Reply to Comment on “Material evidence of a 38 MeV boson”

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We reply to a very recent Comment \(^1\) by Bernhard, Friedrich, Schlüter, and Schöning for the COMPASS Collaboration, in which it is stated that Monte-Carlo simulations of COMPASS data do not support any interpretation of a peaked structure in diphoton invariant-mass distributions below the \(\pi^0\) mass in terms of a new resonance. Here we show, by directly comparing the simulations to the COMPASS data themselves, that the authors’ claim is not substantiated by the Monte-Carlo results presented in the Comment.

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Before directly replying to the Comment \(^1\) of Bernhard, Friedrich, Schlüter, and Schöning (BFSS) (for the COMPASS Collaboration) on our interpretation \(^2\) of a resonance-like structure in recent COMPASS data \(^3, 4\), let us first recapitulate some of the essential features of our work, for those readers who are not so familiar with it.

**MOTIVATION**

In Ref. \(^3\) an \(SO(4,2)\) conformally symmetric model was proposed for strong interactions at low energies, based on the observation \(^3, 5\) that confinement can be described by an anti-De Sitter (aDS) background geometry. The possibility of such a strategy had already been studied, almost a century ago, by H. Weyl \(^6\), who found that the dynamical equations of gauge theories retain their flat-space-time form when subject to a conformally-flat metric instead of the usual Minkowski background. The unification of electromagnetism and strong interactions can be justified by the very subtle balance between these forces in the nucleus, where just one neutron more or less can make the difference between stability or instability.

Confinement of quarks and gluons is modeled by the introduction of two scalar fields which spontaneously break the \(SO(4,2)\) symmetry down to \(SO(3,2)\) and \(SO(3)\otimes SO(2)\) symmetry, respectively. Moreover, a symmetric second-order tensor field is defined that serves as the metric for flat space-time, coupling to electromagnetism. Quarks and gluons, which to lowest order do not couple to this tensor field, are confined to an aDS universe \(^7\), having a finite radius in the flat space-time. This way, the model describes quarks and gluons, which oscillate with a universal frequency — independent of the flavor mass — inside a closed universe, as well as photons, which freely travel through flat space-time.

The fields in the model of Ref. \(^3\) comprise one real scalar field \(\sigma\) and one complex scalar field \(\lambda\). Their dynamical equations were solved in Ref. \(^3\) for the case that the respective vacuum expectation values, given by \(\sigma_0\) and \(\lambda_0\), satisfy the relation

\[
|\sigma_0| \gg |\lambda_0| \quad (1)
\]

A solution for \(\sigma_0\) of particular interest leads to aDS confinement, via the associated conformally flat metric given by \(\sigma\eta_{\mu
\nu}\).

The only quadratic term in the Lagrangian of Ref. \(^3\) is proportional to

\[
- \sigma^2 \lambda^* \lambda \quad (2)
\]

Hence, under the condition of relation \((1)\), one obtains, after choosing vacuum expectation values, a light \(\sigma\) field associated with confinement, and a very heavy complex \(\lambda\) field associated with electromagnetism. Here, we will study the — supposedly light — mass of the scalar field that gives rise to confinement.

The conformally symmetric model of Ref. \(^3\) in itself does not easily allow for interactions between hadrons, as each hadron is described by a closed universe. Therefore, in order to compare the properties of this model to the actually measured cross sections and branching ratios, the model has been further simplified, such that only its main property survives, namely its flavor-independent oscillations. This way the full aDS spectrum is, via light-quark-pair creation, coupled to the channels of two — or more — hadronic decay products for which scattering amplitudes can be measured, thus relating observed resonances to the spectrum of aDS.

The aDS spectrum reveals itself through the structures observed in hadronic invariant-mass distributions. However, as we have shown in the past (see Ref. \(^1\) and references therein), there exists no simple relation between enhancements in the experimental cross sections and the aDS spectrum. Nevertheless, this was studied in parallel, for mesons, in a coupled-channel model in which quarks are confined by a flavor-independent harmonic oscillator
Empirically, based on numerous data on mesonic resonances measured by a large variety of experimental collaborations, it was found that an aDS oscillation frequency of

\[ \omega = 190 \text{ MeV} \] (3)

agrees well with the observed results for meson-meson scattering and meson-pair production in the light \[ ^3P_0 \] heavy-light \[ ^1S_0 \], and heavy \[ ^3S_1 \] [16, 18] flavor sectors, thus reinforcing the strategy proposed in Ref. [2].

A further ingredient of the model for the description of non-exotic quarkonia, namely the coupling of quark-antiquark components to real and virtual two-meson decay channels \[ ^3P_0 \] via quark-pair creation, gives us a clue about the size of the mass of the \( \sigma \) field. For such a coupling it was found that the average radius \( r_0 \) for light-quark-pair creation in quarkonia can be described by a flavor-independent mass scale, given by

\[ M = \frac{1}{2} \omega^2 \mu_0^2, \] (4)

where \( \mu \) is the effective reduced quarkonium mass. In earlier work, the value \( \mu_0 = \sqrt{\mu_0 r_0} = 0.56 [12, 13] \) was used, which results in \( M = 30 \text{ MeV} \) for the corresponding mass scale. However, the quarkonium spectrum is not very sensitive to the precise value of the radius \( r_0 \), in contrast with the resonance widths. In more recent work [20, 21], slightly larger transition radii have been applied, corresponding to values around 40 MeV for \( M \). Nevertheless, values of 30–40 MeV for the flavor-independent mass \( M \) do not seem to bear any relation to an observed quantity for strong interactions. However, in Refs. [2, 22] we have presented experimental evidence for the possible existence of a quantum with a mass of about 38 MeV, which in light of its relation to the \( ^3P_0 \) mechanism we suppose to mediate quark-pair creation. Moreover, its scalar properties make it a perfect candidate for the quantum associated with the above-discussed scalar field for confinement.

**FIRST OBSERVATIONS**

In recent papers [2, 22], we have presented a variety of indications of the possible existence of a light boson with a mass of about 38 MeV, henceforth referred to as \( E(38) \). These indications amounted to a series of low-statistics observations all pointing in the same direction. Each of the results alone, viz., interference effect [22], small flavor-independent oscillations in electron-positron and proton-antiproton annihilation data [24], the excess signals visible [2, 22] in the \( \mu^+ \mu^- \) mass distributions of \( \Upsilon \) \( (2 \, ^3S_1) \rightarrow \pi^+ \pi^- \Upsilon \) \( (1 \, ^3S_1) \rightarrow \pi^+ \pi^- \mu^+ \mu^- \), in \( \Upsilon \) \( (3 \, ^3S_1) \rightarrow \pi^+ \pi^- \Upsilon \) \( (1 \, ^3S_1) \rightarrow \pi^+ \pi^- \mu^+ \mu^- \), in \( \Upsilon \) \( (3 \, ^3S_1) \rightarrow \pi^+ \pi^- \Upsilon \) \( (2 \, ^3S_1) \rightarrow \pi^+ \pi^- \mu^+ \mu^- \), and in the \( e^+e^- \) mass distributions of \( e^+e^- \rightarrow \pi^+\pi^-e^+e^- \), and finally hybrid signal [22], has much too low statistics to make firm claims. However, we noted that all these results point in the same direction.

Indeed, it seems highly unlikely that by sheer coincidence one finds the same kind of oscillations in four different sets of data [22, 24] involving different flavors, statistical fluctuations at \( \pm 38 \text{ MeV} \) in yet another four sets of different data, and finally a resonance-like fluctuation at 38 MeV in a further set of data. Moreover, the resulting scalar mass comes out where it was predicted via our analyses in mesonic spectroscopy (see Ref. [11] and references therein).

**ENHANCEMENT AROUND 40 MEV IN COMPASS DATA**

In Ref. [2], we presented more pieces of evidence, one of which, viz. a small resonance-like signal in the diphoton invariant-mass distribution [3] of the COMPASS Collaboration, is considerably more conclusive than previously reported [22] signals, owing to much higher statistics. The data, depicted in Fig. 1, have been obtained at the two-stage magnetic COMPASS spectrometer attached to the SPS accelerator facility at CERN [3]. These data seem to have enough statistics to substantiate the existence of a light boson with mass around 40 MeV. However, in a more recent version [3] of their work, the COMPASS Collaboration added the following remark to the figure caption regarding the enhancement in Fig. 1:

"**The structures below the \( \pi^0 \) mass peak are artefacts of low energetic photon reconstruction due to secondary interactions in the detector material and to cuts in the reconstruction algorithm. They should not be mistaken for any physical signal."**
Although it may of course be possible to obtain resonance-like structures by artefacts in data collection, we are convinced this is not the case for the signal in the 40 MeV region, because it coincides surprisingly well with the other observations reported in Refs. [2, 22].

Furthermore, it is clear that the light boson cannot be an ordinary hadron emerging from a hadronic vertex, unless at an extremely low rate. Otherwise, it would have been observed long ago. Ordinary hadronization in high-energy collisions gives rise to pions, kaons, and other hadrons that are stable with respect to strong interactions. These are processes in which quark-pair creation and gluonic jets dominate. But on the other hand, judging from the amount of events in the low-mass enhancement in the two-photon data, which is about 10% of the number of events in the $\eta$ signal, it does seem to be produced with a reasonably large rate in the COMPASS experiment. Such a rate indicates that it most probably is a hadronic particle, though with very peculiar properties that still have to be understood.

In this paper we shall assume that the $E(38)$ boson has the shape of a spherical bubble, as predicted by anti-De Sitter confinement [6, 25], i.e., a thin film of glue. Due to possible surface oscillations, such a system almost has a continuum of excitations. If we assume that the stability of the bubble rapidly decreases for excitations and allow for a spreading of some 20 MeV, then we may fully reconstruct the line shape shown in Fig. 1. Moreover, we point out that the small excess in the diphoton data obtained in a different experiment [26] also satisfies the here proposed distribution, albeit with much lower statistics.

A further important ingredient for the reconstruction of the present event distribution is the experimental resolution. Given the $\eta$ signal in the COMPASS [3] data, which is much broader than that of $\pi^0$, and the fact that $\pi^0$ and $\eta$ have decay widths considerably smaller than the bin size of 0.5 MeV, we may assume that the experimental resolution is better at lower invariant mass.

In order to proceed, we compare in Fig. 2 the three observed relevant structures in the COMPASS diphoton data, representing the $\pi^0$, $\eta$, and $E(38)$ bosons. The three enhancements are scaled in width. Also, the very different heights have been adjusted in Fig. 2 so as to allow comparing the line shapes. The data spreading must be entirely due to the experimental resolution. Furthermore, we assume that the $E(38)$ boson is reasonably stable and so should have a spreading comparable to the other two enhancements. This seems to be confirmed by Fig. 2 except for the long $E(38)$ tail at higher invariant mass.

From the representation of the enhancements in Fig. 2 we infer an experimental resolution of about 5.2 MeV in the 40 MeV region. The convolution of the two Gaussians, one for the spreading in the masses of the light bosons and another for the experimental resolution around 40 MeV, for 56,000 generated Monte Carlo (MC) events is shown in Fig. 3.

The here followed procedure is extremely simple, but it reproduces the experimental result quite well (see Fig. 3). In particular, it describes how the peak shifts to a little bit higher value than the expected 38 MeV, and furthermore reproduces the observed tail for larger invariant masses. The central mass of the light boson allows for variations of a few tenths of MeV, from which we may estimate its mass to lie between 38.0 and 38.4 MeV.

We may thus conclude, with very simple assumptions, that the event distribution of COMPASS near 40 MeV may be understood by the production of a light boson with a mass of 38.2±0.2 MeV.

The DELPHI Collaboration performed an analysis [26] of inclusive $\pi^0$ production in $Z^0$ decays. The diphoton decays of $\pi^0$ were reconstructed by using pairs of com-
binations of converted photons as well as HPC photons, which are photons that were reconstructed in the barrel electromagnetic calorimeter of the DELPHI detector. In particular, reasonably high-statistics diphoton data were shown by the DELPHI Collaboration in Fig. 3b (1 converted photon and 1 HPC photon) of Ref. [26], which figure also contains a rather precise background fit.

We apply a similar strategy to the residual signal of the DELPHI data as we did above to the COMPASS data of Ref. [3]. The result of the DELPHI data [26], with an assumed resolution of 10 MeV, is depicted in Fig. 4. So it seems to us that our assumption on the existence of a scalar boson with a mass of about 38.2 MeV, is very plausible, since the setup and experimental conditions of the DELPHI experiment are very different from those of COMPASS.

SIMULATION OF DIPHOTON DATA

In principle, the diphoton invariant-mass distribution below the nominal $\pi^0$ mass has a structure as represented by the red curve in Fig. 5. However, the two electromagnetic calorimeters, ECAL1 at about 6 meters from the target and ECAL2 at about 30 meters downstream, do not accept low-energy photons. This results in the non-observation of the enhancement at zero invariant diphoton mass. Hence, at very low masses no events are observed, since they are removed by the trigger system of the EM calorimeters, as indicated by the yellow area in Fig. 5. It has the effect that at low mass a peak shows up in the data.

In Fig. 5 we depict the low-mass peak for the $\pi^-p$ data of Ref. [3], while in the inset of Fig. 5 we show the low-mass peak for the $pp$ data of Ref. [4]. Note that these low-mass peaks are very different for different experiments, namely the one in the $pp$ data of Ref. [4] is roughly 3.8 times larger than the signal at 25 MeV, whereas the one in the $\pi^-p$ data of Ref. [3] is only about 1.4 times higher than the signal at 25 MeV.

Now, the data selection system does of course also influence the aspect of the data for higher diphoton masses. It may even result in some structures which resemble resonances. Moreover, several physical processes in the experimental setup, not related to the purpose of the experiment, may result in further structures.

The authors of Ref. [1] gave the following list of mechanisms that may result in structures in their data.

- Secondary $\pi^0$ mesons produced in the detector material downstream of the target lead to diphoton masses which are below the nominal $\pi^0$ mass when reconstructed assuming a target vertex.

- Material concentrated in detector groups leads to peak-like structures.

- Secondary $e^+e^-$ pairs from photon conversion in the spectrometer material lead to low-mass structures.
Cuts applied in the reconstruction software lead to additional structure in the low-mass range.

Most of those processes occur, of course, in the EM calorimeter ECAL2, because it is further downstream than ECAL1, and therefore picks up more contamination due to unwanted processes.

These artefacts are reproduced in the MC simulation of Ref. [1] for the reactions under study, using a complete description of the spectrometer material and employing the same reconstruction software as for the real data analysis.

In Fig. 6 we reproduce the three independent simulations reported in Ref. [1]. We also add up these three simulations, with relative weights ECAL1 : ECAL2 : (ECAL1+ECAL2) = 0.48 : 1.00 : 0.86 for both $\gamma$s in ECAL1, both $\gamma$s in ECAL2, and one $\gamma$ in each of the two electromagnetic calorimeters, respectively, in order to have an idea how well they represent the true data of Ref. [3]. It should be noted, however, that summing up three independent simulations is not the same as performing an MC simulation for the complete experimental setup. Therefore, our procedure is not totally reliable, though it is the best we can do with the available information.

We observe from Fig. 6 that for some reason the $\pi^0$ signal, which in the experimental data sets out at about 50 MeV, is not included in the simulations [1]. Because of this omission, the simulated data for one $\gamma$ observed in ECAL1 and another $\gamma$ in ECAL2 have to contribute more than what one would expect from the COMPASS setup.

In Fig. 7 we do include the experimental signal of the $\pi^0$, with its mass at 135 MeV and an average resolution of 12.7 MeV. Once again, this is of course not the correct procedure. But it is all we have at our disposal for a reconstruction of the experimental data. The simulations of Ref. [1] are here taken in proportions ECAL1 : ECAL2 : (ECAL1+ECAL2) = 0.80 : 0.93 : 0.25 of the reported MC data, which seem more reasonable than the previous weights employed in Fig. 6.

At this point, we may conclude that experiment is well reproduced for diphoton invariant masses larger than 50 MeV. Nevertheless, we wonder how the MC distributions of Ref. [1] would work out for higher masses, up to 1.0 GeV. However, for masses below 50 MeV, the simulations of Ref. [1] do not at all agree with experiment.

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FIG. 6: The three diphoton MC distributions of Ref. [1] simulating low-energy $\gamma\gamma$ production, with different weight factors. Black curves: both $\gamma$s in calorimeter ECAL1 or one in ECAL1 and one in ECAL2; green: both $\gamma$s in ECAL2. Weight factors: ECAL1 : ECAL2 : (ECAL1+ECAL2) = 0.48 : 1.00 : 0.86. Blue curve: sum of green and two black curves. Red curve: the experimental data of Ref. [3].

FIG. 7: As FIG. 6, but now with weight factors ECAL1 : ECAL2 : (ECAL1+ECAL2) = 0.80 : 0.93 : 0.25, and a simulation of the $\pi^0$ signal added in the blue curve.
sible that the artefacts produced in the COMPASS setup are just not well studied yet for small diphoton masses.

The MC simulations shown in Ref. [1] were actually produced for the process studied in Ref. [4]. However, in that study the background-to-signal ratio for the enhancement near 40 MeV is the same as for the process considered in Ref. [3]. For completeness, we include in Fig. 8 a comparison of the MC simulations of Ref. [1] and the actual experimental data of Ref. [4]. We find

\[ \text{ArXiv:1204.2349} + \pi^0 \]

\[ M_{\gamma\gamma} \text{ (GeV)} \]

\[ \text{events/1 MeV} \]

FIG. 8: Similar to FIG. 4 but now compared to the actual experimental data of Ref. [4].

that also in this case the experimental data below 50 MeV are not at all well described by the MC simulations of Ref. [1]. The discrepancy between data and simulation at low diphoton masses is even more serious.

In conclusion, we welcome the efforts of the authors of Ref. [1] to explain the observed enhancement in the 35–51 MeV diphoton invariant-mass region by conventional methods. However, with the present MC simulations, the existence of a resonance-like structure at about 38 MeV cannot be excluded at all. We suggest to include in future simulations the possibility of $E(38)$ desintegration in the EM calorimeter ECAL2, since we expect that this tentative light boson has rather stable modes, which could easily survive the 30 meters that separate ECAL2 from the target.

FUTURE

Although the question whether there exists a (scalar) boson with a mass of about 38 MeV does not depend exclusively on the existence of a resonance-like structure in the experimental data of Ref. [3], it is at present the clearest signal we have found in many experiments. Diphoton data for the mass interval 10–100 MeV are very rare and usually with low statistics. Therefore, it is very important that the present issue be settled, which requires a profound understanding of all possible sources of artefacts.