The two-photon decay of a scalar-quirk bound state

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1.1 Introduction

An excess of events containing two photons with invariant mass near 750 GeV has been observed in 13 TeV proton–proton collisions by the ATLAS and CMS collaborations [1, 2]. The cross section $\sigma(pp \to \gamma\gamma)$ is estimated to be

$$\sigma(pp \to \gamma\gamma) = \begin{cases} (10 \pm 3)\ \text{fb} & \text{ATLAS} \\ (6 \pm 3)\ \text{fb} & \text{CMS} \end{cases} \tag{1.1}$$

and there is no evidence of any accompanying excess in the dilepton channel [3]. If we interpret this excess as the two photon decay of a single new particle of mass m then ATLAS data provide a hint of a large width: $\Gamma/m \sim 0.06$, while CMS data prefer a narrow width. Naturally, further data collected at the LHC should provide a clearer picture as to the nature of this excess.

There has been vast interest in the possibility that the diphoton excess results from physics beyond the SM. Most discussion has focused on models where the excess is due to a new scalar particle which subsequently decays into two photons *e.g.* Ref. [4]. The possibility that the new scalar particle is a bound state of exotic charged fermions has also been considered, *e.g.* Refs. [5–9]. Here we consider the case that the 750 GeV state is a non-relativistic bound state constituted by an exotic *scalar* particle χ and its antiparticle, charged under $SU(3)_c$ as well as a new unbroken non-abelian gauge interaction. Having χ be a scalar rather than a fermion is not merely a matter of taste: In such a framework a fermionic χ would lead to the formation of bound states which (typically) decay to dileptons more often than to photons; a situation which is not favoured by the data.

The bound state, which we denote Π, can be produced through gluon–gluon fusion directly (*i.e.* at threshold $\sqrt{s_{gg}} \simeq M_\Pi$) or indirectly via $gg \to \chi^\dagger\chi \to \Pi +$ *soft quanta* (*i.e.* above Π threshold: $\sqrt{s_{gg}} > M_\Pi$). The indirect production mechanism can dominate the production of the bound state, which is an interesting feature of this kind of theory.

1.2 The model

We take the new confining unbroken gauge interaction to be SU(N), and assume that, like SU$(3)_c$, it is asymptotically free and confining at low energies. However, the new SU(N) dynamics is qualitatively different from QCD as all the matter particles [assumed to be in the fundamental representation of SU(N)] are taken to be much heavier than the confinement scale, Λ_N. In fact we here consider only one such matter particle, χ, so that $M_\chi \gg \Lambda_n$ is assumed. In this circumstance a $\chi^\dagger\chi$ pair produced at the LHC above the threshold $2M_\chi$ but below $4M_\chi$ cannot fragment into two jets. The SU(N) string which connects them cannot break as there are no light SU(N)-charged states available. This is in contrast to heavy quark production in QCD where light quarks can be produced out of the vacuum enabling the color string to break. The produced $\chi^\dagger\chi$ pair can be viewed as a highly excited bound state, which de-excites by SU(N)-ball and soft glueball/pion emission [10].

With the new unbroken gauge interaction assumed to be SU(N) the gauge symmetry of the SM is extended to

$$\mathrm{SU}(3)_c \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y \otimes \mathrm{SU}(N). \tag{1.2}$$

This kind of theory can arise naturally in models which feature large colour groups [11–13] and in models with leptonic colour [14–17] but was also considered earlier by Okun [18]. The notation *quirks* for heavy particles charged under an unbroken gauge symmetry (where $M_\chi \gg \Lambda_\mathrm{N}$) was introduced in [10] where the relevant phenomenology was examined in some detail in a particular model[1]. For convenience we borrow their nomenclature and call the new quantum number *hue* and the massless gauge bosons *huons* ($\mathscr{H}$).

The phenomenological signatures of the bound states (quirkonia) formed depend

[1]Some other aspects of such models have been discussed over the years, including the possibility that the SU(N) confining scale is low ($\sim$ keV), a situation which leads to macroscopic strings [19].

on whether the quirk is a fermion or boson. Here we assume that the quirk χ is a Lorentz scalar in light of previous work which indicated that bound states formed from a fermionic χ state would be expected to be observed at the LHC via decays of the spin-1 bound state into opposite-sign lepton pairs ($\ell^+\ell^-$) [10, 17]. In fact, this appears to be a serious difficulty in attempts to interpret the 750 GeV state as a bound state of fermionic quirk particles (such as those of Refs. [5–7]). The detailed consideration of a scalar χ appears to have been largely overlooked[2], perhaps due to the paucity of known elementary scalar particles. With the recent discovery of a Higgs-like scalar at 125 GeV [21, 22] it is perhaps worth examining signatures of scalar quirk particles. In fact, we point out here that the two photon decay is the most important experimental signature of bound states formed from electrically charged scalar quirks. Furthermore this explanation is only weakly constrained by current data and thus appears to be a simple and plausible option for the new physics suggested by the observed diphoton excess.

[2]The idea has been briefly mentioned in recent literature [8, 20].

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