Measurement of Flow Harmonics, Nonlinear Flow Response and Symmetric Cumulants in Large and Small systems with ALICE

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For ALICE Collaboration

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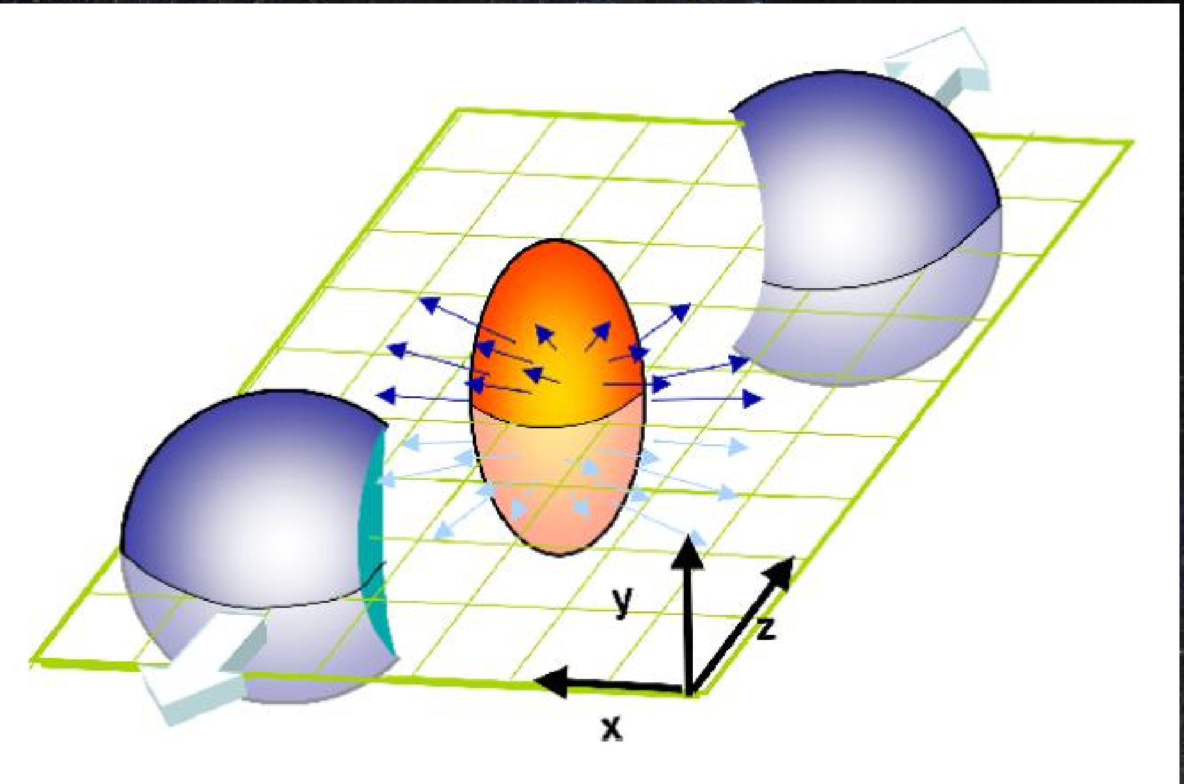
CLHCP

Flow measurement in heavy-ion collision



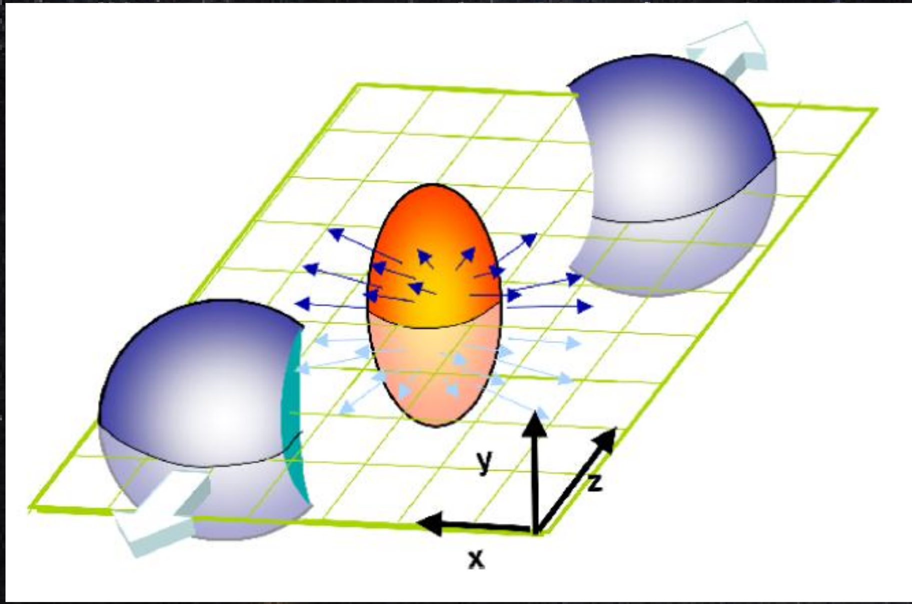
Previous studies showed that
QGP(Quark Gluon Plasma) is formed in the heavy-ion collision
but we can't measure it directly

In hydrodynamic picture, QGP can be described by the nearly-ideal fluid

initial state → expansion → (cool down) final state (particles)

Spatial anisotropies in the initial conditions of the fluid expansion result in final-state **anisotropies in the azimuthal particle spectra**

Flow measurement in heavy-ion collision



Anisotropy in distributions of final-state particles can be measured by Fourier expansion

$$\frac{\mathrm{d}N}{\mathrm{d}\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_n)$$

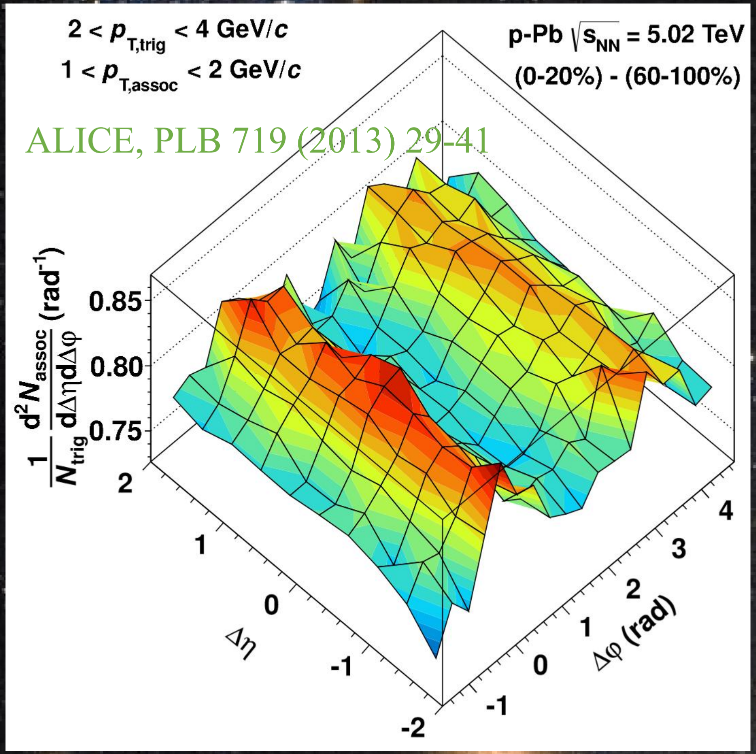
Anisotropic flow coefficients v_n, its correlation and non-linear response to the initial geometry provide detailed information on the initial conditions and transport properties of the created medium

Flow observables could also be measured using multi-particle correlation techiques

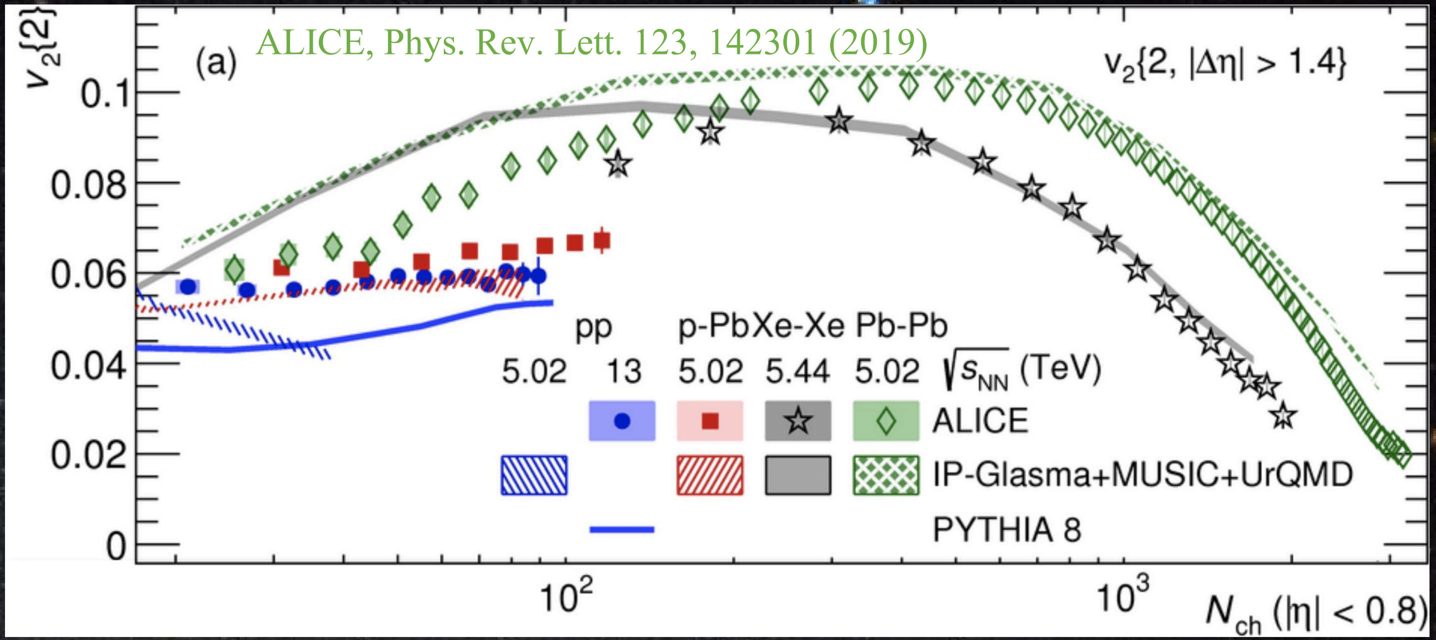
arXiv: 2005.07974

Flow in small system

Double ridge, a sign of collectivity, observed in both pp and p-Pb collisions



- Sizeable flow observed across all collision systems
- Together with multiparticle long-range correlations confirmed collectivity in small systems



Is there fundamental difference between the experimental flow signals in small and large systems?

To achieve this, we want to investigate all possible observables:
$v_n\{2\}$, $v_n\{4\}$, $v_{4,22}$, $v_{5,32}$, $\mathbf{SC(3,2)}$, $\mathbf{SC(4,2)}$, ... in large and small systems, to see flow behaves same or different in large and small system.

Observables

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos n(\varphi - \Psi_n)$$

Flow harmonic coefficients (v_n)**:**

- Characterize the degree of anisotropy in the distribution of emitted particles

Nonlinear flow modes($v_{m,nk}$, $\chi_{m,nk}$, $\rho_{m,nk}$**):**

- Represent nonlinear response to initial geometry

Symmetric cumulants (SC(m,n))**:**

- Characterize the correlations between different order flow coefficients

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

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

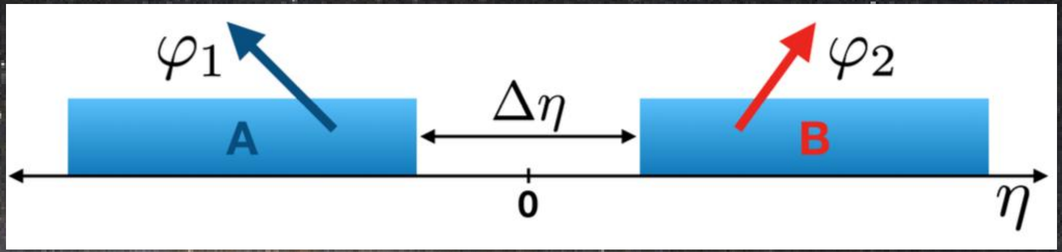
All the observables are calculated using **generic framework**

e.g. $v_n = \langle\langle cos(n\varphi)\rangle\rangle$

the first bracket means average of tracks, the outer bracket means average of events

2- and 3- subevent method

Correlate particles in different η regions to **suppress nonflow contamination**



$$\eta = -ln[tan\frac{\theta}{2}]$$

e.g. $v_n = \langle\langle cos(n(\varphi_1 - \varphi_2))\rangle\rangle$

Observables

2-particle flow haromic

$$v_n\{2\} = \sqrt{\langle\langle 2\rangle\rangle_{n,-n}} = \sqrt{c_n\{2\}}$$

4-particle v_2

$$v_2\{4\} = \sqrt[4]{2\langle\langle 2\rangle\rangle_{2,-2}^2 - \langle\langle 4\rangle\rangle_{2,2,-2,-2}} = \sqrt[4]{-c_2\{4\}}$$

Nonlinear mode (example in n=4)

$$v_{4,22}^{A} = \frac{\langle\langle 3\rangle\rangle_{4,-2,-2}}{\sqrt{\langle\langle 4\rangle\rangle_{2,2,-2,-2}}}$$

$$\rho_{4,22}^{A} = \frac{\langle\langle 3\rangle\rangle_{4,-2,-2}}{\sqrt{\langle\langle 4\rangle\rangle_{2,2,-2,-2}}\sqrt{\langle\langle 2\rangle\rangle_{4,-4}}}$$

$$\chi_{4,22}^{A} = \frac{\langle\langle 3\rangle\rangle_{4,-2,-2}}{\langle\langle 4\rangle\rangle_{2,2,-2,-2}}$$

Symmetric Cumulants and Normalized SC

$$SC(m,n) = \langle\langle 4\rangle\rangle_{m,n,-m,-n} - \langle\langle 2\rangle\rangle_{m,-m}\langle\langle 2\rangle\rangle_{n,-n}$$

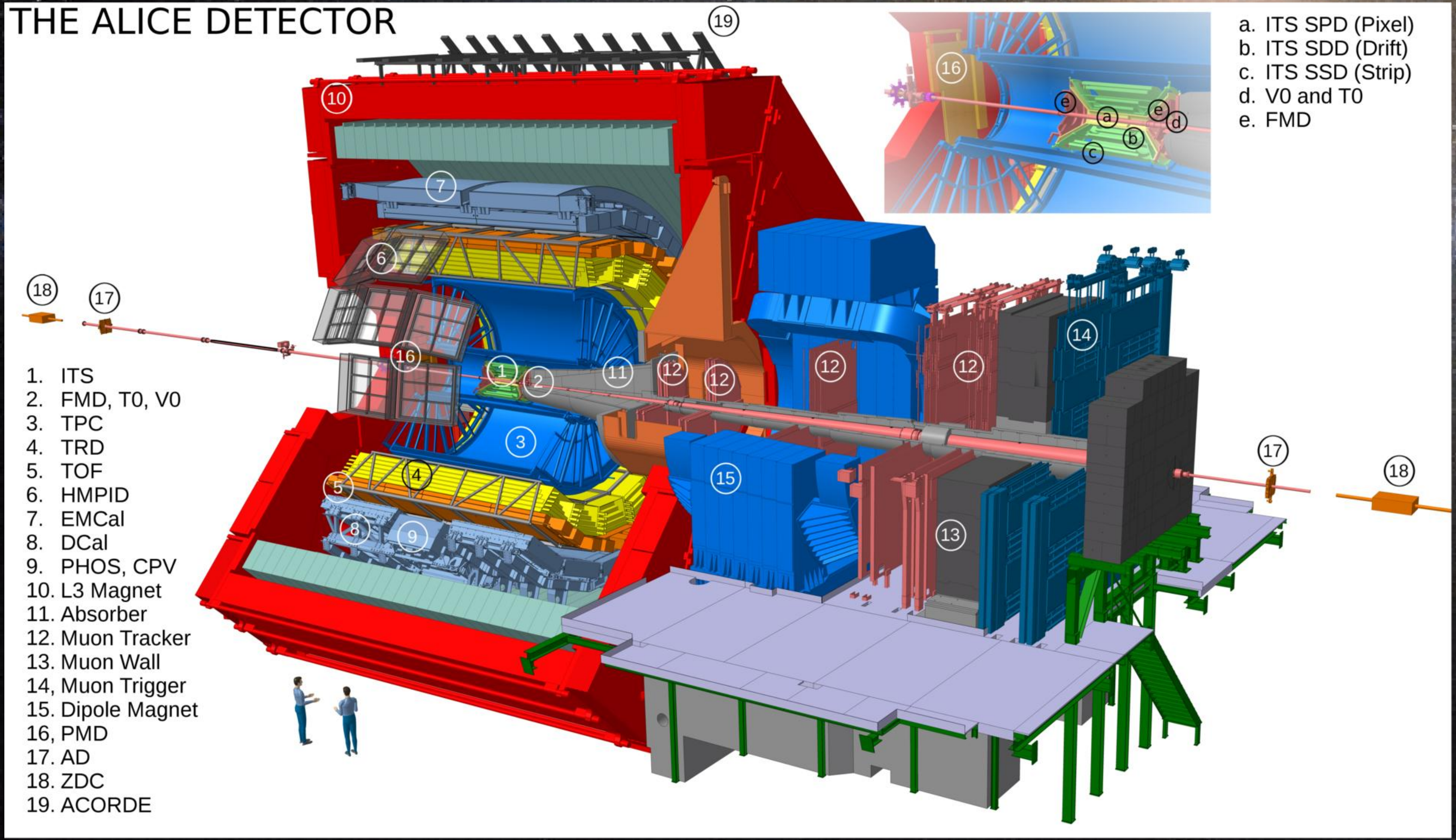
$$NSC(m,n) = \frac{\langle\langle 4\rangle\rangle_{m,n,-m,-n} - \langle\langle 2\rangle\rangle_{m,-m}\langle\langle 2\rangle\rangle_{n,-n}}{\langle\langle 2\rangle\rangle_{m,-m}\langle\langle 2\rangle\rangle_{n,-n}}$$

ALICE detector — A Large Ion Collider Experiment

1. Inner Tracking System (ITS)
- Tracking and triggering

2d. V0 detector
- Triggering and event multiplicity determination

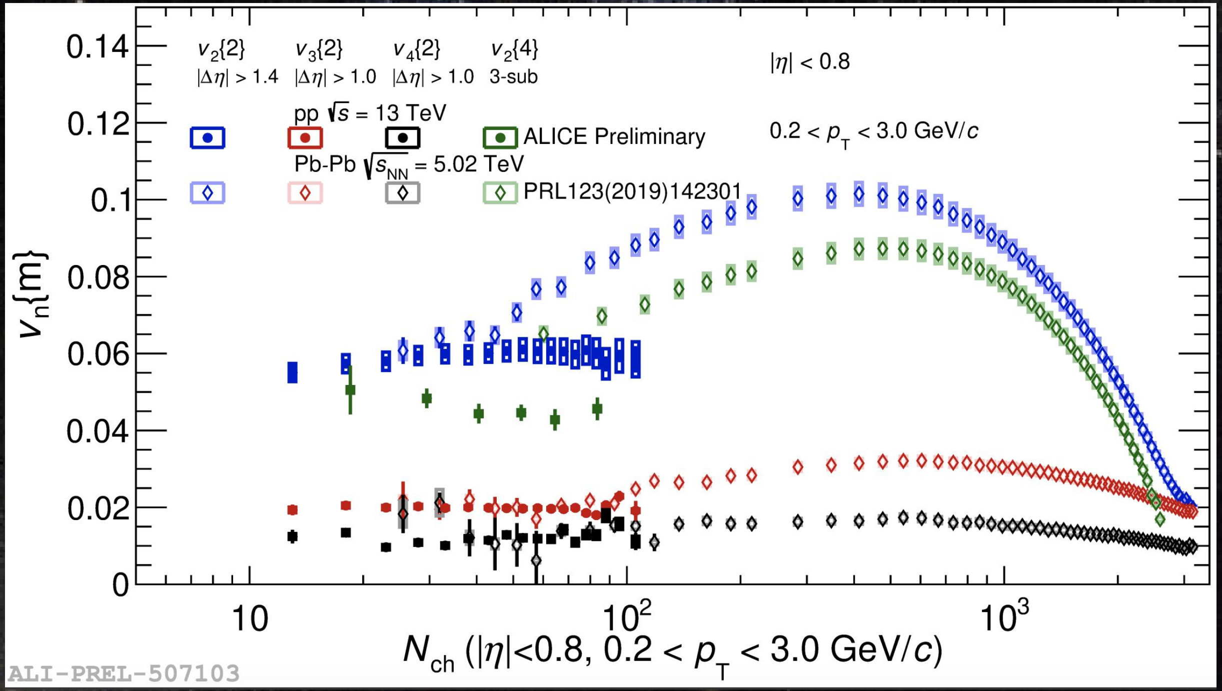
3. Time Projection Chamber (TPC)
- Tracking

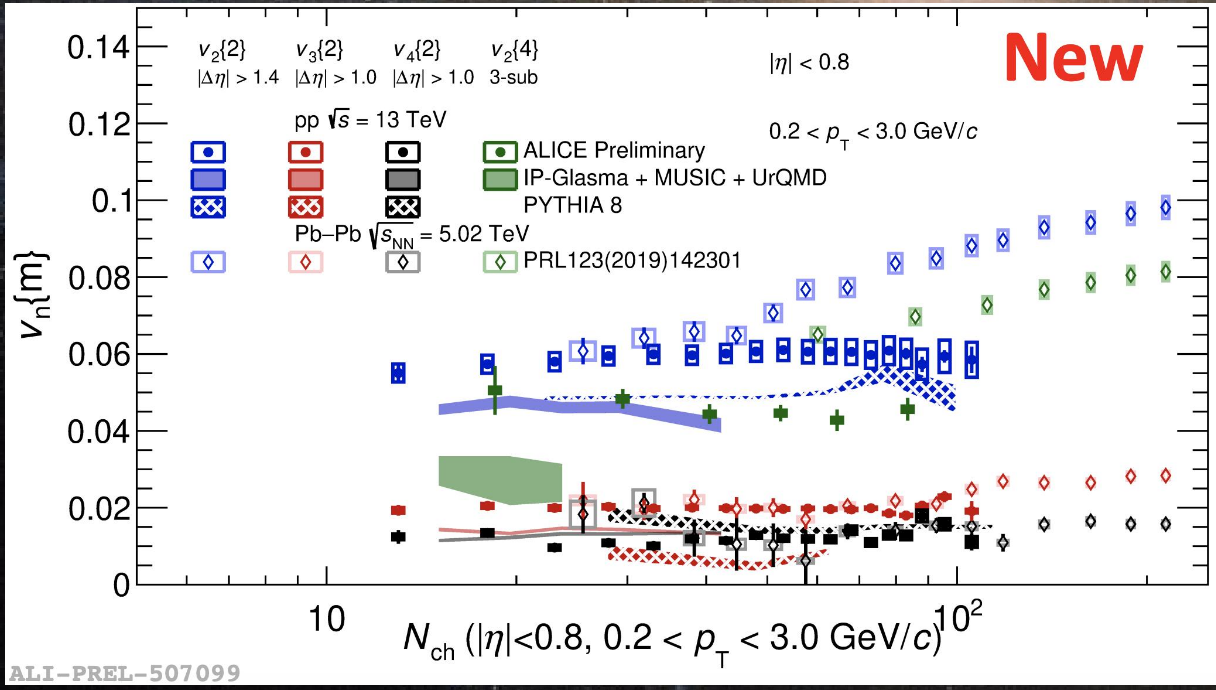


Mainly we calculate the **TPC-TPC** particle correlation
will investigate the **TPC-FMD** correlation (2e. Forward Multiplicity Detector)
in the future

Results

Zoom in





New measurements:

- about 3 times data used in pp v4{2} with better nonflow control

Similarities observed across collision systems

- The magnitudes of v_n in pp are similar as in PbPb at low multiplicities
- The $v_2\{2\}$ suggests a multiplicity dependence qualitatively similar to the $v_2\{2\}$ in Pb—Pb collisons

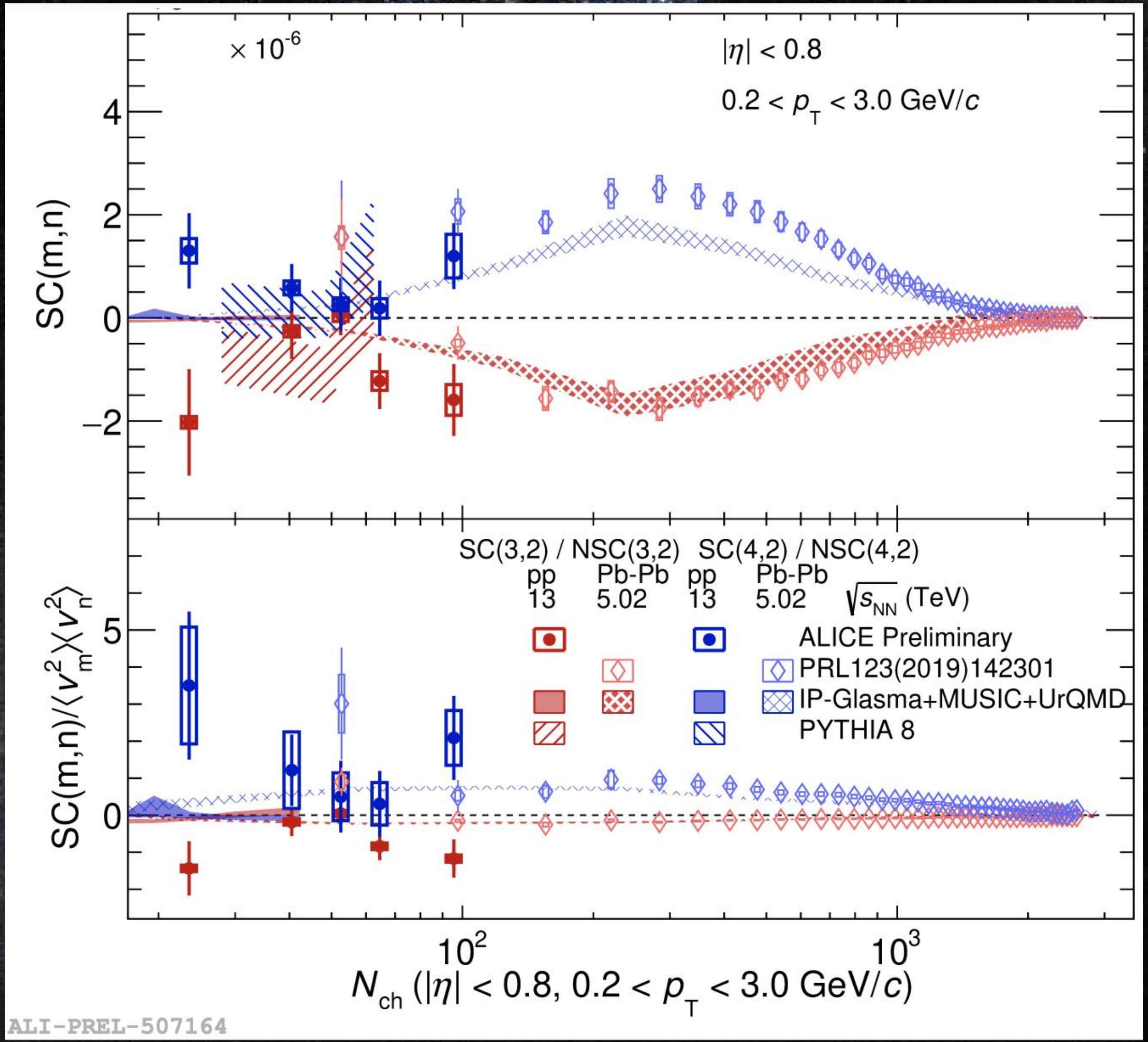
PYTHIA 8 model show:

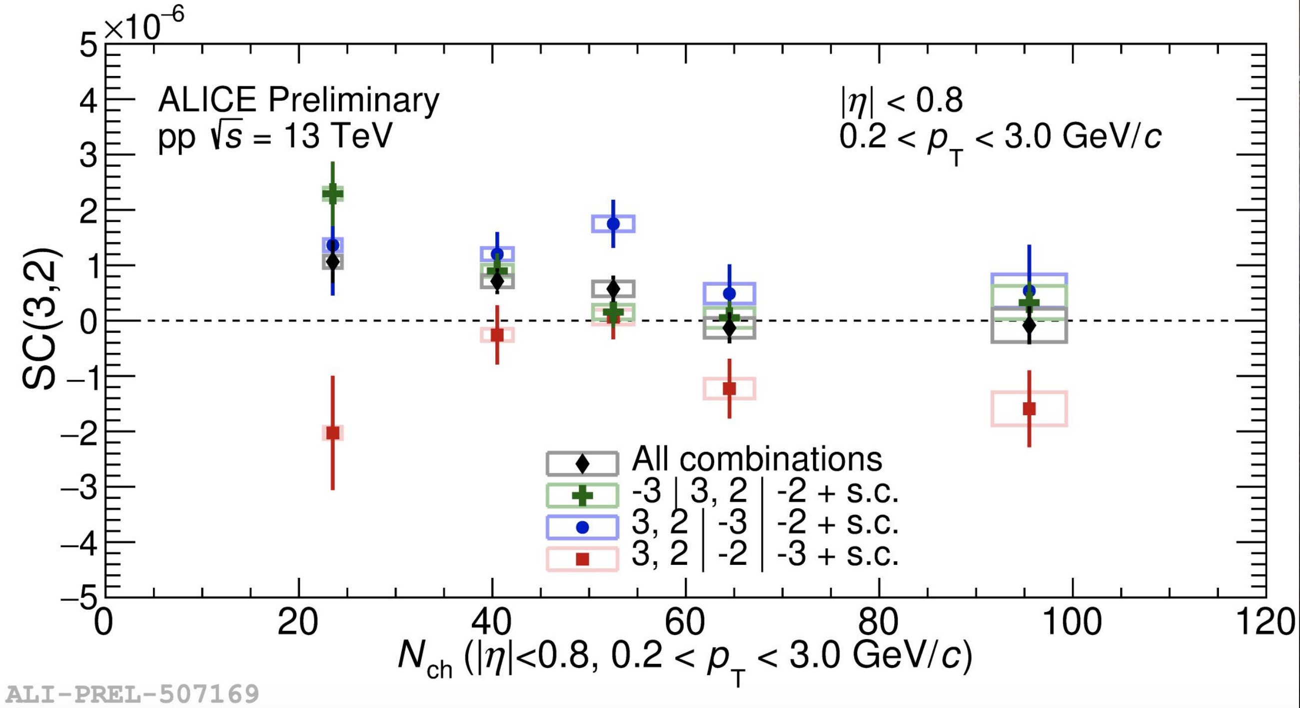
- Negative c3{2} for Nch>60
- v2{2}>v4{2}>v3{2} which is not seen in data. It means data points can not be trivially described by non-flow model only

IP-Glasma+MUSIC+UrQMD model give:

- v2{2}>v3{2}>v4{2}
- underestimate the ALICE measurement

Results

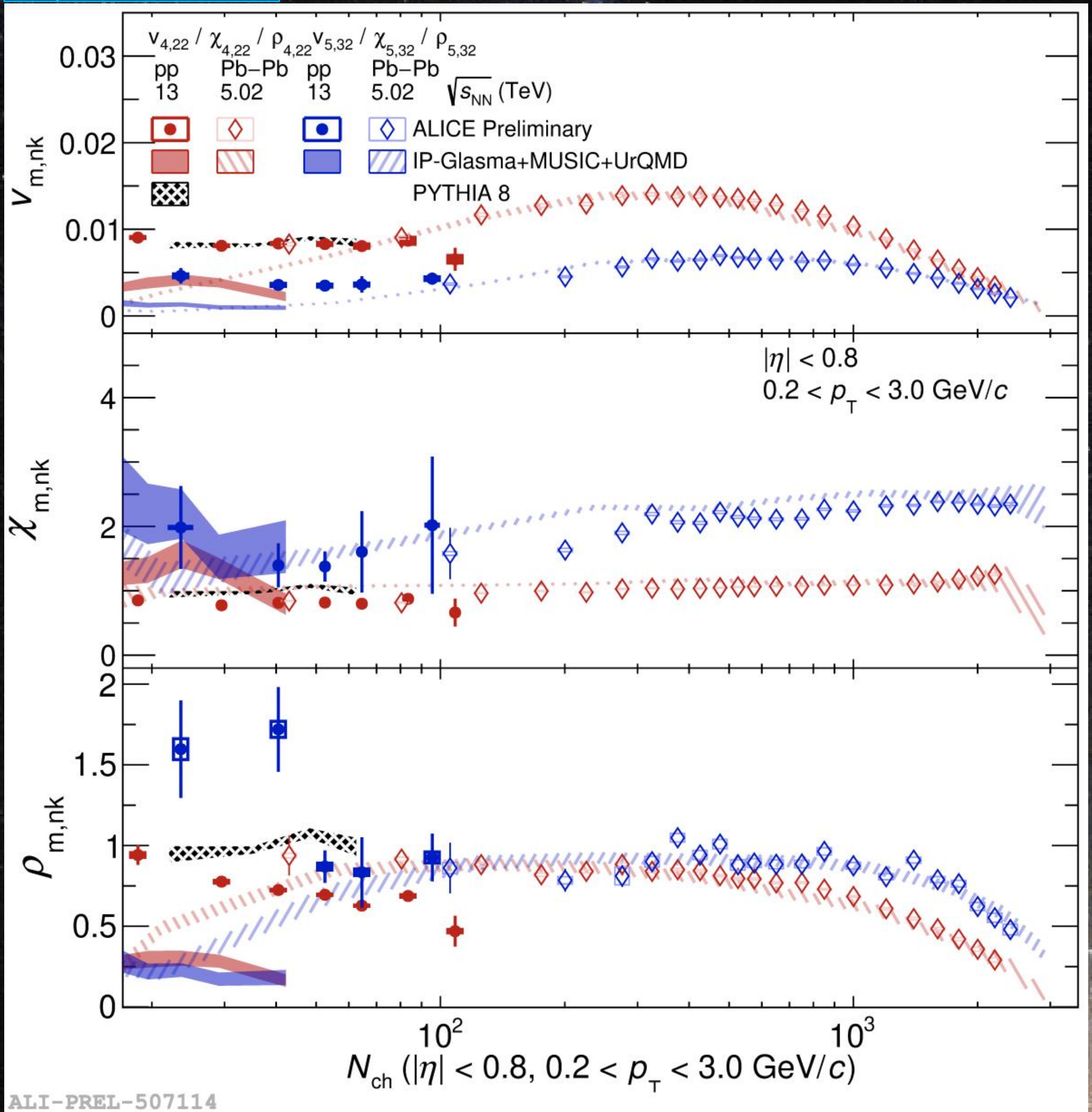




Hint of negative SC(3,2) (2.1σ significance) and positive SC(4,2) (1.9 σ significance) in pp collisions, having same sign as Pb—Pb collisions and PYTHIA8 simulation

- In pp collisions, 3,2|-2|-3 contain least nonflow contamination(validated with PYTHIA 8 simulation) ,while deviation between different 3-subevent methods are not significant in PbPb
- It means that the configurations in 3-subevent matter in pp collisions!

Results



- Similarities observed across collision systems
  - ❖ Indicate a smooth transition between peripheral PbPb and high multiplicity pp collisions for $v_{4,22}, v_{5,32}$ and $\chi_{4,22}, \chi_{5,32}$
  - ❖ In pp collisions, $\rho_{4,22}$ shows a decreasing trend, which indicate the subnucleon structure of proton

- In pp collisions, hydrodynamic model largely **underestimates** $v_{4,22}, v_{5,32}, \rho_{4,22}, \rho_{5,32}$

- PYTHIA 8 fails to describe the multiplicity dependence of $\rho_{4,22}$, **while describe $v_{4,22}$ well**

Summary

- Measurement of flow harmonics, nonlinear flow modes and symmetric cumulants is presented
  - ❖ In pp, flow coefficients and symmetric cumulants studies are updated with much more data. Nonlinear flow in pp is studied for the first time
  - ❖ In PbPb, multiplicity dependence of nonlinear is first investigated.

- The study will help to build coherent picture of flow across system and help us to pin down the origin of flow in small collision systems

END

Thank you for listening!