CP forbidden decays in AA and sphalerons in double diffractive pp collisions

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outline

- New check on CP-odd domains: the CP forbidden decays
- Why large domains are good (the theta is const, peaks in invariant mass)
- Are there CP-odd fluctuations in pp? In double diffractive pp? yes, it has rather developed theory of **sphalerons**
- Maybe those clusters have been already detected

Rafaelle Millo is Ph.D.student of my former student P.Faccioli who is professor at University of Trento. He visited in Dec. 09 for a week and we made (in 2 days) the following paper

Macroscopic Chirality Fluctuations in Heavy Ion Collisions should induce CP forbidden Decays

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If large-size fluctuations of chirality occur in heavy ion collisions, they can be described by a non-zero $\theta(x)$ in some region of space. We propose to look for particular decays of mesons, which are CP forbidden in the vacuum, with vanishing (or extremely small θ. We calculate the rates for some of such decays like $\eta \to \pi\pi$ and concluded that up to about one per mill of etas produced should decay in this way. We also discuss how those can be observed. These decays, as well as charge asymmetries observed are proportional to square of the CP-violating parameter θ averaged over fireball: observation of the decays thus would confirm that CP is locally violated, without complication related to geometry or magnetic field.

- We since have learned that A.R.Zhitnitsky had the same idea before us , he also calculated such decay in hep-ph/0003191
- All the parameters in the answer coinside, but he considered 2 flavors and we did 3 with eta-eta’ mixing., amplitude different by factor 3
- (At that time Kharzeev, Pisarski and Tytgut proposed metastable domains of theta vacua: this is a different
- Idea which did not worked out. Now we are all consider just CP-odd fluctuations

- Decays which were forbidden are now allowed:
  $\eta \Rightarrow \pi^+\pi^-$, $\eta' \Rightarrow \eta\pi$, $\eta' \Rightarrow \pi^+\pi^-$
- in the CP-odd spot <theta> is nonzero => disbalance between instantons and anti-instantons even at freezeout in the near-vacuum state
- Calculated from the chiral Lagrangian at nonzero theta

it is clear that any theta effect can only be visible **if no quark mass is zero:** thus theta-bar variable.

The CP-odd part of the ChPT Lagrangian in the leading chiral order and at leading order in the $1/N_c$ expansion, is equal to[18]

$$L_{eff} = -i\frac{\chi_{top}N_f}{2N_c}\bar{\theta}\left[\mathrm{Tr}[U(x) - U^\dagger(x)] - 2\log\det U(x)\right] \quad (5)$$

where $\bar{\theta}$ is an *effective* θ *parameter.*

$$\bar{\theta} \simeq \frac{F_\pi^2 N_c m_\pi^2}{4N_f\chi_{top}}\theta \quad (6)$$

$$\bar{\theta} \approx 0.06\theta$$

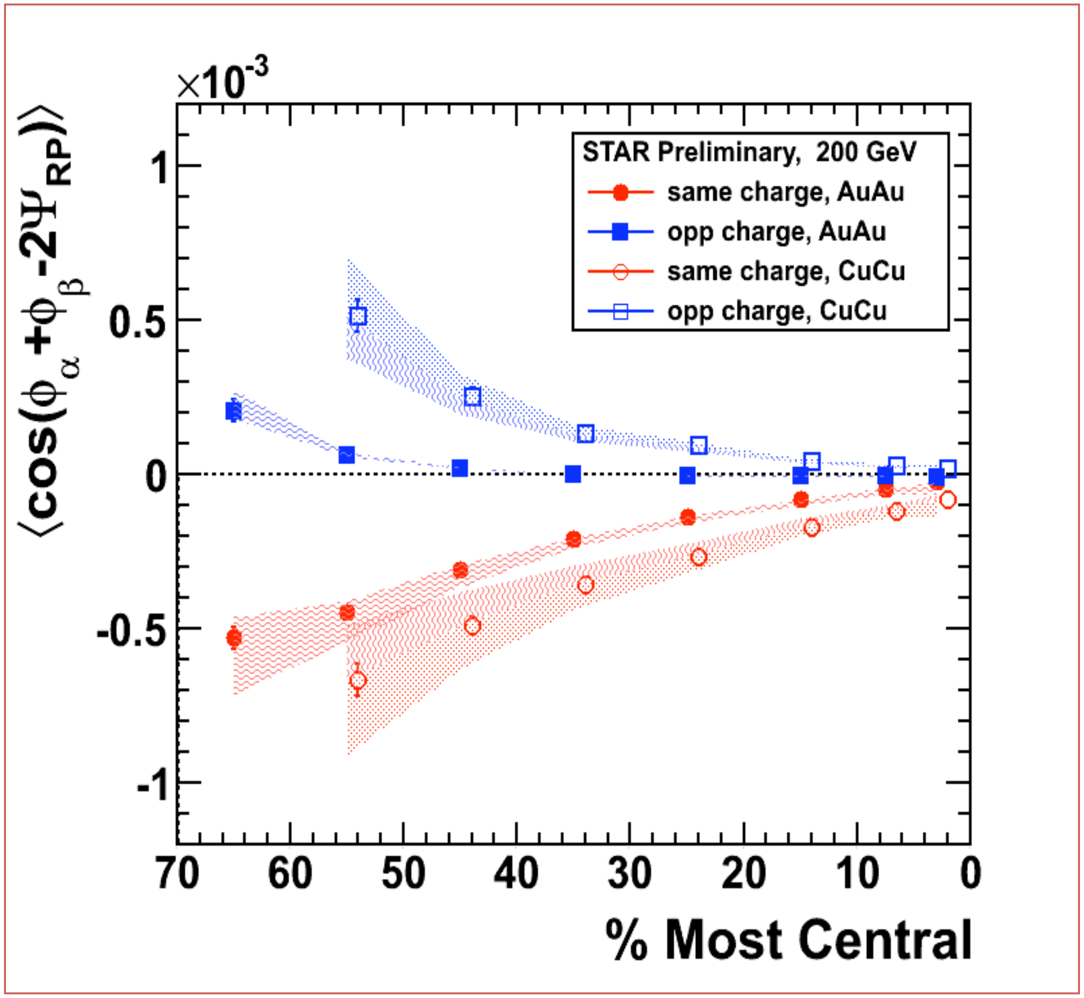
So, even for theta=O(1) thetabar is small

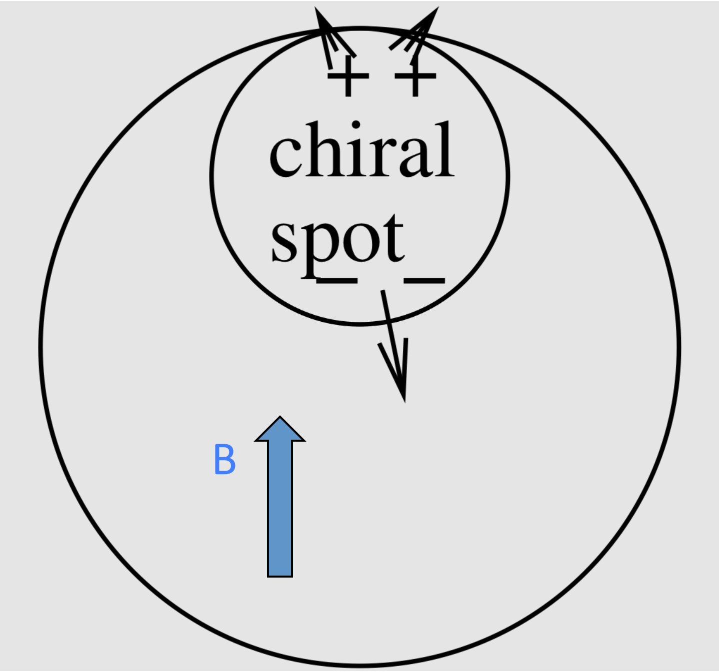
$$\Gamma_{\eta\to\pi^+\pi^-} = \frac{1}{32\pi^2}|A_{\eta\to\pi^+\pi^-}|^2\frac{|\bar{p}_\pi|}{m_\eta^2}\mathrm{d}\Omega$$

$$\simeq \frac{1}{24\pi}\frac{\chi_{top}^2}{F_\pi^6}\bar{\theta}^2\frac{\sqrt{m_\eta^2 - 4m_\pi^2}}{m_\eta^2} \approx 140MeV\bar{\theta}^2$$

$$P_{\eta\to\pi^+\pi^-} = \Gamma_{\eta\to\pi^+\pi^-}\Delta\tau_f\frac{V_{spot}}{V_f} \sim 0.1\theta^2\frac{\Delta\tau_f}{1fm}\frac{V_{spot}}{V_f}$$

What is the size of the "chiral spot"?





+- is strongly quenched in AuAu,
but it is nearly symmetric in CuCu

⇒At freezeout the size is large!
Comperable to the Cu nucleus

Can forbidden decays be observed?

- Because the chiral spot is so large, theta(x)contributes relatively small momentum
- k=O(1/R_{spot})

As a result, the invariant mass of the final state is modified by

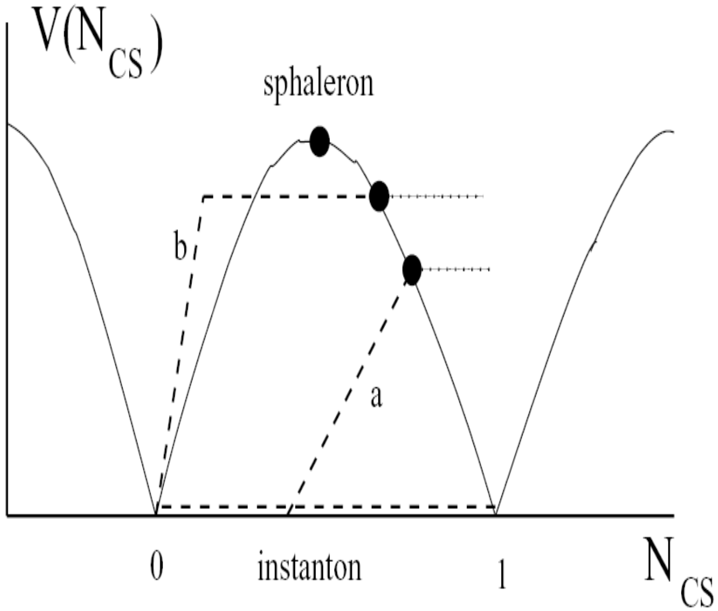
$$M_{inv} = \sqrt{m_\eta^2 - \vec{k}^2} \approx m_\eta[1 - \frac{\vec{k}^2}{2m_\eta^2}] \quad (14)$$

The magnitude of the spot size and the corresponding momenta will be discussed in the next section, for estimate we will use $k = 50 - 100\,MeV$. From the formula above we see that the correction to the mass is then in the range of $-(0.005..0.02)$.

Which is comparable to best experimental resolution in the invariant mass.

Small signal but with 10^9 events and about 10^6 pairs/event perhaps doable

No magnetic field needed, if it gives the same θ as charge asymmetry, it will prove that it is CP-odd



Let us start at the beginning

- The energy of Yang-Mills field versus the Chern-Simons number $N_{CS}=\int d^3x K_0$ is a periodic function, with zeros at integer points.

- The *instanton* (the lowest dashed line) describes tunneling between vacua. It is a path at E=0, it starts and ends at no field strength
- If energy is deposited, the paths (the dashed lines) goes up and emerge from ''under the barrier'' into real (Minkowskian) world at the turning points, where momenta (in the $A_0=0$ gauge) "$\vec{p}$" $=\frac{d\vec{A}}{dt}=\vec{E}=0$ $=>$ the field is magnetic
- Real time motion outside the barrier (shown by horizontal dotted lines) $=>$ explosions
- The maximal cross section corresponds to the top of the barrier, called the sphaleron =''ready to fall'' in Greek, according to Klinkhammer and Manton

Carter-Ostrovsky,ES: QCD sphalerons

- What is the minimal potential energy of static Yang-Mills field, consistent with the constraints:

(i) the given value of (corrected) Chern-Simons number.

(ii) the given value of the r.m.s. size $< r^2 >= \int d^3x r^2 B^2 / \int d^3x B^2$

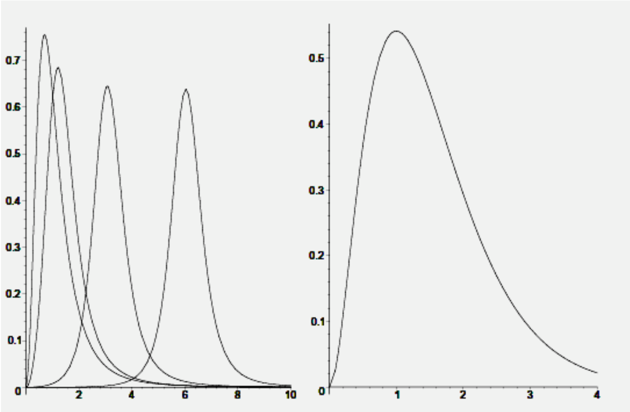
- Solution (found by D.Ostrovsky) is a ball made of three magnetic gluon fields (out of 8 in SU(3)) rotated around x,y,z axes

$B^2/2 = 24(1-\kappa^2)^2\rho^4/(r^2+\rho^2)^4$

$E_{stat} = 3\pi^2(1-\kappa^2)^2/(g^2\rho)$ $\tilde{N}_{CS} = \mathrm{sign}(\kappa)(1-|\kappa|)^2(2+|\kappa|)/4.$

Eliminating κ one gets the topological potential energy,

$\kappa = 0$ gives the sphaleron



Explosion of the Turning States

Left: the snapshots of the r^2 energy
Right: the spectrum of the produced fermions

- Solved both numerically (G.Carter) and analytically (by D.Ostrovsky based on work by Luescher and Schehter from 1977 which can also be via conformal transformation -Zahed)
- Sphalerons at $t = 0$ => (at large t) into a spherical transverse wave $4\pi e(r,t) = \frac{8\pi}{g^2\rho^2}(1-\kappa^2)^2\left(\frac{\rho^2}{\rho^2+(r-t)^2}\right)^3$

- ES+Zahed: new solution to the Dirac equation in exploding backgroun obtained by inversion of the fermionic O(4) zero mode of O(4) symmetric solution.

It explicitly shows how the quark acceleration occurs, starting from zero energy at t=0 to the final spectrum

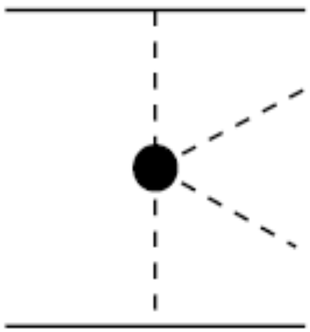
- The sphalerons produce one level crossing $N_F \bar{L}R$ quarks, and the antisphaleron-like clusters the chirality opposite.

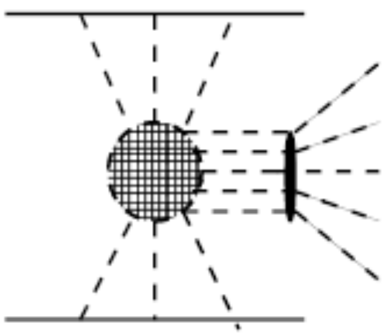
Pomeron from instantons

• Soft Pomeron with ‘‘instanton ladder’’ provides reasonable intercept and slope

•No Odderon SU(3) allows for a colorless combination of 3 gluons.

Perturbatively, the odderon/pomeron ratio is $O(\alpha_s)$ and not as suppressed as the data shows. Instantons are SU(2) beasts and do not allow it.





• Instanton is the only nontrivial field for which straight Wilson lines can be easily analytically calculated
$\int \tau^a A^a_\mu dx_\mu \sim (\tau^a \eta^a_{\mu\nu} e^t_\nu e^l_\mu) \int F(x^2) dt$

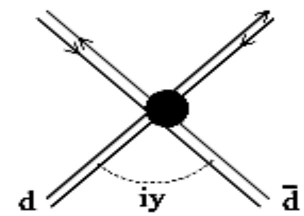
• The trick with rotating cross section to Minkowski seem to work perturbatively and in general (Meggiolaro): we tried it for instanton

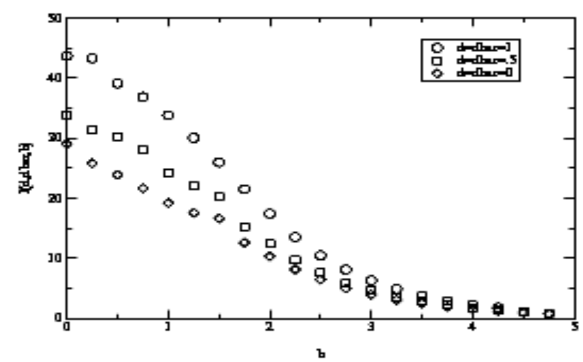
Example of the cleanest process: the double DIS, no hadrons, just excitation of one cluster (sphaleron)

Double-DIS $\gamma^*\gamma^*$ (Next linear collider?)

About the same small gluonic spot without any nucleon

ES, I. Zahed hep-ph/0307103, PRD in press
Two dipoles cross the instanton, the angle is changed to iy at the end of the calculation
$\sigma \sim d_1^2 d_2^2$ times the dimensionless function of the three 2-d vector variables $\mathbf{I}(\vec{d1}/\rho, \vec{d2}/\rho, \vec{b}/\rho)$ explicitly given and tabulated: see b-profile





Semiclassical Double-Pomeron Production of Glueballs, η' and clusters

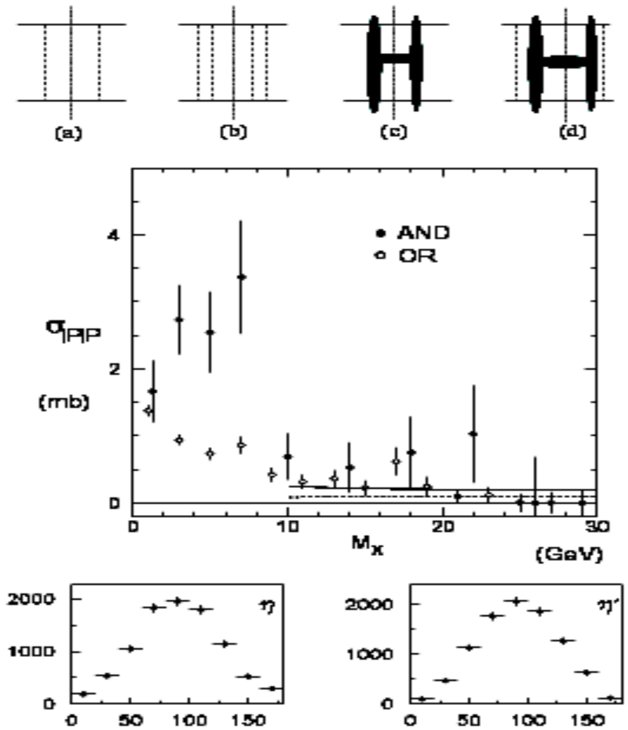
ES and I.Zahed,Phys.Rev. D68 (2003) 034001

Pomeron-Pomeron into cluster, cross section from UA8 collaboration: heavy gluonic clusters with isotropic decay. What are they?

Note: a cross section that is an order of magnitude larger than the one predicted by Pomeron factorization

WA102 collaboration at CERN, pp Double-Pomeron into identified central hadron: strong dependence of the cross section on the azimuthal angle ϕ (between two kicks to two protons), not expected from standard Pomeron phenomenology.

we get $cos^2(\phi)$ for P=+ and $sin^2(\phi)$ for P=-1.



Where the topology (CP-odd fluctuations) in AuAu come from?

- From topology already present in vacuum?

The estimate of the number of sphalerons produced in Au Au collisions have been estimated in [7]. If we only consider the number of vacuum instantons in an initial state "pancake" then we get a so called minimal number

$$N_{sphalerons} > n\rho^2 \pi R_{Au}^2 \sim 10 \qquad (2)$$

while the maximal number in [7] is an order of magnitude larger. This implies that the asymmetry of the fireball is $Q_{top} \sim \sqrt{N_{sphalerons}} = 3 - 10$. As the size of the sphalerons is $\sim \rho \ll R_{Au}$, each of them exploding leads to some chirally asymmetric spots.

- In order to know for sure, sphalerons should be produced in diffractive pp

[7] E. V. Shuryak, Nucl. Phys. A **717**, 291 (2003).

Final comments on sphalerons in pp:

- Double-diffractive cluster production in STAR +"Roman pots" => proposal pending
- Sphaleron produces 6 units of chirality!
  $\bar{u}_R u_L \bar{d}_R d_L \bar{s}_R s_L$
- Expected exclusive channels which are well observed like KKπ etc (but not $\pi\pi\pi$) like it was in η_c decays (Bjorken,Schafer)
- Because pp has magnetic field => charge

asymmetry in final states (Kharzeev)