First-Order Event Plane Correlated v_1 and v_3 in BES-II Au+Au Collisions at STAR

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STAR

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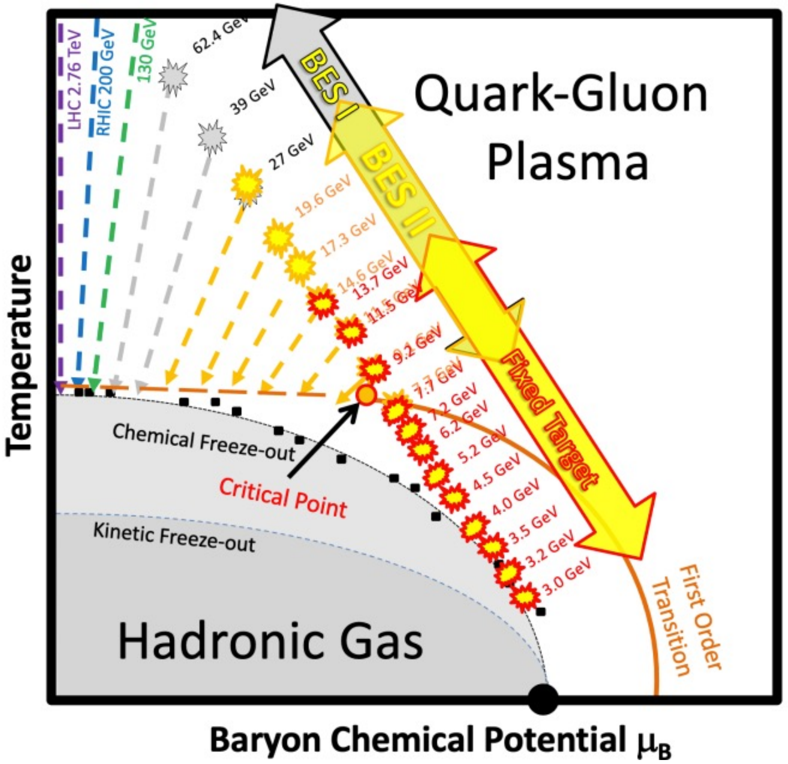
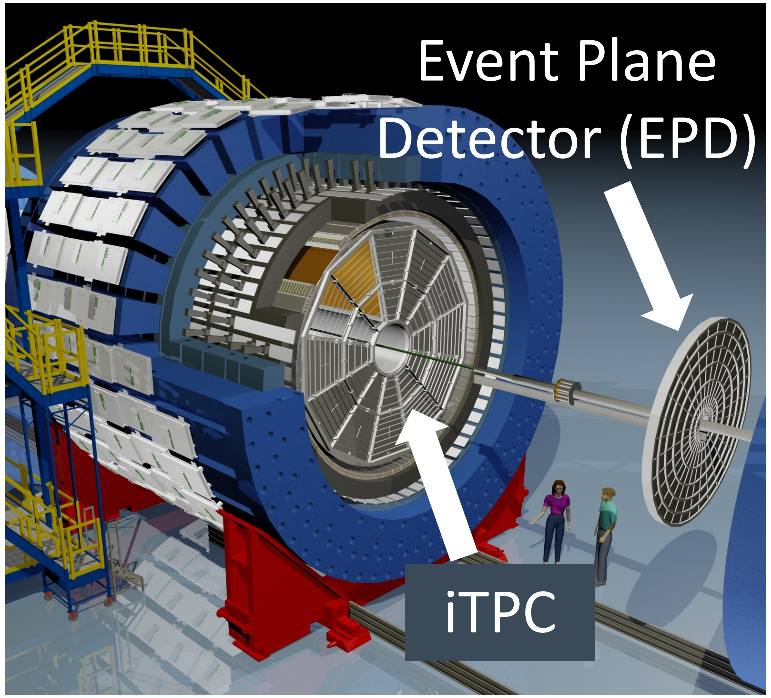
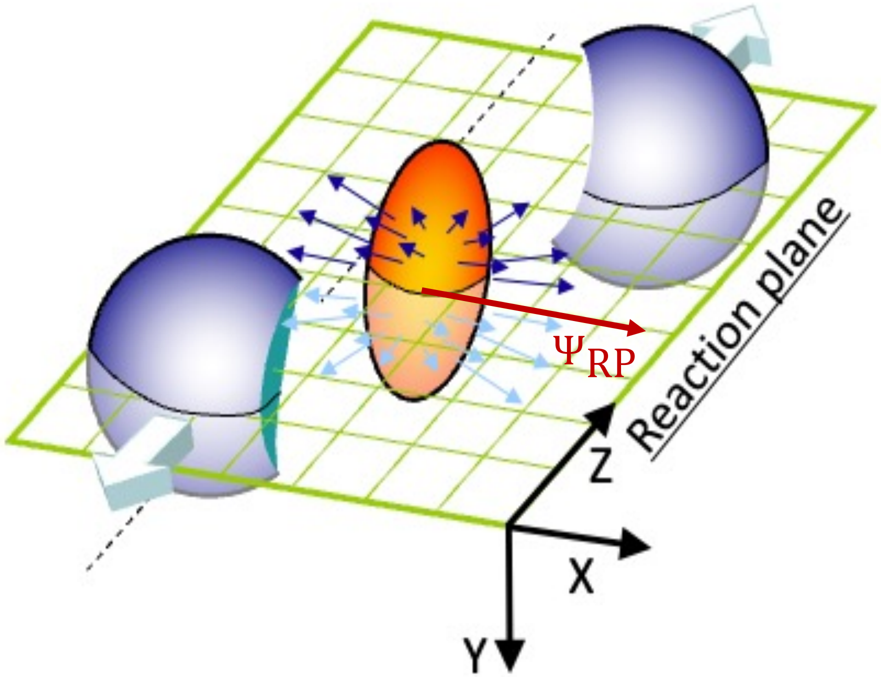
BES-II, Fix Target (FXT) and STAR Upgrade

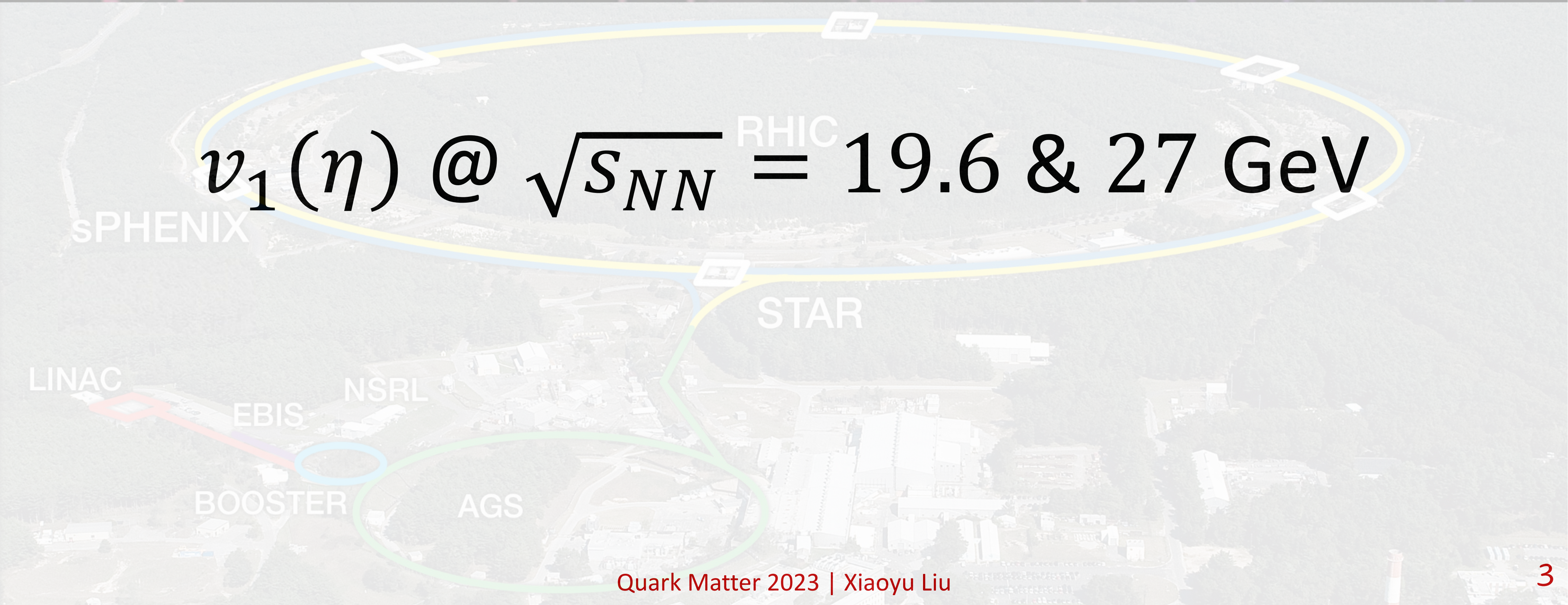




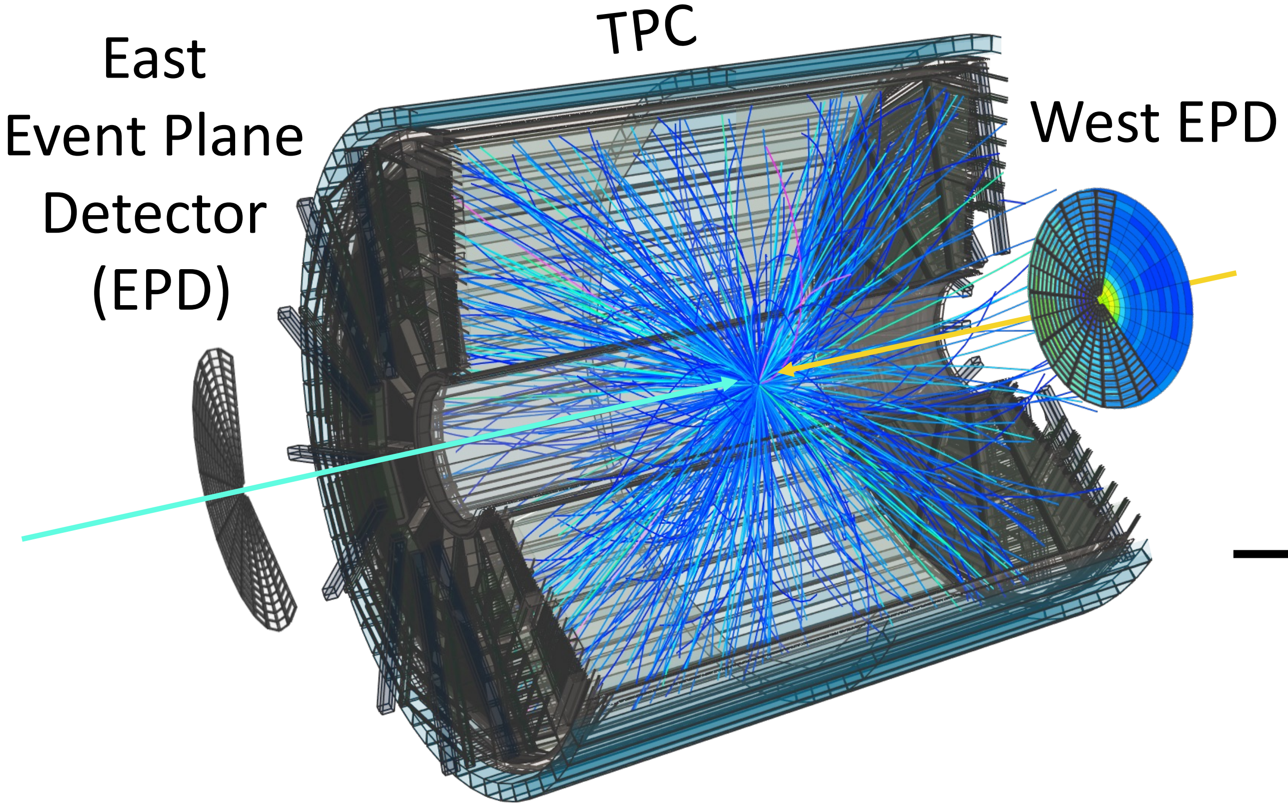


High Statistics Data + Detector Upgrade → Flow Measurements In An Extended Phase Space

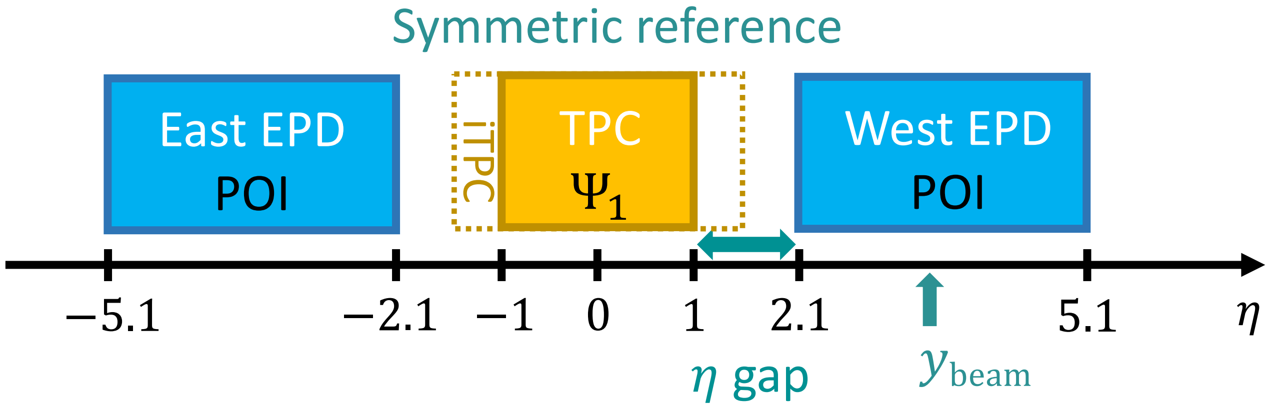
$v_1(\eta)$ @ $\sqrt{s_{NN}} = 19.6$ & 27 GeV



STAR Collider Mode

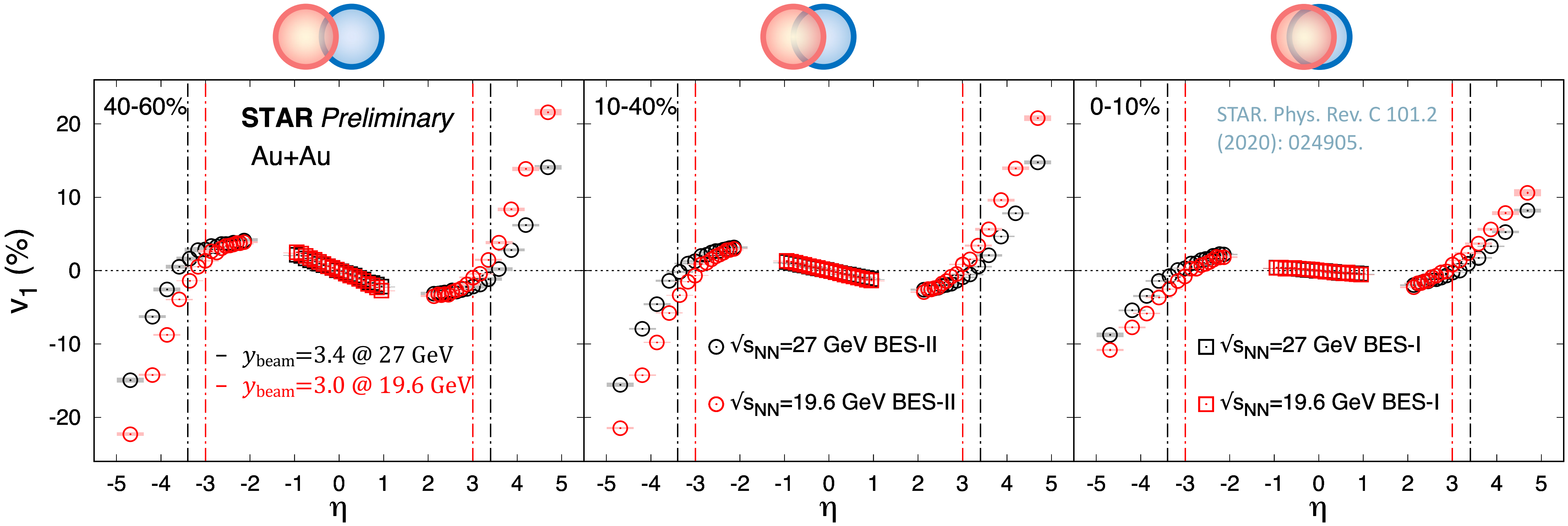


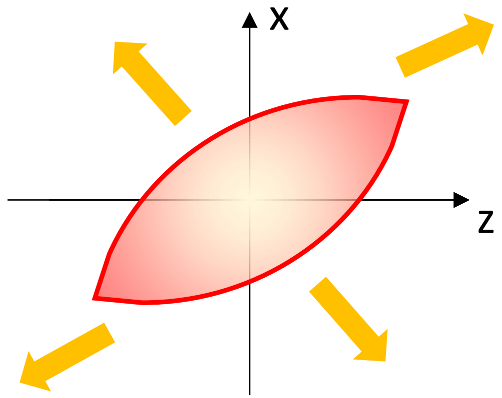
Measure flow over ten units of pseudorapidity (η)!



- EPD is used as the particles of interest region to measure flow at large pseudorapidity.
  - A STAR paper on this analysis is underway, stay tuned!

$v_1(\eta)$ @ $\sqrt{s_{NN}} = 19.6$ & 27 GeV

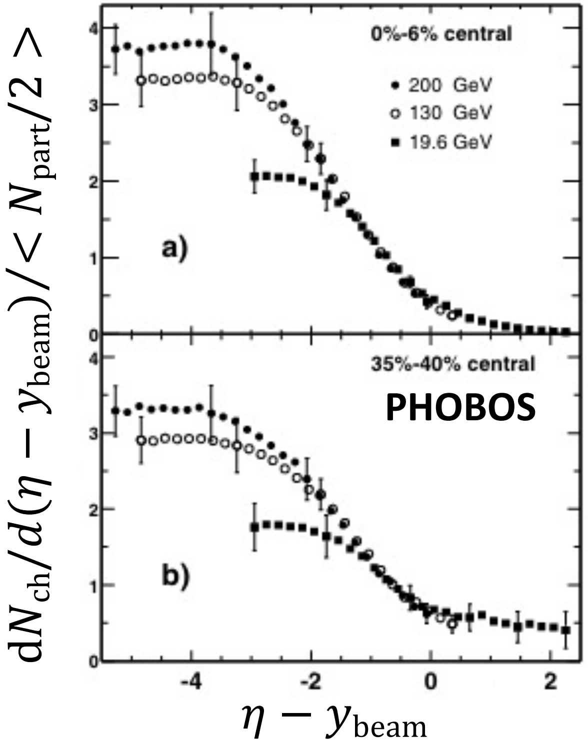




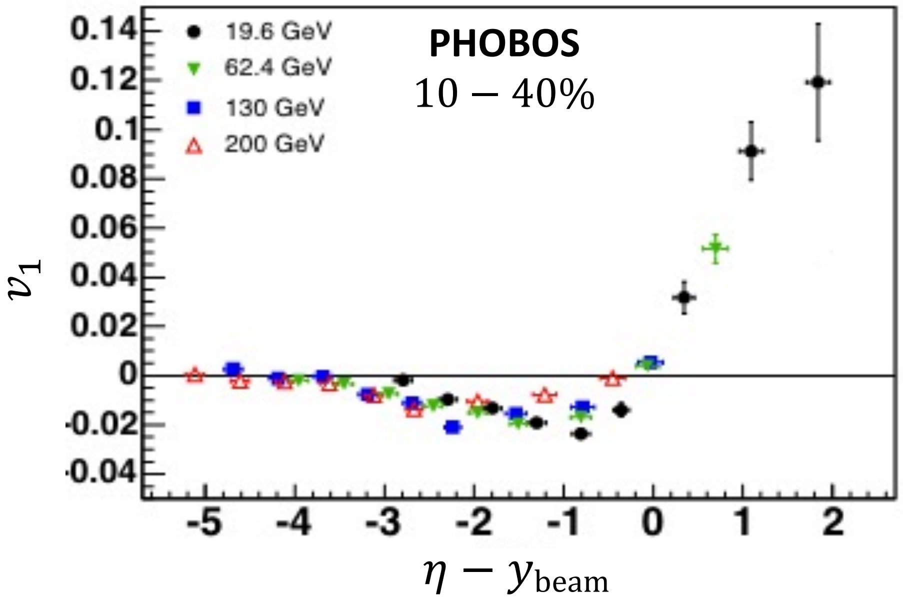
- v_1 at large $|\eta|$ was measured with particles in the full p_T space; v_1 around the mid-rapidity was measured in $0.2 < p_T < 10.0$ GeV/c.

Limiting Fragmentation

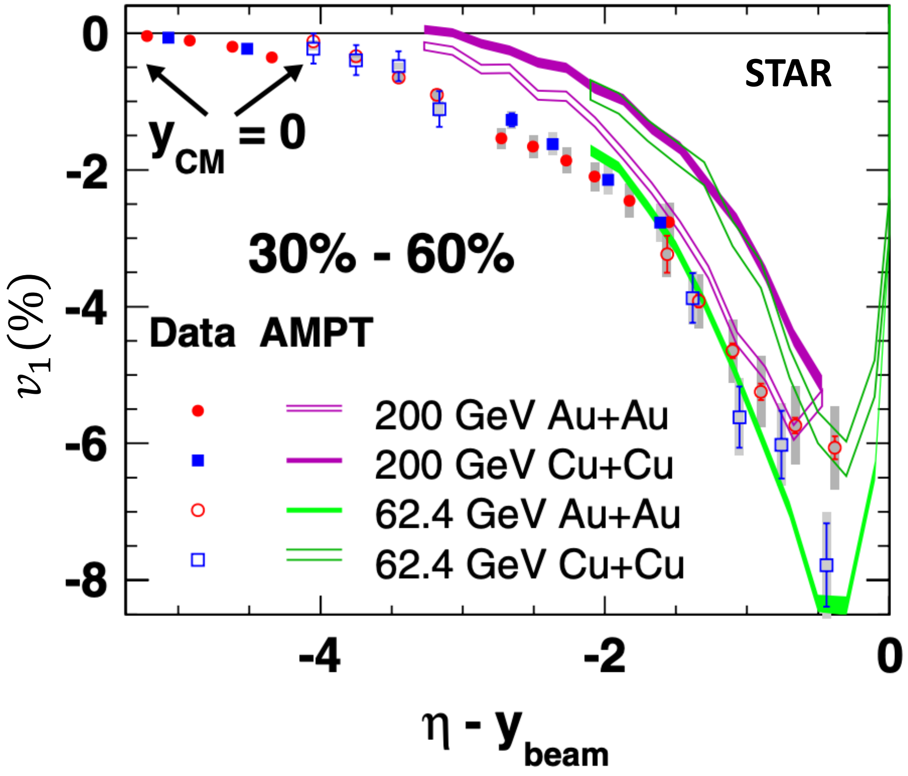
PHOBOS. Phys. Rev. Lett. 91.5 (2003): 052303.



PHOBOS. *Phys. Rev. Lett*. 97.1 (2006): 012301.

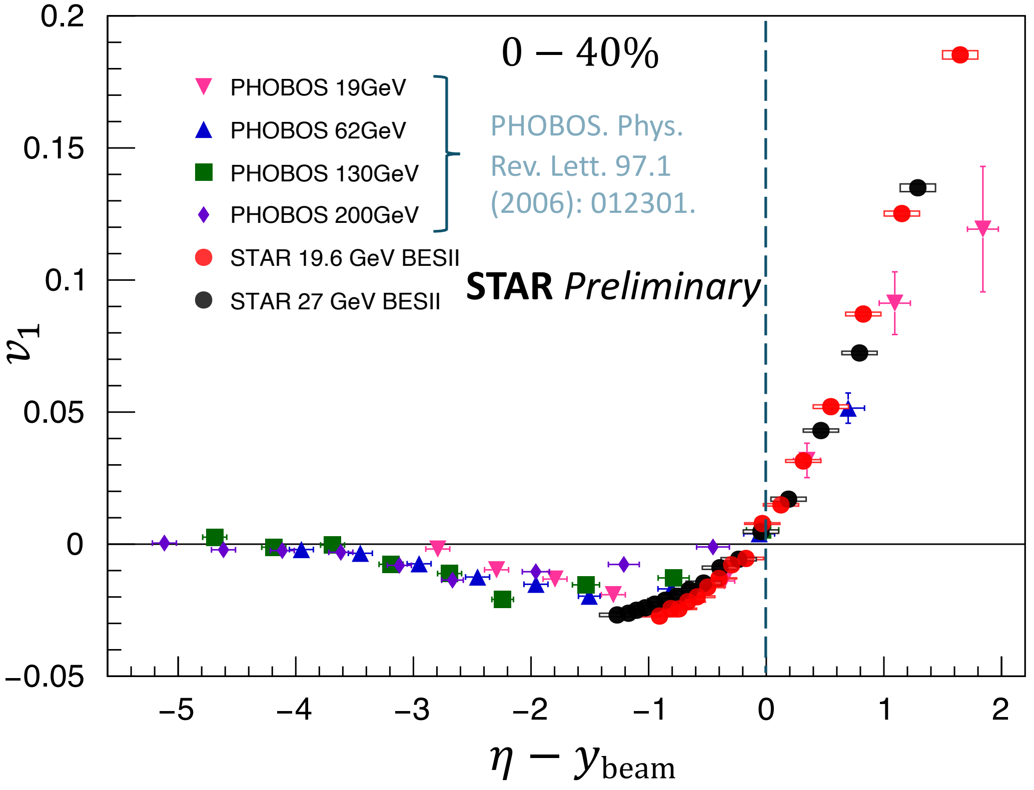


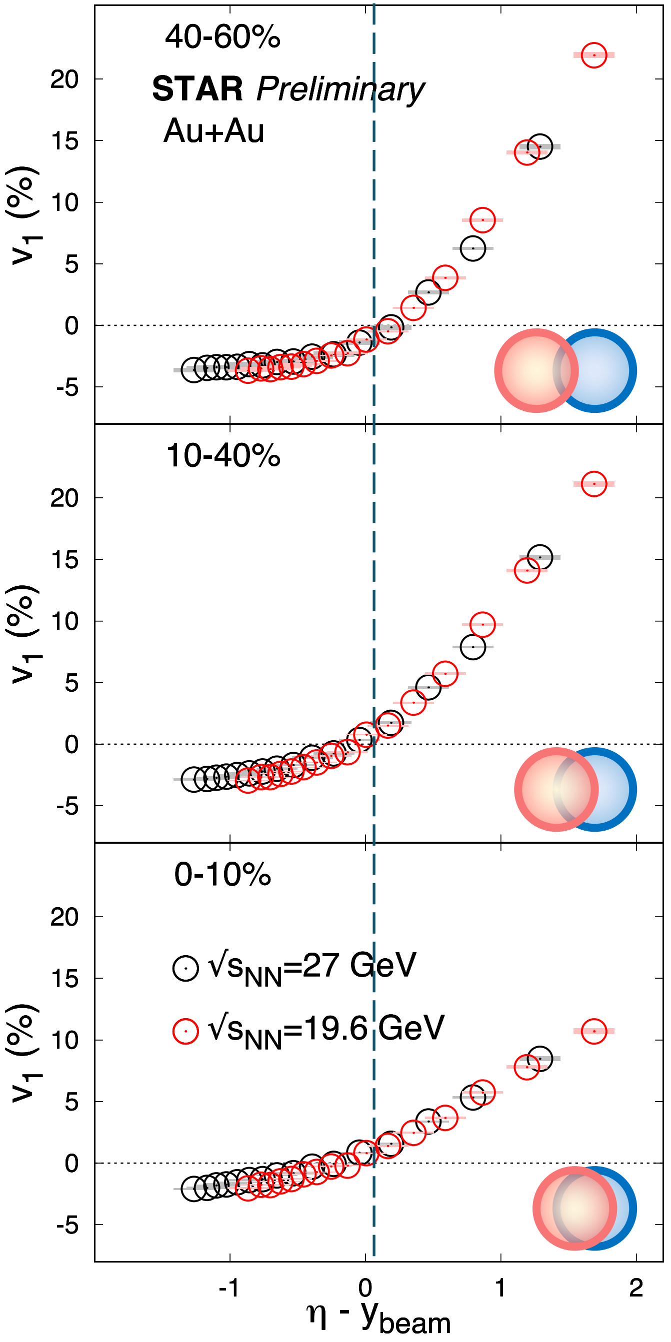
Phys. Rev. Lett. 101.25 (2008): 252301



- "Limiting fragmentation" of v_1?
  - Lack of statistics;
  - limited pseudorapidity coverage.

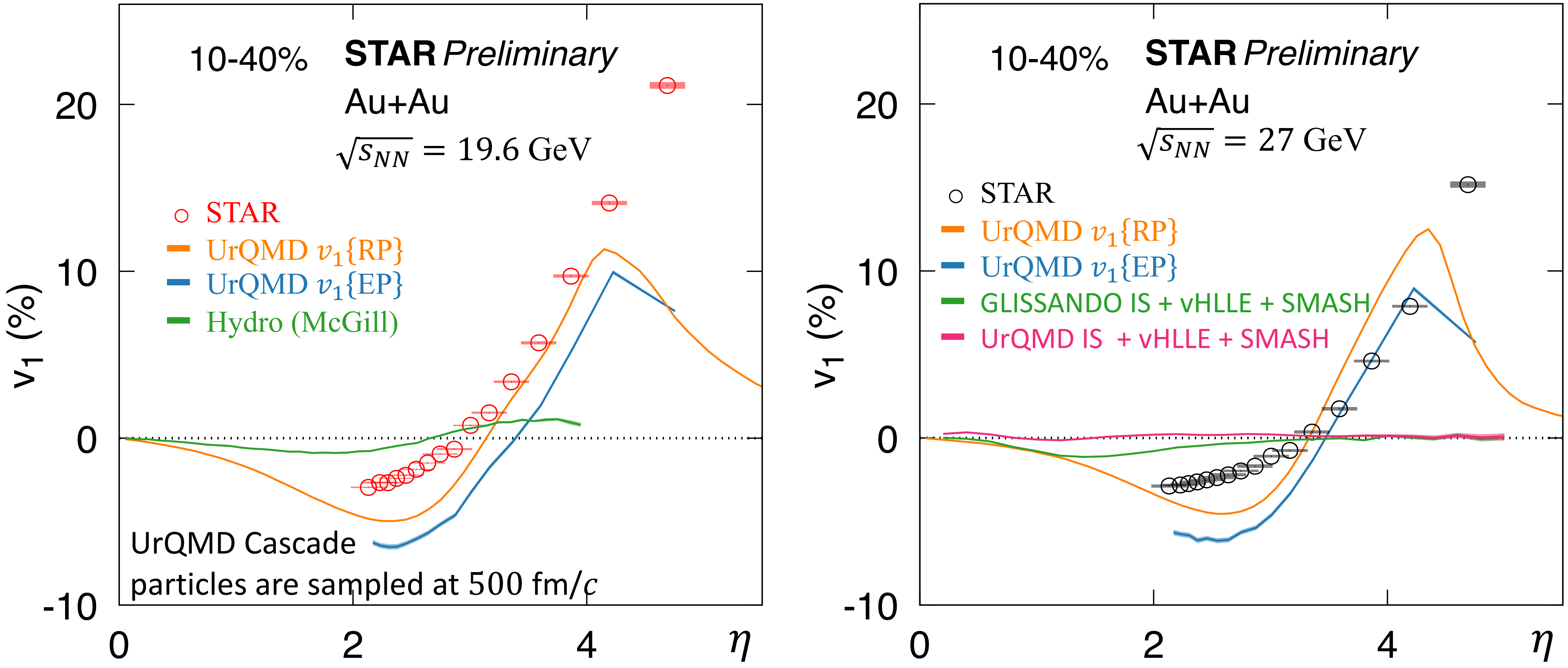
Limiting Fragmentation Of v_1





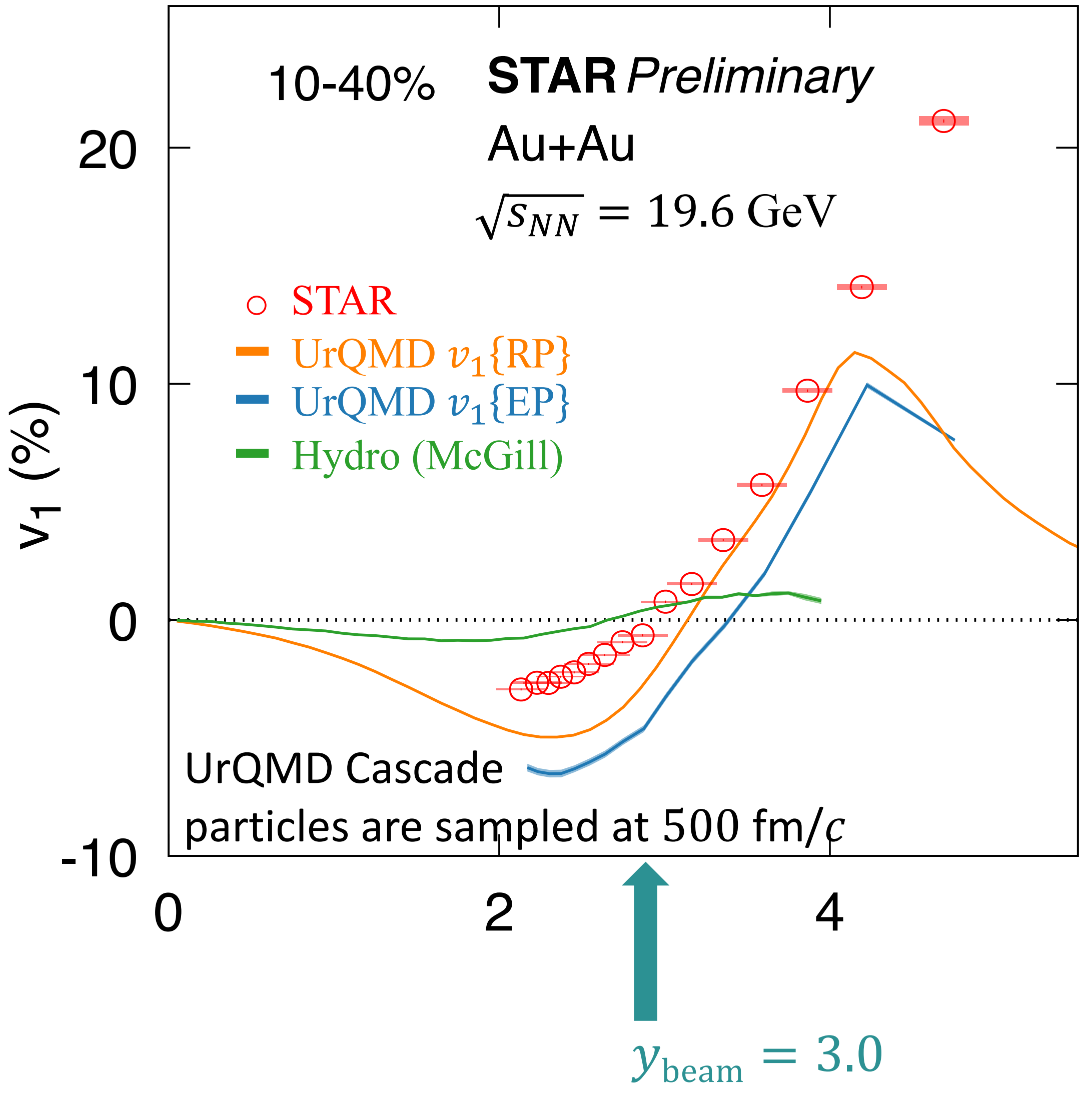
- "Limiting fragmentation" of v_1 observed for all the centralities.
- The phenomenon extends beyond yields to dynamics.

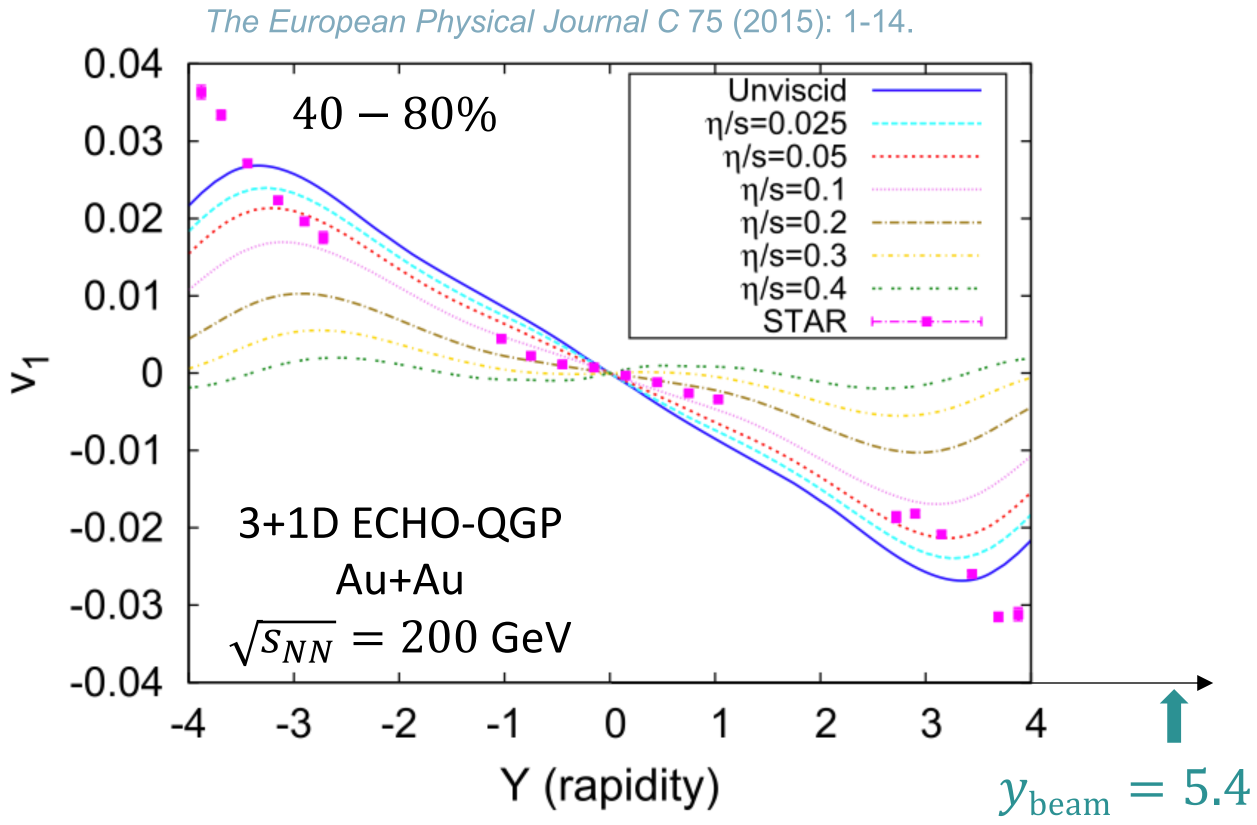
Model Comparison



- Nucleus fragments contribute significantly to v_1 at large $|\eta|$.
- $v_1(\eta)$ can provide unique constrains to the initial stage of the collision.

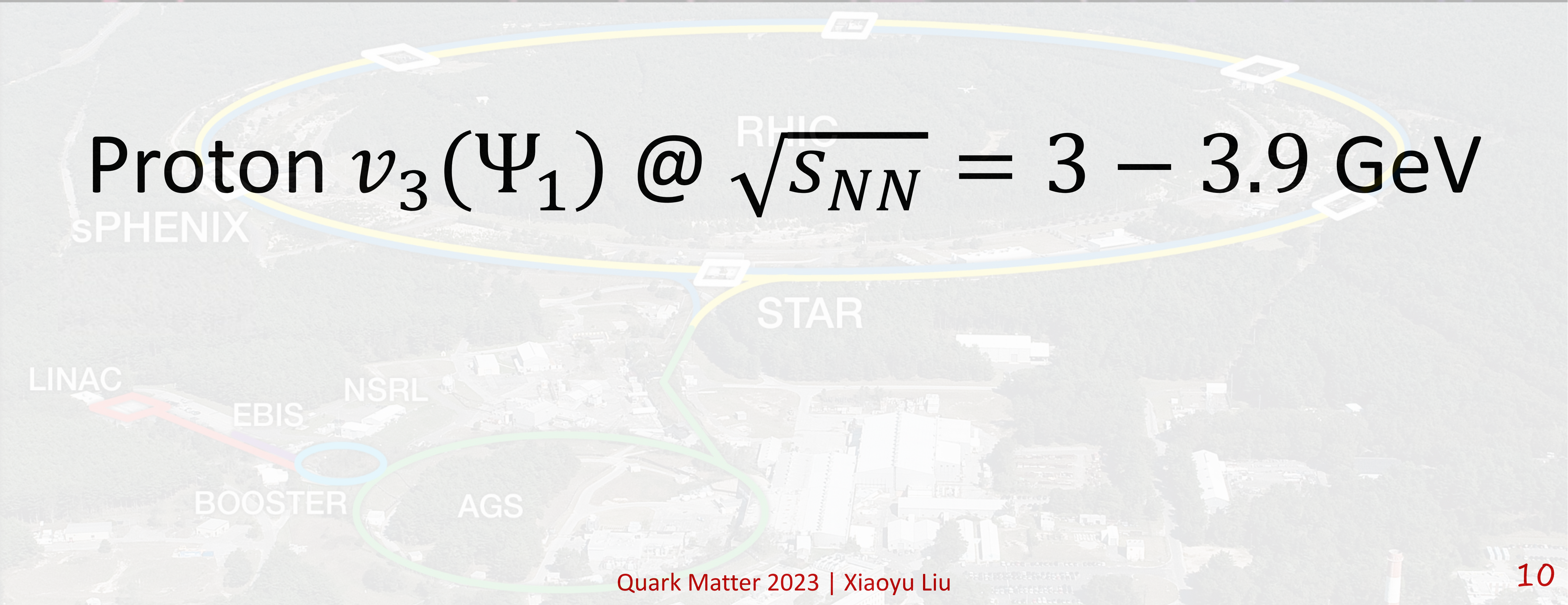
Model Comparison



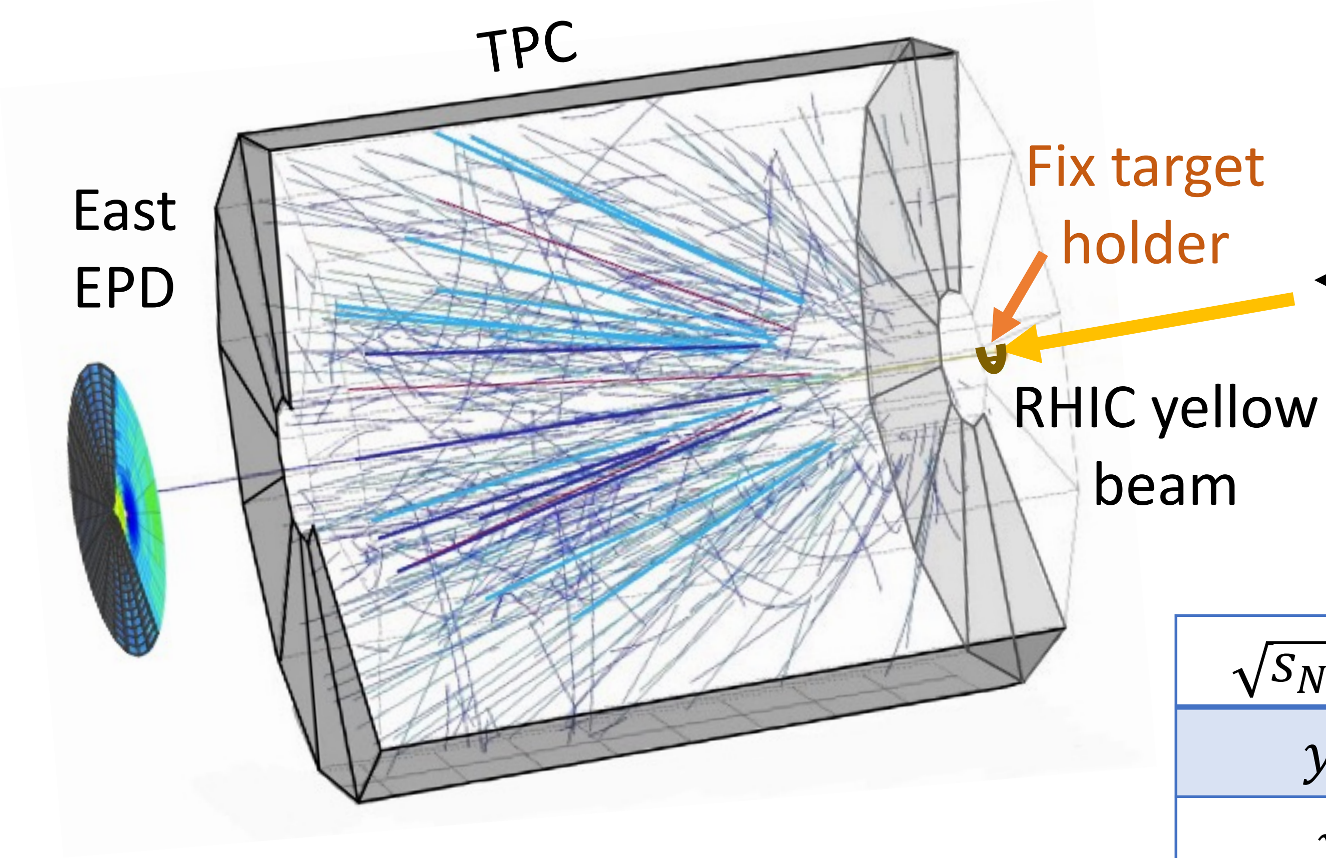


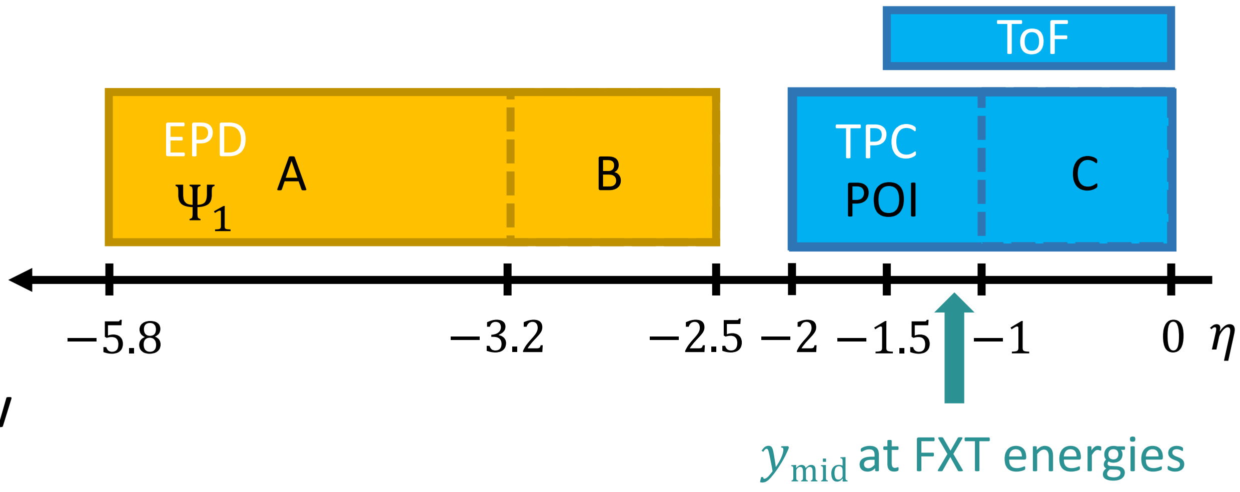
- $v_1(\eta)$ can provide unique constraints on the shear viscosity ($\frac{\eta}{s}(T, \mu_B)$) of the QCD matter.
  - Model calculations are needed.

Proton $v_3(\Psi_1)$ @ $\sqrt{s_{NN}} = 3 - 3.9$ GeV



STAR Fix Target (FXT) Mode

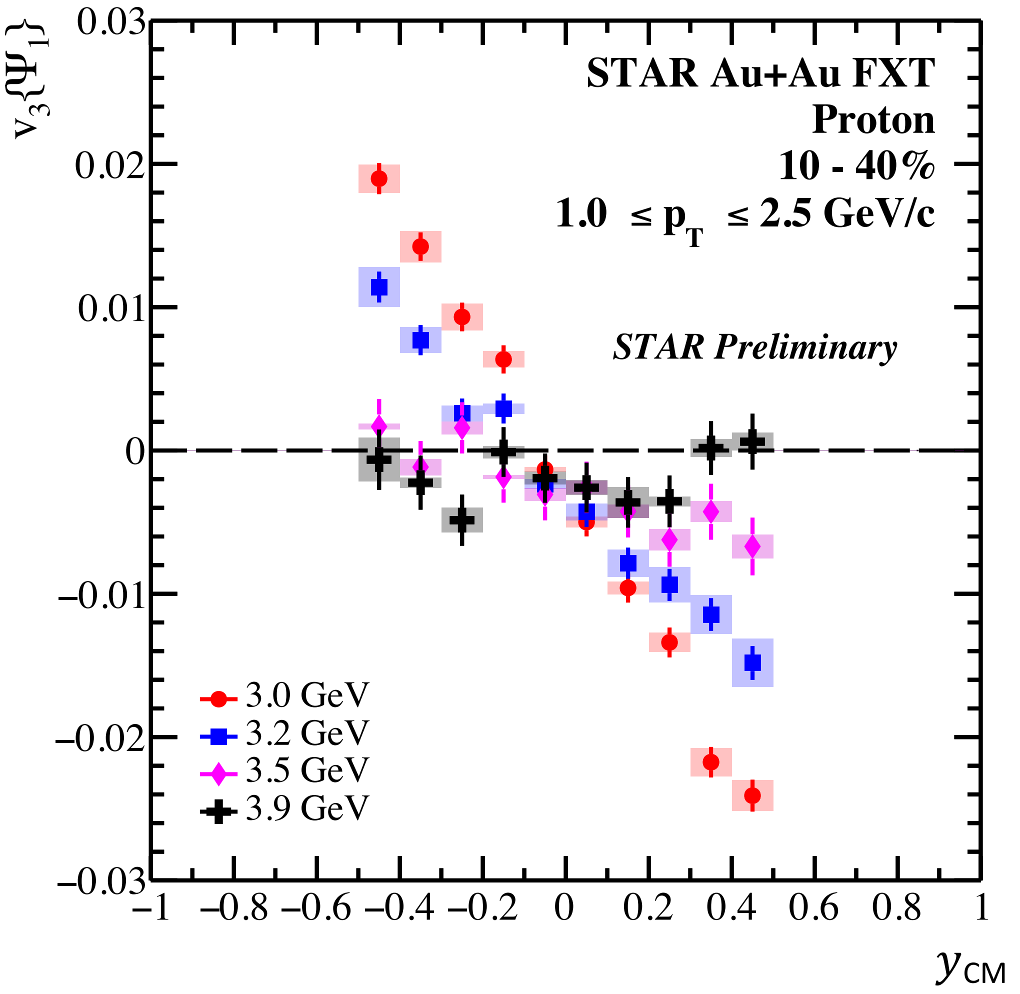


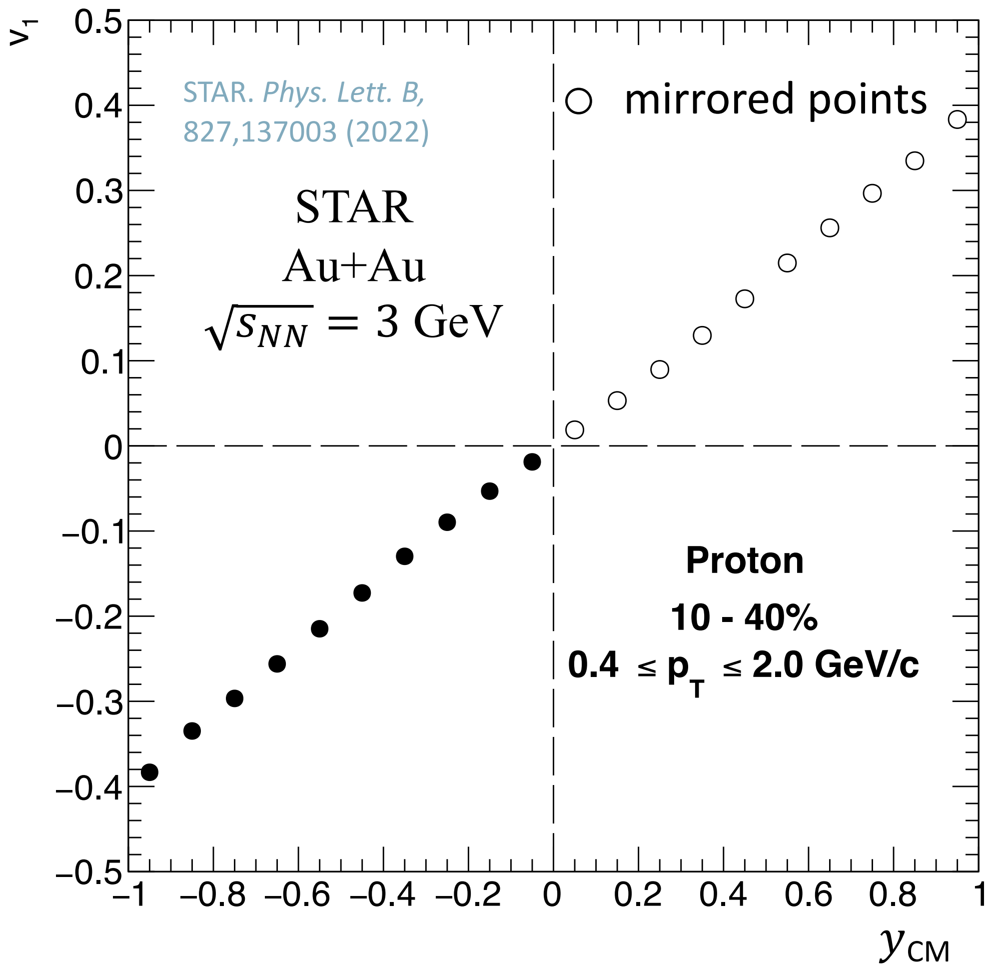


$\sqrt{s_{NN}}$ (GeV)	3.0	3.2	3.5	3.9
y_{beam}	−2.096	−2.278	−2.509	−2.749
y_{mid}	−1.048	−1.139	−1.254	−1.375

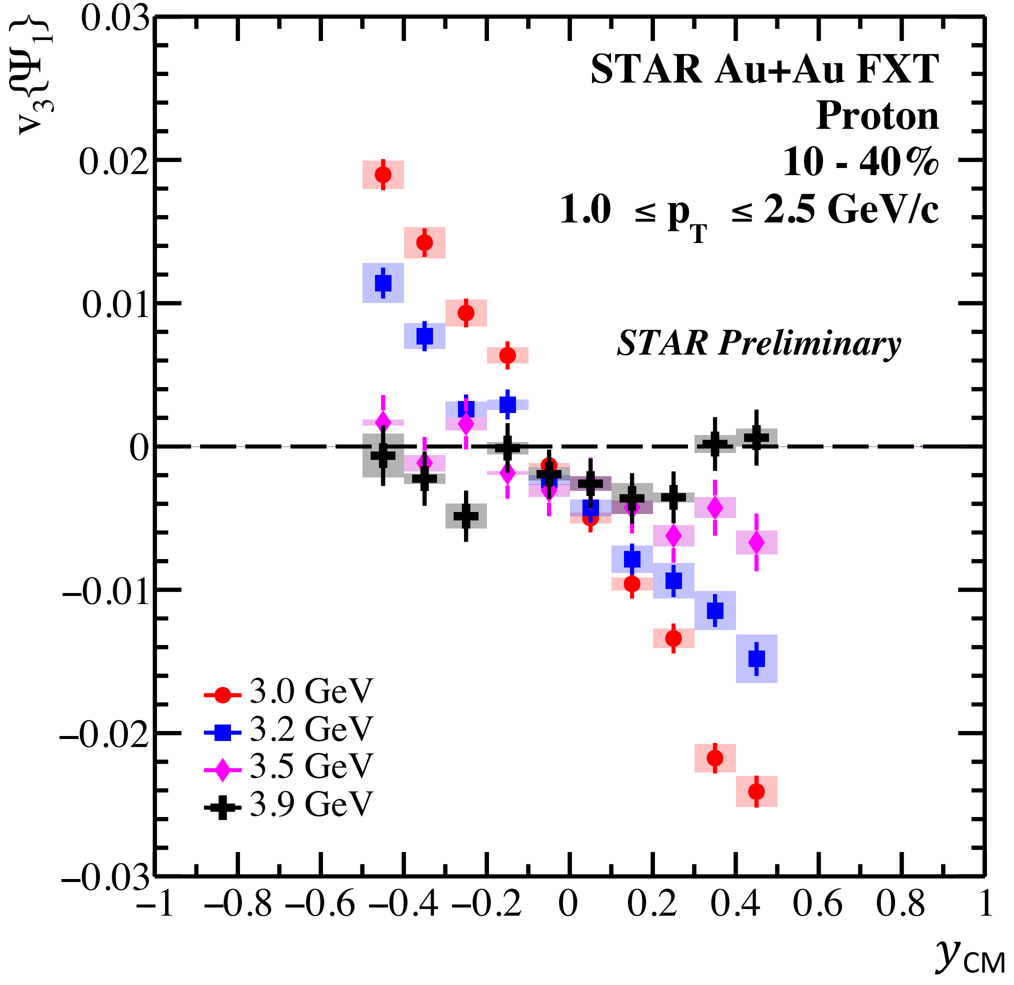
$$y_{\mathrm{CM}} = y - y_{\mathrm{mid}}$$

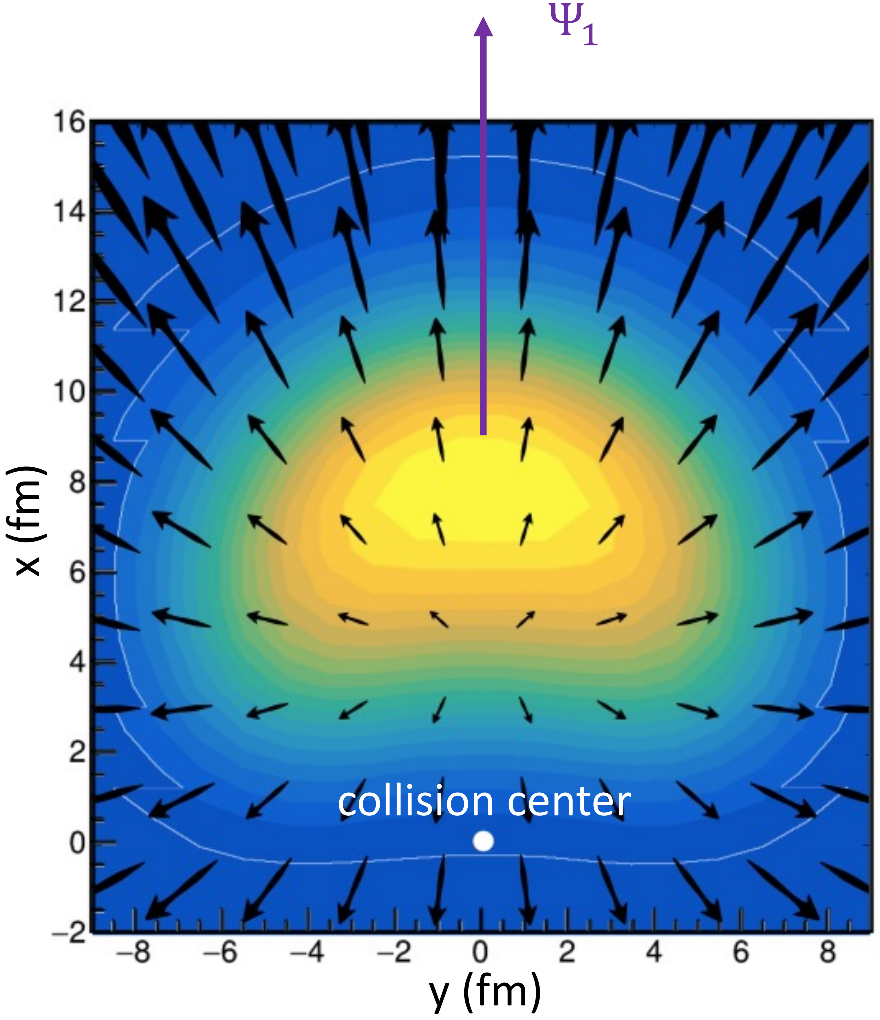
$v_3\{\Psi_1\}$ @ FXT Energies





$v_3\{\Psi_1\}$ @ FXT Energies



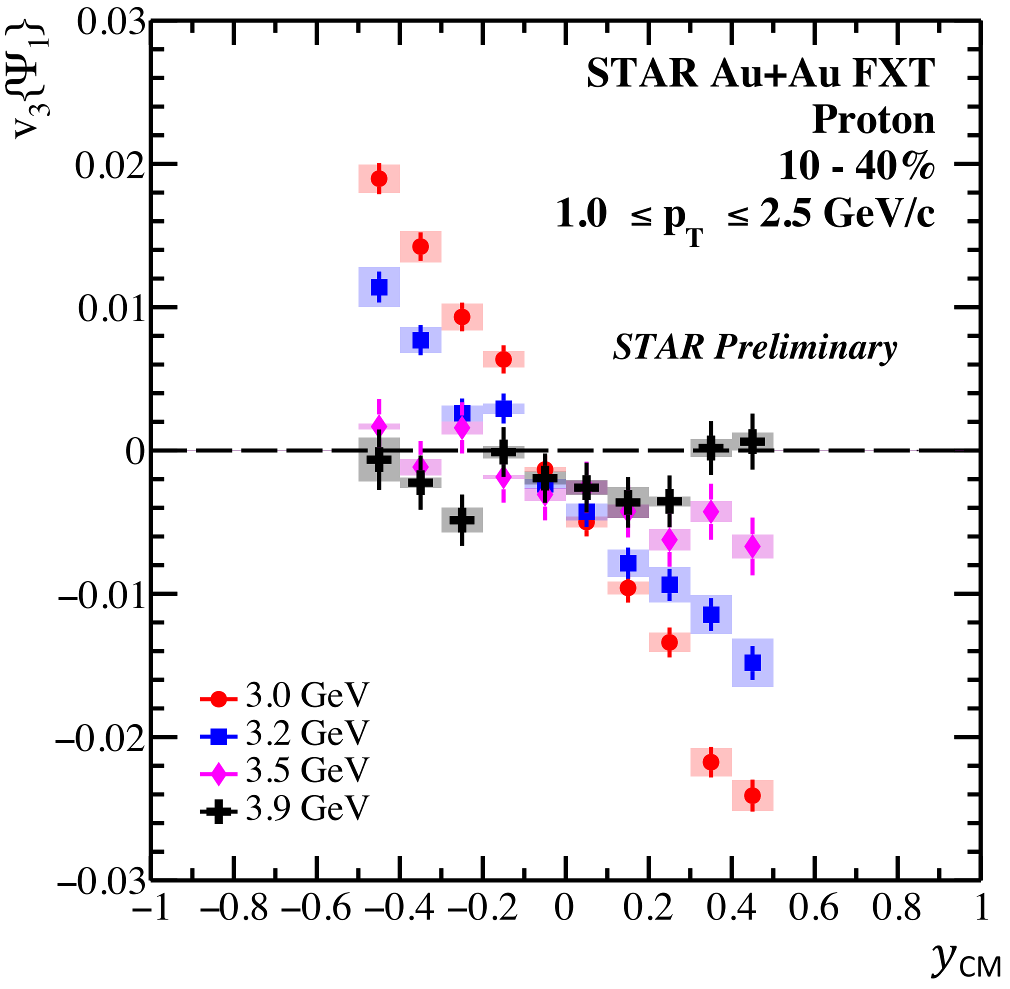


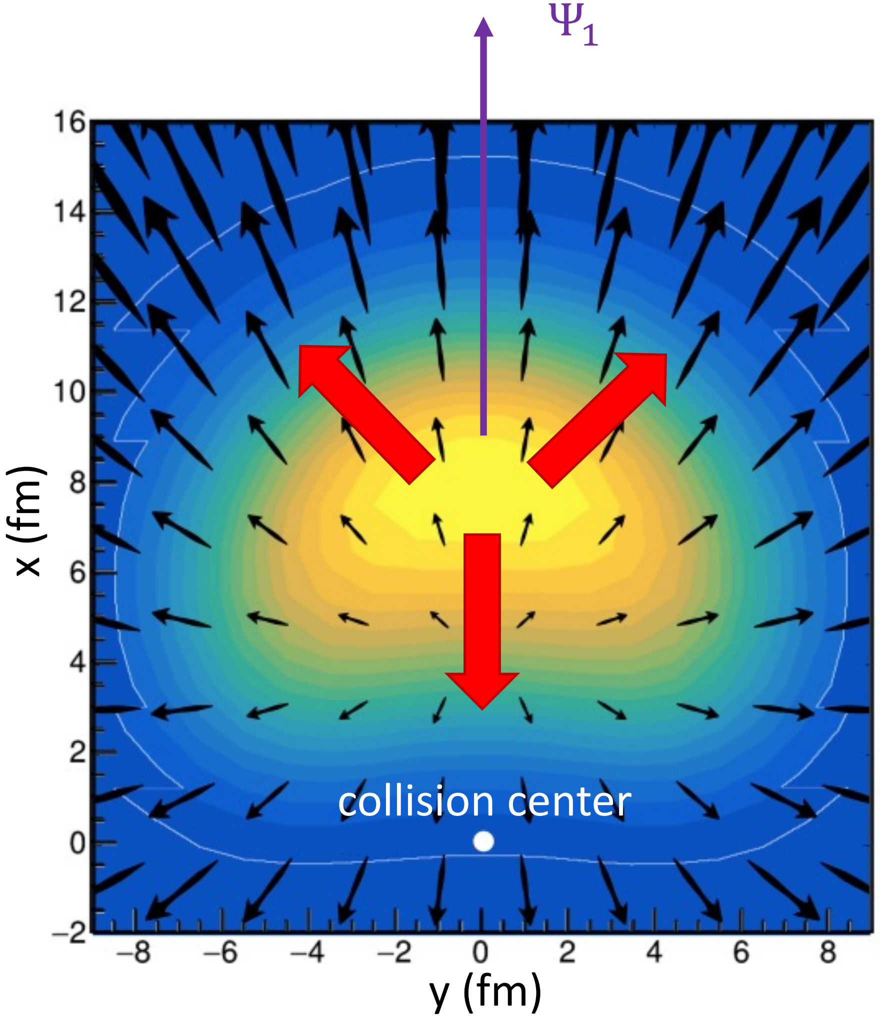
Proton density distribution from JAM @50 fm/c, $\sqrt{s_{NN}} = 3$ GeV, 0.6<rapidity<0.85.

Black arrows represent <p_T> in each cell.

- $v_3\{\Psi_1\}$ opposite to v_1, consistent with JAM simulation of the collision geometry.

$v_3\{\Psi_1\}$ @ FXT Energies





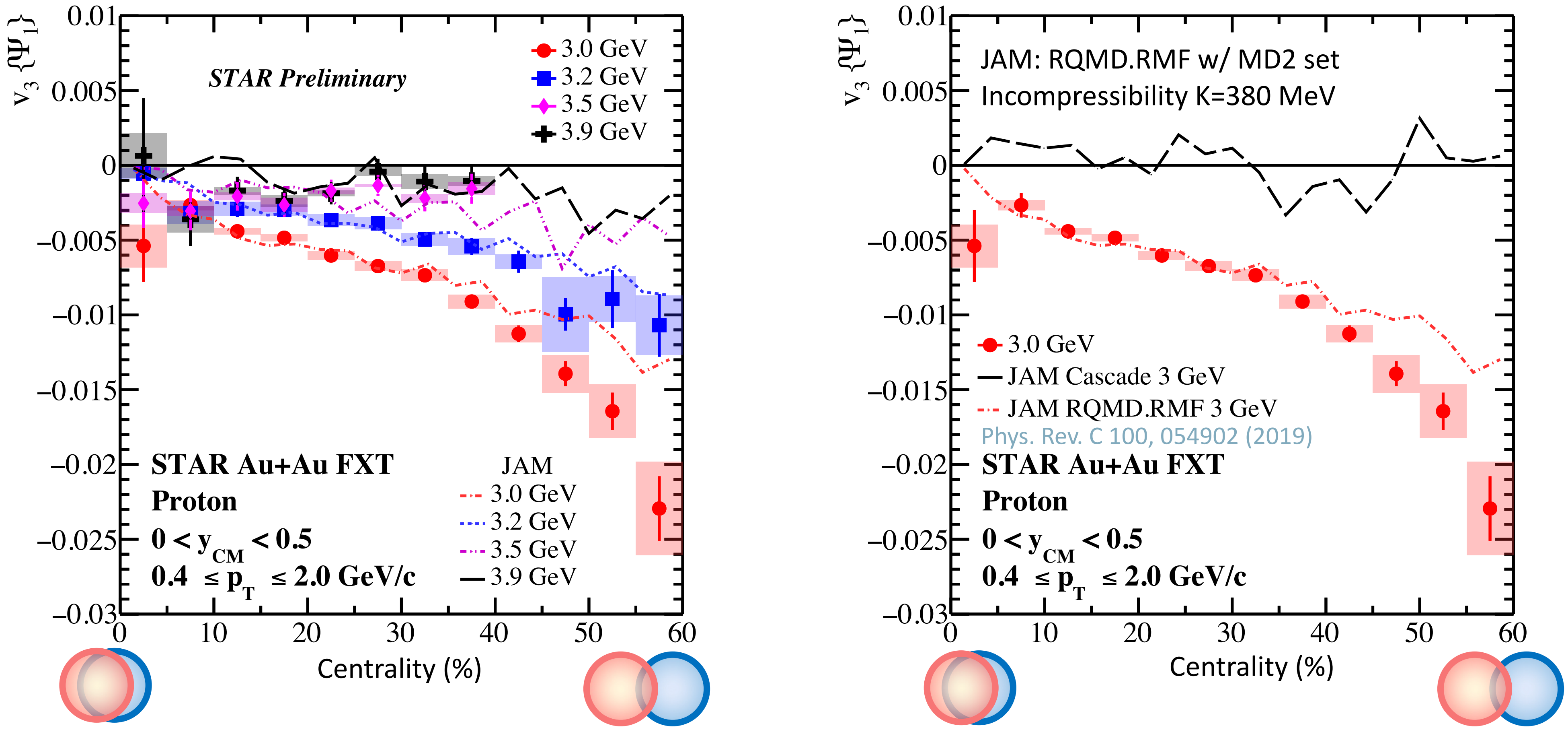
Proton density distribution from JAM @50 fm/c, $\sqrt{s_{NN}}$ = 3 GeV, 0.6<rapidity<0.85.

Black arrows represent <p_T> in each cell.

Red arrows represent pressure gradient

- $v_3\{\Psi_1\}$ opposite to v_1, consistent with JAM simulation of the collision geometry.

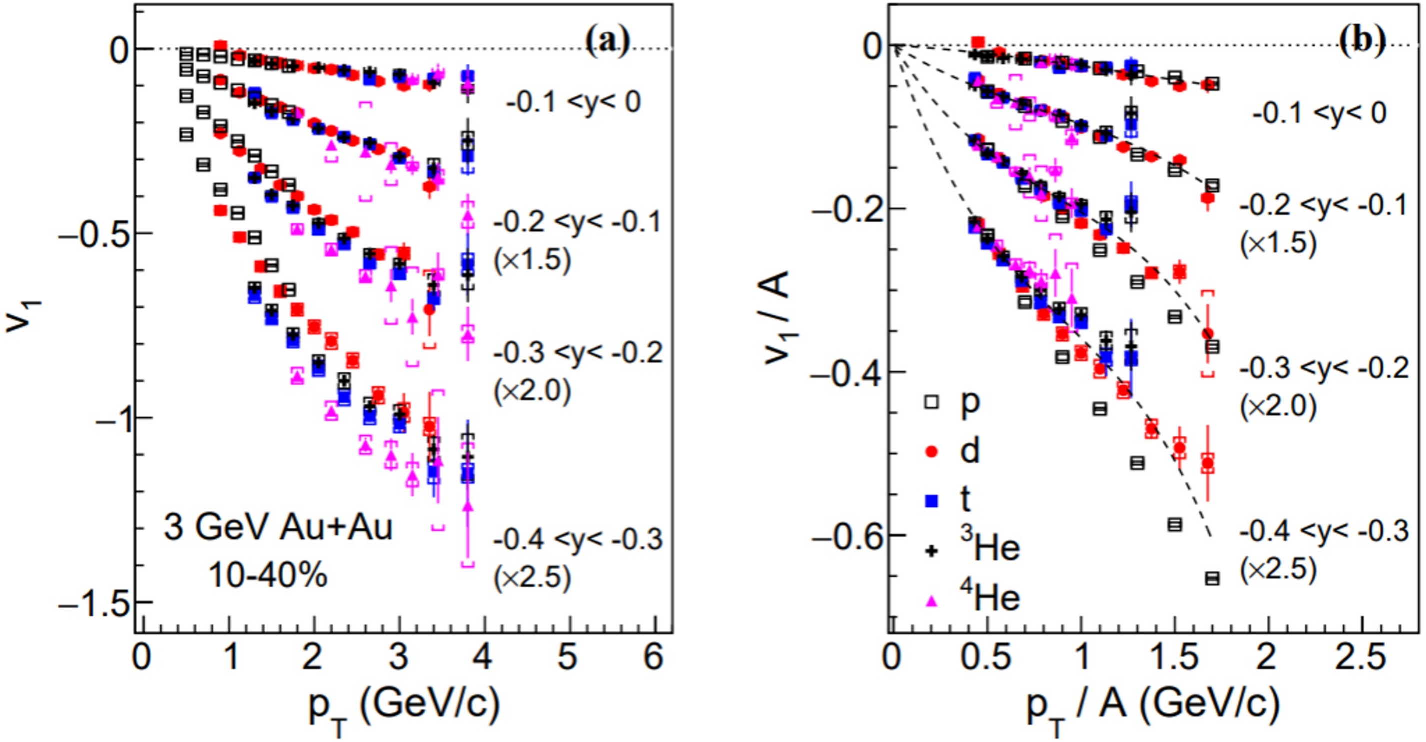
Proton $v_3\{\Psi_1\}$ @ FXT Energies



- $|v_3\{\Psi_1\}|$ increases towards peripheral collisions -> Geometry drives $v_3\{\Psi_1\}$.
- JAM describes the data -> Nuclear potential is essential for the development of $v_3\{\Psi_1\}$.

Light Nuclei v_1 and v_3 @ $\sqrt{s_{NN}} = 3$ GeV

Test Of Coalescence @ $\sqrt{s_{NN}} = 3$ GeV

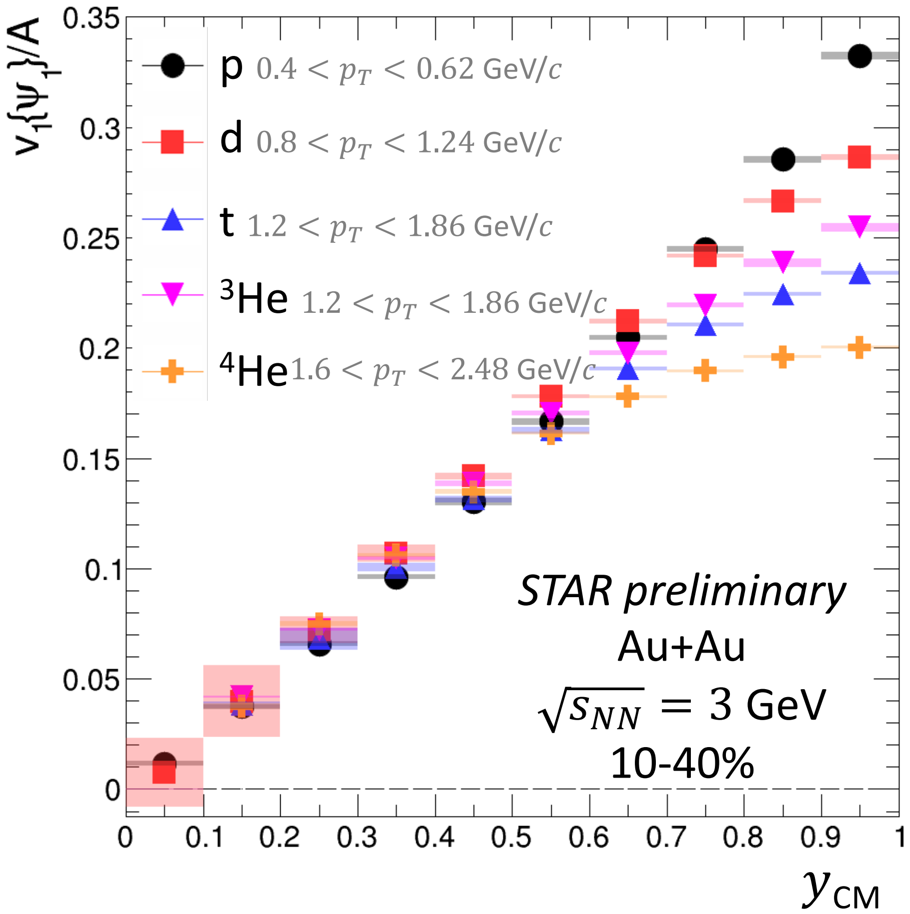


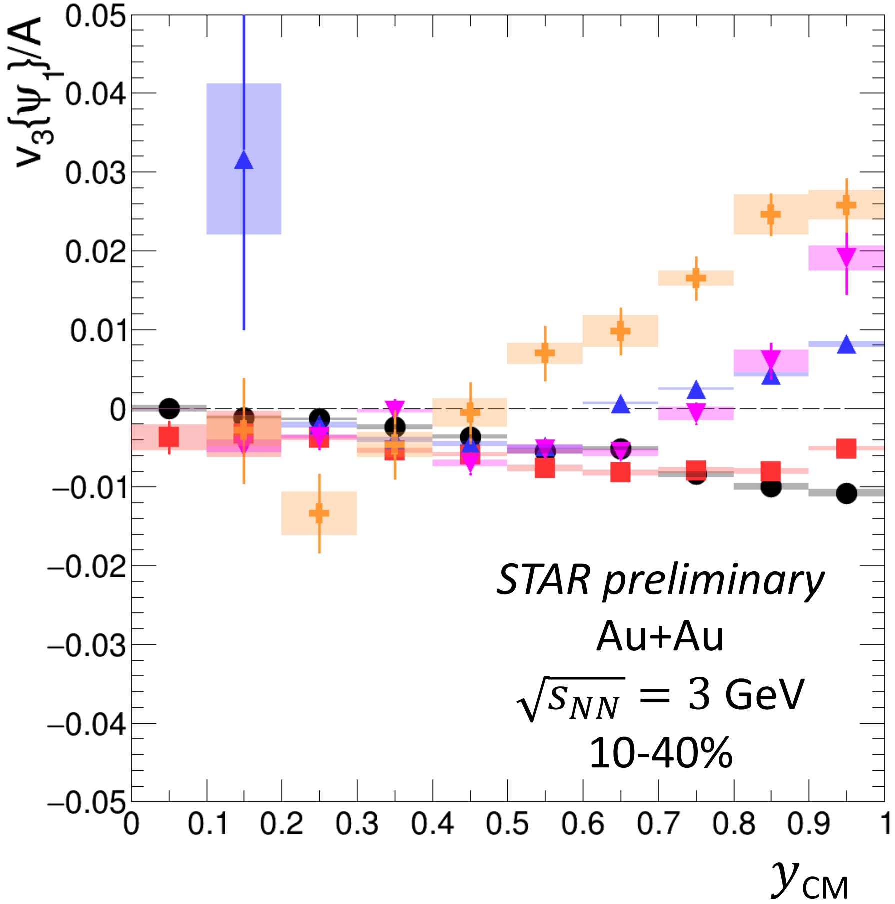
STAR. *Physics Letters B* 827 (2022): 136941.

- STAR observed light nuclei v_1 follows an approximate atomic mass number A-scaling.

➜ Extend this measurement to the target rapidity with the STAR FXT experiment to investigate coalescence across a wide range of rapidity.

Identified Particle v_1, $v_3\{\Psi_1\}$ @$\sqrt{s_{NN}} = 3$ GeV





- A-scaling of v_1 and $v_3\{\Psi_1\}$ holds at $y_{CM} < 0.5$ in $10 - 40$ % at $\sqrt{s_{NN}} = 3$ GeV, indicating that the production of light nuclei comes from coalescence.
- However, this A-scaling of v_1 and $v_3\{\Psi_1\}$ breaks for $y_{CM} > 0.5$.

Summary

Collider: $\sqrt{s_{NN}} = 19.6, 27$ GeV

- $v_1(\eta)$ was measured over ten units of η with high accuracy.
  - "Limiting fragmentation" of v_1 was observed for all the centralities.
  - Model comparisons suggest nuclei fragments contribute significantly to v_1 at large $|\eta|$.

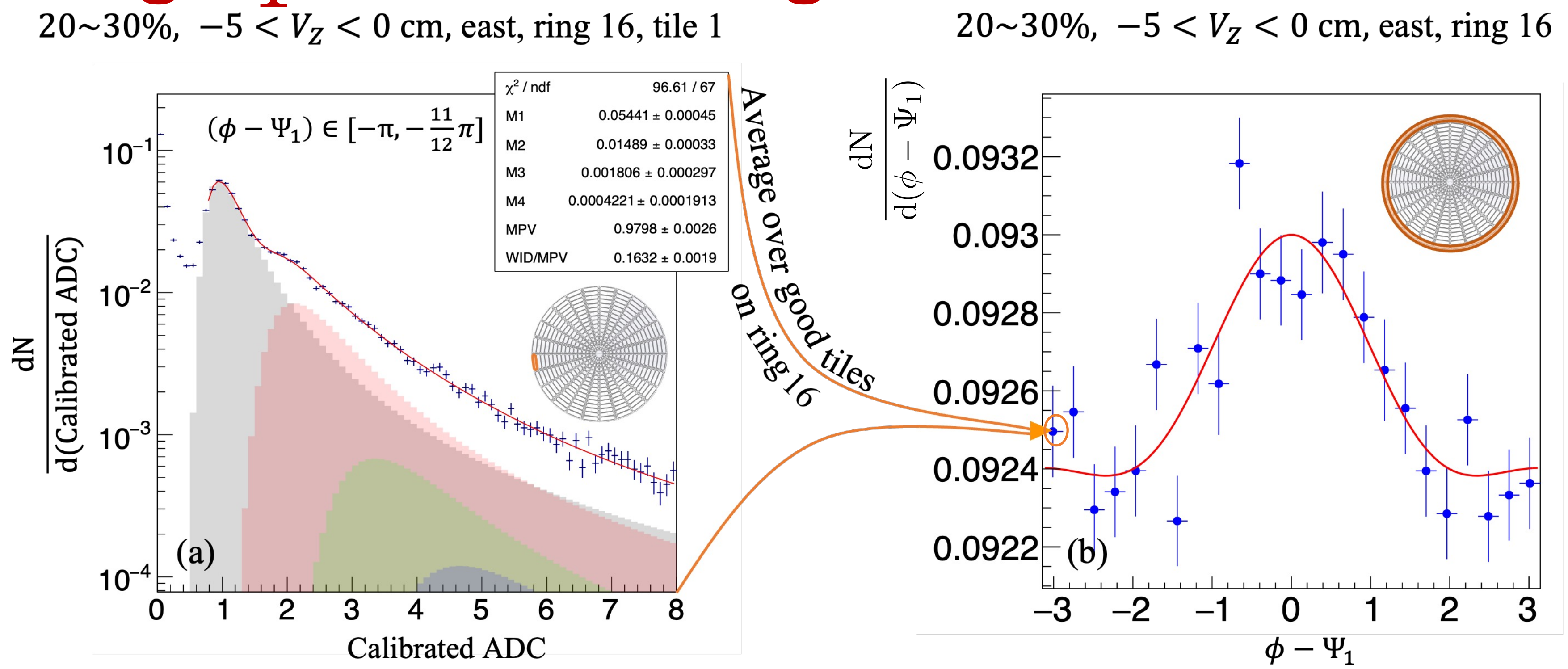
Fix Target: $\sqrt{s_{NN}} = 3, 3.2, 3.5, 3.9$ GeV

- Significant proton $v_3\{\Psi_1\}$ that has opposite sign from $v_1\{\Psi_1\}$ @ FTX energies.
  - Larger $|v_3\{\Psi_1\}|$ for peripheral collisions -> $v_3\{\Psi_1\}$ is driven by the geometry.
  - Comparison with JAM suggests potential is essential for the development of $v_3\{\Psi_1\}$.
- Light nuclei v_1 and $v_3\{\Psi_1\}$ measured over the full rapidity range at 10-40% @ 3 GeV.
  - A-scaling holds below $y_{\mathrm{CM}} < 0.5$, indicating the production of light nuclei comes from coalescence.
  - A-scaling breaks at $y_{\mathrm{CM}} > 0.5$.

Thank you!

Backup

Extracting v_1 From EPD Signals



- The M_k in the fitting parameters represents the fraction of the k-MIP events. Therefore, the averaged number of MIPs can be calaculated by:

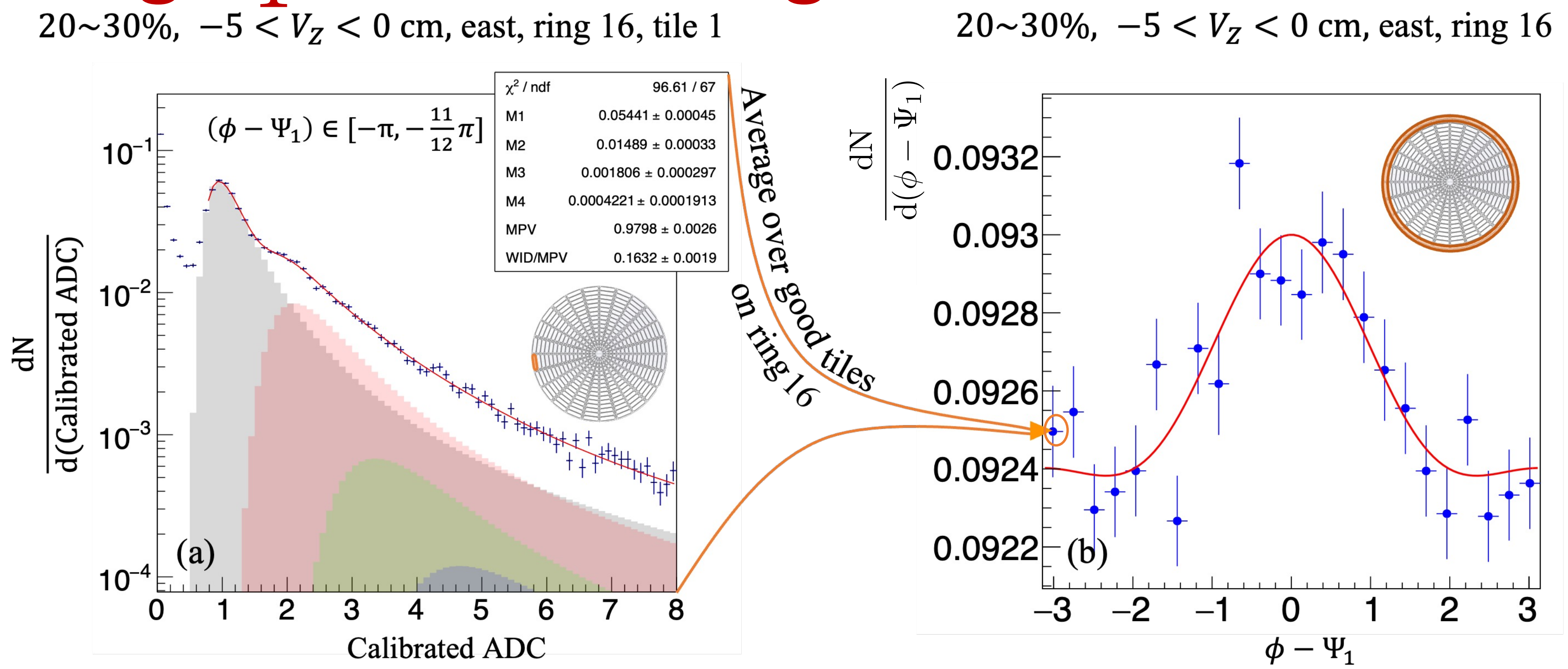
$$N = \sum_{k=1}^{k=4} k \times M_k$$

- The associated error can be calculated by:

$$\sigma^2 = \mathbf{k}\mathbf{\Sigma}\mathbf{k}^\top, \mathbf{k} = (1,2,3,4,0,0)$$

where $\mathbf{\Sigma}$ is the covariance matrix of the fitting parameters.

Extracting v_1 From EPD Signals

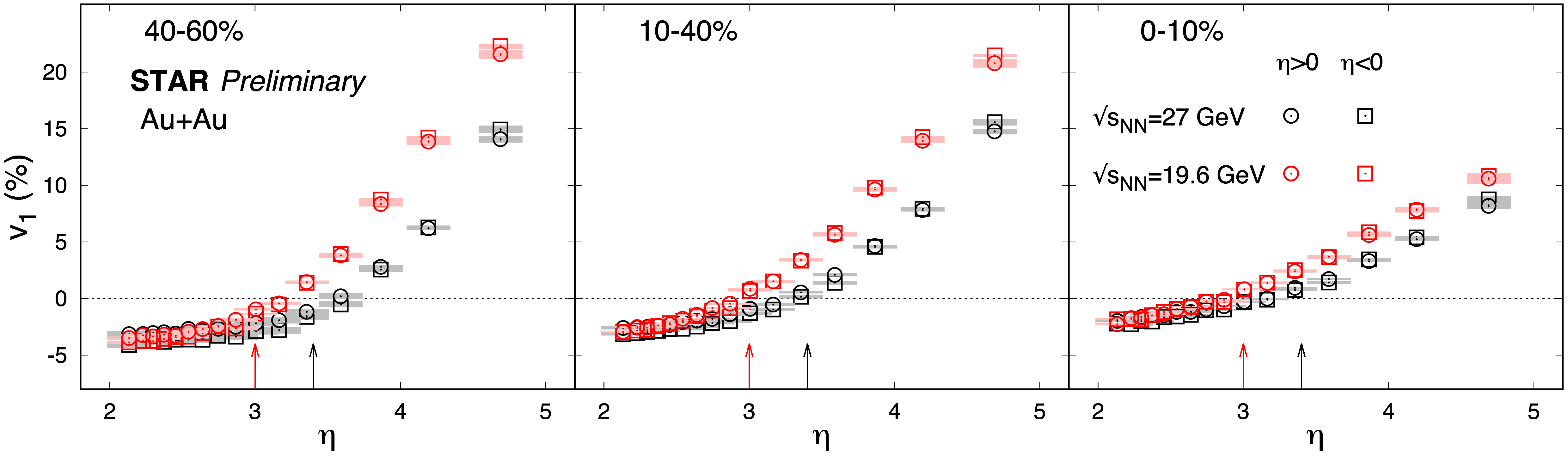


- v_1 (before the resolution correction) can be extracted by fitting the Fourier decomposition of the $(\phi - \Psi_1)$ distribution:

$$\frac{\mathrm{dN}}{\mathrm{d}(\phi - \Psi_1^{\mathrm{TPC}})} = k\{1 + 2v_1 \cos(\phi - \Psi_1^{\mathrm{TPC}}) + 2v_2 \cos[2(\phi - \Psi_1^{\mathrm{TPC}})]\}$$

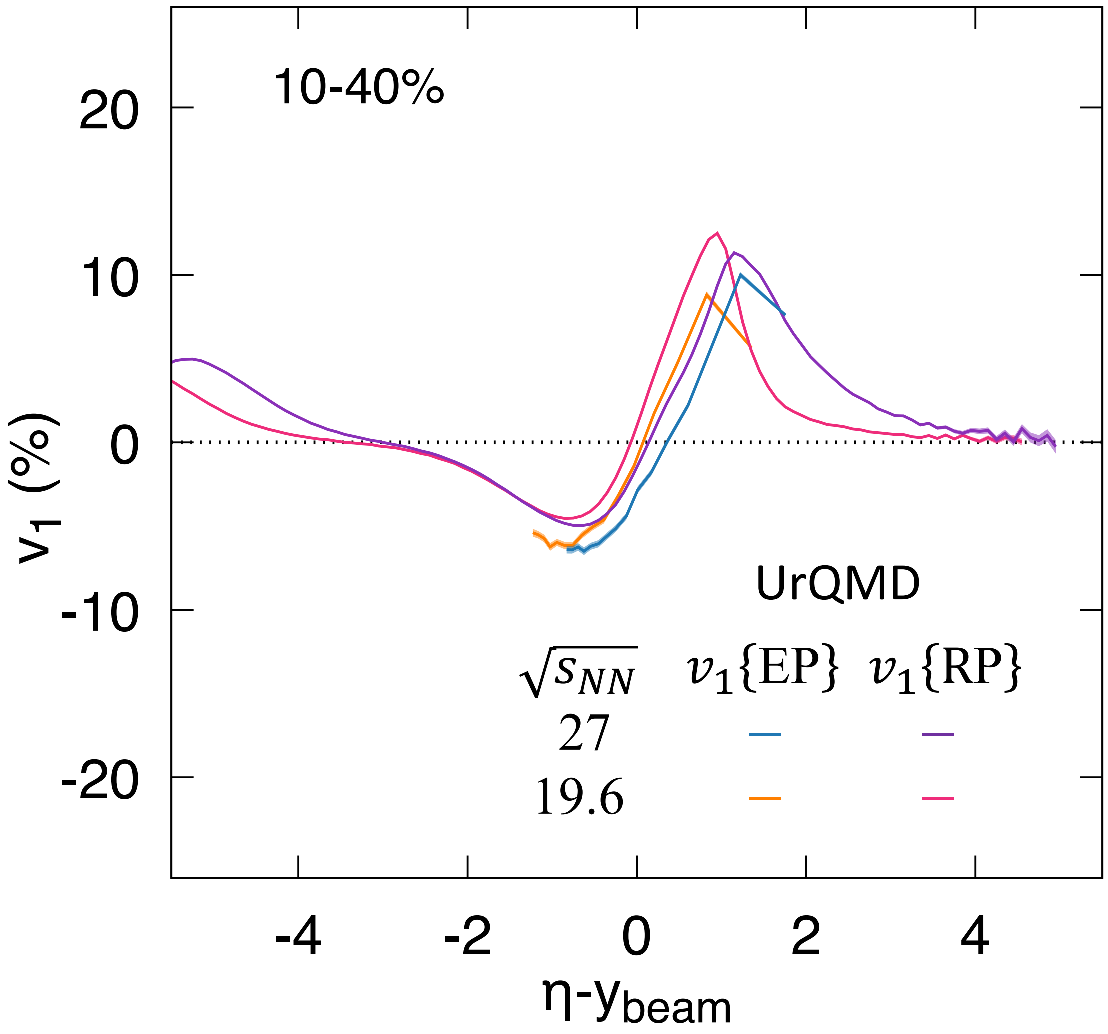
- Resolution correction: $v_1 = \frac{v_1^{\mathrm{uncorrected}}}{R_1^{\mathrm{TPC}}}$ $v_2\{\Psi_1\} = \frac{v_2^{\mathrm{uncorrected}}\{\Psi_1\}}{R_{21}}$

v_1 across wide η at $\sqrt{s_{NN}} = 19.6$ and 27 GeV

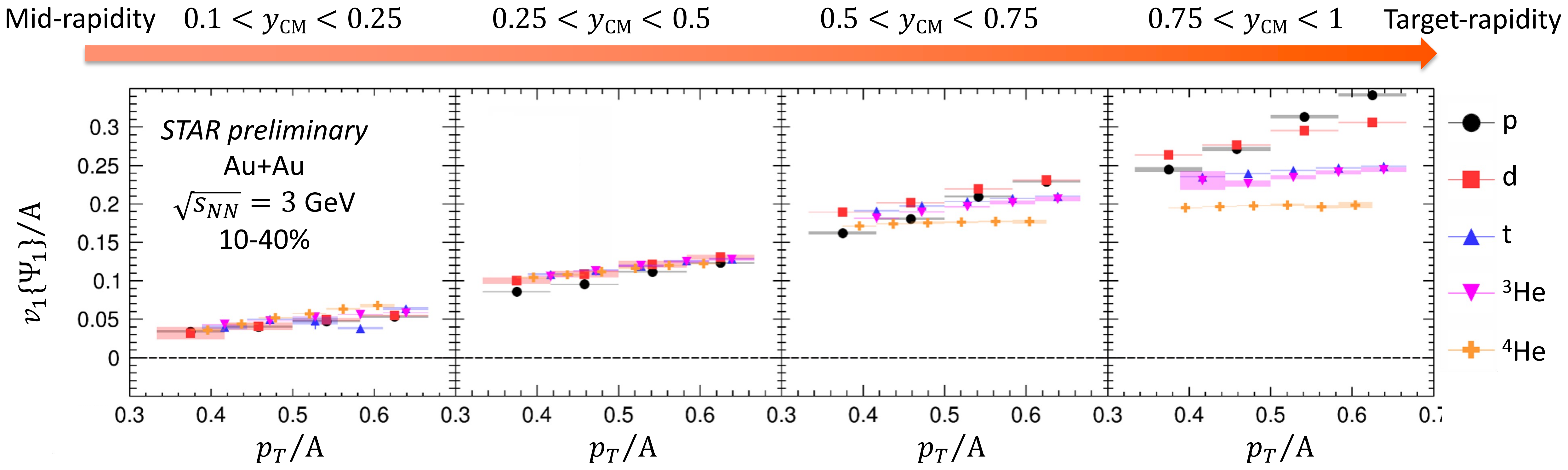


- ✓ Consistency between $v_1(\eta)$ and $-v_1(-\eta)$

UrQMD v_1


10-40%
20
10
0
-10
-20
v_1 (%)
-4
-2
0
2
4
η-y_{beam}
UrQMD
$\sqrt{s_{NN}}$
$v_1\{EP\}$
$v_1\{RP\}$
27
19.6

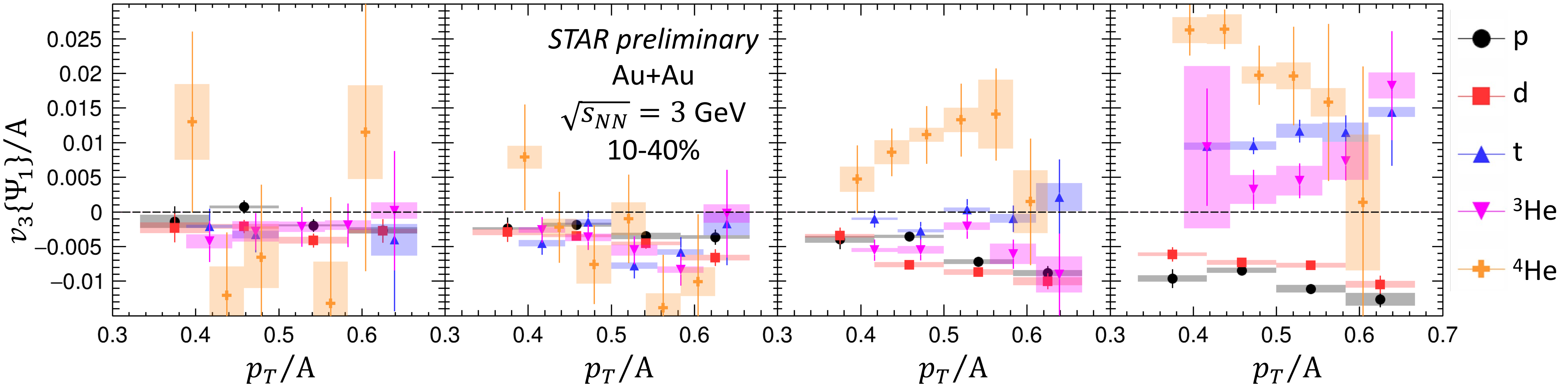
Identified particle $v_1\{\Psi_1\}$ at $\sqrt{s_{NN}} = 3$ GeV



- A-scaling breaks at all p_T at $y_{CM} \sim 0.5$.

Identified particle $v_3\{\Psi_1\}$ at $\sqrt{s_{NN}} = 3$ GeV

Mid-rapidity $0.1 < y_{CM} < 0.25$ $0.25 < y_{CM} < 0.5$ $0.5 < y_{CM} < 0.75$ $0.75 < y_{CM} < 1$ Target-rapidity



- $v_3\{\Psi_1\}$ vs. p_T follows A-scaling around mid-rapidity in 10-40 %.
- Moving to the target rapidity, heavy light nuclei $v_3\{\Psi_1\}/A$ deviates from proton $v_3\{\Psi_1\}/A$.
- $v_3\{\Psi_1\}$ of deuteron, ^{3}He and ^{4}He flip sign near the target rapidity.