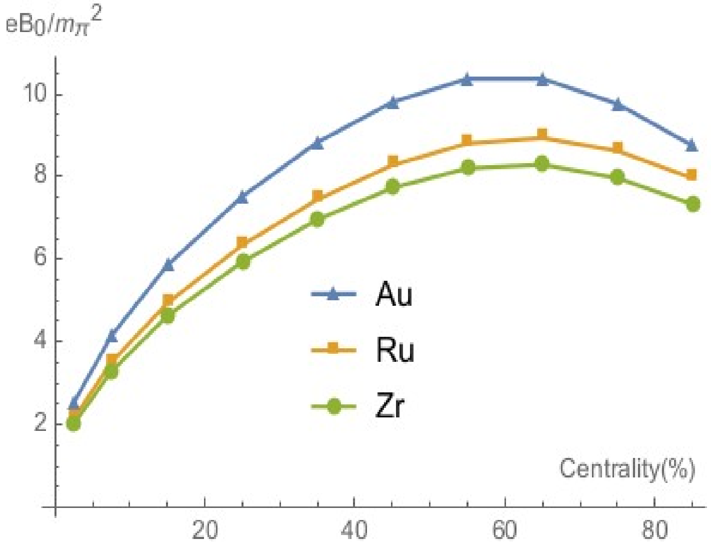
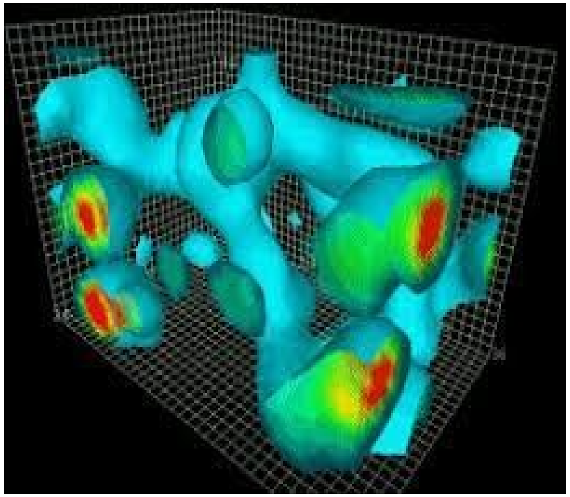
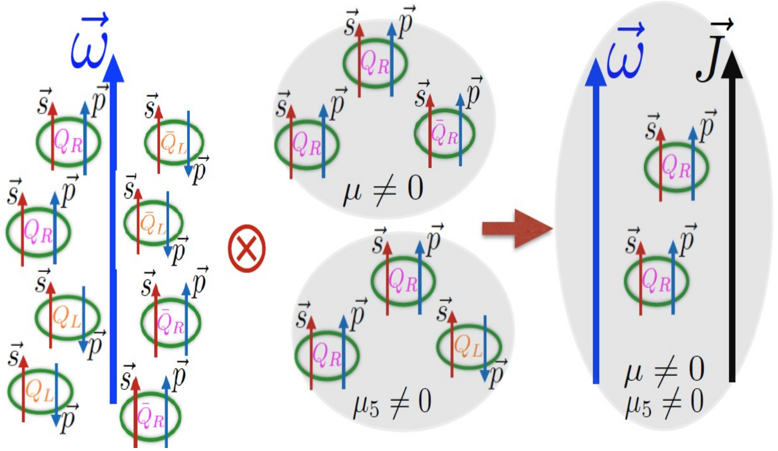
Searches for Chiral Magnetic Effect in Xe-Xe and Pb-Pb collisions with ALICE

Andrea Danu (for the ALICE Collaboration)
~ Institute of Space Science - RO ~

Chiral Magnetic Effect (CME)



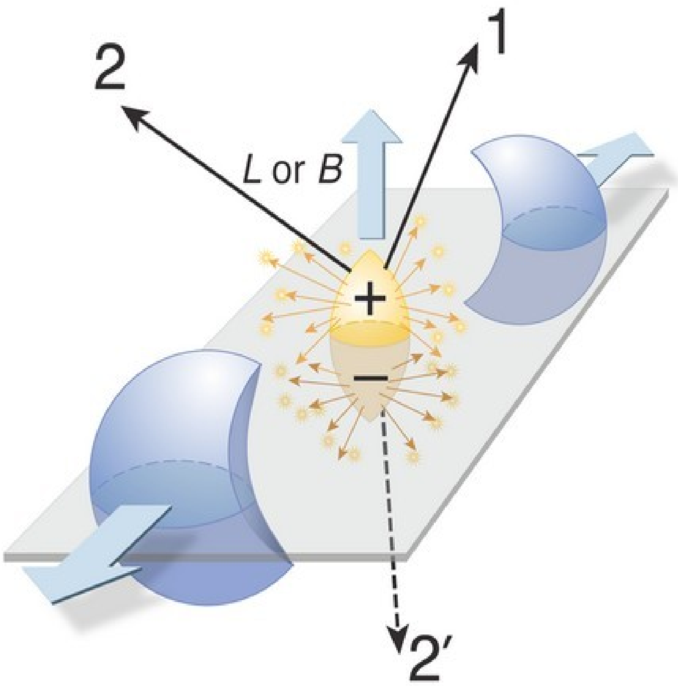




D. Kharzeev, PLB 633, 260 (2006)
D. Kharzeev et al., NPA 797, 67 (2007)
D. Kharzeev et al., PRD 83, 085007 (2011)
D. Kharzeev et al., PPNP 88, 1 (2016)

- **Heavy-ion collisions**: strong magnetic field (B~10^{15} T)
- **Theory**: QCD domains with P and CP symmetries locally broken
- **CME**: electric current along magnetic field
  - Charge separation perpendicular to the reaction plane
- Interpretation of the results complicated by background contributions

Observables



$$\frac{dN}{d\Delta\varphi_\alpha} \sim 1 + 2v_{1,\alpha}\cos(\Delta\varphi_\alpha) + 2a_{1,\alpha}\sin(\Delta\varphi_\alpha) + 2v_{2,\alpha}\cos(2\Delta\varphi_\alpha) + \ldots,$$

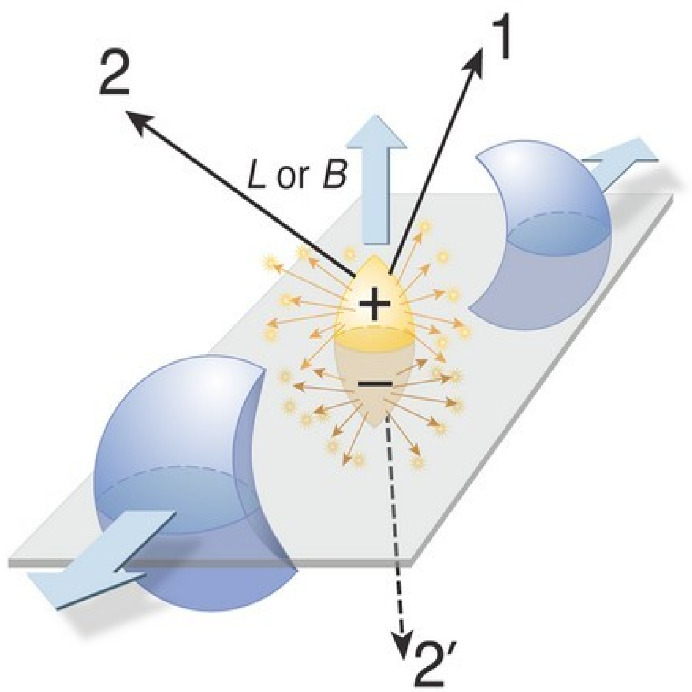
2-particle correlator

STAR, PRC 81, 054908 (2009)

$$\delta_m = \langle \cos[m(\varphi_a - \varphi_b)] \rangle$$

$$\langle \cos(\varphi_a - \varphi_b) \rangle = \langle \cos[(\varphi_a - \Psi_{RP}) - (\varphi_b - \Psi_{RP})] \rangle$$
$$= \langle \cos(\Delta\varphi_a - \Delta\varphi_b) \rangle = \langle v_{1,a} v_{1,b} \rangle + \langle a_{1,a} a_{1,b} \rangle + B_{\mathrm{in}} + B_{\mathrm{out}}$$

Observables



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3-particle correlator

S. Voloshin, PRC 70, 057901 (2004)

$$\gamma_{m,n} = \langle \cos(m\varphi_a + n\varphi_b - (m+n)\Psi_{|m+n|}) \rangle$$

$$\langle \cos(\varphi_a + \varphi_b - 2\Psi_{RP}) \rangle = \langle \cos[(\varphi_a - \Psi_{RP}) + (\varphi_b - \Psi_{RP})] \rangle$$
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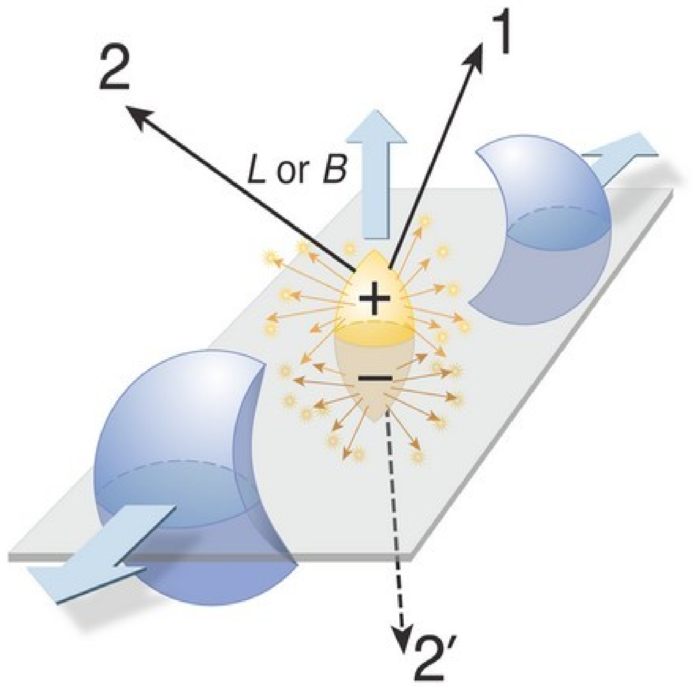
Observables



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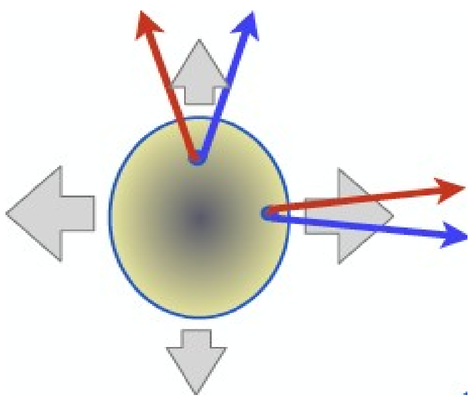
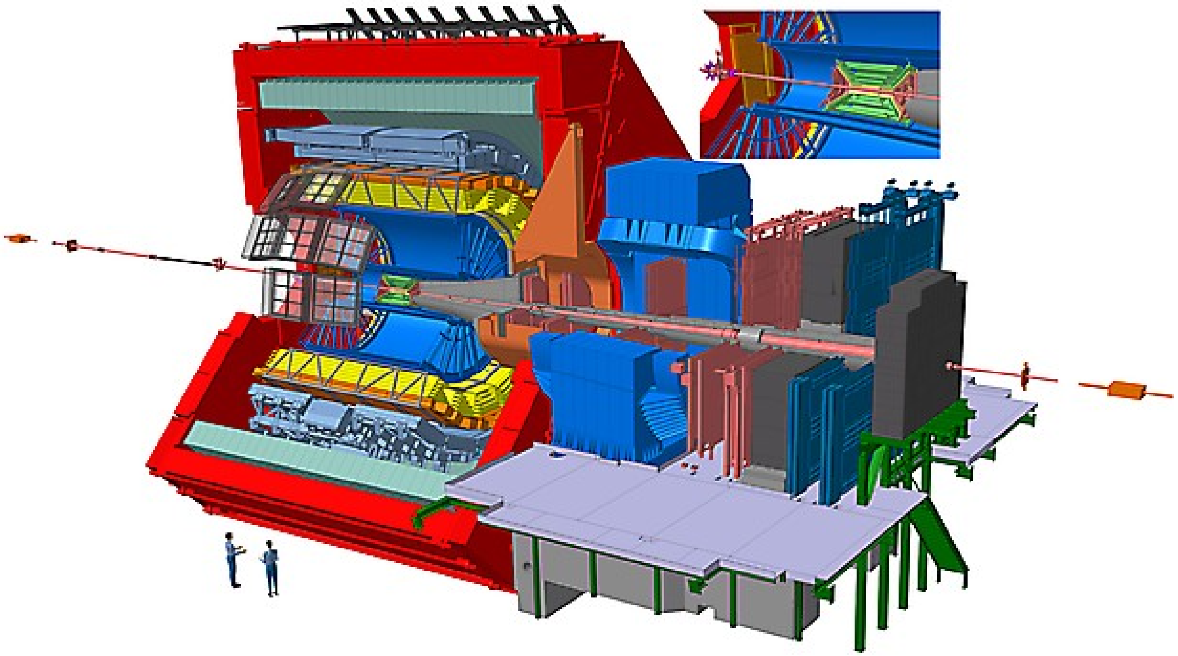
"Flowing clusters"



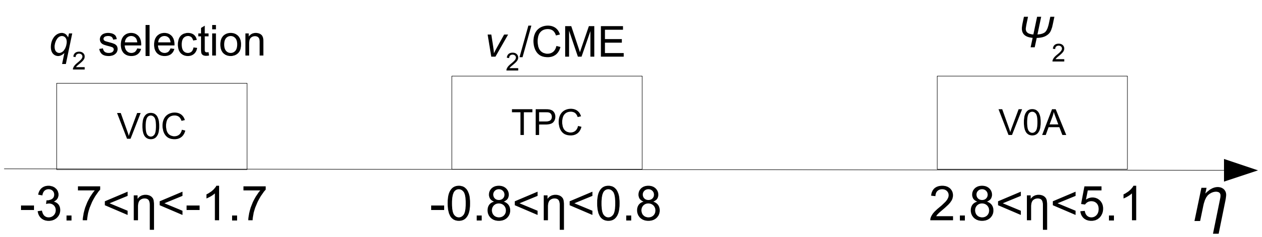
B_{in} and B_{out} background contributions projected onto Ψ_{RP} and perpendicular to it

$$B_{in} - B_{out} \propto v_{2,cluster} \langle \cos(\varphi_a + \varphi_b - 2\varphi_{cluster}) \rangle$$

A Large Ion Collider Experiment



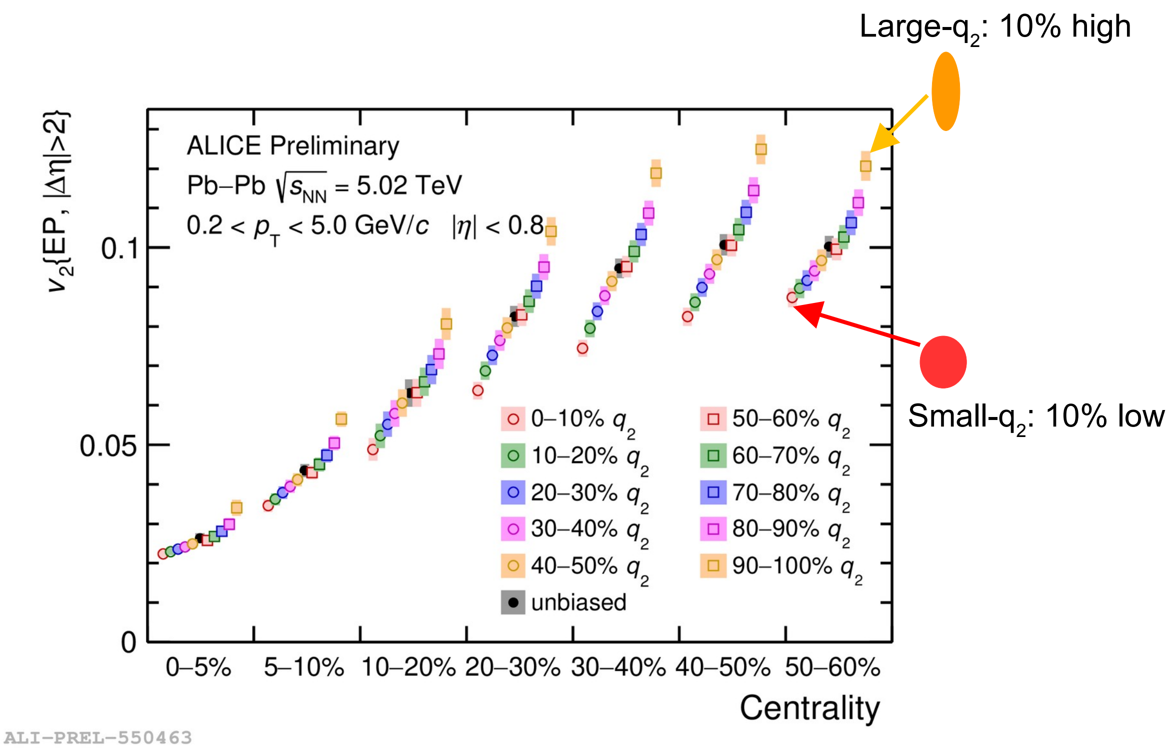
- Inner Tracking System (ITS)
  - Tracking, triggering, vertexing
- Time Projection Chamber (TPC)
  - Tracking, vertexing, Ψ_n
- V0 detector
  - Triggering, centrality, Ψ_n
- Track selection
  - $0.2 < p_T < 5$ GeV/c, $|\eta| < 0.8$



- Pb–Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
  - ~235M events
- Xe–Xe at $\sqrt{s_{NN}}$ = 5.44 TeV
  - ~1M events

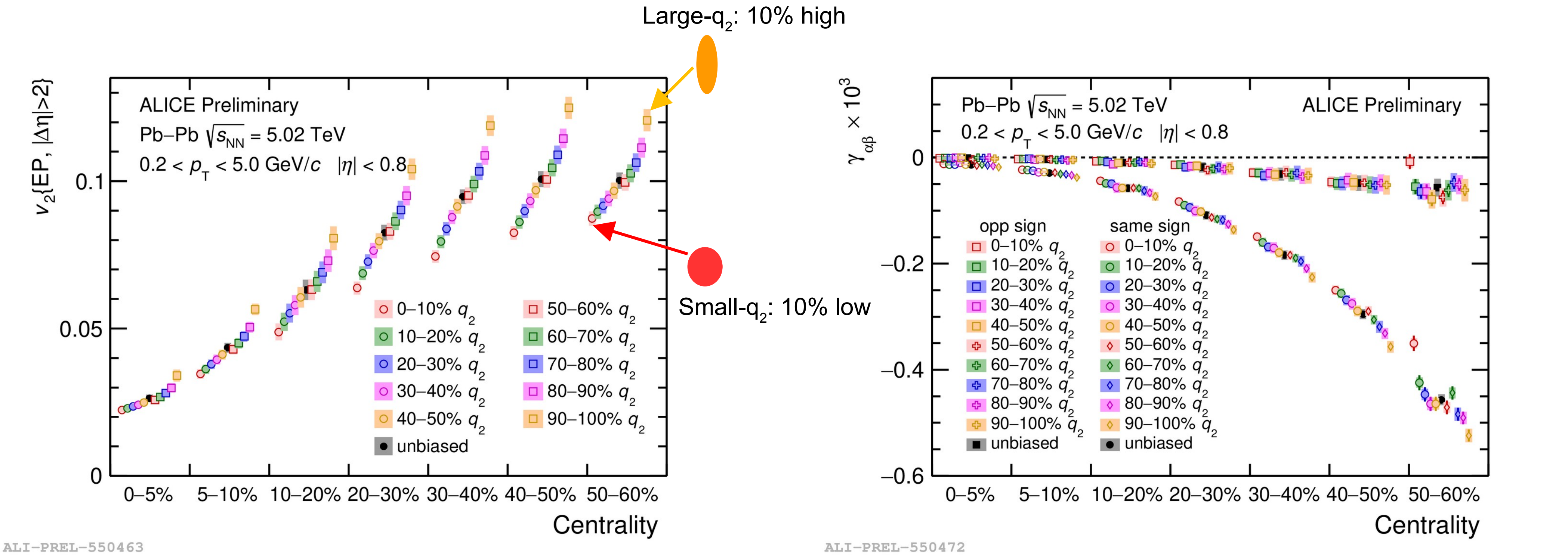
CME ESE in Pb–Pb at 5.02 TeV

CME with ESE



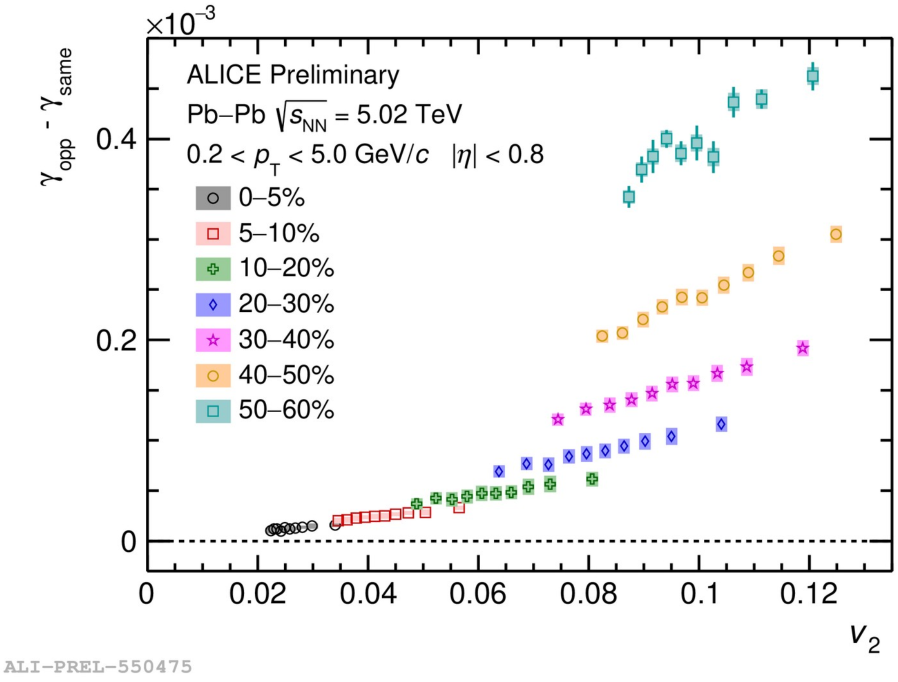
- q_2^{V0C} used to select events with 30% larger or 25% smaller v_2 than the average
  - Non-flow is greatly suppressed by the large separation in rapidity between the TPC and the V0A ($|\Delta\eta|>2.0$)

CME with ESE



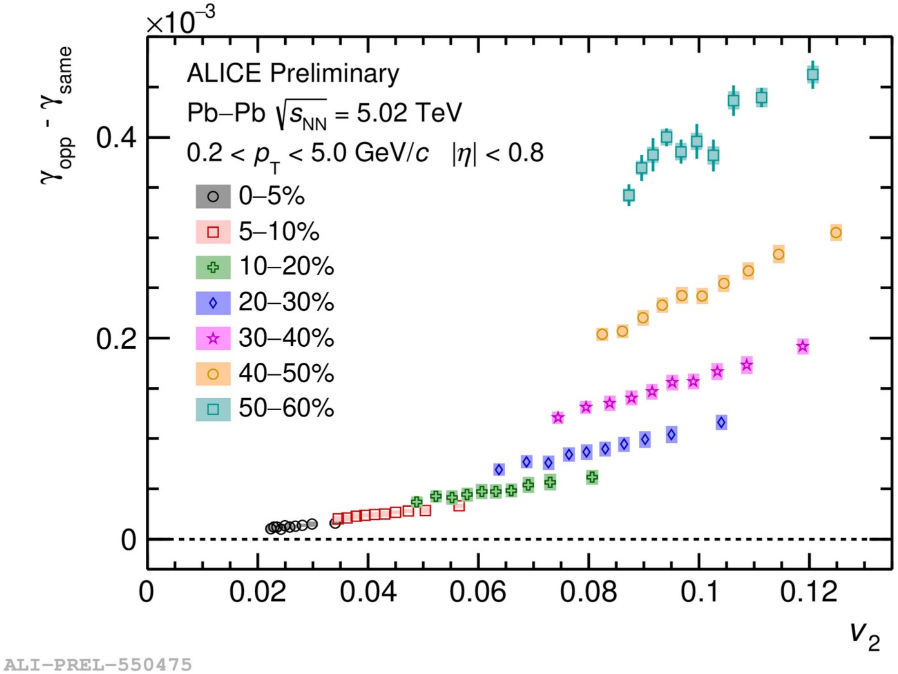
- q_2^{V0C} used to select events with 30% larger or 25% smaller v_2 than the average
  - Non-flow is greatly suppressed by the large separation in rapidity between the TPC and the V0A ($|\Delta\eta|>2.0$)
- γ_{ab} contains potential CME signal as well as background effects
  - Background contributions are suppressed at the level of v_2
- γ_{ab} depends on the event shape selection in a given centrality bin

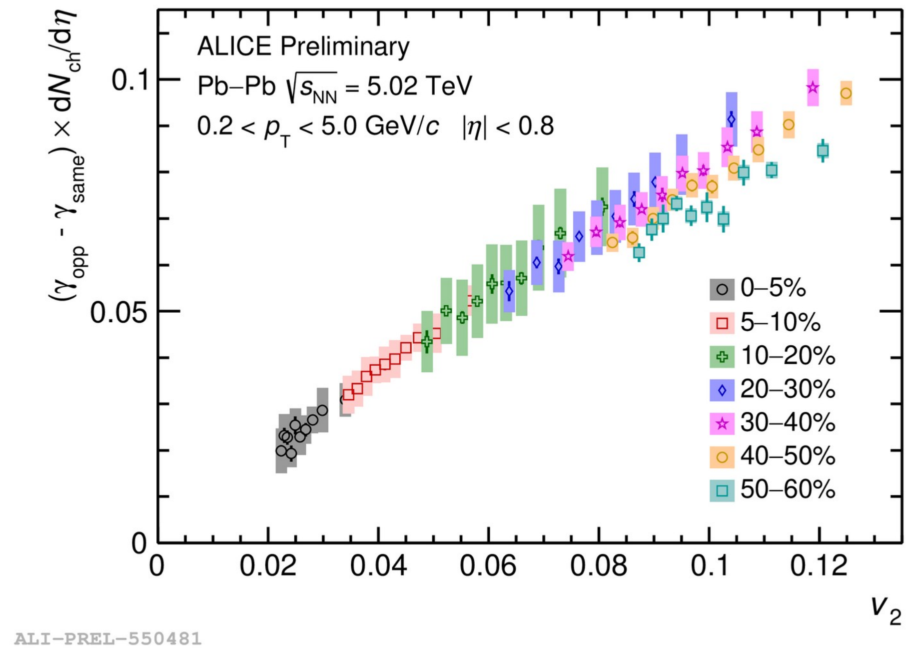
CME with ESE



- γ_{ab} (opp-same) can be used to study the CME
  - γ_{ab} is positive for all centrality classes and decreases with centrality and v_2 (in a given centrality class)

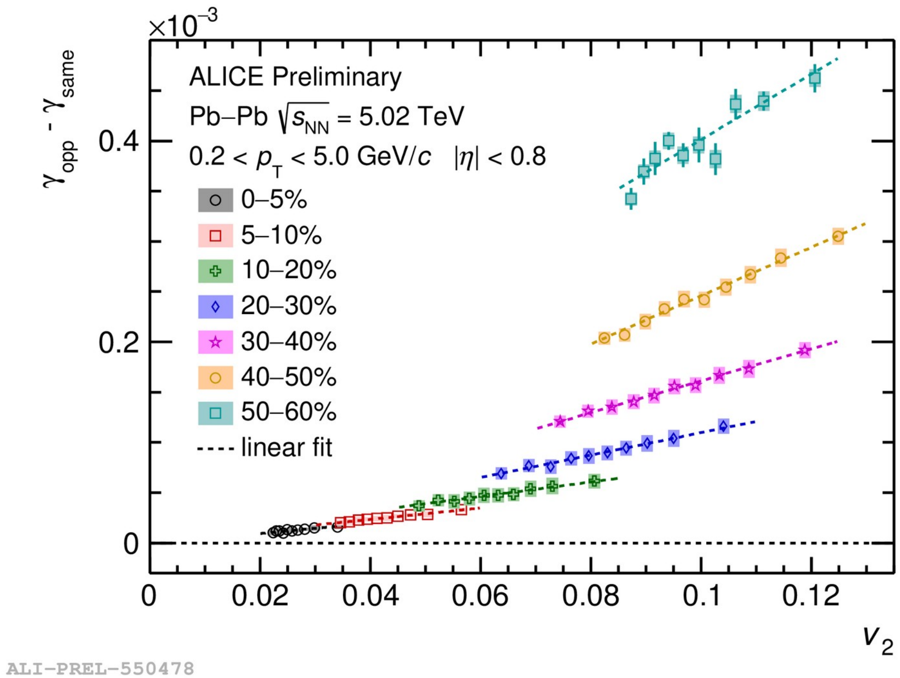
CME with ESE

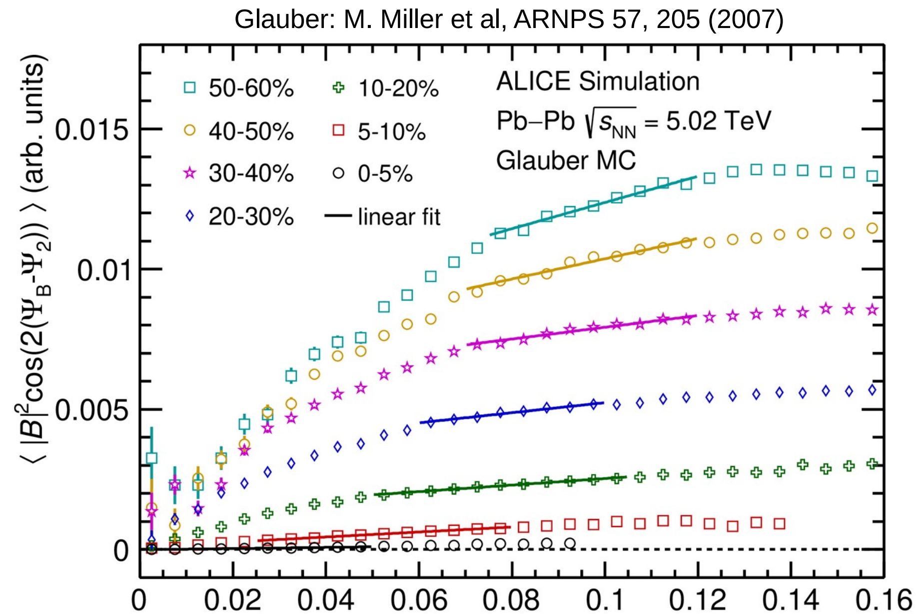




- γ_{ab} (opp-same) can be used to study the CME
  - γ_{ab} is positive for all centrality classes and decreases with centrality and v_2 (in a given centrality class)
  - γ_{ab} approximately scales with multiplicity → large background contribution

Relating data and models





$$e\boldsymbol{B}_s^{\pm}(\tau,\eta,\boldsymbol{x}_\perp) = \pm Z\alpha_{EM}\sinh(Y_0 \mp \eta)\int \mathrm{d}^2\boldsymbol{x}'_\perp \rho_\pm(\boldsymbol{x}'_\perp)[1-\theta_\mp(\boldsymbol{x}'_\perp)] \times \frac{(\boldsymbol{x}'_\perp - \boldsymbol{x}_\perp)\times \boldsymbol{e}_z}{[(\boldsymbol{x}'_\perp - \boldsymbol{x}_\perp)^2 + \tau^2\sinh(Y_0\mp\eta)^2]^{3/2}},$$

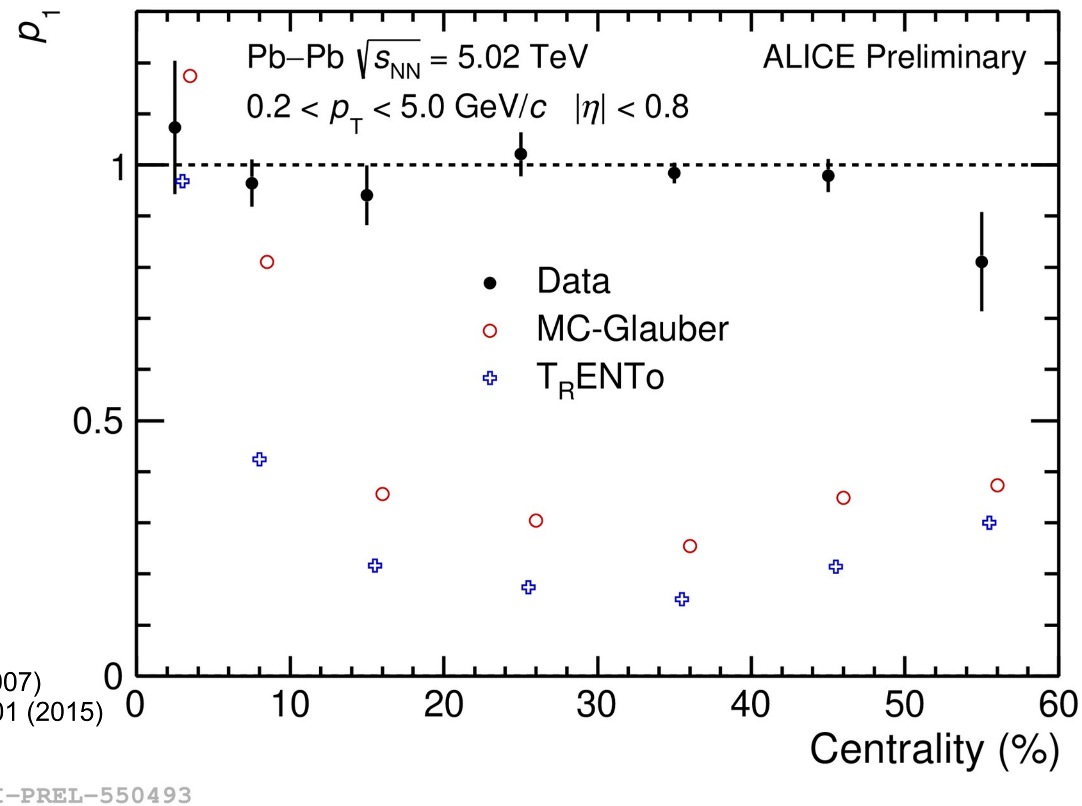
D. Kharzeev et al., NPA 803, 227 (2008)

- Fit γ_{ab} (opp-same) and $<|B|^2\cos(2(\Psi_B-\Psi_2))>$ (expected CME contribution to γ_{ab}) with a linear function to disentangle the potential CME signal from the background

$$P_1(v_2) = p_0(1+p_1(v_2-\langle v_2\rangle)/\langle v_2\rangle)$$

- MC Glauber simulations with parameters tuned to reproduce ALICE results
  - Calculate magnetic field at the origin using spectators with the proper time τ=0.1 fm
  - $<|B|^2\cos(2(\Psi_B-\Psi_2))>$ shows a strong dependence on v_2

Slopes of data and model fits



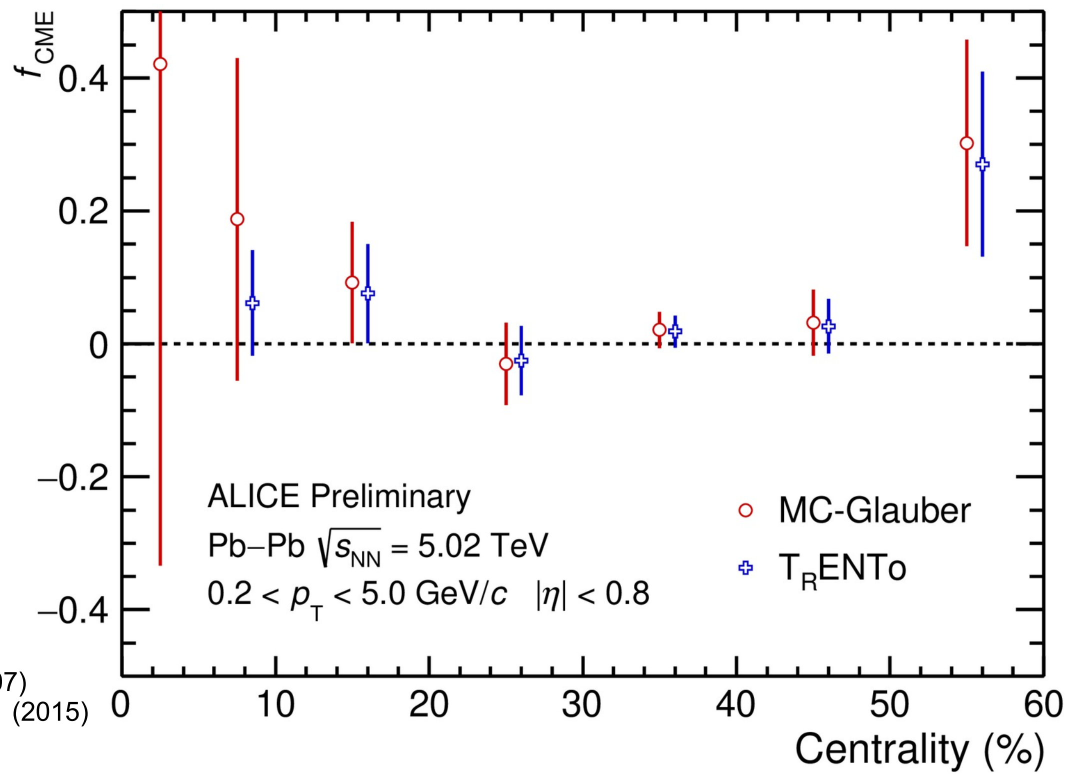
Glauber: M. Miller et al., ARNPS 57, 205 (2007)
TRENTO: J. Moreland et al., PRC 92, 011901 (2015)

- Extract the CME fraction (f_{CME}) by relating the slopes of data and model fits according to

$$f_{\mathrm{CME}} * p_{1,\mathrm{MC}} + (1 - f_{\mathrm{CME}}) * 1 = p_{1,\mathrm{data}}$$

- Assumption: background contribution scales linearly with v_2 and the corresponding slope is unity

CME fraction



Glauber: M. Miller et al., ARNPS 57, 205 (2007)
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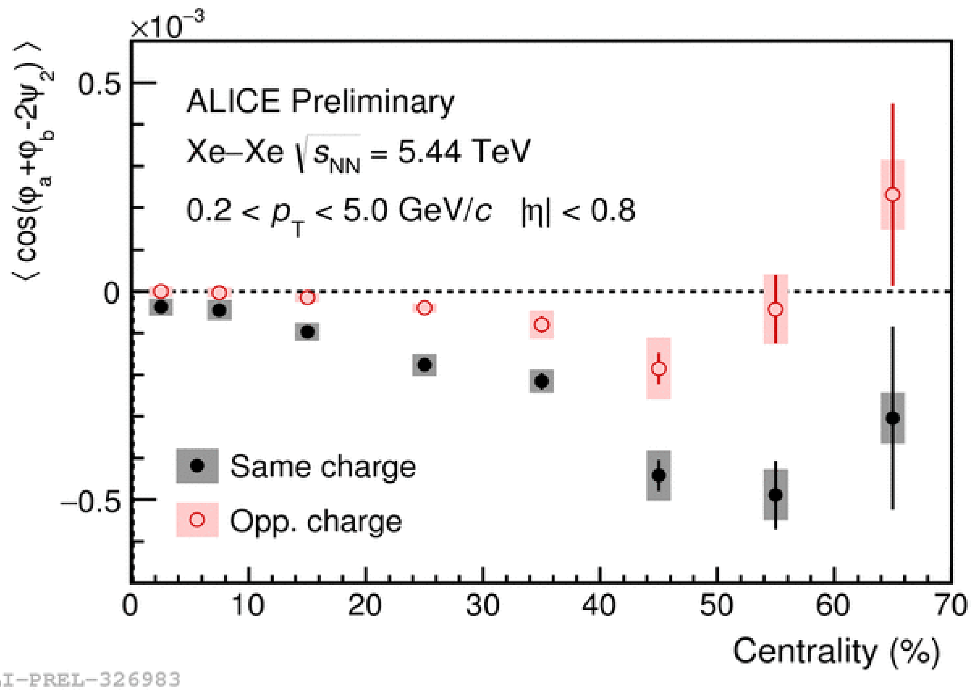
ALI-PREL-550496

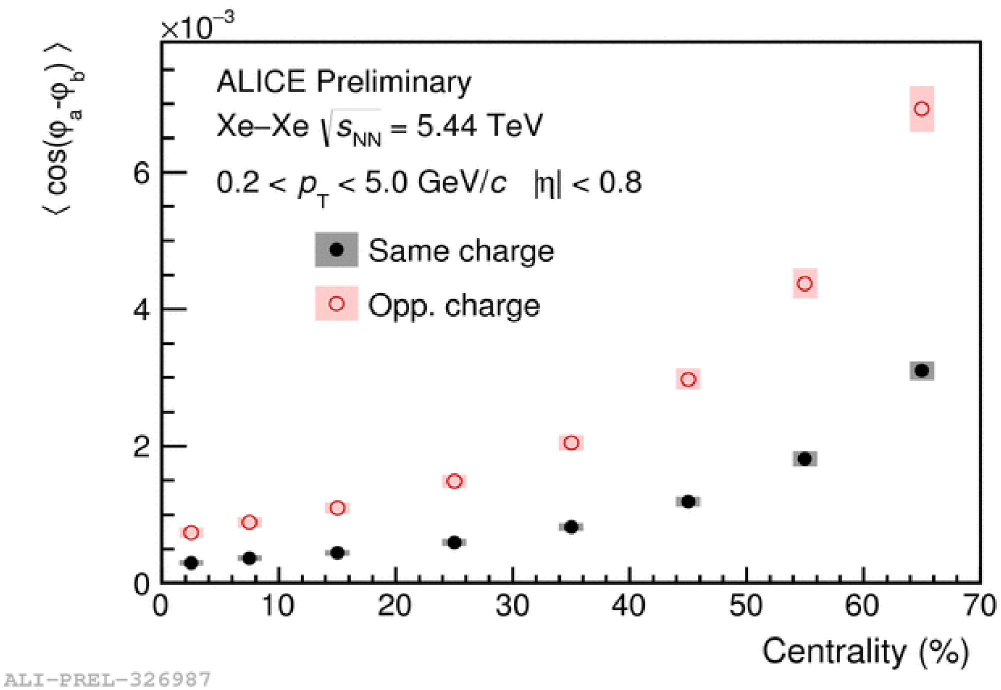
- CME fraction in 0-5% is currently statistically limited
- Combining the points from 5-60% gives
  - f_{CME} (Glauber) = 0.0276 ± 0.0213 → 6.4% at 95% C.L.
  - f_{CME} (TRENTo) = 0.0245 ± 0.0179 → 5.5% at 95% C.L.

CME Xe–Xe vs Pb–Pb collisions

ALICE, arXiv: 2210.15383

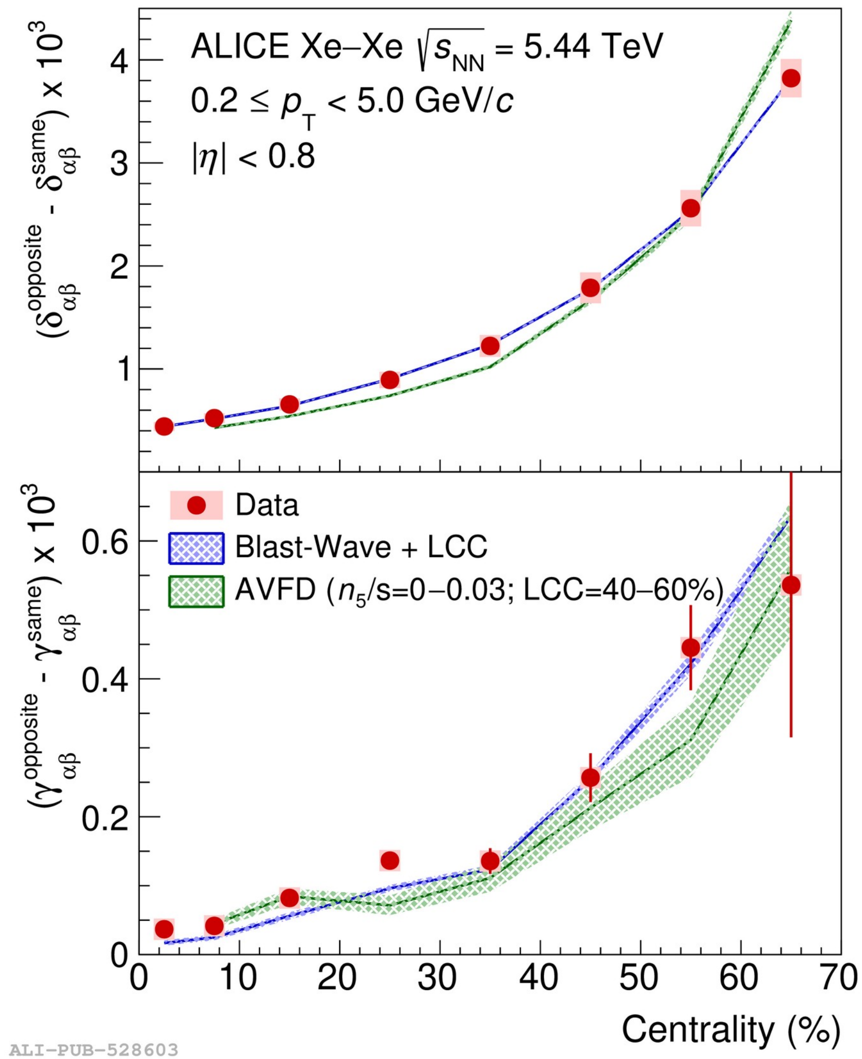
CME in Xe–Xe collisions





- γ_{ab}: consistent with charge separation
- δ_{ab}: background dominates

Model comparisons

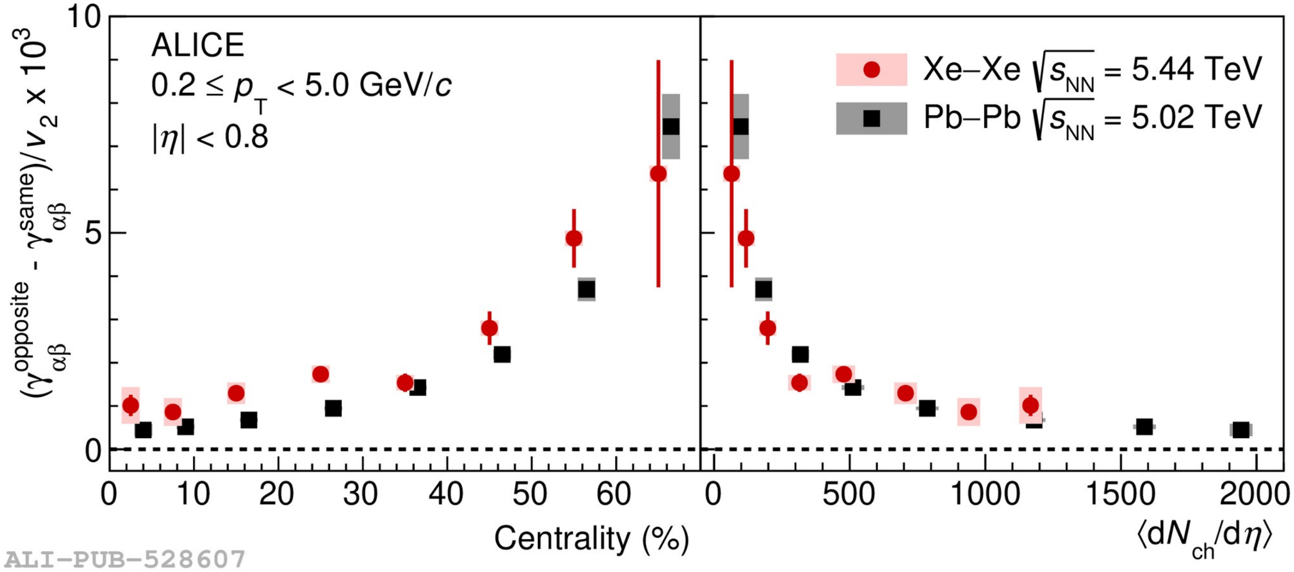


- Blast-Wave + Local Charge Conservation (LCC)
  - Tune the parameters in each centrality class to reproduce v_2 and p_T spectra of π, K, p
  - Tune the number of sources emitting balancing pairs
  - Describes fairly well the measured data points
    - Background dominates measurements
    - Not observed in Pb–Pb collisions

- Anomalous Viscous Fluid Dynamics (AVFD)
  - EbyE IC + E/M fields (field lifetime as input)
  - Tune the parameters in each centrality class to reproduce v_2 and multiplicity P. Christakoglou et al., EPJC 81, 717 (2021)
  - Good agreement with data points
    - Signal consistent with zero

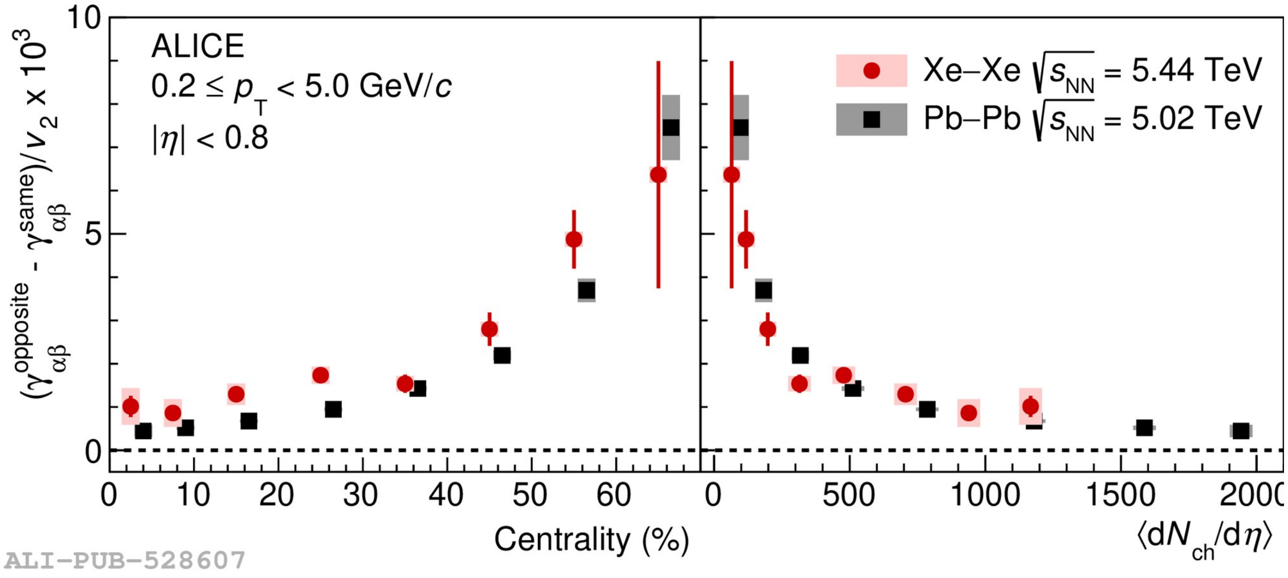
S. Shi et al., AP 394, 50 (2018)
Y. Jiang et al., CPC 42, 011001 (2018)

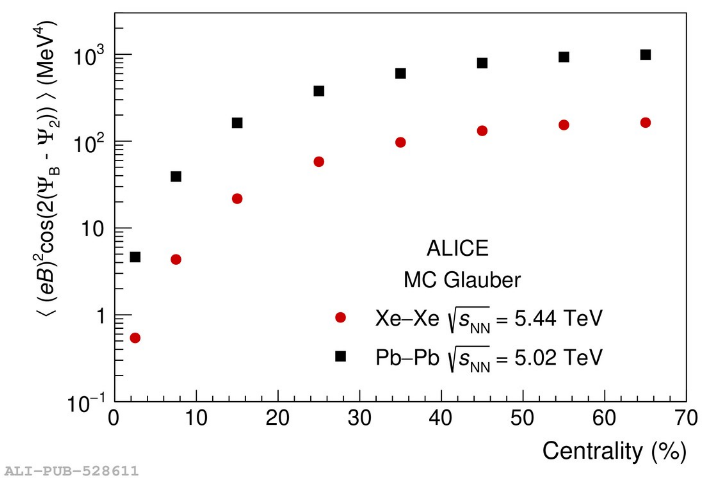
CME fraction in Xe–Xe and Pb–Pb collisions



- γ_{ab} (opp-same) can be used to study CME
  - Similar values in Xe–Xe and Pb–Pb collisions (vs $dN_{ch}/d\eta$) → large background contribution

CME fraction in Xe–Xe and Pb–Pb collisions



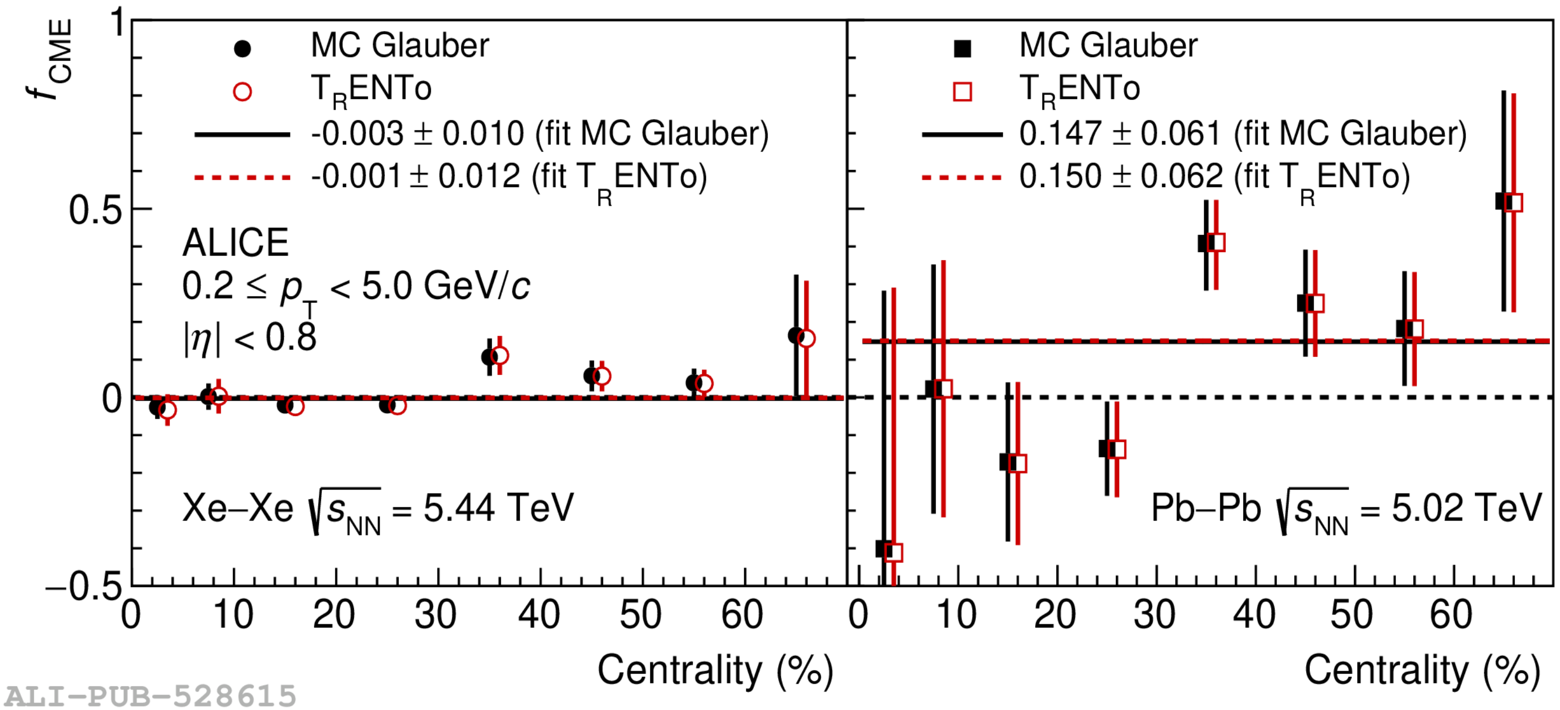


- γ_{ab} (opp-same) can be used to study CME
  - Similar values in Xe–Xe and Pb–Pb collisions (vs dN_{ch}/dη) → large background contribution
- CME fraction extracted using a two-component approach
  - Assumption: both signal and background scale with dN_{ch}/dη
    - dN_{ch}/dη used to compensate for dilution
  - <|B|^{2}cos(2(Ψ_B-Ψ_2))> from MC simulations

$$(dN_{ch}/d\eta)^{Xe} \Delta\gamma_{ab}^{Xe} = s B^{Xe} + b v_2^{Xe}$$
$$(dN_{ch}/d\eta)^{Pb} \Delta\gamma_{ab}^{Pb} = s B^{Pb} + b v_2^{Pb}$$

$$f_{CME} = \frac{sB}{sB + b v_2}$$

CME fraction in Xe–Xe and Pb–Pb collisions



- Consistent with 0 for 0-30% and then becomes positive
- Combining the points from 0-70%
  - f_{CME}^{Xe} = -0.003 ± 0.010 → 2% at 95% C.L.
  - f_{CME}^{Pb} = 0.147 ± 0.061 → 25% at 95% C.L.

$$f_{CME} = \frac{sB}{sB + bv_2}$$

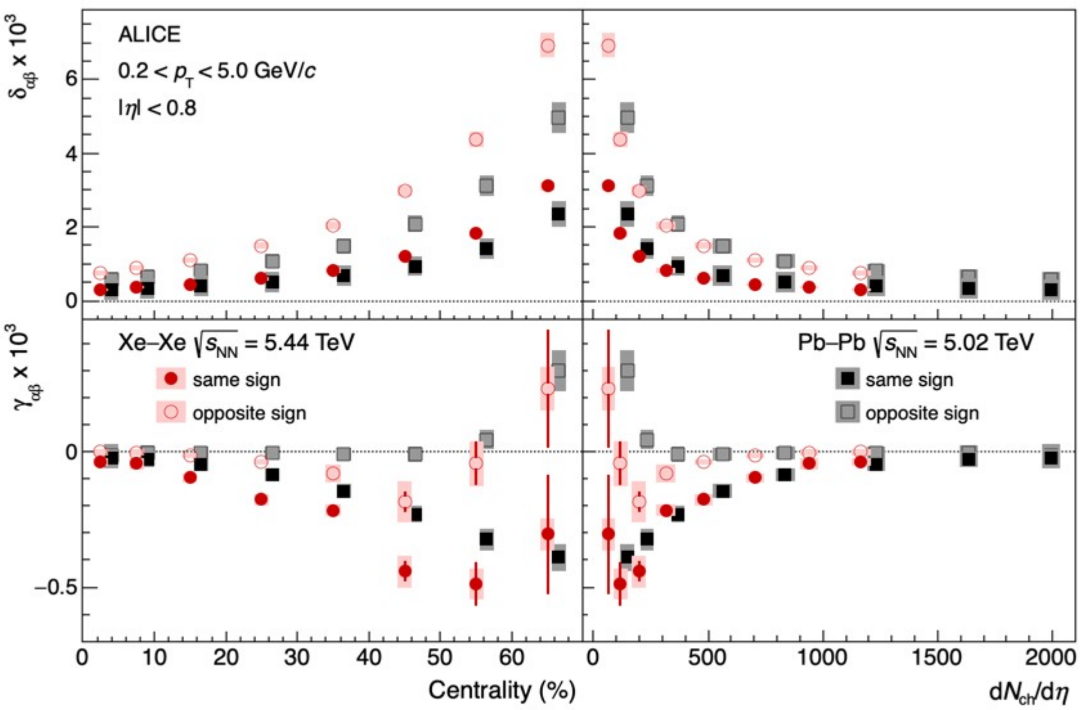
Summary

- Charge-dependent correlations have been studied with ESE and initial state models in 2018 Pb–Pb data
  - γ_{ab} (opp-same) approximately scales with v_2 and multiplicity → large background contribution
  - CME fraction in γ_{ab} for 5-60 % is found to be
    - f_{CME} (Glauber) = 0.0276 ± 0.0213 → 6.4% at 95% C.L.
    - f_{CME} (TRENTo) = 0.0245 ± 0.0179 → 5.5% at 95% C.L.

- First measurement of CME in Xe–Xe collisions
  - γ_{ab} and δ_{ab} similar values as in Pb–Pb collisions within uncertainties → large background contribution
  - CME fraction for Xe–Xe in γ_{ab} for 5-70 % is found to be
    - f_{CME} (Glauber) = -0.003 ± 0.010 → 2% at 95% C.L.
    - f_{CME} (TRENTo) = -0.001 ± 0.012 → 3% at 97% C.L.

THANK YOU!

CME in Xe–Xe and Pb–Pb collisions



- Strong dependence on the charge
- Qualitatively similar centrality dependence
  - Larger magnitude in Xe–Xe than in Pb–Pb collisions
    - Dilution effects arising from different number of particles (CME ~ 1/M)
- Similar values in Xe–Xe and Pb–Pb collisions within uncertainties (vs $dN_{ch}/d\eta$)

ALICE, JHEP 09, 160 (2020)

ALICE, PRL 116, 222302 (2016)
ALICE, PLB 790, 35 (2019)