

# The study of $v_2$ with a new double-differential event categorization using multiplicity and spectator neutrons in PHENIX

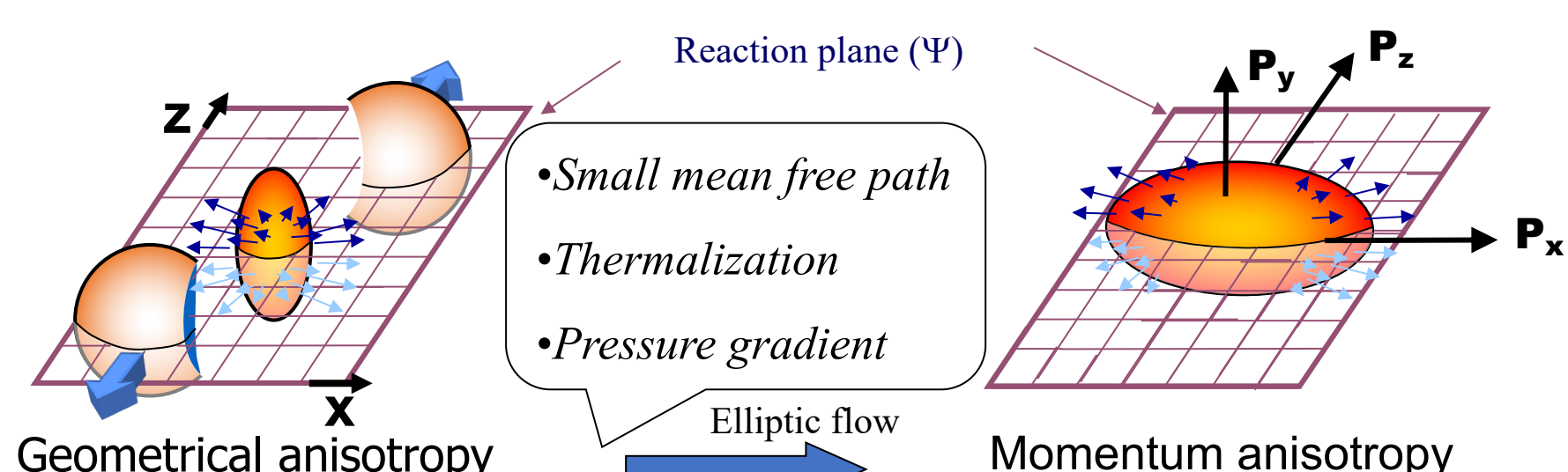
Quark Matter 2023

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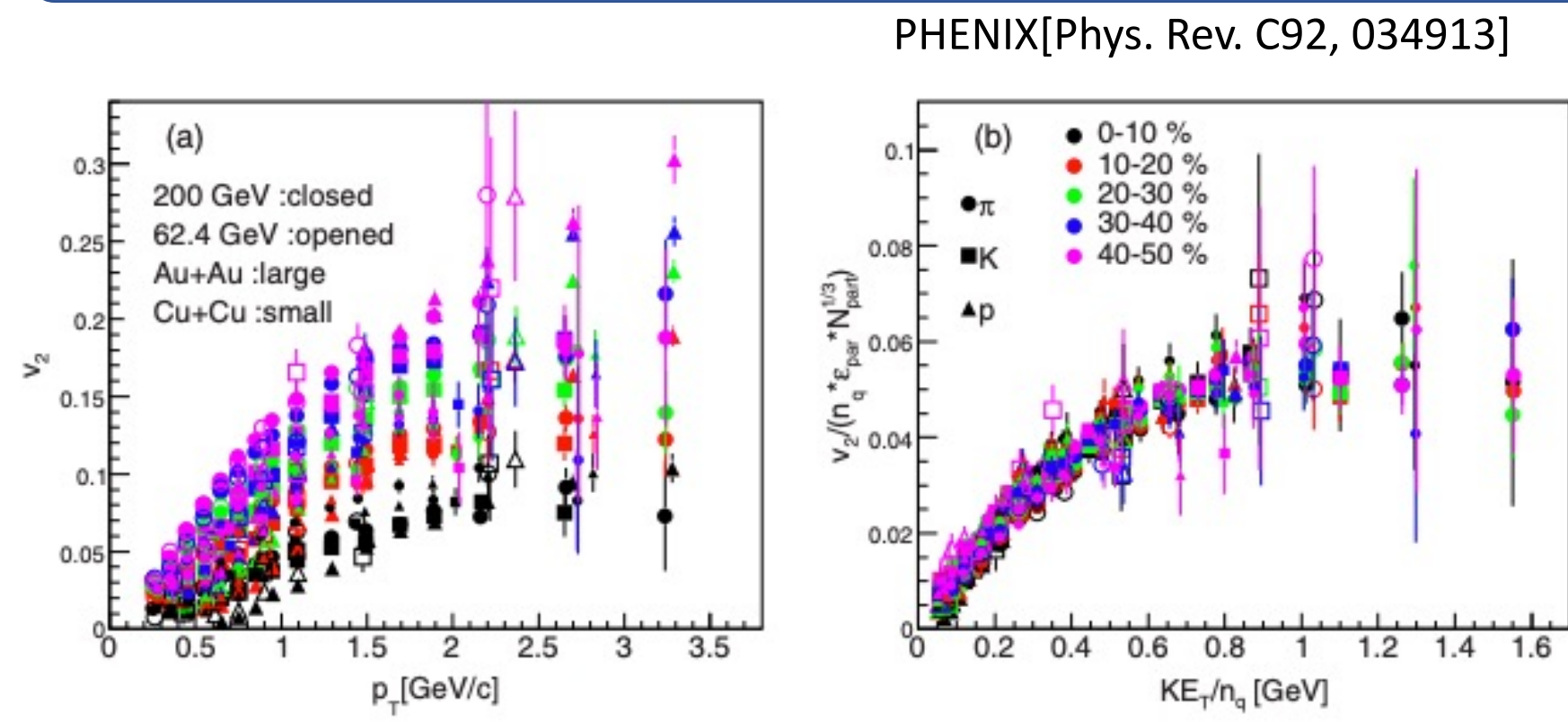
## Elliptic Flow ( $v_2$ )

$v_2$  is the strength of the elliptic anisotropy of produced particles. A sensitive probe to the properties of the hot dense matter produced by heavy ion collisions.



Fourier expansion of the distribution of produced particle angle ( $\phi$ ) to reaction plane ( $\Psi$ )  
 $N(\phi) = N_0 \{1 + 2v_1 \cos(\phi - \Psi) + 2v_2 \cos[2(\phi - \Psi)] + \dots\}$   
 $v_n = \langle \cos[n(\phi - \Psi)] \rangle$   
 $v_2$  is the coefficient of the second term  $\rightarrow$  indicates ellipticity

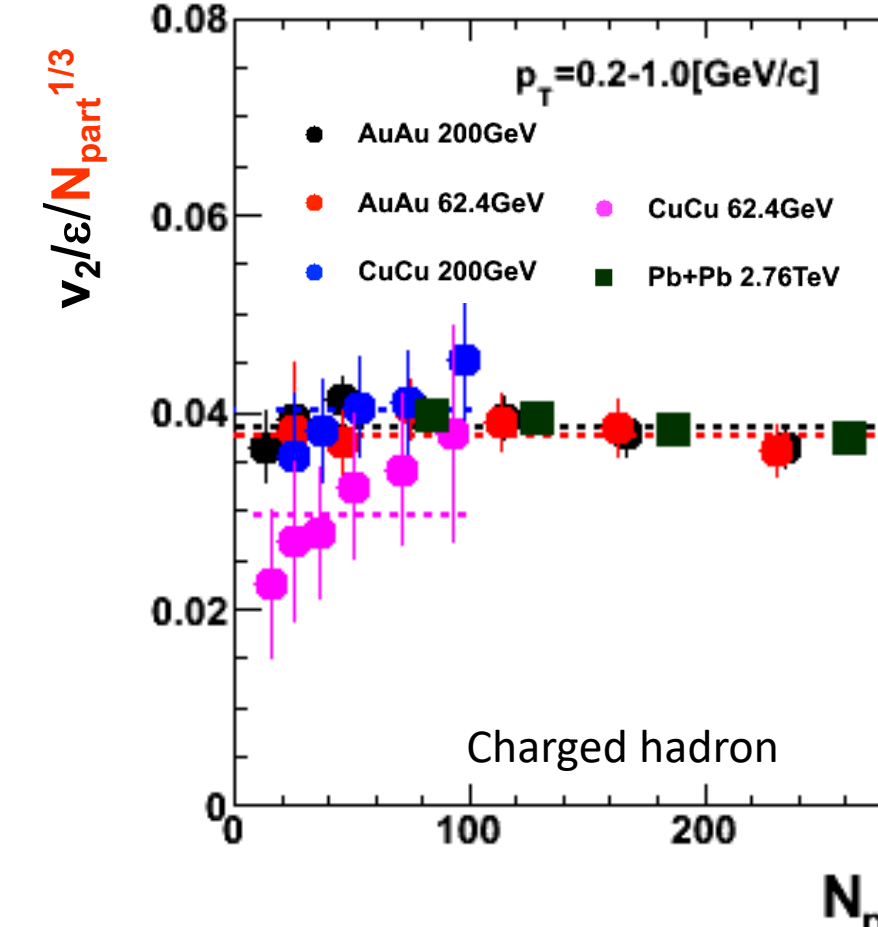
## Previous results of $v_2$ with $N_{part}$ and $dN/d\eta$



-  $v_2$  of different centrality is scaled by  $N_{part}^{1/3}$ . There are 45 different curves for  $\pi/K/p$  of different centralities (0-50 % as 10 % step) for the different energies. In addition to the eccentricity and quark number scaling, the  $N_{part}^{1/3}$  scale the centrality differences and these becomes one curve.

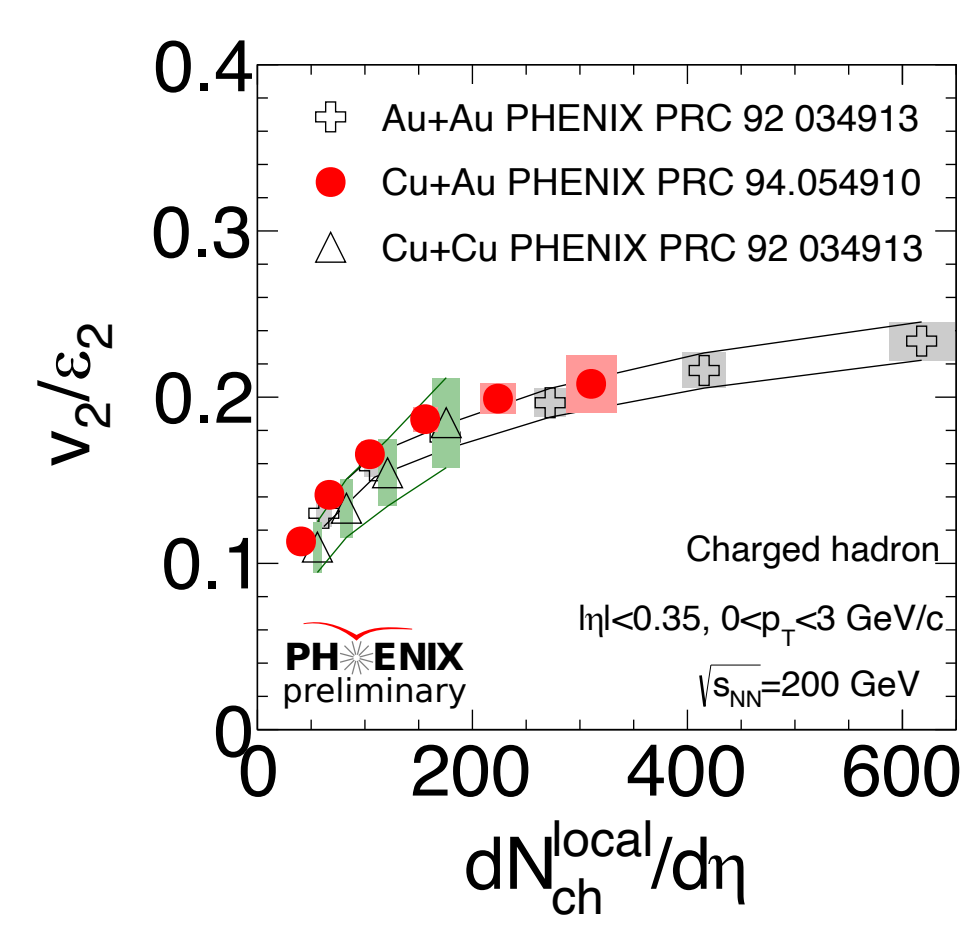
-  $v_2$  with different initial condition seems to be matched with  $N_{part}$  or multiplicity ( $dN/d\eta$ )

PHENIX [Pos WPCF2021 055]



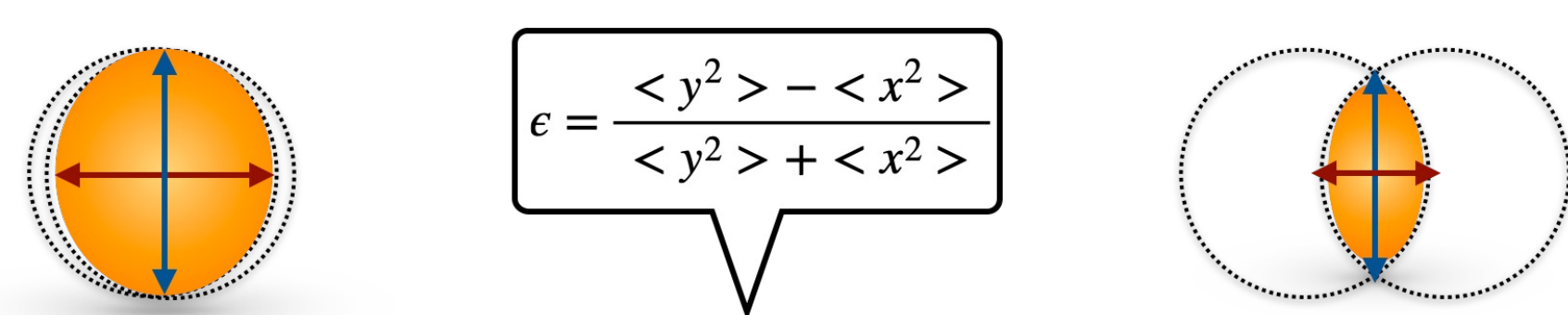
Higher energy (LHC-ALICE 2.76TeV) shows the same tendency of  $v_2$  as RHIC-PHENIX 200GeV.

PHENIX [Nuclear Physics A967, 405-408]

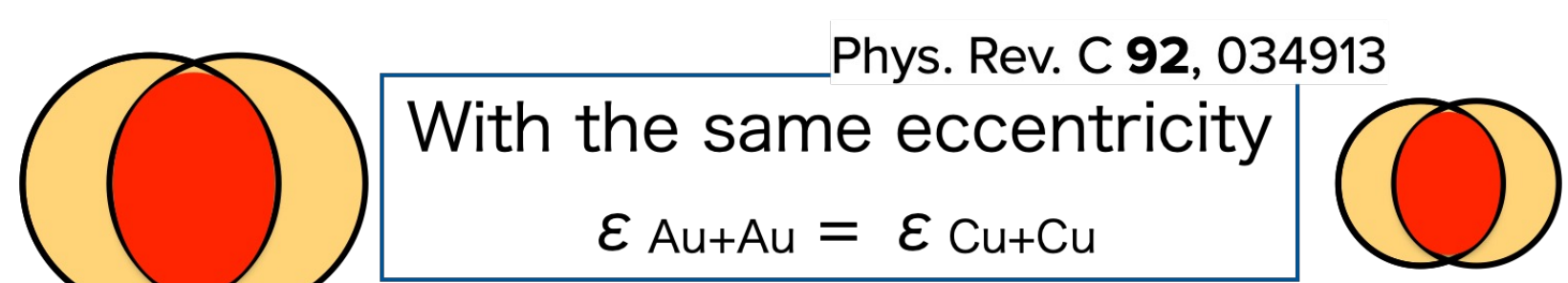


$v_2/\epsilon$  as a function of  $dN/d\eta$  follows one curve among different collision system sizes.

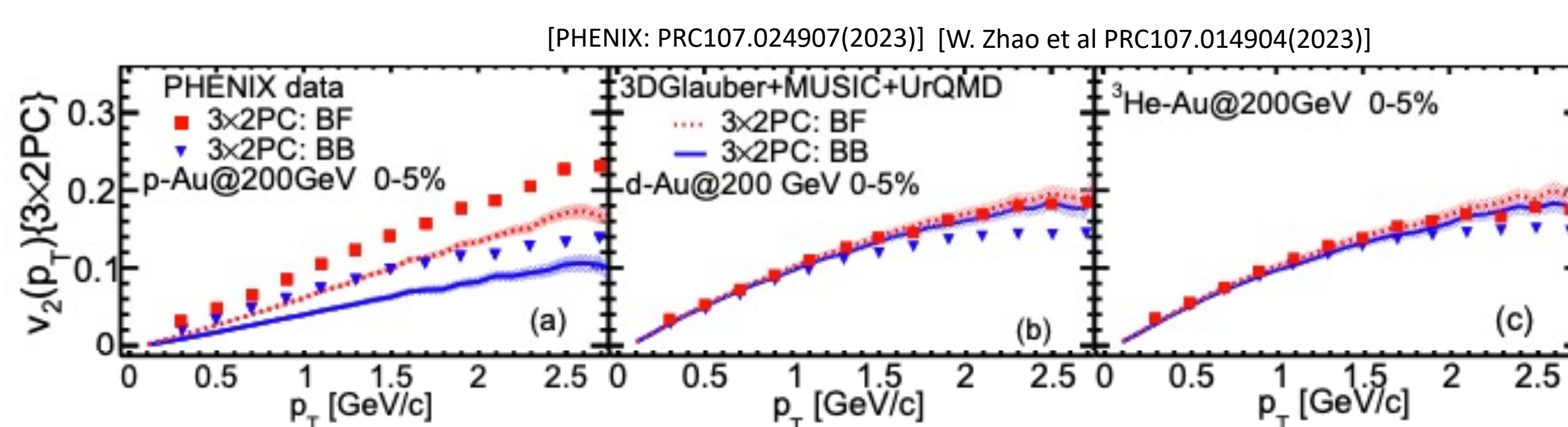
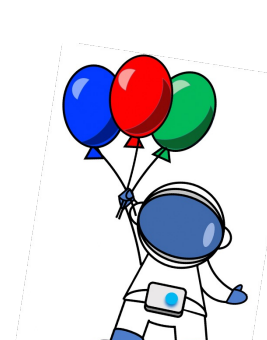
## Motivation and procedure of the 2D event categorization



Small  $\leftarrow$  eccentricity  $\rightarrow$  Large  
 High  $\leftarrow$  multiplicity ( $dN/d\eta$ )  $\rightarrow$  Low  
 Large  $\leftarrow$   $N_{part}$   $\rightarrow$  Small  
 Small  $\leftarrow$   $v_2$   $\rightarrow$  Large

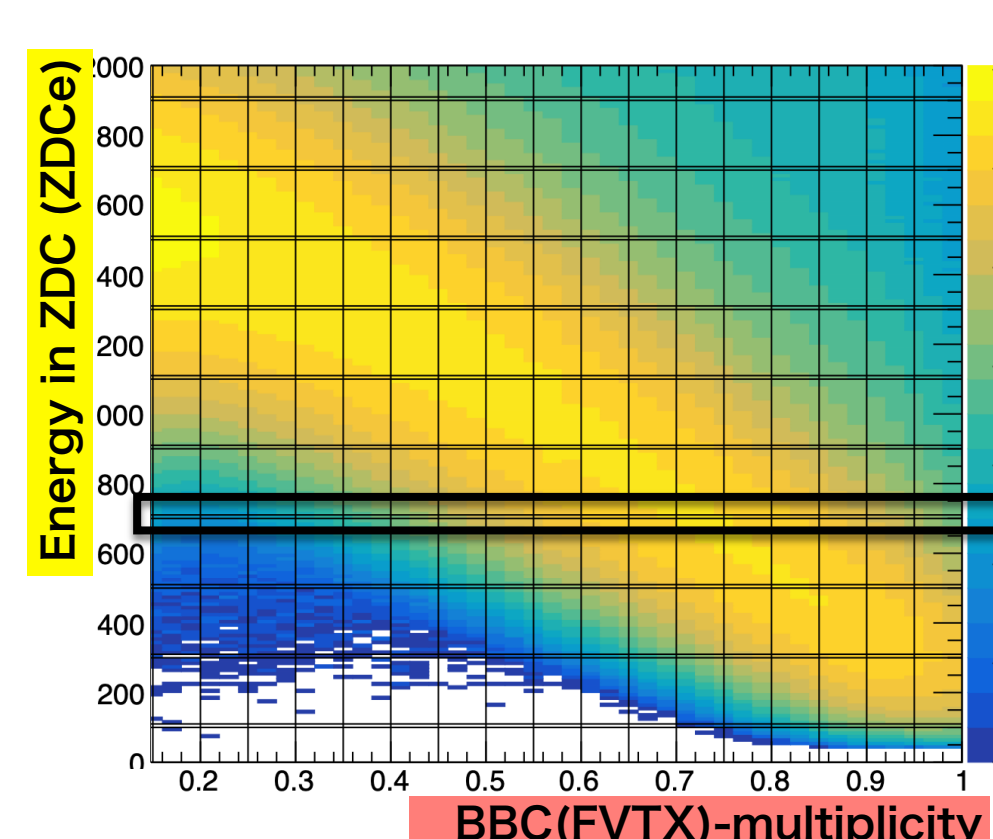


High  $\leftarrow$  multiplicity ( $dN/d\eta$ )  $\rightarrow$  Low  
 Large  $\leftarrow$   $N_{part}$   $\rightarrow$  Small  
 Large  $\leftarrow$   $v_2$   $\rightarrow$  Small

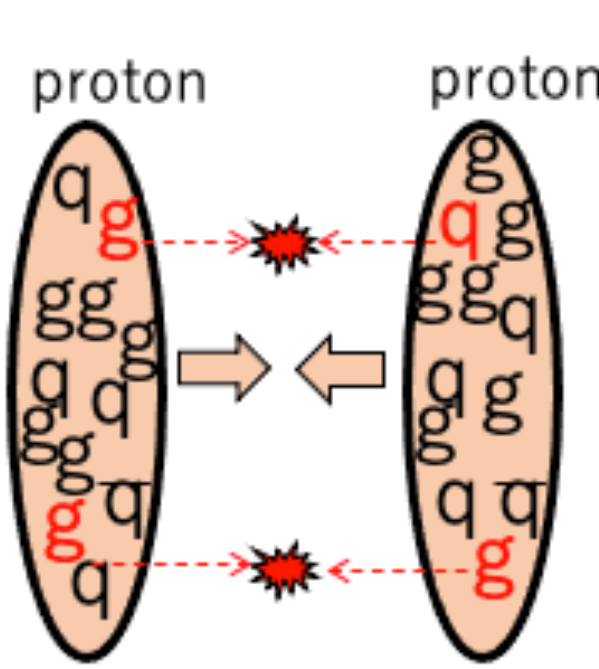
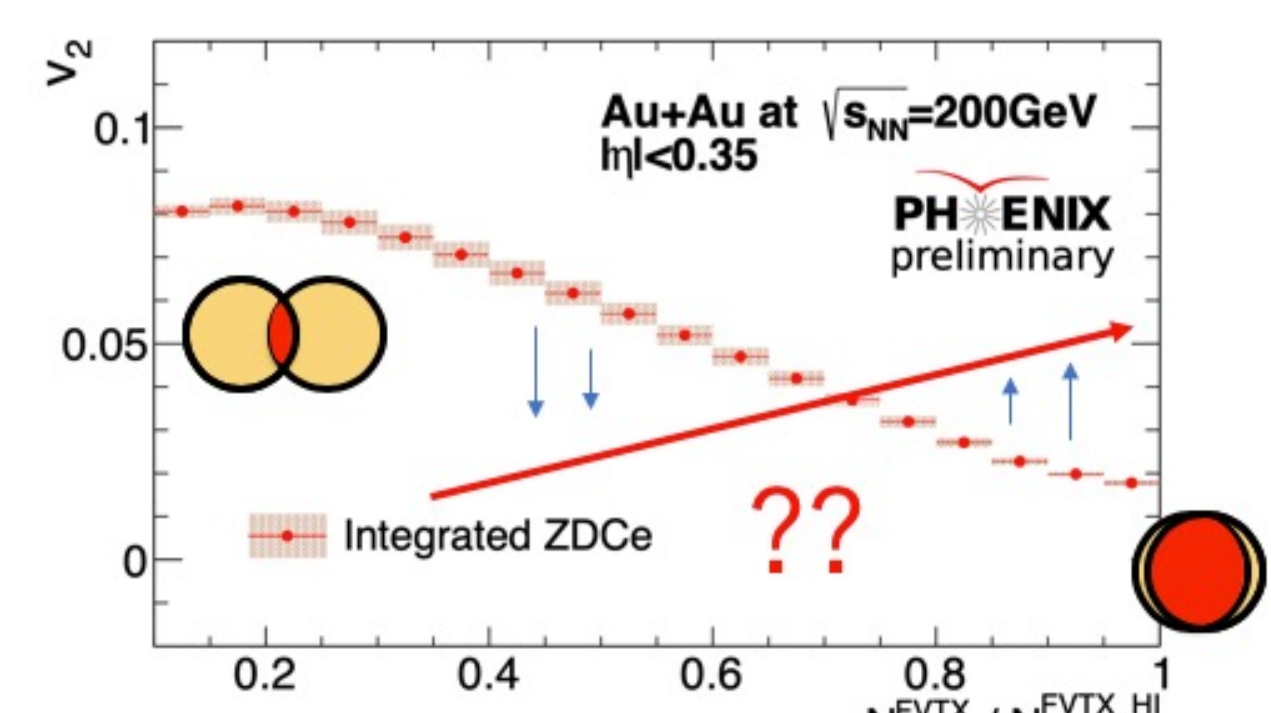
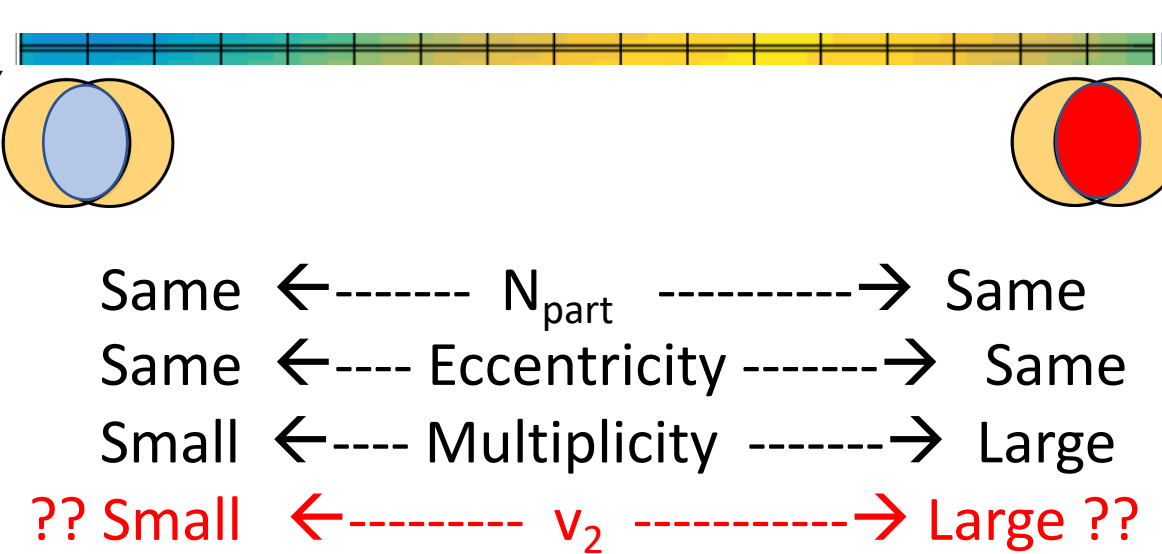


- QGP seems to be formed in small system collisions with relatively large multiplicity.  
 - A wide range of multiplicities exists at fixed  $N_{part}$  because of various effects like MPI, different  $N_{coll}$  values, etc.

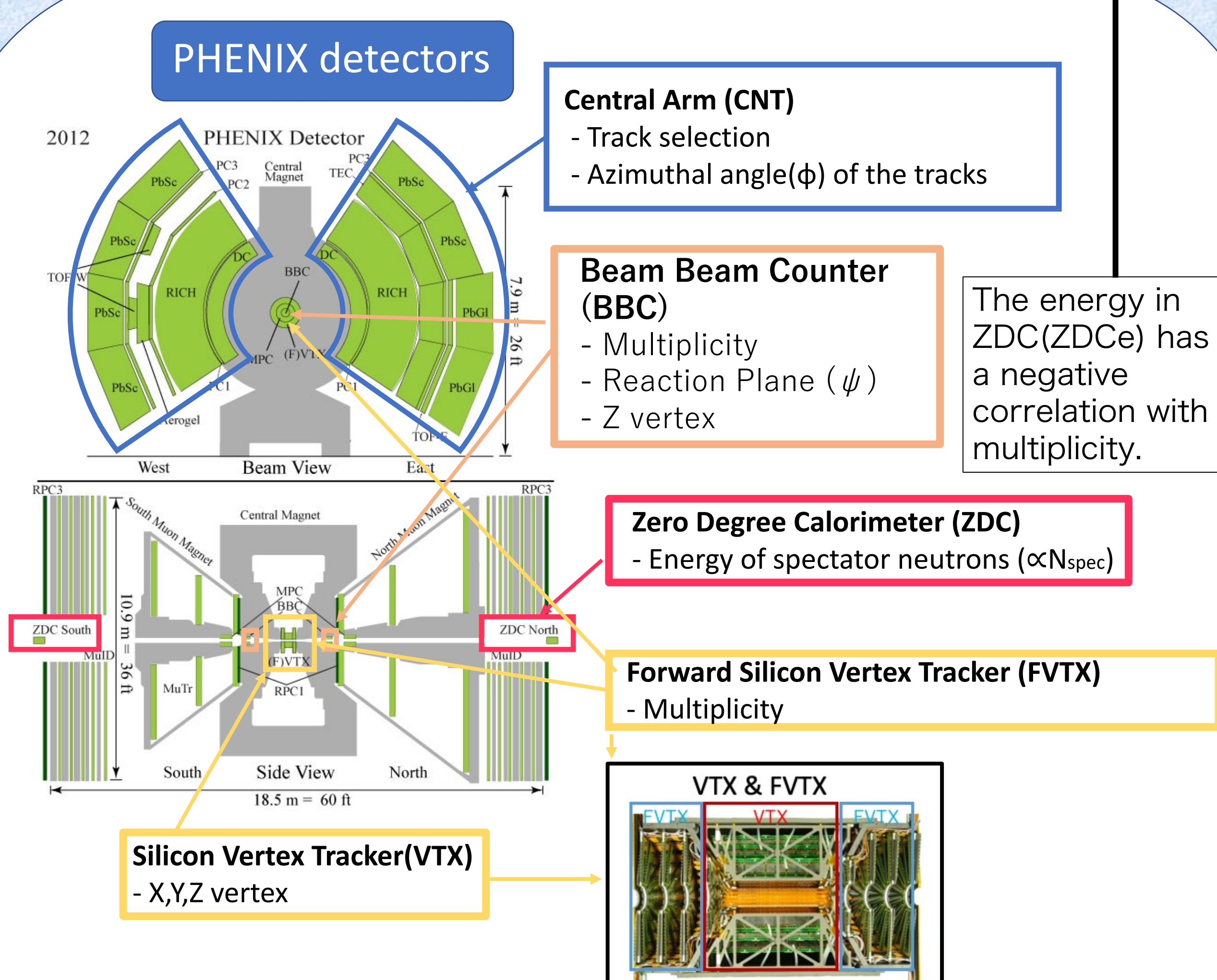
HOW ABOUT AuAu collisions? Is it possible to see such effects like MPI, different  $N_{coll}$  which change only multiplicity but not  $N_{part}$ ?  
 How does it affect  $v_2$ ?



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

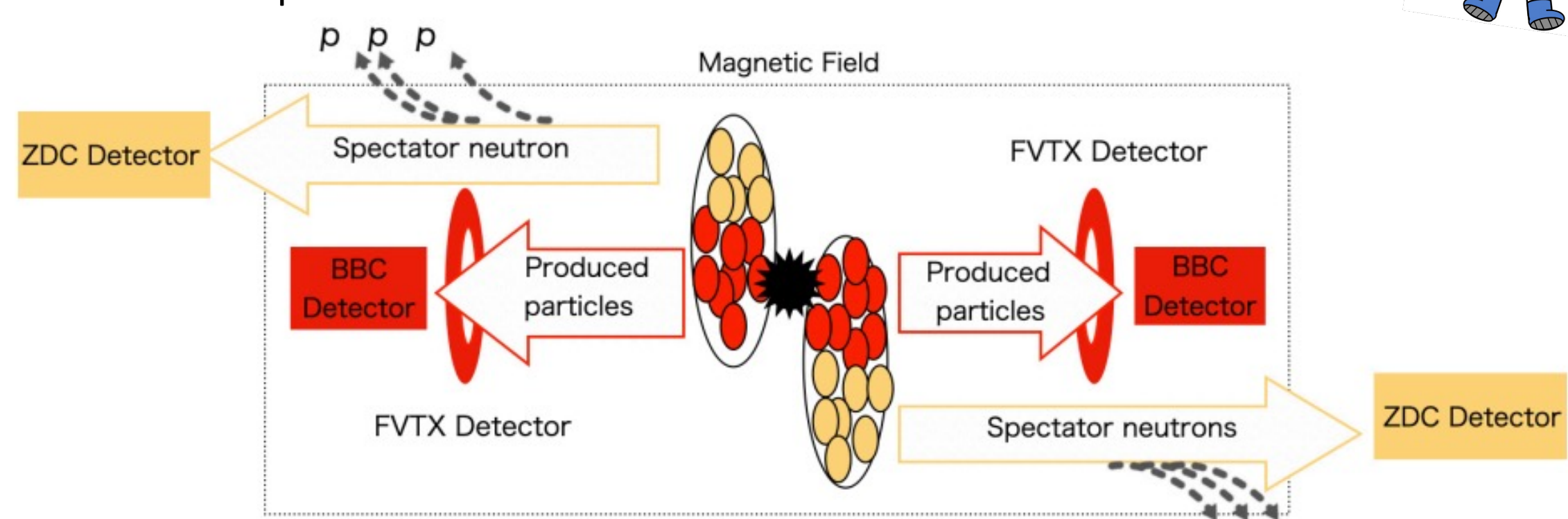


Multi-parton interaction(MPI)



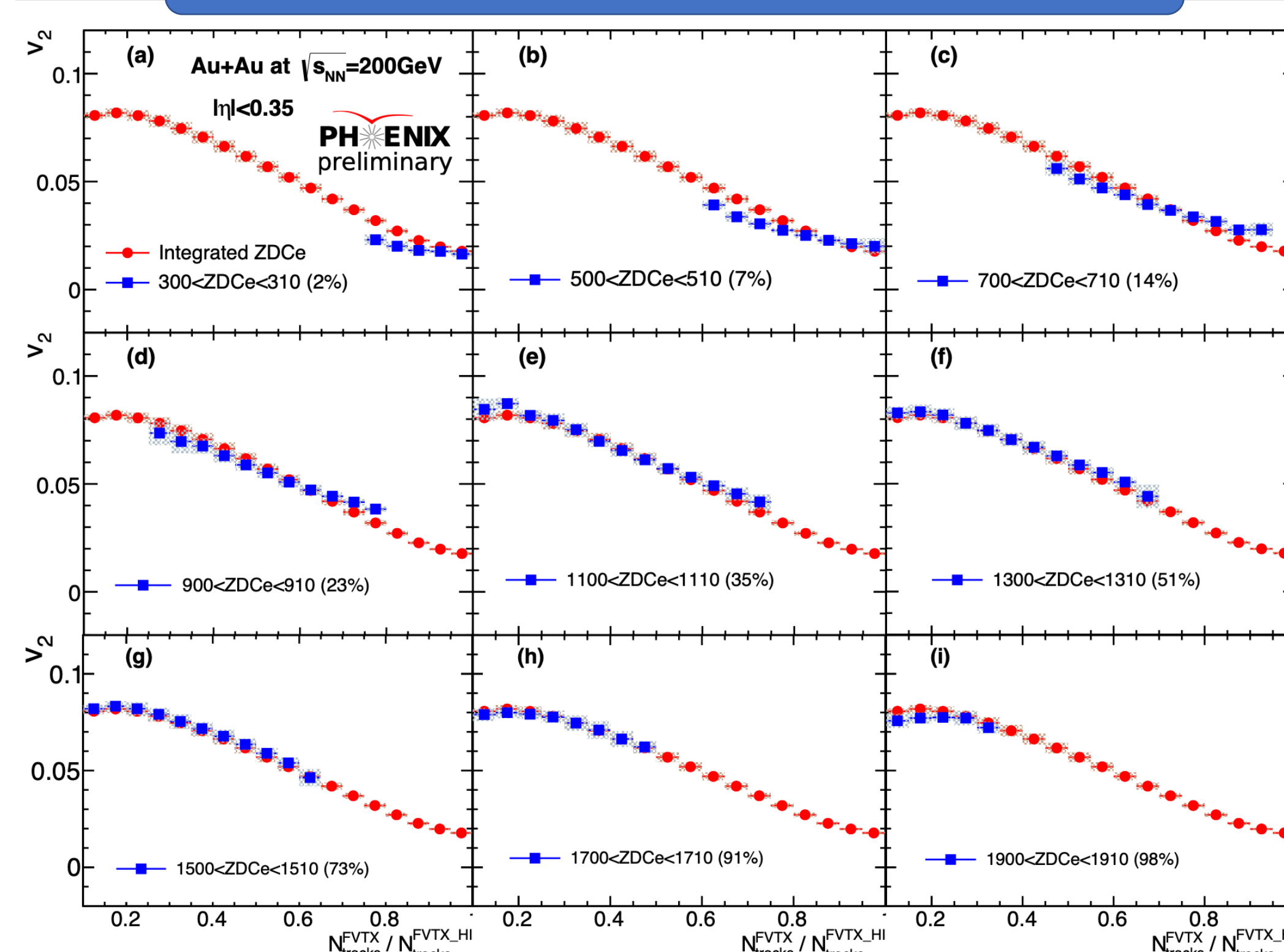
## Measurement of the multiplicity and $N_{part}$

We want to use the multiplicity and  $N_{part}$  info separately.  
 How? It's simple!



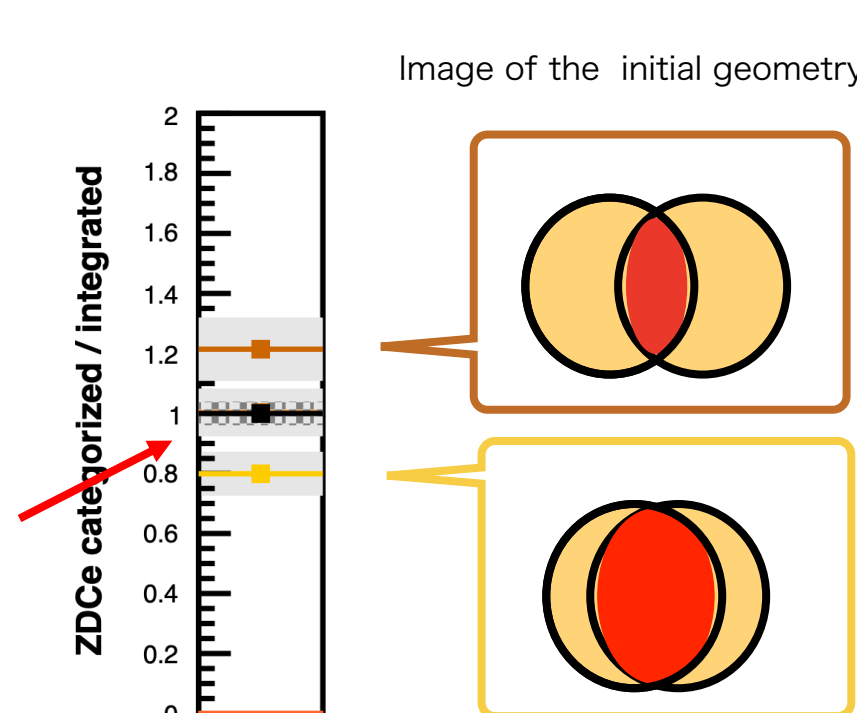
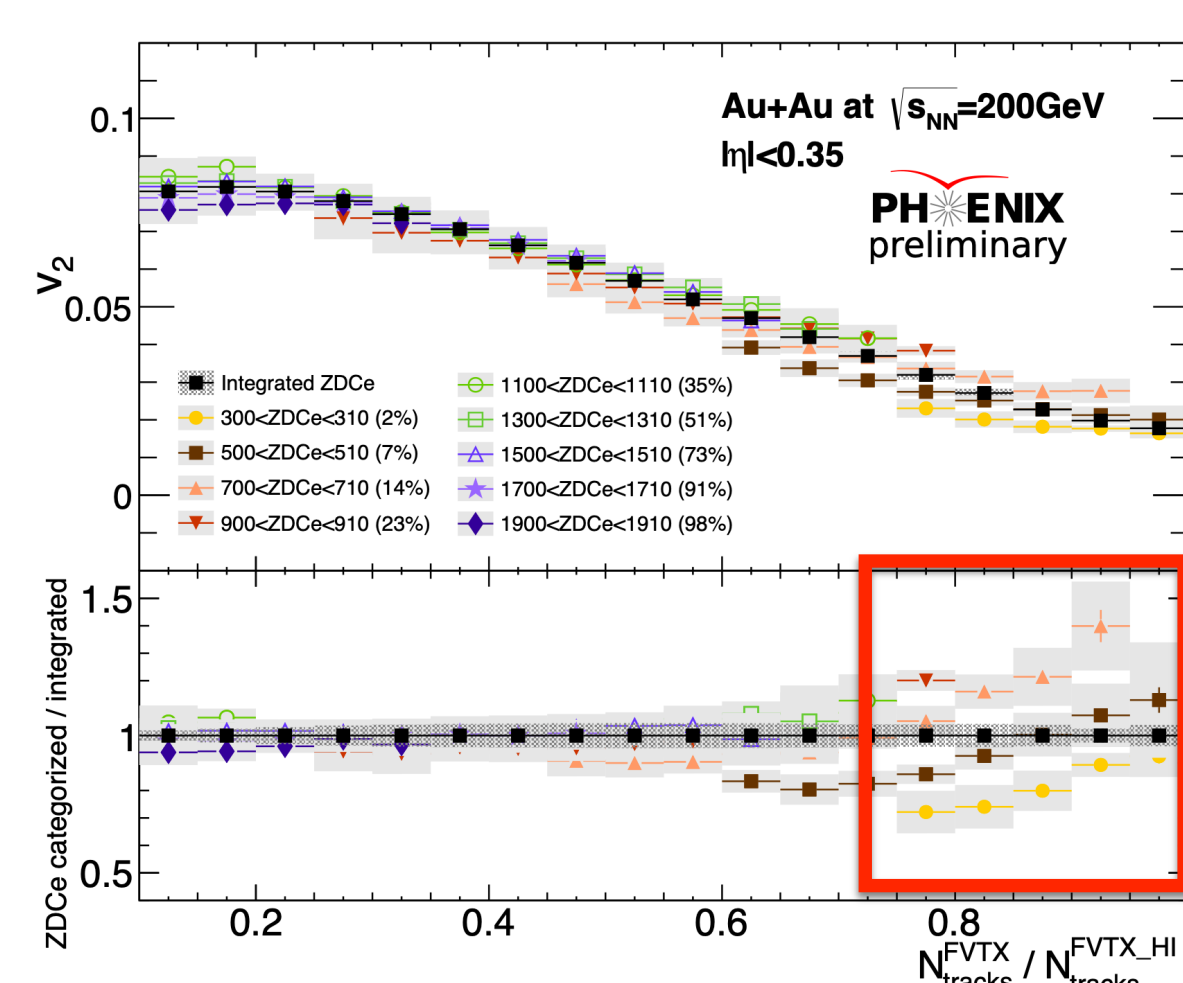
- Particles produced by collision are going into BBC(FVTX).  $\rightarrow$  Multiplicity
- Spectator neutrons are going into ZDC.  $\rightarrow N_{part} + N_{spec} = \text{Const.}$
- Categorize the events by fixed narrow ZDC bins such as 300<ZDCe<310, 500<ZDCe<510, 700<ZDCe<710, and so on.
- Measure the  $v_2$  as a function of the multiplicity with fixed narrow ZDC bins
- RP calibration is done with these new categorizations.

## Results of $v_2$ with 2D event categorization



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

- The ZDC categorization makes  $v_2$  the slope flatter compared with that without ZDC categorization at central collisions, ZDC<910, but does not invert it to positive.  
 - The correlation slopes are both negative for all event categorizations with same ZDCe selections.



These  $v_2$  seem to reflect initial geometry ( $\epsilon$ ) differences since the smaller  $N_{part}$  gives larger  $v_2$ , but these have the same multiplicity.  
 $\rightarrow$  may show the sign of the MPI-like or/and  $N_{coll}$  effect.  $\rightarrow$  need further study

## 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  $N_{coll}$  effect.  $\rightarrow$  need further study
- Possibility for the new event engineering to categorize the events in detail.

