Spin correlations due to antishadowing

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Abstract

The effects of antishadowing related to the spin correlations of particles in multiparticle production are discussed. It is shown that significant spin correlations should be expected at the LHC energies.

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1. Introduction

The importance of the spin degrees of freedom in multiparticle production has been recognized long time ago [1]. That time it was understood that the popular models of particle production were not able to reproduce (through unitarity) elastic scattering data without account for the effects related to the coherence of spins of the final particles [2]. Later Chou and Yang have made conclusion on the correlations between spins of final particles on the basis of their geometrical model of particle production [3]. However, those ideas have not obtained appropriate attention since a dedicated experimental spin studies with polarized beams and targets provide much more information. During recent years a number of significant and unexpected spin effects were discovered. They demonstrated that the spin degrees of freedom will be important even at

TeV energy scale. With the start of the RHIC spin program [4], spin studies moved again to the forefront of high energy physics. However, there will be no experimental possibilities at the LHC similar to ones RHIC has, but the importance of spin effects will definitely remain at such high energies and they will provide important spin correlations. In this Letter we provide a ground for the above statement, i.e., we show that the phenomena of antishadowing [5] expected at the LHC energies [6,7] will be associated with strong coherent spin effects: spins of the final particles should be aligned and this alignment will have an important experimental signatures.

2. Antishadowing and angular momentum conservation

Multiparticle production in the model with antishadowing has been studied in [8]. It should be noted

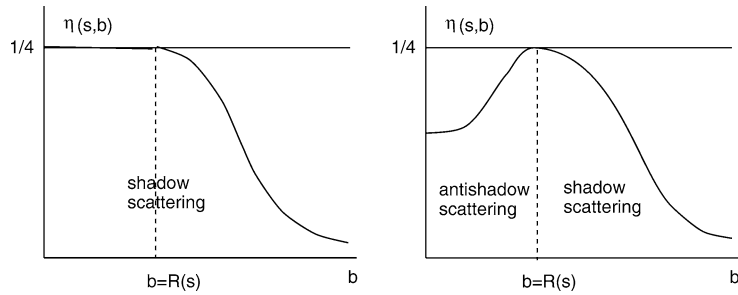*E-mail address:* sergey.troshin@ihep.ru (S.M. Troshin).

Fig. 1. Impact parameter dependence of the inelastic overlap function in the eikonal unitarization scheme (left panel) and in the unitarization scheme with antishadowing (right panel).

that antishadowing is a result of the specific form of amplitude unitarization, U-matrix or rational form of unitarity implementation at high energies. It is characterized by the fact that beyond the threshold value of energy the inelastic overlap function

$$\eta(s, b) \equiv \frac{1}{4\pi} \frac{d\sigma_{\text{inel}}}{db^2}$$

has a peripheral impact parameter dependence. At the LHC energies this peripheral profile with maximum at $b = R(s)$, where $R(s)$ is the interaction radius, is predicted to be very prominent [6]. The eikonal form of unitarization does not lead to such peripheral picture. The difference between two unitarization schemes can be clearly seen in Fig. 1.

Thus, we can conclude that the region around $b = R(s)$ has the highest probability of the multiparticle production in case of antishadowing. Antishadowing leads to suppression of particle production at small impact parameters and the main contribution to the integral multiplicity $\bar{n}(s)$ comes from the region of $b \sim R(s)$ according to the relation:

$$\bar{n}(s) = \frac{\int_0^\infty \bar{n}(s, b) \eta(s, b) b \, db}{\int_0^\infty \eta(s, b) b \, db}. \quad (1)$$

Thus due to peripheral form of the inelastic overlap function the secondary particles will be mainly produced at impact parameters $b \sim R(s)$ and this will lead to imbalance between orbital angular momentum in the initial and final states since particles in the final state will carry out large orbital angular momentum. To compensate the imbalance in the orbital momentum spins of secondary particles should become lined up, i.e., the spins of the produced particles should demonstrate significant correlations when the antishadow scattering mode appears.

Now we will estimate the imbalance between the initial and final states. We use for the model for multiparticle production developed in [8], where overlapping and interaction of peripheral clouds occur at the first stage of hadron interaction. As a result, massive virtual quarks appear in the overlapping region. Massive virtual quarks play a role of scatterers for the valence quarks in elastic scattering; those quarks are transient ones in this process: they are transformed back into the condensates of the final hadrons. However, they can be hadronized and this leads to production of secondary particles in the central region. Moreover, valence quarks can excite a part of the cloud of the virtual massive quarks and these virtual massive quarks will also subsequently fragment into the multiparticle final states. The latter mechanism is responsible for the particle production in the fragmentation region and should lead to strong correlations between secondary particles.

Since we are dealing with constituent quarks, it is natural to expect direct proportionality between multiplicity of secondary particles and number of virtual massive quarks appeared in the intermediate state (due to both mechanisms of multiparticle production) in collision of the hadrons with given impact parameter, i.e.:

$$\bar{n}(s, b) = \alpha(n_{h_1} + n_{h_2}) N_0(s) D_F(b) + \beta N_0(s) D_C(b), \quad (2)$$

with constant factors α and β, n_{h_1} and n_{h_2} being the numbers of valence constituent quarks in the initial hadrons, b is the impact parameter, $N_0(s) \propto \sqrt{s}$, and the functions $D_F(b)$ and $D_C(b)$ are related to the distributions of matter in the valence constituent quarks and of the condensate in the initial hadrons [9]. We will consider symmetrical case of pp-interactions. For

this process the model leads to the equal mean multiplicities of secondary particles in the forward and backward hemispheres, i.e., $\bar{n}_F(s) = \bar{n}_B(s)$ and very small longitudinal momentum transfer is expected between two sides. In that sense this model is very similar to the model developed by Chou and Yang [3], analysis of experimental data performed in this paper confirms the assumption of small longitudinal momentum exchange.

We can consider separately particles production in the forward and backward hemispheres [10]. Let us consider for example particles produced in the forward hemisphere. The orbital angular momentum in the initial state can be estimated as

$$L_i \simeq \frac{\sqrt{s}}{2} \frac{R(s)}{2}, \tag{3}$$

where $R(s)$ is the interaction radius. The orbital angular momentum in the final state is then

$$L_f \simeq \frac{\bar{n}(s)\bar{x}_L(s)\sqrt{s}}{4} \frac{R(s)}{2}, \tag{4}$$

where we have taken into account that $\bar{n}(s)/2$ particles with the average fraction of their longitudinal momentum $\bar{x}_L(s)$ are produced at the impact parameter $R(s)/2$ due to antishadowing (cf. Fig. 1). The average fraction of longitudinal momentum $\bar{x}_L(s)$ according to the hypothesis of limiting fragmentation [11] would not decrease with energy. Thus we arrive to the negative imbalance of the orbital angular momentum

$$\Delta L = L_i - L_f \simeq \frac{\sqrt{s}}{2} \frac{R(s)}{2} \left(1 - \frac{\bar{n}(s)\bar{x}_L(s)}{2} \right), \tag{5}$$

i.e.,

$$\Delta L \simeq -\frac{\sqrt{s}}{2} \frac{R(s)}{2} \frac{\bar{n}(s)\bar{x}_L(s)}{2}. \tag{6}$$

This negative ΔL should be compensated by the total positive spin S of final particles (since the particles in the initial state are unpolarized)

$$S = -\Delta L. \tag{7}$$

This spin alignment of produced particles appears in the antishadowing mode when the particles are produced in the region of impact parameters $b = R(s)$.

The vector of spin $\vec{S}$ lies in the transverse plane but it cannot be detected through the transverse polariza-

tion of single particle due to azimuthal symmetry of the production process (integration over azimuthal angle φ). However, this effect can be traced measuring transverse spin correlations of two particles $\langle s_i s_j \rangle$. The most evident way to reveal this effect is to perform the measurements of the spin correlations of hyperons whose polarizations can be extracted from the angular distributions of their weak decay products.

Spin correlation should be stronger for the light particles and weakening is expected for heavy particles since they should be produced at smaller values of impact parameters.

3. Conclusion

In conclusion we would like to emphasize the main point of this Letter. We expect appearance at the LHC energies strong spin correlations of final particles as a result of the prominent antishadowing.

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