Measurement of v_2 in p+Pb collisions and d+Au collisions

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Outline

* Introduction
  * Azimuthal anisotropy
* Analysis
  * Analysis method(E.P. , 2P.C. , reference fit)
* Result
  * $v_2(p_T)$ centrality dependence in p+Pb collisions
  * v_2 p_T dependence in p+Pb collisions
  * v_2 p_T dependence in d+Au collisions
* Summery

Introduction

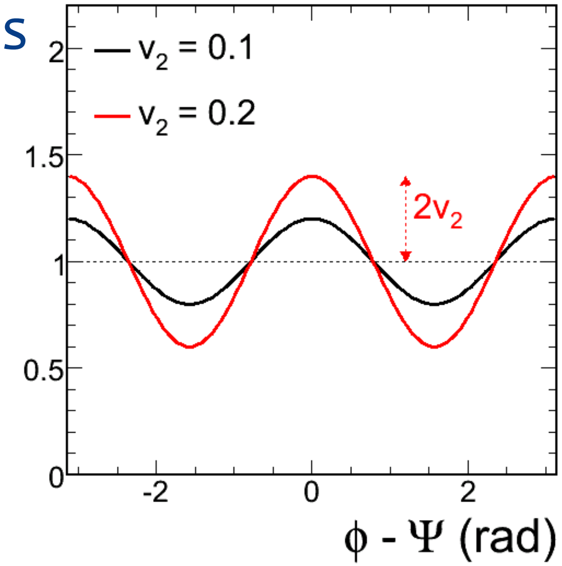
Azimuthal anisotropy (Elliptic flow)

* Azimuthal distribution for emitted particles

$$\frac{dN}{d(\phi - \Psi_n)} \propto 1 + 2\sum v_n cos\{n(\phi - \Psi_n)\}$$

$$v_n = \langle \cos\{n(\phi - \Psi_n)\}\rangle$$

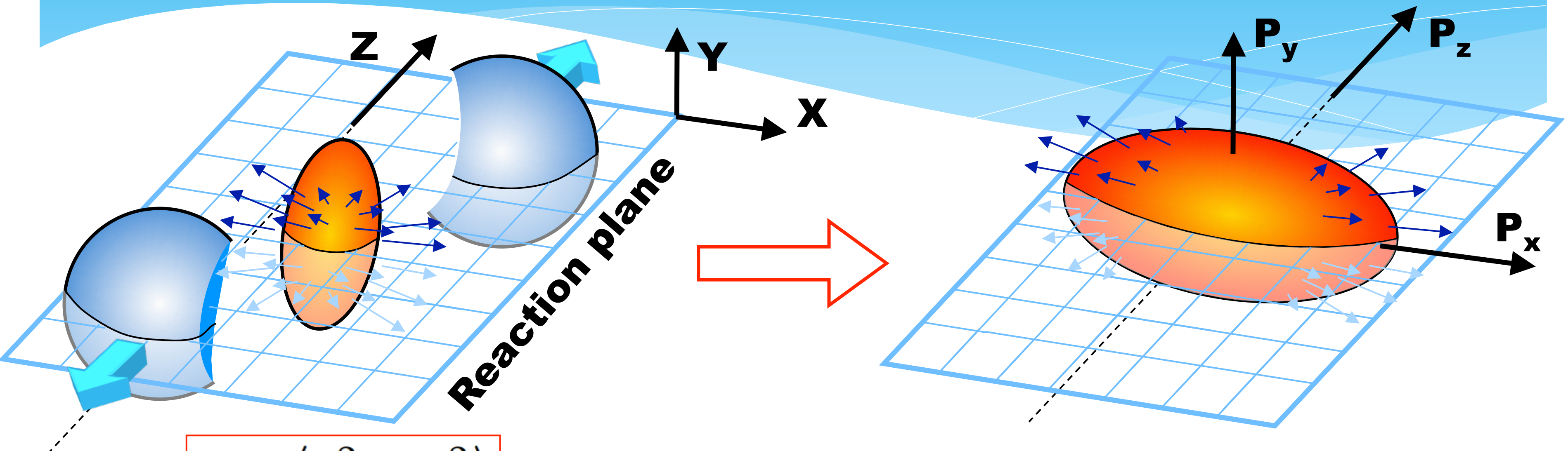
Strength of azimuthal anisotropy



$$v_2 = \langle \cos\{2(\phi - \Psi_2)\}\rangle = \langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \rangle$$

ellipticity of charged particle w.r.t. event plane

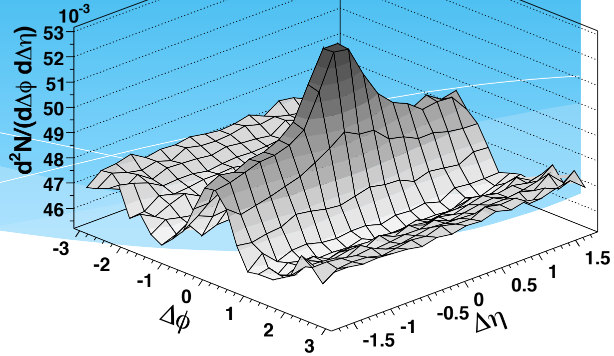
Why Elliptic flow ?



$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \Rightarrow v_2 = \langle \cos 2\phi \rangle$$

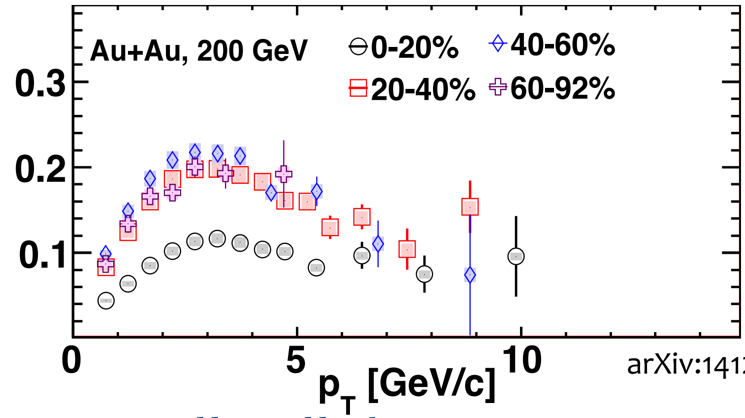
- Initial geometry overlap (eccentricity, ε) ⇒ Final momentum anisotropy (elliptic flow, v_2)
- Sensitive probe for studying properties of the hot dense matter made by heavy ion collisions

Motivation



* Result in Au+Au collisions
  * QGP is created

    →Elliptic flow can be observed



arXiv:1412.1043v1

* Whether or not QGP is created in small colliding system like p+Pb collisions and d+Au collisions

  →Whether or not elliptic flow can be observed

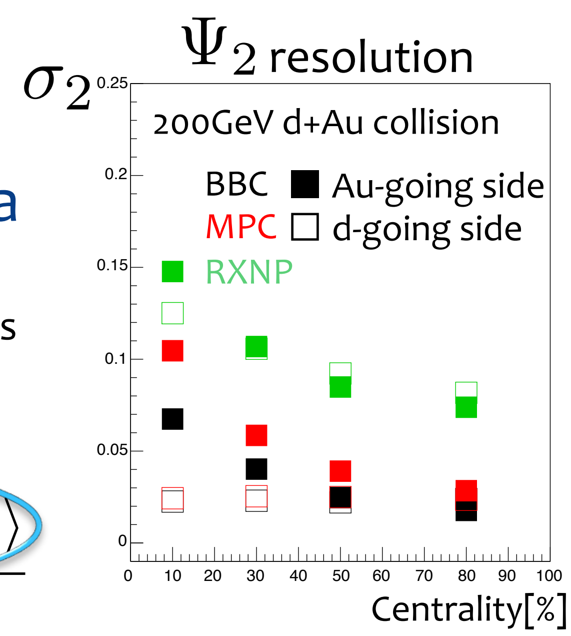
Analysis

1. Event plane method
2. Two particle correlation method
3. Reference fit method

Analysis method (Event plane method)

- Event plane
  - EP is a direction that most particle emitted after freeze-out

$$\Psi_n = \frac{1}{n}\tan^{-1}\left(\frac{\sum_i w_i \cos(n\phi_i)/\sum_i w_i}{\sum_i w_i \sin(n\phi_i)/\sum_i w_i}\right)$$



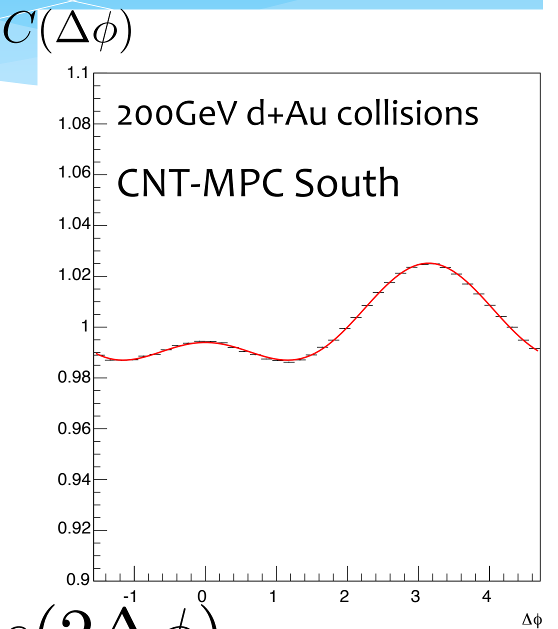
- Measurement of event plane resolution via 3 sub event method

$$\sigma_2^A = \sqrt{\frac{\sigma_2^A\sigma_2^B * \sigma_2^A\sigma_2^C}{\sigma_2^B\sigma_2^C}}$$

v_2^{obs}

- Calculation of v2 $v_2^{true} = \frac{\langle\cos\{2(\phi-\Psi_2)\}\rangle}{\sigma_2}$

Analysis method (2 particle method)



- Event mixing

$$C(\Delta\phi) \equiv \frac{Y_{real}(\Delta\phi)}{Y_{mixed}(\Delta\phi)} \frac{\int Y_{mix}(\Delta\phi) d\Delta\phi}{\int Y_{real}(\Delta\phi) d\Delta\phi}$$

$$\Delta\phi = \phi^{tri} - \phi^{ass}$$

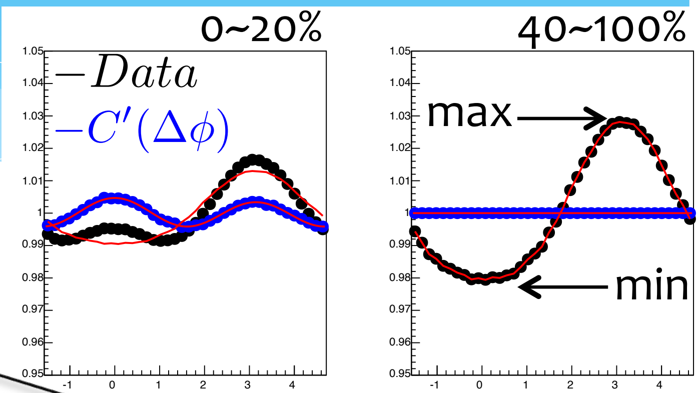
- Fitting into the following function

$$C'(\Delta\phi) = 1 + 2c_1 cos(\Delta\phi) + 2c_2 cos(2\Delta\phi)$$

$$c_2 = c_2^A c_2^B$$

- Calculation c_2 via 3 sub event method $c_2^A = \sqrt{\frac{c_2^A c_2^B * c_2^A c_2^C}{c_2^B c_2^C}}$

Analysis method (Reference fit method)



$$f(\Delta\phi) = (C(\Delta\phi) - min)/(max - min)$$

$$F(\Delta\phi) = a + b * f(\Delta\phi)$$

Fitting 1

Unmodified jet contribution is subtracted

Peripheral data(40%~100%)

$$C'(\Delta\phi) = C(\Delta\phi) - F(\Delta\phi)$$

Fitting 2

Extraction of c_2 parameters w.r.t. reference function

$$C'(\Delta\phi) = 1 + 2c_1 cos(\Delta\phi) + 2c_2 cos(2\Delta\phi)$$

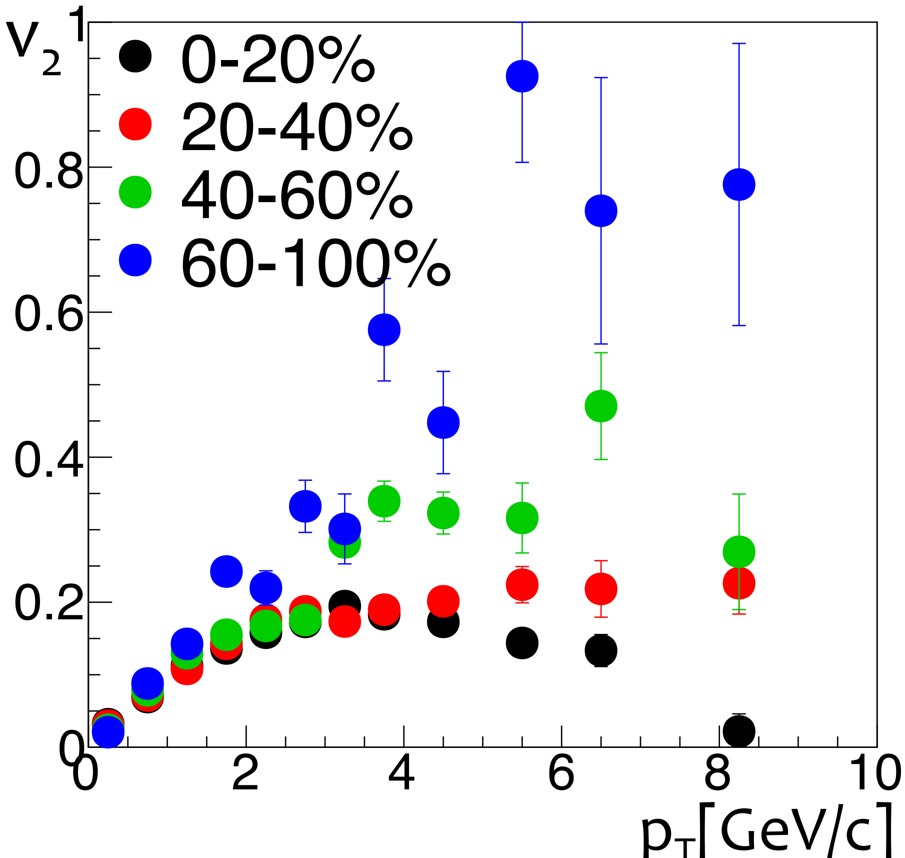
Extracted c_2 parameter is less affected by jet, and are expected to reflect the hydrodynamic collectivity although the signal includes the jet-modification

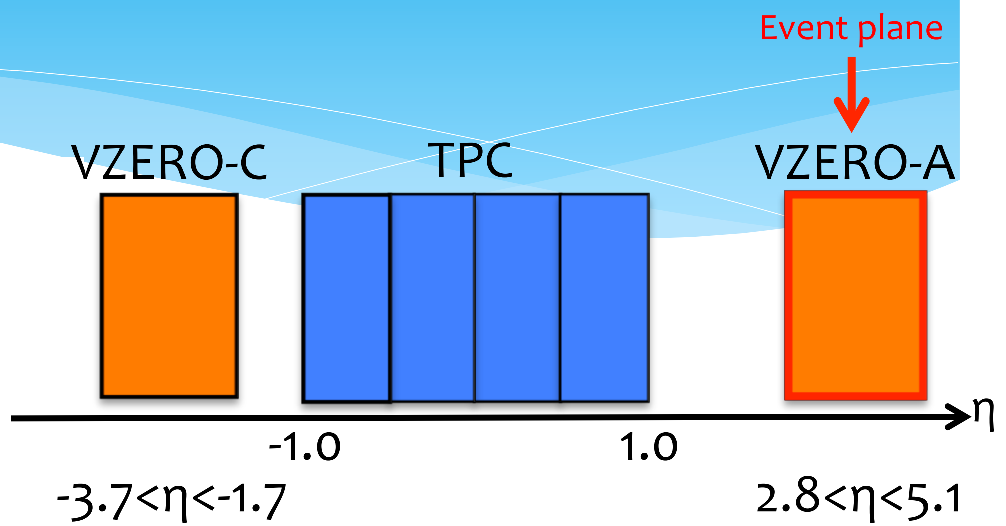
$$c_2^A = \sqrt{\frac{c_2^A c_2^B * c_2^A c_2^C}{c_2^B c_2^C}}$$

Result

$v_2(p_T)$ Centrality dependence in p+Pb collisions

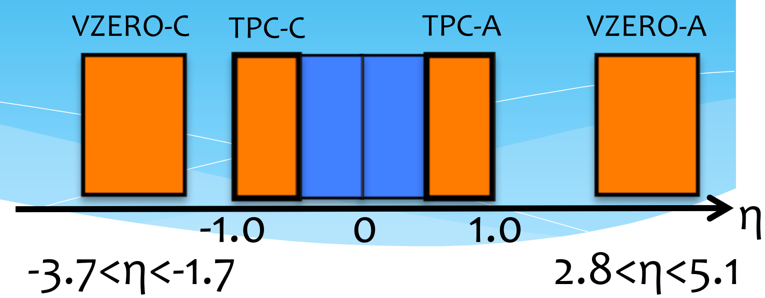
Event plane : VZERO Aside(Pb-going side)
p+Pb 5.02[TeV]





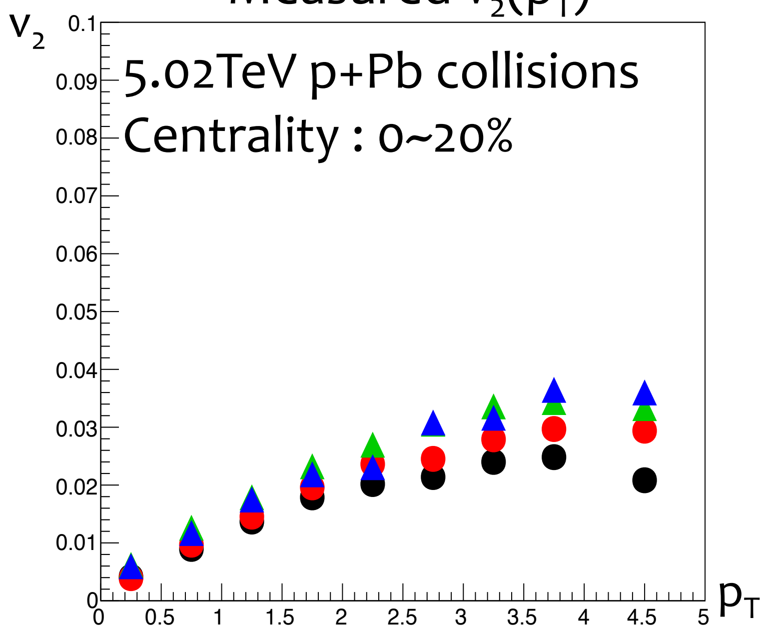
- In peripheral,
  v_2 becomes larger with p_T
- In central,
  v_2 becomes larger up to p_T=3[GeV/c],
  after that, v_2 becomes smaller

v_2 p_T dependence in p+Pb collisions

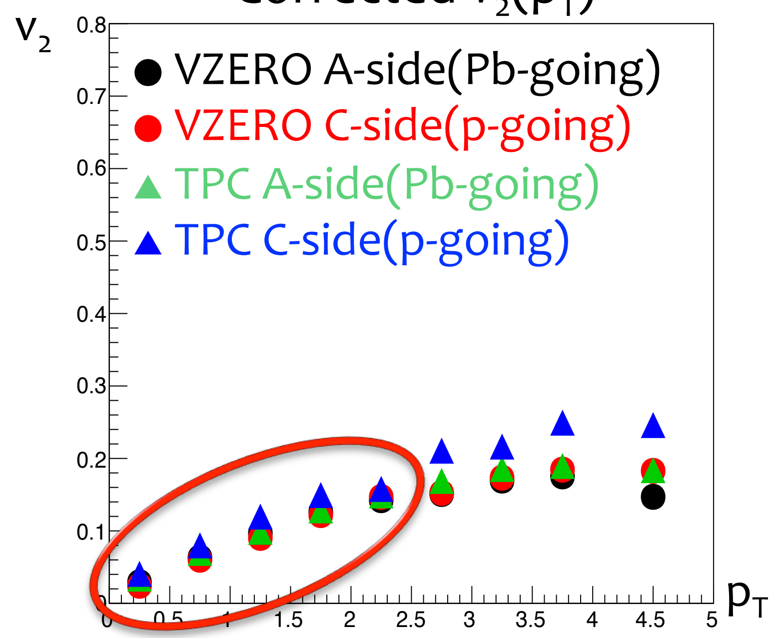


Event plane : Aside(Pb-going) → -1.0<η<0
Event plane : Cside(p-going) → 0<η<1.0

Measured $v_2(p_T)$

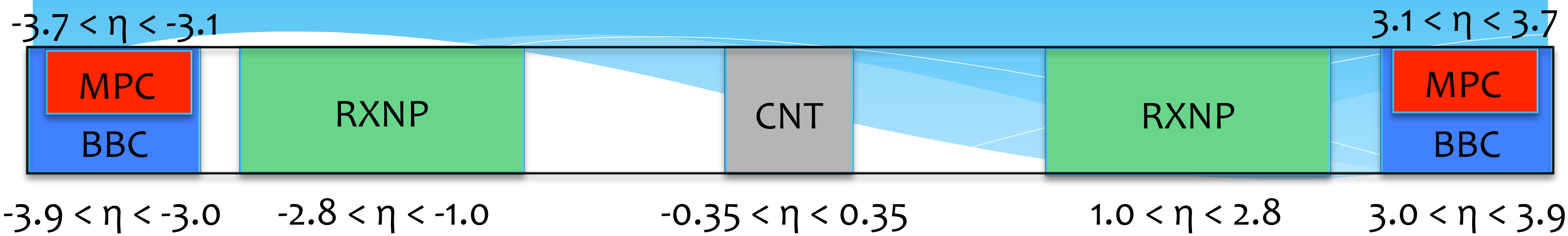


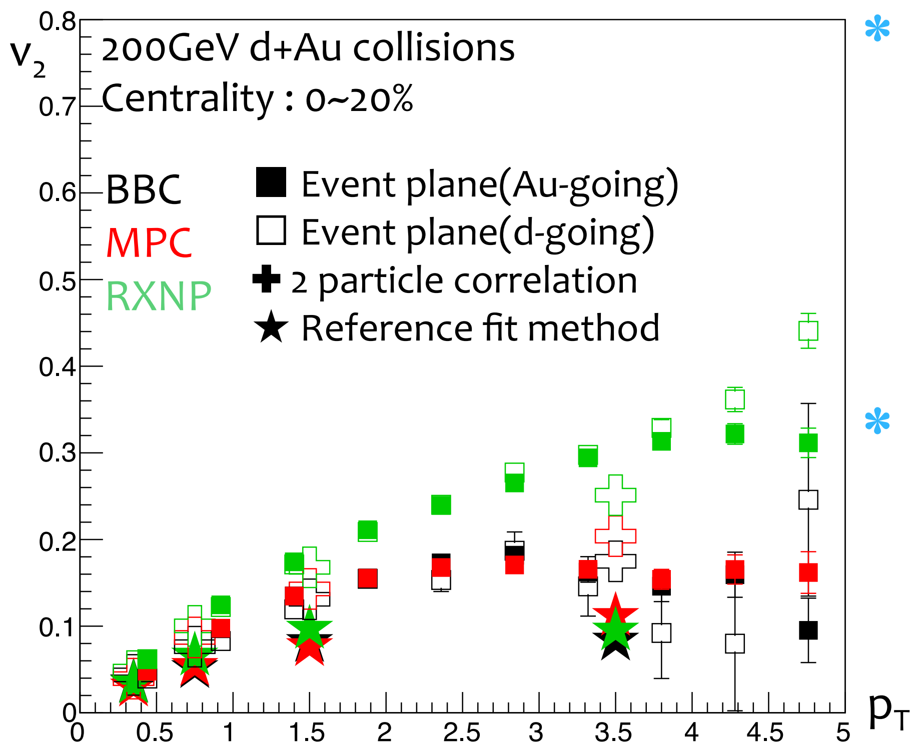
Corrected $v_2(p_T)$



In low p_T, corrected v_2 is consistent more than measured v_2

v_2 p_T dependence in d+Au collisions





- v_2^{RXNP} via event plane method and via two particle correlation method is larger than v_2^{BBC} and v_2^{MPC}
  - eta-gap between CNT and RXNP is narrower than CNT-BBC(MPC)
- v_2^{RXNP} via reference fit method is consistent with v_2^{BBC} and v_2^{MPC}
  - Jet contribution is subtracted
    - **v_2 subtracted jet contribution has finite value**

Summery

* v_2 was measured in p+Pb collisions and in d+Au collisions.
  * In p+Pb collisions
    * In central event, v_2 becomes larger up to p_T=3, after that v_2 becomes smaller
    * In low p_T, corrected v_2 is consistent more than raw v_2
  * In d+Au collisions
    * v_2^{RXNP} is larger than v_2^{BBC} and v_2^{MPC}
    * v_2^{RXNP} via reference fit method is consistent with v_2^{BBC} and v_2^{MPC}

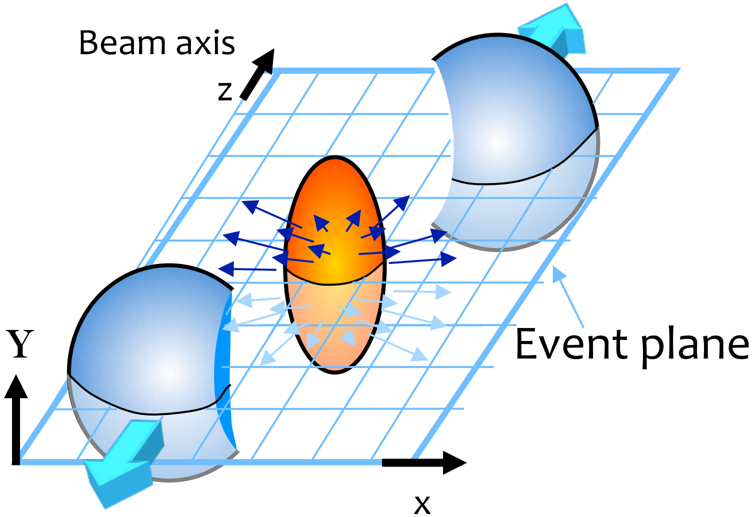
➡ **v_2 subtracted jet contribution has finite value**

Back up

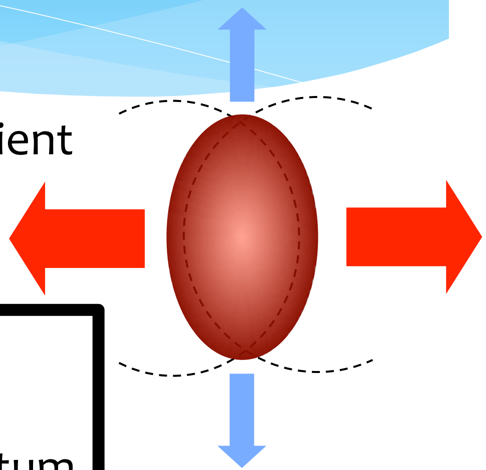
Data set

* ALICE 5.02TeV p+Pb collisions
  * Centrality[%] : 0~20,20~40,40~60,60~100
  * p_T[GeV/c] : 0~0.5,0.5~1.0,1.0~2.0,2.0~4.0,4.0~10.0
  * Detector : TPC,VZERO
  * Analysis method : E.P.
* PHENIX 200GeV d+Au collisions
  * Centrality[%] : 0~20,20~40,40~60,60~100
  * p_T[GeV/c] : 0.2~0.5,0.5~1.0,1.0~2.0,2.0~5.0
  * Detector : CNT,BBC,MPC,RXNP,SMD
  * Analysis method : E.P, 2P.C.,reference fit

Azimuthal anisotropy (Elliptic flow)



Anisotropic pressure gradient



Spatial anisotropy
⬇
Anisotropy of the momentum

* Azimuthal distribution of charged particle

$$\frac{dN}{d(\phi-\Psi_n)} \propto 1 + 2\sum v_n cos\{n(\phi-\Psi_n)\}$$

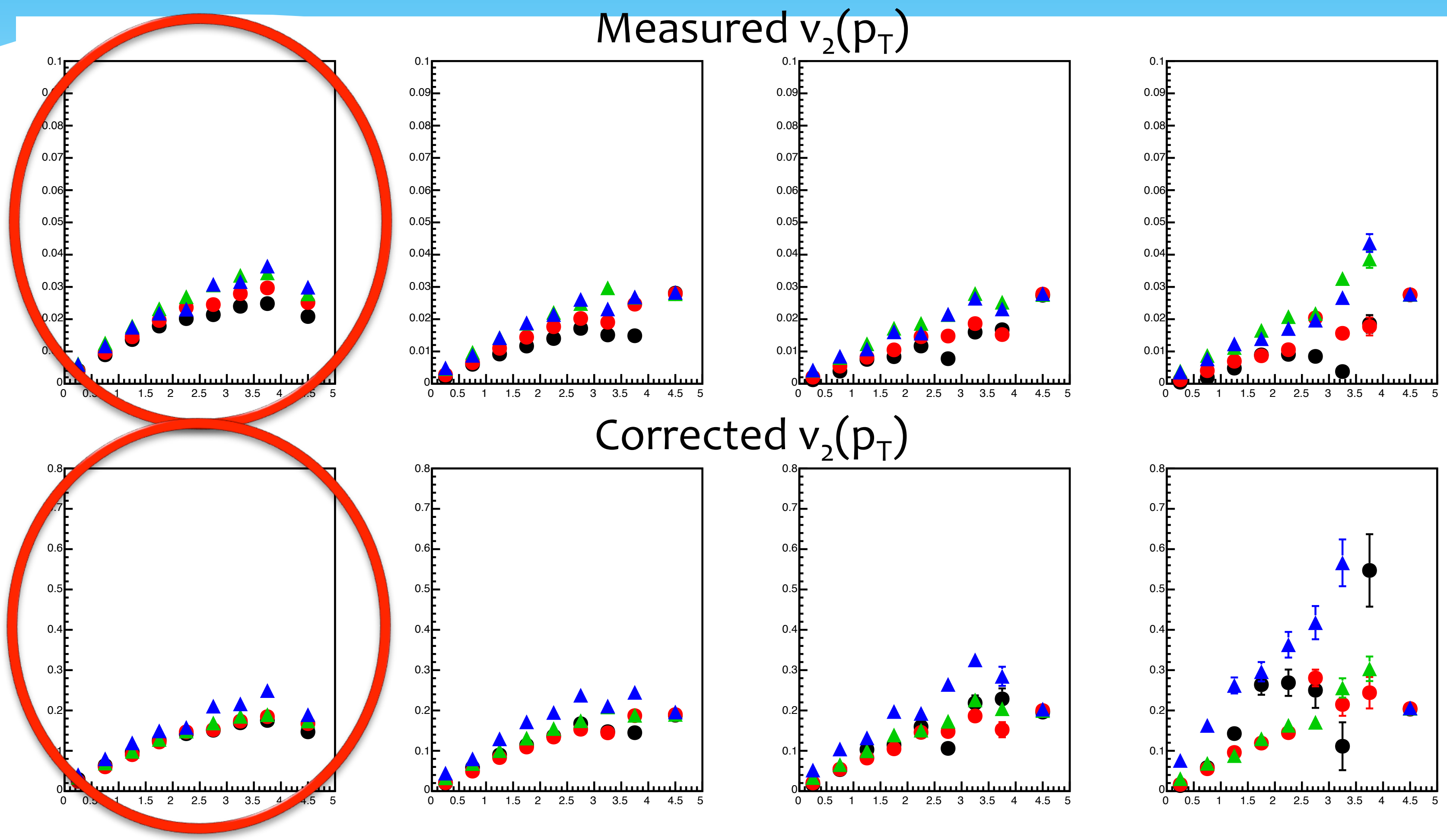
ellipticity of charged particle w.r.t. event plane

$$v_n = \langle \cos\{n(\phi-\Psi_n)\}\rangle$$

Strength of azimuthal anisotropy

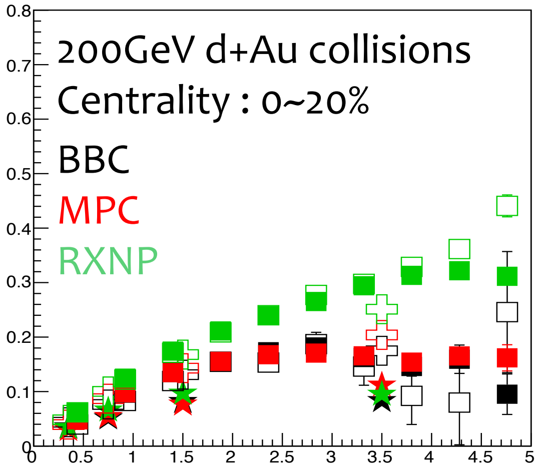
$$v_2 = \langle \cos\{2(\phi-\Psi_2)\}\rangle = \langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \rangle$$

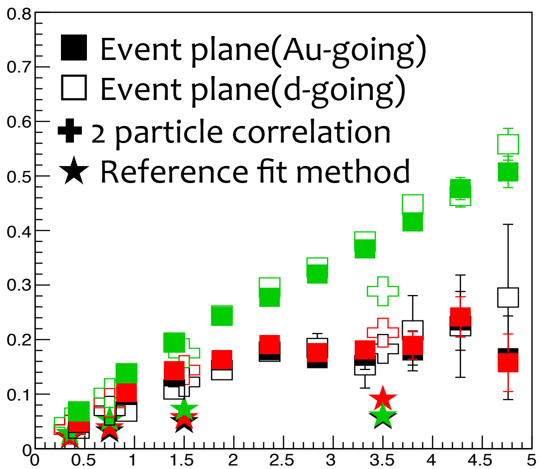
v_2 p_T dependence in p+Pb collisions



In central event, corrected v_2 is consistent more than measured v_2

v_2 p_T dependence in d+Au collisions





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