Measurement of Centrality dependence of identified hadron Elliptic Flow in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions at RHIC - PHENIX

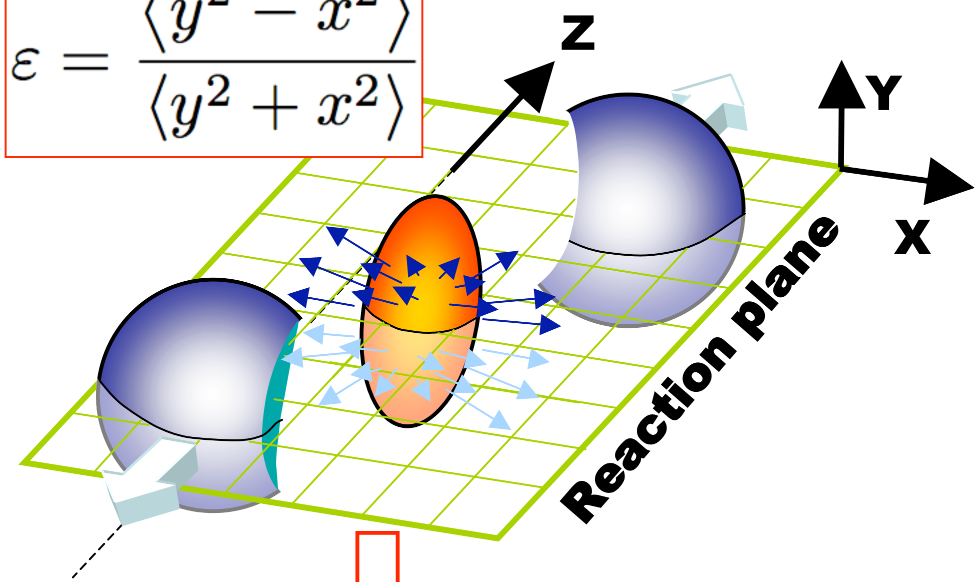
Hiroshi Masui / Univ. of Tsukuba

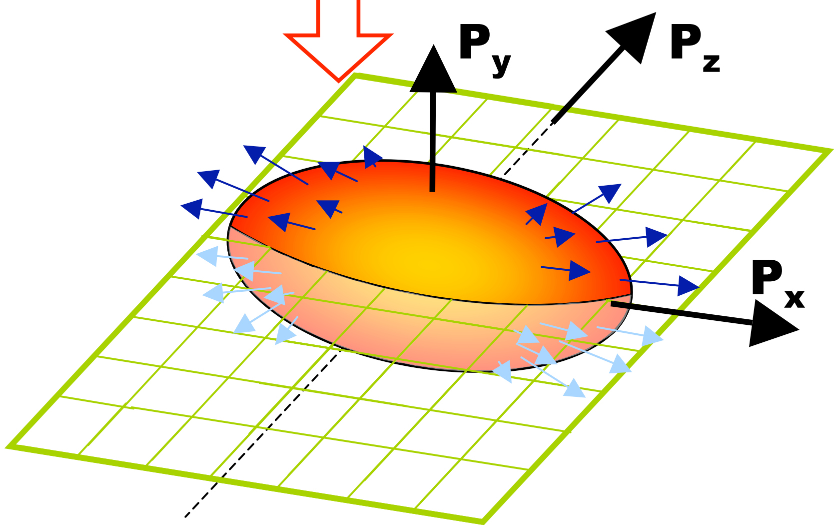
for the PHENIX Collaboration

JPS, 62nd Annual Meeting

Why Elliptic Flow ?

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



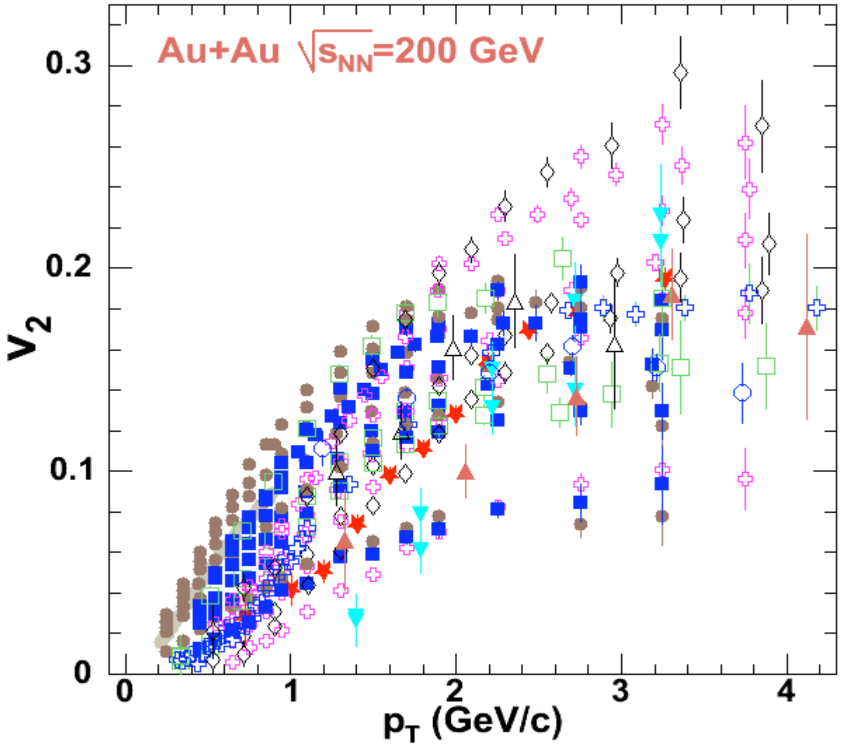


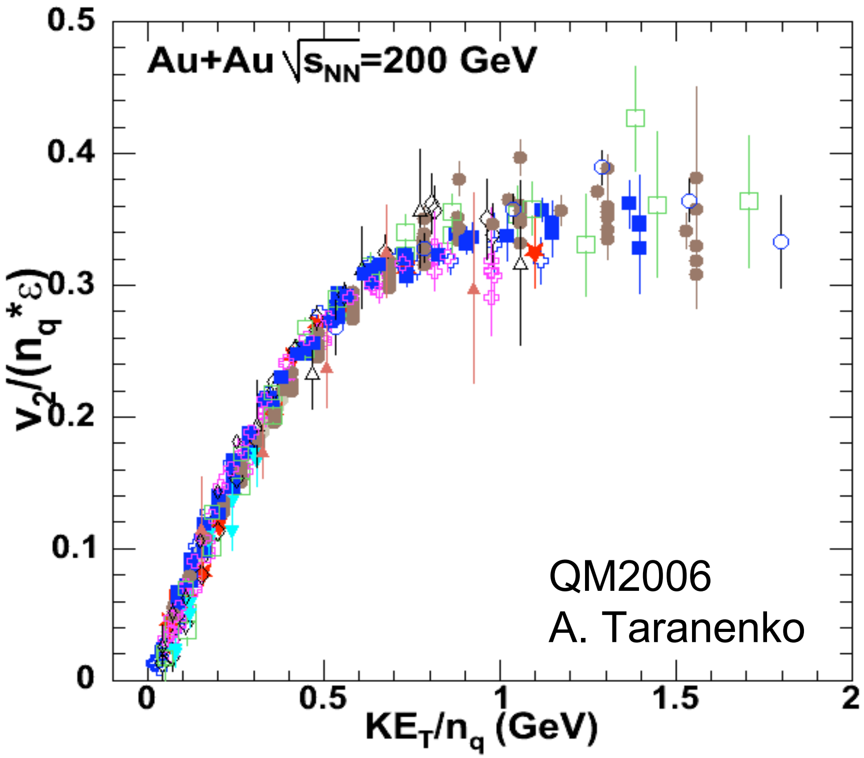
- Sensitive probe in the early stage of heavy ion collisions
  - Initial geometry overlap (eccentricity)
    - Initial density + EOS
    - System size (number of collisions)
  - Final momentum anisotropy (v_2)

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos\left(2[\phi - \Psi]\right)$$

$$v_2 = \langle \cos\left(2[\phi - \Psi]\right) \rangle$$

Universal Scaling of v_2 ?





At mid-rapidity

$$
\begin{aligned}
v_2(p_T, b, A) &\sim F(KE_T/n_q) \times \varepsilon(b, A) \\
\varepsilon(b, A) &- \text{Average } v_2 \text{ of charged hadrons (eccentricity)} \\
KE_T &- \text{Transverse kinetic energy } (KE_T = m_T - m_0) \\
n_q &- \text{Number of quarks}
\end{aligned}
$$

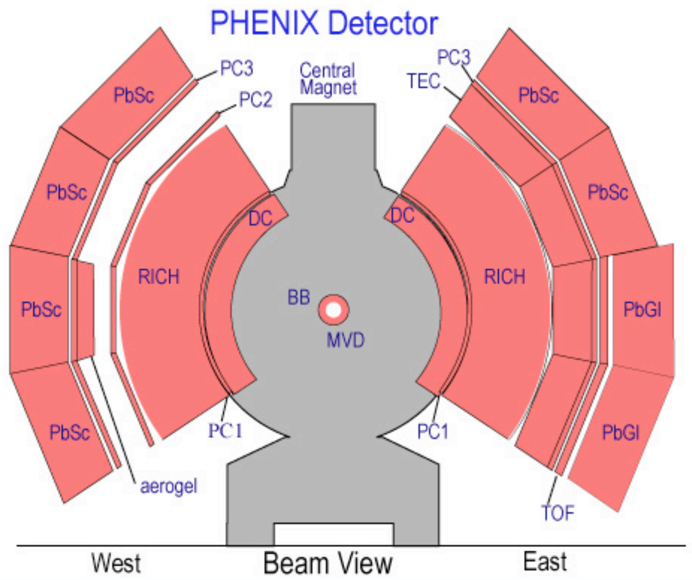
- Universal scaling of v_2 suggest
  - v_2 for a variety of particle species at RHIC are determined through (ε, KE_T/n_q)
  - Its magnitude is established in partonic level before hadronization

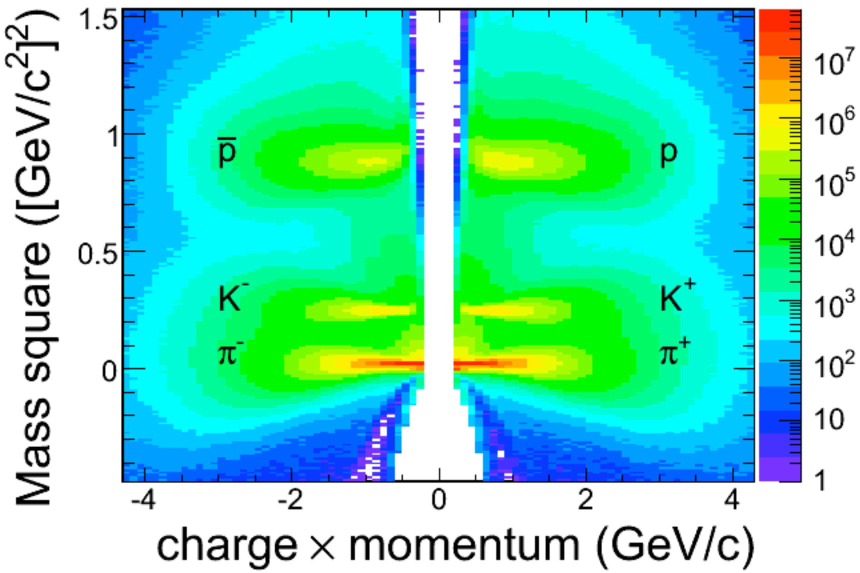
Motivation

- Universal scaling of v_2 has been observed by assuming
  - $\varepsilon \propto \langle v_2 \rangle$ of non-identified charged hadrons
  - $v_2 \propto F(KE_T/n_q)$
- Questions
  - Are these assumptions really correct ?
  - The scaling of v_2 is tested from central to mid-central. How about peripheral collisions ?

- Study the validity of the scaling of v_2 in a wide range of centrality for identified hadrons

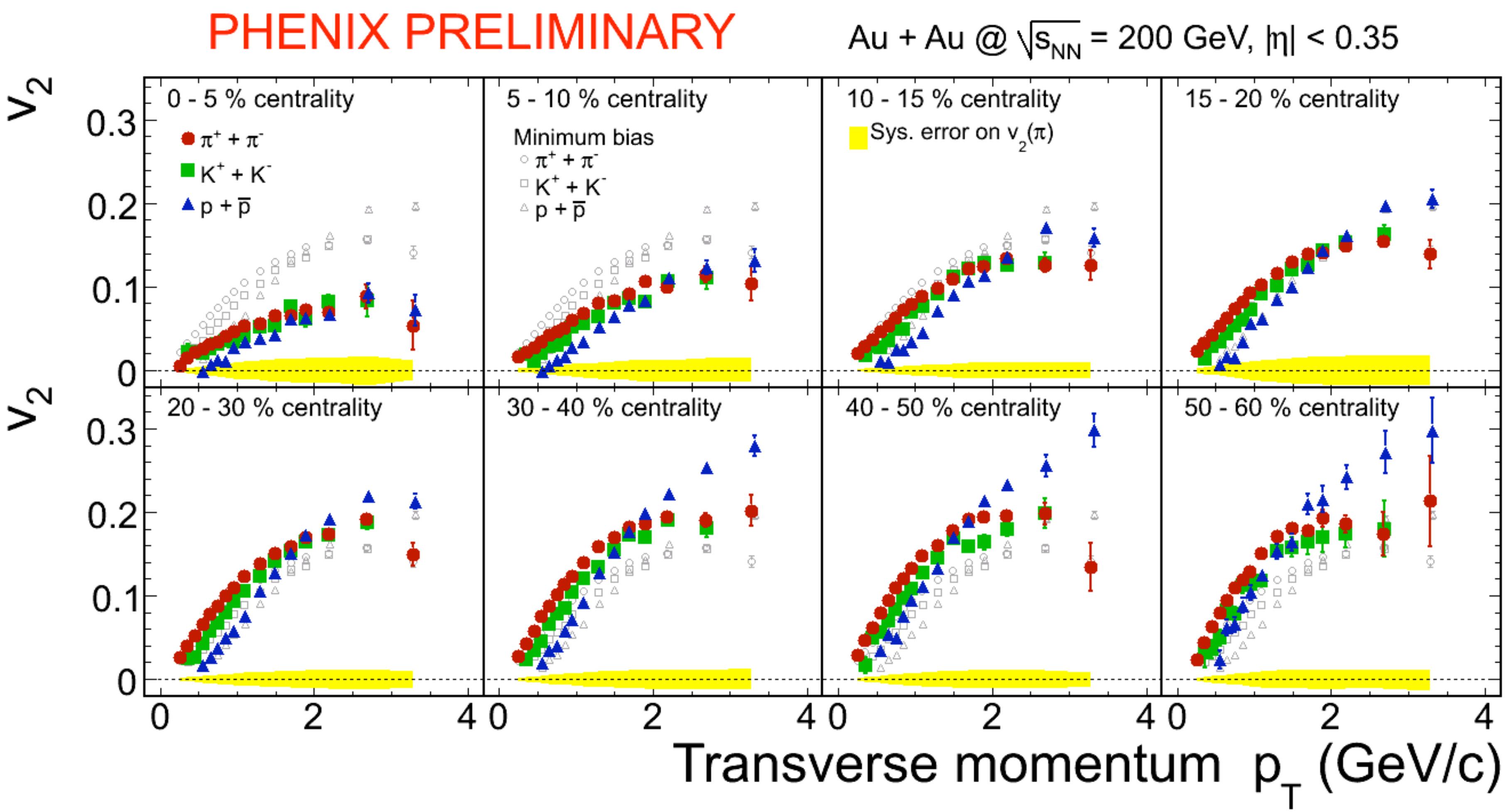
PHENIX Experiment





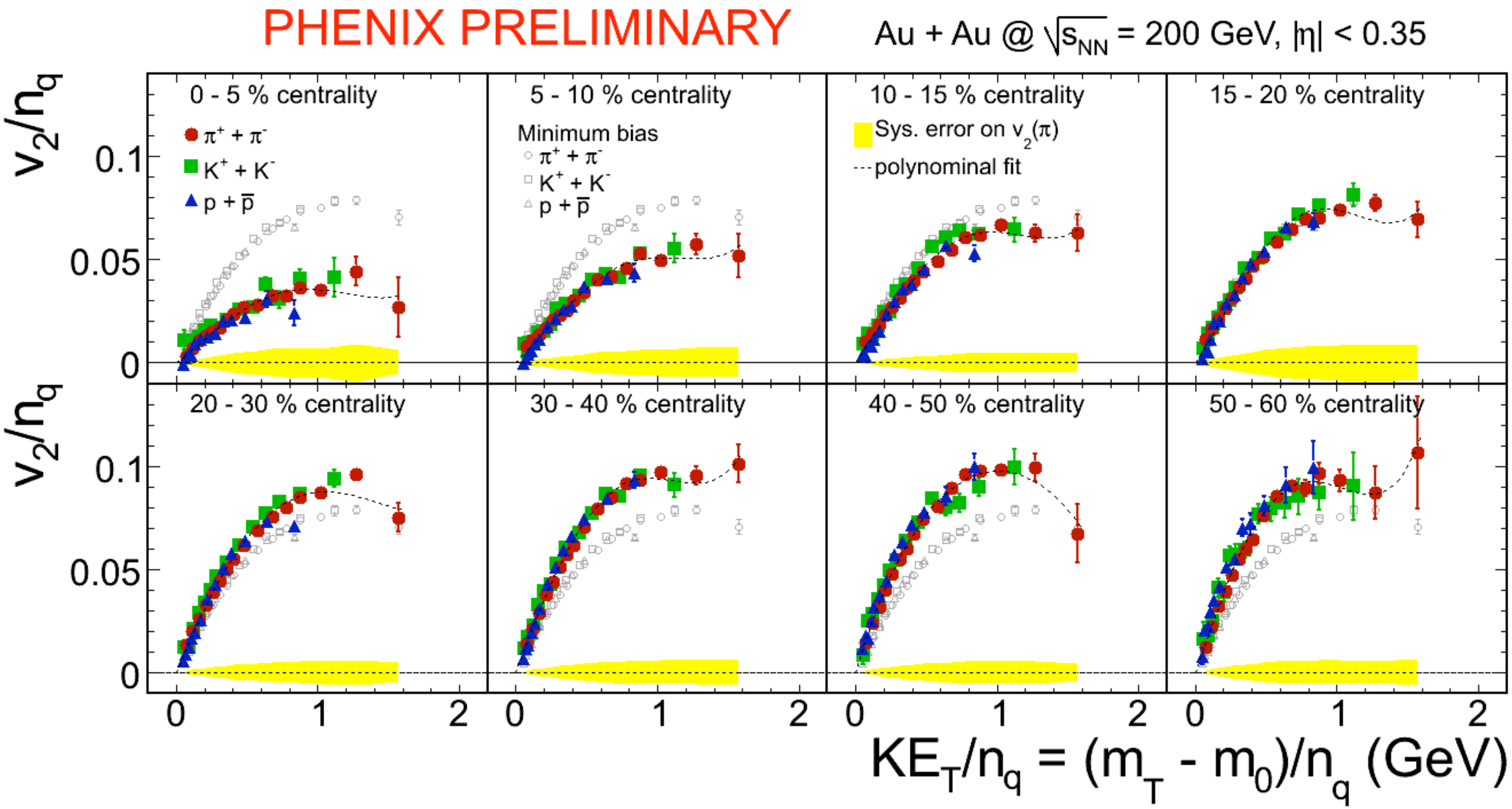
- Vertex, Centrality
  - BBC, ZDC
- Event plane
  - BBC (full azimuth, $|\eta|$ = 3.0 - 3.9) $\Rightarrow$ Large rapidity interval
- Tracking
  - DC, PC
- PID
  - TOF ($|\phi|<\pi/4$, $|\eta|<0.35$), σ_t ~ 120 ps
    - π, p : p_T < 4 GeV/c, K : p_T < 3 GeV/c

Centrality dependence of $v_2(p_T)$



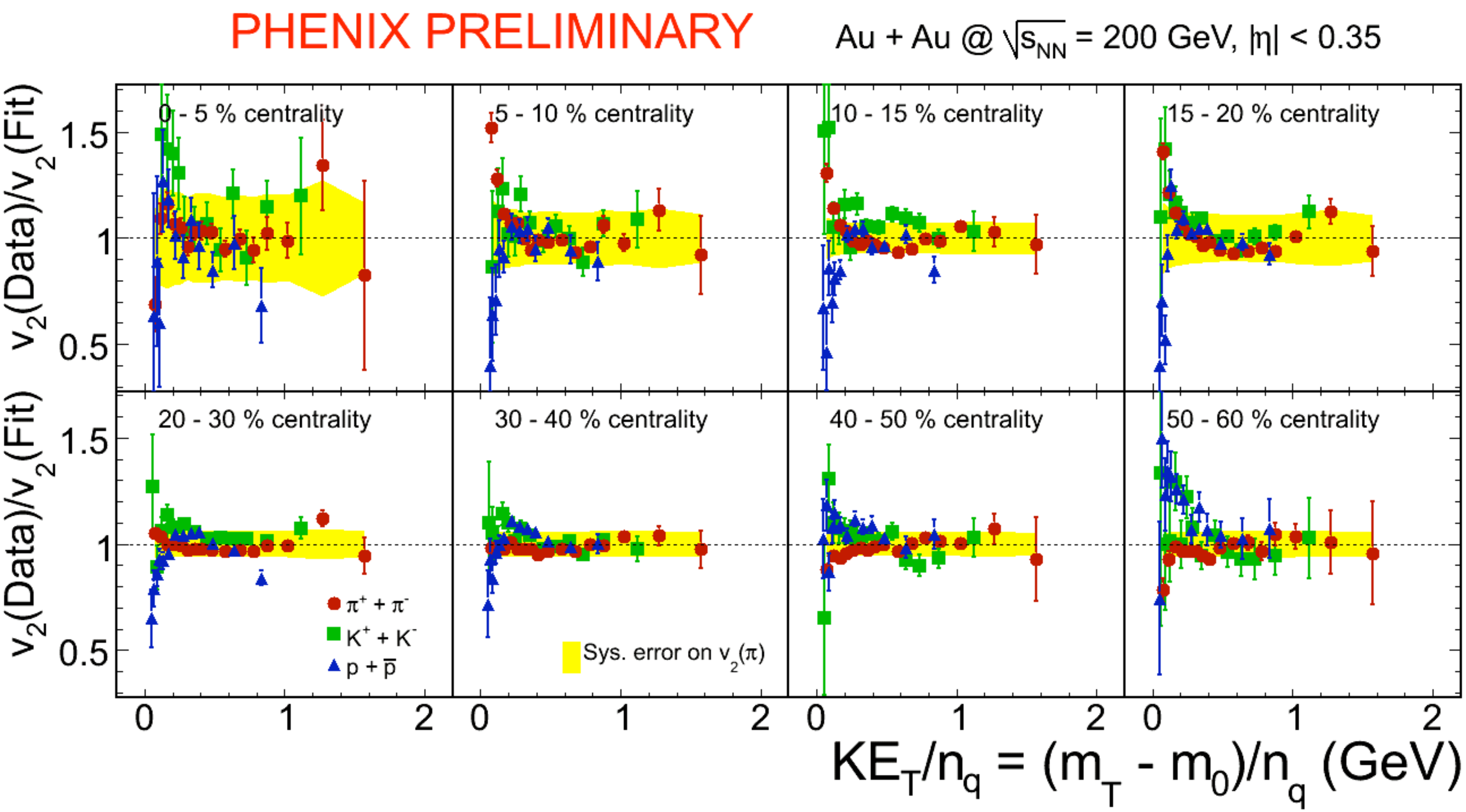
- v_2 increase with increasing centrality
- Similar mass ordering for all centrality

KE_T + NCQ scaling of v_2



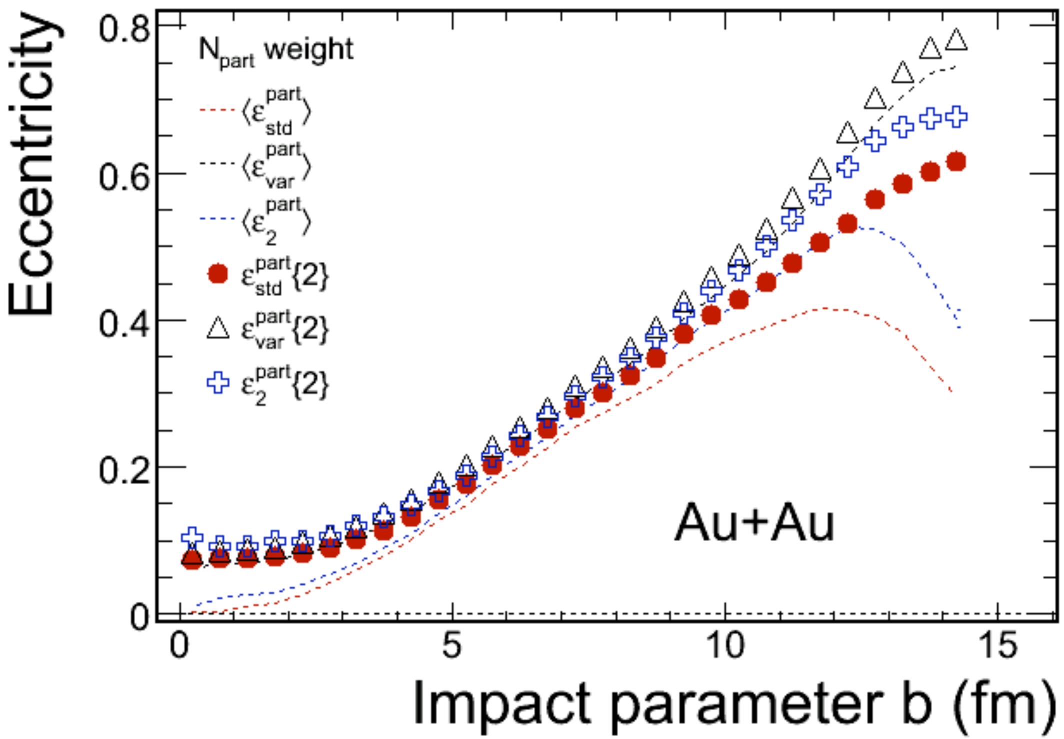
- Scaling holds for all centrality ?
  - Ratio of data to fit (next slide)

v_2(Data)/v_2(Fit)



- Scaling works within systematic errors, except for low KE_T
  - Radial flow ?

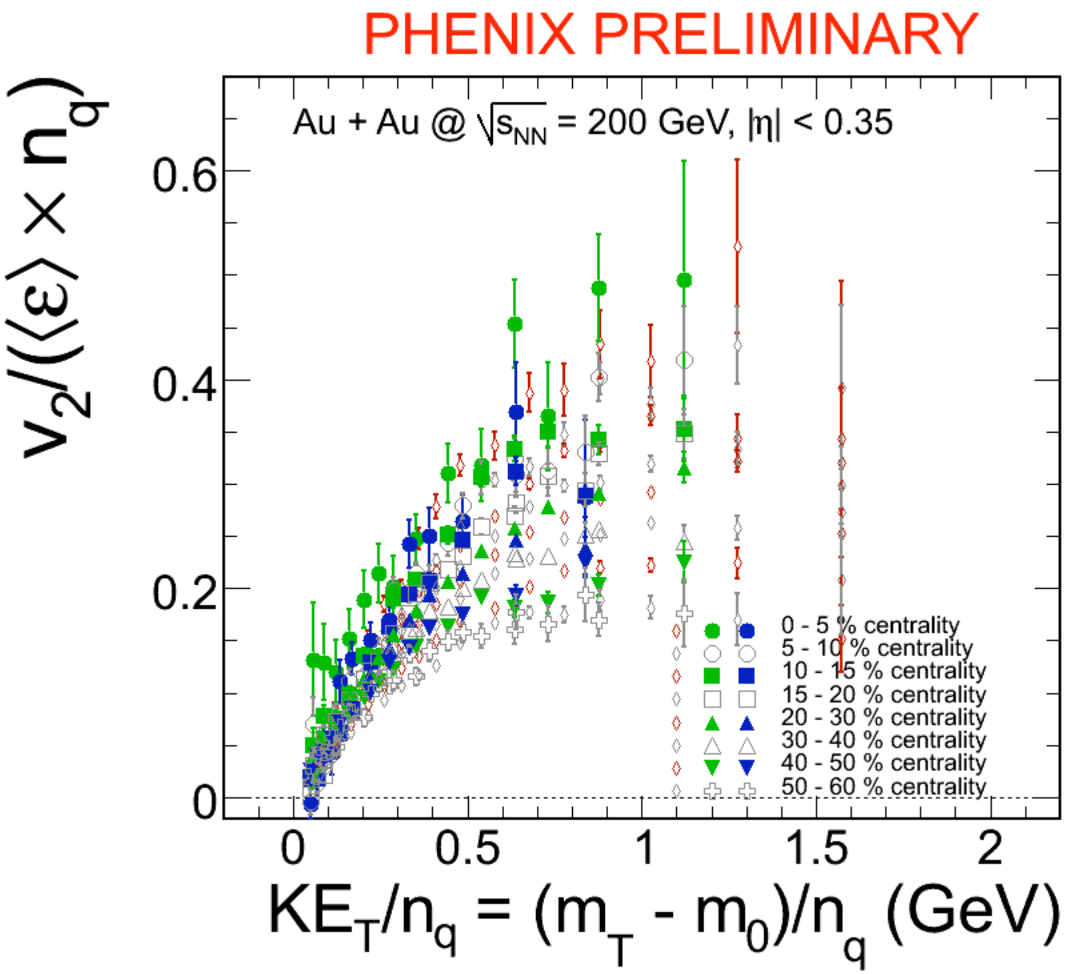
Eccentricity



Systematic error on ε ~ 10 - 20 %

- Eccentricity (ε) is estimated by Glauber MC simulation
  - ε value's are not changed so much in b = 5 - 9 fm (10 - 50 % centrality). $\Delta\varepsilon/\varepsilon \sim$ 10 %
  - Quite different for different definitions of ε at central and peripheral

Eccentricity scaling



* Only statistical errors are shown

* Systematic error on $\langle\varepsilon\rangle$ ~ 10 - 20 %

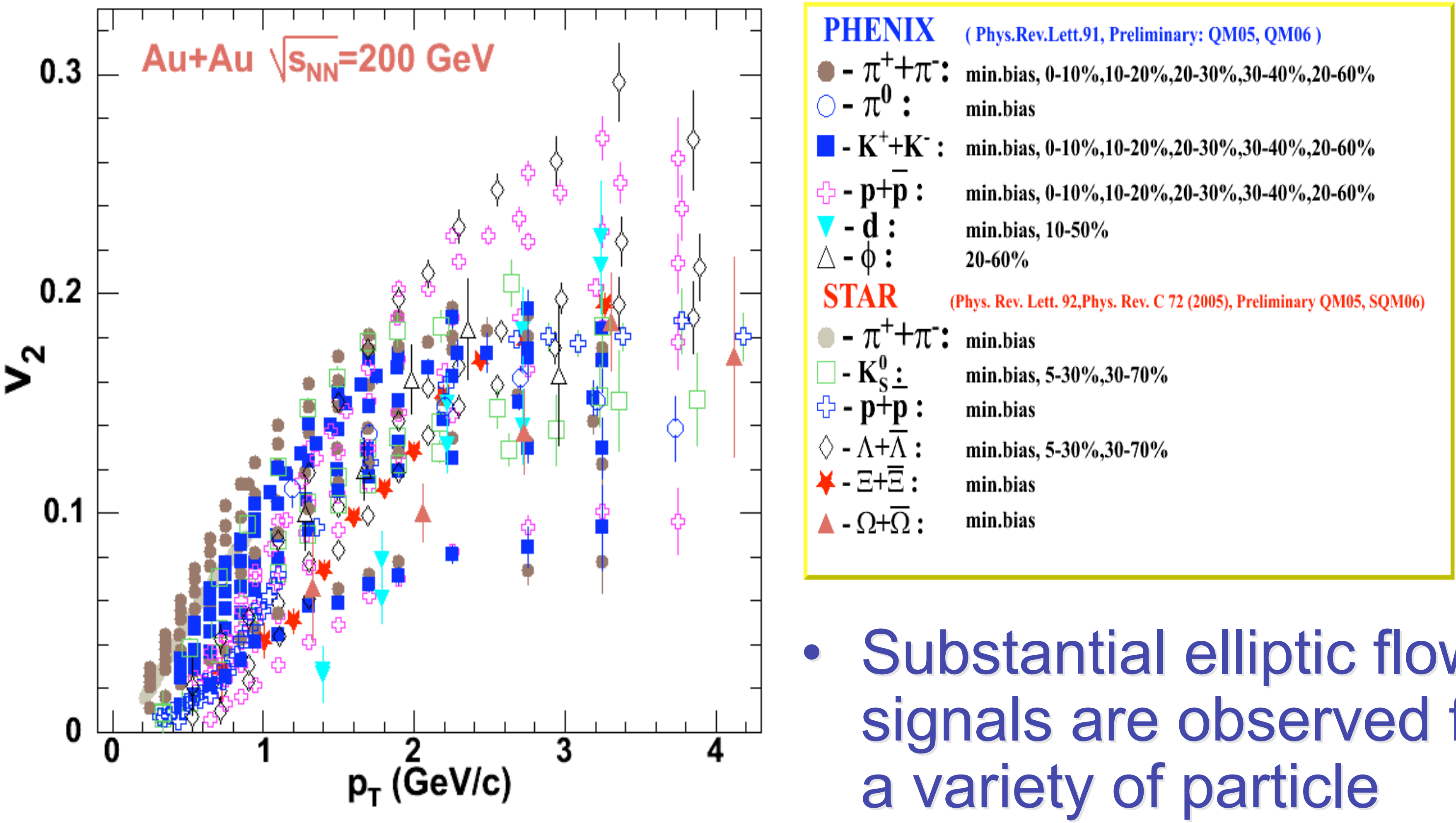
- Scaled v_2 with participant eccentricity
- Start to break even in mid-central at high KE_T
  - Scaling works at low KE_T within systematic errors
- Clear difference between central and peripheral
  - The difference of v_2 is also observed for different eccentricity

Summary

- Study the scaling of $v_2(p_T)$ for identified hadrons in a wide range of centrality
- KE_T + quark number scaling
  - Scaling holds within systematic errors, except for low KE_T
  - New RXNP detector could help us to
    - reduce systematic errors
    - add more statistics at peripheral events
- Eccentricity scaling
  - Scaling breaks even in mid-central at high KE_T
    - works for low KE_T within systematic errors
  - Clear difference between central and peripheral
    - Suggest that $\langle v_2 \rangle \propto \varepsilon \Rightarrow \langle v_2 \rangle \propto \varepsilon \times f(N_{part})$

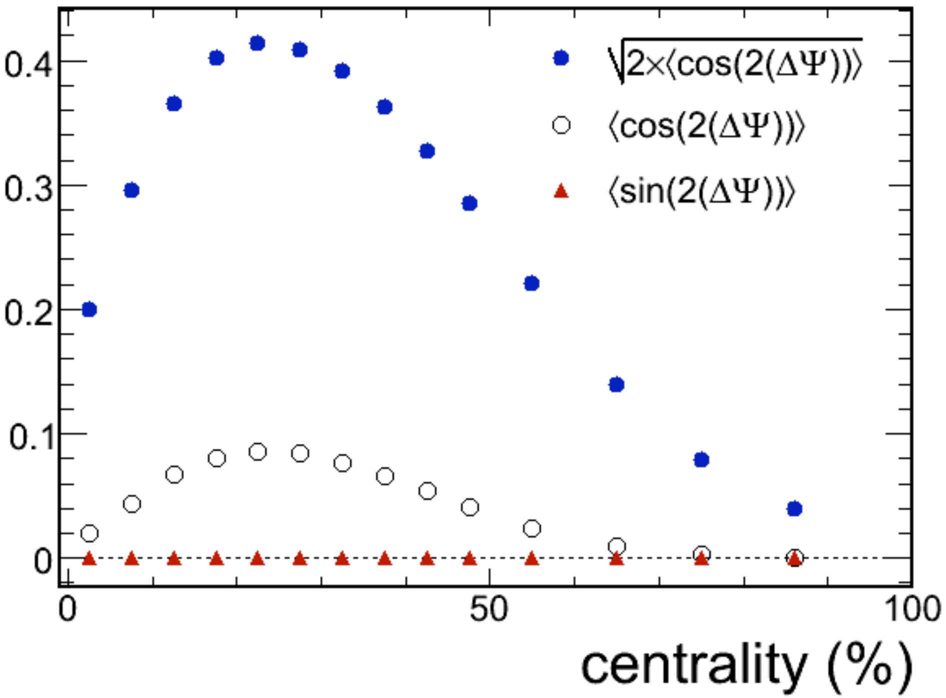
Back up

Elliptic Flow at RHIC



- Substantial elliptic flow signals are observed for a variety of particle species at RHIC

Event plane resolution



- Event plane resolution is determined by multiplicity and v_2
  - Maximum at mid-central
    - High multiplicity, small v_2 at central
    - Low multiplicity, large v_2 at peripheral

Terminology

$$\varepsilon^{w}_{std} = \frac{\{w \cdot (y^2 - x^2)\}}{\{w \cdot (y^2 + x^2)\}}$$

$$w = n_{part}(x, y) \text{ or } n_{coll}(x, y)$$

$$\varepsilon^{w}_{var} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_x^2 + \sigma_y^2}$$

$$\sigma_x^2 = \{x^2\} - \{x\}^2$$

$$\sigma_y^2 = \{y^2\} - \{y\}^2$$

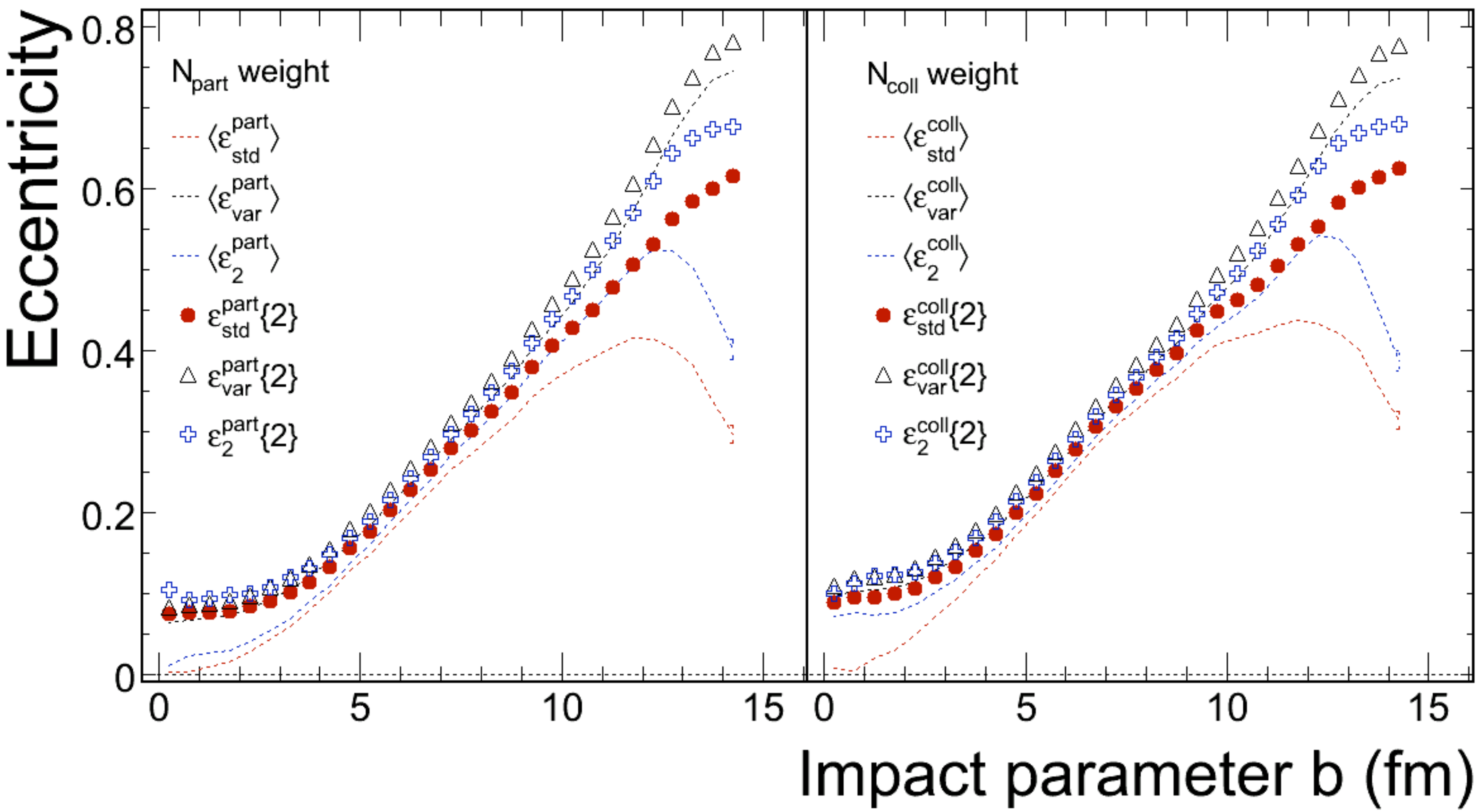
$$\sigma_{xy} = \{xy\} - \{x\}\{y\}$$

$$v_2\{EP_2\} \simeq v_2\{2\} = \sqrt{\langle v_2^2 \rangle}$$

$$\varepsilon\{2\} = \sqrt{\langle \varepsilon^2 \rangle}$$

- Definition of eccentricity
  - ε_{std} : Standard eccentricity
  - ε_{var} (participant eccentricity ε_{part})
  - ε_2 (event plane eccentricity) : ε_{var}, subtract auto-correlation event-by-event (an idea from ShinIchi)
- Weighting
  - ε^{part} (ε^{coll})
    - Calculated by weighting with N_{part} (N_{coll}) distribution
- Averaging
  - $\varepsilon\{2\} \equiv \sqrt{\langle \varepsilon^2 \rangle}$
    - Averaging of ε^2 over all events, then take square root
    - More natural definition like measured v_2
- Total : 3 × 2 × 2 = 12 definitions

Eccentricity



- Estimated by Glauber MC simulation
  - $\varepsilon^{coll} > \varepsilon^{part}$ due to steeper N_{coll} distributions compared to N_{part}