The elliptic flow measurement with new 2D event classification in RHIC-PHENIX

Maya Shimomura for the PHENIX Collaboration

Nara Women's University

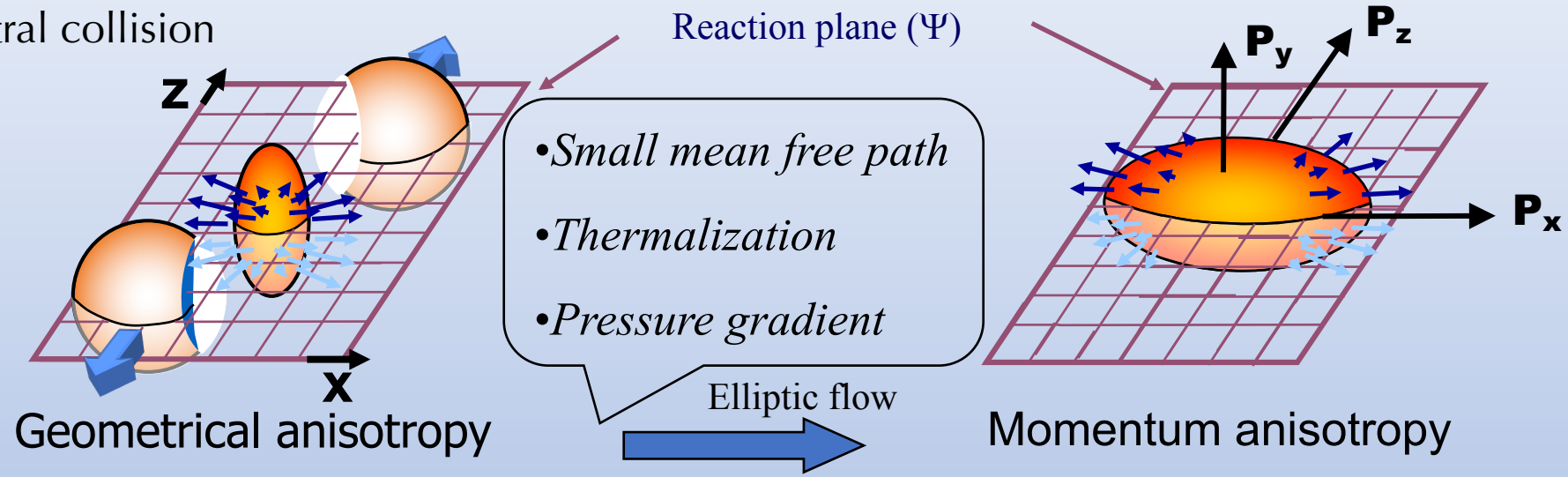
12 October 2023

42nd International Symposium on Physics in Collision (PIC2023)
@ Universidad de Tarapaca, Arica, Chile

Elliptic flow (v_2) in Au+Au

v_2 is the strength of the elliptic anisotropy of produced particles.

non central collision



Fourier expansion of the distribution of produced particle angle (ϕ) to reaction plane (Ψ)

$$N(\phi) = N_0\{1 + 2v_1\cos(\phi - \Psi) + 2v_2\cos[2(\phi - \Psi)] + \ldots\}$$

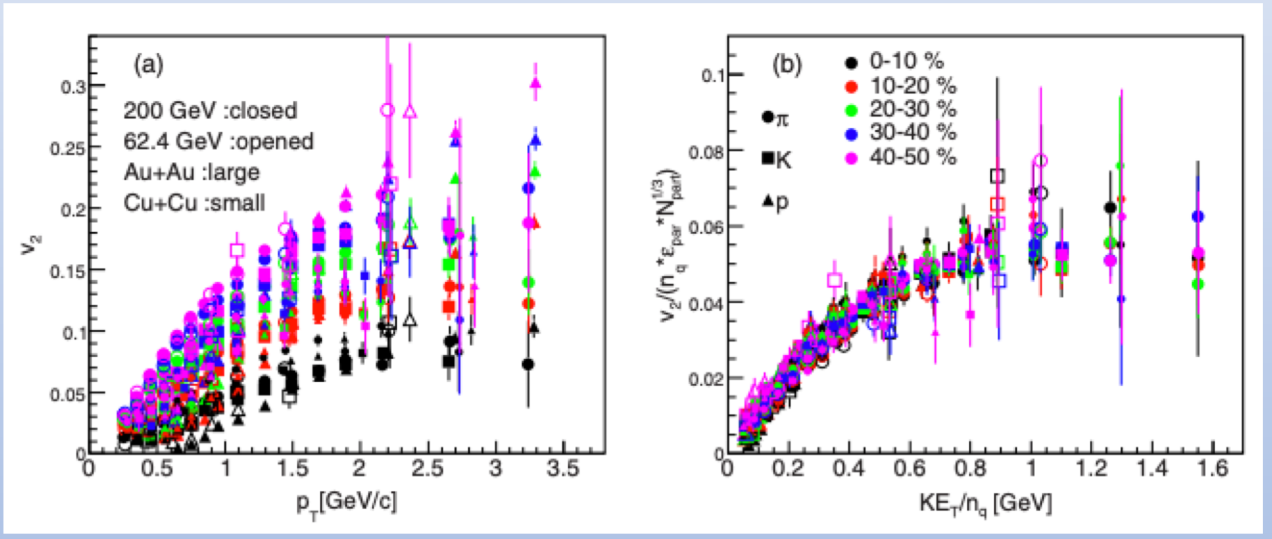
$$v_n = \langle\cos[n(\phi - \Psi)]\rangle$$

v_2 is the coefficient of the second term → indicates ellipticity

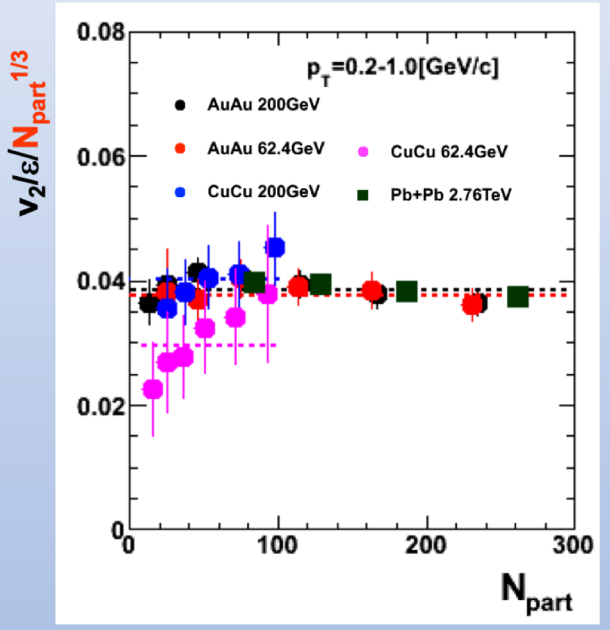
A sensitive probe to the properties of the hot dense matter produced by heavy ion collisions.

v_2 with N_{part} and dN/dη

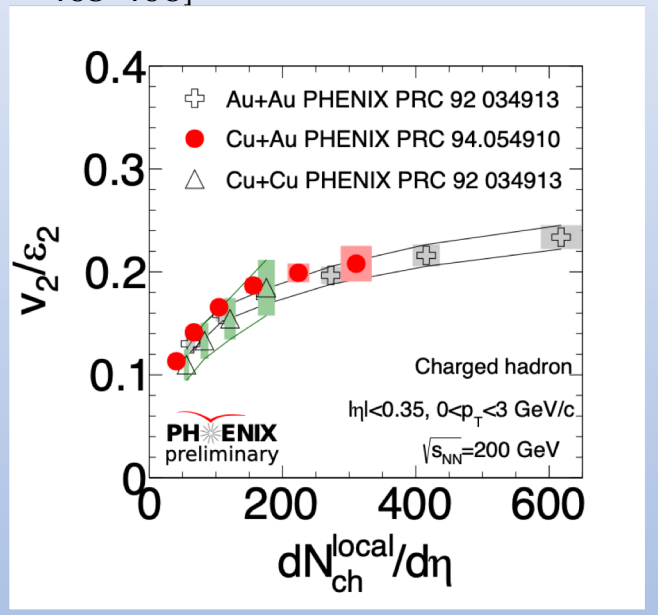
PHENIX[Phys. Rev. C92, 034913]



PHENIX [Pos WPCF20211 055]



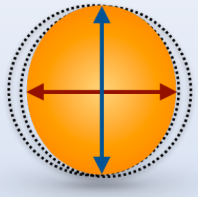
PHENIX [Nuclear Physics A967, 405-408]



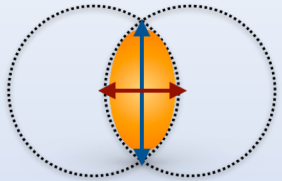
- v_2 of different centrality is scaled by $N_{part}^{1/3}$.

v_2 with different initial condition seems to be matched with N_{part} or multiplicity (dN/dη)

v_2 vs. N_{part} , multiplicity



$$\epsilon = \frac{< y^2 > - < x^2 >}{< y^2 > + < x^2 >}$$



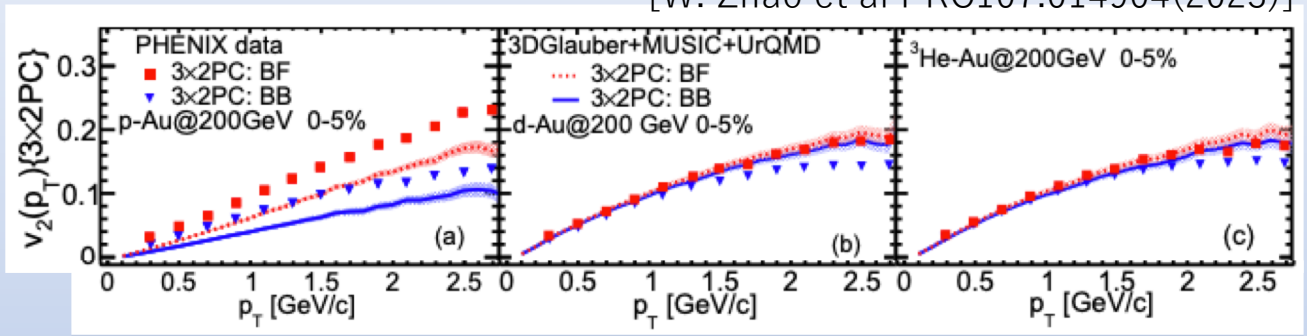
Small ⟵ eccentricity ⟶ Large

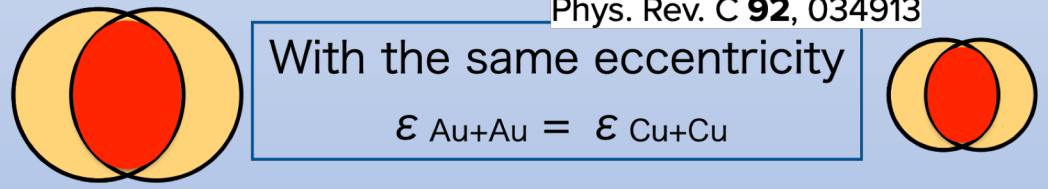
High ⟵ multiplicity (dN/dη) ⟶ Low

Large ⟵ N_{part} ⟶ Small

Small ⟵ v_2 ⟶ Large

[PHENIX: PRC107.024907(2023)]
[W. Zhao et al PRC107.014904(2023)]





Phys. Rev. C **92**, 034913

With the same eccentricity

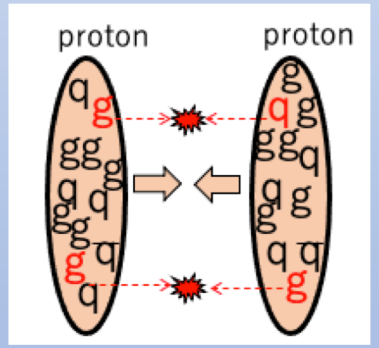
$\varepsilon_{Au+Au} = \varepsilon_{Cu+Cu}$

High ⟵ multiplicity (dN/dη) ⟶ Low

Large ⟵ N_{part} ⟶ Small

Large ⟵ v_2 ⟶ Small

- QGP seems to be formed in small system collisions with relatively large multiplicity.
- A wide range of multiplicities exists at fixed N_{part} because of various effects like MPI, different N_{coll} values, etc.

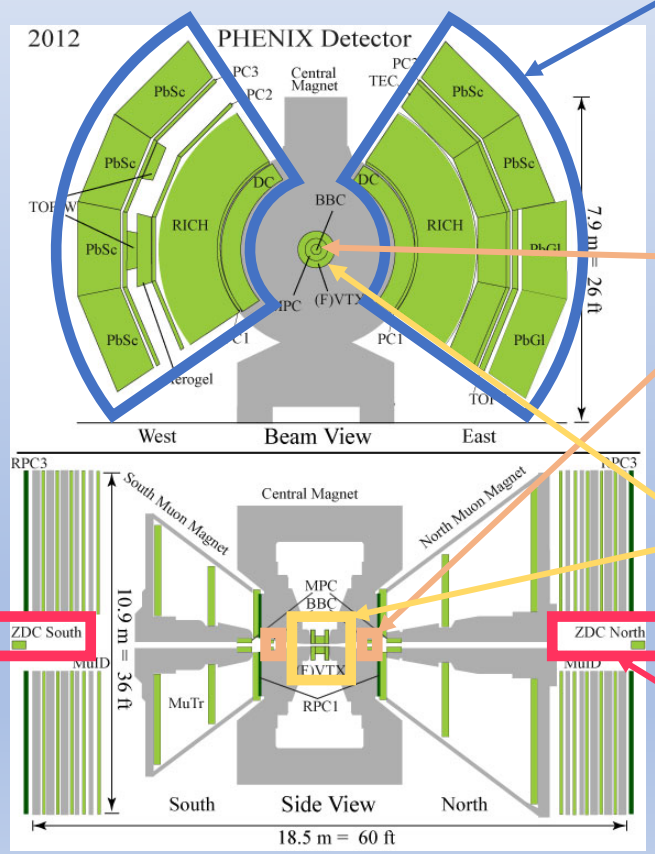


Multi-parton interaction(MPI)

We want to use multiplicity and N_{part} info separately. HOW?

PHENIX Detector

- PHENIX completed the data taking in 2016. Analyses are ongoing.
- The data of Au+Au collision at $\sqrt{s_{NN}} = 200$GeV taken at RHIC-PHENIX in 2014 is analyzed.



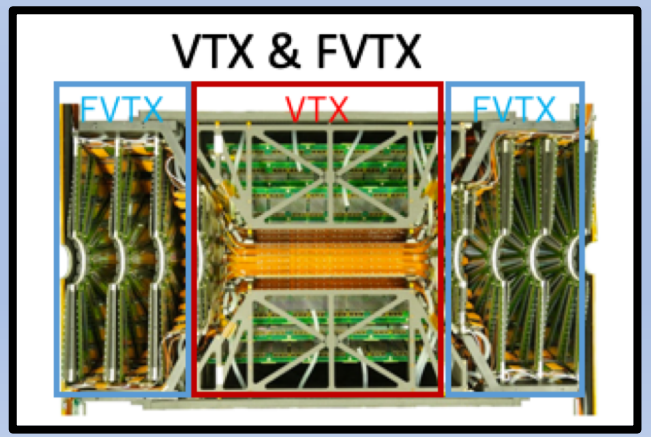
Central Arm (CNT)
- Track selection
- Azimuthal angle(ϕ) of the tracks

$$v_2 = < \cos\{2(\phi - \psi_2)\} >$$

Beam Beam Counter (BBC)
- Multiplicity
- Reaction Plane (ψ)
- Z vertex

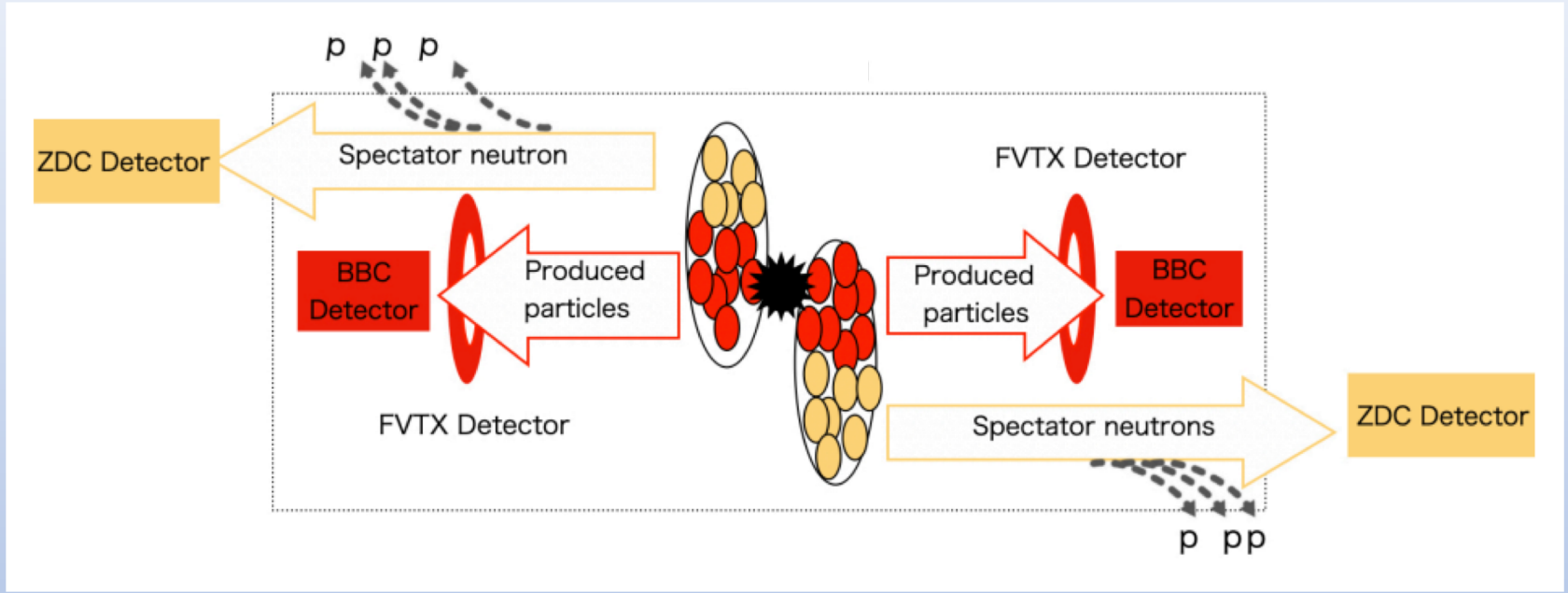
Silicon Vertex Tracker(VTX)
- X,Y,Z vertex

Forward Silicon Vertex Tracker (FVTX)
- Multiplicity

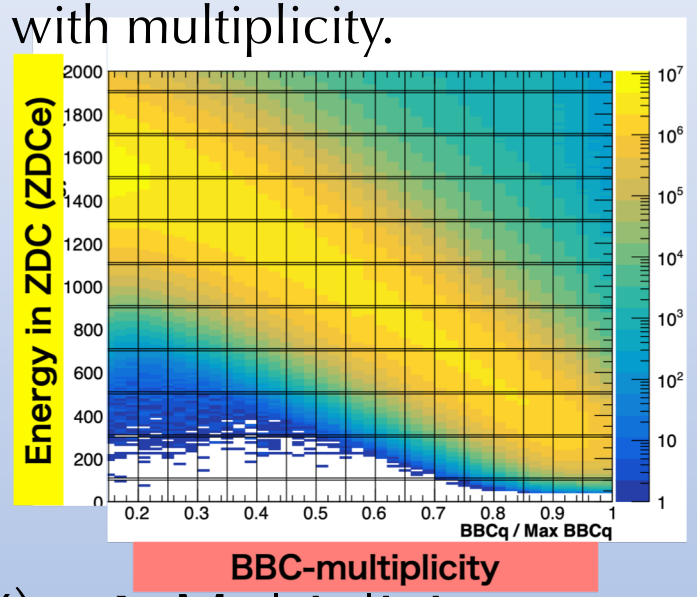


Zero Degree Calorimeter (ZDC)
- Energy of spectator neutrons ($\propto N_{spec}$)

Measurement of the multiplicity and N_{part}



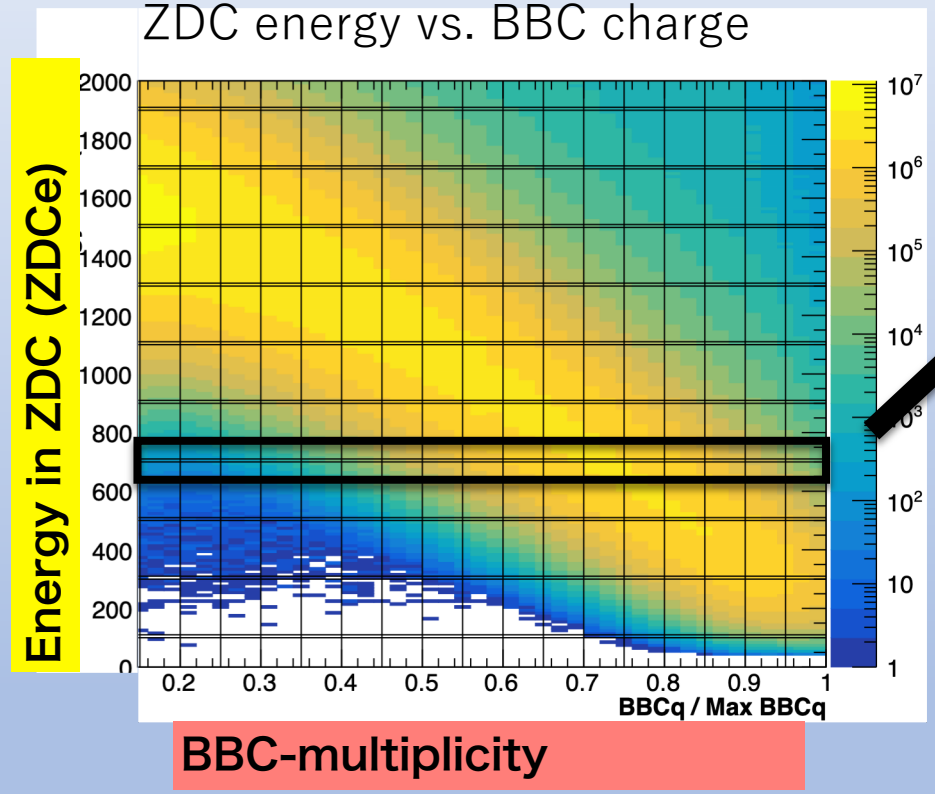
The energy in ZDC(ZDCe) has a negative correlation with multiplicity.



- Particles produced by collision are going into BBC(FVTX). → Multiplicity
- Spectator neutrons are going into ZDC. → $N_{part} + N_{spec}$ = Constant

ZDC(ZDCe) has a negative correlation with BBC

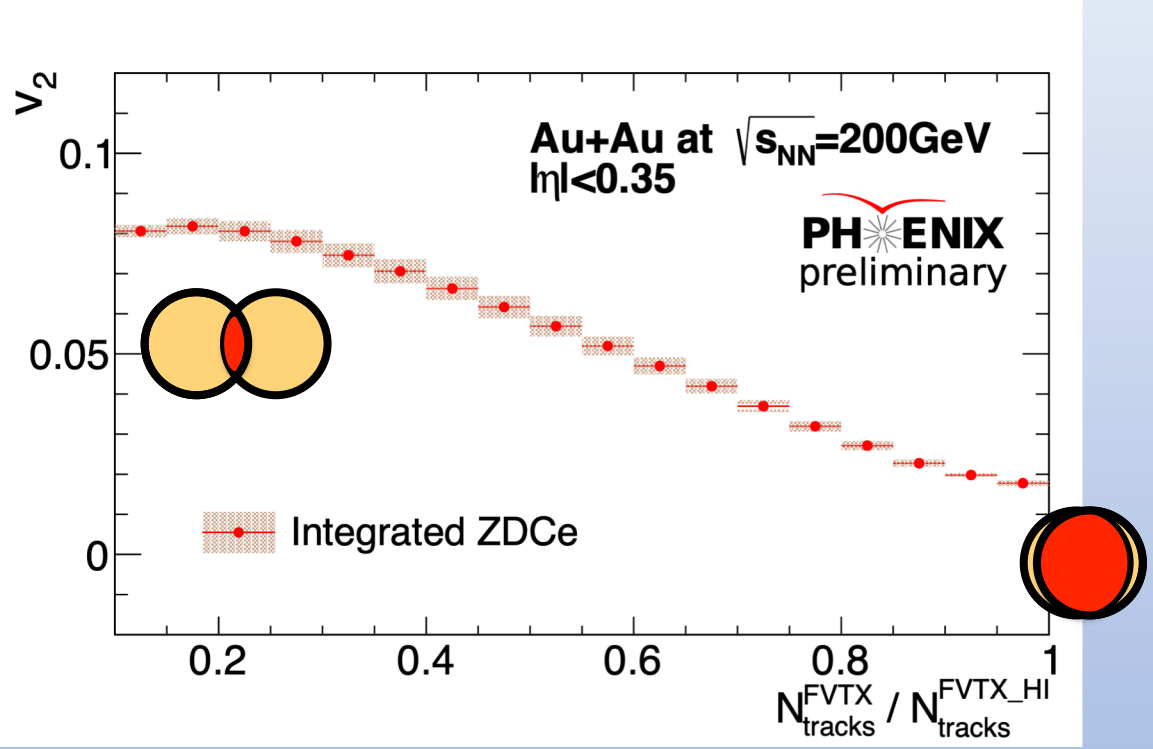
Analysis (New event categorization)



ZDC energy : corresponding N_{spec}, corresponding N_{part}
BBC charge : multiplicity

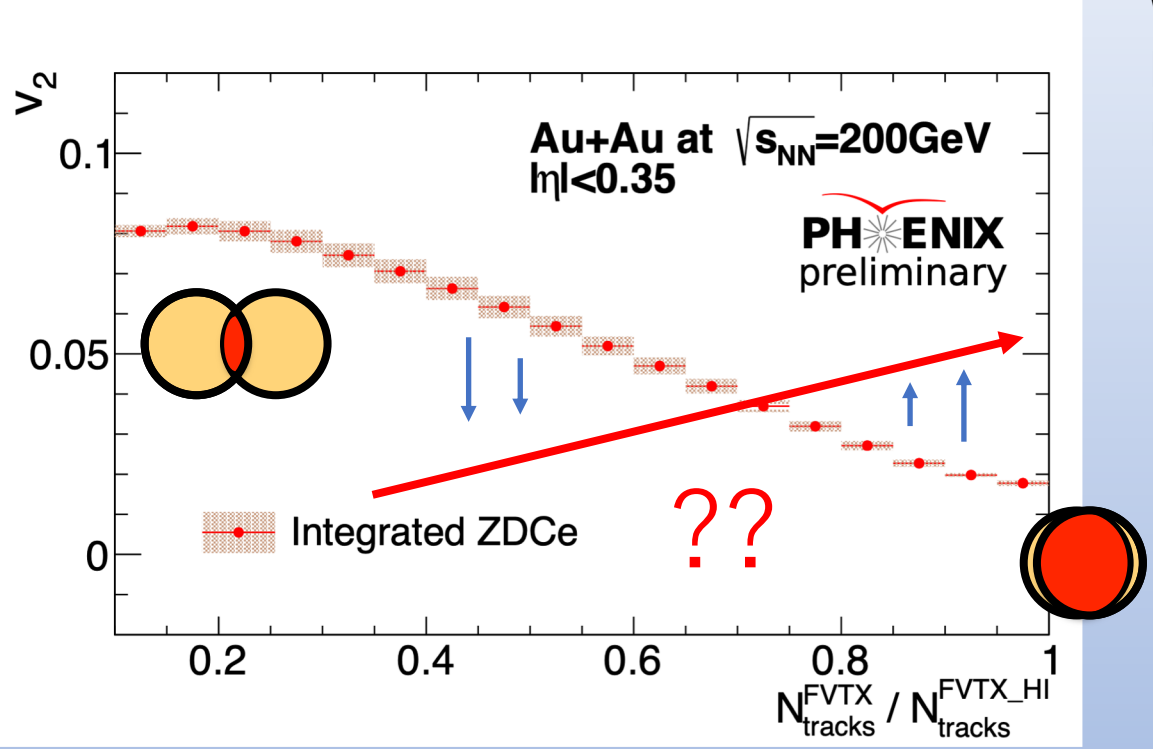
- Measure the v_2 as a function of the multiplicity with fixed narrow ZDC bins such as 300<ZDCe<310, 500<ZDCe<510, 700<ZDCe<710, and so on.

Results: v_2 vs. multiplicity without any ZDC cut

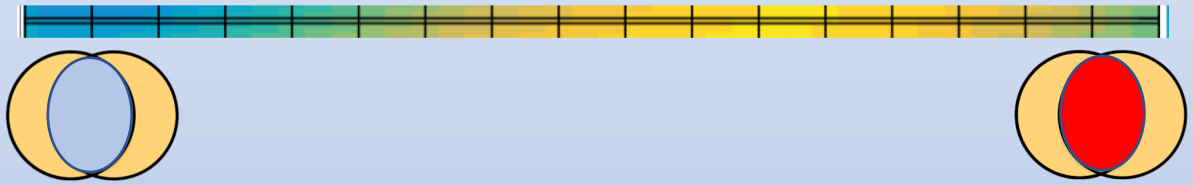


- v_2 without ZDCe event categorization decreases with multiplicity.
- Consistent with the initial geometry.

Results: v_2 vs. multiplicity without any ZDC cut



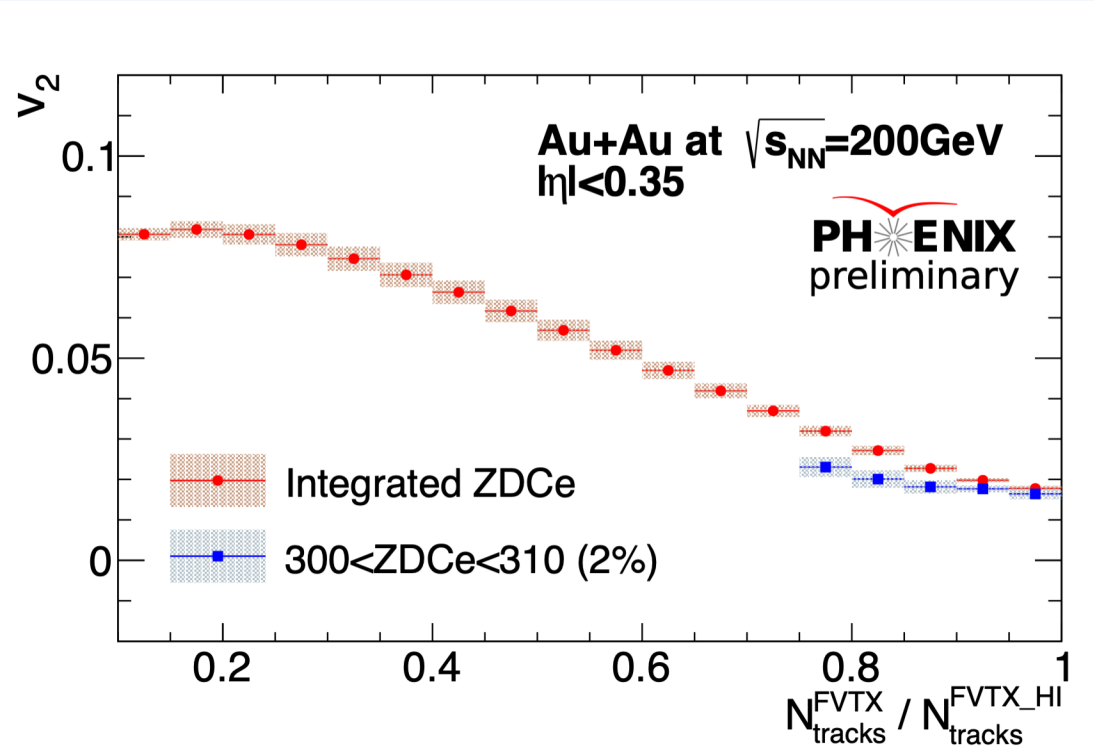
With new categorization, we expect the slope becomes positive **if** the same N_{part} but larger multiplicity gives larger v_2.



Same ←------- N_{part} ----------→ Same
Same ←---- Eccentricity -------→ Same
Small ←---- Multiplicity -------→ Large
?? Small ←--------- v_2 ----------→ Large ??

- v_2 without ZDCe event categorization decreases with multiplicity.
- Consistent with the initial geometry.

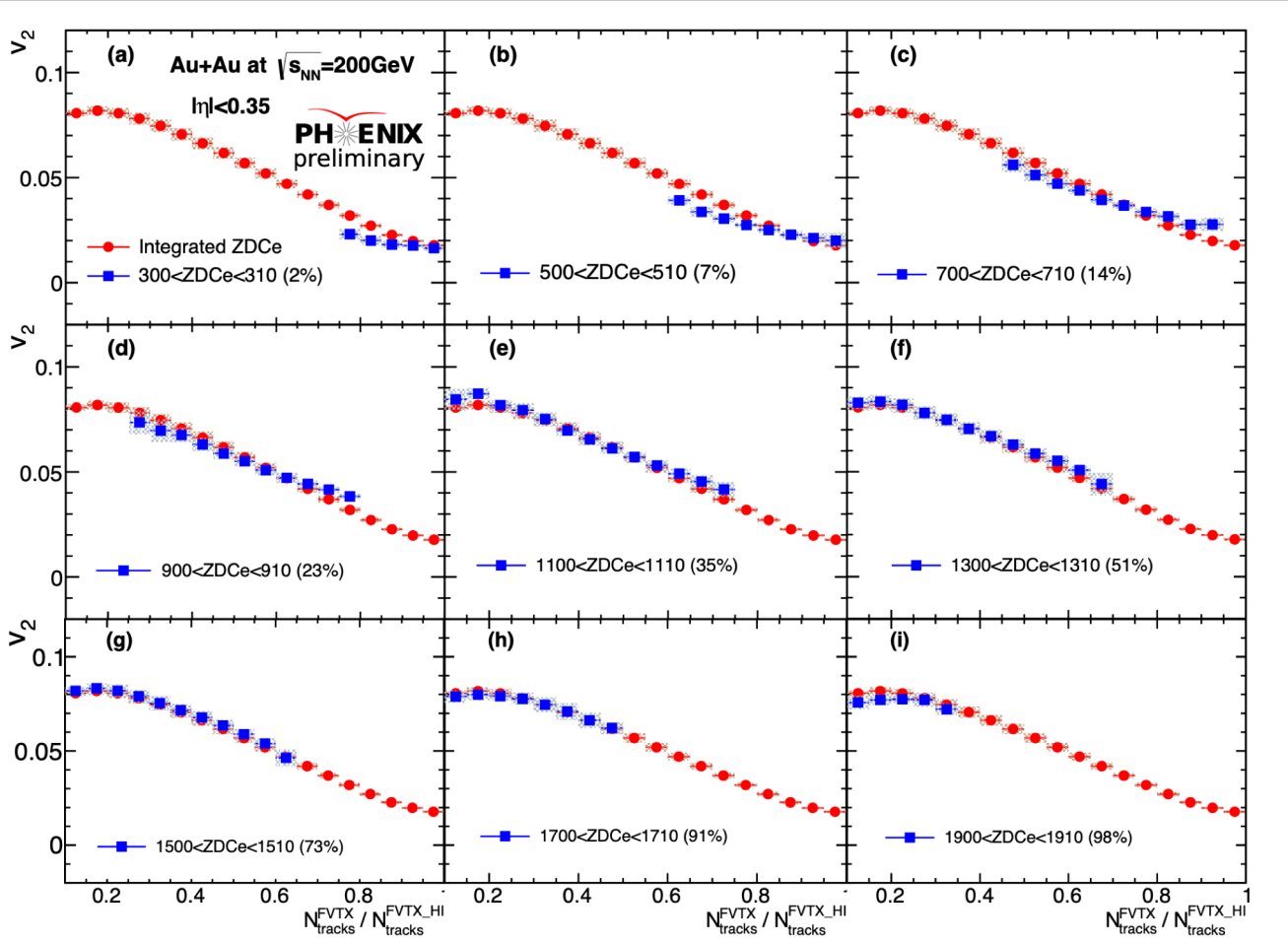
Results: v_2 vs. multiplicity with new ZDC categorization at central collision



Red： without ZDCe event categorization
Blue： with ZDCe event categorization (300<ZDCe<310) which is corresponding to the collision centrality ~ 2%

- The ZDC categorization makes the slope flatter, but does not invert it to positive at very central.

Results: v_2 vs. multiplicity with new ZDC categorization



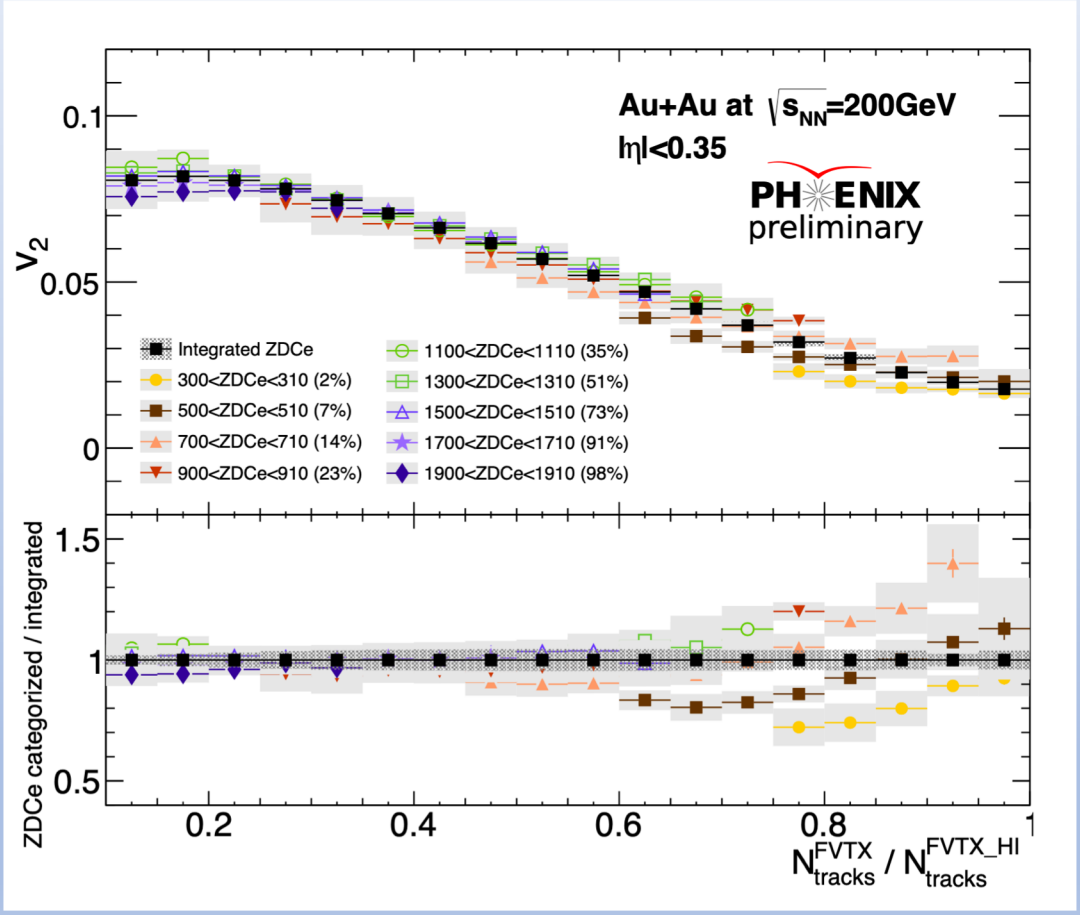
Red： without ZDCe event categorization
Blue： with ZDCe event categorization

The correlation slopes are both negative for all event categorizations with same ZDCe selections.

- The ZDC categorization makes the slope flatter at central collisions.

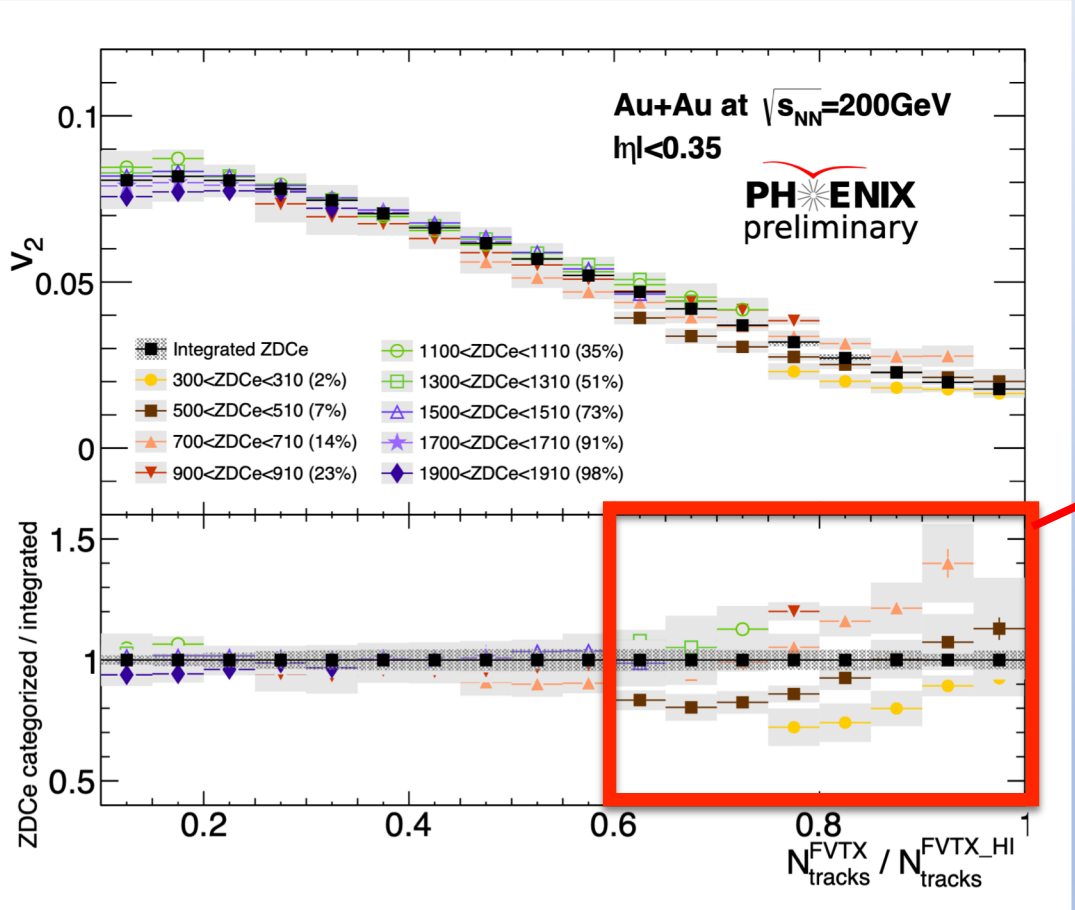
v_2 at different ZDCe event categorization

With fixed eccentricity and N_{part}, measure v_2 as a function of multiplicity.



v_2 at different ZDCe event categorization

With fixed ZDC bins, measure v_2 as a function of multiplicity.



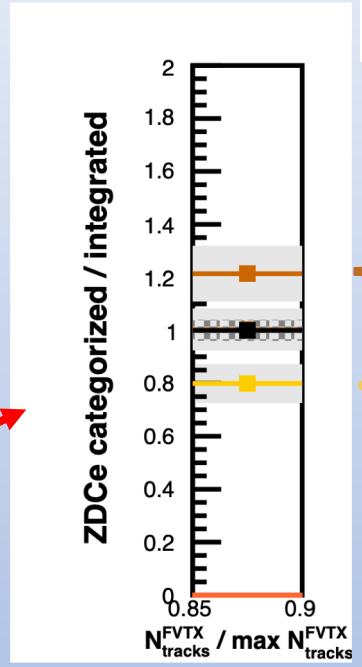
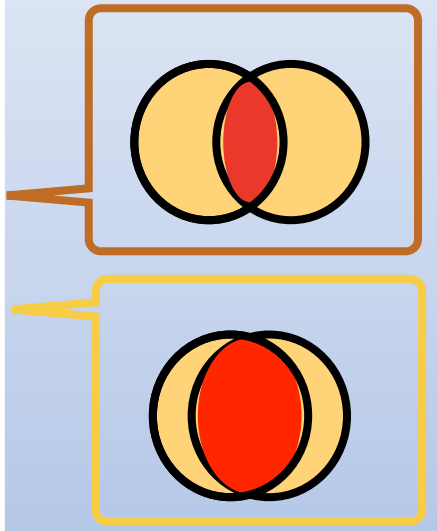


Image of the initial geometry

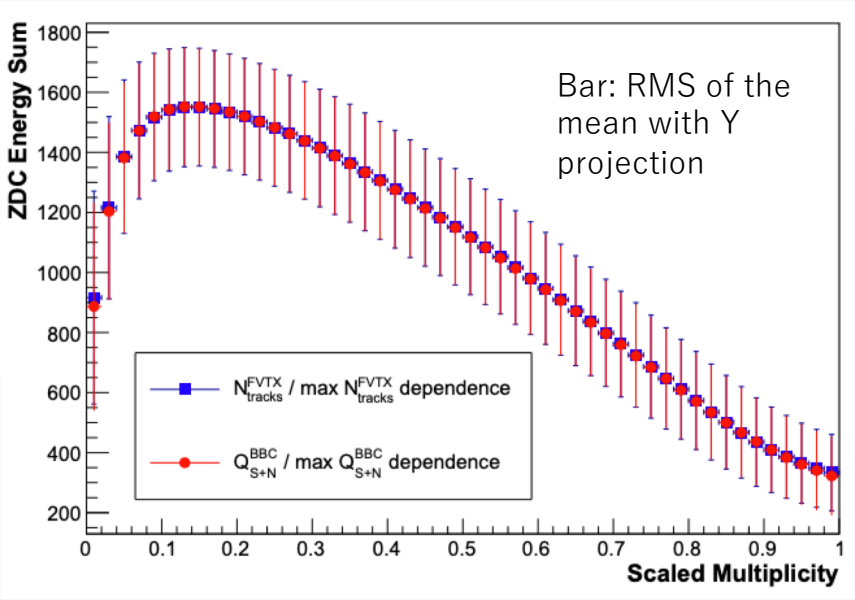


These v_2 seem to reflect initial geometry differences, but they have the same multiplicity.

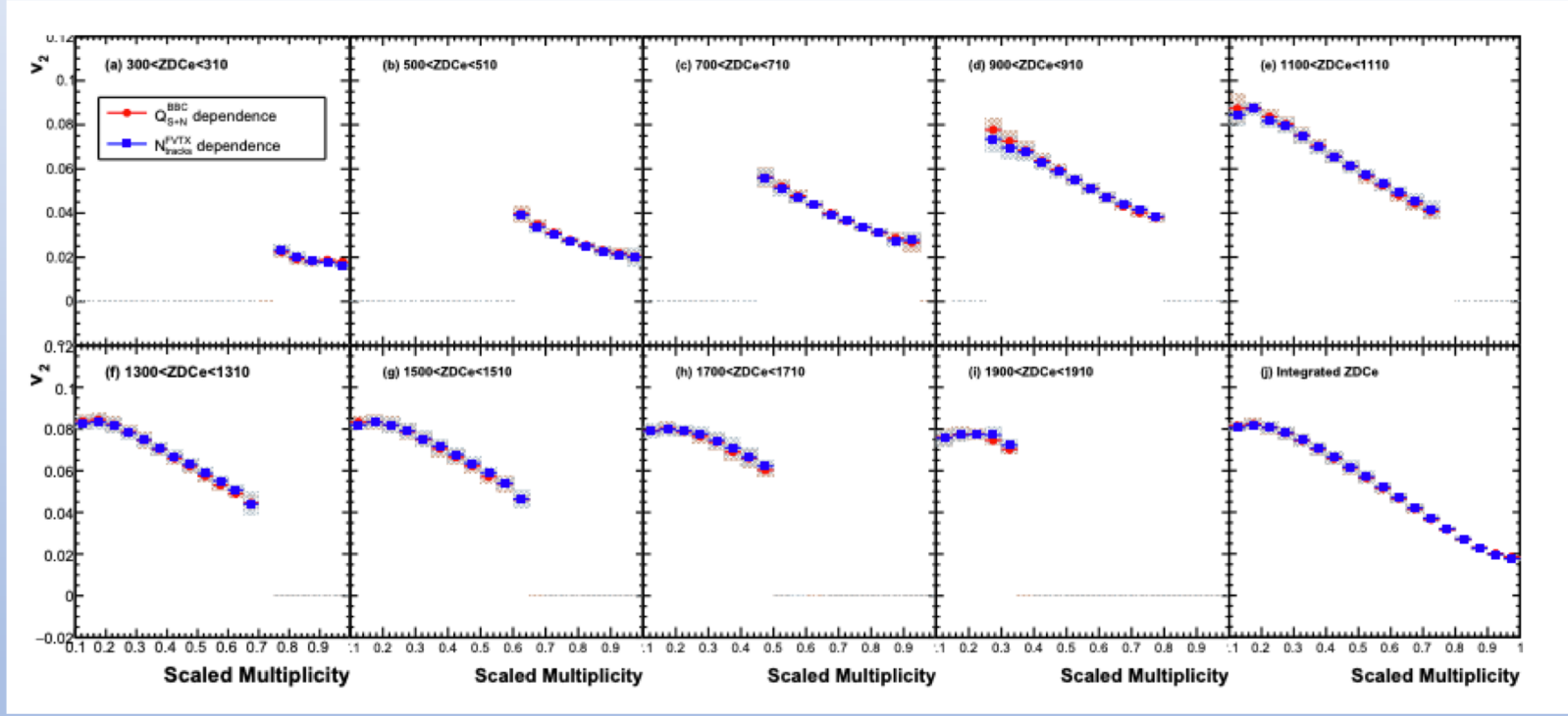
→N_{part} is different but multiplicity is the same.

Results: Rapidity dependence

BBC: $3.1<\eta<3.9$
FVTX:$1.0<\eta<3.0$



v_2 vs. scaled multiplicity



- No difference between BBC and FVTX as multiplicity measuring detectors.

summary

- The new event categorization is introduced in order to study the dependence of v_2 on N_{part} and the multiplicity separately.
- v_2 with this new categorization are measured.
  - It makes the slope flatter compared with no categorization at more central, but does not invert it to positive.
- At same multiplicity, different ZDC classes show different v_2.
  - Different initial geometry gives different v_2 and same multiplicity.
  - The results might show the sign of the MPI-like or/and Ncoll effect. --> need further study
- The results of v_2 vs. multi are same between using BBC and FVTX as multiplicity measuring detectors.
- This categorization can be applied to separate the events in detail.