



Spicy Gluons 2026

Wuhan

Evidence of nuclear geometry-driven flow in light-ion collisions at the LHC

Based on recent work on Phys. Rev. Lett. 137 (2026) 082301

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19 Oct 2026

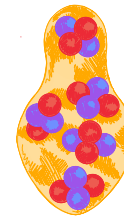


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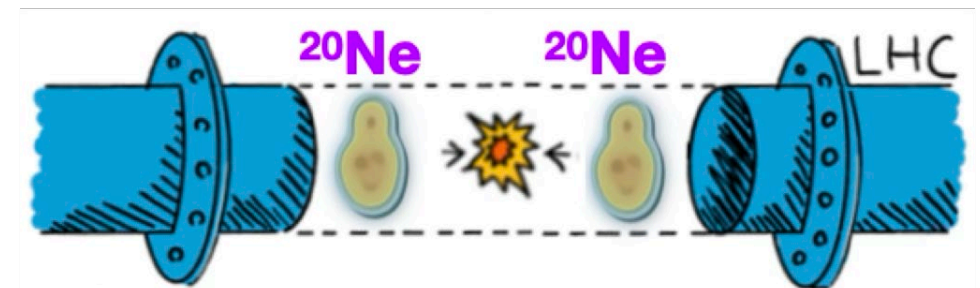
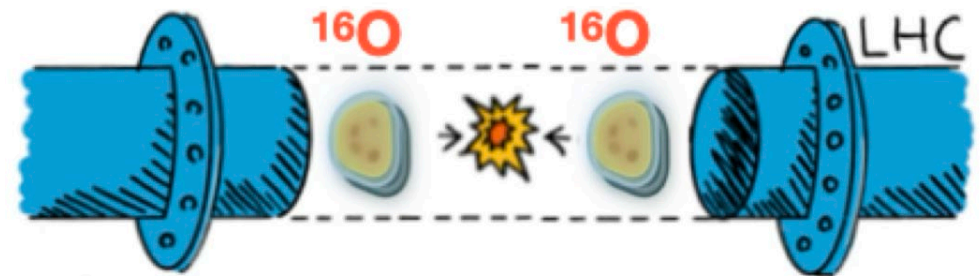
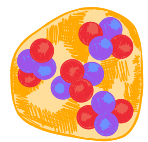


Figures made by Dina Stryger (NBI)

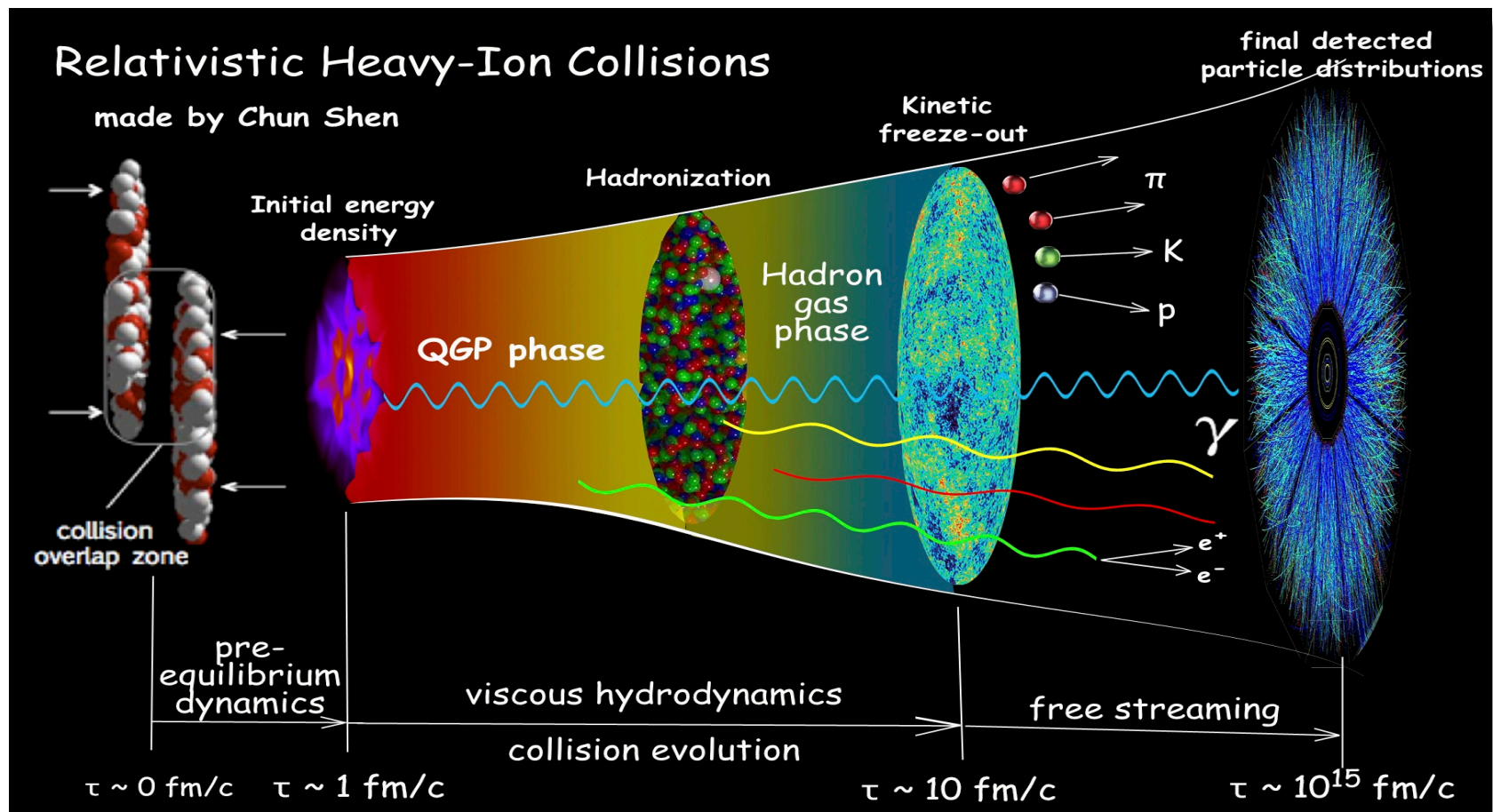
^{20}Ne



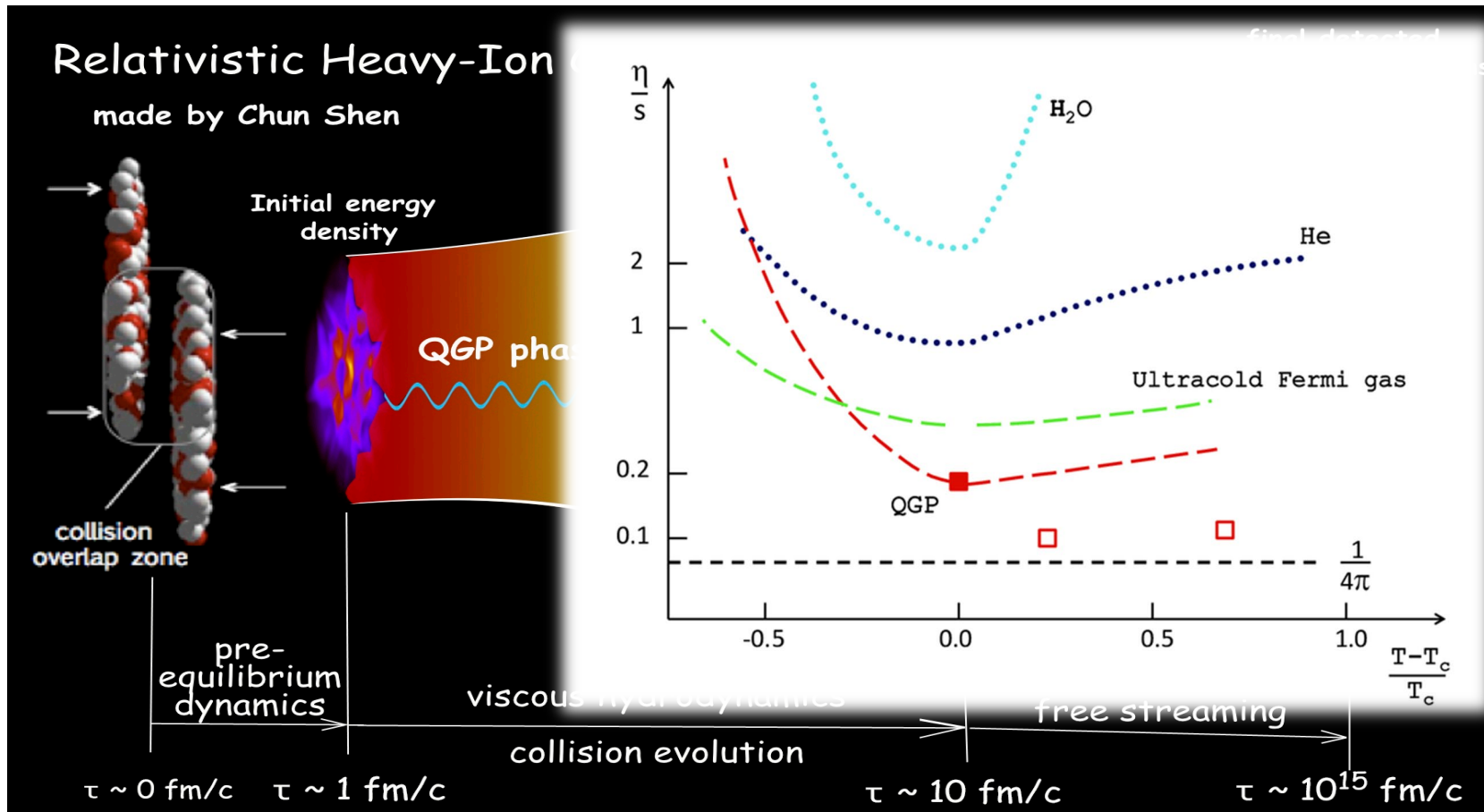
^{16}O



Ultra-relativistic ion collisions



Ultra-relativistic ion collisions



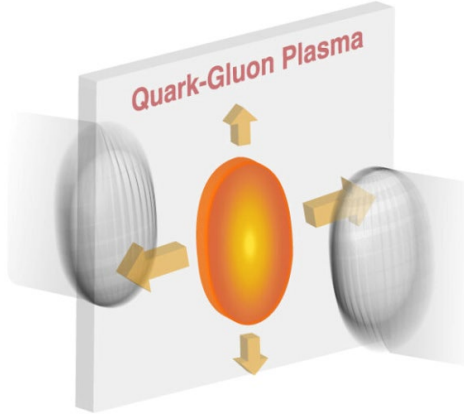
Quark-Gluon Plasma (QGP)

- an extremely hot and dense state of matter where nucleon “melt” and quarks and gluons can move freely
- found to behave as a near-perfect fluid with much lower viscosity than liquid water

[ALICE, EPJC 84 \(2024\) 8, 813](#)

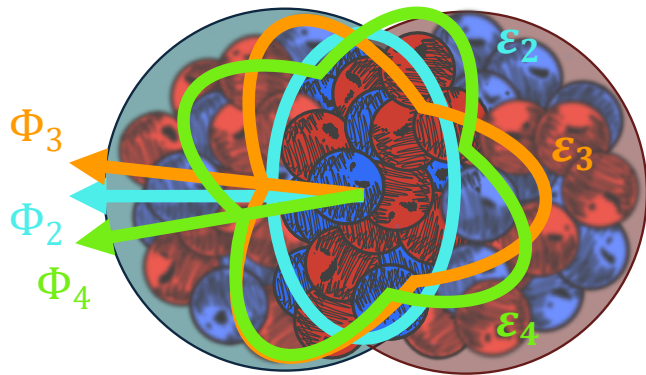
- Primary goal of these collisions is to recreate QGP and study its properties and time evolution.

Collective motion of QGP

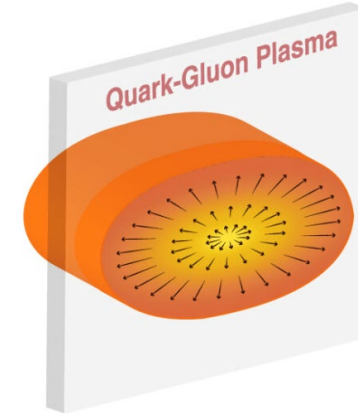


Initial eccentricity

$$\varepsilon_n = \frac{\sqrt{(r^n \cos(n\phi))^2 + (r^n \sin(n\phi))^2}}{\langle r^n \rangle}$$



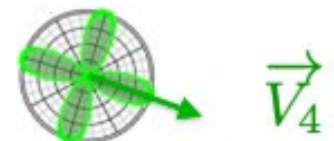
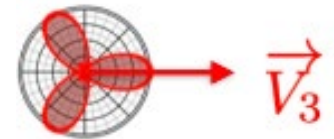
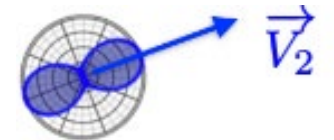
System expansion



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

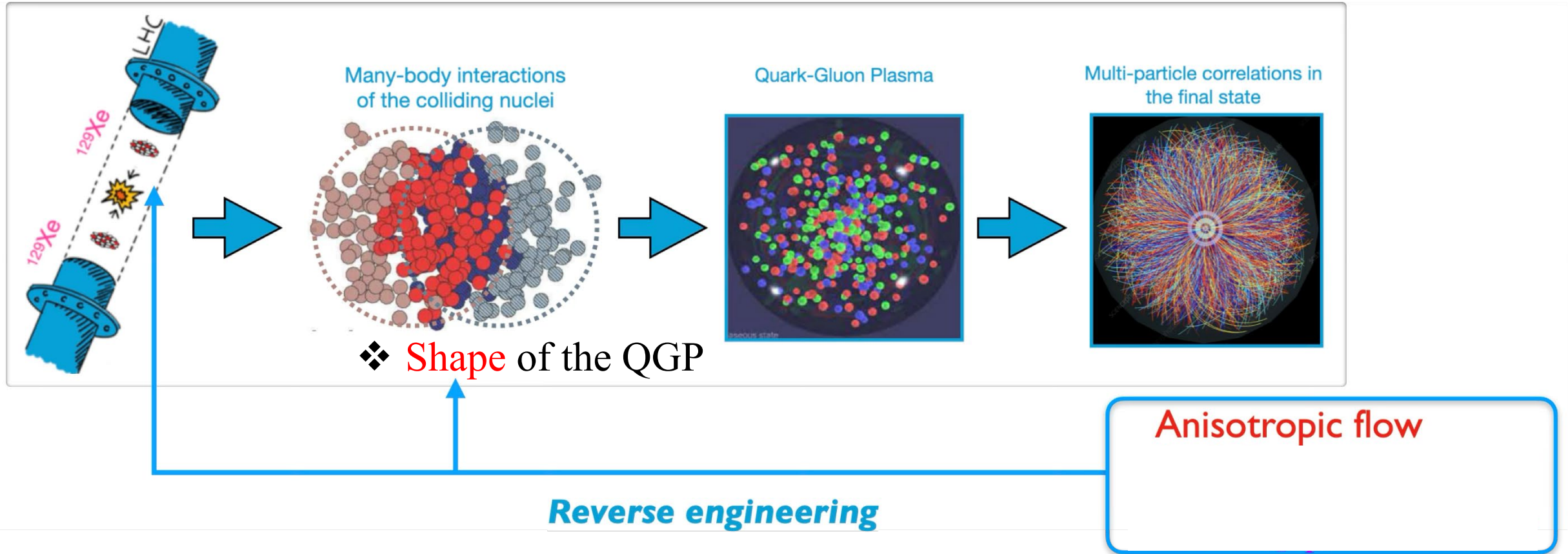
v_n : **anisotropic flow coefficient**

$$\vec{V}_n = v_n e^{in\Psi_n}$$

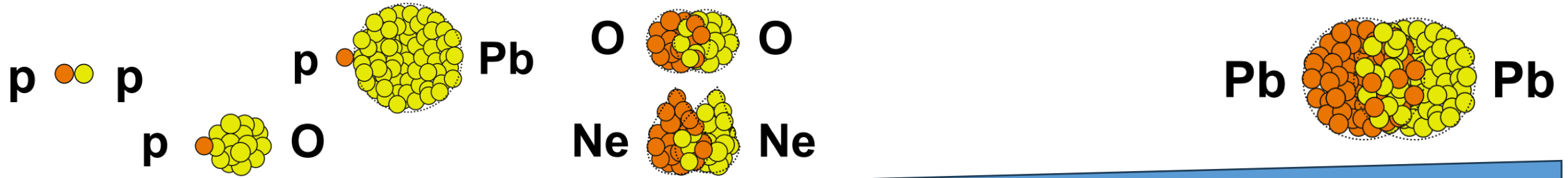


QGP behaves like fluid
→ use hydrodynamic to describe evolution
→ suggests $v_n \propto \varepsilon_n$

“Reverse engineering” with collective motion



Light-ion collisions: unique place to test hydrodynamic in small systems



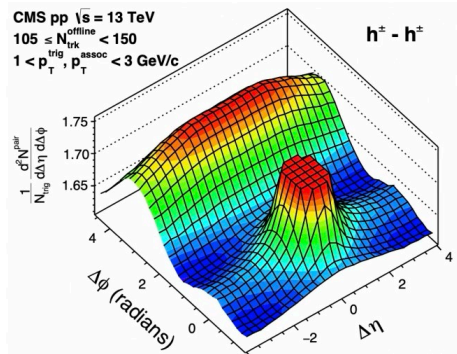
Low multiplicity
Few interactions

High multiplicity
Dense system
Many interactions

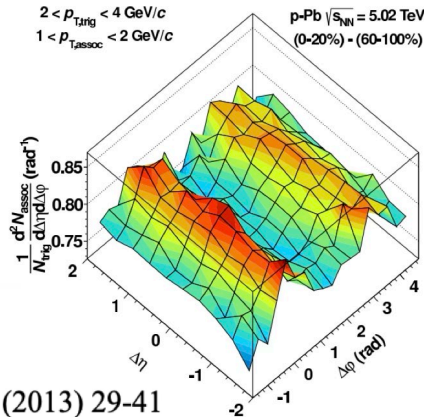
HM pp

HM p-Pb

Pb-Pb

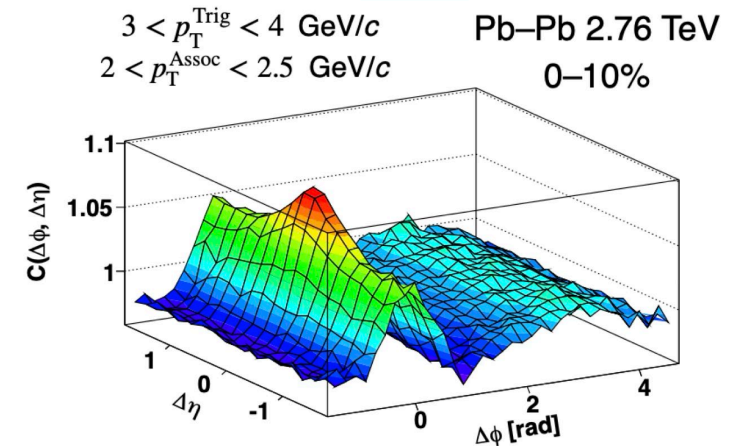


CMS, Phys.Lett. B 765 (2017) 193



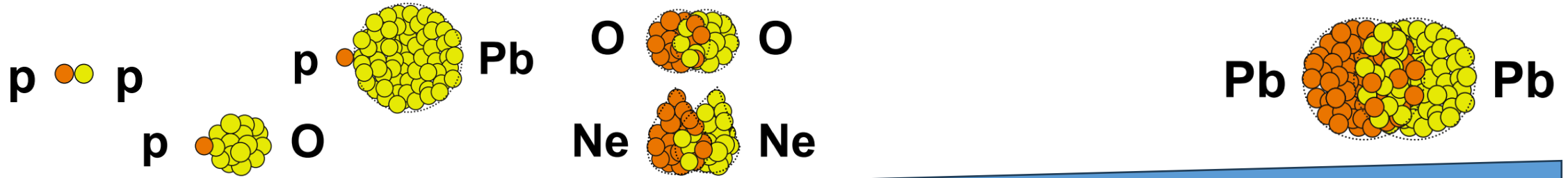
ALICE, Phys.Lett. B 719 (2013) 29-41

Geometry fluctuation-driven flow



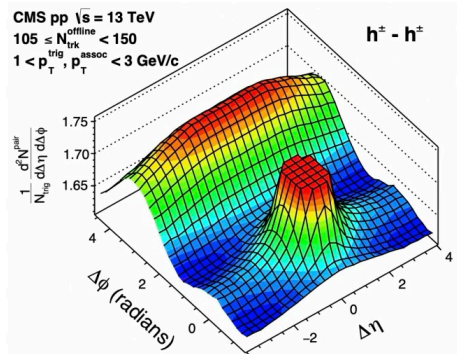
Geometry-driven
flow

Light-ion collisions: unique place to test hydrodynamic in small systems



Low multiplicity
Few interactions

HM pp

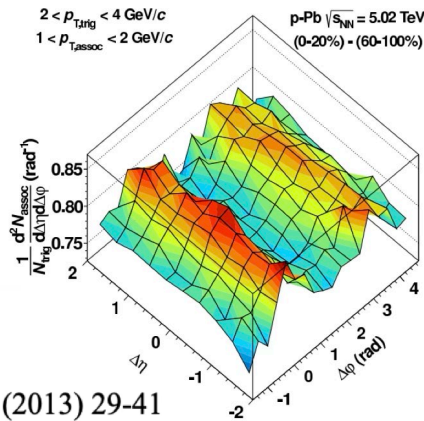


CMS pp $\sqrt{s} = 13$ TeV
 $105 \leq N_{\text{trk}}^{\text{line}} \leq 150$
 $1 < p_{\text{T}}^{\text{trig}}, p_{\text{T}}^{\text{assoc}} < 3$ GeV/c

ALICE, Phys.Lett. B 719 (2013) 29-41

Geometry fluctuation-driven flow

HM p-Pb

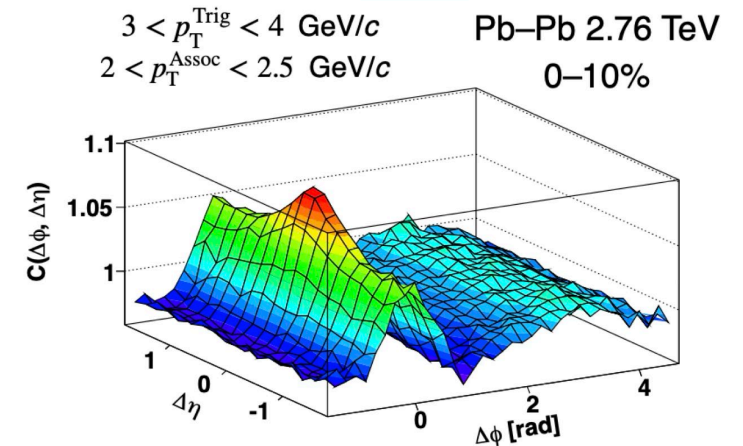


Similar multiplicities to high-mult.
pp/p-Pb collisions but with a very
different geometry and volume

?-driven flow

High multiplicity
Dense system
Many interactions

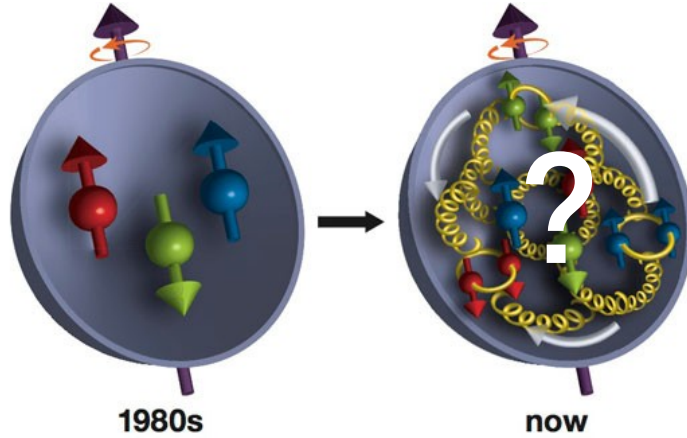
Pb-Pb



**Geometry-driven
flow**

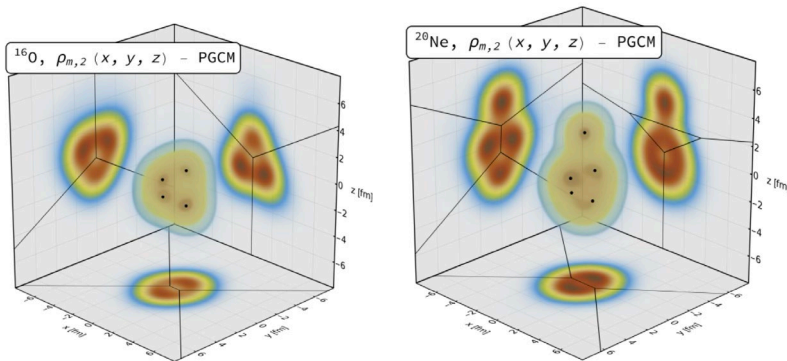
Light-ion collisions: unique place to test hydrodynamic in small systems

Proton inner structure



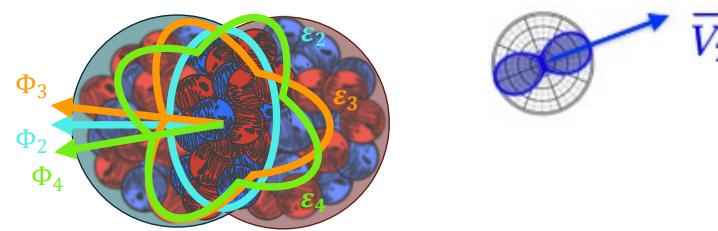
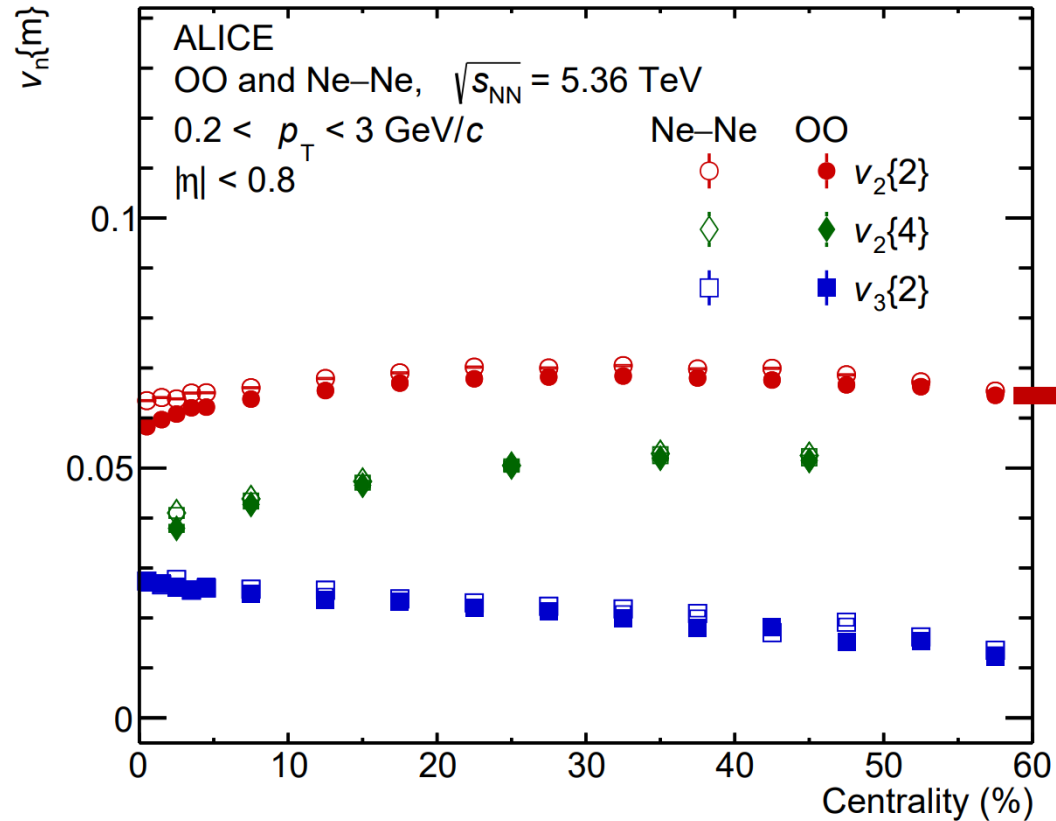
- Understanding of the proton's internal structure has grown increasingly intricate, but its full structural makeup remains unresolved
- The largest uncertainties on modelling the pp and p-Pb collisions

Multi-nucleon correlations-based predictions for ^{16}O and ^{20}Ne



- ^{16}O and ^{20}Ne nuclei are much larger than a single proton therefore sub-nucleonic structure becomes sub-leading.
- Modern *ab-initio* methods provide predictions for the nuclear structure of ^{16}O and ^{20}Ne [Giuliano et al, PRL. 135 (2025) 1, 012302]
- Systematically lower the uncertainties of initial state

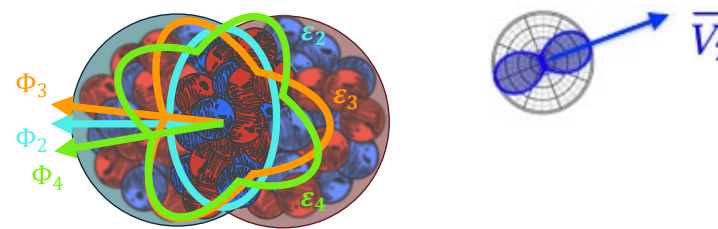
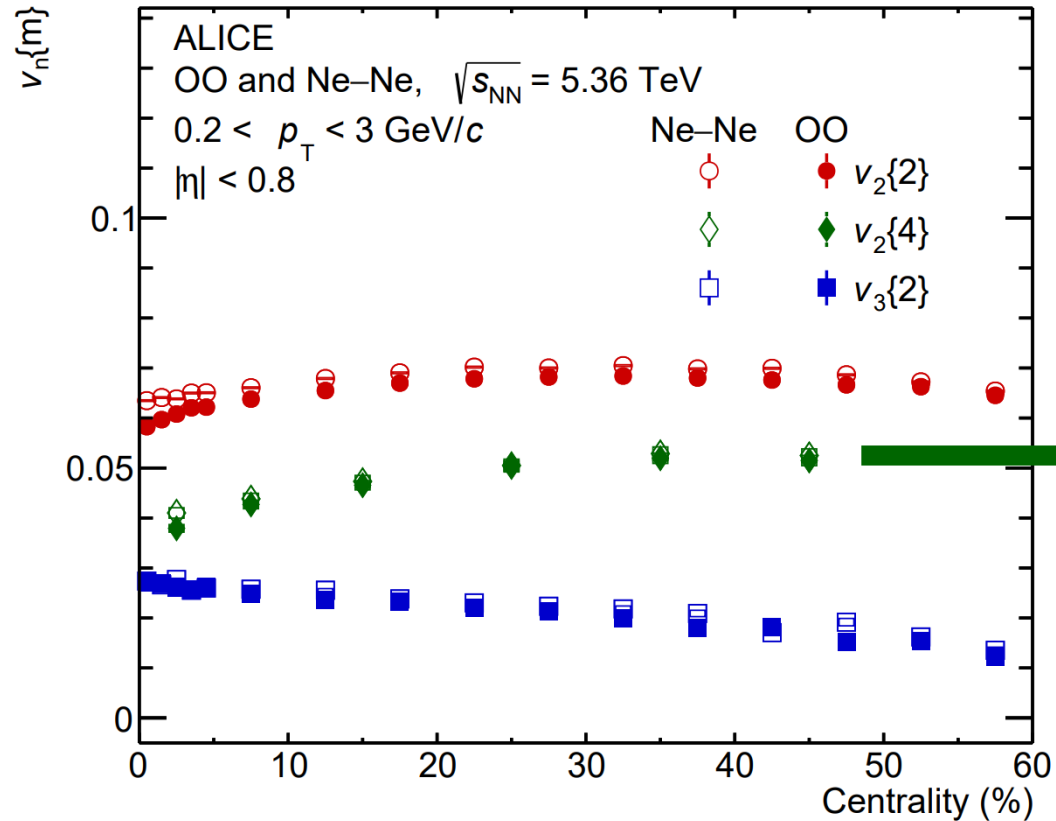
Measurement of v_n in OO and Ne-Ne collisions



First observation of v_n in light-ion collisions with ALICE detector

- $v_2\{2\}$:
 - mild centrality dependence in both systems;
 - rises up to $\sim 30\%$ centrality, then decreases in more peripheral collisions, following the initial-state eccentricity ϵ_2 trend.

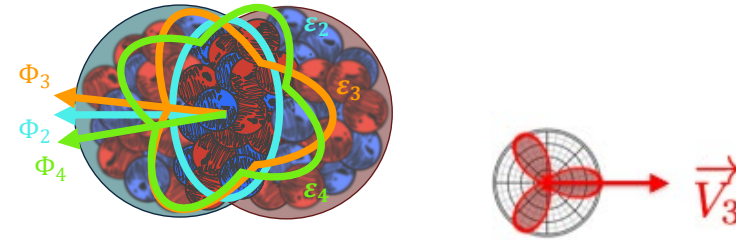
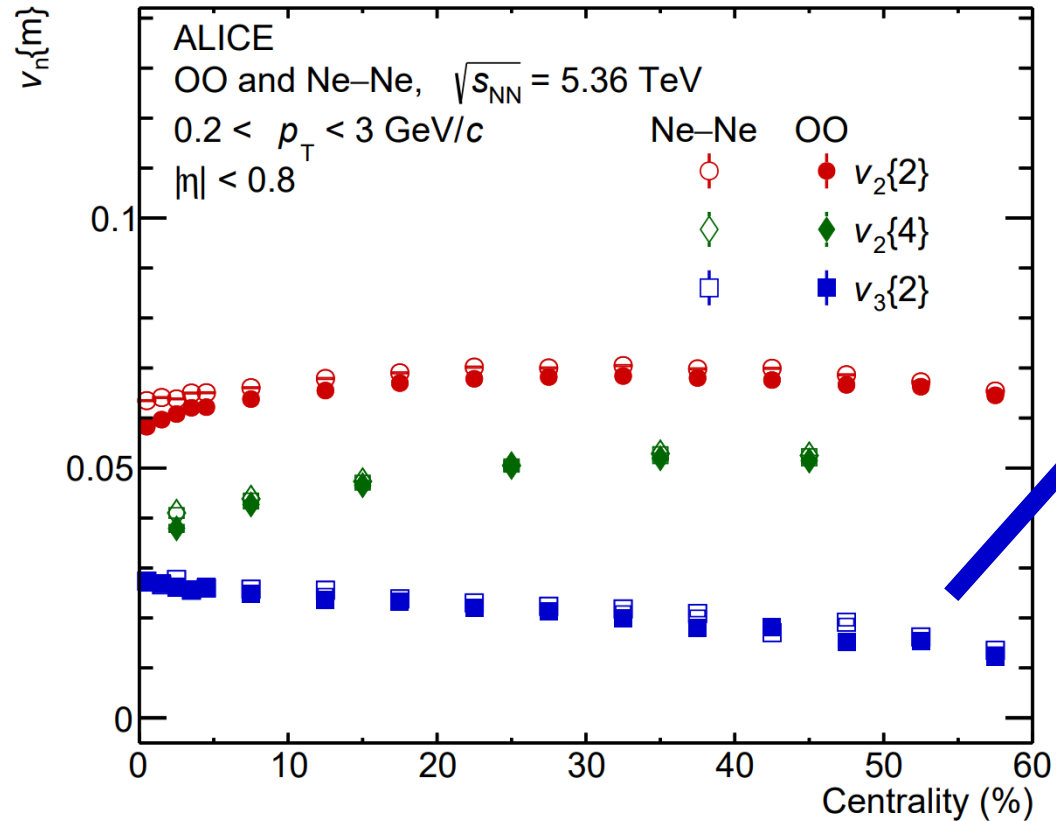
Measurement of v_n in OO and Ne-Ne collisions



First observation of v_n in light-ion collisions with ALICE detector

- $v_2\{4\}$:
 - increases with centrality percentile in [0,50%], with values smaller than $v_2\{2\}$;
 - its nonzero value shows collective anisotropic flow in OO and Ne-Ne collisions.
- $v_2\{2\}$ vs. $v_2\{4\}$:
 - remaining difference (after nonflow suppression) is attributed to event-by-event fluctuations of elliptic flow.

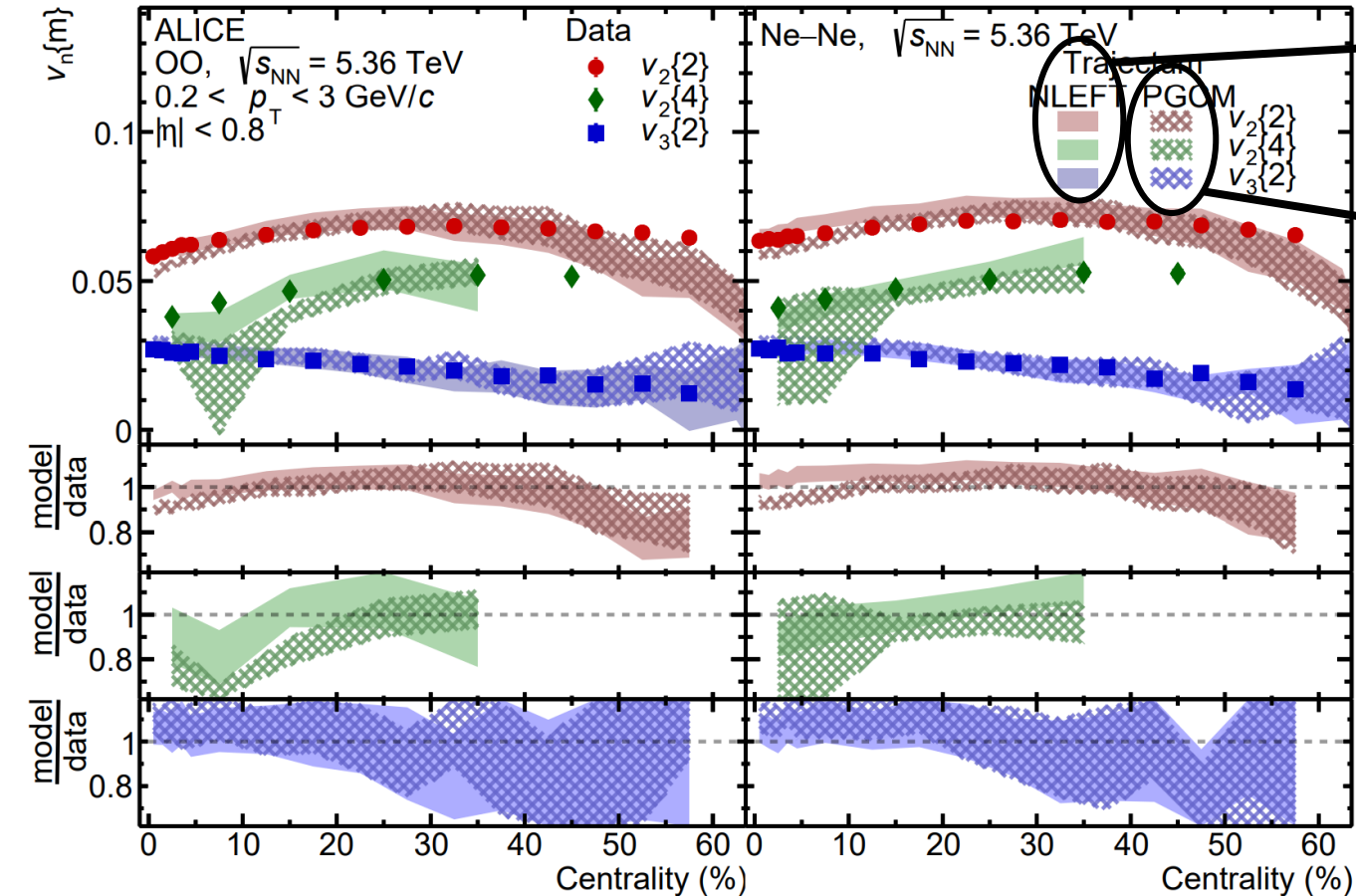
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First observation of v_n in light-ion collisions with ALICE detector

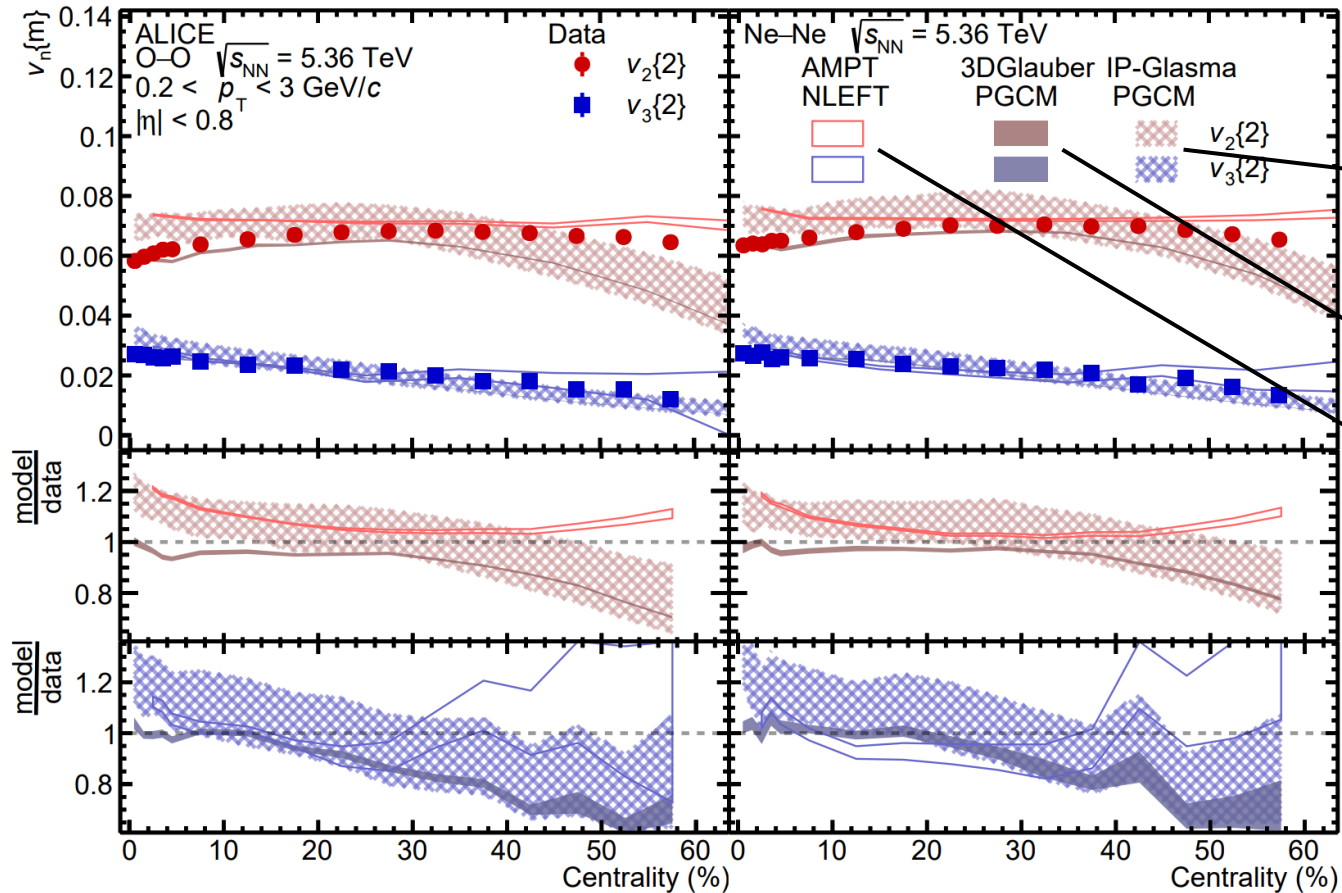
- $v_3\{2\}$:
 - decreases with increasing centrality percentile;
 - its trend and magnitude are similar to pp and p-Pb, consistent with $v_3\{2\}$ originating from initial-state fluctuations.

Comparison to Trajectum



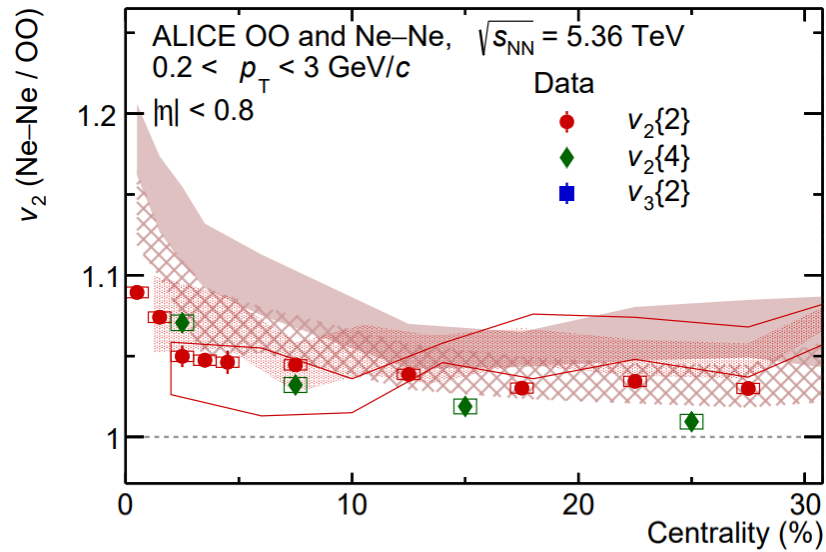
- **NLEFT-based Trajectum:** reproduce both the trend and magnitude of $v_2\{2\}$, $v_3\{2\}$, and $v_2\{4\}$ up to 50% centrality.
- **PGCM-based Trajectum:** slightly worse agreement in central collisions, though within a few percent; in noncentral collisions they are consistent with data.
- Combination of *ab-initio* input + hydrodynamic successfully describe light-ion systems without any extra tuning.
- Light-ion collisions undergo similar hydrodynamic evolution as large systems?
- NS input can largely constrain the initial state of collisions

Comparison to 3DGlauber, IP-Glasma and AMPT

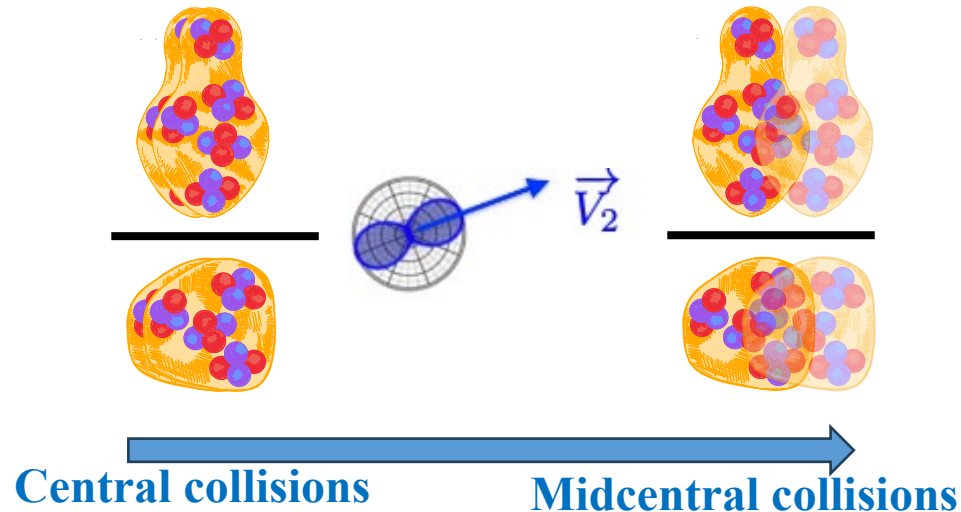


- **IP-Glasma-based calculations:**
 - show reasonable agreement only at intermediate centralities
 - **3DGlauber-based calculation:**
 - consistently underestimate the measured v_2 .
 - **AMPT:**
 - Weak centrality dependence, overestimates v_2
- $v_3\{2\}$
- All model show reasonable agreement, with large uncertainties

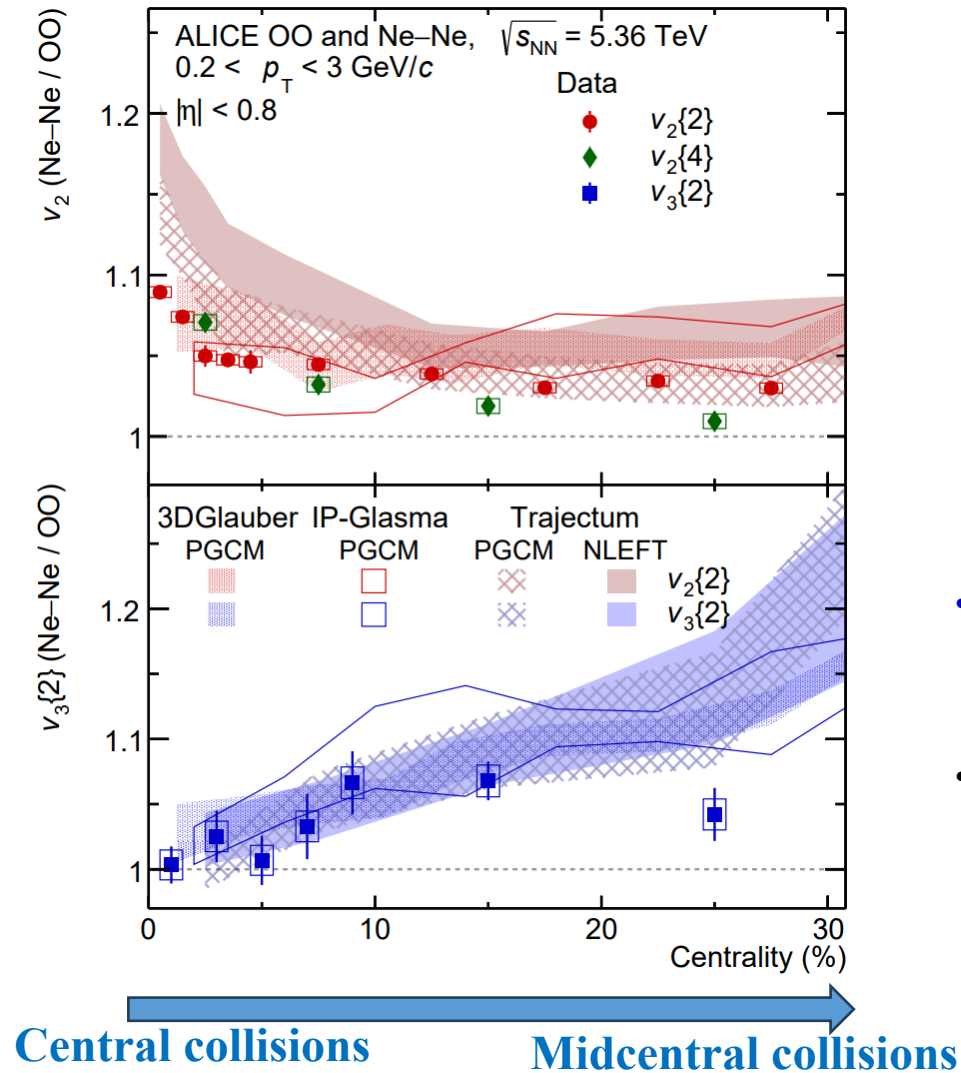
Measurement of system ratio (Ne–Ne/OO) for v_n



- **$v_2\{2\}(\text{Ne-Ne/OO})$** : peaks at ~ 1.08 in ultracentral collisions, drops rapidly to ~ 1.05 by 10% centrality, then shows only weak centrality dependence.
- **$v_2\{4\}(\text{Ne-Ne/OO})$** : similar centrality dependence to the $v_2\{2\}$ ratio.
- Higher values in central collisions are attributed to the stronger quadrupole deformation of ^{20}Ne compared with the tetrahedral ^{16}O .



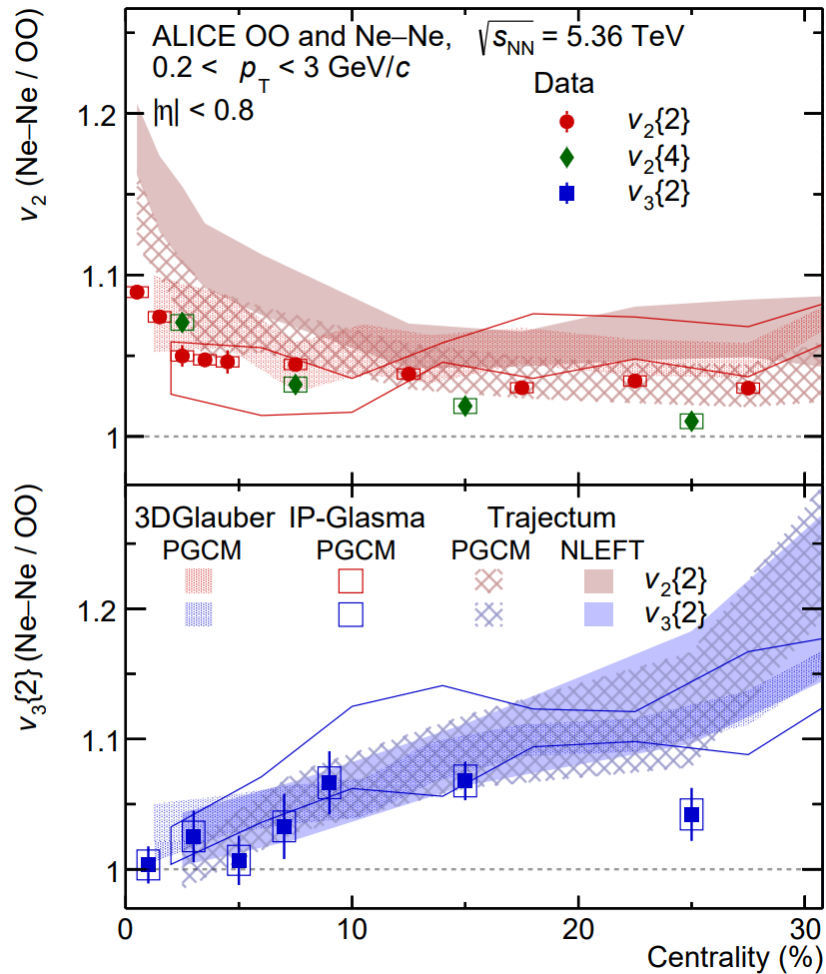
Measurement of system ratio (Ne–Ne/OO) for v_n



Tetrahedral shape of $^{16}\text{O} \rightarrow \varepsilon_3(\text{OO}) \uparrow$
 $\rightarrow v_3\{2\}(\text{Ne–Ne/OO}) \downarrow$

- $v_3\{2\}(\text{Ne–Ne/OO})$: starts near unity in central collisions and increases gradually with centrality percentile, reaching ~ 1.06 at 10%.
- The smaller values in central collisions are attributed to the tetrahedral configuration of ^{16}O

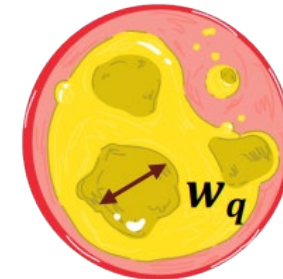
Comparison to multiple models



Model comparison:

- System ratios favor **PGCM-based Trajectum**.
- Individual flow coefficients favor **NLEFT-based Trajectum**.
 → The discrepancy may originate from modeling of the immediate post-collision initial state (energy deposition, nucleon/subnucleon spatial profiles, preequilibrium dynamics, etc.)
- IP-Glasma** and **3DGlauber** capture both trend and magnitude for system ratios, but not individual flow coefficients.
- The main difference between **Trajectum** and **IP-Glasma-based** calculations likely lies in initial conditions and early-time dynamics:
 - **Trajectum** uses subnucleon width $w_q \approx 0.40$ fm
 - **IP-Glasma** and **3DGlauber** use $w_q \approx 0.11$ fm
 - The measurements favor a smaller subnucleon width of approximately 0.1–0.2 fm.

Sub-nucleon width w_q



The flow coefficients exhibit characteristic centrality dependence in light-ion collisions, which was not observed previously in pp and p–Pb collisions.

- **Nuclear-structure inputs + hydrodynamic** works for light-ion collisions
- **Nuclear-structure inputs** can largely reduce the uncertainties of initial state modelling
- **Hydrodynamic** can reproduce multiparticle cumulant measurements in small systems **for the first time**

Ratios of (**Ne–Ne/OO**) substantially reduce final-state effects, serve as precise probes of the initial condition

- Comparison of the measured $v_2\{2\}(\text{Ne–Ne/OO})$ with various hydrodynamic calculations, including state-of-the-art nuclear structure, points to imperfect initial-state configurations, particularly the subnucleon size.
- A framework to constrain fundamental nucleon–nucleon interactions and advance nuclear physics

Thank you for attention!

Models used in this study

Trajectum (Hydrodynamic framework) credit to Giuliano Giacalone, CERN

- Nuclear-structure input: NLEFT (Nuclear Lattice Effective Field Theory) and PGCM (Projected Generator Coordinate Method)
- Subnucleon width: $w_q \approx 0.40 \text{ fm}$, from Bayesian inference using Pb–Pb collisions.

IP-Glasma + JIMWLK + MUSIC + UrQMD credit to Chun Shen, Wayne State University

- IP-Glasma initial conditions + JIMWLK evolution + MUSIC hydrodynamics + UrQMD hadronic cascade
- Nuclear-structure input: PGCM.
- Subnucleon width: $w_q \approx 0.11 \text{ fm}$, inferred from incoherent J/ψ production in HERA data.

3DGlauber + MUSIC + UrQMD credit to Chun Shen, Wayne State University

- 3D Glauber initial conditions + MUSIC hydrodynamics + UrQMD hadronic cascade
- Nuclear-structure input: PGCM.
- Subnucleon width: $w_q \approx 0.11 \text{ fm}$.

AMPT credit to Xinli Zhao, Shanghai Research Center for Theoretical Nuclear Physics

- A Multi-Phase Transport model. Transport (non-hydrodynamic) approach for relativistic heavy-ion collisions.
- Nuclear-structure input: NLEFT.

Structure of Oxygen-16 and Neon-20

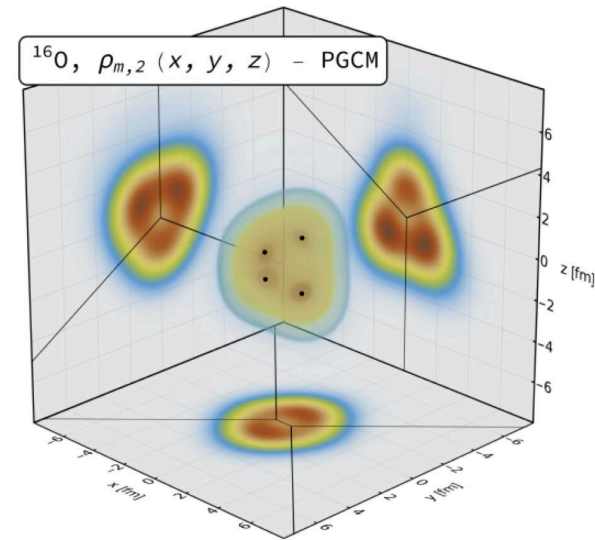
- Nuclear structure predicted by low-energy physics
- The ‘bowling ball’ and the ‘bowling pin’ shape

Projected Generator Coordinate Method (PGCM)

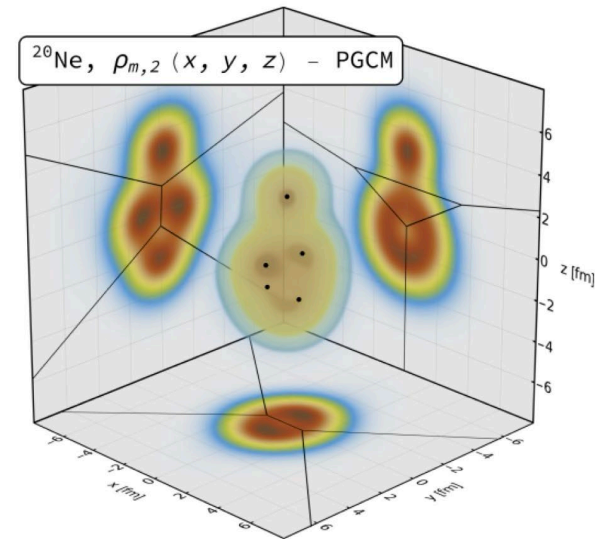
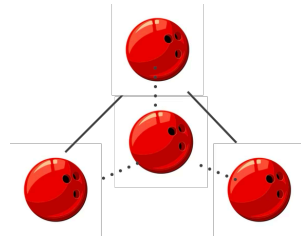
- Energy minimized mean-field states
- Collective correlations from projecting onto good quantum numbers
- Mixing configurations across deformation space

Nuclear Lattice Effective Field Theory (NLEFT)

- From first principles
- Evolve nucleon configurations on lattice
- Many-body correlations and emergent clustering



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