

## Indirect search of exotic mesons: $B \rightarrow J/\psi + \text{Anything}$

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**Summary.** — We reconsider the discrepancy between theory and data in the momentum distribution of slow  $J/\psi$  in  $B$  decays. Besides an update of the standard color singlet and color octet QCD components, we include the contribution from  $XYZ$  exotic mesons, and show that the residual discrepancy could be accommodated considering new  $XYZ$  mesons still unobserved.

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PACS 13.85.Ni – Inclusive production with identified hadrons.

PACS 13.25.Hw – Decays of bottom mesons.

In the last ten years the search for excited charmonium and bottomonium states has revealed the existence of a number of resonances, named  $XYZ$ . Even if containing  $Q\bar{Q}$ ,  $Q = c, b$ , in their decay products, almost none of the  $XYZ$  mesons can be interpreted as a standard  $Q\bar{Q}$  structure, showing production and decay rates in contrast with predictions from potential models. In fig. 1 we show the known [1]  $XYZ$  mesons classified according to their decay modes and compared to the standard  $c\bar{c}$  levels. There are various phenomenological interpretations for the  $XYZ$  mesons. Among the most explored possibilities: i) *hadronic molecules*: bound states of two mesons interacting with each other via pion exchange; ii) *tetraquarks*: compact clusters made up by a diquark, a  $[qq]_{\mathbf{3}_c}$  state, and an antidiquark, a  $[\bar{q}\bar{q}]_{\mathbf{3}_c}$  state; iii) *hybrids*:  $q\bar{q}g$  aggregates; iv) *hadrocharmonium*: a heavy quarkonium state  $Q\bar{Q}$  embedded inside light hadronic matter. Until now the discovery of the exotic mesons has been fairly accidental, it occurred when studying final states expected for the decays of higher standard  $Q\bar{Q}$  states. Here we consider the possibility to reveal the  $XYZ$  not directly, but indirectly, taking into account processes in which they behave as intermediate states. In particular we discuss the inclusive production of  $J/\psi$  in  $B$  decays and consider all the contributions separately following ref. [2].

*The data.* The BaBar Collaboration [3] measured the decay momentum ( $p_\psi$ ) distribution of the prompt  $J/\psi$ 's coming from  $B$ -mesons decays, fig. 2 (full circles).

The theoretical description [3] in terms of two standard QCD components, reveals an excess of events in the low- $p_\psi$  region (red-dashed line in fig. 2). This discrepancy has provoked a variety of phenomenological conjectures.



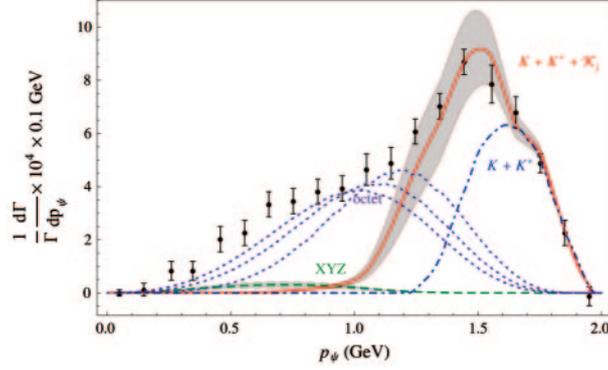


Fig. 3. – (Colour on-line) Color singlet  $B \rightarrow \mathcal{K}J/\psi$ : blue dot-dashed represents  $\mathcal{K} = K, K^*$  [3], red-solid includes also the heavier kaons [4]. Color octet: purple-dotted lines for three values of  $\Lambda_{\text{QCD}} = 300, 500, 800$  MeV and  $p_F = 300$  MeV from right to left, respectively.  $XYZ$ : green-dashed line.

$\mathcal{K} = K_1(1270), K_1(1400), K^*(1410), K_2^*(1430), K_2(1600), K_2(1770), K_2(1980)$ . They are reported in table I of ref. [2] and combined to give the red-solid line of fig. 3.

*Color octet.* The low momentum region is associated to events where the  $c\bar{c}$  pair is produced in color octet configuration, and thus emits soft gluons to fragment into  $J/\psi$ . As proposed in ref. [5] the effect of the emitted gluons on the momentum distribution can be modeled using a non-relativistic shape function (with a characteristic energy scale of  $m_c v^2 \approx \Lambda_{\text{QCD}}$ ). Moreover the motion of the  $b$  quark inside the  $B$  meson can be described using the model given in ref. [6] with a characteristic momentum  $p_F$ , the Fermi momentum. The shape of the color octet component is ruled by the values of  $(\Lambda_{\text{QCD}}, p_F)$ , but the absolute normalization, which depends on the non-perturbative non-relativistic QCD (NRQCD) matrix elements, needs to be adjusted to data.

*XYZ mesons.* Some of the  $XYZ$  mesons have been observed in  $B$ -decays, produced in association with a scalar kaon with known branching ratios (see table II of ref. [2]). Among them  $X(3872), Y(3940), Y(4140)$  and  $Y(4260)$  decay into  $J/\psi$  and light hadrons, and thus do contribute to the  $p_\psi$  spectrum. Besides the  $B \rightarrow \mathcal{K}\mathcal{X}$  modes, we decided to include also  $B \rightarrow \mathcal{K}\mathcal{Y}$  ones, where  $\mathcal{K}$  are all the heavier kaons allowed by kinematics. To determine the relative branching ratios, which are not measured, we use a simple scaling rule for the couplings deduced from a partial wave analysis. All the  $XYZ$  here are considered to be  $J = 1$  resonances. The results are represented by the green-dashed line of fig. 3. Even if very small, the contribution from exotic mesons peaks exactly in the region of the discrepancy between theory and experiment, as first observed in ref. [7].

*Results.* The complete distribution is obtained by summing up the color singlet, color octet and  $XYZ$  components. The values of  $(\Lambda_{\text{QCD}}, p_F)$  and of the absolute normalization of the octet curve are used as free parameters. To best fit data (black-solid curve in fig. 2) we choose the octet component with  $\Lambda_{\text{QCD}} = 500$  MeV and  $p_F = 500$  MeV. Both these values are critically on the high sides of the allowed ranges,  $\Lambda_{\text{QCD}} \in [200, 450]$  MeV and  $p_F \in [300, 450]$  MeV. Yet the black-solid curve in fig. 2 represents a considerable improvement with respect to the old one (red-dashed). Relying on the validity of the NRQCD approach, our results indicate that the inclusion of new resonances of the  $XYZ$  kind feeding the low- $p_\psi$  region would effectively improve the agreement with data.

## REFERENCES

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