Using Event Shape Engineering to investigate the Chiral Magnetic Effect in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

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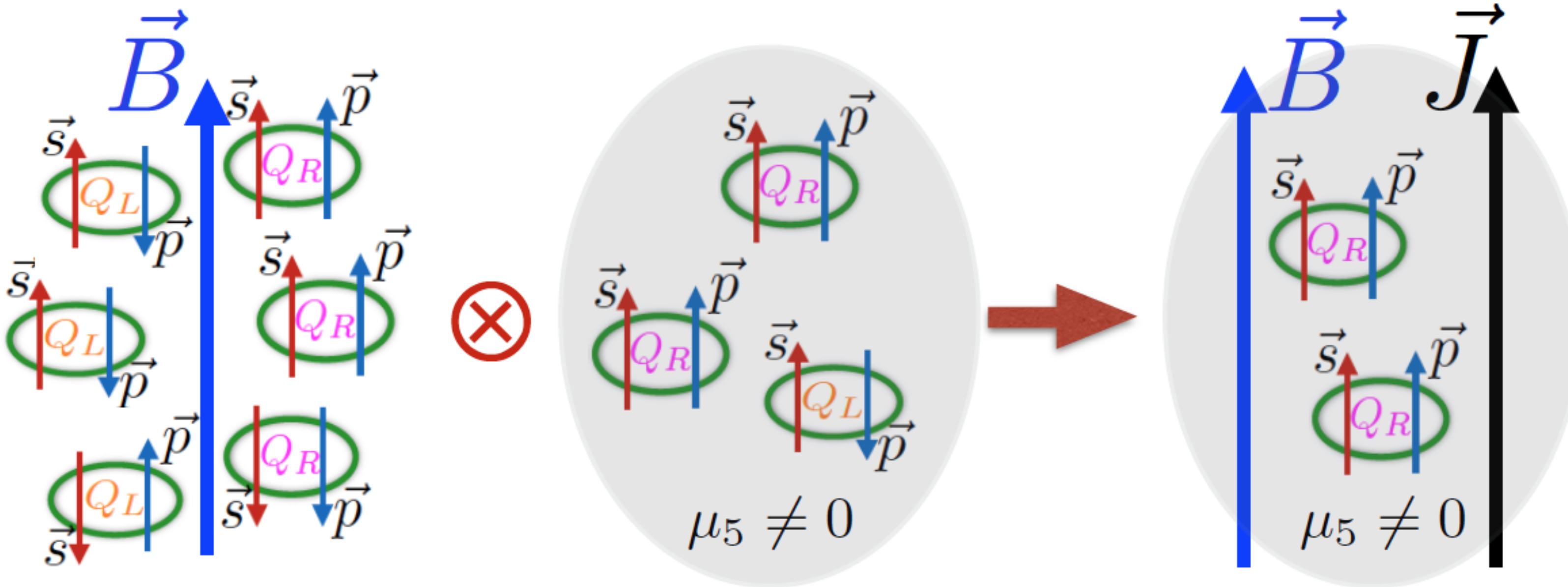
for the ALICE Collaboration

- Chiral Magnetic Effect (CME)
- Event Shape Engineering (ESE)
- ALICE
  - ESE in ALICE
- Results
- Summary

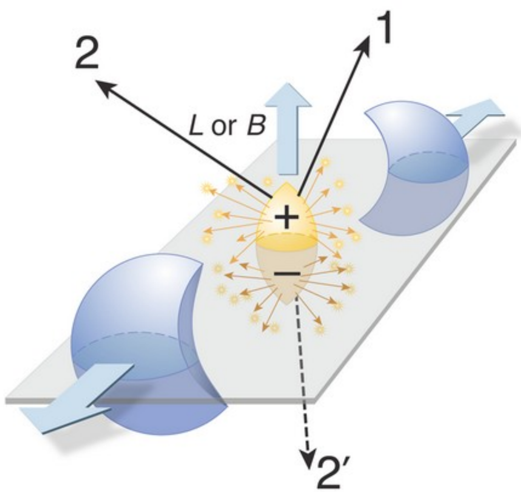
Quark Matter 2017

Chiral magnetic effect (CME)



D. Kharzeev, PLB 633, 260 (2006)
D. Kharzeev et al, NPA 797, 67 (2007)
D. Kharzeev et al, NPA 803, 227 (2008)
K. Fukushima et al, PRD 78, 074033 (2008)
S. Voloshin, PRC 70, 057901 (2004)

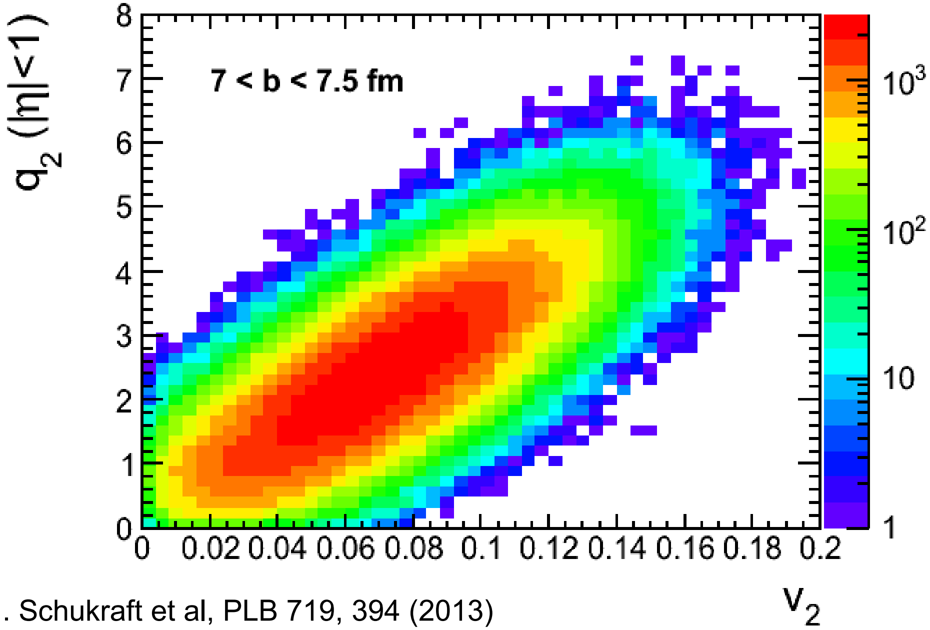
D. Kharzeev et al, PPNP 88, 1 (2016)



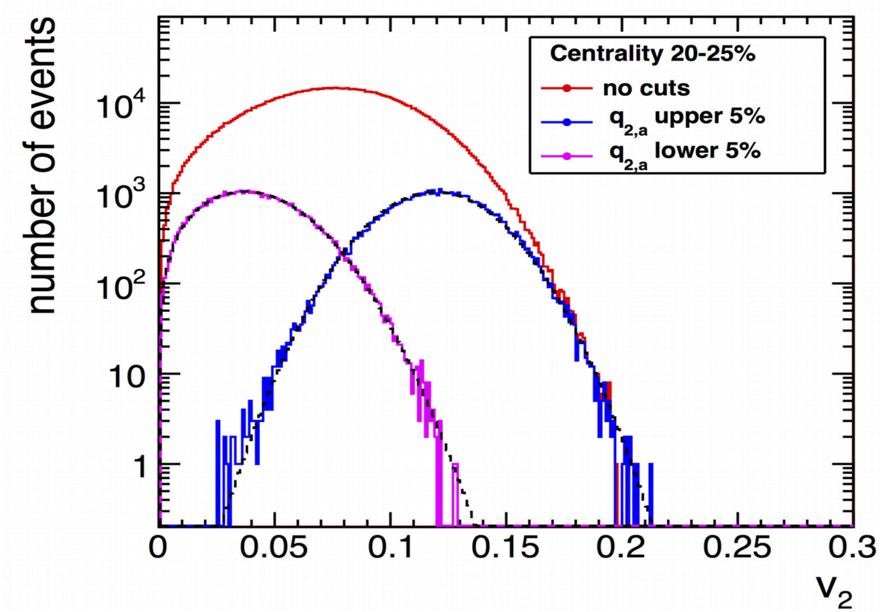
- Heavy Ion Collisions: strong magnetic field (B~10^{15} T)
- Theory: QCD domains with P and CP symmetries locally broken
- Interaction of quarks with these domains and B → spin alignment and induced electric field
- Experimental consequence: *charge separation perpendicular to the reaction plane*
- *Interpretation of the experimental results is complicated by background contributions*

→ use Event Shape Engineering technique to disentangle background effects from potential CME signal

Event Shape Engineering (ESE)



J. Schukraft et al, PLB 719, 394 (2013)
H. Petersen et al, PRC 88, 044918 (2013)
P. Huo et al, PRC 90, 024910 (2014)

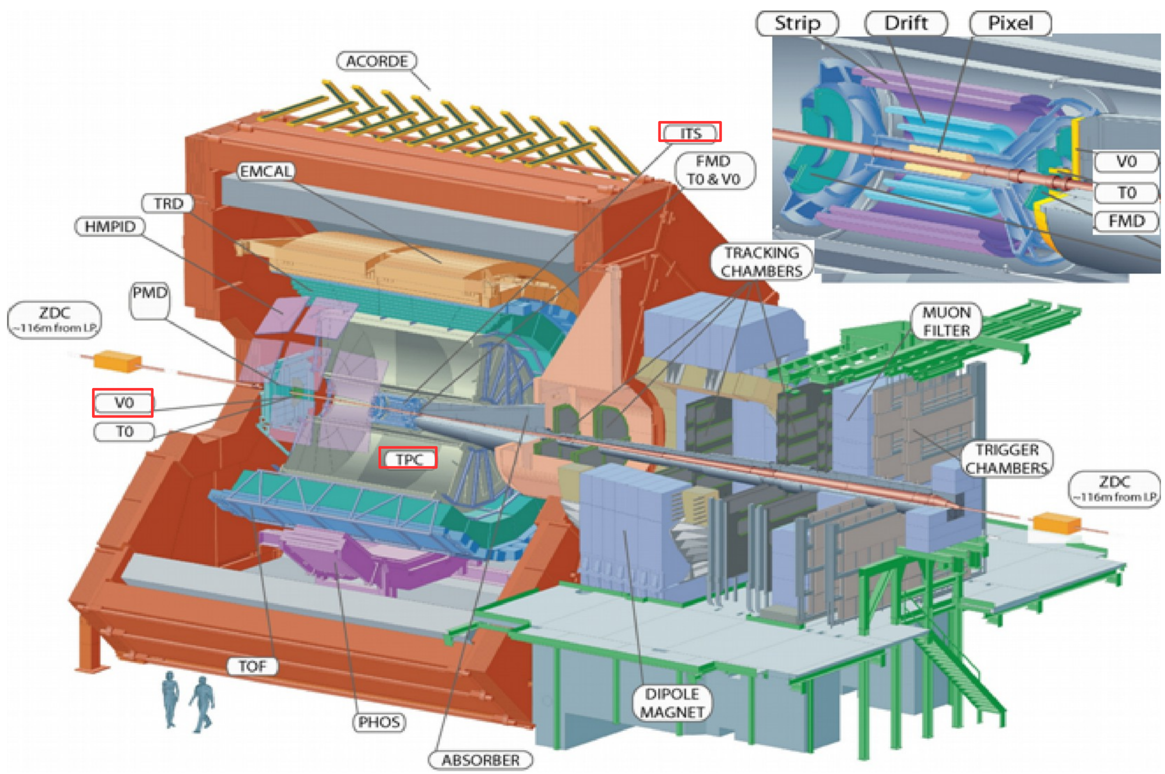


Select events with similar centralities and different shapes based on the event-by-event flow/eccentricity fluctuations

Flow vector → q-distributions

$$Q_{n,x} = \sum_i \cos(n\varphi_i) \qquad Q_{n,y} = \sum_i \sin(n\varphi_i) \longrightarrow Q_n = \{Q_{n,x}, iQ_{n,y}\} \qquad q_n = |Q_n| / \sqrt{M}$$

A Large Ion Collider Experiment

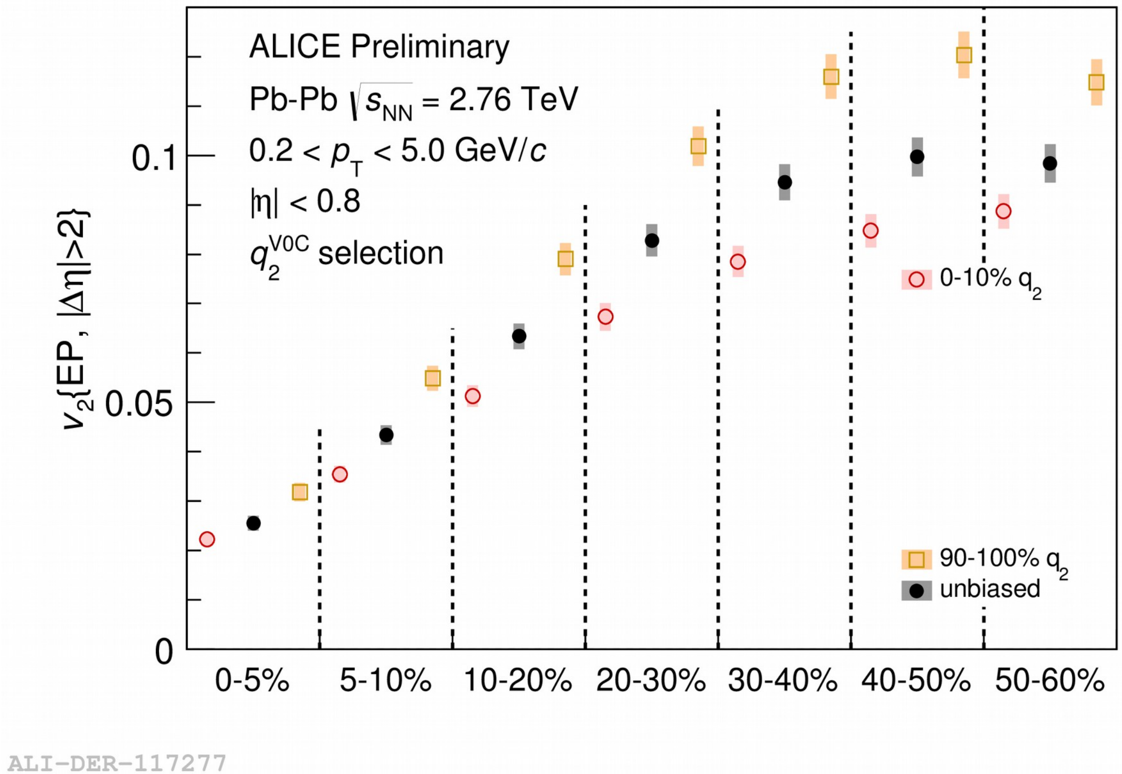


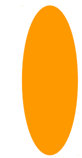
- Inner Tracking System (ITS): tracking, triggering and vertex determination
- Time Projection Chamber (TPC): tracking and vertex determination
- Two scintillator arrays (V0): trigger, determination of centrality and symmetry planes
- Tracks: $0.2<p_T<5$ GeV/c, $|\eta|<0.8$
- ~12.5M minimum-bias Pb-Pb events at $\sqrt{s_{NN}}$ = 2.76 TeV

q_2 selection	v_2/CME	Ψ_2
V0C	TPC	V0A
$-3.7<\eta<-1.7$	$-0.8<\eta<0.8$	$2.8<\eta<5.1$

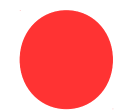
η

ESE in ALICE





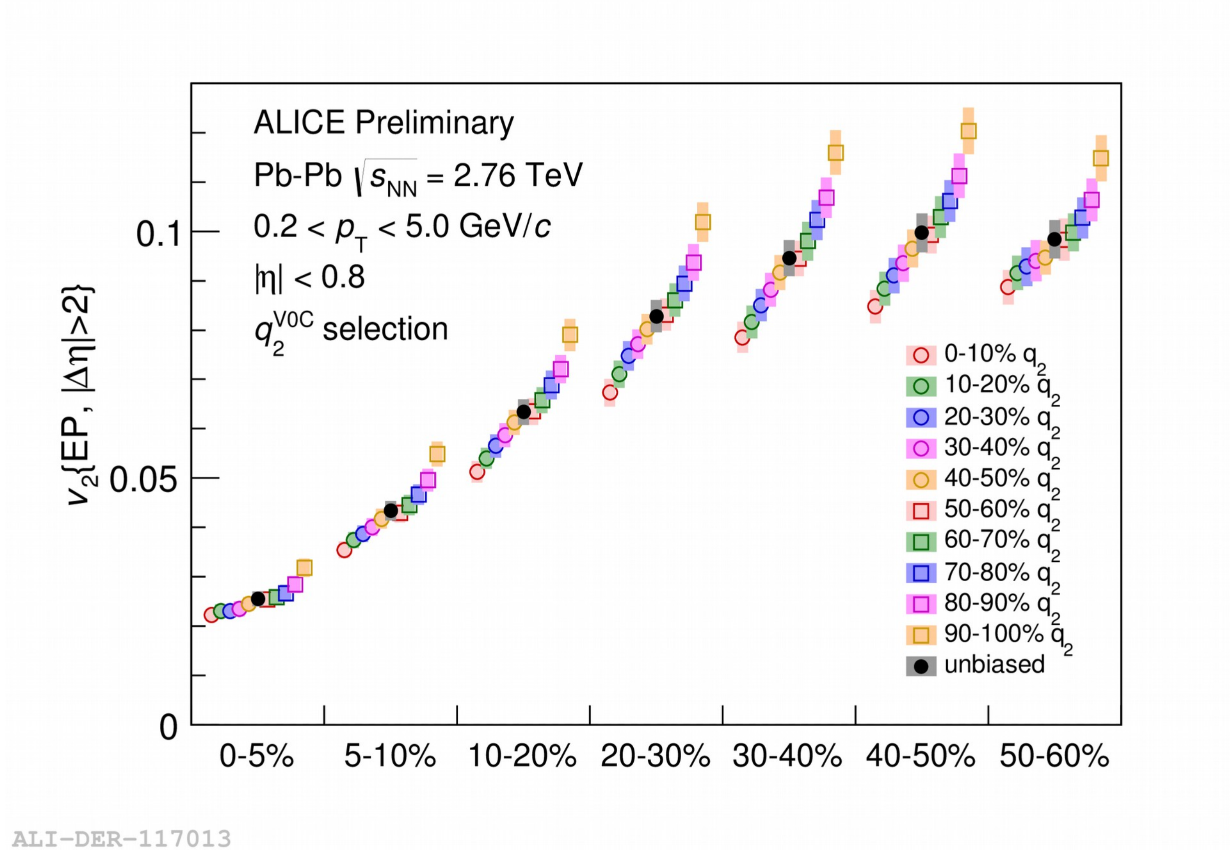
Large-q_2: 10% high

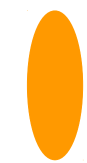


Small-q_2: 10% low

- q_2^{V0C} used to select events with 25% larger or 20% smaller v_2 than the average
- v_2 is measured with event plane method to be consistent with CME measurements
  - Non-flow is greatly suppressed by the large separation in rapidity between the TPC and the V0A ($|\Delta\eta|$>2.0)

ESE in ALICE





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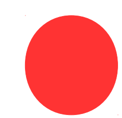
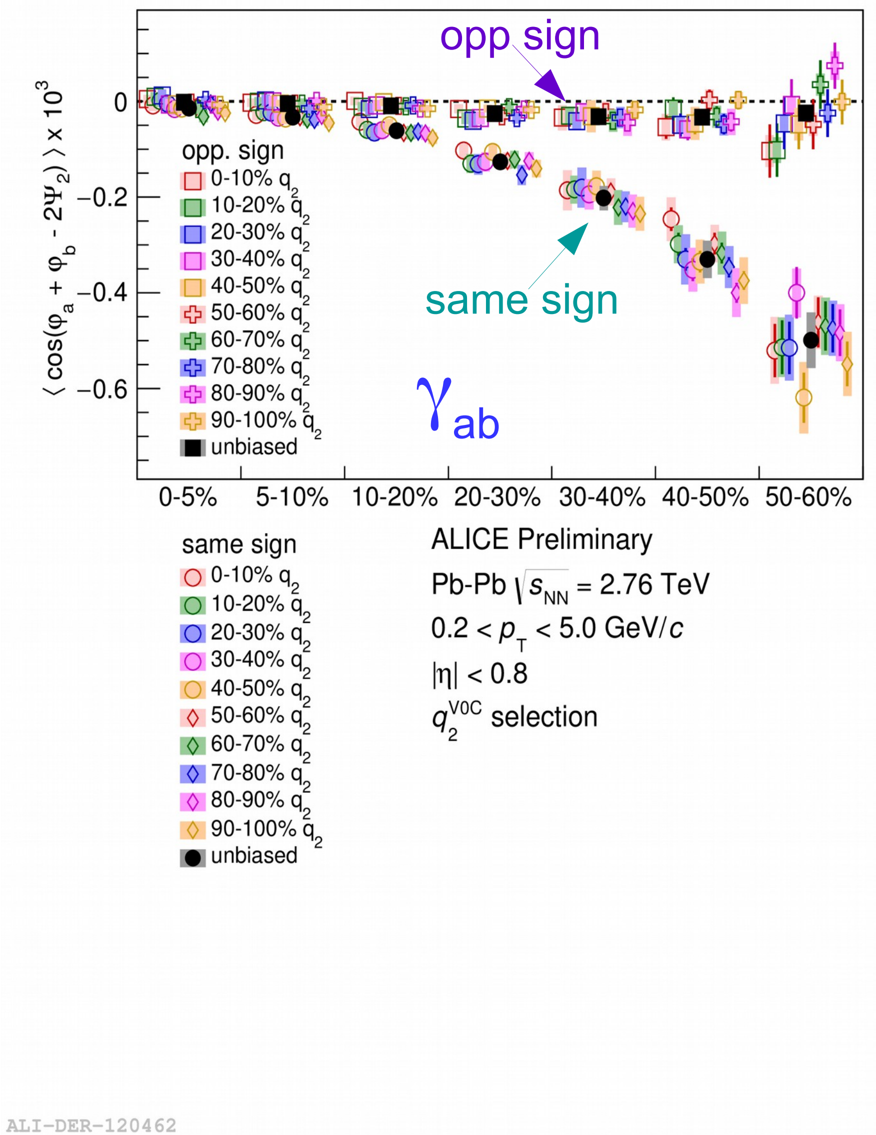


Small-q_2: 10% low

- q_2^{V0C} used to select events with 25% larger or 20% smaller v_2 than the average
- v_2 is measured with event plane method to be consistent with CME measurements
  - Non-flow is greatly suppressed by the large separation in rapidity between the TPC and the V0A (|Δη|>2.0)

CME with ESE (I)



3-particle correlator:

$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle \approx -\langle a_{1,a} a_{1,b} \rangle + B_{\text{in-plane}} - B_{\text{out-plane}}$$

- Correlator contains potential CME signal as well as background effects
  - Background contributions in γ_{ab} are suppressed at the level of ~v_2
- γ_{ab} depends weakly on the event shape selection in a given centrality bin

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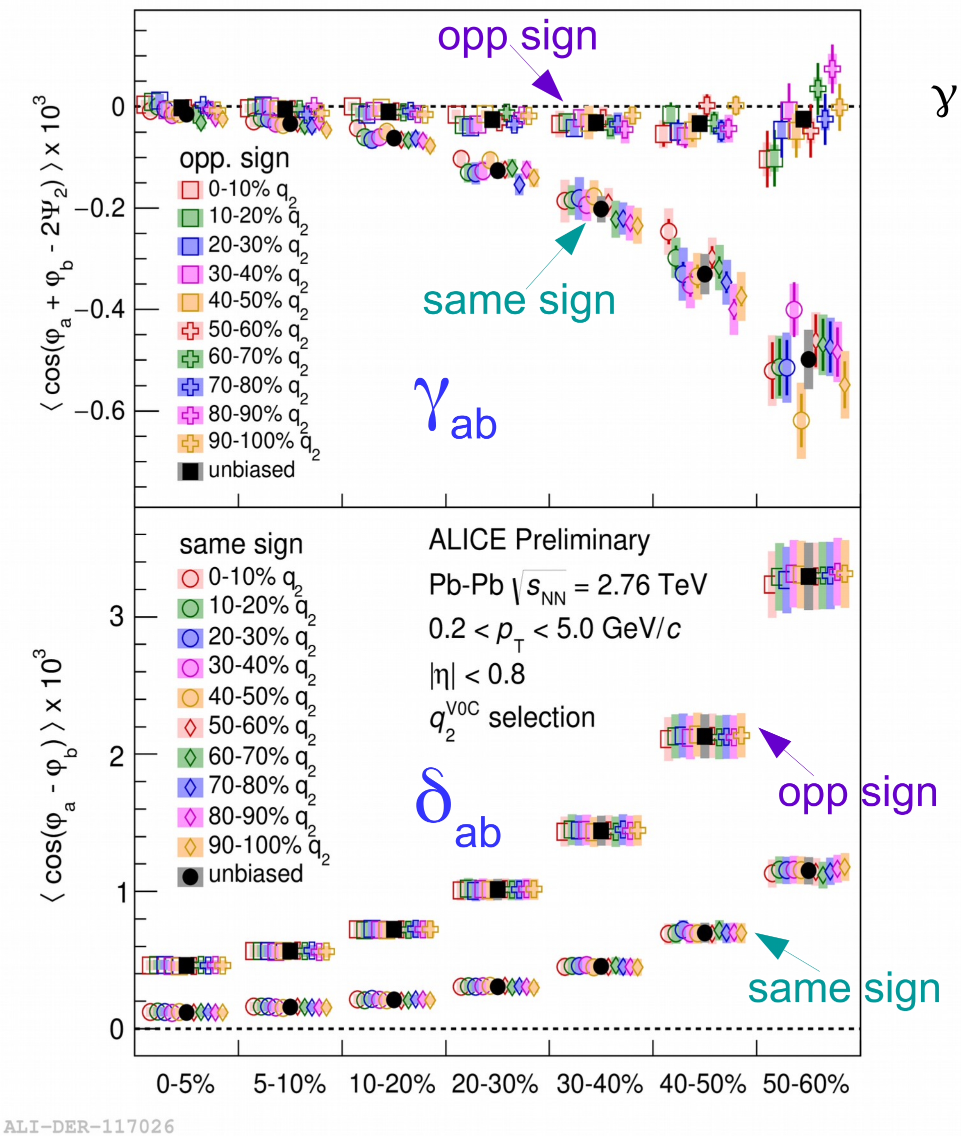


3-particle correlator:

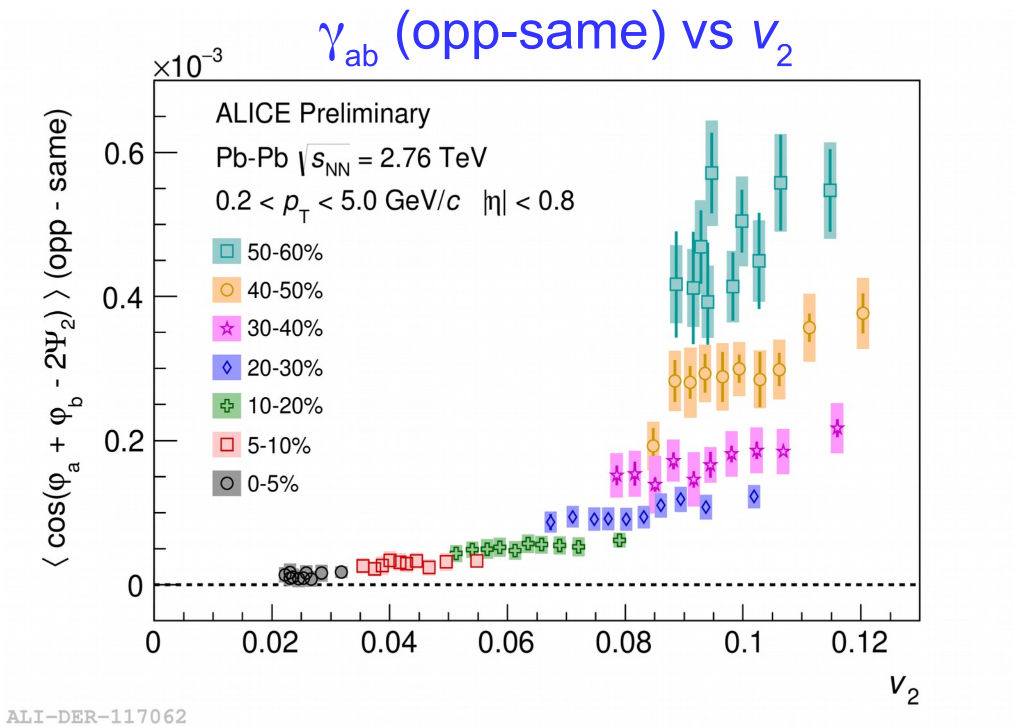
$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle \approx -\langle a_{1,a} a_{1,b} \rangle + B_{\text{in-plane}} - B_{\text{out-plane}}$$

2-particle correlator:

$$\delta_{ab} = \langle \cos(\varphi_a - \varphi_b) \rangle \approx \langle a_{1,a} a_{1,b} \rangle + B_{\text{in-plane}} + B_{\text{out-plane}}$$

- Correlators contain potential CME signal as well as background effects
  - Background contributions in γ_{ab} are suppressed at the level of ~v_2
- γ_{ab} depends weakly on the event shape selection in a given centrality bin
- δ_{ab} shows similar values for ESE and unbiased in a given centrality bin → large non-flow contribution

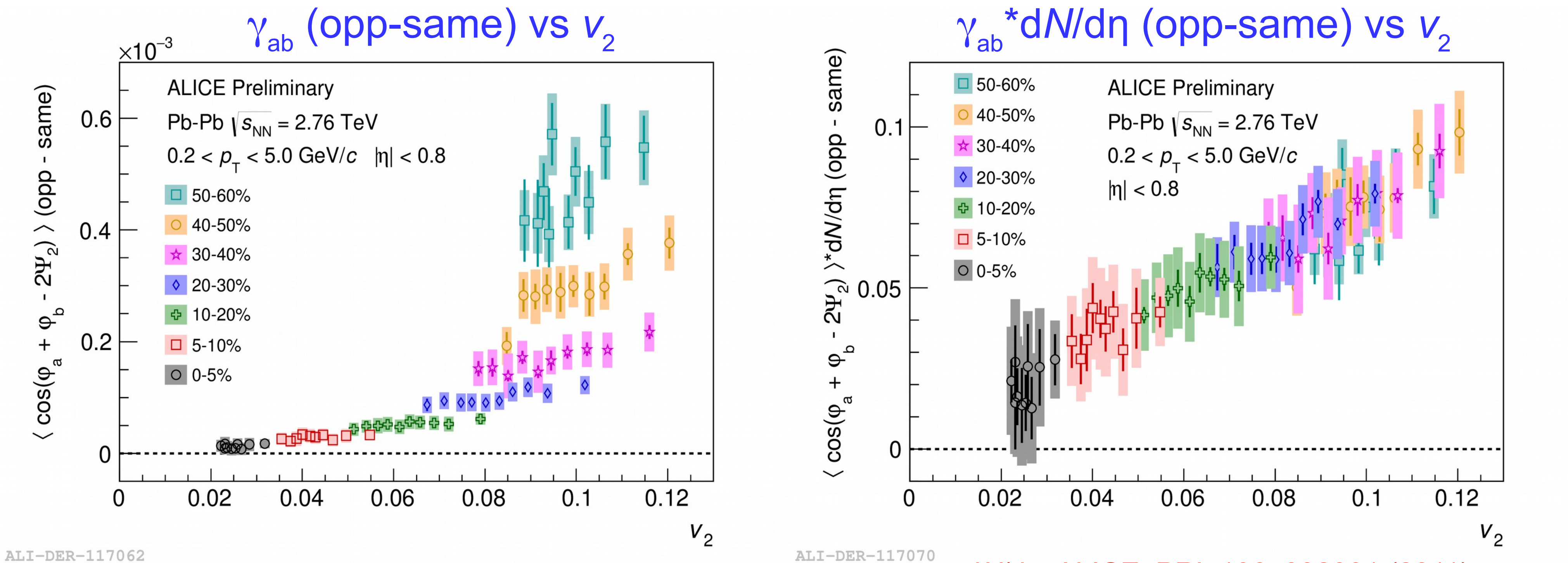
CME with ESE (II)



$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle$$

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

CME with ESE (II)

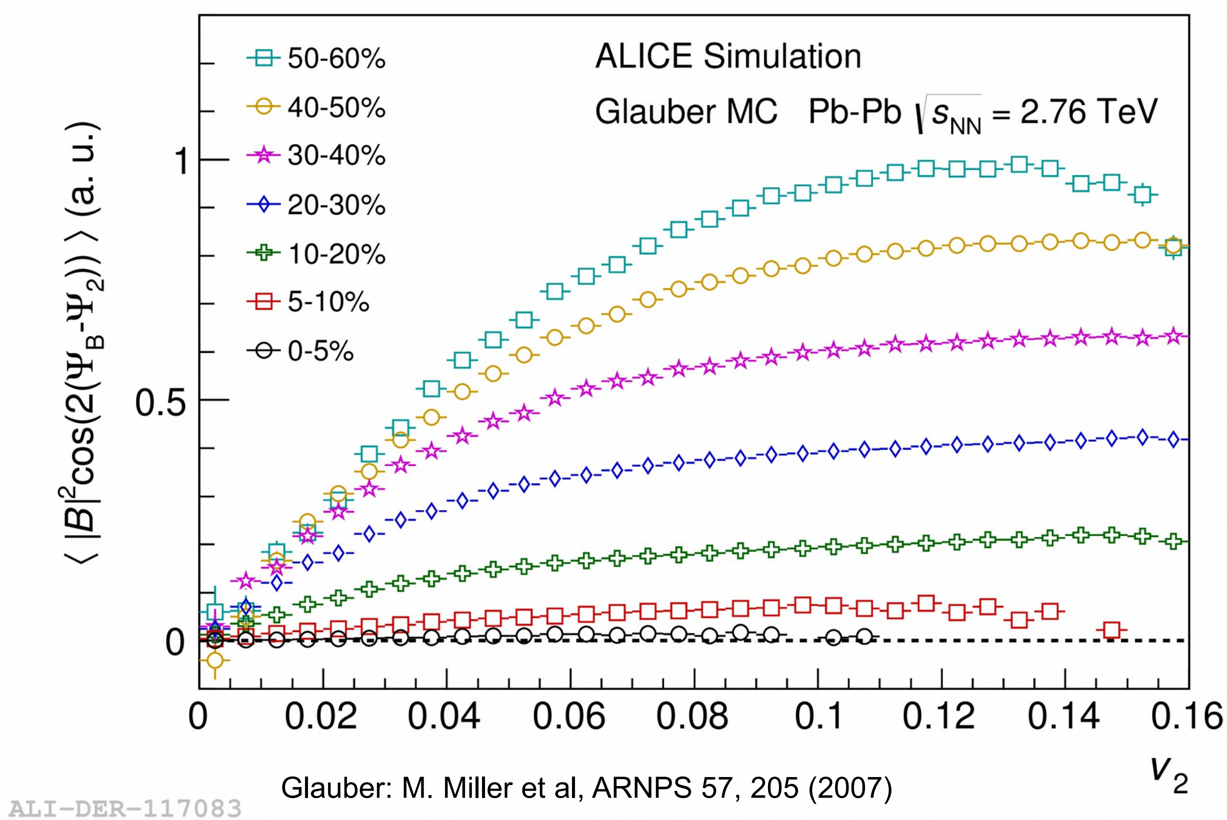


dN/dη: ALICE, PRL 106, 032301 (2011)

$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle$$

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

Does magnetic field depend on v_2 in initial state models?



Glauber: M. Miller et al, ARNPS 57, 205 (2007)

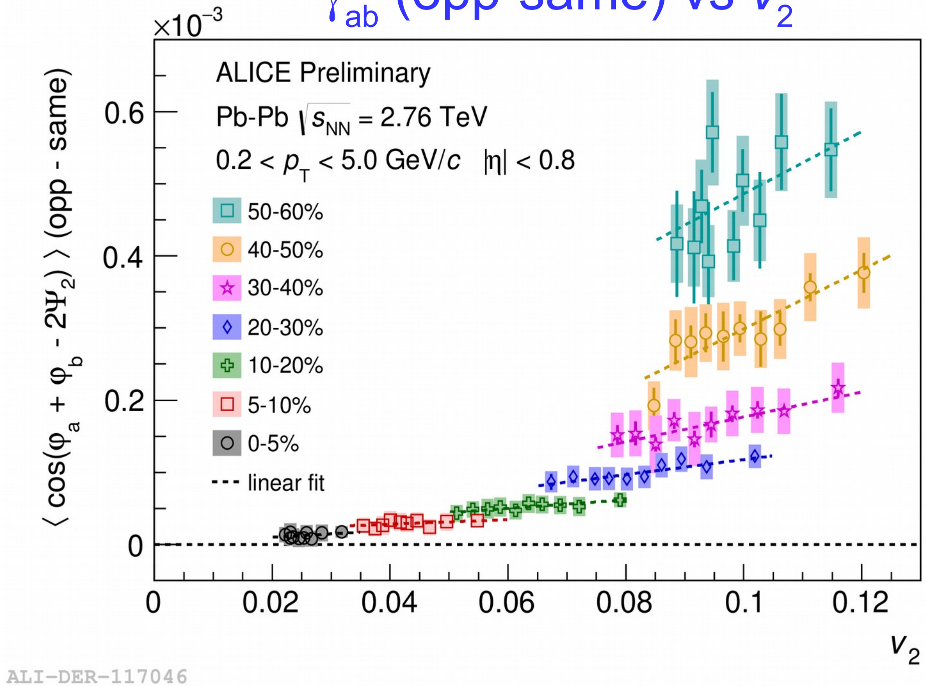
- Perform a MC Glauber simulation to evaluate the dependence of the CME signal on v_2
  - Parameters are tuned to ALICE results
  - Calculate magnetic field at origin using spectators with the proper time τ=0.1 fm
  - $<|B|^2\cos(2(\Psi_B-\Psi_2))>$ represents the expected contribution of the CME to γ_{ab}
    - $<|B|^2\cos(2(\Psi_B-\Psi_2))>$ shows a strong dependence on v_2

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

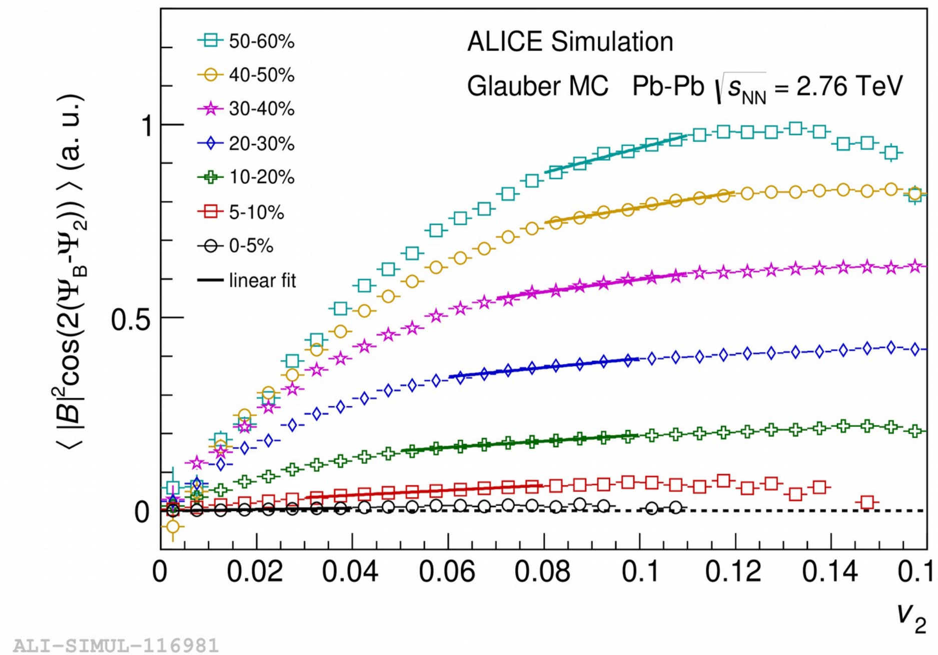
D. Kharzeev et al, NPA 803, 227 (2008)

Relating data and models

γ_{ab} (opp-same) vs v_2



$<|B|^2\cos(2(\Psi_B-\Psi_2))>$ vs v_2



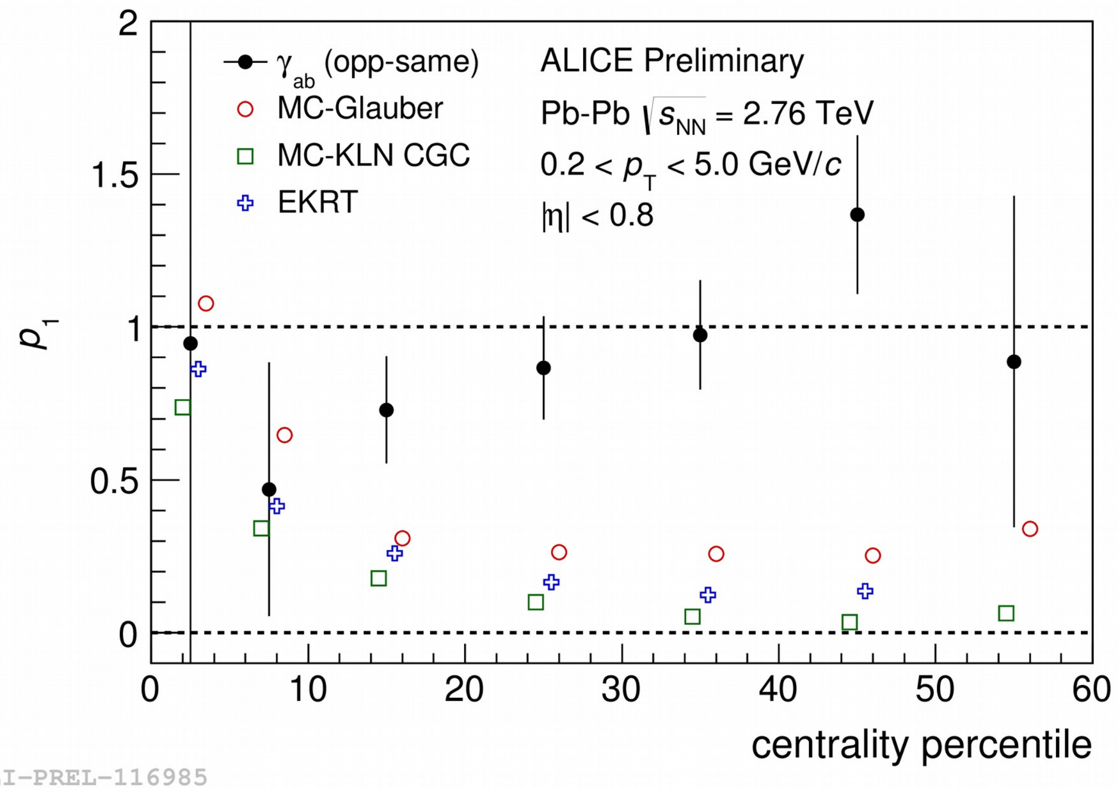
$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle$$

Glauber: M. Miller et al, ARNPS 57, 205 (2007)

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

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

Slopes of data and model fits



Glauber: M. Miller et al, ARNPS 57, 205 (2007)
EKRT: H. Niemi et al, PRC 93, 024907 (2016)
TRENTO: J. Moreland et al, PRC 92, 011901 (2015)
KLN: H. Drescher et al, PRC 76, 041903 (2007)
mckt code v.32, http://faculty.baruch.cuny.edu/naturalscience/physics/dumitru/CGC IC.htm

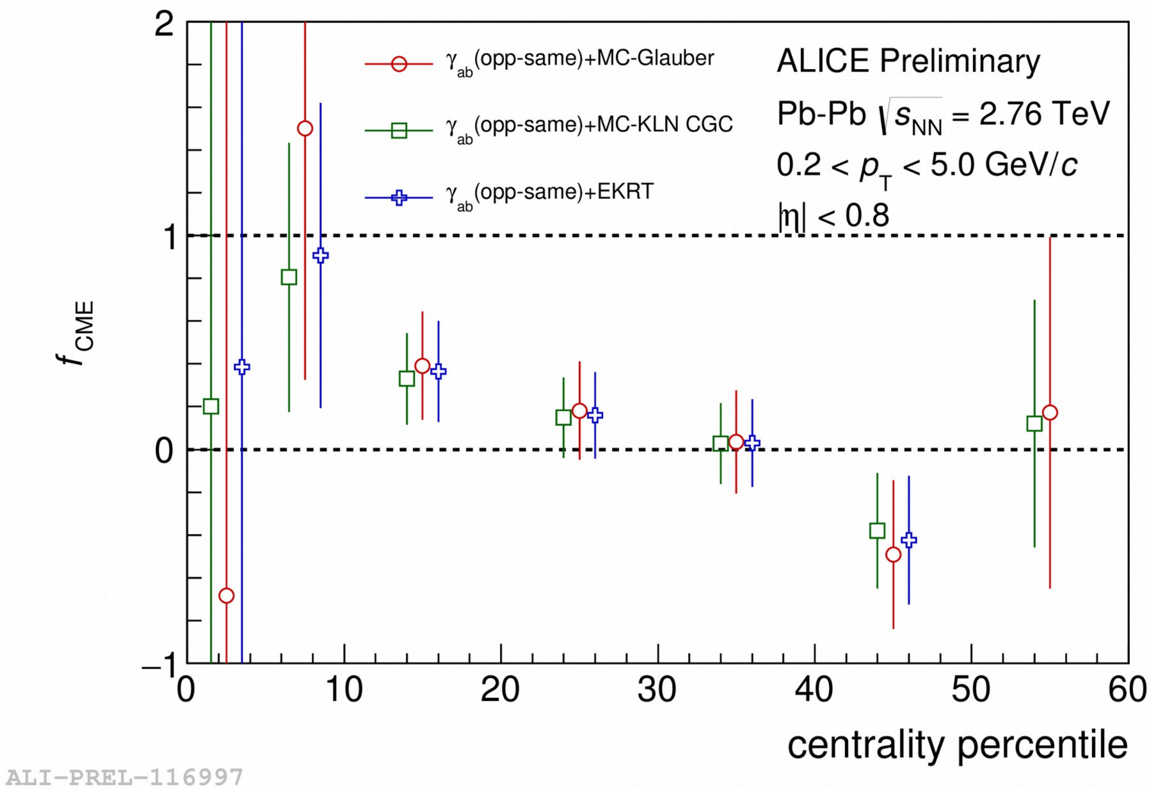
$$\gamma_{ab}=\langle\cos(\varphi_a+\varphi_b-2\Psi_2)\rangle$$

- Extract the CME fraction, f_{CME} relating the slopes of data and model fits according to:

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

- 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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$$\gamma_{ab} = \langle \cos(\varphi_a + \varphi_b - 2\Psi_2) \rangle$$

- CME fraction in 0-10% and 50-60% is currently statistically limited
- Combining the points from 10-50% despite possible centrality dependence gives:

f_{CME} (Glauber) = 0.102±0.129, f_{CME} (KLN) = 0.076±0.104 , f_{CME} (EKRT) = 0.084±0.114

Summary

- CME contribution to the charge-dependent correlation relative to the reaction plane (γ_{ab}) has been studied *for the first time* with the event shape engineering technique and initial state models
  - γ_{ab} (opp-same) approximately scales with v_2 and multiplicity

    → large background contribution
  - Scaling of the CME contribution to γ_{ab} is estimated using Monte Carlo simulations with magnetic field
    - Scaling depends weakly on the initial state models
  - CME fraction in γ_{ab} for 10-50% is found to be

    f_{CME} (Glauber) = 0.102 ± 0.129

    f_{CME} (KLN) = 0.076 ± 0.104

    f_{CME} (EKRT) = 0.084 ± 0.114

Backup

Simulated v_2