Measurements of elliptic flow and triangular flow in forward and backward pseudo-rapidity in Au+Au Collisions at $\sqrt{s_{NN}}$ = 19.6 GeV in RHIC-STAR

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STAR 25 YEARS

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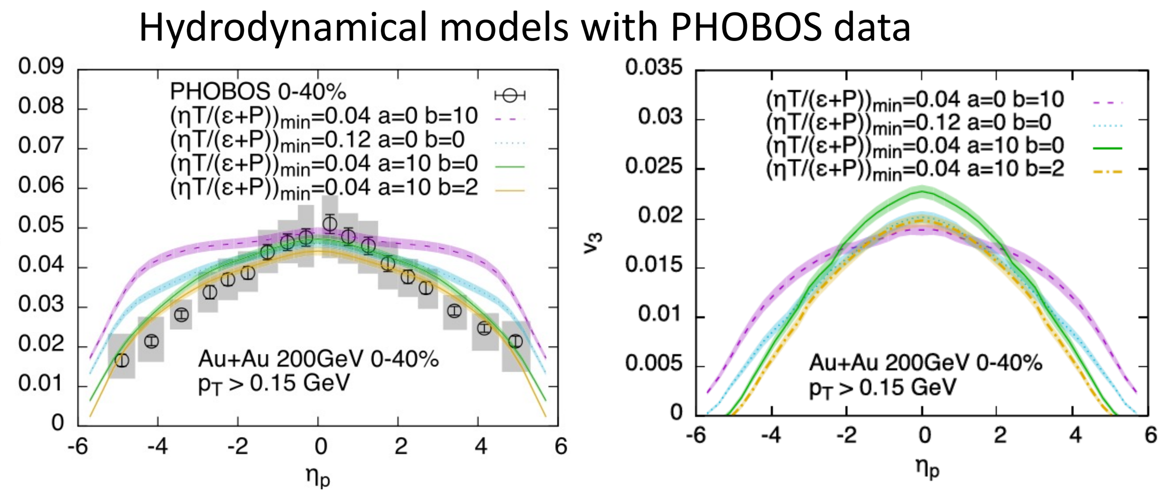
1.Physics Motivation

- Directed flow(v_1), elliptic flow(v_2), and triangular flow(v_3) are sensitive to the equation of state and properties of dense nuclear matter.
- Hydrodynamic models show that the rapidity dependence of v_2 and v_3 is sensitive to the temperature dependence of shear viscosity η/s(T) . PHOBOS reported η dependence of v_2 but with large uncertainties at low energies. No v_3 data are reported in the forward and backward regions so far.

The precise measurements of rapidity dependence of v_n in low energies help to constrain the temperature and baryon chemical potential dependence of η/s!!

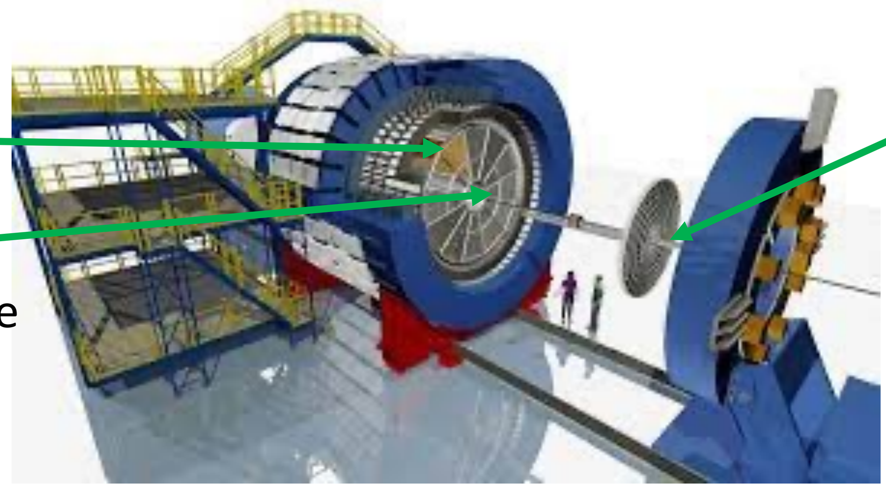
Denicol et.al, PRL 116, 212301 (2016)

Hydrodynamical models with PHOBOS data

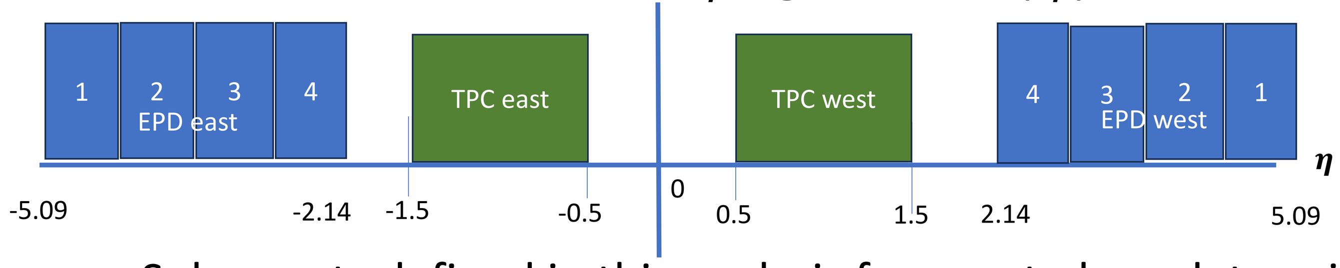


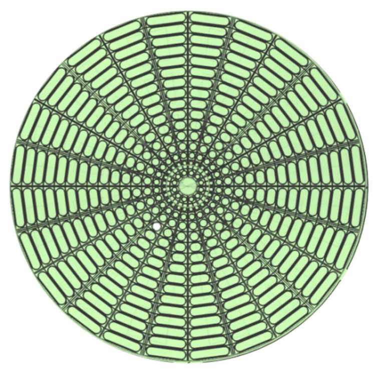
2. STAR experiment

TPC (Time Projection Chamber)
-Reconstruct charged particles.
iTPC (inner TPC)
-better resolution and wider acceptance by the inner TPC upgrade.
(| η |< 1.0 changed to | η |< 1.5)



EPD (Event Plane Detector)
-Measure forward and backward-going charged particles.
-Located in Z= ± 365 cm. Covered η region: 2.14 <|η|< 5.09.





Sub-events defined in this analysis for event plane determination

3.Analysis method

A. M. Poskanzer and S. A. Voloshin. PRC.58,1671(1998)

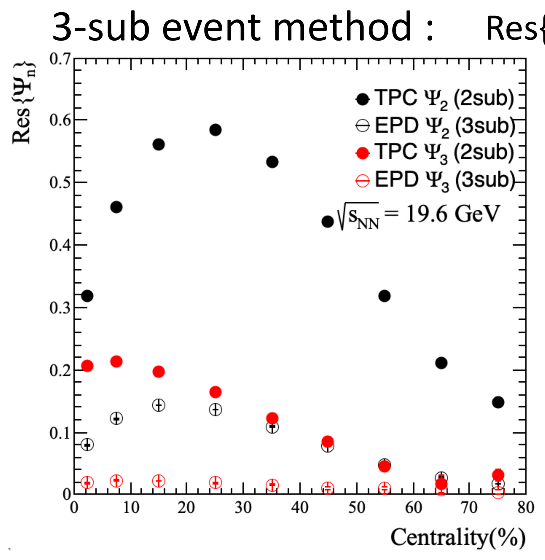
This study used the event plane method to measure v_n.

$$v_n = \frac{\langle \cos n(\varphi - \Psi_n)\rangle}{Res\{\Psi_n\}} \qquad \Psi_n = \frac{1}{n}\tan^{-1}\left(\frac{Q_y}{Q_x}\right) \qquad Q_x = \sum_i^M w_i \cos(n\phi_i),\quad Q_y = \sum_i^M w_i \sin(n\phi_i)$$

n: flow harmonic order

Event plane resolution

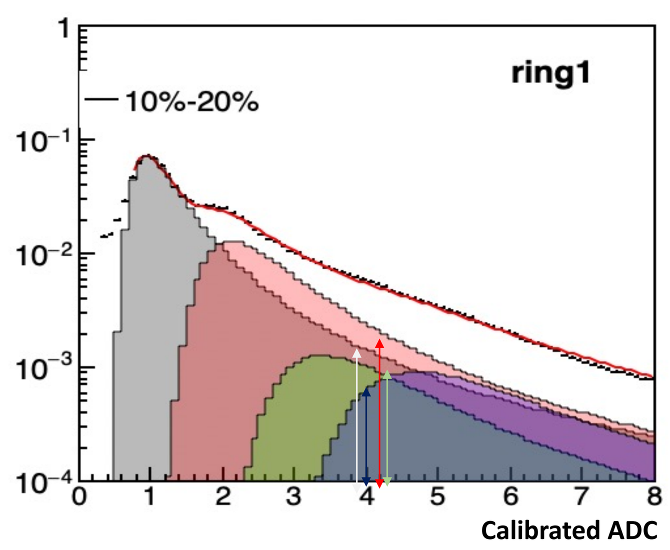
3-sub event method : $Res\{\Psi_{nTPC(E+W)}\} = \sqrt{\frac{\langle\cos(n[\Psi_n^{EPDE}-\Psi_n^{TPC(E+W)}])\rangle\langle\cos(n[\Psi_n^{EPDW}-\Psi_n^{TPC(E+W)}])\rangle}{\langle\cos(n[\Psi_n^{EPDE}-\Psi_n^{EPDW}])\rangle}}$



- For the third order, EPDE-EPDW correlation is almost zero within statistical fluctuations.
- EPD event plane for v_n(|η| < 1.5) was determined as,
  1st order (from inner 4 rings: spectator region)
  2nd and 3rd (from outer 8 rings: participant region)
- TPC event plane (East/West combined) was used for v_n(2.1 < |η| < 5.1) .

EPD multiplicity weight for v_n

Calibrated ADC distribution of EPD

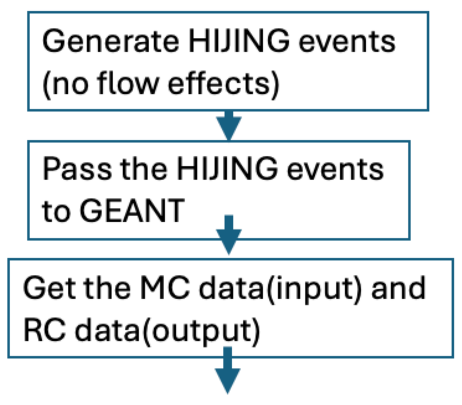


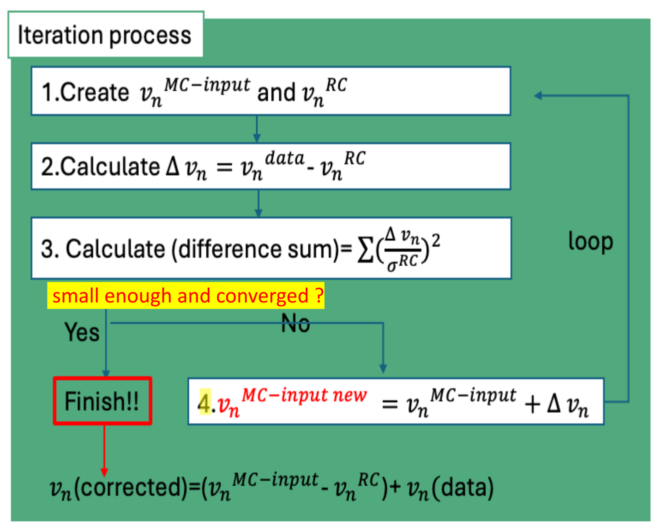
- EPD is the scintillation detector, so tracking is not possible
- Particles lose energy in the EPD tile (ADC)
  Not only primary particles but also secondary particles from interaction with materials, come in EPD.
  -> Need material correction
- The average multiplicity estimated based on the MIP (Minimum Ionization Particle) fitted by the Landau distribution is used as a weight for v_n calculation.

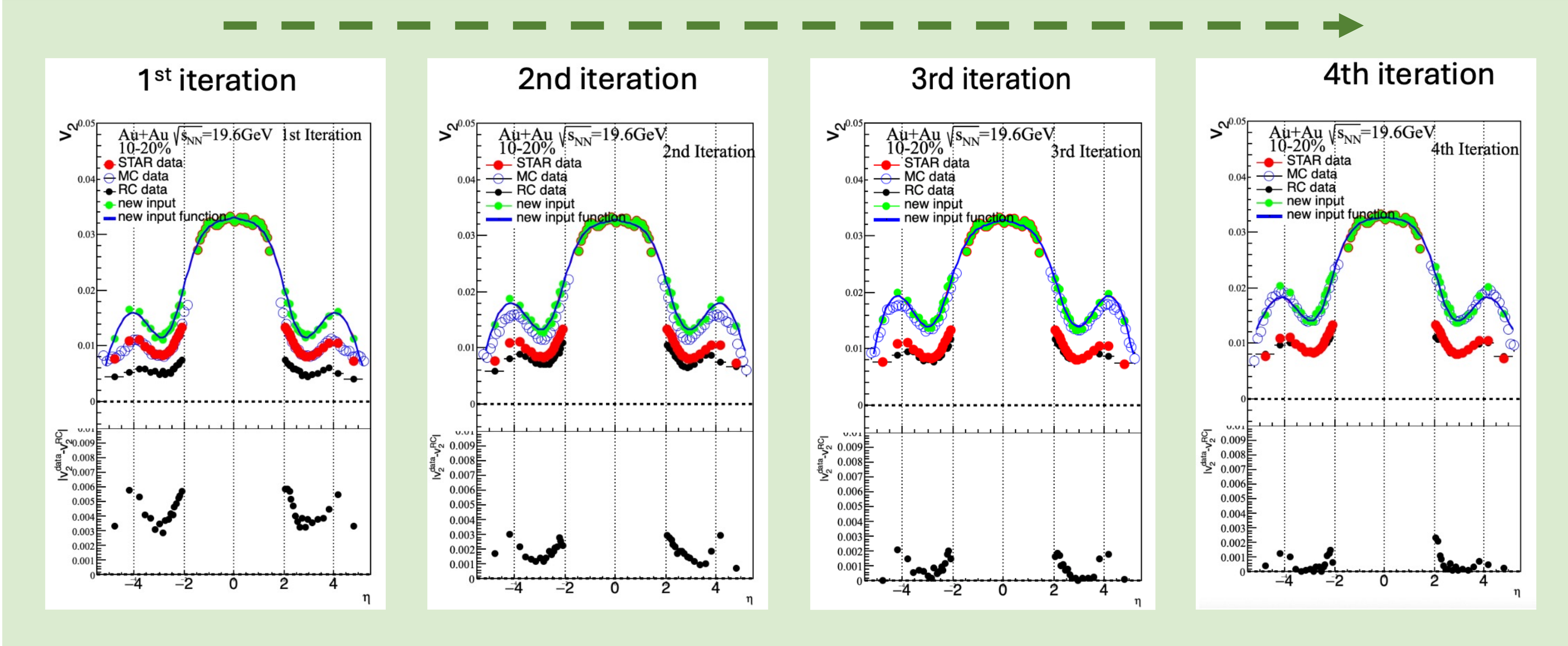
Corrections

For TPC: **Tracking efficiency correction** using embedding data

For EPD: **Detector material effect correction** using HIJING+GEANT.
Input v_n was updated via iteration process so that the reconstructed and real data are matched.

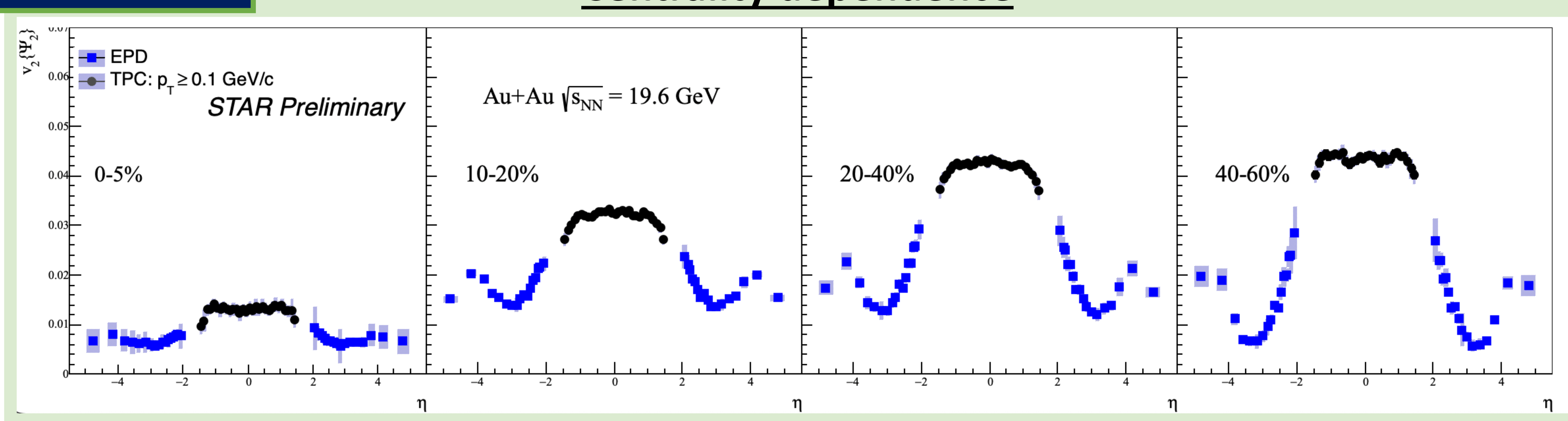






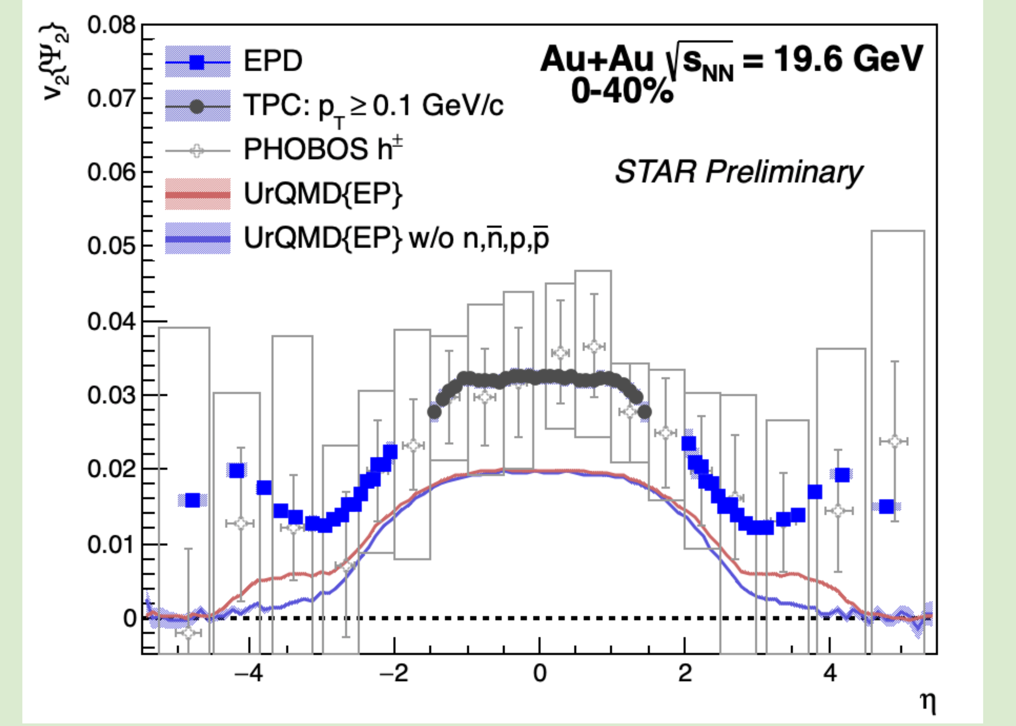
4.Results

Centrality dependence



- v_2 decreases with rapidity, but bump structures seen around |η|= 4.
- The bump starts to appear at |η|~3, which coincides with the beam rapidity at 19.6 GeV (y_{beam}= 3) where spectator contribution starts to come in.
- The bump increases in more peripheral collisions, likely due to spectators.

Model (and PHOBOS) comparison



Compared with two calculations with UrQMD model

1. v_2 using all particles
2. v_2 excluding protons and neutrons

- Our v_2 is consistent with PHOBOS with a better precision.
- Similar bump structures are seen in UrQMD, where spectators are propagated throughout simulation.
- UrQMD v_2 without protons and neutrons (main component of spectators) doesn't show the bump structures.

→ **The bump structures most probably originate from spectators in forward/backward at 19.6 GeV. BES-II is a good opportunity to investigate this effects!!**

5.Summary

- v_2 has been measured in -5.1< η <5.1 with high precision at 19.6 GeV using STAR BES-II data.
- From η and centrality dependence, there is a clear bump structure in v_2, especially in peripheral collisions.
- The spectators are likely contributing to the v_2 bump structure at 19.6 GeV. UrQMD also shows the similar structure.
- Analysis for v_3 is now ongoing.

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