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CHARGED SPIN ONE PARTONS ?

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A B S T R A C T

We investigate the possibility that pointlike charged spin one partons are responsible for the present constancy of the e^+e^- annihilation cross-section into hadrons.

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Recent experimental results ^{1),2),3)} on e^+e^- annihilation into hadrons indicate that the parton model ^{4),5),6)} with partons being identified as quarks and neutral gluons is incomplete. In the present note we analyse the possibility that charged spin one partons are responsible for the present constancy of the e^+e^- annihilation cross-section into hadrons.

The production of pointlike spin one particles was listed as one of the possibilities to explain the behaviour of the e^+e^- annihilation cross-section into hadrons by Bjorken ⁷⁾. If these spin one particles are ordinary hadrons one consequence of this idea is that one should observe finite constant multiplicities. We will here take the attitude that these spin one particles are partons. This way we escape finite constant multiplicities. The question of the actual observability of these particles as physical real particles might well be related to the analogous quark puzzle and will not be discussed here.

The present experimental situation forces us to take these partons as very wee inside the proton : on one hand the quark parton model has been nicely confirmed by neutrino-nucleon interactions ⁸⁾; on the other hand these experiments are not sensitive enough to the wee region $x \sim 0$ (x being Bjorken's scaling variable).

The presence of pointlike wee spin-one particles would lead to a situation in which :

1. the usual quarks dominate electron-proton and neutrino-nucleon inelastic scattering away from $x = 0$;

2. in the vicinity of $x = 0$, the charged spin one partons would start dominating for large values of Q^2 thus giving a break-down of scale invariance in that region;

3. the annihilation of e^+e^- into hadrons would be dominated by charged spin one partons thus leading to a constant cross-section;

4. in the reaction

$$p + p \rightarrow \mu^+ \mu^- + \text{anything}$$

a scaling law different from the quark parton model scaling law ⁹⁾ would be obtained for large values of the invariant mass of the muon pair;

5. The inclusive cross-section for the process

$$p + p \rightarrow \pi + \text{anything}$$

where the pion has large transverse momentum would still be given by the naïve quark parton model prediction

$$E^\pi \frac{d\sigma}{d^3p^\pi} = \frac{1}{(p_\perp^\pi)^4} f\left(\frac{2p_\perp^\pi}{\sqrt{s}}, p_\parallel^\pi\right)$$

but only for values of $p_\perp^\pi / \sqrt{s}$ such that we can be guaranteed that no wee partons were responsible for the collision. This value $p_\perp^\pi / \sqrt{s}$ can be estimated using results on inelastic neutrino-nucleon collisions.

We will now discuss the points mentioned above in more detail. The most general coupling of a virtual photon to two spin one particles has been given by Cabibbo and Gatto ¹⁰⁾. As in the case of the quark parton model we put the form factors equal to one. We are then left with two parameters, one for the magnetic moment and one for the electric quadrupole moment. A magnetic moment leads to an E^2 increase for the e^+e^- annihilation cross-section into hadrons and is therefore not imposed on us by present experimental evidence. For a similar reason we do not consider an electric quadrupole coupling.

This leads us to consider the following phenomenological coupling for the current vector particles vertex :

$$\begin{aligned} & \langle V^\dagger(p', \epsilon') | J_\mu | V(p, \epsilon) \rangle \\ &= \epsilon \cdot \epsilon' (p + p')_\mu + \epsilon' \cdot p \epsilon_\mu + \epsilon \cdot p' \epsilon'_\mu \end{aligned} \quad (1)$$

where ϵ and ϵ' are the polarization four vectors of the incoming and outgoing particles while p and p' are their respective momenta. It is known that such a coupling eventually leads to a violation of unitarity and will

make hadronic contributions to quantum electrodynamics calculations uncontrollable. For the energy range of present experiments these two questions are, however, not yet relevant.

The contribution from (1) to the e^+e^- annihilation cross-section into hadrons is given by:

$$\sigma(e^+e^- \rightarrow \text{hadrons}) = \frac{\pi\alpha^2}{3M_V^2} \left(1 - \frac{M_V^2}{3E^2} - \frac{3M_V^4}{4E^4}\right) \sqrt{1 - \frac{M_V^2}{E^2}} \quad (2)$$

where E is the energy of the incoming electron and M_V is the (scale setting) mass of the spin one particle. Expression (2) agrees with previous calculations ^{10),11),12)} on $e^+e^- \rightarrow W^+W^-$.

Asymptotically (2) gives a constant value for the annihilation cross-section :

$$\lim_{E \rightarrow \infty} \sigma(e^+e^- \rightarrow \text{hadrons}) = \frac{\pi\alpha^2}{3M_V^2} \quad (3)$$

For comparison with experiment we have added to the right-hand side of (2) the usual (coloured) quark parton model contribution : $2\pi\alpha^2/3E^2$. The resulting curve for the ratio

$$R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

is compared with experimental data in Fig. 1 for different values of M_V . We see that there is no difficulty fitting the slope of R and a value of M_V in the range 1.0 - 1.3 GeV seems to be appropriate.

The inclusive distribution $e^+e^- \rightarrow h + \text{anything}$ will be dependent on how the charged vector partons evolve into hadrons and the present model provides no simple picture for how the distribution of the particular hadron under consideration will look like, except for the expectation of a jet-like structure, the angular distribution of the jets being

$$\lim_{E \rightarrow \infty} \frac{d\sigma}{d(\cos\theta)} = \frac{\pi\alpha^2}{4M_V^2} \frac{1}{2} (1 + \cos^2\theta) \quad (4)$$

If we include in (4) the terms of order M_V/E present in (2) and the quark parton model term, we get a slightly flatter distribution (see Fig. 2).

Let us now look at the implications of coupling (1) for deep inelastic electron-proton collisions. We find that its contribution to νW_2 reads:

$$\nu W_2(x, Q^2) = \left(1 + \frac{Q^2}{6M_V^2}\right) x(V^+(x) + V^-(x)) \quad (5)$$

where $V^\pm(x)$ stands for the probability of finding a charged ($\pm$) spin one parton in the proton with fraction x of the proton's momentum in the infinite momentum frame. For $m_p W_1(x, Q^2)$ we find :

$$m_p W_1(x, Q^2) = \frac{1}{3} \left(1 + \frac{Q^2}{4M_V^2}\right) (V^+(x) + V^-(x)) \quad (6)$$

with m_p being the proton mass. Noticeable is the fact that the scale violating terms cancel out in the difference $\nu W_2 - 2xm_p W_1$:

$$\nu W_2 - 2x m_p W_1 = \frac{1}{3} x (V^+(x) + V^-(x)) \quad (7)$$

This difference equals zero for spin $\frac{1}{2}$ partons. As a consequence, the ratio σ_4/σ_T should behave like $1/Q^2$ in the Bjorken limit close to $x = 0$. To (5) and (6) we should still add the usual quark parton terms before comparing with experimental data.

For $V^\pm(x)$ we have considered model dependent functions of a form typical for non-valence quarks ¹³⁾. If we choose $xV^\pm(x) = V_0^\pm (1-x)^9$, the present SLAC data are consistent with $V_0^+ + V_0^- < 0.1$, roughly comparable to the antiquark contributions. In terms of the Kuti-Weisskopf model, as modified by Mc Elhaney and Tuan ¹³⁾, fits to νW_2 can be found where a sizeable part of the "sea" is made up of spin one partons (see Fig. 3). This clearly shows that wee partons which are presently playing a minor role in νW_2 could show up as the dominant contribution for e^+e^- annihilation into hadrons.

As one more place where charged spin one partons could play an important role we mention the reaction $pp \rightarrow \mu^+\mu^- + \text{anything}$. In the parton model this reaction proceeds through the annihilation of a parton-antiparton pair and could therefore be more sensitive to the wee region than lepton-hadron scattering. Taking Q^2 to be the invariant mass squared of the muon pair and s the total centre-of-mass energy squared we obtain the following contribution to the double differential cross-section :

$$\frac{d\sigma}{d(\frac{Q^2}{s})d\xi} = \frac{4\pi\alpha^2}{27 M_V^2} \int_0^1 dx \int_0^1 dy \delta(xy - \frac{Q^2}{s}) \delta(x-y-\xi) [V^+(x)V^-(y) + V^-(x)V^+(y)] \quad (8)$$

with $\xi \equiv 2Q_3/\sqrt{s}$ and Q_3 being the z component of the lepton pair momentum in the proton-proton centre-of-mass system. Because we take both $V^+(x)$ and $V^-(x)$ wee (i.e., important only in the neighbourhood of $x \simeq 0$) the contribution of (8) to the cross-section is small, however, for high Q^2 a scaling law different from the quark parton scaling law is obtained :

$$\frac{d\sigma}{dQ^2} (p+p \rightarrow \mu^+\mu^- + \dots) = \frac{1}{Q^2 M_V^2} g\left(\frac{Q^2}{s}\right) \quad (9)$$

(spin 1 partons)

to be compared to ⁹⁾:

$$\frac{d\sigma}{dQ^2} (p+p \rightarrow \mu^+\mu^- + \dots) = \frac{1}{Q^4} f\left(\frac{Q^2}{s}\right) \quad (10)$$

(spin $\frac{1}{2}$ partons)

Needless to say that higher Q^2 data will be able to distinguish between (9) and (10).

As a last point we mention the process $p+p \rightarrow \pi + \text{anything}$ where the pion has very large transverse momentum. The presence of wee spin one partons will modify the low $p_{\perp}^{\pi}/\sqrt{s}$ behaviour bringing in correction terms involving M_V . These terms will depend strongly on the parton-parton collision dynamics. It is possible to eliminate the influence of wee partons by taking $2p_{\perp}^{\pi}/\sqrt{s}$ larger than 0.2, this value being suggested by the inelastic neutrino-nucleon collisions where antiquarks give sizeable contributions below $x = 0.2$. Barring dynamical cancellations, we thus expect to recover the naïve parton model scaling law.

$$E^{\pi} \frac{d\sigma}{d^3p^{\pi}} = \frac{1}{(p_{\perp}^{\pi})^4} f\left(\frac{2p_{\perp}^{\pi}}{\sqrt{s}}, p_{\parallel}^{\pi}\right) \quad (11)$$

but only for $2p_1^\pi/\sqrt{s} > 0.2$. Whether or not present data should be considered as being in the scaling region is a debated question ¹⁴⁾.

It is clear that e^+e^- annihilation into hadrons is opening a new chapter in our understanding of hadron structure. Whether new constituents have to be introduced or whether our present use of the parton model is much too naïve can only be answered by more experimental results which promise to be very interesting.

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FIGURE CAPTIONS

Fig. 1 : Comparison of the calculated ratio R with experimental data from CEA ^{1),2)} and from Frascati ^{15),16)}.

Fig. 2 : Angular distribution of jets. The flatter curve takes into account terms of order M_V/E .

Fig. 3 : Example of a possible contribution of charged spin one partons to νW_2 .

FIG. 2

FIG 3