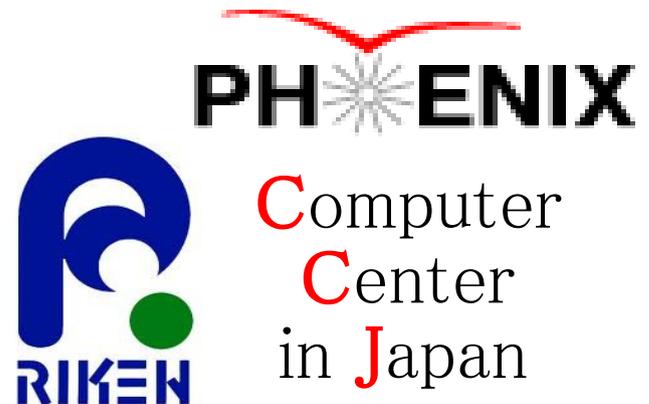
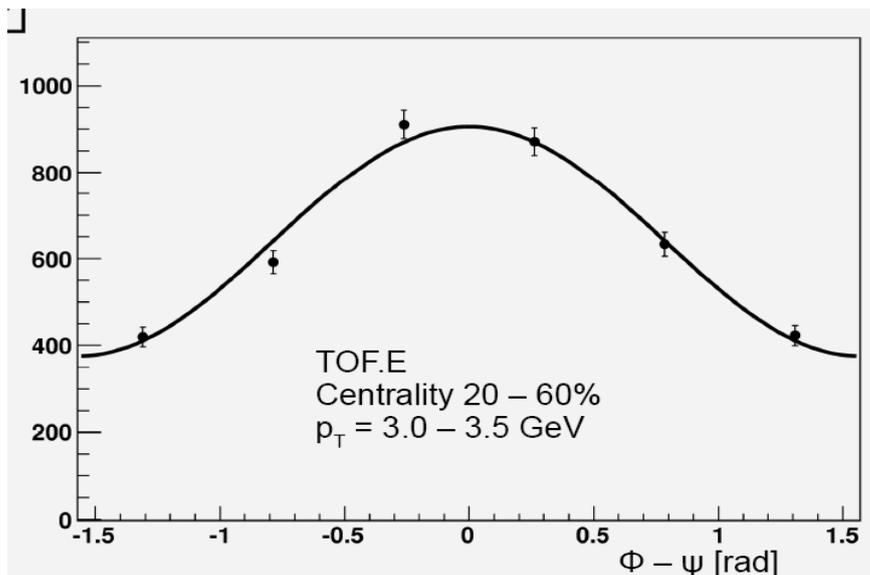
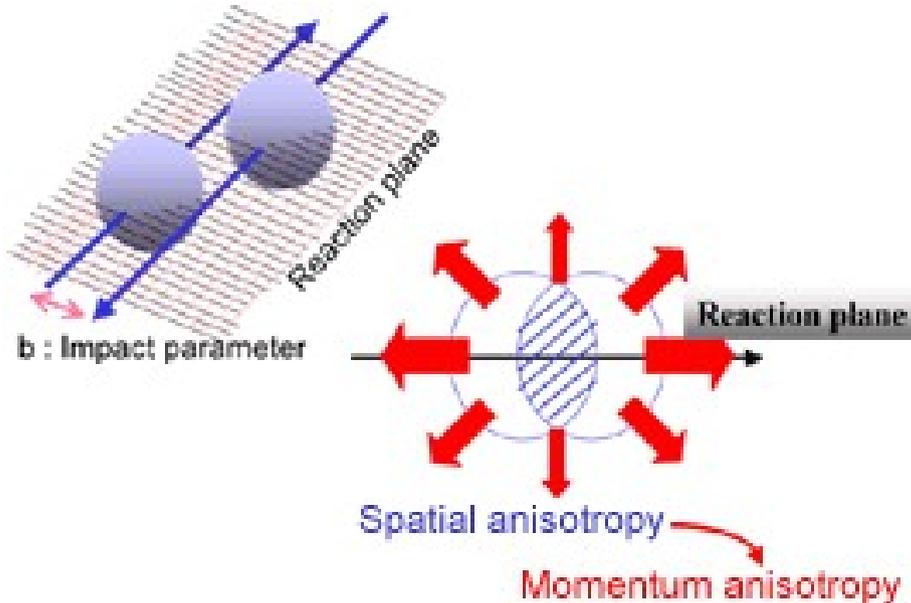


Measurement of azimuthal anisotropy of hadrons
in Au+Au collisions from a beam energy scan
by the PHENIX experiment at RHIC.

Yoshimasa Ikeda, RIKEN
for the PHENIX collaboration



Azimuthal anisotropy



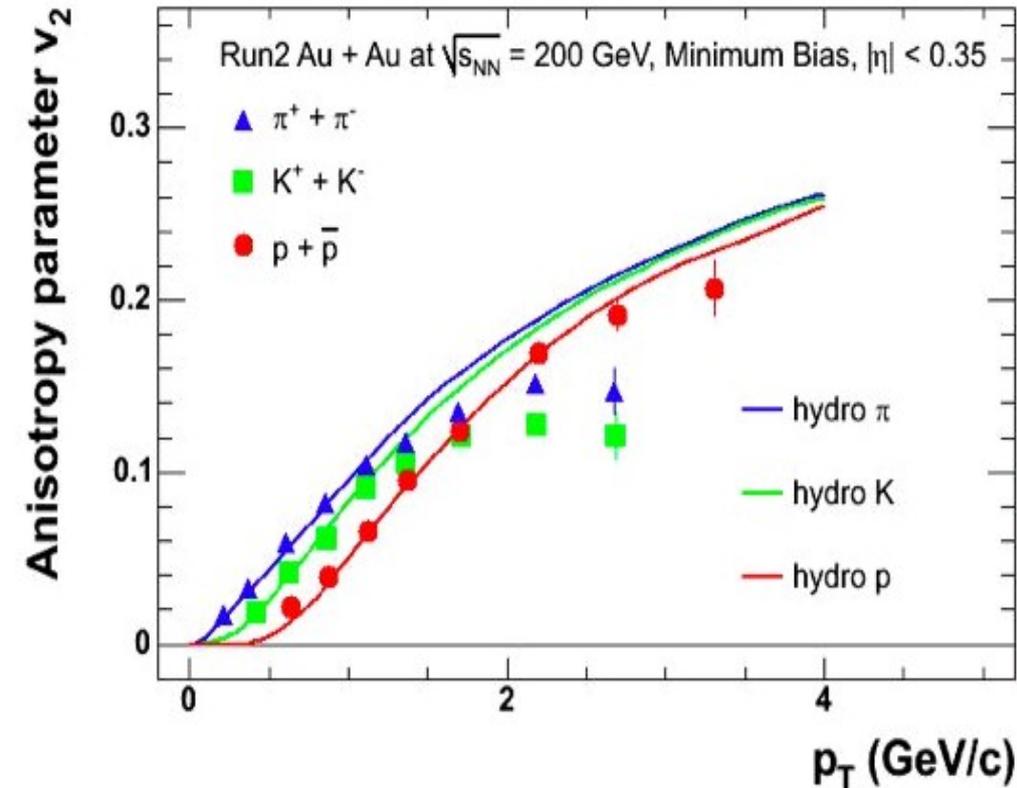
- Azimuthal anisotropy depends on initial kinematics
 - Elliptical particle emission angle distribution for non-central collision
- It is measured as 2nd term of Fourier series (v_2)

$$\frac{dN}{d\Phi} \propto 1 + 2v_2 \cos 2(\Phi - \Psi)$$

Ψ : reaction plane angle

Hydro-dynamics model

PHENIX : P.R.L. 91, 182301 (2003)

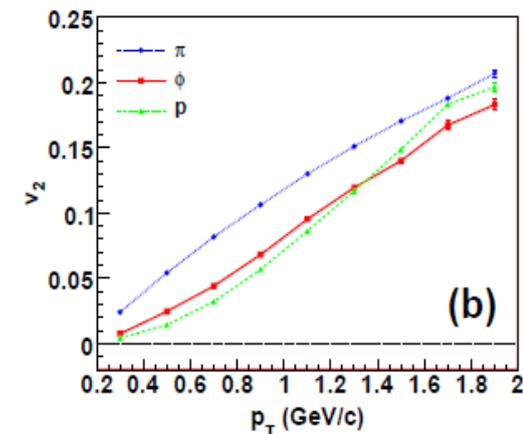
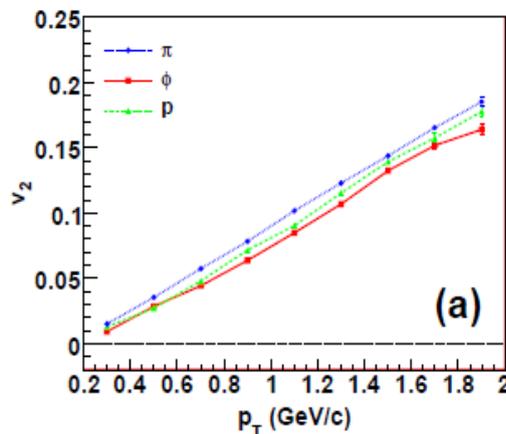


Large v_2 was observed in RHIC and it is agree with hydro-dynamical models.

Rapid thermalization and low viscosity are assumed in the model.

High resolution measurement of PID hadron v_2

- Comparison with rare particle.
 - Deuteron that is formed by p-n (or 6 quarks) should have higher v_2 than proton.
 - Φ meson have small cross section for hadron scattering. The mass is similar to proton or Λ rather than π or K .



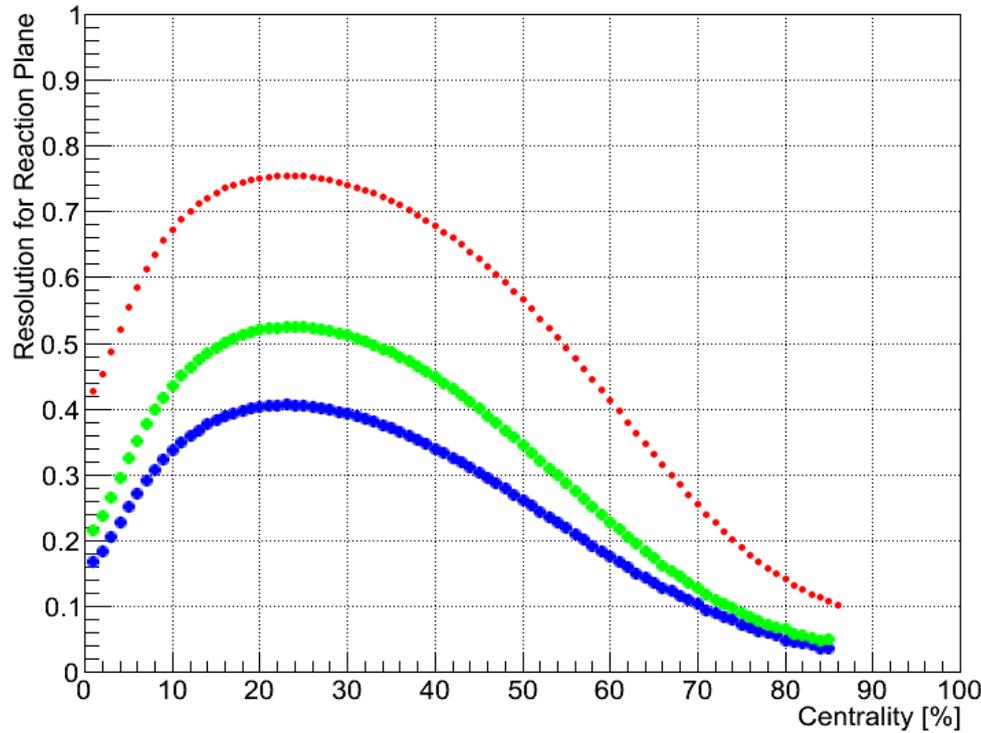
- Study for low energy collision

arXiv:0710.5795

Reaction Plane Resolution

$$Res \Psi = \langle \cos 2(\Psi_{real} - \Psi_{observe}) \rangle$$

Run10 AuAu 200 GeV/c



The observed v_2 is corrected by the correction factor $\langle \cos 2\Delta\Psi \rangle$.

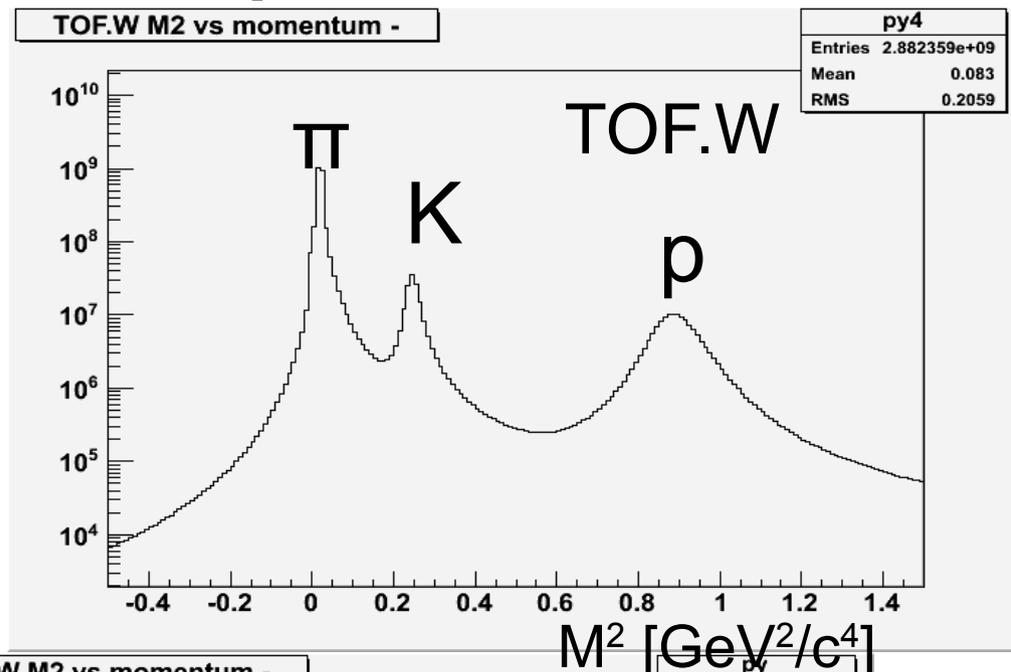
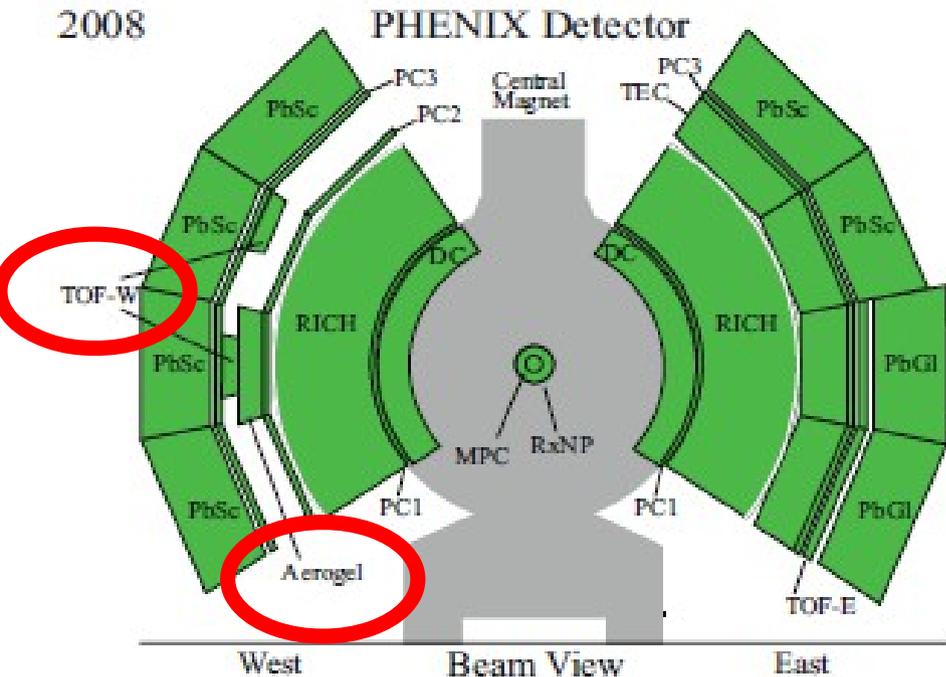
The correction factor is called reaction plane resolution.

$$v_{2_{observe}} = v_{2_{real}} \times \langle \cos 2(\Psi_{real} - \Psi_{observe}) \rangle$$

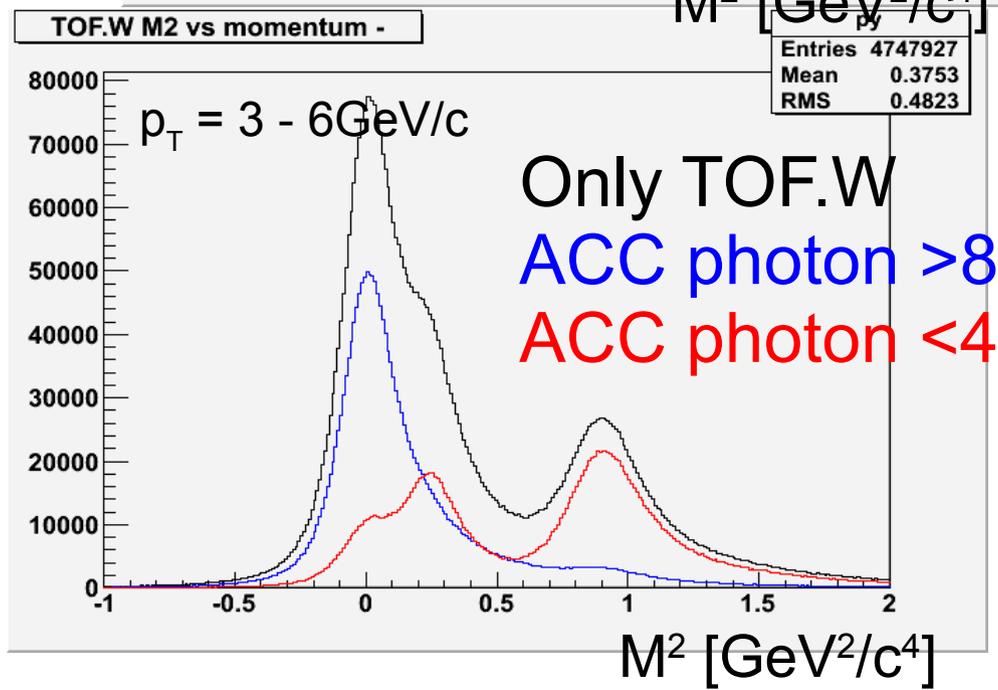
$$\delta v_2 \sim \frac{1}{\langle \cos 2(\Psi_{real} - \Psi_{observe}) \rangle} \times \frac{1}{\sqrt{N}}$$

PID for π , K and proton

2008

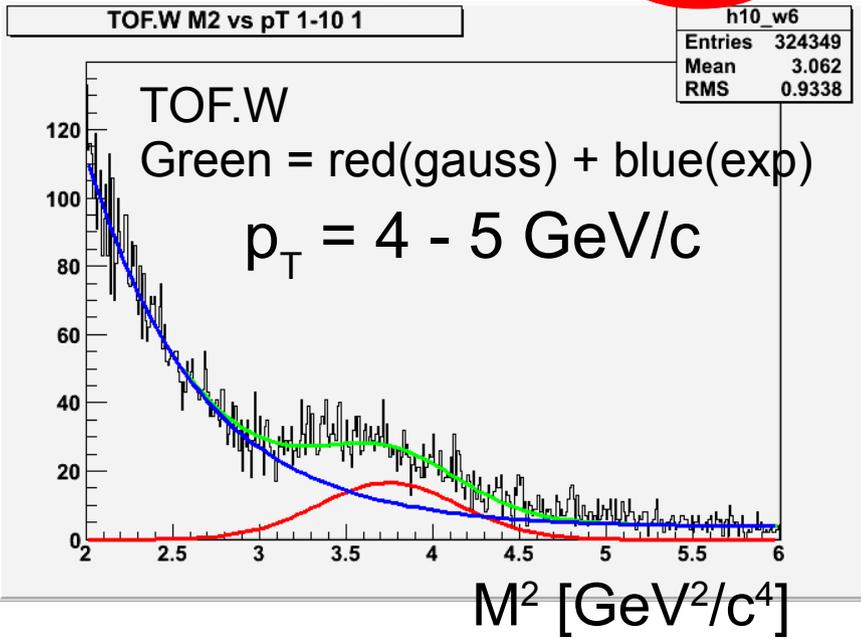
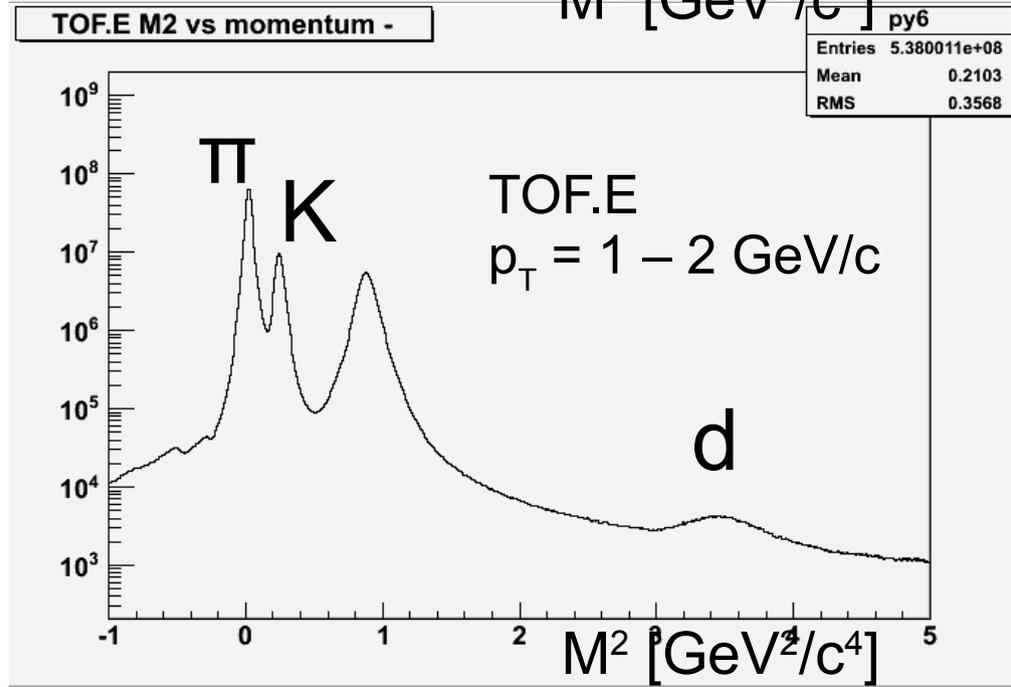
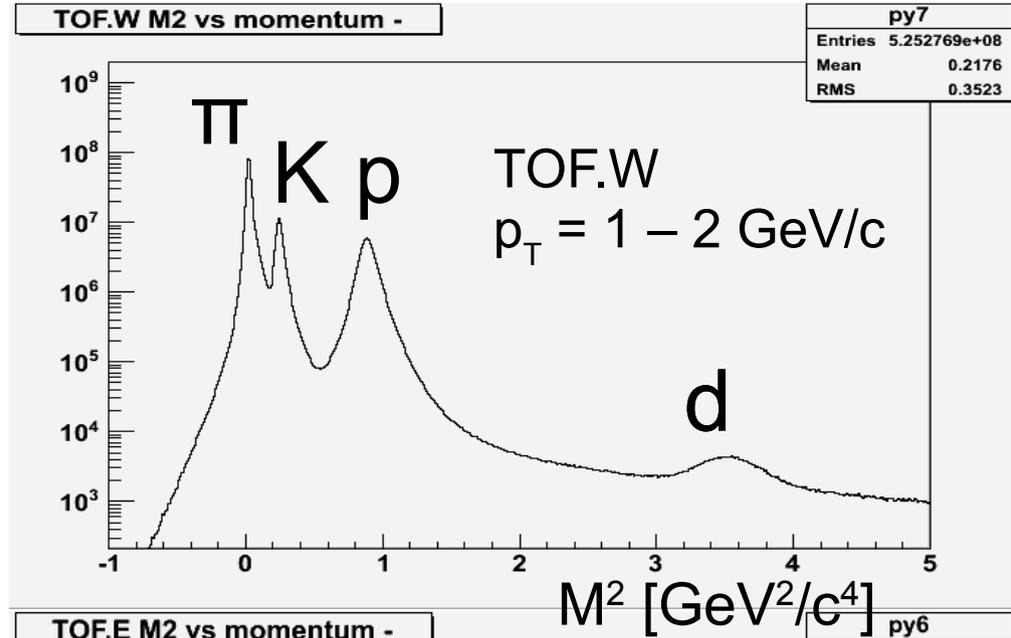
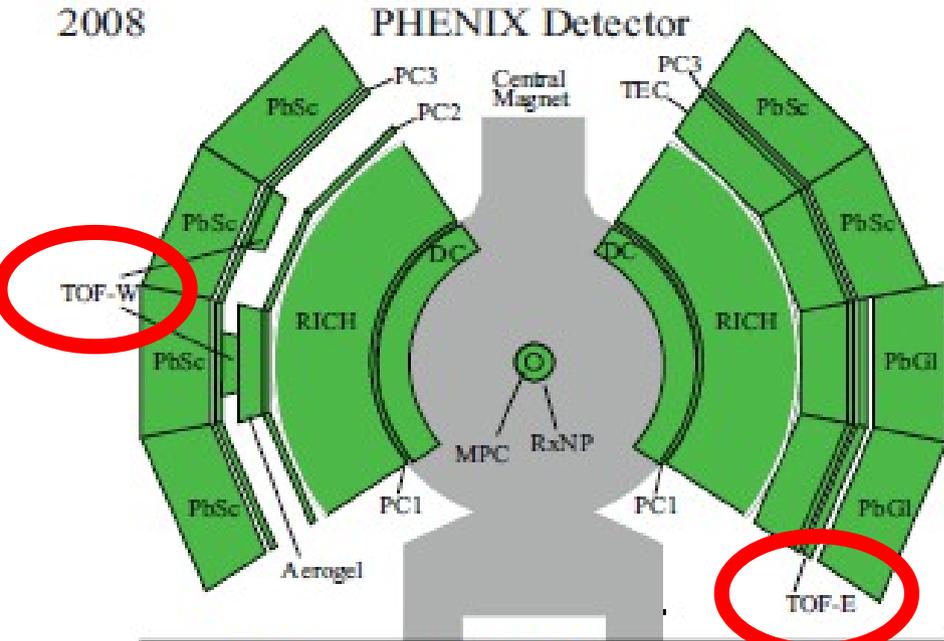


TOF.W was installed before Run7, too

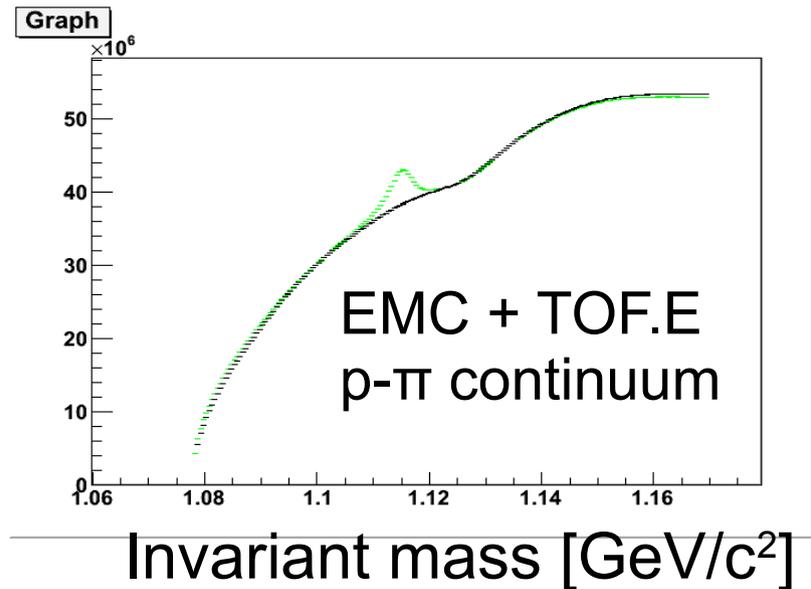
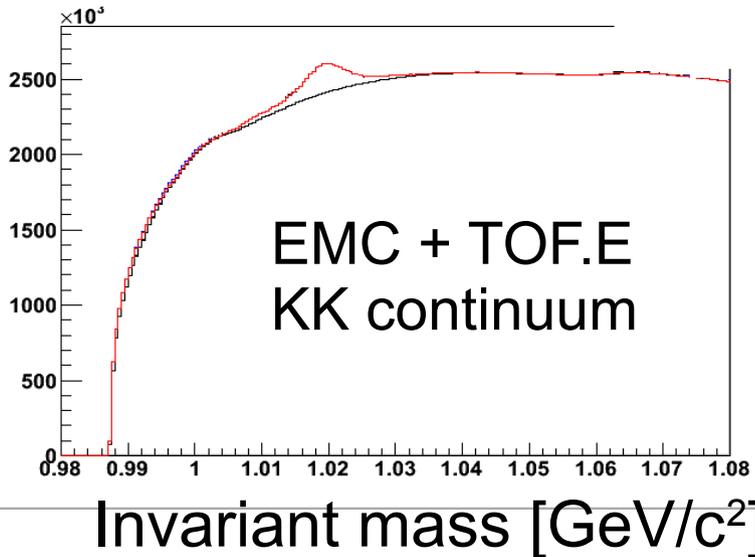
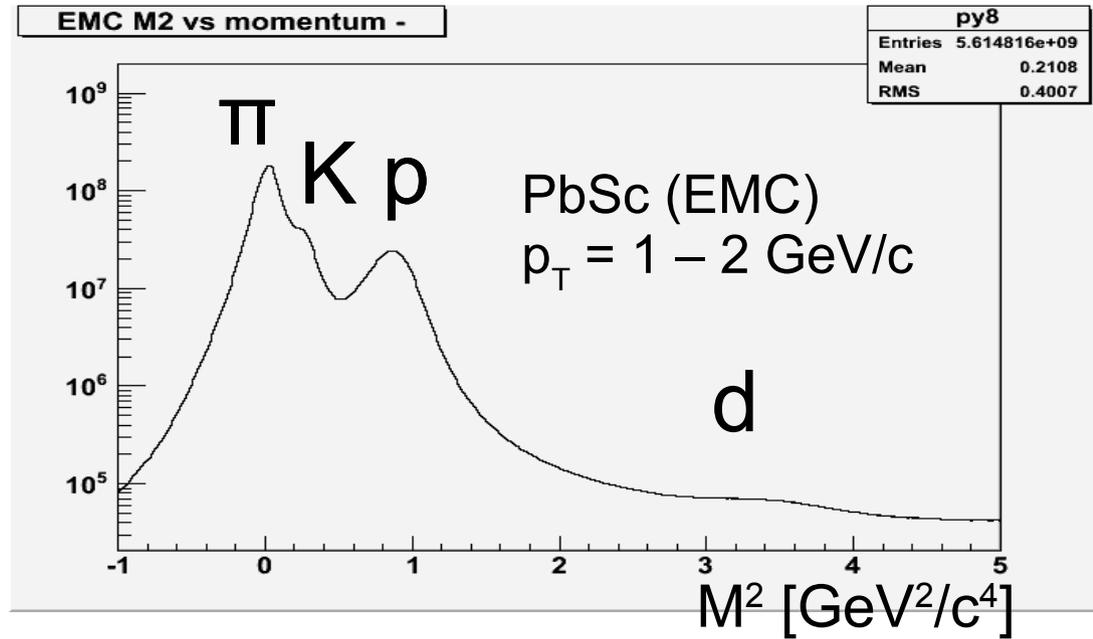
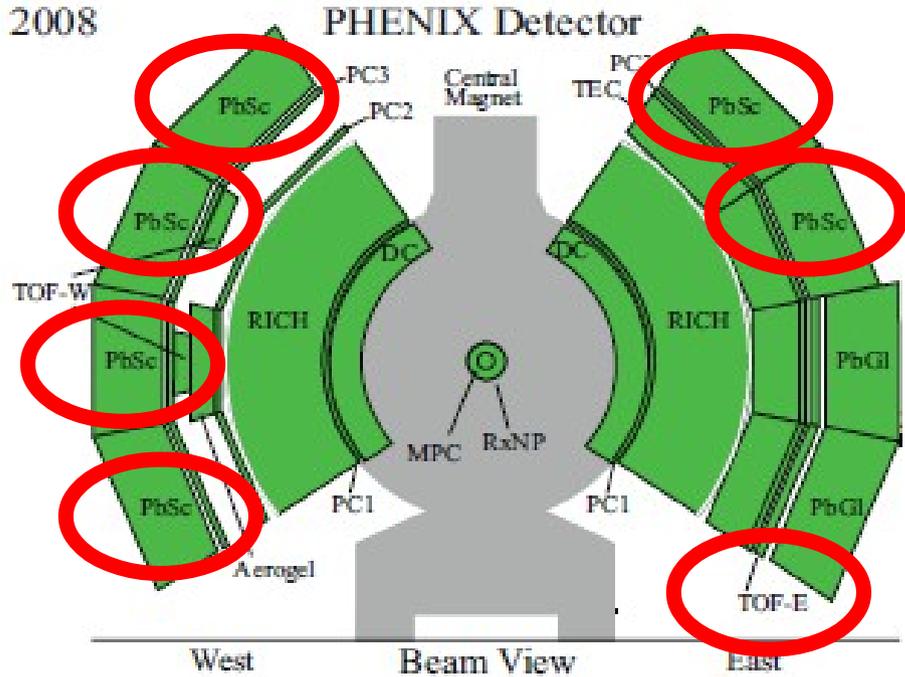


PID for deuteron

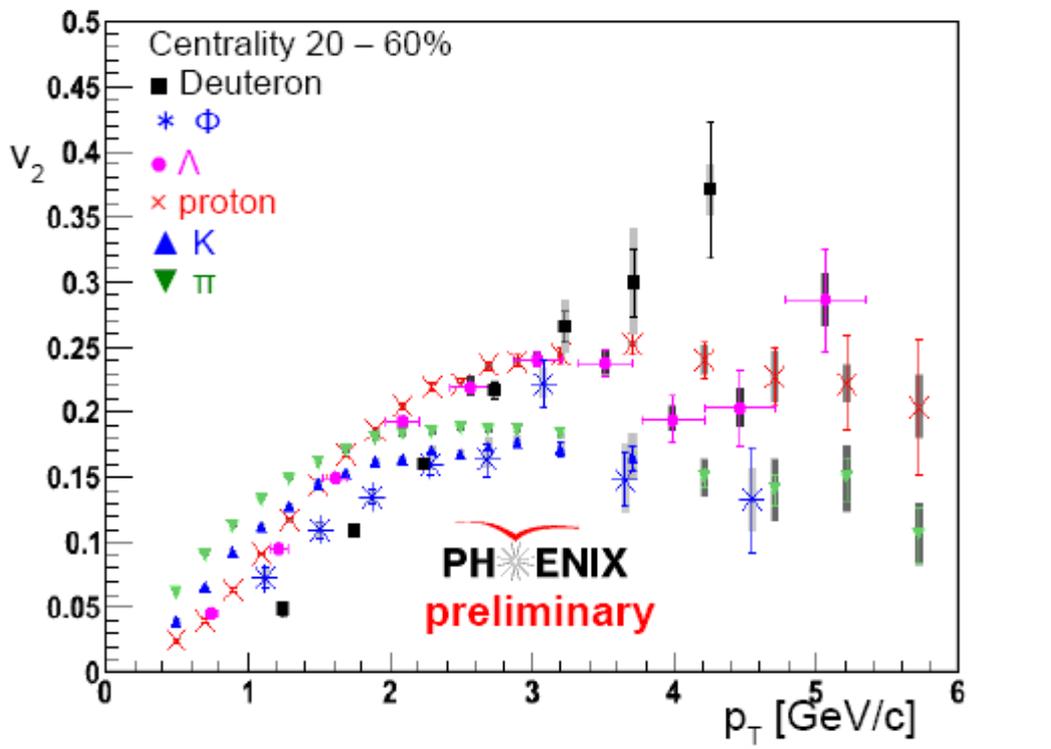
2008



PID for Λ and Φ

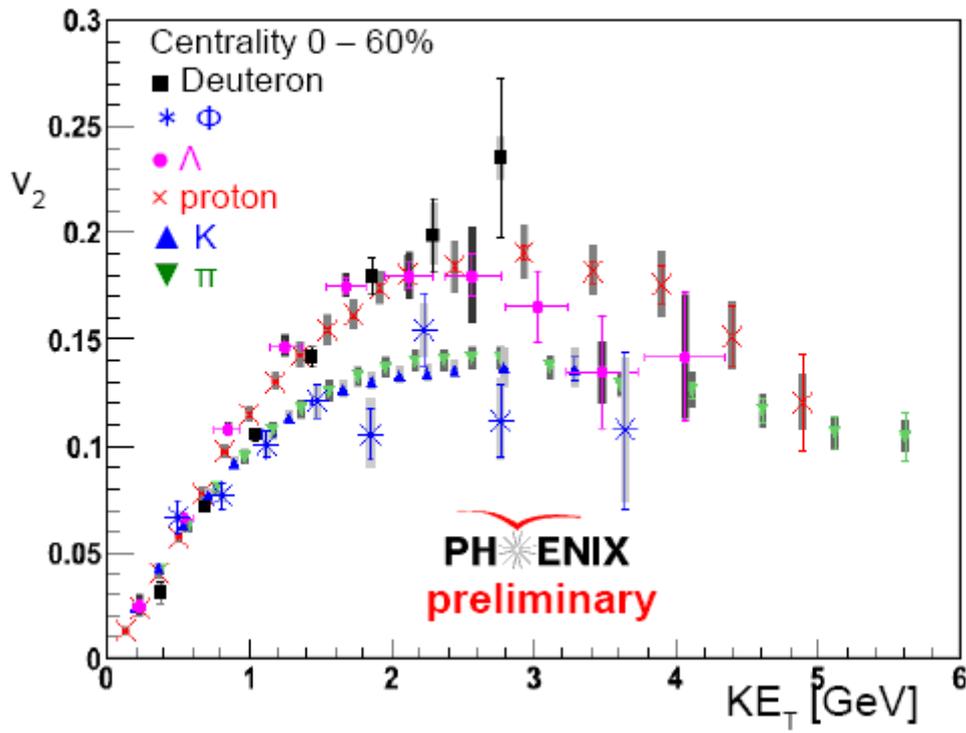


v_2 as p_T for 6 particles



- These are characteristic for each particle specie
- Heavy particle is shifted to high momentum
 - **Collective flow**
- Meson, baryon and Ion are deviated at $p_T > 2 \text{ GeV}/c$
 - **Quark coalescence**

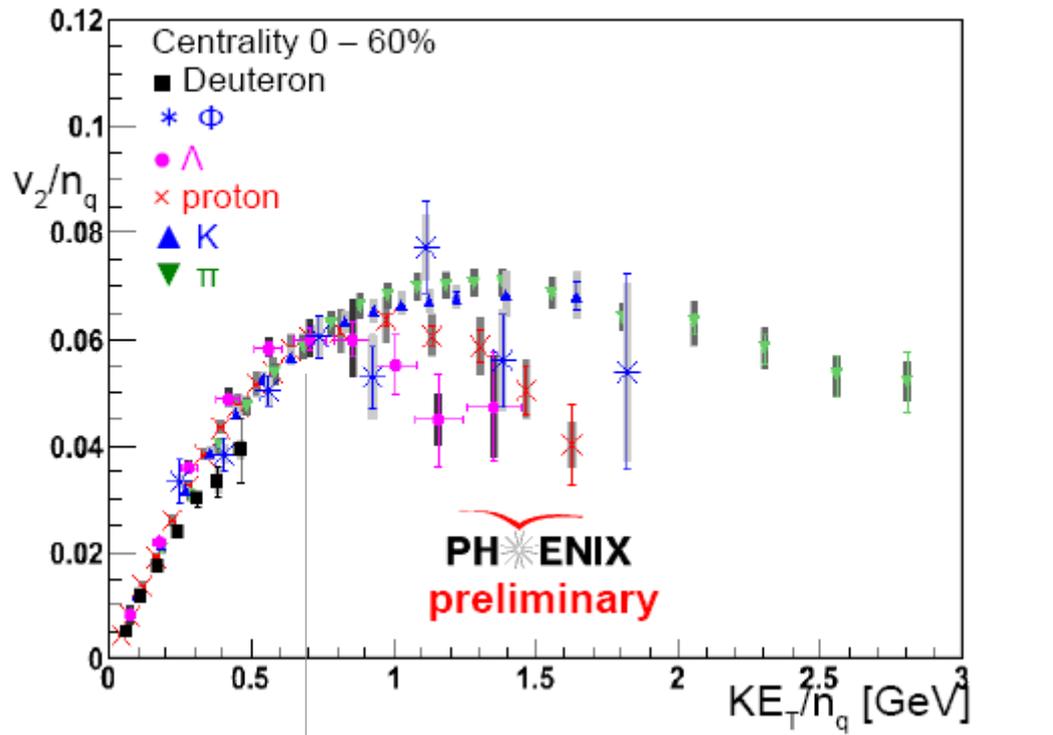
KE_T scaling



- The p_T shift depend on mass is described with KE_T
 - They are consistent separately for mesons or baryons.
- Meson line and baryon line approach at high KE_T .

$$KE_T = M_T - M_0 = \sqrt{(M_0^2 + P_T^2)} - M_0$$

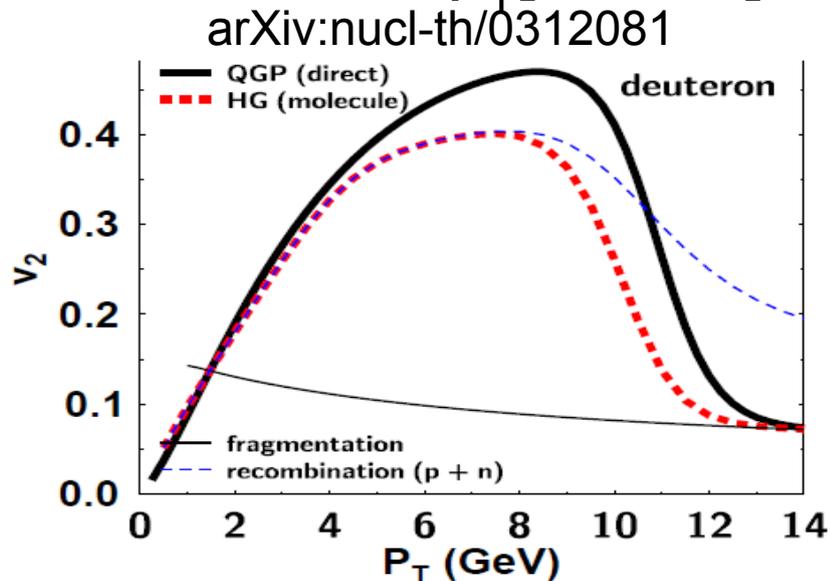
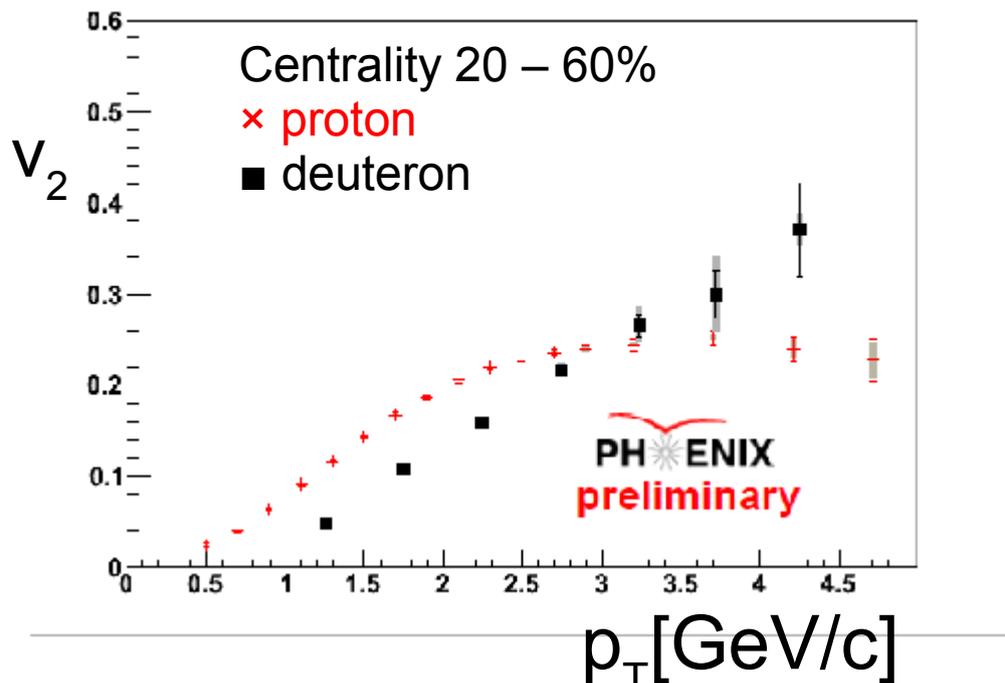
Quark number and KE_T scaling



0.7

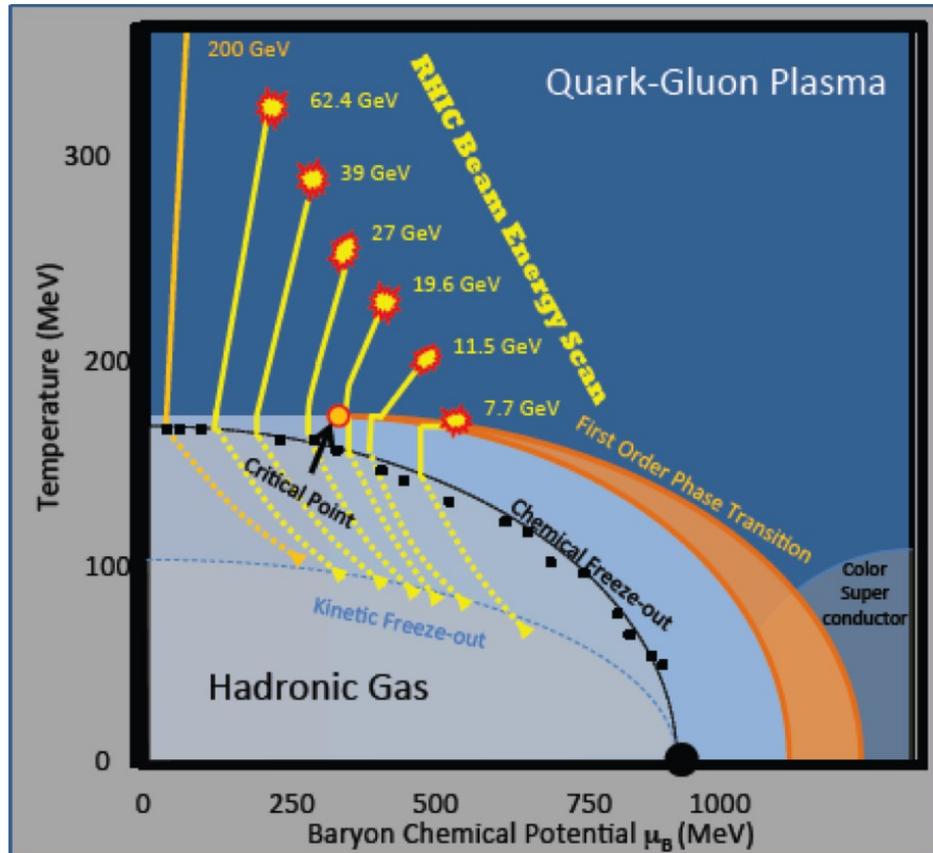
- Consistent for all particles with KE_T and number of constituent quark scaling at $KE_T/n_q < 0.7 \text{ GeV}$.
 - Collective flow of quarks
- They deviate at high KE_T/n_q
 - This indicate a change of particle and v_2 production mechanism.

p-n combination



- The $d v_2$ is higher than $p v_2$ at $p_T > 3 \text{ GeV}/c$.
- Succession of parton number scaling means $p v_2$ and $n v_2$ are very similar.
- Coalescence of p-n or 6 quarks?

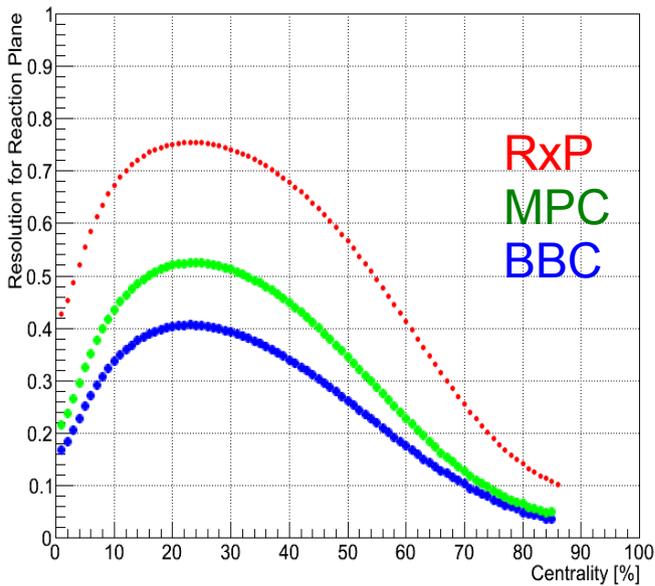
Beam energy scan with v_2 analysis



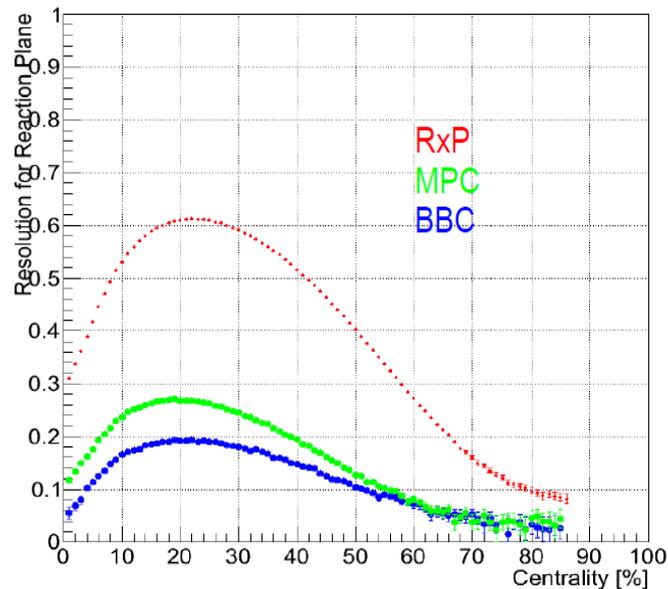
- Different regions of the QCD phase diagram.
- Brake of NCQ scaling
- Threshold of QGP
- Search the Critical point

Reaction Plane Resolution of PHENIX at low energy

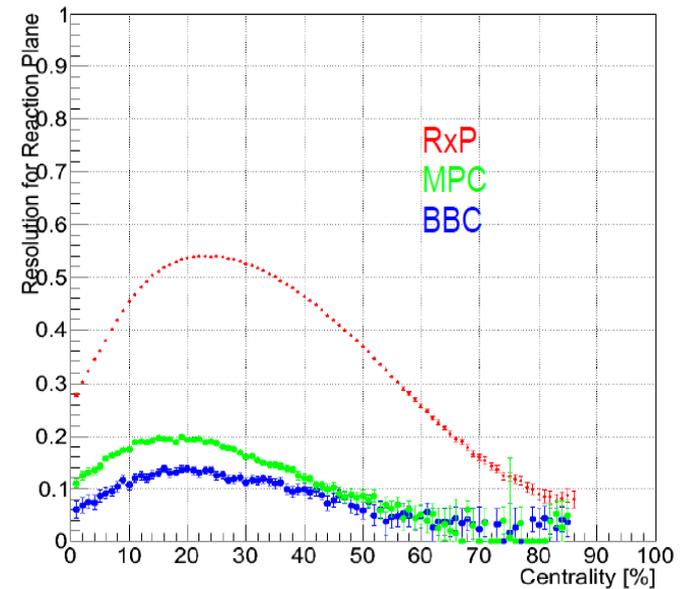
Run10 AuAu 200 GeV/c



Run10 AuAu 62 GeV/c

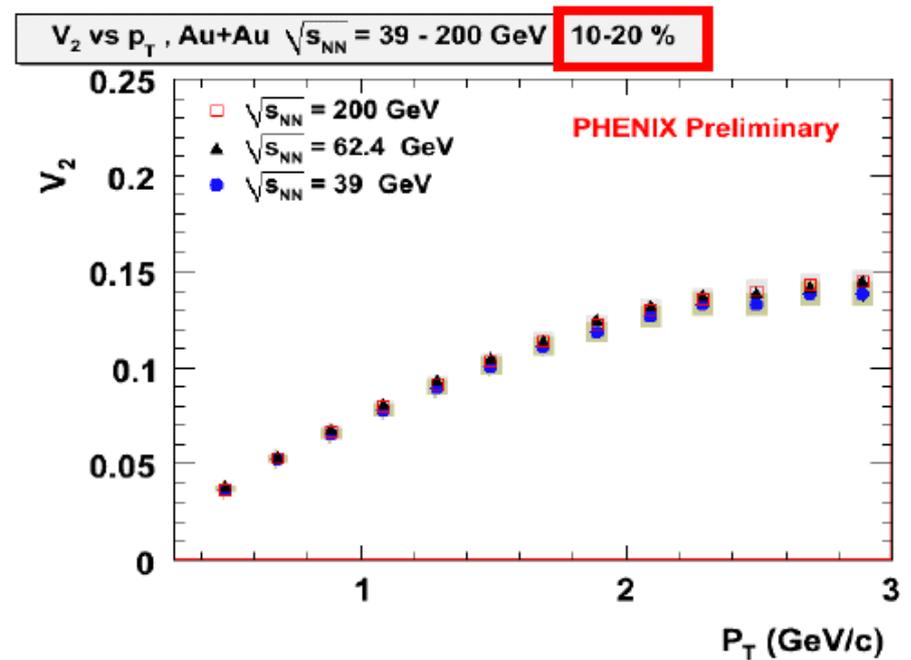
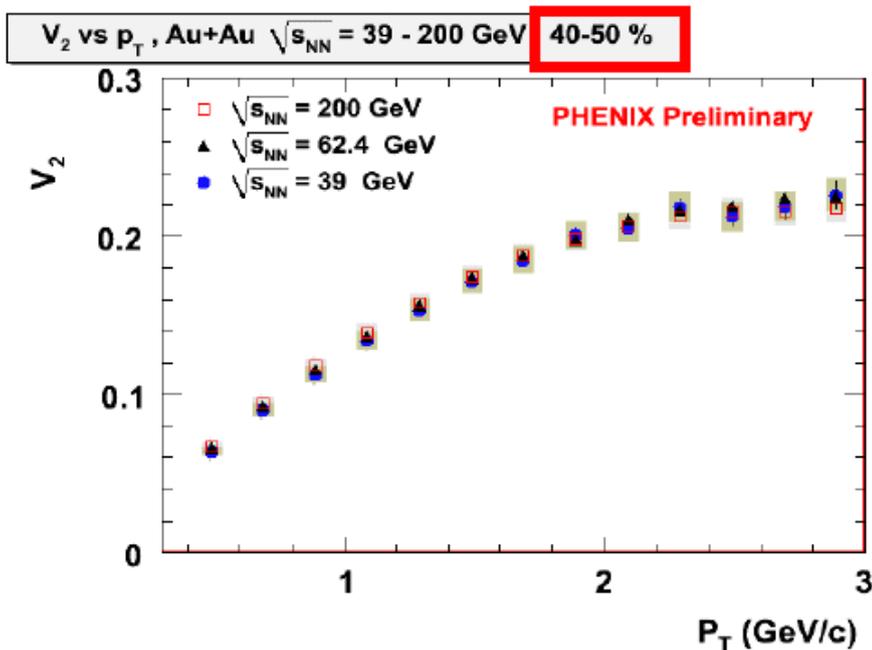


Run10 AuAu 39 GeV/c



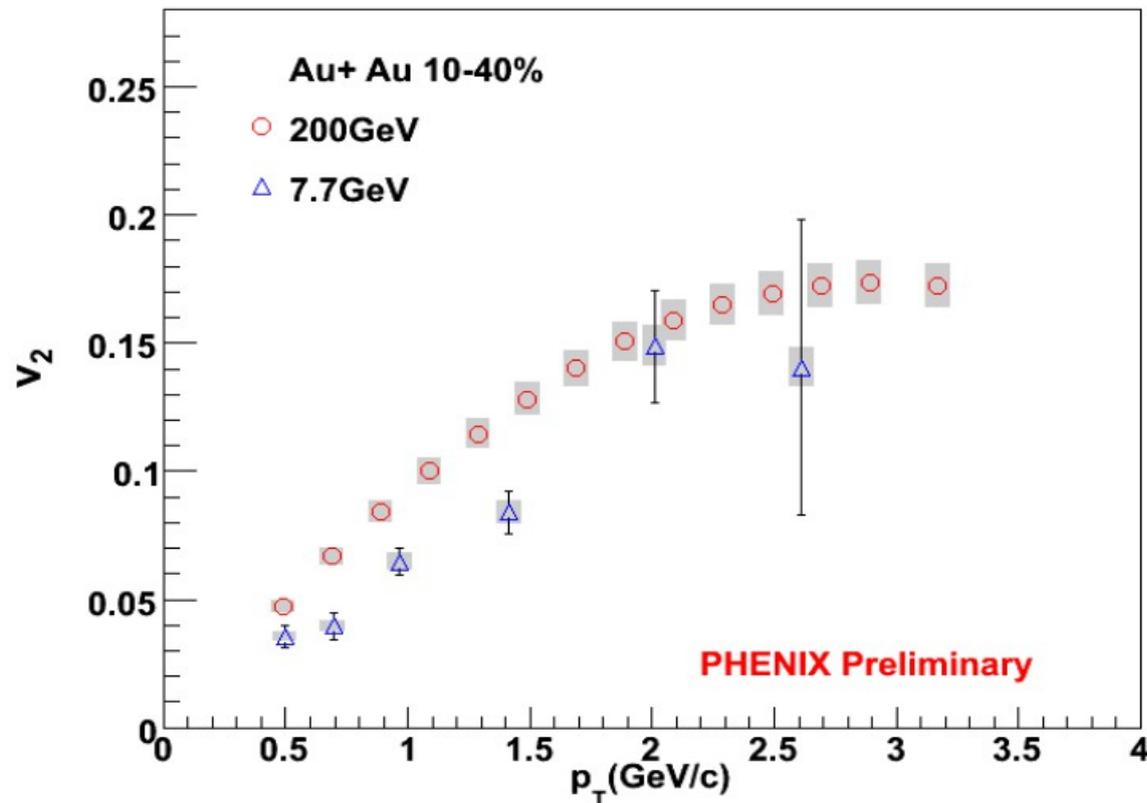
The high resolution of RxP allow the measurement of v_2 at low energy collision

Charged hadron v_2 in $\sqrt{s_{NN}} = 39, 62, 200\text{GeV}$



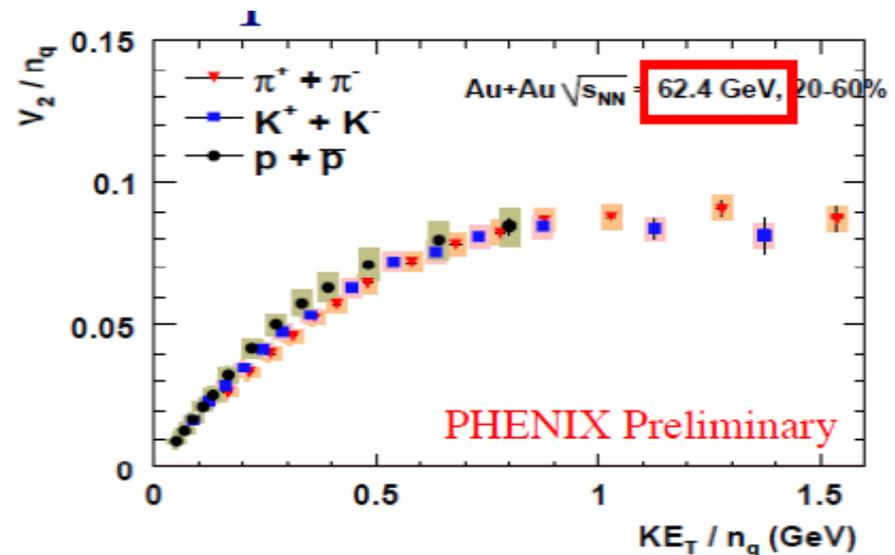
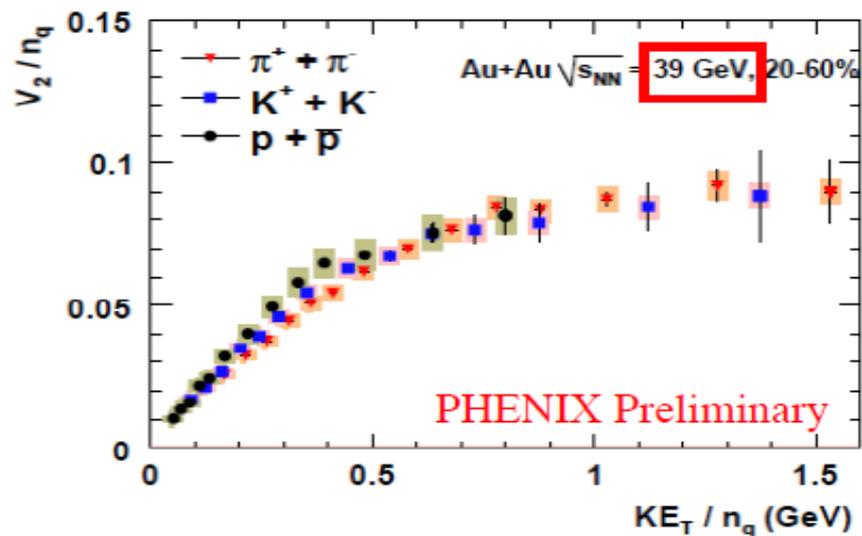
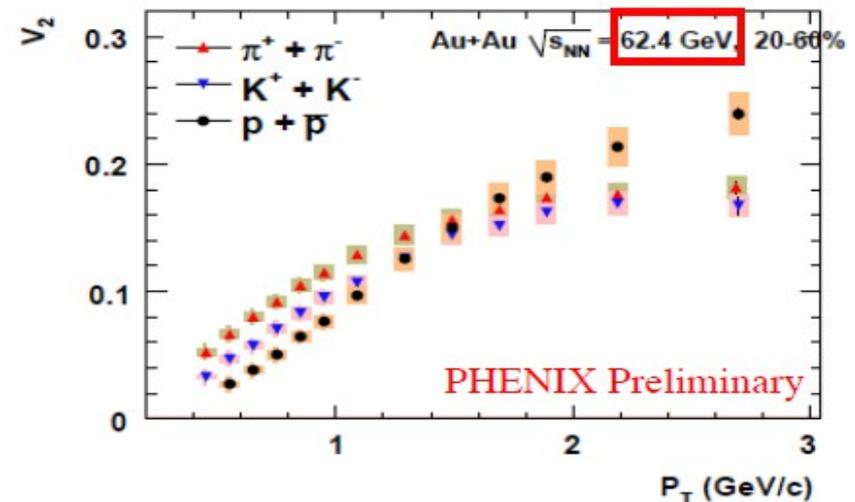
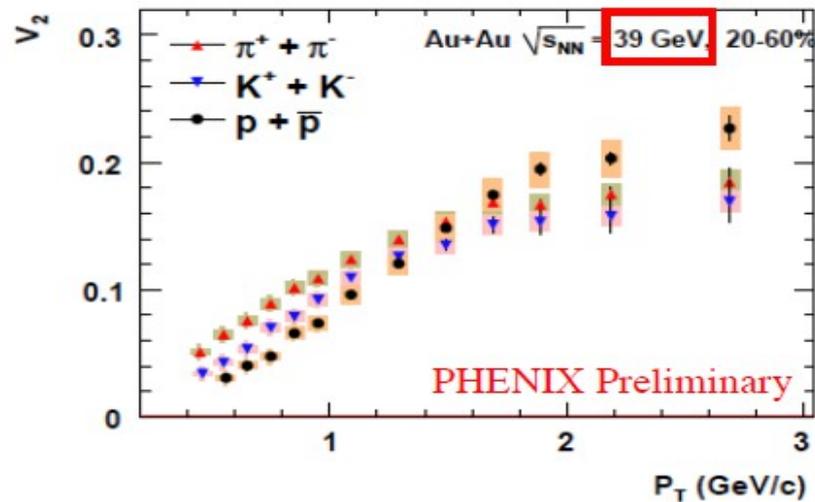
V_2 have no difference from 200GeV to 39GeV

Charged hadron v_2 in $\sqrt{s_{NN}} = 7.7$ GeV



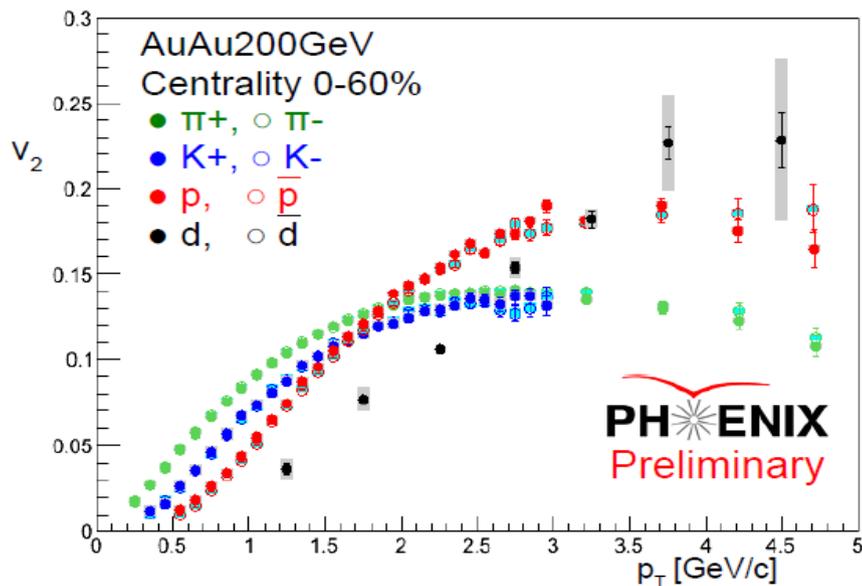
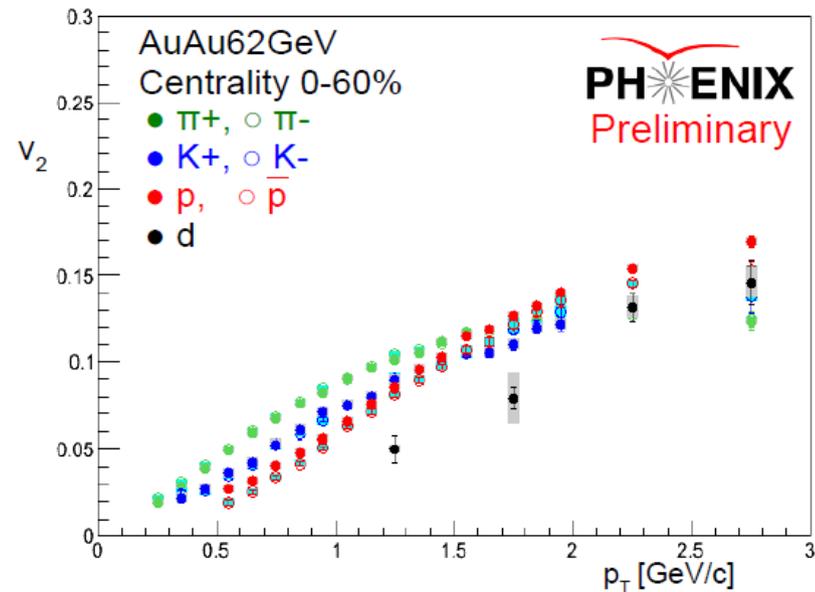
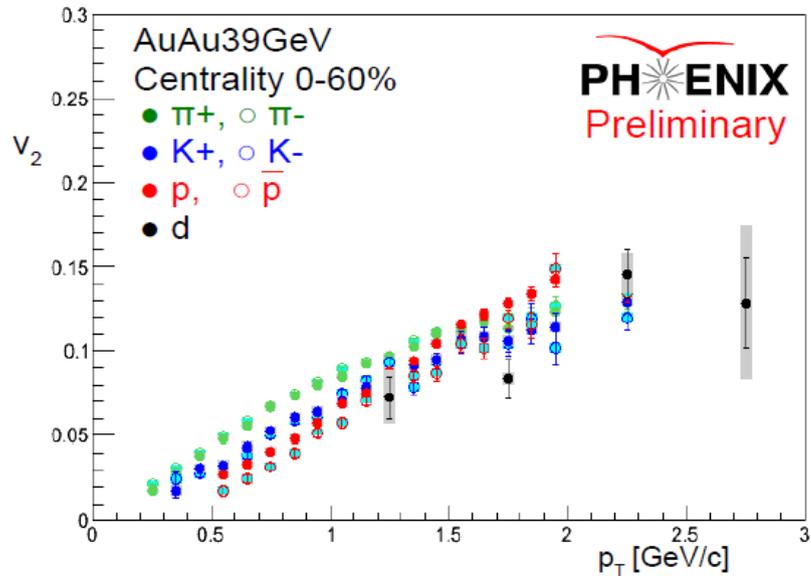
The magnitude of v_2 at 7.7 GeV is significantly lower than the magnitudes at 39, 62 and 200 GeV

PID v_2 in $\sqrt{s_{NN}}=39, 62$ GeV



$p+\bar{p}$ is slightly large with n_q scaling

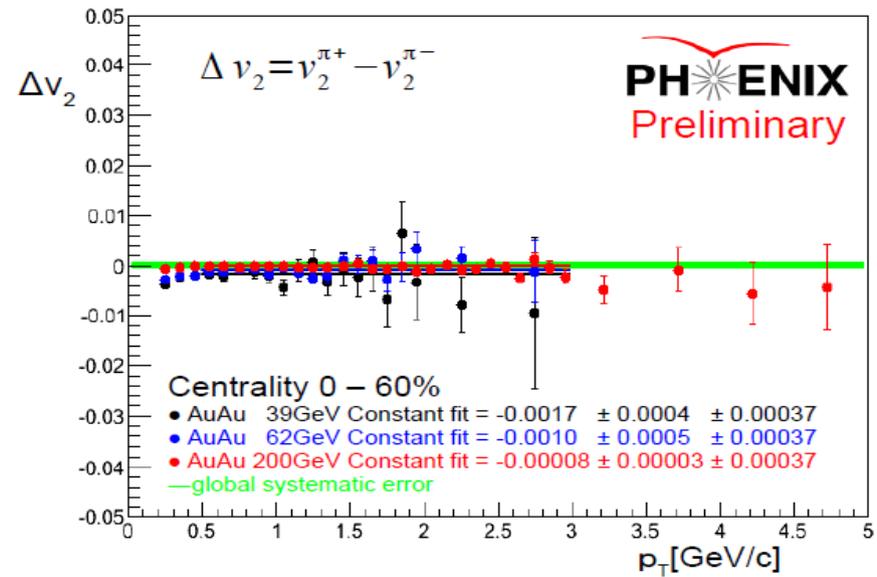
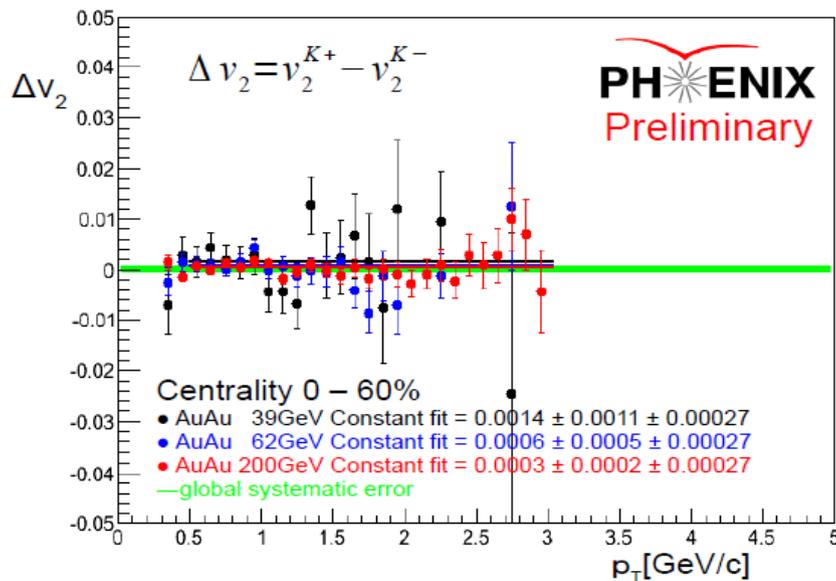
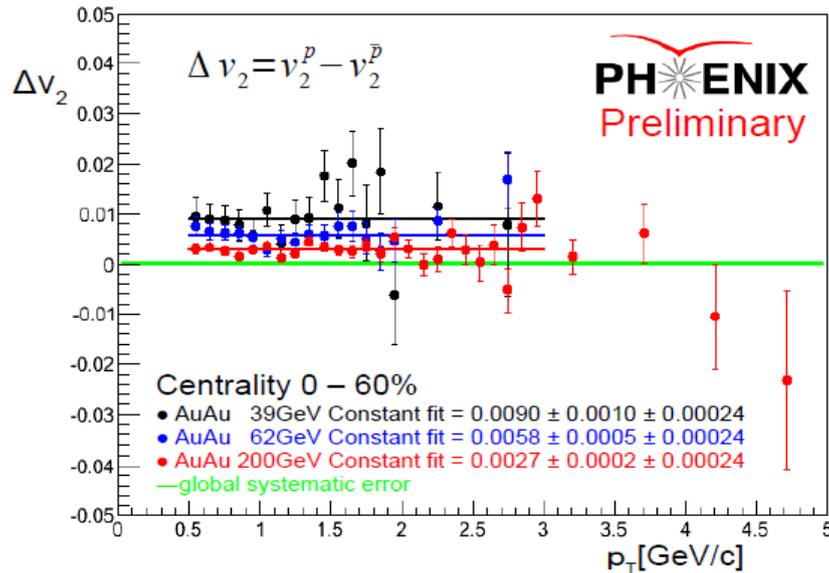
Charge separated PID v_2



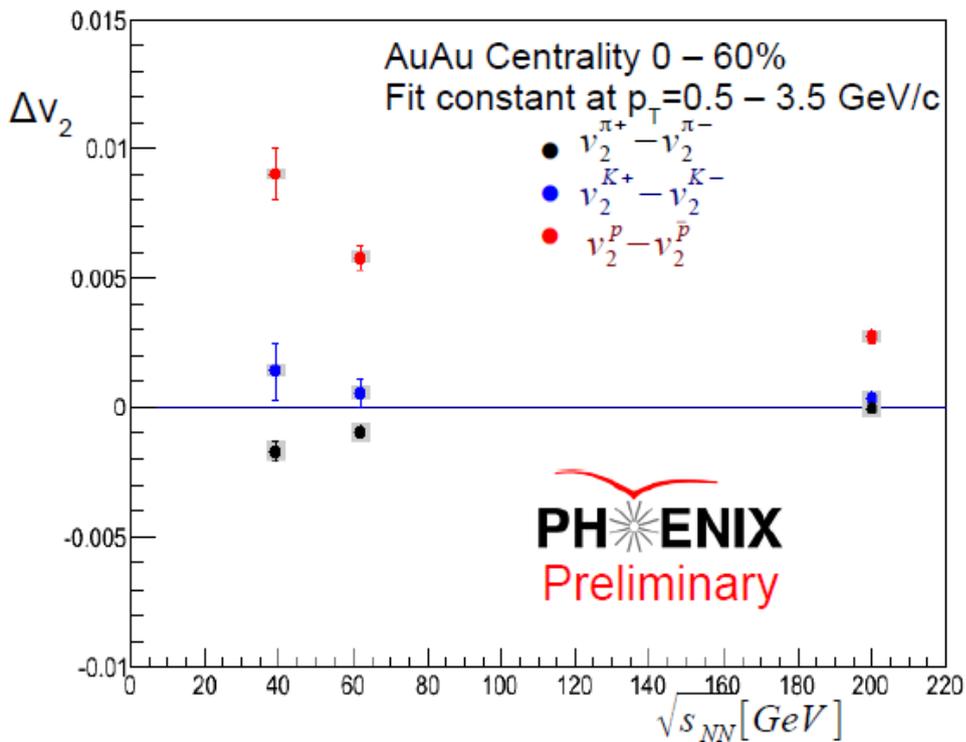
Proton have larger v_2
than that of anti-proton
at low energy collision
(39, 62GeV)

Difference v_2 between +/- charge

- Proton has larger v_2 than that of anti-proton at low energy collision
 - The v_2 difference is flat to momentum.



Δv_2 vs collision energy

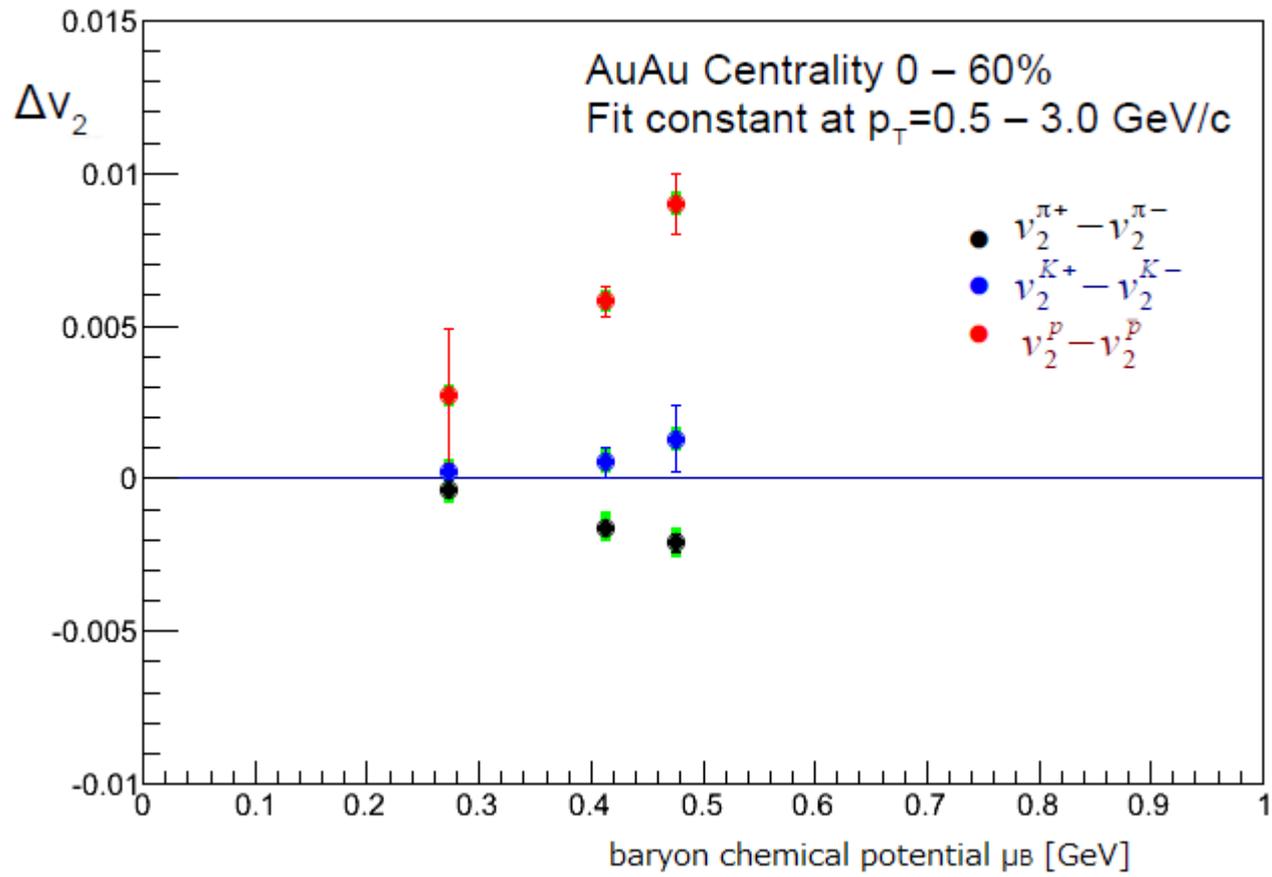


- p- \bar{p} are deviated at low energy collision
 - The v_2 difference is flat to momentum.
- π^- v_2 has slightly larger than π^+
- K v_2 has no difference for +/- charge
- Annihilation effect with large net-baryon ratio ?

Summary

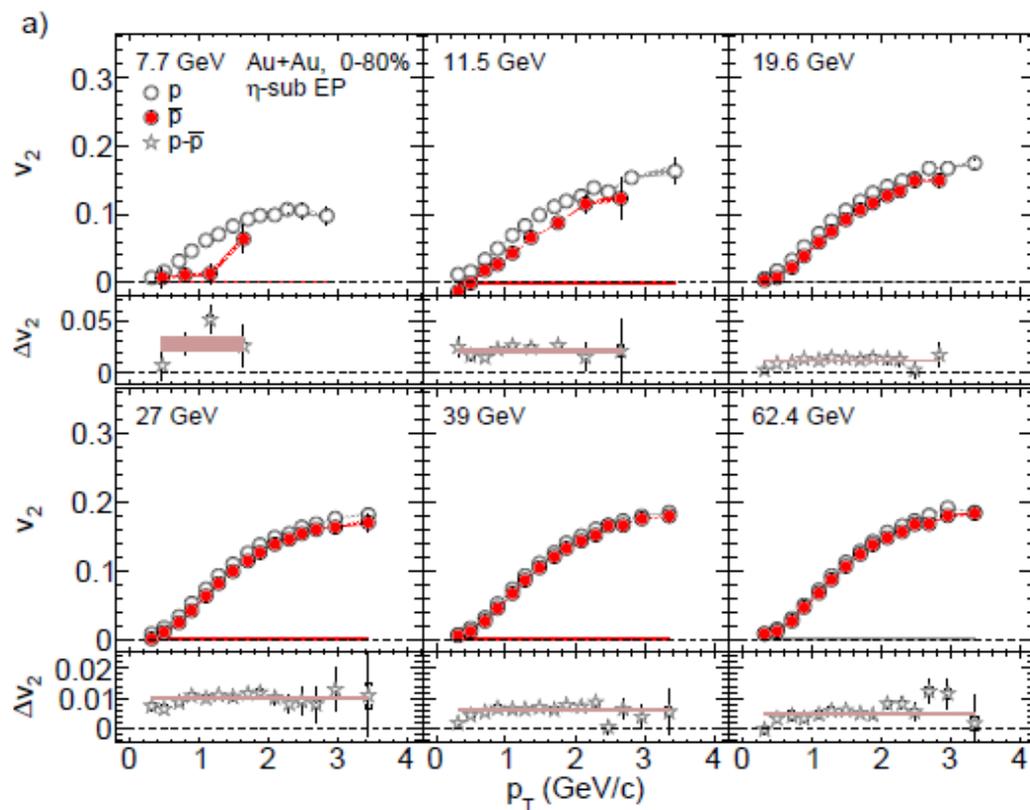
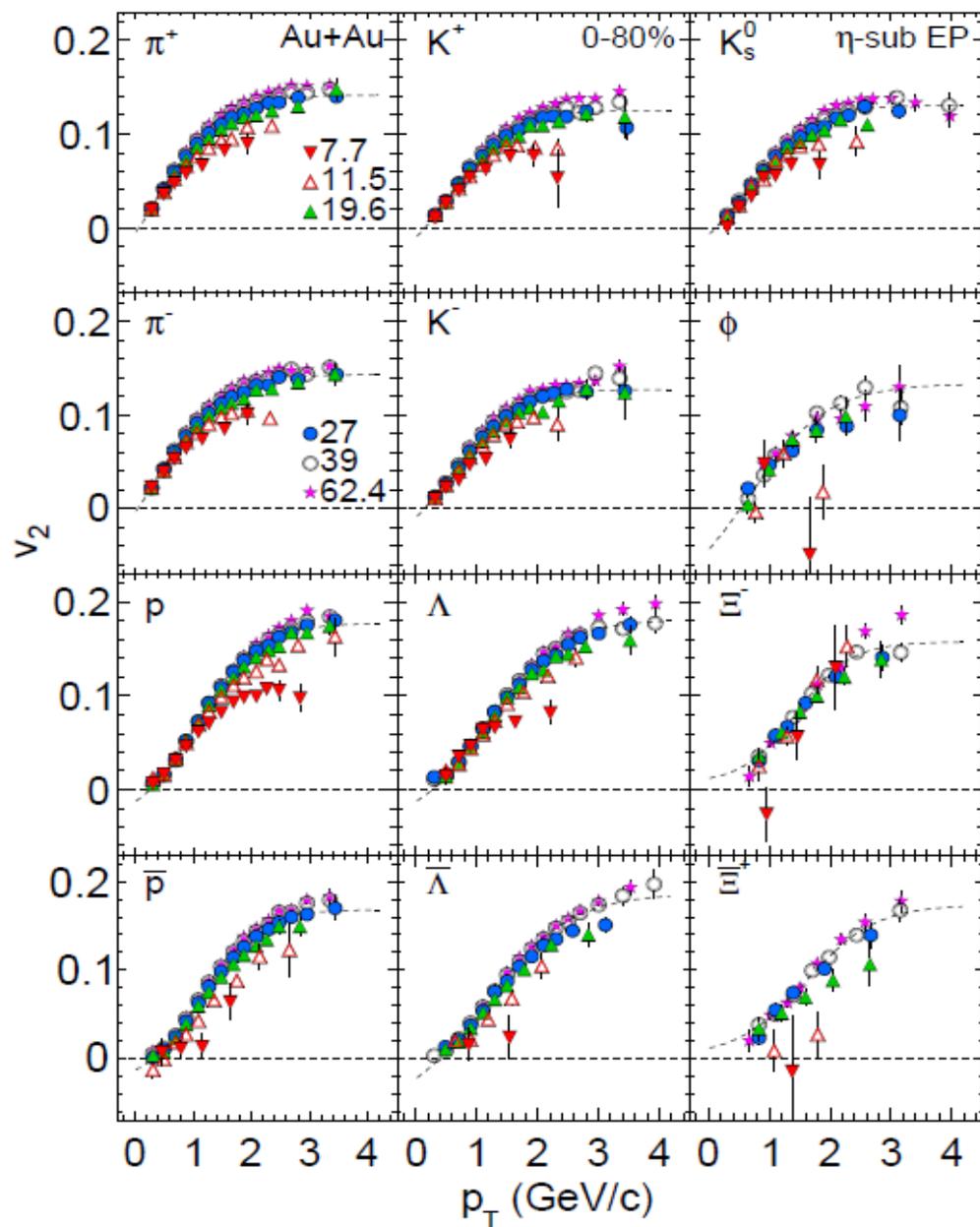
- V_2 of identified particles were measured at Au+Au $\sqrt{s_{NN}}=200, 62$ and 39GeV
- V_2 of all particles are consistent with number of constituent quark scaling at $\sqrt{s_{NN}}=200\text{GeV}$
 - Collective flow of quarks
- They are almost consistent at $\sqrt{s_{NN}}=62$ and 39GeV . But $p v_2$ is slightly large.
- Proton v_2 and anti-proton v_2 are deviated
 - The difference increases to low energy collision
 - The difference is flat to momentum.
 - $\pi^- v_2$ has slightly larger than π^+
 - $K v_2$ has no difference for +/- charge

Backup



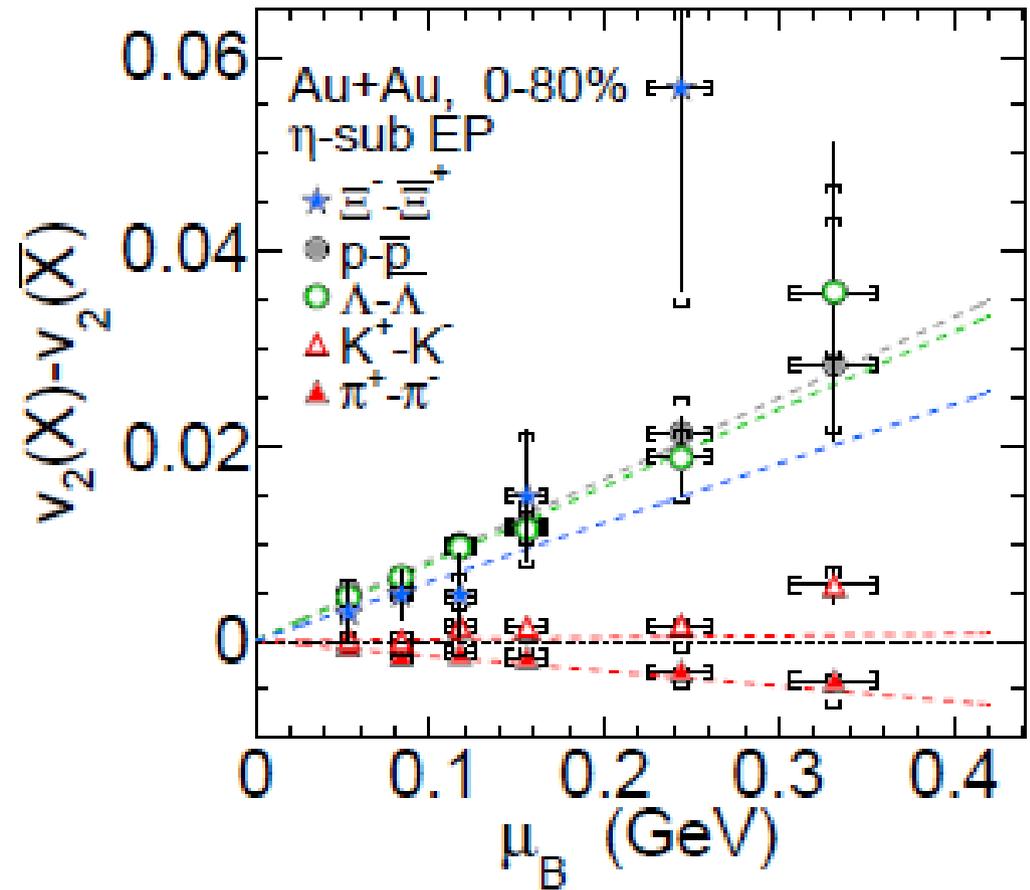
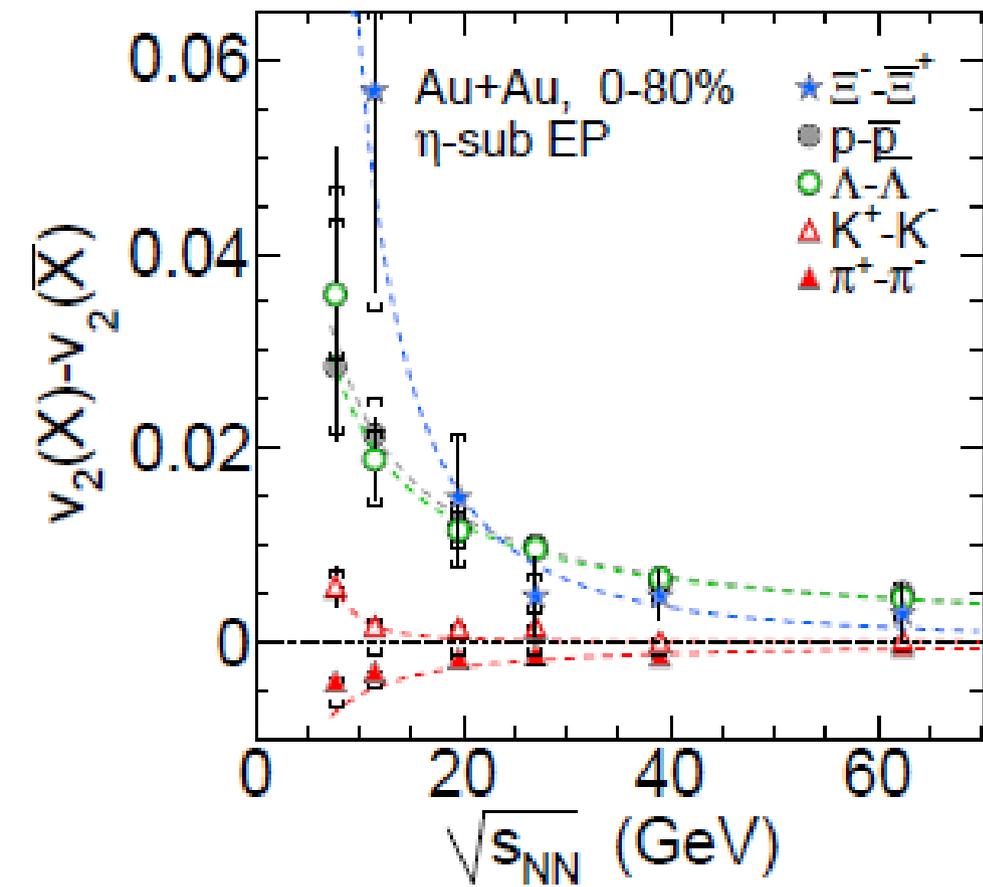
RHIC-STAR

ArXiv:1301.2348v1



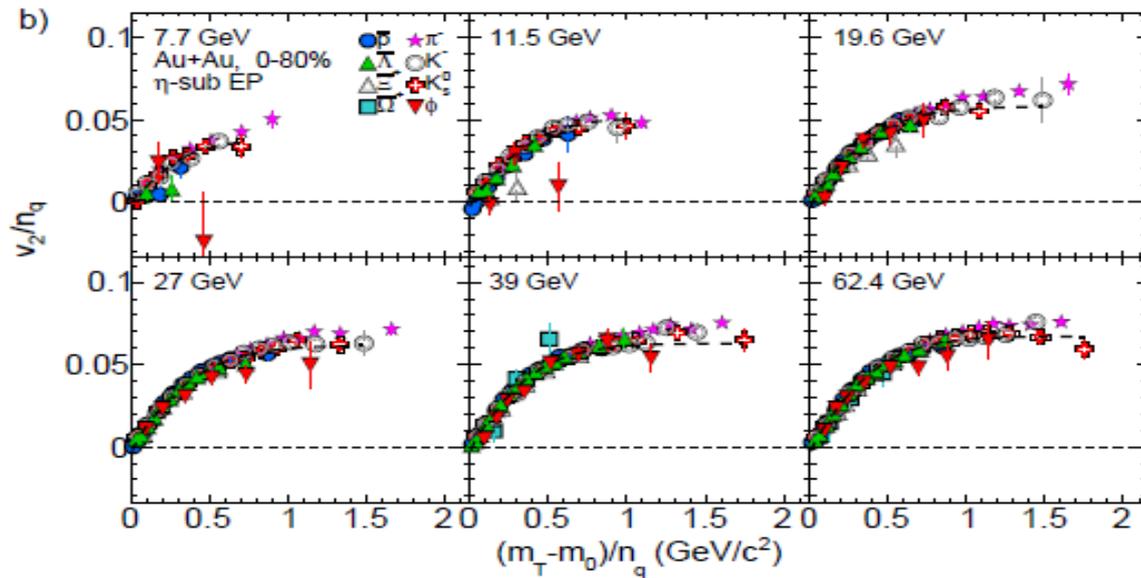
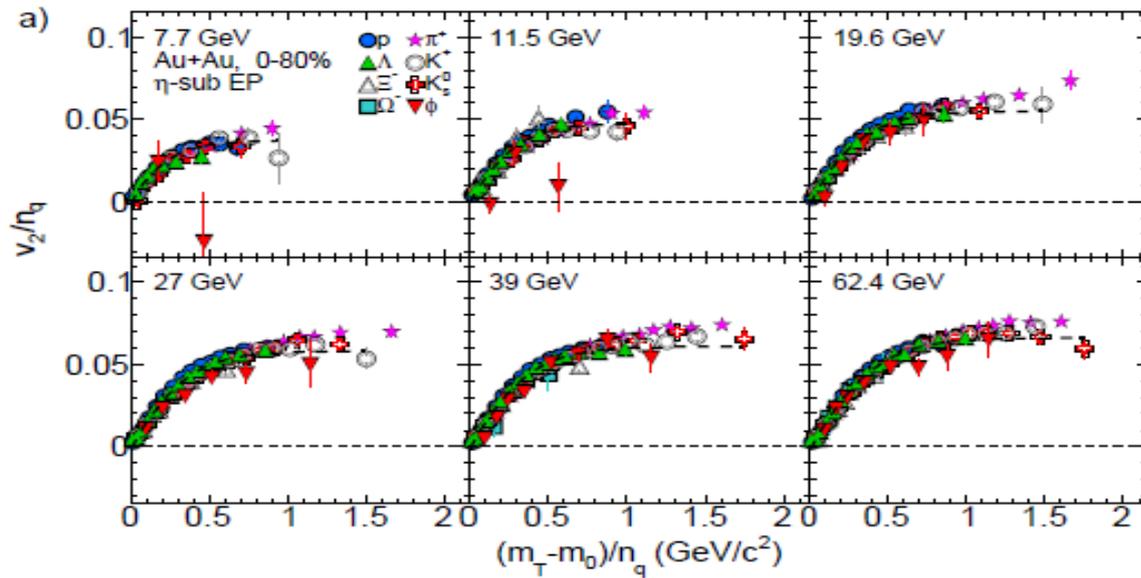
RHIC-STAR

ArXiv:1301.2348v1

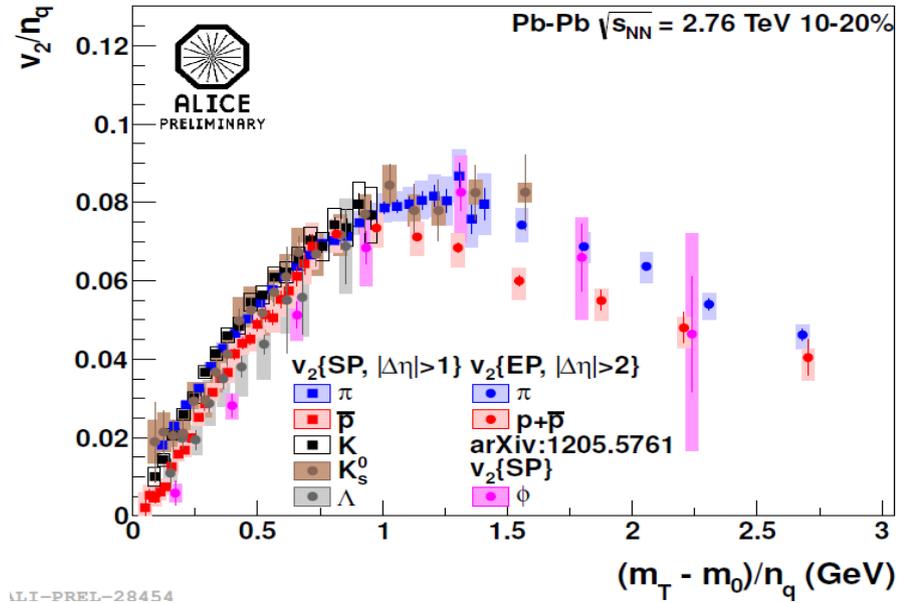
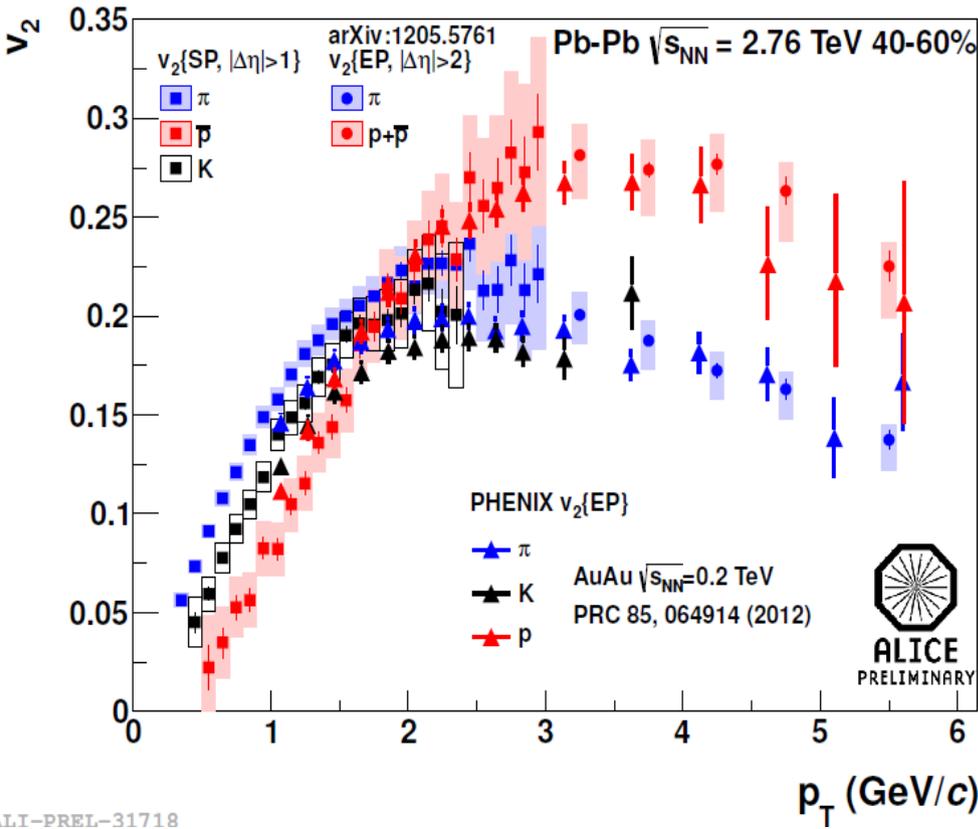


RHIC-STAR

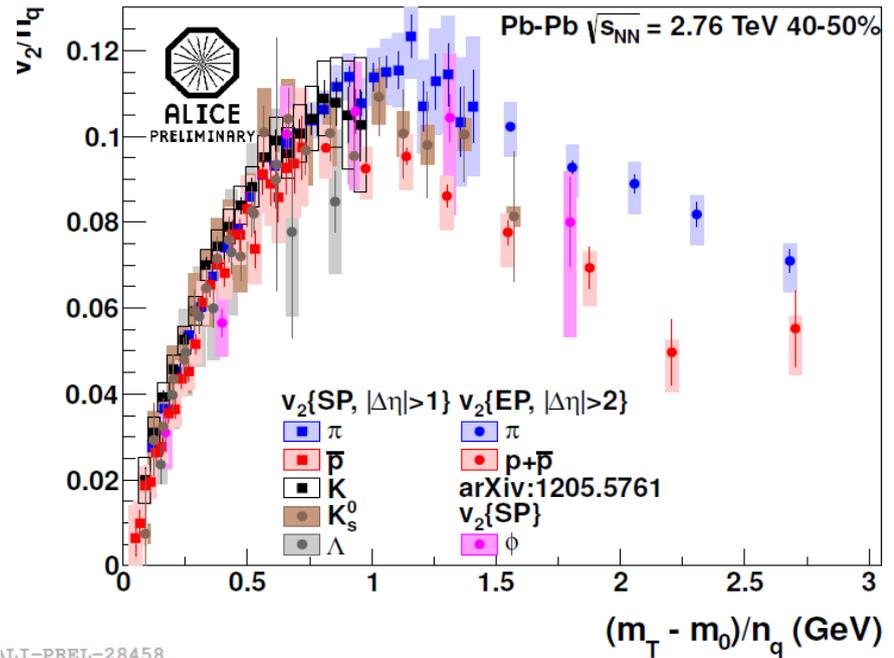
ArXiv:1301.2348v1



LHC-ALICE



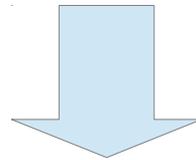
ALI-PREL-28454



ALI-PREL-28458

Motivation of RP detector

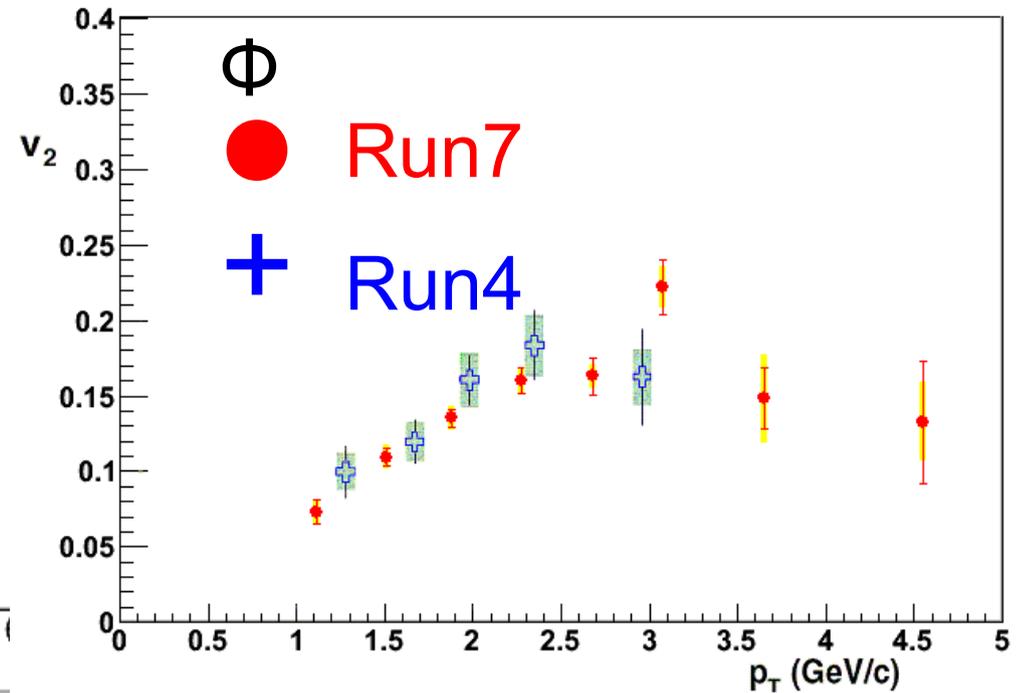
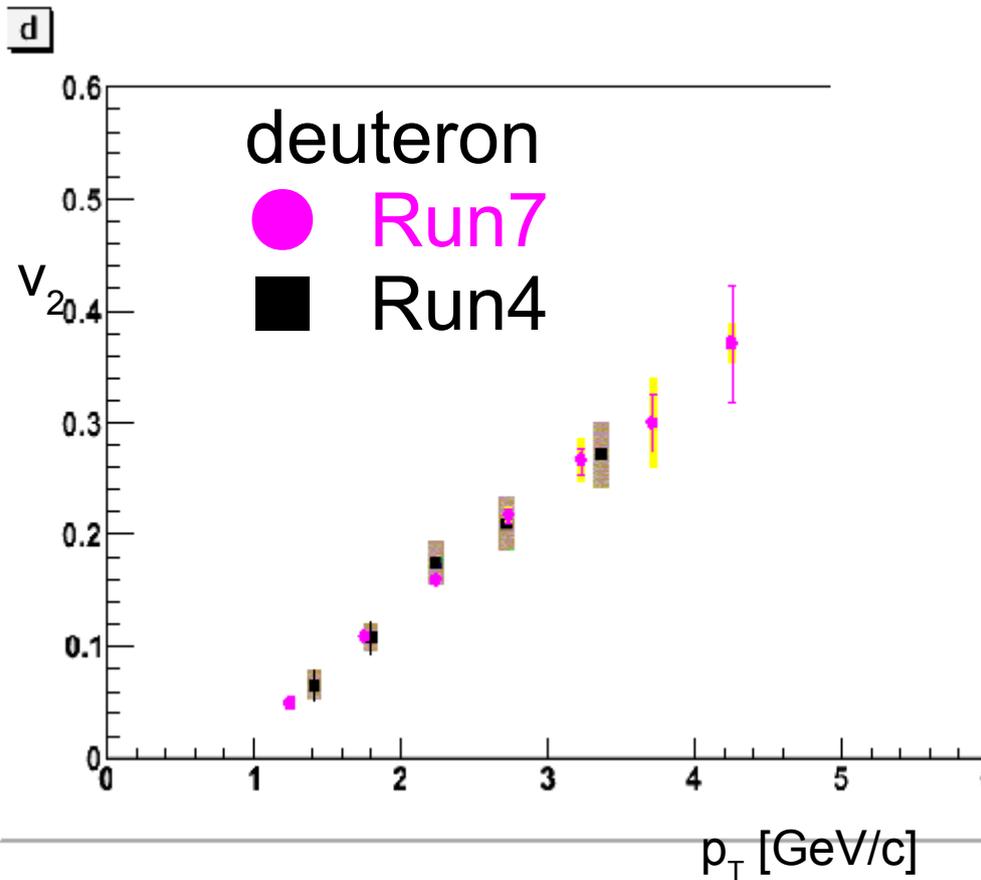
- Measurement of more precise v_2 is expected.
- Poor reaction plane resolution was a major limiting factor of PHENIX v_2 measurement of rare probes such as d , Φ .



Reaction Plane Detector (Rxp) has been constructed and installed to PHENIX in 2007.

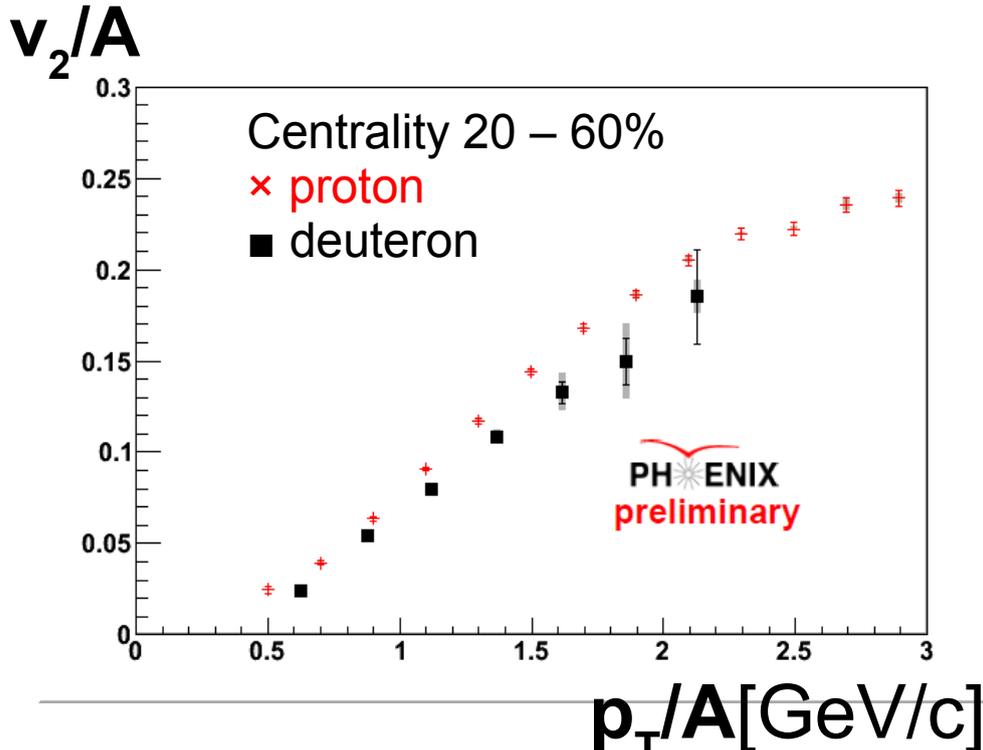
- Reaction plane resolution of $\langle \cos 2\Delta\psi \rangle \sim 0.75$ for minimum bias Au+Au collisions

Comparison with last one



- p_T range is extended to $p_T \sim 4.5$ GeV/c.

Nucleon number scaling



$$v_2^d \sim 2 v_2^p, \quad p_T^d \sim 2 p_T^p$$

- The peak of d v_2 is expected at $p_T=6\text{GeV}/c$.
- D v_2 and p v_2 are very similar on p_T/A scaling.
- It means p v_2 and n v_2 are very similar.
- Coalescence of p-n or 6 quarks?

