Imaging Atomic Nuclei Through High-Energy Nuclear Collisions

Giuliano Giacalone

April 20, 2026

Intersection of nuclear structure and high-energy nuclear collisions 2026

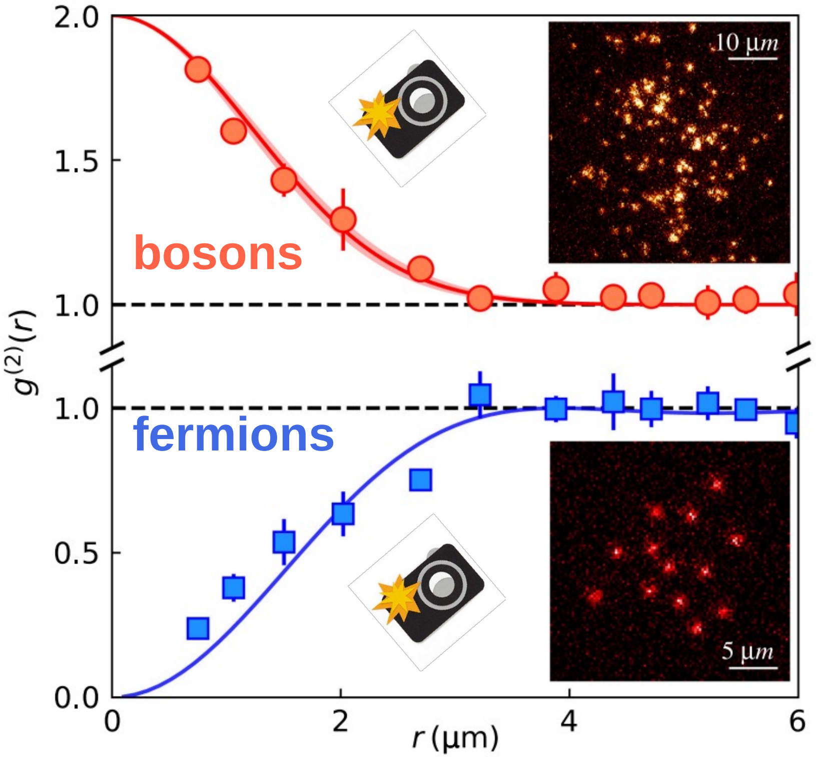
13–24 apr 2026
Yukawa Institute for Theoretical Physics
Asia/Tokyo fuso orario

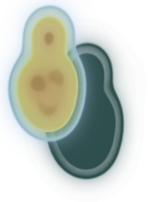
Imaging (static) many-body systems

Classical – one picture with sufficient resolution

Quantum – Stochastic approach

$$|\Psi(\mathbf{r_1}, \mathbf{r_2}, \ldots, \mathbf{r_A})|^2$$





Can we image the atomic nucleus?

two-body correlation function $$g_2(\mathbf{r}_1, \mathbf{r}_2) = \frac{\langle \psi^\dagger(\mathbf{r}_2)\psi^\dagger(\mathbf{r}_1)\psi(\mathbf{r}_1)\psi(\mathbf{r}_2)\rangle}{n^2}$$

[Yao et al., PRL **134** (2025) 18, 183402]

OUTLINE

- Nuclear structure imprints in high-energy nuclear collisions
- Theory foundations – From shapes to correlation functions
- Prospects – Many-body correlations and chiral EFT

  – Future experiments with ions

- Challenges at the interface between high- and low-energy physics

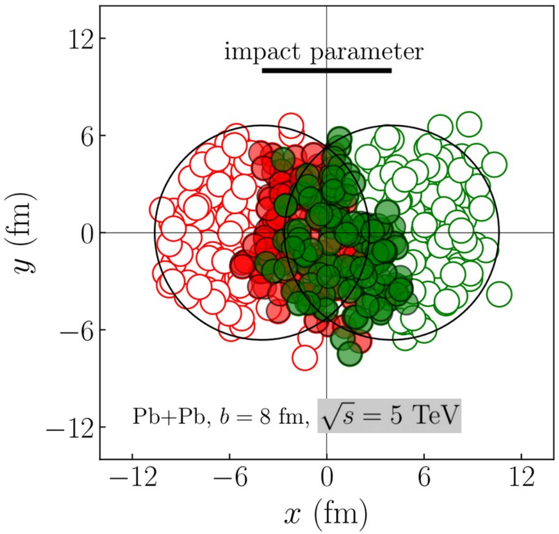
time permitting

Key driving question:

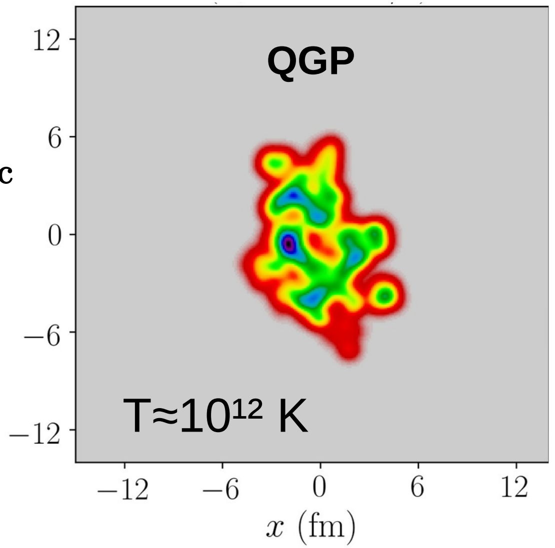
Hagino, Mon Apr 13

What is an advantage/a justification of using relativistic heavy-ion collisions to probe nuclear shapes? → What is the component beyond "just for fun"?

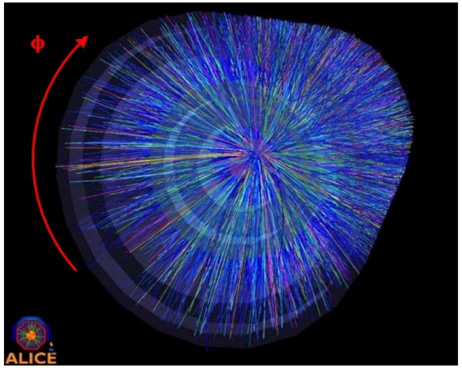
The perfect QCD fluid – 25 years later



≈ 1 fm/c



hydro



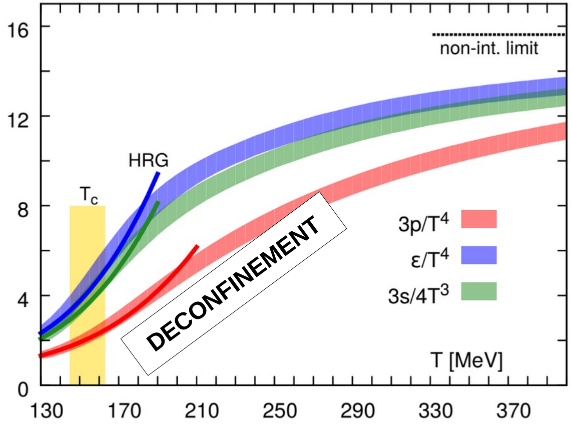
Relativistic fluid description: $T^{\mu\nu} = (\epsilon + P)u^\mu u^\nu - P g^{\mu\nu}$

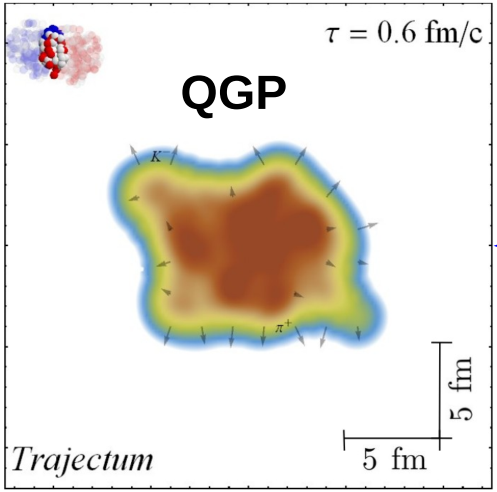
Equation of state from lattice QCD

[HoTQCD collaboration, PRD **90** (2014) 094503]

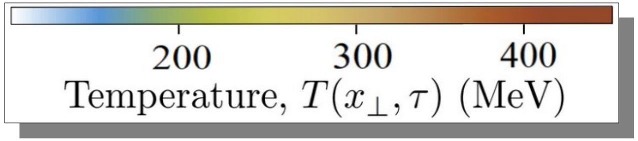
Fluid is viscous (η/s **,** ζ/s **, ...)**

[Romatschke & Romatschke, arXiv:1712.05815]

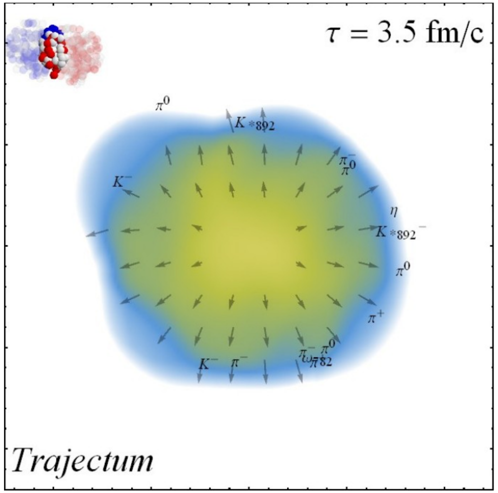


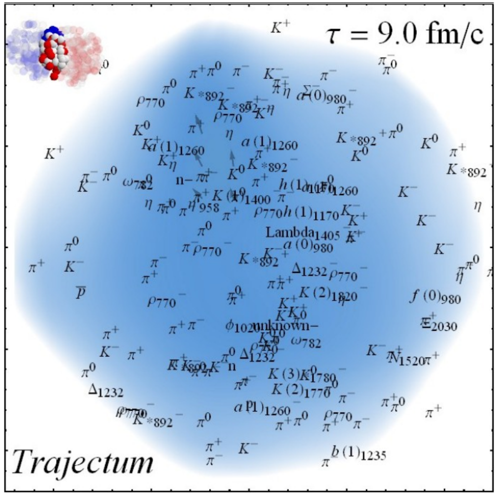


QGP



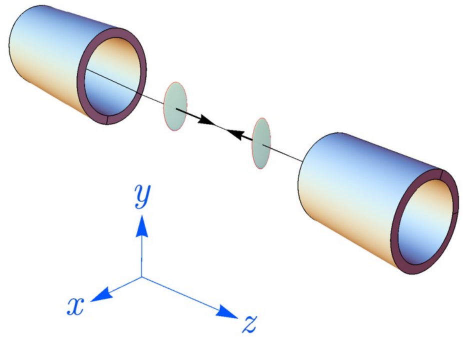
RECONSTRUCTING THE INITIAL STATE





$\tau \approx \infty$

OBSERVABLES



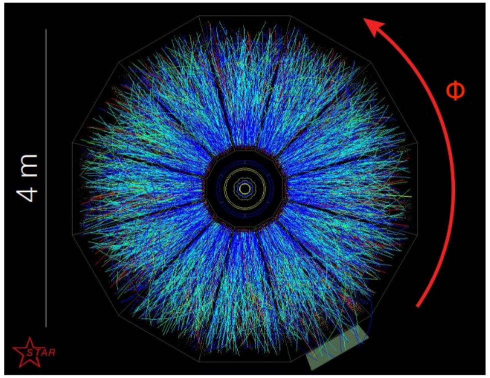
How ?

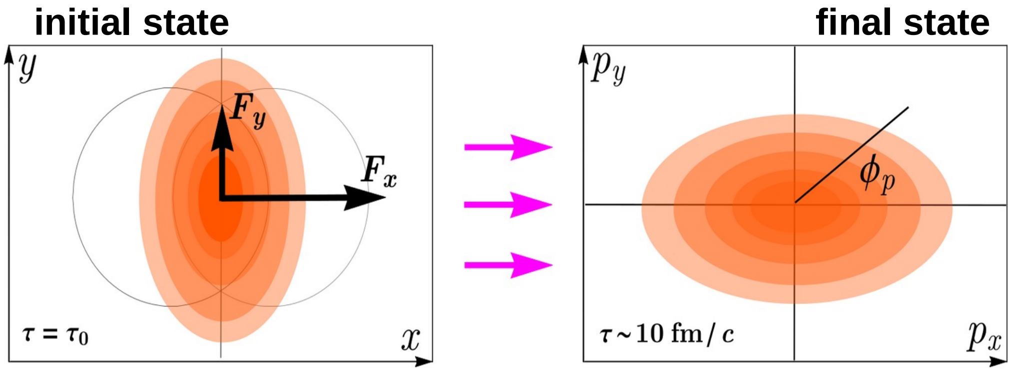
Soft spectra, hydrodynamics, initial-state geometry

The art of event-by-event analysis

[Ollitrault, 1992]

[Heinz, Snellings, 2013]

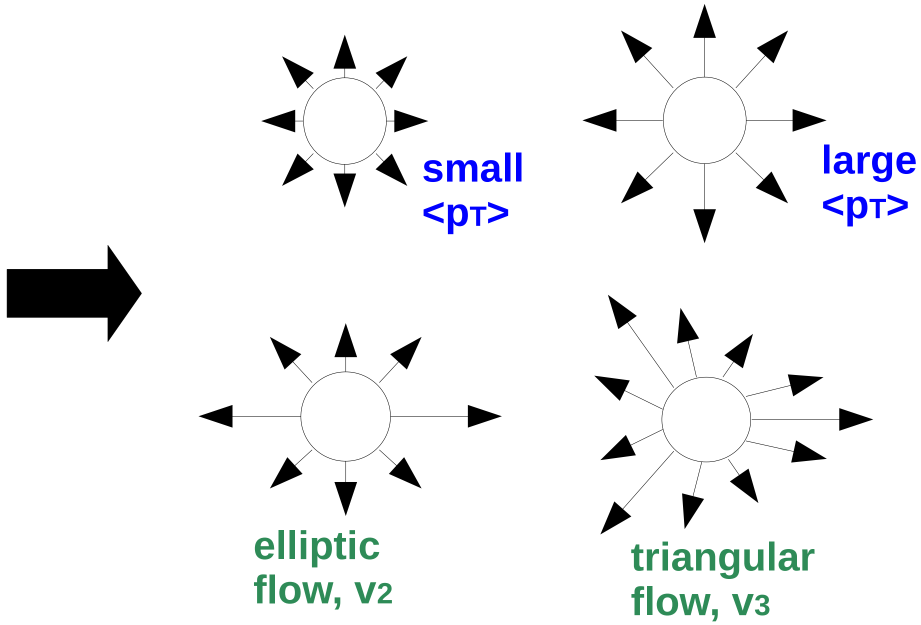




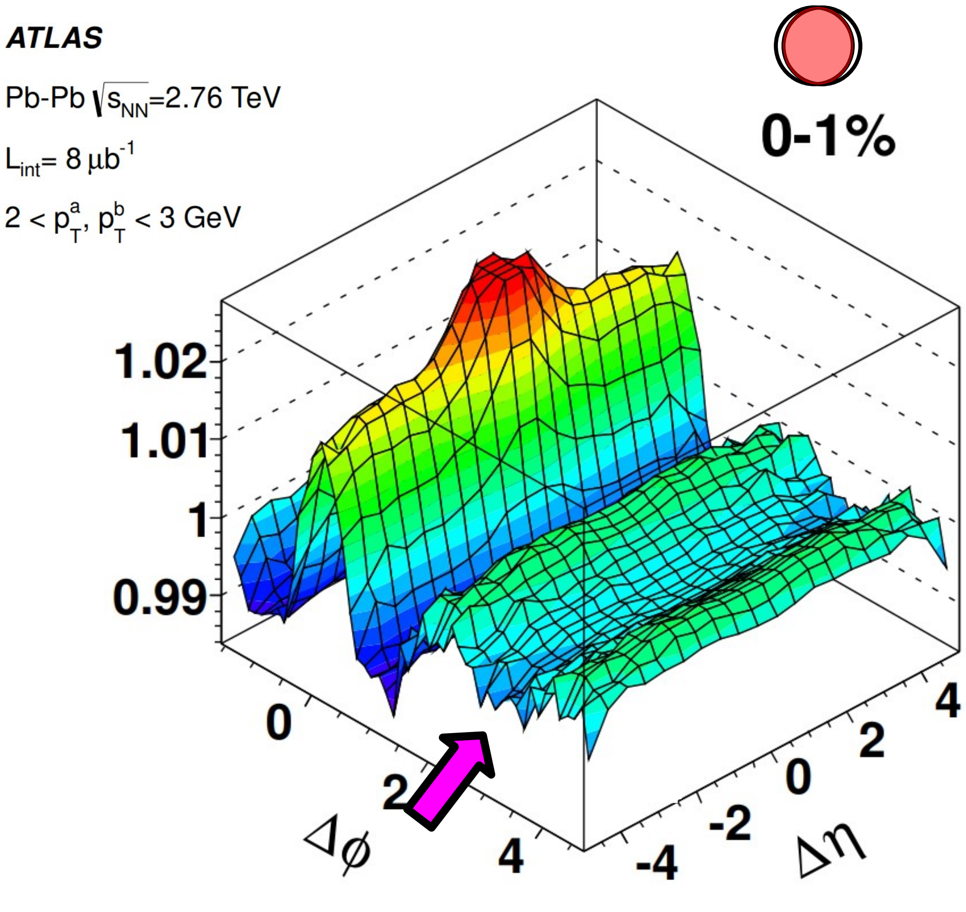
$$F = -\nabla P$$

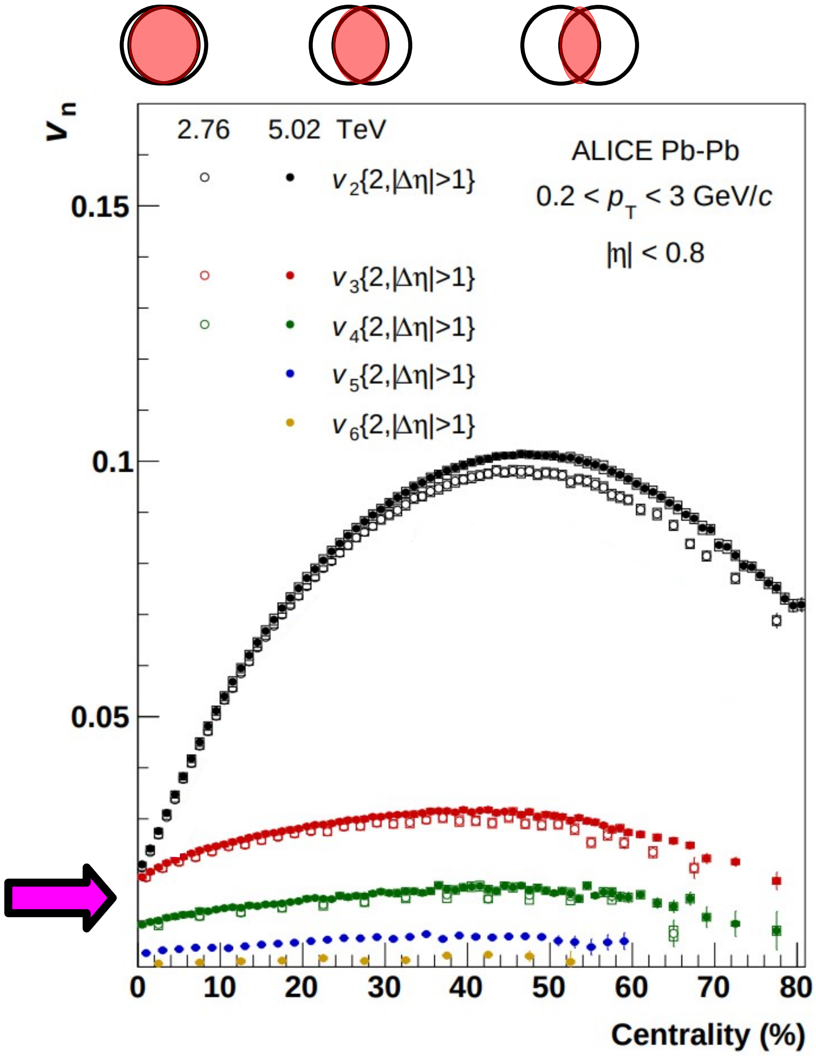
1/R

$$v_2 \propto \int_\phi e^{i2\phi} \frac{dN}{d\phi}$$



Experimental breakthroughs – Collective flow persists in ultra-central collisions

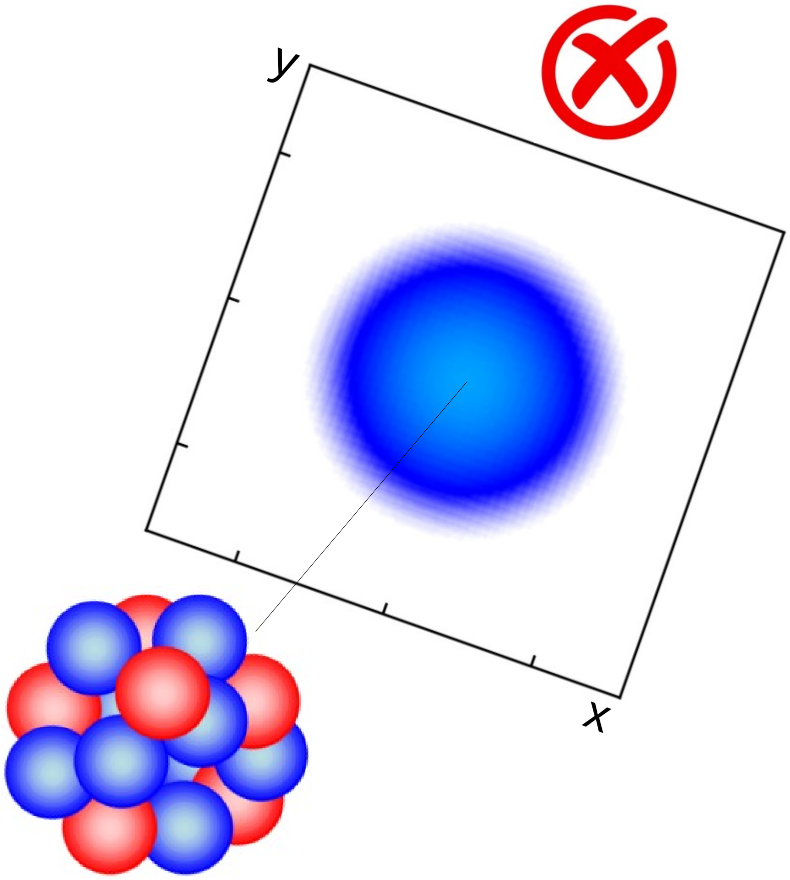


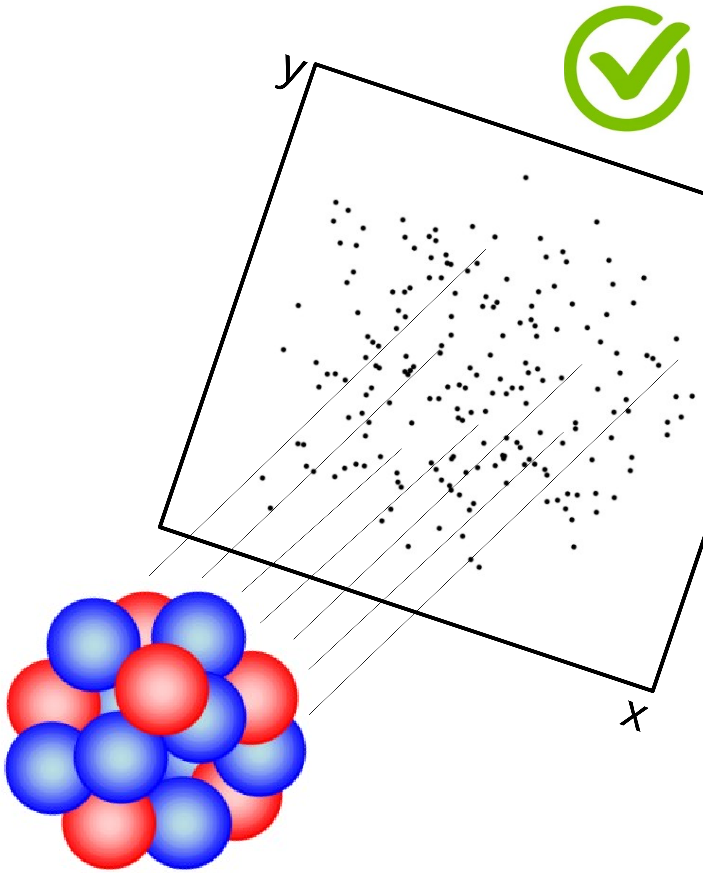


[ATLAS Collaboration, PRC **86** (2012) 014907]

[ALICE Collaboration, JHEP 07 (2018) 103]

Modern paradigm – Essential role of nucleonic degrees of freedom

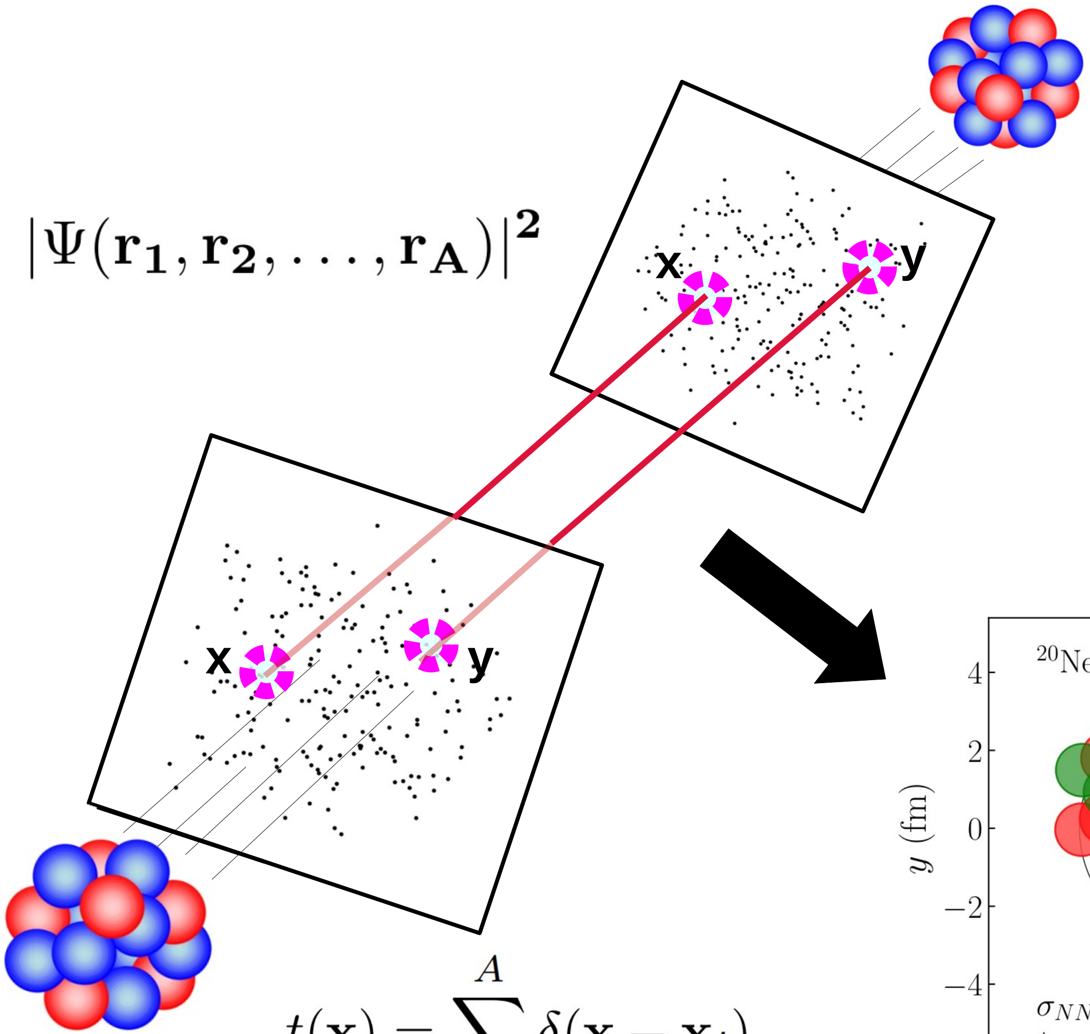




[PHOBOS Collaboration, PRL **98** (2007) 242302]
[Miller *et al.*, Ann.Rev.Nucl.Part.Sci. **57** (2007) 205-243]
[Alver, Roland, PRC **81** (2010) 054905]

Physics of ultra-central collisions

$$\left|\Psi(\mathbf{r_1}, \mathbf{r_2}, \ldots, \mathbf{r_A})\right|^2$$

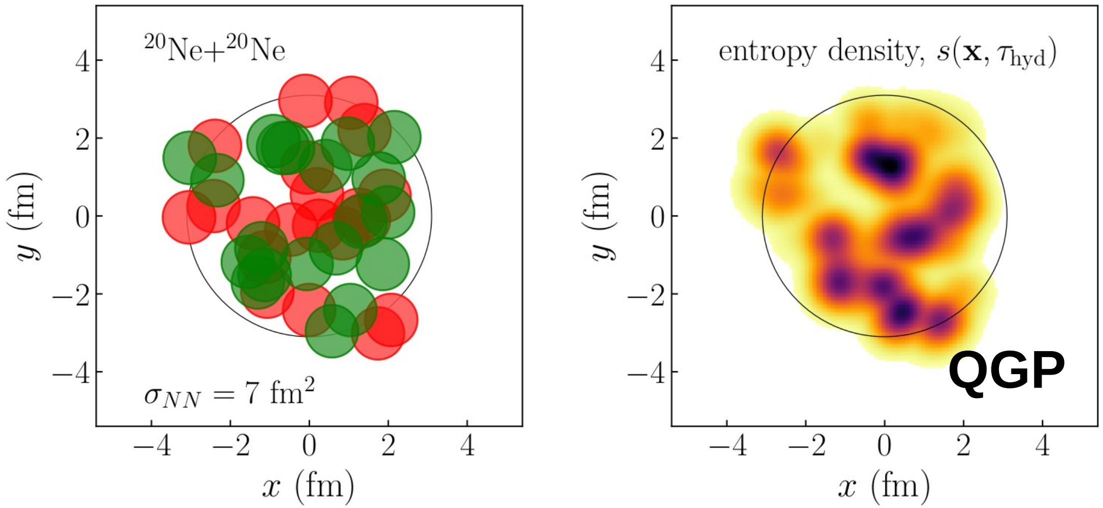


$$t(\mathbf{x}) = \sum_i^A \delta(\mathbf{x} - \mathbf{x}_i)$$

Time scale of scattering ~0.1 fm/c

Typical transverse kick Qs~1GeV

Nucleon positions dictate large-scale structures in the QGP



Ultra-central anisotropic flow – Connection to nuclear structure

Duguet, Thu Apr 16

1) Linear hydrodynamic

To be revisited later…

$$V_\ell \approx \kappa_\ell\, \epsilon_\ell \;\Rightarrow\; \mathrm{Var}(V_\ell) \approx \kappa_\ell^2 \mathrm{Var}(\epsilon_\ell)$$

Particularly well satisfied for l=2,3 $\mathcal{E}^{(1)}_\ell(\mathbf{r}_\perp) \equiv r^\ell_\perp e^{i\ell\phi}$

Gardim et al, PRC (2012,2015)

2) Linearized approximation of initial state fluctuations of the entropy density at midrapidity

$$s(\mathbf{r}_\perp) = \overline{s(\mathbf{r}_\perp)} + \delta s(\mathbf{r}_\perp) \;\Rightarrow$$

Blaizot, Broniowski, Ollitrault, PLB (2014)

① $$\mathrm{Var}(\epsilon_\ell) \equiv \overline{\delta\epsilon_\ell^2} \approx \frac{\overline{\delta\mathcal{E}^{(1)}_\ell \delta\mathcal{E}^{(1)}_{-\ell}}}{\left(\overline{R^{(1)}_\ell}\right)^2} = \frac{\int_{\mathbf{r}_{\perp 1,2}} \mathcal{E}^{(1)}_\ell(\mathbf{r}_{\perp 1})\mathcal{E}^{(1)}_{-\ell}(\mathbf{r}_{\perp 2}) C^{(2)}(\mathbf{r}_{\perp 1},\mathbf{r}_{\perp 2})}{\left(\int_{\mathbf{r}_{\perp 1}} R^{(1)}_\ell(\mathbf{r}_{\perp 1}) C^{(1)}(\mathbf{r}_{\perp 1})\right)^2}$$

② Correlation functions $$C^{(1)}(\mathbf{r}_{\perp 1}) \equiv \overline{s(\mathbf{r}_{\perp 1})} \quad C^{(2)}(\mathbf{r}_{\perp 1},\mathbf{r}_{\perp 2}) \equiv \overline{\delta s(\mathbf{r}_{\perp 1})\delta s(\mathbf{r}_{\perp 2})} = \overline{s(\mathbf{r}_{\perp 1}) s(\mathbf{r}_{\perp 2})} - \overline{s(\mathbf{r}_{\perp 1})}\;\overline{s(\mathbf{r}_{\perp 2})}$$

3) Parametrization of the QGP entropy density

TRENTo ansatz

Thickness function = Matter density in TP

$$t(\mathbf{r}_\perp) \equiv \sum_{i=1}^{A} g(\mathbf{r}_\perp - \mathbf{r}_{\perp i}) \approx \sum_{i=1}^{A} \delta(\mathbf{r}_\perp - \mathbf{r}_{\perp i}) \;\Rightarrow\; s(\mathbf{r}_\perp) = s_0\left(\frac{t(\mathbf{r}_\perp)^p + t'(\mathbf{r}_\perp)^p}{2}\right)^{1/p} \;\xrightarrow{p=1}\; ③\; s(\mathbf{r}_\perp) = s_0 \frac{t(\mathbf{r}_\perp) + t'(\mathbf{r}_\perp)}{2}$$

$$C^{(1)}(\mathbf{r}_{\perp 1}) = s_0 \int_{z_1} \rho^{(1)}(\mathbf{r}_1)$$

$$C^{(2)}(\mathbf{r}_{\perp 1},\mathbf{r}_{\perp 2}) = \frac{s_0^2}{2}\left(\int_{z_1} \delta(\mathbf{r}_1 - \mathbf{r}_2)\rho^{(1)}(\mathbf{r}_1) + \int_{z_{1,2}} \rho^{(2)}(\mathbf{r}_1,\mathbf{r}_2) - \int_{z_1}\rho^{(1)}(\mathbf{r}_1)\int_{z_2}\rho^{(1)}(\mathbf{r}_2)\right)$$

n-body local ground-state densities

$$\rho^{(n)}(\mathbf{r}_1,\ldots,\mathbf{r}_n) = \int d\mathbf{r}_{n+1}\cdots d\mathbf{r}_A\, |\Psi(\mathbf{r}_1,\ldots,\mathbf{r}_A)|^2$$

Duguet *et al.*, PRL (2025)

④ ➡ ① ➡

$$\langle \delta\epsilon_\ell^2 \rangle = \frac{1}{2}\frac{\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\mathcal{E}_{-\ell}^{(1)}(\mathbf{r}_1) + \int_{\mathbf{r}_{1,2}}\rho^{(2)}(\mathbf{r}_1,\mathbf{r}_2)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\mathcal{E}_{-\ell}^{(1)}(\mathbf{r}_2) - \left|\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\right|^2}{\left[\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)R_\ell^{(1)}(\mathbf{r}_1)\right]^2}$$

$$= \frac{1}{2}\frac{\langle \mathcal{E}_\ell^{(2)(1b)}\rangle + \langle \mathcal{E}_\ell^{(2)(2b)}\rangle - |\langle \mathcal{E}_\ell^{(1)}\rangle|^2}{\langle R_\ell^{(1)}\rangle^2}$$

$$\equiv \langle \epsilon_\ell^{(2)(1b)}\rangle + \langle \epsilon_\ell^{(2)(2b)}\rangle - |\langle \epsilon_\ell^{(1)}\rangle|^2$$

$\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)$ = one-body eccentricity operator

Probes two-body correlations

=0 for 0^+ states

$\mathcal{E}_\ell^{(2)(2b)}(\mathbf{r}_1,\mathbf{r}_2)$ = two-body part of squared eccentricity operator

$\mathcal{E}_\ell^{(2)(1b)}(\mathbf{r}_1)$ = one-body part of squared eccentricity operator

Now the "traditional" assumption : participants as independent sources!

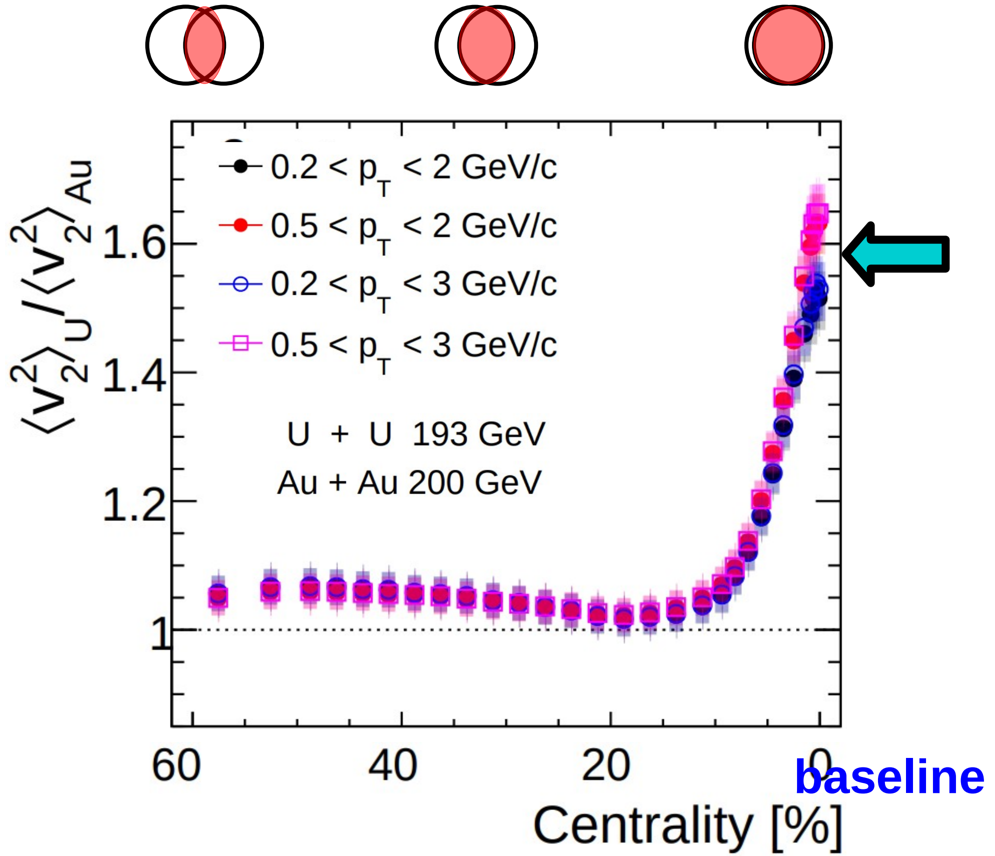
$$\rho^{(2)}(\mathbf{r}_1,\mathbf{r}_2) \approx \rho^{(1)}(\mathbf{r}_1)\rho^{(2)}(\mathbf{r}_2)$$

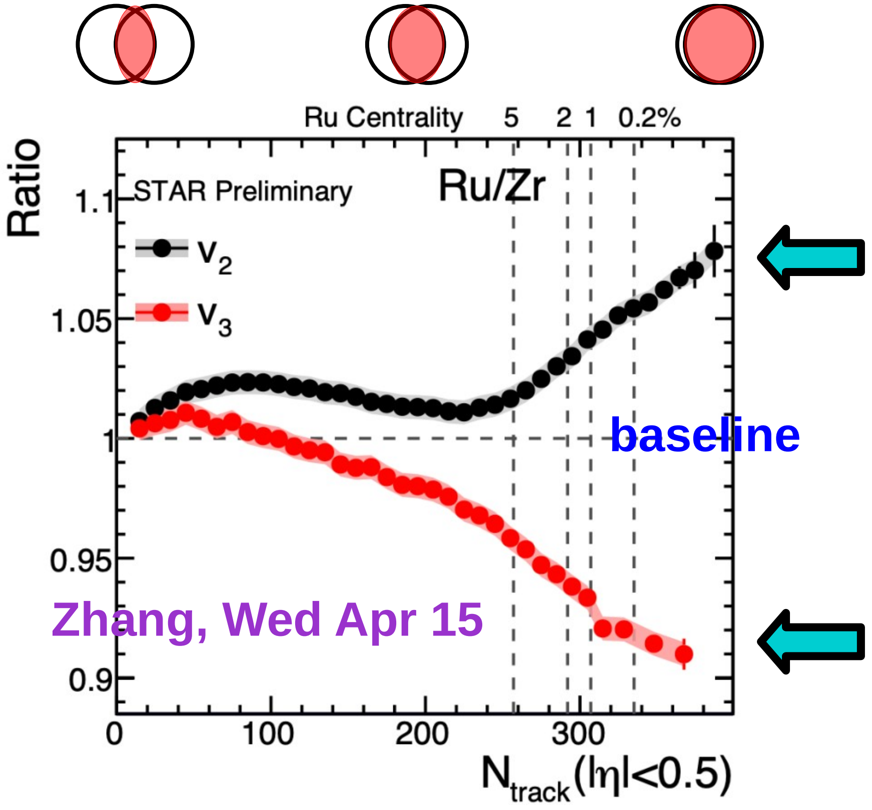
Only the one-body term survives!
(pulling A normalization out of the one-body density)

$$\langle \delta\varepsilon_\ell^2 \rangle = \frac{1}{2A}\frac{\langle r_\perp^{2\ell}\rangle}{\langle r_\perp^\ell\rangle^2}$$

≈ 1.6

[Bhalerao, Ollitrault, PLB **641** (2006) 260-264]
[PHOBOS Collaboration, PRC **77** (2008) 014906]





[STAR Collaboration, Rep. Prog. Phys. 88 108601 (2025)]

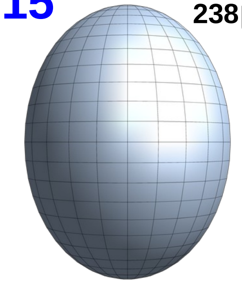
Strong departure from ultra-central baseline

$$\frac{\langle v_2^2\rangle_{\mathrm{X+X}}}{\langle v_2^2\rangle_{\mathrm{Y+Y}}} \simeq \frac{A_Y}{A_X}$$

???

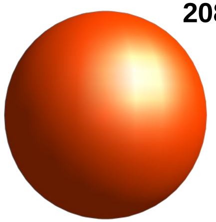
Recent breakthroughs – Collisions available for several nuclear species

2015

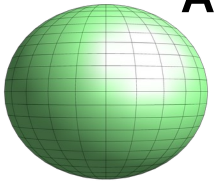


^{238}U

"default" isotopes

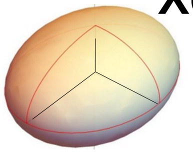


^{208}Pb



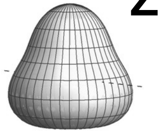
^{197}Au

2018

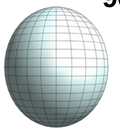


^{129}Xe

2021



^{96}Zr



^{96}Ru

2025

^{20}Ne

^{16}O

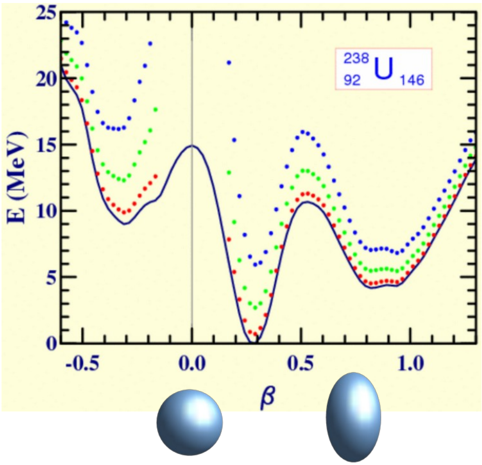
Redescovering the nuclear shape in collider smashups

[Verney, EPJA **61** (2025) 4, 82]

Mean-field approach

$$\delta \frac{\langle \Phi | H | \Phi \rangle}{\langle \Phi | \Phi \rangle} = 0$$

Slater determinant



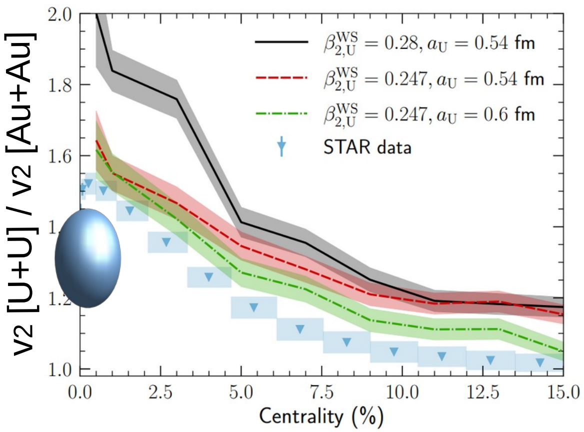
"spontaneous symmetry breaking"

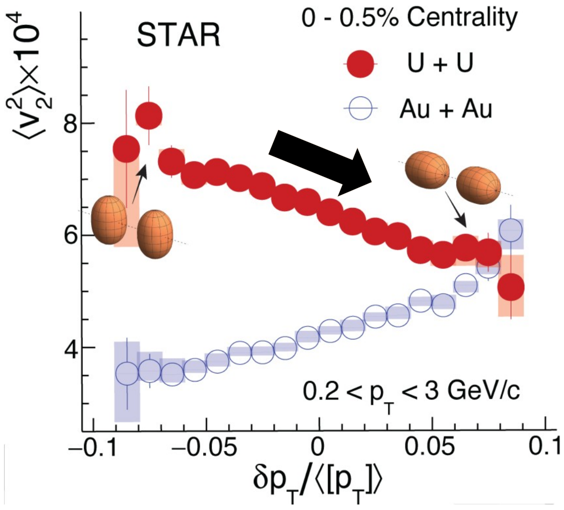
$$\beta \propto \langle \Phi | \hat{Q}_{20} | \Phi \rangle$$

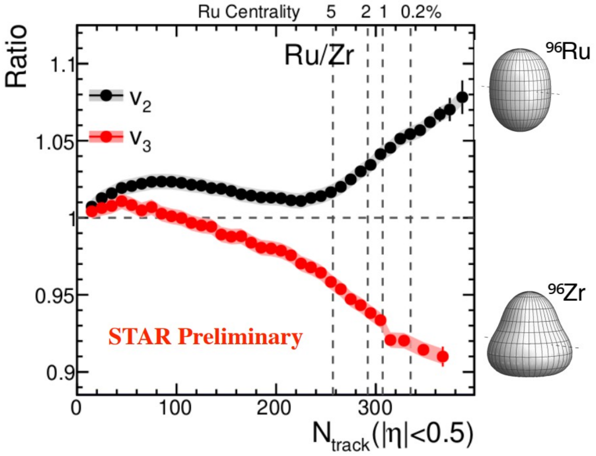
$$\hat{Q}_{20}(\mathbf{r}) \propto r^2 Y_{20}(\theta)$$

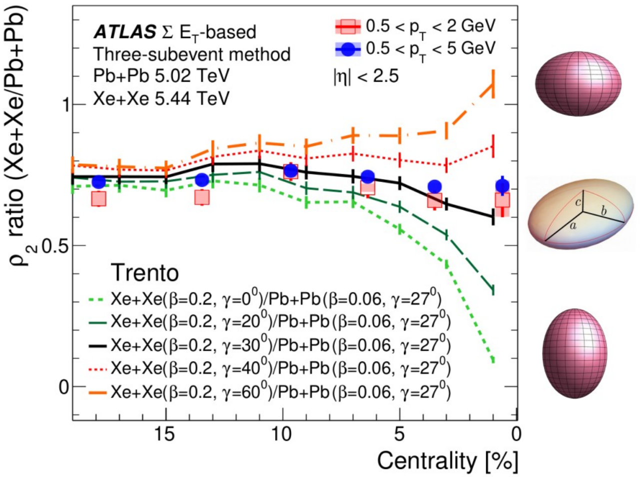
quadrupole operator

“Anomalies” in results fully explained by nuclear-shape effects









[STAR collaboration, PRL **115**, no.22, 222301 (2015)]

[ALICE collaboration, PLB **784**, 82-95 (2018)]

[CMS collaboration, PRC **100**, no.4, 044902 (2019)]

[ATLAS collaboration, PRC **100**, no.4, 044902 (2019)]

[STAR collaboration, PRC **105**, no.1, 014901 (2022)]

[ALICE collaboration, PLB **834**, 137393 (2022)]

[ATLAS collaboration, PRC **107**, no.5, 054910 (2023)]

[STAR collaboration, Nature **635**, no.8037, 67-72 (2024)]

[ATLAS collaboration, PRL **133** (2024) 25, 252301]

[ALICE collaboration, arXiv:2409.04343]

[STAR collaboration, arXiv:2506.17785]

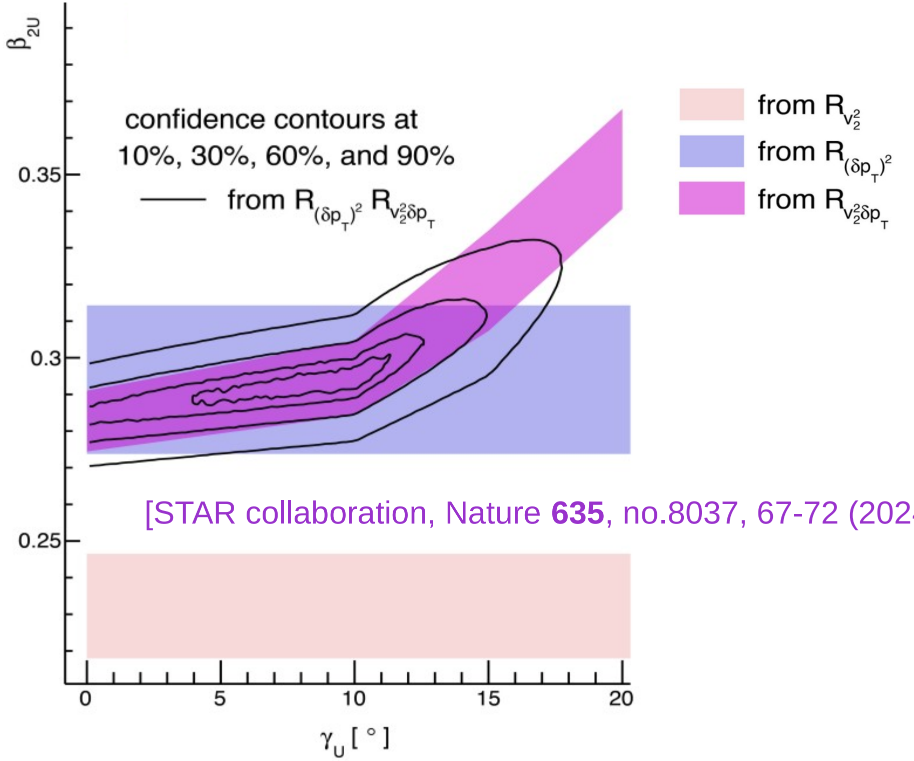
[ATLAS collaboration, arXiv:2509.05171]

[ALICE collaboration, arXiv:2509.06428]

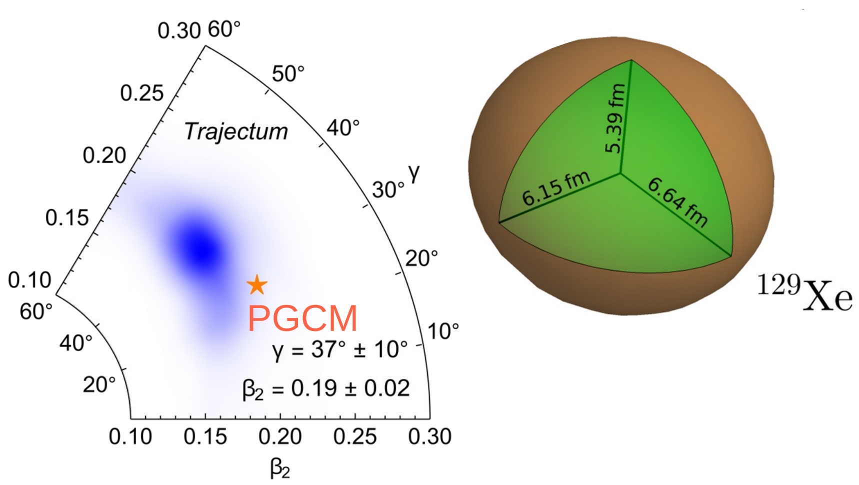
[CMS collaboration, arXiv:2510.02580]

…

Highly quantitative analyses – Nuclear structure information is accessible



[STAR collaboration, Nature **635**, no.8037, 67-72 (2024)]



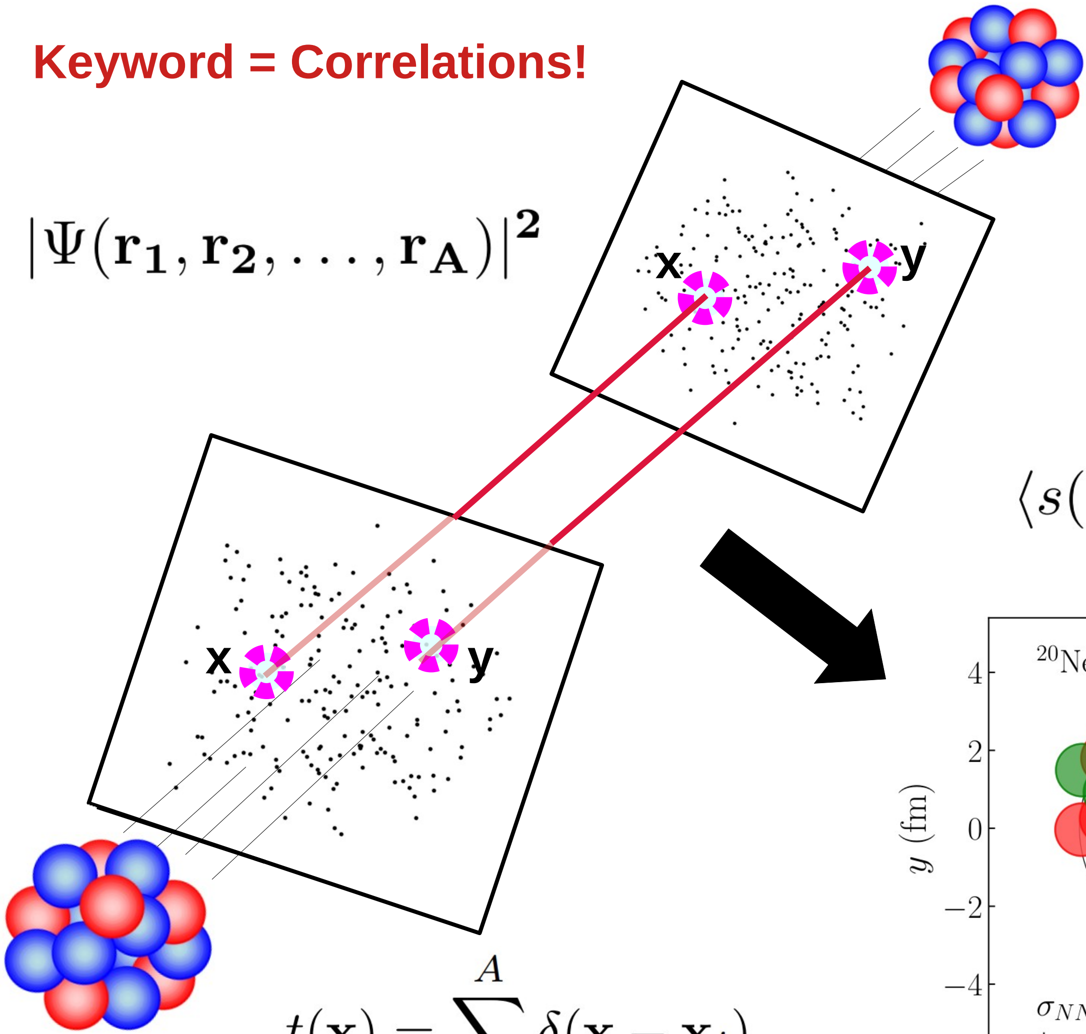
Bayesian analysis within Trajectum framework
[Giacalone, Nijs, van der Schee, in preparation]
[ALICE collaboration, in preparation]

Back to Hagino-san's question – We still do not have an answer …

What is an advantage/a justification of using relativistic heavy-ion collisions to probe nuclear shapes? → What is the component beyond "just for fun"?

Keyword = Correlations!

$$\left|\Psi(\mathbf{r_1}, \mathbf{r_2}, \ldots, \mathbf{r_A})\right|^2$$

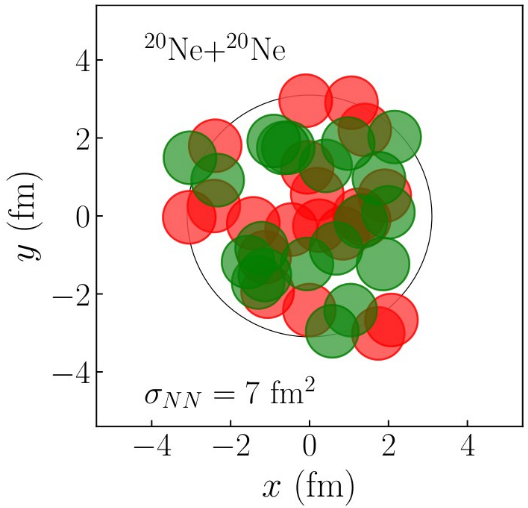


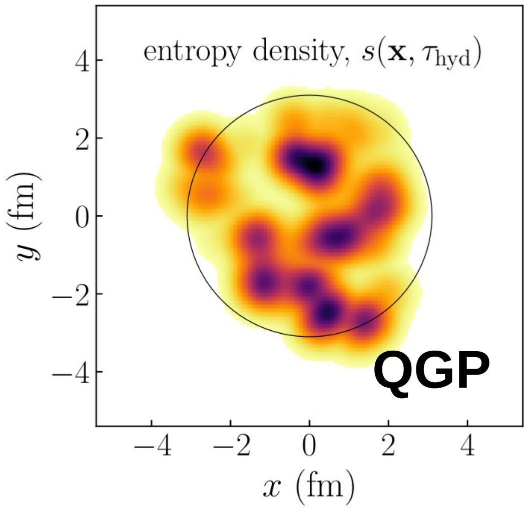
Physics of ultra-central collisions

Long-range correlations from nuclear structure

$$\langle s(\mathbf{x}) s(\mathbf{y}) \rangle \qquad |\mathbf{x}-\mathbf{y}| > 1/Q$$

→ large scales from low-energy physics!





$$t(\mathbf{x}) = \sum_i^A \delta(\mathbf{x} - \mathbf{x}_i)$$

Duguet *et al.*, PRL (2025)

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$$\langle\delta\epsilon_\ell^2\rangle = \frac{1}{2}\frac{\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\mathcal{E}_{-\ell}^{(1)}(\mathbf{r}_1) + \int_{\mathbf{r}_{1,2}}\rho^{(2)}(\mathbf{r}_1,\mathbf{r}_2)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\mathcal{E}_{-\ell}^{(1)}(\mathbf{r}_2) - \left|\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)\right|^2}{\left[\int_{\mathbf{r}_1}\rho^{(1)}(\mathbf{r}_1)R_\ell^{(1)}(\mathbf{r}_1)\right]^2}$$

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$$\equiv \langle\epsilon_\ell^{(2)(1b)}\rangle + \langle\epsilon_\ell^{(2)(2b)}\rangle - |\langle\epsilon_\ell^{(1)}\rangle|^2$$

$\mathcal{E}_\ell^{(1)}(\mathbf{r}_1)$ = one-body eccentricity operator

=0 for 0^+ states

Probes two-body correlations

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$\mathcal{E}_\ell^{(2)(1b)}(\mathbf{r}_1)$ = one-body part of squared eccentricity operator

Nuclear-shape effects? Let us lift the traditional assumption: correlated nucleons!

$$\rho^{(2)}(\mathbf{r}_1,\mathbf{r}_2) \neq \rho^{(1)}(\mathbf{r}_1)\rho^{(2)}(\mathbf{r}_2)$$

Leading-order correction from two-body correlations … the nuclear shape?

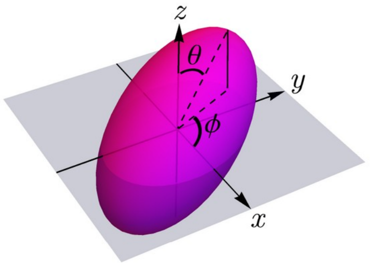
$$\langle\delta\varepsilon_\ell^2\rangle = \frac{1}{2A}\frac{\langle r_\perp^{2\ell}\rangle}{\langle r_\perp^\ell\rangle^2} + \frac{A-1}{A}\frac{\langle r_{1\perp}^\ell\, r_{2\perp}^\ell\, e^{i\ell(\phi_1-\phi_2)}\rangle}{\langle r_\perp^\ell\rangle^2}$$ ✓

Connecting the dots …

Duguet, Thu Apr 16

▶ **Quadrupole rotor model**

ρ_Ω



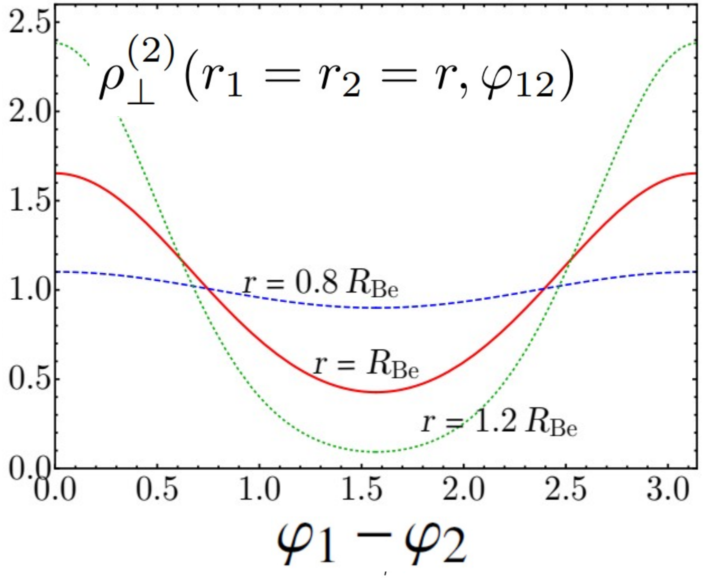
Tranverse plane

Nucleonic position $(\mathbf{r}, z) = (r, \varphi, z)$

$\Omega \equiv (\theta, \phi) =$ orientation of deformed body

$\delta =$ deformation parameter

Blaizot, Giacalone, EPJA (2025)



1- and 2-body laboratory density in transverse plane

$$\rho^{(1)}(\mathbf{r}) \equiv \int dz \int \frac{d\Omega}{4\pi} \rho_\Omega(\mathbf{r}, z) \ = \textbf{spherical}$$

Proportional to intrinsic deformation

Azimuthal modulation

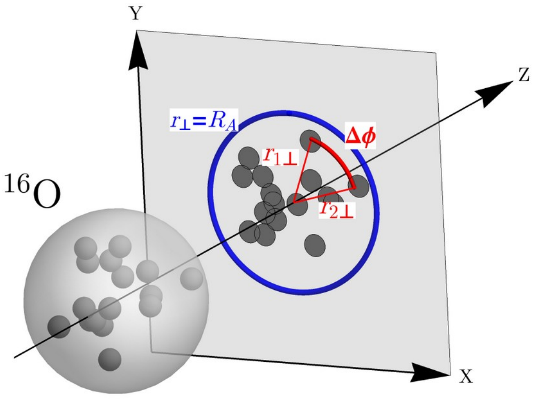
$$\rho^{(2)}(\mathbf{r}_1, \mathbf{r}_2) \equiv \int dz_1 dz_2 \int \frac{d\Omega}{4\pi} \rho_\Omega(\mathbf{r}_1, z_1) \rho_\Omega(\mathbf{r}_2, z_2) \ \propto \delta^2 r_1^2 r_2^2 \cos 2(\varphi_1 - \varphi_2)$$

Evaluate two-body part of the eccentricity operator

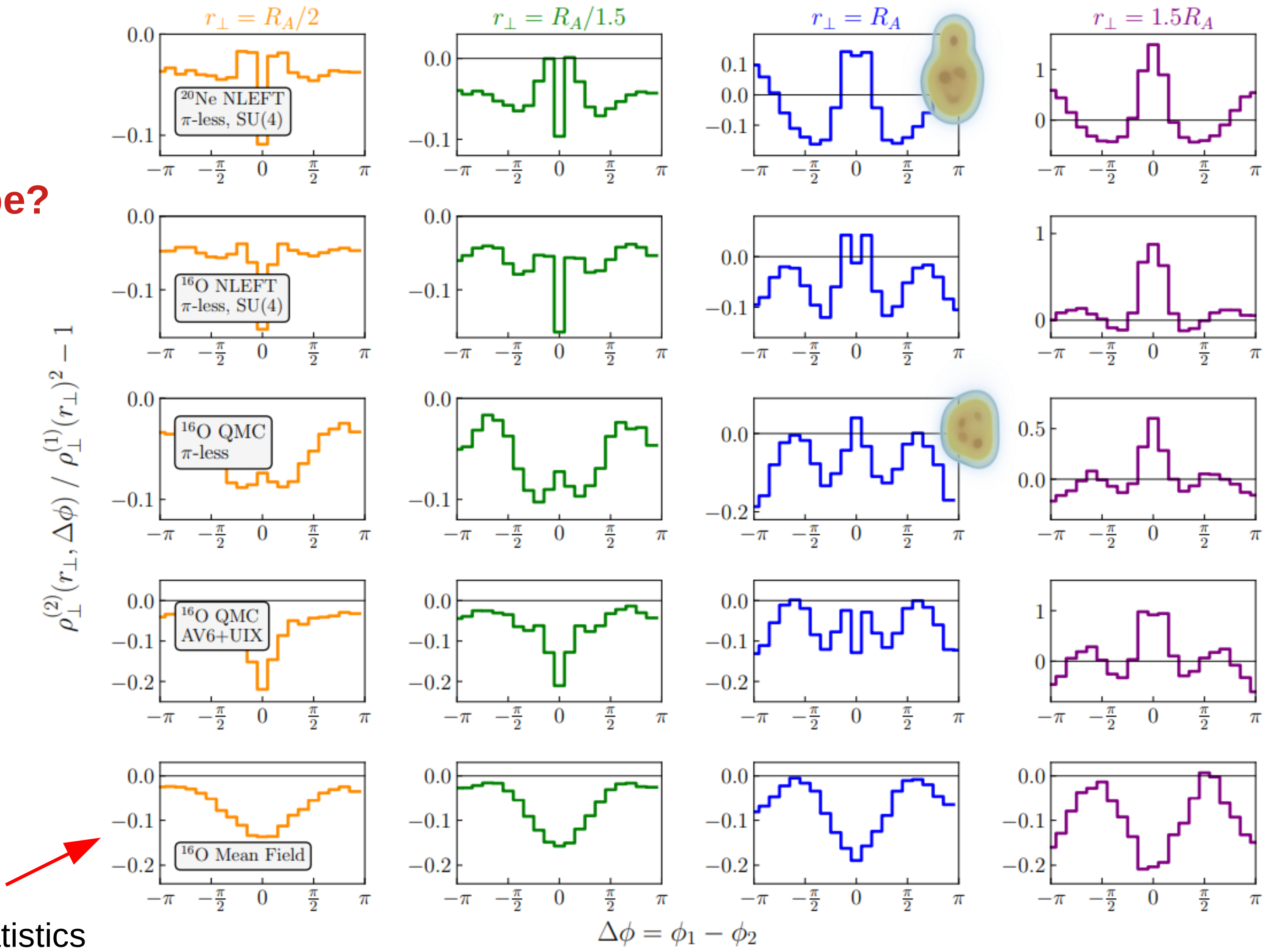
$$\left\langle r_{1\perp}^\ell \, r_{2\perp}^\ell \, e^{i\ell(\phi_1 - \phi_2)} \right\rangle = \int_{\mathbf{r}_{1\perp}, \mathbf{r}_{2\perp}} \rho^{(2)}(\mathbf{r}_1, \mathbf{r}_2) \, r_{1\perp}^\ell \, r_{2\perp}^\ell \, e^{i\ell(\phi_1 - \phi_2)} \quad \propto \quad \delta^2$$

Rotor approximation (now δ = β₂) of ms eccentricity ⟶ $\langle \delta \varepsilon_2^2 \rangle \approx \frac{1.6}{2A} + \left(\frac{A-1}{A}\right) \frac{3}{4\pi} \beta_2^2$

What is the nuclear shape?
High-energy viewpoint

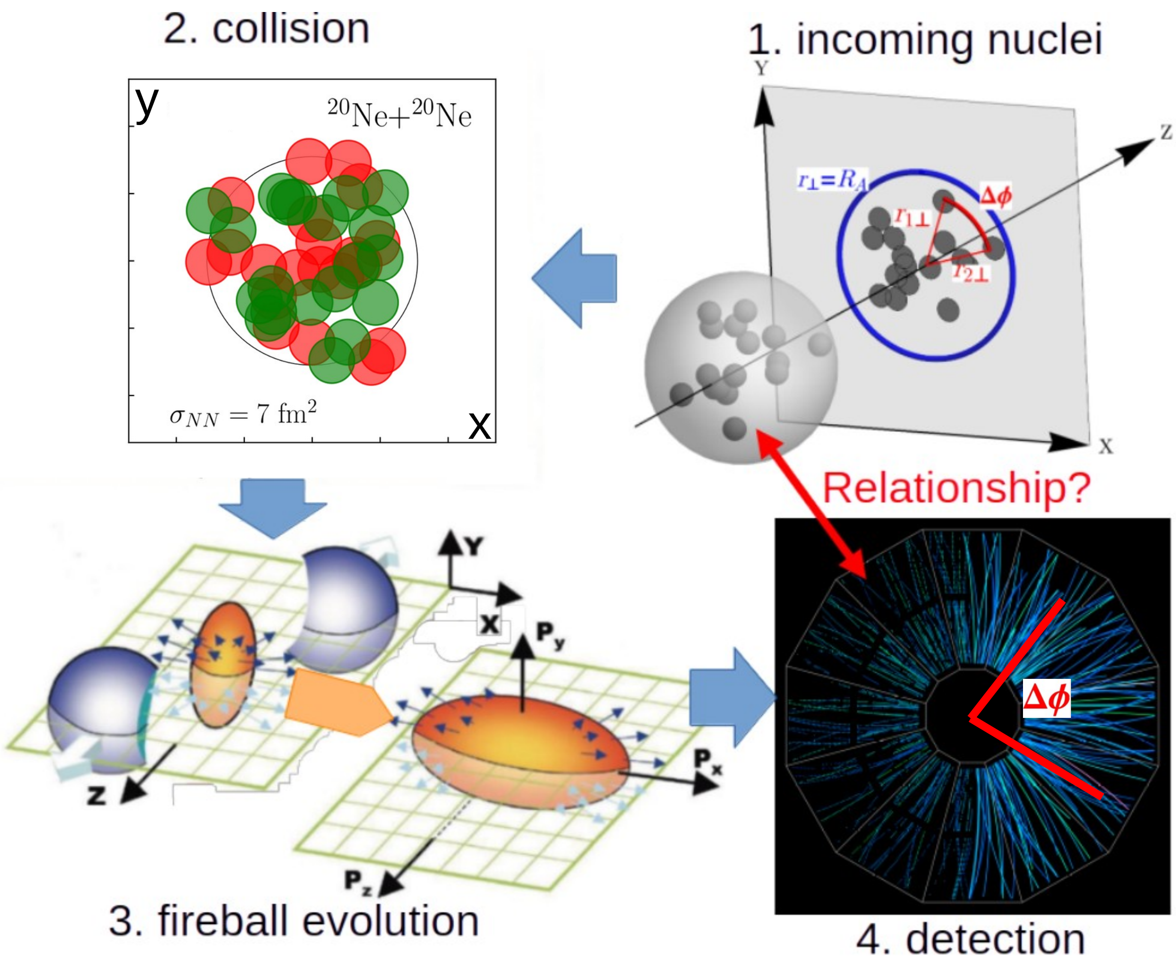


[Blaizot, Giacalone, Lovato, arXiv:2512.18926]



Correlations from Fermi statistics

Heavy-ion collisions – Probing many-body correlations of nucleons



compelling feature of UHIC analyses is that they explicitly probe many-body correlations in the nucleus. Focusing on this aspect, rather than shapes, represents a strength of the approach worth playing to.

[Dobaczewski *et al.*, PRR **7** (2025) 4, 043159]

Werthmann, Fri Apr 17

Answering Hagino-san's question:

What is an advantage/a justification of using relativistic heavy-ion collisions to probe nuclear shapes? $\rightarrow$ What is the component beyond "just for fun"?

HI observable →	Nuclear observable	Classical rotor
$\langle v_n^2 \rangle = \left\langle e^{in(\phi_1-\phi_2)} \right\rangle_{\rm events}$	$\left\langle r_{1\perp}^\ell \, r_{2\perp}^\ell \, e^{i\ell(\phi_1-\phi_2)} \right\rangle_{\Psi_0}$	β_2^2
$\langle \delta[p_T] \, v_2^2 \rangle = \left\langle (p_T - [p_T]) \, e^{i2(\phi_1-\phi_2)} \right\rangle_{\rm events}$	$\left\langle r_{1\perp}^2 r_{1\perp}^\ell \, r_{2\perp}^\ell \, e^{i\ell(\phi_1-\phi_2)} \right\rangle_{\Psi_0}$ [Mehrabpour, Giacalone, Luzum, 2604.00619]	$\beta_2^3 \, \cos 3\gamma$
… many choices	...	...

By design, many-body probes of ground states not accessible in low-energy experiments

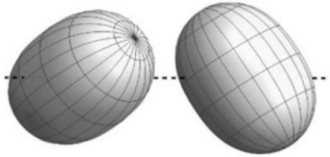
Indirect probes possible, such as Kumar-Cline invariants (sum rules), but many caveats

[Bofos *et al.*, 2602.09890]

The Revolution will be complete when the language is perfect [George Orwell, 1984]

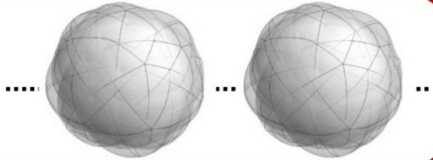
Classical rotor underlines the way practitioners see how HIC

1) Time scale « justifies » a snapshot-frozen orientation picture in each event
2) Average over events includes an averaging over orientation of each deformed body



HIC are of course performed with quantal nuclei

1) Angular momentum projection has no time-scale associated to it
2) Nuclei colliding are spherical and there is no resolution of the intrinsic frame



Duguet *et al.*, PRL (2025) Dobaczewski *et al.*, PRR (2025) Ke, arXiv:2509.09549

It is a matter of k-body (k>1) correlations!

"Shape" as implemented in HIC is a smart tool to produce correlated configs of nucleons

Yet, useful to compare to quantum-projection procedures of mean-field frameworks

Ke, Mon Apr 20

Toward fully-consistent quantum-mechanical framework?

Unitary freedom from surplus structure $U^\dagger(\lambda)U(\lambda) = 1$

Transformed many-body state $|\Psi_R(\lambda)\rangle$ | λ dependent

$$\langle\Psi_L|O|\Psi_R\rangle = \langle\Psi_L|U^\dagger(\lambda)U(\lambda)OU^\dagger(\lambda)U(\lambda)|\Psi_R\rangle$$

λ independent → Observable

Transformed operator $O(\lambda)$ | λ dependent → Non observables

Consistent components needed

Compensate to make up observable

Duguet, Thu Apr 16

More implications – Connection with nuclear interactions

[Weinberg, PLB **251** (1990) 288-292,
NPB **363** (1991) 3-18]

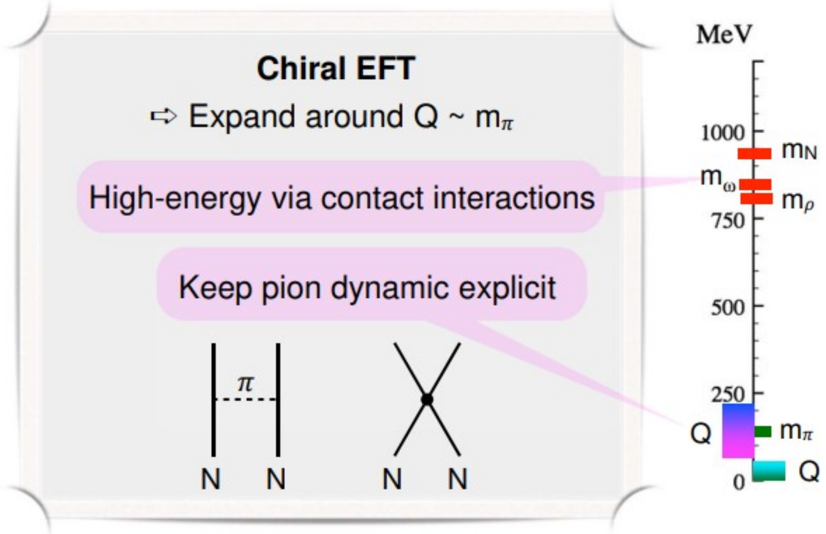
Modern paradigm of nuclear forces

Effective field theory of low-energy QCD

$$\mathcal{H} = \sum_i \mathcal{T}_i + \sum_{i<j} V_{ij} + \sum_{i<j<k} V_{ijk} + \cdots$$

$$m_\pi / m_{\rm QCD} \ll 1$$

Reddy, Wed Apr 22



r-process nucleosynthesis, neutron star EOS and mergers,
neutrinoless double β decay and fundamental symmetries, direct DM searches, …

[Hammer, König, van Kolck, RMP **92** (2020) 2, 025004]
[Epelbaum, Hammer, Meissner, RMP **81** (2009) 1773-1825]

Example of pipeline

Input from heavy-ion collisions!

$$\mathcal{E}_\ell(\mathbf{r}_1)\mathcal{E}_{-\ell}(\mathbf{r}_2) = r_{1\perp}^\ell \, r_{2\perp}^\ell \, e^{i\ell(\phi_1-\phi_2)}$$

CC computations

$$H\psi_n = E_n\psi_n$$

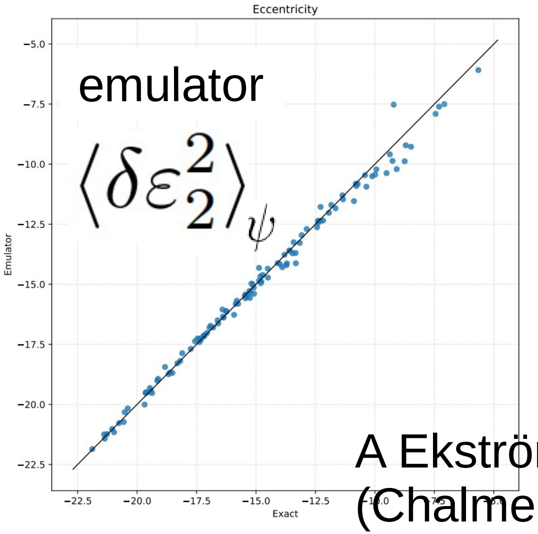
$$\langle \delta\varepsilon_2^2 \rangle_\psi$$

G Hagen (ORNL)

$$\sum_{pq} \bar{\epsilon}_{pq}^{(n)} c_p^\dagger c_q + \frac{1}{4} \sum_{pqrs} \bar{\epsilon}_{pqrs}^{(n)} c_p^\dagger c_q^\dagger c_s c_r$$

A Tichai (TU Darmsadt)

T Miyagi (Tsukuba)



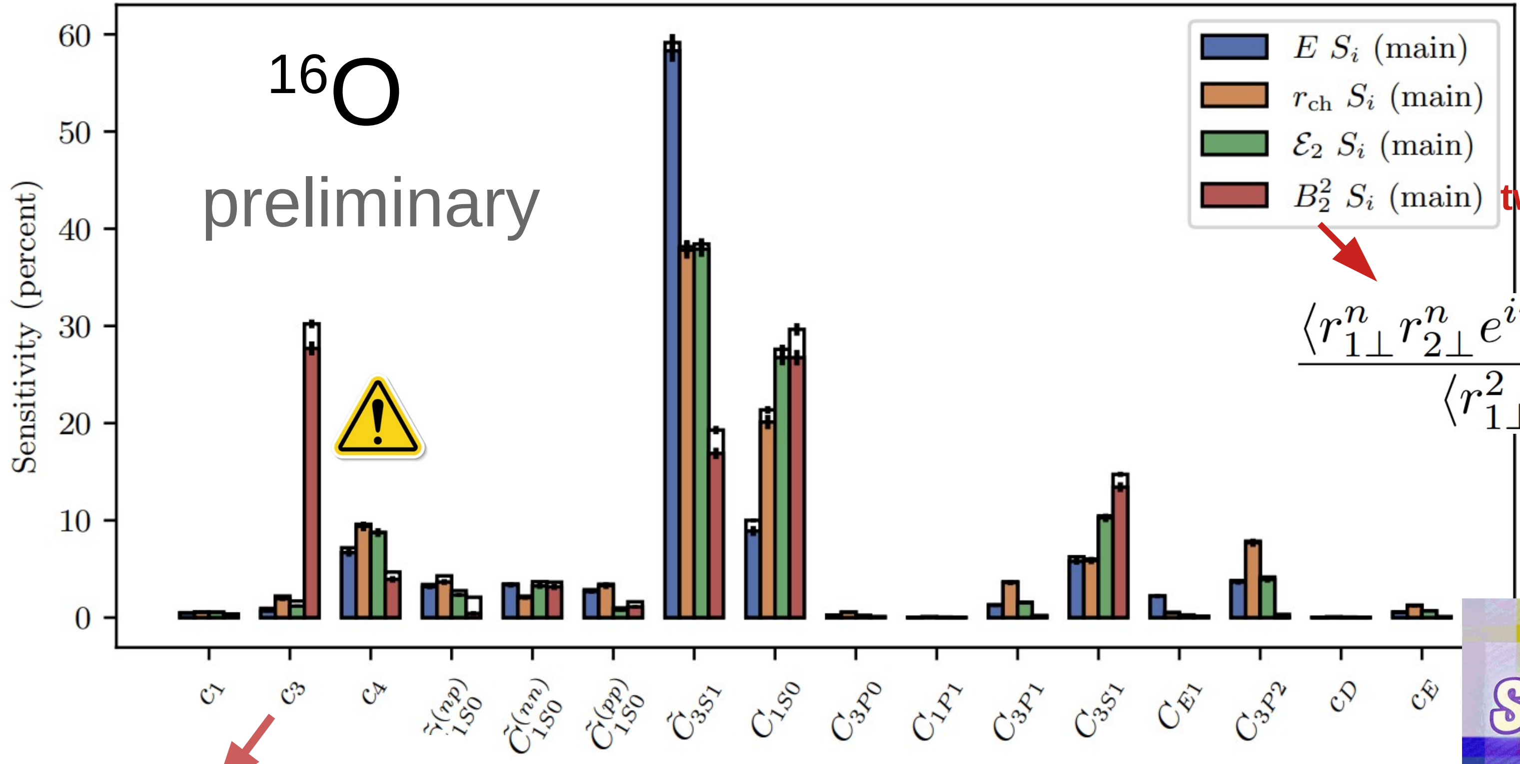
emulator

$$\langle \delta\varepsilon_2^2 \rangle_\psi$$

A Ekström (Chalmers)

How do we probe the nuclear force – Complementarity with low-energy probes

Δ-full chiral EFT expansion at N2LO – 17 low-energy constants



two-body term

$$\frac{\langle r_{1\perp}^n r_{2\perp}^n e^{in(\phi_1-\phi_2)} \rangle}{\langle r_{1\perp}^2 \rangle^2}$$

NNLO
$(Q/\Lambda_\chi)^3$

[with Duguet, Ekström, Hagen, Miyagi, Tichai]

Launched ”New Ion Collisions @ LHC Run 4” initiative

Collect cases that could complement the planned Pb program

Alemany Fernandez, Tue Apr 21

Example of cases

- Ions at masses smaller than ^{16}O (boron-10, lithium-6, helium-4)
  [onset of hydro and jet quenching]
- Increasing O+O statistics by a factor 10-100
  [precision hard probes, Λ polarization, higher-order flow]
- Calcium isotopes (feasibility of ^{48}Ca?)
  [neutron skin physics and EOS]
- Candidates of $0\nu2\beta$ decay for NME studies
  (^{76}Ge and ^{76}Se, the most spectacular)
  (^{136}Ba followed by ^{136}Xe, easier in practice?)
- One case for asymmetric collisions? O+Pb?

Roca Maza, Mon Apr 20

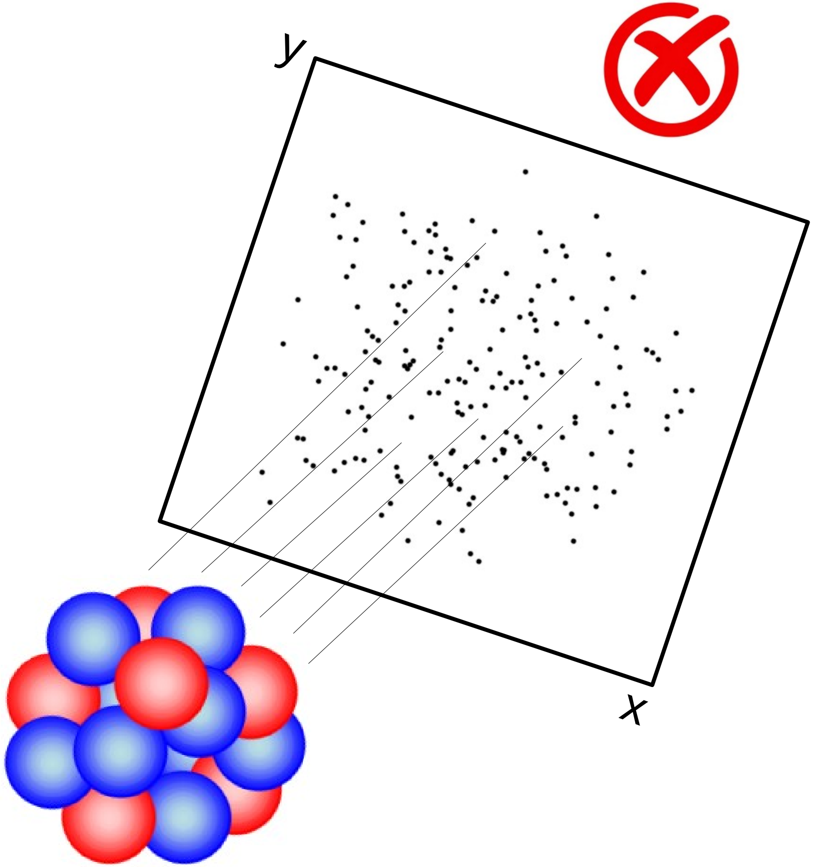
Schenke, Wed Apr 22

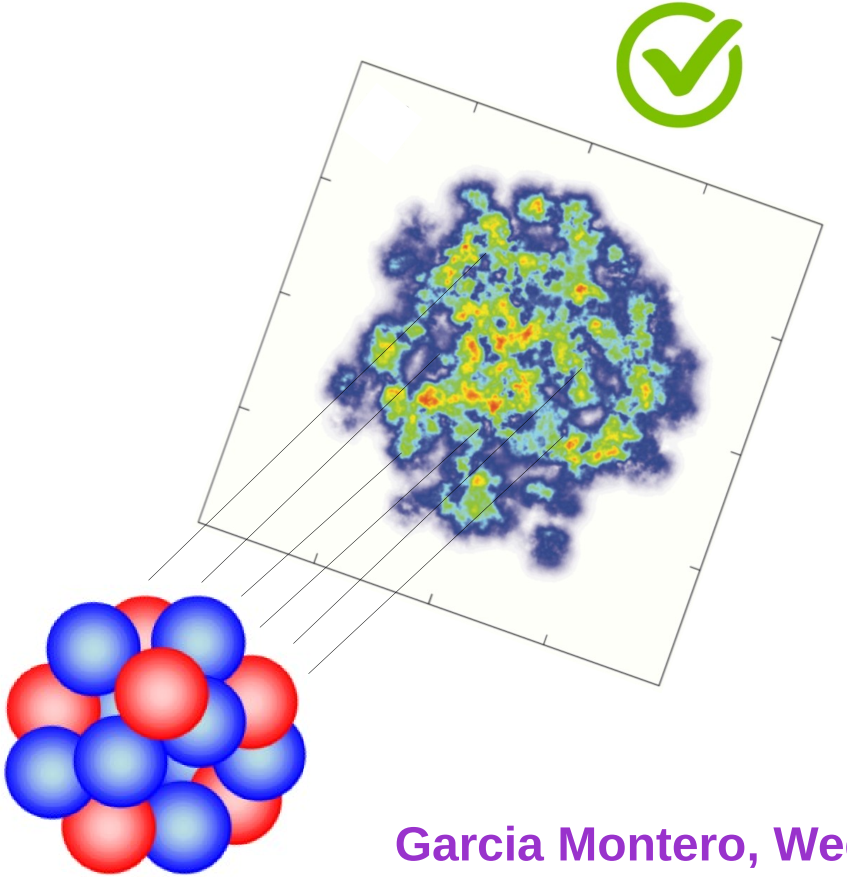
Yao, Mon Apr 13

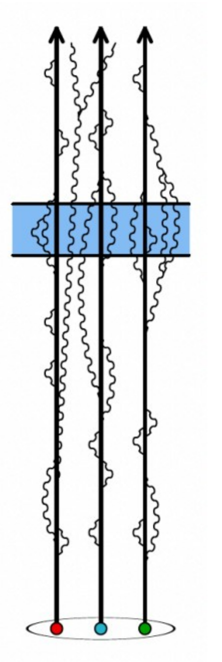
Zhang, Mon Apr 13

+ much physics coming from SMOG2 system of LHCb

Quantifying nuclear structure from data – Challenges at the interface with QCD



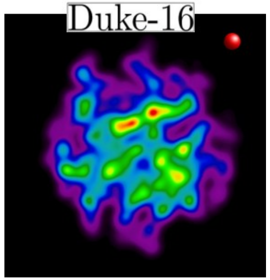


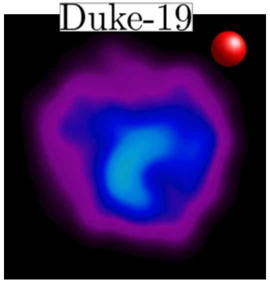


Garcia Montero, Wed Apr 15

Short-scale physics and theoretical uncertainties

Effective phenomenological notions for short-scale physics





constituent size

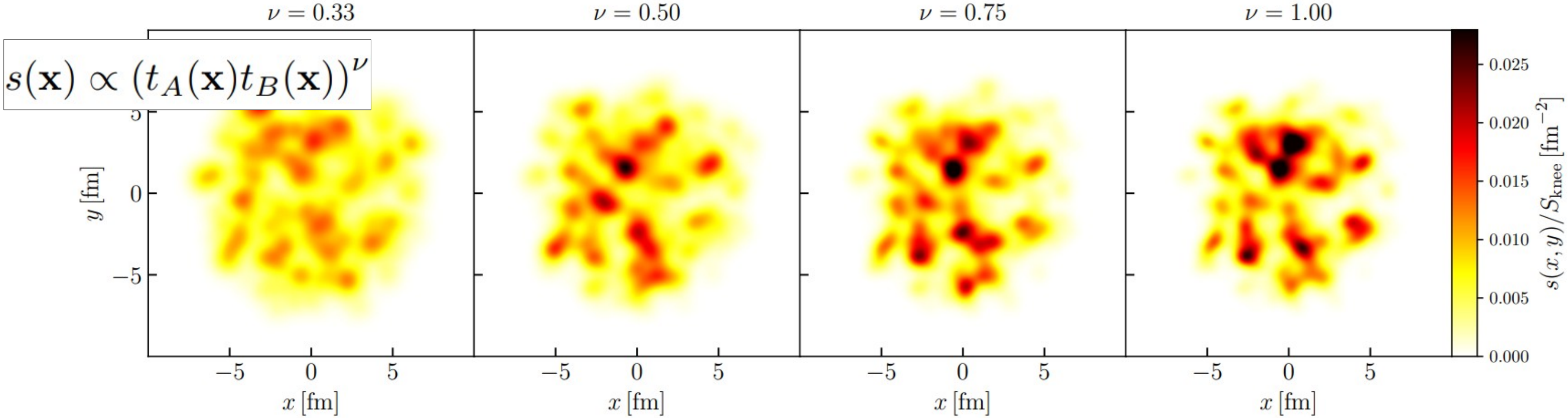
$$t_A(\mathbf{x}) = \sum_{j=1}^{A_A} \lambda_j g(\mathbf{x};\mathbf{x}_j w), \quad g(\mathbf{x};\mathbf{x}_j w) = \frac{1}{2\pi w^2}\exp\left(-\frac{(\mathbf{x}-\mathbf{x}_j)^2}{2w^2}\right)$$

[e.g. Giacalone, arXiv:2208.06839]

energy deposition

$$\epsilon \propto (t_A^p + t_B^p)^{q/p} \xrightarrow{p \to 0} (t_A(\mathbf{x})t_B(\mathbf{x}))^{q/2}$$

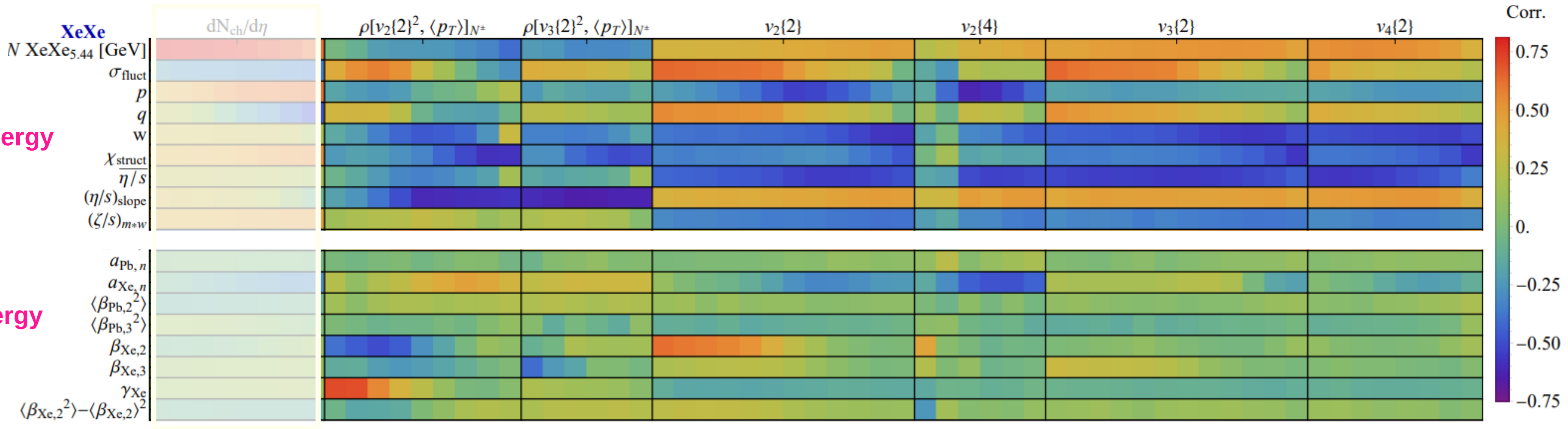
[Zhou, Giacalone, Ollitrault, PRC **113** (2026) 4, 044910]



Important effects – Relative observables to improve theoretical uncertainties

high-energy

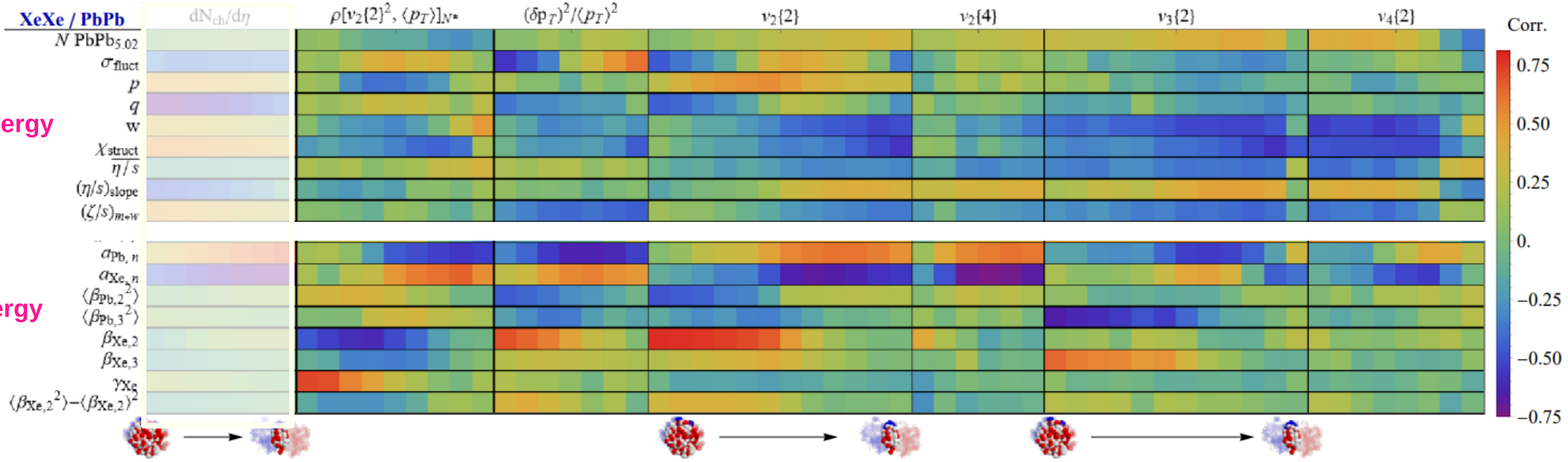
low-energy



[Giacalone, Nijs, van der Schee, in preparation]

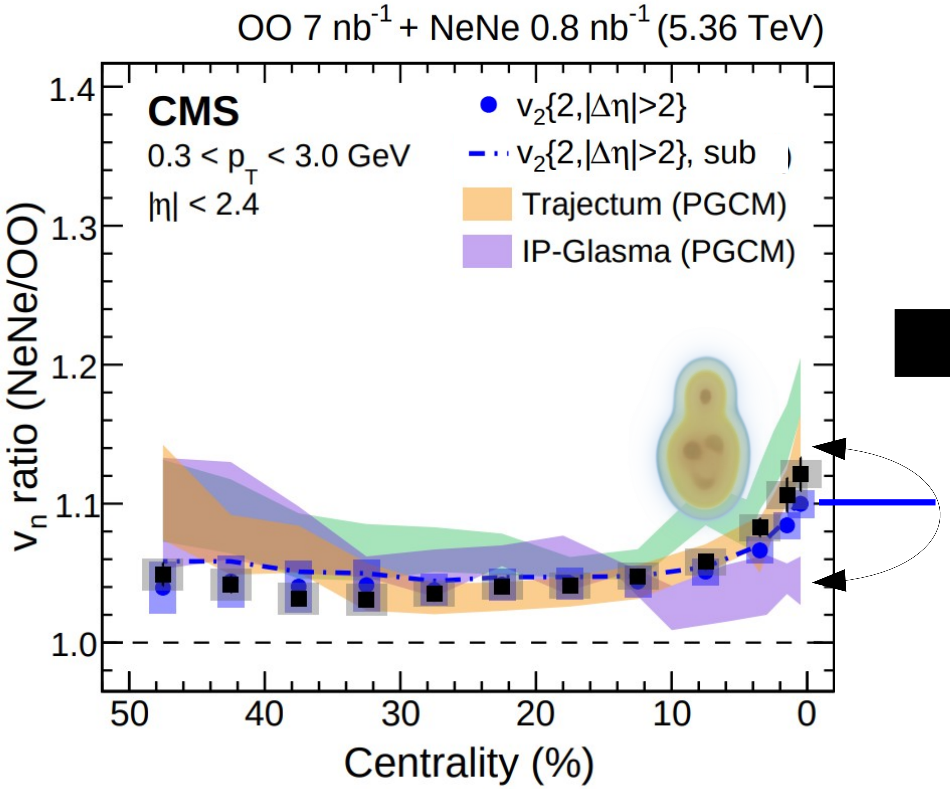
high-energy

low-energy

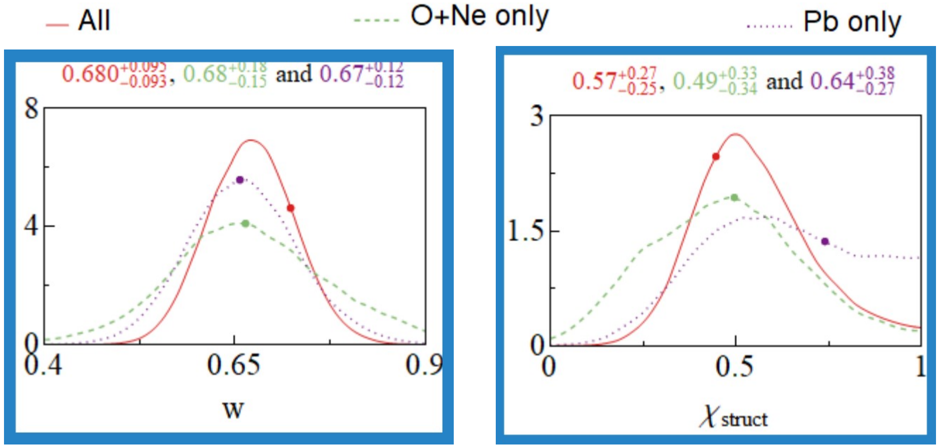


Small-nuclei collisions naturally more impacted – LHC Run from July ‘25

Zhou, Virta, Thu Apr 23



Bayesian fit of light-ion data …



[W. van der Schee, Light Ion Collisions at LHC 2025]

… points to sub-nucleon size of ≈0.3fm

Not bad!

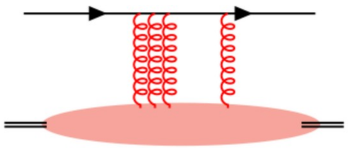
Light-ion data essential to clarify interplay between large- and short-scale physics

Effects of incomplete equilibration seem negligible in central OO and NeNe

Zhao, Tue Apr 14   Werthmann, Fri Apr 17   Ito, Fri Apr 24

COMMENTS / PERSPECTIVES

- The Color Glass Condensate offers a consistent a powerful effective framework for introducing high-energy dynamics

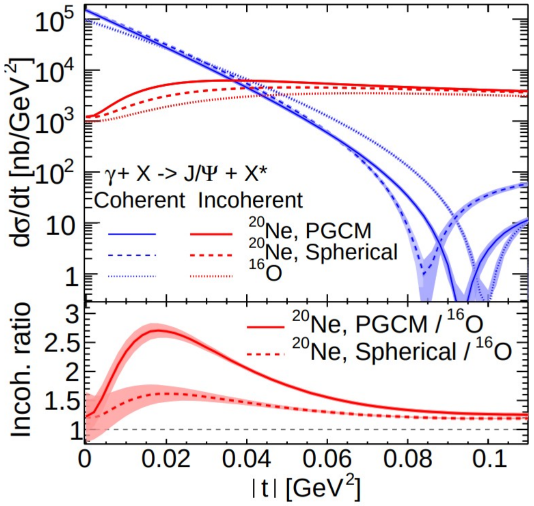


- Future collaboration with EIC or UPC program highly desirable

---- > Does the fit of LHC data return a "nucleon size" consistent with gluon radius of nucleons in γA scattering … hints that this is indeed the case!

--- > EIC constraints into A-A generators (cf. IP-Glasma)

--- > Consistency of "shapes" in vector meson production?



Toward uncertainty-quantified nuclear structure