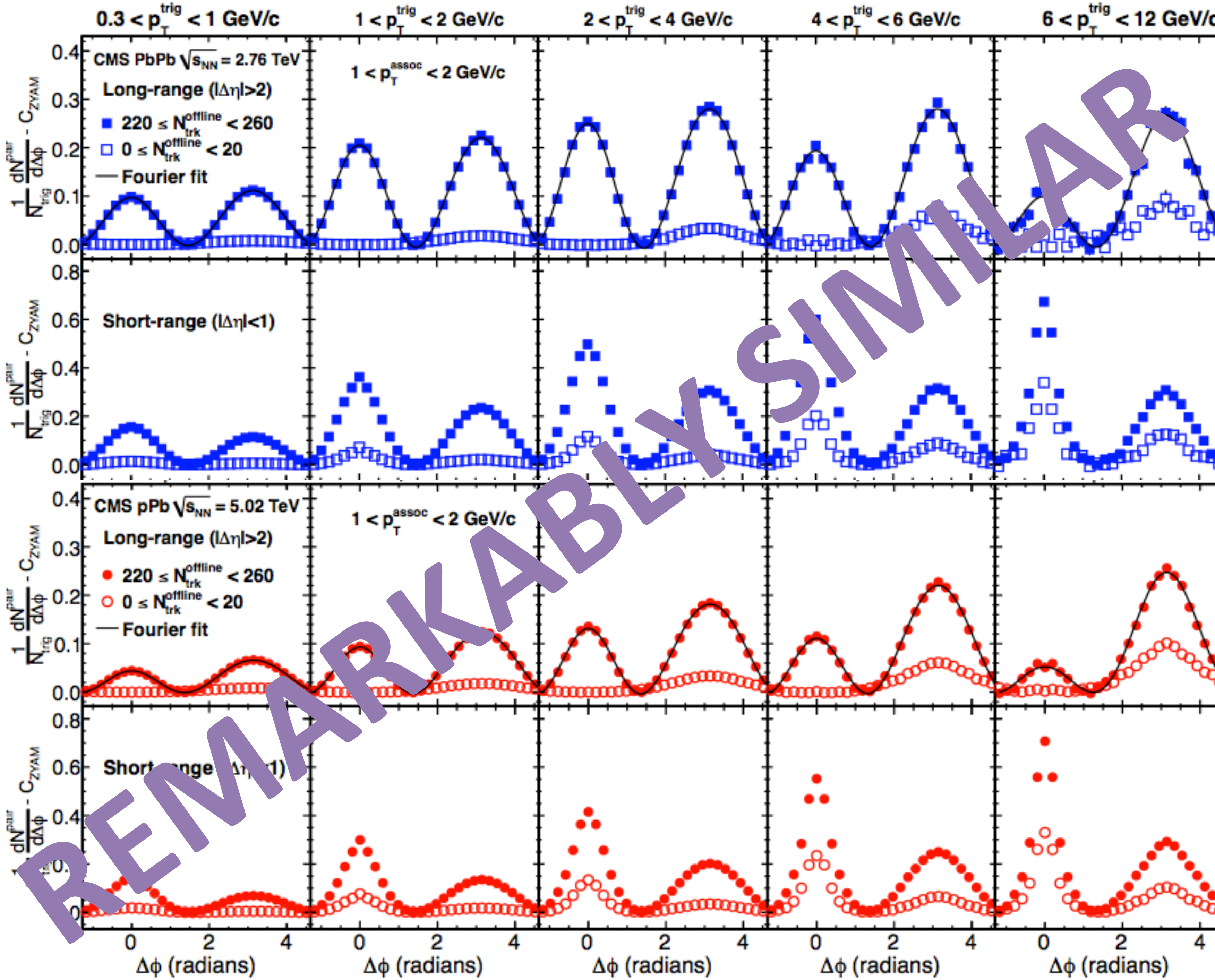
- Let's compare p+Pb with Pb+Pb for similar multiplicity



- yet very different geometry: one (p+Pb) small and dense; the other (Pb+Pb) large and dilute

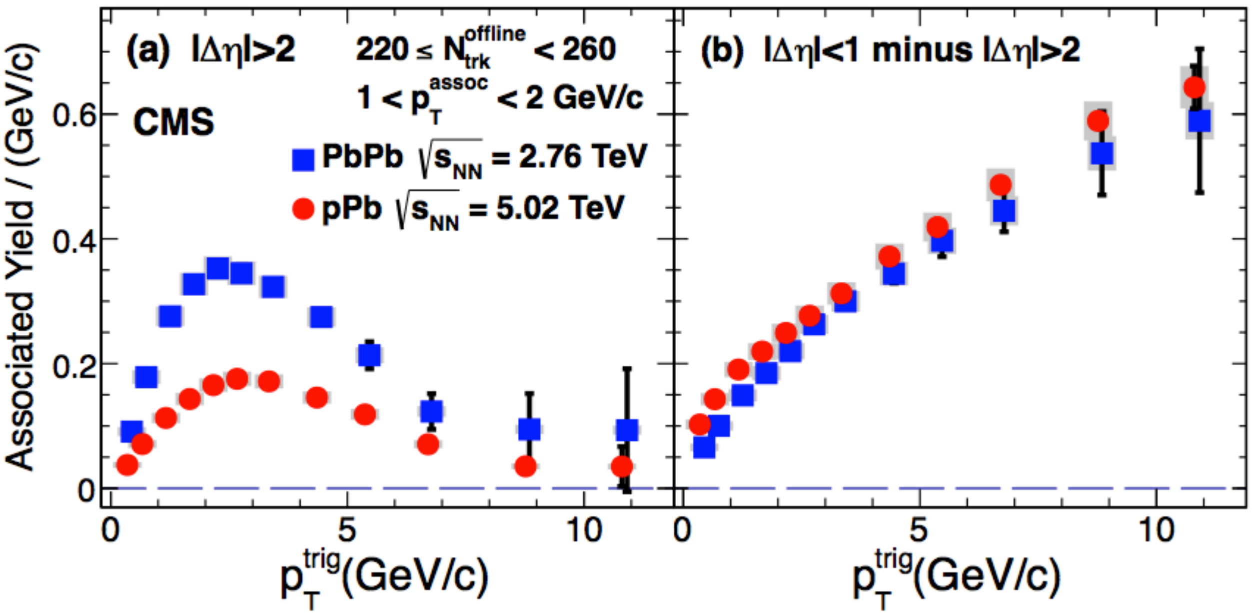
CMS, Phys.Lett. B724 (2013) 213





CMS, Phys.Lett. B724 (2013) 213

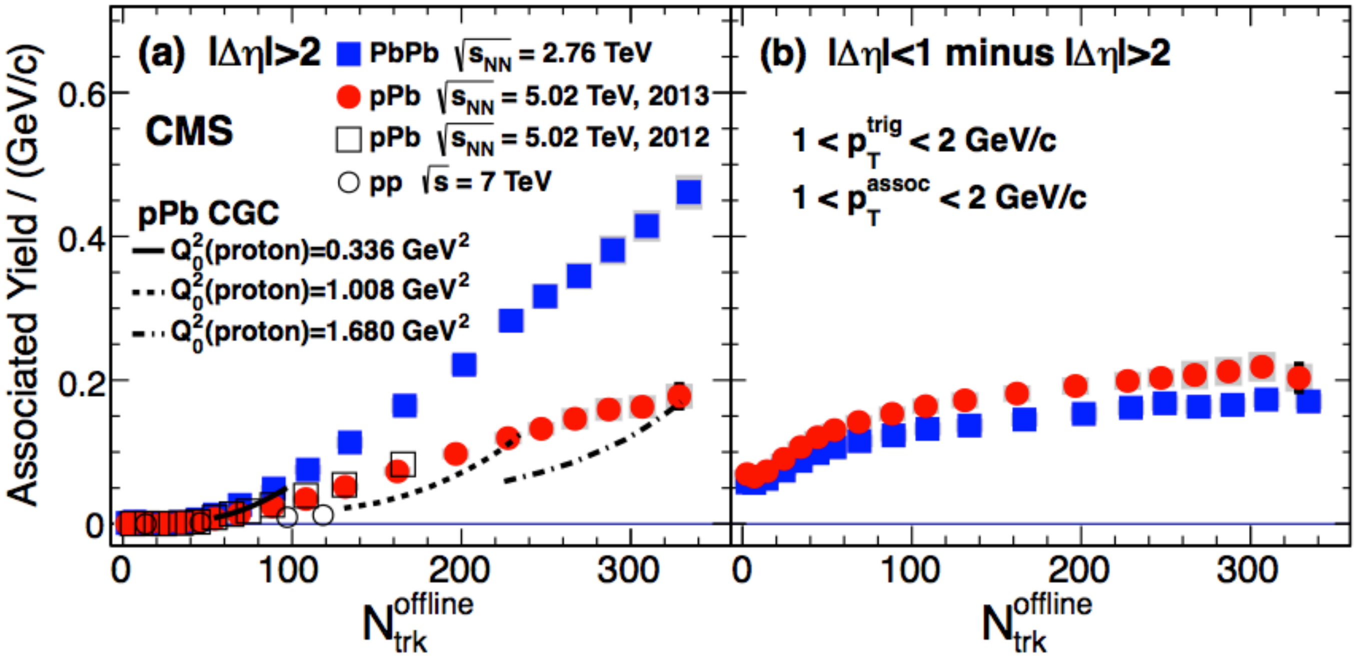
Yield p_T dependence



- Ridge yield peaks at intermediate p_T,
- Jet yield keeps rising
- Similar trends for pA and AA

qualitatively consistent with flow

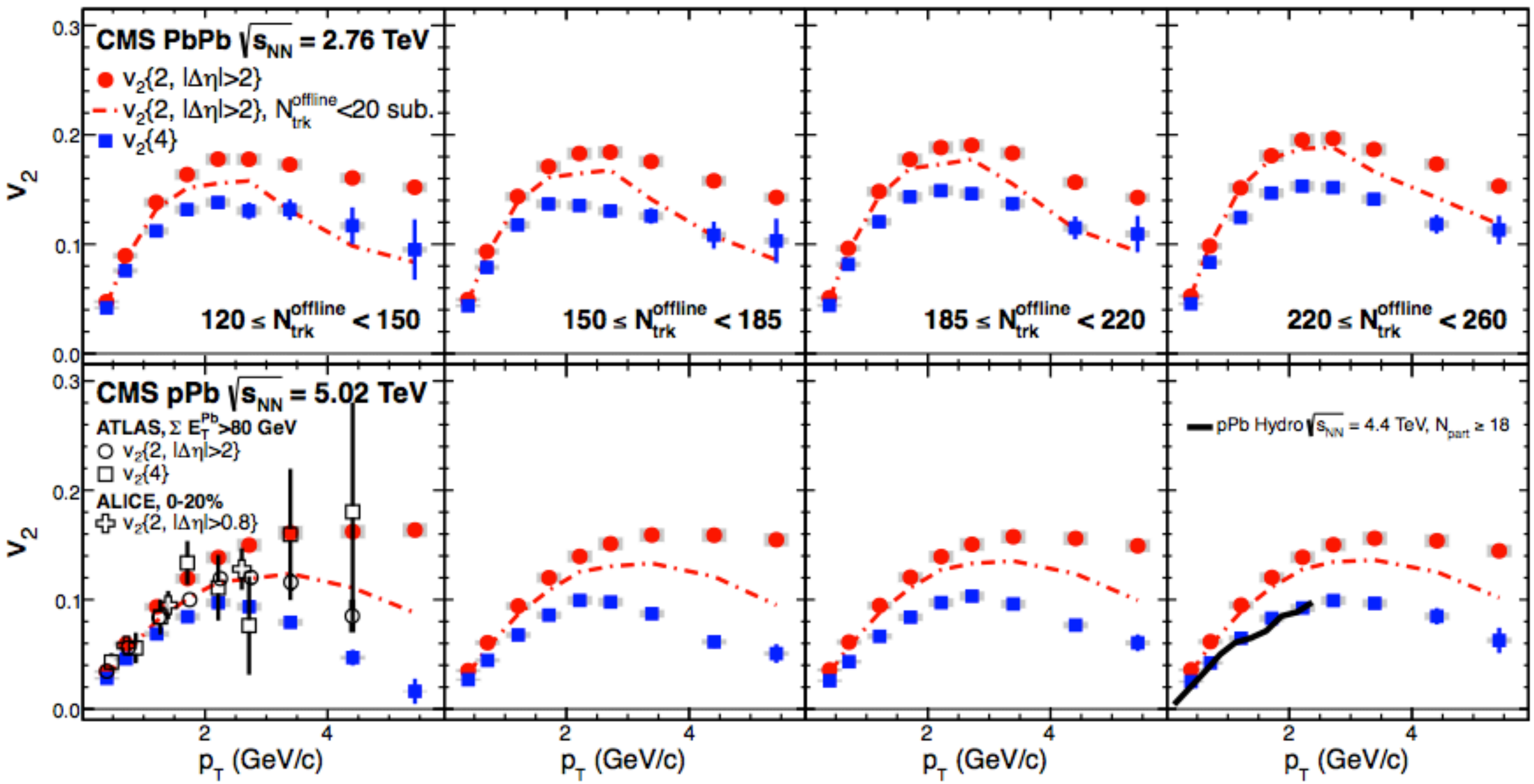
Yield multiplicity dependence



- Ridge yield strongly dependent on multiplicity
- Different from jet yield
- Similar trends for pA and AA

qualitatively consistent with flow

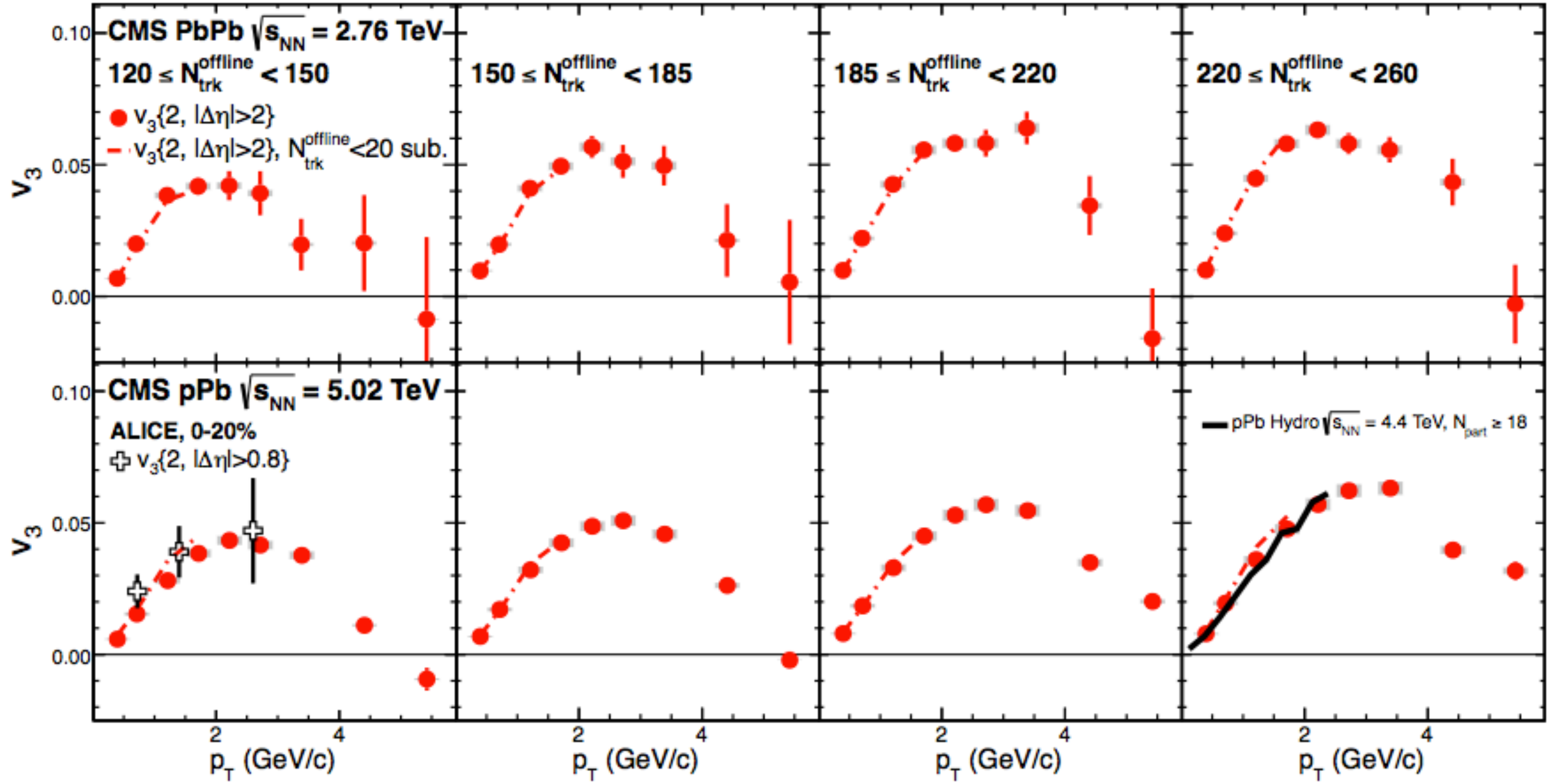
v_2 p_T dependence



- Eliminate jet contribution:
  - 4-p cummulant
  - peripheral-subtraction

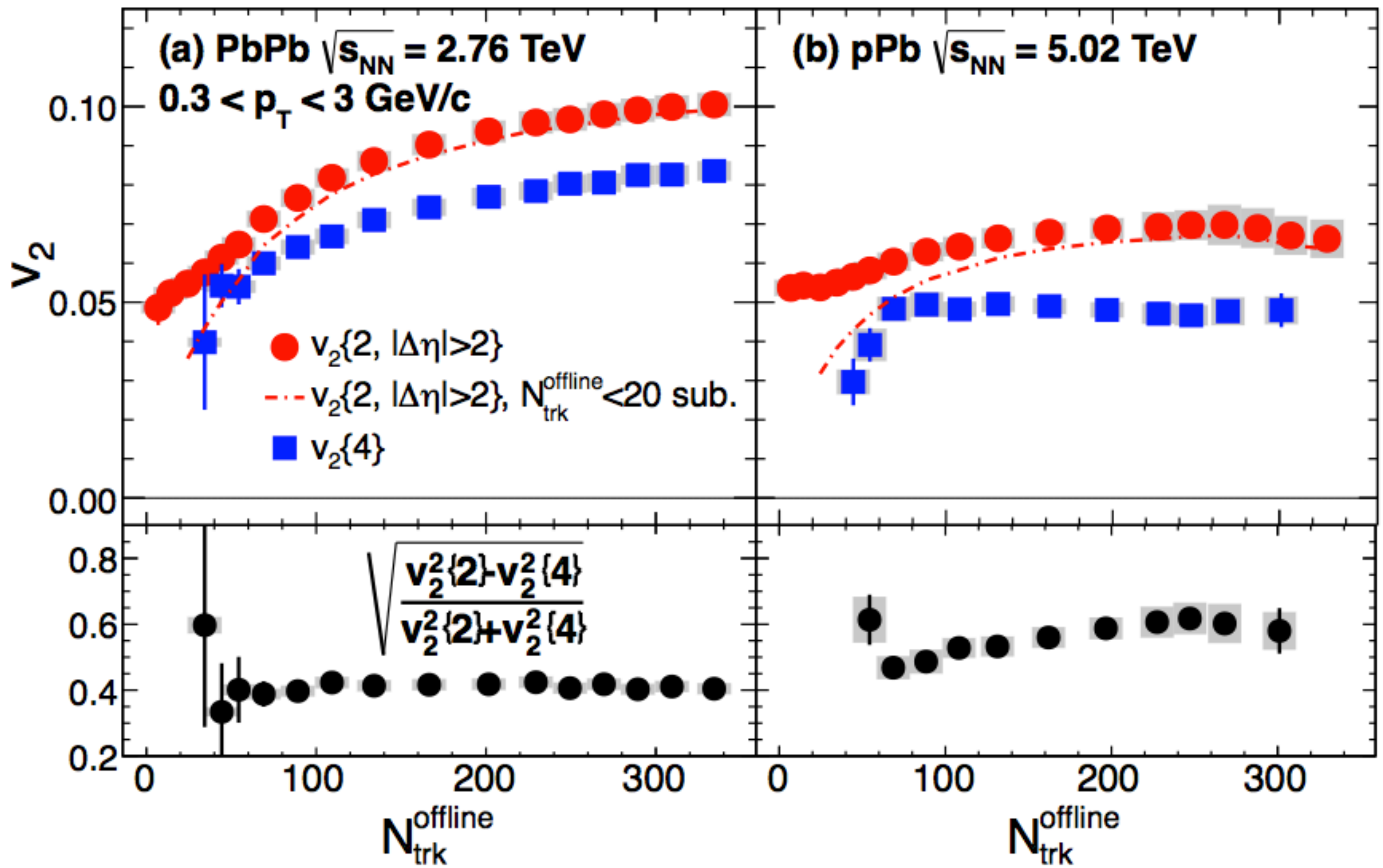
Consistent with hydro: Bozek, PRC85 (2012) 014911

v_3 p_T dependence



Consistent with hydro:
Bozek, PRC85 (2012) 014911

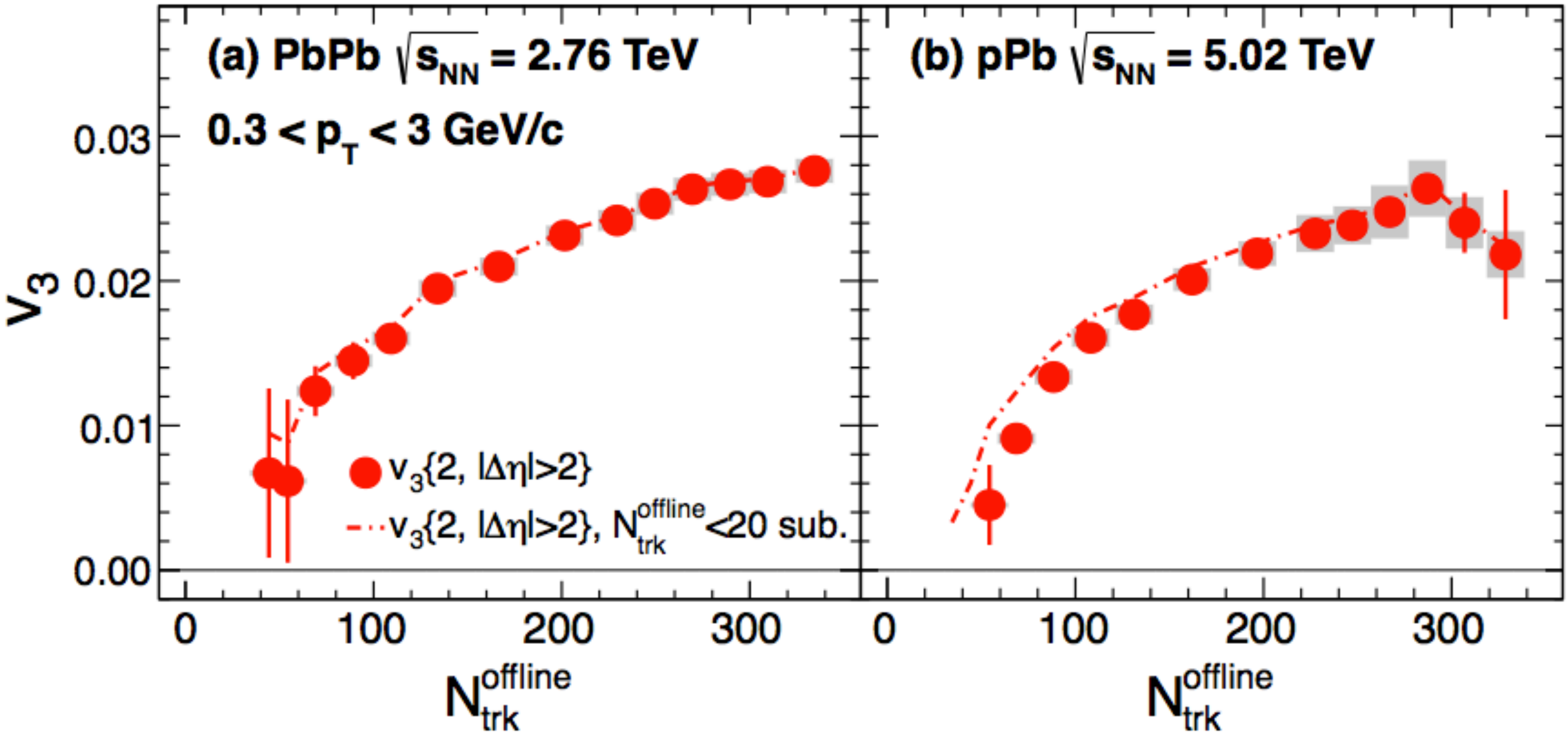
v_2 multiplicity dependence



- Somewhat different trends for pA and AA

Don't expect same trend since geometry very different

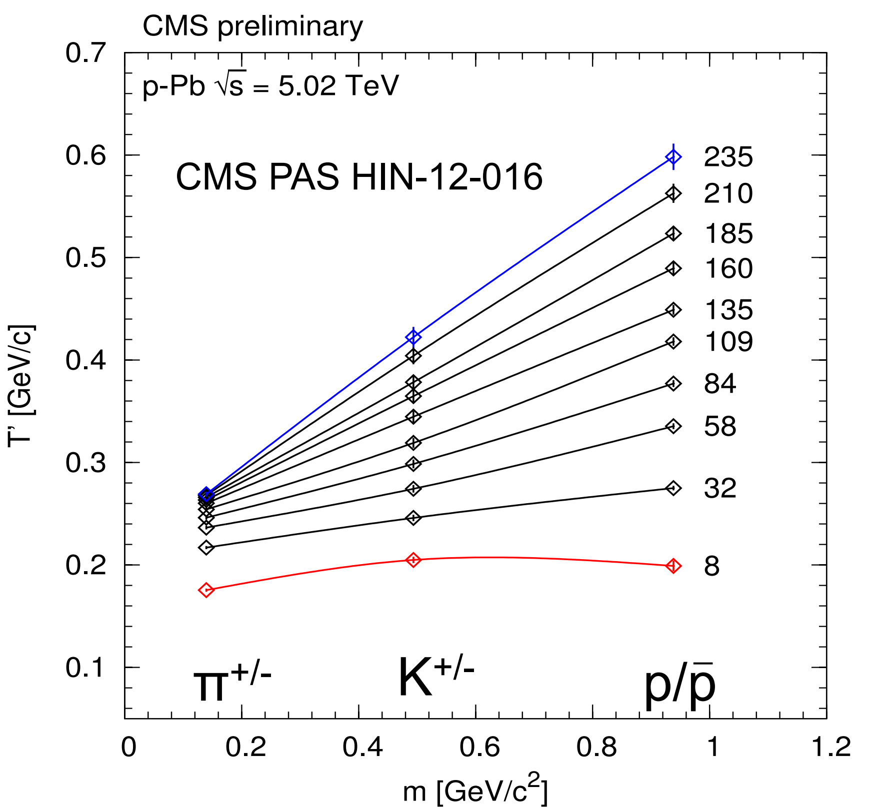
v_3 multiplicity dependence

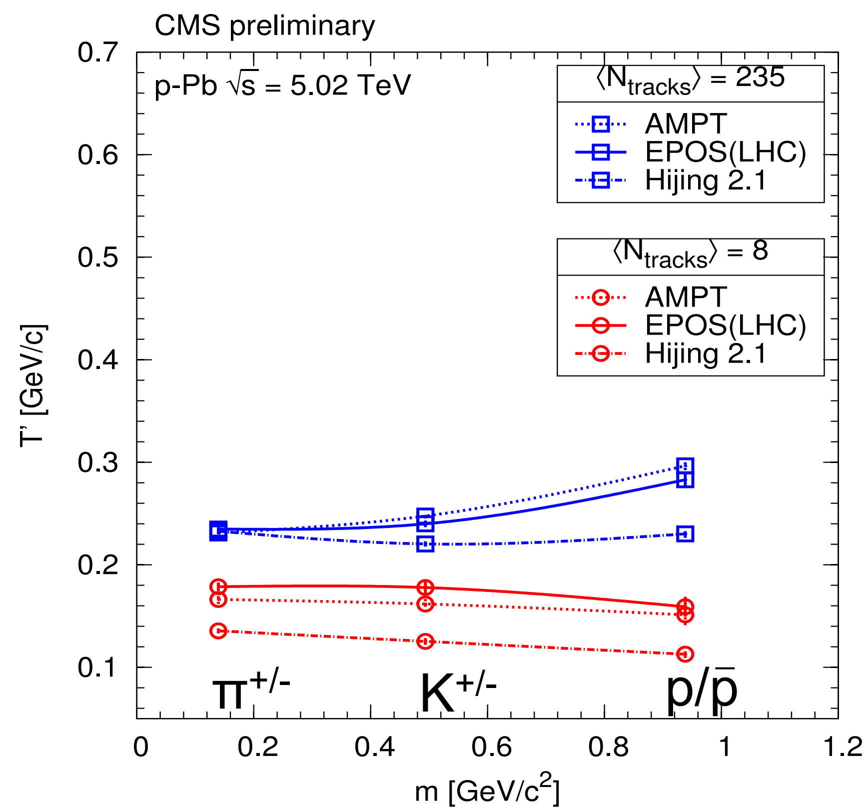


- Strikingly similar trends for pA and AA

AA overall geometry irrelevant, only fluctuations

Mass and multiplicity dependence

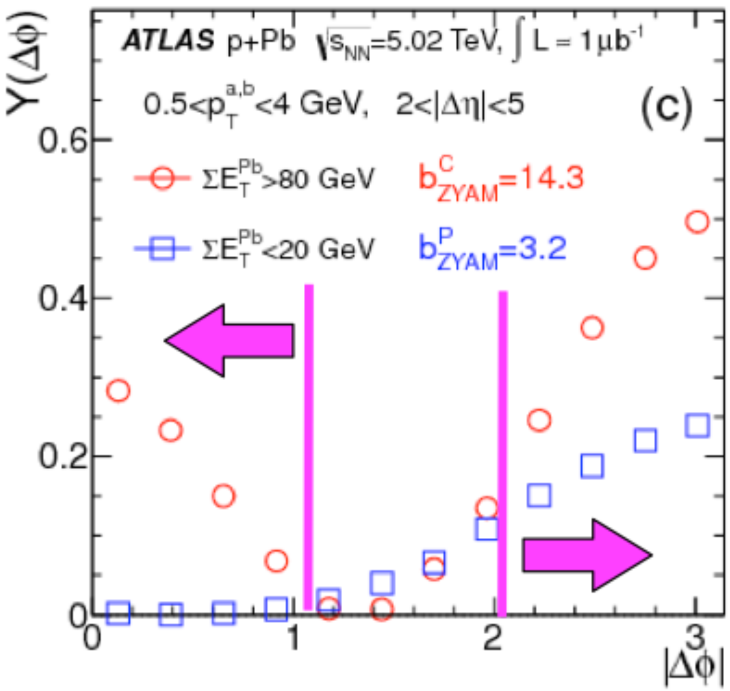


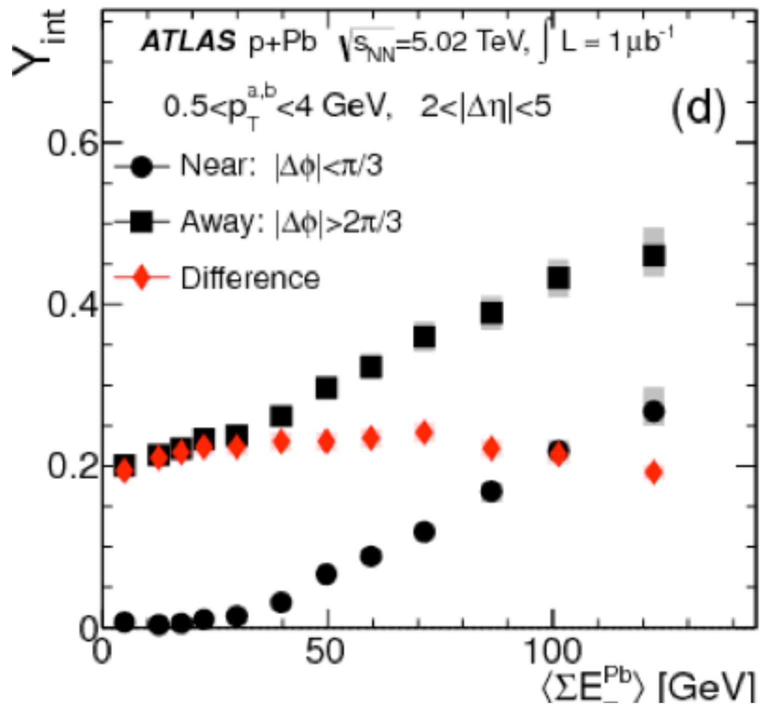


- T rises linearly with particle mass
- Slope increases with multiplicity

- No such effect in MC

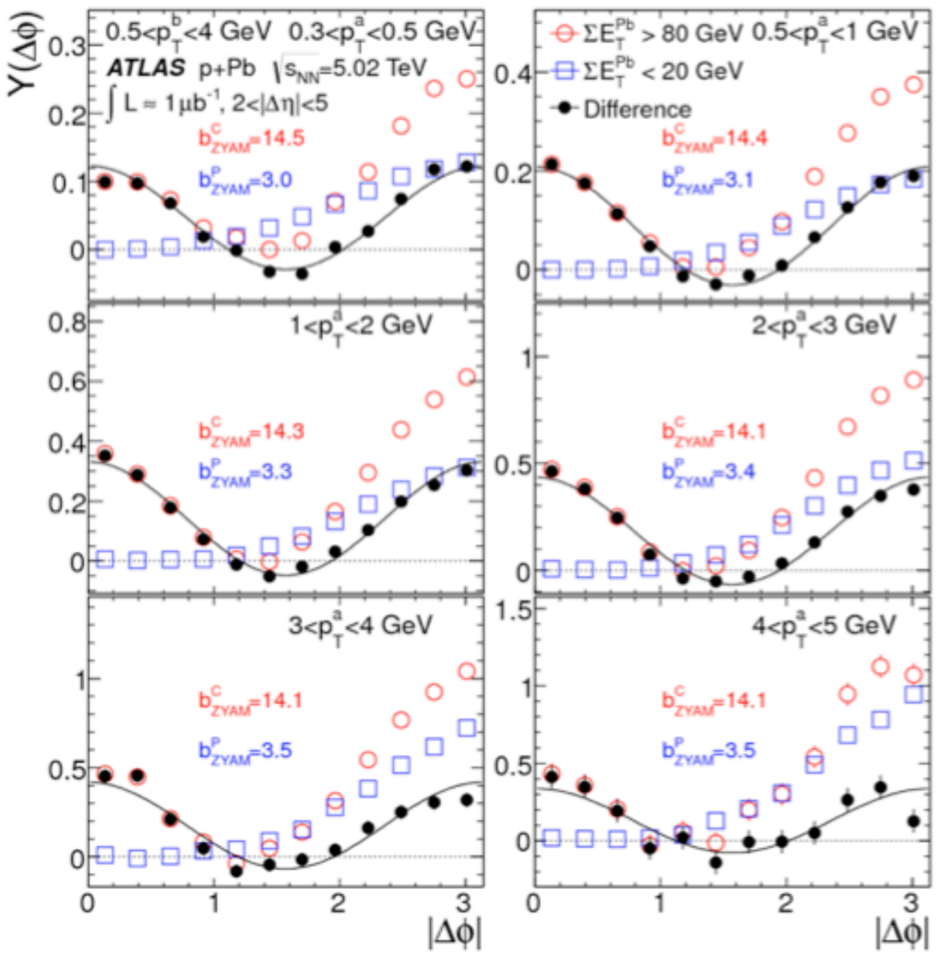
ATLAS





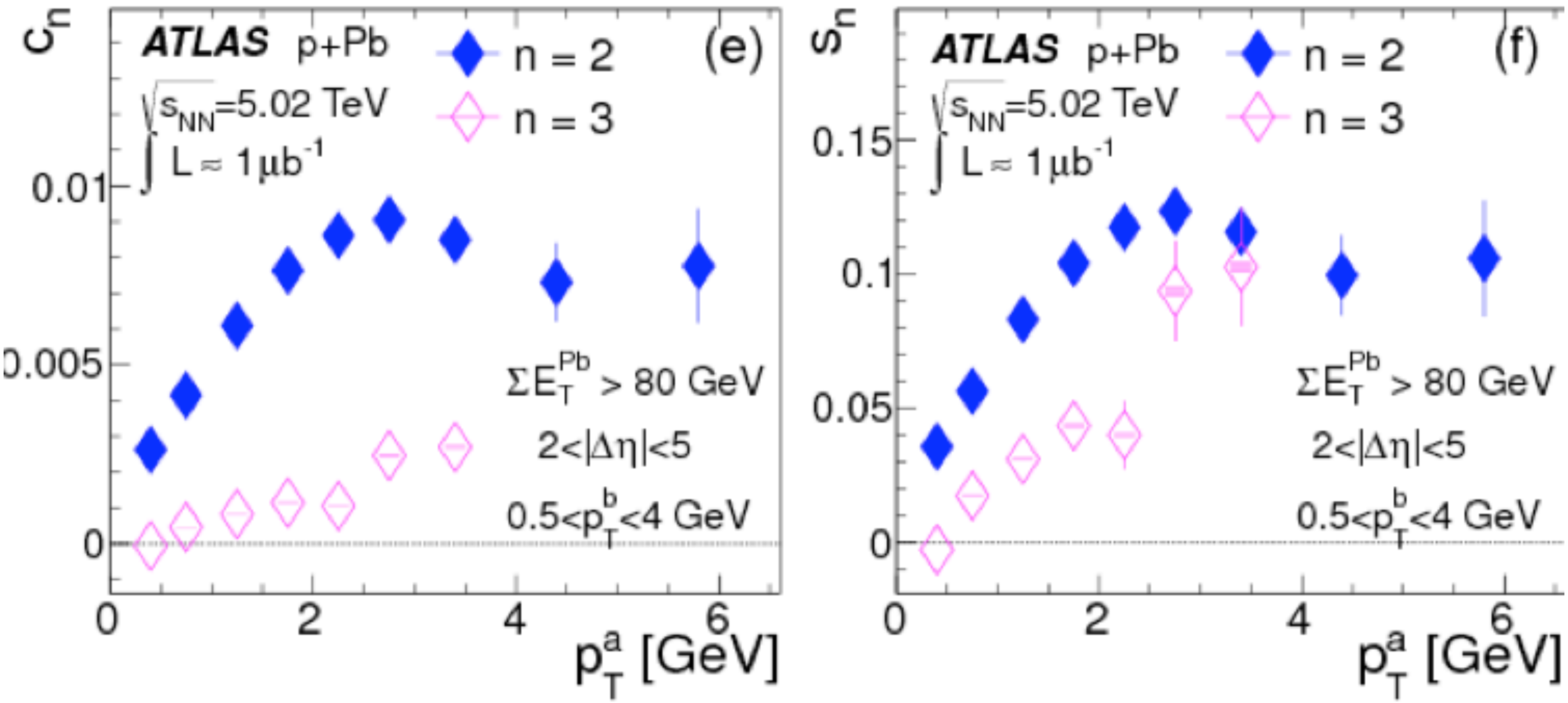
- Ridge clearly visible in central
- Similar increase in near and away side yield from peripheral to central

Correlation function



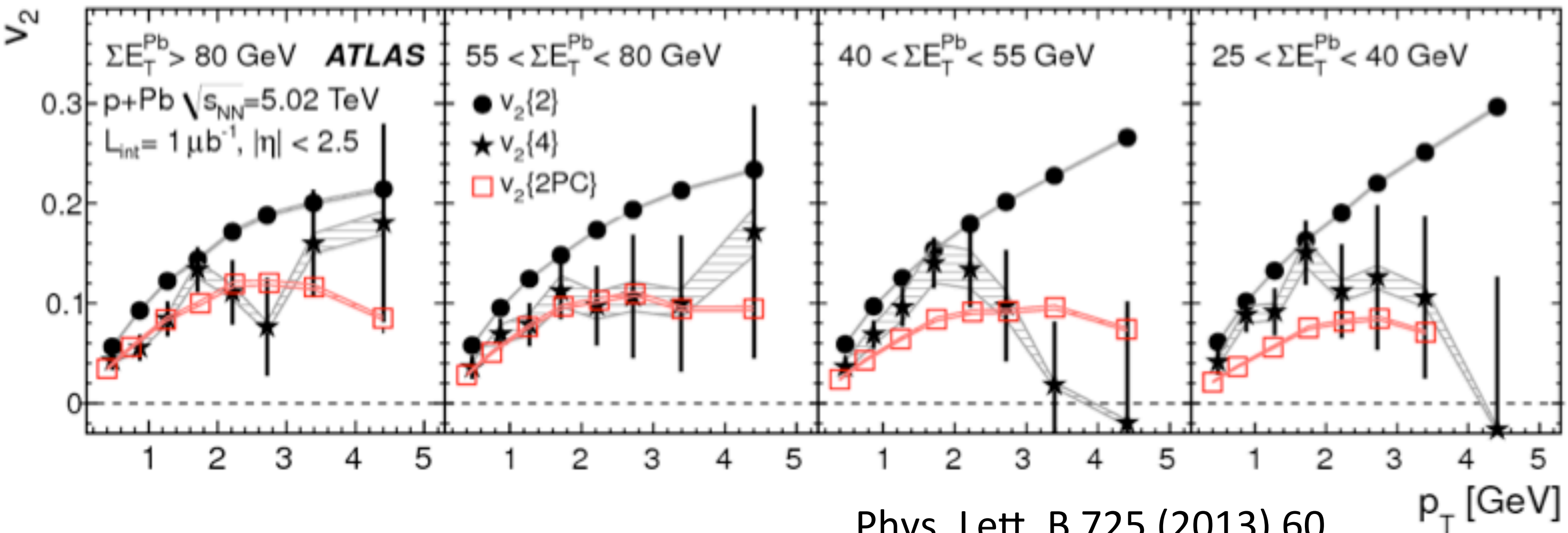
- Symmetric modulation after peripheral subtraction

Fourier decomposition



Significant v_3 component

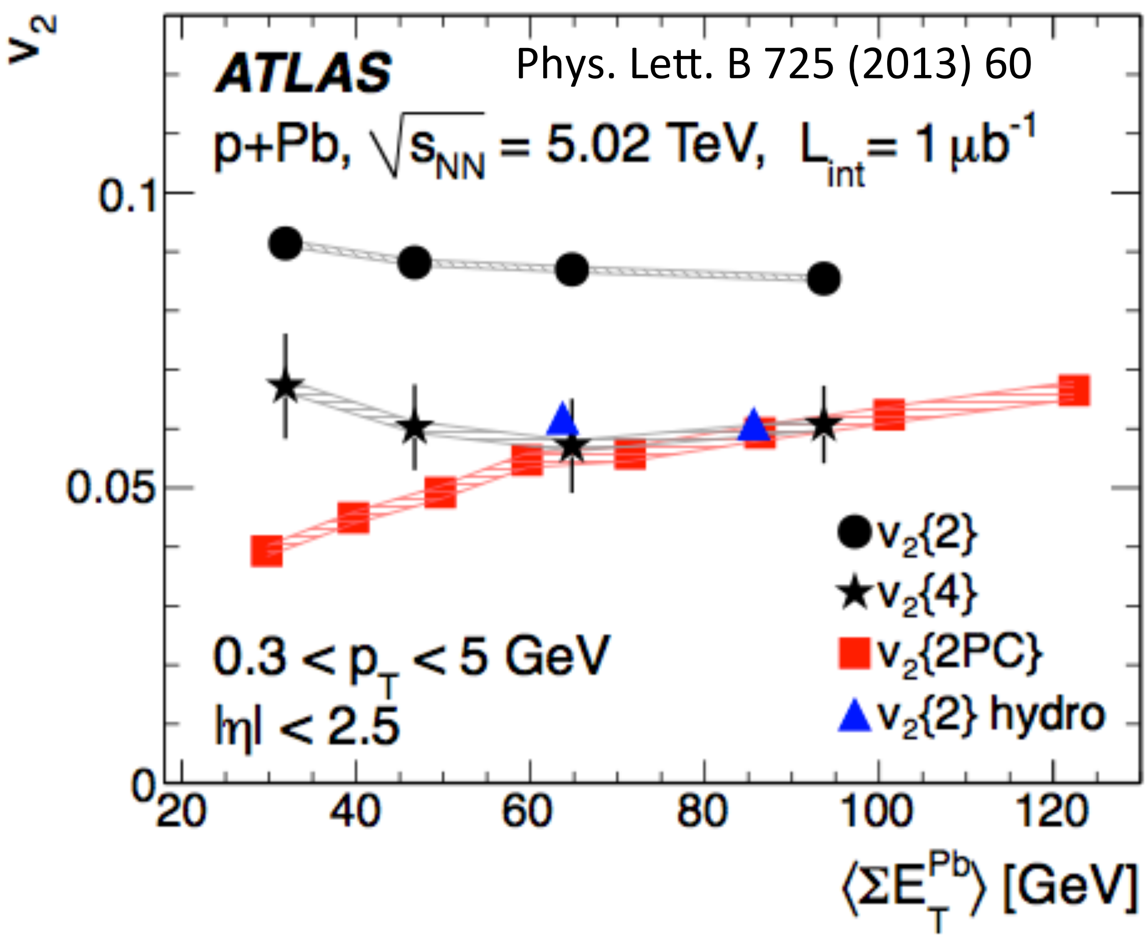
Cummulants



Phys. Lett. B 725 (2013) 60

- Correlations persists for 4-p cummulants

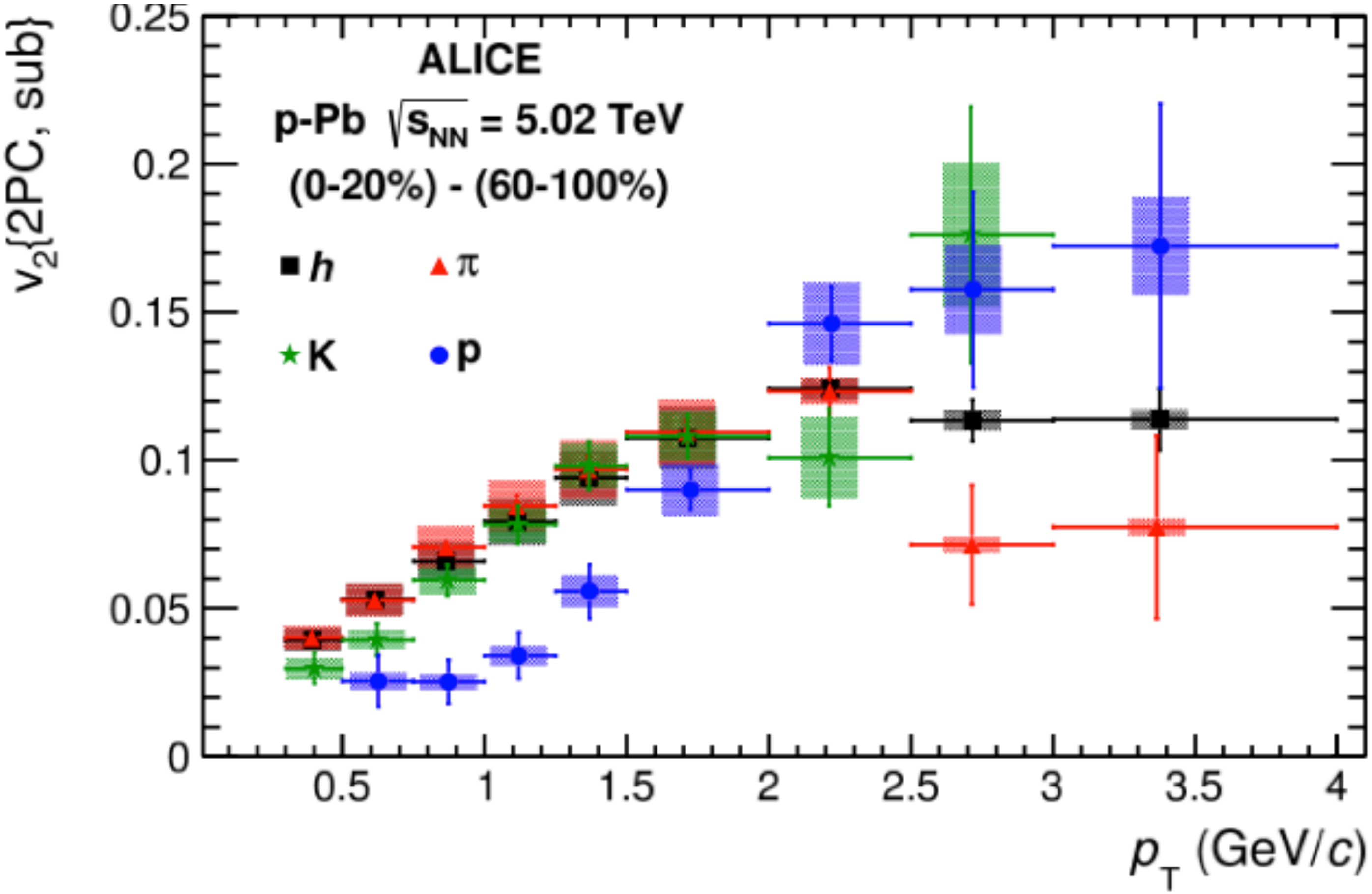
Centrality dependence of v_2



Consistent with hydro

P. Bozek and W. Broniowski, Phys. Lett. B 718 (2013) 1557 [arXiv:1211.0845].

ALICE: PID



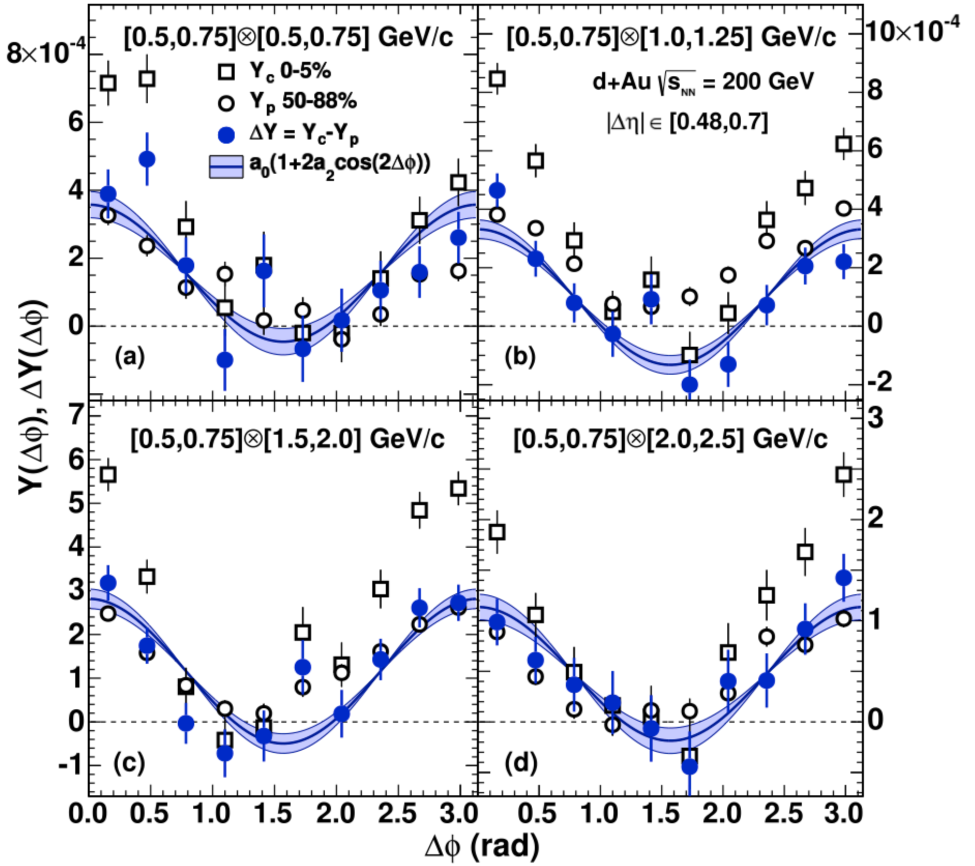
arXiv:1307.3237

Mass ordering as expected from collective flow

Ridge in d+Au at RHIC?

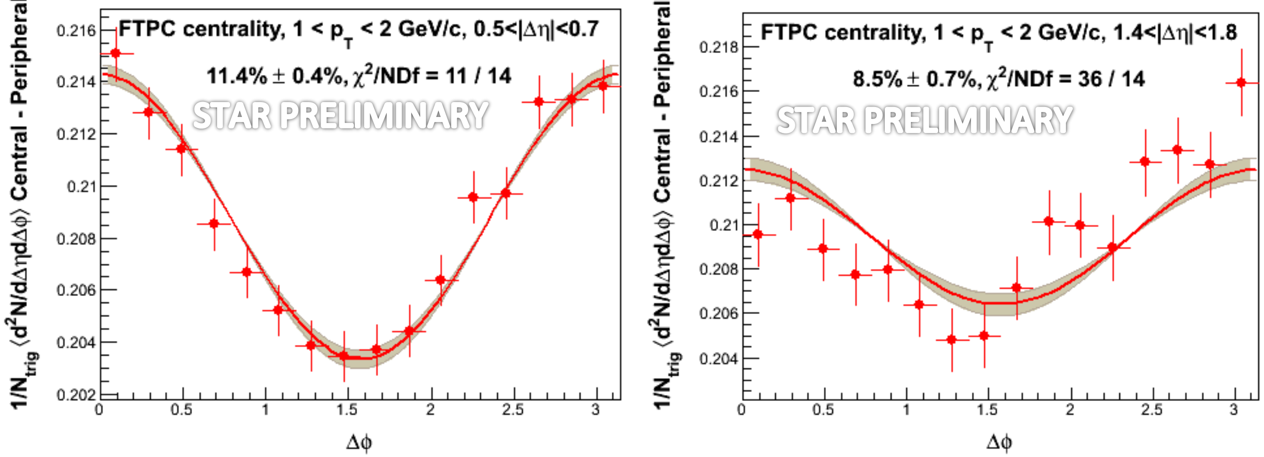
Non-jet correlation in d+Au?

PHENIX arXiv:1303.1794



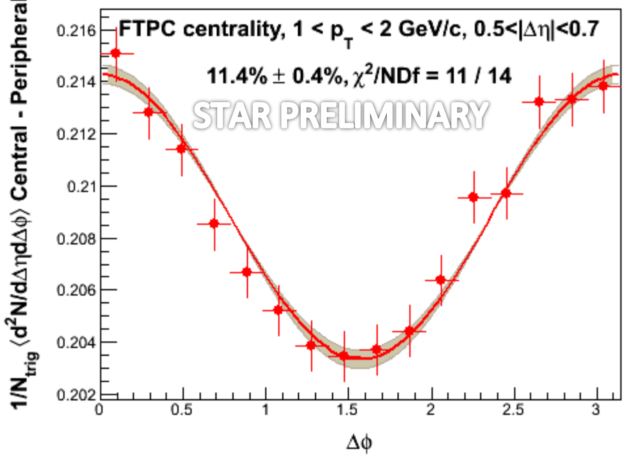
$$Y(\Delta\phi) \equiv \frac{1}{N^t}\frac{dN^{\text{pairs}}}{d\Delta\phi} - b_{\text{ZYAM}}$$

- mid-rapidity
- Per-trigger yield
- Eliminate jet correlations
  - Subtract peripheral from central
  - η gap ($\Delta\eta$>0.48)
- Symmetric, cosine-like correlation remains


FTPC centrality, 1 < p_T < 2 GeV/c, 0.5<|Δη|<0.7
11.4% ± 0.4%, χ^2/NDf = 11 / 14
STAR PRELIMINARY
1/N_{trig} ⟨$d^2N/d\Delta\eta d\Delta\phi$⟩ Central - Peripheral
Δφ
FTPC centrality, 1 < p_T < 2 GeV/c, 1.4<|Δη|<1.8
8.5% ± 0.7%, χ^2/NDf = 36 / 14
STAR PRELIMINARY
1/N_{trig} ⟨$d^2N/d\Delta\eta d\Delta\phi$⟩ Central - Peripheral
Δφ

STAR

STAR



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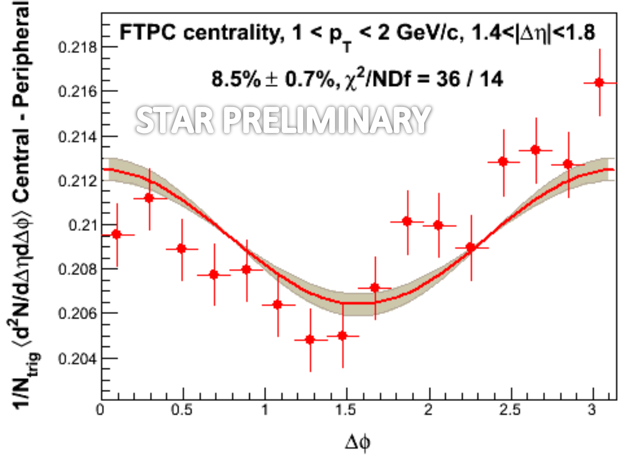
STAR PRELIMINARY
$1/N_{trig}$ ⟨$d^2N/d\Delta\eta d\Delta\phi$⟩ Central - Peripheral
Δϕ



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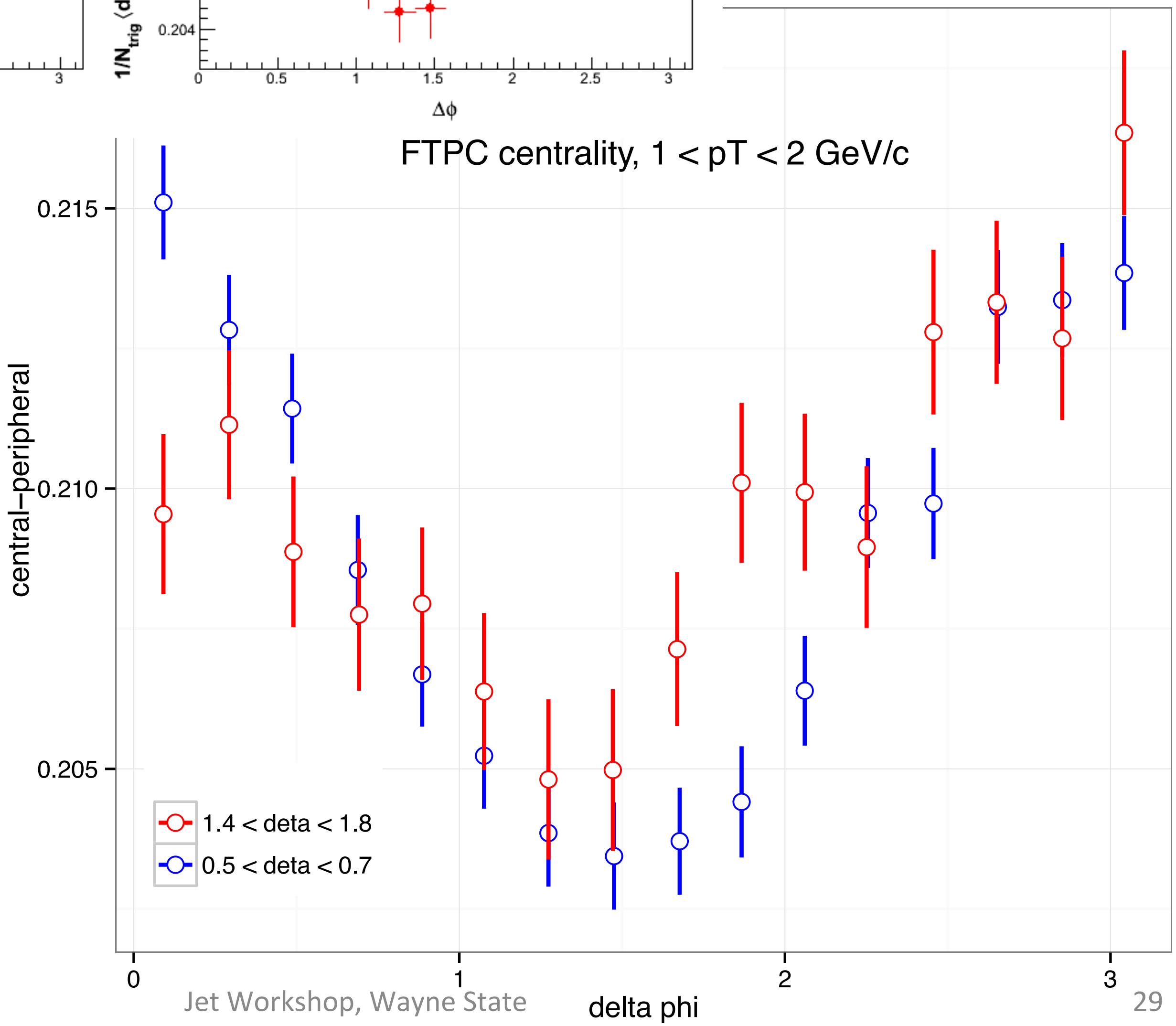
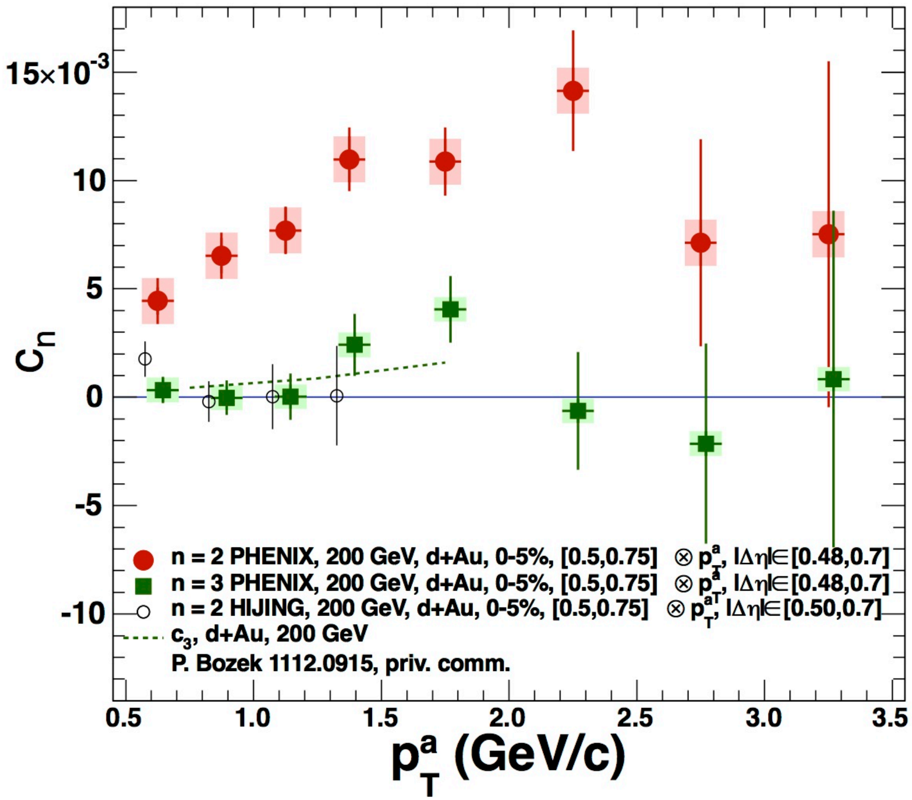
Δϕ



FTPC centrality, 1 < pT < 2 GeV/c
central−peripheral
delta phi
1.4 < deta < 1.8
0.5 < deta < 0.7

Jet-Subtracted Fourier Moments

PHENIX arXiv:1303.1794



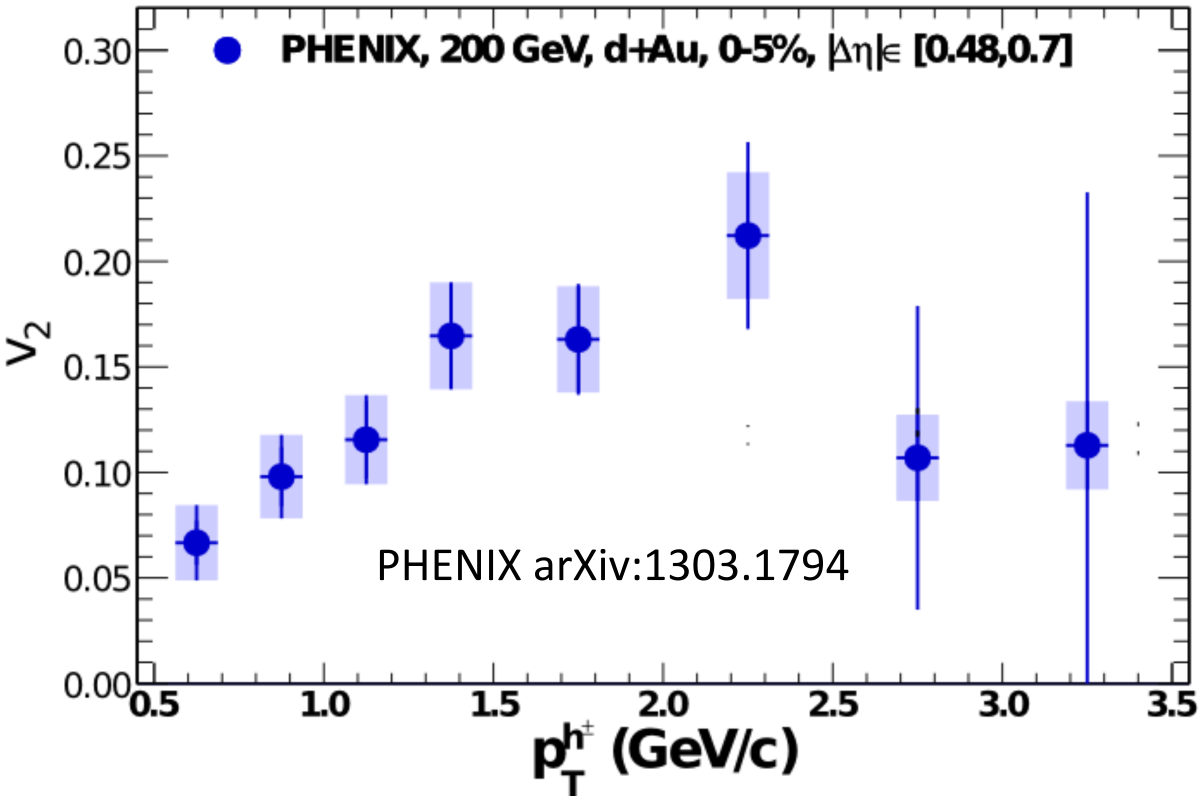
$$\Delta Y(\Delta\phi) \approx a_0 + 2a_2\cos(2\Delta\phi)$$

$$c_n \equiv a_n / \left(b^c_{\mathrm{ZYAM}} + a_0\right)$$

- Fourier moments, c_n, of jet-subtracted distributions vs. associated p_T
- Significant c_2
- No significant c_3
- c_2 from HIJING small
- c_3 consistent with hydro

Fourier Moment v_2

$$c_2\left(p_T^t, p_T^a\right) = v_2\left(p_T^t\right) \times v_2\left(p_T^a\right)$$

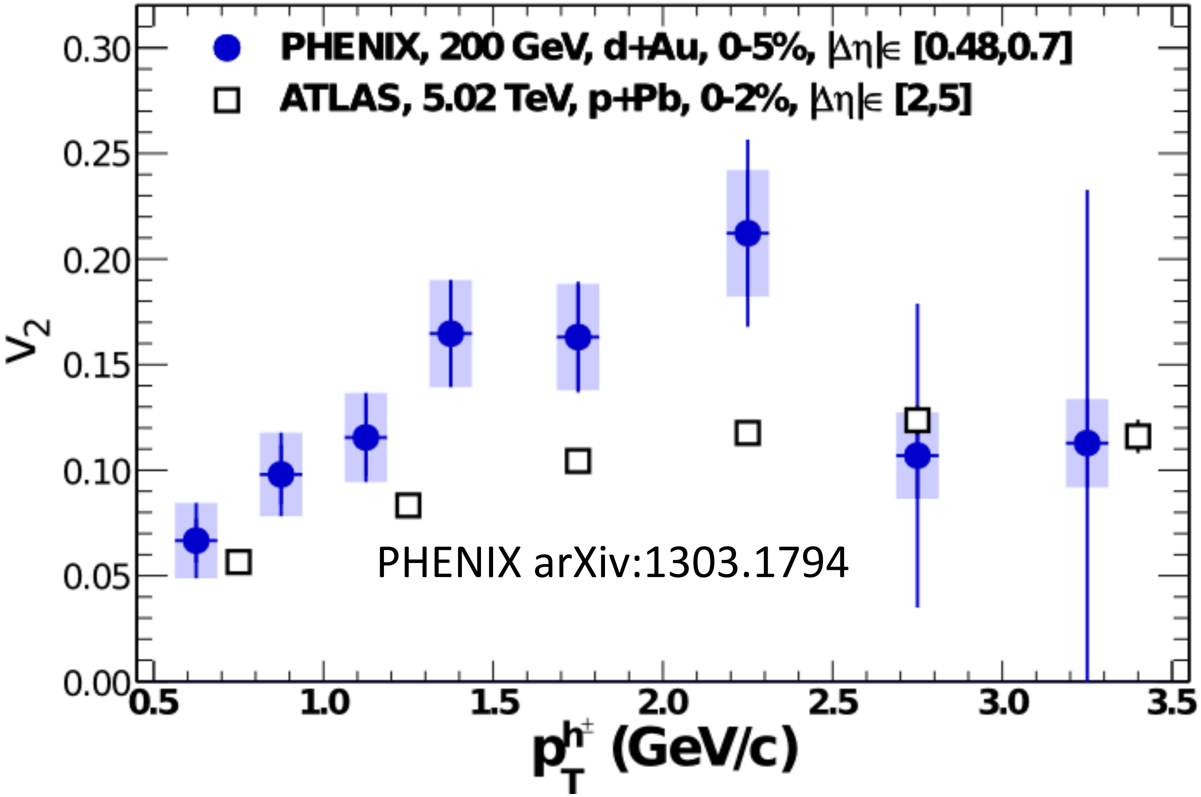


- Inferred quadrupolar anisotropy v_2 of h^{+-} vs. p_T

- significant v_2

Fourier Moment v_2

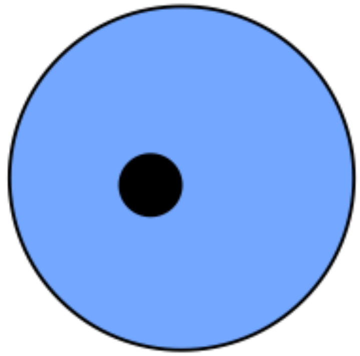
$$c_2\left(p_T^t, p_T^a\right) = v_2\left(p_T^t\right) \times v_2\left(p_T^a\right)$$

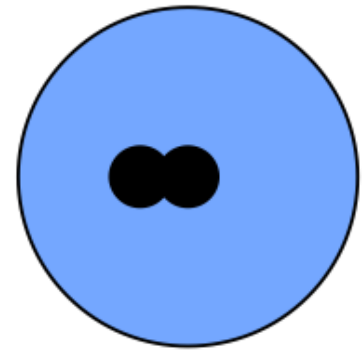


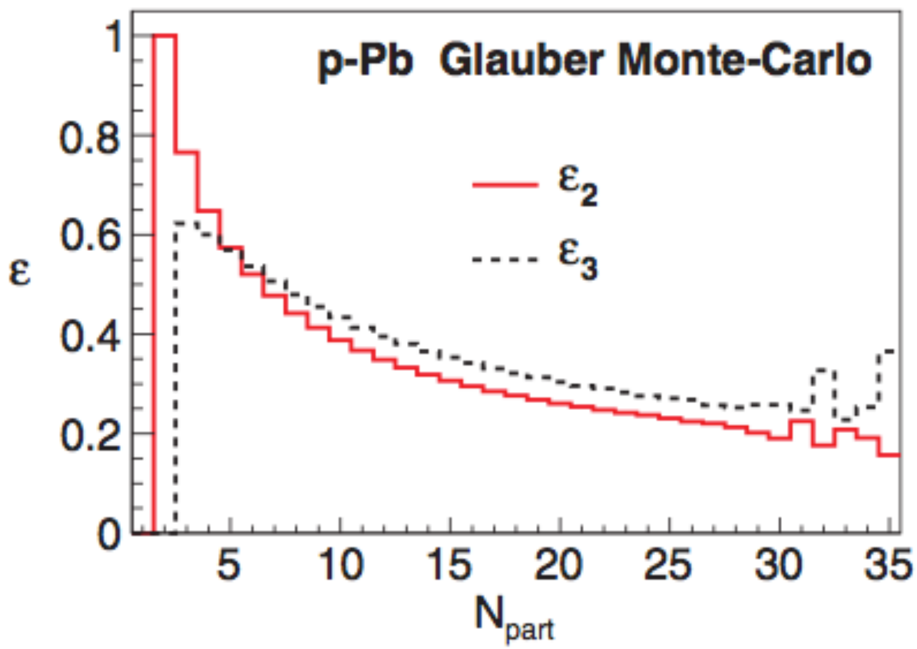
- Inferred quadrupolar anisotropy v_2 of h^{+-} vs. p_T

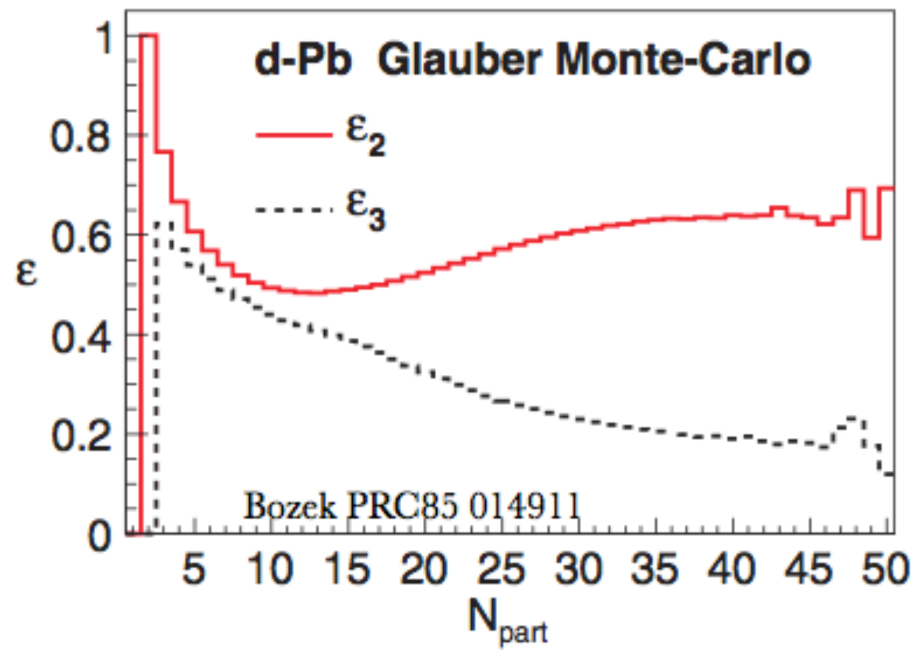
- v_2 d+Au > v_2 p+Pb

p+A vs. d+A

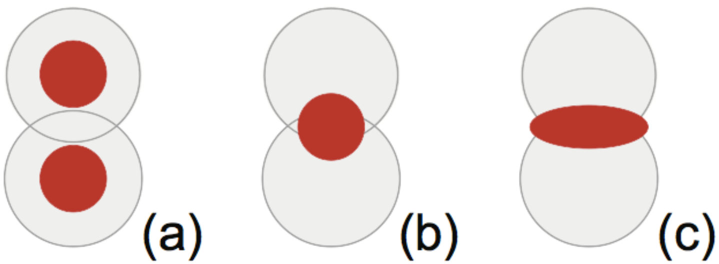




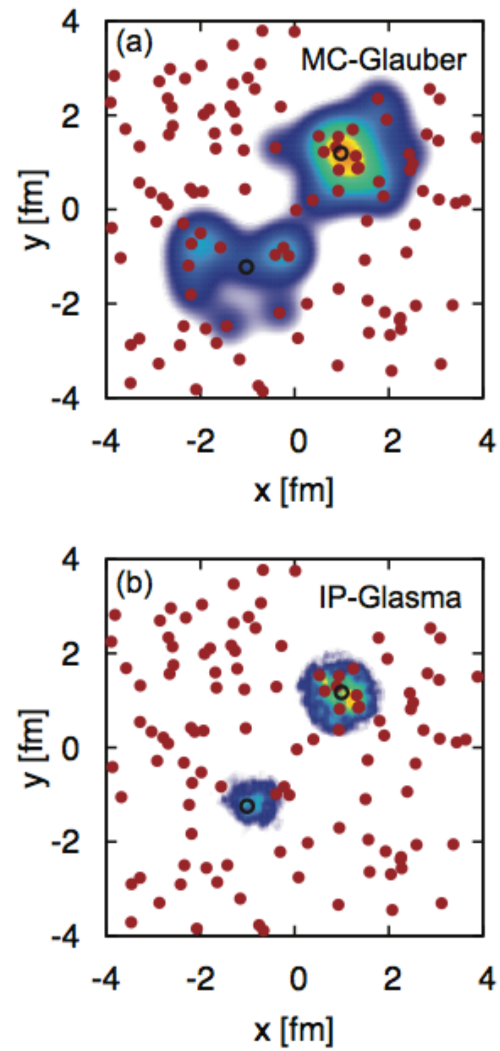

p-Pb Glauber Monte-Carlo
ε_2
ε_3
ε
1
0.8
0.6
0.4
0.2
0
5 10 15 20 25 30 35
N_{part}


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

Initial State Fluctuations



Energy deposition
a) nucleus center, $\varepsilon_2 = 1$
b) overlap region, $\varepsilon_2 = 0$
c) follow shape of overlap, $0 \leq \varepsilon_2 \leq 1$

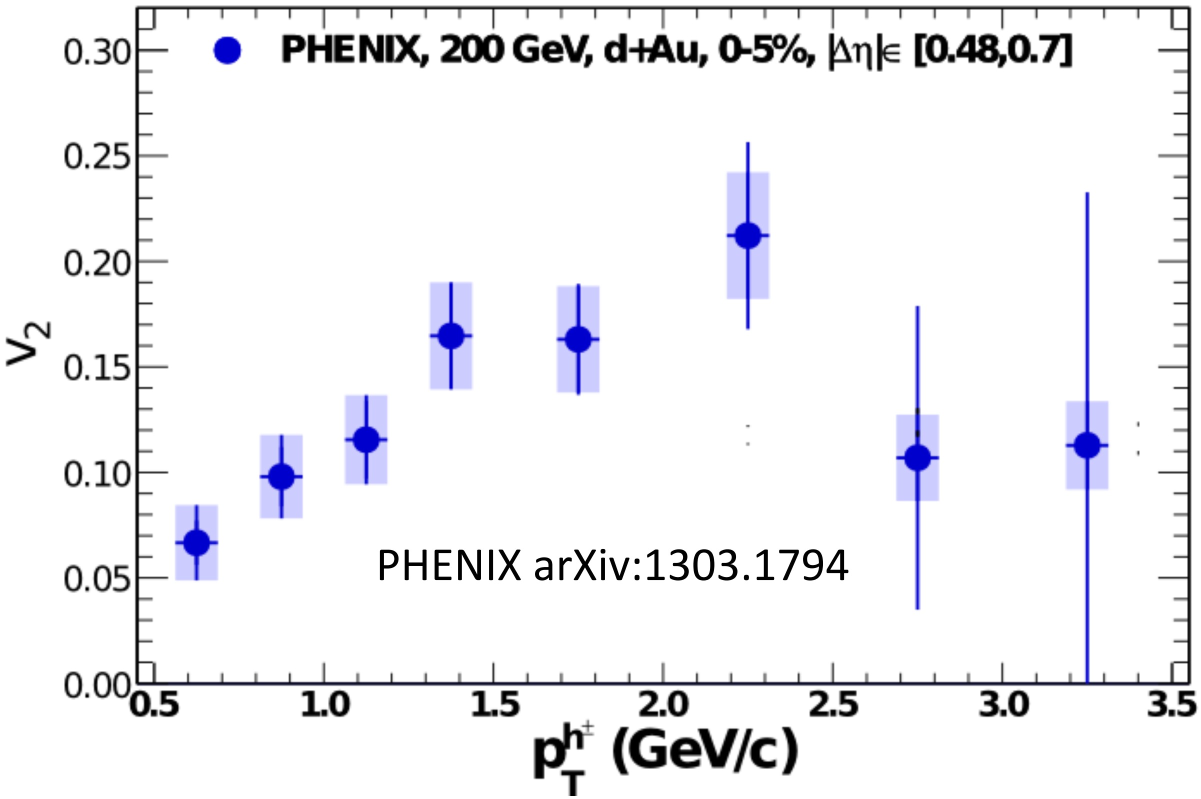


initial energy density distribution

Bzdak, Schenke, Tribedy, Venugopalan, PhysRevC.87.064906, 1304.3403

Fourier Moment v_2

$$c_2\left(p_T^t, p_T^a\right) = v_2\left(p_T^t\right) \times v_2\left(p_T^a\right)$$



- Inferred quadrupolar anisotropy v_2 of h^{+-} vs. p_T

Fourier Moment v_2

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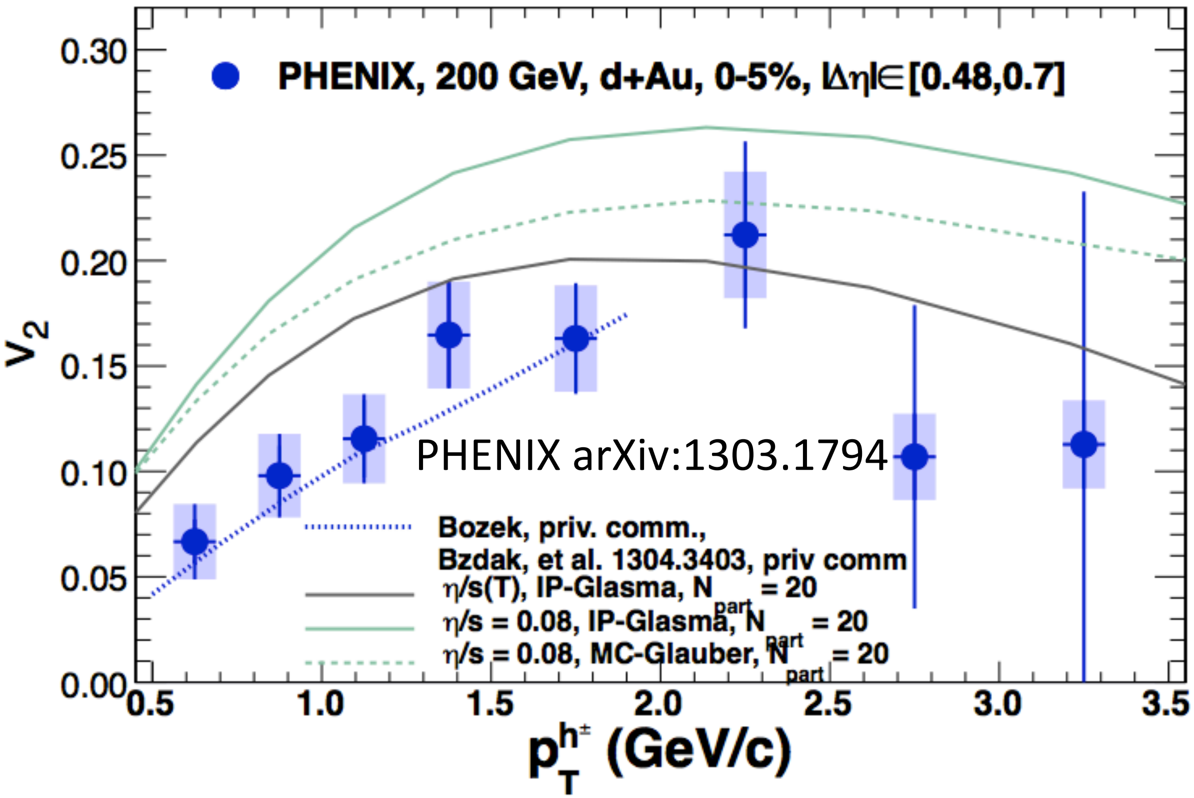
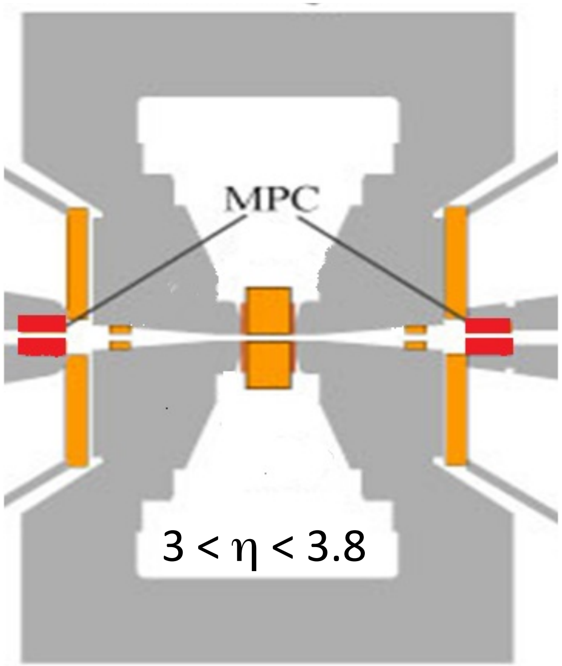
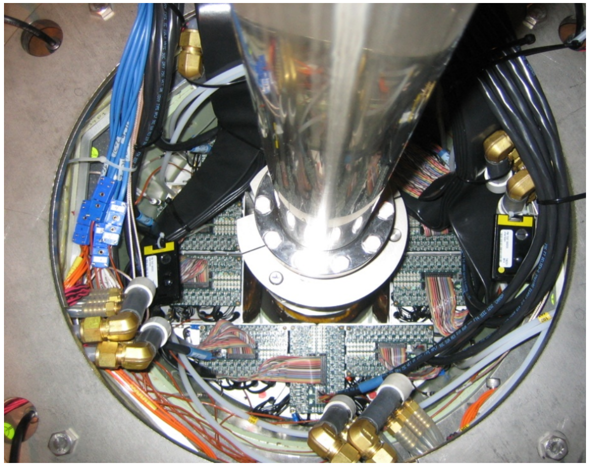


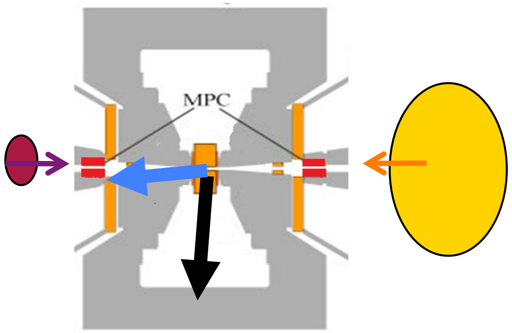
- Inferred quadrupolar anisotropy v_2 of h^{+-} vs. p_T

- v_2 consistent with hydro

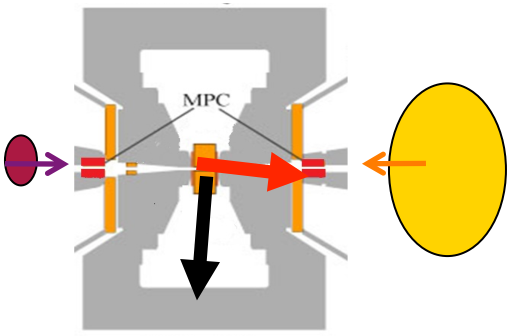
Extending to higher rapidities





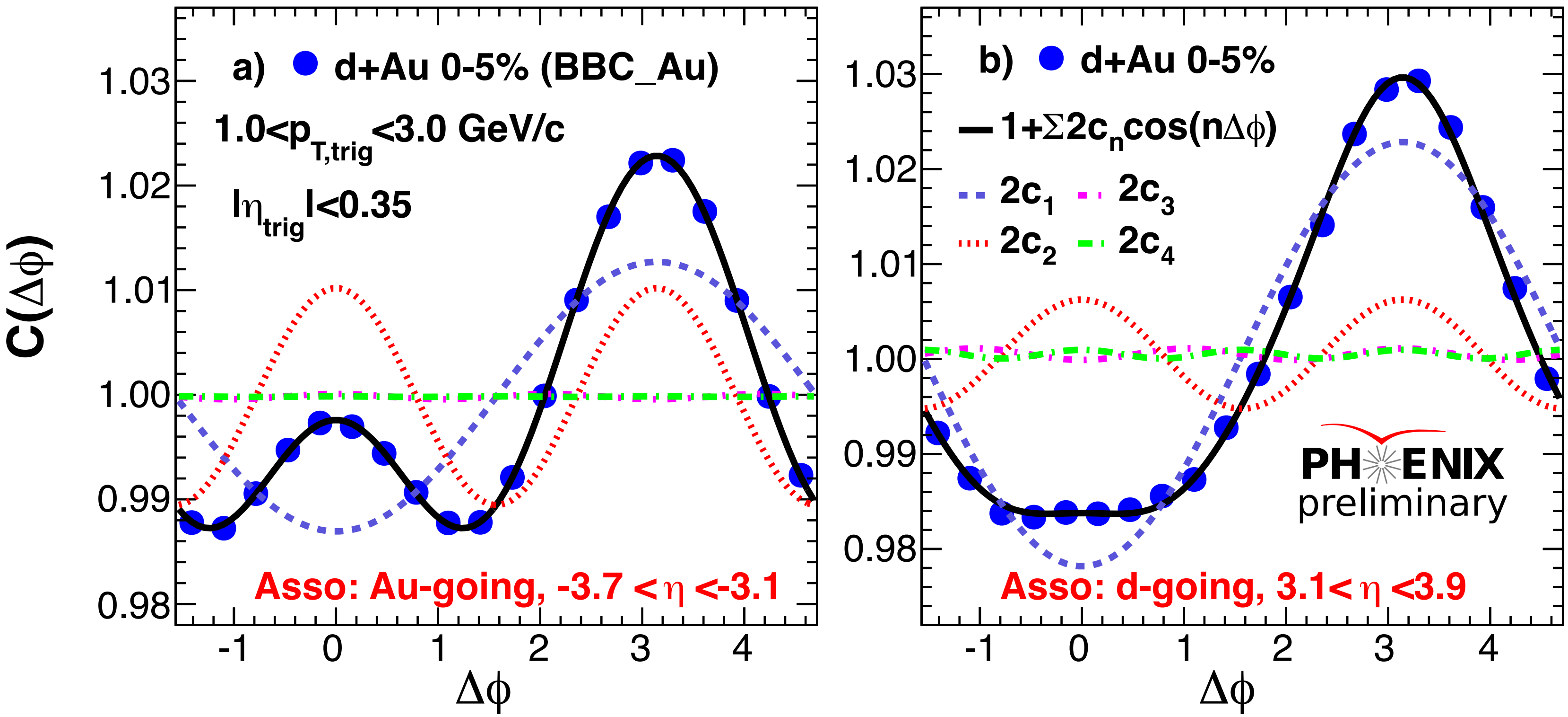


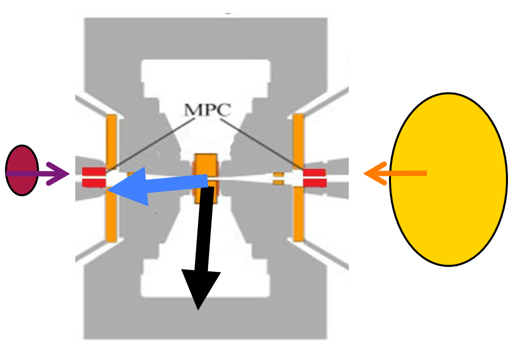
CNT-MPC Au-going
$\Delta\eta = 3.5$
high x in Au

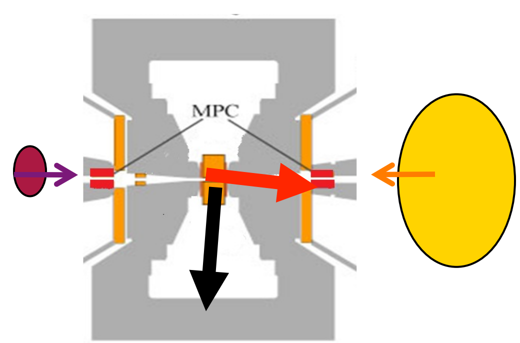


CNT-MPC d-going
$\Delta\eta = 3.5$
low x in Au

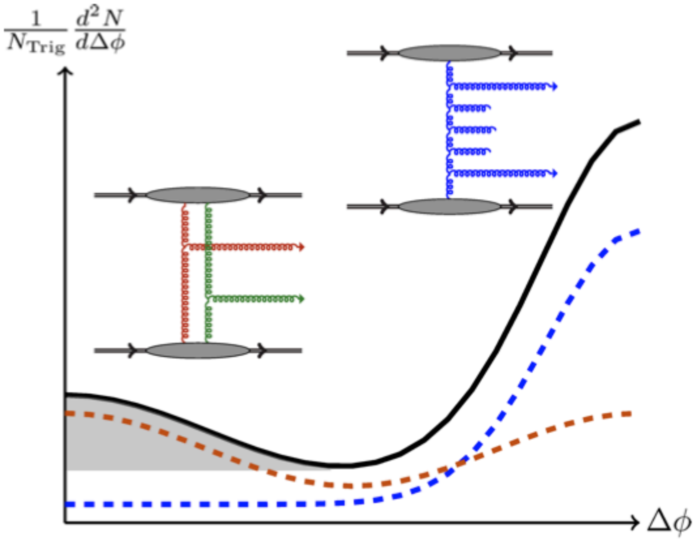
First evidence of long range ridge correlations in d+Au collisions at RHIC!



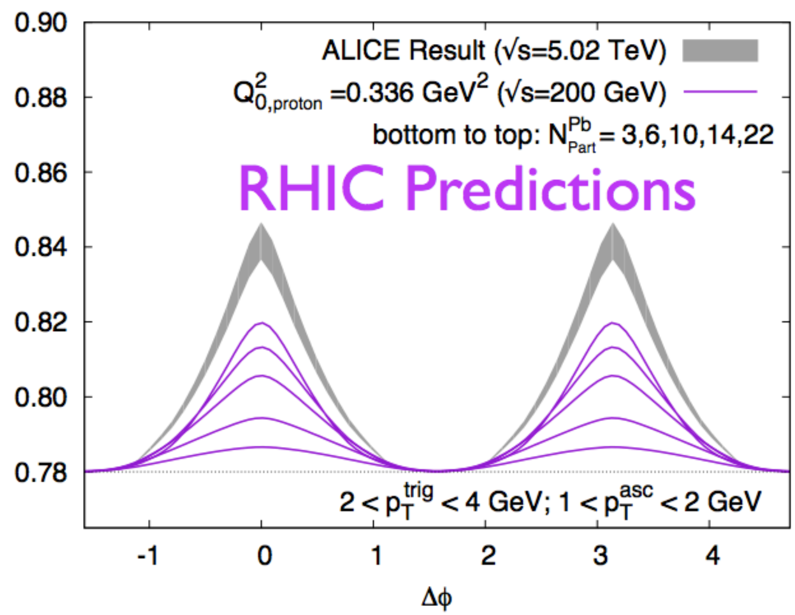




Correlations from Glasma Graphs



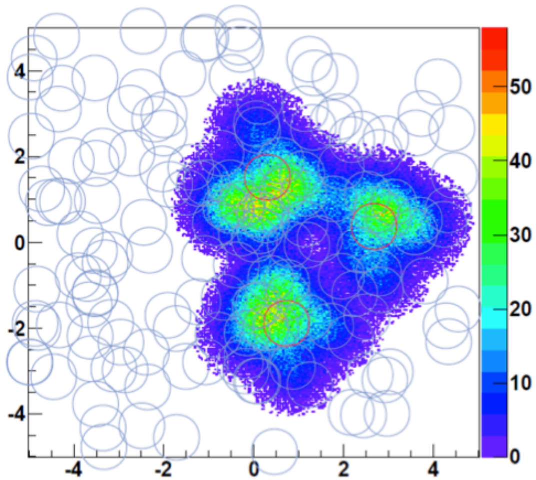
Dusling & Venugopalan 1211.3701, 1302.7018



Dusling, Venugopalan, 1211.3701, 1302.7018, private communication

- Significant signal expected at RHIC
- No quantitative comparison at this point since data not corrected for absolute acceptance

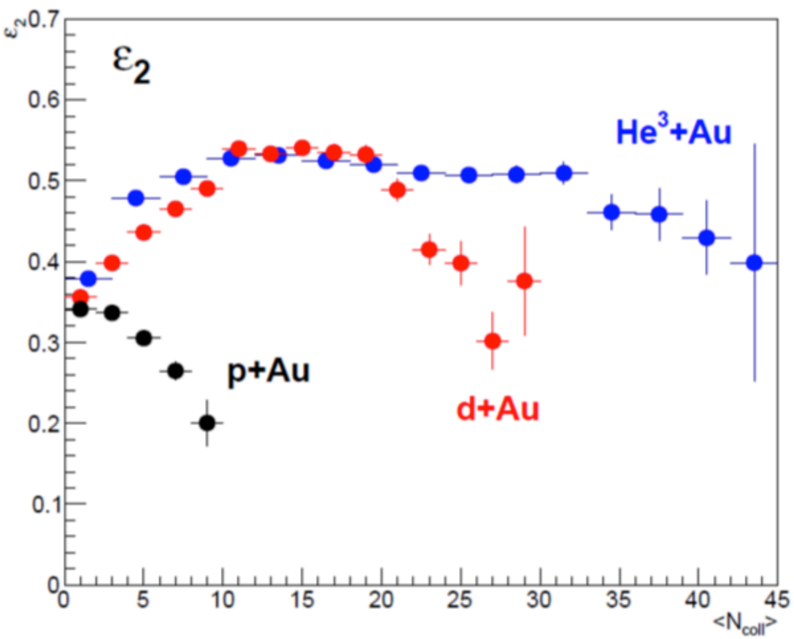
Hydro or Glasma Origin?

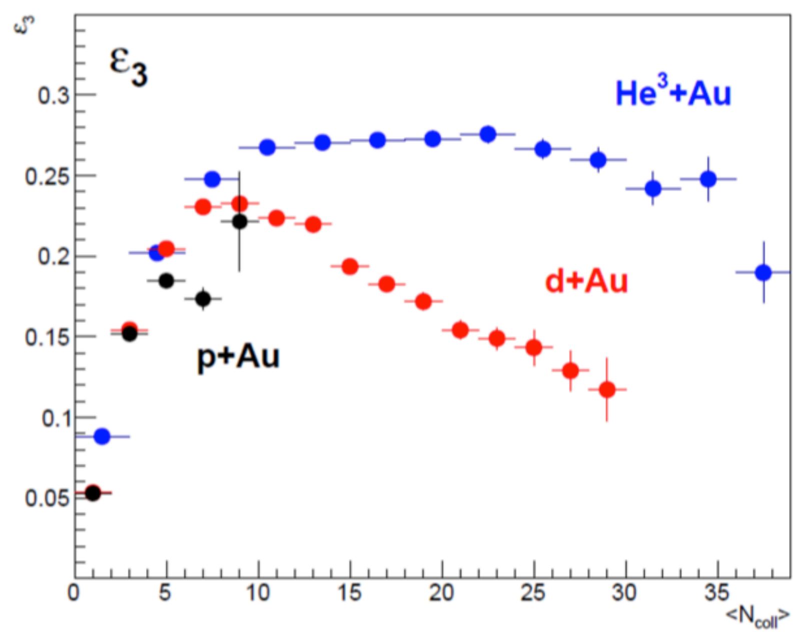


Glauber MC, Gaussian E distribution, σ = 0.4 fm

Eploit versatility of RHIC!

PHENIX requesting ^{3}He+Au, d+Au, p+Au in 2015 with increased acceptance (VTX+FVTX+MPC-EX)



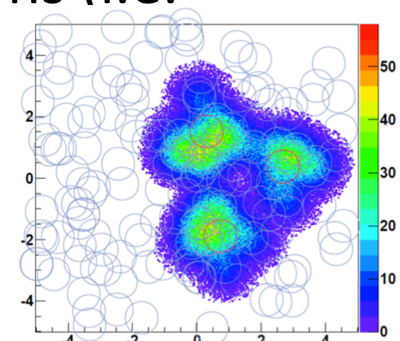


Conclusions

- Features of p(d)+A data strikingly similar to A+A
- Good hydrodynamical description of p(d)+A data
- → paradigm shift (i. e. flow in p(d)+A)?
- No (at least not yet)
  - question of applicability of hydrodynamics
    - System may be too small to speak of pressure gradient between fluid cells with local equilibrium
  - Large uncertainties make quantitative comparison difficult
    - Initial eccentricity, larger viscous corrections

Outlook

- Need consistent description of
  - All systems: p+p, p(d)+A, A+A
  - All observables: $v_{2(3+)}$, spectra, HBT radii
    - both average and event-by-event distributions (i.e. higher moments)



- Experimental judge: systematic study of p+A, d+A, ^{3}He+A at RHIC
- If non-flow source in p(d)+A, non-flow contribution also in A+A?
- Then what will happen to the nearly perfect fluid paradigm?