Highlights of meson spectroscopy: an experimental overview

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Abstract. Quantum Chromodynamics is the theory of the strong interaction, but the properties of hadrons cannot be directly calculated from the QCD Lagrangian. Alternative approaches are then used: Lattice QCD, Effective Field Theories, Quark Models. To test these different approaches, precise measurements of hadron properties are needed. This is the main motivation of the hadron spectroscopy program carried out since many years with different probes in different environments. Recently, the majority of the new results have been obtained using e^+e^- colliders by experiments like BaBar, Belle, BES, CLEO. These, on one hand, have determined big progresses in the field, while, on the other hand, have discovered a large number of states with properties that cannot be easily and exhaustively explained by any theory. In this review, I will make an excursus through the recent experimental results in the meson spectroscopy sector, showing which are the best successes of the theory, and pointing out where we have still some problems. Hints on future perspectives, offered by the forthcoming experimental programs, will be also given.

1. Introduction

The study of hadron properties is carried out following roughly two main complementary theoretical approaches. The first one starts from the basic quark and gluon degrees of freedom and it results in the widely accepted framework of Quantum Chromo Dynamics (QCD) which, at least today, can be exploited only in the perturbative regime. A big theoretical effort is nowadays devoted to the understanding of the hadron structure using Lattice QCD (LQCD) calculations. This is a numerical approach that discretize the equations on a four-dimensions space and solve them by means of MonteCarlo techniques. Here, many important results have been obtained and more are expected in the future by the use of more powerful computers. Nevertheless, this goal presumably will still require some time, and in the meanwhile one can rely on models, eventually based on QCD or LQCD. The second approach, which can be denoted as "phenomenological", uses some parameterization of single hadron properties within a theoretical framework based on general aspects of quarks and gluons dynamics. Many models have been built and applied to describe hadron properties. An important class is provided by Constituent Quark Models (CQM), in which quarks are considered as effective internal degrees of freedom. The idea of quarks as constituent particles of hadrons was introduced in the '60s, before their experimental discovery. At that time, quark confinement was not yet known and quarks were considered to have a very large mass allowing a non-relativistic approach. The modern version of the non-relativistic CQM considers a confinement potential characterized by a linear term and a Coulomb-like one. In the last years, CQM have been considerably refined to include further elements, related to spin-orbit, spin-spin and tensor interactions, and in spite of their simplicity, they can feature a fairly good agreement with the experimental results.

In general, the different theoretical approaches are not sharply separated. On the contrary, they are strongly correlated and the previously mentioned scheme is just mainly introduced for simplifying the discussion. Independently from the used approach, all the theories predict that the hadron spectrum should be more reach than the conventional one. Due to the non-Abelian characteristic of the strong interaction, also gluons can contribute explicitly to the hadron structure and to its parameters. Glueballs made entirely of gluons, hybrids consisting of a $q\bar{q}$ pair combined to an excited gluon, or multi-quarks states must exist. A clear and unambiguous observation of these states will be an important confirmation of the validity of the theoretical framework.

In the following sections, I will briefly reports on the experimental results obtained in the meson spectroscopy sector, comparing them with the theoretical expectations and calculations. In the light of the present situation, the last section is devoted to the perspectives offered by some of the new experimental facilities under construction in the field.

2. The present experimental situation

There have been many experimental developments in hadron spectroscopy during the past years. It is impossible to do justice to all of them in a brief review. Therefore, I will focus only on the meson sector giving some highlights on the topics that I personally consider more tricky or interesting. I'll try to point out where the theory successes in explaining or predicting the new results, and also where it fails. This is useful in order to understand which are the aspects that need further attention.

2.1. Exotic states in the low energy region

QCD considers hadrons made of quarks, antiquarks, and gluons. The known hadrons, the three-quarks baryons and the quark-antiquark mesons, are believed to contain quarks and antiquarks as valence particles while the gluon content is hidden in the sea. This is not justified from the theoretical point of view that, on the contrary, allows the existence of hadrons with an explicit glue content.

Thanks to the great variety of facilities available all over the world, in the last 50 years a wide harvest of data, in the mass range between 1 and 2 GeV/c^2, has been collected with the intention to search for the predicted exotic mesons, *i.e.* hybrids, glueballs, multi-quark states. Within exotics there are states that are, in principle, more easy to be identified since they exhibit non-$q\bar{q}$ quantum numbers. One of the first claim for the existence of a non $q\bar{q}$ meson, namely a 1^{-+} resonance, was made by the BNL experiment E852. In the Partial Wave Analysis (PWA) of 250,000 events from the reaction $\pi^- p \to p\pi^-\pi^-\pi^+$ they announced the discovery of such a state with mass $\sim$ 1593 MeV/c^2 [1]. Similar results and confirmations were then obtained by other experiments, but none of them was so striking that the whole community was convinced that an exotic state had been discovered. In order to better explain this situation, I would like to report about a recent paper from the COMPASS collaboration [2] that is presenting a new evidence of this resonance.

Figure 1(*left*) shows the invariant mass spectrum of the $\pi^-\pi^-\pi^+$ system obtained analyzing 420,000 diffractive events $\pi^- Pb \to X + Pb_{reco}, X \to \pi^-\pi^-\pi^+$. A PWA of this data set has been performed by using the isobar model in which a multi-particle final state is described by a sequence of two-body decays. All known isovector and isoscalar $\pi\pi$ resonances have been included: $\sigma(600)$ and $f_0(1370)$, $\rho(770)$, $f_0(980)$, $f_2(1270)$, and $\rho_3(1690)$. The channel $\sigma(600)\pi$ with $L = 0$ and $J^P = 0^-$ is used to consider a direct 3-body decay into $\pi^-\pi^-\pi^+$. The fit also contains a background wave characterized by a uniform distribution in 3-body phase space added incoherently to the other waves. A total of 42 partial waves are included in the first step

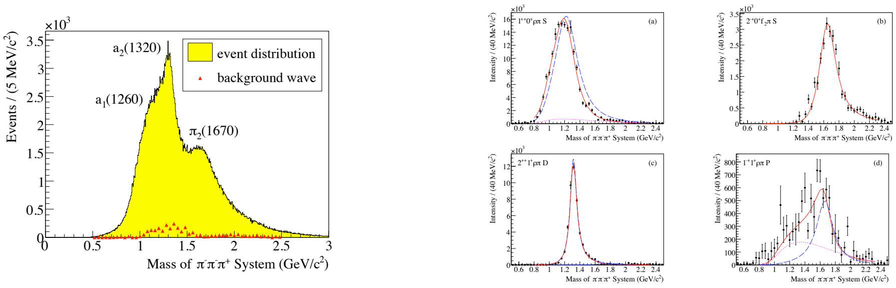

Figure 1. (*left*) Invariant mass of the 3π system for 0.1 GeV$^2/c^2$ $<$t$'$ < 1.0 GeV^2/c^2(histogram), and intensity of the background wave with a flat distribution in 3-body phase space (triangles), obtained from a partial wave analysis in 40 MeV/c^2 bins of the 3π mass and rescaled to the binning of the histogram (from [2]).
(*right*) Intensities of major waves 1^{++} $0^{+}\rho\pi$ S (a), $2^{-+}0^{+}$ $f_2\pi$ S (b), and $2^{++}1^{+}\rho\pi$ D (c), as well as the intensity of the exotic wave $1^{-+}\rho\pi$ P (d), as determined in the fit in mass bins (data points with error bars). The lines represent the result of the mass-dependent fit (from [2]).

of the fit. In a second step of the PWA, a χ^2 fit of the spin-density matrix elements obtained for each mass bin in the first step is performed in the mass range from 0.8 to 2.32 GeV/c^2.

Figure 1(*right*) displays the intensities of the 3 more prominent waves resulting from the fit, together with the exotic $1^{-+}1^{+}\rho\pi$ P wave, whose contribution is ~ 1.7 %.

I do not want to enter into the details of the COMPASS analysis, I just want to stress its complexity that is paradigmatic to understand why the search for non-$q\bar{q}$ state is so hard. The signal of the exotic meson is not evident from the invariant mass plot. It comes out after a complicated and difficult to control analysis procedure. The resonance parameters, that emerge from the fit, mass, width, decay modes, are not always in agreement width those evaluated by different experiments, and the comparison is not straight forward since each collaboration develops its own PWA tools whose ingredients are not exactly the same.

By flipping through the pages of the Particle Data Book [3], we see that in the mass region $1 \div 2$ GeV/c^2 there are hundreds of states. The average level spacing of mesons is 15 MeV/c^2 while the average width is 150 MeV. This implies interferences and makes the experimental spectroscopy a very difficult job.

Table 1. Some mesonic states for which an exotic interpretation has been proposed (see [3] for the full list of references.

State	Exotic interpretation
$f_0(980)$	4q state, molecule
$f_0(1500)$, $f_0(1370)$, $f_0(1710)$	0^{++} glueball candidates
$\eta(1410), \eta(1460)$	0^{-+} glueball candidatess
$f_1(1420)$	0^{++} hybrid, 4q state
$\pi_1(1400)$, $\pi_1(1600)$, $\pi_1(2000)$	1^{-+} hybrid candidates
$\pi(1800)$	0^{-+} hybrid candidate
$\pi_2(1900)$	2^{-+} hybrid candidate
$a_2'(2100)$	1^{++} hybrid candidate

These are the reasons why many states have been considered exotic candidates, but none of them is unambiguously ascribed to the category. Table 1 reports a list of states, with mass in the range 1÷ 2 GeV/c^2, for which an exotic interpretation has been claimed.

2.2. Heavy quarks energy range

In order to overcome the limitations arising in the low energy region, the spectroscopy activity has moved to higher energies. Large data sets have been collected at e^+e^- machines by BaBar, Belle, CLEO, and BES collaborations, but also the Tevatron experiments, CDF and D0, have contributed significantly.

In the sector of heavy quarks, the density of states is not so high and particle widths are narrow, therefore the interference problems are reduced. In particular, in the charmonium energy range only 8 states are present below the $D\bar{D}$ threshold, and their widths are in the MeV range.

The charmonium and bottomonium energy regions are those where CQM are tuned. The mesonic states are described as quark-antiquark pairs bound by an inter-quark force with a short-distance behavior dominated by single-gluon-exchange plus a linearly increasing confining potential that dominates at large separations. Typically, the energy levels are found by solving a non-relativistic Schrödinger equation, although there are more sophisticated calculations that take into account relativistic corrections and other effects. These give energy levels that are characterized by the radial quantum number, n, and the relative orbital angular momentum between the quark and the antiquark, L. The quark and antiquark spins couple to give total

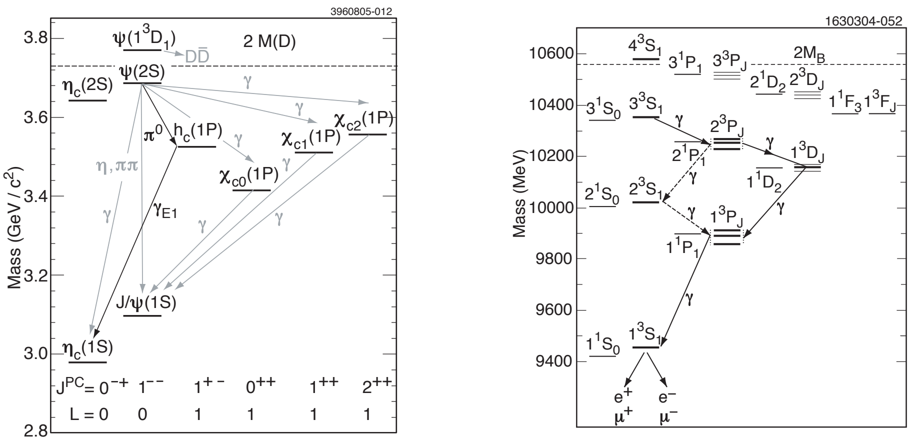

Figure 2. The charmonium (*left*) and bottomonium (*right*) level diagrams resulting from CQM calculations.

spin $S = 0$ (spin-singlet), or $S = 1$ (spin-triplet). S and L combine to give the total angular momentum of the state, J. Spin interactions contribute to the state parameters, thus, in the potential expression, there are additional spin-dependent terms that gives rise to splittings within multiplets, while the splittings of the P-wave $\chi_c(1^3P_{J=0,1,2})$ and higher L states are due to spin-orbit and tensor spin-spin interactions. The results of this approach are shown in Figure 2 where the level schemes of charmonium and bottomonium are shown. In order to test this picture and to fix free parameters, precise measurements of all heavy-quark mesons are desirable.

For mesons, we distinguish two main categories: open-charm*(bottom)* states that carry net charmness*(bottomness)*, and charmonium*(bottomonium)* states where any flavor component is balanced by its antiquark (also called hidden-charm*(bottom)* particles).

Plenty of mesons of both kinds have been produced at e^+e^- machines studing different processes:

- B-meson decays;
- inclusive charmonium(*bottomonium*) production;
- associate charmonium production;
- two photon collisions;
- initial state radiation.

By means of these reactions a deep systematic investigation of the high energy range has been carried out, and interesting results have been obtained.

The J/$\psi(1^3S_1)$ state of charmonium was discovered in 1974 [4] and $\Upsilon(1^3S_1)$ state of bottomonium in 1977 [5]. Then, after several false identifications, $\eta_c(1^1S_0)$ has been finally detected in 1980 [6] allowing to determine the first hyperfine splitting in the hidden flavor meson sector:

$$\Delta M_{hf}(1S)_{c\bar{c}} = M(J/\psi) - M(\eta_c) = 116.6 \pm 1.0\ MeV/c^2 \tag{1}$$

Only recently, other missing singlet states of charmonium $\eta_c'(2^1S_0)$ [7] and $h_c(1^1P_1)$ [8, 9] have been found, and new hyperfine splittings have become accessible. Since both Belle and BaBar have reported more measurements for the η_c' mass, taking the PDG08 [3] average value the hyperfine splitting for $2S$ charmonium states turns out in:

$$\Delta M_{hf}(2S)_{c\bar{c}} = M(\psi') - M(\eta_c') = 49 \pm 4\ MeV/c^2 \tag{2}$$

This result is largely unexpected. Neither CQM nor LQCD calculations can determine for the $2S$ hyperfine splitting a value ~ 2.5 times smaller than that of $1S$.

For the charmonium P wave states, theoretical models predict $\Delta M_{hf}(1P)_{c\bar{c}} = M(^3P) - M(^1P) = 0$. The term $M(^3P)$ corresponds to the center of gravity of the triplet-P states $\chi_{c(0,1,2)}$ and it is precisely known. The identification of the $^1P_1$ (h_c) state has been, on the contrary, extremely difficult. The only way to obtain h_c is via the reaction $\psi' \to \pi^0 h_c$ that in e^+e^- machines has very little phase space. An attempt to find this particle in $p\bar{p}$ annihilations was made at Fermilab by the E760 and E835 experiments, but detector limitations and poor statistics prevented to perform a conclusive measurement [10, 11]. The h_c state has been finally identified by the CLEO experiment in the cascade process $\psi' \to \pi^0 h_c, h_c \to \gamma\eta_c$ in both inclusive and exclusive measurements [12]. Later, the mass determination of h_c has been improved by either CLEO [8] and BES [9] collaborations with more data in the same chain of reactions.

Taking for the h_c mass the value obtained by averaging the CLEO and BES values, the mass splitting for charmonium P states turns out in agreement with the theoretical prediction.

$$\Delta M_{hf}(1P)_{c\bar{c}} = M(^3P) - M(^1P) = 0.0 \pm 0.16\ MeV/c^2 \tag{3}$$

The $b\bar{b}$ bottomonium system is where we expect the best agreement between theory and experiment. The b quarks are the heaviest making hadrons, and the quarks in bottomonium are less relativistic and also have smaller strong coupling constant. Furthermore, the bottomonium states lie in a region where the $q\bar{q}$ potential is dominated by the Coulombic part, and then are less affected by the uncertainties of the confinement term. The $\eta_b(1^1S_0)$ has been recently found by the BaBar collaboration studying radiative decays of $\Upsilon(3S) \to \gamma\eta_b$ and of $\Upsilon(2S) \to \gamma\eta_b$ [13]. Then the first hyperfine splitting in the bottomonium energy range has been determined:

$$\Delta M_{hf}(1S)_{b\bar{b}} = M(\Upsilon) - M(\eta_b) = 69.9 \pm\ 3.1 MeV/c^2 \tag{4}$$

quite in agreement with LQCD theoretical expectations [14], but not with those of CQM [15].

Concerning open-charm mesons, for the states $c(\bar{u}, \bar{d})$ theory and experiment were in agreement till 2003 (see black points in Figure 3). The CQM described the spectrum of heavy-light systems and it was expected to be also able to predict unobserved excited $D_S(c\bar{s})$ mesons with good accuracy. Actually, this turned out to be false, and the discovery of new D_{SJ} states has brought into question potential models. In 2003 two new states $D_S(2317)$ and $D_S(2460)$ were discovered in $e^+e^- \to c\bar{c}$ events, and then deeply studied in B decays by BaBar, Belle and CLEO [16, 17]. The observed decay modes of these particles are consistent with spin-parity assignments $J^P = 0^+$ for the $D_S(2317)$, and $J^P = 1^+$ for the $D_S(2460)$. The identification of these states as the 0^+ and 1^+ $c\bar{s}$ states is difficult within the CQM. These mesons have narrow widths (less than 4 MeV) since they lie below the DK and the D^*K thresholds, respectively. Furthermore, it seems not easy to reproduce their measured mass difference.

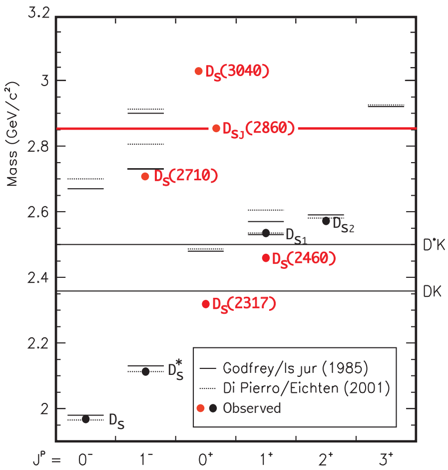

Figure 3. The D_s meson spectrum as predicted by Godfrey and Igsur [18] (solid line) and by Di Pierro and Eichten [19] (pointed line). Experimental values are shown by points.

The situation has become also more tricky in 2006 when BaBar observed another $c\bar{s}$ meson, $D_{sJ}(2860)$, decaying to D^0K^+ and D^+K_S, with mass $2856.6 \pm 1.5 \pm 5.0$ MeV/c^2 and width $47 \pm 7 \pm 10$ MeV [20]. Shortly after, analyzing the D^0K^+ invariant mass distribution in $B^+ \to \bar{D}^0D^0K^+$, Belle established the presence of a $J^P = 1^-$ resonance, $D_{sJ}(2710)$, with mass $2708 \pm 9^{+11}_{-10}$ MeV/c^2 and width $108 \pm 23^{+36}_{-31}$ MeV [21]. Following the interpretation given in [22] $D_{sJ}(2710)$ is most likely the first radial excitation of $D_s^*(2112)$, while for a precise cataloging of $D_{sJ}(2860)$ more experimental information is required. Finally, let me mention that in a BaBar paper regarding $D_{sJ}(2710)$ and $D_{sJ}(2860)$ decays into D^*K final states, another broad structure $D_{sJ}(3040)$ with mass $3044 \pm 8^{+30}_{-5}$ MeV/c^2 and width $239 \pm 35^{+46}_{-42}$ MeV has been observed [23]. Studies of angular distributions for this state have not been attempted due to the limited statistics. In order to perform a classification of this new D_{sJ} state more data are needed.

Similar experimental techniques used for open-charm detection have produced a large number of candidates for charmonium and charmonium-like states, many of which cannot easily fit the current theoretical picture. Figure 4 shows the charmonium spectrum with the new X, Y, Z states recently discovered. These new states are associated with charmonium because their predominant decay is via charmonium states such as the J/ψ or the ψ'. A part from that, their interpretation as $c\bar{c}$ states, is far from obvious.

Among the zoo of X, Y, Z particles let me draw your attention on three of them. The first one is the most known: $X(3872)$. Discovered by Belle in B decays in 2003 [24] has then been confirmed by BaBar [25], CDF [26] and D0 [27]. In addition to the discovery decay mode J/$\psi\pi^+\pi^-$, the X has been observed to decay into J/$\psi\gamma$, J/$\psi\pi^+\pi^-\pi^0$ [30], and $D^0\bar{D}^0\pi^0$ [28, 29].

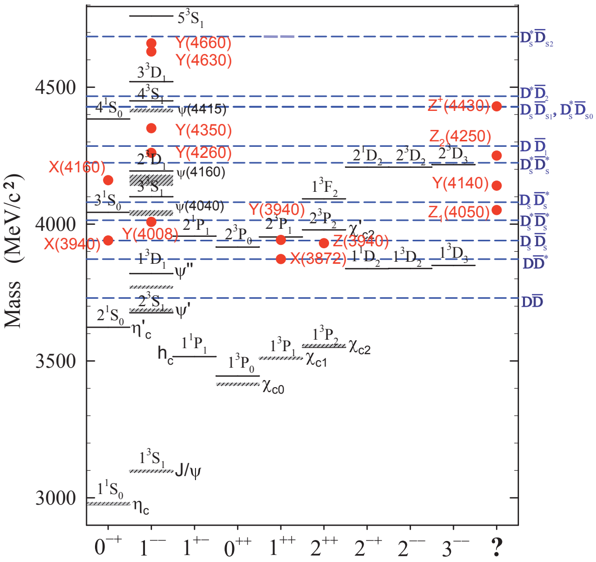

Figure 4. The charmonium spectrum. The solid lines are CQM predictions [18], the shaded lines are the observed conventional charmonium states, the horizontal dashed lines represent various thresholds. The red dots are the newly discovered charmonium-like states placed in the column of the most probable spin assignment. The states in the last column do not fit elsewhere and appear to be truly exotic.

The decay into J/$\psi\gamma$ implies $C = +$, while an analysis by the Belle Collaboration of the decay into J/$\psi\pi^+\pi^-$ strongly favors the quantum numbers $J^{PC} = 1^{++}$, without excluding 2^{++} option [30]. A similar analysis performed by the CDF Collaboration has confirmed Belle conclusions [31], and the tiny phase space available for the decay into $D^0\bar{D}^0\pi^0$ has ruled out the $J = 2$ option, leaving 1^{++} as the only possible. Concerning the mass of this particle, there are clearly two sets of data, the first corresponds to the decay mode J/$\psi\pi^+\pi^-$, the second to $D^0\bar{D}^{*0}$ and $D^0\bar{D}^0\pi^0$ final states. The width is below present detector resolutions < 2.3 MeV (90% C.L.), very unlikely for a state with mass above $D\bar{D}$ threshold. It is worth to remind that this state lies very close to the $D^0\bar{D}^{*0}$ threshold, therefore there is a strong coupling between the resonance and these two particles that can transforms the resonance into a two-particle bound state just below the threshold [32].

The second state I would like to cite, is the $Y(4260)$. This is the first of the "Y" states recently found, and has been discovered by the BaBar collaboration using the technique of initial state radiation [33]. Subsequently, CLEO [34] and Belle [35] have confirmed its existence. The over-population of the 1^{--} column, together with the absence of open-charm decay modes of $Y(4260)$, seems to indicate that this is not a conventional $c\bar{c}$ state. Furthermore, LQCD predicts that the mass of the lowest $c\bar{c}$ hybrid is ~ 4200 MeV/c^2 supporting the hypothesis that the first hybrid, in the charmonium energy range, has been found.

The last particle I would like to mention is one of the less known, $Z(4333)$. It has been discovered in 2008 by Belle studying $B \to K\pi^{\pm}\psi'$ decays. They observed in the $\pi^{\pm}\psi'$ invariant mass distribution a prominent and narrow peak at 4.433 GeV/c^2 [36, 37] corresponding to the first charmonium-like candidate having a non-zero electric charge. BaBar Collaboration has studied the same channels without finding any significant evidence of $Z(4333)$ [38] (see Figure 5), therefore, some doubts remain about the existence of this state. Nevertheless, if this peak has to be interpreted as a meson, it must have an exotic structure: its minimal quark content should be $|c\bar{c}u\bar{d}>$.

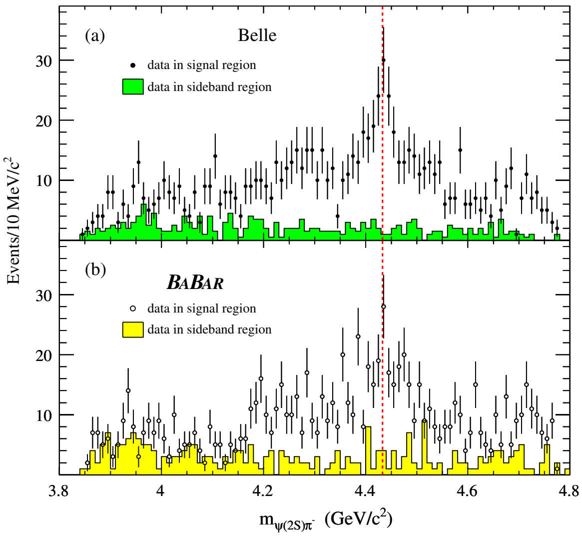

Figure 5. (a) The $\psi'\pi^-$ mass distribution after K^* veto from Belle analysis [36]; the data points represent the signal region, and the shaded histogram represents the background contribution estimated from the sideband regions; (b) shows the corresponding distribution from the BABAR analysis. The dashed vertical line indicates $m_{\psi'\pi^-} = 4.433$ GeV/c^2 [38].

It is not clear at all what most of the new charmonium-like X, Y, Z states are. A few can be identified as conventional states and a few more, probably the $X(3872)$ and $Y(4260)$, are strong candidates for exotic states. These two are the best understood because they have been confirmed by several experiments and observed in different processes. The main challenge of the next years will be thus to understand what the all new states are and to match the experimental findings to the theoretical expectations.

3. Future perspectives

In the previous sections I have tried to underline successes and weak points either of the experimental and of the theoretical programs that are undergoing for meson spectroscopy. To my opinion, long standing problems could be finally solved in the future only if they will be approached in different ways, trying to overcome present limitations. In the near future, e^+e^- experiments will continue to produce plenty of results, but, to my opinion, no big surprises can be expected here, since all the features of these facilities have been already exploited at best. On the side of hadronic machines, certainly some results will arise from LHC experiments. Here, it is worth to remind, only LHCb has been designed with the intention of performing spectroscopic studies; for what concerns ALICE, ATLAS and CMS their main activity is centered on other topics. Nevertheless, also B-factory experiments were designed with either scopes than spectroscopy, but in the end they demonstrate to have excellent capabilities even for spectroscopy. Therefore, I'm ready to be contradicted by the experimental results.

For the low energy region (below 2 GeV) a new set of data will be provided by the GlueX experimental program [39], foreseen for the upgraded 12 GeV JLAB machine. In this energy domain, all the caveats I have expressed before still remain, even if the use of a linearly polarized photon beam is a new tool for this field.

Finally, probably the most ambitious and complete spectroscopy future project is represented by the $\overline{\text{P}}$ANDA [40] experiment at FAIR [41]. FAIR is a new international Facility for Antiproton and Ion Research under construction as a major upgrade of the existing GSI laboratory. FAIR will provide scientists from all over the world with outstanding beams and experimental conditions for studying matter at the level of atoms, nuclei, and other sub-nuclear constituents.

An antiproton beam with intensity up to 2×10^7 $\bar{p}$/s and high momentum resolution ($\delta p/p \simeq 10^{-5}$) will be available at the High Energy Storage Ring (HESR) where the $\overline{\text{P}}$ANDA detector will be installed. $\overline{\text{P}}$ANDA (antiProton ANnihilations at DArmstadt) will carry out a wide scientific program including meson spectroscopy from light to charm quark sector, baryon/antibaryon production, charm in nuclei, and strangeness physics with particular attention to the systems with strangeness S = -2.

Antiproton-proton annihilations have proven to produce large quantities of exotic states [42, 43] with yields comparable to ordinary mesons. This is due to the fact that the annihilation process create a lot of gluons. Furthermore, to perform a complete survey of states, production and formation reactions (see Figure 6) can be alternatively used. The resonance scan via

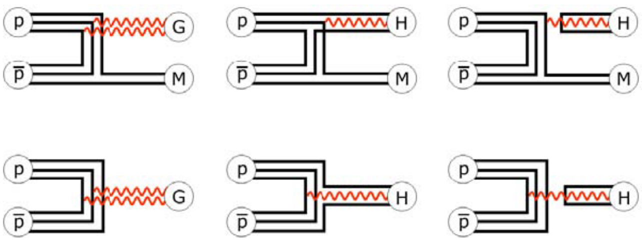

Figure 6. Gluonic excitation are very likely to appear in $p\bar{p}$ annihilation. The upper plots refer to exotic production with a recoil meson, while the lower ones represent formation of states with ordinary quantum numbers. G indicates a glueball, H a hybrid, and M an ordinary $q\bar{q}$ meson.

formation will produce mesons with conventional quantum numbers, while exotic ones will be obtained by having and additional recoil particle to compensate for the spin-parity imbalance. This will turn out in better masses and widths determination with respect to e^+e^- experiments. In fact, here only 1^{--} quantum numbers can be directly accessed allowing precise measurements of the masses and widths of states like the J/ψ and ψ once the energy of the electron and positron beams is known with good accuracy. Other states can be reached by means of secondary decays that eventually result in moderate resolutions. At $\overline{\text{P}}$ANDA we will be able to measure widths down to 100 KeV, while best measurements, performed at e^+e^- colliders, provide tens of MeV. This technique, originally proposed by P. Dalpiaz in 1979 [44], could be successfully employed a few years later at CERN and Fermilab thanks to the development of the stochastic cooling. With this method the masses and widths can be measured with excellent accuracy, determined by the very precise knowledge of the initial $p\bar{p}$ state and not limited by the resolution of the detector. More details about the FAIR project and on the $\overline{\text{P}}$ANDA scientific program can be found elsewhere in these proceedings [45].

4. Conclusions

During the past years there have been many new achievements in meson spectroscopy. In some cases the new results reinforce our understanding in the context of the constituent quark model, while in other cases they demonstrate that we still have much to learn. The game is not yet finished, new and more powerful tools will be available in the future in order to allow us to get a complete and exhaustive understanding of strong interaction.

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