Weak-triplet, color-octet scalars, and the CDF dijet excess

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We extend the standard model to include a weak-triplet and color-octet scalar. This “octo-triplet” field consists of three particles, two charged and one neutral, whose masses and renormalizable interactions depend only on two new parameters. The charged octo-triplet decay into a W boson and a gluon is suppressed by a loop factor and an accidental cancellation. Thus, the main decays of the charged octo-triplet may occur through higher-dimensional operators, mediated by a heavy vectorlike fermion, into quark pairs. For an octo-triplet mass below the $t\bar{t}$ threshold, the decay into $Wb\bar{b}$ or $Wb\bar{s}$ through an off-shell top quark has a width comparable to that into $cs$ or $cb$. Pair production with one octo-triplet decaying into two jets and the other decaying into a $W$ and two soft $b$ jets may explain the dijet-plus-$W$ excess reported by the CDF Collaboration. Using a few kinematic distributions, we compare two mechanisms of octo-triplet pair production: through an $s$-channel coloron and through the coupling to gluons. The higher-dimensional operators that allow dijet decays also lead to $CP$ violation in $B_s - \bar{B}_s$ mixing.

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I. INTRODUCTION

Scalar fields transforming as octets under $SU(3)_c$, the color group of the strong interactions, have been studied in various contexts. The simplest type of color-octet scalar is a singlet under the $SU(2)_W$ group of the weak interactions, and may be referred to as an “octo-singlet.” These lead to pairs of dijet resonances at hadron colliders [1,2], and may explain [3] some deviations from the standard model predictions in the 3$b$ search performed by the CDF collaboration [4]. They also enhance the standard model Higgs boson production through gluon fusion [5]. Octo-singlets appear as composite particles due to technicolor [6] and other strong-coupling dynamics [7,8], or as elementary particles in 6-dimensional extensions of the standard model [9] and in theories with an extended color group [3,10].

Weak-doublet color-octet scalars (i.e., “octo-doublelets”) differ dramatically from octo-singlets because the standard model gauge symmetry allows renormalizable couplings of octo-doublets to the standard quarks [11]. Only if these couplings are highly suppressed or aligned with the standard model Yukawa couplings can the octo-doublets be light enough to be produced at the LHC [12]. An octo-doublet field includes four color-octet states: a charged particle, a neutral one and their antiparticles. The hadron collider signatures of octo-doublets have been explored in [13,14].

In this paper we study “octo-triplets”: real scalar fields that transform in the adjoint representation, $(8,3,0)$, of $SU(3)_c \times SU(2)_W \times U(1)_Y$. An octo-triplet field includes three color-octet states: a particle of charge $+1$, its antiparticle, and a neutral real particle. Akin to octo-singlets, octo-triplets are pair-produced at hadron colliders through their couplings to gluons, and cannot decay into standard model fermions at renormalizable level because the Yukawa couplings are not $SU(2)_W \times U(1)_Y$-invariant. Unlike octo-singlets, octo-triplets cannot decay into gluons unless there are additional fields that generate certain dimension-7 operators.

One-loop decays of octo-triplets into a gluon and an electroweak boson are allowed, leading to interesting collider signatures involving two gluons and two electroweak bosons. We will show, however, that the rate of these decays is accidentally suppressed by 2 orders of magnitude compared to usual one-loop estimates. Thus, new heavy particles could induce the dominant octo-triplet decay modes.

In the presence of some vectorlike quark of mass in the TeV range, the charged octo-triplet may decay into a pair of standard model quarks, or into a $W$ boson and a pair of quarks if it is lighter than the top quark. This leads to a variety of collider signatures, including a dijet resonance, a $W$ boson and two softer jets. If the octo-triplet mass is in the 150–170 GeV range, this signature may explain the $4.1 \sigma$ excess observed by the CDF Collaboration in the dijet resonance plus $W$ final state [15,16]. Some alternative explanations can be found in [3,18–20]. At the LHC, octo-triplets with much larger masses (~1 TeV) may be probed in several final states.

Octo-triplets may be elementary particles (e.g., part of the 75 representation of SU(5) grand unification), or may arise as composite ones, for example, as fermion-antifermion bound states [8]. We treat the octo-triplets as pointlike particles, which is a good approximation only

\footnote{The D0 search in the same channel [17] has a larger background and less data, so that it might not be sensitive enough to the signature proposed here.}