Global discussion on the *Limits of QGP formation*

LHCP 2024

5th June 2024

Traditional signatures of QGP

- Azimuthal anisotropy → Preferred orientations due to pressure gradients (hydro).
    - Mass ordering, # quarks scaling.
- Jet quenching → E. loss in deconfined QCD matter.
- Quarkonia suppression → Sequential suppression as a sign of quarkonia “melting” in QGP.
- Strangeness enhancement → Thermal production due to high-enough energy density QGP.

Complications in QGP searches in small systems

- Azimuthal anisotropy → Hydro. vs shoving/pQCD inspired models.
- Jet quenching → No evidence.
- Quarkonia suppression → QGP droplet vs co-mover interactions. Final, not initial effect.
- Strangeness enhancement and hierarchy with strangeness content → QGP vs pQCD inspired models.

Puzzles in small systems

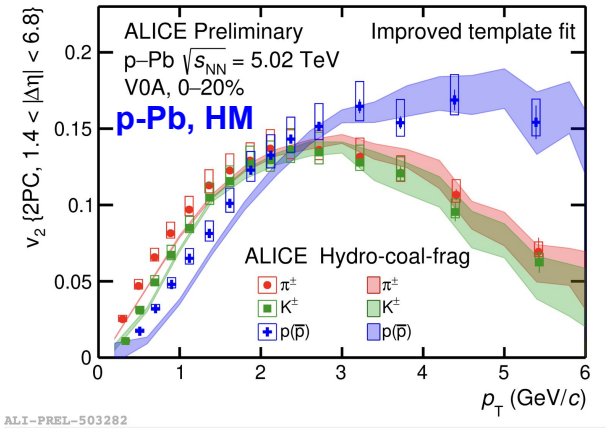
- v_2 in high mult pPb vs p_T, PID dependence, p_T splitting similar to AA
  - Described by hydro + coalescence + fragmentation.
  - Some differences seen in low mult pPb and pp.
  - Ridge and v_2 present in low mult pp and e^+e^-.
- No jet quenching in small systems?
  - R_{AA} and Q_{pA} consistent with unity.
  - But high p_T v_2 similar to PbPb → traditionally understood as jet quenching.
  - Influence of selection bias?
  - Quenching models describing v_2 expect E. loss.
- Non-hydro models describe some measurements, but not all.

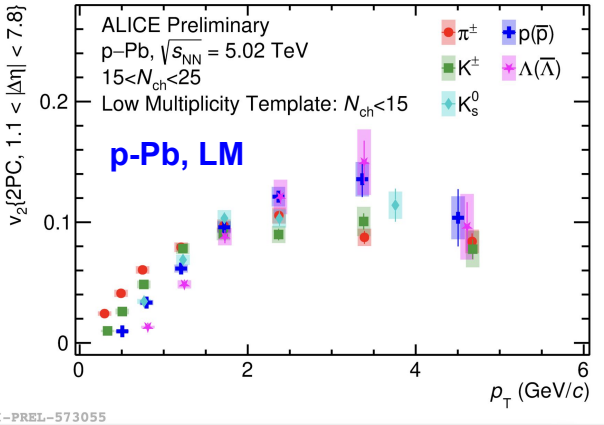
Up for discussion:

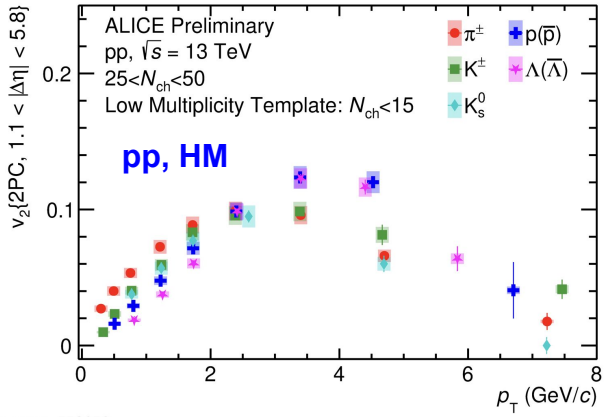
- Is a nonzero v_2 a robust indicator of collective effects?
  - Should we be more careful about considering biases when measuring and interpreting v_2?
  - Or do same physics mechanisms give v_2 in small and large systems?
- Is hydrodynamics applicable in all systems?
  - If it is not hydro in small systems, is it hydro in large systems?
- Question to Angantyr
  - Would it be possible to describe v_2 vs p_T, vs PID?
  - v_2 across centralities and R_{AA} in heavy-ion collisions.
- What to look forward to from Run 3&4 data at the LHC, and at RHIC?
  - High p_T v_2 measurements in pp.
  - New observables?
  - How can OO run help?
  - Can we find the wake in large systems? Validation of hydro.
- What input do we need from theorists?

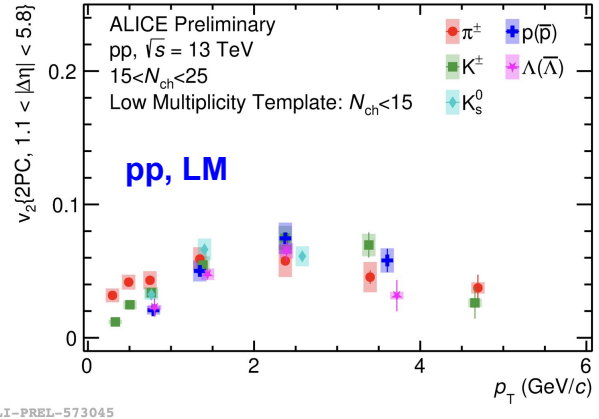
Back Up

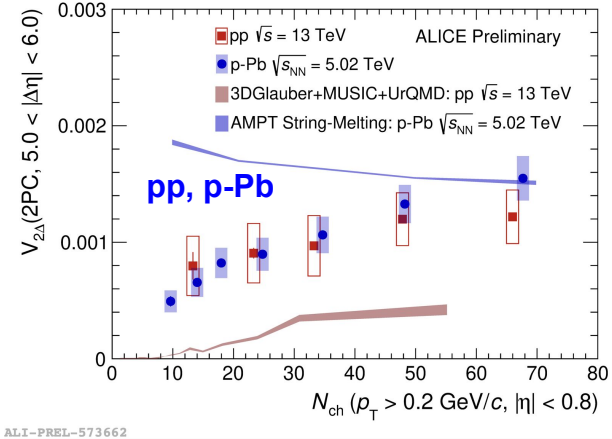
v_2 in p-Pb and pp



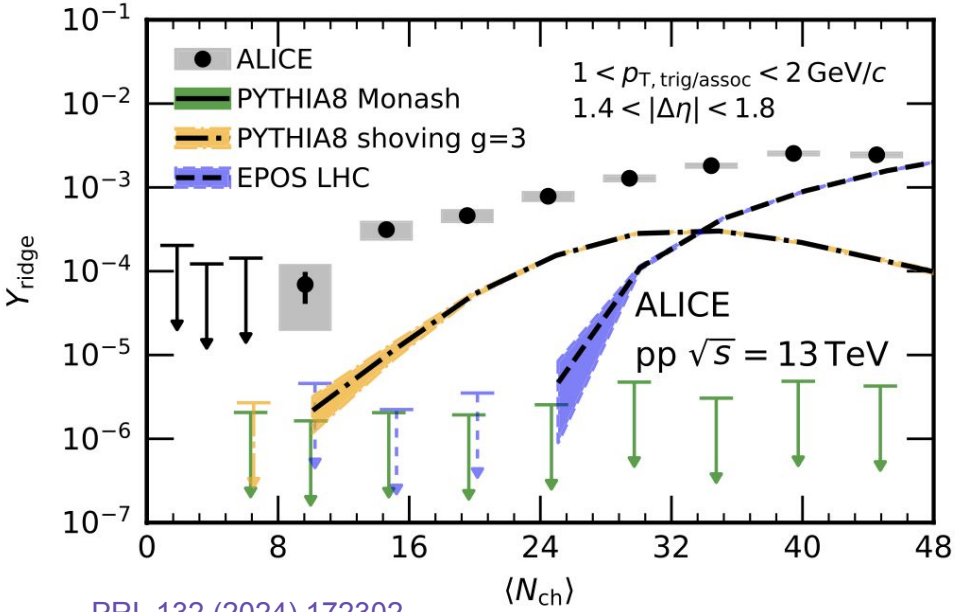




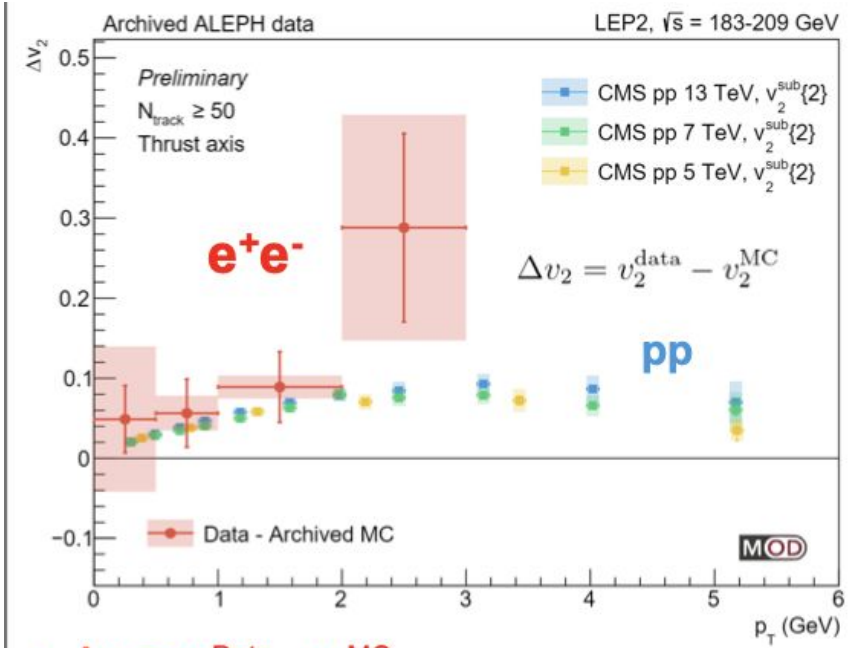




v_2 in very low multiplicity events



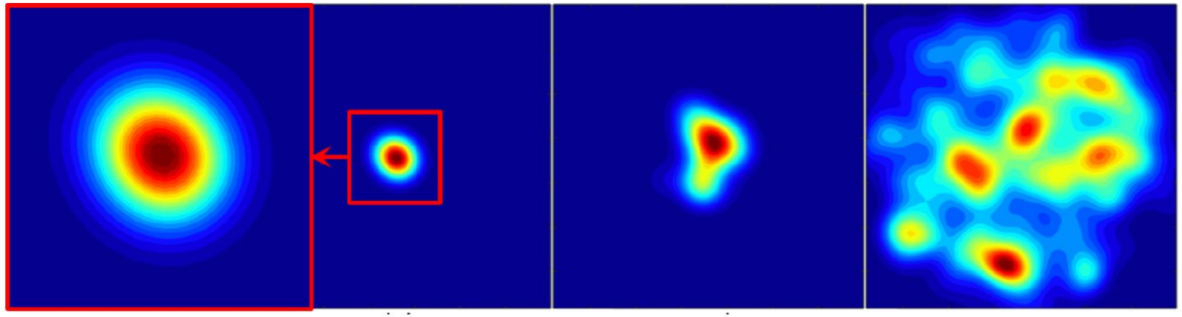
PRL 132 (2024) 172302

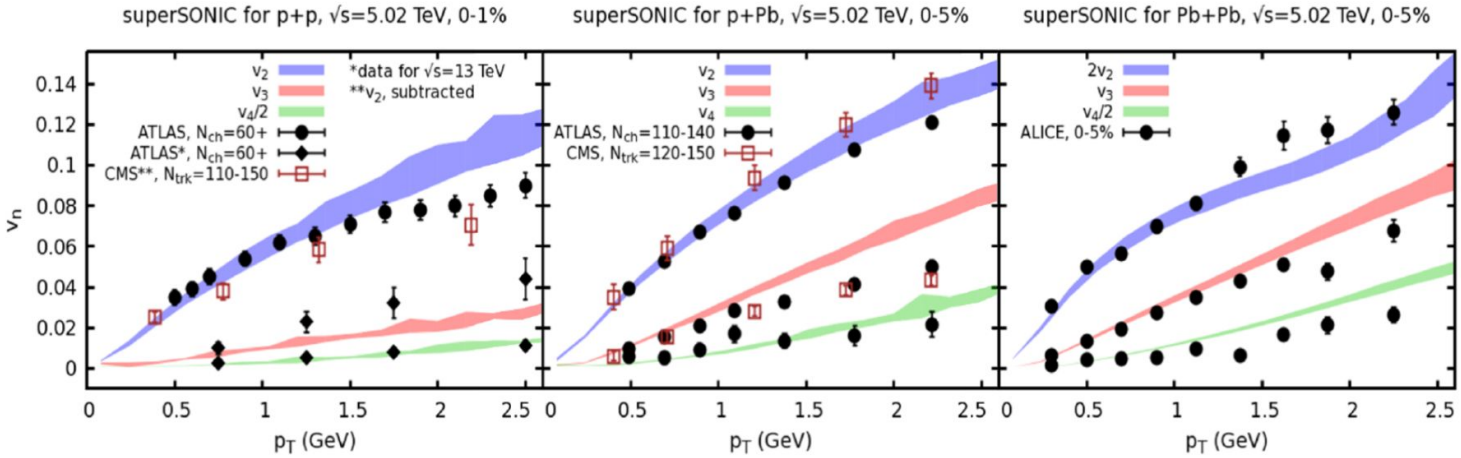


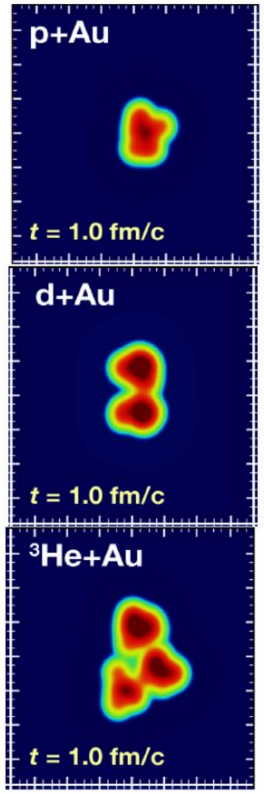
- $\Delta v_2 = v_2^{Data} - v_2^{MC}$
- Similar trend between e^+e^- and pp data

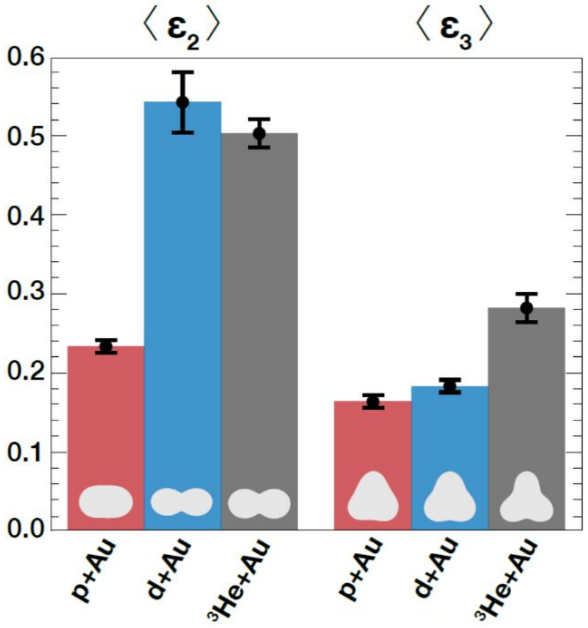
Yen-Jie Lee @ IS2023

“One fluid to rule them all”









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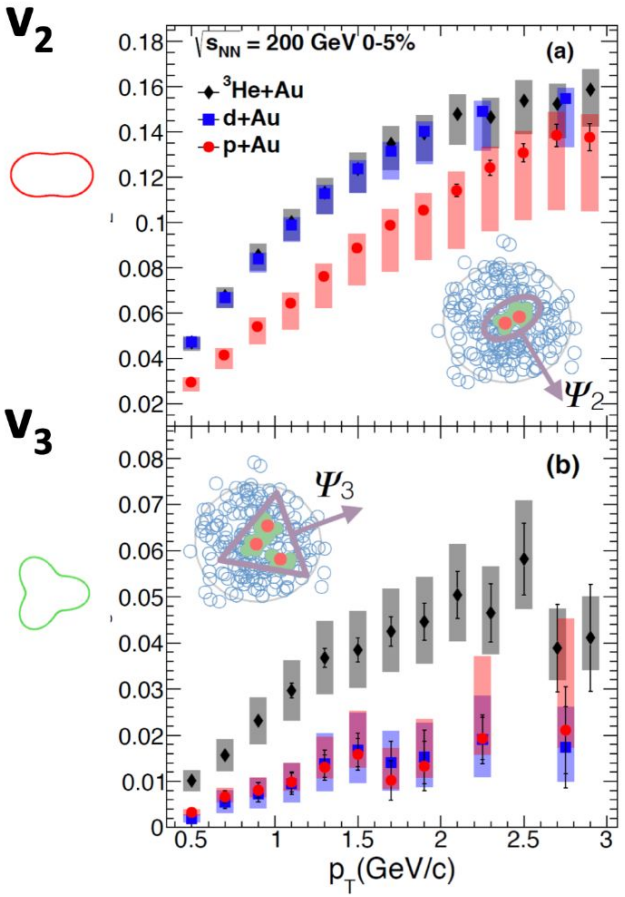
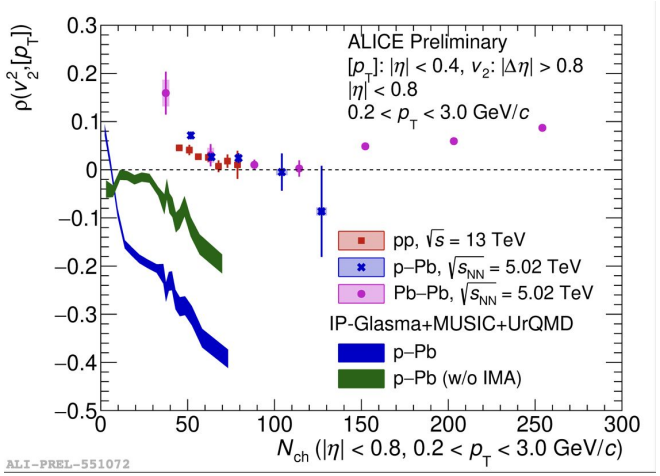
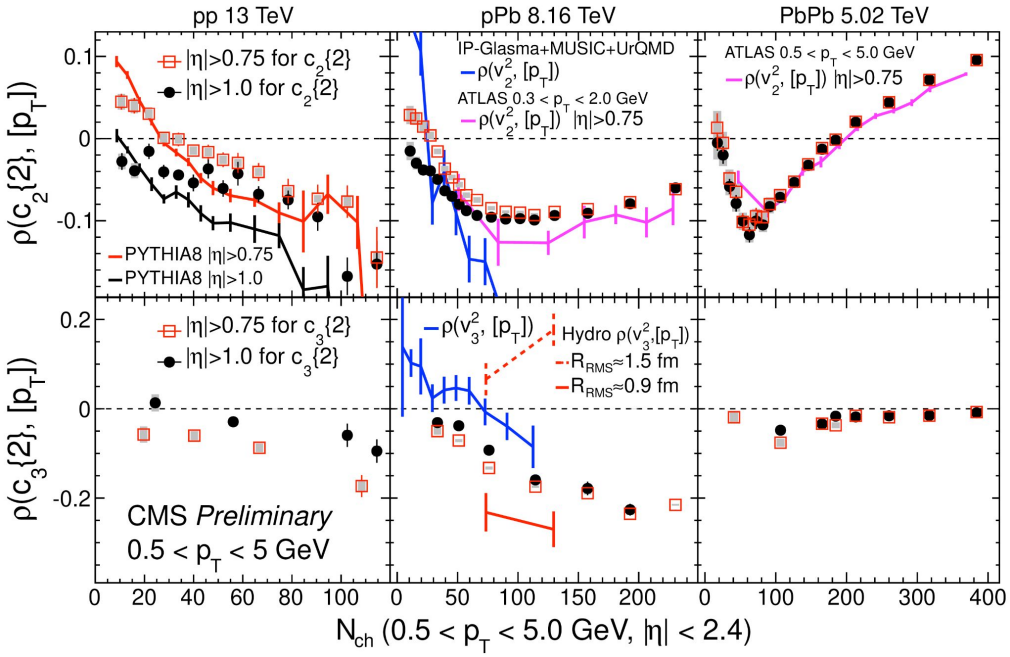
PHENIX collaboration



Even if hydro applies…





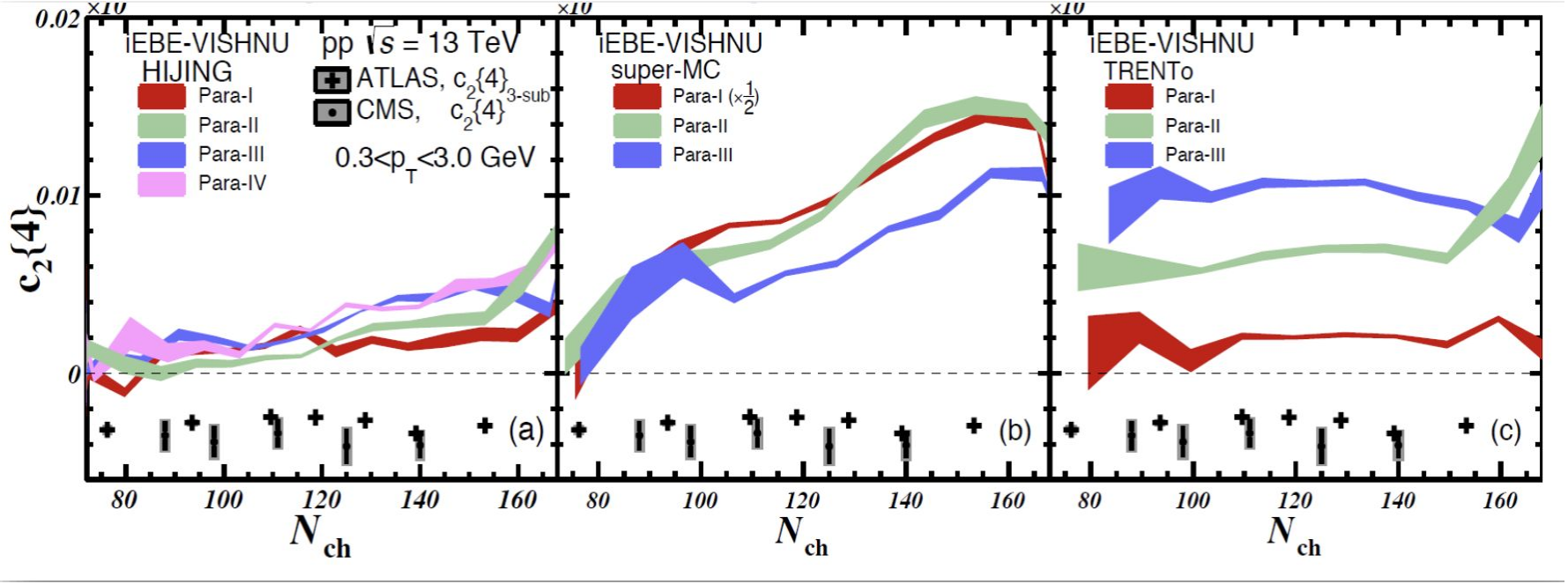
v_2-$\langle p_T \rangle$ correlation

$\langle p_T \rangle$ rises when going from peripheral to central collisions

while v_2 decreases → anti-correlated in a geometrical model.

Challenges geometrical picture?

Even if hydro applies…



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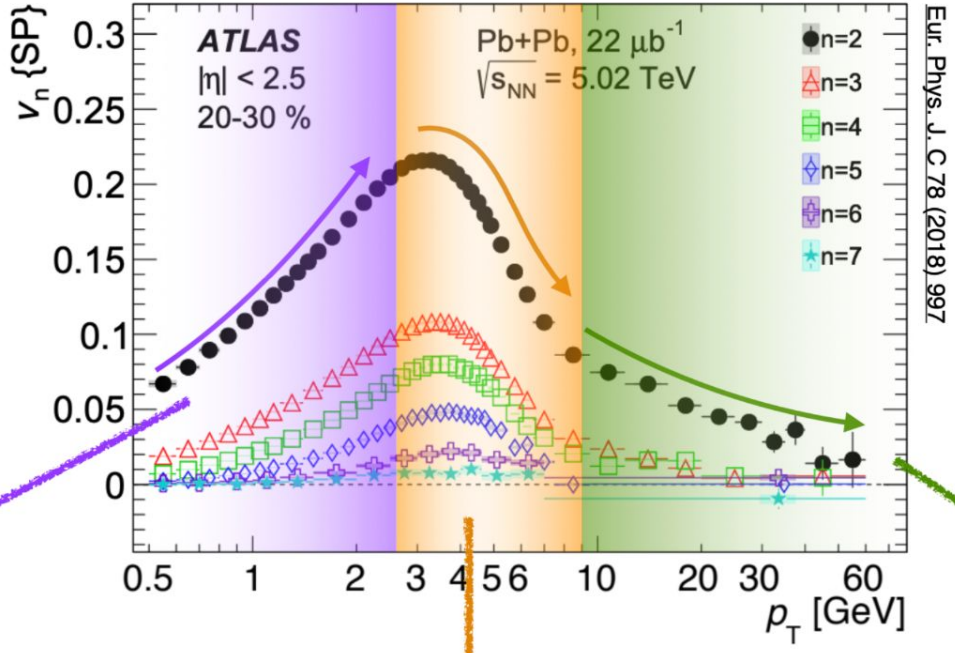
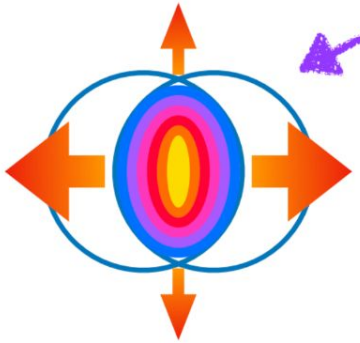
Slide from
K. Hill at QM‘19

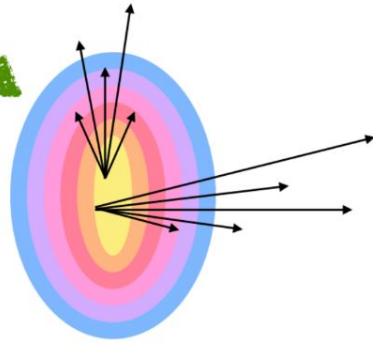


Hydrodynamics



Transition region

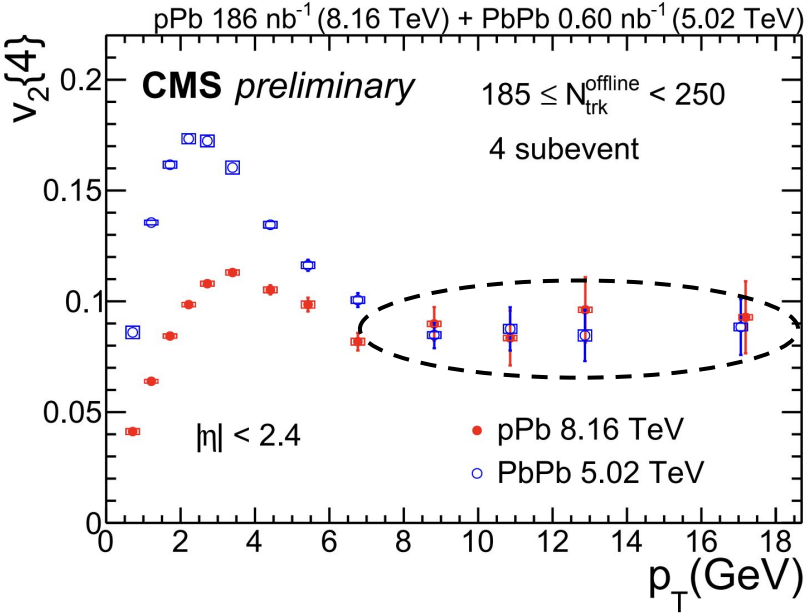
Differential energy loss

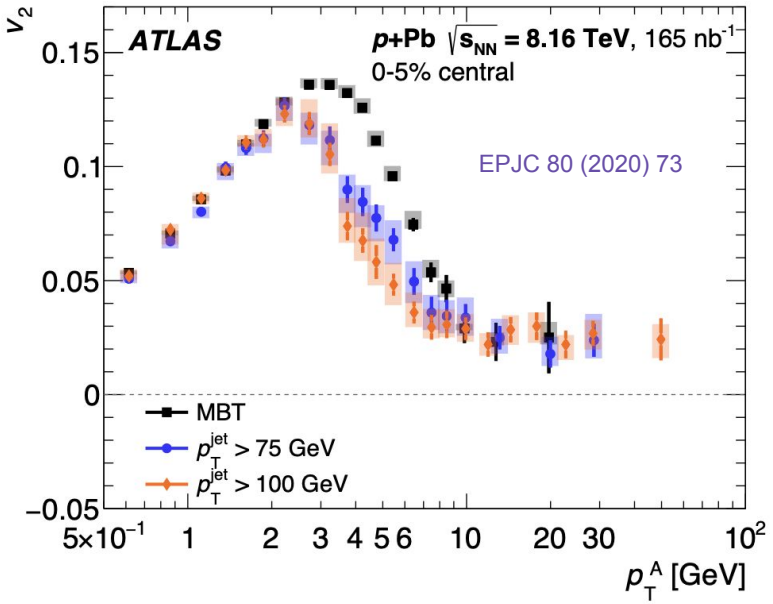


No quenching in small systems

But there is high p_T v_2 in pPb (at pp consistent with zero with uncertainties).

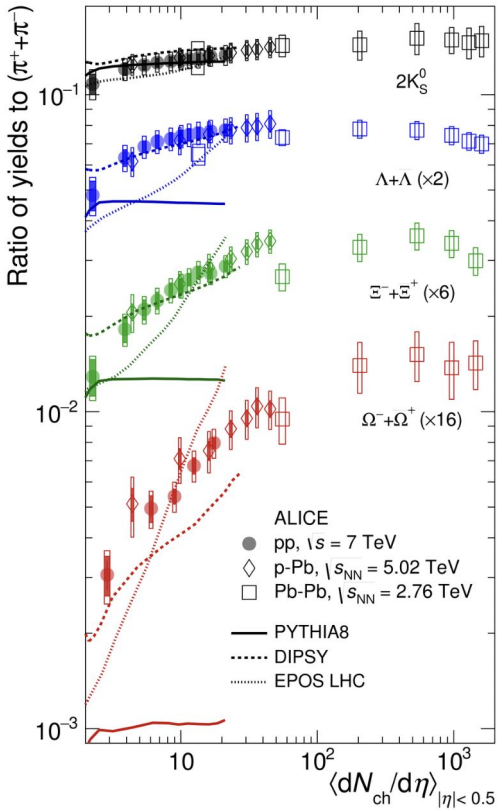
- What is the mechanism? In large systems, it is quenching.
- Can we go higher in p_T both in pPb in pp?



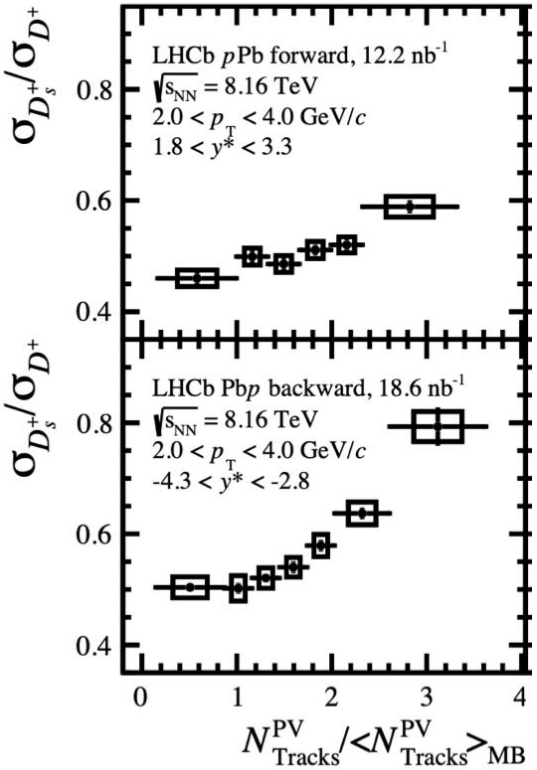


Strangeness enhancement

Nature Physics 13 (2017) 535-539



arXiv:2311.08490



Final State Interactions

- Angantyr model obtains many traditional signatures of QGP, without QGP.
- However, needs final state interactions & spacetime picture (geometry):
  - Interactions among non-perturbative strings, flux tubes.
  - Interactions among hadrons.
  - What about interactions among partons, shower modification (beyond Color Reconn.)?
    - v_2 in high N_{ch} jets could be explained by this partonic rescatterings. (https://arxiv.org/pdf/2401.13137)
- How far can one go without final state partonic interactions (i.e. w/o QGP?)