Anisotropic Flow Measurements in Pb-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV by ALICE

Fabian Ng
for the ALICE Collaboration
Department of Physics

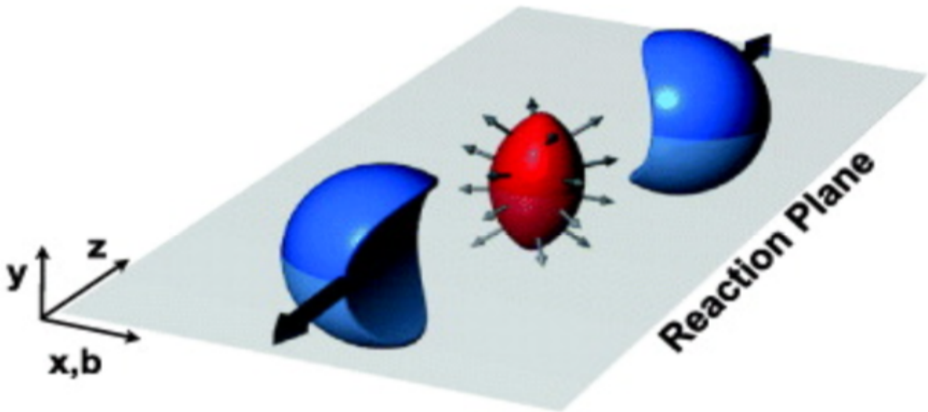
Date: Jan 9th, 2017
33rd Winter Workshop on Nuclear Dynamics

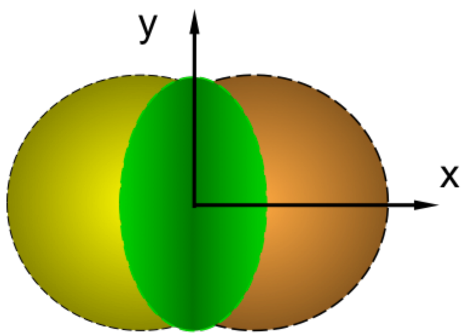
UNIVERSITY of HOUSTON
COLLEGE of NATURAL SCIENCES & MATHEMATICS

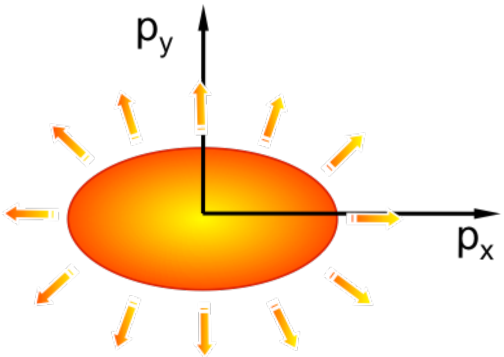
Content

- Introduction to Flow
- Anisotropic Flow Measurements
- Recently published Results from ALICE
- Future Plans

Azimuthal flow







- E,g. Non-central collisions
- Interaction region is anisotropic in coordinate space
- Pressure gradient transforms the initial coordinate space anisotropy into a momentum space anisotropy
- Quantified via flow harmonics v_n

[arXiv:1102.3010v2 [nucl-ex]]

Flow Harmonics v_n

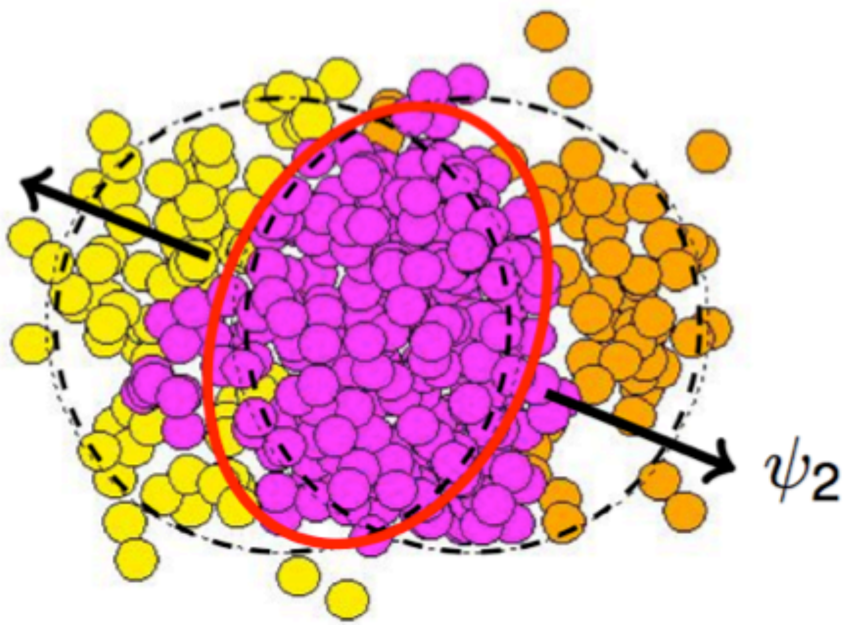
Fourier Expansion of Azimuthal Distribution

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos[n(\phi - \psi_n)]$$

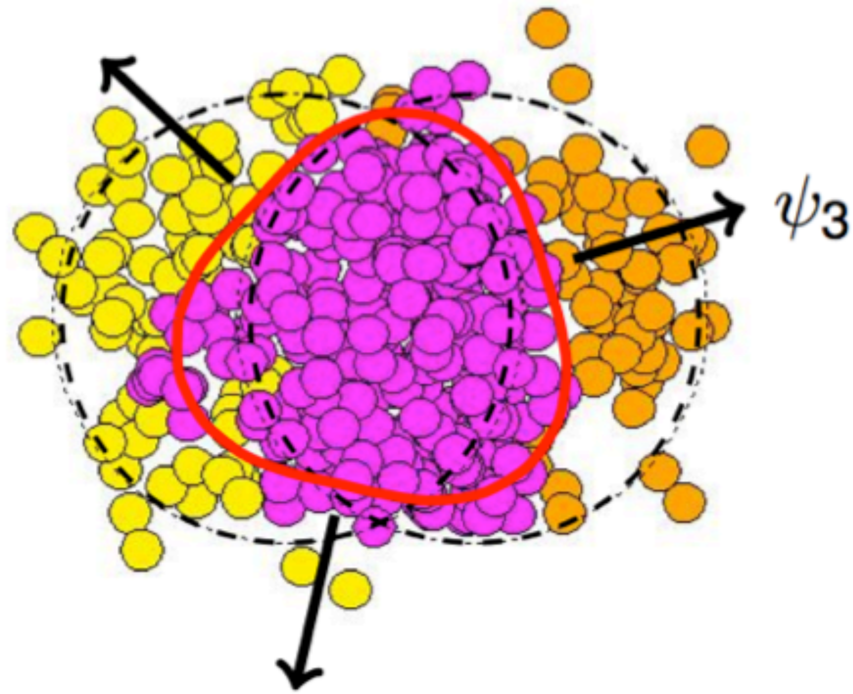
ϕ = Azimuthal angle
ψ_n = Flow angle of n-th order flow harmonic
v_n = Flow (Fourier) coefficient (flow harmonics)

- Reflects the response of the system to spatial anisotropies in the initial state.
- Elliptic flow commonly studied harmonic:
  - ψ_2 - Second harmonic plane
  - v_2 - Second order flow
  - Determined by initial geometry of participant nucleons

Other Flow Harmonics v_n



v_2
Elliptic flow



v_3
Triangular flow

arXiv:1107.0592,M. Luzum

Measurement of Anisotropic Flow

2-Particle Azimuthal Correlation

$$\langle 2 \rangle = \langle e^{in(\varphi_i - \varphi_j)} \rangle$$

- Correlate only distinct particles. (Exclude self-correlation $i \neq j$)
- 2-Particles Cumulant

$$c_n\{2\} = \langle\langle 2 \rangle\rangle$$

- In absence of non-flow $c_n\{2\}$ measures $\langle v_n^2 \rangle$

Ollitrault et al.

Measurement of Anisotropic Flow

4-Particle Azimuthal Correlation

$$\langle 4 \rangle = \langle e^{in(\varphi_i + \varphi_j - \varphi_k - \varphi_l)} \rangle$$

- 4-Particle Cumulant

$$c_n\{4\} = \langle\langle 4 \rangle\rangle - 2\langle\langle 2 \rangle\rangle^2$$

*the subtraction removes non-flow contribution present in two particle correlation

$c_n\{4\}$ measures $\langle v_n^4 \rangle - 2\langle v_n^2 \rangle^2$

Ollitrault et al.

Measurement of Anisotropic Flow

The Flow Coefficient

$$v_n\{2\} = \sqrt{c_n\{2\}}$$

$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$

Fluctuation σ_{vn}

$$* \; \sigma_{v_n} \ll \langle v_n \rangle$$

$$v_n\{2\} = \sqrt{\langle v_n \rangle^2 + \sigma_{v_n}^2}$$

$$v_n\{4\} = \sqrt{\langle v_n \rangle^2 - \sigma_{v_n}^2}$$

- Difference in $v_n\{2\}$ and $v_n\{4\}$ can be used to infer the scale of the fluctuation.
- If the value of v_n does not fluctuate and absence of non-flow, $v_n\{2\} = v_n\{4\}$.
- The effect of non-flow on cumulant: (assuming large multiplicity events are a superposition of low multiplicity events)

$$c_n\{m\} \propto \frac{1}{M^{m-1}}$$

Ollitrault et al.

Flow Vector

The Q_n-vector

$$Q_n \equiv \sum_{i=1}^{M} e^{in\phi_i}$$

M = total multiplicity
Φ_i = Azimuthal angle of *i*-th particle

2-Particle Correlation in term of the Q-vector

$$\langle 2 \rangle = \frac{|Q_n|^2 - M}{M(M-1)}$$

Suppressing Non-Flow Effects

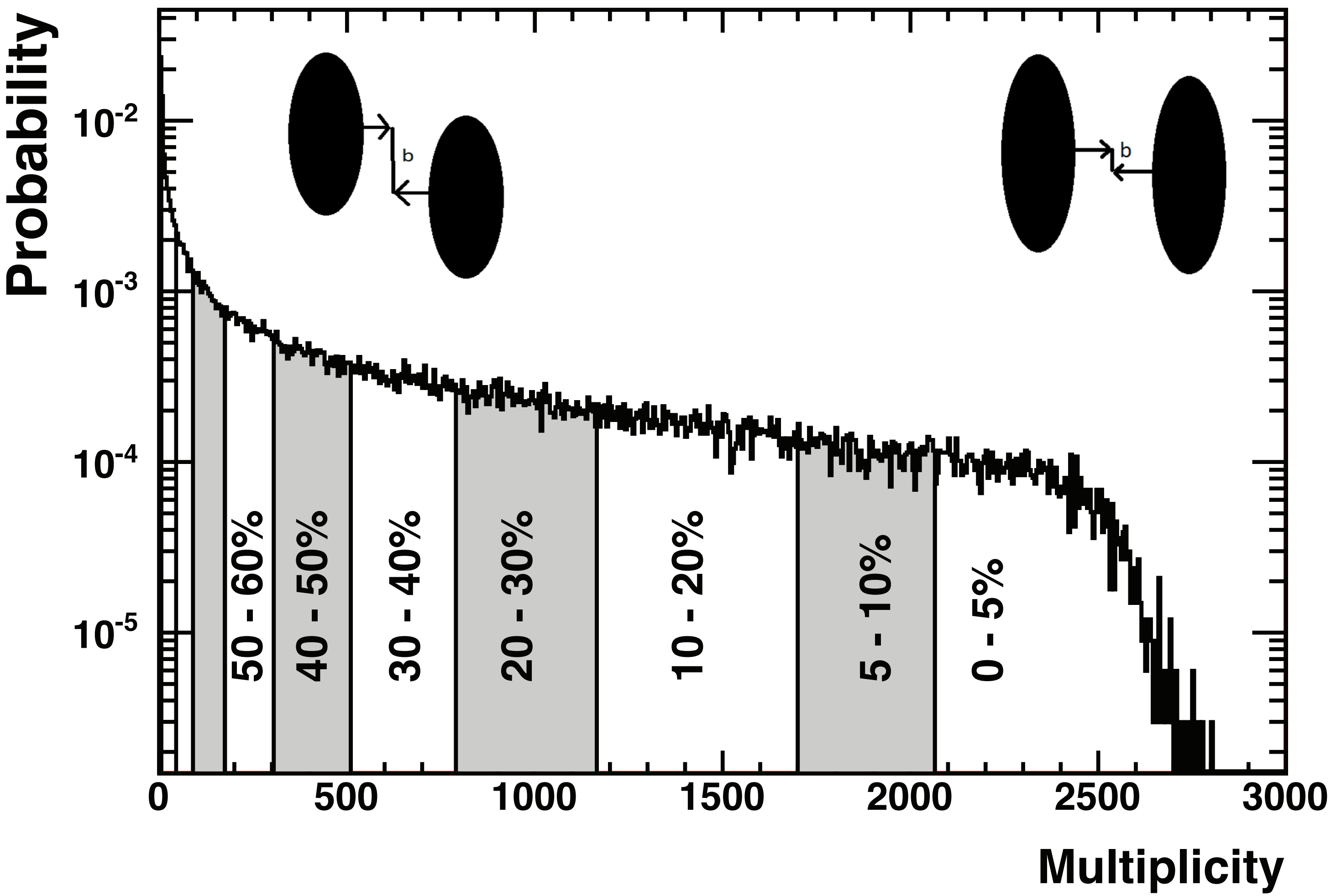
- Non-flow (δ_n) effects:
  - Resonance
  - Jets
  - Track splitting

Placing $|\Delta\eta|$-gap

$$v_n^2\{2\} = \left\langle \frac{Q_n^a Q_n^{b*}}{M^a M^b} \right\rangle$$

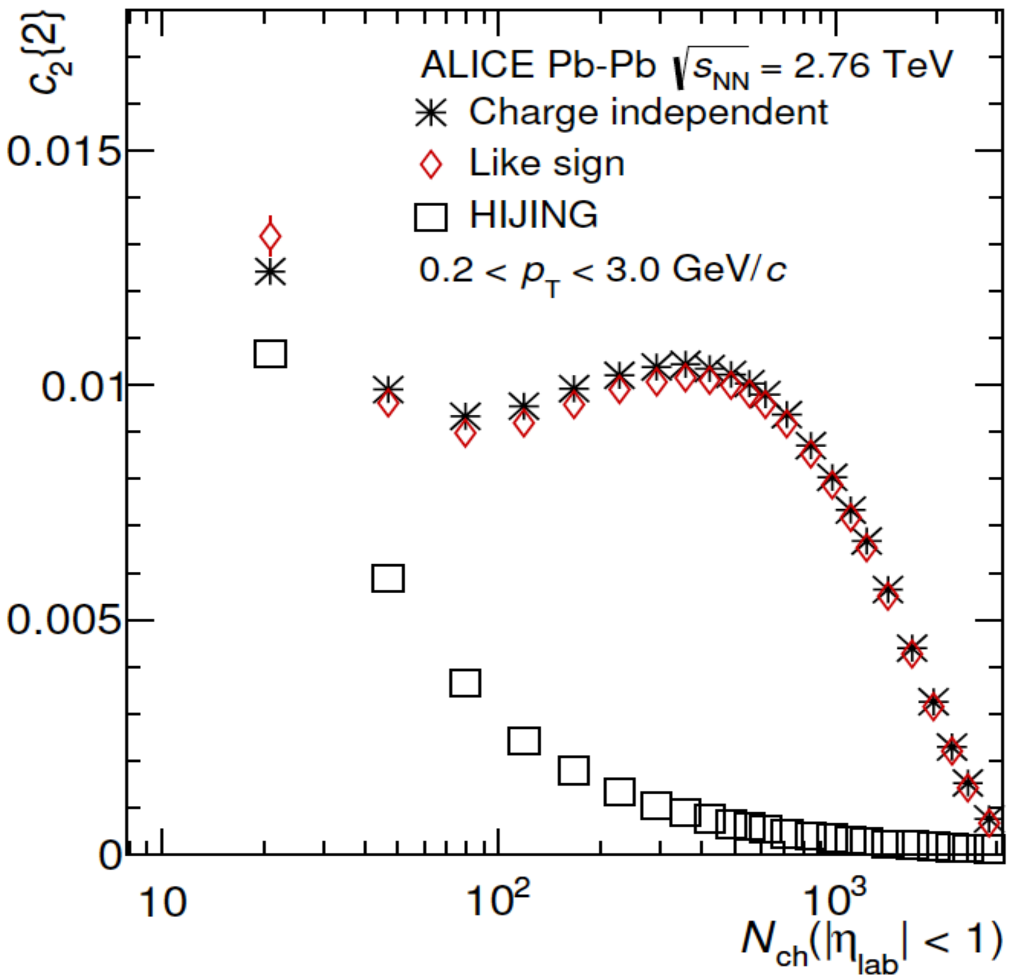
- Every event is divided into two subevents (a & b) separated in η
- Larger $|\Delta\eta|$-gap between the subevents reduces the non-flow effects further

Centrality



Probability
10^{-2}
10^{-3}
10^{-4}
10^{-5}
b
b
50 - 60%
40 - 50%
30 - 40%
20 - 30%
10 - 20%
5 - 10%
0 - 5%
0
500
1000
1500
2000
2500
3000
Multiplicity

$c_2\{2\}$ at the Lower LHC Energy

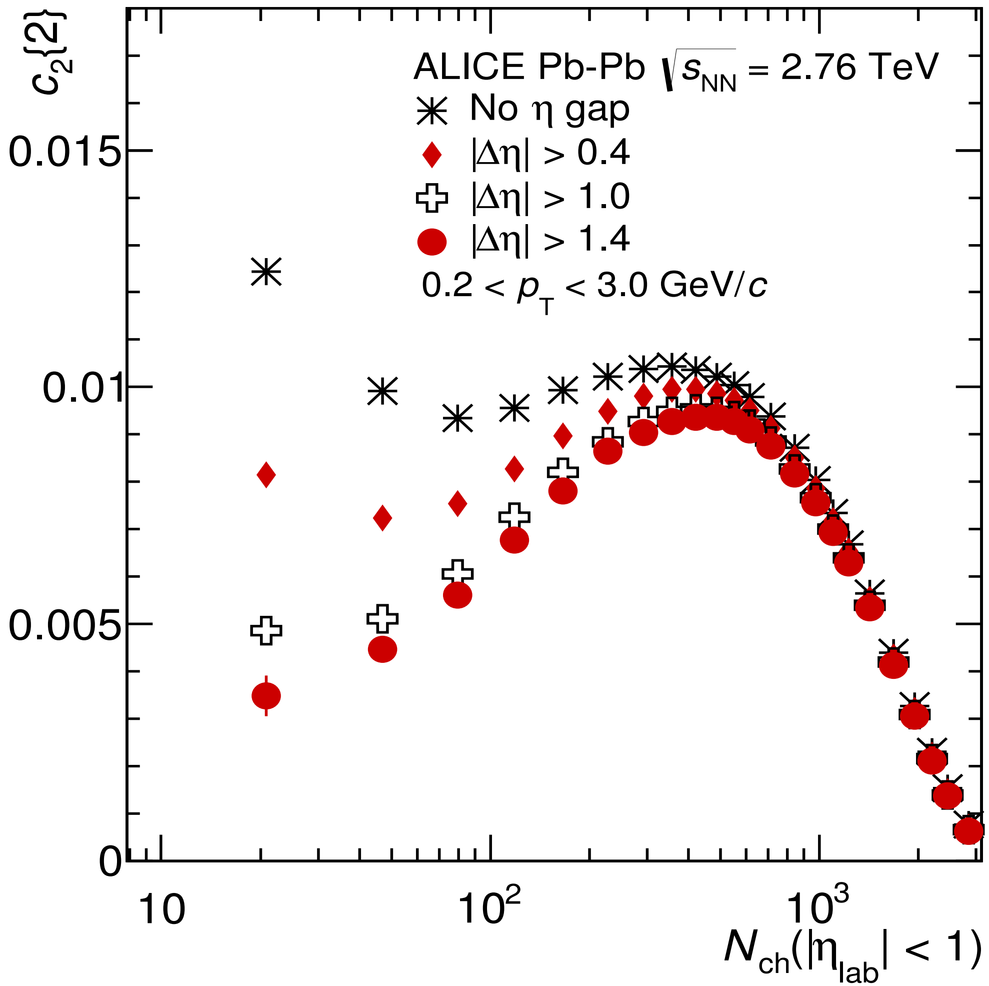


$$c_2\{2\} = v_2^2\{2\}$$

- Data decreases to $N_{ch} \sim 100$, then increases until mid-central collisions N_{ch} ~400.
- Initial state anisotropy decreases at more central events, $c_2\{2\}$ decreases as expected.
- HIJING shows non-flow effects are negligible at large multiplicities.

(PRC 90 (2014) 054901)
[arXiv:1406.2474v2 [nucl-ex]]

Result from applying η-gap



$$c_2\{2\} = v_2^2\{2\}$$

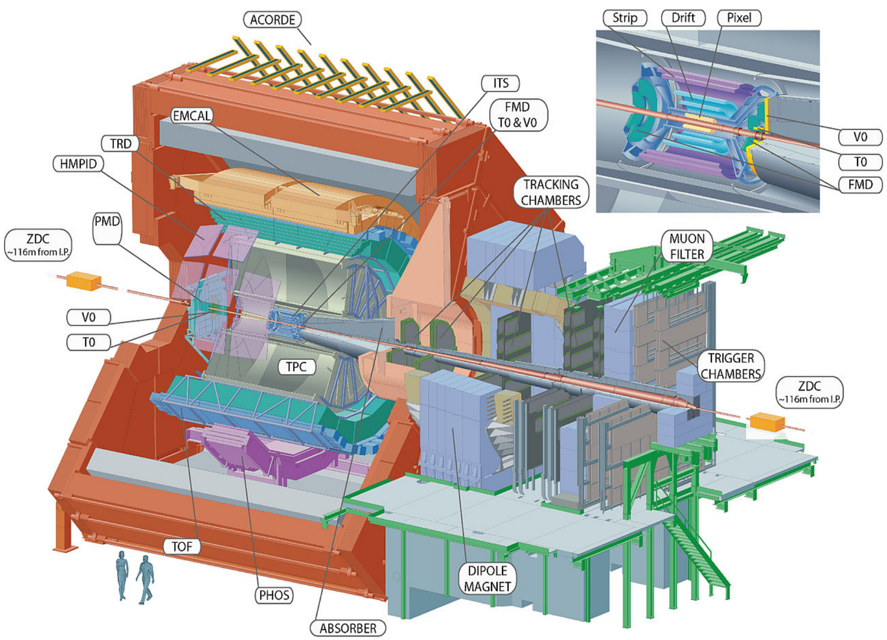
- Low multiplicities:
  - ➢ Non-flow plays prominent role
- Increasing η-gap decreases $c_2\{2\}$
  - ➢ Tracks from non-flow have small relative angle.
- Large multiplicities:
  - ➢ Domination of anisotropic flow

(PRC 90 (2014) 054901)
[arXiv:1406.2474v2 [nucl-ex]]

Analysis details for Higher Energy

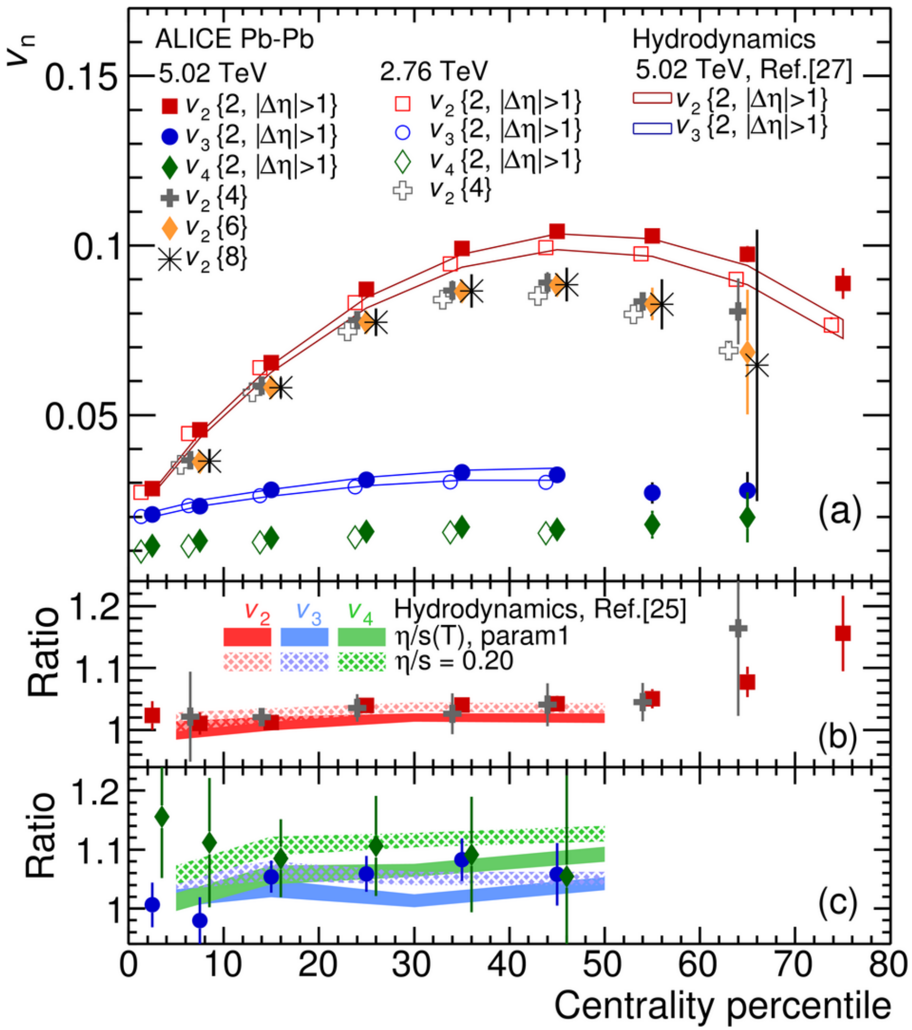
- LHC Pb-Pb 5.02 TeV run late 2015

- Event selection:
  - ✧ Minimum bias trigger
  - ✧ Centrality from V0M detectors
  - ✧ $|PV_z| < 10$ cm
  - ✧ 140k events (very low luminosity)



- Track selection
  - ✧ TPC only tracks
  - ✧ No. TPC Clusters > 70 out of a max. of 159
  - ✧ DCA (distance of closet approach to vertex) < 3 cm
  - ✧ Kinematic cuts: $0.2 < p_t < 5$ GeV/c and $|\eta| < 0.8$

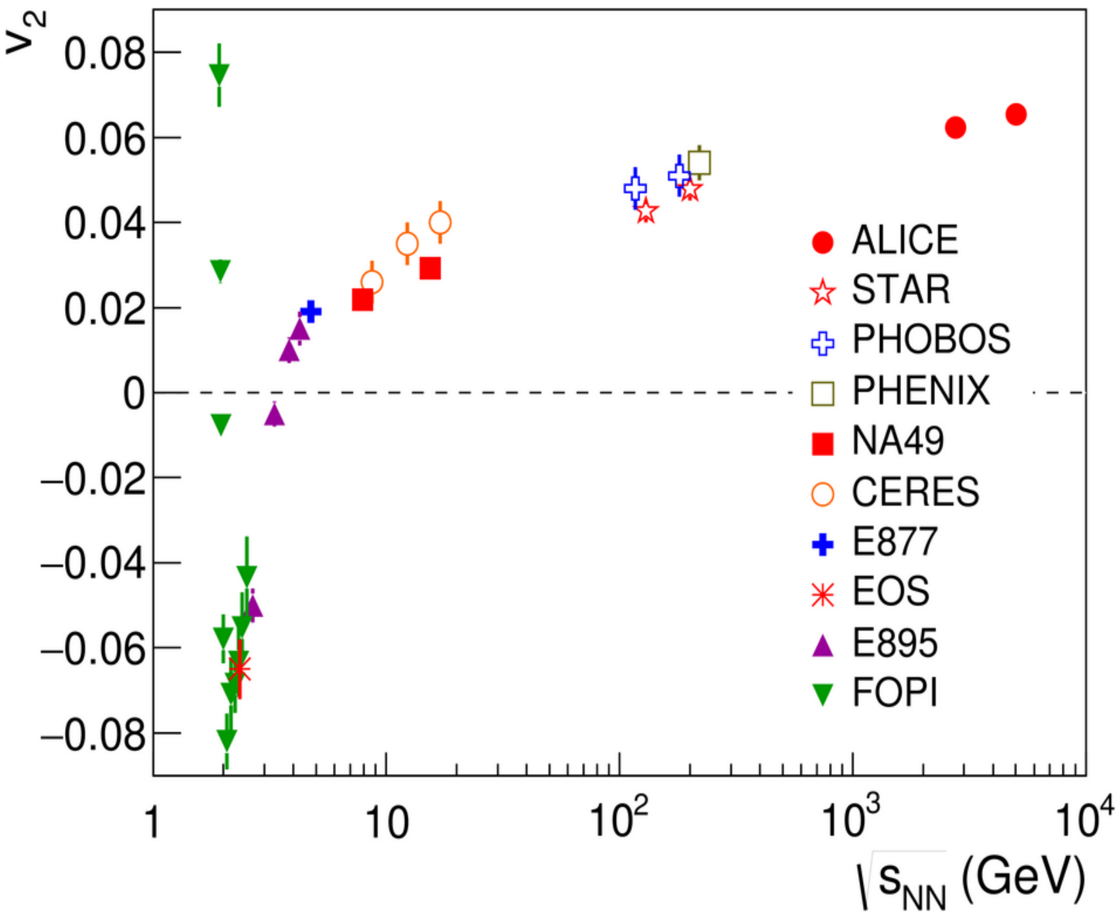
From 2.76 TeV to 5.02 TeV



- Data recorded in Nov. 2015 in Run 2 at LHC
- Ratio of 5.02 TeV to 2.76 TeV:
  - ✧ $v_2\{2, |\Delta\eta| > 1\}$ (red)
  - ✧ $v_2\{4\}$ (gray)
  - ✧ $v_3\{2, |\Delta\eta| > 1\}$ (blue)
  - ✧ $v_4\{2, |\Delta\eta| > 1\}$ (green)
- Values increase:
  - ➢ v_2 (3.0±0.6)%
  - ➢ v_3 (4.3±1.4)%
  - ➢ v_4 (10.2±3.8)%
- Consistent with hydrodynamic predictions

ALICE, PRL 116 (2016) 132302
arXiv:1602.01119

Comparison to SPS and RHIC



- Comparison of p_T integrated $v_2\{4\}$ measured in the 20-30% centrality in Pb-Pb collisions at the LHC with results at lower energies.
- Elliptic flow measured at highest energy $\sqrt{s_{NN}} = 5.02$ TeV.

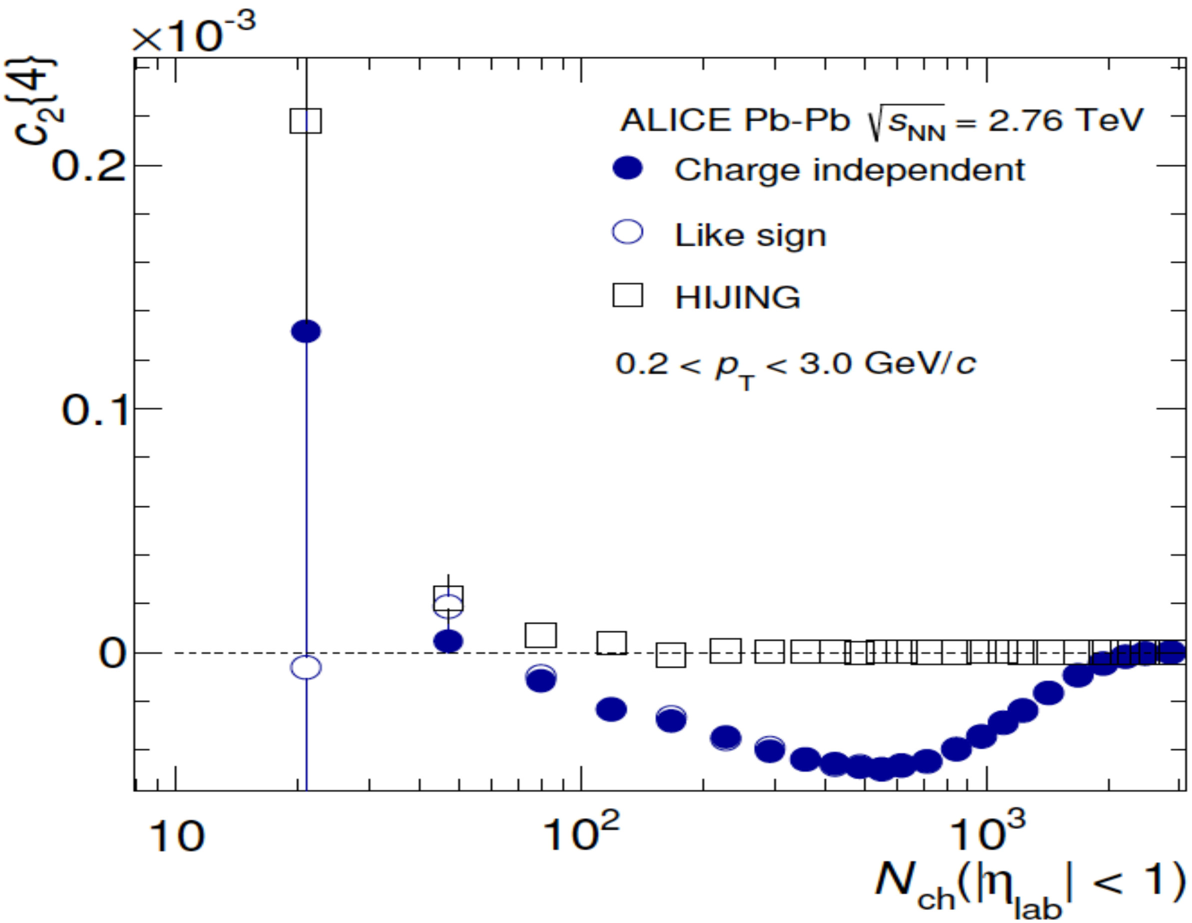
ALICE, PRL 116 (2016) 132302
arXiv:1602.01119

My Future Plans

- Perform v_2, v_3 studies on ultra-central collisions by using 2-, and 4-Particle cumulant methods.
- Uncertainty due to initial conditions in determining η/s for v_n is significant (Nuc. Phys. A 904-905 (2013) 377-380).
- Better understanding of the initial state which is dominated by fluctuations
- Therefore, we propose way to extract v_n from ultra-central collisions, so we can more easily constrain the QGP transport properties.

Thank You

Back up



$\times 10^{-3}$
$c_2\{4\}$
0.2
0.1
0
ALICE Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
Charge independent
Like sign
HIJING
$0.2 < p_T < 3.0$ GeV/c
10
10^2
10^3
$N_{ch}(|\eta_{lab}| < 1)$