New results on CME / magnetic field

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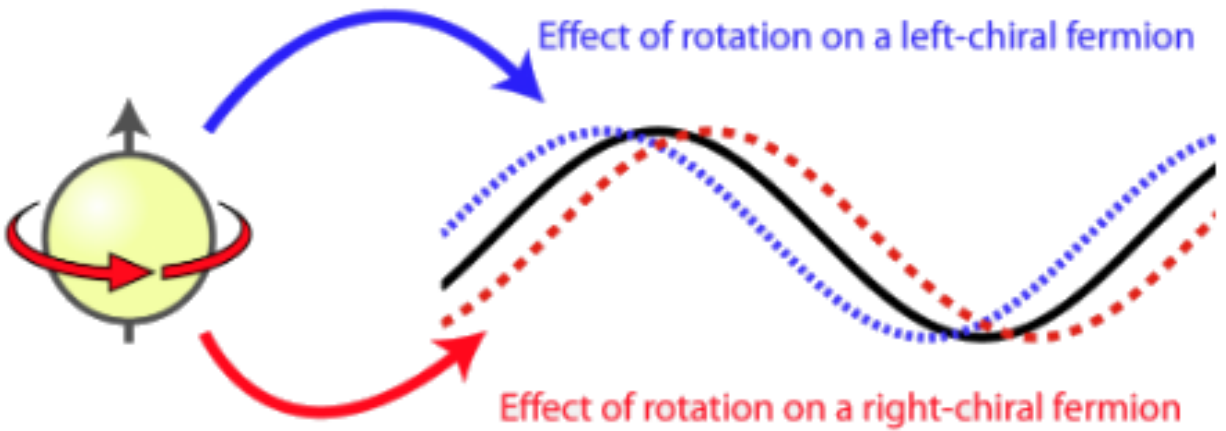
Helicity and chirality

Helicity is the sign of the projection of the spin vector onto the momentum vector

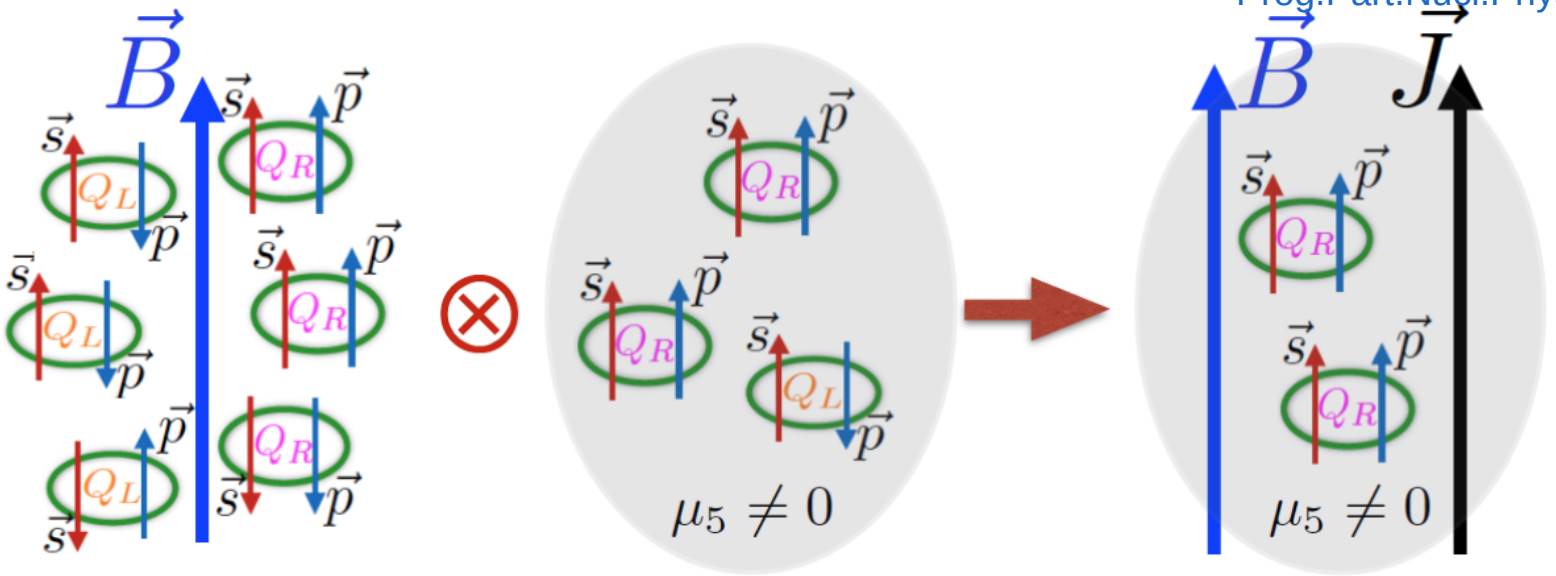
Right-handed: *Left-handed:*

Chirality of a particle is more abstract: It is determined by whether the particle transforms in a right- or left-handed way:



Chiral Magnetic Effect

Prog.Part.Nucl.Phys. 88 (2016) 1-28



External magnetic field in a chiral medium produces charged current

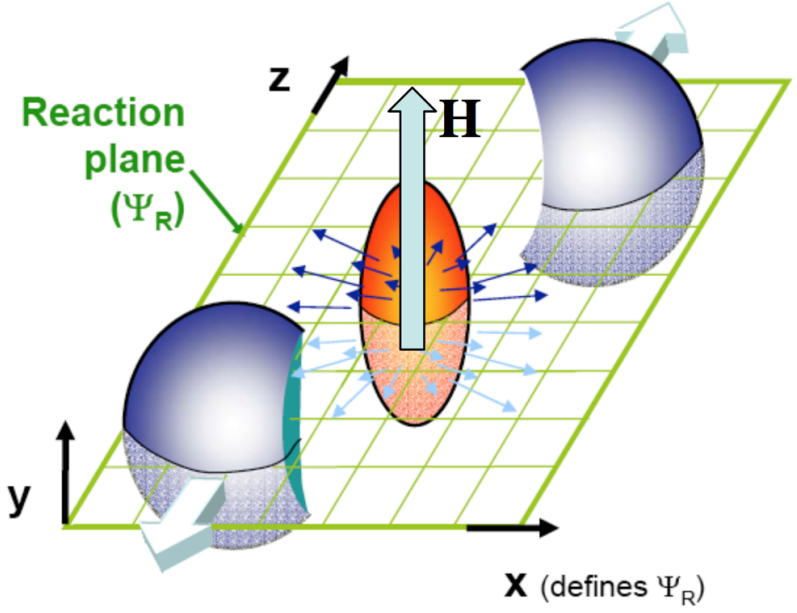
$$J^\mu = \langle \bar{\Psi}\gamma^\mu\Psi \rangle \quad , \quad J_5^\mu = \langle \bar{\Psi}\gamma^\mu\gamma^5\Psi \rangle$$

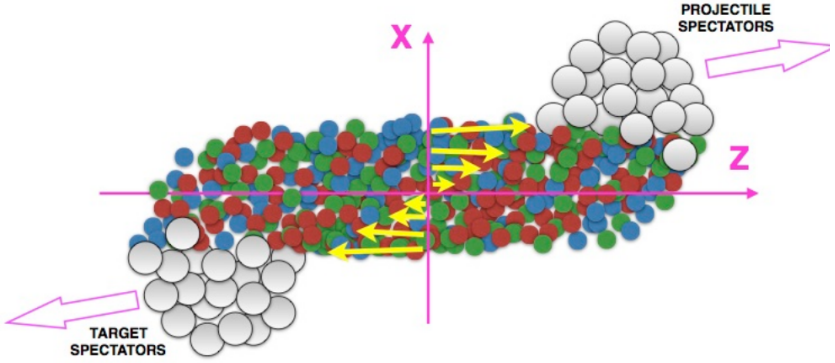
$\mu = \mu_R + \mu_L \qquad \mu_5 = \mu_R - \mu_L$

$$\vec{J} = \frac{e^2}{2\pi^2}\,\mu_5\,\vec{B}$$

Charge separation along magnetic field in chiral medium is predicted

Magnetic field & vorticity in heavy-ion collision





Strong magnetic field induced by charged current:

- B > 10^{14} T
- time ~0.1-1 fm

CME →
splitting of charge hadrons in the direction of magnetic field (⊥ to reaction plane angle)

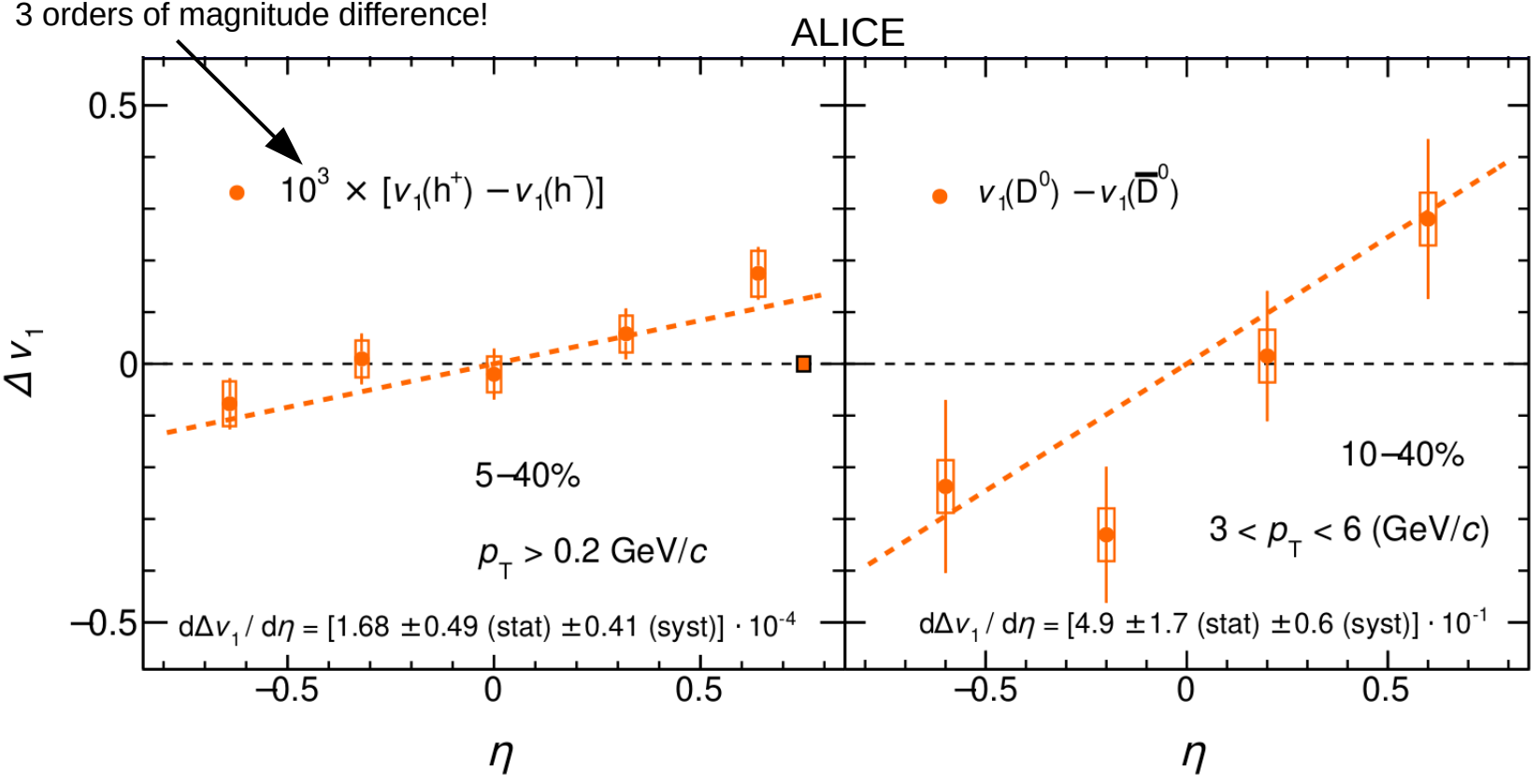
Vorticity effect is similar to MF:

$$\vec{\mathbf{J}} = \frac{1}{\pi^2}\mu_5\mu\vec{\omega}$$

→ charge independent global spin polarization

Charge-dependent directed flow

3 orders of magnitude difference!



Talk by Siyu Tang, ALICE

Talk by Dmitri Kharzeev

Talk by Cesar Bernardes, CMS

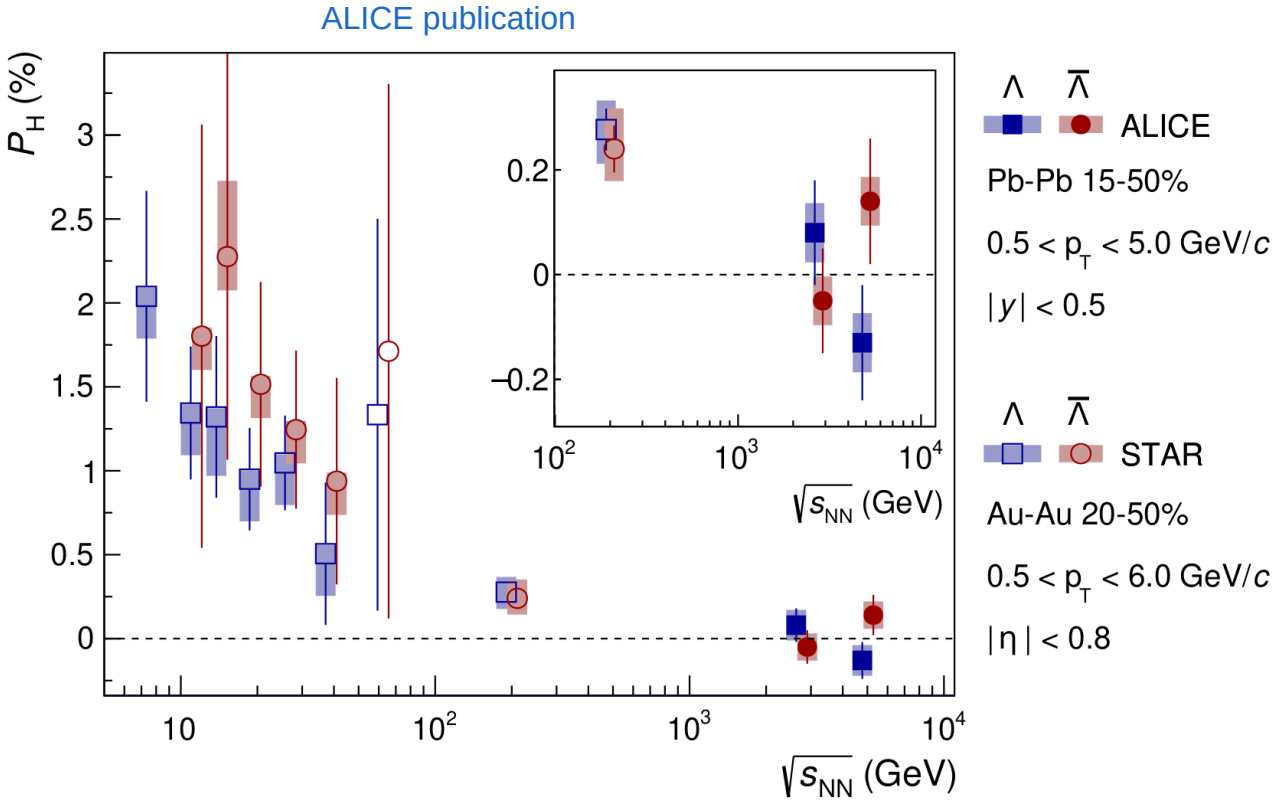
Talk by Xinyue Ju, STAR

ALICE publication

$v_1(D^0)$-v_1(anti-D^0) > 0 with significance of 2.7σ in $3<p_T<6$ GeV/c → sensitive to electromagnetic fields induced by the spectator protons

Lambda polarization

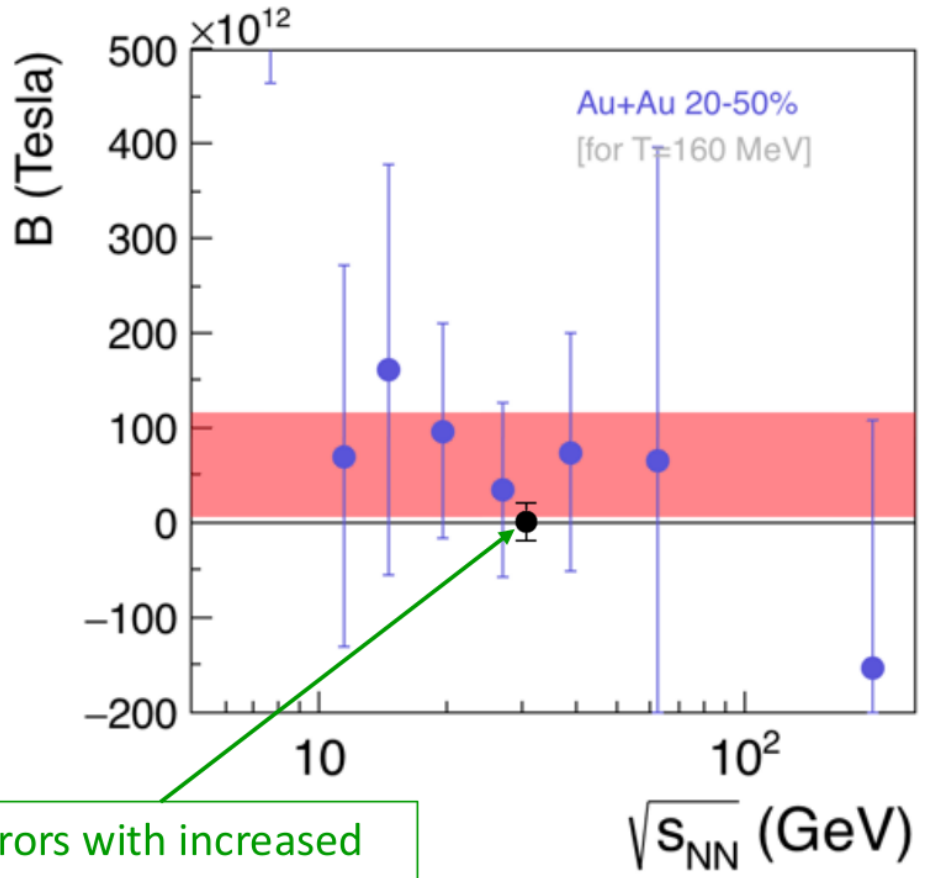
Measurable due to self-analyzing nature of decay → reveal polarization by preferentially emitting daughter proton in spin direction



- Average polarization measured at RHIC indicates the largest vorticity ever measured
- Consistent with 0 at LHC energies
- Difference between Λ and anti-Λ polarization is sensitive to MF

Magnetic field measurement with Λ polarization

Talk by Joseph Adams, STAR

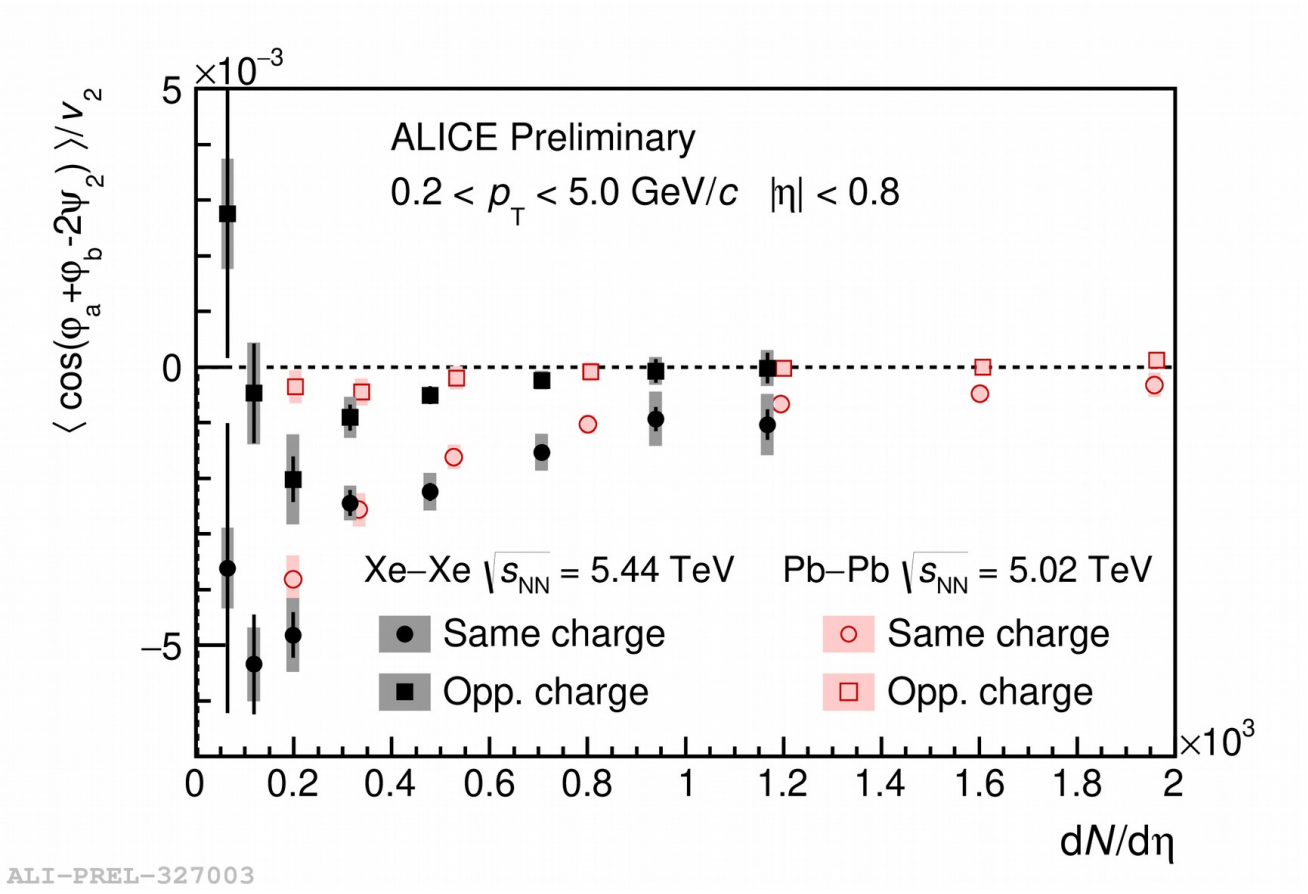


Errors with increased statistics and resolution

STAR, Nature 548 (2017) 62548

- A high-statistics Au+Au run at 27 GeV with new Event Plane Detector allows for a high-precision magnetic field measurement
- This analysis is ongoing
  - ✗ We are not yet able to make a claim of the magnetic field

Search for Chiral Magnetic Effect



Talk by Jie Zhao, STAR
Talk by Sizar Aziz, ALICE
Talk by Yufu Lin, STAR

Large background contribution coupled to v_2

Efforts to measure CME contribution to the observable

- scaling with v_2
- centrality dependence
- mixed harmonics
- different symmetry planes
- different collision systems

Search for CME is challenging due to large background contributions

Summary & Outlook

- Difference in directed flow of D-mesons is observed by ALICE → sensitive to MF?
- STAR analysis of Au+Au collisions @ 27 GeV is ongoing → no indication of MF observation so far
- CME measurements indicate large background contribution (mostly coupled to v_2) → huge efforts to extract signal with different methods

Outlook:

- Adiabaric nuclei collisions at RHIC → non-trivial to interpret taking into account different nuclei shapes and nucleons distribution inside nuclei

Backup

QCD matter under strong magnetic and electric fields

Expected phenomena:

- Electrical conductivity (Ohm's law) $E \neq 0$
- **C**hiral **M**agnetic **E**ffect $B \neq 0, \quad \mu_5 \neq 0$
- **C**hiral **S**eparation **E**ffect $B \neq 0, \quad \mu \neq 0$
- **C**hiral **E**lectric **S**eparation **E**ffect $E \neq 0, \quad \mu \neq 0 \ \& \ \mu_5 \neq 0$

$$\begin{pmatrix} \vec{\mathbf{J}} \\ \vec{\mathbf{J}}_5 \end{pmatrix} = \begin{pmatrix} \sigma & \sigma_5 \\ \sigma_{\chi e} & \sigma_s \end{pmatrix} \begin{pmatrix} \vec{\mathbf{E}} \\ \vec{\mathbf{B}} \end{pmatrix}$$

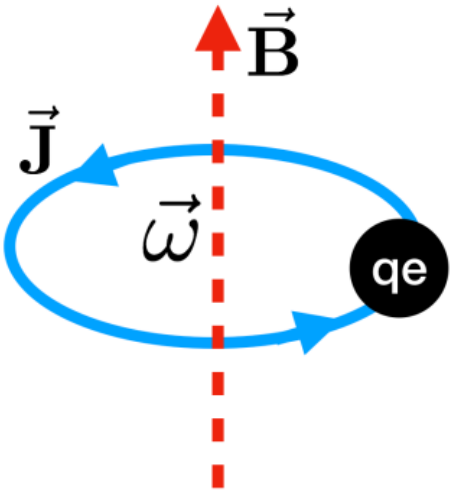
Related effects:

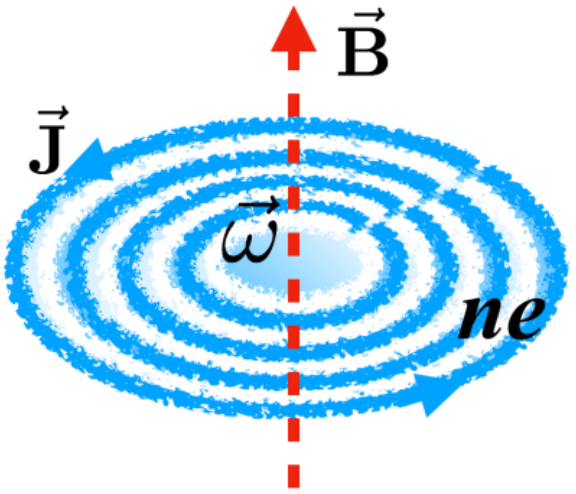
- Chiral Vortical Effect
- Chiral Magnetic Wave
- Chiral Vortical Wave

Magnetic field created by participants

Overlap region:

- charged (initial assymetry + fluctuations
- Rotating (conservation of angular momentum)





Charged rotating fluid should produce magnetic fields.

- Relation between B and ω and n?
- Beam energy / centrality dependence?
- Implications?