Influence of initial-state shape deformations in ultracentral collisions

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Puzzle of ultracentral Pb+Pb elliptic flow

- Pb+Pb ultracentral v2 was measured by CMS [1] 5 years ago
- Hydrodynamic calculations with current initial state models overestimate Pb+Pb ultracentral v2, see eg. [2]

What drives eccentricity of symmetric ultracentral collisions for spherical nuclei? Is the dominant factor correctly modeled?

Nuclear deformation

- In U+U collisions, eccentricity is 70% larger compared with eccentricity calculated with β in the input distribution, for 0-1%
- We investigate shape of Pb as sampled from single particle distribution and the effect on eccentricity
- Deformation in Glauber is currently implemented with a deformed surface in the Fermi distribution [3]:

$$\rho(r,\theta) = \frac{\rho_0}{1+e^{(r-R_0-R_0\beta_2 Y_{20}(\theta)-R_0\beta_4 Y_{40}(\theta))/a}}$$

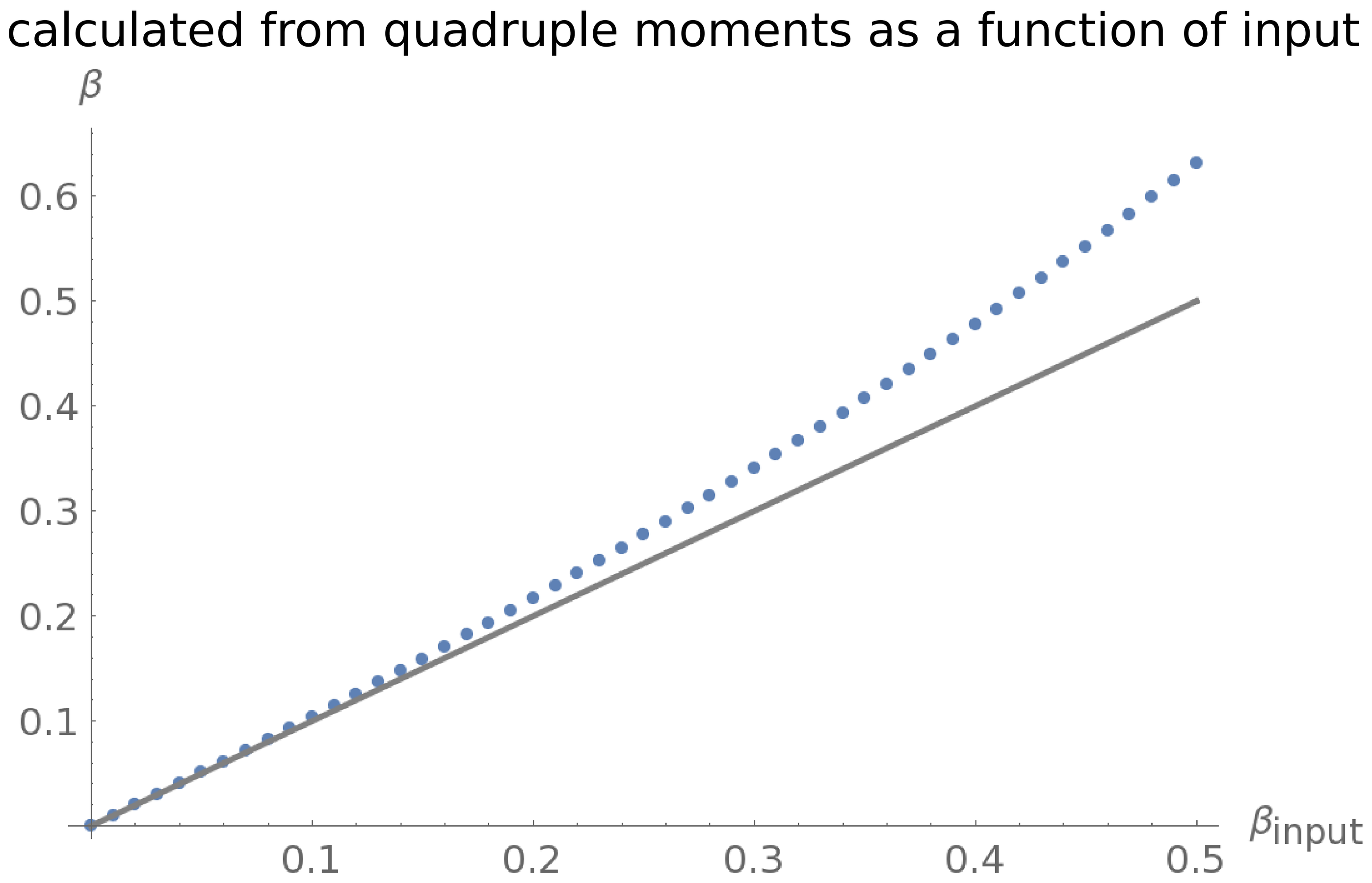
- Event by event we need an effective deformation β. We follow Gilbreth, Alhassid and Bertsch [4] and use the quadruple moment Q. For zero skin depth,

$$Q_{2\mu} = \frac{3}{\sqrt{5\pi}} R^2 A \alpha_{2\mu}$$

$$\beta^2 = \sum_{\mu} \alpha_{2\mu}^2$$

- β calculated from the distribution, with first order skin depth correction, agrees decently with the input (gray: diagonal). ^{238}U radius and skin depth is used

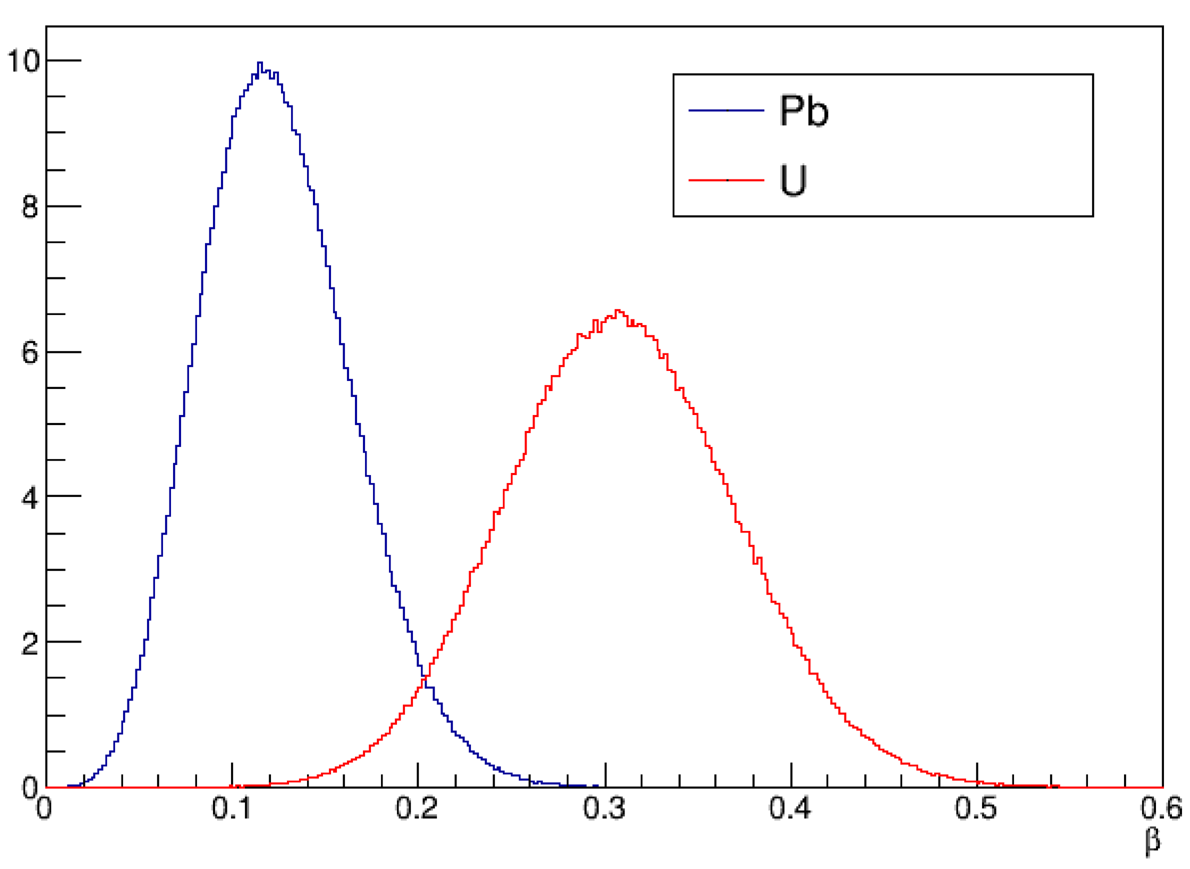
β calculated from quadruple moments as a function of input

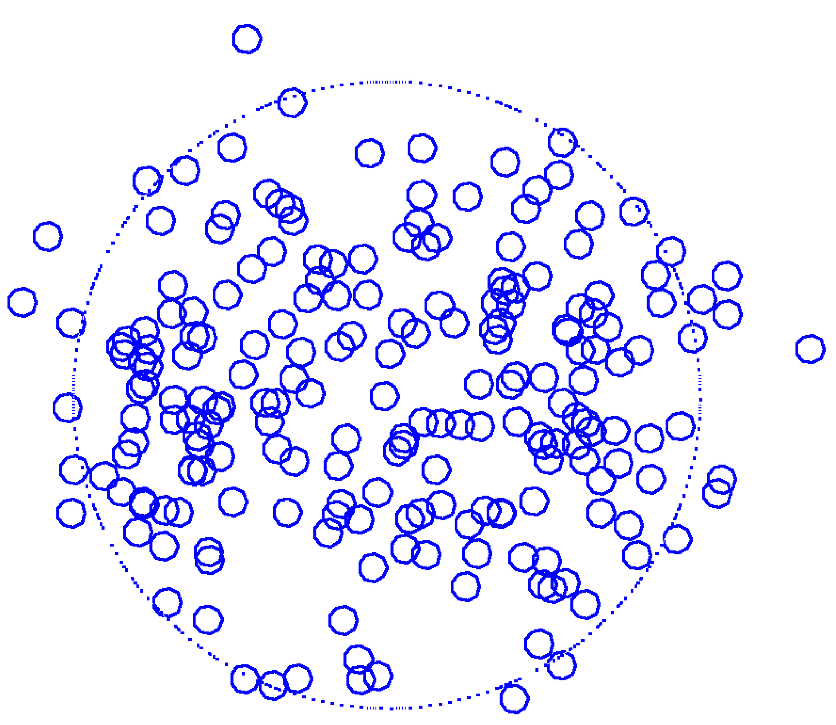


Event by event β distribution

- β for Pb has a wide range, with significant overlap with U, and a sizable rms value 0.13
- In this work we investigate the effect of this wide β distribution. The dependence of β on NN correlations will be shown in later work.

Distribution of β for Pb and U





Highly deformed Pb configuration generated from spherical single-particle distribution, β=0.37

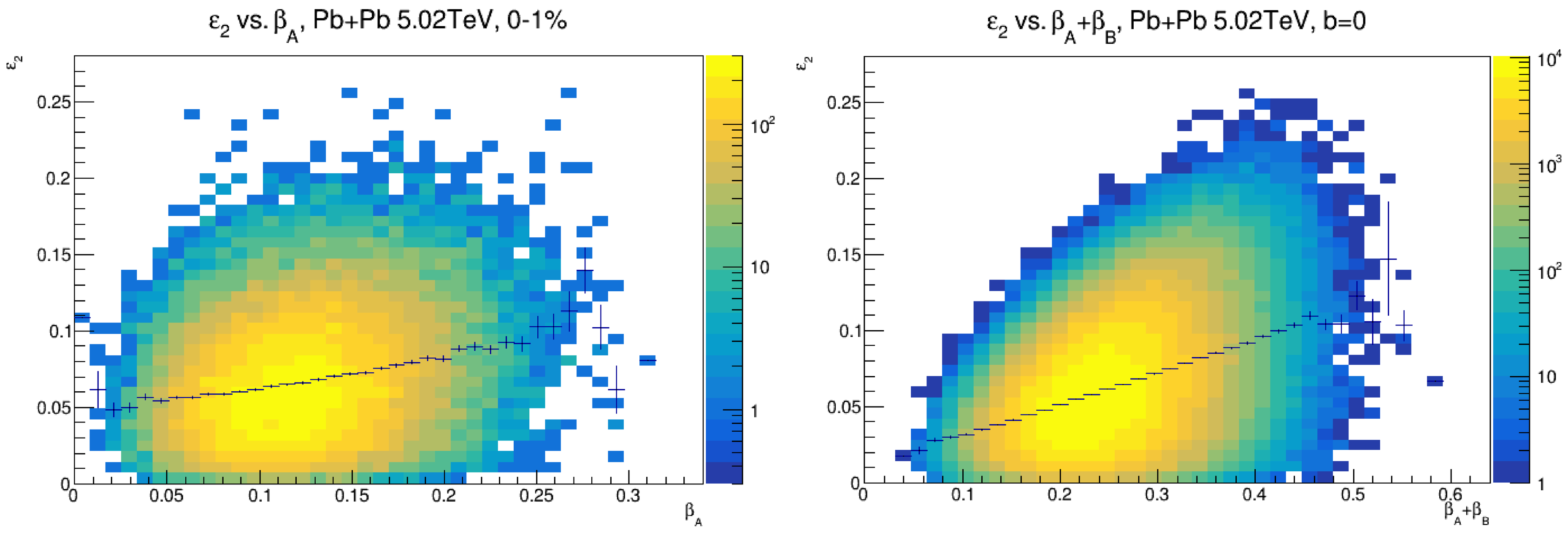
$$\langle x^2 \rangle = 14.3\mathrm{fm}^2$$

$$\langle y^2 \rangle = 7.6\mathrm{fm}^2$$

Nucleons are plotted with radius 0.3fm

Influence of β on eccentricities

- The conditional mean of eccentricity as a function of β is approximately linear. Here we only select on one of the nuclei
- For b=0, the deformation of the nuclei dictates the maximum possible eccentricity. It is hard to get a sizable eccentricity when the deformations of both nuclei are small.

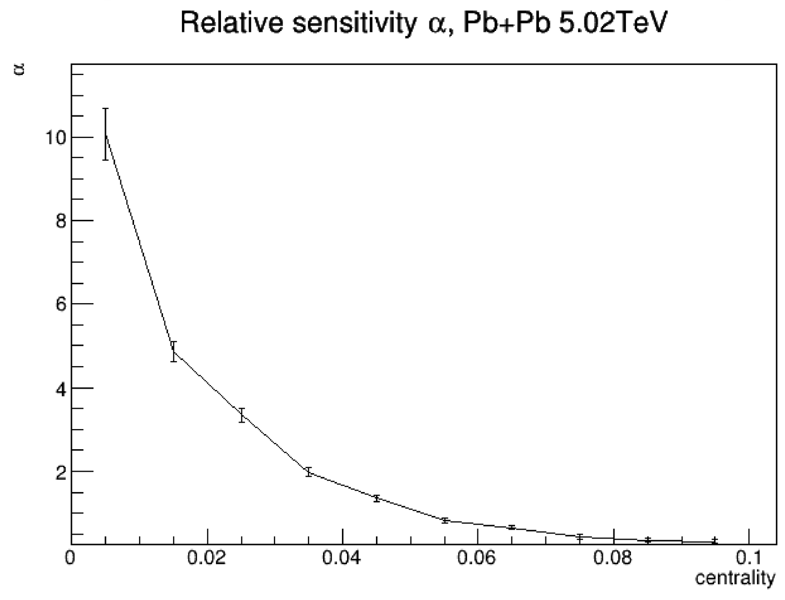


- The linear effect can be captured with a fit

$$\varepsilon_2 = \varepsilon_{20}(1+\alpha(\mathrm{cent})(\beta_{\mathrm{A}}+\beta_{\mathrm{B}}))$$

so α measures the fractional sensitivity to the β's

- We find that α drops quickly as a function of centrality



- In this study eccentricities are calculated from a Monte Carlo quark Glauber code, although we think the effect exists whenever nucleons are sampled from a single-body distribution. Single-particle distribution parameters taken from [3]

Scaling test

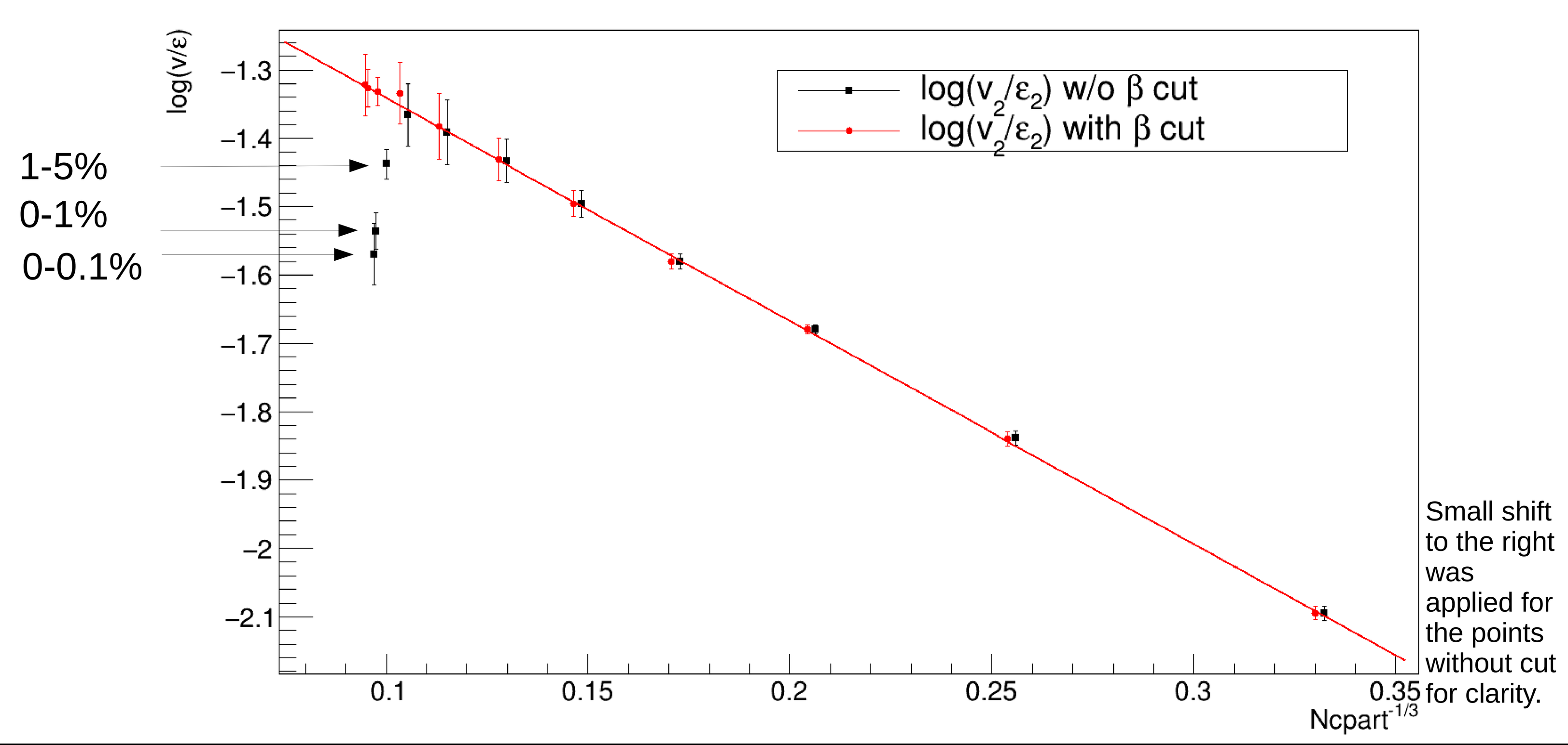
- We model hydrodynamic response by acoustic scaling (see eg. [5])

$$\log\frac{v_n}{\varepsilon_n} \propto -\frac{n^2\eta}{sRT} \propto M^{-1/3} \propto N_{\mathrm{cpart}}^{-1/3}$$

where R and T are characteristic size and temperature, and M is multiplicity. We use number of constituent quark participants as a proxy for multiplicity [7]

- We use ATLAS 5.02TeV Pb+Pb flow data([6]) for pT=0.5-0.8GeV. It contains v2 for ultracentral bins 0-0.1% and 0-1%.
- We find with a cut β<=0.1207, v2 is scaled. βrms=0.094. There is almost no change in e3 so the scaling of v3(see [5]) is preserved

Acoustic scaling without and with a β cut



Summary

- Event by event we calculated the deformation parameter β for each nucleus from the nucleons
- By sampling from the single-body distribution we get a sizable rms β=0.13
- For Pb+Pb collisions, β's determines the maximum possible eccentricity for b=0, and has large effect for 0-5% centrality. Deformation drives central e2 for spherical systems
- Putting a cut on β allows us to get a set of eccentricities that scales v2. This suggests sampling from single-body distribution gives an unphysically wide β distribution

Acknowledgment

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References

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