$Z_0(57)$ AND $E(38)$: POSSIBLE SURPRISES IN THE STANDARD MODEL*

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With the reported observation of the Higgs boson at the LHC, the Standard Model of particle physics seems to be complete now as for its particle content. However, several experimental data at low and intermediate energies indicate that there may be two surprises. First, we propose a tentative new boson $Z_0(57)$, with a mass of about 57 GeV, on the basis of small enhancements we observe in several experiments, using recent data obtained at the LHC as well as much older ones from LEP. If confirmed, we interpret this new particle as a pseudoscalar or scalar partner of a composite Z vector boson. Secondly, we advocate the existence of a very light spinless boson $E(38)$, probably a scalar, with a mass of 38 MeV and decaying into two photons. Theoretical arguments and experimental signals supporting such a novel light boson are presented, including a recent direct experimental confirmation at the Joint Institute for Nuclear Research in Dubna.

1. Introduction

After the observation of a new boson compatible with the Standard-Model (SM) Higgs boson was reported in 2012 by the ATLAS [1] and CMS [2] collaborations, no further particle discoveries at the LHC have been announced so far. Even more significantly, the latest Advanced Cold Molecule Experiment (ACME) [3] measuring a possible electron electric dipole moment has ruled out [4] any new particles that contribute maximally to CP

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violation in one-loop and two-loop diagrams for masses up to about 50 TeV
and 3 TeV, respectively, so beyond the LHC detection range. Thus, both
ATLAS [5] and CMS [6] recently carried out alternative searches at energies
that had already been covered by the Large Electron–Positron Collider, *viz.*
for diphoton resonances (65–110 GeV) [5] and SM-like extra Higgs bosons
(70–110 GeV) [6]. At the same time, CMS did [7] a search for dimuon res-
onances in the mass range of 12–70 GeV. No new discoveries were reported
in these three experiments, though small enhancements at about 95 GeV
[6] and 28 GeV [7] were observed. However, in the latter CMS paper, we
noticed [8] an additional minor enhancement at roughly 57 GeV, which to-
gether with the one at 28 GeV lends further support to our earlier [9, 10]
suggestion of a new spinless boson "$Z_0(57)$" with a mass of about 57 GeV
on the basis of prior experiments. All these experimental signals and our
interpretation will be discussed in Section 2.

On the other hand, there have also been numerous searches for much
lighter particles, which might account for dark matter, discrepancies in the
proton radius, or the muon's anomalous magnetic moment. Recently, the
existence of a very light boson with a mass of about 17 MeV was claimed [11],
in order to explain apparent anomalies in ^{8}Be and ^{4}He nuclear transitions. It
has even been conjectured [12] that such an $X17$ boson might be the media-
tor of a "protophobic fifth force". It also has led to countless other theoretical
speculations over the past four years. In contrast, a recent report [13] by
an experimental team at the Joint Institute for Nuclear Research (JINR)
in Dubna on the possible direct observation of a novel light spinless boson
with a mass of about 38 MeV has received no attention whatsoever. Several
years earlier, we had proposed [14] this so-called $E(38)$ particle on the basis
of asymmetries in leptonic bottomonium decays and apparent oscillations
in charmonium-production data, besides different theoretical arguments. In
Ref. [15], we then showed a clear and more direct $E(38)$ signal, *viz.* in $\gamma\gamma$
decays published [16] by the COMPASS Collaboration, though disputed [17]
by COMPASS yet reaffirmed [18] by us. In Section 3, we shall make the case
for the $E(38)$.

2. Indications of a spinless boson with a mass of about 57 GeV

In Ref. [9], we observed a conspicuous dip at about 115 GeV in several
ATLAS and CMS data, as well as in much earlier data by the L3 Collabo-
ration; see Fig. 1 and Ref. [8] for the corresponding references. The same
figure reveals an enhancement slightly above 125 GeV, probably a prelim-
inary sign then of the Higgs boson. We interpreted [9] the dip as an indi-
cation of a two-particle threshold opening at 115 GeV and a possible sign
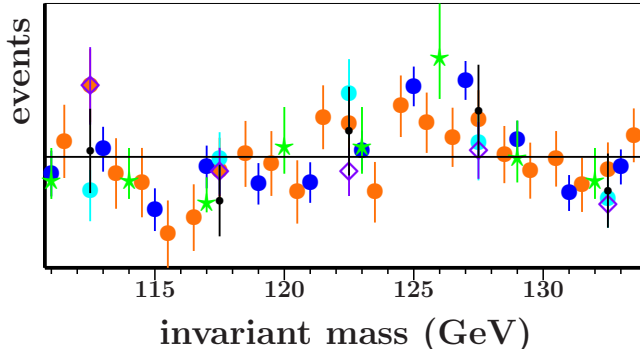of a composite new boson with a mass of about 57 GeV. Natural enhance-

Fig. 1. (Colour on-line) Diphoton ($\bullet$) ($\bullet$) and four-lepton ($\star$) ($\bullet$) signals; invariant-mass distributions of $\tau\tau$ in $e^+e^- \to \tau\tau(\gamma)$ ($\diamond$), and $\mu\mu$ in $e^+e^- \to \mu\mu(\gamma)$ ($\bullet$) (references in Refs. [8, 9]).

ments at two-body production thresholds of composite particles had been predicted by us in Ref. [19]. Possible compositeness of the W and Z intermediate gauge bosons has been considered in many papers (see *e.g.* Ref. [20]) and would necessarily imply the existence of partner states with different quantum numbers. This proposal received support from the CMS data [21] exhibiting a modest enhancement in $\gamma\gamma$ data at about 57 GeV, as we reported in Ref. [10], in which we also showed much older L3 data [22] on $\gamma\gamma\gamma$ decays of the Z boson; see Fig. 2. In the L3 single-photon data from $Z \to \gamma\gamma\gamma$ decays, one notices a small enhancement at 28 GeV. This may be a signal of a $Z \to Z_0\gamma$ decay, where Z_0 is a new spinless boson. Moreover,
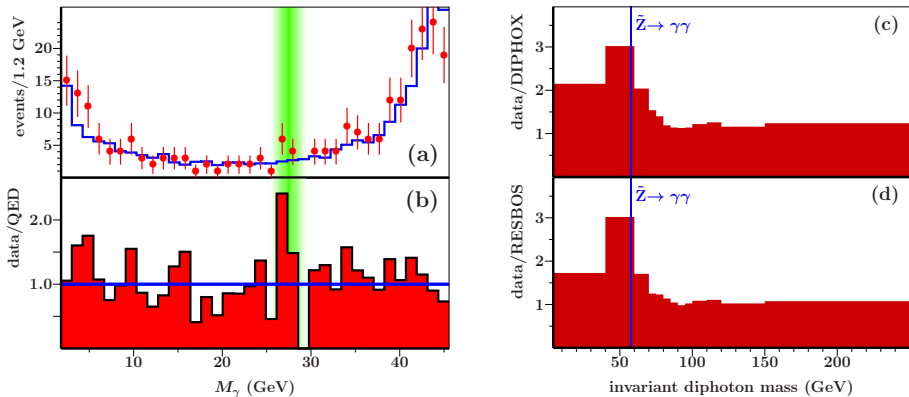

Fig. 2. (Colour on-line) (a) [22]: Single-photon CM energies in $Z \to 3\gamma$ events for $\sqrt{s} = M_Z$; histogram: Monte Carlo expectation from QED; grey/green band: expected photons from $Z \to \gamma Z_0$ for $M_{Z_0} = 57.5$ GeV. (b): As (a) but now measured/QED-expected events. (c), (d) [21]: Measured/expected $\gamma\gamma$ events for two models.

the $\gamma\gamma$ and 1γ enhancements at 57 GeV and 28 GeV, respectively, perfectly satisfy the kinematics of a $Z \to Z_0(57)\gamma$ decay. Finally, additional evidence appears to come from Ref. [7], with two-muon data exhibiting an enhancement at 28 GeV and another, quite modest one at about 57 GeV; see Fig. 3. Since a photon may convert into a muon pair in the CMS detector's strong magnetic field and a (pseudo)scalar boson can also decay to $\mu\mu$, these recent CMS data support our proposed $Z_0(57)$ as well, though much higher statistics will be required for a definite confirmation.
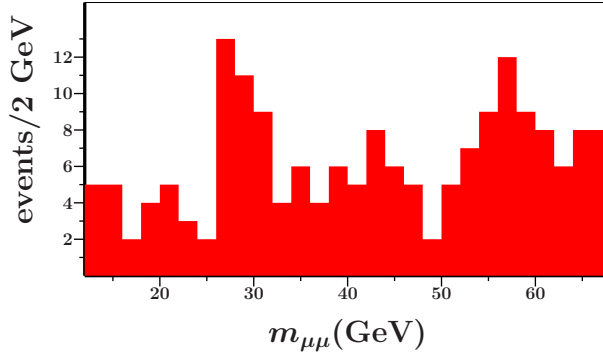

Fig. 3. Data on the dimuon mass distribution in Z decays, taken from Ref. [7].

3. Evidence of a very light spinless boson at 38 MeV

In Ref. [14], we proposed a very light new scalar boson "$E(38)$", with a mass of about 38 MeV, on the basis of indirect experimental indications and a decades-old anti-de Sitter (AdS) model of geometric quark confinement (see Ref. [14] for references). Among the different experimental signals, we highlight here a clear asymmetry in the $\mu^+\mu^-$ invariant mass for the decay chain $\Upsilon\left(2\,^3S_1\right) \to \pi^+\pi^-\Upsilon\left(1\,^3S_1\right) \to \pi^+\pi^-\mu^+\mu^-$ (see Fig. 4). In Ref. [23]
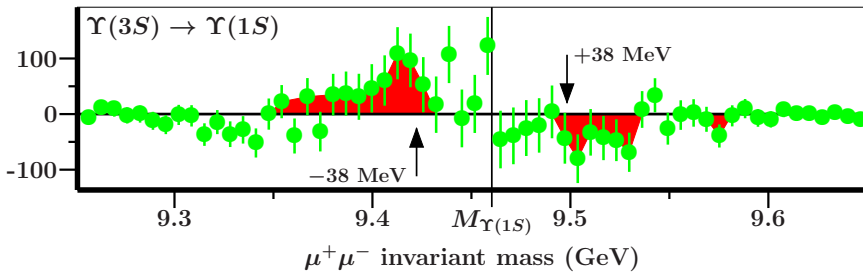

Fig. 4. Excess signal [23] in the invariant $\mu^+\mu^-$ mass for the process $\Upsilon\left(2\,^3S_1\right) \to \pi^+\pi^-\Upsilon\left(1\,^3S_1\right) \to \pi^+\pi^-\mu^+\mu^-$ using bins of 6.5 MeV. Statistical errors are shown by vertical bars. Vertical line indicates $M_{\mu^+\mu^-} = M_{\Upsilon(1\,^3S_1)}$. For further information, see Ref. [14].

(BaBar), both the asymmetry in the data and the failure to explain it were acknowledged. We interpreted it [14] as the undetected emission of several quanta of a new scalar particle with a mass of about 38 MeV, showing up as minor dips and enhancements in the asymmetric $\mu^+\mu^-$ invariant-mass distribution, roughly at multiples of 38 MeV. Such a light scalar could also be responsible for the empirically successful $^3P_0$ [24] mechanism.

A much more direct signal of the proposed $E(38)$ we identified [15] in $\gamma\gamma$ data [16] by the COMPASS Collaboration in a study of the exotic $\eta'\pi^-$ wave. The corresponding structure around 40 MeV is depicted in Fig. 5. Taking the excess data at face value, the significance of the signal is overwhelming. However, COMPASS contested [17] our assessment arguing that the bump must be an artefact resulting from secondary interactions inside the COMPASS spectrometer as well as cuts applied to $\gamma\gamma$ events at very low energies. To support this conclusion, a Monte Carlo (MC) simulation was presented in Ref. [17]. Nevertheless, we argued [18] that the employed MC is inadequate to describe the $E(38)$-like structure and even the actual COMPASS data below 50 MeV. In view of this controversy, it would be good if COMPASS did a dedicated analysis at these energies.
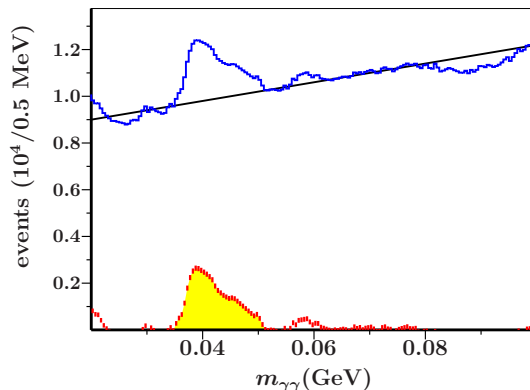

Fig. 5. Top: Signal in the COMPASS [16] $\gamma\gamma$ data, with maximum at ≈ 39 MeV. Bottom: $E(38)$ structure after background subtraction, with about 46.000 events.

The strongest $E(38)$ evidence was published recently [13] by an experimental group at the JINR in Dubna, finding significant $\gamma\gamma$ enhancements at 38 MeV in proton and deuteron scattering off carbon and copper nuclei, though still lacking statistics to be considered a particle observation. So also at JINR and other labs more specific experiments are highly desirable.

To conclude, a remarkable value of 38 MeV was found for the nonperturbative contribution to the pion–nucleon σ term, *viz.* via a scalar light-quark tadpole [25] or condensate [26]. Recently, a surprising value of 38 MeV was also obtained in a lattice computation [27] of the whole πN σ term.

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