Aspects Of ChSB in RQED

Workshop on Electromagnetic Effects in Strongly Interacting Matter SP 2022

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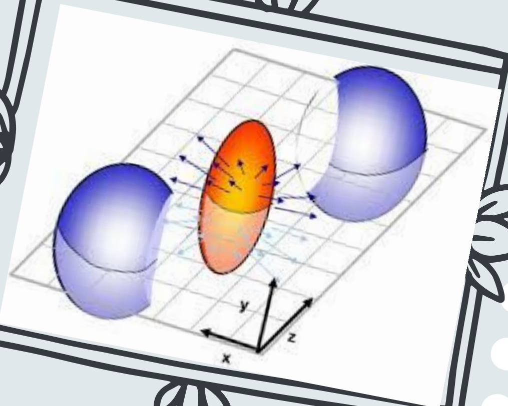
CONTENTS

Motivation

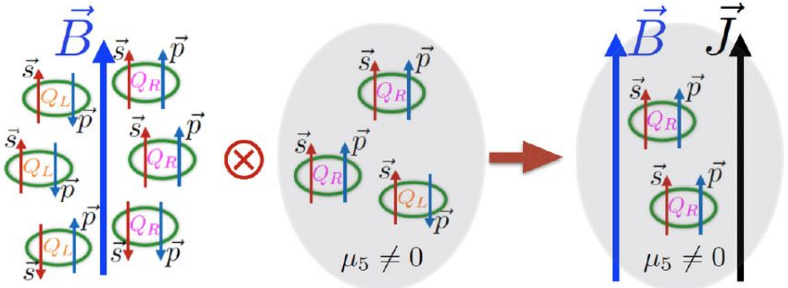
CME, i.e., chirality flip of quarks interacting with topological gauge fields in *HIC* environments has not been observed in isobar collisions, but analogous effects in 3D crystals have

CME was proposed to probe the topological nature of the QCD vacuum in peripheral heavy-ion collisions



[Kharzeev, McLerran and Warringa, NPA 803, 227 (2008).]

Chiral Anomaly

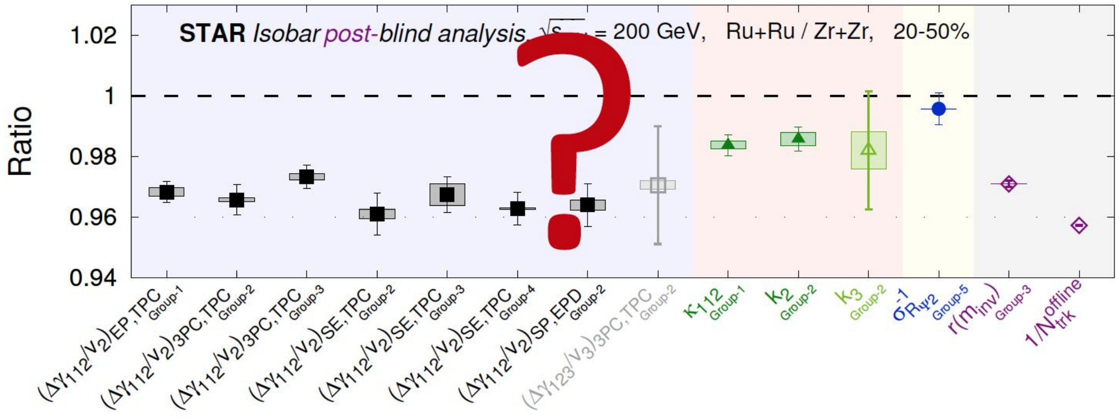


[Kharzeev, McLerran and Warringa, NPA 803, 227 (2008).]

- Chiral anomaly produces a chirality flip of quarks interacting with topologically nontrivial gauge fields
- A non-dissipative current is generated which is independent of temperature and mass, and parametrized by a chiral chemical potential
- $\vec{J} = \sigma \vec{B}$

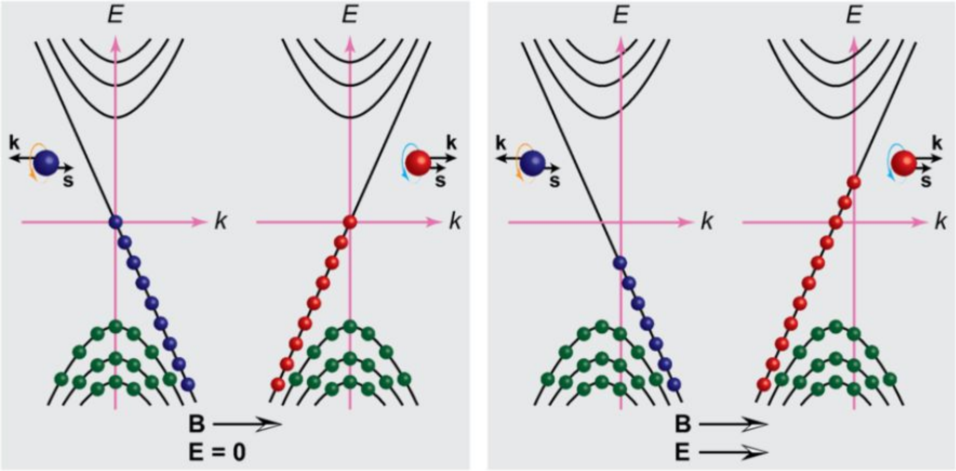
Fukushima, Kharzeev and Warringa, PRD 85, 045104 (2008).

Isobar Collisions



- No signal was observed

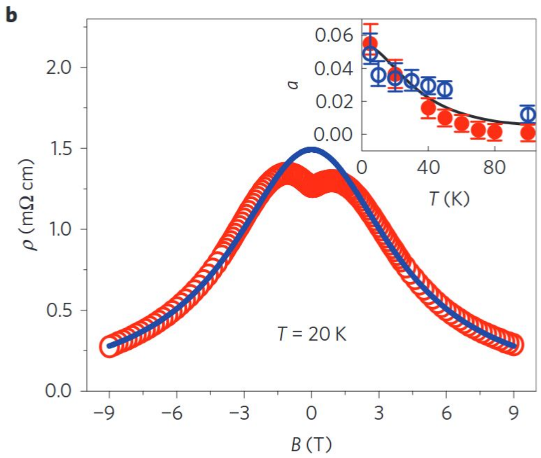
CME in 3D Dirac Materials



- Firstly observed in $ZrTe_5$
- Anomaly realized through $\vec{E} \cdot \vec{B}$
- Current $J = \frac{e^2}{2\pi^2}\mu_5 B, \qquad \mu_5 \propto \vec{E} \cdot \vec{B}$

[Li et al, NPA956 107 2016]

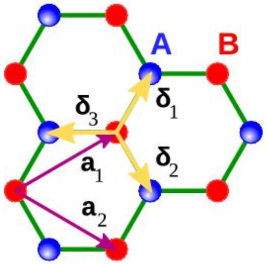
CME in 3D Dirac Materials

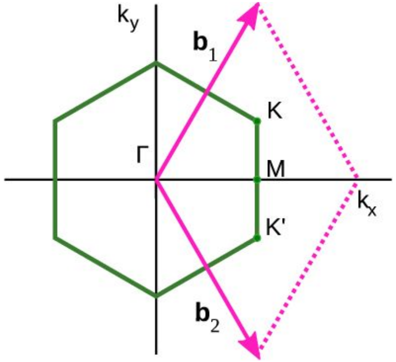


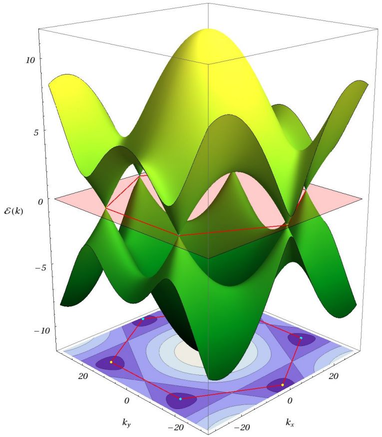
- Magnetoresistance in $ZrTe_5$ in agreement with CME
- Effect observed in other 3D materials too

[Li et al, Nature Phys. 12, 550 (2016).]

Is it possible to observe CME in 2D Dirac Materials?







$$H = \hbar v_f \, \bar{\psi} \, \vec{\gamma} \cdot \vec{k} \, \psi$$

RQED

Gauge and matter fields in mixed dimensions

[Marino (1993); Gonzalez, Guinea, Vozmediano (1994); Gorbar, Guysinin, Miranski (2001).]

REDUCED OR PSEUDO QED

01

GAUGE SECTOR

Gauge fields remain unconstraind to move on the plane

02

STATIC INTERACTIONS

Static charges experience Coulomb rather that logarithmic interactions

03

DIMENSIONAL REDUCTION

QED reduced to an effective non-local theory, RQED

REDUCED OR PSEUDO QED

01

GAUGE FIELDS

Gauge fields are non-perturbatively integrated over *z*

02

CURRENT

$J_z = 0$

03

FERMIONS

Add fermions in (2+1)-dimensions

$$S = \int d^3x \left[\bar{\psi}(i\not{D} + m)\psi + \frac{1}{2} F_{\mu\nu} \frac{1}{\sqrt{-\partial^2}} F^{\mu\nu} + \frac{1}{e^2\xi} \partial_\mu A^\mu \frac{1}{\sqrt{-\partial^2}} \partial_\nu A^\nu \right].$$

PROPAGATORS

MASSLESS FERMIONS:

$$S_0^{-1}(p) = -\gamma^\mu p_\mu$$

PHOTONS:

$$\Delta^0_{\mu\nu}(q) = \frac{1}{2q}\left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) + \frac{\zeta}{q^2}\frac{q_\mu q_\nu}{q^2}$$

ADD A CHERN-SIMONS TERM

LAGRANGIAN:

$$\mathcal{L}_{CS} = \frac{\theta}{2}\varepsilon^{\mu\nu\rho}A_\mu\partial_\nu A_\rho$$

PROPAGATOR:

$$\Delta_{\mu\nu}(q) = \frac{1}{2q}\frac{1}{(1+\theta^2)}\left(\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) + \frac{\zeta}{q^2}\frac{q_\mu q_\nu}{q^2} - \frac{1}{2q^2}\frac{\theta}{(1+\theta^2)}\epsilon_{\mu\nu\rho}q^\rho$$

ADD A CHERN-SIMONS TERM

SOME REMARKS:

- CS coefficient is dimensionless
- No topological photon mass
- RQED is scale invariant
- CS induces Dirac and Haldane mass for fermions

REDUCIBLE FERMIONS

CHIRAL FIELDS:

$$\psi_\pm = \chi_\pm \psi$$

CHIRAL MATRICES:

$$\chi_\pm = \frac{1}{2}(1 \pm \tau), \qquad \tau = \frac{1}{2}[\gamma_3, \gamma_5]$$

CHIRAL PROJECTORS:

$$\chi_\pm^2 = \chi_\pm, \quad \chi_+ \chi_- = 0, \quad \chi_+ + \chi_- = 1$$

MASS TERMS

$m_e\bar{\psi}\psi$

DIRAC

Invariant under P and T

Breaks Chiral Symmetry

$m_o\bar{\psi}\tau\psi$

HALDANE

Chirally Invariant

Breaks P and T

REDUCIBLE FERMIONS

CHIRAL LAGRANGIAN:

$$\mathcal{L}_F = \bar{\psi}_+(i\partial\!\!\!/ - M_+)\psi_+ + \bar{\psi}_-(i\partial\!\!\!/ - M_-)\psi_-$$

With

$$M_\pm = m_e \pm m_o$$

GAP EQUATION

Traits of Chiral Symmetry Breaking in RQED

SCHWINGER-DYSON EQUATIONS

TWO-POINT FUNCTIONS:

$$\begin{aligned} S^{-1}(p) &= S_0^{-1}(p) - \Xi(p) \\ \Delta_{\mu\nu}^{-1}(p) &= \Delta_{0\mu\nu}^{-1}(p) - \Pi_{\mu\nu}(p) \end{aligned}$$

Most general form of the fermion propagator

$$S^{-1}(p) = -A(p)\gamma^{\mu}p_{\mu} + \Sigma(p)$$

SCHWINGER-DYSON EQUATIONS

Rainbow-ladder truncation:

$$\Sigma(p) = 4\pi\alpha \int \frac{d^3k}{(2\pi)^3} \frac{\Sigma(k)}{k^2 + \Sigma^2(k)} \frac{1}{q}$$

QED_3 in $1/N_f$ Approximation:

$$M(p) = 4\pi^2\lambda \int \frac{d^3k}{(2\pi)^3} \frac{M(k)}{k^2 + M^2(k)} \frac{1}{q}$$

Duality:

$$\alpha \to \lambda = \frac{4\alpha}{3\left(1 + \frac{\pi\alpha N_f}{4}\right)}$$

Criticality in QED$_3$

There exists a critical number of fermion flavors above with Chiral Symmetry is restored

RQED

There exist a critical value for the coupling above which is possible to break chiral symmetry

$$\alpha_c = \frac{\pi}{8}$$

SDE+CS

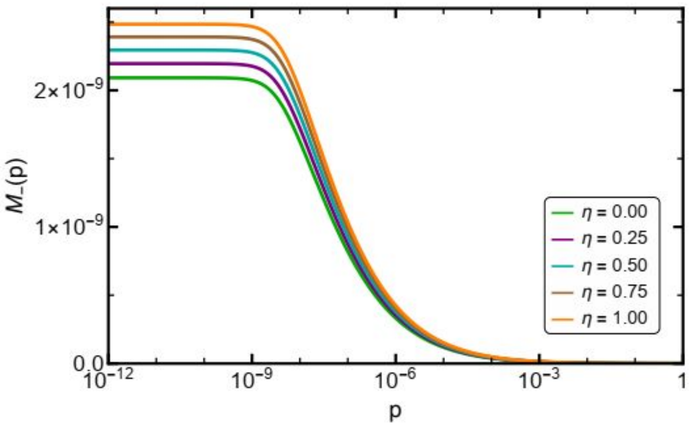
Rainbow-ladder truncation:

$$M_\pm(p) = 2\pi\alpha \int \frac{d^3k}{(2\pi)^3} \Big[\frac{2M_\pm(k)}{k^2 + M_\pm^2(k)} \frac{1}{q(1+\theta^2)} \mp \frac{1}{q^2} \frac{\theta}{1+\theta^2} \frac{k \cdot q}{k^2 + M_\pm^2(k)} \Big]$$

Nontrivial solutions:

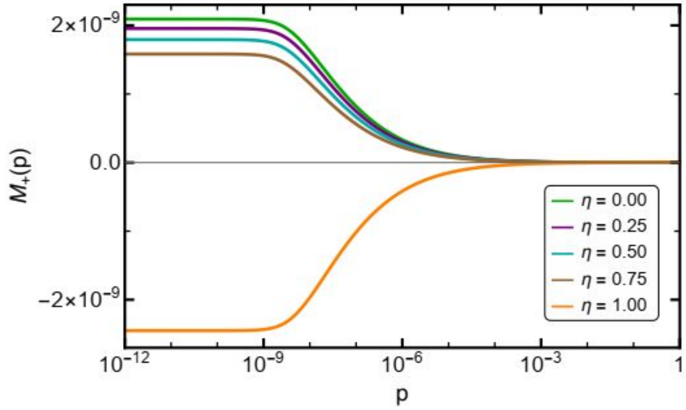
$$\alpha_c = \frac{\pi}{8}(1+\theta^2)$$

SDE+CS



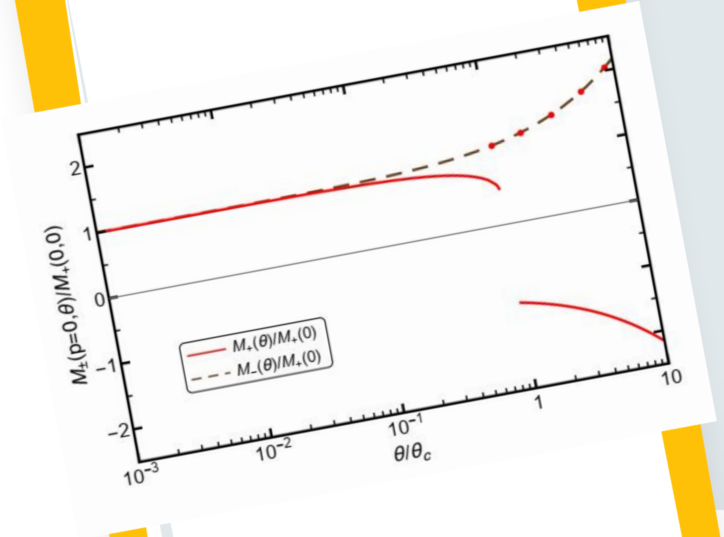
CHIRALITY –

Height of the mass function increases with increasing θ



CHIRALITY +

At a critical value of θ, the mass funCtion flips sign



CHIRAL SYMMETRY

CS restores Chiral Symmetry

OVERLOOK

Further studies on RQED

WHAT WE LEARNT

GENERAL SCENARIO	We have shown that Dirac and Haldane masses appear for small values of Θ, provided the coupling considered is above the critical coupling $\alpha c=\pi/8$.
	CS acts as a dielectric constant
CHIRAL RESTORATION	Large values of θ restore chiral symmetry
	Transition is of first order
CONTRIBUTION	Toy model of QCD
	CME in 2D materials

OTHER STUDIES

01

FINITE T

Chiral transition by effect of a heat bath

PRD102 056020 (2020).

02

FINITE DENSITY

Effect of a chemical potential on the chiral transition

Wokk in progress

03

GAUGE INVARIANCE

More educated truncations of SDE lower the value of the critical coupling

2210.01280 [hep-ph]

¡Gracias!