Search for the Chiral Magnetic Effect at the LHC with CMS



- PRL 118, 122301 (2017)
- arXiv:1708.01602 (submitted to PRC)



Wei Li (Rice University) for the CMS collaboration



Search for the CME in AA $\gamma \equiv \left\langle \cos\left(\phi_{\alpha} + \phi_{\beta} - 2\psi_{RP}\right)\right\rangle = \left\langle \cos\left(\Delta\phi_{\alpha}\right)\cos\left(\Delta\phi_{\beta}\right)\right\rangle$ $\left\langle \sin\left(\Delta\phi_{\alpha}\right)\sin\left(\Delta\phi_{\beta}\right)\right\rangle$ റ്റ് 0.6 ×<u>10</u>-3 റ്പ്പറ്റ് പ്പറ്റ് PRL 110 (2013) 012301 same opp. ALICE Pb-Pb $@\sqrt{s_{NN}} = 2.76 \text{ TeV}$ Ο STAR Au-Au @ $\sqrt{s_{NN}} = 0.2$ TeV $\langle \cos(\varphi_{\alpha} + \varphi_{\beta} - 2) \rangle$ OS (ALICE) same+opp. mean ¢☆ \bigtriangledown o☆ -0.2 -0.4 SS $\left<\cos(\phi_{\alpha}+\phi_{\beta}-2\phi_{c})\right>_{HIJING}$ / V₂{2} -0.6 CME expectation (same charge [13]) 0 10 20 30 40 50 60 70 centrality, %



Data consistent with charge separation from CME

Largely unconstrained

$$\Delta \gamma (\gamma^{os} - \gamma^{ss}) =$$
 SIGNAL + **BKG**

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- ✓ New systems and new strategies!



A litmus test of the CME (any *B* related observable)

<u>Small system (pPb) strikes again!</u>

Charge separation signal: $\Delta \gamma \sim \langle B^2 \cos 2(\Psi_B - \Psi_{EP}) \rangle$



A litmus test of the CME (any *B* related observable)

$\Delta \gamma$ in pPb vs PbPb



Nearly **identical** in pPb and PbPb \Rightarrow A challenge to the CME for $\Delta \gamma$ in AA at the LHC!?

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Nearly **identical** in pPb and PbPb \Rightarrow *A challenge to the CME for* $\Delta \gamma$ *in AA at the LHC!?* But why BKGs are identical? – A new challenge?! Questions/Requests from Huan Zhong – experimental summary @ QCD chirality 2017

CMS γ(OS-SS)/v_{2C} (pPb) ~ (PbPb) peripheral Coincidental or not?

We urge CMS to publish detailed centrality dependence of OS and SS γ Correlators !

What does it take for ALICE to constrain CME fraction to the level of 10% ?

Two major questions yet to be answered:

- i. What's the exact origin of BKG in $\Delta \gamma$?
- ii. Any CME signal, if BKG is removed?

CMS collaboration arXiv:1708.01602



Particle **α**, **β** sliced within lηl < 2.4 (Tracker) Particle **c** fixed at 4.4 < lηl < 5 (HF)

 $|\eta_c - \eta_{\alpha,\beta}| > 2$ to minimize Ψ_2 -indep. BKG or "nonflow"

Origin of background in $\Delta \gamma$?

$$\mathbf{\gamma} = \left\langle \cos\left(\phi_{\alpha} + \phi_{\beta} - 2\Psi_{EP}\right)\right\rangle \cong \frac{\left\langle \cos\left(\phi_{\alpha} + \phi_{\beta} - 2\phi_{c}\right)\right\rangle}{V_{2,c}}$$

 Ψ_{EP} -independent

between \mathbf{a} ($\boldsymbol{\beta}$) and \mathbf{c}

short-range correlations (jets, clusters etc.)

"Nonflow"

$$\Psi_{\text{EP}}$$
-dependent

between **α** and **β** (jet, clusters etc.)

both correlate to Ψ_{EP} (elliptic flow)

Charge-dep. due to charge conservation, ordering etc.





Ψ_{FP} -independent BKG $\left\langle \cos 2\left(\phi_{\alpha}-\Psi_{EP}\right)\right\rangle \cong \frac{\left\langle \cos 2\left(\phi_{\alpha}-\phi_{c}\right)\right\rangle}{v_{2,c}}$ CMS (b) 5.02 TeV pPb 8.16 TeV 0.15 V_n^{sub} on=2 **□**n=3 Ś , < ال∆ا 0.05 v n=4 200 300 400 100 0 N^{offline} PRL 120, 092301 (2018)

Negligible with (1) large $|\Delta \eta|$ and (2) high multiplicities



$$\Delta \gamma^{BKG} = \kappa \cdot \nu_2 \cdot \Delta \delta$$

where $\delta \equiv \left\langle \cos(\phi_{\alpha} - \phi_{\beta}) \right\rangle$

(two-particle corr.)



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Lect. Notes Phys. 871 (2013) 503

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New systems and new strategies! (pPb)

New strategy (I): higher-order correlator

3rd-order harmonic correlator

$$\gamma_{123} \equiv \left\langle \cos\left(\phi_{\alpha} + 2\phi_{\beta} - 3\Psi_{3}\right) \right\rangle$$

CME signal free: no charge separation w.r.t. Ψ_3 For Ψ_3 -dep. BKG:

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Generalize to all orders

$$\gamma_{1,n-1;n} = \left\langle \cos(\phi_{\alpha} + (n-1)\phi_{\beta} - n\Psi_n) \right\rangle$$
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$$\Delta \gamma_{123} = \kappa \cdot v_3 \cdot \Delta \delta$$

If BKG dominant (i.e., for pPb)

$$\frac{\Delta \gamma_{112}}{v_2 \delta} \approx \frac{\Delta \gamma_{123}}{v_3 \delta} \dots$$





Differential data in $\Delta\eta$, Δp_T and \overline{p}_T for all centrality/N_{trk} in *arXiv:1708.01602*



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 $\Delta \delta^{\text{pPb}} > \Delta \delta^{\text{PbPb}}$ $(v_2^{\text{pPb}} < v_2^{\text{PbPb}})$ \downarrow $\Delta \gamma^{\text{pPb}} \approx \Delta \gamma^{\text{PbPb}}$





Can we directly see the linearity: $\Delta \gamma^{BKG} \sim v_2$?



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Vary event Ellipticity within a centrality/N_{trk} class



PbPb, various centralities



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 $\Delta \delta$ deviates from constant at high q₂/v₂





<u>Upper limits on the $\Delta \gamma^{\text{CME}}$ at the LHC</u>



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(systematic limited!)

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New approaches also provide insights to future RHIC RHIC program (**NOT** 100% compatible with BKG?)

Outlook at the CMS/LHC



CME: higher precision with full centrality scan **Magnetic field:** D₀ directed flow

CVE: baryon number separation (Λ - Λ , Λ -p) **Vorticity:** Λ polarization (transverse and longitudinal)

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Highly rapidity differential!

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Backups





Collective phenomena observed in pPb



Can we learn about other exotic phenomena of QGP using small systems?















<u>Higher-order γ correlator</u>

$$\gamma_{123} \equiv \left\langle \cos\left(\phi_{\alpha} + 2\phi_{\beta} - 3\Psi_{3}\right)\right\rangle$$
$$= \left\langle \cos\left(\phi_{\alpha} - \phi_{\beta}\right)\cos\left(3\phi_{\beta} - 3\Psi_{3}\right)\right\rangle - \left\langle \sin\left(\phi_{\alpha} - \phi_{\beta}\right)\sin\left(3\phi_{\beta} - 3\Psi_{3}\right)\right\rangle$$

 $\langle ab \rangle = \langle a \rangle \langle b \rangle \Rightarrow$ a and b are independent of each other. Factorization if two-particle correlations are EP independent

This is the case in flow-driven BKG scenario, where clusters are first produced and then decay isotropically in their rest frame

Namely, two-particle p.d.f.

$$p(\phi_{\alpha}, \phi_{\beta}, \Psi_{n}) = p(\phi_{\alpha}, \Psi_{n})p(\phi_{\beta}, \Psi_{n}) \Big[1 + C(|\phi_{\alpha} - \phi_{\beta}|)\Big]$$

where
$$p(\phi, \Psi_{n}) = 1 + 2v_{n}\cos n(\phi - \Psi_{n})$$

$$C(|\phi_{\alpha} - \phi_{\beta}|) = c_{1}\cos\Delta\phi + \dots$$

<u>Higher-order γ correlator</u>

The CME contribution to this correlator should be $<a_1^*a_3>$, much smaller than for gamma112.

It could have been tested by pPb data but I have not thought about it before so it's not done in CMS paper.