Weyl and Dirac Semimetals as a Laboratory for High Energy Physics,

Braga, Portugal, June 25-28, 2025

Chiral Magnetic Effect: current status and open problems

Dmitri Kharzeev

U.S. DEPARTMENT OF ENERGY
Office of Science

Center for Nuclear Theory
Stony Brook University

C²QA Co-design Center for Quantum Advantage

Brookhaven National Laboratory

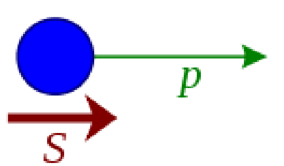
Chirality in subatomic world: chiral fermions

Fermions:
E. Fermi,1925

Dirac equation:
P. Dirac, 1928

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

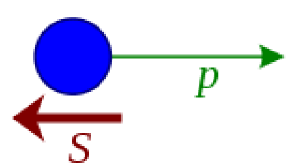
Right-handed:



Weyl fermions:
H. Weyl, 1929

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

Left-handed:



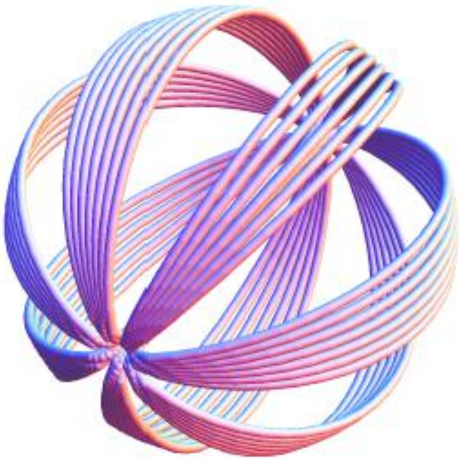
Majorana fermions:
1937

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

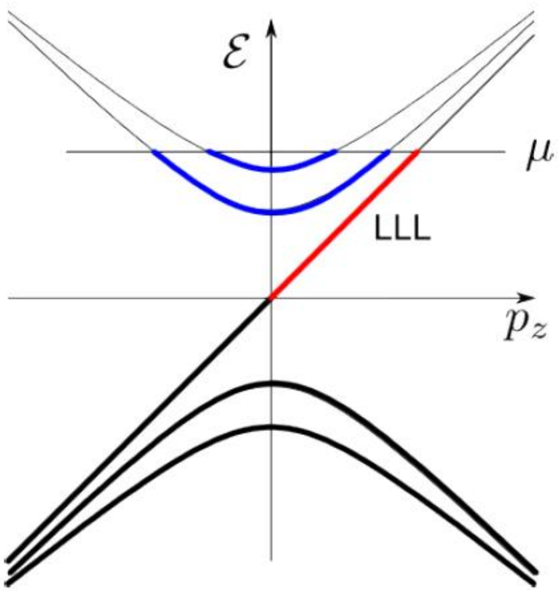
$$\psi_c := i\psi^*$$

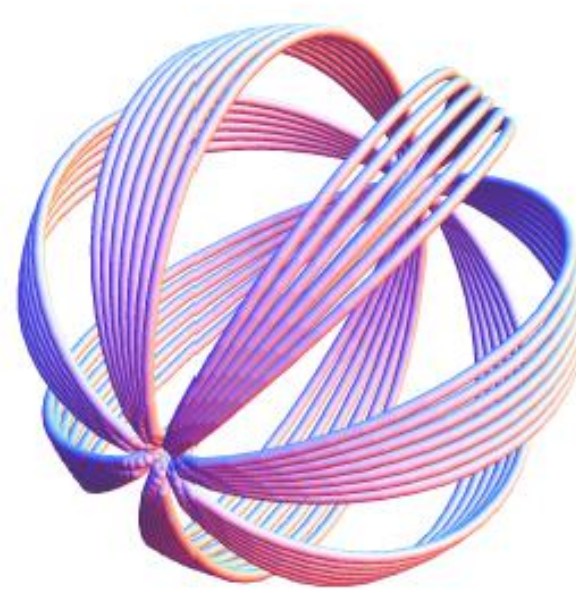
Chirality of gauge fields

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

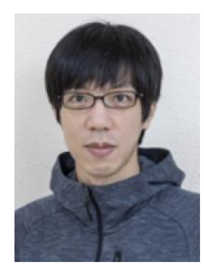


Chiral anomaly: chirality transfer from fermions to gauge fields (or vice versa)





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

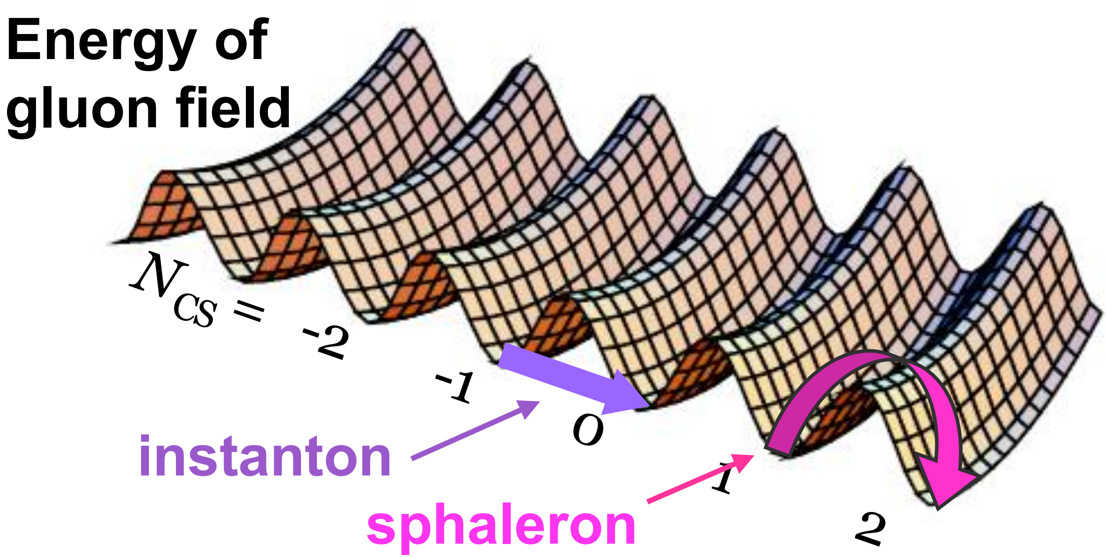


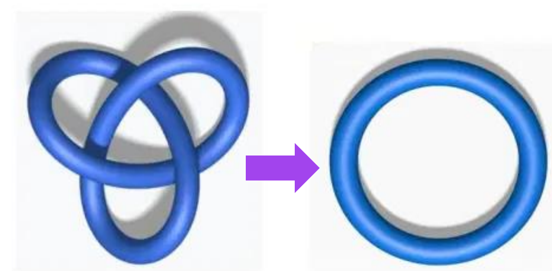
Chirality in the vacuum of the Standard Model

The instanton and sphaleron solutions in non-Abelian gauge theories describe transitions between topological sectors of the vacuum marked by different integer values of the Chern-Simons number:

$$N_{CS} \equiv \int d^3x K_o \qquad K_\mu = \frac{1}{16\pi^2}\epsilon_{\mu\alpha\beta\gamma}\left(A^a_\alpha \partial_\beta A^a_\gamma + \frac{1}{3} f^{abc} A^a_\alpha A^b_\beta A^c_\gamma\right)$$

QCD (Quantum ChromoDynamics) vacuum:





Chirality and the origin of Matter-Antimatter asymmetry in the Universe

A.D. Sakharov, 1967

Sakharov conditions for baryogenesis:

1. Baryon number violation
2. C and CP symmetries violation
3. Interactions out of thermal equilibrium

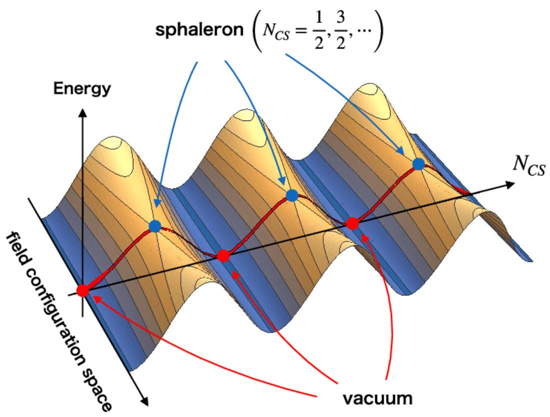
VIOLATION OF CP INVARIANCE, C ASYMMETRY, AND BARYON ASYMMETRY OF THE UNIVERSE

A. D. Sakharov
Submitted 23 September 1966
ZhETF Pis'ma 5, No. 1, 32-35, 1 January 1967

The theory of the expanding Universe, which presupposes a superdense initial state of matter, apparently excludes the possibility of macroscopic separation of matter from antimatter; it must therefore be assumed that there are no antimatter bodies in nature, i.e., the Universe is asymmetrical with respect to the number of particles and antiparticles

Chirality and the origin of Matter-Antimatter asymmetry in the Universe

Within the Standard Model, baryon number violating sphaleron transitions in hot electroweak plasma operate in the expanding Early Universe.



Graphics: Hamada, Kikuchi,'20

Can we study these processes in the lab?

No – the temperature of electroweak phase transition is too high, $T_{EW} \approx 160\ GeV \sim\ 10^{15}$ K

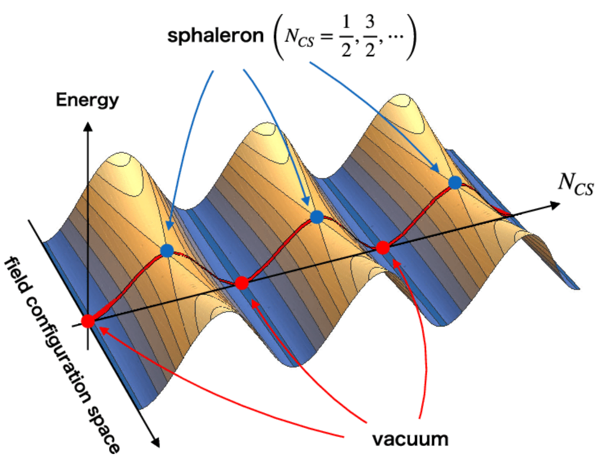
But: we can study analogous processes in another non-Abelian gauge theory of the Standard Model – QCD!

Generation of chirality in the QCD plasma

The temperature of QCD phase transition is 1,000 times lower:
$T_{QCD} \approx 160\ MeV \sim\ 10^{12}$ K

QCD plasma can be produced and studied in the ongoing heavy ion experiments at RHIC (BNL) and LHC (CERN).

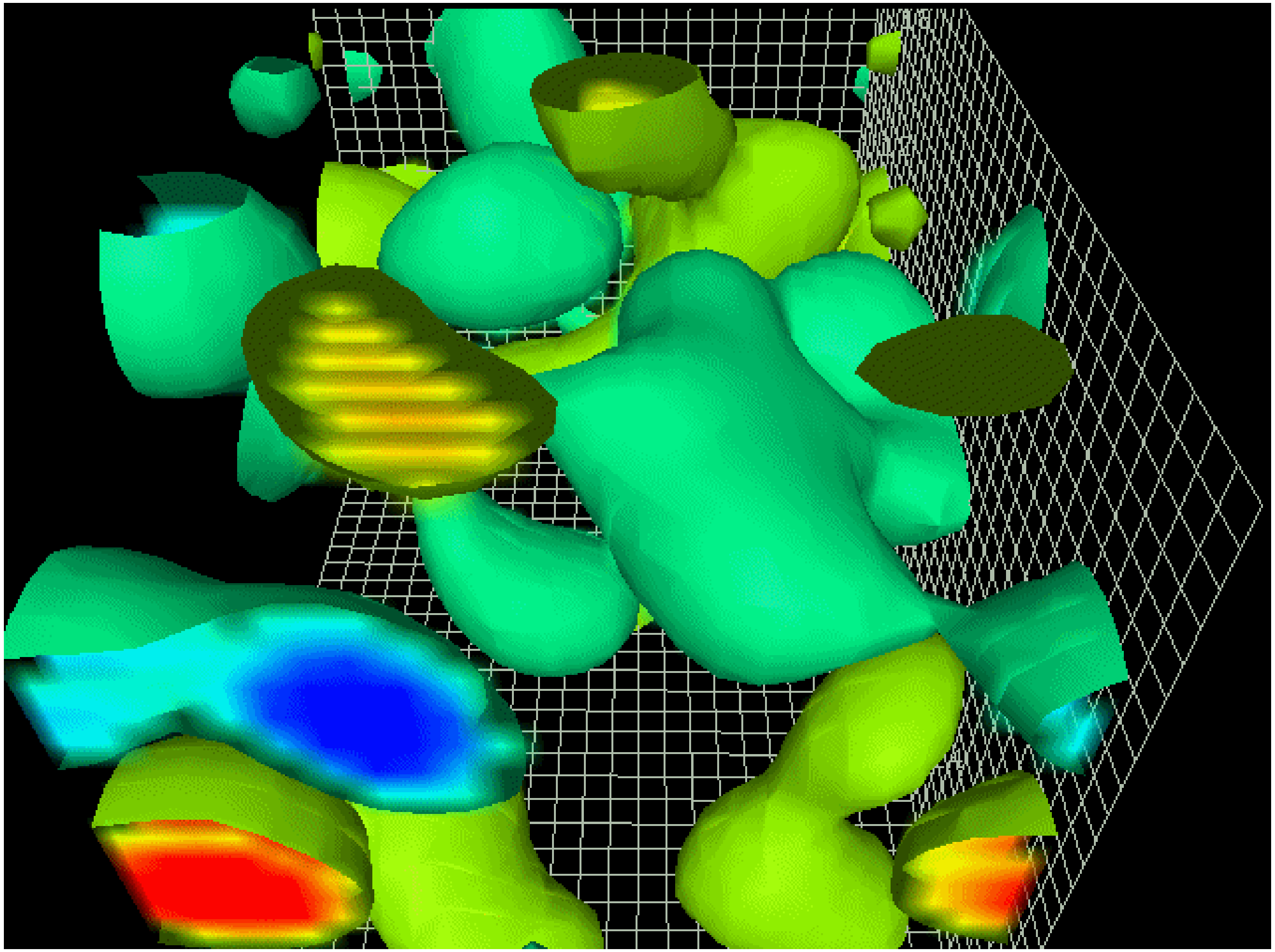
QCD sphalerons induce chirality violation (instead of baryon number violation), and rapid expansion of the produced plasma drives it out of thermal equilibrium –
thus we expect to see a substantial **generation of net chirality**, <u>of fluctuating sign</u>, **in heavy ion collisions**!



Graphics: Hamada, Kikuchi,'20

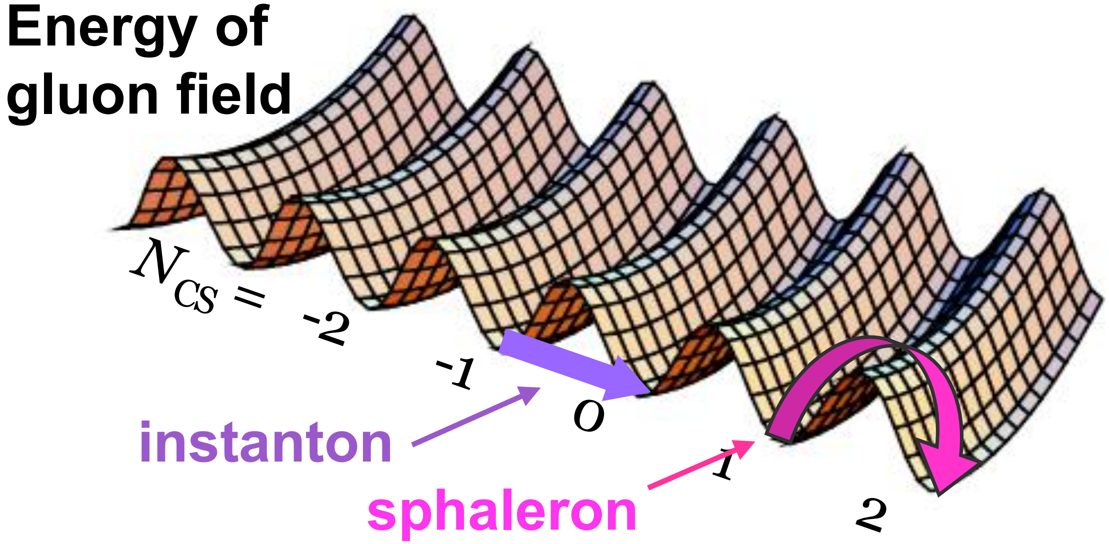
Topological transitions in QCD vacuum

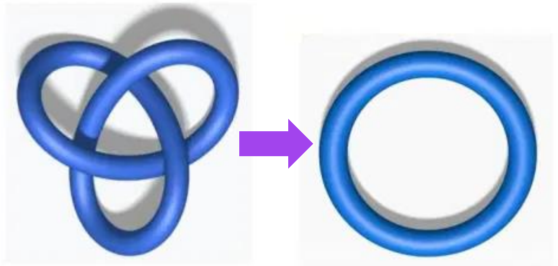
D. Leinweber



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.

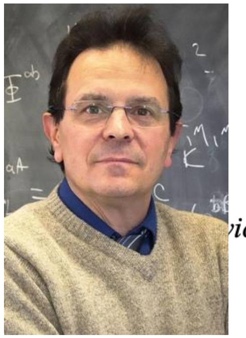




Is it possible to directly observe these chirality-changing transitions in experiment?

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]
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ice de Physique Théorique, CP 225, Université Libre de Bruxelles, Boulevard du Triomphe, 1050 Bruxelles, Belgiu
(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 $\eta \rightarrow \pi^0\pi^0$, 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]

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[b] *Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1, Canada*

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"

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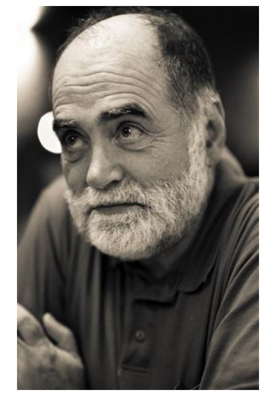
Received 15 November 2007; received in revised form 28 January 2008; accepted 3 February 2008



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

Chiral magnetic effect

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

[1] *Yukawa Institute, Kyoto University, Kyoto, Japan*
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(Received 2 September 2008; published 31 October 2008)

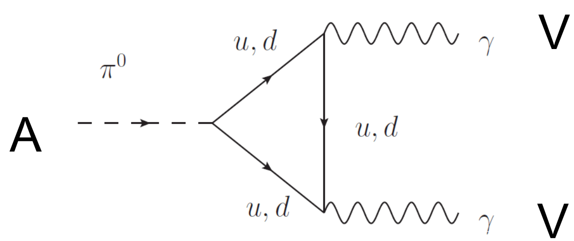
Chiral Magnetic Effect (CME)

Chiral anomaly

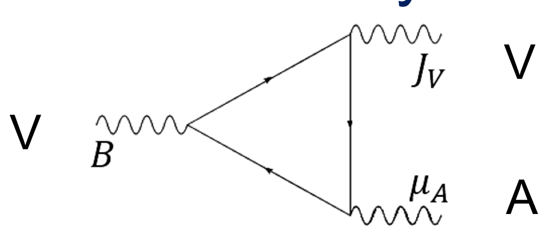
The axial current is not conserved:

$$\partial_\mu J^\mu_A = \frac{e^2}{2\pi^2}\vec{E}\cdot\vec{B}$$

S. Adler '69
J. Bell, R. Jackiw '69



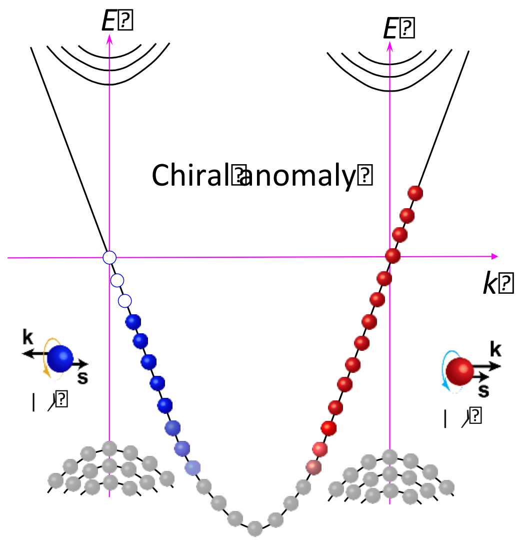
The chiral charge is not conserved;
a chirally imbalanced state of chiral fermions is not
a true ground state of the system!



Chiral anomaly

$$J_A \equiv -J_L + J_R$$

LEFT **RIGHT**



In classical background fields (E and B), chiral anomaly induces an imbalance between left- and right-handed fermions;

$$\partial_\mu J^\mu_A = \frac{e^2}{2\pi^2}\vec{E}\cdot\vec{B}$$

chiral chemical potential:

$$\mu_5 = \frac{1}{2}(\mu_R - \mu_L)$$

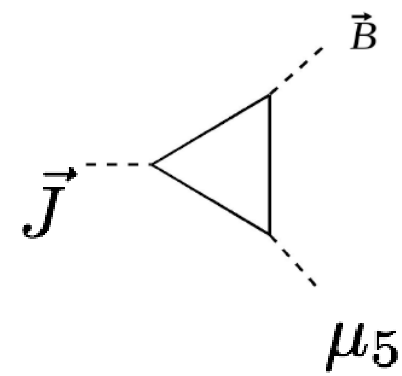
Adler; Bell, Jackiw (1969); Nielsen, Ninomiya (1983)

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!

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

Coefficient is fixed by the chiral anomaly, no corrections

Chirally imbalanced system is a non-equilibrium state

Chiral magnetic conductivity: discrete symmetries

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

P – parity

T – time reversal

P-odd
T-odd

P-even
T-odd

P-odd

<u>P-odd effect!</u>

T-even

<u>Non-dissipative current!</u>
(non-equilibrium)

Effect persists in hydrodynamics!

D.Son, P.Surowka '09

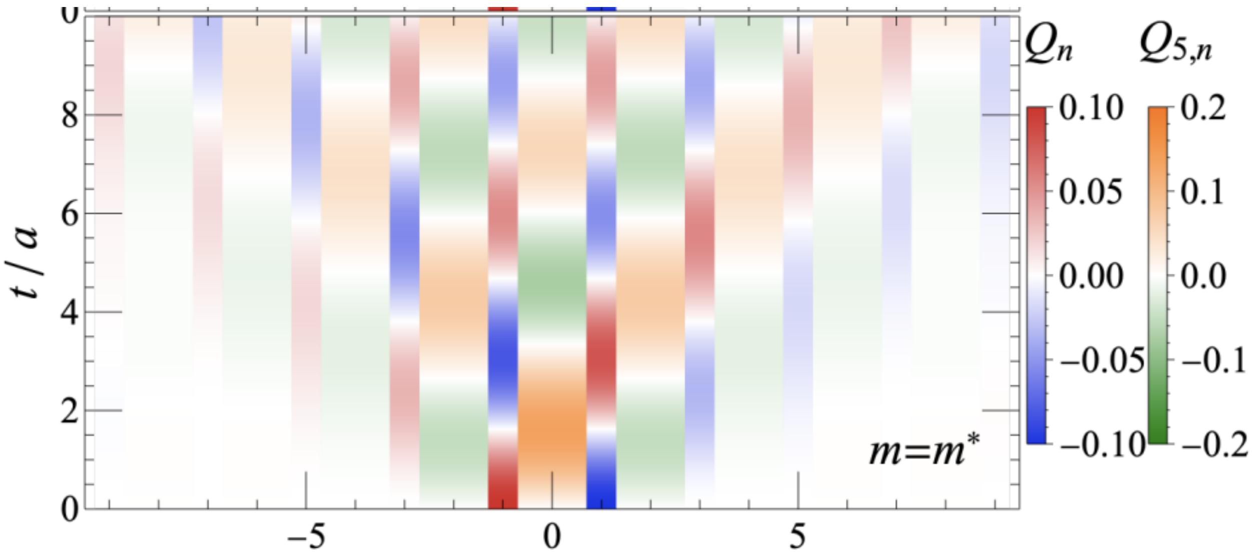
DK, H.U.Yee '11

cf Ohmic conductivity:

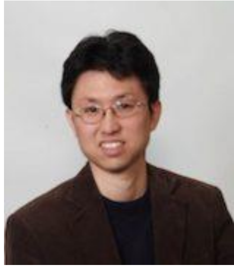
$$\vec{J} = \sigma \vec{E}$$

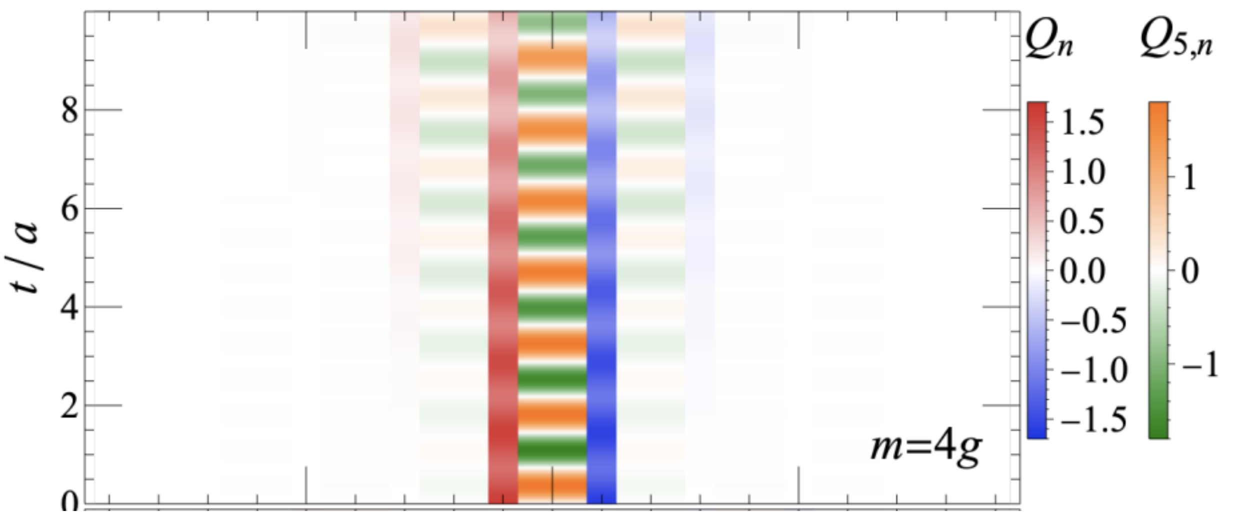
T-odd, dissipative

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

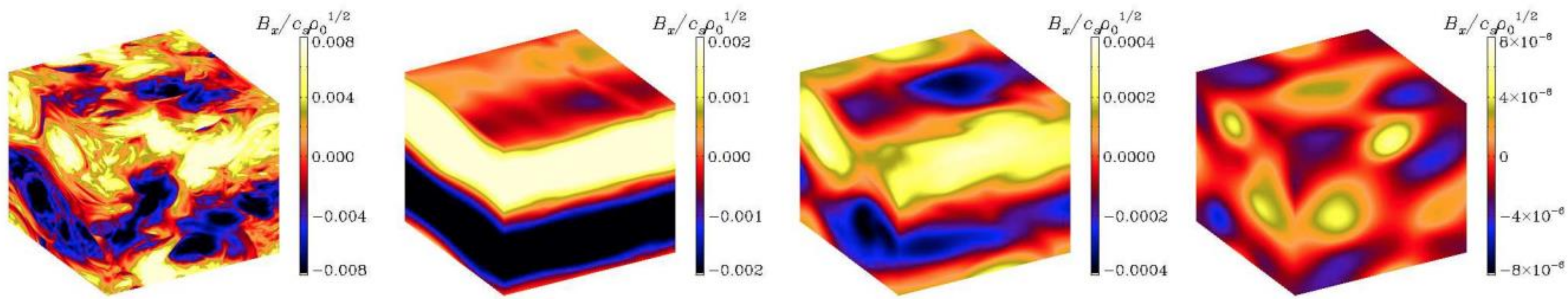
K. Ikeda, DK, S. Shi, arXiv:2305.05685; PRD’23

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

CrossMark

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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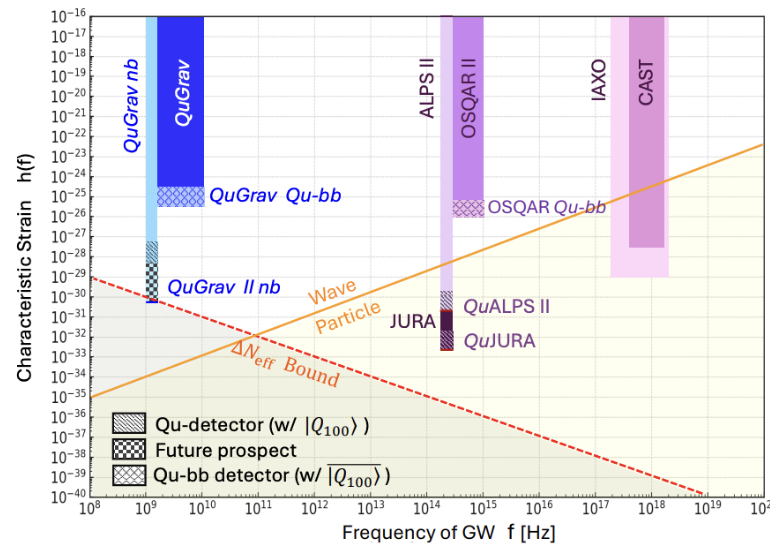
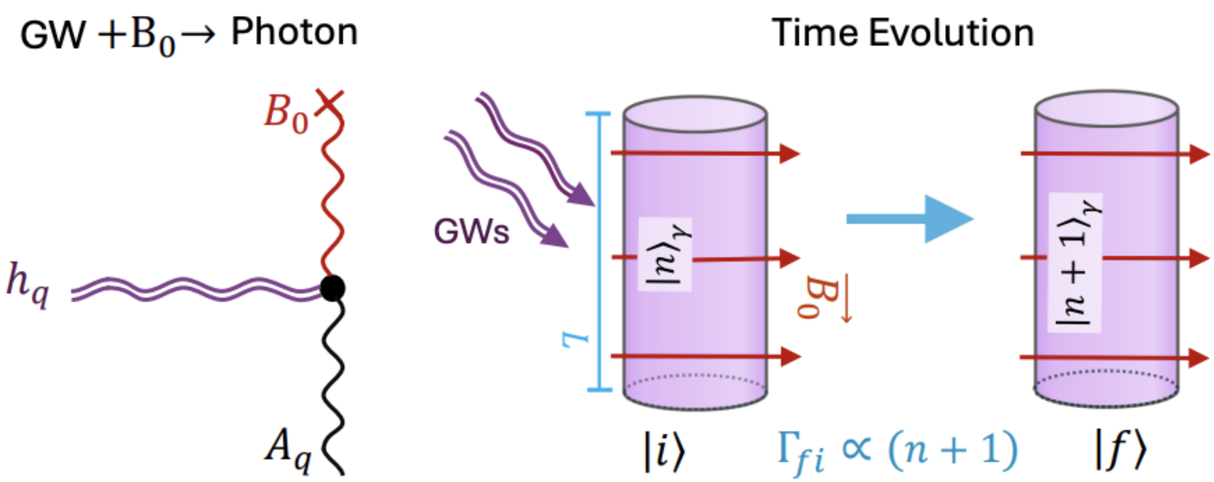
arXiv:2506.09459



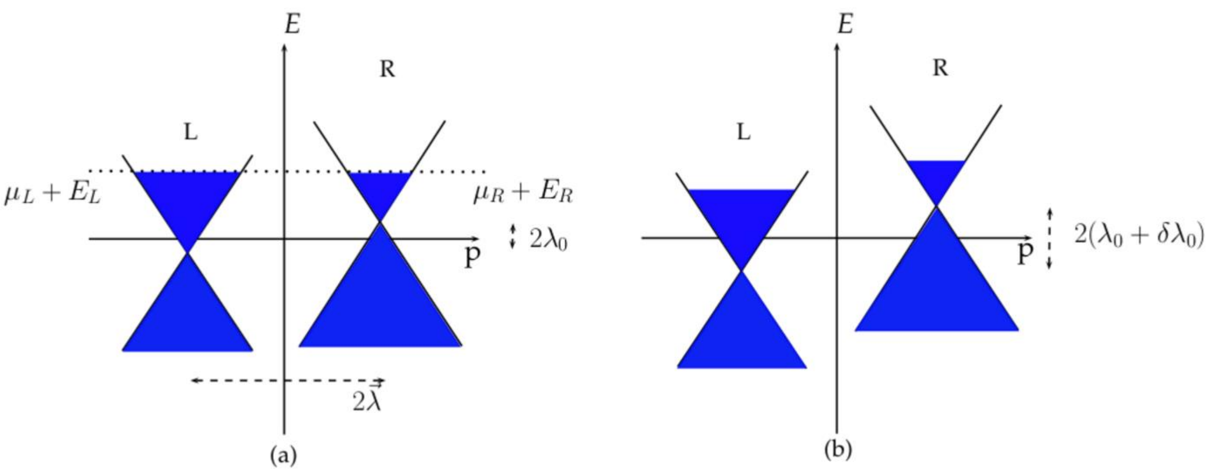


Condensed matter analog: CME induced by strain

Strain induced Chiral Magnetic Effect in Weyl semimetals

Alberto Cortijo[1], Dmitri Kharzeev[2,3], Karl Landsteiner[4] and Maria A.H. Vozmediano[1,*]

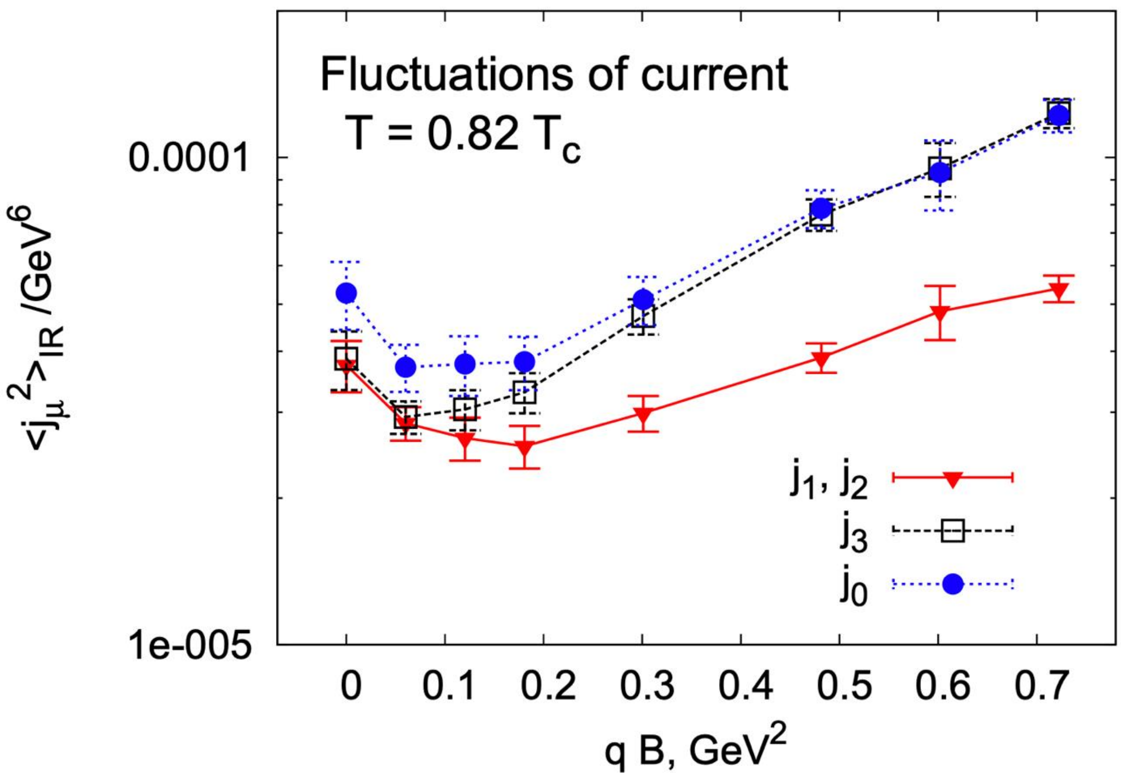
Phys.Rev.B 94 (2016) 24, 241405

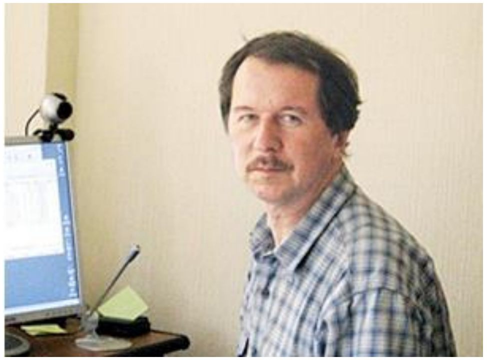


$\mathbf{J} \approx 10^5 \mathbf{B}\ A/m^2$, ~ 1 μA

“Numerical evidence for chiral magnetic effect in lattice gauge theory”,

P. Buividovich, M. Chernodub, E. Luschevskaya, M. Polikarpov, arXiv 0907.0494; PRD’09





M. Polikarpov
1952-2013

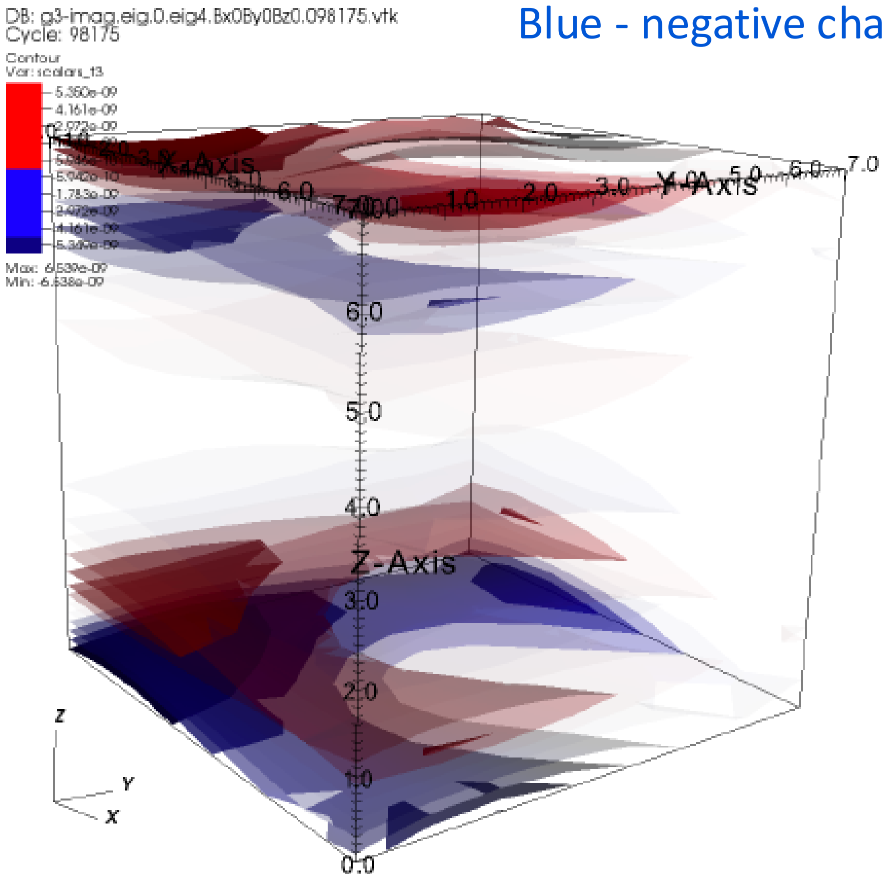
Fluctuations of electric current along the direction of magnetic field are enhanced

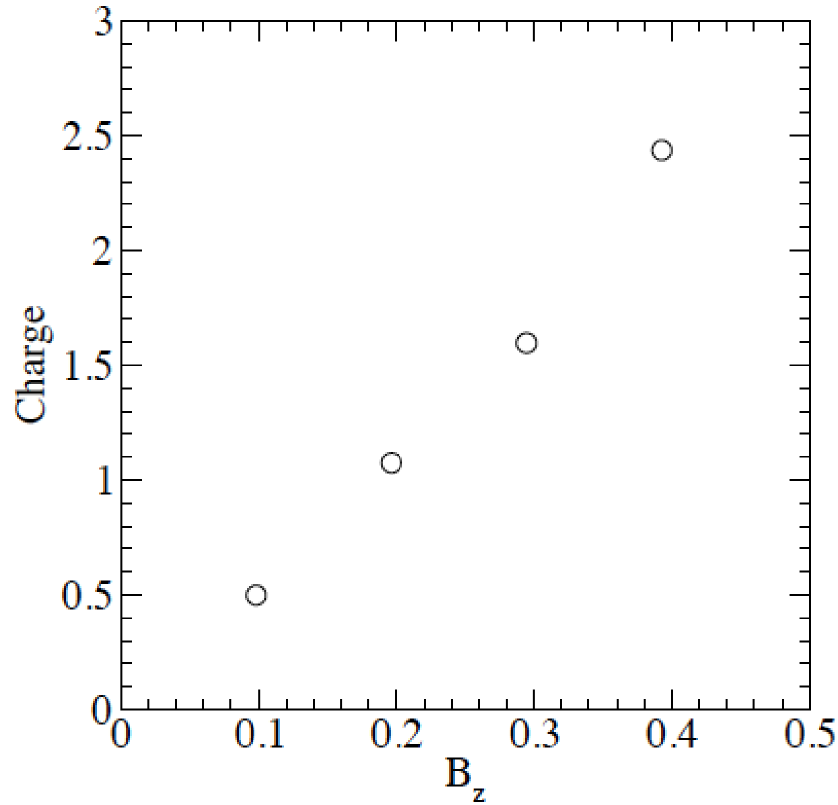
“Chiral magnetic effect in 2+1 flavor QCD+QED”,

M. Abramczyk, T. Blum, G. Petropoulos, R. Zhou, ArXiv 0911.1348, PRD

Red - positive charge

Blue - negative charge



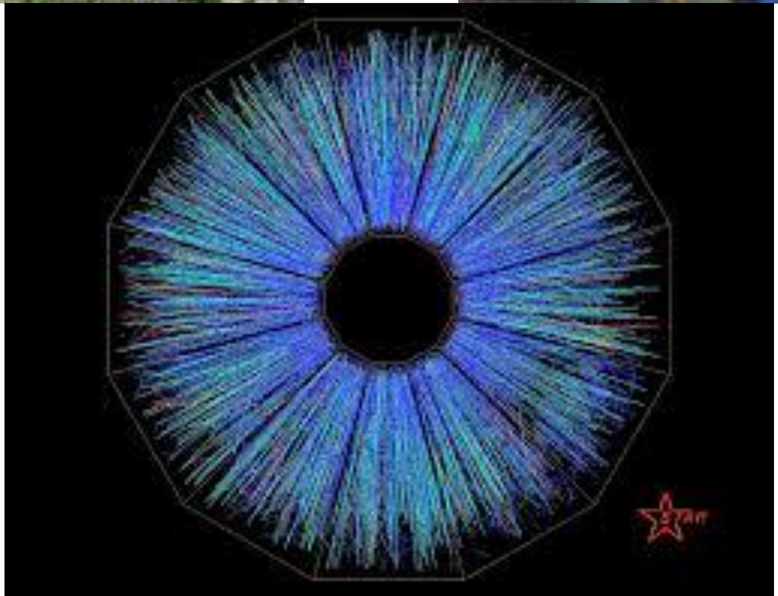


2+1 flavor Domain Wall Fermions, fixed topological sectors, 16^3 x 8 lattice

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]

Heavy ion collisions as a source of the strongest magnetic fields available in the Laboratory

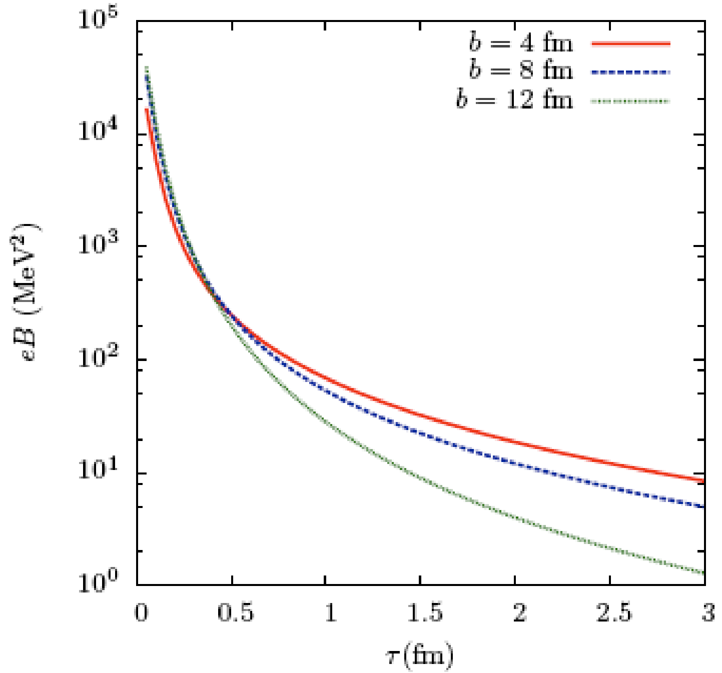
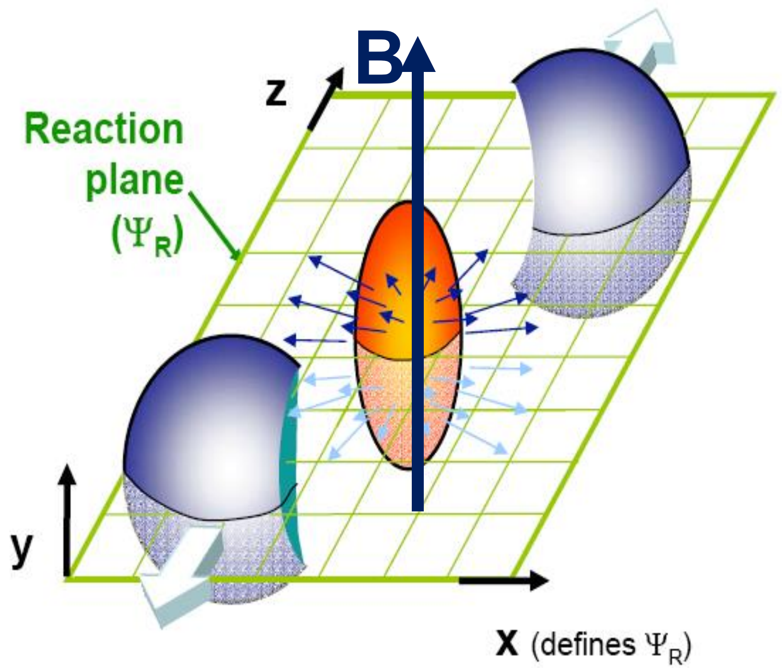
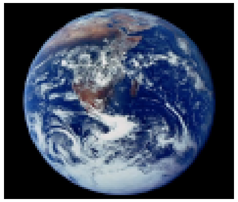


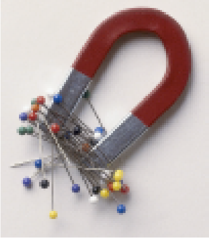
Fig. A.2. Magnetic field at the center of a gold-gold collision, for different impact parameters. Here the center of mass energy is 200 GeV per nucleon pair ($Y_0 = 5.4$).



DK, McLerran, Warringa, Nucl Phys A803(2008)227

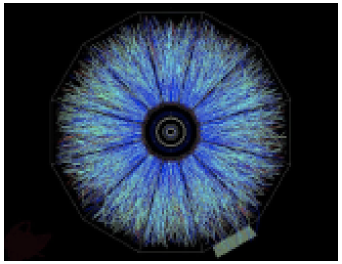
Comparison of magnetic fields





The Earths magnetic field	0.6 Gauss
A common, hand-held magnet	100 Gauss
The strongest steady magnetic fields achieved so far in the laboratory	4.5×10^5 Gauss
The strongest man-made fields ever achieved, if only briefly	10^7 Gauss
Typical surface, polar magnetic fields of radio pulsars	10^{13} Gauss
Surface field of Magnetars	10^{15} Gauss

http://solomon.as.utexas.edu/~duncan/magnetar.html



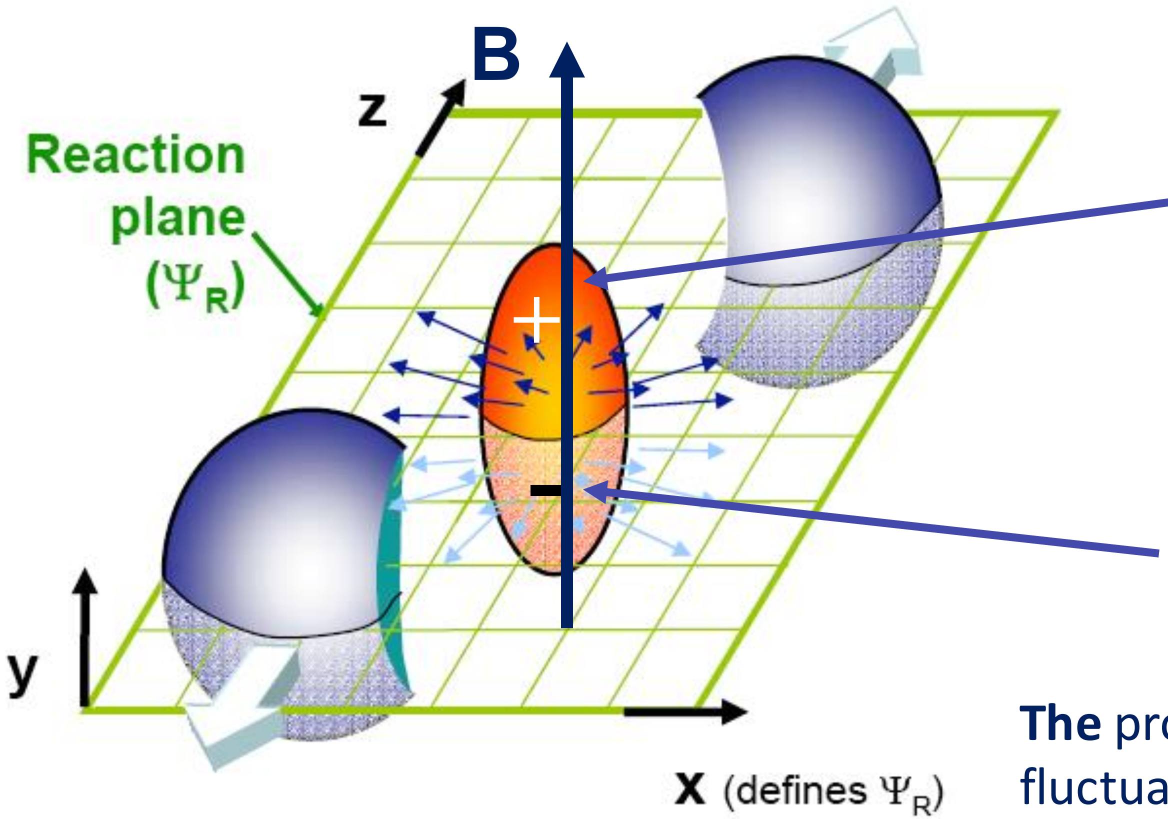
Heavy ion collisions: the strongest magnetic field ever achieved in the laboratory

Off central Gold-Gold Collisions at 100 GeV per nucleon

$$eB(\tau = 0.2\,\mathrm{fm}) \;=\; 10^3 \sim 10^4\ \mathrm{MeV}^2 \sim 10^{17}\,\mathrm{Gauss}$$

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

Electric dipole moment due to chiral imbalance



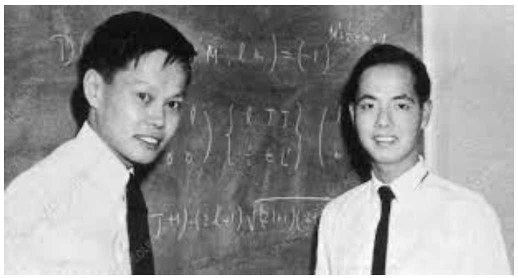
excess of positive charge

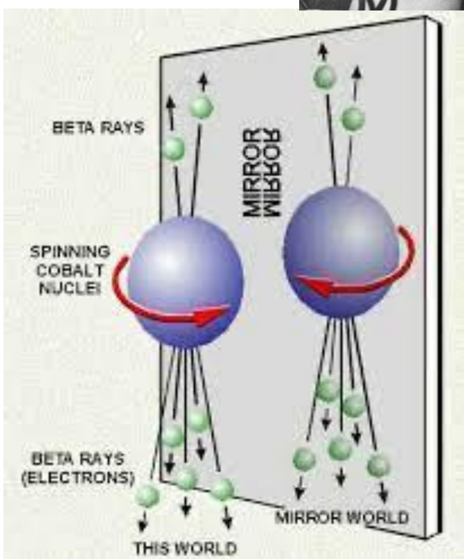
excess of negative charge

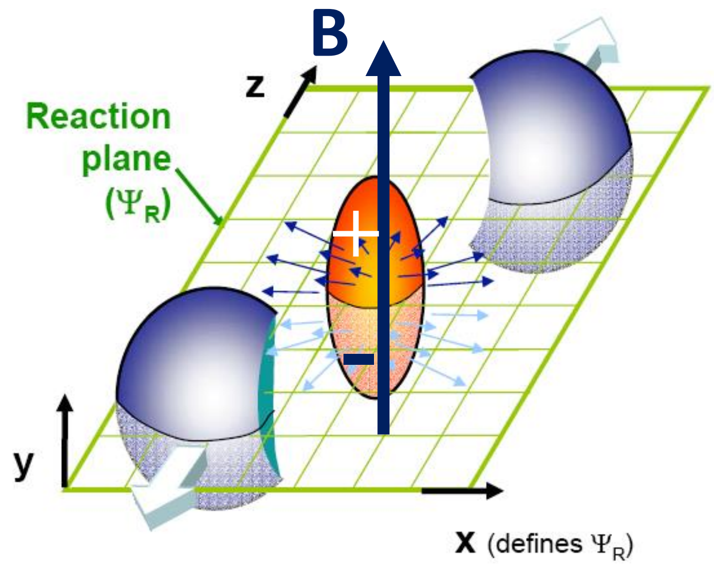
The problem:
fluctuating sign, reflecting topological fluctuations in QCD
- backgrounds!

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

CME as a probe of topological transitions and Event-by-event parity violation in QCD plasma



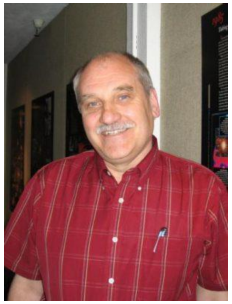




Global Parity violation in Weak interactions

Local, Event-by-event Parity violation in Strong Interactions ?

Separating the signal from background: the beginning



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

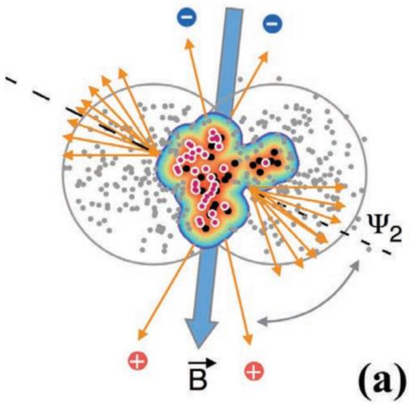
Parity violation in hot QCD: How to detect it

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.

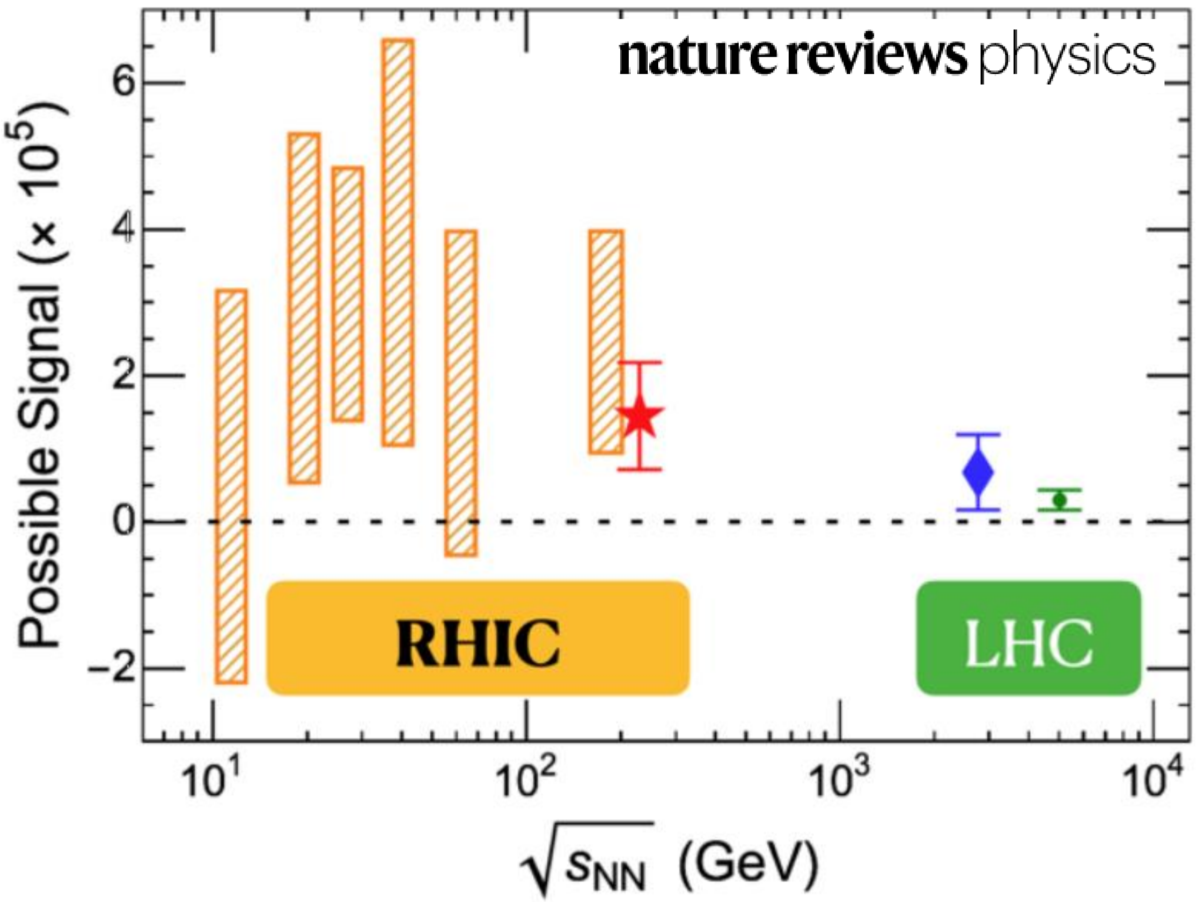


$$\begin{aligned}\langle\cos(\phi_a-\Psi_2)\cos(\phi_b-\Psi_2)\\ -\sin(\phi_a-\Psi_2)\sin(\phi_b-\Psi_2)\rangle \qquad (1)\\ =\langle\cos(\phi_a+\phi_b-2\Psi_2)\rangle=(v_{1,a}v_{1,b}-a_a a_b)\,\langle\cos(2\Psi_2)\rangle\end{aligned}$$

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

Review of CME with heavy ions: DK, J. Liao, S. Voloshin, G. Wang, Rep. Prog. Phys.'16

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

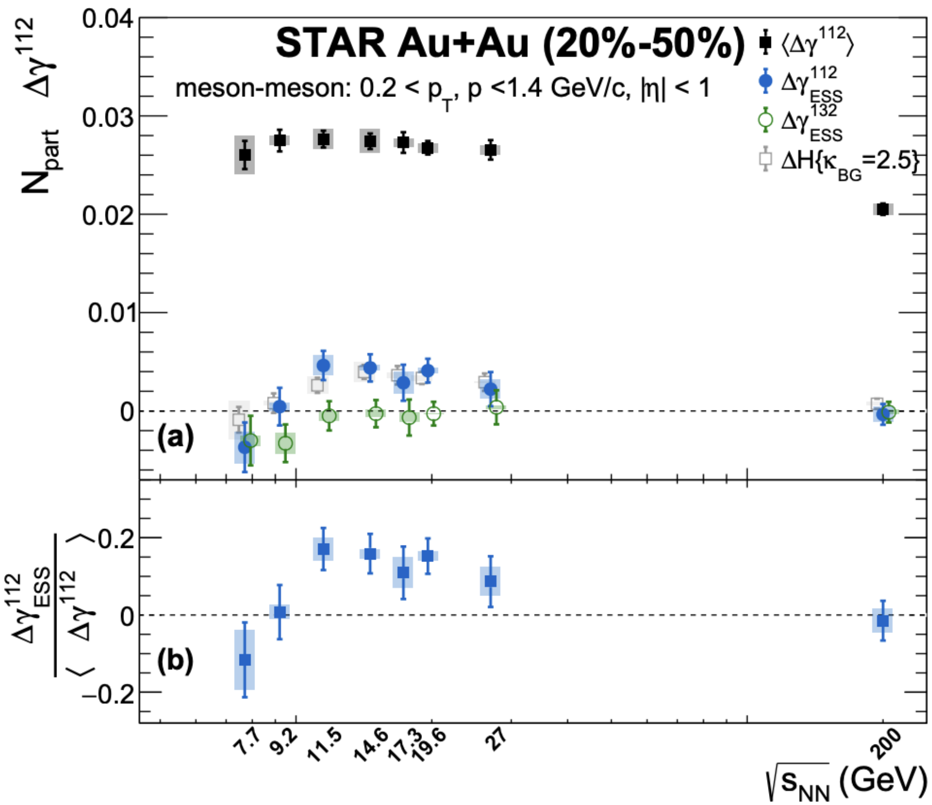


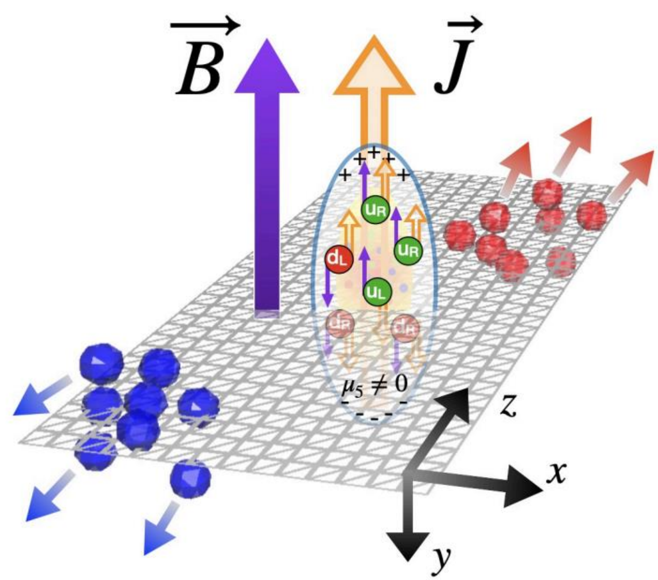
Very recent news: STAR result on CME in beam energy scan

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

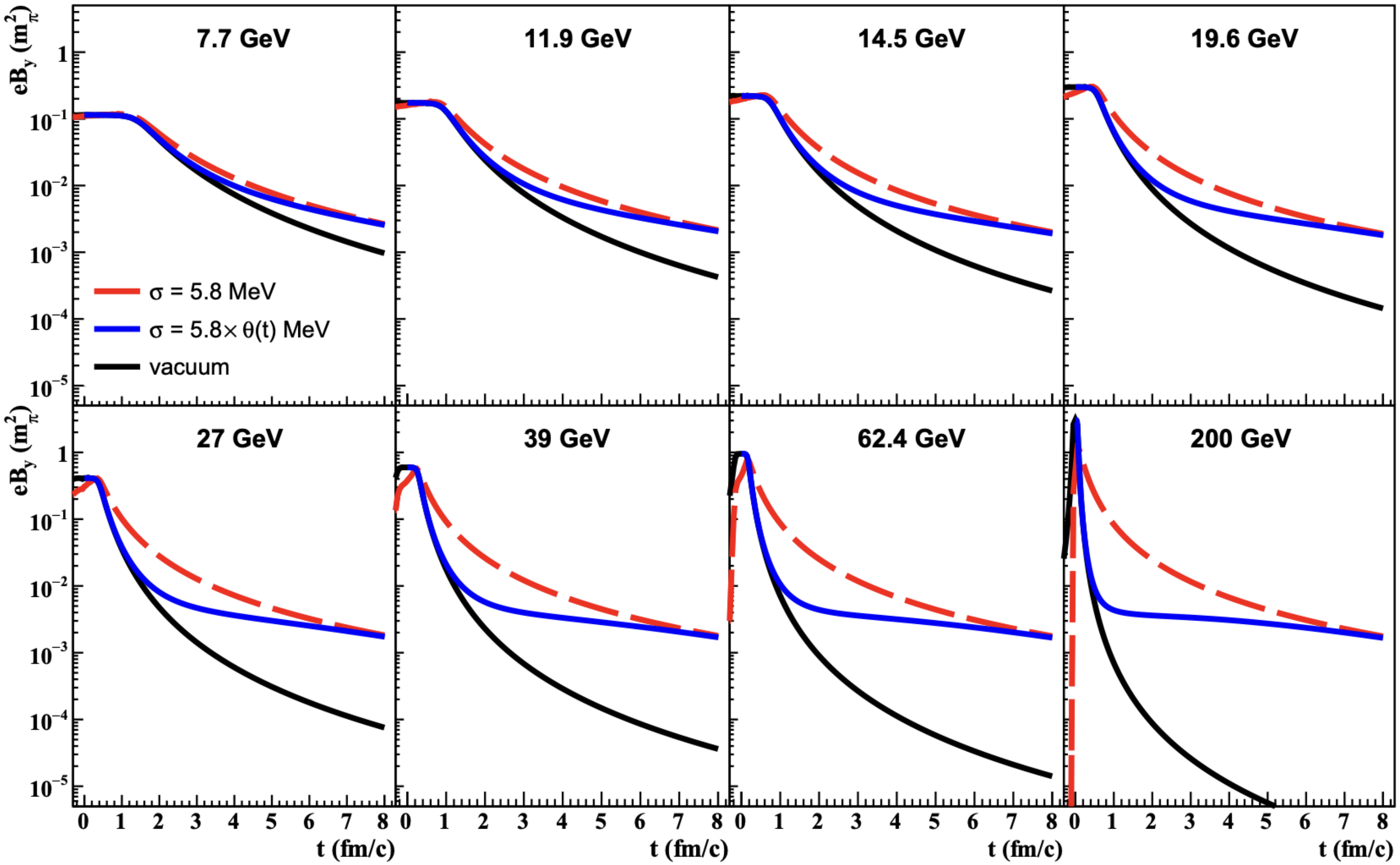
arXiv:2506.00275

The STAR Collaboration

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:



H. Li et al, arXiv: 2306.02829 PRC(2024)

Why CME at low energies?

But there may also be another reason, revealed through the real-time simulations: enhancement of topological fluctuations near the critical point

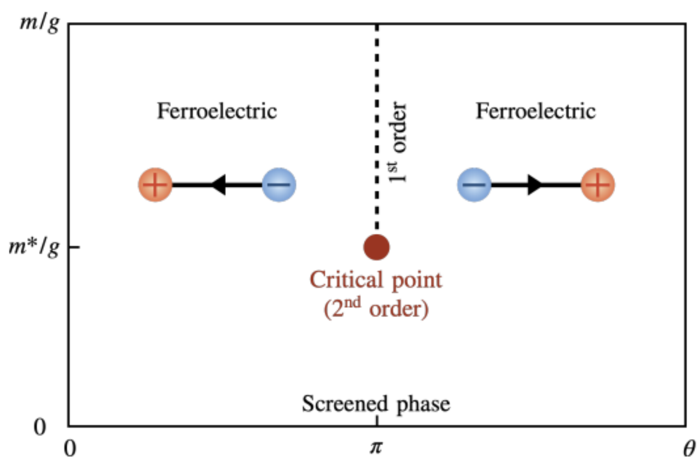
LETTER | OPEN ACCESS

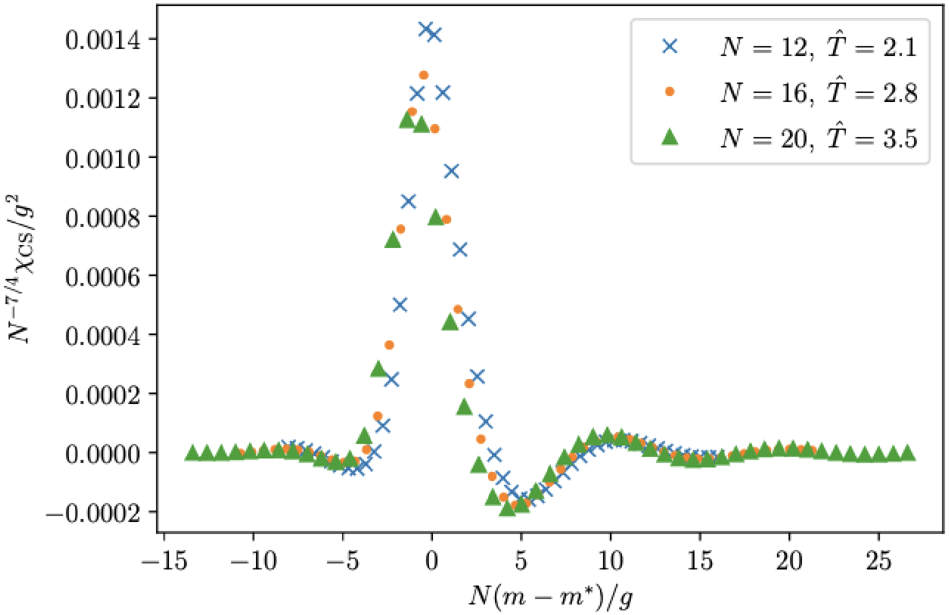
Real-time dynamics of Chern-Simons fluctuations near a critical point

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

Show more

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





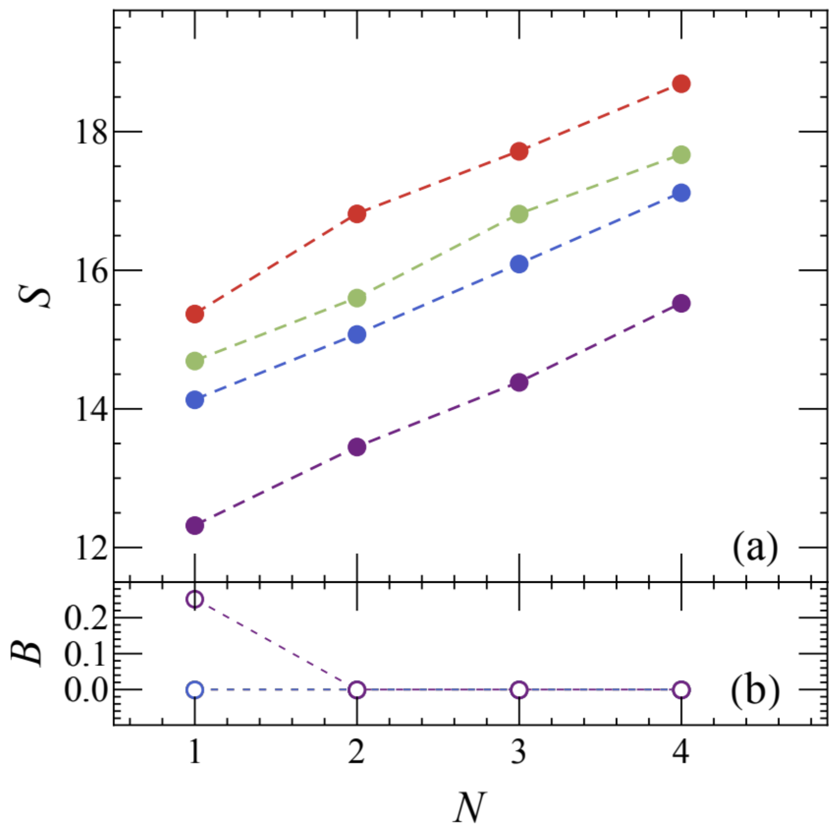
Also: K.Fukushima, M. Ruggieri, R. Gatto (2010)

Better CME observables with machine learning

Optimal Observables for the Chiral Magnetic Effect from Machine Learning

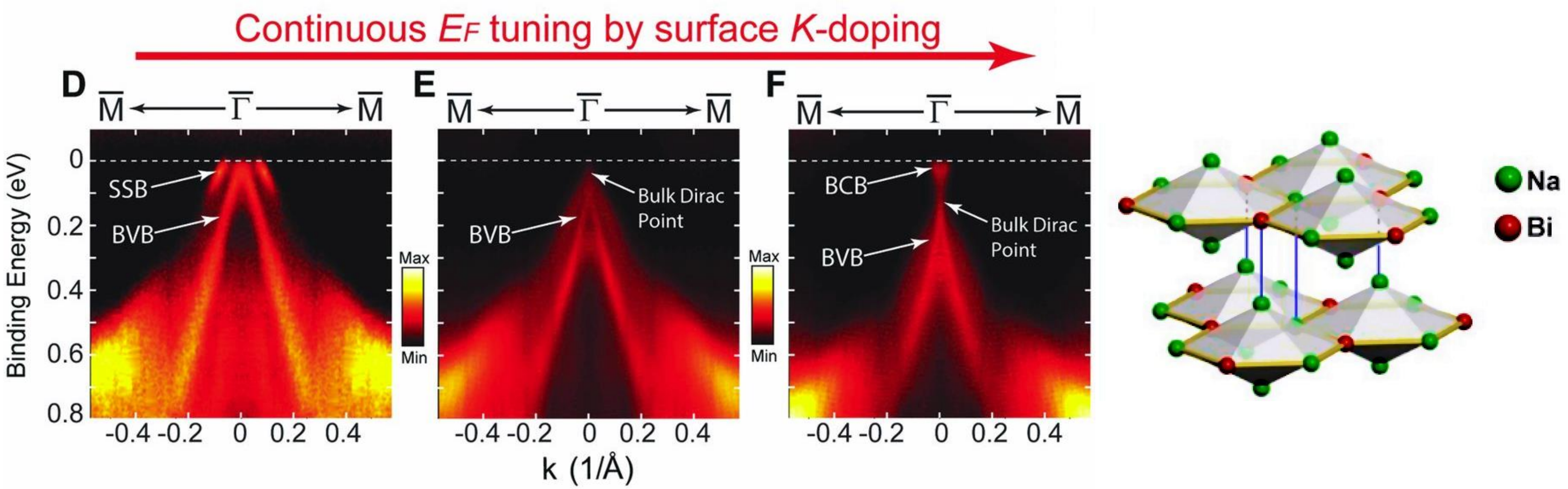
Yuji Hirono,[1,*] Kazuki Ikeda,[2,3,†] Dmitri E. Kharzeev,[3,4,‡] Ziyi Liu,[5,§] and Shuzhe Shi[5,6,¶]

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)

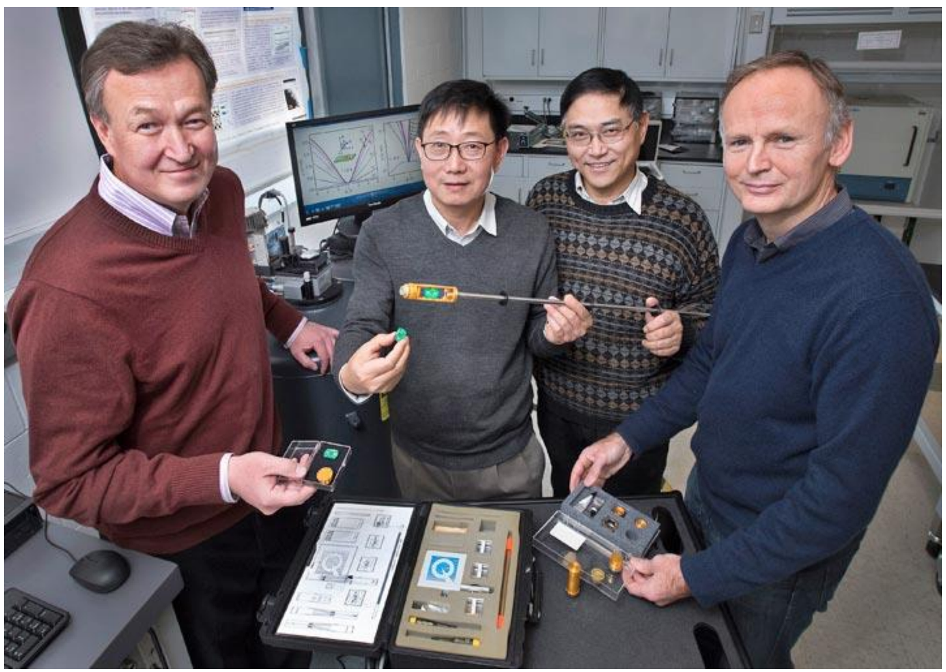
Even number of space-time dimensions –
so chiral anomaly operates, can study CME!

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]

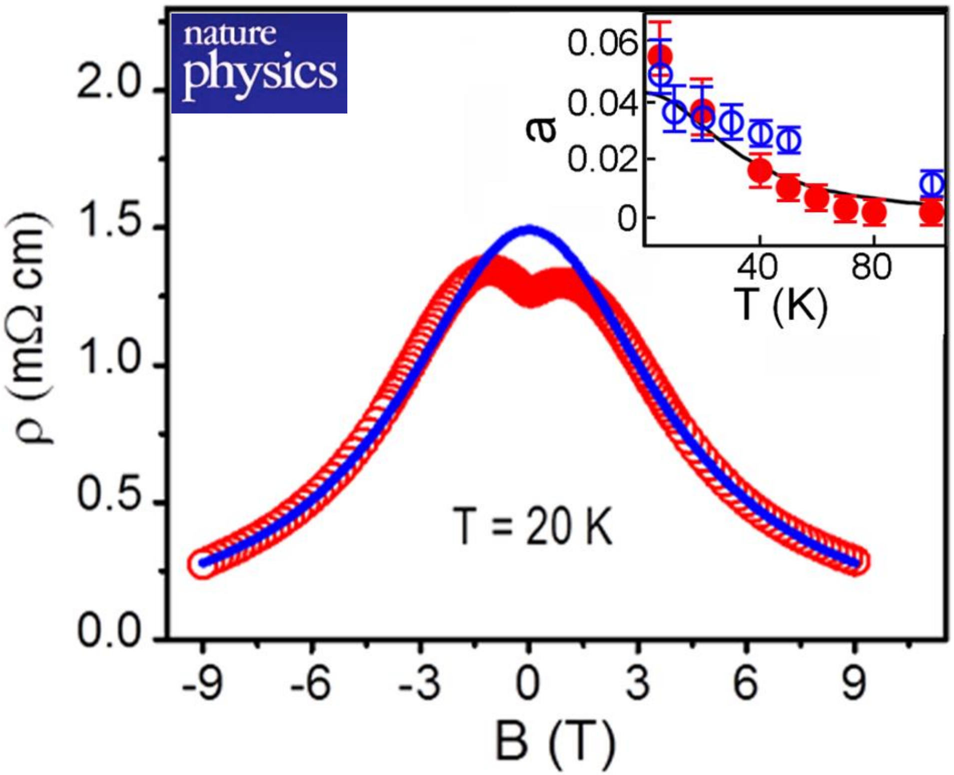
Parallel electric and magnetic fields source the chiral anomaly: $\partial_\mu J^\mu_A = \frac{e^2}{2\pi^2}\vec{E}\cdot\vec{B}$

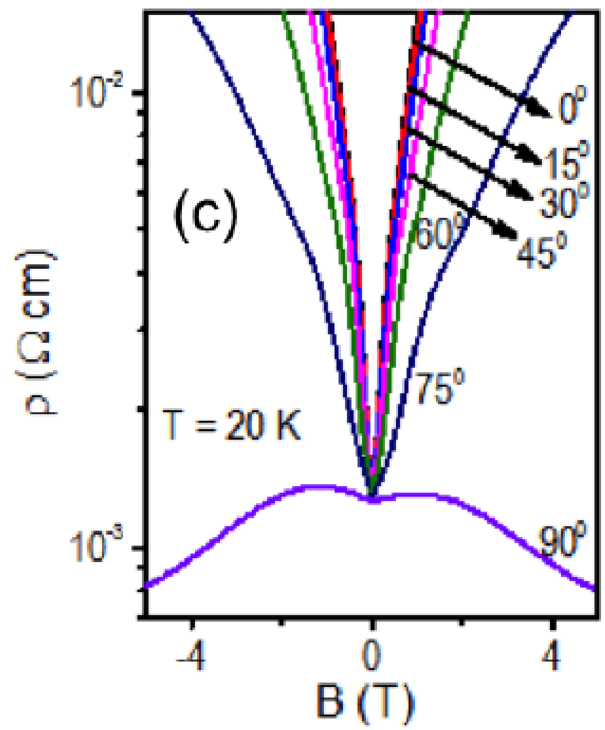
and thus the chiral chemical potential $\mu_5 \sim EB\,\tau$

The CME current is $J \sim \mu_5 B^2 \tau$ – longitudinal magnetoconductivity ~ 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

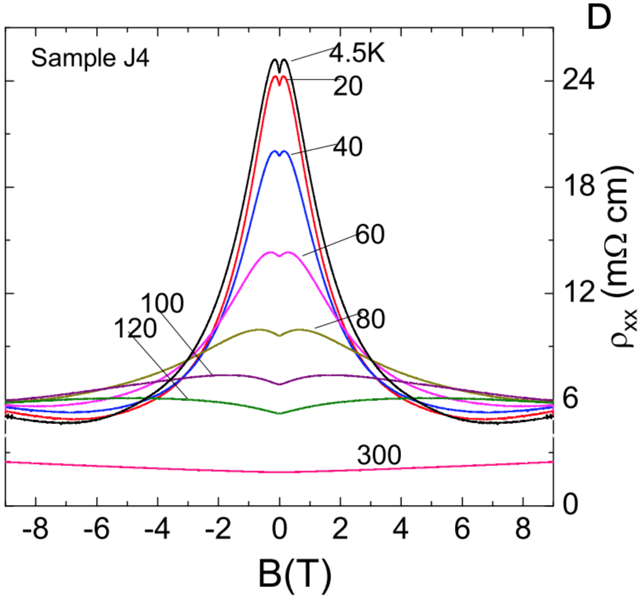
Impressive results from other groups:

arXiv:1503.08179

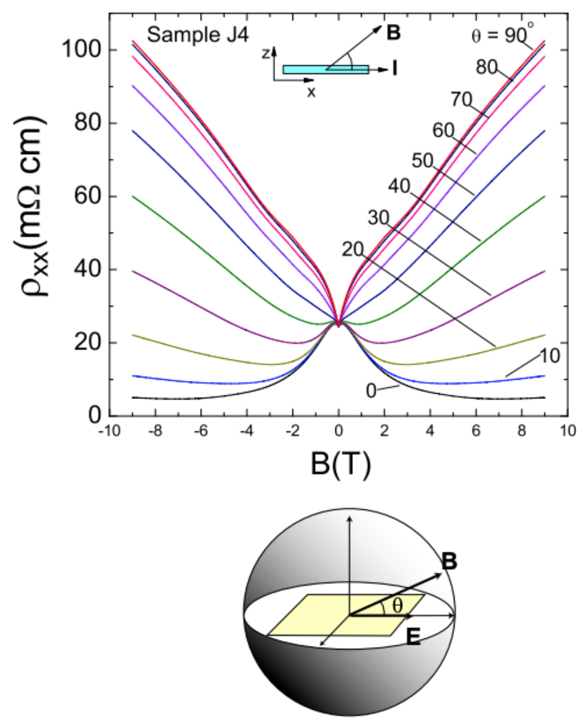
Signature of the chiral anomaly in a Dirac semimetal – a current plume steered by a magnetic field*

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)

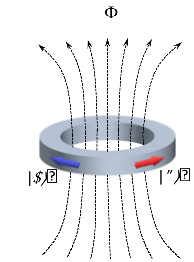
D



Science '15

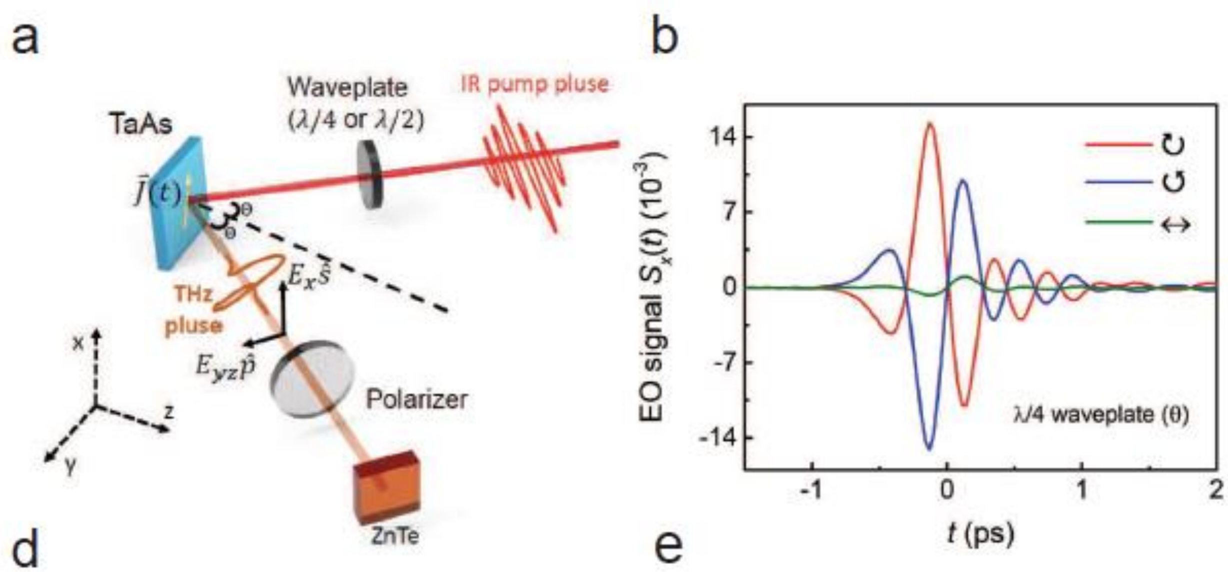


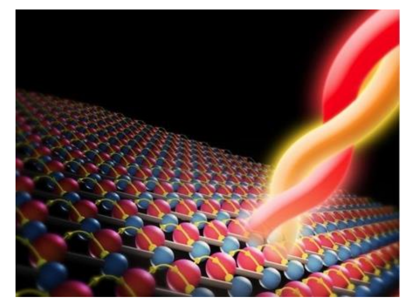
CME in chiral materials: optical measurements



Chiral terahertz wave emission from the Weyl semimetal TaAs

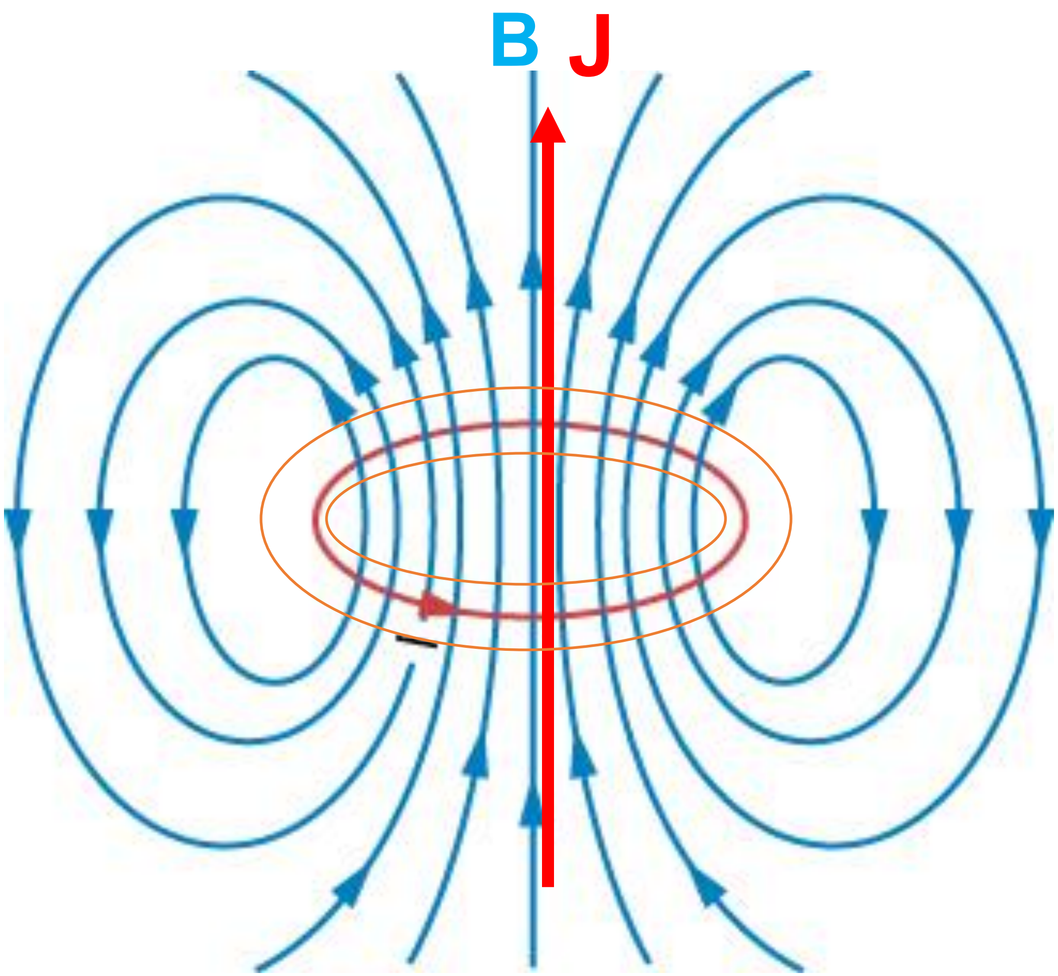
Y. Gao[1], S. Kaushik[2], E.J. Philip[2], Z. Li[3,4], Y. Qin[1,5], Y.P. Liu[6], W.L. Zhang[1], Y.L. Su[1], X. Chen[2], H. Weng[4,7], D.E. Kharzeev[2,8,9*], M.K. Liu[2*] & J. Qi[1*]





nature COMMUNICATIONS

Chiral magnetic instability



Transfer of chiral charge of the fermions to the magnetic helicity

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

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

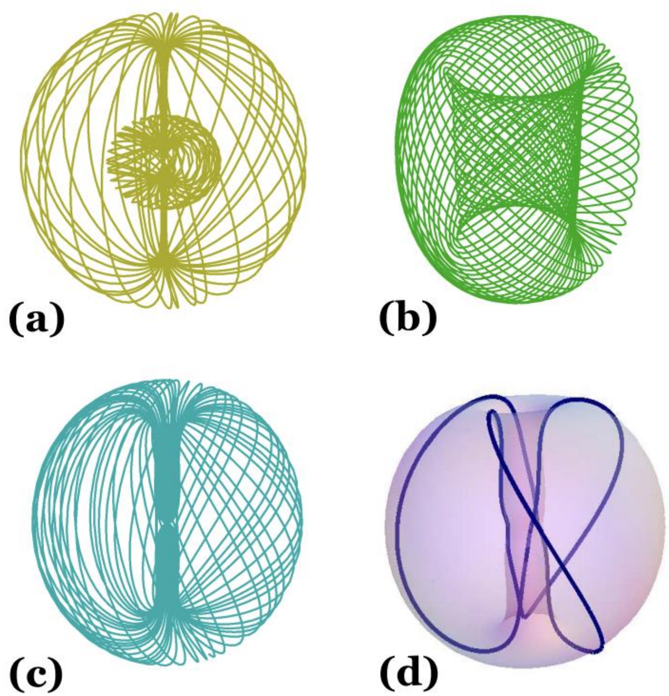
Free magnetized knots of parity-violating deconfined matter in heavy-ion collisions

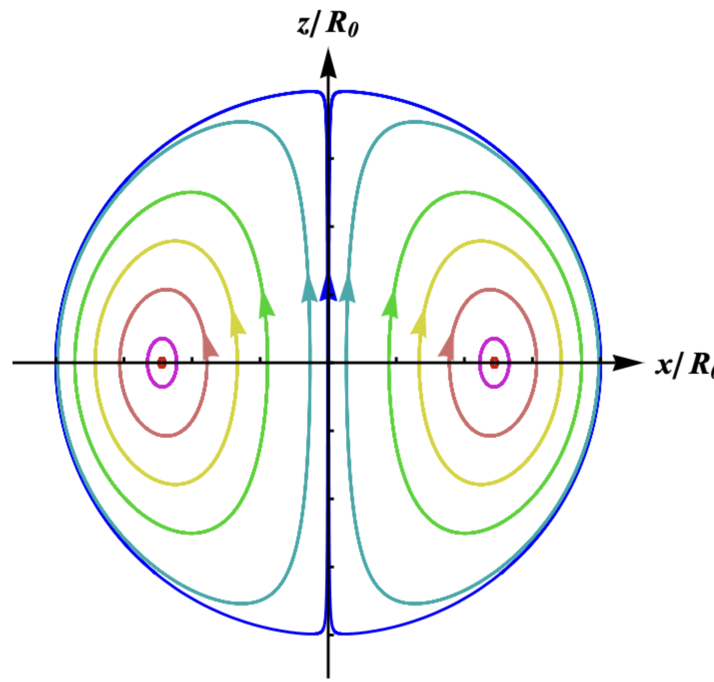
M. N. Chernodub*

Laboratoire de Mathématiques et Physique Théorique, Université François-Rabelais Tours, Fédération Denis Poisson - CNRS, Parc de Grandmont, 37200 Tours, France
DMPA, University of Gent, Krijgslaan 281, S9, B-9000 Gent, Belgium

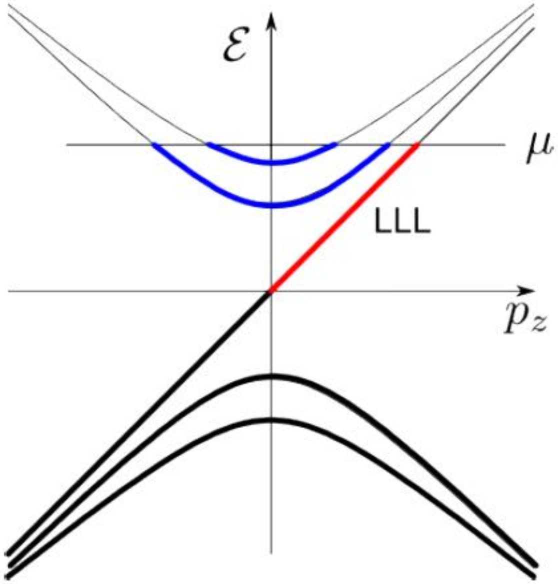
(Dated: February 7, 2010)

arXiv:1002.1473

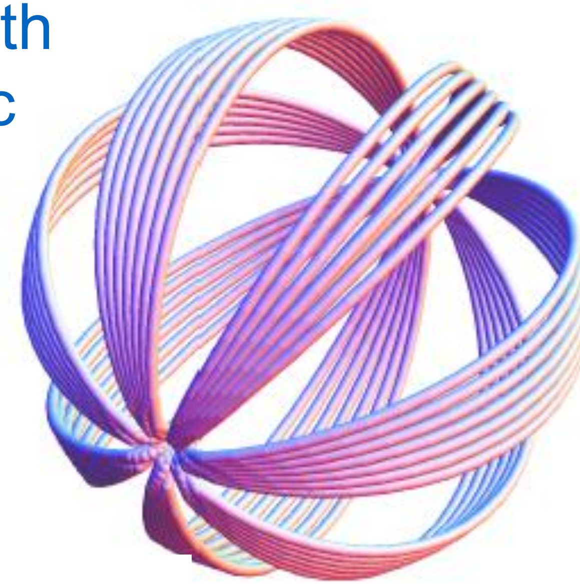




Inverse cascade of magnetic helicity



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

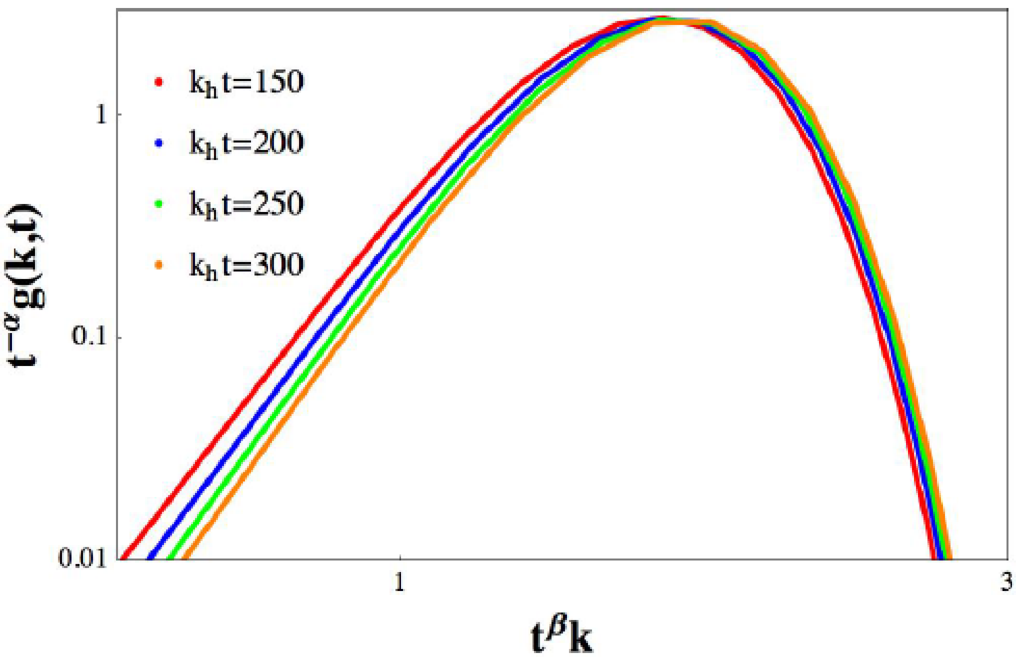


Increase of of magnetic helicity reduces μ_A

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

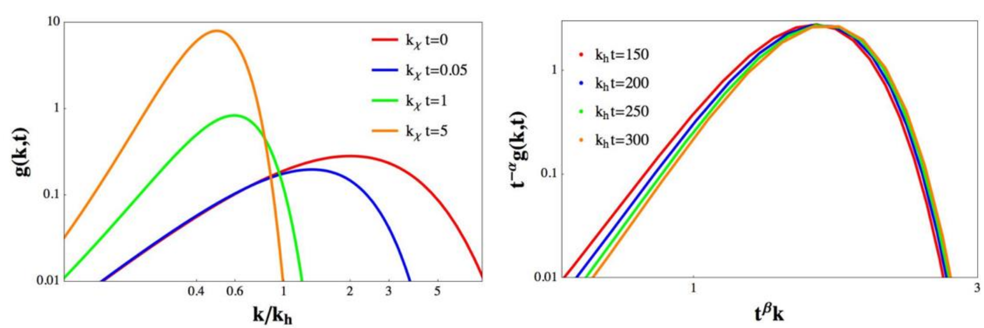
Can chiral magnetic instability be observed in chiral materials?

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

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

PRD (2015)

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

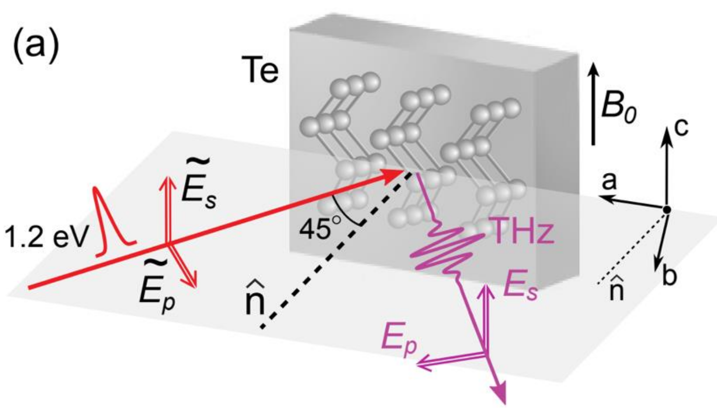
Observation of a dynamic magneto-chiral instability in photoexcited tellurium

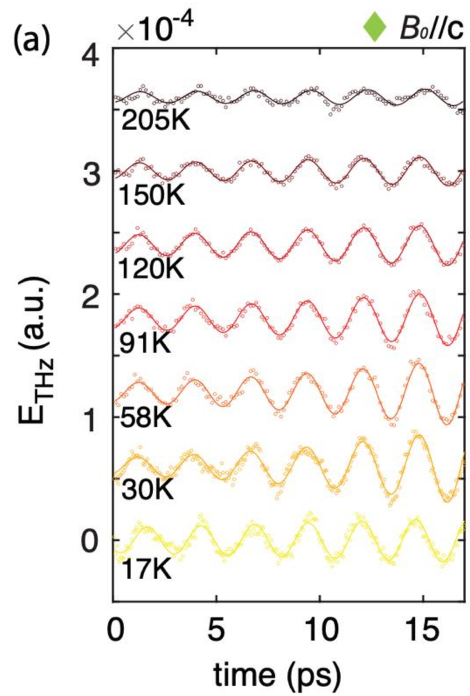
Yijing Huang,[1,2,*] Nick Abboud,[3,*] Yinchuan Lv,[1,2] Penghao Zhu,[1,4,5] Azel Murzabekova,[1,2] Changjun Lee,[6,2] Emma A. Pappas,[1,2] Dominic Petruzzi,[1,2] Jason Y. Yan,[1,2] Dipanjan Chauduri,[1,2] Peter Abbamonte,[1,2] Daniel P. Shoemaker,[6,2] Rafael M. Fernandes,[1,4] Jorge Noronha,[3] and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

Many novel phenomena to be explored at the current and future experimental facilities (RHIC, LHC, EIC).

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