Search for the chiral magnetic effect with the ALICE experiment

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- Charge separation with respect to reaction plane
- Two necessary conditions
  - Configuration with non-zero chirality
    Caused by topologically non-trivial gluonic fields in QCD vacuum
  - Strong magnetic field
    Caused by spectator protons in collisions
    - CME depends on both strength and lifetime of magnetic field

Chiral magnetic effect (CME)

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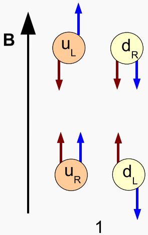

Figure: Red arrows correspond to momentum, blue arrows to spin. Plot taken from Kharzeev et al (Nucl.Phys.A803:227-253,2008)

- (1) In strong magnetic fields, spin is (anti) aligned for (negative) positive particles
- (2) Interaction with (right-handed) chiral medium will flip chirality.
  - Spin flipping energetically suppressed in strong magnetic fields, so momentum flips instead!
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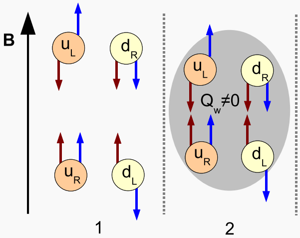

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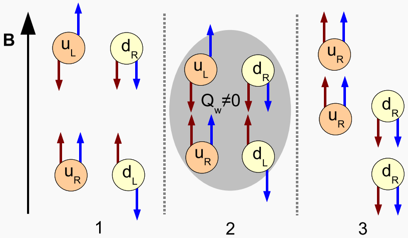

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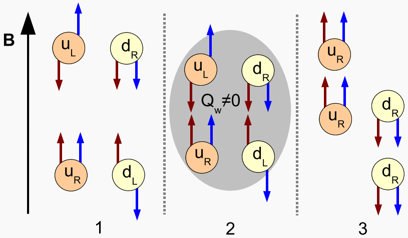

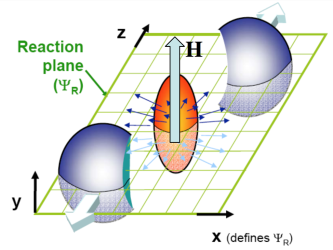

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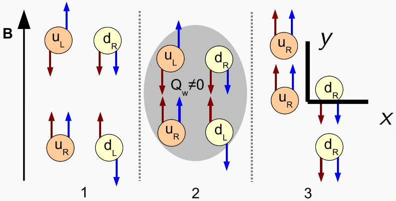
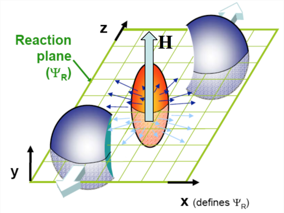
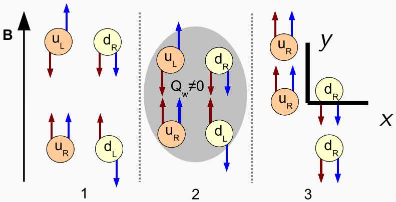
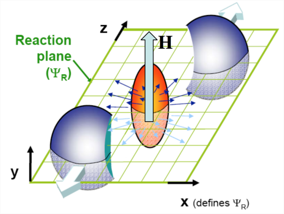




- $\gamma_{11} = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$
- Simplified example (plot above)
  - Coordinate system aligned with Ψ_{RP} so $\Psi_{RP} = 0$!
  - OS pairs: $\phi_\alpha = \frac{1}{2}\pi$ and $\phi_\beta = -\frac{1}{2}\pi$, making $\gamma_{11} = 1$
  - SS pairs: $\phi_\alpha = \phi_\beta = \frac{1}{2}\pi$ $(-\frac{1}{2}\pi)$ for positive (negative) pairs. In both cases, $\gamma_{11} = -1$.
- Key point: difference in correlator value depending on same sign (SS) or opposite sign (OS) pairs!
  - Difference quantified by $\Delta\gamma_{1,1} = \gamma_{1,1}(OS) - \gamma_{1,1}(SS)$
  - $\Delta\gamma_{1,1}$ does not contain charge independent Ψ_2 independent background thanks to OS - SS subtraction





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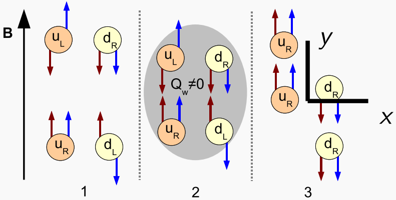

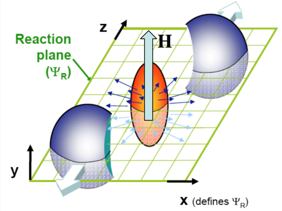

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- Ψ_{RP} is not experimentally accessible, but can be approximated by event plane Ψ_2
  - Correlator must be subsequently corrected for event plane resolution!
- In addition, there are also 2 particle correlators without reference to any symmetry plane according to $\delta_m = \langle \cos(\mathrm{m}[\phi_\alpha - \phi_\beta]) \rangle$
  - Contain contributions from correlations unrelated to azimuthal asymmetry
  - As for $\gamma_{1,1}$, calculate δ_1 for OS and SS pairs
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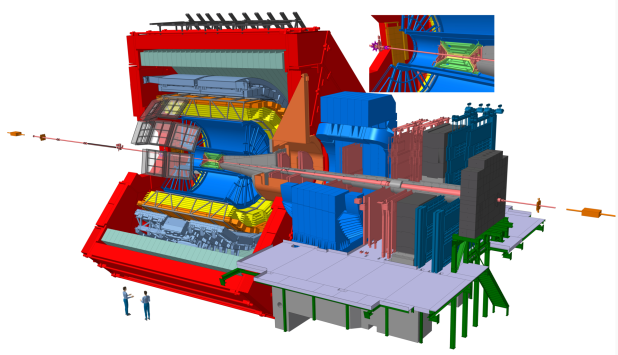
ALICE



- ITS used for vertex determination and tracking
- TPC used for tracking and event plane determination
- V0 for triggering, centrality determination and event plane determination

Analysis

- Two analyses: 5.02 TeV Pb–Pb collisions and 5.44 TeV Xe–Xe collisions (**new** for QM2019)
- In both cases event cuts used were
  - MB events in 0-90% centrality
  - Centrality determined with V0 (forward rapidity) detectors
- Primary tracks subject to criteria
  - $0.2 < p_T < 5.0$ GeV/c
  - $|\eta| < 0.8$

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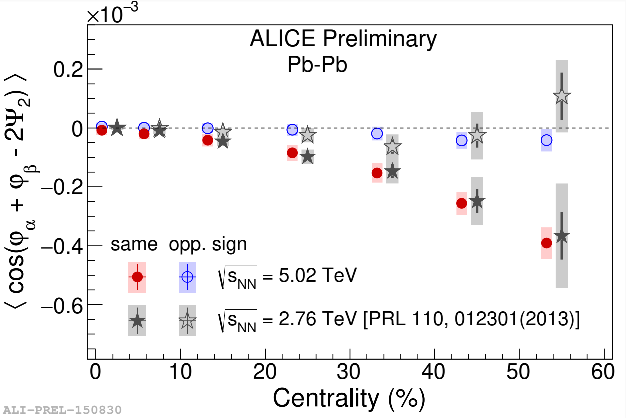
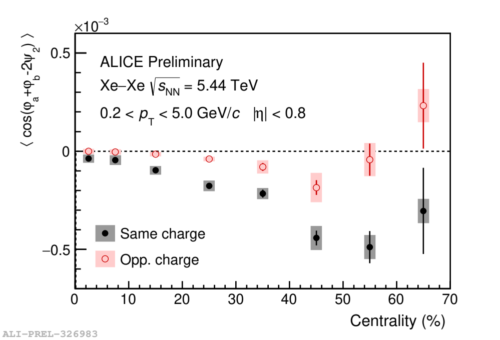
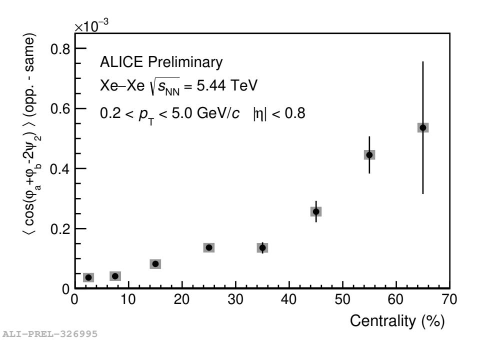


- 2015 Pb–Pb data taking sample much larger than 2010 one
- Opposite sign close to 0, while same sign is negative
  - Clear signs of charge dependence

Results

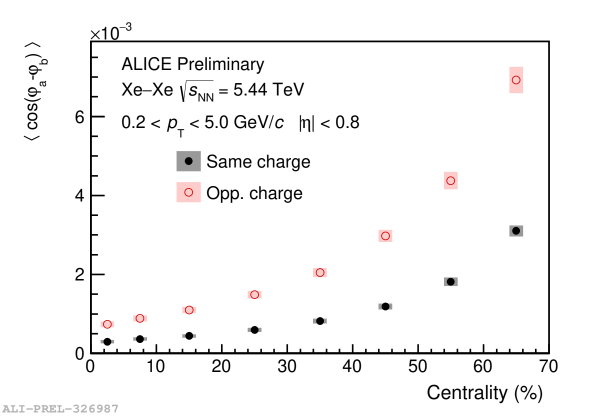
$\gamma_{1,1}$ in Xe–Xe (new)





- Charge dependence that increases for peripheral events
  - Similar behaviour as in Pb–Pb collisions
- More peripheral events means more spectator protons, so stronger *B* field
  - In line with expectation of CME-like signal

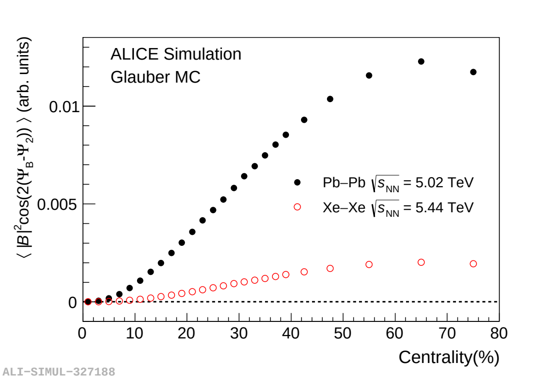
δ_1 in Xe–Xe (new)



- δ_1 has significant charge dependence that increases towards peripheral collisions
  - Indication of a large background presence in $\gamma_{1,1}$

Results

B field comparison Xe–Xe versus Pb–Pb (new)



- *B* field in Pb–Pb collisions is much stronger than in Xe–Xe
  - If significant CME contribution, $\Delta\gamma_{1,1}$ should be larger

Results

Differential $\gamma_{1,1}$ Xe–Xe (new)

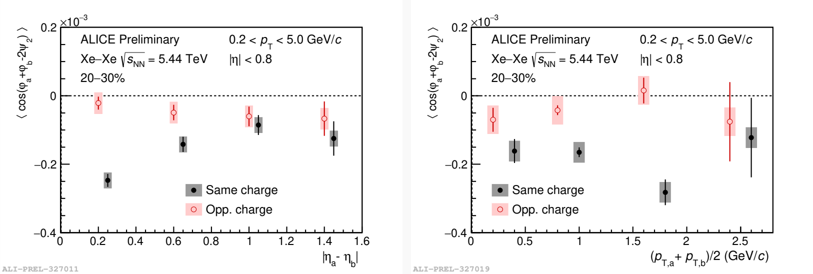


Figure: Left: η difference $|\eta_\alpha - \eta_\beta|$. Right: p_T average $(p_{T,\alpha} + p_{T,\beta})/2$

- Differential $\gamma_{1,1}$ results in centrality bin of 20-30%
  - Probe if there is a kinematic region with strong contribution to signal
- Both for η difference and p_T average same behavior
  - Weak/no dependence for opposite sign pairs
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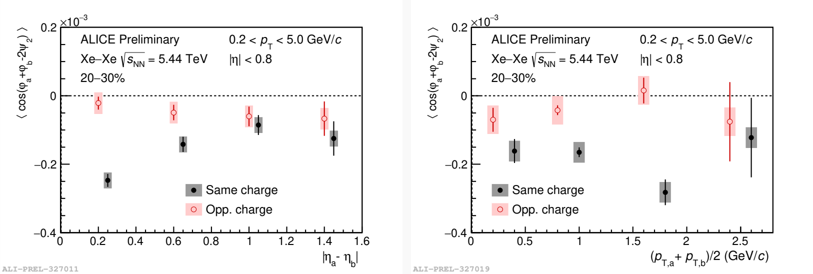

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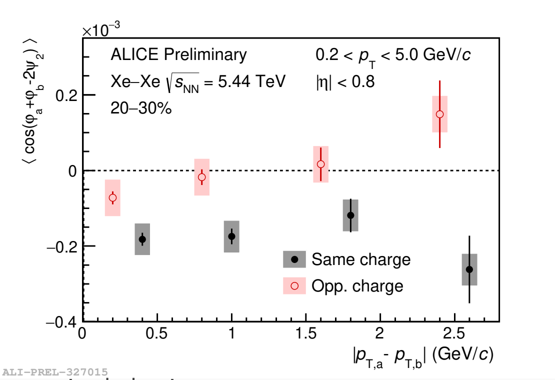

- For p_T difference, opposite behavior
  - Strong dependence for opposite sign pairs
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Conclusion

- $\gamma_{1,1}$ has been measured at 5.02 TeV Pb–Pb collisions and 5.44 TeV Xe–Xe collisons as well as δ_1 in Xe–Xe
- Additionally, differential $\gamma_{1,1}$ shown for Xe–Xe collisions
  - Opposite sign pairs show weak dependence on η difference and p_{T} average
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- In both collision systems
  - similar charge dependence seen for $\gamma_{1,1}$
  - δ_1 in Xe–Xe found to have strong charge dependence
  - Indication that non CME contribution to $\gamma_{1,1}$ are significant
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  - Another ALICE analysis using event shape engineering found an upper limit of 26-33% at 95% confidence level
  - In a CMS study, an upper limit of 7% at 95% confidence level was found (Phys. Rev. C 97, 044912 (2018))
- New methods are in development
- For more information, posters by
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    Measurements of charge-dependent correlations in Xe–Xe collisions with ALICE
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Backup

B field determination

- MC Glauber simulations tuned to ALICE data
- Centrality determined using simulated V0M multiplicity
- B field determined with eq. A.6 from Kharzeev et al (Nucl.Phys.A803:227-253,2008)
  - $eB_s^{\pm}(\tau,\eta,\mathbf{x}_\perp) = \pm Z\alpha_{\mathrm{EM}} \sinh\left(Y_0 \mp \eta\right) \int d^2\mathbf{x}'_\perp \rho_\pm(\mathbf{x}'_\perp)[1-\theta_\mp(\mathbf{x}'_\perp)] \times \frac{(\mathbf{x}'_\perp - \mathbf{x}_\perp)\times e_z}{[(\mathbf{x}'_\perp - \mathbf{x}_\perp)^2 + \tau^2 \sinh(Y_0 \mp \eta)^2]^{3/2}}$