Indications of a (pseudo)scalar partner of the Z boson at 57 GeV

based on

Eef van Beveren and George Rupp, arXiv:1811.02274 [hep-ph]

CFisUC, Coimbra University and CeFEMA, IST, Lisbon

I. Introduction: backwards in energy and time

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Introduction

- The new-physics discoveries at the LHC promised by many high-energy theorists have not materialised so far and the recent ACME-II experiment has now ruled out most of the common Beyond-Standard-Model extensions up to an energy scale beyond LHC's range.
- Thus, it appears opportune that LHC experiments focus again on lower energy regions, in which new physics may have been overlooked by LEP.
- Indeed, both ATLAS and CMS have very recently presented diphoton data, in the invariant-mass ranges of 65–110 GeV and 70–110 GeV, respectively.
- Thus, it is highly desirable that — if experimentally feasible — both ATLAS and CMS try to extend their diphoton measurements to even lower energies, in order to have a more complete overlap with dimuon data in the same energy range.
- In the present talk, an interpretation is presented of small enhancements at 28 and 57 GeV as well as a dip at 115 GeV, in different data taken by several independent experiments.

ATLAS CONF Note

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Search for resonances in the 65 to 110 GeV diphoton invariant mass range using 80 fb^{-1} of pp collisions collected at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

A search for low-mass diphoton resonances is performed using 80 fb^{-1} of pp collision data collected with the ATLAS detector at the Large Hadron Collider. Pairs of isolated photon candidates with high transverse momentum are selected, probing the diphoton invariant mass spectrum in the range 65 to 110 GeV. No significant excess with respect to the Standard Model expectation is found, and a limit at the 95% confidence level is set on narrow resonance fiducial cross-section times branching ratio ranging from 30 to 101 fb.

Search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV in the diphoton final state in proton-proton collisions at $\sqrt{s} = 8$ and 13 TeV

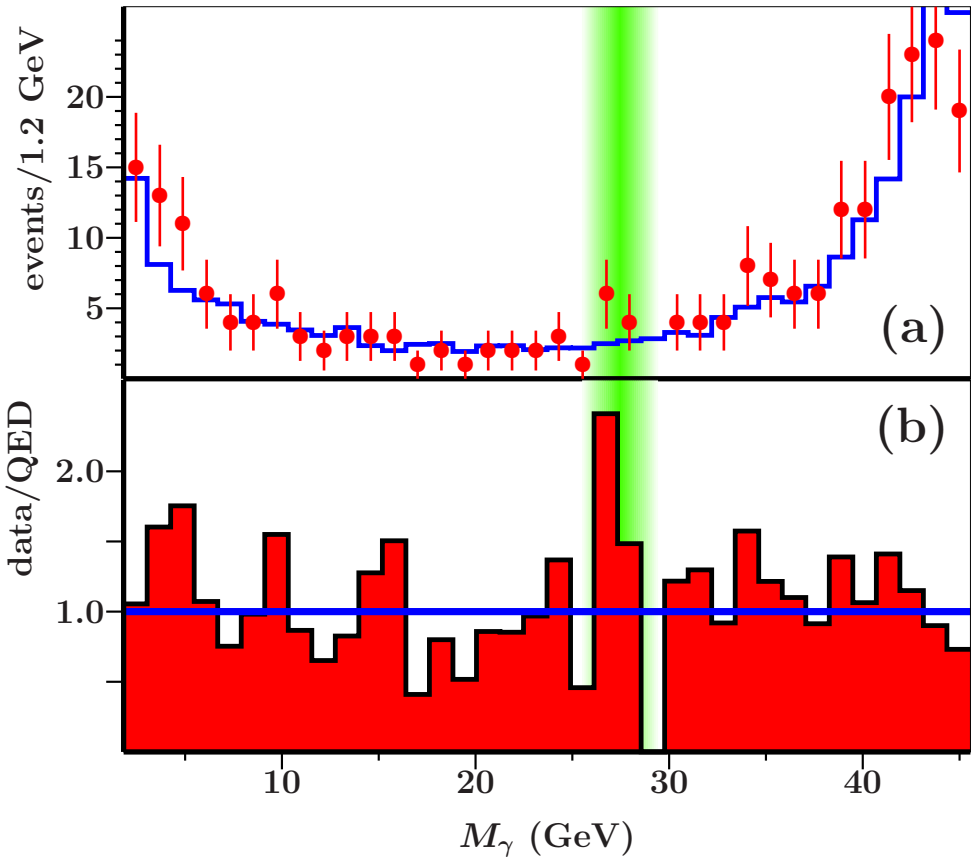
The CMS Collaboration*

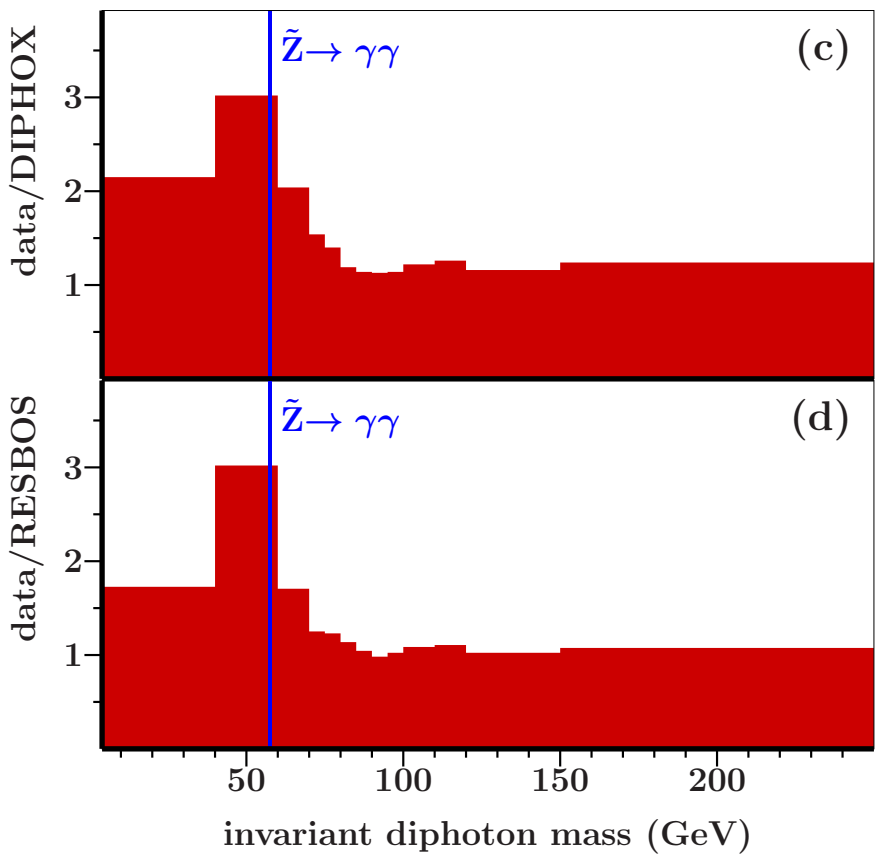
Abstract

The results of a search for a standard model-like Higgs boson in the mass range between 70 and 110 GeV decaying into two photons are presented. The analysis uses the data set collected with the CMS experiment in proton-proton collisions during the 2012 and 2016 LHC running periods. The data sample corresponds to an integrated luminosity of 19.7 (35.9) fb^{-1} at $\sqrt{s} = 8$ (13) TeV. The expected and observed 95% confidence level upper limits on the product of the cross section and branching fraction into two photons are presented. The observed upper limit for the 2012 (2016) data set ranges from 129 (161) fb to 31 (26) fb. The statistical combination of the results from the analyses of the two data sets in the common mass range between 80 and 110 GeV yields an upper limit on the product of the cross section and branching fraction, normalized to that for a standard model-like Higgs boson, ranging from 0.7 to 0.2, with two notable exceptions: one in the region around the Z boson peak, where the limit rises to 1.1, caused by the presence of Drell–Yan dielectron production where both electrons are misidentified as isolated photons, and a second due to an observed excess with respect to the standard model prediction, which is maximal for a mass hypothesis of 95.3 GeV with a local (global) significance of 2.8 (1.3) standard deviations.

M. Acciarri *et al.* [L3 Collaboration], Phys. Lett. B **345** (1995) 609

[CMS Collaboration], CMS-PAS-HIG-13-001 (2013)

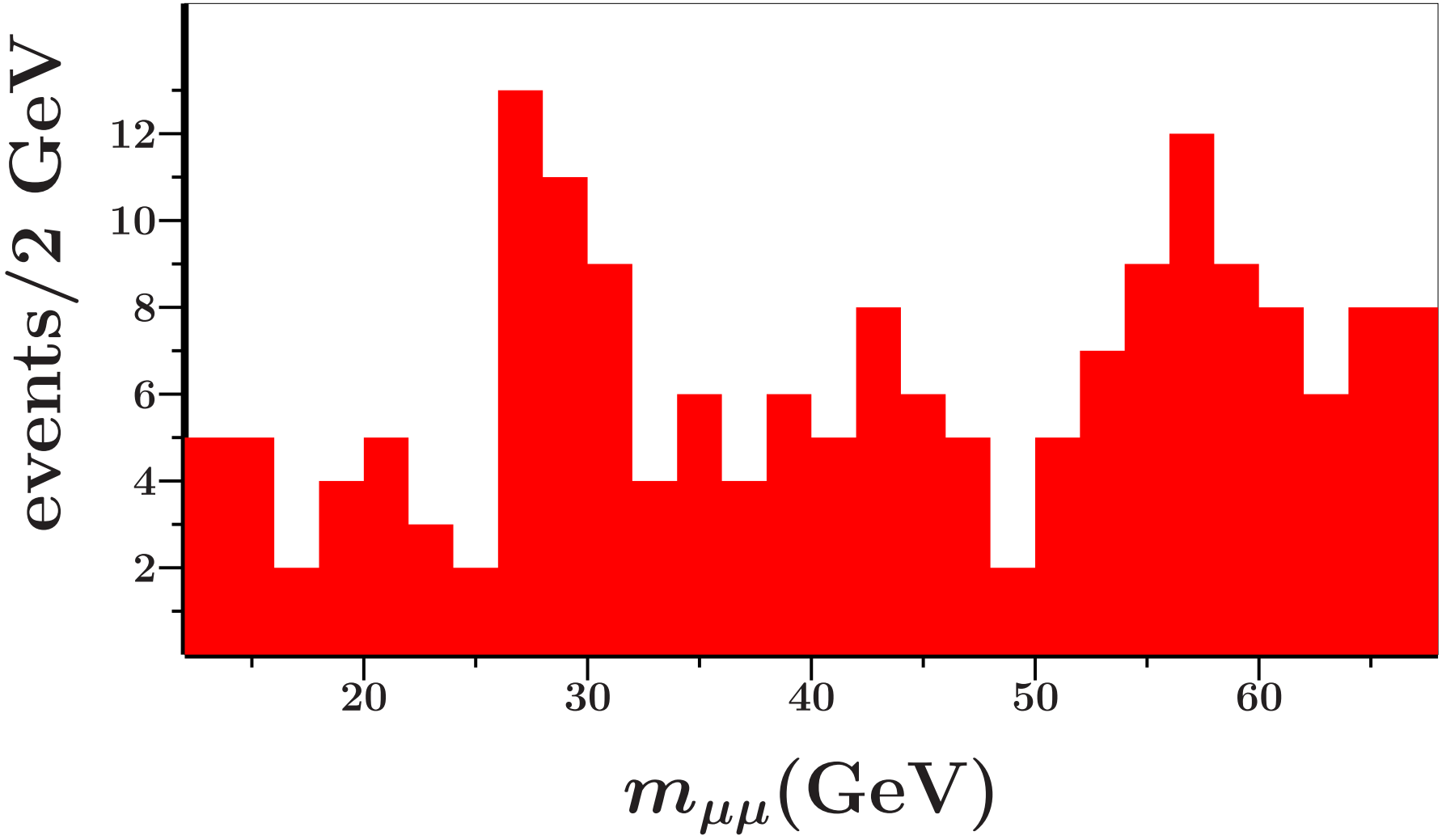




(a): The three single-γ CM energies in $Z \to 3\gamma$ events, for $\sqrt{s} = M_Z$. Histogram: MC simulation based on QED. Green band: expected 1γ energies from $Z \to \gamma Z_0$, with $m_{Z_0} \approx 57.5$ GeV.
(b): Same as (a), but now measured events divided by QED-expected events.

(c, d): Measured over expected events for diphoton invariant-mass distributions, with two data simulators (DIPHOX, RESBOS).

A. M. Sirunyan *et al.* [CMS Collaboration], arXiv:1808.01890.



Data of the dimuon mass distribution in Z decays, taken from the CMS paper (Fig. 2, upper).

Mod. Phys. Lett. A **32** (2017) 1750057 [arXiv:1610.07709 [hep-ph]]

Excited weak bosons and their decays

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Abstract

The weak bosons are not elementary gauge bosons, but bound states of two fermions. Here the excitations of the weak bosons are discussed. Especially we study the decays of these excited states into weak bosons and photons.

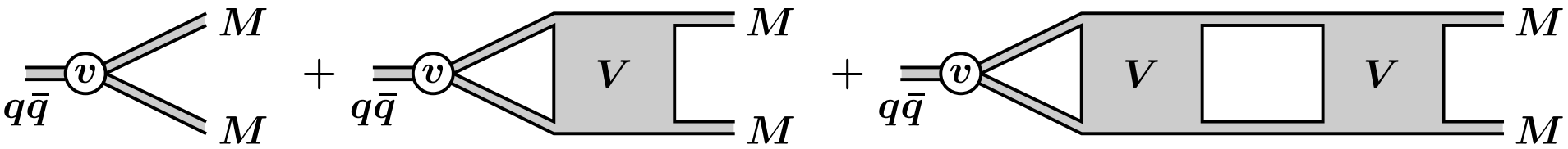
The weak bosons might not be elementary gauge bosons, but bound states of two fermions, analogous to the ρ-mesons in QCD. The weak bosons are the ground states. The scalar boson with a mass of 125 GeV, discovered at the LHC (ref. 1,2), would be an excitation of the Z-boson.

The weak bosons are bound states of a fermion and its antiparticle, which are denoted as "haplons" (see also ref. 7 and 9). Their dynamics is described by a confining gauge theory, denoted as "quantum haplodynamics" (QHD).

We assume that the boson $S(0)$ is the particle, discovered at CERN - thus the mass of $S(0)$ is about 125 GeV. In analogy to QCD we expect that the masses of the other p-wave states are between 0.26 TeV and 0.41 TeV.

Production amplitudes in the RSE formalism

E. van Beveren & GR, Annals Phys. **323** (2008) 1215;
Europhys. Lett. **81** (2008) 61002, **84** (2008) 51002



General multichannel form in terms of RSE T-matrix:

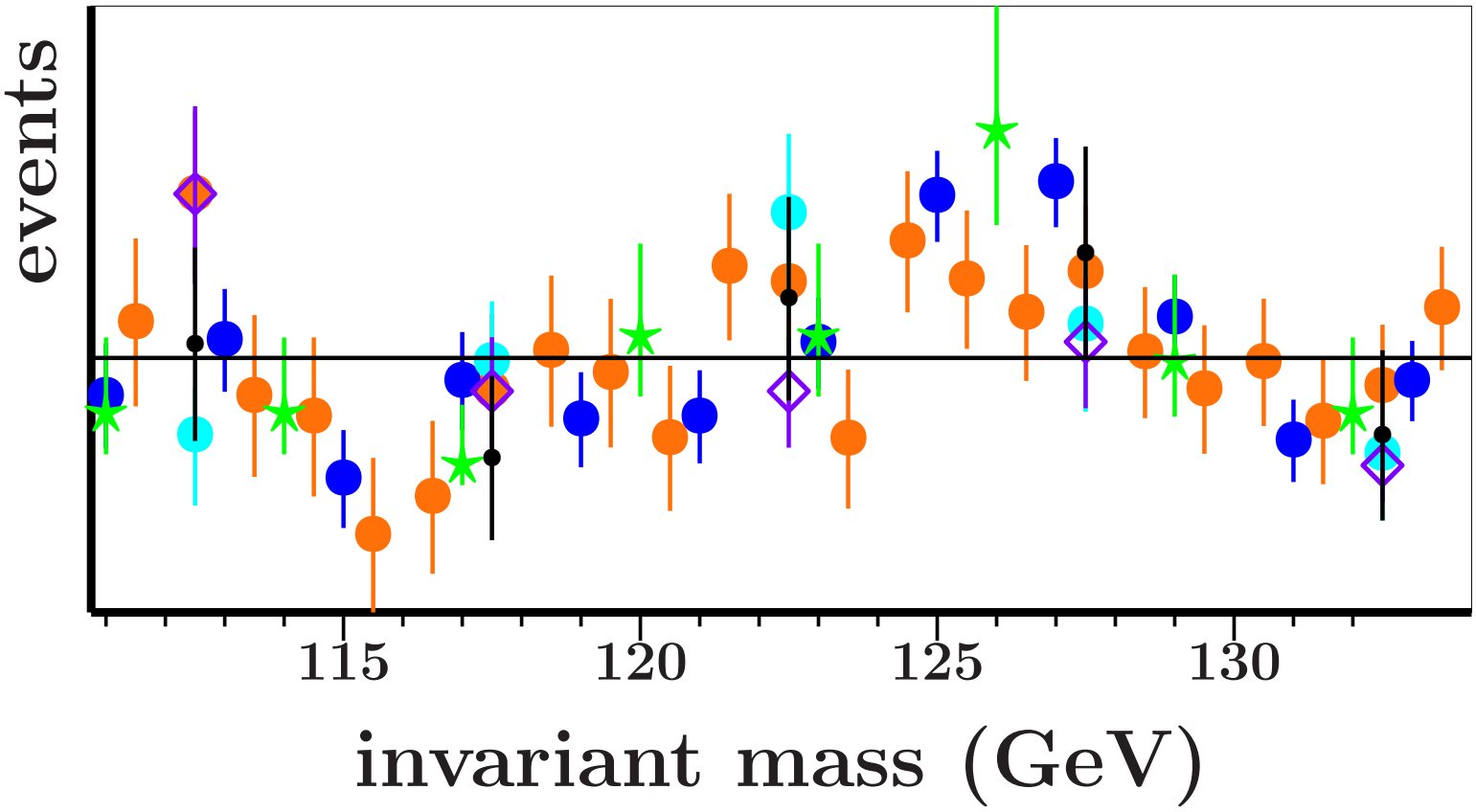
$$P_k = \mathrm{Re}(Z_k) + i \sum_l Z_l T_{kl} \ , \tag{1}$$

with Z_k a complex kinematical function (spherical Hankel function).
This production amplitude manifestly satisfies extended unitarity:

$$\mathrm{Im}(P_k) = \sum_l T^\star_{kl} P_l \ . \tag{2}$$

E. van Beveren, S. Coito, and G. Rupp, EPJ Web Conf. **95** (2015) 02007 [arXiv:1411.4151 [hep-ph]].

E. van Beveren and G. Rupp, arXiv:1811.02274 [hep-ph]



Diphoton signals published by CMS and ATLAS, four-lepton signals by CMS Collaboration and ATLAS, invariant-mass distributions for $\tau\tau$ in $e^+e^- \to \tau\tau(\gamma)$ and $\mu\mu$ in $e^+e^- \to \mu\mu(\gamma)$ by L3.

Our interpretation of the data

- If the heavy gauge bosons are composed of more elementary fermions, the vector Z may decay into a composite pseudoscalar Z_0 and a photon, analogously to the decay $\rho(770)^0 \to \pi^0\gamma$, or into a composite scalar plus a photon, like $\phi(1020) \to f_0(980)\gamma$. This Z_0 may on its turn decay into $\gamma\gamma$ or $\mu^+\mu^-$.
- If in the decay $Z \to Z_0\gamma$ the photon gets an energy of 28 GeV, then the Z_0 must have a mass of about 57 GeV.
- The 1995 L3 three-photon decays of the Z may suggest a one-photon data accumulation at 28 GeV, and the 2013 CMS data a $\gamma\gamma$ enhancement at 57 GeV.
- The 2018 CMS dimuon data suggest enhancements at 28 GeV and possibly also at 57 GeV. Note that a $\mu^+\mu^-$ pair with 28 GeV invariant mass may be produced by a single photon.
- Diphoton, four-lepton, $\tau\tau$, and $\mu\mu$ data exhibit a similar broad enhancement in the range 115–133 GeV, with a sharp dip at 115 GeV. Assuming compositeness, this may indicate the production threshold of a boson pair, each with a mass of $\approx$57 GeV.

Conclusions

- Dimuon and diphoton data below the Higgs mass reveal small yet interesting enhancements and structures that may hint at compositeness in the heavy-gauge-boson sector.
- Our consistent interpretation of these data amounts to the existence of a scalar or pseudoscalar partner state of the Z boson with a mass of about 57 GeV, the pseudoscalar assignment being the most likely one.
- Dimuon and diphoton data with higher statistics are needed, if possible also new data on three-photon decays of the Z, in order to confirm or rule out a $Z_0(57)$, and also look for possible other partner states.
- In view of dips in the data way above the Higgs mass, identified in arXiv:1304.7711, more data in the range 125–300 GeV, or even up to 1 TeV so as to accommodate e.g. Fritzsch's model, would also be most welcome. This might confirm the presence of several other production thresholds involving different composite partner states, allowing subsequent experiments to pin them down.