Could the Gluon Contribution to the Proton Spin be Probed?

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Abstract

Central pseudoscalar production in pp scattering is suppressed at small values of $Q_\perp$. Such a behavior is expected if the production occurs through the fusion of two vectors. We argue that an extension of the experiment could probe the gluon contribution to the proton spin.

1 Introduction

The use of a glueball-$q\bar{q}$ filtering method has been recently advocated to study central hadron production in pp scattering [1]. At this occasion, it was noticed that, somewhat surprisingly, pseudoscalar production (and in general $q\bar{q}$ mesons production) was suppressed at small values of $Q_\perp$ [2], where Q is defined as the difference of the momenta transferred from the two protons.

We show in this talk that such a behavior is precisely expected if a pseudoscalar meson is produced through the fusion of two vector intermediaries. Furthermore, we argue that an extension of the experiment would test the gluon contribution to the proton spin.

In Sect. 2 we introduce the basic formulæ. We provide the $Q_\perp$ distribution of the pseudoscalar production cross section. This allows for a comparison between π^0, η and $\eta\prime$ production and a test of the nature of the process. In Sect. 3 we add the contribution of massive vectors. Finally, in Sect. 4 we advocate extending the study to non-exclusive channels $pp \to \tilde{p}\tilde{p}X$, where

$\tilde{p}$ are jets corresponding to p fragmentation, to observe the QCD equivalent of the process. We then argue that a measurement of the production cross section at $Q_\perp = 0$ would provide a test of the gluon contribution to the proton spin.

2 The basic formulæ

The WA102 and GAMS collaborations [2, 3] have examined in kinematical detail the reaction $pp \to ppX$ where X is a single resonance produced typically in the central region of the collision between a proton beam and an hydrogen target.

We will be more particularly interested in the case where X is a $J^P = 0^-$ state, notably π^0, η or $\eta\prime$, because in that case the kinematics are entirely determined since the momenta of all protons are known and the disintegration of X is entirely measured (e.g. in the $\gamma\gamma$ mode).

The production cross section is affected by two distinct mechanisms: *i)* the emission of the intermediaries from the protons and *ii)* the fusion of those intermediaries into the resonance X.

We will mainly interested in the low transferred momenta régime. For this reason, we consider as intermediaries only the lowest-lying particles, mainly pseudoscalars and vectors. The reasons for not considering heavier particles such as axials or tensors are explained in Ref. [4].

In this framework, the production of a pseudoscalar resonance through the fusion of two intermediaries in parity conserving interactions could arise from scalar-pseudoscalar (SP) fusion if no factor of momenta is allowed, or, vector-pseudoscalar (VP) or vector-vector (VV) fusion if the momentum variables can be used [5, 6].

In the case of SP fusion, the only pseudoscalar which could be involved in the π^0, η and $\eta\prime$ production is the particle itself, but we still need to find a low-lying scalar, possibly the "sigma" or a "pomeron" state. Moreover, due to the absence of any derivative coupling, the observed suppression of the production cross section at small $Q_\perp$ cannot occur since non trivial helicity transfer is needed (see Ref. [6] for details). In the case of VP fusion, the VPP coupling involves one derivative and should obey Bose and $SU(3)$ symmetry. For instance, a $\rho^0\pi^0\pi^0$ coupling is well-known to be forbidden. We conjecture that the argument can be extended to $U(3)$ symmetry (in particular $\rho^0\eta\prime\pi^0$), which removes the discussion of VP fusion from our analysis. This leaves

VV fusion as the only alternative.

Vector-vector fusion is possible through the vector-vector-pseudoscalar (VVP) coupling

$$C_{VVP} = \epsilon_{\mu\nu\alpha\beta} q_1^\mu q_2^\nu \epsilon_1^\alpha \epsilon_2^\beta \ , \tag{1}$$

where q_1 and q_2 are the momenta of the exchanged vectors with polarizations ϵ_1 and ϵ_2 respectively. This coupling is well known from the anomalous decay $\pi^0 \to \gamma\gamma$. When evaluated in the X rest frame with $k = q_1 + q_2$ and $Q = q_1 - q_2$, it yields simply

$$C_{VVP} = -\frac{1}{2} m_X \vec{Q} \cdot (\vec{\epsilon}_1 \times \vec{\epsilon}_2) \ , \tag{2}$$

where clearly the difference $\vec{Q}$ between q_1 and q_2 3-momenta appears now as a factor and we thus expect a suppression at small $\vec{Q}$. But this is insufficient in itself to explain the suppression observed at small $Q_\perp = |\vec{Q}_\perp|$, where $\vec{Q}_\perp$ is defined as the vector component of $\vec{Q}$ transverse to the direction of the initial proton beam. However, as seen from (2), the polarizations of the vectors play an essential role. In particular, in the X rest of frame, $\vec{\epsilon}_1 \times \vec{\epsilon}_2$ must have components in the $\vec{Q}$ direction, which implies that both $\vec{\epsilon}_1$ and $\vec{\epsilon}_2$ must have components in the plane perpendicular to $\vec{Q}$, that is, the exchanged vectors must have transverse polarization (helicity $h = \pm 1$). In other terms, the production process will be proportional to the amount of intermediate vectors with $h = \pm 1$.

If we consider now the emission of a vector from a fermion, we observe that in the high-energy limit the helicity of the fermion cannot change. In the X rest frame, assumed to lie in the central region of the production, the colliding fermions cannot (unless they were backscattered, a situation contrary to the studied kinematical region) emit $h = \pm 1$ vectors in the forward directions, as this would violate angular momentum conservation.

We thus reach the conclusion that in the above-mentioned kinematical situation, the production of pseudoscalar mesons by two-vector fusion cannot happen if $\vec{Q}$ is purely longitudinal, but requires $\vec{Q}_\perp \neq \vec{0}$ [1].

It is easy to write down the differential cross section for the central production of pseudoscalar resonance X in the reaction $pp \to ppX$. When p

[1] There is still a loophole: $\vec{q}_1$ and $\vec{q}_2$ must have transverse components, but in a small area of phase space we could still have $\vec{Q}_\perp = (\vec{q}_1 - \vec{q}_2)_\perp = \vec{0}$. The explicit calculation below shows this is not significant.

fragmentation is not allowed for, it seems phenomenologically more reasonable to treat the p as a pointlike particle.

We use the following notations: $p_1 = (E;0,0,p)$ is the beam proton momentum, p_2 the target proton momentum, p_3 the momentum of the outgoing proton closest to the beam kinematical area and p_4 the momentum of the outgoing proton closest to the target kinematical area. The transferred momenta to the intermediate vectors are $q_1 = p_1 - p_3$ and $q_2 = p_2 - p_4$ respectively, and the momentum of the resonance X is then defined as $k = (W;\vec{k}_\perp, k_\parallel) = q_1 + q_2$ with $k^2 = m_X^2$ and $W = \sqrt{m_X^2 + k_\perp^2 + k_\parallel^2}$. We also define $Q = (\omega;\vec{Q}_\perp, Q_\parallel) = q_1 - q_2$ as the difference between the momenta transferred from the two protons.

The differential cross section reads

$$\begin{aligned} \frac{d\sigma}{dQ_\perp dk_\perp dk_\parallel d\varphi} &\simeq \frac{1}{(2\pi)^4}\frac{1}{128WEp}\frac{k_\perp Q_\perp}{|(2p-Q_\parallel)(2E-W)-k_\parallel\omega|} \\ &\times 16(g_{ppV_1}g_{ppV_2}g_{V_1V_2P})^2E^2p^2\frac{k_\perp^2Q_\perp^2\sin^2\varphi}{(t_1-m_{V_1}^2)^2(t_2-m_{V_2}^2)^2}\ , \end{aligned} \tag{3}$$

where g_{VVP} stands for the coupling constant of the VVP interaction, g_{ppV} stands for the coupling constant of the ppV interaction, $t_{1,2}$ are the square of the momentum transfer to each vector, m_V is the mass of the exchanged vector, m_X the resonance mass and m the proton mass. We have chosen as integration variables: $Q_\perp = |\vec{Q}_\perp|$, $k_\perp = |\vec{k}_\perp|$, $k_\parallel$ and φ defined as the angle between the two transverse vectors $\vec{k}_\perp$ and $\vec{Q}_\perp$.

Due to the smallness of t_1 and t_2 we have only included in the cross section (3) the dominant contribution to the averaged square of the invariant matrix amplitude $\mathcal{M}$ at the lowest order in the vector exchange (see Ref. [4] for details).

Now one can clearly see the suppression of the cross section at small $Q_\perp$ (and indeed $\lim_{Q_\perp\to 0} d\sigma = 0$), as it is seen experimentally.

Once the expression for the differential cross section is presented, we may now enter into conjectures about the nature of the vectors exchanged. The simplest candidates for elementary particles are of course photon or gluon, with the possible addition as an example of the massive vectors ρ, ω and ϕ. We will first consider the case of $t_1, t_2 \to 0$; it is then quite clear that the dominant contribution to the simplified cross section (3) comes from the exchange of massless vectors, so we neglect temporally the possible contributions of massive vectors. Then, we are left with photons or gluons. However,

in the present situation, gluon exchange seems not to be the dominant contribution, as it would lead to a large number of $\eta\prime$ and η and no π^0, which is clearly not the experimental situation [7]. Most probably, the selection of isolated protons in the final state is too restrictive for gluon exchange to take place significantly. So then, we conclude that a pure photoproduction hypothesis may be the main contribution to the cross section at very low transferred momenta.

Assuming the photoproduction mechanism as the main effect responsible of the pseudoscalar production, we would like to point out that very relevant information can be obtained here of the (t_1, t_2) behavior of the $\gamma\gamma$-pseudoscalar form factor, a question highly discussed in the literature [8].

We will see however that the experiment does not allow isolation of this low t_1 and t_2 kinematical region, and that at least the lowest vectors need to be included.

3 Adding the massive vectors

The low t_1 and t_2 régime is however difficult to observe experimentally, due to the presence of experimental set-up restrictions, leading to a loss of acceptance when the transverse momenta of the outgoing protons decreases. This seems to be specially sensitive for the "slow proton". As a result, this domain of parameter space is inadequate for a detailed comparison to experiment.

In practice, we could work at fixed $k_\perp$ in order to avoid the experimental restrictions, and explore the $Q_\perp$ dependence of the cross section. In that case, however, other vector exchanges provide largely enhanced contributions to the pseudoscalar production which must be added to the photon-photon fusion contribution (see Ref. [4] for details).

We have performed such a calculation using formula (3) above. The VVP coupling coefficients can be obtained along the lines of [9] and are given in [4], while the ppV ones are estimated in [10].

The behavior obtained confirms the low $Q_\perp$ suppression, but the general structure of the curve and its peak value are very sensitive to vertex form factors, on which we have little independent information. These form factors, (both at the proton and pseudoscalar vertex) can be combined in a single function $f(t_1)\cdot f(t_2)$, which could of course be fitted directly from experiment.

This offers on one hand the possibility to gather information on form factors, in particular on the VVP ones [11], but as the main point of the

paper is concerned (Sec. 4 below), this "background" does not affect the conclusions (since only the $Q_\perp \to 0$ suppression is of importance).

4 Extending the approach to gluons

In this final section, we would like to advocate for an extension of the present study to non-exclusive processes $pp \to \tilde{p}\tilde{p}X$, where $\tilde{p}$ are jets corresponding to p fragmentation, in order to observe the QCD equivalent of the production mechanism (gluon-gluon fusion).

In this case indeed, we must distinguish between gluons emitted from the fermionic partons (and obeying the helicity constraints discussed at the beginning of the previous section) and "constituents" or "sea" gluons. The latter simply share part of the proton momentum and their helicity is in no way constrained. Helicity $h = \pm 1$ gluons can then be met even for $\vec{Q}_\perp = \vec{0}$, and in that case we would expect that the production distributions in $Q_\perp$ could be considerably affected.

In this possible extension of the experiments, the $\eta\prime$ and η now produced at small $Q_\perp$ are sensitive to the polarization of the individual gluons in the proton. Such polarization of the individual gluons is always present independently of the total polarization of the gluons in the proton, and is in itself not indicative of the fact that a significant proportion of the proton spin could be carried by the gluons. If such would be the case however, and a net polarization of the gluons exists, a similar experiment conducted with polarized beams or target would lead to a difference in the production rates of $\eta\prime$ and η at small $Q_\perp$, and provide a direct measurement of this polarization.

In summary, we have shown in this talk that the experimental evidence of the suppression at small $Q_\perp$ of the central pseudoscalar production in pp scattering can be explained if the production mechanism is through the fusion of two vectors. We also have proposed an extension of such experiments in order to observe the QCD equivalent of the process and to provide a test for the gluon contribution to the proton spin.

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References

[1] F. E. Close and A. Kirk, Phys. Lett. B 397 (1997) 333.

[2] D. Barberis et al., WA102 Collaboration, Phys. Lett. B 397 (1997) 339.

[3] D. Alde et al., GAMS Collaboration, Phys. Lett. B 397 (1997) 350.

[4] P. Castoldi, R. Escribano and J.-M. Frère, Phys. Lett. B 425 (1998) 359.

[5] F. E. Close, Phys. Lett. B 419 (1998) 387.

[6] T. Arens, O. Nachtmann, M. Diehl and P. V. Landshoff, Z. Phys. C 74 (1997) 651.

[7] D. Barberis et al., WA102 Collaboration, Phys. Lett. B 427 (1998) 398.

[8] J.-M. Gérard and T. Lahna, Phys. Lett. B 356 (1995) 381.

[9] P. Ball, J.-M. Frère and M. Tytgat, Phys. Lett. B 365 (1996) 367.

[10] M. M. Nagels et al., Nucl. Phys. B 147 (1979) 189.

[11] J.-M. Gérard and G. López Castro, Phys. Lett. B 425 (1998) 365.