Elliptic flow of light nuclei in heavy ion collisions at STAR

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Outline

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- **Analysis Method**
- **Results and Discussions**
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  - ✓Centrality Dependence
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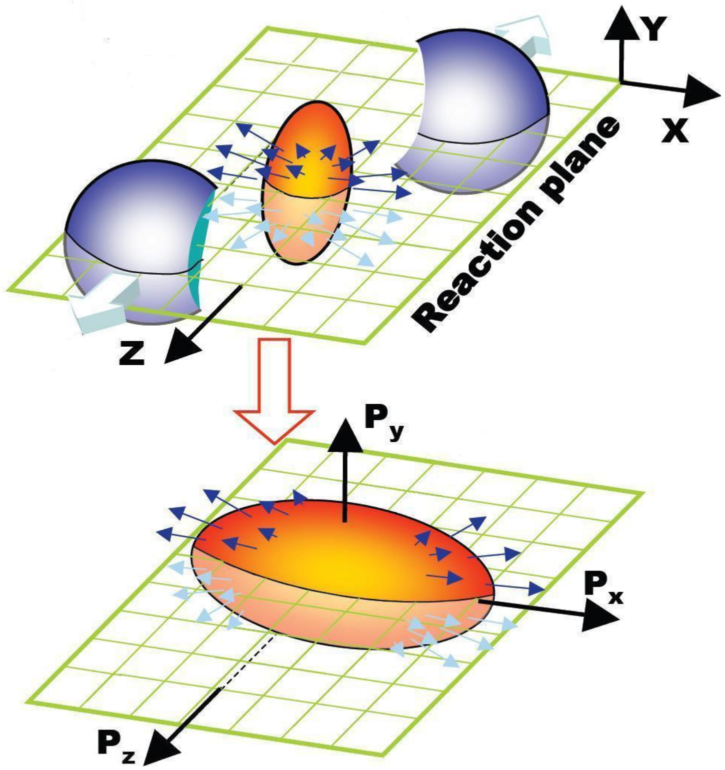
Introduction



$$\varepsilon = \frac{< y^2 - x^2 >}{< y^2 + x^2 >}$$

Coordinate-Space Anisotropy

Momentum-Space Anisotropy

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + 2\sum_{n=1}^{\infty} v_n(p_T, y)\cos(n(\phi - \Psi_r))\right)$$

$$v_n = \langle \cos(n(\phi - \Psi_r)) \rangle \qquad \phi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

- Elliptic flow (v_2) is a good probe of the early stage of the collision.

Motivation

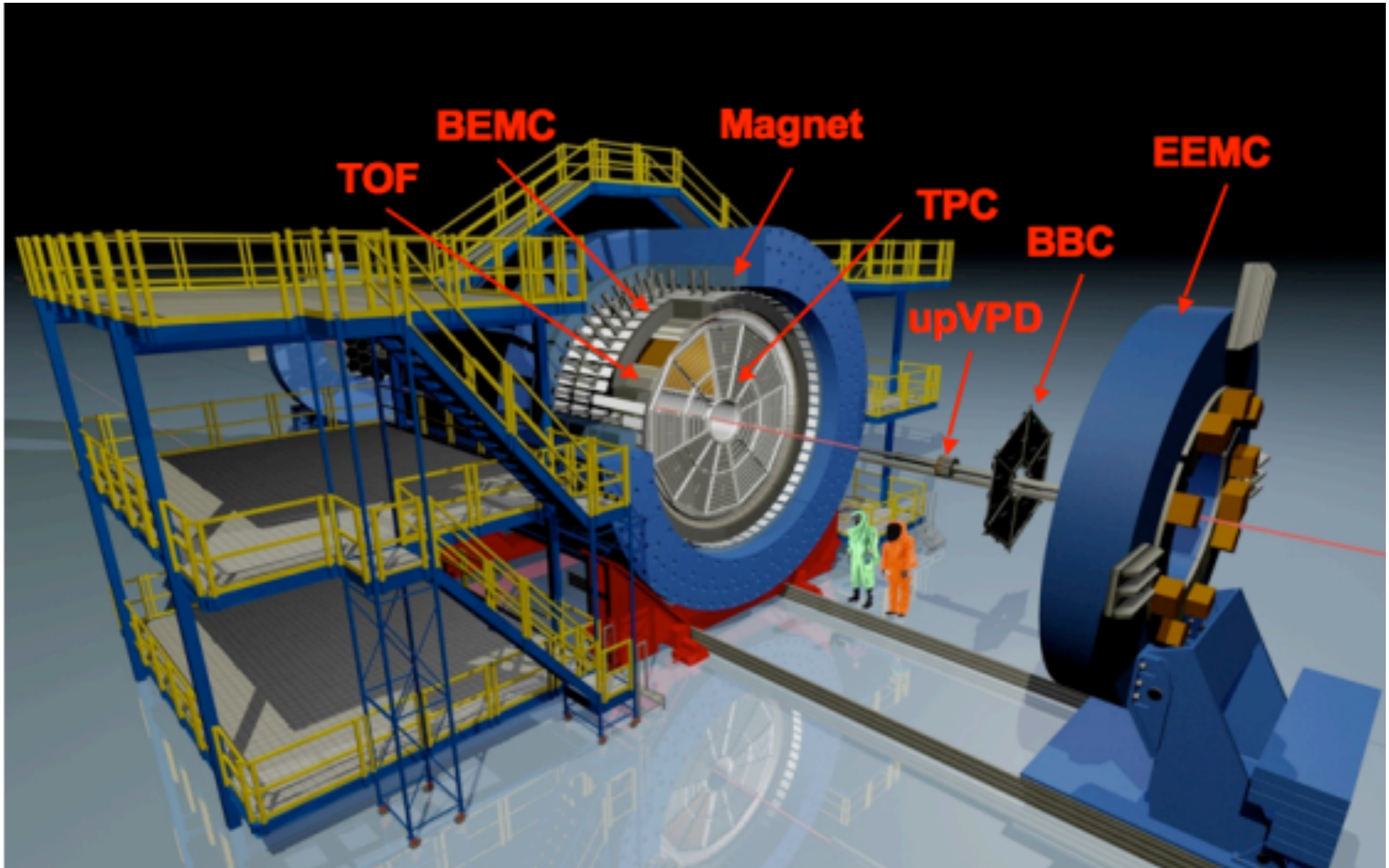
- Light nuclei and anti-nuclei are formed through coalescence of nucleons (produced/participant) and anti-nucleons*. This formation process is generally believed to happen at a late stage of the evolution due to their small binding energy.

- Production of light nuclei provides information of space-momentum correlation among these nucleons.

- By studying the v_2 of light nuclei and comparing to that of their constituent nucleons, we will have a better understanding of coalescence process for hadronization.

*H.H. Gutbrod et al., Phys. Rev. Lett. 37, 667 (1976).

STAR Detector



✓*Full azimuthal particle identification*.

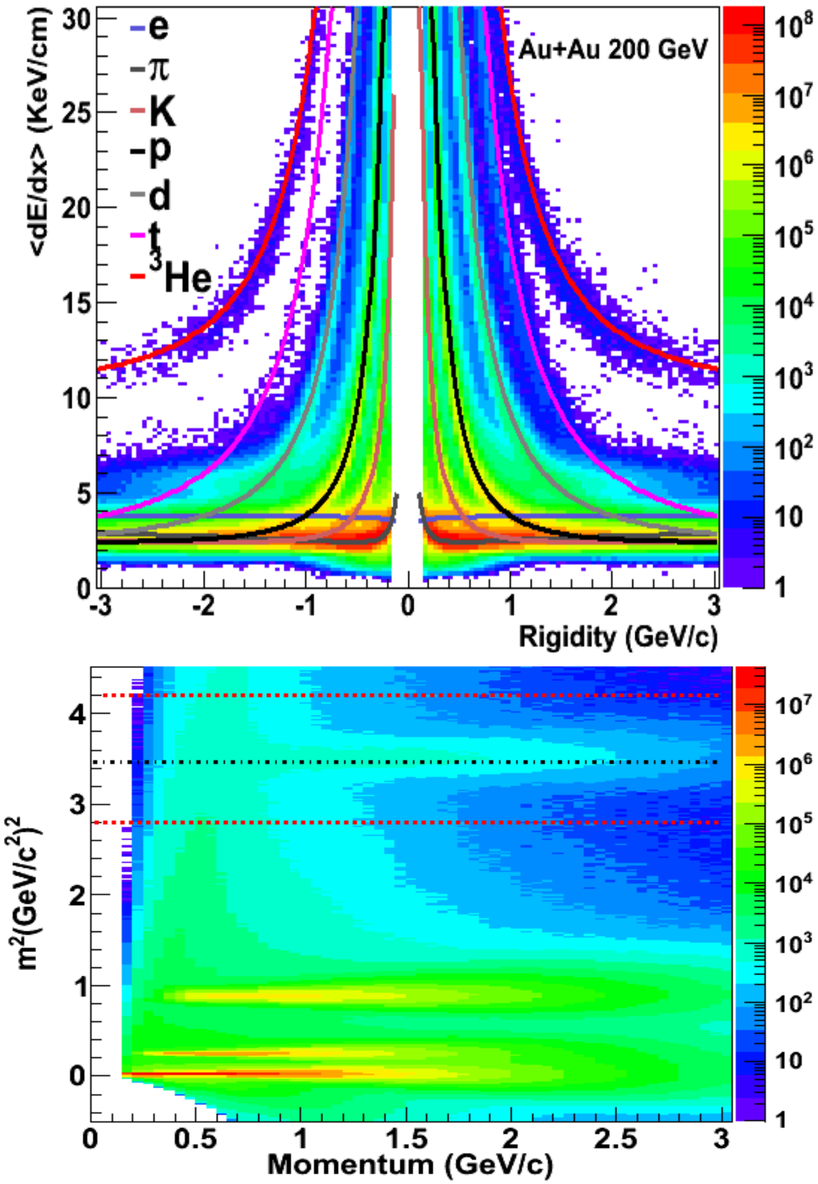
Data Set

Data : Run 7 Au+Au 200 GeV
Number of events: ~62 M

Data : Run 10 Au+Au 39 GeV
Number of events: ~14 M

➢Measurement of the ionization energy loss (dE/dx) of charged tracks in the TPC gas are used to identify the light nuclei.

➢In run 10 Au+Au 39 GeV TOF information is used to enhance the light nuclei identification at high momentum region.

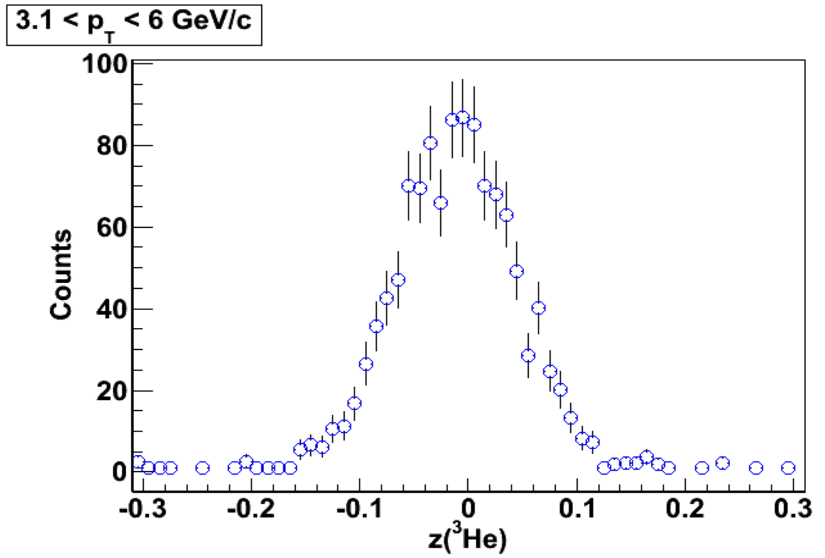


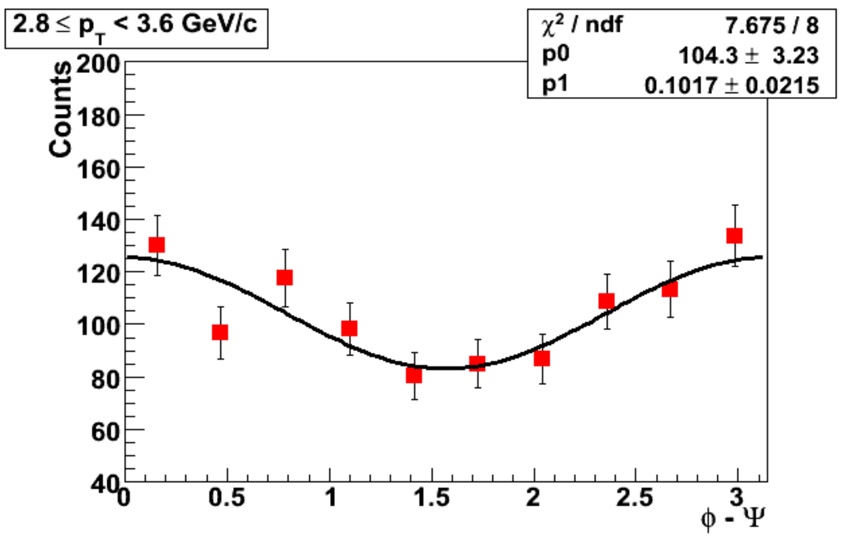
Analysis Method

- ^{3}He signal is almost background free for $p_T > 1.4$ GeV/c.

$$Z = \ln\left(\frac{(dE/dx)_{measure}}{(dE/dx)_{predict}}\right)$$

- TPC is used to determine the event plane.



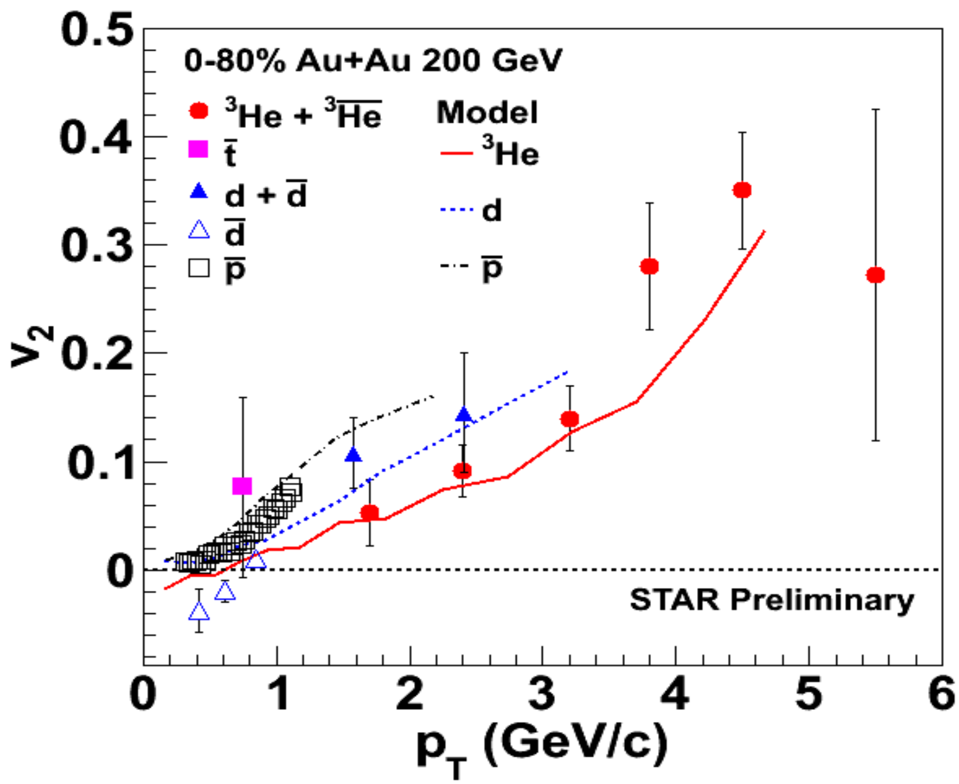


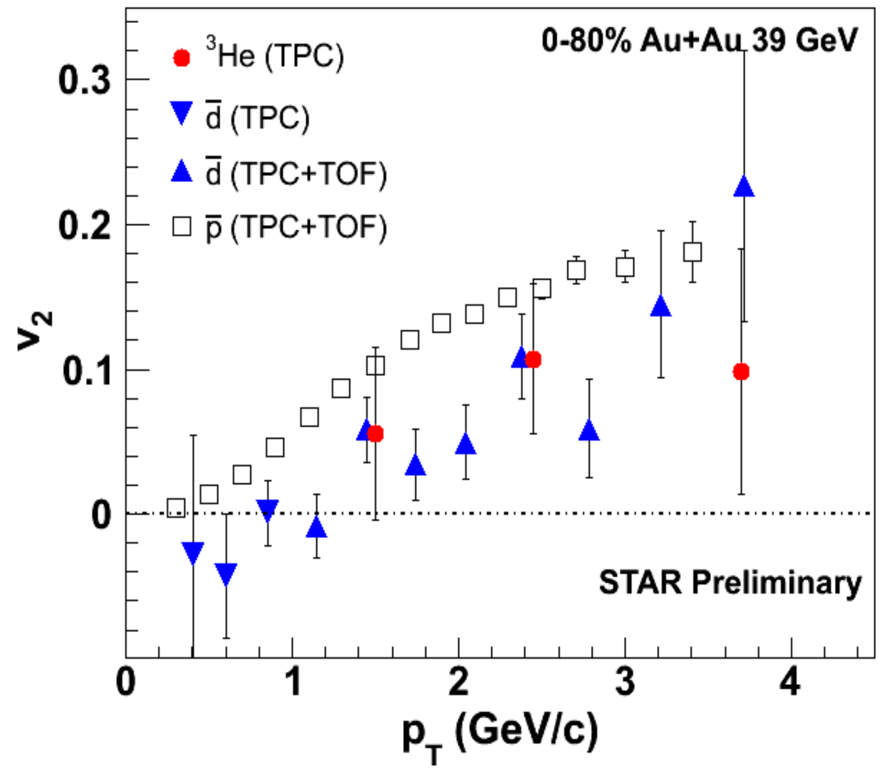
$$\frac{dN}{d\phi} \propto 1 + 2v_2^{obs}\cos[2(\phi - \Psi_R)]$$

$$v_2^{final} = \frac{v_2^{obs}}{R_2}$$

R_2 is the second order event plane resolution

v_2 vs. p_T





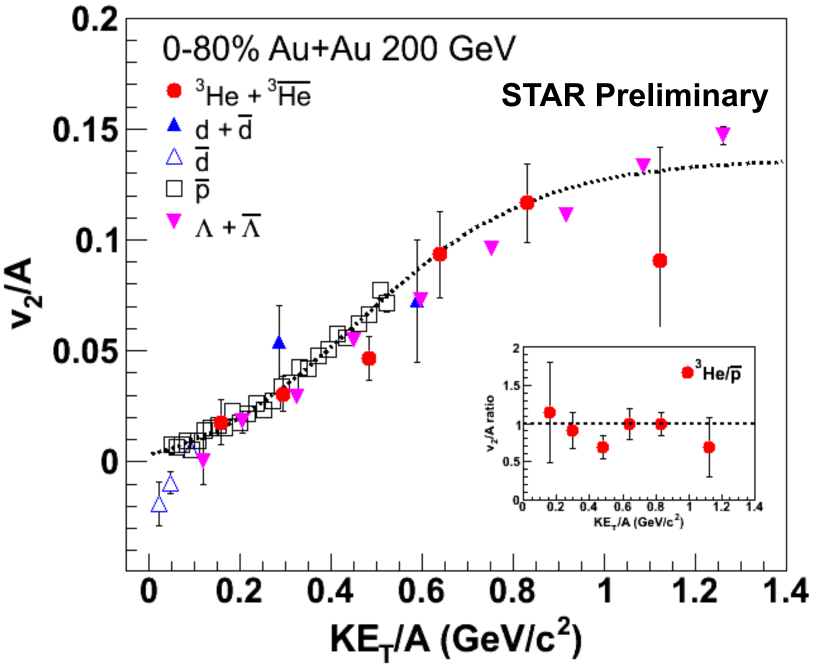
d($\bar{d}$) data: STAR, arXiv:0909.0566 [nucl-ex]

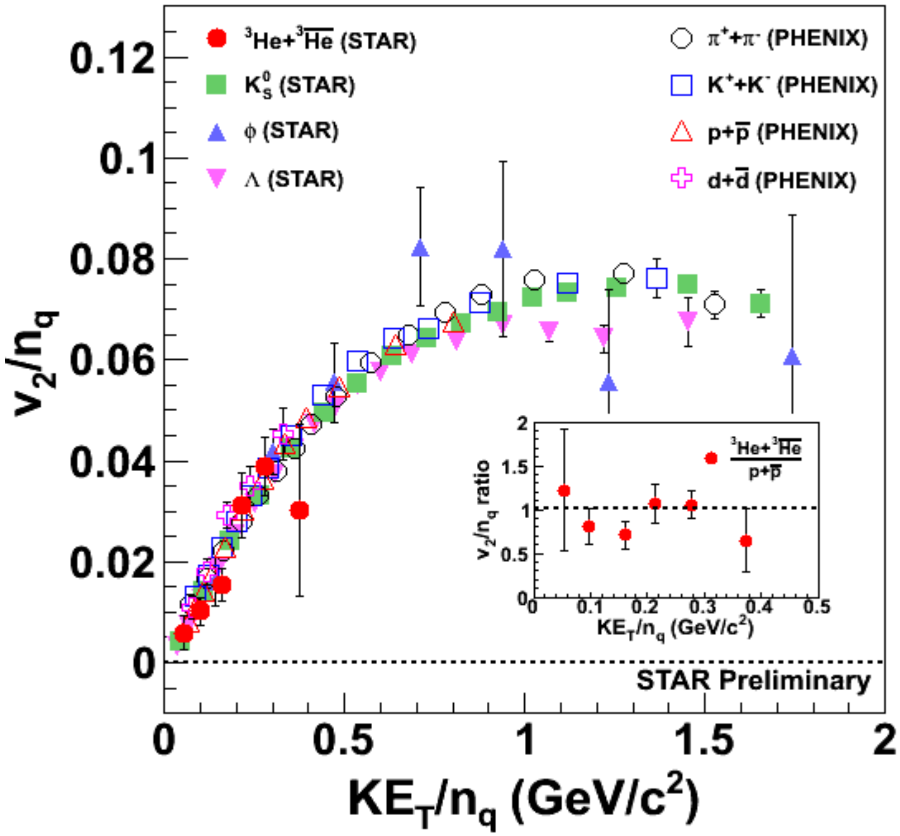
$\bar{p}$: A. Schmah (STAR), QM 2011

- ➢ v_2 of light nuclei increases with p_T in both beam energies.
- ➢ v_2 of light nuclei is well described by the dynamical coalescence model in Au+Au 200 GeV.

Model Calculations: S. Zhang et al., Phys. Lett. B 684 (2010) 224

NCQ Scaling: Au+Au 200 GeV



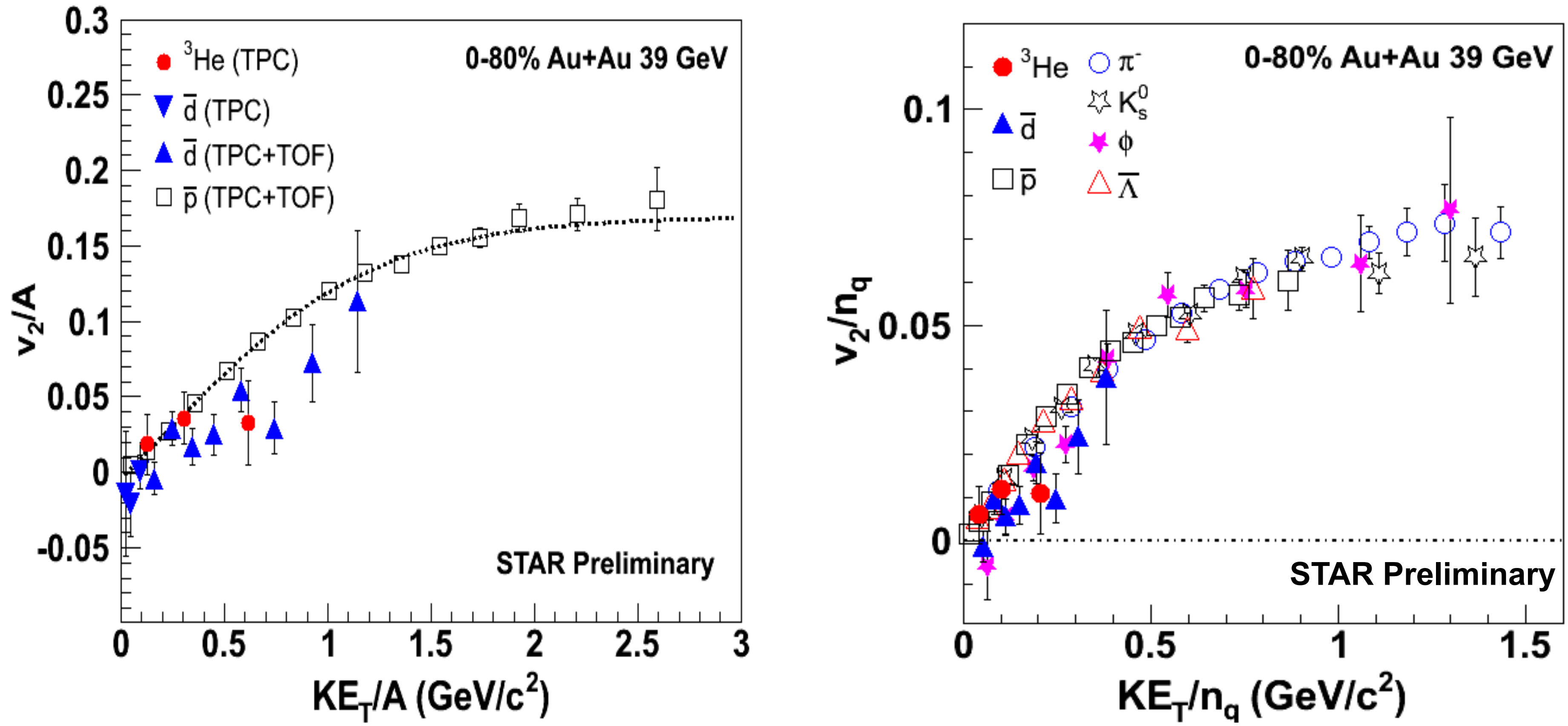


STAR, PRC 72, 014904 (2005)
STAR, arXiv:0909.0566 [nucl-ex]
PHENIX, PRL 99, 052301 (2007)

d(p+n) : n_q = 2 x 3 ^{3}He(2p+n) : n_q = 3 x 3

- v_2 of light nuclei follow the atomic mass number (A) scaling within errors.
- v_2 of light nuclei scaled to the number of constituent quarks (NCQ) of their constituent nucleons, are consistent with NCQ scaled v_2 of baryons and mesons.

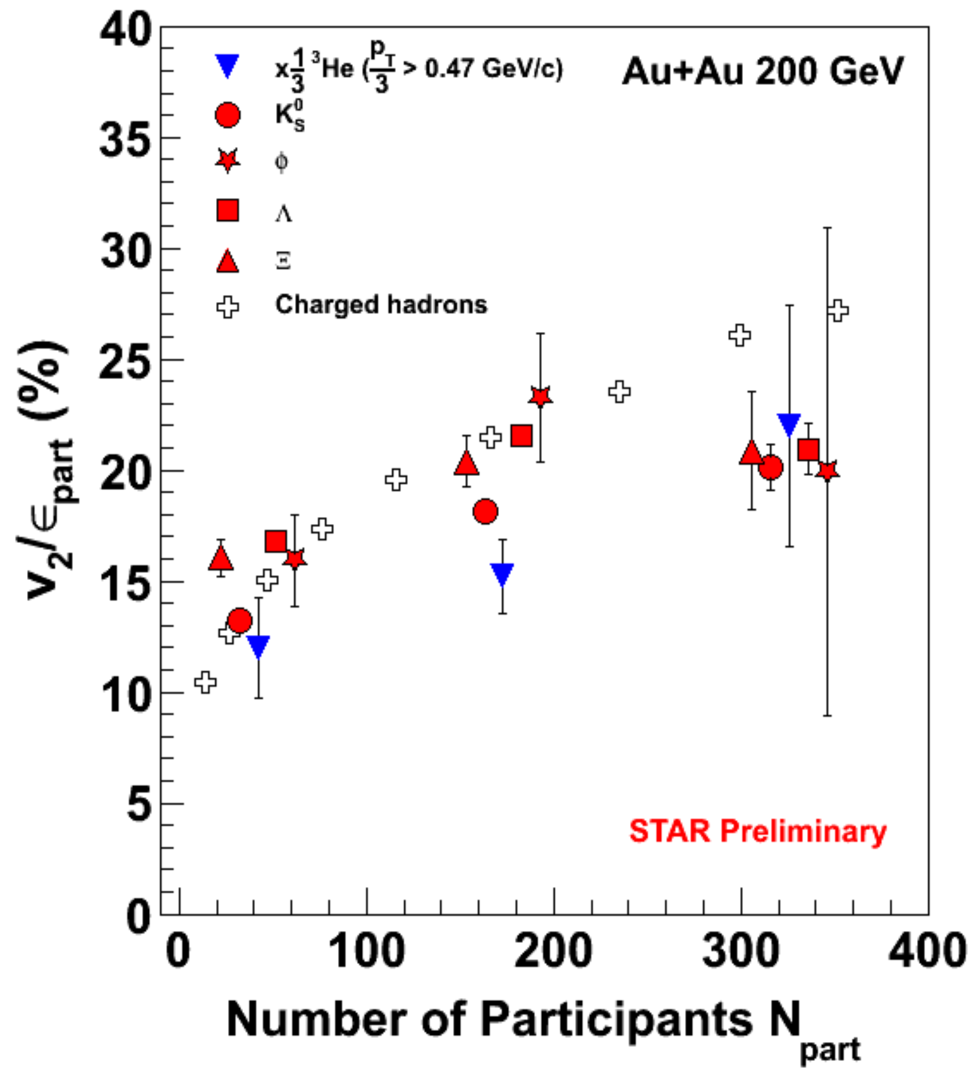
NCQ Scaling: Au+Au 39 GeV

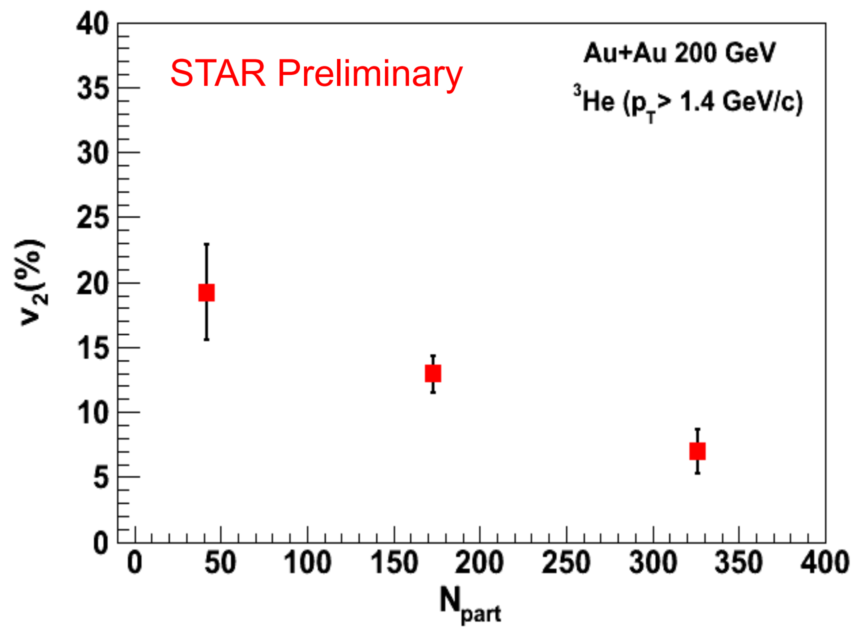


A. Schmah (STAR), QM 2011

- v_2 of light nuclei seem to follow the atomic mass number (A) scaling in Au+Au 39 GeV.
- NCQ scaling holds good for v_2 of light nuclei in Au+Au 39 GeV.

Centrality Dependence

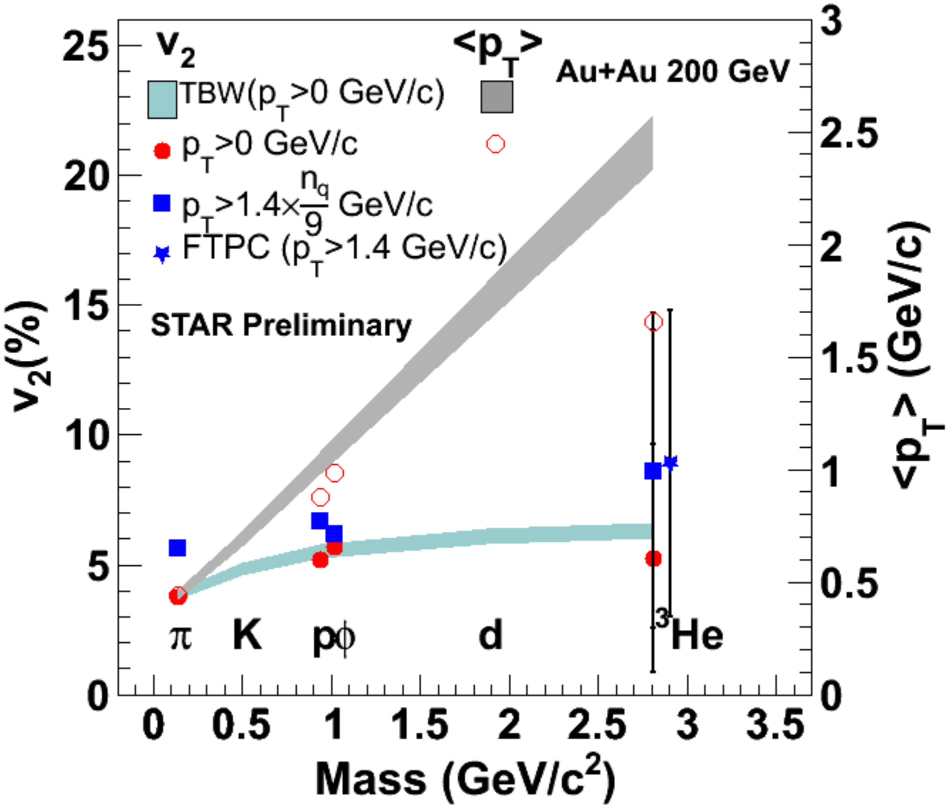




- Similar to other hadrons, at more central collision the larger value of v_2/ε indicates stronger collective expansion.

STAR, PRC 77, 054901 (2008)

Mass Dependence

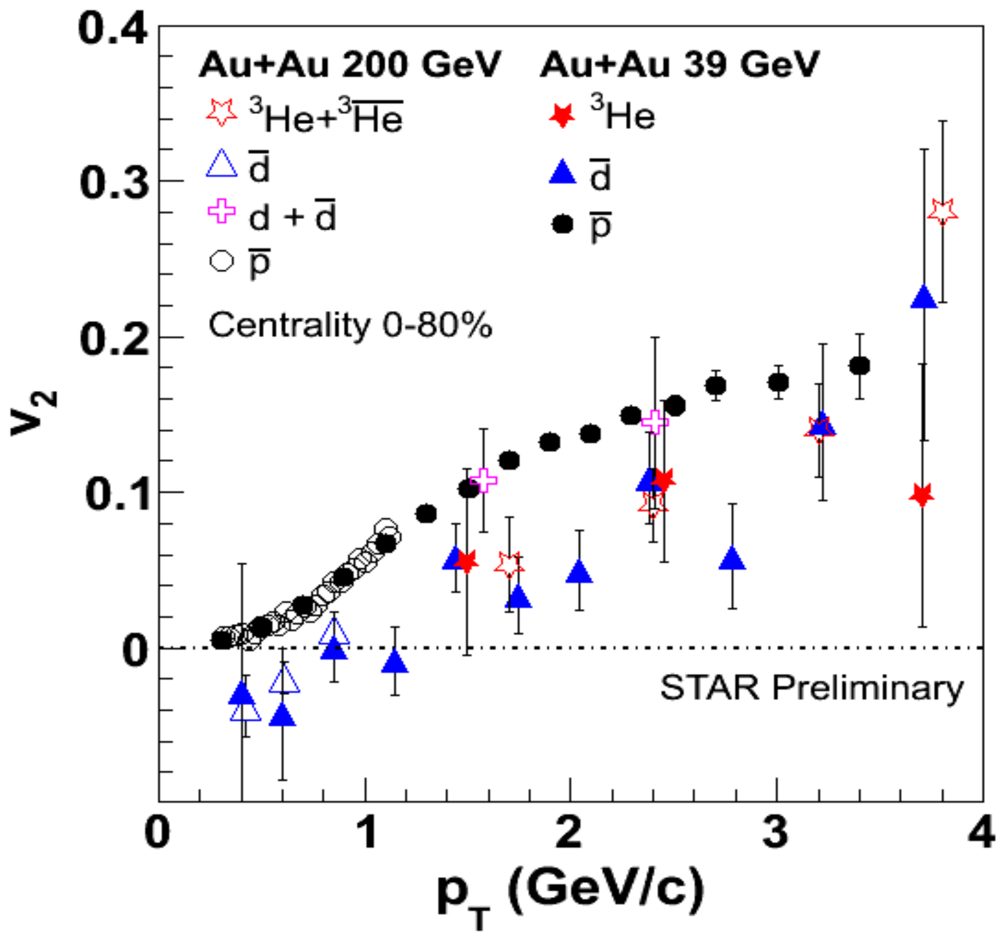


✓*Systematic uncertainties are under study*.

- Tsallis Blast-wave (TBW) parameters obtained from the simultaneous fits to p_T spectra and v_2 of π, K and p are used to predict the p_T spectra and v_2 of d and ^{3}He.
- Both v_2 and $\langle p_T \rangle$ trends are consistent with expectations from TBW model fit.
- v_2 values up to ^{3}He mass has reasonable agreement within the Blast-wave formalism but differences seen in $\langle p_T \rangle$ beyond proton mass.
- v_2 of ^{3}He measured from different event plane detectors (TPC and FTPC) are consistent with each other.

π, *p* spectra: STAR, PRL 97, 152301 (2006)
π, *p* v_2: STAR, PRC 72, 014904 (2005)
STAR, PRC 77, 054901 (2008)
ϕ spectrum and v_2: STAR, PRL 99, 112301 (2007)
^{3}He spectrum: STAR, arXiv:0909.0566 [nucl-ex]
TBW: Z. Tang et al., PRC 79, 051901 (2009)
Z. Tang et al., arXiv:nucl-ex/1101.1912

Energy Dependence



- Light nuclei v_2 is comparable in both beam energies.

Summary

➢v_2 of light nuclei are measured in Au+Au 200 GeV and 39 GeV using event plane method.

➢p_T dependence of v_2 is well described by Dynamical Coalescence Model.

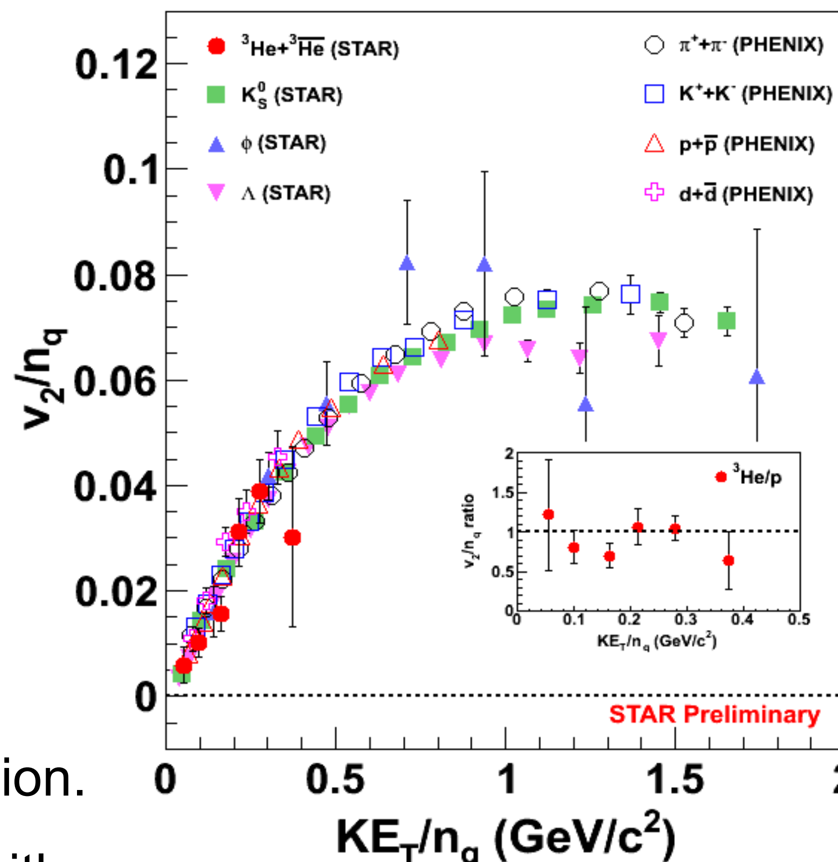
➢v_2 of light nuclei seem to follow the atomic mass number scaling.

➢Number of constituent quark scaling holds good for v_2 of light nuclei.

➢At more central collision the large value of v_2/ε indicates stronger collective expansion.

➢Both v_2 and $<p_T>$ trends are consistent with expectations from Blast-wave model fit.

➢Light nuclei v_2 is comparable in both beam energies.




Thank You!
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Back-up

Tsallis Blast-Wave Model

$$\frac{dN}{m_T dm_T d\phi} \propto m_T \int_0^{2\pi} d\phi_s \int_{-Y}^{+Y} dy \cosh(y) \times \int_0^R r dr (1 + \frac{q-1}{T} E_T)^{-1/(q-1)}$$

Z. Tang et al., PRC 79, 051901 (2009)
Z. Tang et al., arXiv:nucl-ex/1101.1912

where

$$E_T = m_T \cosh(y) \cosh(\rho) - p_T \sinh(\rho) \cos(\phi_b - \phi)$$

$$\rho = \sqrt{(r\cos(\phi_s)/R_X)^2 + (r\sin(\phi_s)/R_Y)^2}(\rho_0 + \rho_2 \cos(2\phi_b))$$

$$\tan(\phi_b) = (R_X/R_Y)^2 \tan(\phi_s)$$

ρ = Flow profile in transverse rapidity
ϕ_s = Azimuthal angle of the co-ordinate space
ϕ_b = Angle of the flow direction
q = Degree of non-equilibrium

T (MeV)	q	ρ_0	ρ_2	$\frac{R_X}{R_Y}$	χ^2/ndf
88.3 $\pm$ 1.2	1.049 $\pm$ 0.003	0.86 $\pm$ 0.013	0.054 $\pm$ 0.001	0.89 $\pm$ 0.002	512.6 /137