Quark Matter '08, Jaipur, India

What can we learn about confinement and chiral symmetry breaking from heavy ion collisions?

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Even a fully successful and quantitative model of heavy ion collisions will be of limited value to the broad scientific community if it does not bring us closer to answering the fundamental physics questions, such as:

What is the mechanism of confinement?

What is the origin of chiral symmetry breaking?

What is the origin of mass?

….

Two concrete examples will be considered here; both highlight the role of quantum anomalies in QCD matter

The scale anomaly of QCD

$$\mathcal{L} = -\frac{1}{4} G^a_{\mu\nu} G^a_{\mu\nu} + \sum_f \bar{q}^a_f (i\gamma_\mu D_\mu - m_f) q^a_f;$$

Classical scale invariance is broken by quantum effects:

scale anomaly

$$\theta^\mu_\mu = \frac{\beta(g)}{2g} G^{\alpha\beta a} G^a_{\alpha\beta} + \sum_q m_q \bar{q} q$$

trace of the energy-momentum tensor

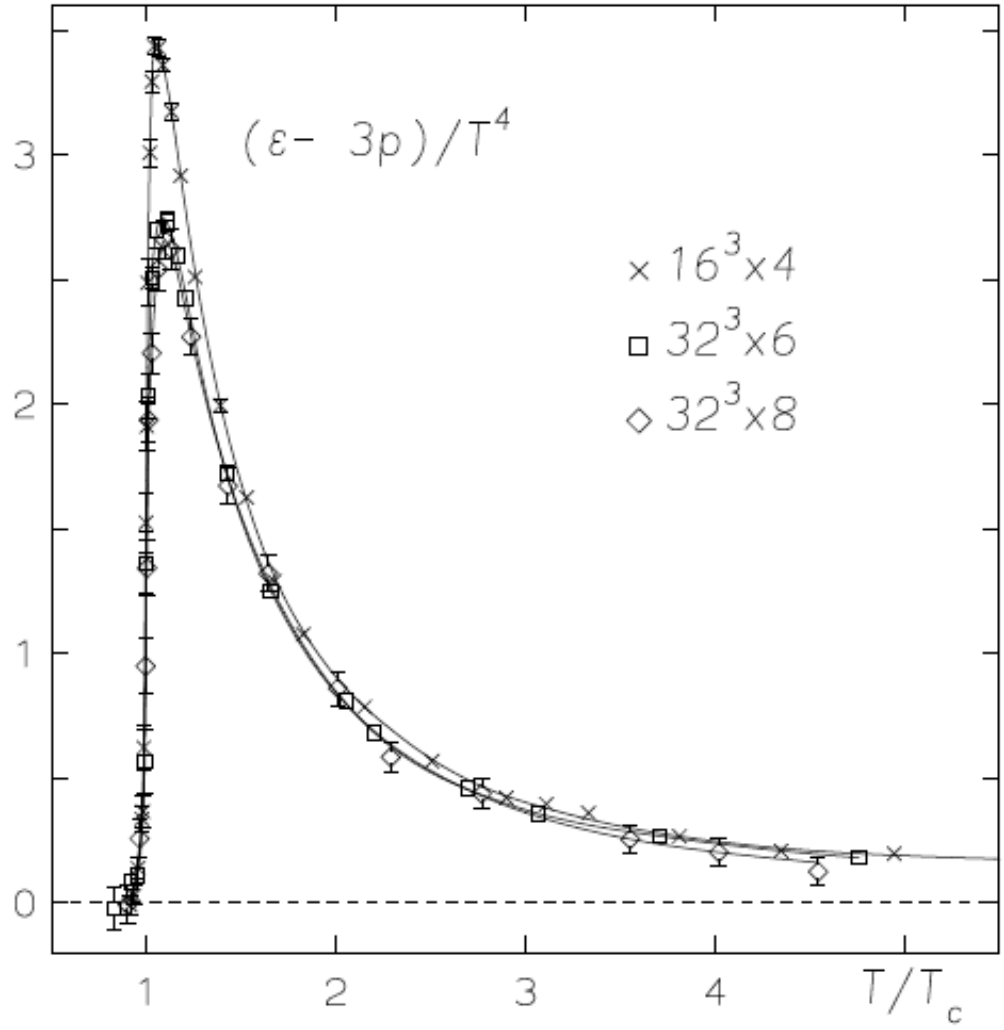
"beta-function"; describes the dependence of coupling on momentum

Hadrons get masses
Quarks get confined

coupling runs with the distance

Scale anomaly in QCD matter

SU(3),
pure gauge



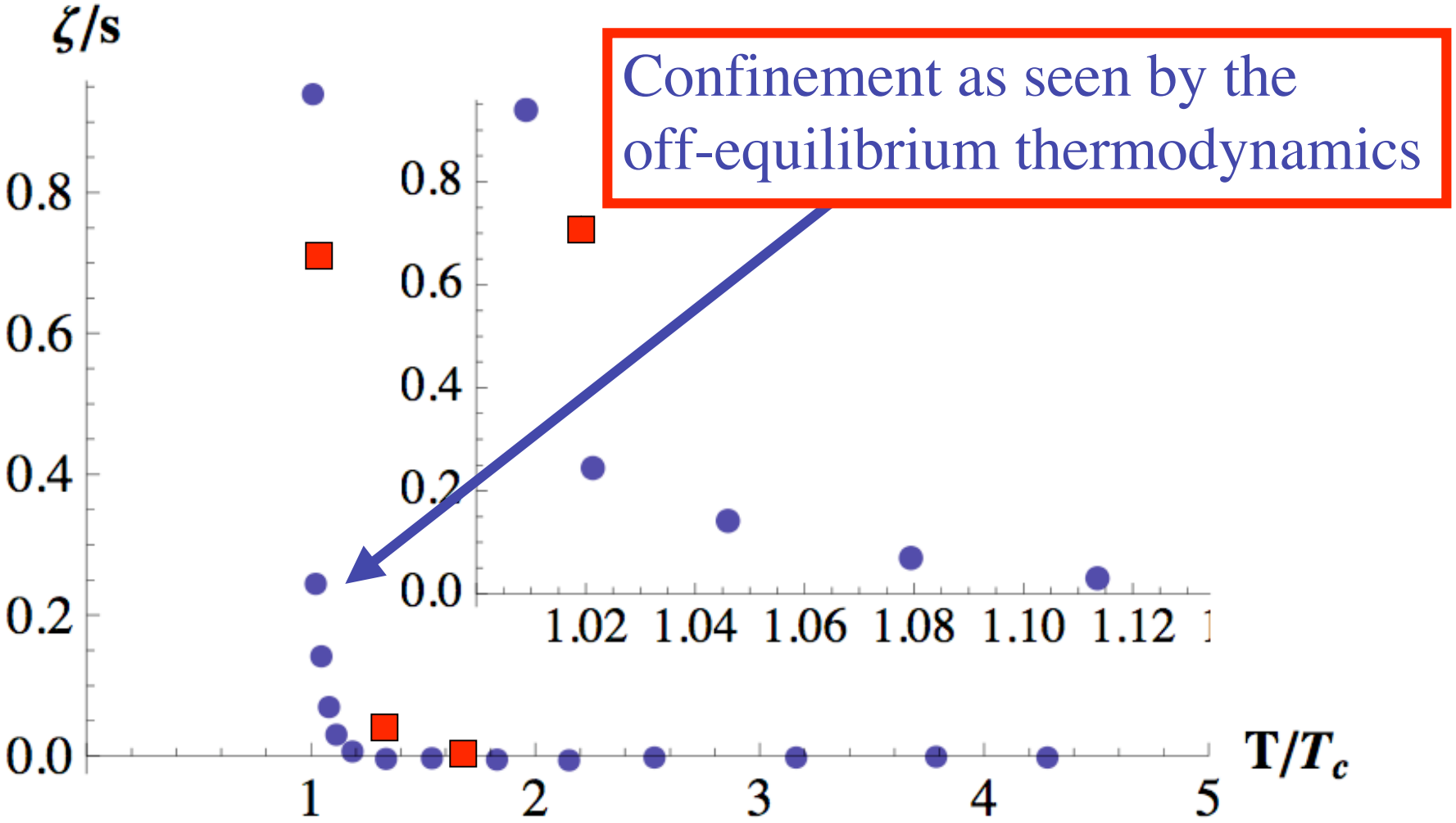
Talks by
J. Ellis,
S. Gupta,
F. Karsch,
Z. Fodor,
…

The lattice data from G.Boyd, J.Engels, F.Karsch, E.Laermann, C.Legeland, M.Lutgeimer, B.Petersson, hep-lat/9602007

Bulk viscosity

● Kharzeev-Tuchin arXiv:0705.4280 [hep-ph]

■ Meyer arXiv:0710.3717[hep-lat]



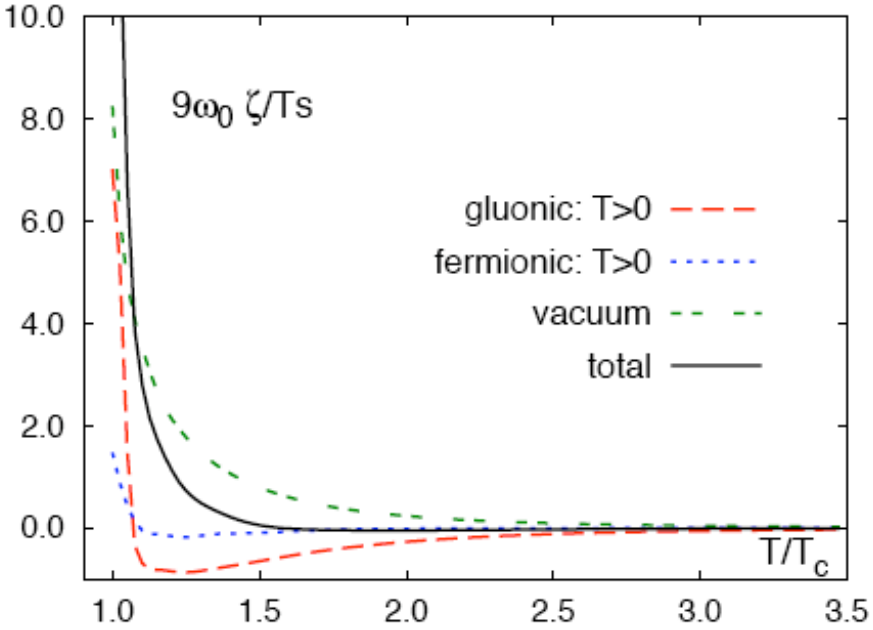
Confinement as seen by the off-equilibrium thermodynamics

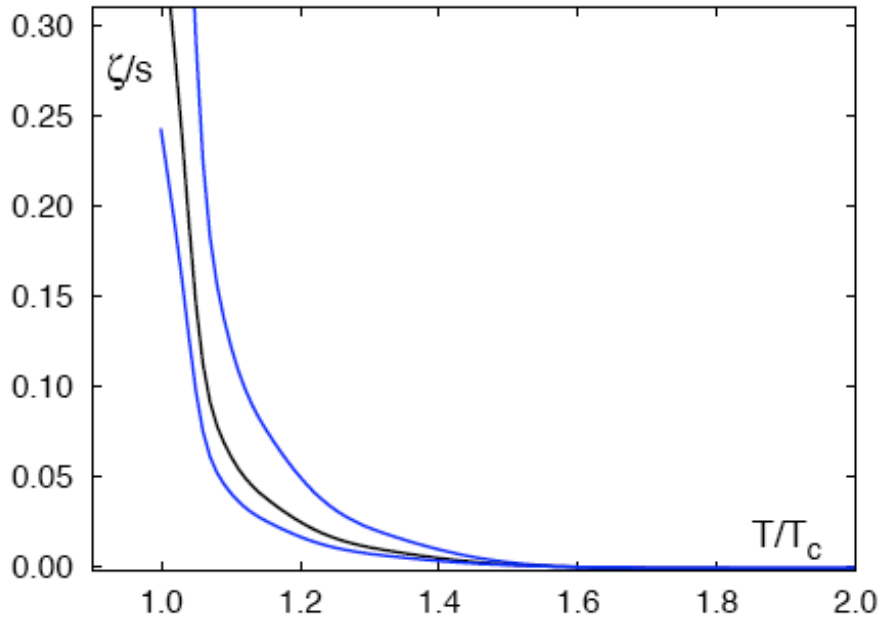
Model studies: Mizutani, Muroya, Namiki, ‘88; Paech, Pratt ‘06; Chen, Wang ‘07

Bulk viscosity in full QCD

Qualitatively similar results:

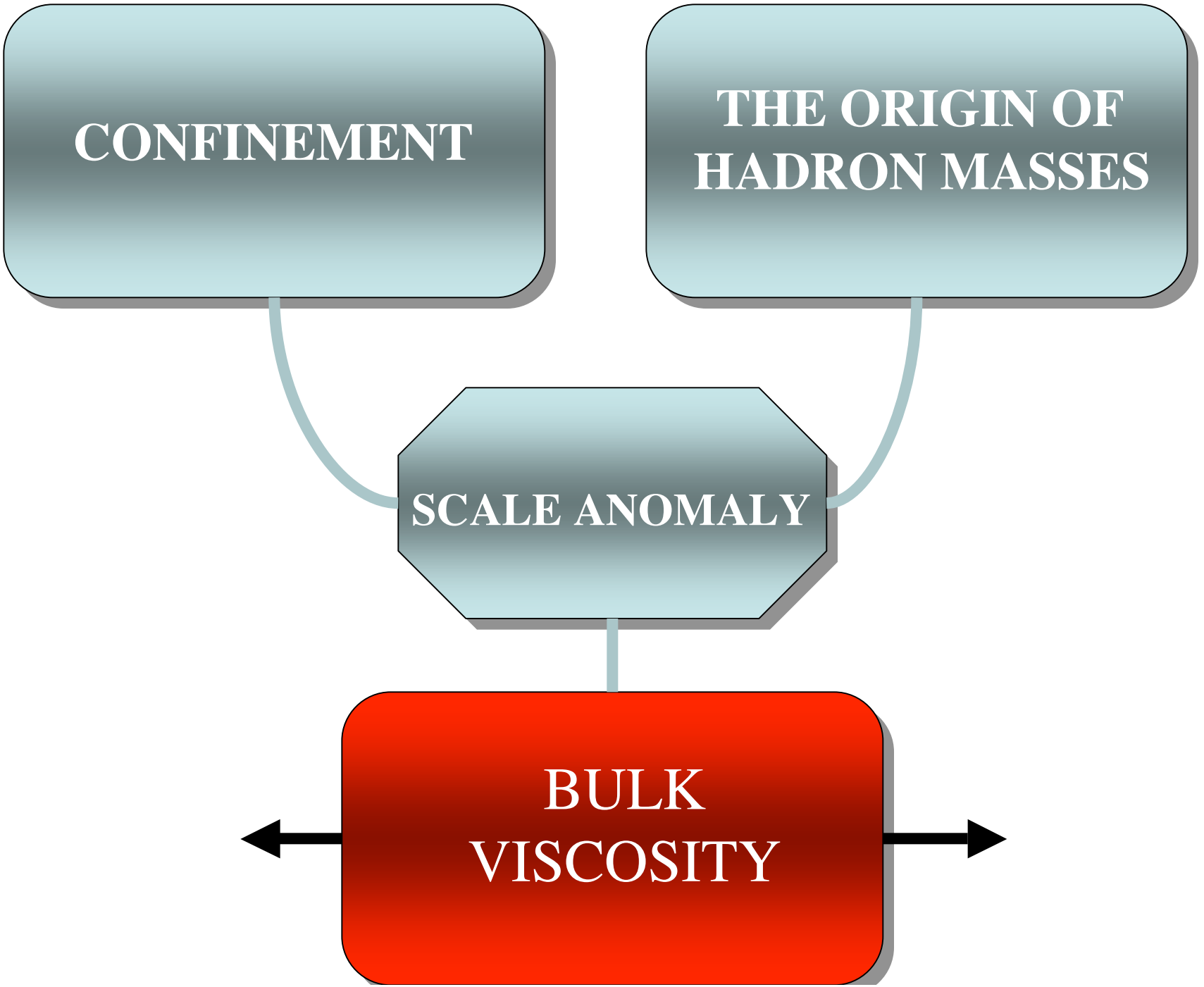
F.Karsch, DK, K.Tuchin,
arXiv:0711.0914

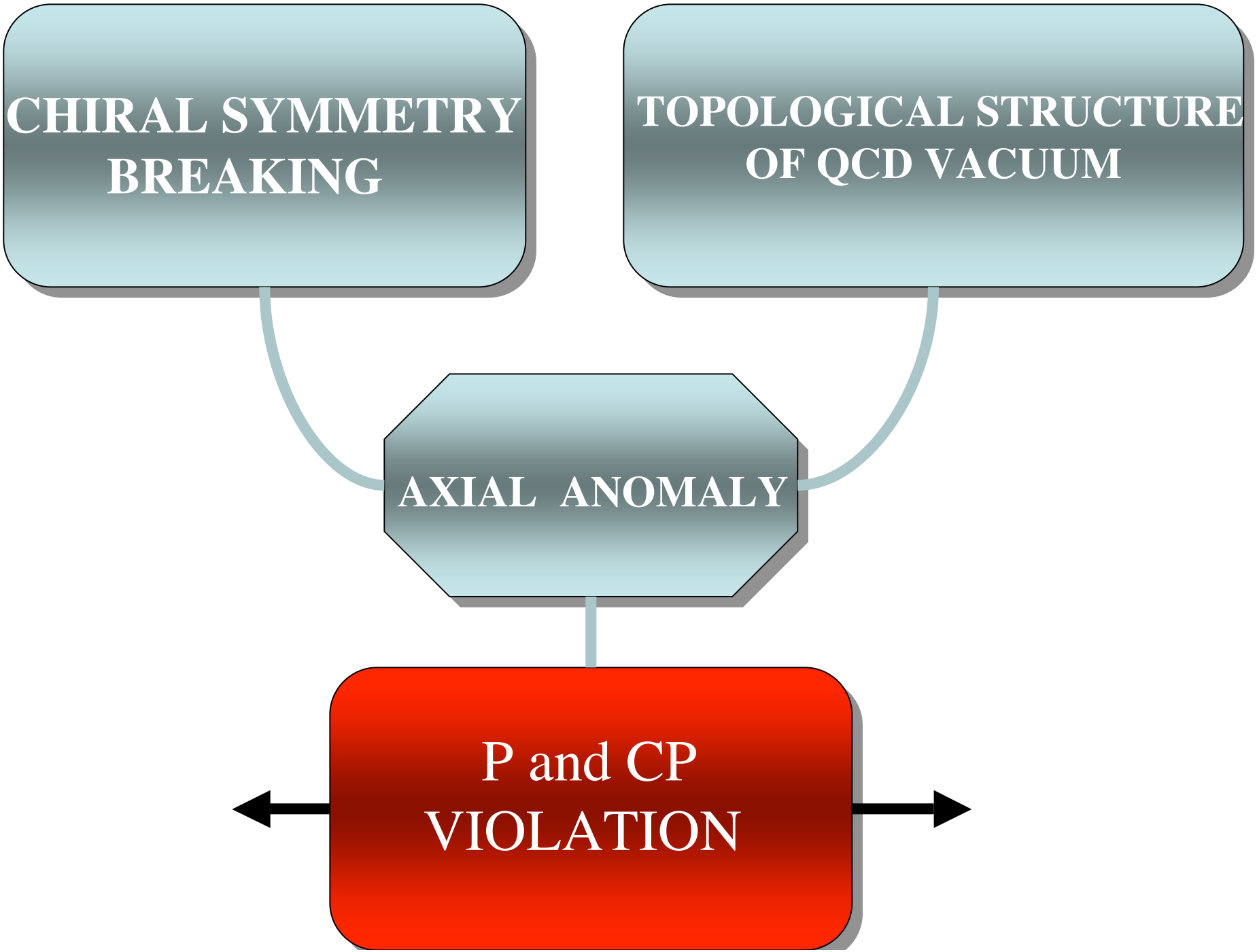


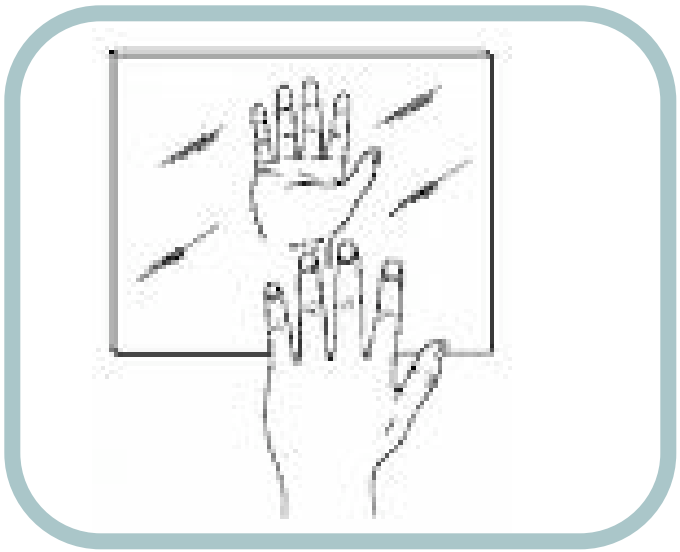


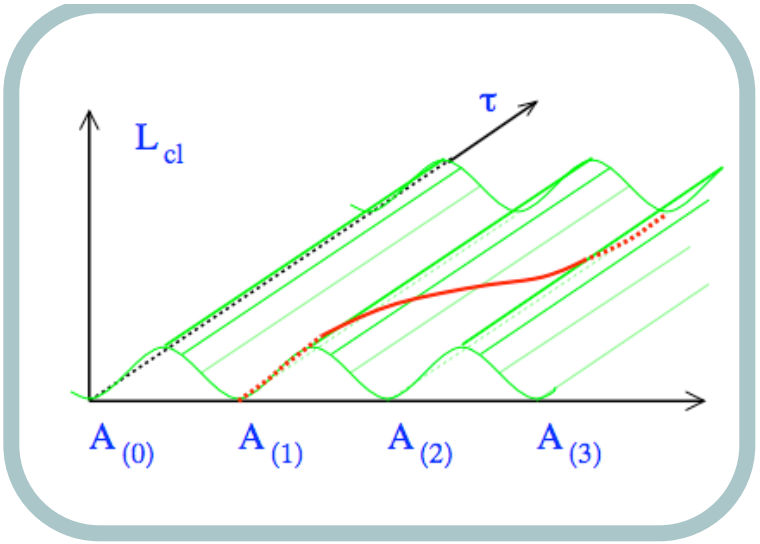
+ Near the chiral critical point: divergence of bulk viscosity

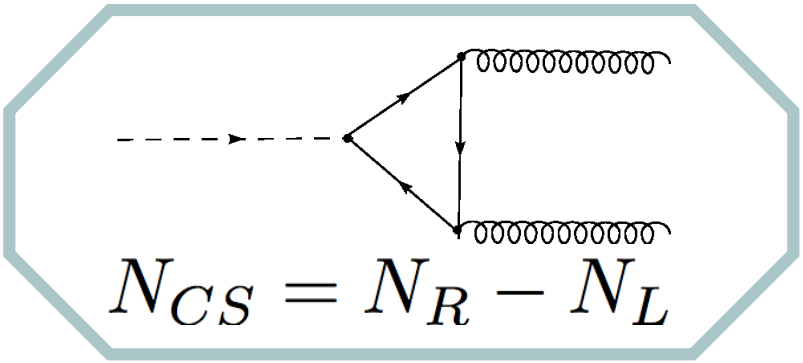
Talks by V. Koch, M. Stephanov,….

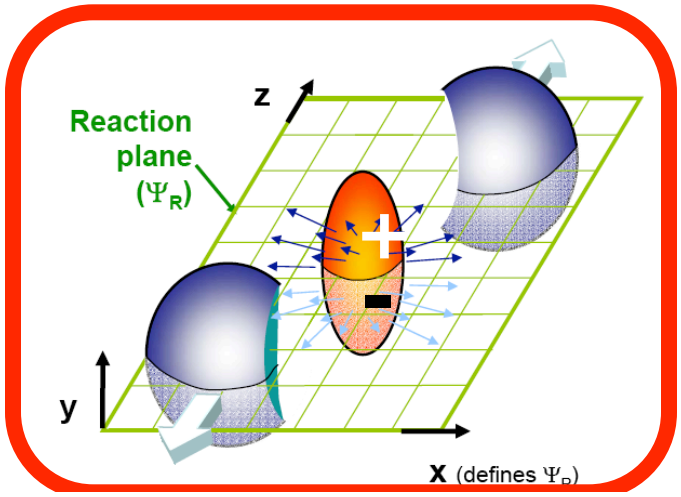

CONFINEMENT
THE ORIGIN OF HADRON MASSES
SCALE ANOMALY
BULK VISCOSITY


CHIRAL SYMMETRY BREAKING
TOPOLOGICAL STRUCTURE OF QCD VACUUM
AXIAL ANOMALY
P and CP VIOLATION





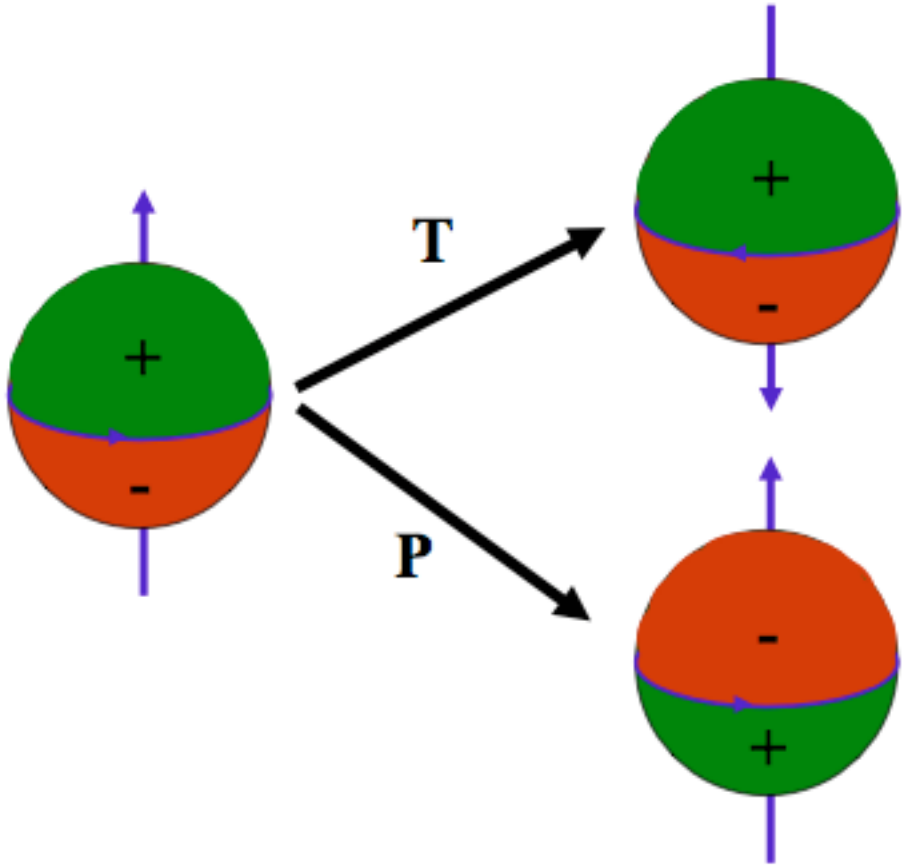




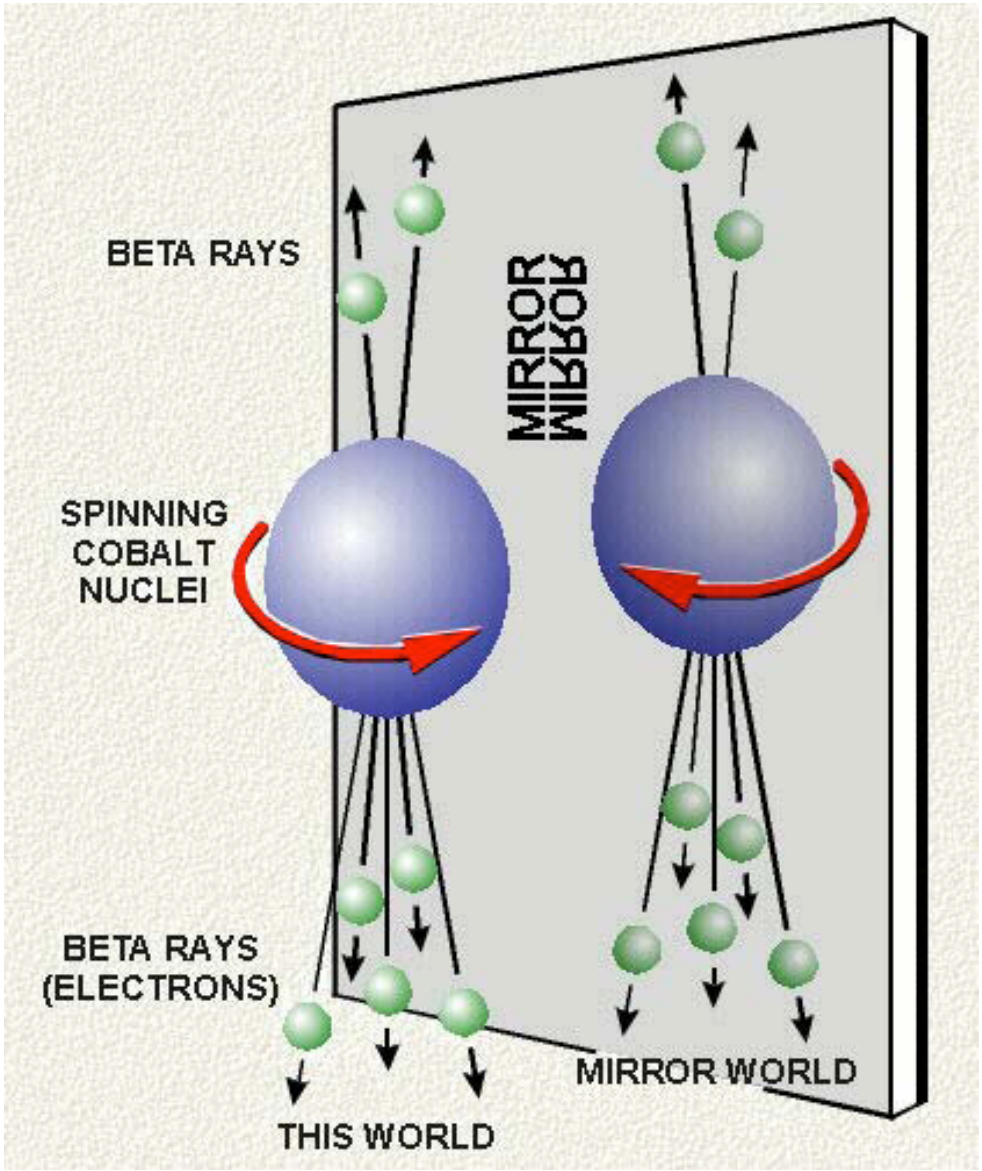
DK'04
DK, A. Zhitnitsky'07
DK, L. McLerran and H. Warringa '07

Talks by H. Warringa, S. Voloshin + STAR poster 205

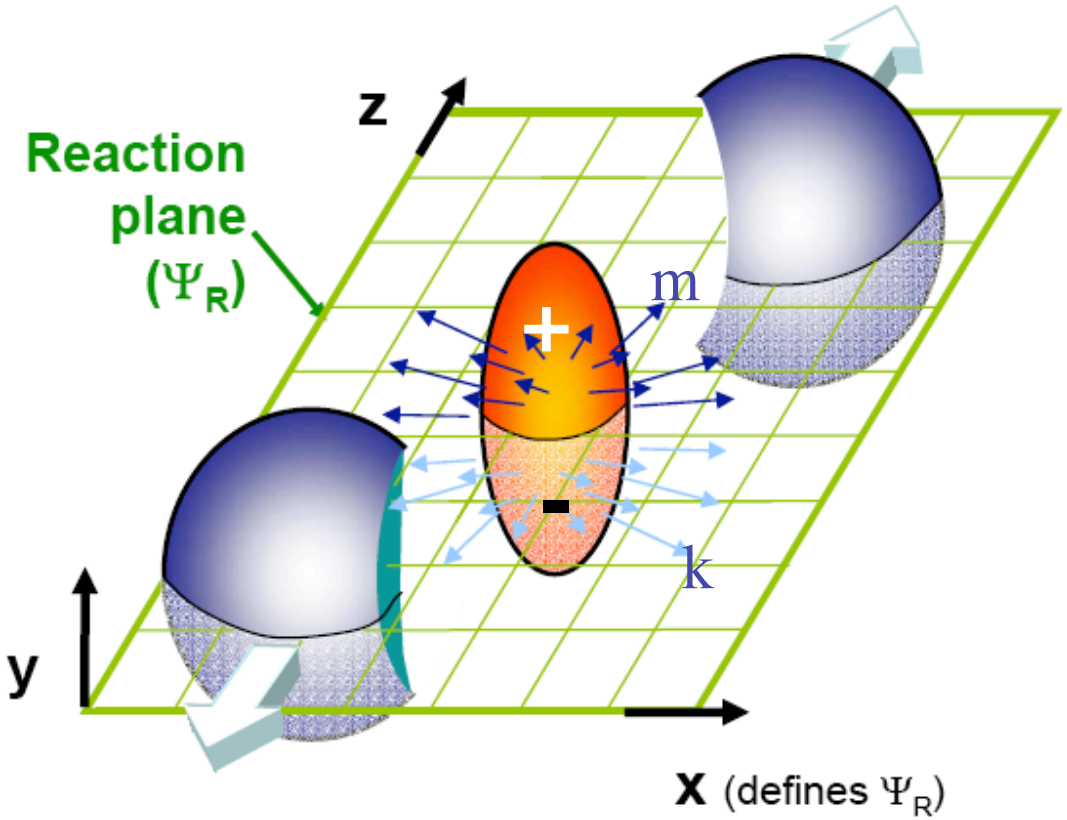
Charge asymmetry w. r.t. reaction plane violates T, P, and (by CPT theorem) CP:



Analogy to P violation in weak interactions



Charge asymmetry w.r.t. reaction plane: how to detect it?



S.Voloshin, hep-ph/0406311

We need
a sensitive measure
of the asymmetry

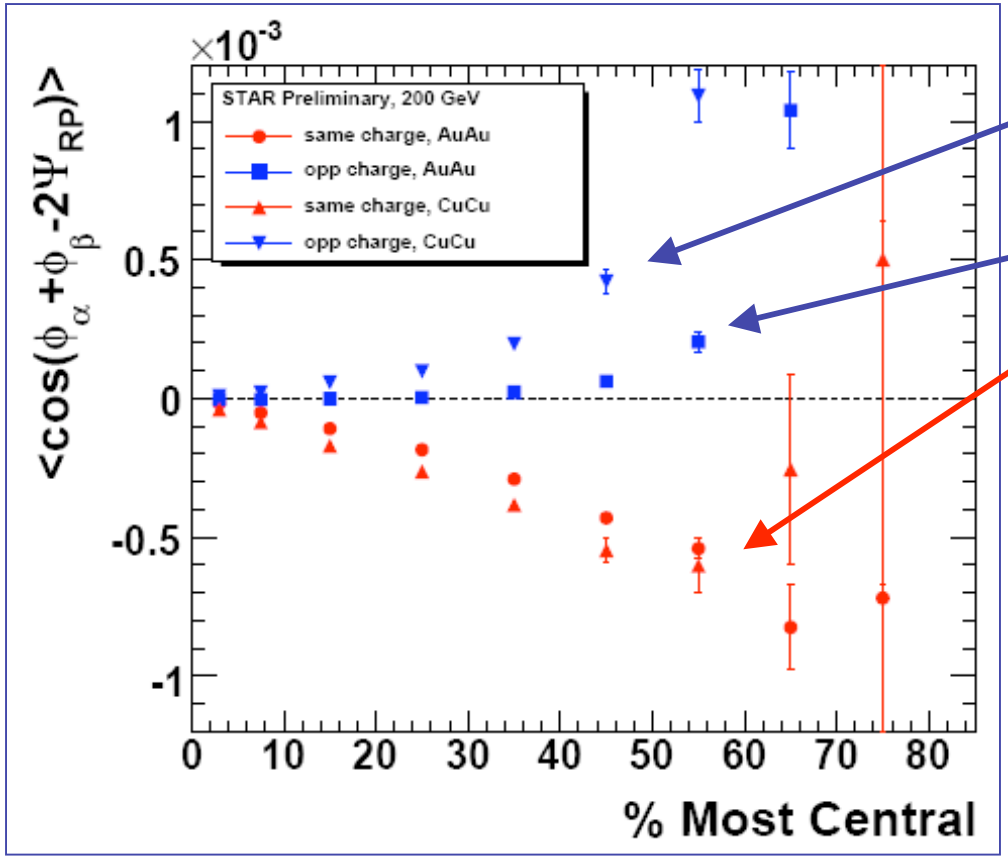
The method:
"mixed harmonics"

$$a^k a^m = \langle \sum_{ij} \sin(\varphi_i^k - \Psi_R)\ \sin(\varphi_j^m - \Psi_R) \rangle$$

Expect $a^+a^+ = a^-a^- > 0; \quad a^+a^- < 0$

Strong P, CP violation at high T ?

Charge asymmetry w.r.t. reaction plane,
~ - $a^k a^m$



Need to analyze the systematics and backgrounds - vigorous ongoing work!

S. Voloshin [STAR Coll.] Poster 205, QM'08

P and CP violation as a signature of deconfinement and chiral symmetry breaking

P and CP violation (charge separation via the "chiral magnetic effect") requires:

- deconfinement - need to separate (anti-) quarks with opposite electric charges spatially
- restored chiral symmetry - charge separation is only possible if chirality is conserved

If observed conclusively:

- would prove the creation of deconfined and chirally symmetric phase
- would establish experimentally the presence of topological configurations of gluon fields and their role in χSB