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Exploring the effects of α-clustered structure of ^{16}O nuclei in ^{16}O-^{16}O collisions at the LHC within a CGC + Hydro framework

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Based On:
S. Prasad, N. Mallick, R. Sahoo, and G. G. Barnaföldi, Phys. Lett. B 860, 139145 (2025)

Introduction

- Quark-gluon plasma (QGP) is a thermalised and deconfined medium of partons exhibiting collective behaviour
- Recently, QGP-like signatures in high multiplicity pp and p-Pb collisions have been observed
- Small systems like pp, p-Pb are interesting from QGP point of view

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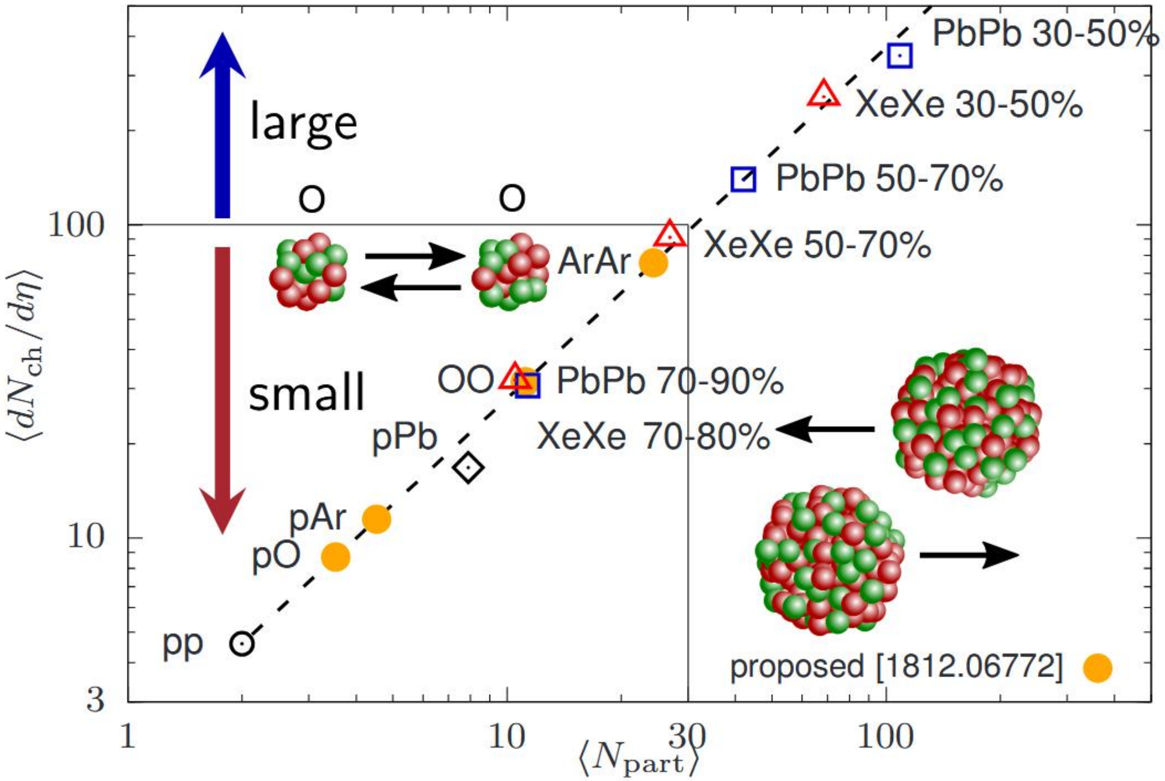
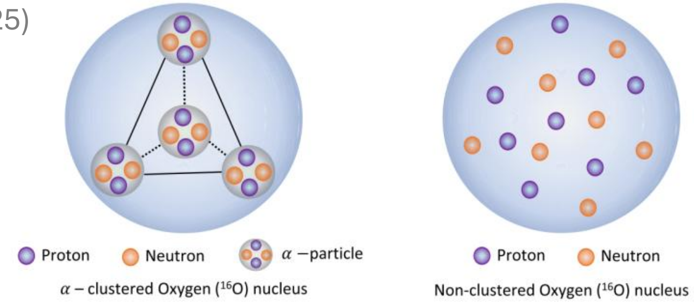
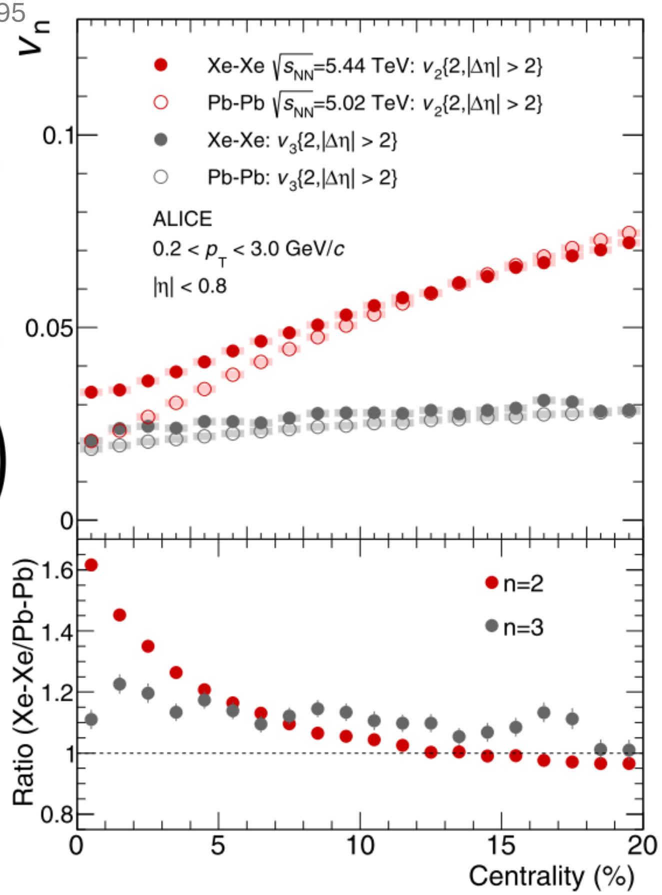




$$\frac{dN}{d\phi} \propto \left(1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\phi - \psi_n)\right]\right)$$

- v_n: Coefficients of Fourier expansion → Anisotropic flow coefficients
- v_2: Elliptic Flow, v_3: Triangular flow

ALICE Collaboration, Physics Letters B 784 (2018) 82-95



Nuclear structure of Oxygen

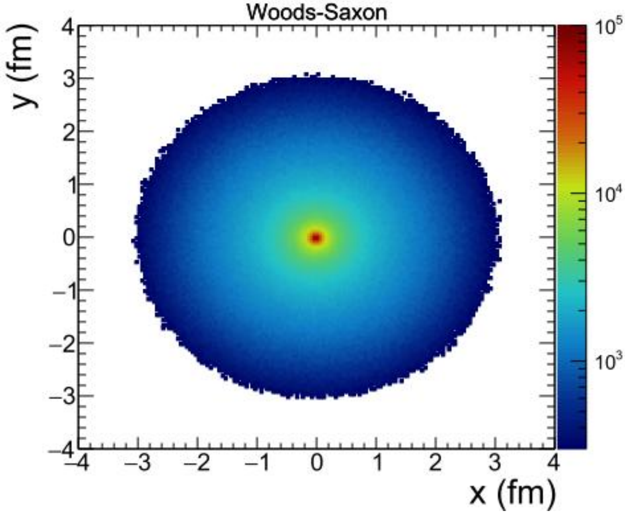
Woods-Saxon nuclear density

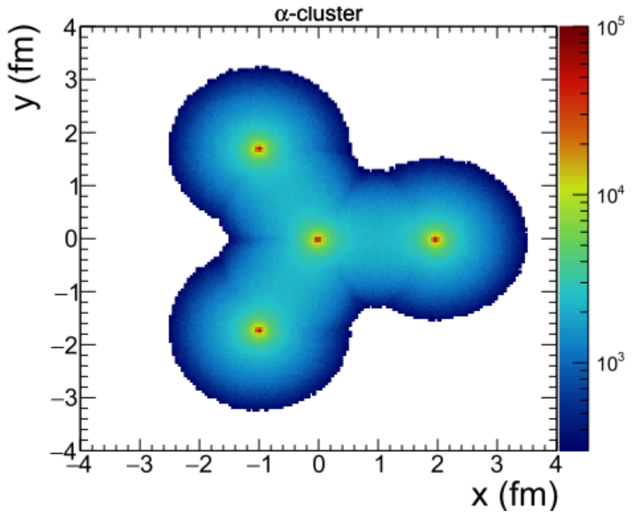
- Mean radius, r_0 = 2.608 fm
- Nuclear skin depth, a = 0.513 fm
- Deformation parameter, w = −0.051

$$\rho(r) = \rho_0 \frac{1 + w\left(\frac{r}{r_0}\right)^2}{1 + \exp\left(\frac{r - r_0}{a}\right)}$$

α-cluster structure

- Four α-particles at the corners of a regular tetrahedron of side length 3.42 fm
- Inside the α-particles, (2p, 2n) are distributed following a Woods-Saxon nuclear profile (r_0= 0.964 fm, w = 0.517 and a = 0.322 fm)
- The regular tetrahedron is rotated in 3D to make each nucleus unique





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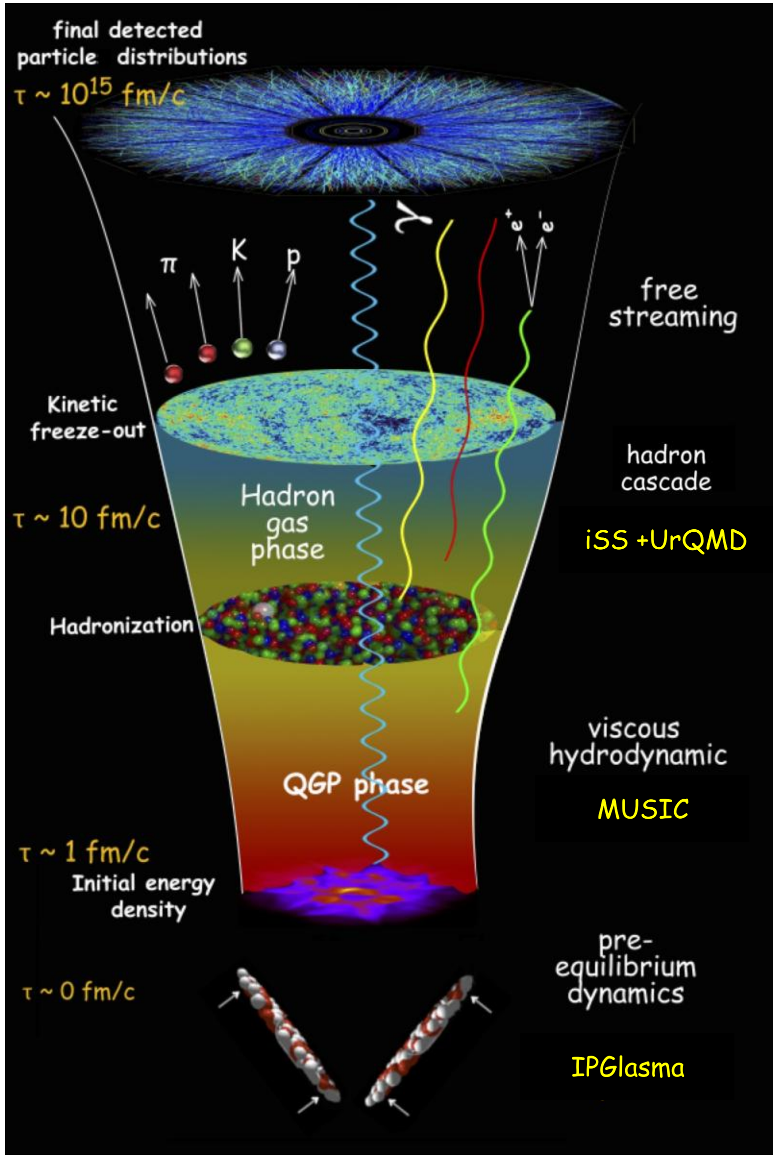
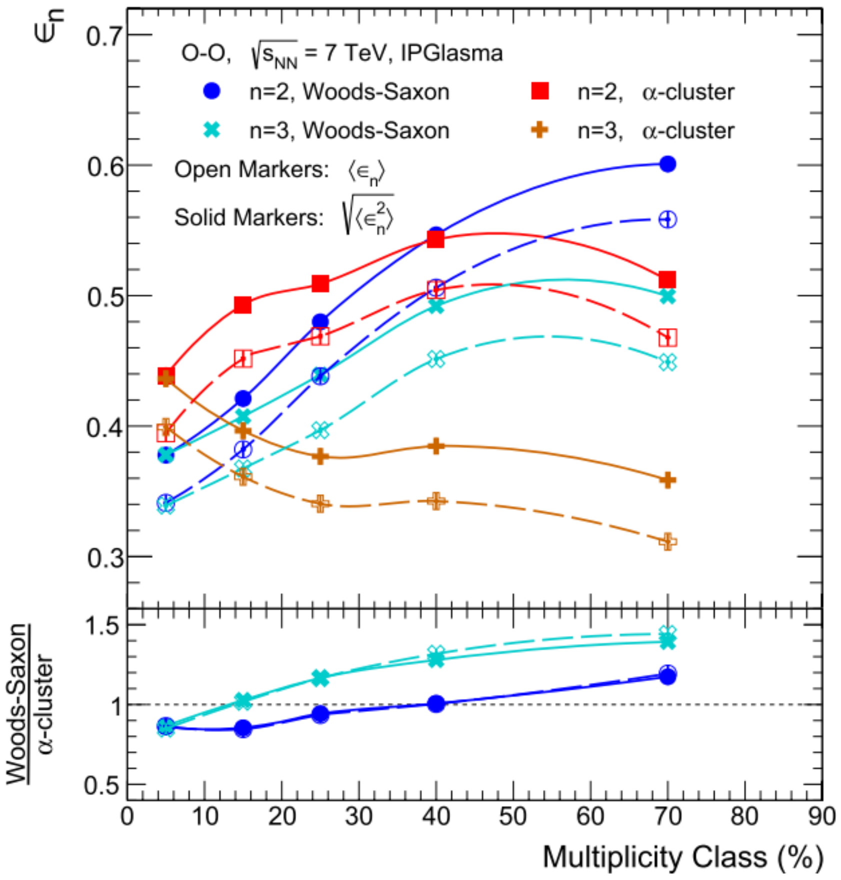
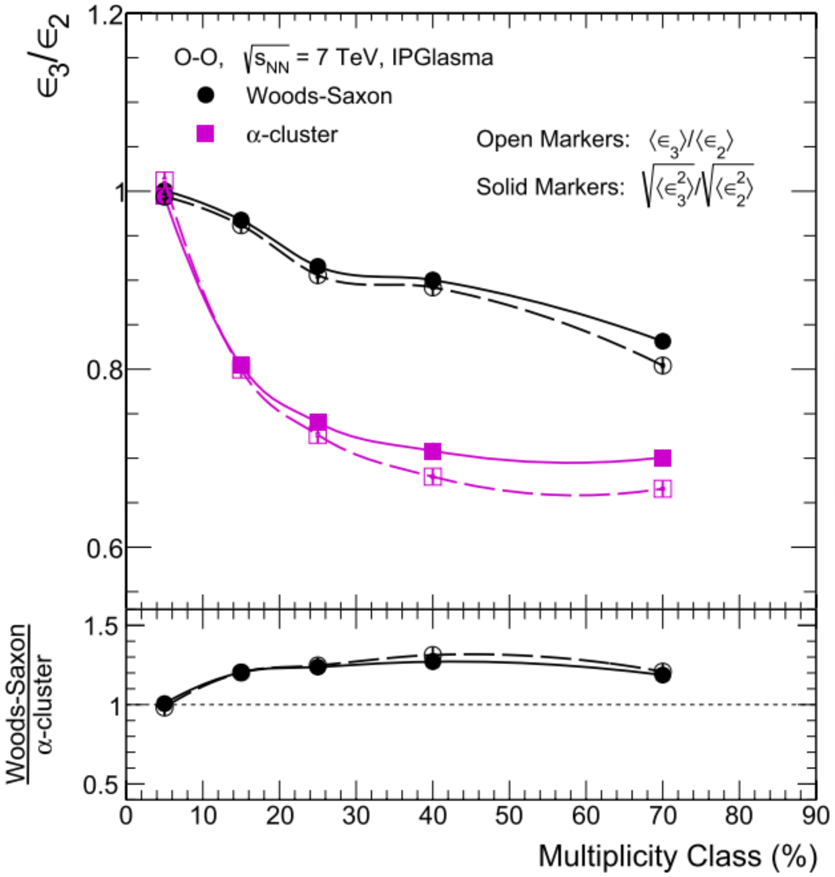


Results: Eccentricity and Triangularity





- The eccentricity and triangularity can quantify the degree of elliptic and triangular nature of participant overlap region

$$\epsilon_n = \frac{\sqrt{\langle r^n \cos(n\phi_{\text{part}})\rangle^2 + \langle r^n \sin(n\phi_{\text{part}})\rangle^2}}{\langle r^n\rangle}$$

- Eccentricity: initial spatial anisotropy based on geometry of the overlap region
- Triangularity: spatial anisotropy generated due to density fluctuations

- For α-cluster case, ϵ_3 decreases with a decrease in final state multiplicity → Opposite trend as compared to Woods-Saxon
- Sharp fall in ϵ_3/ϵ_2 from (0-10)% to (10-20)% multiplicity class

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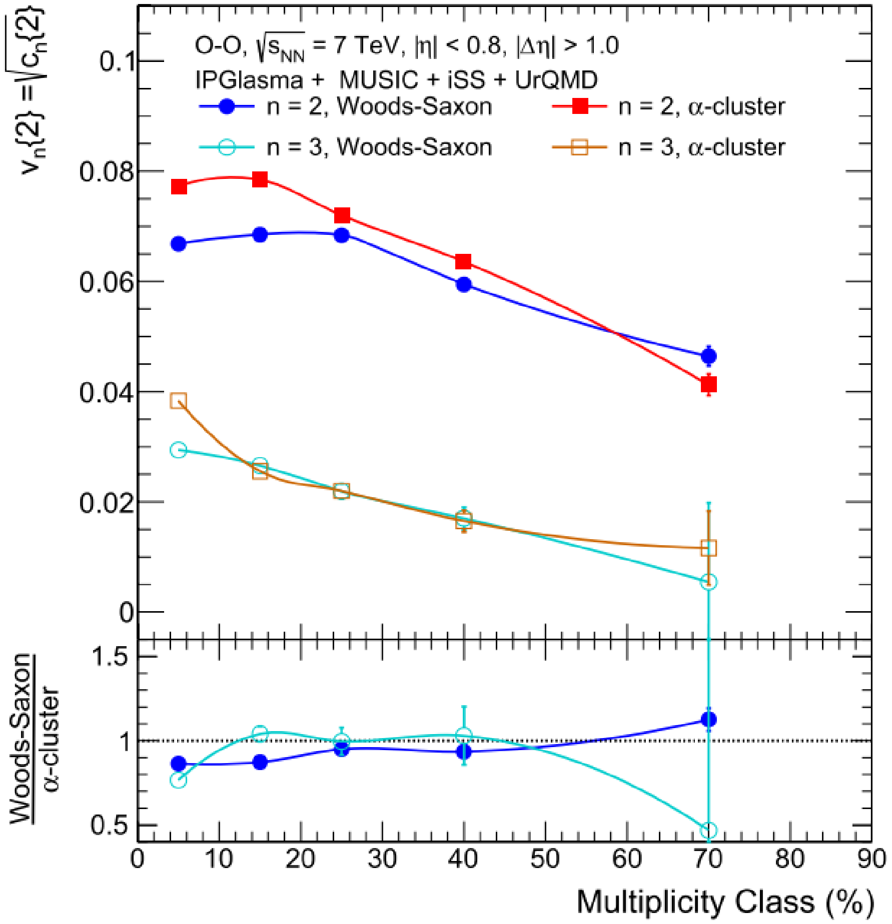
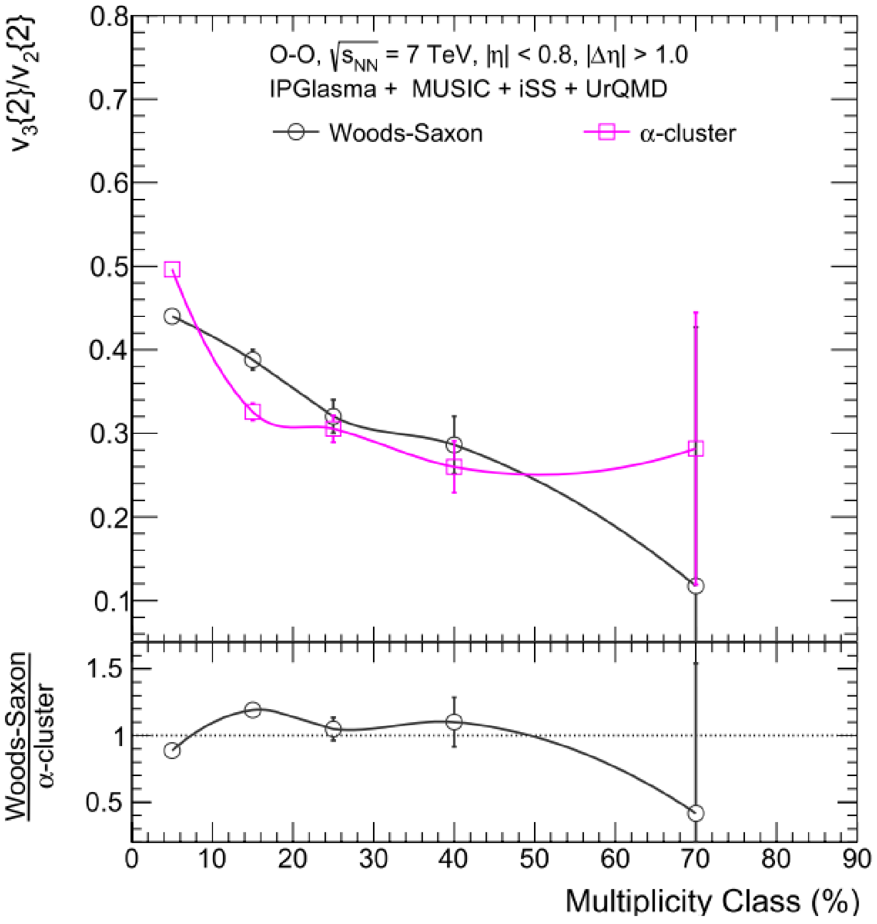
Results: Elliptic and Triangular Flow

- Q-cumulant method is used
- Both v_2 and v_3 decreases with decrease in multiplicity
- v_2 for α-cluster is greater than Woods-Saxon except for (50-90)% multiplicity class
- For (0-10)% Mult. Class, v_3 for α -cluster is greater than Woods-Saxon





- For (0-10)% Multiplicity class, v_3/v_2 is higher for α-cluster case as compared to Woods-Saxon, after which Woods-Saxon leads the values
- Similar to ϵ_3/ϵ_2, we find a sharp drop in the value of v_3/v_2 from (0-10)% to (10-20)% multiplicity class

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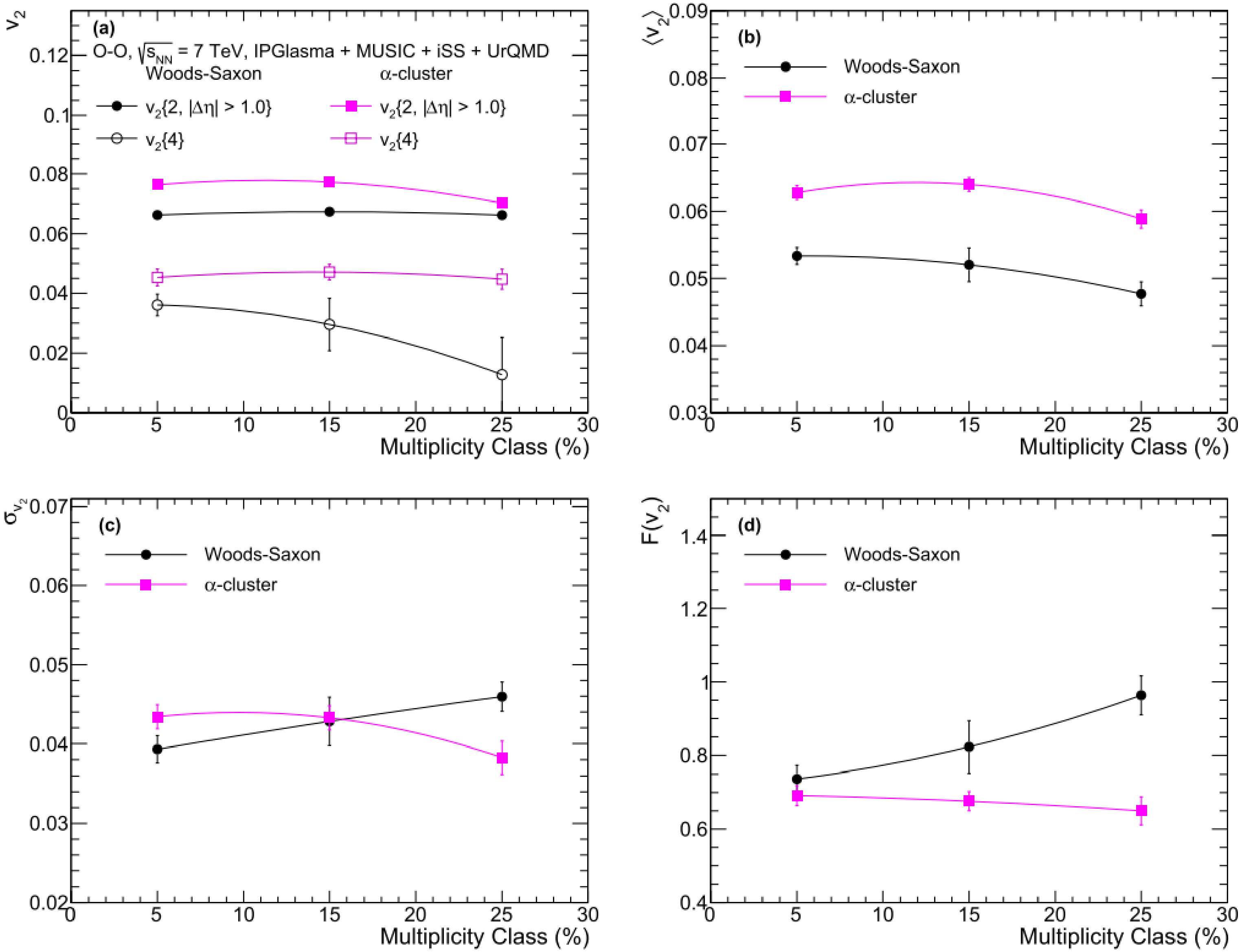
Results: Flow Fluctuations



$$\langle v_n \rangle = \sqrt{\frac{v_n^2\{2, |\Delta\eta|\} + v_n^2\{4\}}{2}}$$

$$\sigma_{v_n} = \sqrt{\frac{v_n^2\{2, |\Delta\eta|\} - v_n^2\{4\}}{2}}$$

$$F(v_n) = \frac{\sigma_{v_n}}{\langle v_n \rangle}$$

- $v_2\{4\}$ is nearly independent of change in multiplicity class within (0-30)%
- $\langle v_2 \rangle$ for both Woods-Saxon and α-cluster cases decrease with decrease in final state multiplicity
- σ_{v_2} has opposite trends for Woods-Saxon and α-cluster cases
- $F(v_2)$ increases when going from (0-10)% to (20-30)% Multiplicity class

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Summary

- In this study, we have investigated the effect of the presence of α-clustered structure on final state anisotropic flow and their fluctuations in O-O collisions
- This study uses a hybrid of IPGlasma + MUSIC + iSS + UrQMD model
- One finds both elliptic and triangular flow values are larger for the α-cluster case as compared to a Woods-Saxon profile
- Observables related to fluctuations can be more suitable to probe the initial α-cluster structure in O-O collisions at LHC
- Although the study of nuclear density profile is a matter of low energy nuclear physics, the present study motivates us to look for signatures of clustered nuclear structure in the high energy collider experiments

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Thank You