



Theoretical Study of Cluster Structures in Light Nuclei Across Energy Scales

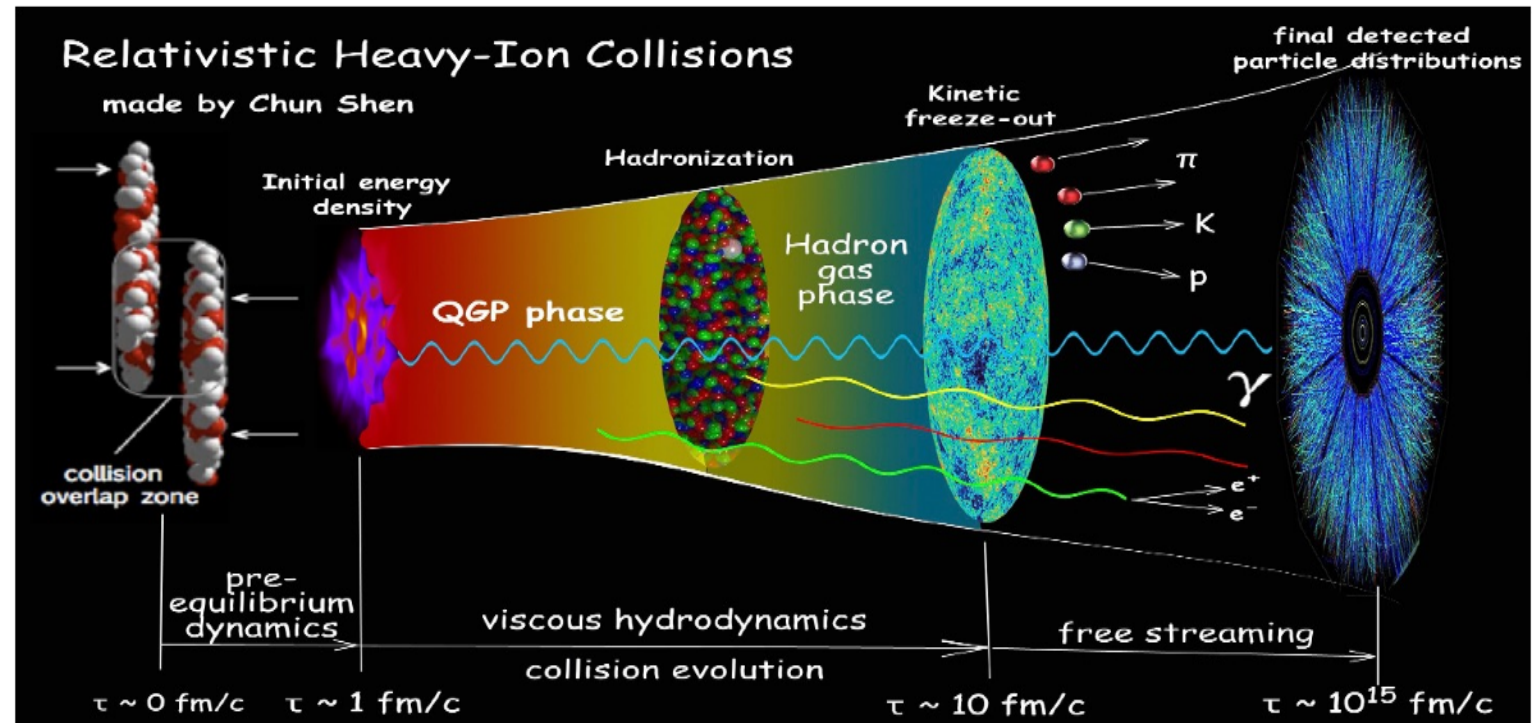
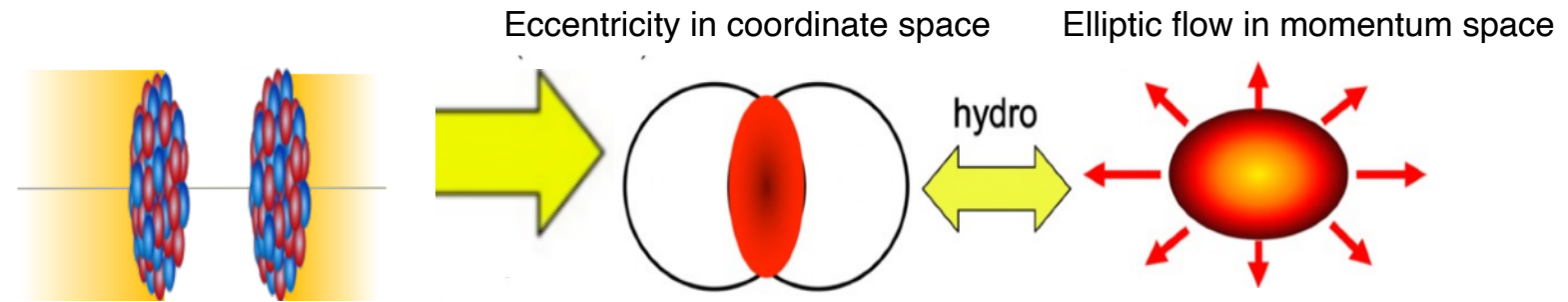
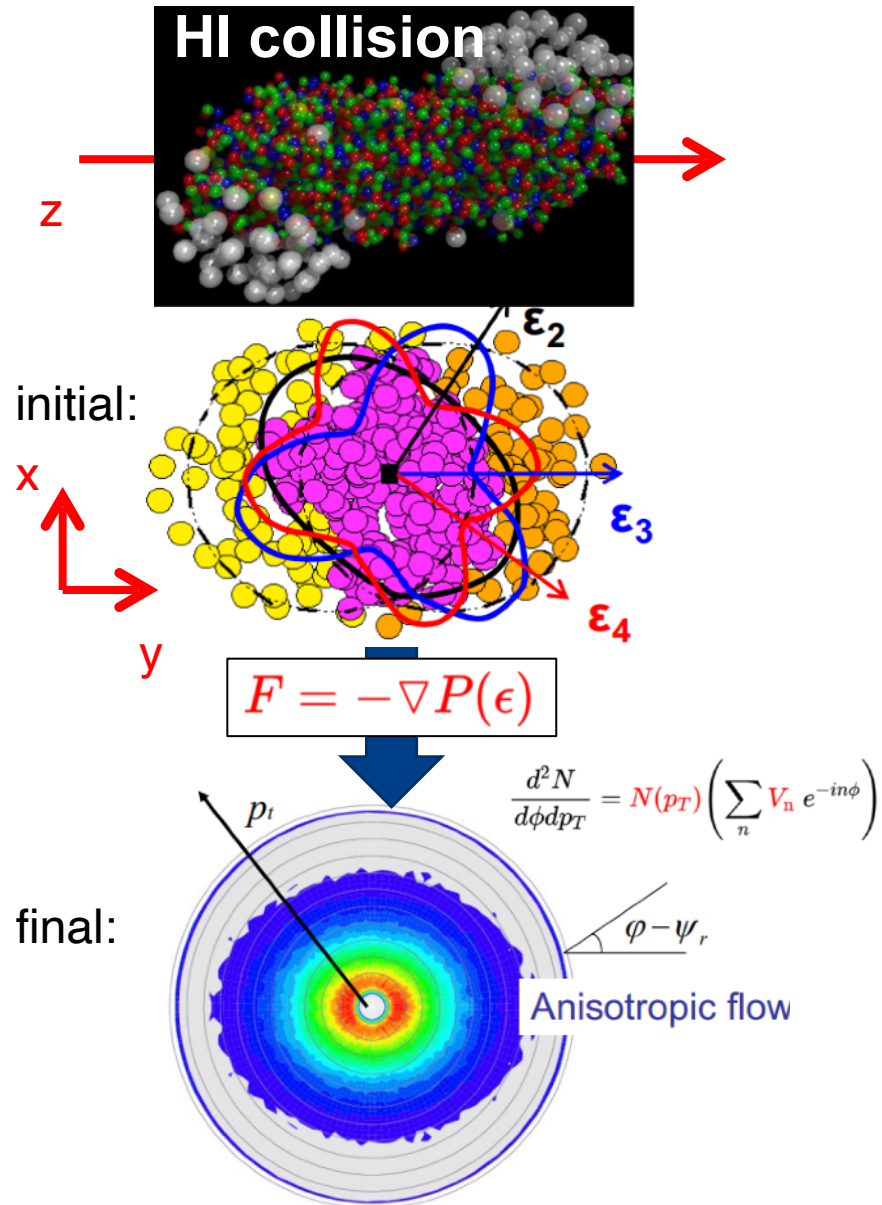
跨能量尺度轻核团簇结构理论研究

马国亮（复旦大学）

合作者: 李沛, 孙开佳, 周波

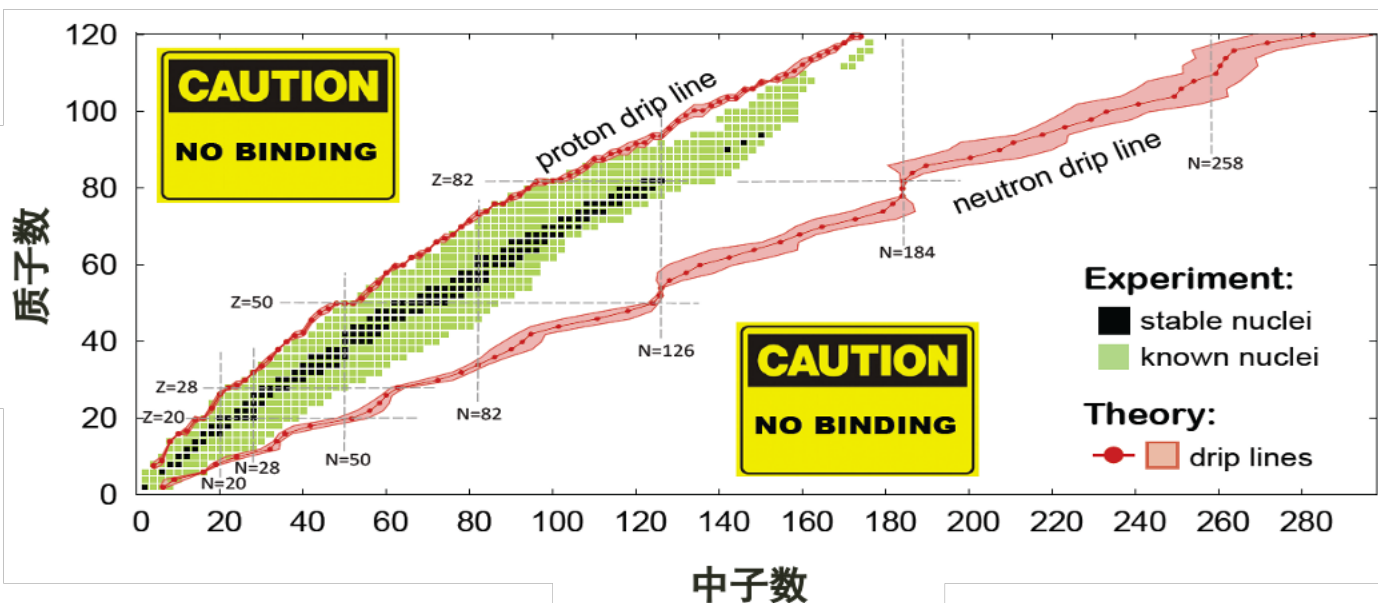
高能与低能核物理交叉学术研讨会，华东师范大学，2026.5.15-18日

Heavy-ion collisions



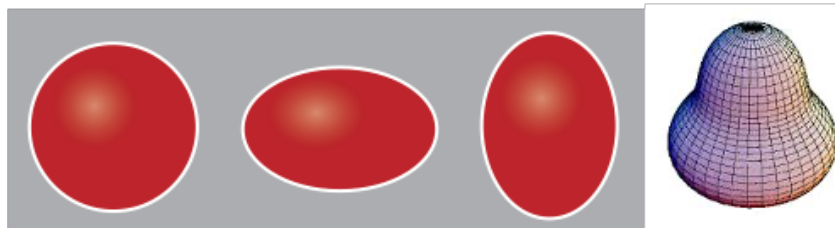
Nuclear structure

Stable nuclei: ~ 300 ; Predicted: ~ 8000 Observed: $\sim 3400+$)

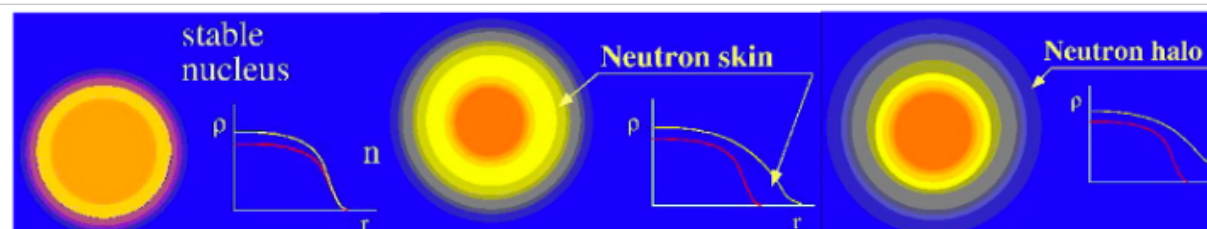


- Limits of nuclear existence
- Changes in shell structure
- Disappearance and emergence of magic numbers
- Exotic radioactivity
- New mechanisms of nuclear reactions and collective phenomena
- **nuclear structure**

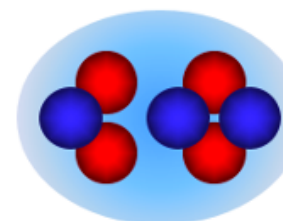
Deformation



Neutron skin/halo

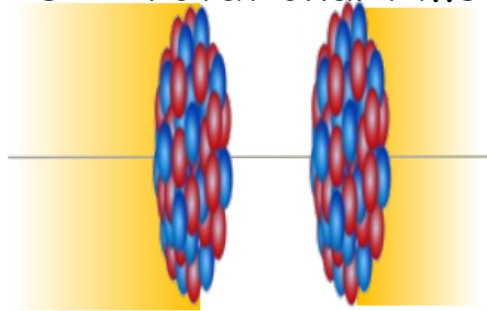


Clustering

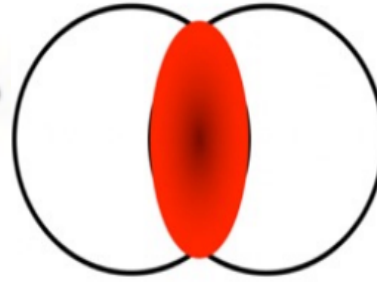
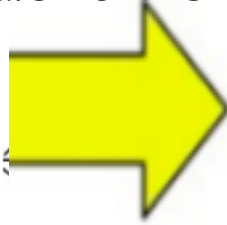


Imaging nuclear structure with HICs

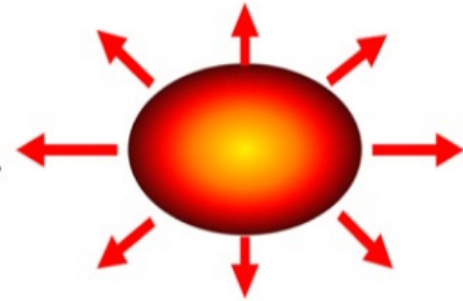
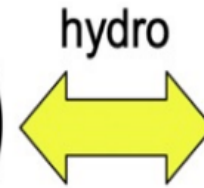
$10^{-25} \text{ s} \ll \text{rotational time scale } 10^{-21} \text{ s}$



Constraints from
nuclear structure

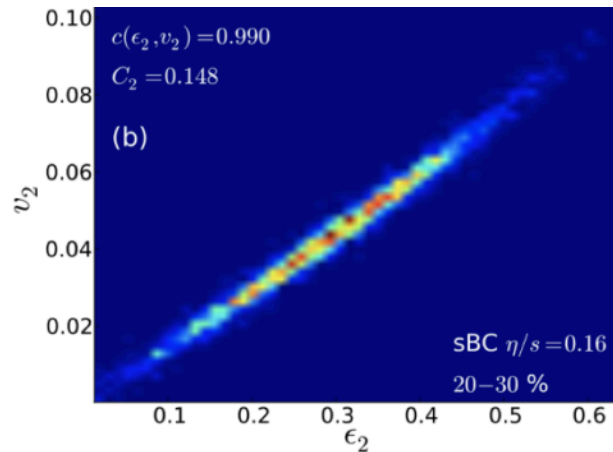
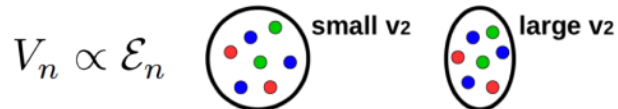


Initial condition



Constraints from
Heavy ion observables

Shape $\longleftrightarrow$ Anisotropic flow



PRC 87 (2013) 5, 054901

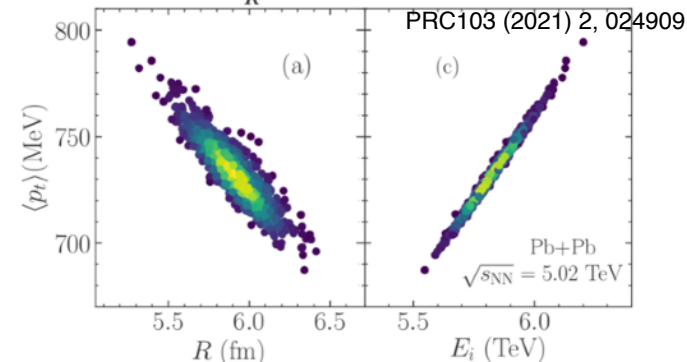
Size $\longleftrightarrow$ Transvers momentum

$$\frac{d\langle p_t \rangle}{\langle p_t \rangle} \propto \frac{dE}{E}$$

$$\frac{d\langle p_t \rangle}{\langle p_t \rangle} \propto -\frac{dR}{R}$$

$$[p_T] \propto \frac{1}{R}$$

$$[p_T] \propto E_i$$



Nuclear deformation imprint on initial QGP

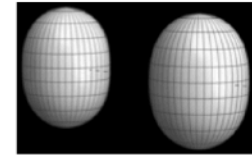


In liquid drop model,
nuclear surface:

Jiangyong Jia, Phys.Rev.C 105 (2022), 014905 and 044905



$$\rho(r, \theta, \phi) = \begin{cases} 1 & r < R(\theta, \phi) \\ 0 & r > R(\theta, \phi) \end{cases}$$



UCC collisions and ignoring nucleon fluctuations →

$$\frac{\delta d_{\perp}}{d_{\perp}} = \sqrt{\frac{5}{16\pi}} \beta_2 \left(\cos \gamma D_{0,0}^2 + \frac{\sin \gamma}{\sqrt{2}} [D_{0,2}^2 + D_{0,-2}^2] \right), \quad \epsilon_2 = -\sqrt{\frac{15}{2\pi}} \beta_2 \left(\cos \gamma D_{2,0}^2 + \frac{\sin \gamma}{\sqrt{2}} [D_{2,2}^2 + D_{2,-2}^2] \right)$$

Nuclear size: $d_{\perp} \equiv 1/R_{\perp}$



Nuclear shape:

$$\mathcal{E}_2 \propto \langle r_{\perp}^2 e^{i2\phi} \rangle$$

$$\mathcal{E}_3 \propto \langle r_{\perp}^3 e^{i3\phi} \rangle$$

$$\mathcal{E}_4 \propto \langle r_{\perp}^4 e^{i4\phi} \rangle$$

...

$\langle (\delta d_{\perp}/d_{\perp})^3 \rangle$	$\langle \epsilon_2^2 (\delta d_{\perp}/d_{\perp}) \rangle$	$\langle \epsilon_2^2 (\delta d_{\perp}/d_{\perp})^2 \rangle - \langle \epsilon_2^2 \rangle \langle (\delta d_{\perp}/d_{\perp})^2 \rangle$
$\frac{\sqrt{5}}{896\pi^{3/2}} \cos(3\gamma) \beta_2^3$	$-\frac{3\sqrt{5}}{112\pi^{3/2}} \cos(3\gamma) \beta_2^3$	$-\frac{3}{896\pi^2} \beta_2^4$
$\langle (\delta d_{\perp}/d_{\perp})^4 \rangle - 3 \langle (\delta d_{\perp}/d_{\perp})^2 \rangle^2$	$\langle \epsilon_2^4 \rangle - 2 \langle \epsilon_2^2 \rangle^2$	$(\langle \epsilon_2^6 \rangle - 9 \langle \epsilon_2^4 \rangle \langle \epsilon_2^2 \rangle + 12 \langle \epsilon_2^2 \rangle^3) / 4$
$-\frac{3}{7168\pi^2} \beta_2^4$	$-\frac{9}{56\pi^2} \beta_2^4$	$\frac{27(373-25 \cos(6\gamma))}{32 \times 8008\pi^3} \beta_2^6$

HIC experimental observations



□ How to explore more detailed structural information:

Correlation between different ϵ_n

$$\text{NSC}(m, n) = \frac{\langle \epsilon_m^2 \epsilon_n^2 \rangle - \langle \epsilon_m^2 \rangle \langle \epsilon_n^2 \rangle}{\langle \epsilon_m^2 \rangle \langle \epsilon_n^2 \rangle}$$



Correlation between different v_n

$$\text{nsc}(m, n) = \frac{\langle v_n^2 v_m^2 \rangle - \langle v_m^2 \rangle \langle v_n^2 \rangle}{\langle v_m^2 \rangle \langle v_n^2 \rangle}$$

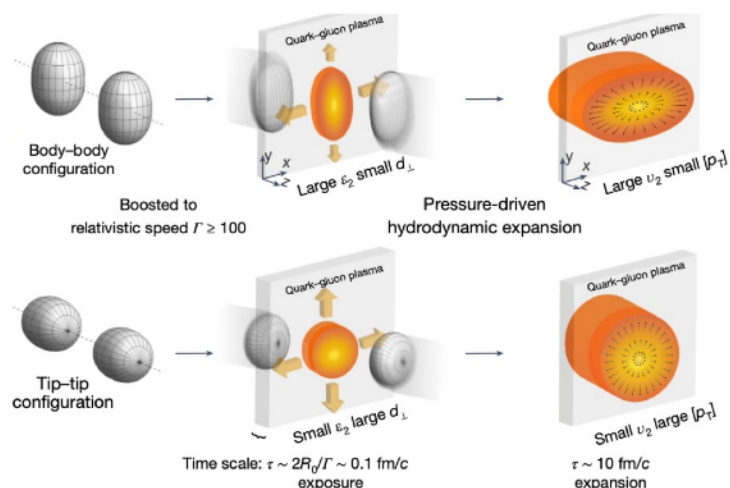
Correlation between ϵ_n (shape) and $\delta d_\perp$ (size)



Correlation between v_n and δp_T

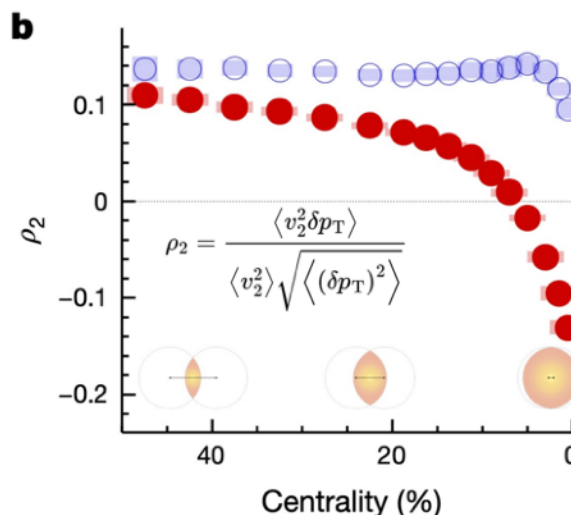
$$\rho_n(\epsilon_n^2, \delta d_\perp) = \frac{\text{cov}(\epsilon_n^2, \delta d_\perp)}{\sqrt{\text{Var}(\epsilon_n^2) \text{Var}(\delta d_\perp)}}$$

$$\rho(v_n^2, \delta p_T) = \frac{\text{cov}(v_n^2, \delta p_T)}{\sqrt{\text{Var}(v_n^2) \text{Var}(\delta p_T)}}$$



$v_2 \nearrow$ $p_T \searrow$

$v_2 \searrow$ $p_T \nearrow$



spherical baseline Au+Au

different sign!

prolate U+U

$\beta_{2U} = 0.297 \pm 0.015$

$\gamma_U = 8.5^\circ \pm 4.8^\circ$

STAR (张春健, 马余刚等), *Nature* 635, 67-72 (2024)

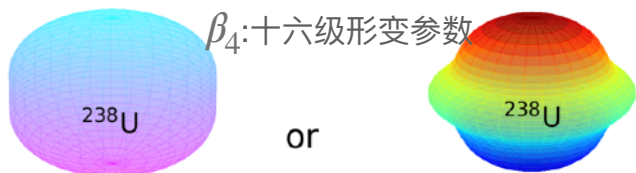
New proposed observables in HICs



New proposal:

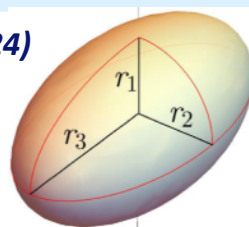
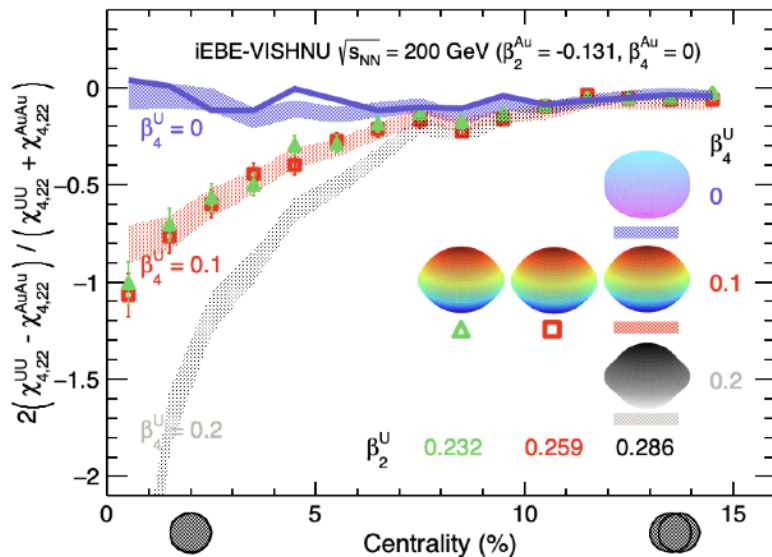
$$\rho_{4,2} \equiv \left(\frac{\langle \varepsilon_2^4 \delta d_{\perp}^2 \rangle}{\langle \varepsilon_2^4 \rangle \langle d_{\perp}^2 \rangle^2} \right)_c \equiv \frac{1}{\langle \varepsilon_2^4 \rangle \langle d_{\perp}^2 \rangle^2} [\langle \varepsilon_2^4 \delta d_{\perp}^2 \rangle + 4 \langle \varepsilon_2^2 \rangle^2 \langle \delta d_{\perp}^2 \rangle - \langle \varepsilon_2^4 \rangle \langle \delta d_{\perp}^2 \rangle - 4 \langle \varepsilon_2^2 \rangle \langle \varepsilon_2^2 \delta d_{\perp}^2 \rangle - 4 \langle \varepsilon_2^2 \delta d_{\perp}^2 \rangle^2]$$

Hao-jie Xu, Jie Zhao, Fuqiang Wang, *Phys. Rev. Lett.*, **132**, 262301 (2024)

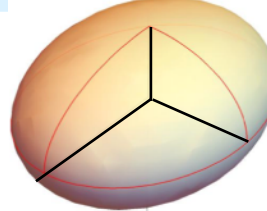


β_4 : 十六级形变参数

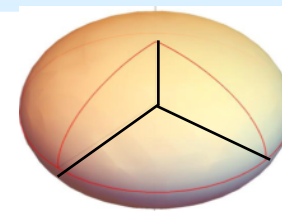
$$R = R_0(1 + \beta_2 Y_{20} + \beta_3 Y_{30} + \beta_4 Y_{40} + \dots),$$



$\gamma = 0$
 $r_1 = r_2 < r_3$
prolate

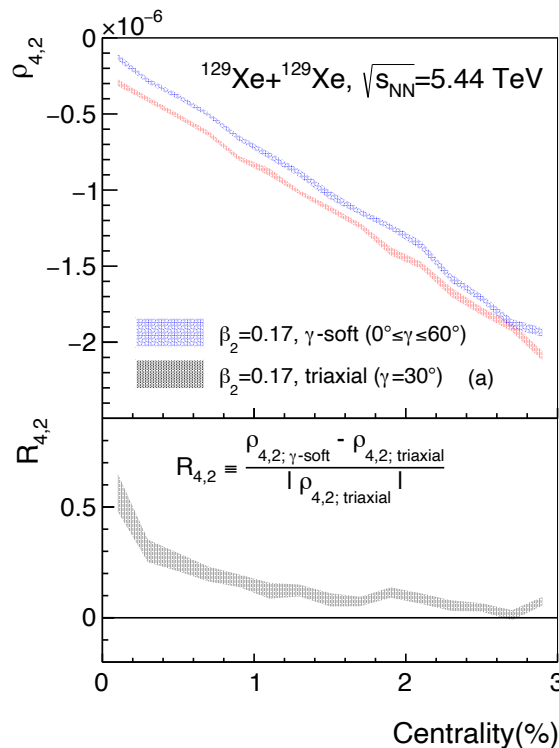


$\gamma = 30^\circ$
 $r_1 \neq r_2 \neq r_3$
triaxial

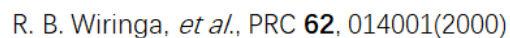


$\gamma = 60^\circ$
 $r_1 < r_2 = r_3$
oblate

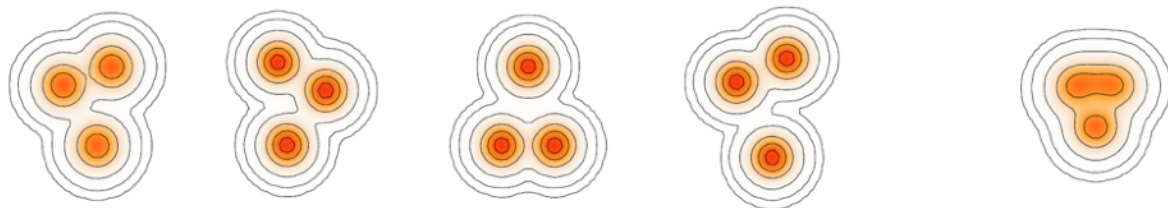
Shujun Zhao, Hao-jie Xu, You Zhou, Yu-Xin Liu, Huichao Song, *Phys. Rev. Lett.* **133** (2024) 192301



- HIC can extract information about the hexadecapole deformation of atomic nuclei
- 6-particle correlations allow to differentiate triaxial (fixed $\gamma = 30^\circ$) and γ -soft (fluctuating γ) structures

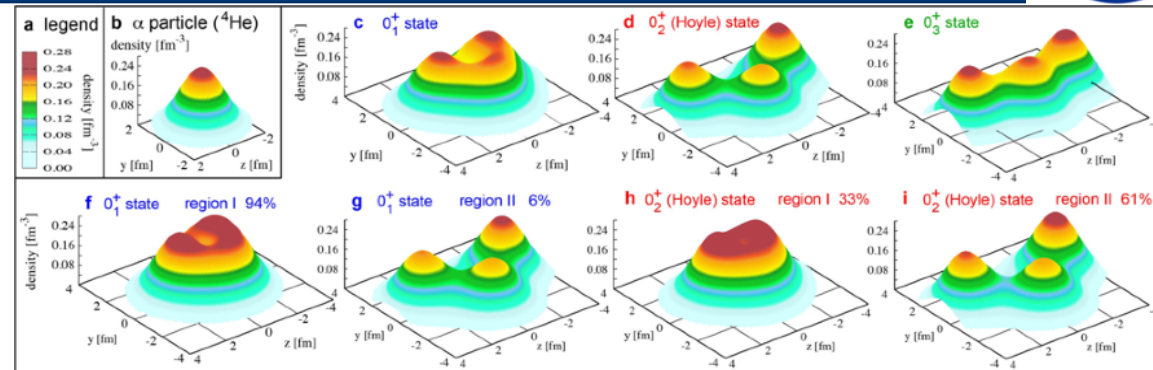


Clusters in ^{12}C

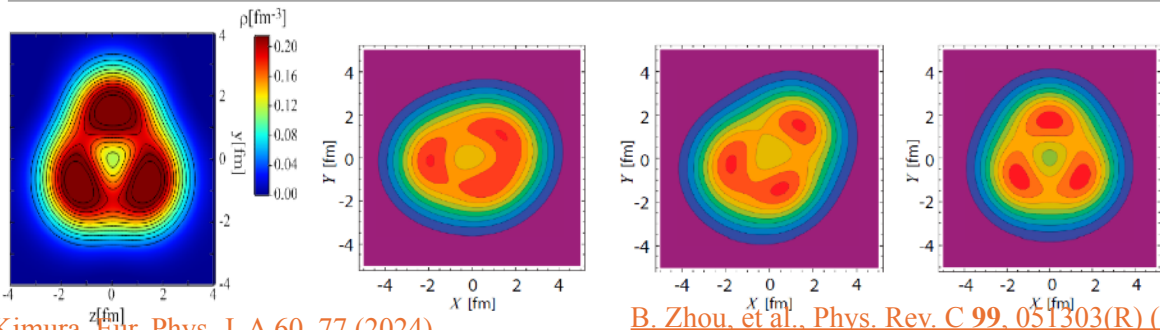


$$\begin{aligned}
 |\langle 1|0_1^+\rangle| &= 0.30 & |\langle 2|0_1^+\rangle| &= 0.25 & |\langle 3|0_1^+\rangle| &= 0.15 & |\langle 4|0_1^+\rangle| &= 0.08 & |\langle 5|0_1^+\rangle| &= 0.94 \\
 |\langle 1|0_2^+\rangle| &= 0.72 & |\langle 2|0_2^+\rangle| &= 0.71 & |\langle 3|0_2^+\rangle| &= 0.61 & |\langle 4|0_2^+\rangle| &= 0.61 & |\langle 5|0_2^+\rangle| &= 0.04
 \end{aligned}$$

M. Chernykh, et al., PRL 98, 032501 (2007)

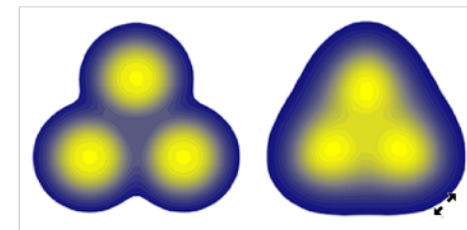
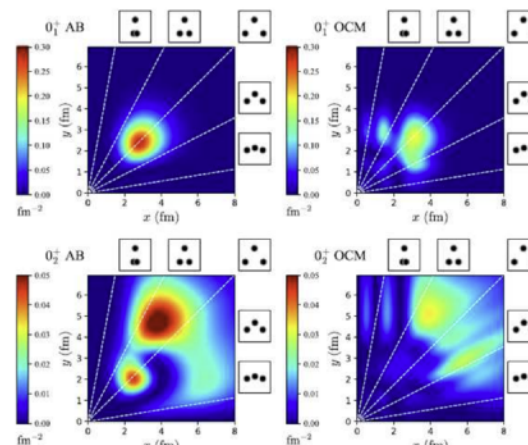


Otsuka, et al., Nat Commun 13, 2234 (2022)

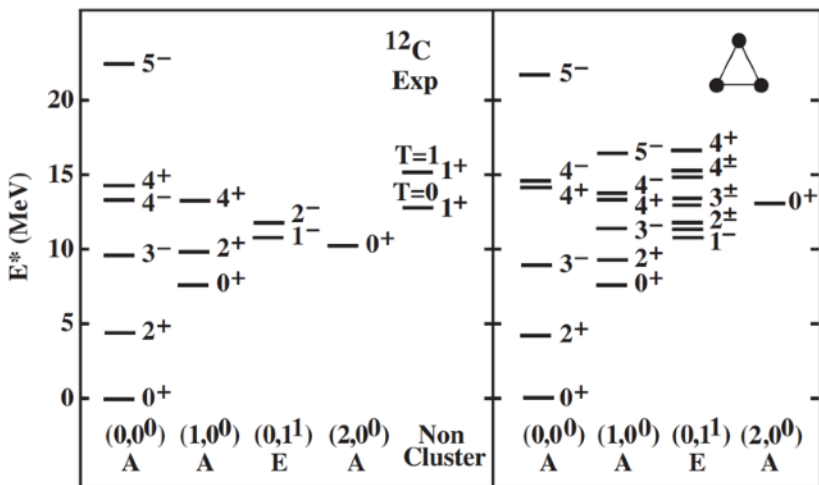


I. Kimura, Eur. Phys. J. A 60, 77 (2024)

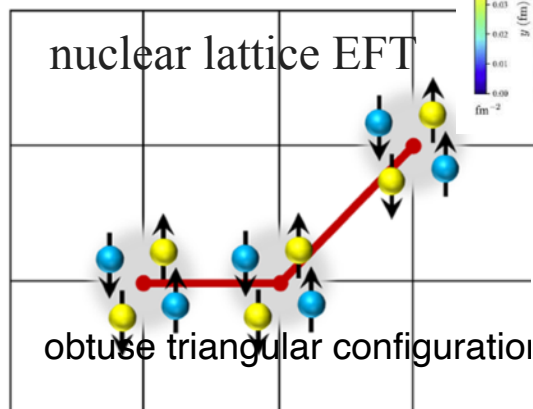
B. Zhou, et al., Phys. Rev. C 99, 051303(R) (2019)



W. Broniowski and F. Ruiz Arriola, Phys. Rev. Lett. (2014)

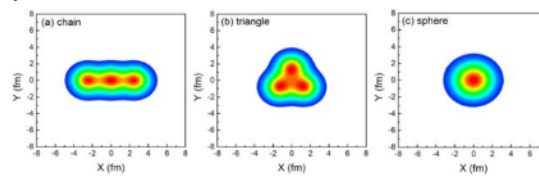


D J Marin-Lambarri, et al., PRL 113, 012502 (2014)

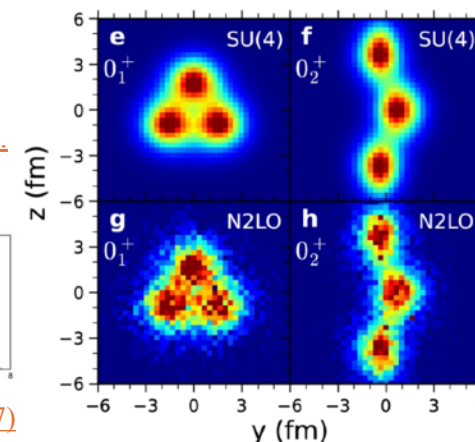


E. Epelbaum, et al., PRL 109, 252501 (2012)

L. Fortunato, Few-Body Syst 65, 1 (2024)



B. S. Huang, et al., PRC95, 034606 (2017)

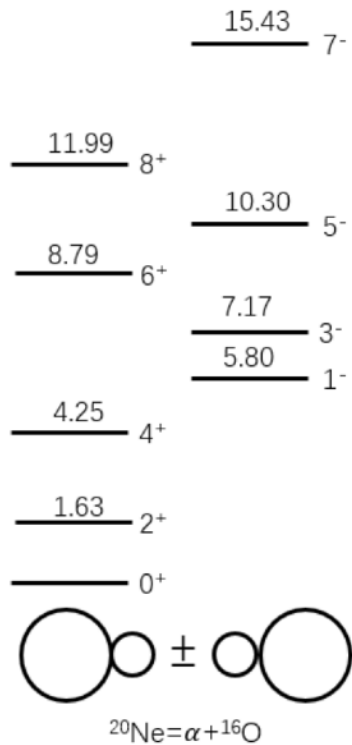


S. Shen, et al., Nat Commun 14, 2777 (2023)

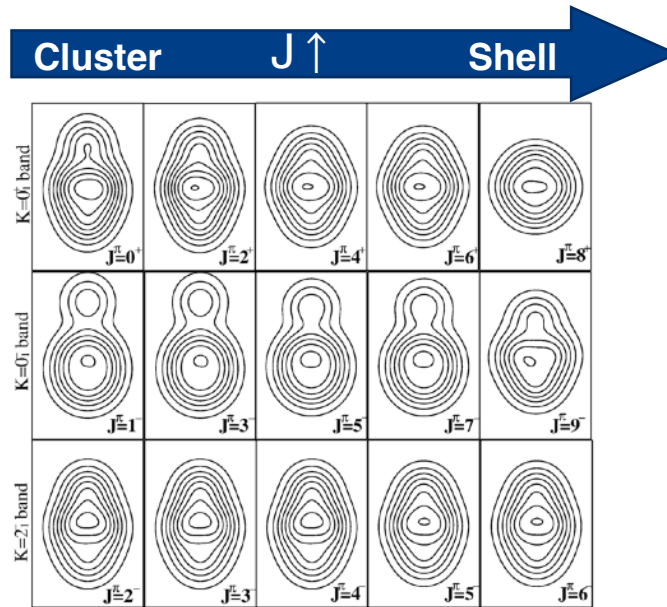
Clusters in ^{20}Ne

^{20}Ne large deformation
or significant cluster structure

Prog. Theor. Phys. 40, 277 (1968)



Antisymmetrized Molecular
Dynamics Model (AMD)

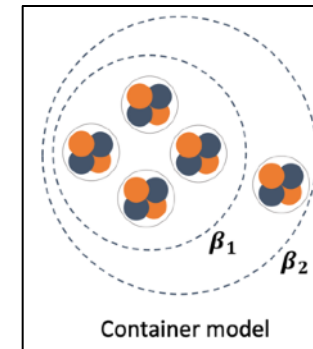


➤ ^{20}Ne with localized cluster with $\alpha + ^{16}\text{O}$

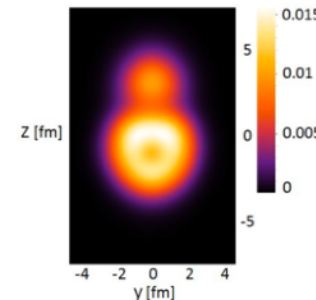
PHYSICAL REVIEW C **110**, 034909 (2024)

	β_2	β_3
^{20}Ne	0.666	0.250

Nonlocalized THSR model



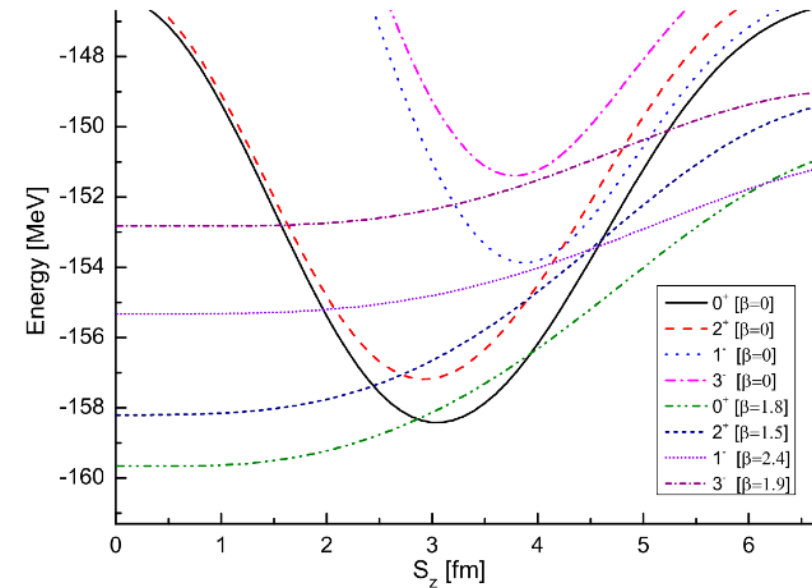
Pauli repulsion



B.Zhou, Y.Funaki, H.Horiuchi, Y.-G.Ma, G.Ropke, P.Schuck, A.Tohsaki, and T.Yamada. Nat Commun 14, 8206 (2023)

$$\hat{\Phi}_{\text{Ne}}(\beta, S) = \mathcal{A} \left\{ \exp \left[- \sum_k \frac{8(\xi - S)_k^2}{5B_k^2} \right] \phi(\alpha) \phi(^{16}\text{O}) \right\}$$

$$B_k^2 = b^2 + 2\beta_k^2$$



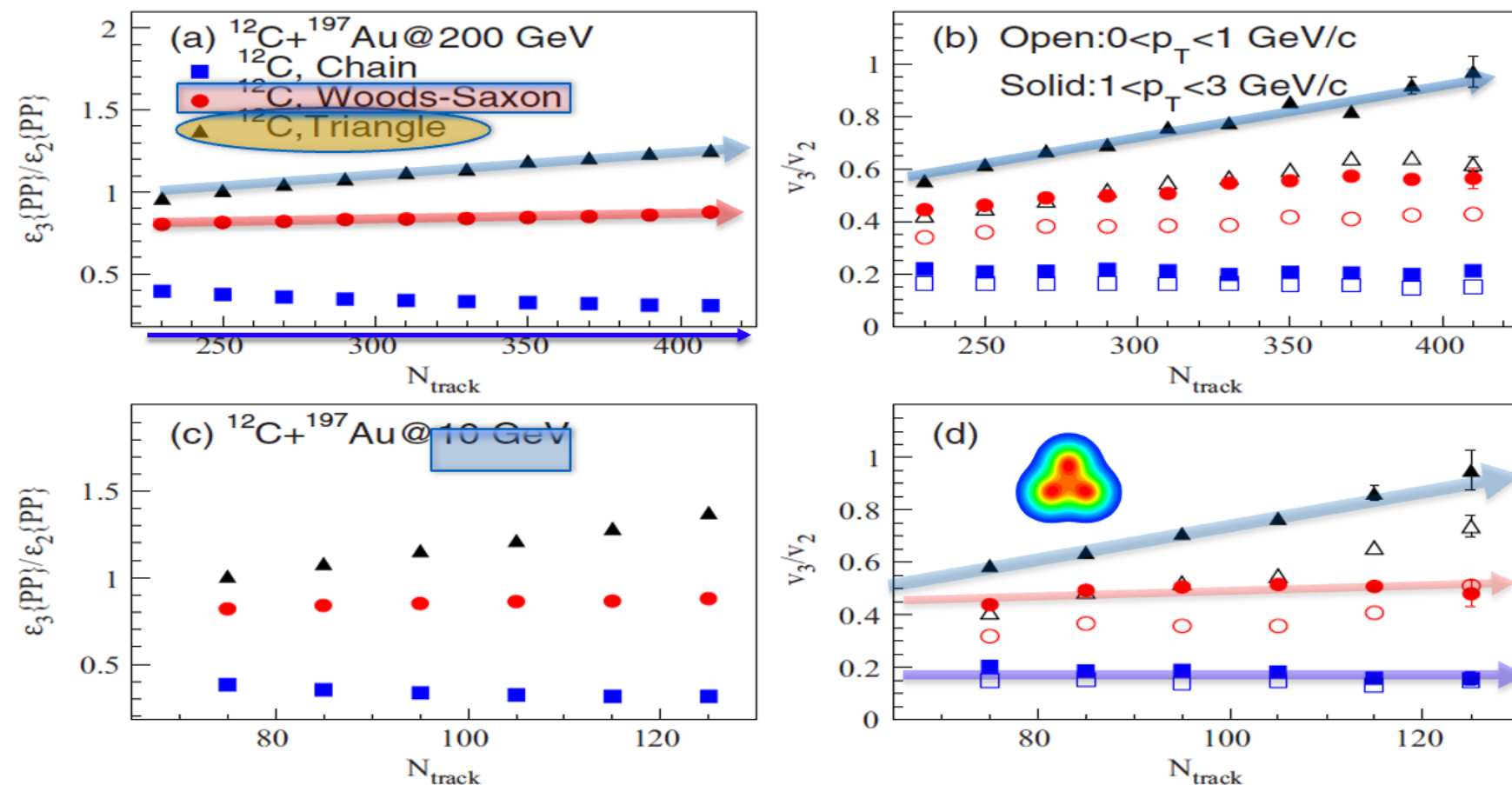
Or with nonlocalized cluster with 5- α

Cluster effect on HICs

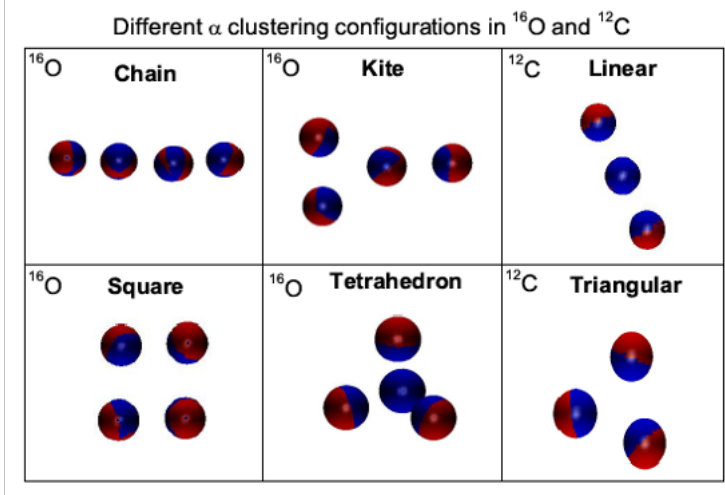
PHYSICAL REVIEW C **95**, 064904 (2017)

Nuclear cluster structure effect on elliptic and triangular flows in heavy-ion collisions

S. Zhang,¹ Y. G. Ma,^{1,2,3,*} J. H. Chen,¹ W. B. He,⁴ and C. Zhong¹



Cluster structures from EQMD model



v_3/v_2 increases with the multiplicity
→ triangle 3- α ^{12}C

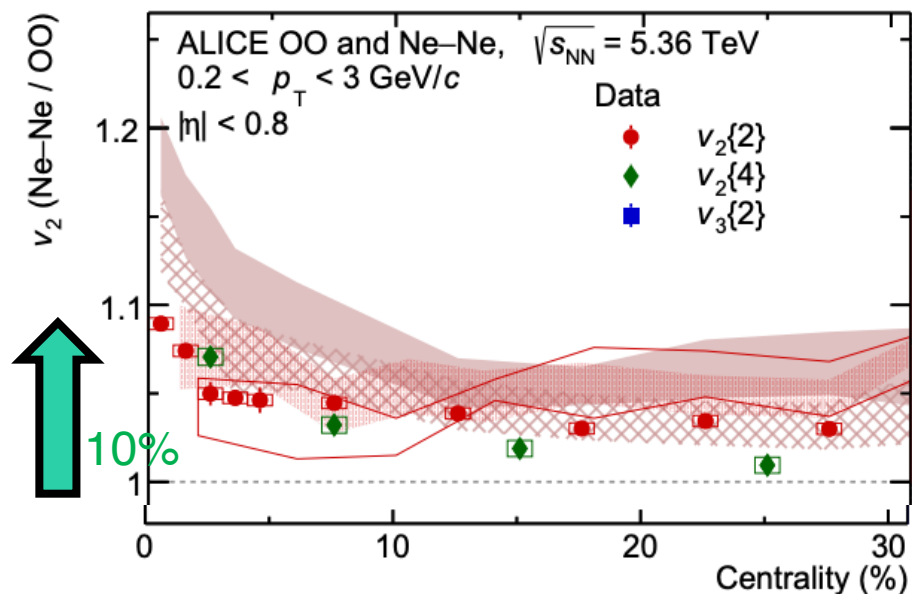
- v_3/v_2 ratio is a sensitive probe for studying cluster structures in HICs!

Light-ion collisions



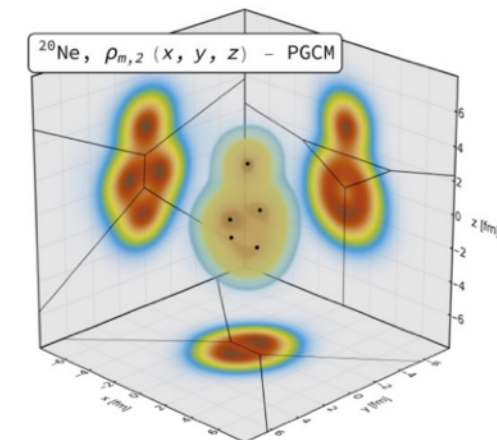
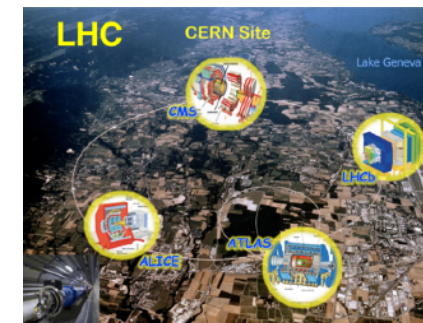
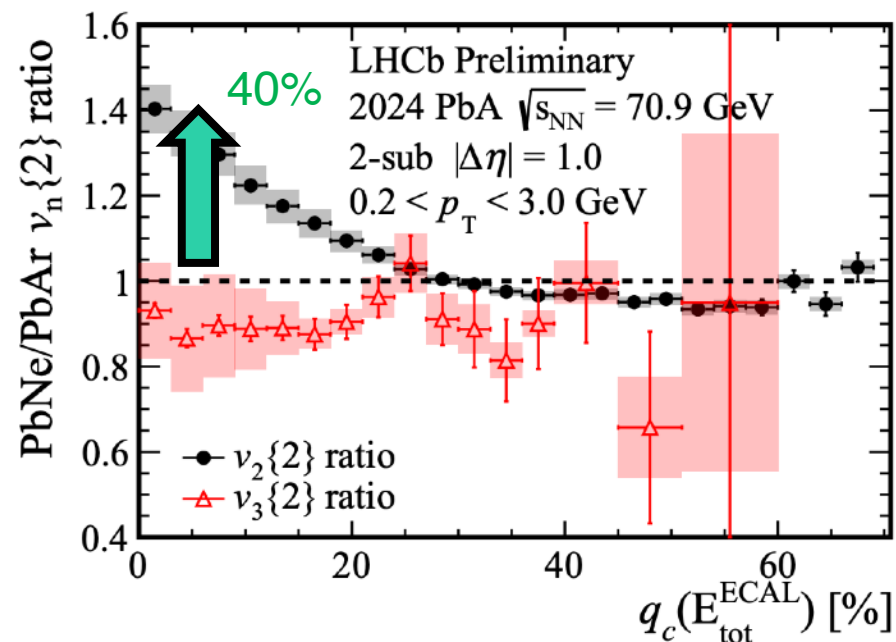
arXiv: 2509.06428, 2509.05171, 2510.02580

ALICE/ATLAS/CMS: Ne+Ne/O+O



arXiv: 2509.12399

LHCb: Pb+Ne/Pb+Ar



Phys.Rev.Lett. 135 (2025) 1, 012302

➤ Evidence for Bowling-Pin structure of the Ne nucleus. Just the general shape! More details?

Clusters in ^{20}Ne

P.Lei, B. Zhou, GLM, PRL 136, 082302 (2026)

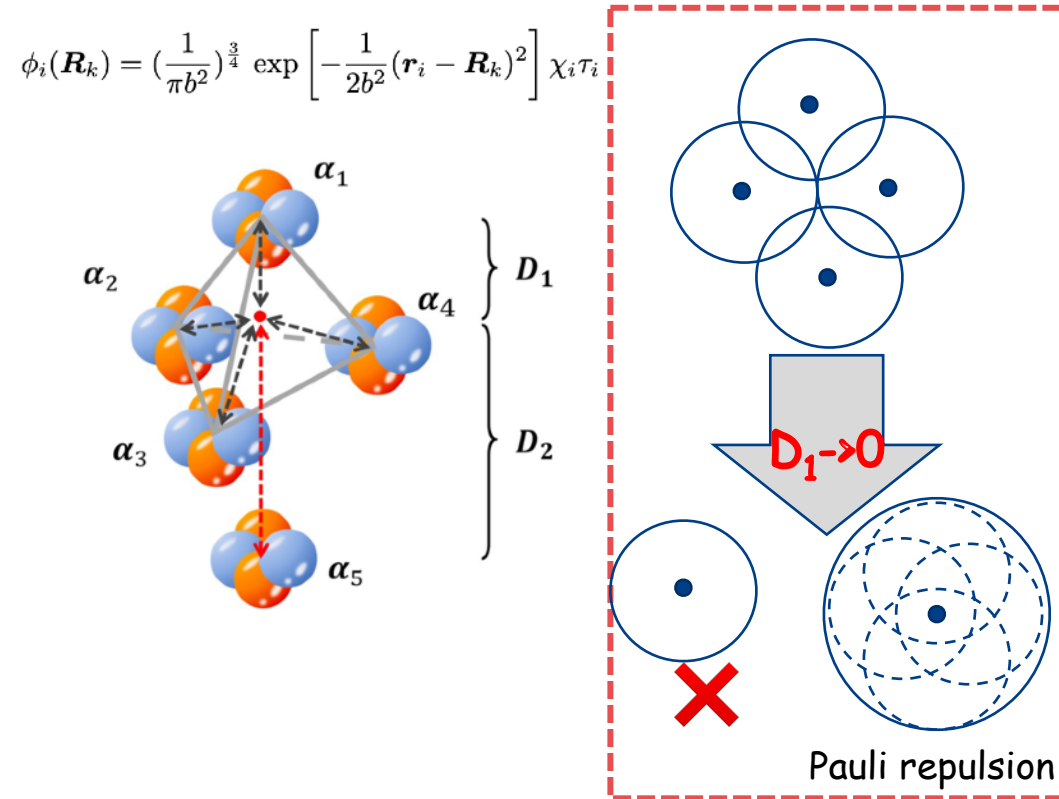


Nucl. Phys. A 1006, 122077 (2021)

Front.Phys. 15 (2020) 14401

Two parameters: D_1 and D_2 ($D_2 > D_1/3$)

frozen α + core (tetrahedron)



Prog. Theor. Phys. 40, 277 (1968)

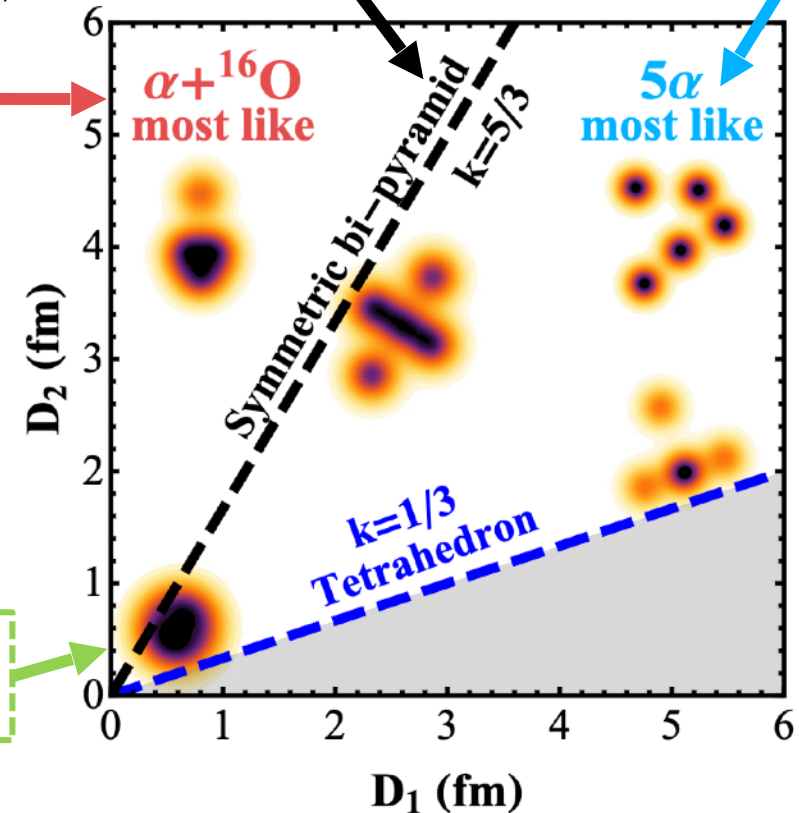
AMD model
(localized
two-cluster)

$D_1 \rightarrow 0$

$D_1 \rightarrow 0$ $D_2 \rightarrow 0$
Shell model
(Spherical)

Clusters with
 D_{3h} symmetry

Loose and
nonlocalized-like



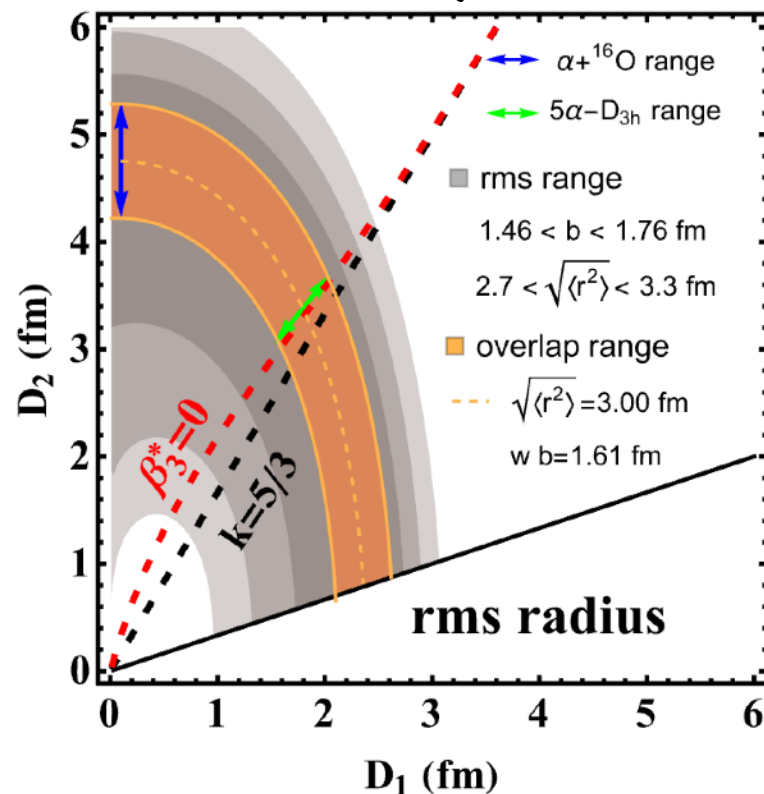
all parameters : D_1 D_2 (local structural parameters) and b (harmonic oscillator size parameter)

Clusters in ^{20}Ne

- How to estimate the systematic error of the theoretical model?

Two parameters: D_1 and D_2 ($D_2 > D_1/3$)

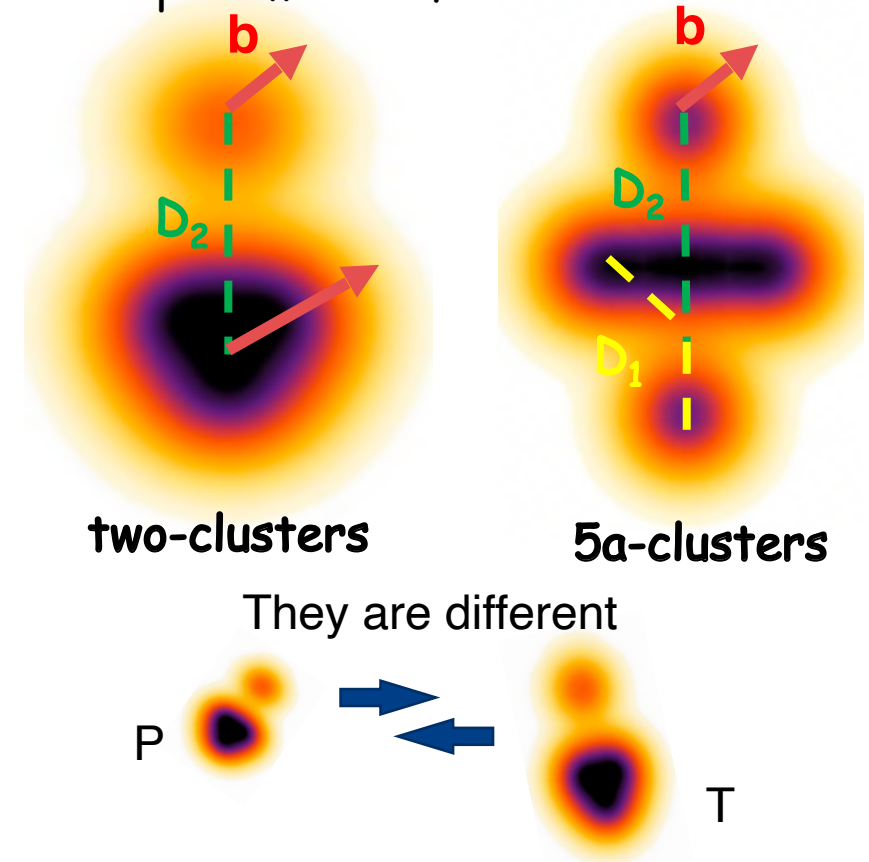
frozen α + core (tetrahedron)



rms radius
($3.0 \pm 10\%$) fm
 $b \in (1.46, 1.76)$ fm
↓
 D_1 D_2 range

- How to consider **shape mixing** ?

All parameters fluctuate



- Can HIC image cluster structure?

Symmetric cumulant NSC(n, m)

Analytical results w/o fluctuation

$$|\Phi^{\text{Brink}}\rangle = \frac{1}{\sqrt{N!}} |\det\{\phi_1(\mathbf{r}_1)\dots\phi_N(\mathbf{r}_N)\}\rangle$$

$$\rho(\mathbf{a}) = \frac{\langle \Phi^{\text{B}}(\mathbf{R}) | \frac{1}{A} \sum_{j=1}^A \delta(\mathbf{r}_j - \mathbf{r}_g - \mathbf{a}) | \Phi^{\text{B}}(\mathbf{R}) \rangle}{\langle \Phi^{\text{B}}(\mathbf{R}) | \Phi^{\text{B}}(\mathbf{R}) \rangle}$$

$$\rho(r_{\perp}, \phi) = \int [\mathcal{R}_p(\phi_{p,1}, \theta_p, \phi_{p,2}) \rho(x, y, z) + \mathcal{R}_t(\phi_{t,1}, \theta_t, \phi_{t,2}) \rho(x, y, z)] / 2 dz$$

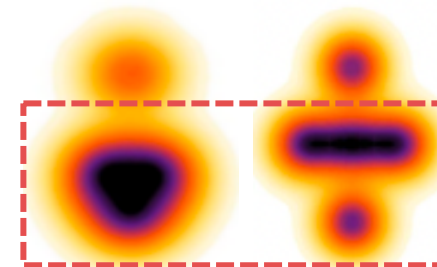
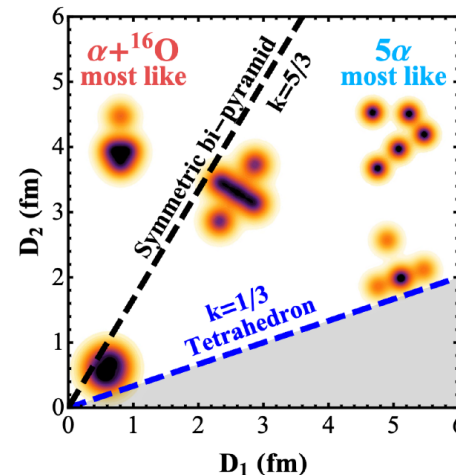
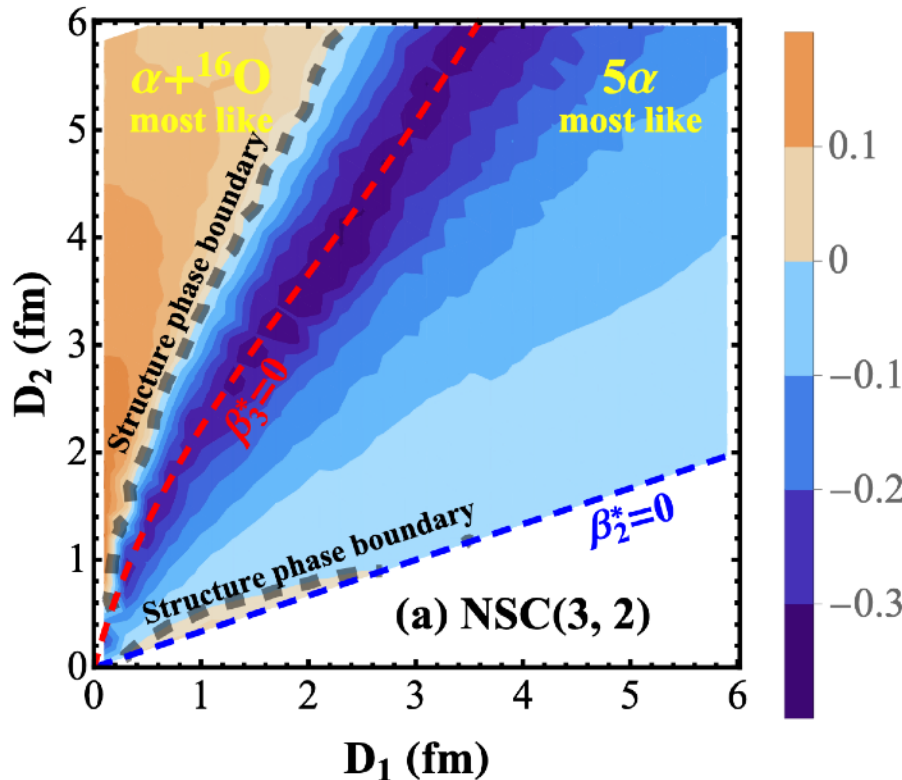


$$\varepsilon_n e^{in\Phi} = - \frac{\int r_{\perp}^n e^{in\phi} \rho(r_{\perp}, \phi) d^2r}{\int r_{\perp}^n \rho(r_{\perp}, \phi) d^2r}$$

$$\text{NSC}(m, n) = \frac{\langle \varepsilon_m^2 \varepsilon_n^2 \rangle - \langle \varepsilon_m^2 \rangle \langle \varepsilon_n^2 \rangle}{\langle \varepsilon_m^2 \rangle \langle \varepsilon_n^2 \rangle}$$

only geometry effect!

$$\text{NSC}(m, n) = \frac{\langle \varepsilon_m^2 \varepsilon_n^2 \rangle - \langle \varepsilon_m^2 \rangle \langle \varepsilon_n^2 \rangle}{\langle \varepsilon_m^2 \rangle \langle \varepsilon_n^2 \rangle}$$

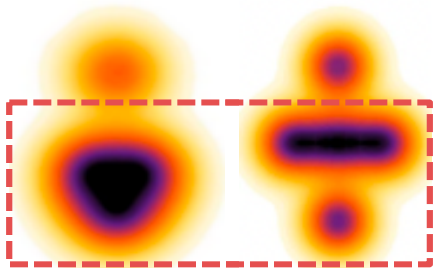
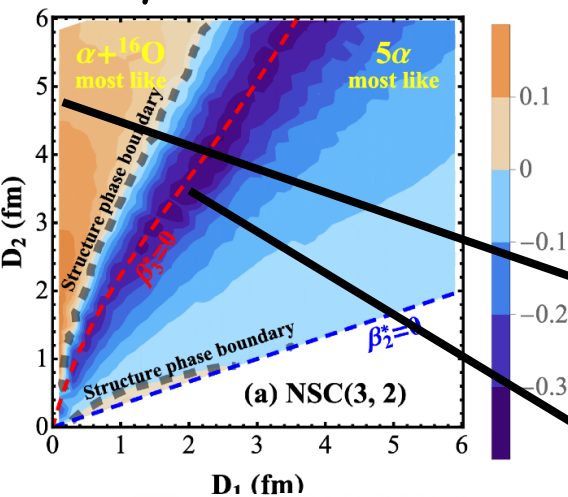


✓ The structure of ^{20}Ne can be determined by the **positive** or **negative** NSC(2, 3) value.

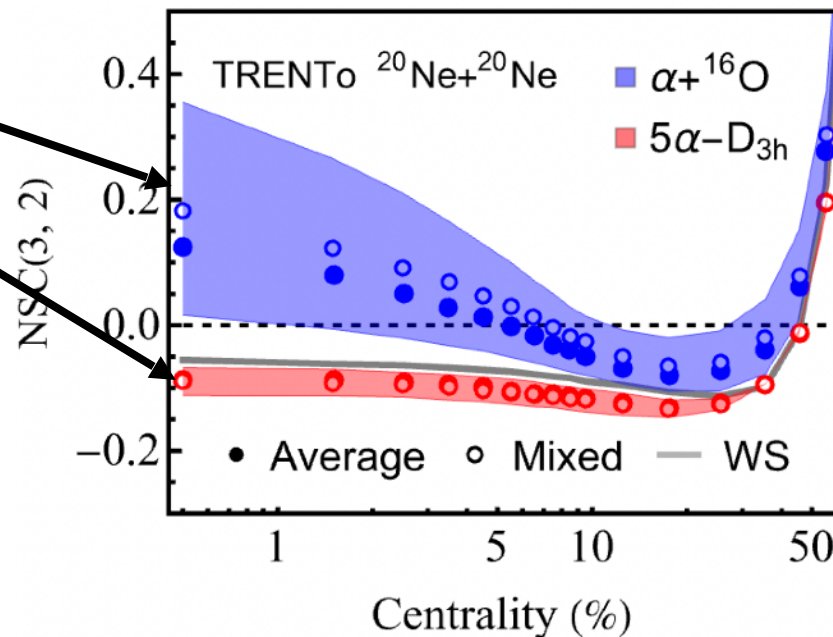
✓ Correlation strength NSC(2, 3) $\propto k = D_2/D_1$.

Symmetric cumulant NSC(n, m)

Analytical results w/o fluctuation

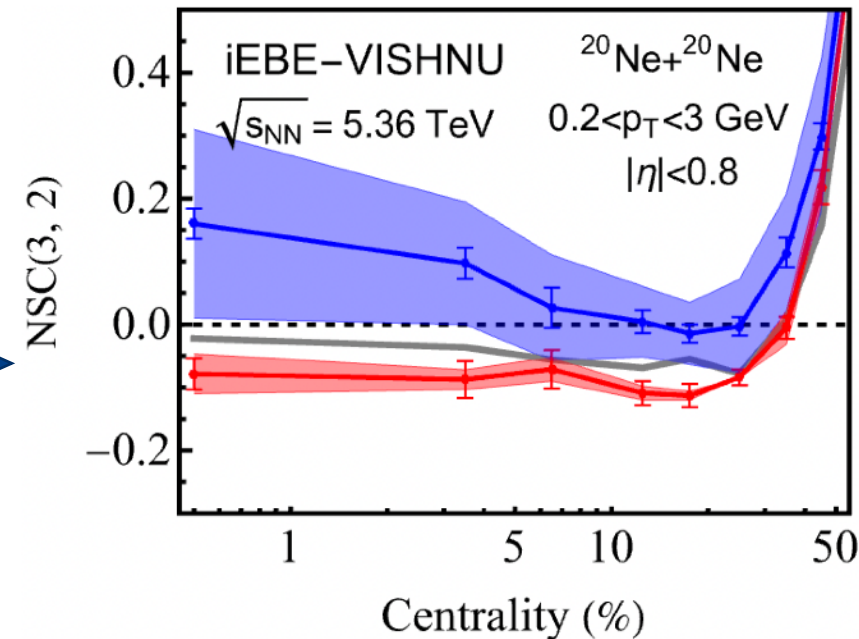


TRENTTo results w initial fluctuation



hydro evolution

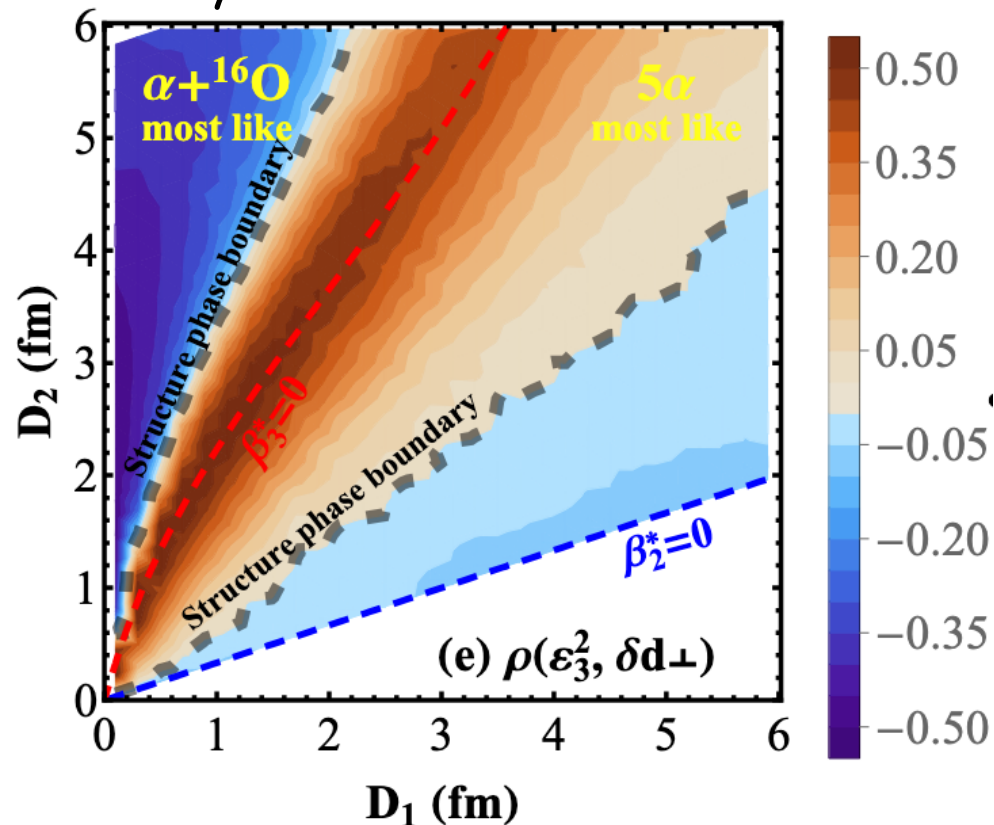
Hydro results w all fluctuations



- ✓ The fluctuations of initial and final state do not affect the sign of NSC(2, 3).
- ✓ Shape mixing does not affect the sign of NSC(2, 3).

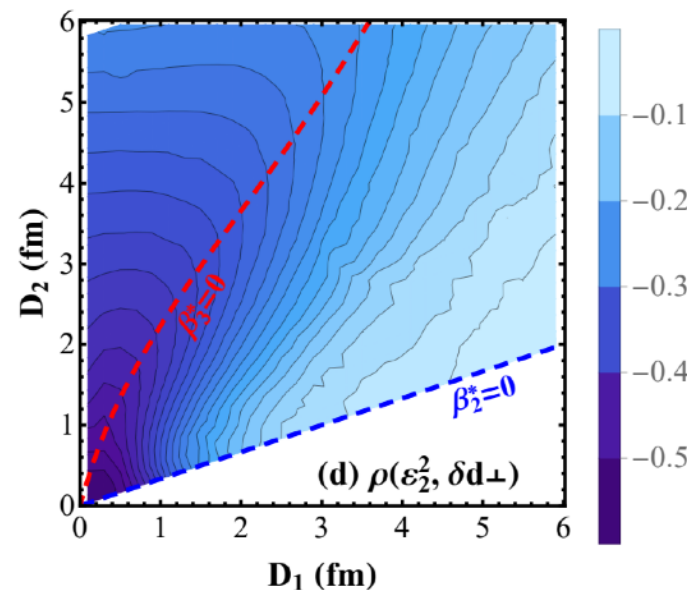
Pearson correlation v_n -[p_T]

Analytical results w/o fluctuation

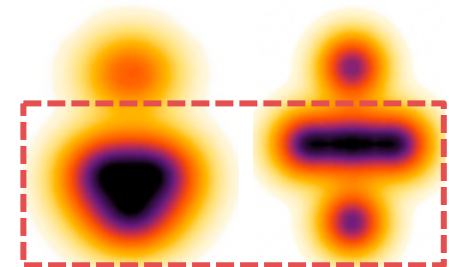
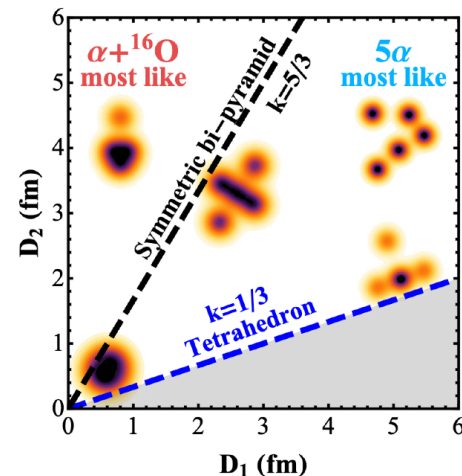


only geometry effect!

$$\rho_n(\varepsilon_n^2, \delta d_{\perp}) = \frac{\text{cov}(\varepsilon_n^2, \delta d_{\perp})}{\sqrt{\text{Var}(\varepsilon_n^2)\text{Var}(\delta d_{\perp})}}$$



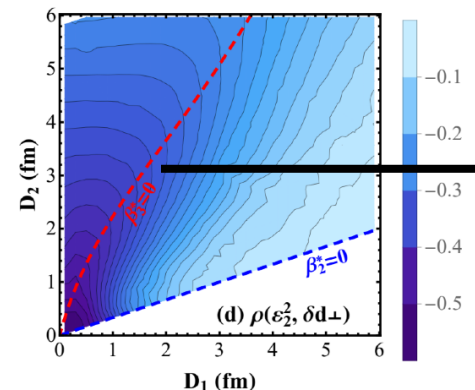
$\rho_2 < 0$



- ✓ The structure of ^{20}Ne can be determined by the **positive** or **negative** ρ_3 value, but ρ_2 not
- ✓ Correlation strength $\rho(\varepsilon_3^2, \delta d_{\perp}) \propto k = D_2/D_1$

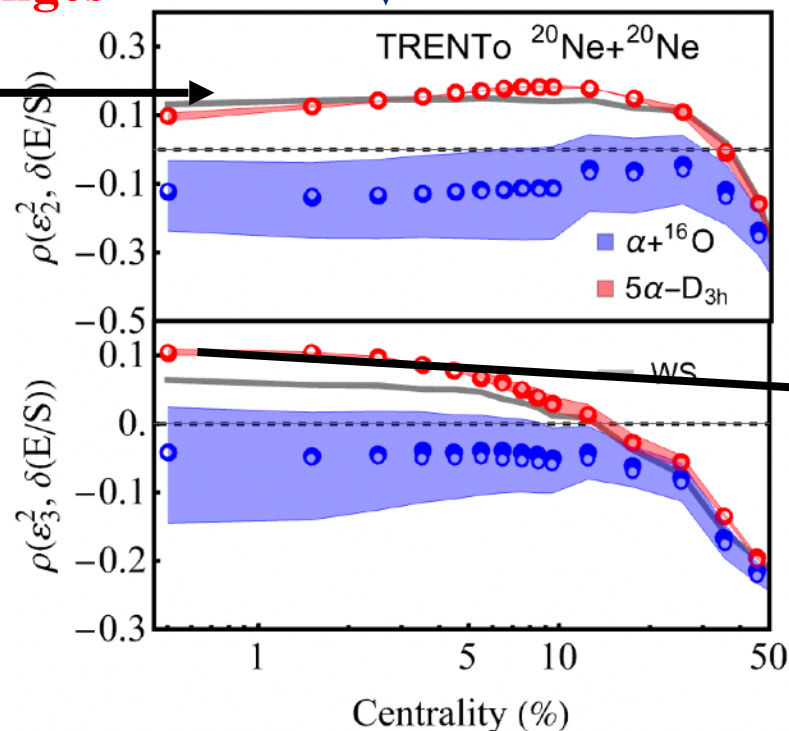
Pearson correlation v_n -[pT]

Analytical results w/o fluctuation



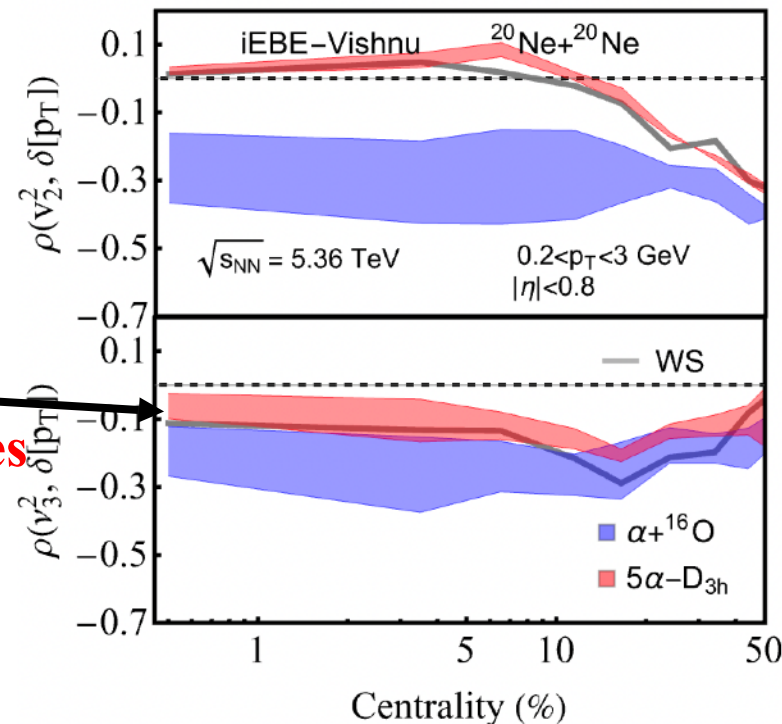
ρ_2 changes
sign

TRENTo with initial fluctuation



hydro
evolution

Hydro with all fluctuations



➤ The sign of ρ_2 changes due to the **initial** fluctuations.

➤ The sign of ρ_3 changes due to the **final** hydro fluctuations.

✓ Fortunately and finally, the shape of ^{20}Ne can be determined by the sign of ρ_2

- Heavy ion collisions probe nucleon to partonic dynamics (MeV–TeV), serving as a snapshot of initial-state nuclear structure.
- HIC observables sensitively detect nuclear-structure imprints, complementing traditional nuclear studies.
- Future LHC light-ion experiments require joint efforts across high- and low-energy nuclear physics for new discoveries.

Thanks for attention!

3-dim. H.O. w.f. in xyz coordinate

$$N = 2(n-1) + l = n_x + n_y + n_z$$

$$\phi_{(n_x, n_y, n_z)}(r) = \phi_{n_x}(x)\phi_{n_y}(y)\phi_{n_z}(z)$$

By taking R in a z-direction,

$$(000)' = \phi_{(000)}\left(r - \frac{1}{2}R\right) = \phi_0(x)\phi_0(y)\phi_0\left(z - \frac{R}{2}\right)$$

$$(000) = \phi_{(000)}\left(r + \frac{1}{2}R\right) = \phi_0(x)\phi_0(y)\phi_0\left(z + \frac{R}{2}\right)$$

$$\phi_0(z) = \left(\frac{2\nu}{\pi}\right)^{3/4} e^{-\nu z^2}$$

$$\phi_1(z) = 2\sqrt{\nu}z\phi_0(z)$$

$$\phi_2(z) = \frac{1}{\sqrt{2}}(1 - 4\nu z^2)\phi_0(z)$$

Expansion of $(000)'$ with the completeness relation,

$$\sum_{n_x, n_y, n_z} |(n_x, n_y, n_z)\rangle \langle (n_x, n_y, n_z)| = 1$$

$$(000)' = \sum_{n_x, n_y, n_z} |(n_x, n_y, n_z)\rangle \langle (n_x, n_y, n_z)| (000)'\rangle$$

$$\langle (000) | (000)' \rangle = \int \phi_0(z + R/2)\phi_0(z - R/2)dz = e^{-\frac{\nu}{2}R^2}$$

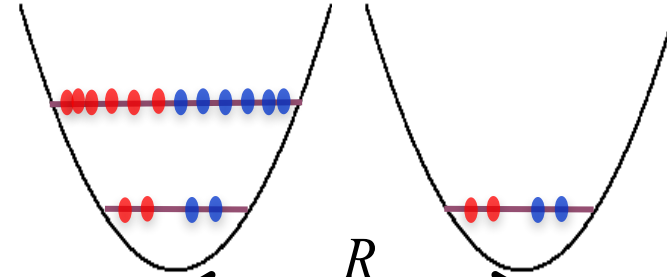
$$\langle (001) | (000)' \rangle = \int \phi_1(z + R/2)\phi_0(z - R/2)dz = \sqrt{\nu}R e^{-\frac{\nu}{2}R^2}$$

$$\langle (001) | (000)' \rangle = \int \phi_1(z + R/2)\phi_0(z - R/2)dz = -\frac{\nu}{\sqrt{2}}R^2 e^{-\frac{\nu}{2}R^2}$$

$$= \sum_{n_z} (00n_z) \langle (00n_z) | (000)' \rangle = e^{-\frac{\nu}{2}R^2} \left\{ (000) + \sqrt{\nu}R(001) - \frac{\nu}{\sqrt{2}}R^2(002) + \dots \right\}$$

Backup

^{20}Ne (α - ^{16}O): Brink w.f.



$$= \frac{n_0}{\sqrt{4!16!}} \det \left[\phi_{(000)} \left(\mathbf{r}_1 - \frac{4}{5} \mathbf{R} \right) n_{p \uparrow} (1) \cdots \phi_{(000)} \left(\mathbf{r}_4 - \frac{4}{5} \mathbf{R} \right) n_{n \downarrow} (4) \phi_{(000)} \left(\mathbf{r}_5 + \frac{3}{5} \mathbf{R} \right) n_{p \uparrow} (5) \cdots \phi_{(001)} \left(\mathbf{r}_{20} + \frac{1}{5} \mathbf{R} \right) n_{n \downarrow} (20) \right]$$

$$= \frac{n_0}{\sqrt{4!16!}} \det \left[(000)'^4 (000)^4 (100)^4 (010)^4 (001)^4 \right]$$

By taking R in a z -direction,

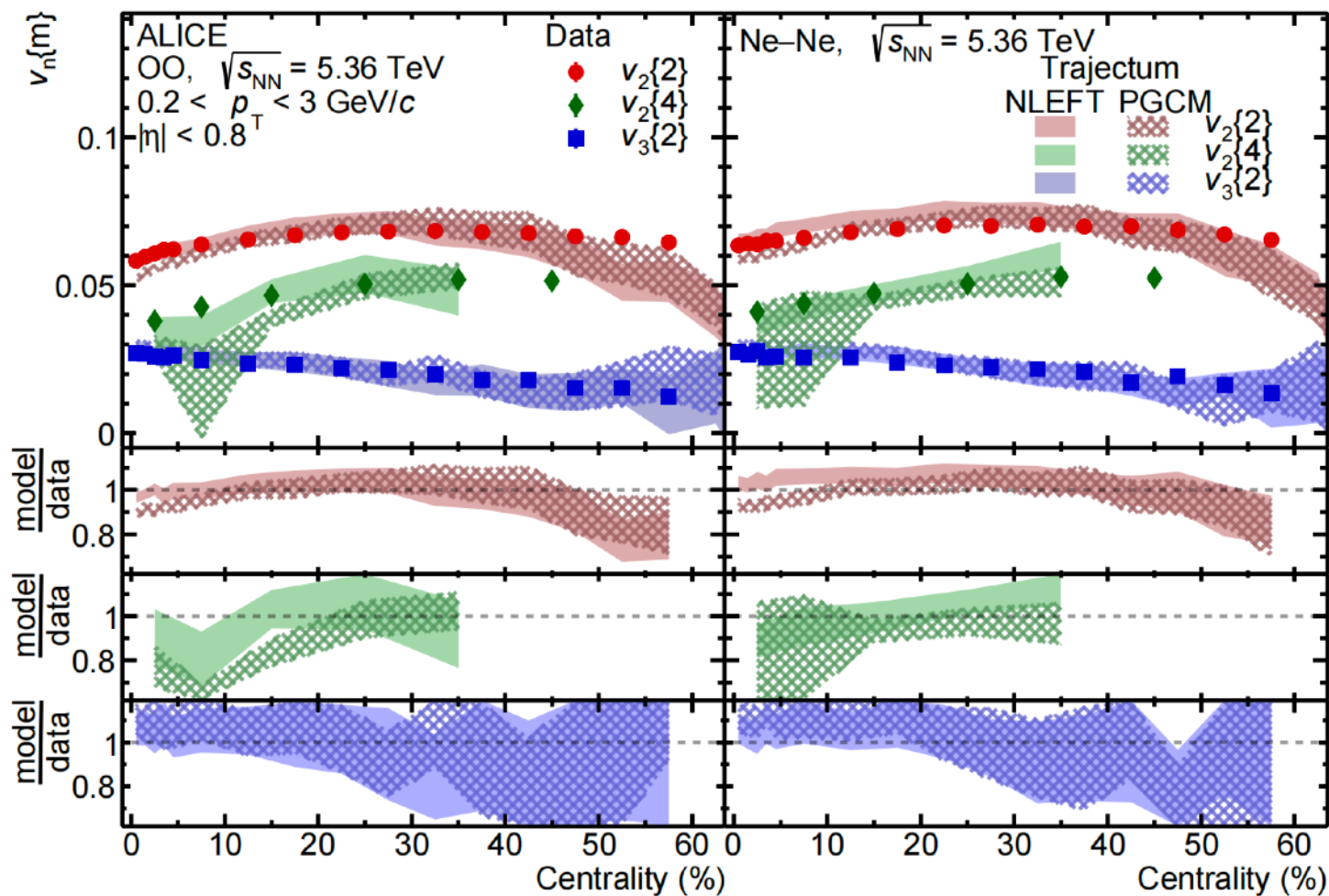
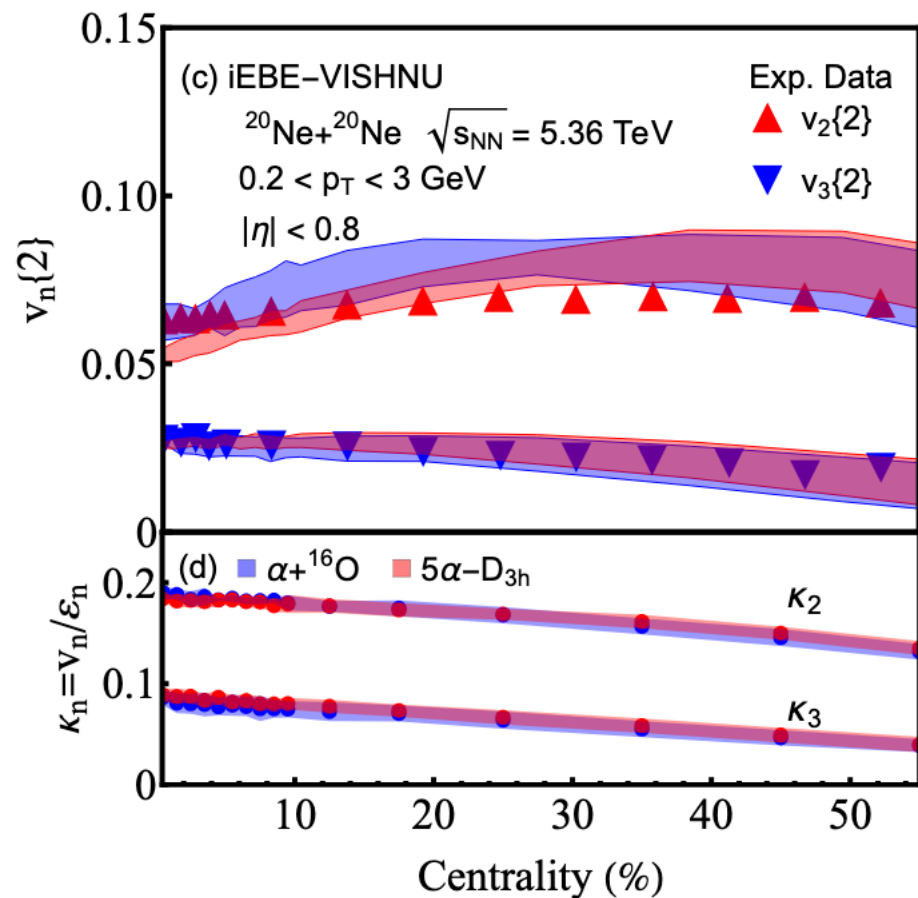
$$(000)' = \phi_{(000)} \left(\mathbf{r} - \frac{4}{5} R \hat{z} \right) = \sum_{n_z} (00n_z) \left\langle (00n_z) \middle| (000)' \right\rangle = e^{-\frac{\nu}{2} R^2} \left\{ (000) + \sqrt{\nu} R (001) - \frac{\nu}{\sqrt{2}} R^2 (002) + \cdots \right\}$$

When $R \rightarrow 0$

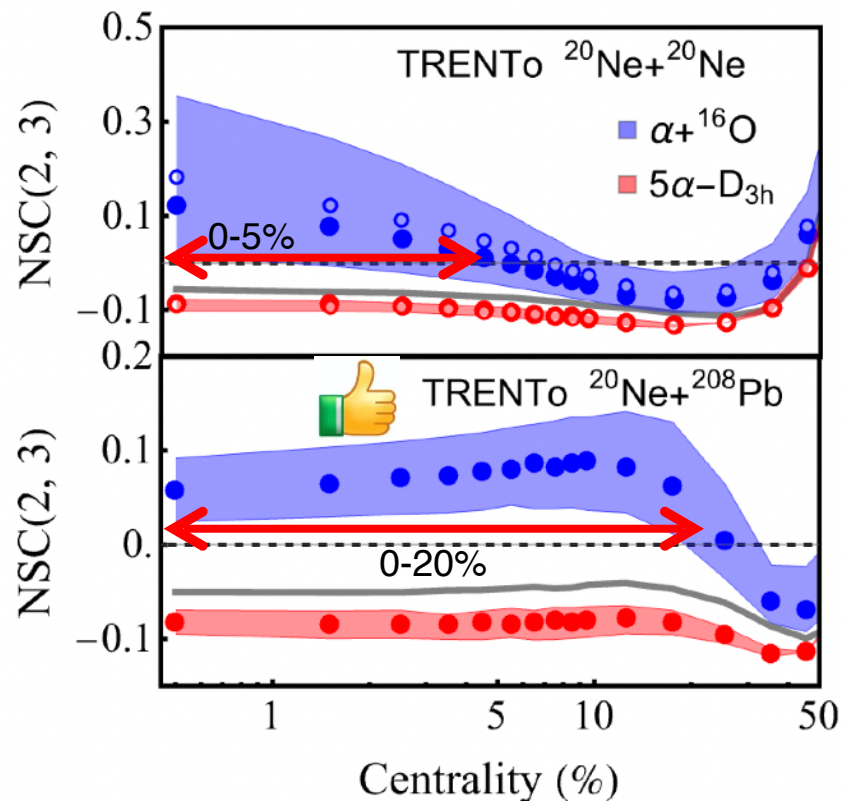
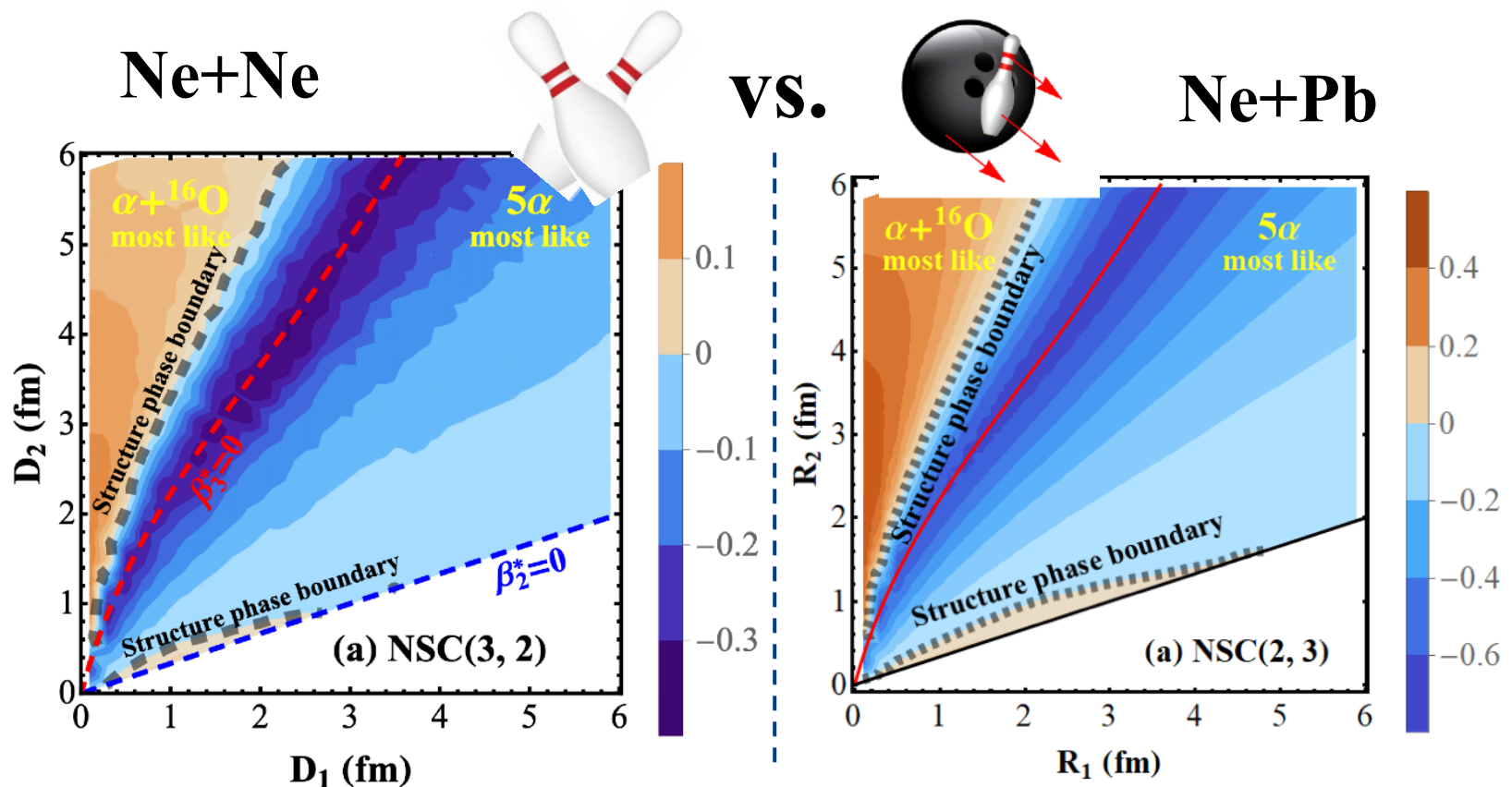
$$\Psi(\alpha - 16O, R) \propto \det \left[(000)^4 (100)^4 (010)^4 (001)^4 (002)^4 \right]$$

Backup

$v_n\{2\}$ compared to ALICE data



Ne+Ne vs. Ne+Pb



✓ The correlation strength of Ne+Pb **increases** compared to Ne+Ne.

✓ The distinguishable range of centrality of Ne+Pb **increases** compared to Ne+Ne.
 (0-20%) (0-5%)

Ne+Pb study in pipeline.

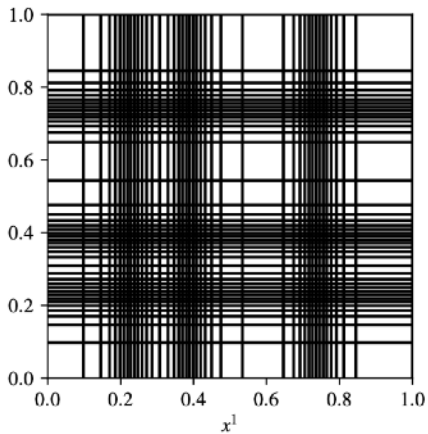


Adaptive monte carlo sampling



A novel Monte Carlo method inspired by VEGAS

--Adaptive Monte Carlo sample



Density with

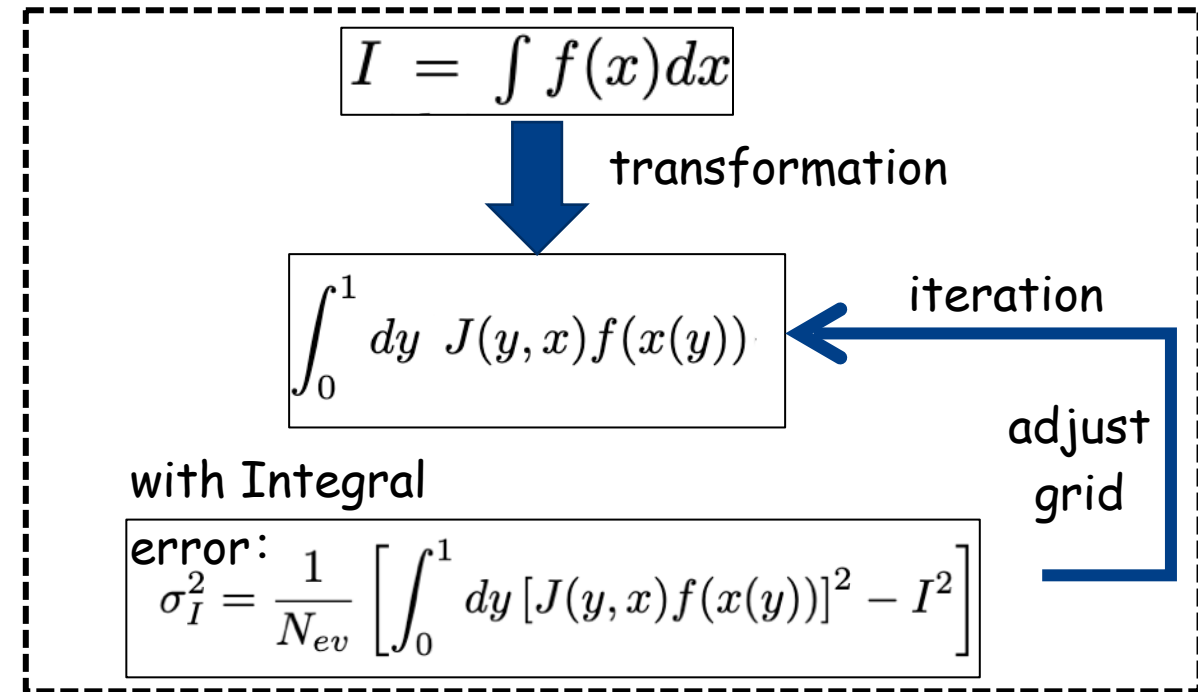
- high-dimensional
(48d for ^{16}O , 624d for ^{208}Pb)
- strongly coupled A-body
- complex structure

sampling with wave function

(cluster model/Shell model):

$$\rho_{corr}^{(A)}(\mathbf{r}_1, \mathbf{r}_2, \dots, \mathbf{r}_A) = |\Phi(\mathbf{r}_1, \mathbf{r}_2, \dots, \mathbf{r}_A)|^2$$

arXiv: 2511.23293



Sample from simple functions $g(y)$



Inverse
transformation

Samples of complex distribution $f(x)$

compared with MCMC

Quantifiable!

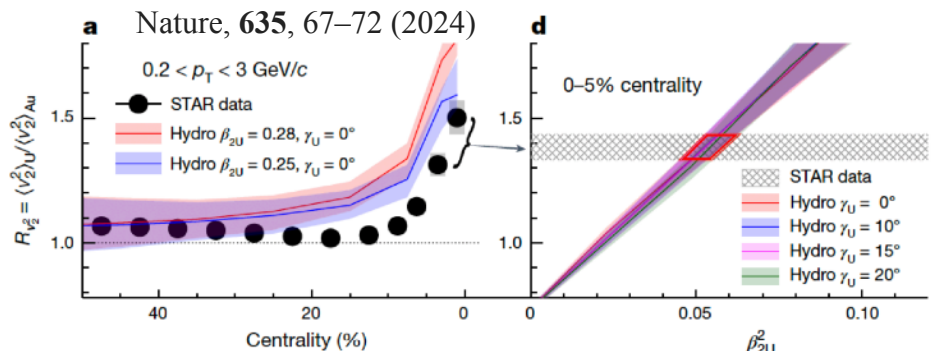
Accurate!

High efficiency!

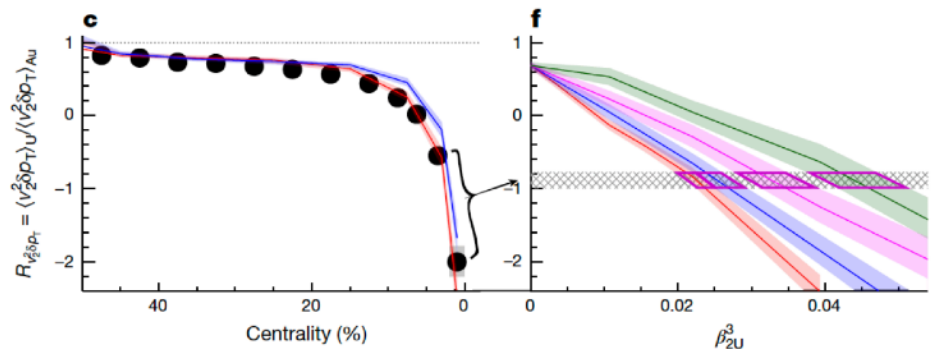
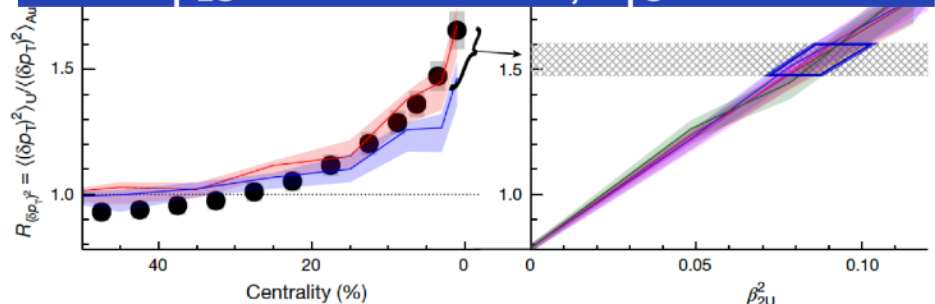
Deformation



238U+238U/197Au+197Au:



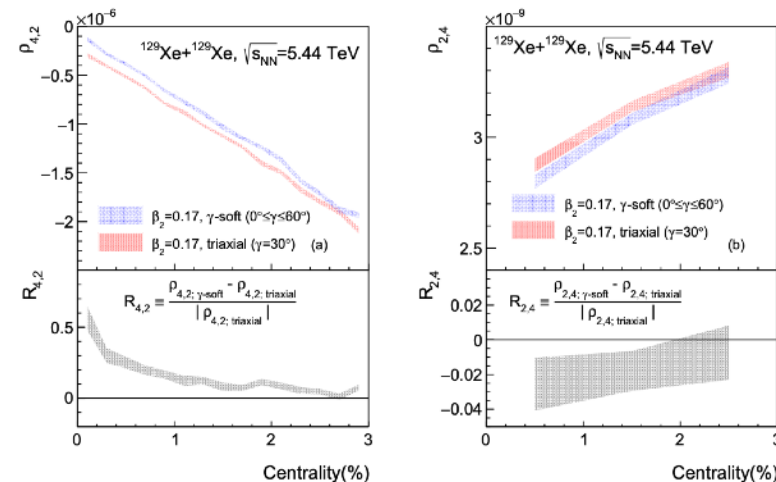
STAR: $\beta_{2U} = 0.297 \pm 0.015$; $\gamma_U = 8.7^\circ \pm 4.5^\circ$



129Xe+129Xe/208Pb+208Pb:

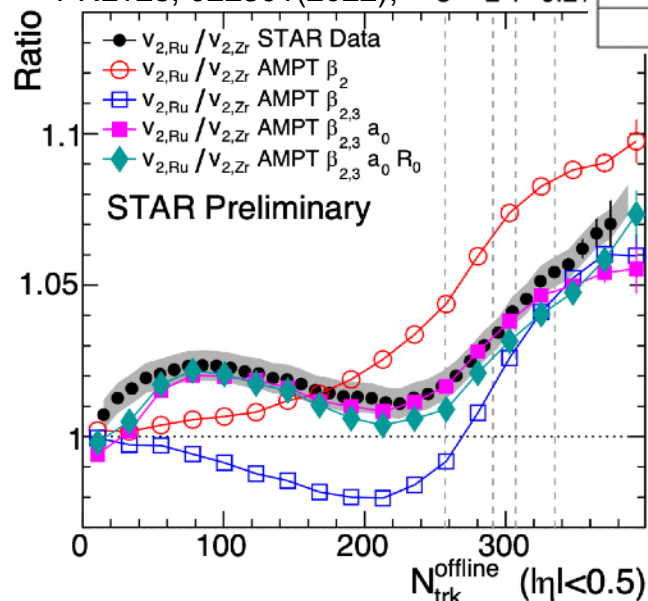
Phys.Rev.Lett. 133 (2024) 192301

$$\begin{aligned} \langle v_2^2 \rangle &= a_1 + b_1 \beta_2^2 \\ \langle (\delta p_T)^2 \rangle &= a_2 + b_2 \beta_2^2 \\ \langle v_2^2 \delta p_T \rangle &= a_3 - b_3 \beta_2^3 \cos(3\gamma) \end{aligned}$$

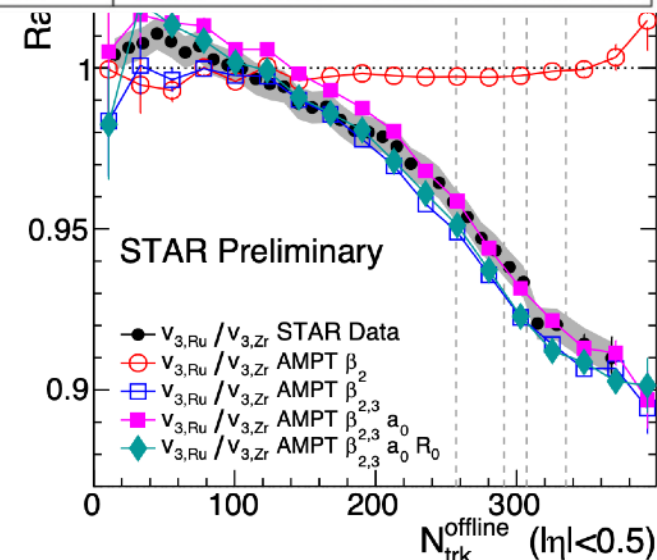


96Ru+96Ru/96Zr+96Zr:

PRL128, 022301(2022); 5 2 1 0.29



Species	β_2	β_3	a_0	R_0
Ru	0.162	0	0.46 fm	5.09 fm
Zr	0.06	0.20	0.52 fm	5.02 fm

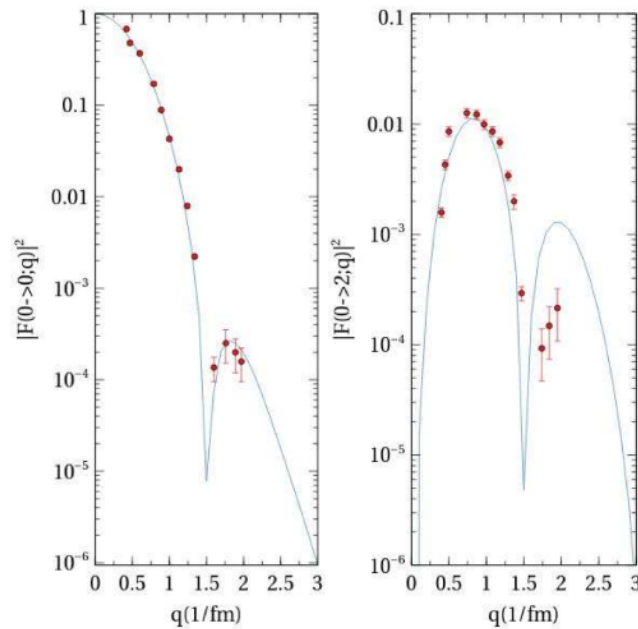
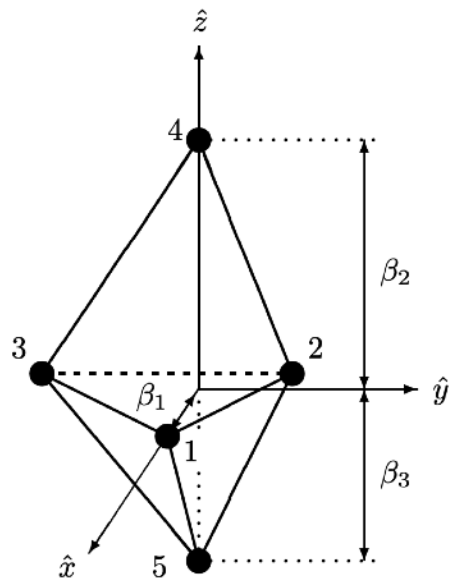


Clusters in ^{20}Ne

^{20}Ne large deformation
or significant cluster structure

Nucl.Phys.A 1006 (2021) 122077

Algebraic Collective Model (ACM)



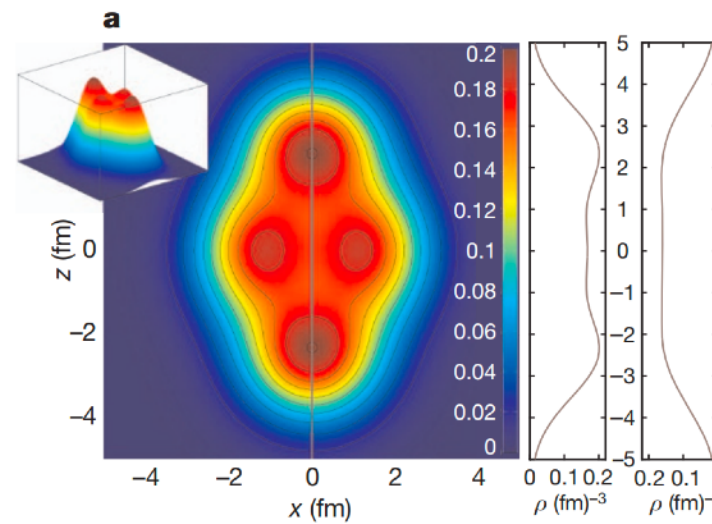
PHYSICAL REVIEW C **110**, 034909 (2024)

	β_2	β_3
^{20}Ne	0.666	0.250

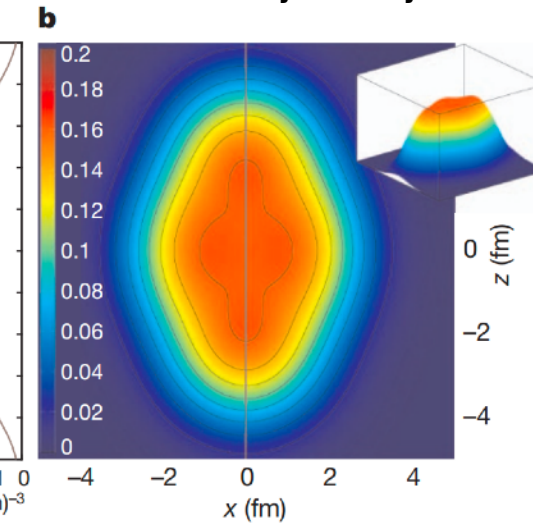
Energy-density functionals

Nature 487 (2012) 341-344

relativistic functional **DD-ME2**



non-relativistic Skyrme **SLy4**



➤ Evidence of ^{20}Ne with D_{3h} symmetry