Orientation Resolution in Uranium-Uranium Collisions

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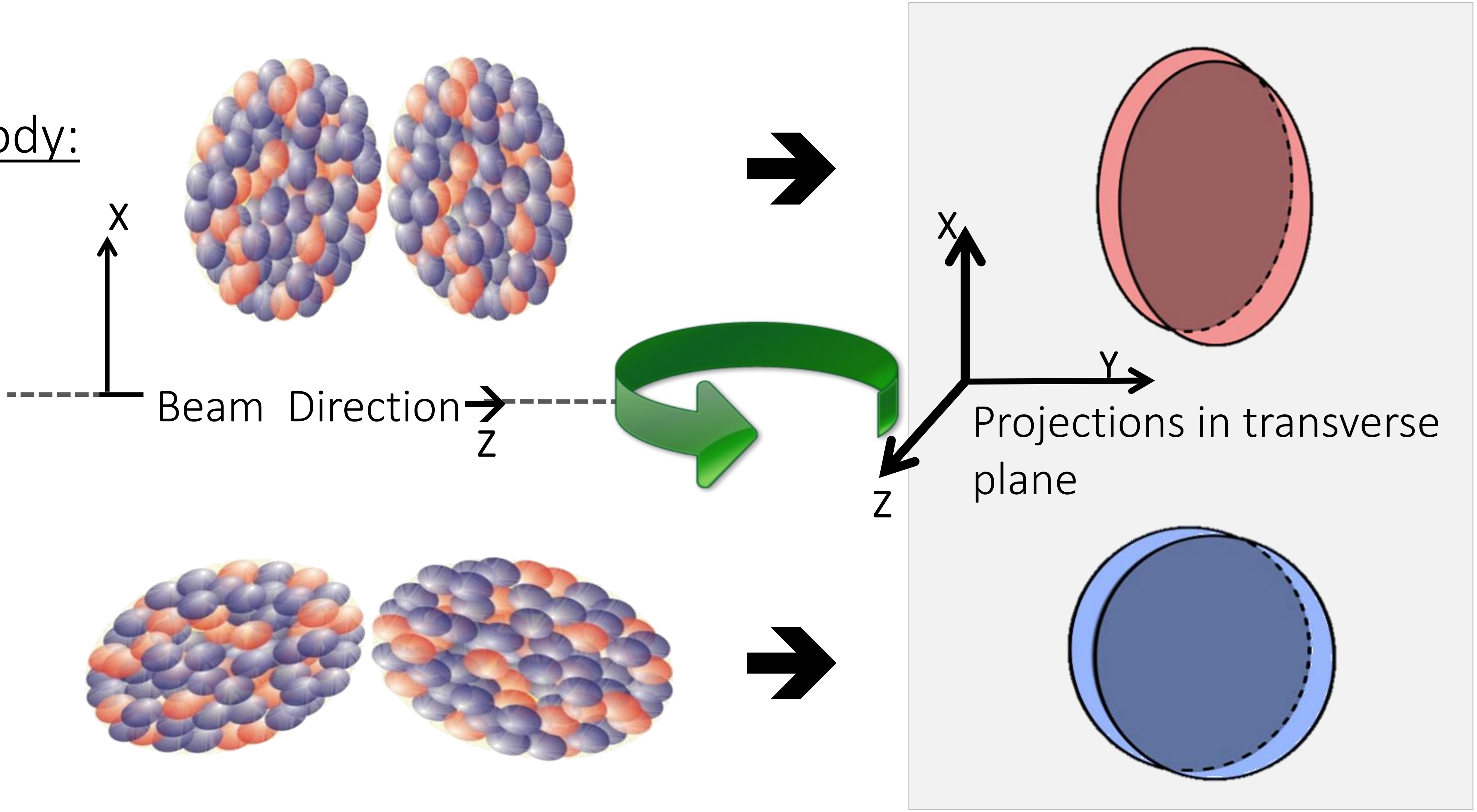
Definitions for desired collision configurations

Body-body:

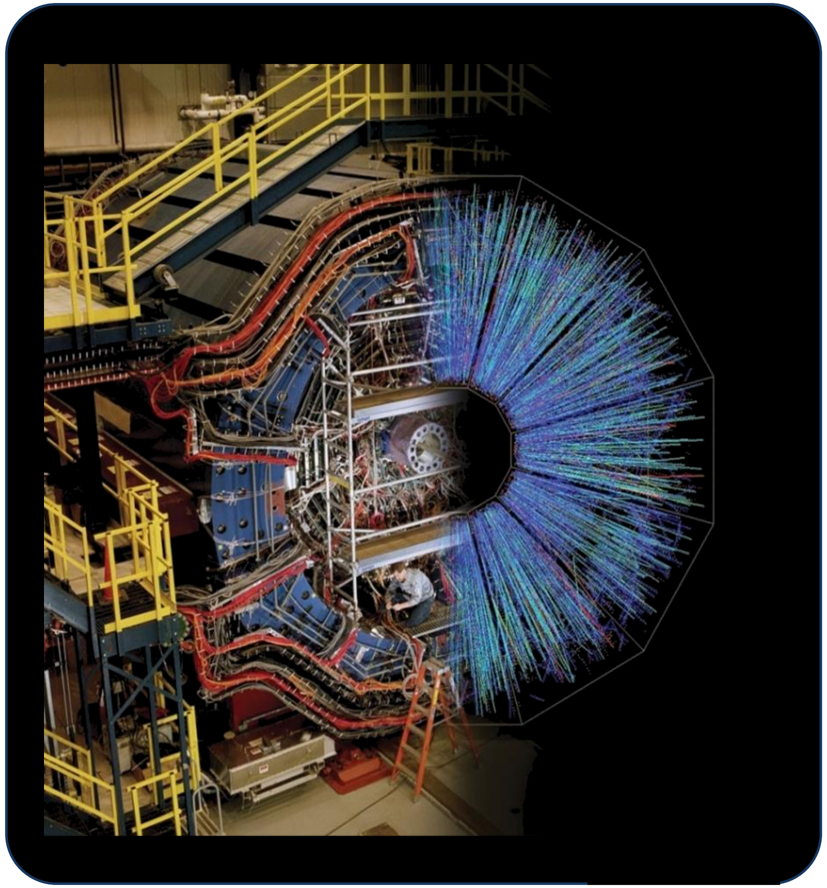
Tip-tip:



Motivation

Selection of tip-tip and body-body collision configurations opens up interesting features in the RHIC uranium data.

- Body-body collisions can be used to study the azimuthal behavior of the path length dependence in jet quenching.
- Tip-tip collisions provide the highest density collisions systems.
- For more, see papers by Heinz and Kuhlman: PRL 94 (2005) 132301
  PRC 72 (2005) 037901



Introduction

1. Initial condition model
   - We use a two parameter MC-Glauber model with fluctuations to study deformed Uranium nuclei
2. Selecting collision orientation
   - We discuss the experimental controls available for selecting orientations
   - We address a model derived "knee" structure in the centrality dependent ellipticity
3. Zero degree calorimeters
   - We use the model analogue of ZDCs to select on fully overlapping collisions
   - We construct an explicit definition for tip-tip and body-body collisions to study the configuration selection efficiency
   - We use forward and backward ZDC correlations to remove noise in tip-tip selection generated by asymmetric ZDC signals

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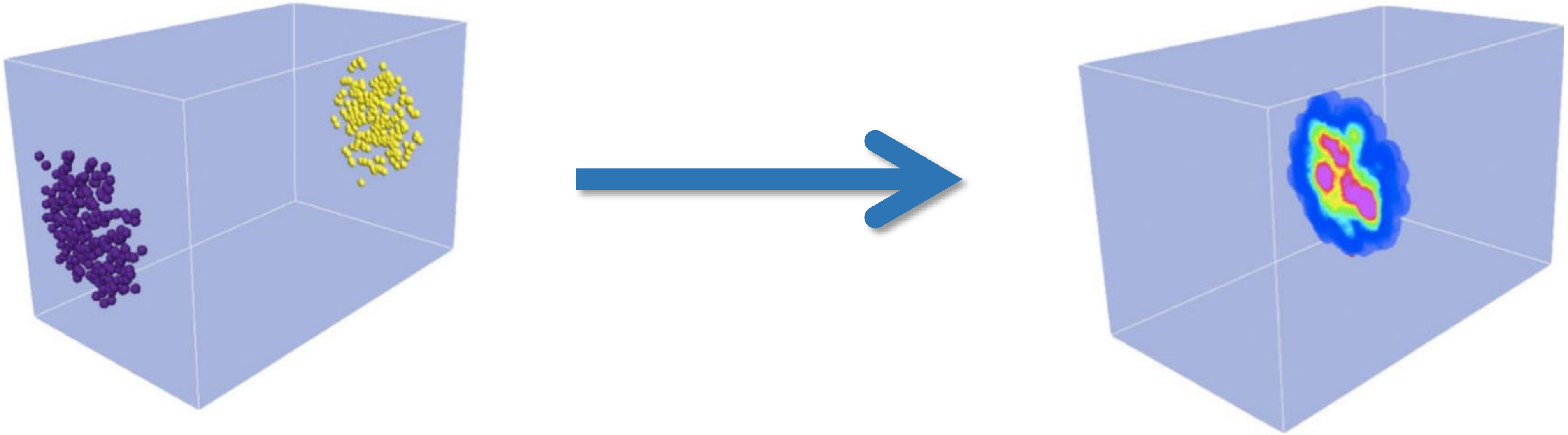


Initial condition model

Deformed Woods Saxon Potential

Uranium has a prolate shape given according to the deformed Woods-Saxon potential

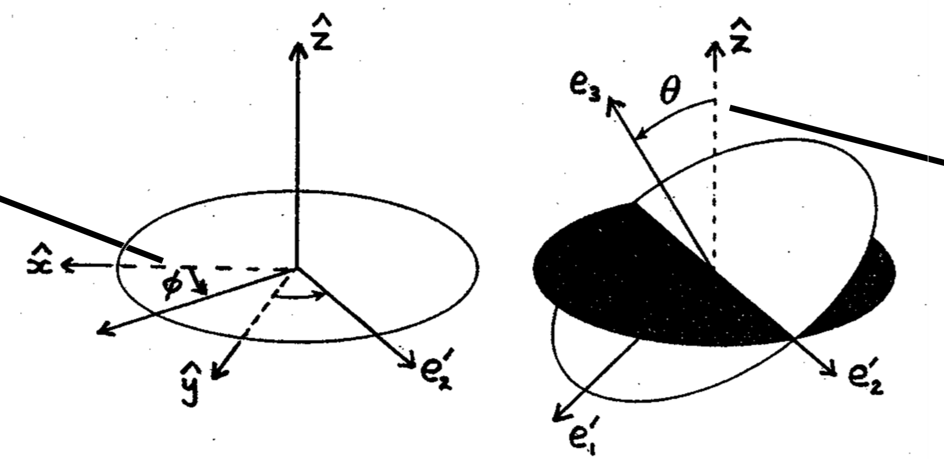
$$\rho(r,\theta) = \frac{\rho_0}{1 + e^{(r - R[1+\beta_2 Y_2^0(\theta) + \beta_4 Y_4^0(\theta)])/d}}$$

$\beta_2 = 0.28$ $\quad d = 0.44$

$\beta_4 = 0.093$ $\quad R = 6.86$

$\rho_0 = 0.166$

Azimuthal angle φ



Polar angle θ

Monte Carlo Glauber (1/2)

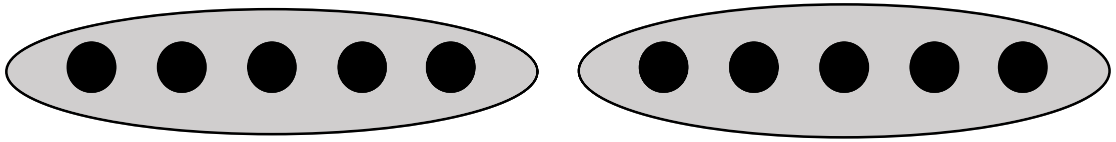
The two-component Monte Carlo Glauber model is used to determine the entropy production from each collision event

$$\frac{dS}{dy} = \frac{(1-\alpha)N_p}{2} + \alpha N_b \qquad \alpha = 0.12$$

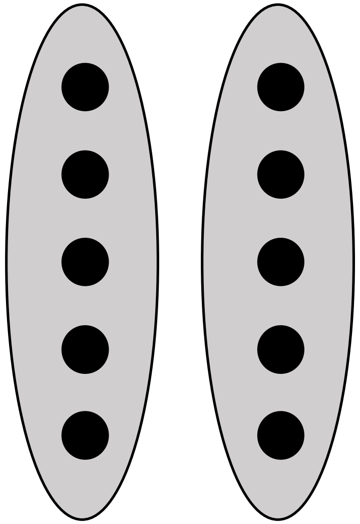
MC-Glauber is motivated by an observed nonlinear dependence of multiplicity on N_p in collisions between spherical nuclei.

Monte Carlo Glauber (2/2)

Binary collisions N_b allow for events with the same number of participants N_p to contribute very different initial integrated entropy densities.



$\boldsymbol{N_p = 10, N_b = 25}$

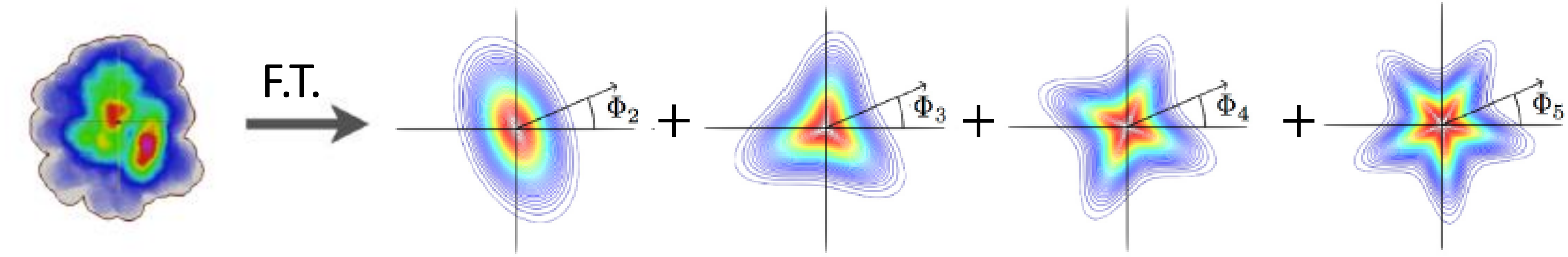


$\boldsymbol{N_p = 10}$
$\boldsymbol{N_b = 5}$

Eccentricities

The shape of the energy distribution e(x,y) in the transverse plane can be described by r^2-weighted eccentricity coefficients

$$\varepsilon_n e^{in\Phi_n} = -\frac{\int dxdy r^2 e^{in\varphi} e(x,y)}{\int dxdy r^2 e(x,y)}$$



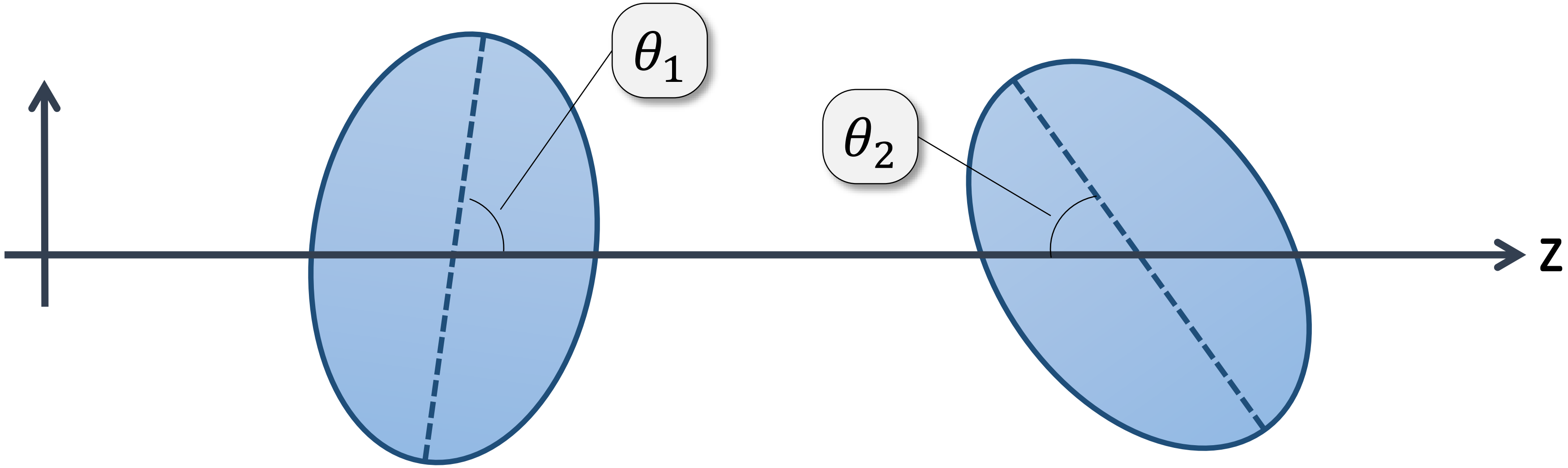
Multiplicity Fluctuations

We implement multiplicity fluctuations as a weight at each nucleon using a Γ distribution

$$\Gamma(u,\kappa) = \frac{u^{\kappa-1}\kappa^{\kappa}e^{-\kappa u}}{\Gamma(\kappa)}, u = \frac{e_{max}}{\langle e_{max}\rangle} \in [0,\infty)$$

We use $1/\kappa = 0.9175$ for the scale parameter of this distribution which has a variance of $\sigma^2 = 1/\kappa$ and average $\langle u\rangle = 1$.

Rybczynski, Broniowski, Stefanek PRC 87 (2013) 044908



Selecting collision orientations

Experimental observables

$$\text{Experiment} \leftrightarrow \text{Initial Condition}$$

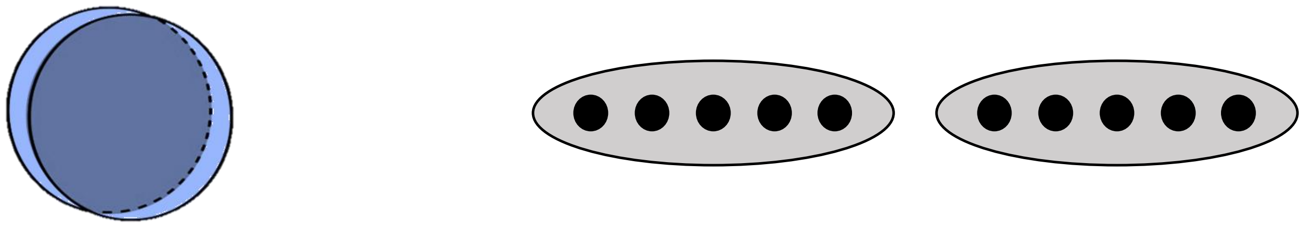
$$v_2 \leftrightarrow \varepsilon_2$$

$$dN/dy \leftrightarrow dS/dy$$

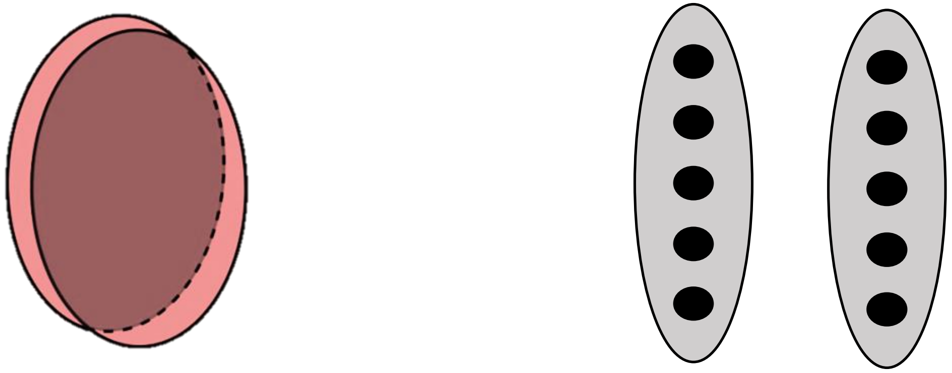
The experimental elliptic flow v_2 and integrated particle distribution dN/dy are used to select orientations—these map linearly to their initial condition analogues ε_2 and dS/dy.

Definitions for desired collision configurations using experimental observables

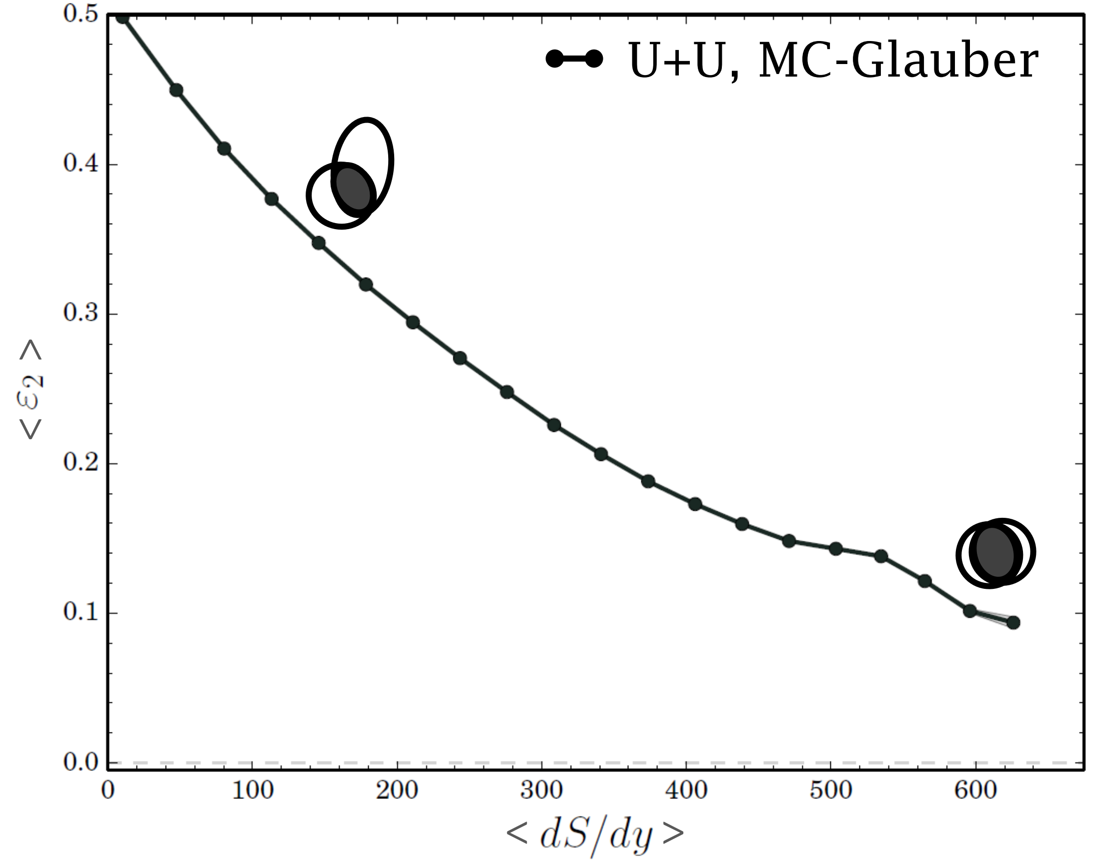
Tip-tip events have small ε_2 and **large N_b**

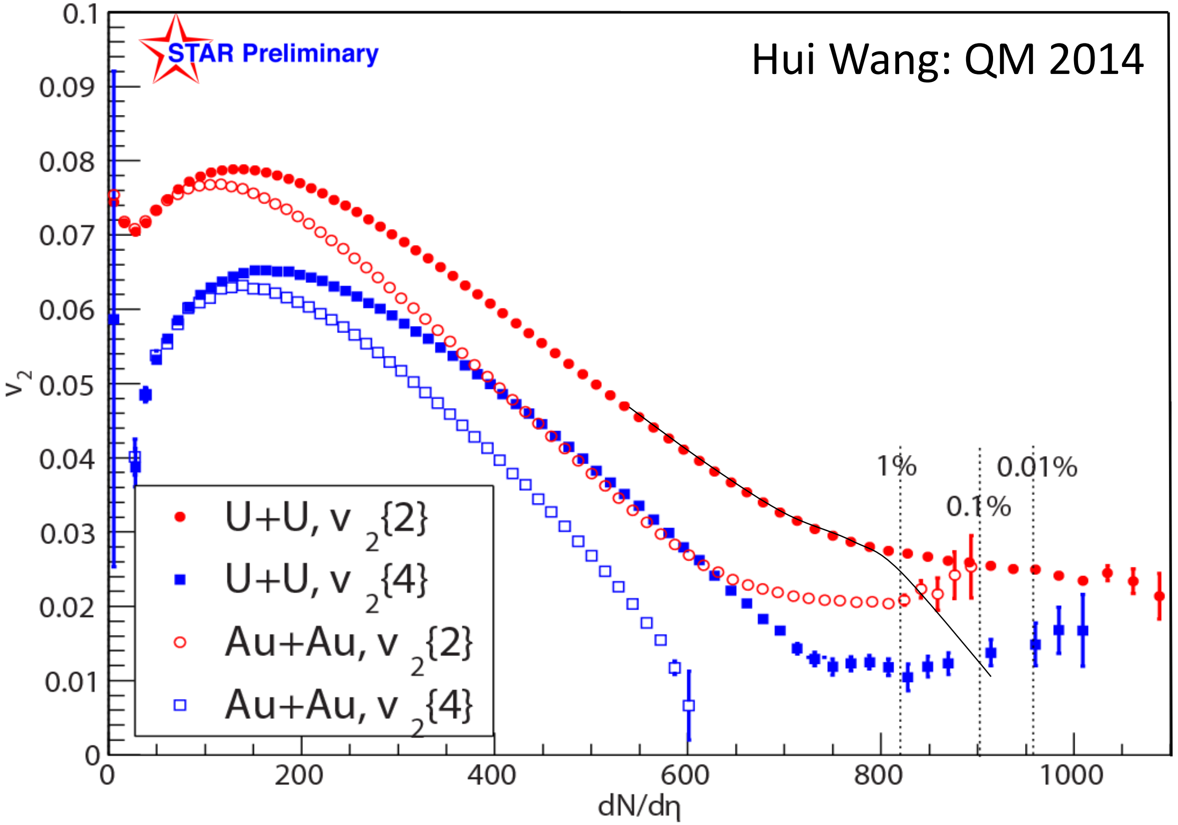


Body-body events have **large ε_2** and small N_b



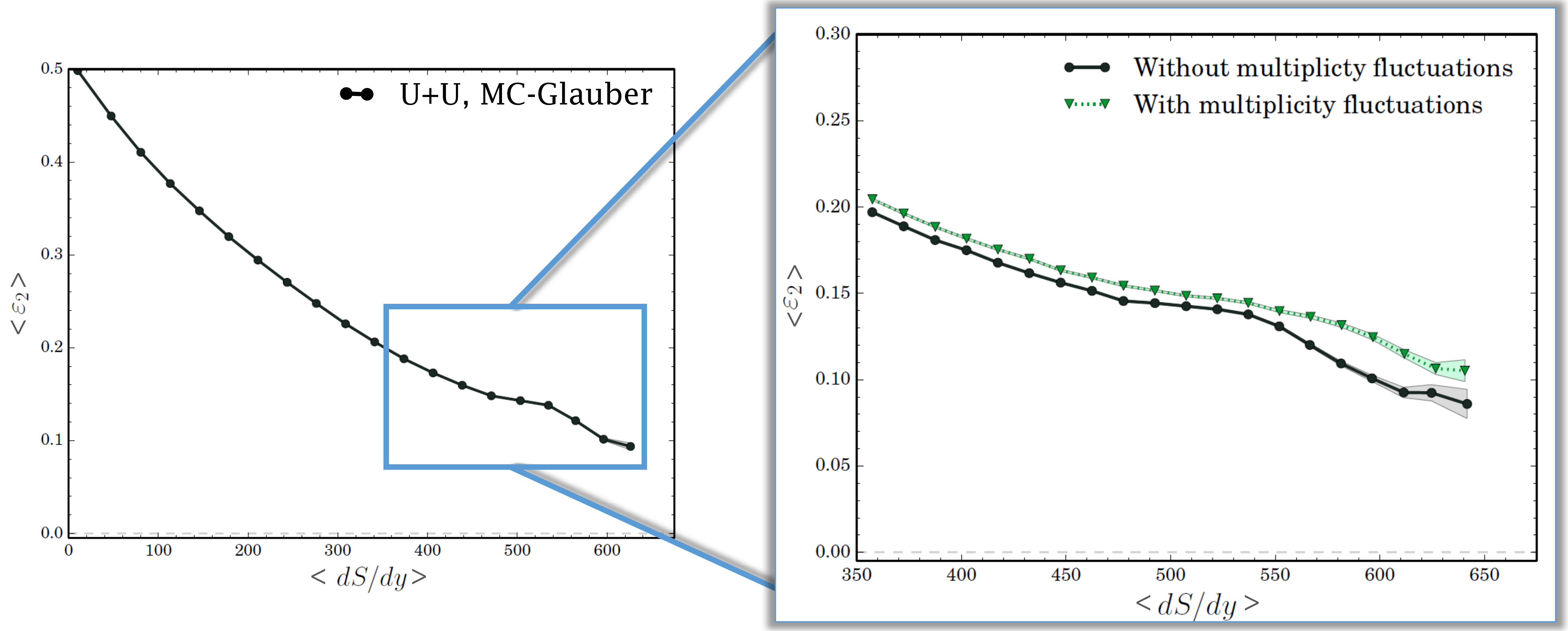
A model dependent "knee" structure





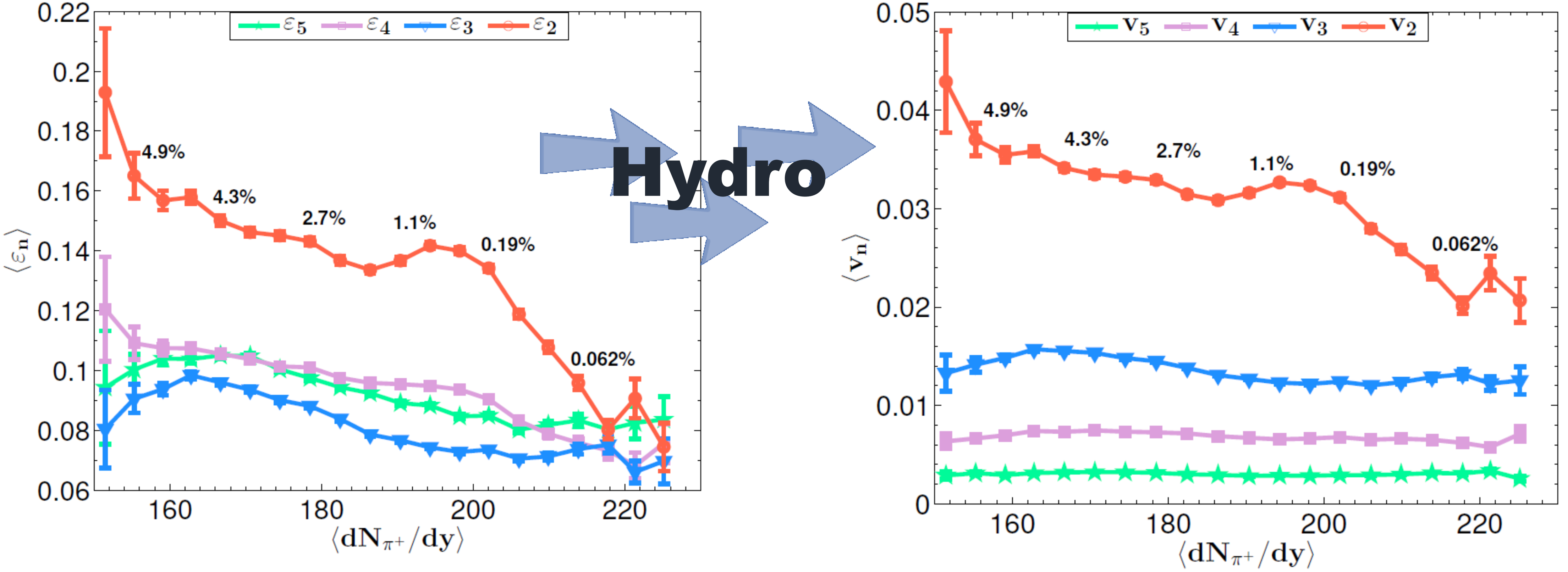
Within the two parameters mixed model, a preferential selection of tip-tip events at high dS/dy results in a "knee" structure in the centrality dependent ellipticity. The knee structure is not seen in STAR results.

"Knee" structure with multiplicity fluctuations

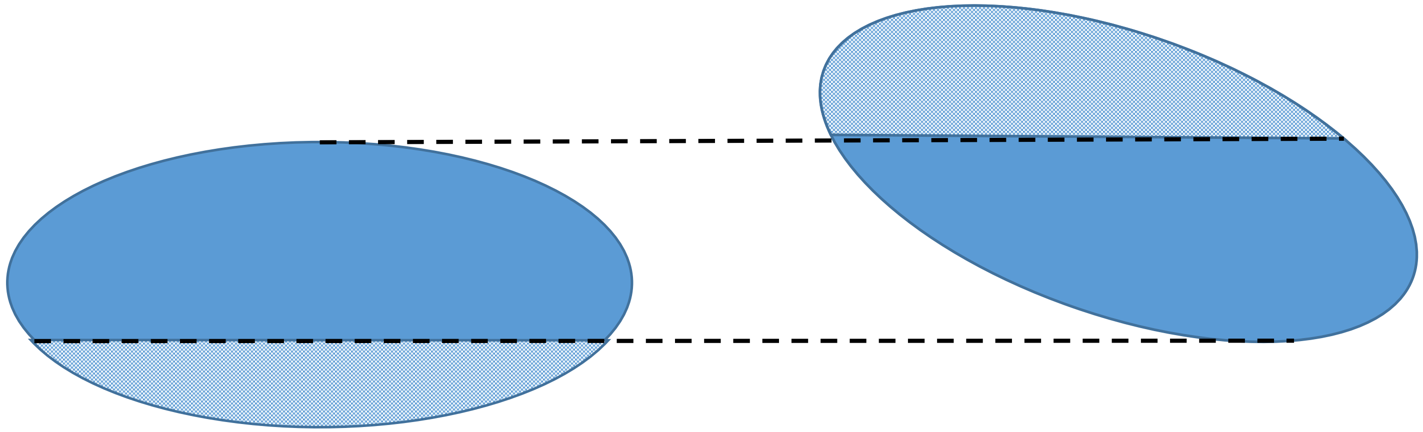


Adding multiplicity fluctuations shifts the "knee" to larger multiplicity and slightly diminishes the effect.

“Knee” structure with hydrodynamics



The “knee” is seen in ε_2 and weakly in ε_4. Event-by-event viscous hydrodynamics are run for a subset of the data for direct comparison to experiment. We find the “knee” is preserved in the final elliptic flow v_2.



Zero Degree Calorimeters:

Tightening the collision geometry by using information about spectators

Zero Degree Calorimeters

Experiment	↔	Initial Condition
v_2	$\leftrightarrow$	ε_2
dN/dy	$\leftrightarrow$	dS/dy
$\%ZDC$	$\leftrightarrow$	$\%N_s$

ZDCs catch neutrons that pass through a collision without participating, giving an idea of the collision overlap—the model analogue is the number of nucleon spectators $N_s = 2\mathrm{A} - N_p$.

We use MC-Glauber initial conditions with multiplicity fluctuations and select on 1% of events that have the smallest N_s.

Definitions for desired collision configurations using Euler angles

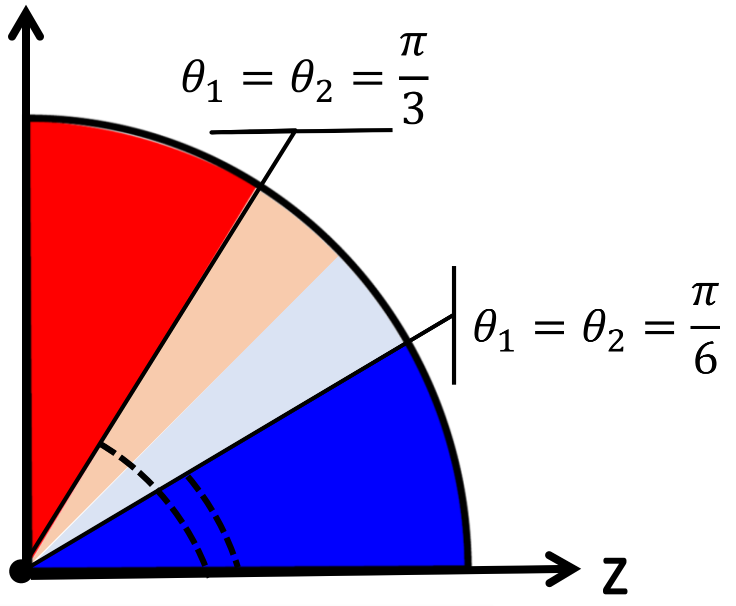
Tip-tip

$$\sqrt{\frac{\cos^2(\theta_1)+\cos^2(\theta_2)}{2}} > \frac{\sqrt{3}}{2}$$

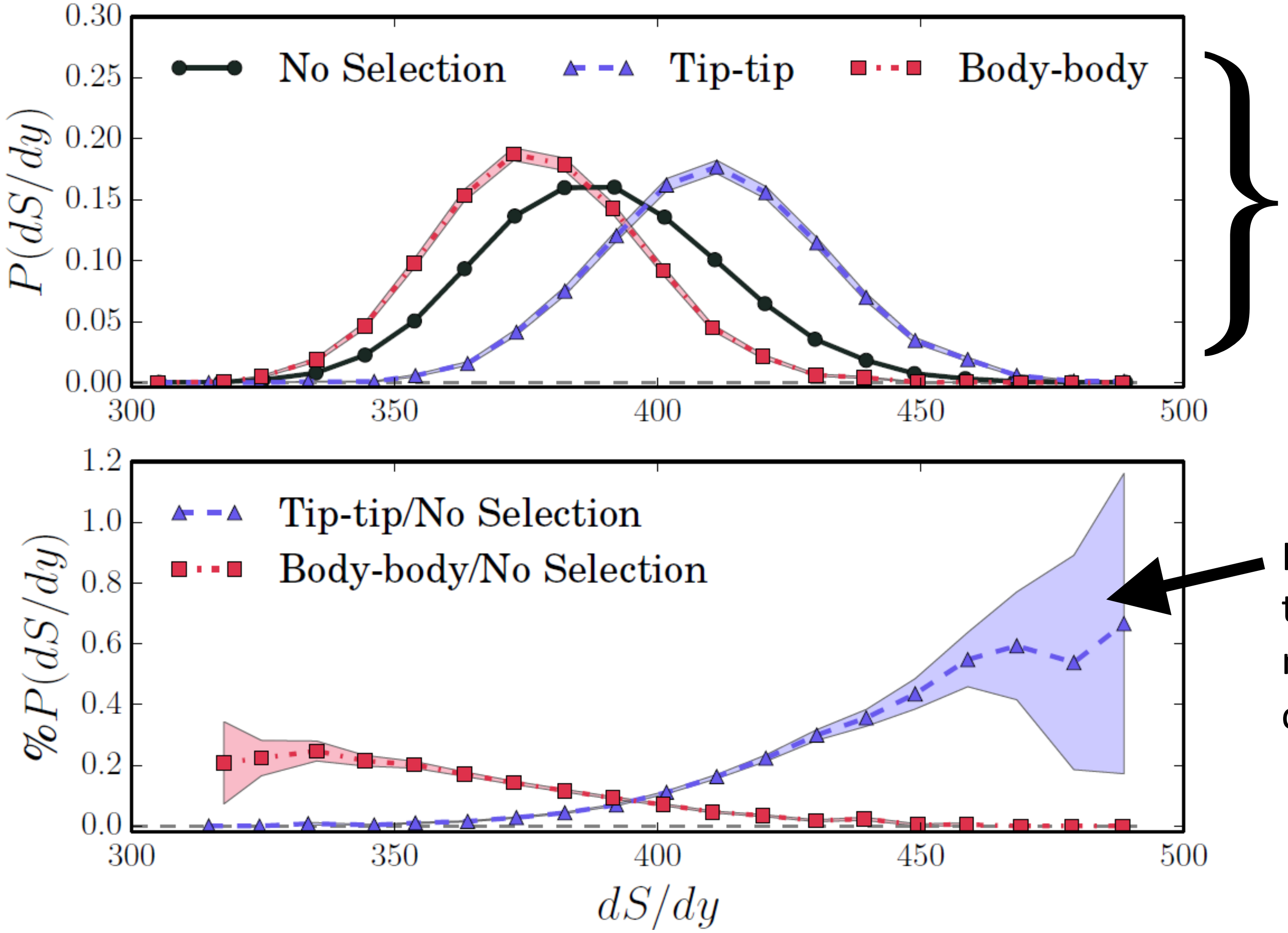
Body-body

$$\sqrt{\frac{\cos^2(\theta_1)+\cos^2(\theta_2)}{2}} < \frac{1}{2}$$

$$|\varphi_1 - \varphi_2| < \pi/10$$



Multiplicity distributions for different collision configurations for 1% ZDC selected events

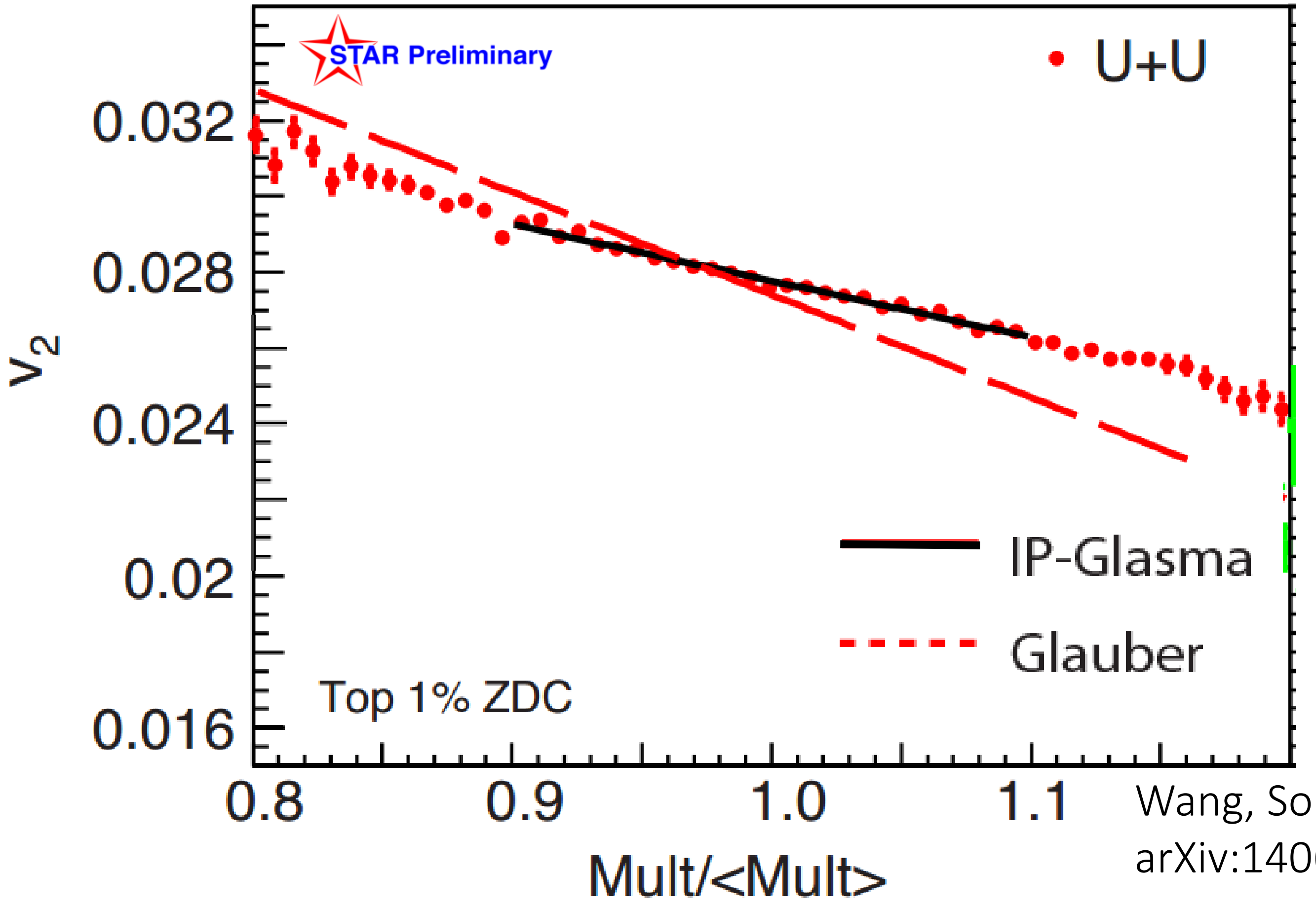


Consistent with suggestion by Heinz and Kuhlman

High selection efficiency for tip-tip is a result of the nonlinearity of N_p in the two component Glauber model

Lower dS/dy have more body-body. Higher dS/dy have more tip-tip.

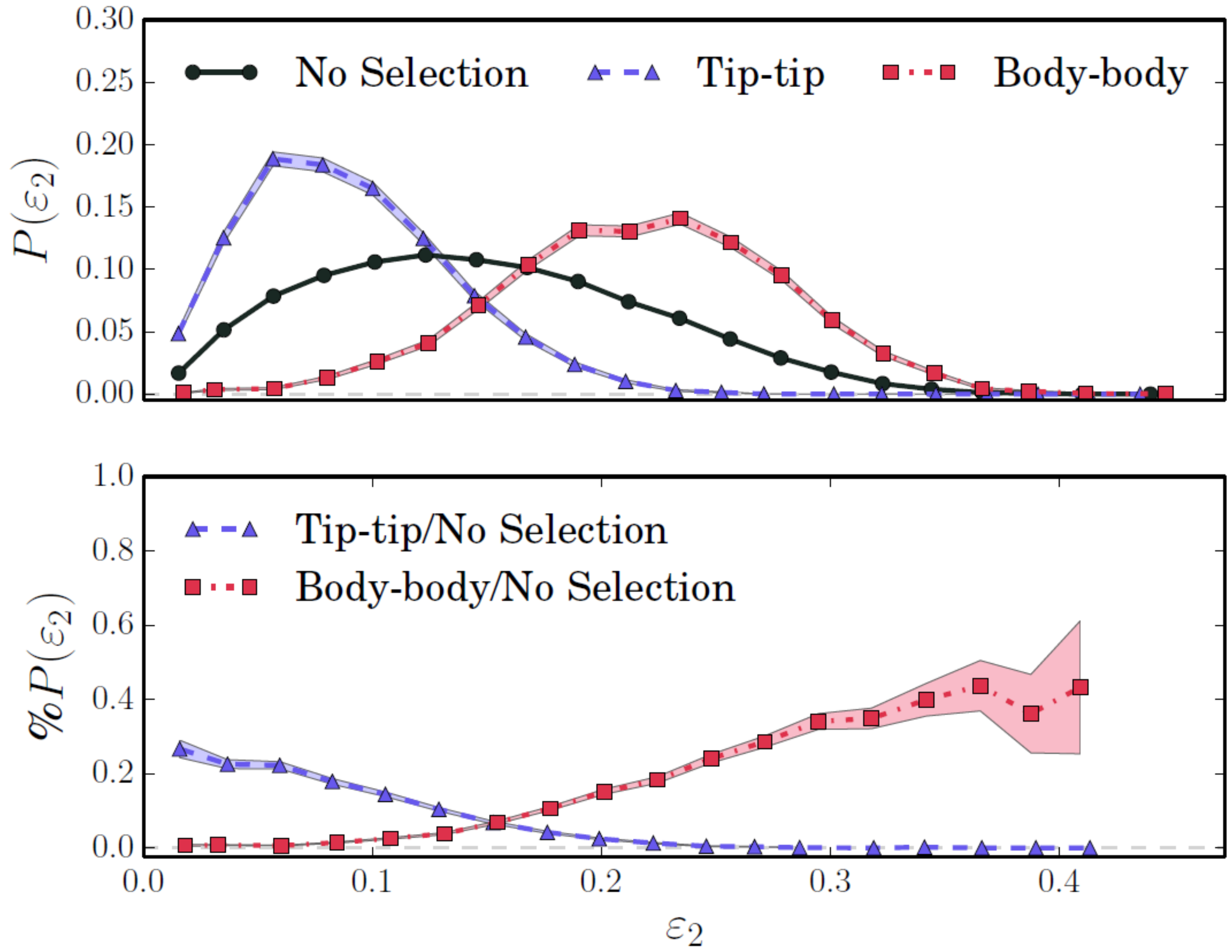
Model differences in elliptic flow vs multiplicity



Wang, Sorensen
arXiv:1406.7522 [nucl-ex]

The nonlinear dependence of N_p on N_b in the 2-component Glauber model results in a steeper slope than in the STAR data and in the IP-Glasma model.

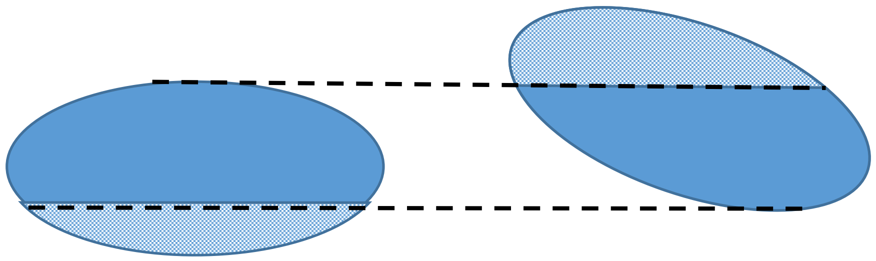
Ellipticity distributions for different collision configurations for 1% ZDC selected events



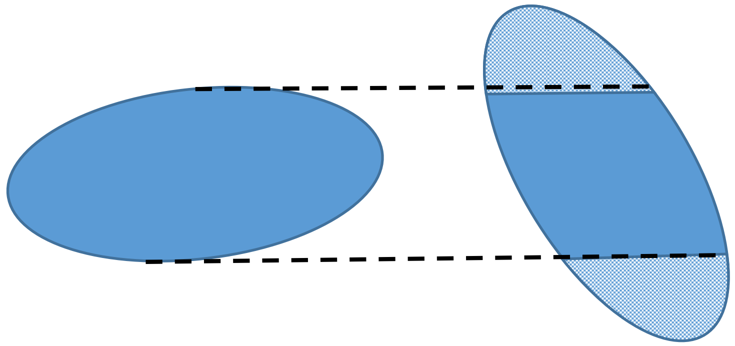
Lower ε_2 have more tip-tip. Higher ε_2 have more body-body.

Correlating ZDCs for additional constraints on collision geometry (1/2)

Events with symmetric ZDC signature are better described by the tip-tip collision criteria than asymmetric events (spectator regions are shaded).



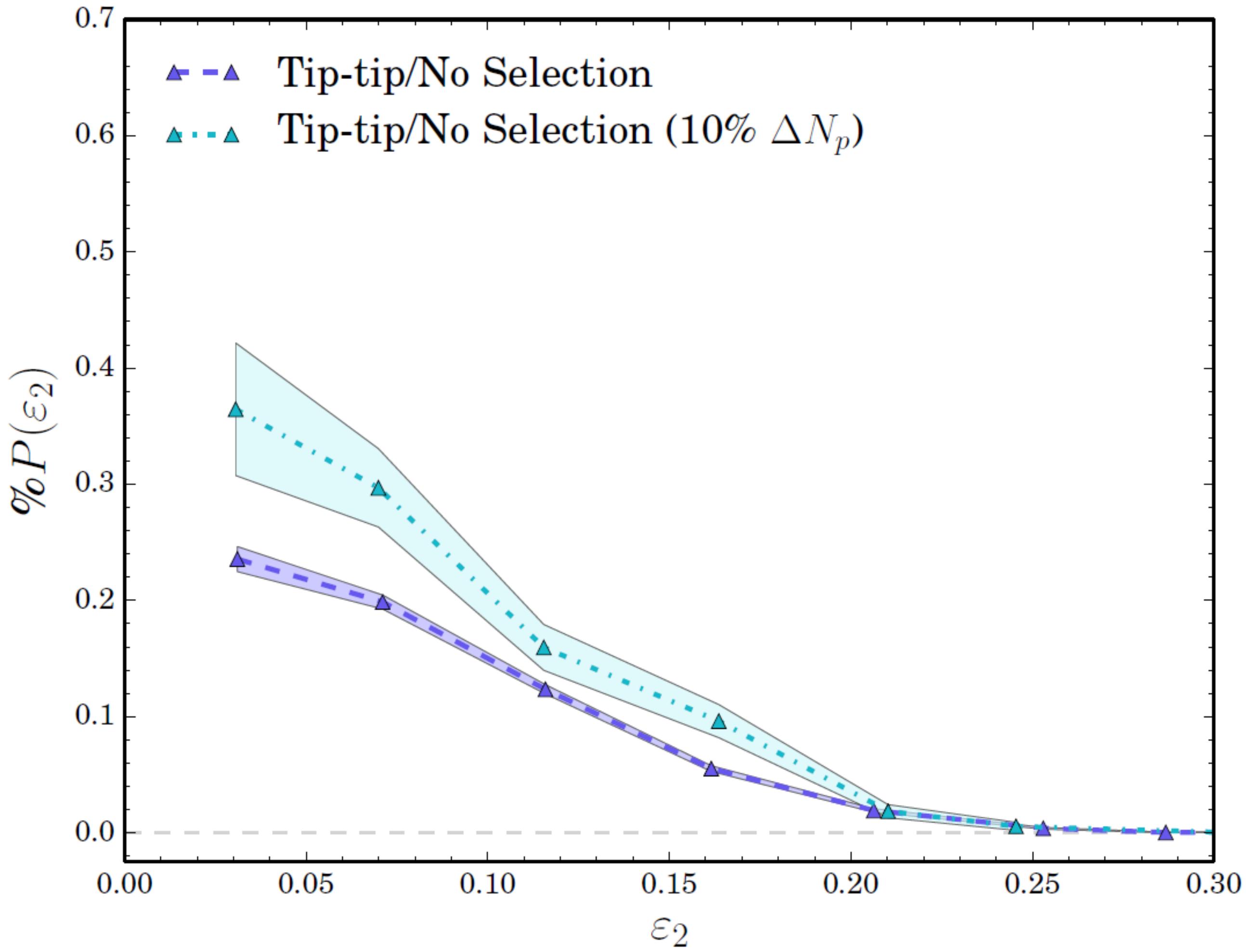
Symmetric ZDC signature contributes more tip-tip



Asymmetric ZDC signature contribute less tip-tip

We define $\Delta N_s = |N_{s,1} - N_{s,2}|$ and select events from the bottom 10% of ΔN_s to diminish the contribution of asymmetric collisions and increase tip-tip selection efficiency.

Correlating ZDCs for additional constraints on collision geometry (2/2)



Selection efficiency of tip-tip collisions increases by removing asymmetric noise.

Conclusions, future study

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The MC-Glauber "knee" structure in the multiplicity dependent ellipticity is preserved after hydrodynamic evolution. It is weakened by multiplicity fluctuations.

For events cut on 1% ZDC, selection efficiency for tip-tip by cutting additionally on large dS/dy is $\sim$50%, for body-body by cutting on low dS/dy it is never above 20%. These numbers are model dependent and correlate with the "knee" structure.

Selection efficiency of ε_2 is $\sim$25% for tip-tip and $\sim$40% for body-body. Tip-tip results can be improved to $\sim$35% using ZDC correlation.

Future study

In the process of running a hydrodynamic analysis of collision events that includes multiplicity fluctuations in the initial conditions.

Will use correlated forward and backward ZDC to study tip-body collisions.

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