Study of identified particle higher harmonics azimuthal anisotropy in 200GeV Au+Au collisions at RHIC-PHENIX experiment

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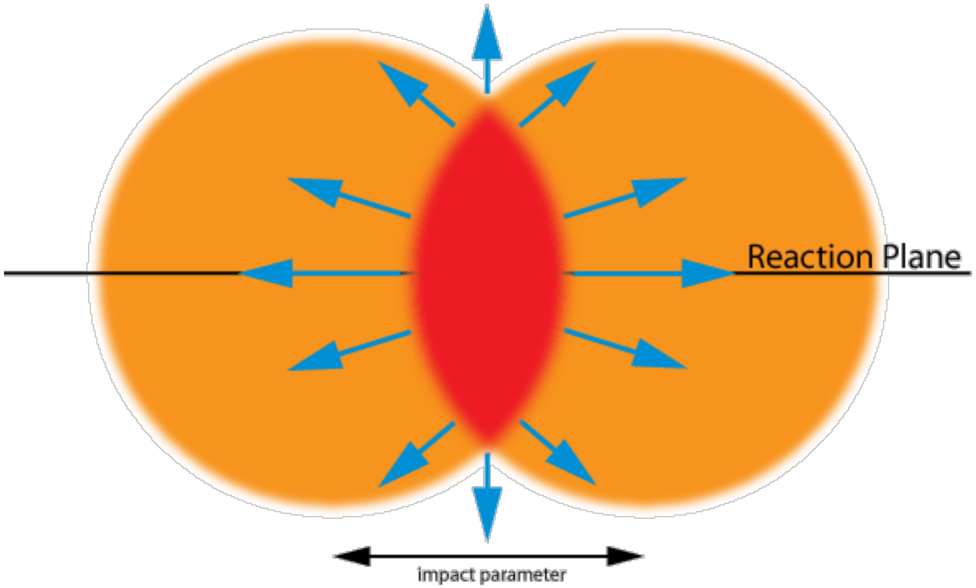
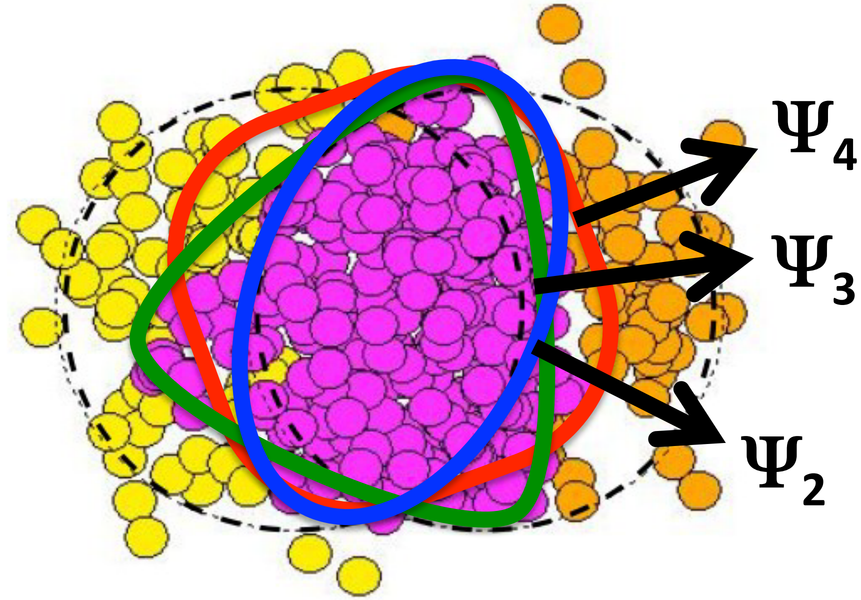
ATHIC2012 in Pusan

Outline

- ✓ Introduction
- ✓ Data set and PHENIX detectors
- ✓ Results
- ✓ Summary

Azimuthal anisotropy





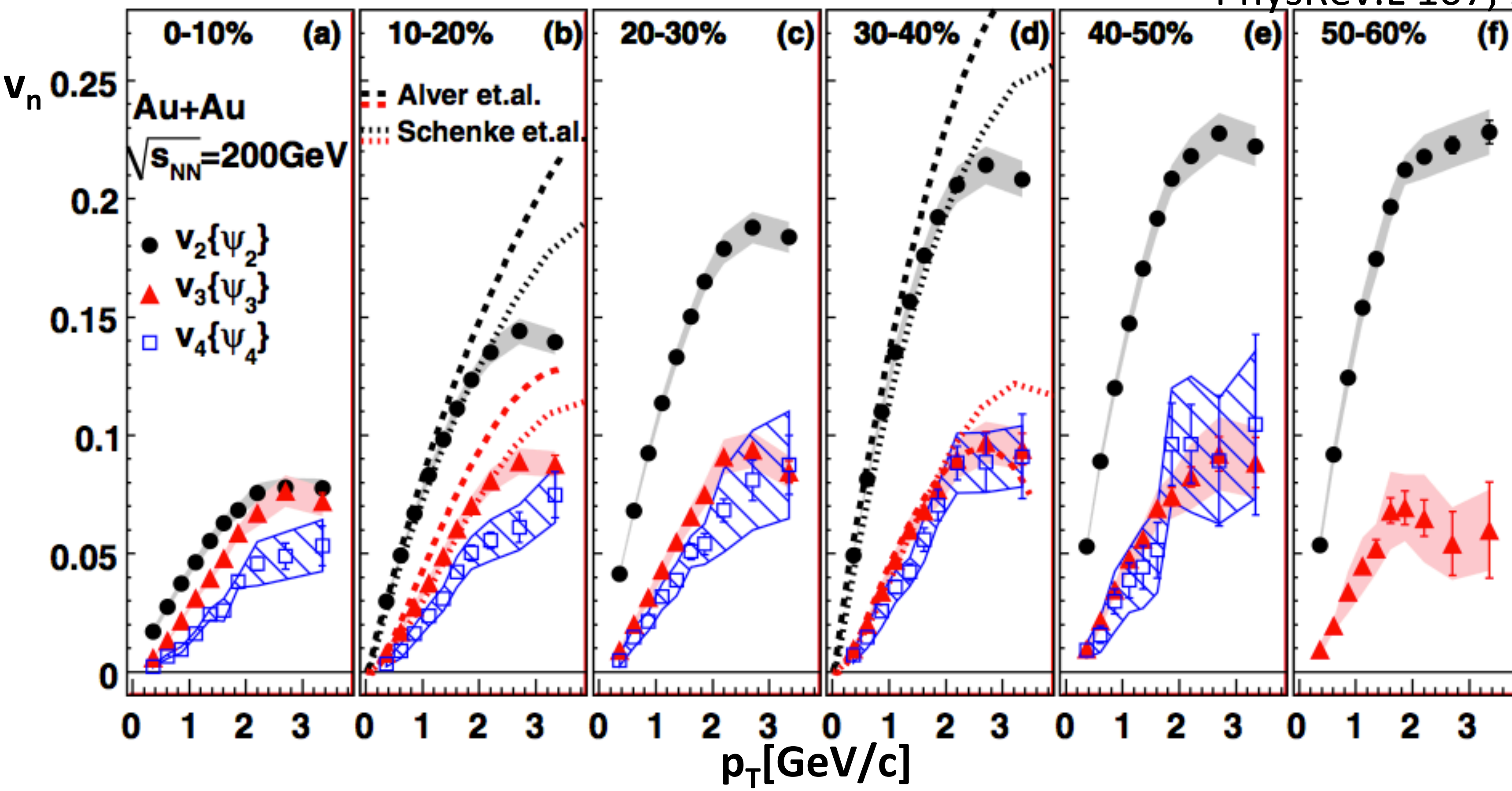
$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left[1 + 2\sum_{n=1}^{\infty}\nu_n \cos\{n(\phi - \Psi_n)\}\right]$$

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

- **Because higher harmonics flows are more sensitive to initial geometry and η/s of QGP, they are studied actively.**

Charged particle azimuthal anisotropy

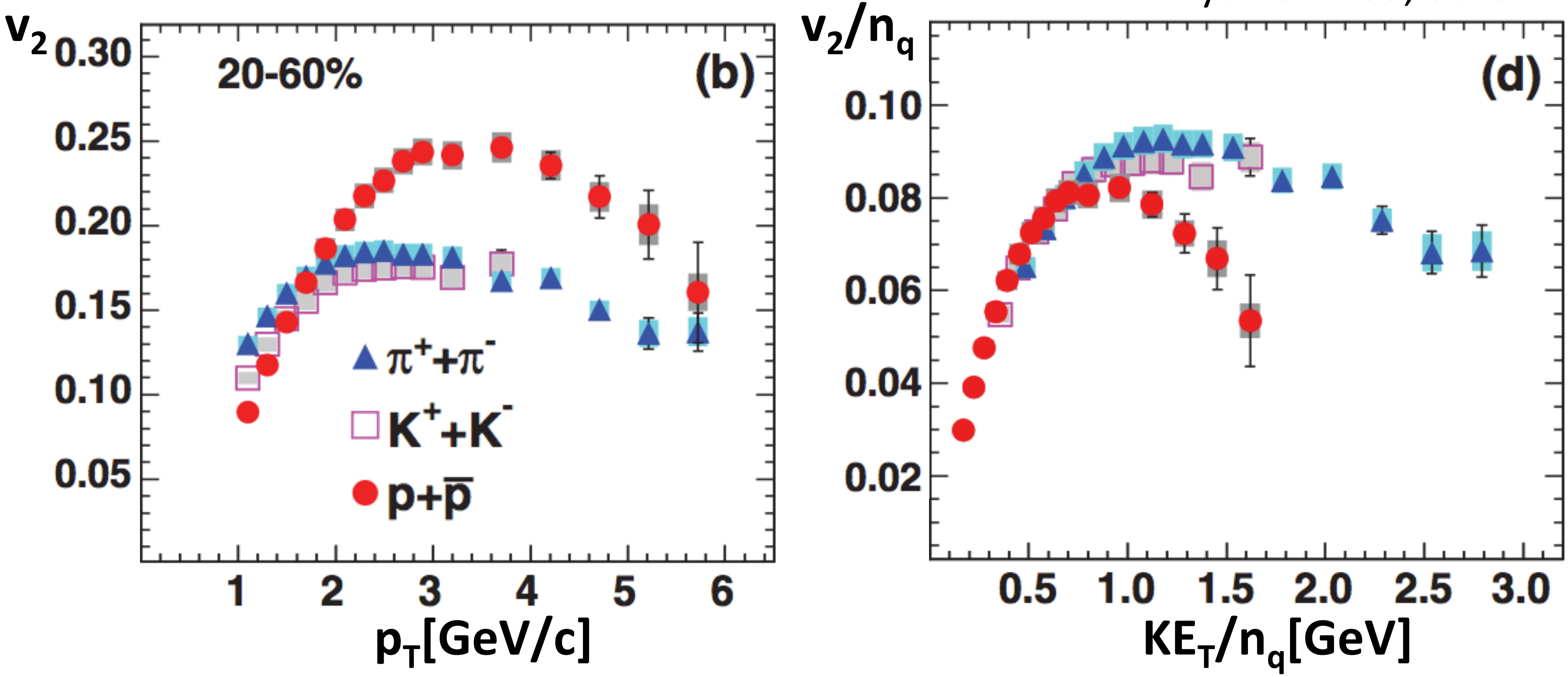
PhysRev.L 107, 252301



- v_2 has strong centrality dependence, v_3, v_4 have weak dependence.
- Because higher harmonics are mainly made by initial geometry deformation, v_3 and v_4 don't have large centrality dependence.

Particle identified elliptic anisotropy

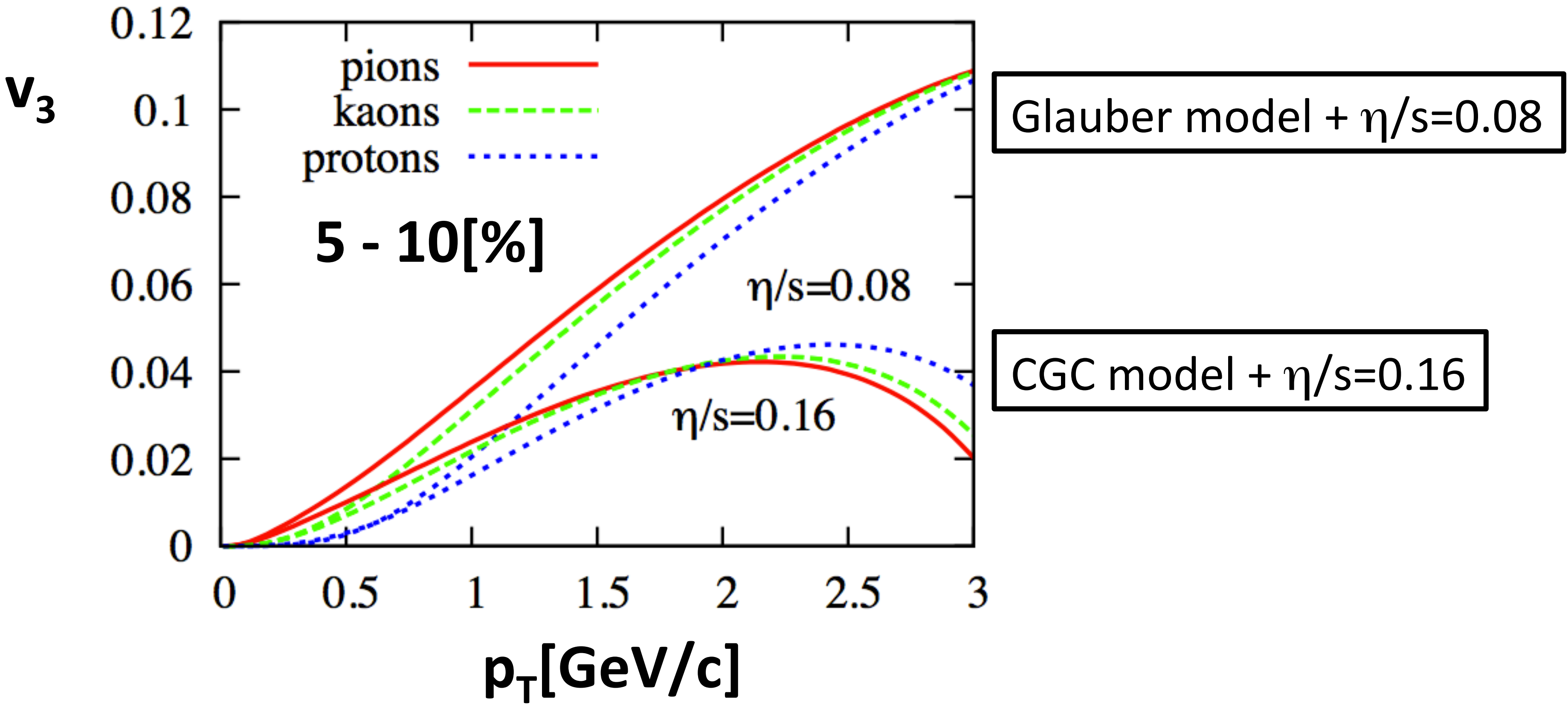
Phys.Rev.C 85, 064914



- $v_2(p_T)$ of π, K, p has mass ordering less than 2[GeV/c].
- meson and baryon have different behavior.
- $v_2(KE_T)$ is well scaled by the number of constituent quarks.

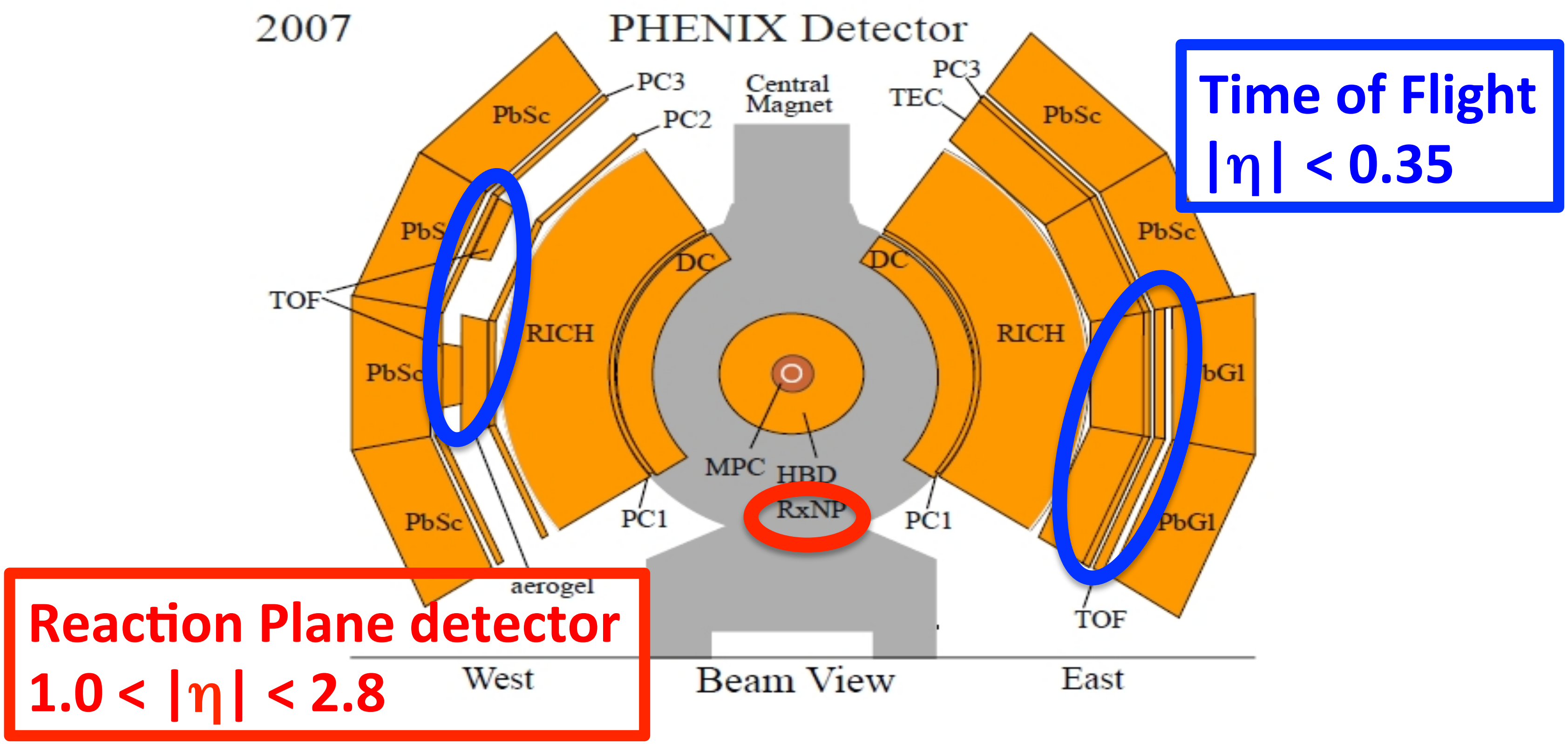
Theory prediction

Phys.Rev.C 82, 034913



- These models predict different strength.
- Both predict that particle identified v_3 has mass ordering like v_2.

Data Set and PHENIX detectors



- Data is 200GeV Au+Au collisions obtained during 2007 run period.

- Emitted particle angle is measured by Central arm.
- Event Plane(Ψ_2, Ψ_3, Ψ_4) are calculated by Reaction Plane detector.

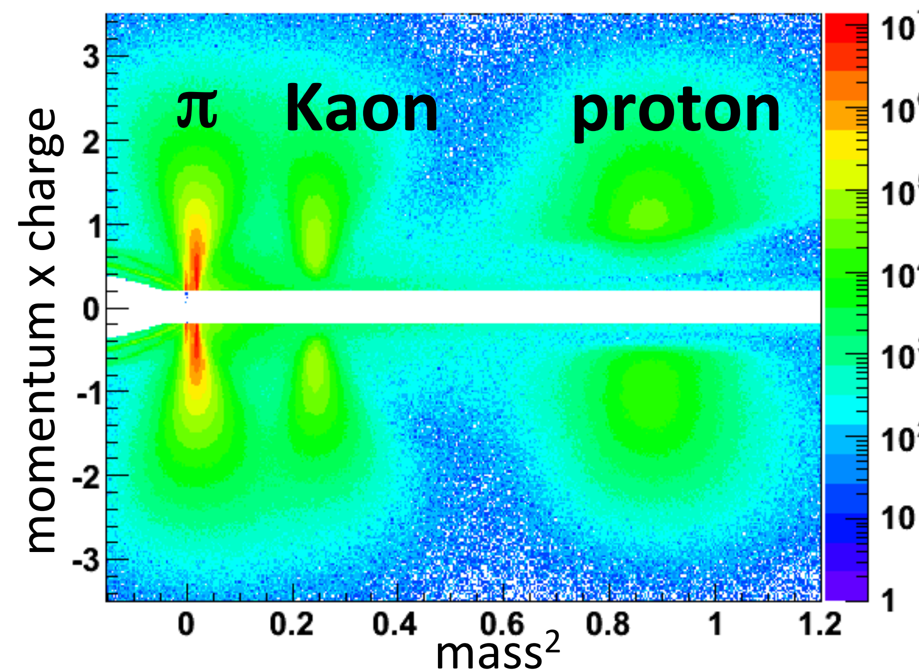
Separating particle species

Particle species are selected via time-of-flight method by TOF.E&W.
RICH and AGEL are used for finer separating particle species.

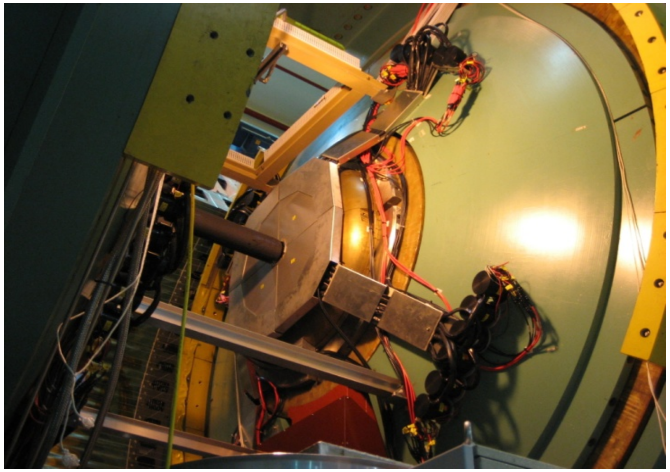
TOF.E detector

$$m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

mass² distribution via TOF.E



Event Plane calculating



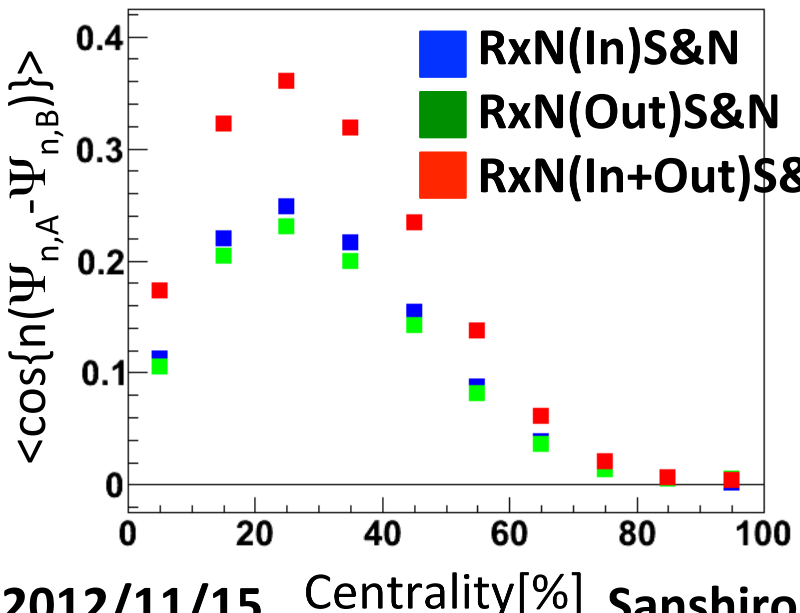
Reaction Plane detector(RxN)
Inner : 1.5 < |η| < 2.8
Outer : 1.0 < |η| < 1.5

Event Plane is calculated by three steps.

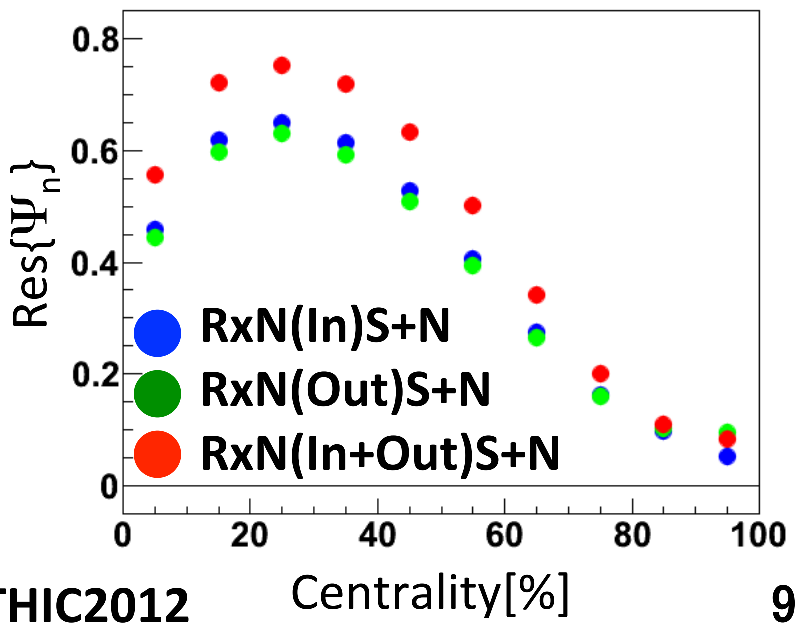
1. gain correction
2. re-centering
3. flattening

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

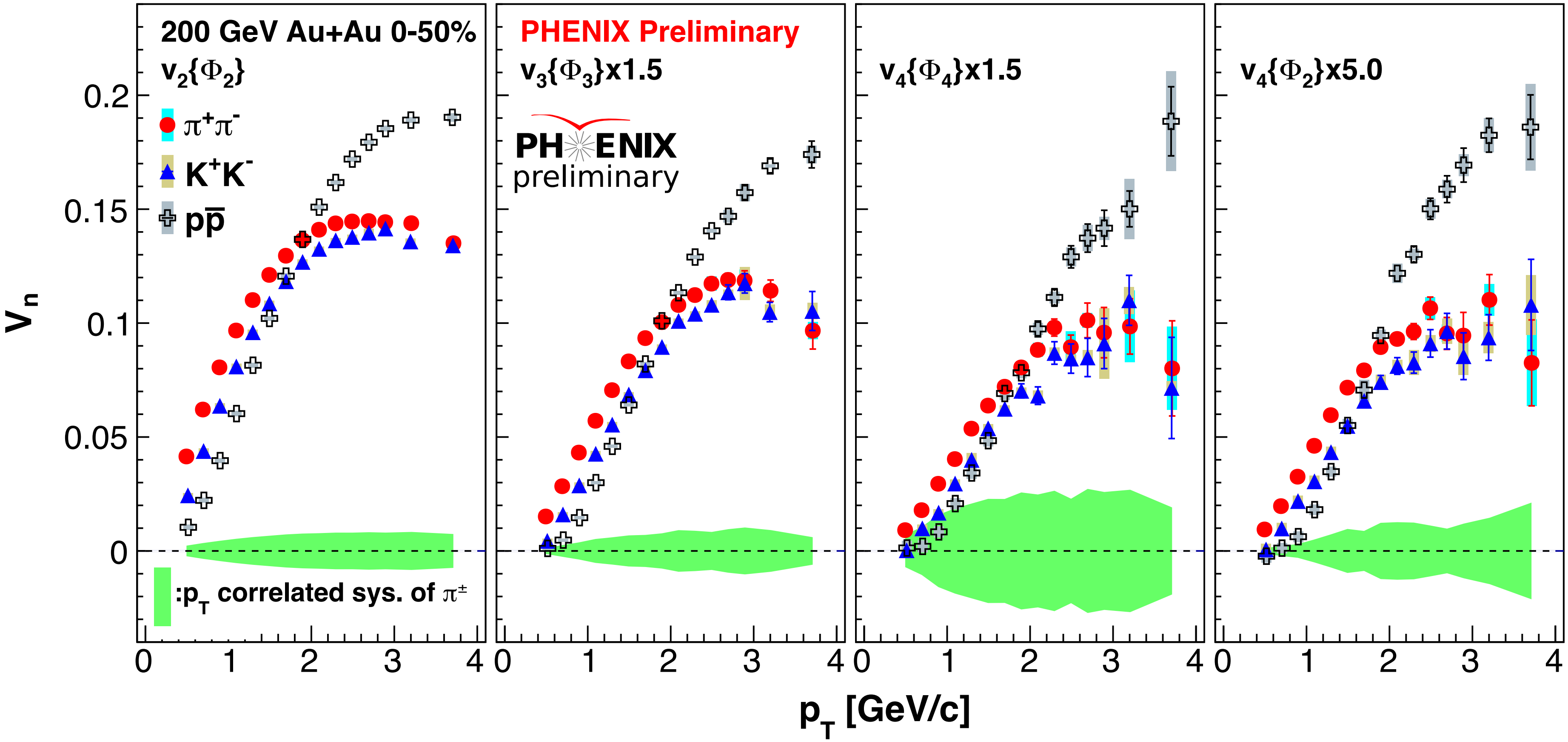
2nd Event Plane correlation



2nd Event Plane resolution

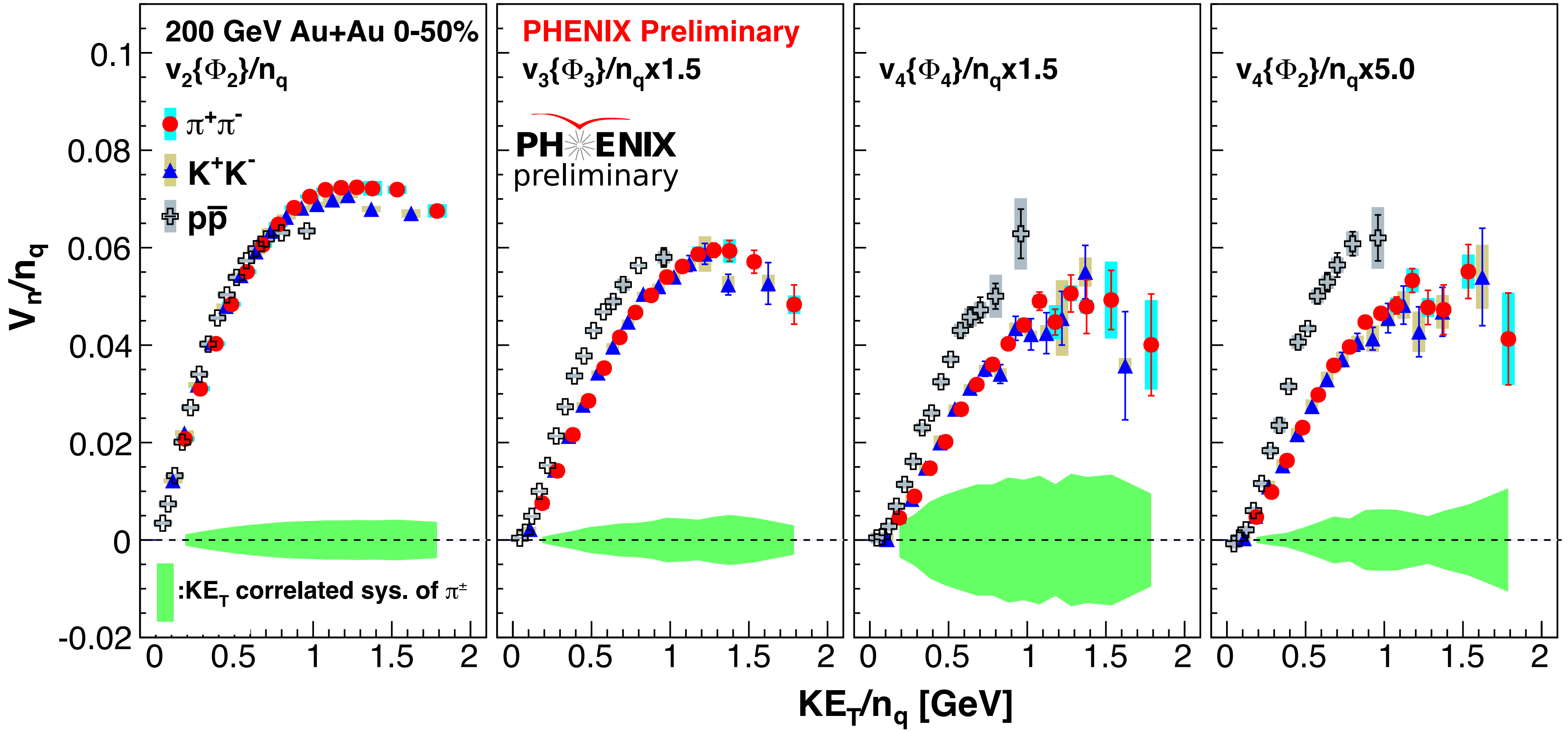


Results of PIDed v_n



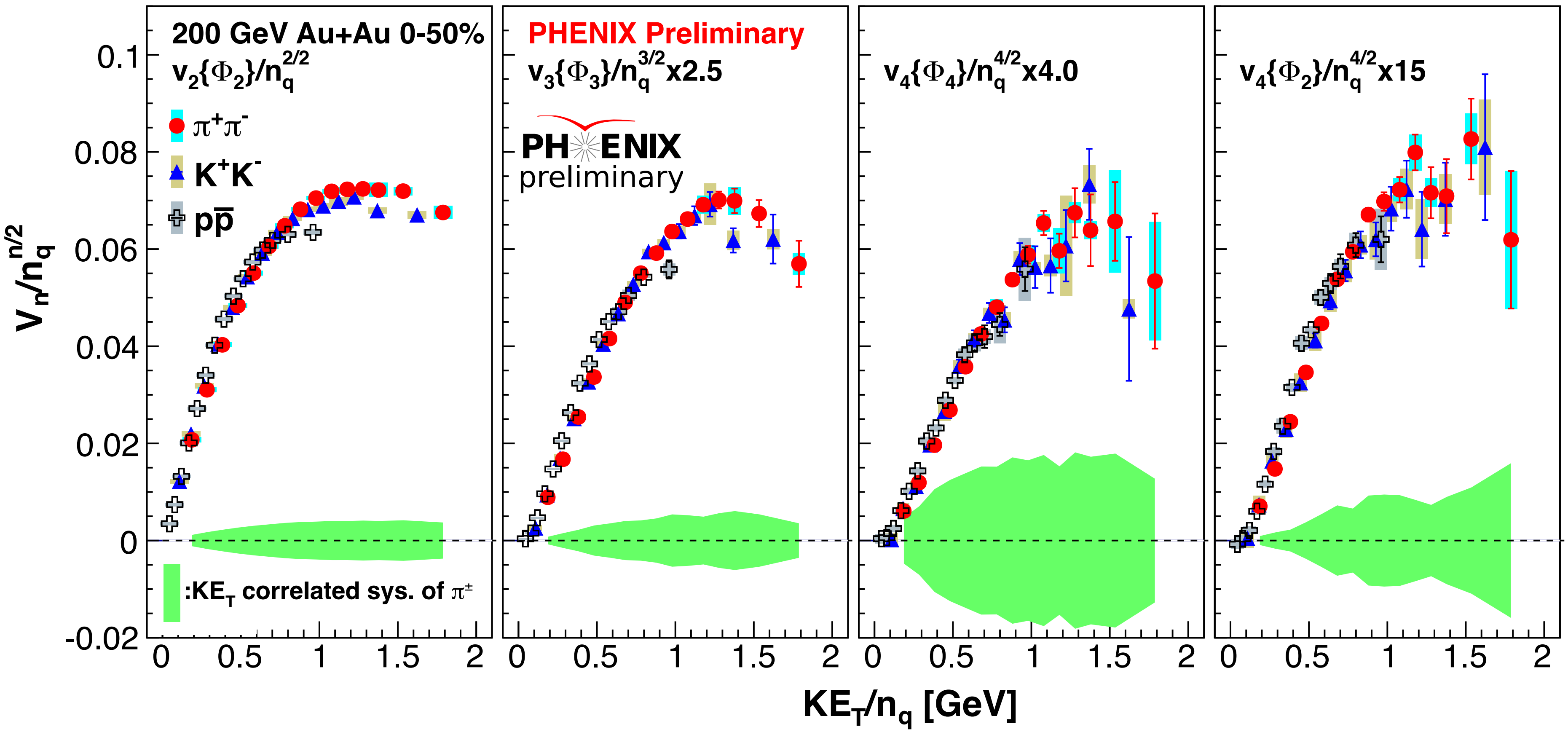
- All harmonics have mass ordering less than 2[GeV/c].
- Meson and baryon have different behavior.
- Higher harmonics have same behavior as v_2.

Results of quark scaling of PIDed $v_n(KE_T)$



- v_2 is well scaled by the number of constituent quarks.
- v_3, v_4 and $v_4(\Psi_2)$ are not well scaled.

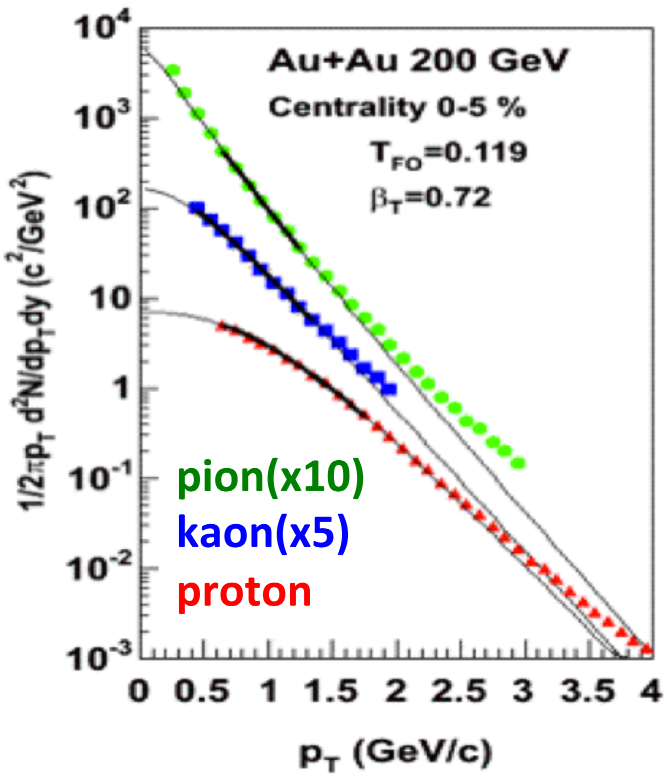
Results of modified scaling



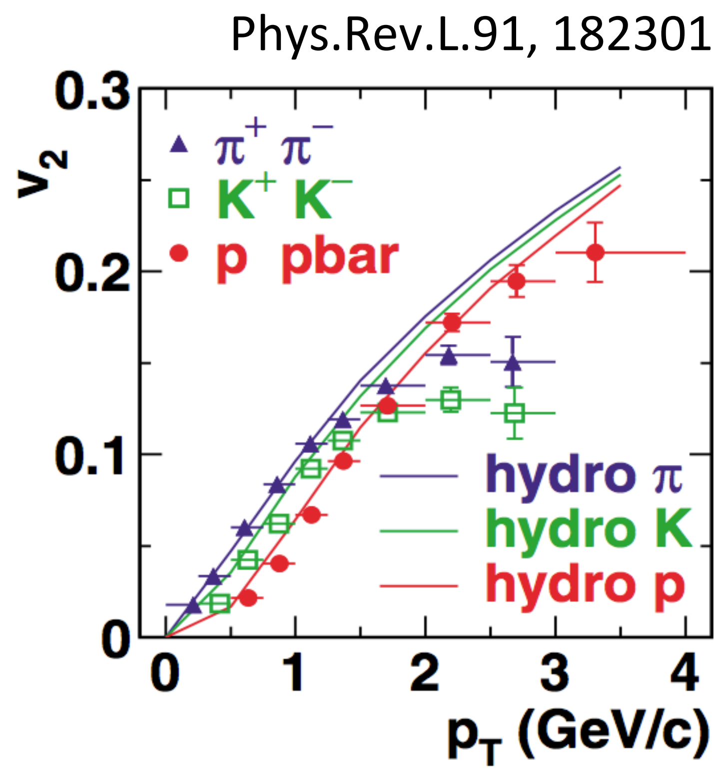
- **This scale works well for all harmonics.**

(a) : $v_2(KE_T)/n_q$
(b) : $v_n^{1/n}$
(a)+(b) : $v_n(KE_T)/n_q^{n/2}$

Comparison model calculation



Phys.Rev.L.91, 182301



- Low p_T part of identified particle spectra are well described by radial flow depending on the mass of the hadrons.
- Particle identified v_2 are well described by hydro model in low p_T.

Blast Wave Model

BW model describes final state from the information at freeze-out.
Spectra and v_n are fitted at the same time in this analysis.

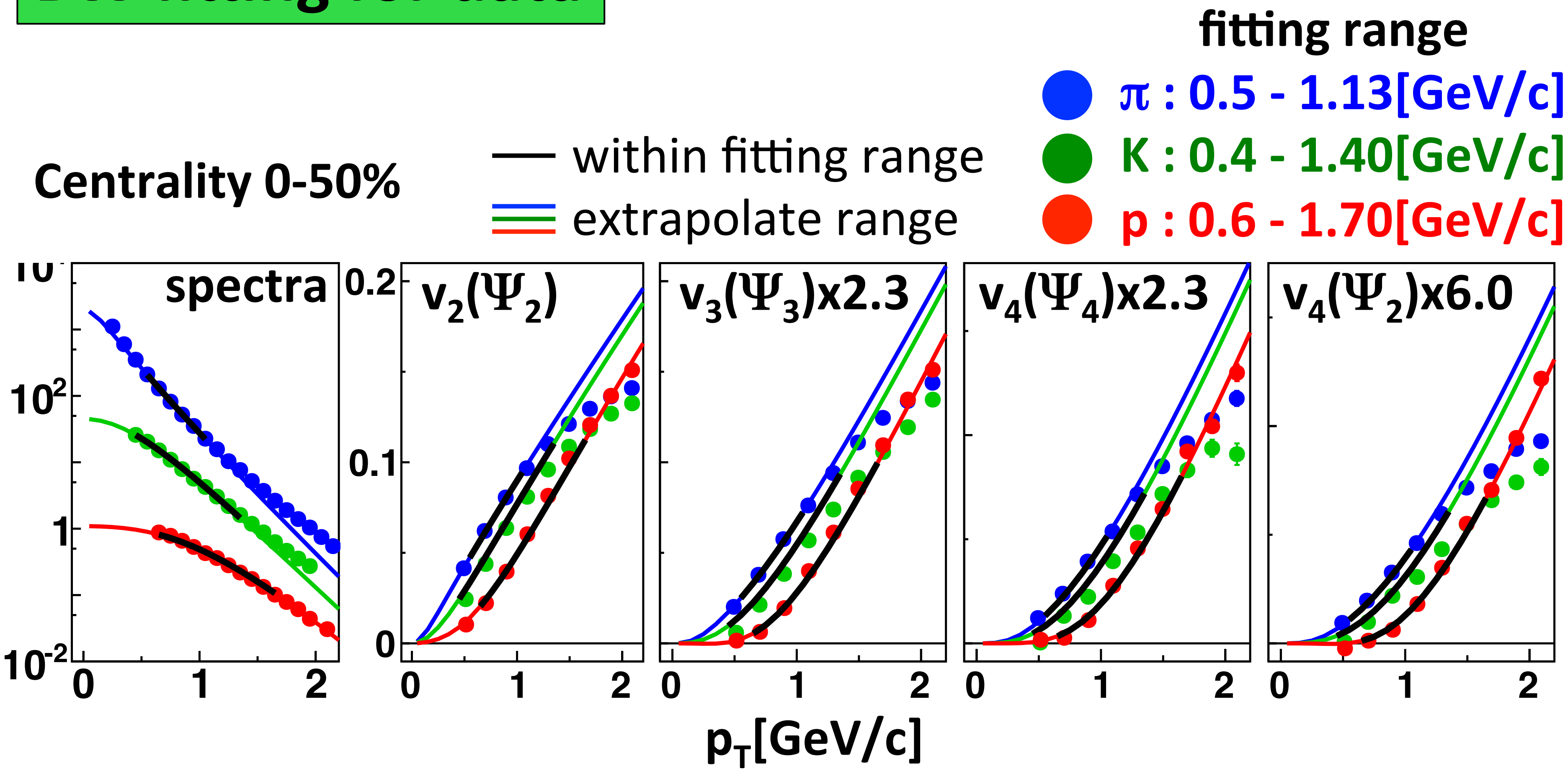
$$\frac{dN}{p_T dp_T} \propto \int\int r dr d\phi m_T I_0(\alpha_T) K_1(\beta_T)$$

$$v_n = \frac{\int\int r dr d\phi \cos\{n\phi\} I_n(\alpha_T) K_1(\beta_T)(1 + 2s_n \cos\{n\phi\})}{\int\int r dr d\phi I_0(\alpha_T) K_1(\beta_T)(1 + 2s_n \cos\{n\phi\})}$$

T_f : temperature
ρ_0 : average velocity
ρ_n : velocity anisotropy
(anisotropy in velocity)
s_n : geometrical anisotropy
(like eccentricity at freeze-out)

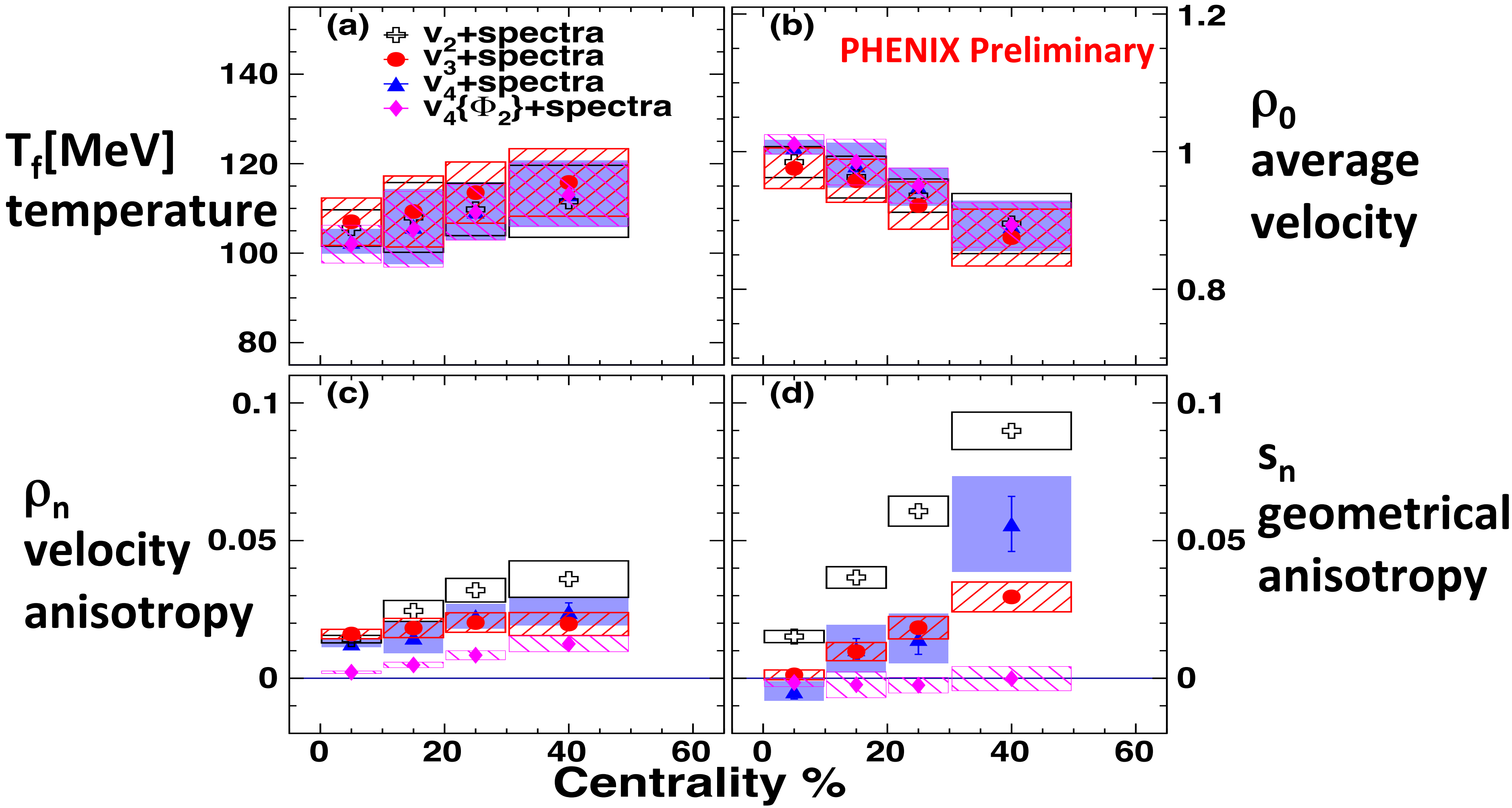
$\rho(\phi, r) = \rho_0(1+2\rho_n \cos(n\phi))*r$
$\alpha_T(\phi, r) = (p_T/T_f)\sinh(\rho(\phi, r))$
$\beta_T(\phi, r) = (m_T/T_f)\cosh(\rho(\phi, r))$

BW fitting for data



- Not only spectra and v_2 but also v_3, v_4, $v_4(\Psi_2)$ are well described.
- Higher harmonics are created as a result of the both initial geometrical anisotropy and hydrodynamic expansion.

Freeze-out Parameters

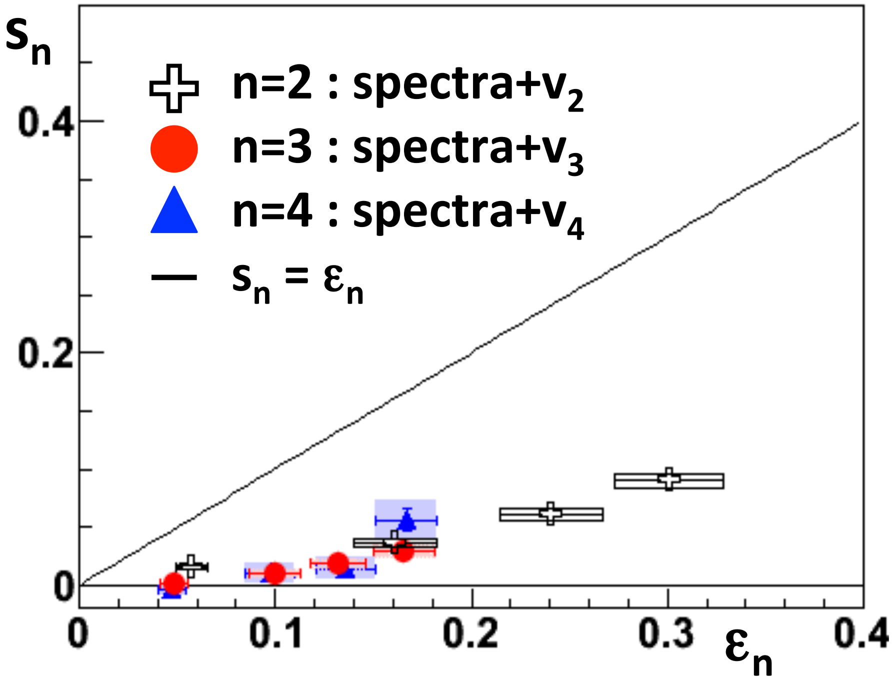


- ρ_n is similar behavior with charged v_n centrality dependence.

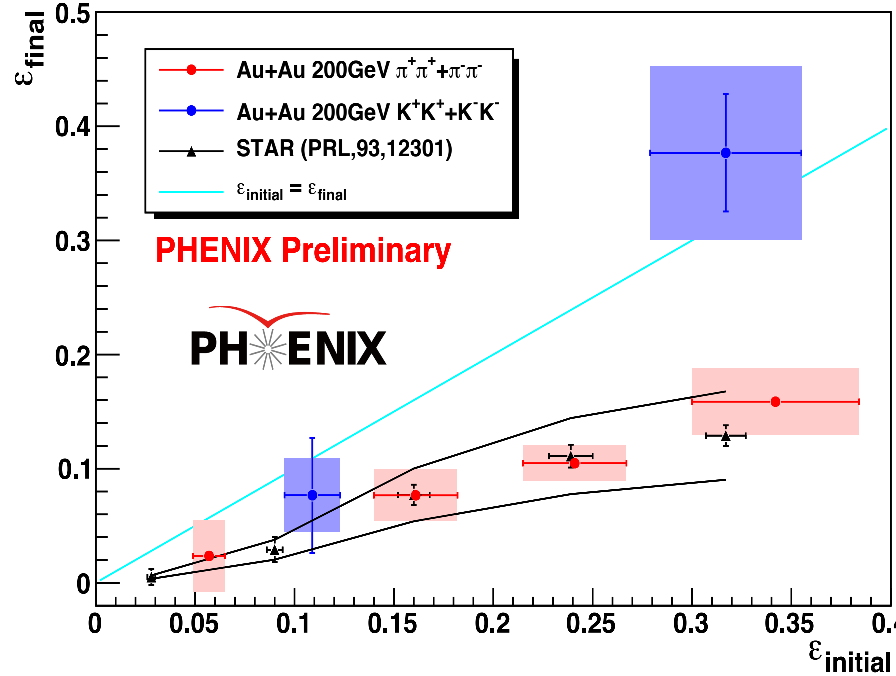
Comparison of initial/final geometrical anisotropy

Takafumi (QM2012)

BW

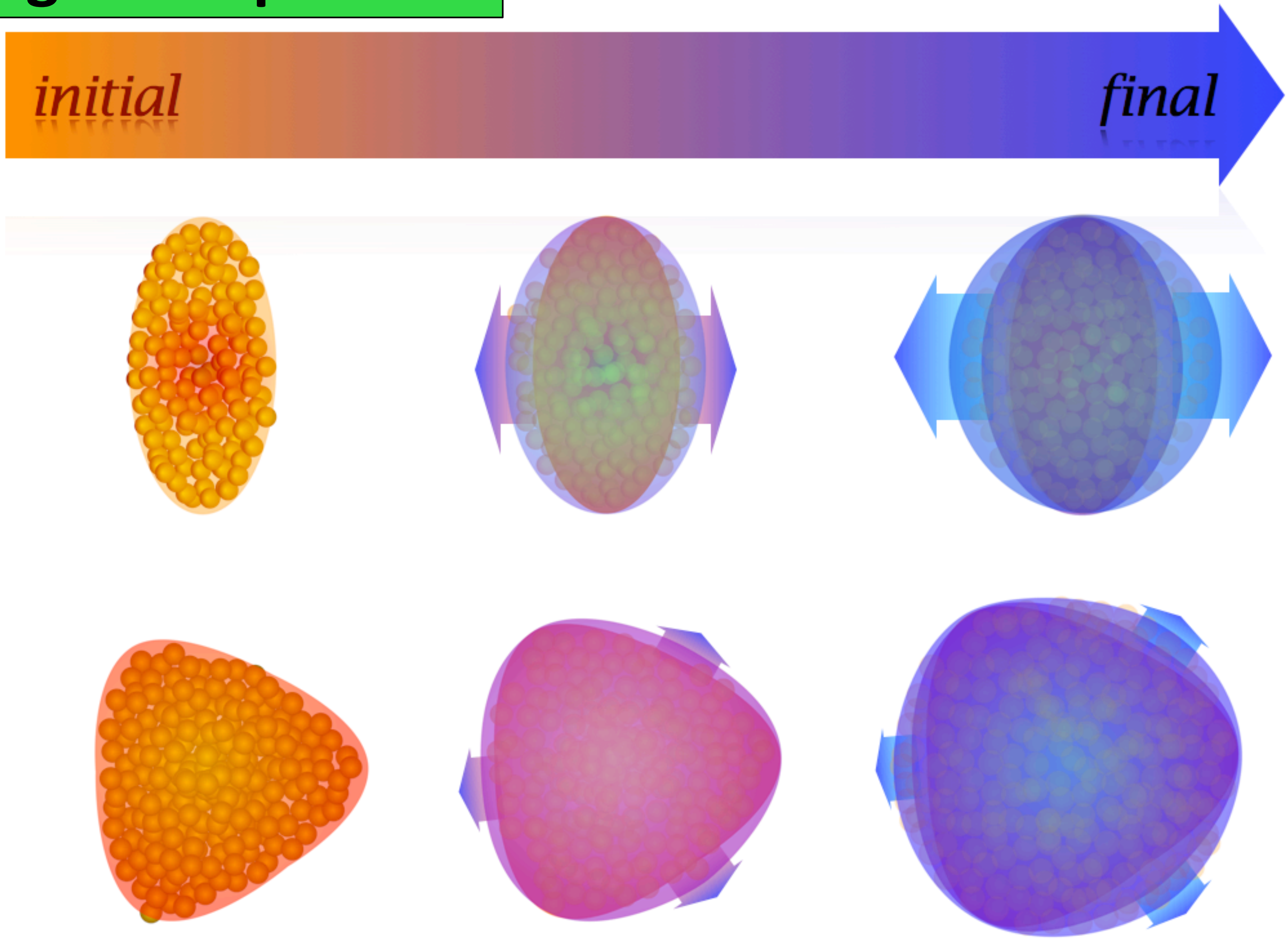


HBT (2nd order geometrical anisotropy)



- Geometrical anisotropies are thought to be converted to velocity anisotropies during expansion process.
- BW result is similar behavior with HBT result.

Image of expansion



Summary

- Higher harmonics azimuthal anisotropy of identified particles are measured.
- Each harmonics has mass ordering in low p_T and different behavior among meson and baryon.
- Modified scaling works well w.r.t. all harmonics.

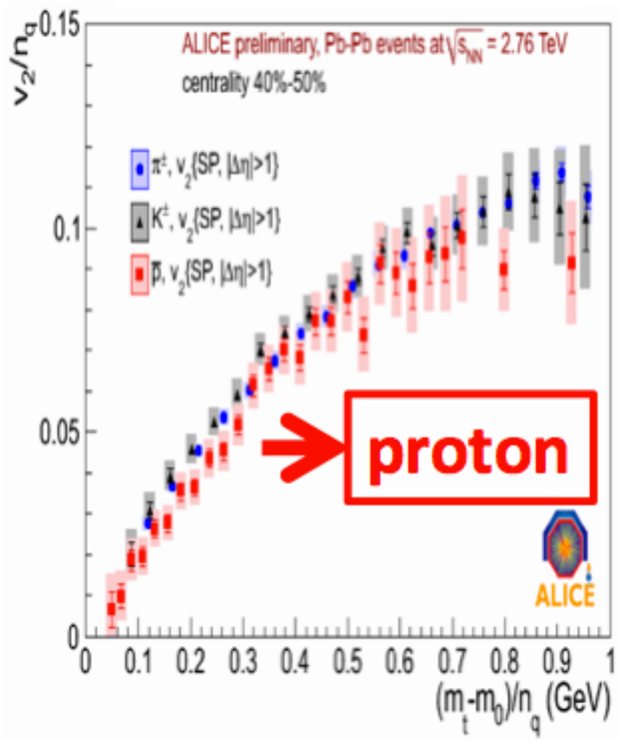
- BW describes well spectra and all harmonics.
- Parameters at freeze-out are obtained by BW fitting.
- Geometrical anisotropy at freeze-out gets small from initial during expansion process.
- Comparison of initial/final geometry is similar to HBT.

Thank you!!

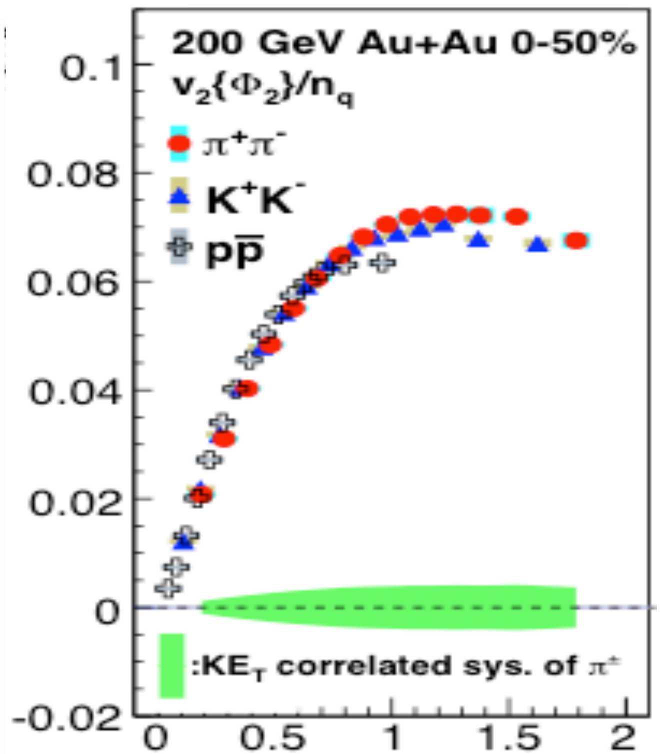
Back Up

Comparison scaling among different energy

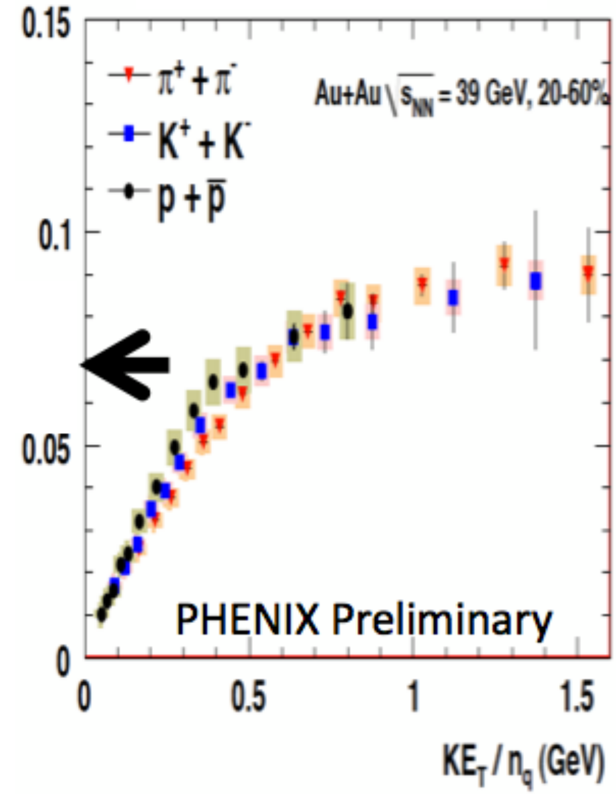
Pb+Pb 2760GeV



Au+Au 200GeV

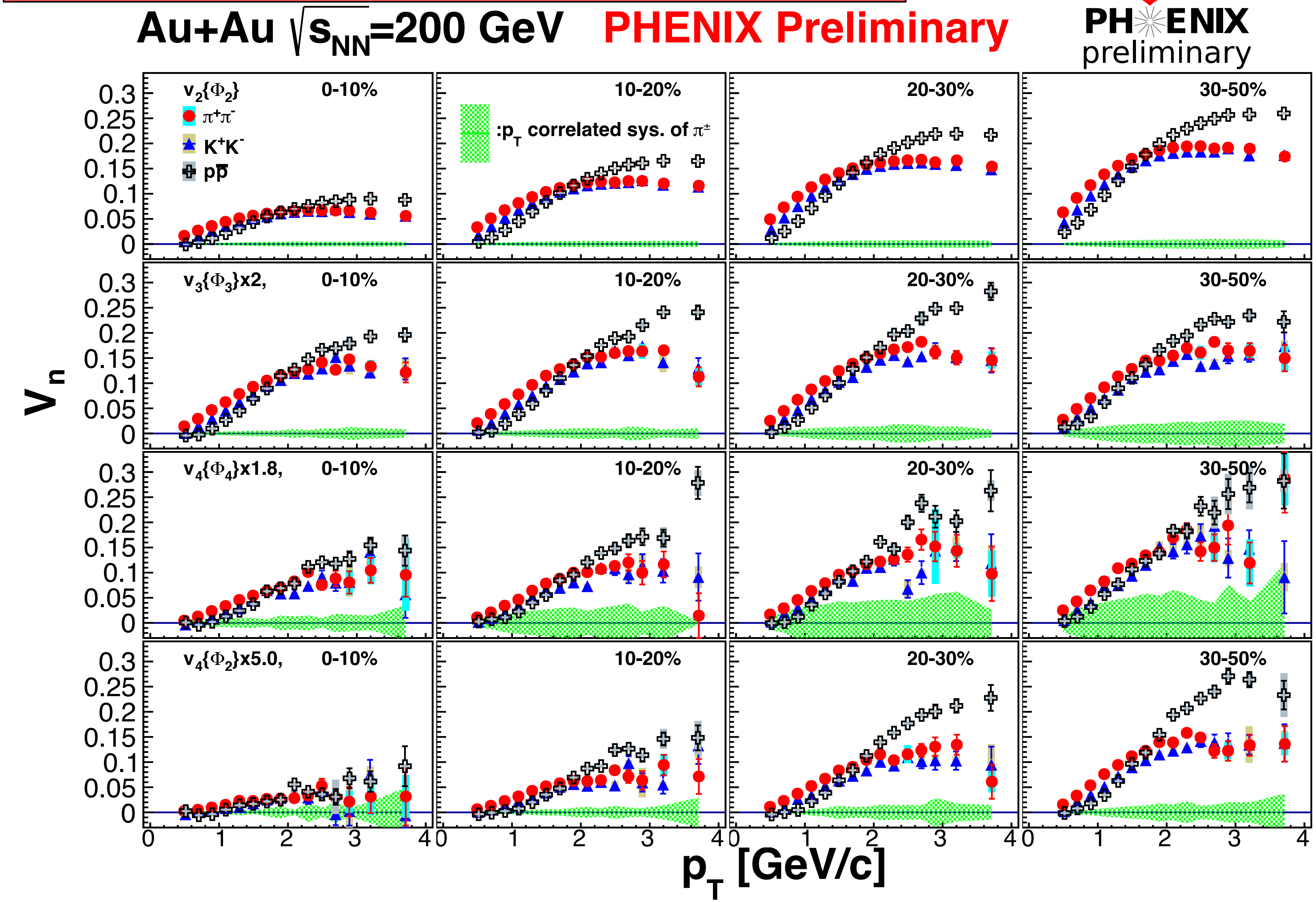


Au+Au 39GeV

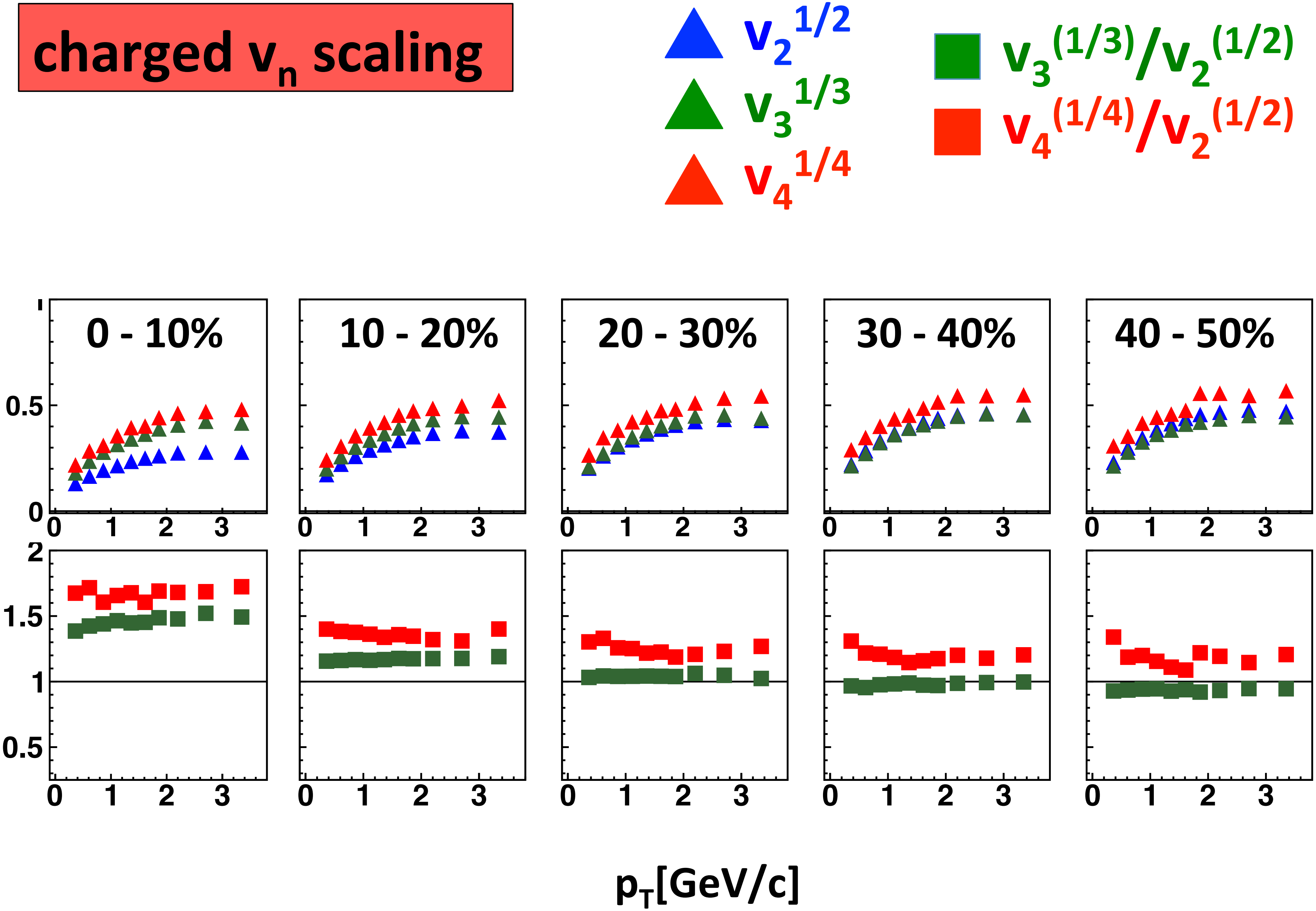


- Proton is shifted
  Is the strength of radius expansion related?

PIDed v_n with fine centrality bin

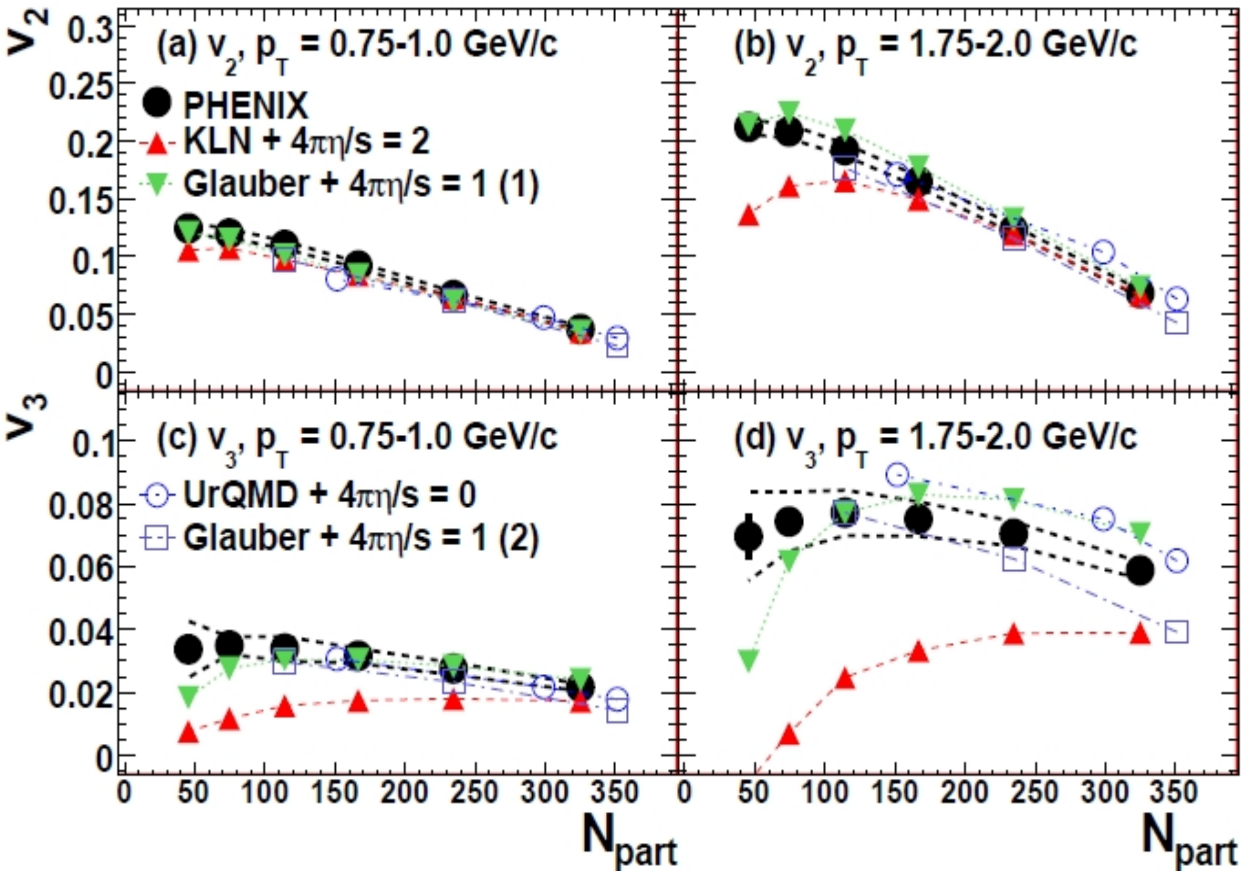


charged v_n scaling



Comparison charged v_n with model calculation

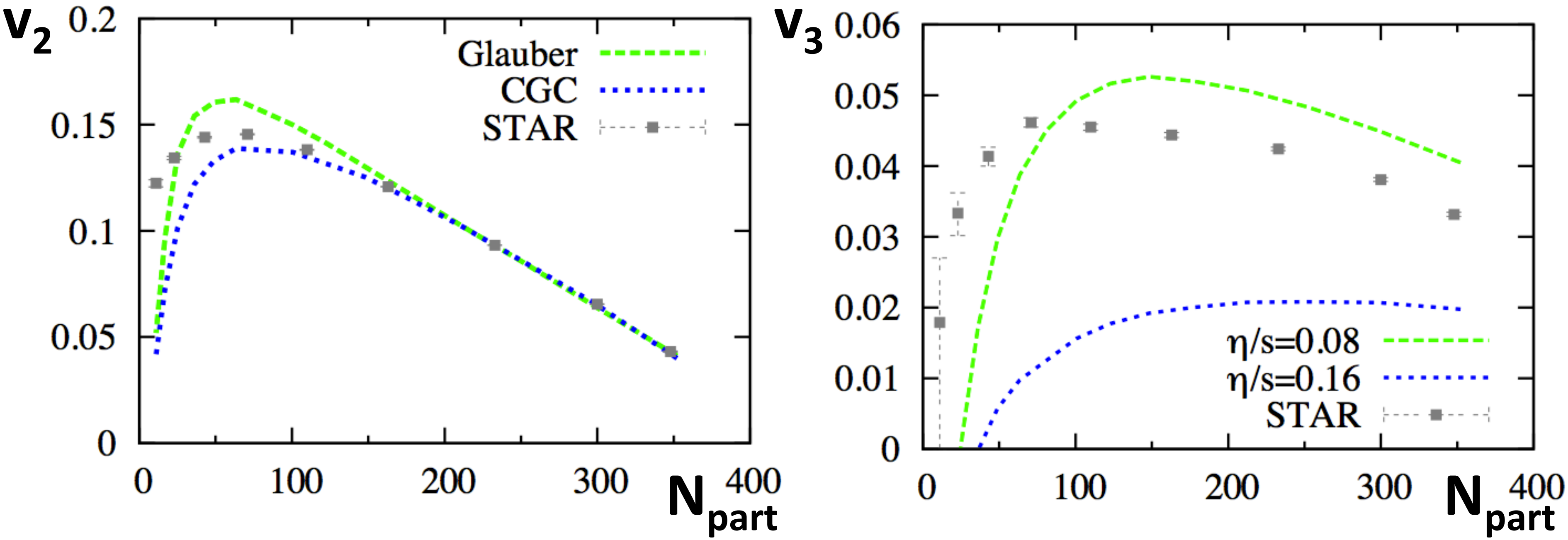
PhysRev.L 107, 252301



- Though model can describe v_2 well, it is not always true that they always describe v_3.

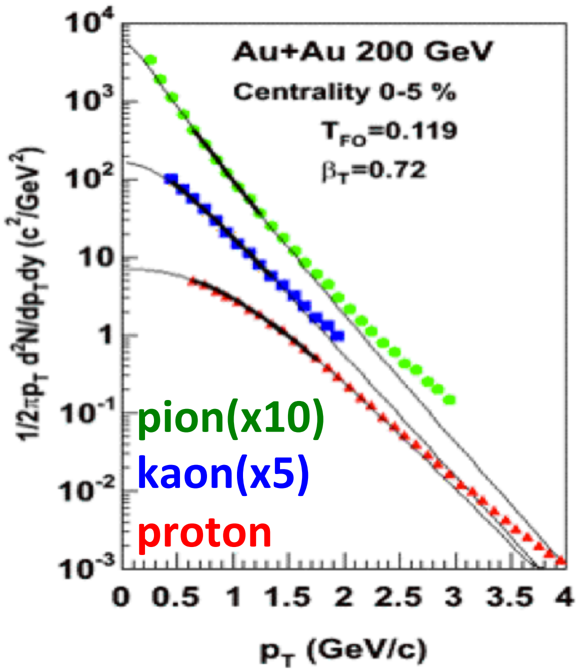
Comparison charged v_n with model calculation

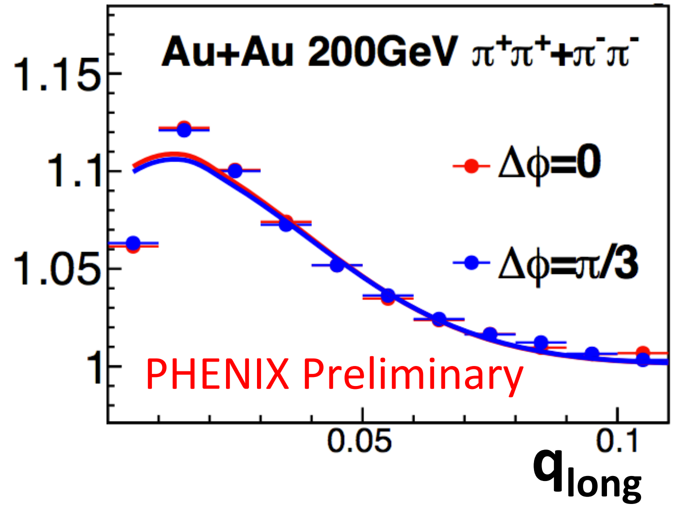
Phys.Rev.C 82, 034913



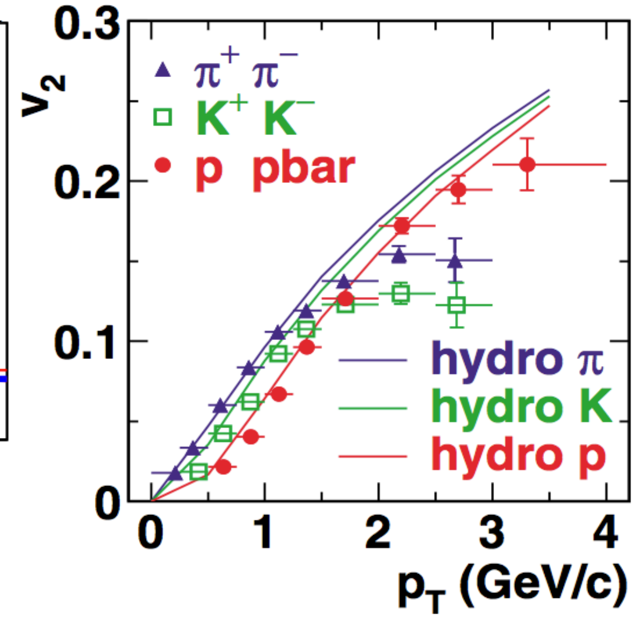
- **Both model well describe v_2 behavior.**
  Glauber+η/s=0.08
  CGC+η/s=0.16
- **Both model don't well describe v_3.**

Model calculation



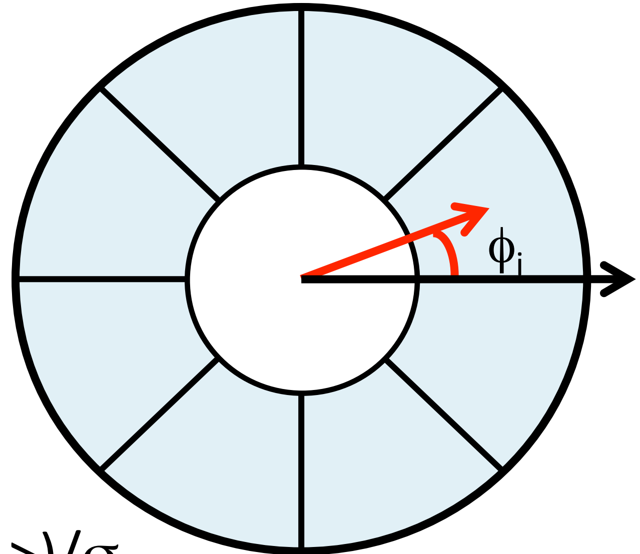


Phys.Rev.L.91, 182301



- Low p_T part of identified particle spectra are well described by radial flow depending on the mass of the hadrons.
- HBT analysis provides space-time information (size and shape) of matter at freeze-out.
- Particle identified v_2 are well described by hydro model in low p_T.

Event Plane Calculation



1. Gain correction

$$w_i = adc_i/\langle adc\rangle$$

$$Q_{x,n} = \Sigma w_i \cos(n\phi_i)\ ,\ Q_{y,n} = \Sigma w_i \sin(n\phi_i)$$

$$\Phi_n = \mathrm{atan2}(Q_{x,n}, Q_{y,n}) / n$$

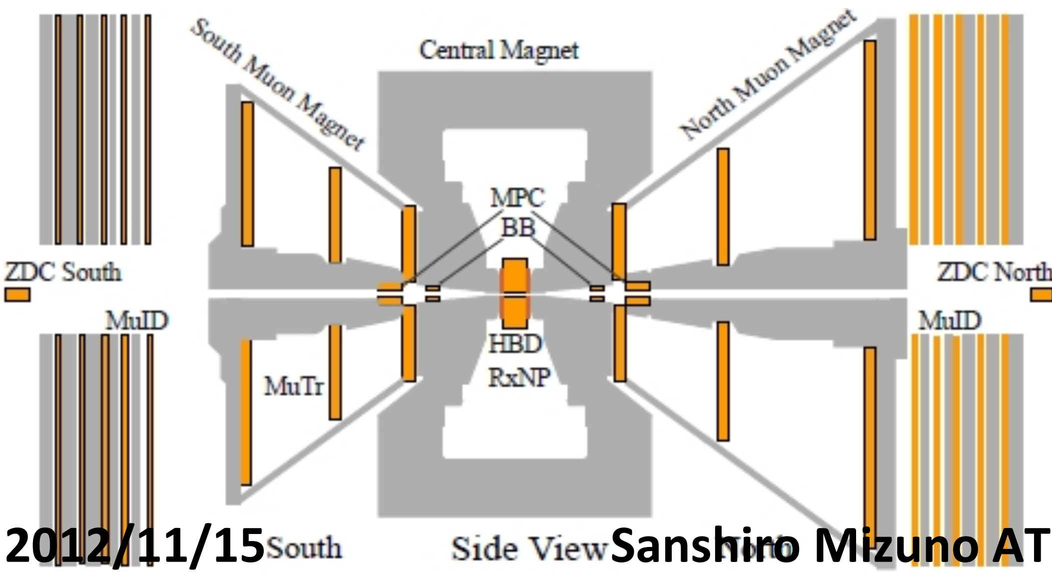
2. Re-centering

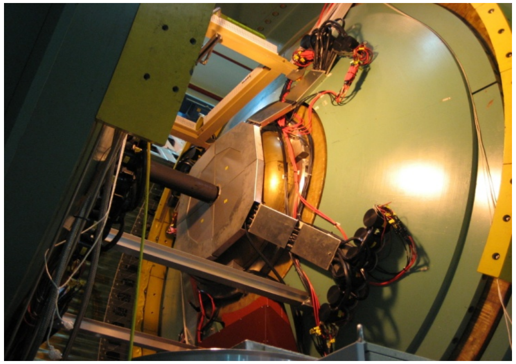
$$Q'_{x,n} = (Q_{x,n}-\langle Q_{x,n}\rangle)/\sigma_{Qx,n}\ ,\ Q'_{y,n} = (Q_{y,n}-\langle Q_{y,n}\rangle)/\sigma_{Qy,n}$$

$$\Phi'_n = \mathrm{atan2}(Q'_{x,n}, Q'_{y,n}) / n$$

3. Flattening

$$n\Phi''_n = n\Phi'_n + \Sigma 2/i\{-\langle\sin(in\Phi'_n)\rangle\cos(in\Phi'_n)+\langle\cos(in\Phi'_n)\rangle\sin(in\Phi'_n)\}$$

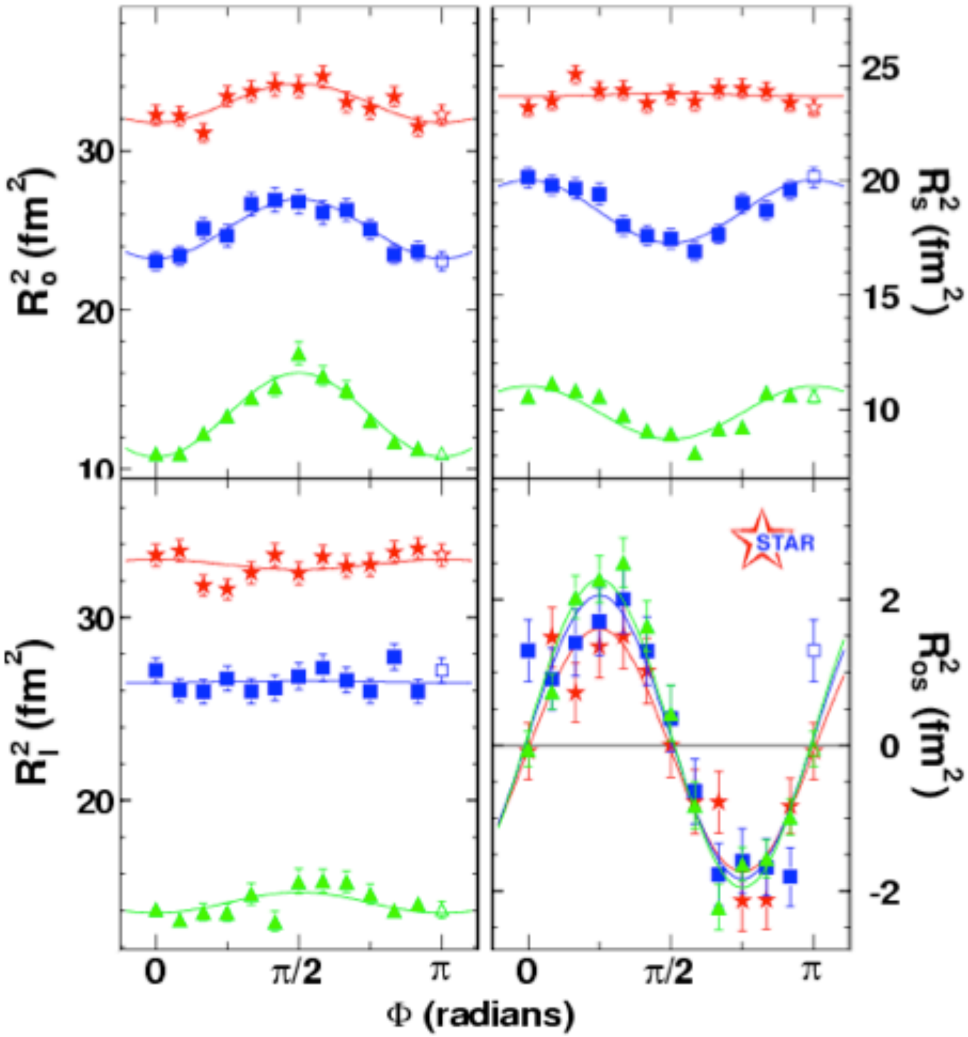




reaction plane detector(RxN)
inner $1.5 < |\eta| < 2.8$
outer $1.0 < |\eta| < 1.5$

HBT

Phys.Rev.Lett. 93, 012301



$$R_{s,n}^2 \equiv \langle R_s^2(\phi)\cdot\cos(n\phi)\rangle$$

$$\varepsilon = 2\frac{R_{s,2}^2}{R_{s,0}^2} = 2\frac{R_{os,2}^2}{R_{s,0}^2} = -2\frac{R_{o,2}^2}{R_{s,0}^2}$$