Charge Asymmetry Dependence of Anisotropic Flow in pPb and PbPb collisions with CMS

- and its implication to the Chiral Magnetic Wave

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On behalf of CMS collaboration

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Strong Magnetic Field in heavy-ion collisions

- Strong B field in non-central collisions
  - RHIC - $10^{19}$ Gauss
  - LHC – $14 \times$ RHIC
  - Induces number of novel quantum phenomena in QGP

- Chiral anomaly in QCD
Imbalance in left/right handed quarks + Magnetic Field

\[ \vec{J} = \frac{e^2}{2\pi^2} \mu_5 \vec{B} \]
Anomalous Chiral Effects

Analogous to Ohm’s law \[ \vec{J} = \sigma \vec{E} \]

\[ \vec{j}_V = \frac{N_c e}{2\pi^2} \mu_A \vec{B} \]  

\[ \vec{j}_A = \frac{N_c e}{2\pi^2} \mu_V \vec{B} \]

- **Chiral Magnetic Effect (CME)**
  - Vector charge separation along B (electric)

- **Chiral Separation Effect (CSE)**
  - Axial charge separation along B
Probing (novel (long, range (correlation on (phenomena (in (pPb (collision with (identified (particles (at (CMS (Zhenyu 'Chen (Rice 'University) for (the (CMS (Collaboration)) for (the (CMS (Collaboration))

Hot Quarks Workshop 2014

07/02/2017

Coupling of electric and axial charge densities

\[
\left( \partial_0 \mp \partial_1 v_\chi - D_L \partial_1^2 \right) j_L^{0, R} = 0
\]
Chiral Magnetic Wave

\[ j_A = \frac{N_c e}{2\pi^2} \mu_v B \]

\[ j_v = \frac{N_c e}{2\pi^2} \mu_A B \]

Coupling of electric and axial charge densities

\[ (\partial_0 \pm \partial_1 \nu_{\chi} - D_L \partial_1^2) j_L^0, R = 0 \]
Event-by-Event fluctuating charge asymmetry parameter

\[ A_{\text{ch}} = \frac{N^+ - N^-}{N^+ + N^-} \]
Event-by-Event fluctuating charge asymmetry parameter

\[ A_{ch} = \frac{N^+ - N^-}{N^+ + N^-} \]
Event-by-Event fluctuating charge asymmetry parameter

\[ A_{ch} = \frac{N^+ - N^-}{N^+ + N^-} \]
Event-by-Event fluctuating charge asymmetry parameter

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

\[ \frac{d(N_+ - N_-)}{d\phi} = (\bar{N}_+ - \bar{N}_-)[1 - r_e \cos(2\phi)] \]

\[ \frac{dN_{\pm}}{d\phi} = \bar{N}_{\pm} [1 + (2v_2 + r_e A) \cos(2\phi)] \]

\[ \nu_{2,\pm} \approx \nu_{base,2,\pm} \mp r_e A_{ch} / 2 \]
Previous Measurements

STAR

ALICE
(Phys.Rev. C93 (2016))
1. CMW in a smaller system (pPb)

\[ \langle (eB)^2 \cos[2(\psi_B - \Psi_{RP})] \rangle \]

Smaller B field  B field direction ≠ Reaction Plane

arXiv:1610.00263
Z.Tu’s talk at 3pm!
2. Third Order Harmonics

- CMW mechanism predicts the slope of the third harmonic to be zero
- Orientation of the triangular flow has no correlation with RP
- Measurement of $v_3$ slope in PbPb - crucial in testing CMW
1. CMW in pPb and PbPb

Significant nonzero slope observed in pPb: Challenges CMW!
1. CMW in pPb and PbPb

Significant nonzero slope observed in pPb: Challenges CMW!
1. CMW in pPb and PbPb

![Graph showing CMS preliminary data]

- **Similar normalized pPb and PbPb Slope**
- In all multiplicity ranges

**Challenges CMW**

- pPb $\sqrt{s_{NN}} = 5.02$ TeV
- PbPb $\sqrt{s_{NN}} = 5.02$ TeV

**Graph Details**

- $0.3 \leq p_T < 3.0$ GeV/c
- $r_{\text{norm}}(v_2)$
- $N_{\text{trk}}^{\text{offline}}$
- $N_{\text{trk}}^{\text{offline}}$ vs $r_{\text{norm}}(v_2)$

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Neutral cluster decays locally into charged pairs with a certain $\eta$ separation
Clusters with small $P_T \rightarrow$ More likely to contribute to $A_{ch}$

A. Bzdak, P. Bozek
Local Charge Conservation

When $P_T$ is small, $V_2$ is proportional to $P_T$


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1. Clusters with small $P_T \rightarrow$ More likely to contribute to $A_{ch}$
2. When $P_T$ is small, $V2$ is proportional to $P_T$

\[ v_{2, \pm}^{\pm} \sim v_{2, \pm}^{base} \mp r_e A_{ch}/2 \]
1. Clusters with small $P_T$ → More likely to contribute to $A_{ch}$
2. When $P_T$ is small, $V_3$ is proportional to $P_T$

Larger $A_{ch}$

More $h^+$ with small $P_T$

Less $h^-$ with small $P_T$

Smaller $V_3$ for $h^+$

Larger $V_3$ for $h^-$

$V_3$ has same $A_{ch}$ dependence as $V_2$
Prediction of LCC

- LCC predicts the same pattern as in $V_2$ vs $A_{ch}$ for $P_T$ as a function of $A_{ch}$

- $(V_3 \text{ slope})/(V_2 \text{ slope}) \sim V_3/V_2$ - Same after normalizing
  - CMW predicted no $V_3$ slope
Mean PT show the same pattern as V2: Supports LCC interpretation!
Pt as a function of Ach

- The normalized PT slope of pPb and PbPb are similar
The normalized PT slope of pPb and PbPb are similar.
V₃ as a function of A_{ch}

Normalized V2 slope and V3 slope are almost identical in PbPb!
(Challenges CMW interpretation, Supports LCC interpretation)
V3 as a function of Ach

Normalized $v_2$ and $v_3$ are almost identical in all centrality ranges

- Supports LCC interpretation!

- Challenges CMW interpretation!
Summary

- Charge Asymmetry dep. of V_n measured in pPb and PbPb at CMS
  - 1. Significant nonzero v2 slope has been observed in pPb
  - 2. Normalized v2 slope parameters of PbPb and pPb are similar
  - 3. Normalized slope parameters of v2 and v3 are almost identical in PbPb
  - 4. Mean PT shows the same pattern when plotted vs Ach

- The results above support Local charge conservation interpretation and challenge CMW interpretation
Comparison of pPb and PbPb v2 slope

**CMS Preliminary**

$185 \leq N_{\text{trk}}^{\text{offline}} < 220$

$0.3 \leq p_T < 3.0 \text{ GeV/c}$

$|\Delta\eta| > 1$

\[
\frac{V_2^- - V_2^+}{V_2^- + V_2^+} \quad \text{ versus } \quad \text{Corrected } A_{\text{ch}}
\]

PbPb $r_{\text{norm}}^v (v_2) = 0.108 \pm 0.005$

pPb $r_{\text{norm}}^v (v_2) = 0.149 \pm 0.008$

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Apple-to-apple comparison with ALICE

CMS Preliminary

Cent. 30-40%
0.2 \leq p_T < 5.0 \text{ GeV/c}
|\eta| < 0.8

\frac{V^{-} \cdot V^{+}}{V_{n}^{+} + V_{n}^{-}}

r^{\text{norm}}(ALICE) = 0.137 \pm 0.013
r^{\text{norm}}(CMS) = 0.131 \pm 0.002

Corrected $A_{ch}$
The distribution of Charge Asymmetry

**Figure:**

- **Title:** CMS Preliminary
- **Y-axis:** Observed $A_{ch}$
- **X-axis:** PbPb 5.02 TeV
- **Legend:**
  - Cent. 30-40%
  - $0.3 \leq p_T < 3.0$ GeV/c
  - $|\eta| < 2.4$

**Details:**

- The histogram shows the distribution of $A_{ch}$ in different centrality classes and $p_T$ ranges.
- The CMS logo and the University of Chicago logo are present.

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