Centrality Dependence Of Soft Photon Production and Its Collective Flow in Au+Au Collisions At $\sqrt{s_{NN}}$=200GeV

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XXIV QUARK MATTER
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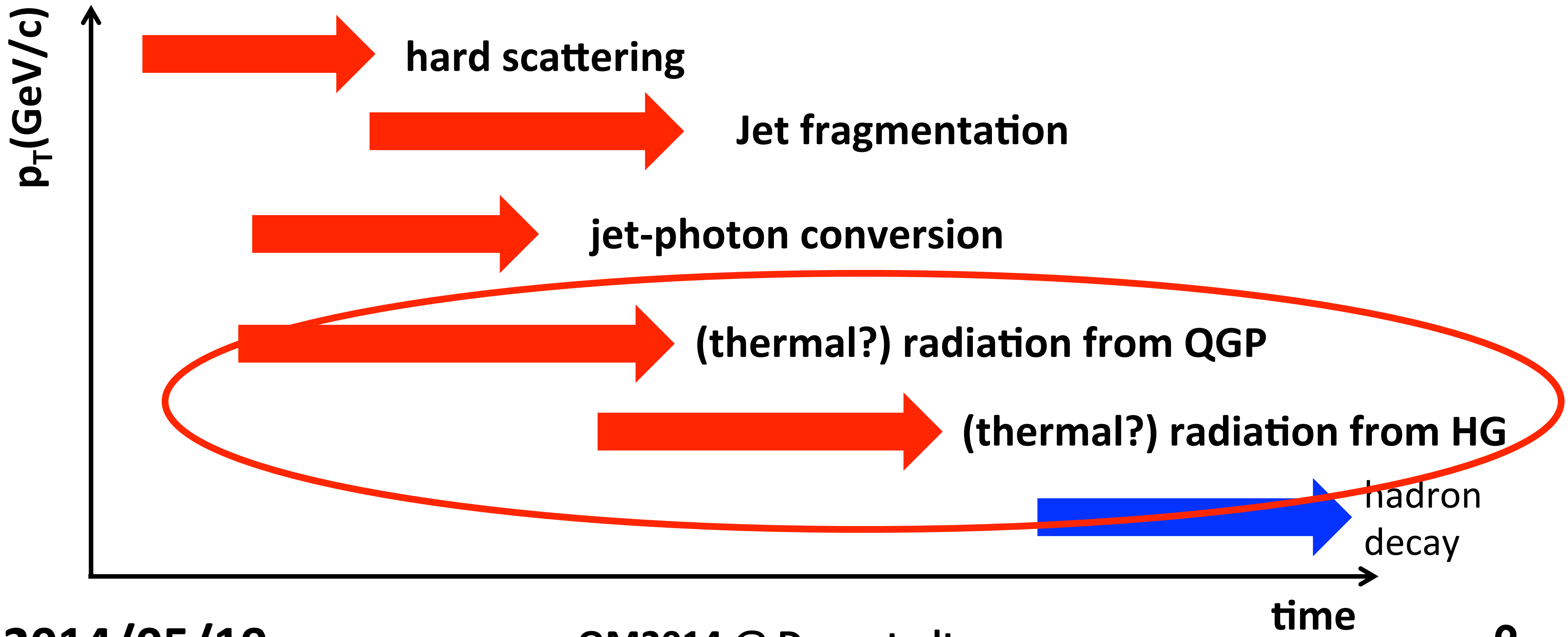
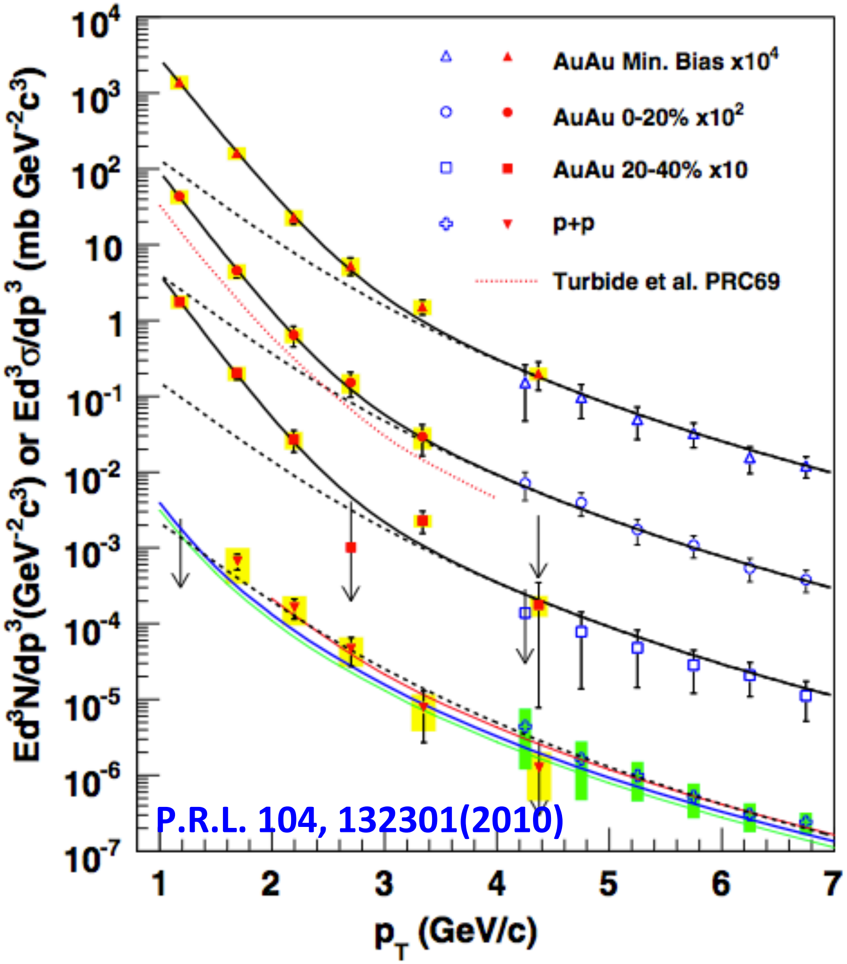
What are direct photons ?

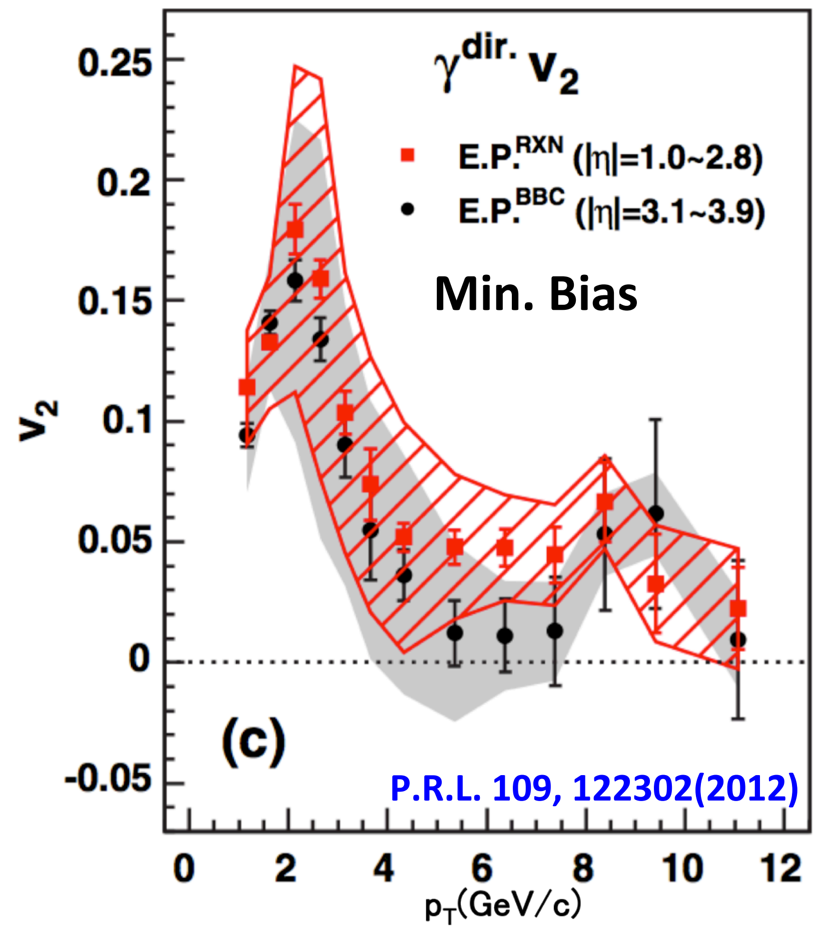
Direct photons: all photons except those coming from hadron decays.

- **Good probe since they penetrate the QGP**
- **Created during all stages of the collision**



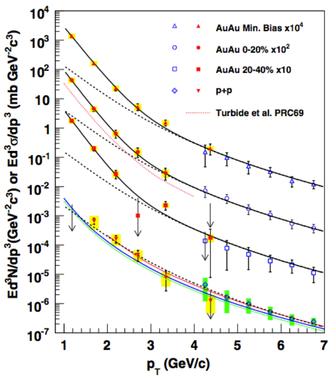
Previous soft photon results from PHENIX

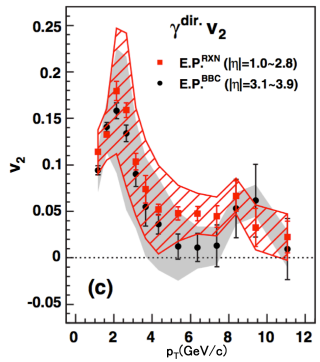




There is a large excess with respect to scaled p+p, and very large flow in the 1-4 GeV/c region.

Direct photon puzzle



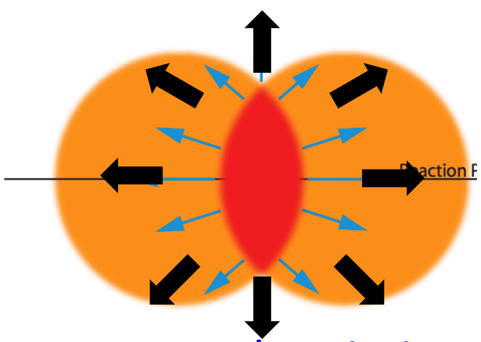


Yield enhancement

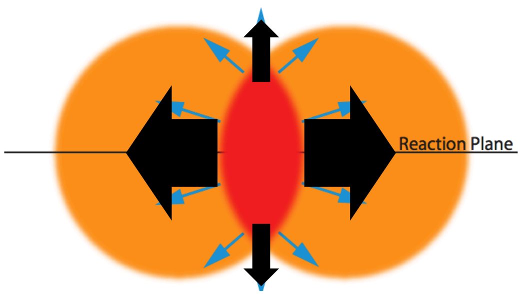
Suggests early emission when temperature is high at or above 300MeV

Large elliptic flow (v_2)

Suggests late emission, when temperature is low, collective motion is large



Integrated emission



differential emission

It is a challenge for models to explain simultaneously the excess of direct photon yield and the large elliptic flow (v_2).

Motivation

To resolve the puzzle and constrain photon production mechanisms, more differential measurements are needed.

- **Complete centrality dependence**
- **Higher order azimuthal anisotropy**

In this talk, we'll extend earlier (published) centrality selections both for yields and v_2, and show new results for v_3 and v_2/v_3.

Centrality dependence of the $\gamma^{dir.}$ yield

Photons by external conversion

M_{HBD}: Real track
M_{vtx} : Measured track

Published

Real photons in EMCal : 1 - 20 GeV/c
large errors at low p_T (resolution, contamination)
Virtual photons from e^+e^- : 1 - 4 GeV/c

New method

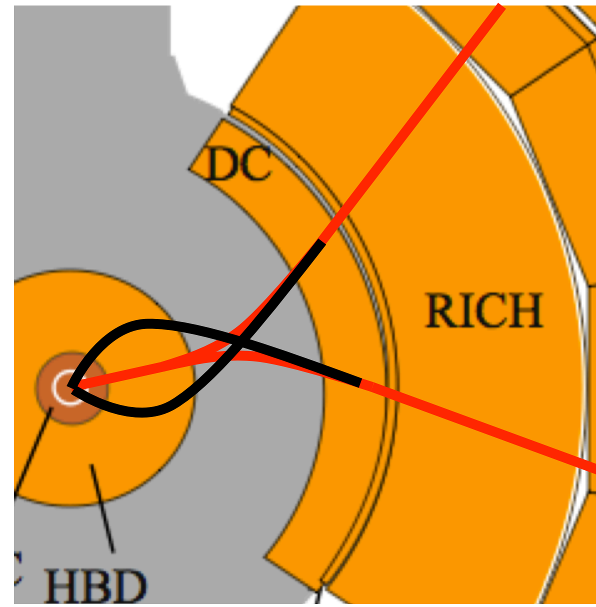
Real photons are measured by e^+e^- pair from **external photon conversion** at the HBD readout plane.

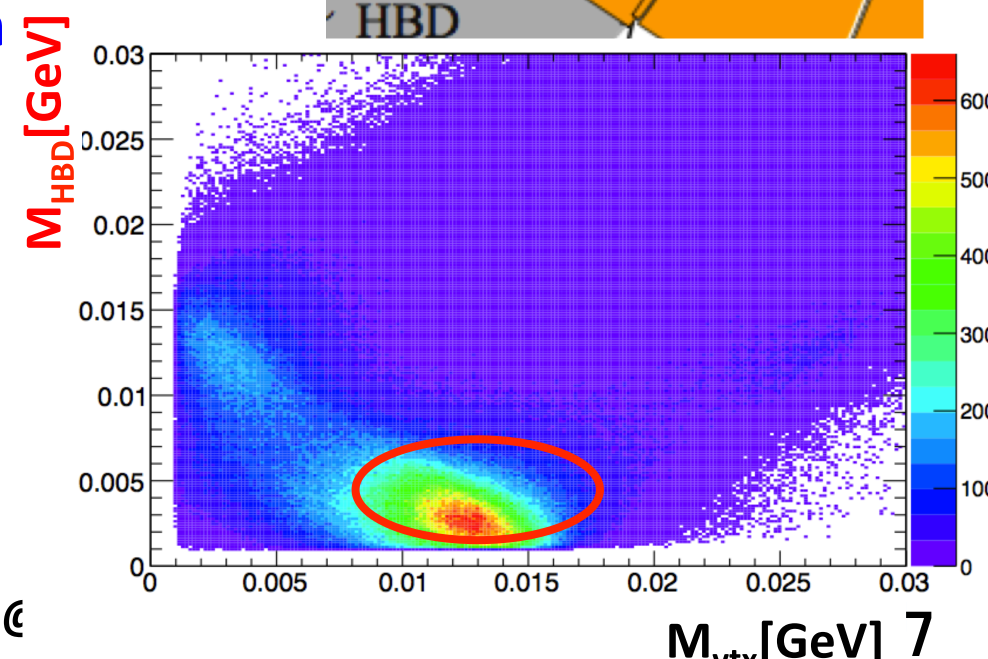
✓ less hadron contamination
✓ good momentum resolution

p_T range : **0.4 ~ 5GeV/c**

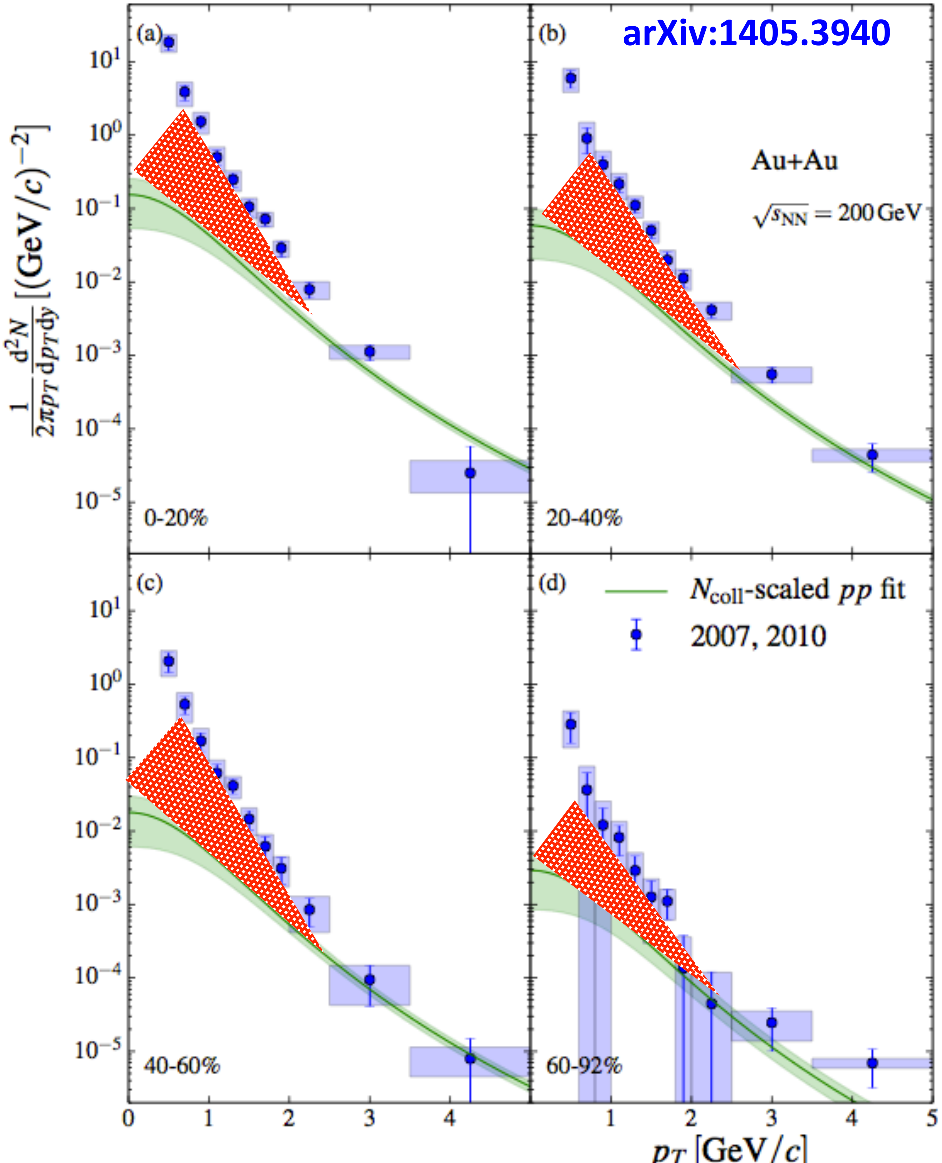
Extended to lower p_T

low statistics





Enhancement of the direct photon yield



The yields from p+p data are fitted by

$$a(1+\frac{p_T}{b}^2)^c$$

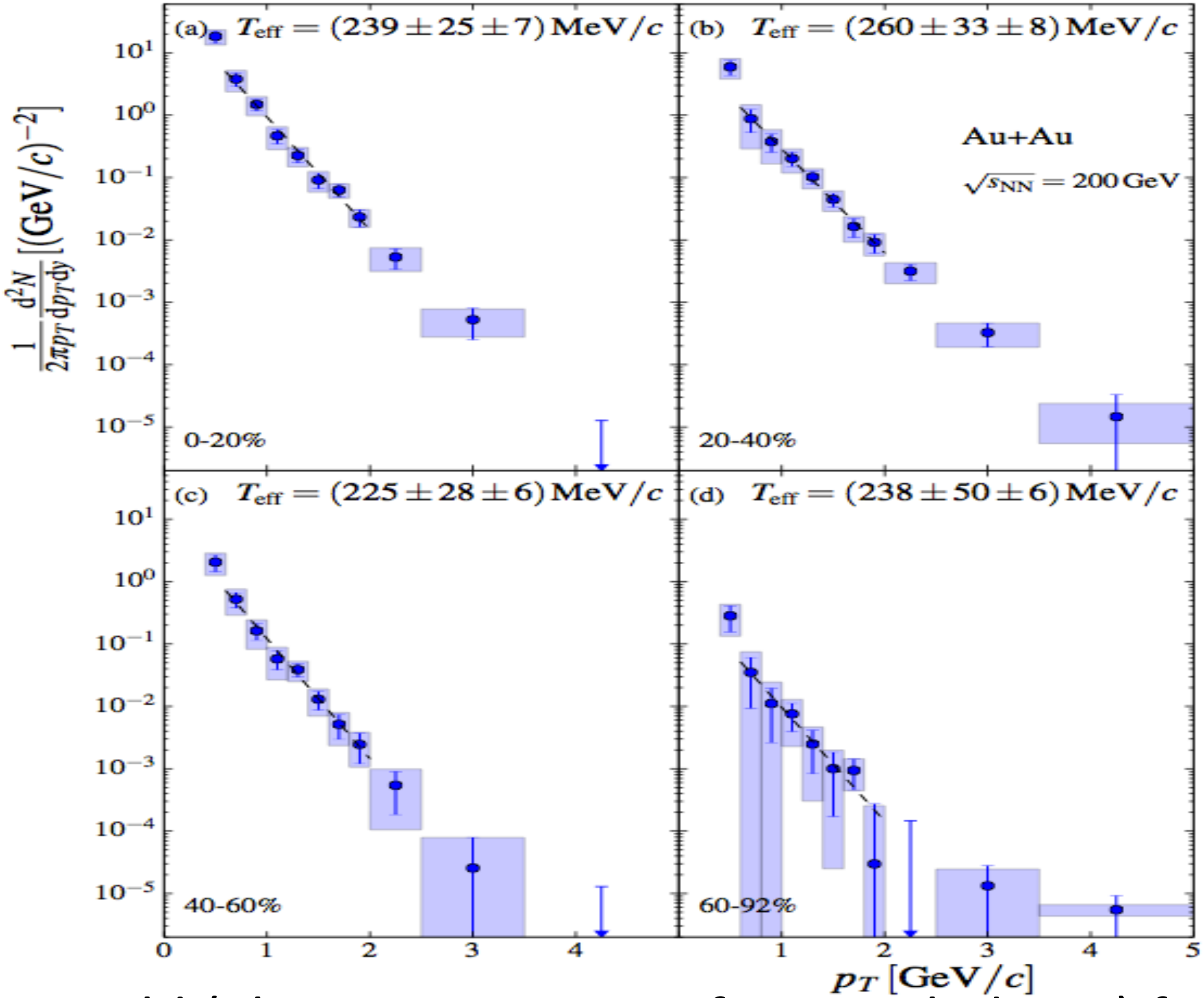
extrapolated below 2 GeV/c.

$$T_{AA} = < N_{coll} > / \sigma_{pp}$$

Compared with a green line which is expected from p+p data, **enhancements** are observed.

Excess photon yield

arXiv:1405.3940

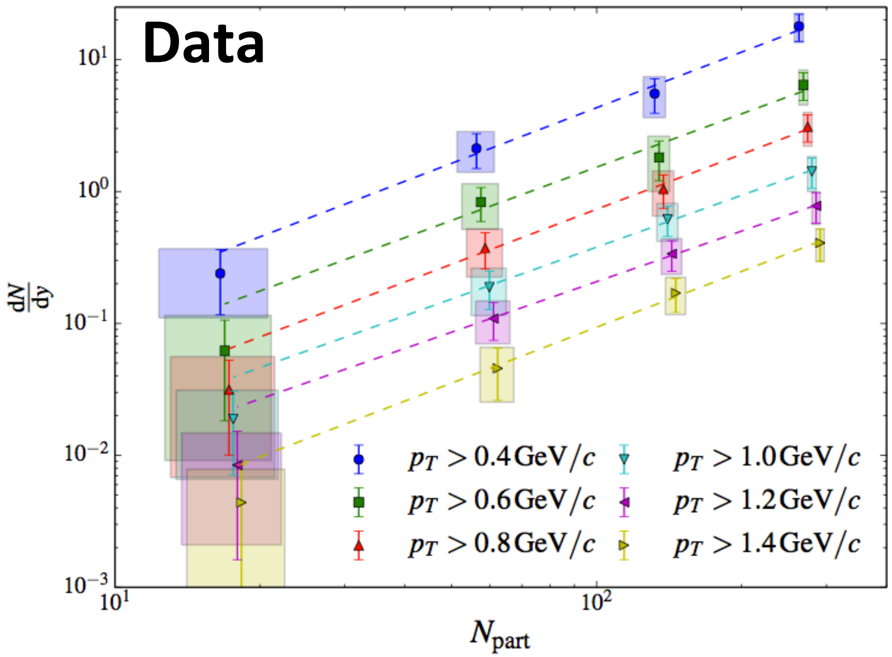


$$Ae^{-p_T/T_{eff}}$$

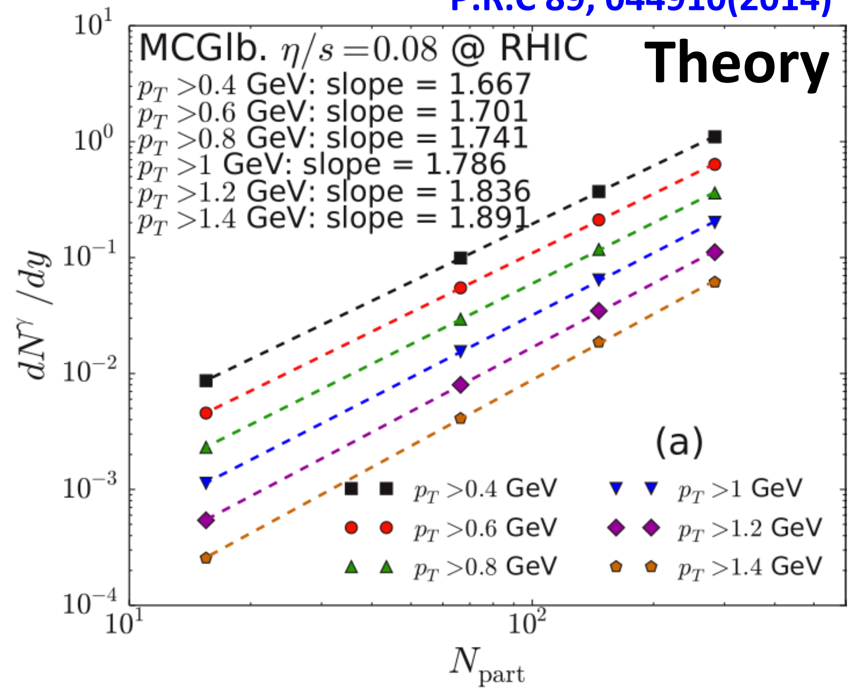
Excess yield (above expectation from scaled p+p) fitted with an exponential. The slopes are comparable within uncertainties.

Centrality (N_{part}) dependence of the yield

arXiv:1405.3940



P.R.C 89, 044910(2014)



Excess of photon yield increases with power-law function, $F = AN_{part}^{\alpha}$

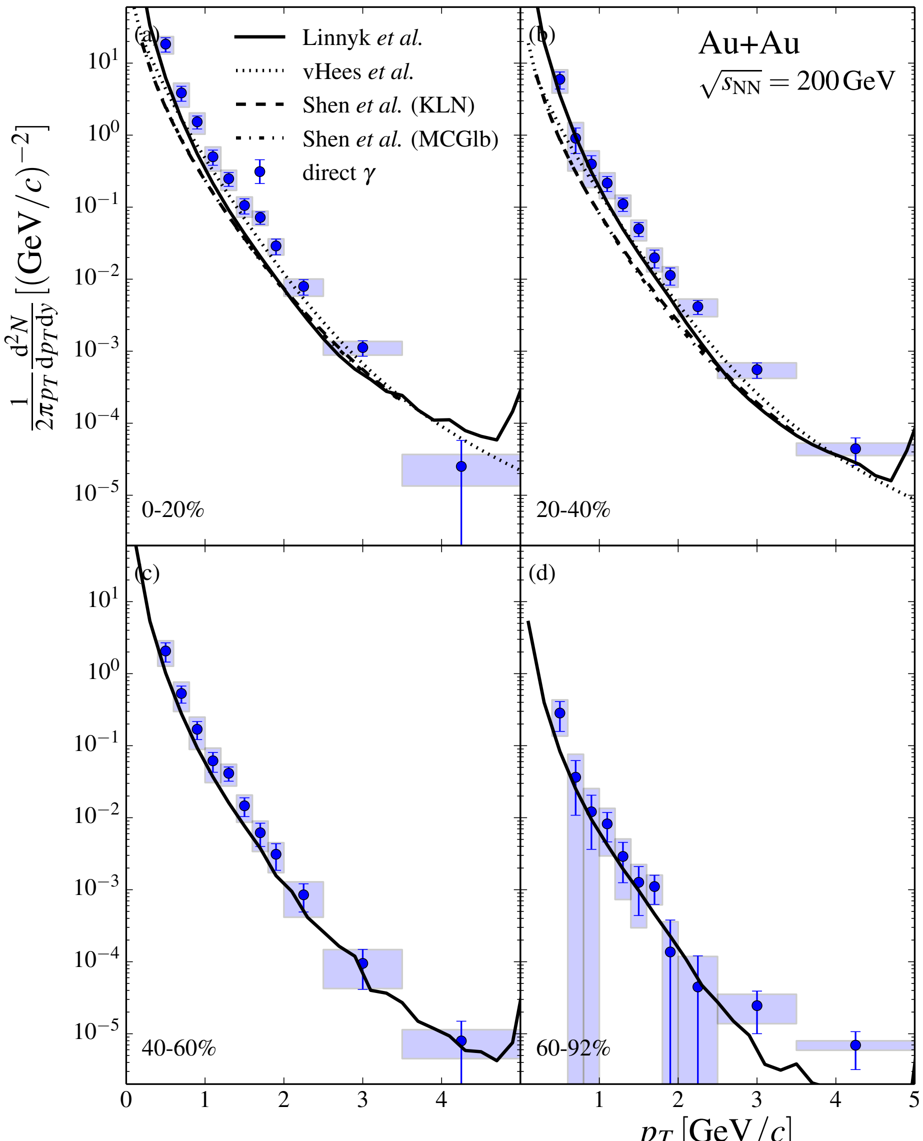
α=1.48±0.08(stat.)±0.04(sys.) ≈ 3/2

The centrality dependence is not an artifact of the very low p_T points:
same slope as we increase lower limit of integration
(upper limit is always 2GeV/c).

The shape of direct photon p_T spectra doesn't depend on centrality.

Yield: data vs theories

arXiv:1405.3940



Linnyk et al.: PHSD transport model; Linnyk, Cassing, Bratkovskaya, P.R.C 89, 034908(2014)

vHees et al.: Fireball model; van Hees, Gale, Rapp; P.R.C 84, 054906(2011)

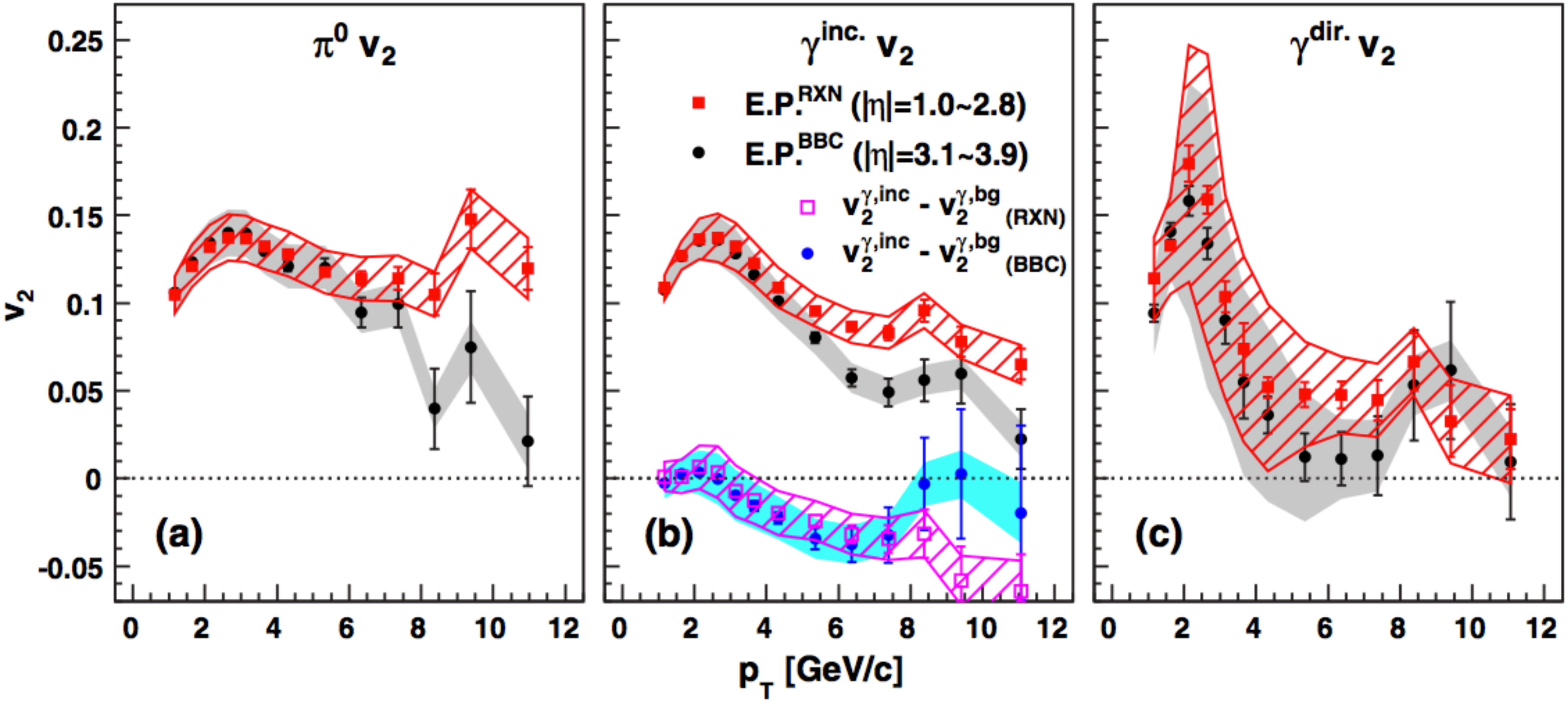
Shen et al.: Ohio hydro for two different initial conditions; Shen, Heinz, Paquet, Gale; P.R.C 84, 064903(2014)

The yield itself is still not perfectly described.

$\gamma^{dir.}$ Azimuthal anisotropy

Flow measurement: the method

P.R.L. 109, 122302(2012)



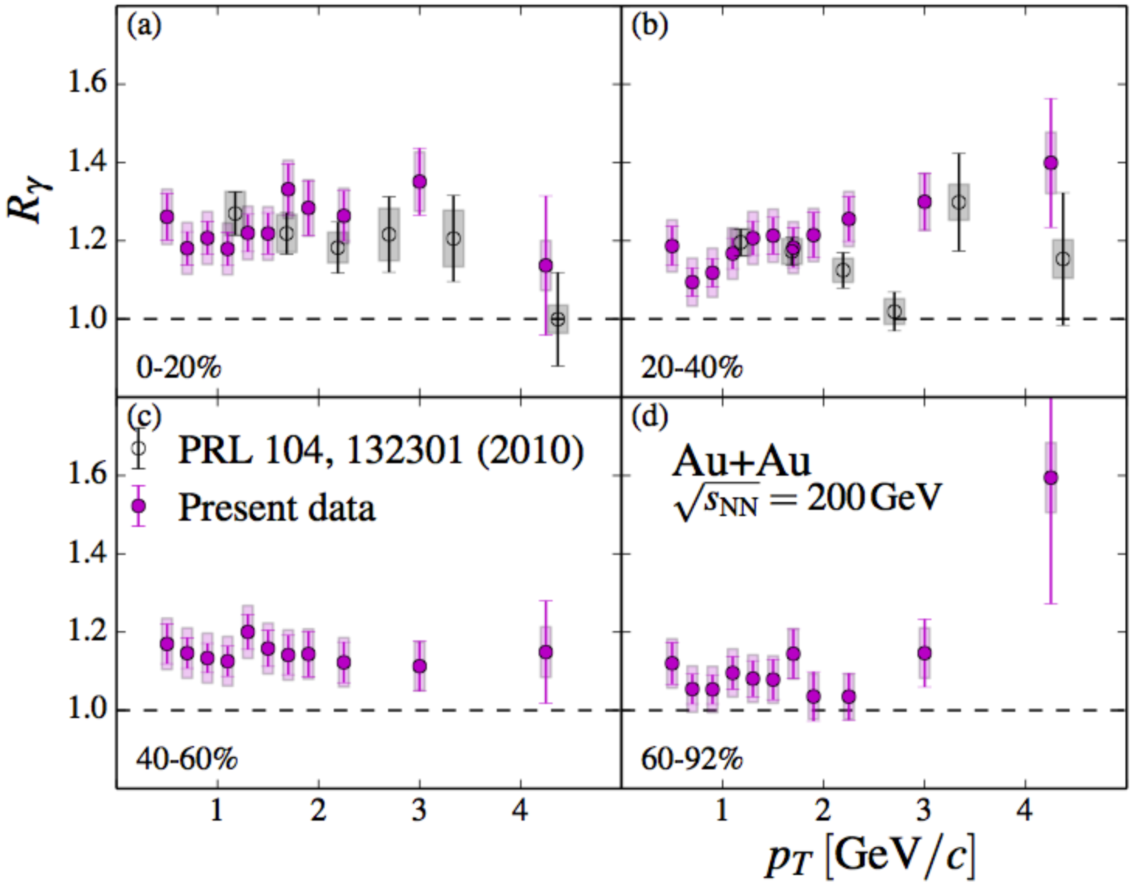
The magnitude of the direct photon v_2 is comparable to the hadron (and hadron decay photon) v_2.

$$\nu_n^{dir.} = \frac{R_\gamma \nu_n^{inc.} - \nu_n^{dec.}}{R_\gamma - 1}$$

Therefore, R_γ is a crucial component.

R_γ measured by real and virtual photons

arXiv:1405.3940



P.R.L. 104, 132301(2010)
virtual photon analysis

Present data
external conversion analysis

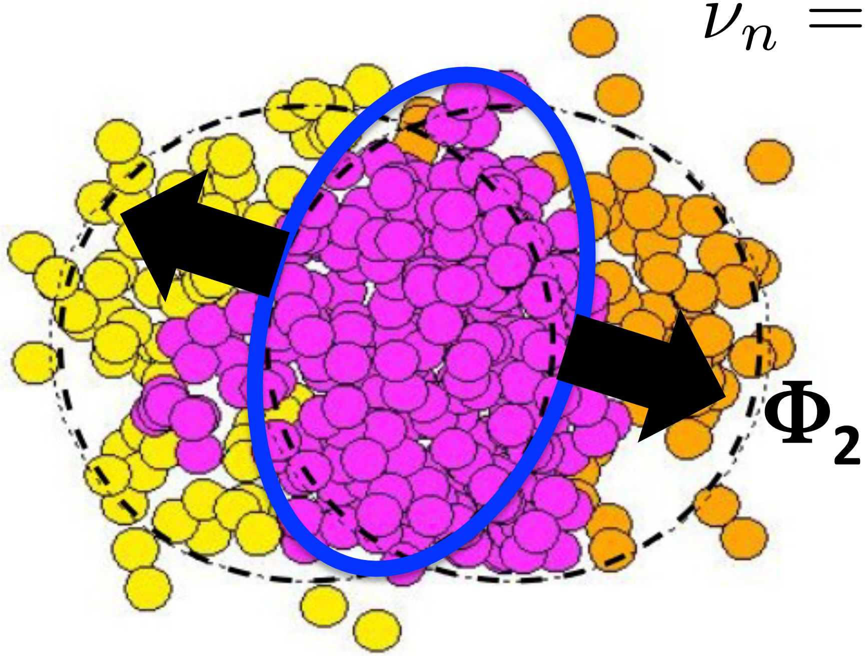
$$R_\gamma = N_{inc.}/N_{dec.}$$

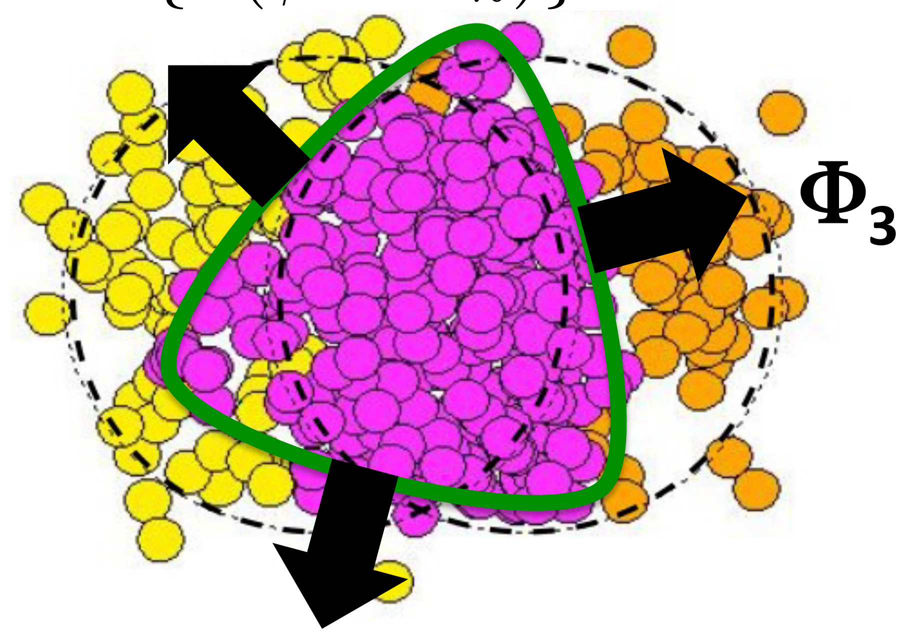
R_γ measured with real (conversion) photons is consistent with the earlier virtual photon measurement.

Higher order azimuthal anisotropy

$$\frac{dN}{d(\phi - \Psi_n)} = N_0[1 + 2\sum_{n=1}^{\infty} v_n cos\{n(\phi - \Phi_n)\}]$$

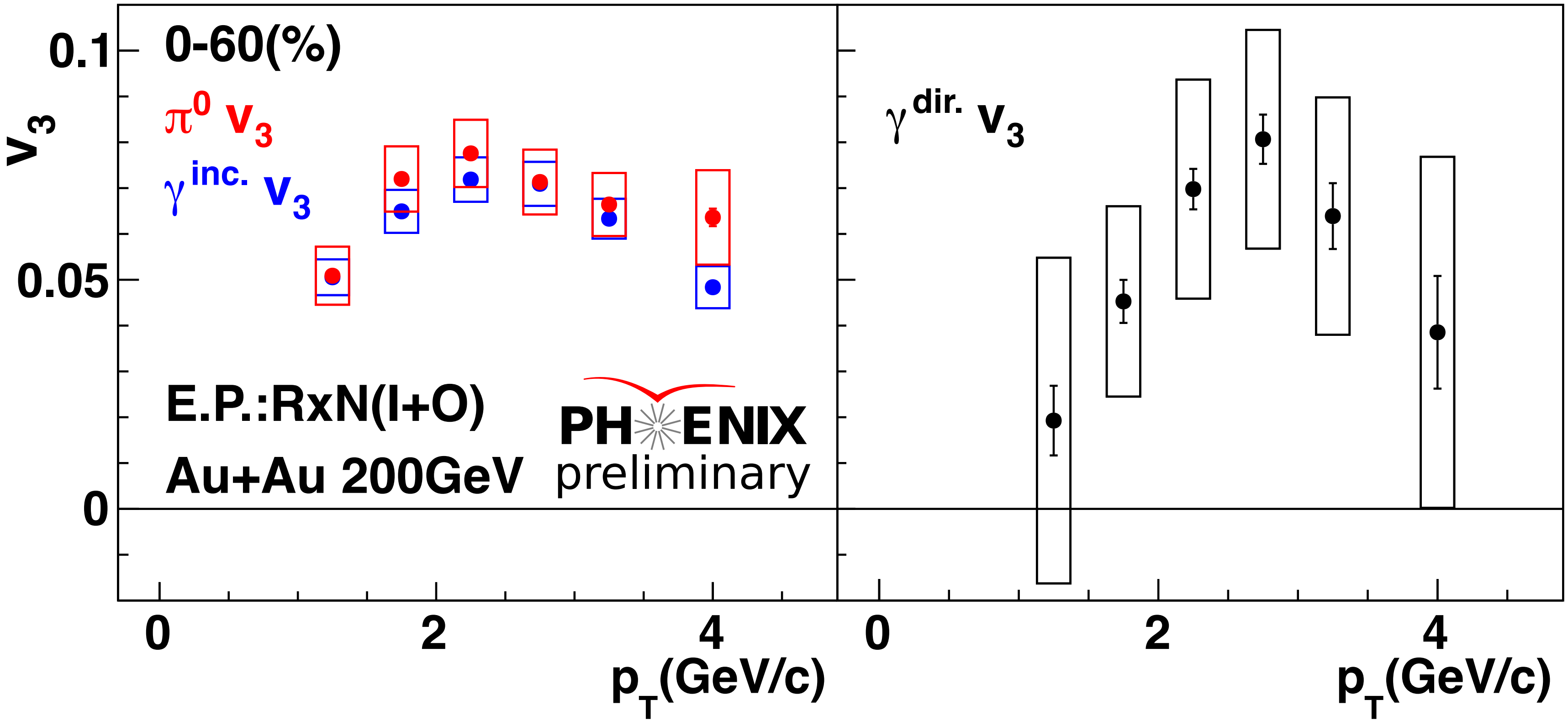
$$\nu_n =< cos\{n(\phi - \Phi_n)\} >$$





Dominant component is v_2;
v_3 comes from participant fluctuations, viscosity dampens higher order terms.

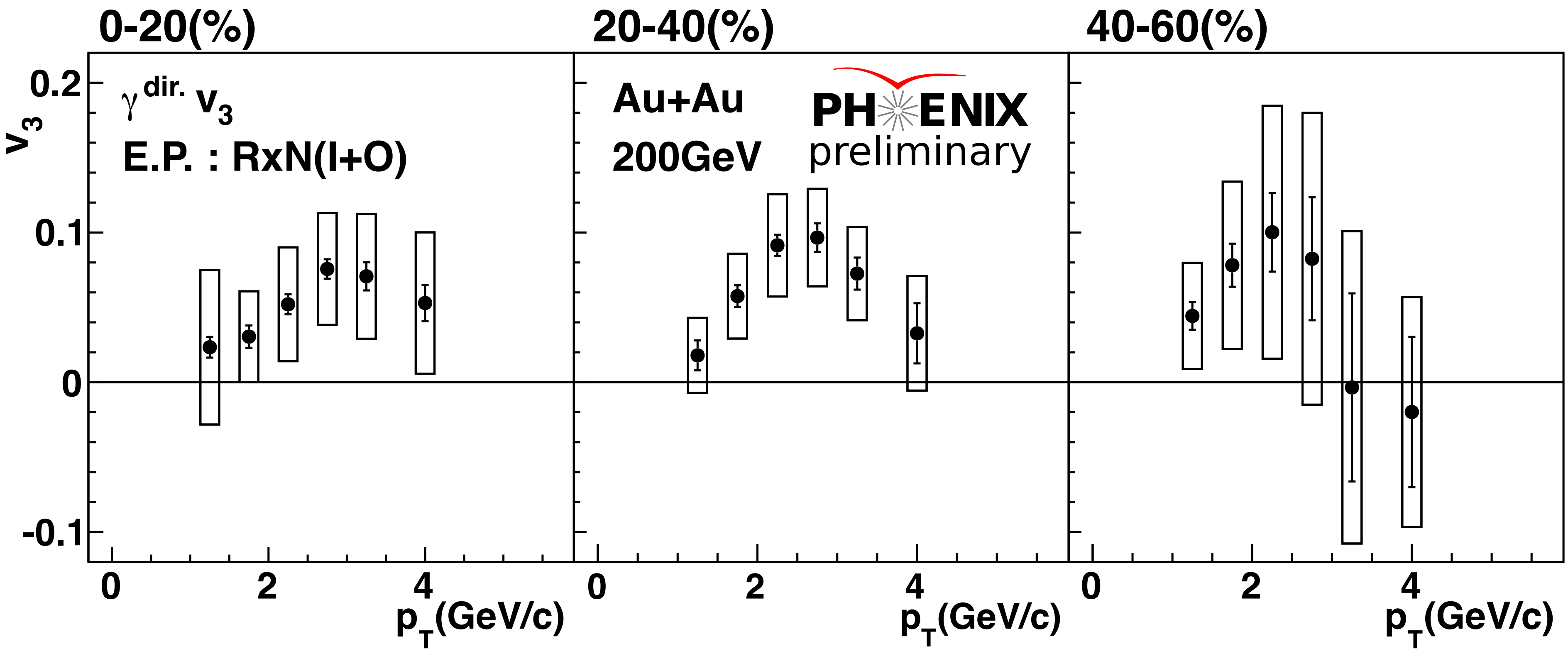
$\gamma^{dir.}$ v_3 measurement



The magnitude of $\gamma^{dir.}$ v_3 is similar to π^0, a similar trend as a seen in case of v_2.

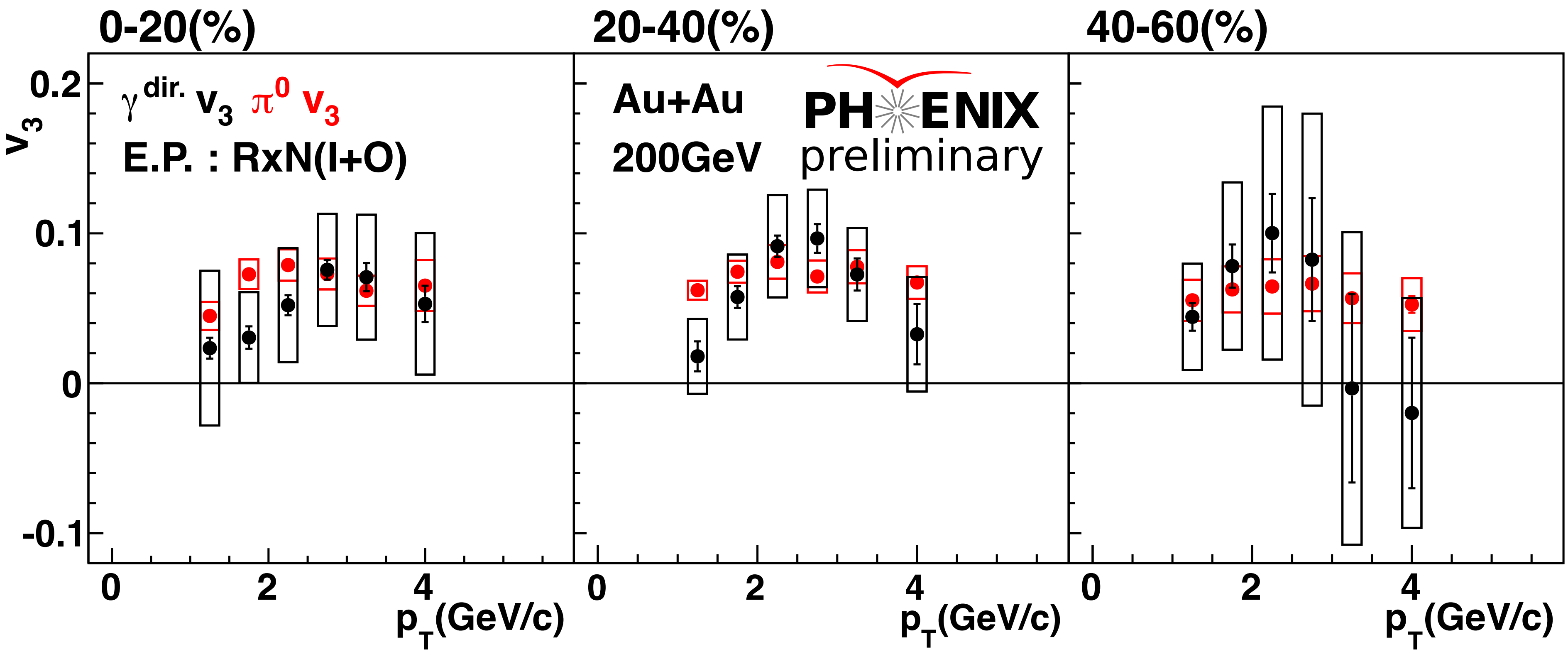
Photon azimuthal asymmetries may be affected by expansion of QGP.

Centrality dependence of $\gamma^{dir.}$ v_3



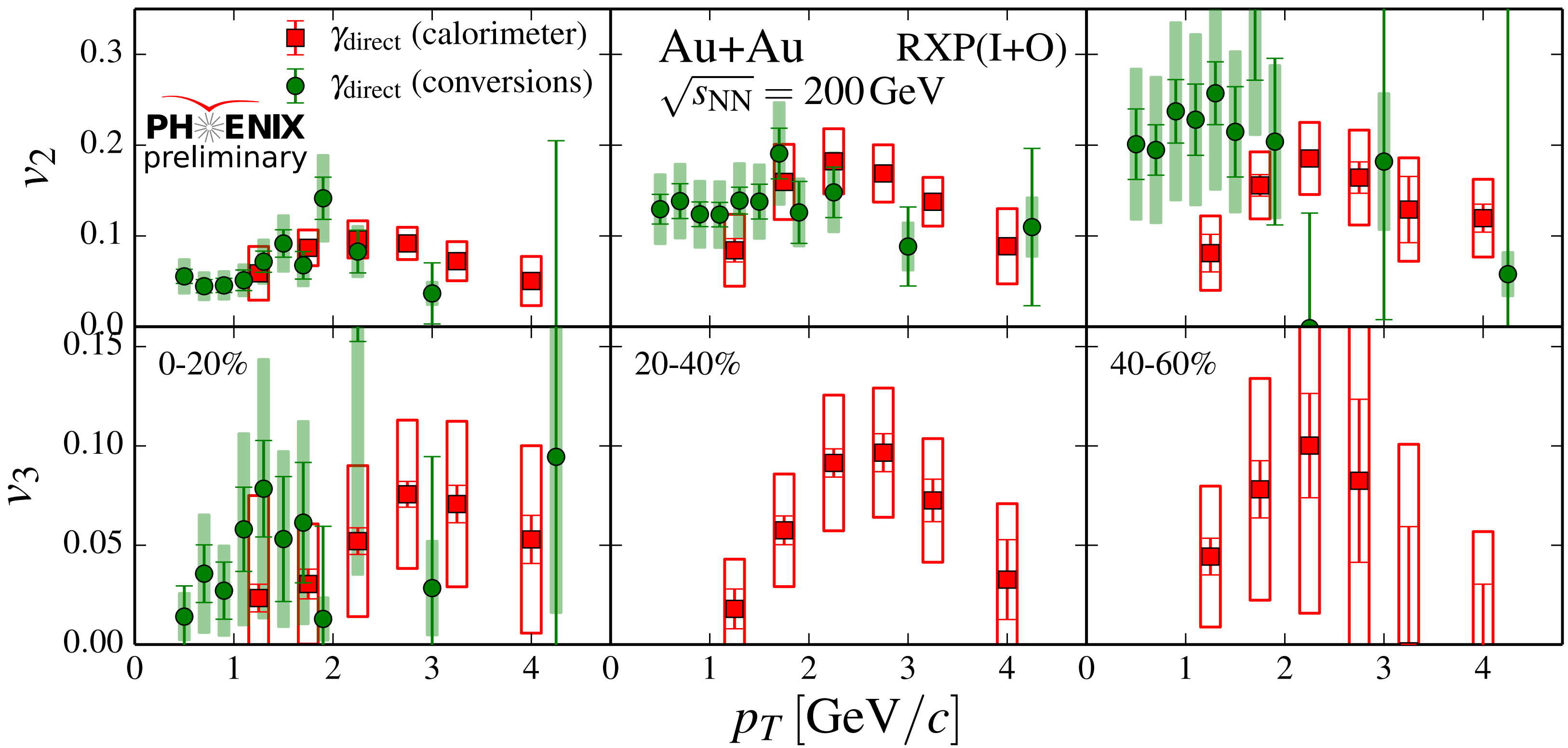
η range of RxN(I+O) is from 1.0 to 2.8.
Non-zero, positive v_3 is observed in all centrality bins.
No strong centrality dependence: similar tendency as for charged hadrons (P.R.L. 107, 252301 (2011)) and π^0.

$\gamma^{dir.}$ and π^0 v_3 show similar trend



The centrality (in)dependence of $\gamma^{dir.}$ v_3 is also observed for π^0 v_3.

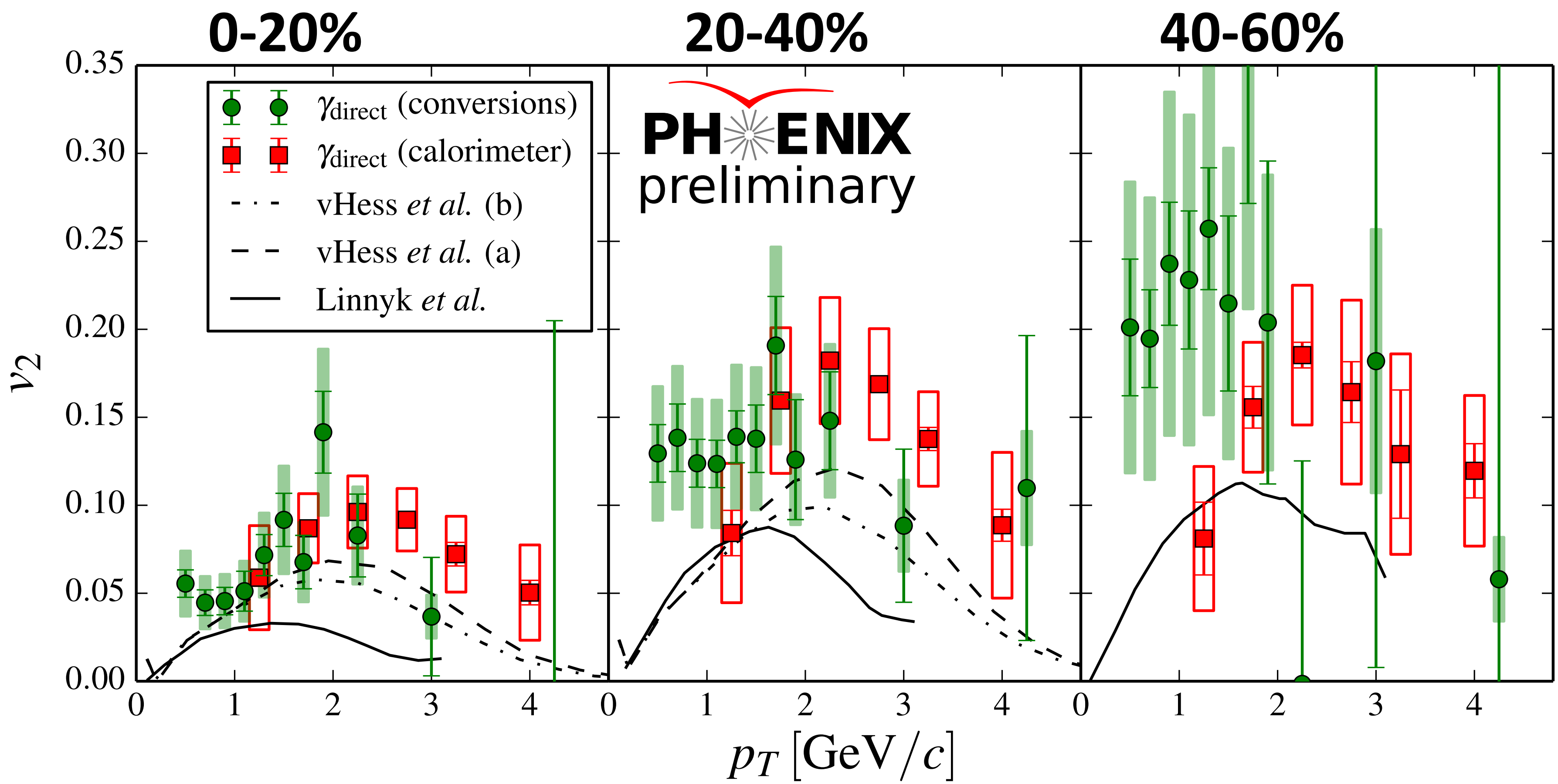
Comparison of $\gamma^{dir.}$ v_n with the two methods



The calorimeter and conversion photon measurements are consistent within systematic uncertainty.

$\gamma^{dir.}$ v_n are extended to lower p_T, by the conversion photon analysis.

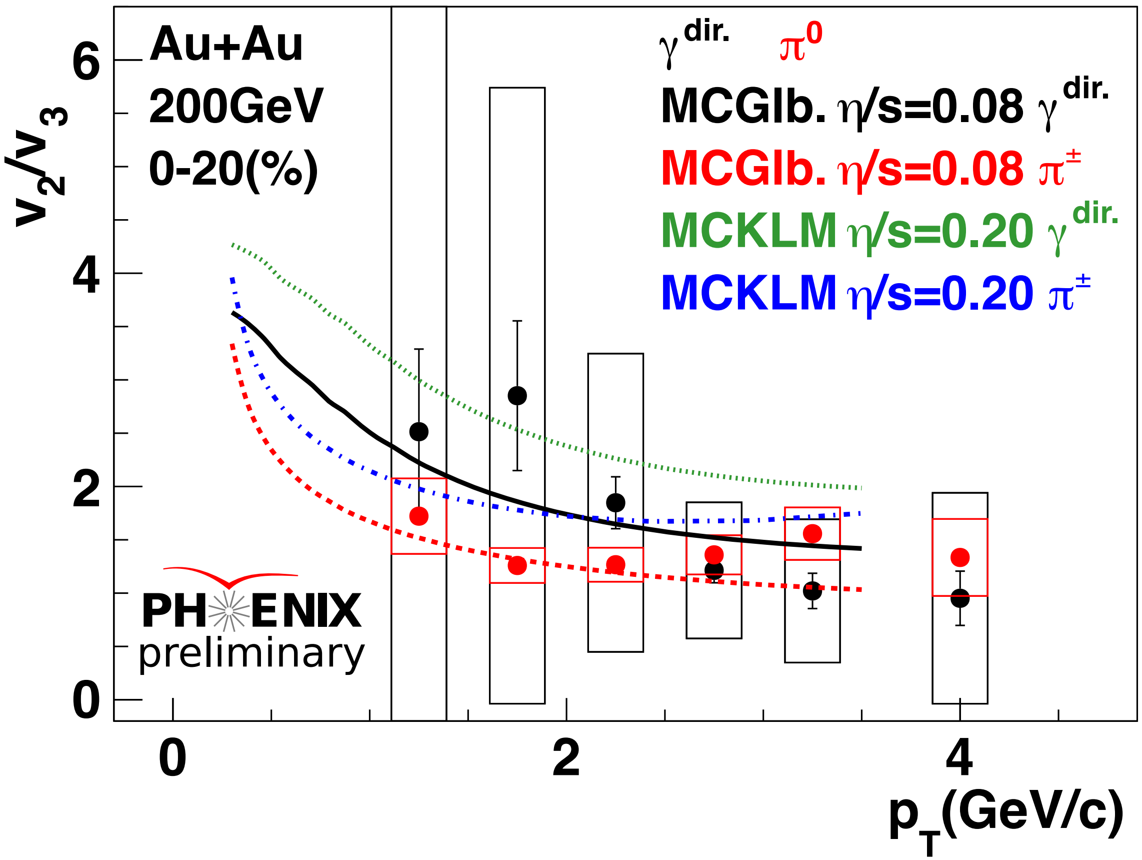
Comparison $\gamma^{dir.}$ v_2 with theoretical calculations



van Hees et al: P.R.C 84, 054906 (2011)

Linnyk et al.: PHSD model, private communication

The ratio of $\gamma^{dir.}$ & π^0 v_2/v_3



Theory curves: private communication by Ch. Shen, Ch. Gale, J.-F. Paquest, U. Heinz as in 1403.7558, Calculated for RHIC.

So far all uncertainties are assumed to be uncorrelated.
The ratios – both for π^0 and γ – slightly prefer lower η/s values.

Summary

Soft photons are expected to do provide important keys to understand photon production mechanisms and medium properties, including viscosity.

Centrality dependence of direct photon yield

The shape of p_T spectra doesn't have strong centrality dependence.
The excess of yield increases with centrality like N_{part}^{α} with $\alpha \approx 1.48$.

3rd order Azimuthal anisotropy

Direct photon has as large v_3 as hadrons, which is similar to the case of v_2.
Non-zero, positive direct photon v_3 is observed in all centrality bins.
Direct photon is expected to be a viscometer of QGP.

Posters for direct photon from PHENIX

Systematic studies of the centrality dependence of soft photon production in Au+Au collision with PHENIX

photon measurement with external photon conversion method

Benjamin BANNIER (G-01)

Direct photon collective flow in Au+Au collisions at $\sqrt{s_{NN}}$=200GeV

Direct photon v_3 measurement by real photon with Calorimeter

Sanshiro MIZUNO (H-20)

The detector information

Central Arm: Measure electrons and photons

$|\eta| < 0.35$

Reaction Plane Detector (RxN): Estimate Event Plane

Inner : $1.5 < |\eta| < 2.8$

Outer : $1.0 < |\eta| < 1.5$

MPC: Estimate Event Plane

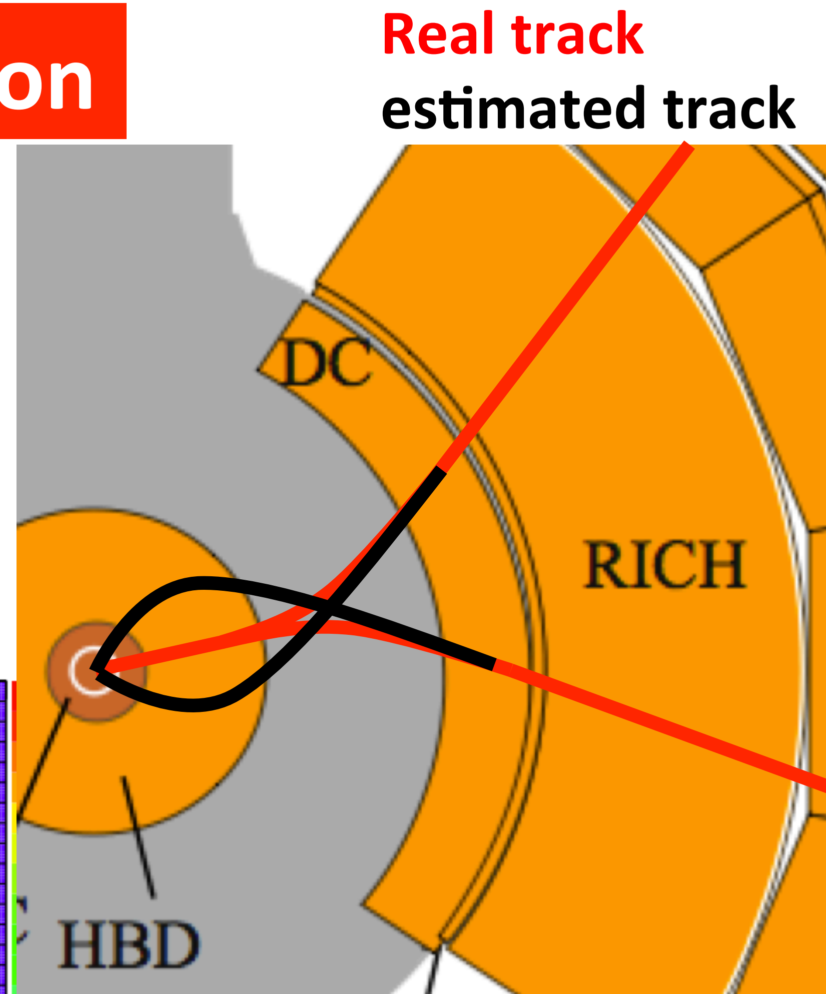
$3.1 < |\eta| < 3.8$

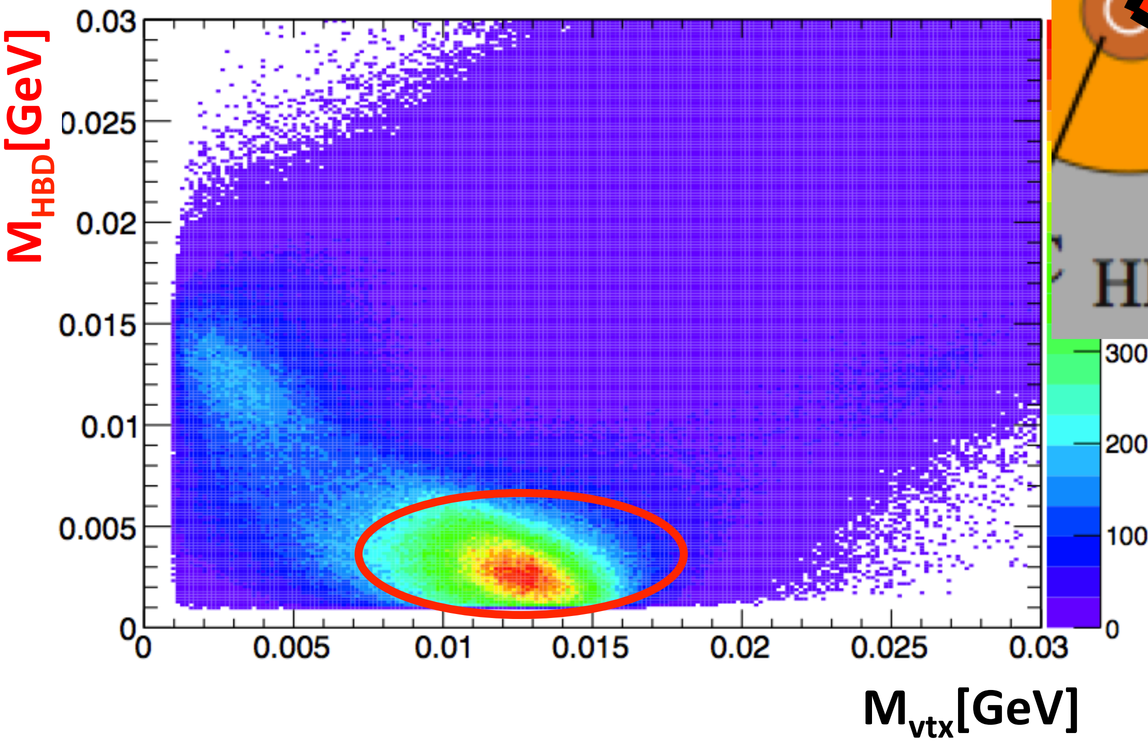
BBC: Estimate Event Plane

$3.1 < |\eta| < 3.9$

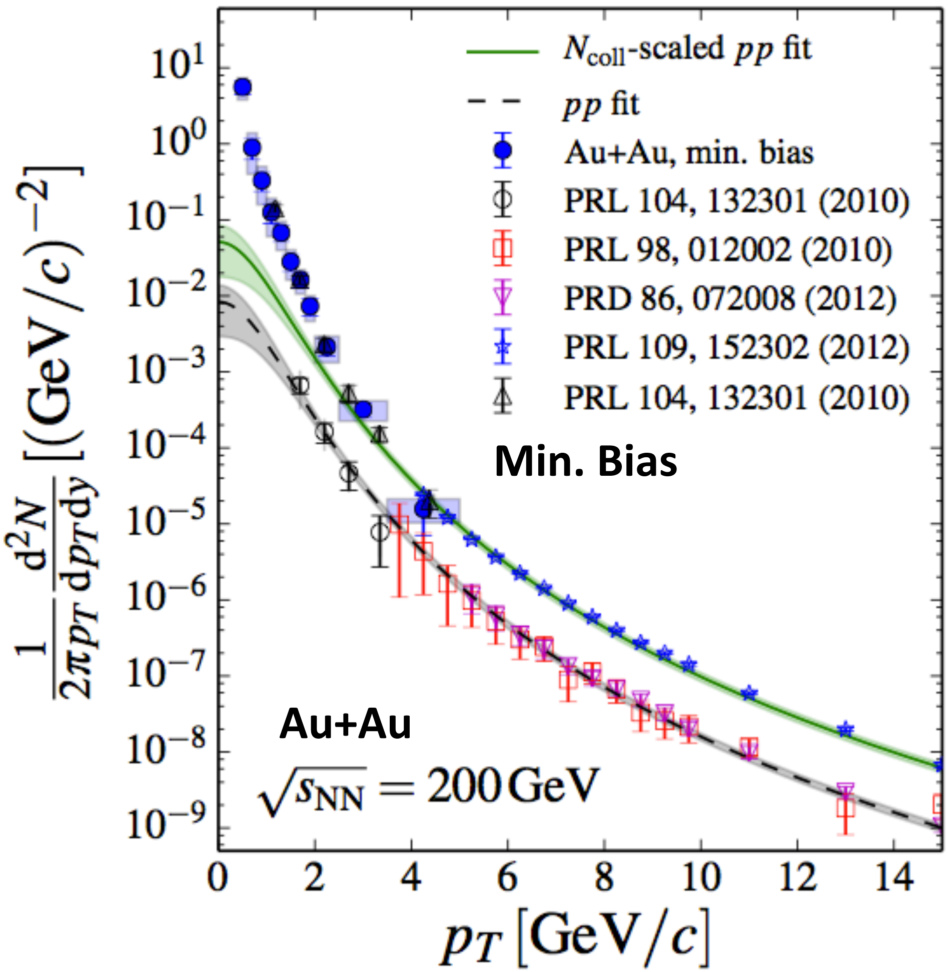
External conversion photon

1) real photon converts to e^+e^- in HBD backplane
2) default assumption: track come from the vertex
3) momentum of the conversion tracks will be mis-measured (see black tracks)
4) apparent pair-mass (about 12MeV) will be measured for phtons
5) assume the same tracks originate in the HBD backplane
6) re-calculate momentum and pair mass with this "alternate tracking model"
7) for true converted photons M_{atm} will be around zero





Comparable measurement is achieved



Ncoll-scaled pp fit
external conversion
pp virtual photon
pp in EMCal(Run2003 data)
pp in EMCal(Run2006 data)
AuAu in EMCal(Run2004 data)
AuAu from virtual photon(Run4 data)

Using external photon conversion method achieved good agreement with previous results.

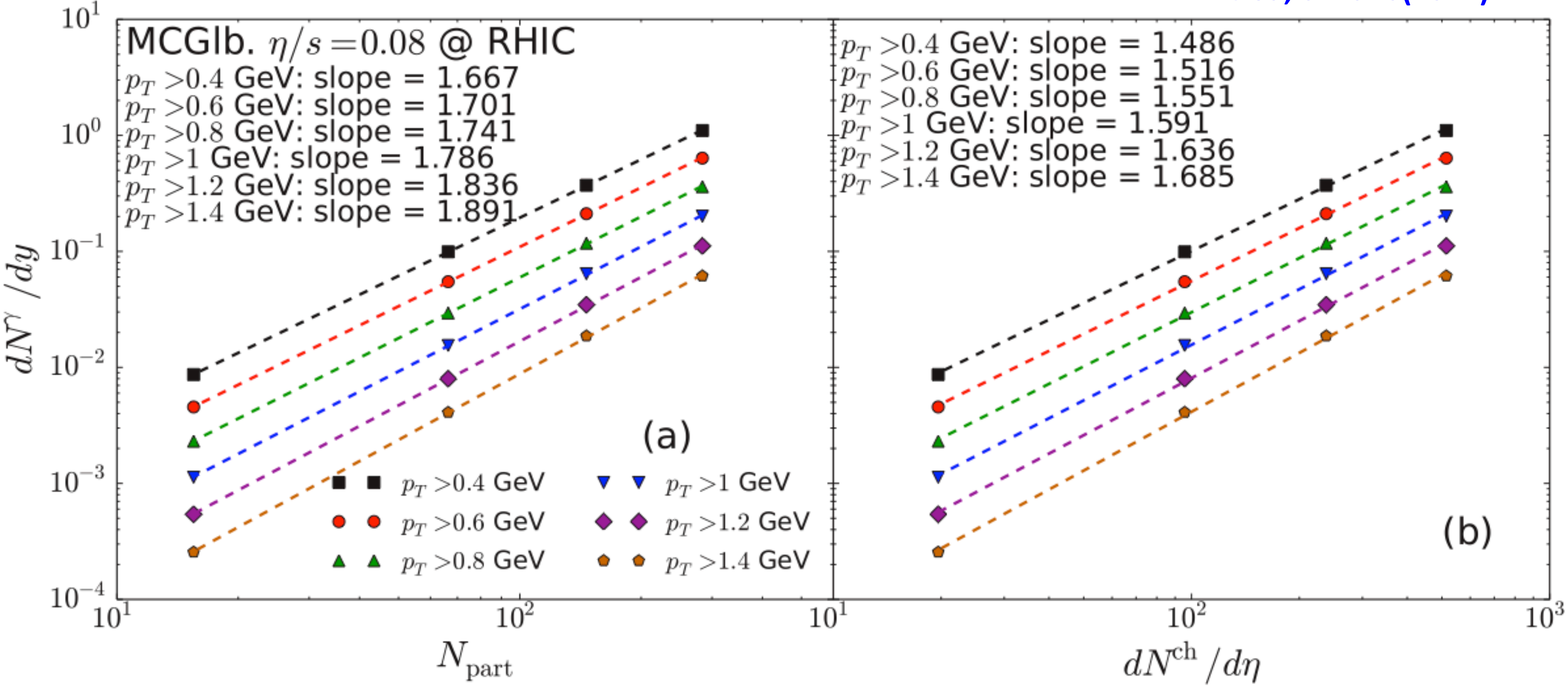
The table of excess of direct photon yield

TABLE III. Fitted parameters from fitting power-law fits $\frac{dN}{dy} = AN_{\mathrm{part}}^{\alpha}$ for integrated yields with different lower p_T^{ee} limits.

p_T^{min} (GeV/c)	α	A
0.4	$1.47 \pm 0.19 \pm 0.07$	$(2.77 \pm 2.64 \pm 1.41) \times 10^{-3}$
0.6	$1.52 \pm 0.23 \pm 0.15$	$(5.78 \pm 6.64 \pm 5.17) \times 10^{-4}$
0.8	$1.63 \pm 0.22 \pm 0.18$	$(1.68 \pm 1.91 \pm 1.67) \times 10^{-4}$
1.0	$1.45 \pm 0.19 \pm 0.08$	$(1.99 \pm 1.87 \pm 1.28) \times 10^{-4}$
1.2	$1.41 \pm 0.18 \pm 0.08$	$(1.49 \pm 1.37 \pm 0.91) \times 10^{-4}$
1.4	$1.47 \pm 0.20 \pm 0.09$	$(5.00 \pm 5.18 \pm 3.44) \times 10^{-5}$

Centrality (N_{part}) dependence of yield

P.R.C 89, 044910(2014)



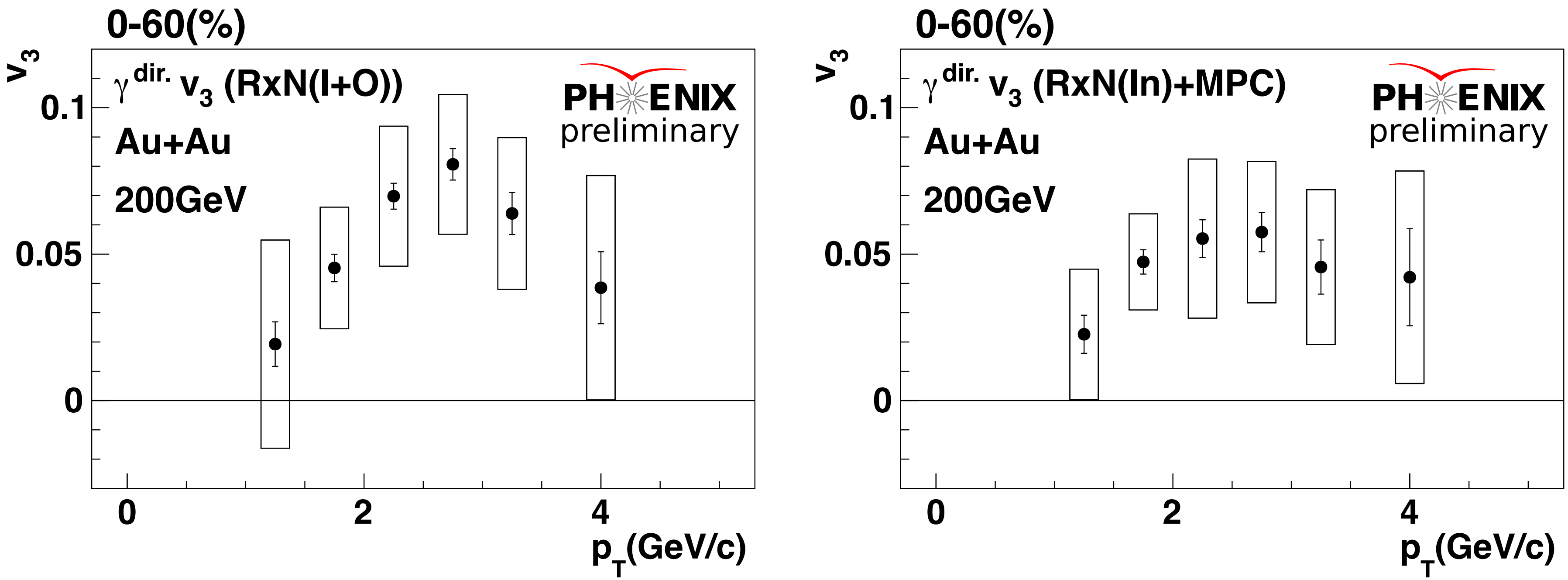
Theoretical calculation of excess of the photon yield.

The analysis information

$\gamma^{dir.}$ v_n with external conversion photon analysis
charged π v_n
$\gamma^{inc.}$ v_n with external conversion photon analysis
Rγ with external conversion photon analysis

$\gamma^{dir.}$ v_n with Calorimeter
π^0 v_n with Calorimeter
$\gamma^{inc.}$ v_n with Calorimeter
Rγ with external conversion photon analysis

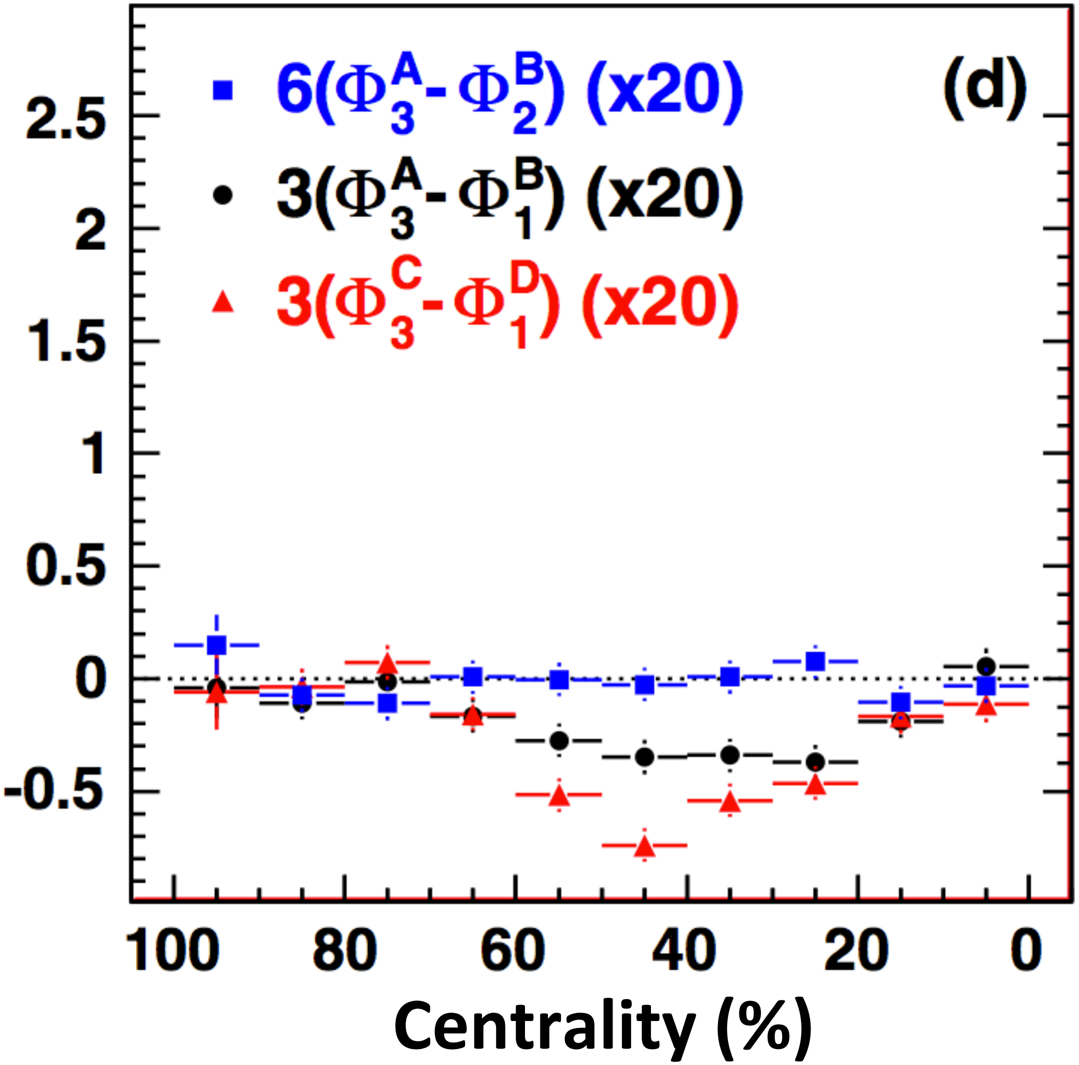
Comparison $\gamma^{dir.}$ v_3



RxN(I+O) : $1.0 < |\eta| < 2.8$
RxN(In)+MPC : $1.5 < |\eta| < 3.8$

The magnitude of v_3 is comparable.

2nd and 3rd order E.P. correlation

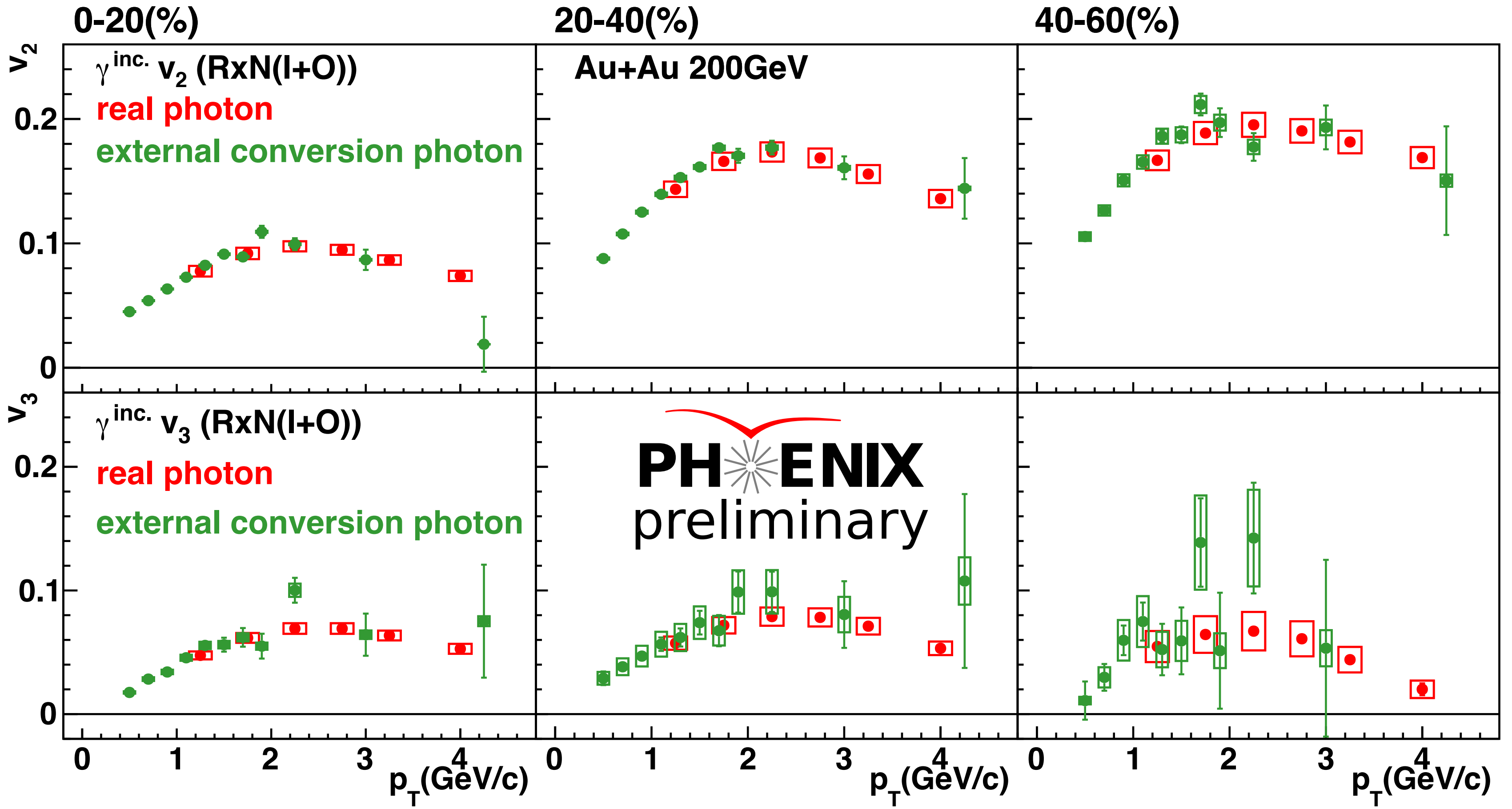


$$< \cos\{6(\Phi_3^A - \Phi_2^B)\} >$$

It is known that they have weak correlation.

It is considered that 3rd order of Event Plane is defined as a deformation of initial geometry.

Comparison of inclusive photon v_n



Inclusive photon v_n is measured via conversion photon, and p_T range is extended to low p_T region.

The table of systematic uncertainty of $\gamma^{dir.}$ v_3

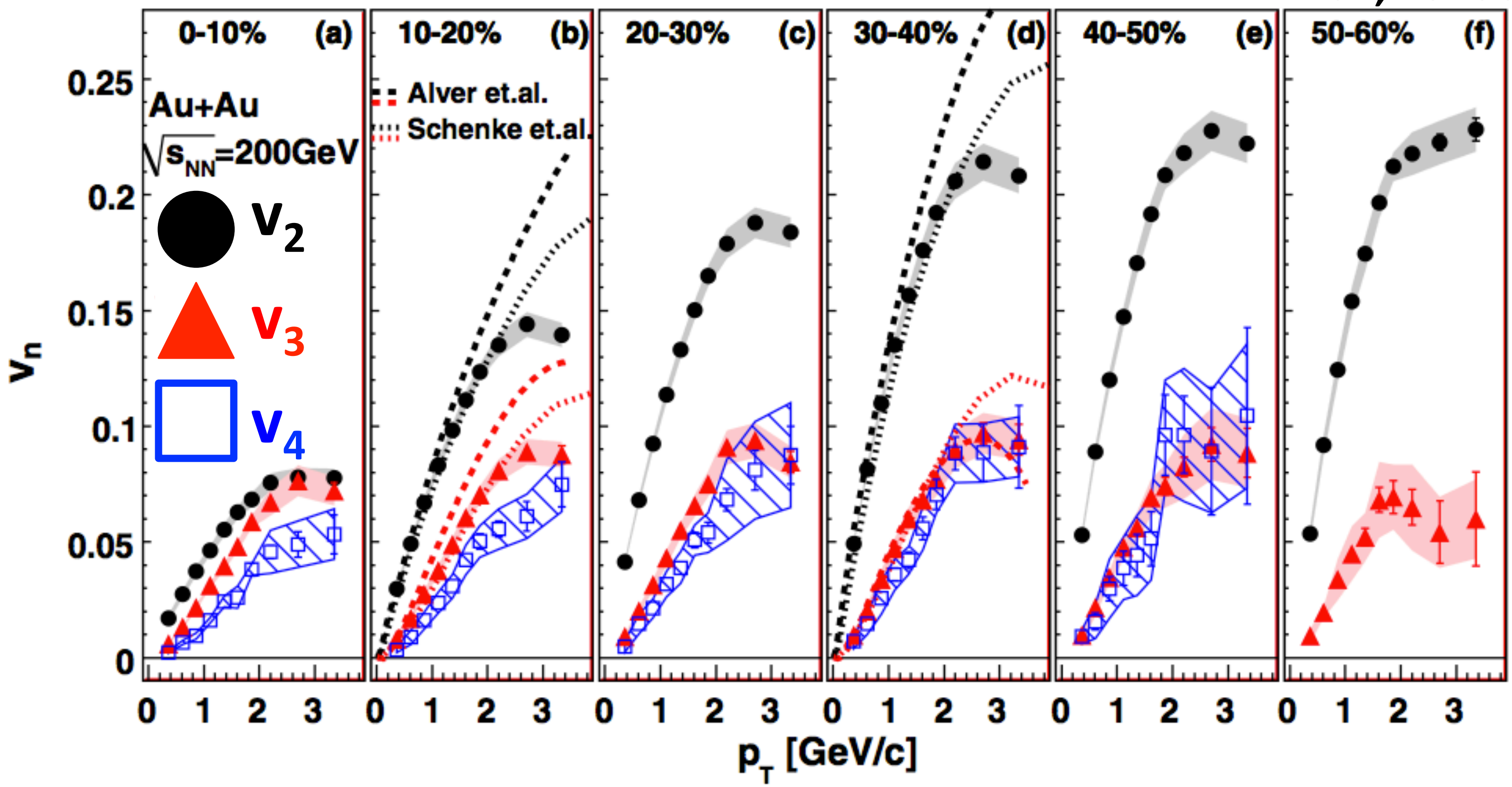
The table of systematic uncertainty of $\gamma^{dir.}$ v_3 (relative value)				
centrality(%)	π^0	$\gamma^{inc.}$	R_γ	Event Plane
0-20	15.8	3.2	28.8	5.9
20-40	3.8	2.1	36.2	9.1
40-60	8.8	1.4	43.9	23.0
20-60	4.6	1.5	39.5	13.2
0-60	8.9	4.0	29.2	6.4

They are the relative value of systematic uncertainty propagated to $\gamma^{dir.}$ v_3.

π^0, $\gamma^{inc.}$ and R_γ is considered to be independent for harmonics.

Measurement of higher order v_n

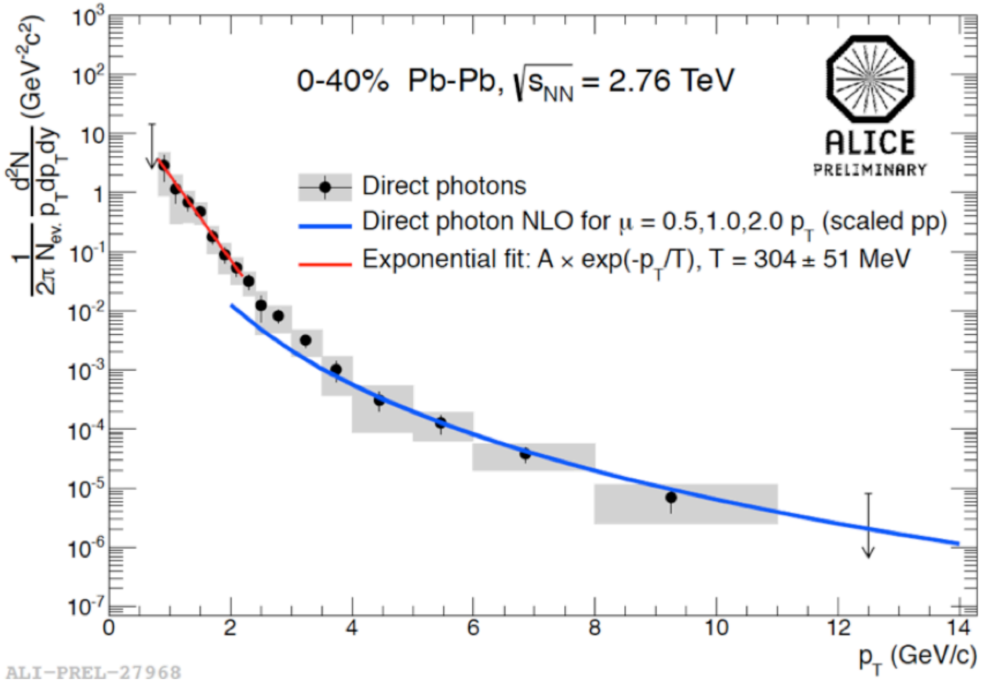
P.R.L. 107, 252301(2011)

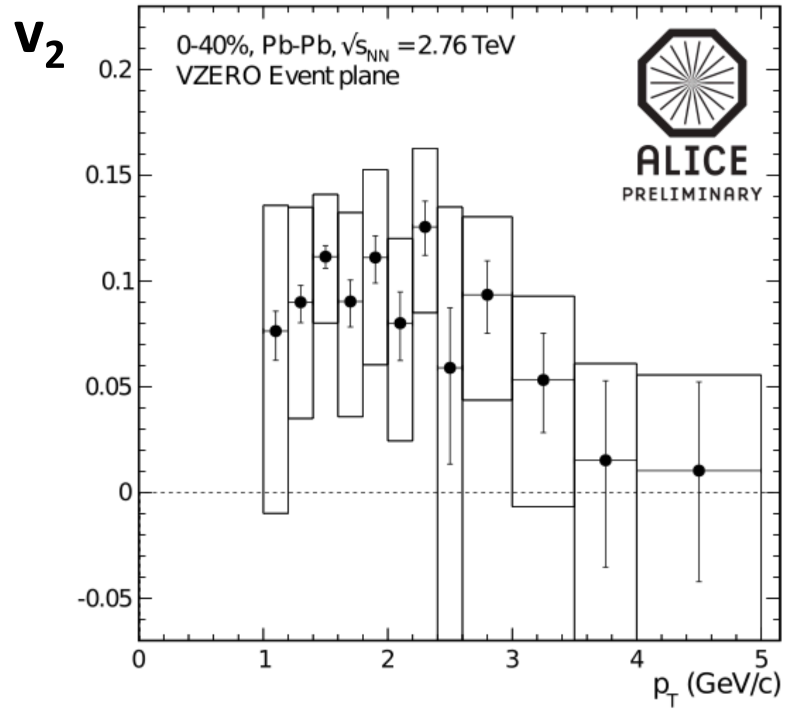


v_3 and v_4 have weak centrality dependence while v_2 has strong.
It indicates v_3 and v_4 are created by the initial geometry deformation.

$\gamma^{dir.}$ measurement by ALICE

arXiv:1212.3995v2





Similar trend with RHIC-PHENIX is observed by LHC-ALICE.