The study of v_2 as a function of multiplicity with a new event categorization.

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Outline

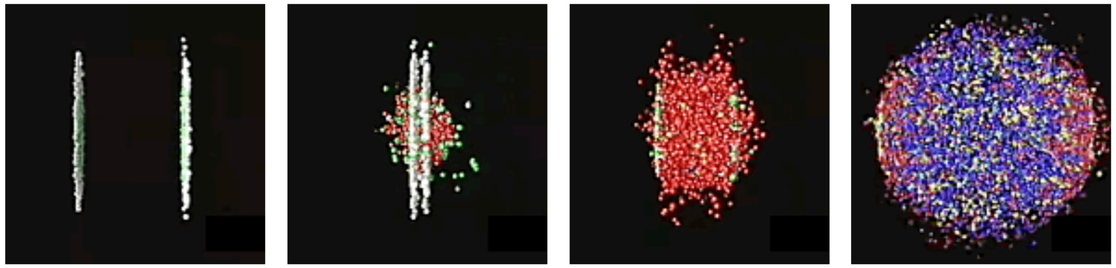
1. Introduction
2. Motivation
3. Analysis Procedure
4. Results and Discussion
5. Summary

Introduction

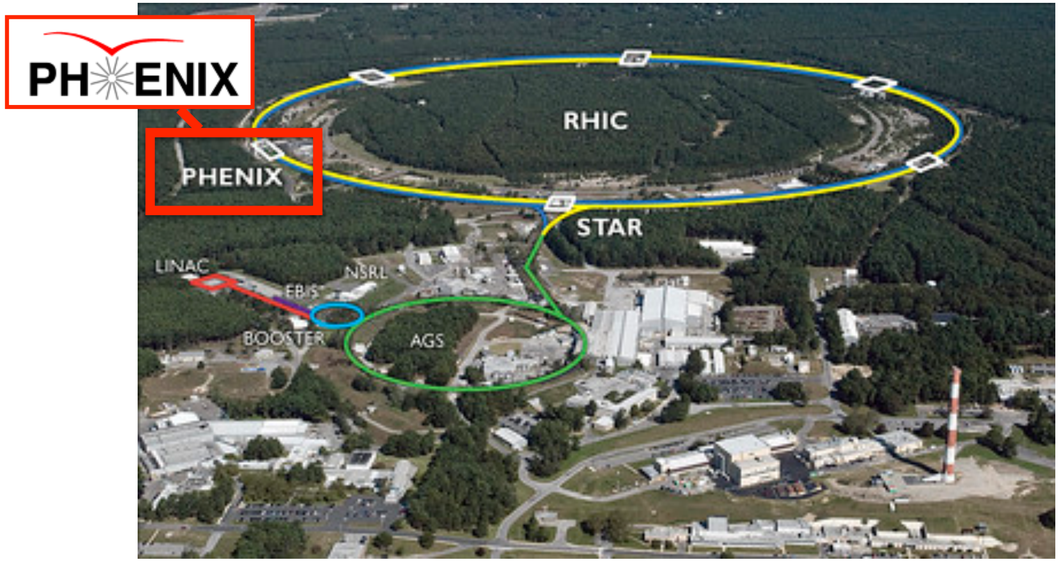
1. RHIC-PHENIX experiment

- One of the relativistic heavy ion collider (RHIC) experiments at Brookhaven National Laboratory.

- It collides heavy ions at relativistic energy to create a hot state, **QGP**, dense nuclear matter in which quarks and gluons are not bound into hadrons.



1. Ions about to collide* 2. Ion collision 3. Quarks, gluons freed 4. Plasma created



Introduction

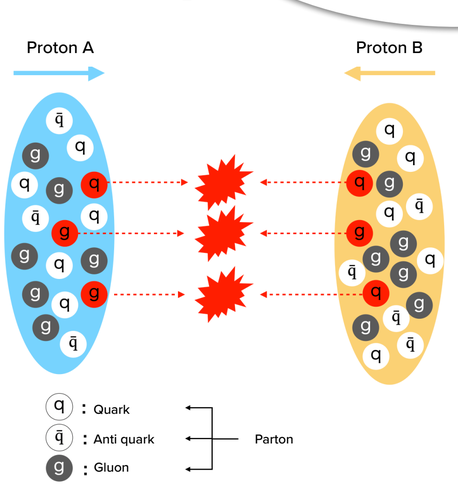
Note:
more interacting partons will make a larger multiplicity

2.The QGP-like phenomenon in the small collision system

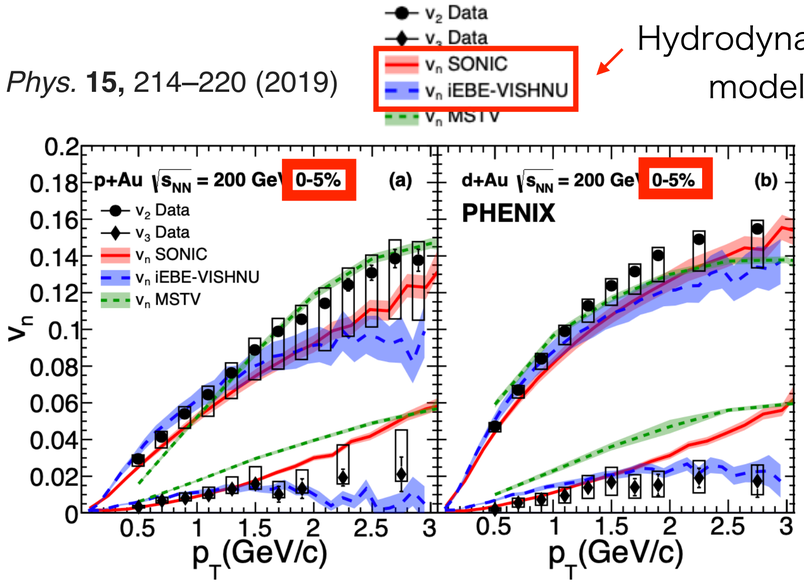
- The collective-like effect has been discovered in small systems at high multiplicity.

→ attract attention to **multi-parton interaction (MPI)**

MPI image



Nat. Phys. **15,** 214–220 (2019)



Hydrodynamical models

Basic idea

Trying to observe a multiple parton collision effect, like energy density dependence, in Au+Au collision.

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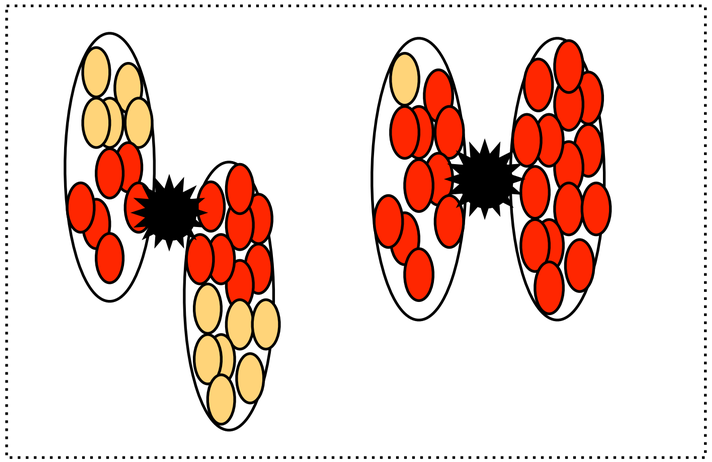
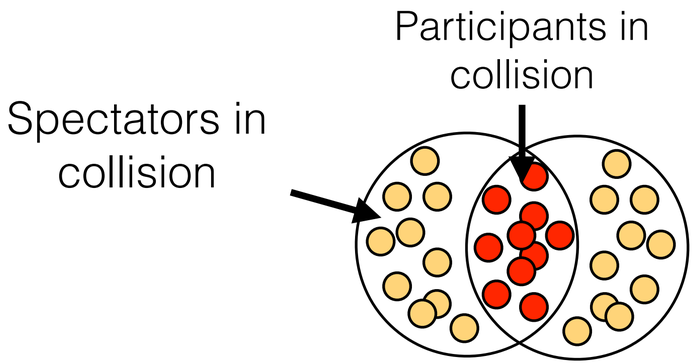
Introduction

3. Basic Idea



The number of participants (N_{part}) : Event by Event (random)
In general, the multiplicity is proposed to the N_{part}

With the same N_{part} events selection,
how does the changing multiplicity affect energy density?



Azimuthal anisotropy v_2, which is supposed to increase as the final energy density increases, is a GOOD TOOL!!

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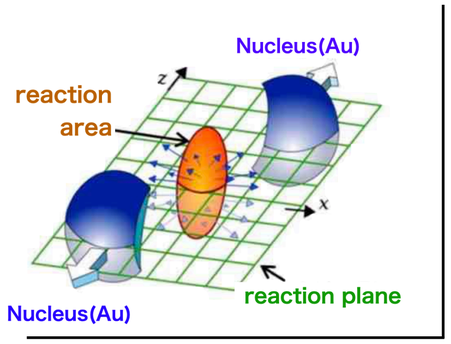
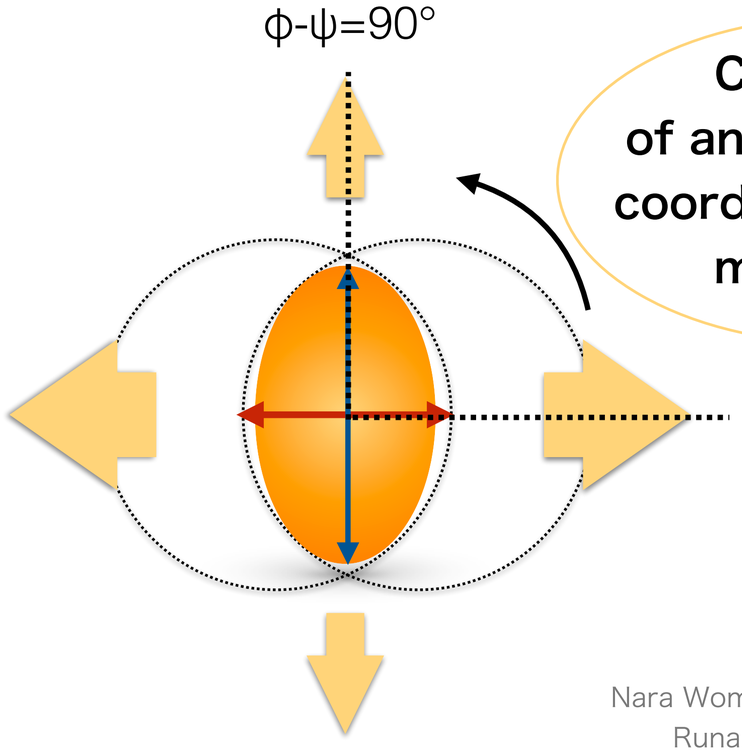
Introduction

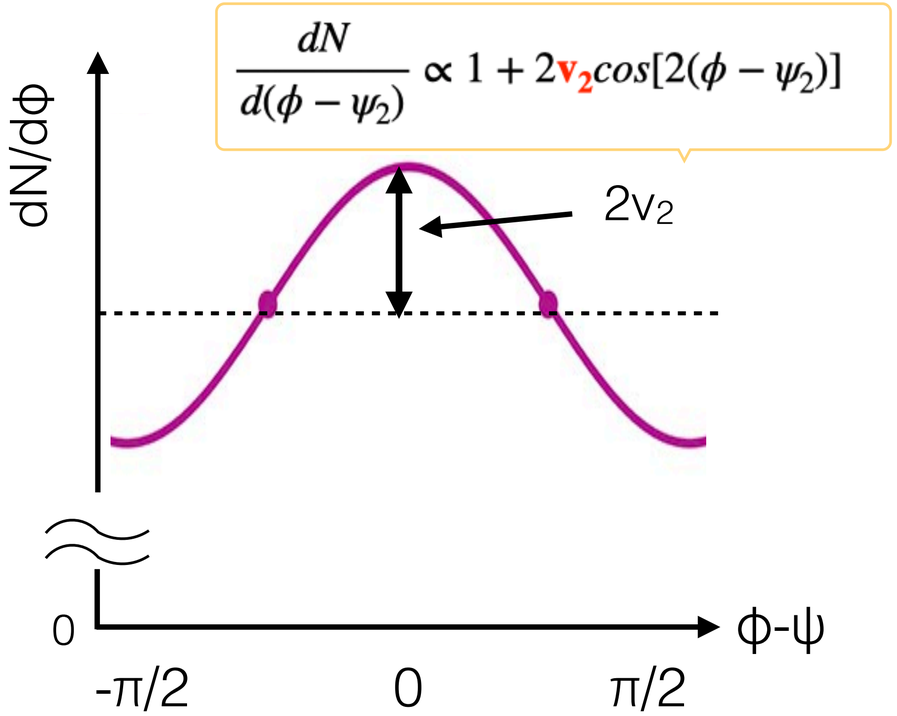
4. Azimuthal anisotropy, v_2

- In the non-central collision, the interaction region has an almond shape at the initial stage.
- If there is QGP in the reaction region, the particles have collective motion so the emission of particles in azimuth is influenced by the pressure gradient





Conversion of anisotropy from coordinate space to momentum



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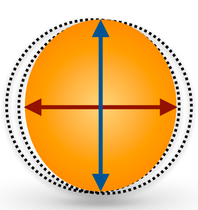
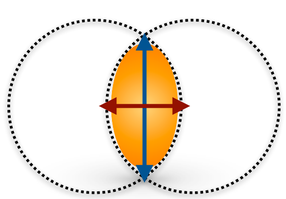
Introduction

5. Relation between v_2 and …



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



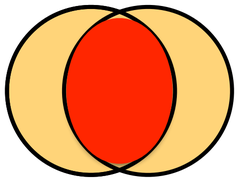
Small ⟵ eccentricity ⟶ Large

High ⟵ multiplicity (dN/dη) ⟶ Low

Large ⟵ N_{part} ⟶ Small

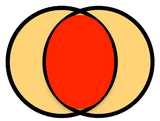
Small ⟵ v_2 ⟶ Large

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



With the same eccentricity

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



Au+Au Cu+Cu

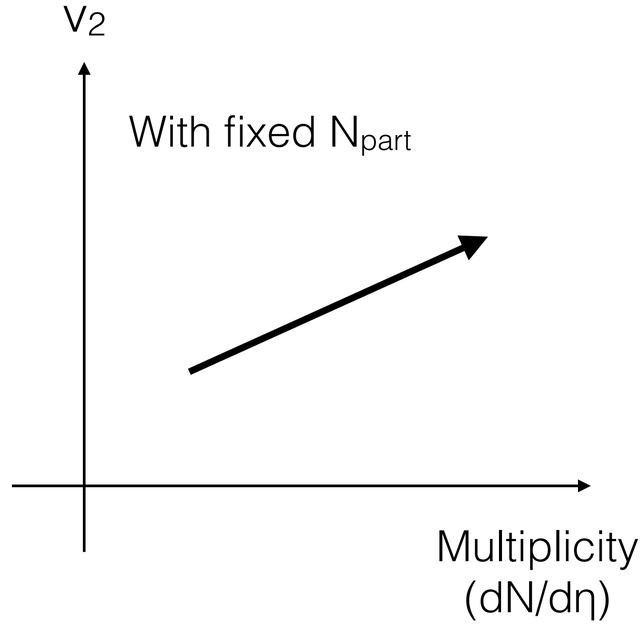
High ⟵ multiplicity (dN/dη) ⟶ Low

Large ⟵ N_{part} ⟶ Small

Large ⟵ v_2 ⟶ Small

With fixed N_{part}, which means fixed eccentricity, how does v_2 vs. multiplicity go?

→ with MPI effect, we expected that …



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Motivation

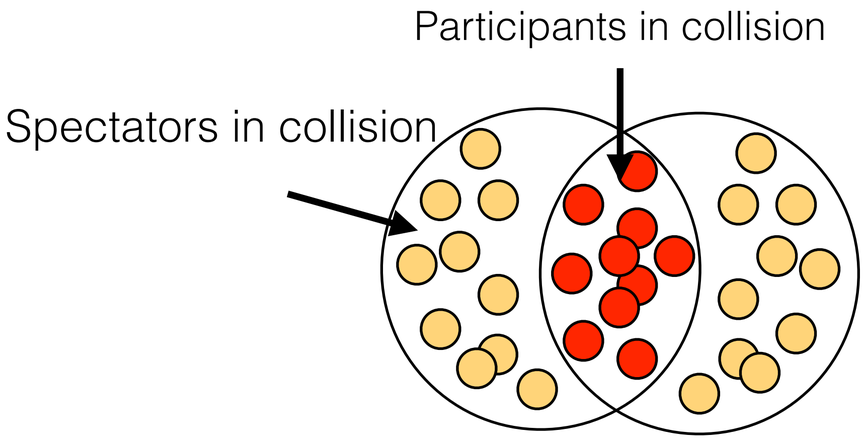
- **Motivation**
  - Study of the relation between the number of participants (N_{part}) and multiplicity in more detail, and how it affects v_2.
- **Study's feature**
  - The event categorization in this analysis is new. It is with more detail than centrality to categorize events to analyze v_2.

Analysis Procedure

- **the number of participants (N_{part}) and the number of spectators (N_{spec}) in the collision.**

A: mass number

$$N_{part} + N_{spec} = A \text{ (const)}$$
$$\therefore N_{part} = A - N_{spec}$$



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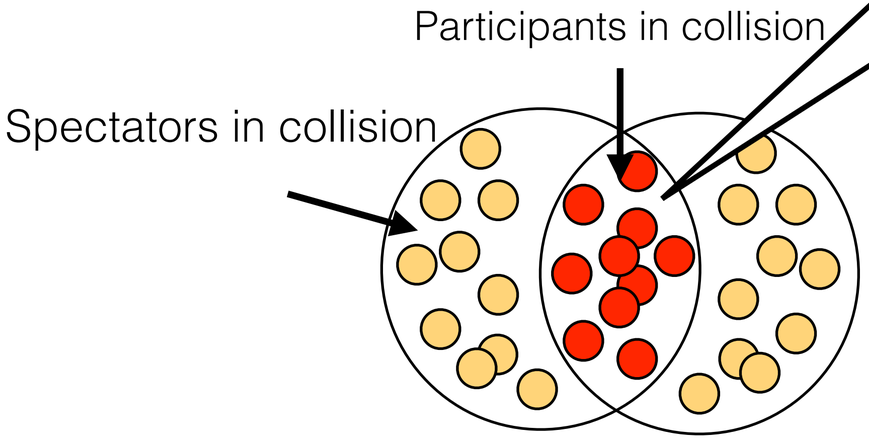
Analysis Procedure

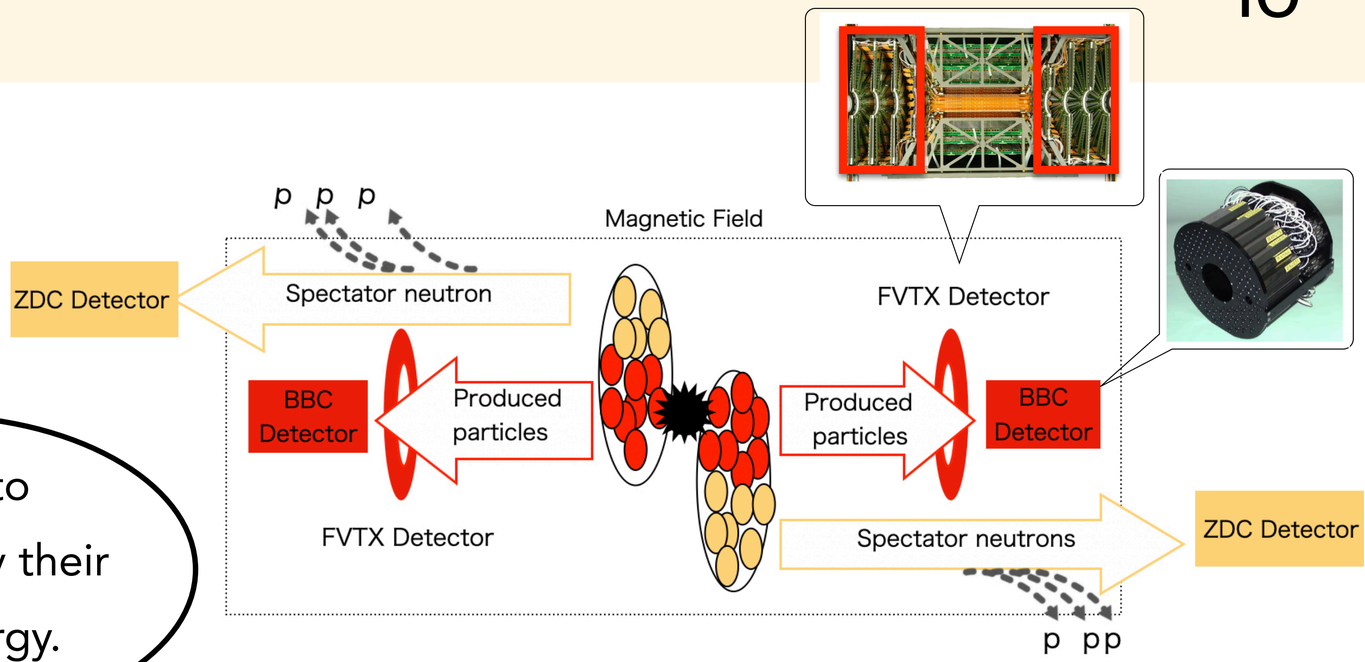
- **Measurement of N_{spec} and multiplicity**

A: mass number

$$N_{part} + N_{spec} = A \text{ (const)}$$
$$\therefore N_{part} = A - N_{spec}$$

converted to new particles by their collision energy.





- Measurement the energy of spectator neutrons($\propto N_{spec}$)
  → **Zero Degree Calorimeter (ZDC)**

- Measurement of the multiplicity
  → **• Beam Beam Counter (BBC)**
  • Forward Silicon Vertex Tracker (FVTX)

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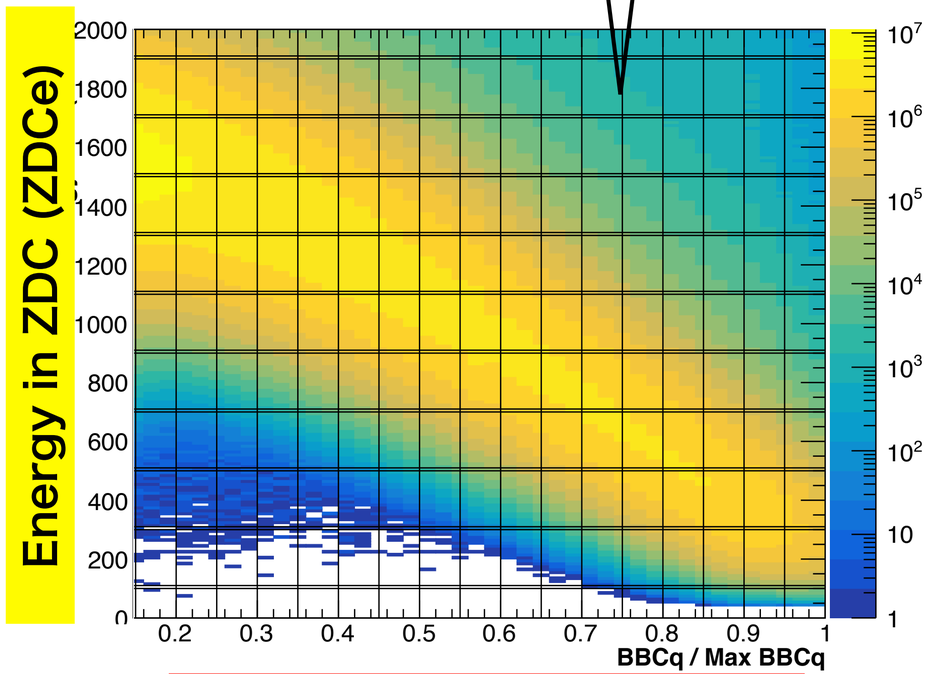
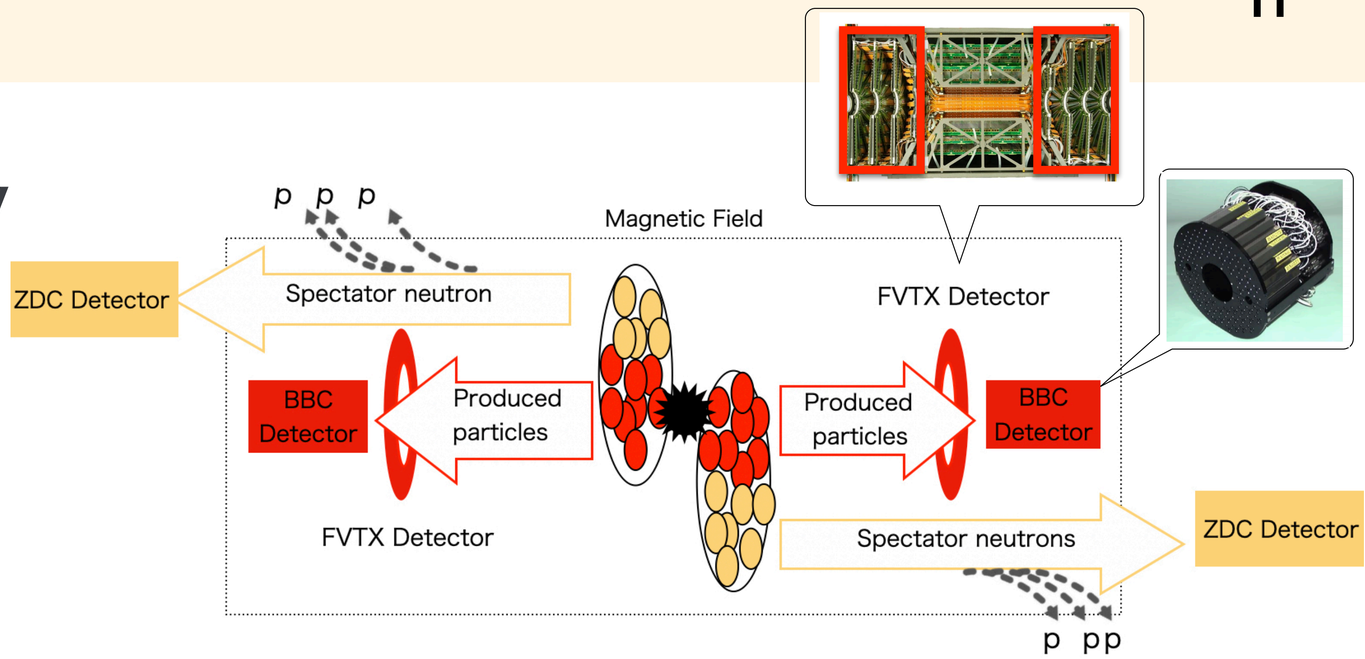
Analysis Procedure

- **Correlation of ZDC-energy and multiplicity**

The energy in ZDC(ZDCe) ($\propto N_{spec}$) has a negative correlation with multiplicity.



BBC-multiplicity



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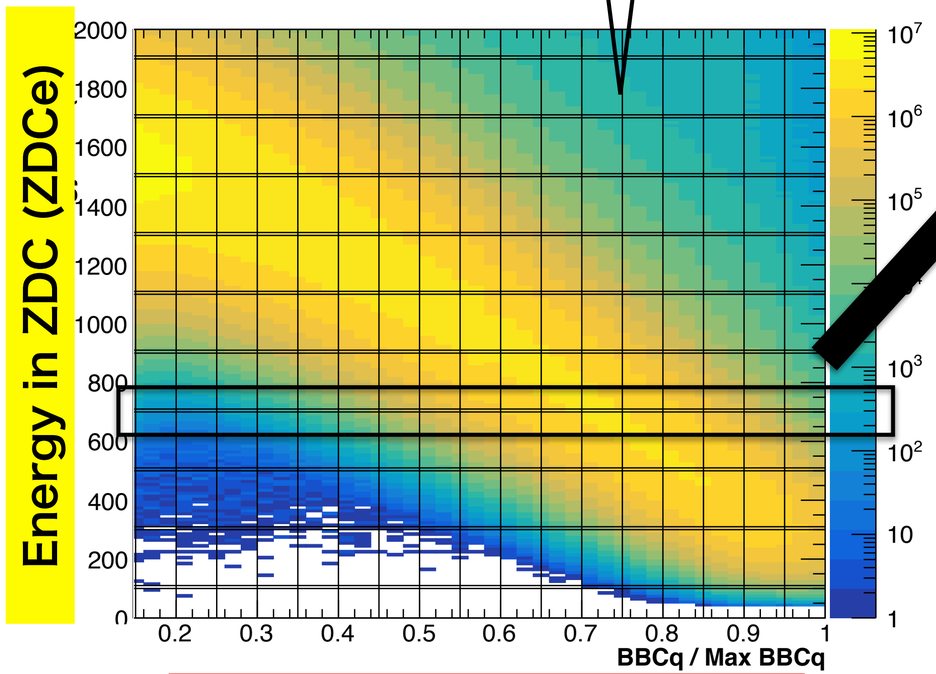

BBC-multiplicity

By fixing a narrow ZDC bins we studied how v_2 changes with the multiplicity.

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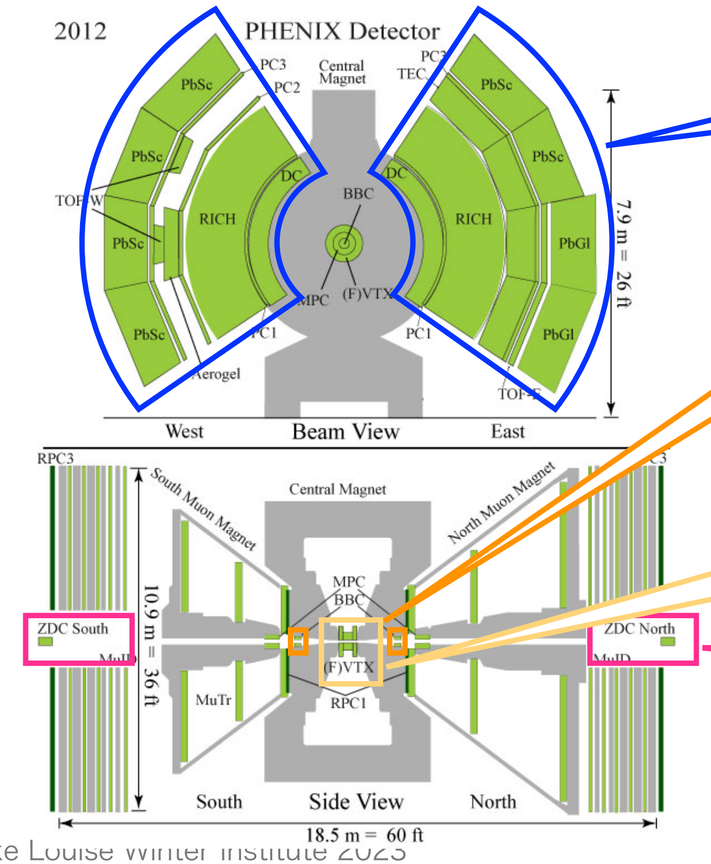
PHENIX detector

- **Main detectors in this analysis**

The data of Au+Au collision at $\sqrt{s_{NN}}$ = 200GeV taken at RHIC-PHENIX in 2014 is analyzed.



Central Arm (CNT)

- Tracking (ϕ)

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

Beam Beam Counter (BBC)

- The number produced particles
- Reaction Plane (ψ)

Forward Silicon Vertex Tracker (FVTX)

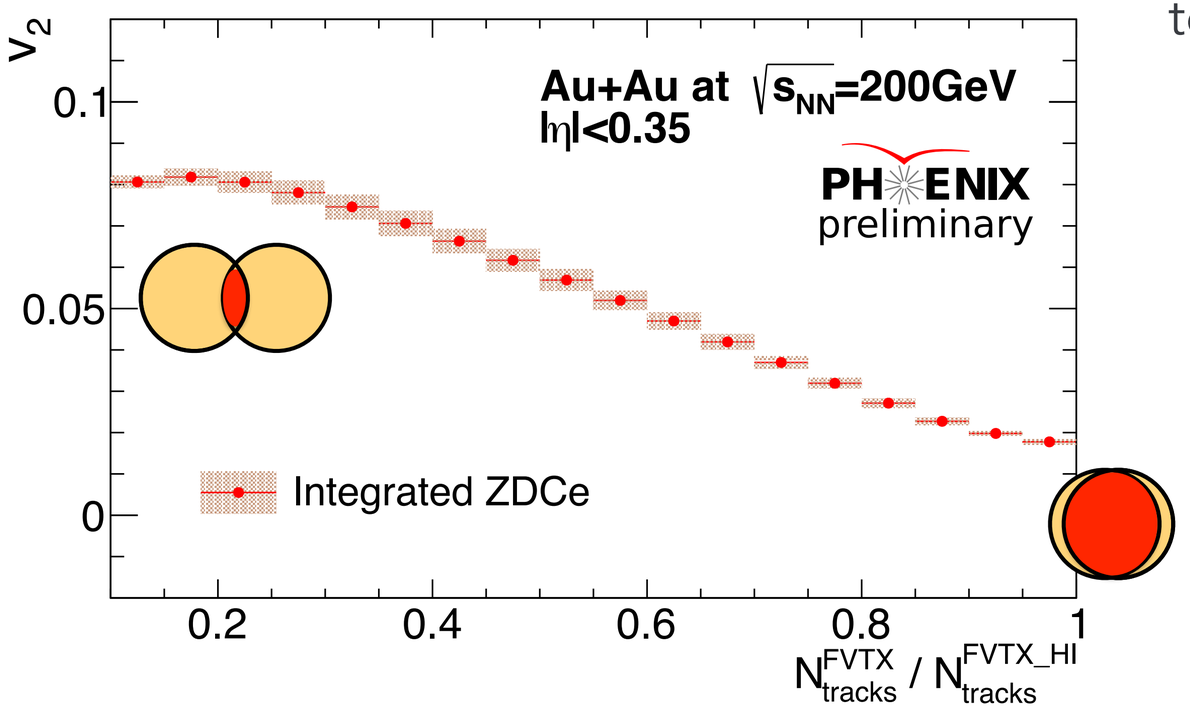
- The number produced particles

Zero Degree Calorimeter (ZDC)

- The energy of spectator neutrons ($\propto N_{spec}$)

Result: v_2 without ZDCe event categorization

v_2 as a function of **FVTX**-multiplicity



- v_2 without ZDCe event categorization decreases as the number of FVTX-multiplicity increases, this tendency correctly reflecting the initial geometry.

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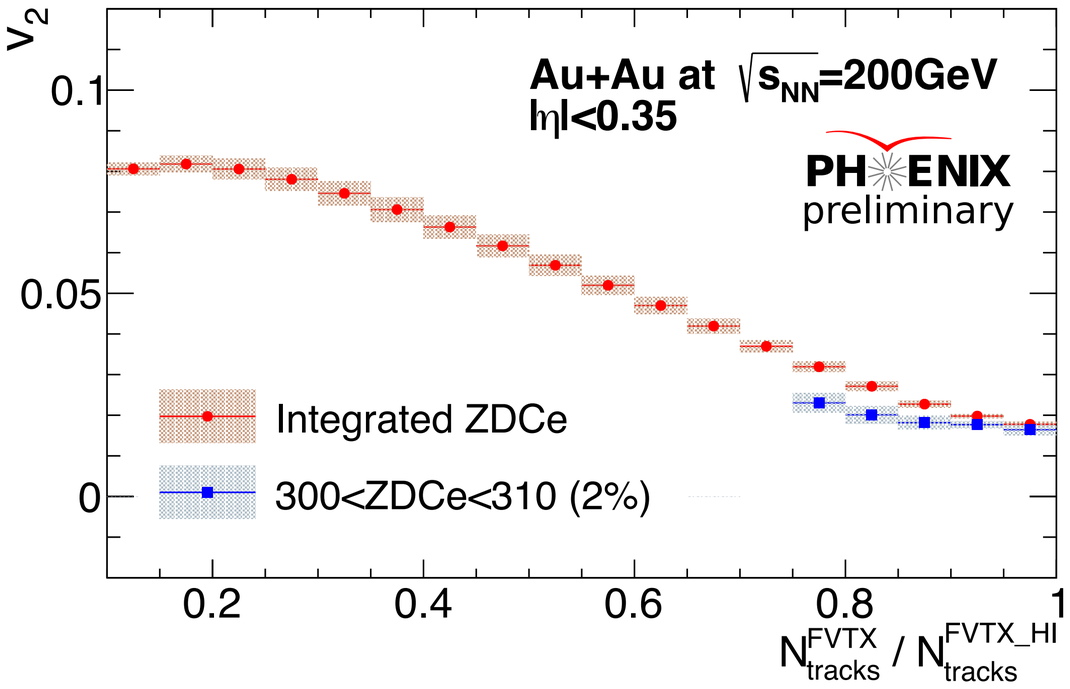
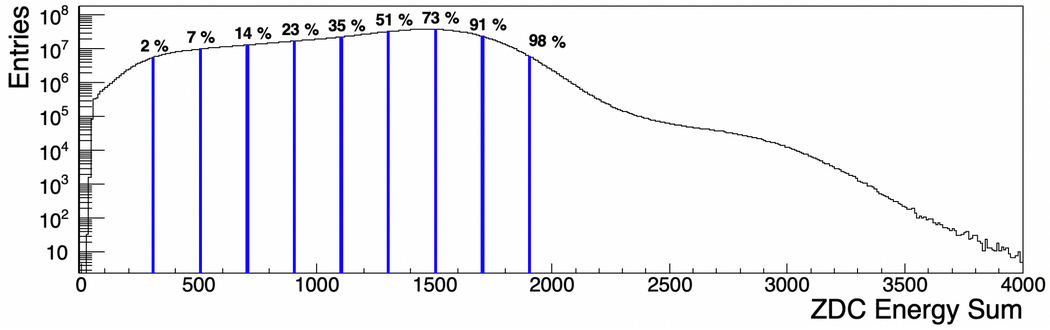
Results: v_2 with ZDCe event categorization

v_2 as a function of **FVTX**-multiplicity



- **The tendency of v_2 with ZDCe event categorization is the same as without one (previous slide).**
- **There are absolute difference (later slides)**
- **Red**： without ZDCe event categorization

  Blue： with ZDCe event categorization (300<ZDCe<310)



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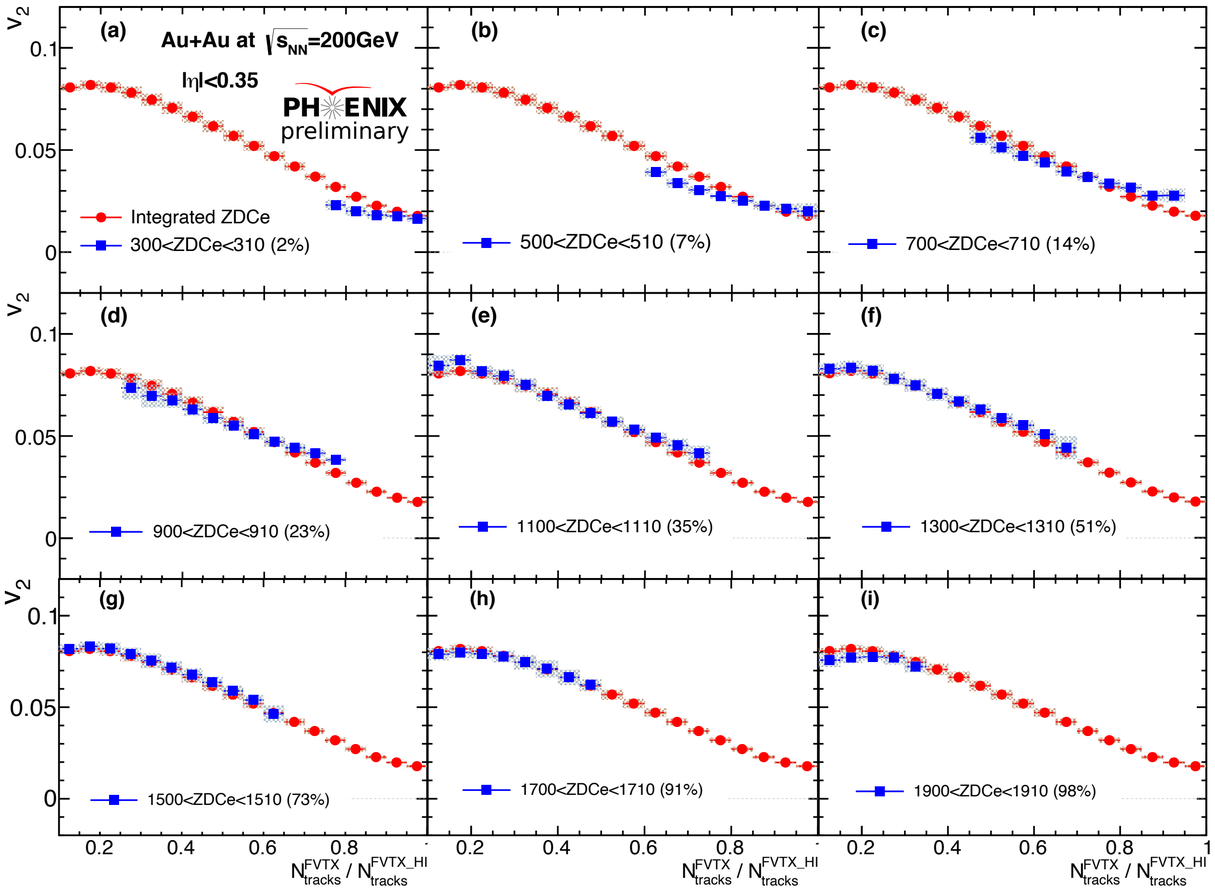
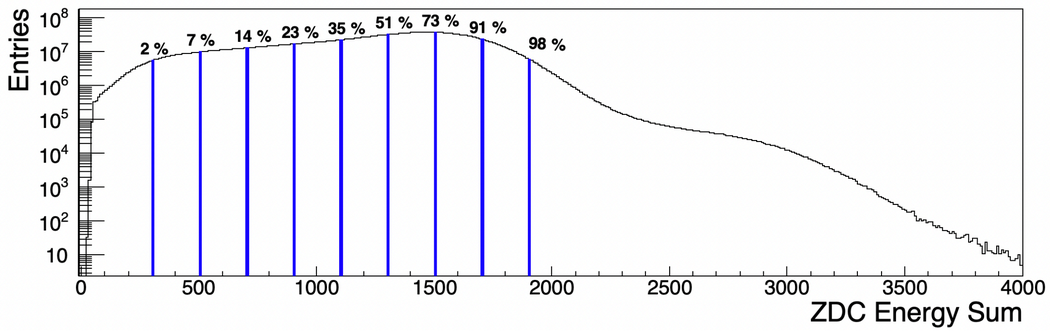
Results: v_2 with ZDCe event categorization

v_2 as a function of **FVTX**-multiplicity

Red : without ZDCe event categorization (same plots in all panels)

Blue : with ZDCe event categorization





- In each panel, different ZDCe event categorization is applied.
- **In all ZDCe event categorizations, the tendency is the same, that v_2 decrease as FVTX- multiplicity increase.**

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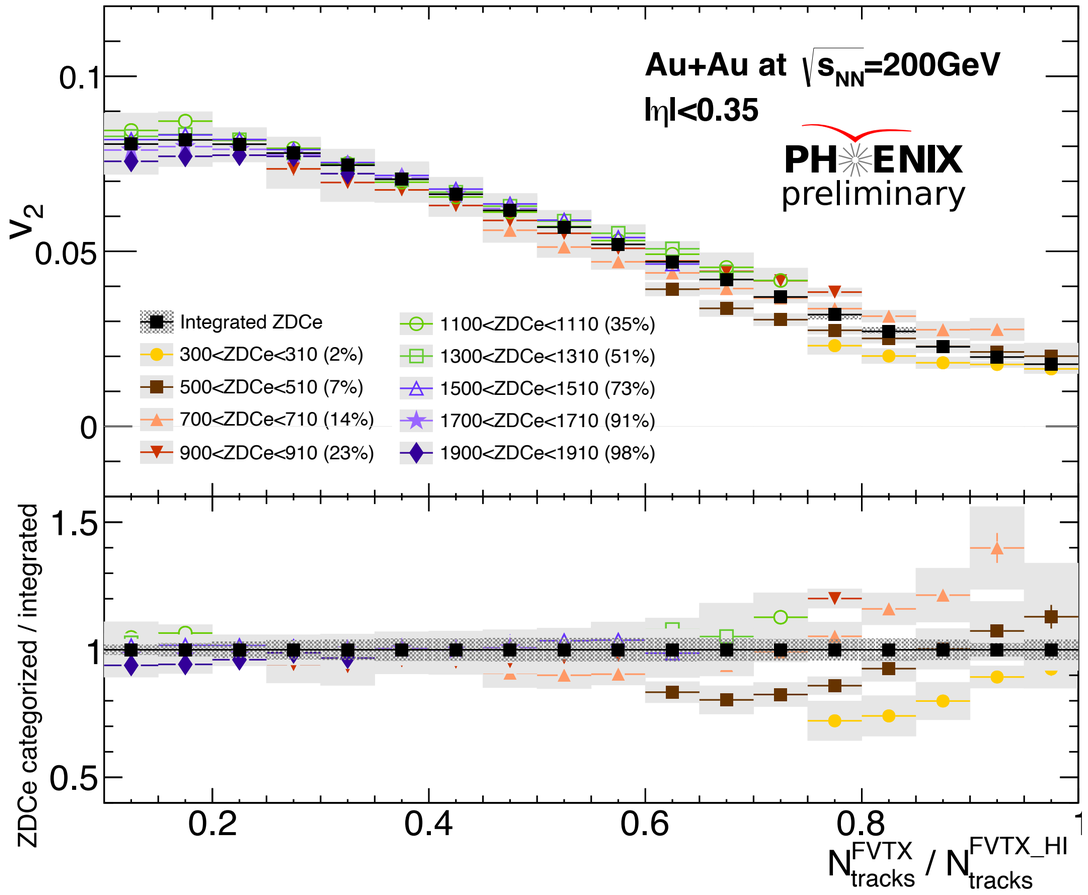
Results: v_2 at different ZDCe event categorization

v_2 as a function of **FVTX**-multiplicity



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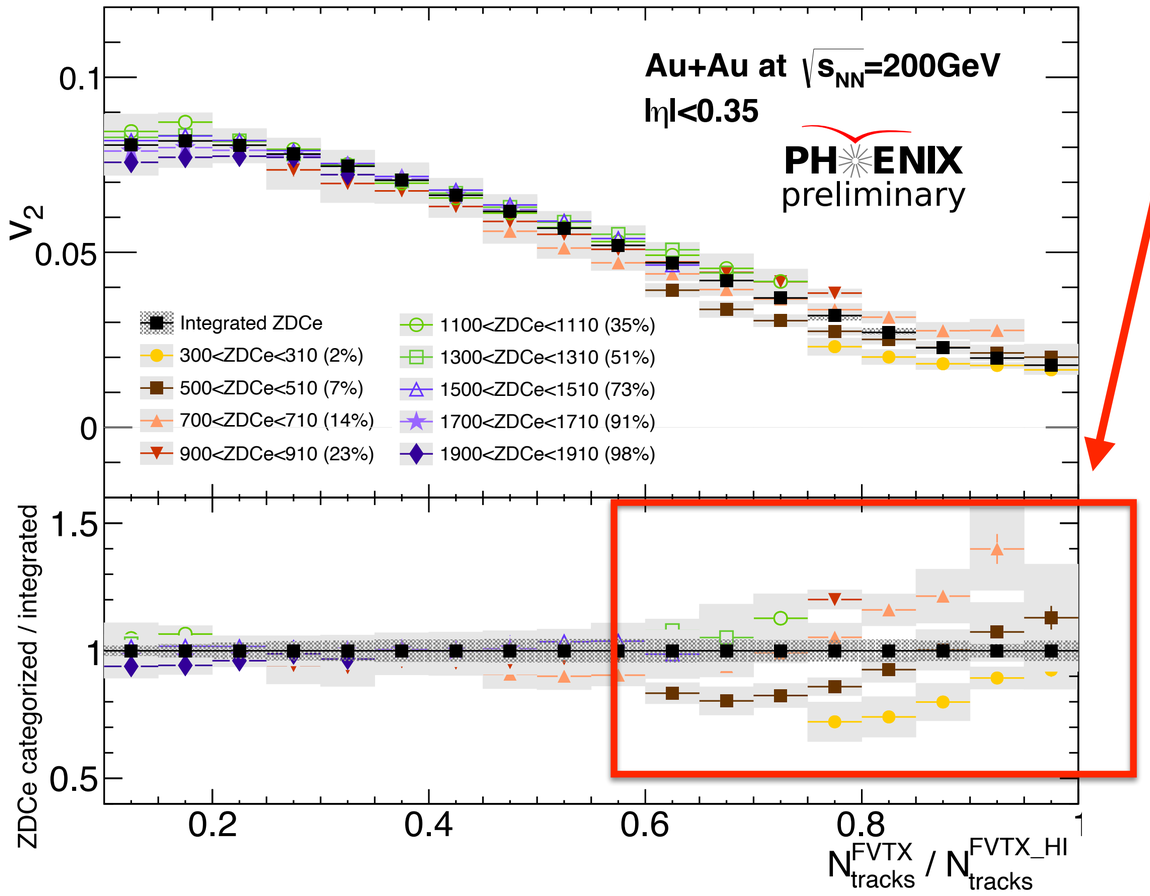
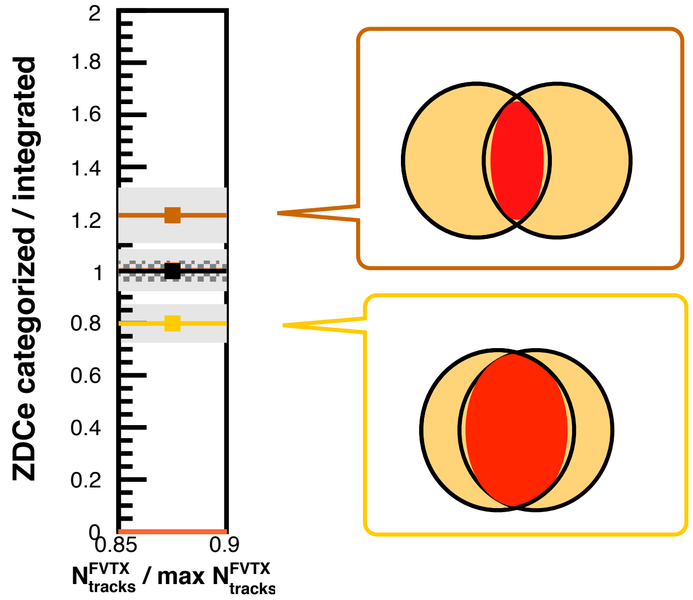
Results: v_2 at different ZDCe event categorization

v_2 as a function of **FVTX**-multiplicity



- At higher multiplicity classes, v_2 has differences between them in each ZDCe event class.
  → **These v_2 should reflect initial geometry differences, but they result in the same multiplicity.**

Image of the initial geometry



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Summary

- We studied v_2 as a function of FVTX-multiplicity and v_2 as a function of BBC-multiplicity, with event categorization using ZDC-energy to identify the same initial geometry.

- As a result, we found that the v_2 decreased as the multiplicity increased. The tendency is consistent qualitatively with the result without ZDCe event selection.
  → We are thinking that comparing the results and some kinds of simulations, to check how much exactly the ZDCe event selection identifies the same initial geometry. At this point, no conclusion can be made on the presence or absence of MPI.

- We found that different v_2 in different ZDCe event categorizations but in the same multiplicity event class.
  → These results suggest that there are events that result in the same multiplicity at different N_{part}. We are interested in this difference: what causes these.

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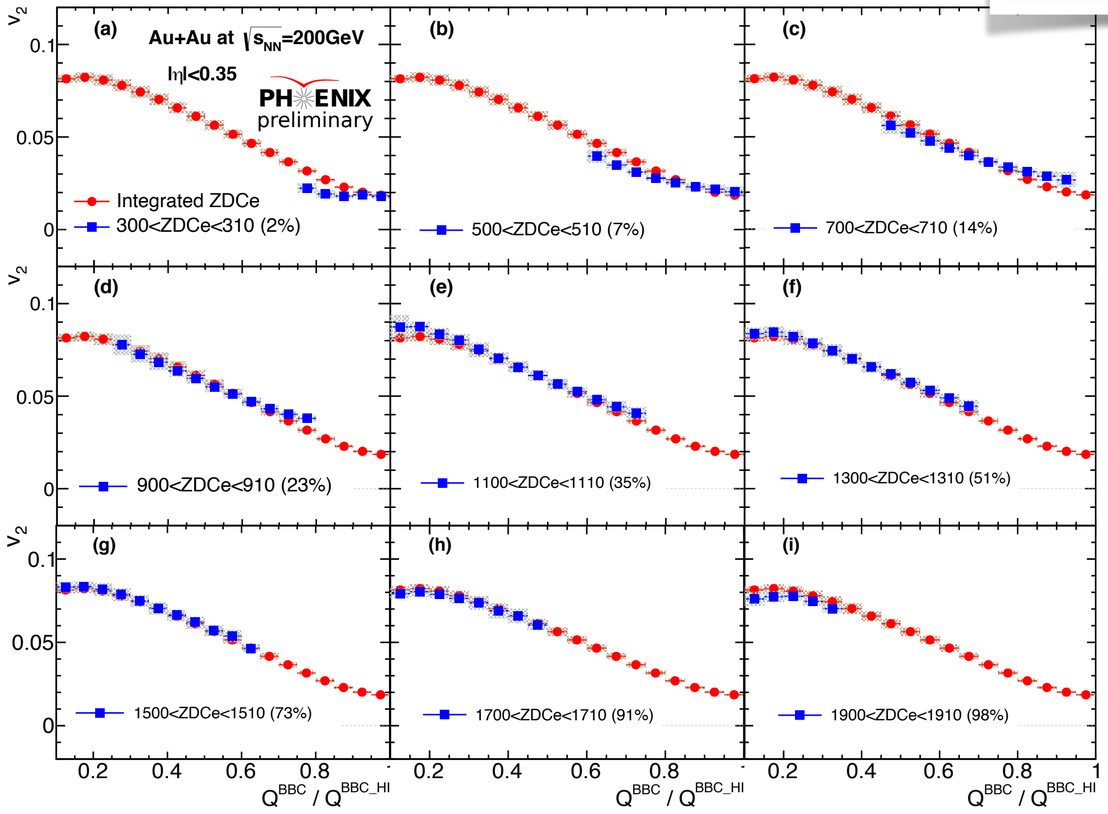
Back Up

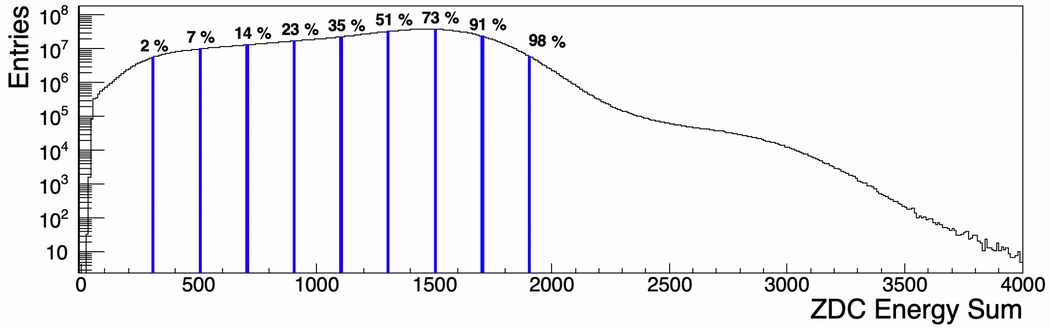
Results: v_2 with ZDCe event categorization

v_2 a s function of **BBC**-multiplicity

Red： without ZDCe event categorization (same plots in all panels)

Blue： with ZDCe event categorization





- **The tendency is the same as v_2 depending on FVTX-multiplicity.**

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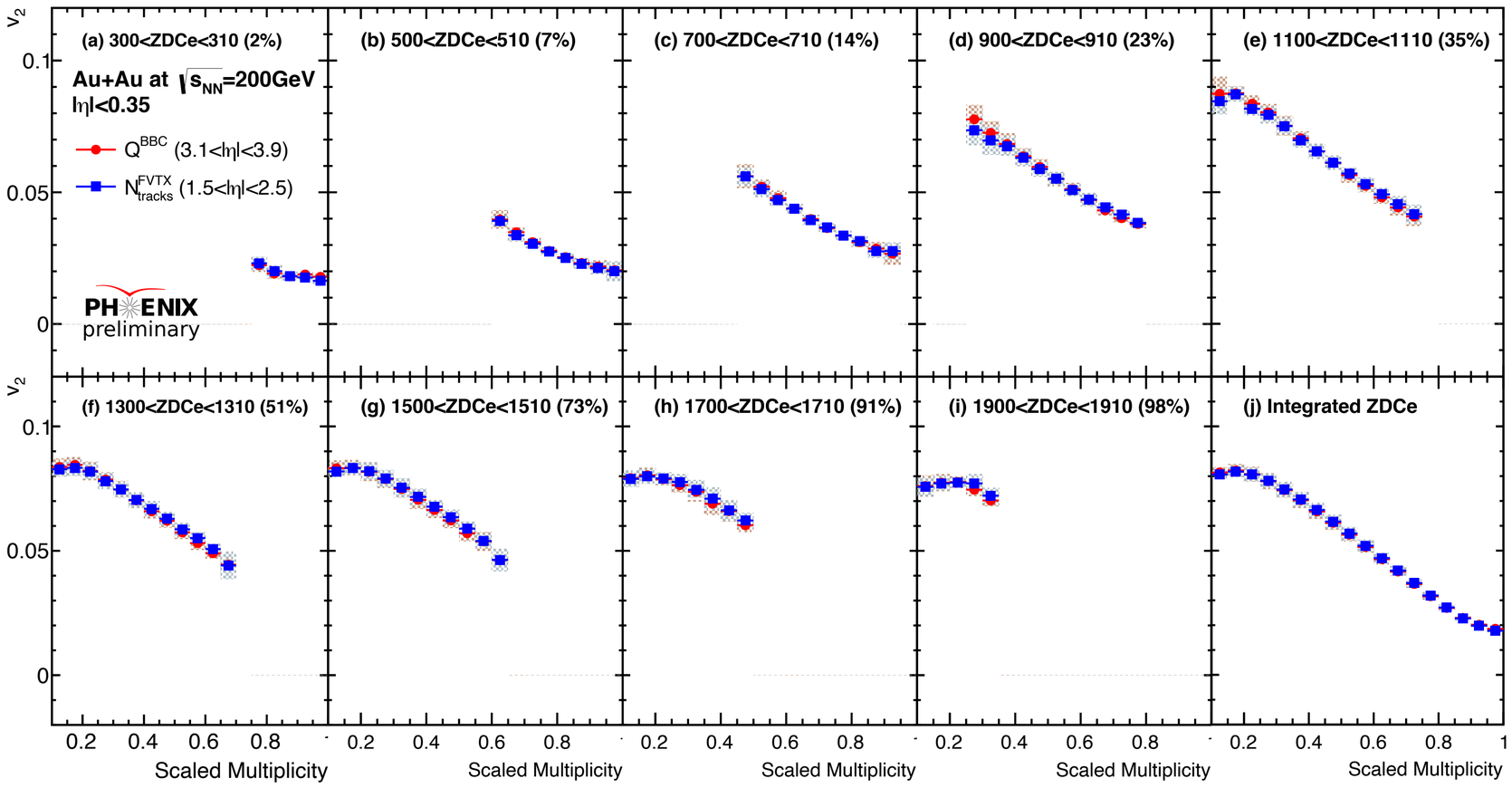
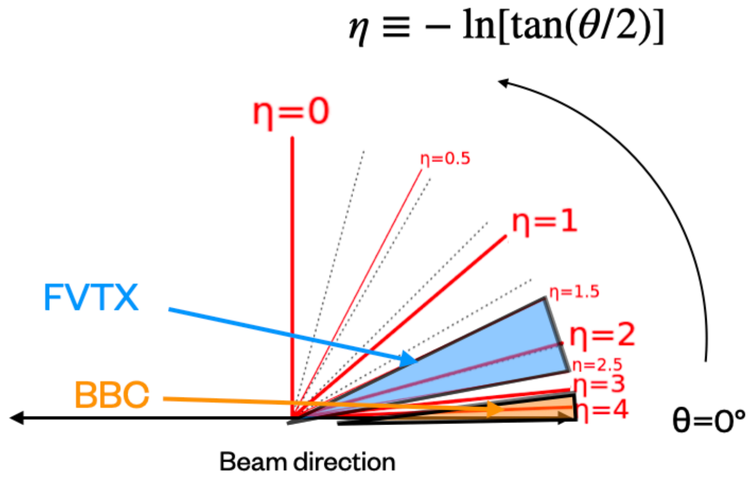
Results: multiplicity at different rapidity

Differences in multiplicity depending on the rapidity range of FVTX(1.5<|η|<2.5) and BBC(3.1<|η|<3.9) are not shown.





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  → We are thinking that comparing the results and some kinds of simulations, to check how much exactly the ZDCe event selection identifies the same initial geometry. At this point, no conclusion can be made on the presence or absence of MPI.

- The v_2 depending on FVTX-multiplicity and one depending on BBC-multiplicity are the same.
  → The rapidity coverages of the multiplicity detectors don't affect the results.

- We found that different v_2 in different ZDCe event categorizations but in the same multiplicity event class.
  → These results suggest that there are events that result in the same multiplicity at different Npart.
  We are interested in this difference: what causes these.

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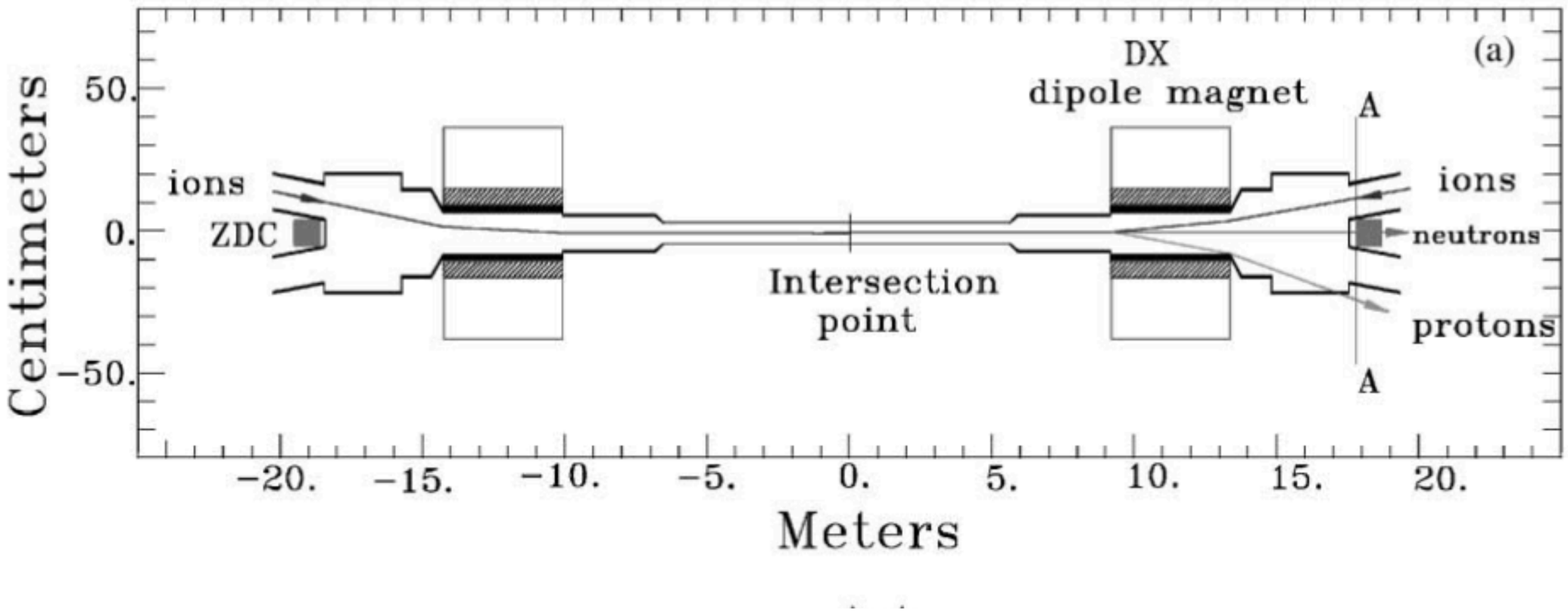
DX
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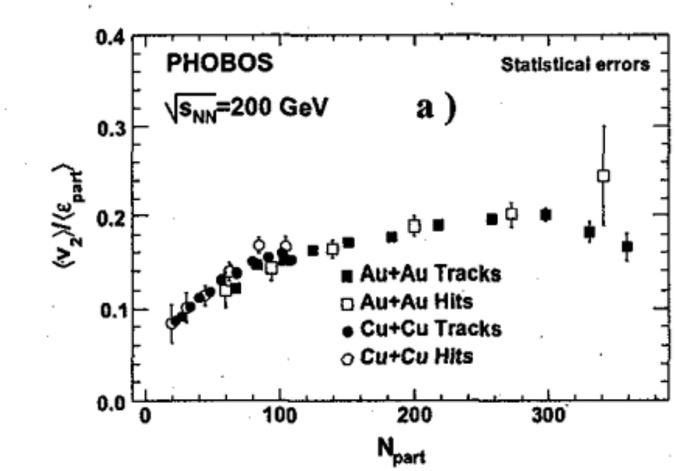
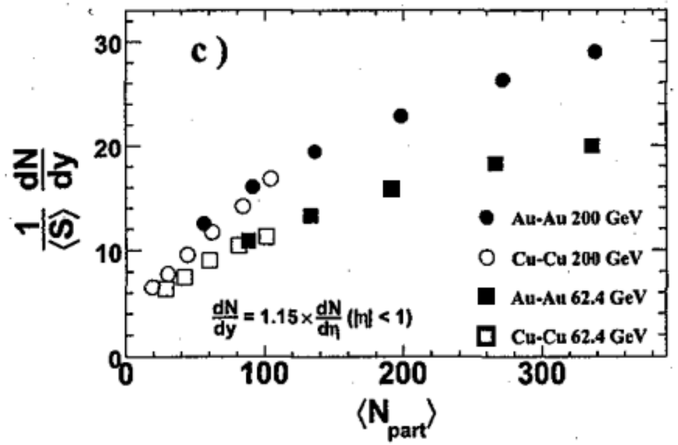
15.
20.
Meters





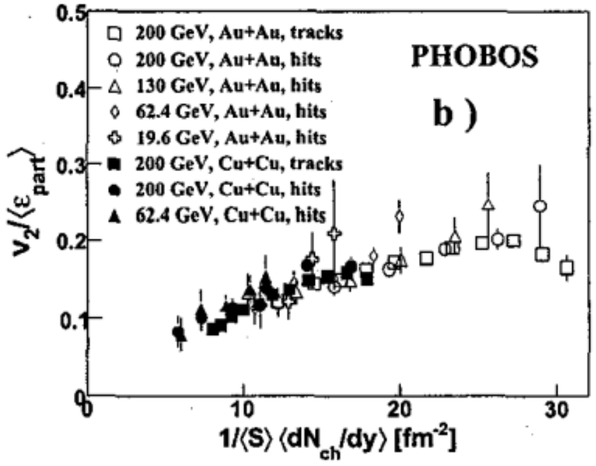


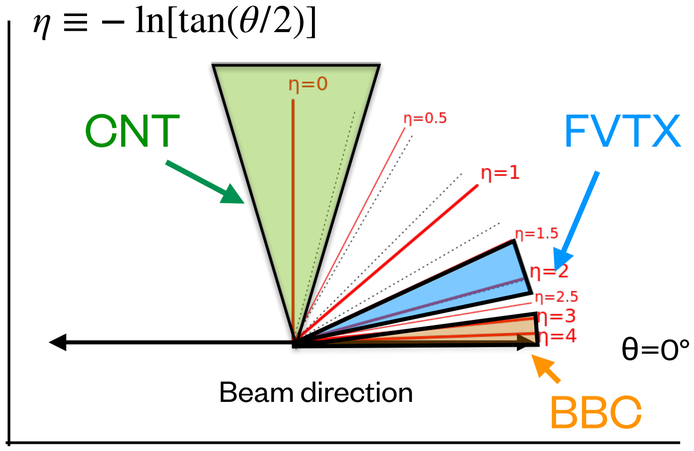
Figure 2. Panel a) $v_2/\langle\varepsilon_{\rm part}\rangle$ versus $N_{\rm part}$ for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV. Panel b) shows $v_2/\langle\varepsilon_{\rm part}\rangle$ as function of mid-rapidity ($|\eta| < 1$) particle area density $1/\langle S\rangle\langle dN/dy\rangle$ for Cu+Cu and Au+Au collisions. The bars in the plots represent the statistical errors. Panel c) correlation plot of midrapidity particle area density $1/\langle S\rangle\langle dN/dy\rangle$ as function of $N_{\rm part}$ calculated in Glauber MC for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}}$ = 62.4 and 200 GeV.

Results: multiplicity at different rapidity

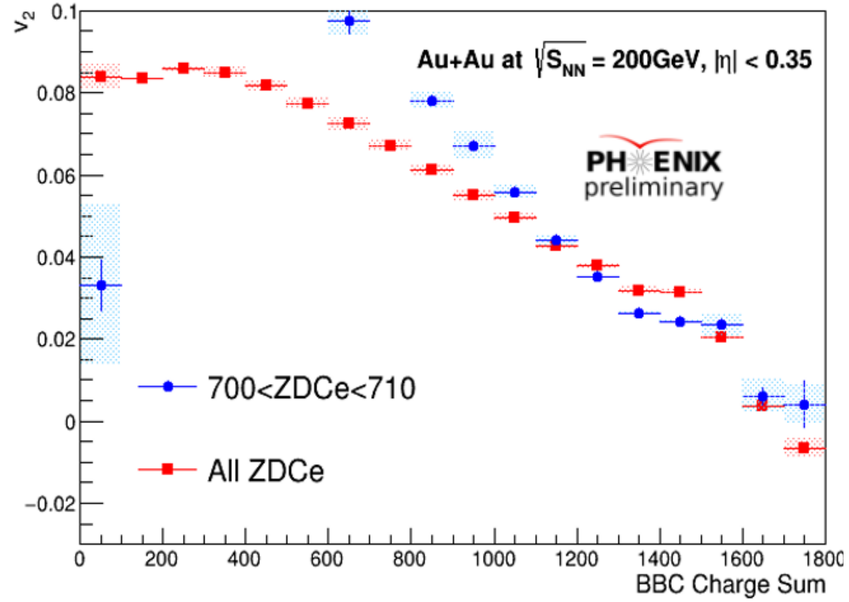
Red : without ZDCe event categorization

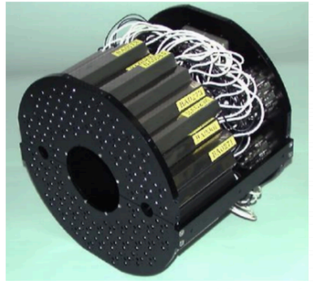
Blue : with ZDCe event categorization

The different tendencies are can be seen in v_2 as a function of BBC-multiplicity and v_2 as a function of CNT-multiplicity when the ZDCe event cut is applied.

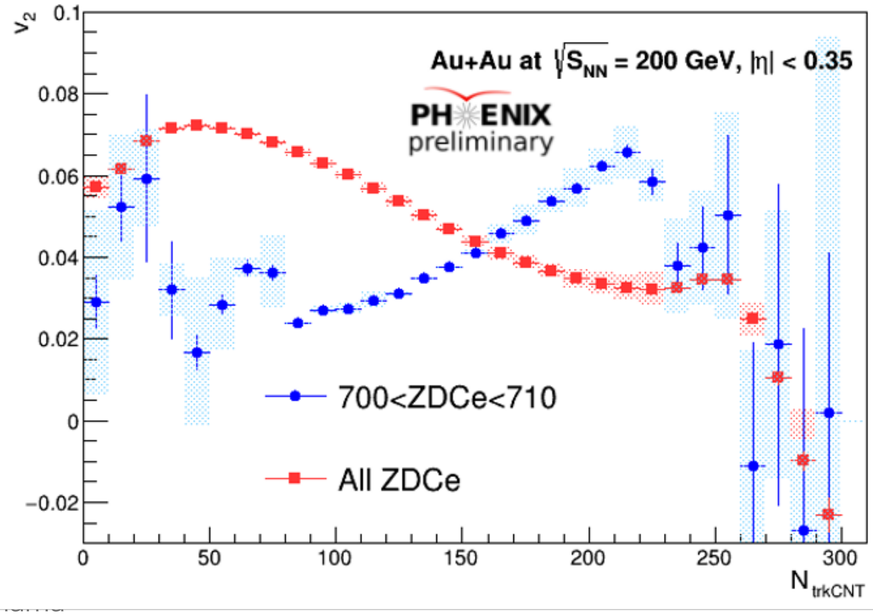


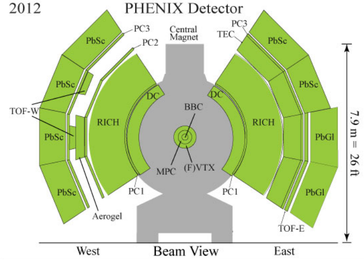
v_2 as a function of BBC-multiplicity : $3.1 < |\eta| < 3.9$





v_2 as a function of CNT-multiplicity: $|\eta| < 0.35$



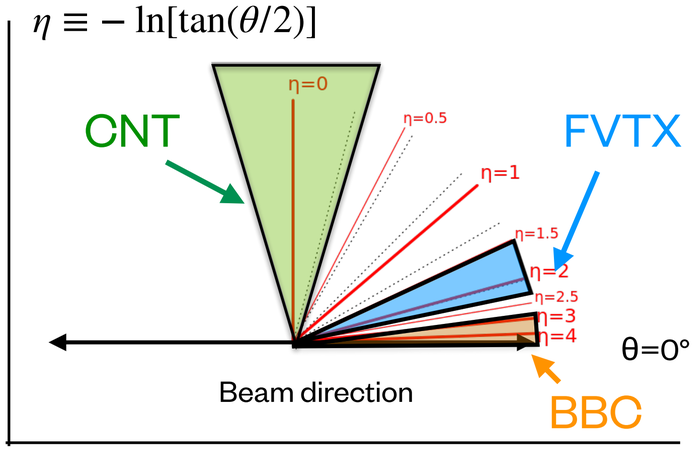


Results: multiplicity at different rapidity

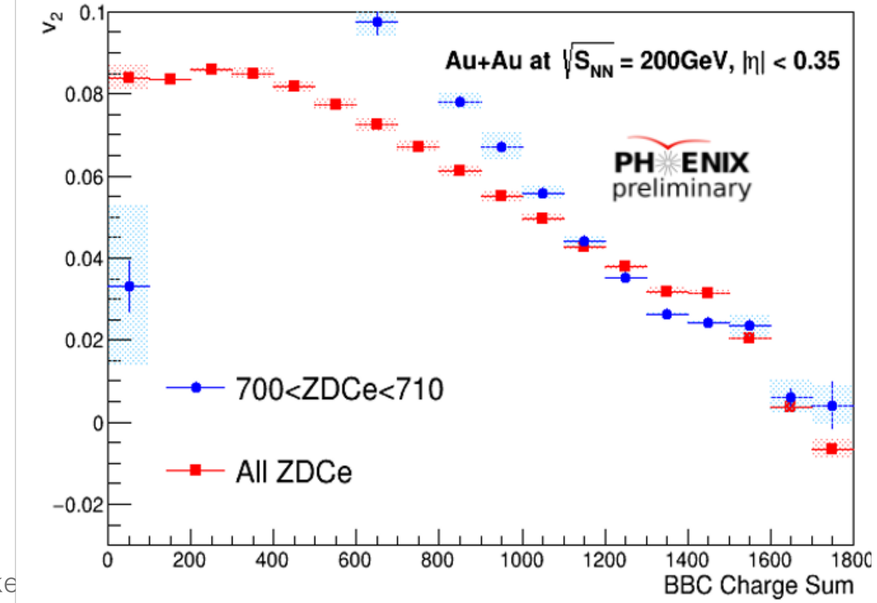
Bias caused by the detector's shape is there

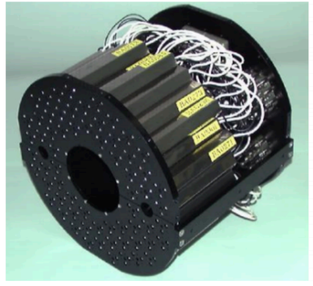
Red : without ZDCe event categorization

Blue : with ZDCe event categorization

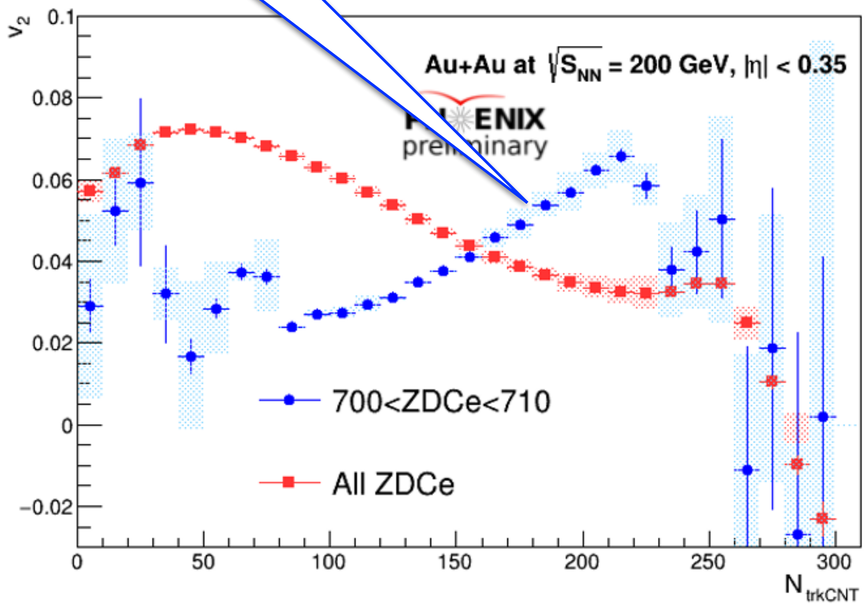


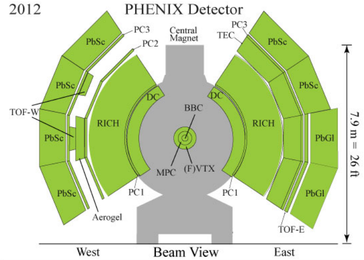
v_2 as a function of BBC-multiplicity : 3.1 < |η| < 3.9





v_2 as a fun[illegible]n of CNT-multiplicity: |η| < 0.35





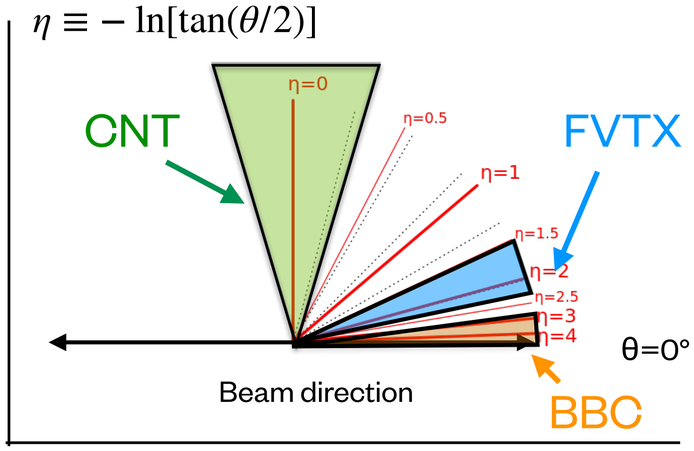
Results: multiplicity at different rapidity

Red： without ZDCe event categorization

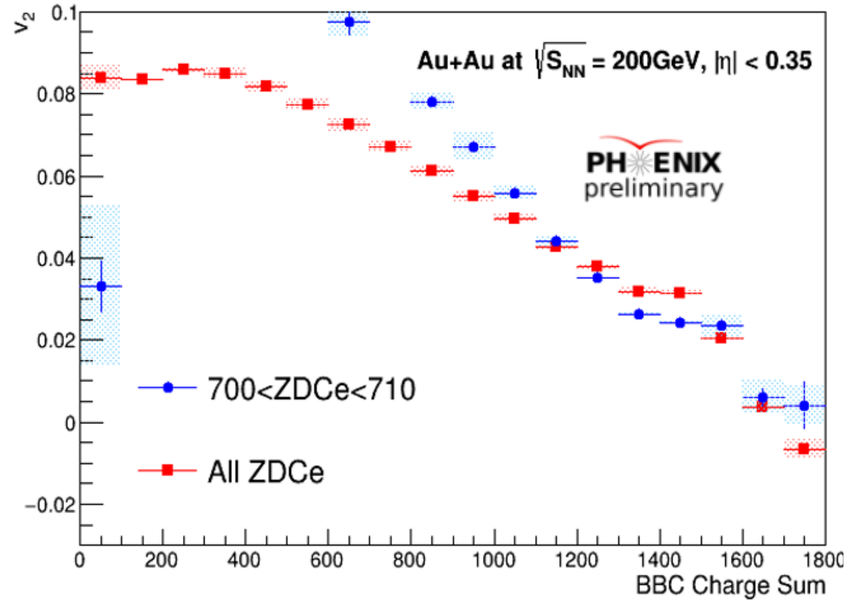
Blue： with ZDCe event categorization

We study the v_2, as a function of different rapidity in the condition of bias of detector shape never generate.

- **v_2 vs. BBC-multiplicity**
- **v_2 vs. FVTX- multiplicity**



v_2 as a function of BBC-multiplicity : 3.1 < |η| < 3.9



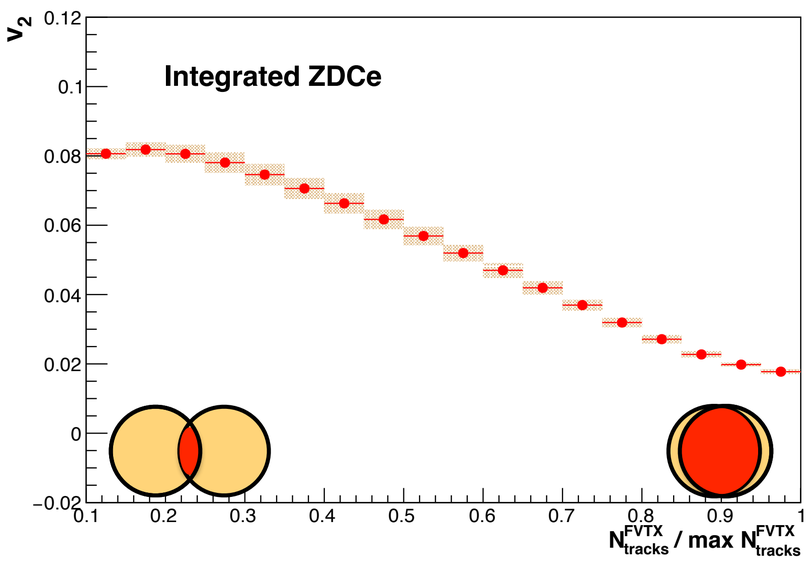
v_2 as a function of FVTX-multiplicity : 1.5 < |η| < 2.5

Result: v_2 without ZDCe event categorization

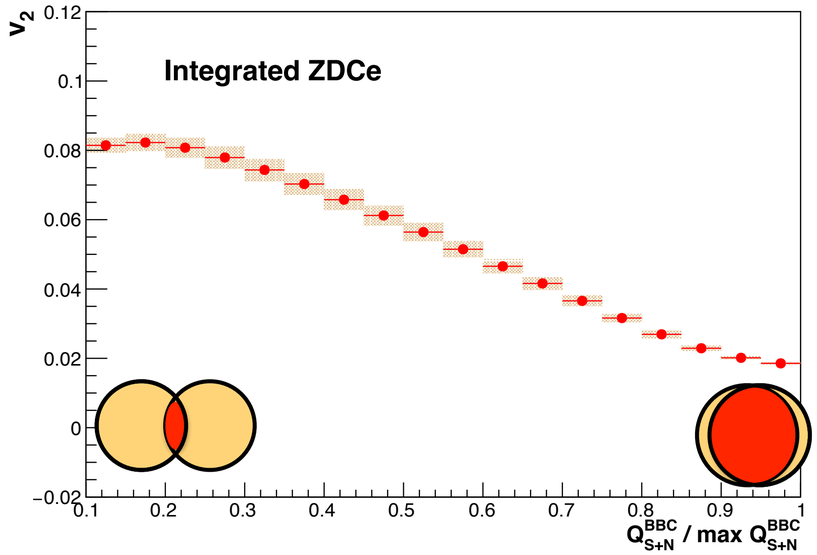
v_2 decrease as the number of produced particles increases

→ the tendency is consistent qualitatively with the previous study of v_2 depending on centrality.

v_2 as a function of **FVTX**-multiplicity

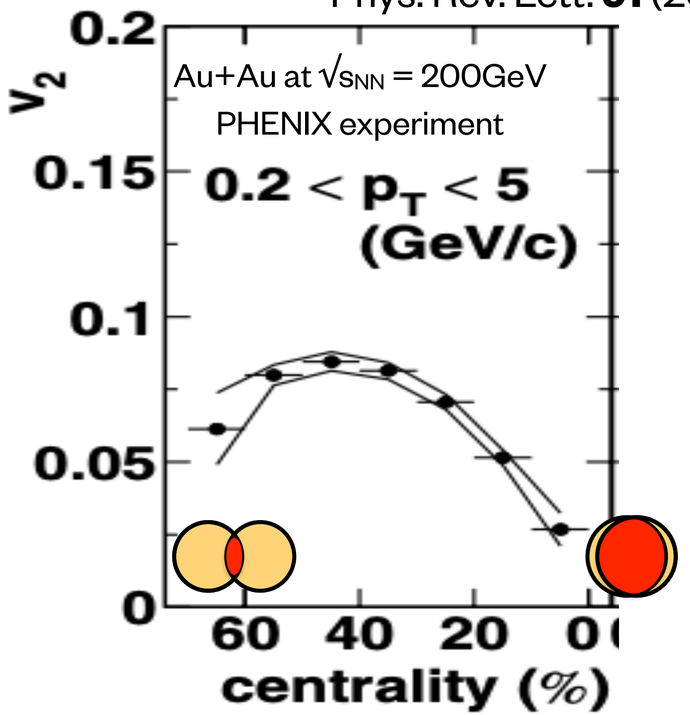


v_2 a s function of **BBC**-multiplicity



Previous result:
v_2 as a function of **centrality**

Phys. Rev. Lett. **91** (2003)



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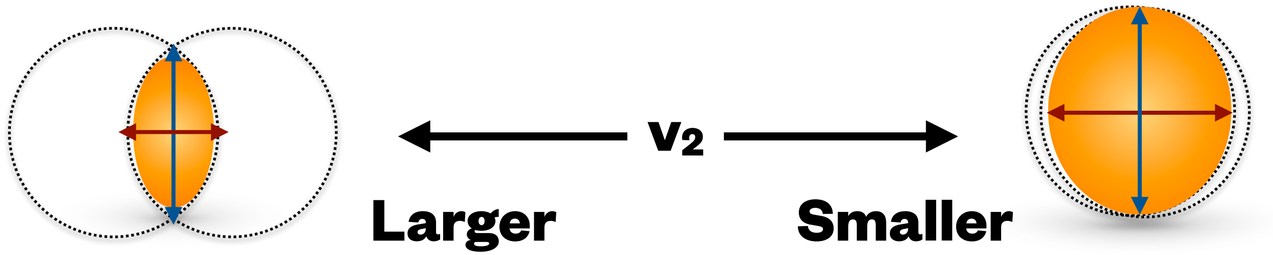
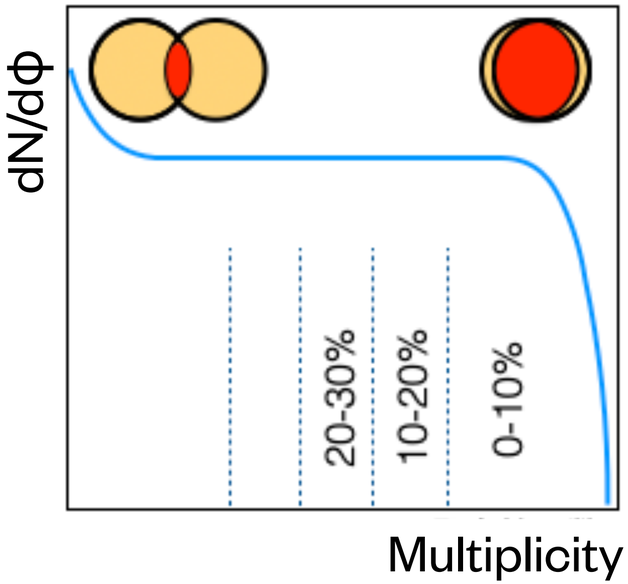
Introduction

4. Correlation of centrality and v_2

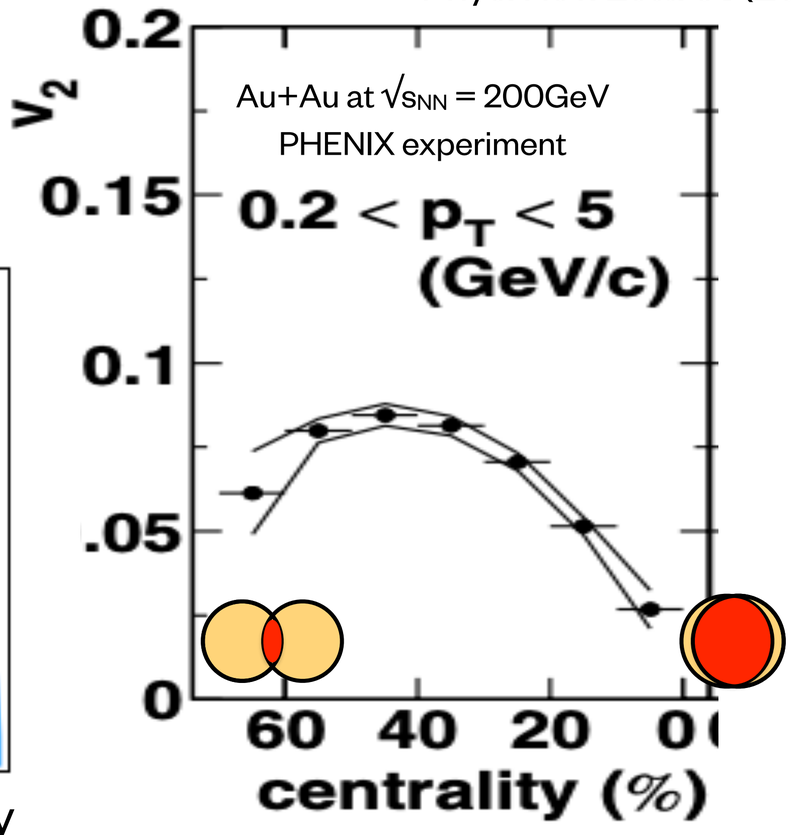


- Centrality reflects the volume of the reaction region



Previous result:
v_2 as a function of **centrality**

Phys. Rev. Lett. **91** (2003)



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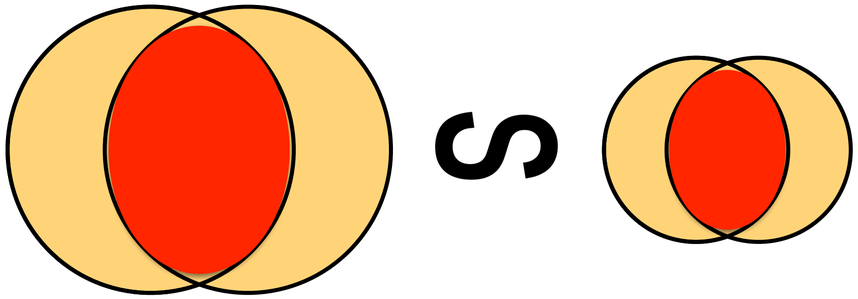


Au+Au

v_2^{Au}

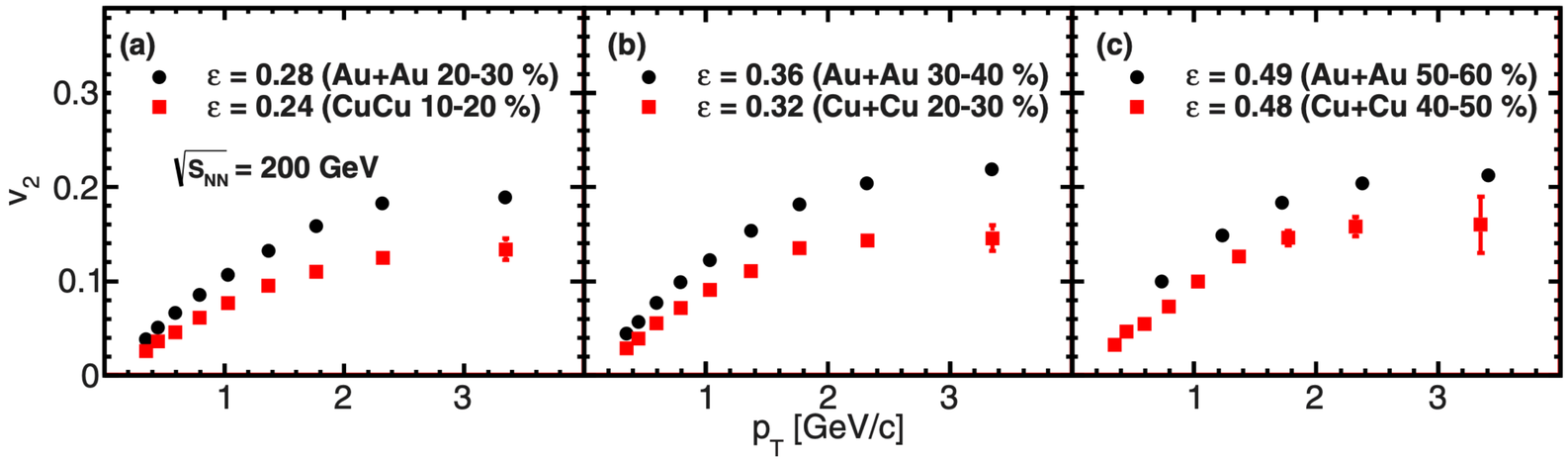
>

Cu+Cu

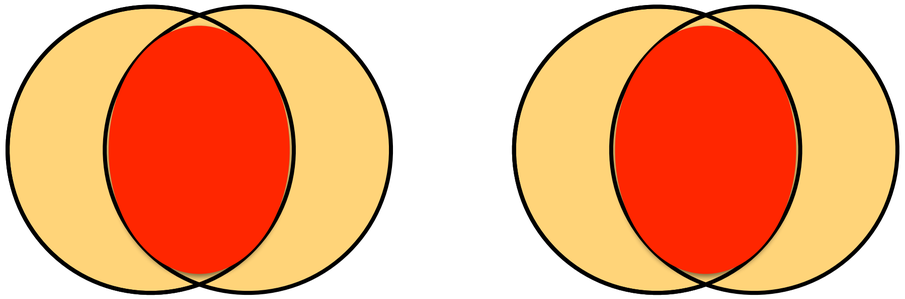
v_2^{Cu}

- v_2 will be larger when more energy injecting into the reaction region at the same eccentricity.
- Since the injecting energy is converted to the energy for producing the particles, the multiplicity reflects the energy injected into the collision.

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



Introduction



Au+Au

v_2^{Au}

>

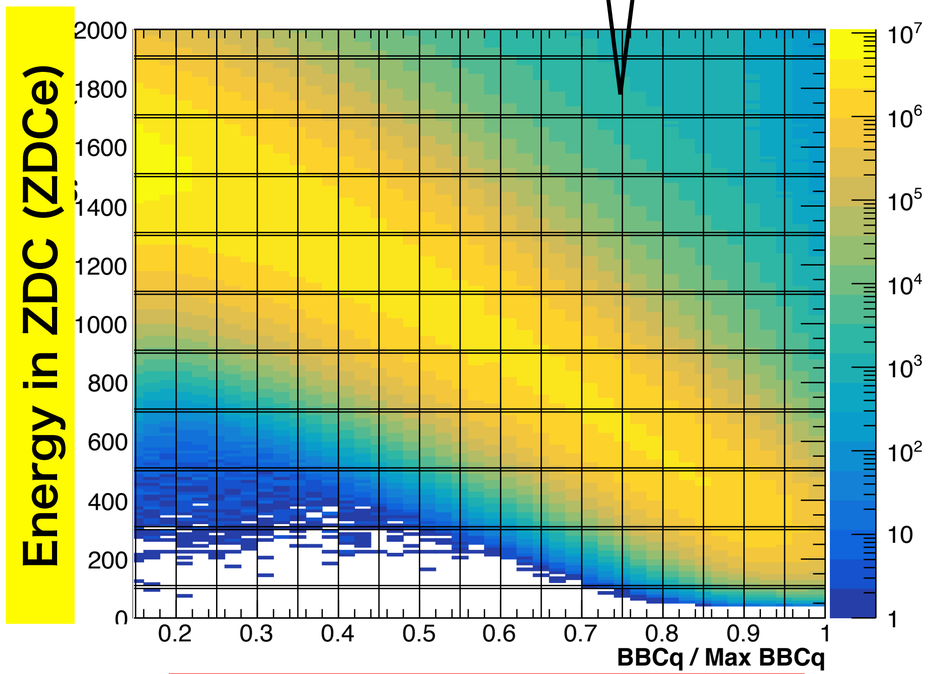
Au+Au

v_2^{Au}

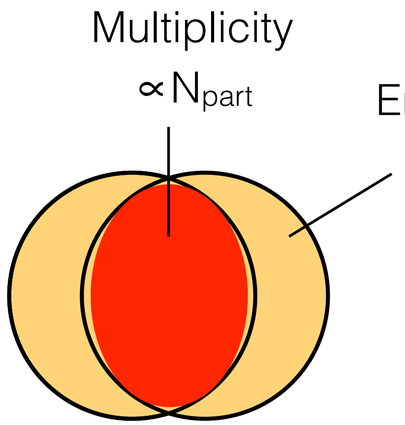
- v_2 will be larger when more energy injecting into the reaction region at the same eccentricity.
- Since the collision energy is converted to the energy for producing the particles, the multiplicity reflects the energy injected into the collision.

Analysis Procedure

The energy in ZDC(ZDCe) ($\propto N_{spec}$) has a negative correlation between multiplicity.



BBC-multiplicity



A: mass number

$$N_{part} + N_{spec} = A \text{ (const)}$$

$$\therefore N_{part} = A - N_{spec}$$

Fixing a narrow ZDC bin we studied how does v_2 change with the multiplicity.

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