Disoriented Chiral Condensate: possible applications

E. Kuraev, Z. Silagadze
YINR Novosibirsk

Alushta-2002

Introduction

QCD Lagrangian looks „deceptively simple":

$$L_{QCD}=\bar{q}(i\hat{D}-m)q-\frac{1}{2}\mathrm{tr}\,G_{\mu\nu}G^{\mu\nu},$$

$$\hat{D}=\hat{\partial}+ig\hat{A},\quad G_{\mu\nu}=\partial_\mu A_\nu-\partial_\nu A_\mu-g[A_\mu,A_\nu],$$

$$A_\mu=\frac{\lambda_a}{2}A_\mu^a,\quad a=1\dots 8\quad (SU(3)).$$

However 1) L_{QCD} do not contain hadrons (colorless)
2) selfinteraction – computational complexity
3) α_s too large at low energies.

But things are not so bad: many important features of low-energy dynamics are governed by symmetries of QCD and their breaking patterns.

For light quark flavors: $U_R(3)\times U_L(3)$:

$$q_R\to e^{i\frac{\lambda_0}{2}\theta_R^0}q_R;\quad q_L\to e^{i\frac{\lambda_0}{2}\theta_L}q_L;\qquad \lambda_0=\sqrt{\frac{2}{3}}\,I.$$

$$q_R\to e^{i\frac{\lambda_a}{2}\theta_R^a}q_R,\quad q_L\to e^{i\frac{\lambda_a}{2}\theta_L^a}q_L.$$

Fate of symmetry

$$U_R(3)\times U_L(3)=U_R(1)\times U_L(1)\oplus SU_R(3)\times SU_L(3)\qquad R\pm L=\begin{matrix}V\\A\end{matrix}$$

$U_R(1) \times U_L(1) = U_V(1) \times U_A(1)$

$U_V(1)$ is conserved in low energy limit (Charge-barion number)

$U_A(1)$ is broken due to quantum anomaly: As a result η' meson much more heavier than η.

Nonvanishing quark-antiquark condensate $\langle \bar{q}_R q_L \rangle \neq 0$ breaks $SU_R(3) \times SU_L(3) \to SU_V(3)$.

Goldstone bosons — eight pseudoscalar mesons (π, K, η) appears.

Mesons as a exitations on the $\bar{q}q$ condensate ground state.

$$\bar{q}_R q_L \sim \bar{q}q + \bar{q}\gamma_5 q$$

$\phi_{ab} = \bar{q}_{Rb} q_{La}$: $\Phi = S + iP = \frac{\lambda_a}{2}(\sigma_a + i\pi_a) + \frac{\lambda_0}{2}(\sigma_0 + i\pi_0)$.

$$\phi^+ = \phi$$

Effective Lagrangian for the field ϕ:

$$\mathcal{L} = \mathrm{Tr}(\partial_\mu \phi^+ \partial^\mu \phi) - V(\phi, \phi^+) + \mathcal{L}_{SB}$$

Symm. breaking

mesons self-interaction

$$V(\phi, \phi^+) = m^2 \mathrm{Tr}(\phi^+\phi) + \lambda \mathrm{Tr}(\phi^+\phi)^2 + \lambda' [\mathrm{Tr}(\phi^+\phi)]^2$$

higher orders excluded for renormalizable theory

$$\mathcal{L}_{SB} = \mathrm{Tr}(\phi + \phi^+)H + c(\det\phi + \det\phi^+).$$

$H = \frac{\lambda_0}{2} h_0 + \frac{\lambda_a}{2} h_a$: h_0, $h_8 \neq 0$ to preserve the isospin symmetry and PCAC.

h_8 generate mass difference π, K.

Scalar partner?

Physics of determinant term is related to $U_A(1)$ quantum anomaly – instantons (t. Hooft)

Linear σ-model – neglect effects of s-quark.

$$\phi = \frac{1}{2}(\sigma + i\vec{\pi}\vec{\tau}), \quad \vec{\tau} \to \text{Pauli matrices.}$$

$$\phi^+\phi = \frac{1}{4}(\sigma^2 + \vec{\pi}^2), \quad \mathrm{Tr}(\phi^+\phi)^2 = \frac{1}{8}(\sigma^2 + \vec{\pi}^2)^2$$

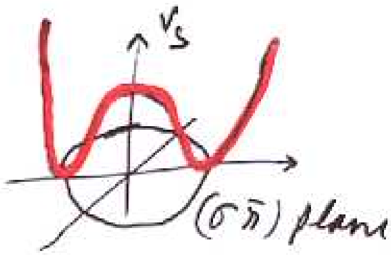
$$\mathcal{L} = \frac{1}{2}(\partial_\mu \sigma \partial^\mu \sigma) + \frac{1}{2}(\partial_\mu \vec{\pi} \partial^\mu \vec{\pi}) - \frac{\lambda_s}{4}(\sigma^2 + \vec{\pi}^2 - v^2)^2 + H\sigma,$$

$\lambda_s = \lambda' + \frac{1}{2}\lambda$; $v^2 = -\frac{m^2}{\lambda_s}$; $H = h_0$.

λ_s – the strength of the symmetry preserving term;
v – location of minimum ;
H – the strength of symmetry-breaking term.

Chiral limit $H=0$: the linear sigma model potential

$$V_s = \frac{\lambda_s}{4}(\sigma^2 + \vec{\pi}^2 - v^2)^2$$



"Mexican hat"

Chiral symm. is spontaneously broken $\langle\sigma\rangle = v$

(Pion field cannot develop nonzero vacuum expectation without parity violating).

The symmetry breaking term $V_{SB} = -H\sigma$ tilts the mexican hat

$\langle\sigma\rangle = \sigma_0 \neq v$

$$\sigma = \sigma_0 + \sigma'$$

$$\mathcal{L} \sim \frac{1}{2} m_\sigma^2 \sigma'^2 + \frac{1}{2} m_\pi^2 \vec{\pi}^2,$$

$$m_\pi^2 = \lambda_s(\sigma_0^2 - v^2); \quad m_\sigma^2 = \lambda_s(3\sigma_0^2 - v^2).$$

The vacuum expectation σ_0 is determined from the condition:

$$\frac{\partial V(\sigma,\vec{\pi})}{\partial\sigma}\Big|_{\vec{\pi}=0} = 0 \Rightarrow H = \lambda_s\sigma_0(\sigma_0^2 - v^2) = \sigma_0 m_\pi^2.$$

The PCAC relation:

$$\partial^\mu \vec{J}_{5\mu} = f_\pi m_\pi^2 \vec{\pi}.$$

Axial-vector current $\vec{J}_{5\mu}$ can be identified as a Noether current, associated with the $SU_A(2)$ transformation

$$\phi \to e^{i\frac{\tau_i}{2}\theta_i}\phi\, e^{i\frac{\tau_i\theta_i}{2}} : \quad \delta\sigma = -\pi_i\theta_i, \quad \delta\pi_i = \sigma\theta_i$$

$$\delta(\sigma^2+\vec{\pi}^2) = 0$$

$$\delta\mathcal{L} = \sigma\partial_\mu\pi_i\partial^\mu\theta_i - \pi_i\partial_\mu\sigma\partial^\mu\theta_i - H\pi_i\theta_i$$

$$\partial^\mu J^i_{5\mu}(x) = -\frac{\partial}{\partial\theta_i(x)}\delta\mathcal{L} = H\pi_i$$

So we identify

$$H = f_\pi m_\pi^2$$

Now we get:

$$\sigma_0 = f_\pi,\ \lambda_s = \frac{m_\sigma^2 - m_\pi^2}{2f_\pi^2};\ V^2 = \frac{m_\sigma^2 - 3m_\pi^2}{m_\sigma^2 - m_\pi^2} f_\pi^2;\ H = f_\pi m_\pi^2.$$

$M_\sigma = 600\,\frac{\text{MeV}}{c^2}$; $\lambda_s = 20$, $V = 90\,\text{MeV}$, $H = (120\,\text{MeV})^3$.

Disoriented chiral condensate

The linear sigma model in chiral limit $H \to 0$ has a generate minimum at $\sigma^2 + \vec{\pi}^2 = V^2$.

Vacuum state (our world) points in the σ-direction.

$\langle\sigma\rangle = f_\pi$; $\langle\vec{\pi}\rangle = 0$.

Vacuum state spontaneously violate the chiral symmetry.

Is whether one can change the vacuum state by some perturbation?

Really, it's possible.

In the case of ferromagnet one can change the magnetization in some large enough volume.

As a lava from a volcano cools below the Curie temperature the (weak enough) Earth magnetic field aligns the magnetization of ferromagnetic grains.

Lee and Wick (P.R. D9, 2291 (1974)) argued that domain formation phenomenon is possible in QFT.

The experimental method to alter the properties of vacuum is called „Vacuum engineering".

 (DCC)

Disoriented chiral condensate (DCC) formation is one of the new phenomena which may happen in very high energy collisions.

In such a collisions there is some probability that a high multiplicity final state will be produced with high entropy.

Collision fragments form a hot shell expanding isotropically with the velocity of order c.

This shell effectively shields the inner region up to hadronization time and then it breaks up into hadrons.

The hadronization time is rather large $\sim 3-5 \frac{fm}{c}$ and during this time the inner region has no idea about the chiral orientation of the normal, outside vacuum.

So the formation is possible of relatively large space domains where CC is temporarily disoriented. At later times DCC will relax back to the normal vacuum by emitting coherent burst of pion radiation.

Let us search the dynamics of initial vacuum exitation.

A short time after the collision $\sim 0.3-0.8$ fm/c the energy density drops enough to produce collective π and σ modes. At this stage linear σ-model is valid.

Initially the σ and π fields are surrounded by a thermal bath. We need σ-model at finite temperature

For this aim let decompose fields into the slowly varying classical part (the condensate) and high frequency thermal fluctuations:

$$\phi(x) = \phi_{cl}(x) + \delta\phi(x). \quad \langle\phi\rangle_{th} = \phi_{cl}\, ; \langle\delta\phi\rangle_{th} = 0$$

$\langle\,\rangle_{th}$ - thermal average.

$$\langle V_s\rangle_{th} = \frac{\lambda_s}{4}\left(\phi_{cl}^2 + \langle\delta\phi^2\rangle_{th} - v^2\right)^2$$

We will show now

$$\langle\delta\phi^2\rangle_{th} = \frac{T^2}{12}$$

Let decompose $\delta\phi(x)$ into the annihilation and creation operators:

$$\delta\phi(x) = \int \frac{d^3k}{(2\pi)^{3/2}} \frac{1}{\sqrt{2\omega_k}} \left(a(\vec{k})\, e^{-ikx} + a^+(k)\, e^{ikx}\right), \quad \omega_k = \sqrt{\vec{k}^2 + m^2}$$

$$[a(\vec{k}), a^+(\vec{k}')] = \delta^{(3)}(\vec{k}-\vec{k}').$$

At thermal equilibrium the thermal bath is homogeneous over the (large) spatial volume.

$$\langle\delta\phi^2\rangle_{th} = \frac{1}{V}\int d^3x\, \langle\delta\phi^2\rangle_{th} =$$

$$= \frac{1}{V}\int \frac{d^3k}{2\omega_k} \langle a(k)a^+(k) + a^+(k)a(k)\rangle_{th}.$$

Using $\langle a^\dagger(k)a(k)\rangle_{th} = \dfrac{V/(2\pi)^3}{e^{\frac{\omega_k}{T}}-1}$

we obtain:

$$\langle \delta\phi^2\rangle_{th} = \int \frac{d^3k}{(2\pi)^3}\,\frac{1}{\omega_k(e^{\frac{\omega_k}{T}}-1)} \xrightarrow[m\to 0]{} \frac{T^2}{12}.$$

each isotopic mode (π_0, π_+, π_-) give the same contribution. σ-meson do not contribute - it's too heavy and the condition $\frac{\omega_k}{T} \gg 1$ is not valid for them.

Then the thermal effective potential takes the form:

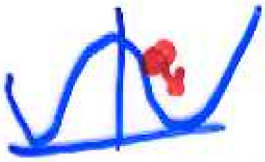
$$\langle V_s\rangle_{th} = \frac{\lambda_s}{4}\left(\sigma^2 + \vec{\pi}^2 + \frac{T^2}{4} - v^2\right)^2.$$

Minimum energy configuration corresponds to

$$\langle\sigma\rangle = \sqrt{v^2 - \frac{T^2}{4}} \quad ; \quad T_c = 2v = 180\,\text{MeV}.$$

σ-condensate completely melts down at $T_c = T$. And the information about „correct" orientation is lost. System finds itself out equilibrium situation — — near the top of Mexican hat

The vacuum expectation values will begin to develop while the system is „rolling down" towards the valley



This process will take some time.

Meanwhile the Goldstone modes (pions) will be **tachyonic:**

$$m_\pi^2 = \lambda_S(\langle\sigma\rangle^2 - v^2) < 0$$

(Effective σ is small: $V_S \approx \frac{\lambda_S}{4}\sigma^4 - H\sigma = 0$

$\langle\sigma\rangle \approx \left(\frac{4H}{\lambda_S}\right)^{1/3} \approx 3\,\mathrm{MeV} \ll f_\pi$)

The „oscillation frequences $\omega_k = \sqrt{\vec{k}^2 + m_\pi^2}$ will be imaginary for $\vec{k}^2$ small enough (long enough wavelengths).

Goldstone modes will grow with time exponentially. Zero mode ($\vec{k}=0$) is amplified most effectively.

As a result, a large sized correlated region will be formed with a nearly uniform field.

When the fields approach to the bottom of the potential this mechanism ceases to operate.

Let estimate the time of „rolling down".

<u>Technical details</u>

$$\Phi = \sigma + i\vec{\pi}\vec{\tau}$$

$U_V(1)$: $\Phi \to e^{i\frac{\lambda_0}{2}\theta_V^0}\,\Phi\, e^{-i\frac{\lambda_0}{2}\theta_V^0} = \Phi$

$U_A(1)$: $\Phi \to e^{i\frac{\lambda_0}{2}\theta_A^0}\,\Phi\, e^{i\frac{\lambda_0}{2}\theta_A^0} = e^{i\lambda_0\theta_A^0}\,\Phi \neq \Phi$

$SU_V(3)$: $\Phi \to e^{i\frac{\lambda_a}{2}\theta_V^a}\,\Phi\, e^{-i\frac{\lambda_a}{2}\theta_V^a} \neq \Phi$

$SU_A(3)$: $\Phi \to e^{i\frac{\lambda_a}{2}\theta_A^a}\,\Phi\, e^{+i\frac{\lambda_a}{2}\theta_A^a} \neq \Phi$

$$\left(e^{i\frac{\vec{\theta}\vec{\tau}}{2}}\,\Phi\, e^{i\frac{\vec{\theta}\vec{\tau}}{2}}\right)_A = \sigma + \delta\sigma + i\vec{\tau}(\vec{\pi} + \delta\vec{\pi})$$

$$\left(e^{i\frac{\vec{\theta}\vec{\tau}}{2}}\,\Phi\, e^{-i\frac{\vec{\theta}\vec{\tau}}{2}}\right)_V = \sigma + \delta\sigma + i\vec{\tau}(\vec{\pi} + \delta\vec{\pi})$$

Let investigate

$$\partial^r \vec{y}_r = 0 \; ; \; \partial^r \vec{y}_{5r} = \mu \vec{\pi}$$

which are valid during the evolution.
Applying A and V- variations and use Noether theorem

$$\vec{y}_r = \frac{\partial}{\partial(\partial_r \vec{\theta}_V)} \delta \mathcal{L} \Big|_V \; ; \; \vec{y}_{5r} = \frac{\partial}{\partial(\partial_r \vec{\theta}_A)} \delta \mathcal{L}$$

we obtain

$$\vec{y}_{5r} = \sigma \partial_r \vec{\pi} - \vec{\pi} \partial_r \sigma \; ;$$

$$\vec{y}_r = \vec{\pi} \times \partial_r \vec{\pi} .$$

Introducing proper time $\tau = \sqrt{t^2 - x^2}$; $\partial_r = \frac{x_r}{\tau} \frac{d}{d\tau}$:

$$\vec{y}_r = \frac{x_r}{\tau} \vec{\pi} \times \dot{\vec{\pi}} \; ; \; \vec{y}_{5r} = \frac{x_r}{\tau} (\vec{\pi} \dot{\sigma} - \sigma \dot{\vec{\pi}})$$

further

$$\partial_r \vec{y}^r = \frac{2}{\tau} \vec{\pi} \times \dot{\vec{\pi}} + \tau \frac{d}{d\tau} \left(\frac{\vec{\pi} \times \dot{\vec{\pi}}}{\tau} \right) = \frac{1}{\tau} \frac{d}{d\tau} (\tau \cdot \vec{\pi} \times \dot{\vec{\pi}}) = 0$$

$$\partial_r \vec{y}_5^r = \frac{1}{\tau} \frac{d}{d\tau} [\tau (\vec{\pi} \dot{\sigma} - \sigma \dot{\vec{\pi}})] = \mu \vec{\pi}$$

It follows:

$$\vec{\pi} \times \dot{\vec{\pi}} = \bar{a}/\tau \; ; \; \vec{\pi} \dot{\sigma} - \sigma \dot{\vec{\pi}} = \frac{\vec{b}}{\tau} + \frac{\mu}{\tau} \int_{\tau_0}^{\tau} \tau' \vec{\pi}(\tau') d\tau'.$$

$\vec{a}, \vec{b}$ - constant vectors.

$$\vec{a} \cdot \vec{b} = 0$$

Triad $\vec{a}, \vec{b}, c = \bar{a} \times \bar{b}$:

$$\left\{ \pi_a = 0 ; \left\{ \begin{array}{l} \pi_b \dot{\pi}_c - \pi_c \dot{\pi}_b = \frac{a}{\tau} ; \\ \pi_b \dot{\sigma} - \sigma \dot{\pi}_b = \frac{b}{\tau} ; \\ \pi_c \dot{\sigma} - \sigma \dot{\pi}_c = 0 . \end{array} \right. \right.$$

"Motion" is planar

$$\frac{\pi_c}{\sigma} = \frac{a}{b} = \text{const.}$$

for the case $b \gg a$: $\pi_c \ll \sigma$. So the motion in plane (σ, π_b). Let introduce

$$\pi_b = \rho \cdot \sin\theta \; ; \; \sigma = \rho \cos\theta$$

Than: $$\rho^2 \dot{\theta} = -\frac{b}{\tau}.$$

consequence of $\partial_\mu \gamma^\mu = 0$ and PCAC.

$\pi_b = \rho \sin\theta$
$\sigma = \rho \cos\theta$

Equation of motion:

$$\Box \vec{\pi} = -\lambda(\sigma^2 + \pi^2 - v^2)\vec{\pi}$$

$$\frac{1}{\tau}\frac{d}{d\tau}\left(\tau \frac{d\pi_b}{d\tau}\right) = -\lambda(\rho^2 - v^2)\pi_b$$

in terms of radial variable:

$$\ddot{\rho} + \frac{\dot{\rho}}{\tau} = \frac{b^2}{\rho^3 \tau^2} - \lambda(\rho^2 - v^2)\rho \; ; \quad (\rho^2 - v^2)\rho \simeq 2v^3 g$$

$$g = \frac{\rho - v}{v};$$

$$s = \sqrt{2\lambda}\, v\tau$$

$$s^2 \ddot{g} + s\dot{g} + s^2 g = \left(\frac{b}{v^2}\right)^2, \quad s \sim \frac{b}{v^2}$$

$$\tau_R \sim \frac{b}{\sqrt{2\lambda}\, v^3}$$ $\Rightarrow$ estimation of rolling down time.

Let consider now the formation and growth process of correlated domain.

$$m^2(t) = M_i^2\,\theta(-t) - m_f^2\,\theta(t) \quad \text{— tachyonic for } t>0.$$

Use the decomposition of field:

$$\phi(\bar{x},t) = \int \frac{d^3k}{(2\pi)^{3/2}} \frac{1}{\sqrt{2\omega_k}}\left[a(\bar{k})u_k(t)e^{i\bar{k}\bar{x}} + a^+(\bar{k})u_k^*(t)e^{-i\bar{k}\bar{x}}\right].$$

$$\left[\frac{d^2}{dt^2} + \bar{k}^2 + m^2(t)\right]u_k(t) = 0 \;\rightarrow\; \begin{cases} u_k(t) = e^{-i\omega_k t}, & t<0,\ \omega_k = \sqrt{M_i^2+\bar{k}^2}; \\ u_k(t) = A_k e^{\alpha_k t} + B_k e^{-\alpha_k t}, & \alpha_k = \sqrt{m_f^2 - k^2},\ t>0 \end{cases}$$

Matching at $t=0$: $\quad u_k^< = u_k^>\ ;\ \dot{u}_k^< = \dot{u}_k^>$:

$$A_k = \frac{1}{2}\left(1 - i\frac{\omega_k}{\alpha_k}\right);\quad B_k = \frac{1}{2}\left(1 + i\frac{\omega_k}{\alpha_k}\right).$$

The information about domain size is encoded in the equal-time correlation function

$$G(\bar{x},t) = \frac{1}{V}\int d^3y \,\langle \phi(\bar{x}+\bar{y},t)\,\phi(\bar{y},t)\rangle_{th}$$

$|\bar{x}| < L_D$: $\phi(\bar{x}+\bar{y},t)\,\phi(\bar{y},t) = \phi^2(y,t)$: $G = G(0,t)$ large

$|\bar{x}| \gg L_D$: $G(x,t) \to 0$ zero

L_D – is the domain size.

Neglecting $\langle aa\rangle_{th} \simeq \langle a^+a^+\rangle_{th} = 0$

$$G(\bar{x},t) = \frac{1}{V}\int \frac{d^3\bar{k}}{2\omega} |u_k(t)|^2 \left[\langle a a^+\rangle_{th} + \langle a(-k)a^+(-k)\rangle_{th} + \delta(\bar{0})\right] e^{i\bar{k}\bar{x}}.$$

Putting $\delta(0) = \frac{V}{(2\pi)^3}$; $\langle a^+(k) a(k) \rangle_{th} = \frac{V/(2\pi)^3}{e^{\frac{w_k}{T}} - 1}$

we obtain

$$G(\bar{x},t) = \int \frac{d^3k}{(2\pi)^3} \frac{1}{2w_k} |u_k(t)|^2 \, cth\left(\frac{w_k}{2T}\right) e^{i\bar{k}\bar{x}}.$$

Puttin further $cth\left(\frac{w_k}{2T}\right) = 1$ and using

$$|u_k(t)|^2 = \frac{1}{2}\left(1 + \frac{w_k^2}{\alpha_k^2}\right) ch(2\alpha_k t) + \frac{1}{2}\left(1 - \frac{w_k^2}{\alpha_k^2}\right)$$

we obtain for correlation function:

$$\tilde{G} = G(\bar{x},t) - G(\bar{x},0) = \frac{1}{4\pi^2 z^2} \int_0^{m_f} \frac{kz \cdot \sin kz}{w_k} \left(1 + \frac{w_k^2}{\alpha_k^2}\right) sh^2(\alpha_k t) \, dk$$

with $z = |\bar{x}|$, $k = |\bar{k}|$. $\quad w_k^2 = m_i^2 + \bar{k}^2$;

$\alpha_k^2 = m_f^2 - \bar{k}^2$.

$$\tilde{G} = \frac{m_i^2 + m_f^2}{16\pi^2 z^2} \int_0^{m_f} dk \cdot \frac{\sin kz}{w_k \alpha_k^2} e^{f(k)};$$

$g(k) = 2\alpha_k t + \ln kz$; $(g)_{extr} = g(k_0) - \frac{2t}{m_f}(k - k_0)^2$;

$g''(k_0) = -\frac{4t}{m_f}$; $\quad k_0 = \sqrt{\frac{m_f}{2t}}$

steepest descent method give:

$$\tilde{G}(\bar{x},t) = \hat{G}(0,t)\,\frac{\sinh(\kappa_0 z)}{\kappa_0 z}\,e^{-\frac{m x^2}{g t}}$$

$$L_D(t) = \sqrt{\frac{8t}{m_\ell}}\ ;$$

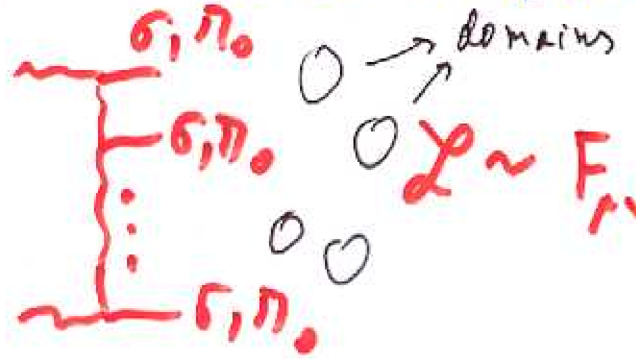
using $t = \frac{6}{\sqrt{2\lambda}\,v^3}$; $m_\ell^2 = \frac{1}{2}\lambda_s v^2$

$$L_D = \frac{1}{v}\sqrt{\frac{8\,6}{\lambda_s v^2}} = 1.4\,fm \cdot \sqrt{\frac{6}{v^2}}\,.$$

It was shown by Blaizot and Krzywicki PRD50 442, 1994 that probability for $\underline{6}$ to be large is small.

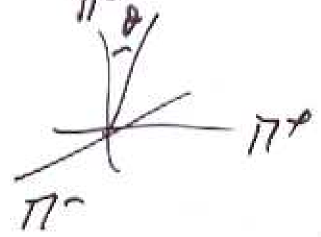
Typically DCC domains are quite small and so „formation of an observable DCC is likely to be a rather natural but rare phenomenon".

Formation of domains at Z_1, Z_2, $\gamma\gamma$ collisions



$$\mathcal{L} \sim F_{\mu\nu}F^{\mu\nu}\sigma_{(x)} + F_{\mu\nu}\tilde{F}_{\mu\nu}\pi_0(x)$$

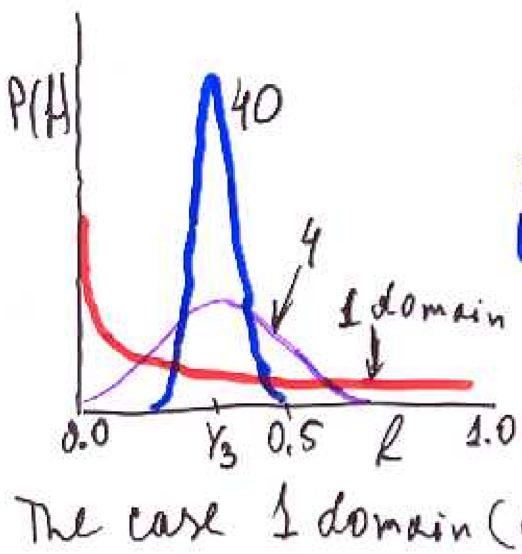
For a single ideal domain in isospin space:
f – fraction of π^0



$$f = \frac{|\pi_0|^2}{|\pi_0|^2 + |\pi_+|^2 + |\pi_-|^2} = \cos^2\theta \; ; \quad P(f)\,df = P(\Omega)\,d\Omega \sim d\cos\theta$$

isotropic (uniform) distribution in isospin space

$$P(f) \sim \frac{df}{\sqrt{f}}$$



The probability distribution for the fraction of neutral pions from 1; 4; and 40 domains

S. Gavin Nucl. Phys. A590 (1995), 163

$N \to \infty$: many uncorrelated small domains

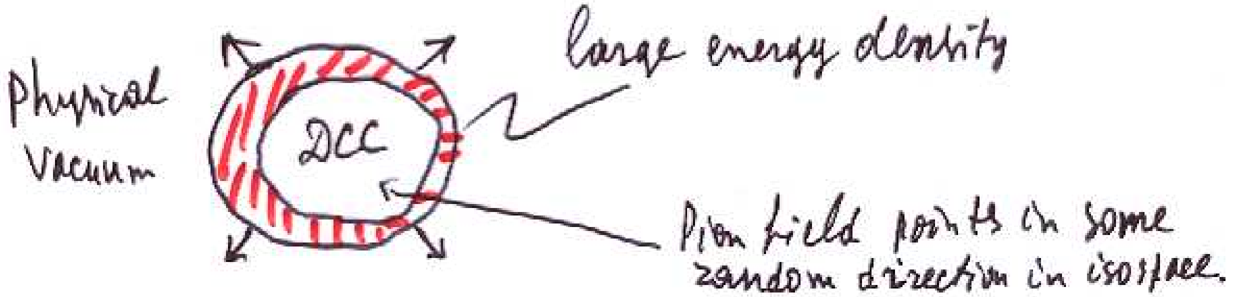
The case 1 domain (absence of neutral pions) agree with Centauros. Gaussian distr with $\langle f \rangle = \frac{1}{3} \Rightarrow$ contradict Centauros.

In tachionic mode the grows of fields as e^{t/τ_R} expected to be cutted due to nonlinearities of equations.
The linearized equation of motion imply that the average domain size is $R_D \sim 2\tau_R \sim m_\sigma^{-1}$

For $m_\sigma = 600$ MeV $R_D \sim$ pion radii (0,3 fm)
But m_σ is reduced in the high-energy density heavy ion environment.
Phase transition of 2-order (Correlation length is infinite):

$$\tau^{-1}_{R\,eff} \sim m_\sigma^{eff} \sim (T_c^2 - T^2)^{1/2}, \quad T_c = 132 \text{ MeV}$$

So, domain size up to 7 fm is possible. $m_\sigma^{eff}(T_c) \simeq 300 \frac{MeV}{c^2}$



$$\frac{dP(f)}{df} = \frac{1}{2\sqrt{f}} :$$

10% probability than in claster of 100 pions only 1 is neutral:
DCC might perhaps be an explanation of the mysterious Centauro events

Anselm and Ryskin estimate For RHIC:

MeV·fm ≈ 200

$P \cdot X = 2\pi$

Au-Au

$\sqrt{S_{NN}} = 200\,\text{GeV}$

$V \simeq 300\,\text{fm}^3$

$B = \frac{1}{7}\,\text{GeV} \approx 1/m_\pi$

$$n = \frac{(2\pi)^3}{V} \cdot \frac{dN}{dy} \cdot \frac{B^2}{2\pi E} e^{-BP_\perp} = \begin{cases} \frac{350\,\text{fm}^3}{V}, & P_\perp < 500\,\text{MeV} \\ \frac{2500\,\text{fm}^3}{V}, & P_\perp < 200\,\text{MeV} \end{cases}$$

$n > 1$:

условие Бозе-конденсации выполнено.

Central region Au + Au: 1000 pions for unit of rapidity noncoherent.

$$N_{dcc} \simeq \frac{\Delta V \cdot \gamma^3}{m_\pi} \simeq 30-100, \quad P_\perp < \frac{2}{\gamma}, \gamma > 3\,\text{fm}.$$

$$\left(E \frac{dN}{dp^3}\right)_{dcc} \simeq N_{dcc} \left(\frac{\gamma^2}{4\pi}\right)^{3/2} e^{-\frac{p^2\gamma^2}{4}}:$$

$f\left(E\frac{dN}{d^3p}\right) \to \pi^0$; $(1-f)\left(E\frac{dN}{d^3p}\right) \to$ charged.

Are Centauros an evidence DCC formation?

We would not any definite answer

An experiment at the Tevatron has been designed to look for DCC.

People leads to think more about non-equilibrium processes in h-e. nuclear collisions.