Measuring the gluon spin in protons through η' central production

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The investigation of a proposed glueball filter in proton-proton collisions led us to show that its action is in fact easily understood in terms of kinematics. While the procedure proposed stays of interest in reducing background when looking for centrally produced resonances of specified spin and parity, we stress that it can be put to advantage in giving access to the polarization of gluons in the inital protons.

1. Introduction

A "glueball filtering" method has been recently advocated [1] to study central production in pp scattering. The proposed method consists in studying the $Q_\perp$ behaviour of the production cross section. Considering the 2 protons in the process $p(p_1)p(p_2) \to p(p_3)p(p_4)X(k)$, the momenta transferred at each proton vertex are erspectively: $q_1 = p_3 - p_1, q_2 = p_4 - p_2$ while the variable Q is simply the difference of these momenta: $Q = q_1 - q_2$ and $Q_\perp$ is its projection in the direction transverse to the beam. It has been advocated that glueballs would be produced even at low values of $Q_\perp$, where quark states would be suppressed. Quite surprinsingly however, even known "glue-rich" states, like η or η' were observed to be suppressed at small values of $Q_\perp$ [2]. We have thus studied this situation [3] and found that rahter than being a glueball filter, the variable $Q_\perp$ merely distinguishes between the production kinematics of the various spin and parity states. In particular, as we will develop below, pseudoscalars of low mass can only be produced significantly through the fusion of 2 vectors (either fundamental, like gluons or photons, or composite, like the nonet of vector mesons), thus the announced behaviour merely results from these simple kinematics and the nature of the quark-vector couplings in the proton. Of course, the suggested cut in $Q_\perp$ stays a good strategy in reducing background when looking for a specific state, for exemple the glueball candidates f_0 around 1500 MeV. **More interestingly even, the argument can be turned back, and central production of η or η' at low $Q_\perp$ could be used to measure the spin carried by gluons in the initial protons.**

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2. The production process

The WA102 and NA12 experiments [2,4] have examined the reaction $pp \to ppX$ where X is a single resonance produced typically in the central region of the collision.

Their experimental set-up allowed them a complete kinematical study, with redundant measurements of the protons and X momenta.

We will be more particularly interested in the case where X is a $J^P = 0^-$ state, notably π^0, η or $\eta\prime$. Neglecting heavier tensor intermediaries, the production of a pseudoscalar resonance through the fusion of two intermediaries in parity conserving interactions could arise from scalar-pseudoscalar (SP) or vector-axial (VA) fusion if no factor of momenta is allowed, or, vector-pseudoscalar (VP), vector-vector (VV) or axial-axial (AA) fusion if the momentum variables can be used [5,6]. Since the first axial resonance is rather heavy, we restrict our discussion to SP, VP or VV fusion.

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 also need 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). Such (SP) fusion is thus obviously disfavoured by experiment. 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.

Here, 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 $h = \pm 1$).

The emission of vectors from light fermions is, as well known, restrictive in helicities. In the high-energy limit the vector only couples to $\bar{f}_L\gamma^\mu f_L$ and $\bar{f}_R\gamma^\mu f_R$, that is, 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 $\vec{Q}_\perp \neq \vec{0}$ [2].

It is easy to write down the differential cross section for the central production of X and the details are given in [3], and the result indeed vanishes when $Q_\perp$ goes to zero. Although it may seen daring to treat the p as a pointlike particle in the process considered, this approximation of the ppV (V any vector) coupling seems phenomenologically more reasonable than the use of a quark parton model when strictly exclusive processes are considered (where p fragmentation is not allowed for).

Under the experimental conditions, the differential cross section thus simplifies to (for details see [3] and references therein).

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

where the suppression at small $Q_\perp$ is manifest as it is observed 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 most obvous candidates, specially for $t_1, t_2 \to 0$ are the photons and gluons. However, the kinematical area explored by, for instance, the collaboration WA102, makes it impossible to observe the photonic contribution. We will return

[2] 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 shows this is not significant.

later to the gluon contribution, but for the moment, let us just stress that it is disfavoured by experiment in the exclusive $pp \to ppX$ channel. Indeed, while gluon exchange would forbid the central production of single pions, these dominate in fact the observation. We thus have to consider in [3] the exchange of the lightest massive vectors ρ, ω and ϕ. The couplings of each of the vectors to the proton are known, and their coupling to π, η, η' were obtained along the lines of ref. [9]. Here the comparison to experiment is made difficult by the need to account for phenomenological form factors, in particular at the proton vertices. The differential cross section correctly reproduces both the size of the reactions, and the observed low $Q_\perp$ suppression -with an amazing similarity to the observed curves- while the later decrease for very large $Q_\perp$ can be fitted by an exponential dependence in t_1, t_2 .Details of this exponential form factor need to be determined from experiment; however if the dominant effect indeed takes place at the proton vertex, (see hovever for instance [8]),it should be universal for all X considered, namely, π, η, or η' .

3. Gluon scattering and the spin of gluons inside the proton

As we have seen above, the gluon-gluon scatternig doesn't play a predominant role in the exclusive central production processes 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. We would like to advocate 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). This will have profound inmplications on the low $Q_\perp$ behaviour of the differential cross section?

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 share part of the proton momentum but 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.

4. Conclusions

In summary, we have shown 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, and that the corresponding $Q_\perp$ cut is merely selecting states on a kinematical basis, rather than being a specific glueball filter. This cut still proves very useful in extracting particular resonnances from the background (in particular the f_0). Furthermore, this kinematical study has put us on the track of an extension, which **would probe directly the gluon contribution to the proton spin**.

The experimental extension we suggest goes in two steps. First, we must include the partially inclusive reactions $pp \to jet\ jet\ X$, and check the $Q_\perp$ distribution in this case; contribution from gluon gluon fusion into X should signal itself both by favouring the η, η' over the π, and by populating the low $Q_\perp$ region in proportion to the amount of $h = \pm 1$ gluons in the proton. After this, considering polarised beam and target should allow to study the behaviour of the low $Q_\perp$ contribution as a function of the polarisation, and decide thus on the net spin carried by gluons in the proton.

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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. P. Castoldi, R. Escribano and J.-M. Frère, hep-ph9712387, Phys.Lett. B425 (1998) 359-364.
4. D. Alde et al., GAMS Collaboration, Phys. Lett. B 397 (1997) 350.
5. F. E. Close, hep-ph/9710450.
6. T. Arens, O. Nachtmann, M. Diehl and P. V. Landshoff, Z. Phys. C 74 (1997) 651.
7. D. Barberis et al., WA102 Collaboration, hep-ex/9803029 Phys.Lett.B427 (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 109 (1976) 1.
11. J.-M. Gérard and G. López Castro, hep-ph/9709404.