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IDEAS ON DETECTION AND MEASUREMENT OF STRENGTH OF THE CHROMO-MAGNETIC VACUUM BACKGROUND FIELD IN HIGH ENERGY REACTIONS

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Dedicated to Andrzej Bialas in honour of his 60th birthday

We review ideas on a new type of measurements which are sensitive to the QCD vacuum color-magnetic fluctuations: correlations in the axial asymmetry of the hadronic final states and joint decay probabilities of the resonances produced in the high energy e^+e^- collisions.

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1. Introduction

According to current theoretical ideas the vacuum state of QCD has a rich structure [1]. It is characterized by condensates of quarks and gluons. We shall study here possible effects of the gluon condensate on the process of string fragmentation. We follow ideas originating from paper by Nachtmann and Reiter [2] (see also [3] and [4]):

- the chromomagnetic vacuum field changes the trajectory of partons created in the high energy collisions, giving rise to various correlations between parton and, indirectly, hadron momenta.
- the chromomagnetic vacuum field polarizes the spin of quarks and anti-quarks in a way analogical to the transverse spin polarization of the electrons and positrons emitting the synchrotron radiation

Many will find these ideas extremely simple-minded. In principle, we do not reject such critics, however let us notice, that consideration of simple models often gives unexpected insight into the problem. In addition, what we propose is a contact with reality *i.e.* **measurements**. If the effects we describe are found, a sound theory certainly will follow.

2. The QCD vacuum structure

Following Ref. [1] let us consider the QCD vacuum as a sort of 'ether" showing a domain structure. Inside one domain the color-magnetic vacuum fields are highly correlated. From one domain to the next the correlation is small. Of course, the orientation of the color fields inside a domain and the domain sizes fluctuate.

The color correlations are characterized by the invariant distance a. The color fields at the origin of the Minkowski space, for instance, should be highly correlated with the field in the region

$$| x^2 | \leq a^2 . \tag{1}$$

The size a of the color domains and the fluctuation time τ of the color fields may be estimated on dimensional grounds

$$a \approx \tau \approx \Lambda^{-1},$$

where Λ is the QCD scale parameter. A detailed model for the QCD vacuum [5] as well as lattice calculations [6] indicate that correlation length is of order 0.2 - 0.35 fm *i.e.* smaller albeit not much smaller than a typical radius R of a light hadron: $R \approx 0.7 - 1$ fm.

3. Color string breakup

Let us consider high energy e^+e^- collision. At the stage of fragmentation of a color electric string, spanned between the initial $(q\bar{q})_i$ pair created in the collision, the secondary $(q\bar{q})_s$ pairs are created. For our discussion we adopt a very simplified picture of this breakup: all quarks have the same color and antiquarks have the same anti-color. Thus, in a domain of the constant chromomagnetic vacuum field with non-zero component along the string, all quarks turn in a plane transverse to the string in one direction and antiquarks in the opposite direction.

Is it reasonable to assume, that final state partons are indeed contained within the same color-magnetic field domain of the vacuum? At first glance this is inconsistent with the small correlation radius a. However condition (1) means that color fields are correlated in the vicinity of the light cone, therefore all except "wee" partons remain in the same domain for a large span of time. In the case of hadron collisions, where initial partons are separated in the transverse plane by a distance of order hadron radius R, the final state partons will share the same vacuum domain for time separations

$$| t_1 - t_2 | \leq \gamma_1 R (1 - \frac{a^2}{R^2}), \tag{2}$$

where t, γ is the proper time and Lorentz factor of the parton [3]. Thus the relative size a/R of the vacuum domain determines the strength of the effects attributable to the coherent action of the color magnetic vacuum field. We will come back to this point later.

Of course, even in the e^+e^- case one should take into account quantum uncertainty of the transverse position of the parton emerging from the string fragmentation process, what amounts to condition

$$k_T a \geq 1, \tag{3}$$

for all partons belonging to the same vacuum domain.

Let us consider trajectories of secondary $(q\bar{q})_s$ pairs in more detail. The reasoning which follows has been inspired by the model of origin of the jet handedness by Ryskin [7]. At the beginning, the transverse (with respect to the common axis of jets $\vec{l}$) momenta of these new partons are balanced

$$\vec{q}_\perp = -\vec{\bar{q}}_\perp$$

but, when moving in the the color magnetic field, they acquire equal, additional momenta $\delta\vec{q}_\perp = \delta\vec{\bar{q}}_\perp$ (as they have opposite color charges and move in opposite directions in the transverse plane). As the result we get a triad of vectors

$$\vec{q}_\perp^{\,\prime} = \vec{q}_\perp + \delta\vec{q}_\perp; \quad \vec{\bar{q}}_\perp^{\,\prime} = \vec{\bar{q}}_\perp + \delta\vec{q}_\perp; \quad \vec{l} \quad . \tag{4}$$

with the handedness *i.e.* the sign of the mixed product $(\vec{q}_\perp^{\,\prime} \times \vec{\bar{q}}_\perp^{\,\prime}) \cdot \vec{l}$ uniquely defined by the relative orientation of $\vec{l}$ and the background chromomagnetic field $\vec{B}$. *In a constant vacuum field all triads (in both jets) have the same handedness.*

For comparison, in the Ryskin model [7] the chromomagnetic fields are produced by the color-dipole moments of the original quark and anti-quark. The direction of these fields and thus the relative handedness of triads (1) in the opposite jets depends on the spin alignment for the original $(q\bar{q})_i$ pair, but is always CP-symmetric. In the particular case of the aligned spins, as in the case of e^+e^- collisions, *handedness produced by color-dipole chromomagnetic fields is opposite for the quark and anti-quark jets.* As will be discussed later the effect of a constant vacuum chromomagnetic field can be easily distinguished from the other QCD effects merely by observing the *"wrong sign" handedness correlation* between jets. This property seems to be very important since if we propose a measurement based on so speculative reasoning, we have to be sure that interpretation of its results cannot be obtained by standard theory, in this case perturbative QCD.

The value of the additional transverse momentum $\mid \delta\vec{q}_\perp \mid$ acquired by the parton can be roughly related to the strength of the vacuum chromomagnetic field assuming that the parton before loosing its color charge traverses a typical hadronization distance $1/\Lambda$ [3]. Then

$$\mid \delta\vec{q}_\perp \mid = \frac{\sqrt{\alpha_s}\langle \mid (\vec{B}\cdot\vec{l}) \mid \rangle}{\Lambda}. \tag{5}$$

It is interesting to note that $\mid \delta\vec{q}_\perp \mid$ may be quite substantial. One parameter characterizing the vacuum fields is the expectation value of the square of the gluon field strength introduced by Vainstein *et al.* [8]. Using the experimental value given in the recent review of non-perturbative methods in QCD [9],

$$\langle 0 \mid 4\pi\alpha_s \vec{B}^a\vec{B}^a \mid 0\rangle \approx (700\ \mathrm{MeV})^4$$

we have $\sqrt{\alpha_s}\langle \mid (\vec{B}\cdot\vec{l}) \mid \rangle/\Lambda \approx 200$ MeV *i.e.* a quantity comparable to the average parton transverse momentum ($\approx$ 400 MeV)! Thus, at the parton level the axial asymmetry induced by the vacuum field may be large enough but, of course, it is washed out to a large extent after the hadronization.

4. Measurement of the axial asymmetry at the hadron level

Transfer of the axial asymmetry from the parton level to the hadron level is possible, at least in principle, due to the local retention of the parton quantum numbers in the hadronization process. A possibility of discovering of such an asymmetry may crucially depend on the proper choice of the kinematical variables which we employ in our analysis of the hadronic final state.

The first one was originally proposed by Nachtmann [10]. Nachtmann showed that a three particle correlation in a jet can probe the helicity of the parton initiating the jet. The idea was rediscovered by Efremov, Mankiewicz and Tornqvist [11], and they named the correlation the 'handedness' of a jet.

To measure jet handedness typically one chooses [12] the oppositely charged tracks of the highest momentum and from their momenta $\vec{k}_+$, $\vec{k}_-$ one constructs quantity (related to the jet handedness)

$$\omega = \vec{t}\cdot(\vec{k}_+ \times \vec{k}_-), \tag{6}$$

where $\vec{t}$ is the thrust axis in the jet direction. A signal of an axial asymmetry of the jet would be visible as a nonzero mean $\langle\omega\rangle$. In the Nachtmann model it is proportional to the polarization of the initial quark. The correlation between ω_1 and ω_2 in the opposite jets:

$$R_\omega = (\langle\omega_1\omega_2\rangle - \langle\omega_1\rangle\langle\omega_2\rangle) \tag{7}$$

was for the first time considered by Efremov, Potashnikova and Tkatchev [13]. So defined ω and R_ω measures indeed the axial asymmetry of the final hadronic state, however its application to our problem has to be considered as rather limited. Its has two drawbacks. It tests asymmetry locally and in addition momenta of hadrons (mostly pions) in the central region of the e^+e^- collisions are very weakly related to the parton momenta. For these reasons in paper [14] we have proposed a different method which takes into account that the *asymmetry induced into parton state by the interaction with the vacuum background chromomagnetic field has global character i.e.* it is distributed over the whole interaction volume. So, we construct a measure of the jet handedness from cumulative variables. At first, we define cumulant of the transverse momentum for positive and negative particles separately

$$\vec{P}_\perp^{\pm}(y_{\mathbf{min}}, y_{\mathbf{max}}) = \sum_j \vec{k}_{\perp j}\Theta(y_{\mathbf{max}} - y_j)\Theta(y_j - y_{\mathbf{min}})\Theta(\pm Q_j)\,, \tag{8}$$

where $\vec{k}_{\perp j}, y_j, Q_j$ denote the transverse momentum, rapidity and charge of the j-th particle, $\Theta(x)$ is the step function equal to $1(0)$ for $x > 0 (x < 0)$. This quantity is the sum of the transverse momenta of all positive (negative) particles in the rapidity range $(y_{\mathbf{min}}, y_{\mathbf{max}})$.

$$P_\perp(y_{\mathbf{min}}, y_{\mathbf{max}}) = \mid (\vec{P_\perp}^{+}(y_{\mathbf{min}}, y_{\mathbf{max}}) + \vec{P_\perp}^{-}(y_{\mathbf{min}}, y_{\mathbf{max}})) \mid \tag{9}$$

is the length of the total transverse momentum vector in the above rapidity range.

The standard assumption of the local compensation of transverse momentum, equivalent to the assumption that $(q\bar{q})_s$ pairs do not carry momentum transverse to the jet axis, leads to the prediction, that far from the phase space boundary $P_\perp$ remains independent of $\Delta y = \mid y_{\mathbf{min}} - y_{\mathbf{max}} \mid$ *i.e.* does not depend on the number of $q\bar{q}$ pairs created in the rapidity range $(y_{\mathbf{min}}, y_{\mathbf{max}})$. However, in the model with the background chromomagnetic field the situation is different: each $(q\bar{q})_s$ pair acquires the transverse momentum $2 \mid \delta\vec{q}_\perp \mid$. It is randomly oriented in the plane transverse to the jet direction, thus we expect that the average value of the transverse momentum cumulant grows proportionally to the square root of the average number $N_{q\bar{q}}$ of $(q\bar{q})_s$ pairs in the rapidity range $(y_{\mathbf{min}}, y_{\mathbf{max}})$:

$$\langle P_\perp(y_{\mathbf{min}}, y_{\mathbf{max}})\rangle \approx \sqrt{N_{q\bar{q}}} \mid \delta\vec{q}_\perp \mid = \sqrt{\bar{n} \mid y_{\mathbf{min}} - y_{\mathbf{max}} \mid} \mid \delta\vec{q}_\perp \mid\,, \tag{10}$$

where $\bar{n}$ is the average number of $q\bar{q}$ pairs per unit rapidity interval and $\langle\ \rangle$ denotes an average over events. In other words the transverse momentum shows the effect of diffusion.

Employing the cumulative variables $\vec{P}_{\perp}^{\pm}$ we can construct the mixed product analogical to that in Eq. (3):

$$\Omega(y_{\mathbf{min}}, y_{\mathbf{max}}) = (\vec{P}_{\perp}^{+}(y_{\mathbf{min}}, y_{\mathbf{max}}) \times \vec{P}_{\perp}^{-}(y_{\mathbf{min}}, y_{\mathbf{max}})) \cdot \vec{l}, \qquad (11)$$

where $\vec{l}$ is the direction along the common axis of the two jets. Its sign is related to the handedness of triads (1). Note that we do not use vector $\vec{t}$ oriented in the jet direction, as in formula (3), in order to avoid a singularity at the rapidity $y = 0$, so that we can integrate over the rapidity range which includes this point. We can define also the correlation function R_{Ω}

$$R_{\Omega} = (\langle \Omega_1 \Omega_2 \rangle - \langle \Omega_1 \rangle \langle \Omega_2 \rangle), \qquad (12)$$

where $\Omega_1 = \Omega(y_{\mathbf{min}}, y_{\mathbf{max}})$ and $\Omega_2 = \Omega(-y_{\mathbf{min}}, -y_{\mathbf{max}})$. This quantity is, in turn, analogical to R_{ω} defined in Eq. (4).

As we have seen before, the handedness of triads (1) induced by the chromomagnetic vacuum background field in the opposite jets is the same. Let us see how it is transferred to the quantity Ω defined above.

The assumptions of the local retention of the parton quantum numbers, of the momentum conservation and the isospin symmetry lead to the approximate expressions in terms of the quark momenta

$$\vec{P}_{\perp}^{+}(y_{\mathbf{min}}, y_{\mathbf{max}}) \approx \frac{1}{3}(1+\beta)\sum_{i} \vec{q}_{\perp i} + \frac{1}{3}(1-\beta)\sum_{i} \vec{\bar{q}}_{\perp i}, \qquad (13)$$

$$\vec{P}_{\perp}^{-}(y_{\mathbf{min}}, y_{\mathbf{max}}) \approx \frac{1}{3}(1-\beta)\sum_{i} \vec{q}_{\perp i} + \frac{1}{3}(1+\beta)\sum_{i} \vec{\bar{q}}_{\perp i}. \qquad (14)$$

$\sum_i$ extends over all $(q\bar{q})_s$ pairs falling into the rapidity range $(y_{\mathbf{min}}, y_{\mathbf{max}})$. It should be noted that relations (10) and (11) are applicable for both jets only in the central rapidity range, where parton states in both jets are neutral in charge and flavor.The situation is much less clear in the quark (anti-quark) fragmentation regions — we will come back to this problem later.

The parameter β in the above formulas can be related to the experimentally measured quantity

$$\langle \Delta P_{\perp} \rangle = \langle | \vec{P}_{\perp}^{+} - \vec{P}_{\perp}^{-} | \rangle \approx \frac{4}{3}\beta \langle | \sum_{i} \vec{q}_{\perp i} | \rangle \approx \frac{4}{3}\beta \sqrt{N_{q\bar{q}}} \langle q_{\perp} \rangle \qquad (15)$$

where, in analogy with formula (7), we have used the argument about the random walk in the transverse momentum plane to get

$$\langle | \sum_i \vec{q}_{\perp i} | \rangle \approx \sqrt{N_{q\bar{q}}} \langle q_\perp \rangle . \tag{16}$$

Note that this formula does not contain $\vec{B}$ because of cancelation of the $\delta\vec{q}_{\perp i}$ components in (12). From (2), (8), (10), (11) and (12) we get

$$\Omega(y_{\mathbf{min}}, y_{\mathbf{max}}) \approx \Omega(-y_{\mathbf{min}}, -y_{\mathbf{max}}) \approx \frac{8}{9}\beta\sqrt{N_{q\bar{q}}}\sqrt{\alpha_s}\langle q_\perp\rangle \frac{(\vec{B}\cdot\vec{l})}{\Lambda} . \tag{17}$$

The average $\langle\Omega\rangle$ vanishes, as for the randomly oriented chromomagnetic vacuum field $\langle(\vec{B}\cdot\vec{l})\rangle = 0$. The correlation function R_Ω has a non zero value

$$R_\Omega(y_{\mathbf{min}}, y_{\mathbf{max}}) \approx \frac{4}{9}\langle\Delta P_\perp\rangle^2 \alpha_s \frac{\langle | (\vec{B}\cdot\vec{l}) | \rangle^2}{\Lambda^2} , \tag{18}$$

where we employed the formula (12) to eliminate $\beta N_{q\bar{q}}$, so that R_Ω is related to the vacuum field strength only through the parameters which can be measured in the same experiment.

Both methods of the detection of the axial asymmetry of the final hadronic state, "global" and "local", can be improved in several ways. In an experiment with particle identification we could employ strong flavor correlations between partons and hadrons. The $s\bar{s}$ pair should be strongly correlated with K^+K^- pair in the hadronic final state, so construction of ω, R_ω, $P_\perp$, $\Delta P_\perp$ and Ω from $K^\pm$ momenta may be beneficial in spite of very much diminished statistics provided that the effect of secondary interactions (different for K^+ and K^-) can be taken into account.

Similarly, we could construct quantities sensitive to the axial asymmetry from momenta of reconstructed particles and resonances Λ, $\bar{\Lambda}$, $\rho^\pm$, $K^{*\pm}$. These objects represent higher level in the fragmentation cascade and are better related to the parton level both in momentum and flavor space.

Also, it is important to note, that measurements of $\langle P_\perp\rangle$ and R_Ω are independent, so we may choose $P_\perp$ as a "trigger" for the events with large vacuum background field fluctuations. For example we can select for further analysis only those two-jet events for which $P_\perp$ exceeds by one or two standard deviations the average $\langle P_\perp\rangle$ for both jets.

At the end of this section let us note that we have discussed the effect of the chromomagnetic vacuum field on the fragmentation of a single color string, such as we encounter in e^+e^- annihilation into hadrons. In hadron-hadron and nucleus-nucleus collisions the domain of the chromomagnetic vacuum field may or may not overlap with many strings of different colors, depending on the relative size of the hadron and the vacuum field domain. If a was comparable to R an accidental color coherence between strings would lead to stronger effects and interesting phenomenology.

5. Spin polarization in the chromomagnetic vacuum field

Let us assume now that the chromomagnetic vacuum field has a component transverse to the common jet axis in the high energy e^+e^- collision. We will consider quarks and antiquarks created in the string fragmentation process as moving in the external chromomagnetic field B_c^a. In the rest system of the quark, we find the interaction hamiltonian

$$H_q = \mu_q \sigma \frac{\lambda^a}{2} \boldsymbol{B}_c^{\prime a} , \tag{19}$$

where $\boldsymbol{B}_c^{\prime a} = \gamma B_c^a$ is the Lorentz-transformed color field vector ,

$$\mu \approx \frac{g}{2m_q}$$

is the quark magnetic moment and λ^a is the SU(3) generator matrix with the color index a [2]. Now, when the effect depends on the vacuum chromomagnetic field component transverse to the jet direction, the non-covariant aspect of our theory becomes more apparent. Having no better choice we relate $\boldsymbol{B}_c^a$ to the rest system of the e^+e^- collision. For the antiquark in its rest system we find in a similar way

$$H_{\bar{q}} = -\mu_q \sigma \frac{(\lambda^a)^*}{2} \boldsymbol{B}_c^{\prime a} . \tag{20}$$

For the simple case when the chromomagnetic field factorizes into a space-time and a color-vector:

$$\mu_q \boldsymbol{B}_c^a = \boldsymbol{n} \eta^a , \tag{21}$$

where $|\, \boldsymbol{n} \,| = 1$ and η^a is a real vector in the color space ($a = 1, \ldots, 8$), we obtain

$$\begin{aligned} H_q &= \tfrac{1}{2}(\sigma \cdot \boldsymbol{n})(\lambda^a \eta^a) \\ H_{\bar{q}} &= -\tfrac{1}{2}(\sigma \cdot \boldsymbol{n})(\lambda^a \eta^a)^* . \end{aligned} \tag{22}$$

Various spin and color orientations of quarks and antiquarks correspond to different energy levels. It is clear that by emission of gluon radiation the higher energy levels will get depopulated, resulting in a polarization in the spin and color space. At the end of polarization process system would end up in the states

$$| q\rangle = \Downarrow \cdot \zeta_{\rm min} ,$$
$$| \bar{q}\rangle = \Uparrow \cdot \zeta^*_{\rm min} ,$$

where $\zeta_{\rm min}$ is the state in color space corresponding to the lowest eigen-value of $\lambda^a \eta^a$ matrix. If we estimate the build-up time $\tau_{\rm pol}$ for the polarization due to gluon spin flip synchrotron radiation from the analogous formula from electrodynamics we get [3] for quark of mass m_q

$$\tau_{\rm pol} \approx \frac{1}{\gamma_q^2} \frac{m_q^5}{\alpha_s (gB_c)} . \tag{23}$$

Taking for gB previously quoted values we estimate that at least for light quarks with $m_q \approx 5 - 10$ MeV, $\tau_{\rm pol}$ is much smaller than typical hadronization time.

Thus we encounter a remarkable situation: all quarks created in the same domain of the chromomagnetic vacuum field during string fragmentation process are 100 % polarized along the axis transverse to thrust axis of the e^+e^- collision. The antiquarks have the opposite polarization. Can we relate this effect to correlations in the final hadronic state?

The problem how to probe the polarization carried by a quark through the distribution of its fragments was attacked by many authors *e.g.* [10, 11, 15], and many others. In these papers polarization of quark *initiating* a jet is considered. Here we consider *polarization of the secondary partons* created during the fragmentation process, in particular the polarization transverse to the jet axis.

Let us consider hadron inclusive distributions in the central rapidity region, far from the initial quark (antiquark) fragmentation region. P- and T- invariance allows for a dependence of the distributions of hadrons $h^\pm$ on the azimuth angle around jet axis [15]. This dependence can be expressed as

$$D_{h^\pm}(P, \vec{n}, \vec{h}_\perp, h_\parallel) = \bar{D}(| \vec{h}_\perp |, h_\parallel) \left\{ 1 \pm A_h(h_\parallel) P \frac{\vec{n} \cdot (\vec{t} \times \vec{h}_\perp)}{| \vec{t} \times \vec{h}_\perp |} \right\} , \tag{24}$$

where P is polarization of quarks (antiquarks), $\vec{n}, \vec{h}_\perp$ are the polarization direction and hadron direction in the transverse plane, $\vec{t}$ thrust axis of the e^+e^- collision. In the above formula there is no explicit dependence on $h_\parallel$ of the polarization dependent part of the distribution because all centers of emission (quarks and antiquarks) in the central rapidity region are uniformly distributed and identically polarized. The function $A(h_\perp)$ contains two factors: the spin analyzing power of the fragmentation process and the difference of probabilities that quark (antiquark) fragments into positive (negative) particle. For our proposed measurement it is essential that positive particle is more often created from quark than antiquark as the polarization of quarks and antiquarks is opposite (this fact is taken into account by $\pm$ sign before polarization dependent part of the formula). The polarization P may depend on Lorentz factor γ of the parton from which hadron originates. Single particle distribution asymmetry vanishes when averaged over events, as the orientation of the vector $\vec{n}$ is random. However let us consider the two particle distribution

$$D_{h_1h_2}(P,\vec{n},\vec{h}_{1\perp},h_{1\parallel},\vec{h}_{2\perp},h_{2\parallel}) = \bar{D}(|\vec{h}_{1\perp}|,h_{1\parallel})\bar{D}(|\vec{h}_{2\perp}|,h_{2\parallel}) \times \left\{1 + sgch(h_1)A_h(h_{1\parallel})P\frac{\vec{n}\cdot(\vec{t}\times\vec{h}_{1\perp})}{|\vec{t}\times\vec{h}_{1\perp}|}\right\} \times \left\{1 \pm sgch(h_2)A_h(h_{2\parallel})P\frac{\vec{n}\cdot(\vec{t}\times\vec{h}_{2\perp})}{|\vec{t}\times\vec{h}_{2\perp}|}\right\}, \quad (25)$$

where $sgch(h)$ is the sign of the hadron charge. In the above formula we have assumed that h_1 and h_2 are not directly correlated through *e.g.* transverse momentum conservation or resonace decays. Also we have assumed, that quark and anti-quark spin polarization comes only from the synchrotron radiation mechanism so that Lund-type correlation resulting from the angular momentum conservation [16] has to be excluded. In addition we have to avoid confusion with the Bose-Einstein correlations. All that amounts to taking pairs of hadrons which are

- not identical
- far from each other in the rapidity space
- far from the phase space boundary
- far from the fragmentation region of the quark which initiates the jet

After integration over random directions of $\vec{n}$ we get:

$$D_{h_1h_2}(P,\vec{h}_{1\perp},h_{1\parallel},\vec{h}_{2\perp},h_{2\parallel}) = \bar{D}(|\vec{h}_{1\perp}|,h_{1\parallel})\bar{D}(|\vec{h}_{2\perp}|,h_{2\parallel}) \times \{1 \pm A^2P^2\cos(\phi_1-\phi_2)\}, \quad (26)$$

where sign plus (minus) before A corresponds to equal (opposite) charges of hadrons h_1, h_2.

Let us define the two-particle correlation function $R(\vec{h}_{1\perp},\vec{h}_{2\perp})$ (for simplicity we omit the longnitudinal hadron momentum)

$$R_{h_1h_2}(P,\vec{h}_{1\perp},\vec{h}_{2\perp}) = 1 - \frac{D(P,\vec{h}_1,\vec{h}_2)}{\bar{D}(P,\vec{h}_1)\cdot\bar{D}(P,\vec{h}_2)}. \quad (27)$$

Then formula (26) gives

$$R_{h_1h_2}(P, \vec{h}_{1\perp}, \vec{h}_{2\perp}) = \pm A^2 P^2 \cos(\phi_1 - \phi_2)\,. \tag{28}$$

As mentioned before, P may depend on particles Lorentz factors γ_1, γ_2.

The first objection the reader might raise in this place is that such correlations, if existed, would have been seen long time ago in the Bose-Einstein and other correlations studies. However we think that it is not necessarily the case, because the variables traditionally chosen for this purpose (spatial angle or the invariant momentum transfer $Q^2 = (p_1 - p_2)^2$) may easily obscure the effect. Still, we do think that in order to observe our effect, special selections have to be applied. As in the case of the measurement of R_Ω sensitivity of the method can be improved be selections leading to better correlations between the momentum and flavor of quarks and hadrons.

Another approach to the detection of the spin polarization of quarks and antiquarks is the measurement of joint decay distributions of particles and resonances created in the color string fragmentation process. The most obvious measurement is to pick out Λs in the final state, since their decay is self-analysing. In the symmetric quark model, the Λ baryon has a rather simple spin-flavor wave function. All its spin is carried by the quark s, while the ud-pair is coupled to $S = 0, I = 0$. The recent measurement of Λ polarization from Z^0 decays [18] by ALEPH Collaboration at LEP agrees with the prediction of the standard model for s-quark polarization and thus, indirectly, seems to confirm good spin transfer from s-quark to Λs. Thus Λ decay seems to be particularly well suited to the measurement of the spin polarization of quark $s(\bar{s})$ created in the fragmentation of the color string.

Let $\vec{n}$ be, as before, a random polarization direction in the plane transverse to the jet axis and $\vec{\omega}$ the unit vector in the direction of the proton (antiproton) from $\Lambda(\bar{\Lambda})$ decay in their respective rest frames. The single angular decay distribution has the form

$$R(\vec{n}, \vec{\omega}) = 1 \pm P\alpha(\vec{\omega} \cdot \vec{n})\,, \tag{29}$$

and reduces to the constant term after integration over random directions $\vec{n}$ as expected because Λ is not polarized. The $\pm$ sign refers to $\Lambda, \bar{\Lambda}$ decays.It should be noted that when defining the Λ decay reference frame we do not specify its production plane as in Ref. [17] where Λ polarization was indeed observed. For the joint decay distribution of the $\Lambda\Lambda$ ($\bar{\Lambda}\Lambda$) system we have

$$R(\vec{n}, \vec{\omega}_1, \vec{\omega}_2) = \{1 \pm P\alpha(\vec{\omega}_1 \cdot \vec{n})\}\{1 \pm P\alpha(\vec{\omega}_2 \cdot \vec{n})\}\,. \tag{30}$$

Integrating over random direction $\vec{n}$ we get

$$R(\phi_1, \phi_2) = 1 \pm (P\alpha)^2 \cos(\phi_1 - \phi_2)\,, \tag{31}$$

where ϕ is the azimutal angle of proton (antiproton) from the Λ ($\bar{\Lambda}$) decay around thrust axis of e^+e^- collision and $\pm$ signs refer to $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ systems. As in the case of the azimutal distributions of hadrons (25) we should consider only $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ pairs very distant in the rapidity space in order to avoid correlations we are not concerned with. In fact, we should rather use only $\Lambda\Lambda$ or $\bar{\Lambda}\bar{\Lambda}$, as in this case at least one Λ ($\bar{\Lambda}$) does not come from the jet initiating quark.

A difficulty of the above described measurement is the crossection. Let us note, that ALEPH collaboration having to its disposition more then 10^6 hadronic e^+e^- events found that its data have too little sensitivity for a measurement of the transverse polarization correlation of the leading Λ and $\bar{\Lambda}$ predicted by the Standard Model [19].

Finally, one could imagine measuring the joined decay distributions for $\rho^{\pm}, K^{\star\pm}$. They would be sensitive to the transverse polarization correlation of quarks and antiquarks provided that off-diagonal terms $\rho_{0,\pm 1}$ or background — resonance interference terms $\rho_{s,\pm 1}$ of the density matrix do not vanish.

6. Conclusions

The vacuum domain structure, characterized by the color-magnetic field correlations within certain invariant volume (1) is a solid, albeit not confirmed be the experiment, piece of theory. No doubt that it is potential source for a long range correlations between particles created inside such a volume. In order to get more definite predictions we have left this solid ground, treating the structured vacuum field as a sort 'ether", a stable, classic color-magnetic field of random orientation, which interacts with color charges created in the fragmentation process. Doing so we are certainly wrong in many points, but if the idea contains a grain of truth, axial asymmetry correlations around the jet axis must result. We have proposed several types of measurements. None of them is easy.

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