Search for local parity violation in strong interaction at LHC energies

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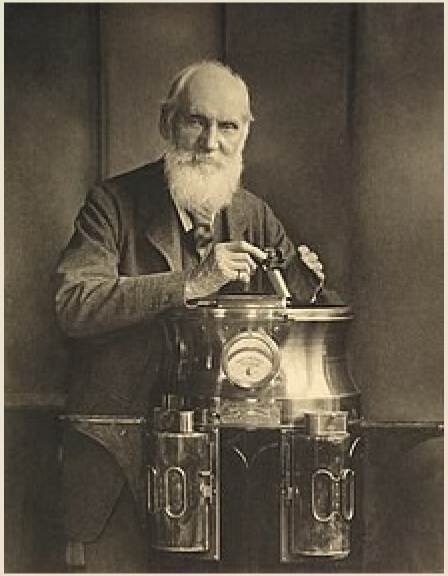
ALICE-INDIA

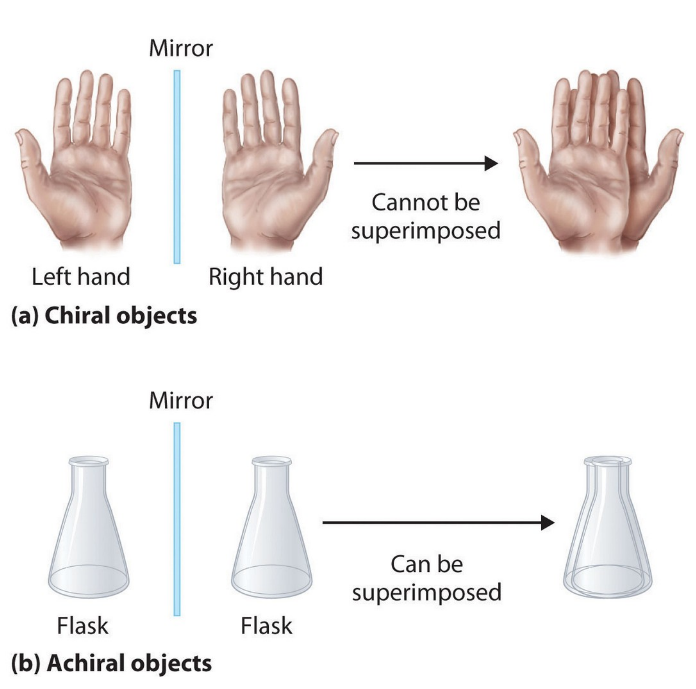
Study of Chiral Magnetic Wave phenomena

Chirality: the definition

"I call any geometrical figure, or groups of points, chiral, and say it has chirality, if its image in a plane mirror, ideally realized, cannot be brought to coincide with itself."



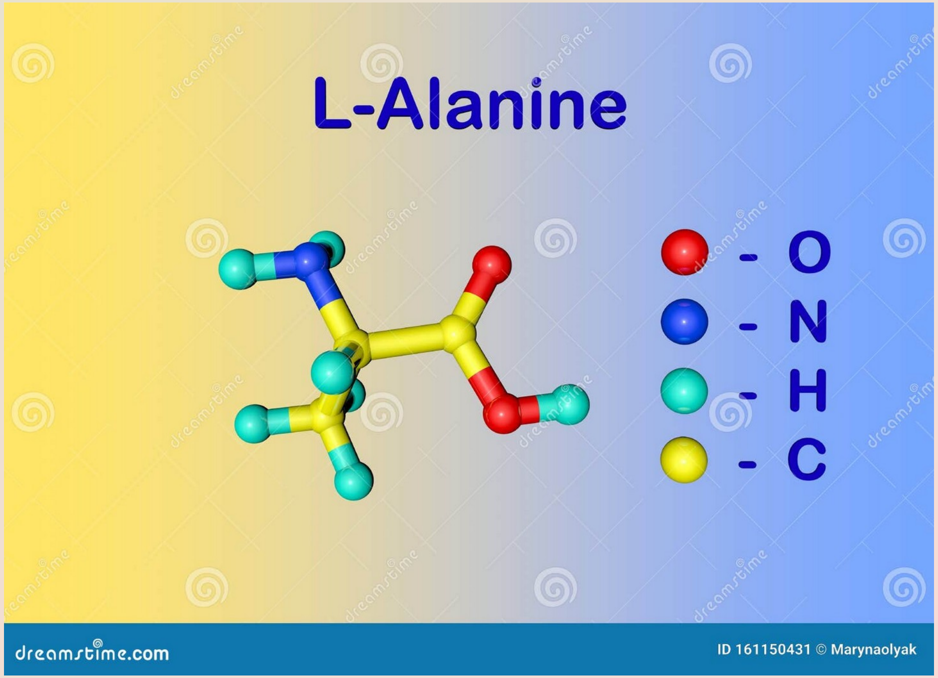
https://www.britannica.com/biography/William-Thomson-Baron-Kelvin



https://chem.libretexts.org/Bookshelves/Organic_Chemistry

Nature prefers left-right asymmetry

https://www.thoughtco.com/dna-373454



https://www.dreamstime.com/molecular-structure-l-alanine-Amino-acid-used-biosynthesis-proteins-medical-background-scientific-d-illustration-image161150431

- ✓ Every organism on earth contains right handed DNA and left handed amino acids

E. Gibney, Nature, 25 September, 2014

Chirality in subatomic world

- ✓ **Right chiral :** *Spin parallel to momentum direction*
- ✓ **Left chiral** : *Spin antiparallel to momentum direction*

- ✓ CP violation observed in weak interactions

Phys.Rev.Lett. 13 (1964) 138

Phys.Rev.Lett. 113 (2014) 118103

- ✓ Origin of biological homochirality

CP violation in strong interactions ?

JETP Lett. 5 (1967) 24-27

- ✓ Improve the understanding of matter-antimatter asymmetry

PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

T. D. LEE, *Columbia University, New York, New York*

AND

C. N. YANG,† *Brookhaven National Laboratory, Upton, New York*

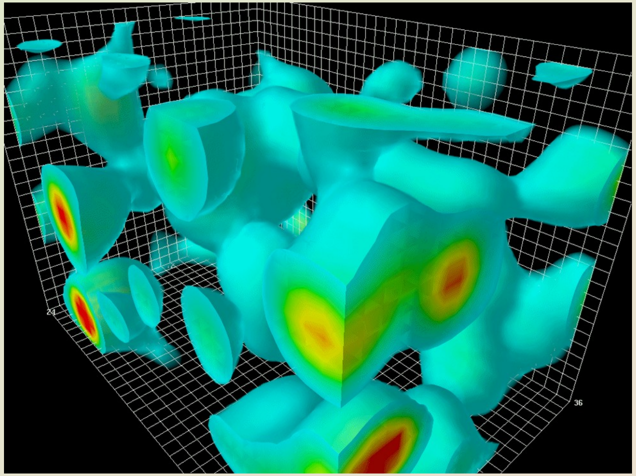
(Received June 22, 1956)

The question of parity conservation in β decays and in hyperon and meson decays is examined. Possible experiments are suggested which might test parity conservation in these interactions.

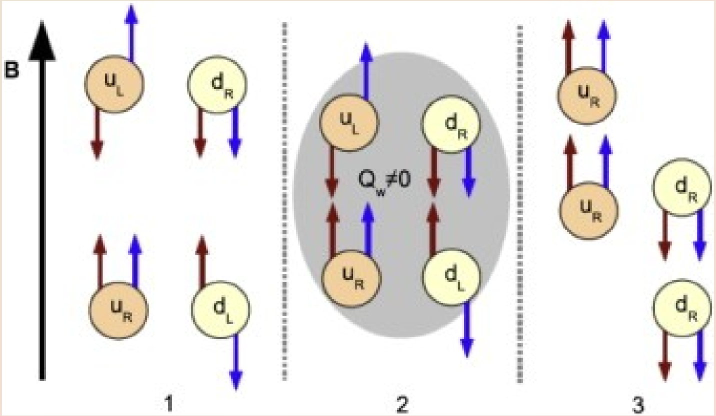
Phys.Rev. 106 (1957) 1371

The Nobel Prize in Physics 1957: "for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles"

QCD vacuum and chiral effects



D. Leinweber, http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/



Prog. in Particle and Nuclear Physics 75 (2014) 133-151

- ✓ QCD vacuum fluctuations
- ✓ Non zero topological charge
- ✓ Chirality imbalance

$$N_L^f - N_R^f = 2Q_W$$

- ✓ *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

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

Heavy-ion collisions

- ✓ Chiral symmetry restoration
- ✓ Deconfinement
- ✓ QCD vacuum transitions
- ✓ Extremely strong magnetic field (~10^{15} tesla)

Phys.Lett.B 710 (2012) 171-174

VOLUME 81, NUMBER 3 PHYSICAL REVIEW LETTERS 20 JULY 1998

Possibility of Spontaneous Parity Violation in Hot QCD

Dmitri Kharzeev,[1] Robert D. Pisarski,[2] and Michel H. G. Tytgat[2,3]
[1]*RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973-5000*
[2]*Department of Physics, Brookhaven National Laboratory, Upton, New York 11973-5000*
[3]*Service de Physique Théorique, CP 225, Université Libre de Bruxelles, Boulevard du Triomphe, 1050 Bruxelles, Belgium*
(Received 3 April 1998)

We argue that for QCD in the limit of a large number of colors, the axial U(1) symmetry of massless quarks is effectively restored at the deconfining phase transition. If this transition is of second order, metastable states in which parity is spontaneously broken can appear in the hadronic phase. These metastable states have dramatic signatures, including enhanced production of η and η' mesons, which can decay through parity violating decay processes such as $\eta \to \pi^0\pi^0$, and global parity odd asymmetries for charged pions. [S0031-9007(98)06613-7]

PACS numbers: 11.10.Wx, 11.30.Er, 12.38.Mh, 12.39.Fe

It may be possible to observe the phase transition(s) from hadronic to quark and gluon degrees of freedom through the collisions of heavy nuclei at ultrarelativistic energies. In the region of central rapidity, the relevant phase transitions are those at nonzero temperature; these phase transitions can be studied by numerical simulations of lattice gauge theory. At present, simulations indicate that for three colors coupled to light quarks, there is at most one phase transition, controlled by the chiral

show that metastable states with spontaneous parity violation arise in the hadronic phase, and would produce striking experimental signatures.

The large N limit of SU(N) gauge theories is believed to be a reasonable approximation even for $N = 3$ [8]. We assume that confinement holds for all N, with the masses of mesons and glueballs of order one as $N \to \infty$; interactions between mesons and/or glueballs are suppressed by powers of $1/N$.

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

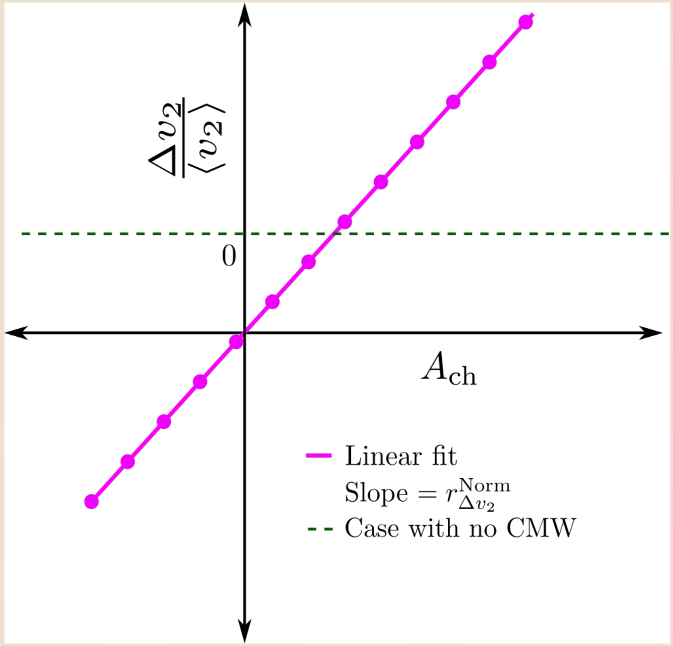
Experimental observable

✓ **Charge dependent elliptic flow**

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

✓ **Normalised slope**

$$r_{\Delta v_2}^{Norm} = \frac{d\left(\frac{\Delta v_2}{\langle v_2 \rangle}\right)}{d A_{ch}}$$



Phys.Rev.Lett. 107 (2011) 052303

✓ **Background**

- Local charge conservation (LCC)
- Can be probed by similar measurement with v_3

Phys. Lett. B 726, (2013) 239-243

✓ ***CMW SIGNAL***

- $r_{\Delta v_2}^{Norm} > 0$
- $r_{\Delta v_2}^{Norm} > r_{\Delta v_3}^{Norm}$

ALICE detector

- ✓ <u>Inner Tracking System (ITS)</u>
- *Tracking*
- *Vertexing*

ALICE, JINST 3 (2008) S08002

- ✓ <u>Time Projection Chamber (TPC)</u>
- *Tracking and vertexing*
- *Momentum measurement*
- *Particle Identification (PID)*

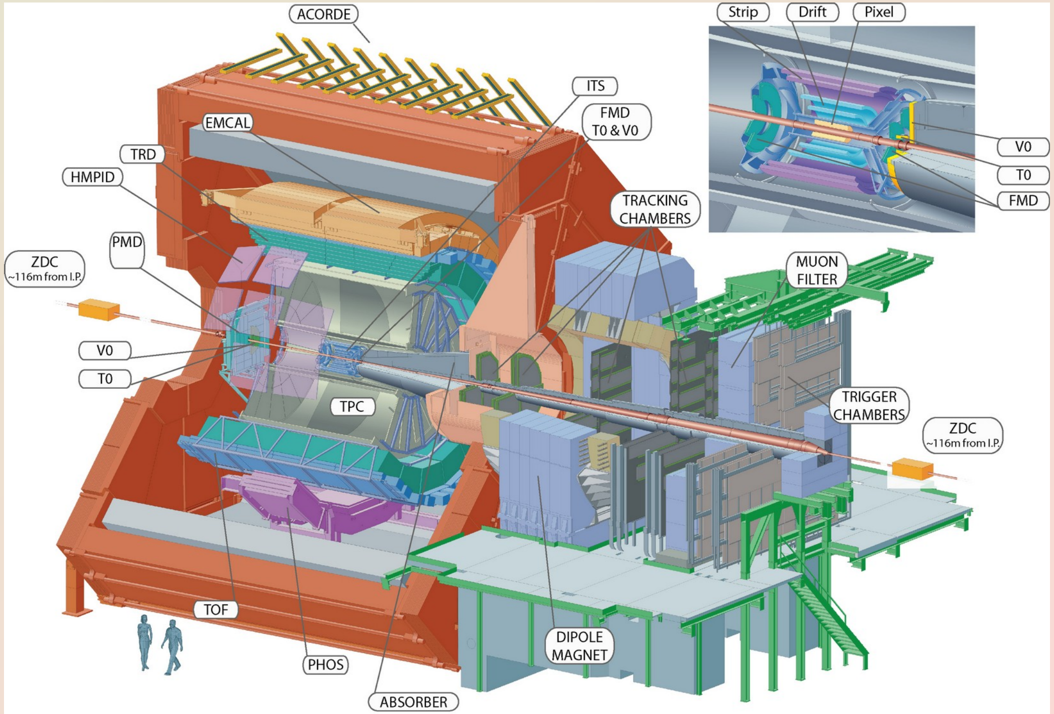
ALICE, Nucl.Instrum.Meth.A 622 (2010) 316-367

- ✓ <u>Time Of Flight (TOF)</u>
- *Particle Identification (PID)*

ALICE, CERN-LHCC-2000-012

- ✓ <u>V0 detectors (V0A & V0C)</u>
- *Centrality estimator*
- *Trigger*

ALICE, JINST 8 (2013) P10016



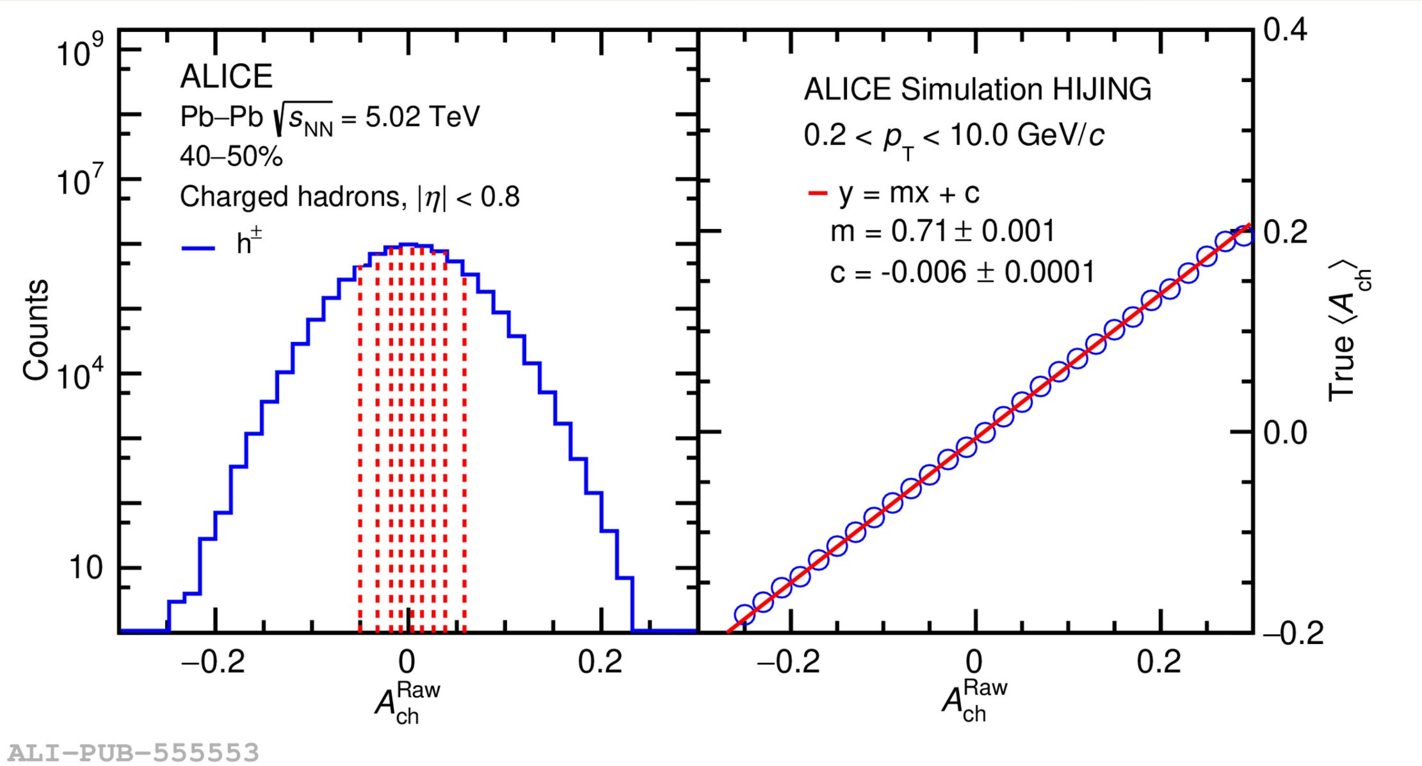
https://alice-figure.web.cern.ch/node/3400

Analysis details

System	Pb-Pb
Center of mass energy (TeV)	5.02
Total No. of events	240 million
Particles	Unidentified hadrons, pions, kaons and protons
Flow calculation method	Q-cumulant *Phys.Rev.C 83 (2011) 044913*
Flow calculation kinematics	$0.2 < p_T < 2.0$ GeV/c
Centrality	0-60 % *ALICE, Phys. Rev. C 88 (2013) 044909*
A_{ch} kinematics	$p_T > 0.2$ GeV/c, $\|\eta\| < 0.8$

Charge asymmetry

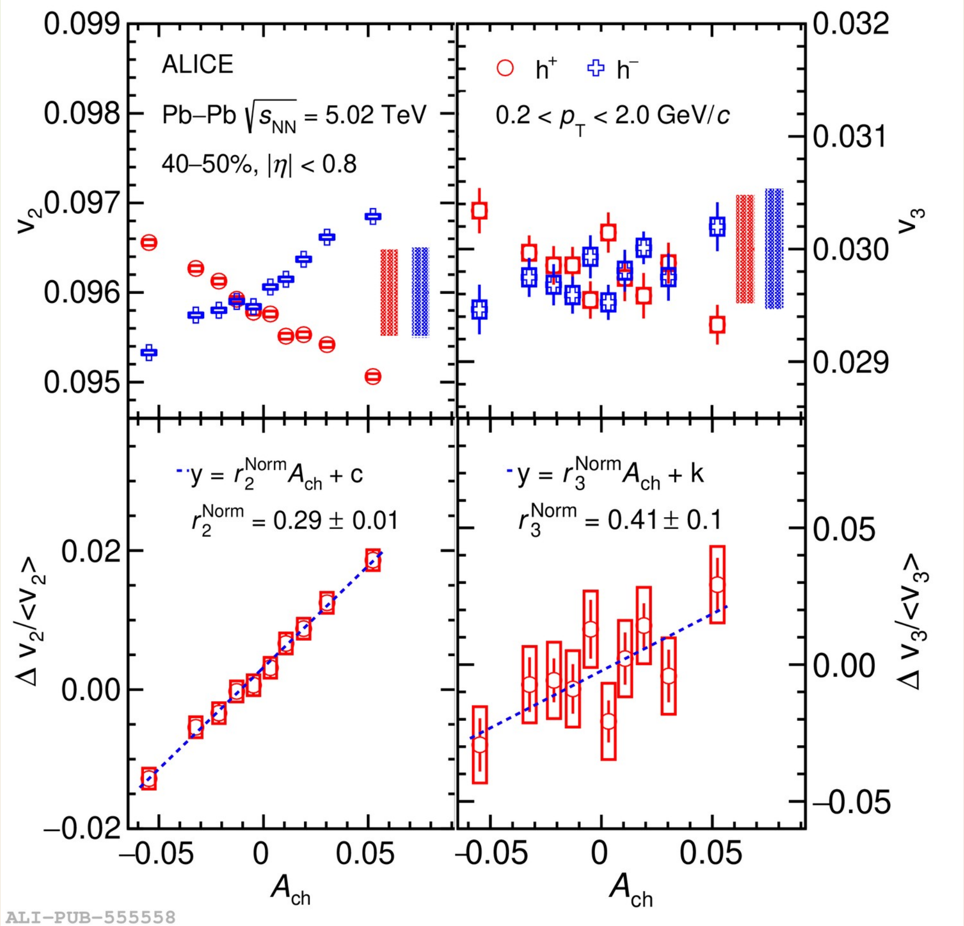
$$A_{ch} = \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$



- ✓ Flow coefficients are calculated in quantile bins of charge asymmetry
- ✓ X axis is shifted according to pol1 function

ALICE, JHEP 12 (2023) 067

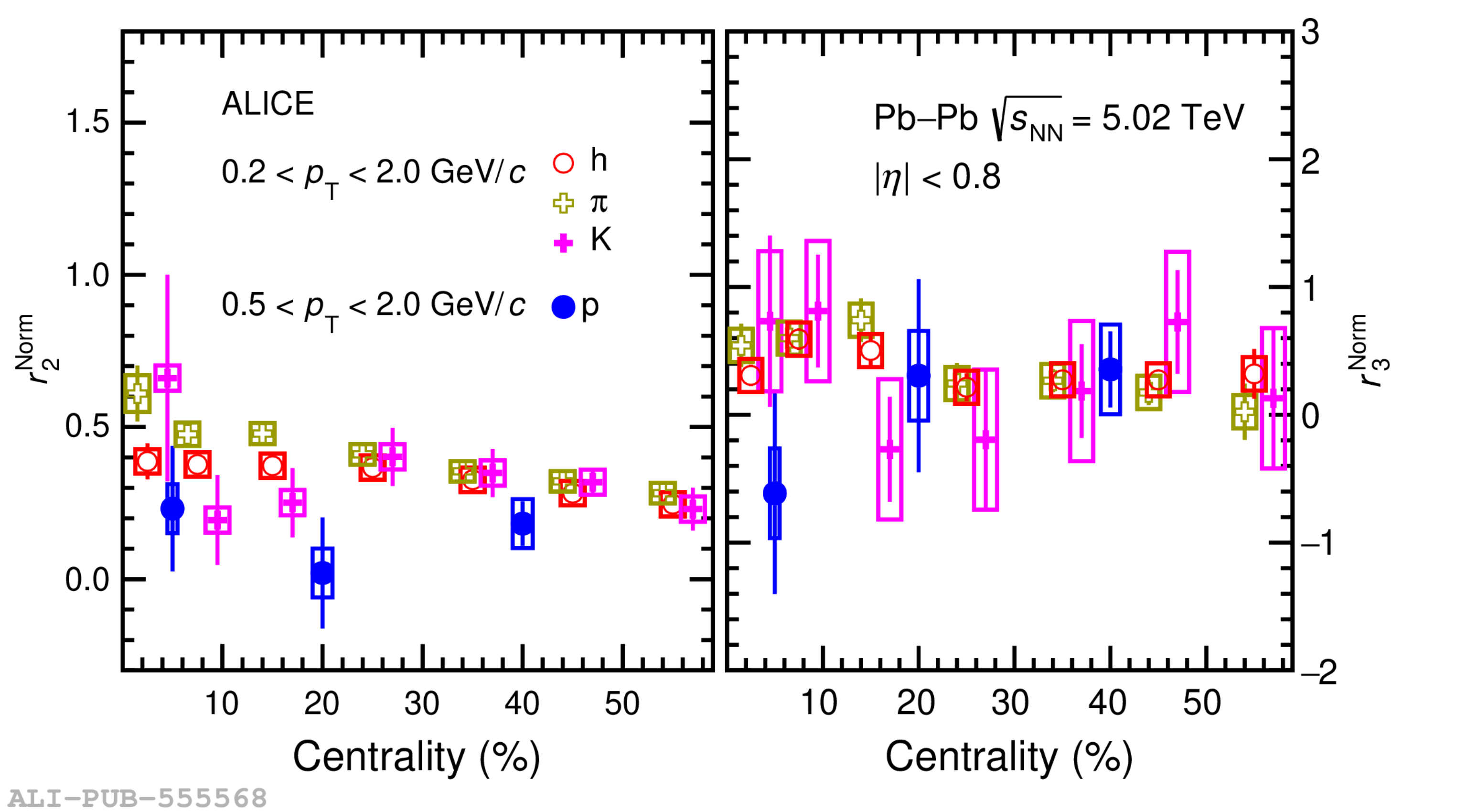
Flow coefficients



- ✓ Decreasing (increasing) trend of v_2 for positive (negative) hadrons
- ✓ Same trend observed for v_3 but with larger fluctuations
- ✓ $r_{\Delta v_2}^{Norm} > 0, \quad r_{\Delta v_3}^{Norm} > 0$
- ✓ $r_{\Delta v_3}^{Norm} > r_{\Delta v_2}^{Norm}$

ALICE, JHEP 12 (2023) 067

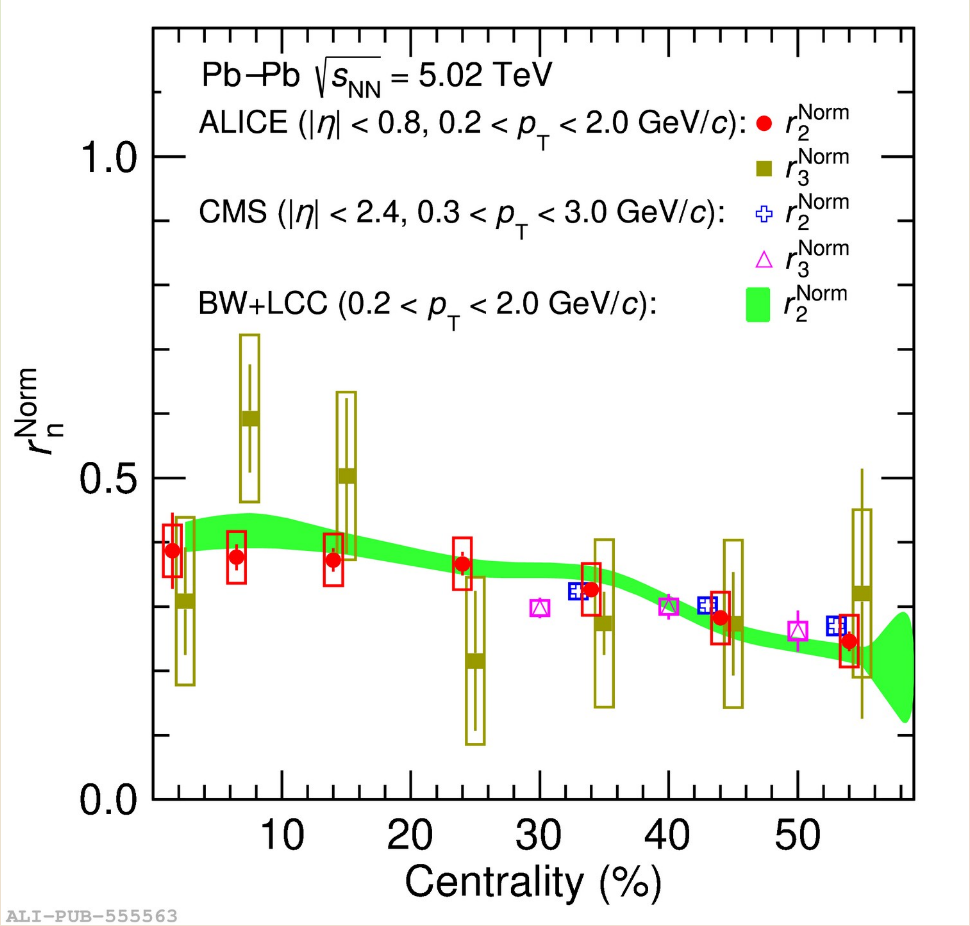
Normalised slopes



- ✓ Normalised slopes are consistent with each other within uncertainties
- ✓ Experimental input for theoretical calculations

ALICE, JHEP 12 (2023) 067

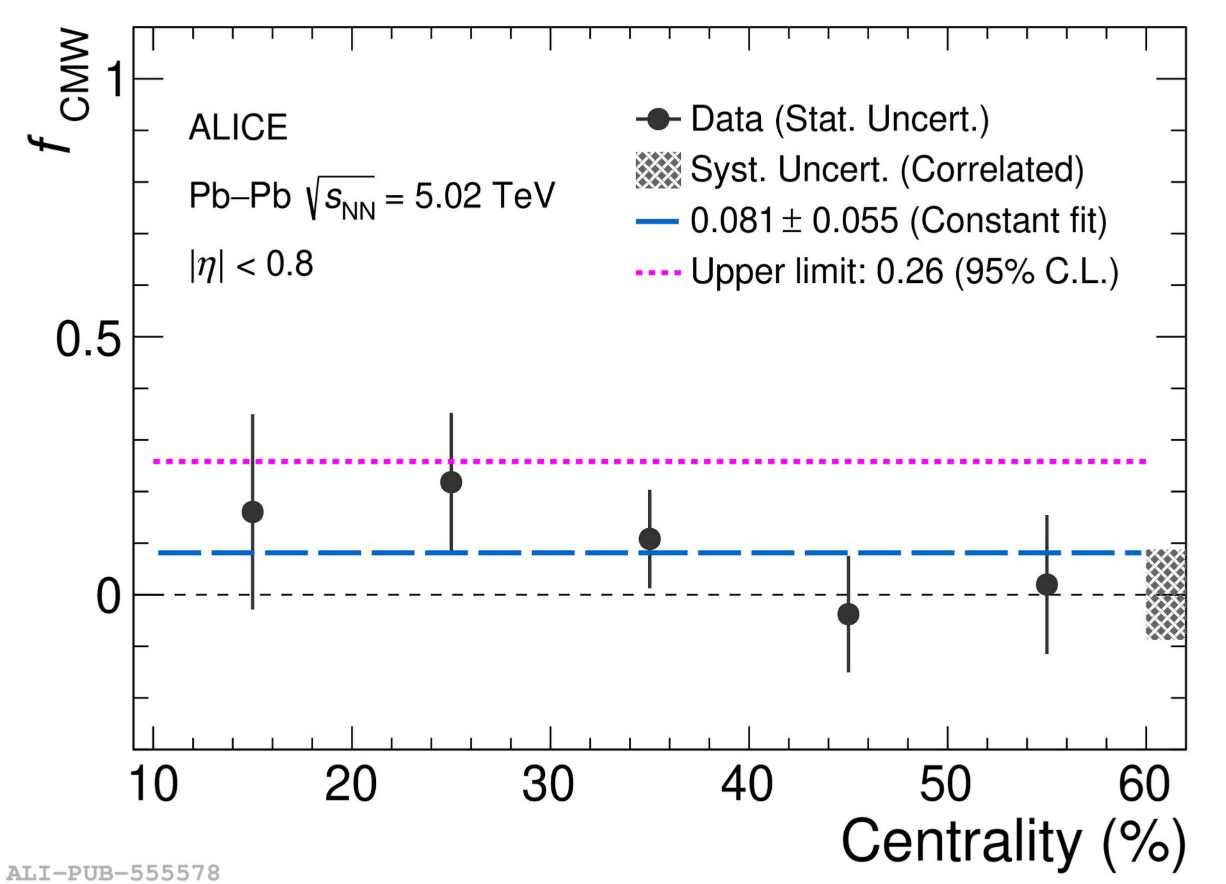
Comparison with CMS and model



- ✓ ALICE and CMS results are consistent within uncertainties
- ✓ Measurements can be explained by background only scenario modeled by BW+LCC

ALICE, JHEP 12 (2023) 067
Phys. Rev. C 107, L031902
CMS, Phys.Rev.C 100 (2019) 6, 064908

Estimation of upper limit



- ✓ Upper limit = 26% at 95% confidence level

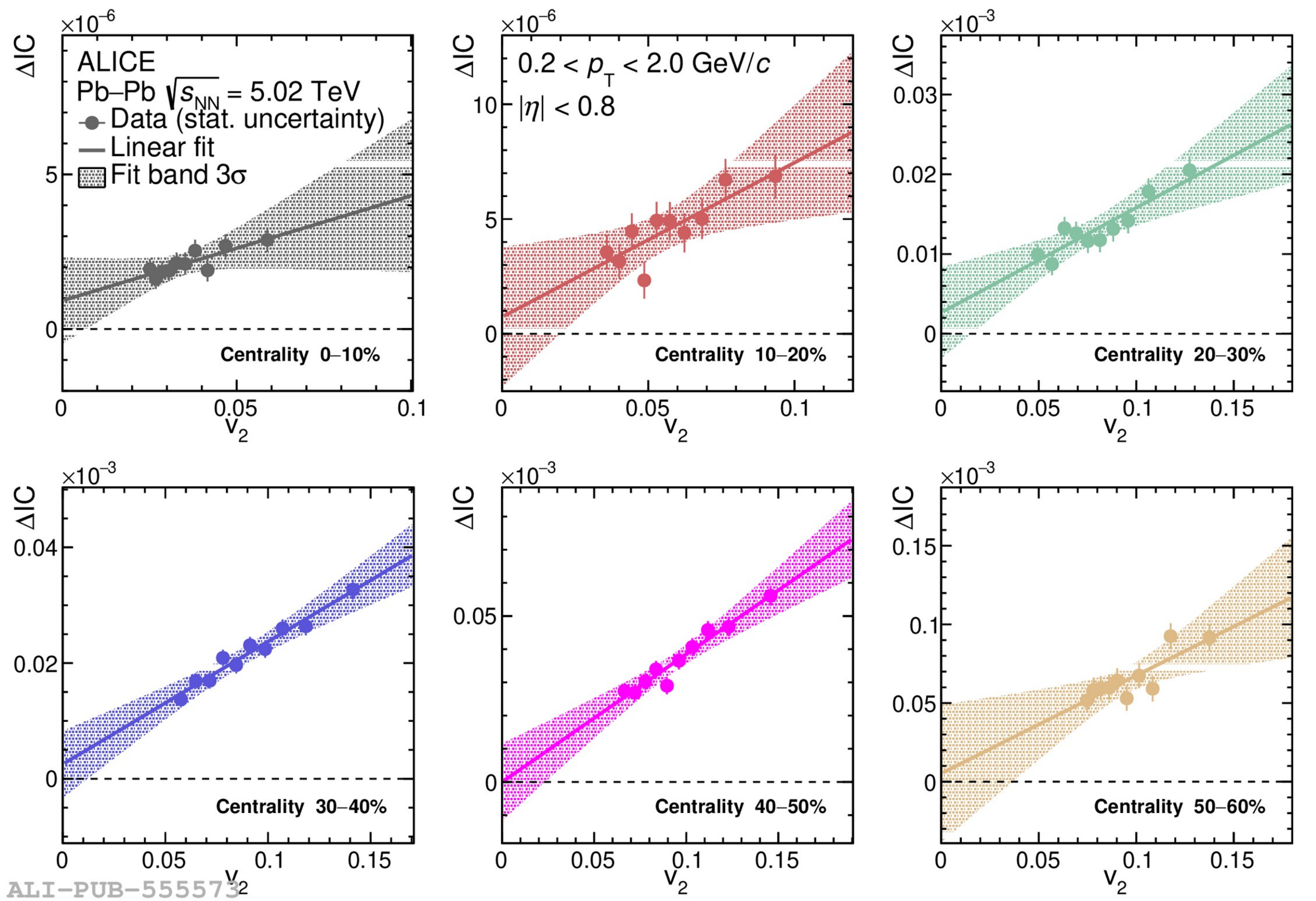
ALICE, JHEP 12 (2023) 067

Summary

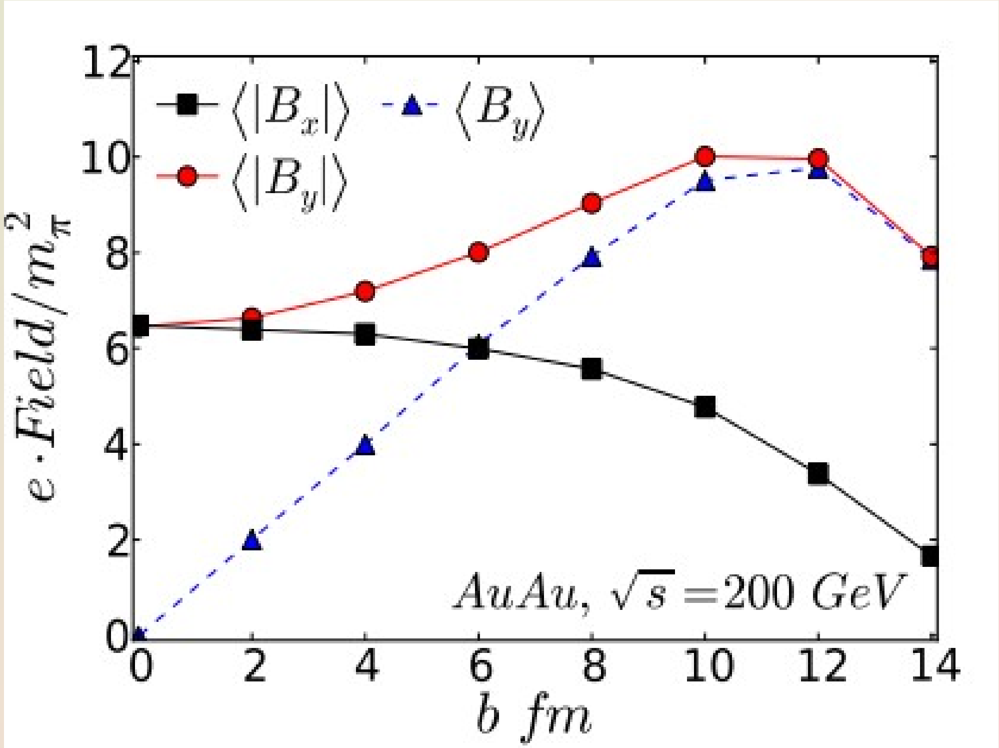
- ✓ v_2 and v_3 are calculated as a function of net charge asymmetry separately for positive and negative identified and unidentified hadrons
- ✓ Normalised differences of both v_2 and v_3 between positive and negative hadrons have been fitted with pol1 function to obtain the respective $r^{Norm}_{\Delta v_2}$ and $r^{Norm}_{\Delta v_3}$ slopes
- ✓ Positive values for both of the normalised slopes are obtained
- ✓ Signal observable $\left(r^{Norm}_{\Delta v_2}\right)$ for CMW is consistent with observable that represents background $\left(r^{Norm}_{\Delta v_3}\right)$
- ✓ BW+LCC model explain the measurements
- ✓ An upper limit of 26% at 95% confidence level is established for CMW signal

Backup

Delta Int. Covariance



Fields



$\langle|B_x|\rangle$
$\langle B_y\rangle$
$\langle|B_y|\rangle$
$e \cdot Field/m_\pi^2$
$AuAu,\ \sqrt{s} = 200\ GeV$
$b\ fm$
0
2
4
6
8
10
12
14