How Far That Little Candle Throws His Beams!

Collectivity in small systems: experimental insights and open questions

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HENPIC Seminar 10/2026



Act I

Infinite riches in a little room

Christopher Marlowe, The Jew of Malta

Extending the QGP picture to small collision systems

QGP the uncrowned king

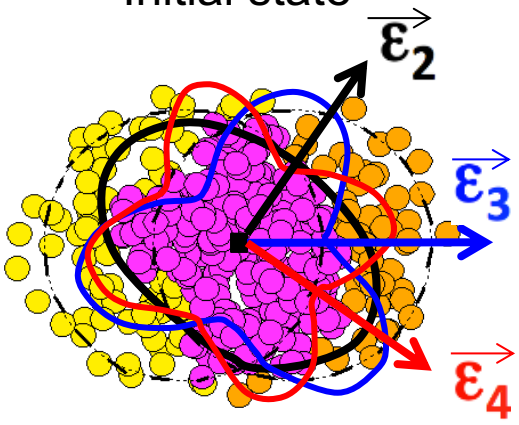
BROOKHAVEN NATIONAL LABORATORY Newsroom Media & Communications Office

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

Monday, April 18, 2005

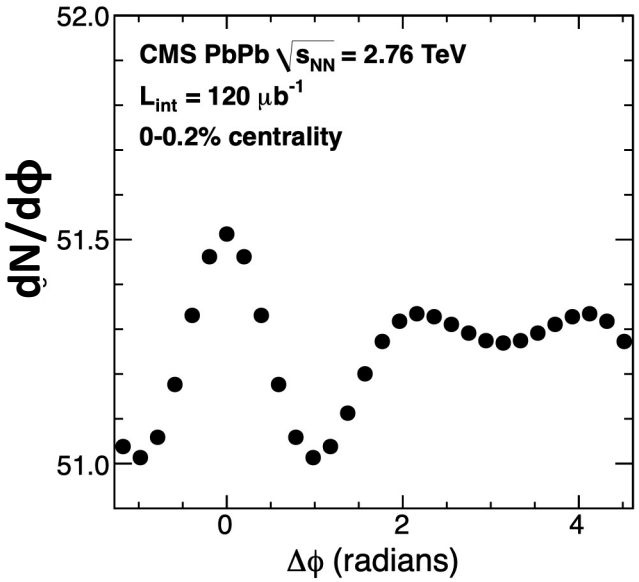
Initial state



Hydro-response

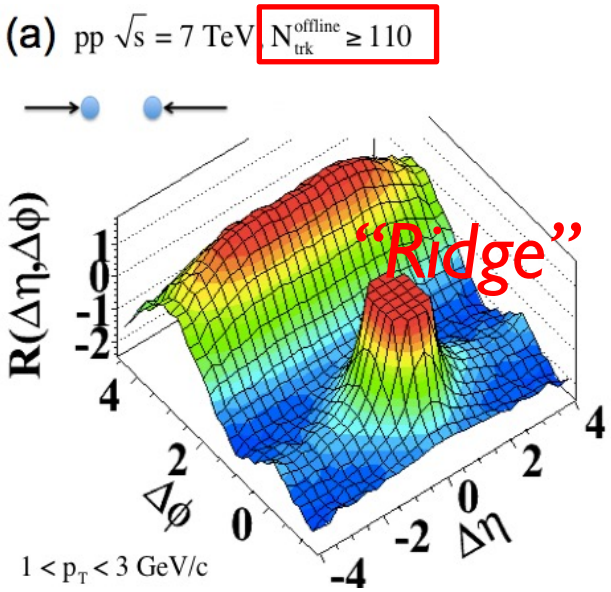
Space-time dynamics

Particle distribution

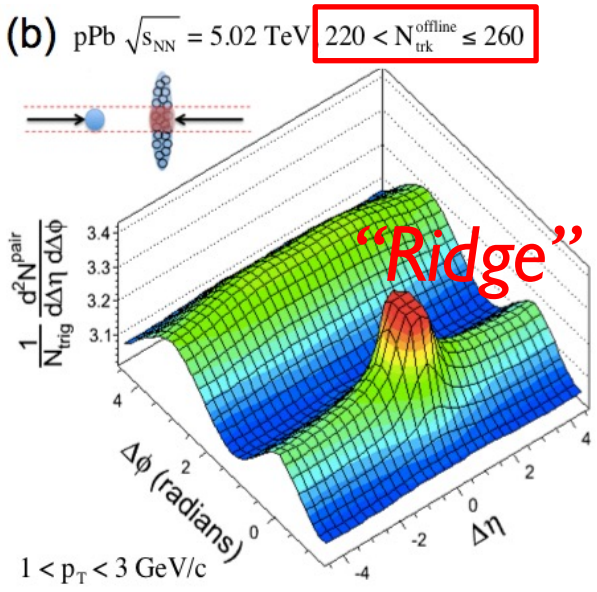


$$\vec{\epsilon}_n \equiv \epsilon_n e^{in\Phi_n^*} \equiv -\frac{\langle r^n e^{in\phi} \rangle}{\langle r^n \rangle}$$

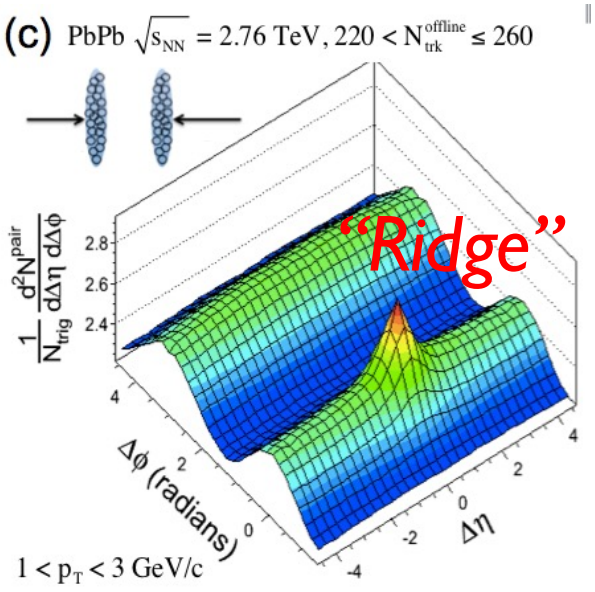
Ridge, ridge, ridge!!



JHEP 09 (2010) 091



PLB 724 (2013) 213



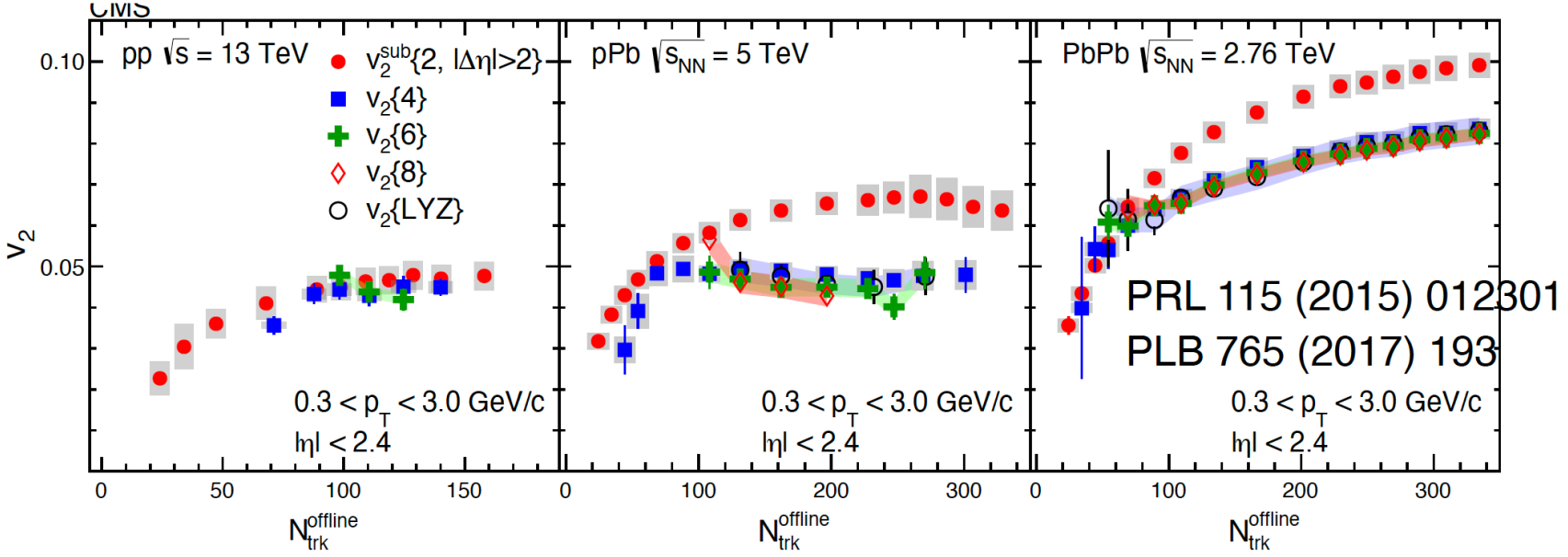
PLB 724 (2013) 213

"Ridge" everywhere

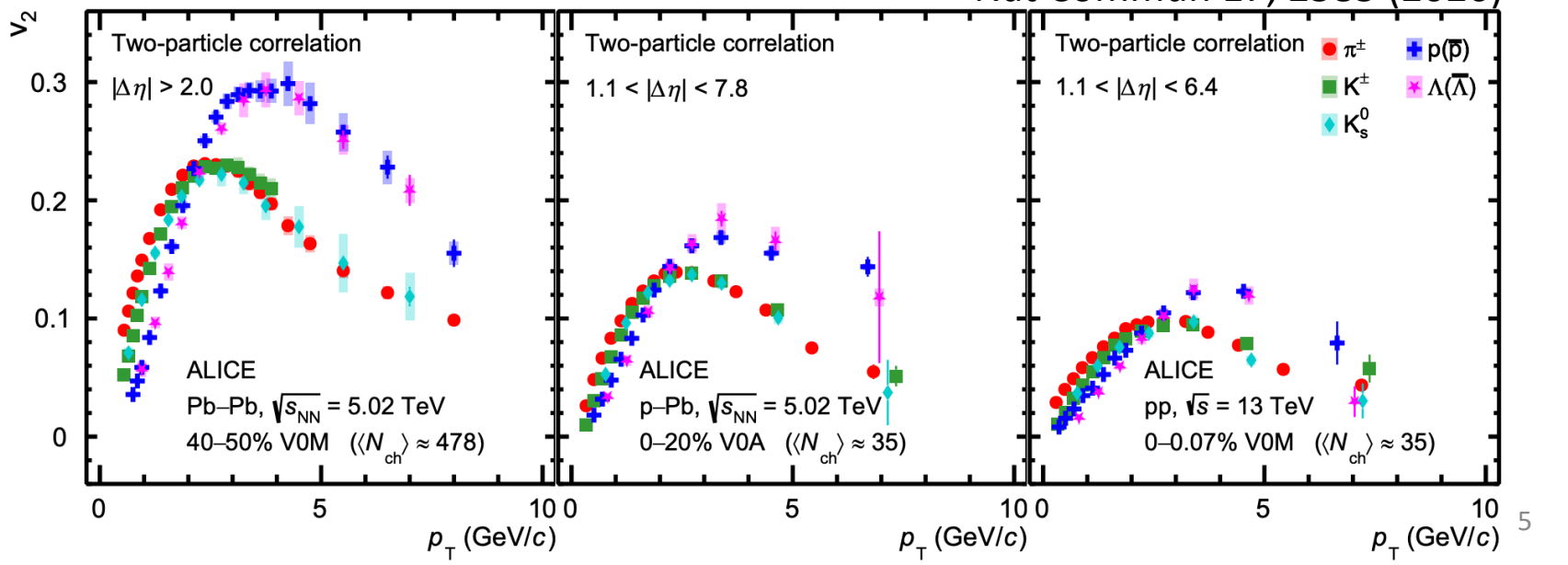
Surprising but not unfeasible with multi parton interactions

The real question: is there a QGP droplet?

Similar "Collective Flow" signatures



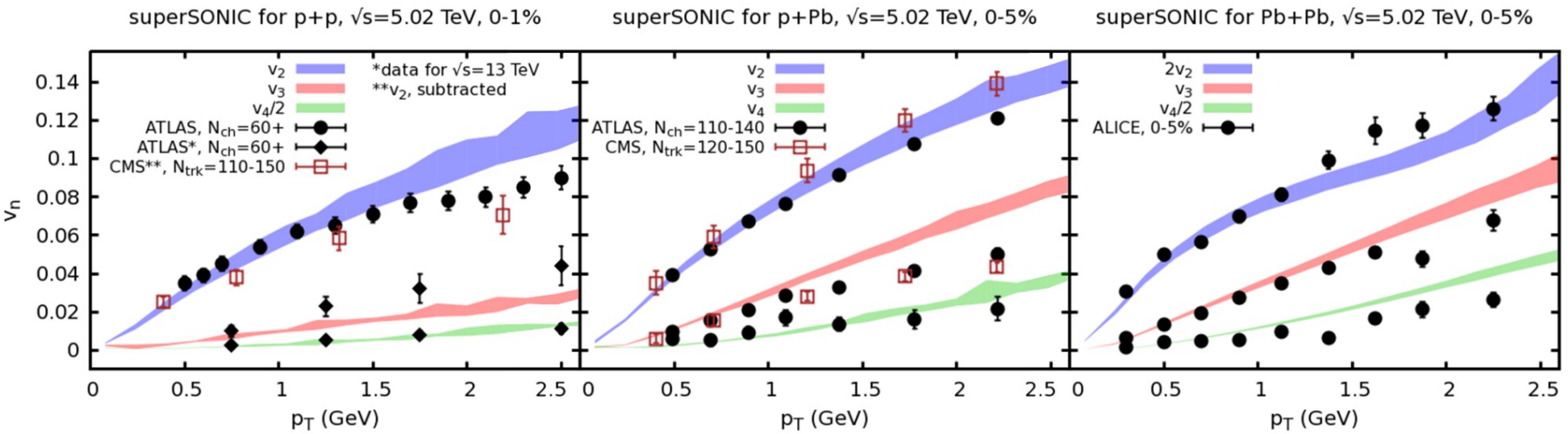
Nat Commun 17, 2585 (2026)



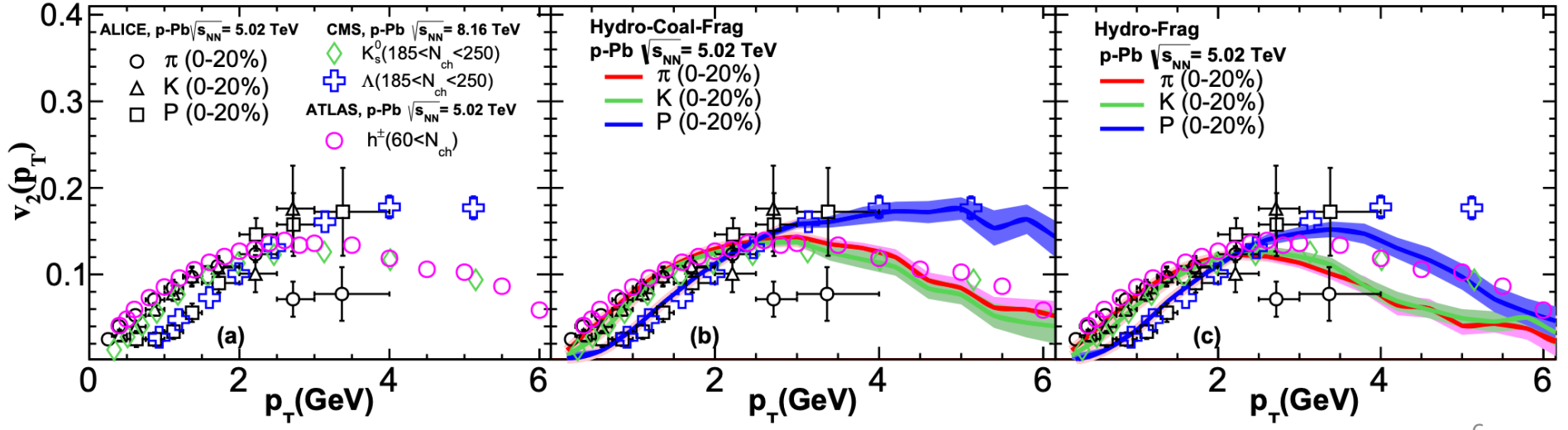
Hydrodynamics "performs" in small systems

PLB 774 (2017) 351

One Fluid to Rule Them All



PRL 125 (2020) 072301



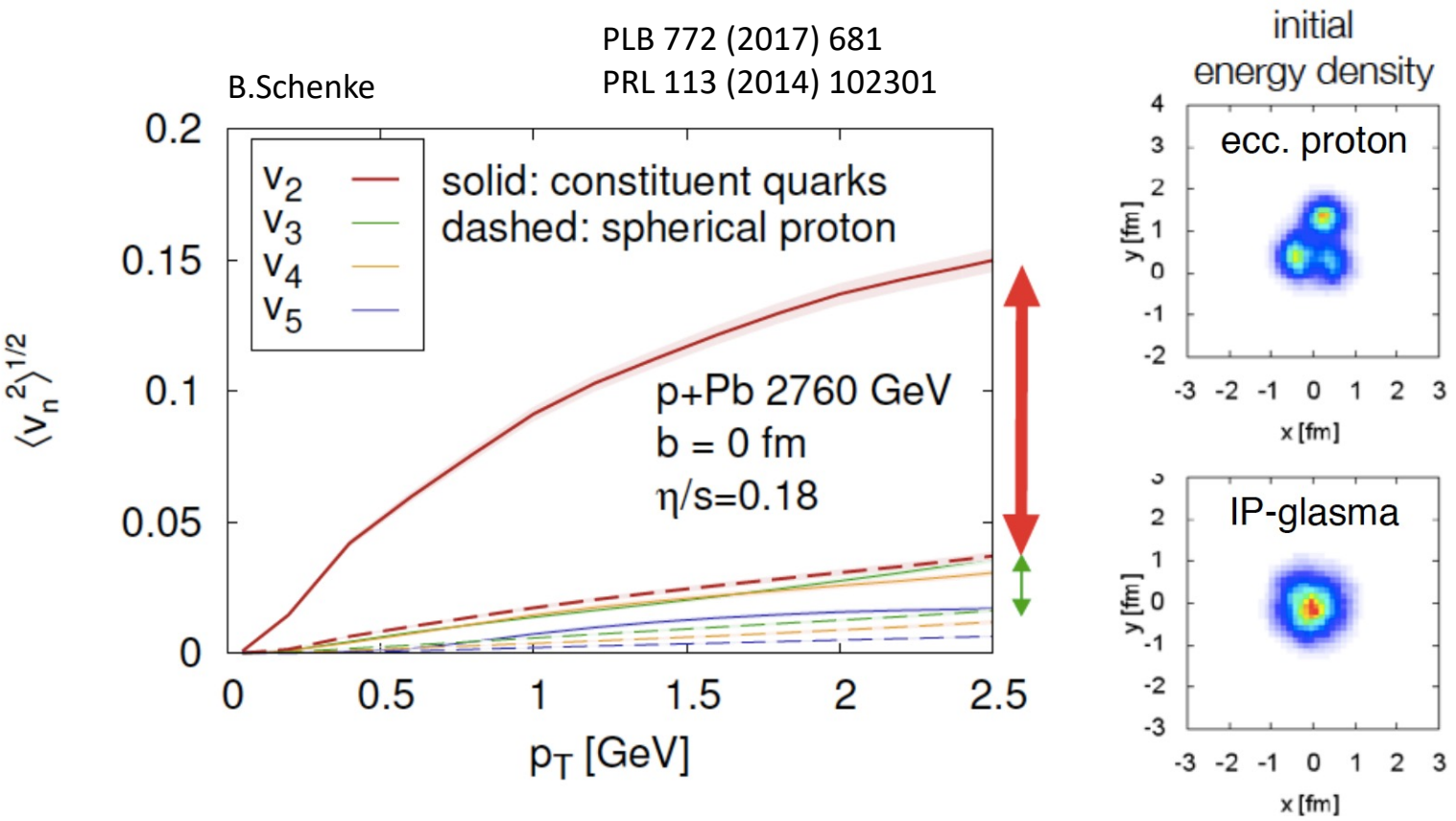
Act II

The truth is rarely pure and never simple

Oscar Wilde, The Importance of Being Earnest

Initial conditions and the puzzle of hydrodynamic response

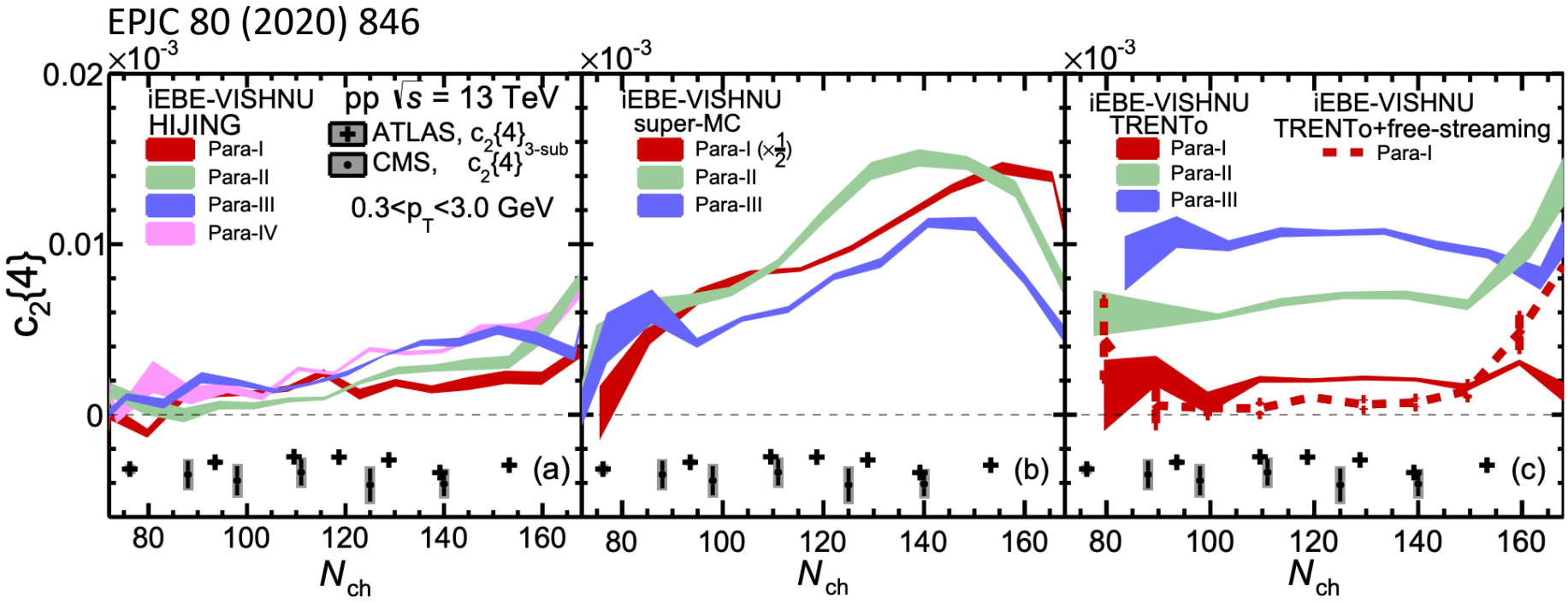
Sensitivity to initial conditions



Hydro calculations are extremely sensitive to initial conditions

Partonic structure of protons are barely controlled

$c_2\{4\}$ puzzle of hydro response



Hydro calculations cannot capture the negative sign of $c_2\{4\}$

A puzzle in hydro evolution rather than initial conditions

See Shujun's talk

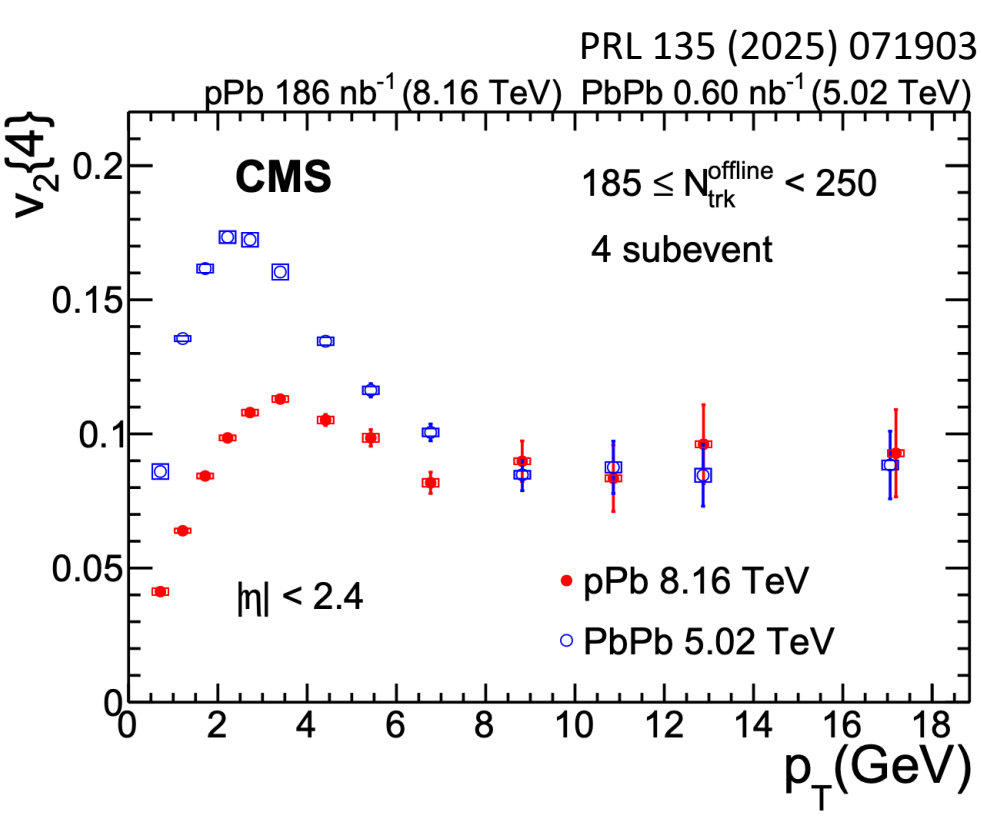
Act III

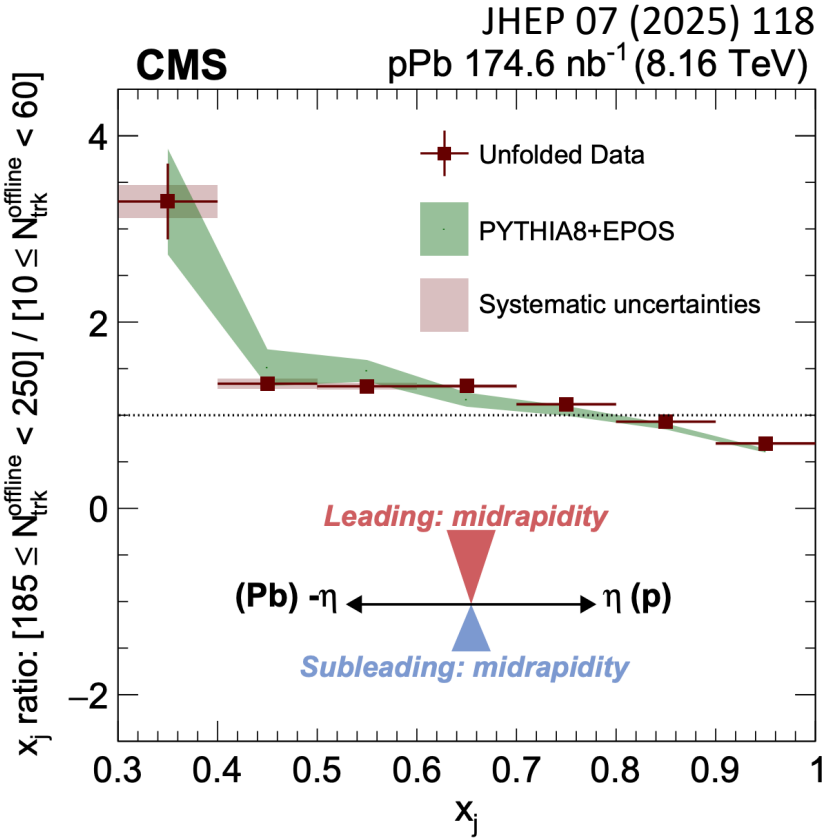
There are more things in heaven and earth…

William Shakespeare, Hamlet

More puzzles from hard probes and spin polarization

No "QGP" in the hard sector?





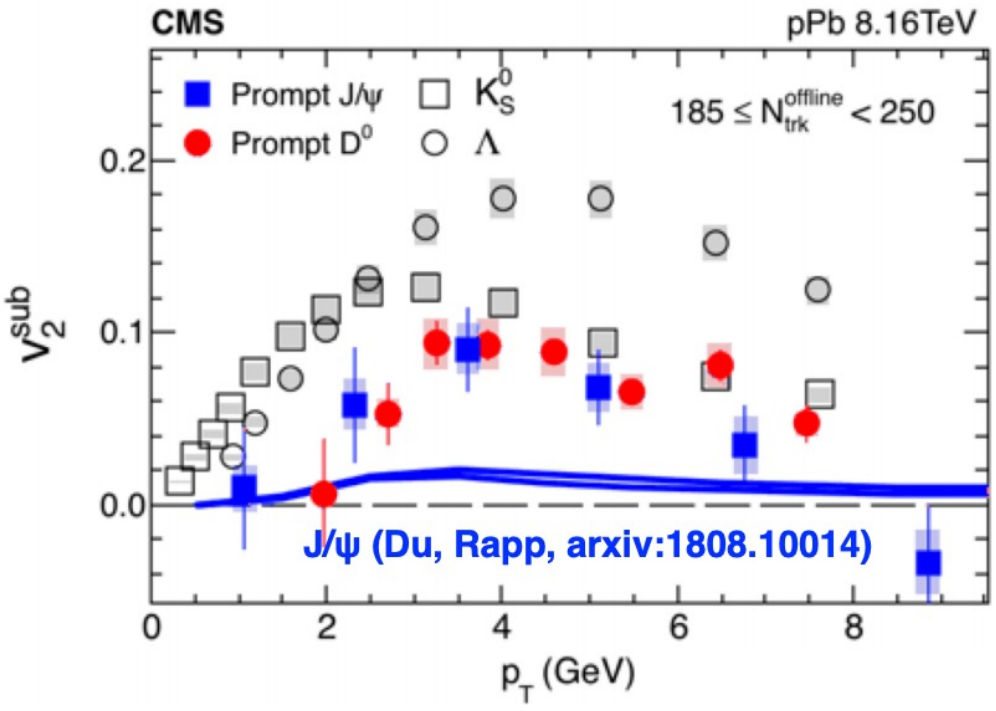
Significant v_2 observed for high pT particles in pPb

Consistent magnitude with PbPb collision – Jet quenching?

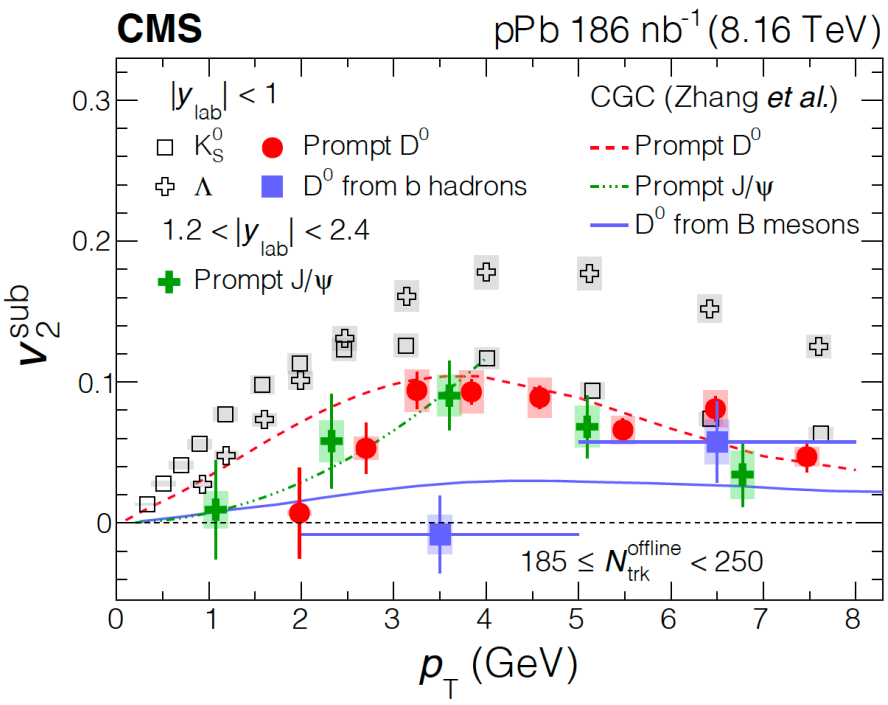
No direct evidence from analyses involving jets – Why?

No "QGP" in the hard sector?

PLB 791 (2019) 172



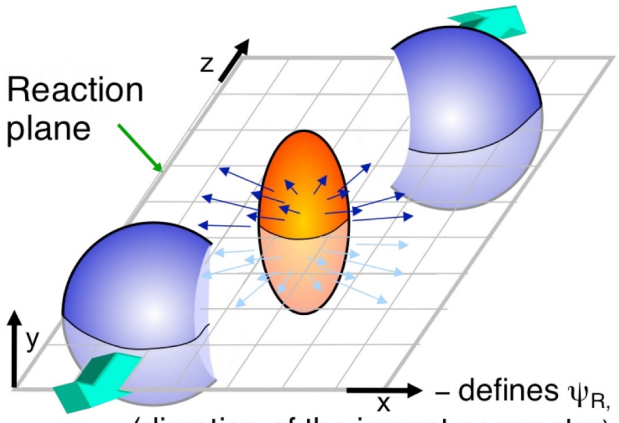
PLB 813 (2021) 136

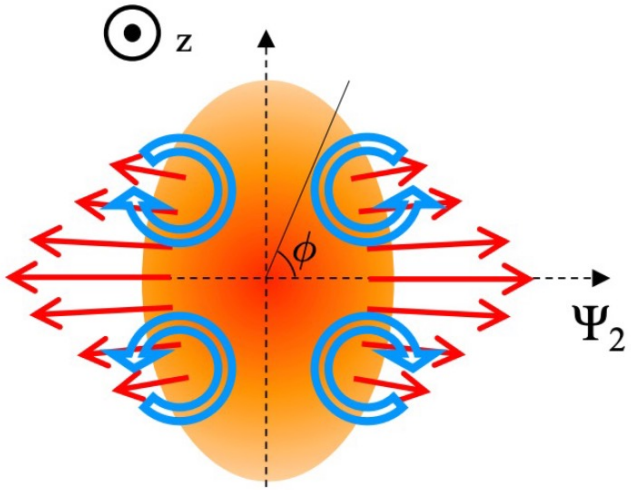


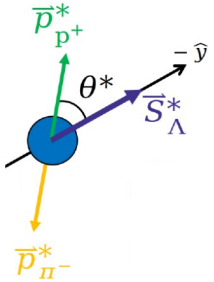
Hydrodynamic calculations cannot describe
the observed heavy flavor flow in small collision systems

CGC calculations do capture the magnitude of D^0 and J/ψ v_2

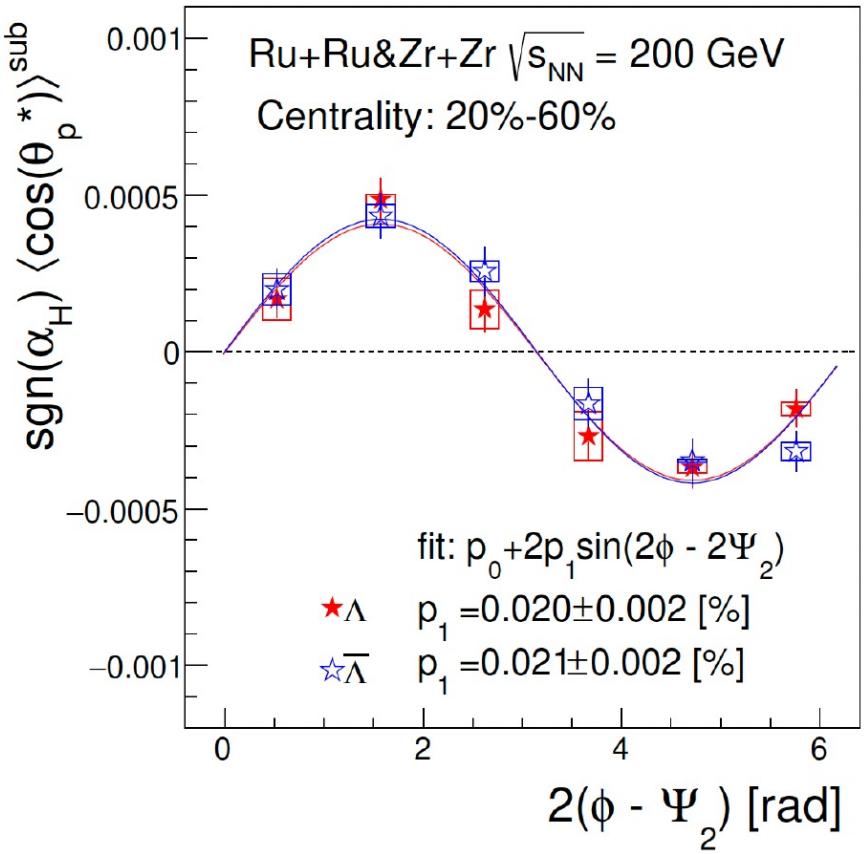
The new king brings new questions







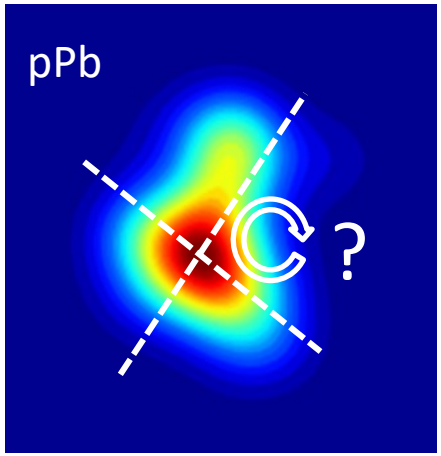
PRL 131 (2023) 202301

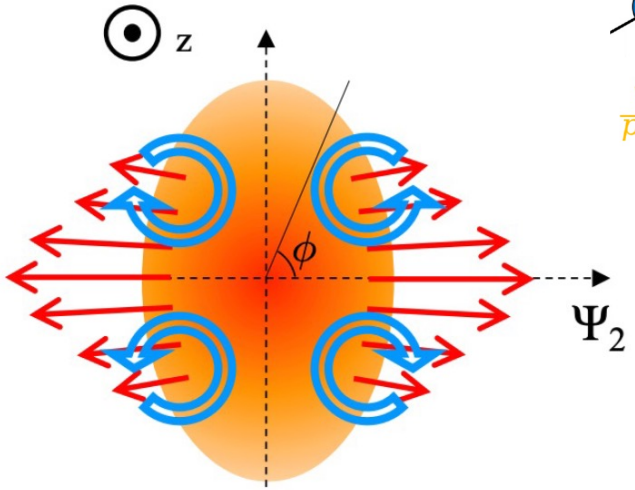


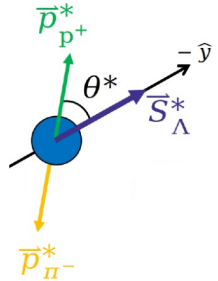
Simple expectation of vorticity from the anisotropic expansion of QGP

Measured through Lambda polarization: parity violating weak decay

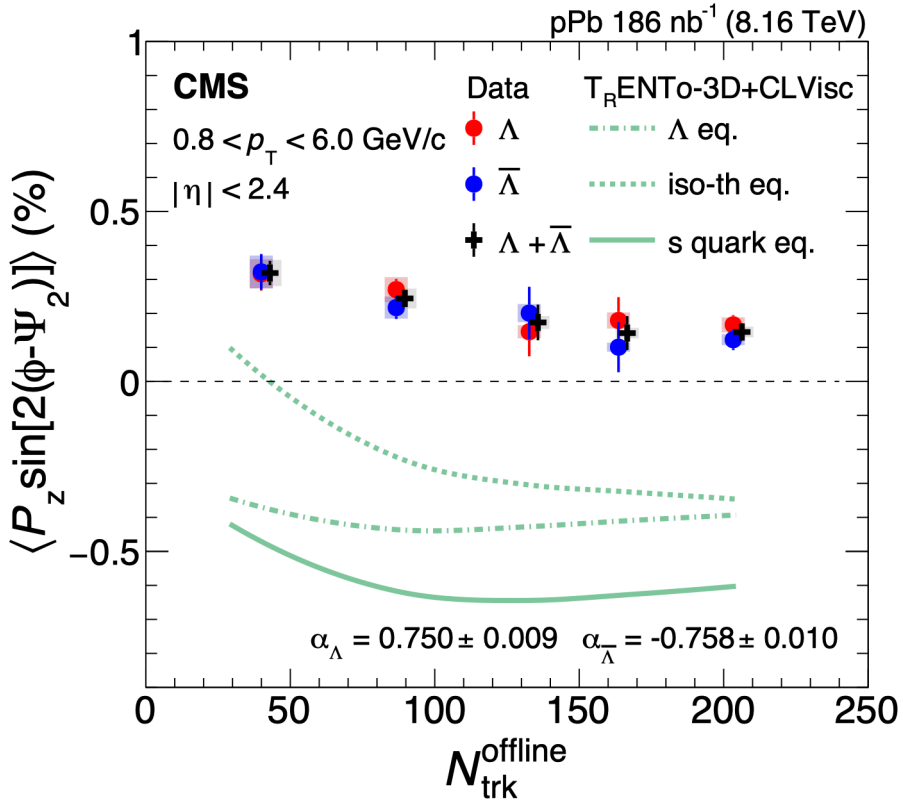
The new king brings new questions







PRL 135 (2025) 132301



Significant hyperon local polarization observed in pPb collision

Hydro-vorticity framework can not capture data

New puzzle: what are the mechanisms in small systems

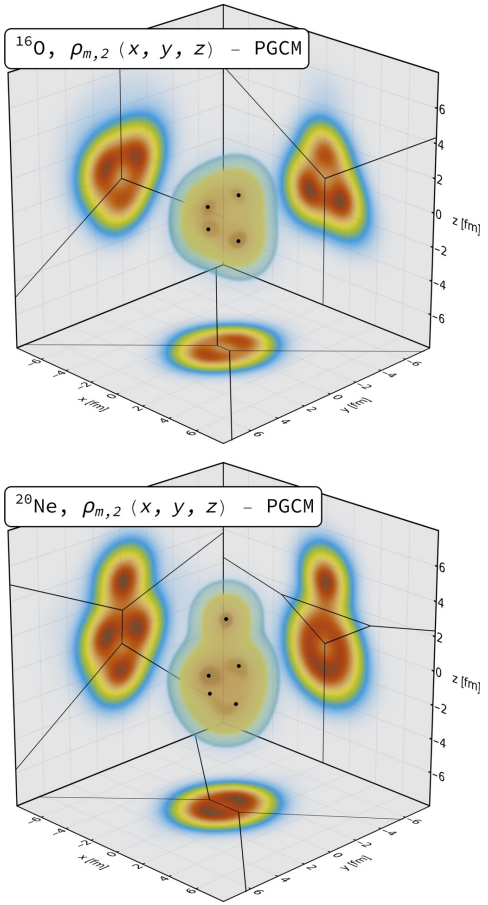
Act IV

By indirections find directions out

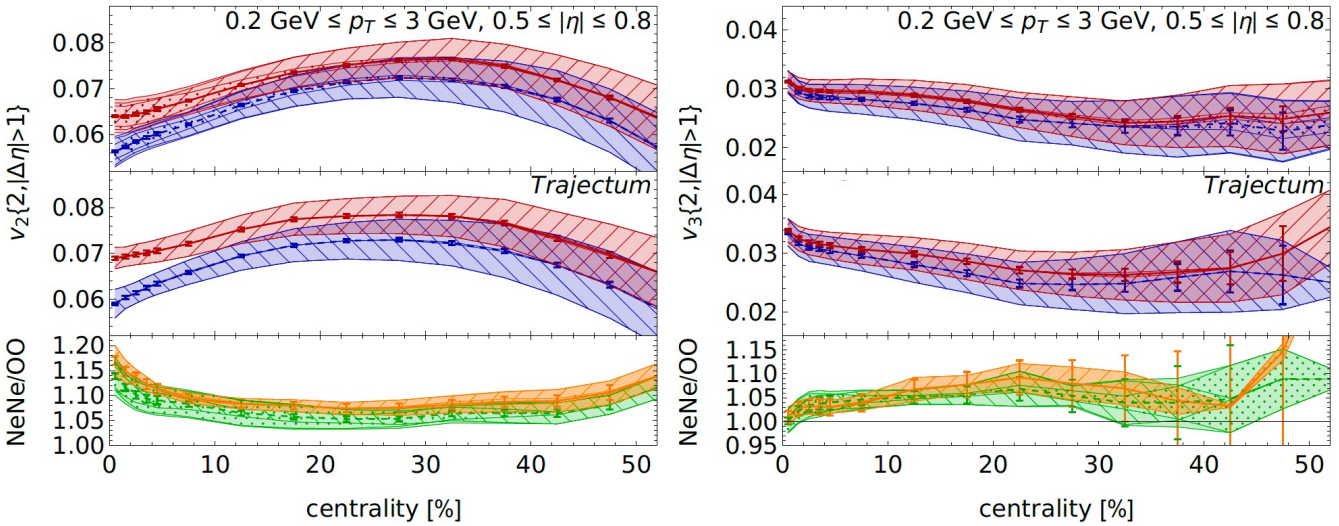
William Shakespeare, Hamlet

Controlled test and the search for missing physics

A initial-states-controlled “bowling” game



PRL 135 (2025) 012302

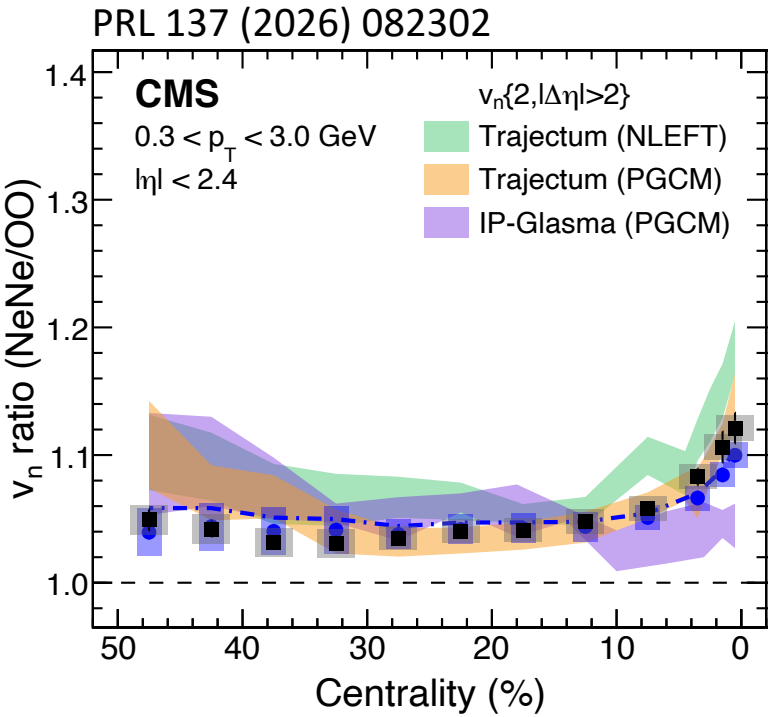


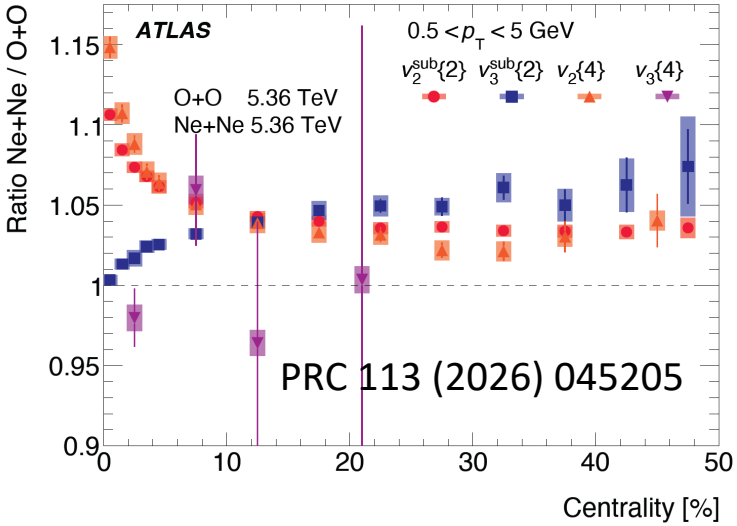
Exotic deformation predicted by *ab-initio* nuclear structure calculations

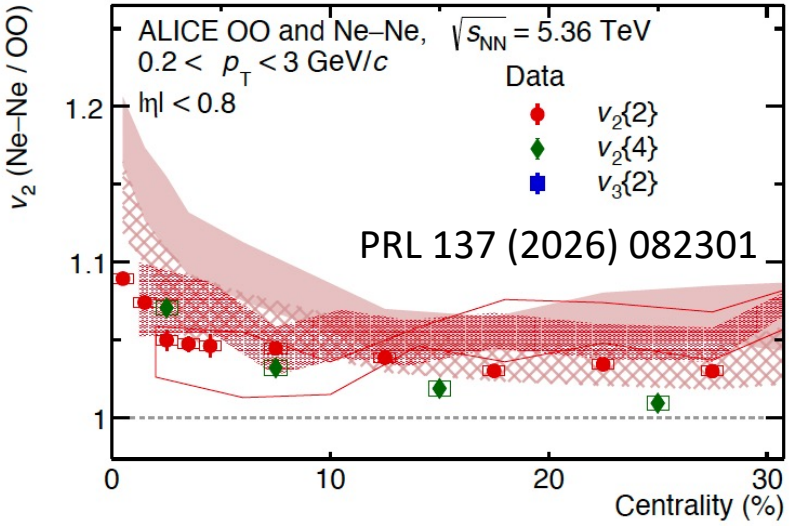
Imprints in v_n ratios expected in most central collisions

Provide precision characterization of collectivity in small systems

The "bowling feast" at LHC





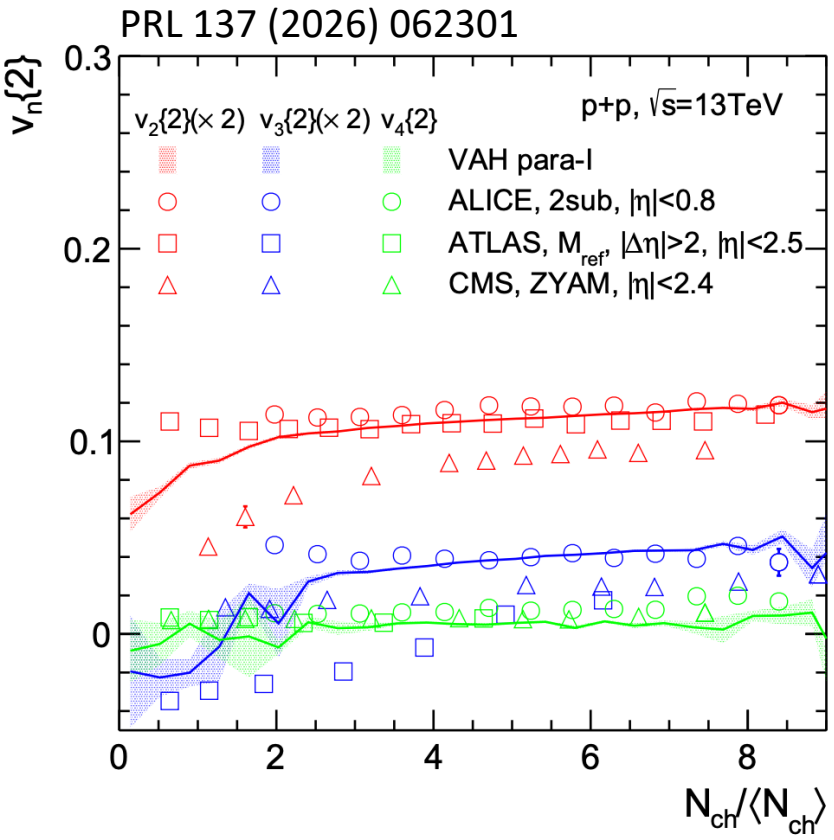


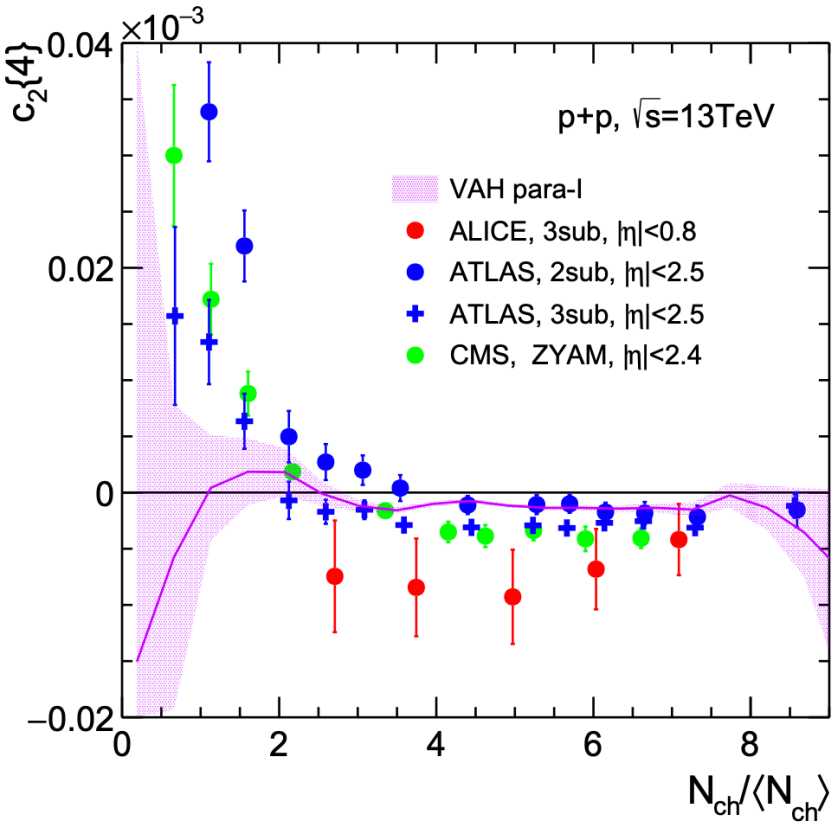
Significant effects observed in central collisions

Evidence of geometry response

Could this be pushed into even smaller systems?

Improving hydro for small systems

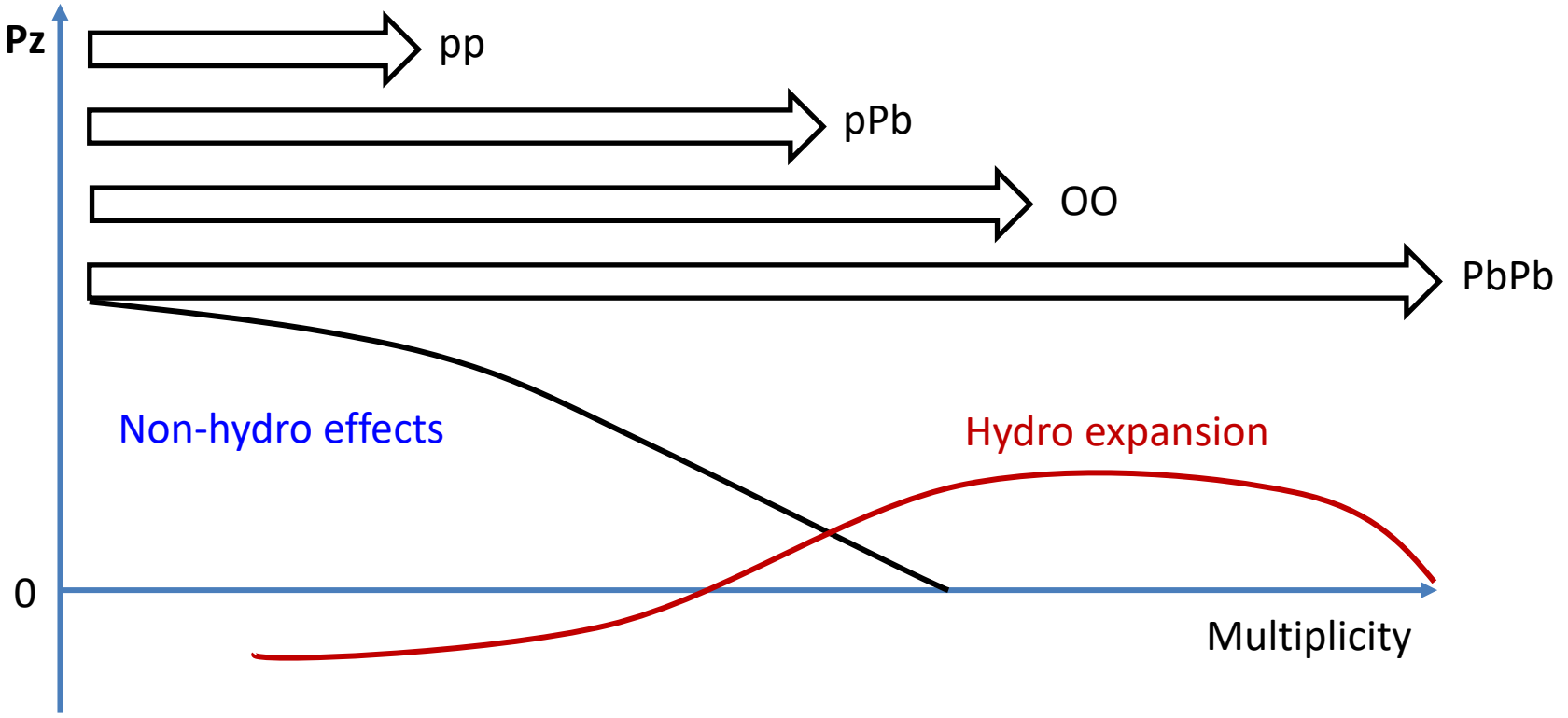




Viscous Anisotropic Hydrodynamics developed to solve the $c_2\{4\}$ puzzle

I leave this part to Shujun

Hyperon polarization across systems



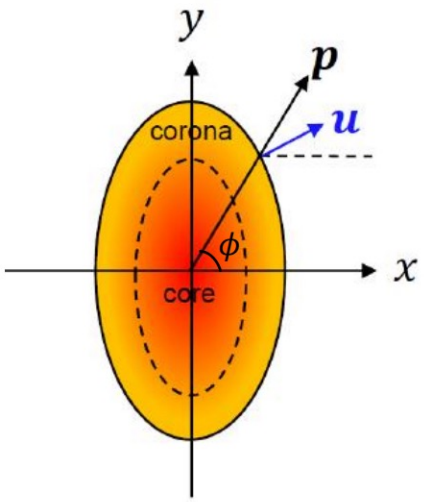
A naïve guess of contributions to hyperon local polarization

How do they evolve and what is the implication for AA and vice versa?

Polarization measurements and model calculations across pp, pA, AA on-going

Core-corona + color-field correlators

- Longitudinal polarization from the corona of glasma (early hadronization) :



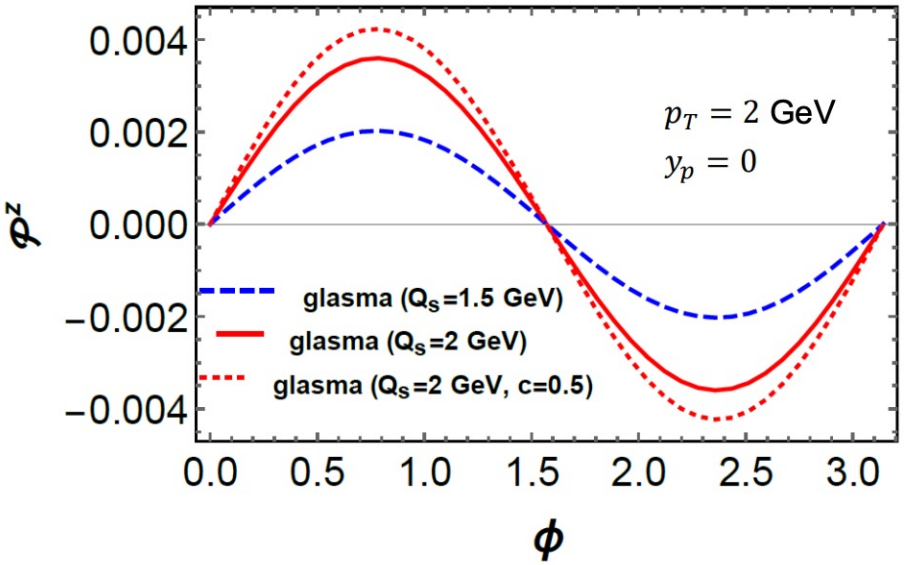
weak initial anisotropic flow
from pressure gradient

traveling time in corona

$\boldsymbol{p} \times \boldsymbol{u}$ structure

$$\mathcal{P}^z \approx \frac{\hbar(N_c^2-1)Q_s^2\Delta t}{16M_\Lambda N_c^2 \epsilon_{\boldsymbol{p}} \int d\Sigma\cdot p f_V^{\rm s}} \int d\Sigma\cdot p(p^x u^y - p^y u^x) \times f_V^{\rm s}\left(1-f_V^{\rm s}\right)\left((1-2f_V^{\rm s})u^0 + Q_s/\epsilon_{\boldsymbol{p}}\right), \quad f_V^{\rm s} = \frac{1}{e^{p\cdot u/Q_s}+c}.$$

(the overall sign is related to the freeze-out hypersurface)



H. Sung, B. Müller, DY, arXiv: 2507.23210

✓ consistent sign & comparable order of magnitude with observations

Slide taken from Di-Lun Yang's Initial Stages talks

Act V

It's wanting to know that makes us matter

Tom Stoppard, Arcadia

Toward a unified picture of QCD matter from small to large

Few questions to move forward

- Can controlled geometry separate initial-state structure from dynamical response? How far can we go to safely use the chain of initial geometry to final anisotropies?

- Can improved hydrodynamics describe flow observables consistently across system sizes? And what are the impact on already settled questions?

- How can we reconcile high momentum and heavy flavor anisotropy with constraints on jet quenching? What are the role of non-final-state effects for other observables?

- What drives the spin polarization? And how it evolves from pp to AA? What are the polarization effects imprints on other observables?

The show must go on!!