Global and Geometrical Observables in U+U Collisions

RHIC User's Meeting
6/26/13
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Outline

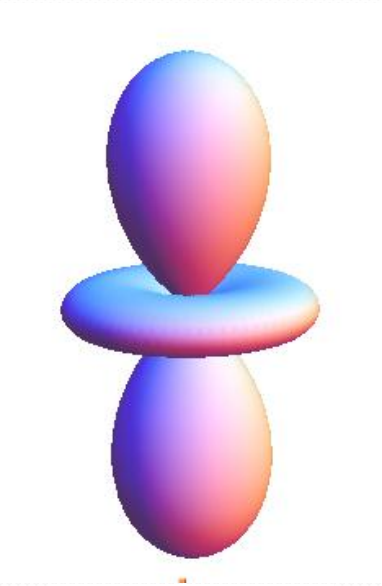
- Geometry Introduction
- Physics Motivation
- Charged Particle Multiplicity
- Transverse Energy Production
- Elliptic Flow
- Geometry Selection Prospects
- Summary

U + U Geometry

- Uranium has an asymmetric shape like a football.
- The length is ~30% longer than the diameter.

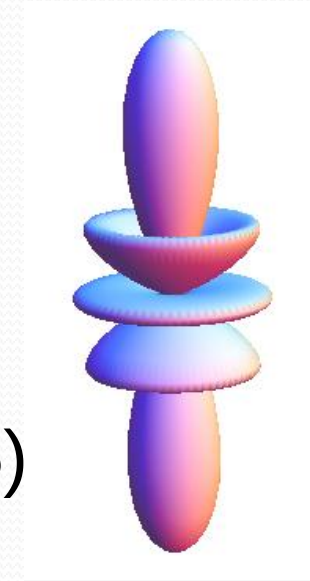
$$\rho = \frac{\rho_0}{1 + \exp([r - R']/a)},$$
$$R' = R\left[1 + \beta_2 Y_2^0(\theta) + \beta_4 Y_4^0(\theta)\right],$$

$Y_2^0(\theta,\phi)$



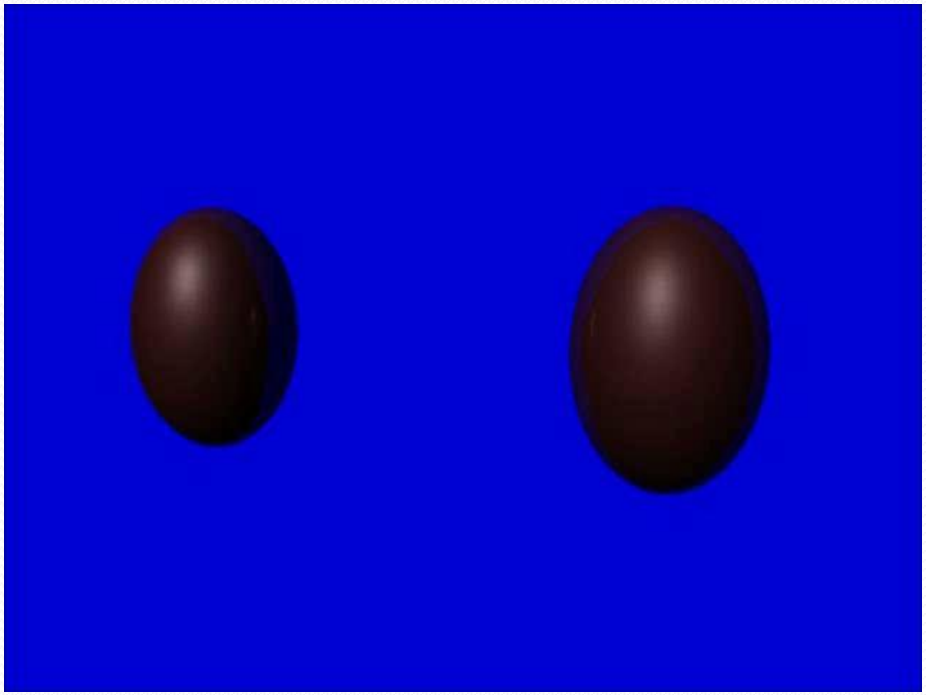
- A = 238
- R = 6.38 fm
- a = 0.535 fm
- β_2 = 0.28
- β_4 = 0.093
- Y = spherical harmonics

$Y_4^0(\theta,\phi)$

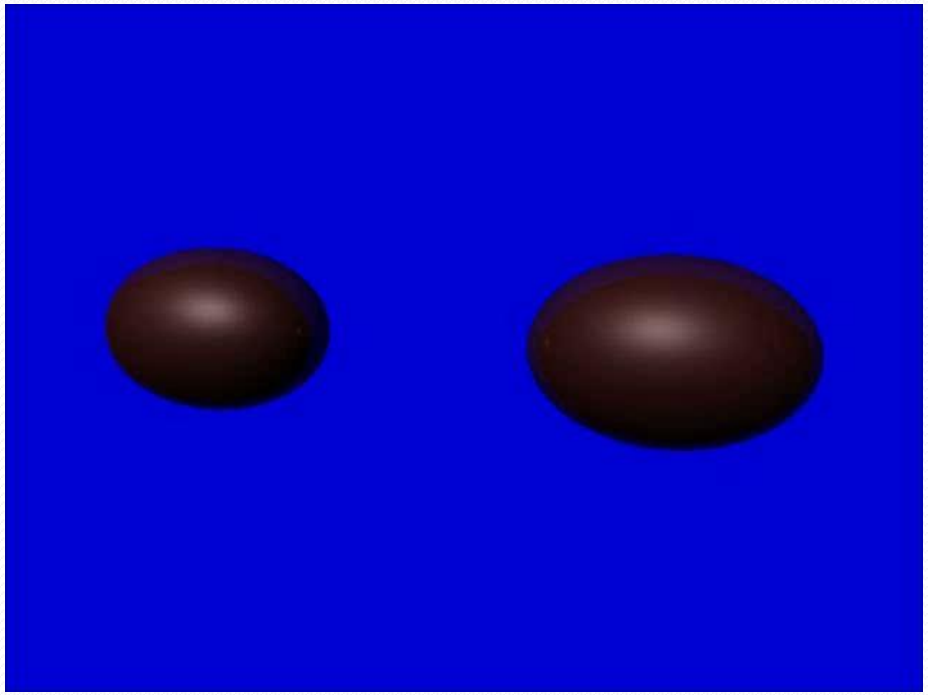


U+U Geometrical Orientation

Body-Body



Tip-Tip



Using the U+U Geometry

- Higher energy density generated in tip-tip collisions.

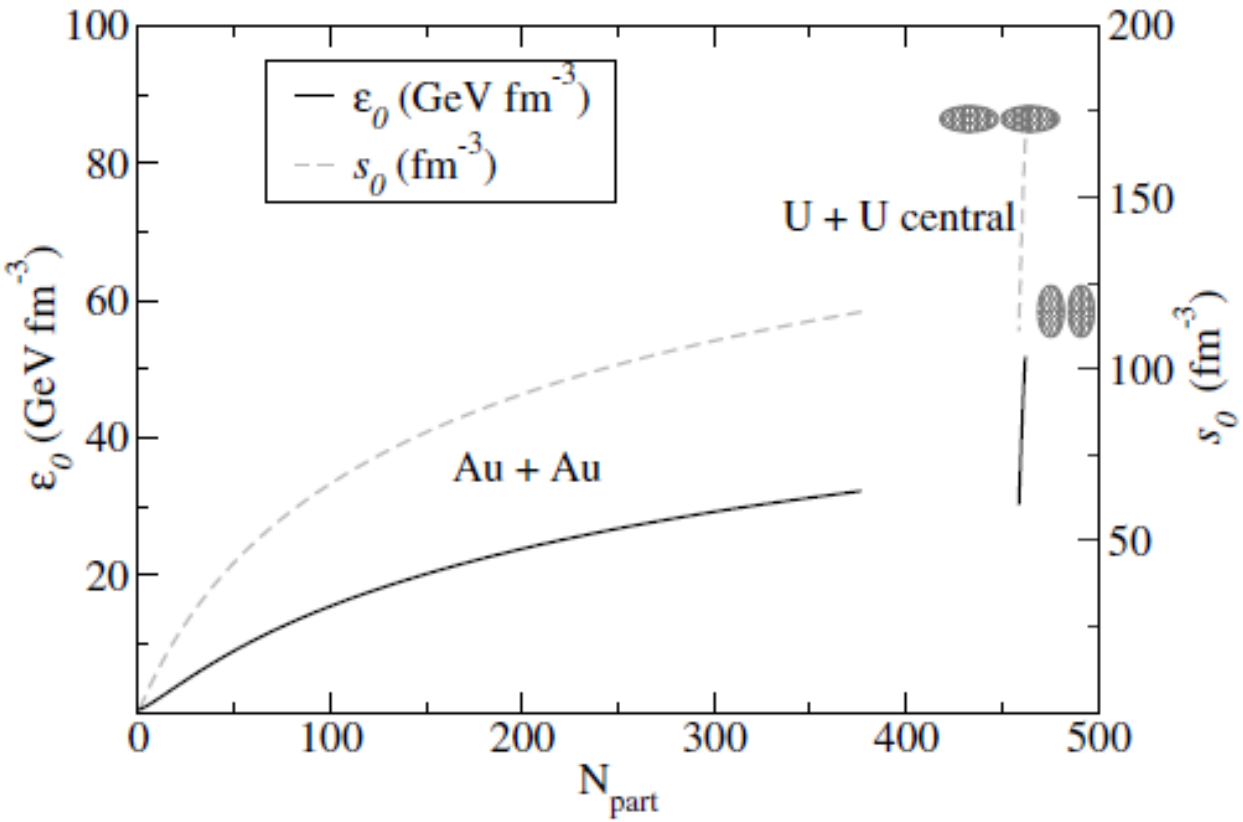
- Measuring v_2 for selected collision geometries can help us understand the effect of the initial geometry on v_2 and fluctuations. v_2 in central U+U collisions is expected to be higher than in central Au+Au collisions.

- The geometry can be exploited to study the path length dependence of energy loss (R_{AA}). The difference between out-of-plane and in-plane energy loss could be a factor of 2 larger than observed in Au+Au collisions.

- The magnetic field generated in tip-tip and body-body collisions is small, so signals for the chiral magnetic effect (CME) should disappear.

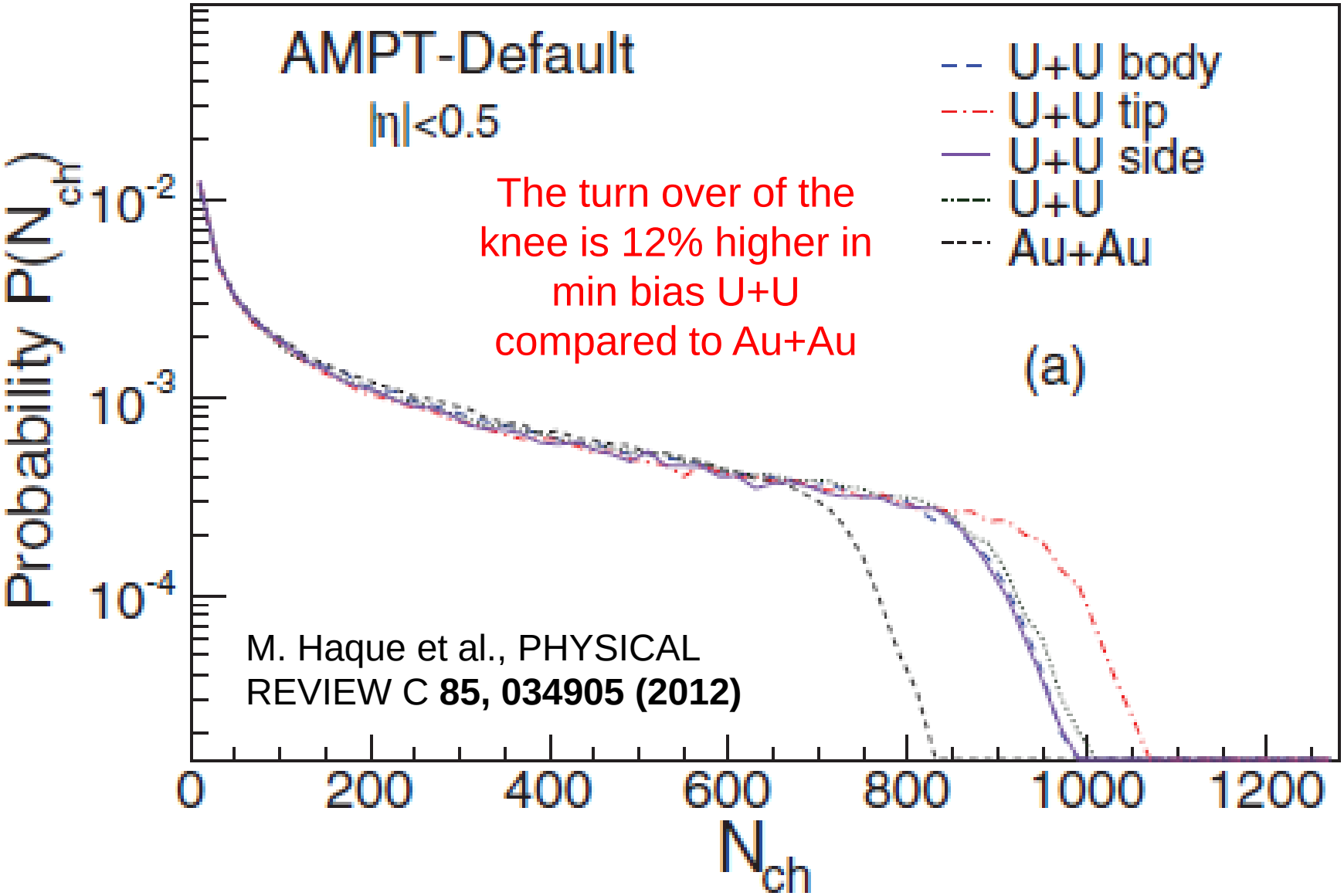
U+U Energy Density Expectations

There is an expected increase in the maximum peak energy density of 62% in tip-tip collisions compared to central Au+Au collisions.



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

AMPT Multiplicity predictions

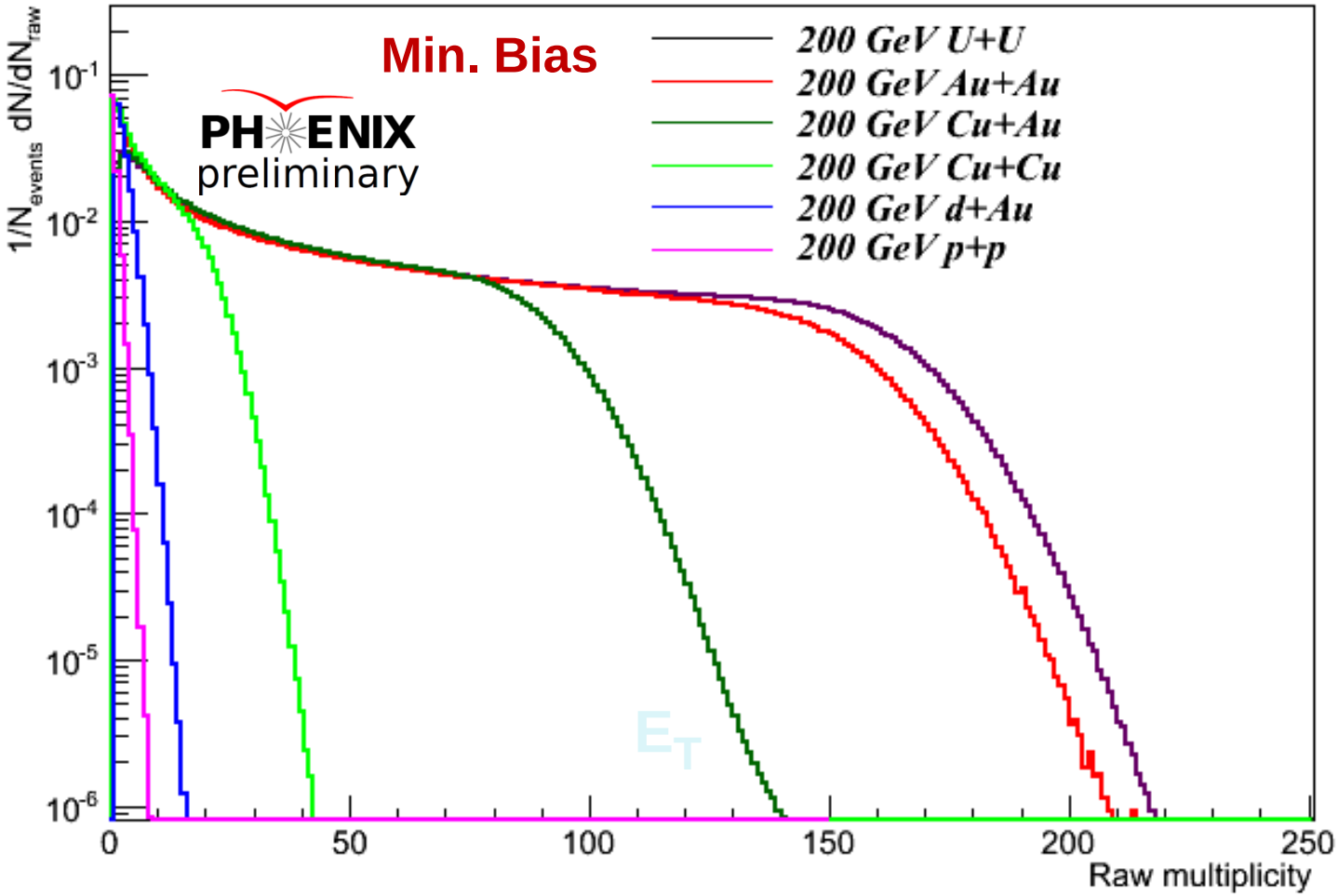


The turn over of the knee is 12% higher in min bias U+U compared to Au+Au

M. Haque et al., PHYSICAL REVIEW C **85, 034905 (2012)**

PHENIX Minimum Bias Multiplicity: U+U vs. Au+Au

PHENIX U+U dataset: 1.2 billion events in 2.9 weeks.

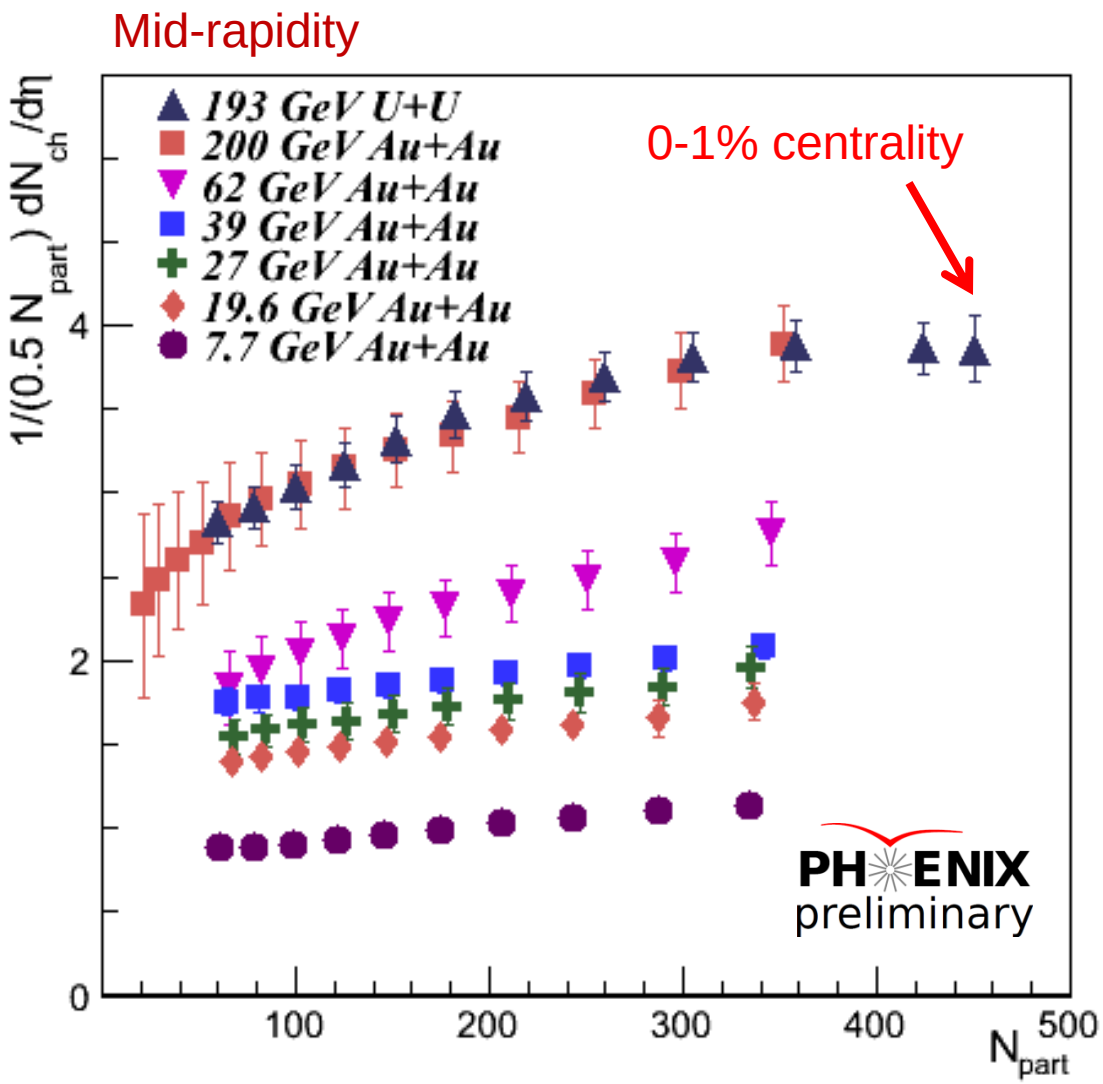


The turnover of the knee is ~13% higher in U+U than Au+Au.

These are all raw values. No corrections for acceptance, efficiency, etc. have been applied.

dN/dη: U+U vs. Au+Au

The 200 GeV Au+Au analysis is described in Phys. Rev. C71 (2005) 034908

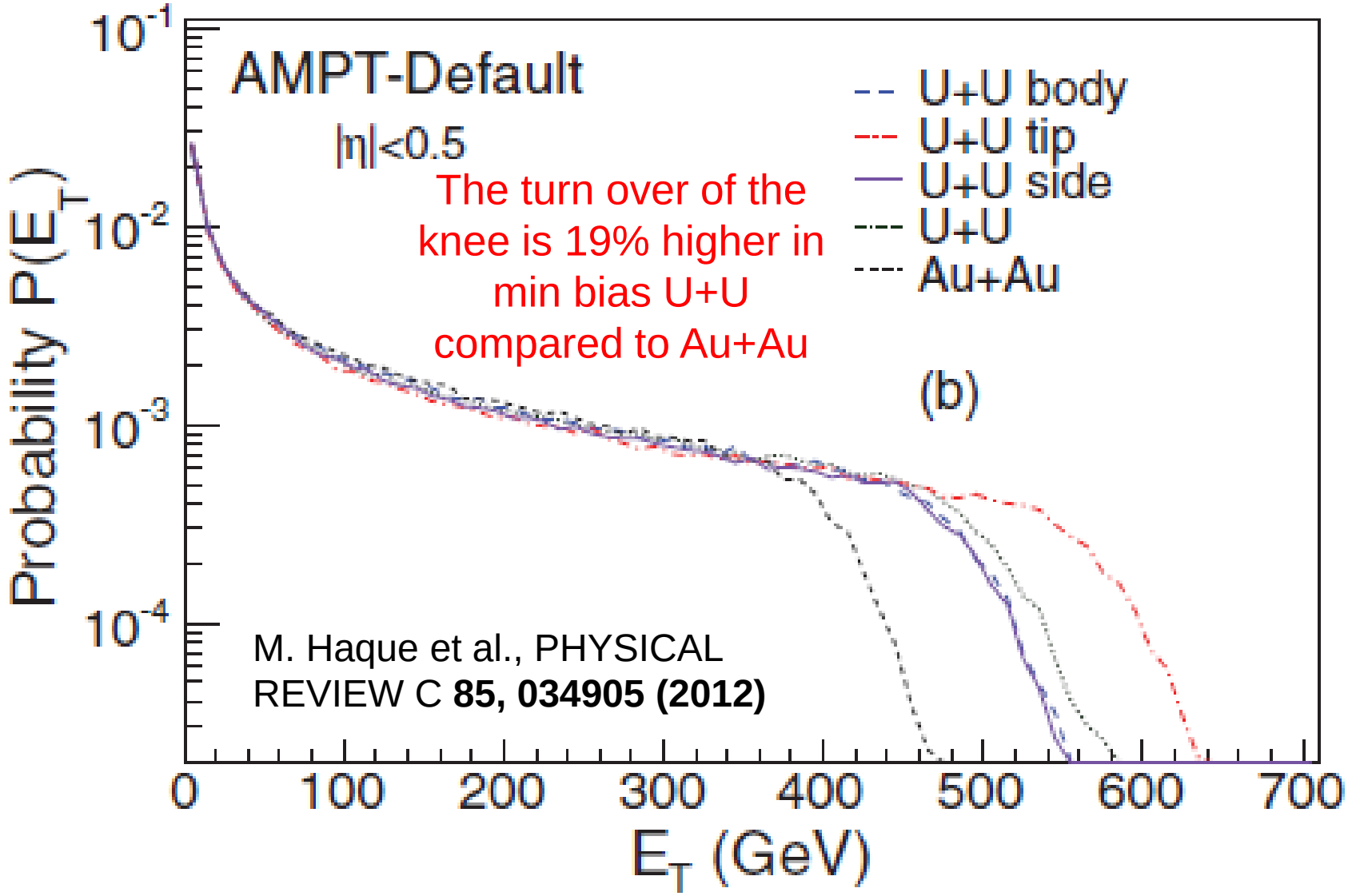


The Au+Au and U+U particle densities are similar.

There is an increase in particle density for more central collisions at all collision energies.

The particle density increases with increasing collision energy.

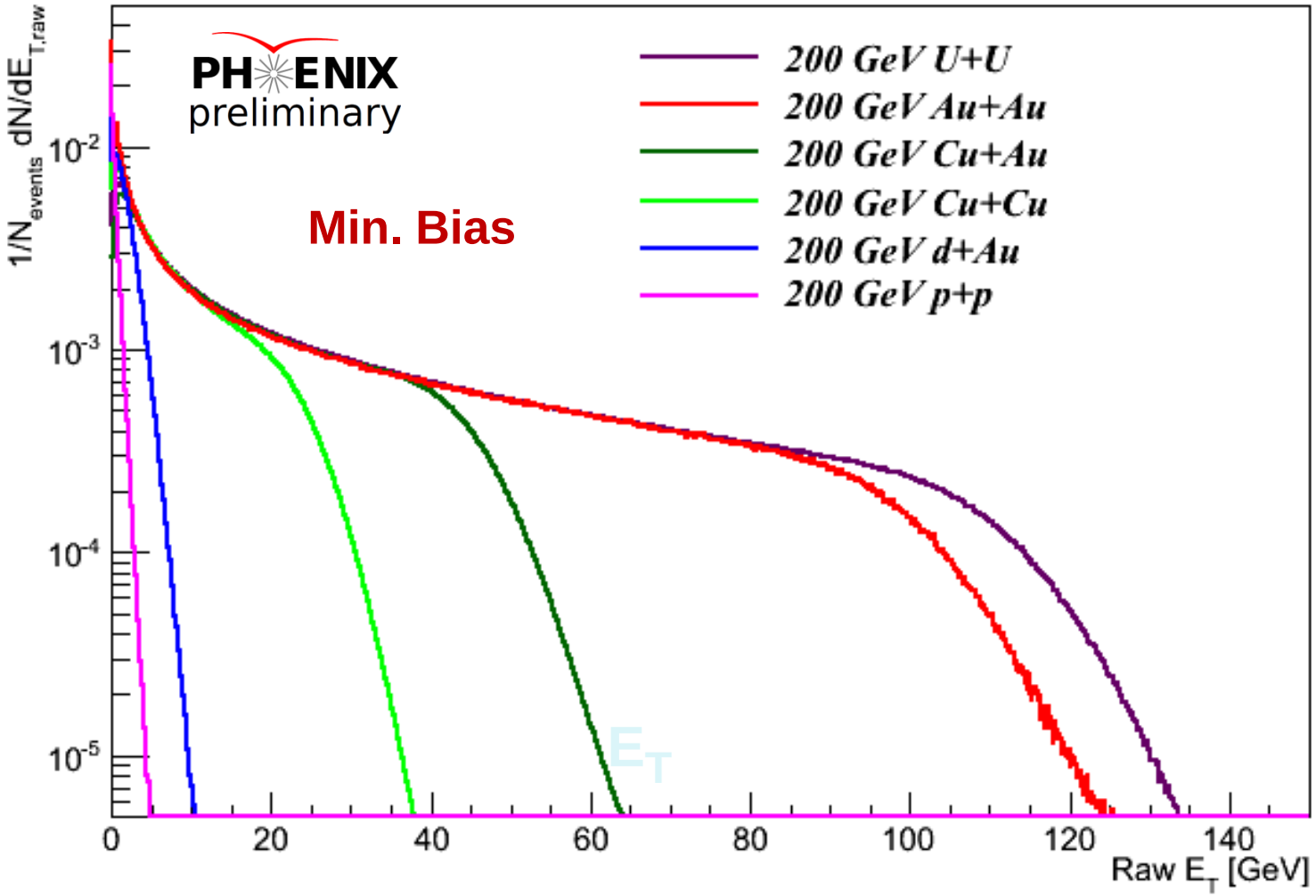
AMPT Multiplicity, E_T predictions



The turn over of the knee is 19% higher in min bias U+U compared to Au+Au

M. Haque et al., PHYSICAL REVIEW C **85, 034905 (2012)**

PHENIX Minimum Bias E_T: U+U vs. Au+Au

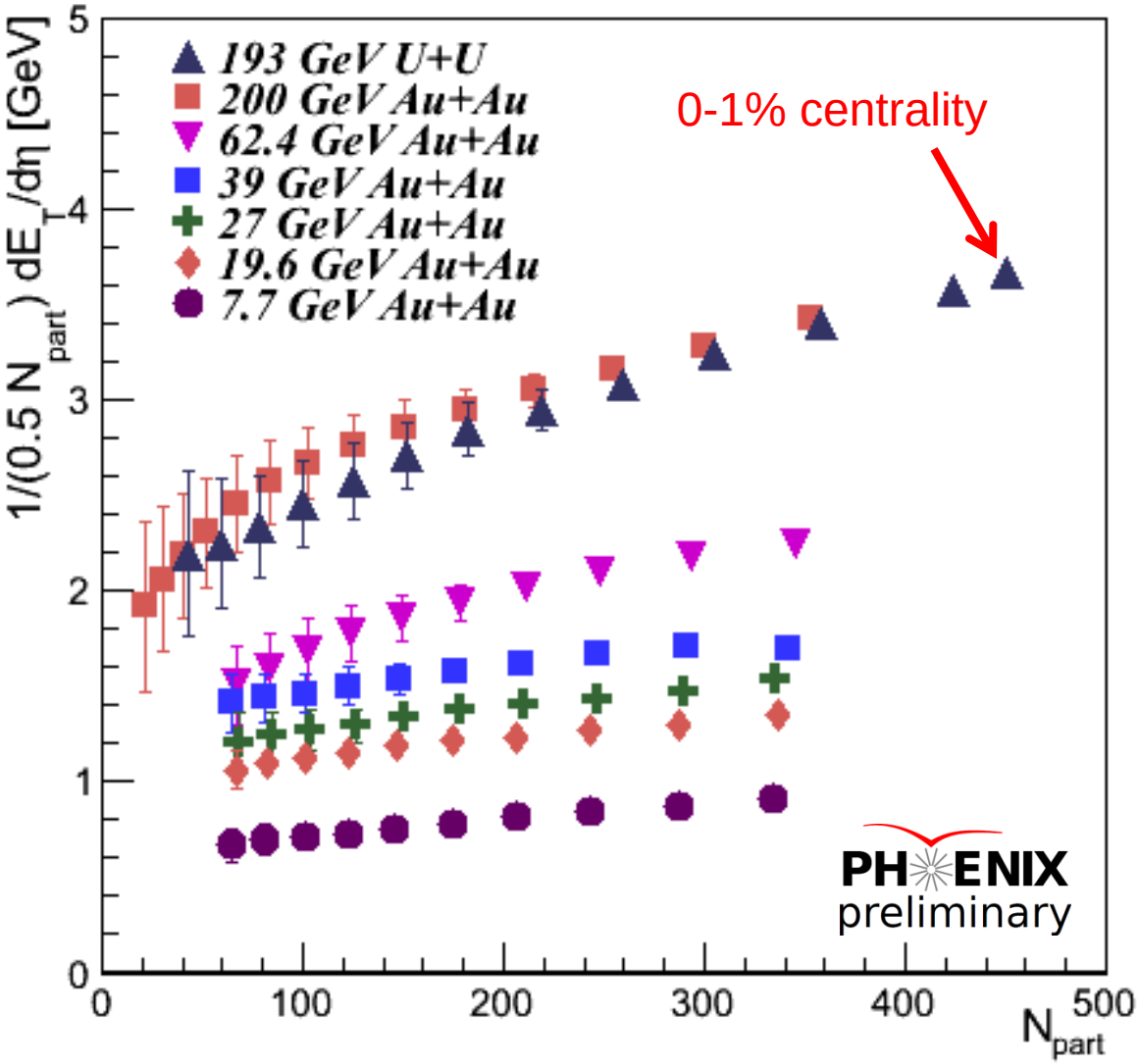


The turnover of the knee is ~21% higher in U+U than Au+Au.

These are all raw values. No corrections for acceptance, efficiency, etc. have been applied.

$dE_T/d\eta$: U+U vs. Au+Au

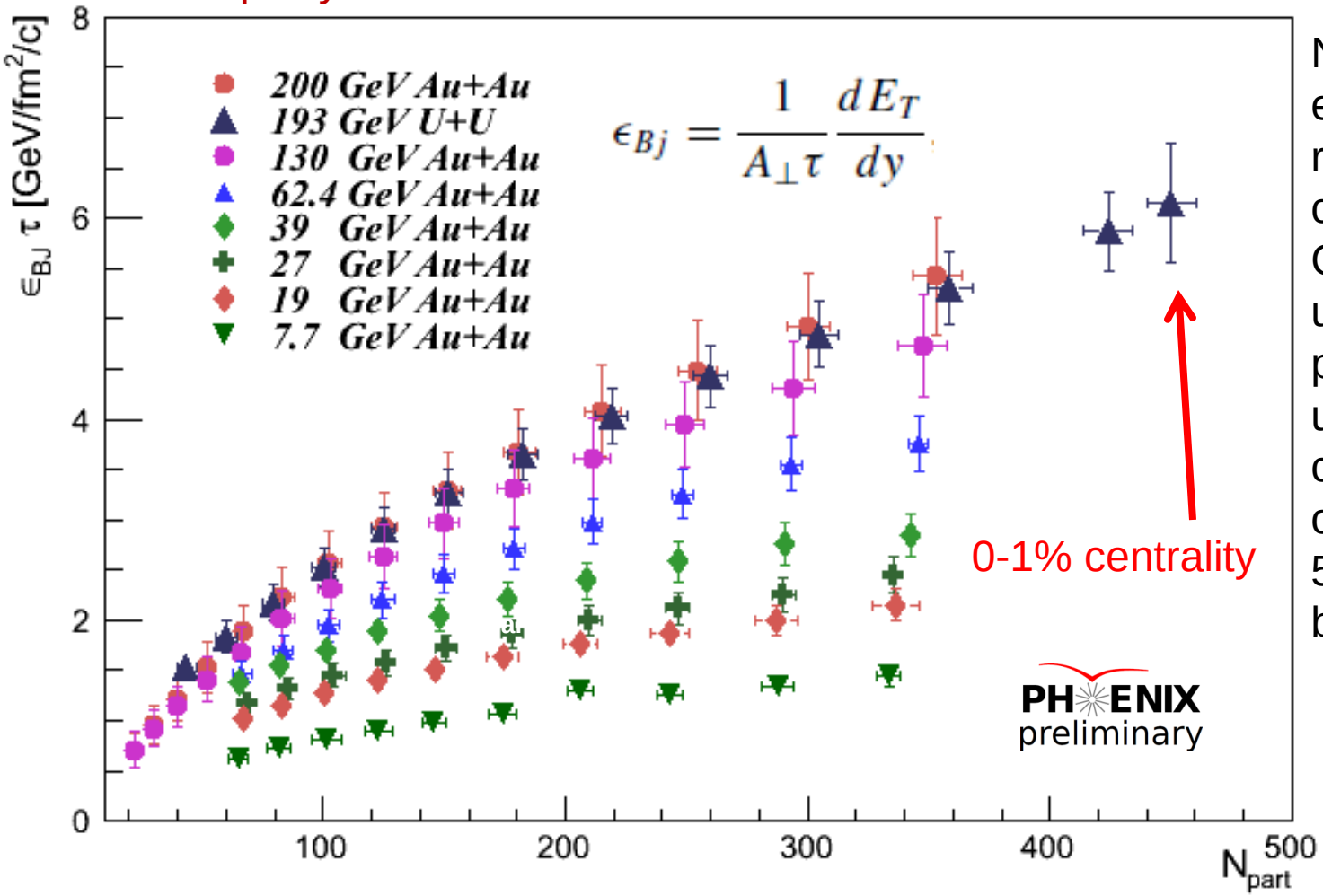
Mid-rapidity



- The energy density increases in central U+U collisions is higher than in central Au+Au collisions.
- There is an increase in transverse energy production for more central collisions at all collision energies.
- Transverse energy production increases with increasing collision energy.

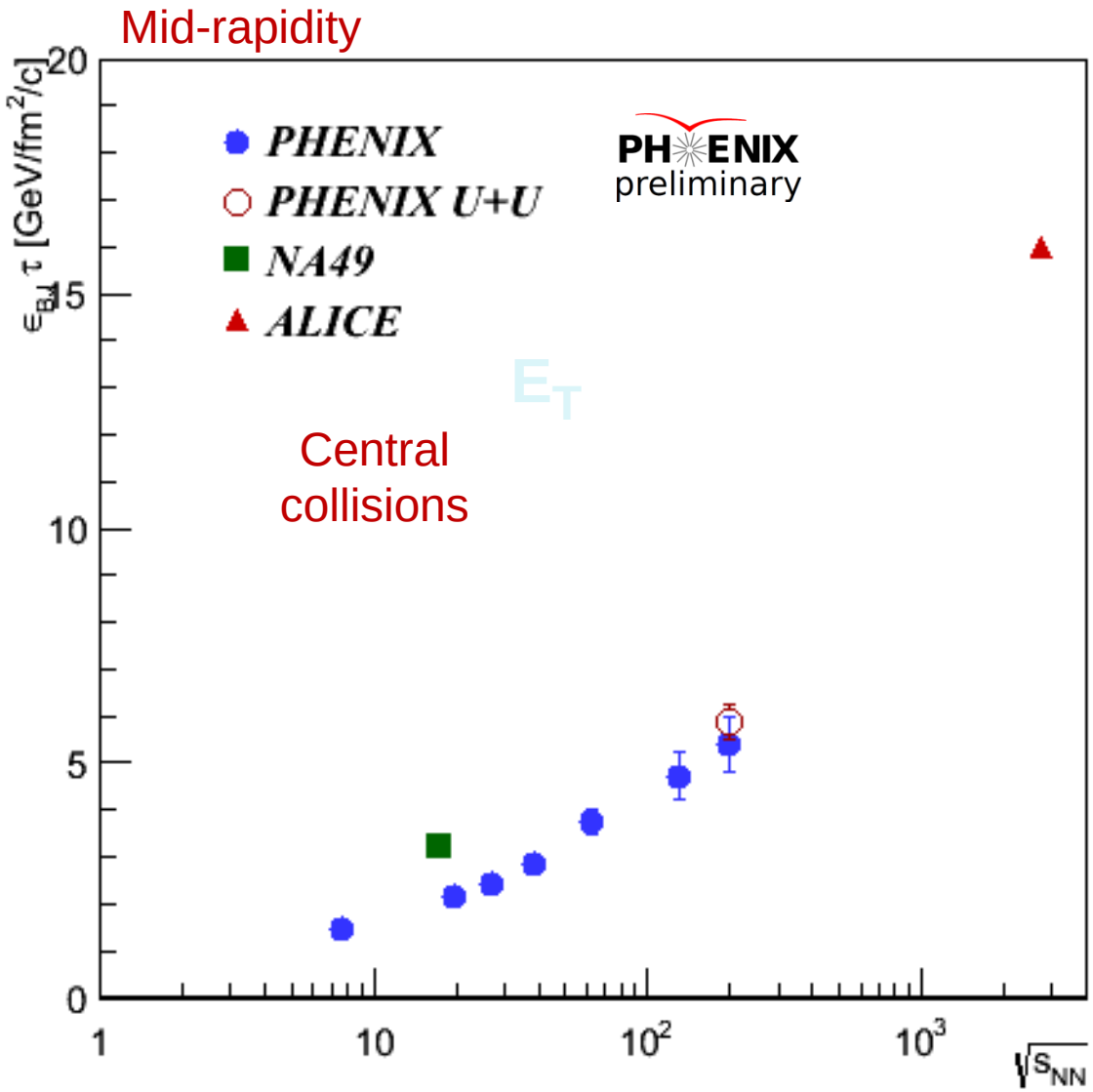
Bjorken Energy Density

Mid-rapidity



New RHIC energy density record in U+U collisions = 6.15 GeV/fm^2/c. The upper U+U point is for the upper 1% centrality bin. All other points are 5% centrality bins.

Bjorken Energy Density: Excitation Function

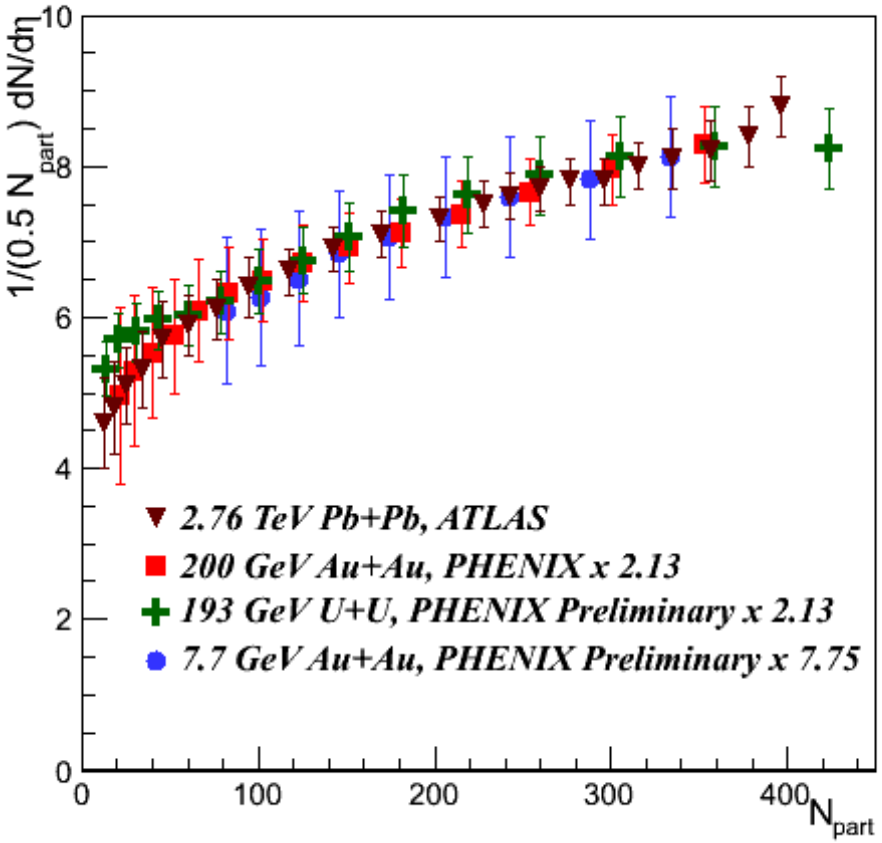


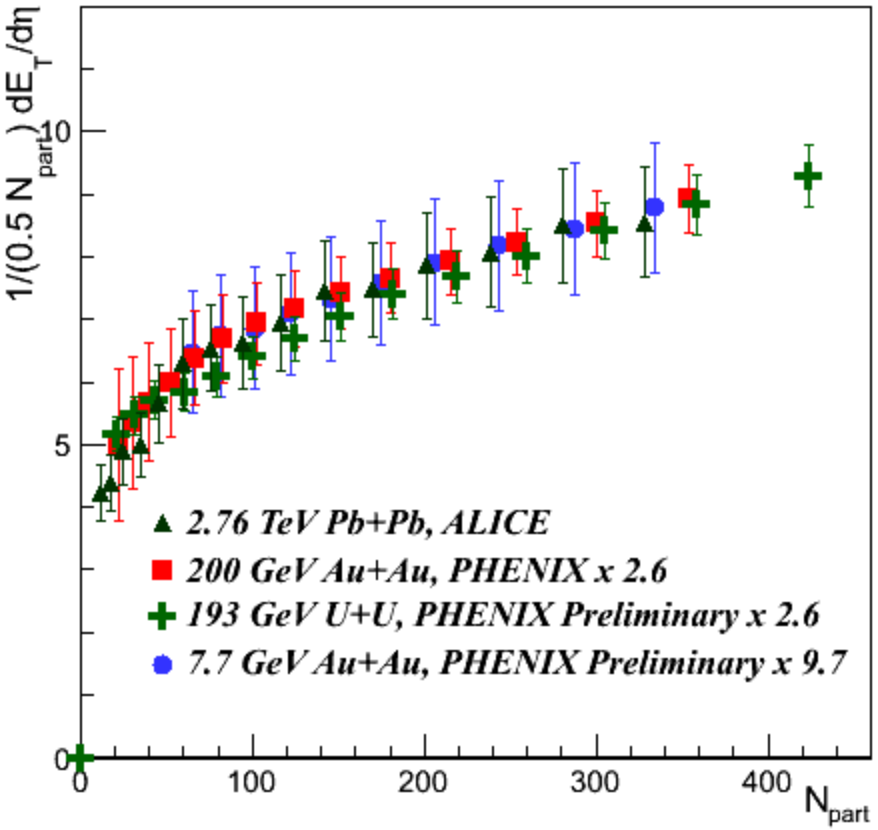
Monotonic behavior is observed in E_T production in 0-5% central Au+Au collisions below 200 GeV.

ε_{BJ} increases in Au+Au collisions by a factor of 11.1 when going from 7.7 GeV to 2.76 TeV.

ε_{BJ} increases in Au+Au collisions by a factor of 3.0 when going from 200 GeV to 2.76 TeV.

N_{part}-dependence of $dN/d\eta$, $dE_T/d\eta$

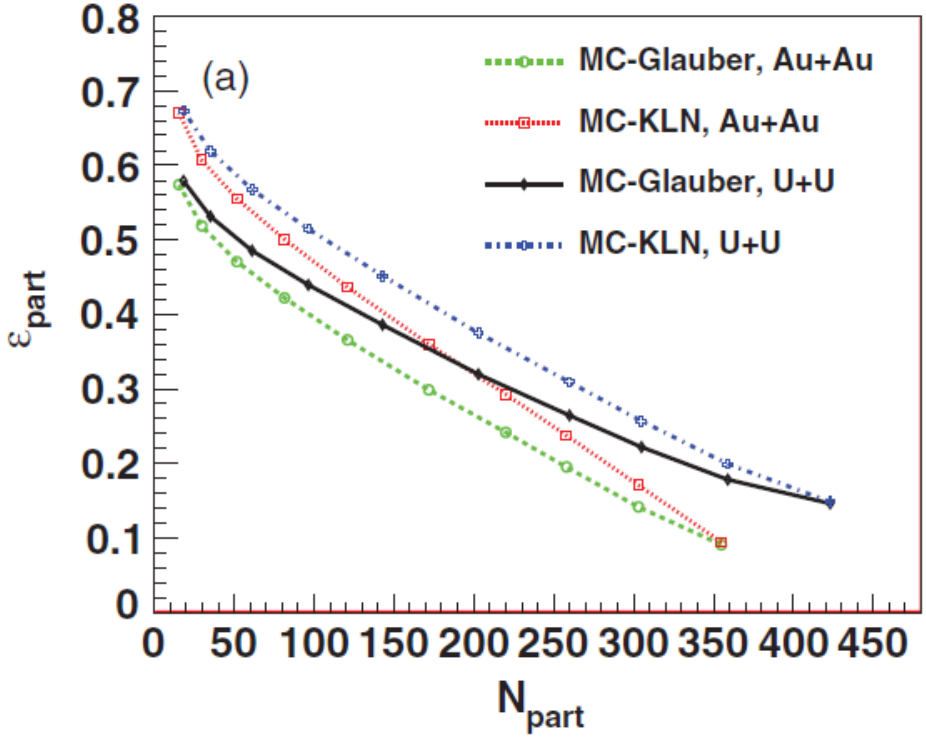


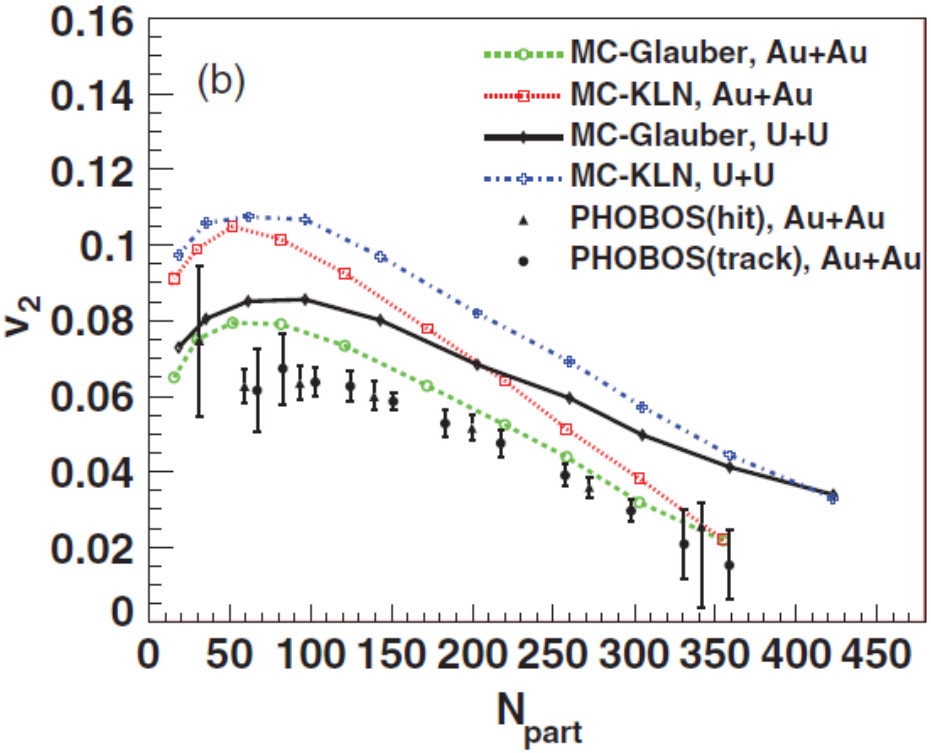


The shape of the centrality dependence in U+U collisions is consistent with Au+Au collisions. The shape is driven by geometry.

U+U Elliptic Flow Predictions

T. Hirano et al., Phys. Rev. C83, 021902(R) (2011)

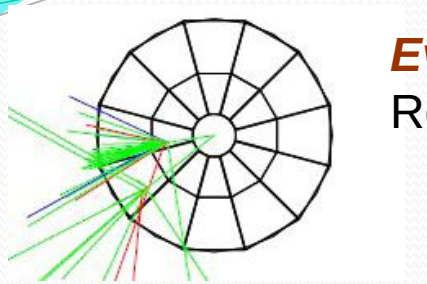




The initial participant eccentricity increases as a function of N_{part} in U+U compared to Au+Au collisions…

v_2 is expected to increase in U+U vs. Au+Au at all centralities.

Measuring the Event Plane in PHENIX

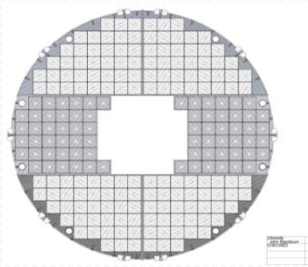


***Event plane detectors*:**

Reaction plane detector

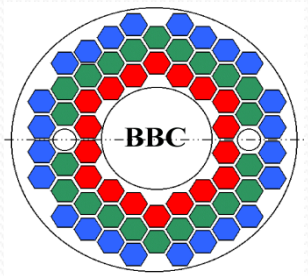
RXN_{IN} (1.5<|η|<2.8)

RXN_{OUT} (1.0<|η|<1.5)



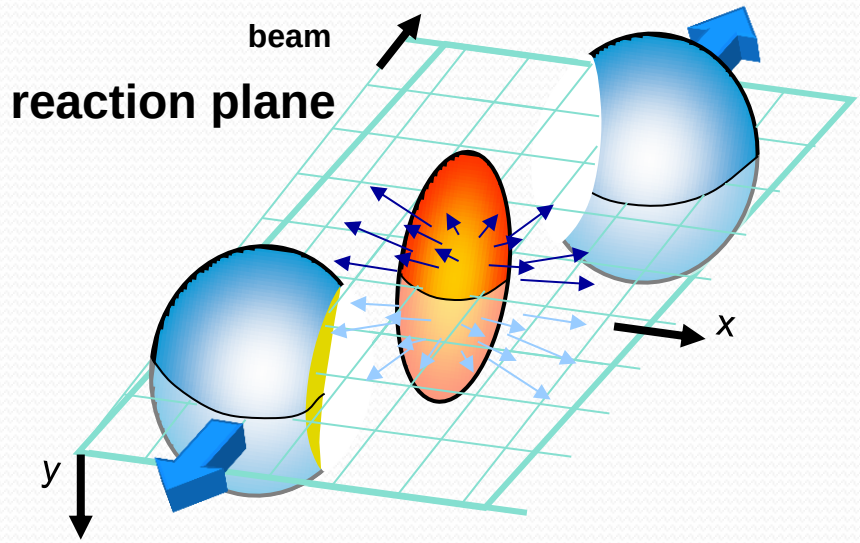
Muon piston Calorimeter

MPC (3.1<|η|<3.9)

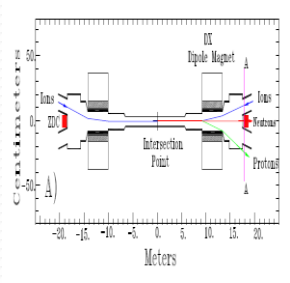


Beam-beam counter

BBC (3.1<|η|<3.9)



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



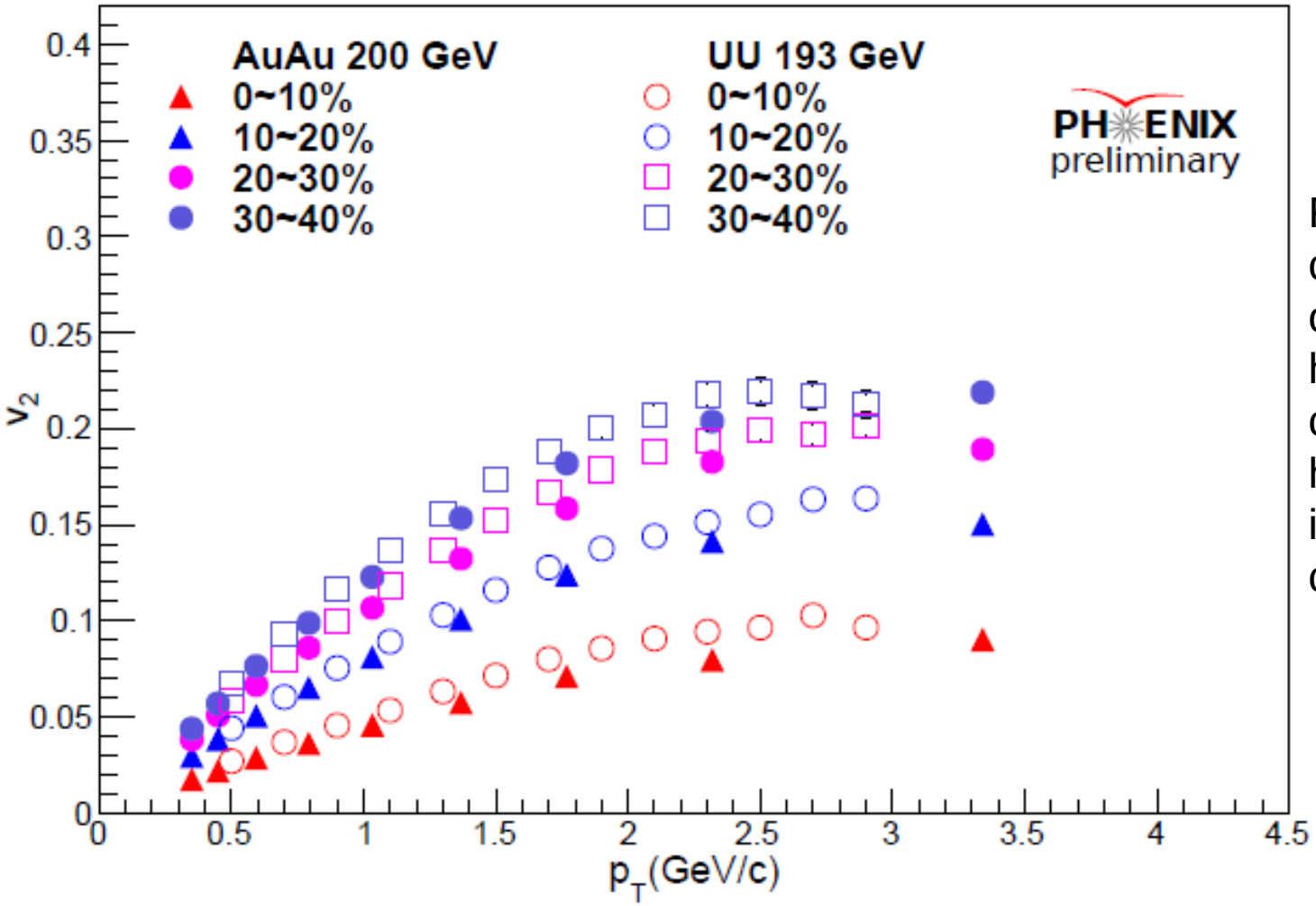
Zero Degree Calorimeters(**ZDC**)

Shower Max Detectors(**SMD**)

ZDC-SMD (|η|>6.5)

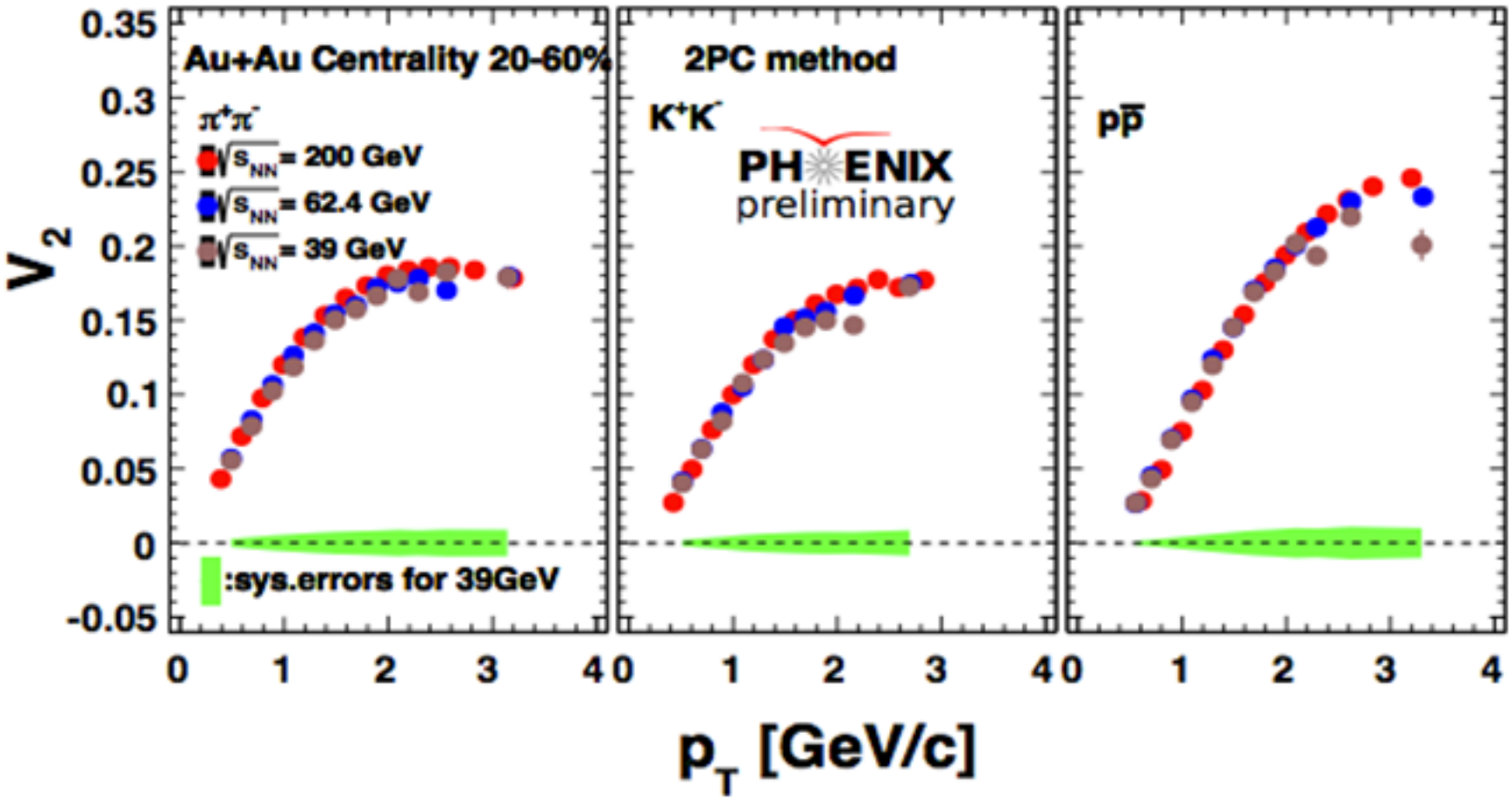
Ψ_1 by spectator

Elliptic Flow: U + U vs Au+Au



For a given centrality, the v_2 of charged hadrons in U+U collisions is higher than that in Au+Au collisions.

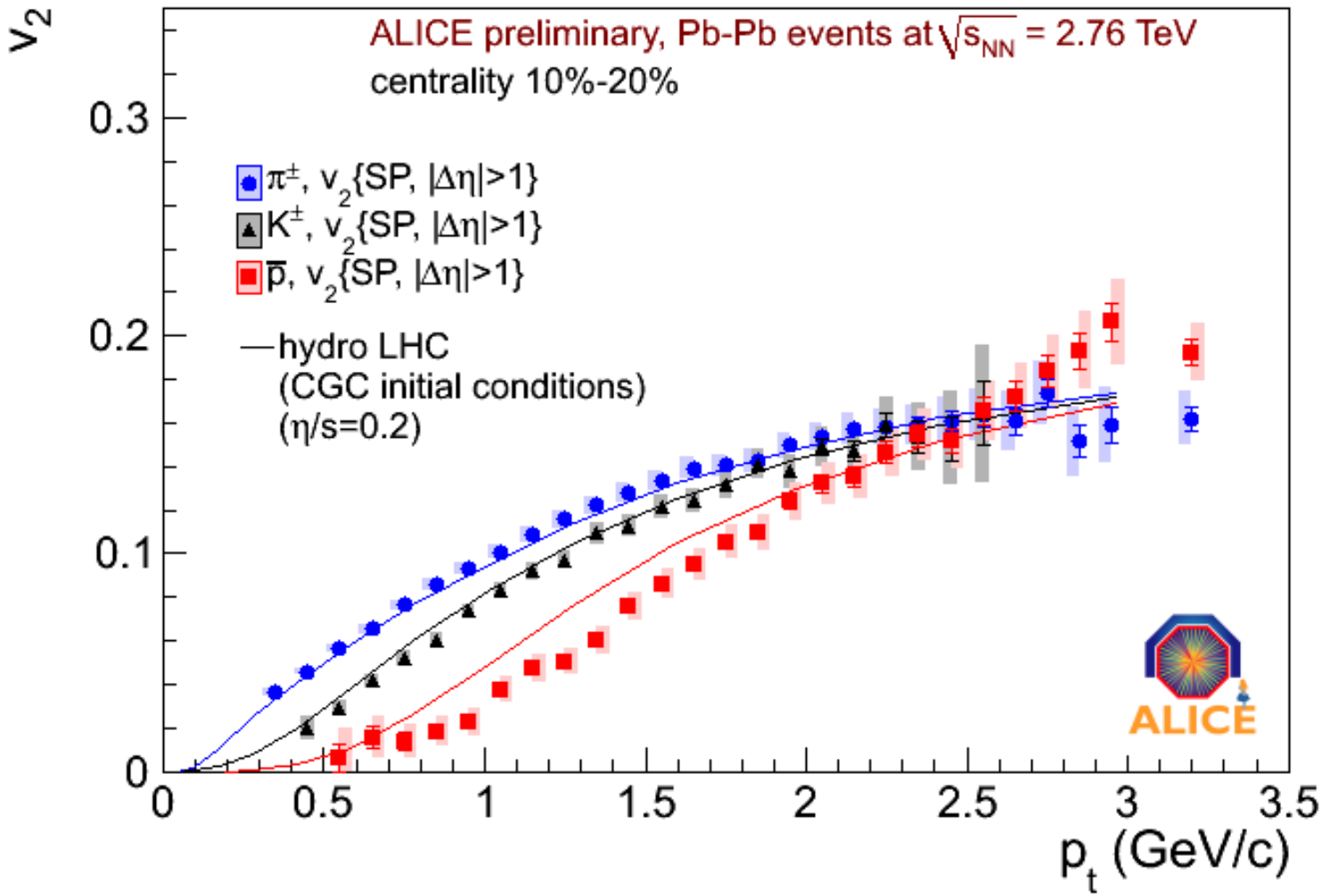
Identified Particle v_2: Au+Au



The pion, proton, and kaon v_2 measurements change very little as a function of sqrt(s_{NN}) from 39 GeV to 200 GeV. The energy density increases by a factor of 2 over this range.

Identified Particle v_2: LHC Results

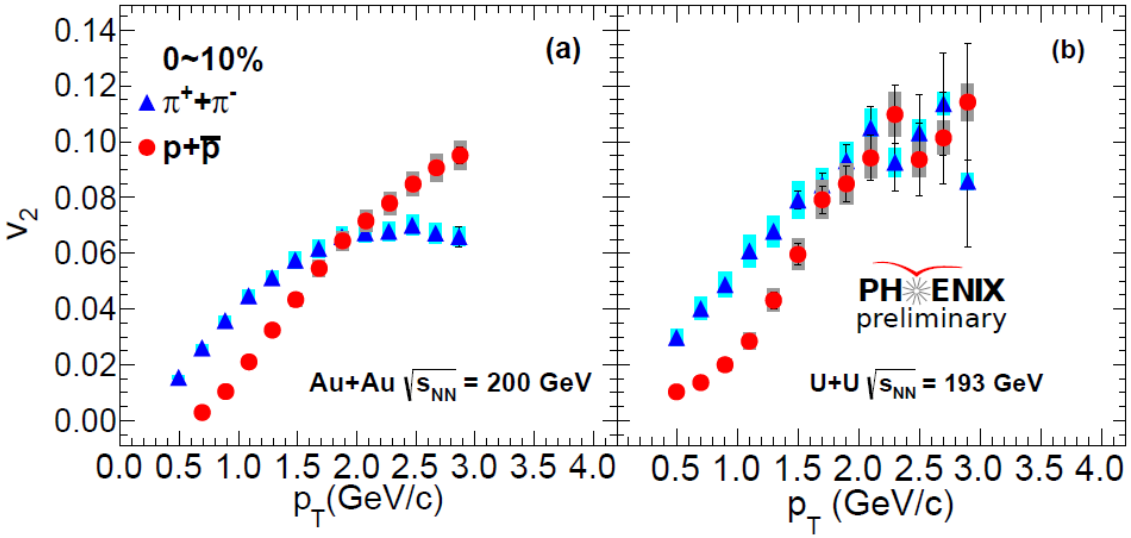
M. Krzewicki@ALICE QM2011

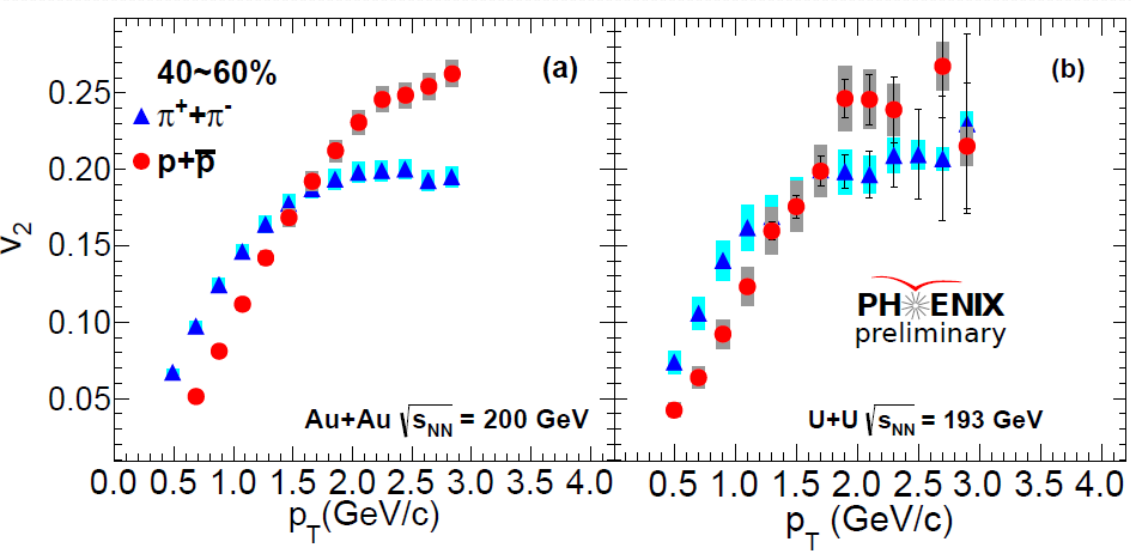


A strong mass ordering of the v_2 of identified particles is observed in 2.76 TeV Pb+Pb collisions. The energy density is 3 times larger than in 200 GeV Au+Au collisions.

Identified Particle v_2: U+U Collisions

10% of full statistics

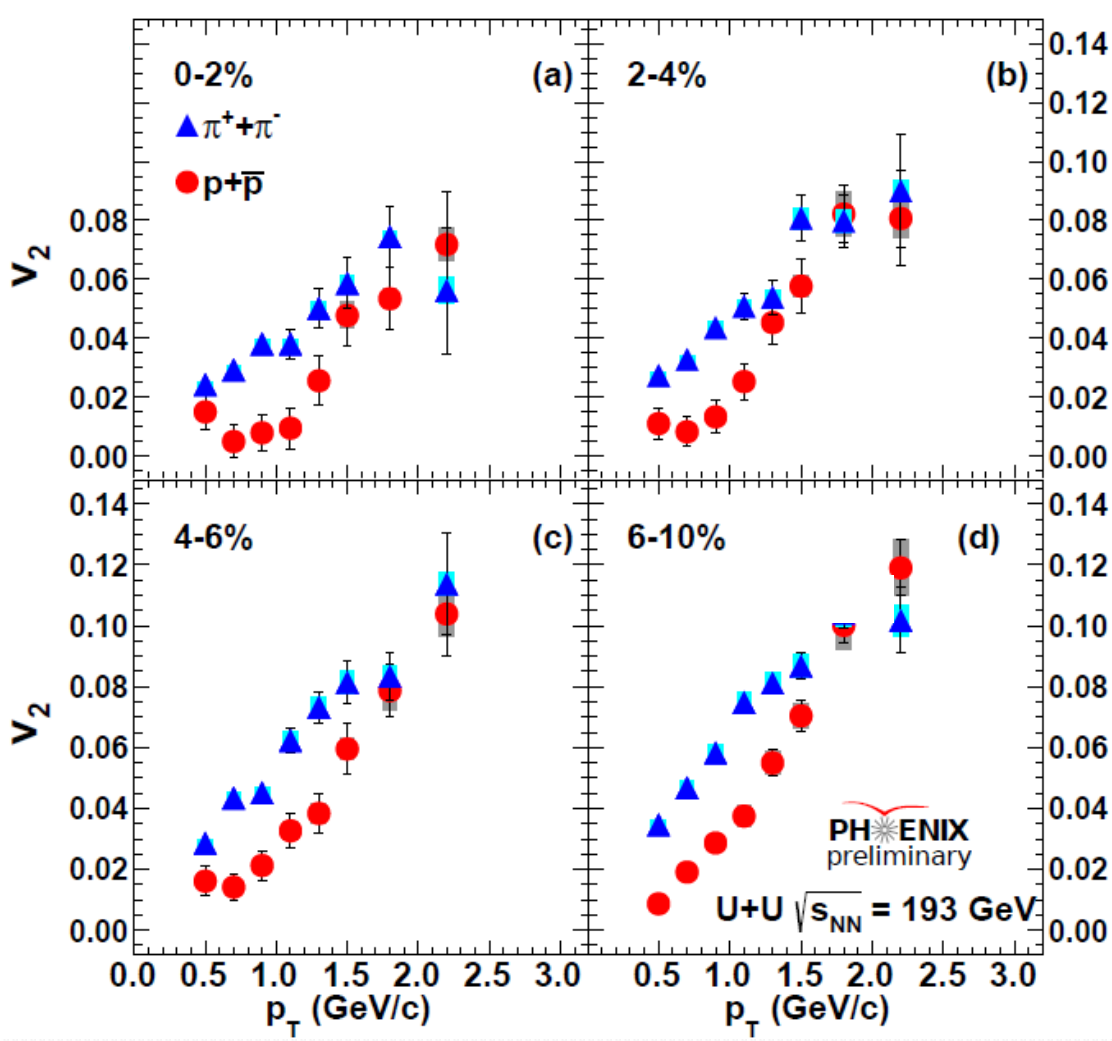




There is a slight difference observed in the slope of the proton v_2 in U+U compared to Au+Au collisions at 200 GeV.

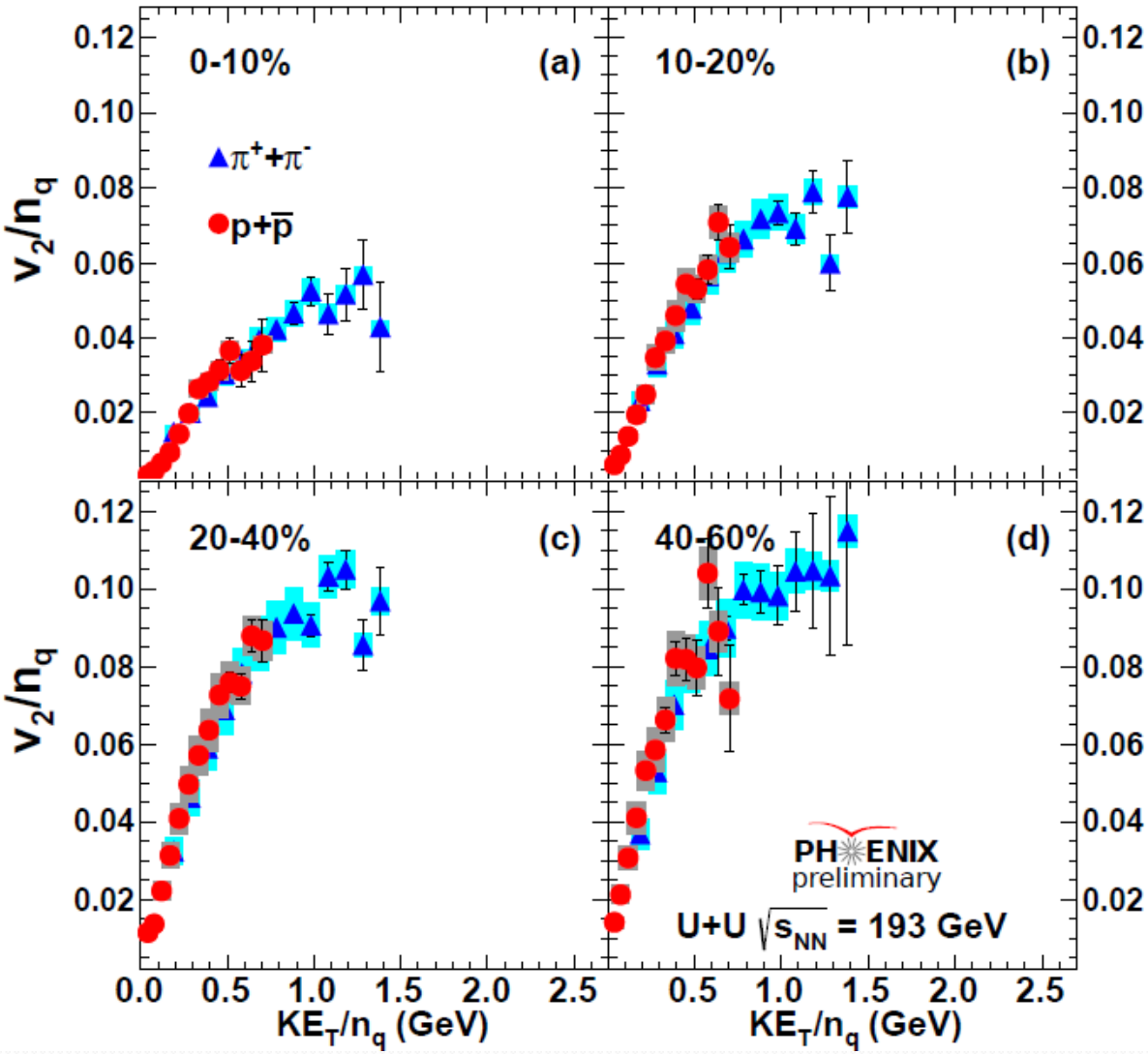
This behavior disappears in peripheral collisions.

v_2 in Central U+U Collisions



- A stronger separation in the pion and proton v_2 is observed when selecting 0-2% central U+U collisions.

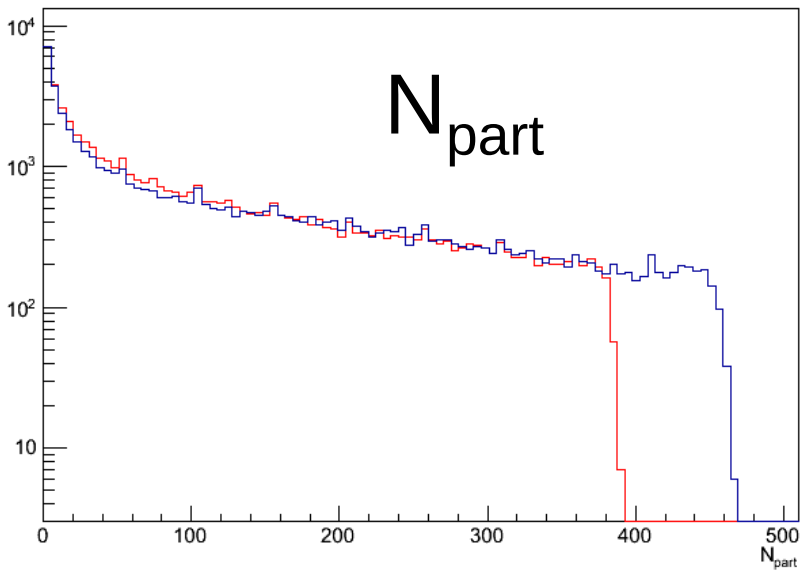
Constituent Quark Scaling of v_2 in U+U Collisions

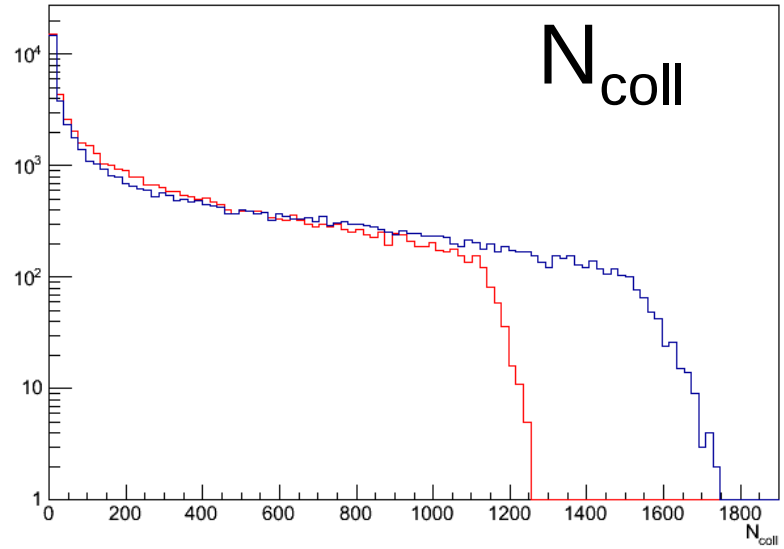


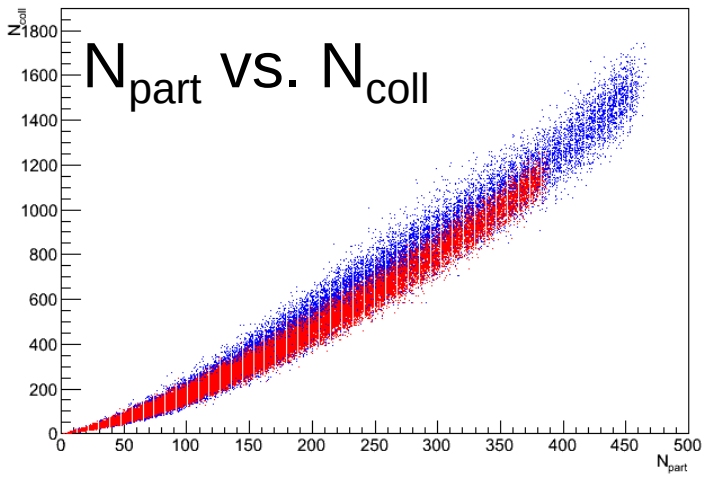
- Constituent quark scaling holds in 193 GeV U+U collisions for pions and protons.
- Currently working on v_2 measurements of pions for p_T<0.5 GeV/c.

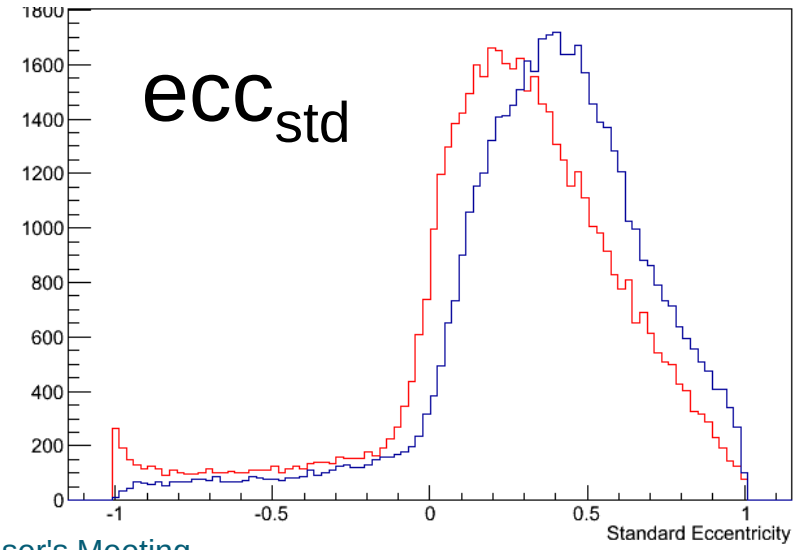
Glauber model results: U+U vs. Au+Au

Red: Au+Au **Blue: U+U**

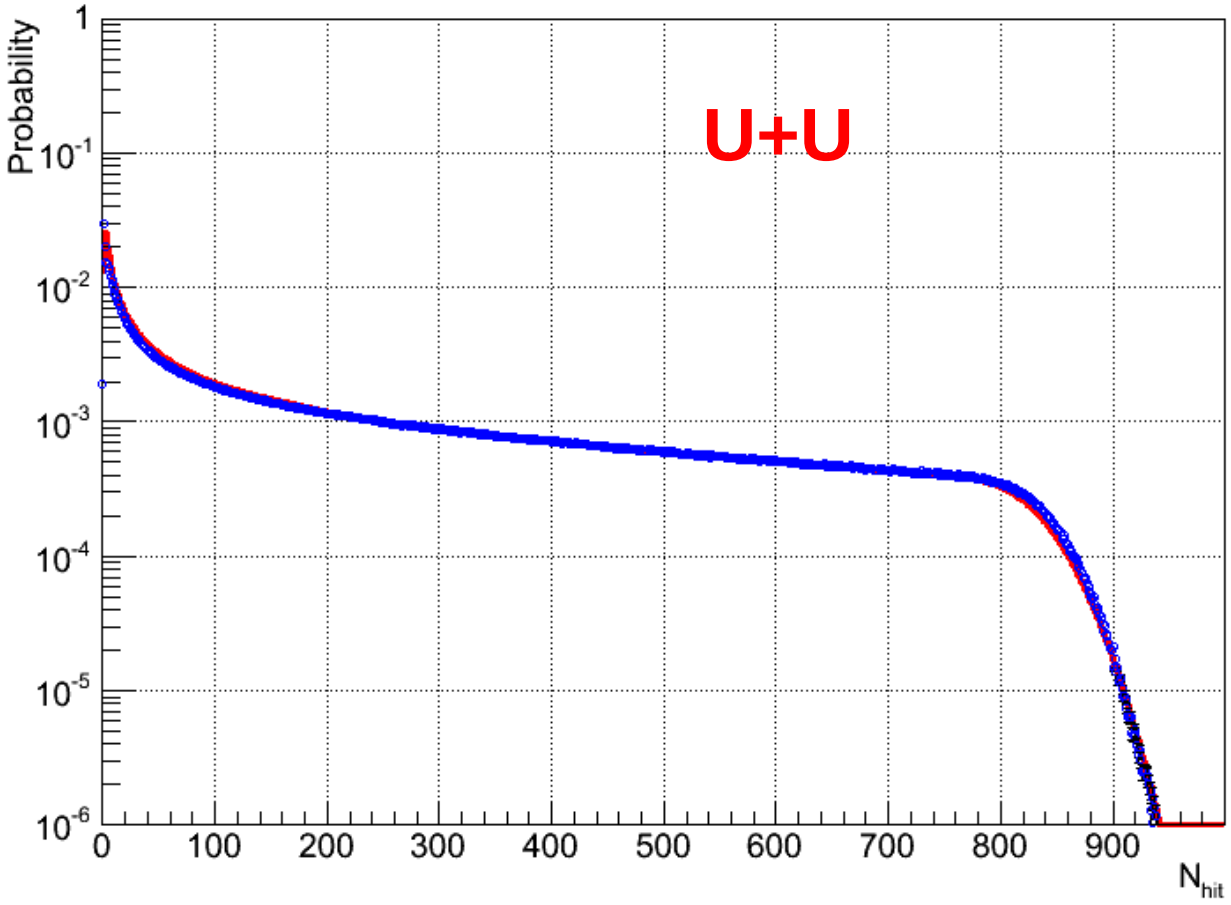






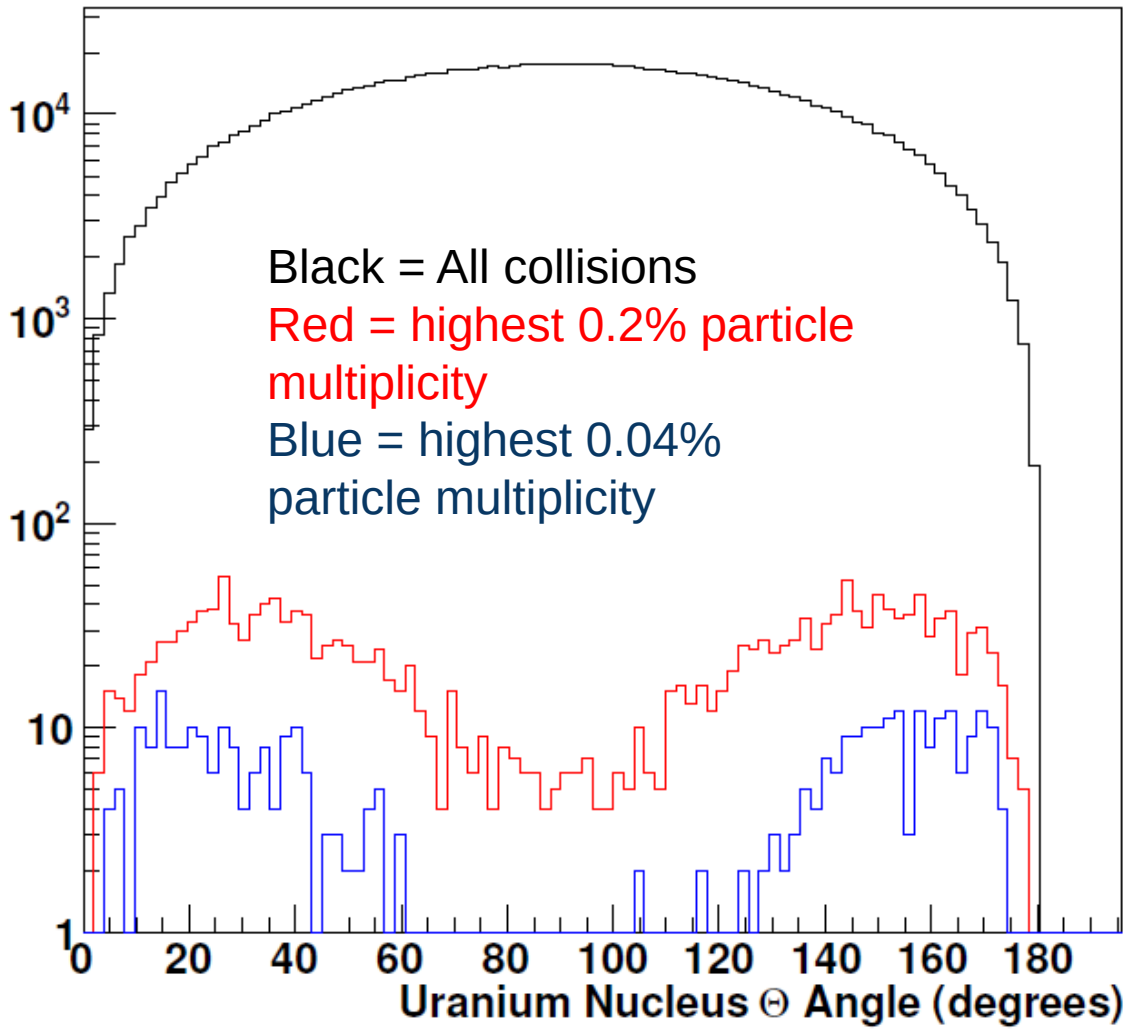


Can Geometry be Selected Using N_{part} alone?



- Centrality in PHENIX is determined with the total charge distribution from the BBC (blue).
- The red curve is a negative binomial distribution fit folded by N_{part}.
- The negative binomial distribution fit describes the data very well.
- There is no evidence of a tail due to varied geometry beyond the knee.

U+U geometry selection vs. particle multiplicity

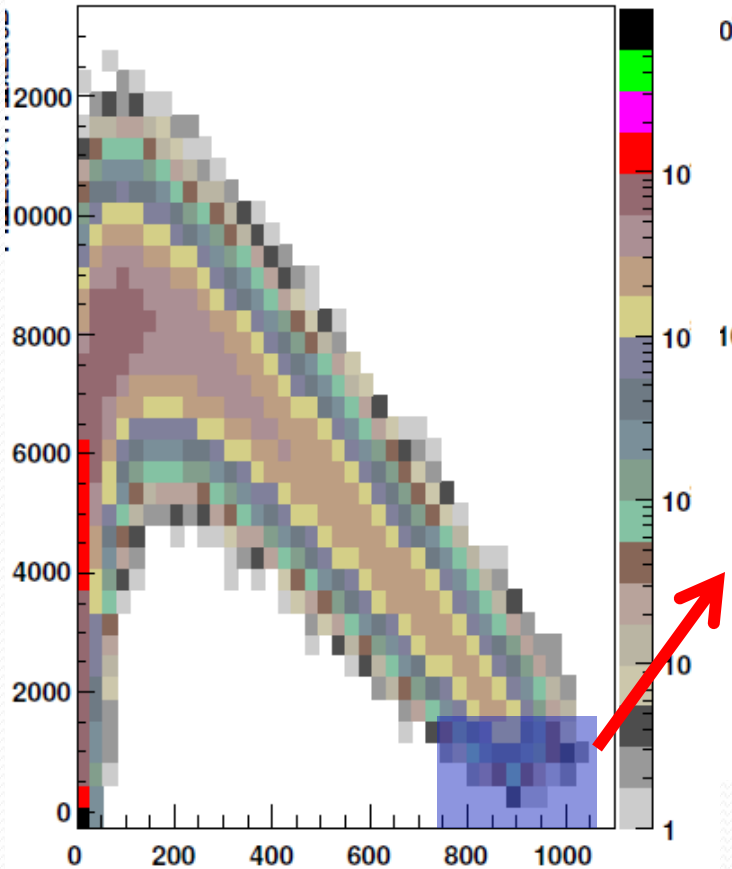


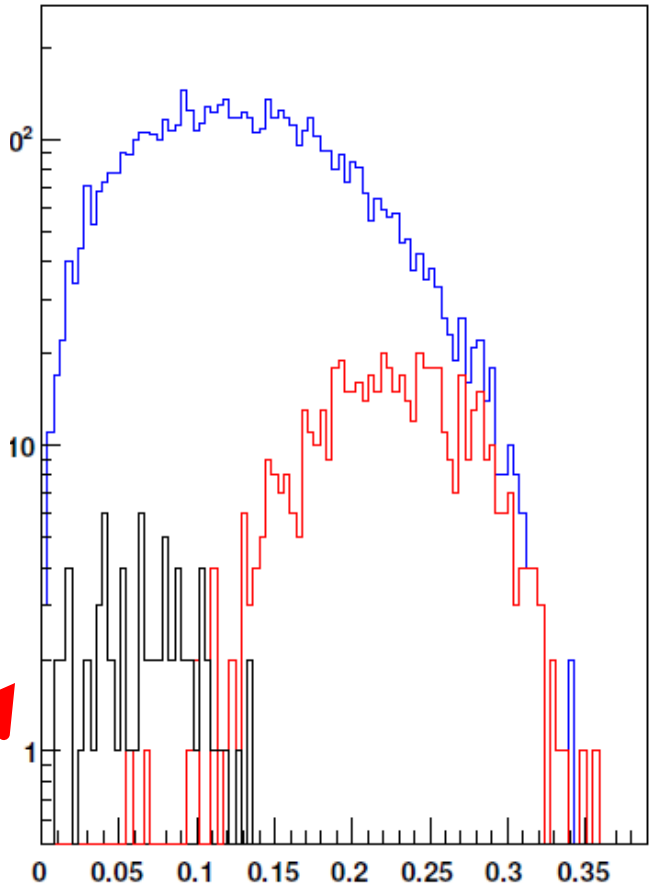
- This plot is the result of a Glauber Monte Carlo with the deformed geometry implemented.

- Cutting very hard into the multiplicity distribution is necessary before enrichment of the tip-tip geometry becomes apparent.

U+U geometry selection with the Zero Degree Calorimeters

Model of ZDC energy vs. charged particle multiplicity. Selecting top 0.6% centrality (blue box).





Participant Eccentricity

- The upper 0.6% central collisions are selected. All selected events have b<2 fm.

- Blue = ε_{part} for all 0.6% central collisions.
- Red = ε_{part} within 30° of body-body.
- Black = ε_{part} within 30° of tip-tip.

- It may be possible to use v_2 to select the geometry.

Summary

- PHENIX has recorded a significant U+U dataset.

- A new record for energy density achieved in RHIC collisions has been achieved.

- v_2 in U+U collisions is systematically higher than in Au+Au collisions for all centralities, as expected.

- A stronger separation in pion and proton v_2 is seen in central U+U collisions compared to Au+Au collisions.

- Constituent quark scaling holds in U+U collisions.

- It may be possible to select tip-tip configurations using a combination of charged particle multiplicity, ZDC energy, and v_2. This analysis is underway.