# Measurement Of Direct Photon Collective Flow In Au+Au $\sqrt{s_{NN}}$=200GeV collisions at RHIC-PHENIX experiment

Sanshiro Mizuno
for the PHENIX collaboration
University of Tsukuba, RIKEN

mail to : s1230082@u.tsukuba.ac.jp

筑波大学
University of Tsukuba

RIKEN

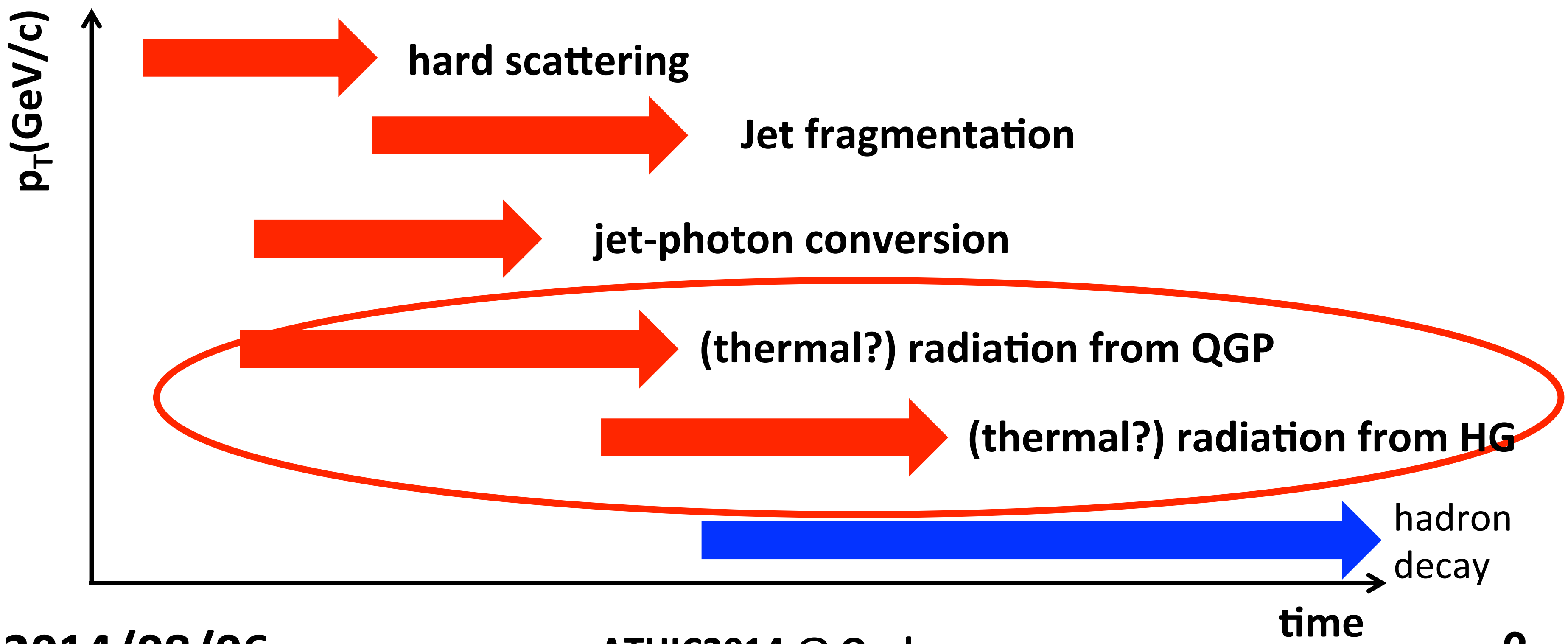
PHENIX

ATHIC2014
OSAKA

# 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**

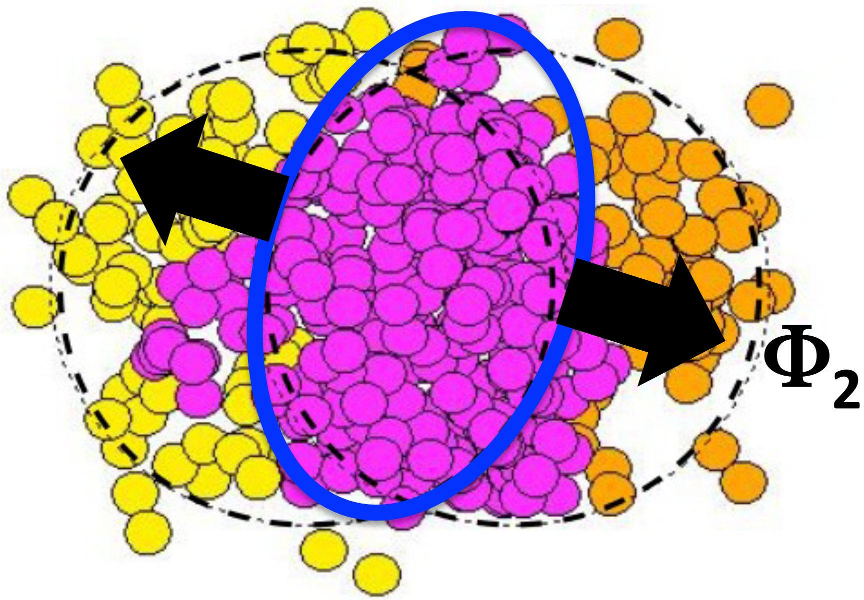


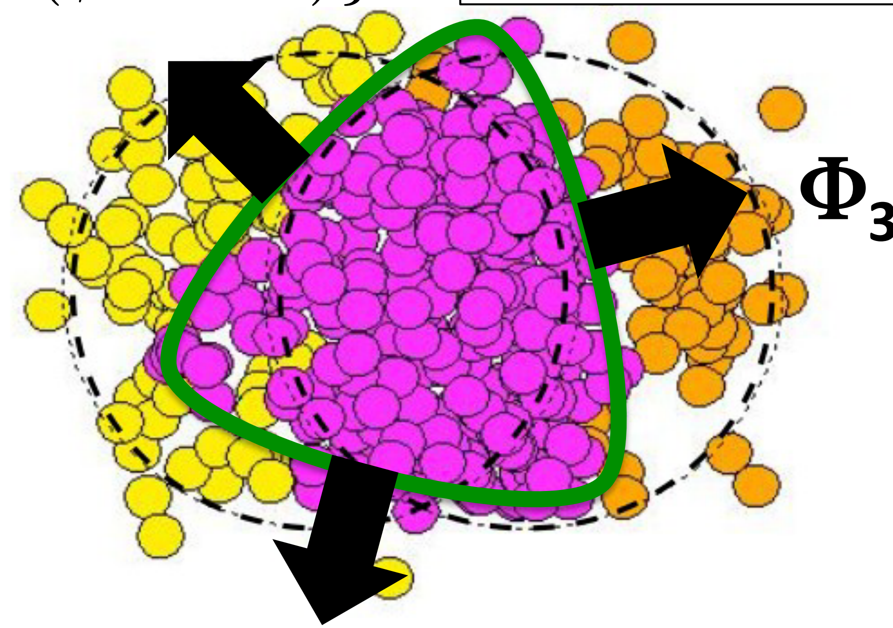
# Higher Order Azimuthal Anisotropy

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

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

$\Phi_n$ : Event Plane



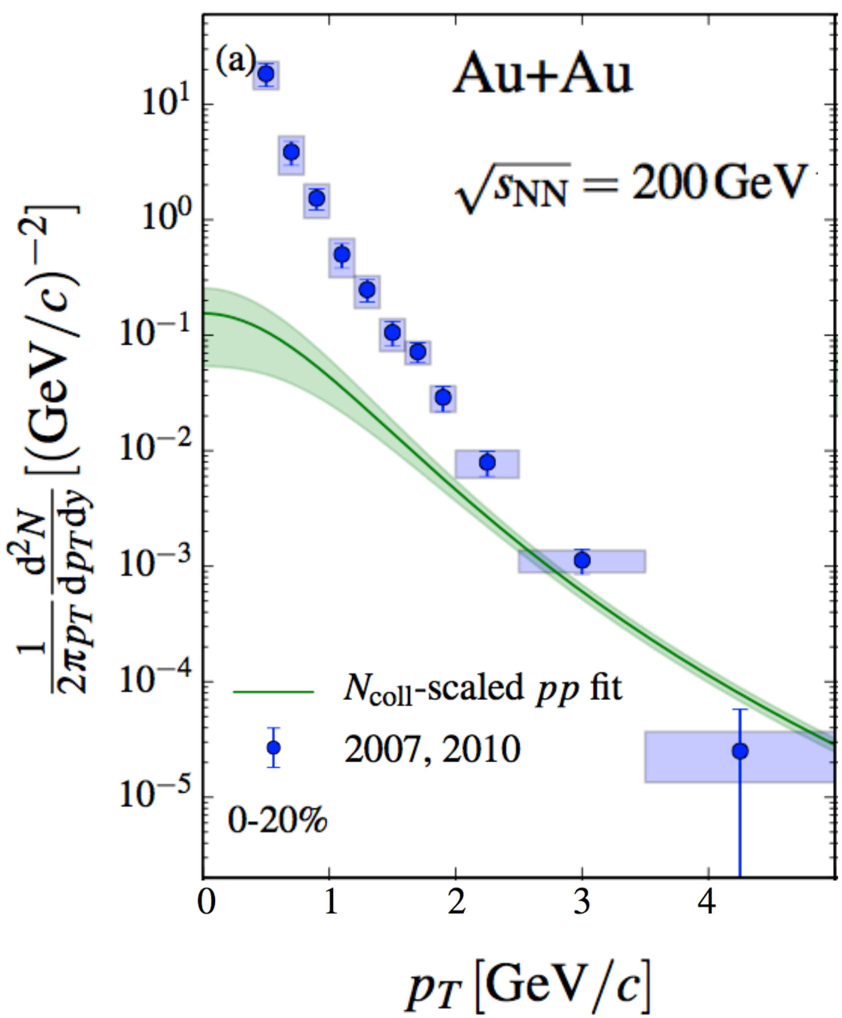




$v_3$ comes from participant position fluctuations, viscosity dampens higher order terms.

- **Define initial geometry calculating model**
- **Constrain $\eta/s$ 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.

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

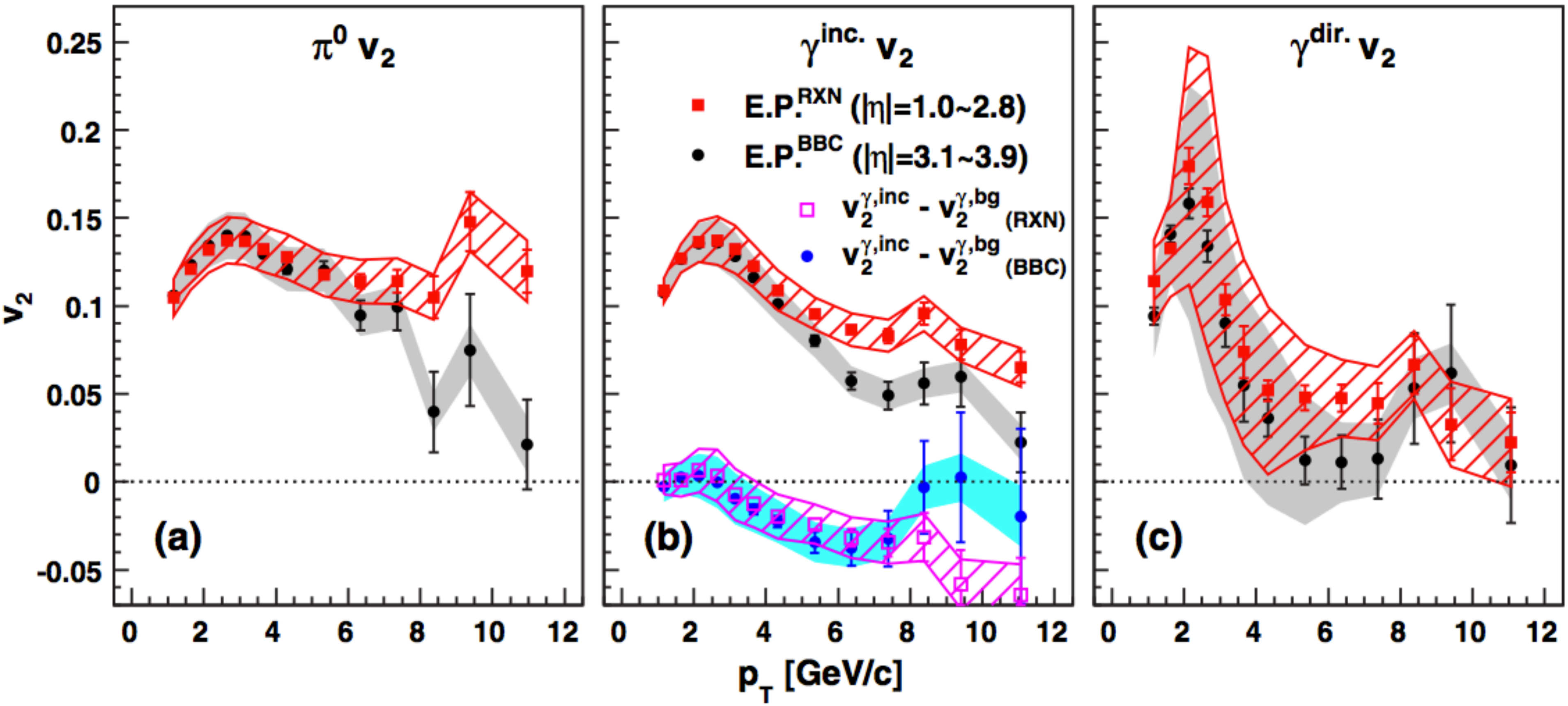
The excess of $p_T$ spectra are fitted and effective temperature is extracted.

It is about 240 MeV.

Photons are emitted from very hot medium at early time of collisions.

# Direct Photon Elliptic Flow ($v_2$)

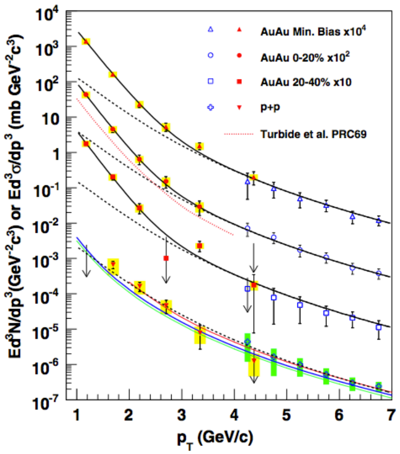
P.R.L. 109, 122302(2012)

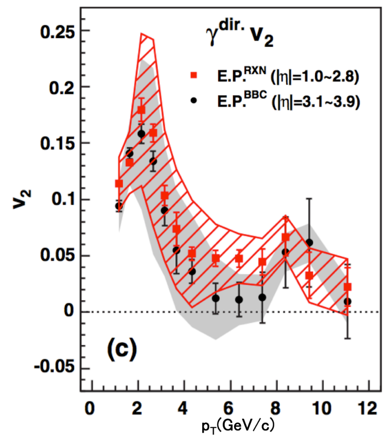


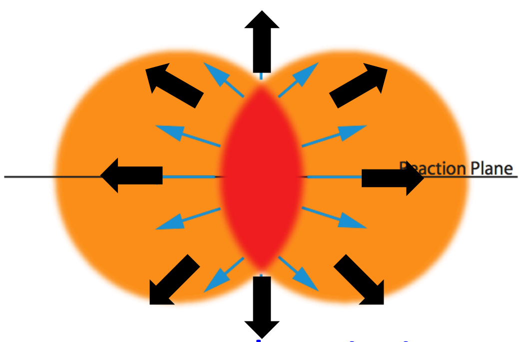

It is observed that positive $\gamma^{dir.}$ $v_2$ in low $p_T$ and the magnitude of it is comparable to that of hadron $v_2$.

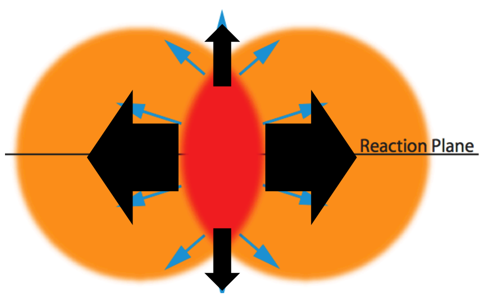
Photon is emitted at late time of collisions, when temperature is low.

# 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 ($v_2$).

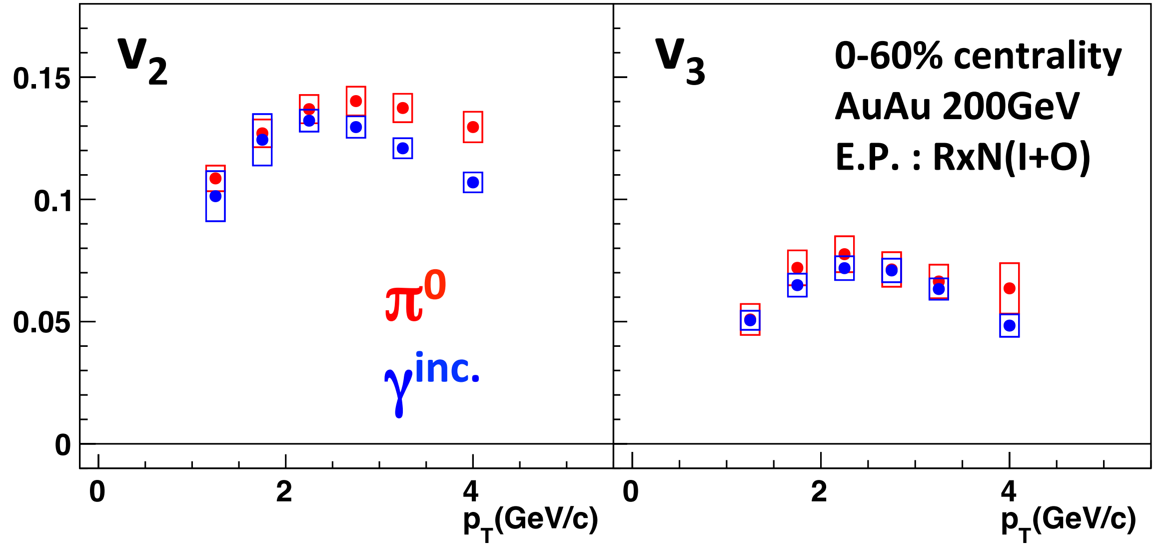
# Motivation

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

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

It could help understanding and constrain photon production mechanism.
In this talk, new results for $v_3$ in several centralities are shown.

# Analysis Flow



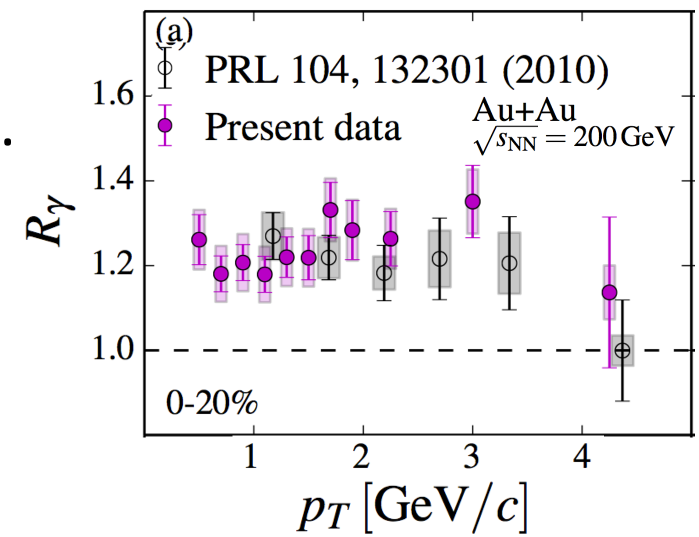

**$\pi^0$, $\gamma^{inc.}$ $v_n$ measurement**

arXiv:1405.3940

**$\gamma^{dec.}$ $v_n$ estimation from $\pi^0$ $v_n$**

Mesons spectra are assumed by $m_T$ scaling.

Mesons $v_n$ are assumed by NCQ scaling.




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

$R_\gamma$ measured by external photon conversion method is used.

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

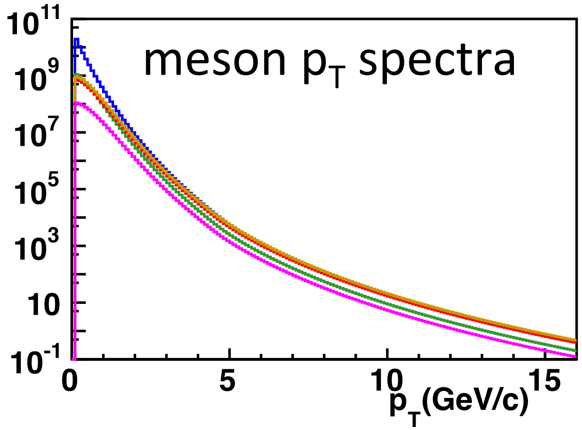
$$R_\gamma = N_{inc.}/N_{dec.}$$

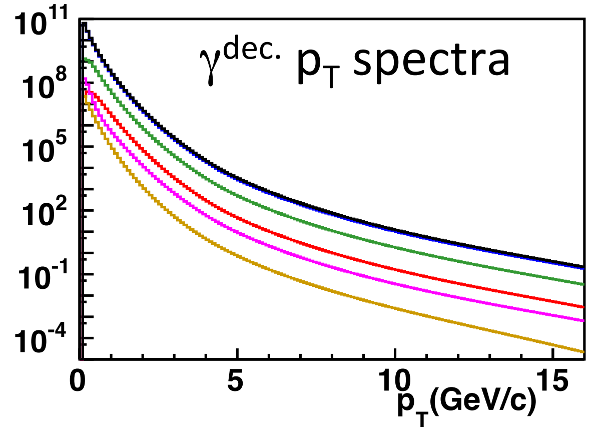
# Hadronic Decay Photon

π ρ
η η'
ω all $\gamma^{dec.}$

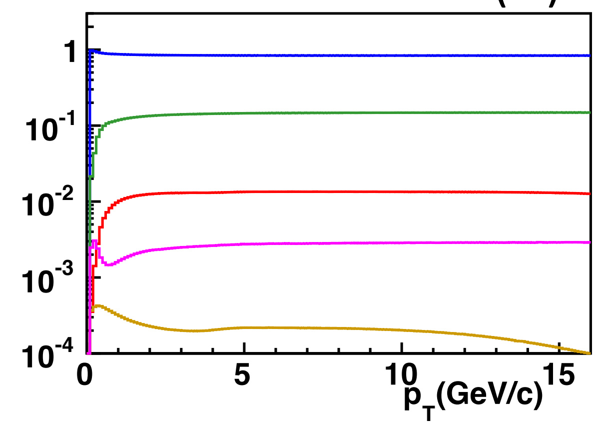
The $p_T$ spectra and $v_n$ are estimated from π.

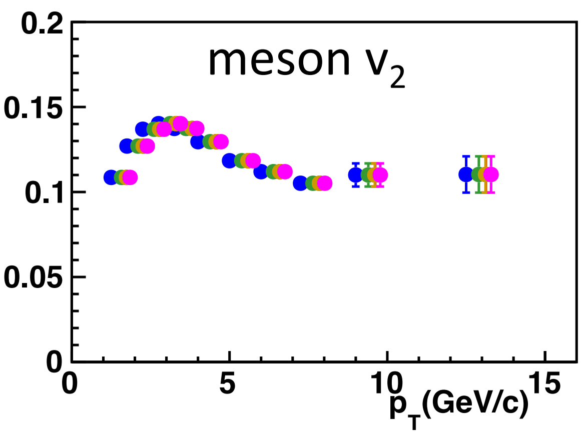
- $p_T$ spectra : $m_T$ scaling
- $v_n$ : quark number scaling

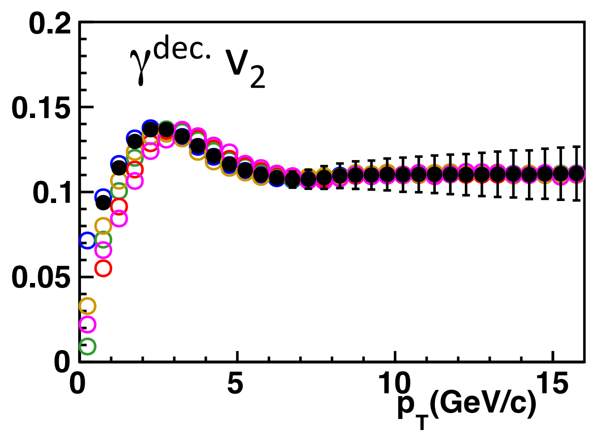



contribution ratio ($R^i$)




$m_T$ scaling

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

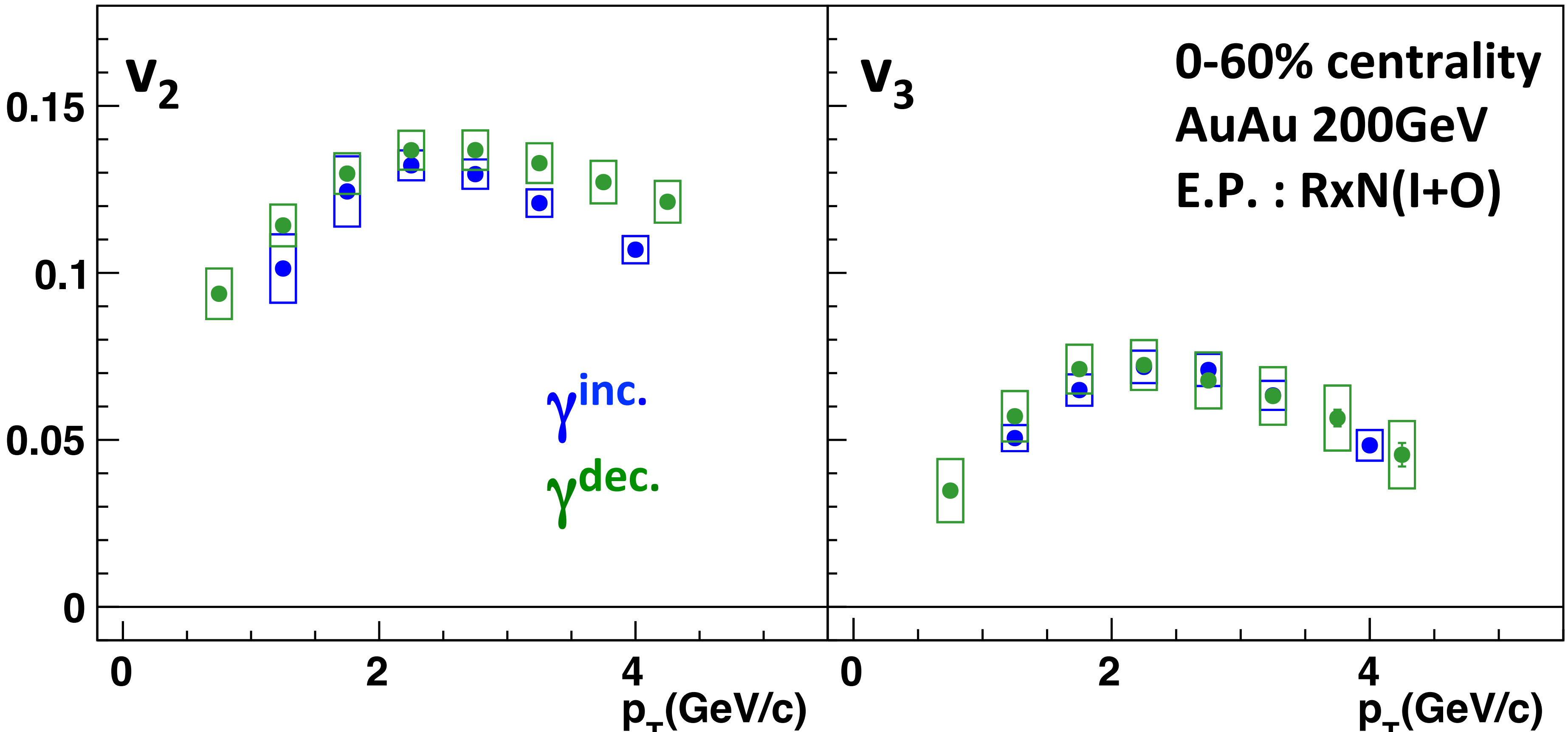
decay photon $v_n$

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

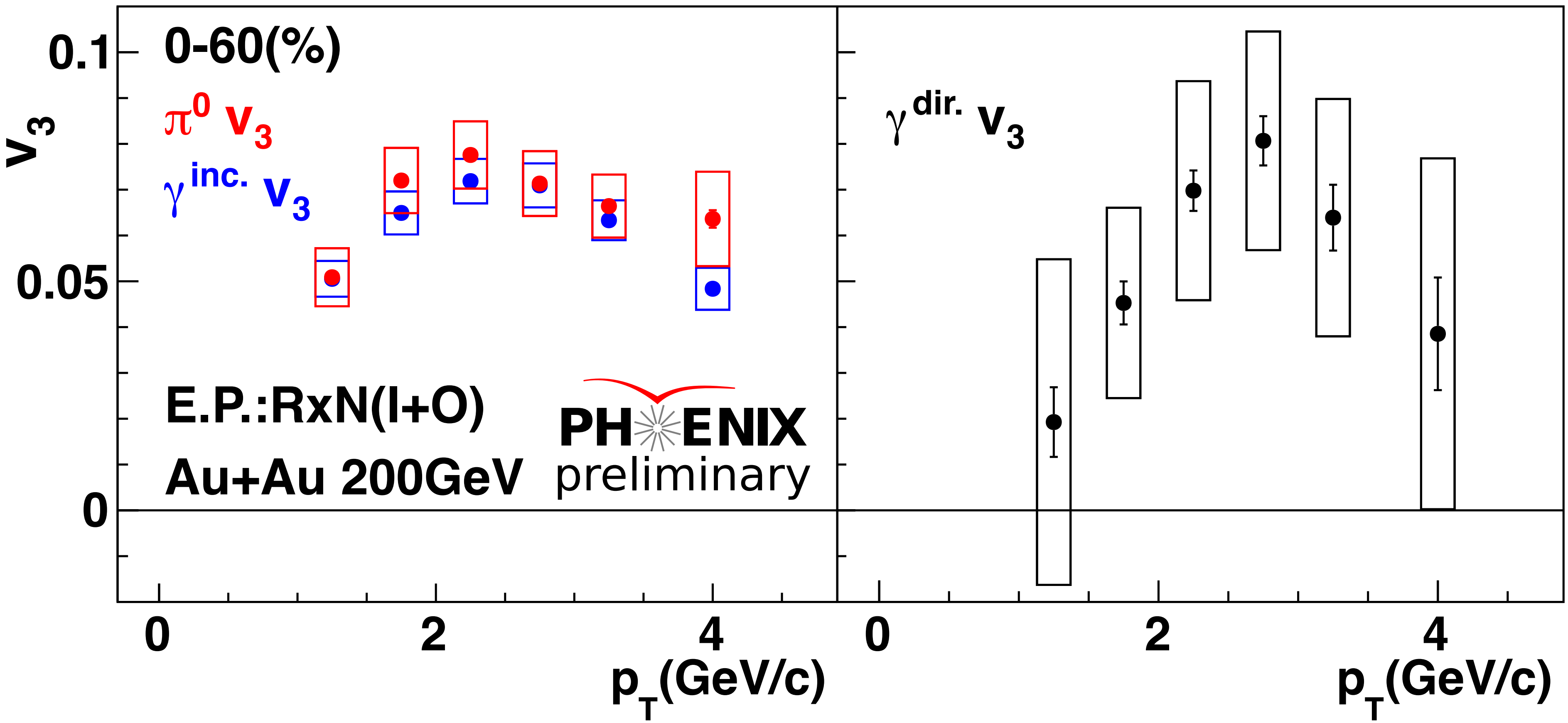
# Inclusive and decay photon $v_n$ comparison

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

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



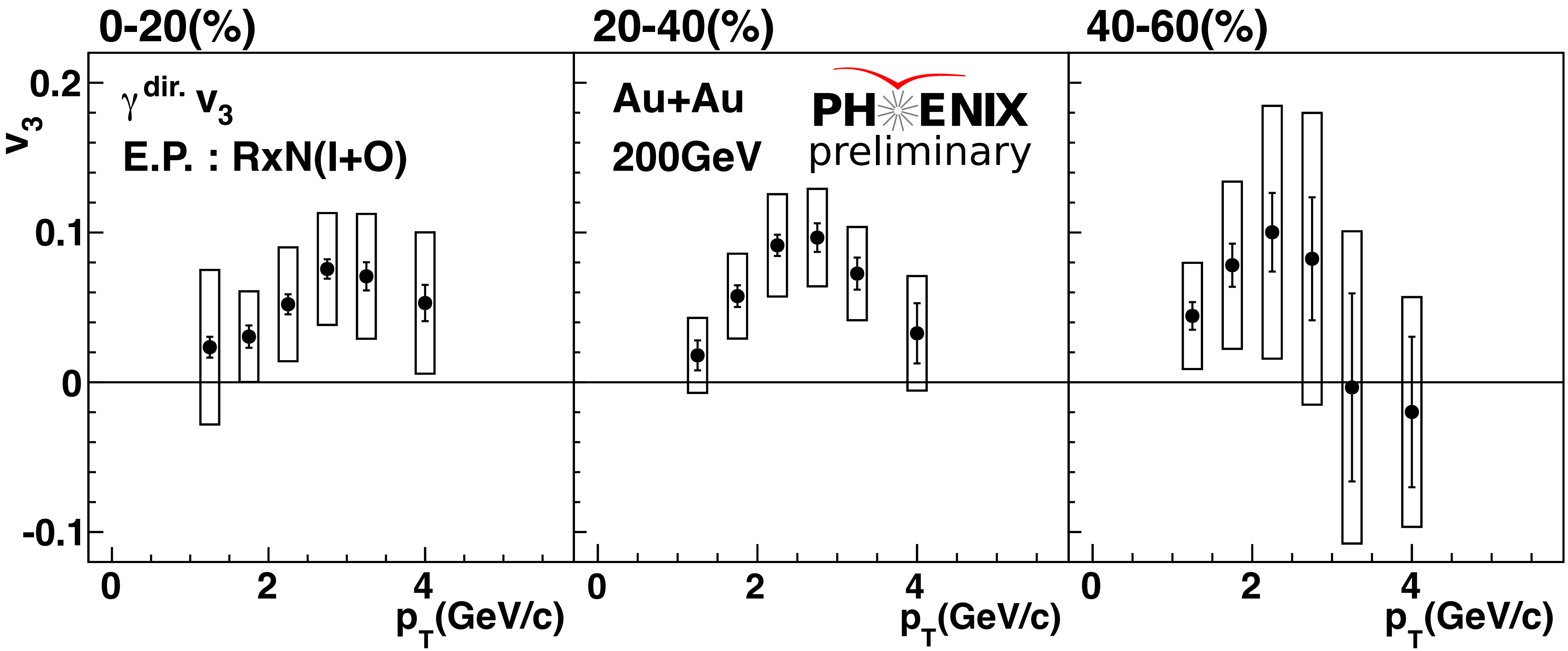
# The Result of Direct Photon $v_3$




The magnitude of $\gamma^{dir.}$ $v_3$ is similar to $\pi^0$, 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 $v_3$

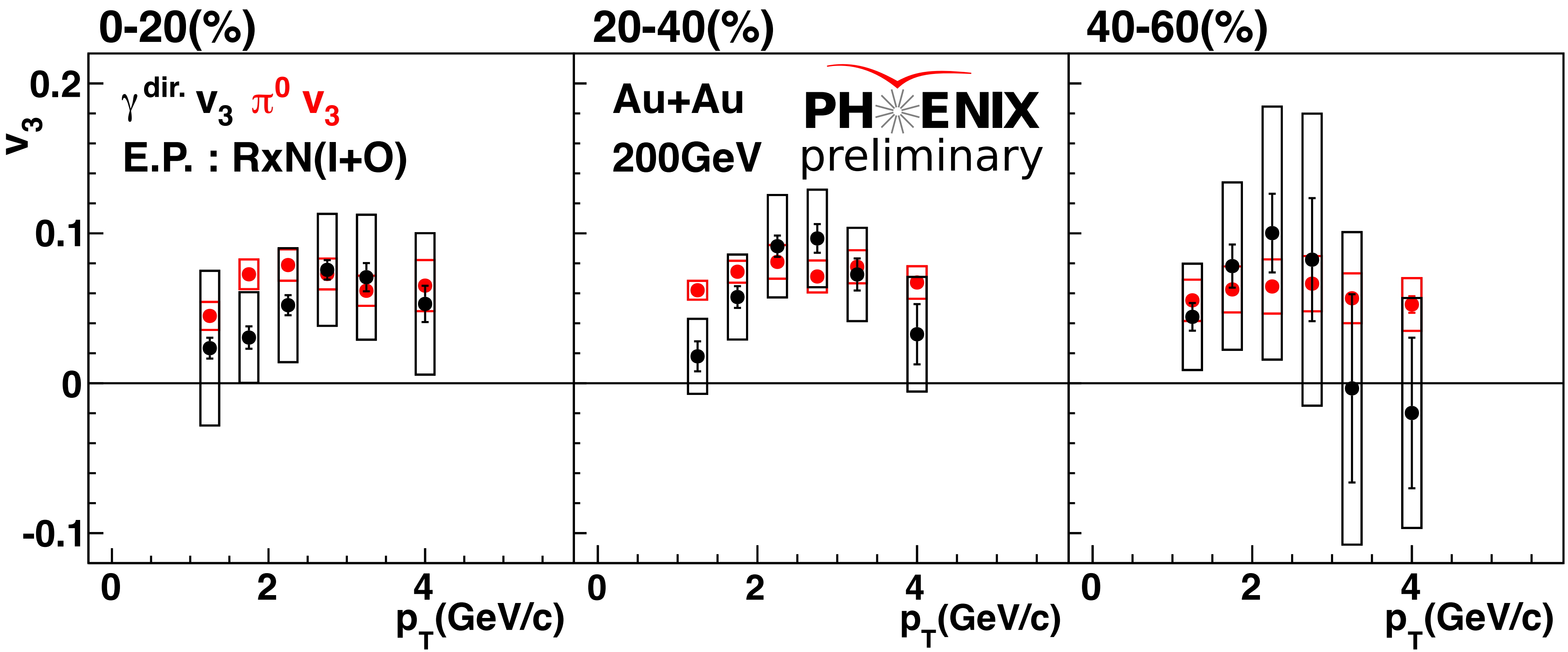



$\eta$ range of RxN(I+O) is from 1.0 to 2.8.

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

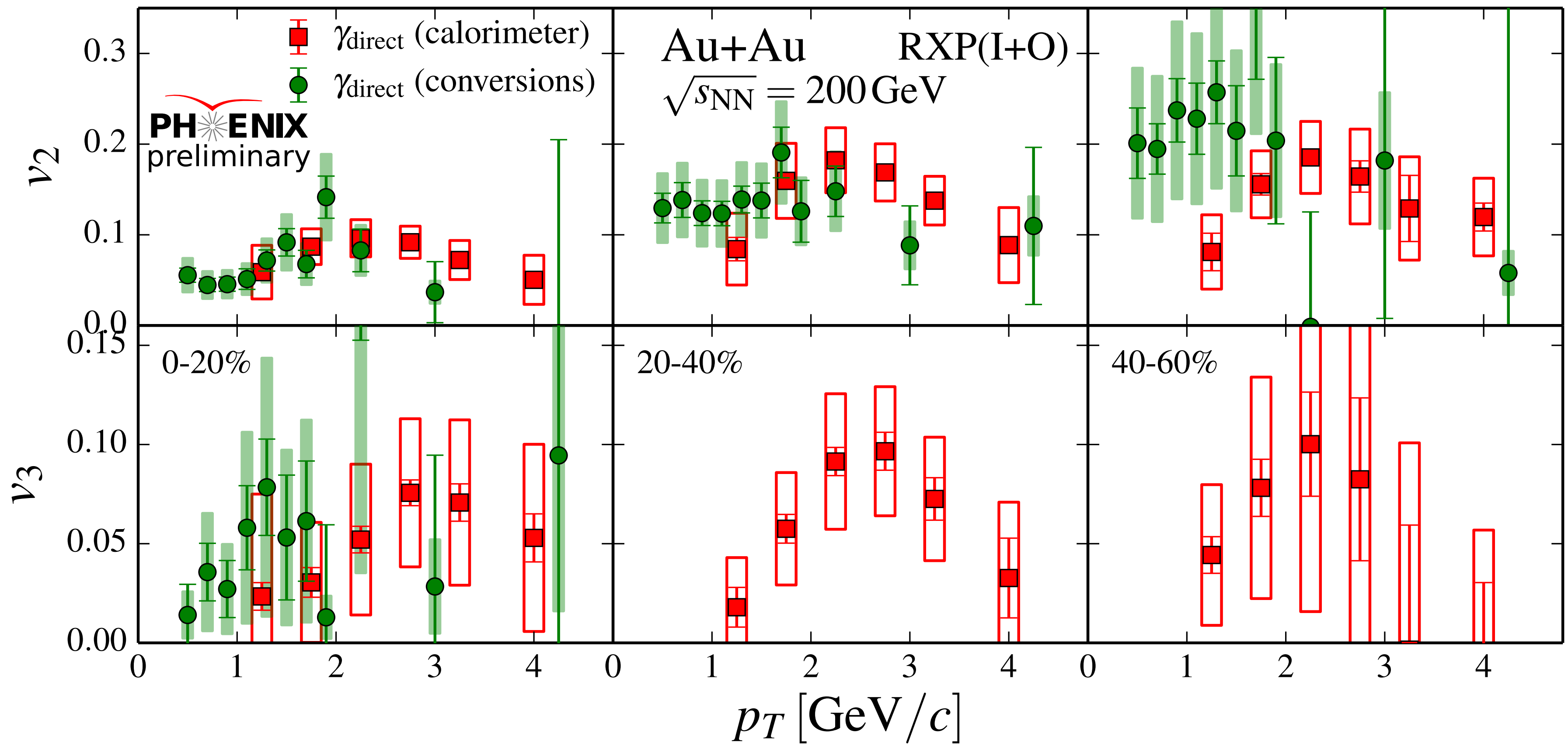
No strong centrality dependence: similar tendency as for charged hadrons (P.R.L. 107, 252301 (2011)) and $\pi^0$.

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




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

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

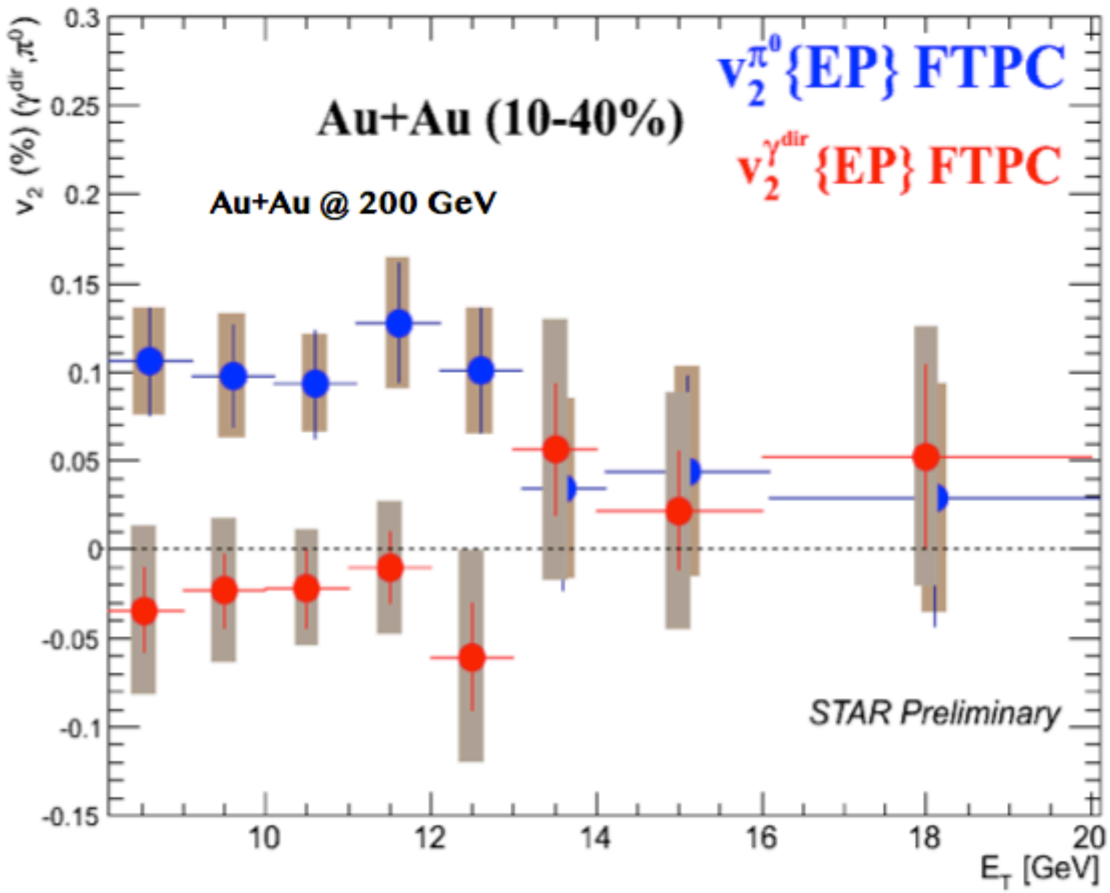



The calorimeter and conversion photon measurements are consistent within systematic uncertainty.

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

Ahmed M. Hamed shown at QM

✓ BEMC: |η| < 1.0, FTPC: 2.5 < |η| < 4.0

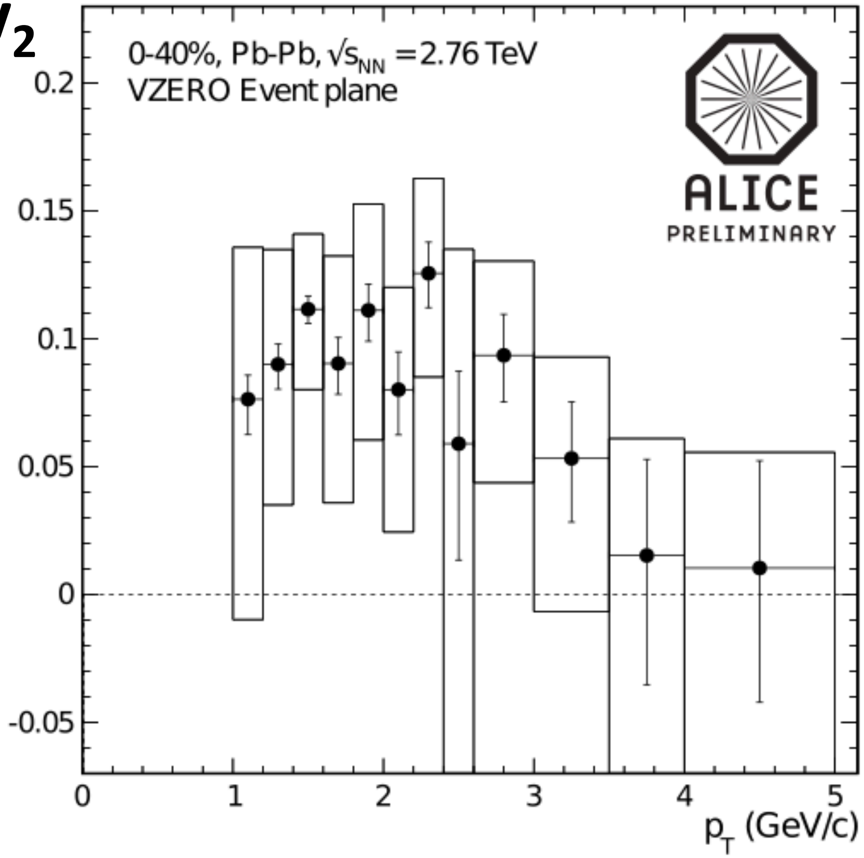



$\gamma^{dir.}$ $v_2$ in high $E_T$ region are consistent with 0 within systematic uncertainty, while $\pi^0$ has positive $v_2$.

# photon $v_n$ measurement by ALICE

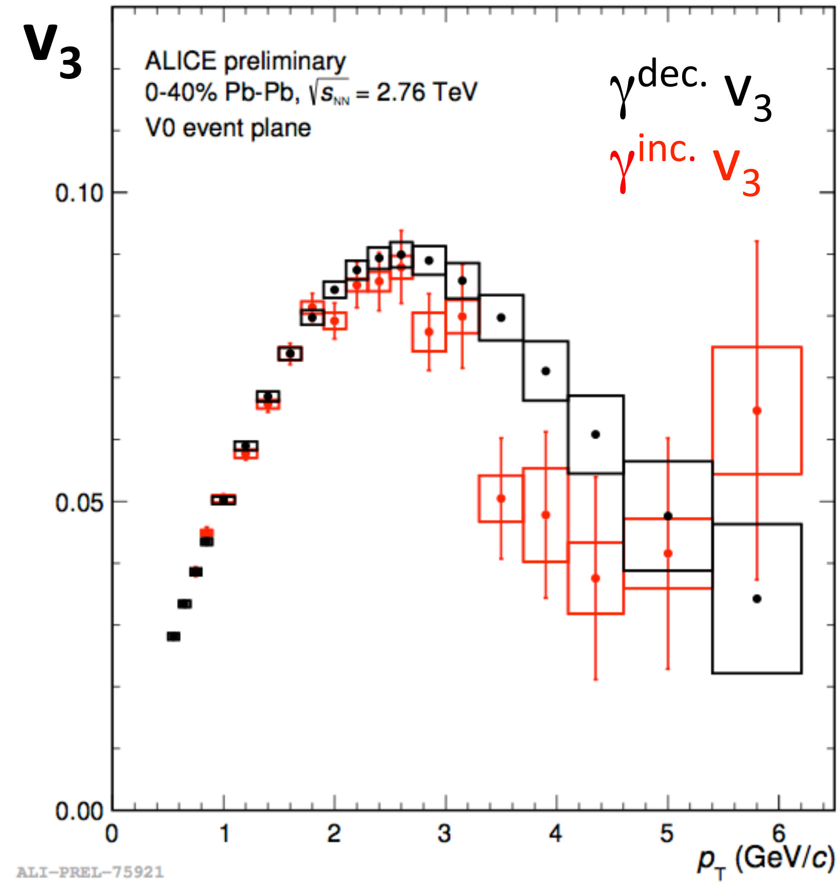
arXiv:1212.3995v2

$v_2$




Friederike shown at QM

$v_3$




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

# Summary

Soft photons are expected to do 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 $v_3$.

The other experiment also study direct photon $v_n$ measurement.

# 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

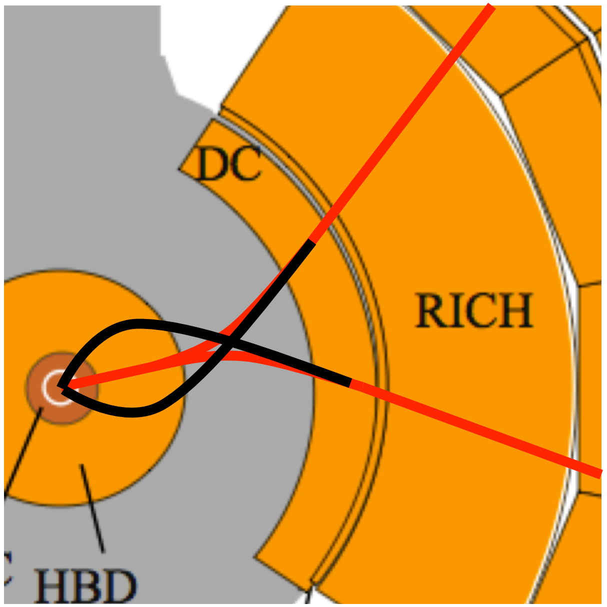
**$3.1 < |\eta| < 3.8$**

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.

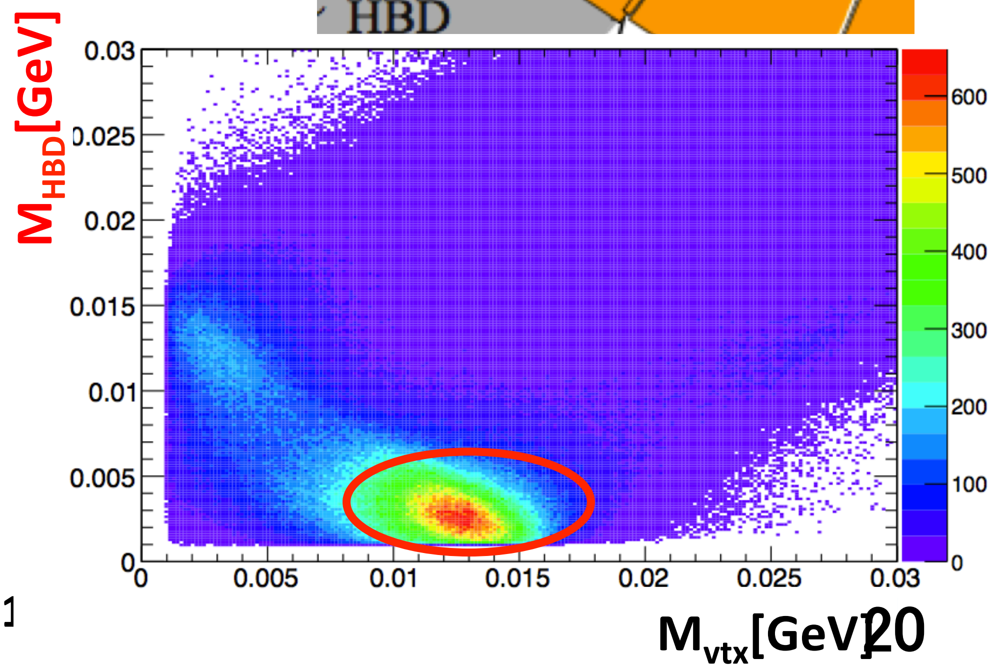
✓ less hadron contamination

✓ good momentum resolution

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

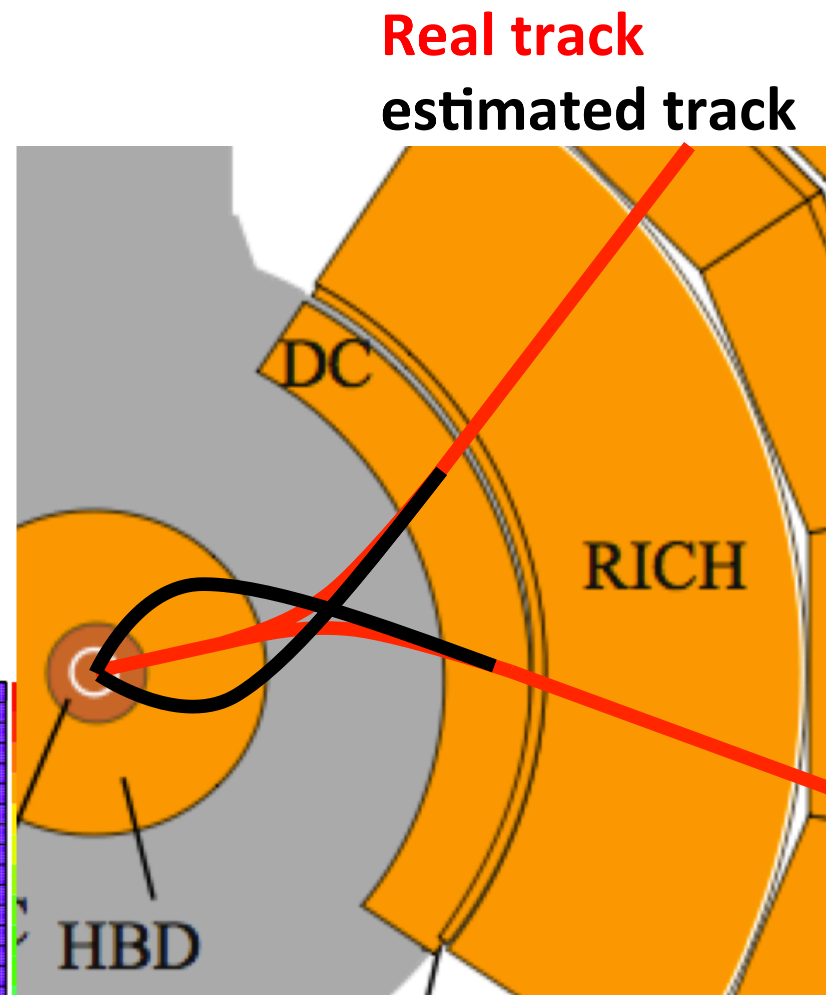
**Extended to lower $p_T$**

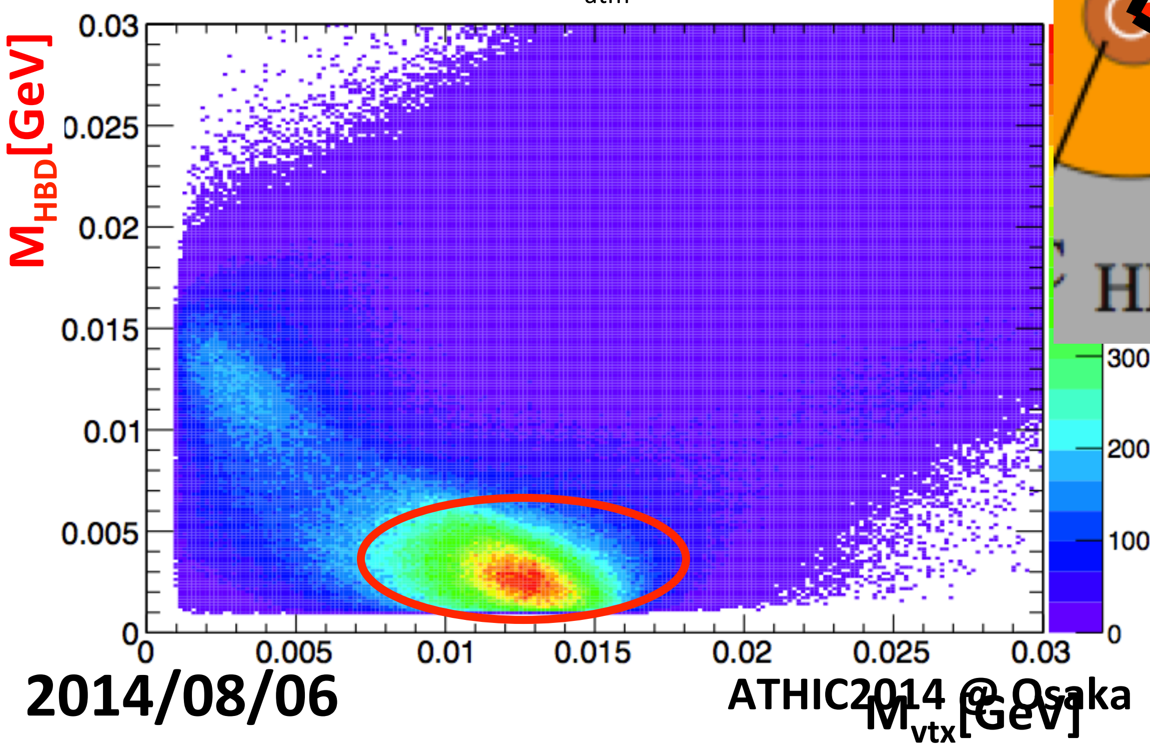
**low statistics**



# External conversion photon

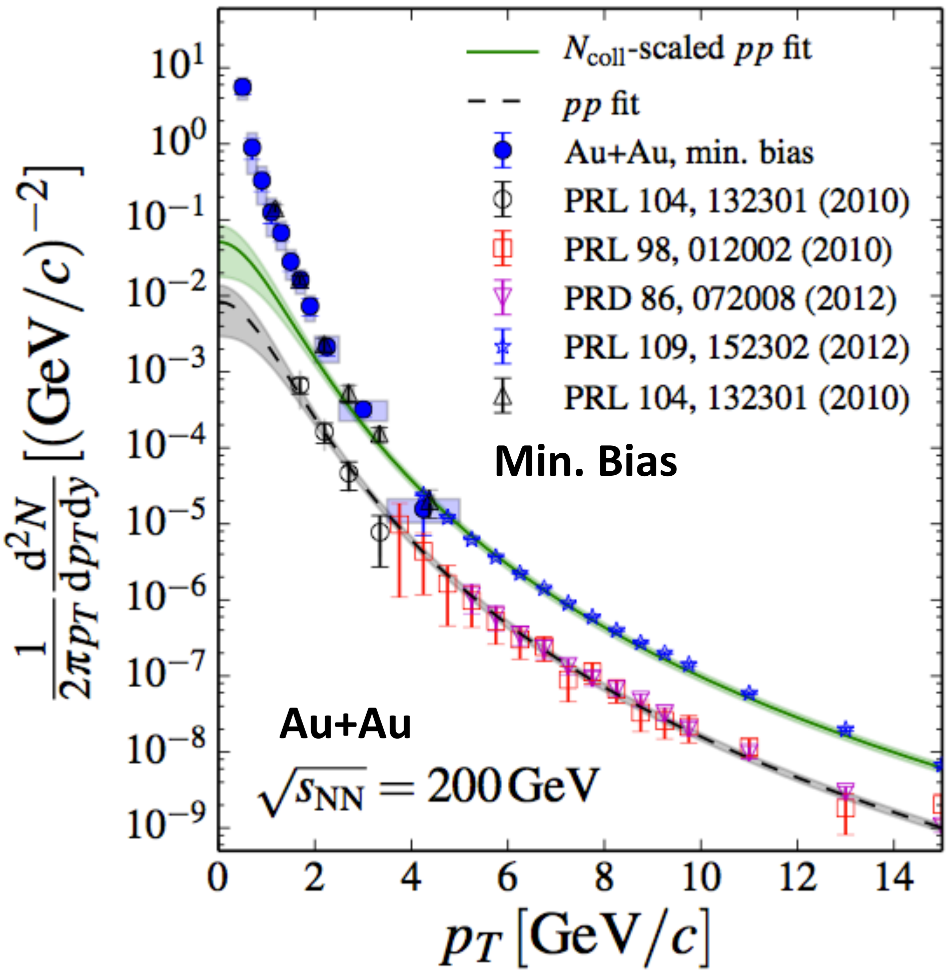
1) real photon converts to $e^+e^-$ in HBD backplane
2) default assumption: track come from the vertex
3) momentum of the conversion tracks will be mis-measured (see black tracks)
4) apparent pair-mass (about 12MeV) will be measured for phtons
5) assume the same tracks originate in the HBD backplane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

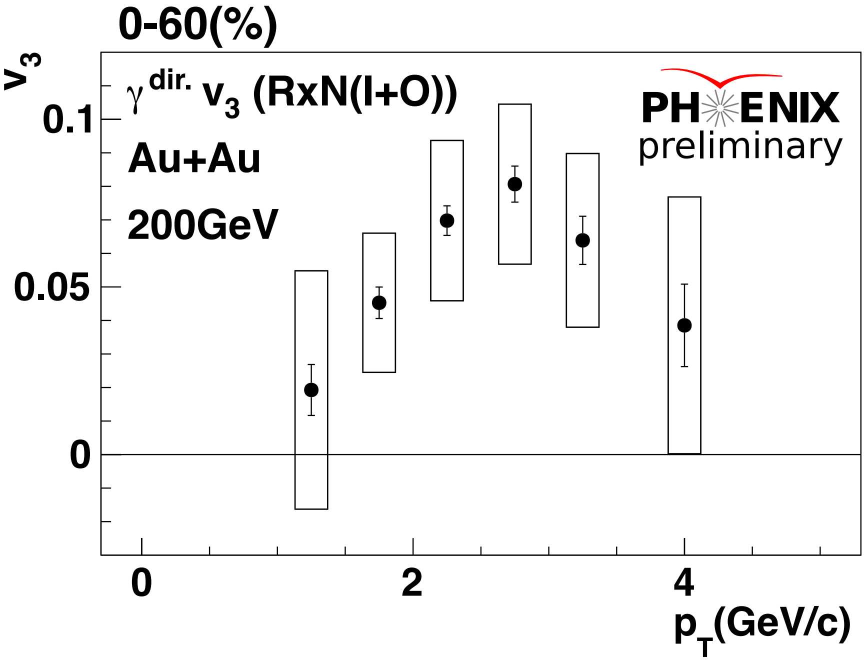
Using external photon conversion method achieved good agreement with previous results.

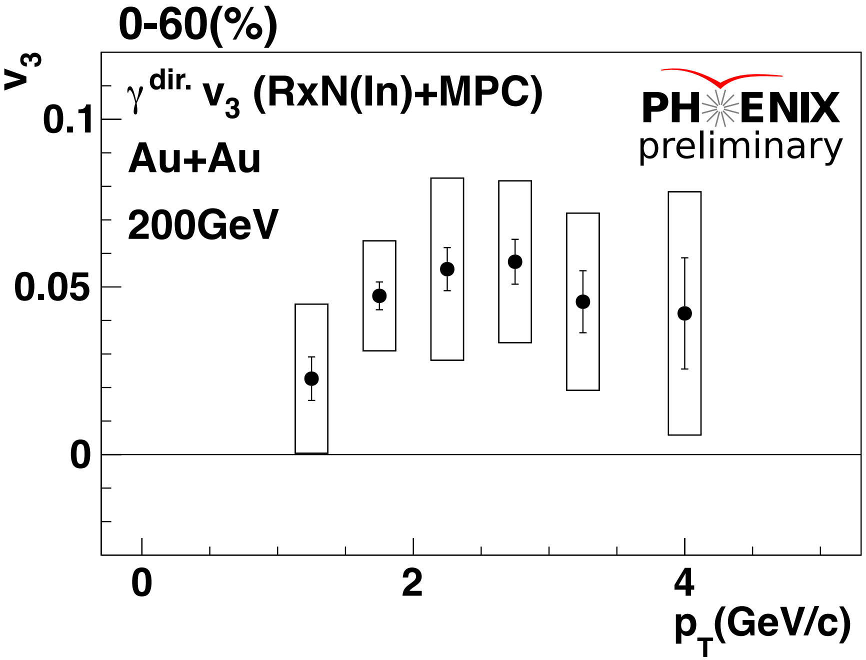
# The analysis information

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

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

# Comparison $\gamma^{dir.}$ $v_3$

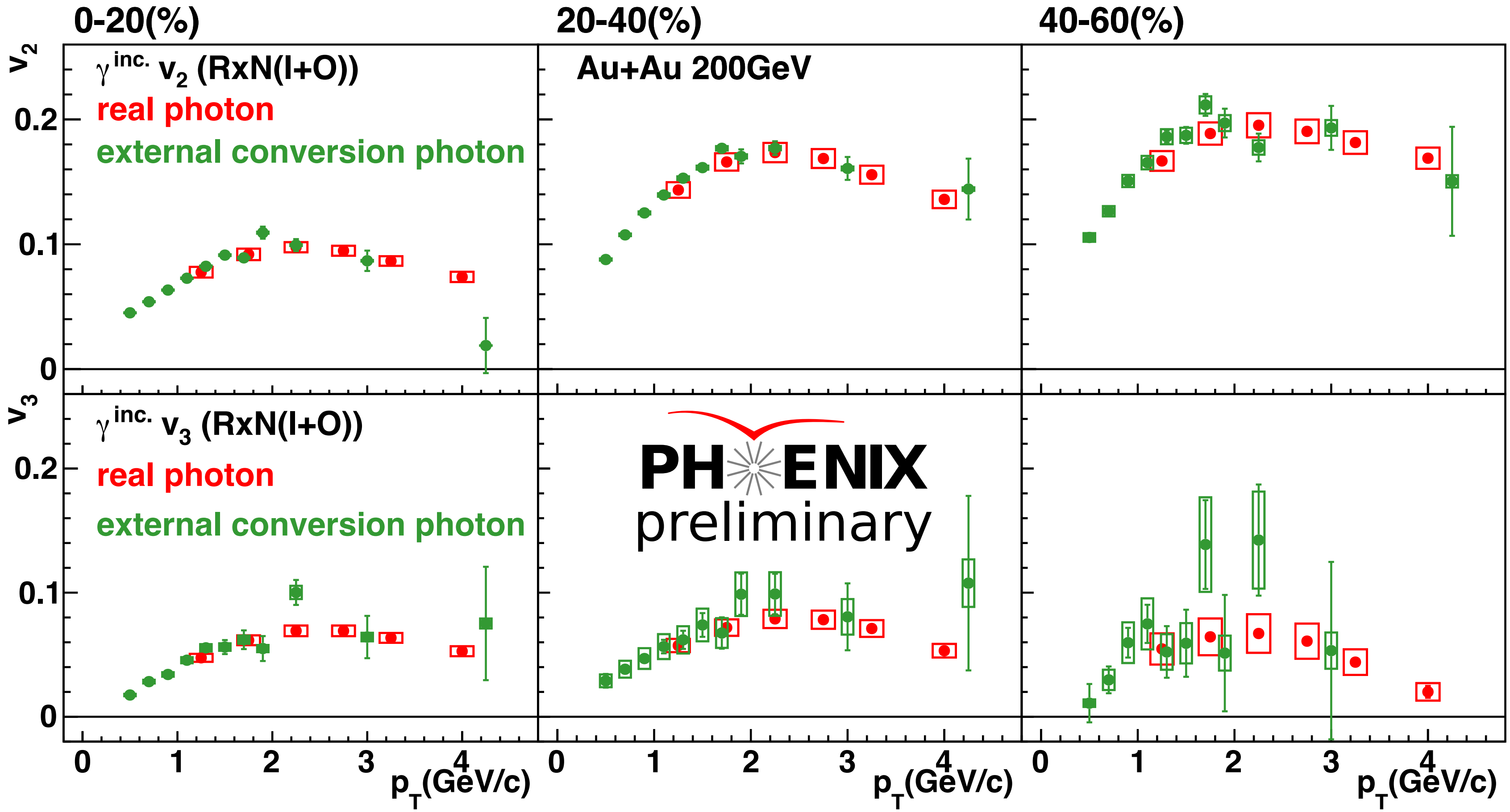



RxN(I+O) : $1.0 < |\eta| < 2.8$
RxN(In)+MPC : $1.5 < |\eta| < 3.8$

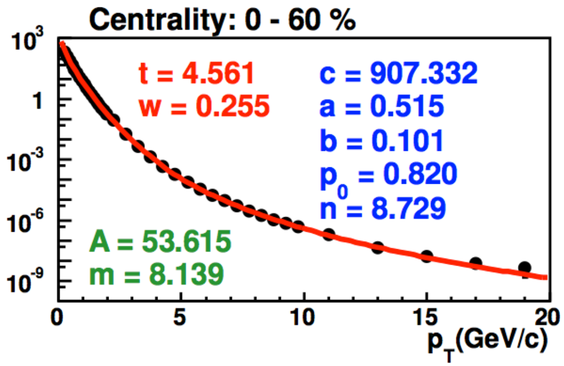
The magnitude of $v_3$ is comparable.

# 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

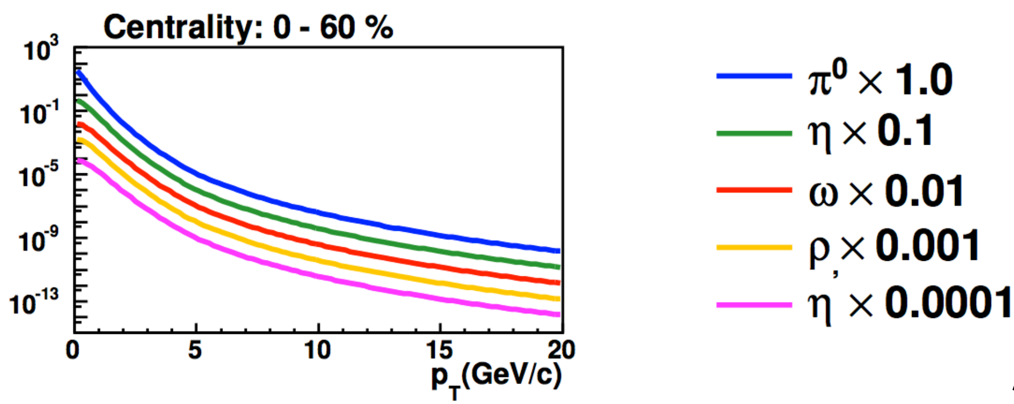



$$T(p_T)=\frac{1}{1+\exp((p_T-t)/w)}$$

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

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

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




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

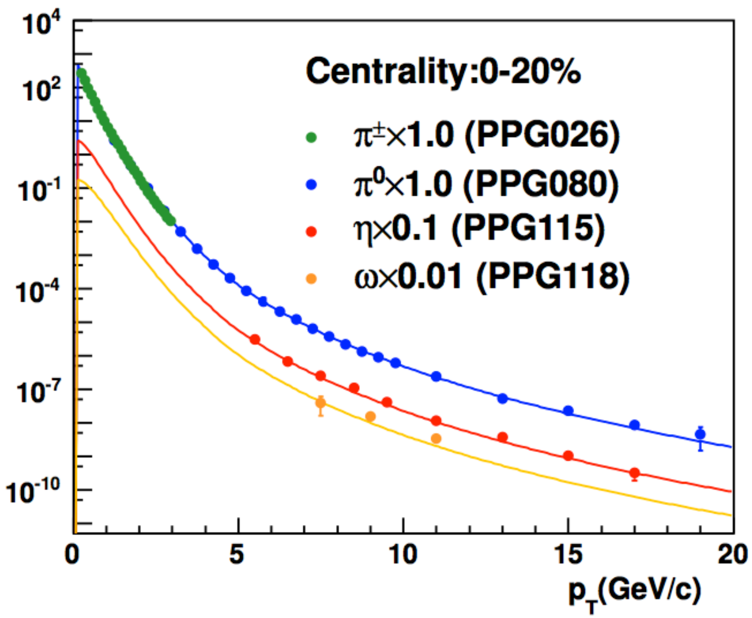
$\pi^{\pm}$ and $\pi^0$ $p_T$ spectra are fitted and its function is used for estimating the other meson $p_T$ spectra by $m_T$ scaling.

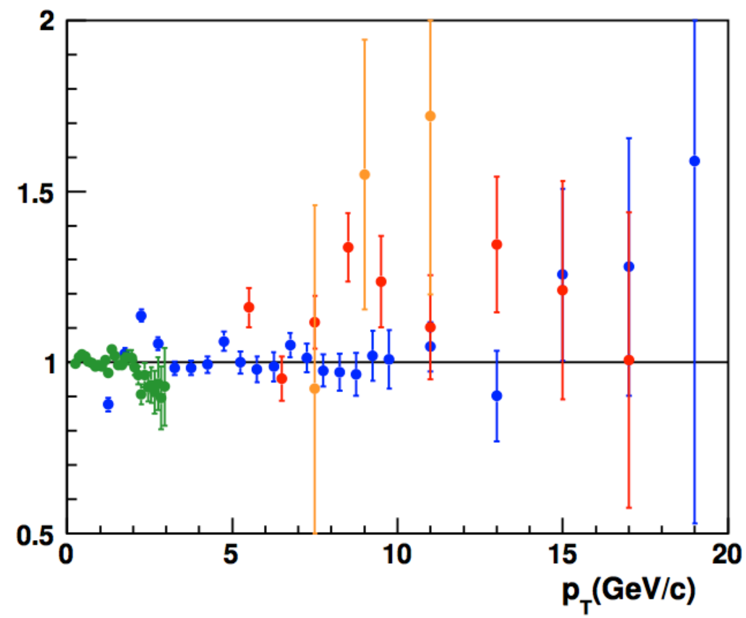
They are used as a input.

# Input decay photon : $p_T$ spectra

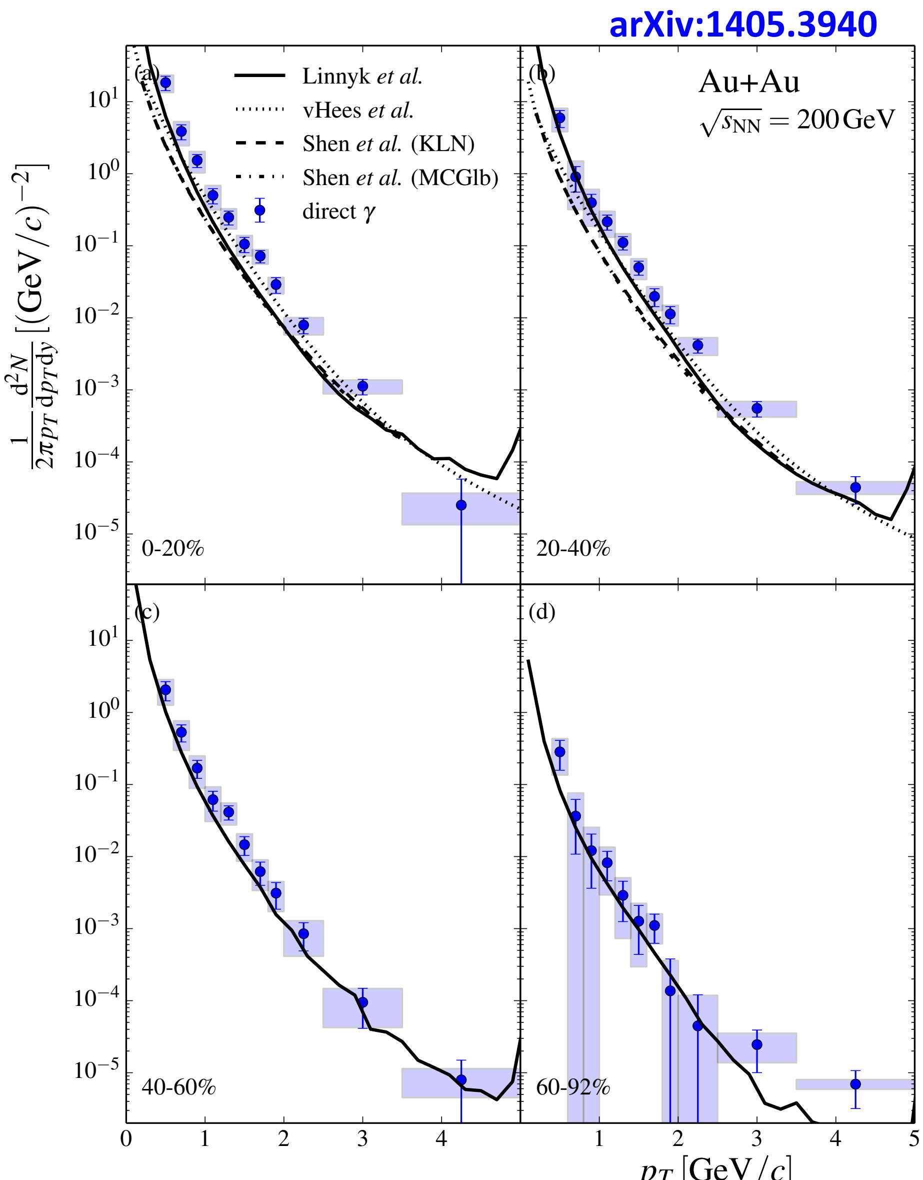
The ratio of Each meson $p_T$ spectra to $\pi^0$ $p_T$ spectra is known to be constant at high $p_T$.

| The table of each meson spectra ratio to $\pi^0$ | |
|---|---|
| $\eta/\pi^0$ | 0.45±0.060 |
| $\omega/\pi^0$ | 0.83±0.120 |
| $\rho/\pi^0$ | 1.00±0.300 |
| $\eta'/\pi^0$ | 0.25±0.075 |



# Yield : data vs theories



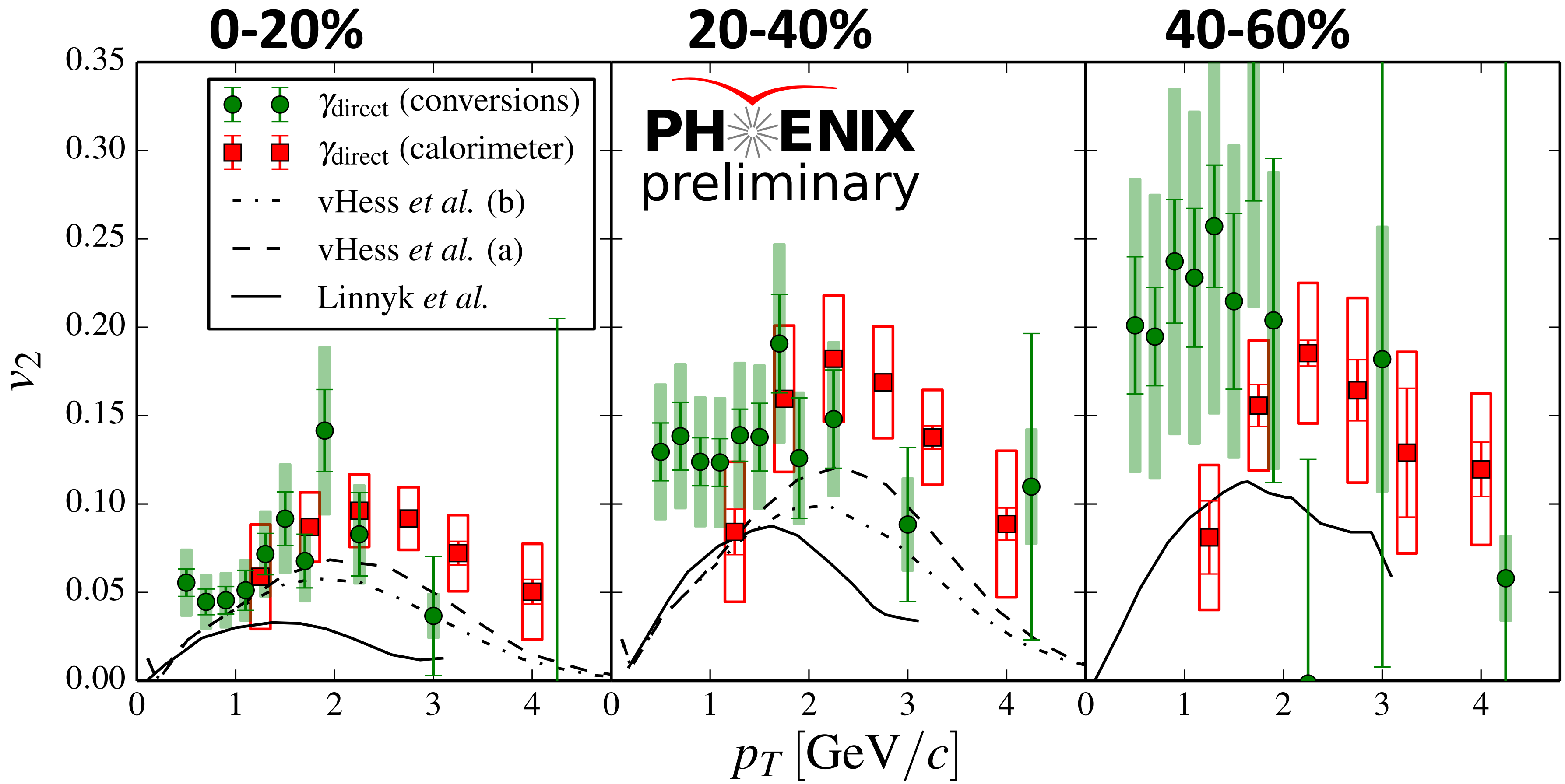

Linnyk et al.: PHSD transport model; Linnyk, Cassing, Bratkovskaya, P.R.C 89, 034908(2014)

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