IX Conference on Chirality, Vorticity and Magnetic Fields in Quantum Matter

ICTP-SAIFR, São Paulo, Brazil, July 7-11, 2025

Chiral Magnetic Effect in heavy ion collisions: past, present, and future

Dmitri Kharzeev

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Brookhaven National Laboratory

Outline

- What is Chiral Magnetic Effect (CME)?
- The energy dependence of CME in heavy ion collisions:

  the case for lower energies
- Broader connections
- Outlook

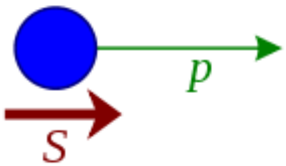
Chirality in subatomic world: chiral fermions

Fermions:
E. Fermi,1925

Dirac equation:
P. Dirac, 1928

$$(i\partial\!\!\!/ - m)\psi = 0$$

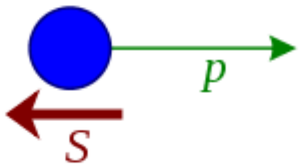
Right-handed:



Weyl fermions:
H. Weyl, 1929

$$\sigma^\mu \partial_\mu \psi = 0$$

Left-handed:



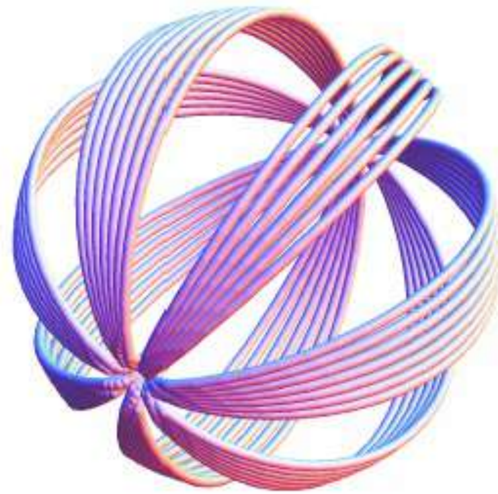
Majorana fermions:
1937

$$-i\partial\!\!\!/ \psi + m\psi_c = 0$$

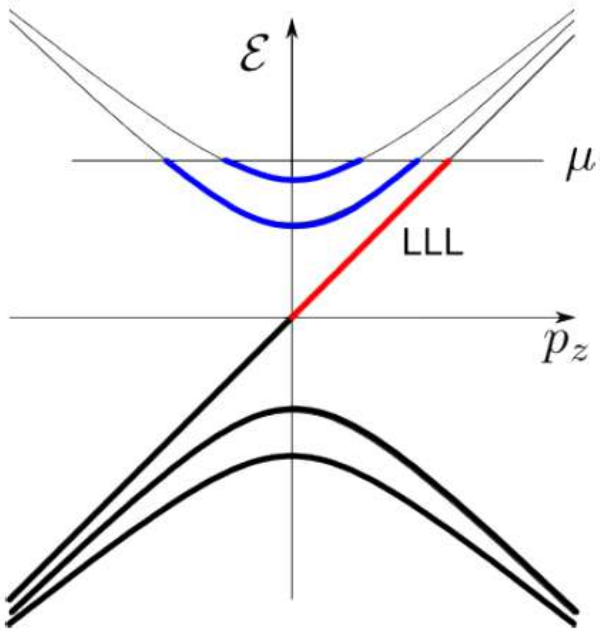
$$\psi_c := i\psi^*$$

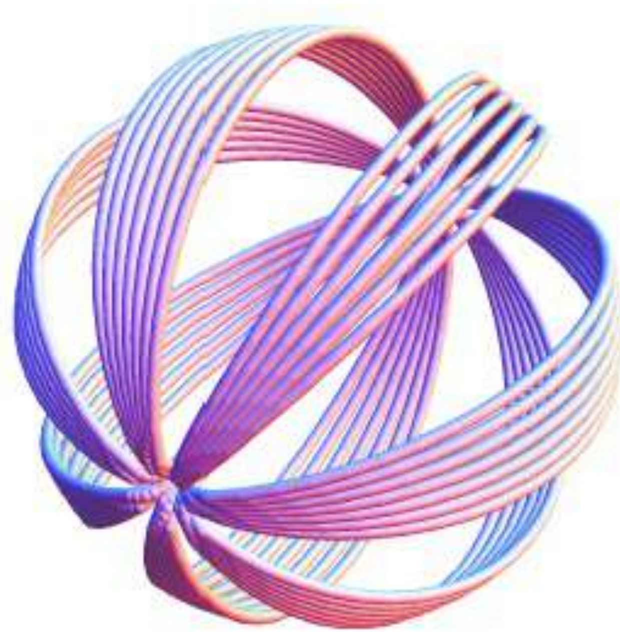
Chirality of gauge fields

Gauge fields can form **chiral knots** – for example, knots of magnetic flux in magnetohydrodynamics (magnetic helicity), characterized by Chern-Simons number



Chiral anomaly: chirality transfer from fermions to gauge fields (or vice versa)

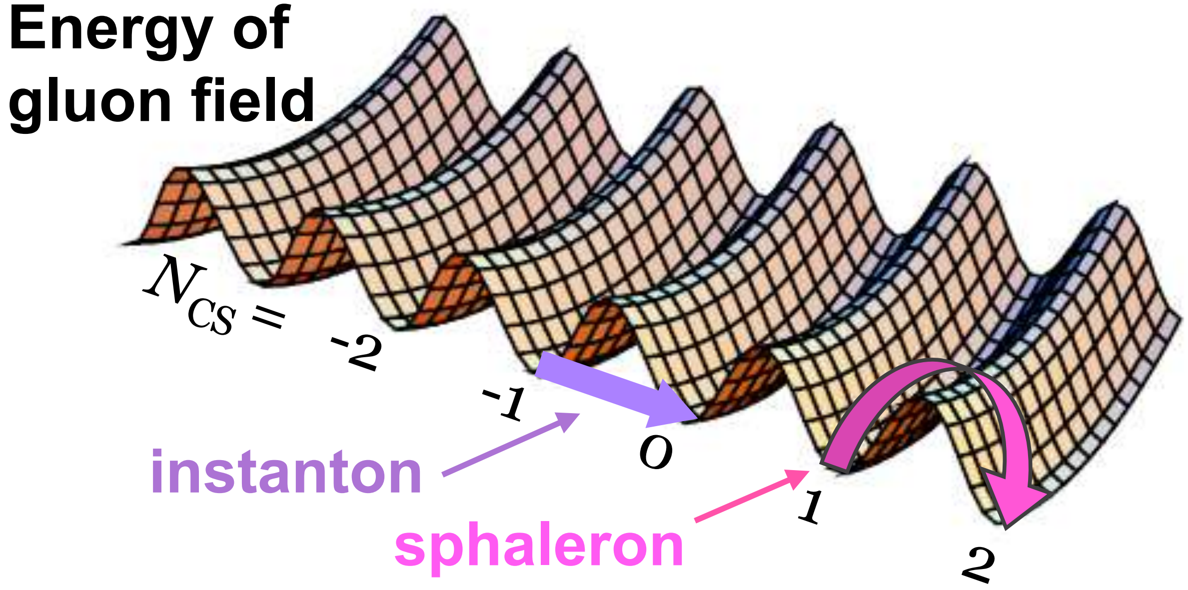


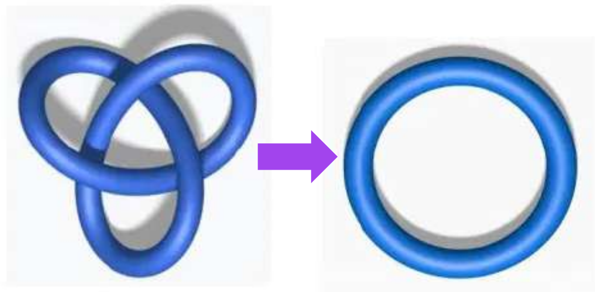


From: Y. Hirono, DK, Y. Yin,
PRD 92 (2015) 12

Chirality in the vacuum of the Standard Model

Topological chirality-changing transitions between the vacuum sectors of QCD are responsible for the spontaneous chiral symmetry breaking and thus most of the mass of visible Universe.

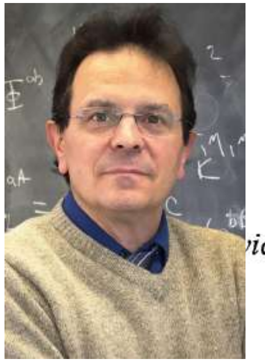




Is it possible to directly observe these chirality-changing transitions in experiment?

We addressed this problem in the 1998 paper with Rob Pisarski and Michel Tytgat:

VOLUME 81, NUMBER 3 PHYSICAL REVIEW LETTERS 20 JULY 1998



Possibility of Spontaneous Parity Violation in Hot QCD

Dmitri Kharzeev,[1] Robert D. Pisarski,[2] and Michel H. G. Tytgat[2,3]
[1]*RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973-5000*
[2]*Department of Physics, Brookhaven National Laboratory, Upton, New York 11973-5000*
ice de Physique Théorique, CP 225, Université Libre de Bruxelles, Boulevard du Triomphe, 1050 Bruxelles, Belgi
(Received 3 April 1998)

We argue that for QCD in the limit of a large number of colors, the axial U(1) symmetry of massless quarks is effectively restored at the deconfining phase transition. If this transition is of second order, metastable states in which parity is spontaneously broken can appear in the hadronic phase. These metastable states have dramatic signatures, including enhanced production of η and η' mesons, which can decay through parity violating decay processes such as $\eta \to \pi^0\pi^0$, and global parity odd asymmetries for charged pions. [S0031-9007(98)06613-7]

A working group with STAR experimentalists was formed to find a way to detect this local parity violation (chirality imbalance):

J. Sandweiss, S. Voloshin, J. Thomas, E. Finch, A. Chikanian, R. Longacre, …

But after a few years of hard work it has become clear that the proposed pion correlations are very difficult to detect.

Detecting the topological structure of QCD vacuum

Topological transitions in the QCD plasma change chirality of quarks. However, quarks are confined into hadrons, and their chirality cannot be detected in heavy ion experiments.

Therefore , to observe these chirality-changing transitions we have to find a way to convert chirality of quarks into something observable – perhaps, a (fluctuating) **electric dipole moment of the QCD plasma**? This would require an external **magnetic field** or an **angular momentum**.

Parity violation in hot QCD: Why it can happen, and how to look for it

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Received 23 December 2004; received in revised form 27 October 2005; accepted 23 November 2005

hep-ph/0406125

Physics Letters B 633 (2006) 260–264

This idea was developed further:

Charge separation induced by $\mathcal{P}$-odd bubbles in QCD matter

Dmitri Kharzeev [a,*], Ariel Zhitnitsky [b]

[a] *Physics Department, Brookhaven National Laboratory, Upton, NY 11973-5000, USA*
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Received 19 June 2007; received in revised form 17 September 2007; accepted 1 October 2007

The effects of topological charge change in heavy ion collisions: "Event by event $\mathcal{P}$ and $\mathcal{CP}$ violation"

Dmitri E. Kharzeev [a], Larry D. McLerran [a,b], Harmen J. Warringa [a,*]

[a] *Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, USA*
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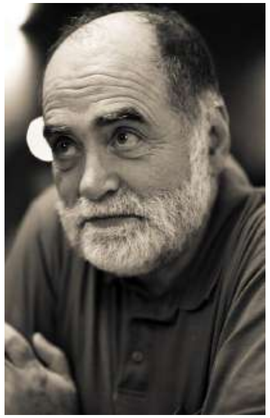
Received 15 November 2007; received in revised form 28 January 2008; accepted 3 February 2008



PHYSICAL REVIEW D **78,** 074033 (2008)

Chiral magnetic effect

Kenji Fukushima,[1,*] Dmitri E. Kharzeev,[2,+] and Harmen J. Warringa[2,‡]

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(Received 2 September 2008; published 31 October 2008)

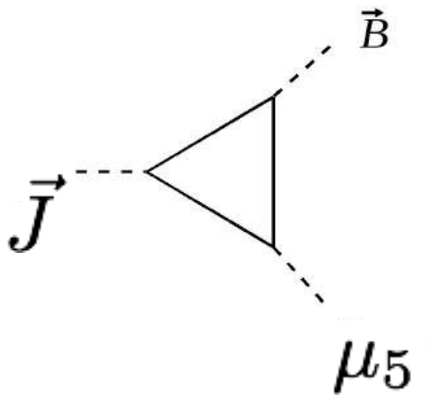
Chiral Magnetic Effect (CME)

Chiral Magnetic Effect

DK'04; DK, A. Zhitnitsky '07; DK, L.McLerran, H.Warringa '07; K.Fukushima, DK, H.Warringa, "Chiral magnetic effect" PRD'08; Review and list of refs: DK, arXiv:1312.3348 [Prog.Part.Nucl.Phys]

Chiral chemical potential is formally equivalent to a background chiral gauge field: $\mu_5 = A_5^0$

In this background, and in the presence of B, vector e.m. current is generated:



$$\partial_\mu J^\mu = \frac{e^2}{16\pi^2} \left(F_L^{\mu\nu} \tilde{F}_{L,\mu\nu} - F_R^{\mu\nu} \tilde{F}_{R,\mu\nu} \right)$$

Compute the current through

$$J^\mu = \frac{\partial \log Z[A_\mu, A_\mu^5]}{\partial A_\mu(x)}$$

Absent in Maxwell theory!

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

Coefficient is fixed by the chiral anomaly, no corrections

Chirally imbalanced system is a non-equilibrium state

Chiral magnetic conductivity: discrete symmetries

P – parity
T – time reversal

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

P-odd
T-odd

P-even
T-odd

P-odd

P-odd effect!

T-even

Non-dissipative current!
(non-equilibrium)

Effect persists in hydrodynamics!

D.Son, P.Surowka '09

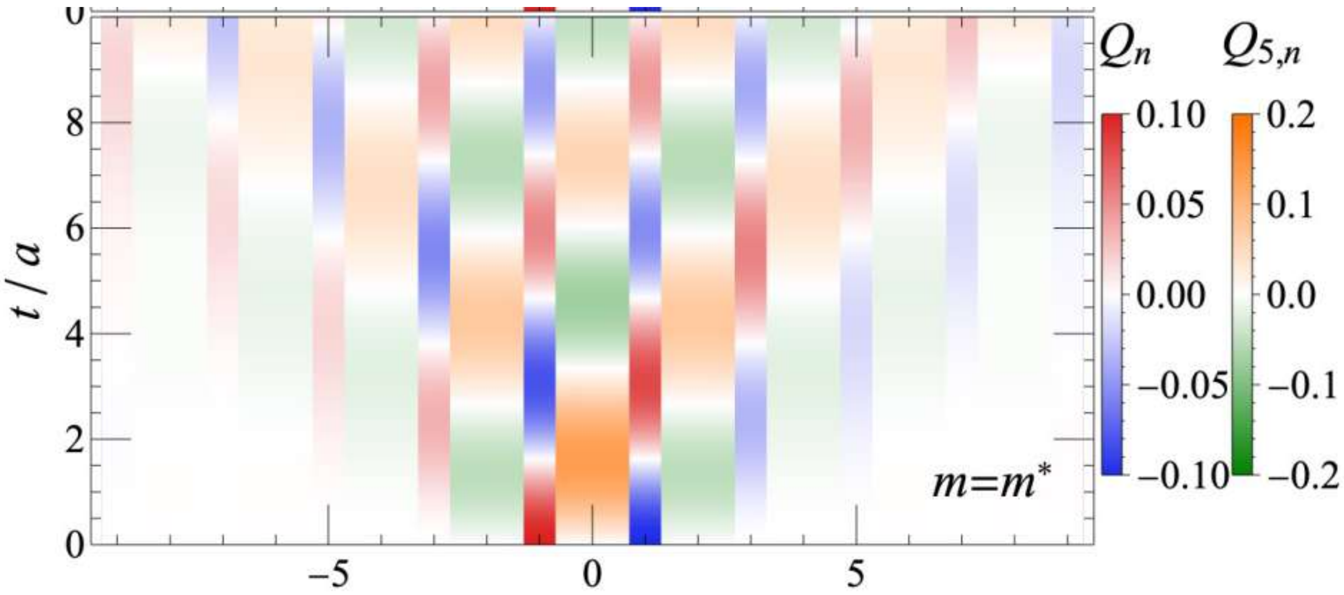
DK, H.U.Yee '11

cf Ohmic conductivity:

$$\vec{J} = \sigma \vec{E}$$

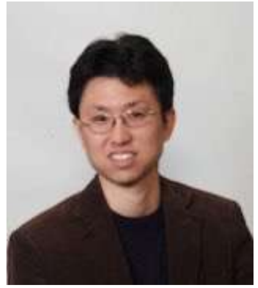
T-odd,
dissipative

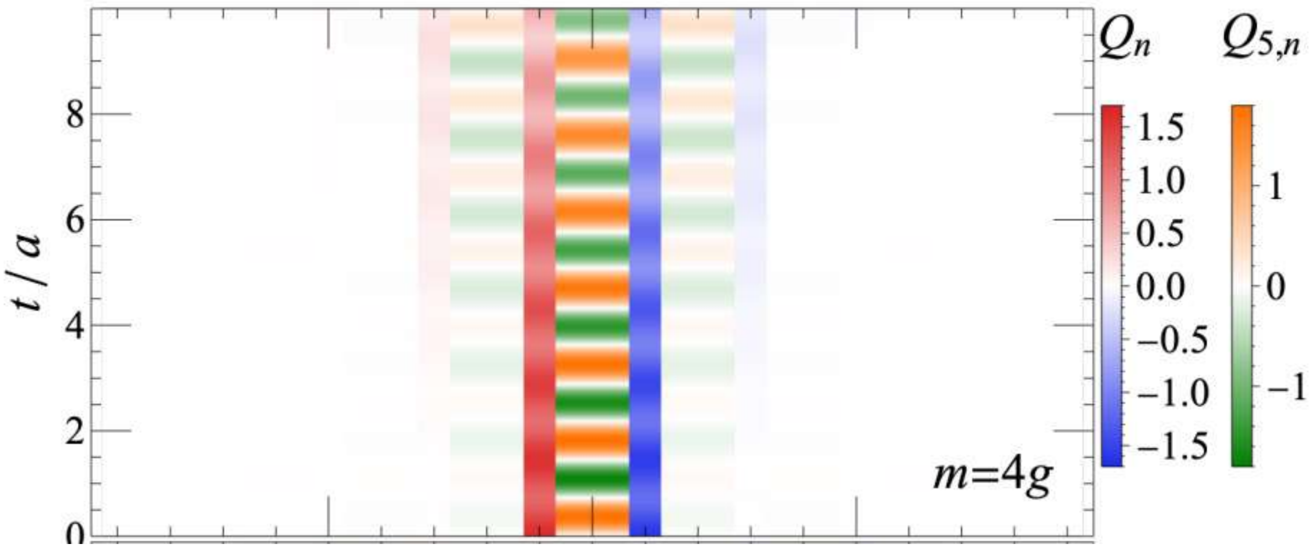
Chiral magnetic waves



Chiral magnetic wave: coupled oscillations of electric and chiral charges

DK, H.U. Yee, ’10





Quantum simulation reveals the existence of a novel nonlinear chiral magnetic wave at large m/g

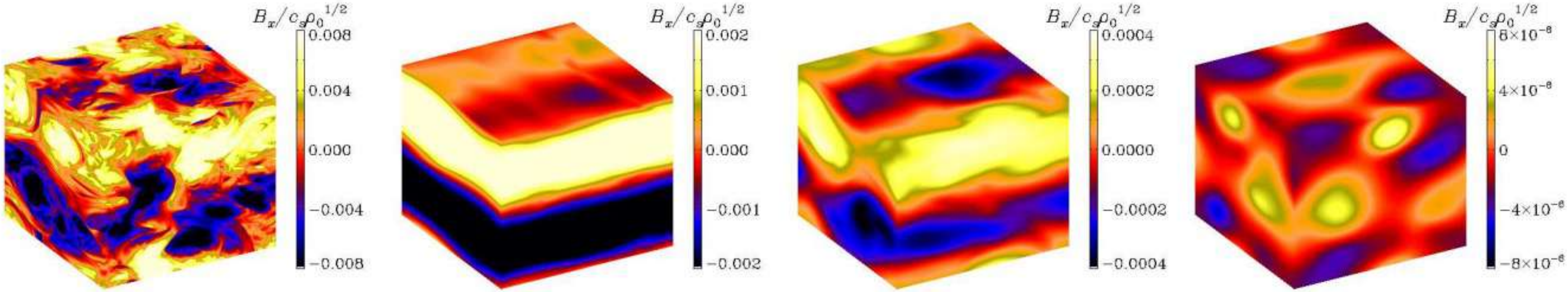
K. Ikeda, DK, S. Shi, arXiv:2305.05685; PRD’23

CME in the Early Universe

ASTROPHYS. J. 845, L21 (2017)
Preprint typeset using LATEX style emulateapj v. 08/22/09

THE TURBULENT CHIRAL MAGNETIC CASCADE IN THE EARLY UNIVERSE

AXEL BRANDENBURG[1,2,3,4], JENNIFER SCHOBER[3], IGOR ROGACHEVSKII[5,1,3], TINA KAHNIASHVILI[6,7], ALEXEY BOYARSKY[8], JÜRG FRÖHLICH[9], OLEG RUCHAYSKIY[10], AND NATHAN KLEEORIN[5,3]



THE ASTROPHYSICAL JOURNAL, 911:110 (14pp), 2021 April 20
https://doi.org/10.3847/1538-4357/abe4d7

Relic Gravitational Waves from the Chiral Magnetic Effect

Axel Brandenburg[1,2,3,4], Yutong He[1,2], Tina Kahniashvili[3,4,5], Matthias Rheinhardt[6], and Jennifer Schober[7]

Bringing gravitational waves to light

QuGrav: Bringing gravitational waves to light with Qumodes

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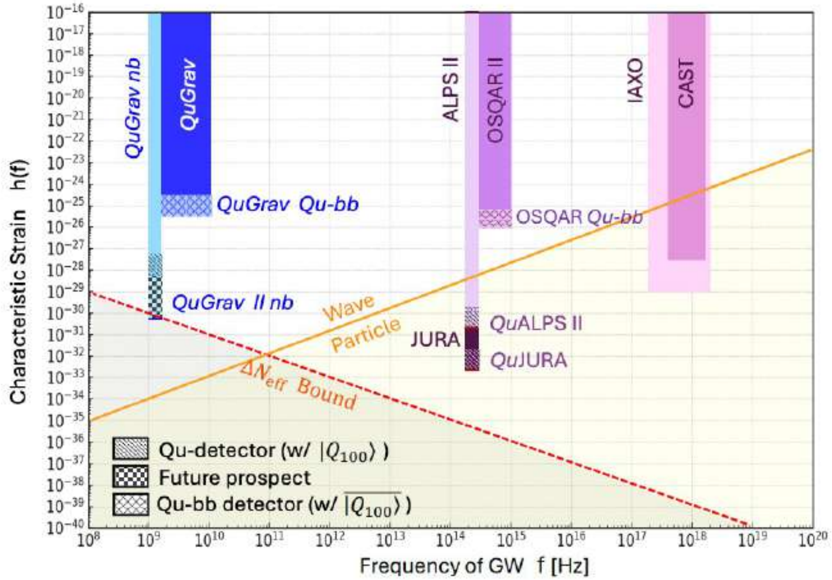
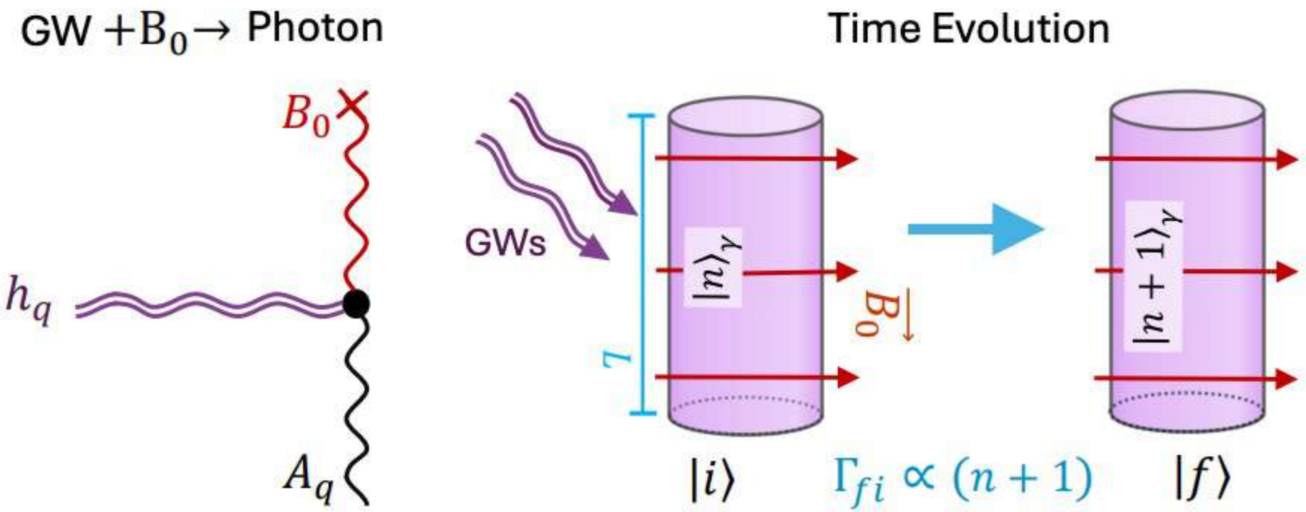
Saba Shalamberidze
Center for Nuclear Theory, Department of Physics and Astronomy, Stony Brook University, New York 11794-3800, USA

arXiv:2506.09459

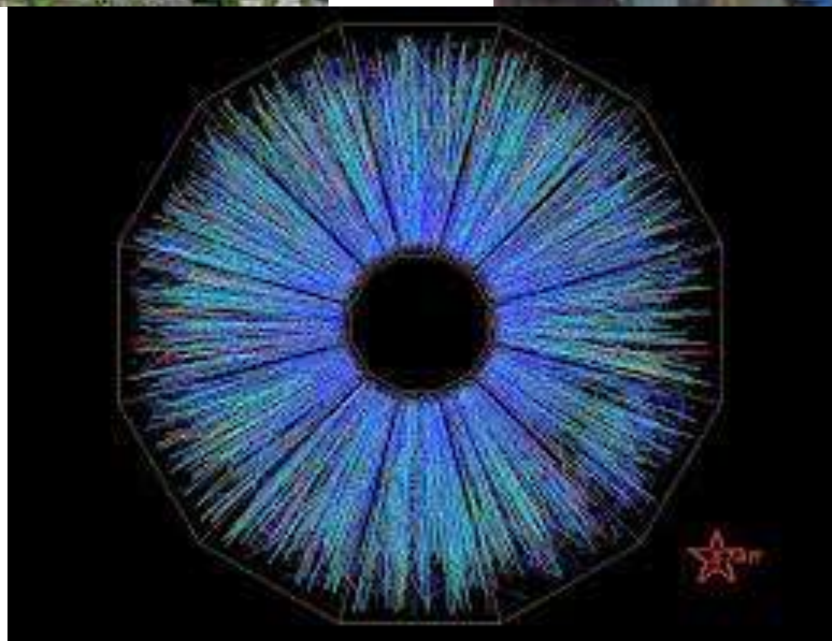




Can one detect QCD topological transitions in heavy ion collisions?

Relativistic Heavy Ion Collider (RHIC) at BNL

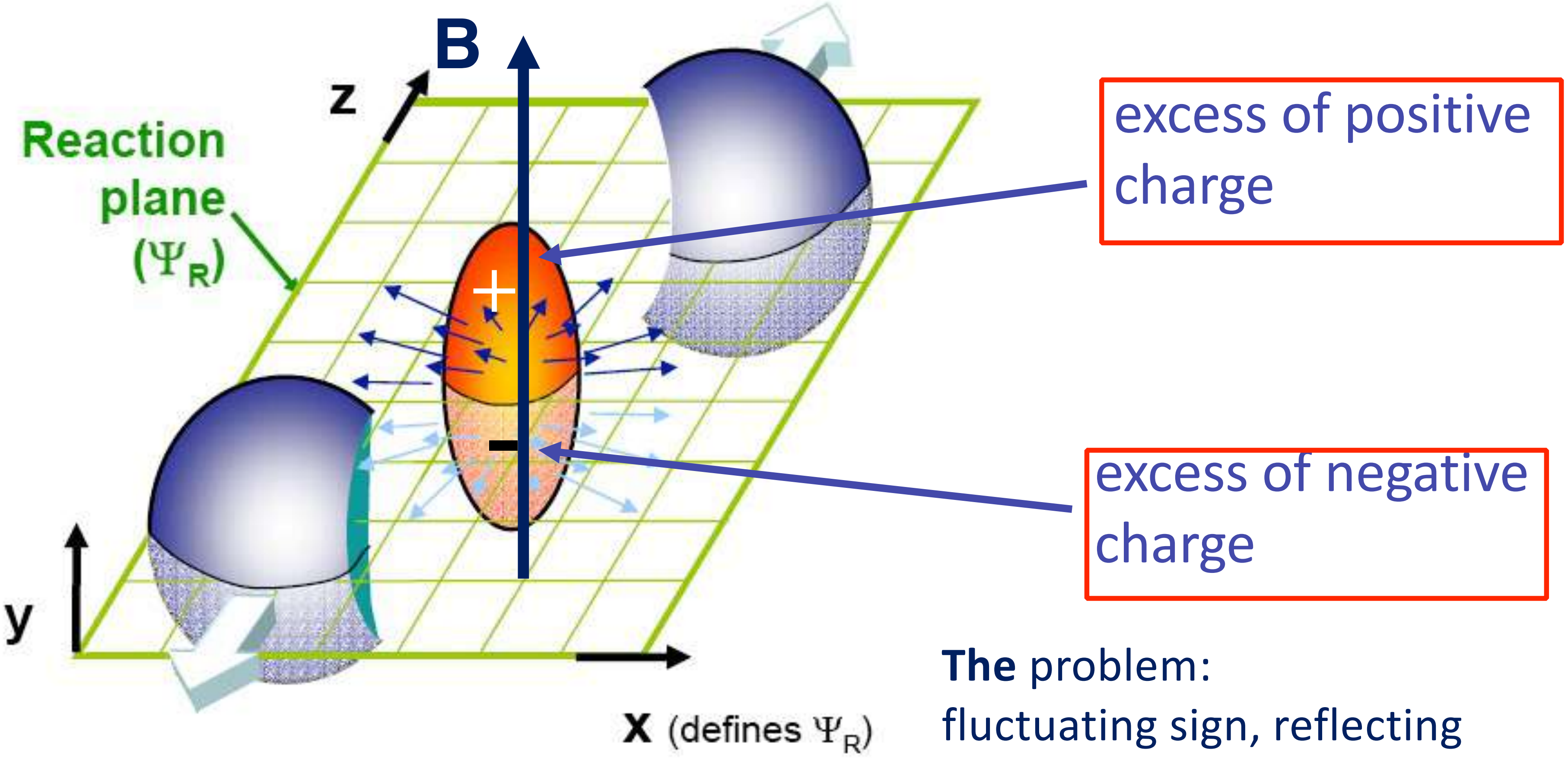
The STAR Collaboration at RHIC



Charged hadron tracks in a Au-Au collision at RHIC [STAR experiment]

CME as a probe of topological transitions and chiral symmetry restoration in QCD plasma

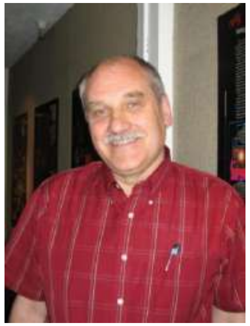
Electric dipole moment due to chiral imbalance



The problem:
fluctuating sign, reflecting topological fluctuations in QCD
- backgrounds!

DK, hep-ph/0406125; Phys.Lett.B633(2006)260

Separating the signal from background: the beginning

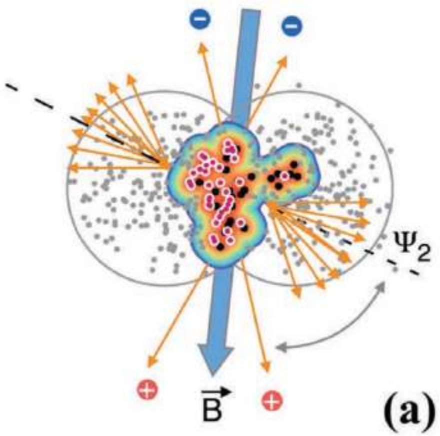


PHYSICAL REVIEW C **70**, 057901 (2004)

Parity violation in hot QCD: How to detect it

Sergei A. Voloshin
Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48201, USA
(Received 5 August 2004; published 11 November 2004)

In a recent paper (hep-ph/0406125) Kharzeev argues for the possibility of *P*- and/or *CP*-violation effects in heavy-ion collisions, the effects that can manifest themselves via asymmetry in $\pi^{\pm}$ production with respect to the direction of the system angular momentum. Here we present an experimental observable that can be used to detect and measure the effects.



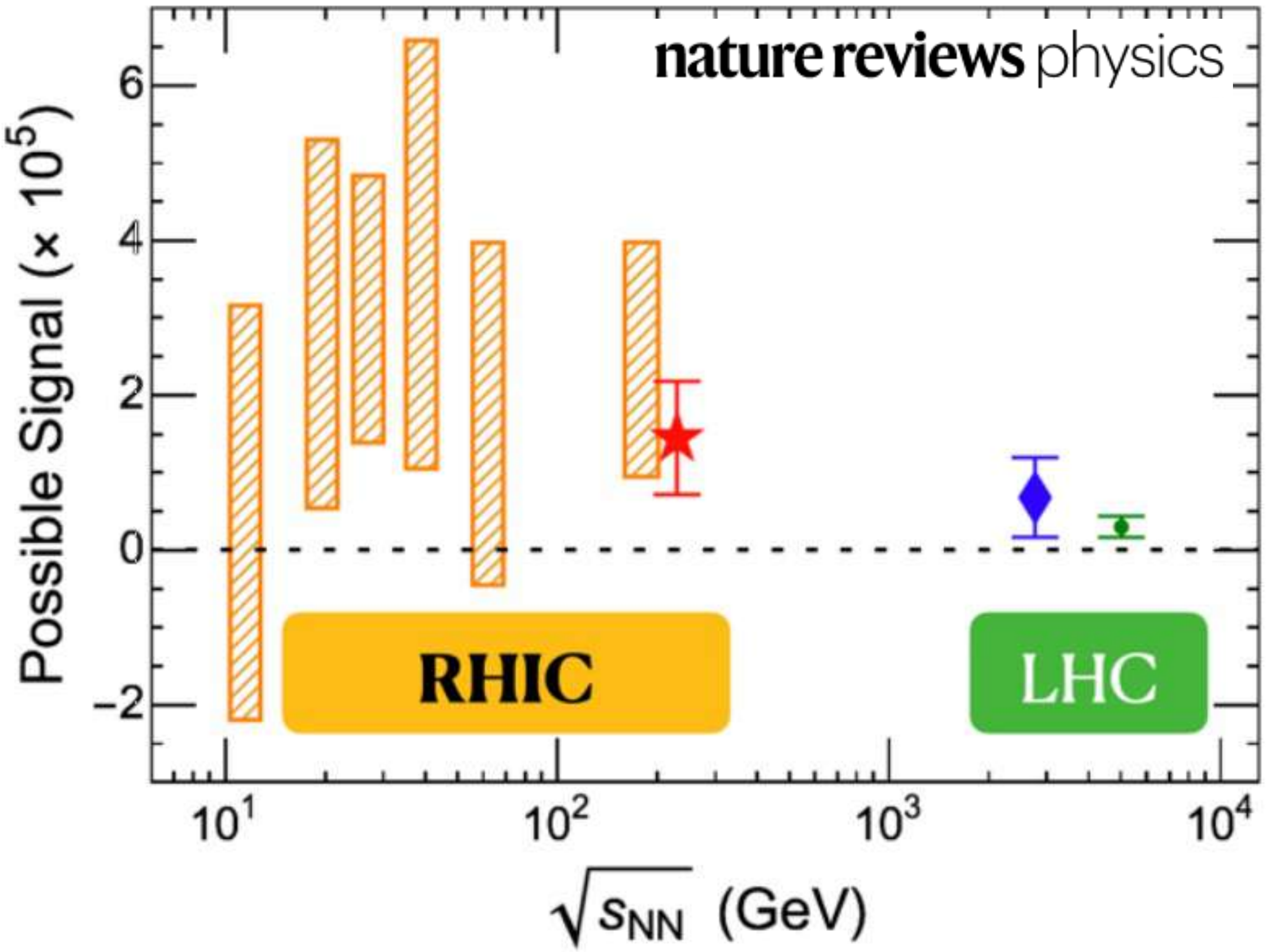
(a)

$$\langle\cos(\phi_a-\Psi_2)\cos(\phi_b-\Psi_2) - \sin(\phi_a-\Psi_2)\sin(\phi_b-\Psi_2)\rangle \qquad (1)$$
$$=\langle\cos(\phi_a+\phi_b-2\Psi_2)\rangle = (v_{1,a}v_{1,b}-a_a a_b)\langle\cos(2\Psi_2)\rangle$$

Measure the difference of charged hadron fluctuations along and perpendicular to magnetic field (direction of $\vec{B}$ is defined by the reaction plane)

Reviews of CME with heavy ions: DK, J. Liao, S. Voloshin, G. Wang, Rep. Prog. Phys.'16
DK, J. Liao, P. Tribedy, IJMPE 33 (2024) 09

Review + Compilation of the current data: DK, J. Liao, Nature Reviews (Phys.) 3 (2021) 55



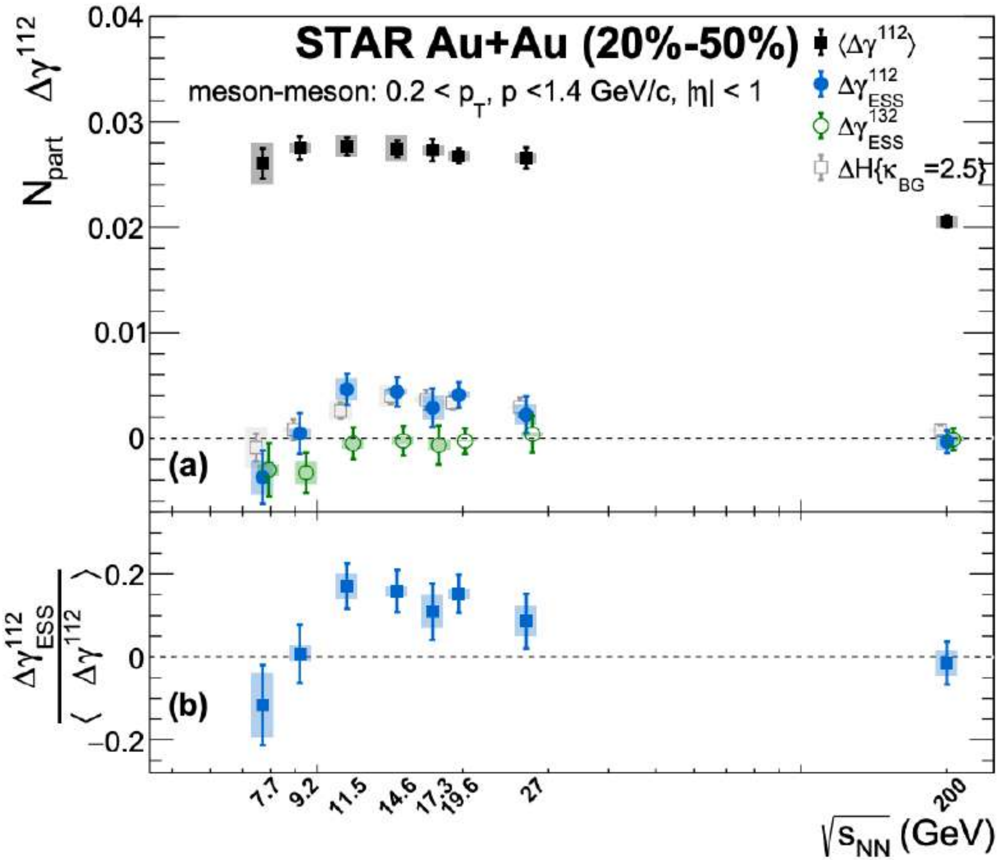
Very recent news: STAR result on CME in beam energy scan

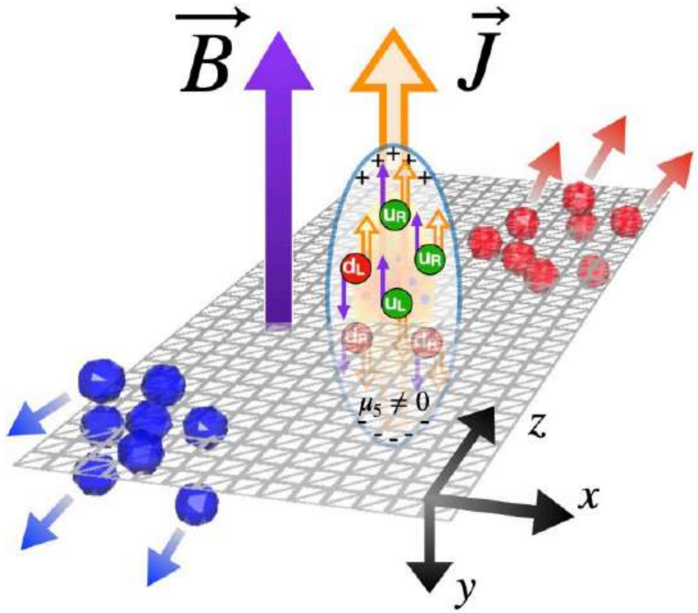
Talk by Huan Huang

Charge Separation Measurements in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7–200 GeV in Search of the Chiral Magnetic Effect

The STAR Collaboration

arXiv:2506.00275





Charge Separation Measurements in Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7–200 GeV in Search of the Chiral Magnetic Effect

The STAR Collaboration

arXiv:2506.00275

In summary, we have presented measurements of charge separation correlations along the magnetic field direction using Au+Au collisions at RHIC from $\sqrt{s_{NN}}$= 7.7 to 200 GeV energies, with the flow-related background effectively suppressed. We report a remaining charge separation signal in mid-central Au+Au collisions, positive finite with around 3σ significance at each of the center-of-mass energies of $\sqrt{s_{NN}}$= 11.5, 14.6, and 19.6 GeV. The results at $\sqrt{s_{NN}}$= 17.3 and 27 GeV also show positive values but with a lower significance of 1.3σ and 1.1σ. Below $\sqrt{s_{NN}}$= 10 GeV or at $\sqrt{s_{NN}}$= 200 GeV, the charge separation is consistent with zero. When the data between $\sqrt{s_{NN}}$= 10 and 20 GeV are combined, the significance rises to 5.5σ. The absence of a definitive CME signal from the top RHIC energy and the LHC energies [42, 77] can constrain the dynamical evolution of the magnetic field in the QGP phase in these collisions.

Why CME at low energies?

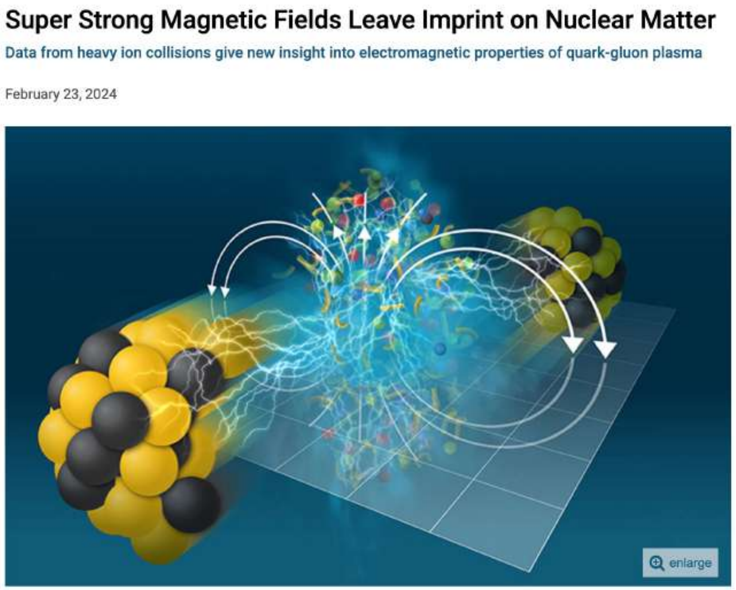
One reason is the **longer-living magnetic field** B.

Several effects combine to increase the lifetime of B at low energies:

1. Slower spectator protons (kinematics)

2. Stronger stopping of electric charge

3. Stronger Faraday effect in a conducting plasma,
   increase of electric conductivity with the chemical potential



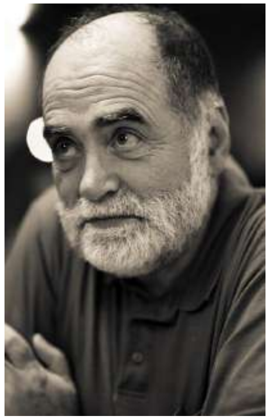
Slower spectator protons

$$\boldsymbol{B} = \boldsymbol{B}_s^+ + \boldsymbol{B}_s^- + \boldsymbol{B}_p^+ + \boldsymbol{B}_p^-,$$

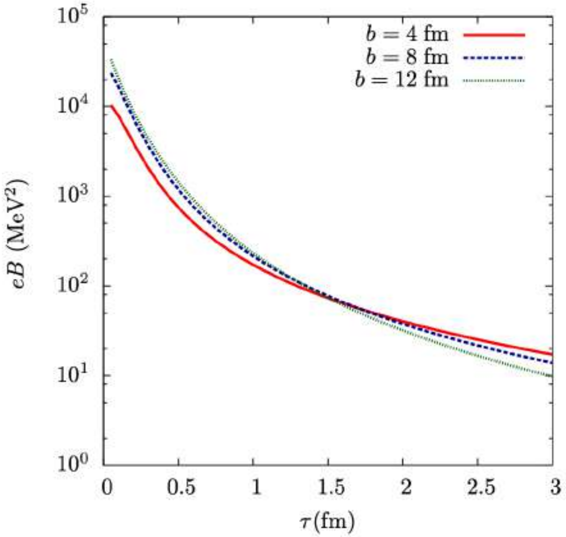
spectators participants

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

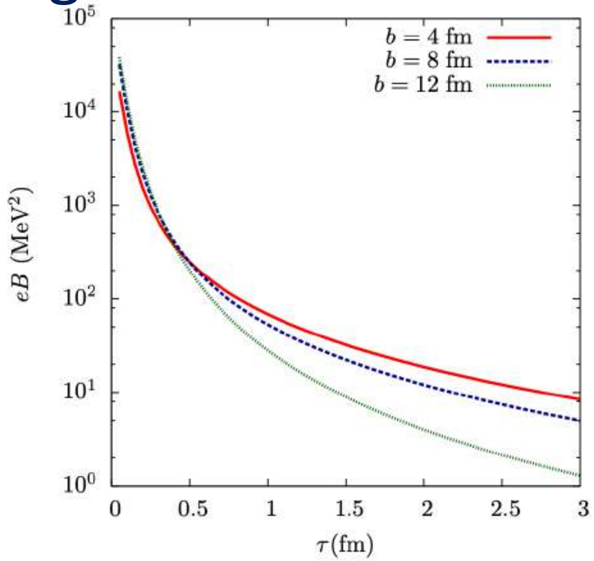
Longer lifetime
at lower energies:

DK, L. McLerran, H. Warringa,
arXiv:0711.0950; NPA'08



62 GeV



200 GeV

Stronger stopping

$$\boldsymbol{B} = \boldsymbol{B}_s^+ + \boldsymbol{B}_s^- + \boldsymbol{B}_p^+ + \boldsymbol{B}_p^-,$$

spectators participants

$$e\boldsymbol{B}_p^{\pm}(\tau,\eta,\boldsymbol{x}_\perp) = \pm Z\alpha_{EM}\int \mathrm{d}^2\boldsymbol{x}'_\perp \int_{-Y_0}^{Y_0} \mathrm{d}Y\, f(Y)\sinh(Y\mp\eta)\rho_\pm(\boldsymbol{x}'_\perp)\theta_\mp(\boldsymbol{x}'_\perp)\times \frac{(\boldsymbol{x}'_\perp-\boldsymbol{x}_\perp)\times\boldsymbol{e}_z}{\left[(\boldsymbol{x}'_\perp-\boldsymbol{x}_\perp)^2+\tau^2\sinh(Y\mp\eta)^2\right]^{3/2}}. \quad \text{(A.8)}$$

$$f(Y) = \frac{a}{2\sinh(aY_0)}e^{aY}, \quad -Y_0 \le Y \le Y_0. \quad \text{(A.7)}$$

Experimental data shows that $a \approx 1/2$, consistent with the baryon junction stopping mechanism (see [63] and references therein).

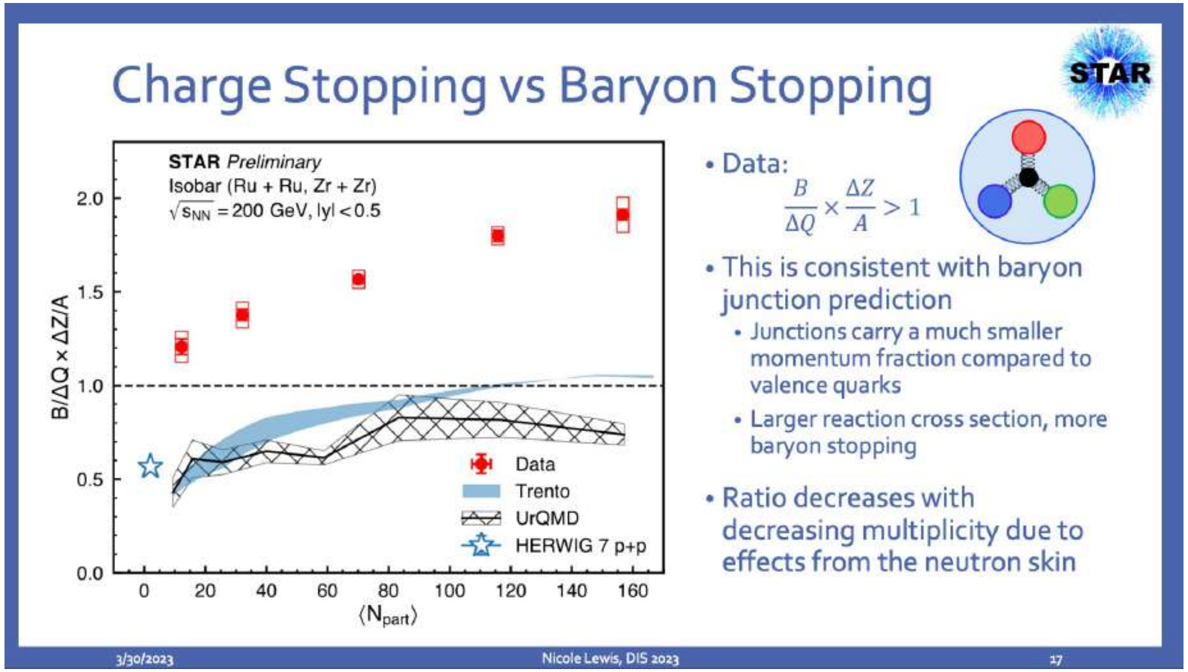
[63] D. Kharzeev, Phys. Lett. B **378**, 238 (1996) [arXiv:nucl-th/9602027].

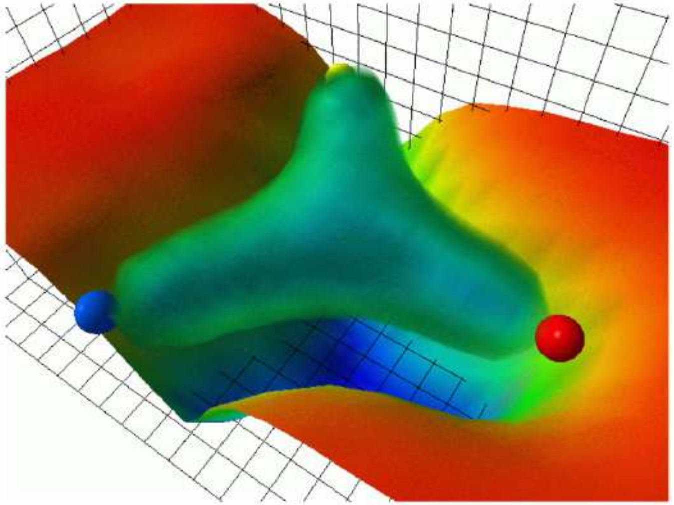
DK, L. McLerran, H. Warringa, arXiv:0711.0950; NPA'08

Longer lifetime
at lower energies

Stronger stopping

D. Leinweber et al, 05







Recent progress in theory:

Baryon-number - flavor separation in the topological expansion of QCD

arXiv:2405.04569
JHEP(2024)

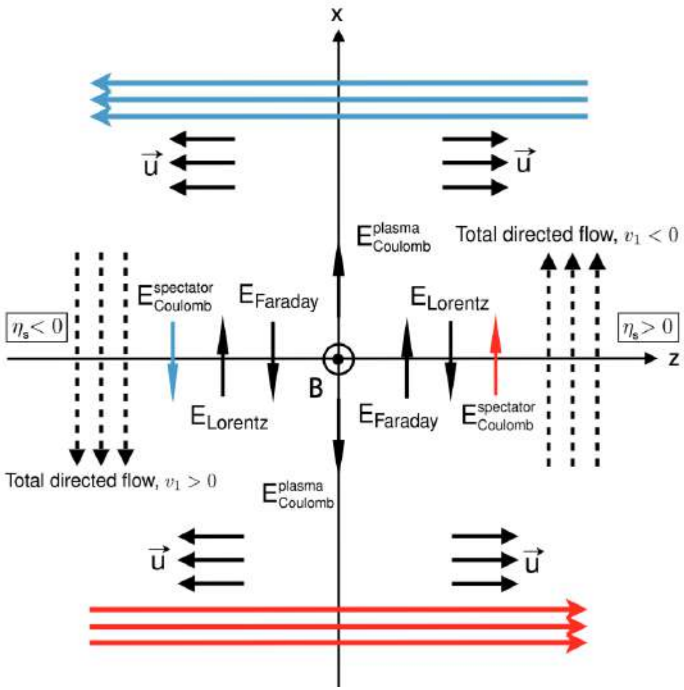
David Frenklakh[a] , Dmitri Kharzeev[a,b] , Giancarlo Rossi[c,d] and Gabriele Veneziano[e,f]

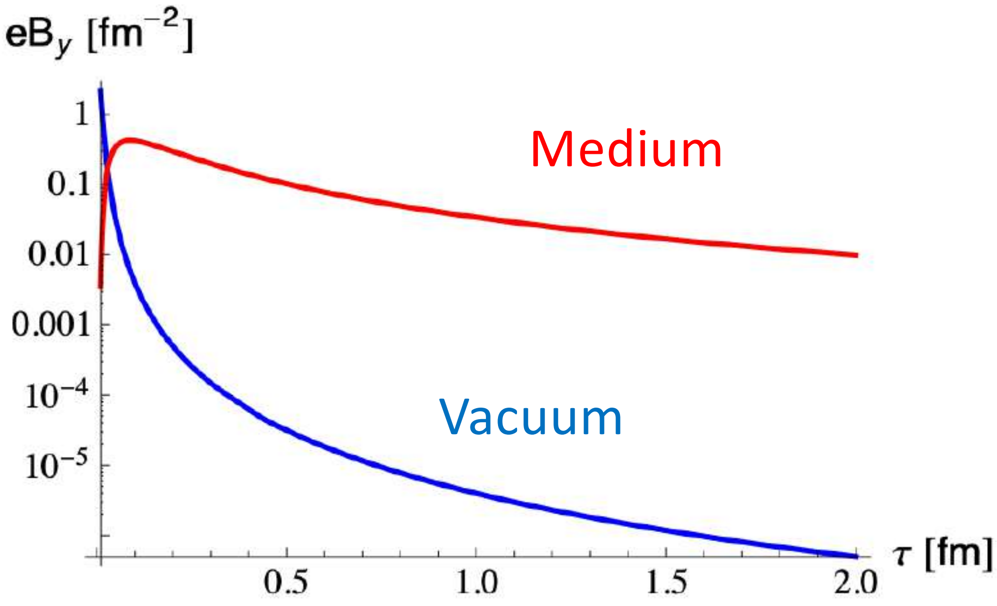
Medium effects on magnetic field

Faraday effect slows down the decay of magnetic field.
[K. Tuchin PRC 88 (2013)]

A number of other medium effects contribute as well:

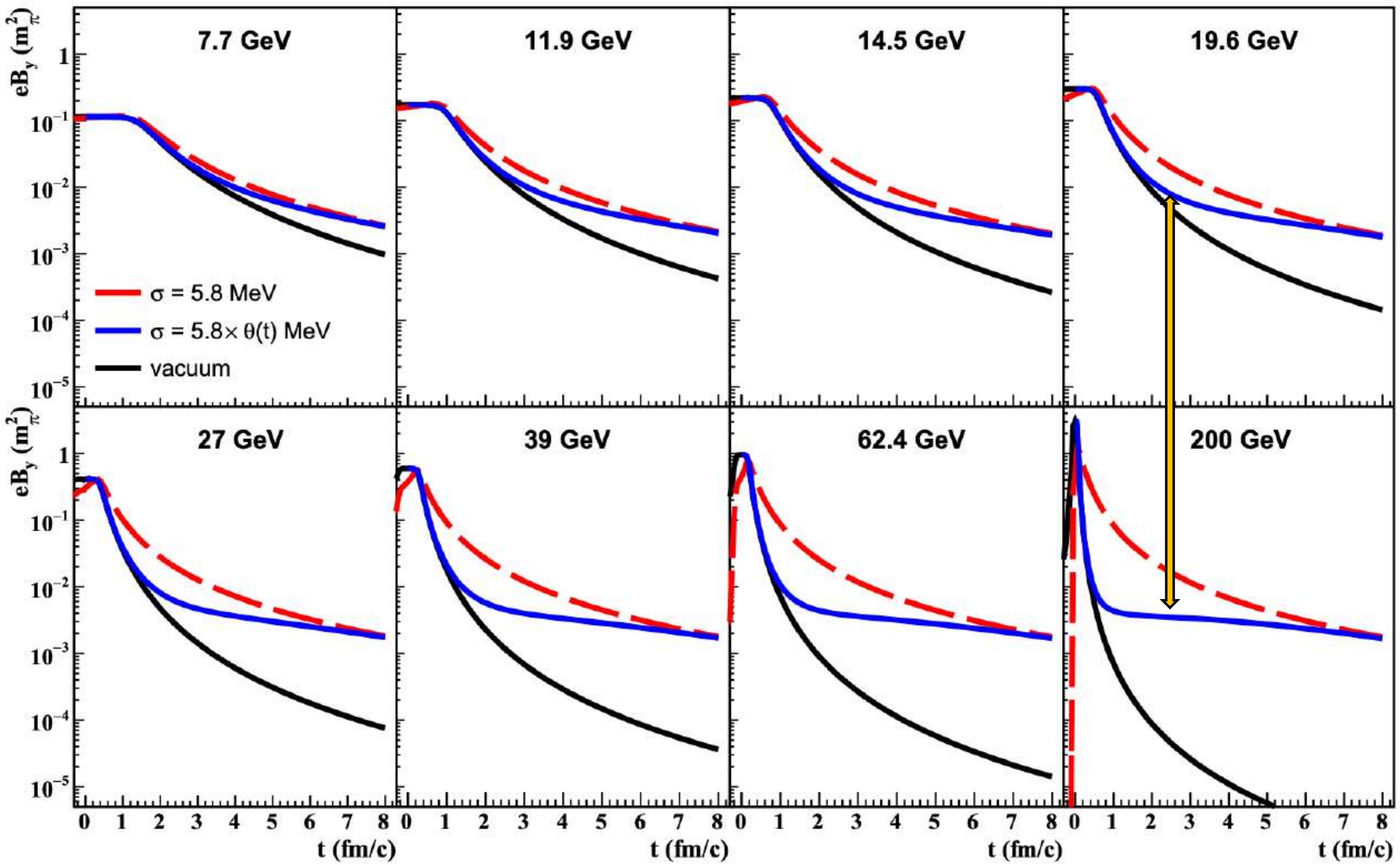
U. Gursoy, DK, K. Rajagopal, PRC 89(2014) 054905;
U. Gursoy, DK, E. Marcus, K. Rajagopal, C. Shen, PRC 98 (2018)





Why CME at low energies?

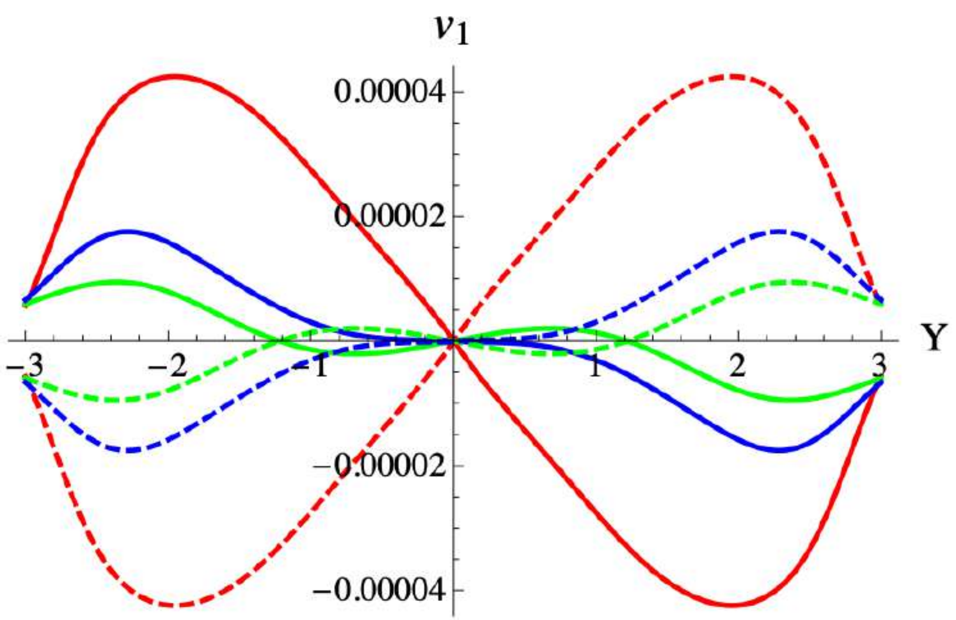
One reason is the longer-living magnetic field:



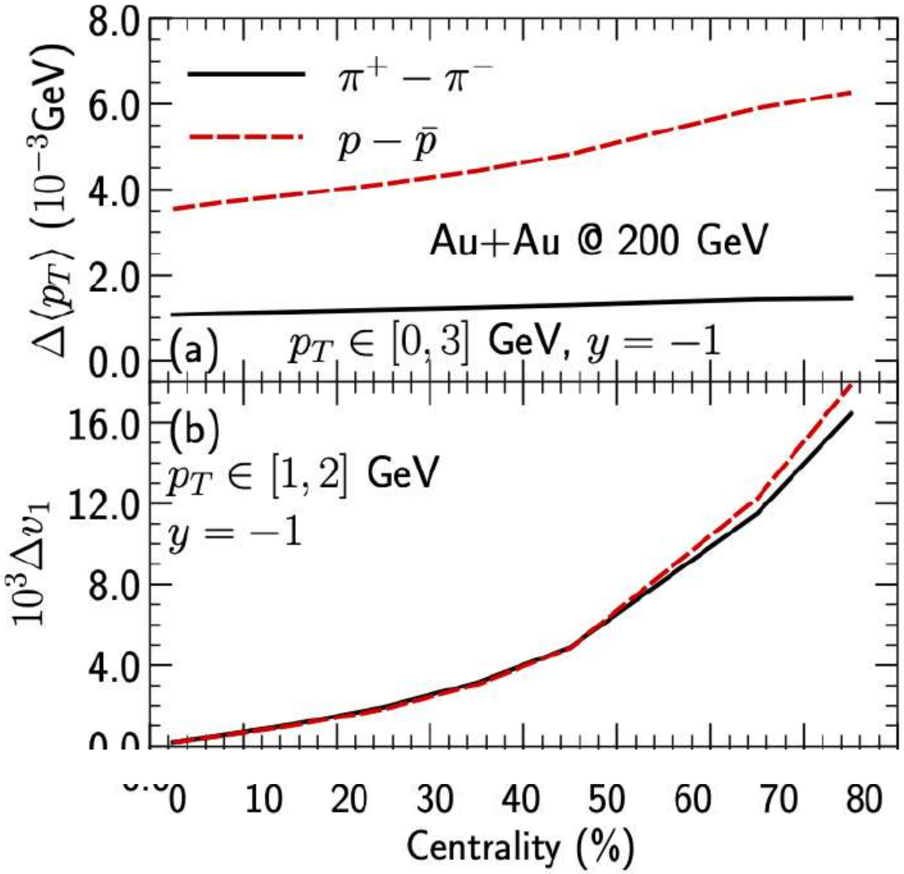
H. Li, X. Xia, X-G. Huang, Huan Huang,

arXiv: 2306.02829 PRC(2024)

Experimental manifestation of magnetic field: charge dependence of directed flow



U. Gursoy, DK, K. Rajagopal, PRC 89(2014) 054905



U. Gursoy, DK, E. Marcus, K. Rajagopal, C. Shen, PRC 98 (2018)

Talk by Aihong Tang

Magnetic field observation via the charge dependence of v_1

PHYSICAL REVIEW X **14**, 011028 (2024)

Featured in Physics

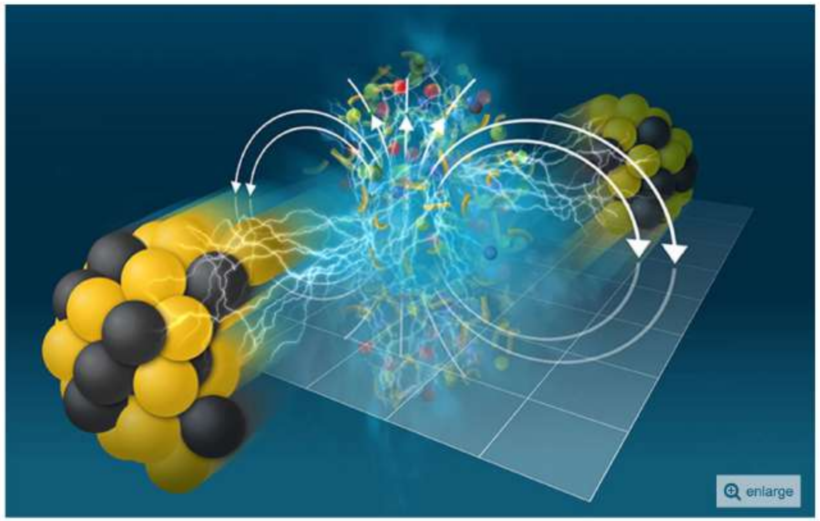
Observation of the Electromagnetic Field Effect via Charge-Dependent Directed Flow in Heavy-Ion Collisions at the Relativistic Heavy Ion Collider

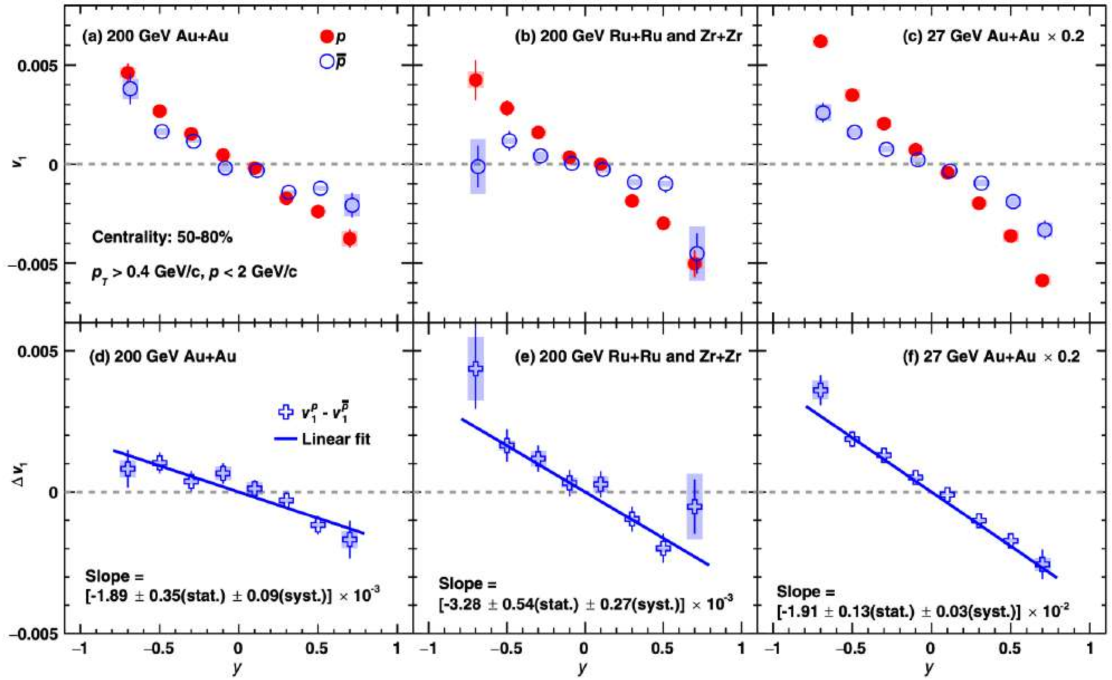
(STAR Collaboration)

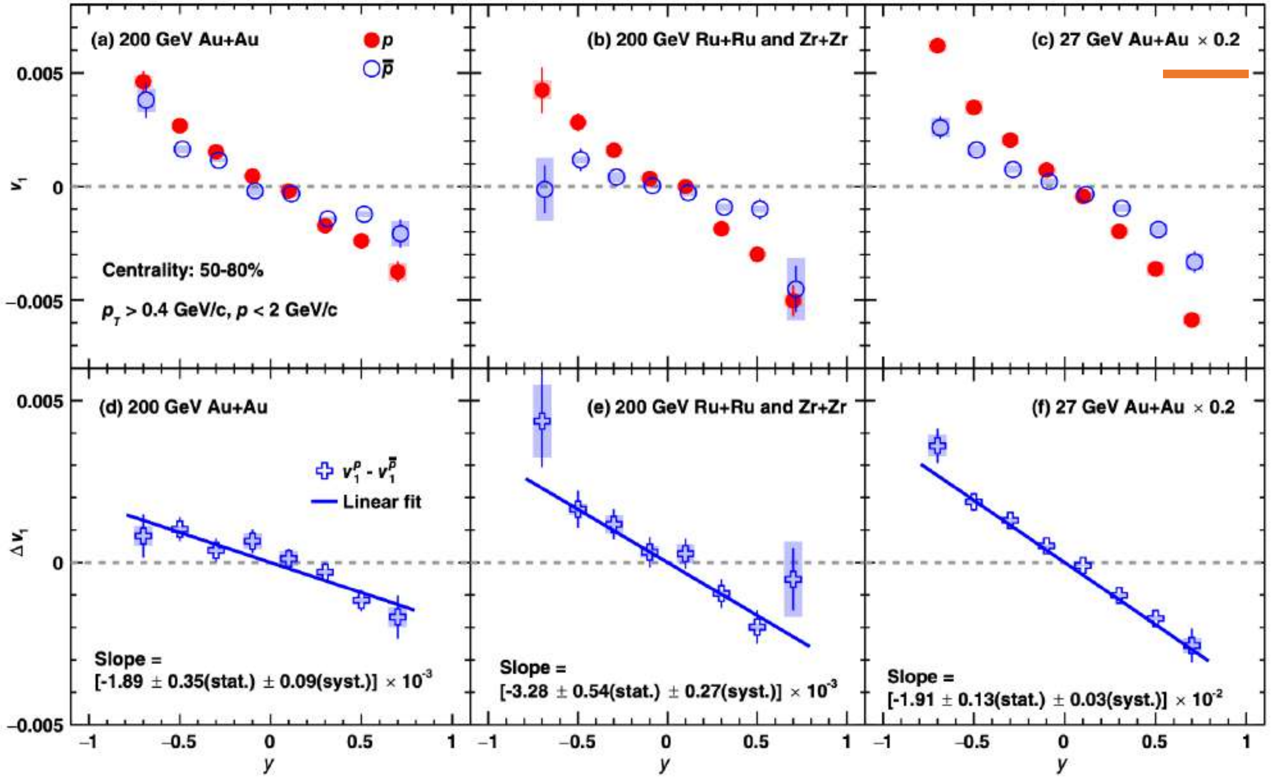
Super Strong Magnetic Fields Leave Imprint on Nuclear Matter

Data from heavy ion collisions give new insight into electromagnetic properties of quark-gluon plasma

February 23, 2024







Talk by Aihong Tang

This charge splitting is stronger in collisions at $\sqrt{s_{NN}} = 27$ GeV, corroborating the idea that the electromagnetic field decays more slowly at low energies.

PHYSICAL REVIEW X **14,** 011028 (2024)

Featured in Physics

Observation of the Electromagnetic Field Effect via Charge-Dependent Directed Flow in Heavy-Ion Collisions at the Relativistic Heavy Ion Collider

Why CME at low energies?

Another reason: enhancement of topological fluctuations near the critical point.

Chiral magnetic effect in the PNJL model

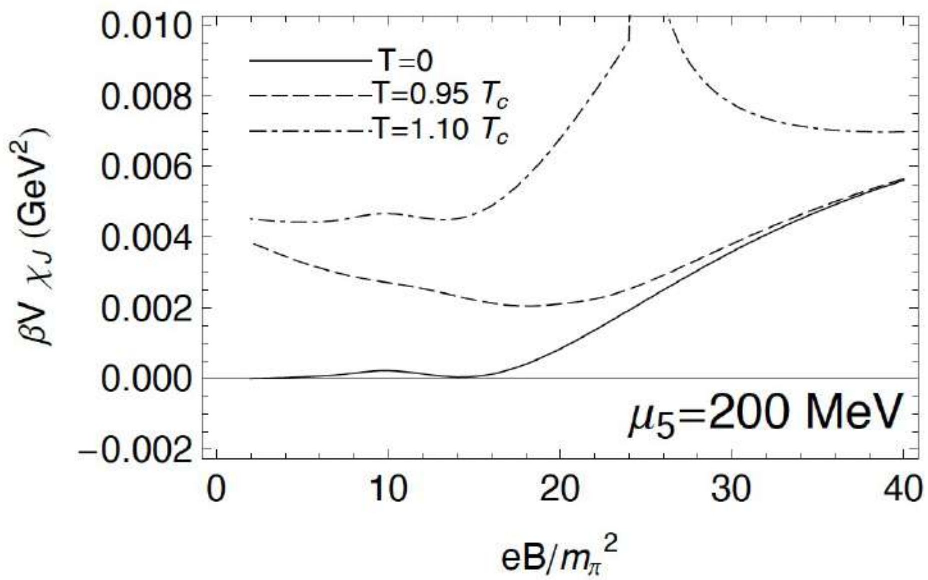
Kenji Fukushima[*] and Marco Ruggieri[†]
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

Raoul Gatto[‡]
Departement de Physique Theorique, Universite de Geneve, CH-1211 Geneve 4, Switzerland

PRD 81 (2010)

$$\chi_J = \langle j_3^2 \rangle - \langle j_3 \rangle^2 = -\frac{1}{\beta V}\frac{\partial^2 \Omega}{\partial A_3^2}\bigg|_{A_3=0}$$

Critical point in the (T,B) plane:



CME enhancement near the critical point in the (T,μ) plane

The enhancement of topological fluctuations near the critical point revealed through real-time quantum simulations:

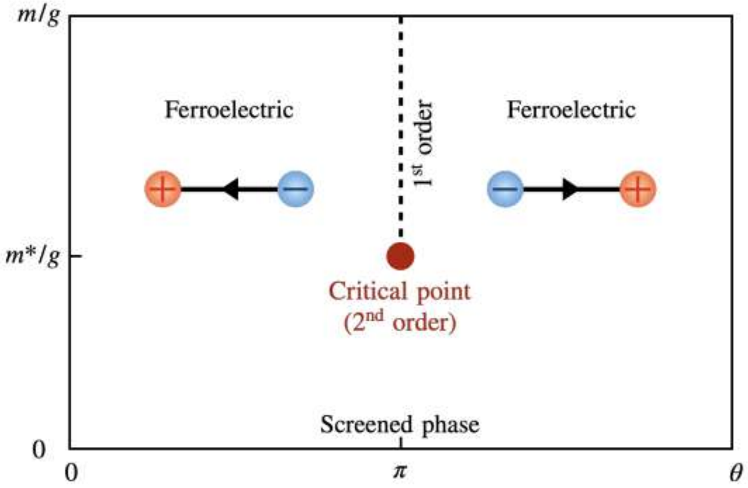
LETTER | OPEN ACCESS

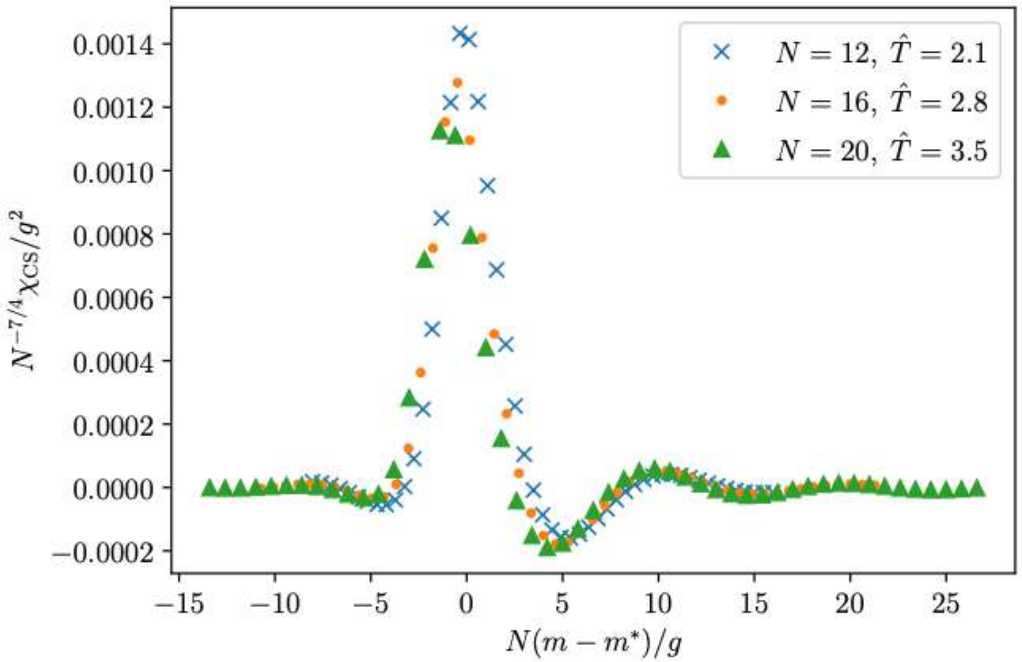
Real-time dynamics of Chern-Simons fluctuations near a critical point

Kazuki Ikeda[1,*], Dmitri E. Kharzeev[2,3,4,†], and Yuta Kikuchi[3,‡]

Show more

Phys. Rev. D **103**, L071502 – **Published 21 April, 2021**





CME energy dependence

The effects of topological charge change in heavy ion collisions: "Event by event $\mathcal{P}$ and $\mathcal{CP}$ violation"

2007

Dmitri E. Kharzeev, [a] Larry D. McLerran [a,b] and Harmen J. Warringa [a]

7.4 Beam Energy Dependence

We are very uncertain about the beam energy dependence, since our result will depend strongly on what we take as our initial time. If the initial time scales with the longitudinal size of the nucleus, $R\exp(-Y_0)$, we expect no beam-energy dependence at all for b_{ab}. However if it turns out to be better to use the inverse saturation momentum for initial time, we can get a large dependence. In such case we always expect (as long as the pancake approximation stays good and a quark gluon plasma is formed) that a_{ab} and b_{ab} are smaller at larger beam energies, we never expect them to become larger.

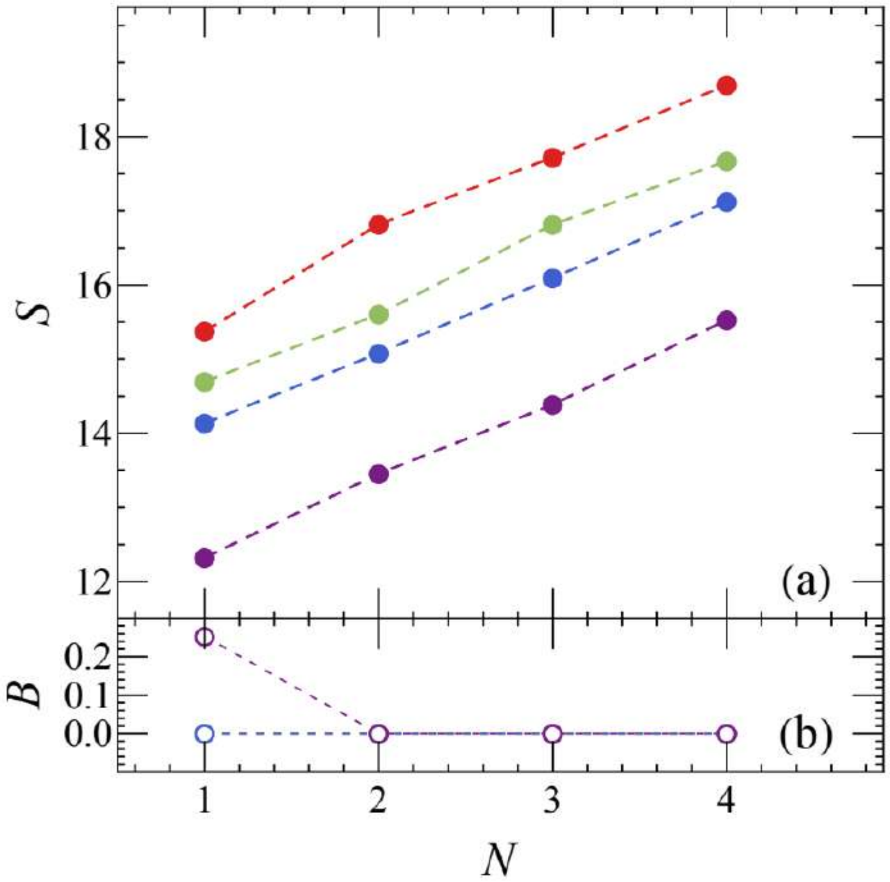
Note: this does **not** mean that CME is absent at 200 GeV, just that the effect is likely stronger at lower energies

Better CME observables via machine learning?

Optimal Observables for the Chiral Magnetic Effect from Machine Learning

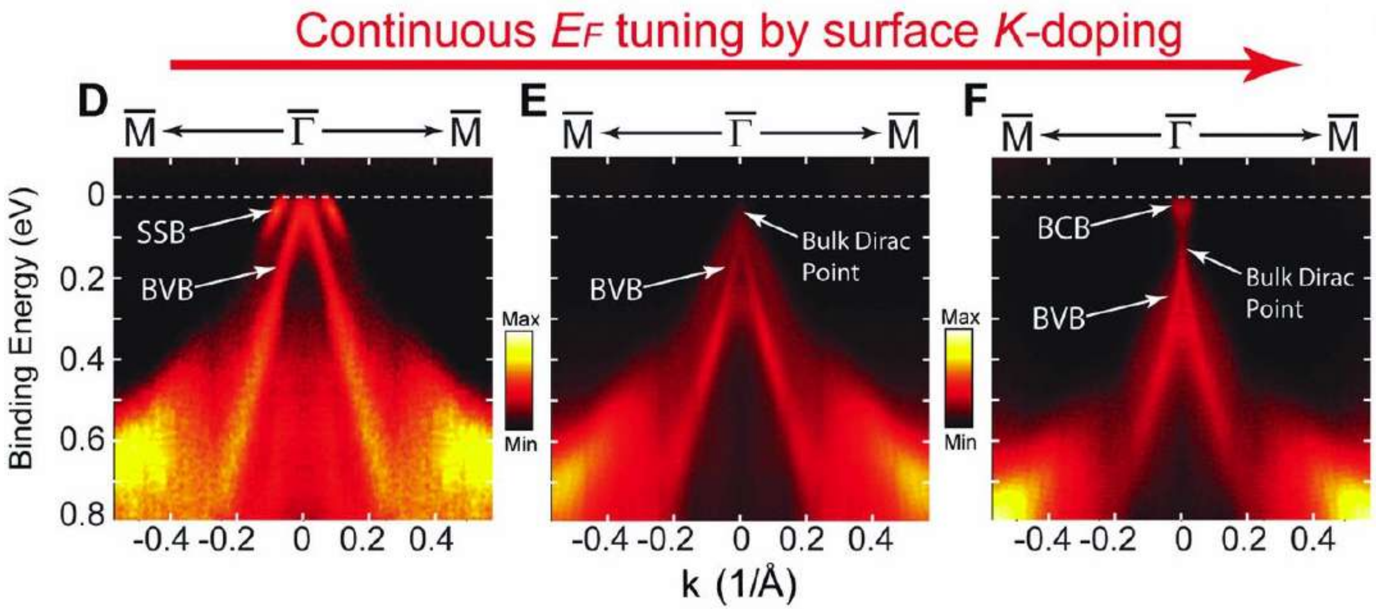
Yuji Hirono,[1,*] Kazuki Ikeda,[2,3,†] Dmitri E. Kharzeev,[3,4,‡] Ziyi Liu,[5,§] and Shuzhe Shi[5,6,¶]

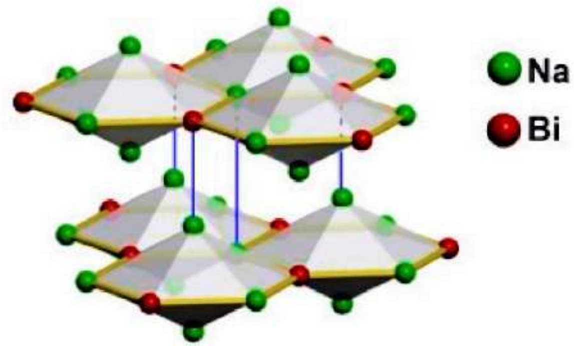
arXiv: 2504.03248



Up to 90% higher sensitivity to CME signal than "standard" observables

CME in Dirac & Weyl semimetals





Recent reviews:

N.P. Ong and S. Liang, Nature Rev. Phys. (2021); P. Narang, C. Garcia, C. Felser, Nature Mat. (2021)

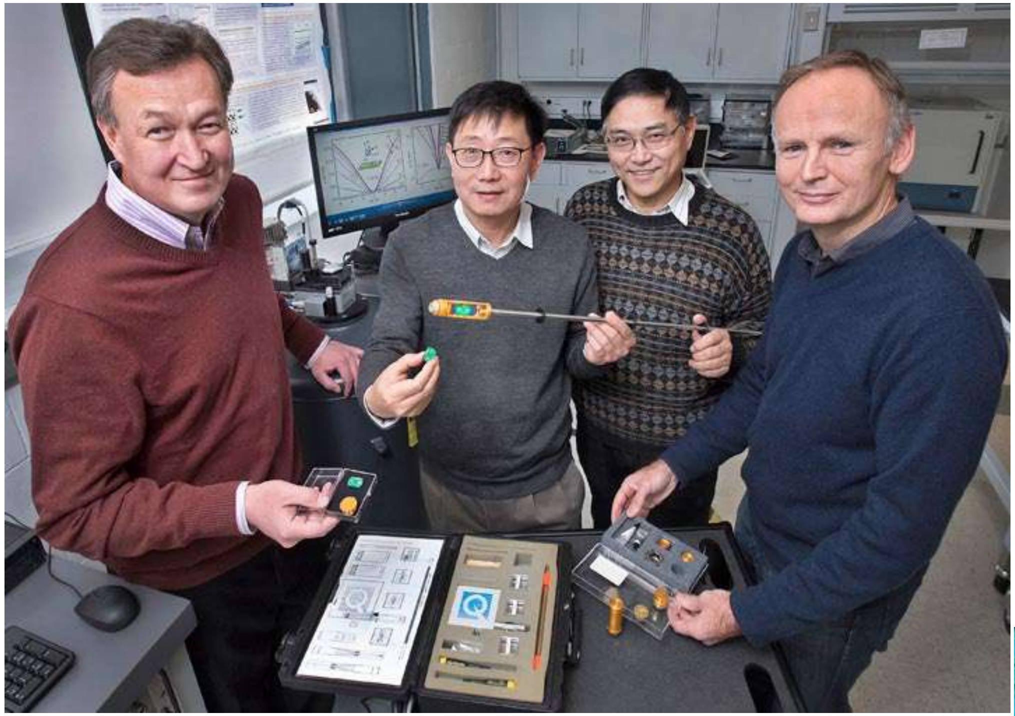
Even number of space-time dimensions –
so chiral anomaly operates, can study CME!

CME in chiral materials

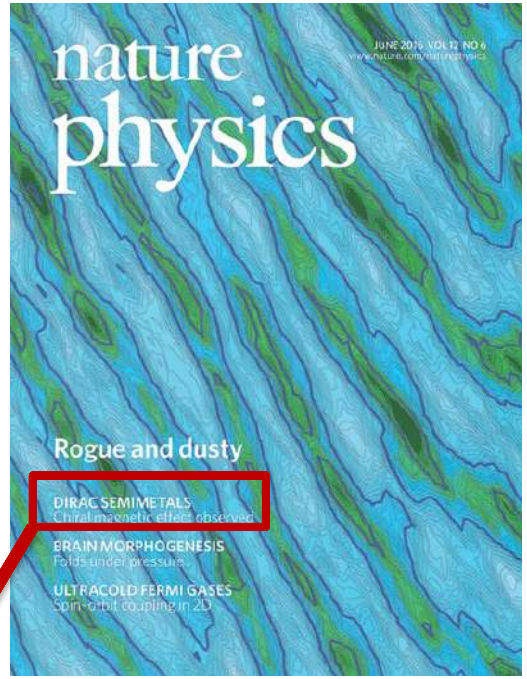
Observation of the chiral magnetic effect in $ZrTe_5$

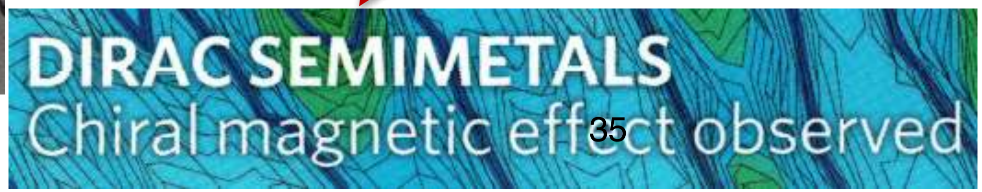
Qiang Li,[1] Dmitri E. Kharzeev,[2,3] Cheng Zhang,[1] Yuan Huang,[4] I. Pletikosić,[1,5] A. V. Fedorov,[6] R. D. Zhong,[1] J. A. Schneeloch,[1] G. D. Gu,[1] and T. Valla[1]

BNL - Stony Brook - Princeton - Berkeley



Nature Phys. 12 (2016) 550





arXiv:1412.6543 [cond-mat.str-el]

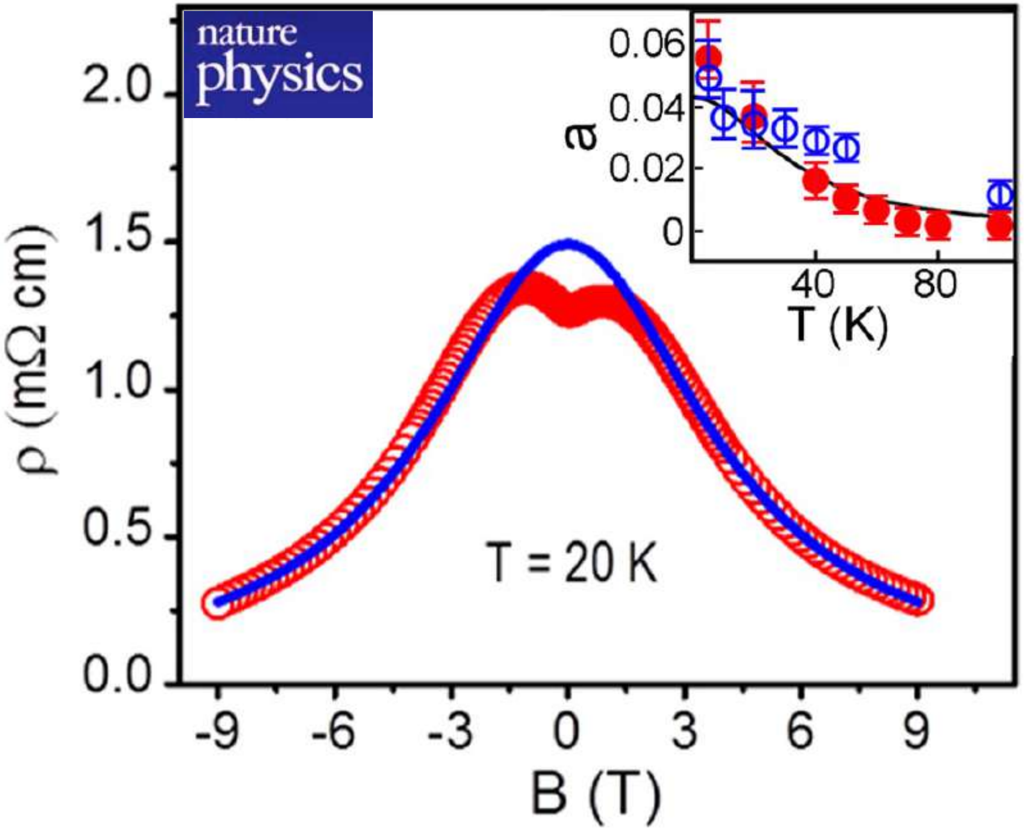
Parallel electric and magnetic fields source the chiral anomaly: $\partial_\mu J^\mu_A = \frac{e^2}{2\pi^2}\vec{E}\cdot\vec{B}$

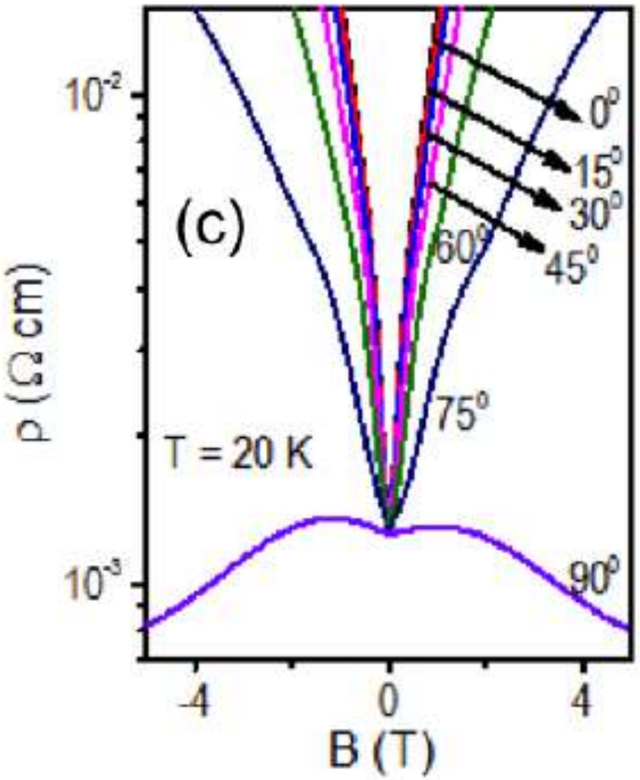
and thus the chiral chemical potential $\mu_5 \sim EB\tau$

The CME current is $J \sim \mu_5 B^2 \tau$ – longitudinal magnetoconductivity $\sim B^2$ (at weak B)

D. Son, B. Spivak '13

Q. Li et al,
Nature Physics **12**, 550 (2016)
arXiv:1412.6543





CME in chiral materials

Impressive results from other groups:

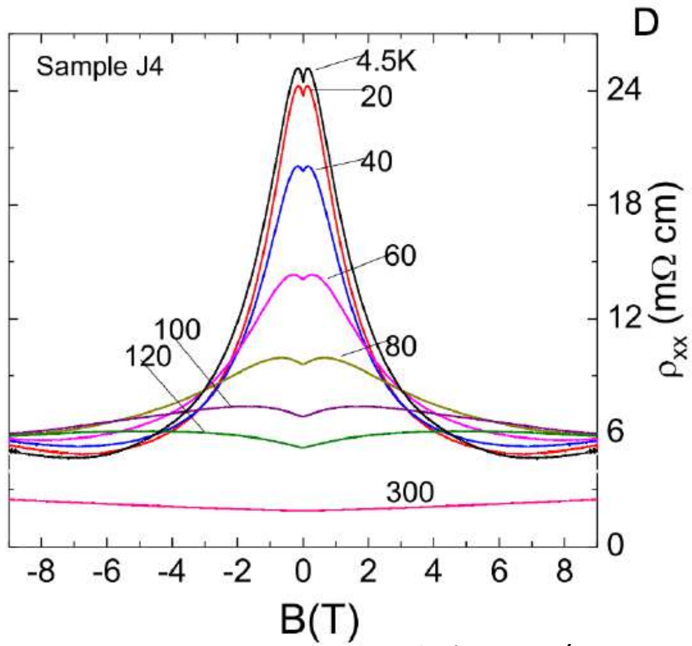
arXiv:1503.08179

Signature of the chiral anomaly in a Dirac semimetal – a current plume steered by a magnetic field*

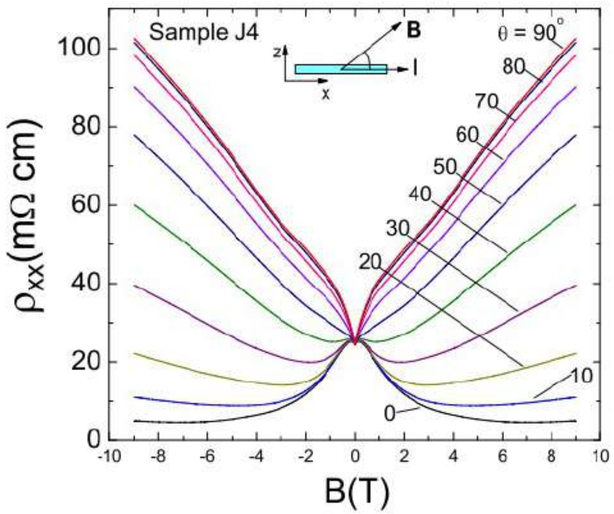
Jun Xiong[1], Satya K. Kushwaha[2], Tian Liang[1], Jason W. Krizan[2], Wudi Wang[1], R. J. Cava[2], and N. P. Ong[1]

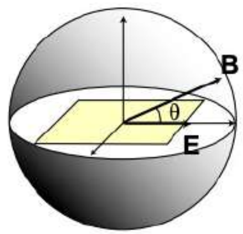
Departments of Physics[1] and Chemistry[2], Princeton University, Princeton, NJ 08544

(Dated: March 30, 2015)

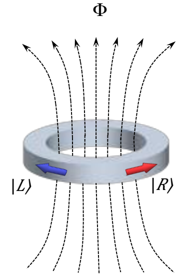


Science '15



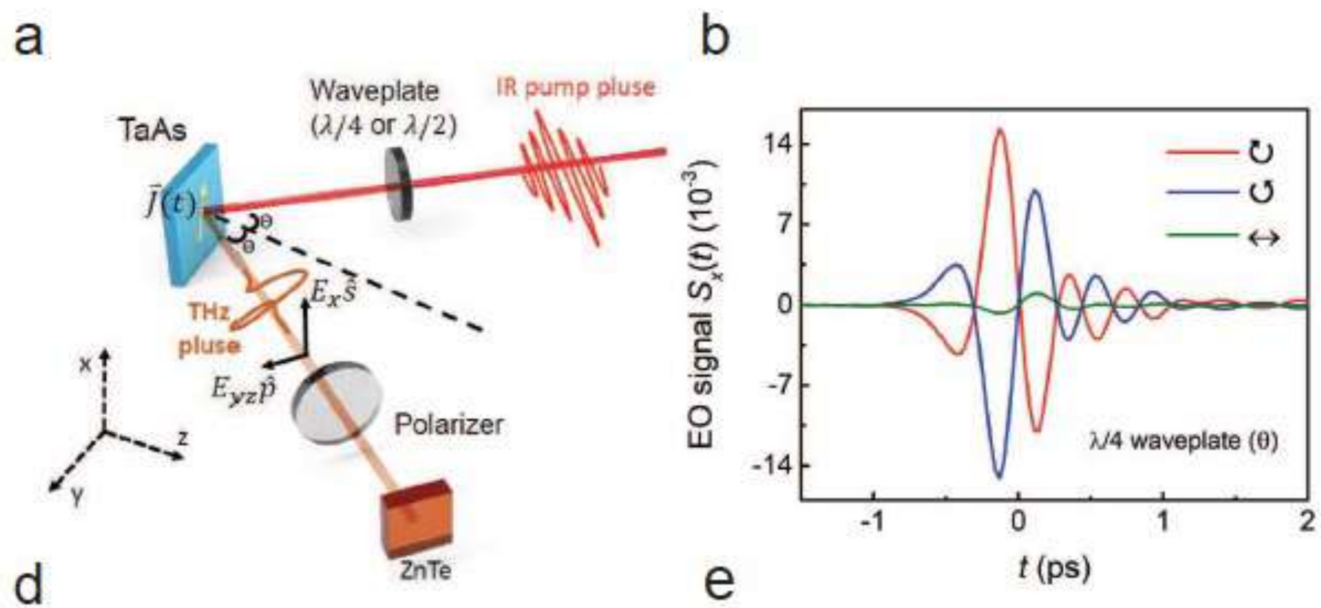


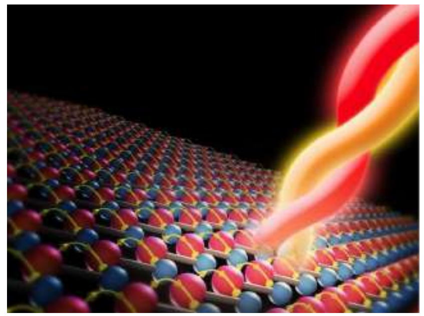
CME in chiral materials: optical measurements



Chiral terahertz wave emission from the Weyl semimetal TaAs

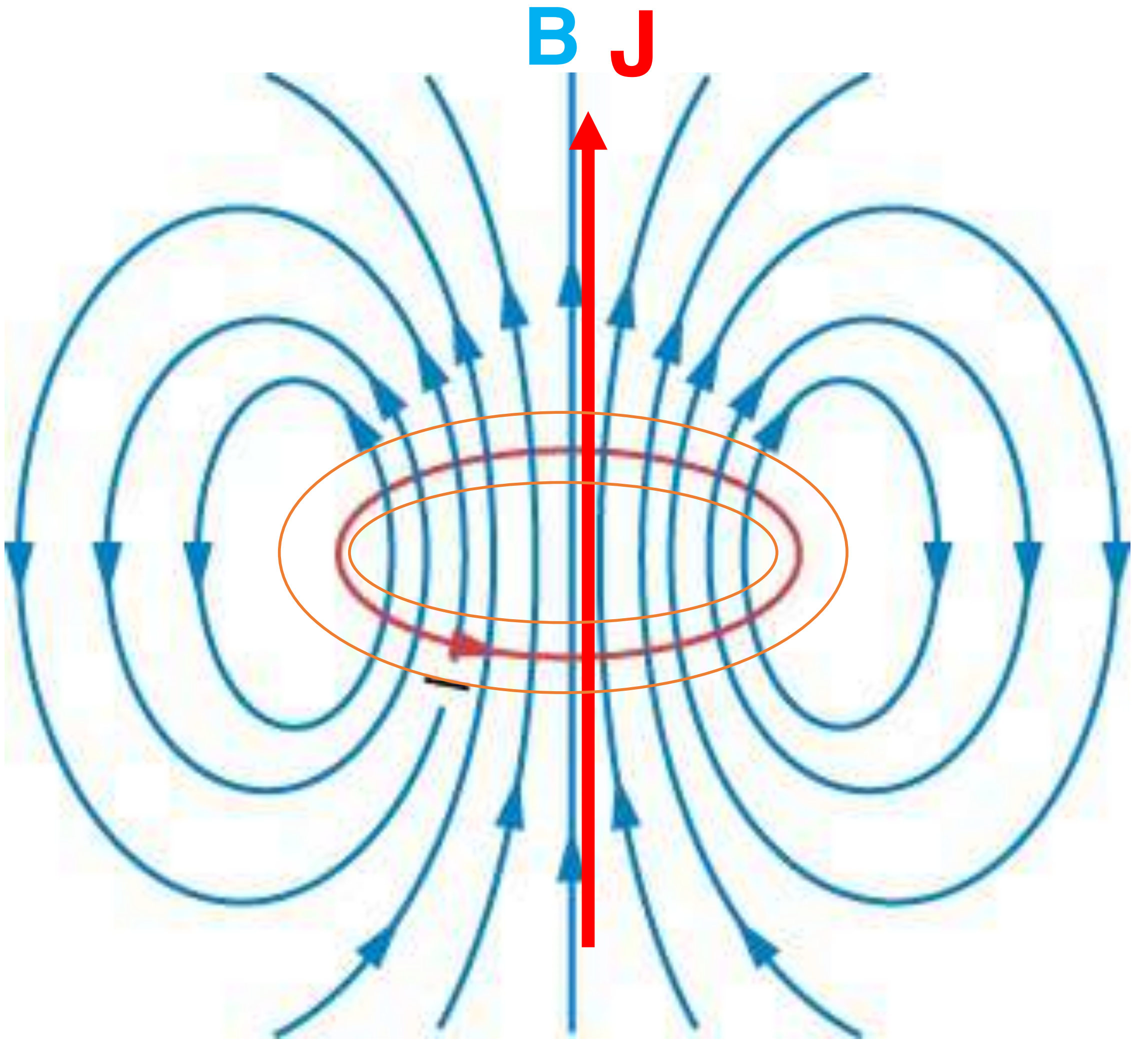
Y. Gao [1], S. Kaushik[2], E.J. Philip [2], Z. Li[3,4], Y. Qin[1,5], Y.P. Liu[6], W.L. Zhang[1], Y.L. Su[1], X. Chen[2], H. Weng [4,7], D.E. Kharzeev [2,8,9★], M.K. Liu[2★] & J. Qi [1★]





nature COMMUNICATIONS

Chiral magnetic instability

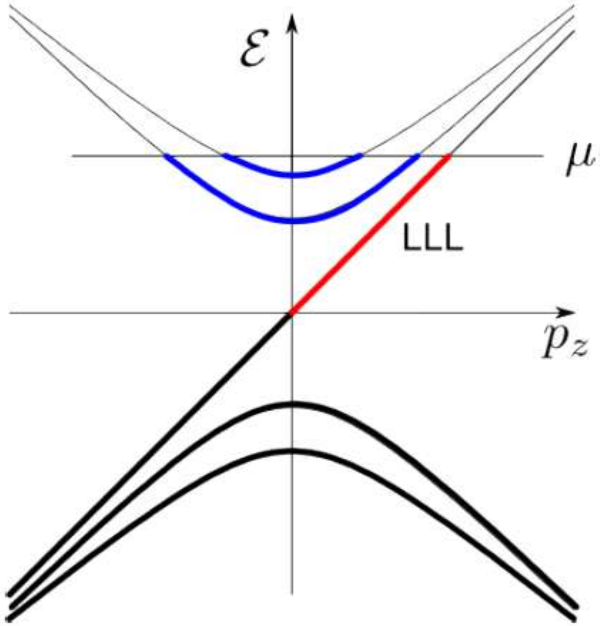


Transfer of chiral charge of the fermions to the magnetic helicity

$$h_0 \equiv h_m + h_F = \text{const}$$

$$h_m \equiv \int d^3x \, \boldsymbol{A} \cdot \boldsymbol{B}$$

Inverse cascade of magnetic helicity



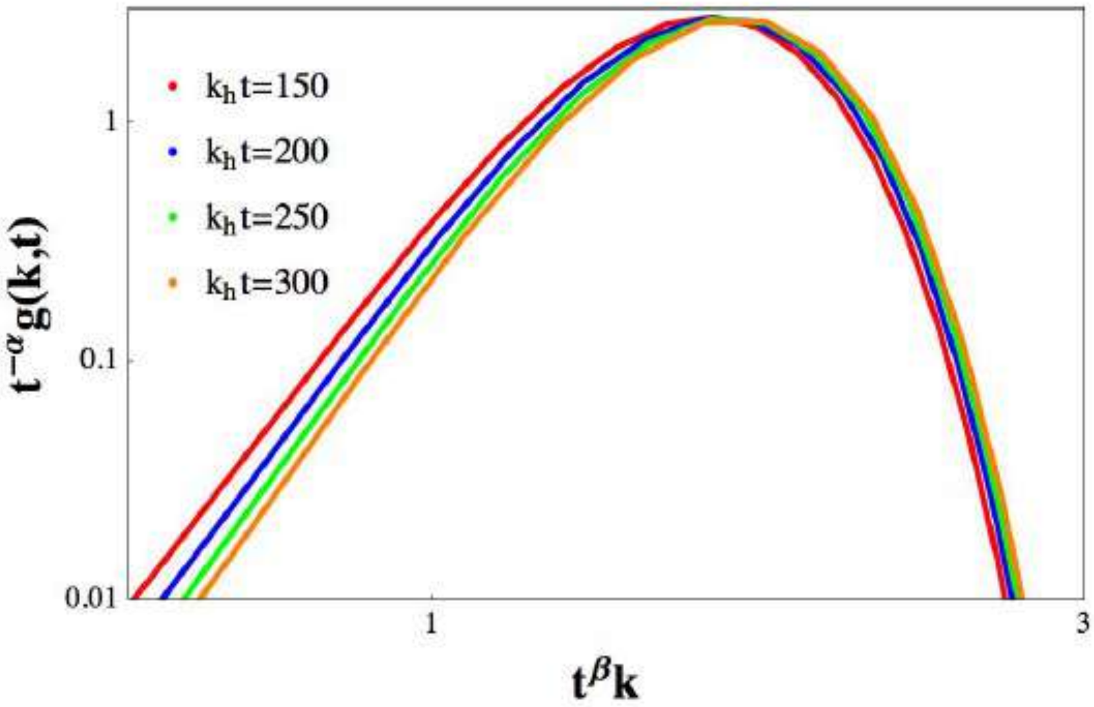
Instability at k< $c_A \mu_A$ leads to the growth of magnetic helicity

Increase of of magnetic helicity reduces μ_A

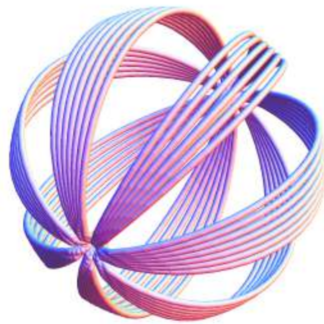
Inverse cascade:

M.Joyce and M.Shaposhnikov, PRL 79 (1997) 1193;
R.Jackiw and S.Pi, PRD 61 (2000) 105015;
A.Boyarsky, J.Frohlich, O.Ruchayskiy, PRL 108 (2012) 031301; PRD 92 (2015) 043004;
H.Tashiro, T.Vachaspati, A.Vilenkin, PRD 86 (2012) 105033

Self-similar inverse cascade of magnetic helicity driven by CME



helical magnetogenesis in the Universe?



Work by A. Brandenburg, T. Vachaspati, A. Boyarsky, O. Ruchaysky, T. Kaniashvili,..

$$g(k,t) \sim t^{\alpha}\tilde{g}(t^{\beta}k) \qquad \alpha = 1\,, \qquad \beta = 1/2$$

Y. Hirono, DK, Y.Yin, PRD'15

N. Yamamoto, PRD'16

Possible link between "helical magnetogenesis" and baryogenesis in Early Universe:

DK, E.Shuryak, I.Zahed, arXiv:1906.0480, PRD

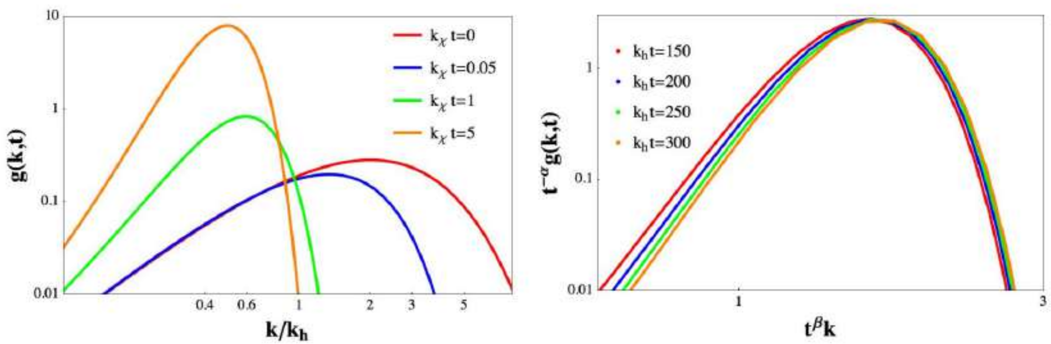
Can chiral magnetic instability be observed in chiral materials?

Self-similar inverse cascade of magnetic helicity driven by the chiral anomaly

PRD (2015)

Yuji Hirono,[1] Dmitri E. Kharzeev,[1,2,3] and Yi Yin[2]

see (2.1). We expect that our findings apply to all systems that possess the CME current. In addition to the quark-gluon plasma discussed above, the growth of magnetic helicity can be expected in Dirac semimetals that exhibit the CME in parallel electric and magnetic fields [33]. Experimentally, this generation of magnetic helicity can manifest itself through the emission of circularly polarized photons in the THz frequency range characteristic for Dirac semimetals [34].



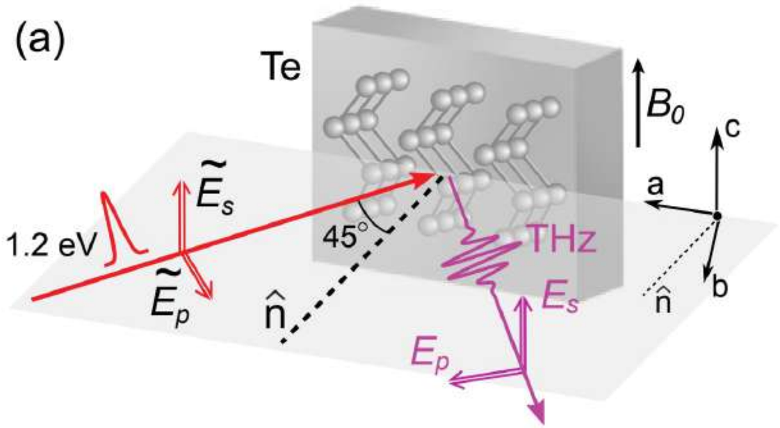
Chiral magnetic instability

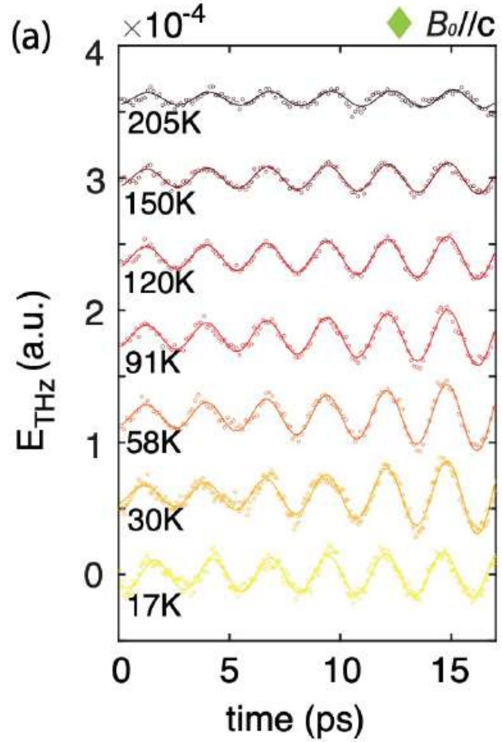
Observation of a dynamic magneto-chiral instability in photoexcited tellurium

Yijing Huang,[1,2,*] Nick Abboud,[3,*] Yinchuan Lv,[1,2] Penghao Zhu,[1,4,5] Azel Murzabekova,[1,2] Changjun Lee,[6,2] Emma A. Pappas,[1,2] Dominic Petruzzi,[1,2] Jason Y. Yan,[1,2] Dipanjan Chauduri,[1,2] Peter Abbamonte,[1,2] Daniel P. Shoemaker,[6,2] Rafael M. Fernandes,[1,4] Jorge Noronha,[3] and Fahad Mahmood[1,2]

[1]*Department of Physics, The Grainger College of Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois 61801, USA*
[2]*Materials Research Laboratory, The Grainger College of Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois 61801, USA*

arXiv:2502.05170





Sinusoids with amplitudes **growing in time**

Summary

The interplay of chirality and quantum anomalies is fascinating.

The STAR CME result at lower RHIC energies is a major milestone in a 25+ year long quest for observing the effects of QCD topology.

Dirac and Weyl semimetals enable tabletop experiments on CME, with results that are potentially important for applications (qubits, sensing, transducers, …)