Measurement of flow harmonics, nonlinear flow response and symmetric cumulants in large and small systems with ALICE

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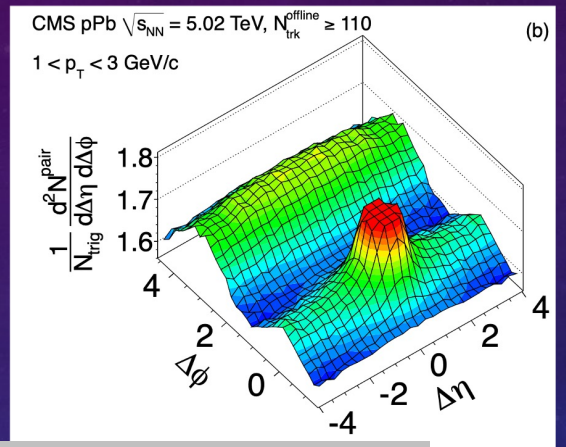
Quark Matter, Krakow, Poland, 6 April 2022

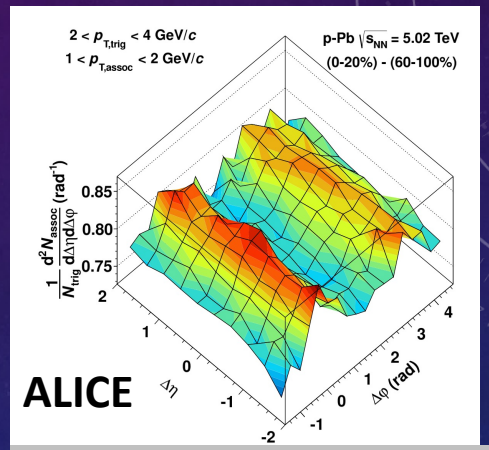
INTRODUCTION

- 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



CMS, PLB 718 (2013) 795

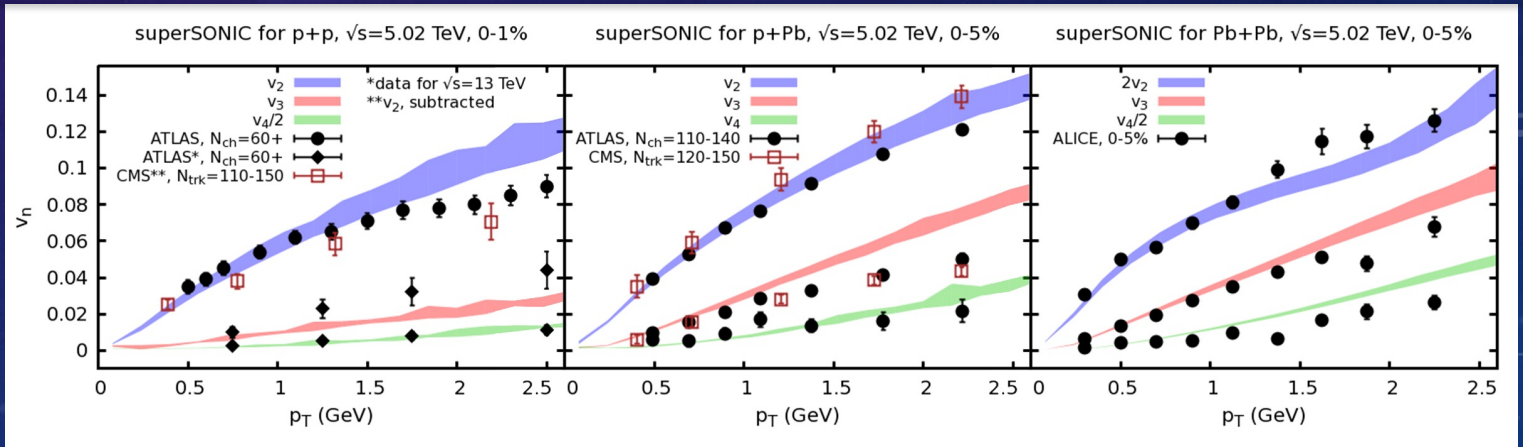


ALICE, PLB 719 (2013) 29-41

- **"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

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

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

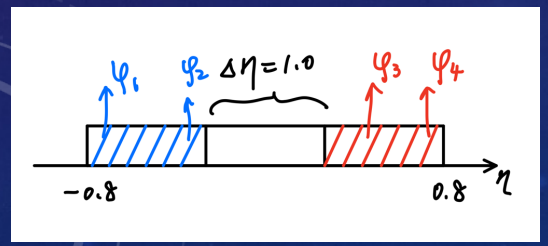
OBSERVABLES

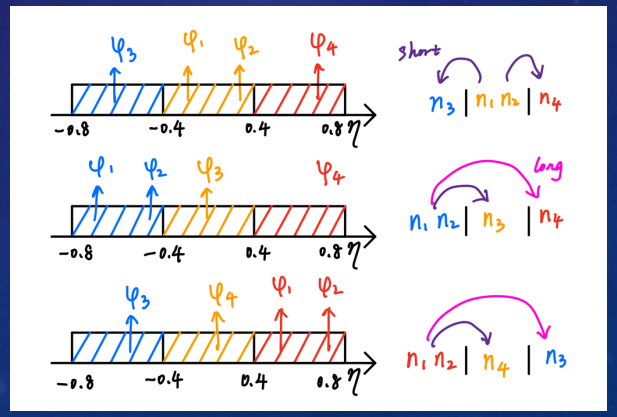
- Flow harmonic coefficients (v_n):
  - Characterize the degree of anisotropy in the distribution of emitted particles
- Nonlinear flow modes ($v_{m,nk}, \chi_{m,nk}, \rho_{m,nk}$): Bhalerao et al. PLB 742 (2015) 94-98
  - Represent nonlinear response to initial geometry
- Symmetric cumulants (SC(m,n)): Bilandzic et al. PRC 89 (2014) 6, 06490
  - Characterize the correlations between different order flow coefficients

TWO- AND THREE-SUBEVENT METHOD

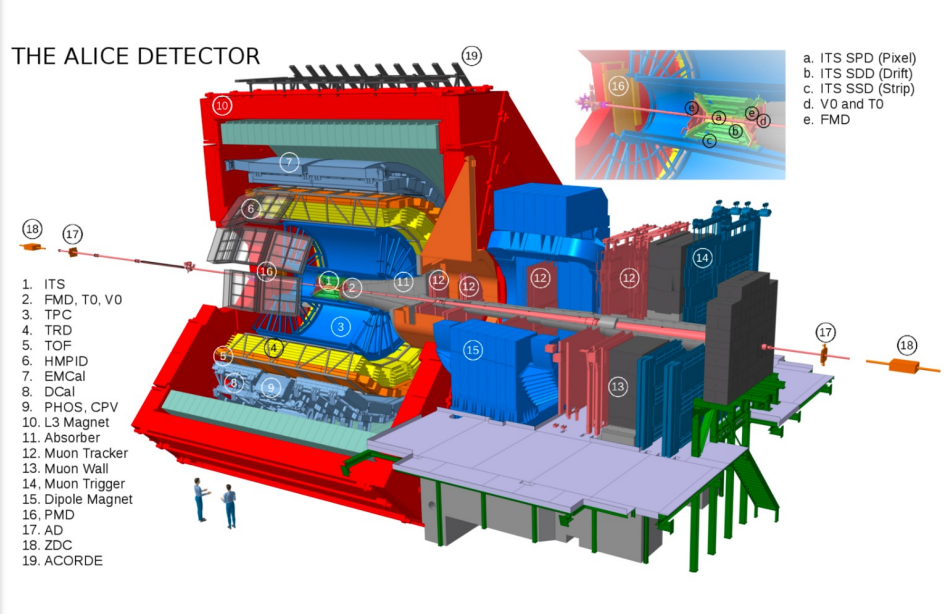
- Particle correlations use subevent methods to suppress nonflow contamination
- Correlate particles in different η regions

e.g. $\ll \cos(n_1\varphi_1 + n_2\varphi_2 - n_3\varphi_3 - n_4\varphi_4) \gg$



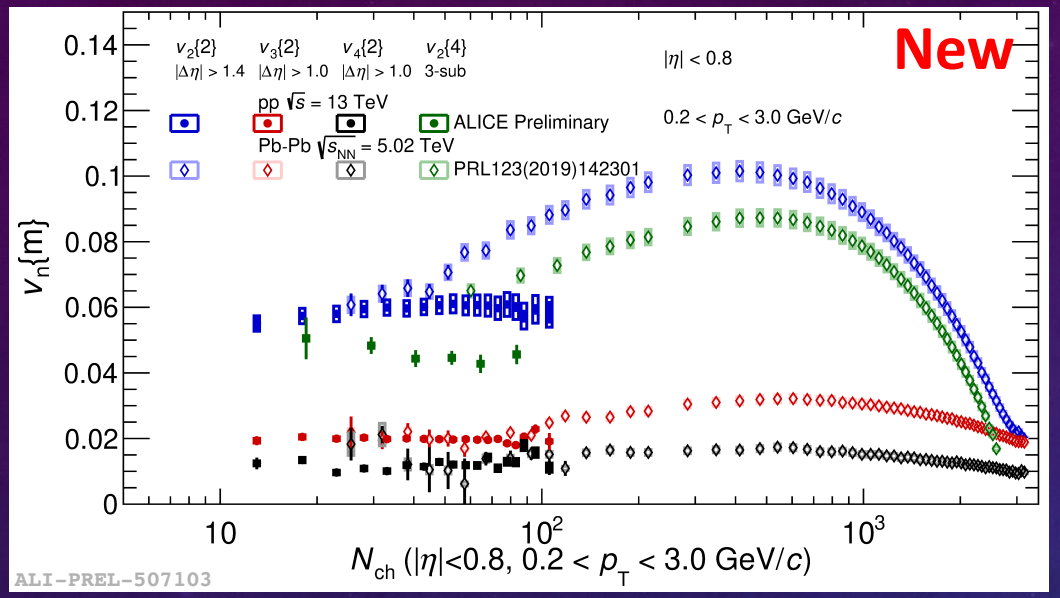


ALICE DETECTOR

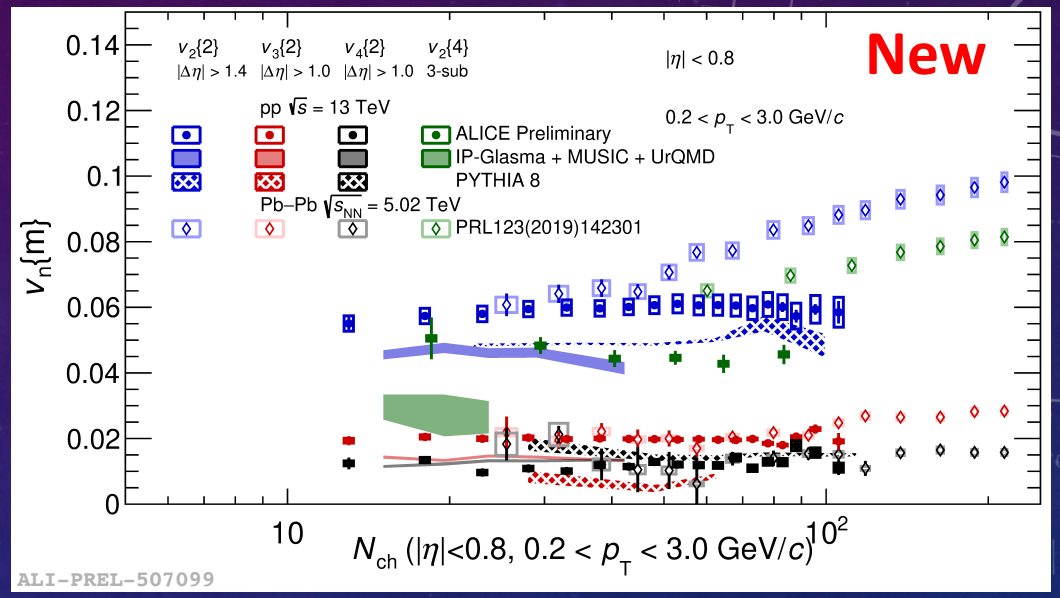


- $-0.8 < \eta < 0.8$
- $0.2 < p_T < 3.0$ GeV/c
- Pb—Pb : $\sqrt{s_{NN}}$ = 5.02 TeV
- pp: $\sqrt{s}$ = 13 TeV

RESULTS (FLOW HARMONIC COEFFICIENTS)



Zoom

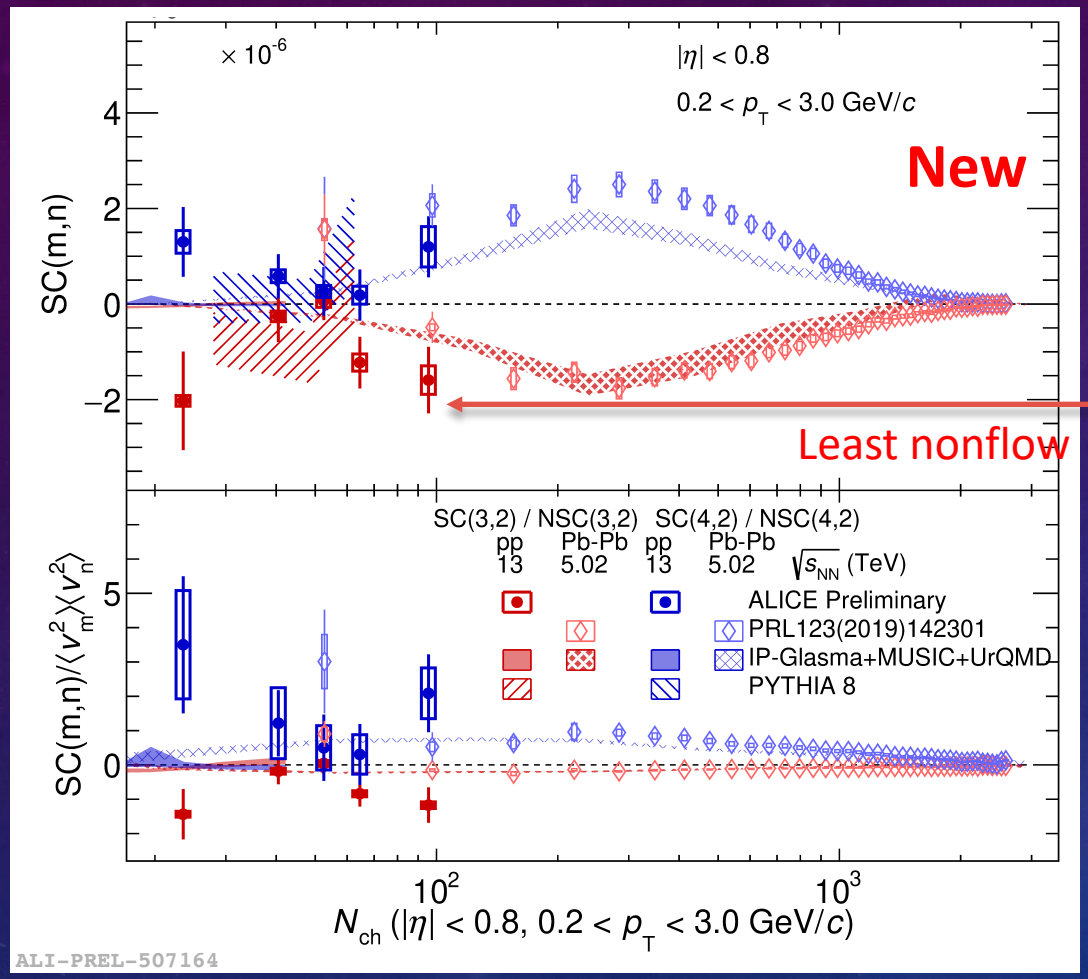


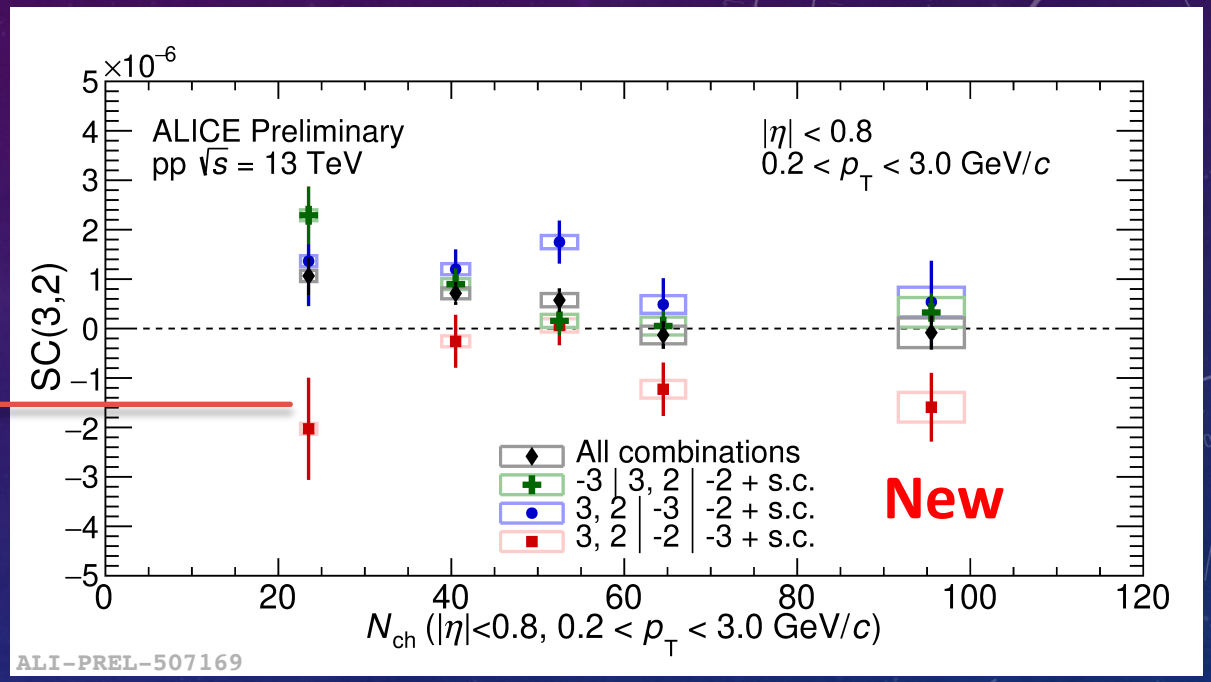
- New measurements:
  - ~3 times more data used in pp $v_4\{2\}$ with better nonflow control
- Similarities observed across collision systems.
  - The magnitudes of v_n in pp are similar as in Pb—Pb at low multiplicities
  - The $v_2\{2\}$ suggests a multiplicity dependence qualitatively similar to the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

- 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

RESULTS (SYMMETRIC CUMULANTS)



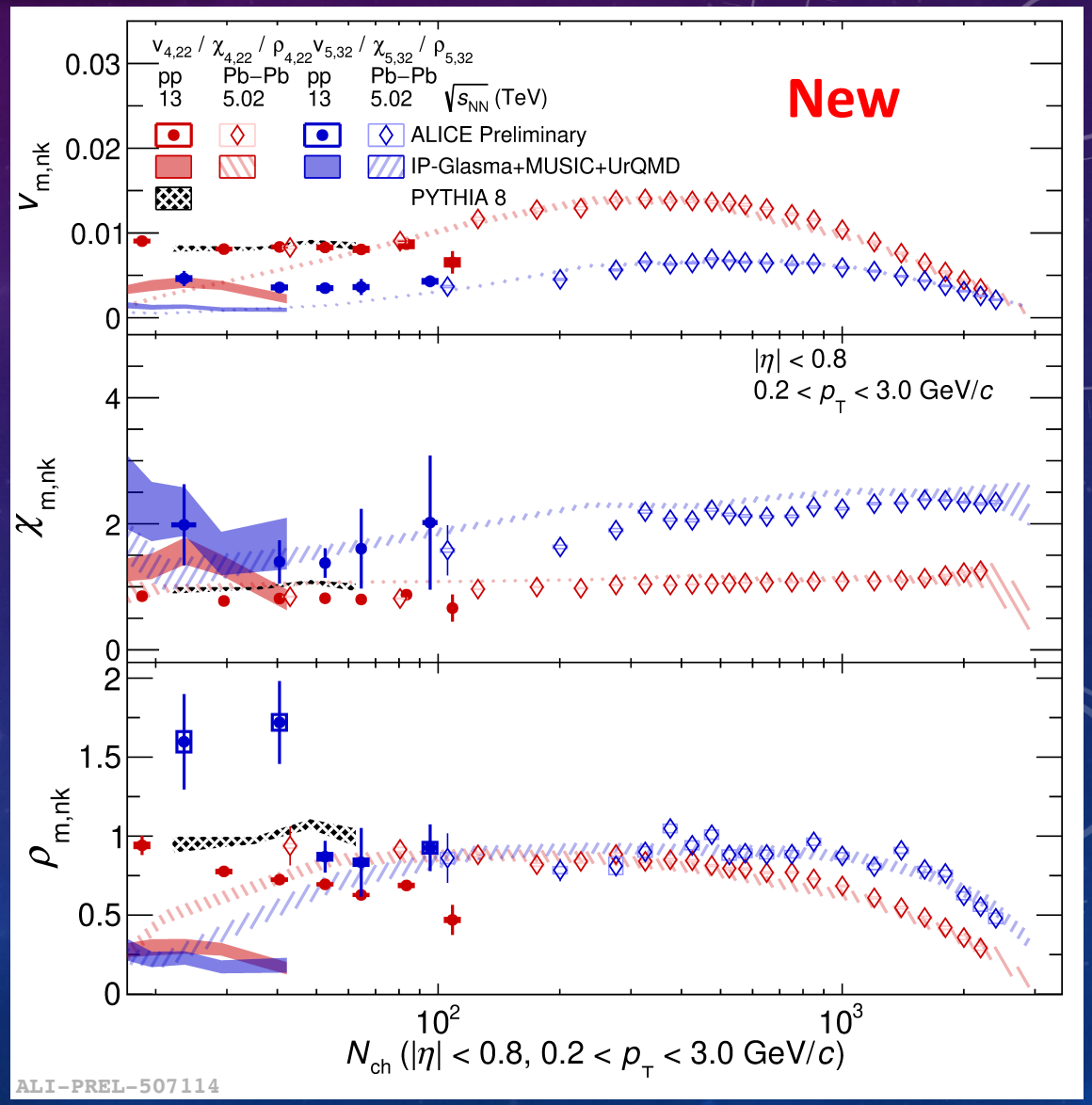


Hint of negative SC(3,2) (2.1σ significance) and positive SC(4,2) (1.9σ significance) in pp collisions, having same sign as Pb—Pb collisions

- 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?



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