P.Buividovich, M.Chernodub, D.Kharzeev, T.K., E.Luschevskaya, M.I.Polikarpov, PRL 105 132001
V. Braguta, P. Buividovich, T. K., S. Kuznetsov, M.I. Polikarpov, PoS LATTICE2010 190
P. Buividovich, T. K., M.I. Polikarpov (in preparation)

Local CP-violation in quark-gluon plasma: a lattice study.

Tigran Kalaydzhyan

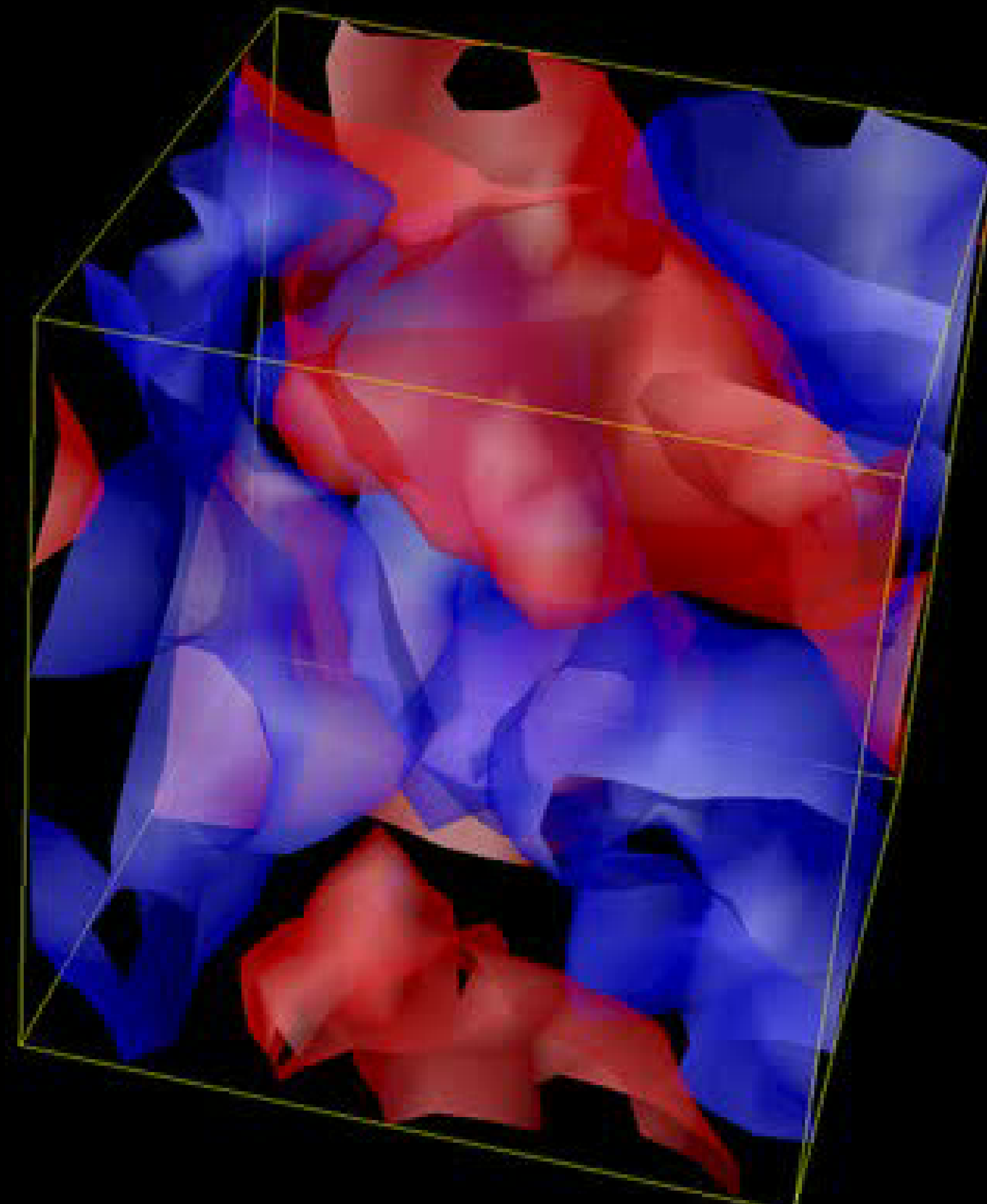
DESY THEORY WORKSHOP
September 27 - 30, 2011
Cosmology meets Particle Physics: Ideas & Measurements
DESY Hamburg, Germany

Topological charge density

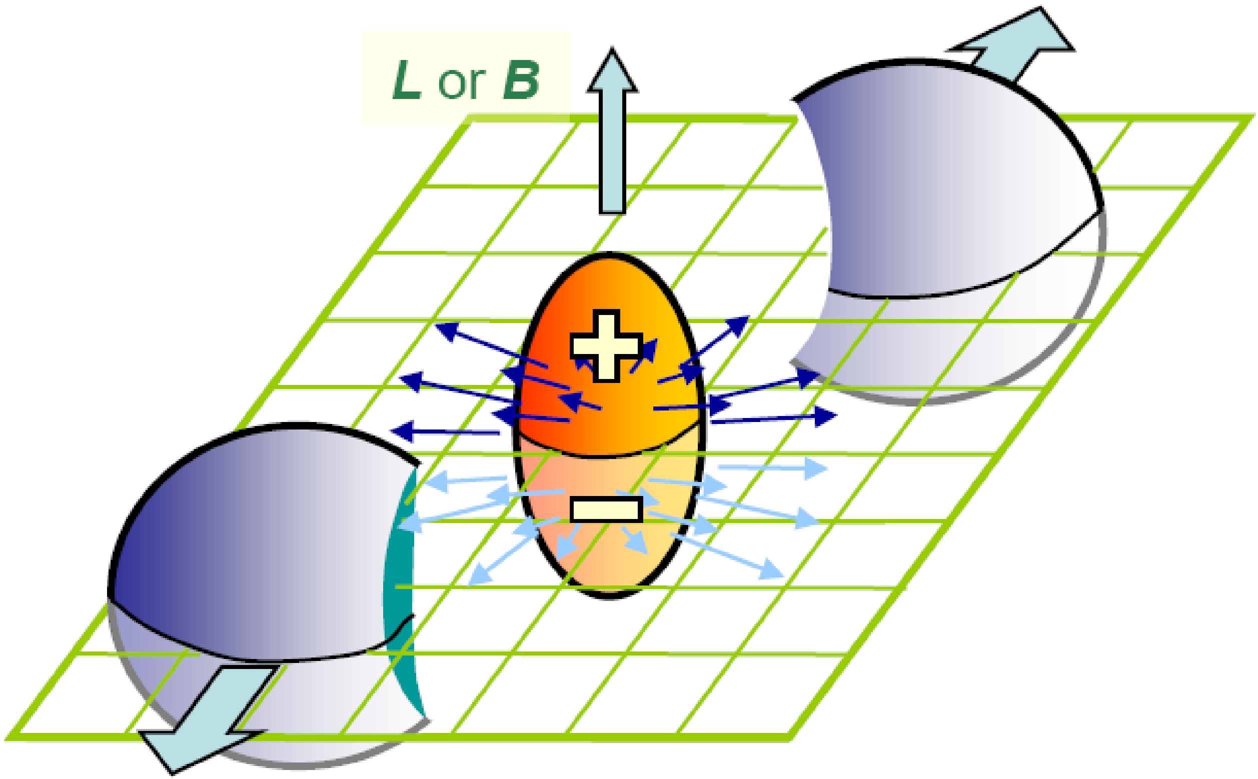
$$G^{a\mu\nu}\tilde{G}^{a}_{\mu\nu}$$

⇩

$$\rho_R \neq \rho_L$$



Chiral Magnetic Effect



Excess of positive charge

$$J^{\mu} = \kappa_B B^{\mu}$$

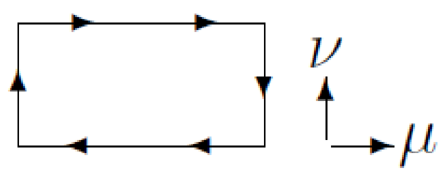
Excess of negative charge

Abelev *et al.* (2009-2010), Kharzeev, McLerran, Warringa (2007)

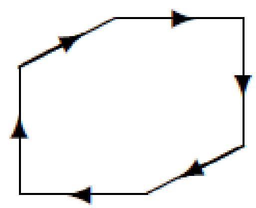
Step 1: Lattice action

$$S = -\beta \sum_{x,\mu>\nu} \left\{ \frac{5}{3} \frac{P_{\mu\nu}}{u_0^4} - r_{\rm g} \frac{R_{\mu\nu} + R_{\nu\mu}}{12\, u_0^6} \right\} + c_{\rm g}\, \beta \sum_{x,\mu>\nu>\sigma} \frac{C_{\mu\nu\sigma}}{u_0^6},$$

$$R_{\mu\nu} = \frac{1}{3} \mathrm{Re\,Tr}$$



$$C_{\mu\nu\sigma} \equiv \frac{1}{3} \mathrm{Re\ Tr}$$



$$r_{\rm g} = 1 + .48\, \alpha_s(\pi/a)$$

$$c_{\rm g} = .055\, \alpha_s(\pi/a)$$

Lüscher and Weisz (1985), see also
Lepage hep-lat/9607076

Step 2: Monte Carlo

- Heat bath for SU(2)

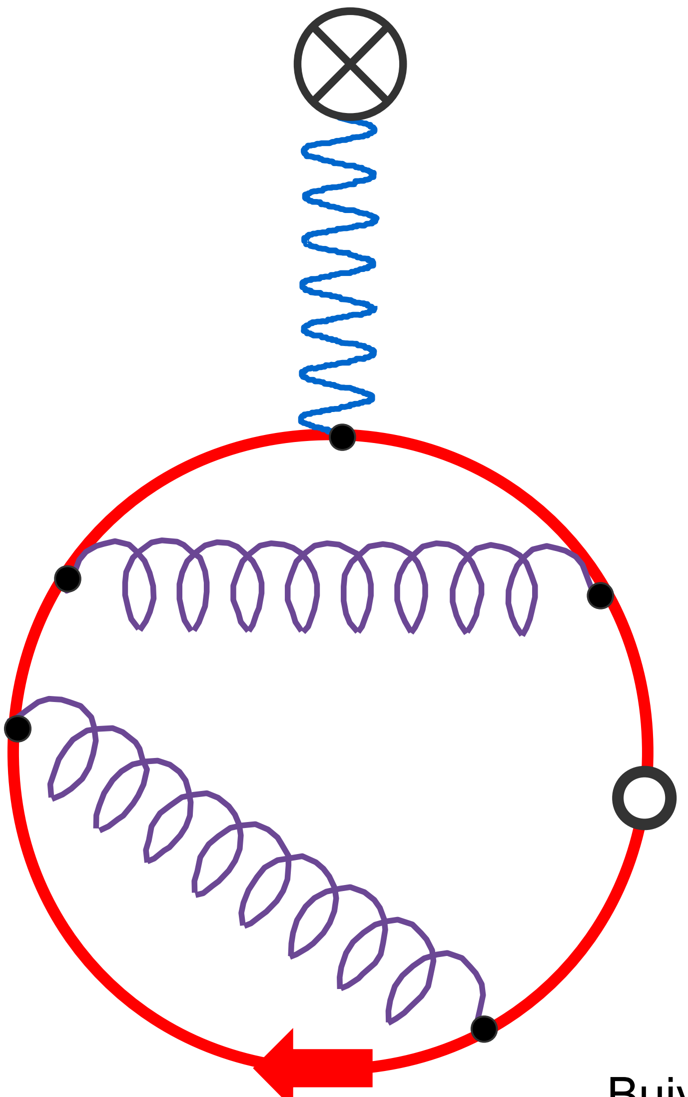
- Using the standard algorithm for each subgroup. Cabibbo & Marinari (1982)

$$a_1 = \begin{pmatrix} \alpha_1 & \\ & 1 \end{pmatrix} \qquad a_2 = \begin{pmatrix} 1 & \\ & \alpha_2 \end{pmatrix} \qquad a_3 = \begin{pmatrix} \alpha_{11} & & \alpha_{12} \\ & 1 & \\ \alpha_{21} & & \alpha_{22} \end{pmatrix}$$

- Overrelaxation. Adler (1981)

- Cooling (smearing) for some particular cases. DeGrand, Hasenfratz, Kovács (1997)

Step 3: Fermions & B-field



$$D_{ov}(0)=\frac{1}{a}\left(1-A\left(A^{+}A\right)^{-1/2}\right)$$

$$A=1-a\,D_W(0)$$

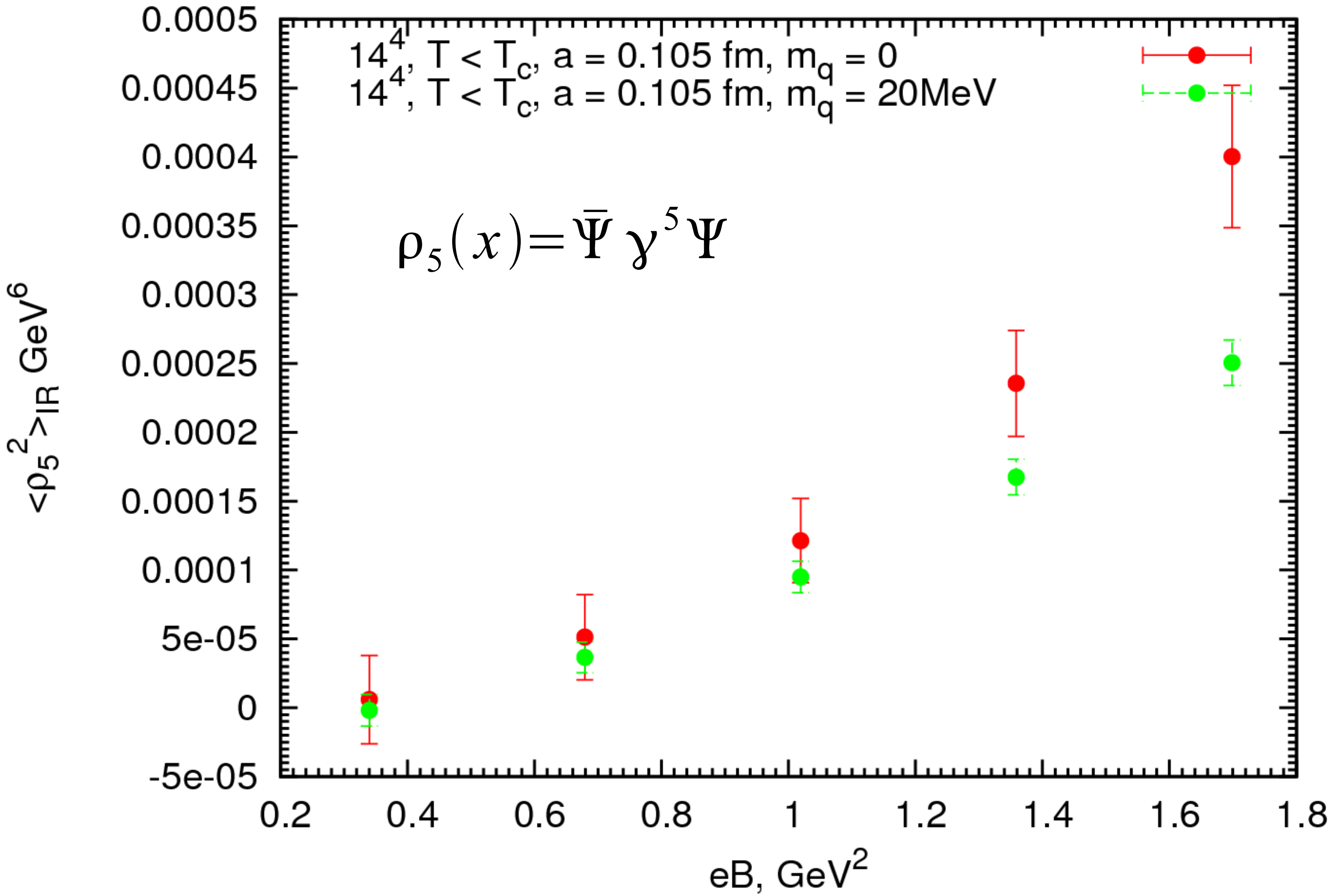
Neuberger overlap operator (1998)

$$\langle\bar{\Psi}\,\hat{\Gamma}\,\Psi\rangle\sim Tr\left[\hat{\Gamma}\,D_{ov}^{-1}\right]$$

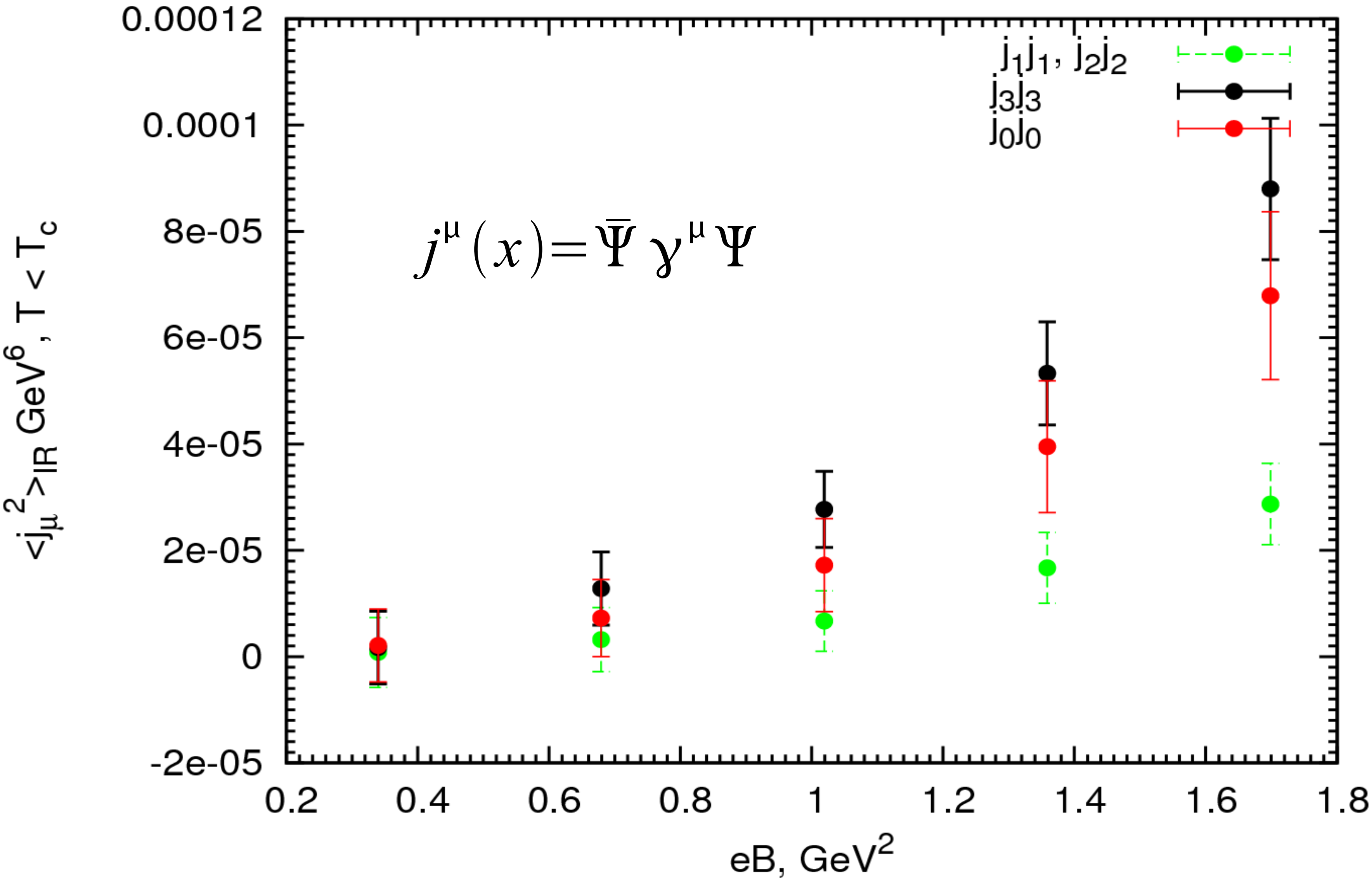
$$\hat{\Gamma}\in\{1,\gamma^{5},\gamma^{\mu},\sigma_{\mu\nu}\ldots\}$$

Buividovich, Chernodub, Luschevskaya, Polikarpov (2009)

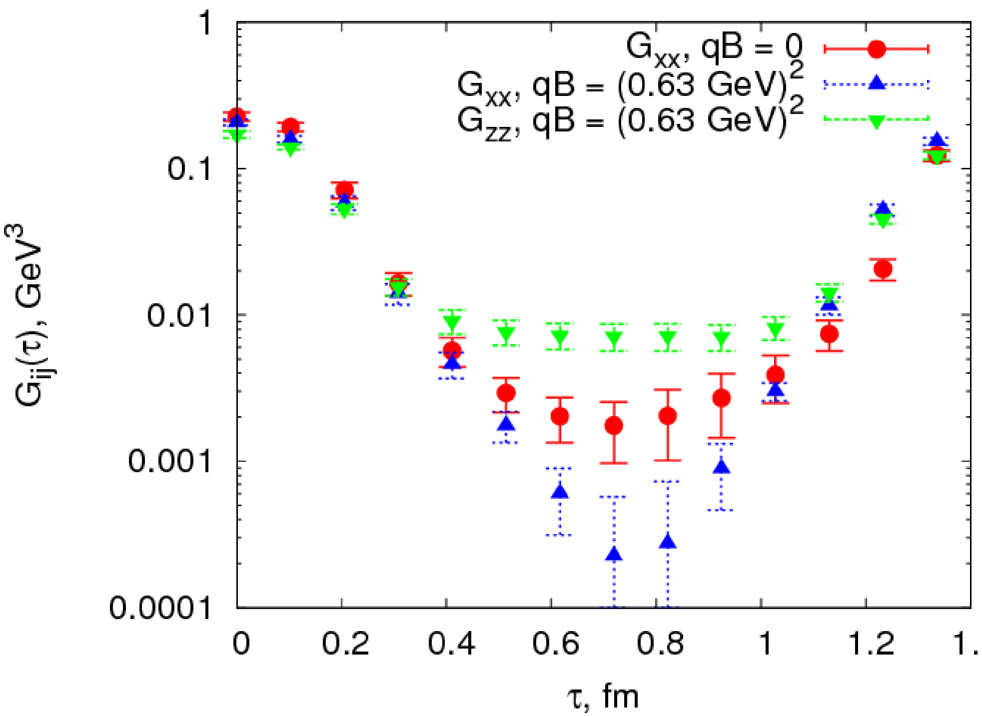
Fluctuations of chirality



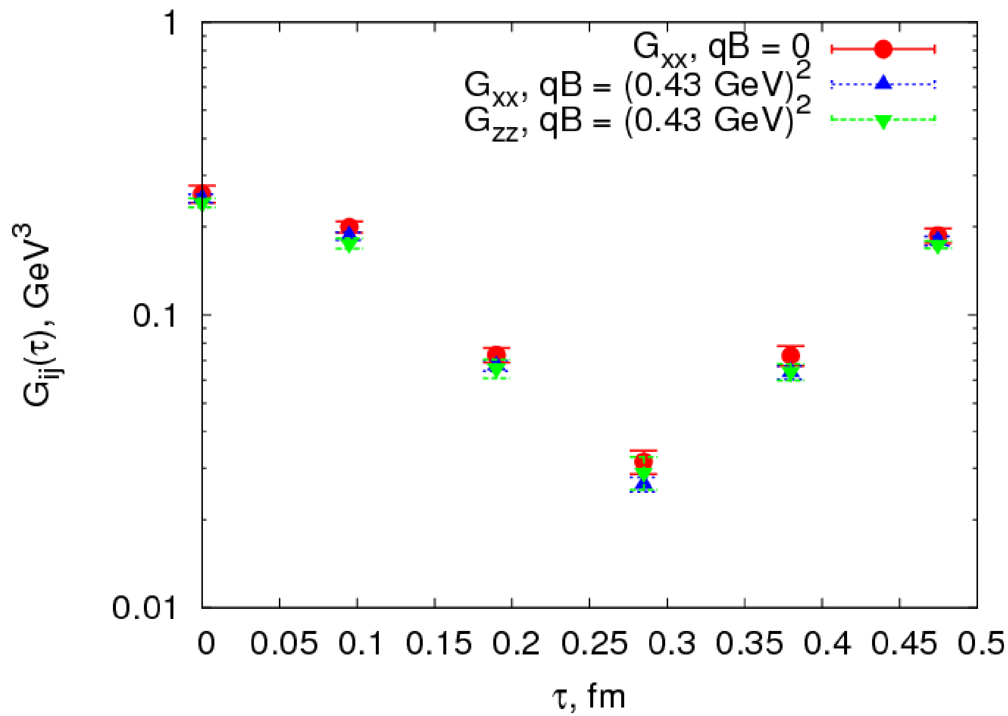
Current fluctuations



Current-current correlator



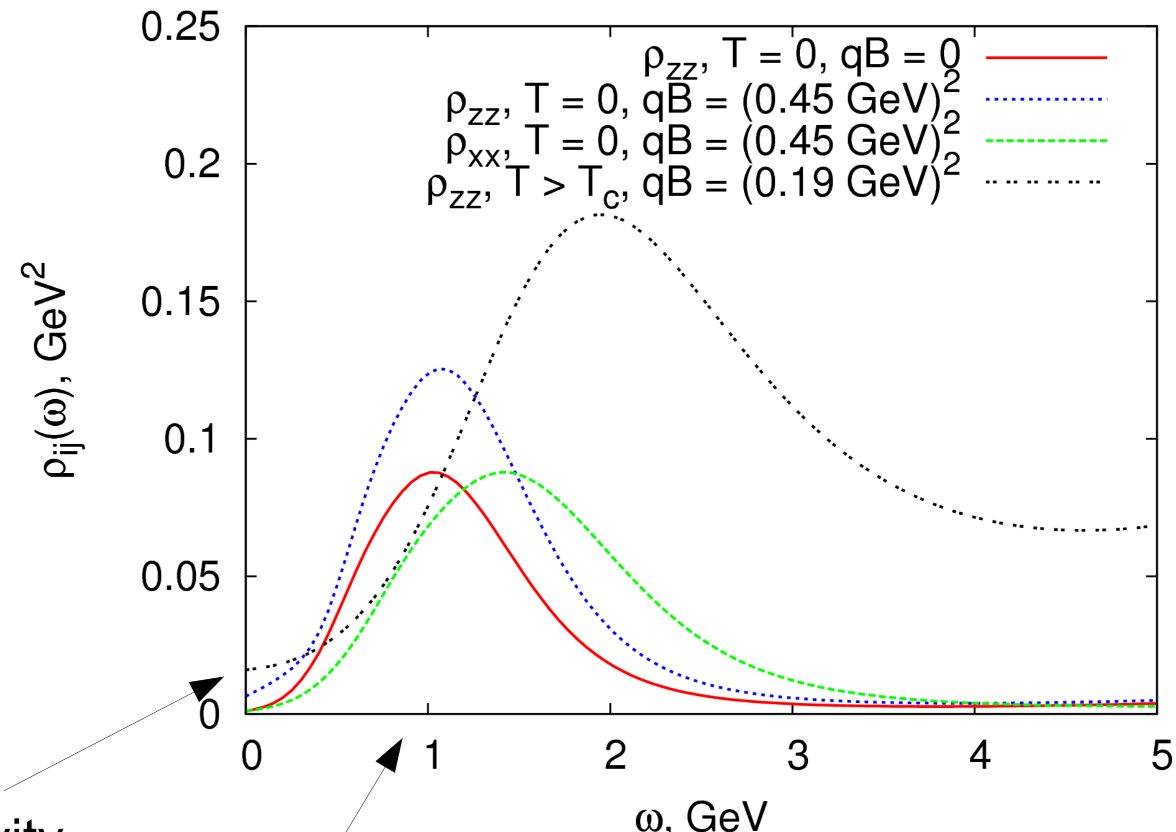
CONFINEMENT



DECONFINEMENT (T=350 MeV)

$$G_{ij}(\tau) = \int d^3\vec{x} \langle J_i(\vec{0},0) J_j(\vec{x},\tau) \rangle$$

... and its spectral function

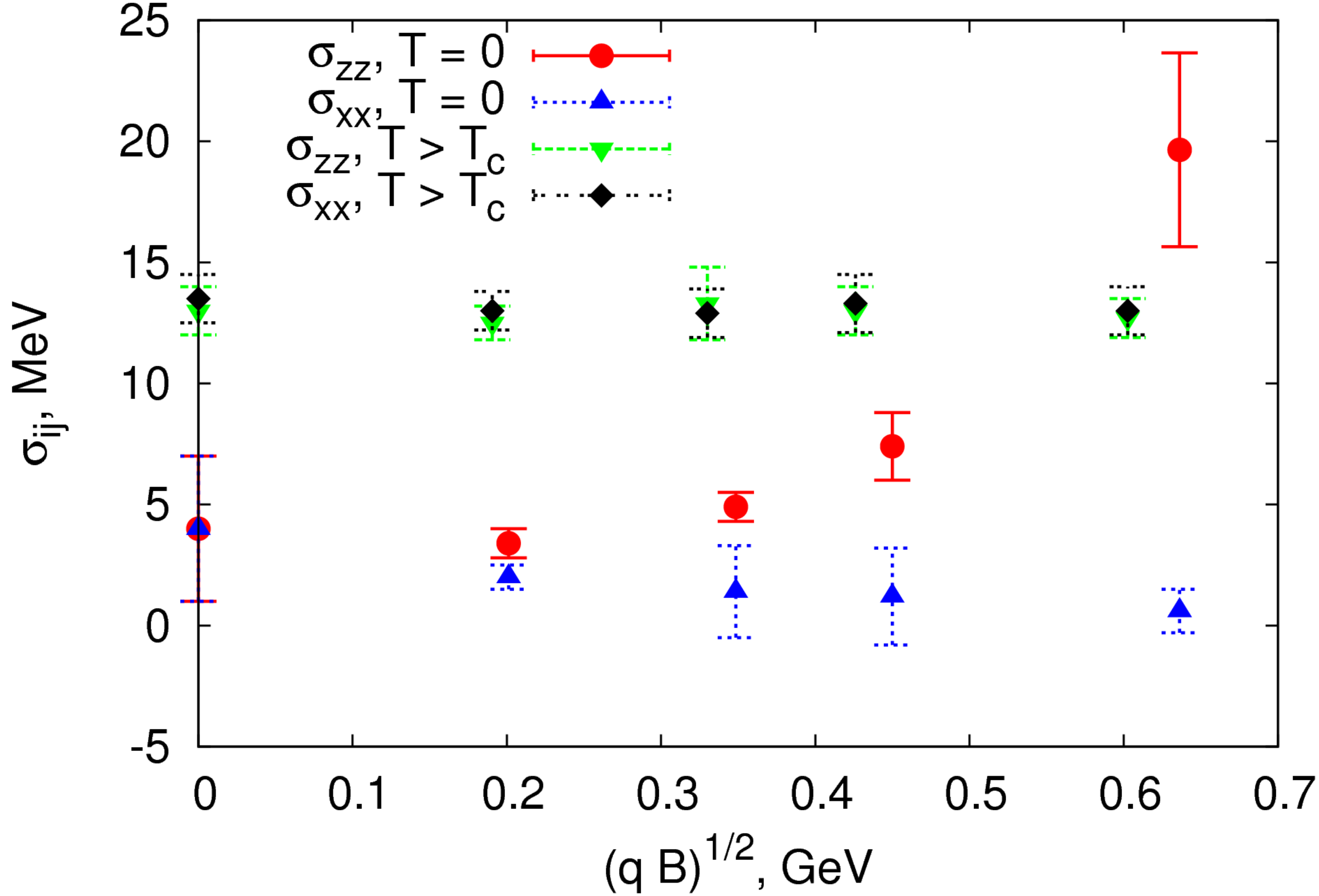


Conductivity

Meson masses

$$G_{ij}(\tau)=\int_0^\infty \frac{d\omega}{2\pi}\left[\frac{\omega}{2T}\frac{\cosh\left(\omega\left(\tau-\frac{1}{2T}\right)\right)}{\sinh\left(\frac{\omega}{2T}\right)}\right]\rho_{ij}(\omega)$$

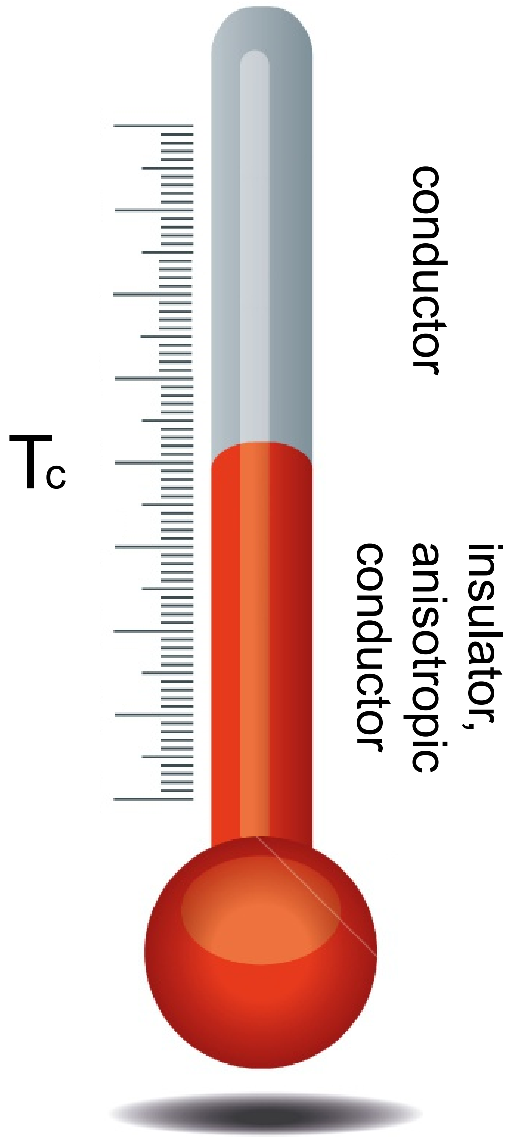
Electrical conductivity



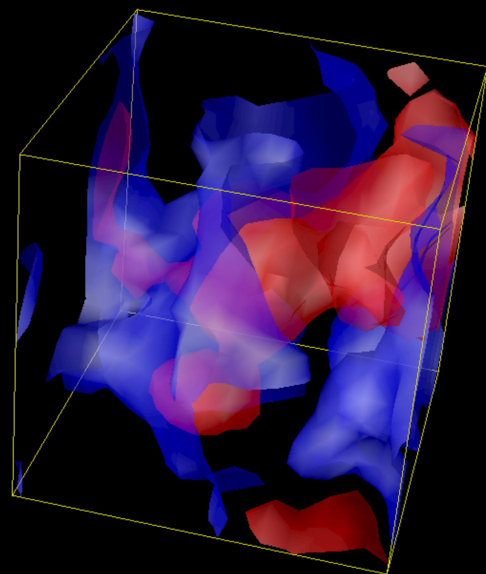
P.V. Buividovich, M.N. Chernodub, D.E. Kharzeev, T.K.,
E.V. Luschevskaya, M.I. Polikarpov (2010)

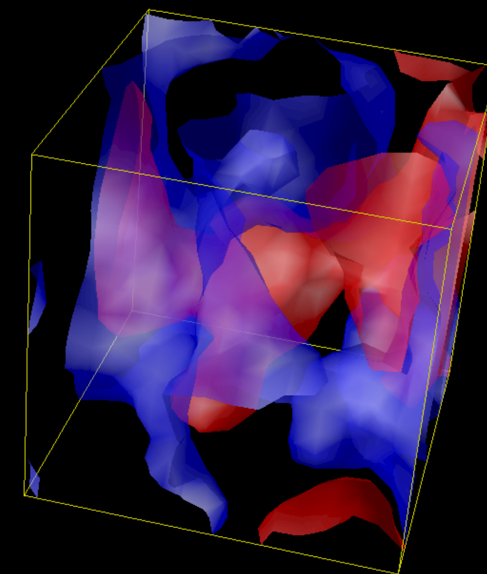
$$\sigma_{ij} = \frac{\lim_{\omega\to 0} \rho_{ij}(\omega)}{4T}$$

What does it mean?



- There are similar effects for $T > T_c$ and thus the local CP-violation is present in the both confinement and deconfinement phases
- Above T_c vacuum is a conductor
- Below T_c vacuum is either an insulator (for $B = 0$) or an anisotropic conductor (for strong B)
- This supports the idea of the CME as a macroscopic current.

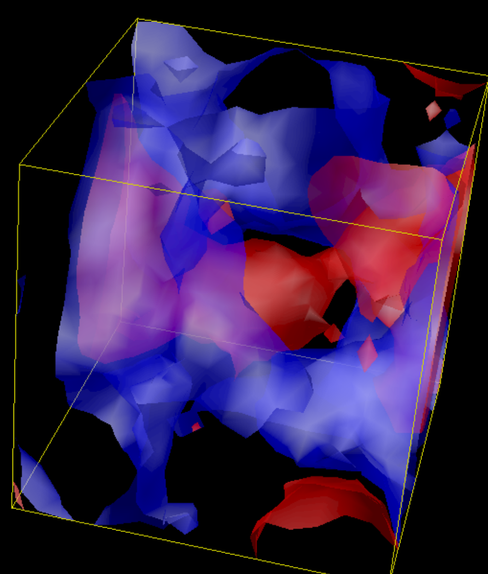


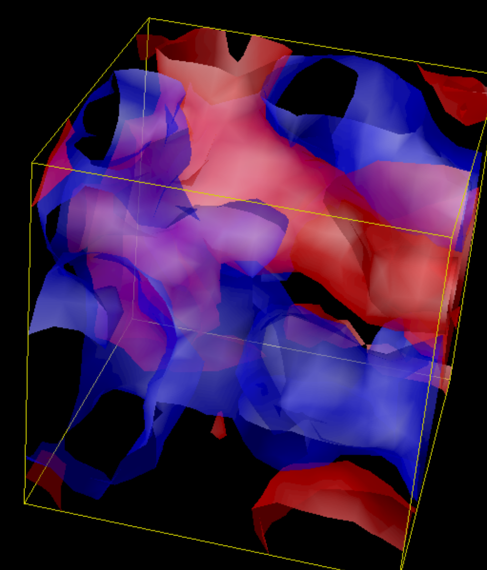


Negative topological charge density

Where is it localized?

Positive topological charge density





Inverse Participation Ratio

Observables:

$$\rho_\lambda(x) = \psi_\lambda^{*\alpha}(x)\ \psi_{\lambda\alpha}(x)$$ ← „Chiral condensate“ for eigenvalue λ

$$\rho_\lambda^5(x) = \left(1 - \frac{\lambda}{2}\right) \psi_\lambda^{*\alpha}(x)\gamma_{\alpha\beta}^5\, \psi_\lambda^\beta(x)$$ ← „Chirality“ = Topological charge density

Inverse Participation Ratio (inverse volume of the distribution):

$$IPR = N \sum_x \rho_i^2(x)$$

$$\sum_x \rho_i(x) = 1$$

Unlocalized: ρ(x) = const,	IPR = 1
Localized on a site:	IPR = N
Localized on fraction f of sites:	IPR = 1/ f

Fractal dimension (performing the number of measurements with finite lattice spacing):

$$IPR(a) = \frac{const}{a^d}$$

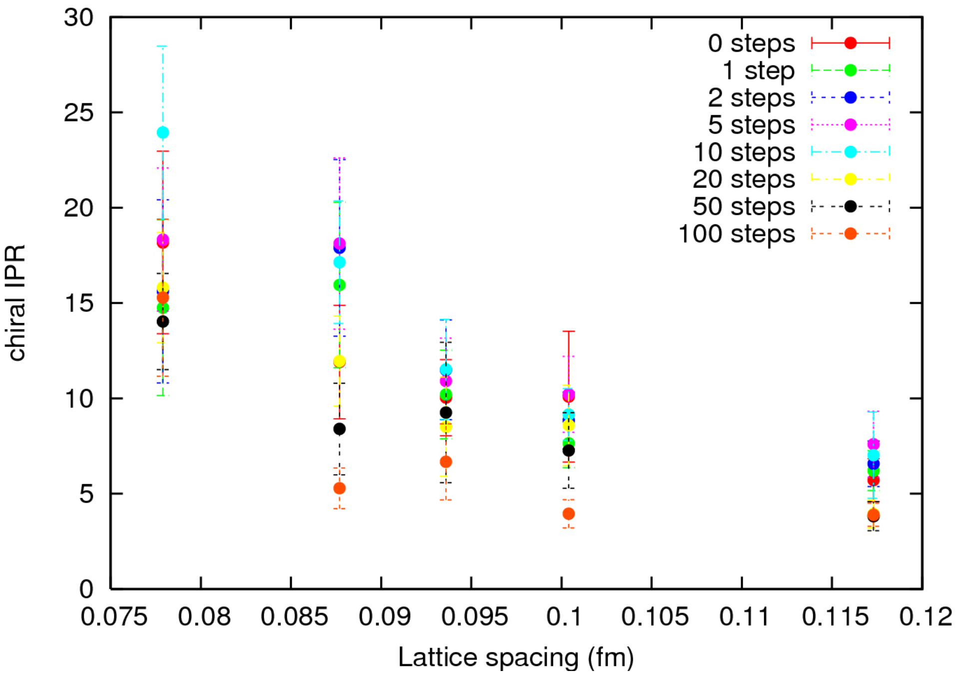
Localization of zero-modes

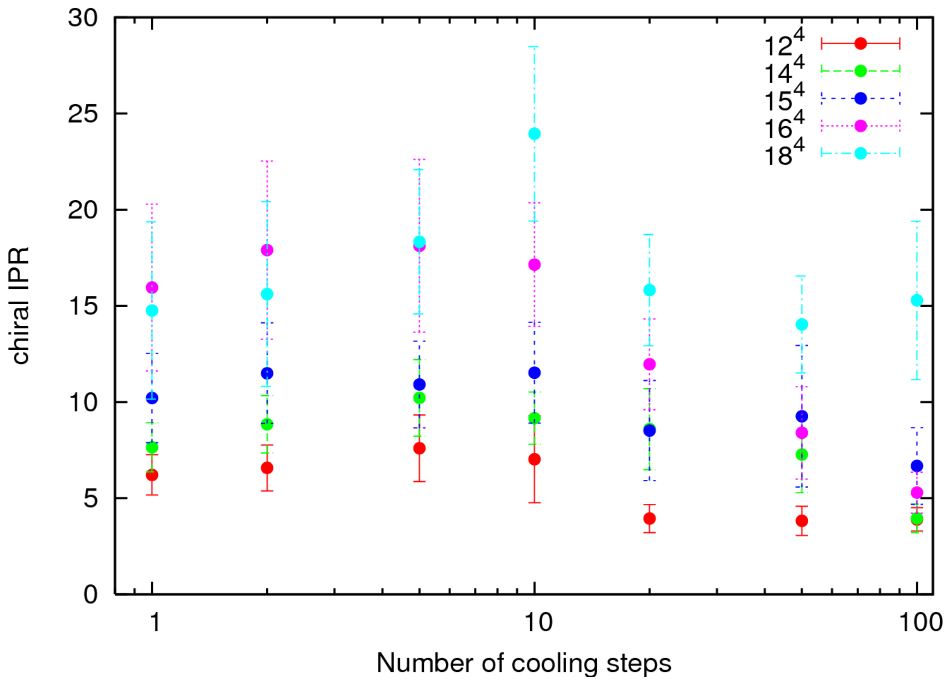
Definition:

$$\mathrm{IPR}_0 = V \left[\frac{\int_V d^4x\, (\rho_0(x))^2}{\left(\int_V d^4x\, \rho_0(x)\right)^2} \right]_{\lambda=0} ,$$

$$\rho_\lambda(x) = \psi_\lambda^{*\alpha}(x)\; \psi_{\lambda\alpha}(x)$$

$$\rho_\lambda^5(x) = \left(1 - \frac{\lambda}{2}\right) \psi_\lambda^{*\alpha}(x) \gamma^5_{\alpha\beta}\, \psi_\lambda^\beta(x)$$

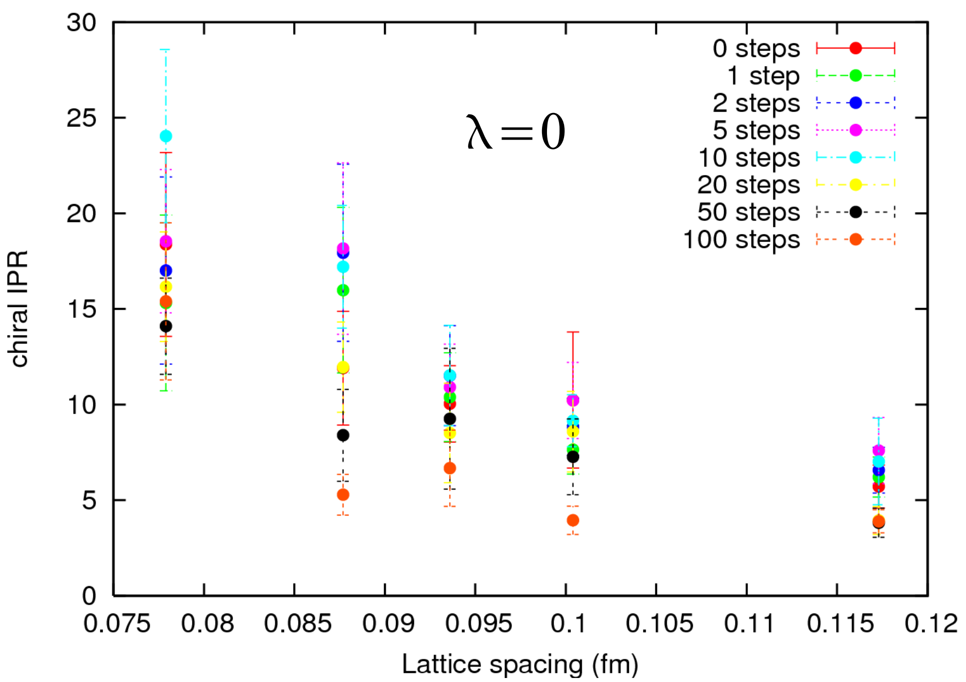




Topological charge density

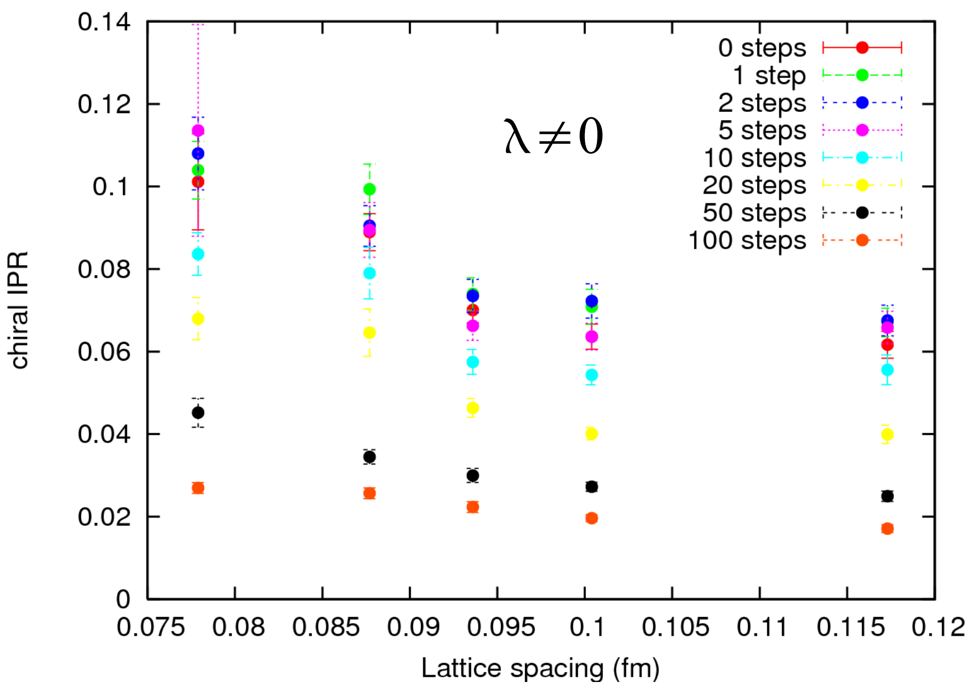
Definition 1:

$$\mathrm{IPR}_0^5 = V \left[\frac{\int_V d^4x \, |\rho_0^5(x)|^2}{\left(\int_V d^4x \, |\rho_0^5(x)| \right)^2} \right]_{\lambda=0} ,$$

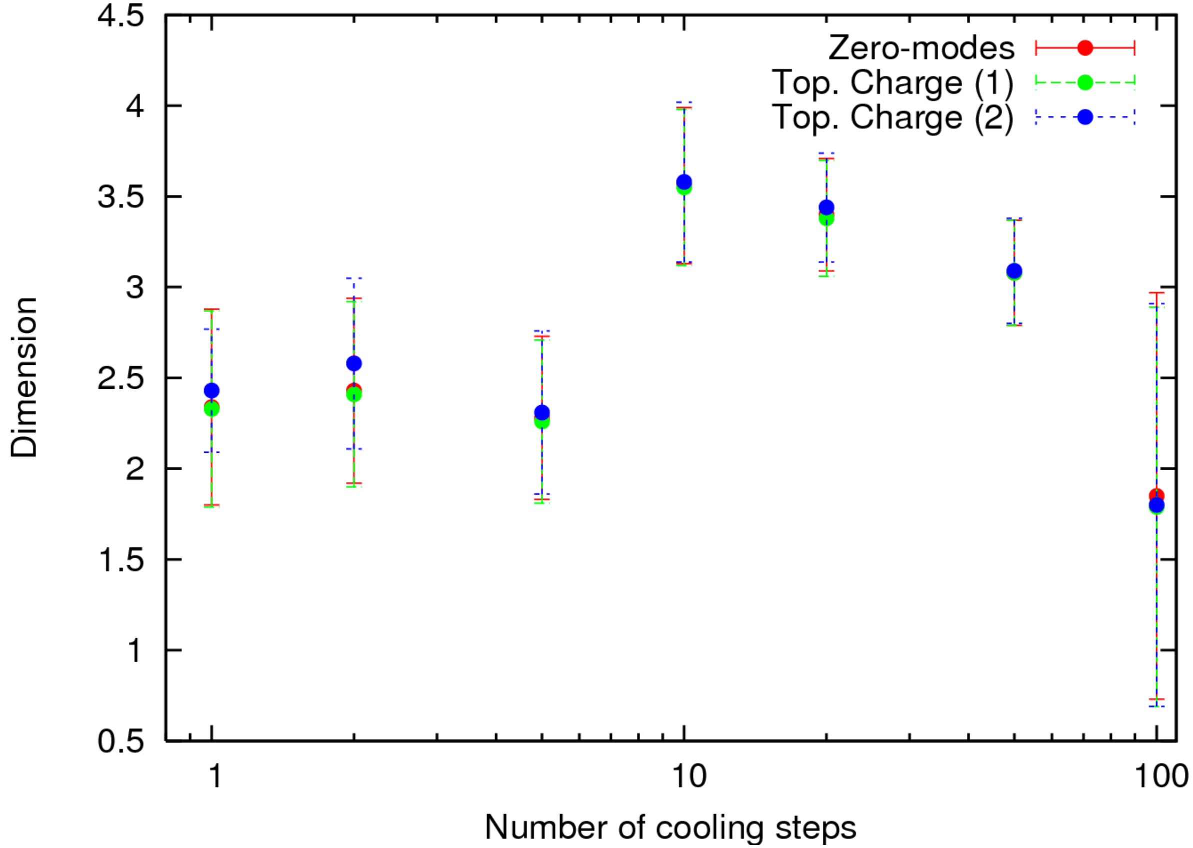


Definition 2:

$$\mathrm{IPR}_0^5 = V \left[\frac{\int_V d^4x \, \left(\rho_0^5(x)\right)^2}{\left(\int_V d^4x \rho_0(x) \right)^2} \right]_{\lambda=0} ,$$



Fractal dimension



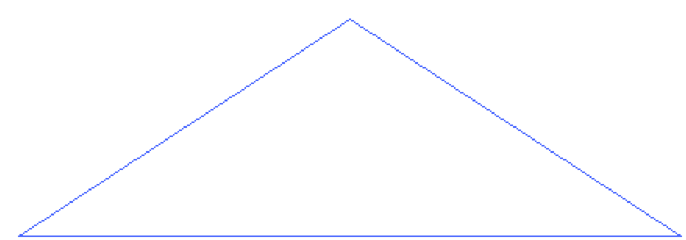
Our result: d = 2 ÷ 3

d = 0: instantons

d = 1: percolating monopoles

d = 2: percolating vortices

d = 3: low-dim. domains



About low-dimensional defects in QCD see also
V.I. Zakharov, Phys.Atom.Nucl. 68 (2005) 573
[hep-ph/0410034]

Thank you for the attention!

and

Have a good time!