Origin of collectivity in QCD systems

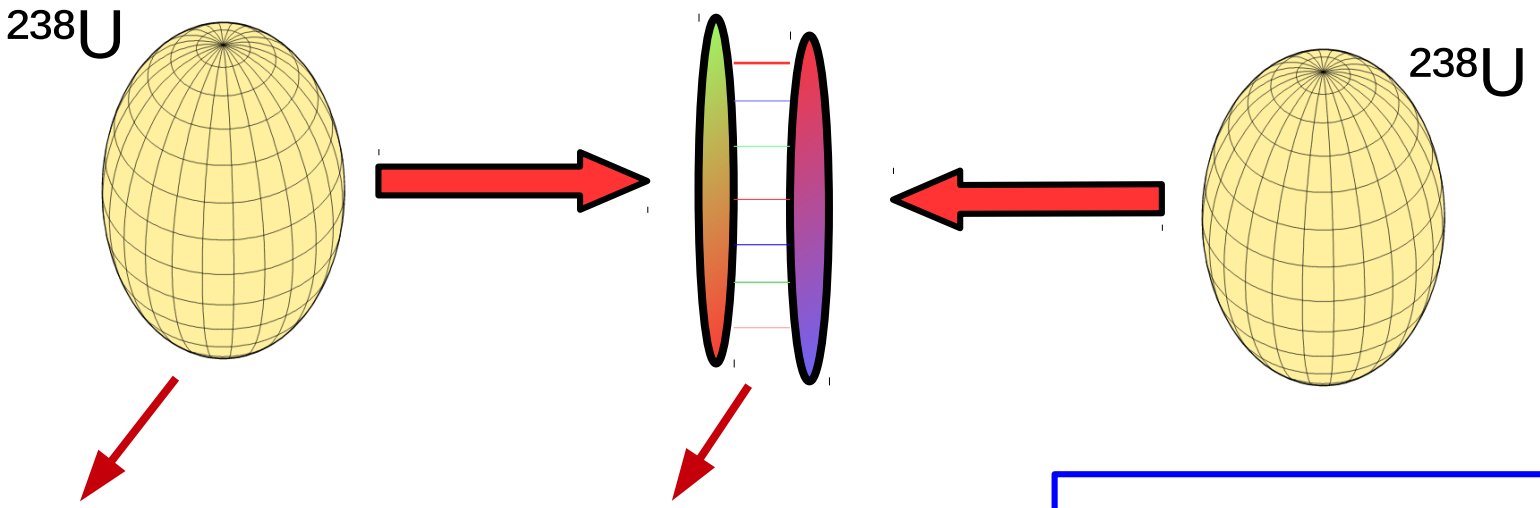
by

GIULIANO GIACALONE

09 / 06 / 2021

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

Collectivity: defining paradigm of nuclear phenomenology.



Quadrupole correlations in many-body system.

Effective description:
'ellipsoidal' surface.

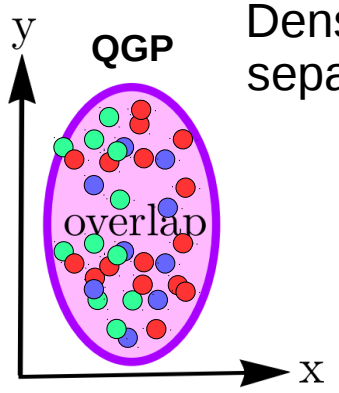
$$R(\Theta,\Phi) = R_0\left[1+\beta Y_{2,0}(\Theta,\Phi)\right]$$

Huge densities of gluons at small x.

Effective description:

$$\rho^a(x^-,x_\perp) \quad A^\mu_{1,2}(x)$$

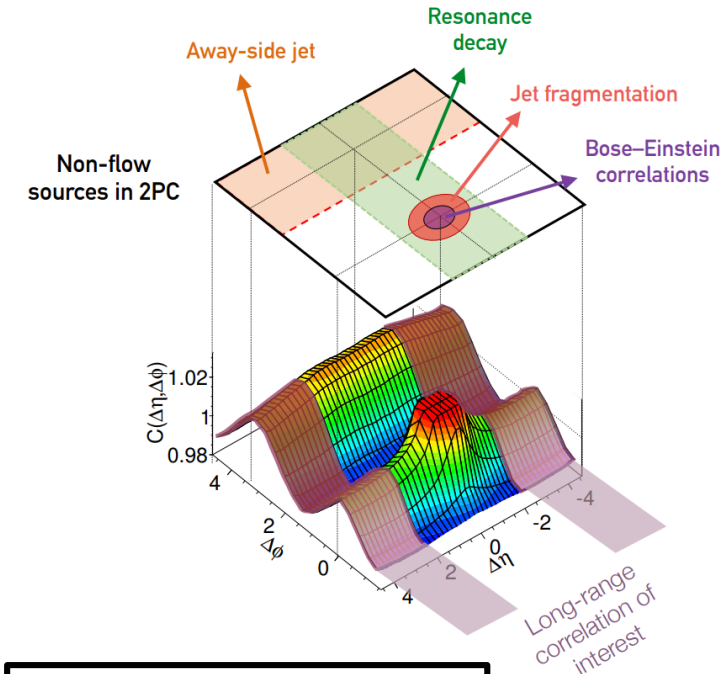
Color Glass Condensate.



Dense system with a separation of scales.

Effective description:

$$\vec{F} = -\vec{\nabla}P$$



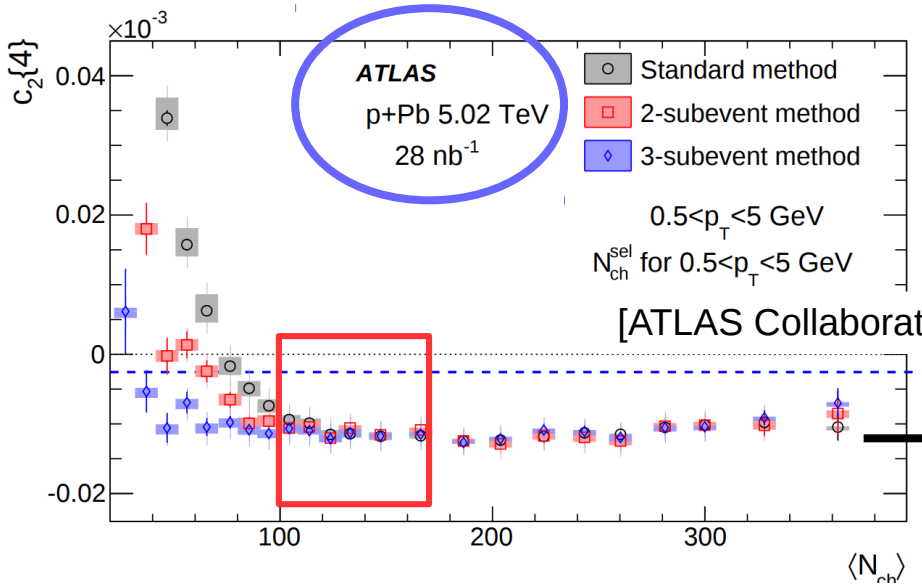
Experimentally ubiquitous. (pp?)

Indicators: $c_2\{2,4\}$.

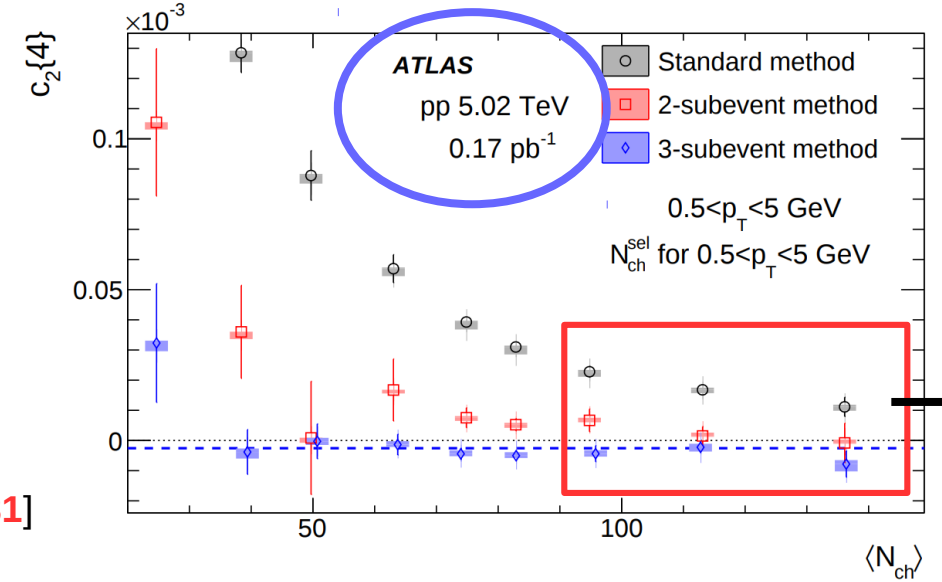
No evidence so far in e^+e^- and e^-p collisions.

[ZEUS Collaboration, **1912.07431**]

[Badea et al., **1906.00489**]



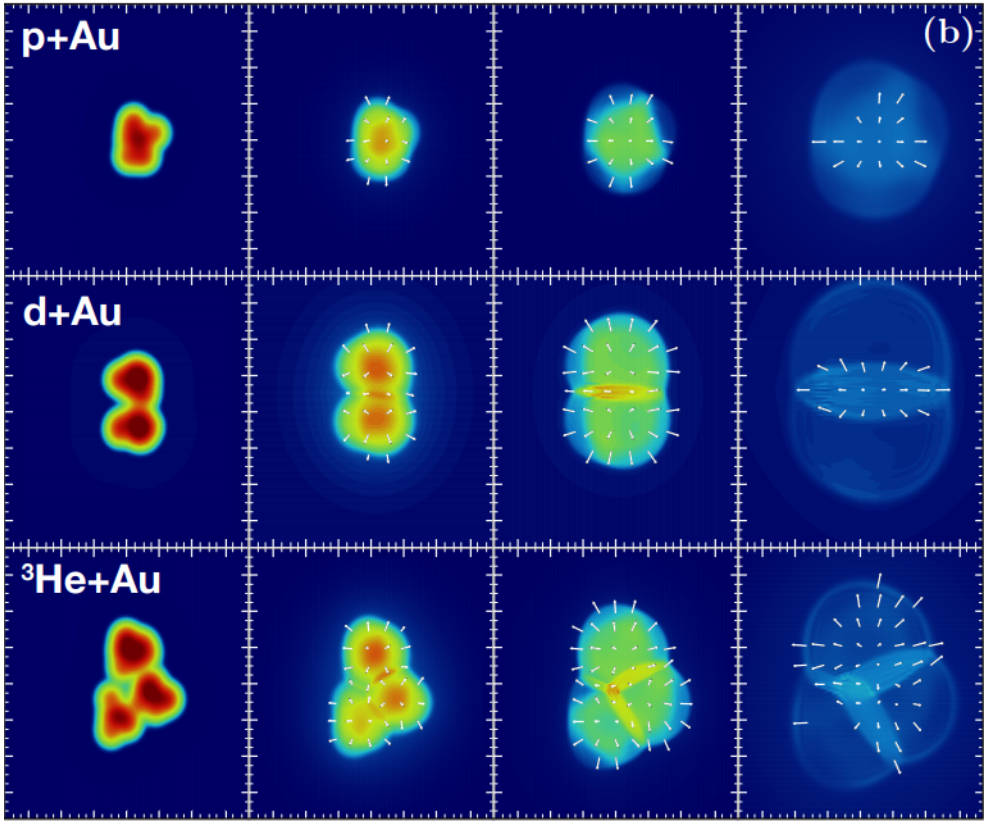
[ATLAS Collaboration, **1708.03559**]



→ **excellent**

→ 🤨

ORIGIN OF COLLECTIVITY : SCATTERING (FINAL STATE)



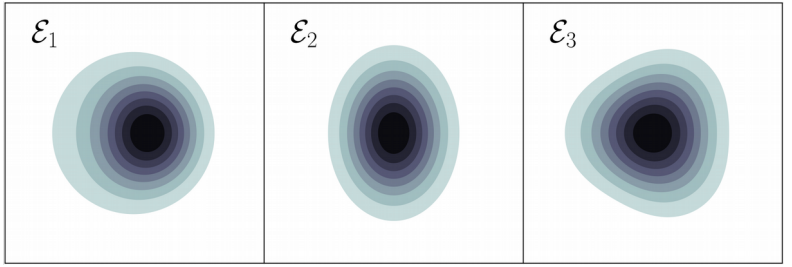
[PHENIX Collaboration, 1805.02973]

Anisotropy from anisotropy:

$$\vec{F} = -\vec{\nabla} P$$

more generic.
If there are interactions (“Hydro”):

$$V_n \propto \mathcal{E}_n$$



Revamping the question: collectivity = hydrodynamics ?

"Qualifying" the QGP. [Kurkela, Wiedemann, Wu, **1905.05139**]

Generating collectivity is actually easy. [Kurkela, Mazeliauskas, Törnkvist, **2104.08179**]
[Roch, Borghini, **2012.02138**]
[Borghini, Feld, Kersting **1804.05729**]

FRONTIER:

Thermalization → "Hydrodynamization"

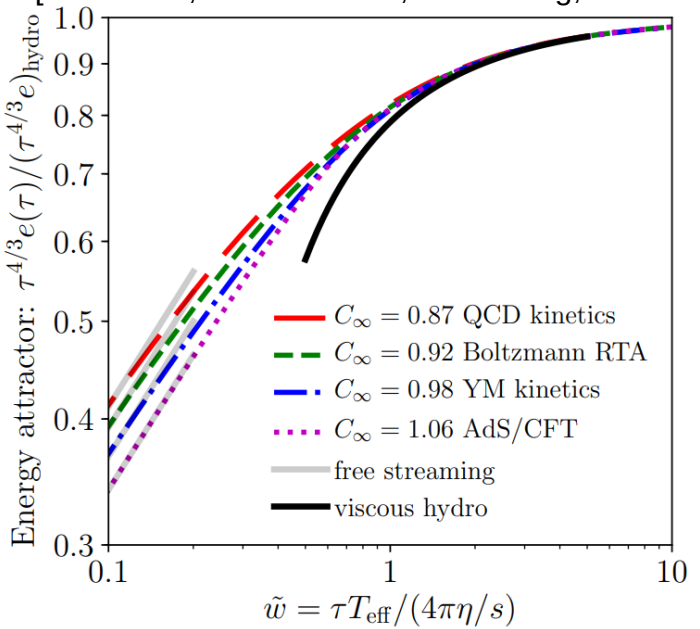
Towards off-equilibrium hydrodynamics.

Microscopic details less important.

[Berges, Heller, Mazeliauskas, Venugopalan, **2005.12299**]
[Romatschke, Romatschke, **1712.05815**]

PHENOMENOLOGICAL PROGRAM?

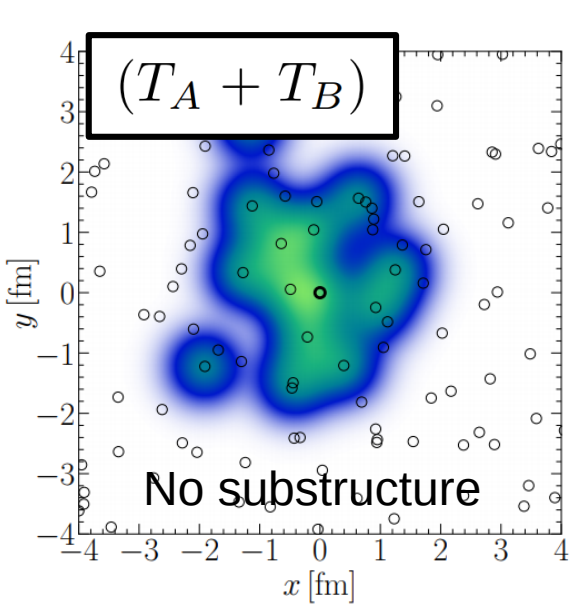
[Giacalone, Mazeliauskas, Schlichting, **1908.02866**]

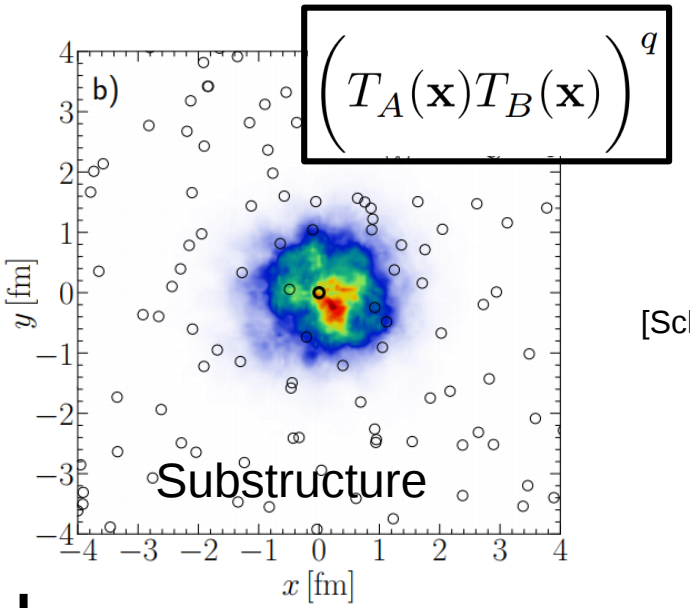


Collective nucleons at high energy?

[Mäntysaari, Schenke **1603.04349**, **1607.01711**]

Role of sub-structure depends **dramatically** on energy deposition.





[Schenke **2102.11189**]

- **Describes v_n cumulants in pA.**
- Does not describe rho(v_2^2,<pT>)<0.
- Not viable for Pb-Pb collisions

[Bożek **1601.04513**]

[Kozlov, Luzum, Denicol, Jeon, Gale **1405.3976**]

[Bożek, Broniowski **1304.3044**]

- Describes rho(v_2^2,<pT>)<0 in pA.
- Works in both p-Pb and Pb-Pb collisions.

[Nijs, van der Schee, Gürsoy, Snellings **2010.15130**, **2010.15134**]

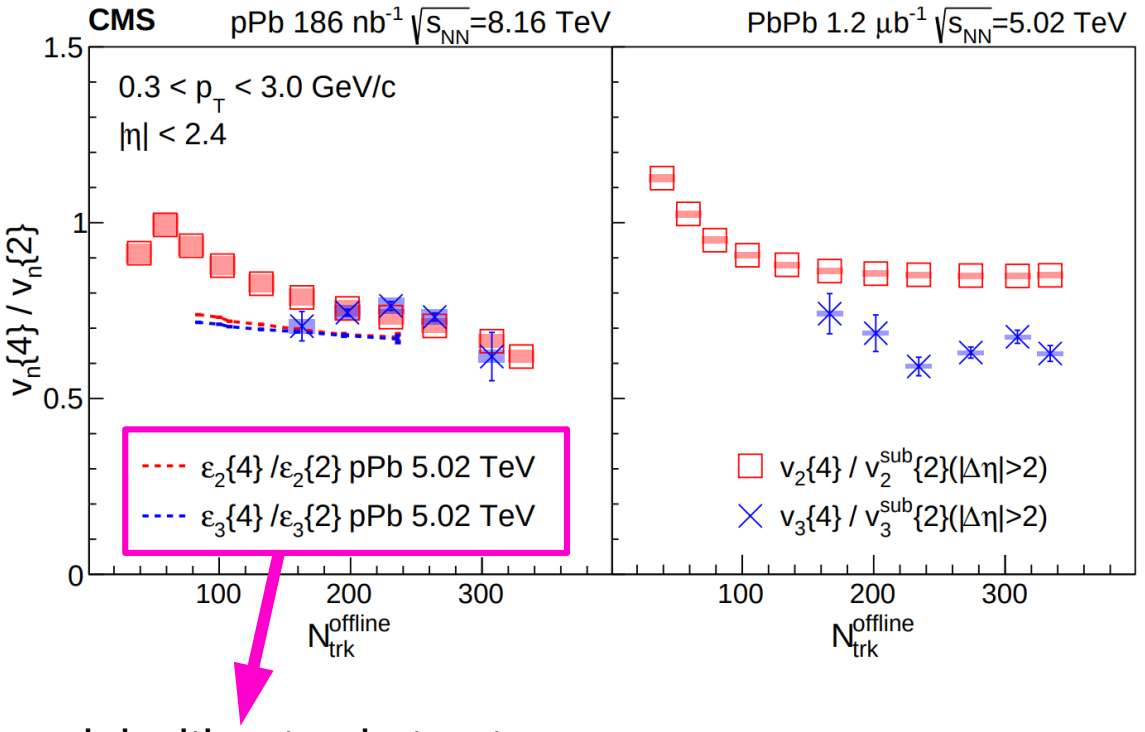
[Schenke, Shen, Teaney, **2004.00690**]

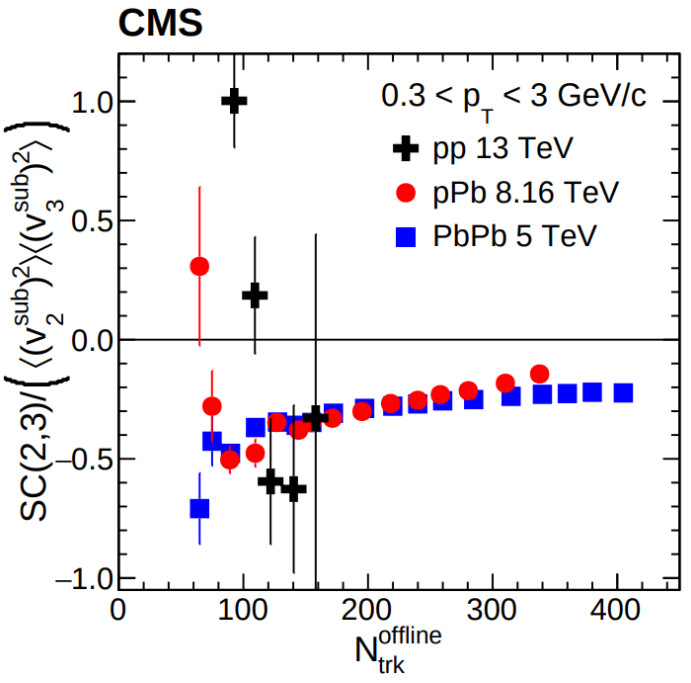
[Bass, Bernhard, Moreland **1808.02106**]

Spectacular observations of collectivity in pPb collisions.

[CMS Collaboration, 1904.11519]

[CMS Collaboration, 1709.09189, 1905.09935]



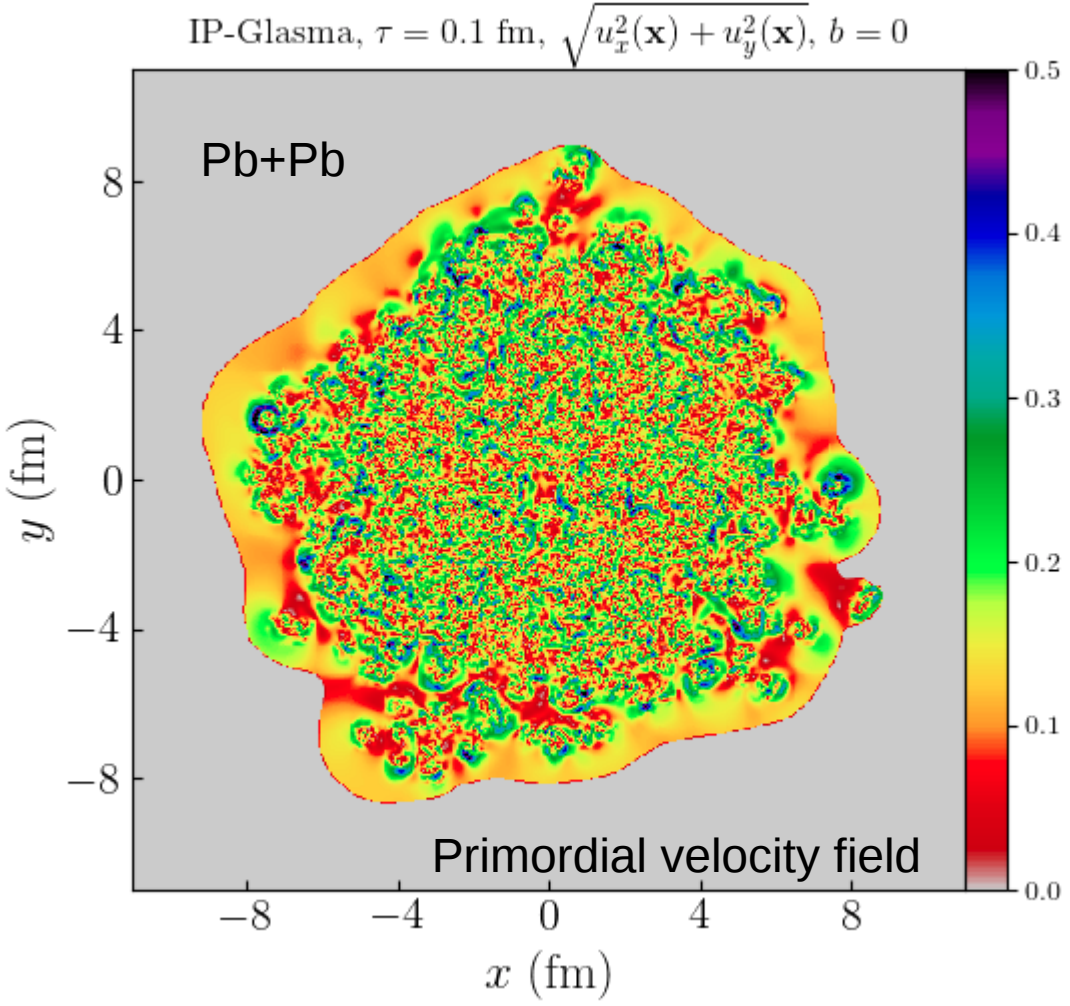


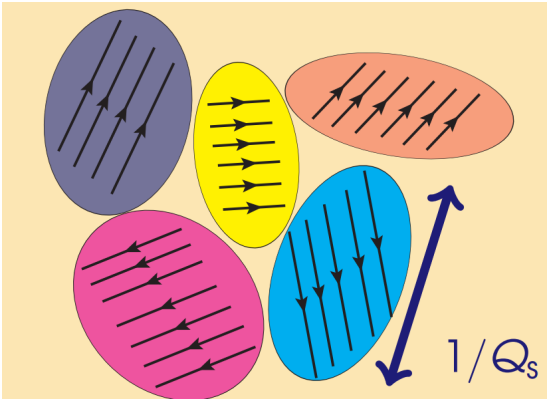
model <u>without</u> substructure.

[Giacalone, Noronha-Hostler, Ollitrault 1702.01730]

Do we understand any of this? Goal for the future.

ORIGIN OF COLLECTIVITY: INITIAL STATE





[Altinoluk, Armesto **2004.08185**]

"MOMENTUM" ANISOTROPY

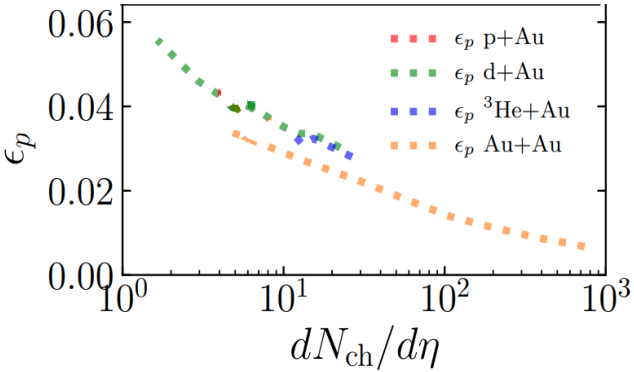
Hybrid CGC+hydro formalism.

$$\mathcal{E}_{2p} \propto \langle T^{xx} - T^{yy} + 2iT^{xy} \rangle$$

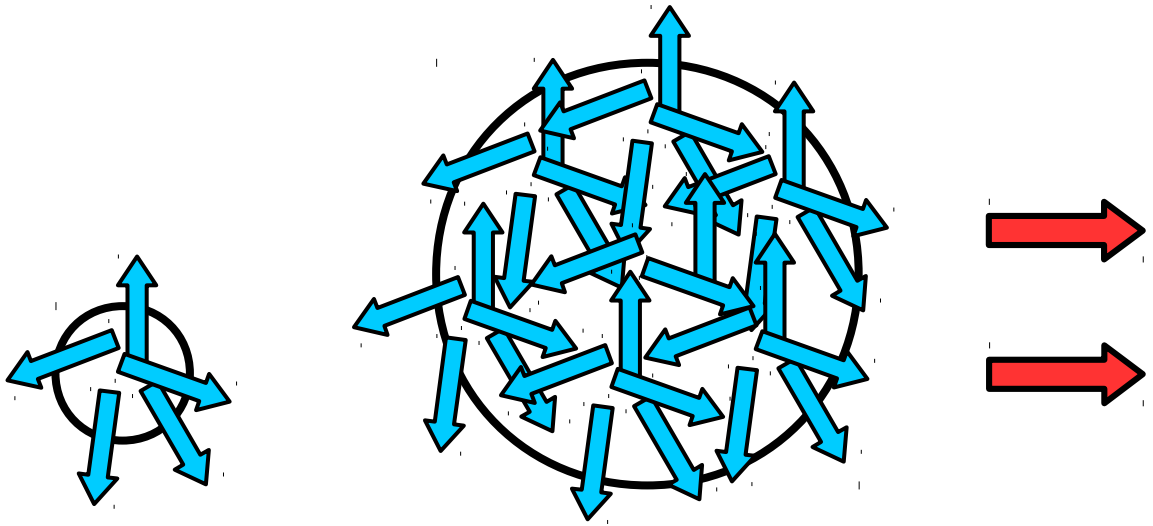
[Schenke, Shen, Tribedy **2005.14682**]

We only know it is relevant for very small systems (dN/dη ~ 10).

[Schenke, Shen, Tribedy, **1908.06212**]



Observations? One has to be creative.
<u>Recent realization:</u> system-size dependence at fixed dN/dη.



Larger e_p
Smaller size
Larger <pT>

Smaller e_p
Larger size
Smaller <pT>

In IP-Glasma+MUSIC:

$$\rho(\varepsilon_p^2, \langle p_t \rangle) > 0$$

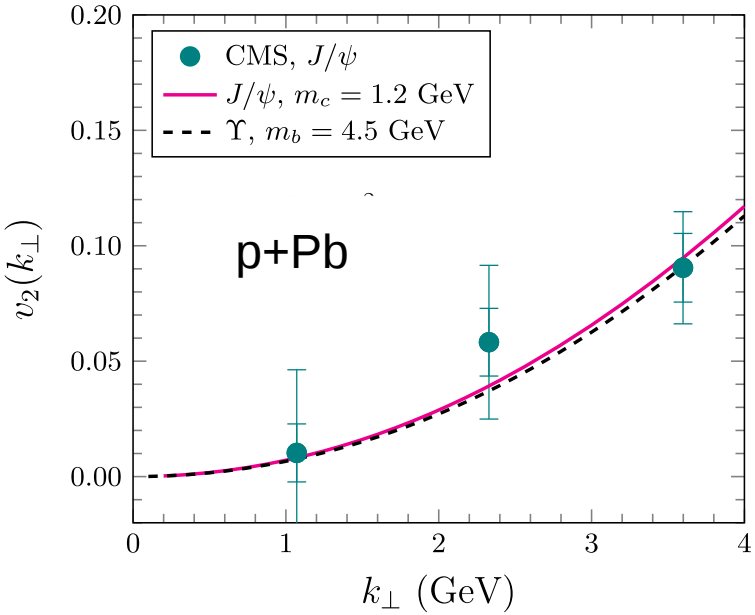
Thus, if v_2 is driven by e_p :

$$\rho(v_2^2, [p_t]) > 0$$

For dN/dη < 10.
Universal feature.

[Giacalone, Schenke, Shen, **2006.15721**]

MORE PROBES OF INITIAL STATE – TOWARDS EIC?



Collectivity of heavy mesons in pPb collisions.
Dilute-dense results yield sizable v2 values.

[Zhang, Marquet, Qin, Wei, Xiao, **1901.10320**]

[CMS Collaboration **1810.01473**]

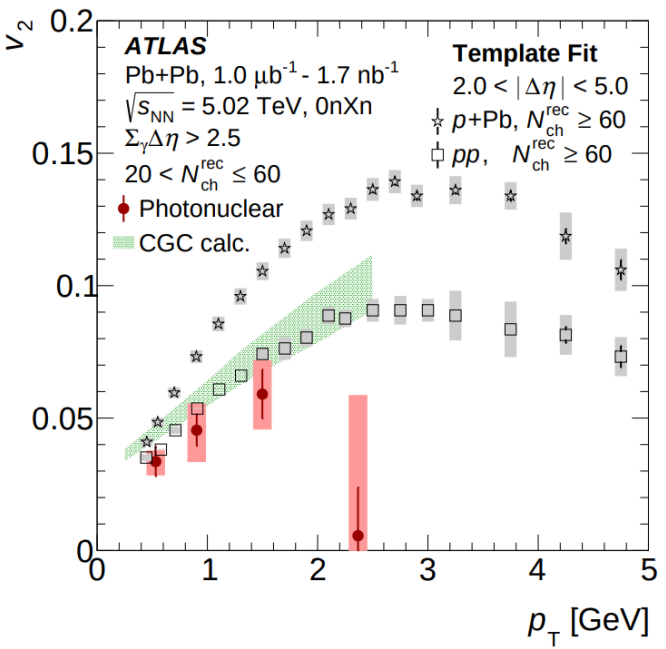
[ALICE Collaboration **1709.06807**]

Collectivity in gamma-nucleus collisions (UPC).

A probe of the initial state. CGC?
Bridge with EIC physics.

[ATLAS Collaboration **2101.10771**]

[Shi, Wang, Wei, Xiao, Zheng, **2008.03569**]



- **SUMMARY**

- **COLLECTIVITY: PARADIGM OF NUCLEAR PHENOMENOLOGY**

- **RESPONSE TO GEOMETRY: “HYDRO”**
  - Assessing the nature of the “QGP” from experiments.
  - Structure of high-energy nucleons ↔ Tests of energy deposition.
  - Need for theory-to-data comparisons for c{n>2} in pA.

- **BEYOND THE GEOMETRY: PRIMORDIAL FLOW**
  - Hybrid CGC+Hydro framework – New ideas for small systems.
  - Observables in pA to probe initial-state correlations → towards EIC.

THANK YOU!