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

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Outline

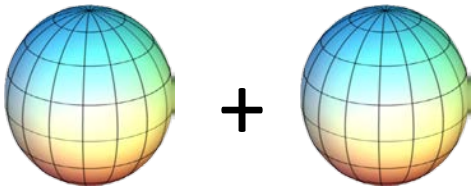
- Motivation
- STAR detector and data set
- Azimuthal anisotropy in U+U collisions
- Selection of body-body and tip-tip enhanced samples
- Triangular flow in U+U collisions
- Summary

Motivation for U+U Collisions

Allows us to manipulate the initial geometry and study:

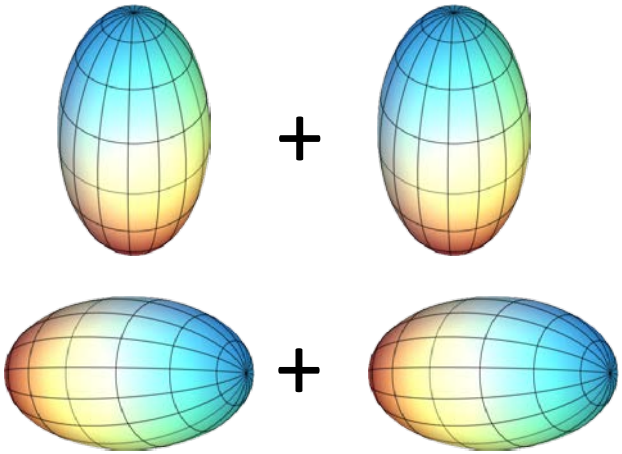
- How multiplicity depends on N_{part} and N_{coll}
- Path-length dependence of jet quenching
- Particle production in heavy-ion collisions
- Other effects

Au+Au Collisions



Oblate

U+U Collisions

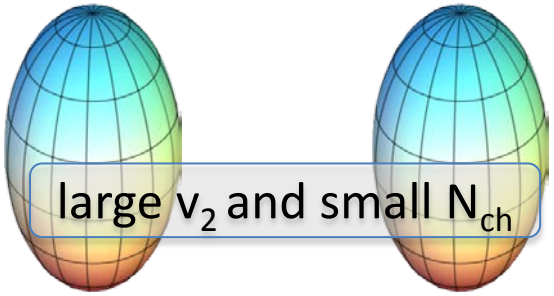


Prolate

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

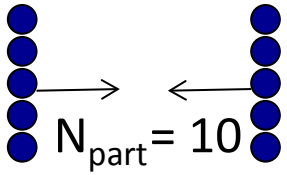
Selecting Body-body or Tip-tip

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

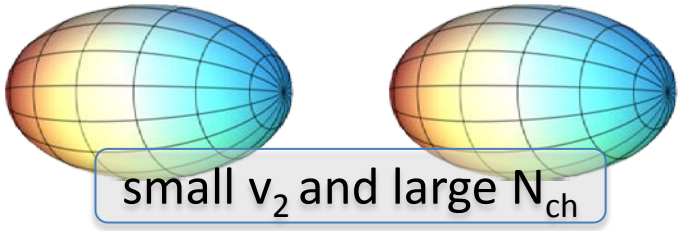


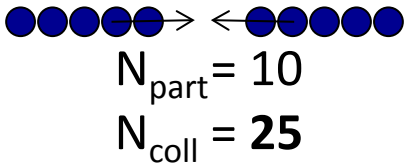
fully overlapping

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



**idealizations*



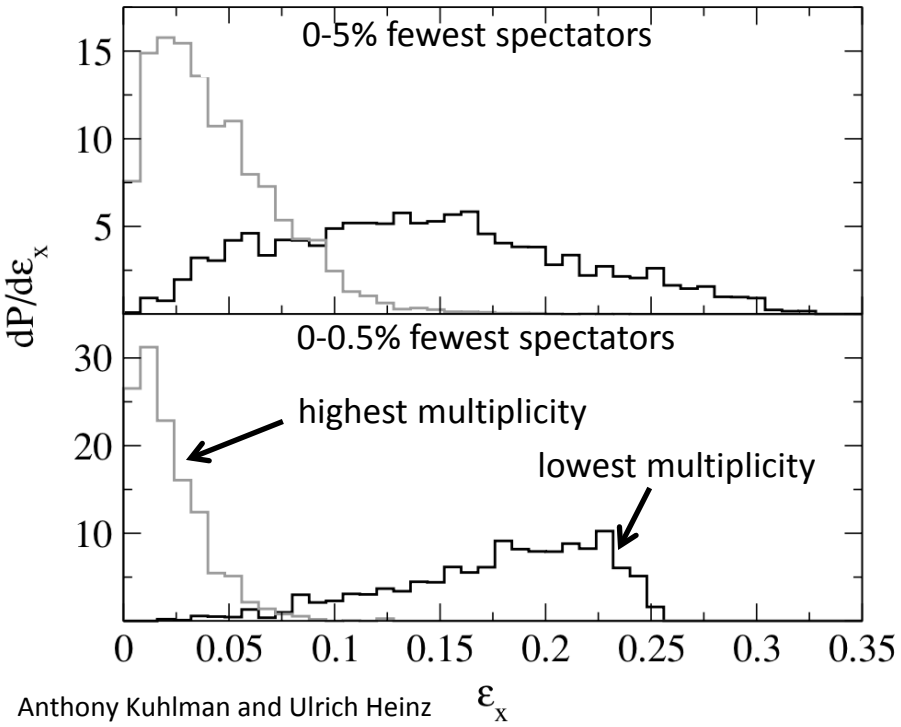


If dN/dη depends on N_{coll}, large dN/dη should correlate with small v_2.

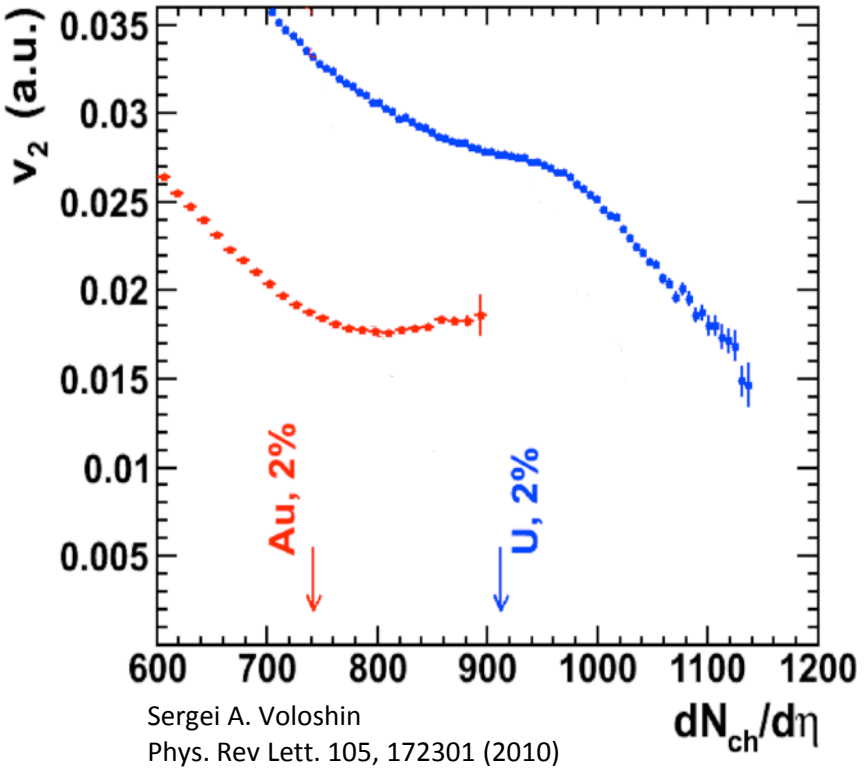
➪*Central U+U collisions are ideal for testing particle production*

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)



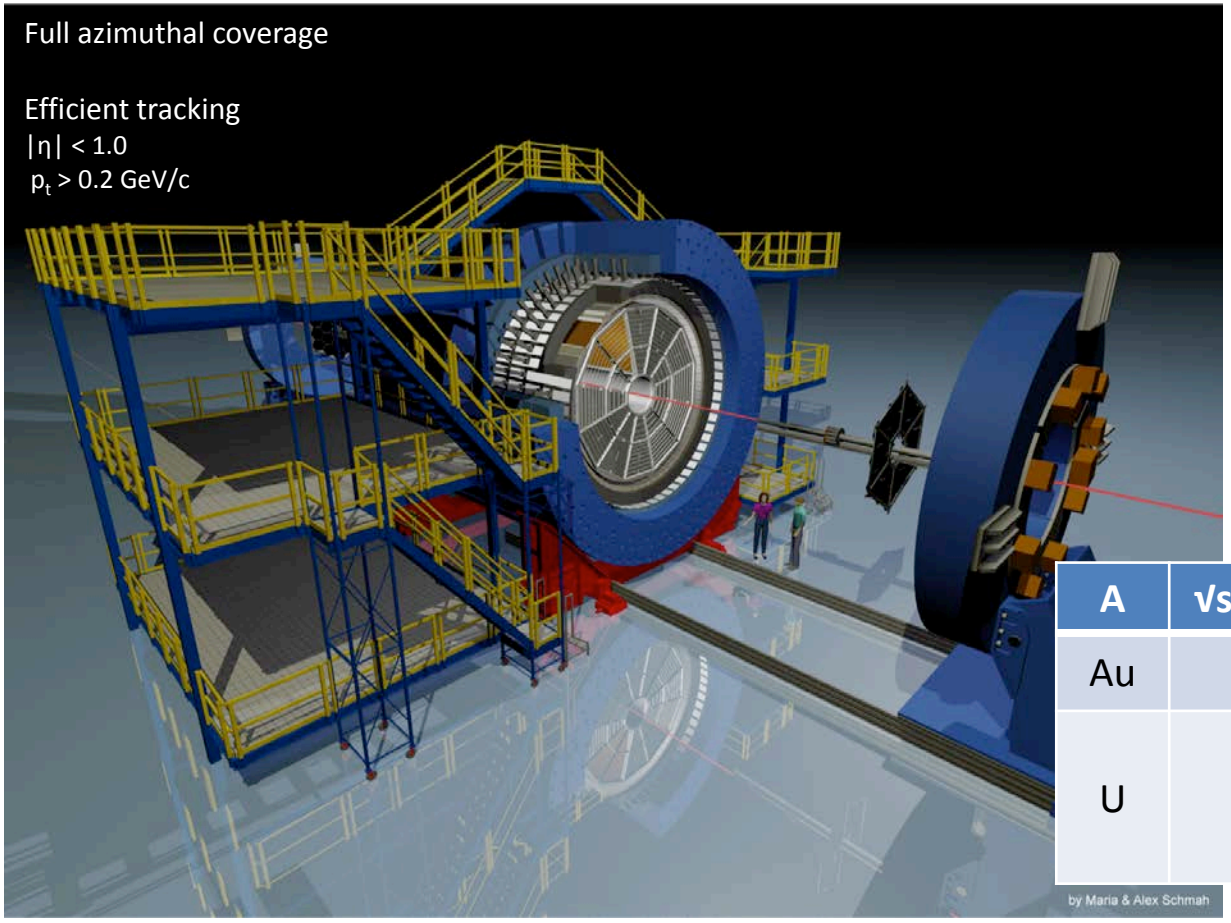
Sergei A. Voloshin
Phys. Rev Lett. 105, 172301 (2010)

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

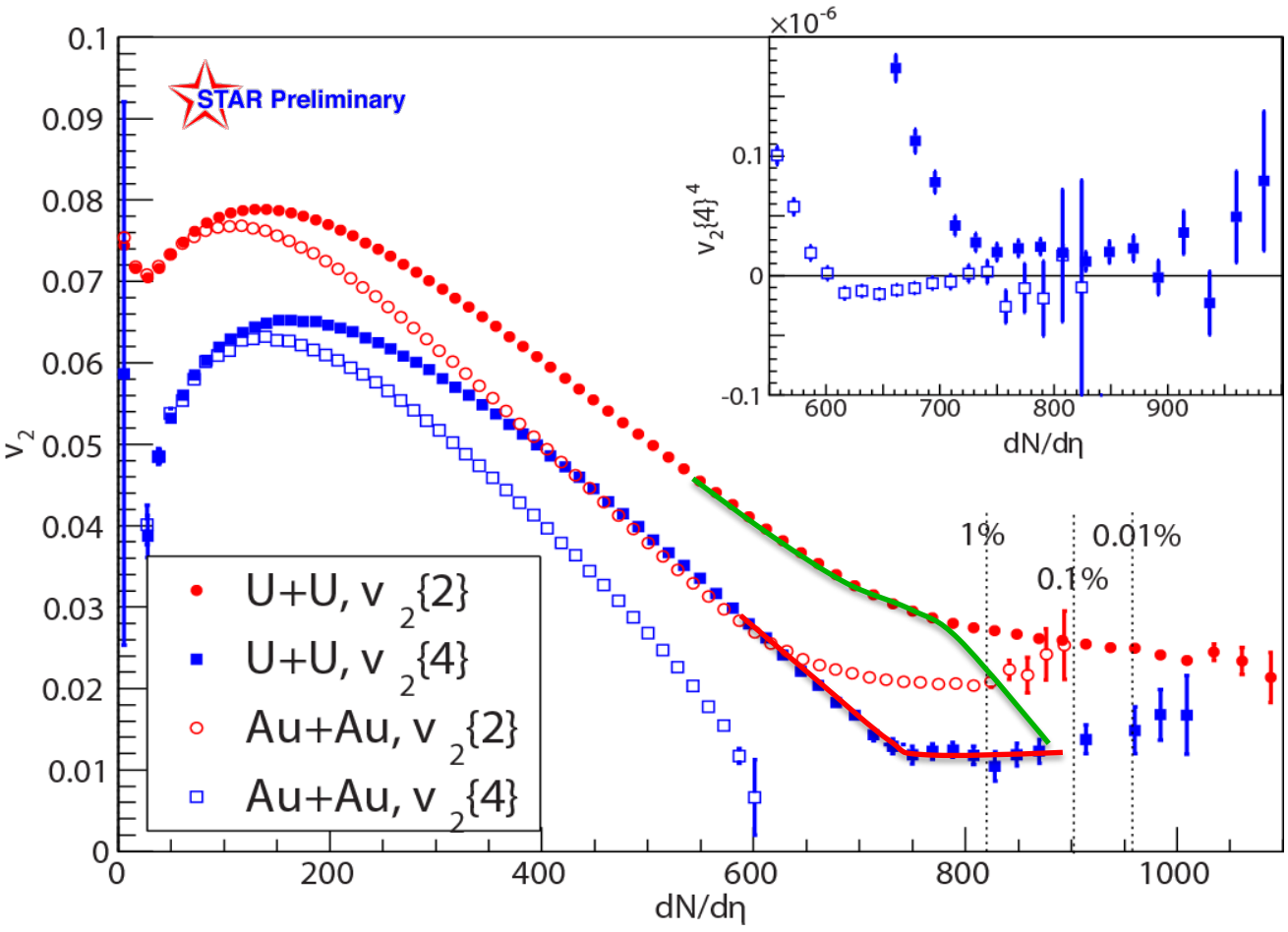
A	$\sqrt{s_{nn}}$ GeV	Year	Events (x10^6)
Au	200	2011	700 (mini-bias)
U	193	2012	360 (mini-bias) 13 (central 1% ZDC)

We've measured the efficiency-corrected 2nd and 4th cumulants using Q-cumulants

Bilandzic, et. al. Phys. Rev. C 83: 044913,2011

$$v_n^2\{2\} = \left\langle\left\langle e^{in(\phi_i-\phi_j)}\right\rangle_{i\neq j}\right\rangle \qquad v_n^4\{4\} = -\left\langle\left\langle e^{in(\phi_i+\phi_j-\phi_k-\phi_l)}\right\rangle_{i\neq j\neq k\neq l}\right\rangle + 2v_n^4\{2\}$$

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

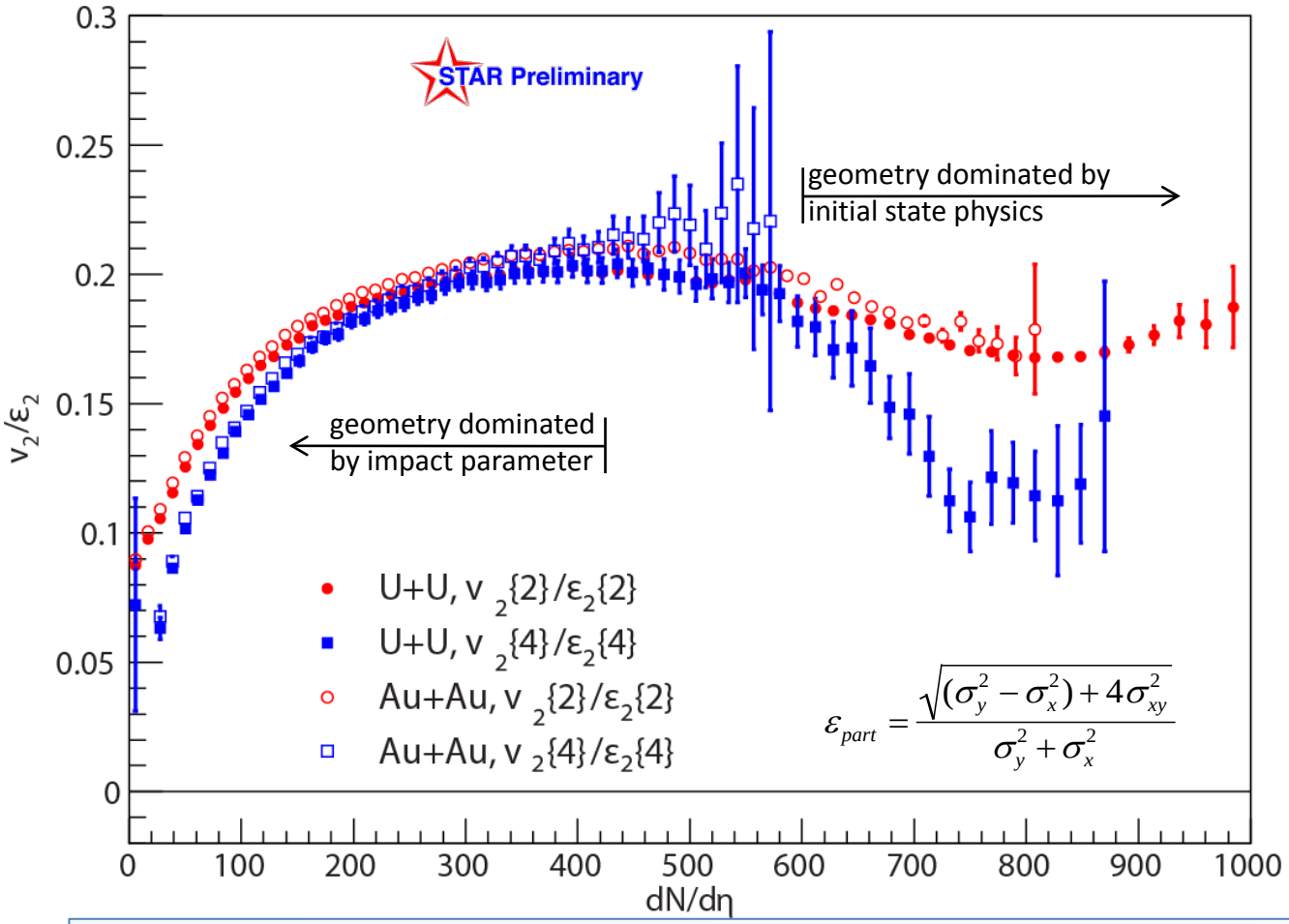
- Result of intrinsic prolate shape of the Uranium nucleus
- Au $v_2\{4\}^4$ becomes consistent with zero

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

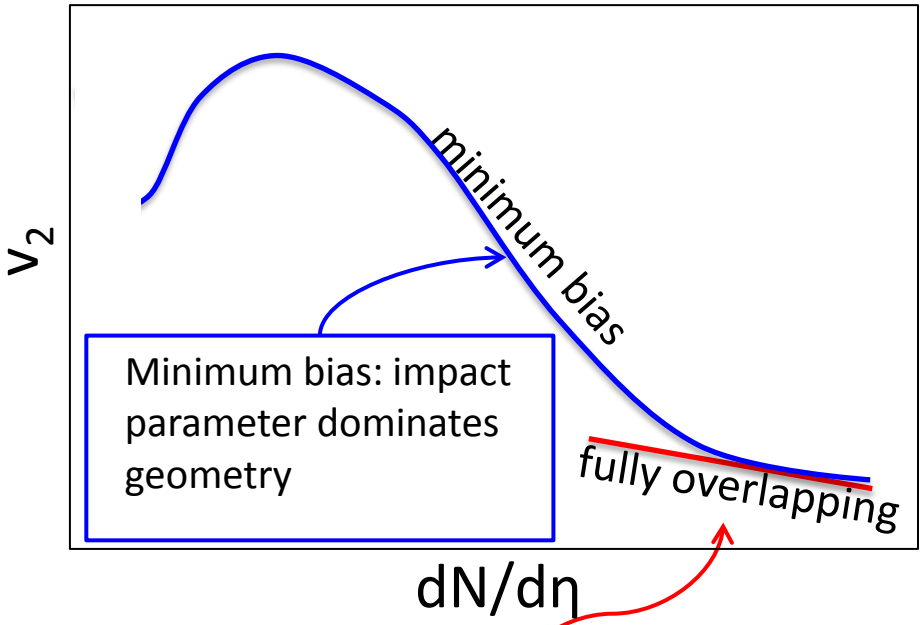
Instead of saturating or slowly rising, v_2/ε_2 drops in the most central collisions

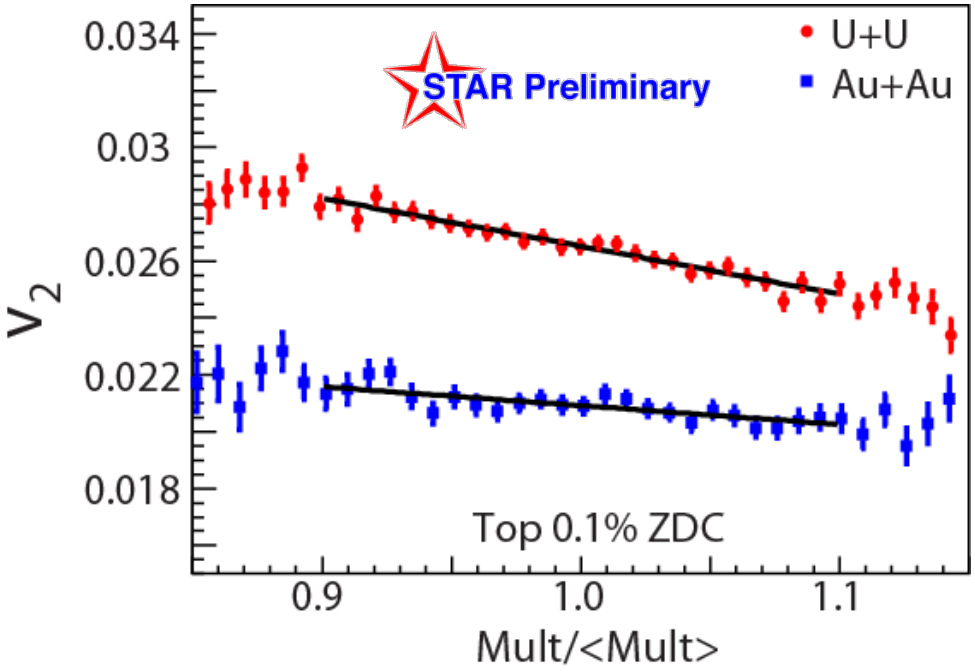
The drop is sharper for U+U $v_2\{4\}/\varepsilon_2\{4\}$

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



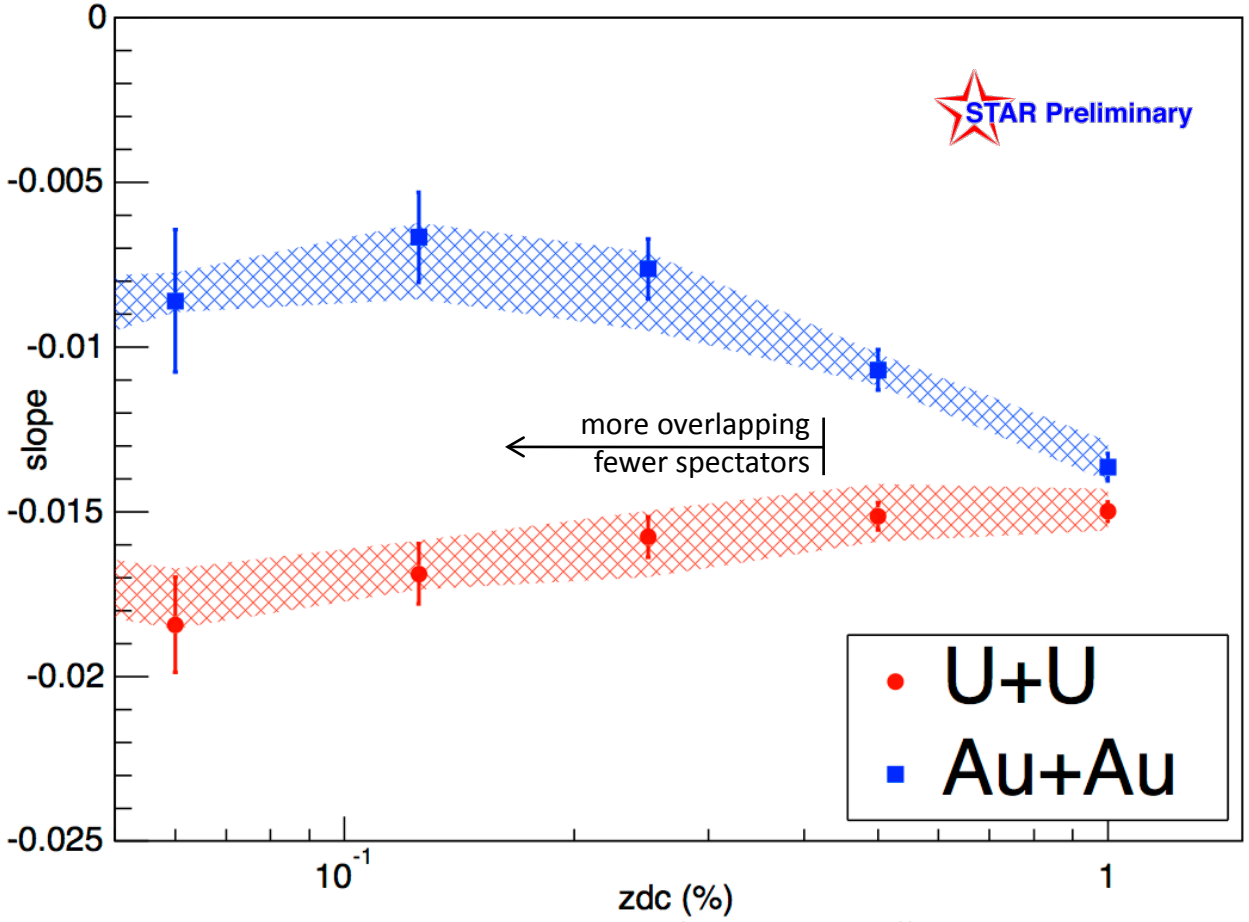


Central ZDC selection b->0

- 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



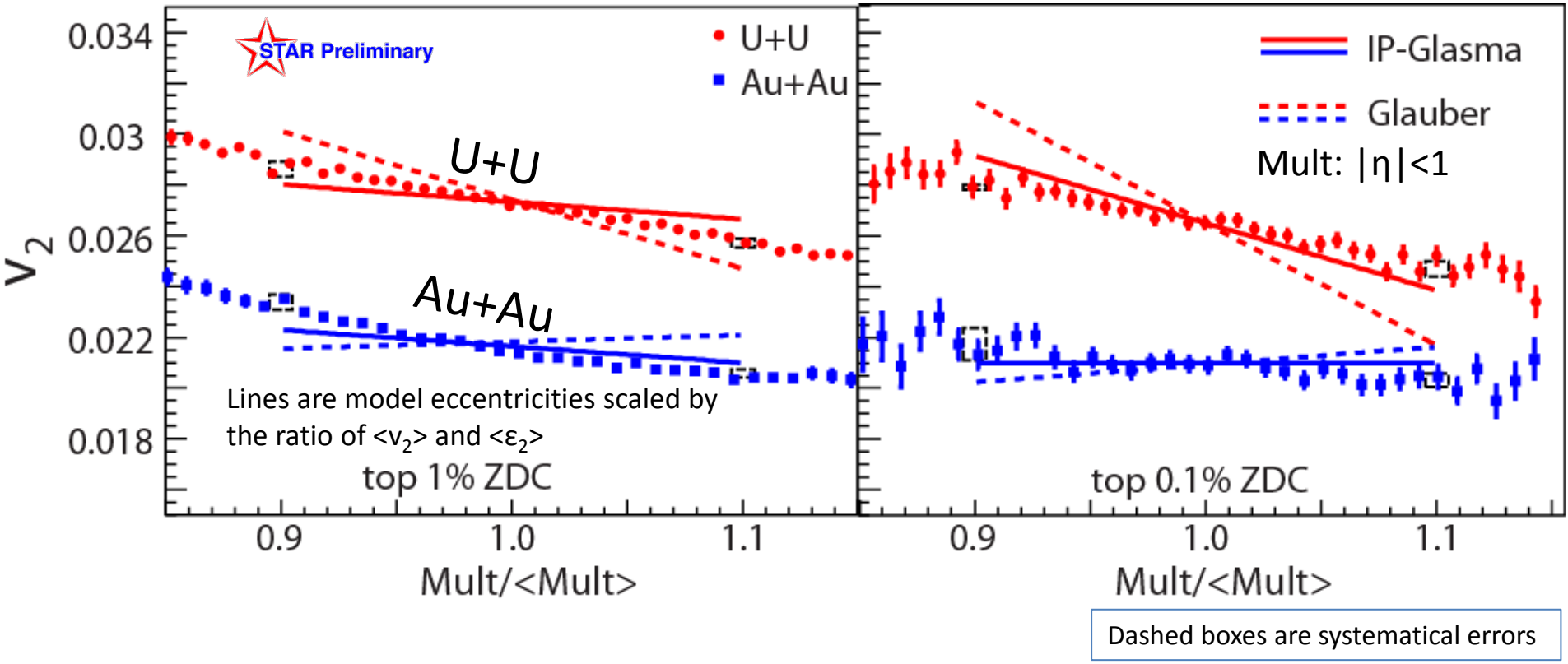
Systematical errors are estimated by varying fitting range and efficiency correction

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

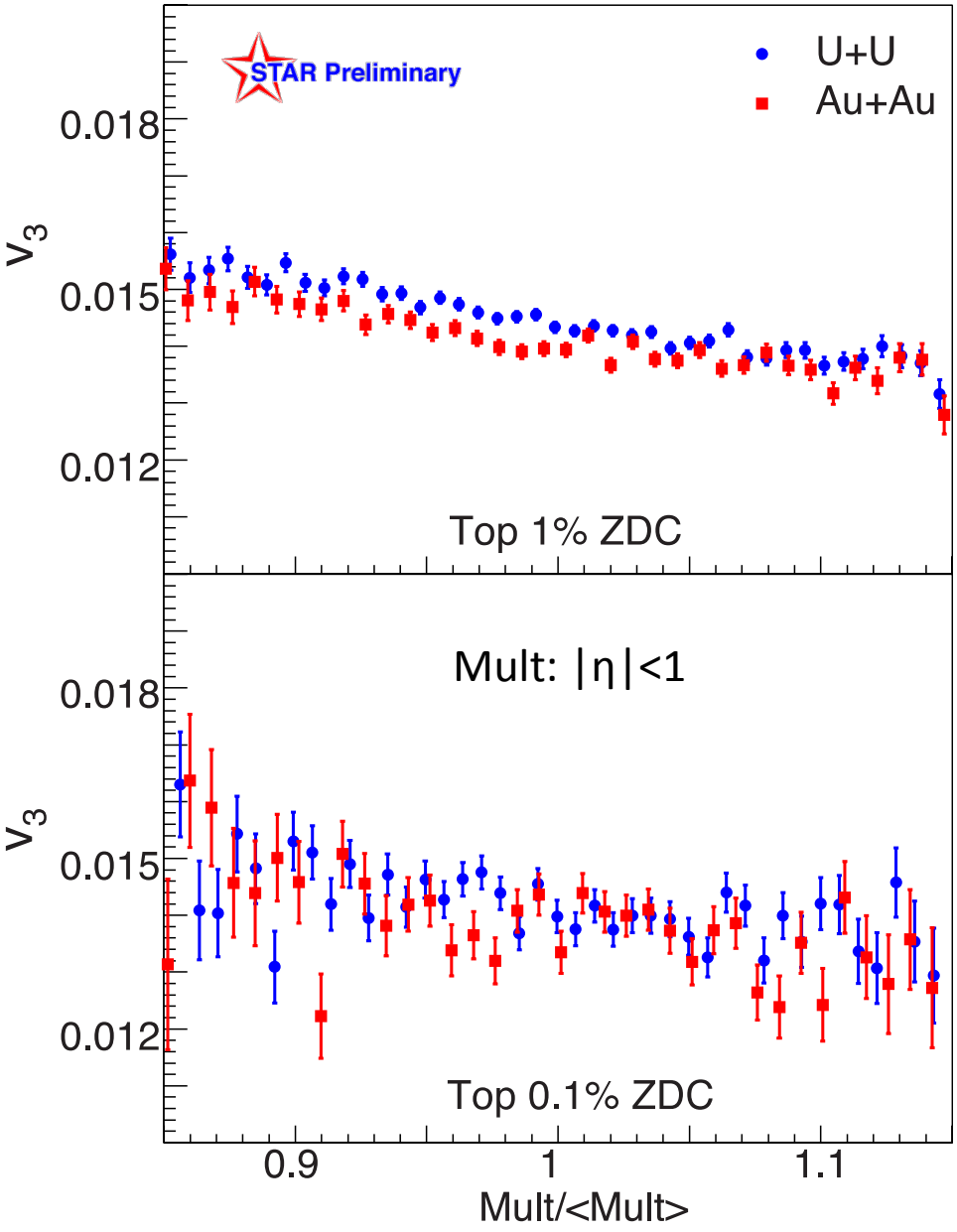


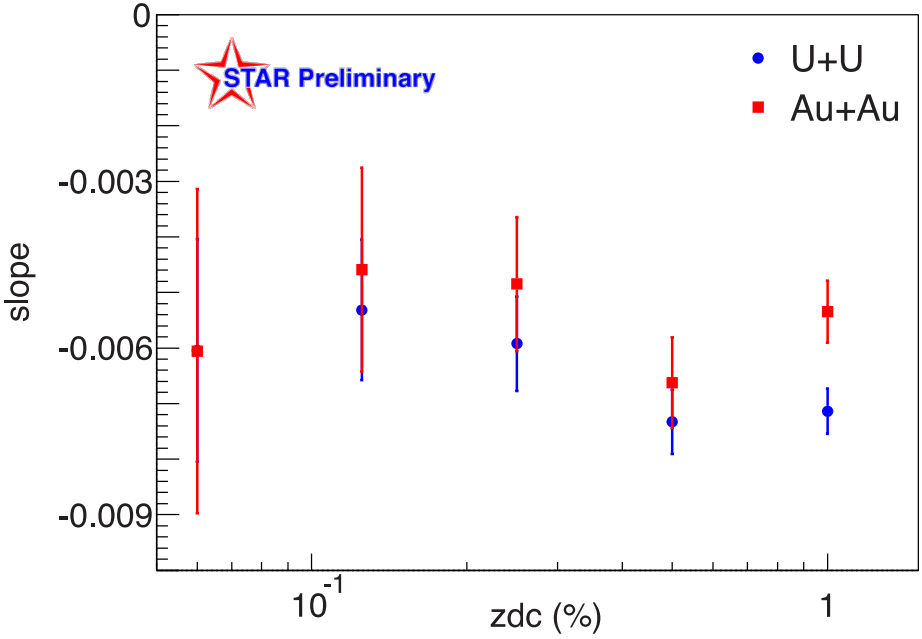
Dashed boxes are systematical errors

- Glauber plus 2-component model overpredicts U+U data and predicts positive 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

Triangular Flow





- Test the impact of Uranium's prolate shape on initial state fluctuations
- The slope of v_3 vs. multiplicity is small and negative in both systems
- We observe no differences between U+U and Au+Au in slope parameter

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
- Central U+U v_3 results are systematically larger than Au+Au, although no differences are observed in the slope parameter

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