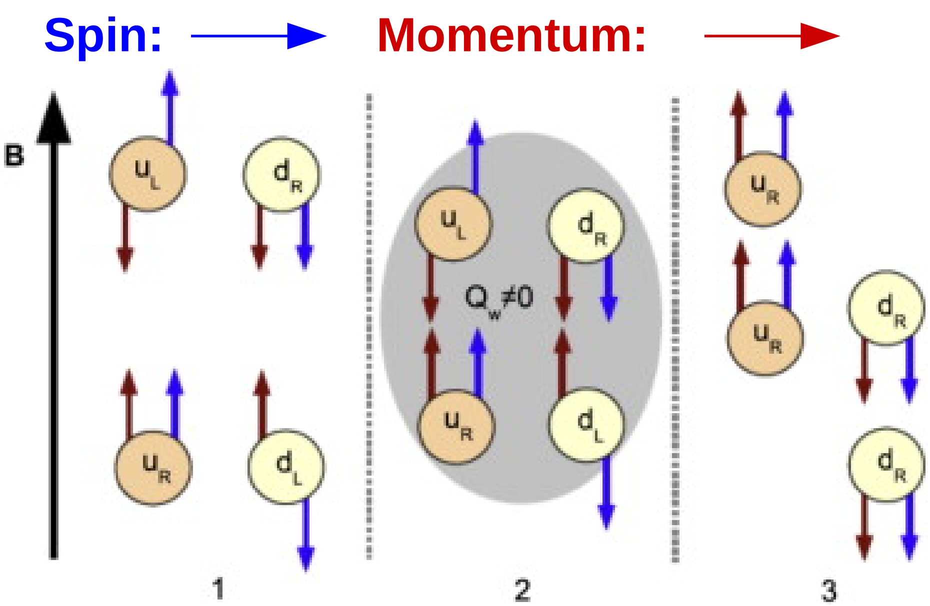
Search for the Chiral Magnetic Wave (CMW) with ALICE at the LHC

Outline:

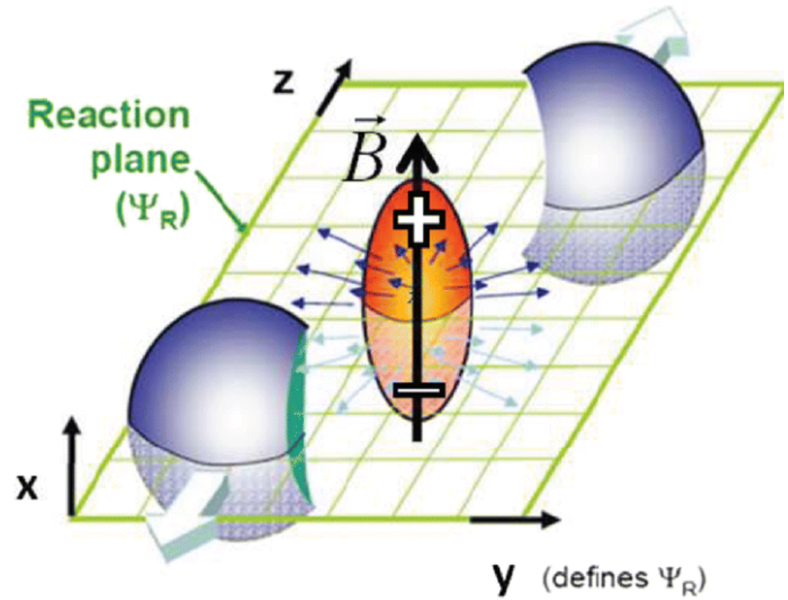
- Motivation
- Observable
- Analysis details
- Results
- Summary and outlook

Prottay Das (for the ALICE Collaboration)
National Institute Of Science Education and Research
HBNI

Motivation



Heavy-ion collisions



- **Chiral Magnetic Effect (CME):** $j_V = \frac{N_c e}{2\pi^2} \mu_A B$
- **Chiral Separation Effect (CSE):** $j_A = \frac{N_c e}{2\pi^2} \mu_V B$
- **Chiral Magnetic Wave (CMW)**:
  CME + CSE
- Induces **parity odd domains**

- Chiral symmetry restoration
- QCD vacuum transitions
- Extremely strong magnetic field ($\sim 10^{19}$T)

All the necessary conditions are possible to be achieved in Heavy-ion collisions

Phys.Rev.Lett. 81 (1998) 512-515

Observables

✔ Charge dependent elliptic flow

$$v_2^{h^\pm} = v_2 \mp r \frac{A_{ch}}{2}, \qquad A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

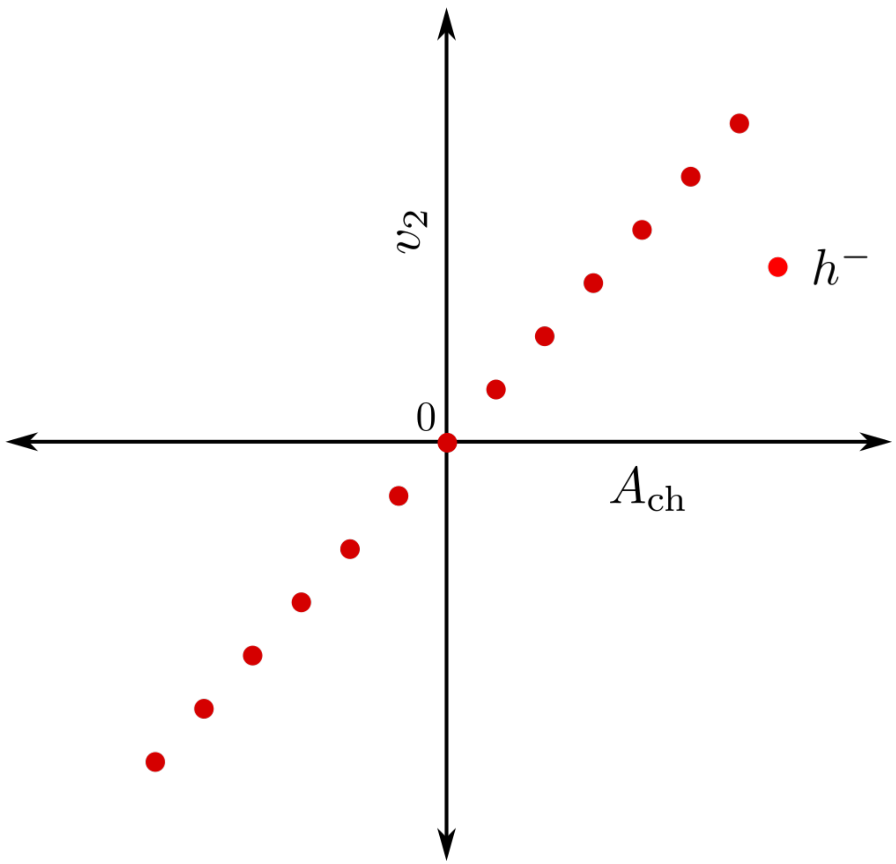
✔ **CMW observable**:
Normalised slope , $r^{Norm}_{\Delta v_2} = \frac{d\left(\frac{\Delta v_2}{\langle v_2 \rangle}\right)}{d A_{ch}}$

$$\Delta v_2 = v_2^{h^-} - v_2^{h^+} \qquad \langle v_2 \rangle = \frac{v_2^{h^-} + v_2^{h^+}}{2}$$

✔ **Possible background**:
Local charge conservation (LCC)

- Probe the background:
Similar measurement with v_3

For illustration purpose



Phys.Rev.Lett. 107 (2011) 052303
Phys.Rev.C 100 (2019) 6, 064908
arXiv:2010.09955

Observables

- ✔ Charge dependent elliptic flow

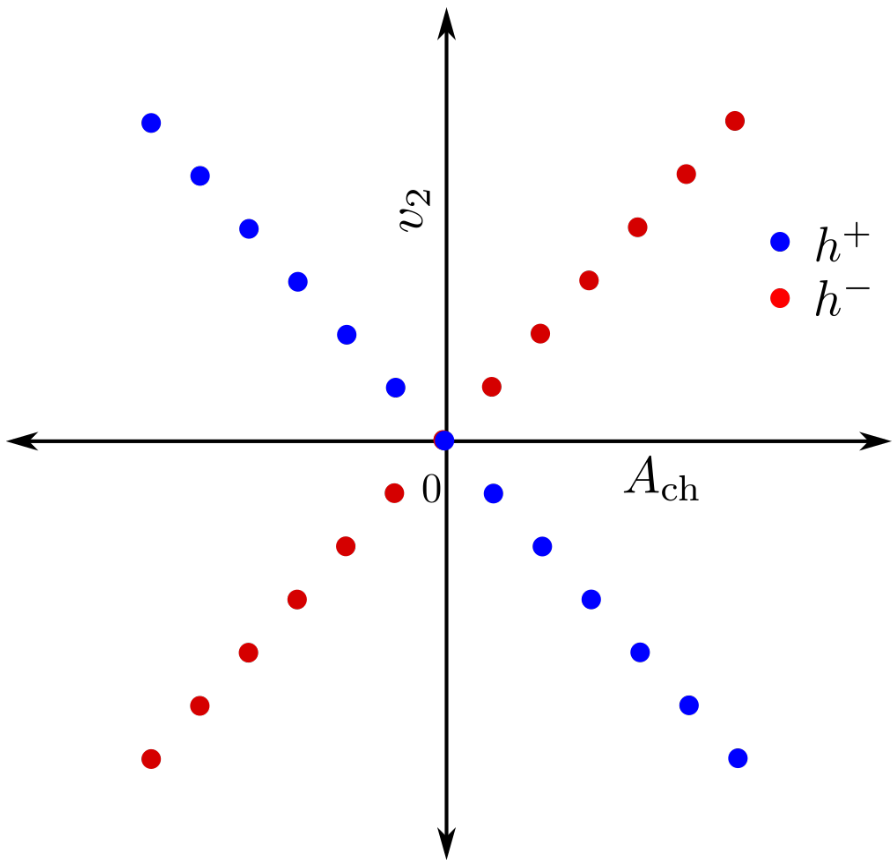
$$v_2^{h^\pm} = v_2 \mp r\frac{A_{ch}}{2}, \qquad A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

- ✔ **CMW observable**:
  Normalised slope , $r_{\Delta v_2}^{Norm} = \frac{d\left(\frac{\Delta v_2}{\langle v_2 \rangle}\right)}{d\,A_{ch}}$

$$\Delta v_2 = v_2^{h^-} - v_2^{h^+} \qquad \langle v_2 \rangle = \frac{v_2^{h^-} + v_2^{h^+}}{2}$$

- ✔ **Possible background**:
  Local charge conservation (LCC)
- Probe the background:
  Similar measurement with v_3

For illustration purpose



Phys.Rev.Lett. 107 (2011) 052303
Phys.Rev.C 100 (2019) 6, 064908
arXiv:2010.09955

Observables

- Charge dependent elliptic flow

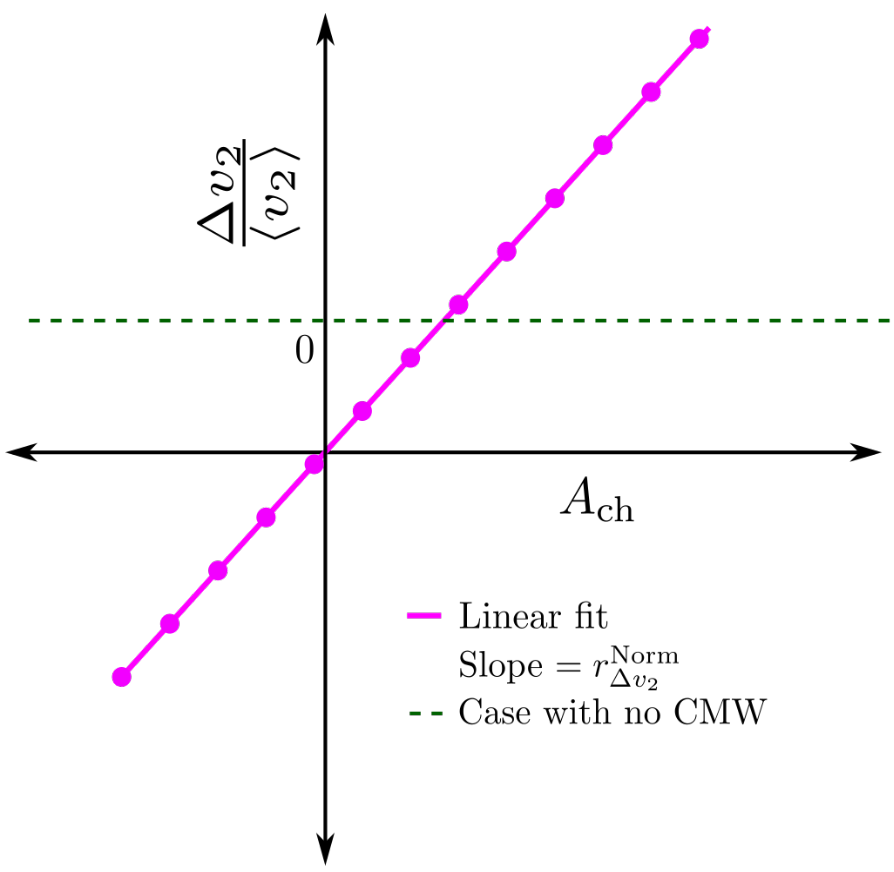
$$v_2^{h^\pm} = v_2 \mp r \frac{A_{ch}}{2}, \qquad A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$$

- **CMW observable**:
  Normalised slope , $r^{Norm}_{\Delta v_2} = \frac{d\left(\frac{\Delta v_2}{\langle v_2 \rangle}\right)}{d\,A_{ch}}$

$$\Delta v_2 = v_2^{h^-} - v_2^{h^+} \qquad \langle v_2 \rangle = \frac{v_2^{h^-} + v_2^{h^+}}{2}$$

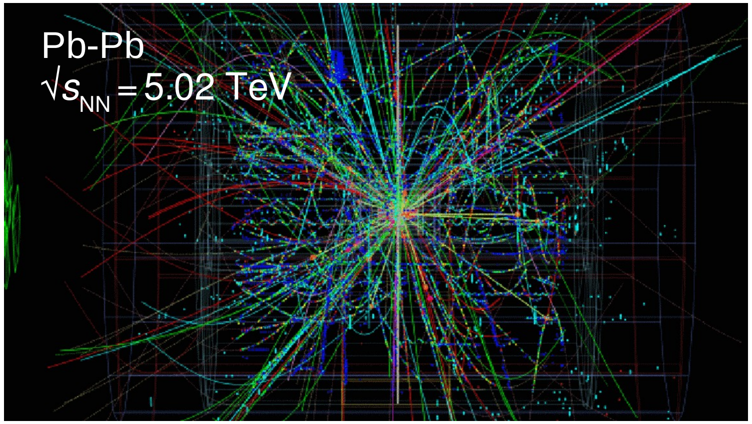
- **Possible background**:
  Local charge conservation (LCC)
- Probe the background:
  Similar measurement with v_3

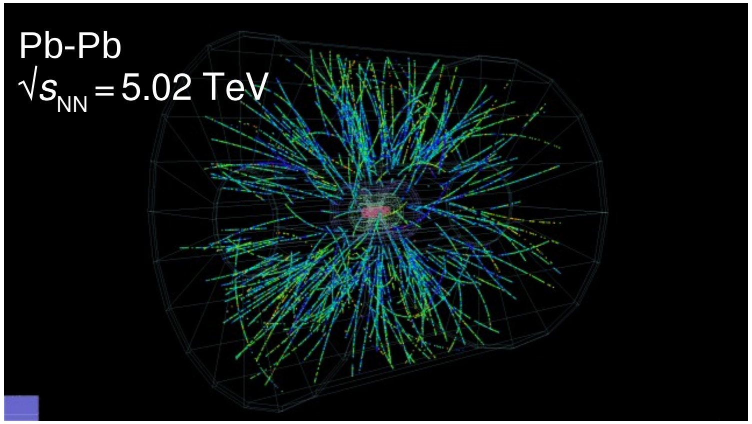
For illustration purpose



Phys.Rev.Lett. 107 (2011) 052303
Phys.Rev.C 100 (2019) 6, 064908
arXiv:2010.09955

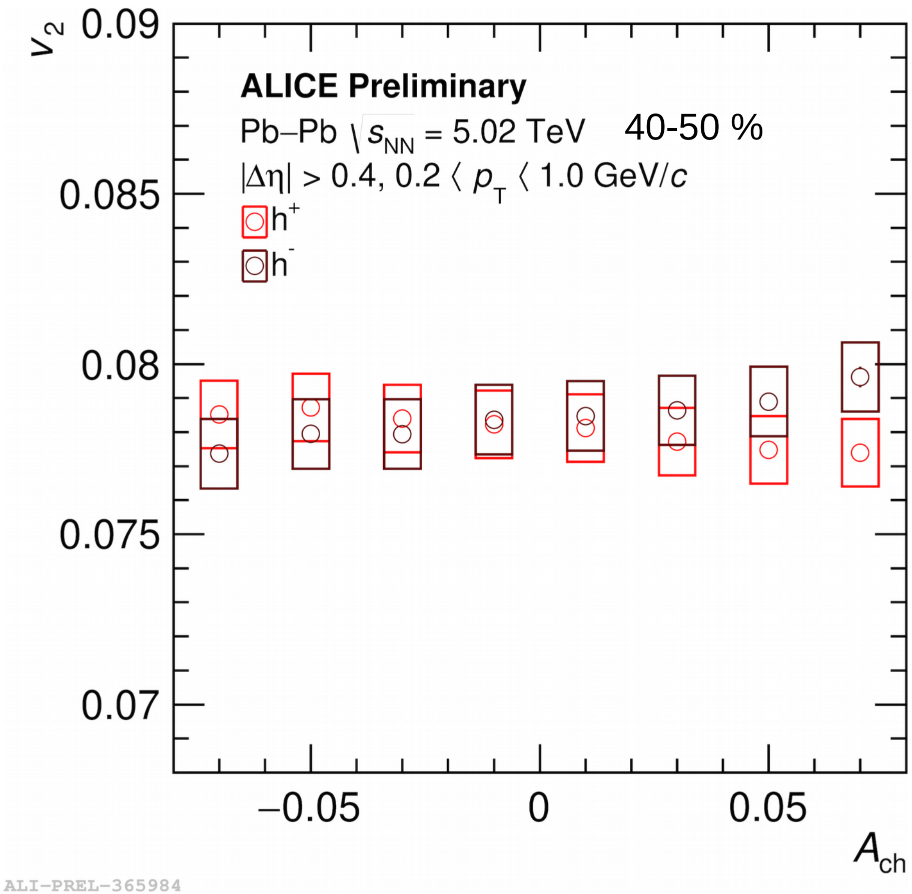
Analysis details

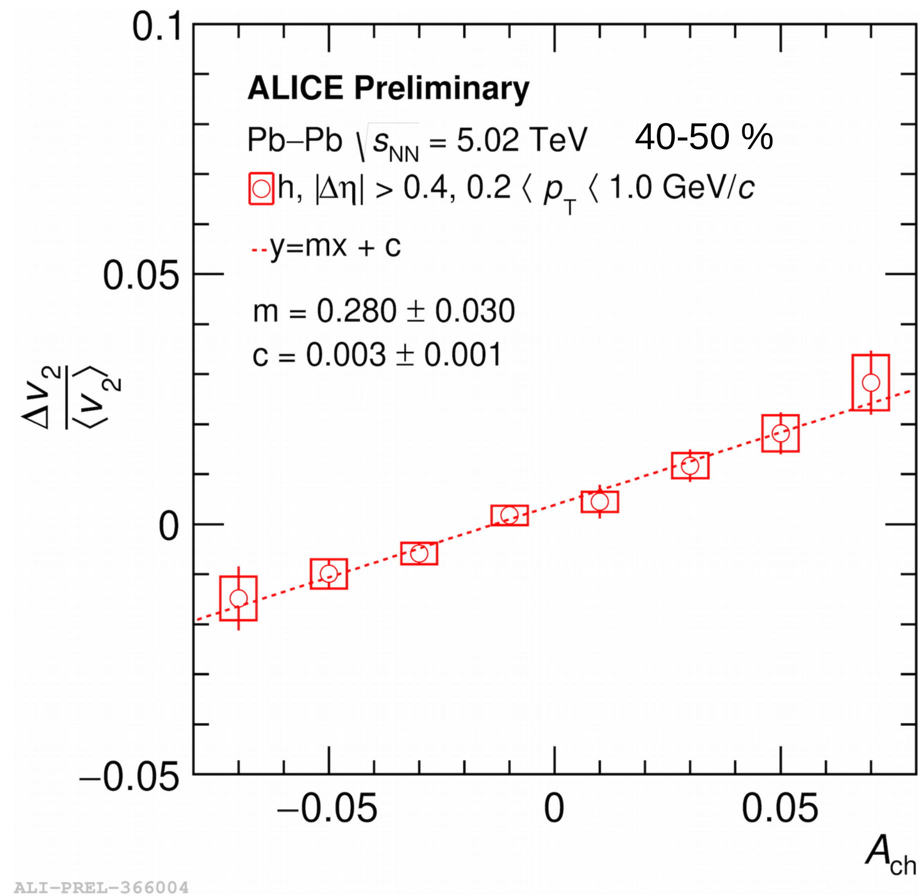




No. of events	~60×10^6
Kinematic range	$\|\eta\|<0.8$ $0.2<p_T<0.5$ GeV/c (pions) $0.2<p_T<1.0$ GeV/c (hadrons)
Non flow suppression	$\|\Delta\eta\| > 0.4$ between subevents
Charge asymmetry (A_{ch})	$0.2<p_T<10$ GeV/c, $\|\eta\|<0.8$, 10 uniform bins (-0.1 to 0.1)

v_2 vs charge asymmetry





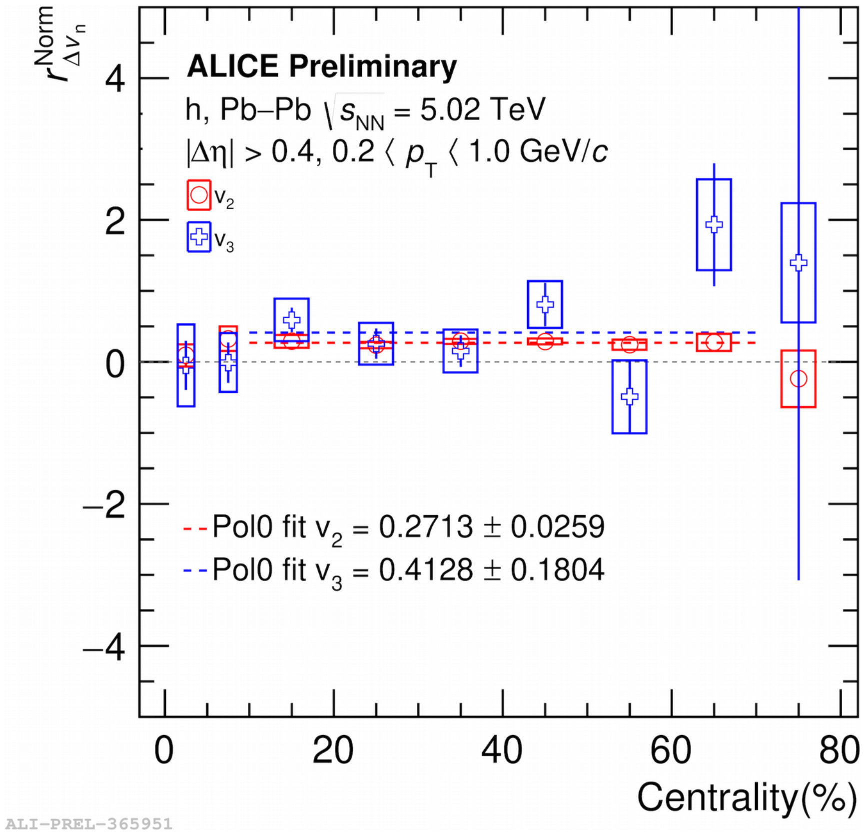
✔ Finite $r^{Norm}_{\Delta v2}$ is observed

$$A_{ch} = \frac{N^{+} - N^{+}}{N^{+} + N^{+}}$$

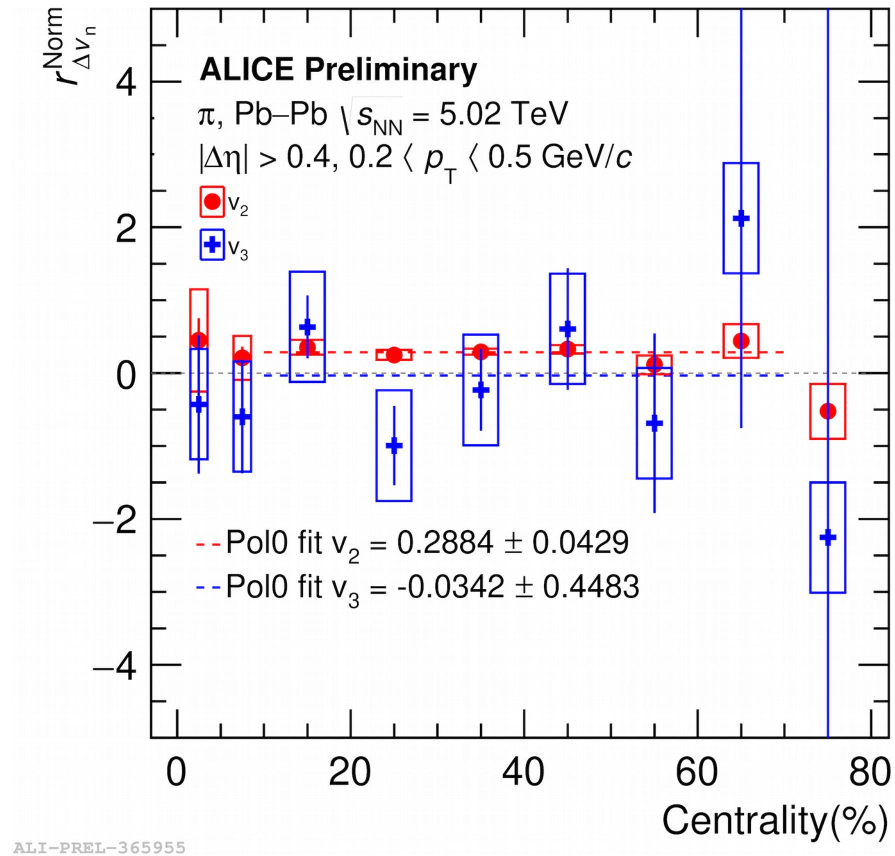
$$r^{Norm}_{\Delta v_n} = \frac{d\left(\frac{\Delta v_n}{\langle v_n \rangle}\right)}{d A_{ch}}$$

Centrality dependence of $r^{Norm}_{\Delta v_n}$

Hadrons



Pions



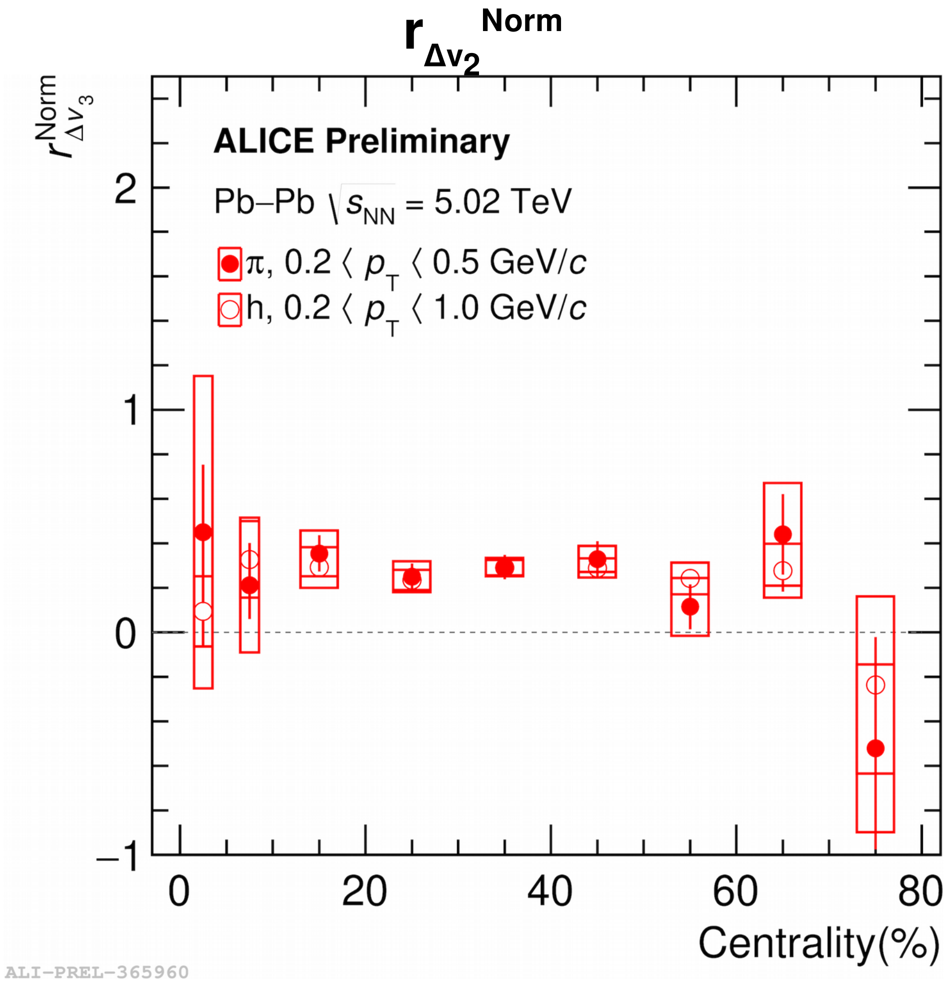
✔ $r^{Norm}_{\Delta v_2}$ is compatible with $r^{Norm}_{\Delta v_3}$

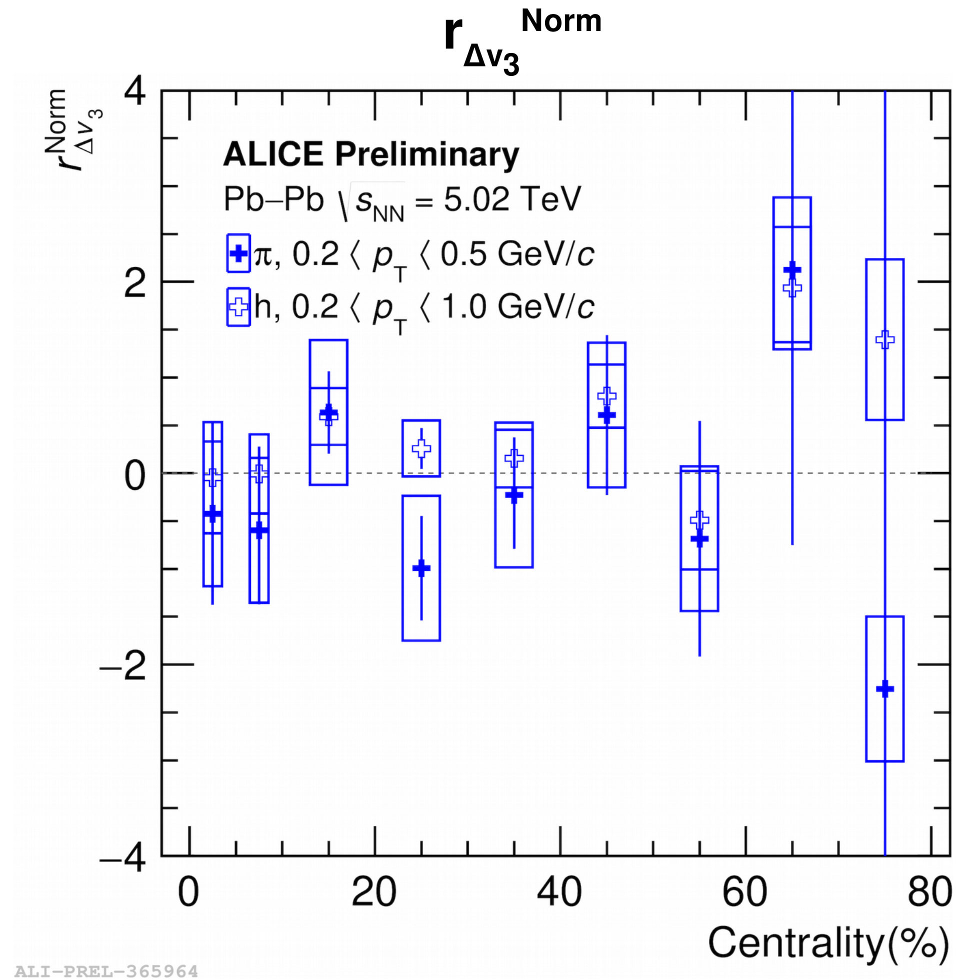
Summary and outlook

- ✔ Measurement of CMW studies are presented for pions and charged hadrons in Pb-Pb collisions at 5.02 TeV with ALICE.
- ✔ $r^{norm}_{\Delta v3}$ has large uncertainties
- ✔ $r^{norm}_{\Delta v2}$ is compatible with $r^{Norm}_{\Delta v_3}$
- ✔ Measurement to be done with high statistics (2018 datasets) in Pb-Pb collisions.

BACKUP

Comparison of $r^{Norm}_{\Delta v_n}$ between hadrons, pions

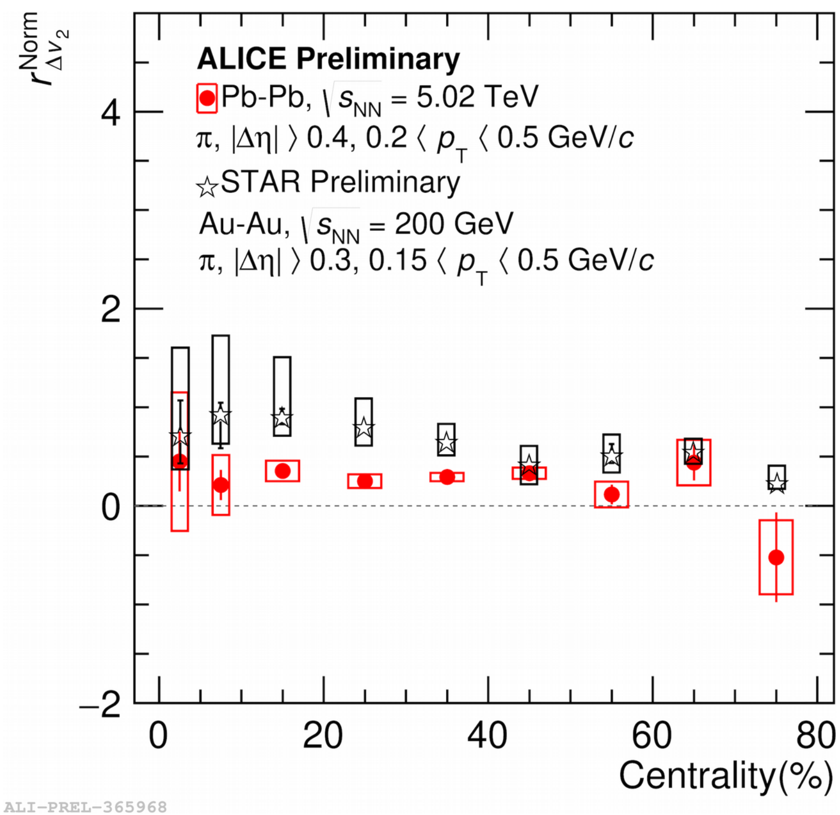




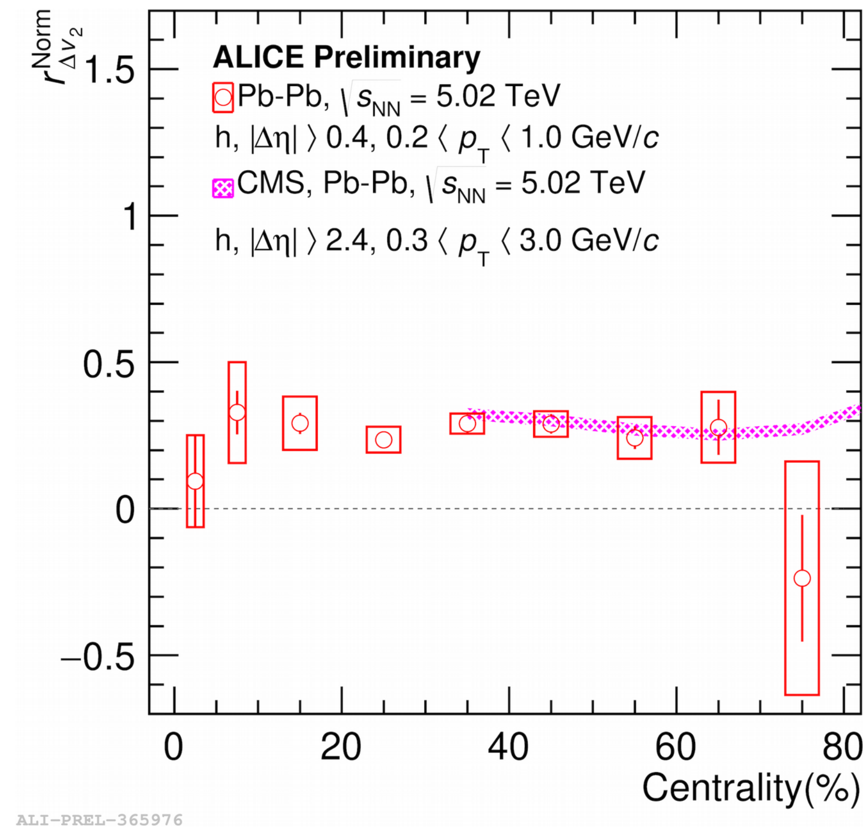
- ✔ $r^{Norm}_{\Delta v_2}{}^{h} \approx r^{Norm}_{\Delta v_2}{}^{\pi}$
- ✔ $r^{Norm}_{\Delta v_3}{}^{h}$ is compatible with $r^{Norm}_{\Delta v_3}{}^{\pi}$

Comparison of $r^{Norm}_{\Delta v_2}$ in ALICE, STAR and CMS

Comparison with STAR



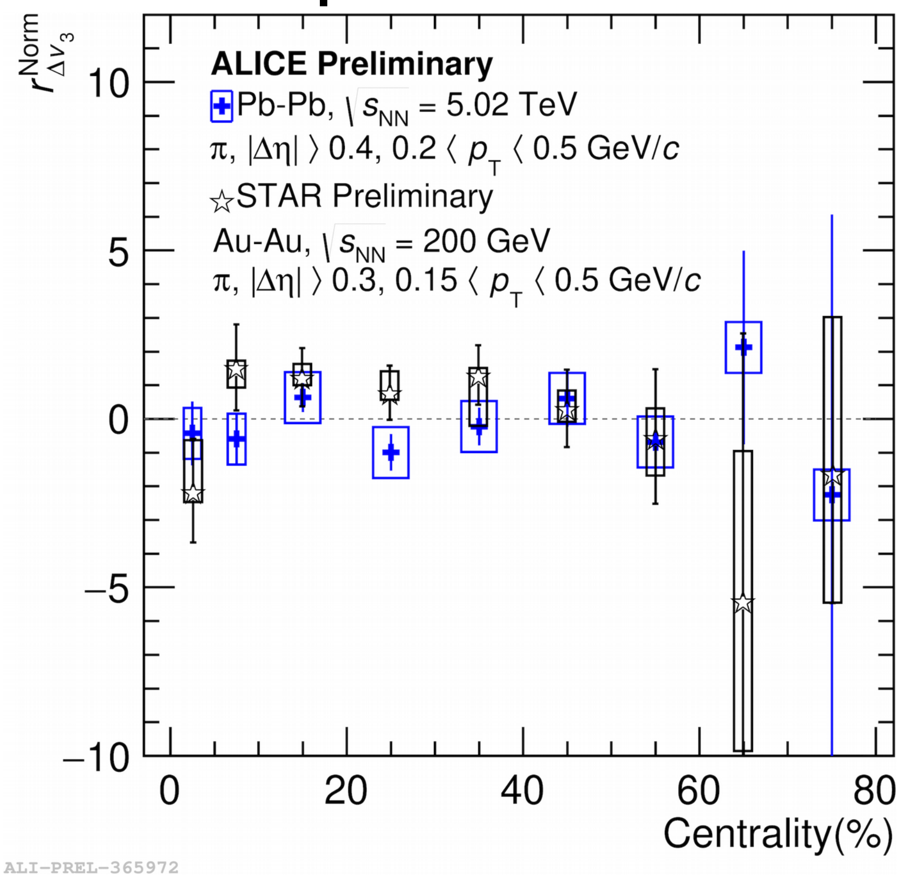
Comparison with CMS



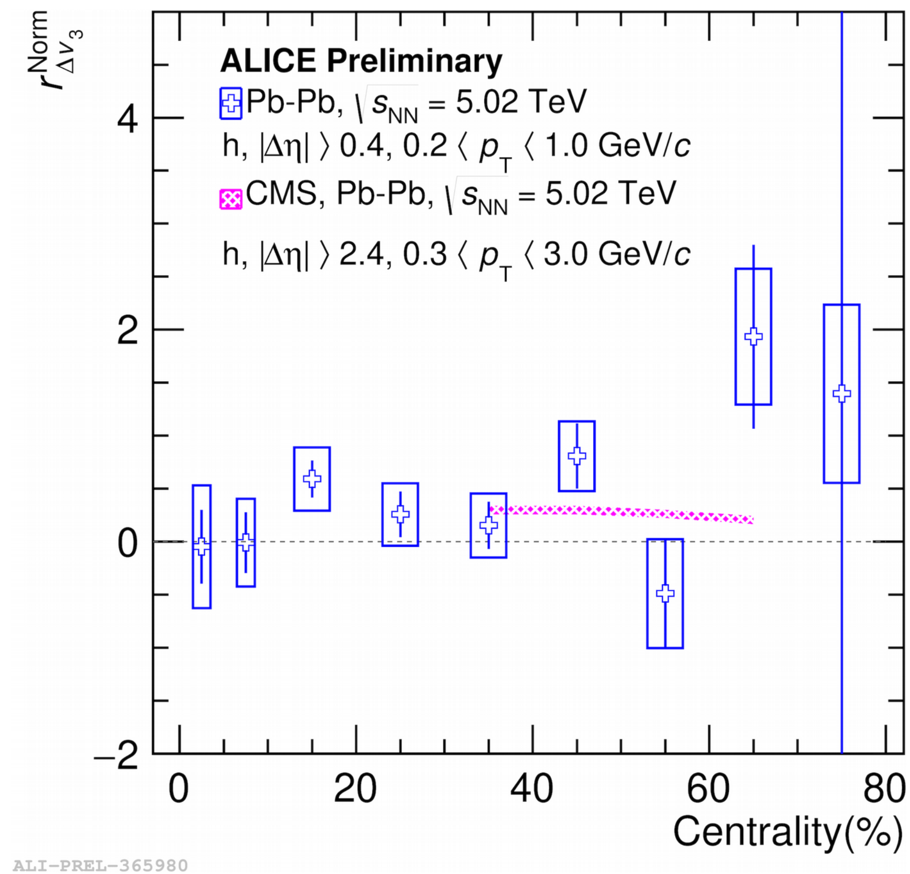
- ✔ $r^{Norm}_{\Delta v_2}$ h(ALICE) ≈ $r^{Norm}_{\Delta v_2}$ h(CMS)
- ✔ $r^{Norm}_{\Delta v_2}$ π(ALICE) < $r^{Norm}_{\Delta v_2}$ π(STAR)

Comparison of $r^{Norm}_{\Delta v_3}$ in ALICE, STAR and CMS

Comparison with STAR



Comparison with CMS



✔ No observed discrepancies in $r^{Norm}_{\Delta v_3}$ between ALICE, STAR and CMS, but uncertainties are large

Observable

- ✔ Charge dependent elliptic flow $v_2^{h^\pm} = v_2 \mp r \frac{A_{ch}}{2}$ with $A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$

- ✔ **CMW observable**: Normalised Slope , $r_{\Delta v_2}^{Norm} = \frac{d\left(\frac{\Delta v_2}{\langle v_2 \rangle}\right)}{d A_{ch}}$

  where $\Delta v_2 = v_2^{h^-} - v_2^{h^+}$, $\langle v_2 \rangle = \frac{v_2^{h^-} + v_2^{h^+}}{2}$

- ✔ **Possible background**: Local charge conservation
- Minimise the background: Measurement at low p_T
- Probe the background: Similar measurement with v_3

Phys.Rev.Lett. 107 (2011) 052303
Phys.Rev.C 100 (2019) 6, 064908
arXiv:2010.09955