Measurement Of Direct Photon 3rd Order Azimuthal Anisotropy In Au+Au collisions At $\sqrt{s_{NN}}$=200GeV at RHIC-PHENIX experiment

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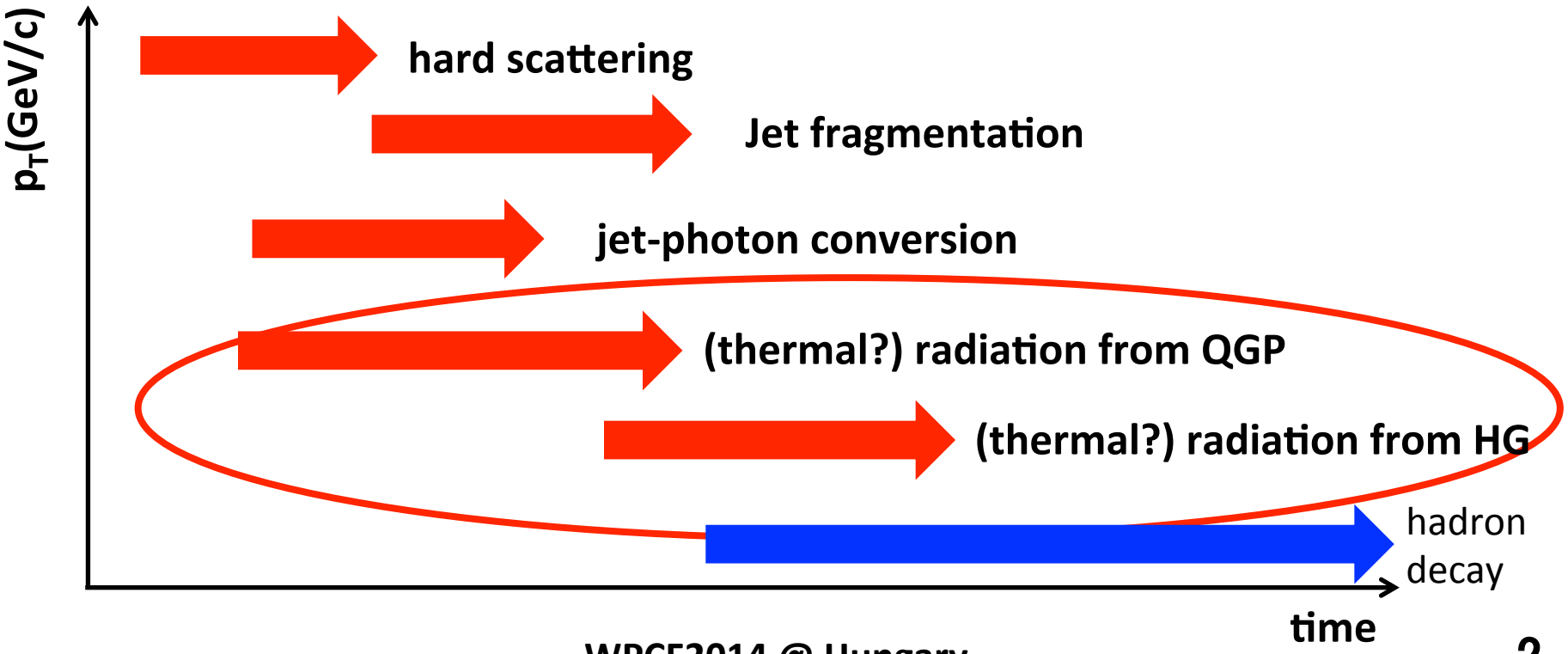
What are direct photons ?

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

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

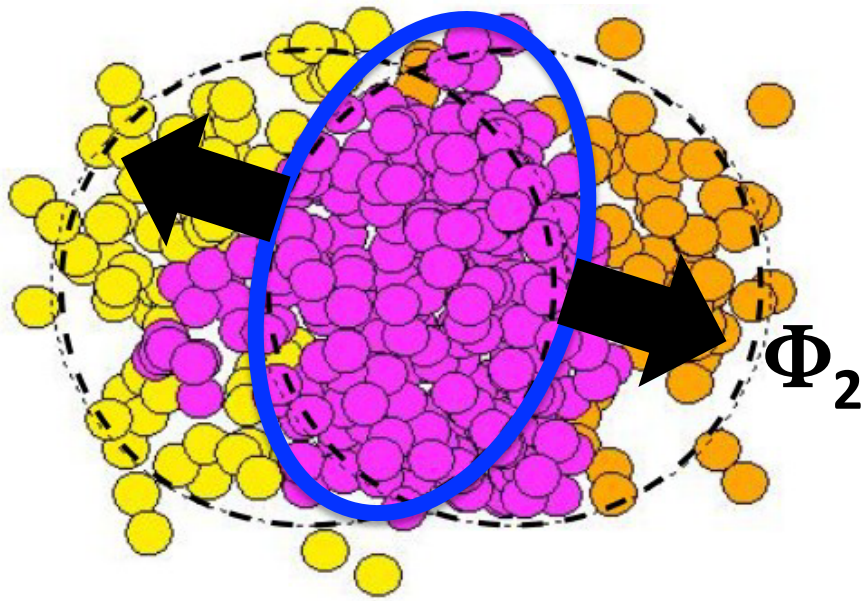


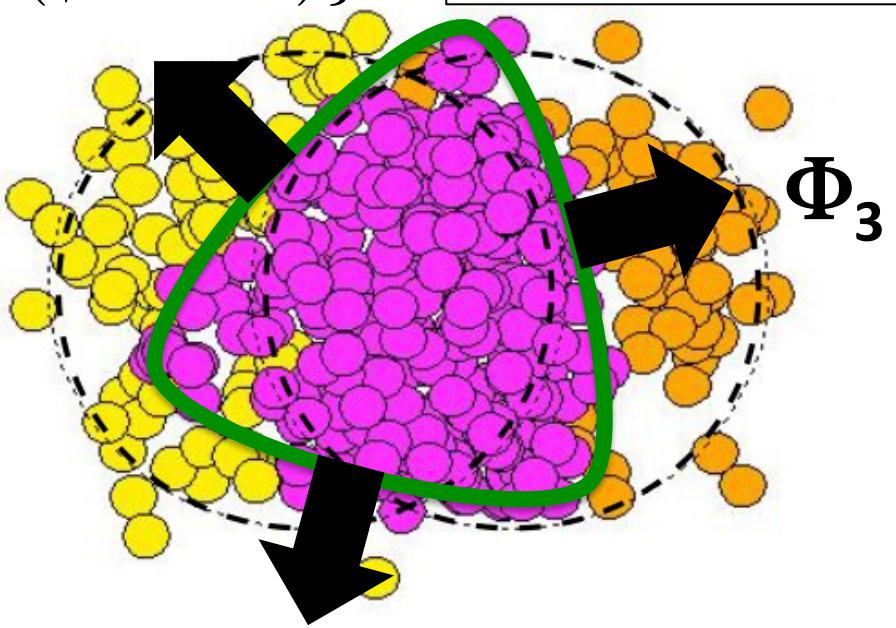
Higher Order Azimuthal Anisotropy

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

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

Φ_n : Event Plane



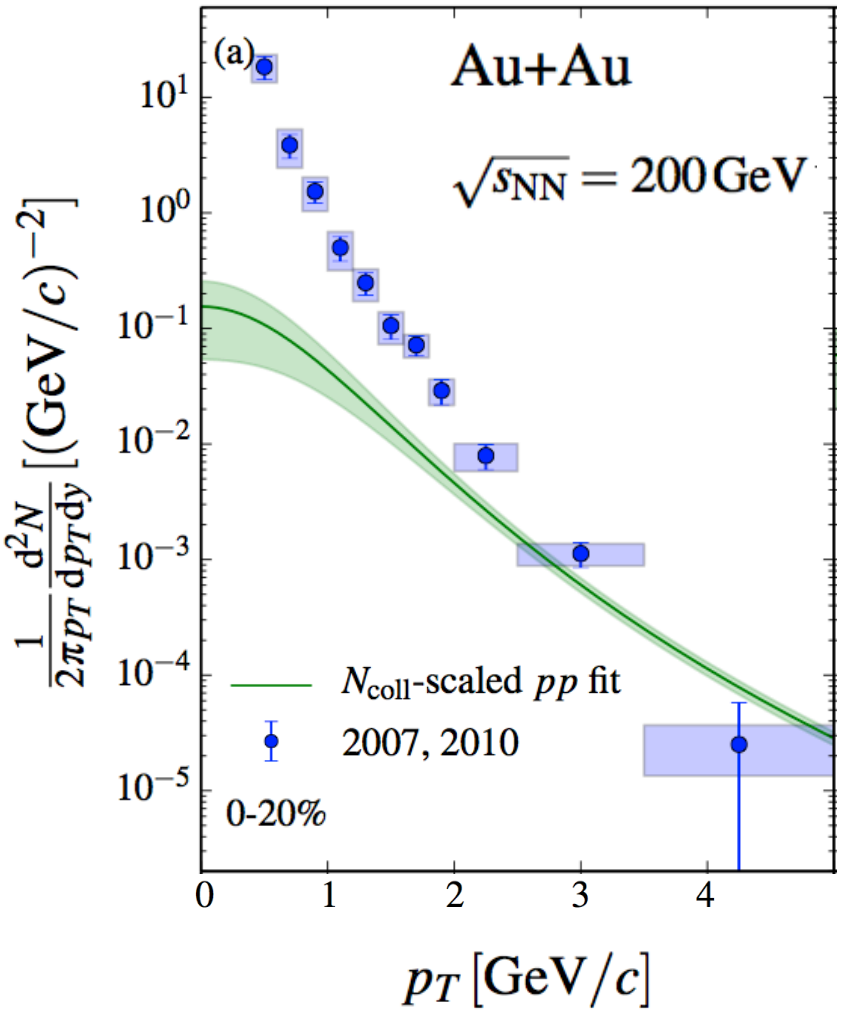


v_3 comes from participant position fluctuations, viscosity dampens higher order terms.

- **Define initial geometry calculating model**
- **Constrain η/s of QGP**

Direct Photon p_T spectra

arXiv:1405.3940v1



$$a(1 + p_T^2/b)^c$$

The p_T spectra from p+p data is fitted and extrapolated below 2 GeV/c.

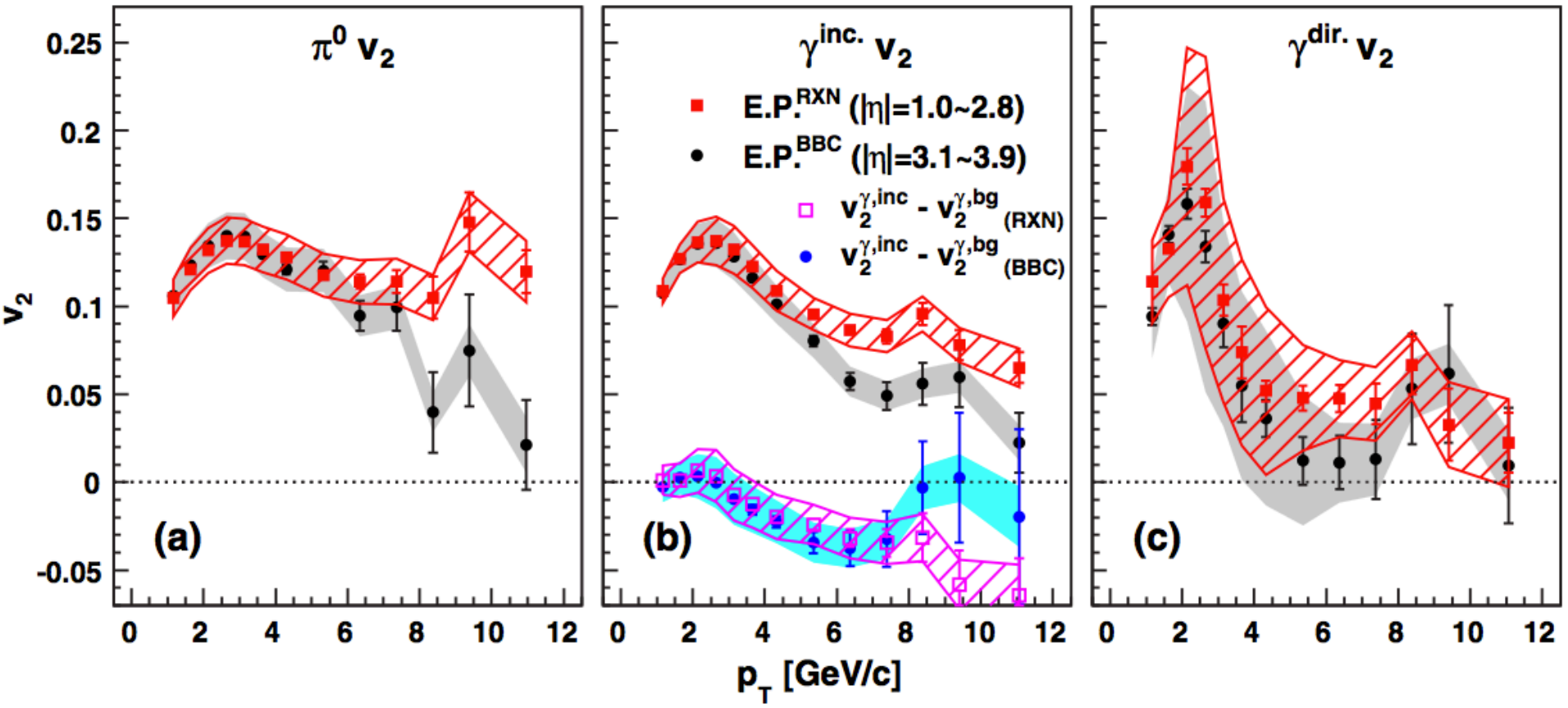
$$Ae^{-p_T/T_{eff}}$$

The excess of p_T spectra are fitted and effective temperature is extracted.

It is about 240 MeV.
Photons are emitted from very hot medium at early time of collisions.

Direct Photon Elliptic Flow (v_2)

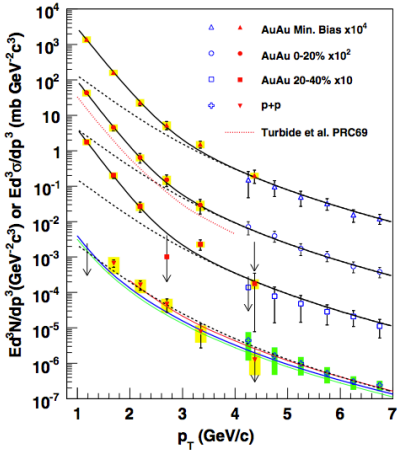
P.R.L. 109, 122302(2012)

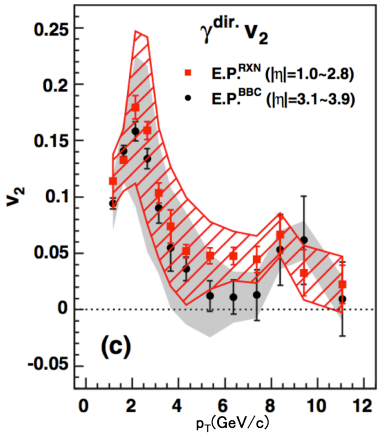


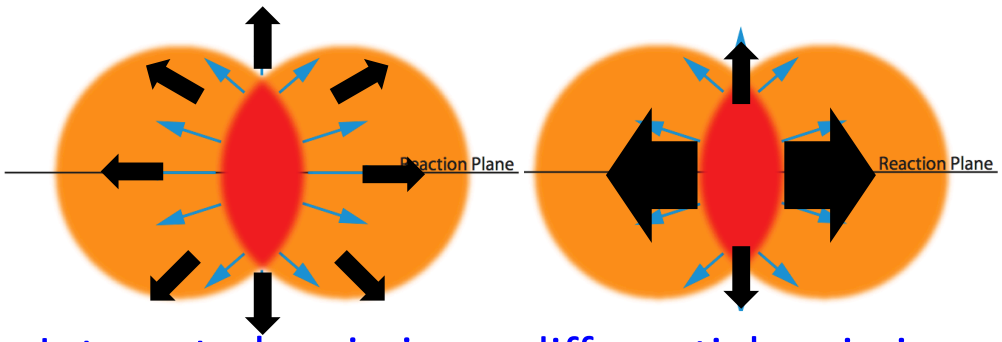
It is observed that positive $\gamma^{dir.}$ v_2 in low p_T and the magnitude of it is comparable to that of hadron v_2.

Photons are emitted at late time of collisions, when temperature is low.

Direct Photon Puzzle







Integrated emission differential emission

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

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.

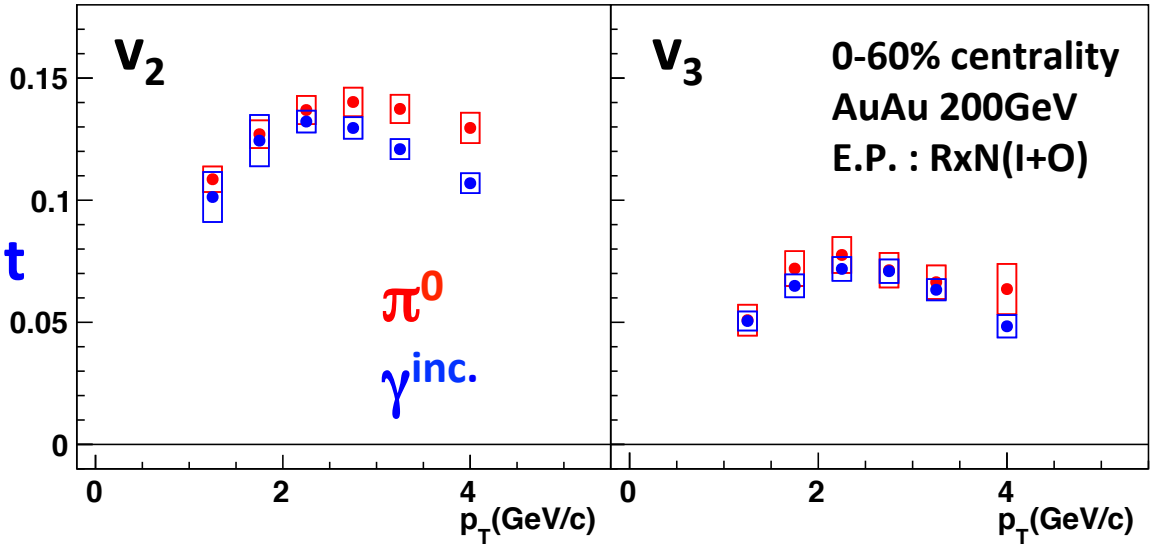
- **Higher order azimuthal anisotropy (v_3)**

Photons have different emission angular pattern depending on their production mechanism.
v_3 measurement could constrain photon production mechanism.

In this talk, the results for v_3 in several centralities are shown.

Analysis Flow

1. π^0, $\gamma^{inc.}$ v_n measurement

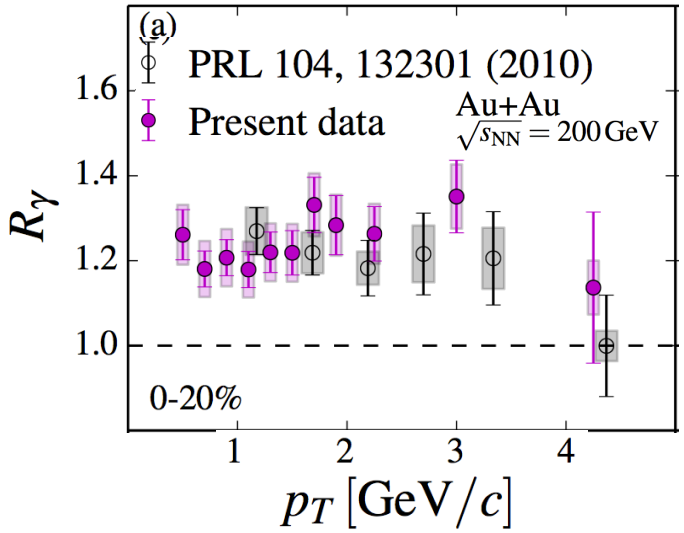


arXiv:1405.3940

2. $\gamma^{dec.}$ v_n estimation from π^0 v_n

Mesons spectra are assumed by m_T scaling.

Mesons v_n are assumed by NCQ scaling.



3. $\gamma^{dir.}$ v_n calculation

R_γ measured by external photon conversion method is used.

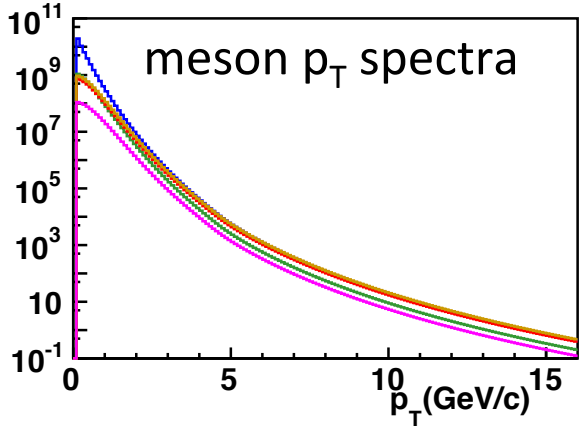
$$\nu_n^{dir.} = \frac{R_\gamma \nu_n^{inc.} - \nu_n^{dec.}}{R_\gamma - 1}$$

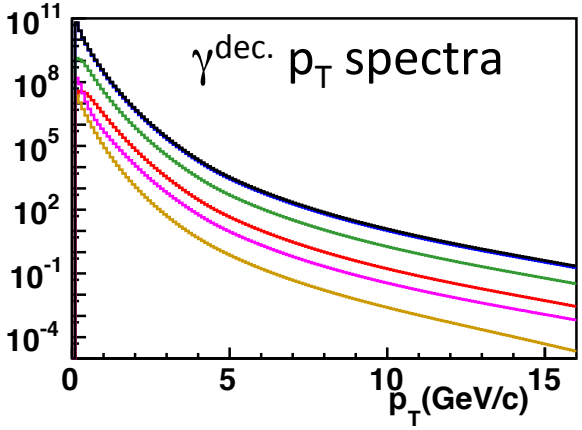
$$R_\gamma = N_{inc.}/N_{dec.}$$

Hadronic Decay Photon

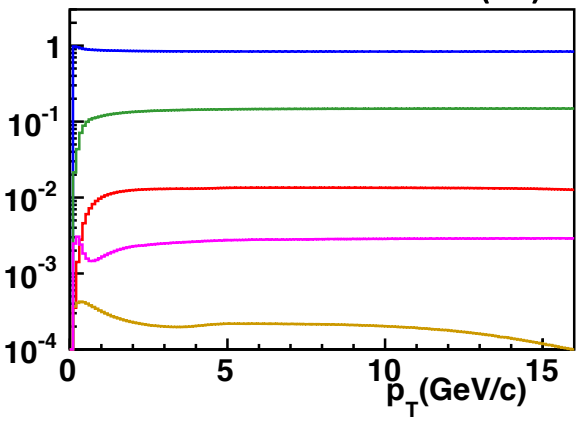
π ρ
η η′
ω **all $\gamma^{dec.}$**

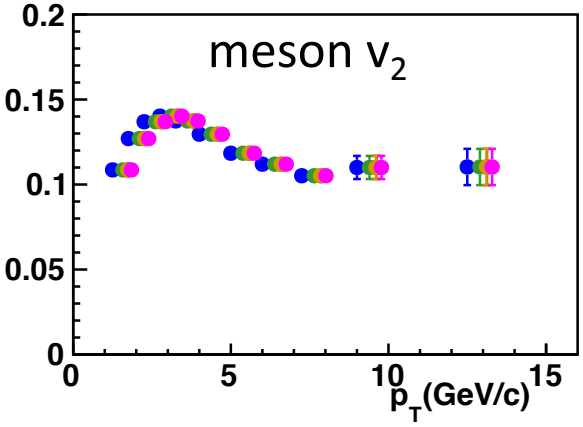
The p_T spectra and v_n are estimated from π.
- p_T spectra : m_T scaling
- v_n : quark number scaling

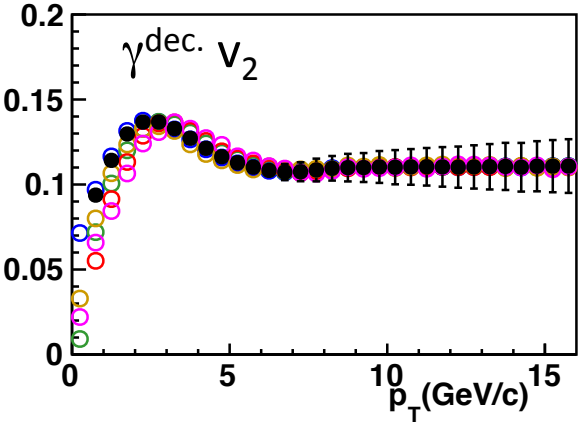




contribution ratio (R^i)







m_T scaling

$$p_T' = \sqrt{p_{T,\pi^0}^2 + M_{meson}^2 - M_{\pi^0}^2}$$

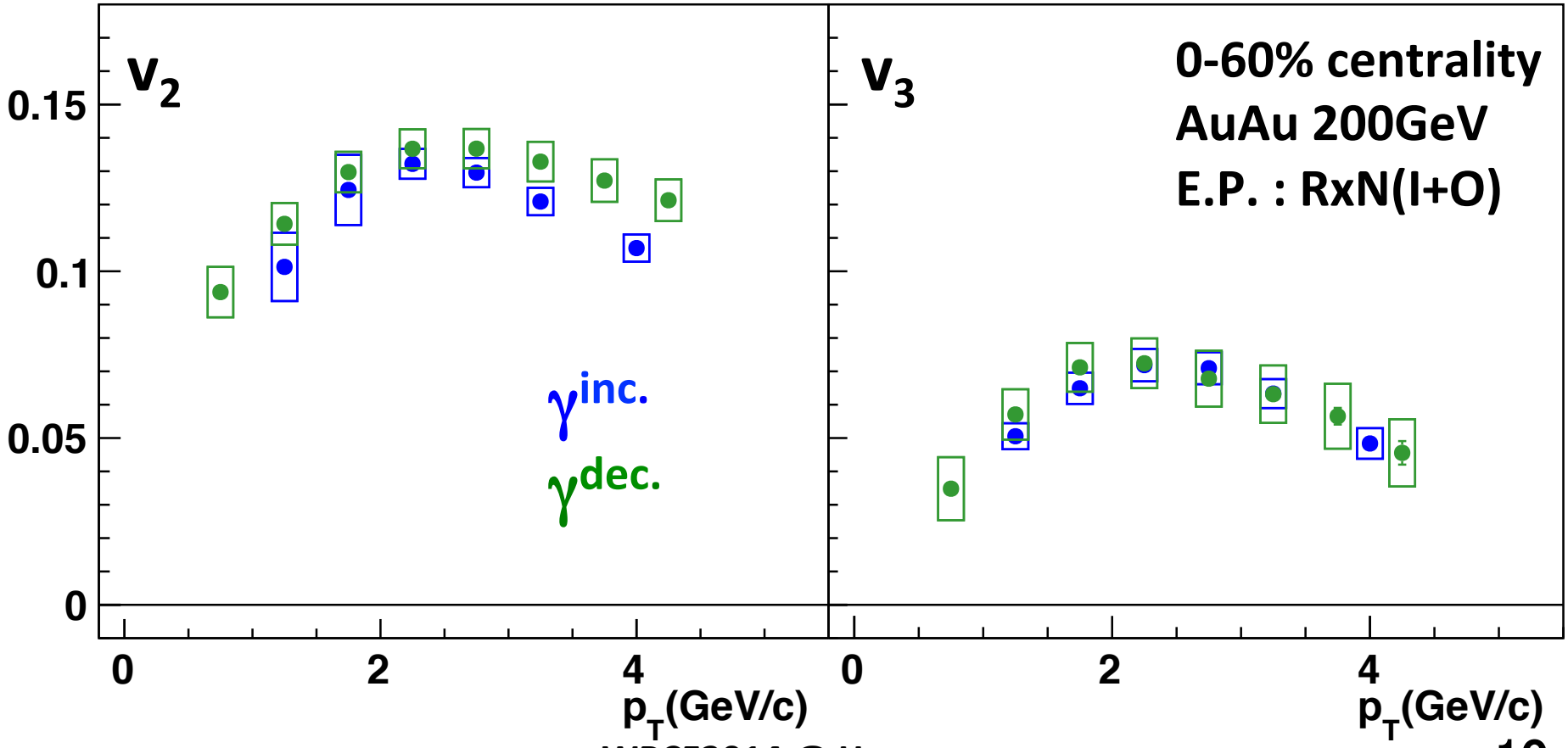
decay photon v_n

$$v_n^{dec.} = \sum_i R^i v_n^{dec.i}$$

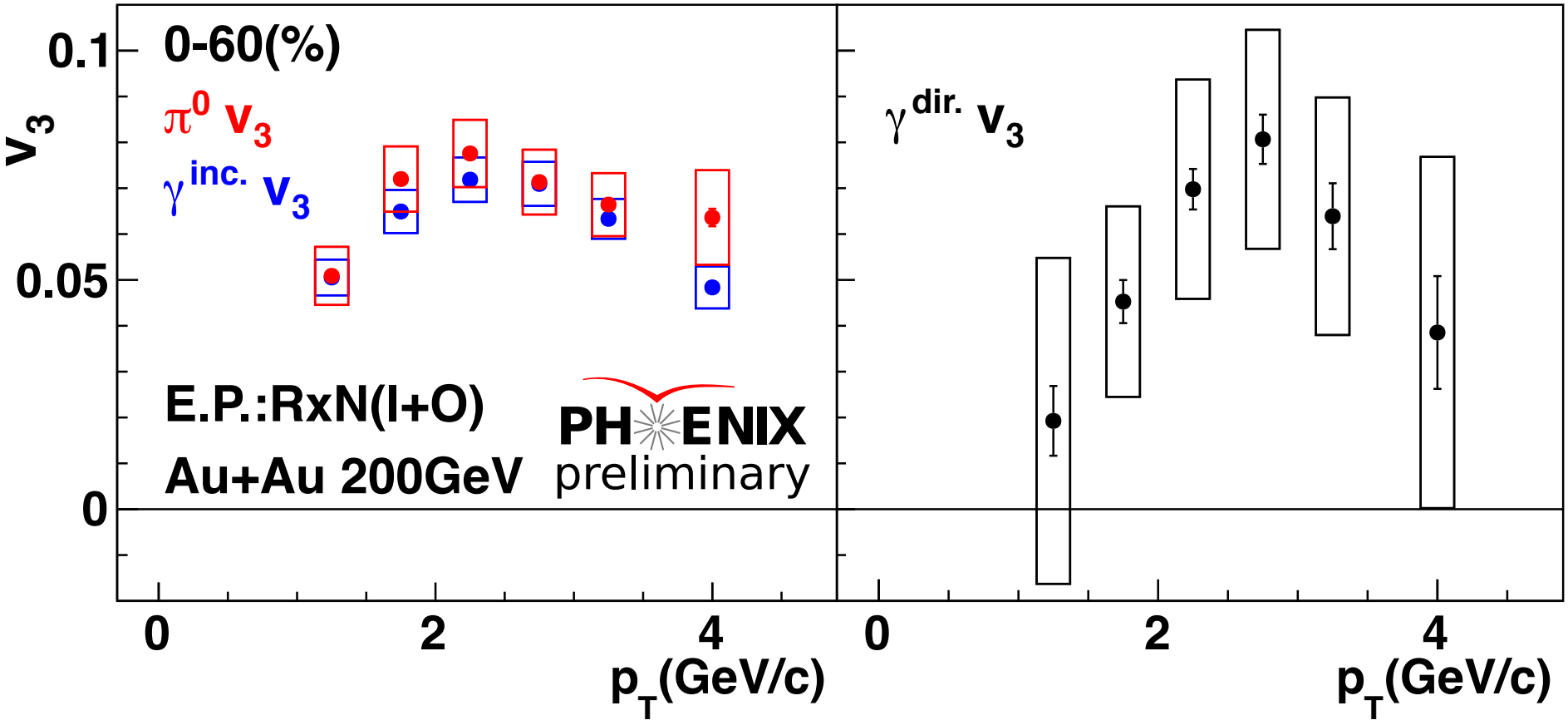
Inclusive and decay photon v_n comparison

Direct photon v_n are extracted from these deviation via below function.

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



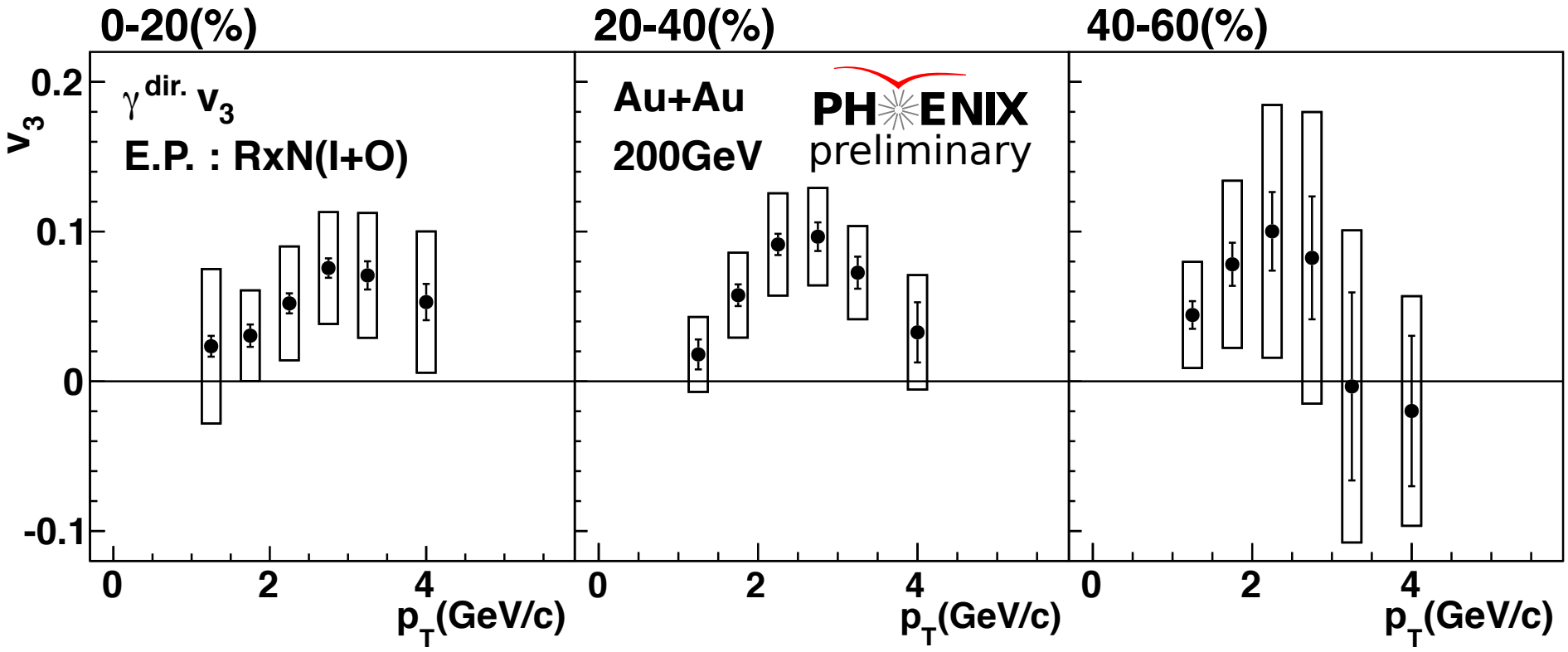
The Result of Direct Photon v_3



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 Direct Photon v_3

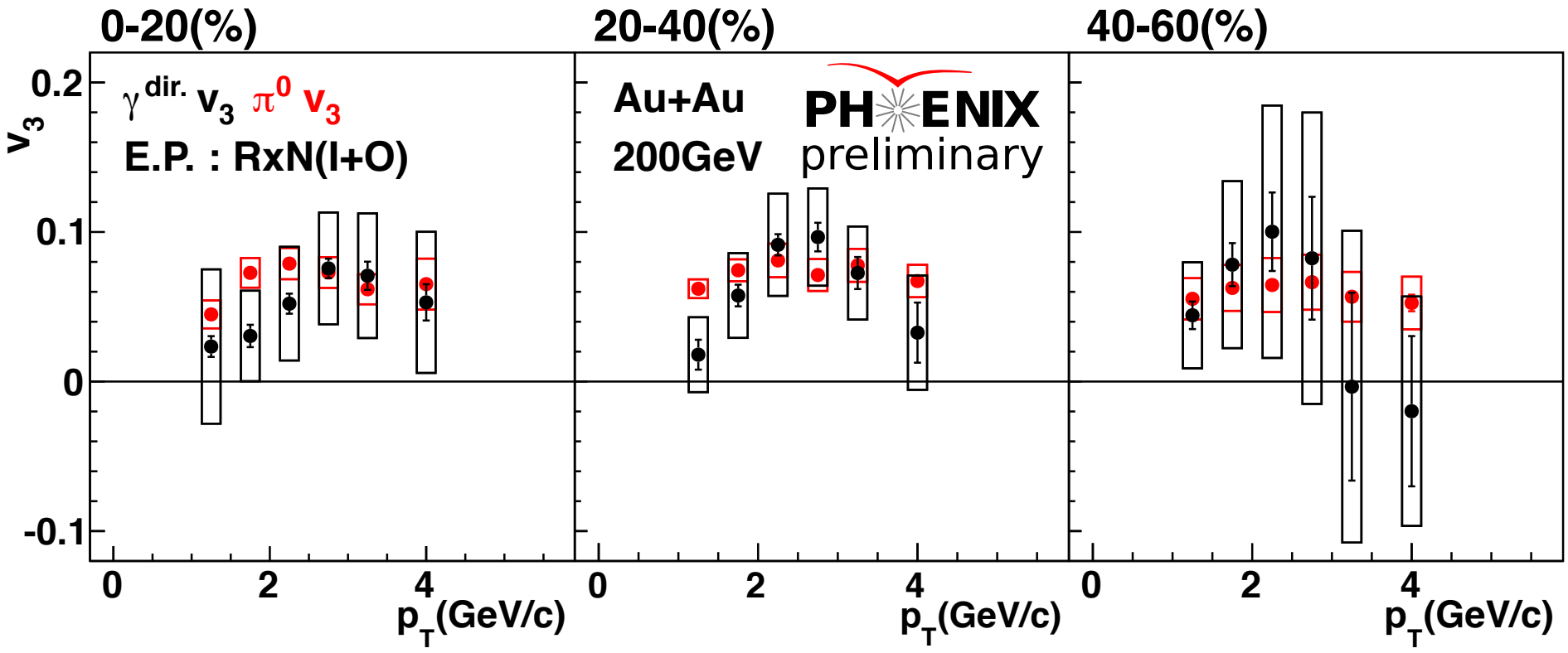


η range of RxN(I+O) is from 1.0 to 2.8.

Non-zero, positive v_3 is observed in all centrality bins.

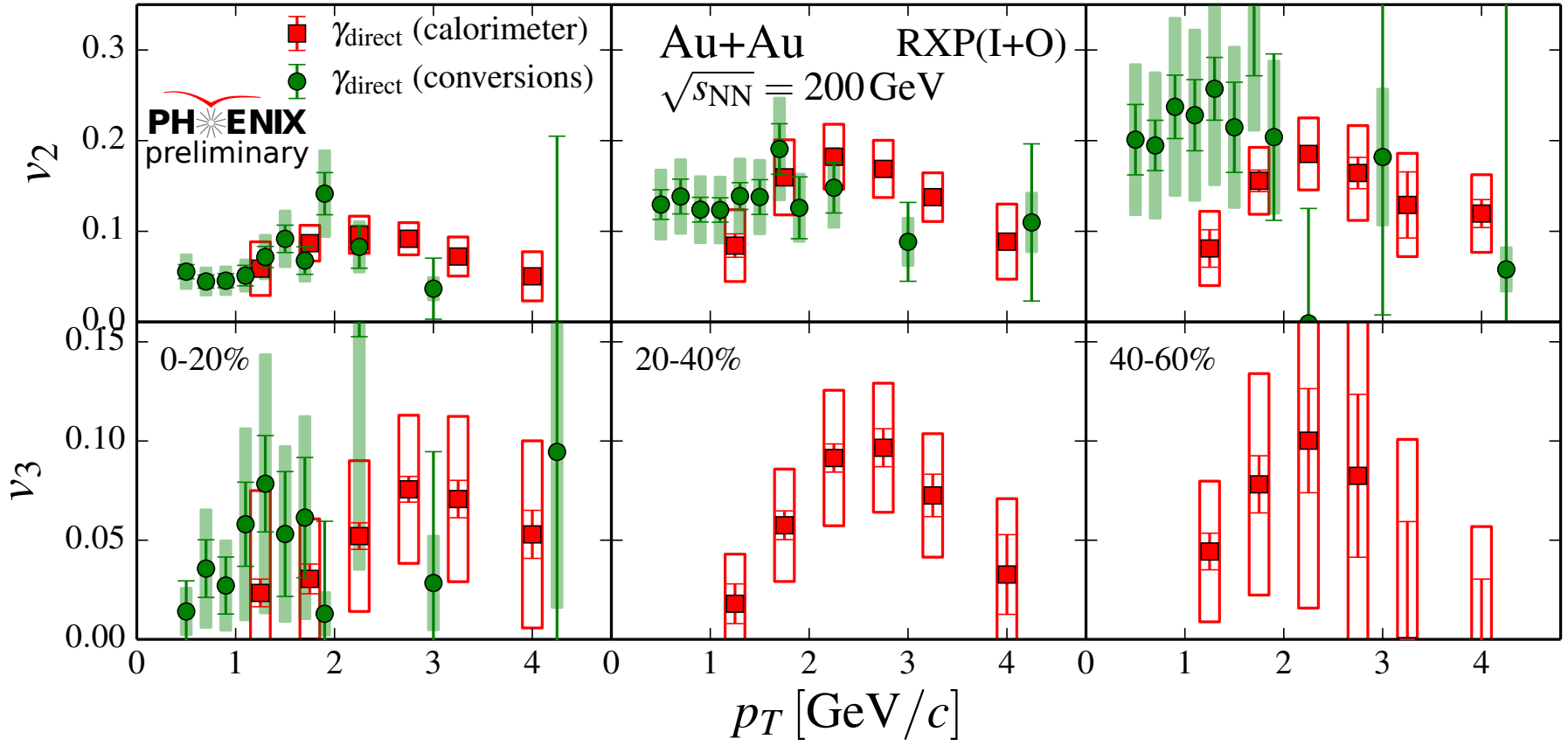
No strong centrality dependence: similar tendency as for charged hadrons (P.R.L. 107, 252301 (2011)) and π^0.

$\gamma^{dir.}$ 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.

Summary

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

Direct photon v_3 are measured in several centrality bins.
It is observed that
- non-zero and positive $\gamma^{dir.}$ v_3
- the strength of $\gamma^{dir.}$ v_3 is comparable to hadron v_3

They are similar trend to $\gamma^{dir.}$ v_2.
- don't have strong centrality dependence

It is similar tendency to hadron v_3.

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

$3.1 < |\eta| < 3.8$

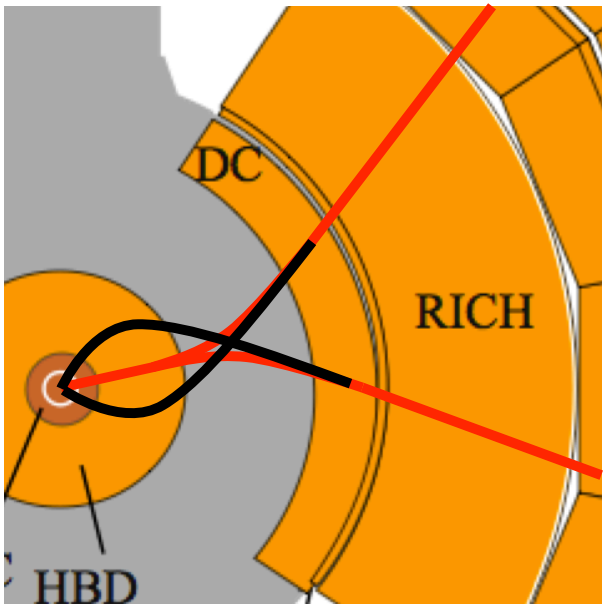
BBC: Estimate Event Plane

$3.1 < |\eta| < 3.9$

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.

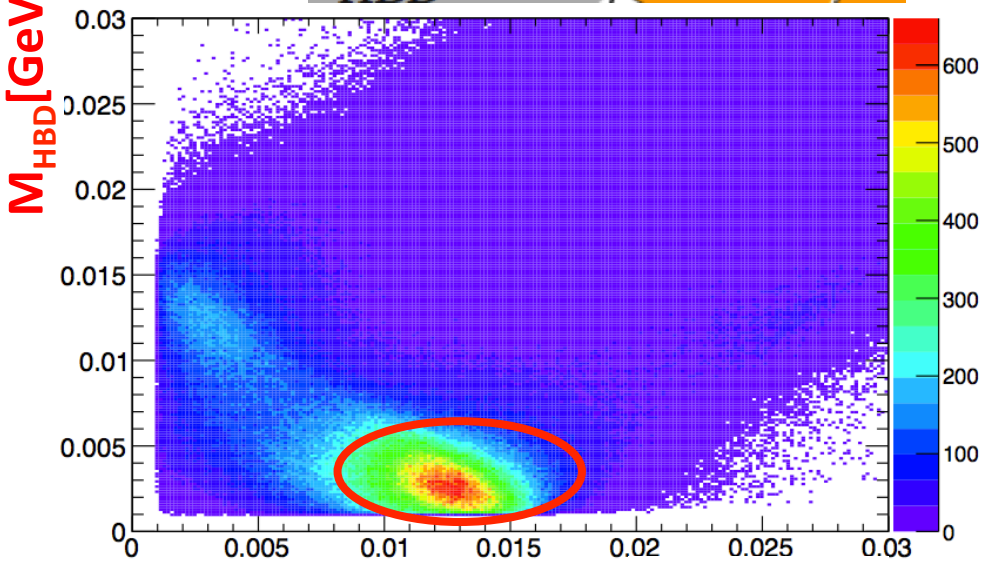
✓ less hadron contamination

✓ good momentum resolution

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

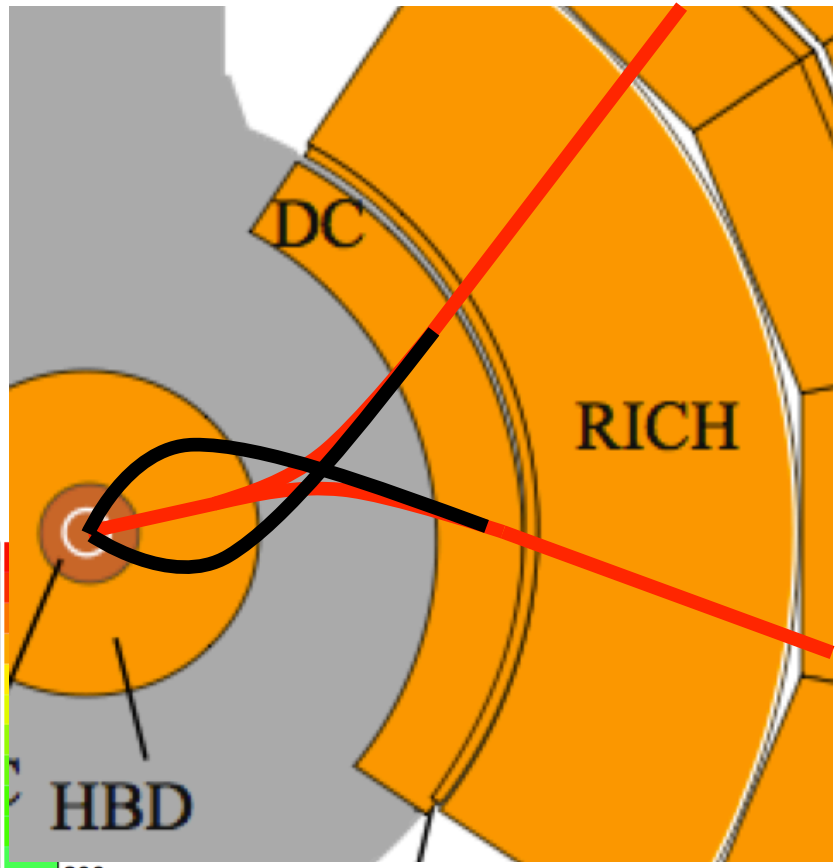
Extended to lower p_T

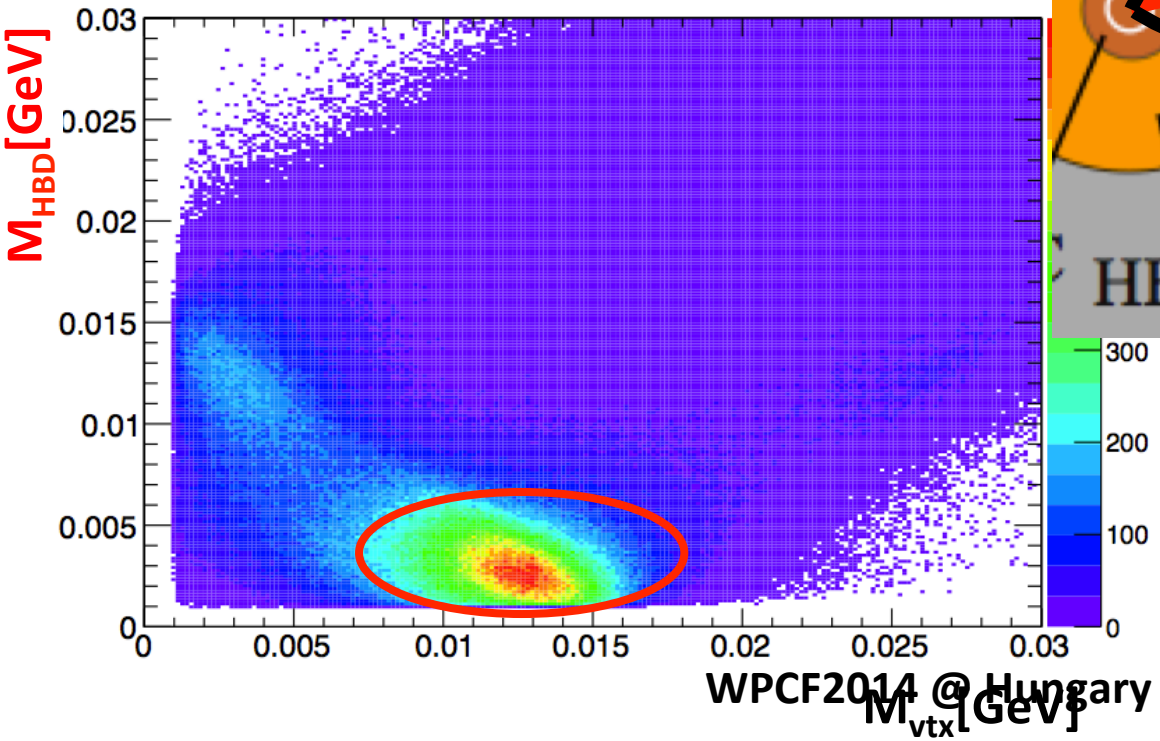
low statistics



External conversion photon

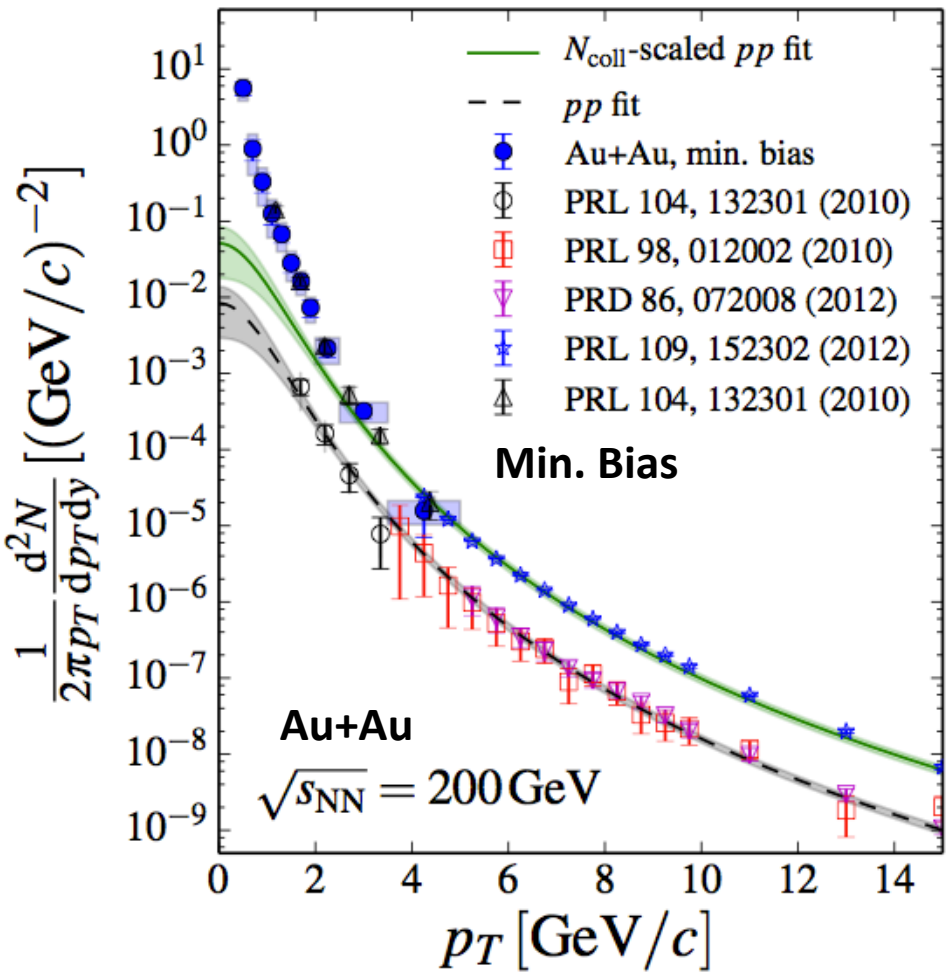
1) real photon converts to e^+e^- in HBD backplane
2) default assumption: track come from the vertex
3) momentum of the conversion tracks will be mis-measured (see black tracks)
4) apparent pair-mass (about 12MeV) will be measured for phtons
5) assume the same tracks originate in the HBD backplane
6) 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

arXiv:1405.3940



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)

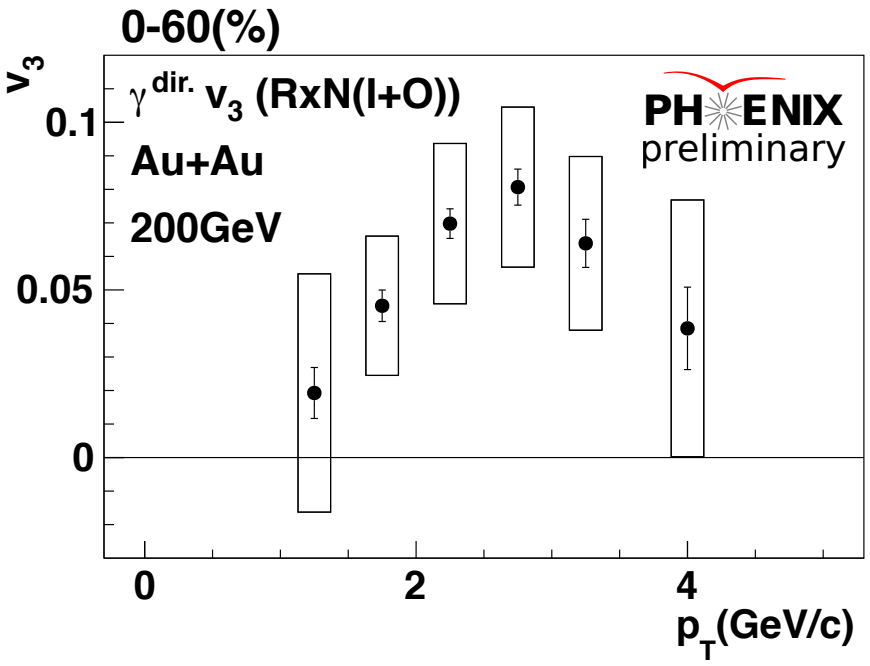
Using external photon conversion method achieved good agreement with previous results.

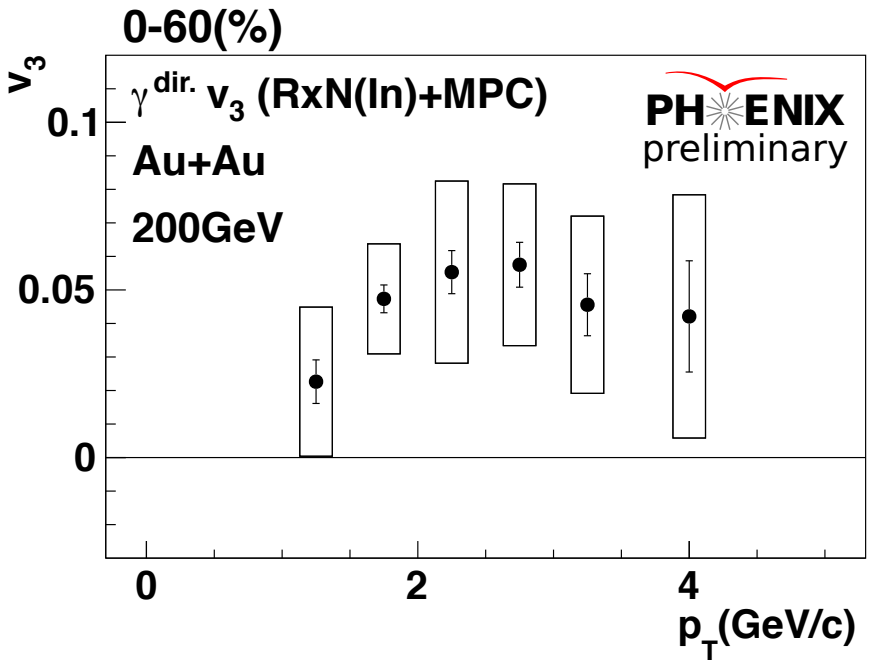
The analysis information

$\gamma^{dir.}$ 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

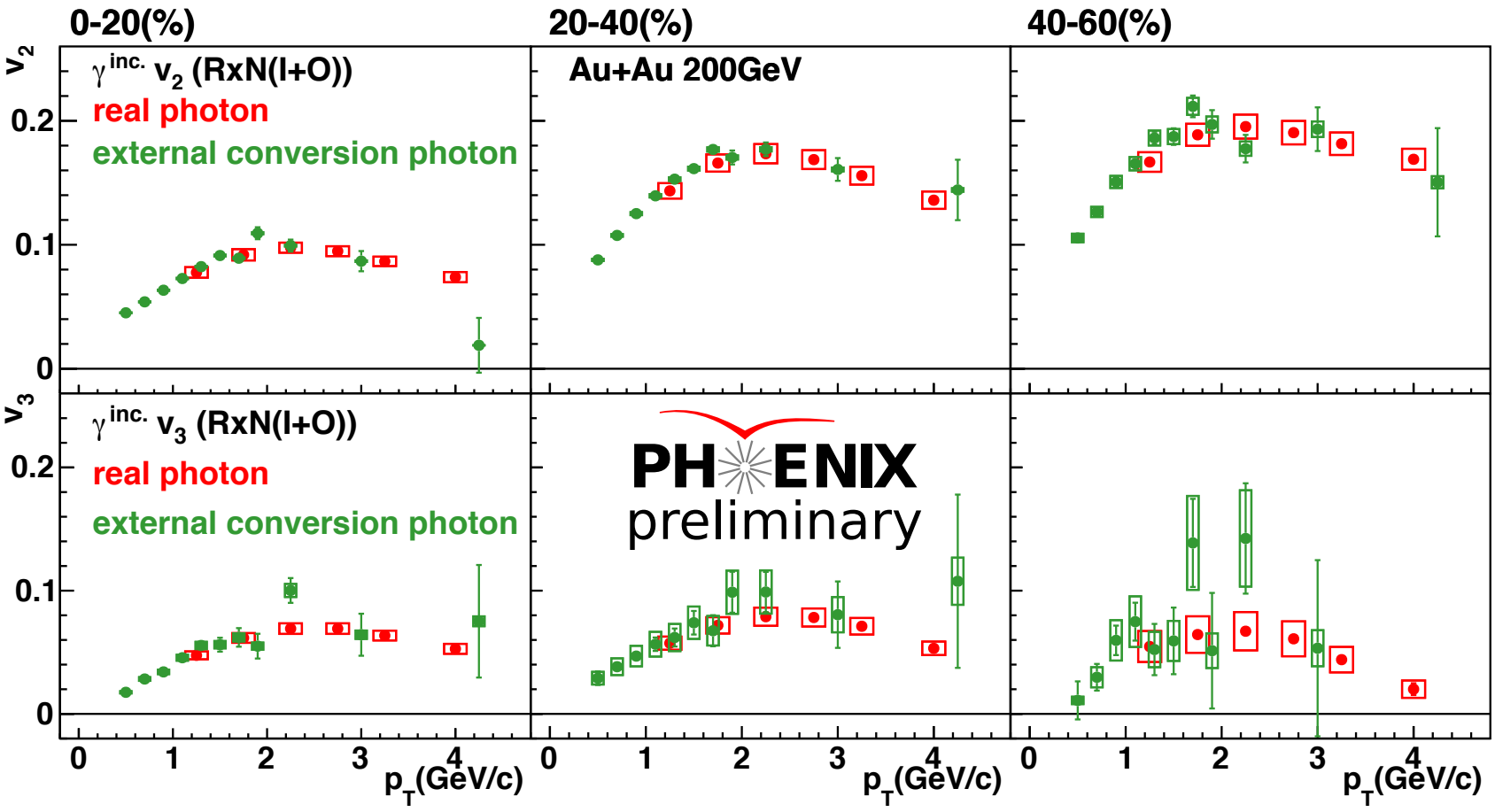




RxN(I+O) : $1.0 < |\eta| < 2.8$
RxN(In)+MPC : $1.5 < |\eta| < 3.8$

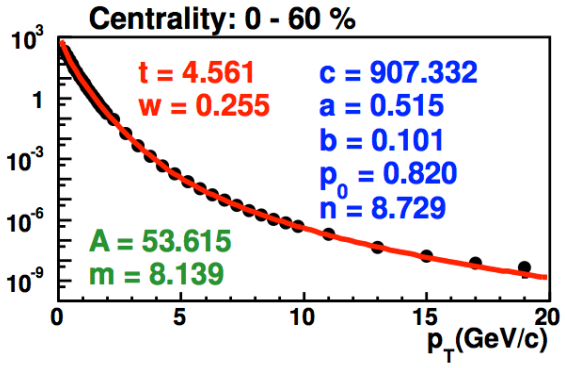
The magnitude of v_3 is comparable.

Comparison inclusive photon v_n



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

Input decay photon : p_T spectra

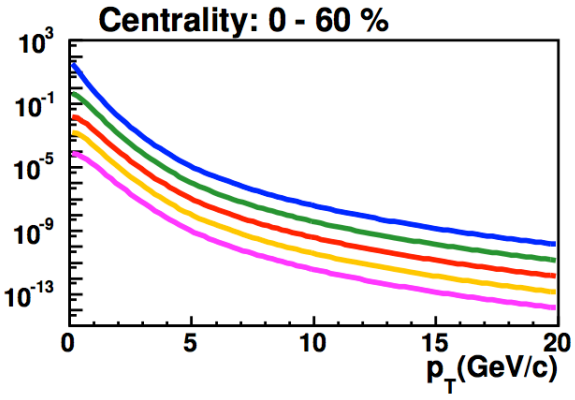


$$T(p_T)=\frac{1}{1+\exp((p_T-t)/w)}$$

$$F_0=\frac{c}{(\exp(-a*p_T-b*p_T^2)+p_T/p_0)^n} : \text{0-10GeV/c}$$

$$F_1=\frac{A}{p_T^m} : \text{6-20GeV/c}$$

$$\frac{d\sigma}{p_T dp_T}=T(p_T)F_0+(1-T(p_T))F_1$$



$\pi^0 \times 1.0$
$\eta \times 0.1$
$\omega \times 0.01$
$\rho \times 0.001$
$\eta' \times 0.0001$

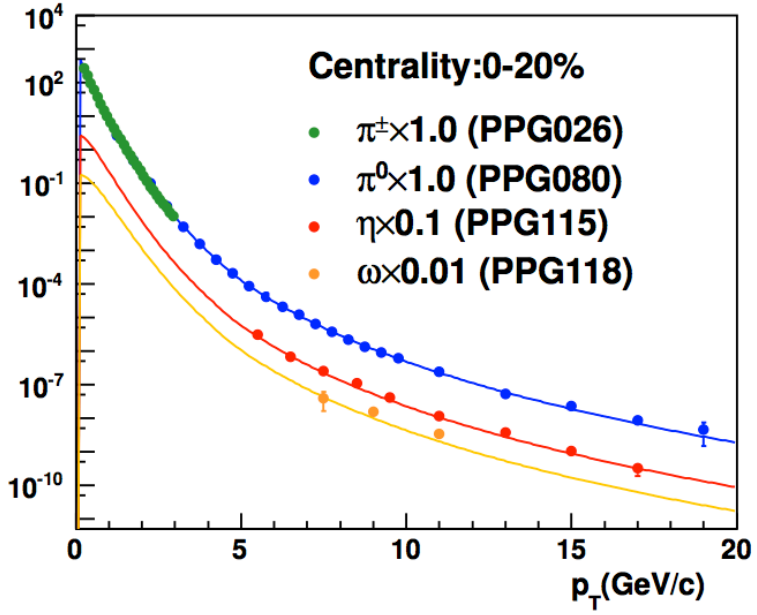
$$p_T' = \sqrt{p_{T,\pi^0}^2 + M_{meson}^2 - M_{\pi^0}^2}$$

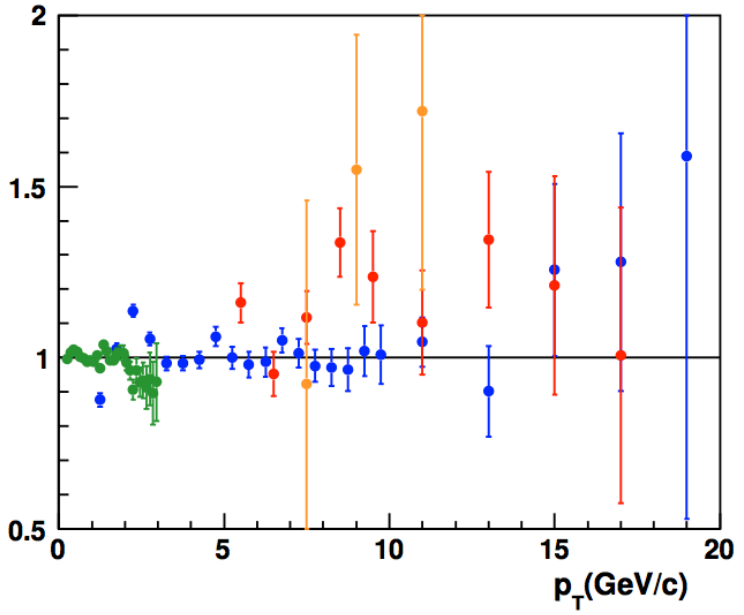
$\pi^{\pm}$ and π^0 p_T spectra are fitted and its function is used for estimating the other meson p_T spectra by m_T scaling.
They are used as a input.

Input decay photon : p_T spectra

The ratio of Each meson p_T spectra to π^0 p_T spectra is known to be constant at high p_T.

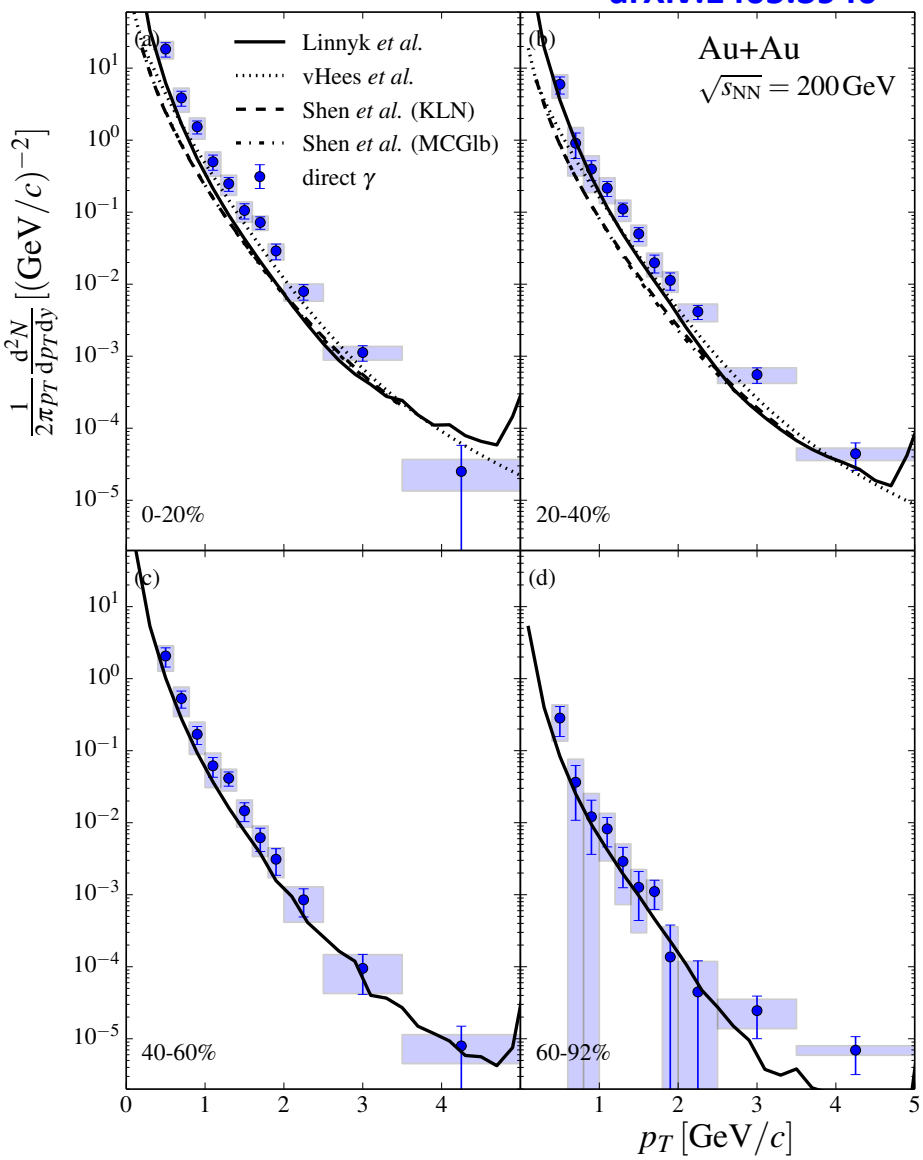
The table of each meson spectra ratio to π^0	
η/π^0	0.45±0.060
ω/π^0	0.83±0.120
ρ/π^0	1.00±0.300
η'/π^0	0.25±0.075





Yield : data vs theories

arXiv:1405.3940



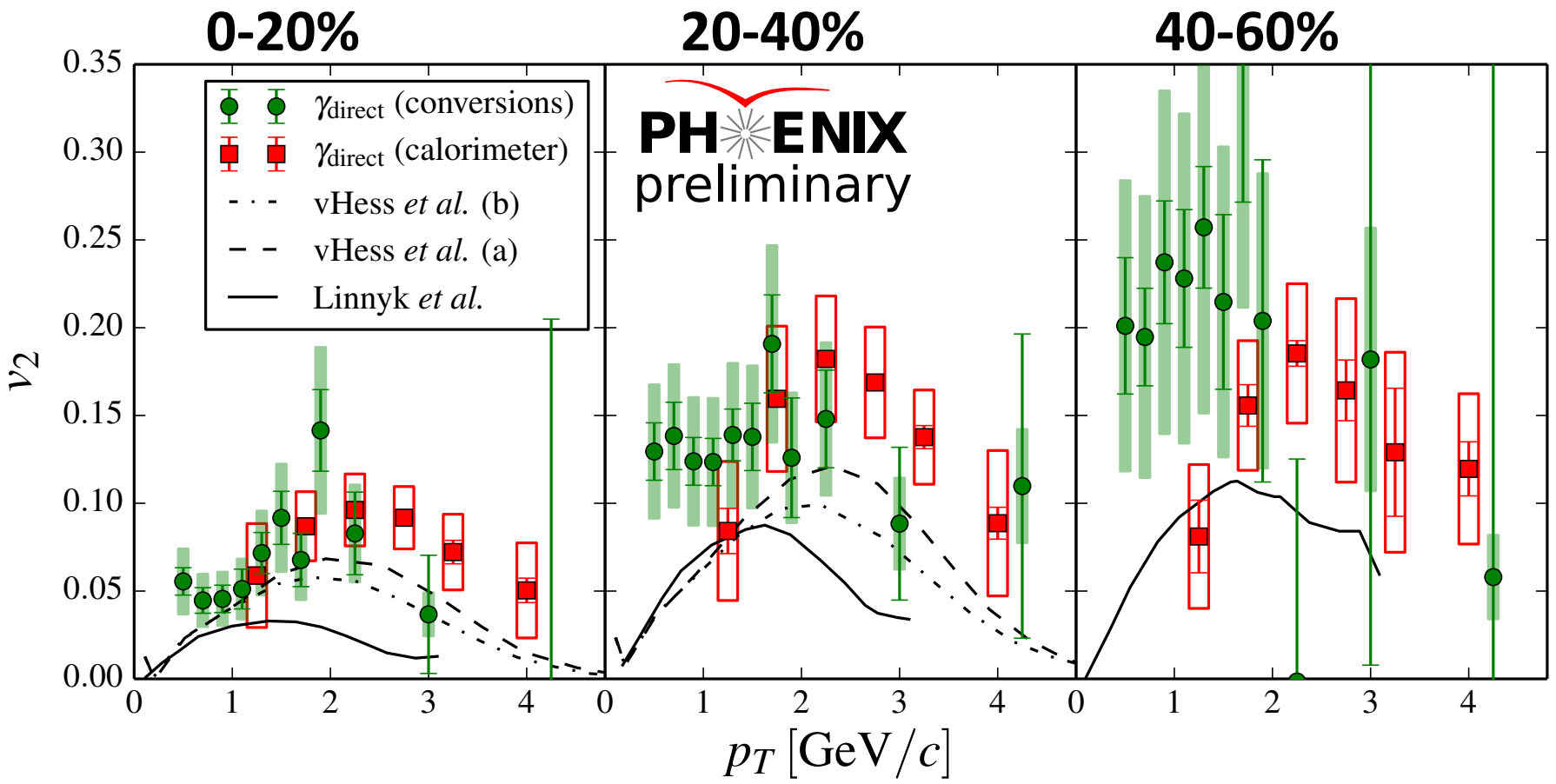
Linnyk et al.: PHSD transport model; Linnyk, Cassing, Bratkovskaya, P.R.C 89, 034908(2014)

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.

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

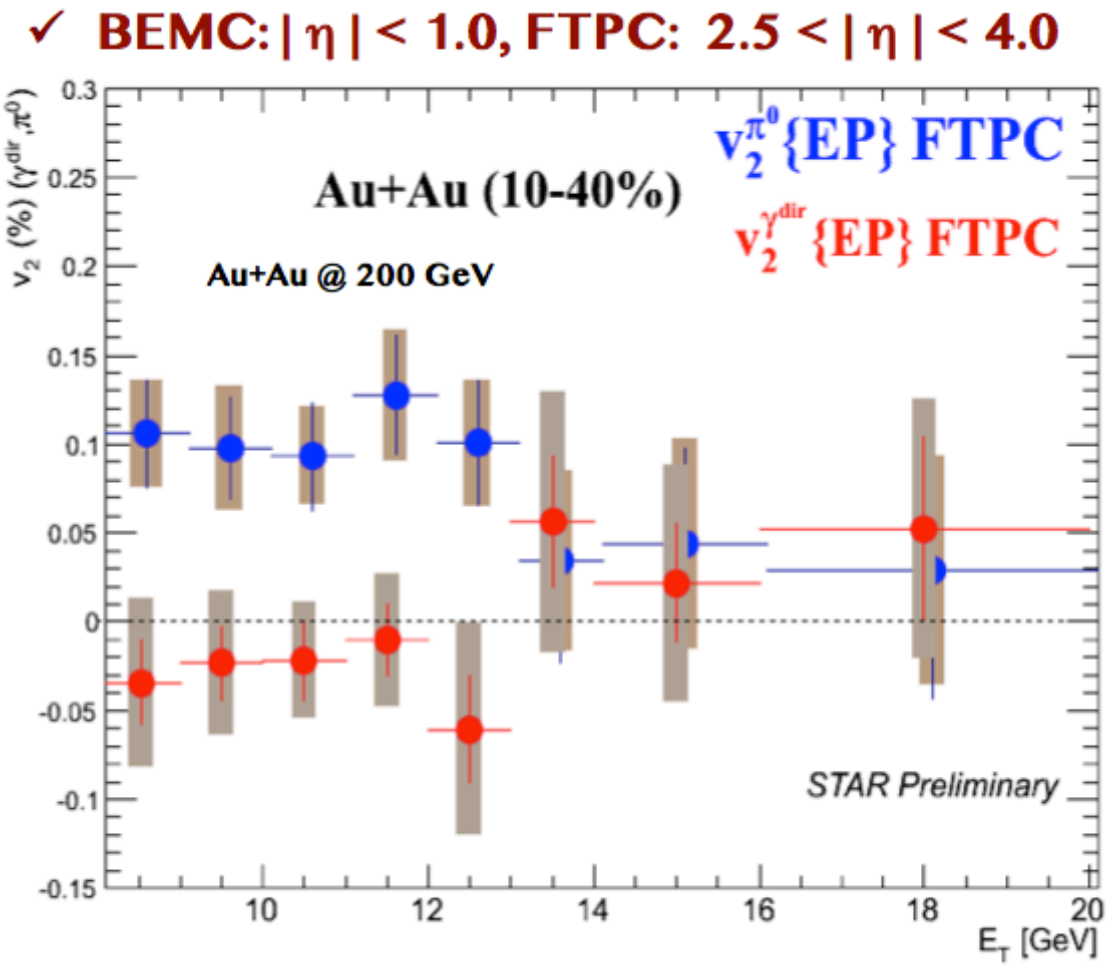


van Hees et al: P.R.C 84, 054906 (2011)

Linnyk et al.: PHSD model, private communication

π^0 and $\gamma^{dir.}$ v_2 measurement by STAR

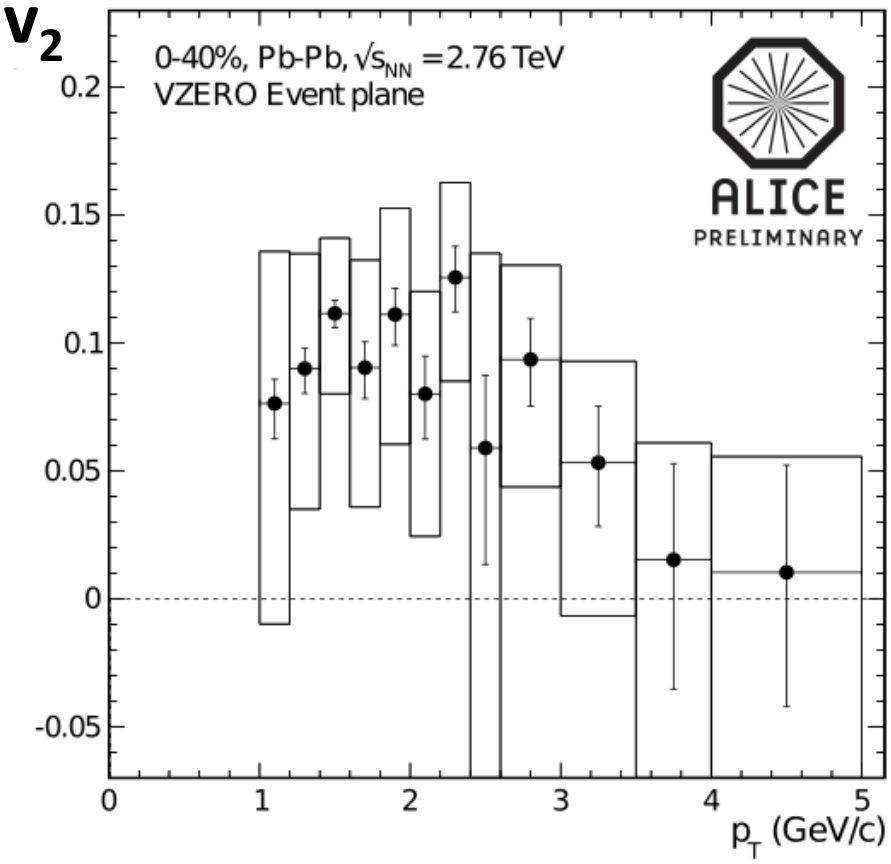
Ahmed M. Hamed
shown at QM



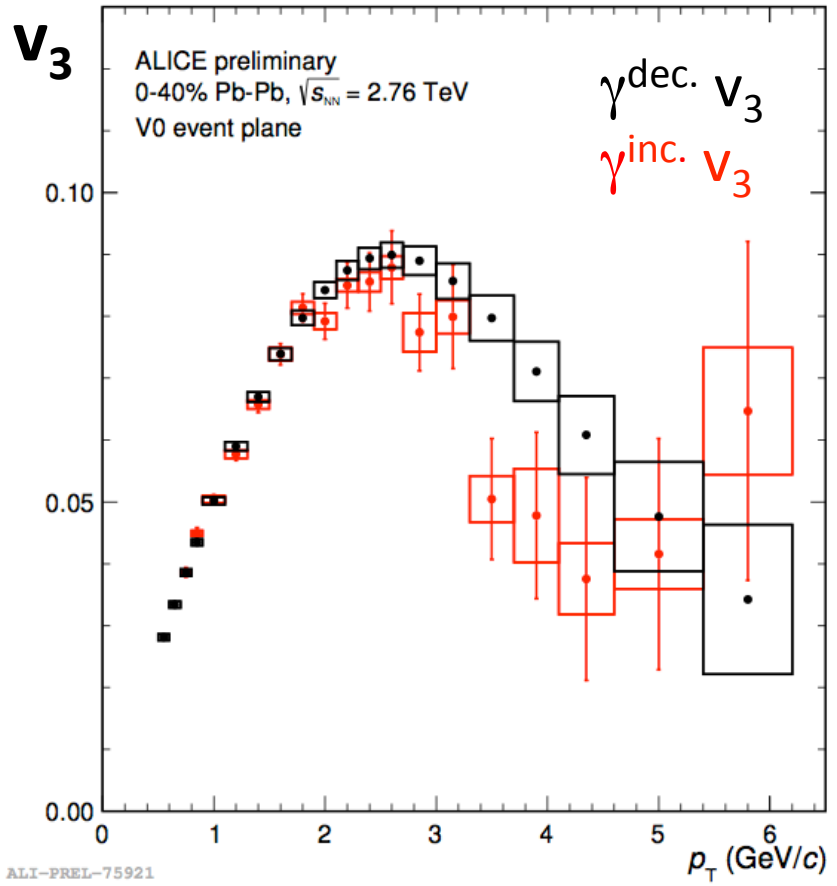
$\gamma^{dir.}$ v_2 in high E_T region are consistent with 0 within systematic uncertainty, while π^0 has positive v_2.

photon v_n measurement by ALICE

arXiv:1212.3995v2



Friederike shown at QM



It is also observed that $\gamma^{dir.}$ v_2 is positive in low p_T at LHC-ALICE.
v_3 measurement is ongoing.