The Study Of Direct Photon Azimuthal Anisotropy At RHIC-PHENIX Experiment

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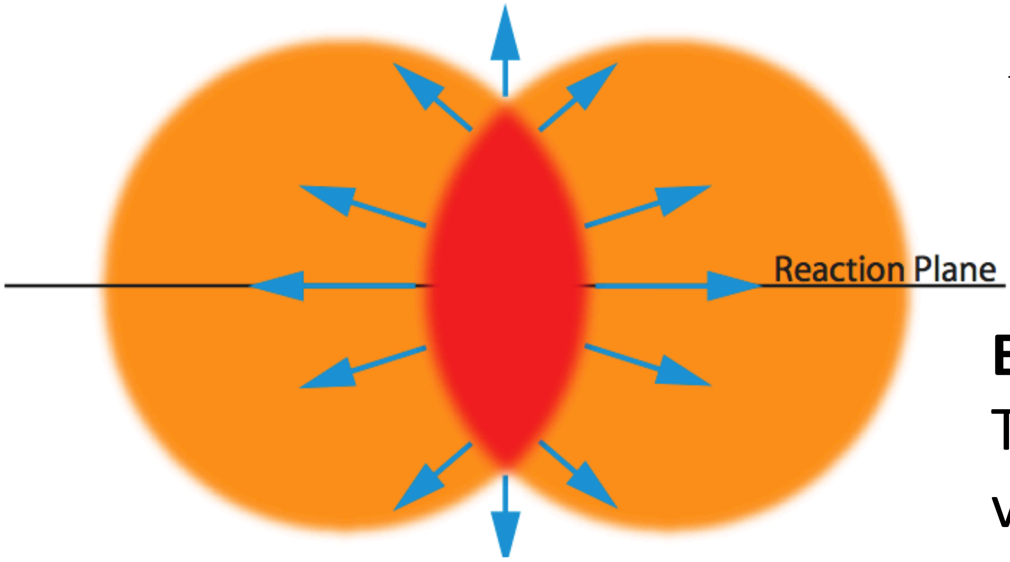
30pTR-10

What is Azimuthal Anisotropy?



$$E\frac{d^3N}{dp^3} \propto [1 + 2\sum_{n=1}^{\infty} \nu_n cos\{n(\phi - \Phi_n)\}]$$

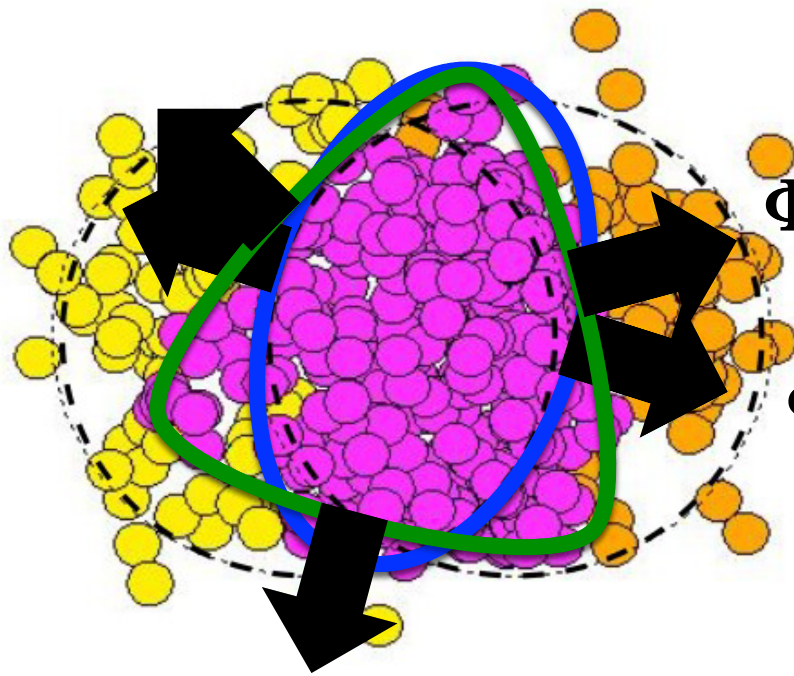
$$\nu_n =< cos\{n(\phi - \Phi_n)\} >$$

Event Plane(Φ_n) :
The base direction for expansion
v_n : strength of anisotropy

Azimuthal anisotropy is relative deviation of the number of emitted particle between in and out of plane.

It is strongly related to **initial geometry** and **η/s of QGP**.
Expansion makes anisotropy in momentum space.

Higher Order Anisotropy



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Event Plane(Φ_n) :
The base direction for expansion
v_n : strength of anisotropy

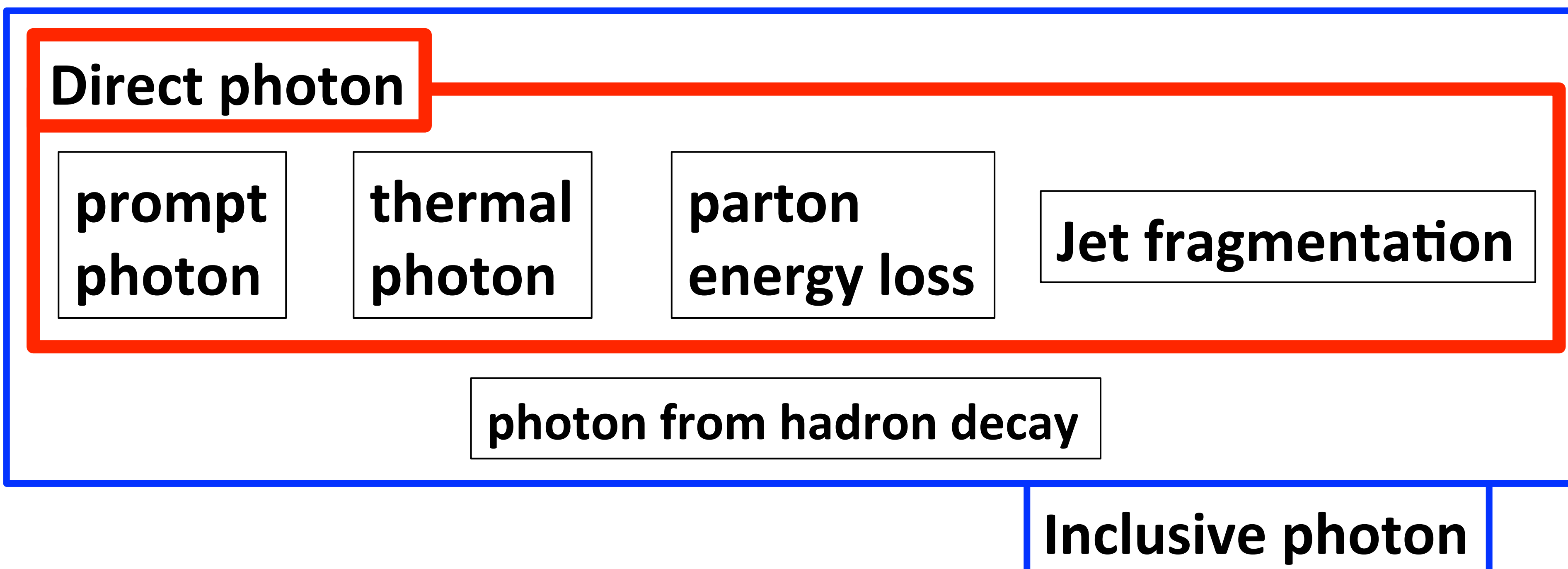
Initial geometry is deformed because of statistics fluctuation.
It makes higher order azimuthal anisotropy.

It is important to constrain initial geometry calculating model and η/s of QGP.

What is Direct Photon?

Direct photon is all photons except ones from hadron decay.

- **Penetrating QGP without scattering**
- **Created from various sources**

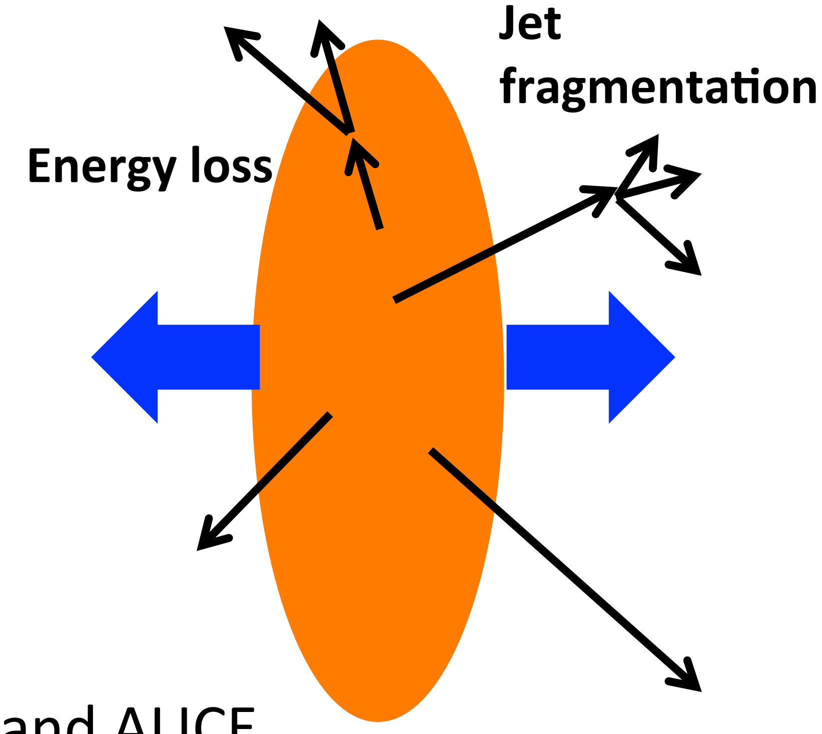


Direct Photon Azimuthal Anisotropy

It is expected that the photon sources are identified by azimuthal anisotropy measurement (initial geometry dependence).

- **prompt : v_2~0**
- **Jet fragmentation : v_2>0**
- **parton energy loss : v_2<0**
- **thermal QGP : $v_2 \geq 0$**
- **thermal HG : v_2>0**

Superposition is measured.



$\gamma^{dir.}$ v_2 has been measured at PHENIX and ALICE.

Direct Photon v_2

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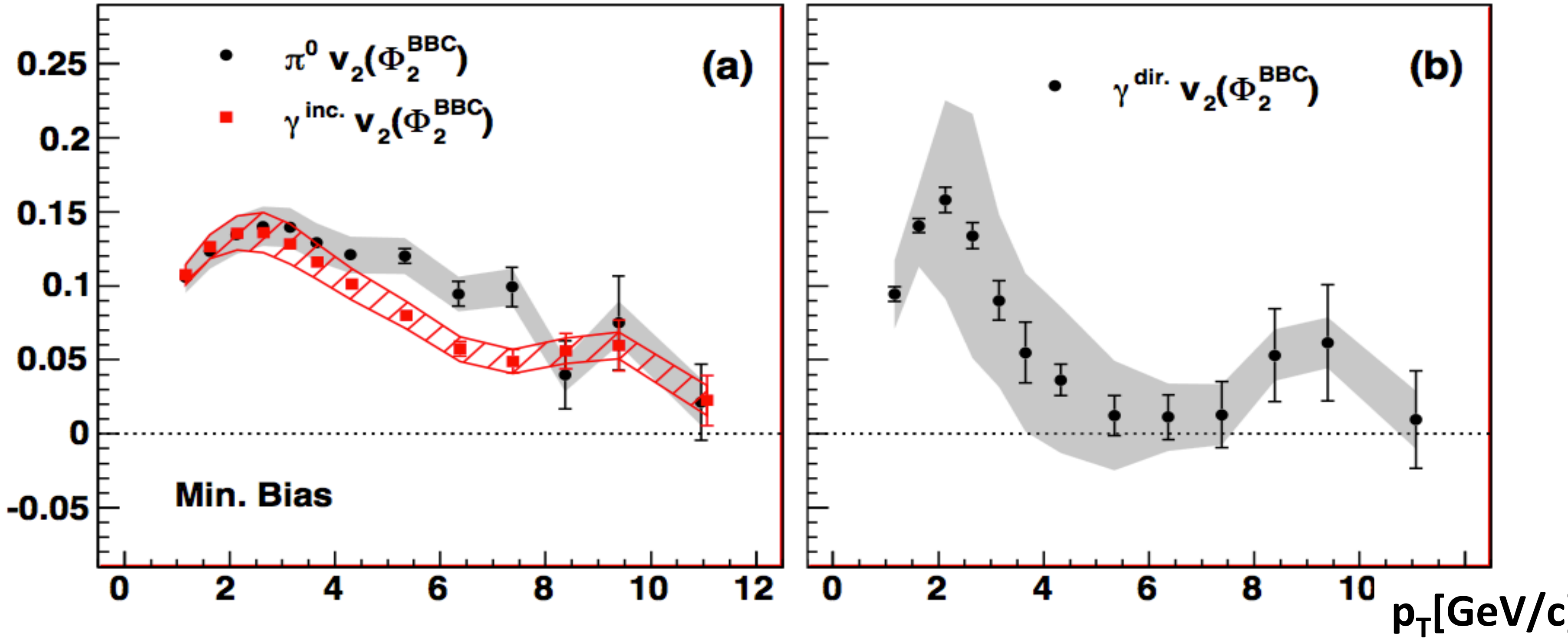


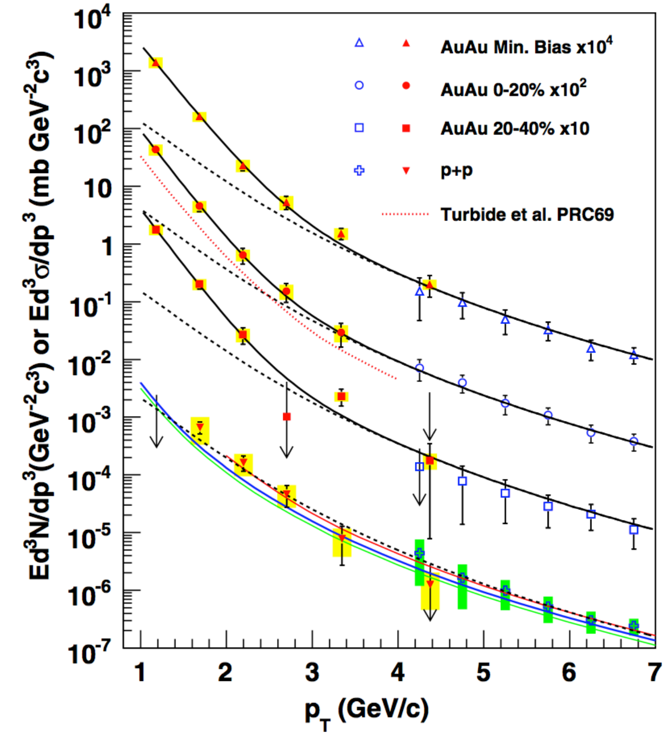
$\gamma^{dir.}$ v_2 is close to 0 in high p_T, which is consistent with expectation.
It has strong v_2 as one of hadron in low p_T.

ALICE also measure $\gamma^{dir.}$ v_2 and it is found that it has similar trend.

Deviation of Temperature

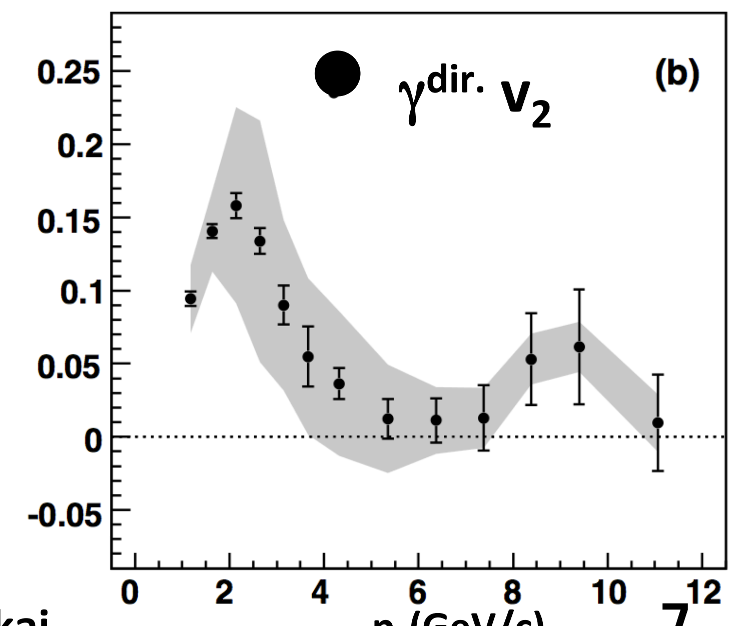
T_γ = 233±14±19 MeV is observed by direct photon spectrum.
It is much higher than T_{had} = 100-120 MeV which is freeze-out temperature.

$T_\gamma >> T_{had}$

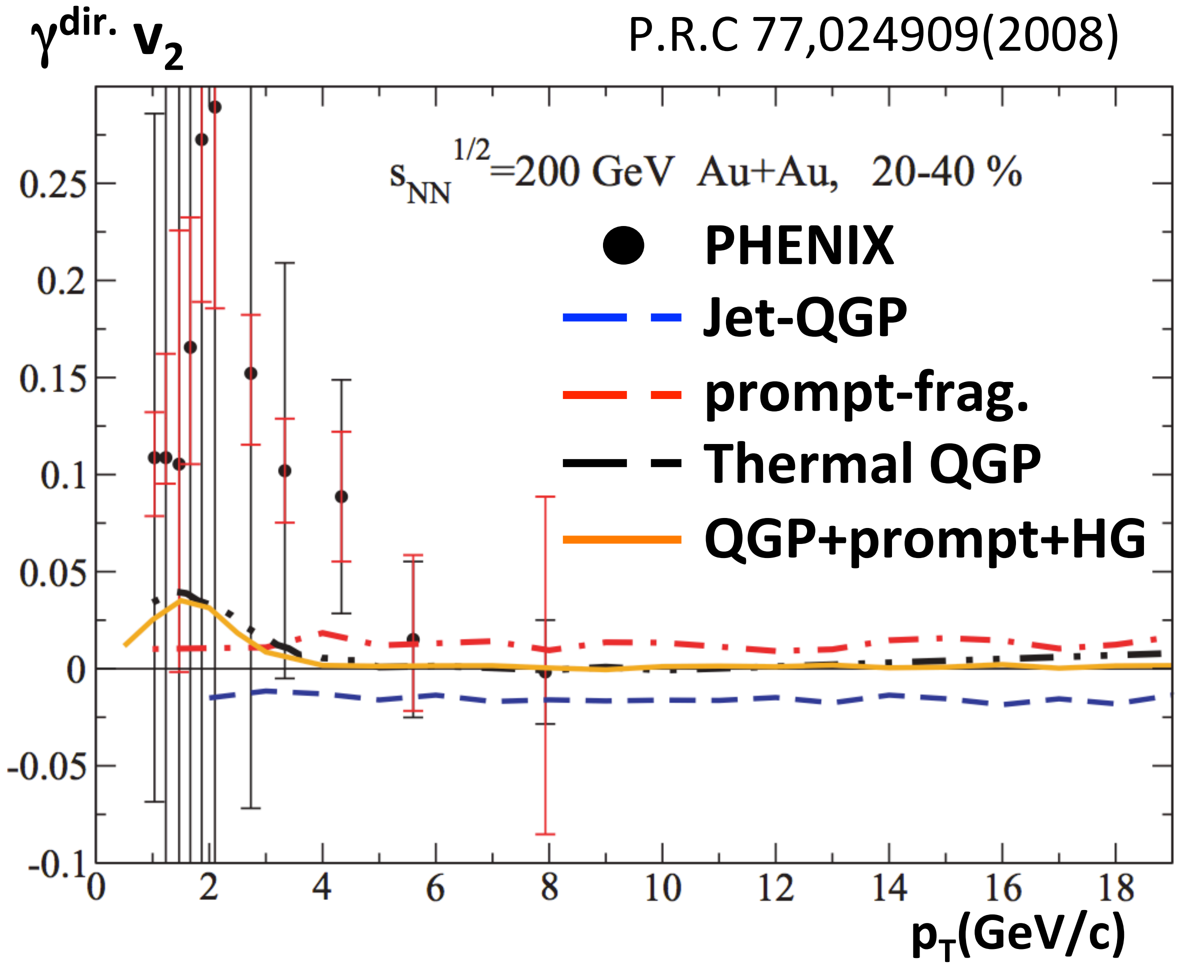


Azimuthal anisotropy is created from initial geometry deformation.
It is needed the enough expansion time to have large v_2.

$T_\gamma \sim T_{had}$



Underestimation for $\gamma^{dir.}$ v_2

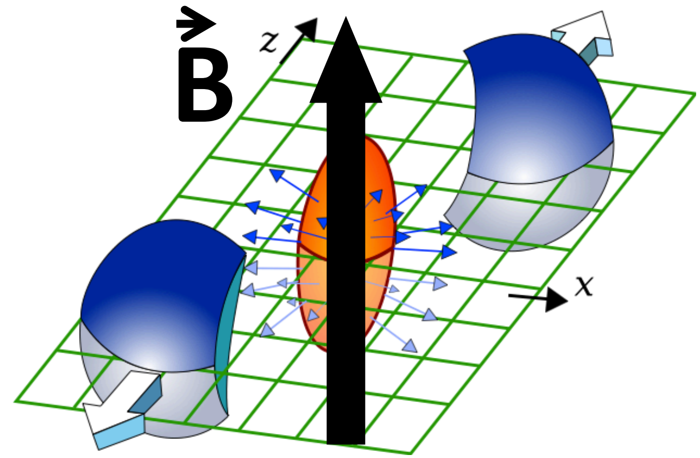


Model calculation is underestimated for v_2 while spectra is well described.

Additional component is needed to describe experiment results.

- **Strong magnetic field**
- **Blue shift**

What makes large v_2?



$\vec{B} \perp R.P.$

Magnetic Field effect

2nd of Event Plane is strongly correlated with Reaction Plane while 3rd is not.

v_2 is strong : v_3 is weak

Blue shift effect

Observed temperature is affected by flow and it is overestimated.

v_2 and v_3 are strong

$$T_{obs} \sim T_{real} \sqrt{\frac{1+ < \beta >}{1- < \beta >}}$$

<β> : average expansion velocity

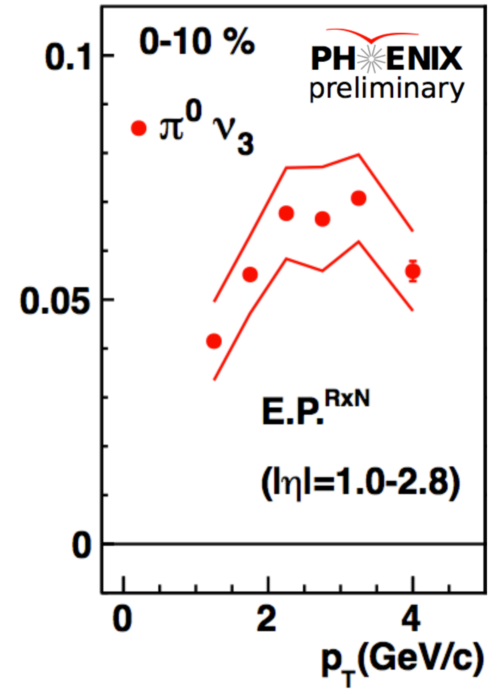
v_3 measurement helps to understand.

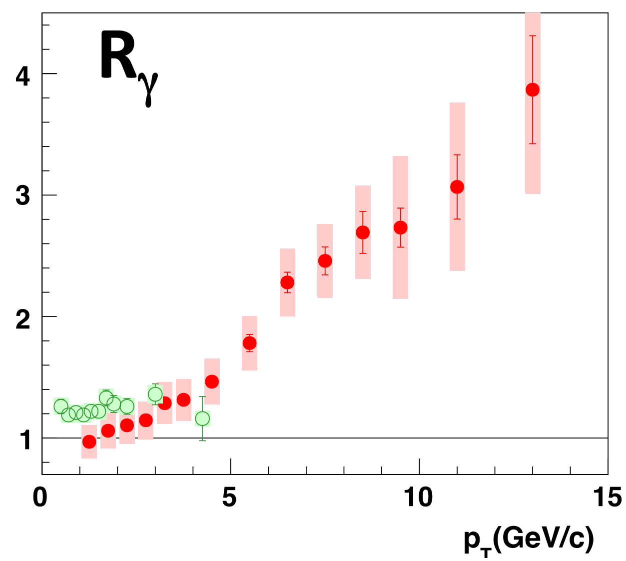
Analysis flow

- ✓ π^0 and $\gamma^{inc.}$ v_n measurement
- ✓ $\gamma^{dec.}$ v_n simulation
  It is simulated from π^0 v_n.
- ✓ $\gamma^{dir.}$ v_n calculation

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

$$R_\gamma = N^{inc.}/N^{dec.}$$





Summary

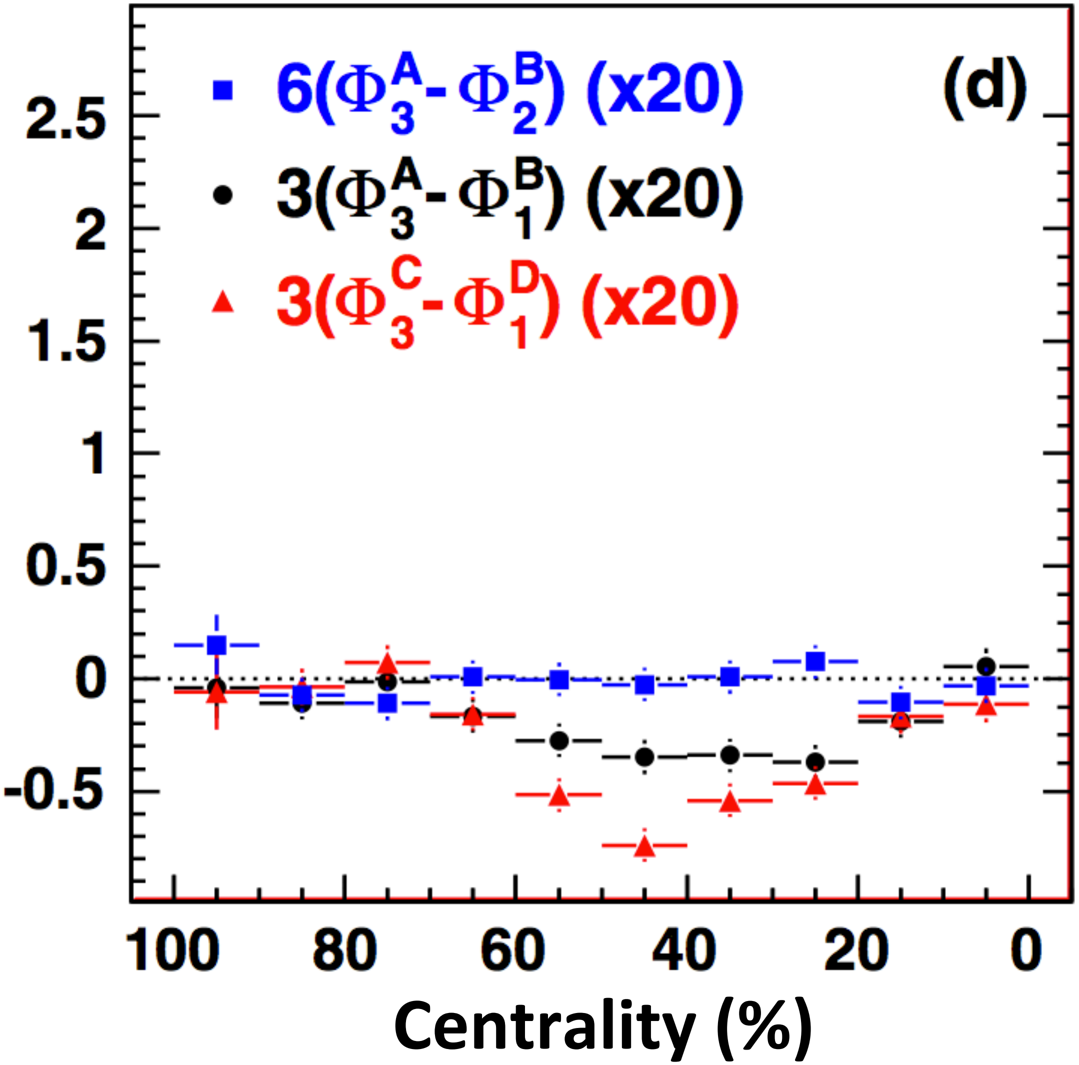
Direct photon is powerful tools to study QGP.
Azimuthal anisotropy is related with initial geometry.
Higher order is thought to be more important.

Direct photon v_2 has been measured at PHENIX and ALICE.
It is found that it has as strong v_2 as hadron, but it is not yet understood.
Model calculation is underestimated.

Direct photon v_3 is expected to help understanding.
Measurement is ongoing.

BACK UP

2nd and 3rd of Event Plane correlation



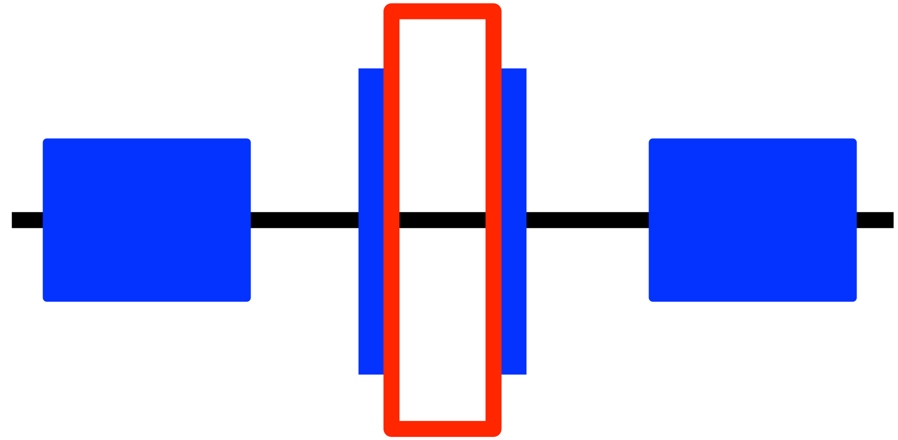
$$< \cos\{6(\Phi_3^A - \Phi_2^B)\} >$$

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.

Event Plane

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

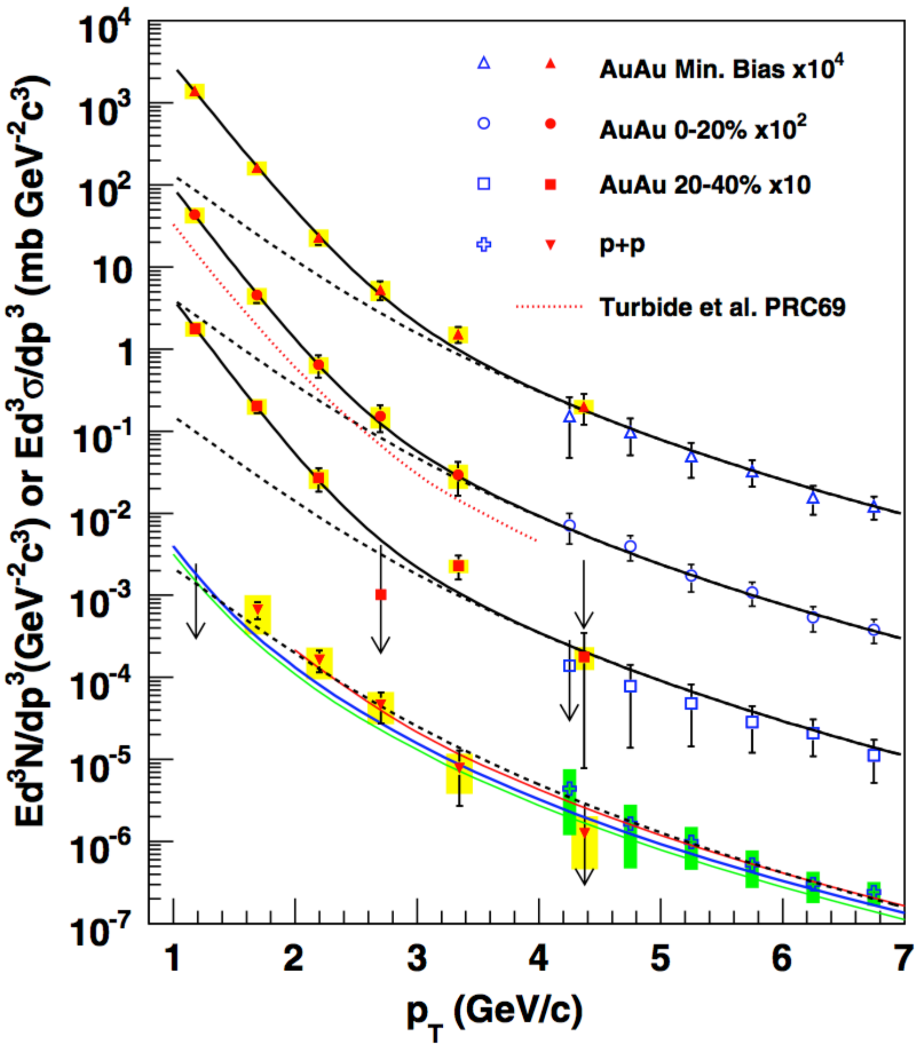


The angles of particle emission and Event Plane are measured by different detectors in order to auto-correlation (e.g. Jet).
Event Plane is determined as a strong direction of flow.

$$Q_x = < w_i \cos(n\phi_i) >$$
$$Q_y = < w_i \sin(n\phi_i) >$$
$$\Phi_n = atan2(Q_y, Q_x)/n$$

i : direction of detector
w_i : weight

QGP temperature measurement



Direct photon at low p_T provides temperature of QGP.

T_{eff} = 233 ± 14 ± 19 MeV (Min. Bias.)
T_{ini} = 300~600 MeV

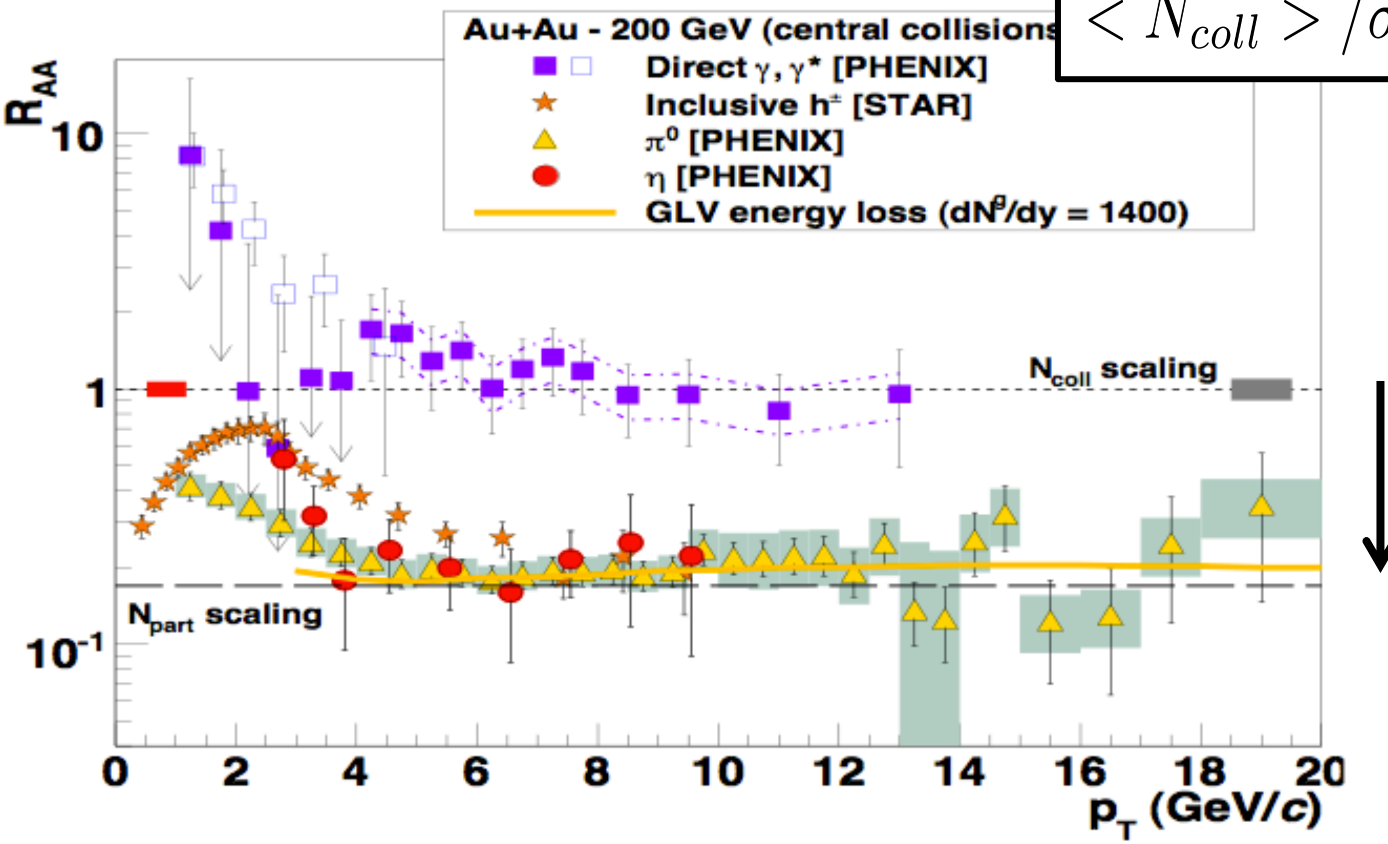
T_{eff}(LHC) = 304±51 MeV (2.76TeV,0-40%)

T = 170MeV (Lattice QCD)
T = 100-120MeV (hadron freeze-out)

The photon from hot matter is observed.

$\gamma^{dir.}$ is not suppressed

$$R_{AA} = \frac{(1/N^{evt}_{AA}) d^2 N_{AA}/dp_T dy}{< N_{coll} > / \sigma^{inel}_{pp} \times d^2 \sigma_{pp}/dp_T dy}$$



Hadron is suppressed.

R_{AA} of direct photon is consistent with unity in high p_T.
This is consistent with the expectation that $\gamma^{dir.}$ coming from initial scattering is dominant.

Measurement of higher order v_n

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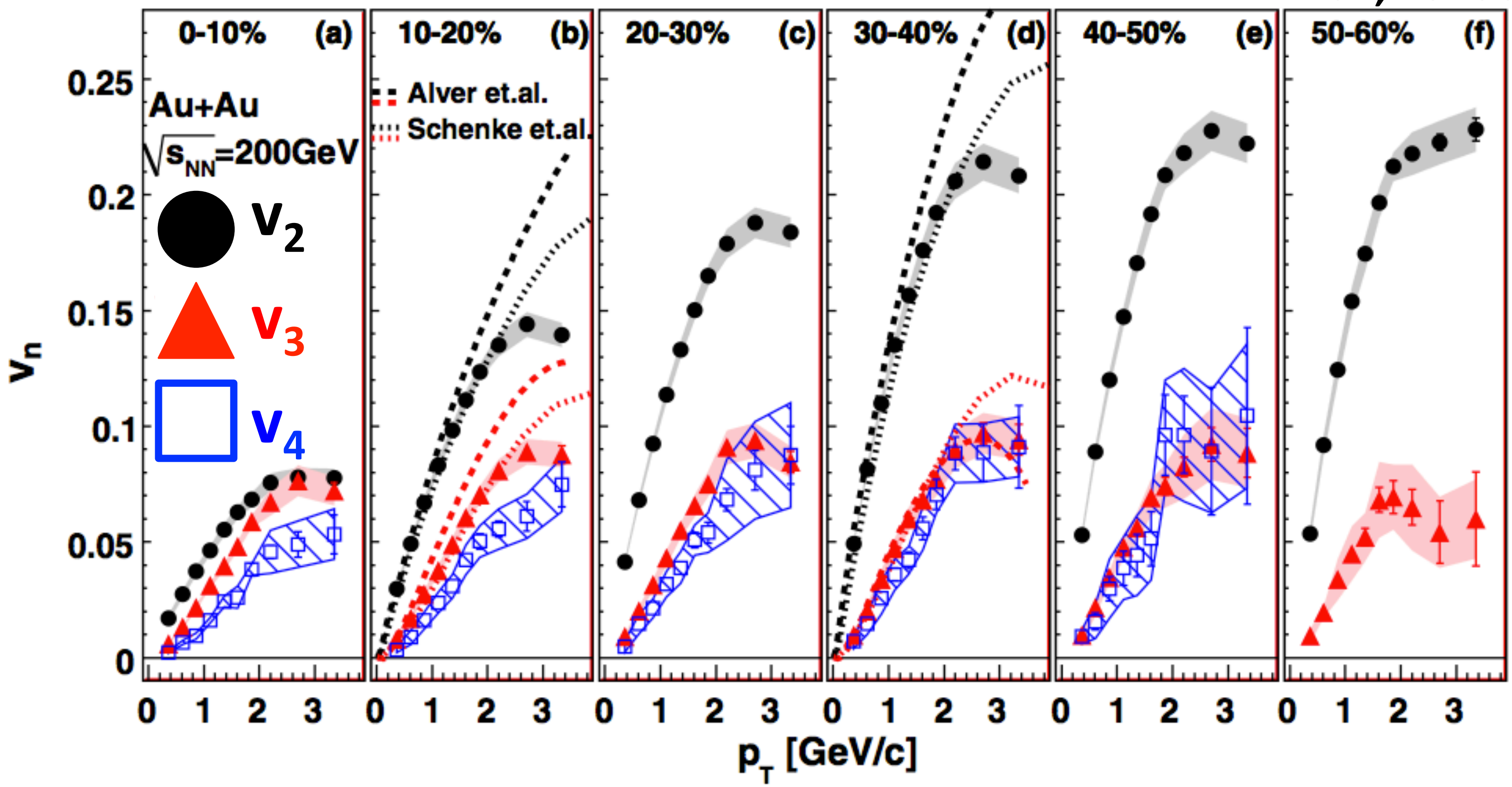
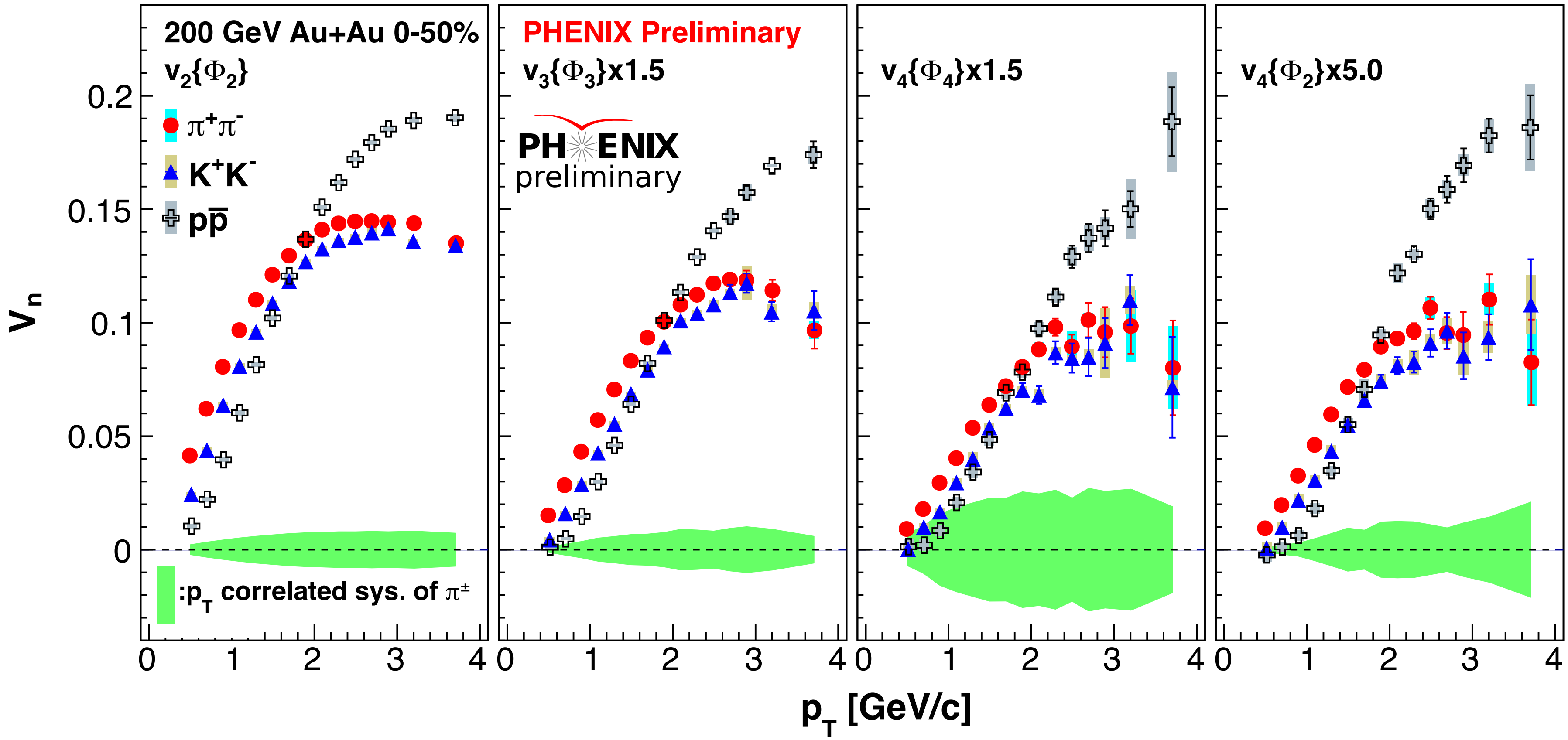


v_3 and v_4 have weak centrality dependence while v_2 has strong.
It indicates v_3 and v_4 are created by the initial geometry deformation.

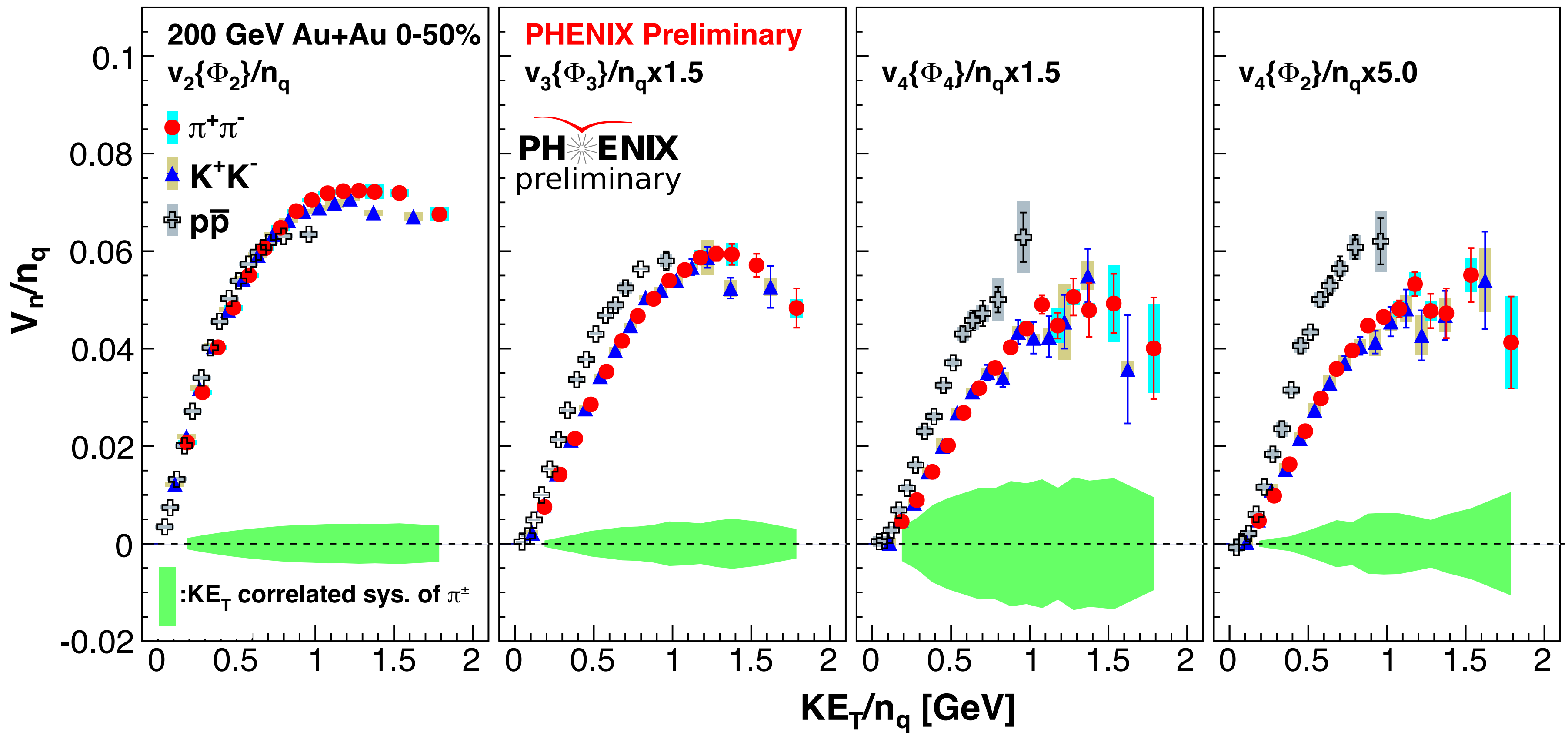
PID v_n measurement



v_n has mass and meson/baryon dependence.

Higher harmonics are created from initial geometry deformation, they are affected by the effect of QGP expansion.

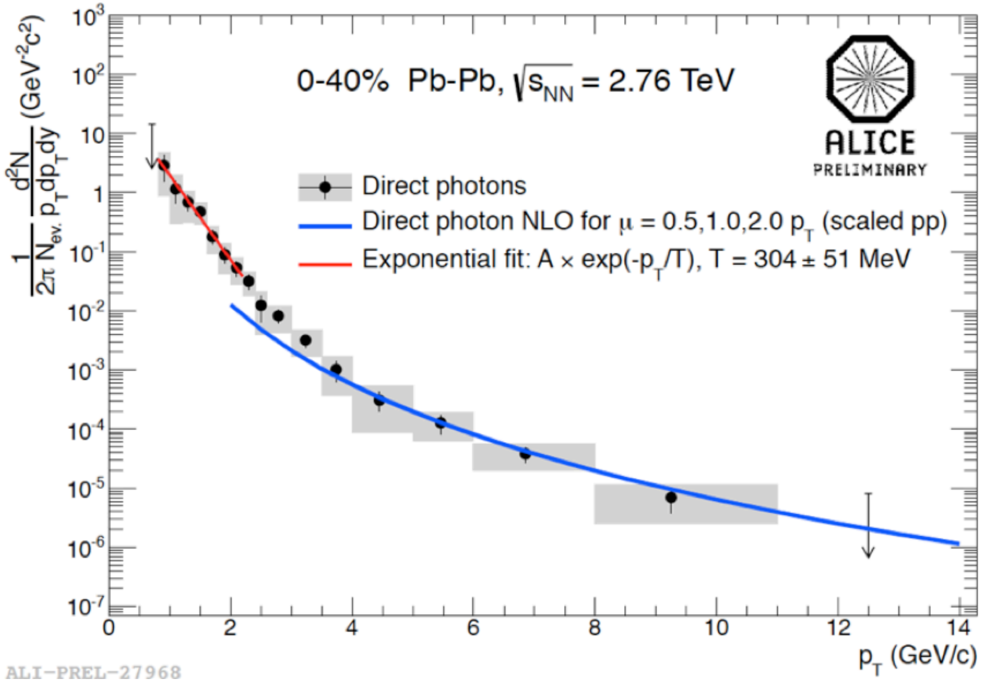
KE_T scaling for PID v_n

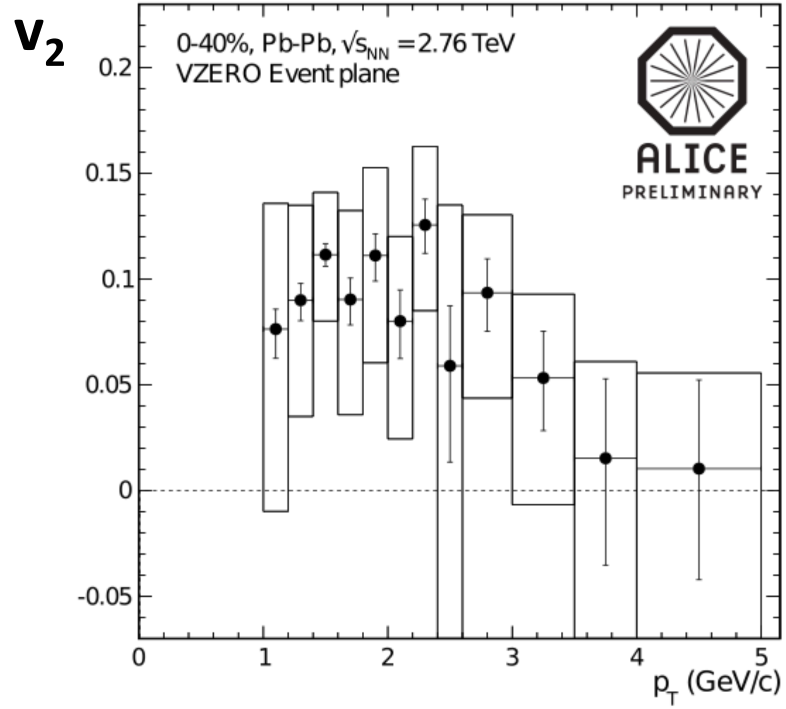


Meson is scaled well, while proton isn't scaled.

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

arXiv:1212.3995v2

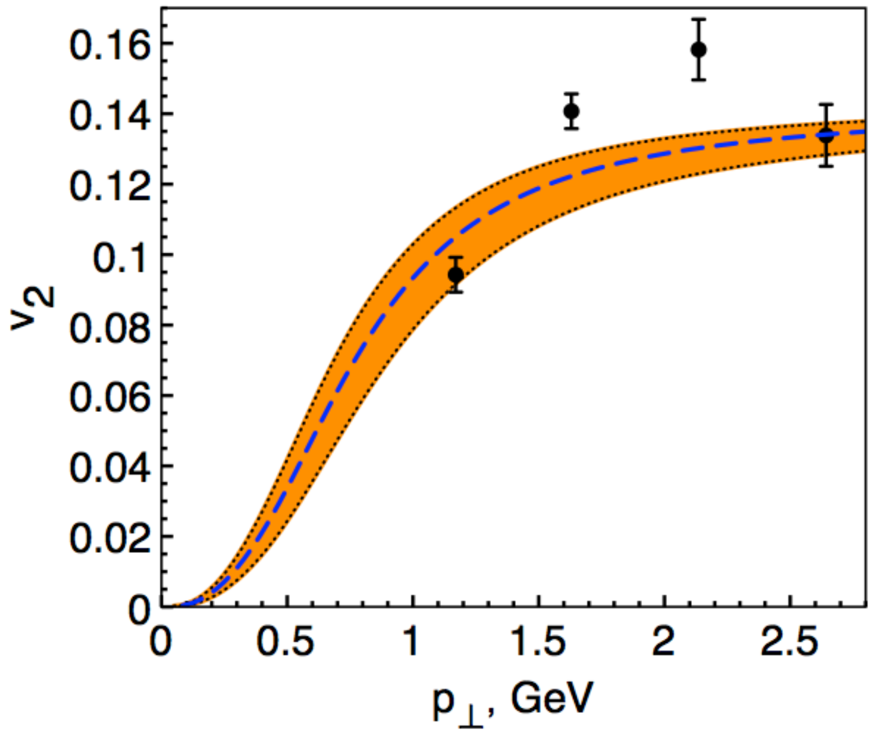


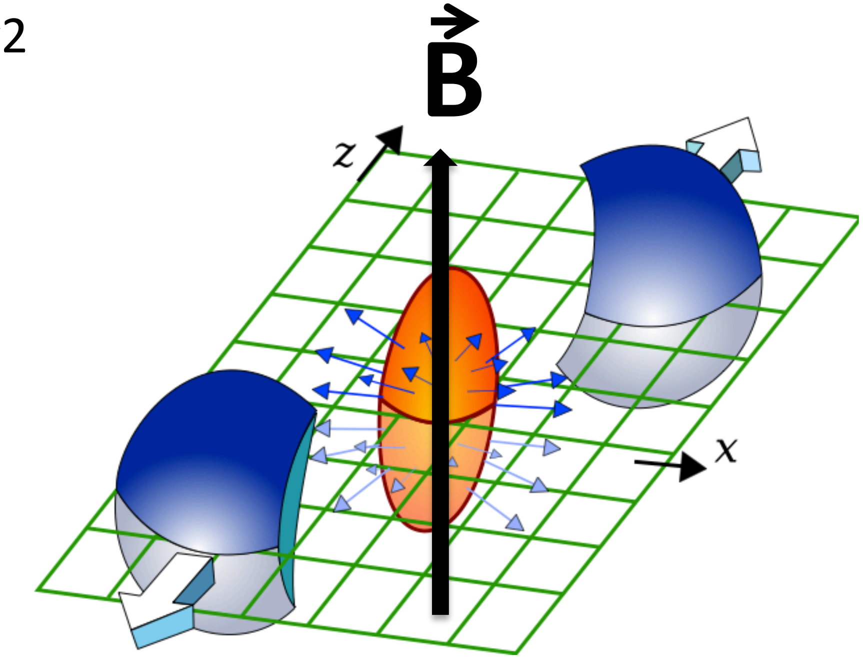


Similar trend with RHIC-PHENIX is observed by LHC-ALICE.

Strong magnetic field effect

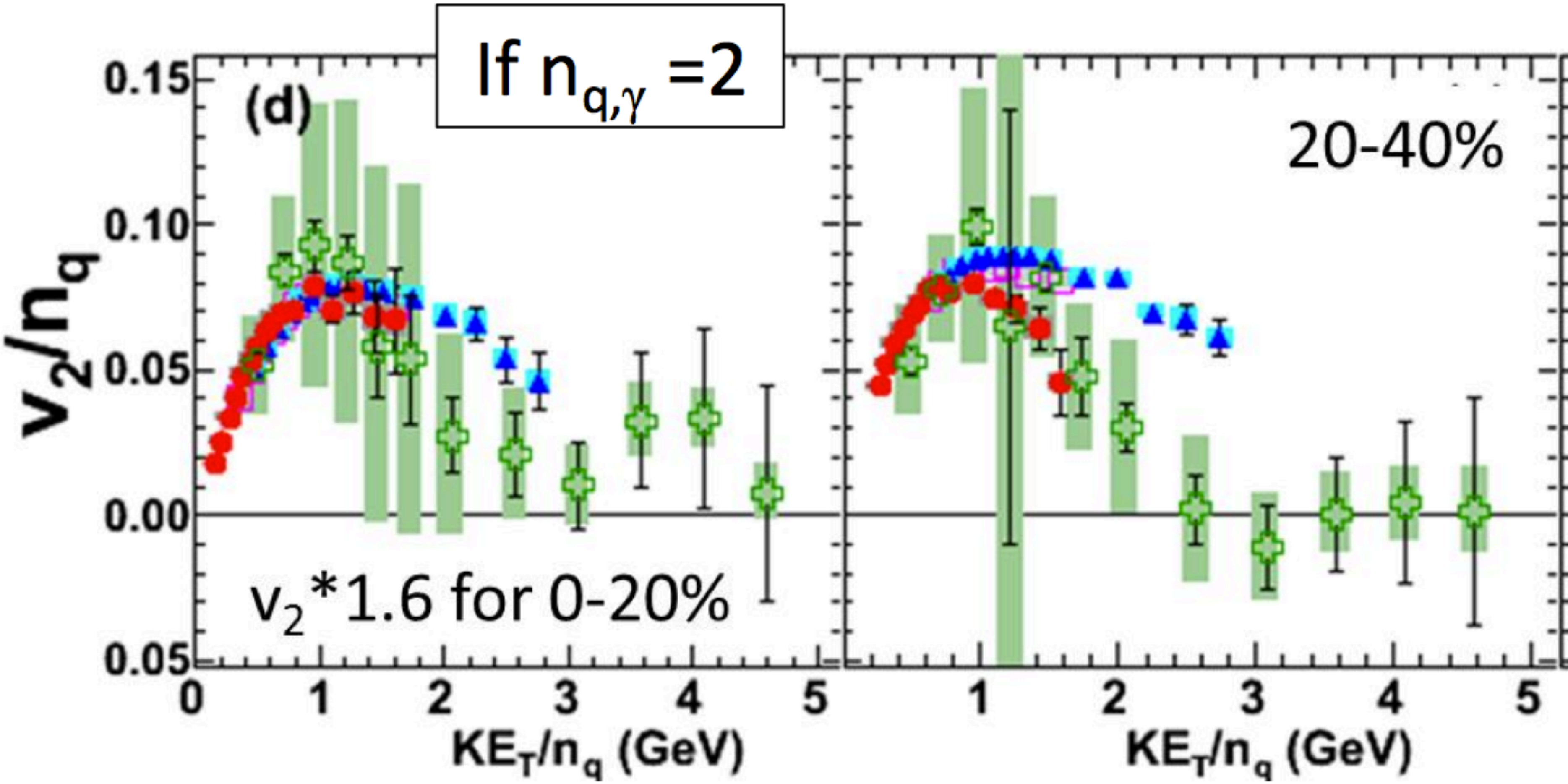
arXiv:1206.1334v2





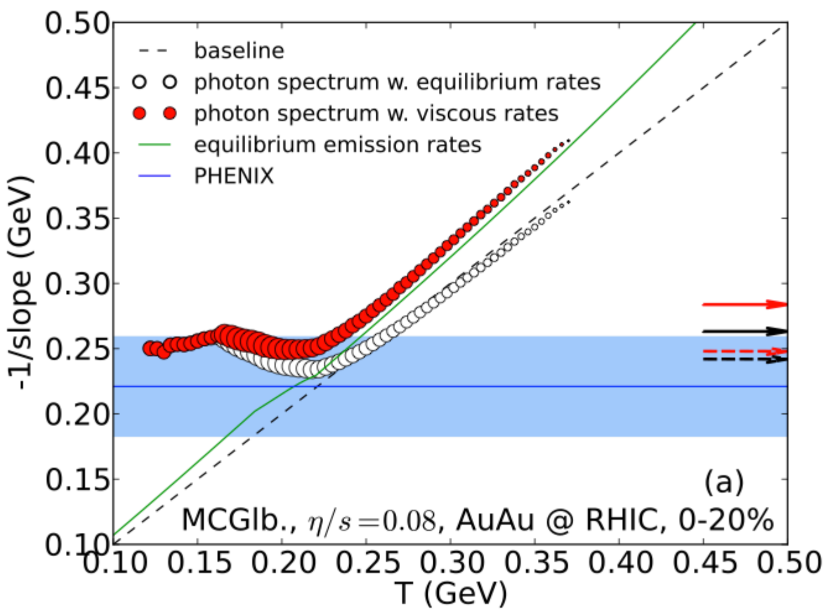
Strong magnetic field is thought to affect photon emit angle.
It is created in perpendicular direction to Reaction Plane.

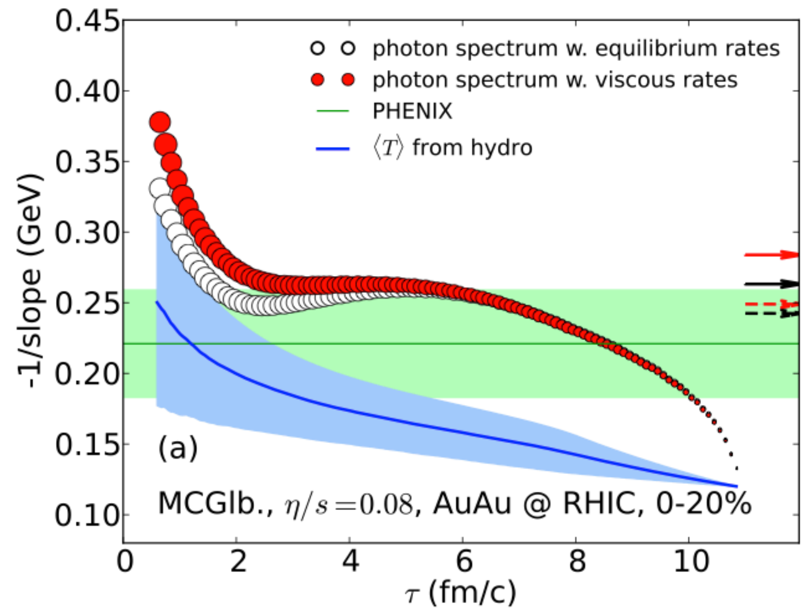
Quark annihilation effect



Late state photon production with q-q annihilation effect seems to work well.

arXiv:1308.2440v2

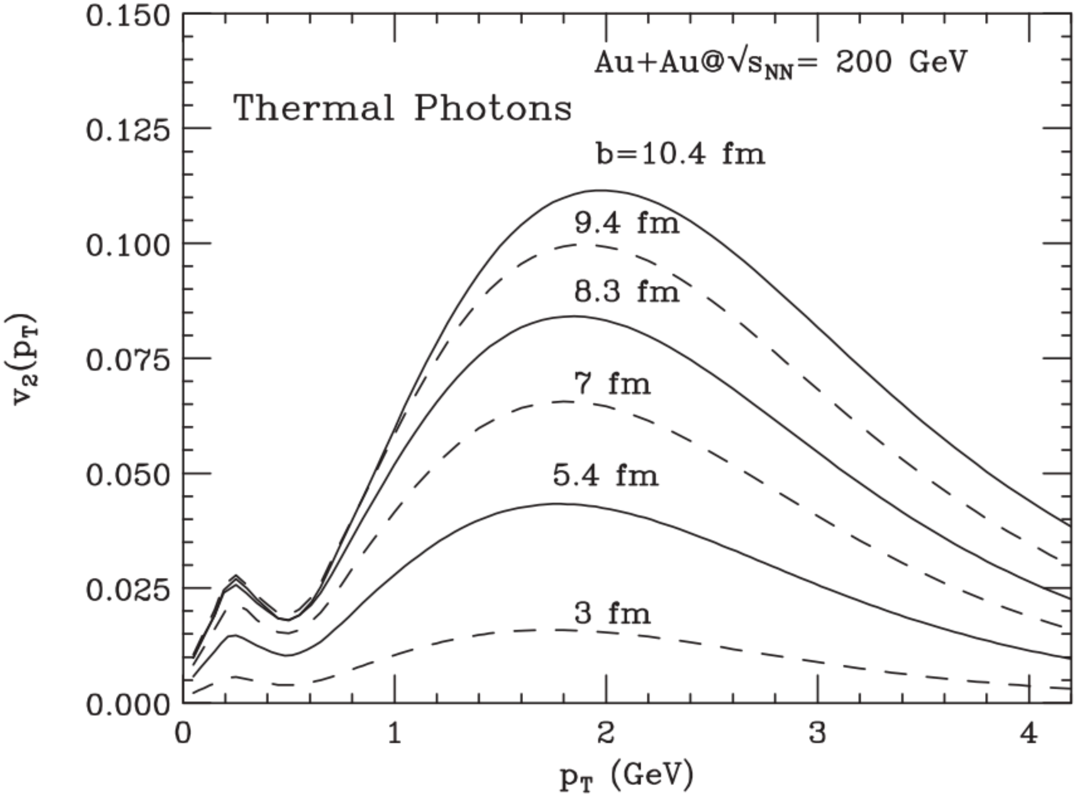




Measured temperature is shifted from real temperature due to flow effect.

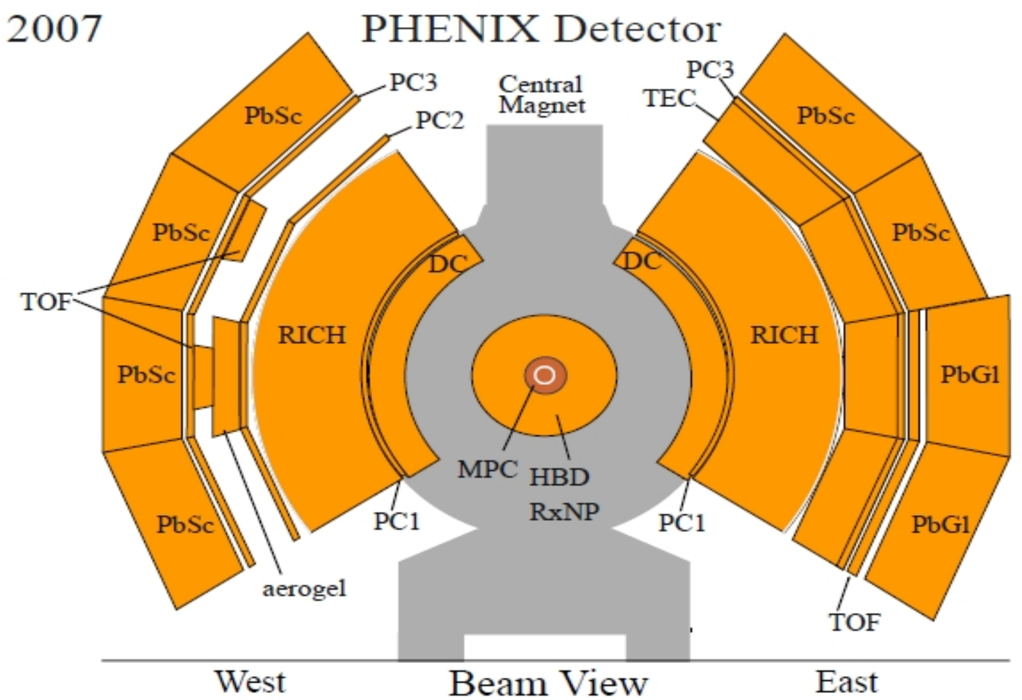
Thermal photon v_2

P.R.L. 96,202302(2006)



Much smaller than PHENIX direct photon v_2.

PHENIX detector



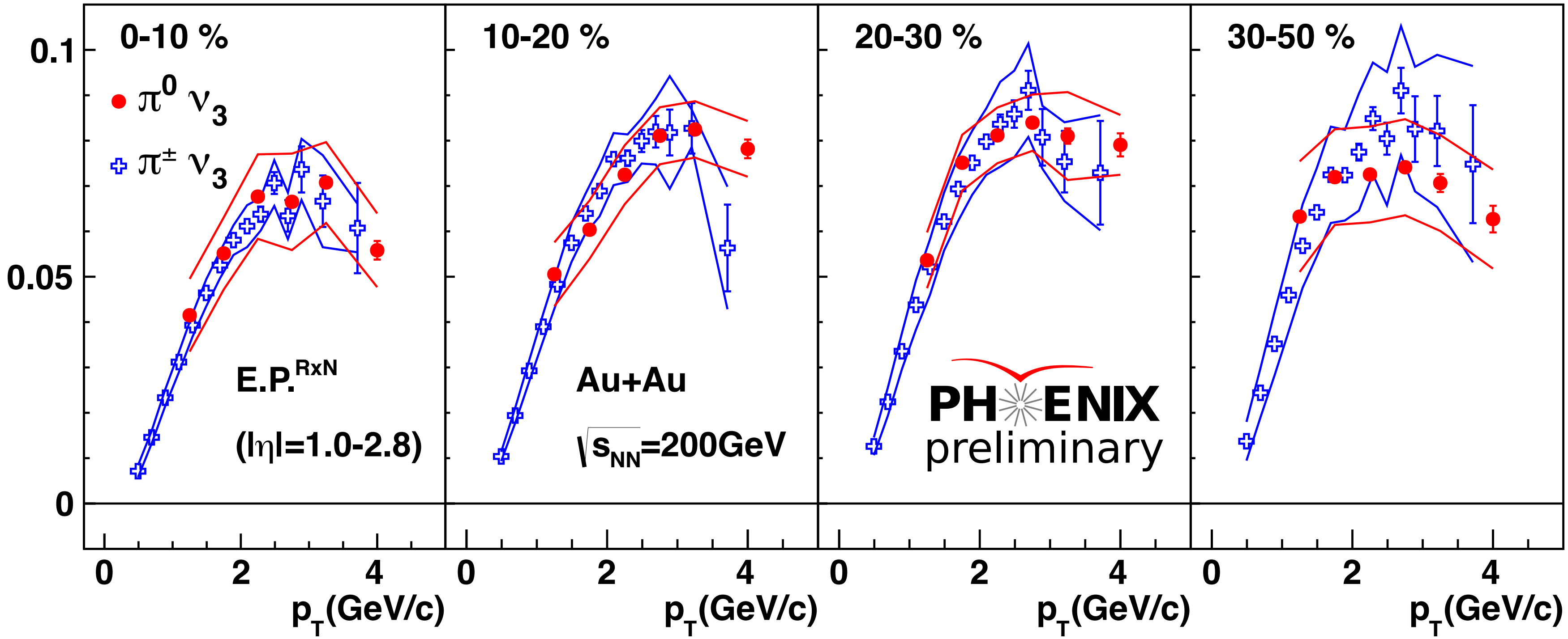
CNT
coverage $|\eta|<0.35$
ϕ : 180

- Tracking detector
  DC, PC1, PC2, **PC3**
- particle identification
  RICH, TOF, AGEL, **EMCal**

EMCal is used to detect photon.
PC3 is used to remove charged particle.

Event Plane is measured by RxN detector.

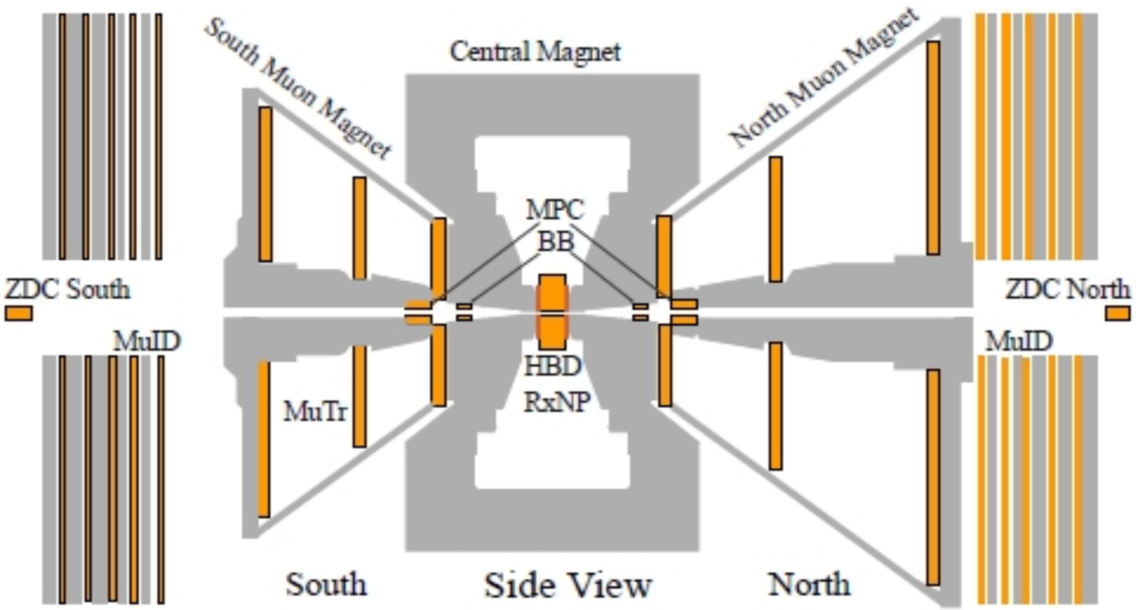
Check to be consistent with $\pi^{\pm}$ v_3



π^0 v_3 is measured up to 4.0 GeV/c with several centralities.
It is confirmed to be consistent with $\pi^{\pm}$ v_3.

Decay photon v_n is simulated from π^0 and the other meson v_3.

PHENIX CNT DETECTORS IN SIDE VIEW



- BBC($3.1<|\eta|<3.8$)
- MPC($3.1<|\eta|<3.8$)
- RxN($1.0<|\eta|<2.8$)

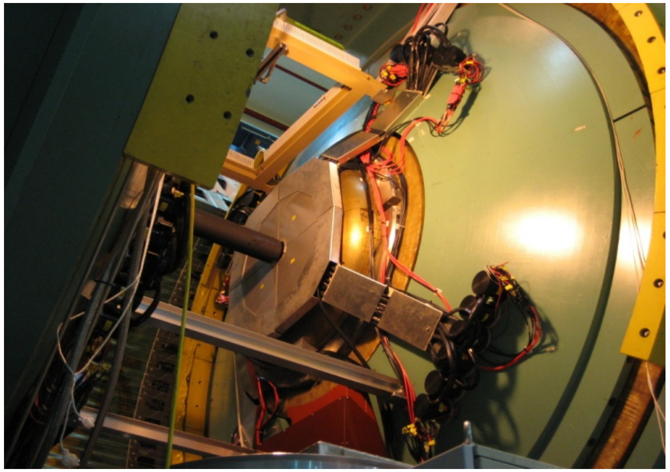
Event are classified by these detectors.
Event Plane are measured by these detectors.

Event Plane calculation

Event Plane is calculated by three steps.

1. gain correction
2. re-centering
3. flattening

$$\nu_{n,real} = \nu_{n,obs} / \mathrm{Res}\{\Psi_{\mathrm{n}}\}$$

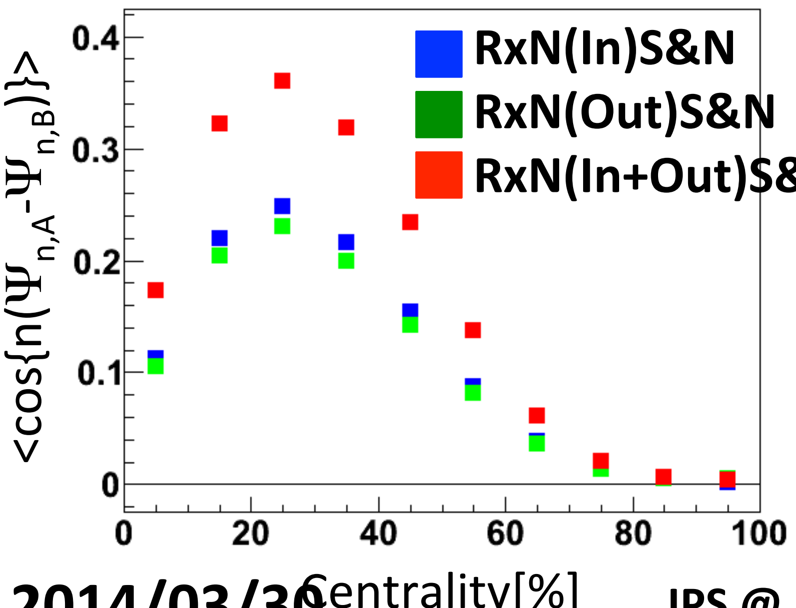


Reaction Plane detector(RxN)

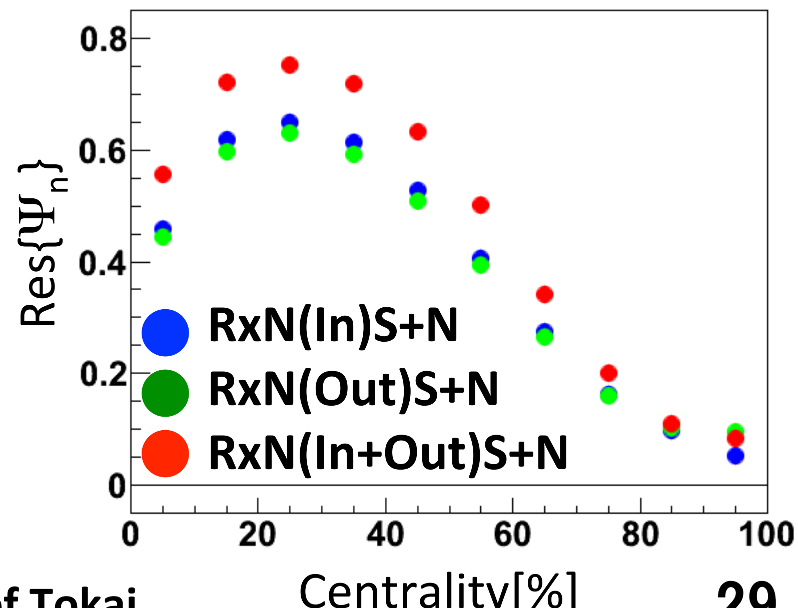
Inner : 1.5 < |η| < 2.8

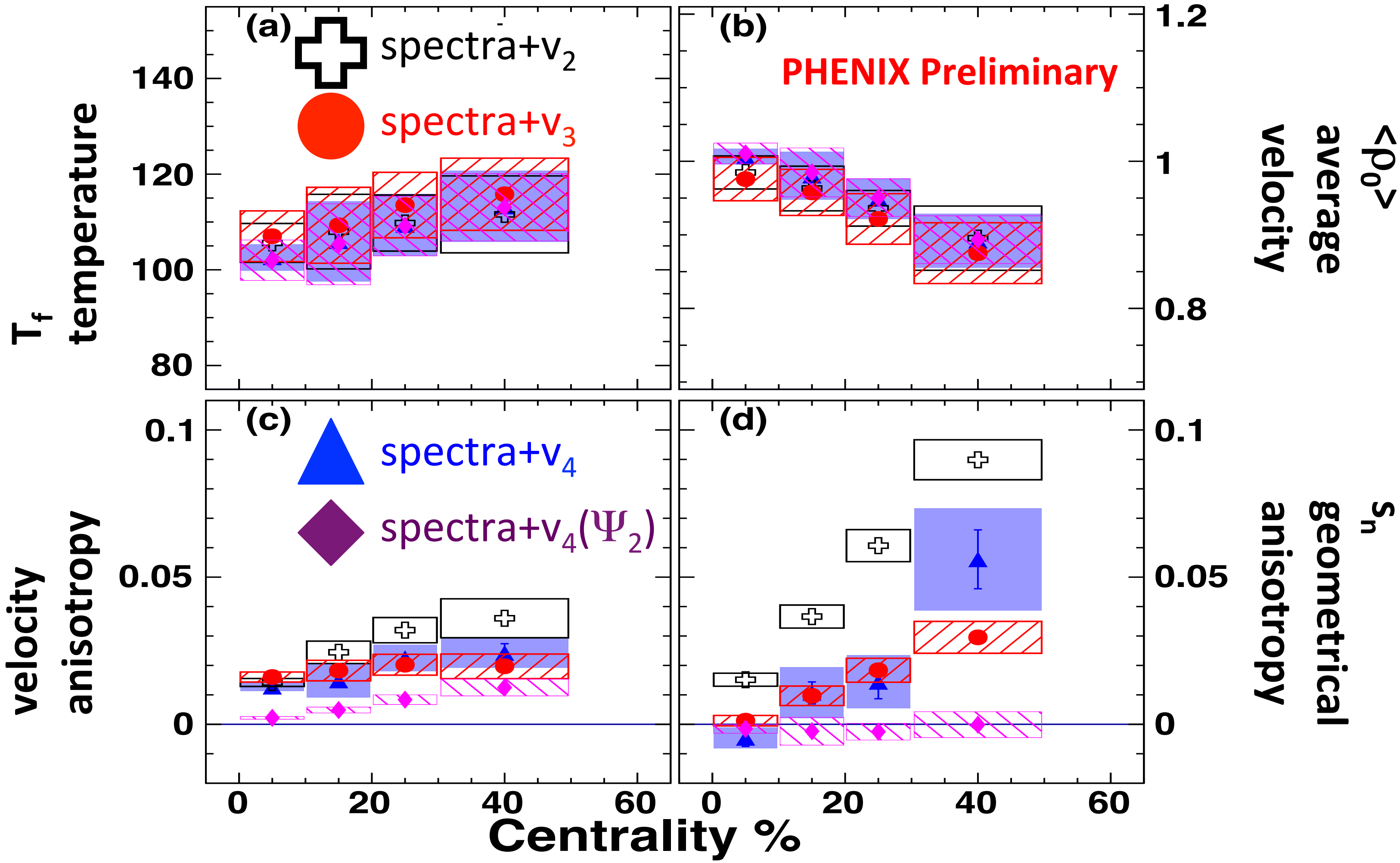
Outer : 1.0 < |η| < 1.5

2nd Event Plane correlation

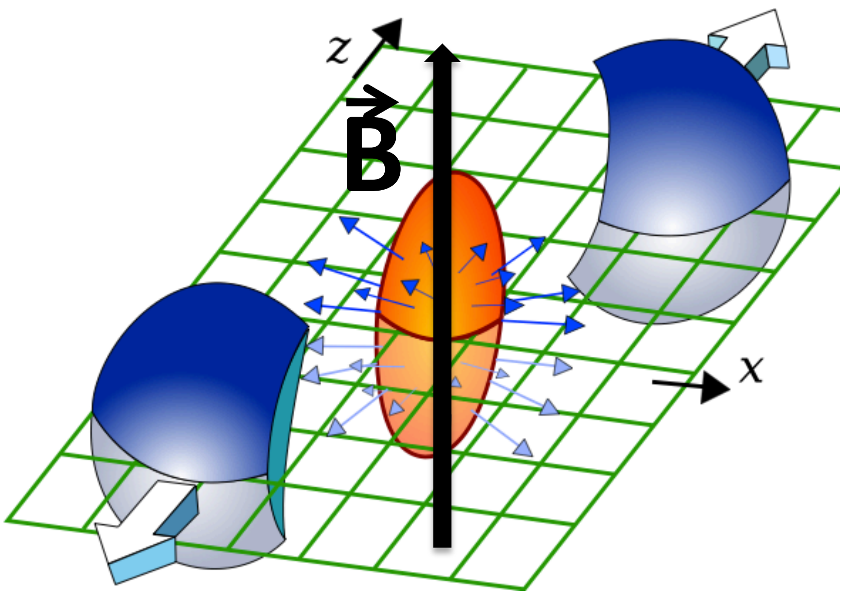


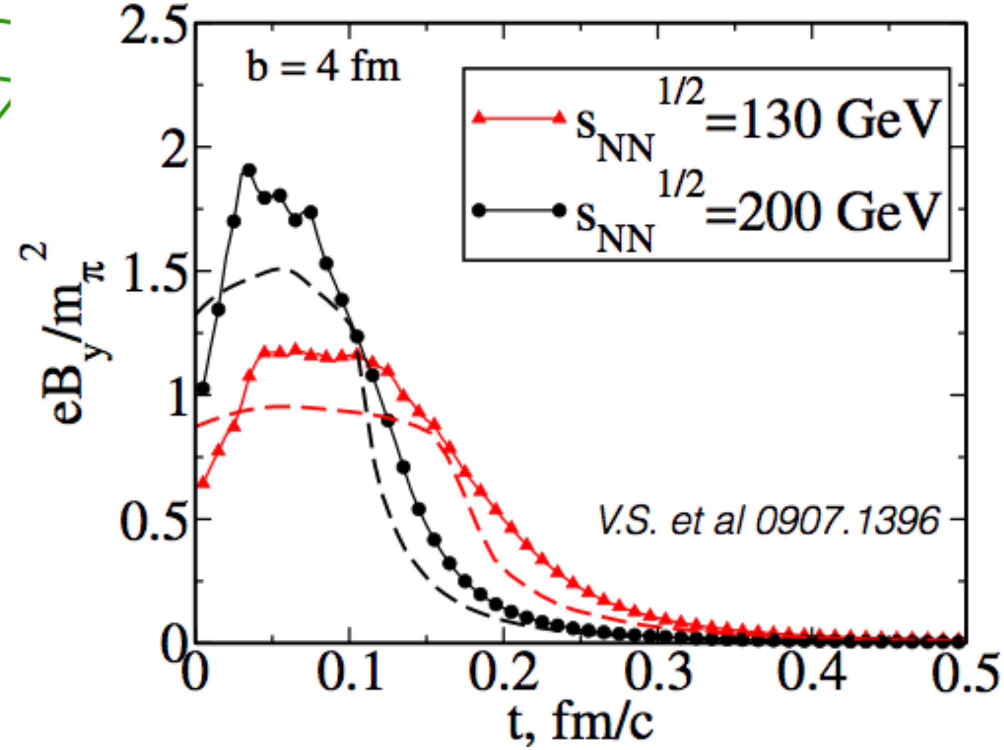
2nd Event Plane resolution





ρ_n behavior is similar to centrality dependence of charged particle v_n.
s_3 and s_4 are smaller than s_2 but not zero in non-central.





It is estimated about 10^{17}[Gauss].

It related to photon production angle??