

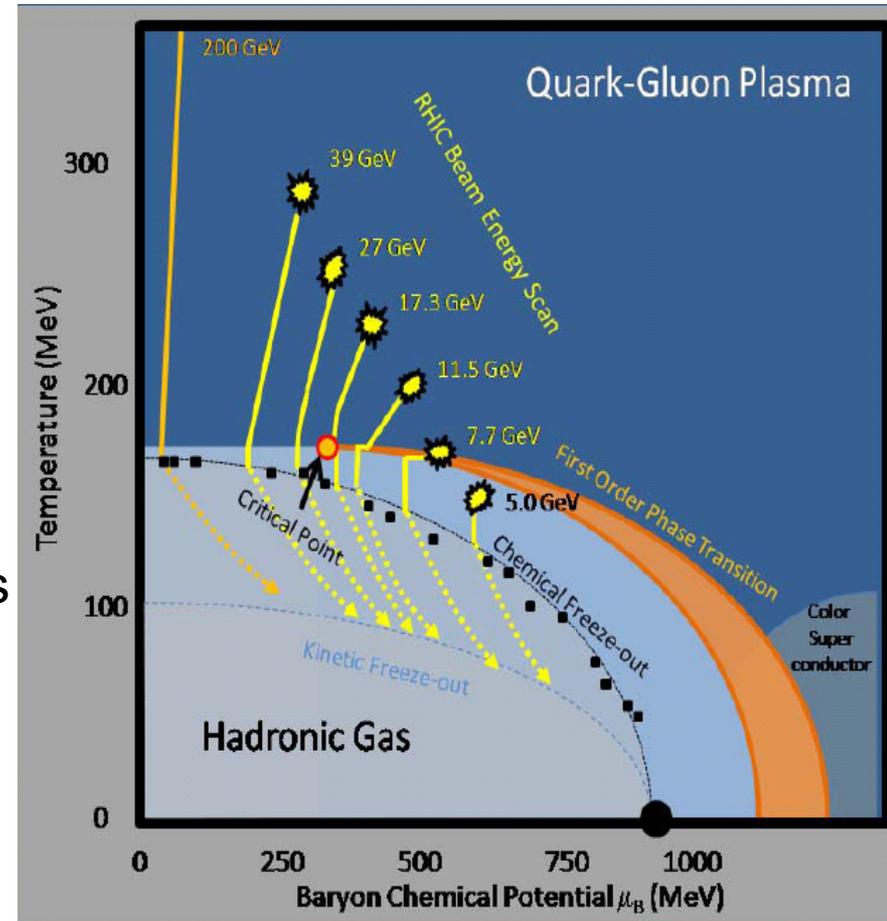
Beam Energy Dependence of Directed and Elliptic flow Measurements from the STAR Experiment

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Outline

- Introduction
- The STAR Experiment
- v_1 results
 - 62.4 GeV and higher beam energies
 - BES results
- v_2 results
 - 62.4 GeV and higher beam energies
 - BES result
- Summary and Conclusions



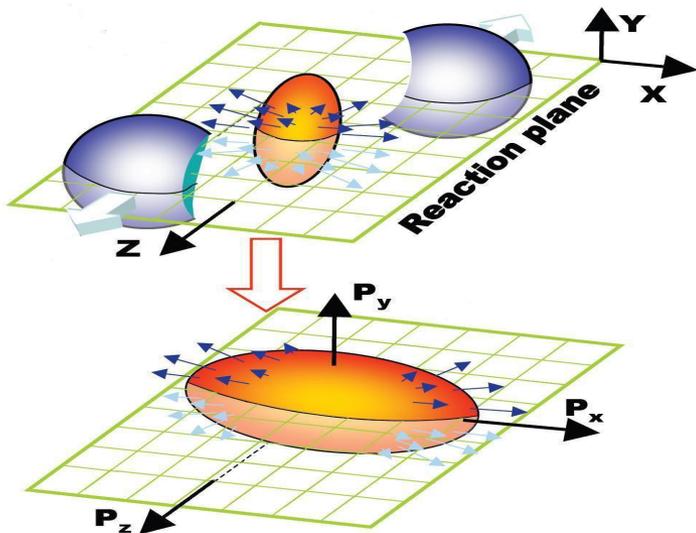
RHIC BES

<http://drupal.star.bnl.gov/STAR/starnotes/public/sn0493>

$\sqrt{s_{NN}}$	39	27	18	11.5	7.7	5.0(?)
μ_B	112	151	230	300	410	550

Introduction

Anisotropic flow: Anisotropy of the azimuthal distribution of particles with respect to the reaction plane: Fourier expansion of the particle's azimuthal distribution with respect to the reaction plane is given by:

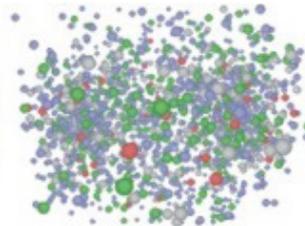
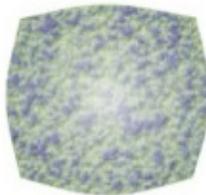
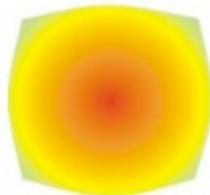
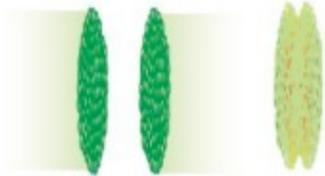


$$E \frac{d^3N}{d^3p} \propto \left(1 + \sum_{n=1}^{\infty} 2v_n \cos n(\phi - \Psi_r) \right)$$

$$v_n = \langle \cos n(\phi - \Psi_r) \rangle$$

$$\phi = \tan^{-1} \left(\frac{p_y}{p_x} \right)$$

Directed flow v_1
Elliptic flow v_2



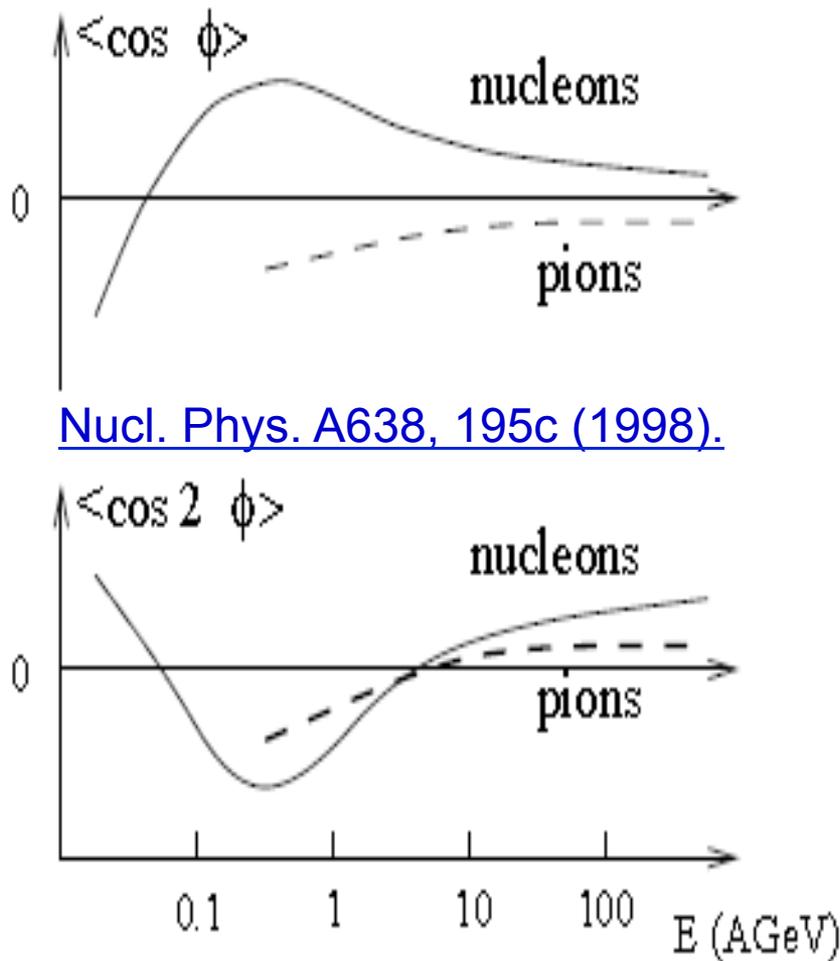
v_1 and v_2 probe the very earliest stage of the collision.

D

$\phi, \Omega, \Xi, \Lambda$

π, K, p

v_1 and v_2 : Beam Energy Dependence

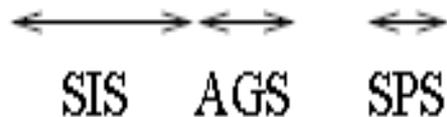


[Nucl. Phys. A638, 195c \(1998\).](#)

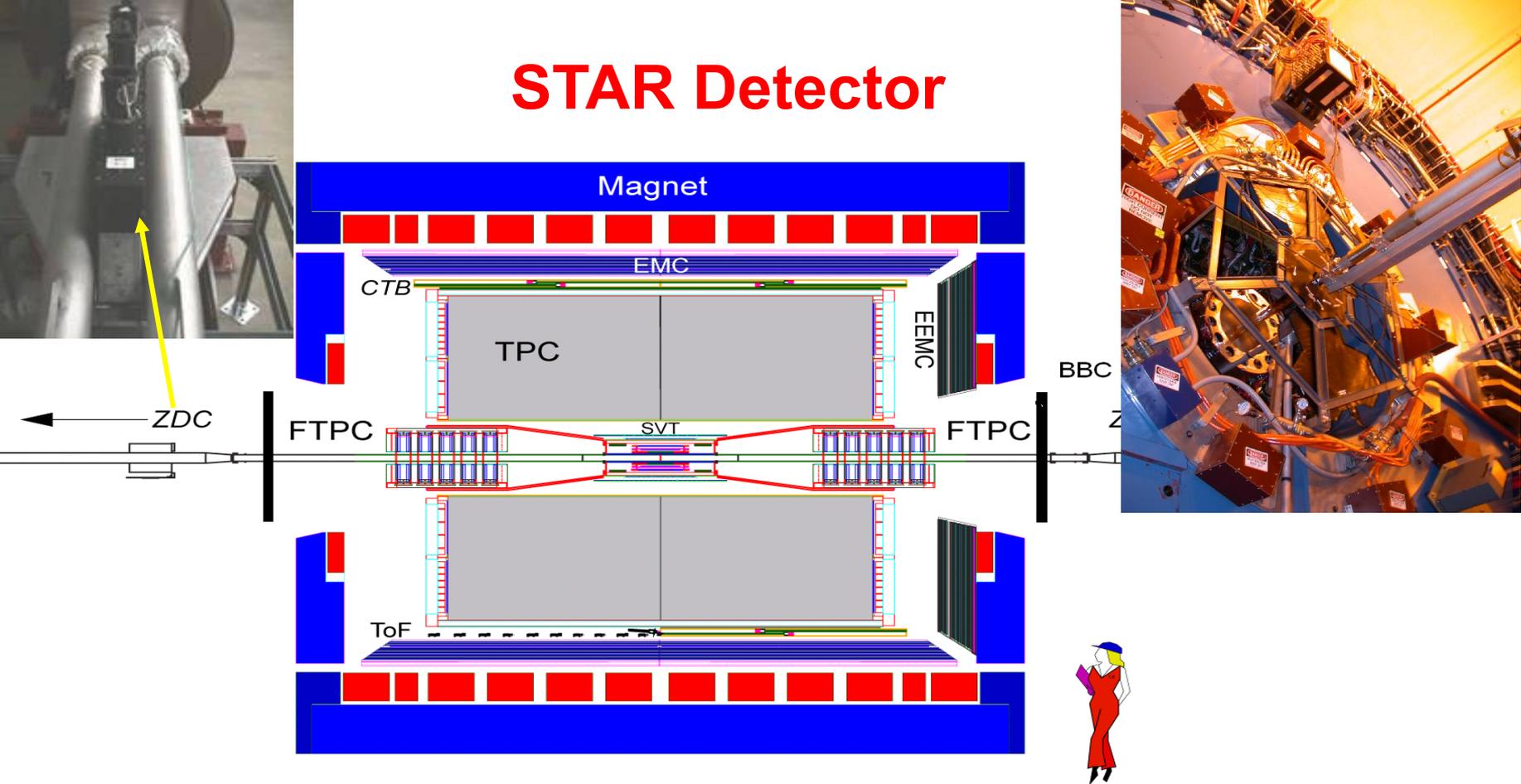
As beam energy increases from the SPS region to RHIC, data & models



v_2 grows larger while v_1 near mid-rapidity shows opposite trend.

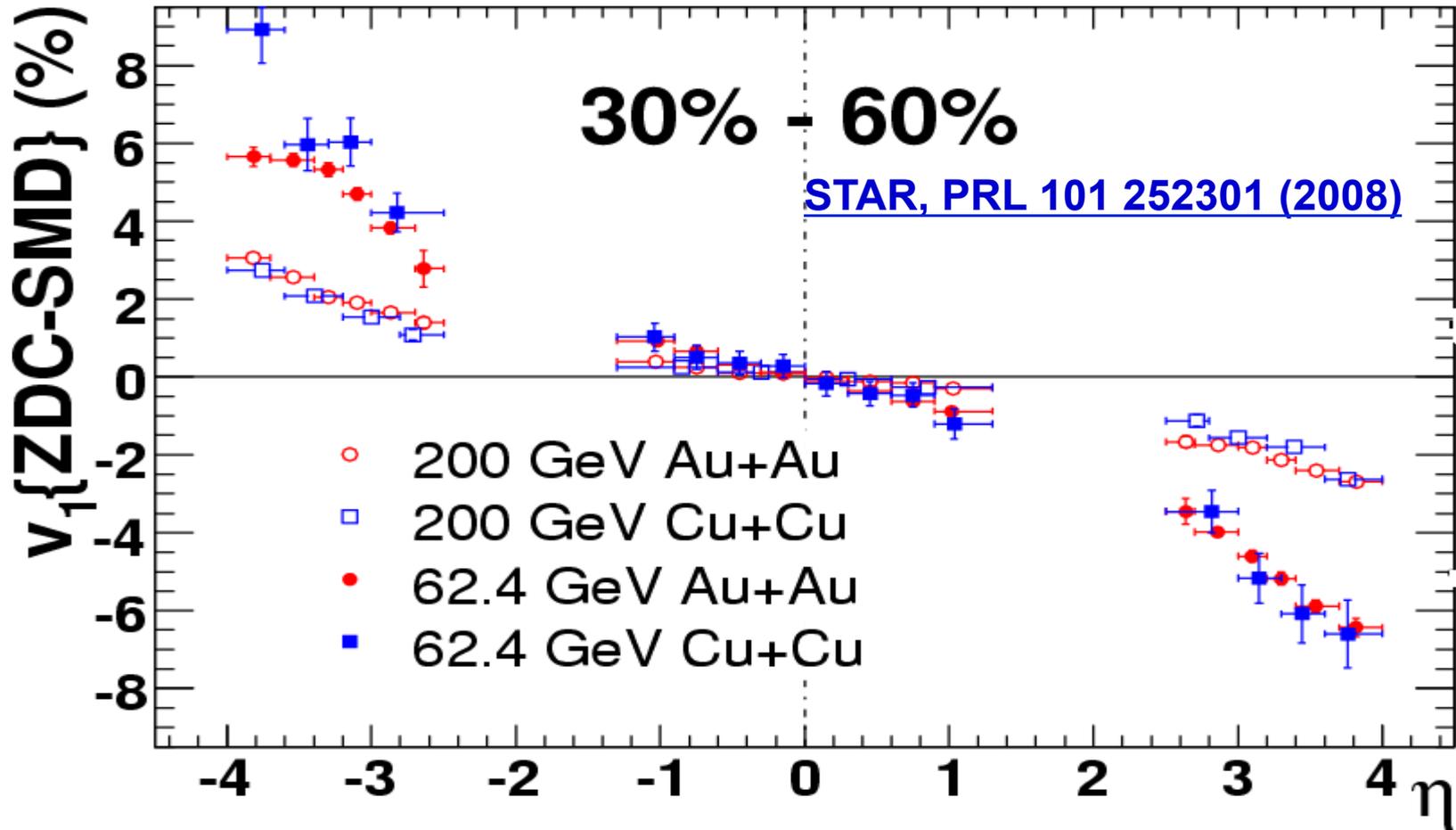


STAR Detector



- TPC($-1.0 < |\eta| < 1.0$) is used to reconstruct the second order event plane
- FTPC($2.5 < |\eta| < 4.0$) is used to reconstruct the 1st and (or) 2nd order event plane
- ZDC-SMD($\eta > 6.4$) is used to reconstruct the first-order event plane from spectator neutrons at 62.4 GeV and higher energies
- BBC($3.3 < |\eta| < 5.0$) is used to reconstruct the first-order event plane at 39 GeV and lower beam energies

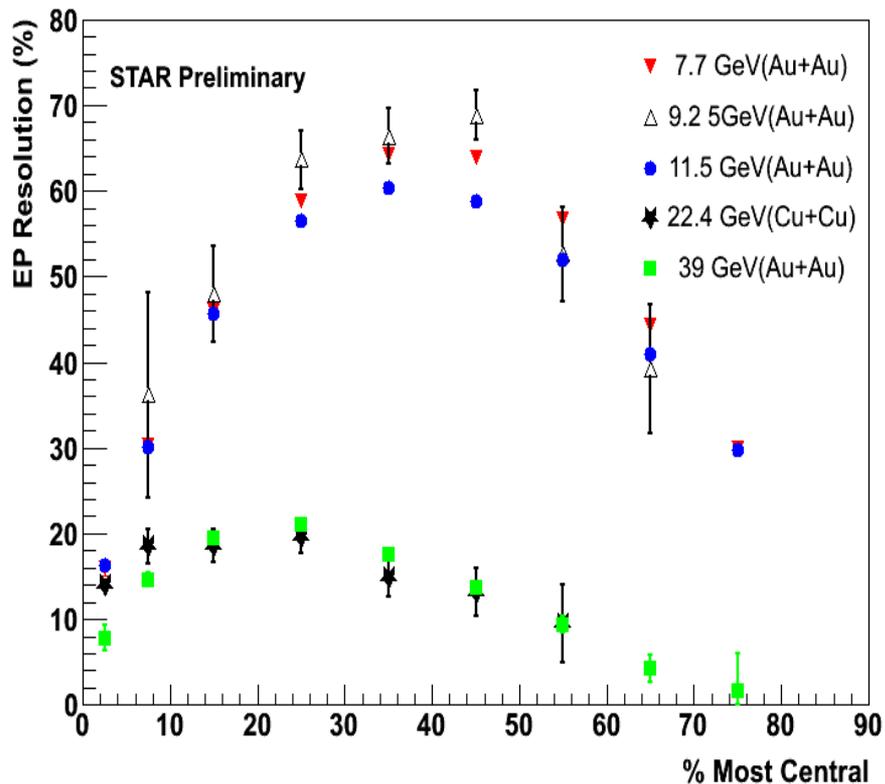
$v_1(\eta)$ at 62.4 and 200 GeV



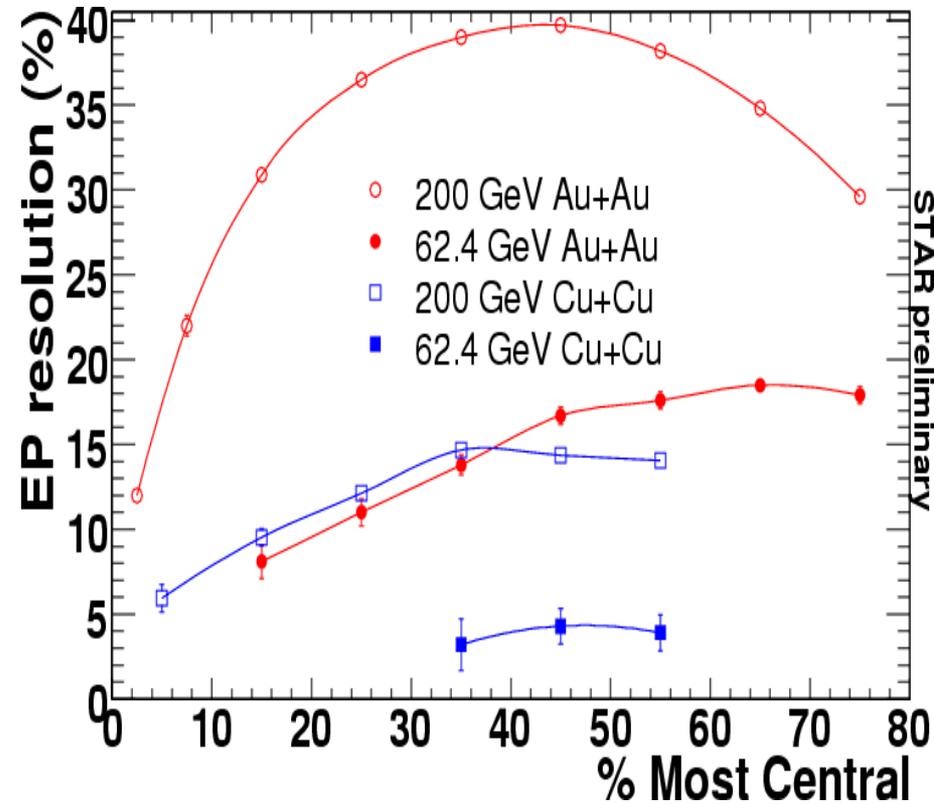
At 62.4 & 200 GeV, no difference within errors between AuAu & CuCu
Beam energy dependence scales with η/y_{beam} (see later)

Directed flow from BES: Event Plane Resolutions

Resolution of 1st-order event plane from STAR BBC



Resolution of 1st-order event plane from STAR ZDCSMD

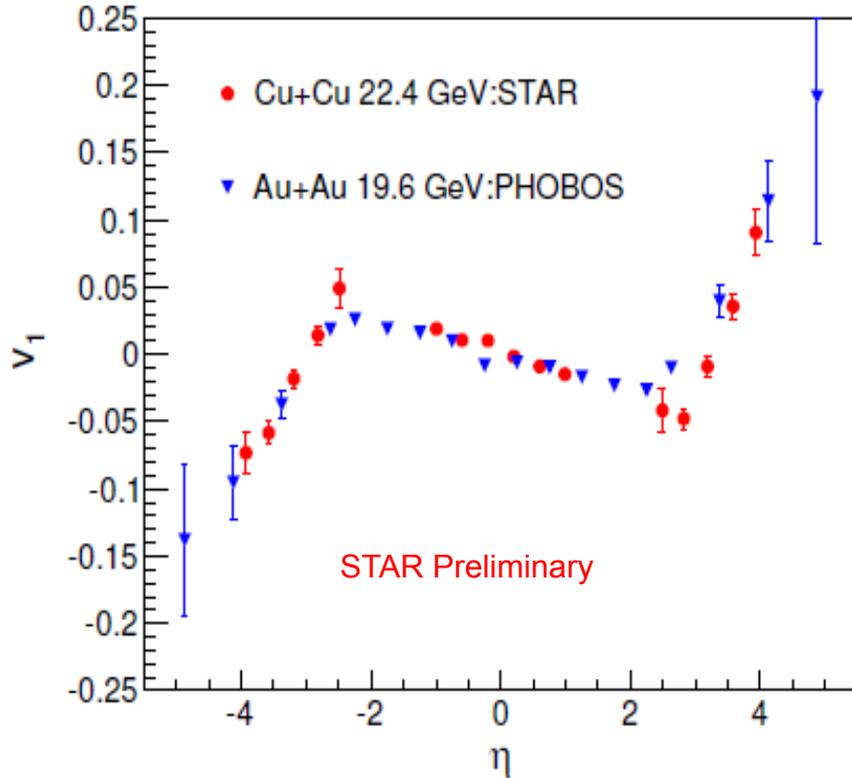


STAR detector is well suited for directed flow measurement at low beam energies



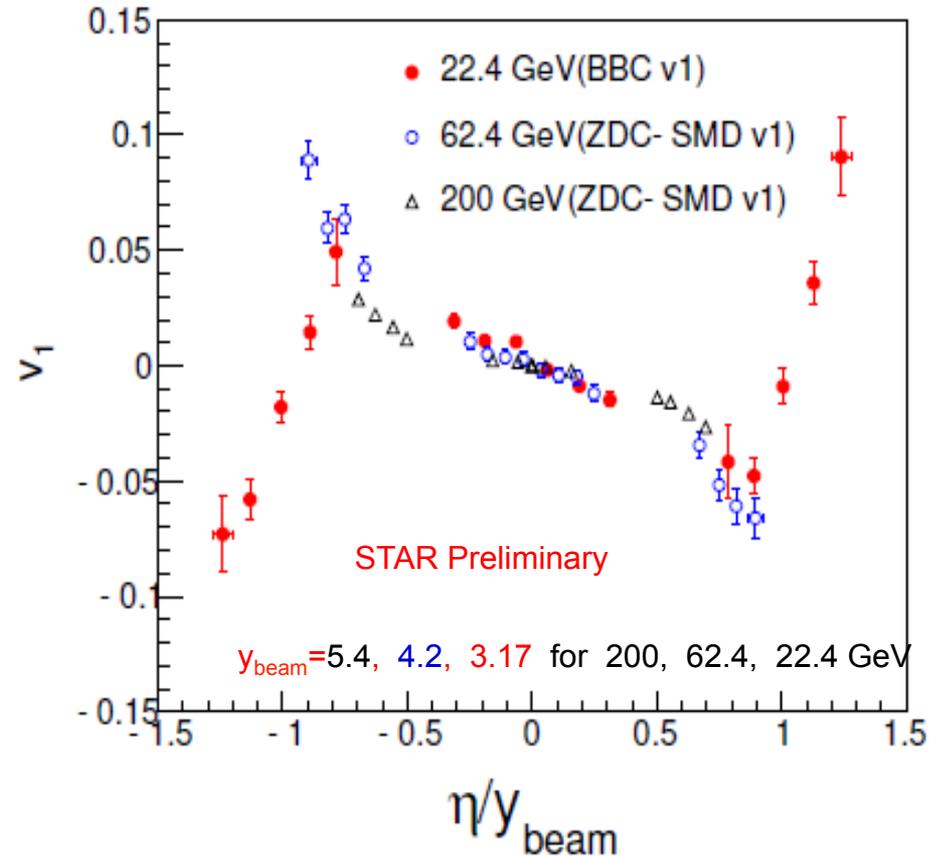
Directed flow at 22.4 GeV CuCu (0-60%) Collisions

Comparison with PHOBOS



Phys. Rev. Lett. 97, 012301 (2006)

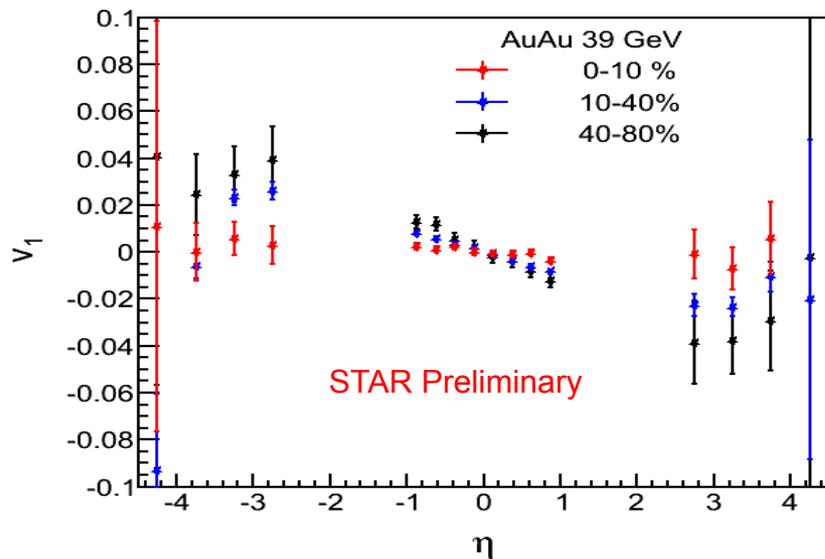
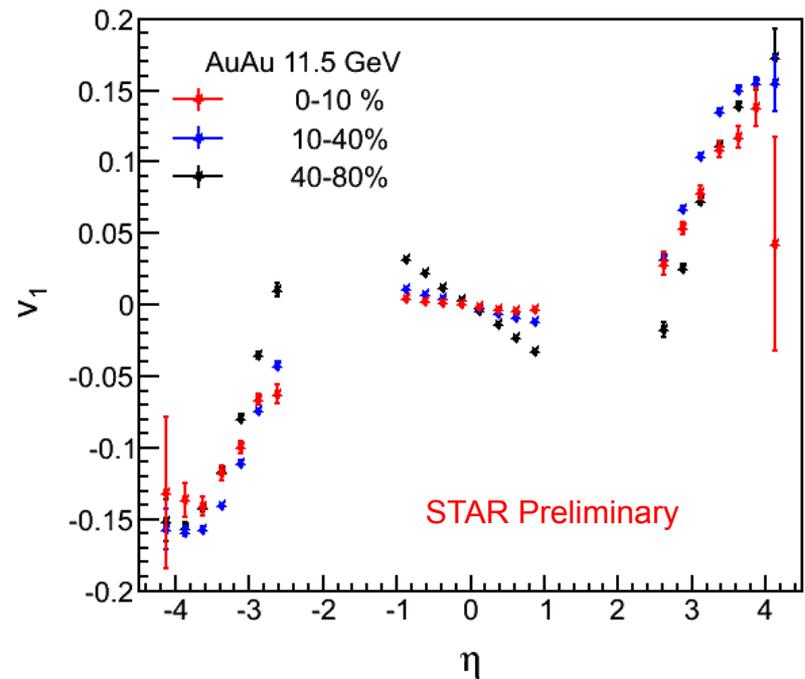
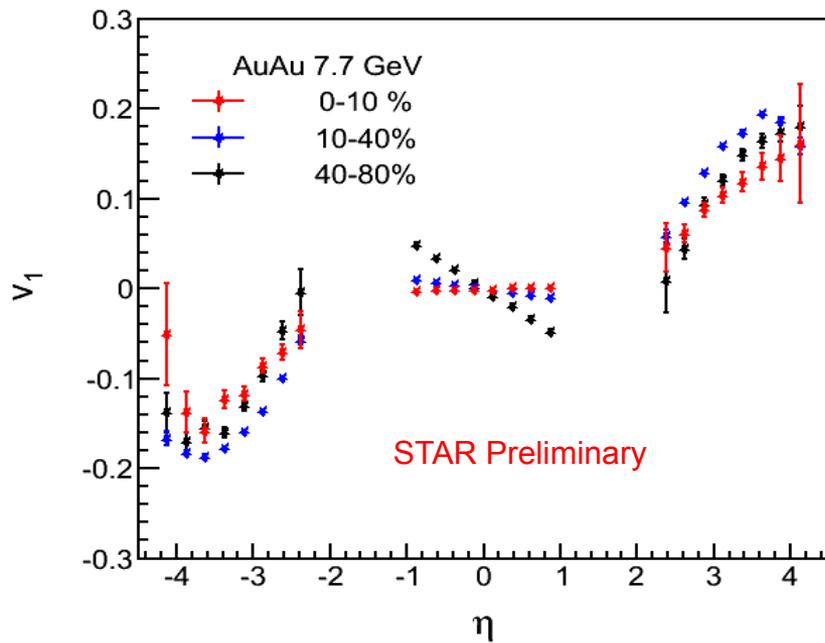
Comparison with STAR



Phys. Rev. Lett. 101 (2008) 252301

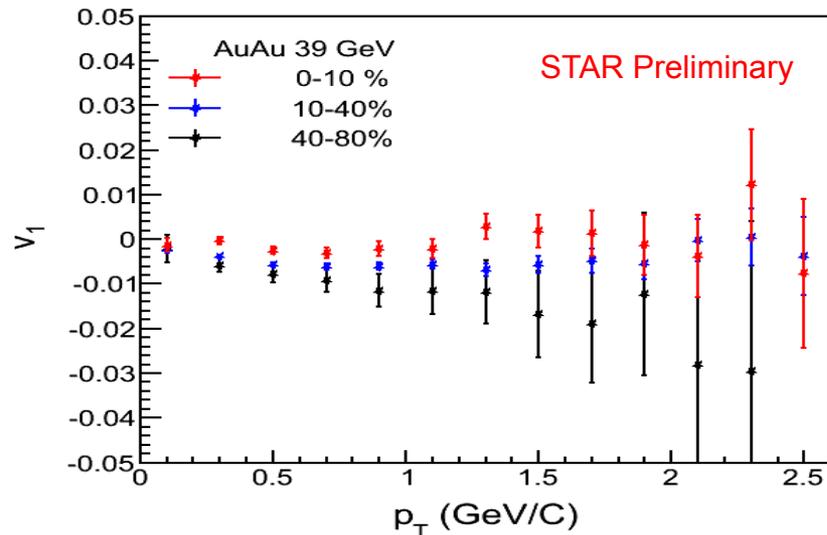
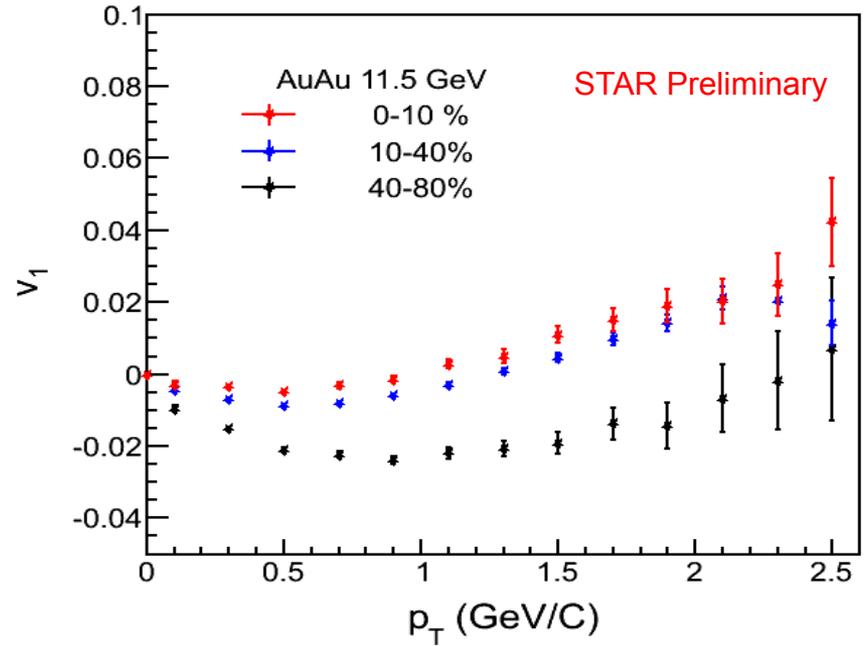
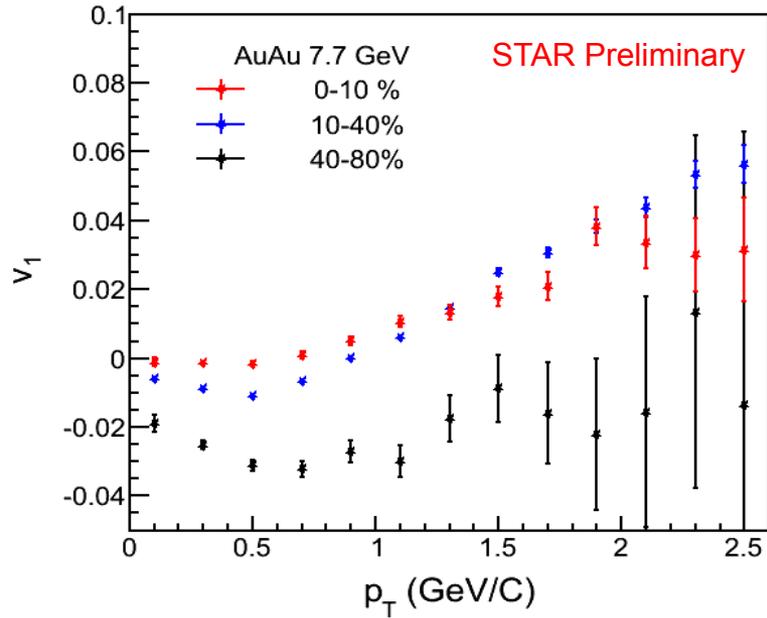
Differences in directed flow (v_1) between AuAu and CuCu are quite small.
Consistent with the 62.4 and 200 GeV result

Directed flow at BES energies: $v_1(\eta)$



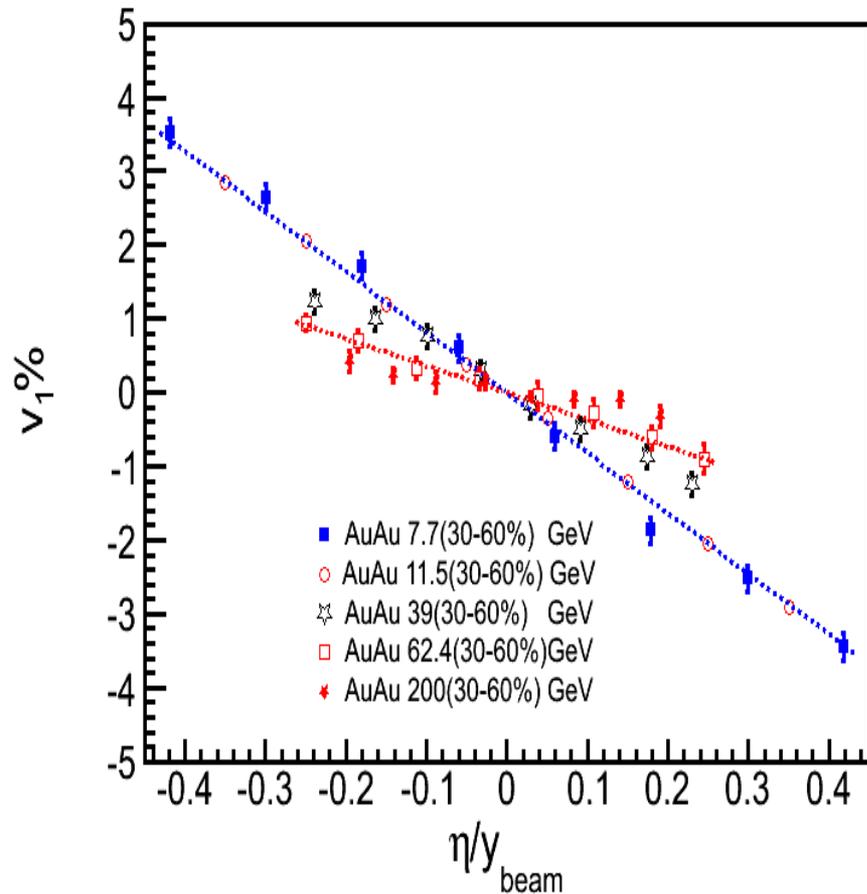
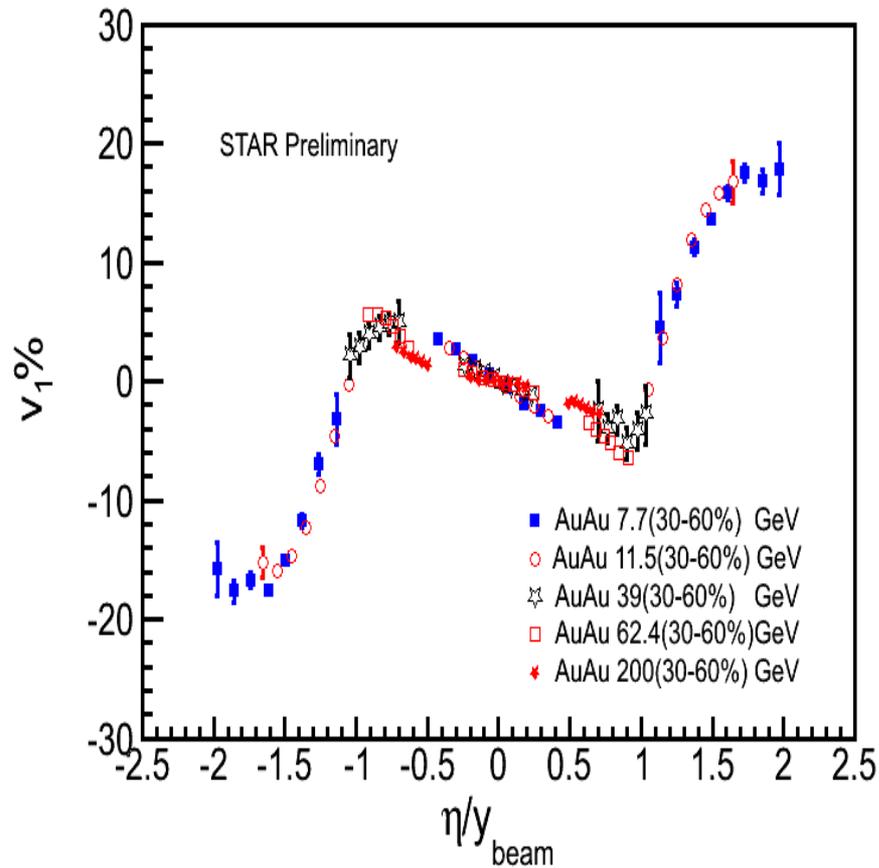
Strong Centrality dependence of $v_1(\eta)$ is observed in BES similar observation to high beam energies.

Directed flow at BES energies: $v_1(p_t)$



Strong Centrality dependence of $v_1(p_t)$ is observed in BES.

Directed flow at BES energies

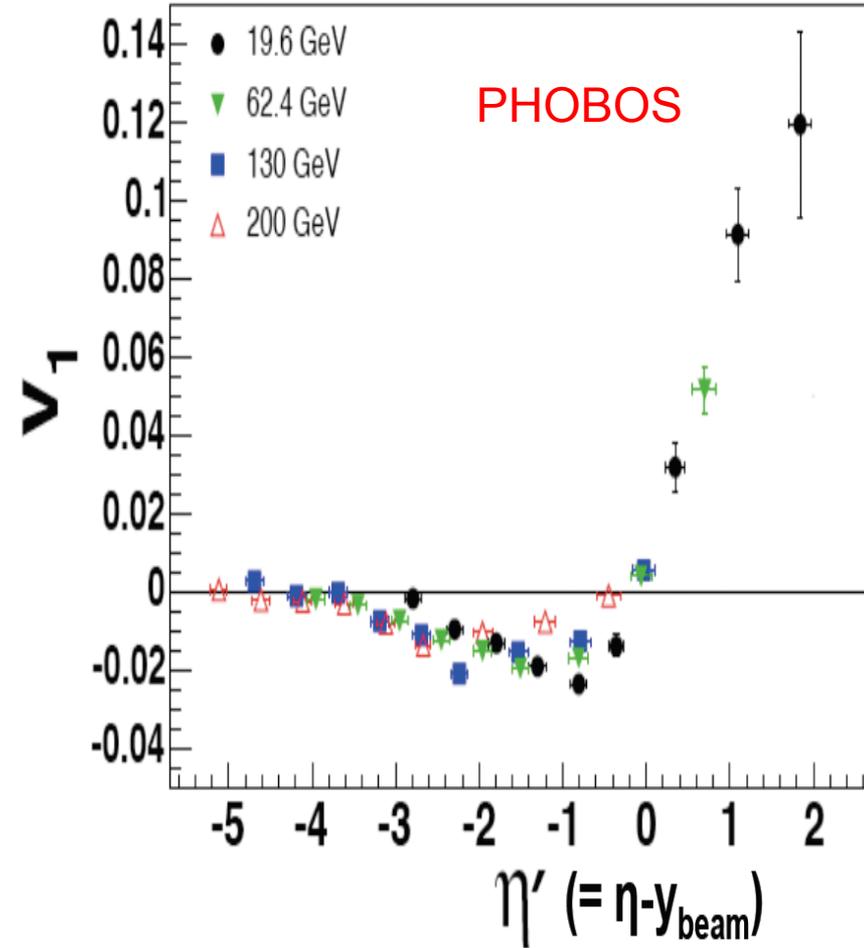
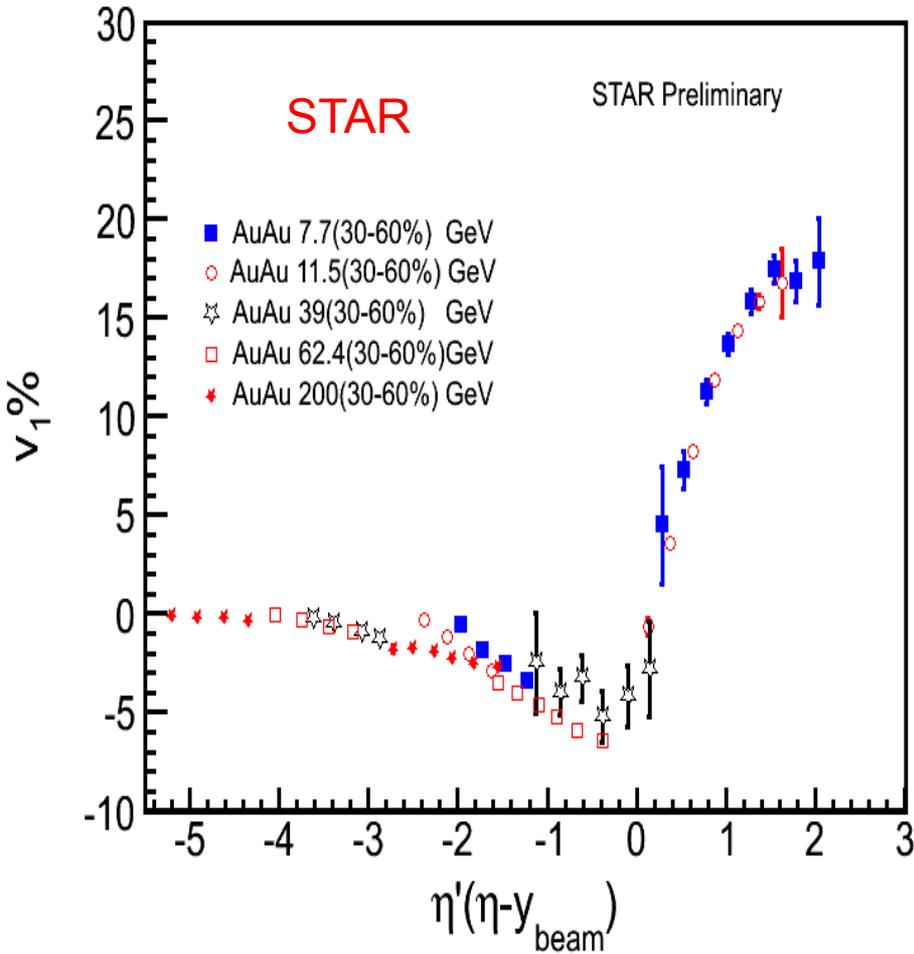


Phys. Rev. C **81** (2010) 24911

Scaling in v_1 vs. η/y_{beam}

Directed flow (v_1) measured by STAR and PHOBOS

PRL 97 012301 (2006)



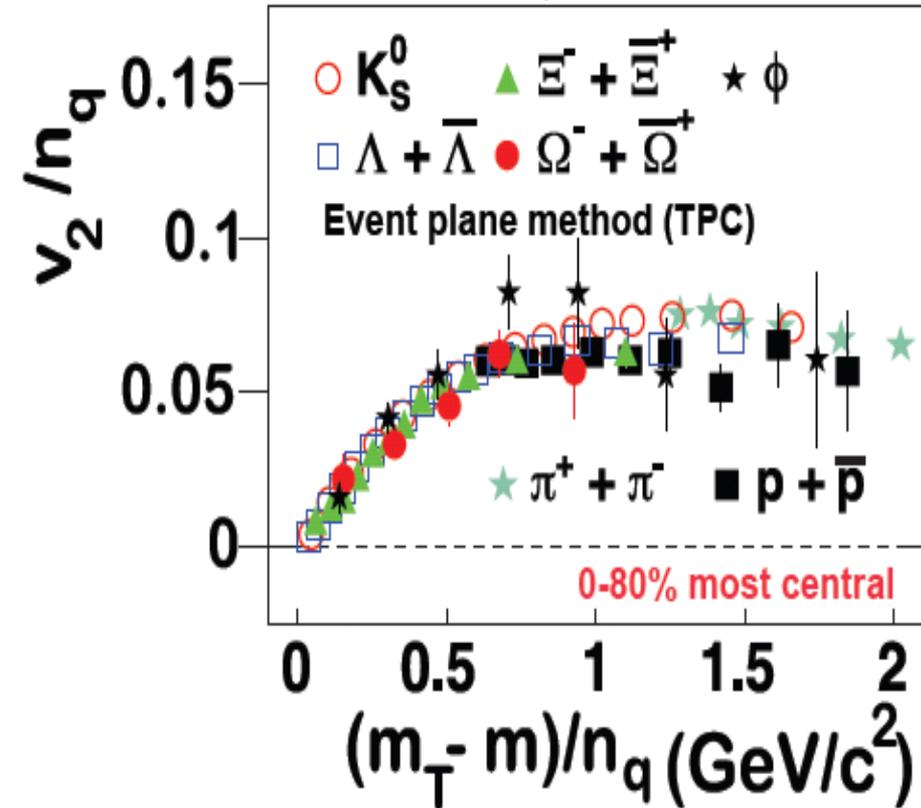
Scaling in v_1 vs. $\eta' (= \eta - y_{\text{beam}})$

$v_2(p_t)$ at 200 GeV

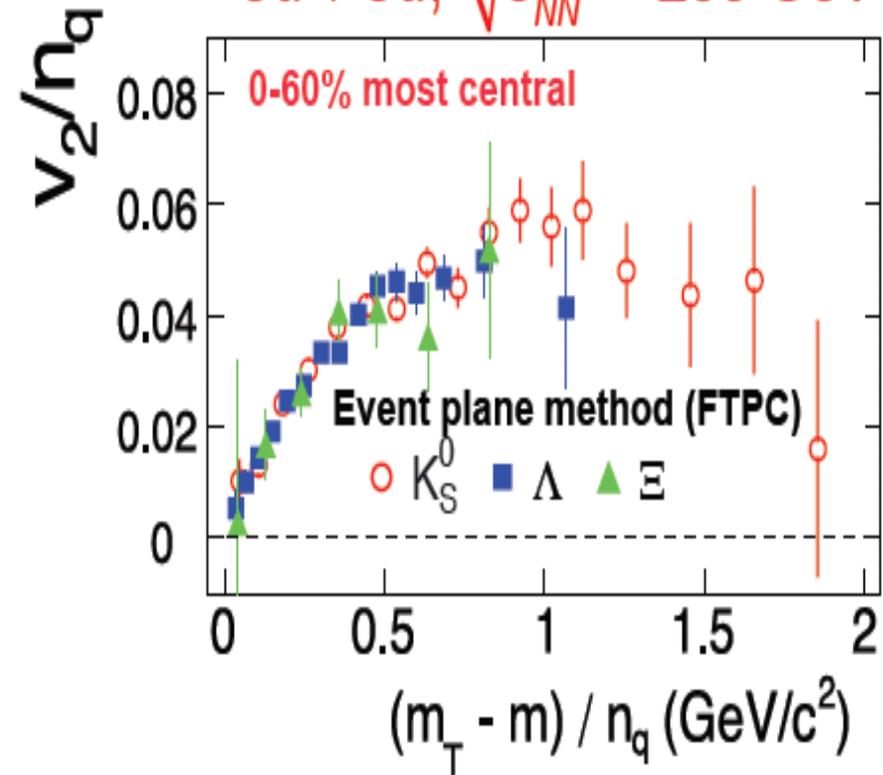
PRC 81 (2010) 044902

PRC 99 (2007) 112301

$Au + Au, \sqrt{s_{NN}} = 200 \text{ GeV}$



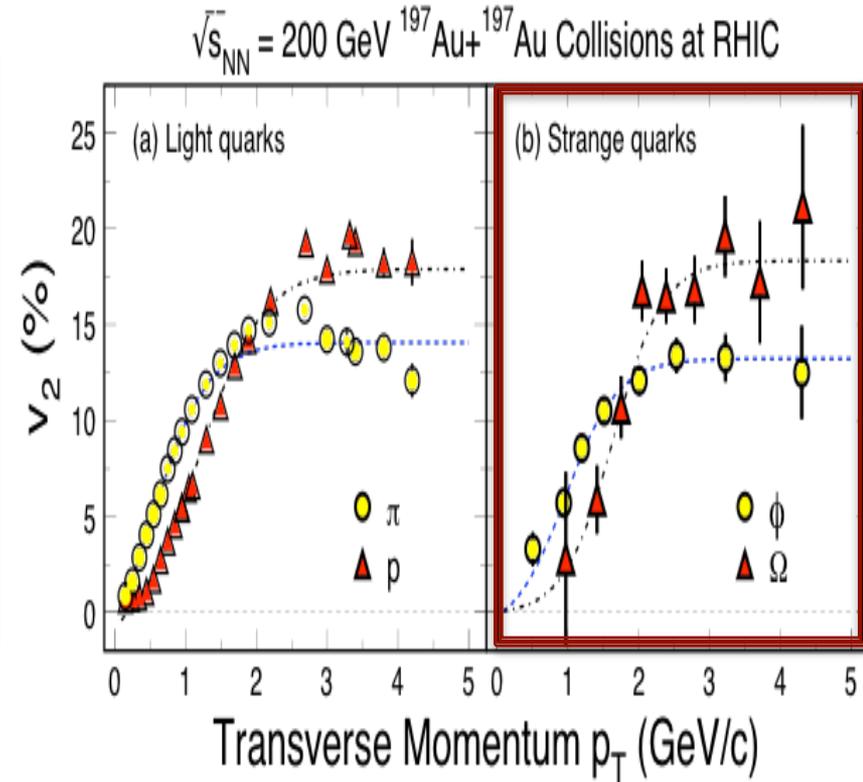
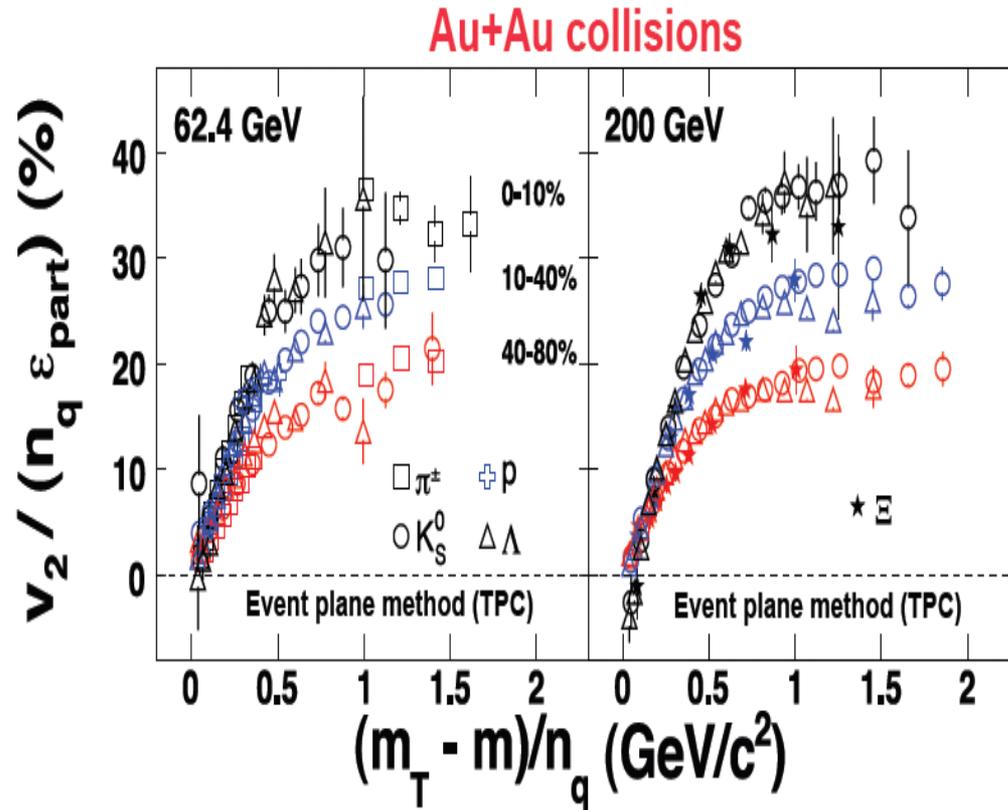
$Cu + Cu, \sqrt{s_{NN}} = 200 \text{ GeV}$



NCQ scaling works for Au+Au and Cu+Cu Collisions at 200GeV

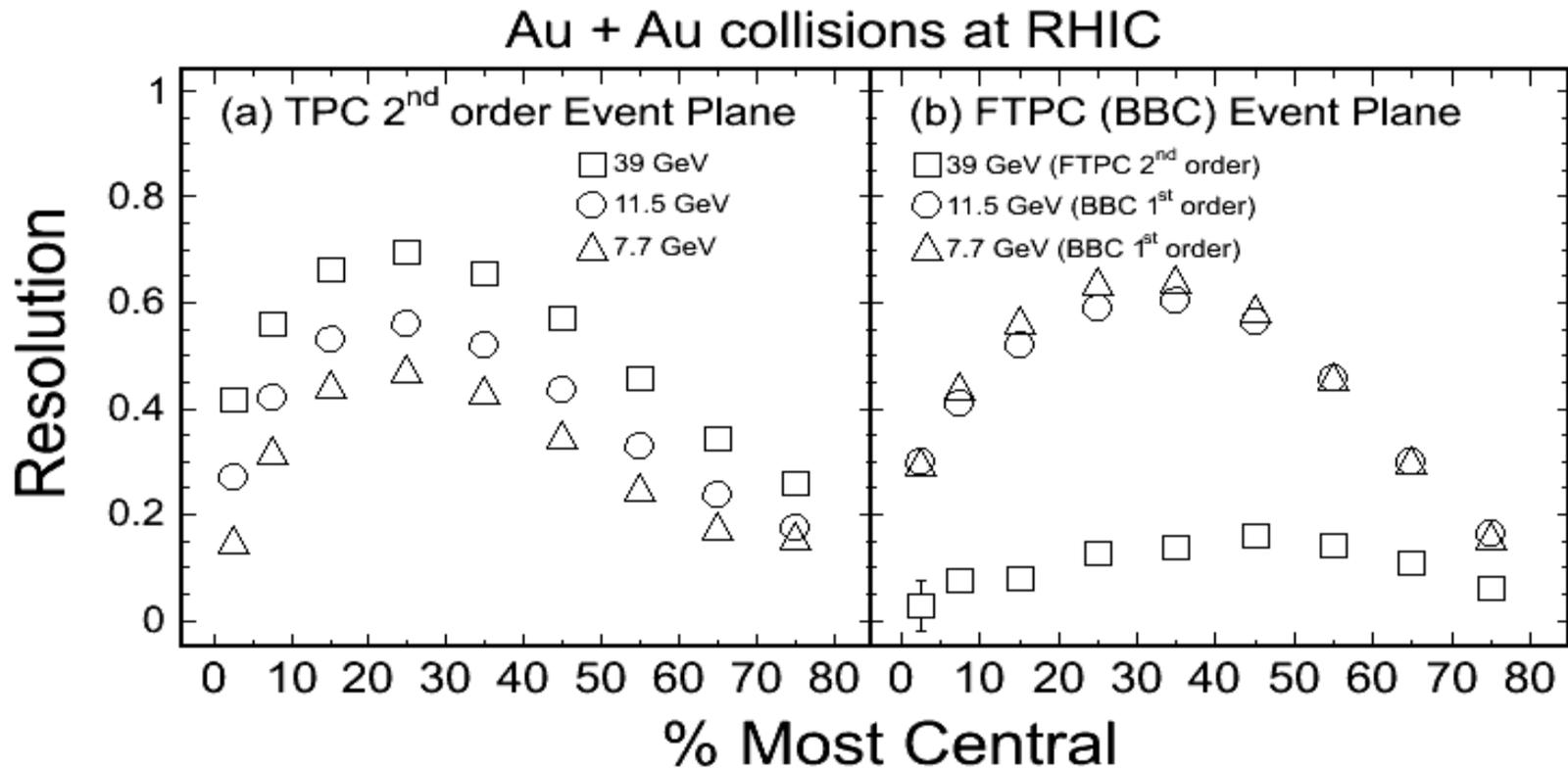
$v_2(p_t)$ at 200 and 62.4 GeV

PRC 77 (2008) 054901



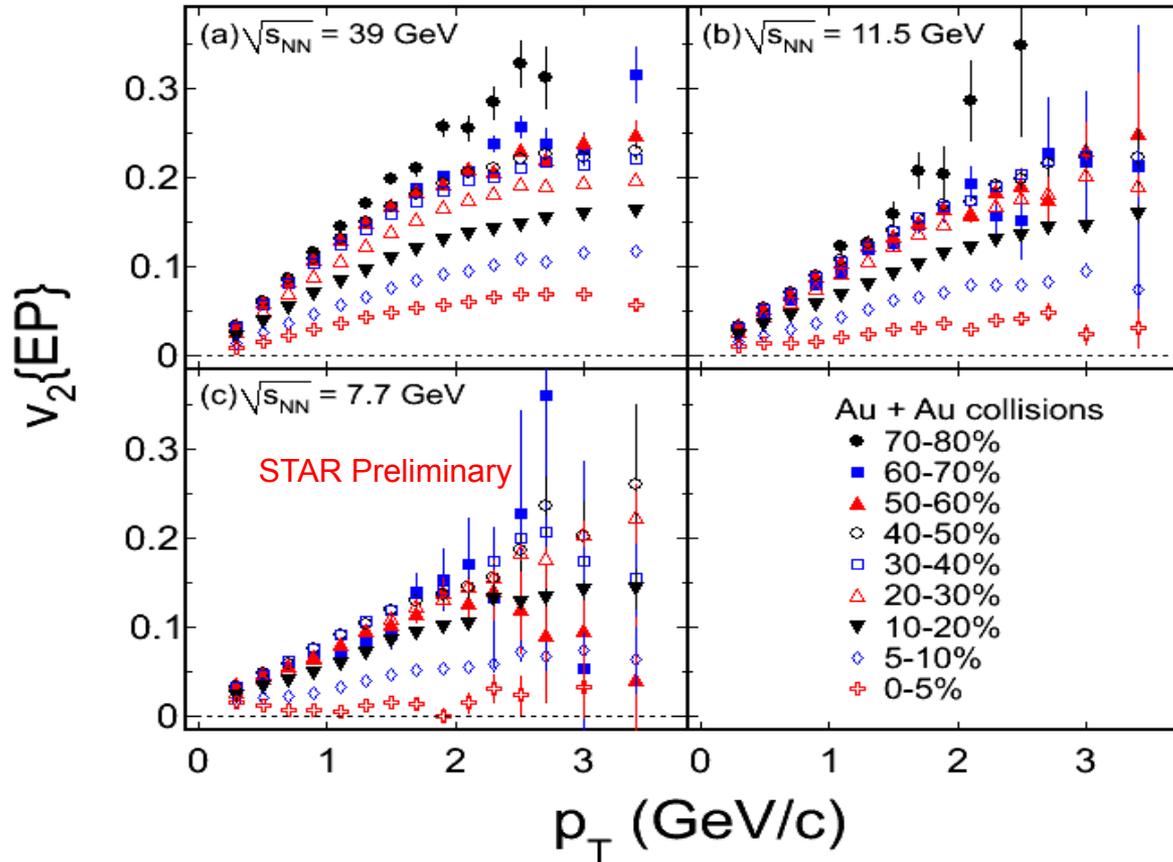
Strong Centrality dependence of $v_2(p_t)$ is observed at 62.4 and 200 GeV Au+Au collisions
 More central collisions have stronger collectivity
 Similar v_2 pattern for light and strange quarks (s-quark hadrons have smaller interaction strength in hadronic medium)

Elliptic flow from BES: Event Plane Resolutions



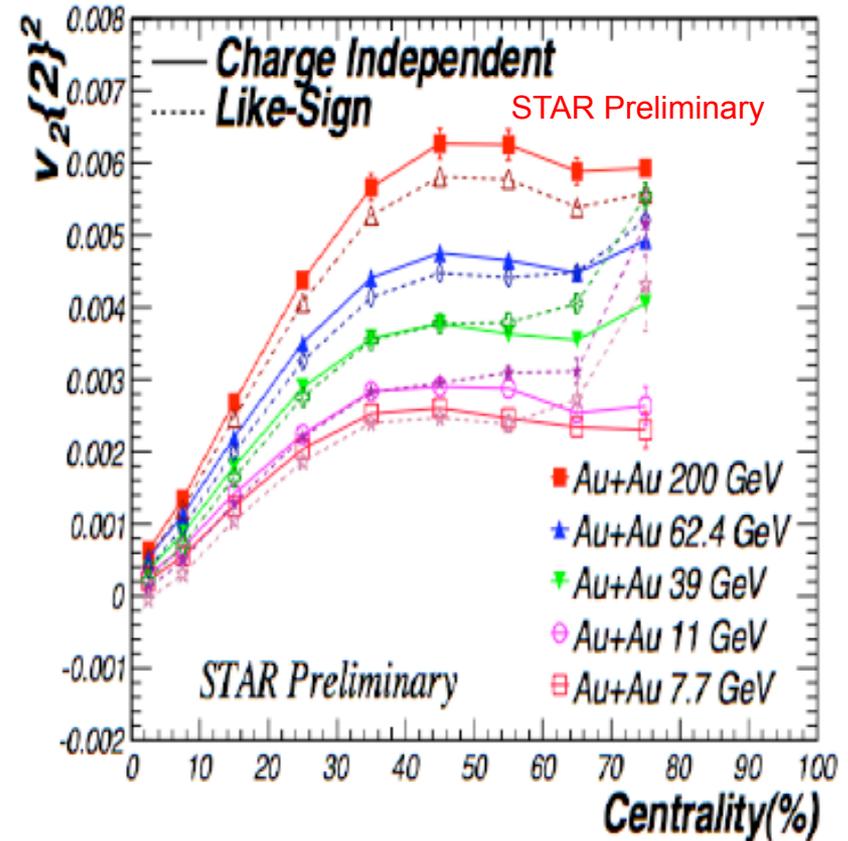
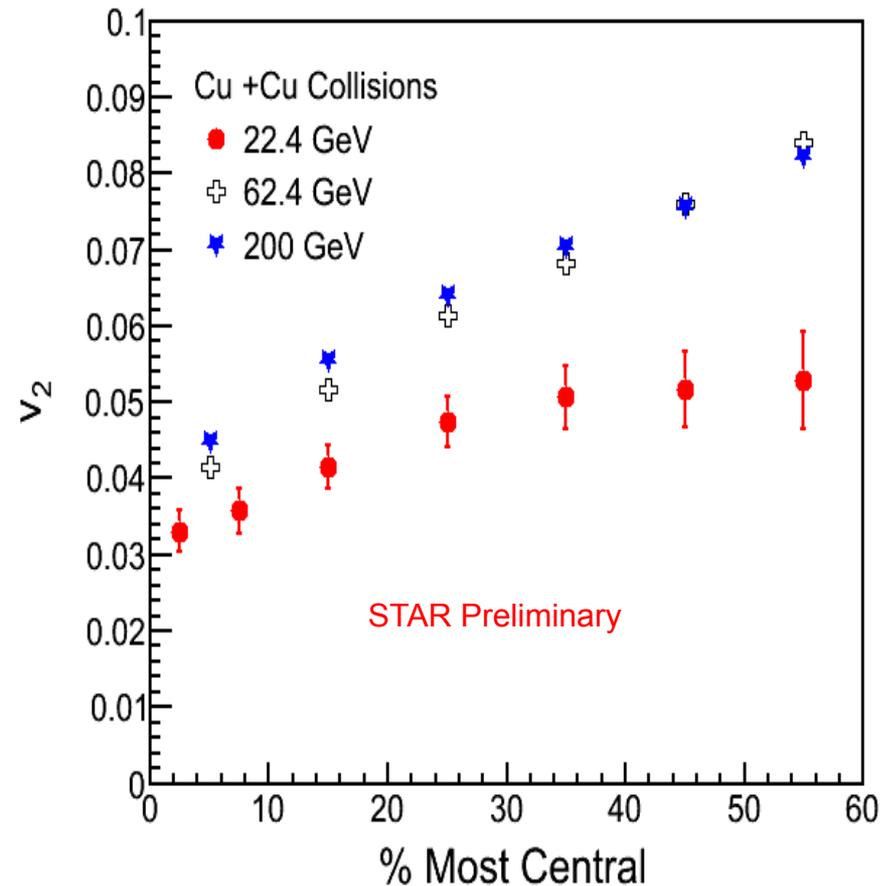
Second order TPC event Plane resolution decreases when Beam Energy decreases but still good for elliptic flow measurement at BES energies

Elliptic flow at BES energies



Centrality dependence of $v_2(p_T)$ in BES: a similar observation to high beam energies.

Beam Energy Dependence of v_2 (centrality)

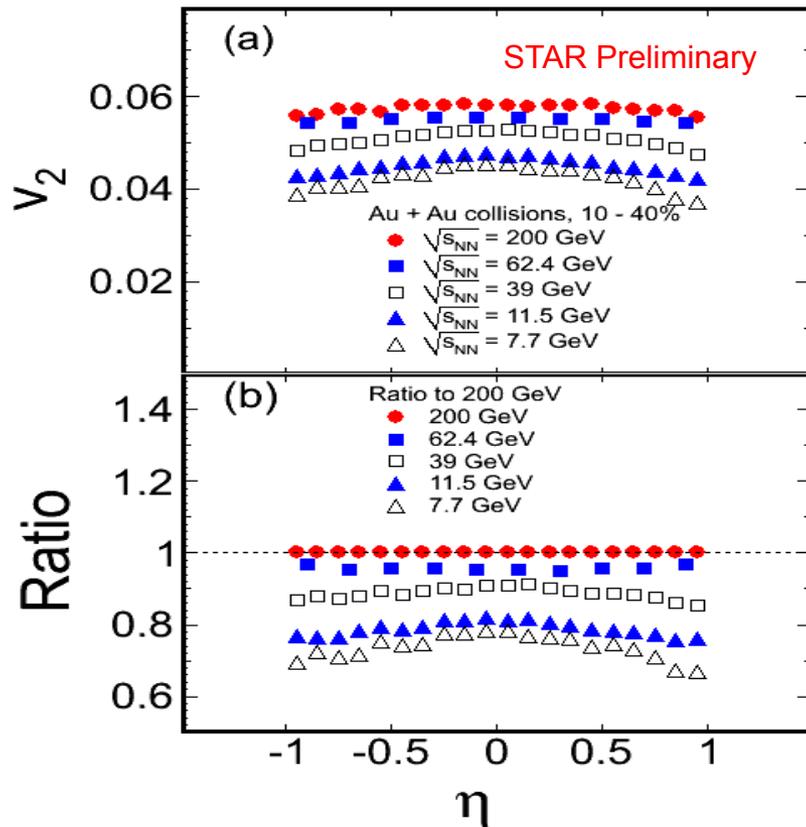


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v_2 increases with beam energy for same centrality.

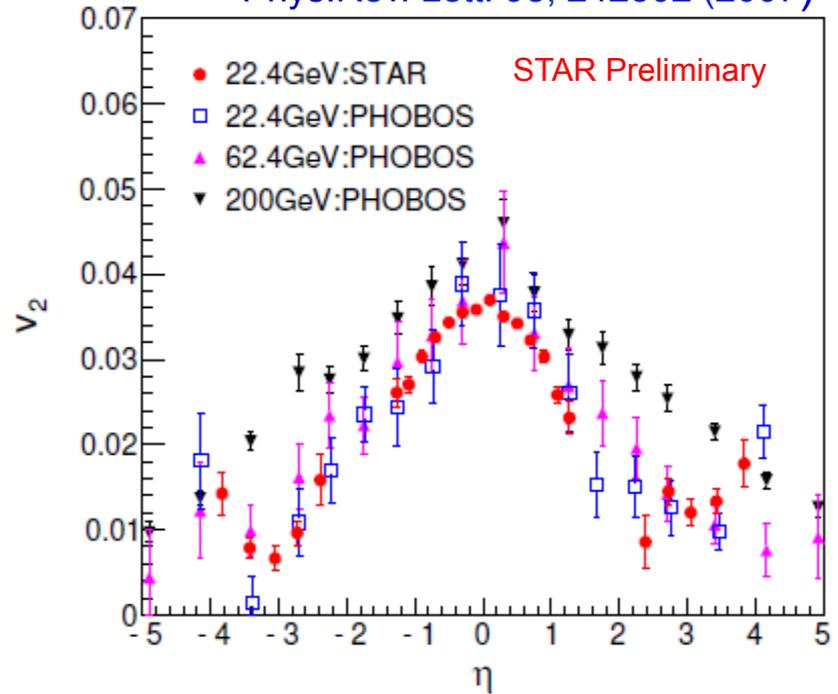
Beam Energy Dependence of $v_2(\eta)$

10-40% Au + Au collisions.



0-60% Cu + Cu collisions at 22.4 GeV

Phys.Rev. Lett. 98, 242302 (2007)

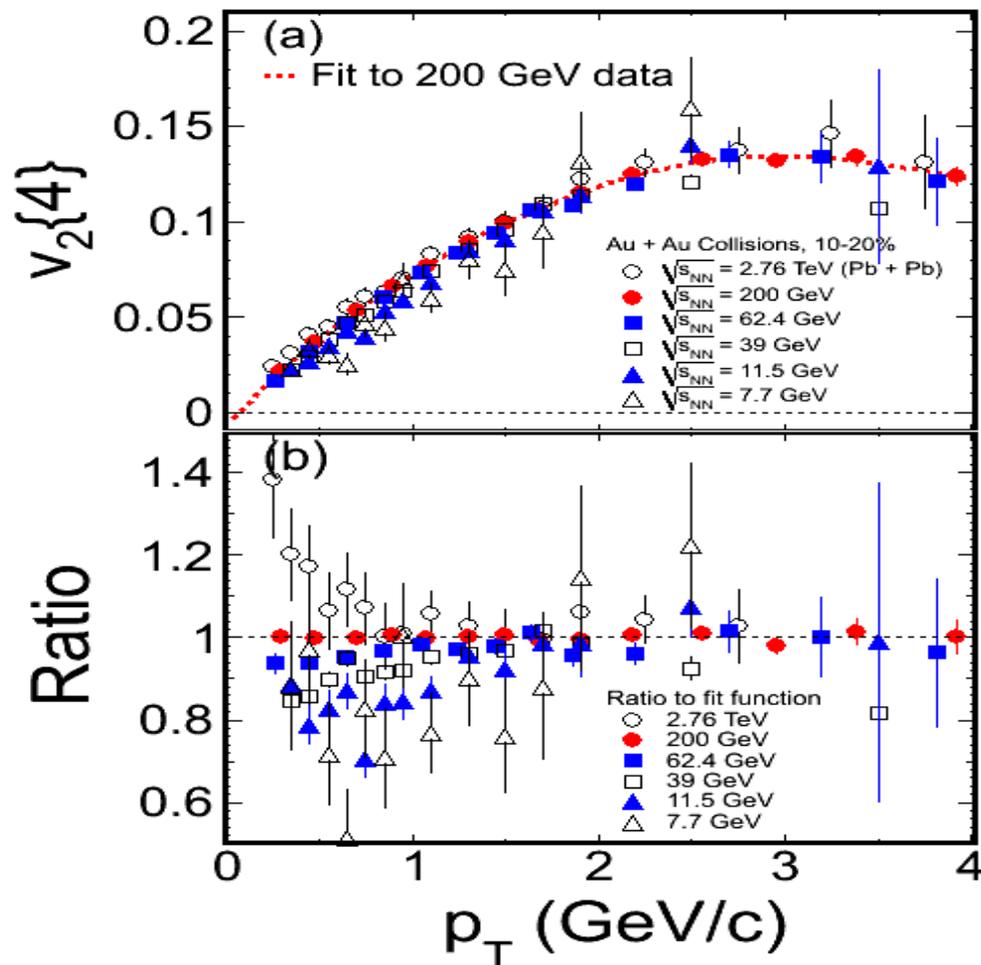
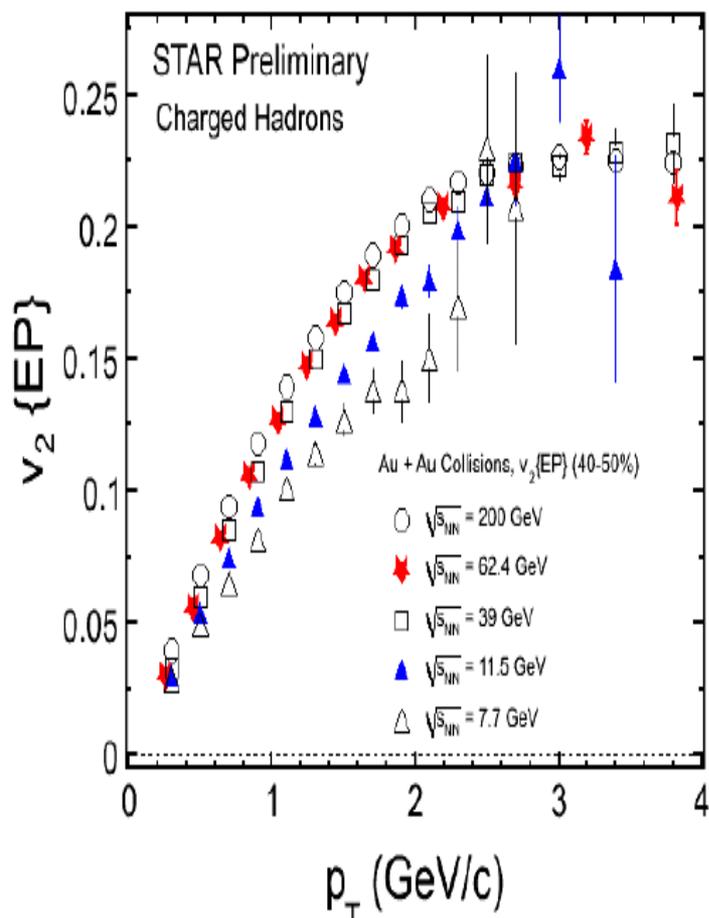


0-40% Cu + Cu collisions: PHOBOS

$v_2(\eta)$ increases with beam energy.

Beam Energy Dependence of $v_2(p_t)$

arXiv:1011.3914 [nucl-ex]



$v_2(p_t)$ slightly increases from 7.7 GeV to 39 GeV.

$v_2(p_t)$ does not change much with changing beam energy from 39 to higher energies

Summary/Conclusions

Directed flow:

- Preliminary results of directed flow at 39, 11.5 and 7.7 GeV (AuAu Collisions) and 22.4 GeV (CuCu collisions) are presented.
- STAR results at low beam energies follow trend shown by data at 62.4 & 200 GeV (system-size independence + beam energy dependence scales with η/y_{beam}).

Elliptic flow:

- Preliminary results of elliptic flow at 39, 11.5 and 7.7 GeV (AuAu Collisions) and 22.4 GeV (CuCu collisions) are presented.
- Elliptic flow as a function of transverse momentum $v_2(p_T)$ for $p_T > 0.5$ GeV does not change much with changing beam energy from 39 GeV to higher energies
- Elliptic flow as a function of centrality $v_2(\text{centrality})$ and pseudo-rapidity $v_2(\eta)$ increases with beam energy



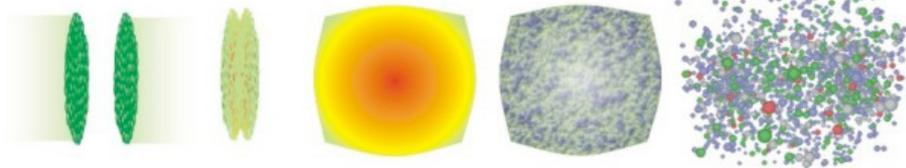
Nepal

Thank You



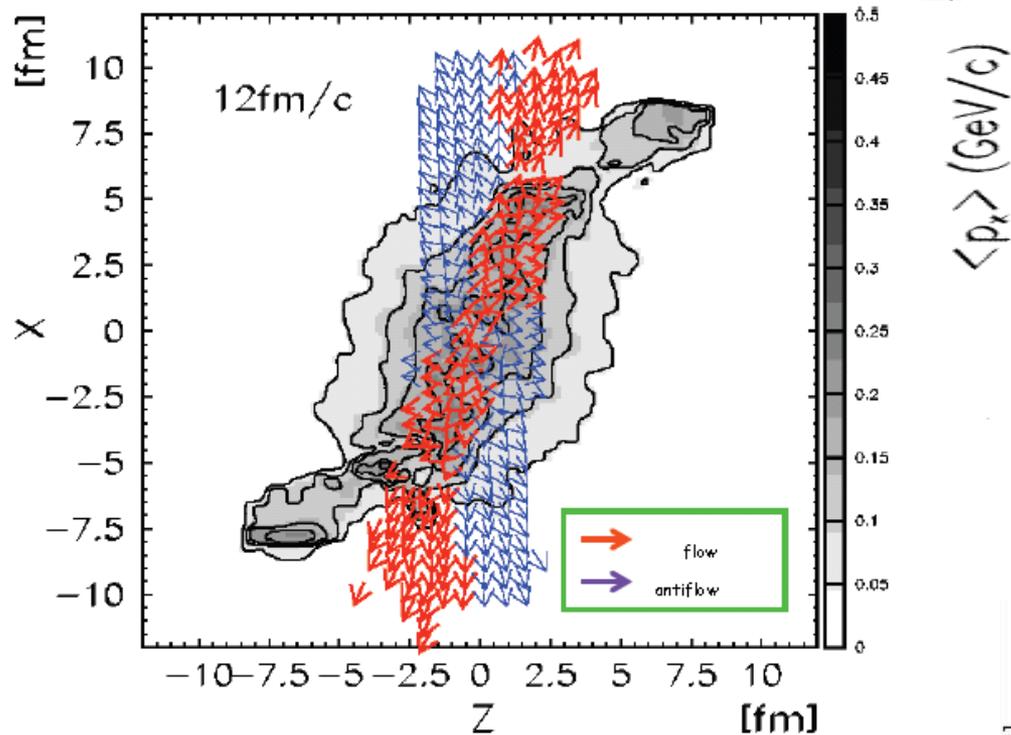
Colorado

Back Up Slides



$v_1(y)$ Structure

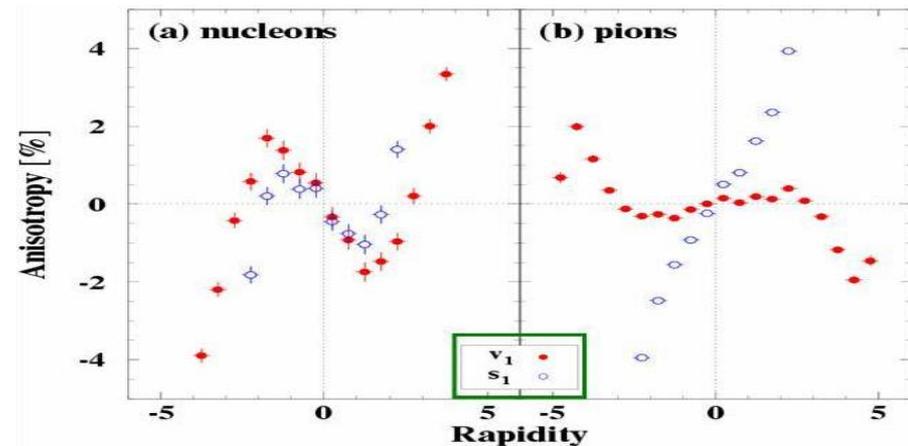
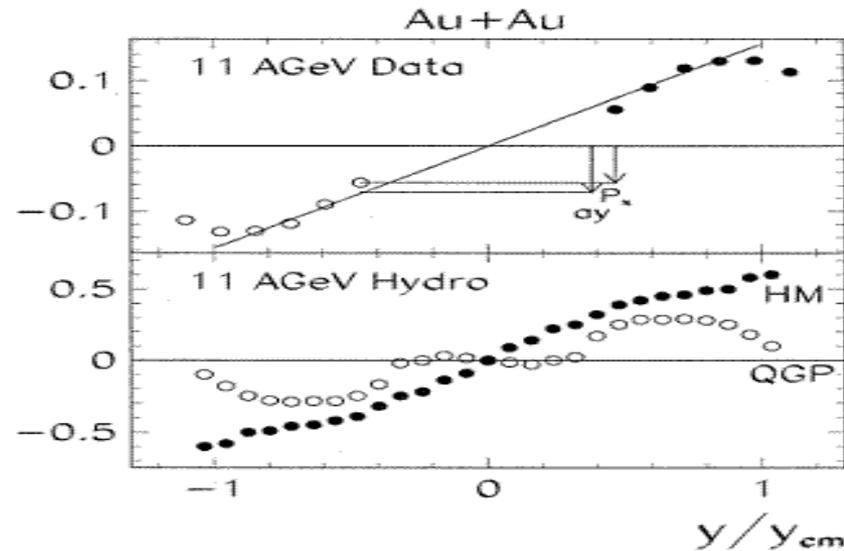
L.P. Csernai, D. Rohrlich PLB 458, 454 (1999)



See also J. Brachmann et al., PRC 61, 24909 (2000).

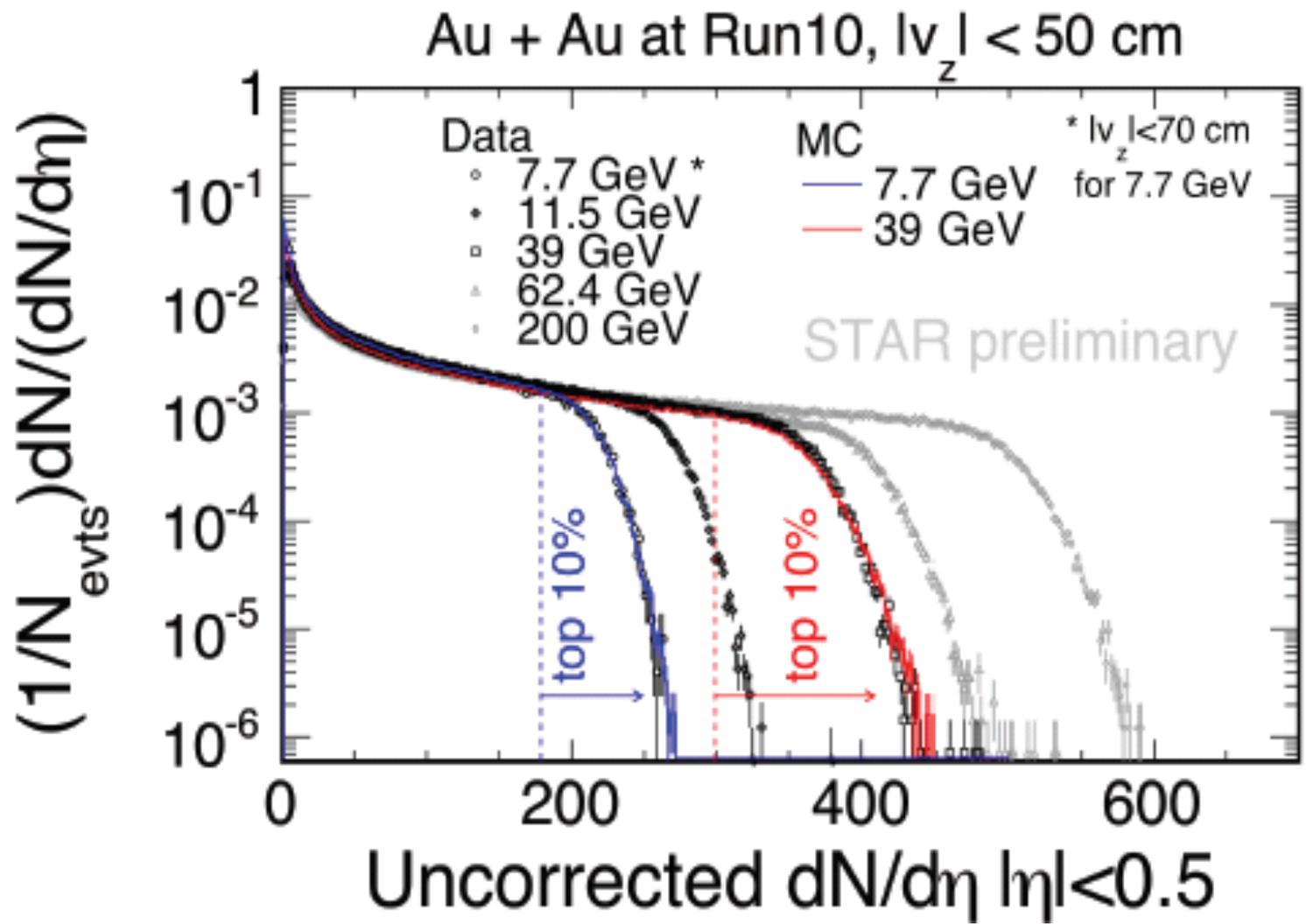
Models predict that anti-flow/3rd flow component, with QGP $\Rightarrow v_1(y)$ flat or crosses zero 3 times (so-called "wiggle").

Baryon stopping + positive space-momentum correlation may also give wiggle structure in v_1 : NO QGP necessary



R. Snellings, H. Sorge, S. Voloshin, F. Wang, N. Xu, PRL 84, 2803 (2000)

also H. Liu et al., PRC 59, 348 (1999).



Elliptic flow at BES energies

