E(38) and $Z_0(57)$: possible surprises in the Standard Model

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- Search for heavy and light new particles
- Photon and dimuon data in the EW sector: 1995–2018
- Compositeness *à la* Fritzsch
- Dip at about 115 GeV in several data
- Production amplitudes and threshold enhancements
- Our interpretation of the data
- Theoretical and model indications of light scalar
- Experimental indications of a very light boson
- Confirmation of $E(38)$ at JINR in Dubna
- Conclusions

Searches for heavy and light new particles

- Besides the reported observation of the Higgs, no new particles have been discovered at the LHC. Moreover, the recent ACME-II experiment has now ruled out most of the common Beyond-Standard-Model extensions up to energies above the LHC's range.
- Thus, both ATLAS and CMS have very recently focused on possible new physics at lower energies, which may have been overlooked at LEP. In particular, $\gamma\gamma$ data have been taken in the invariant-mass ranges of 65–110 GeV and 70–110 GeV, respectively.
- At other labs, searches have been carried out for very light new particles, which might be responsible for dark matter, discrepancies in the proton radius, or the muon's anomalous magnetic moment.
- 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.
- Also, evidence will be shown for the existence of a new, very light spinless boson, from a variety of low-energy data.

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

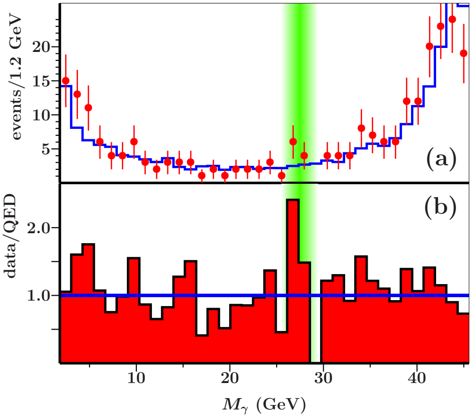
The CMS Collaboration*

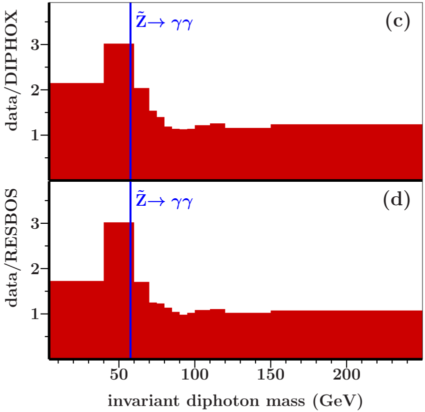
Abstract

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)

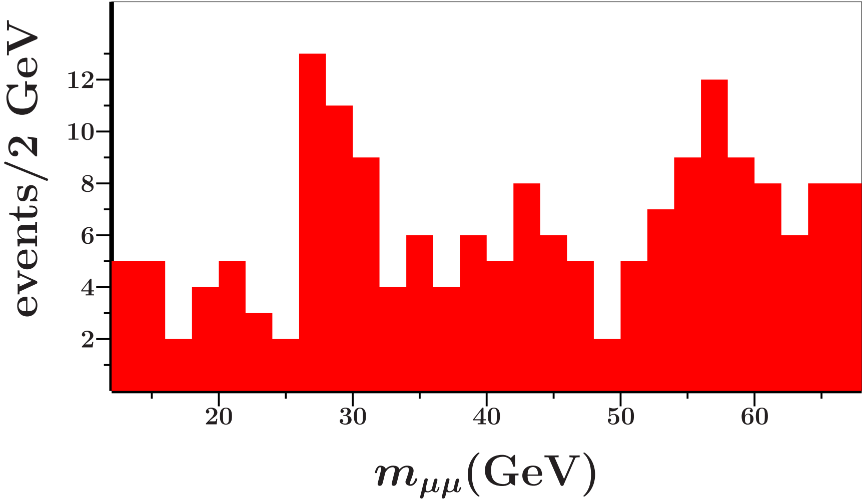




(a): The three single-γ CM energies in $Z \to 3\gamma$ events, for $\sqrt{s} = M_Z$. Histogram: MC simulation based on QED. Green band: expected 1γ energies from $Z \to \gamma Z_0$, with $m_{Z_0} \approx 57.5$ GeV.
(b): Same as (a), but now measured events divided by QED-expected events.

(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.

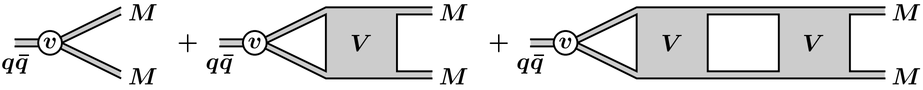
The weak bosons might not be elementary gauge bosons, but bound states of two fermions, analogous to the ρ-mesons in QCD. The weak bosons are the ground states. The scalar boson with a mass of 125 GeV, discovered at the LHC (ref. 1,2), would be an excitation of the Z-boson.

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:

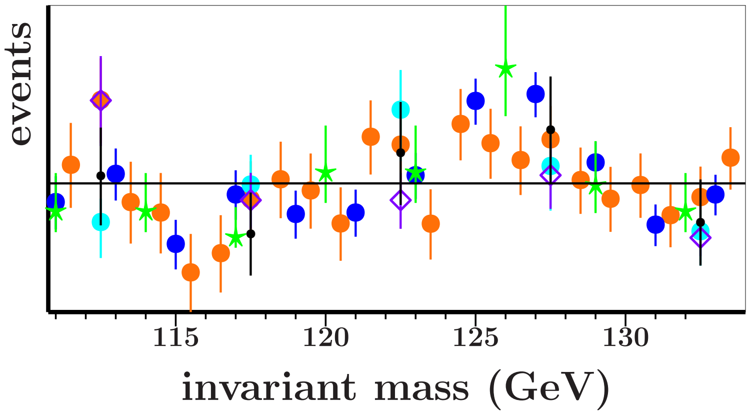
$$P_k = \mathrm{Re}(Z_k) + i \sum_l Z_l \, T_{kl} \ , \qquad (1)$$

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

$$\mathrm{Im}(P_k) = \sum_l T^{\star}_{kl} \, P_l \ . \qquad (2)$$

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.

“A Light Scalar Explanation of $(g-2)_\mu$ and the KOTO Anomaly”

Jia Liu, Navin McGinnis, Carlos E. M. Wagner, Xiao-Ping Wang, 2001.06522

Abstract

The KOTO experiment has recently performed a search for neutral Kaons decaying into neutral pions and a pair of neutrinos. Three events were observed in the KOTO signal region, with an expected background of about 0.05. Since no clear signal of systematic errors have been found, the excess of events in the decay $K_L \to \pi^0 \nu \bar{\nu}$ is quite intriguing. One possibility to explain this anomaly would be the presence of a scalar ϕ with mass of the order of the pion mass and inducing decays $K_L \to \pi^0 \phi$ which mimic the observed signal. A scalar with mass of the order of the pion mass and a coupling to muons of the order of the Standard Model Higgs coupling could also explain the muon anomalous magnetic moment anomaly $(g-2)_\mu$. We built on these facts to show that a light singlet scalar with couplings to the leptons and quarks as the ones induced by mixing with Higgs states in two Higgs doublet models may lead to an explanation of both anomalies. More specifically, we show that this is the case in the so-called type-X models in which leptons and quarks couple to two different Higgs doublets, and for scalar masses that are in the range between **40** and 70 MeV. Due to the relatively large coupling to leptons required to fit $(g-2)_\mu$, the scalar lifetime accidentally falls into the sub-nanosecond range which is essential to evade the severe proton beam dump experiments and astrophysical constraints, though it becomes sensitive to constraints from electron beam dump experiments. The additional phenomenological properties of this model are discussed.

Theoretical and model indications of a light scalar

- The $^3P_0$ model for hadronic decay via the creation of a light quark-antiquark pair with vacuum quantum numbers is empirically successful.
  L. Micu, Nucl. Phys. B **10** (1969) 521.

- In the Nijmegen unitarised quark model and its more recent versions, string breaking giving rise to a $^3P_0$ pair creation occurs at a confining-potential energy of 30–40 MeV.
  E. van Beveren, G. Rupp, T. A. Rijken, and C. Dullemond, Phys. Rev. D **27** (1983) 1527.

- An anti-De-Sitter model for geometric quark confinement was derived using a heavy and a light scalar field, via the latter's associated conformally flat metric. The same field may be responsible for the $^3P_0$ mechanism.
  C. Dullemond, T. A. Rijken, and E. van Beveren, Nuov. Cim. A **80** (1984) 401.

- A vacuum light-quark condensate can bridge the gap bewteen the perturbative Gell-Mann–Oakes–Renner prediction for the pion-nucleon sigma term and the experimental values. In a bubble model, an estimate of 38 MeV was obtained for it.
  W. R. Gibbs, Mod. Phys. Lett. A **18** (2003) 1171.

- About 38 MeV was also the value for the non-perturbative contribution to the πN σ term in the quark-level linear σ model, via a σ-meson tadpole graph.
  M. D. Scadron, G. Rupp, and R. Delbourgo, Fortschr. Phys. **61** (2013) 994.

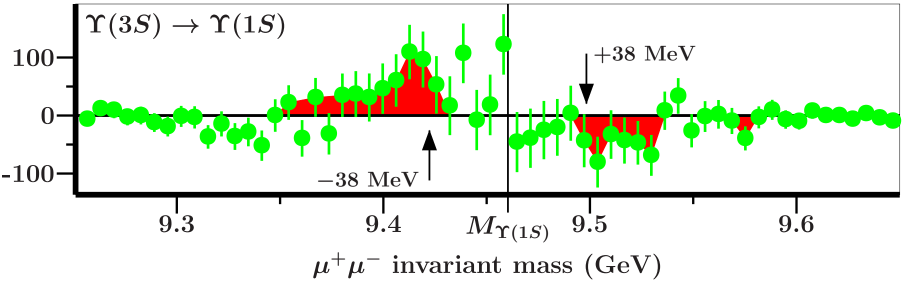
- A very recent lattice calculation resulted in $\sigma_{\pi N} = (38 \pm 3 \pm 3)$ MeV.
  L. Varnhorst [Budapest-Marseille-Wuppertal collaboration], Nucl. Part. Phys. Proc. **00** (2018) 1.

- There are several other theoretical suggestions for a very light boson, though not directly in the context of strong interactions. See: E. van Beveren, talk at COST action, Coimbra, Febr. 2019.

E. van Beveren and G. Rupp, arXiv:1102.1863 [hep-ph]

Data extracted from

E. Guido [BaBar Collaboration], arXiv:0910.0423 [hep-ex]

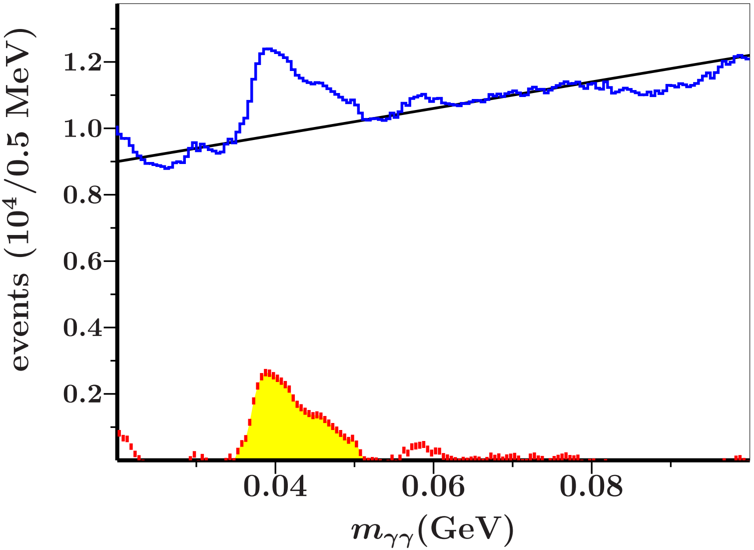


Event distribution of the excess signal taken from Ref. [21] in the invariant-$\mu^+\mu^-$-mass distribution for the reaction $\Upsilon\left(3\,{}^3S_1\right) \to \pi^+\pi^-\Upsilon\left(1\,{}^3S_1\right) \to \pi^+\pi^-\mu^+\mu^-$, using bins of 6.5 MeV. Statistical errors are shown by vertical bars. The shaded areas (dark, red in online version) are discussed in the text. The vertical line indicates $M_{\mu^+\mu^-} = M_{\Upsilon(1\,{}^3S_1)}$.

E. van Beveren and G. Rupp, arXiv:1202.1739 [hep-ph]

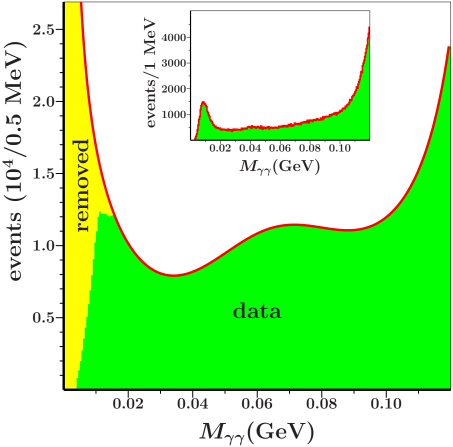
Data extracted from

T. Schlüter [COMPASS Collaboration], arXiv:1108.6191 [hep-ex]



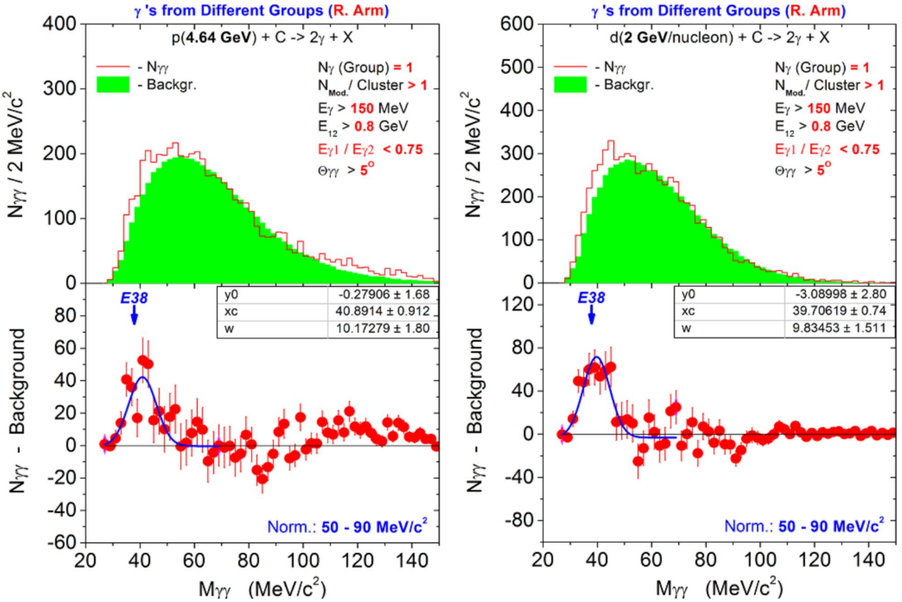
E. van Beveren and G. Rupp, arXiv:1204.3287 [hep-ph]

From Reply to Comment arXiv:1204.2349 [hep-ex] on arXiv:1202.1739 [hep-ph]



Invariant two-photon mass distributions below the nominal π^0 mass. The red curve in principle indicates the general aspect of such a distribution. Data removed by the trigger system are represented by the yellow area. So the green area in principle represents the final data. The resulting low-mass peak of the main figure coincides with the $\pi^- p$ data of Ref. [3], whereas, in the inset, we display the low-mass peak for the pp data of Ref. [4].

Kh. Abraamyan *et al.*, EPJ Web of Conferences **204** (2019) 08004
(Baldin ISHEPP XXIV, JINR, Dubna, 17-22 September 2018)



Conclusions

- We consistently interpret small signals in $\gamma\gamma$, $\gamma\gamma\gamma$, $\mu^+\mu^-$, $\tau^+\tau^-$, and four-lepton data, taken over many years at LEP and the LHC, as the existence of a pseudoscalar or (less likely) scalar partner state of the Z boson, with a mass of about 57 GeV.
- 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 the hadronic sector, we have presented both indirect and direct evidence of a very light new boson, with a mass of about 38 MeV. This so-called $E(38)$ was very recently confirmed by an experimental group at the JINR in Dubna, though with still insufficient statistics to consider it a definite observation.
- High-statistics dedicated experiments, at other labs as well, are needed to establish the $E(38)$ as a new particle.
- If confirmed, the compatibility of the $E(38)$ with QCD and chiral symmetry should be studied theoretically.

Dziękuję za uwagę!