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Reaction Plane Correlated Triangular Flow in Au+Au Collisions at $\sqrt{s_{NN}} = 3.0$ GeV from STAR

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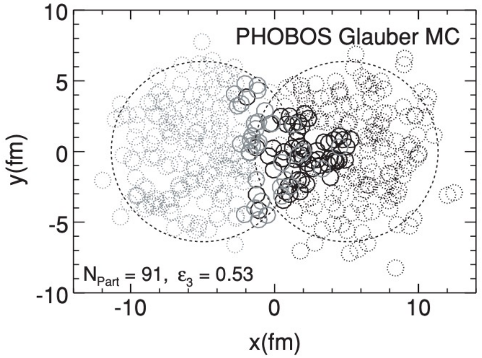
STAR

Motivation



B. Alver & G. Roland, Phys. Rev. C 81, 054905

- Most STAR analyses of triangular flow (v_3) have been using collider mode data ($\sqrt{s_{NN}} = 7.7 - 200$ GeV) with a focus on rapidity-even v_3 studies.
  - v_3 arises from event-by-event collision geometry fluctuations.
  - v_3 has no direct correlation to the first-order event plane (Ψ_1), only to Ψ_3.

- Some models show that v_3 should fall to zero at much lower energies (~5 GeV) [1].

- Recent HADES results show there is a v_3 at $\sqrt{s_{NN}} = 2.4$ GeV, but now correlated to Ψ_1 [2].

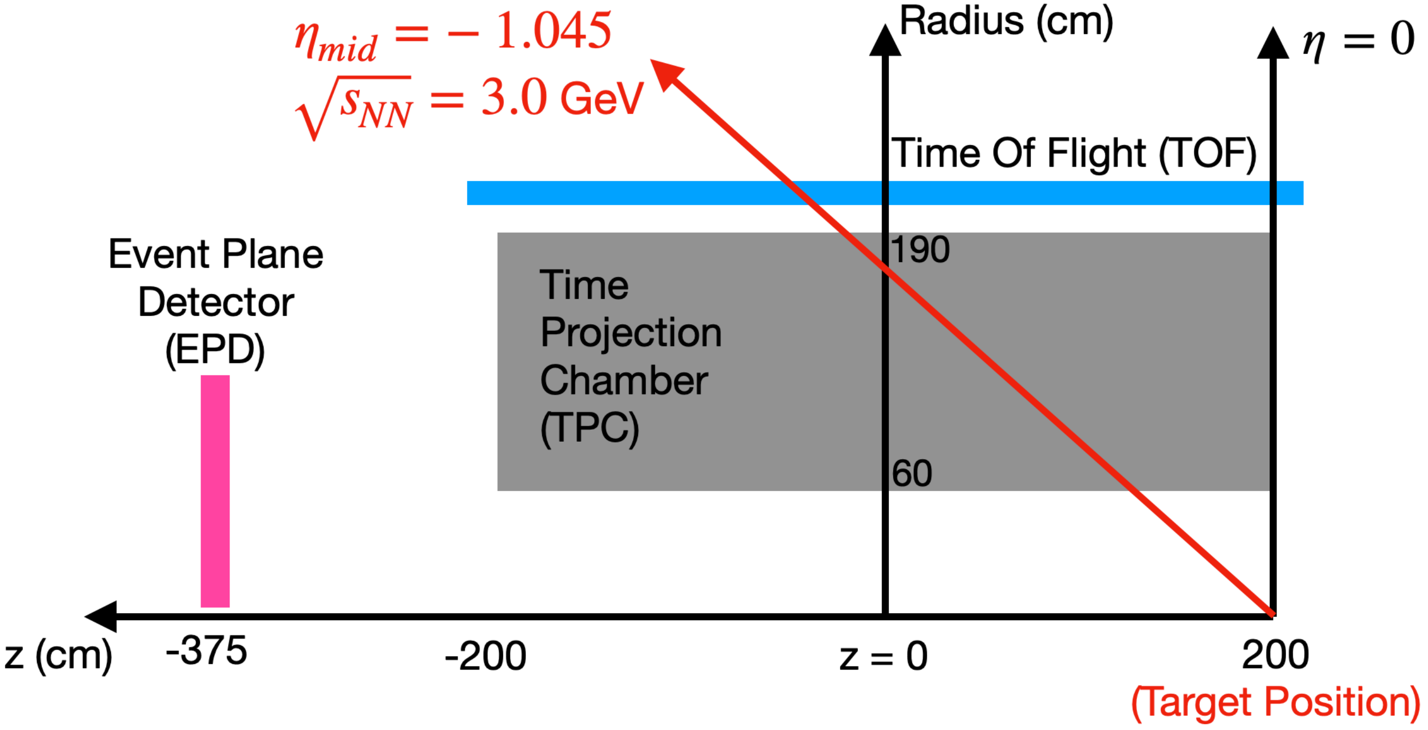
- STAR fixed target (FXT) mode provides a unique opportunity to reach energies down to $\sqrt{s_{NN}} =$ 3.0 GeV.

- What kind of v_3 will we see at 3.0 GeV? If there is a correlation to Ψ_1, can we understand the source?

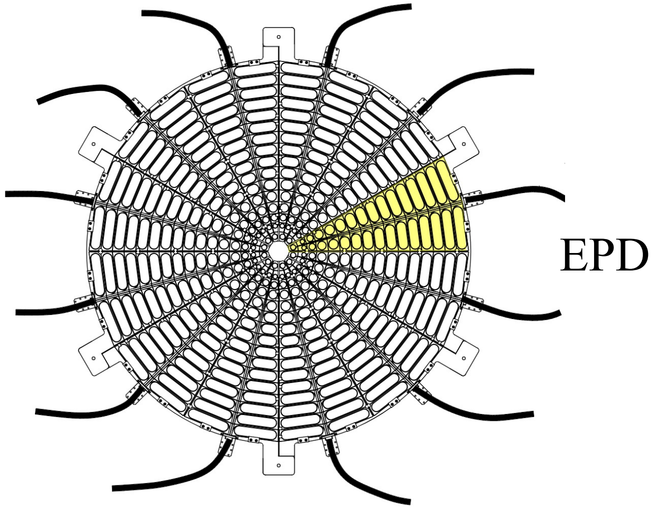
[1] J. Auvinen and H. Petersen, Phys. Rev. C 88, 064908
[2] J. Adamczewski-Musch *et al.,* Phys. Rev. Lett. 125, 262301

STAR Fixed Target Experimental Setup

- Au foil target + Au beam
  - $E_{beam} = 3.85$ GeV
  - $y_{mid} = -1.045$
  - Beam used is the one pointing in the negative direction during normal collider operation; Forward direction is negative.

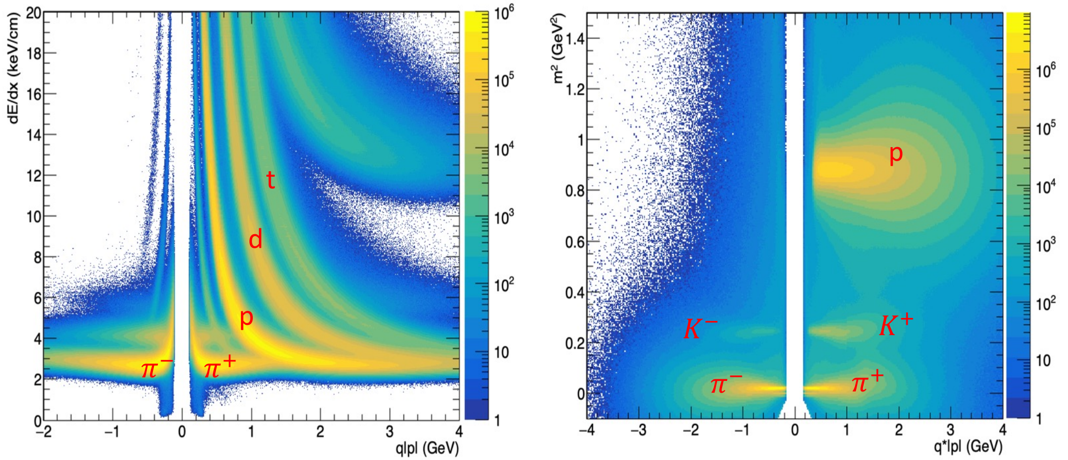


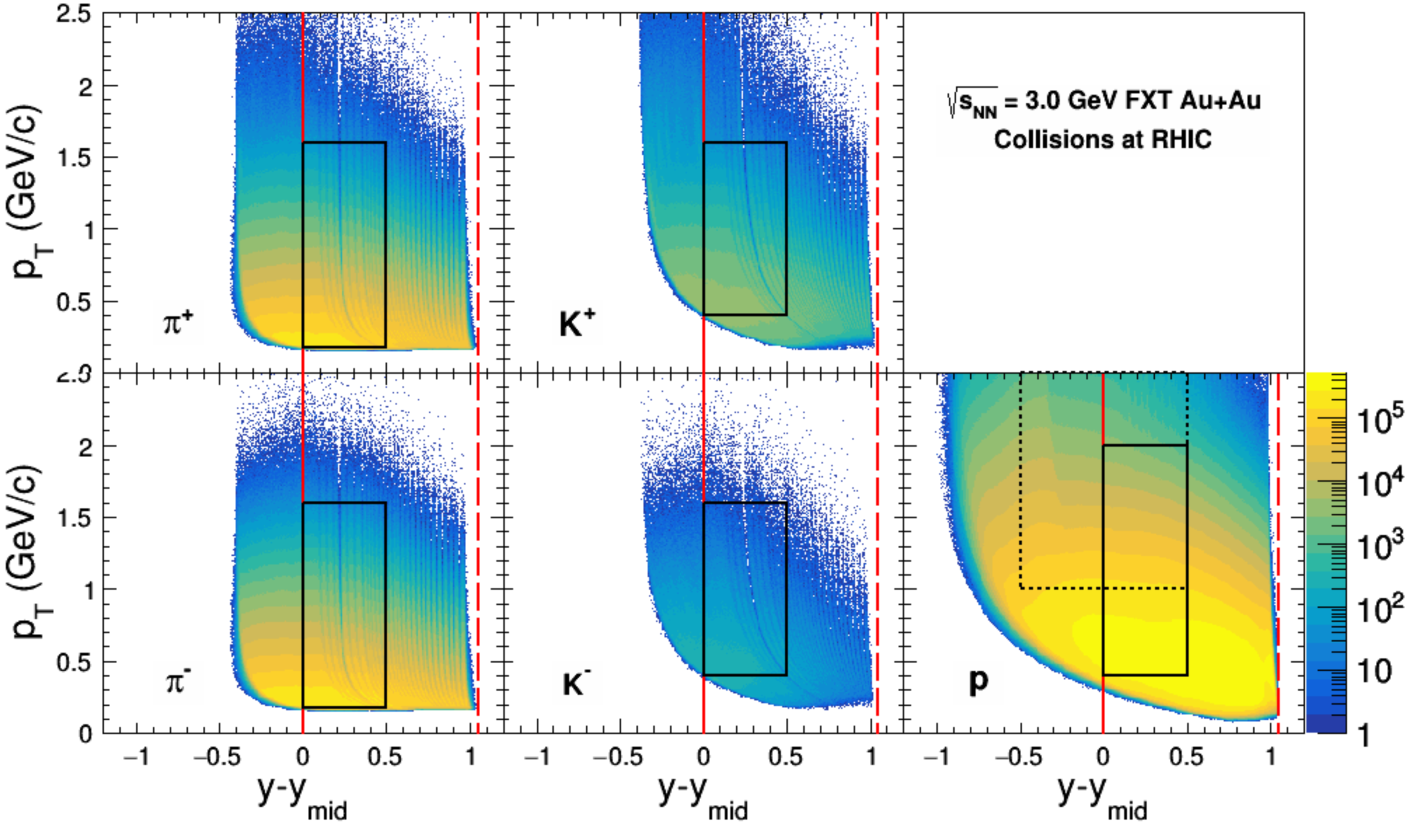
- Time Projection Chamber (TPC) and Time-of-Flight (TOF) used for particle identification.
- Event Plane Detector (EPD) used for event plane reconstruction.



Particle Identification

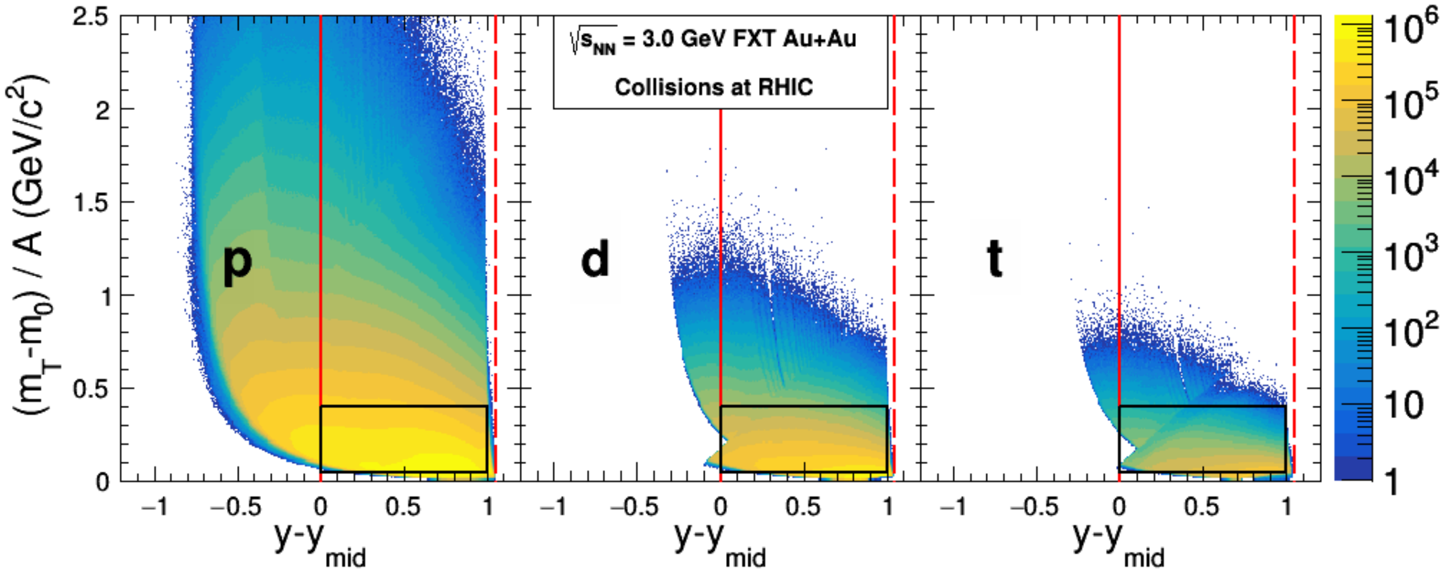
- $\pi^{\pm}$ and $K^{\pm}$ are identified with dE/dx and m^2 info; protons identified with dE/dx.
- Black solid boxes = acceptance for v_3 vs centrality.
- Black dashed box = acceptance for v_3 vs rapidity.
- Red solid (dashed) lines = mid (target) rapidity.





Particle Identification

- Alternate acceptance made for proton, deuteron, and triton comparisons.
- Rather than p_T, we used $m_T - m_0$ scaled by mass number A.
- Black solid boxes = acceptance for v_3 vs centrality.
- Red solid (dashed) lines = mid (target) rapidity.



- d and t identification:
  - dE/dx cuts vary for $|\vec{p}|$ bins of 0.1 GeV/c when
    - $|\vec{p}| \in [0.4, 3.0)$ for deuterons.
    - $|\vec{p}| \in [1.0, 4.0)$ for tritons.
  - For other $|\vec{p}|$, constant dE/dx and m^2 cuts are both used.

Analysis Methods

- Flow vectors $\overrightarrow{Q_m}$ are used to reconstruct event planes [3].
  - $m =$ order of event plane harmonic; Ψ_m
- Weights w_i are p_T for TPC tracks and truncated nMIP (TnMIP) values for EPD hits.
- 0.3 < TnMIP < 2.0
  - Hits with TnMIP < 0.3 are rejected.
  - Hits with TnMIP > 2.0 are replaced with 2.0.

$$\vec{Q_m} = (Q_{m,x}, Q_{m,y}) = \left(\sum_i w_i \cos(m\phi_i), \sum_i w_i \sin(m\phi_i)\right)$$

$$\Psi_m = \frac{1}{m} \tan^{-1}\left(\frac{Q_{y,m}}{Q_{x,m}}\right)$$

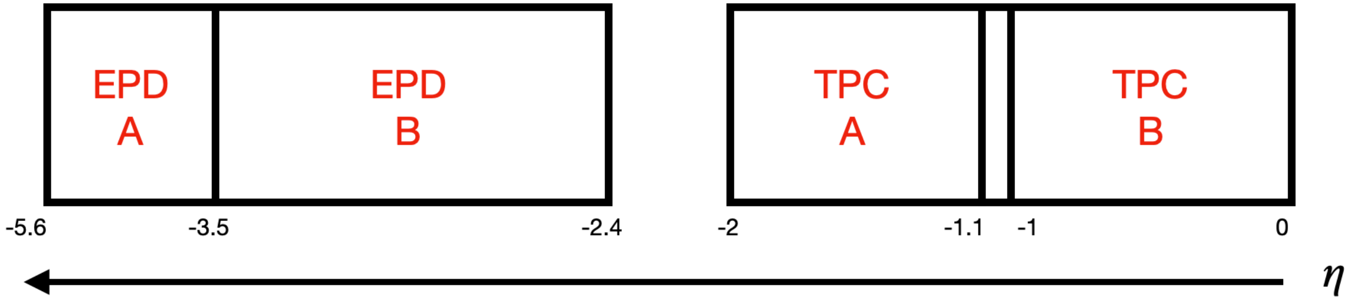
- Recentering and Fourier shifting (10 terms) used to correct non-uniform detector effects.

$$\vec{Q}_{m,recentered} = \vec{Q}_m - \langle \vec{Q}_m \rangle$$

$$\Delta\Psi_m = \sum_{j=1}^{\infty} \frac{2}{jm} [\langle -\sin(jm\Psi_m)\rangle \cos(jm\Psi_m) + \langle \cos(jm\Psi_m)\rangle \sin(jm\Psi_m)]$$

[3] A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)

Analysis Methods


EPD A

EPD B

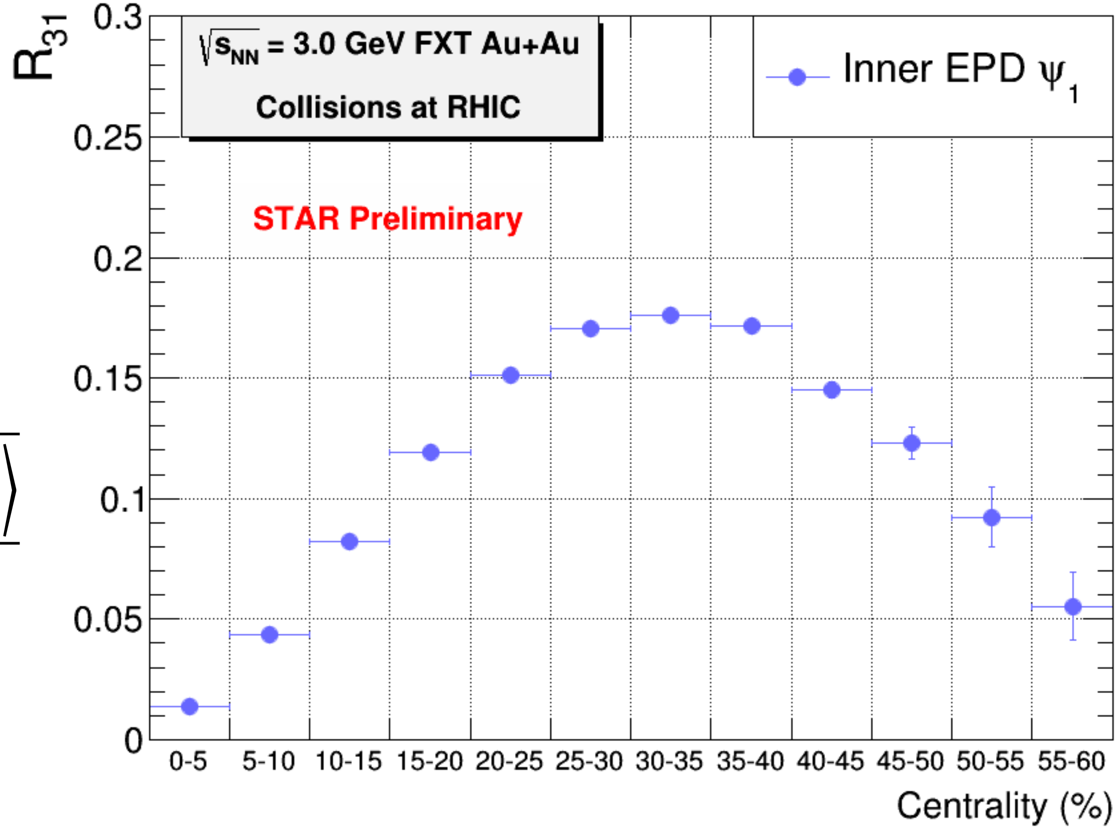
TPC A

TPC B

- 3 subevents used to calculate event plane resolution R_{nm}.
  - n = order of flow harmonic; v_n
  - EPD A: inner 8 rings (> 5 hits).
  - EPD B: outer 8 rings (> 9 hits).
  - TPC B: $-1 < \eta < 0$ (> 5 tracks).

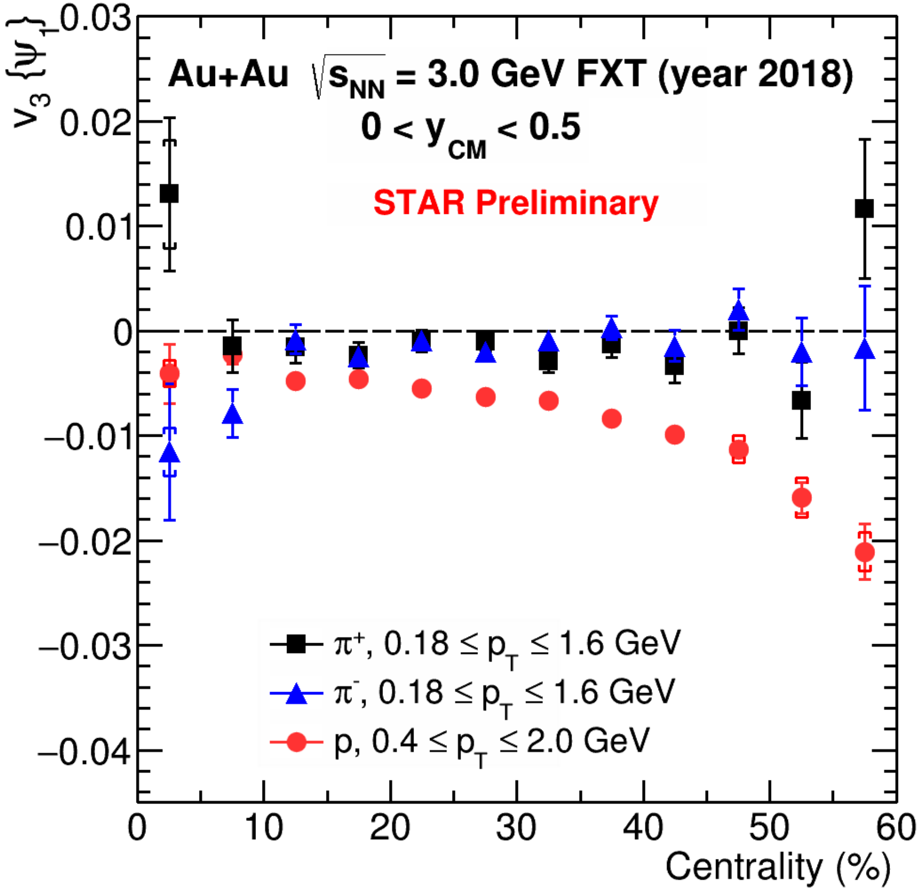
$$R_{nm} = \sqrt{\frac{\left\langle \cos\left(n\left(\Psi_m^{EPD,A} - \Psi_m^{EPD,B}\right)\right)\right\rangle \left\langle \cos\left(n\left(\Psi_m^{EPD,A} - \Psi_m^{TPC,B}\right)\right)\right\rangle}{\left\langle \cos\left(n\left(\Psi_m^{EPD,B} - \Psi_m^{TPC,B}\right)\right)\right\rangle}}$$

$$v_3\{\Psi_1\} = \frac{\left\langle \cos\left(3\left(\phi - \Psi_1\right)\right)\right\rangle}{R_{31}}$$



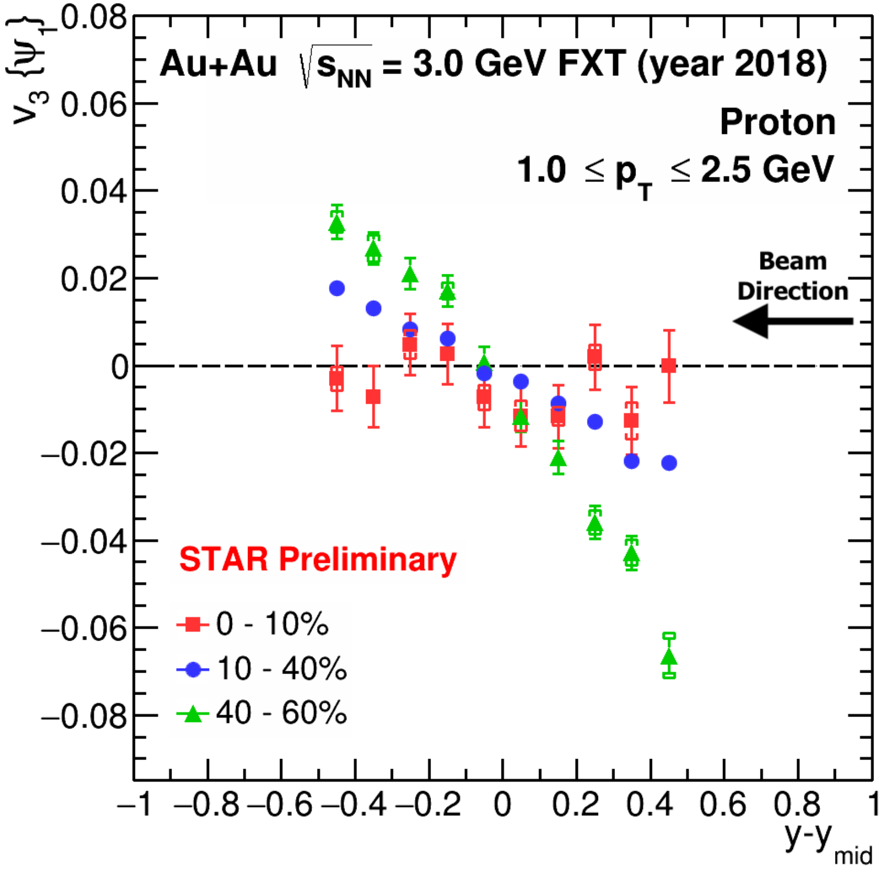
Centrality Dependence

- Backward region ($0 < y_{CM} < 0.5$) shows significant non-zero v_3 for protons.
- v_3 is correlated to Ψ_1 at $\sqrt{s_{NN}} = 3$ GeV.
- Effect has a strong dependence on centrality.

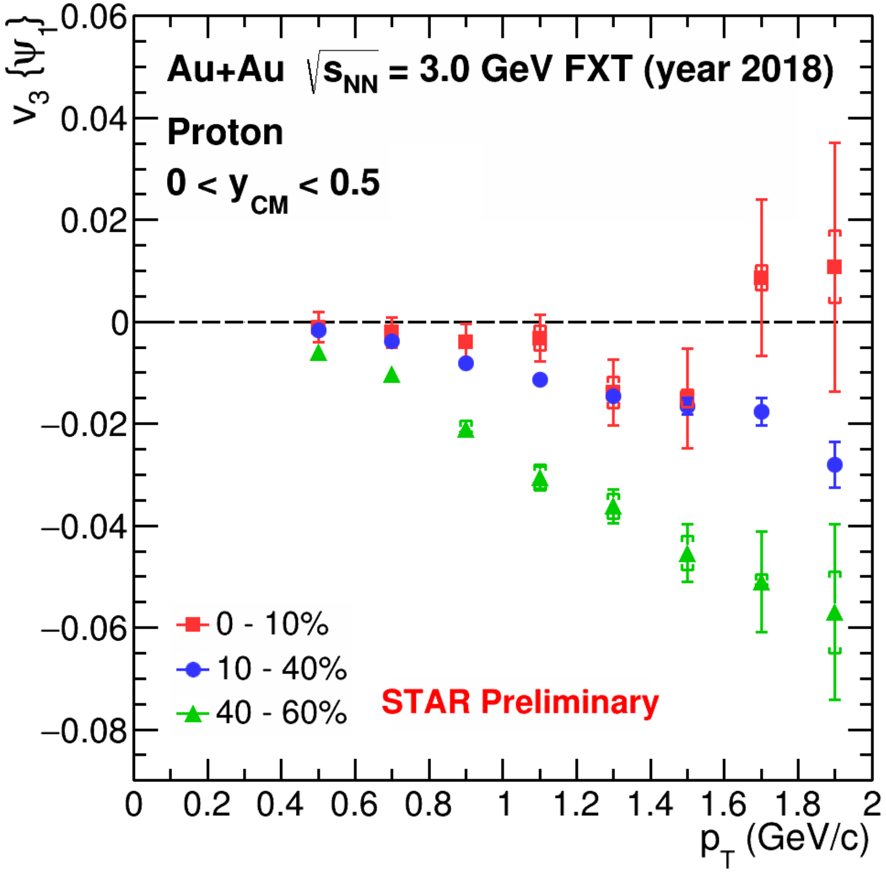


- All systematic uncertainties in the following include contributions from
  - Event/track QA cuts
  - Event plane resolution
  - Pion and proton identification cuts.
- Pions show no significant signal of v_3.
- No conclusion can be made about kaons (not shown) due to low statistics.

Rapidity and p_T – Protons



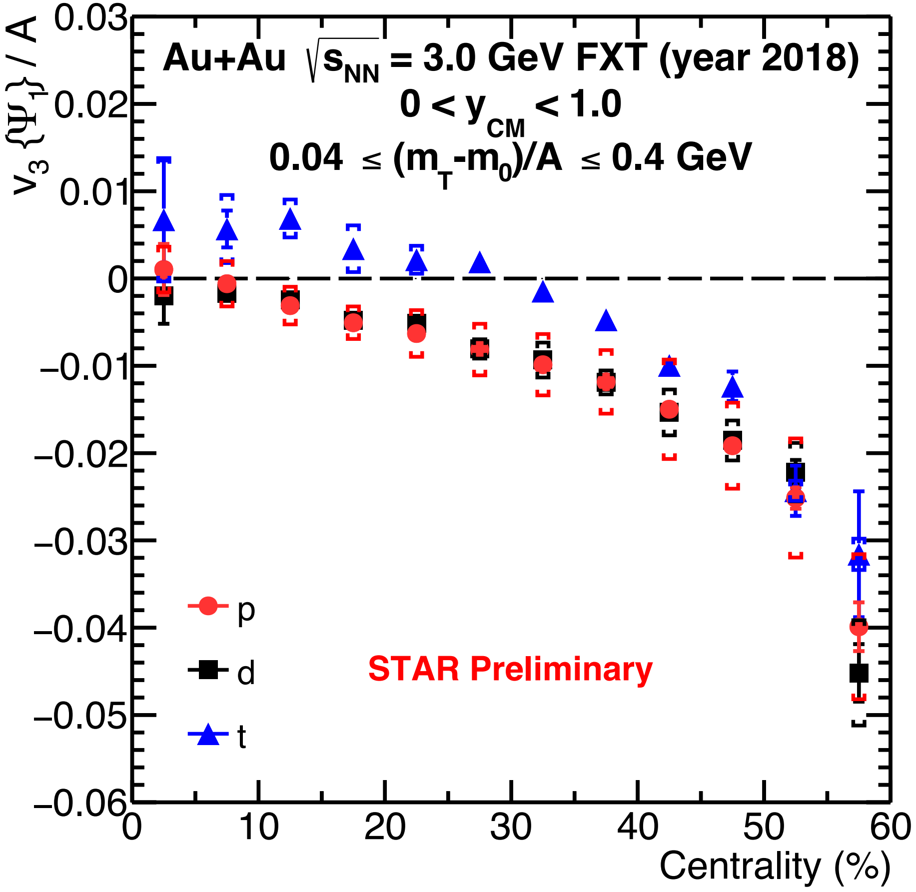
- Proton $v_3\{\Psi_1\}$ is rapidity odd.
- Negative slope; opposite sign to v_1 at 3 GeV [4,5].
- Strength increases with y and p_T.



[4] M. A. et al. (STAR Collaboration), Phys. Lett. B 827, 136941 (2022).
[5] M. A. et al. (STAR Collaboration), Phys. Lett. B 827, 137003 (2022).

Nuclear Mass Number Scaling (A)

- A-scaling supports that nuclei are formed via coalescence.
- Significant non-zero $v_3\{\Psi_1\}$ observed for deuterons and tritons.
- In this acceptance region, deuterons scale with mass number, tritons do not.
- Triton results are currently under investigation for the following effects:
  - Fragmentation effects
  - Other unexpected effects



- All three species include TPC reconstruction efficiency corrections.
- $A = N_{proton} + N_{neutron}$
  - 2 for deuterons.
  - 3 for tritons.

Conclusions and Plans

- Measurements of $v_3\{\Psi_1\}$ at $\sqrt{s_{NN}} = 3.0$ GeV have been presented.

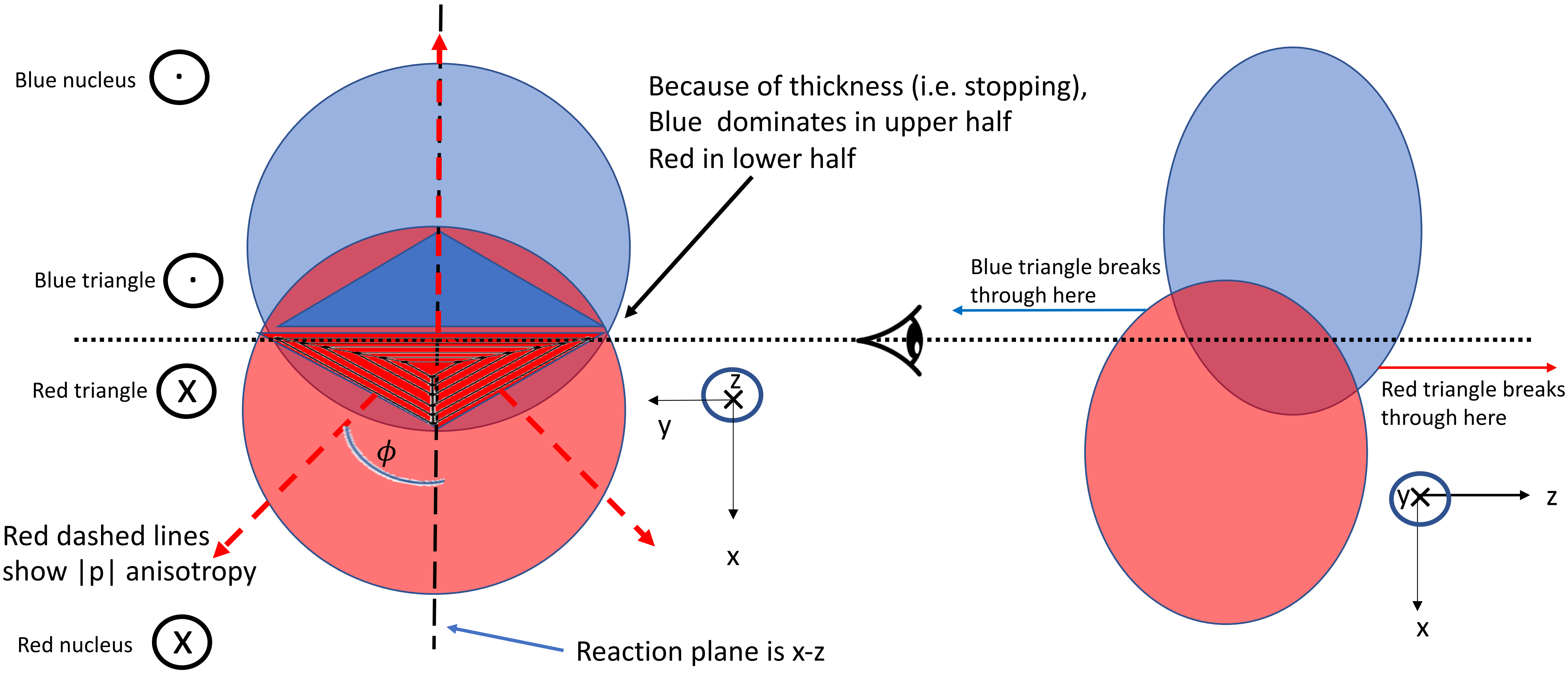
- Protons show a strong $v_3\{\Psi_1\}$ signal.
  - Rapidity odd.
  - Opposite slope to v_1 at 3 GeV.
  - Increases with centrality, rapidity, and p_T.

- The nuclear mass number scaling ($v_3\{\Psi_1\}/A$) for proton, deuteron, and triton was studied.
  - In our first look, deuterons scale with A while tritons do not.
  - Tritons show opposite sign of $v_3\{\Psi_1\}$ in more central collisions.

- Future Plans:
  - Incorporate more recent 3 GeV dataset from STAR with much higher statistics.
  - Use model simulations for deeper understanding of the source of $v_3\{\Psi_1\}$.
  - Investigate A scaling of $v_3\{\Psi_1\}$ in more depth.

Backup

Where does the triangular geometry come from?



Blue nucleus ⊙

Blue triangle ⊙

Red triangle X

Red nucleus X

Because of thickness (i.e. stopping),
Blue dominates in upper half
Red in lower half

Red dashed lines show |p| anisotropy

Reaction plane is x-z

Blue triangle breaks through here

Red triangle breaks through here

BEAM VIEW

SIDE VIEW