Imaging the initial condition by
(1) higher order event anisotropy v_n
(2) multi-particle correlation
(3) direct photon v_2
from the RHIC-PHENIX experiment

ShinIchi Esumi for the PHENIX collaboration
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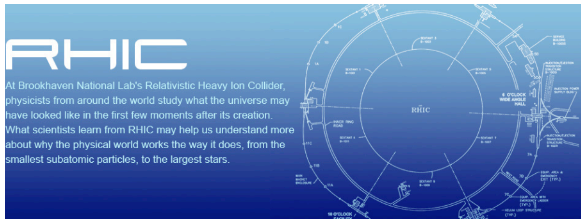
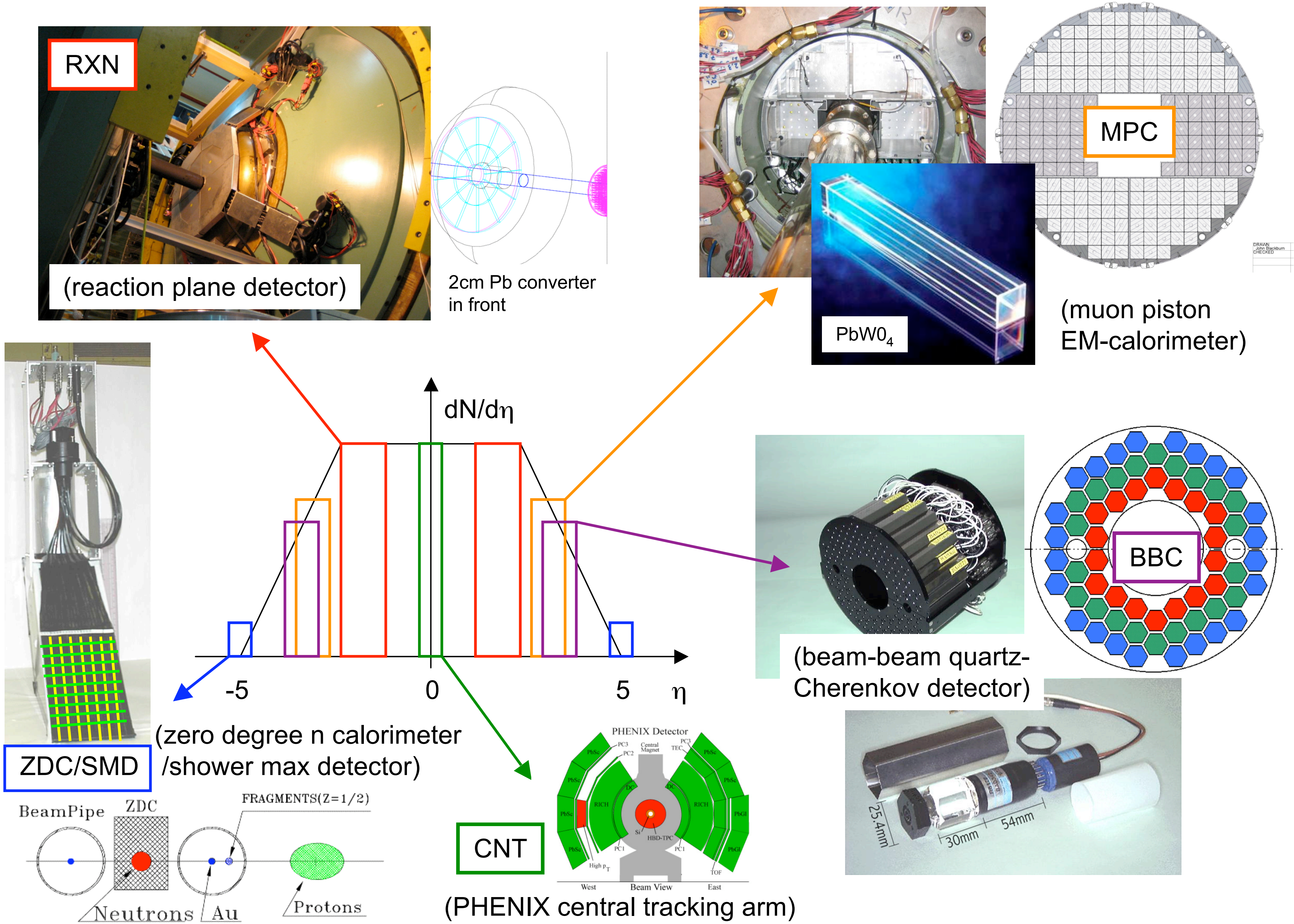
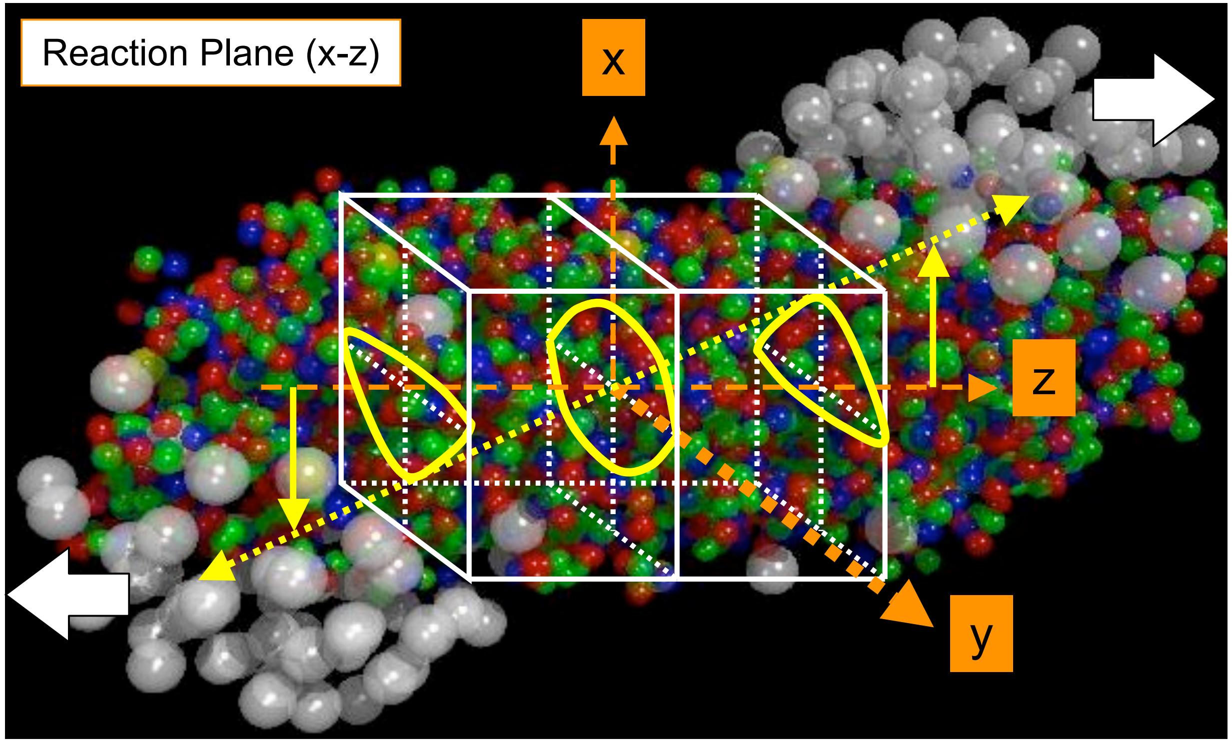


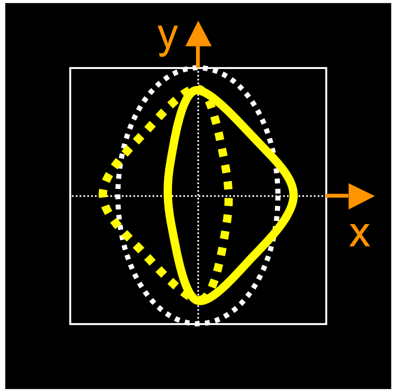
PHENIX

筑波大学
University of Tsukuba

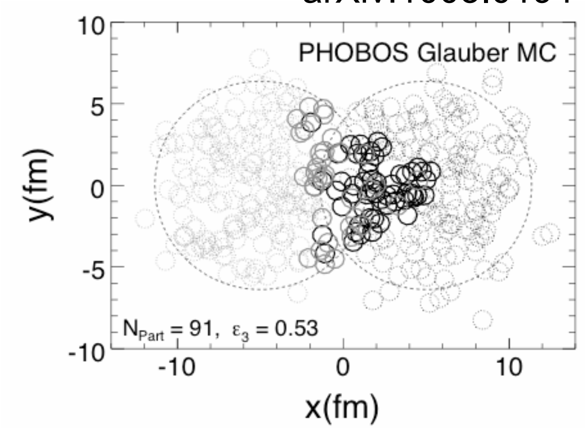

RXN
(reaction plane detector)
2cm Pb converter
in front
MPC
PbW0$_4$
(muon piston
EM-calorimeter)
dN/dη
-5
0
5
η
BBC
(beam-beam quartz-
Cherenkov detector)
25.4mm
30mm
54mm
ZDC/SMD
(zero degree n calorimeter
/shower max detector)
BeamPipe
ZDC
FRAGMENTS(Z=1/2)
Neutrons
Au
Protons
CNT
PHENIX Detector
West
Beam View
East
(PHENIX central tracking arm)

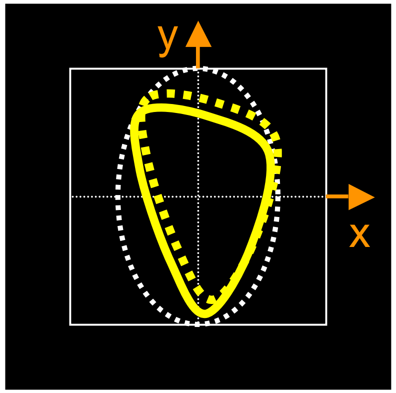
v_3 and initial fluctuation





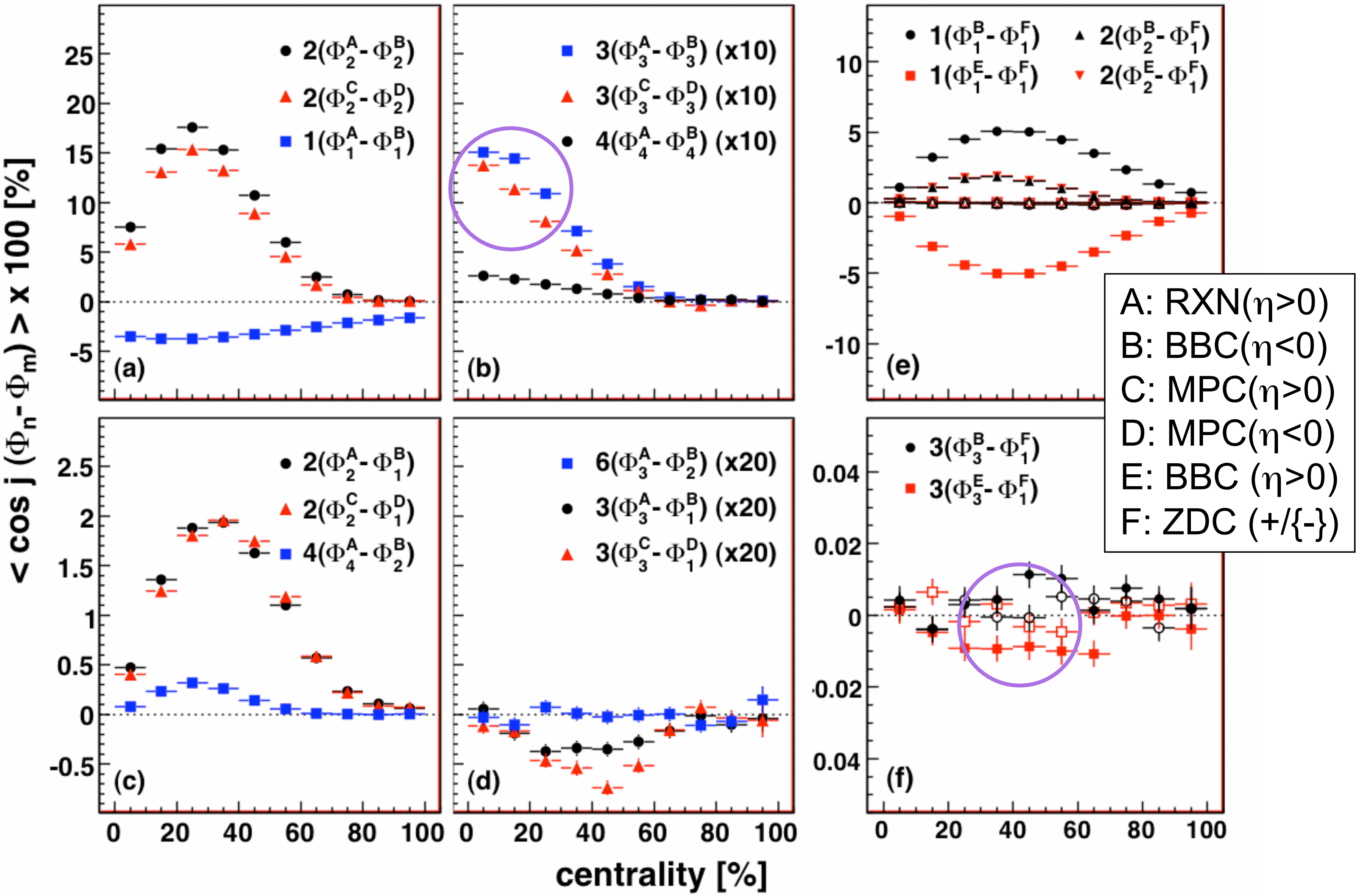
arXiv:1003.0194



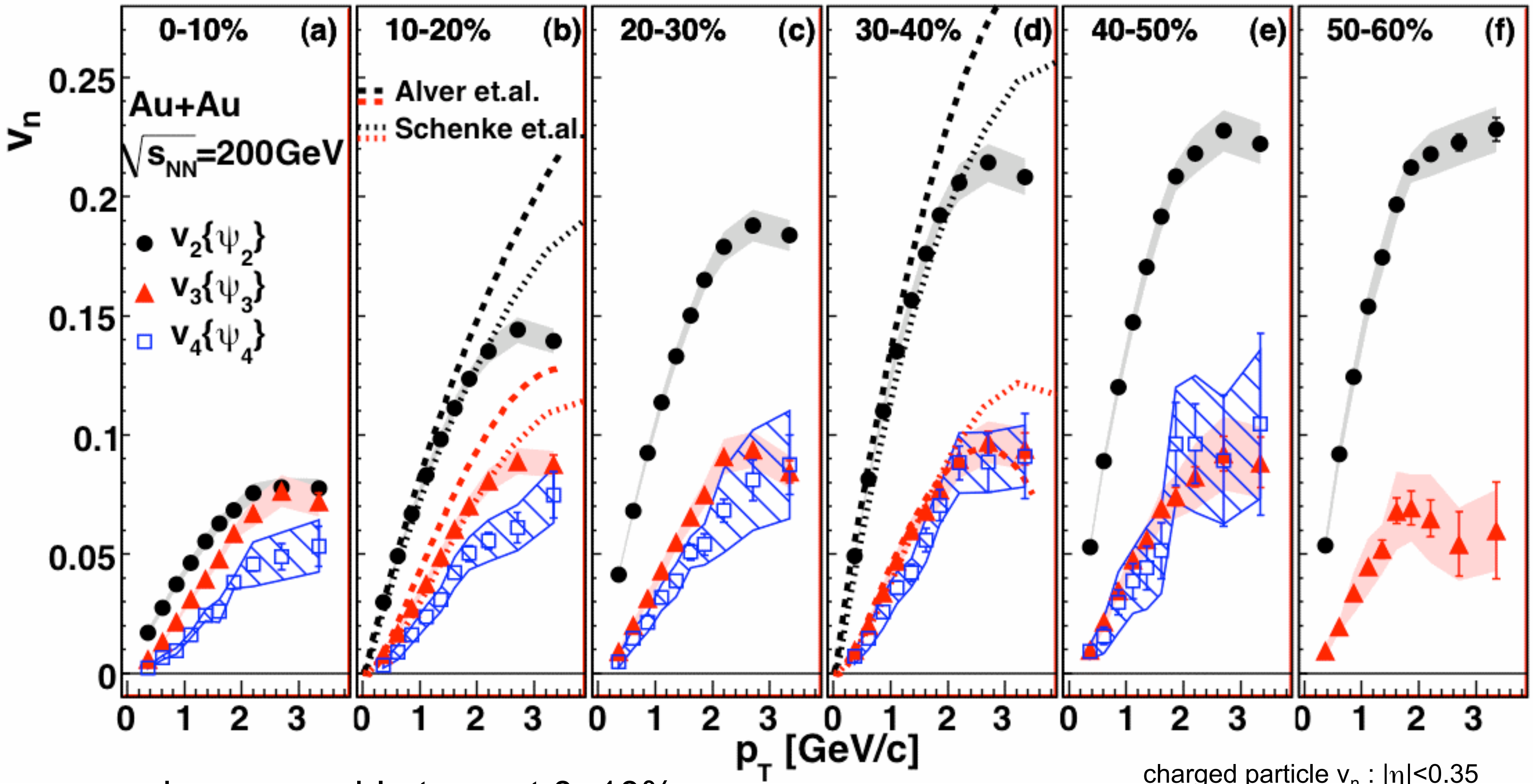


black-disk --> sign-flipping v_3
initial fluctuation --> no-sign-flipping v_3

Indication of strong non-flipping and weak sign-flipping v_3



Centrality and p_T dependences of v_n at 200GeV Au+Au



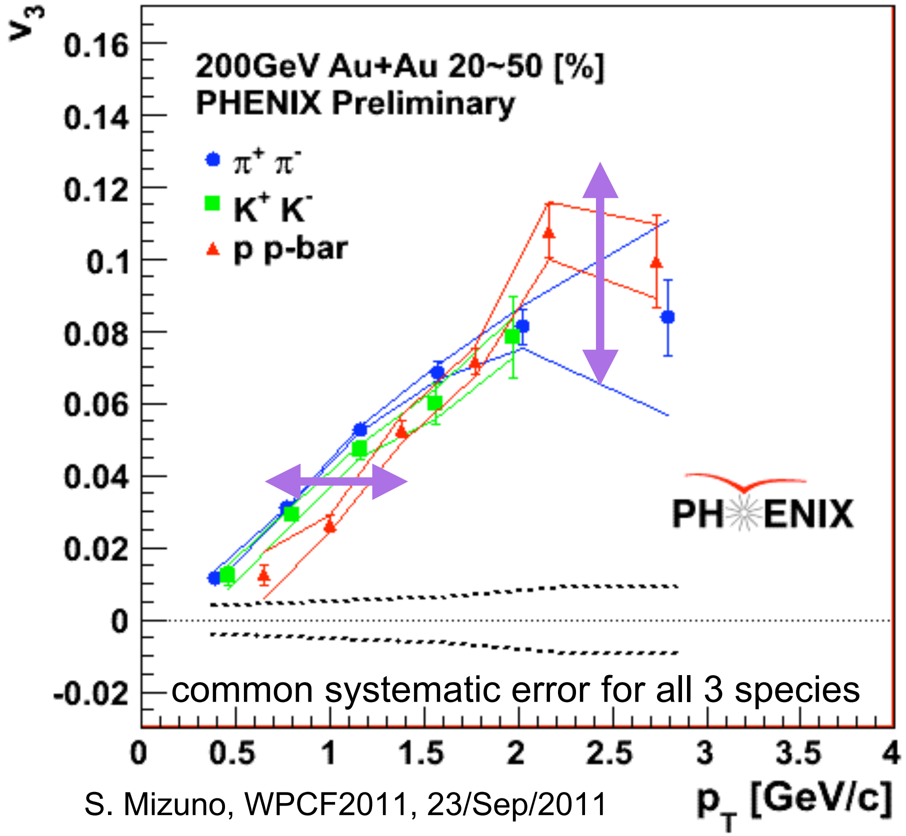
charged particle v_n : $|\eta|<0.35$
reaction plane Φ_n : $|\eta|=1.0\sim2.8$

v_3 is comparable to v_2 at 0~10%
weak centrality dependence on v_3
$v_4\{\Phi_4\} \sim 2 \times v_4\{\Phi_2\}$

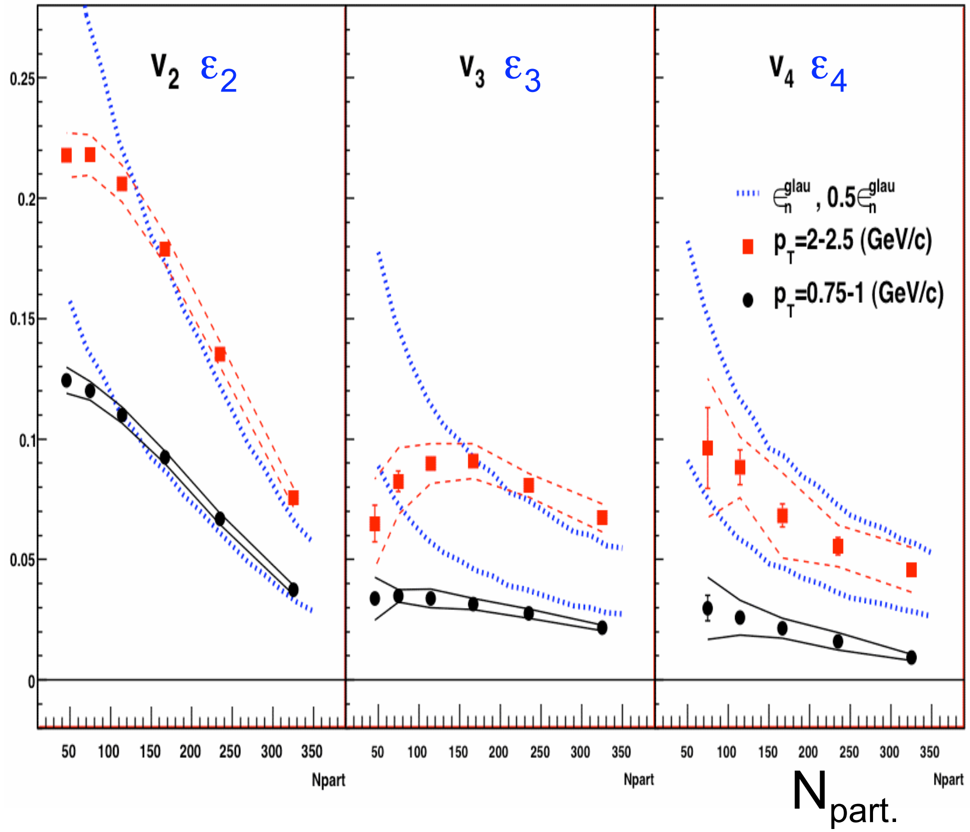
All of these are consistent
with initial fluctuation.

Particle dependence of v_3 shows the similar mass-splitting and Baryon / Meson difference like v_2.

How the initial geometrical anisotropy was transformed into the final momentum anisotropy?



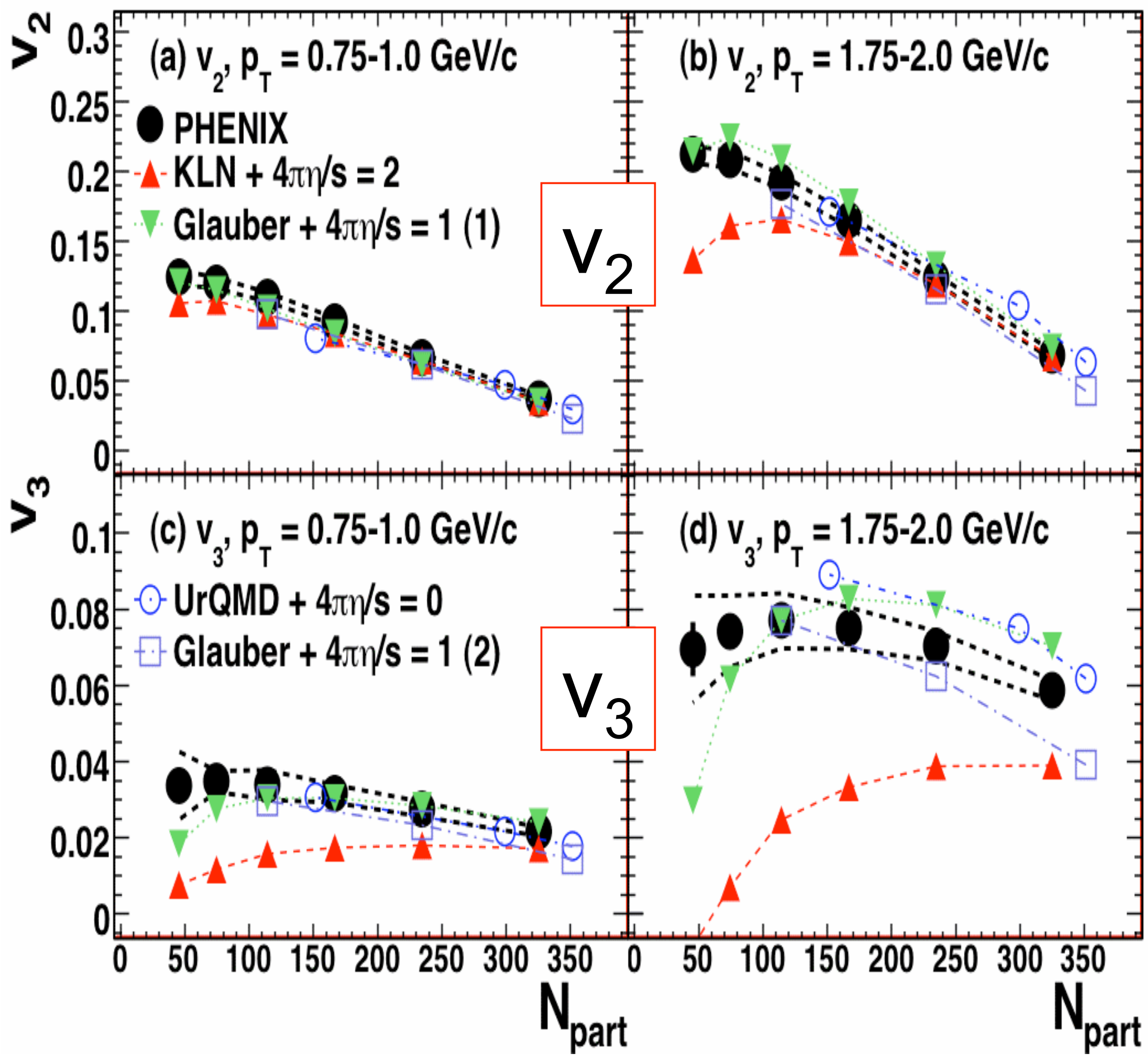
S. Mizuno, WPCF2011, 23/Sep/2011



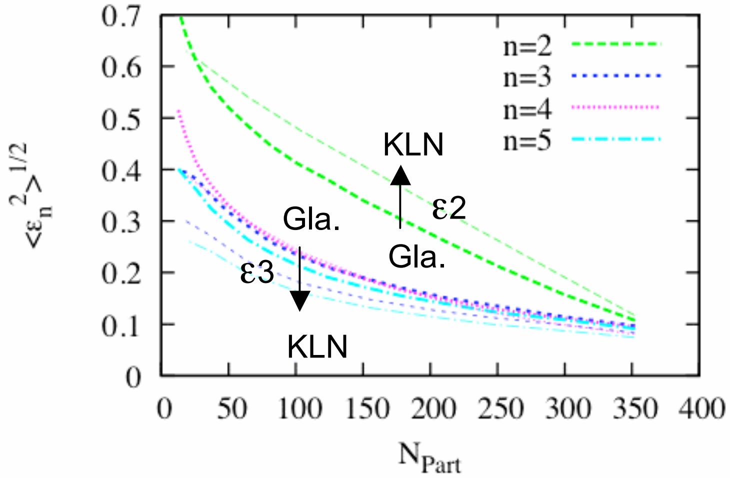
v_3 reflects the collective expansion.

v_3 breaks the degeneracy

arXiv:1105.3928



PRC82.034913



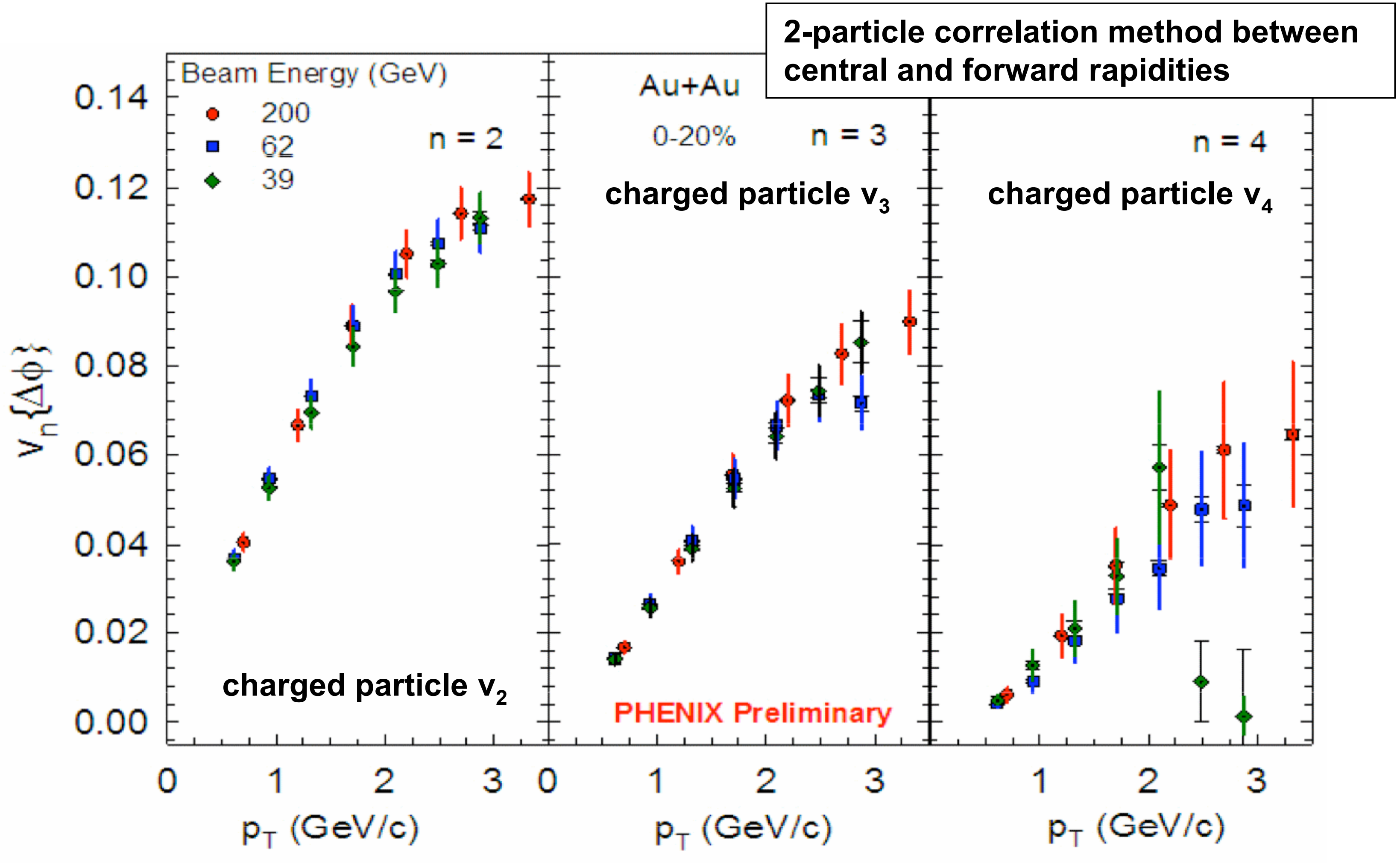
v_3 provides an additional constraining power on the hydro-model parameters.

Glauber & $4\pi\eta/s=1$ works better.

CGC-KLN & $4\pi\eta/s=2$ fails.

B. Alver et. al., Phys. Rev. C82, 034913(2010).
B. Schenke et. al., Phys. Rev. Lett. 106, 042301(2011).
H. Petersen et. al., Phys. Rev. C82, 041901(2010).

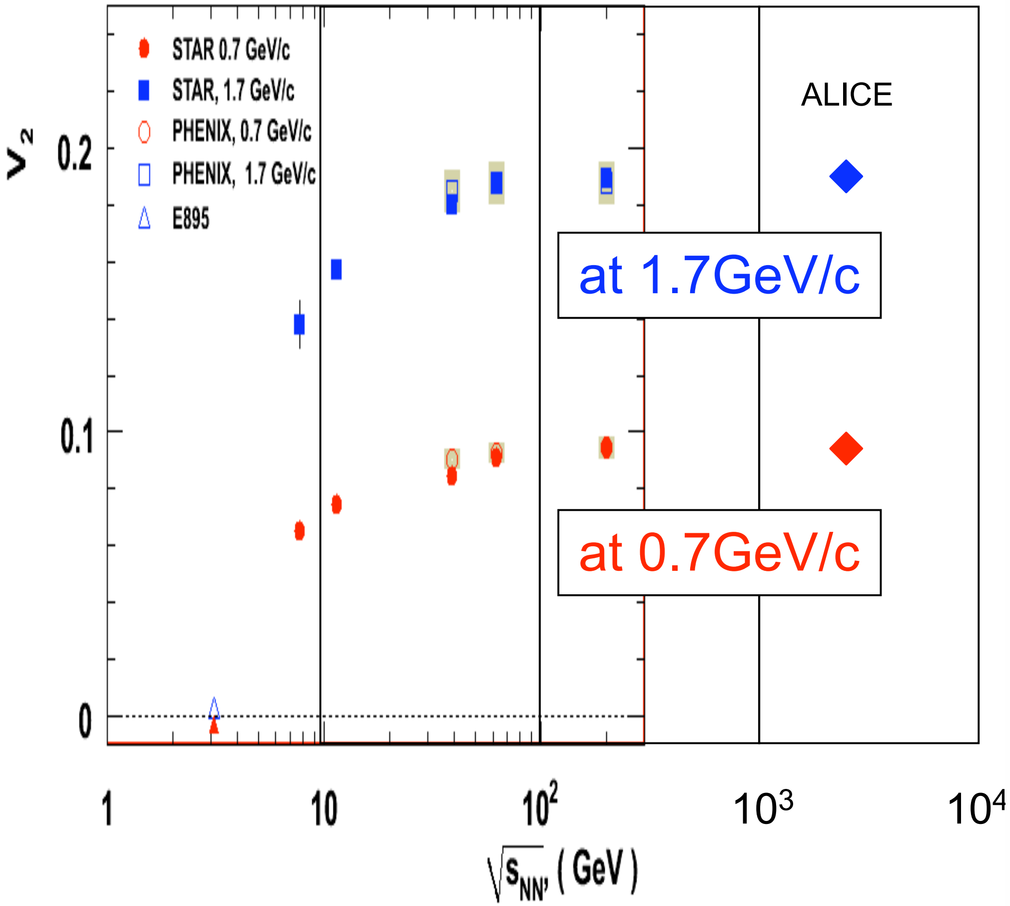
Beam energy dependence 39/62/200GeV Au+Au

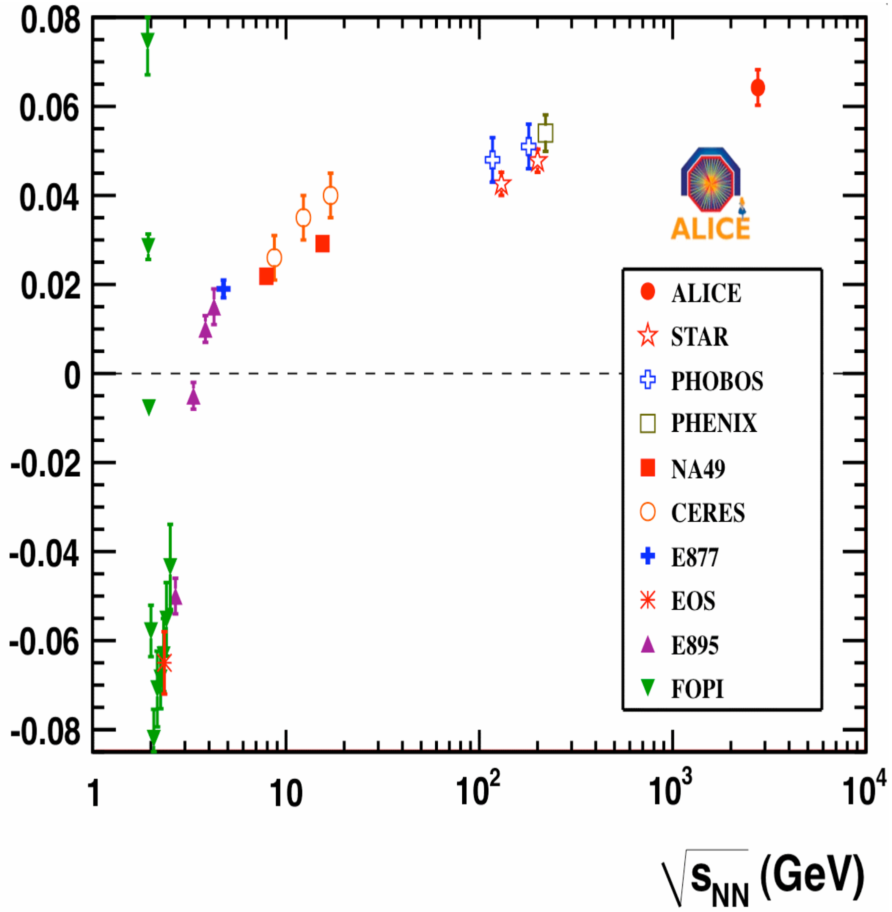


similar hydro-properties down to 39GeV

Beam energy dependence of <v_2> and $v_2(p_T)$

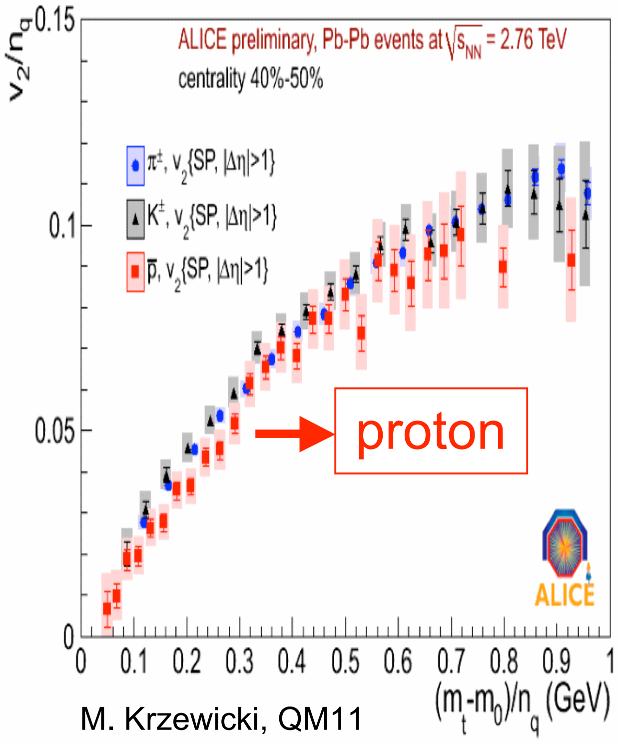
Preliminary, STAR, PHENIX and E895 data



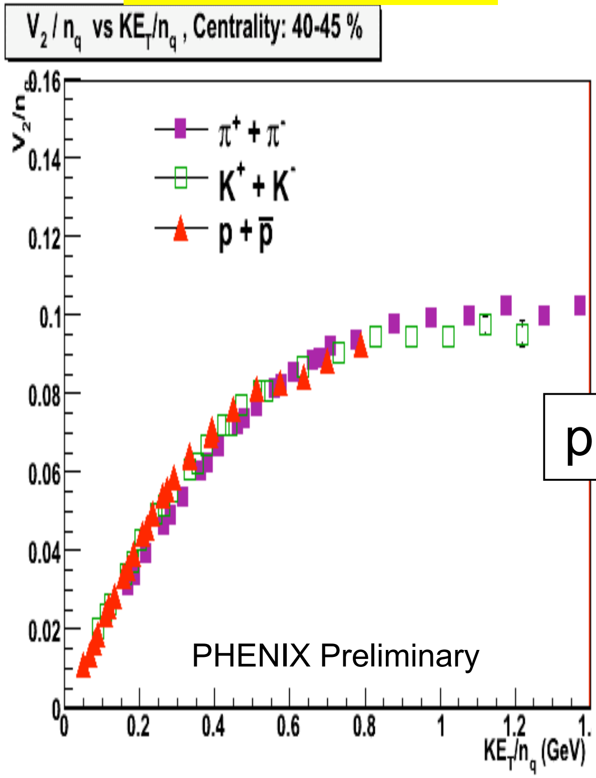


Small deviations in $(m_T-m_0)/n_q$ scaled v_2

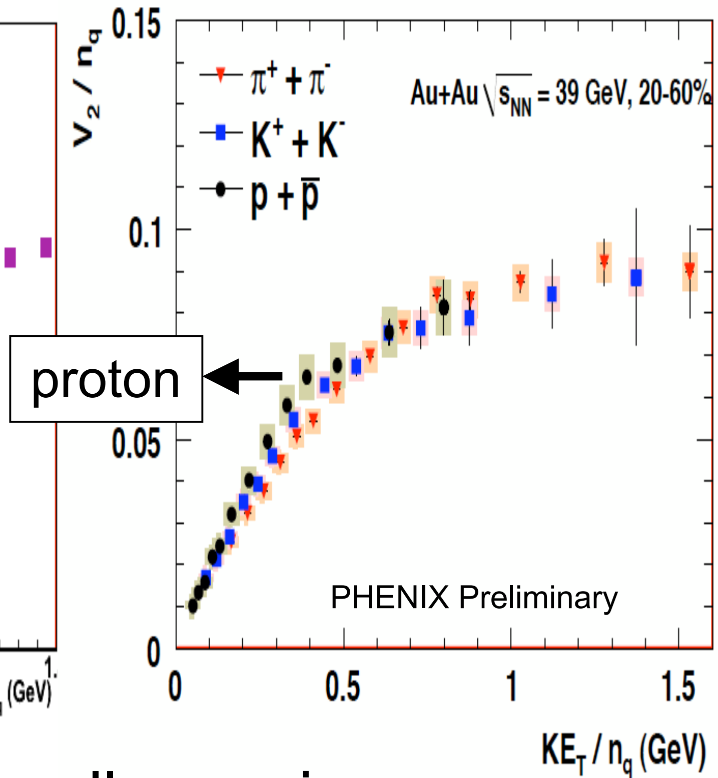
Pb+Pb 2.76TeV



Au+Au 200GeV

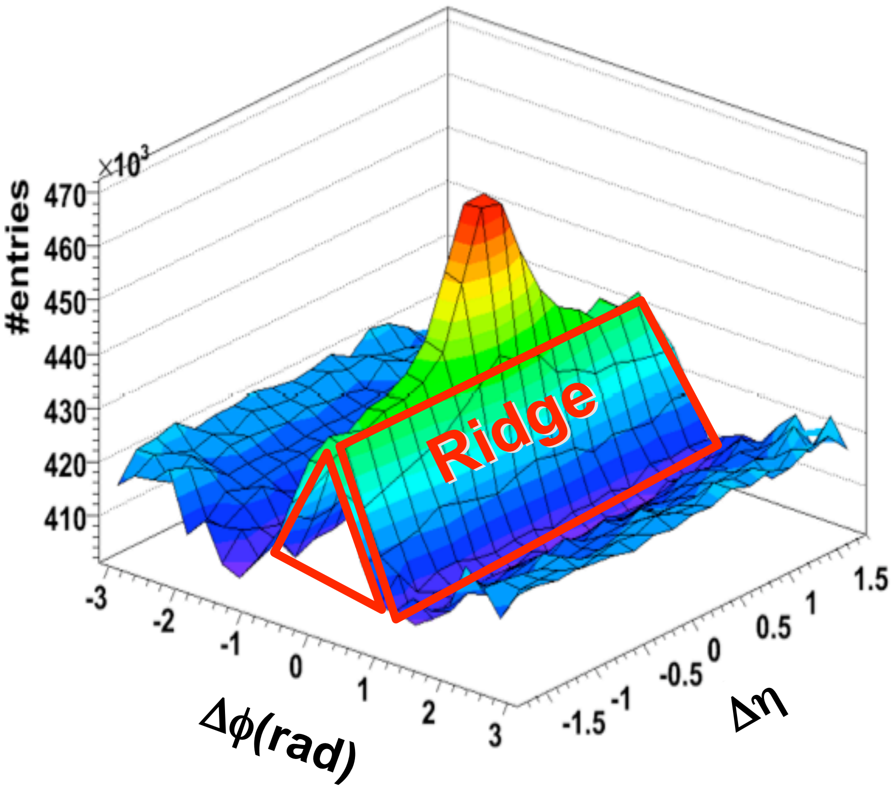


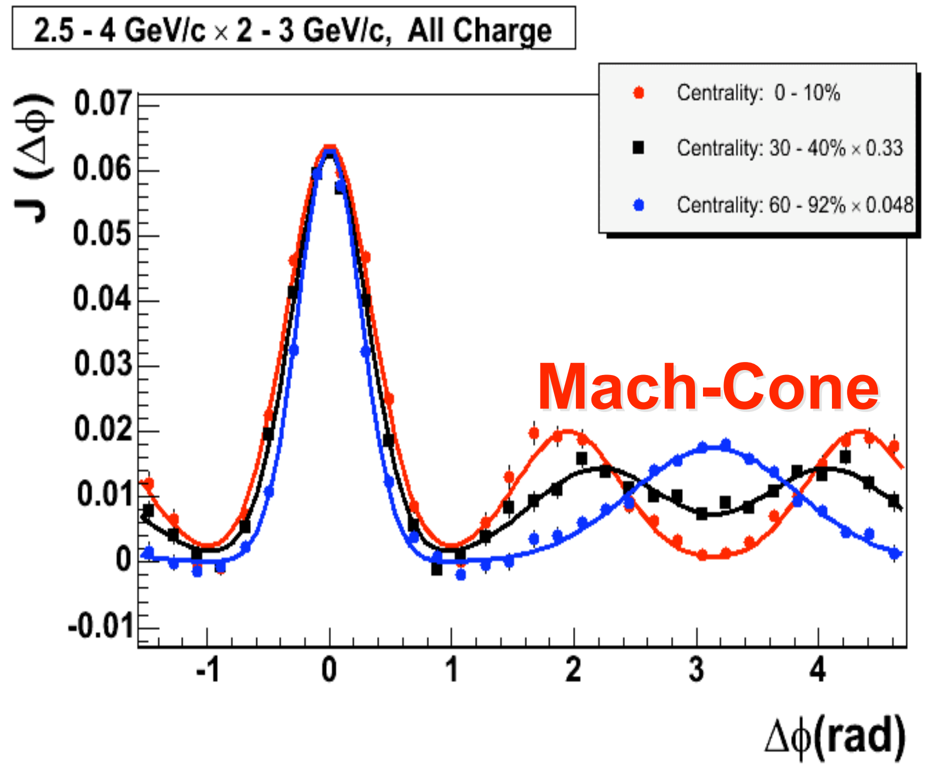
Au+Au 39GeV



roughly $(m_T-m_0)/n_q$ scaled for all energies
larger p_T shift for heavier particles
radial flow increases with energy

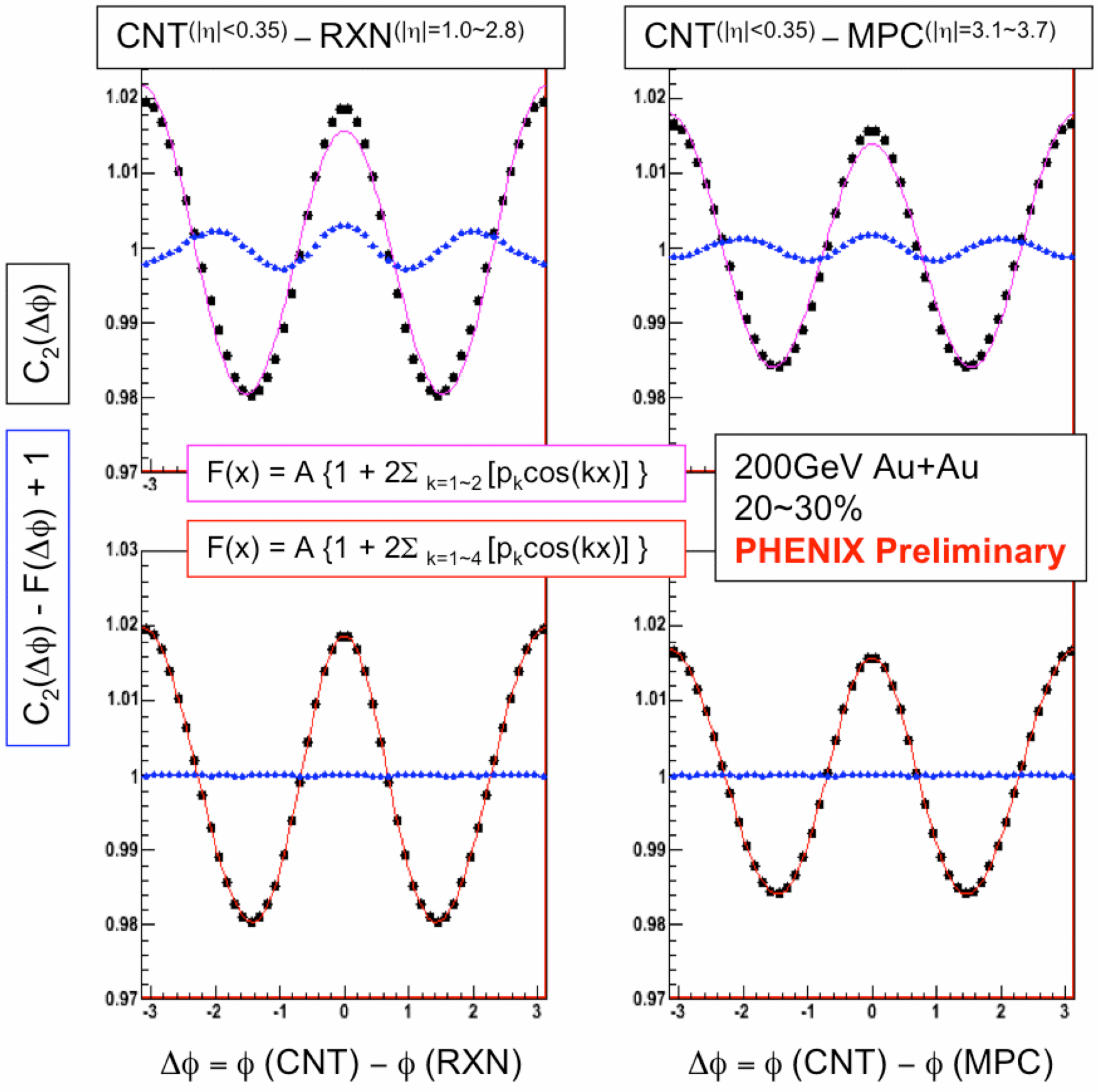
Does v_3 explain ridge and mach-cone?





ridge : long range $\Delta\eta$ correlation at near-side
cone : double peak/shoulder at away-side (long in $\Delta\eta$)
v_3 : initial fluctuation is common over wide range of η

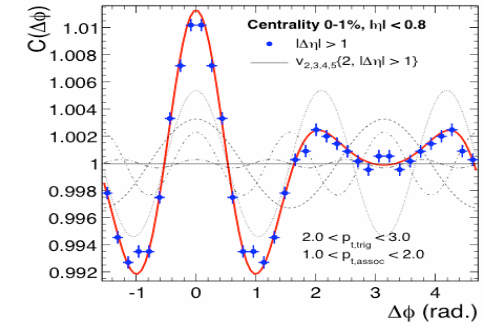
The answer is YES with |Δη| gap.



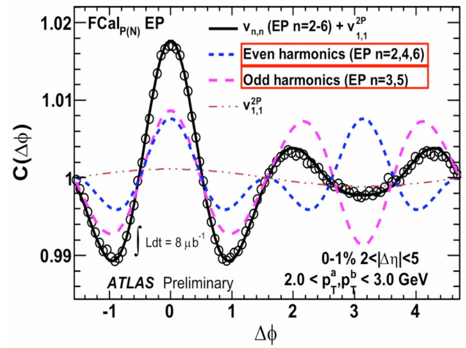
The data are unchanged, only the interpretations are being changed.

This has also been shown by various experiments.

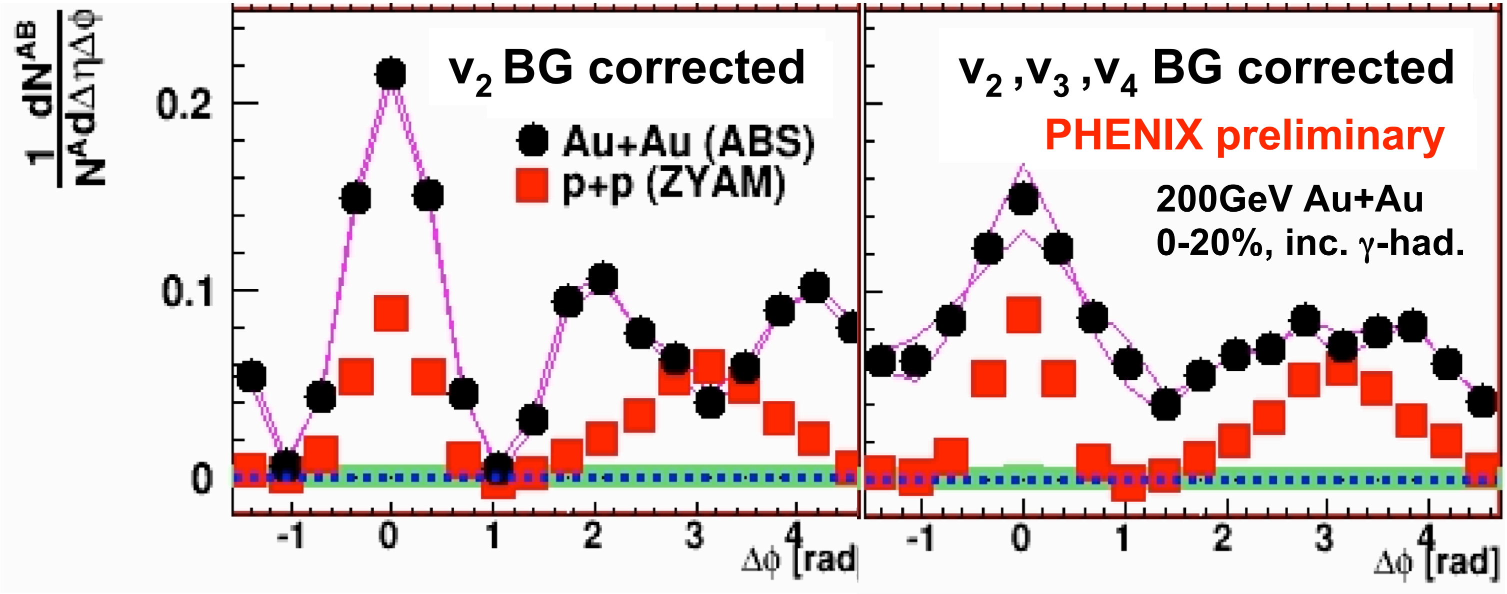
arXiv:1105.3865

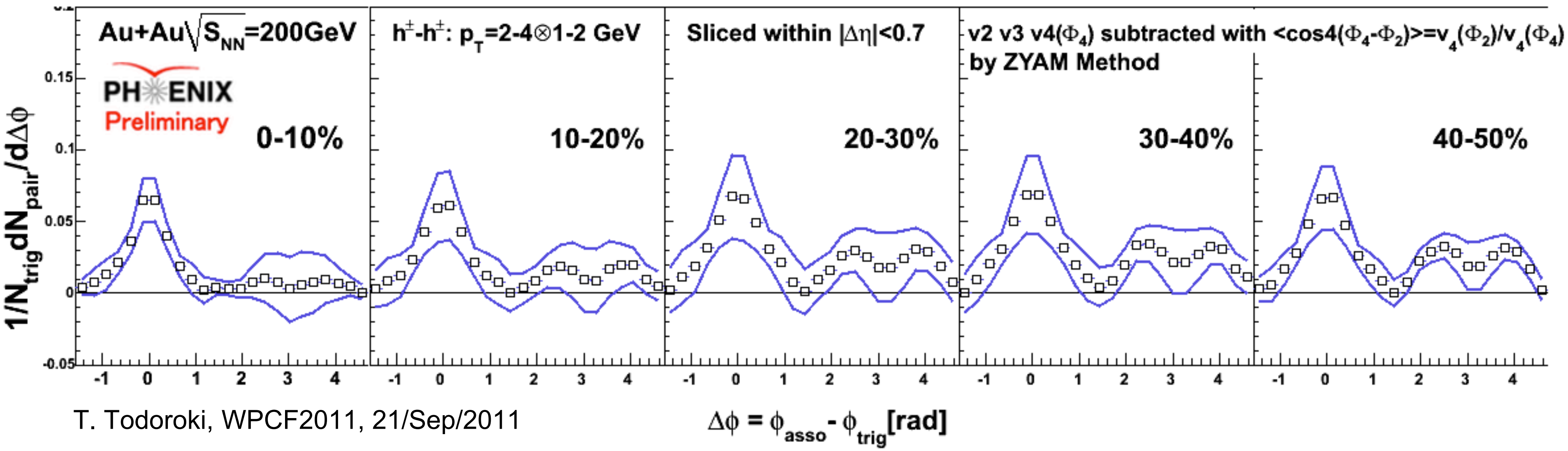


J. Jia, QM11



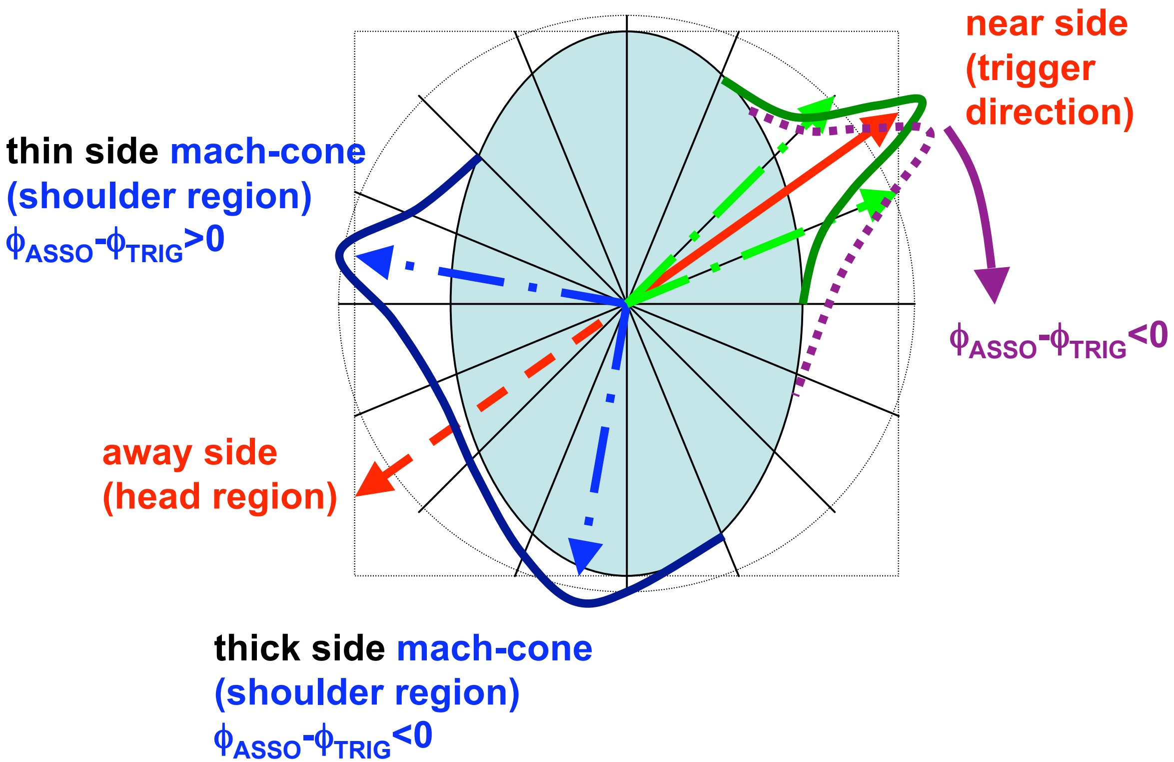
Not completely yet, without $|\Delta\eta|$ gap.

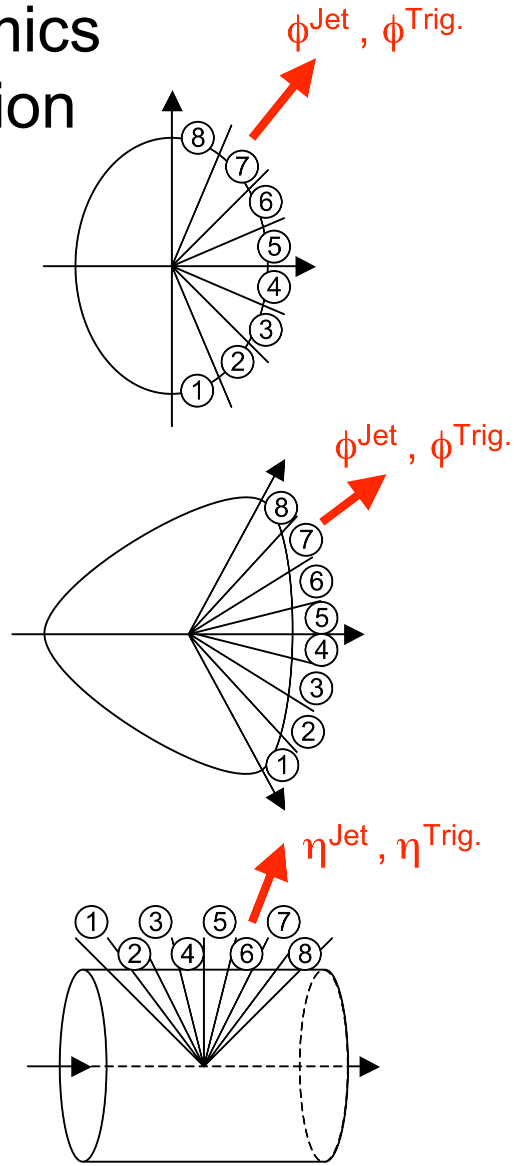




T. Todoroki, WPCF2011, 21/Sep/2011

Probe the transverse geometry and/or dynamics with trigger angle selected 2-particle correlation including the HBT correlation





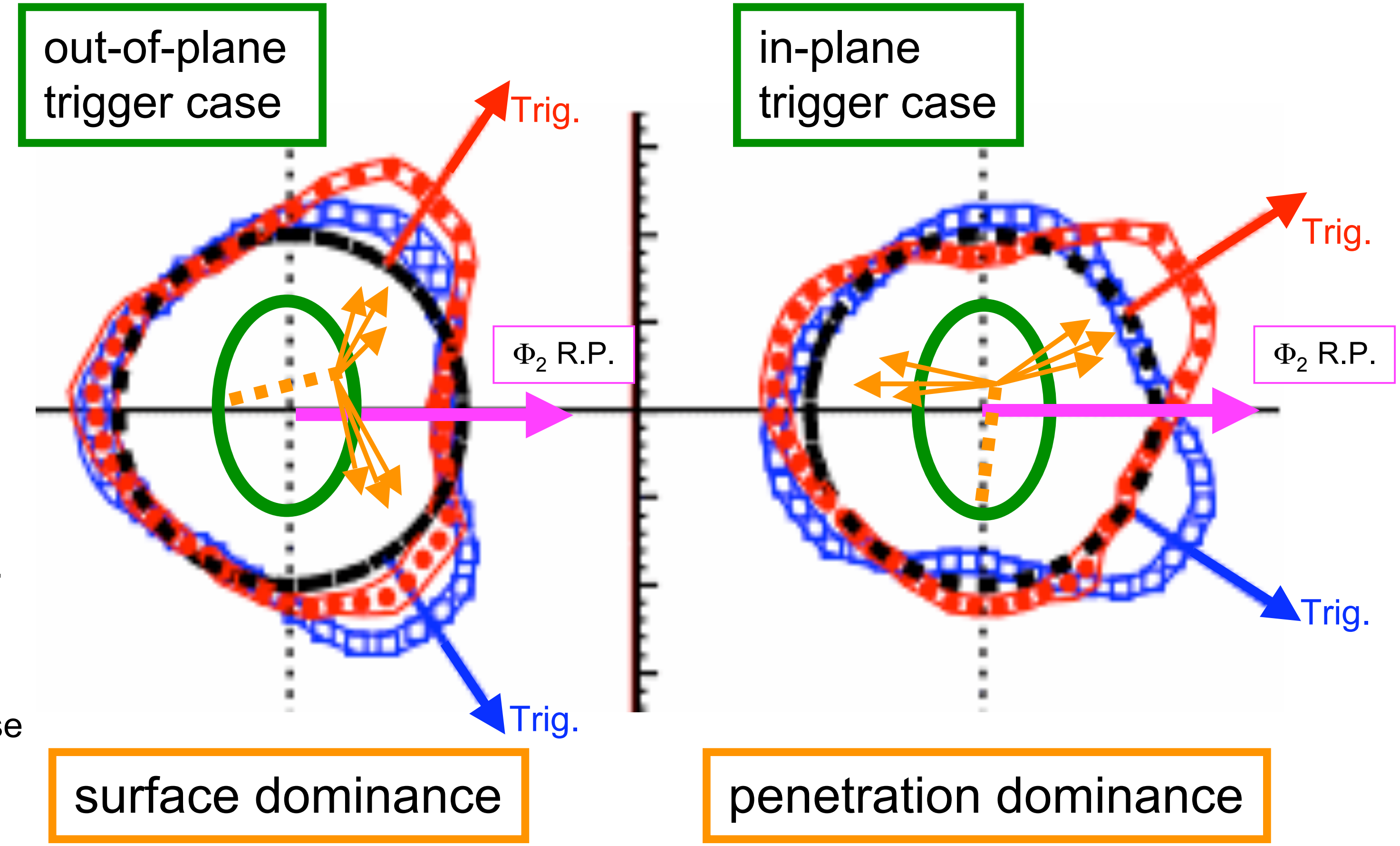
Observed left/right asymmetry remains after “the usual/normal” v_3 subtraction.

200GeV Au+Au -> h-h, 20-50%
(p_T^{Trig}=2~4, p_T^{Asso}=1~2GeV/c)
v_2,$v_4\{\Phi_2\}$ only subtraction
PHENIX preliminary

Trigger angle selection w.r.t. Φ_2 separately for left(up) / right(down)

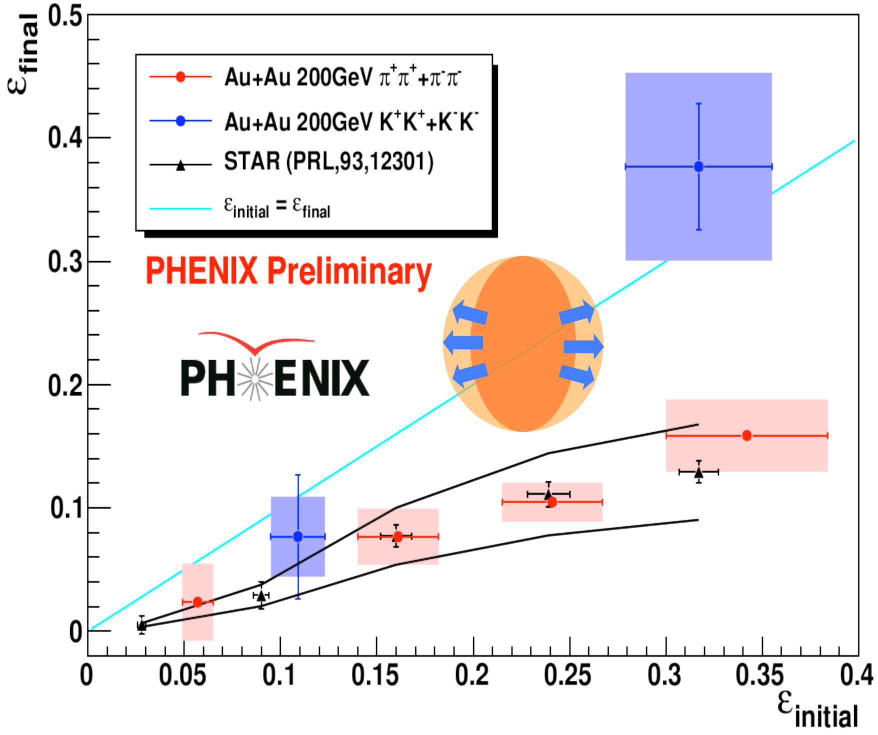
Trigger angle selected 2-part. corr. data are plotted in polar coordinate by rotating Φ_2 R.P. angle as X-axis.

Flow subtracted yield is shown radially with base line. ■■■■■■

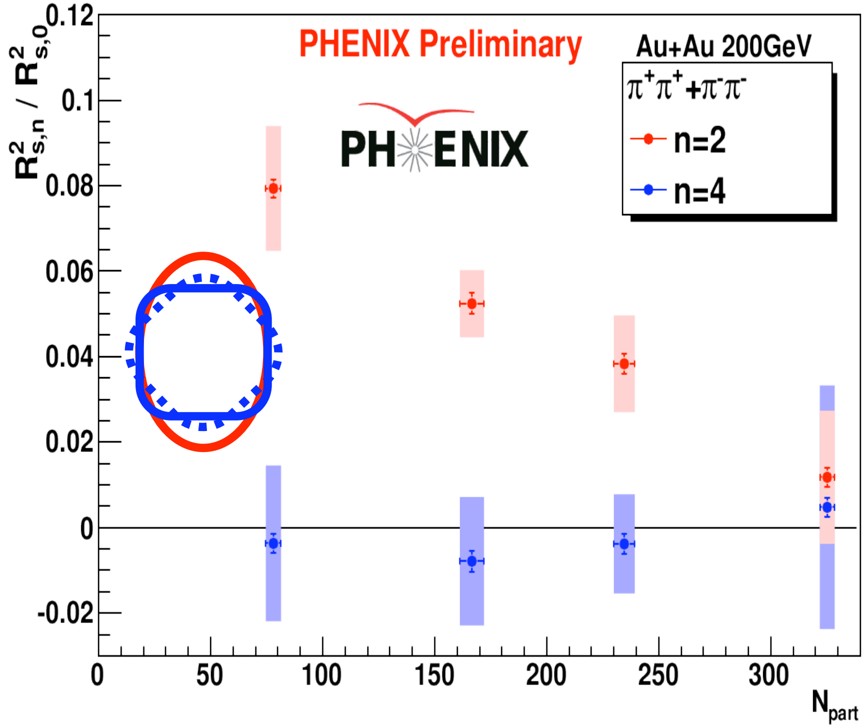


Two competing processes seen

Geometrical source anisotropy
via HBT measurement at the end of freeze-out

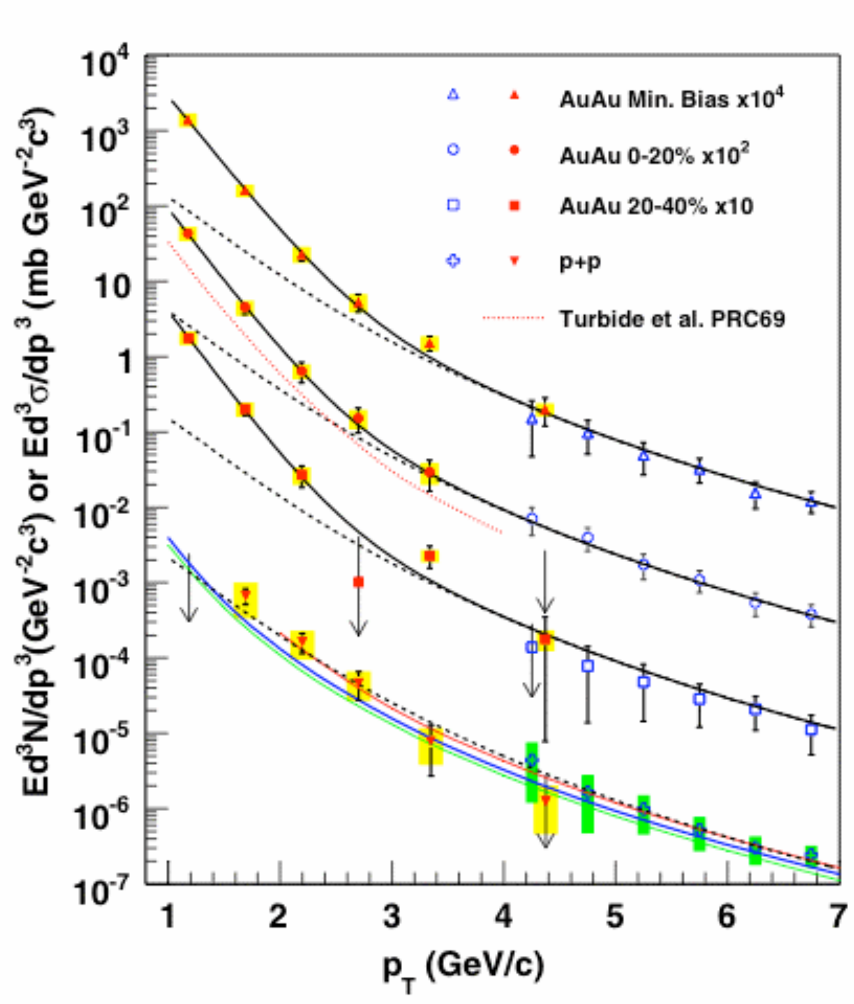


T. Niida, WPCF2011, 20/Sep/2011

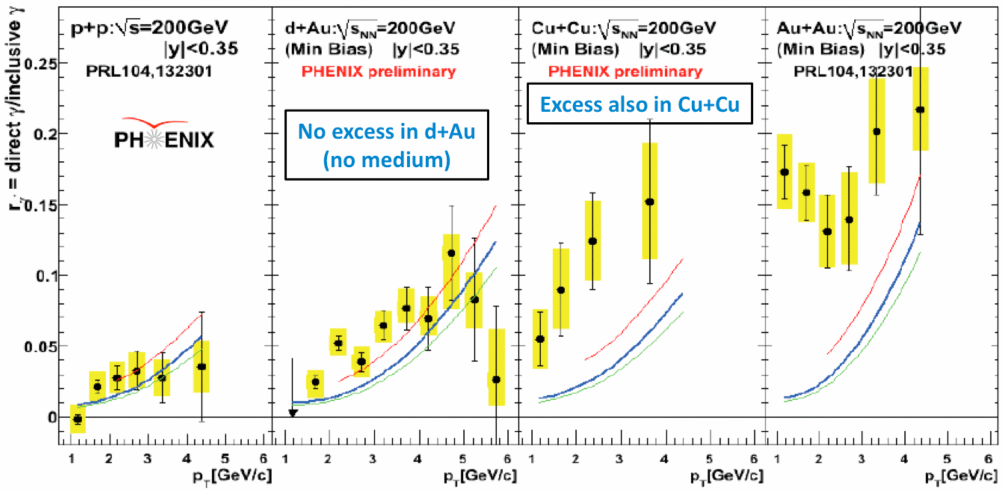


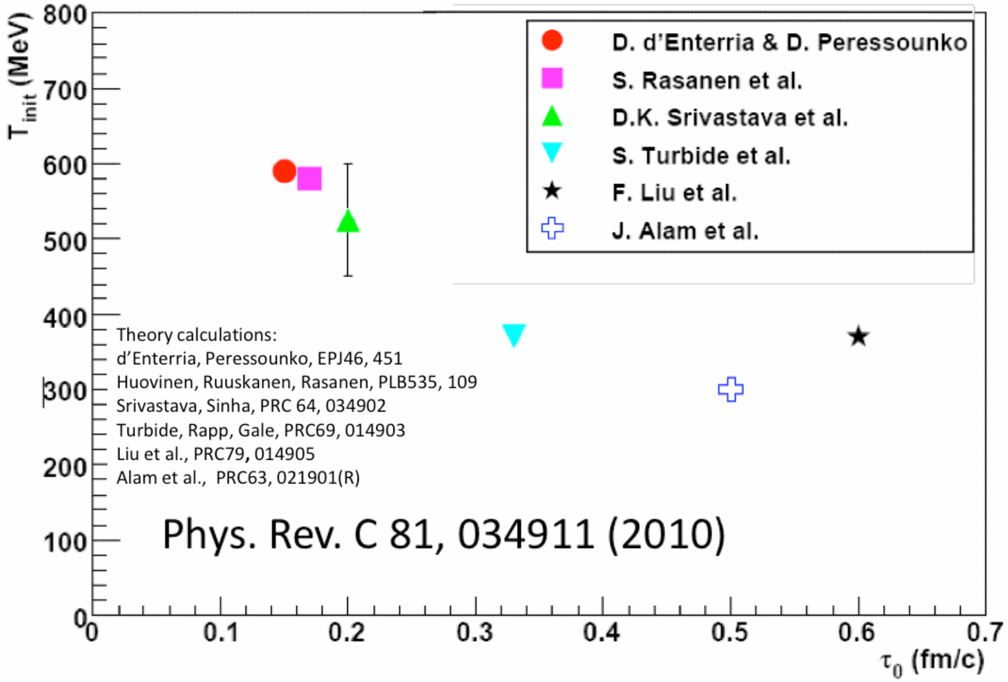
It might be different
from the v_2-v_4 relation

Direct (Thermal) photons



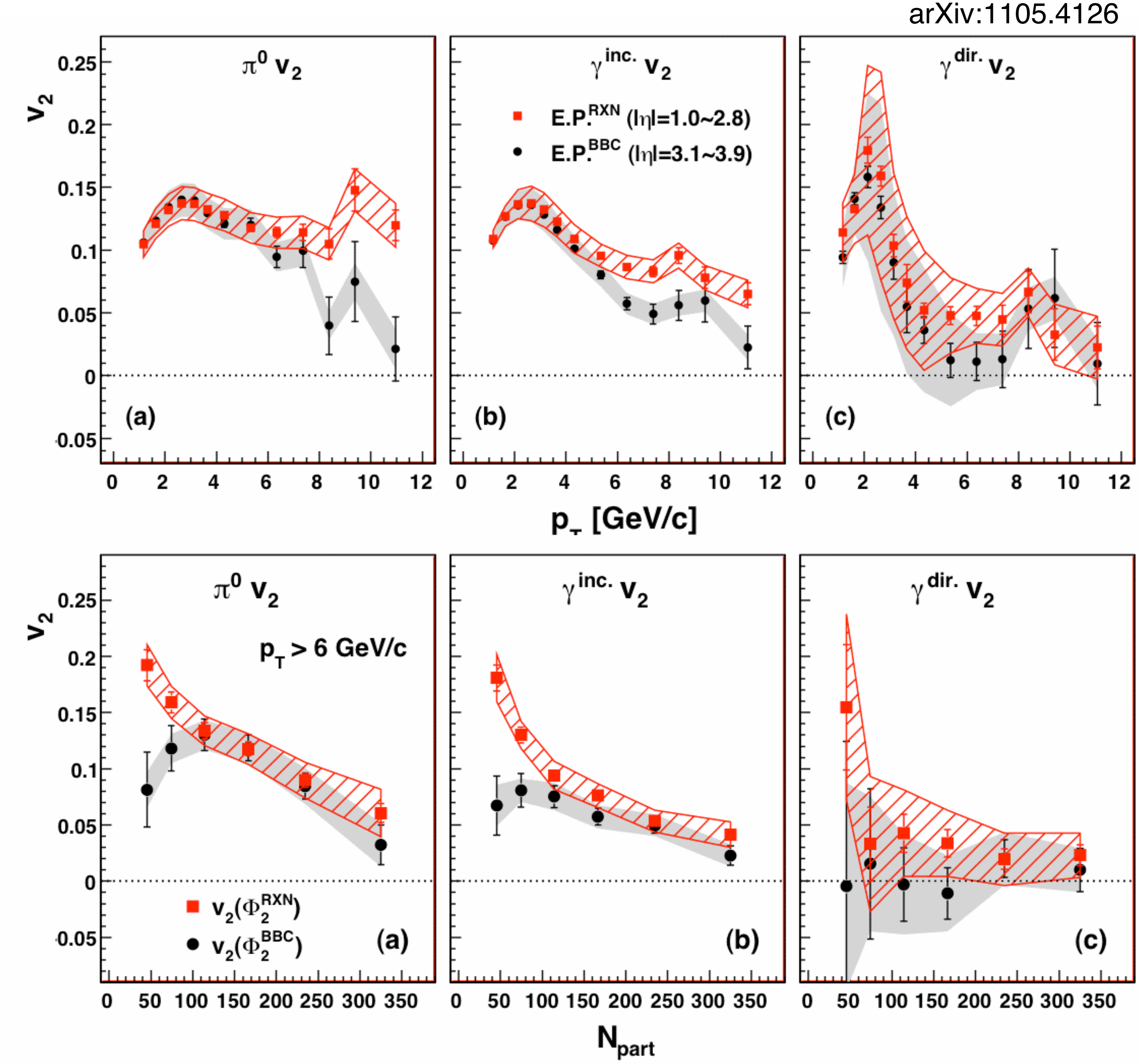
□ Fraction of direct photons compared to pQCD





$\gamma^{dir.}$ v_2 extracted from $\gamma^{inc.}$ v_2, π^0 v_2 and R_γ ratio

arXiv:1105.4126



significant difference between π^0 and $\gamma^{inc.}$ v_2 above 5GeV/c

difference between $v_2^{\{RXN\}}$ and $v_2^{\{BBC\}}$ is due to jet bias

surprisingly large $\gamma^{dir.}$ v_2 is seen, similar to hadron v_2 at low p_T

$\gamma^{dir.}$ v_2 is small at high p_T, consistent with prompt photon


PHENIX
ILLINOIS

Summary

- Significant higher order event anisotropy observed
  - Consistent with initial geometrical fluctuation
  - Break degeneracy: Glauber & $4\pi\eta/s=1$ favored
- Almost perfect fluidity from 39GeV to 2.76TeV
  - m_T-m_0 scaling for v_2 <---> radial flow
- Multi-particle correlation analysis in progress
  - Strong impact from v_n on Mach cone and ridge
  - C_2 <-> v_n with or without $|\Delta\eta|$ gap cut
- Direct photon v_2 observed
  - Small at high p_T --> consistent with pQCD
  - Large in low p_T --> challenge to theory

Backup slides

$\varepsilon_3^{Glauber}$ (> .or. <) $\varepsilon_3^{CGC\text{-}KLN}$?

PRC82.034913

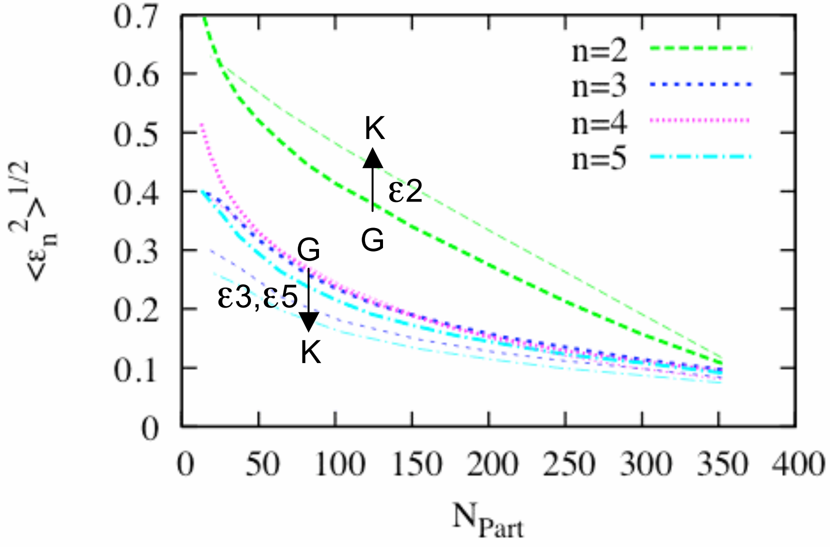


FIG. 7: (Color online) Root mean square eccentricities $\varepsilon_n^{\rm rms}$ for $n = 2, 3, 4, 5$ for Au-Au collisions at 200 GeV per nucleon, versus the number of participant nucleons $N_{\rm Part}$. $N_{\rm Part}$ is used as a measure of the centrality in nucleus-nucleus collisions: it is largest for central collisions, with zero impact parameter [53]. Thick lines: Monte-Carlo Glauber model [50]; Thin lines: Monte-Carlo KLN model [52].

arXiv:1104.0650

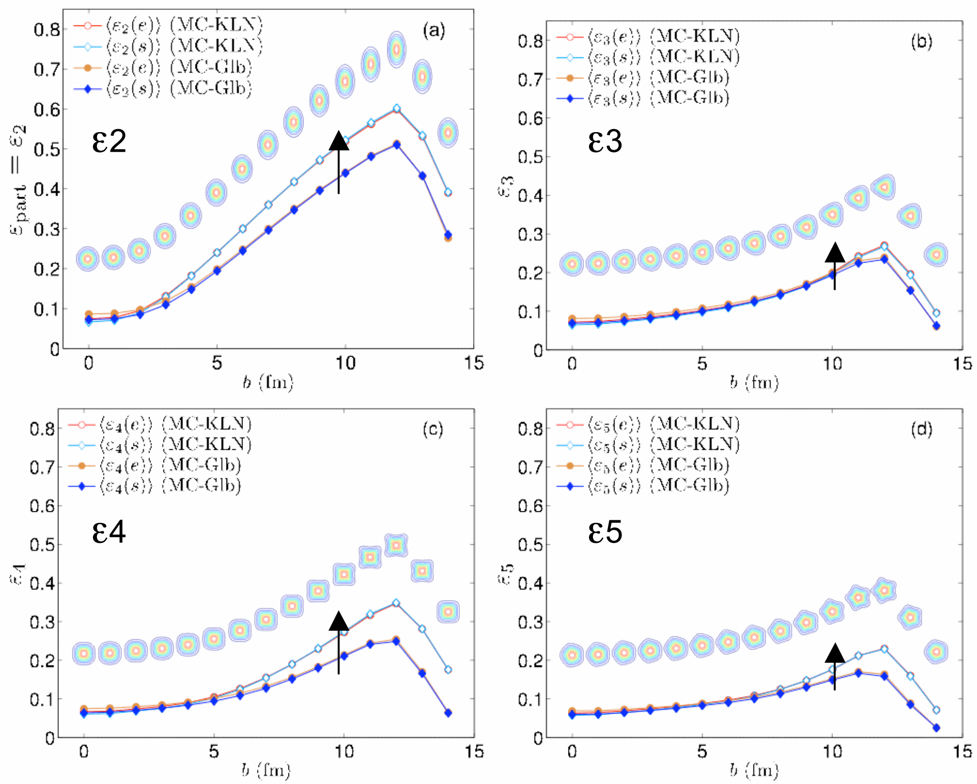
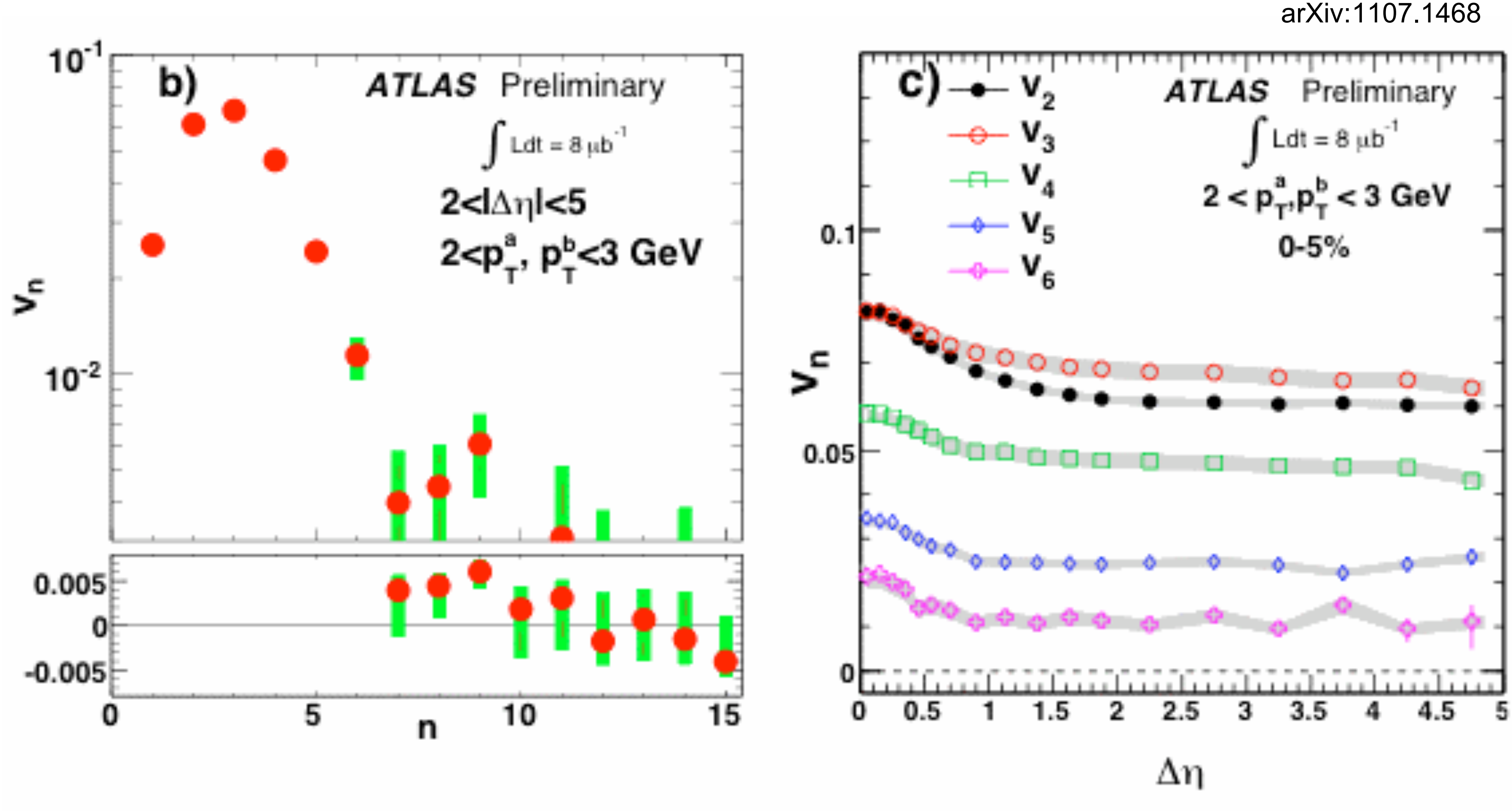


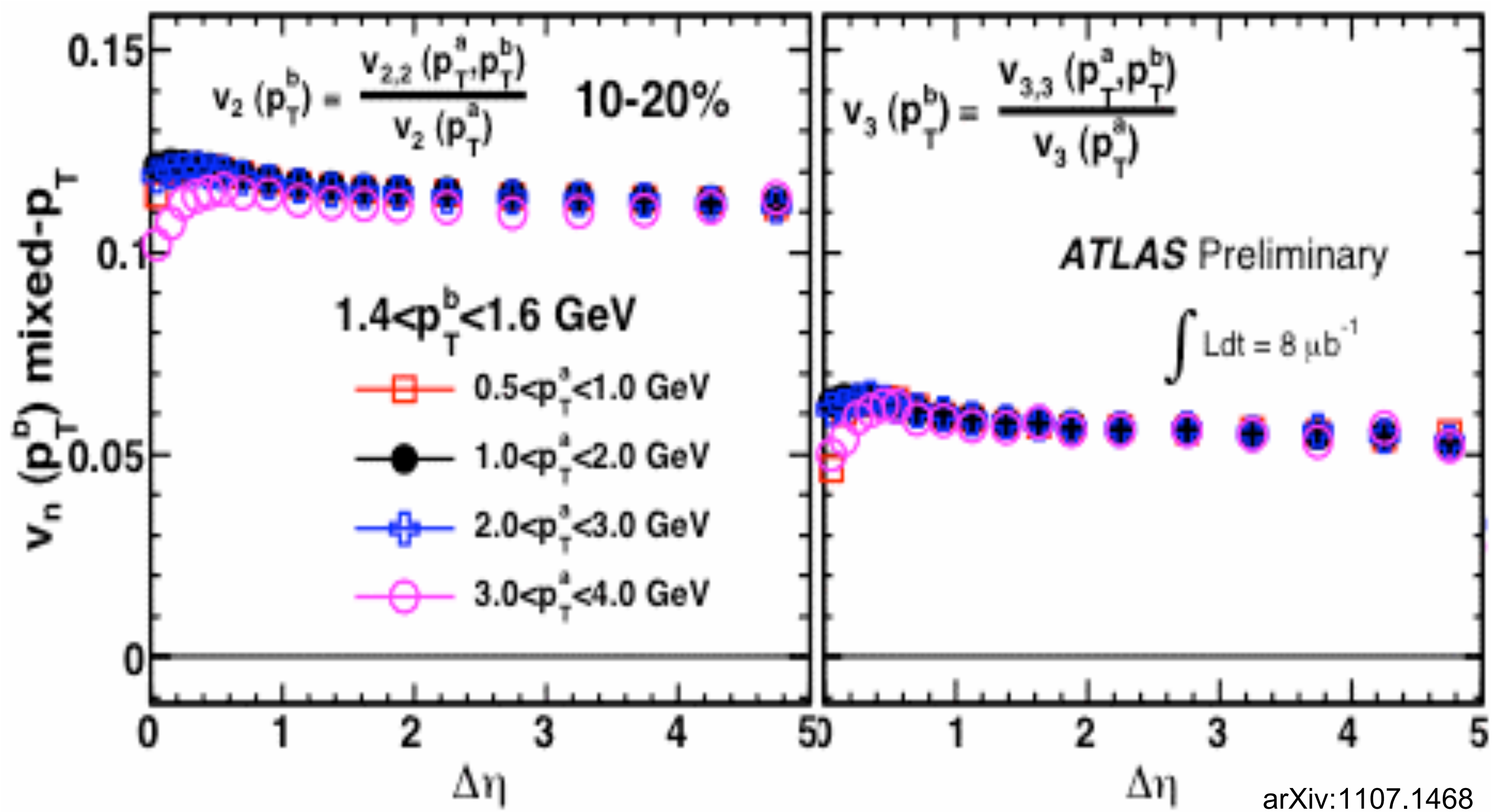
FIG. 5: (Color online) Harmonic eccentricity coefficients $\varepsilon_2 = \varepsilon_{\rm part}$ (a), ε_3 (b), ε_4 (c) and ε_4 (d) as functions of impact parameter, calculated from the MC-Glauber (filled symbols, solid lines) and MC-KLN models (open symbols, dashed lines), using the energy density (circles) or entropy density (triangles) as weight function. The contour plots illustrate deformed Gaussian profiles $e(r, \phi) = e_0 \exp\left[-\frac{r^2}{2\rho^2}(1+\varepsilon_n \cos(n\phi))\right]$, with eccentricity $\varepsilon_n(e)$ taken from the MC-KLN model at the corrsponding impact parameter.

$|\Delta\eta|$ dependence of v_n from LHC-ATLAS

arXiv:1107.1468

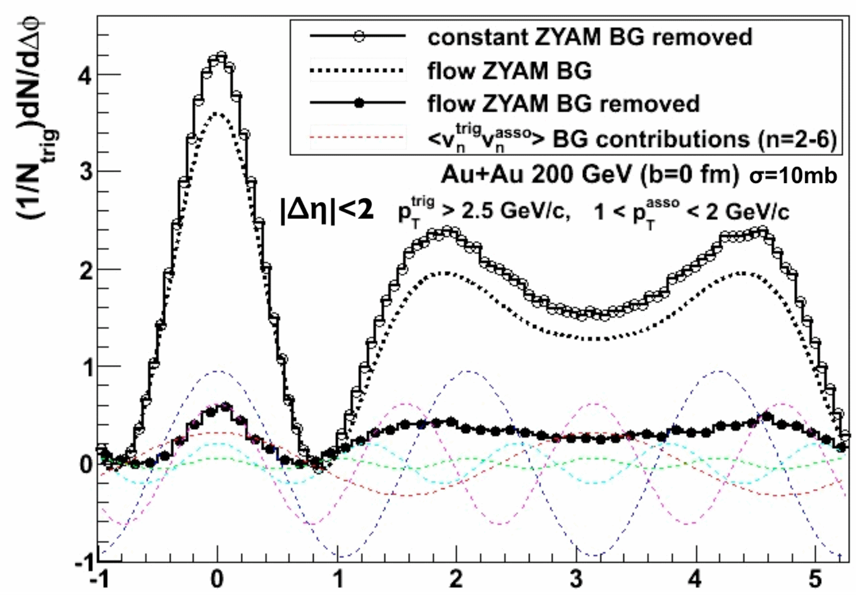


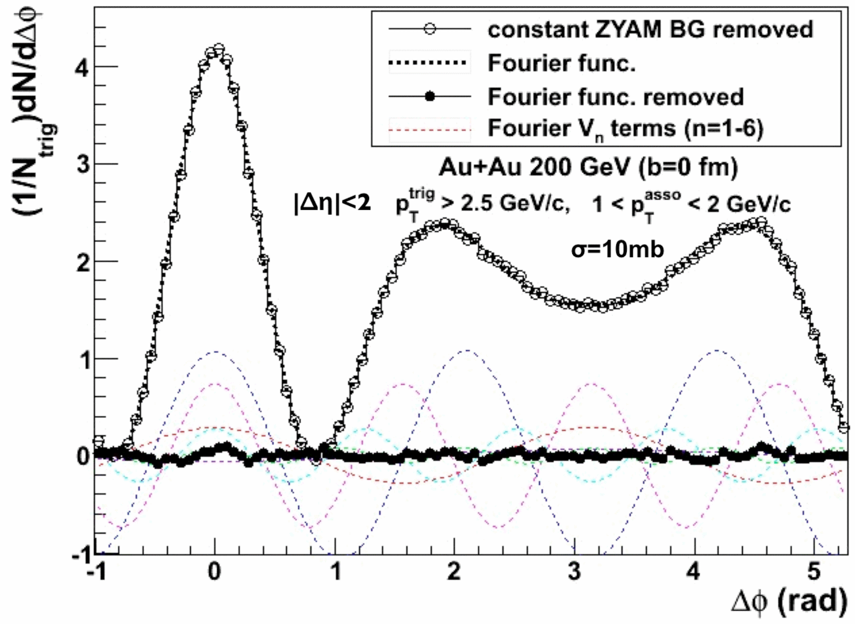
$|\Delta\eta|$ dependence of ($v_n^{trig.}$ x $v_n^{asso.}$) with $v_n\{C_2$ global fit$\}$, which they call v_n factorization in ATLAS



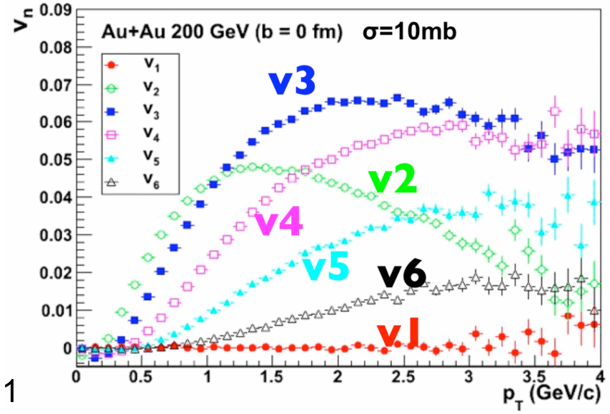
arXiv:1107.1468

AMPT correlation test shows some remaining effects

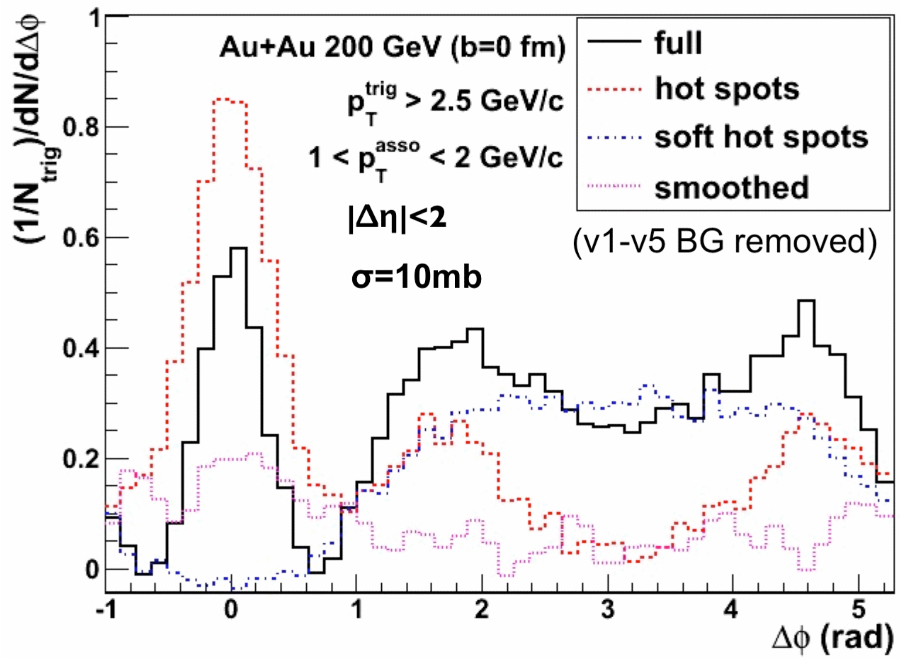




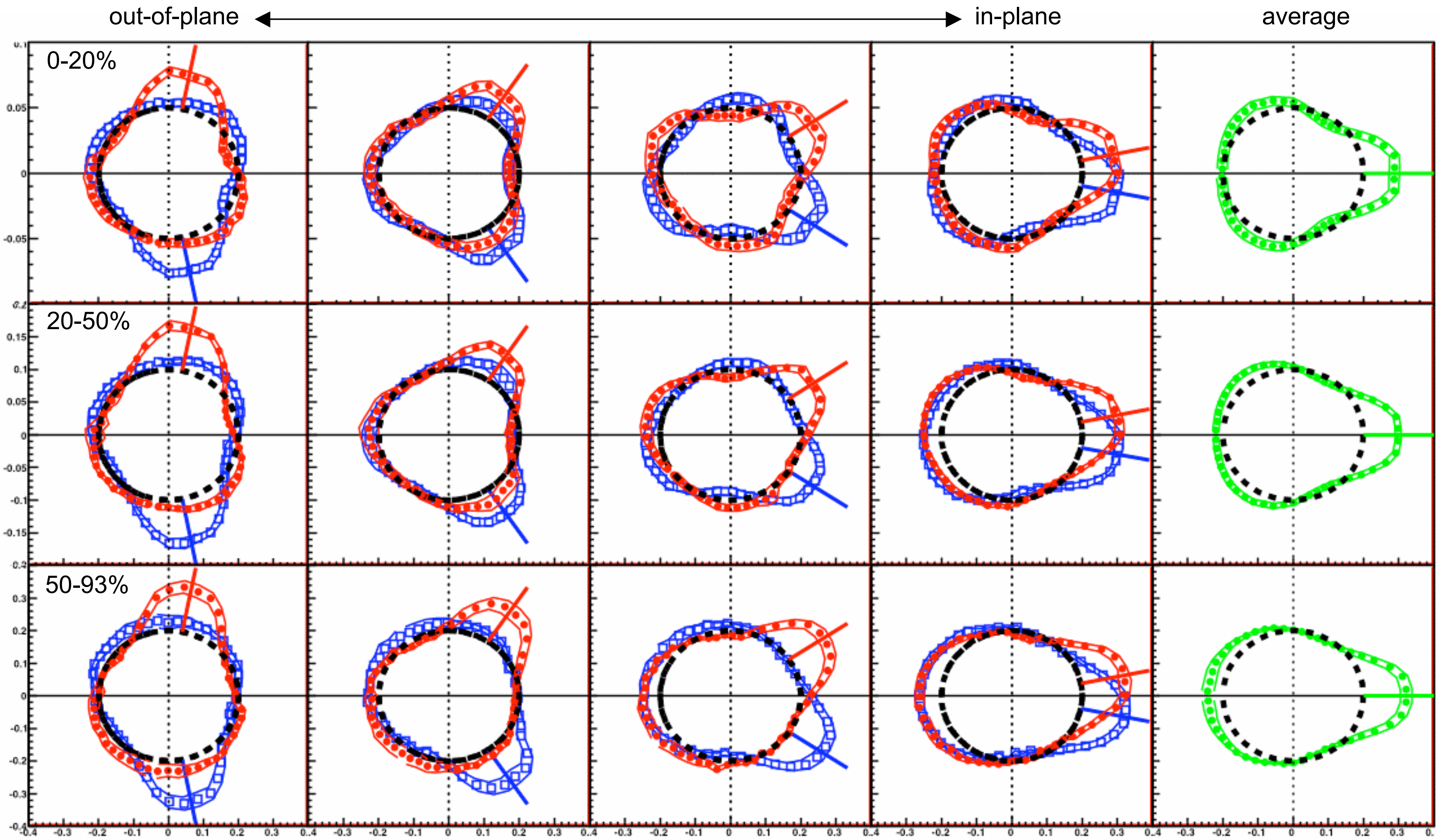
without |Δη| gap



G-L. Ma, QM11



Flow subtracted 2-particle ΔΦ correlation with trigger angle selection in 200GeV Au+Au

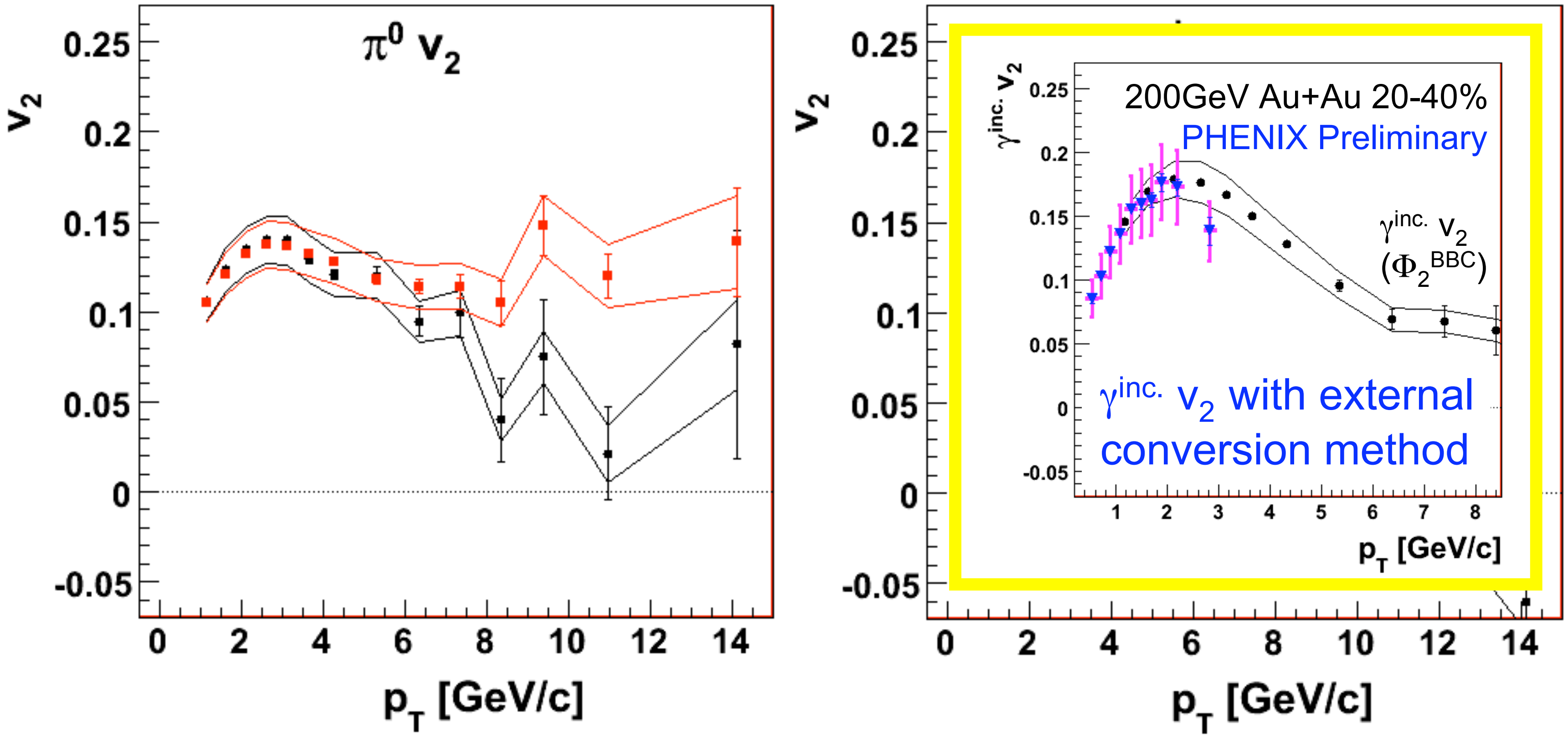


200GeV Au+Au -> h-h (p_T^{Trig}=2~4GeV/c, p_T^{Asso}=1~2GeV/c)
$v_2(v_4\{\Phi_2\})$-only subtraction **PHENIX preliminary**

Measurement of π^0 and $\gamma^{inc.}$ v_2

200GeV Au+Au (min. bias)

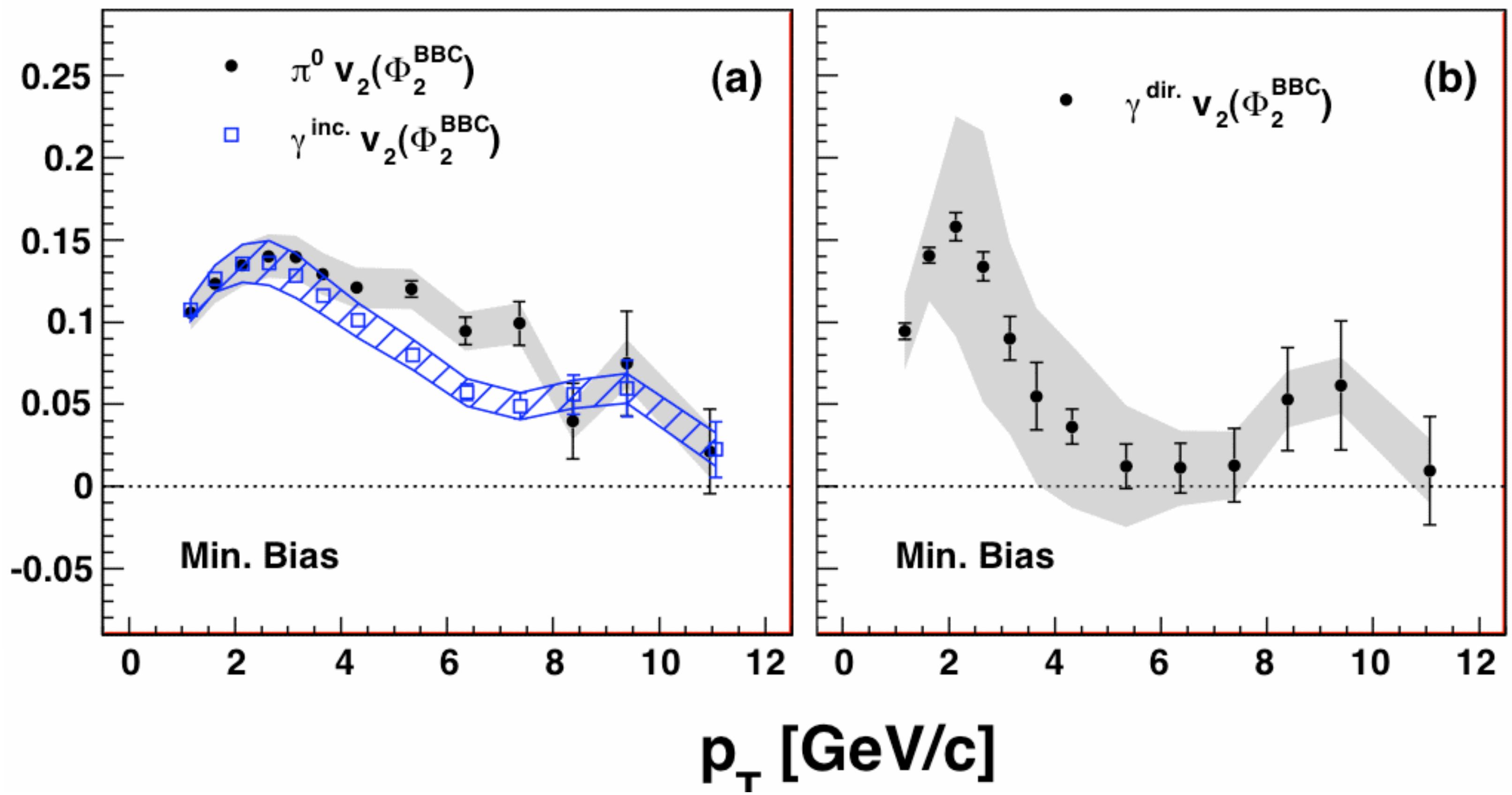
arXiv:1105.4126



significant difference between π^0 and $\gamma^{inc.}$ v_2 above 5GeV/c, difference between $v_2^{\{RXN\}}$ and $v_2^{\{BBC\}}$ due to jet bias.

$\gamma^{dir.}$ v_2 extracted from $\gamma^{inc.}$ v_2, π^0 v_2 and R_γ ratio

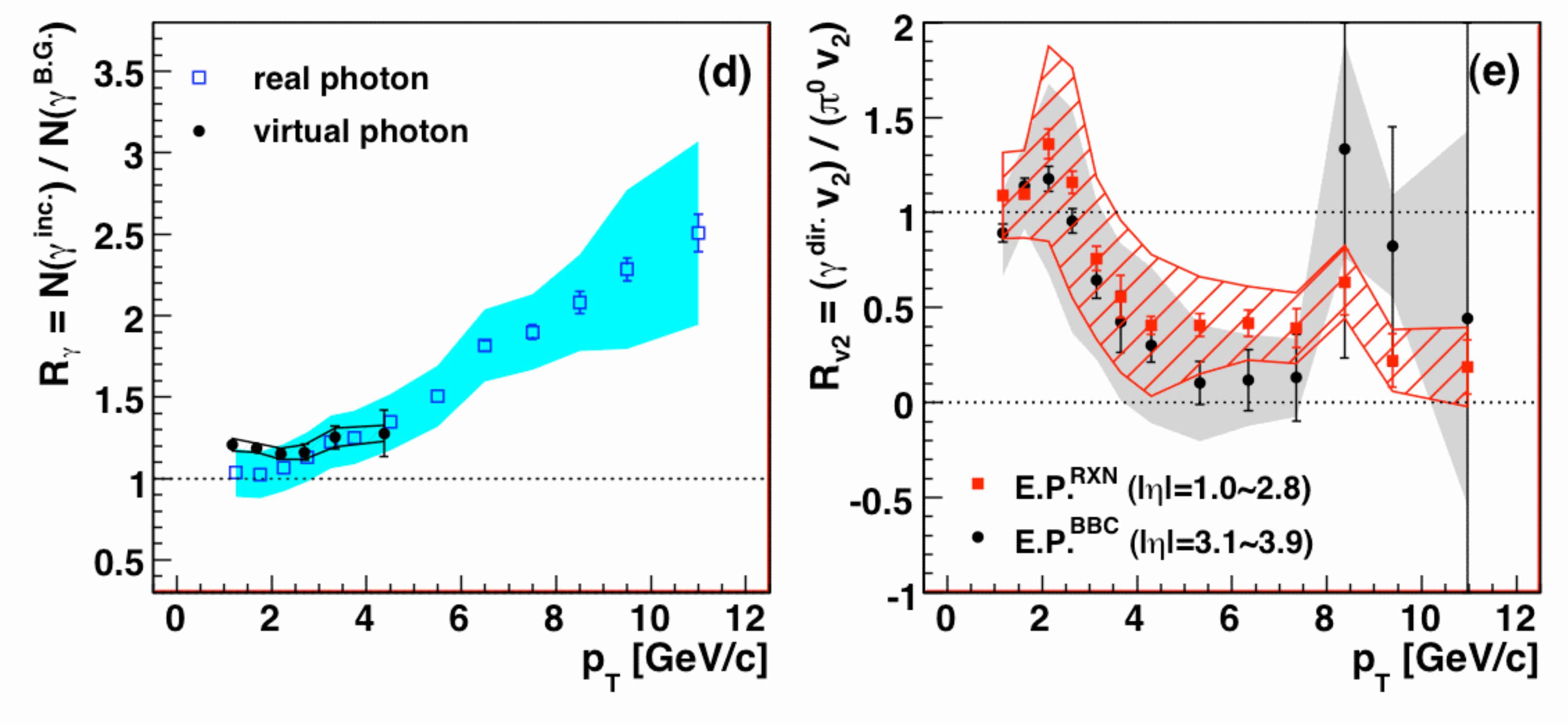
arXiv:1105.4126



R_γ ratio and v_2 ratio

200GeV Au+Au (min. bias)

arXiv:1105.4126

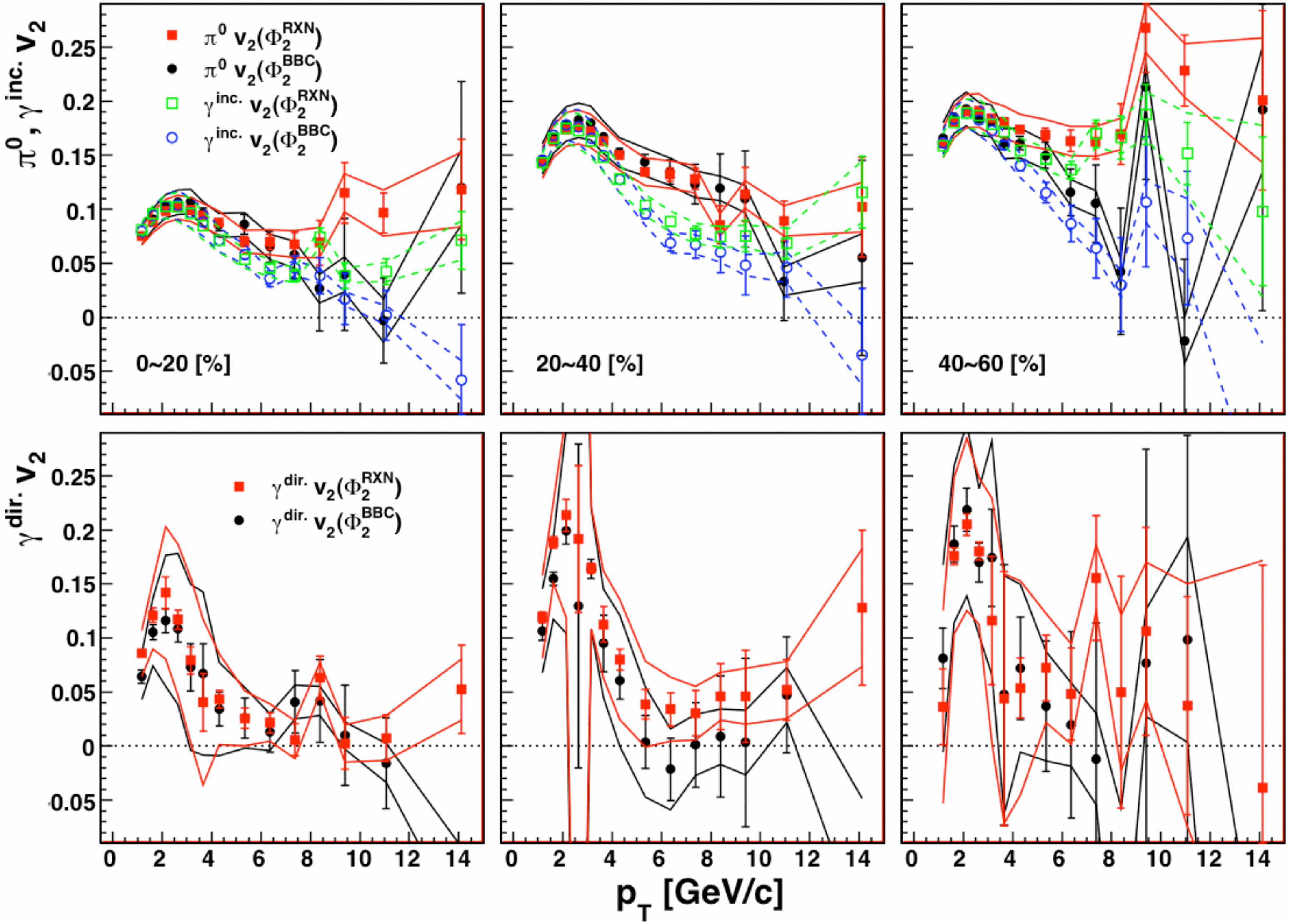


$\gamma^{dir.}$ v_2 is small at high p_T ---> consistent with prompt photon

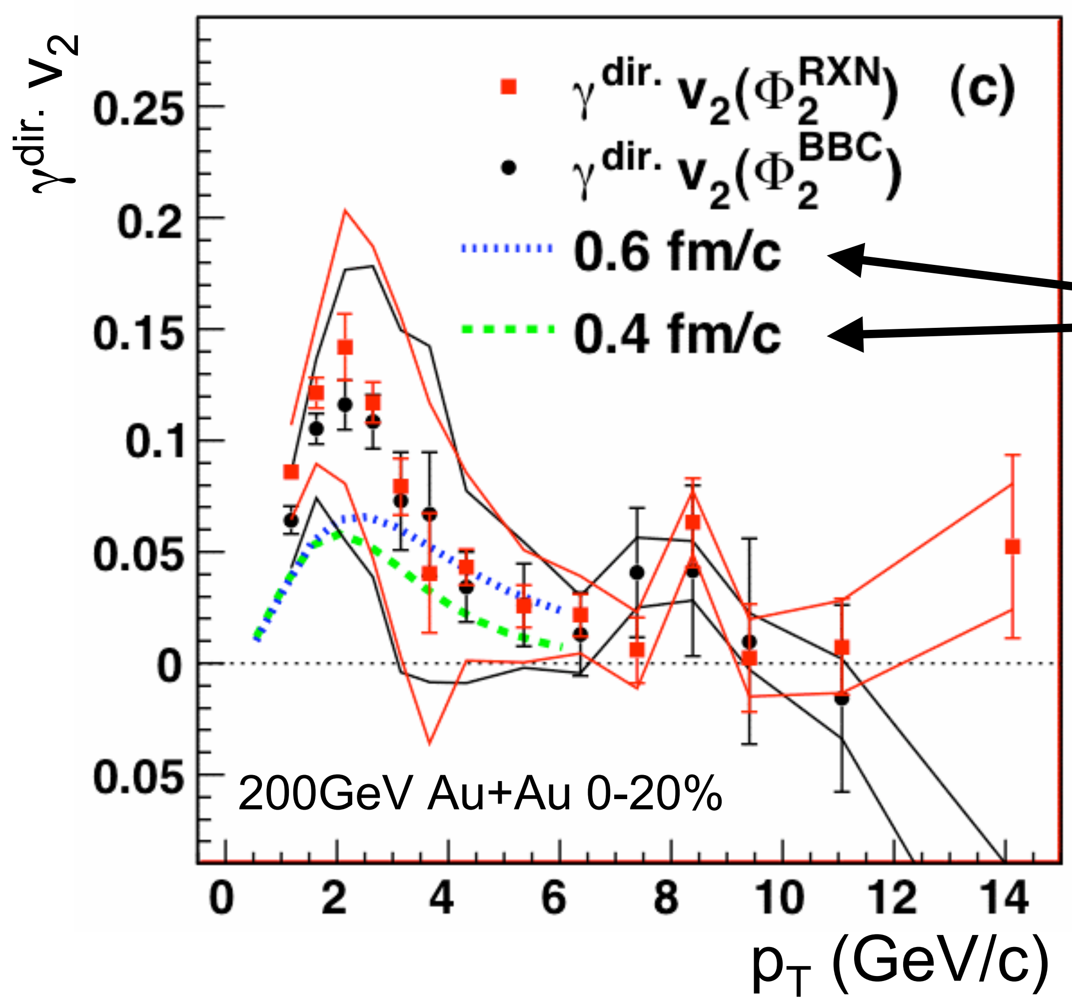
surprisingly large $\gamma^{dir.}$ v_2 seen, similar to hadron v_2 at low p_T.

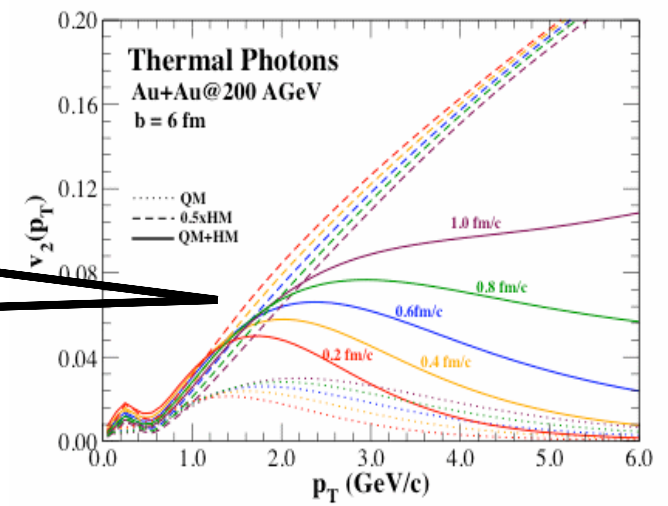
Centrality and p_T dependences of $\gamma^{inc.}$ v_2, π^0 v_2 and $\gamma^{dir.}$ v_2

arXiv:1105.4126



Comparison of $\gamma^{dir.}$ v_2 with model calculations





R. Chatterjee and D. K. Srivastava
PRC 79, 021901(R) (2009)
PRL96, 202302 (2006)

Several models have failed in v_2 magnitude with similar shape

Large v_2 of low p_T thermal photon
--> challenge to theory calculations