Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics B 911 (2016) 106–126

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Collider tests of (composite) diphoton resonances

Emiliano Molinaro, Francesco Sannino *, Natascia Vignaroli

CP[3]-Origins and the Danish IAS, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark

Received 3 June 2016; accepted 30 July 2016

Available online 4 August 2016

Editor: Hong-Jian He

Abstract

We analyze the Large Hadron Collider sensitivity to new pseudoscalar resonances decaying into diphoton with masses up to scales of few TeVs. We focus on minimal scenarios where the production mechanisms involve either photon or top-mediated gluon fusion, partially motivated by the tantalizing excess around 750 GeV reported by ATLAS and CMS. The two scenarios lead respectively to a narrow and a wide resonance. We first provide a model-independent analysis via effective operators and then introduce minimal models of composite dynamics where the diphoton channel is characterized by their topological sector. The relevant state here is the pseudoscalar associated with the axial anomaly of the new composite dynamics. If the Standard Model top mass is generated via four-fermion operators the coupling of this state to the top remarkably explains the wide-width resonance reported by ATLAS. Beyond the excess, our analysis paves the way to test dynamical electroweak symmetry breaking via topological sectors.

1. The relevance of the diphoton channel

The diphoton channel has proved extremely successful in discovering new (pseudo)scalar particles such as the Higgs boson [1,2]. Earlier π_0 and η' decays into $\gamma\gamma$ provided instrumental to demonstrate the composite nature of the QCD hadrons. Furthermore, a tantalizing excess around

* Corresponding author.
E-mail address: sannino@cp3-origins.net (F. Sannino).

http://dx.doi.org/10.1016/j.nuclphysb.2016.07.032

750 GeV has been reported by the LHC experimental Collaborations [3,4] in the current run at $\sqrt{s} = 13$ TeV. More specifically, with 3.2 fb^{-1}, ATLAS observes an excess in the number of events, respectively of about 7.8 and 4.3, for the diphoton invariant mass bins at 730 and 770 GeV. This corresponds to a local significance of 3.9σ at 750 GeV, under the assumption of a large width of about 45 GeV. With 2.6 fb^{-1} CMS measures an excess around 760 GeV, corresponding to a local significance of 2.6σ.

It is therefore timely to investigate the LHC reach and constraints from the diphoton channel. Because of the intriguing excess around 750 GeV, we first specialize our analysis around this energy range. Minimal models that can explain the excess entail gluon fusion production through new colored states [5–11] or photon fusion production [12–15] that typically lead to a narrow resonance (see also [16,17]). If a wide-width scenario, currently favored by ATLAS [3], is confirmed, it can be achieved via a direct coupling to the top quark [18,19]. This induces the production of the pseudoscalar resonance via top-mediated gluon fusion. Alternative ways to obtain a wide width are via exotic decay topologies [20–25] or invoking a coupling to an invisible sector [26–29].

Here we therefore consider two production mechanisms, the photon and top-mediated gluon fusion. We will first rely on an effective field theory approach and then consider minimal models of composite dynamics. We discuss the current constraints and excesses coming from the LHC run at $\sqrt{s} = 8$ TeV (LHC-8) as well as the run at $\sqrt{s} = 13$ TeV (LHC-13). We observe that when the resonance is photo-produced one can constrain it up to high mass values of the order of 5 TeV with around 100 fb^{-1}. If the diphoton resonance is produced via top-mediated gluon fusion the reach is up to 2 TeV with 100 fb^{-1}, due to the quick drop of the production cross section with its mass.

Minimal models of composite dynamics all predict a pseudoscalar state with specific couplings to the electroweak (EW) gauge bosons which arise from the topological sector of the underlying theory [5,30]. This state is the analogue of the η' of QCD. This makes the models ideal case-studies for the diphoton channel. The composite pseudoscalar resonance also offers a natural explanation for the observed excess at 750 GeV, as shown in [5]. Other composite realizations have been explored in [19,31–38].

We first review the effective Lagrangian for minimal models of composite dynamics augmented by the gauged version of the Wess–Zumino–Witten term [39–44]. We then move to its phenomenology in the two limits of photon and gluon fusion production of the η'-like state. We will see that if the Standard Model (SM) top mass is generated via four-fermion operators, the coupling of this state to the top naturally explains the wide-width resonance reported by ATLAS.

Our results demonstrate that topological sectors stemming directly from the underlying dynamics give rise to novel signatures in the diphoton and EW channels that open a new avenue to test natural theories of EW symmetry breaking at present and near future collider experiments. In that respect, our analysis complements phenomenological studies of composite dynamics that, so far, have been mostly focused on spin-one resonances [45,46].

The paper is structured as follows: in section 2 we set up the analysis via an effective operator framework and study the photon and the top-mediated gluon fusion production mechanisms. We also compare with current collider limits and discuss the observed excesses at 750 GeV. We then determine the LHC-13 reach for higher masses. In section 3 we introduce the minimal models of composite dynamics and their effective Lagrangian including the topological terms. For the two envisioned production mechanisms we analyze the LHC-13 reach and constraints stemming from these terms. We finally offer our conclusions in section 4. Further details related to the topological terms can be found in the appendix.