Possible mechanism of the condensation of the slow moving pion gas

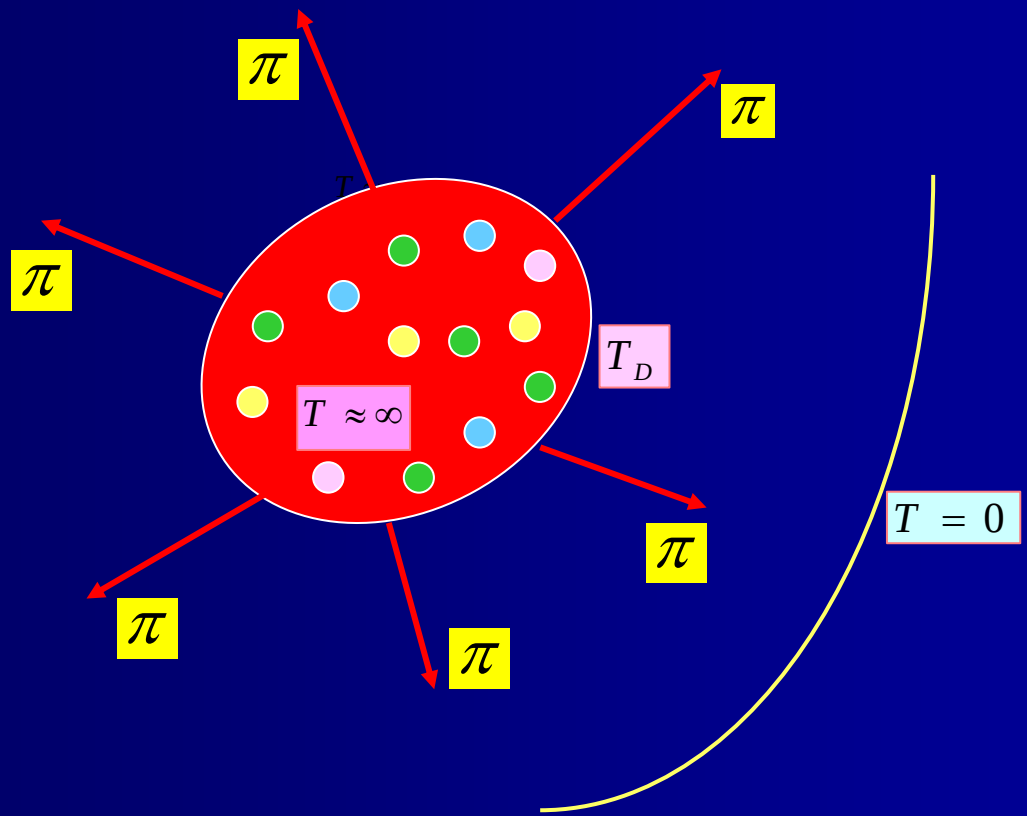
Edward Kuraev
JINR,
Dubna, Russia

Assumption (G.E.Solyakin,, 2004, PIYAF; S.M.Eliseev, JINR, private communications):

At heavy ion collisions the set of the slow pions probably is created.

This media has a size of sphere around the colliding point about several fm. One possible mechanism of it creation is **excitation of physical vacuum** (**EPV**) [M.Volkov et al. Part.& Nucl.,Let.,5(2004)122, hep-ph/0402163]

EPV: The part of energy is released by physical vacuum and is revealed (formation of quark-gluon plasma – **QGP**).
QGP is spread and cooling through transformation to the set of slow pions at the temperature of deconfinement $T_D \approx 140\,MeV.$



Let us estimate the Bose-Condensation temperature (chemical potential turns to zero):

$$T_B = 3.31\hbar^2 \left(\frac{N}{V}\right)^{2/3} \left(g^{2/3} m_\pi\right)^{-1} \approx T_D \approx 140\, MeV,$$

N~10, V~(10fm)^3, g~1.

[L. Landau, E. Lifshitz. Statistical Physics]

At further spreading $T<T_B$ one can expect the appearance of condensate. Naive analogy with Bose-gas for the ratio of "stopped" ($\varepsilon = 0$) molecules fraction is:

$$\frac{N_{\varepsilon=0}}{N} = 1 - \left(\frac{T}{T_B}\right)^{3/2}, \quad T < T_B,$$

(the pressure do not depend on volume).

Pion gas has some specific:

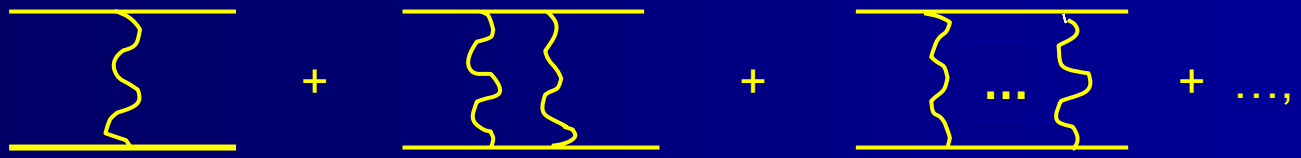
1) It is not stopped ($\varepsilon_{kin} > 0$);
2) It is coupled to subsets of pions that moving with same velocity:

$$v_o = \left(\frac{2k}{Nm_\pi c^2}\right)^{1/2} << c$$

with k – their total kinetic energy.

The mechanism of the interaction:

Pions may scatter each other elastically without large transversal moments. For rather small velocity differences the many photon (gluon) exchanges can be essential



which can be parameterized in terms of the wave function-solution of Bethe-Salpiter equation: Sommerfeld-Watson-Sakharov factor:

$$\left|\psi(0,v)\right|^2 = \frac{x}{1-e^{-x}} \approx 1+\frac{x}{2}, \quad x = \frac{\pi\alpha}{v}, \; v = \left| v_1 - v_2 \right|,$$

v - relative velocity.

For γ - exchanges the pionium atom can be created, but for α_s=1/137 the size of it is about 300 fm.

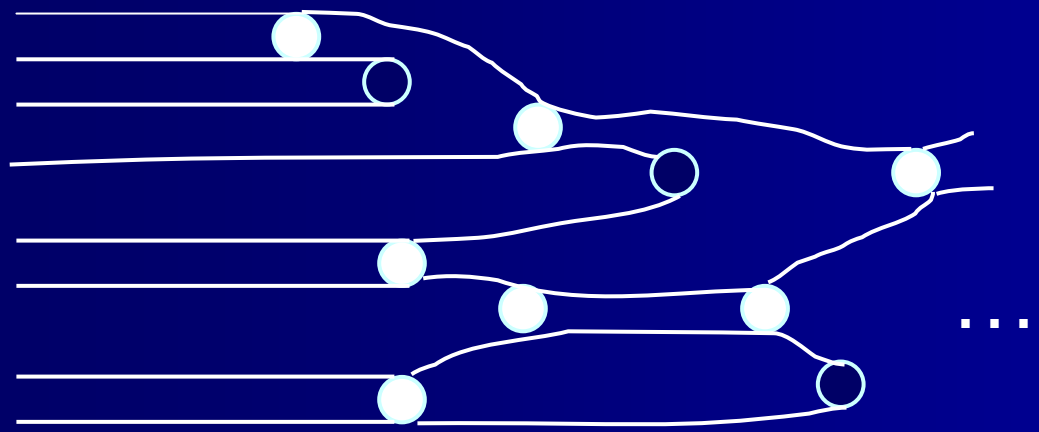
Much shorter distances provided by pure gluon exchange α_s/π~0.1; relative velocities can vary from $\alpha_s c$ up to v_0.

Schematically the interaction amplitude can be presented as a sum of two terms:

$$A_{ij} = a + \frac{b}{v_{ij}}.$$

Yang-Mills had proved in 1953 that gluons provide the attraction between hadrons (reinforce the gravitation).

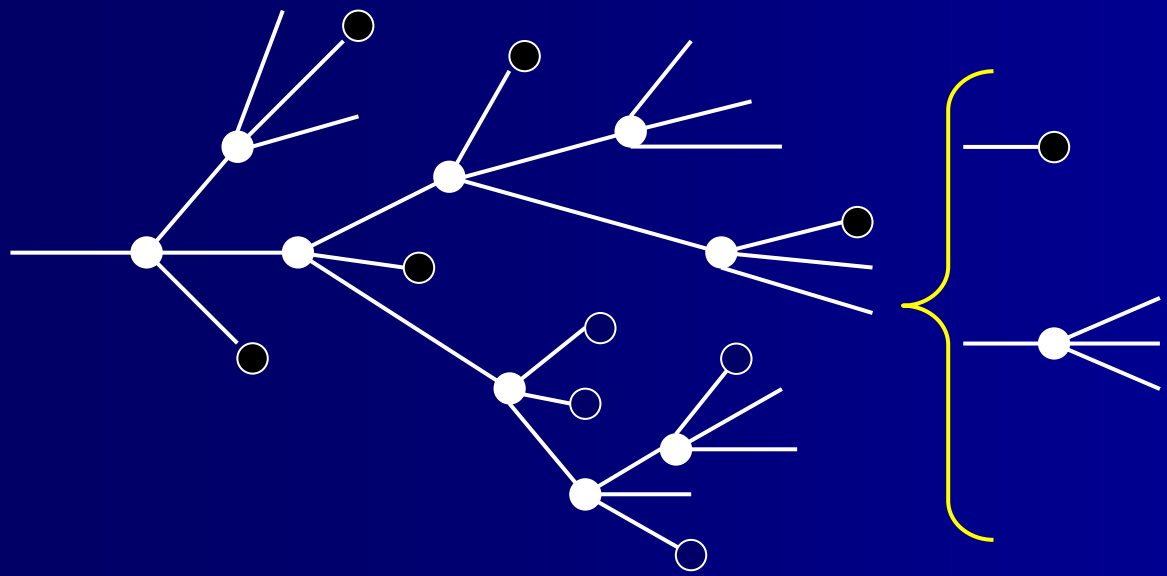
The dynamics of the set of N pions can be expressed in terms of these two types of vertices. Namely one can consider White ( ) or Black ( ) types:



After B-type the interaction of particles is “stopped”, and becomes of the part of the condensate and ruled out from the further dynamics.

This process, being considered backward in time has a resemblance with percolation process, widely studied in many applications of solid state physics.

[A.L. Efros "Physics and geometry of disorder", Quant, 19 (1982)], from N.V.Gogol "Dead souls" about the spreading the rumors:



- person with opinion (does not spread rumors)
- person spreads to 3 another persons

One can obtain (very roughly) the relative pairs velocities distribution:

$$P(v) \sim \sum_{pairs\ (ij)} \frac{1}{(N_{pairs})!} \int_{v}^{v_0} \prod_{i \neq j} \frac{dv_{ij}}{v_{ij}} \sim \left(\frac{v_0}{v} \right)^{\gamma}$$

with the positive quantity γ of order 1 ($\sim \alpha_s$, N_C).

The probability of the pion condensate can be expressed in form:

$$\frac{dw}{d\omega} \sim \left(1 - \frac{\omega}{\omega_c}\right)^{\eta}.$$

Concentration of white-type vertices **ω** is less than the critical ones ω_c .

In this way it can arrange (pure qualitative) the formula for the ratio of the number of "stopped" pions to the number as a function of temperature:

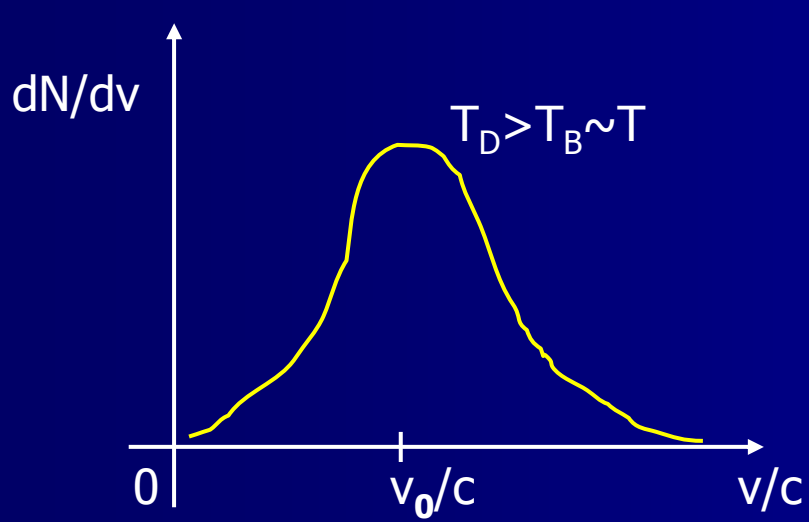
$$\frac{N_{\varepsilon=\varepsilon_0}}{N} = \left(1 - \left(\frac{T}{T_B}\right)^{\gamma}\right)^{\eta}, \quad 0 < T < T_B, \quad \gamma, \eta > 0.$$

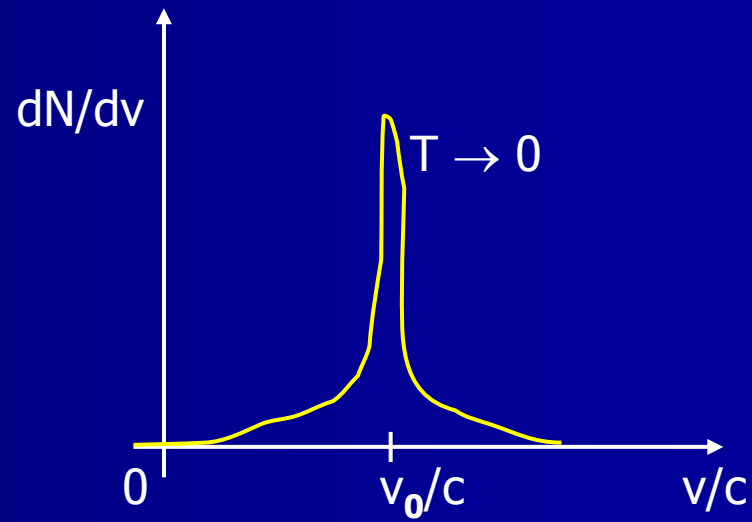
Let us consider the expected experimental consequences of creation of pionic condensate.

Charged pions produce muons: $\pi^{+/-} \rightarrow \mu^{+/-} + \nu_\mu$ (10^{-7} sec); neutral ones: $\pi^0 \rightarrow 2\gamma$ (10^{-16} sec).

At the rest of pion the energy of neutrino $E_\mu \approx 110$ MeV for photon $E\gamma \approx 70$ MeV.

Velocity distributions of pions have sharp peak around v_0/c:





The lack of understanding of some features of hadrons interactions and the necessity of improving recent theories.

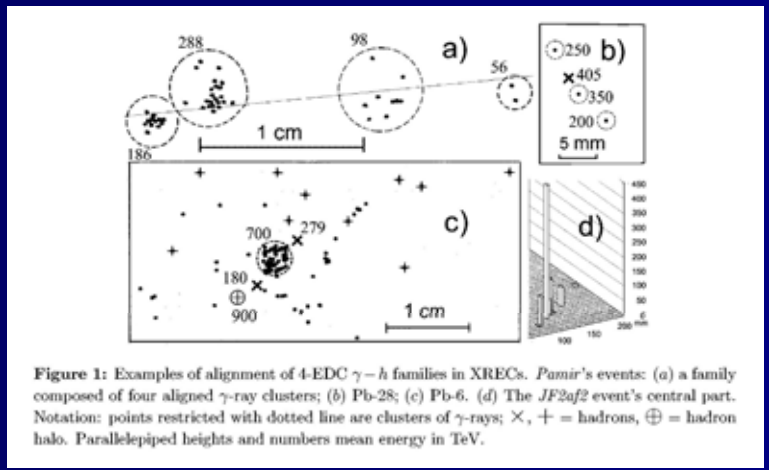
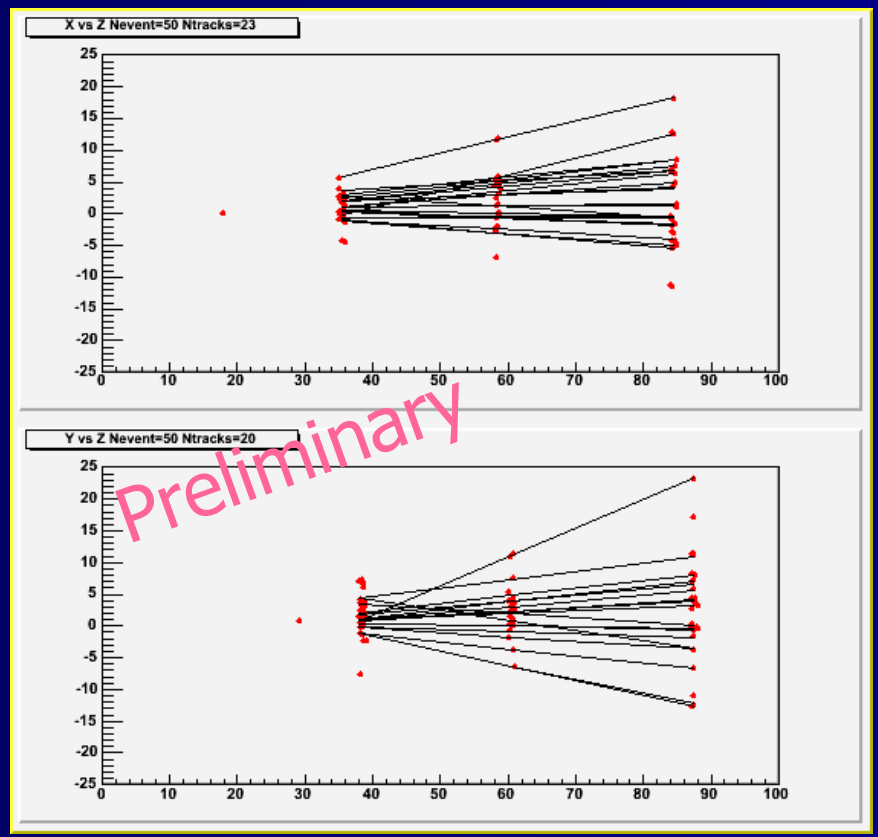


Figure 1: Examples of alignment of 4-EDC $\gamma - h$ families in XRECs. *Pamir*'s events: (*a*) a family composed of four aligned γ-ray clusters; (*b*) Pb-28; (*c*) Pb-6. (*d*) The *JF2af2* event's central part. Notation: points restricted with dotted line are clusters of γ-rays; $\times$, $+$ = hadrons, $\oplus$ = hadron halo. Parallelepiped heights and numbers mean energy in TeV.

[R.Mukhamedshin.JHEP05(2005)049].

"The alignment phenomenon of the most energetic subcores of atmospheric nuclear-electromagnetic cascades found in X-rays-emulsion chamber experiments with γ-h families cannot be explained with quark-gluon string models without assuming a process of a coplanar particle generation with large p_T at $\sqrt{s} \geq 4TeV$ ".

SVD-2 pA -> n_{ch} , project "THERMALIZATION"



Events with high multiplicity...