Measurements of identified hadron flow in Au+Au, Cu+Au and U+U collisions

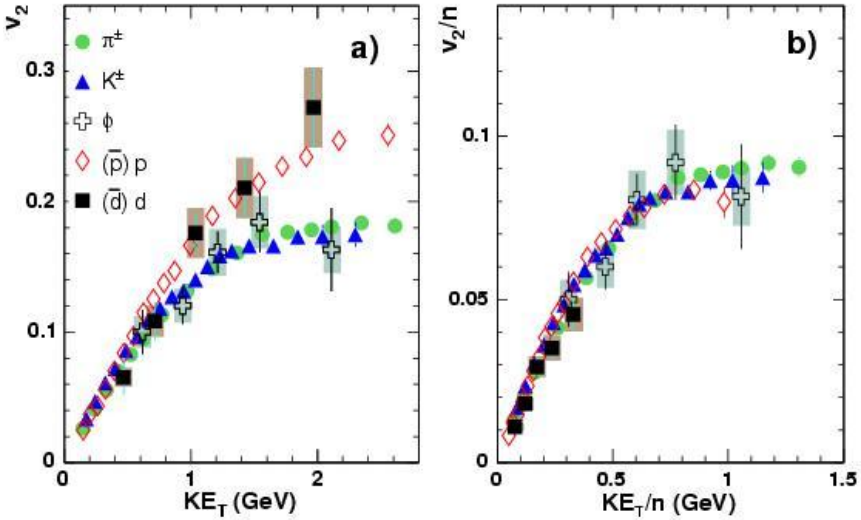
Shengli Huang

Vanderbilt University

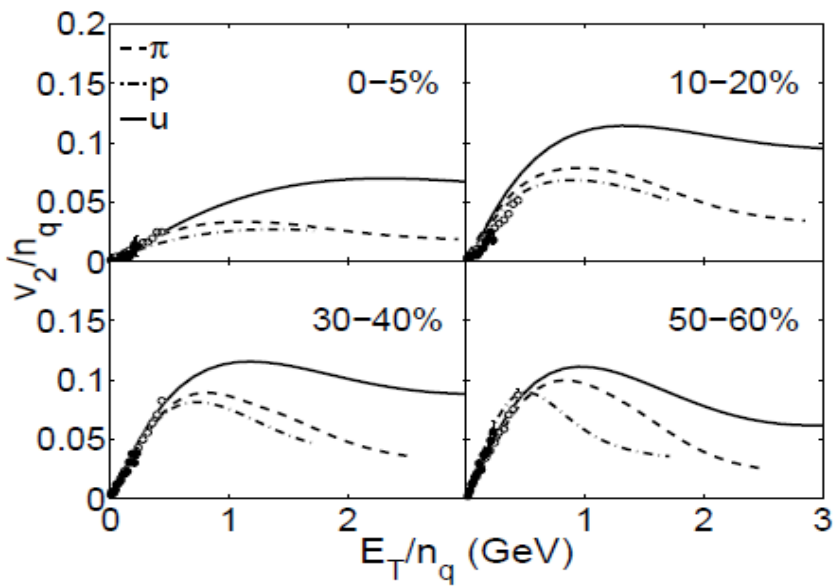
Outline

- Motivation and analysis methods
- N_q scaling in Au + Au at 200 GeV
- Pion and proton v_2 in U + U at 193 GeV
- Pion and proton v_1 and v_2 in Cu + Au at 200 GeV
- Summary and outlook

Motivation : nq scaling



PHENIX, PRL. 99, 052301 (2007)



C. B. Chiu, R. C Hwa et al. PRC.78.044903

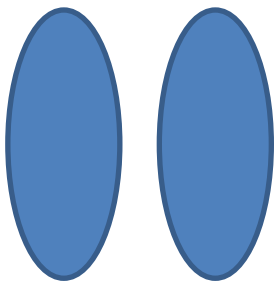
◆Baryon and meson elliptic flow follow the number of constituent quark (n_q) scaling

◆N_q scaling will break at intermediate p_T and peripheral centrality, if we assume that π is mainly from the recombination of thermal (T) and shower (S) partons but proton is mainly from TTS or TSS .

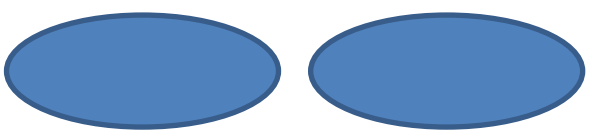
Can we test dependence of the centrality and p_T for n_q scaling breaking?

Flow in U + U (1): The geometry and density effect

U + U 193 GeV

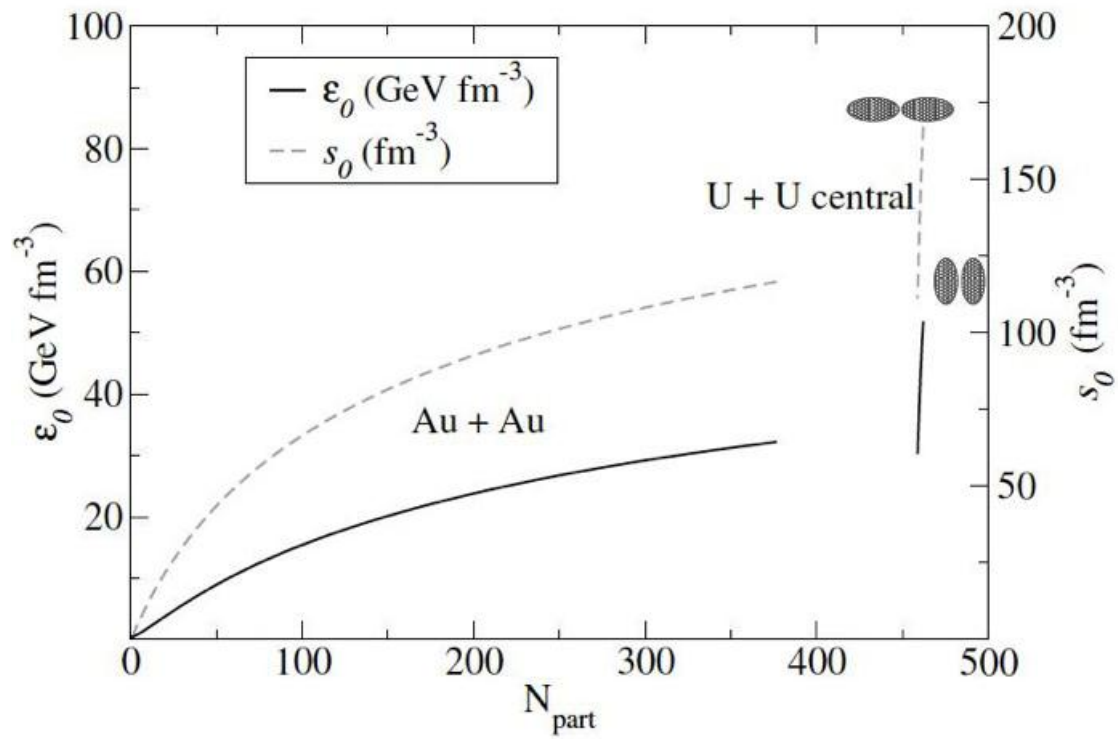


Body-body



Tip-tip

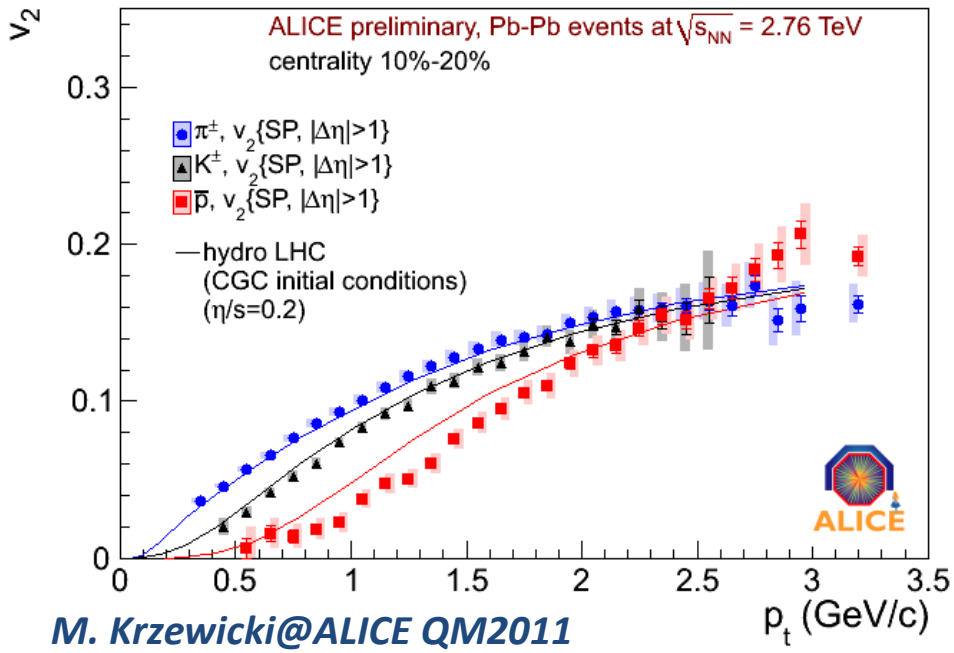
U. Heinz and A. Kuhlman, PRL **94, 132301 (2005)**



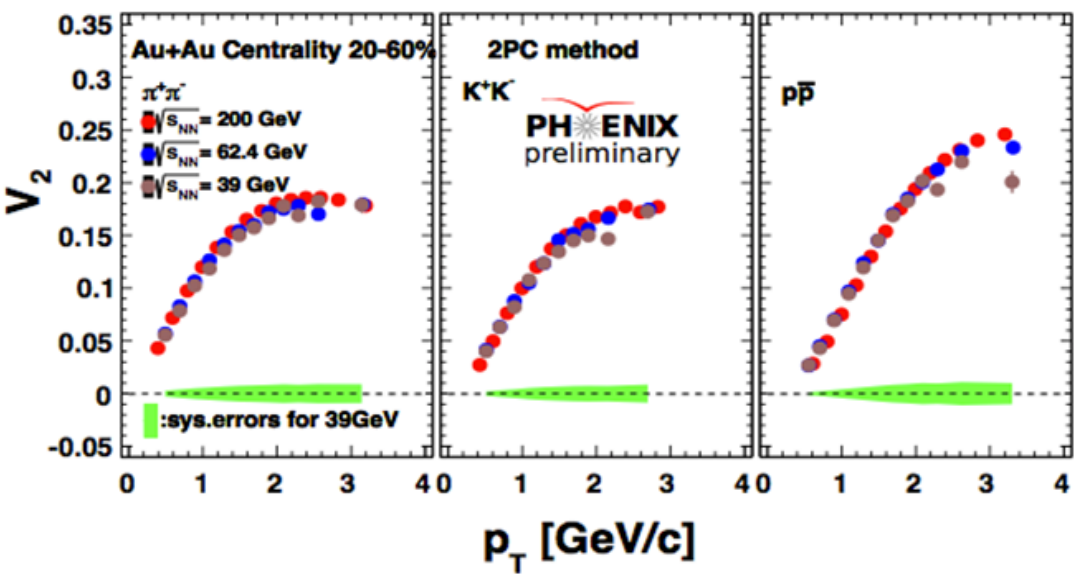
1. The geometry is significantly different for body-body and tip-tip collisions

2. The medium density in U + U at 193 GeV is around 30~60% higher than that in central Au + Au at 200GeV

Flow in U + U (2): Mass ordering

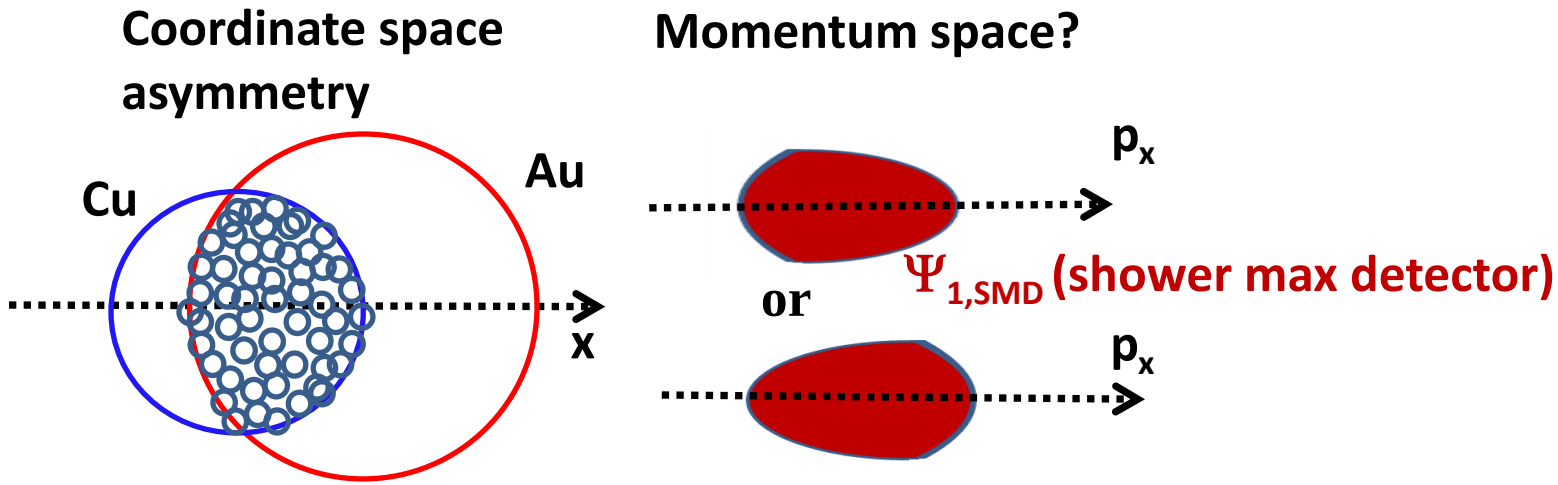


M. Krzewicki@ALICE QM2011



- Strong mass ordering is observed from v_2 of identified particles in LHC (2.76 TeV), where the density increases by 2.5 compared to RHIC (200 GeV).
- In RHIC, the proton v_2 almost keeps consistent while medium density almost increases a factor of 2 in Au + Au collision from 39 GeV to 200 GeV
- How about ultra-central U + U collisions at 193 GeV?

Flow in Cu + Au (I) : flow in an asymmetric collision

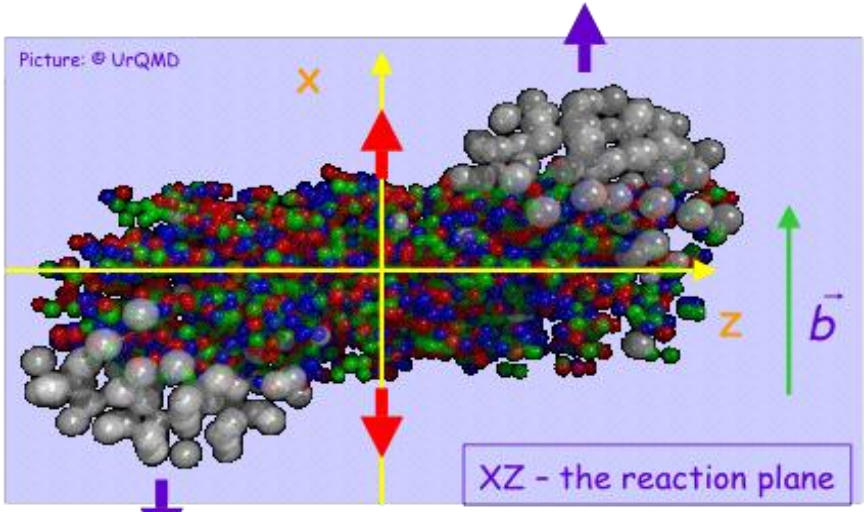


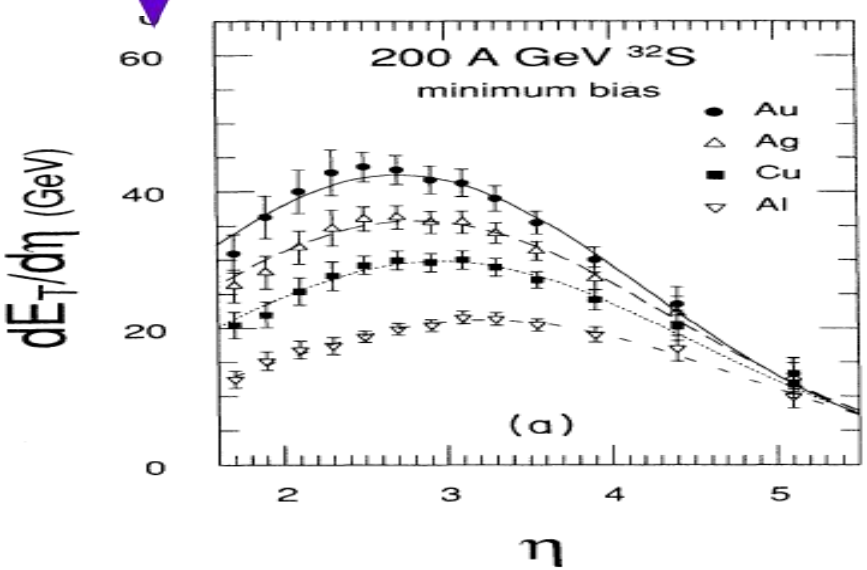
- An asymmetric coordinate space will lead to an asymmetric density profile and pressure gradient
- Event-by-event geometry fluctuation
- The energy loss for jets from Au or Cu side will be different

$\Psi_{1,SMD}$: Combination of $\Psi_{1,SMD}^{South}$(Au-going) with flipped $\Psi_{1,SMD}^{North}$ (Cu-going). The direction of Ψ_1 plane is decided by the Au spectators

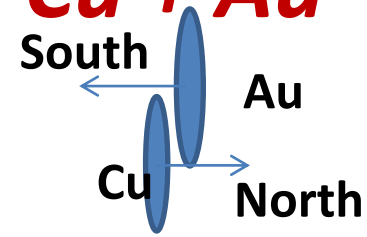
- Measurements v_1, v_2 in Cu + Au will help us to understand the effect of the asymmetric density, geometry and their fluctuation.

Flow in Cu + Au (2) : anti-flow effect in Cu + Au

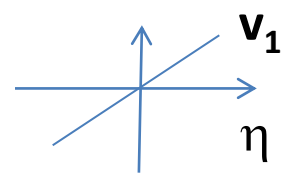




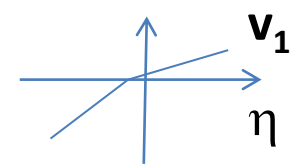
WA80 PRC 44 (1991) 2736



Ψ_1: by Au-going spectators on the south side



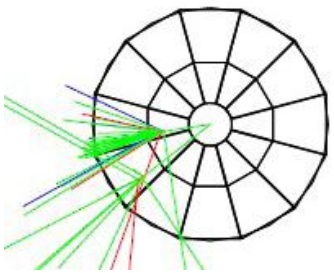
Au + Au



Cu + Au

- Large v_1 is observed at forward and backward rapidity in Au + Au, which may be due to anti-flow effect
- Shift of mass center may bring this anti-flow effect into mid-rapidity $|\eta|<0.35$ in Cu + Au collisions
- Measure the v_1 of identified particle will further help us to address the dynamic mechanisms under this asymmetric distribution

PHENIX Detectors for Event Plane

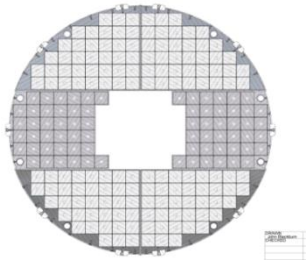


***Event plane detectors*:**

Reaction plane detector

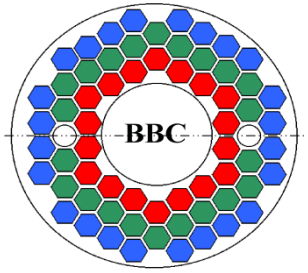
RXN_{IN} (1.5<|η|<2.8)

RXN_{OUT} (1.0<|η|<1.5)



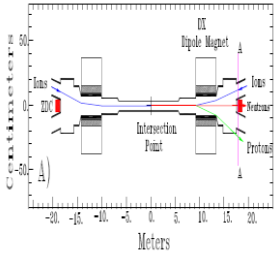
Muon piston Calorimeter

MPC (3.1<|η|<3.9)



Beam-beam counter

BBC (3.1<|η|<3.9)

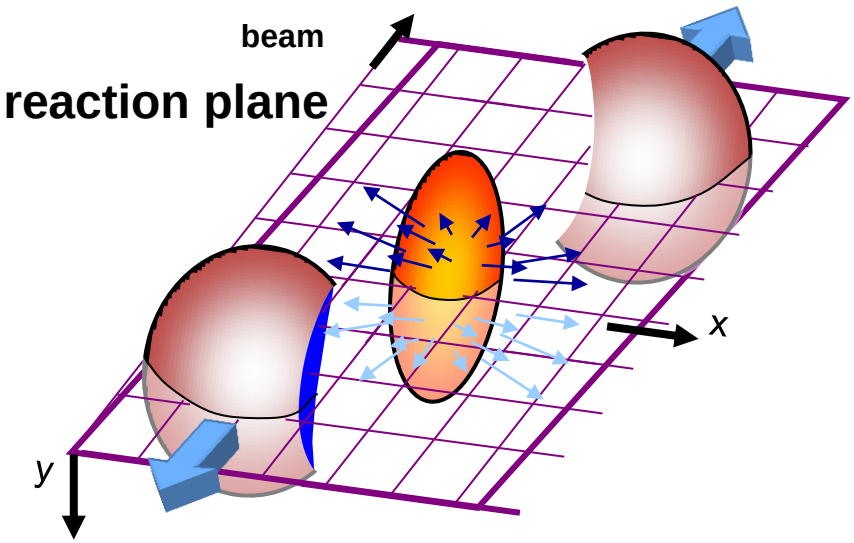


Zero Degree Calorimeters(**ZDC**)

Shower Max Detectors(**SMD**)

ZDC-SMD (|η|>6.5)

Ψ_1 by spectator

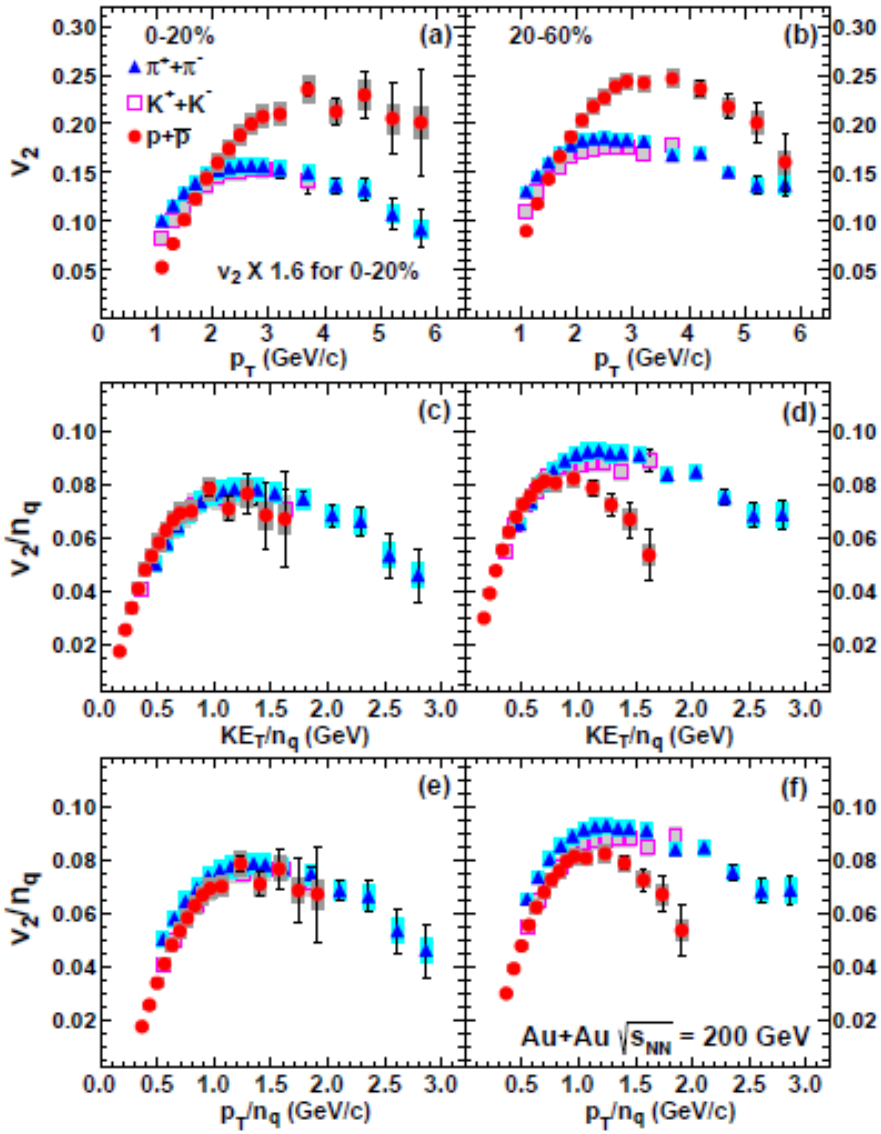


$$dN/d\Delta\phi \sim 1 + 2\sum_{n=1}^{\infty} v_n cos(n\Delta\phi)$$

(I) Identified particles flow in Au +Au at 200 GeV:

The centrality and p_T dependence for n_q scaling breaking

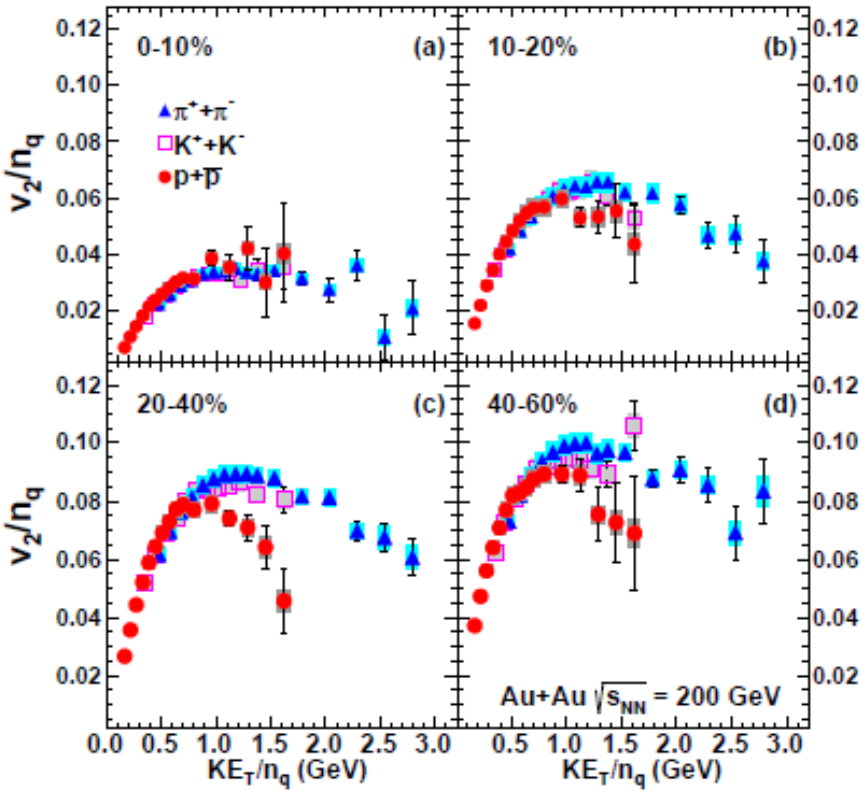
V_2 of identified hadrons in 200 GeV AuAu

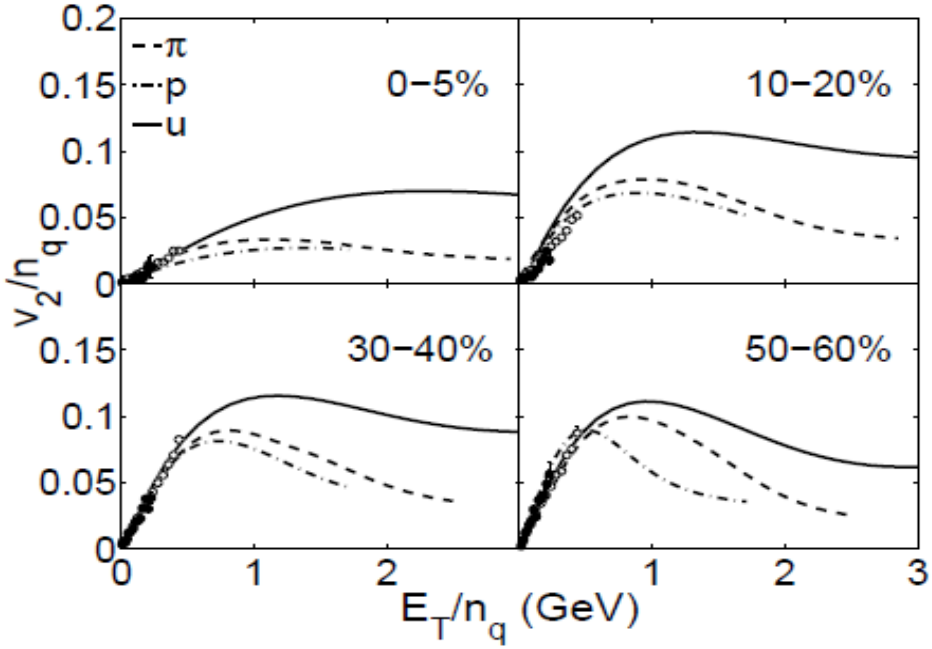


- In 0-20% central Au + Au collisions at 200 GeV, the v_2 proton is higher than that of pion still p_T of 6 GeV/c. While in 20-60% centrality, they approach each other.
- A break of n_q scaling is observed in 20-60% centrality at $KE_T > 0.7$ GeV. But in the 0-20% centrality, this break is still roughly held.
- It indicates the mechanisms for pion and proton production are different at intermediate p_T for different centralities

PHENIX *Phys. Rev. C 85, 064914 (2012)*

The centrality dependent n_q scaling



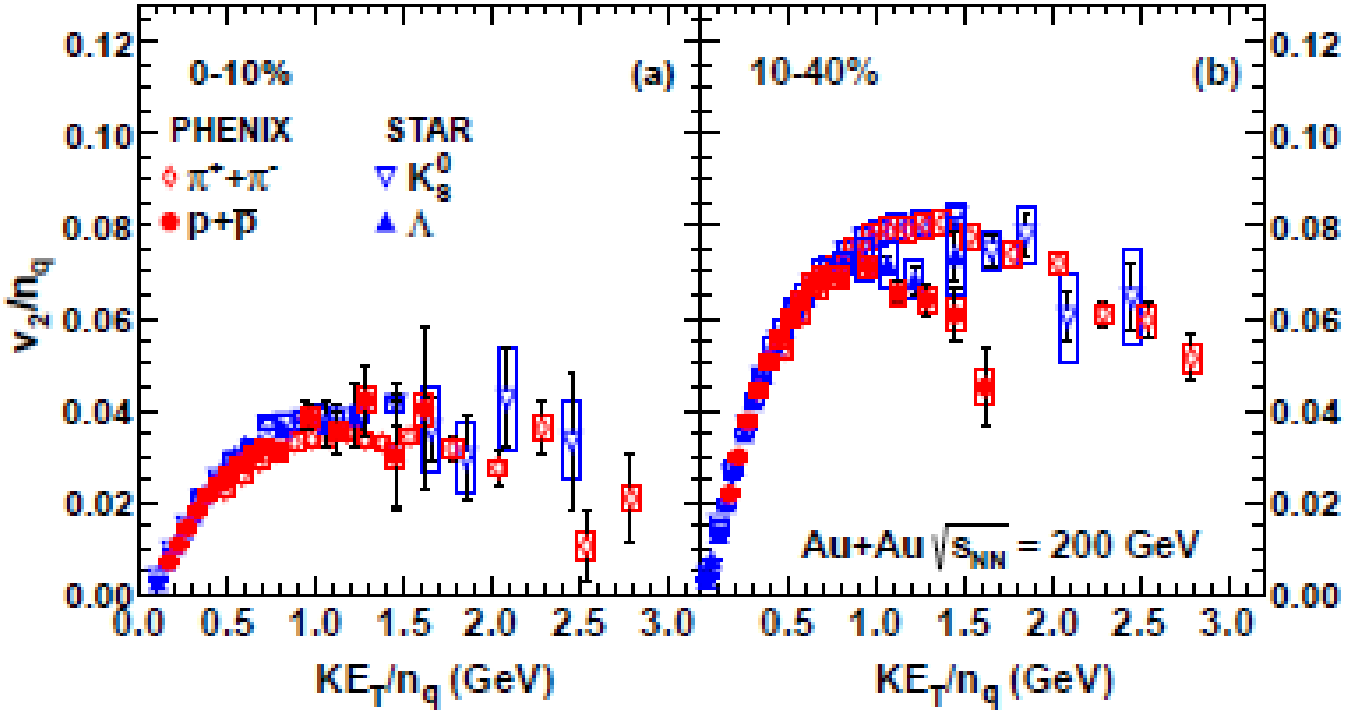


C. B. Chiu, R. C Hwa et al. PRC.78.044903

- The n_q scaling shows strong centrality dependence. In 0-10% centrality class, the n_q scaling appears to hold to $KE_T/n_q = 1.5$ GeV, supporting parton recombination. It starts to break as $KE_T/n_q > 0.7$ GeV in 10-20% centrality.

- It is consistent with recombination model calculation qualitatively

Comparing with v_2 of K_s and Lambda



Phys. Rev. C 77, 054901 (2008)

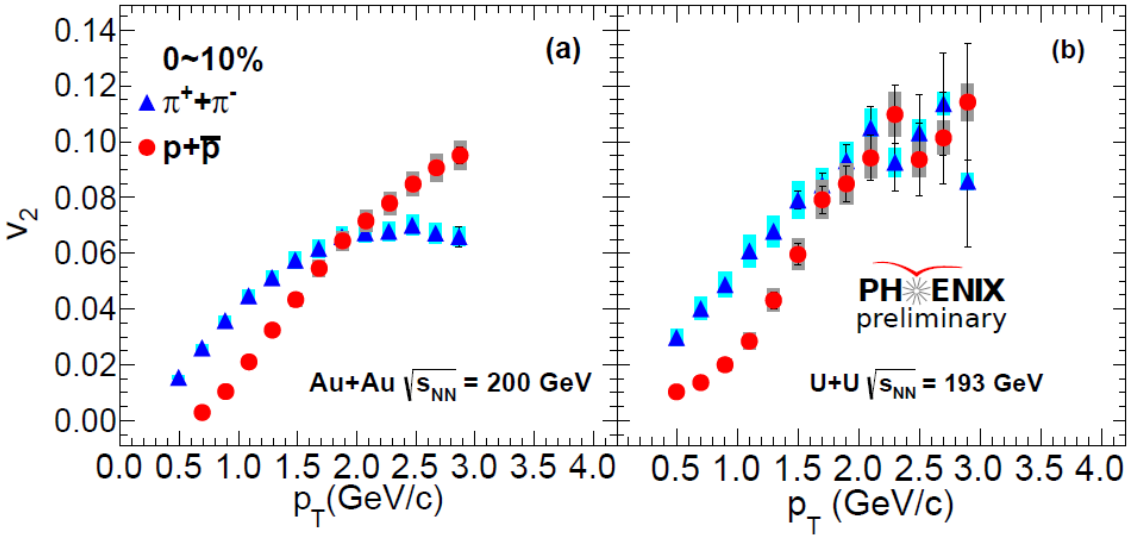
- The v_2 of pions and protons measured from PHENIX are consistent with v_2 of K_s and Lambda from STAR in overlap p_T region.
- The more accurate measurements from PHENIX indicates a clear breaking of n_q scaling in $KE_T > 0.7$ GeV in 10-40% centrality

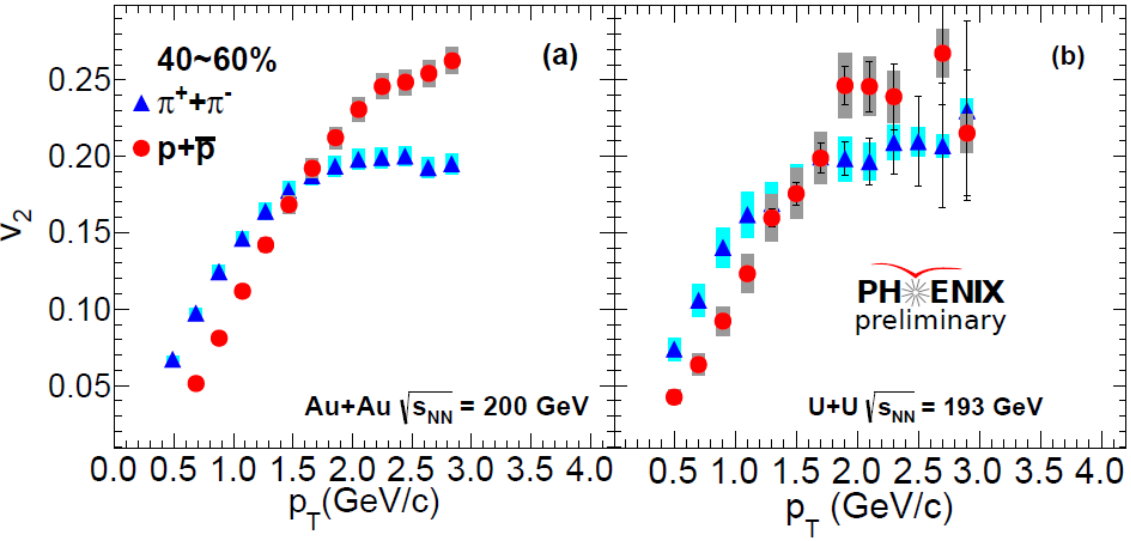
(II) Identified particles flow in U + U 193 GeV:

The geometry and density effect

π & p v_2 in U + U at 193 GeV

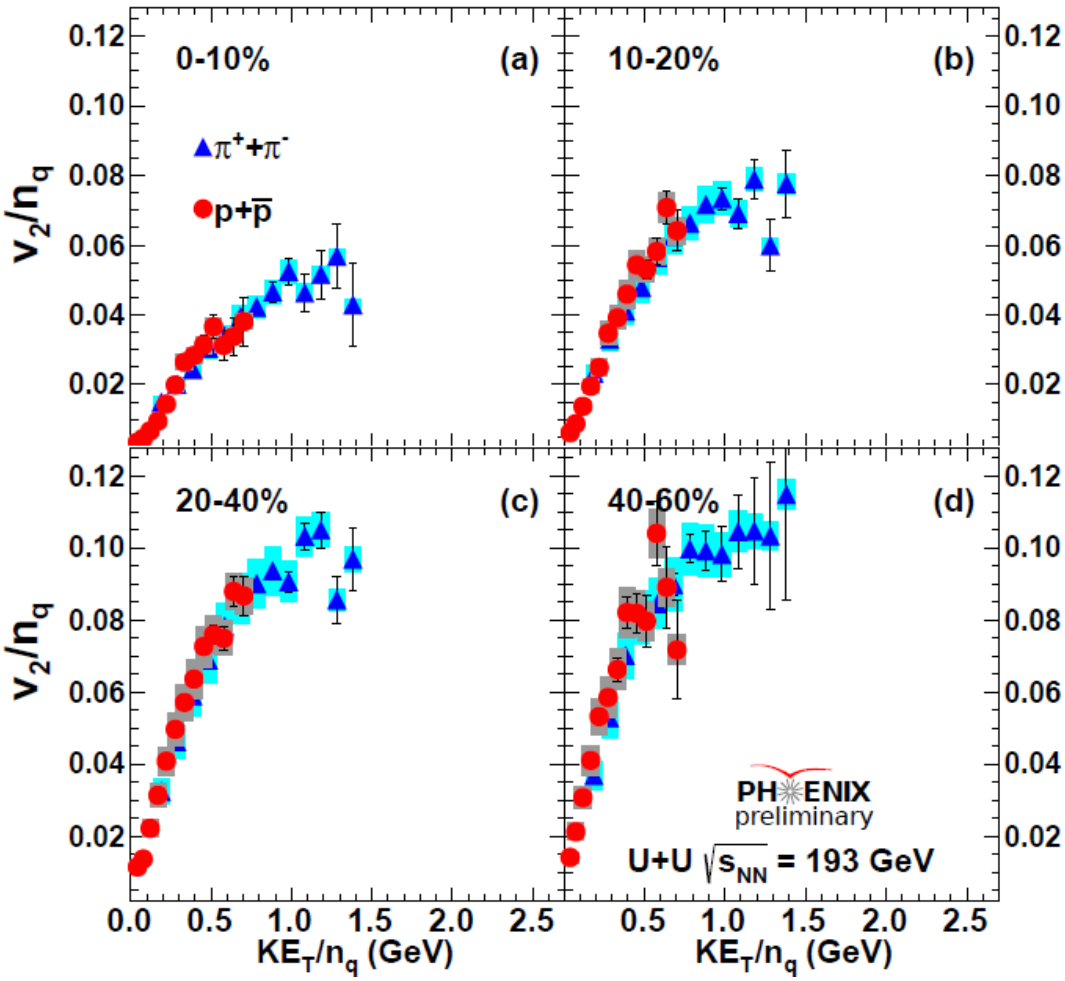
10% of full statistics





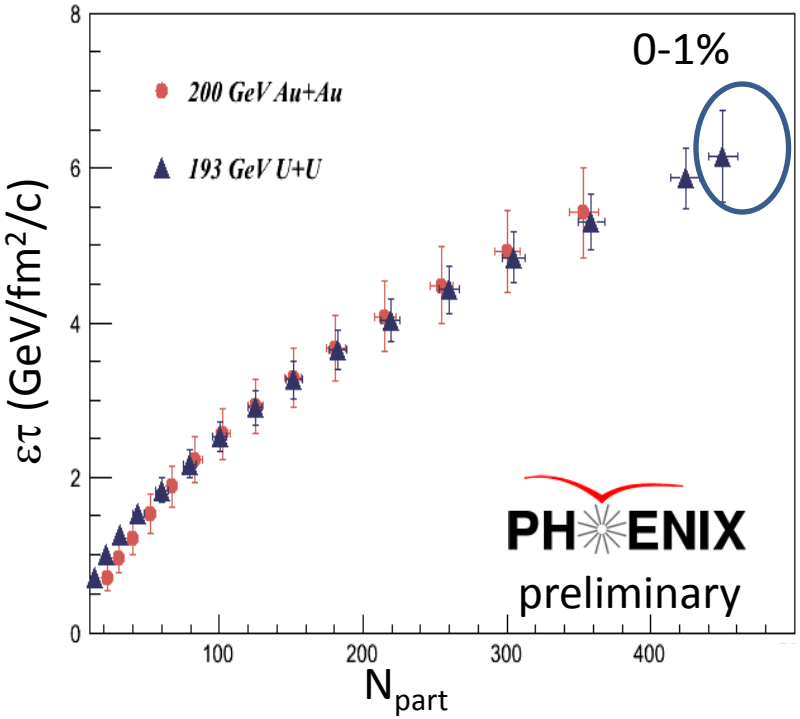
- In 0-10% U + U collisions at 193 GeV, the slope of proton v_2 is a little bit different with that in 0-10% Au + Au collisions at 200 GeV
- But this behavior disappears in peripheral collision such as 40-60% centrality

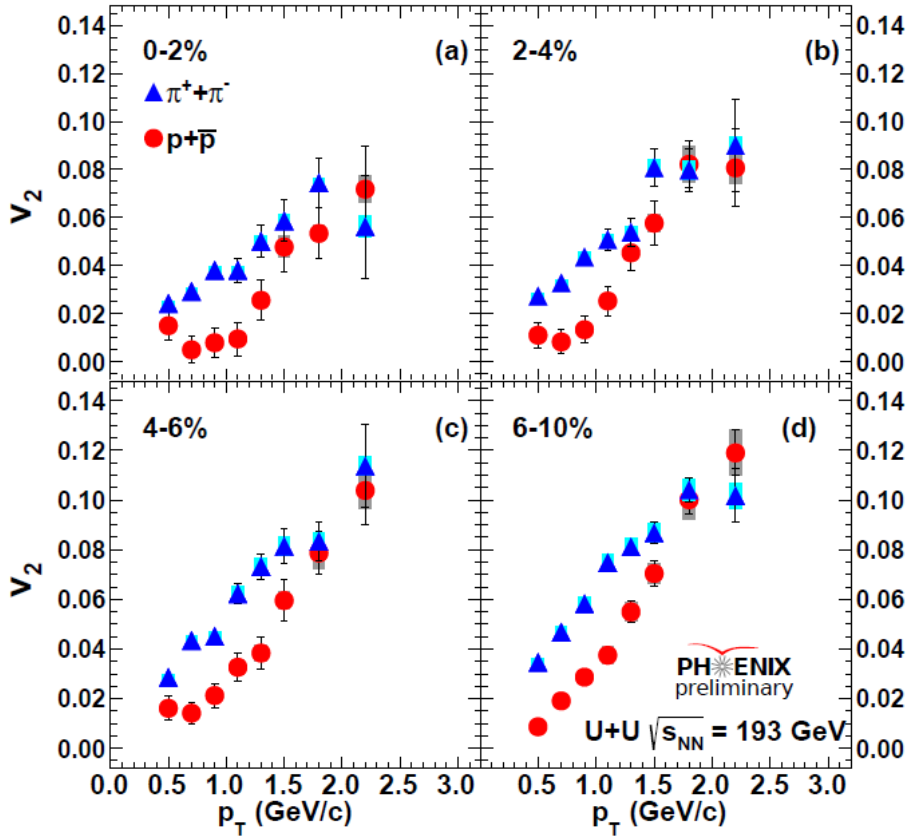
N_q scaling in U + U at 193 GeV



- ✓ The n_q scaling is still held in U + U collision at 193 GeV with v_2 of pions and protons in each centrality bin
- ✓ In the future, the measurement for v_2 of pion at more lower $p_T < 0.5$ GeV/c will be done to further test the n_q scaling

π & p v_2 in 0-2% central U + U collision





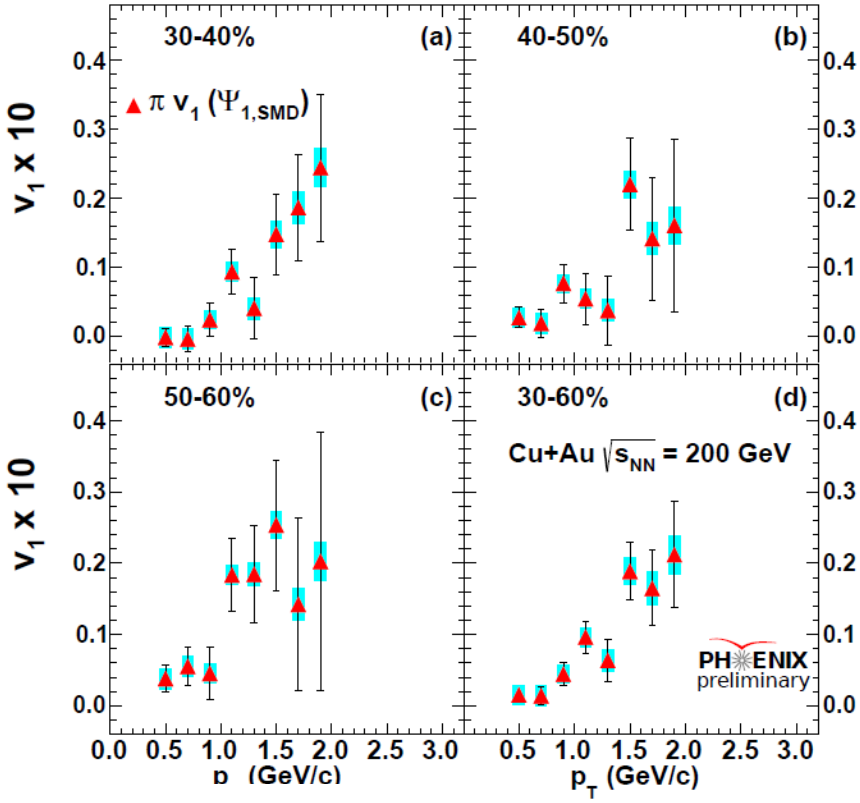
- The $\varepsilon\tau$ only increases around 20% from 0-10% Au + Au to 0-1% U + U collision.
- Strong mass ordering for π & p v_2 in 0-2% central U + U collision at 193 GeV are observed even though the increase in $\varepsilon\tau$ is relatively small. **Radial flow or geometry?**
- The geometry separation will be done in near future

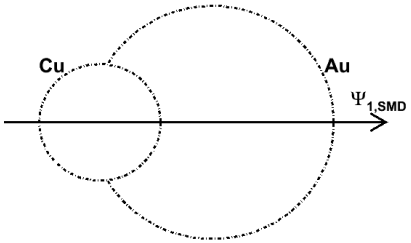
(III) Identified particles flow in Cu + Au at 200 GeV:

Flow in an asymmetric collisions

π v_1 in Cu + Au at 200 GeV

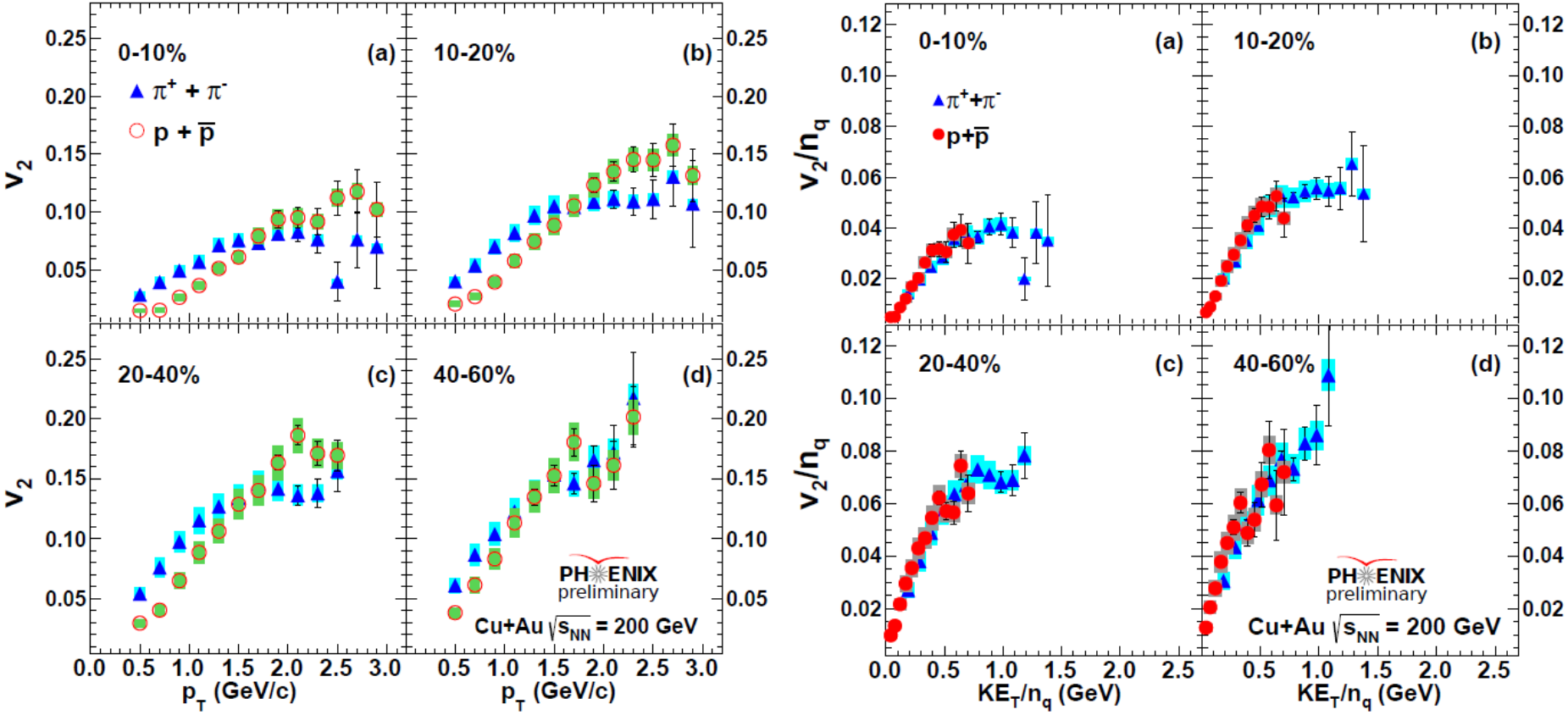
20% of full statistics





- Sizeable positive v_1 is observed at p_T > 1GeV/c with $\Psi_{1,smd}$, which direction is decided by the Au spectators. It indicates that there are more particles emitted from the Au side than from the Cu side .
- It may be due to asymmetric density profile, pressure gradient and anti-flow effect
- The v_1 of protons will be measured in near future after production of full statistics. It will help us to further address the physics of this positive v_1

π & p v_2 in Cu + Au at 200 GeV

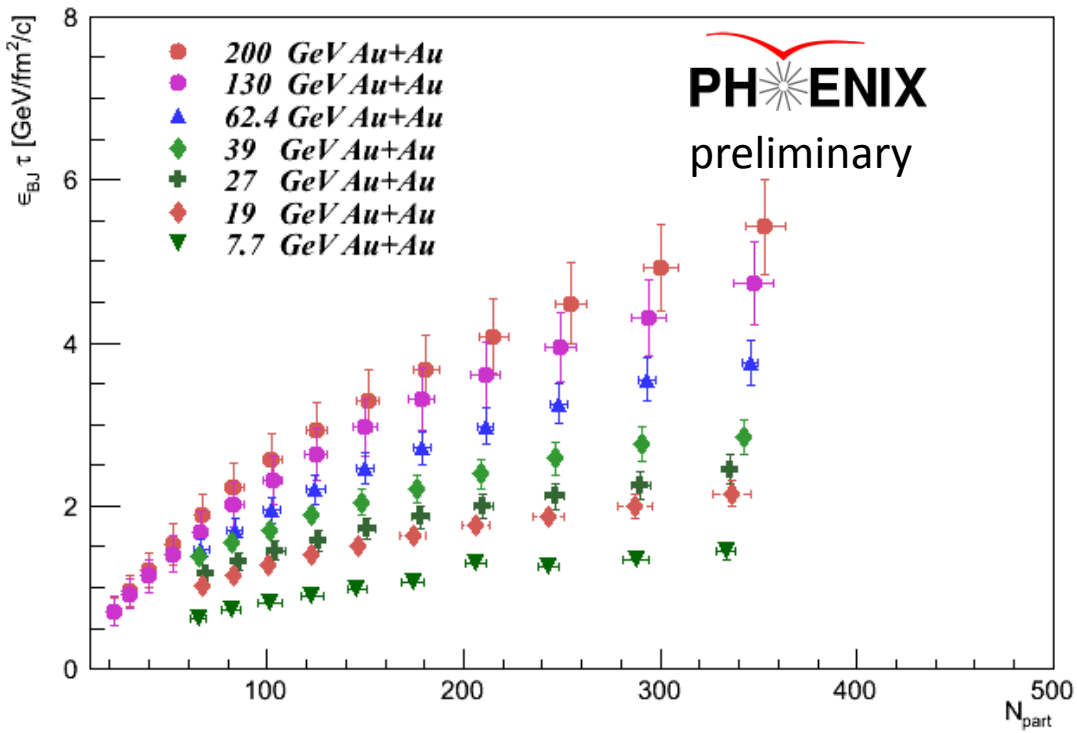


- The v_2 of pions and protons are measured as a function of p_T and centrality
- The n_q scaling is held in Cu + Au collisions at 200 GeV

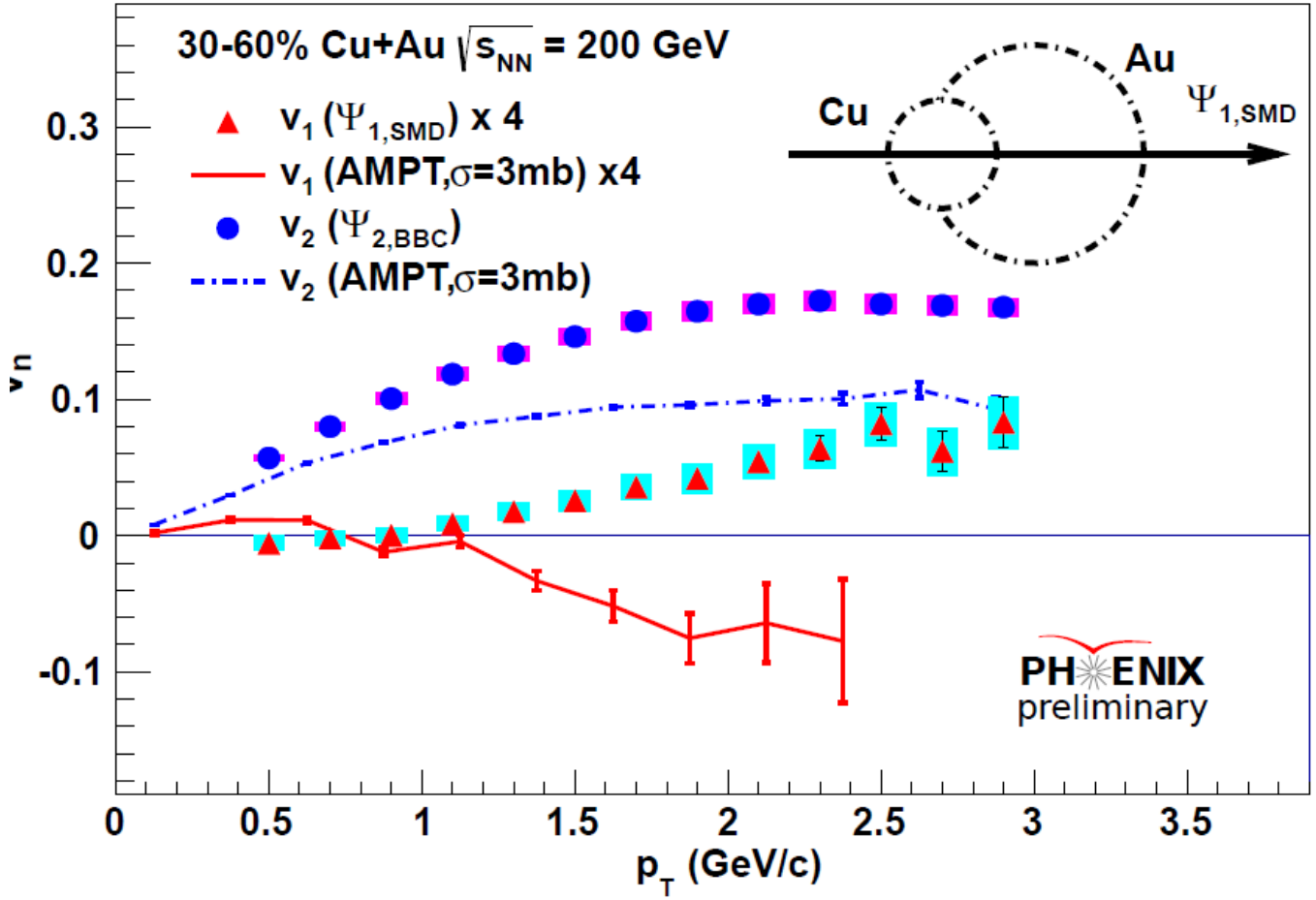
Summary and Outlook

- In Au + Au collisions, the n_q scaling is broken as $KE_T/n_q > 0.7$ GeV in 10-20% centrality. Alternatively, in 0-10% centrality class, the universal n_q scaling appears to hold to $KE_T/n_q = 1.5$ GeV. It is consistent with calculation of recombination model.
- In the ultra-central U + U collision such as 0-2%, strong mass ordering is observed for the v_2 of pions and protons, even though the density of $\varepsilon\tau$ only increases by around 20% when compared to 0-10% centrality Au + Au collisions
- A sizeable positive v_1 for charged pion are observed at $p_T > 1$GeV/c in Cu + Au collision at 200 GeV with $\Psi_{1,SMD}$, which indicates that there are more particles emitting from the Au side than from the Cu side in middle rapidity $|\eta|<0.35$. The v_1 and v_3 of pions and protons will be measured in near future after production of full statistics
- N_q scaling is held in Cu + Au and U + U collisions. In U + U 0~2% centrality, more detailed testing will be done with full statistics

Backup 1


200 GeV Au+Au
130 GeV Au+Au
62.4 GeV Au+Au
39 GeV Au+Au
27 GeV Au+Au
19 GeV Au+Au
7.7 GeV Au+Au
PHENIX
preliminary
$\epsilon_{BJ}\,\tau$ [GeV/fm^2/c]
N_{part}
0
2
4
6
8
100
200
300
400
500

Backup 2


30-60% Cu+Au $\sqrt{s_{NN}}$ = 200 GeV
v_1 ($\Psi_{1,SMD}$) x 4
v_1 (AMPT,σ=3mb) x4
v_2 ($\Psi_{2,BBC}$)
v_2 (AMPT,σ=3mb)
Cu
Au
$\Psi_{1,SMD}$
PHENIX
preliminary
v_n
p_T (GeV/c)
0.3
0.2
0.1
0
-0.1
0
0.5
1
1.5
2
2.5
3
3.5