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

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Outline:

- Motivation
- ALICE detectors
- Analysed data, event and track cuts
- Results
- Summary and outlook
Motivation

✔ QCD vacuum: Degenerate

✔ Generates chirality imbalance:
  \[ N_L^f - N_R^f = 2Q_W \text{, } Q_W = \text{Winding number} \]

✔ Axial and vector current:

✔ Induces parity odd domains

Chiral Magnetic Effect (CME):
\[ j_\nu = \frac{N_c e}{2\pi^2} \mu_A B \]

Chiral Separation Effect (CSE):
\[ j_A = \frac{N_c e}{2\pi^2} \mu_\nu B \]

Chiral Magnetic Wave: Combination of electric charge (CME) and chiral charge density (CSE)

Anisotropic flow

✔ Spatial anisotropy of the interacting system results into momentum anisotropy

✔ Characterised by:

\[
E \frac{d^3 N}{d^3 p} = \frac{d^2 N}{2 \pi p_T dp_T dy} \left( 1 + \Sigma 2 v_n \cos \left[ n \left( \varphi - \Psi_{n,R} \right) \right] \right)
\]

✔ 2\textsuperscript{nd} fourier coefficient \( v_2 \): elliptic flow

Observable for chiral magnetic wave studies

$\Delta v_2 = \frac{A_{ch}}{2}$ with $A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}$

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

where $\left<v_2\right> = \frac{v_2^h + v_2^+}{2}$

**Possible background**: Local charge conservation
Minimise the background: Measurement in low $p_T$
Probing the background: Similar measurement with $v_3$

**Possible candidate to look at**: Pions due to less difference in absorption cross section between particles and antiparticles
ALICE detector

V0: V0A (2.8 < \( \eta \) < 5.1) & V0C (-3.7 < \( \eta \) < -1.7)
✔ Trigger, centrality

TimeProjectionChamber (TPC):
(| \( \eta \) | < 0.9)
✔ Primary vertex and tracking
✔ Momentum measurement
✔ PID through dE/dx
### Analysed data, event and track selection

<table>
<thead>
<tr>
<th>Collision system and energy</th>
<th>Pb-Pb, 5.02 TeV</th>
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</thead>
<tbody>
<tr>
<td>No. of events</td>
<td>~60M</td>
</tr>
<tr>
<td>PID selection of $\pi$</td>
<td>$</td>
</tr>
<tr>
<td>Hadron selection</td>
<td>$0.2 &lt; p_T &lt; 1.0$ GeV/c</td>
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<tr>
<td>Subevents</td>
<td>$</td>
</tr>
<tr>
<td>Charge Asymmetry ($A_{ch}$)</td>
<td>$0.2 &lt; p_T &lt; 10$ GeV/c, $</td>
</tr>
</tbody>
</table>
$v_2$ and $v_3$ vs $A_{ch}$ in 40-50 % centrality for hadrons

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

$r_{\Delta v_n}^{\text{Norm}} = \frac{d\left(\frac{\Delta v_n}{\langle v_n \rangle}\right)}{dA_{ch}}$

Finite $r_{\Delta v_2}^{\text{Norm}}$ and $r_{\Delta v_3}^{\text{Norm}}$ is observed
$r_{\Delta v_3}^{\text{Norm}}$ has large uncertainties

✓ $r_{\Delta v_2}^{\text{Norm}}$ is compatible with $r_{\Delta v_3}^{\text{Norm}}$ for both hadrons and pions
Comparison of $r_{\Delta v_2}^{\text{Norm}}$ in ALICE, STAR and CMS

**Comparison with STAR**

<table>
<thead>
<tr>
<th>ALICE Preliminary</th>
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<tbody>
<tr>
<td>Pb-Pb, $s_{NN} = 5.02$ TeV</td>
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<td>$\pi$, $</td>
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<table>
<thead>
<tr>
<th>STAR Preliminary</th>
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<tbody>
<tr>
<td>Au-Au, $s_{NN} = 200$ GeV</td>
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<tr>
<td>$\pi$, $</td>
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</table>

- ✔ $r_{\Delta v_2}^{\text{Norm}}$, $\pi$(ALICE) $\approx r_{\Delta v_2}^{\text{Norm}}$, $\pi$(CMS)
- ✔ $r_{\Delta v_2}^{\text{Norm}}$, $h$(ALICE) $< r_{\Delta v_2}^{\text{Norm}}$, $h$(STAR)

**Comparison with CMS**

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<th>CMS, Pb-Pb, $s_{NN} = 5.02$ TeV</th>
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<td>h, $</td>
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No observed discrepancies in \( r_{\Delta v_3}^{\text{Norm}} \) between ALICE, STAR and CMS, but uncertainties are large.
Summary

✔ First measurement of normalised $\Delta v_2$ and $\Delta v_3$ slope of pions and of charged hadrons in Pb-Pb collision in ALICE.

✔ $r_{\Delta v_2}^{\text{ALICE}} \approx r_{\Delta v_2}^{\text{CMS}}$ (ALICE)

✔ $r_{\Delta v_2}^{\text{ALICE}} < r_{\Delta v_2}^{\text{STAR}}$ (STAR)

✔ $r_{\Delta v_3}^{\text{ALICE}}$ has large uncertainties

✔ $r_{\Delta v_2}^{\text{ALICE}}$ is compatible with $r_{\Delta v_3}^{\text{ALICE}}$

Outlook

✔ Analysis to be done in high statistics data taken in 2018
Comparison of $r^{\text{Norm}}_{\Delta v_n}$ between hadrons, pions

ALICE Preliminary

$Pb-Pb \ \| s_{NN} = 5.02$ TeV

$\pi$, $0.2 < p_T < 0.5$ GeV/$c$

$h$, $0.2 < p_T < 1.0$ GeV/$c$

$r^{\text{Norm}}_{\Delta v_2}$

$r^{\text{Norm}}_{\Delta v_3}$

has large uncertainties

$r^{\text{Norm}}_{\Delta v_3}$ $h$ is compatible with $r^{\text{Norm}}_{\Delta v_3} \pi$

$r^{\text{Norm}}_{\Delta v_2} h \approx r^{\text{Norm}}_{\Delta v_2} \pi$

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\( v_2 \) and \( v_3 \) vs \( A_{ch} \) in 40-50 \% centrality for pions

\[
A_{ch} = \frac{N^+ - N^-}{N^+ + N^-}
\]

\[
r_{\Delta v_n}^{Norm} = \frac{d \left( \frac{\Delta v_n}{\langle v_n \rangle} \right)}{d A_{ch}}
\]

Finite \( r_{\Delta v_2}^{Norm} \) and \( r_{\Delta v_3}^{Norm} \) is observed.
The strong magnetic field along with non zero electric and axial charge density leads to vector and axial currents called **Chiral Magnetic Effect** and **Chiral Separation Effect** respectively.

**Chiral Magnetic Effect:**
\[ j_v = \frac{N_c e}{2\pi^2} \mu_A B \]

**Chiral Separation Effect:**
\[ j_A = \frac{N_c e}{2\pi^2} \mu_v B \]

**Chiral Magnetic Wave:**
Combination of electric charge and chiral charge density.
Motivation

✔ QCD vacuum: Degenerate

✔ Generates chirality imbalance:
\[ N_L^f - N_R^f = 2 Q_W, \quad Q_W = \text{Winding number} \]

✔ Axial current:
\[
\partial_\mu j_A^\mu = -\frac{e^2}{16\pi^2} \epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} - \frac{g^2}{16\pi^2} \text{tr} \epsilon^{\mu\nu\rho\sigma} G_{\mu\nu} G_{\rho\sigma}
\]

✔ Induces parity odd domains

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Chiral Magnetic Effect (CME): \[ j_\nu = \frac{N_c e}{2\pi^2} u_A B \]

Chiral Separation Effect (CSE): \[ j_A = \frac{N_c e}{2\pi^2} u_\nu B \]

Chiral Magnetic Wave: Combination of electric charge (CME) and chiral charge density (CSE)