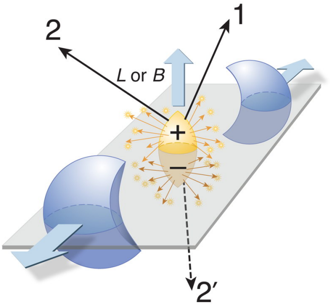
Magnetic-Field-Induced insulator-conductor transition in quenched lattice gauge theory ArXiv:0907.0494, 1003.2180

Pavel Buividovich

Lattice 2010

Magnetic phenomena in hadronic matter



Magnetic field comparable with nuclear scale!!! [Kharzeev, McLerran '98]

Very strong magnetic fields

- Noncentral heavy-ion collisions:

$$B \sim 10^{15}\ Tl, \quad \sqrt{eB} \sim 10\ Mev \ldots 500\ MeV$$

- Early Universe after electroweak phase transition:

$$B \sim 10^{16}\ Tl, \quad \sqrt{eB} \sim 1\ GeV$$

- Magnetars:

$$B \sim 10^{10}\ Tl, \quad \sqrt{eB} \sim 1\ MeV$$

- Strong laser pulses in PHELIX:

$$B \sim 10^{7}\ T, \quad \sqrt{eB} \sim 0.01\ MeV, \quad I \sim 10^{23}\ W/cm^2$$

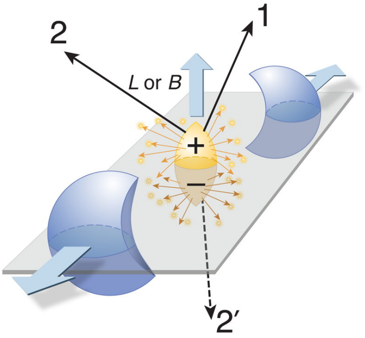
Magnetic phenomena in hadronic matter

- Quarks are charged particles with spin 1/2
- ⇒ Paramagnetism, Diamagnetism
- Strong dependance of plasma parameters on the magnetic field
- Masses of particles, heat capacity, viscosity change ...

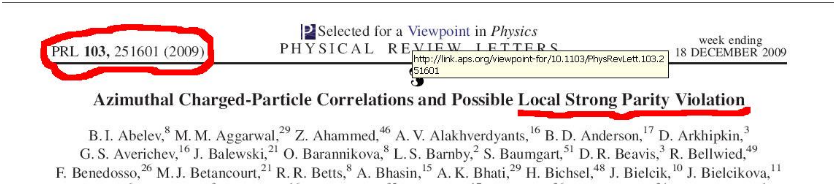
Chiral magnetic effect

- CME: in systems with nonzero chirality magnetic field $\vec{B}$ induces charge separation $\parallel \vec{B}$ [Kharzeev, McLerran, Warringa]
- charge separation $\Rightarrow$ Electric current, Electric dipole moment
- Nonzero chirality: created due to topology? Atyah-Singer theorem

Chiral magnetic effect



Chiral magnetic effect:STAR@RHIC



PRL **103,** 251601 (2009) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 18 DECEMBER 2009

http://link.aps.org/viewpoint-for/10.1103/PhysRevLett.103.251601

Azimuthal Charged-Particle Correlations and Possible Local Strong Parity Violation

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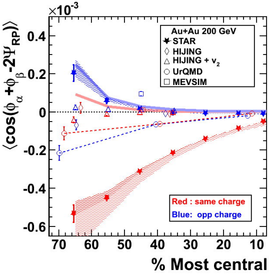
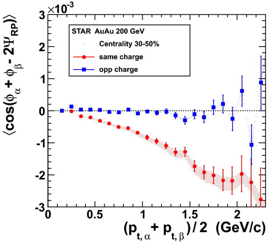
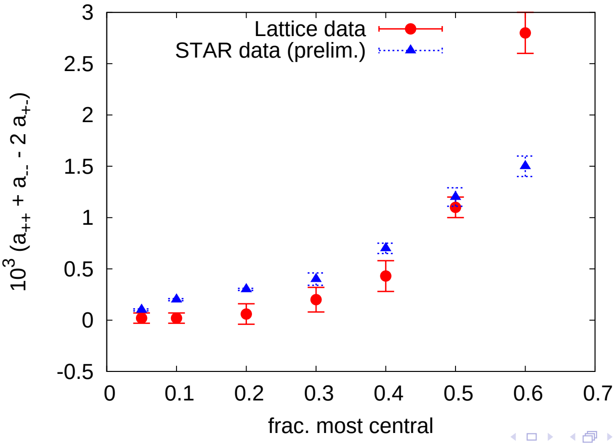
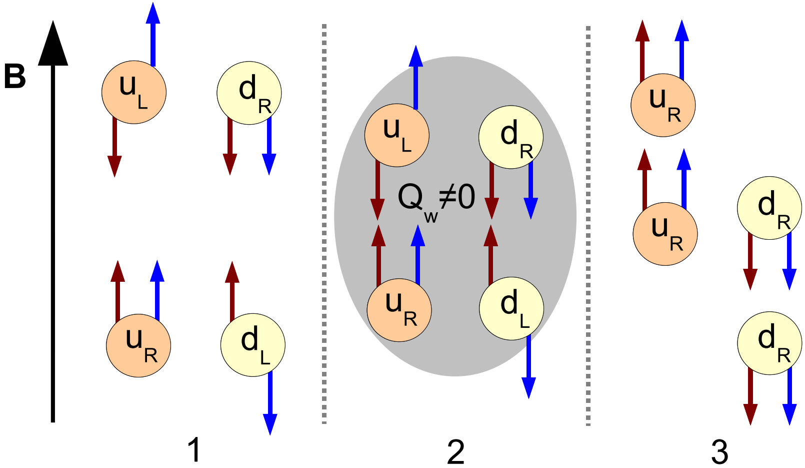




Chiral magnetic effect:
STAR@RHIC vs. ITEP Lattice



Chiral magnetic effect: mechanism [Kharzeev, McLerran'98]

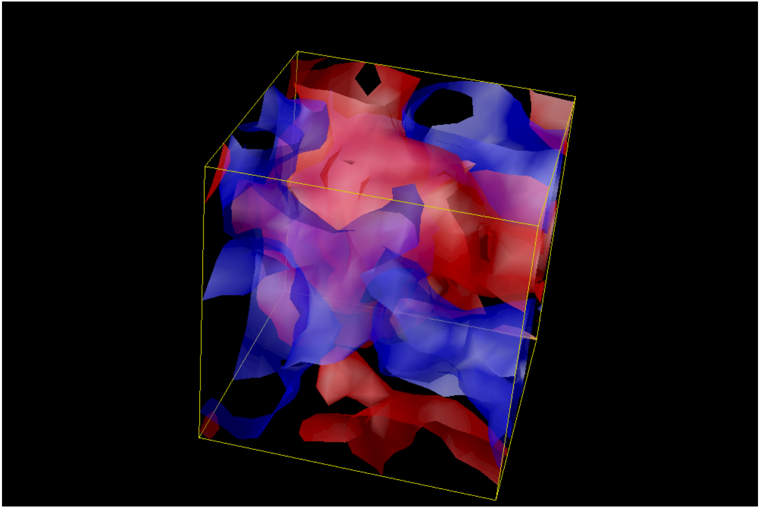


Chiral magnetic effect: mechanism [Kharzeev, McLerran'98]

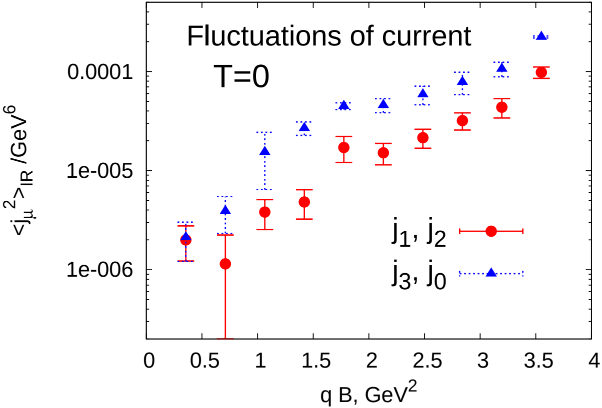
- In a strong magnetic field ⇒ magnetic moment is conserved
- ⇒ Tunneling transitions between different topological vacua change the momentum
- ⇒ Electric current!
- Separated charge in a very strong field:

$$\Delta q = 2Q$$

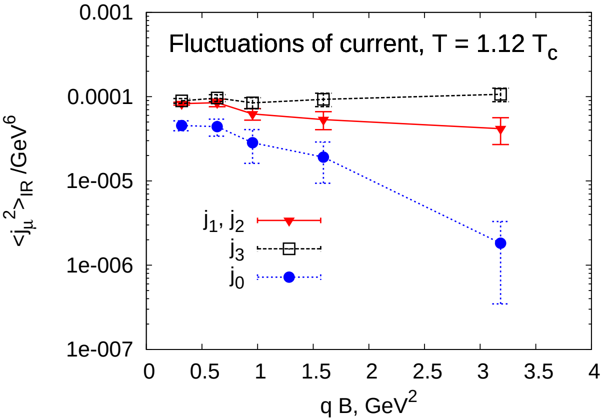
Real vacuum of non-Abelian gauge theories



Chiral magnetic effect: Numerical results, $T = 0$



Chiral magnetic effect: Numerical results, $T > T_c$

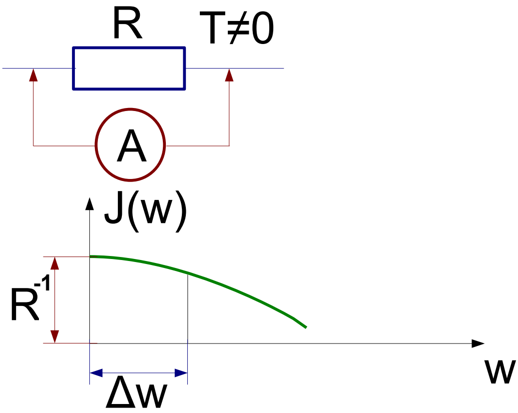


Fluctuations of current and conductivity

- Nyquist formula:

$$R^{-1} = \frac{\langle J^2 \rangle}{4kT\,\Delta w}$$

Fluctuations of current and conductivity



Green-Kubo formulas

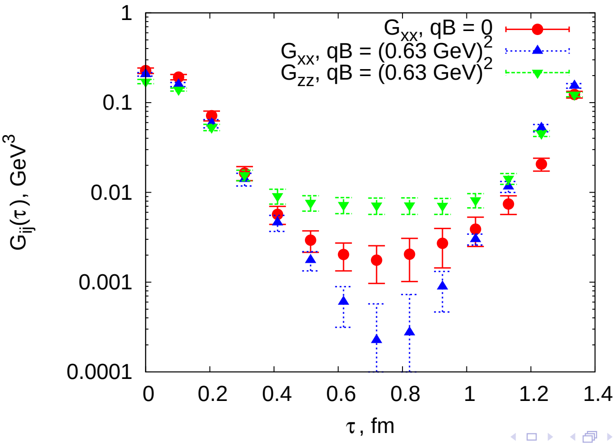
$$G_{ij}(\tau) = \int d^3\vec{x} \langle j_i\left(\vec{0}, 0\right) j_j(\vec{x}, \tau)\rangle,$$

$$G_{ij}(\tau) = \int\limits_0^{+\infty} \frac{dw}{2\pi} K(w, \tau)\, \rho_{ij}(w),$$

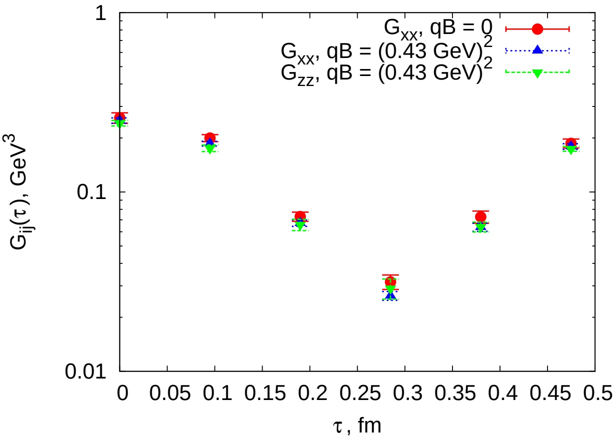
$$K(w, \tau) = \frac{w}{2T} \frac{\cosh\left(w\left(\tau - \frac{1}{2T}\right)\right)}{\sinh\left(\frac{w}{2T}\right)},$$

$$\sigma_{ij} = \lim_{\omega\to 0} \frac{\rho_{ij}(\omega)}{4T}$$

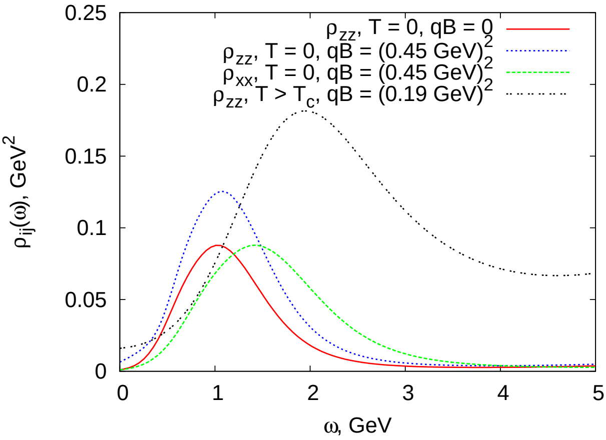
Current-current correlators at small temperatures



Current-current correlators: QGP



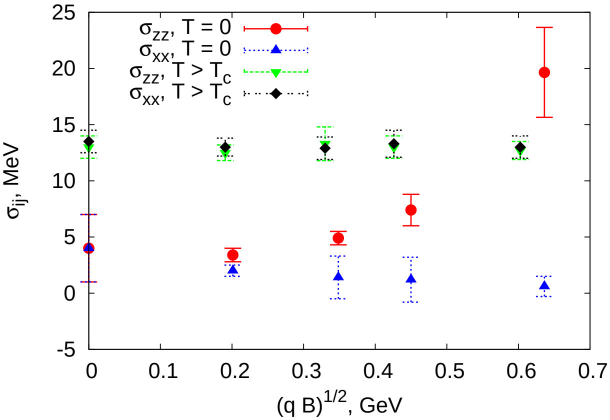
Spectral functions (Max. Entropy Method)



Anisotropic conductivity in magnetic field

- Confining vacuum of non-Abelian gauge theory - electric insulator!
- Magnetic field induces conductivity along its direction
- Quark-gluon plasma - isotropic conductor
- Magnetic field practically does not affect the conductivity of plasma

Conductivity vs. magnetic field

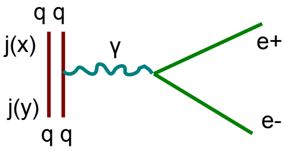


Theoretical explanation?

- Plausible assumption: vacuum is an insulator due to "something like" Anderson localization
- Strong magnetic field changes dimensionality $D = 4 \Rightarrow D = 2$ (localization at the Landau levels)
- Localization properties can change with dimensionality (conter-intuitive for Anderson)...
- Chiral magnetic spiral? [Kharzeev, Basar, Dunne'2010]

Experimental consequences

- Anisotropic fluctuations of the number of produced charged particles w.r.t. the reaction plane (existing STAR RHIC data)
- V.E.V. $\langle j_\mu(x) j_\nu(y) \rangle$ is related to the polarization of soft photons
- Polarization of soft virtual photons $\Leftrightarrow$ Angular correlations of soft dileptons



Conclusions

- Chiral magnetic effect: enhanced fluctuations of electric current along the magnetic field
- Fluctuations of electric current ⇒ electric conductivity
- Magnetic field induces anisotropic conductivity of cold hadronic matter
- In experiment:
  - Additional anisotropy of charged reaction products
  - Angular correlations of soft dileptons

Thank you for your attention!!!

Basic references:

- K. Fukushima, D. E. Kharzeev, H. J. Warringa, The Chiral Magnetic Effect, Phys.Rev. D 78 (2008) 074033, ArXiv:0808.3382
- STAR Collaboration @ RHIC, Azimuthal Charged-Particle Correlations and Possible Local Strong Parity Violation, PRL 103, 251601 (2009), ArXiv:0909.1739
- P. V. Buividovich et al., Magnetic-Field-Induced insulator-conductor transition in SU(2) quenched lattice gauge theory (2010), ArXiv:1003.2180