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 eq. [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 $\beta$ 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]:
  $$\rho(r,\theta) = \frac{\rho(0)}{1 + e^{-r/R_c}} R_c^2 \sin(\theta)$$
- Event by event we need an effective deformation $\beta$. We follow Gilbreth, Alhassid and Bertsch [4] and use the quadruple moment $Q_{2n}$.
  $$\beta = \sum_p\alpha_p$$
  $\beta$ calculated from the distribution, with first order skin depth correction, agrees decently with the input (gray: diagonal). 238U radius and skin depth is used

β calculated from quadruple moments as a function of input $\beta_{\text{input}}$

- $\beta$ 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 $\beta$ distribution. The dependence of $\beta$ on NN correlations will be shown in later work.

Event by event $\beta$ distribution

- Highly deformed Pb configuration generated from spherical single-particle distribution, $\beta=0.37$
  
  $$\langle x^2 \rangle = 14.36 \text{fm}^2$$
  $$\langle y^2 \rangle = 7.66 \text{fm}^2$$
  Nucleons are plotted with radius 0.3fm

Influence of $\beta$ on eccentricities

- The conditional mean of eccentricity as a function of $\beta$ 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.

Scaling test

- We model hydrodynamic response by acoustic scaling (see eg. [5])
  $$\log \frac{e_3}{e_2} \propto -\frac{nT}{R^3} \propto M^{-1/3} N_{v2}^{-1/3}$$
  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 $pT=0.5-0.8$GeV. It contains $v2$ for ultracentral bins 0-0.1% and 0-1%.
- We find with a cut $\beta\leq0.1207$, $v2$ is scaled. $\beta_{\text{rms}}=0.094$. There is almost no change in $e3$ so the scaling of $v3$(see [5]) is preserved

Summary

- Event by event we calculated the deformation parameter $\beta$ for each nucleus from the nucleons
- By sampling from the single-body distribution we get a sizable rms $\beta=0.13$
- For Pb+Pb collisions, $\beta$'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 $\beta$ allows us to get a set of eccentricities that scales $v2$. This suggests sampling from single-body distribution gives an unphysically wide $\beta$ distribution

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References