Z^0 decay and axigluons

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The total first-order chiral-color contribution to the Z^0 decay is computed. It is argued that the corresponding enhancement of the total width of the Z^0 could lead to either the discovery or the exclusion of a light axigluon at the SLAC Linear Collider or the CERN e^+e^- collider LEP.

Gauge theories have played a crucial role in the development of physics in the past 35 years. They have been successfully applied to the description of quite unrelated phenomena ranging from condensed matter to particle theory. As an example, electroweak gauge theory has been spectacularly confirmed by the discovery of the W and Z bosons at CERN.

Quantum chromodynamics (QCD) is generally believed by nuclear and particle physicists to be the correct theory underlying the nuclear force, at least at low energy. However, the recent start of the new Z^0 factories, the SLAC Linear Collider (SLC) and the CERN e^+e^- collider (LEP) opens wide the door to the discovery of new high-energy symmetries. One such proposed extension of the standard model is offered by chiral-color theory.[1] This alternative to QCD predicts the existence of a color octet of massive axigluons, corresponding to the broken generators of the $SU(3)_L \times SU(3)_R$ chiral-color gauge group. At the Fermi mass this symmetry spontaneously breaks down to the familiar $SU(3)_{QCD}$. Several mass bounds have been set on the axigluon[2,3] and two possible windows are left: from 50 to 150 GeV and above 310 GeV.

It is the purpose of this Brief Report to examine how the presence of the axigluon modifies the width of the Z^0. A few authors have already studied how a light axigluon can open new Z^0 decay channels and thus be detected through the enhancement of multijet events.[4] We argue that even an axigluon heavier than the Z^0 could be detected at SLC or LEP via a sensitive increase in the latter's total decay width.

The dominant decay mode of the Z^0 is depicted in the Feynman diagram of Fig. 1(a) the vector boson splits into a quark-antiquark pair which will produce two back-to-back hadrons jets upon hadronization. This process makes up about 70% of the total Z^0 width, whereas leptonic decays or higher-order QCD decays have quite smaller branching ratios.

The lowest-order chiral-color correction to the Z^0 decay is depicted in the diagrams c and d of Fig. 1. The branching ratio of this axigluon bremsstrahlung has been computed by Rizzo[4] and is given by the dashed curve of Fig. 2 as a function of the axigluon mass. The analytic form of this three-jet decay width is given by

$$\Gamma_3 = \frac{e^2}{4\pi} m_Z \left(\frac{\alpha_s}{\pi} T \right) \sum_f V_f \ , \tag{1}$$

where e is the charge of the electron, α_s is the strong coupling constant, and m_Z is the mass of the Z^0. The sum over flavors is applied to $V_f = v_f^2 + a_f^2$, where v_f and a_f are the vector and axial-vector couplings of the quarks to the Z^0. T is the three-body phase-space integral which has been computed in Ref. 2. It appears here as a function of the ratio of the Z^0 and axigluon masses m_Z/m_A. It is divergent for m_A approaching zero and goes to zero in the kinematical limit $m_A \geq m_Z$.

This treatment of the axigluon bremsstrahlung is too naive, however. Indeed, when the axigluon is emitted collinearly with the two quarks, the resulting two-jet event cannot be distinguished from a genuine two-jet event originating, e.g., from the diagram a of Fig. 1. If color were not confined, one would still be capable of differentiating the two mechanisms by measuring the invariant mass of the jets. Hadronization, however, rearranges the original momenta so that jets actually contain very little information about their seeds and cannot be considered as residues of single partons. Moreover, for low axigluon masses, collinear and infrared divergences yield an unphysically high branching ratio.

These features prevent us from comparing the cross sections obtained directly from diagrams c and d of Fig. 1 with experiment. Nevertheless, such a comparison can take place when cuts are introduced in the three-body phase space. These cuts would exclude regions where the three jets cannot be resolved and should be consistent with the jet definitions used by experimentalists. The resulting three-jet branching ratio is then finite for a zero axigluon mass and remains systematically lower than the dashed curve of Fig. 2. Since axigluons lighter than 50 GeV seem to be excluded,[2] it appears thus that the enhancement of three-jet events in the decay of the Z^0 would be very difficult to detect.

However, the interference of the two-jet diagrams a and b of Fig. 1 only involves virtual axigluons and is thus no longer subject to a kinematical limit when $m_A \geq m_Z$. As a consequence, the resulting partial width might thus still be of importance for heavier axigluons. It is given by

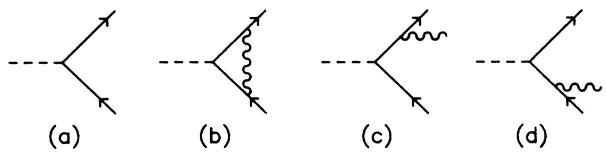

FIG. 1. Feynman diagrams. Straight lines are quarks, dashed lines are Z^0, and curved lines are axigluons.

$$\Gamma_2=\frac{e^2}{4\pi}m_Z\left[\frac{\alpha_s}{\pi}L\right]\sum_f V_f\ , \tag{2}$$

where the notation is the same as for Eq. (1) and quarks are still taken to be massless. The loop momentum integral L has also been computed in Ref. 2. Like T, it is a function of m_Z/m_A but it is not zero when $m_A \geq m_Z$. Nevertheless, L is also divergent for $m_A=0$. However, when Γ_2 is added to Γ_3 to form the total first-order chiral-color contribution to the width of the Z^0, those divergences cancel, as expected by the Kinoshita-Lee-Nauenberg theorem.[5]

The total first-order branching ratio $(\Gamma_2+\Gamma_3)/(2.5$ GeV) is shown in Fig. 2 by the solid line. It indeed remains finite for a zero axigluon mass, and goes (slowly) to zero when $m_A \gg m_Z$. As it turns out, even an axigluon as heavy as the Z^0 would still contribute up to 3% of the latter's width. This effect is quite remarkable since, with a yearly production of 10^6-10^7, Z^0, LEP is expected to measure the Z^0 width with an error of 2%. The possible observation of a Z^0 lifetime shorter than what is expected from the standard model could thus be explained by the presence of an axigluon lighter than 150 GeV.

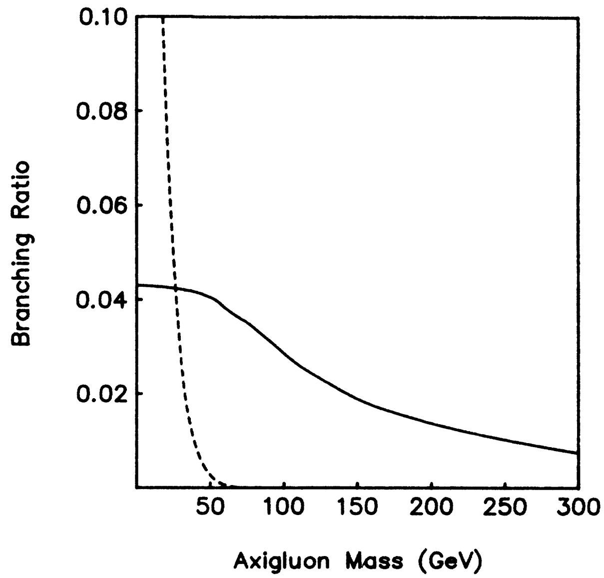

FIG. 2. Branching ratios of axigluonic decays. The dashed line corresponds to the contribution of diagrams c and d of Fig. 1 whereas the solid line corresponds to the first-order contribution of all diagrams of Fig. 1.

The present statistics reported from LEP (Ref. 6) already yield an accuracy of about 5%. This, though, does not yet provide any new limit on chiral color since the effect we describe here contributes at most 4%. Nevertheless, as the months go by and more and more data is being gathered at LEP, the existence of a light axigluon might soon be ruled out or confirmed.

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