Understanding of Radial and Elliptic expansion with Quark number scaling and Blast wave model in 200GeV Au+Au at RHIC-PHENIX

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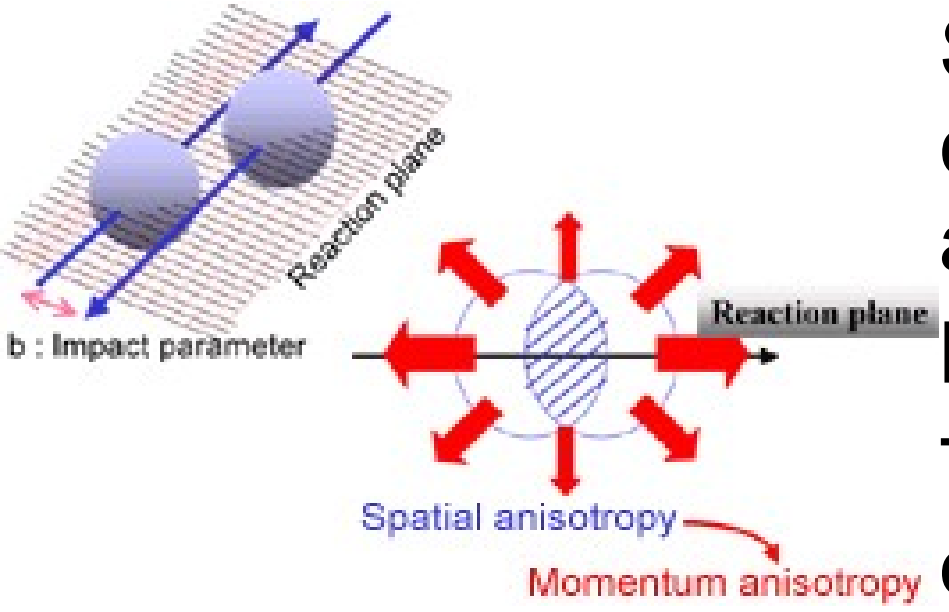
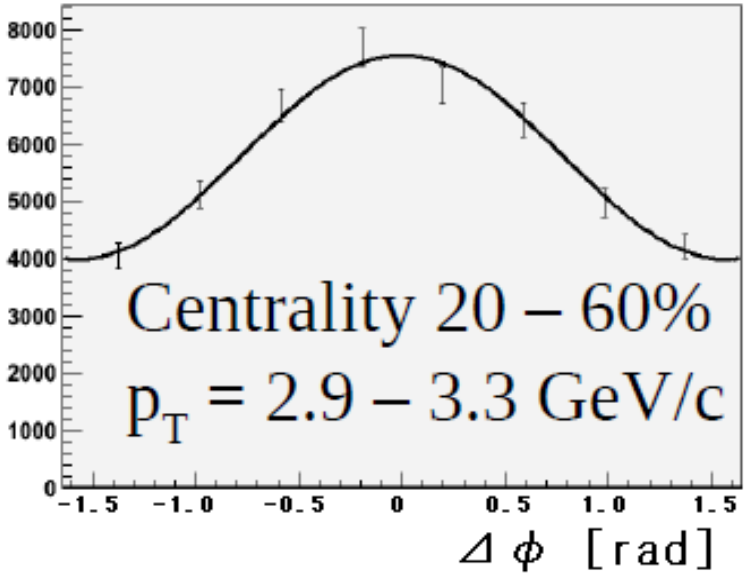
for the PHENIX collaboration
(Riken)

Azimuthal anisotropy





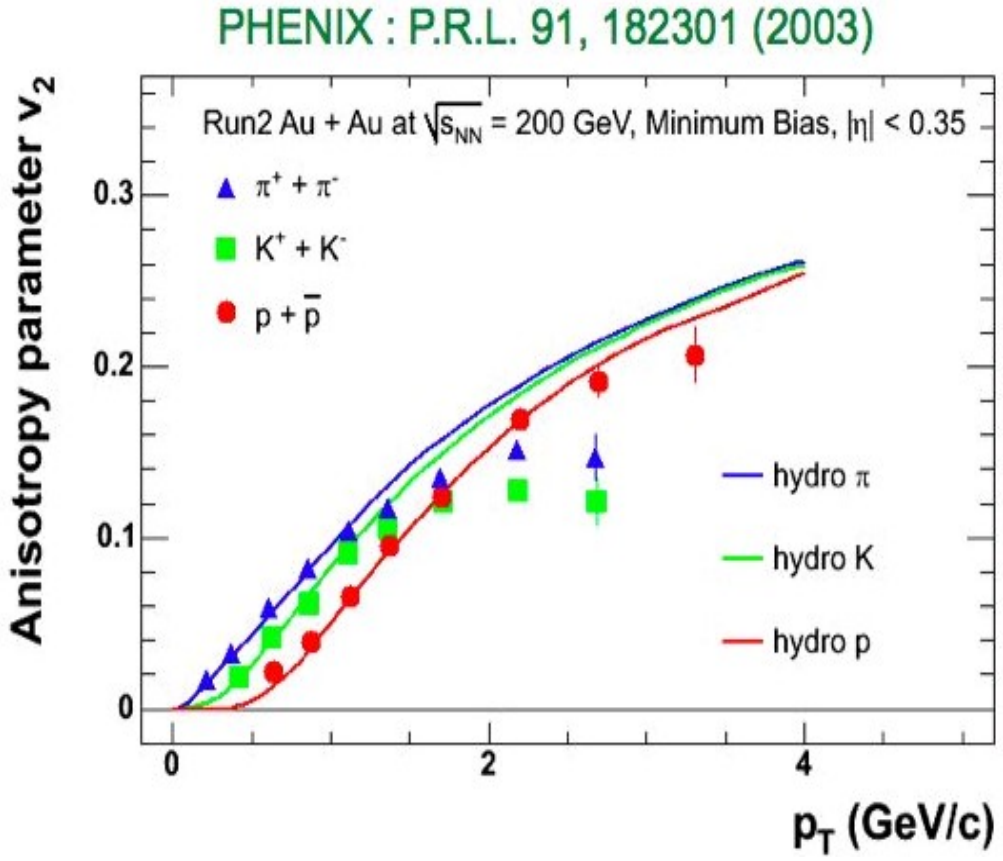
Spatial anisotropy in non-central collision provides azimuthal anisotropy of particle emission.

The large anisotropy is an evidence of the formation of a hot and dense partonic matter.

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

Ψ : reaction plane angle

Motivation of v_2 measurement



Large v_2 was observed in RHIC.

The values agreed with hydro-dynamical models.

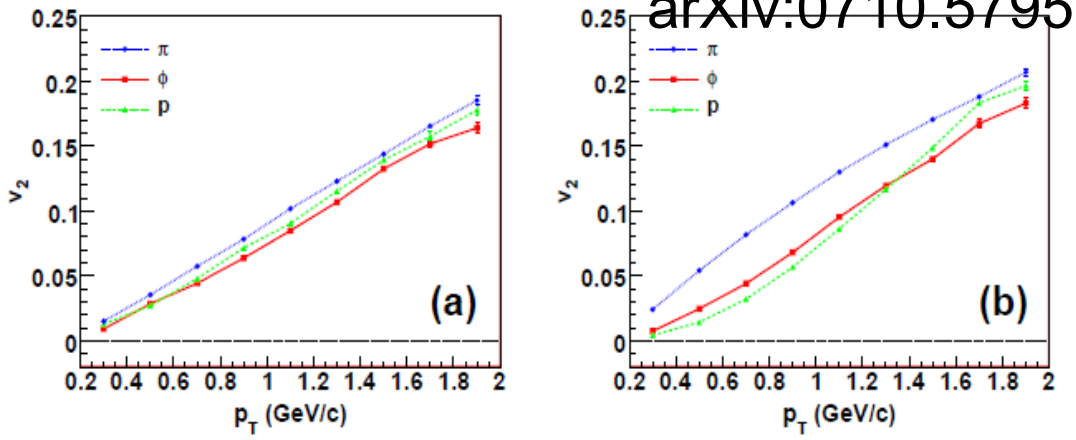
It suggests rapid thermalization and quark flow.

The v_2 values are different for each particle.

Motivation of 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.

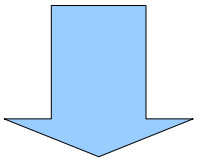
arXiv:0710.5795



- The slope difference by mass can be used to BW model calcuration.

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.

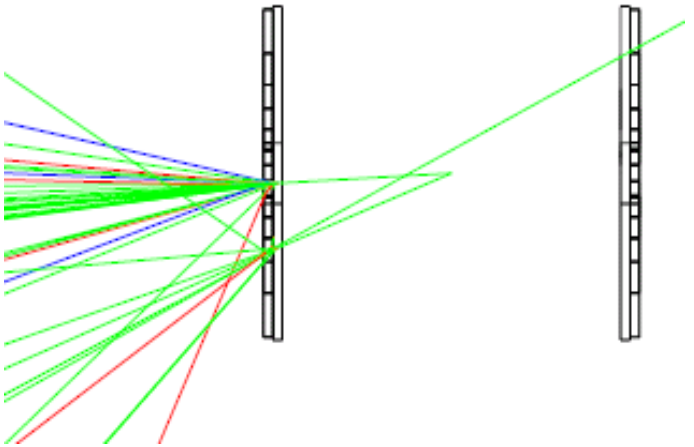
- Reaction plane resolution of <cos2⊿ψ> ~0.75 for minimum bias Au+Au collisions

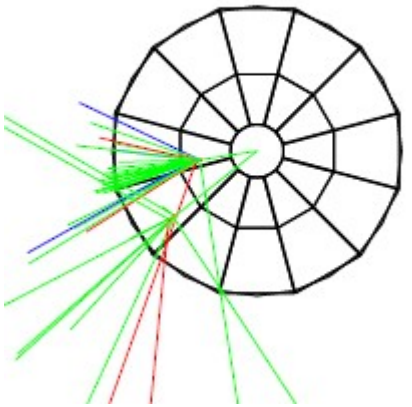
Reaction Plane Detector

The reaction plane detector was installed just before Run7 (2007).

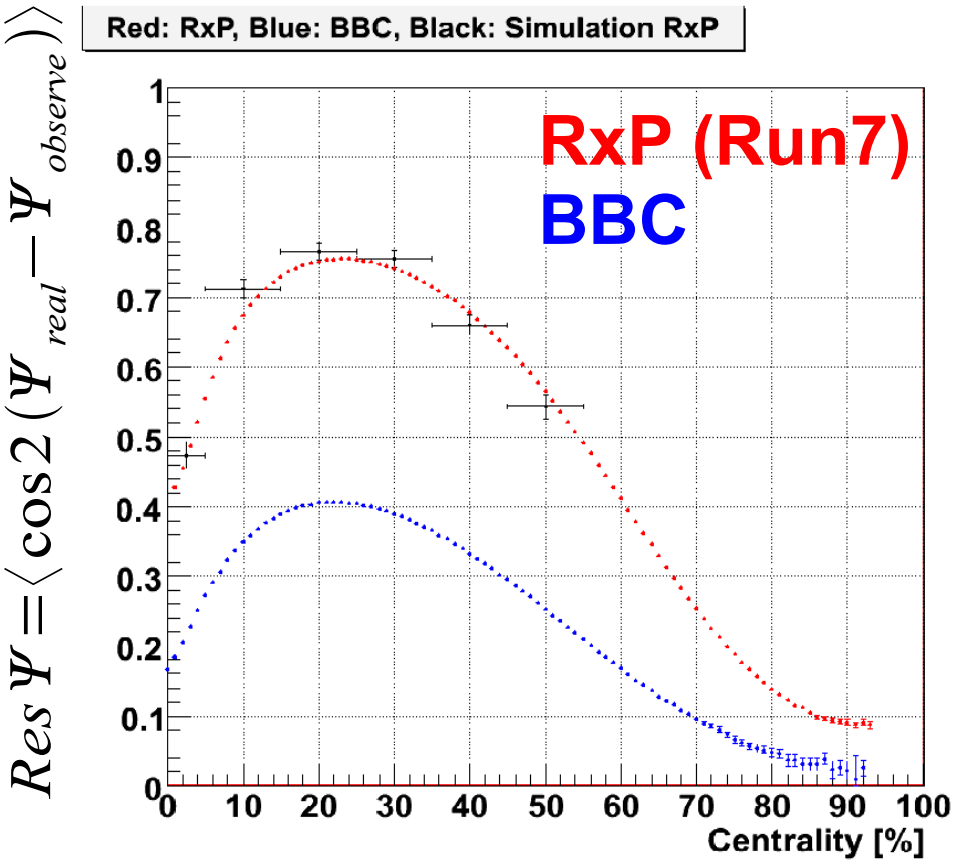
35cm

Collision piont





Reaction Plane Resolution



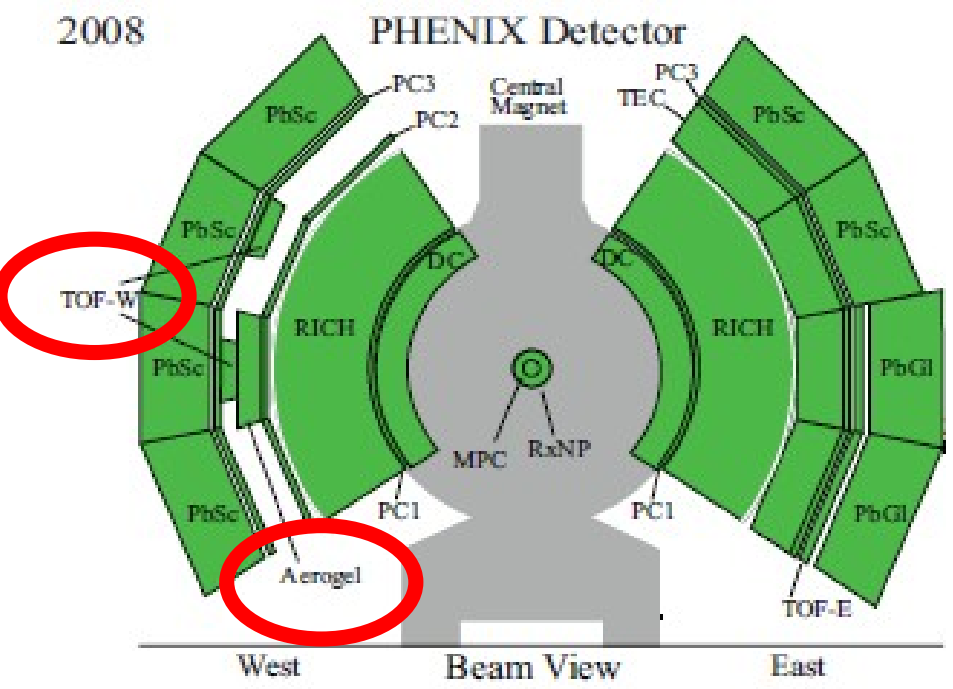
the reaction plane resolution was improved by a factor of two.

- The observed v_2 strength is only less than 40% of its real value.

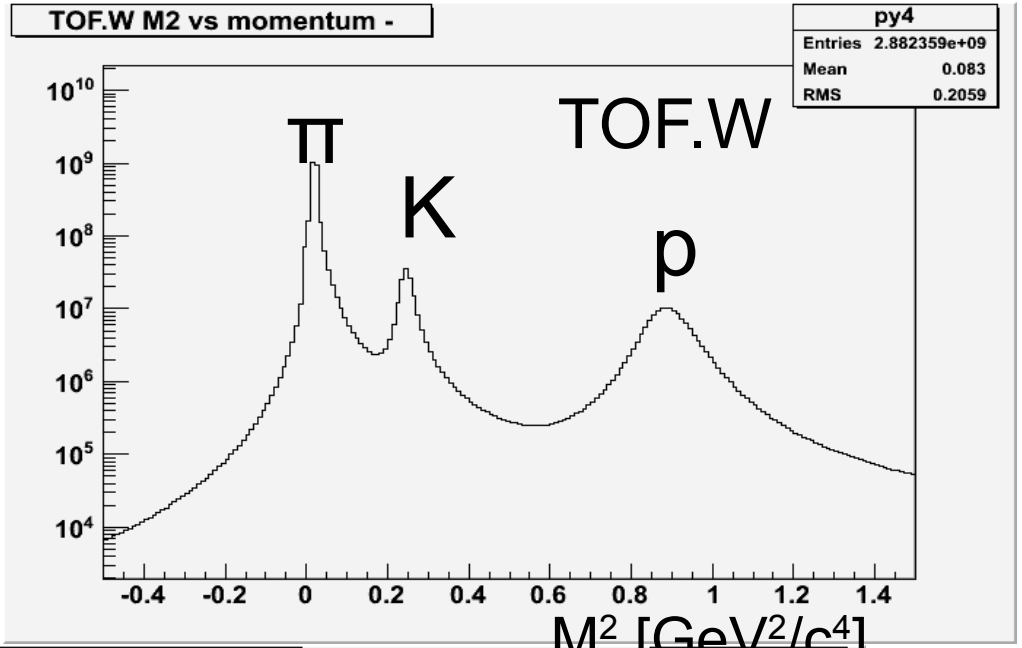
$$v_{2\,observe} = v_{2\,real} \times \langle \cos 2(\Psi_{real} - \Psi_{observe}) \rangle$$

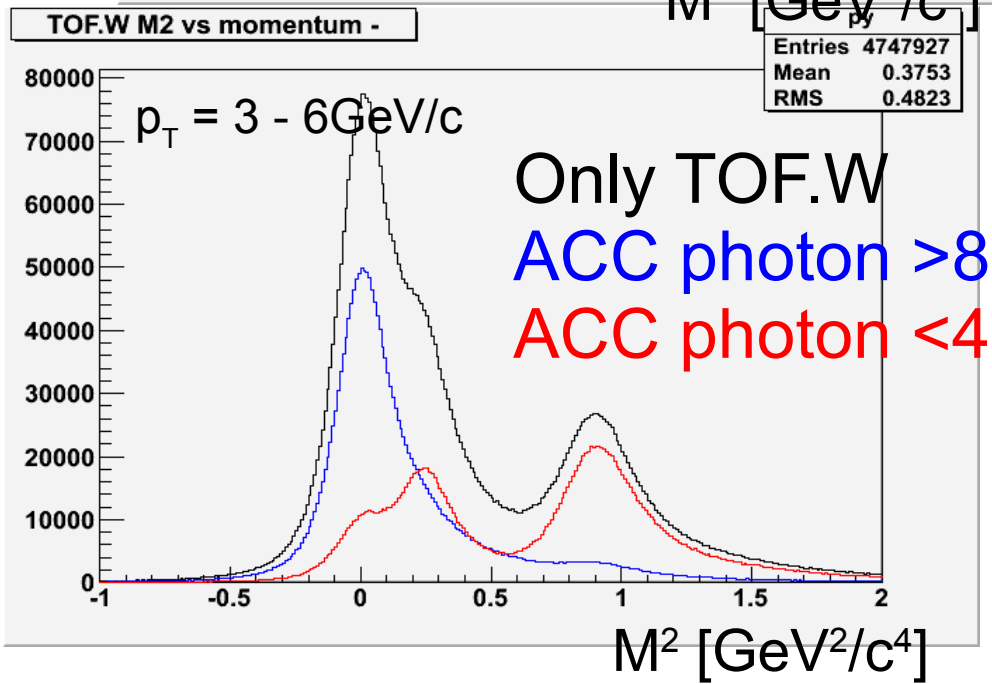
$$\delta v_2 \sim \frac{1}{\langle \cos 2(\Psi_{real} - \Psi_{observe}) \rangle} \times \frac{1}{\sqrt{N}}$$

PID for π, K and proton

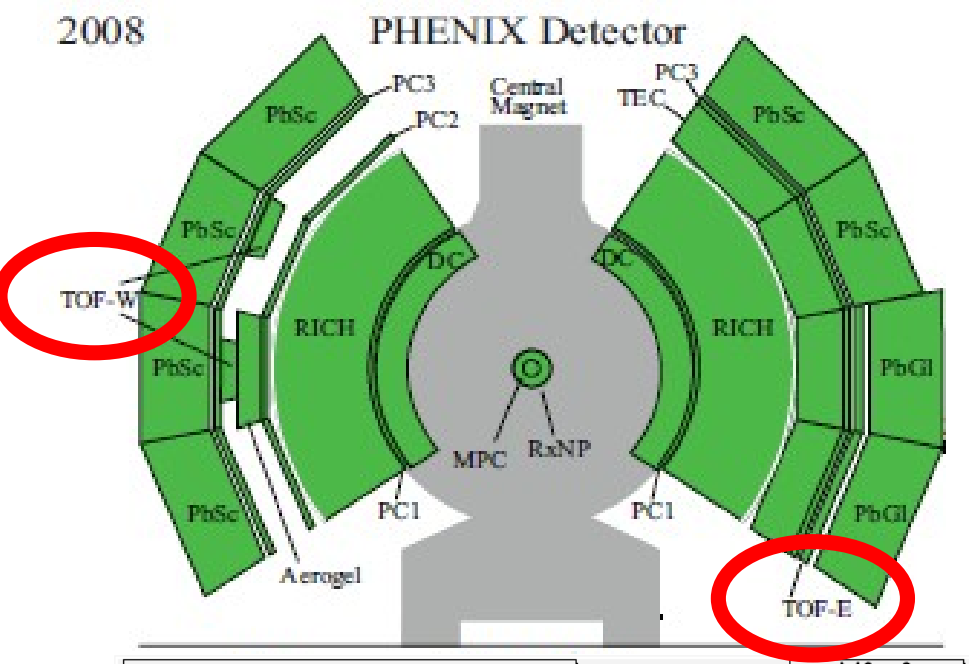


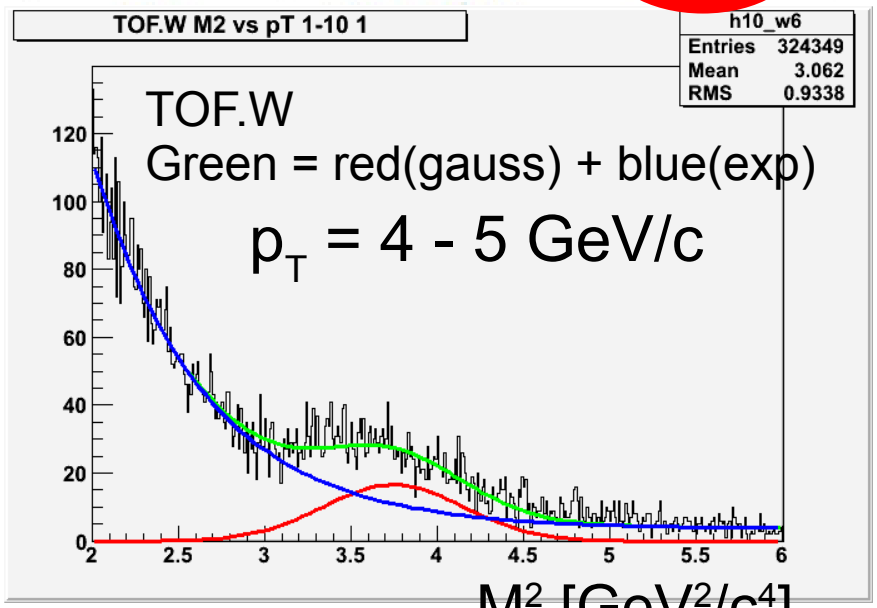
TOF.W was installed before Run7, too

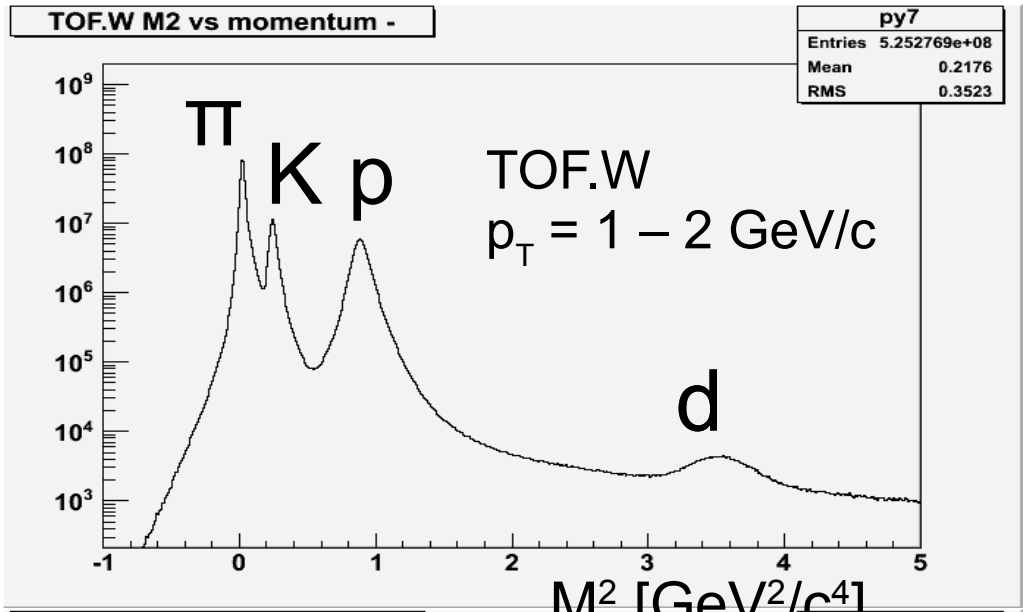


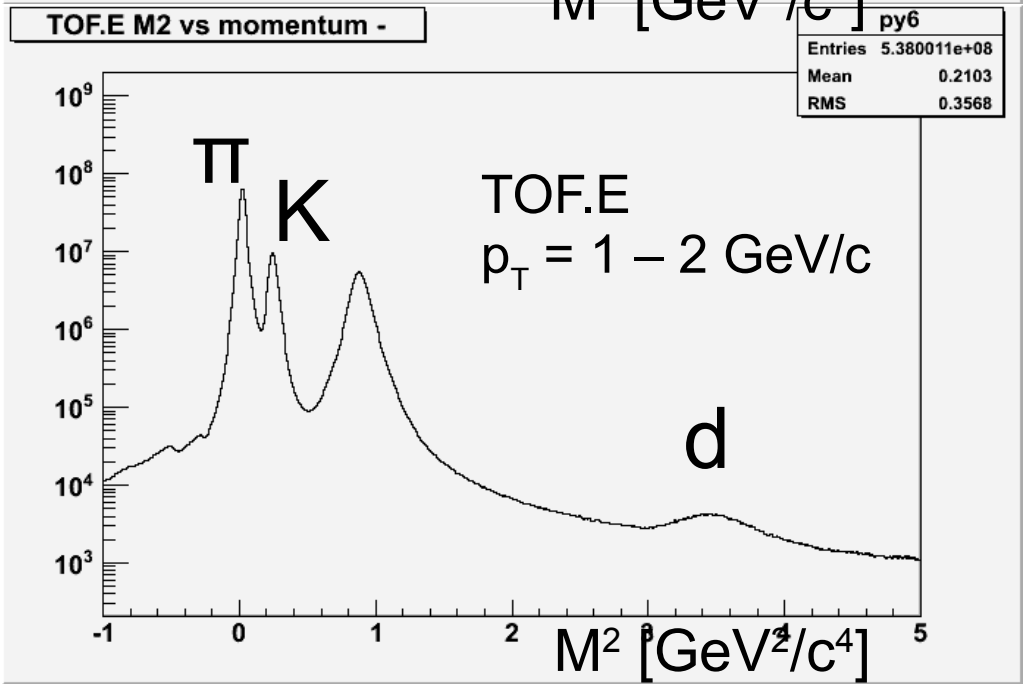


PID for deuteron

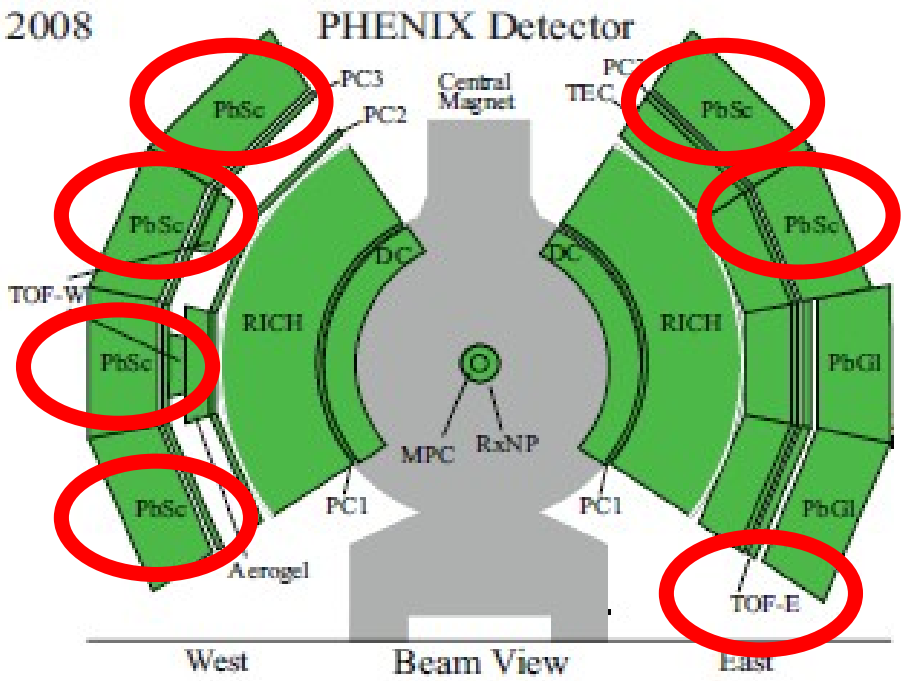


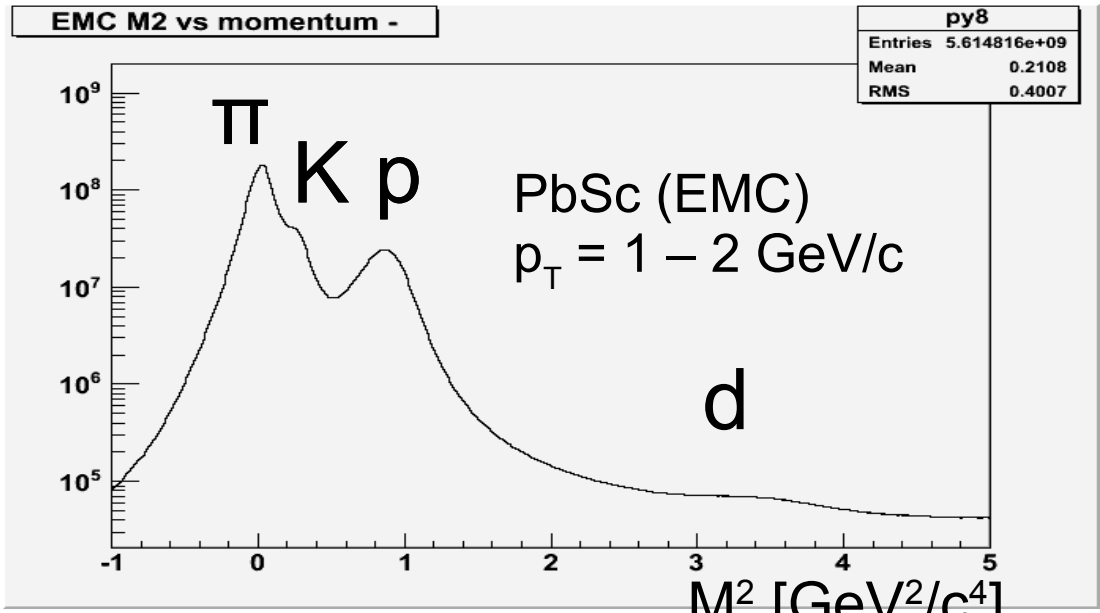


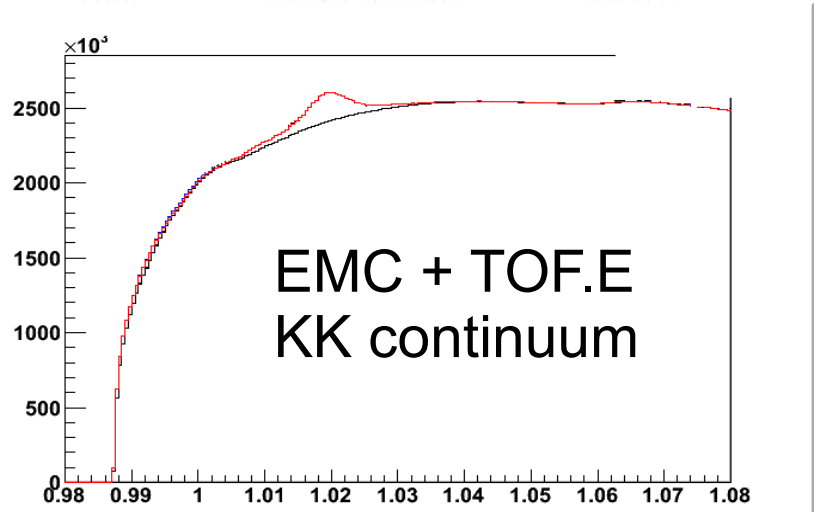


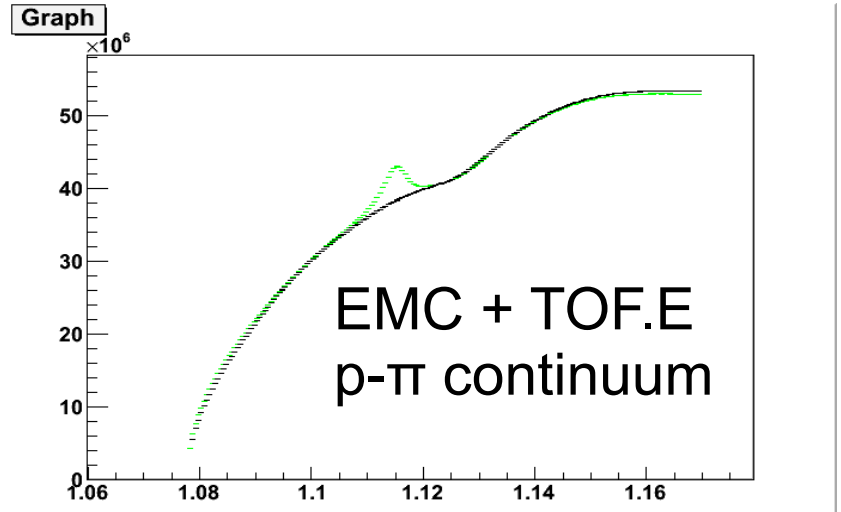


PID for Λ and Φ

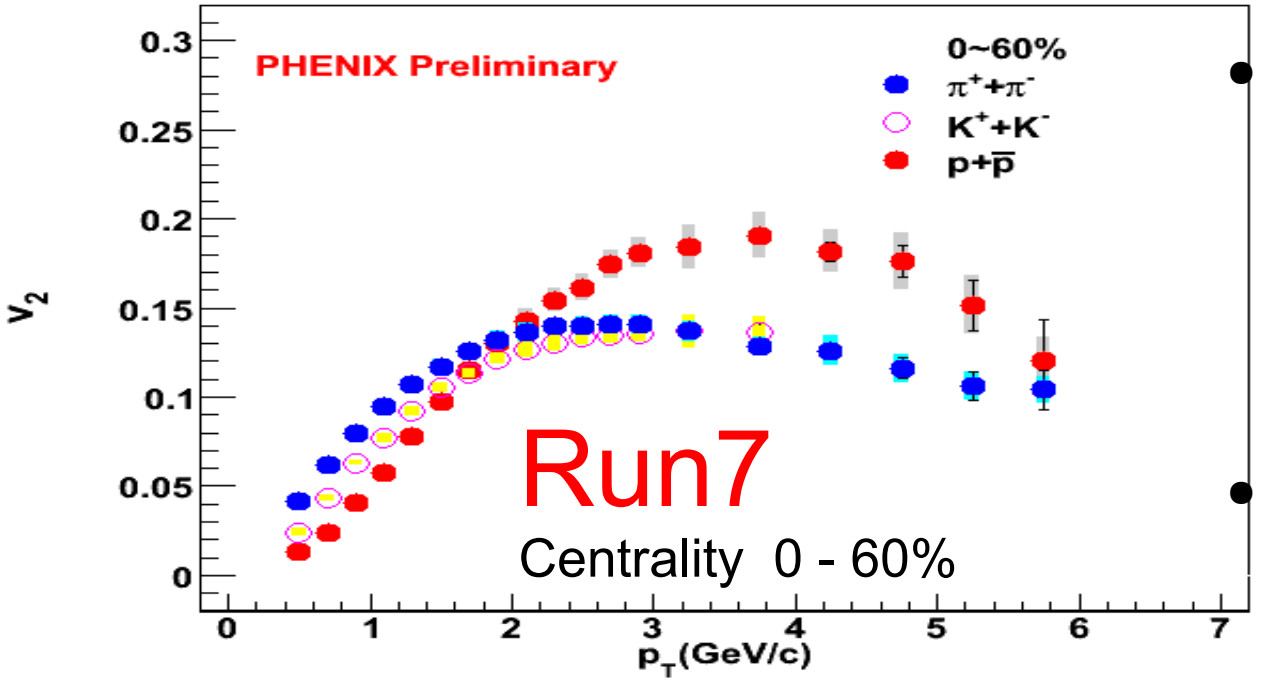




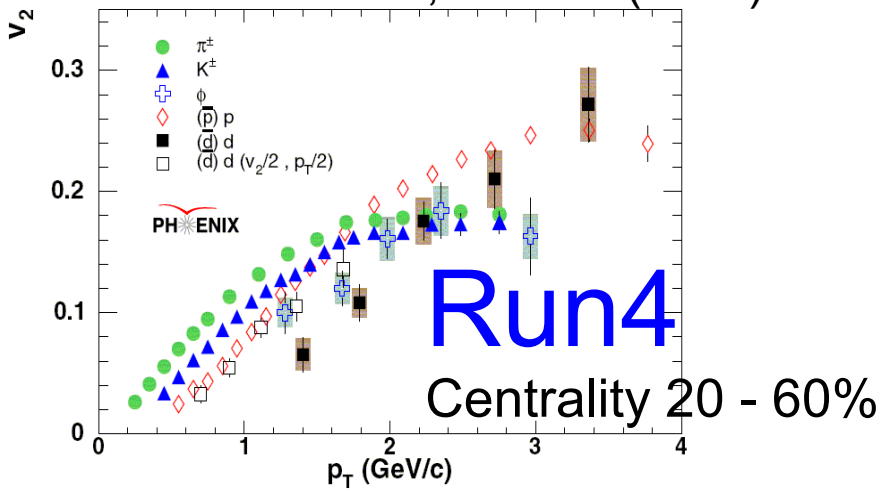




v_2 on PHENIX-Run7

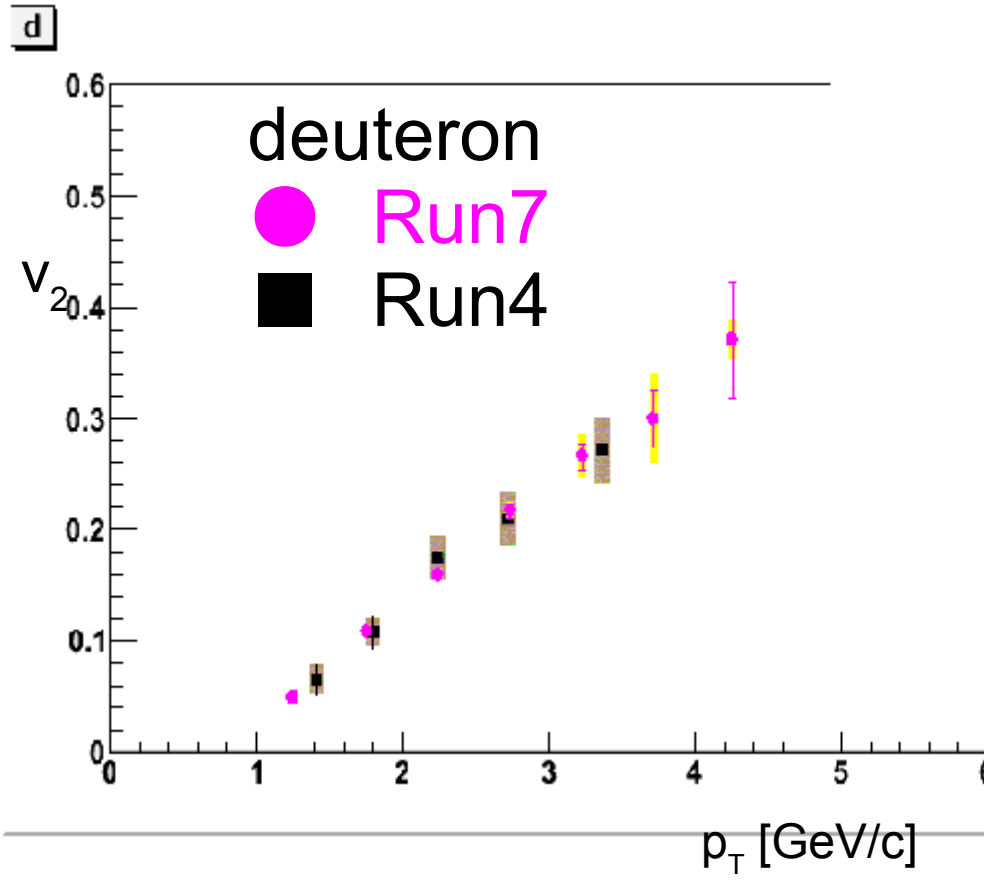


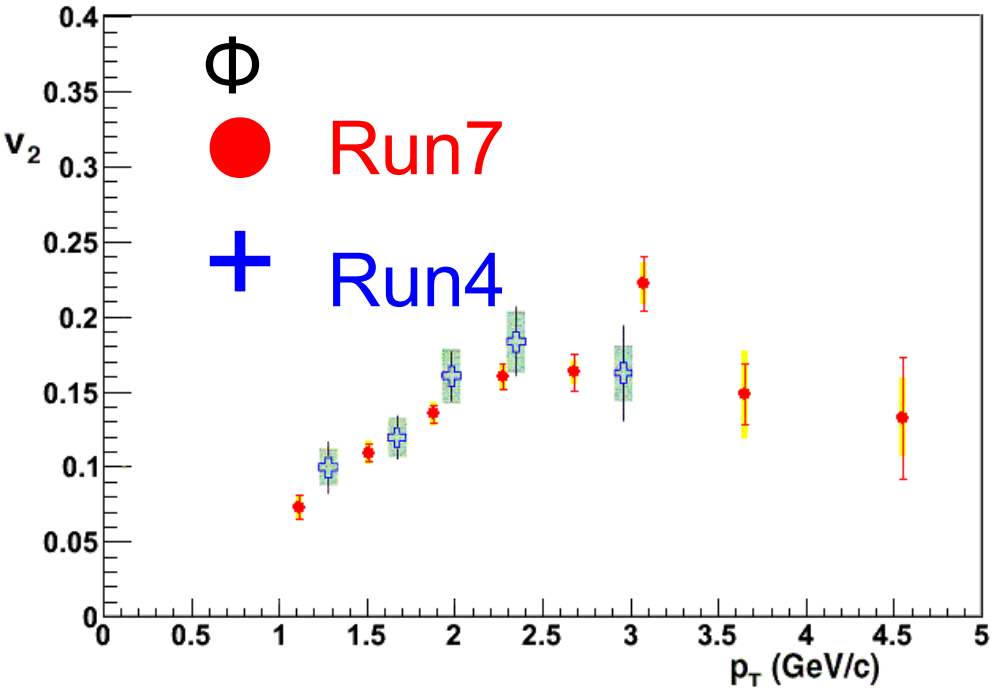
PHENIX. PRL. 99, 052301 (2007)



- Run7 have 2 times of RP resolution and 4 times of statistic from Run4.
- TOF.W and ACC work well, too.
- p_T range is extended to p_T = 6 GeV/c.

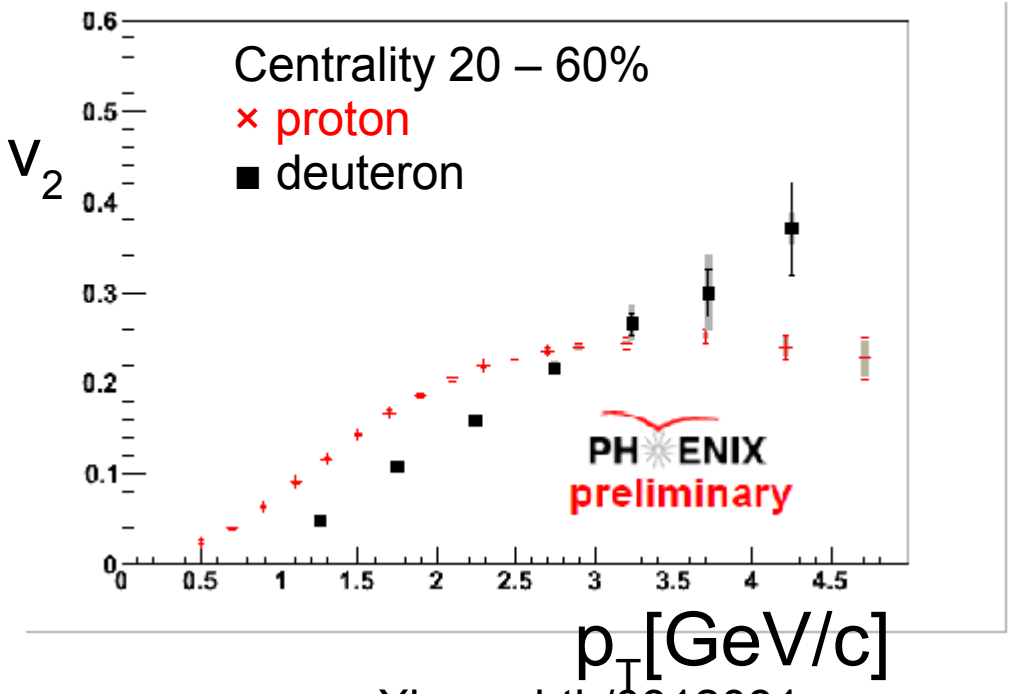
Comparison with last one





- p_T range is extended to p_T ~ 4.5 GeV/c.

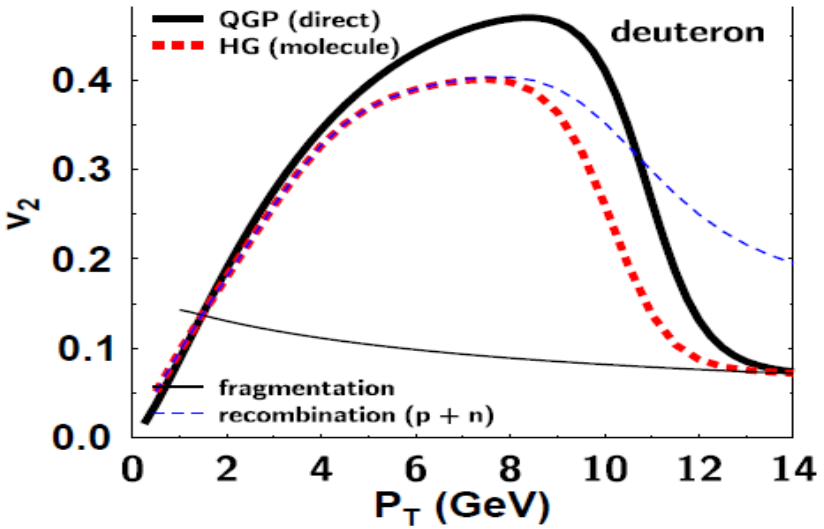
Nucleon number scaling



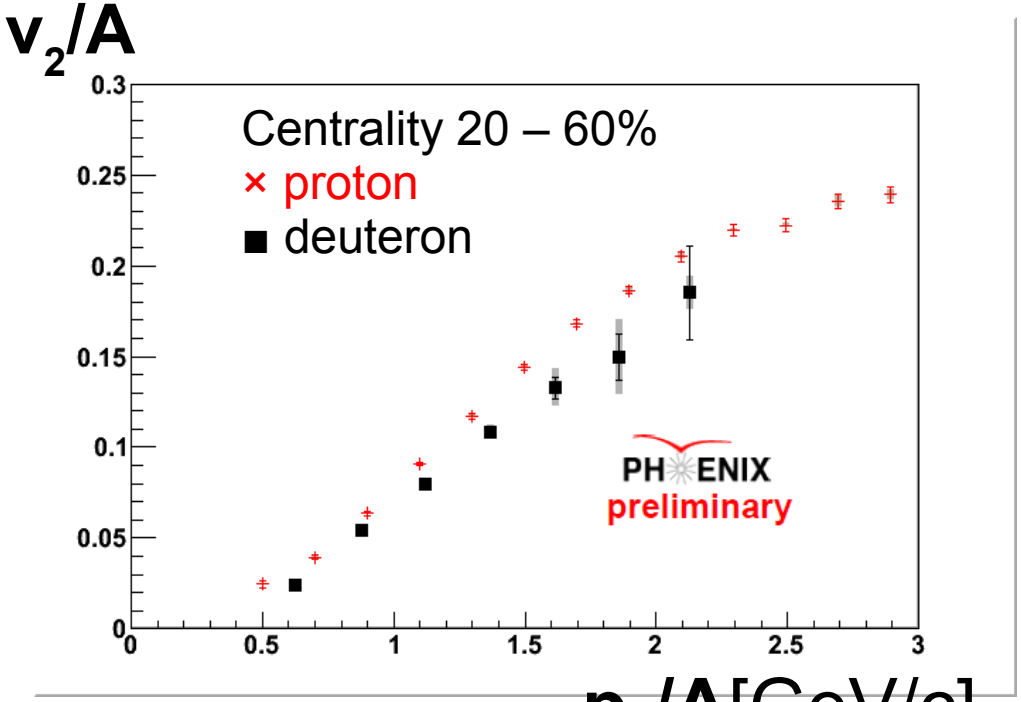
$$v_2^d \sim 2\, v_2^p, \quad p_T^d \sim 2\, p_T^p$$

- The peak of d v_2 is expected at p_T=6GeV/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?

arXiv:nucl-th/0312081



Nucleon number scaling



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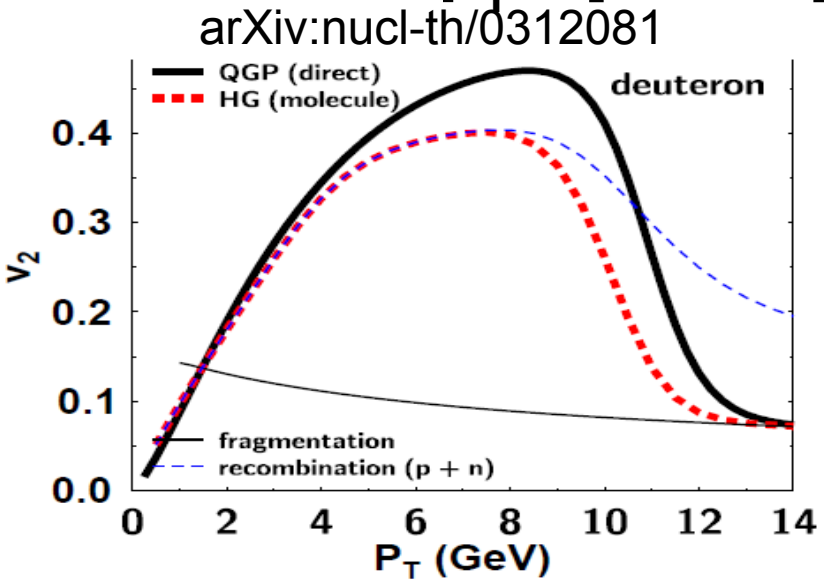
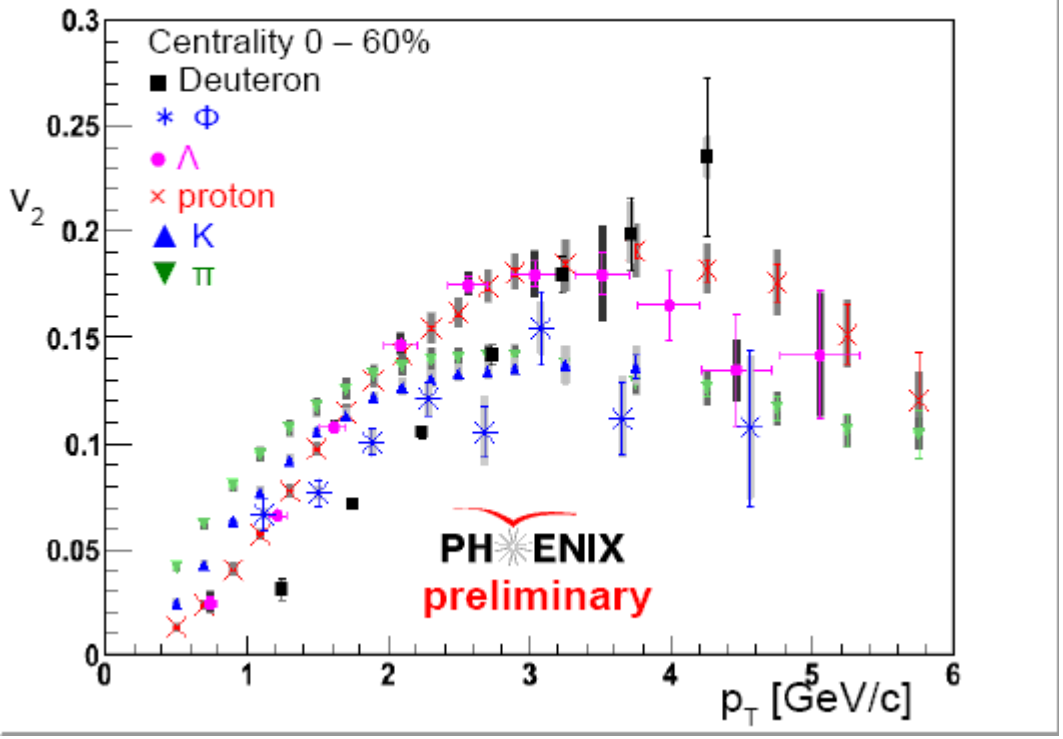
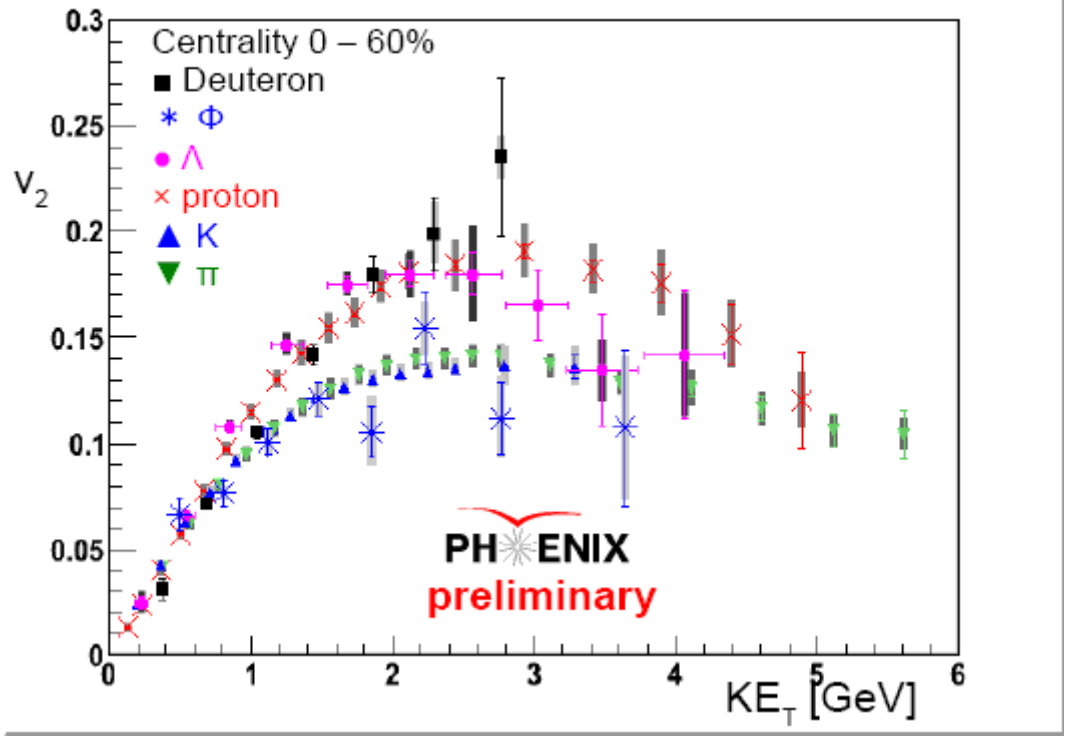


v_2 as p_T for 6 particles



- D v_2 is higher than p v_2 at p_T> 3 GeV/c
- Λ v_2 similar to p v_2
- Φ v_2 similar to meson (π or K) rather than baryon (p or Λ) at mid-p_T range (p_T= 2 – 5 GeV/c).

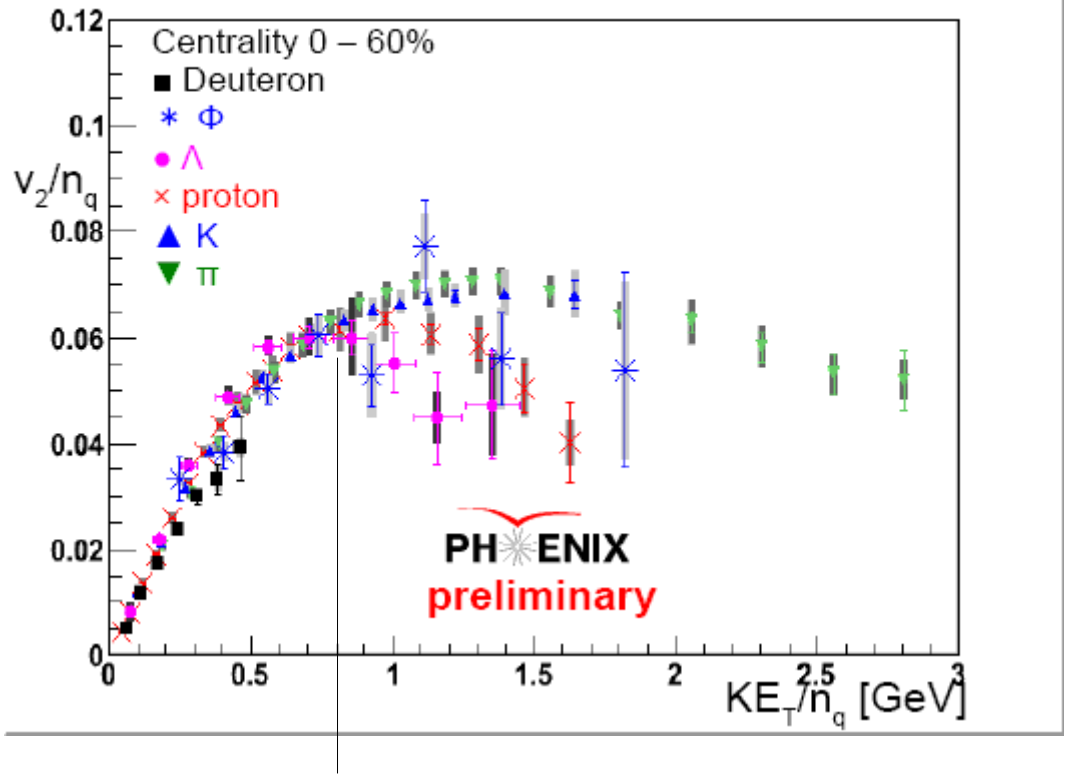
KE_T scaling



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

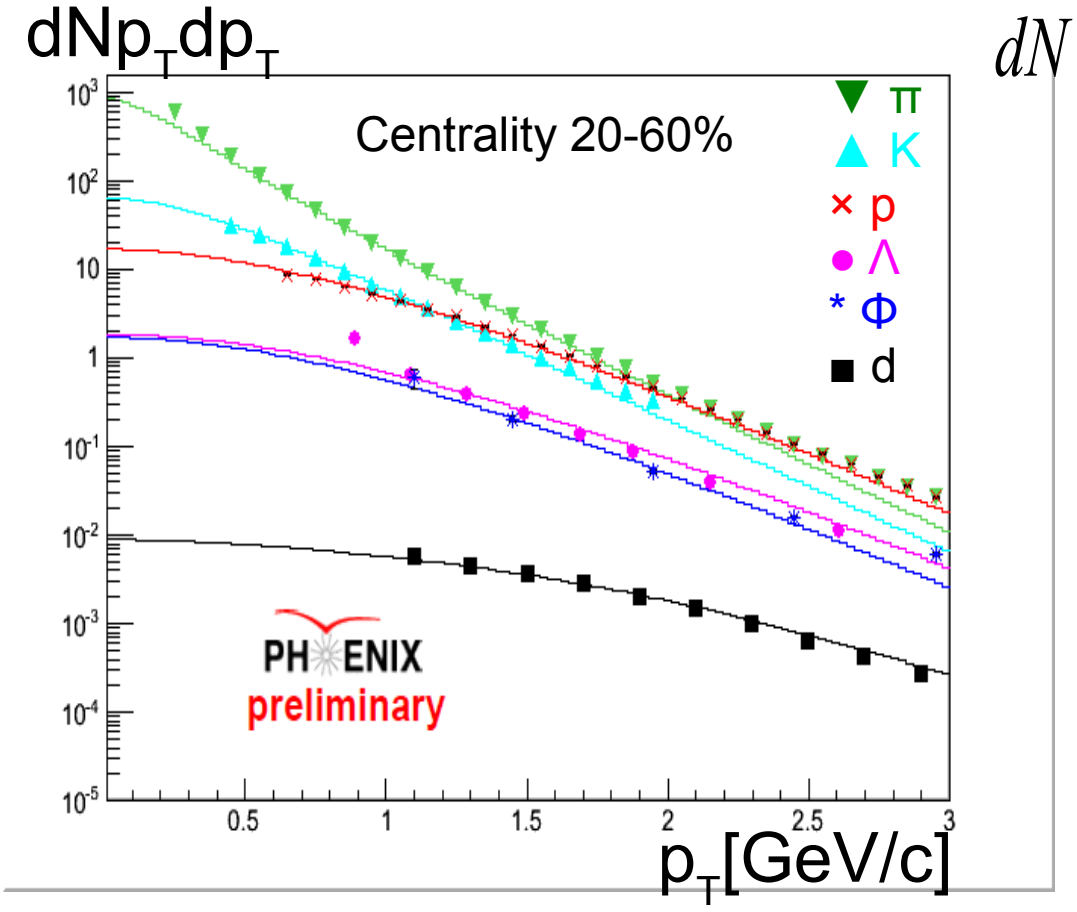
- The p_T shift depend on mass is rejected on KE_T
  - They are consistent between mesons or baryons.
  - The values are determined by centrality, KE_T and quark number.
- Meson line and baryon line approach at high KE_T.

Quark number and KE_T scaling



- Consistent for all particles on KE_T and quark number scaling at $KE_T/n_q<0.8$GeV.
- They deviate at high KE_T/n_q
- This indicate a change of particle and v_2 production mechanism.

Function of Blast wave for spectra



$$dN\ p_T dp_T = \int dx\, W\, BesselK1(\beta)\, BesselI0(\alpha)$$

$$\beta = \frac{m_T}{T}\cosh\rho = \frac{m_T}{T}\,\frac{e^{\rho}+e^{-\rho}}{2}$$

$$\alpha = \frac{p_T}{T}\sinh\rho = \frac{p_T}{T}\,\frac{e^{\rho}-e^{-\rho}}{2}$$

$$\rho = \operatorname{artanh}(G\beta_T) = \frac{1}{2}\log\frac{1+G\beta_T}{1-G\beta_T}$$

Glauber Monte Carlo

$W : SpaceWeight(x, y)$

$G : Gradient(x, y)$

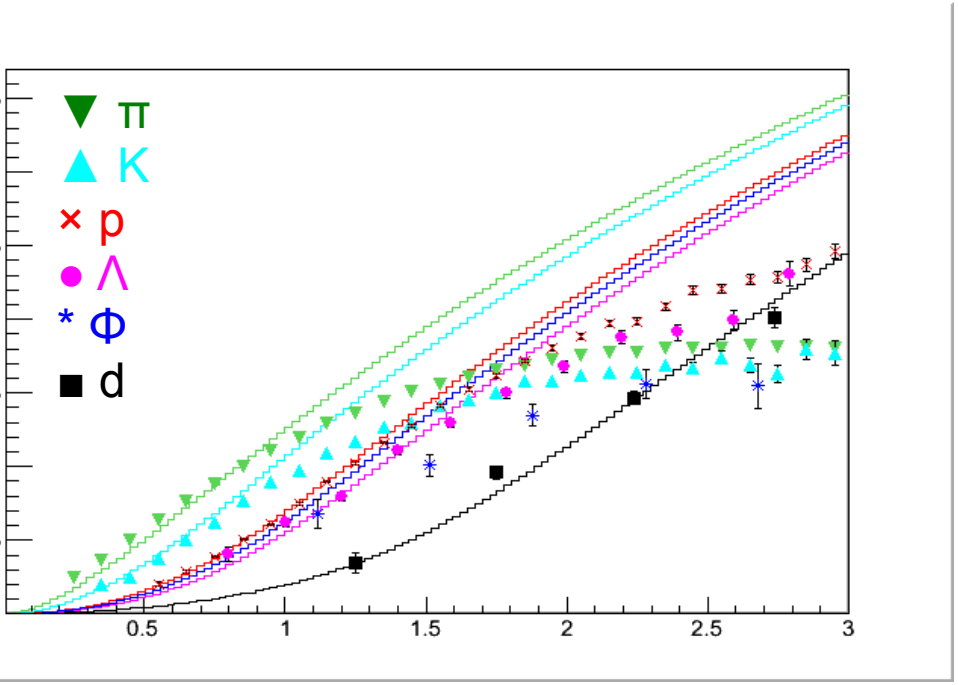
Free Parameters

$T : Freeze\,out\,temperature(GeV)$

$\beta_T : Radial\ flow\,velocity$

Function of Blast wave for elliptic flow

$$v_2 = \int dx\, W\, BesselK1(\beta)\, BesselI(2,\alpha)\cos(2\phi_B)$$



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Glauber Monte Carlo

$W : SpaceWeight(x, y)$

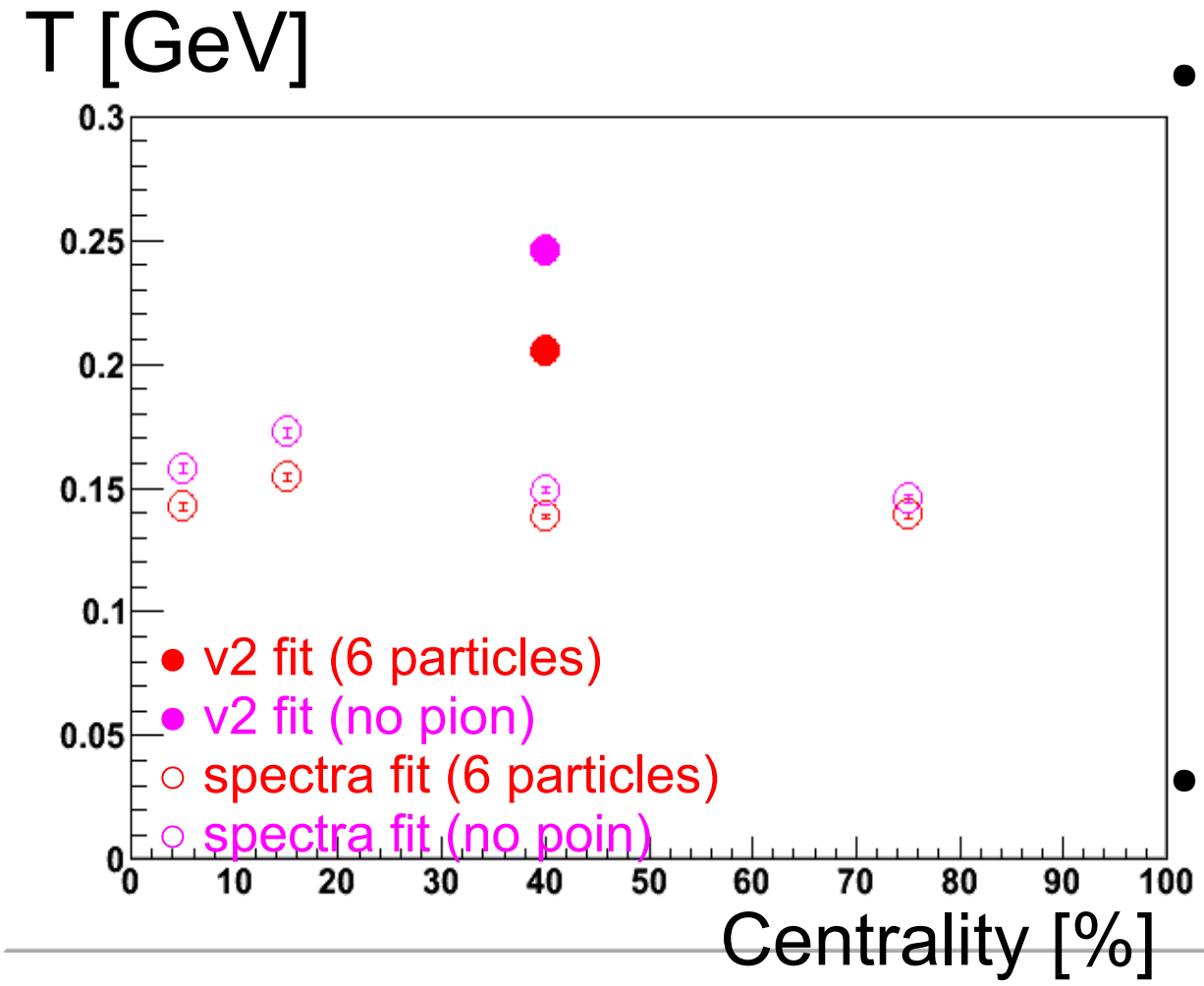
$G : Gradient(x, y)$

$\phi_B : Boost\ angle(x, y)$

Free Parameter → $T : Freeze\ out\ temperature(GeV)$

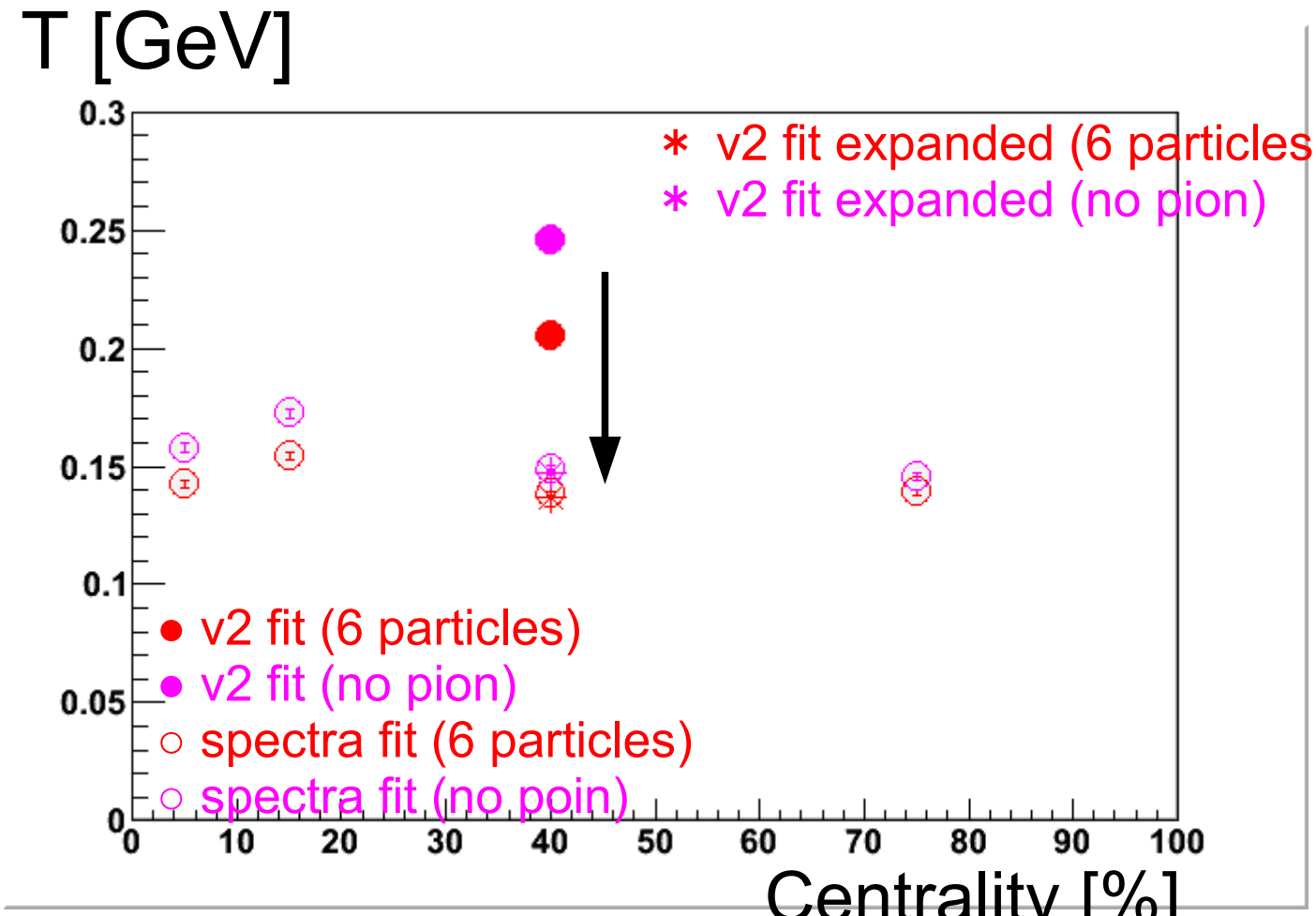
Given by spectra fit → $\beta_T : Radial\ flow\ velocity$

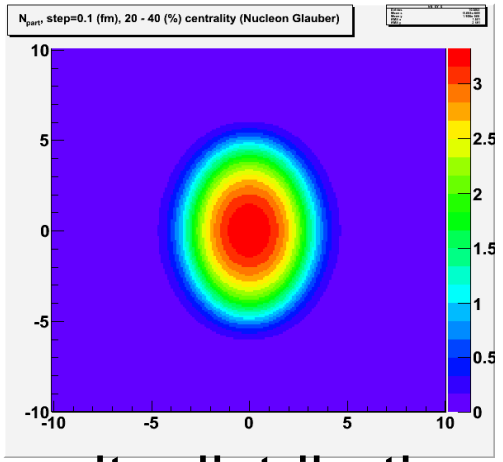
Temperature of BW for spectra and elliptic flow



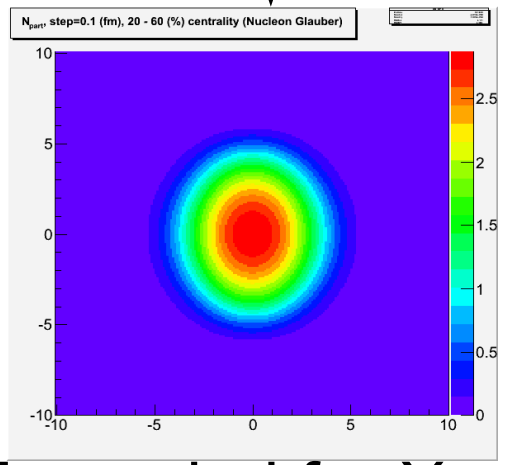
- Temperature of v_2 is not consistent with that of spectra since βT or another parameter is fixed by distribution of Glauber Monte Carlo
- Is it should be consist or not?

Expanded Glauber Monte Carlo





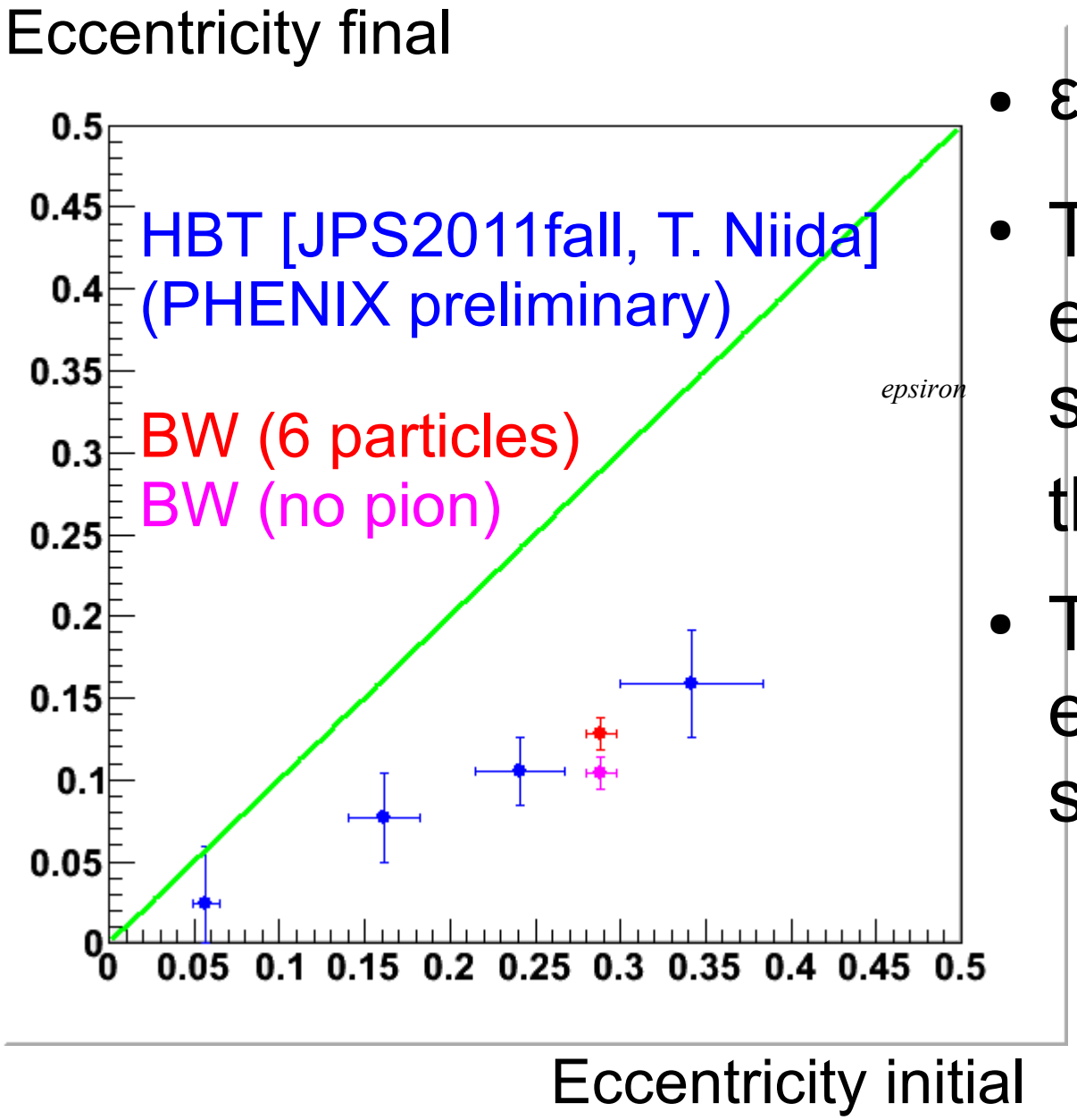
Density distribution
of Glauber Monte Carlo



Expanded for X-axis

The eccentricity of density distribution is adjusted to fit both of the temperature.

Final Eccentricity by BW fit



- $\varepsilon_{final} < \varepsilon_{initial}$
- The eccentricity estimated by BW fit with spectra and v_2 agree that of HBT analysis.
- They agree system expansion from initial state before freeze out.

$$\epsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

Summary1

- The new reaction plane detector worked well.
  - We can see rare particles by the good resolution.
- .v_2 is depend on n_q.
  - Consistent for all particles on KE_T and n_q scaling at $KE_T/n_q<0.8$GeV.
  - Φ v_2 is similar to other mesons on KE_T.
- v_2 have no depend on the quark number at high p_T range.
  - Production mechanism is different.
- D v_2 is higher than p at $p_T>3$ GeV/c
  - d v_2 and p v_2 are consistent on parton number scaling or KE_T/n_q scaling

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

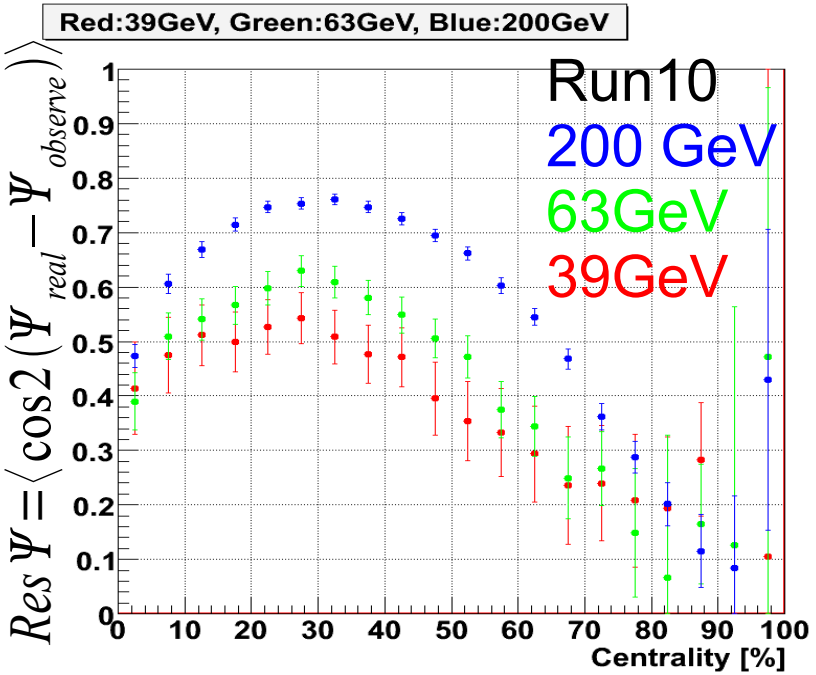
$$p_T^d \sim 2\, p_T^p$$

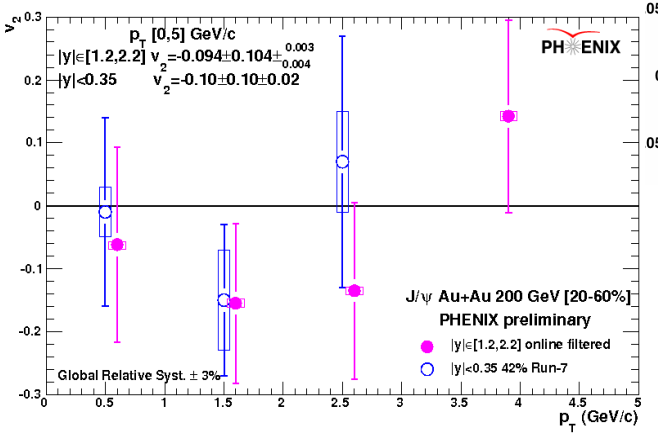
Summary2

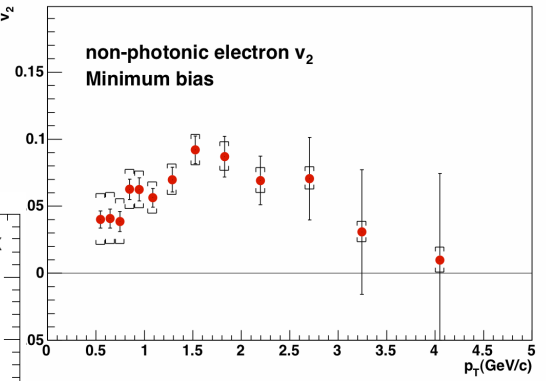
- T of spectra of 6 particles BW fit by glauber seems flat to centrality.
- T of v_2 of BW fit with initial glauber system is not flat to centrality and it is higher than that of spectra, especially at peripheral.
- The same T of bwfit of v2 and spectra can be described by expanded glauber distribution
  - The eccentricity of final state of system is consistent with that of HBT analysis.

Next step

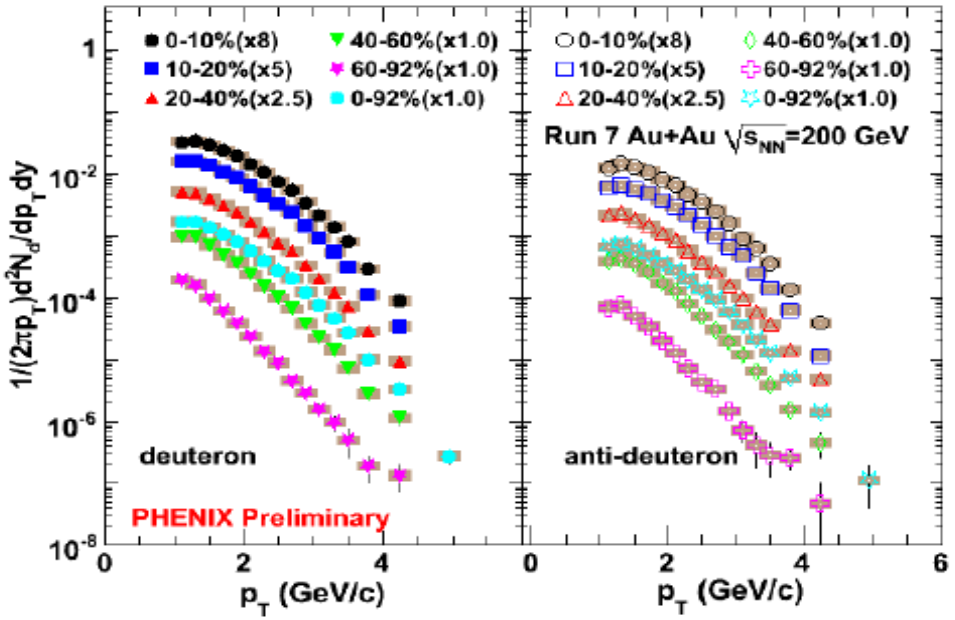
- Low energy scan of quark number scaling (200, 63, 39 GeV on Run10)
  - Threshold of collision energy for QGP?
- D meson v_2 by VTX on Run11
  - Charm production is faster than other quarks?



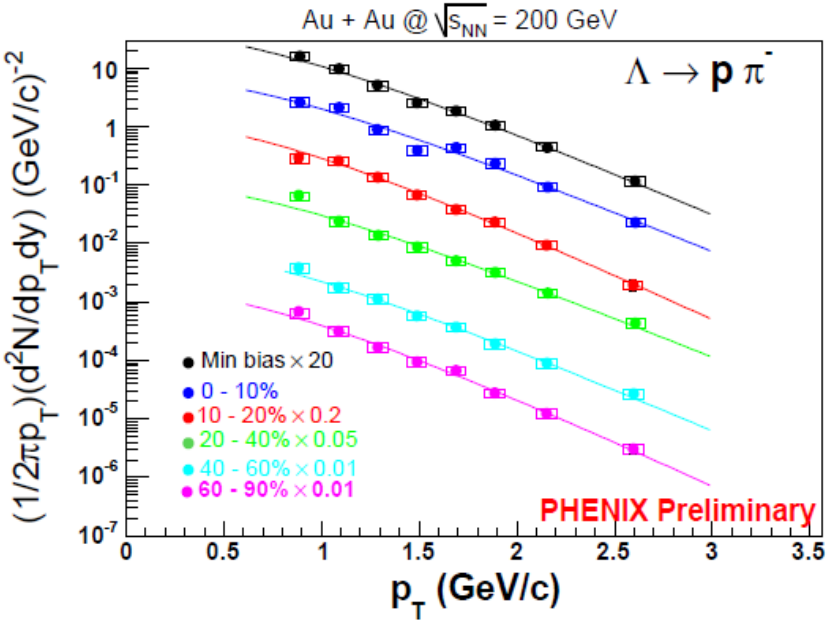




AN678



AN440



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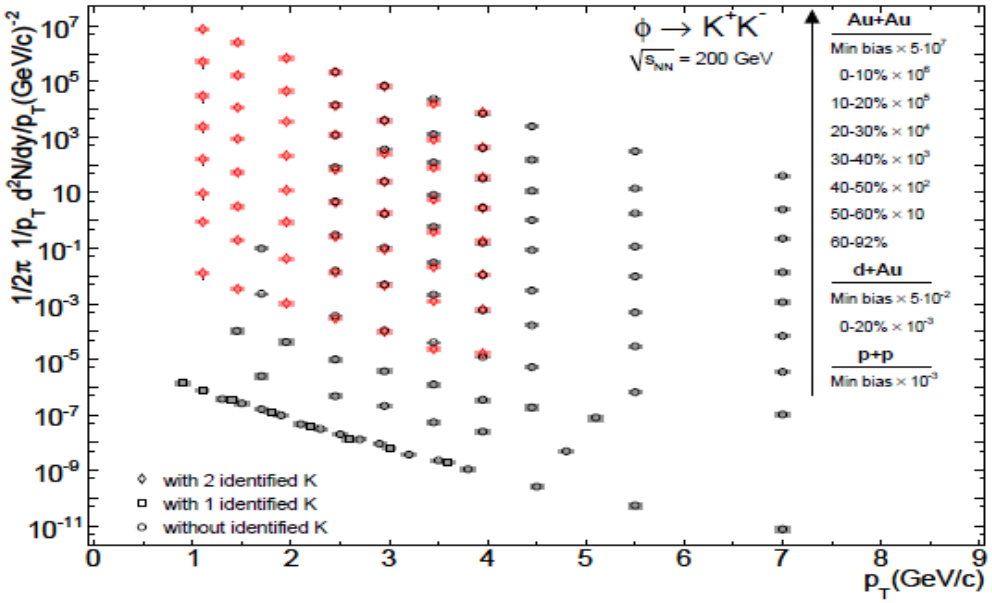
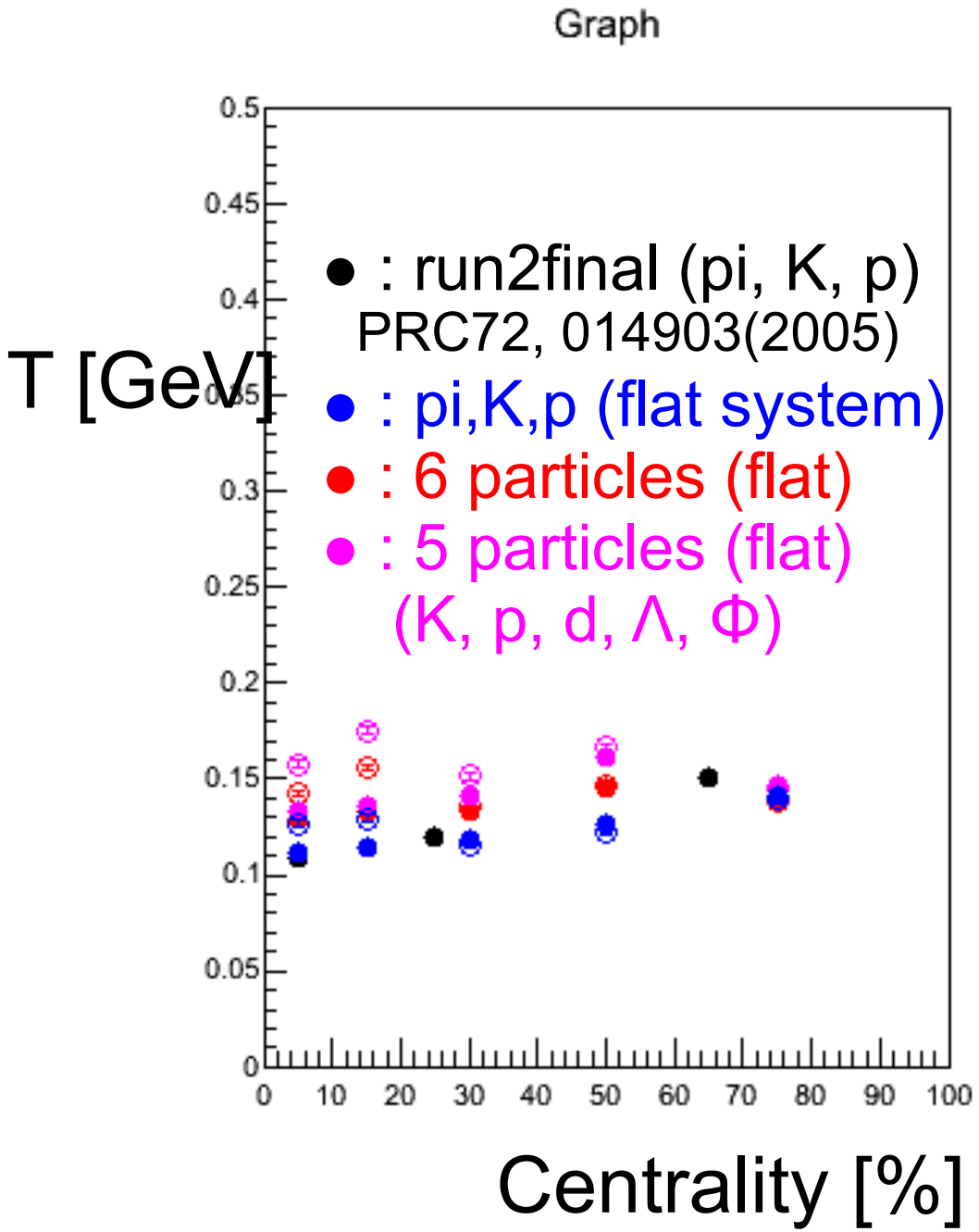
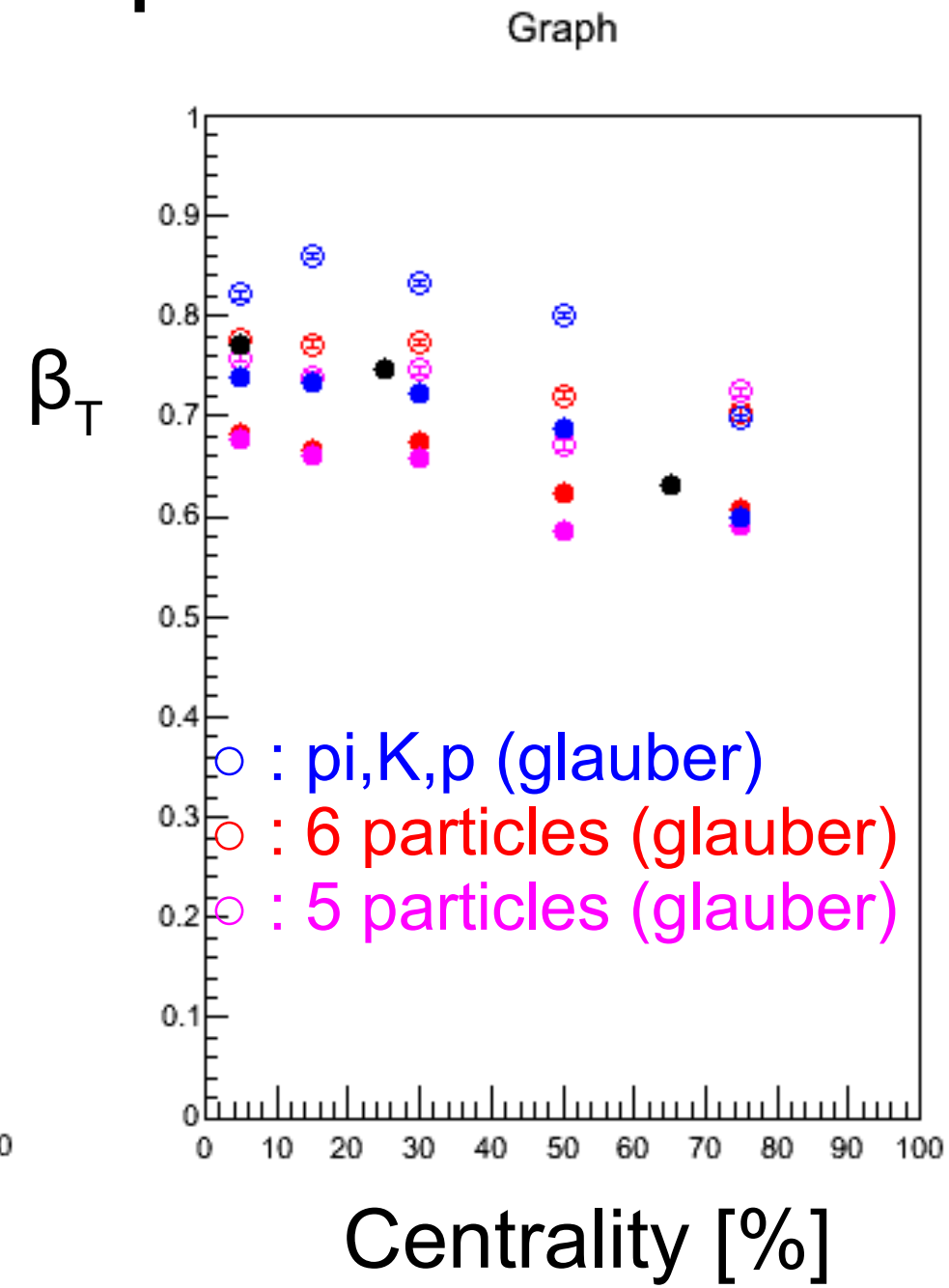


Figure 8: ϕ-meson p_T spectra. Results of this analysis are shown in red.

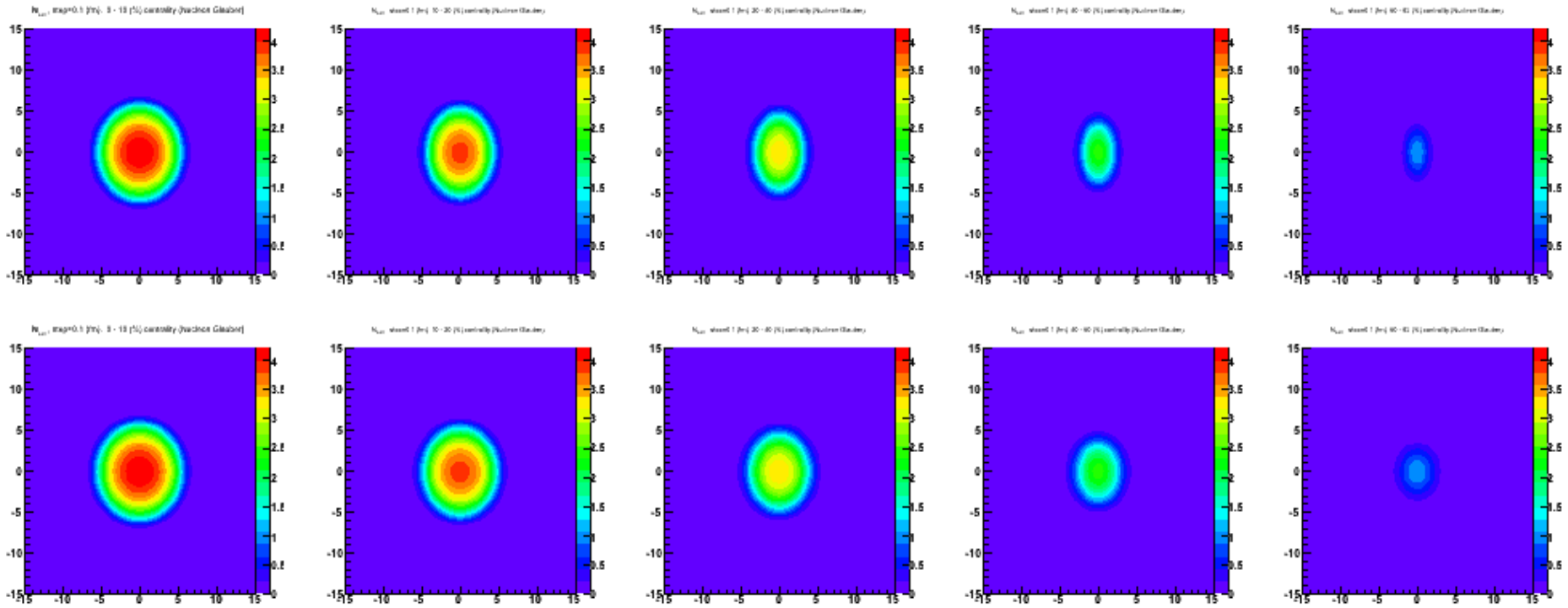
BW fit for spectra





Expansion for X-axis on Glauber Monte Carlo

initial glauber



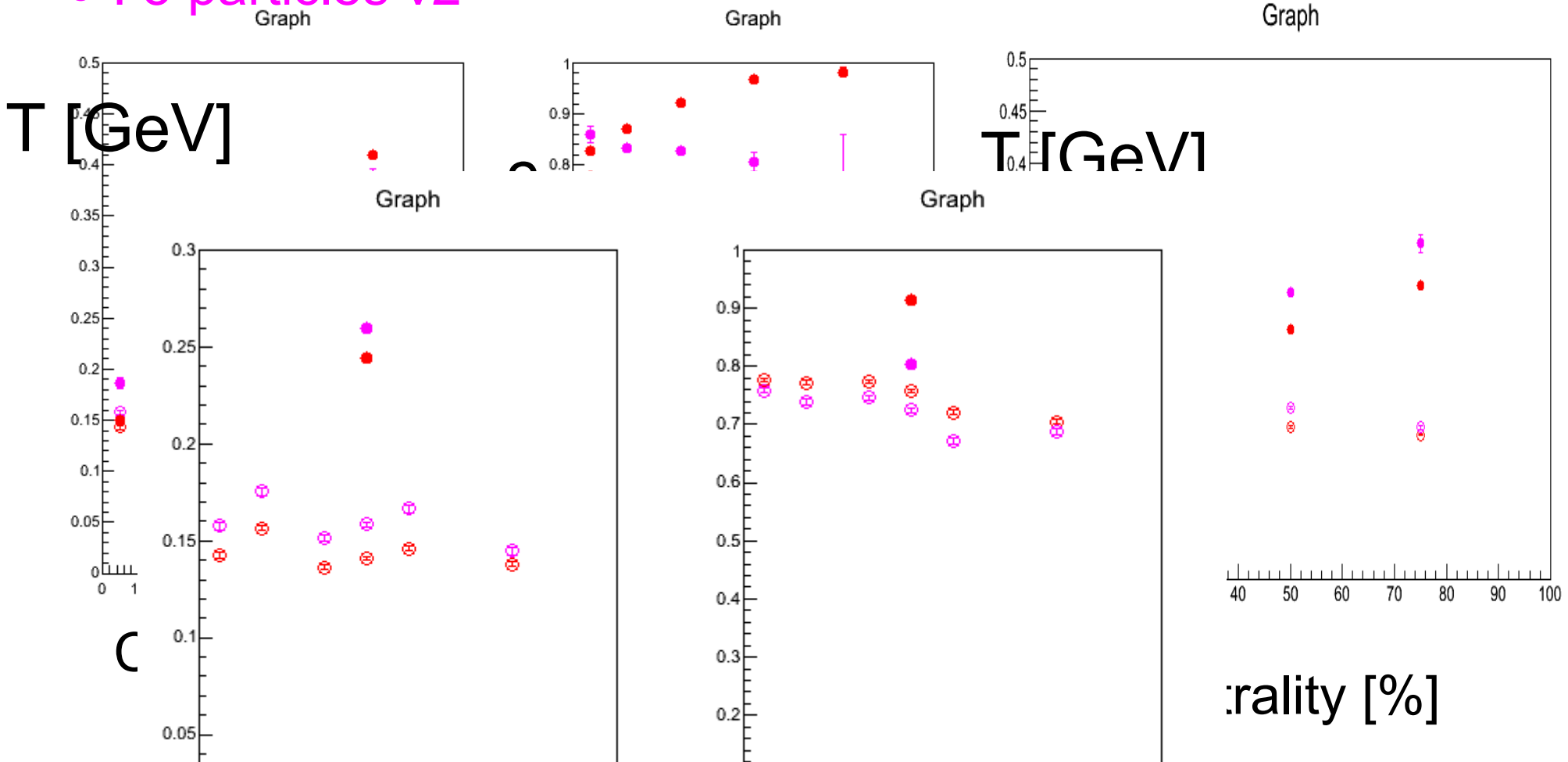
expanded

Centrality

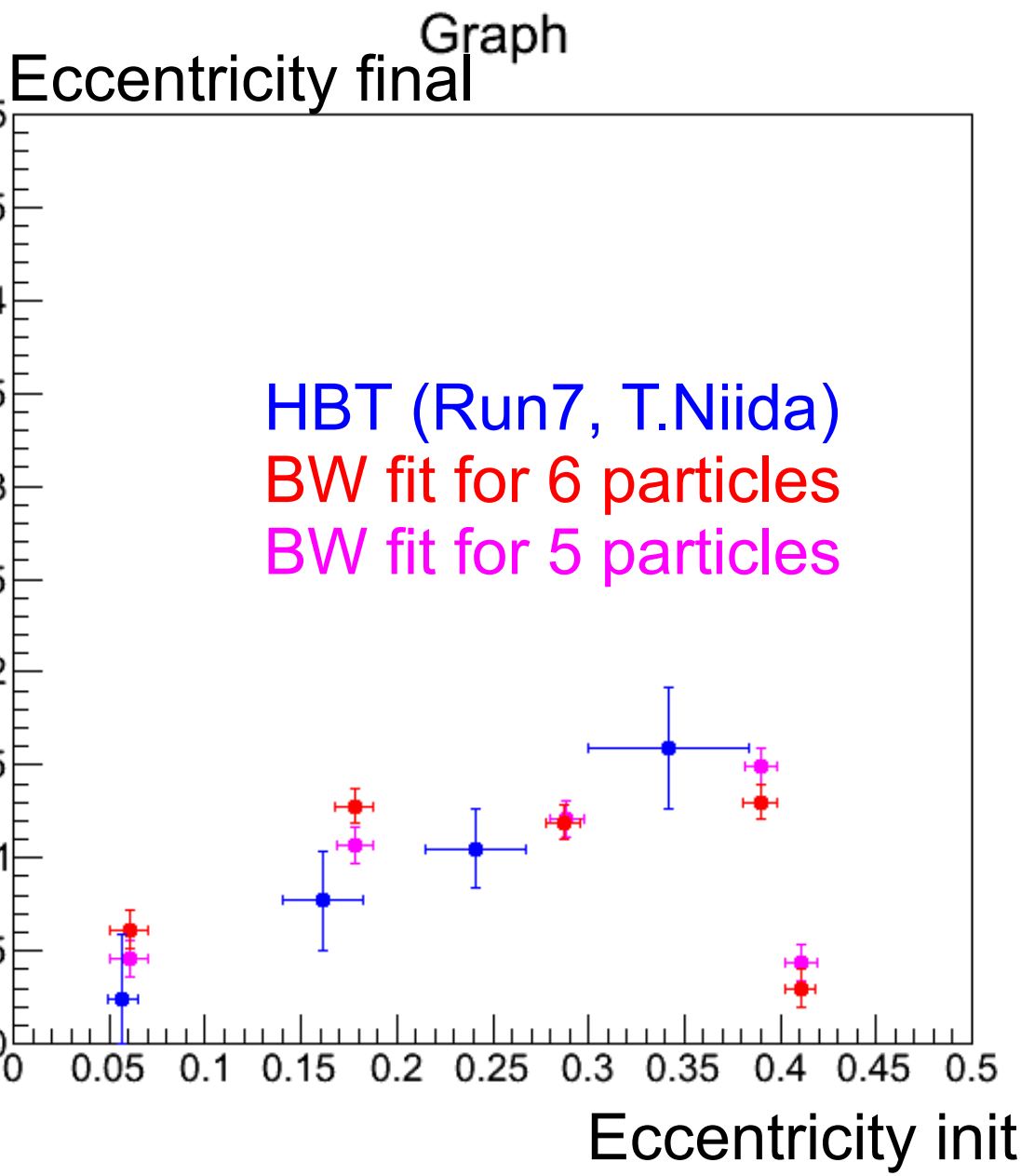
0-10% 10-20% 20-40% 40-60% 60-93%

Comparison of bw fit of v2 and spectra

- ○ : 6 particles spectra
- ○ : 5 particles spectra
- ● : 6 particles v2
- ● : 5 particles v2



Estimated Eccentricity



○ : 6 particles spectra
○ : 5 particles spectra
● : 6 particles v2
● : 5 particles v2
* : 6 particles v2 (expanded)
* : 5 particles v2 (expanded)