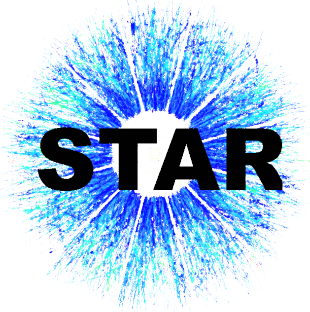


BROOKHAVEN NATIONAL LABORATORY

Flow measurements and selection of body-body and tip-tip enhanced samples in U+U collisions at STAR

Hui Wang (for STAR Collaboration)

Brookhaven National Lab

Office of Science
U.S. Department of Energy

Outline

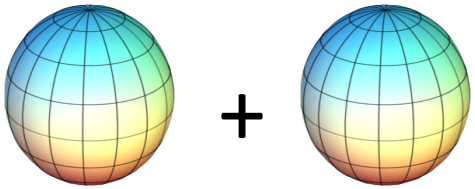
- Motivation
- STAR detector and data set
- Azimuthal anisotropy in U+U collisions
- Selection of body-body and tip-tip enhanced samples
- Summary

Motivation for U+U Collisions

Allows us to manipulate the initial geometry and study:

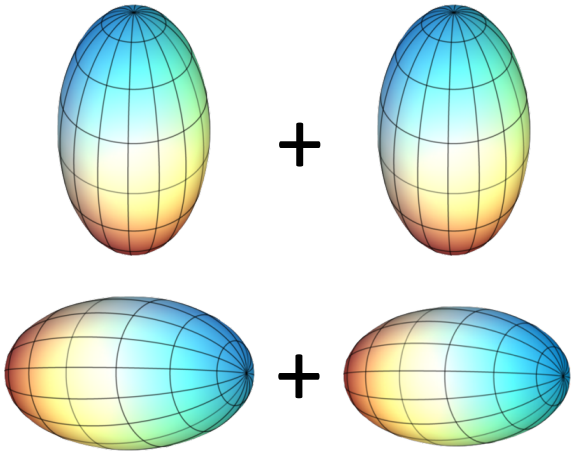
- How multiplicity depends on N_{part} and N_{coll}
- Path-length dependence of jet quenching
- Particle production in heavy-ion collisions
- Other effects

Au+Au Collisions



Oblate

U+U Collisions

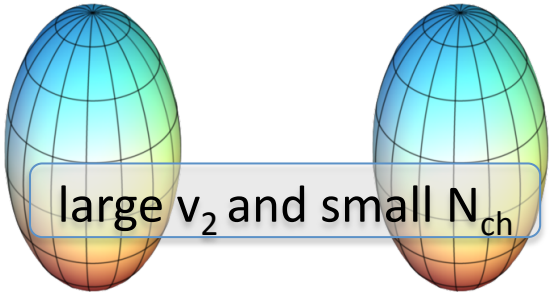


Prolate

Can we see a difference between Au+Au and U+U and preferentially select body-body or tip-tip U+U collisions?

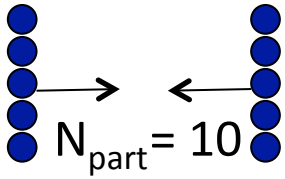
Selecting Body-body or Tip-tip

In two-component model, multiplicity depends on the N_{part} and N_{coll} and since v_2 is propotional to initial eccentricity

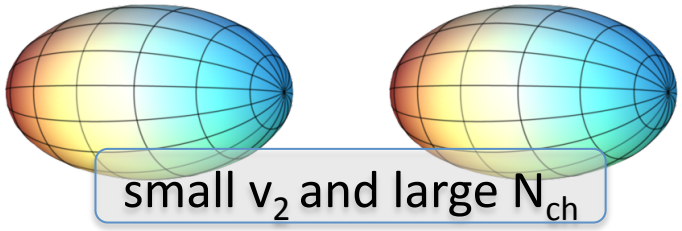


fully overlapping

$$n_{AA} \propto n_{pp}[(1-x_{hard})\frac{N_{part}}{2} + x_{hard}N_{coll}]$$



*idealizations

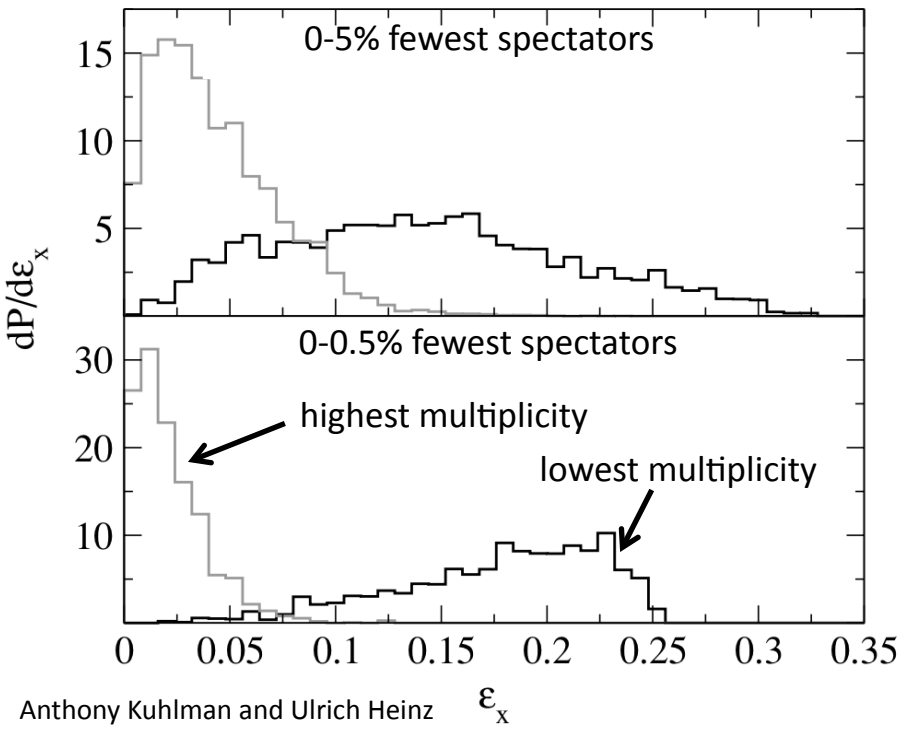


If dN/dη depends on N_{coll}, large dN/dη should correlate with small v_2.

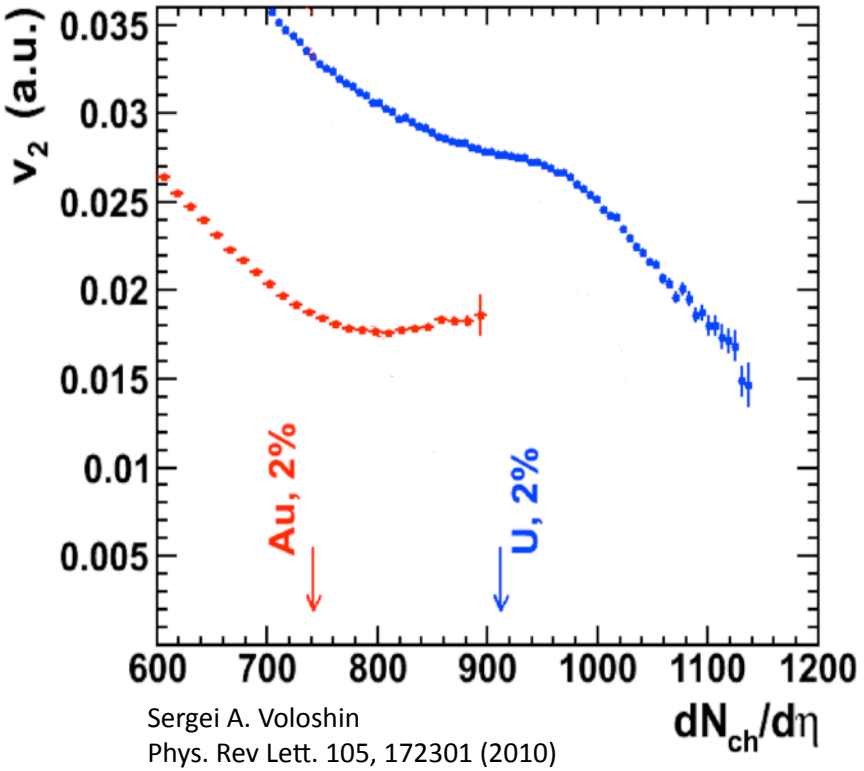
➪ *Central U+U collisions are ideal for testing particle production*

Strategy: select events with few spectators (fully over-lapping), then measure v_2 vs. multiplicity: **how strong is the correlation?**

Expectations from Models



Anthony Kuhlman and Ulrich Heinz
Phys. Rev. C 72, 037901 (2005)



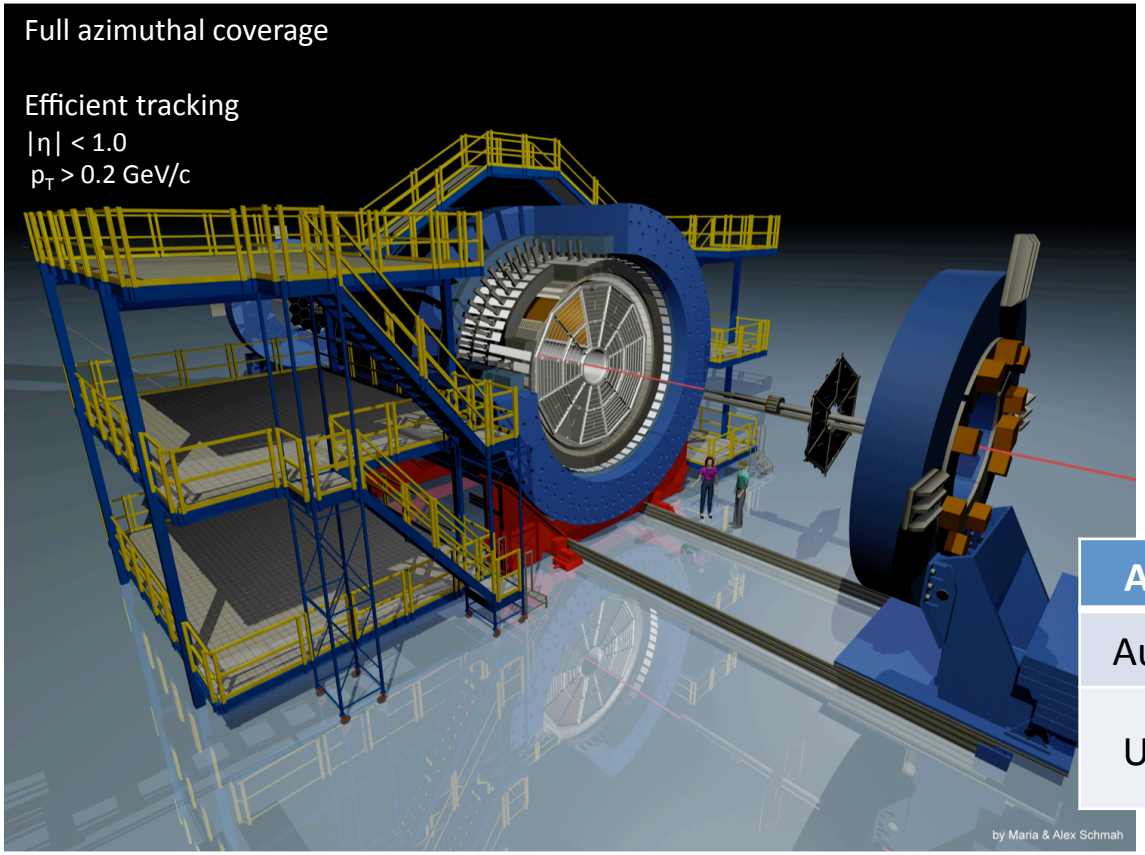
Sergei A. Voloshin
Phys. Rev Lett. 105, 172301 (2010)

Simulations show that after selecting most fully overlapping collisions,

- high multiplicity events correlate with small eccentricity (tip-tip)
- lower multiplicity with large eccentricity (body-body)

The correlation of tip-tip collisions with high multiplicity *and* small eccentricity leads to a kink in v_2 at high dN/dη

STAR Detector and Data Set



- U+U data collected in a 3 week exploratory run
- ZDCs counting spectator neutrons used to select central collisions

A	$\sqrt{s_{NN}}$ GeV	Year	Events (x10^6)
Au	200	2011	700 (mini-bias)
U	193	2012	360 (mini-bias) 13 (central 1% ZDC)

We've measured the v_1 using event plane method

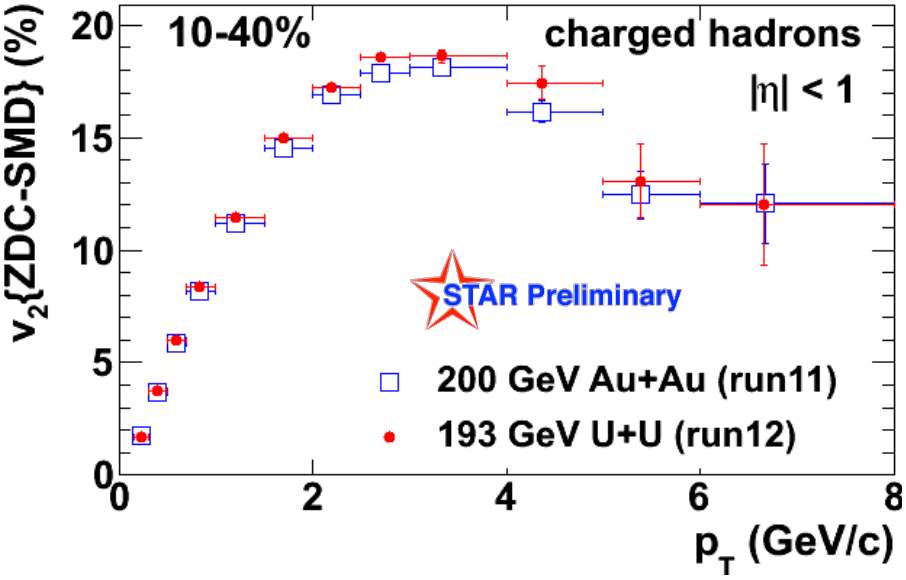
- For event plane method, we use ZDC-SMDs

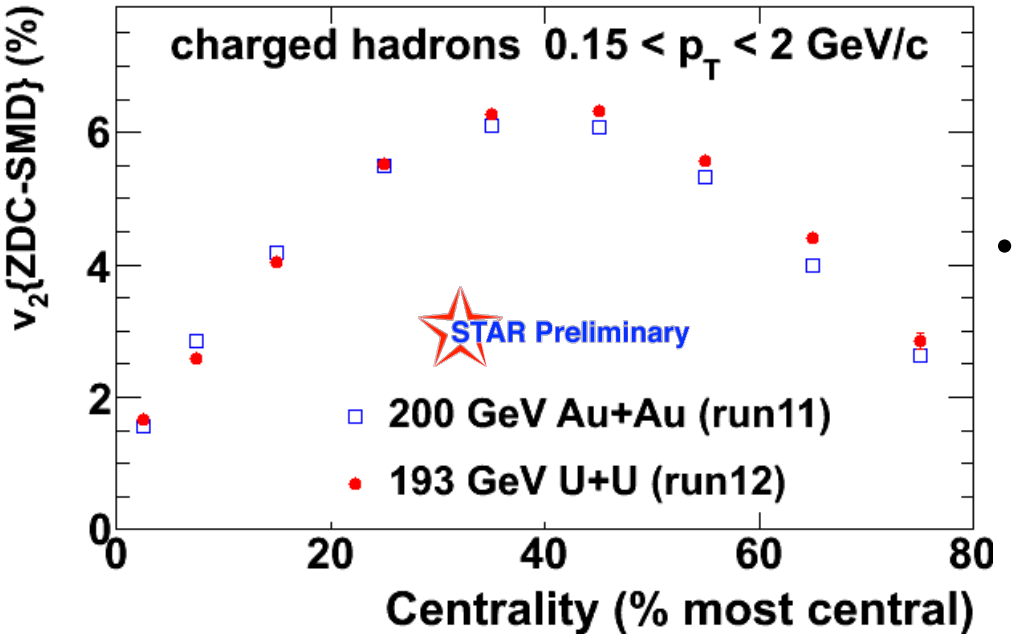
We've measured the v_2 using both event plane and Q-cumulants method

- For Q-cumulants method, we use efficiency-corrected 2nd and 4th order cumulants

v_2\{ZDC-SMD\}

- v_2 was measured with respect to the 1st order EP, obtained from STAR ZDC-SMDs.
- $v_2(p_T)$ looks similar between Au+Au and U+U for 10-40% collisions.



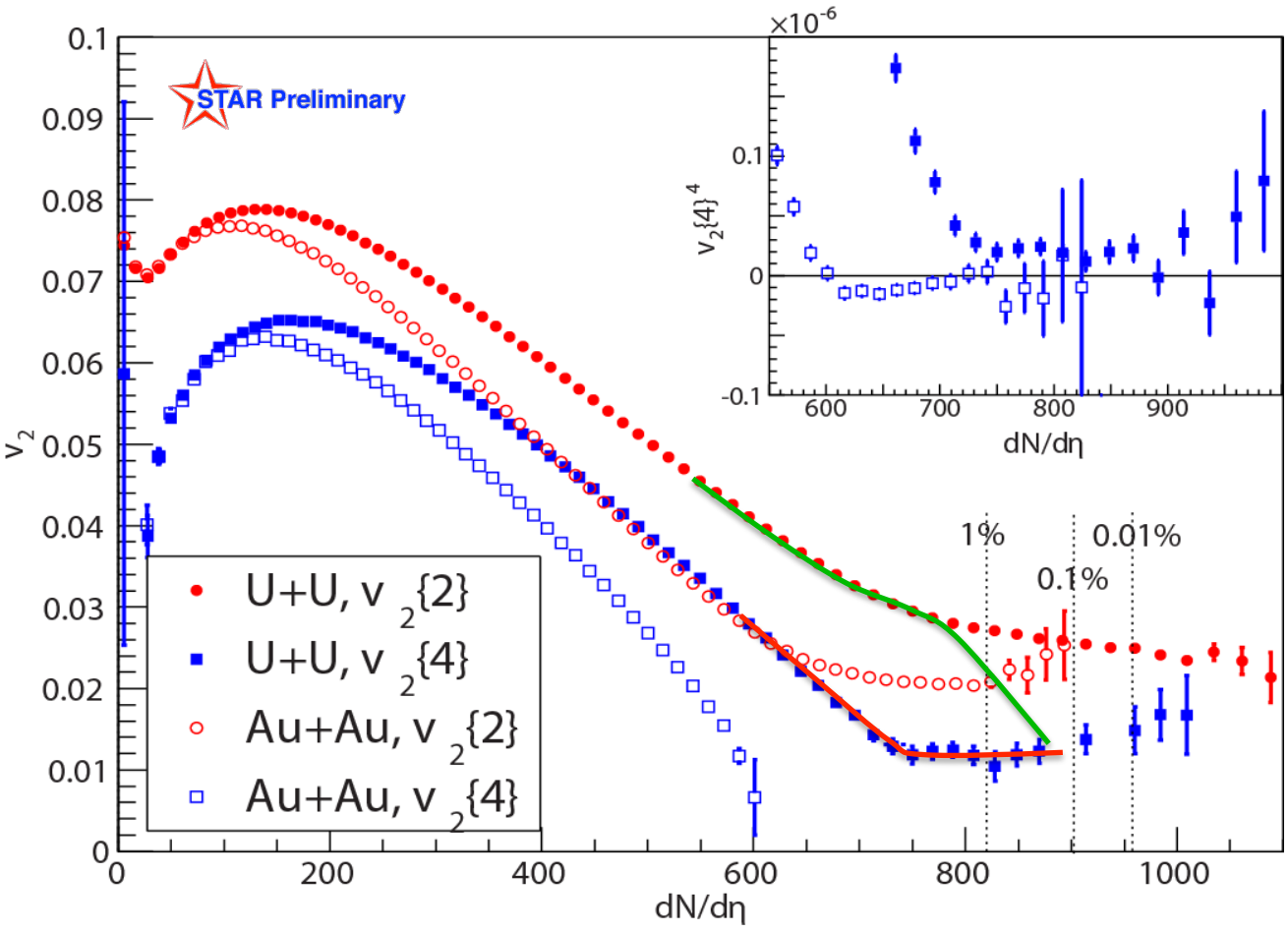


- The p_T-integrated v_2 are close to each other for minbias collisions of Au+Au at 200 GeV and U+U at 193 GeV.

Statistical errors only

In order to see differences, we need to move to central collisions

Minimum-bias U+U and Au+Au



No evidence of knee structure for central U+U

- Glauber plus 2-component model suggests knee structure at ~2% centrality
- Knee washed out by additional multiplicity fluctuations?[1]
- Other interpretations?

[1]Maciej Rybczyński, et. al. Phys.Rev. C87 (2013) 044908

The U+U $v_2\{4\}$ results are non-zero in central

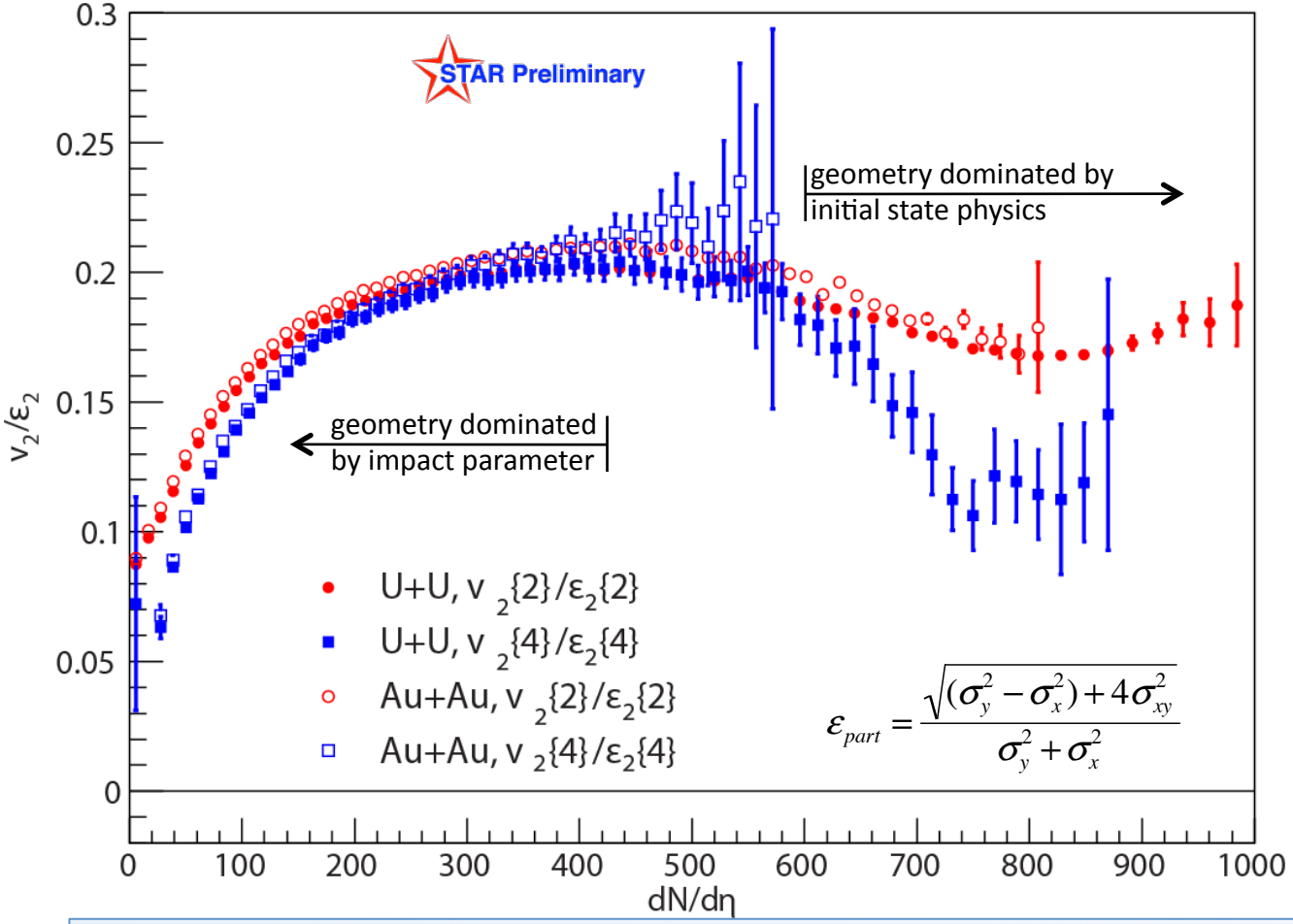
- Result of intrinsic prolate shape of the Uranium nucleus
- Au $v_2\{4\}^4$ becomes consistent with zero

Dashed lines represent top centrality percentages for U+U collisions based on multiplicity, curves are used to guide the eye

$v_2\{4\}$ data: we see the prolate shape of the Uranium nucleus ✓

The lack of a knee indicates a weakness in our multiplicity models

v_2/ε_2



v_2/ε_2 follows the same trend for U+U and Au+Au

- As long as the oblate shape of Au is accounted for

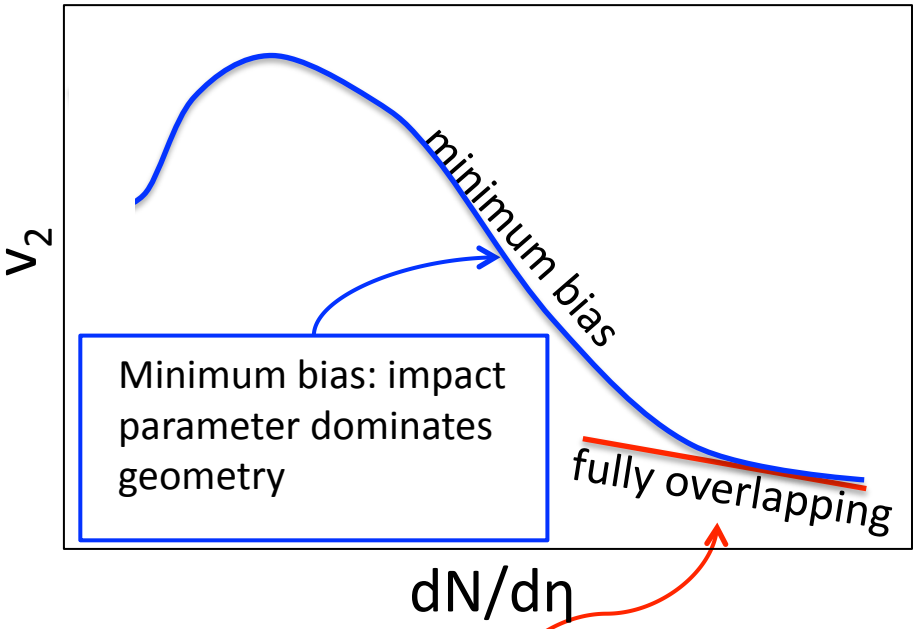
Instead of saturating or slowly rising, v_2/ε_2 drops in the most central collisions

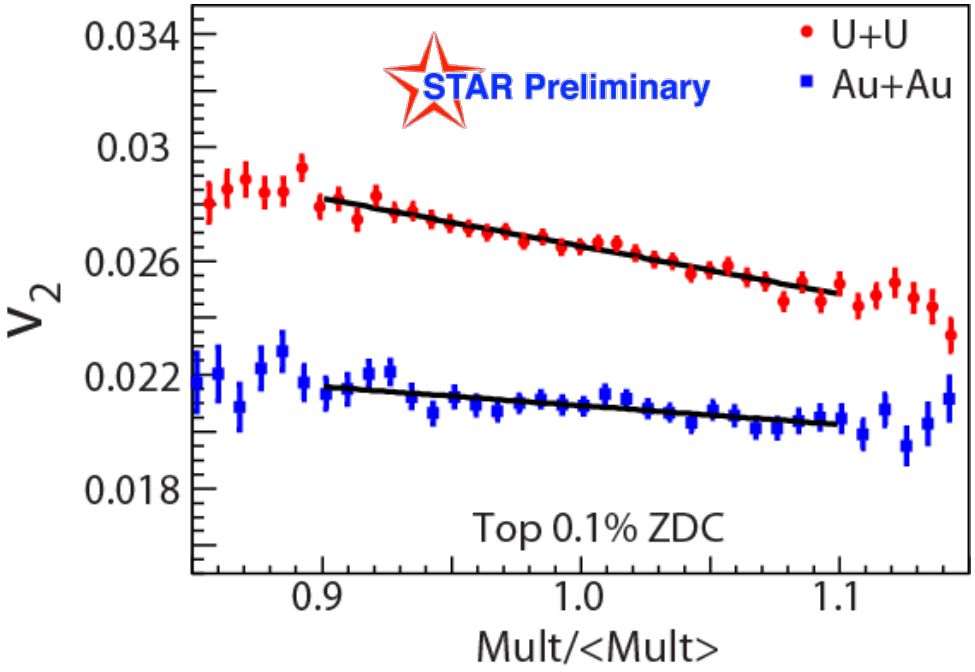
The drop is sharper for U +U $v_2\{4\}/\varepsilon_2\{4\}$

Results suggest an overestimation of ε_2 in central collisions or deviation from $v_2 \propto \varepsilon_2$ (non-flow, hydro fluctuations?)

Very central collisions provide a stringent test of models

Studying Full Overlap Events



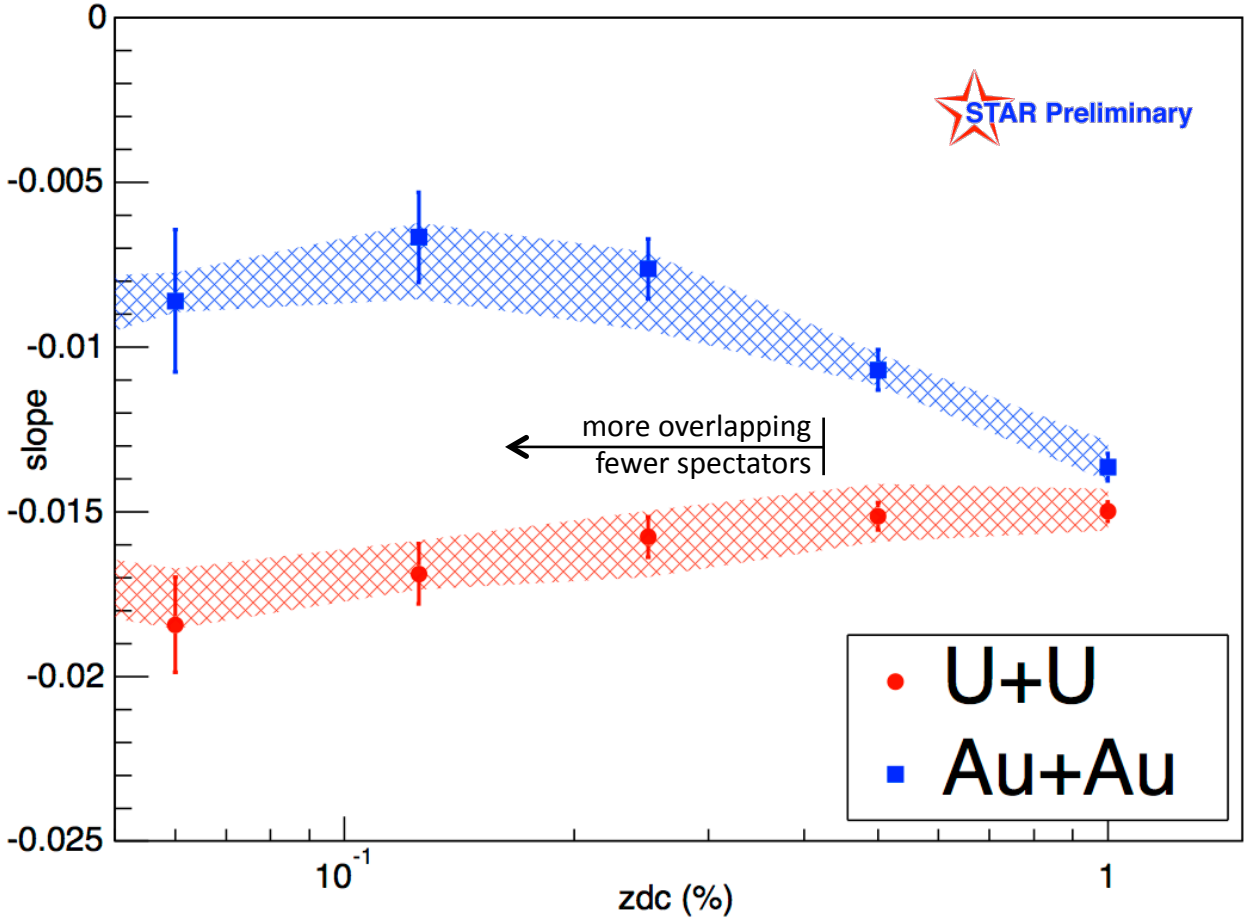


Central ZDC selection b->0

- Au+Au dN/dη is dominated by fluctuations
  - No correlation between v_2 and multiplicity
- U+U dN/dη depends on geometry & fluctuations
  - Larger v_2 associated with small multiplicity

- Use slope of v_2 vs dN/dη in U+U to look for correlation between dN/dη and geometry
  - Expect a strong negative slope
- Use Au+Au as the control sample to show we select full overlap
  - Expect a zero or slightly positive slope

Slope vs. ZDC



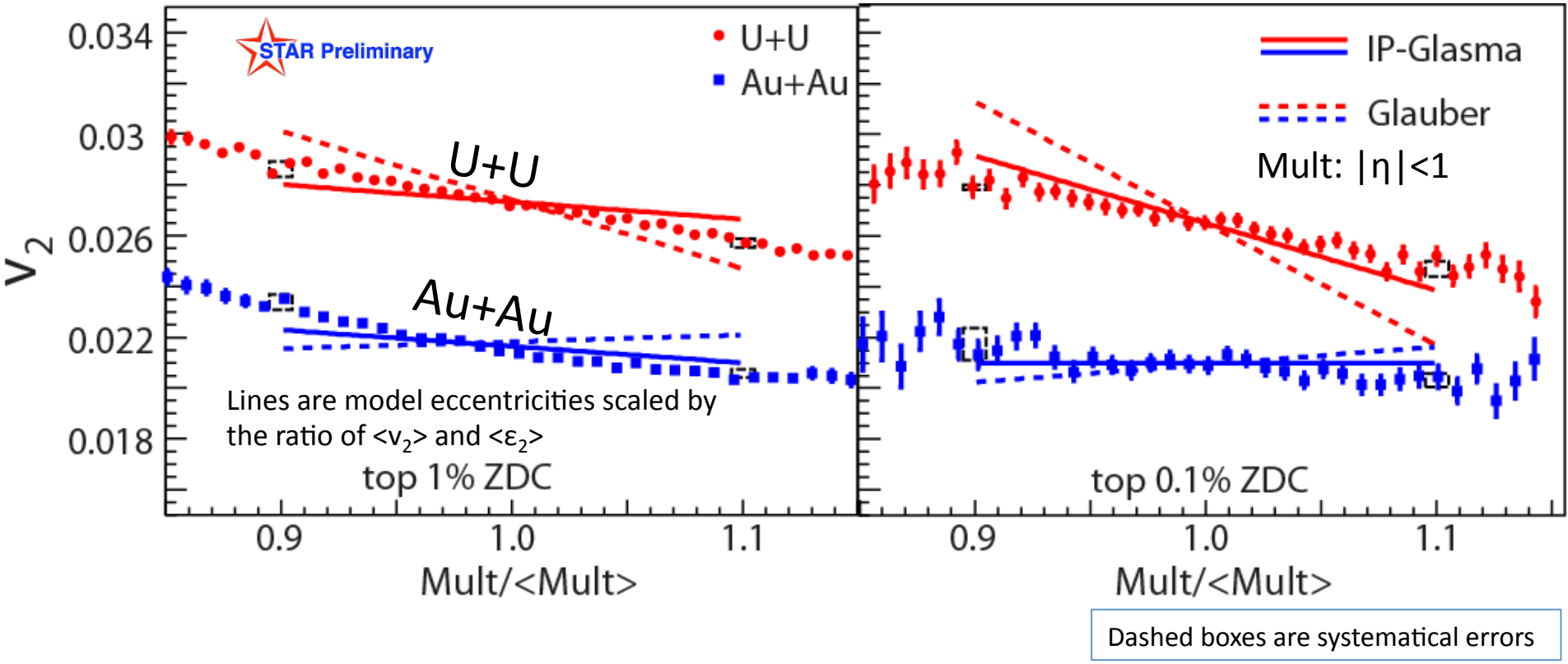
Systematical errors are estimated by varying fitting range and efficiency correction

ZDC Centrality	U+U	Au+Au
0.125%	6	4
0.25%	7	5
0.5%	9	6
1.0%	12	8
2.0%	17	12

Number of spectator neutrons in each direction from Glauber model

- For tighter cuts, the U+U slope becomes steeper than the Au+Au control sample
- Demonstrates that dN/dη is larger for tip-tip U+U collisions: dN/dη can be used to select tip-tip vs body-body enhanced samples

IP-Glasma vs. Glauber



- Glauber plus 2-component model overpredicts U+U data and predicts negative slopes for Au+Au data
- IP-Glasma model[1] (solid color lines) matches data better, especially for top 0.1% ZDC

[1]Bjoern Schenke, Prithwish Tribedy and Raju Venugopalan
arXiv:1403.2232

Summary

- U+U collisions open up a stringent testing ground of initial states and multiplicity production models
- No evidence of kink structure in central v_2 results from current analysis, more fluctuations than NBD? [1]
- v_2/ε_2 turns over in central collisions for both Au+Au and U+U!?
  - Overestimation of ε_2 in Glauber model?
- The combination of ZDC and multiplicity can be used to select body-body or tip-tip enhanced samples of central U+U collisions
  - High multiplicity events are biased toward tip-tip enhanced collisions, low multiplicity toward body-body enhanced collisions
  - Data show weaker correlations than model predictions: larger multiplicity fluctuations?
- IP-Glasma model does a better job of describing data

[1] Maciej Rybczyński, et. al. Phys.Rev. C87 (2013) 044908

Back Up

Glauber Model

- Assume deformed Woods-Saxon distribution

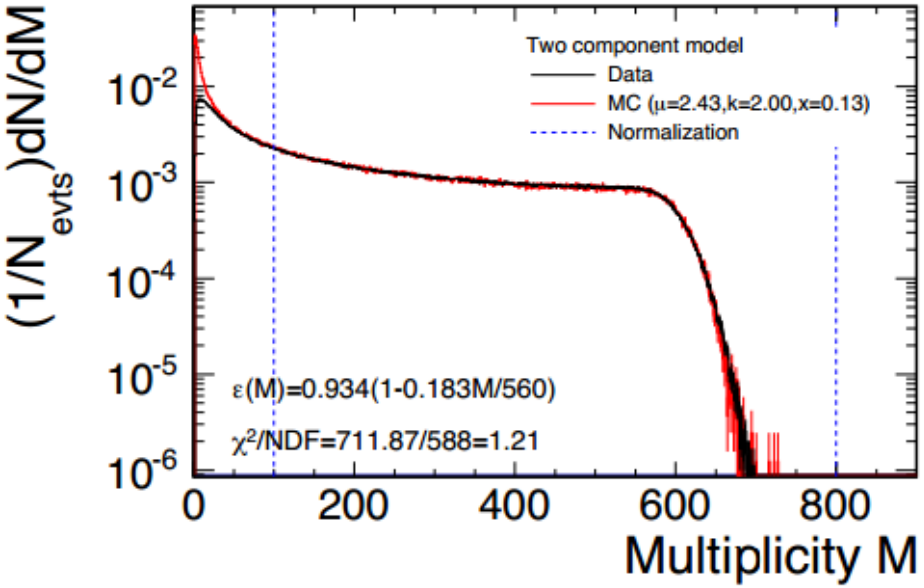
$$\rho = \frac{\rho_0}{1+\exp([r-R']/d)} \qquad R' = R[1+\beta_2 Y_2^0(\theta)+\beta_4 Y_4^0(\theta)]$$

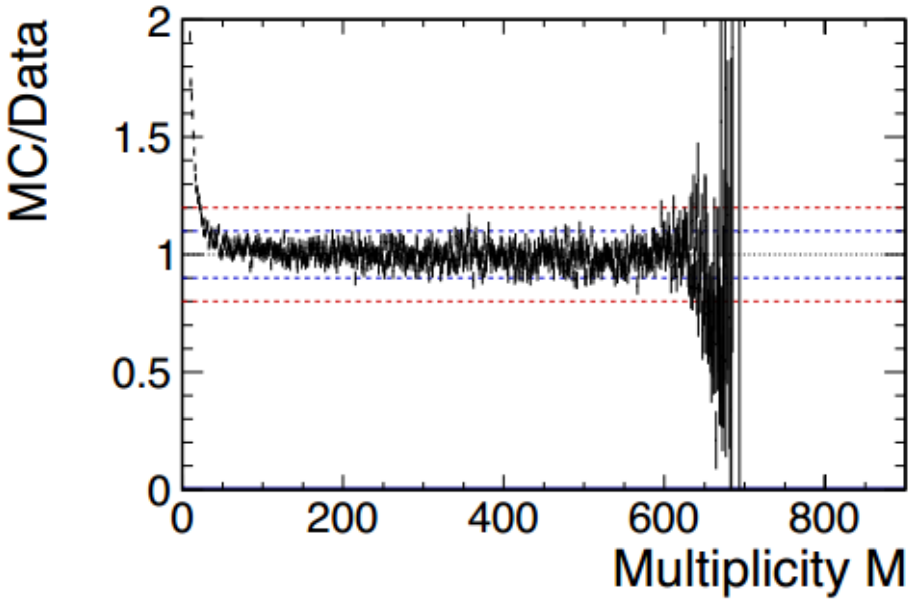
- Average number of particles from each nucleon follows 2-component model

$$n_{AA} \propto n_{pp}[(1-x_{hard})\frac{N_{part}}{2}+x_{hard}N_{coll}]$$

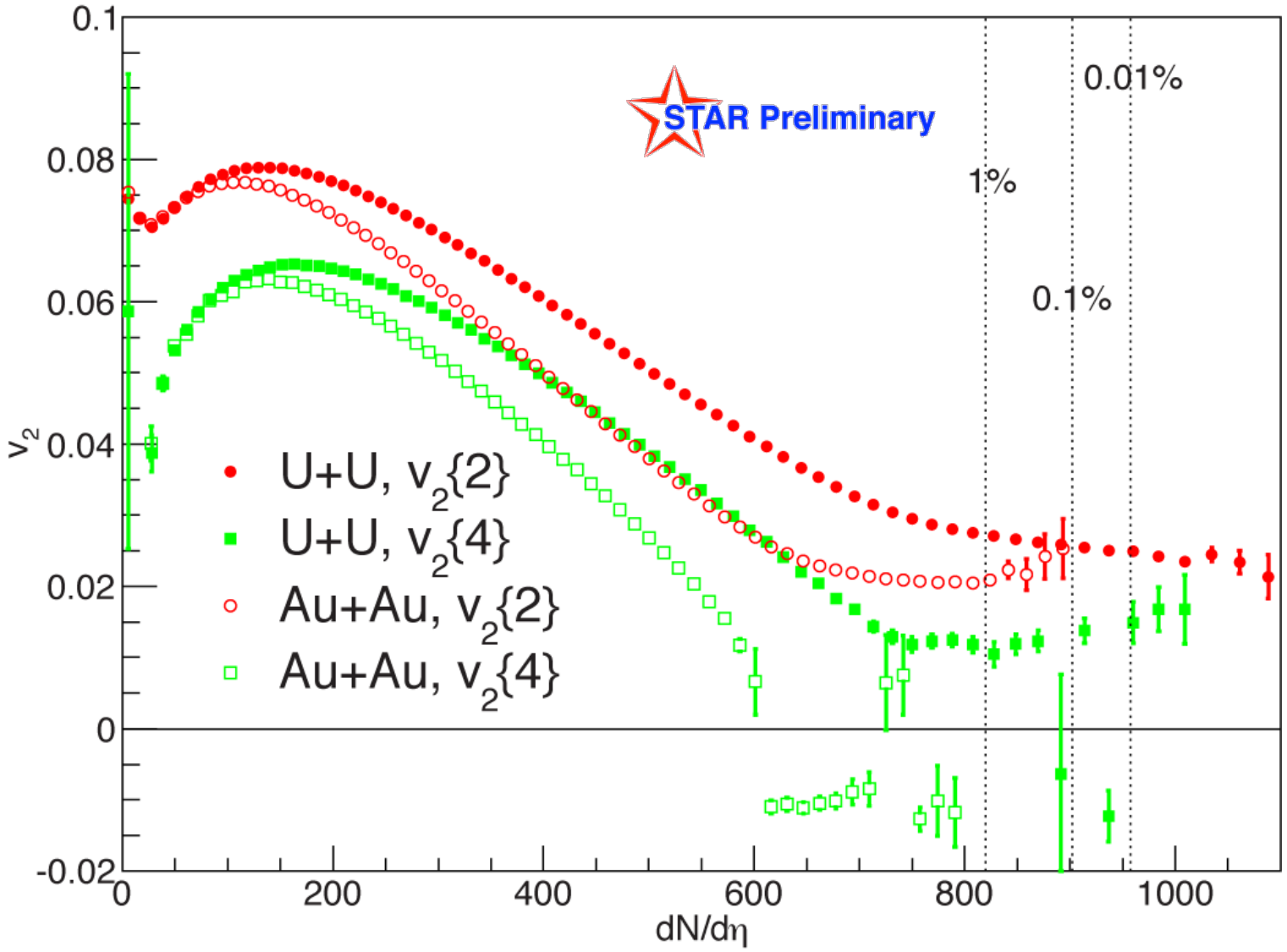
- Generate N_{ch} by sampling a negative binomial distribution with parameters n_{AA} and k=2

Hiroshi Masui, et. al.
Physics Letters B 679 (2009) 440–444



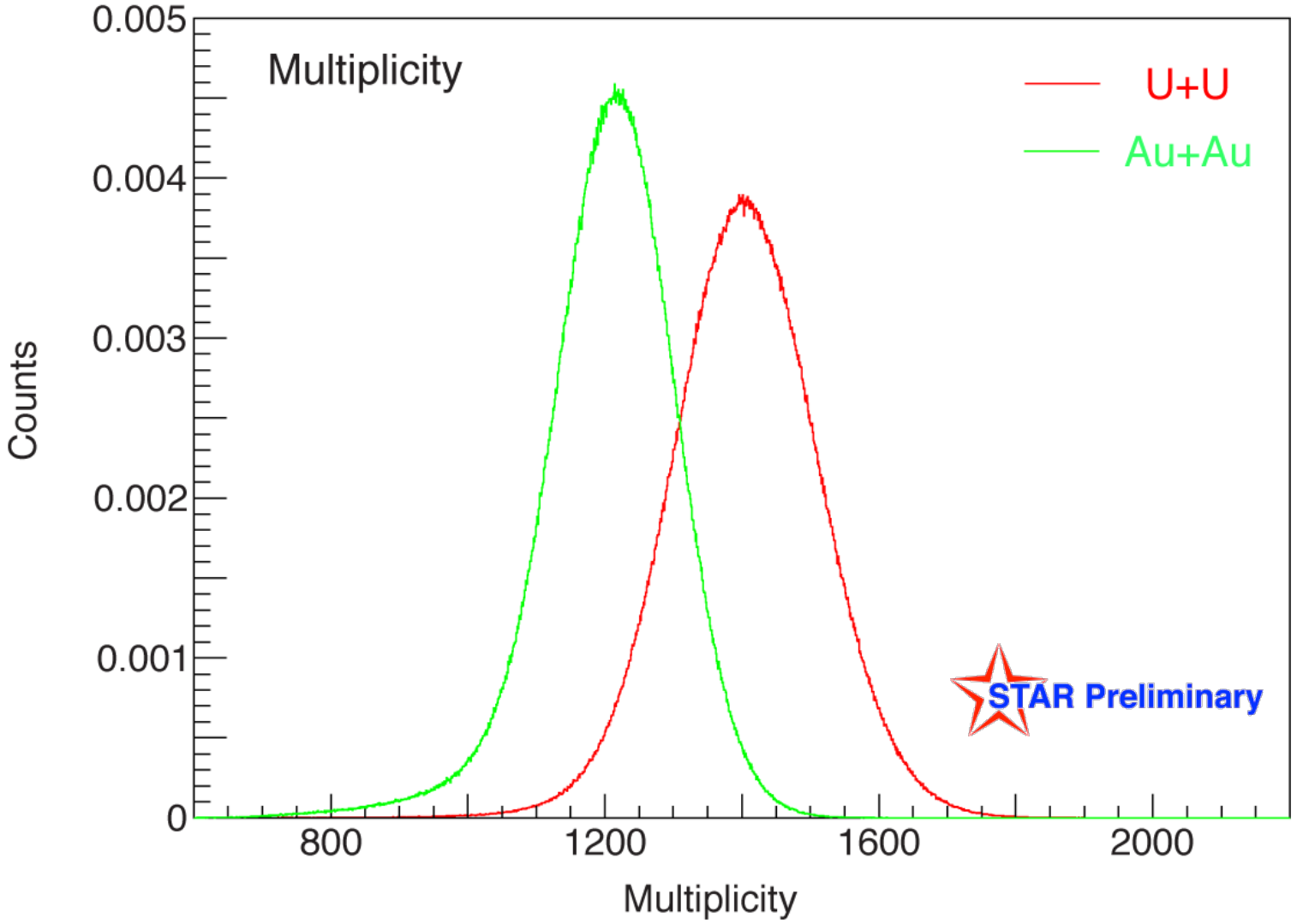


Minimum-bias U+U and Au+Au



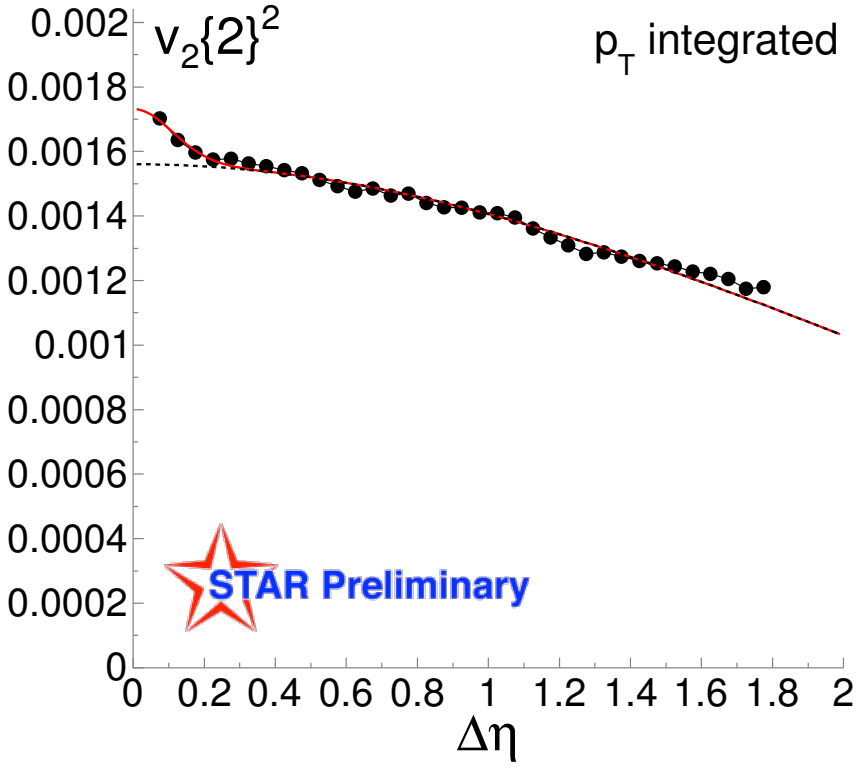
The $v_2\{4\}$ results are calculated from $v_2\{4\}^4$ and by taking the fourth root

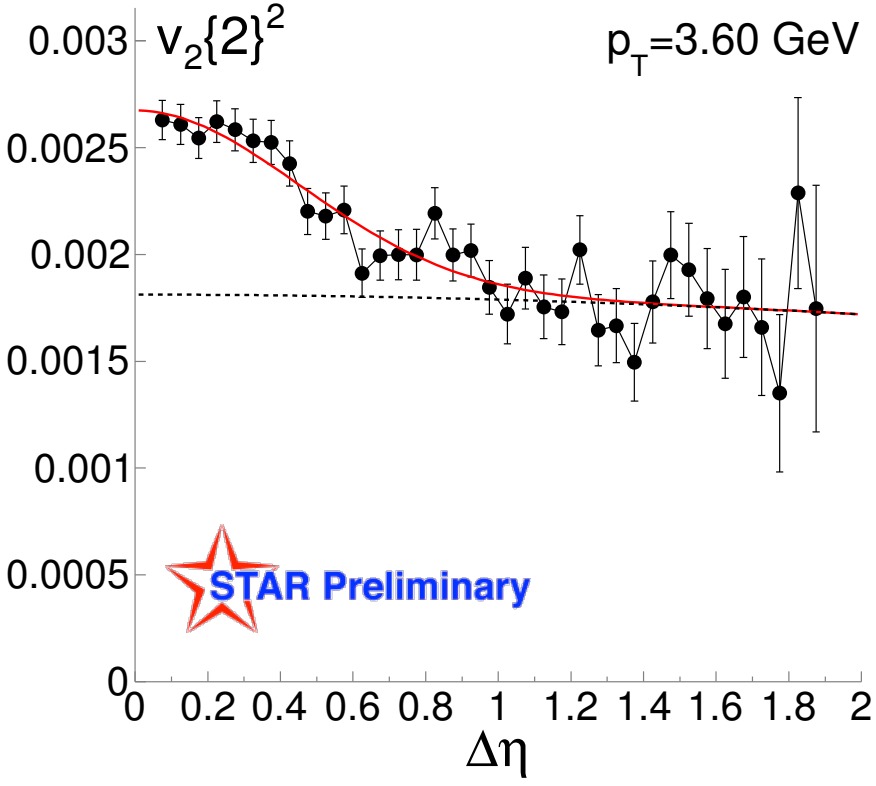
Multiplicity



The corrected multiplicity distribution for 1% central ZDC events

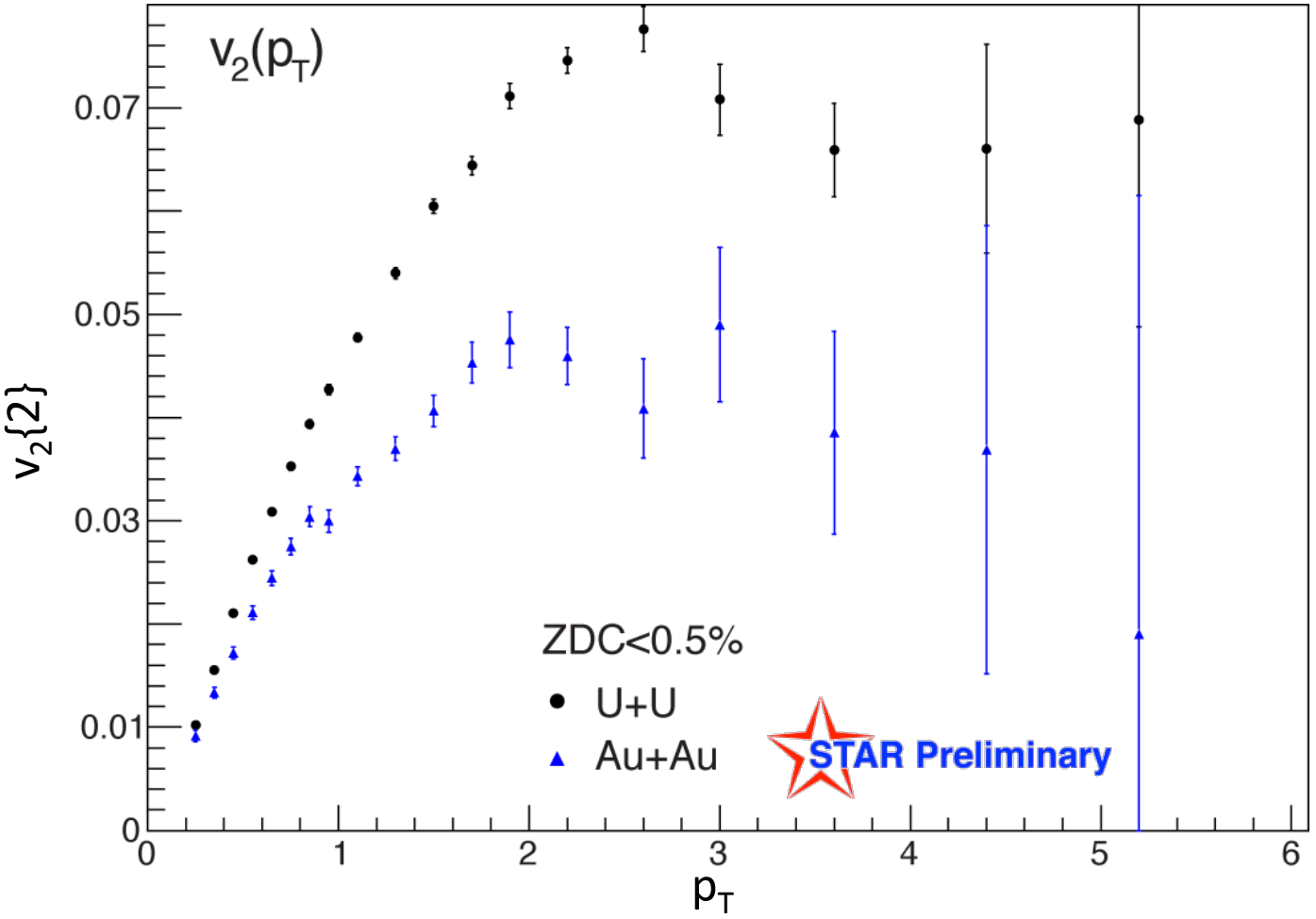
Δη dependence





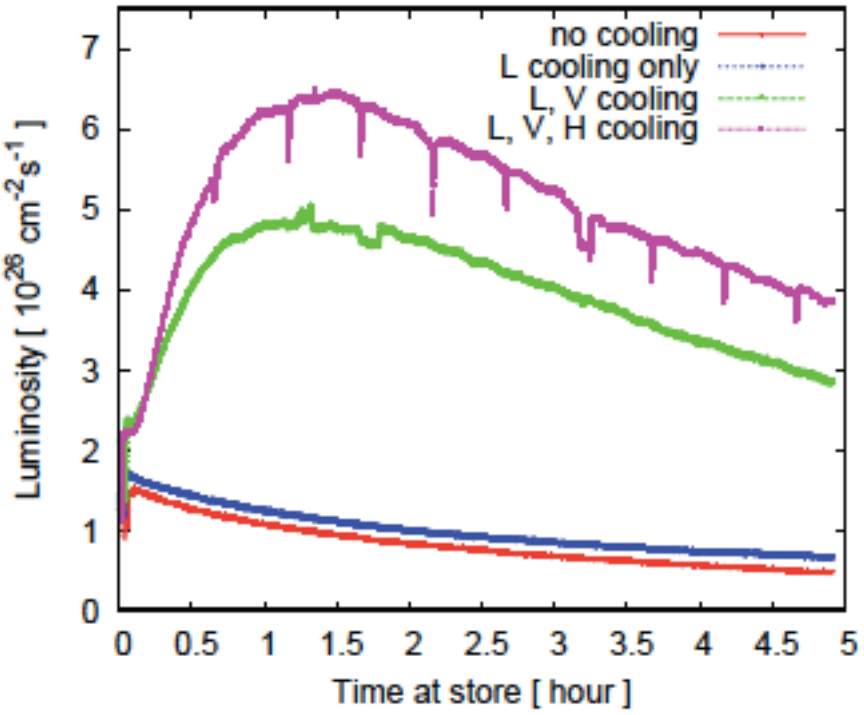
Remove peak at small Δη to reduce non-flow effects

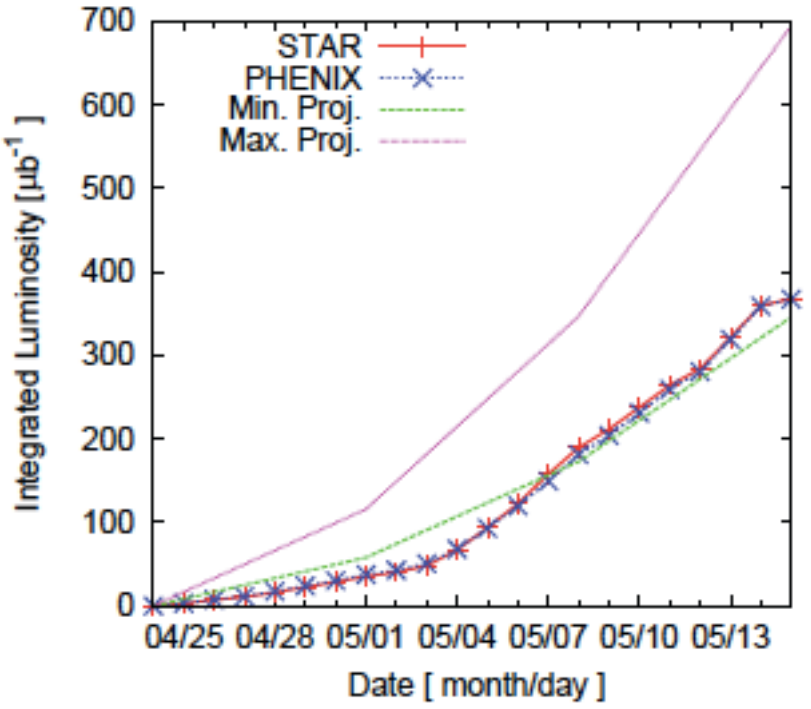
Toward Path Length Dependence of Quenching



- Larger difference in-plane vs out-of-plane path length in U+U?
  - Need to split U+U results into multiplicity bins (body-body vs. tip-tip)
  - A larger-sized data sample of central U+U events will be needed

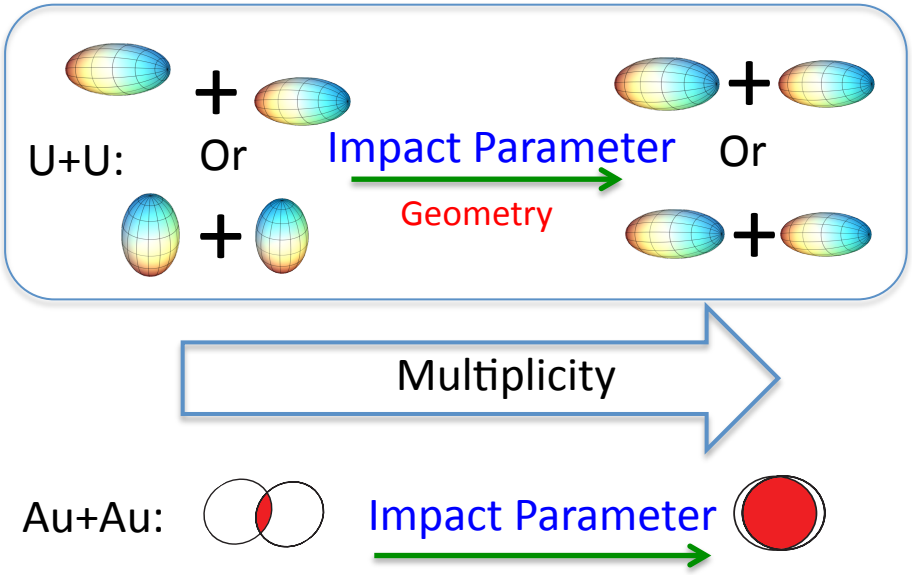
Collection of U+U data sample

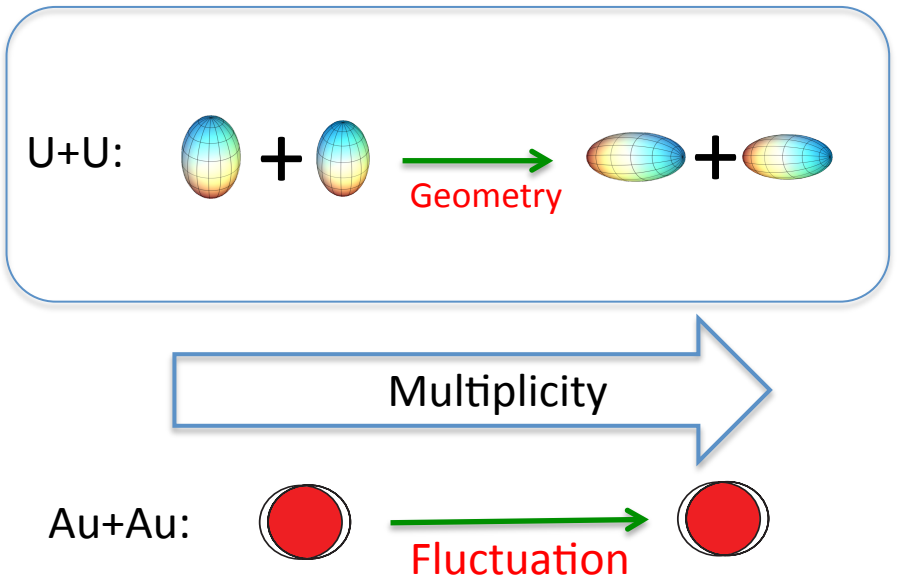




Implementation of cooling led to huge improvement in accessible luminosity
Made acheivement of possible goals

Studying Full Overlap Events

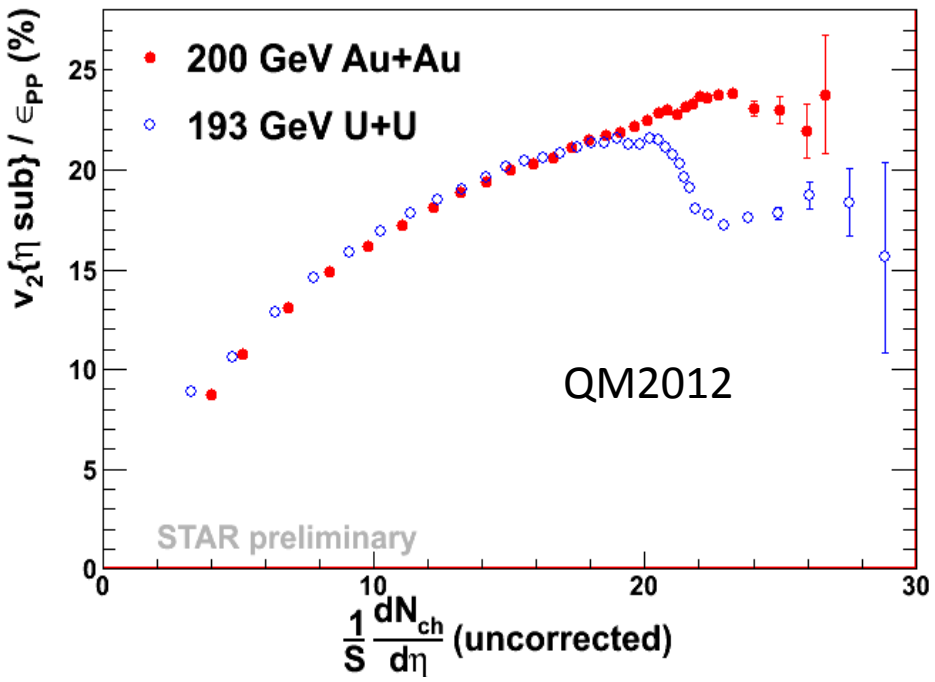


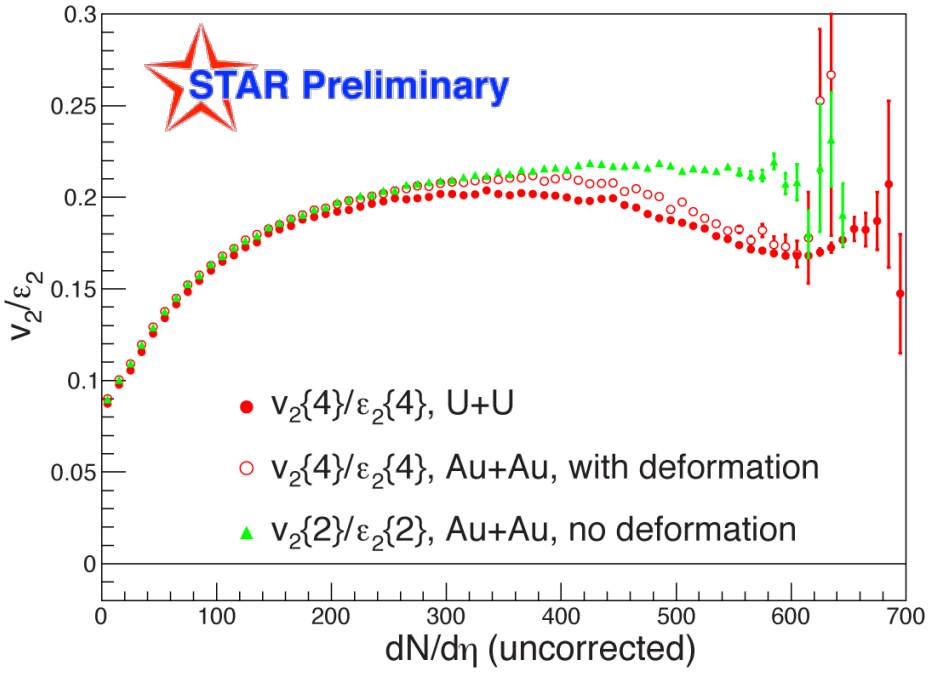


- Without selection on over-lapping region, the impact parameter will dominant geometry
- We will see correlations between v_2 and multiplicity for both Au+Au and UU
  - Larger v_2 associated with small multiplicity

- With the selection on fully over-lapping region, the impact parameter effects are reduced
- The multiplicity difference in Au+Au is dominant by fluctuations
  - No correlation between v_2 and multiplicity
- The multiplicity difference in U+U is dominant by geometry
  - Larger v_2 associated with small multiplicity

Effects of deformation in Au





- Previous study assume no deformation for Au nuclei
- With deformation in Au+Au, the split between U+U and Au+Au is reduced