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Mesonic Spectra: Experimental Data and Their Interpretation*

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Abstract. We discuss experimental data and their interpretation. In particular, we argue that spectra of quark-antiquark systems should better be studied from configurations with well-defined quantum numbers, the most suitable system being charmonium. We suggest probable future findings based on the existing low-statistics data for charmonium and bottomonium. We also briefly review our findings for the E(38 MeV) and Z(57.5 GeV) bosons.

Observation and its interpretation are human activities not restricted to a handful of experts but open to anyone who feels the need to express an opinion. A nice example of the importance of observation is the meticulous registration of atomic and molecular line spectra during the nineteenth and the twentieth century. Moreover, its history of interpretation shows exemplarily the struggle of the human mind to escape from prevailing standard models. It starts with the color-separation theory of Wollaston, based on his pioneering observation in the early 1800s of seven dark lines in the solar spectrum. Decades later that interpretation was proven to be wrong by Kirchhoff and Bunsen, based on the observation of emission spectra. Thomson's plum-pudding model in the early 1900s, shortly after the discovery of electrons, was the last attempt to keep observation within accepted theories. Finally, Bohr's proposal gave the breakthrough for a solid description of line spectra and the emergence of a new standard model. A century full of observation, improving equipment and new discoveries had passed in order to figure it out.

The history of atomic and molecular line spectra resembles that of mesonic spectra. But it fails when it comes to high-quality data. Bohr's model could be tested on a wealth of experimental results. Models for mesonic resonances do not have such luxury at their disposal, which has culminated in a plethora of

* Talk presented by E. van Beveren

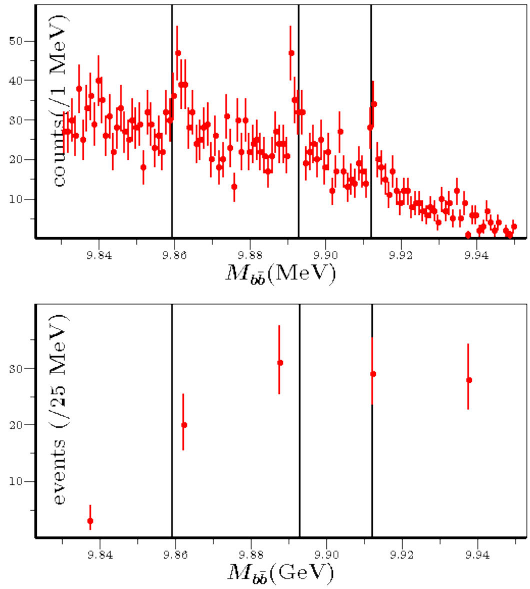

Fig. 1. The 1P beautonium states. Top: ARGUS data (DESY, 1985). Bottom: ATLAS data (CERN, 2011).

speculations. Though one wishes that future experiments will improve on statistics, the reality is quite different, as is most strikingly exhibited in Fig. 1, where three-decades-old data [1] on $b\bar{b} \to \Upsilon\gamma$ are compared to more recent results [2]. In this short paper we will highlight some of our somewhat speculative suggestions about the interpretation of mesonic spectra based on observation but not yet confirmed by dedicated experiments.

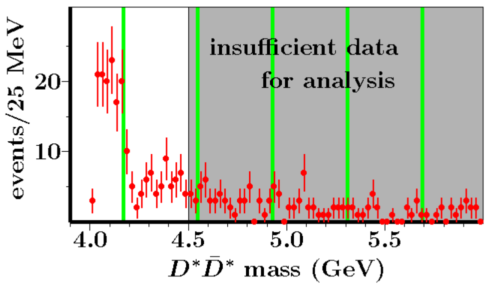

Fig. 2. The $D^*\bar{D}^*$ mass distribution measured and published by the BABAR Collaboration.

At several occasions we have pointed out the indispensable need for high-statistics data on two-particle mass distributions. As an example may serve the data shown in Fig. 2, where we represent a $D^*\bar{D}^*$ mass distribution measured and published by the BABAR Collaboration [3]. At first sight these data do not give us further information on the $c\bar{c}$ vector-meson spectrum. Indeed, a bin size of 25 MeV is clearly too large for the narrow dominantly-D states and even for the somewhat broader dominantly-S states, whereas also the number of events is barely enough to show an enhancement of the $\psi(4040)$. However, one must bear in mind the following.

In the first place, the reconstruction of a pair of D^* mesons out of kaons, pions and photons is a far from trivial task. The procedure is indicated in Ref. [3]. But it is not clear to us what fraction of produced $D^*\bar{D}^*$ pairs is recognized that way. We assume that it is a relatively small fraction.

Next, we know from theory that the higher the $c\bar{c}$ vector meson mass, the smaller its coupling to $D^*\bar{D}^*$. The reason is that, under the assumption of ${}^3P_0$ quark-pair creation, the number of possible two-meson configurations to which a $c\bar{c}$ vector meson couples grows rapidly with radial excitation [4]. Consequently, the coupling to a specific channel, in the present case $D^*\bar{D}^*$, diminishes substantially for higher radial excitations, thus leading to decreasing enhancements.

Finally, S- and D-wave $c\bar{c}$ vector states mix, which implies that pure S- or D-wave states do not exist in nature. But mixing also has two other interesting consequences. Namely, the dominantly D-wave states almost decouple from meson-pair production, leading to narrow resonances and small mass shifts, whereas the relatively broad S-wave states can easily dominate in decay and so confound their classification. The second consequence of mixing is that the dominantly S-wave states couple more strongly to meson.pair production than expected for pure S-wave states, giving rise to larger widths and considerable mass shifts [5].

So the question comes up why, in the absence of good data, we insist on dealing with $c\bar{c}$ vector mesons. The answer to that question rests in our belief that these mesons form the backbone of quark-antiquark $q\bar{q}$ spectra:

1. In the process $e^-e^+ \to D^*\bar{D}^*$, vector-meson dominance ensures the production of $c\bar{c}$ vector states. Hence, there is no confusion with different quantum numbers.

2. Little to no influence is expected from non-strange, strange and bottom $q\bar{q}$ pairs.

Consequently, when we know the full details of the $c\bar{c}$ vector spectrum, we can easily fill up the gaps for the remaining configurations and then use that for the analyses of different flavor combinations.

In Fig. 3 we have depicted the poor data for the $D^*\bar{D}^*$ mass distribution, together with a comparison to our predictions [6]. The crosses on the horizontal axis indicate the masses of bare $c\bar{c}$ vector states, *i.e.*, the spectrum in the absence of two-meson configurations, where in our model [5] S- and D-states are degenerate. By allowing $c\bar{c}$ to couple to open-charm configurations, the predicted dominantly-D states shift only a few MeV, whereas the mass shifts for the dominantly-S states are of the order of 100-300 MeV. The enhancement indicated by $\Lambda_c\Lambda_c$ is explained in Ref. [7] (see also Fig. 4). Given the importance of the $c\bar{c}$ vector states for meson spectroscopy, it escapes us why after four decades high-statistics data still do not exist. But maybe Fig. 5 explains it. In the following we will make some suggestions about the $b\bar{b}$ vector spectrum, as well as the E(38 MeV) and Z(57.5 GeV) bosons.

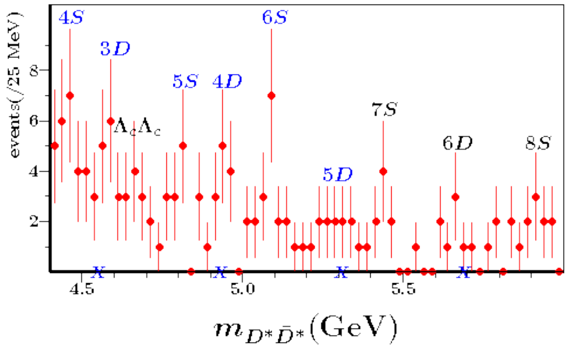

Fig. 3. The poor data for the $D^*\bar{D}^*$ mass distribution together with a comparison to our predictions.

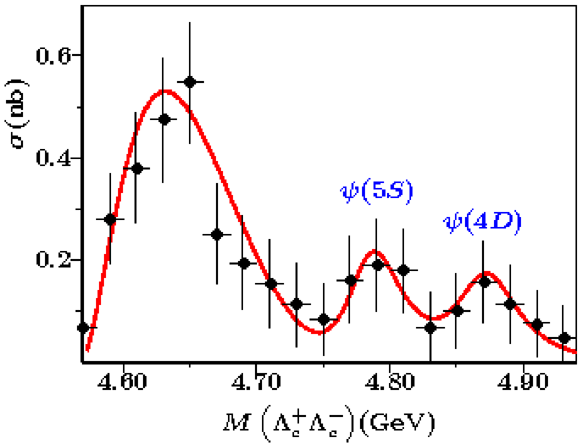

Fig. 4. $\psi(5S)$ and $\psi(4D)$ besides the large signal ($Y(4660)$) at the $\Lambda_c\Lambda_c$ threshold.

In Fig. 6 we show our result for the $\Upsilon(2D)$ $b\bar{b}$ vector state at about 10.5 GeV, some 70 MeV below the $B\bar{B}$ threshold. The data are taken from Ref. [8], while our analysis is discussed in Ref. [9]. A bound state as close to threshold as the $\Upsilon(2D)$ is supposed to have a large influence on the threshold enhancement. In Fig. 7 we have depicted R_b-ratio data from Ref. [10], in which one indeed observes a large threshold enhancement peaking at about 10.58 GeV, followed by two more modest enhancements above the $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds. The figure also shows that the former enhancement is listed under $\Upsilon(4S)$ in Ref. [11] and, moreover, that our model does not agree with that assignment. This is substantiated in Fig. 8, where TE stands for threshold enhancement, BW for Breit-Wigner line shape. In view of the above discussion on the decrease of resonance enhancements, it seems to us quite reasonable that the $\Upsilon(4S)$ is a modestly peaked structure. Moreover, its central mass at about 10.73 GeV agrees better with our model predictions.

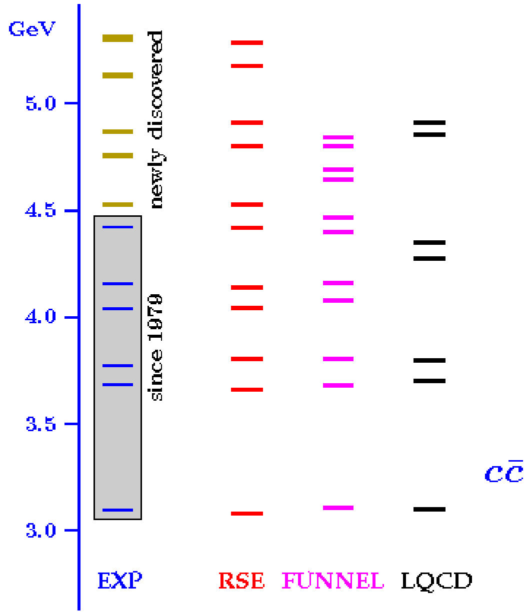

Fig. 5. The 2009 $c\bar{c}$ vector spectrum. EXP: PDG + new states; RSE: PRD **21**, (1980); FUNNEL: representative for MOST other models; LQCD: representative for lattice QCD.

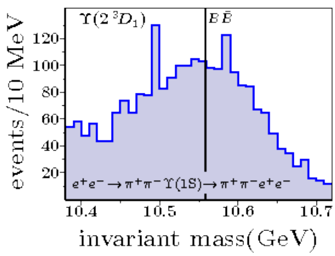

Fig. 6. Our result for the Υ(2D) $b\bar{b}$ vector state at about 10.5 GeV, some 70 MeV below the $B\bar{B}$ threshold.

The discovery of the E(38) boson [12] is discussed in the web version of the talk [13] (click `start`, then `E38`, and check the slides from `r0` to `compass2`). The slides `r0` and `ρ0` show why we expected a quantum of about 30–40 MeV, to be associated with quark-pair creation, already since the 1980s. Hints from experimental results came later as exhibited in slides from `wobbles` to `more`. More promising data [14, 15] are shown in slides from $\gamma\gamma$ to `compass2`. However, the COMPASS Collaboration contested our proposal by claiming that the enhancement at about 38 MeV is due to an artifact, the details of which are explained in Ref. [16]. Now it must be mentioned that the COMPASS Collaboration has done excellent work on light-meson spectroscopy [17]. Unfortunately, in the effort to substantiate the artifact claim, the COMPASS Collaboration compared apples and

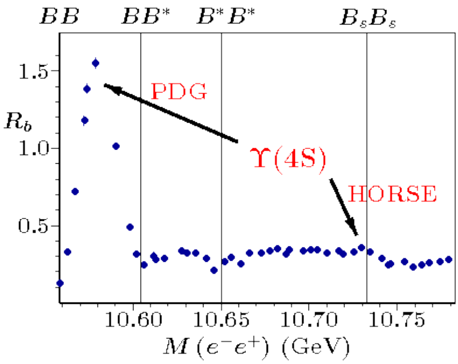

Fig. 7. The R_b-ratio data from Ref. [10] with a large threshold enhancement peaking at about 10.58 GeV, followed by two more modest enhancements above the $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds.

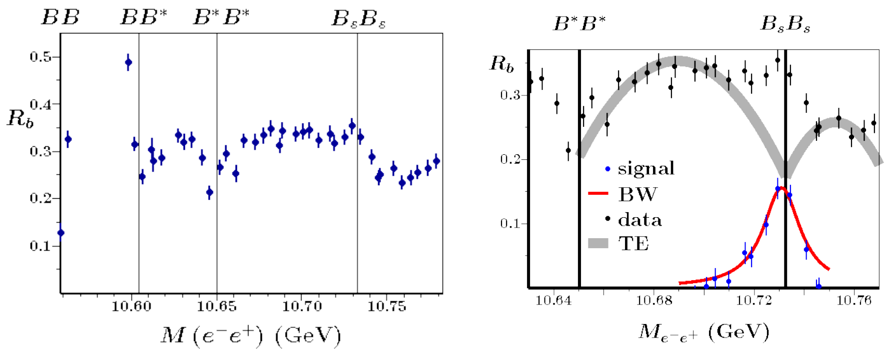

Fig. 8. Left: detail enhancements. Right: threshold enhancements and resonances.

oranges by referring to the low-statistics data of Ref. [14] instead of to the high-statistics data of Ref. [15]. But even the Monte-Carlo simulation for the former data do not minimally confirm their explanation, as shown in Fig. 9. We are still awaiting the follow-up on Ref. [18], which tentatively confirmed the existence of the E(38) [19].

For our suggestion of the existence of a boson at about 57.5 GeV, we only see some hints in experimental data. In Fig. 10 [20] we observe a rather sharp dip in the amplitude at about 115 GeV. When we sift through other observations in that energy region from the CMS, ATLAS and LEP Collaborations and combine the data [20–23] in Fig. 14, we find some indications of agreement. Now, such a sharp minimum in the data could indicate the onset of a threshold enhancement, moreover inflated due to the presence of a resonance at about 125 GeV, and most probably resulting from the creation of a pseudoscalar (or scalar) boson pair of half the onset mass each The L3 Collaboration might have searched for such a boson in $Z \to \gamma\gamma\gamma$ [24]. But with a total of 87 events not much statistics can be expected, as we see in Figs. 11 and 12. Nevertheless, a small effect is visible

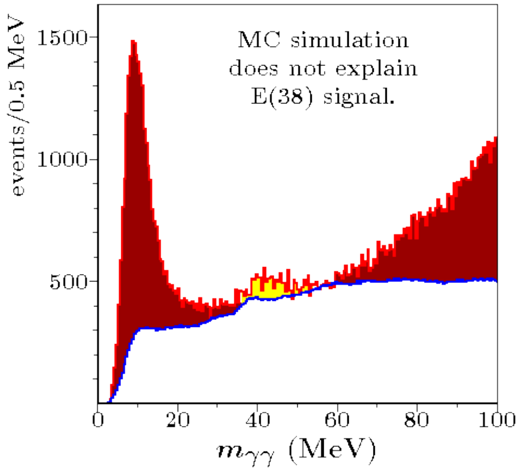

Fig. 9. Diphoton Monte-Carlo simulation from the COMPASS Collaboration compared to the data.

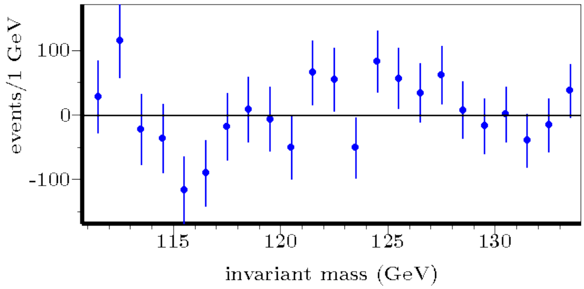

Fig. 10. Diphoton data from the CMS Collaboration.

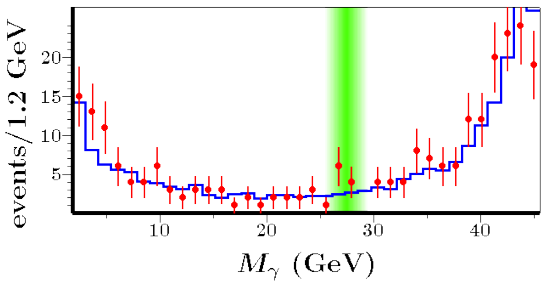

Fig. 11. $Z \to \bar{Z}\gamma \to \gamma\gamma\gamma$. Solid line: QED expectation. The shaded area represents the expected one-photon energy for $M(\bar{Z}) = 57.5$ GeV.

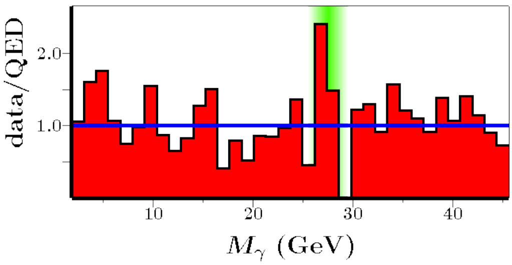

Fig. 12. Data divided by QED. The excess is where expected for $\bar{Z}$ of 57.5 GeV.

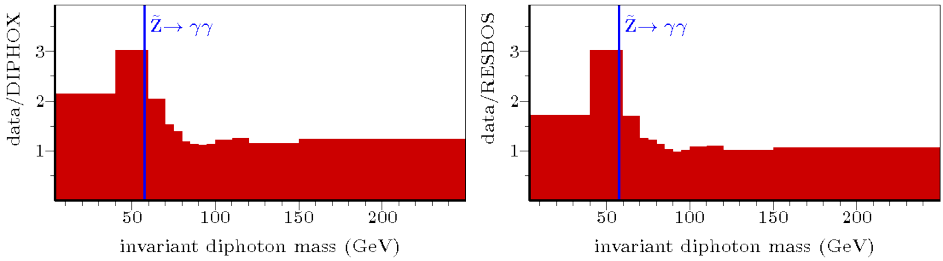

Fig. 13. Diphoton data from the CMS Collaboration compared to Standard-Model predictions DIPHOX (left) and RESBOS (right).

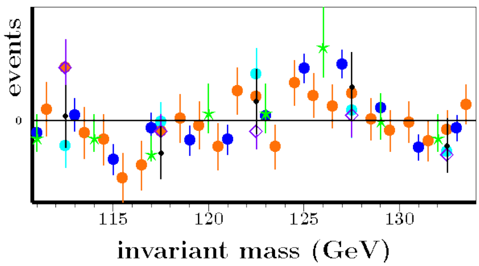

Fig. 14. Other LHC and LEP data agree. Shown are the data for CMS $\gamma\gamma$, ATLAS $\gamma\gamma$, CMS 4 leptons, ATLAS 4 leptons, L3 $e^+e^- \to \tau^+\tau^-(\gamma)$ and L3 $e^+e^- \to \mu^+\mu^-(\gamma)$.

precisely where expected. Further indications come from comparison of diphoton data from the CMS Collaboration with predictions of DIPHOX and RESBOS [25], shown in Fig. 13. It should not be too difficult to obtain clean data at LHC to improve the $Z \to 3\gamma$ statistics.

Acknowledgment

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