INTRODUCTION

- Flow-like effects observed in small systems:
  - Long-range, near-side angular correlations
  - Anisotropic flow coefficients with similar magnitude as in large systems
  - Many other similarities observed

  *Song et al. NST 28 (2017) 7, 99*

- “One fluid to rule them all.”

  *Weller et al. PLB 774 (2017) 351-356*

Is that really the case?

- Is there fundamental difference between the experimental flow signals in small and large systems?
- More observables to investigate experimentally!
METHODS

OBSERVABLES

• Flow harmonic coefficients ($v_\eta$):
  • Characterize the degree of anisotropy in the distribution of emitted particles
• Nonlinear flow modes ($v_{m,nk}$, $\lambda_{m,nk}$, $\rho_{m,nk}$):
  • Represent nonlinear response to initial geometry
• Symmetric cumulants (SC(m,n)):
  • Characterize the correlations between different order flow coefficients

TWO- AND THREE-SUBEVENT METHOD

• Particle correlations use subevent methods to suppress nonflow contamination
• Correlate particles in different $\eta$ regions
  e.g. $\ll \cos(n_1 \varphi_1 + n_2 \varphi_2 - n_3 \varphi_3 - n_4 \varphi_4) \gg$

All the observables are calculated with particle correlation method with generic framework.

Bilandzic et al. PRC 89 (2014) 6, 06490

Bhalerao et al. PLB 742 (2015) 94-98

-0.8 < $\eta$ < 0.8
• 0.2 < $p_T$ < 3.0 GeV/c
• Pb—Pb : $\sqrt{s_{NN}}$ = 5.02 TeV
• pp: $\sqrt{s}$ = 13 TeV

Mingrui Zhao for the ALICE collaboration, QM2022
RESULTS (FLOW HARMONIC COEFFICIENTS)

- New measurements:
  - ~3 times more data used in pp $v_4\{2\}$ with better nonflow control
  - Similarities observed across collision systems.
    - The magnitudes of $v_n$ in pp are similar as in Pb—Pb at low multiplicities
    - The $v_2\{2\}$ suggests a multiplicity dependence qualitatively similar to the $v_2\{2\}$ in Pb—Pb collisions

- PYTHIA 8 gives:
  - Negative $c_3\{2\}$ for $N_{ch} > 60$.
  - $v_2\{2\} > v_4\{2\} > v_3\{2\}$, which is not seen in data

Data points can not be trivially described by non-flow model only
- Positive $c_2\{4\}$ for the entire $N_{ch}$ range
- IP-Glasma+MUSIC+UrQMD:
  - Predicts $v_2\{2\} > v_3\{2\} > v_4\{2\}$ and real-valued $v_2\{4\}$
  - Underestimates the ALICE measurements

Mingrui Zhao for the ALICE collaboration, QM2022
RESULTS (SYMMETRIC CUMULANTS)

- Hint of negative SC(3,2) (2.1σ significance) and positive SC(4,2) (1.9σ significance) in pp collisions, having same sign as Pb—Pb collisions.

- Deviations between different 3-subevent methods are not sizable in Pb—Pb system.
- In pp collisions, 3,2|-2|-3 (and symmetric configuration) contain least nonflow contamination (validated with PYTHIA 8 simulation).
- Configurations in 3-subevent method matter in pp collisions!
RESULTS (NONLINEAR HYDRODYNAMIC FLOW)

- Similarities observed across collision systems
  - Indication for a smooth transition between peripheral Pb—Pb and high multiplicity pp collisions for $v_{4,22}$, $v_{5,32}$ and $\chi_{4,22}, \chi_{5,32}$ (flow fluctuations dominant region)
  - In pp collisions, $\rho_{4,22}$ shows a decreasing trend, and there is indication of smaller value of $\rho_{5,32}$ in higher multiplicity region. The trends indicate subnucleon structure (hotspots) of proton

- In pp collisions, hydrodynamic model largely underestimates the $v_{4,22}$, $v_{5,32}$ and $\rho_{4,22}$, $\rho_{5,32}$
- PYTHIA 8 fails to describe the multiplicity dependence of $\rho_{4,22}$
  - It is surprising to see that PYTHIA 8 describe the $v_{4,22}$ very well. Is this by accident or not?