XXVI Quark Matter, Chicago, February 5-11, 2017

New quantum effects in relativistic magnetohydrodynamics

D. Kharzeev

BEST COLLABORATION

Based on work with Y.Hirono (BNL) and Y.Yin (MIT)

Stony Brook University

RIKEN BNL Research Center

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Quantum hydrodynamics of QCD plasma

A striking finding of RHIC and LHC heavy ion experiments is the quantum fluid behavior of QCD plasma.

Two ways in which quantum physics affects hydrodynamics:

1. Quantum effects on “conventional” transport coefficients (KSS bound on shear viscosity-to-entropy ratio, bulk viscosity from conformal anomaly, …)

2. New transport coefficients of entirely quantum nature (Chiral magnetic conductivity, chiral vortical conductivity, ..)

Chiral Magnetohydrodynamics (CMHD)

To establish the role played by quantum effects in heavy ion collisions, we need to develop relativistic Magneto-hydrodynamics taking account of anomalies –

Chiral Magnetohydrodynamics (CMHD)

[XXI century development in hydrodynamics!]

This effort has already begun, and is one of the major thrusts of the BEST Theory Collaboration

Plenary talks by Y. Hirono, Q. Wang

BEST COLLABORATION

Chiral Magnetic Effect Task Force Report

Vladimir Skokov (co-chair),[1,*] Paul Sorensen (co-chair),[2,†] Volker Koch,[3]
Soeren Schlichting,[2] Jim Thomas,[3] Sergei Voloshin,[4] Gang Wang,[5] and Ho-Ung Yee[6,1]

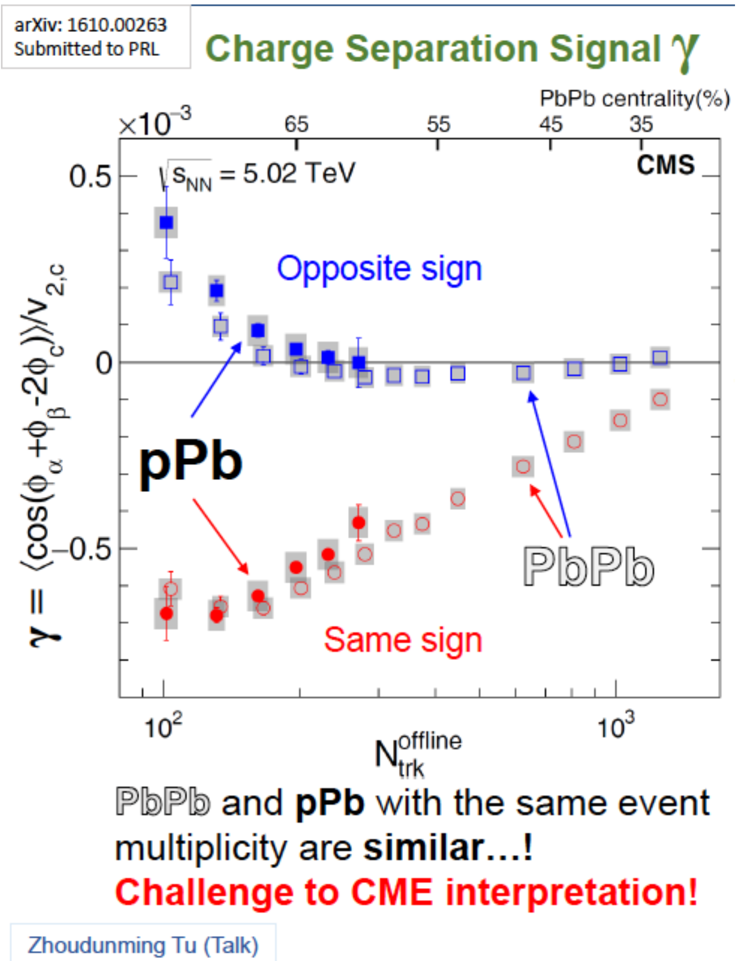
arxiv:1608.00982

The unique identification of the chiral magnetic effect in heavy-ion collisions would represent one of the highlights of the RHIC physics program and would provide a lasting legacy for the field. The current plan for completing the RHIC mission envisions a second phase of RHIC. We have specifically investigated the case for colliding nuclear isobars (nuclei with the same mass but different charge) and find the case compelling. We recommend that a program of nuclear isobar collisions to isolate the chiral magnetic effect from background sources be placed as a high priority item in the strategy for completing the RHIC mission.

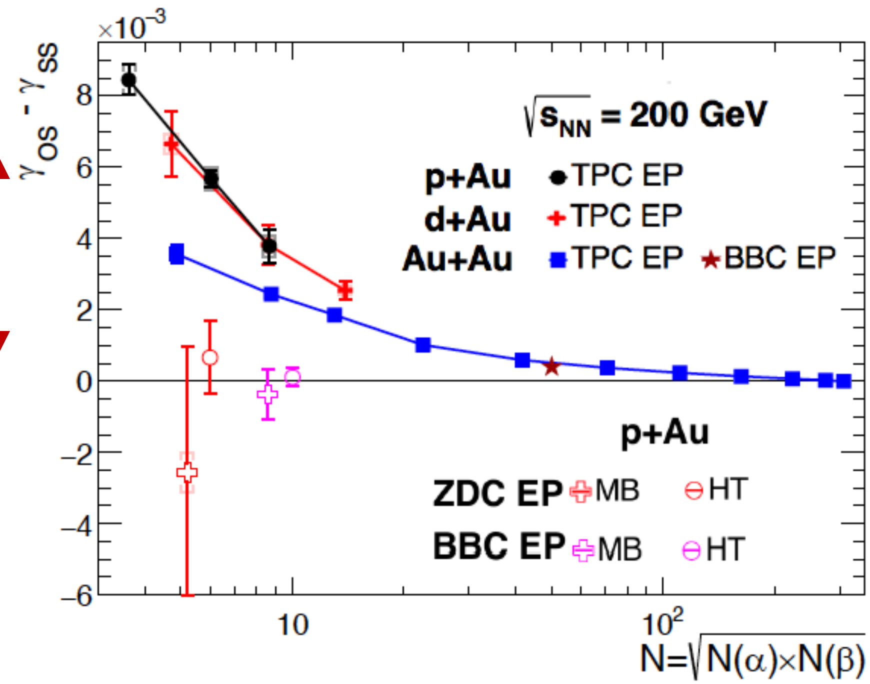
See also: DK, J.Liao, S.Voloshin, G.Wang, Prog.Part.Nucl.Phys.88(2016)1

Approved dedicated 2018 CME run at RHIC with Zr (Z=40), Ru (Z=44) isobars

Implications of pA and dA data for the CME studies in AA collisions



CMS talks: Y.J.Lee, S.Park, Z.Tu



STAR talks: A.Schmah, P.Tribedy, L.Wen

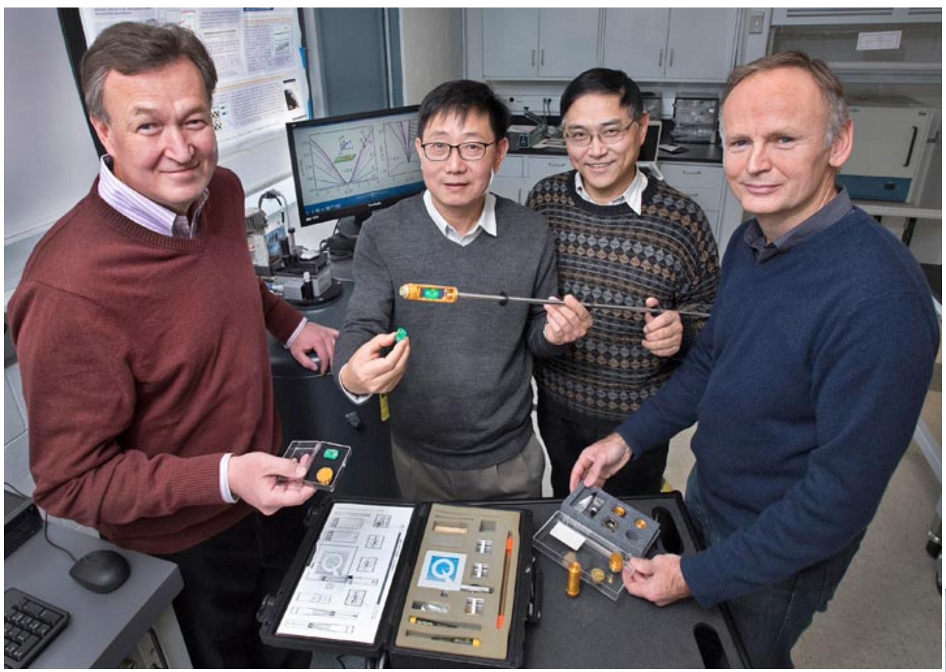
Rapidity separation can dramatically reduce background!

Broader implications

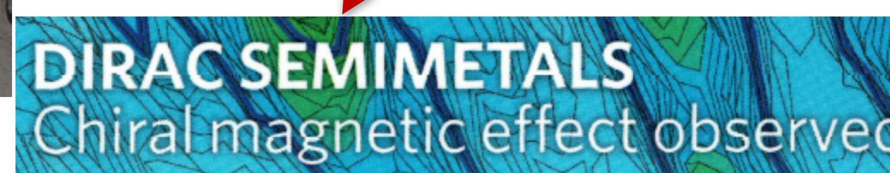
Observation of the chiral magnetic effect in $ZrTe_5$

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]

Broader implications of CME

nature physics

Home | Current issue | Comment | Research | Archive ▾ | Authors & referees ▾ | About the journal ▾

home ▸ most read

Most read

This list of most read articles is created by calculating article views for the previous 15 days. It is refreshed daily.

Showing: 1–25 of 50 Results per page: Up to 25 results per page

Letter | 08 February 2016

Chiral magnetic effect in $ZrTe_5$

Qiang Li, Dmitri E. Kharzeev, Cheng Zhang, Yuan Huang, I. Pletikosić, A. V. Fedorov, R. D. Zhong, J. A. Schneeloch, G. D. Gu & T. Valla

A magnetotransport study of zirconium pentatelluride now reveals evidence for a chiral magnetic effect, a striking macroscopic manifestation of the quantum and relativistic nature of Weyl semimetals.

Feature | 01 December 2016

The quasiparticle zoo

Liesbeth Venema, Bart Verberck, Iulia Georgescu, Giacomo Prando, Elsa Couderc, Silvia Milana, Maria Maragkou, Lina Persechini, Giulia Pacchioni & Luke Fleet

Quasiparticles are an extremely useful concept that provides a more intuitive understanding of complex phenomena in many-body physics. As such, they appear in various contexts, linking ideas across different fields and supplying a common language.

Review | 09 December 2012

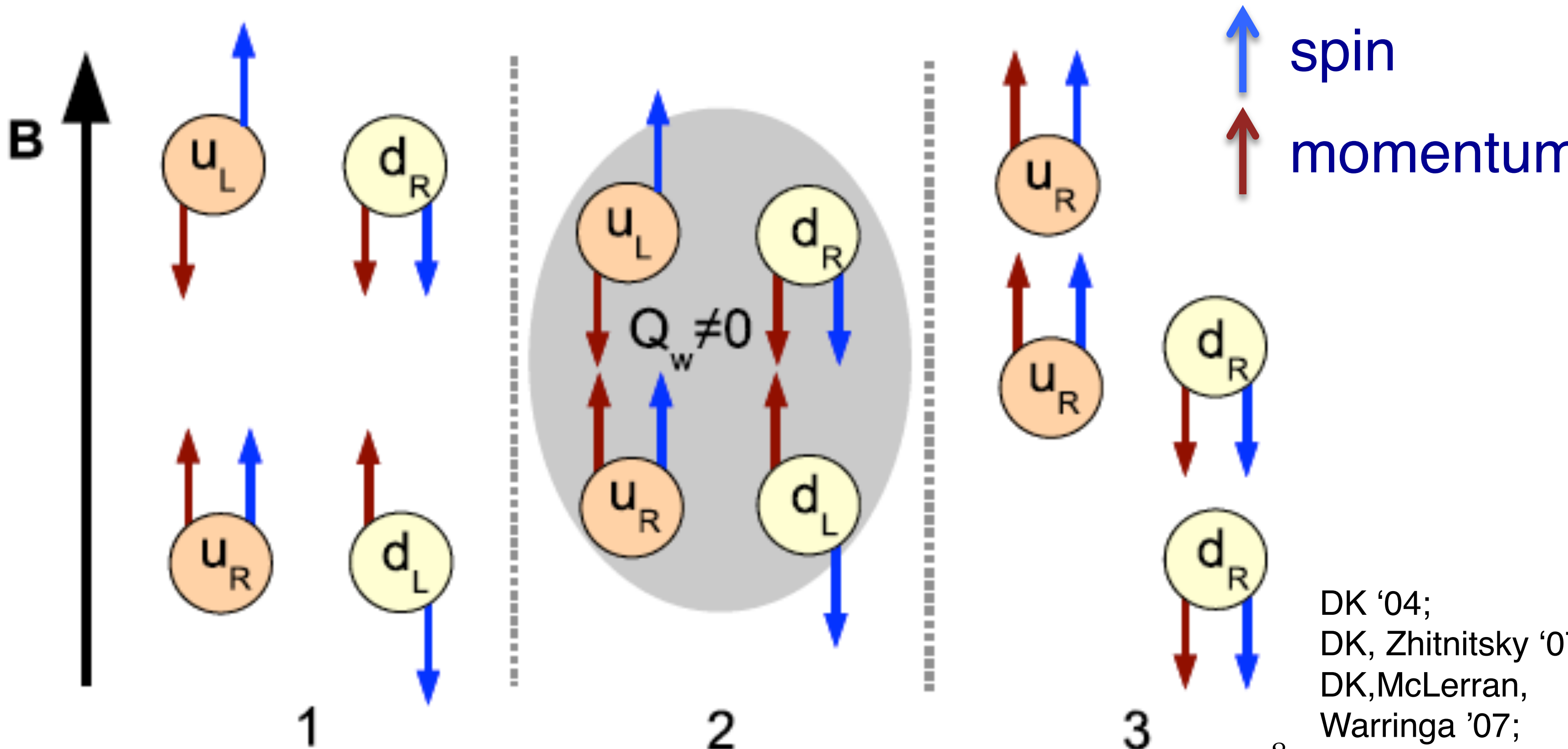
Quantum biology

Neill Lambert, Yueh-Nan Chen, Yuan-Chung Cheng, Che-Ming Li, Guang-Yin Chen & Franco Nori

Could biological systems have evolved to find the optimal quantum solutions to the problems thrown at them

Chirality in 3D: the Chiral Magnetic Effect

chirality + magnetic field = current



Review: DK, arxiv:1312.3348 (Prog.Part.Nucl.Phys'14)

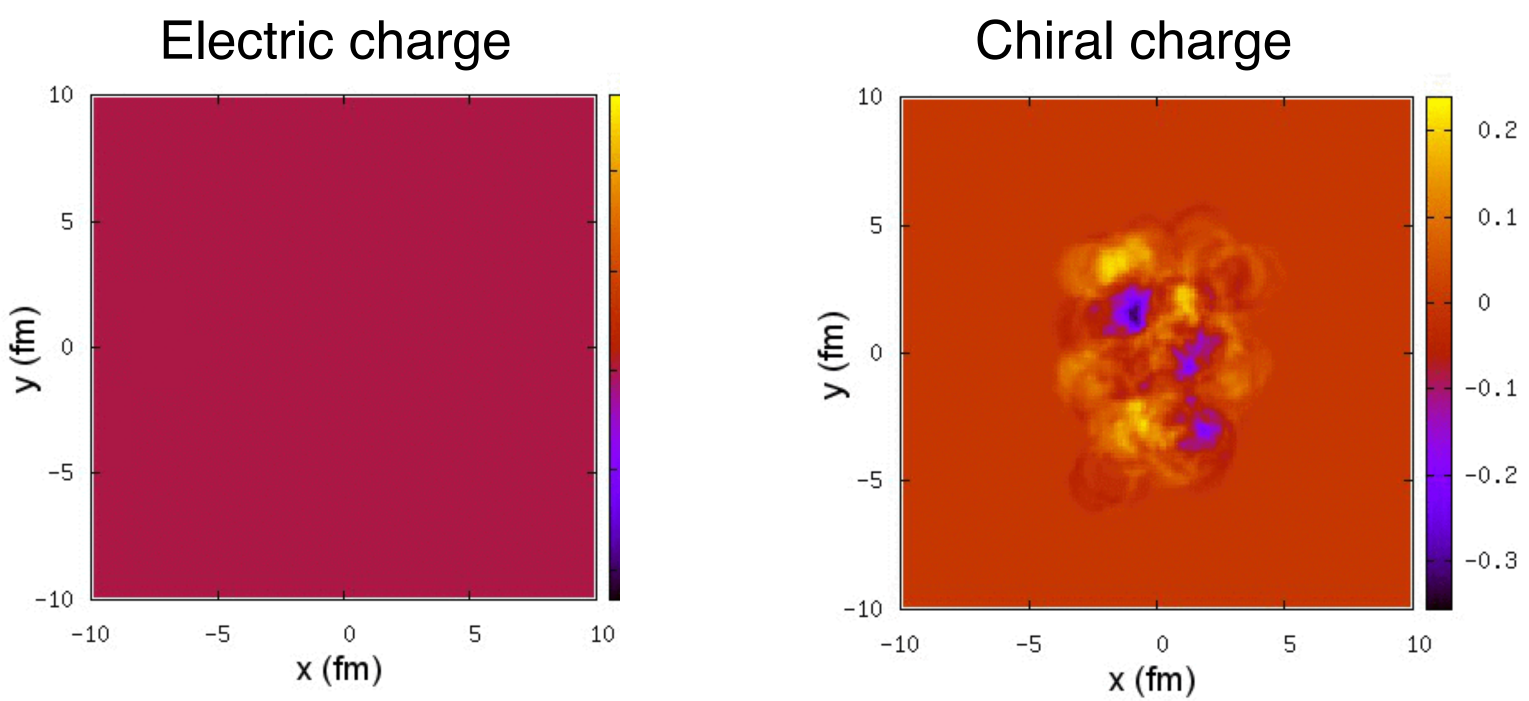
DK '04;
DK, Zhitnitsky '07
DK,McLerran, Warringa '07;
Fukushima, DK, Warringa '08

Hydrodynamics and symmetries

- Hydrodynamics: an effective low-energy TOE. States that the response of the fluid to slowly varying perturbations is completely determined by conservation laws (energy, momentum, charge, ...)
- Conservation laws are a consequence of symmetries of the underlying theory
- What happens to hydrodynamics when these symmetries are broken by quantum effects (anomalies of QCD and QED)?

Son, Surowka; Landsteiner, Megias, Pena-Benitez; Sadofyev, Isachenkov; Kalaydzhyan, Kirsch; DK, Yee; Zakharov; Jensen, Loganayagam, Yarom; Neiman, Oz; ….

CMHD



Y.Hirono, T.Hirano, DK, (Stony Brook – Tokyo), arxiv:1412.0311
(3+1) ideal CMHD (Chiral MagnetoHydroDynamics)

BEST Theory Collaboration (DOE)

BEST COLLABORATION

Two new effects in CMHD:

1. Generation of quantized CME current due to magnetic reconnections in the hydrodynamical evolution - this mechanism does not require any <u>external</u> chirality source

Y. Hirono, DK, Y. Yin, PRL 117(2016) 172301

2. Chiral magnetic turbulence – a new kind of self-similar turbulent cascade in hydrodynamics driven entirely by the chiral anomaly

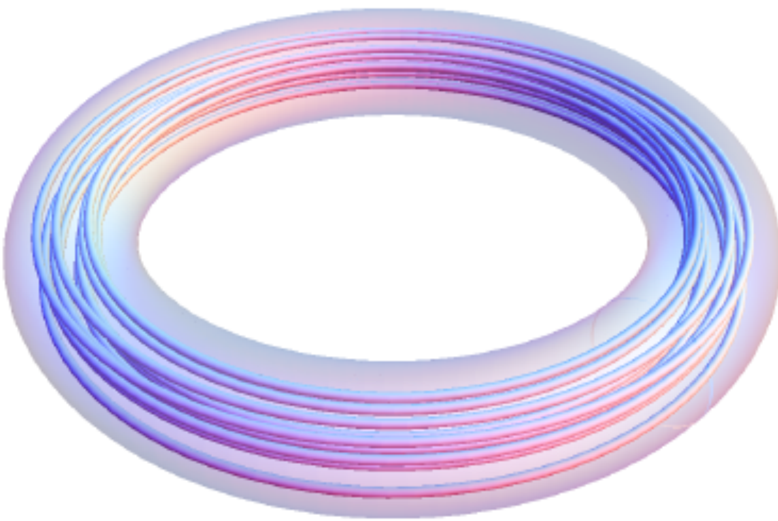
Y. Hirono, DK, Y. Yin, PRD 92(2015) 125031

Quantized CME from knot reconnections

Magnetic helicity is the measure of "knottedness" of magnetic flux - Chern-Simons 3-form

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

Y. Hirono, DK, Y. Yin, PRL 117(2016) 172301

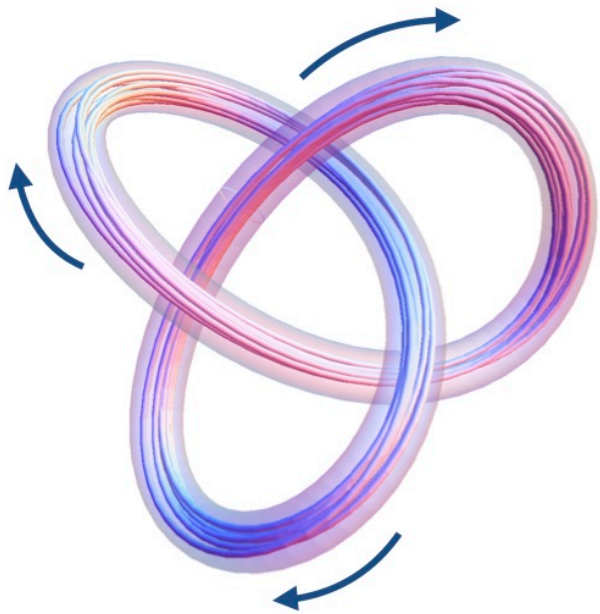


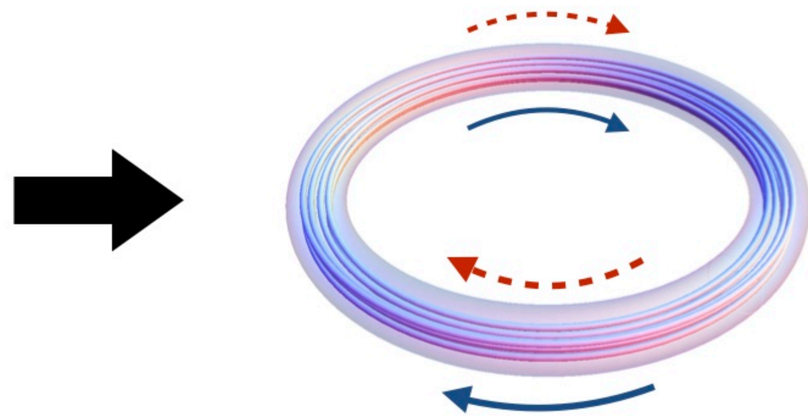
Consider a tube (unknot) of magnetic flux, with chiral fermions localized on it.

To turn it into a (chiral) knot, we need a magnetic reconnection.

What happens to the fermions during the reconnection?

Y. Hirono, DK, Y. Yin,
PRL 117(2016) 172301





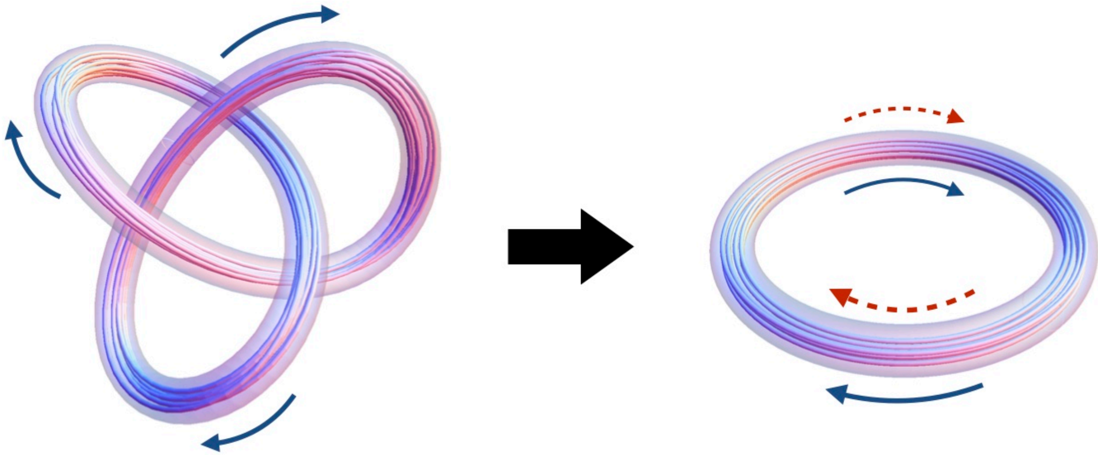
Changing magnetic flux through the area spanned by the tube will generate the electric field (Faraday's induction):

$$\frac{d}{dt}\Phi_B = -\oint_C \boldsymbol{E} \cdot d\boldsymbol{x}$$

The electric field will generate electric current of fermions (chiral anomaly in 1+1 D):

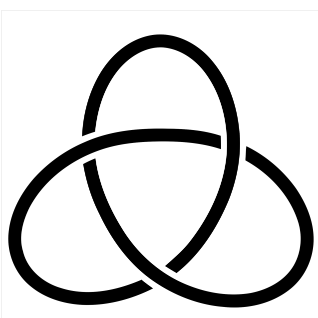
$$\Delta J = \Delta J_R + \Delta J_L = \frac{q^3 \Phi^2}{2\pi^2 L}$$

Y. Hirono, DK, Y. Yin,
PRL 117(2016) 172301



Helicity change per magnetic reconnection is $\Delta\mathcal{H} = 2\Phi^2.$

Multiple magnetic reconnections leading to non-chiral knots do not induce net current (need to break left-right symmetry).



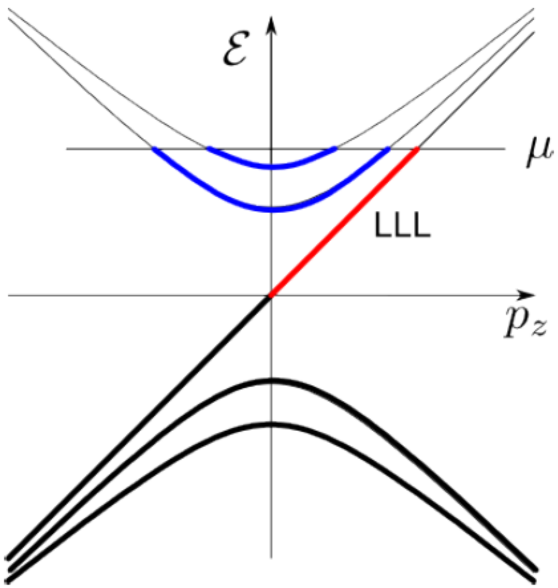
For N_+ positive and N_- negative crossings on a planar knot diagram, the total magnetic helicity is:

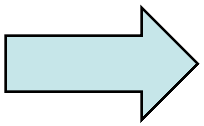
$$\mathcal{H} = 2(N_+ - N_-)\Phi^2$$

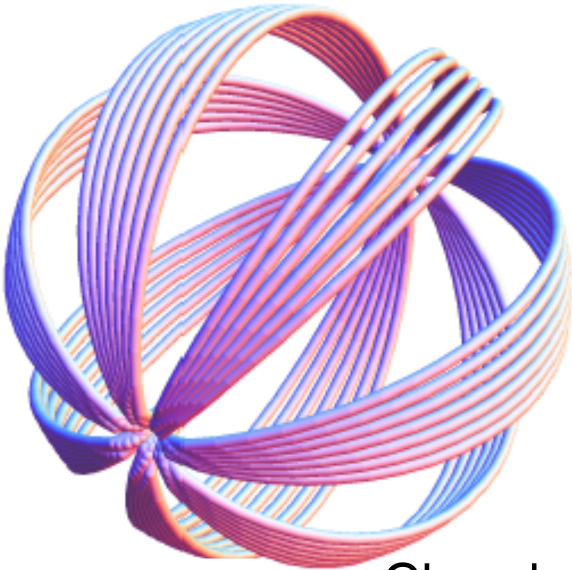
The total current induced by reconnections to a chiral knot:

$$J = \frac{q^3\mathcal{H}}{4\pi^2 L}$$

Chirality transfer from fermions to magnetic helicity







Chandrasekhar-Kendall states (ApJ, 1957)

$$\partial_\mu j_A^\mu = C_A \boldsymbol{E} \cdot \boldsymbol{B}$$

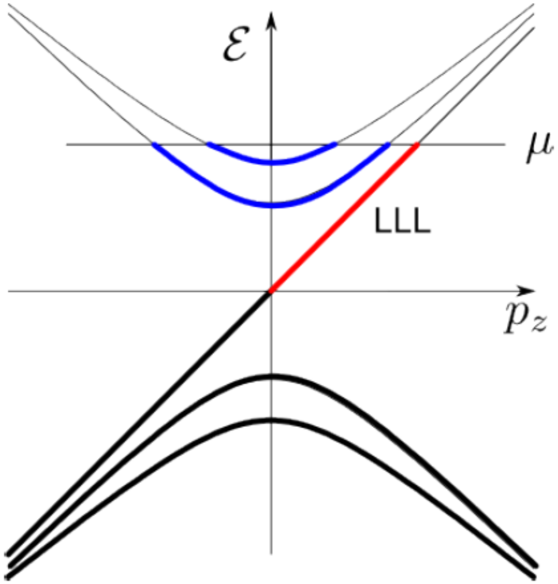
$$h_m \equiv \int d^3x \; \boldsymbol{A} \cdot \boldsymbol{B}$$

$$\int d^3x \; \boldsymbol{E} \cdot \boldsymbol{B} = -\frac{1}{2} \frac{\partial h_m}{\partial t}$$

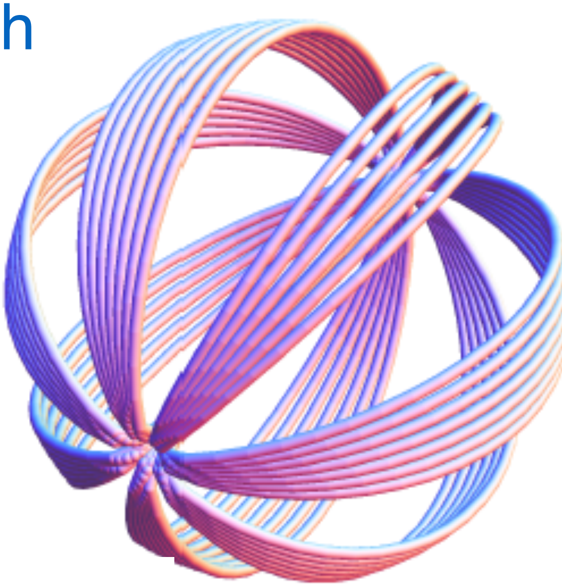
$$h_0 \equiv h_m + h_F = \text{const}$$

Y. Hirono, DK, Y. Yin, Phys.Rev.D92 (2015) 125031

Inverse cascade of magnetic helicity



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

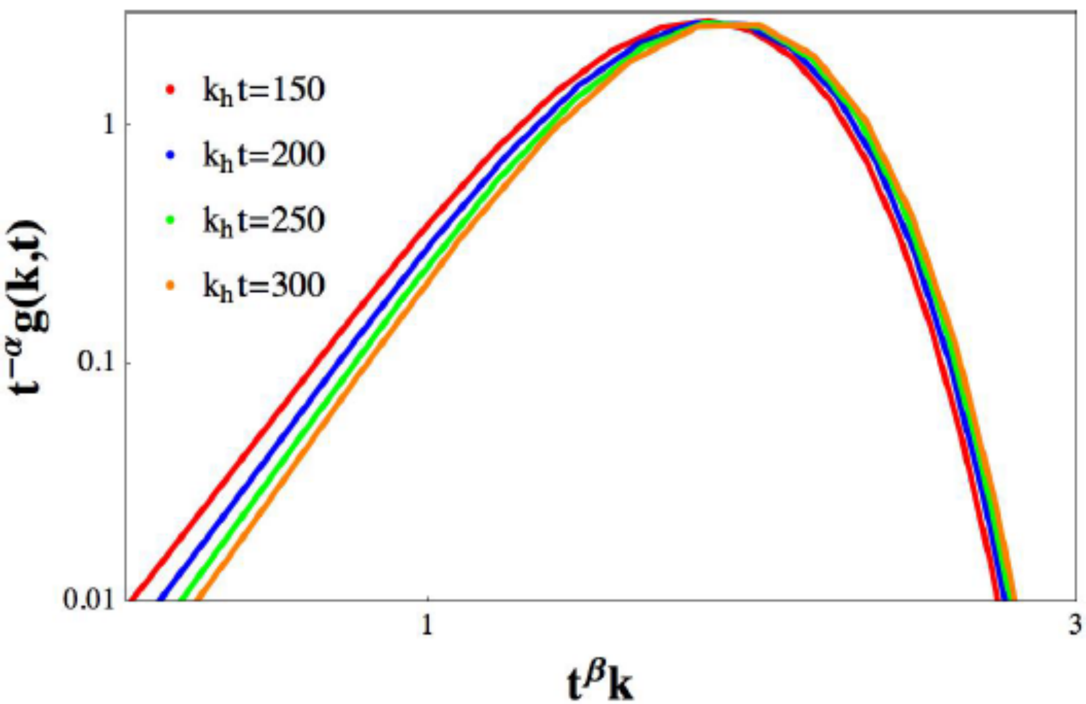


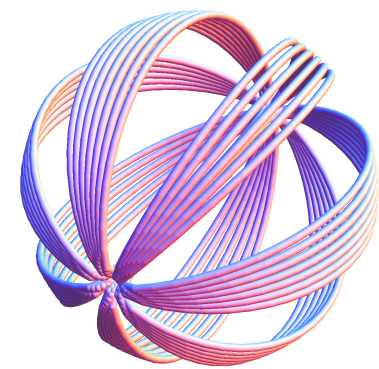
Increase of of magnetic helicity reduces μ_A

Inverse cascade:

M.Joyce and M.Shaposhnikov, PRL 79 (1997) 1193;
R.Jackiw and S.Pi, PRD 61 (2000) 105015; …

Self-similar cascade of magnetic helicity driven by CME





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

Y. Hirono, DK, Y. Yin, Phys.Rev.D92 (2015) 125031;
N. Yamamoto, Phys.Rev.D93 (2016) 125016

Summary

1. Magnetic reconnections in the hydrodynamical evolution induce a quantized chiral magnetic current

2. Chiral anomaly leads to a new kind of self-similar turbulent cascade in hydrodynamics – “chiral magnetic turbulence”

3. Chiral magnetohydrodynamics is a very rich theory with the behavior that still has to be understood – a lot of work to be done in theory and experiment!