Methods for anisotropic flow measurements with the MPD Experiment at NICA

Dim Idrisov, Vinh Ba Luong, Arkadiy Taranenko, Petr Parfenov

(NRNU MEPhI)

This work is supported by:
- the RFBR according to the research project no. 18-02-40086
- the European Union‘s Horizon 2020 research and innovation program under grant agreement No. 871072

The 5th international conference on particle physics and astrophysics

5-9 October 2020

Outline

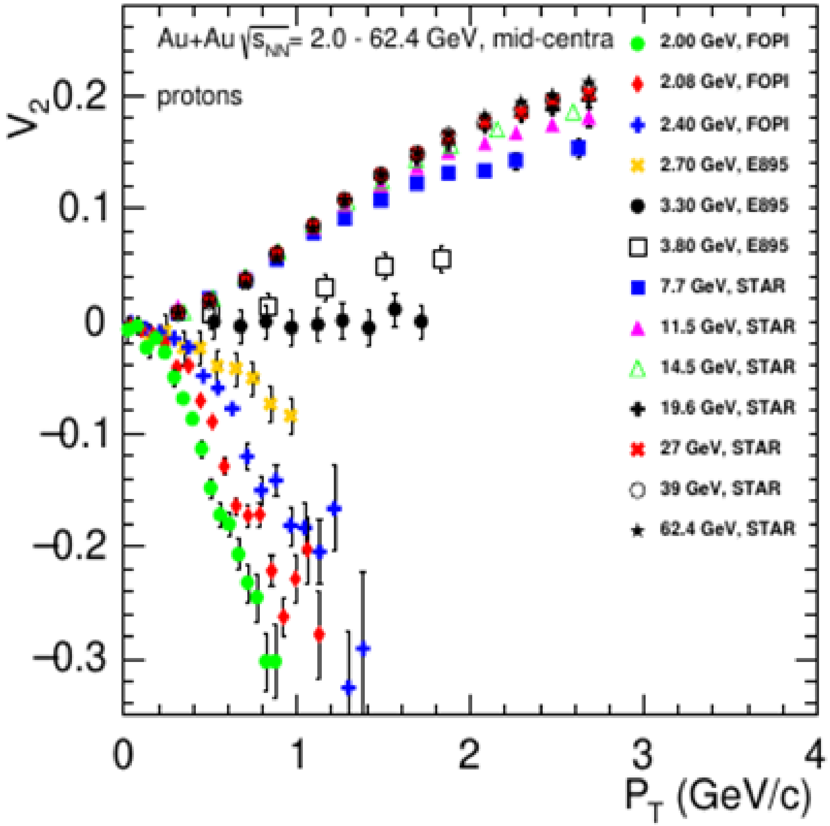
- Anisotropic flow at NICA energies
- Description of direct cumulant and event plane methods
- Sensitivity of different orders of cumulants to elliptic flow fluctuations
- Feasibility study for elliptic flow of charged hadrons :
  - for Au+Au, Bi+Bi collisions at $\sqrt{s_{NN}}$ = 7.7 and 11.5 GeV in UrQMD model
  - for reconstructed UrQMD events in MPD detector at NICA
  - Comparison Bi+Bi with Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV
- Summary and outlook

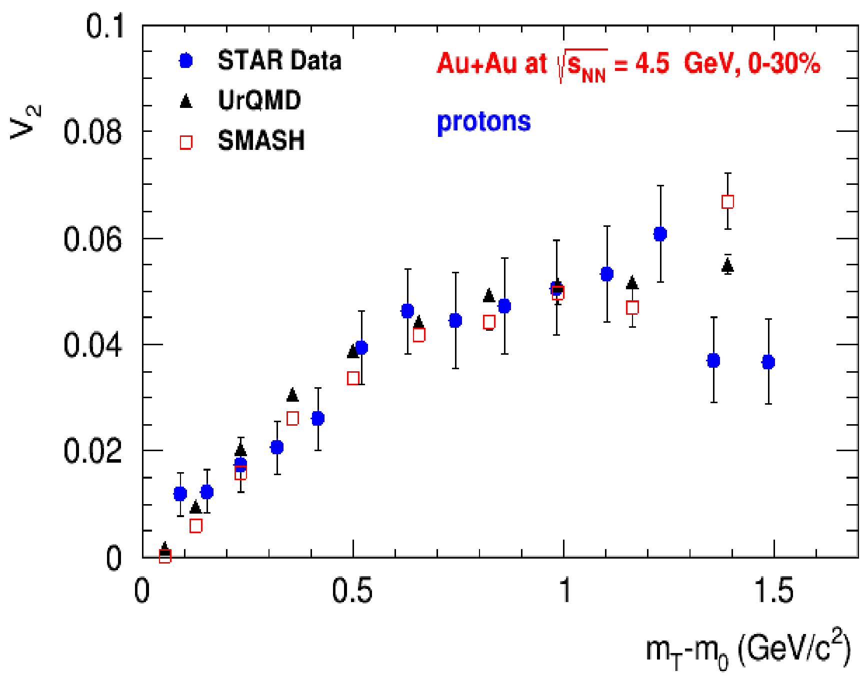
Elliptic flow at NICA energies

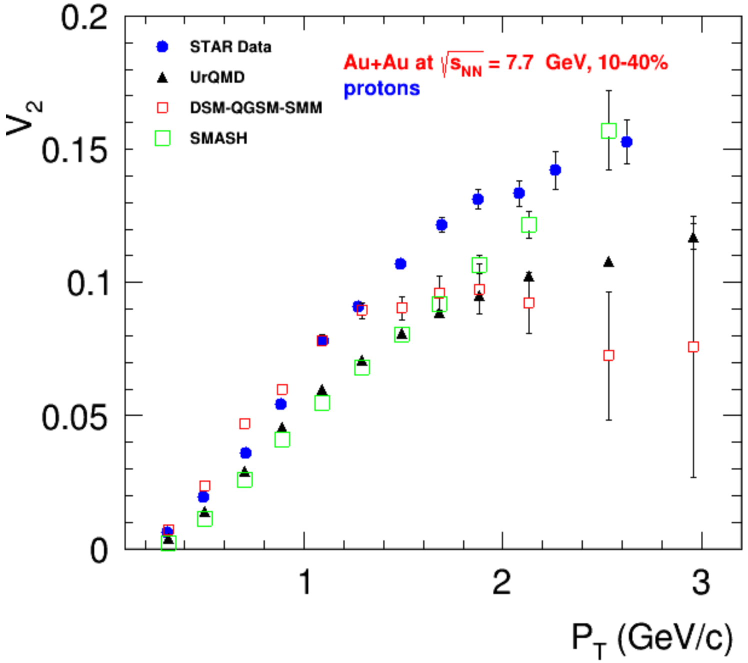
$$\frac{dN}{N_0 d(\phi-\psi_R)} = \frac{1}{2\pi}(1+\sum_1^{\infty} 2\mathrm{v}_n \cos(n(\phi-\psi_R)))$$

v_1 - direct flow

v_2 - elliptic flow







- **At √sNN=4.5 GeV pure string/hadronic cascade models give similar v_2 signal compared to STAR data**
- **At √sNN=7.7 GeV pure string/hadronic cascade models underpredict v_2**
- **v_2 is sensitive to the properties of strongly interacted matter**

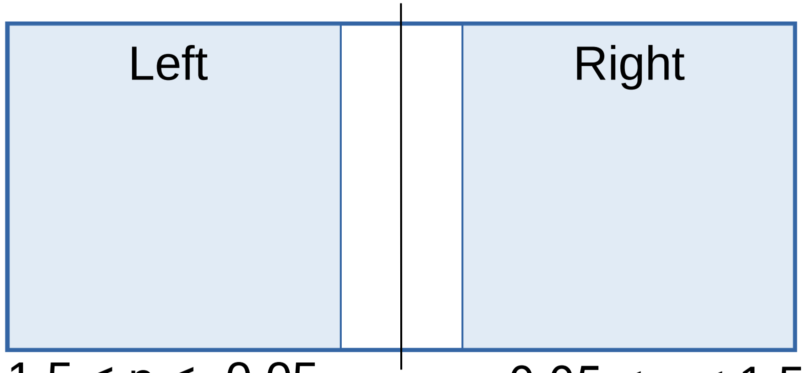
Description of event plane method

$$\mathbf{Q}_n = \sum_{j=1}^{N} w_n(j)\, e^{in\phi_j} = |\mathbf{Q}_n|\, e^{in\Phi_n} \qquad (1)$$

$$Q_n \cos(n\Psi_n) = X_n = \sum_i w_i \cos(n\phi_i),$$
$$Q_n \sin(n\Psi_n) = Y_n = \sum_i w_i \sin(n\phi_i),$$

$$\Psi_n = \left(\tan^{-1}\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right)/n \qquad (2)$$

- η-sub EP method: resolution of the reaction plane Ψ_2 obtained from 2 sub-events



$-1.5 < \eta < -0.05$ $\qquad$ $0.05 < \eta < 1.5$

Left half ($\eta<-0.05$) → η_-

Right half ($\eta>0.05$) → η_+

$$v_2\{\eta\text{-sub,EP}\} = \frac{\langle cos[n(\phi_{\eta\pm} - \Psi_{2,\eta\mp})]\rangle}{\sqrt{\langle cos[n(\Psi_{2,\eta+} - \Psi_{2,\eta-})]\rangle}} \qquad (3)$$

Description of direct cumulant method for flow measurements

2 and 4 particle azimuthal correlations

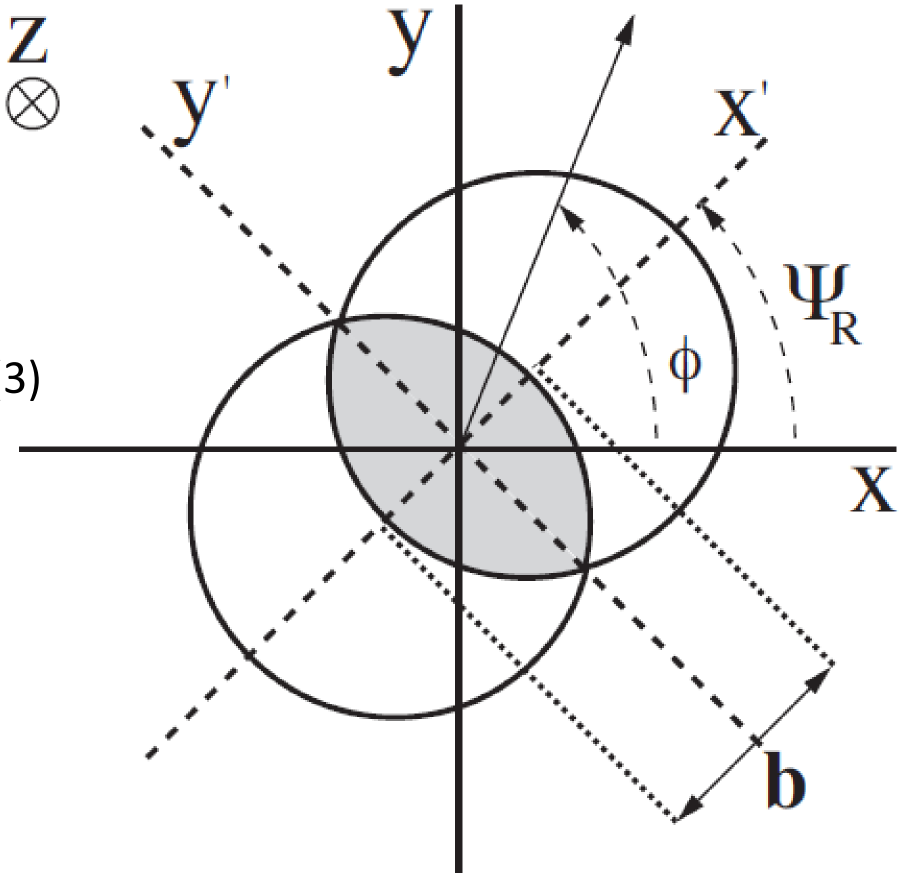
$$\langle 2\rangle_n = \frac{|Q_n|^2 - M}{M(M-1)} \quad (1) \quad \text{where} \quad Q_n = \sum_{i=1}^{M} e^{in\varphi_i} \quad (2)$$

$$\langle 4\rangle_n = \frac{|Q_n|^4 + |Q_{2n}|^2 - 2\left|Q_{2n}Q_n^*Q_n^*\right| - 4M(M-2)|Q_n|^2 + 2M(M-3)}{M(M-1)(M-2)(M-3)} \quad (3)$$

Elliptic flow estimate with direct cumulant method

$$\langle 2\rangle_n = \mathrm{v}_n^2 + \delta_n \qquad \langle 4\rangle_n = \mathrm{v}_n^4 + 4\mathrm{v}_n^2\delta_n + 2\delta_n^2 \quad (4)$$

$$\mathrm{v}_n\{2\} = \sqrt{\langle\langle 2\rangle\rangle} \qquad \mathrm{v}_n\{4\} = \sqrt[4]{2\langle\langle 2\rangle\rangle^2 - \langle\langle 4\rangle\rangle} \quad (5)$$



This method was introduced by Ante Bilandzic in Phys. Rev. C83:044913, 2011

Sensitivity of different orders cumulants to elliptic flow fluctuations

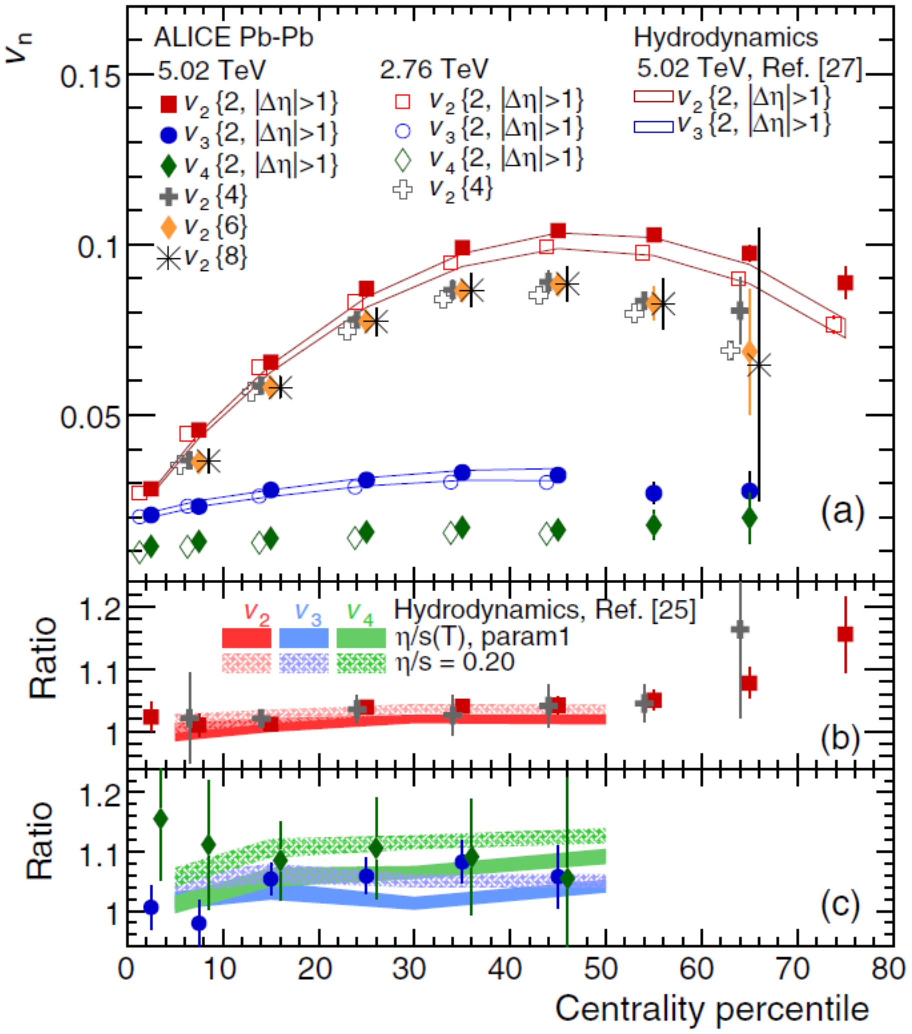
- How fluctuations affect the measured values of v_n. The effect of the fluctuations on v_n estimates can be obtained from

$$\left\langle v_n^2 \right\rangle = \bar{v}_n^2 + \sigma_{v_n}^2, \quad \left\langle v_n^4 \right\rangle = \bar{v}_n^4 + 6\sigma_{v_n}^2 \bar{v}_n^2$$

$$v_n\{2\} = \sqrt{\left\langle v_n^2 \right\rangle}, \quad v_n\{4\} = \sqrt[4]{2\left\langle v_n^2 \right\rangle^2 - \left\langle v_n^4 \right\rangle}$$

- The difference between $v_n\{2\}$ and $v_n\{4\}$ is sensitive to not only nonflow but also to the event-by-event v_n fluctuations.

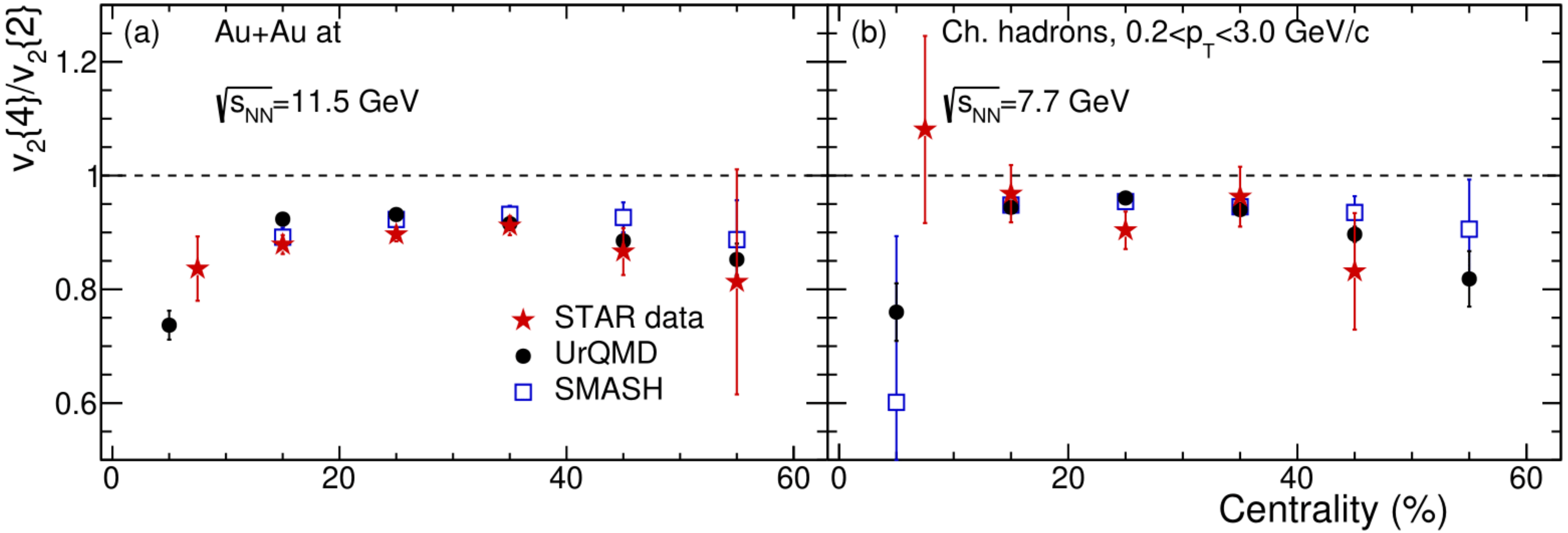
$$v_n\{2\} = \bar{v}_n + \frac{1}{2}\frac{\sigma_{v_n}^2}{\bar{v}_n}, \quad v_n\{4\} = \bar{v}_n - \frac{1}{2}\frac{\sigma_{v_n}^2}{\bar{v}_n}$$



J. Adam et al. The ALICE Collaboration Phys. Rev. Lett. 116 (2016) 132302

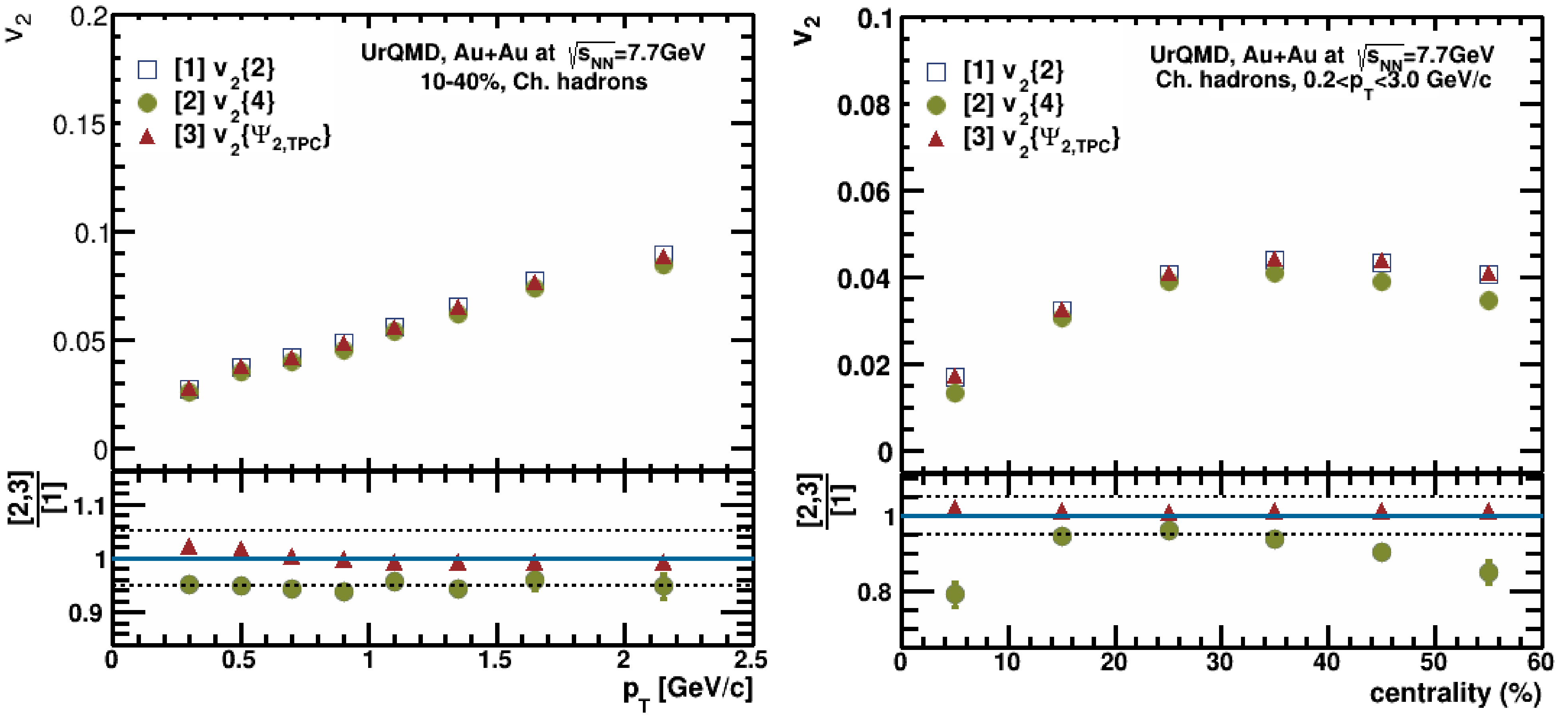
Comparison of models results with STAR data for Au+Au collisions at 11.5 GeV and 7.7 GeV

L. Adamczyk et al. (STAR Collaboration). Phys. Rev. C 86, 054908 (2012)



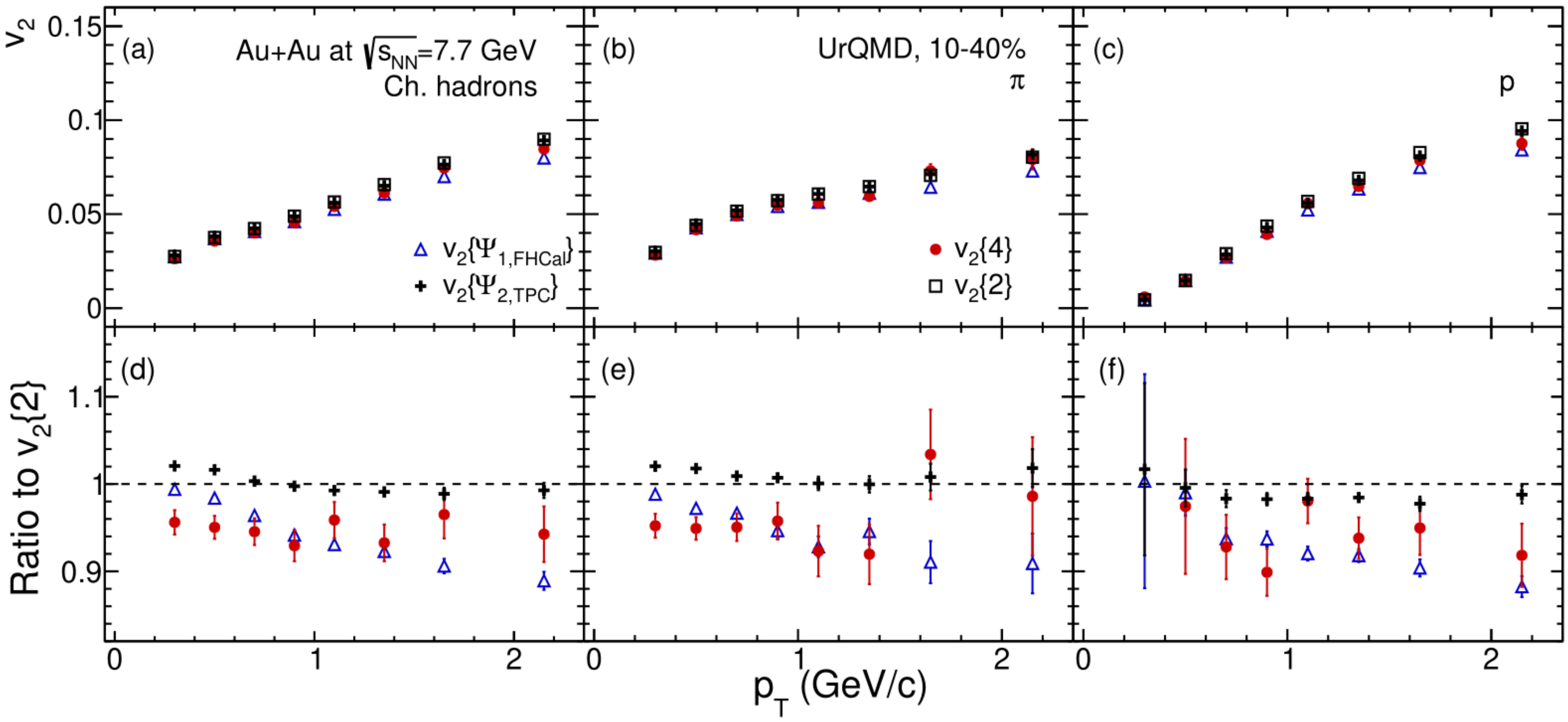
- Fluctuation driven difference between $v_2\{4\}$ and $v_2\{2\}$ is reproduced in UrQMD and SMASH models
- Flow measurements for models were done using STAR-like analysis method

Results for v_2 from UrQMD model of Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV



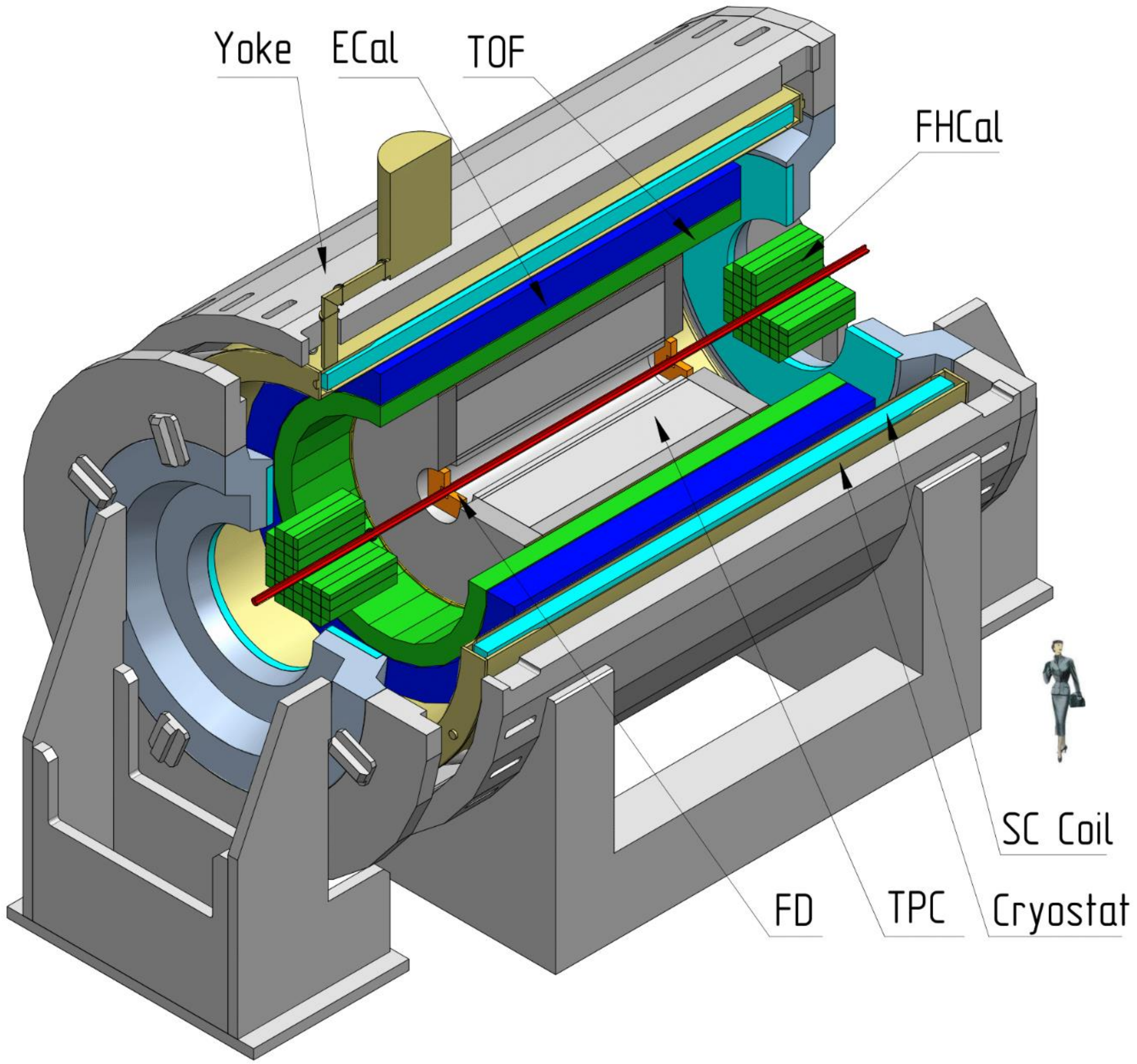
- $v_2\{2\}$ is in a good agreement with $v_2(\psi_{2,TPC})$ at 10-40% centrality
  - $v_2\{4\}$ is smaller than $v_2\{2\}$ due to fluctuations and nonflow

Methods comparison



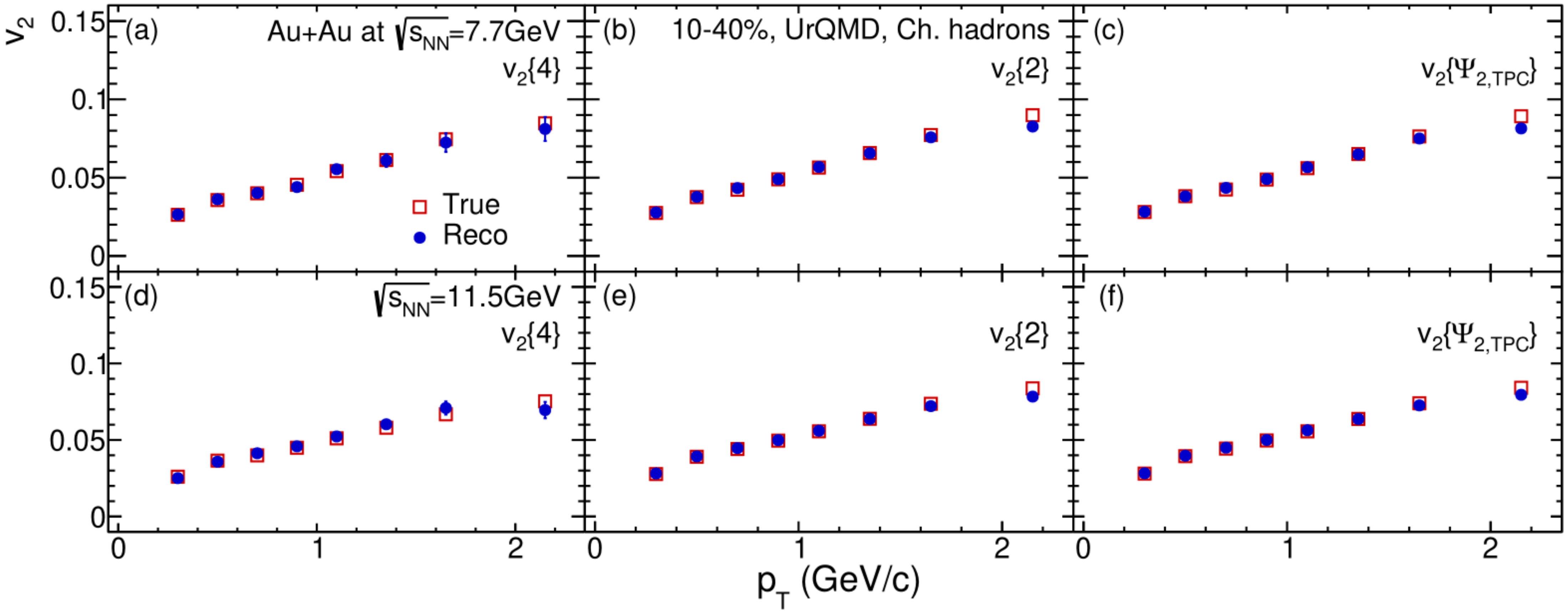
- $v_2\{2\}$ and $v_2(\psi_{2,TPC})$ are in a good agreement
- $v_2\{4\}$ and $v_2(\psi_{1,FHCal})$ are smaller than $v_2\{2\}$ due to fluctuation and nonflow

Flow performance study with MPD (NICA)



- Total number of reconstructed Au+Au, Bi+Bi minimum bias events - 9 M, at 7.7 and 11.5 GeV
- Full reconstruction procedure was done using GEANT4 simulation
- Particle selection:
  - charged hadrons
  - $0.2<p_T<3$ GeV/c
  - $|\eta|<1.5$ (TPC), $2<|\eta|<5$ (FHCal)
  - Number of TPC hits >16
  - Primary tracks selected
- Same methods ($v_2\{2\}$, $v_2\{4\}$, $v_2\{\eta\text{-sub,EP}\}$) were used for reconstructed data

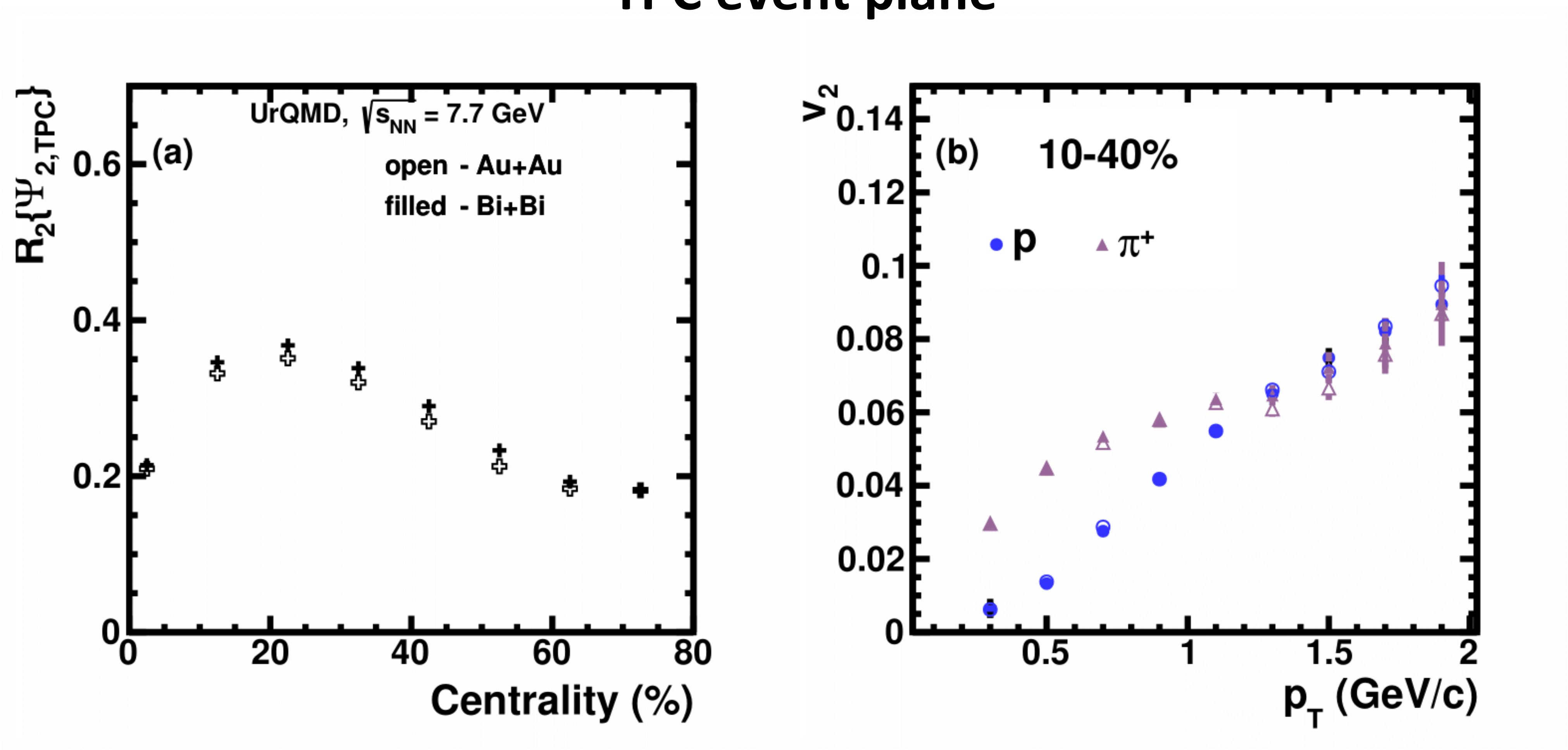
Performance study of v_2 for Au+Au at 7.7 and 11.5 GeV in MPD



Reconstructed and generated v_2 values are in a good agreement for all methods

Au+Au vs. Bi+Bi collisions for reconstructed data in MPD

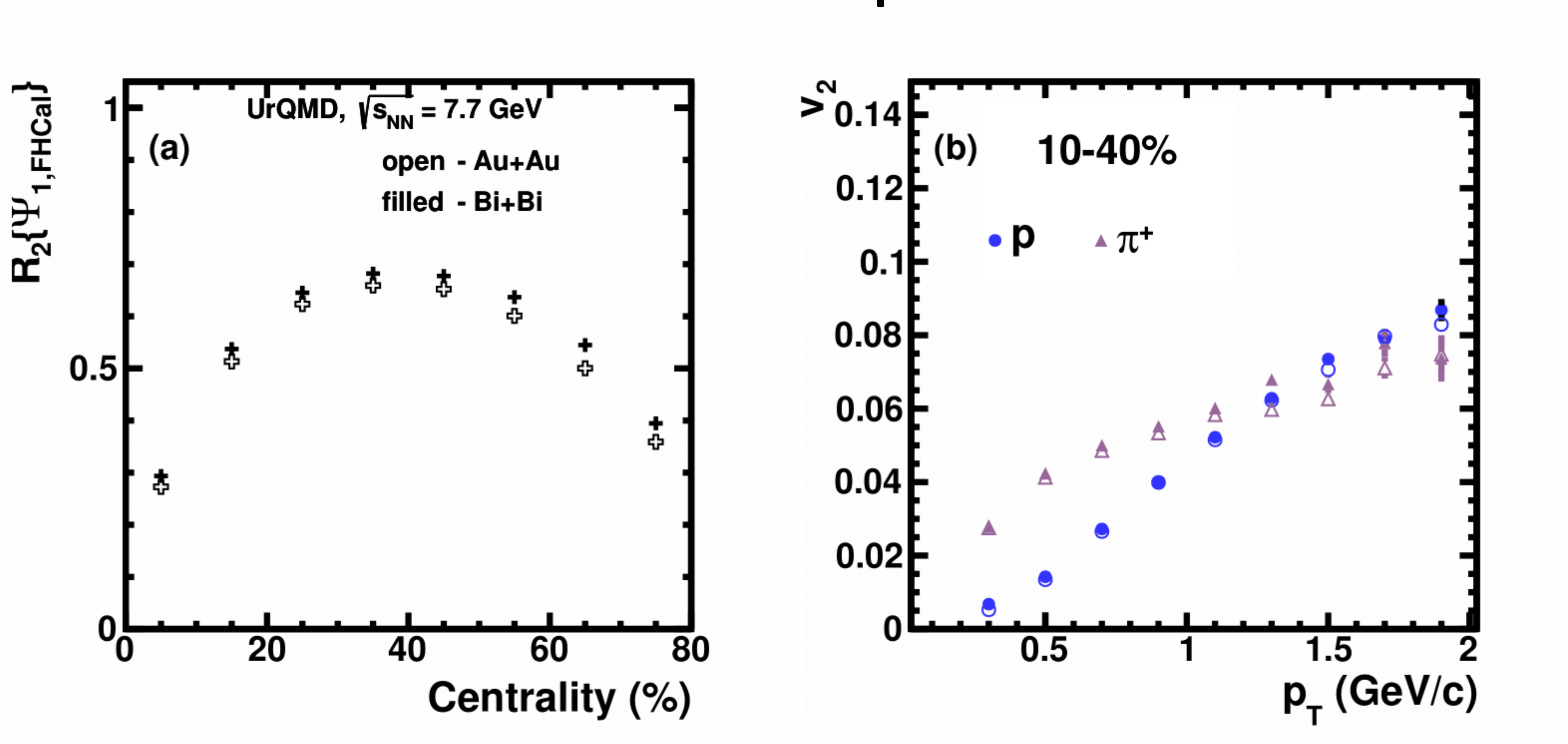
TPC event plane



Expected small difference between colliding systems

Au+Au vs. Bi+Bi collisions for reconstructed data in MPD

FHCal event plane



Expected small difference between colliding systems

Summary and outlook

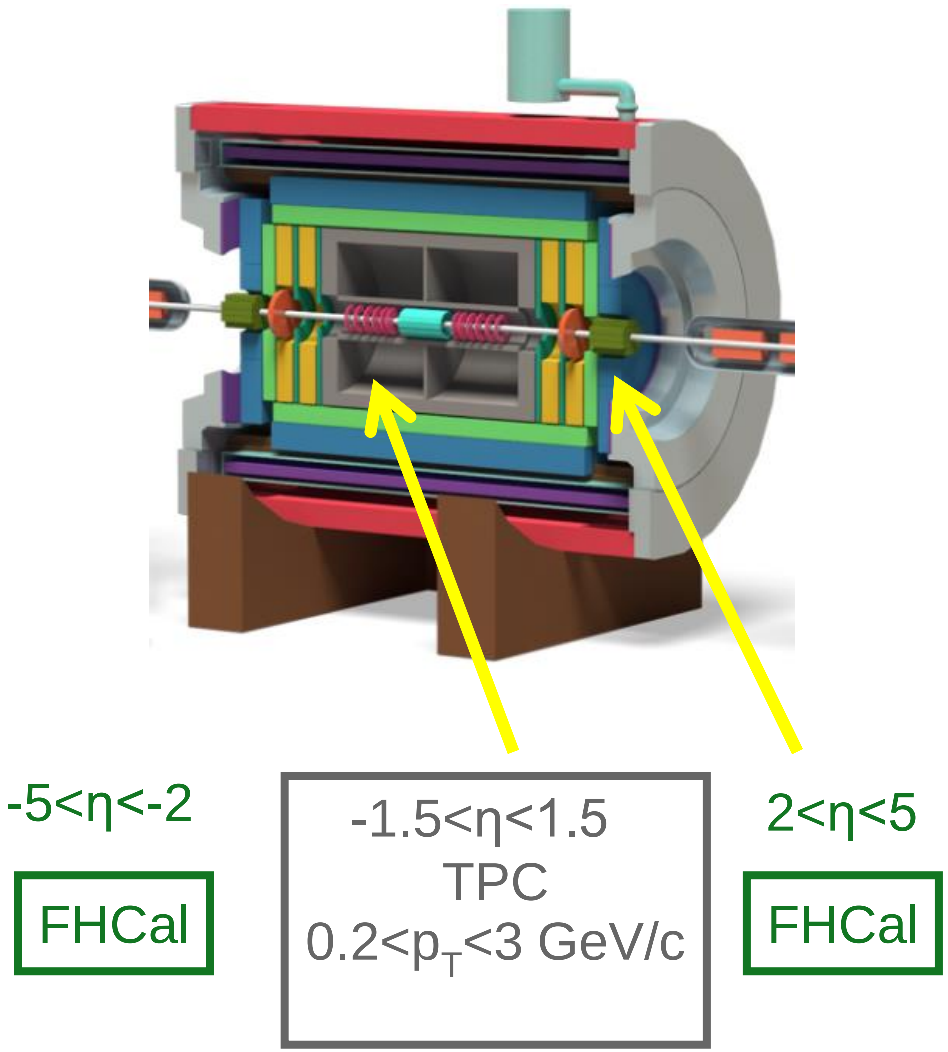
- **Comparison of models with STAR data shows that at NICA energies v_2 grows non-monotonically with increasing beam energy**
- **UrQMD, SMASH models reproduce $v_2\{4\}$ / $v_2\{2\}$ ratio for centrality range 0-60%.**
- **v_2 in UrQMD model for Au + Au collisions at 7.7 GeV:**
  - $v_2\{2\}$ have good agreement with $v_2(\psi_{2,TPC})$ at 10-40% centrality.
  - $v_2\{4\}$ and $v_2(\psi_{1,FHCal})$ are smaller than $v_2\{2\}$ due to fluctuation and nonflow
- **Measurement of elliptic flow v_2 of charged hadrons using direct cumulant and event plane methods was implemented in MPD.**
  - v_2 reconstructed and model data are in a good agreement.
- **Comparison of results for Au+Au and Bi+Bi collisions shows expected small difference between colliding systems.**

Thank you for you attention

Backup

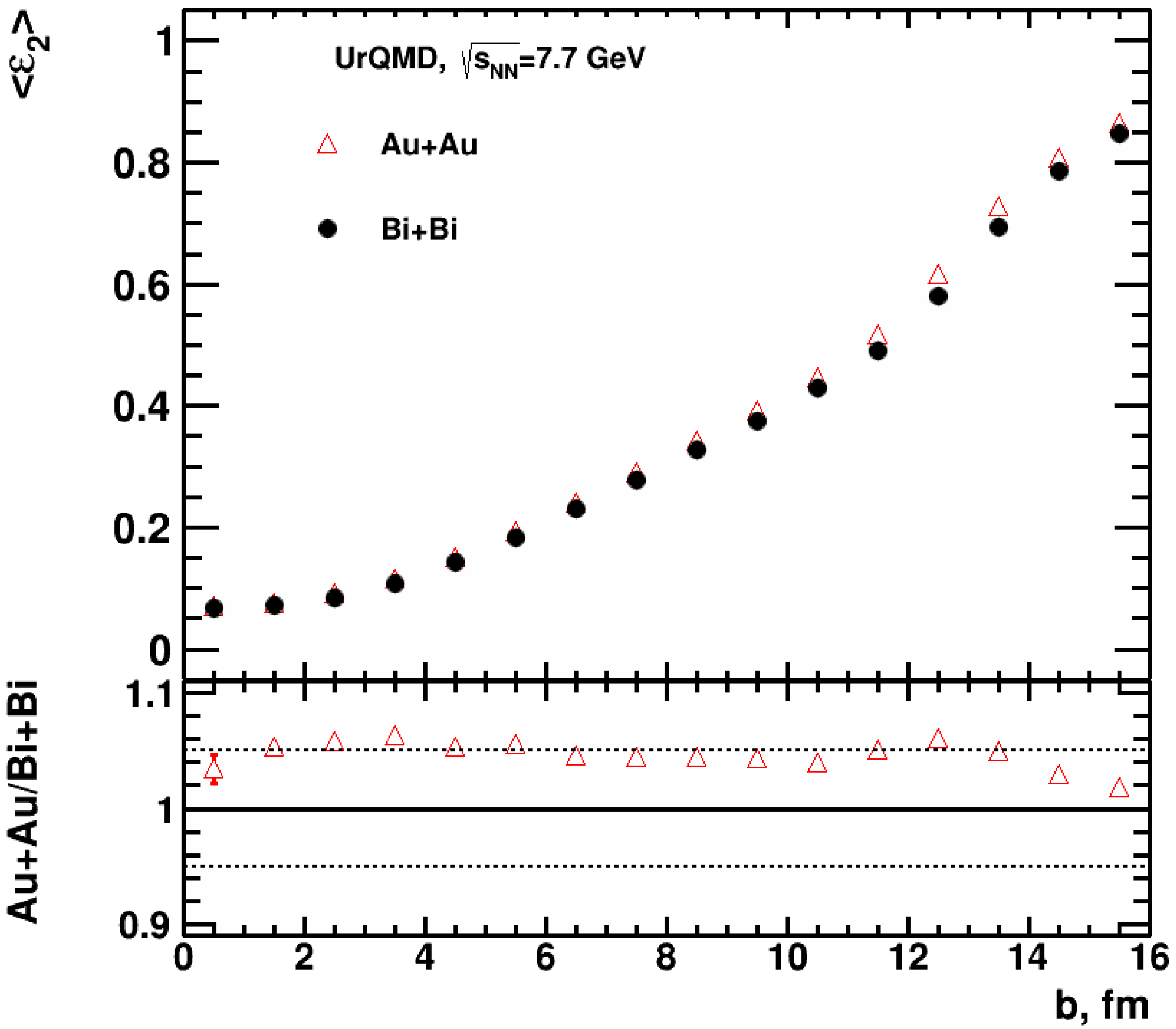
Flow performance study with MPD (NICA)

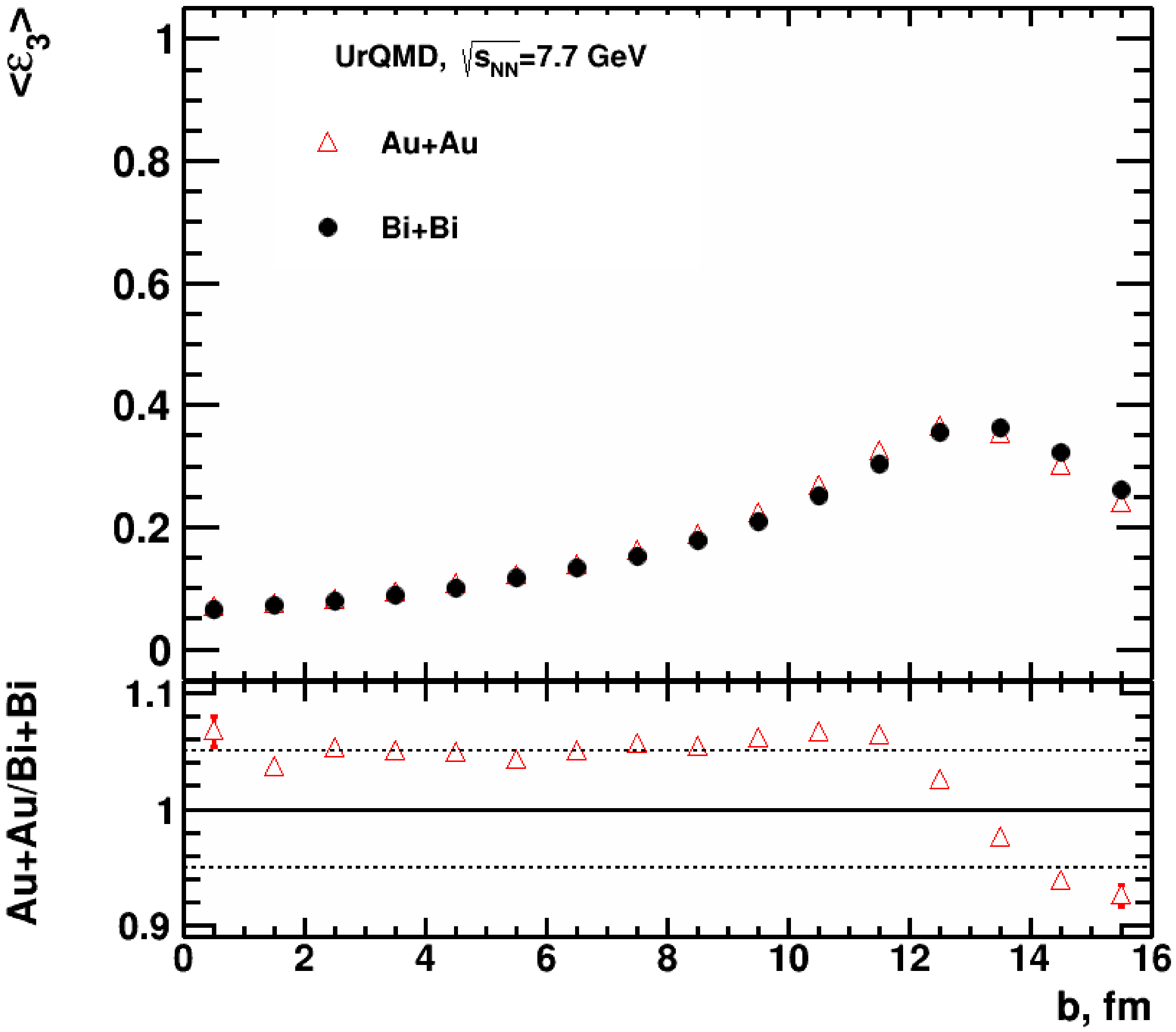
Multi Purpose Detector (MPD)



- Total number of reconstructed Au+Au, Bi+Bi minimum bias events - 9 M, at 7.7 and 11.5 GeV
- Full reconstruction procedure was done using GEANT4 simulation
- Particle selection:
  - charged hadrons
  - $0.2<p_T<3$ GeV/c
  - $|\eta|<1.5$ (TPC), $2<|\eta|<5$ (FHCal)
  - Number of TPC hits >16
  - Primary tracks selected
- Same methods ($v_2\{2\}$, $v_2\{4\}$, $v_2\{\eta\text{-sub,EP}\}$) were used for reconstructed data

Eccintricity: Bi+Bi vs Au+Au





UrQMD model predicts small difference between ε_n of Au+Au and Bi+Bi

Sensitivity of different orders cumulants to elliptic flow fluctuations

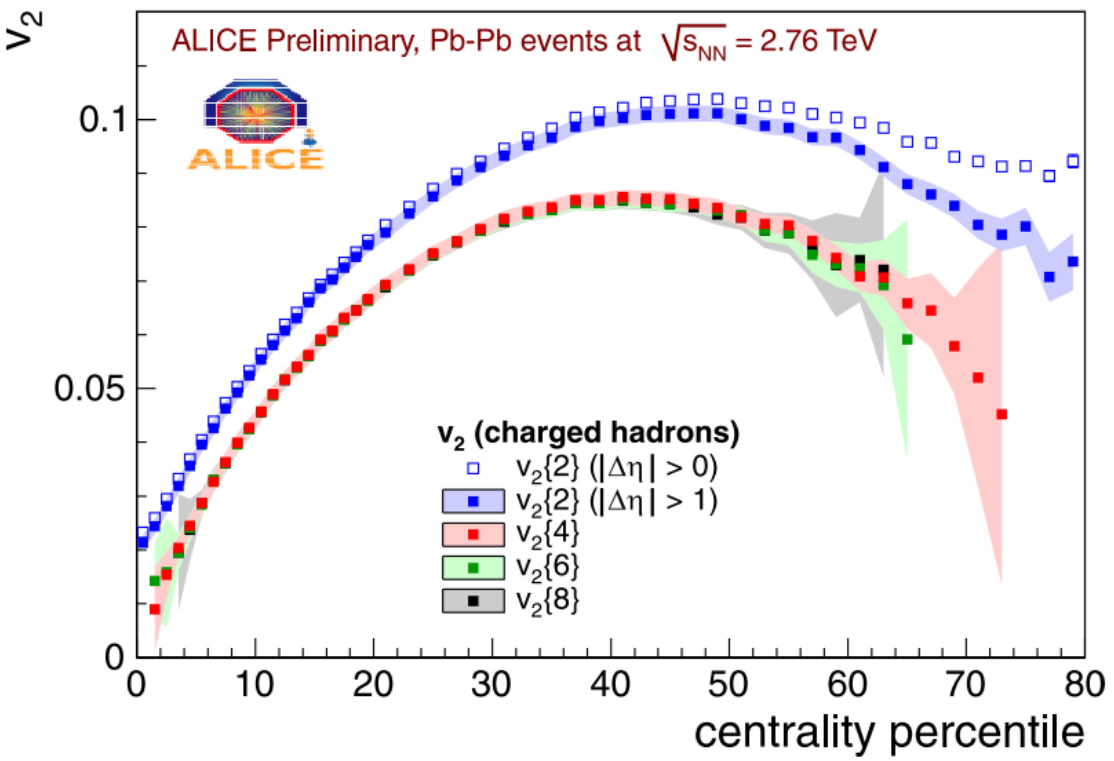
- How fluctuations affect the measured values of v_n. The effect of the fluctuations on v_n estimates can be obtained from

$$\langle v_n^2 \rangle = \bar{v}_n^2 + \sigma_{v_n}^2, \quad \langle v_n^4 \rangle = \bar{v}_n^4 + 6\sigma_{v_n}^2 \bar{v}_n^2$$

$$v_n\{2\} = \sqrt{\langle v_n^2 \rangle}, \quad v_n\{4\} = \sqrt[4]{2\langle v_n^2 \rangle^2 - \langle v_n^4 \rangle}$$

- The difference between $v_n\{2\}$ and $v_n\{4\}$ is sensitive to not only nonflow but also to the event-by-event v_n fluctuations.

$$v_n\{2\} = \bar{v}_n + \frac{1}{2}\frac{\sigma_{v_n}^2}{\bar{v}_n}, \quad v_n\{4\} = \bar{v}_n - \frac{1}{2}\frac{\sigma_{v_n}^2}{\bar{v}_n}$$

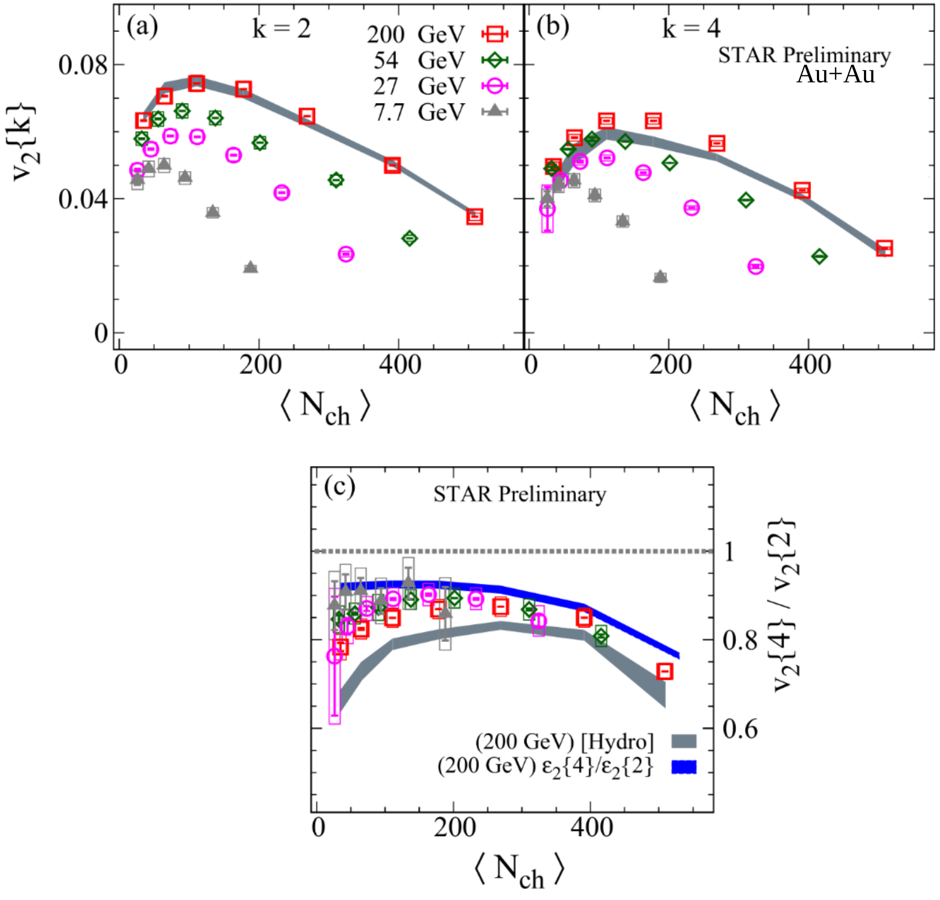


The difference between $v_n\{2\}$ with and without $\Delta\eta$ gap is driven by the contribution from nonflow

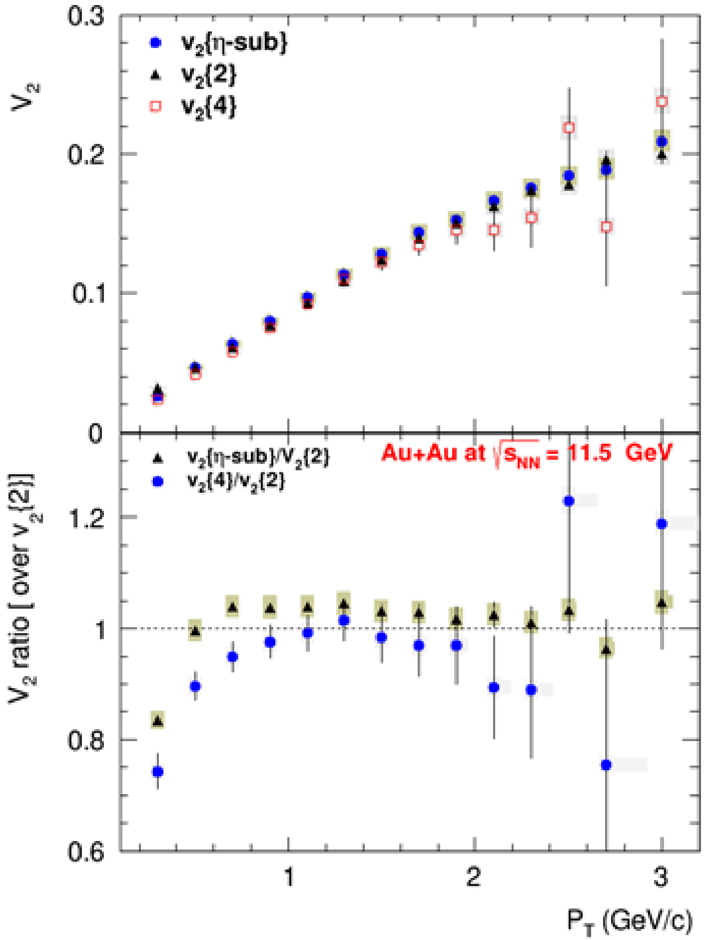
Ilya Selyuzhenkov for the ALICE collaboration, Prog.Theor.Phys.Suppl. 193 (2012) 153-158

Cumulant results from Beam Energy Scans

Niseem Magdy, Nucl.Phys.A 982 (2019) 255-258

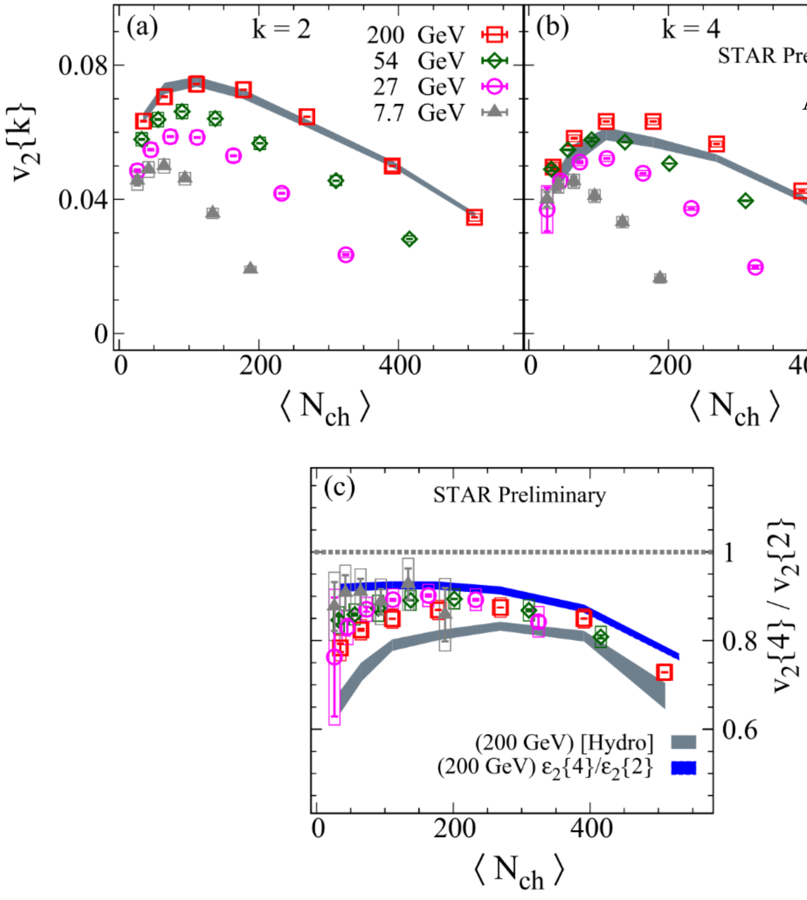


L. Adamczyk et al. (STAR Collaboration). Phys. Rev. C 86, 054908 (2012)



- The magnitude and trend of the fluctuations, have weak beam energy dependence
  - Methods of flow measurements have different sensitivity to flow fluctuations

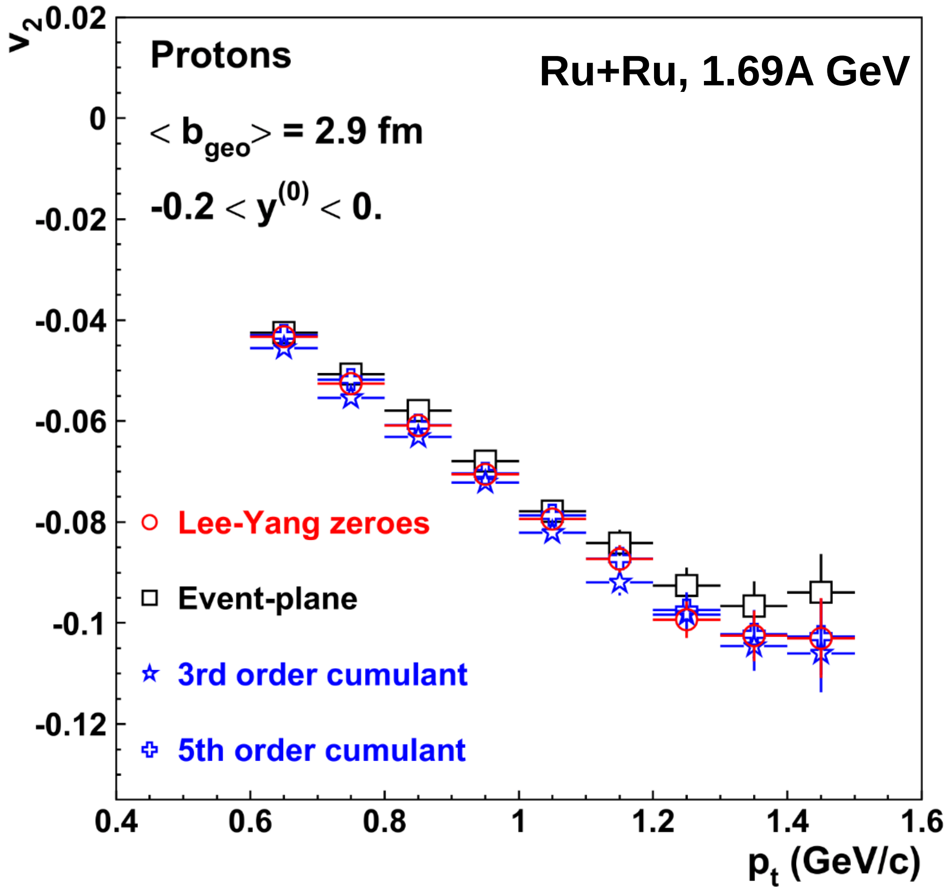
Cumulant results from Beam Energy Scans



Comprasssion of (a) $v_2\{2\}$ vs. $\langle N_{ch} \rangle$, (b) $v_2\{4\}$ vs. $\langle N_{ch} \rangle$ and (c) thir ratio for Au+Au collisions

Niseem Magdy, Nucl.Phys.A 982 (2019) 255-258

arXiv:1807.07638



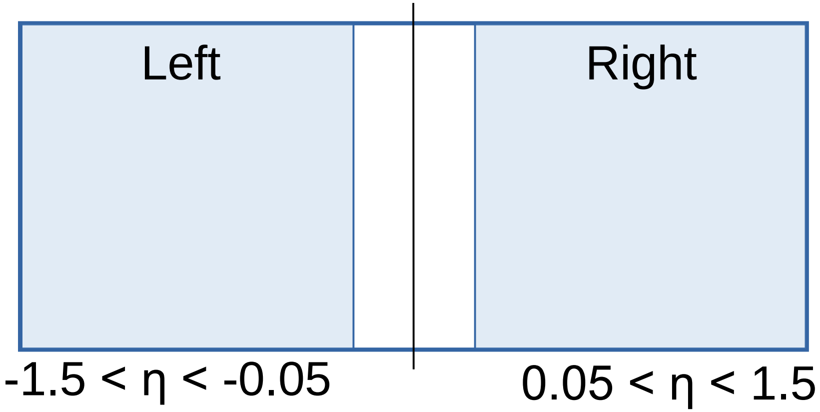
v_2 versus transverse momentum for protons measured in semi-central events and around mid-rapidity.

N. Bastid, et al., Phys.Rev. C72 (2005) 011901

arXiv:nucl-ex/0504002

Results for v_2 from UrQMD model of Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV

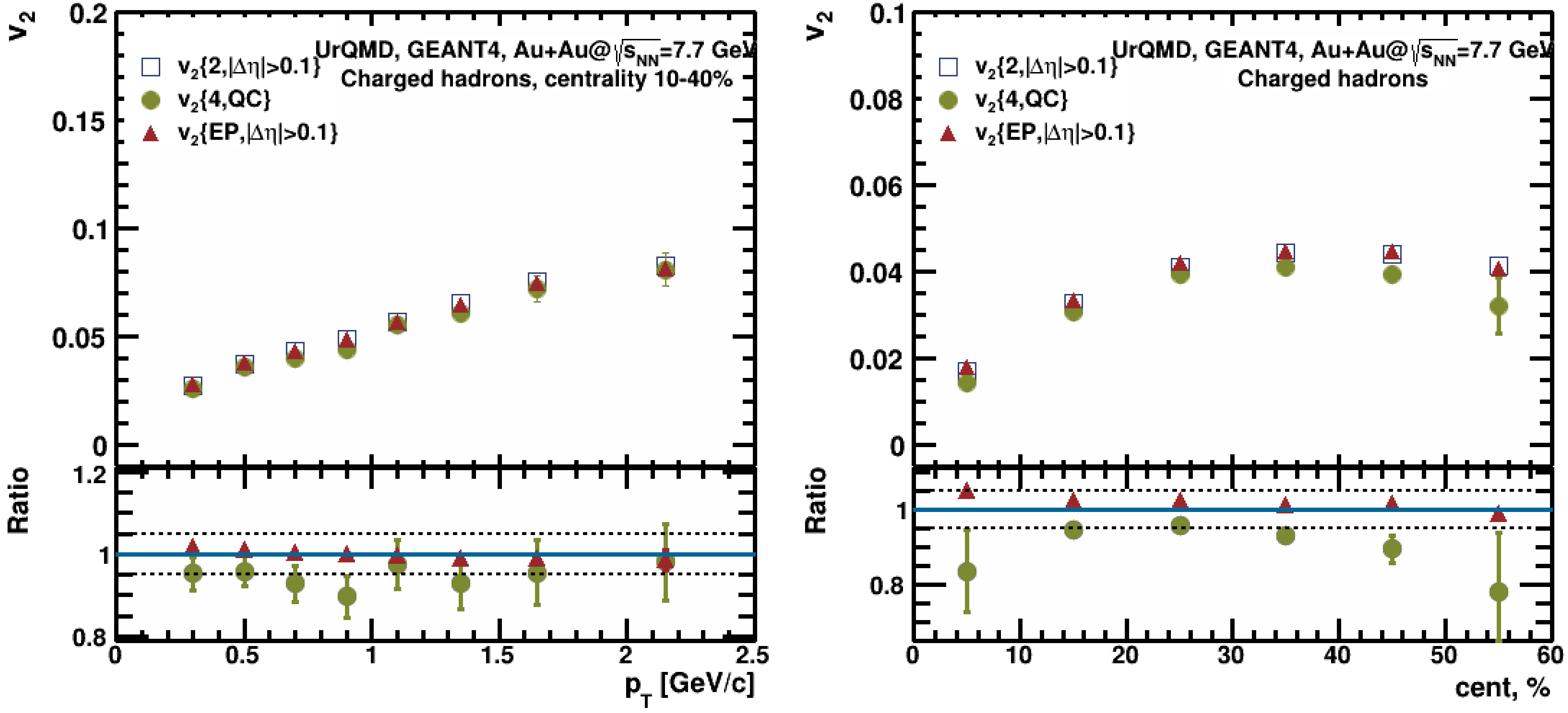
- Total number of generated minimum bias events - 88 M
- Particle selection: charged hadrons, $0.2<p_T<3$ GeV/c
- Configuration of cumulant method:
  1. RFP and POI: charged hadrons;
  2. calculations were performed taking into account the effect of autocorrelation
- All 3 methods have the same kinematical cuts



Left half ($\eta<-0.05$) → η_-

Right half ($\eta>0.05$) → η_+

Results for v_2 for reconstructed events of MPD



$v_2\{2\}$ and $v_2\{4\}$ are in good agreement with $v_2\{\eta\text{-sub,EP}\}$ at 10-40% centrality

Description of direct cumulant method for flow measurements

2 and 4 particle azimuthal correlations

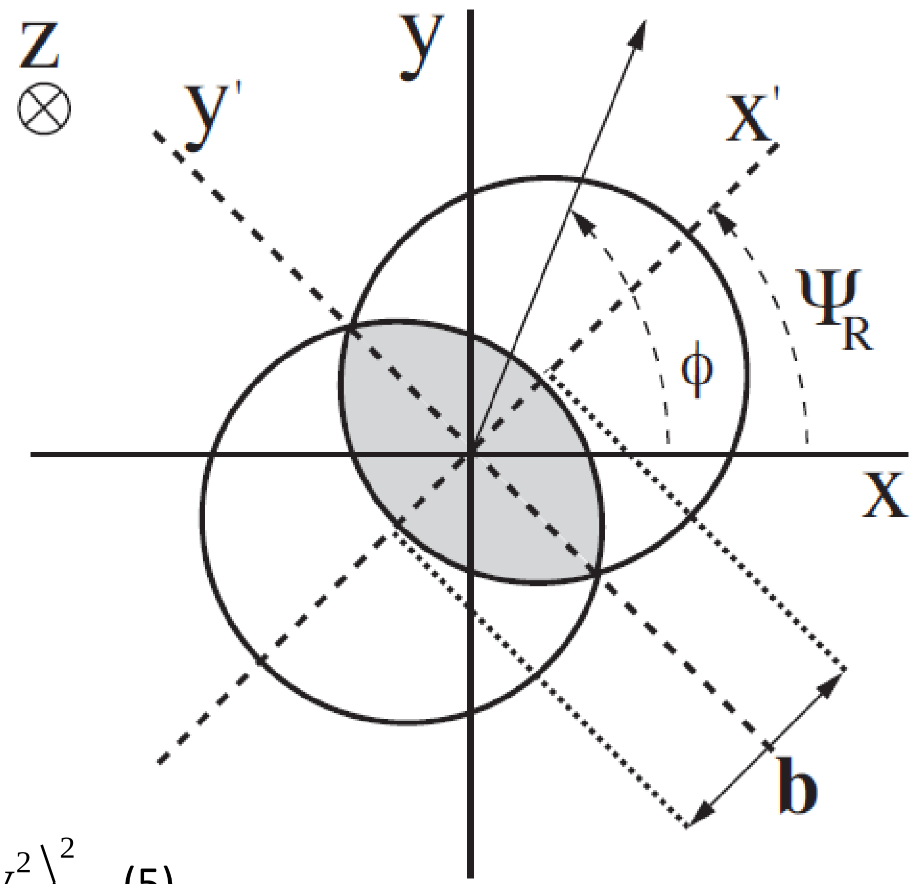
$$\left\langle v_n^2 \right\rangle \simeq \left\langle e^{in(\varphi_1-\varphi_2)} \right\rangle + \delta_n \quad (1)$$

$$\left\langle v_n^4 \right\rangle \simeq \left\langle e^{in(\varphi_1+\varphi_2-\varphi_3-\varphi_4)} \right\rangle - 2\cdot\left\langle e^{in(\varphi_1-\varphi_3)} \right\rangle\left\langle e^{in(\varphi_2-\varphi_4)} \right\rangle \quad (2)$$

Elliptic flow estimate with direct cumulant method

$$\left\langle v_n^2 \right\rangle = \frac{|Q_n|^2 - M}{M(M-1)} \quad (3) \quad \text{where} \quad Q_n = \sum_{i=1}^{M} e^{in\varphi_i} \quad (4)$$

$$\left\langle v_n^4 \right\rangle = \frac{|Q_n|^4 + |Q_{2n}|^2 - 2\left|Q_{2n}Q_n^*Q_n^*\right| - 4M(M-2)|Q_n|^2 + 2M(M-3)}{M(M-1)(M-2)(M-3)} - 2\cdot\left\langle v_n^2 \right\rangle^2 \quad (5)$$



This method was introduced by Ante Bilandzic in Phys. Rev. C83:044913, 2011