Electromagnetic fields in small systems

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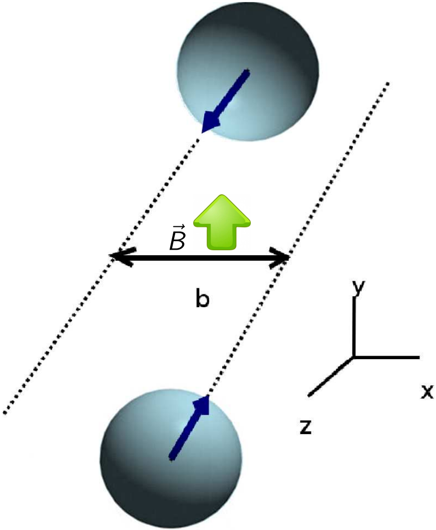
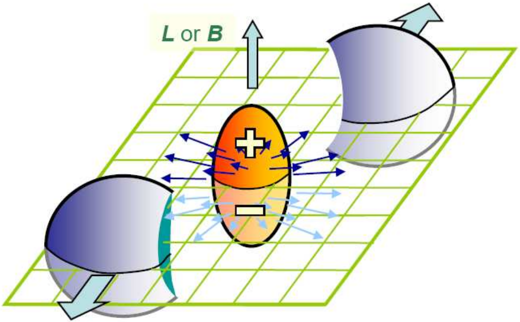
Work in preparation with Piotr Bozek, Adam Bzdak

Strong Magnetic fields in the initial stage

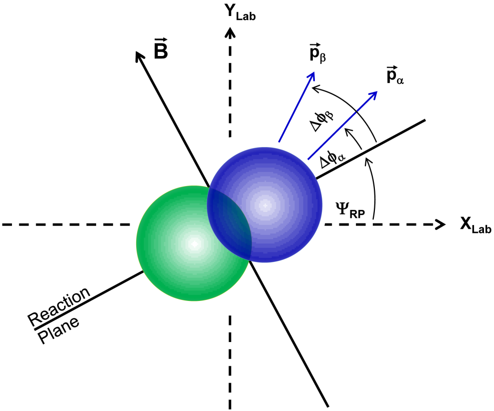


Strong Magnetic fields in the initial stage + Parity odd domains → Chiral Magnetic Effect



Fukushima, Kharzeev, Mclerran, Warringa,..

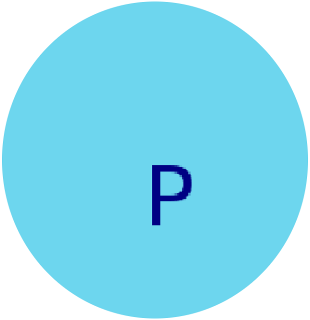
Chiral Magnetic Effect: Observable



$$\gamma^{ab} = \langle cos\left(\phi^a + \phi^b - 2\psi_{RP}\right)\rangle. \qquad (1)$$

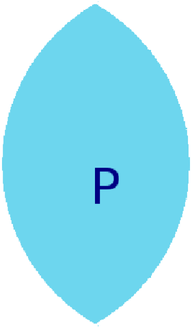
Voloshin 2004

Magnetic field & Ellipticity tied up



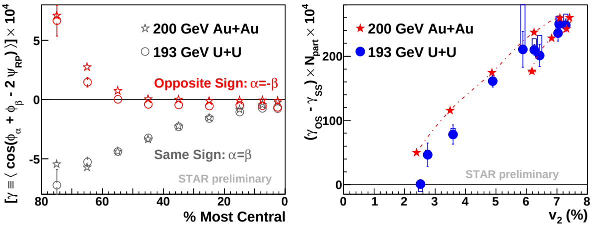
$S = 0 \implies \vec{B} = 0$. For such full overlap collisions, $\epsilon_2 = 0$ as well.

Magnetic field & Ellipticity tied up

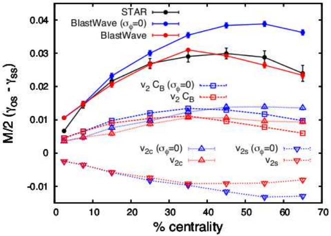


$S \neq 0 \implies \vec{B} \neq 0$. For such mid-overlap collisions, $\epsilon_2 \neq 0$ as well.

CME or v_2 ?

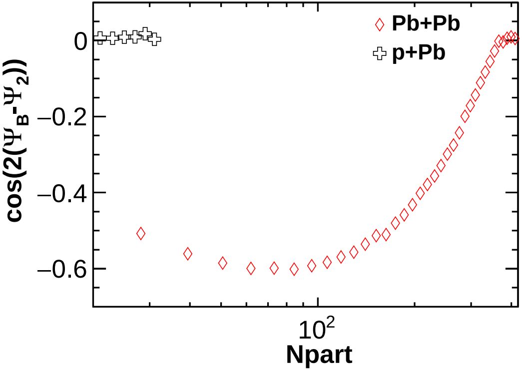


from 1210.5498



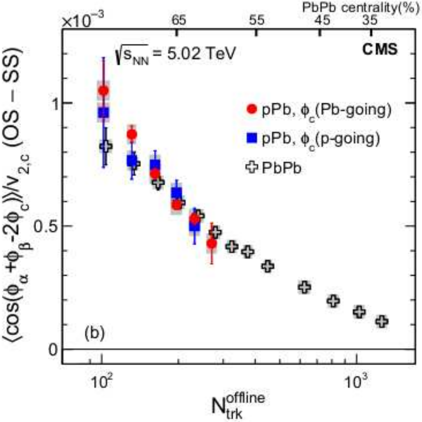
from 1009.4283 (S. Schlichting and S. Pratt)

Pb+Pb vs p+Pb: what is expected ?



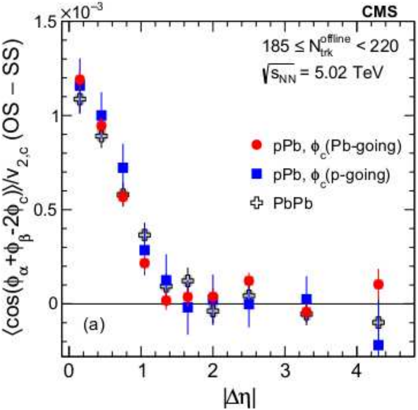
as concluded in 1610.07964

Pb+Pb vs p+Pb: similar correlation observed!



from 1610.00263

Pb+Pb vs p+Pb: similar correlation observed!



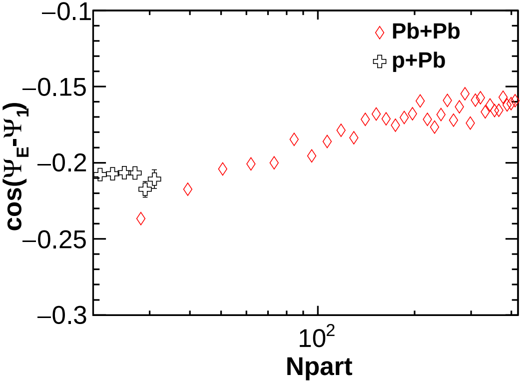
from 1610.00263

Pb+Pb vs p+Pb: CME or not

- while it is clear atleast in p+Pb case that one do not expect it to be CME and the debate is ongoing on the interpretation of the data, we ask whether the EM fields in p+Pb can be accessed in any other way or not

Pb+Pb vs p+Pb: 2 observations

Pb+Pb vs p+Pb: Similar angular correlation between E and Ψ_1



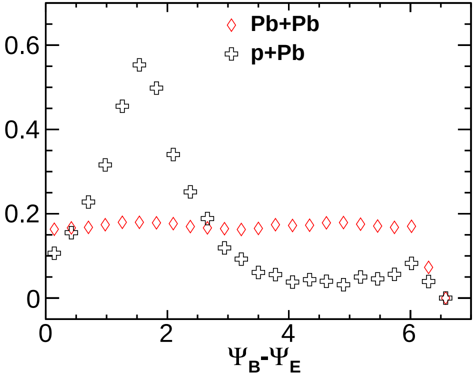
Pb+Pb vs p+Pb: Similar angular correlation between E and Ψ_1

- Pb+Pb and central p+Pb: Nucleon position fluctuation gives rise to both E as well as directed flow and try to make them back to back
- Non-central p+Pb: Geometry of the Pb nucleus gives rise to both E as well as directed flow and try to make them back to back

Pb+Pb vs p+Pb: 2 observations

- Similar angular correlation between E and Ψ_1
-

Pb+Pb vs p+Pb: Strong angular correlation between E and B in p+Pb unlike in Pb+Pb



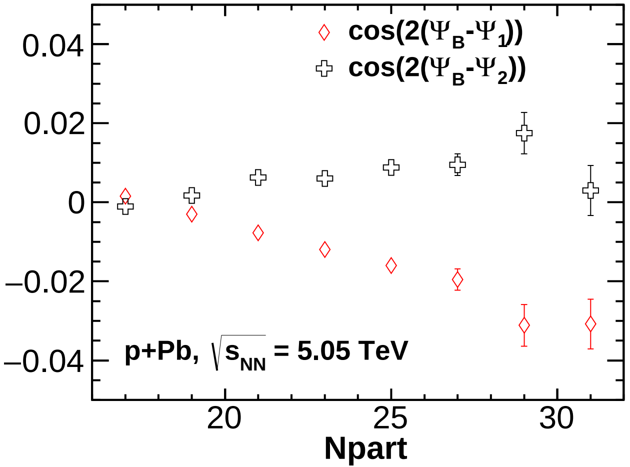
Pb+Pb vs p+Pb: Strong angular correlation between E and B in p+Pb unlike in Pb+Pb

- The EM fields due to each moving source are orthogonal to each other (property of the Lienard-Wiechart potential)
- The EM fields due to superposition of a bunch of moving charges
  - no more orthogonal in general
  - are also orthogonal if they move with same velocity
- in p+Pb, all but one proton move with same velocity giving rise to strong angular correlation between the E and B fields
- in Pb+Pb, protons from the two nuclei have opposite velocities which is enough to decorrelate the E and B fields

Pb+Pb vs p+Pb: 2 observations

- Similar angular correlation between E and Ψ_1
- The above correlation can be brushed off into an angular correlation between B and Ψ_1 in p+Pb; not true for Pb+Pb as no correlation between B and E.
  NOTE: The correlation between B and Ψ_1 in p+Pb is strongest for central p+Pb, with more non-central collisions, the number of protons from Pb that are close to the fireball decrease resulting in weakening of the correlation between B and E and thus between B and Ψ_1.
- Is this correlation between B and Ψ_1 in p+Pb helpful ? Can it give rise to non-zero $\langle cos(2(\Psi_B - \Psi_1))\rangle$? Non-zero charge separation w.r.t the directed flow event plane as signature of CME in p+Pb ?

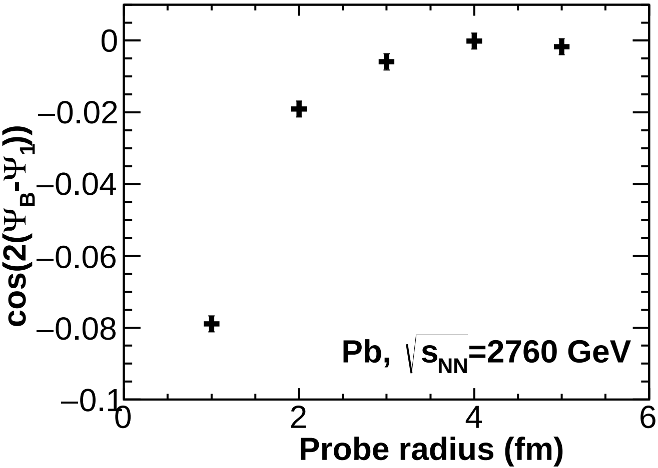
$\langle cos(2(\Psi_B - \Psi_{1,2}))\rangle$



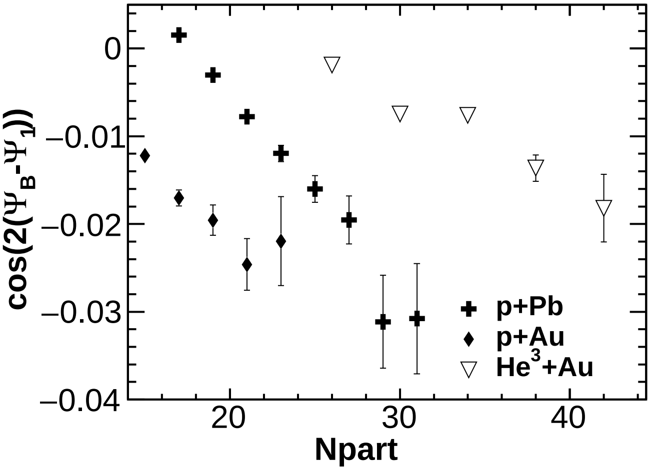
Optimal size for probe

- Contribution of a nucleon at $\vec{r}$ to
  - EM field fall like $\sim 1/r^2$
  - ε_1 (first order eccentricity) grow like $\sim r^3$
- For large probe size, the above is a source for decorrelation as those nucleons that contribute to EM field do not drive the first order eccentricity. Hence a small probe like proton is the ideal choice to maximise the correlation between B and Ψ_1.

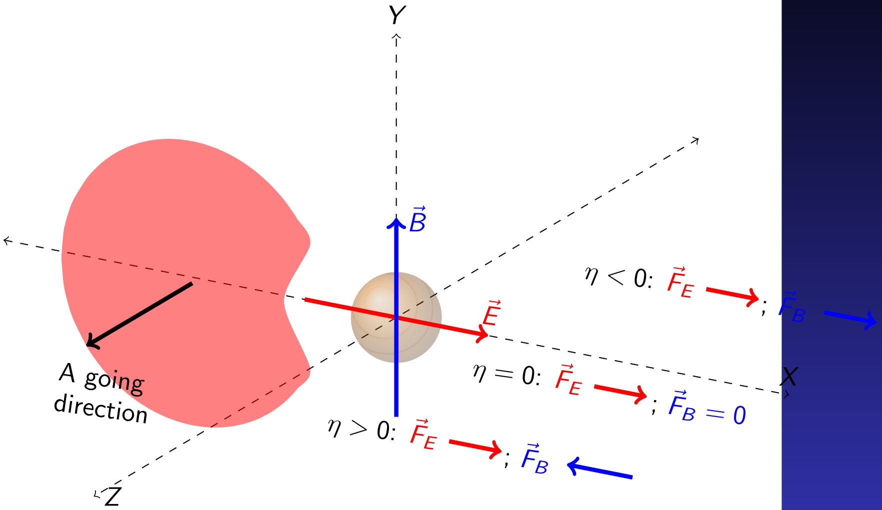
Optimal size for probe



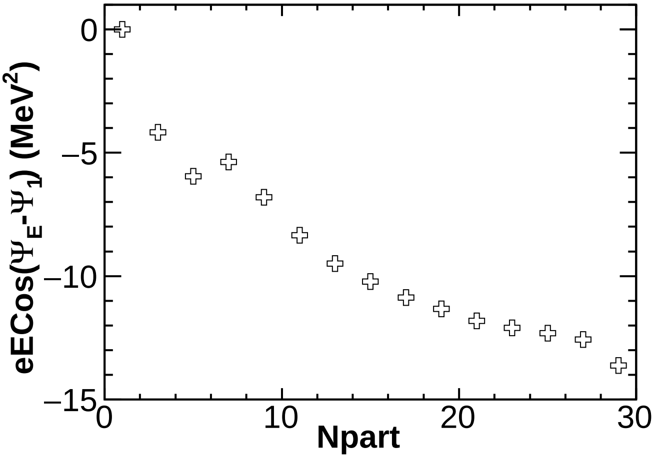
$\langle cos(2(\Psi_B - \Psi_1))\rangle$: across systems



Lorentz force on heavy quark: alt. to access EM field



Lorentz force at mid-rapidity



Summarising

- Interpretation of data on charge separation in heavy ion is still inconclusive on whether CME has been observed or not
- The recent observation of similar charge separation w.r.t the second order event plane in p+Pb where there is null expectation from CME has validated the importance of non-CME like background contribution to such signal
- We find that although null result is expected w.r.t second order event plane, when we replace the second order event plane with the first order event plane, non-zero CME signal is expected.
- Unlike in heavy ion collisions where the correlation between B and Ψ_2 is geometry driven, the correlation between B and Ψ_1 in central p+Pb is fluctuation driven. This could have positive implication in minimising background.
- Interesting phenomenological consequence on heavy quark flow due to early time Lorentz force. For e.g., at mid-rapidity, there should be charge splitting in the directed flow of heavy quark for central collisions that should reduce as one goes to peripheral collisions.

THANK YOU FOR YOUR ATTENTION