Chiral magnetic effect @ NICA

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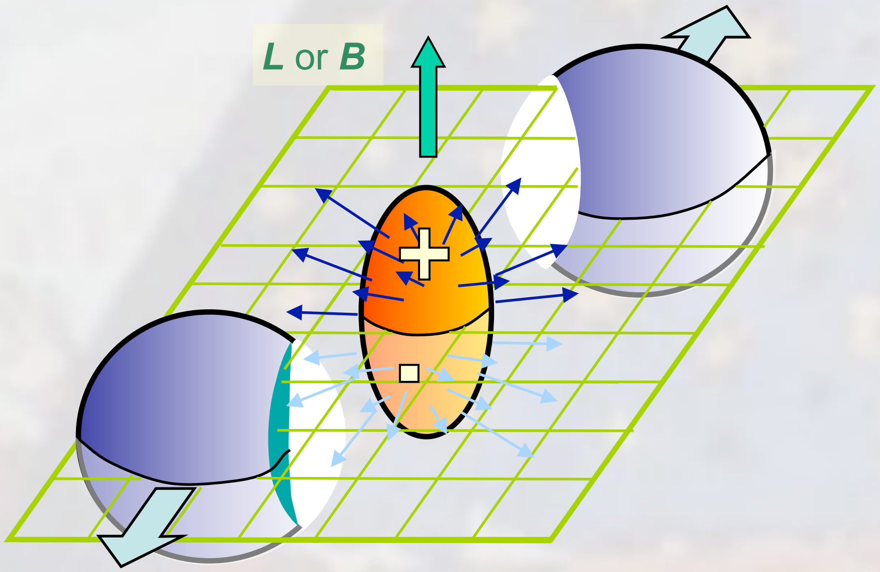
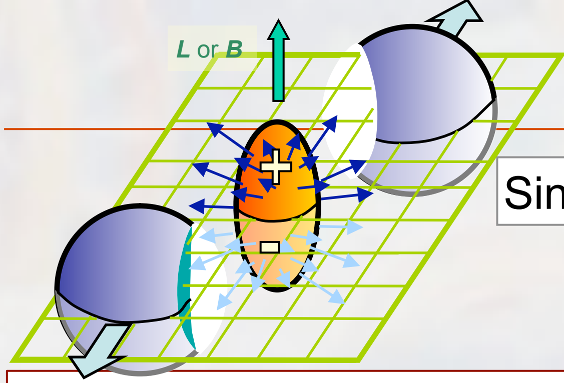


Outline:

- CME dependence on energy
- Signal and Backgrounds



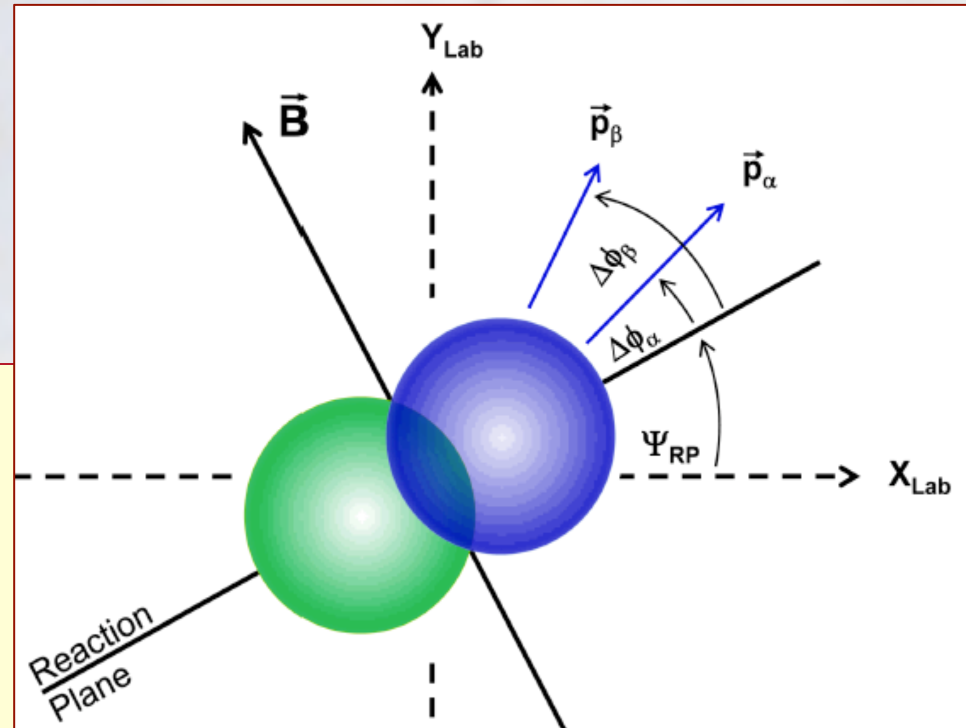
Observable

S.A. Voloshin, Phys. Rev. C 70 (2004) 057901

Single particle effective distribution

$$\Delta\phi = (\phi - \Psi_{RP})$$

$$\frac{dN_\alpha}{d\phi} \propto 1 + 2v_{1,\alpha}\cos(\Delta\phi) + 2\,v_{2,\alpha}\cos(2\Delta\phi) + \ldots$$
$$+\; 2a_{1,\alpha}\sin(\Delta\phi) + 2\,a_{2,\alpha}\sin(2\Delta\phi) + \ldots,$$



- The effect is too small to see in a single event
- The sign of topological charge varies and $\langle a \rangle = 0$ ➔ one has to measure correlations, $\langle a_\alpha a_\beta \rangle$, P -even quantity (!)
- Consider only first harmonic
- $\langle a_\alpha a_\beta \rangle$ is expected ~ 10^{-4}
- $\langle a_\alpha a_\beta \rangle$ can not be measured as $\langle \sin\varphi_\alpha \sin\varphi_\beta \rangle$

due to large contribution from effects not related to the orientation of the reaction plane

➔ the difference in corr's in- and out-of-plane

$$\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle =$$
$$= \langle \cos\Delta\phi_\alpha \cos\Delta\phi_\beta \rangle - \langle \sin\Delta\phi_\alpha \sin\Delta\phi_\beta \rangle$$
$$= [\langle v_{1,\alpha} v_{1,\beta} \rangle + B^{in}] - [\langle a_\alpha a_\beta \rangle + B^{out}].$$

$B^{in} \approx B^{out}, \quad v_1 = 0$

A practical approach:
three particle correlations

$$\langle \cos(\phi_a + \phi_\beta - 2\phi_c) \rangle = \langle \cos(\phi_a + \phi_\beta - 2\Psi_{RP}) \rangle\, v_{2,c}$$

CME vs $\sqrt{s_{nn}}$

$$CME = \langle a_i a_j \rangle \sim \left(\int dt B \times R \right) \times 1 / N \times \kappa$$

Magnetic field

Shaleron/instanton rate

Multiplicity dilution factor

Correlation surviving probability

Magnetic field -- higher at lower energy

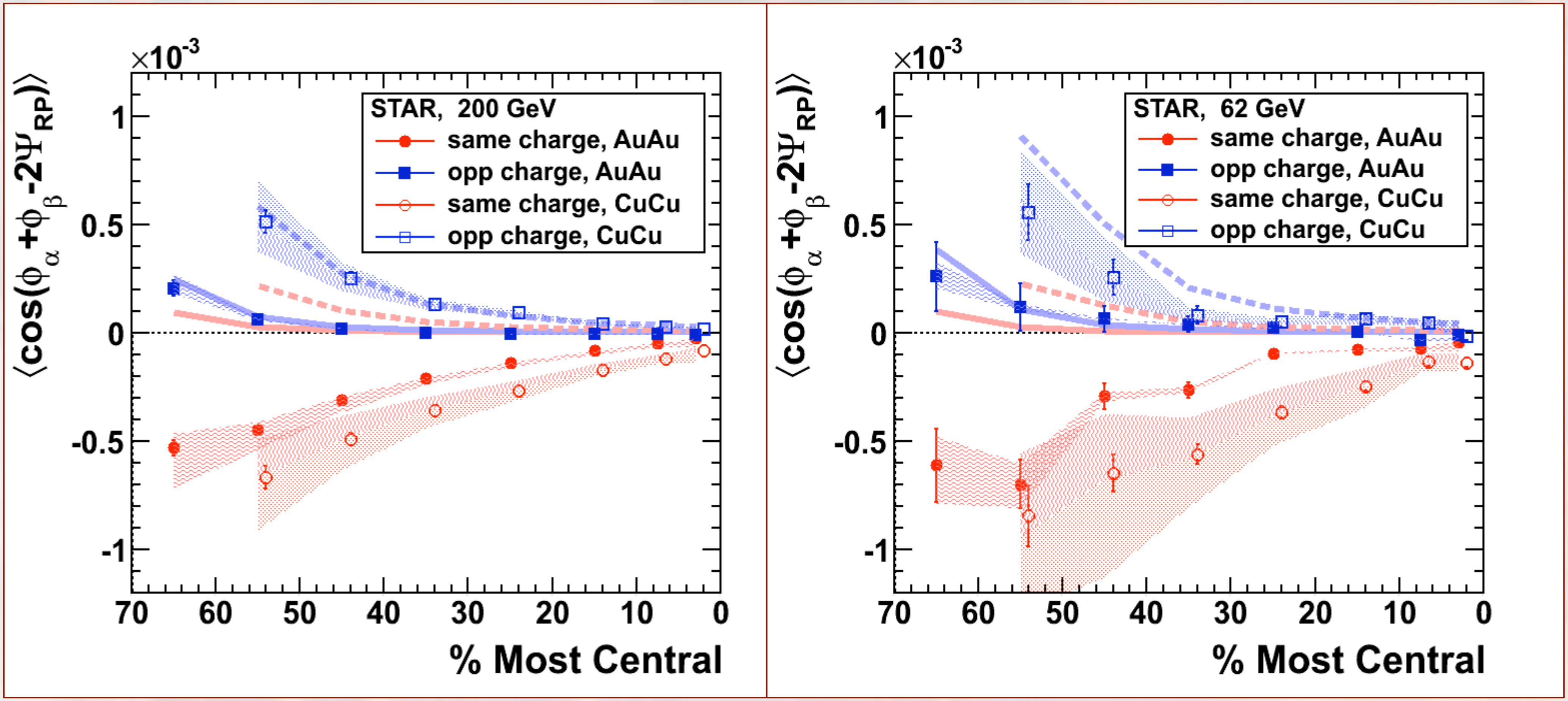
Rate -- ??

Multiplicity decreases

Surviving probability - supposedly strongly suppressed in confined phase (?).

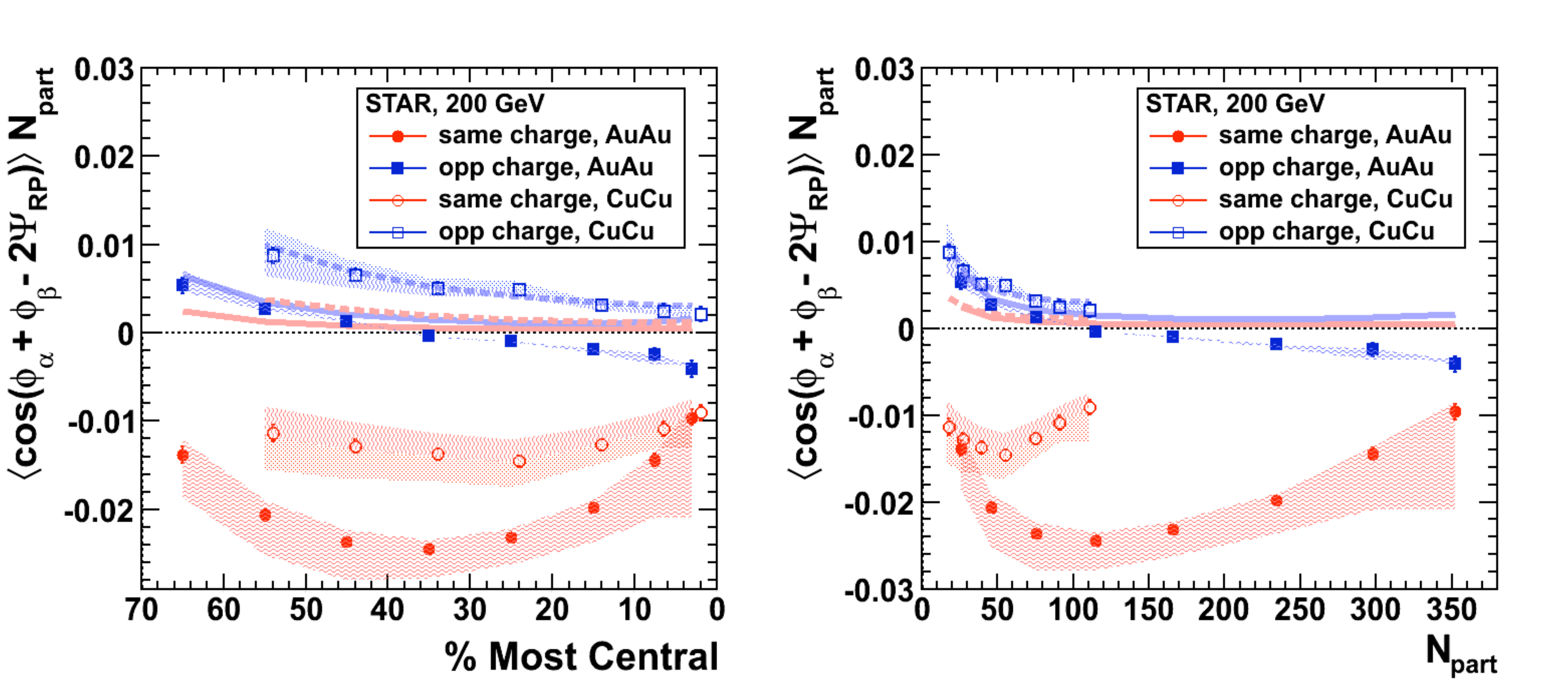
➡ "Threshold" like behavior with energy

Au+Au and Cu+Cu: 200 vs 62 GeV



+/– signal at lower energy is stronger, qualitatively in agreement with "theory"

Au+Au and Cu+Cu @ 200 GeV



The signal is multiplied by N_{part} to remove "trivial" dilution due to multiplicity increase in more central collisions

Opposite charge correlations scale with N_{part}, (suppression of the back-to-back correlations ?)

Same charge signal is suggestive of correlations with the reaction plane

Opposite charge corr's are somewhat stronger in CuCu compared to AuAu at the same N_{part}

Backgrounds

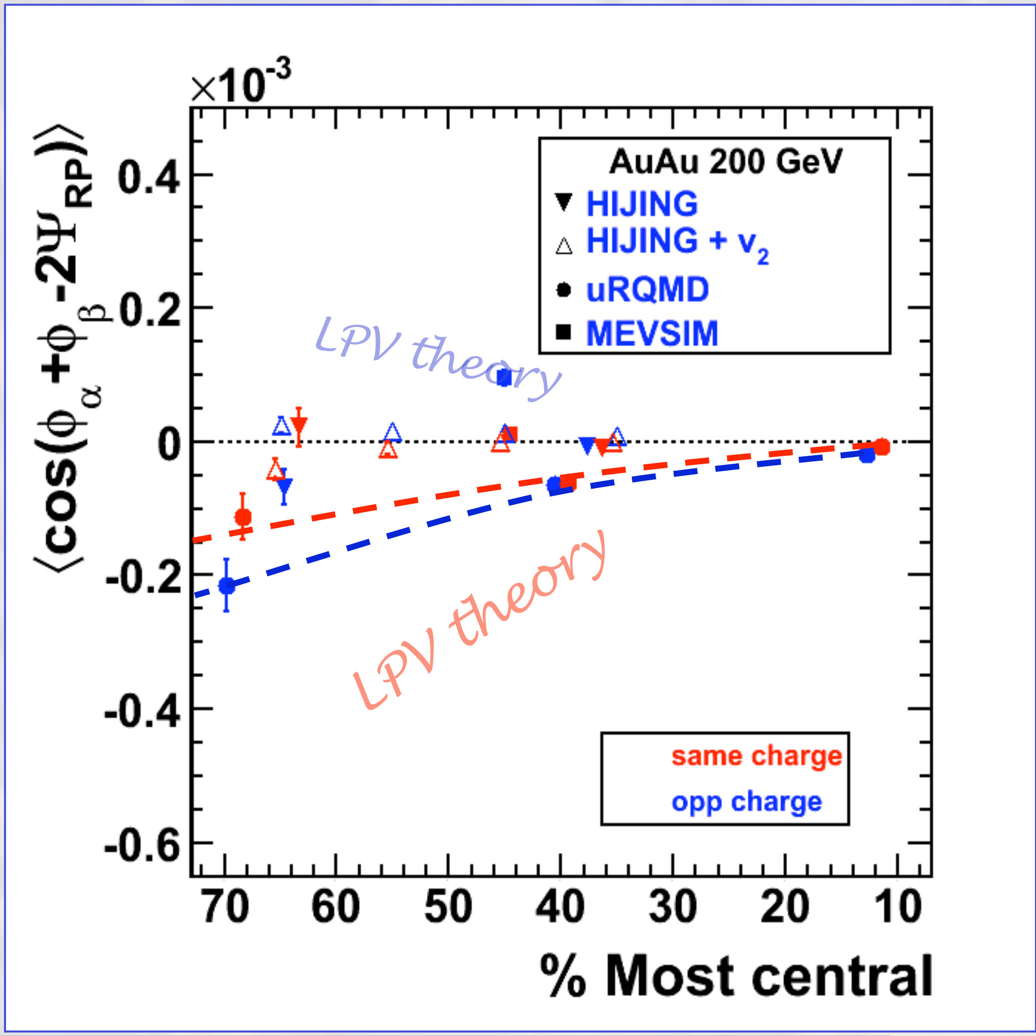
I. Physics (RP dependent).
Can not be suppressed

$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle =$$
$$= \langle\cos\Delta\phi_\alpha \cos\Delta\phi_\beta\rangle - \langle\sin\Delta\phi_\alpha \sin\Delta\phi_\beta\rangle$$
$$= [\langle v_{1,\alpha}v_{1,\beta}\rangle + B^{in}] - [\langle a_\alpha a_\beta\rangle + B^{out}].$$

- "Flowing clusters"/RP dependent fragmentation

$$\langle\cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP})\rangle =$$
$$= A_{clust}\,\langle\cos(\phi_\alpha + \phi_\beta - 2\phi_{clust})\rangle_{clust}\, v_{2,clust}$$

- Global polarization, v_1 fluctuations, …



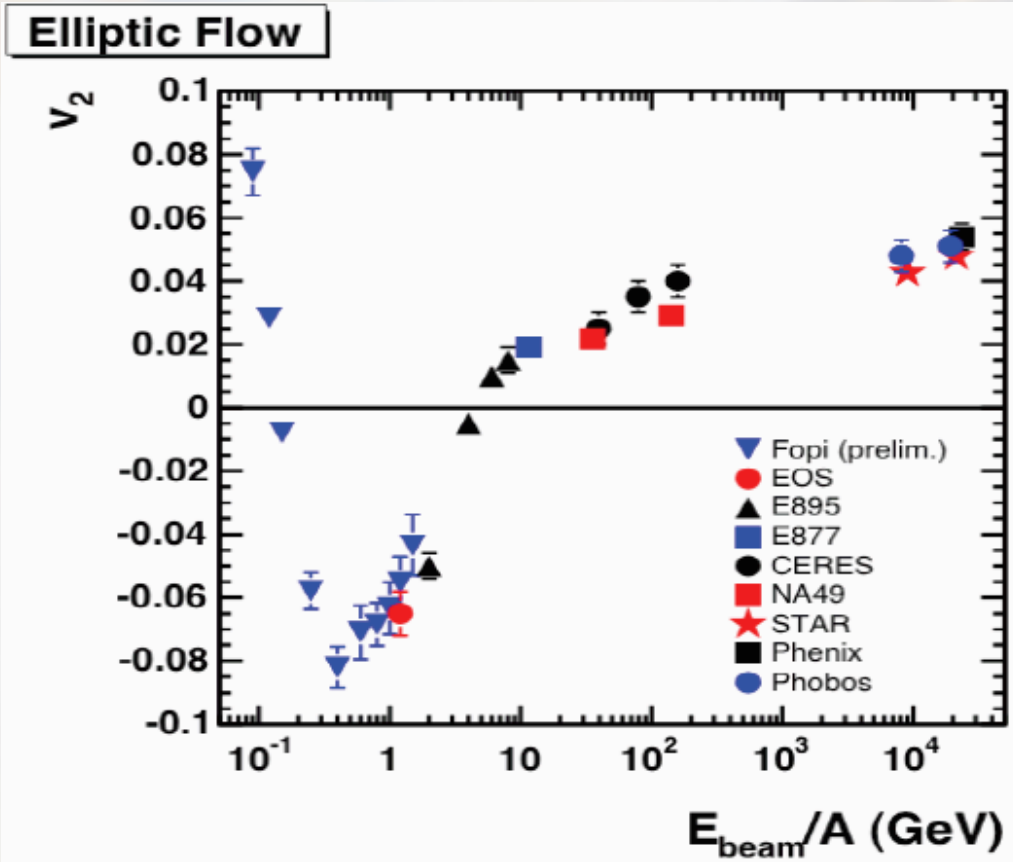
(+,+) and (-,-) results are combined as "same charge"
HIJING+v2 = added "afterburner" to generate flow
MEVSIM: flow as in experiment, number of resonances maximum what is consistent with experiment

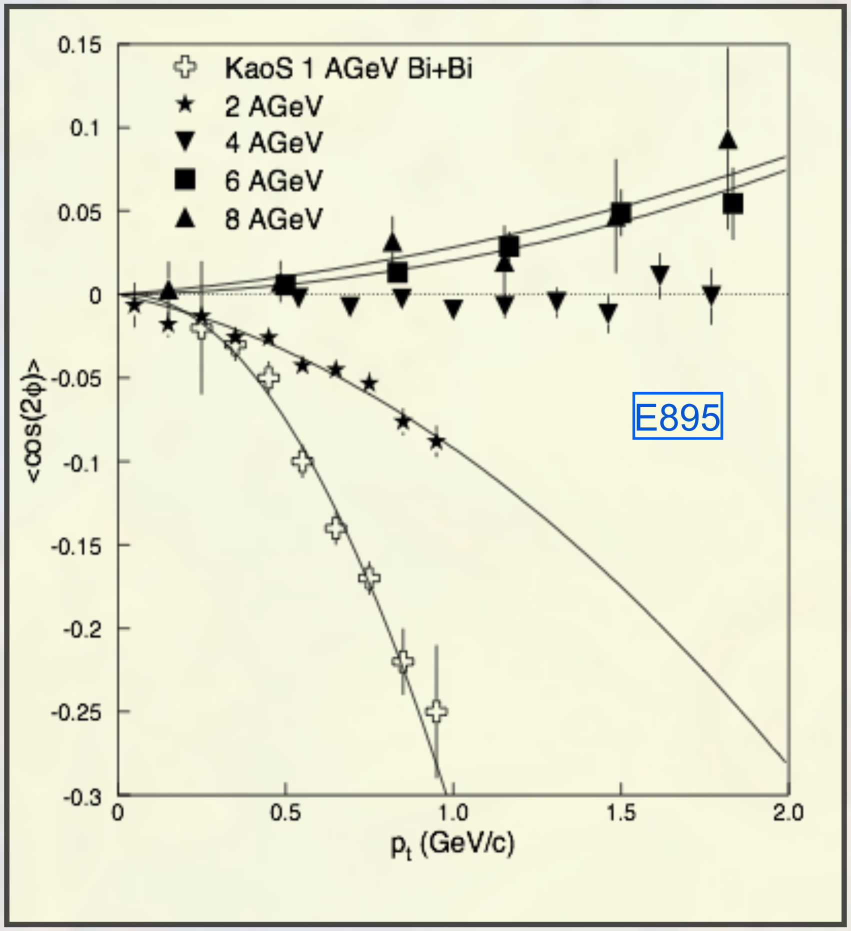
II. RP independent. (depends on method and in general can be greatly reduced)

$$\langle\cos(\phi_a + \phi_\beta - 2\phi_c)\rangle \overset{?}{=} \langle\cos(\phi_a + \phi_\beta - 2\Psi_{RP})\rangle\, v_{2,c}$$

Event generators: the signal is not zero, but different from expectations (e.g. same charge ~ opp. charge)

Elliptic flow at lower energies



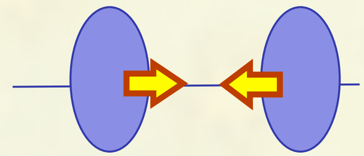


Elliptic flow vanishes at E_{lab} = 4 GeV !

Future program

Dedicated experimental and theoretical program focused on the local parity violation, and more generally on non-perturbative QCD: structure of the vacuum, hadronization, etc.

Experiment:



- U+U central body-body collisions

Such collisions ("easy" to trigger on) will have low magnetic field and large elliptic flow – clean test of the *LPV* effect.

- Beam energy scan / Critical point search

Look for a critical behavior, as *LPV* predicted to depend strongly on deconfinement and chiral symmetry restoration

- Isobaric beams

Colliding isobaric nuclei (the same mass number and different charge) and by that controlling the magnetic field

$$^{96}_{44}\mathrm{Ru}+{}^{96}_{40}\mathrm{Zr}$$

Note that such studies will be also very valuable for understanding the initial conditions, baryon stopping, origin of the directed flow, etc.

- High statistics PID studies / properties of the clusters

in particular with neutral particles; also in pp2pp experiment

Summary

1. Needs reliable calculations of the magnetic field

   and the effects of the electro-magnetic filed (e.g. anisotropic flow).

2. Background can be relatively smaller (!) at lower energies.

Future program. Theory.

Theory:

- Confirmation and detail study of the effect in Lattice QCD

Theoretical guidance and detailed calculations are needed:

- Dependence on collision energy, centrality, system size, magnetic field, PID, etc.
- Understanding physics background !
- Size/effective mass of the clusters, quark composition (e.g. equal number of q-qbar pairs of different flavors?).

PHYSICAL REVIEW D 80, 054503 (2009)

Numerical evidence of chiral magnetic effect in lattice gauge theory

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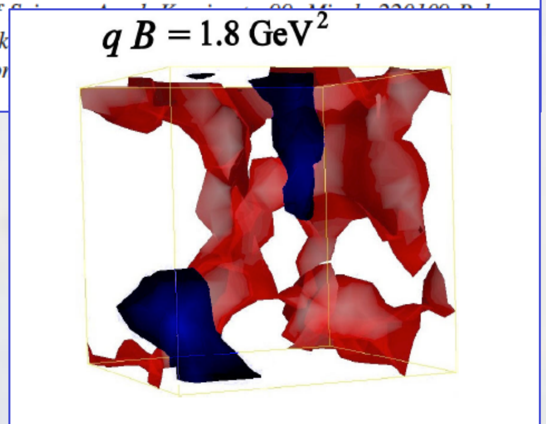

FIG. 2 (color online). The same as in Fig. 1 but for $qB = 1.8\ \mathrm{GeV}^2$ and for the configuration of non-Abelian gauge field.

Chiral magnetic effect in 2+1 flavor QCD+QED

arXiv:0911.1348v1 [hep-lat] 6 Nov 2009

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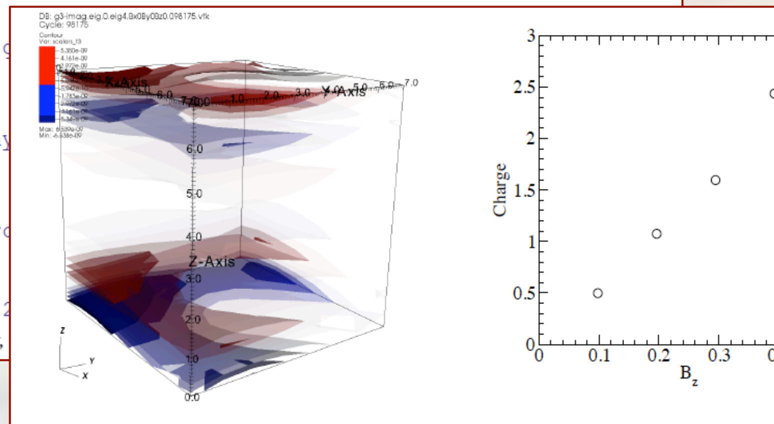
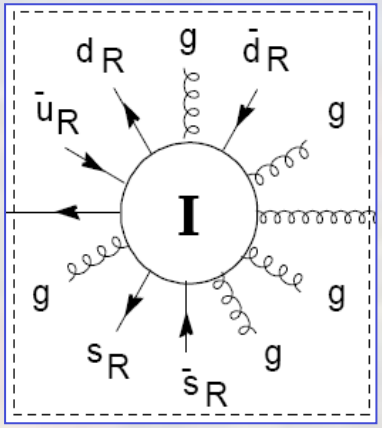


Figure 2: Left panel: Charge separation computed from a single near-zero-mode for a continu discretized on an 8^4 lattice. $B_z = 0.098175$. Translational invariance is broken in the $x-y$ Landau states of the quarks. Right panel: total amount of charge separated to the lower half in the z direction for the same configuration. All modes with chirality close to one are include The same amount, but with opposite sign resides in the top half.

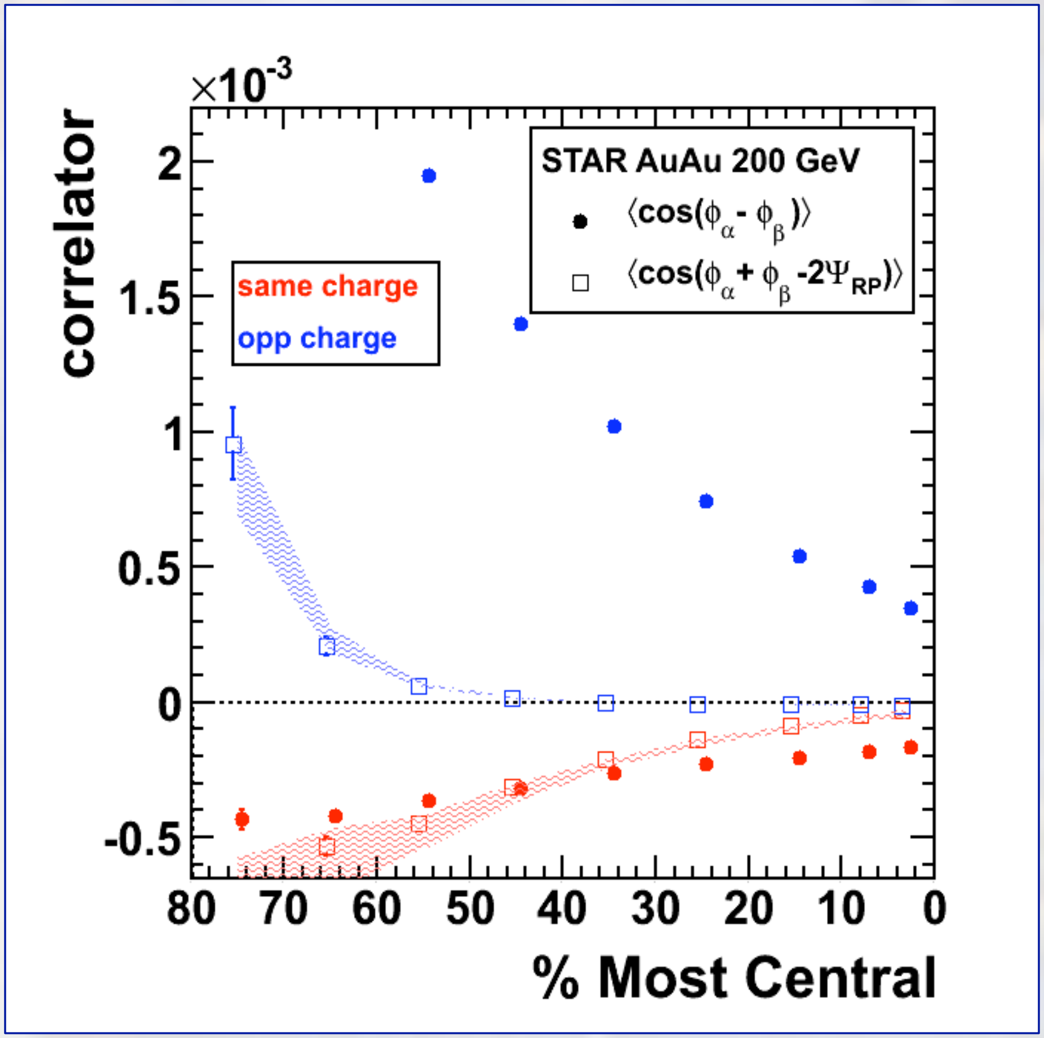
Nonperturbative Phenomena and Phases of QCD

Edward V. Shuryak

$$M_{sph} \approx \frac{30}{g^2(\rho)\rho} \sim 2.5\, GeV$$



Two-particle correlations and background



Two "remarkable" cancellations:
-- $\langle\cos(\varphi_1+\varphi_2)\rangle$, opposite sign, very close to zero
-- $\langle\cos(\varphi_1+\varphi_2)\rangle$, same sign, very close to $\langle\cos(\varphi_1-\varphi_2)\rangle$

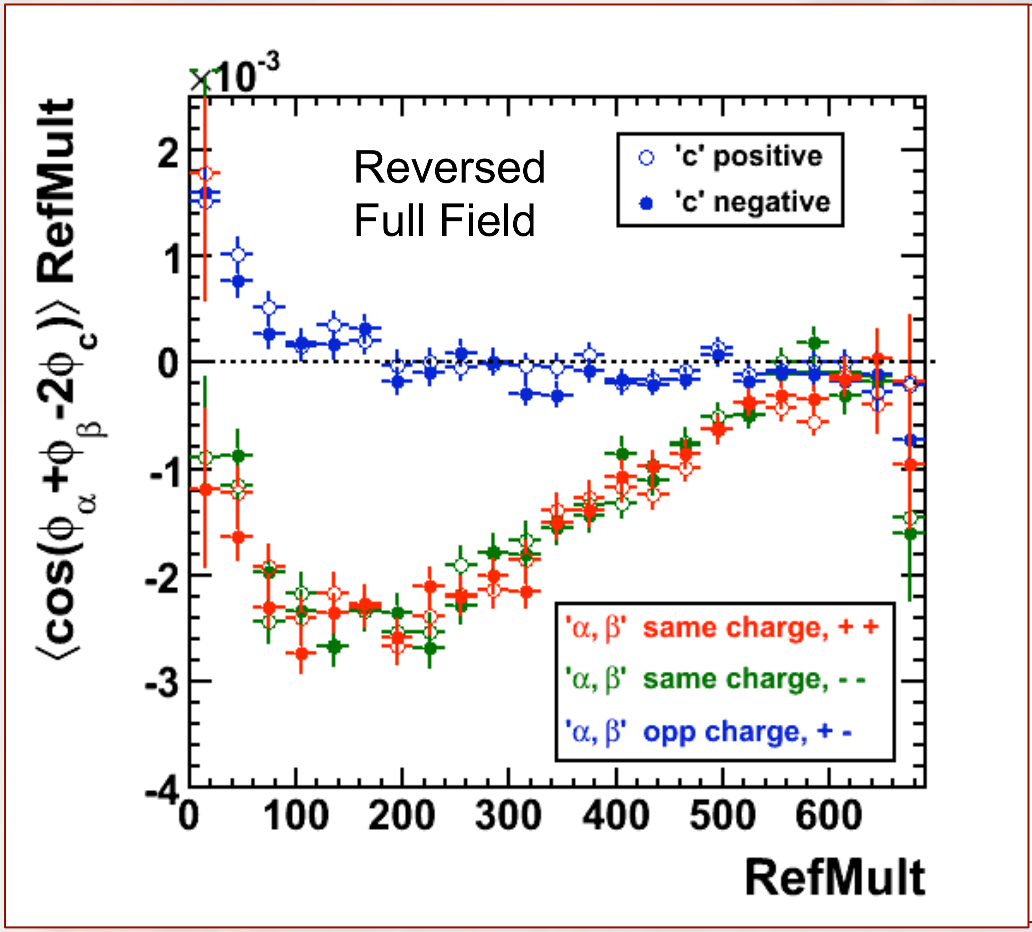
Consider 2-particle correlations of a type $\sim[a + 2b\cos(\varphi_1-\varphi_2)]$

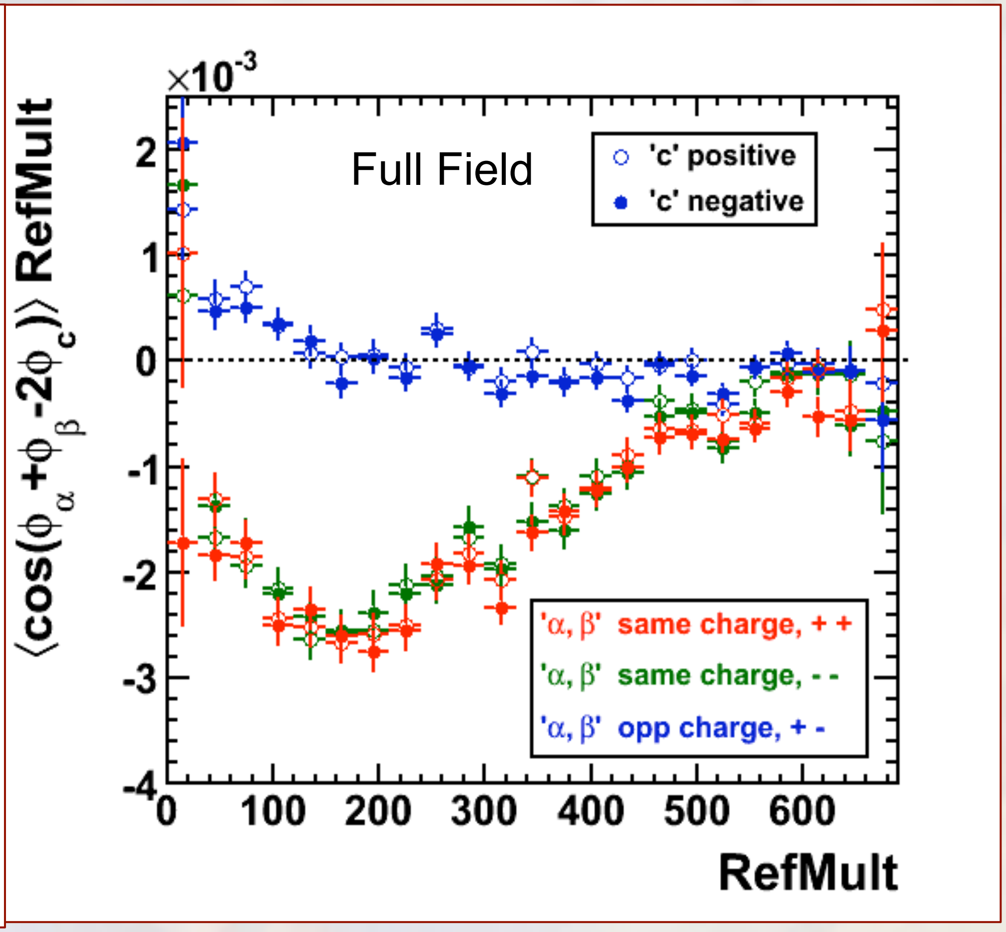
It leads to $\langle\cos(\varphi_1-\varphi_2)\rangle \approx b$
and $\langle\cos(\varphi_1+\varphi_2)\rangle = 2\,b\,v_2$

Solid – $\left\langle \cos\left(\varphi_1-\varphi_2\right)\right\rangle = \left\langle c_1c_2+s_1s_2\right\rangle$

Open -- $\left\langle \cos\left(\varphi_1+\varphi_2-2\Psi_{RP}\right)\right\rangle = \left\langle c_1c_2-s_1s_2\right\rangle$

Charge combinations



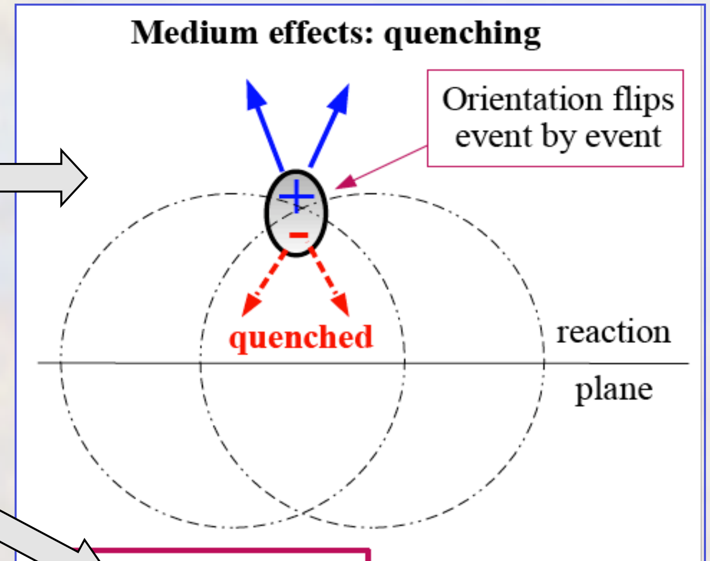


The results are independent of the charge of "c" particle.
(Note results for 3 particles all of the same charge)

Charge separation: expectations/predictions

Kharzeev, PLB 633 260 (2006) [hep-ph/0406125]
Kharzeev, Zhitnitsky, NPA 797 67 (2007)
Kharzeev, McLerran, Warringa, NPA 803 227 (2008)
Fukushima, Kharzeev, Waringa, PRD 78, 074033

- Same charge particles are preferentially emitted in the same direction, along or opposite to the system orbital momentum and magnetic field.
- Unlike-sign particles are emitted in the opposite directions.
- "Quenching" in a dense medium can lead to suppression of unlike-sign ("back-to-back") correlations.
- The effect has a "typical" Δη width of order ~ 1.
- The magnitude of asymmetry ~ 10^{-2} for midcentral collisions ➔ 10^{-4} for correlations.
- Effect is likely to be most pronounced at p_t ≤ ~ 1 GeV/c, though radial flow can move it to higher p_t
- Asymmetry is proportional to the strength of magnetic field
- "Signature" of deconfinement and chiral symmetry restoration



$$A_{\pi+} = -A_{\pi-} \simeq \frac{Q}{N_{\pi+}}$$