

Spectroscopy

New States

X(3872)

The nature of the narrow state observed in both B decays and $p\bar{p}$ annihilation is still uncertain.

After the discovery in $J/\psi\pi\pi$ decay mode, substantial experimental progress was made in the last two years:

- Observation of other decay modes:
 - (a) $J/\psi + \gamma$ (by both Belle and BaBar)
 - (b) $J/\psi + 3\pi$ (only by Belle)
 - (c) $D\bar{D}\pi^0 \simeq D\bar{D}^*$ (only by Belle)
- Study of the angular distributions (by Belle and CDF)
 - (a) Belle rules out 0^{++} and 0^{-+}
 - (b) CDF rules out all but 1^{++} and 2^{-+}
- Study of the dipion mass distribution (Belle, CDF)
- Improved measurement of the D mass (CLEO)

A precise measurement of difference between the X(3872) mass and the $D\bar{D}^*$ threshold energy is crucial for understanding its nature. The 2σ discrepancy between the peak in $J/\psi\pi\pi$ and the one in $D\bar{D}^*$ is intriguing, and may suggest the existence of a doublet of states, therefore redundancy among experiments is crucial.

Action Items:

- Confirmation by BaBar (and CDF or D0) of the other decay modes, especially $D\bar{D}^*$, with an accurate new measurement of the mass. CDF has an extremely clean and large D^* sample, and it is known that prompt X production is very copious: search of the associated D vertex and plot of the invariant mass distribution close to threshold may yield an important result.
- the search for other charmonium transitions (such as $\psi'\gamma$ or $\chi_c(1P)\pi\pi$) can help understanding its nature: even upper limits will be useful to challenge theory predictions.

Z(3930)

The state Z observed by Belle in $\gamma\gamma \rightarrow D\bar{D}$, seems to fit well the charmonium interpretation, as a $\chi_{c2}(2P)$ candidate, even if 40-50 MeV below the expected mass range. It is important though to improve the measurement of the ratios between neutral and charged decay modes.

Action Items:

- A redundant, simultaneous measurement by BaBar (via $\gamma\gamma$ fusion mechanism), CDF (via 2 gluon fusion), of the $D\bar{D}$ AND of the $D\bar{D}^*$ decay modes will further test the nature of this state.
- Search for radiative decays to J/ψ and ψ' is probably not statistically within reach, if the state is conventional excited charmonium.

X(3940)

The fourth peak in the J/ψ recoil mass spectrum is most likely a pseudoscalar as all the other states found in double charmonium production. Conventional charmonium predictions put the $\eta_c(3S)$ candidate 100 MeV above, but this is the most likely hypothesis at the moment. Evidence of a bump in the $D\bar{D}^*$ decay mode and of no signal in the $D\bar{D}$ mode rule out the 0^{++} . The width of the bump in the exclusive mode is statistically still compatible with the inclusive one, but may suggest that more than one peak are present. Therefore it is very important to increase the statistical significance of this signal, and to have an independent measurement by BaBar.

Action Items:

- The analysis of the angular distributions is made difficult by the continuum subtraction, nonetheless it is the prime way to check quantum numbers of this state.
- The pseudoscalar nature of the state may suggest to search for it in the exclusive $K\bar{K}\pi$ decay mode, not just in double charmonium production (where stats may be very low), but in the exclusive reconstruction of B decays, as well as in $\gamma\gamma$, where $\eta_c(2S)$ was discovered and confirmed.
- As in the case above, the state, which decays in $D\bar{D}^*$ may also be produced in 2 gluon fusion at CDF and therefore is likely to show up as a bump in the $M(D\bar{D}^*)$ spectrum. It will therefore be challenging to disentangle the Z(3930) from the X(3940), if both are produced.

Y(3940)

The wide bump observed in B decays to $KJ/\psi\omega$ is still experimentally unclear and lacks a theory explanation. An independent confirmation by BaBar is needed before even speaking about a new resonance. No guesses on the possible quantum numbers have been made yet. It is also possible that the wide bump is produced by two or more merging resonances. In principle both Z(3930) -if 2^{++} - and X(3940) - if 0^{-+} - can decay to $\omega J/\psi$. Z(3930) is unlikely to be observed in two body B decays, though.

Action Items:

- Belle needs to perform a detailed study of the 4 body phase space $J/\psi 3\pi$ to clean the $\omega J/\psi$ signal. A check of this signal by BaBar is mandatory.
- A study of the angular distribution is needed to assign quantum numbers, in the lucky case of a single resonance.

Y(4260) and Y(4350?)

The discovery by BaBar of a vector state decaying to $J/\psi\pi\pi$, was soon after confirmed by CLEO both in analysis of ISR data, and by taking data at $\sqrt{s} = 4.26$. CLEO has observed both neutral and charged dipion: fractions are consistent with $I=0$. CLEO has positive evidence of decay to $J/\psi K\bar{K}$, needs confirmation.

The state is in an energy region characterized by the dip of the R ratio. Belle has studied the $D\bar{D}$ cross section in ISR and observes a sudden drop just before the Y(4260).

The interpretation of Y(4260) as $\psi(4S)$ charmonium is not supported by theory predictions. The most popular hypothesis on the nature of this state include charmonium hybrid and/or tetraquark.

Action Items:

- The three mass measurements (by Belle, BaBar, CLEO) of the peak range from 4260 to 4290. Also the ISR yields show some inconsistency. Further checks by all experiments are needed.

- CLEO (and, after 2007, BES) have the chance to directly scan this energy region, to measure mass, width, and other decay modes of this resonance.
- The same also applies to the energy region above 4300 which however might be a challenge for BES.
- The search of dipion transitions to the ψ' has so far yielded only the observation (BaBar) of a new enhancement, about 90 MeV above. An independent analysis by Belle can help clarifying the experimental pattern.
- CLEOc should consider additional data accumulation in direct production at a mass closer to the Belle central value and should try to disentangle the open charm decay modes in its direct production sample,
- There is little reason why similar structures should not also exist in the case of Υ vector mesons above threshold. The tetraquark- and hybrid-question can be addressed cleaner in the bottom-context. In view of this possibility an evaluation if dedicated scans above Upsilon(4S) are feasible in (Super)B-Factories is necessary.

$$h_c$$

The discovery of the h_c was very important to the understanding of onia, but its mass and production rate are still poorly measured. An improved mass measurement is important (i) to resolve a possible small discrepancy with E835 (and try to match their quoted errors), (ii) to provide a firm number for comparison with lattice calculations, and (iii) to definitively settle whether the h_c lies below the triplet center-of-gravity.

Action Item:

- CLEOc needs to use its 30M ψ' sample to make an improved mass measurement study of $h_c \rightarrow \eta_c$ with both (i) inclusive η_c decays and (ii) exclusive η_c decays, including channels not considered in the previous analyses.

$$\eta'_c$$

The mass and width of the 2^1S_0 state of charmonium are still poorly known. **Action Items:**

- CLEOc, followed eventually by BESIII, needs to look at these singlets in their ψ' data.
- BaBar needs to update its $\gamma\gamma$ fusion analysis; Belle needs to do one.

Searches

η_b and h_b

The B -factories have access to these either by running at $s = M_{3S}^2$ (or perhaps 2S) or via ISR with $s' = M_{3S}^2$. CLEO has a large sample of $\Upsilon(3S)$ and $\Upsilon(2S)$ data, but some of the “tricks” used to find the h_c cannot be easily used for bottom counter-part in that they hinge, at least in part, on knowing the 1^1S_0 mass.

Action Items:

- CLEO needs to make one last multi-faceted attempt to find these scalars in its CLEOIII data samples.
- BaBar and/or Belle need to generate some simulation to assess their ability to see the $\eta_b^{(l)}$, either in ISR production of the vector Υ states or in dedicated asymmetric running.
- In general, BaBar and Belle need to be encouraged to start to think more about onia physics, especially trigger flexibility and efficiency.