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CHIRAL COLOUR AND AXIGLUONS*

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In the framework of chiral colour theory, it is shown how the choice of gauge couplings is constrained by low energy phenomenology. The requirement that there be a massless gluon yields a relationship between the two coupling constants. Their allowed values as the mass of the axigluon are further constrained by present e^+e^- data.

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1. Introduction

The recent results from LEP and CDF have provided a striking confirmation of the standard model strong and electroweak interactions. This success has nevertheless left many of us unsatisfied, since the discovery of "new physics" hence seems to be postponed to the first runs of the next generation of colliders. Nevertheless, the high statistics to be obtained in the meantime at TEVATRON, LEP and TRISTAN, might already hint at particular values of top and Higgs masses, or, more exotically, at supersymmetry, left–right symmetric models or chiral colour.

It is our purpose here to examine some implication of this latter gauge extension of QCD, which we shall hereafter denote QC^2D, for Quantum Chiral Colour Dynamics [1]. A number of papers have already been devoted to the study of axigluon (the eight extra massive gauge vectors associated with QC^2D) signatures in high energy processes [2-5]. As a result, the mass of the axigluon octet could be constrained to be no less than 50 GeV [6], and to lie outside the range of 150 to 310 GeV [7].

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As we shall show here, these mass bounds were all obtained while assuming a discrete symmetry of the lagrangean. Since this symmetry remains totally unmotivated, we shall here show how to relax this unnecessary assumption. It will then turn out that the lower limit of 50 GeV on the axigluon mass remains valid.

In the next Section, we shall describe QC²D and explain how its axigluons have to couple to quarks in order to preserve QCD at low energy. Although the results we will obtain are the same as those of [8], the approach used here is different and should bring more insight on the symmetry breaking mechanism.

In the following Section, we will present the results of a phenomenological analysis of e^+e^- data which puts some limits on the parameters of the theory. A more detailed description of this analysis can be found in [8].

2. From QCD to QC²D

With $SU(3)_L \otimes SU(3)_R$ as its gauge group, QC²D is a simple extension of QCD. Upon spontaneous symmetry breaking, only the diagonal subgroup $SU(3)_V$ survives at low energy: we recover thus QCD by idetifying $SU(3)_V = SU(3)_{\text{colour}}$. The eight generators which correspond to the broken part of $SU(3)_L \otimes SU(3)_R$ yield eight massive gauge vectors, the axigluons.

Although we shall not dwell upon any particular symmetry breaking mechanism (many have been proposed [1,9]), it is understood that it does not take place at such high energy that QC²D would forever remain unseen. To have any predictive power, the QC²D and electroweak symmetry breaking mechanisms breaking mechanism must be intertwined.

The QC²D quark lagrangean is chiral:

$$\mathcal{L}_q = \overline{\psi}\gamma^\mu \partial_\mu \psi + g_L \overline{\psi}\gamma^\mu L_\mu T_L \psi_L + g_R \overline{\psi}\gamma^\mu R_\mu T_R \psi_R \,. \tag{2.1}$$

The 2×8 gauge fields L_μ and R_μ transform as the adjoint representation of the $SU(3)_L$ and $SU(3)_R$ groups, while g_L and g_R are their respective coupling strengths. The mass eigenstates, gluons G_μ and axigluons A_μ, are given by a unitary transformation of L_μ and R_μ:

$$\begin{aligned} L_\mu &= \cos\theta\, A_\mu + \sin\theta\, G_\mu, \\ R_\mu &= -\sin\theta\, A_\mu + \cos\theta\, G_\mu. \end{aligned} \tag{2.2}$$

To recover QCD at low energy, some conditions have to be imposed on the gluon. Two equivalent alternatives are possible:

1) One can impose that the gluon G_μ has a pure vector QCD coupling g_s to quarks. This is the constraint used in [8]. Inserting (2.2) into lagrangean (2.1), with $\psi_{L,R} = \frac{1}{2}(1 \pm \gamma_5)\psi$, it is obvious that this condition can only

be fulfilled if the three parameters g_L, g_R and θ are linked by the two conditions:

$$g_s = g_L \sin\theta \doteq g_R \cos\theta \tag{2.3}$$

2) One can also demand the gluon to be massless. Whatever the symmetry breaking mechanism is, ultimately the fields G_μ must carry the adjoint representation of the diagonal subgroup of $SU(3)_L \otimes SU(3)_R$. Therefore, they must be coupled to the quarks *via* the $T_L + T_R$ linear combination of generators. Again, upon insertion of (2.2) into (2.1), it is clear this can only be realized if condition (2.3) is verified.

It is interesting to notice that it is analogous to what happens in the electroweak model. In that case, however, a careful assignment of hypercharges is crucial for the argument based on a pure vector coupling of photons to fermions to remain valid. Similarly to the Z^0 boson, the axigluon has a mixed $V + A\gamma_5$ coupling to quarks, with

$$\begin{aligned} V &= g_s \cot 2\theta\,, \\ A &= g_s \frac{1}{\sin 2\theta}\,. \end{aligned} \tag{2.4}$$

In contrast to the electroweak model, however, this coupling is universal for quarks. In the limit where $g_L = g_R$ the vector coupling disappears,hence the name " axigluon".

It must be emphasized that all QC^2D predictions up to date have been computed in this $g_L = g_R$ limit. Some argue that this condition is necessary to ensure strong parity conservation. This argument is however fallacious, since for $g_L \neq g_R$ with Eq. (2.3) holding QC^2D is exactly recovered at low energy. At intermediate energies, of the order of the axigluon mass, there should be strong parity violation even in the symmetric case. Finally, for much higher energies there is no fundamental principle to demand parity conservation. To impose the discrete symmetry $g_L = g_R$ onto the QC^2D lagrangean is as unnatural as demanding $g = g'$ in the electroweak model.

As an upshot, QC^2D is a gauge extension of QCD, with QCD as its low energy limit. It predicts the existence of eight massive vector bosons, the axigluon, which have a mixed vector–axialvector coupling to quarks given by Eq. (2.4). These axigluon are characterized by their mixing angle with gluons and their mass. Experimental bounds on the allowed values of these two parameters are presented in the next Section.

3. Axigluons at LEP and TRISTAN

A not too heavy massive axigluon should significantly contribute to the decay of the Z^0 *via Bremsstrahlung* from decay quarks [10] (if $m_A < m_Z$) or via radiative corrections (also for $m_A > m_Z$) [11].

The standard model with N_ν massless neutrinos predicts for the Z^0 a width of $\Gamma_{Z^0} \approx 2.073 = 0.166 N_\nu$ GeV. Experimentally, this width has been measured at LEP with better than 5% accuracy, $\Gamma_{Z^0} \approx 2.6 \pm 0.15$ GeV [12]. It thus results that the number of massless neutrinos is at present $N_\nu \approx 3.17 \pm 0.18$. As statistics are accumulating, this number will be known more and more precisely. The emergence of a fractional number of neutrinos (bigger than three) would either signal the existence of massive fourth generation neutrino, or indicate a more exotic departure from standard model physics, like QC^2D.

We have shown in Fig. 1 the lines of 1–5% axigluon branching ratio in the (θ, m_A) plane. If the Z^0 width is measured with a 5% accuracy without any significant deviation from the standard model (as is the case by now), *i.e.* $\Gamma_{Z^0} \approx 2.57$ GeV, the region to the left of the leftmost curve (labelled 5%) is forbidden. If the agreement with the standard model remains when lower experimental errors are reached, the allowed area in the (θ, m_A) plane will shrink more and more to the right.

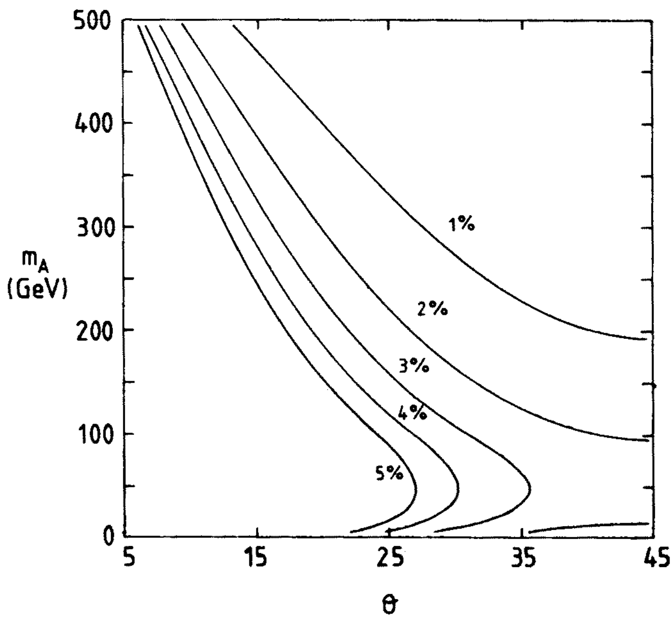

Fig. 1. Z^0 decay: lines of constant branching ratio. Values of θ and m_A lying to the left of the 5% curve are forbidden at present.

It is clear that light axigluons with small mixing angles are already excluded, whereas heavy axigluons with maximal mixing ($\theta \approx \frac{\pi}{4}$) will be difficult to detect. This tendency is fairly obvious from phase space considerations and from the fact that axigluons have a stronger coupling to quarks at low mixing angles (2.4).

The remaining area of the (θ,m_A) plane is further constrained by lower energy e^+e^- data gathered at TRISTAN. The fit of the hadronic e^+e^- cross-sections from 22 to 61.25 GeV yields the upper and lower curves of Fig. 2. They define an area where $\chi^2_{\min} \leq \chi^2 \leq \chi^2_{\min} + 2.3$, *i.e.* where the values of θ and m_A should both be within one standard deviation of the best fit, which was found to be $m_A = 338$ GeV and $\theta = 7.3°$ with $\chi^2/dof \approx \frac{50}{83}$. The limiting curve to the left is the 5% accuracy curve of Fig.1.

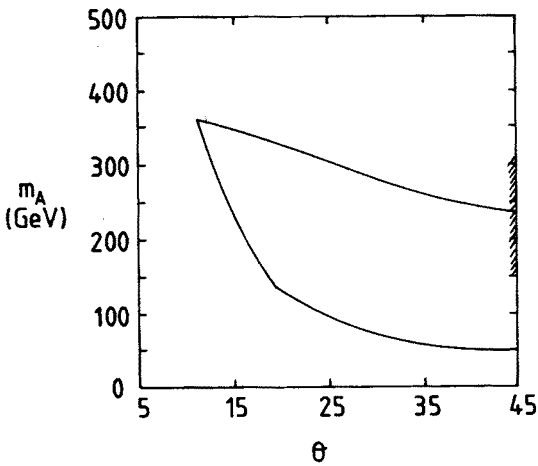

Fig. 2. Global fit to all e^+e^- processes. Values of θ and m_A lying inside the solid contour are within one standard deviation of the best fit. The hatched area is forbidden from hadron collision data.

If the values of θ and m_A were to lie below the lower curve, the axigluon would provoke an increase in the hadron production which is incompatible with the data. It turns out, however,that the data themselves seem to be in excess by one to two standard deviations of the standard model predictions. This "TRISTAN anomaly", which sets in at around 56 GeV, was announced last Summer by the AMY, TOPAZ and VENUS collaborations. Although the statistical errors on these measurements are still quite large, it seems that with all three TRISTAN detectors measuring the same tendency, we are facing a real effect.

It is slight anomaly which explains the existence of the upper curve in Fig.2. Such an upper bound on the axigluon mass was not present in a previous analysis [6] (performed at $\theta = \frac{\pi}{4}$), because the experimental input used there was based on an analysis by the CELLO collaboration [13] which only included data up to 46.6 GeV.

It is important, though, to keep in mind that, while the lower curve in Fig.2 provides a definite lower bound on the axigluon mass, the upper bound is true only if QC²D is the correct explanation to the TRISTAN anomaly. As always, a statistical fit only makes sense if the fitted model is the correct one.

The hatched region from 175 to 310 GeV on the $\theta = 45°$ axis corresponds to the values of the axigluon mass which have been excluded from hadronic collider data [7]. This analysis has been performed with symmetric QC²D coupling $g_L = g_R$, and is thus only valid for $\theta = 45°$. Unfortunately, the contribution of the mixing angle θ to the total proton–antiproton cross–section is non–trivial and does not factorize (as it is the case in the e^+e^- processes described above).

A complete reanalysis of this hadronic data with an asymmetric coupling $g_L \neq g_R$, would certainly yield a drastic shrinking of the allowed area in the (θ, m_A) plane, but has not yet been performed.

4. Conclusions

We have shown that an asymmetric QC²D coupling $g_L \neq g_R$ does not modify previous lower bounds on the axigluon mass [6]. However, its disallowed window from 175 to 310 GeV [7], originating from hadron collision data, will be modified by different left and right couplings. Finally, it is interesting to notice that if the TRISTAN anomaly is to be explained by QC²D, it gives rise to an upper bound of 375 GeV on the axigluon mass, for any choice of the couplings.

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