Brief Reports

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Photoproduction of colored pseudo-Goldstone bosons at very high energy

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We estimate the photoproduction cross section of the color-octet pseudo-Goldstone bosons P_8^0 and P_8^3 in *e-p* collisions at very high energy. The calculated rates are within detectability limits, especially for the P_8^3 state which, besides, cannot be produced in hadron-hadron interactions.

Hypercolor ideas have recently been given a lot of attention.[1] This is both because of their theoretical importance as an alternative to elementary scalar fields in the spontaneous-symmetry-breaking phenomenon and because of their phenomenological implications. Indeed, a most appealing feature of the hypercolor scenario is the unavoidable existence of pseudo-Goldstone bosons (PGB's) with masses light compared to the typical mass scale of ~ 1 TeV of the hypercolor strong forces. This fact provides us with a realistic means of testing the dynamical-symmetry-breaking mechanism of gauge theories. Clearly, we can hope to produce those PGB's in future accelerator machines like LEP, ISABELLE, the *pp* Tevatron collider, etc.

As stated above hypercolor constitutes an extremely attractive alternative to spontaneous symmetry breaking via elementary scalars. These Higgs bosons also have a chance to be detected in those accelerator facilities.[2] We are therefore interested in the phenomenological discrimination between both mechanisms. The phenomenology associated to PGB search has been discussed a great deal in the literature.[1,3,4] As a general rule, e^+e^- collisions are better suited than hadron-hadron collisions for the production of either Higgs bosons or PGB's. In *pp* or $p\bar{p}$ collisions, for instance, the Higgs boson may be produced via gluon-gluon interactions.[5] However, although cross sections are not that small, the expected low luminosity and the large background make actual detection difficult.

The PGB's in current existing models fall into two main mass categories. On the one hand, there are colored PGB's with masses in the $\sim 160-250$ GeV mass range and, on the other hand, colorless PGB's in the few GeV ($\lesssim 8$ GeV) mass scale.[6,7] To actually produce those colored massive PGB's (e.g., P_8^0) requires very energetic collisions (beyond LEP capabilities) such as the ones to be reached at ISABELLE or at the Fermilab Tevatron collider. To be definite, estimates have been given for P_8^0 production through the anomaly-dominated gluon-gluon fusion process. At $\sqrt{s} = 800$ GeV the cross sections are on the order of $10^{-36}-10^{-35}$ cm^2.[7] As far as the light PGB's are concerned they are more likely to be seen in e^+e^- annihilation processes at LEP.[3]

In this paper we consider color-octet PGB production in *e-p* colliding machines as an alternative to the use of *pp* or $p\bar{p}$ interactions. Our motivation for this is twofold. In the first place, the background problems are not as severe and second, since a large fraction of the electroproduction reaction proceeds via quasireal photon bremsstrahlung, the effective luminosity for γp interactions is relatively large. Indeed, for a projected luminosity of

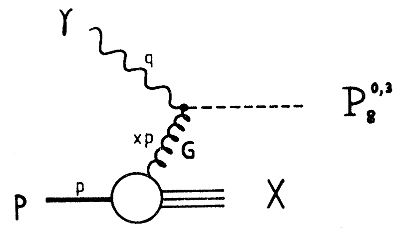

FIG. 1. Kinematics for PGB photoproduction in *e-p* scattering.

10^{32} cm^{-2} sec^{-1} for the HERA machine, one may reasonably infer an effective luminosity for photoproduction processes of 10^{31} cm^{-2} sec^{-1}. In what follows, we shall calculate the photoproduction cross section for reactions $\gamma p \to P_8^0 X$ and $\gamma p \to P_8^3 X$. We remark in passing that this latter PGB cannot be produced in pp ($p\bar{p}$) collisions via the gluon-gluon-fusion mechanism.

To begin with, we give in Fig. 1 some useful kinematics. The photoproduction cross section is given by

$$\sigma(\gamma p \to PX) = \int dx\, G(x) \frac{4\pi^2}{M_P{}^3} \Gamma(P \to \gamma g) \times x\,\delta(x - M_P{}^2/s)\ , \tag{1}$$

where P stands for P_8^0 or P_8^3, $G(x)$ is the gluon distribution function in the proton, and $s=(q+p)^2$.

The widths $\Gamma(P_8^{0,3} \to \gamma g)$ have been given in the literature.[3] They involve the anomalous vertex

$$V_P(xp,q) = xA_P \epsilon_\gamma^\mu \epsilon_g^\nu q^\alpha p^\beta \epsilon_{\mu\nu\alpha\beta}$$

with $A_P \equiv (\sqrt{2}/2)(S_P/4\pi^2 F)$. Here $F \simeq 250$ GeV is the hyperpion decay constant and S^P is the corresponding anomaly factor, $S_{P_8^0} = g_S e \frac{1}{3} N$ and $S_{P_8^3} = g_S e N$, where N is the number of hypercolors. Equation (1) then becomes

$$\sigma(\gamma p \to PX) = G\left[x = \frac{M_P{}^2}{s}\right] \frac{\pi A_P{}^2}{8} \frac{M_P{}^2}{s}\ . \tag{2}$$

Taking the simple scale-invariant form for the distribution function $G(x)$,

$$G(x) = \frac{n+1}{2} \frac{(1-x)^n}{x}\ ,$$

we get

$$\sigma(\gamma p \to P_8^{0,3} X) = \frac{n+1}{16}\left[1 - \frac{M_P{}^2}{s}\right]^n \pi A_{P_8^{0,3}}{}^2\ . \tag{3}$$

If we set $n=5$, and since $s \simeq 4E_\gamma^{\text{lab}} E_P^{\text{lab}}$, we obtain at the highest HERA energies

$$\sigma(\gamma p \to P_8^3 X) \simeq 2\times 10^{-36} \times \left[\frac{N}{4}\right]^2 \text{cm}^2\ ,$$
$$\sigma(\gamma p \to P_8^0 X) \simeq 2\times 10^{-37} \times \left[\frac{N}{4}\right]^2 \text{cm}^2 \tag{4}$$

for $M_P = 245(4/N)^{1/2}$. In Eq. (4) we have used

$$\alpha_s(Q^2) = \frac{12\pi}{21 \ln(Q^2/\Lambda^2)}$$

at $Q^2 = M_P{}^2$ with $\Lambda = 300$ MeV.

These cross sections are even larger at still higher energies. Their asymptotic values are

$$\sigma\left[\gamma p \to \begin{Bmatrix} P_8^3 \\ P_8^0 \end{Bmatrix} X\right] \underset{s\to\infty}{\sim} \begin{Bmatrix} 1 \\ \frac{1}{9} \end{Bmatrix} \times (n+1) \left[\frac{N}{4}\right]^2 \times 10^{-35}\ \text{cm}^2\ .$$

At $\sqrt{s} = 350$ GeV, our cross section for P_8^0 photoproduction is two orders of magnitude larger than the corresponding cross section for P_8^0 production in pp ($p\bar{p}$) collisions.[7] At still larger energies this difference narrows down and, eventually, for sufficiently high $\sqrt{s}$, the latter cross section overcomes the photoproduction cross section. This different behavior is due to the factor $(1 - M_P/\sqrt{s})^{2n}$ appearing in the cross section for $pp \to P_8^0 X$, compared to the factor $(1 - M_P{}^2/s)^n$ of Eq. (3). Of course HERA energies will not reach this asymptotic regime. We stress once more that for the production of the P_8^3 state, hadron-hadron interactions are inappropriate and consequently e-p reactions may be a unique source for their production. At this point a remark is in order. We took for the gluon distribution function a Q^2-independent parametrization. This choice was simply dictated by our ignorance on the actual shape of the gluon distribution function. We have, however, extended its use to very high Q^2 values where $G(x)$ might have changed appreciably. The general trend of parton (gluon) distributions is to shrink towards the low-x region as Q^2 increases. Our value of x is in the region of $x \sim 0.5$ and therefore the above cross sections would be reduced in an amount which cannot be easily estimated, since it is very sensitive to the initial shape of $G(x)$ at low values of Q^2. Here, we only note that the effect of scaling violations is less severe in our case than in pp ($p\bar{p}$) collisions at the same value of $\sqrt{s}$, since the factor $G(x = M^2/s)$ of Eq. (2) is replaced by $[G(x = M/\sqrt{s})]^2$ in the pp ($p\bar{p}$) cross section. Of course, the effect of scaling violations is reduced or even inverted going to large enough values of $\sqrt{s}$.

To conclude, we may briefly summarize our results as follows. We were interested in the production of neutral-colored hypermesons, and more specifically, the production of the P_8^0 and P_8^3 states. Since these pseudo-Goldstone bosons are expected to be rather massive (~ 250 GeV), in fact too heavy to be produced at LEP, we have considered the possibility of detecting them in *e-p* machines, i.e., at HERA. *pp* and $p\bar{p}$ collider machines have been previously suggested for the production of the P_8^0 via gluon-gluon annihilation.[7] The P_8^3 state, on the contrary, cannot be produced in *pp* (or $p\bar{p}$) by this mechanism. Therefore, an *e-p* machine turns out to be a unique means for the production of the colored P_8^3 boson. Furthermore, the background is somewhat reduced and the effective luminosity quite large due to the quasireal photon dominated cross section. In addition, the photon energy is easy to control by measuring the energy loss of the scattered electron. The resulting cross sections lie within experimentally detectable limits at the top HERA energies. It is an unfortunate fact that HERA capabilities shall not extend to higher energies in order that one could reach energy regions comfortably above the production threshold for these PGB states. Of course, it is not at all excluded that the hypercolor group be SU(N) with $N>4$ and, consequently, the cross section for their production at HERA would be larger, both because of the available phase space (the masses of the $P_8^{0,3}$ states being lower) and the extra $(N/4)^2$ factor coming from the anomaly. Finally, we like to point out that a positive signal in such processes should be taken as a confirmation of hypercolor, since the production cross section for a Higgs boson of comparable mass in a photoproduction process is several orders of magnitude below the production rates given above.[8]

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[1]S. Weinberg, Phys. Rev. D 19, 1277 (1979); L. Susskind, *ibid.* 20, 2619 (1979); S. Dimopoulos and L. Susskind, Nucl. Phys. B155, 237 (1979); M. A. B. Bég, H. D. Politzer, and P. Ramond, Phys. Rev. Lett. 43, 1701 (1979); E. Eichten and K. D. Lane, Phys. Lett. 90B, 125 (1980).

[2]G. Barbiellini *et al.*, DESY Report No. 79/27, 1979 (unpublished).

[3]J. Ellis, M. K. Gaillard, D. V. Nanopoulos, and P. Sikivie, Nucl. Phys. B182, 529 (1981).

[4]A. Ali and M. A. B. Bég, Phys. Lett. 103B, 376 (1981); S. Dimopoulos and J. Ellis, Nucl. Phys. B182, 505 (1981); J. A. Grifols, Phys. Lett. 102B, 277 (1981); G. J. Gounaris and A. Nicolaidis, Phys. Lett. 102B, 144 (1981); J. Ellis, D. V. Nanopoulos, and P. Sikivie, Phys. Lett. 101B, 387 (1981).

[5]H. M. Georgi, S. L. Glashow, M. E. Machacek, and D. V. Nanopoulos, Phys. Rev. Lett. 40, 692 (1978).

[6]S. Dimopoulos, Nucl. Phys. B168, 69 1980 ; Peskin, *ibid.* B175, 197 (1980); S. Dimopoulos, S. Raby, and P. Sikivie, Nucl. Phys. B176, 449 (1980); P. Sikivie, CERN Report No. TH.2951-CERN, 1980 (unpublished).

[7]S. Dimopoulos, S. Raby, and G. L. Kane, Nucl. Phys. B182, 77 (1981).

[8]J. Abad *et al.*, Phys. Rev. D 24, 2837 (1981).