

Excited B and D Mesons at OPAL

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ABSTRACT: Two recent OPAL publications dealing with spectroscopy of heavy-light mesons will be discussed here. In the charm sector, a search for a narrow radial excitation of the $D^{*\pm}$ is performed. No signal is seen, and an upper limit of the production rate of narrow radial excitations close to the predicted mass of 2.629 GeV is derived. Orbitally excited $B_J^{(*)}$ mesons are investigated in another analysis, where for the first time a measurement of their branching ratio into final states involving a B^* is performed. Attempts are made to separate the $B_J^{(*)}$ signal into the four contributing resonances.

1. Introduction

The spectra of mesons consisting of one heavy and one light quark can be described perturbatively in the framework of Heavy Quark Effective Theory (HQET). Precise predictions of the masses of excited mesons have been made. Their experimental verification will help tune HQET phenomenology and thus improve our general understanding of QCD. The spectrum of B mesons as expected from one such prediction [1] is displayed in Figure 1. The excited states are expected to decay by strong interaction, mainly via emission of one or two pions. Allowed decay modes are depicted by arrows. Two-pion decays of each orbital excitation to both members of the ground state doublet are also expected, but probably phase-space suppressed. Where kinematically possible, also decays involving a ρ meson might contribute. Decays of radial excitations that proceed in two steps with an intermediate orbital excitation are also allowed. A very similar spectrum is predicted for D mesons, but the mass splittings within the doublets are larger there due to the smaller charm quark mass.

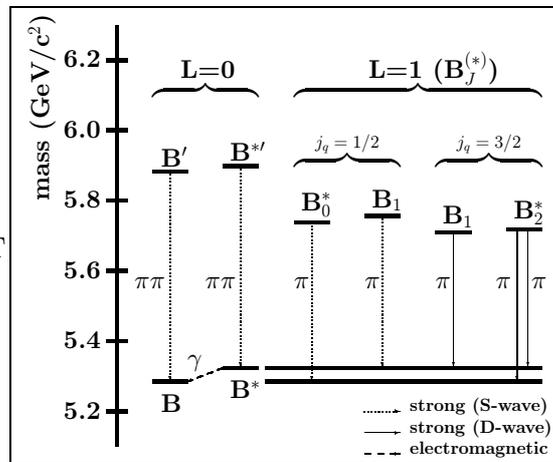


Figure 1: Spectrum of B mesons.

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Experimental access to excited heavy-light mesons turned out to be severely constrained at present and past experiments due to limited mass resolution, large background, and insufficiently large candidate samples. The existing results on excited heavy-light mesons are therefore partially inconclusive, and even contradictory in several cases (see concluding remarks in Sections 2 and 3).

Recent work on heavy-light meson spectroscopy with LEP1 data contributed by the OPAL collaboration will be discussed in this paper. A search for a narrow $D^{*'}$, the first radial excitation of the D^* meson, is presented in Section 2 [2]. Section 3 contains a summary of the results obtained by OPAL in the investigation of $B_J^{(*)}$ mesons [3], where $B_J^{(*)}$ is a common notation for the four orbitally excited B mesons with orbital angular momentum $L = 1$. A brief comparison of the OPAL results with contributions by other experiments will be included in both sections.

2. A Search for a Narrow Radial Excitation of the D^* Meson

The DELPHI collaboration reported an observation of a narrow ($< 15 \text{ MeV}/c^2$) resonance in $D^{*+}\pi^+\pi^-$ final states¹ a couple of years ago [4], whose mass coincided very well with the predicted mass of the first radial excitation of the D^* meson. Despite this agreement, the observation was a surprise because a much larger $D^{*'}$ width was favoured: The $D^{*'+} \rightarrow D^{*+}\pi^+\pi^-$ decay is most likely dominated by the S-wave contribution, which usually leads to widths of the order of $100 \text{ MeV}/c^2$ in comparable systems. The association of the observed resonance with $D^{*'}$ has therefore been questioned, despite the lack of good alternative explanations [5].

The interesting result seen by DELPHI has triggered a similar analysis at OPAL [2], where $D^{*+}\pi^+\pi^-$ combinations are looked at in search of any narrow resonant structure with a mass close to both DELPHI observation and HQET $D^{*'}$ prediction. The D^{*+} mesons are reconstructed in their decay chain $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$. A combination of D^{*+} candidates with two pions results in the desired $D^{*'+}$ candidates.

Figure 2 shows the mass spectrum of $D^{*+}\pi^+\pi^-$ combinations found by OPAL. No sign of a narrow resonance is seen in a wide mass region around the signal reported by DELPHI. A clear peak over the non-resonant background was expected from Monte Carlo including a resonance with parameters adjusted to the DELPHI observation.

In absence of any evidence for a signal in the investigated mass range, an upper limit on the production rate of narrow radial excitations close to the predicted mass of 2.629 GeV is derived:

$$f(Z \rightarrow D^{*'\pm}(2629)) \times \text{Br}(D^{*'+} \rightarrow D^{*+}\pi^+\pi^-) < 3.1 \times 10^{-3} \quad (95\% \text{ C.L.})$$

This result does not depend significantly on specific properties of radial excitations and is thus valid also for other possible narrow resonances in the mass region in question. No production of narrow $D^{*'}$ or similar resonances in primary $c\bar{c}$ events or $b\bar{b}$ events is observed, and separate limits for these two cases are obtained:

$$f(c \rightarrow D^{*'+}(2629)) \times \text{Br}(D^{*'+} \rightarrow D^{*+}\pi^+\pi^-) < 0.9 \times 10^{-2} \quad (95\% \text{ C.L.})$$

¹Charge conjugates are always implied.

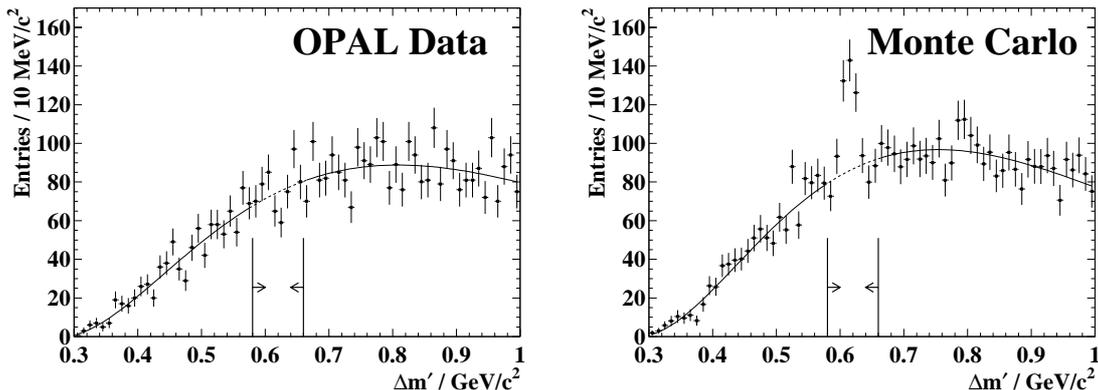


Figure 2: Mass spectrum of $D^{*+}\pi^+\pi^-$ candidates seen by OPAL (left). No narrow resonance is found. An upper limit on the production rate of a possible narrow radial excitation is calculated for a mass inside the mass window represented by the arrows. The right plot shows the corresponding spectrum for a Monte Carlo simulation including a resonance similar to the one reported by DELPHI.

$$f(b \rightarrow D^{*+}(2629)) \times \text{Br}(D^{*+} \rightarrow D^{*+}\pi^+\pi^-) < 2.4 \times 10^{-2} \quad (95\% \text{ C.L.})$$

This non-observation of the resonance seen by DELPHI is supported by other, as yet preliminary analyses by CLEO [6] and ZEUS [7].

3. Investigation of the Decay of Orbitally Excited B Mesons

The orbital excitations $B_J^{(*)}$ of the B meson spectrum are well established; however, the large mass of the B quark leads to only small mass splittings between the individual states. These mass splittings are smaller than or of about the same size as the widths of the individual $B_J^{(*)}$ states. Therefore the resonances overlap, and it is experimentally very difficult to distinguish them.

The main handle to improve knowledge about the $B_J^{(*)}$ substructure is a close investigation of their decay. Figure 1 shows that mainly the decays $B_J^{(*)} \rightarrow B^*\pi$ and $B_J^{(*)} \rightarrow B\pi$ are expected. In particular, three out of the four states can only decay into exactly one of those two final states. A separation of $B_J^{(*)} \rightarrow B^*\pi$ from $B_J^{(*)} \rightarrow B\pi$ decays would thus be a very useful tool to gain insight into the composition of the $B_J^{(*)}$ spectrum. To distinguish these decays is very difficult, because the B^* mesons decay to $B\gamma$, and thus the only visible difference in the final state is a low-energetic photon. Many other sources for low energy photons lead to a background level large enough to render any attempt to reconstruct a full $B\gamma\pi$ final state virtually impossible for current experiments.

OPAL [3] reconstructs $B_J^{(*)}$ candidates by first tagging $b\bar{b}$ events looking at B decay vertices, high p_t leptons, and jet shapes. All tracks with suitable kinematic properties are then combined to form inclusive B candidates. With an additional pion, one obtains a mass distribution with a clear excess caused by $B_J^{(*)} \rightarrow B\pi(X)$ decays (see Fig. 3a). Here, X represents possible additional final state particles like another pion from two-pion transitions which are expected to be suppressed, but not excluded. Also, X includes photons from $B_J^{(*)} \rightarrow B^*\pi \rightarrow B\gamma\pi$ cascade decays.

A good description of the background is mandatory to obtain useful results after background subtraction. All important background sources are studied independently at OPAL by creating samples that are enriched in the respective type of background. The shape of these samples is then compared to corresponding data samples, and the relative size of the background samples in Monte Carlo is weighted to match the data best. The resulting background-subtracted distribution is shown in Figure 3b. Because the efficiency to reconstruct $B_J^{(*)}$ decays is mass-dependent, an efficiency-correction is applied to obtain the $B_J^{(*)}$ mass distribution (Fig. 3c).

A combination of $B\pi$ candidates with photons to obtain $B_J^{(*)} \rightarrow B^*\pi \rightarrow B\gamma\pi$ candidates would completely dilute the $B_J^{(*)}$ signal due to bad mass resolution and large background. A different approach is therefore used by OPAL. The number and quality of photon candidates that can be combined with a $B\pi$ candidate to form a $B^*\pi$ candidate with acceptable properties is evaluated into a B^* weight. $B\pi$ combinations from $B_J^{(*)} \rightarrow B^*\pi$ decays tend to have a higher B^* weight than $B\pi$ combinations from $B_J^{(*)} \rightarrow B\pi$ decays. By cutting on this weight, the sample of $B\pi$ candidates can thus be divided into two subsamples: One is enriched in $B\pi$ combinations from $B_J^{(*)} \rightarrow B^*\pi$ decays, the other is enriched in $B_J^{(*)} \rightarrow B\pi$ decays. However, no specific photon candidate is assigned to the $B\pi$ candidates in the former sample. The invariant mass of a $B_J^{(*)} \rightarrow B^*\pi$ candidate is calculated as the invariant mass of the $B\pi$ distribution, plus the world average mass difference of the B^* and B mesons.

The efficiencies to reconstruct $B_J^{(*)} \rightarrow B\pi$ and $B_J^{(*)} \rightarrow B^*\pi$ decays are different for the two (B^* -enriched and B^* -depleted) samples. This allows to calculate for the first time the branching ratio of $B_J^{(*)}$ decays to final states involving a B^* :

$$\text{Br}(B_J^{(*)} \rightarrow B^*\pi(X)) = 0.85_{-0.27}^{+0.26}(\text{stat.}) \pm 0.12(\text{syst.})$$

Due to the inclusive character of the B meson reconstruction, a final state with more light particles (X) than the reconstructed pion cannot be distinguished from a pure $B^*\pi$ final state. Specifically, $B_J^{(*)} \rightarrow B^*\pi\pi$ decays might contribute.

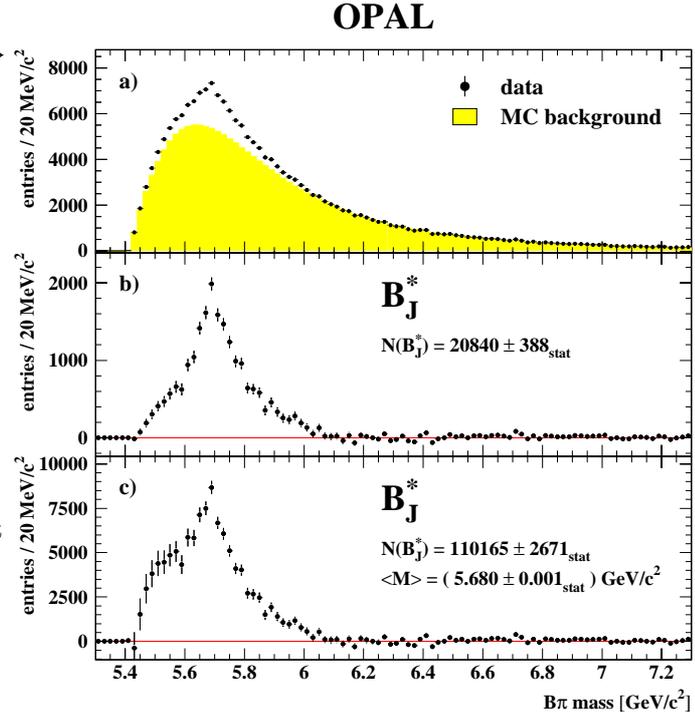


Figure 3: Invariant mass distribution of $B\pi$ combinations in OPAL data (top). A clear signal from $B_J^{(*)} \rightarrow B\pi(X)$ decays is visible. Below are the background-subtracted (centre) and efficiency-corrected mass distributions (bottom).

The goal to disentangle the contributions of the four individual resonances to the $B_J^{(*)}$ peak remains ambitious. A simultaneous fit to the background-subtracted and efficiency-corrected mass distributions of both $B\pi$ samples is performed in the HQET framework to obtain measurements of some parameters at the price of fixing others at their predicted values. Still, parts of the fit are inherently unstable, and the systematic errors are large. Furthermore, similar fits by ALEPH [8] and L3 [9] lead to different conclusions on the masses of the broad $B_J^{(*)}$ resonances, the existence of radial excitations, and the contribution of di-pion transitions. The most reliable OPAL fit results are the mass of the narrow B_1 , found to be $M(B_1(3/2)) = (5.738_{-0.006}^{+0.005} \pm 0.007)\text{GeV}/c^2$, and its width of $\Gamma(B_1(3/2)) = (18_{-13-23}^{+15+29})\text{MeV}/c^2$.

4. Conclusion

Years after the end of the LEP1 program, heavy flavour spectroscopy with LEP1 data is still an active field. OPAL has recently contributed new results on radially excited D mesons and on orbitally excited B mesons. However, in both cases comparison with the results obtained by other collaborations shows that the results obtained at LEP are not sufficiently clear to solve all questions we would like to answer in this field: In the charm sector the DELPHI and OPAL collaborations disagree on whether a narrow radial excitation of the D^* mesons is present or not. $B_J^{(*)}$ mesons are well established, but attempts to separate the $B_J^{(*)}$ peak into the contributions of the four individual $B_J^{(*)}$ states (and possibly radial B excitations) lead to contradictory results among the ALEPH, L3 and OPAL collaborations. Using a novel approach to separate $B_J^{(*)} \rightarrow B^*\pi(X)$ from $B_J^{(*)} \rightarrow B\pi(X)$ decays, OPAL performs the first measurement of the branching ratio $\text{Br}(B_J^{(*)} \rightarrow B^*\pi(X))$.

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