$XYZP$ spectroscopy at a charm photoproduction factory

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The discovery of a plethora of new resonance candidates, especially in the charmonium spectrum, is challenging the paradigm of the quark model in which mesons and baryons are classified according to their valence quark configurations. Approximately two dozen $XYZP$ states, with P referring to pentaquarks, have been observed, mainly in heavy hadron decays and in e^+e^- annihilation [1]. In many cases these signals appear in complicated final states and may be hindered by kinematic effects. Exploring alternative production mechanisms is, in some cases, needed to confirm existence, and in all cases to obtain more information on their structure. At high energies, (quasi-real) photoproduction is especially appealing since many of the $XYZP$ states could be produced directly and observed decaying to relatively simple final states, eliminating some of the kinematical effects. Furthermore, one can use the polarization of beam and target to achieve a precise separation of the various production mechanisms, which is not possible, for example, at hadron colliders. Another advantage is that one can scan different center-of-mass energies by detecting the scattered electron at different angles, while keeping the beam at the nominal energy. This cannot be done by the existing e^+e^- τ-charm factories, where one has to tune carefully the beam energy to do so.

Three candidates stand out in particular: the $X(3872)$, $Z_c(3900)$ and the $Y(4260)$. The $X(3872)$ state is by far the best known. Its most unusual feature is the strength of isospin violation observed in decays, $\mathcal{B}(X \to J/\psi\,\omega)/\mathcal{B}(X \to J/\psi\,\pi^+\pi^-) = 1.1 \pm 0.4$ [2], which is impossible for ordinary charmonium. Furthermore, the mass of the $X(3872)$ is within a fraction of an MeV from the $\overline{D}^0 D^{0*}$ threshold, making it a good candidate for a threshold bound state. Since the $X(3872)$ has sizeable branching fractions to $J/\psi\,\rho$ and $J/\psi\,\omega$, peripheral photoproduction involving light vector meson exchange can result in sizable yields. The charged $Z_c(3900)^+$ is observed as a resonance in $J/\psi\,\pi^+$, making it a good candidate for a four-quark state. Finally, there is an overpopulation of hidden-charm vector resonances. Three ordinary ψ states appear in the inclusive R_D measurements, leaving no room for other vectors like the $Y(4260)$. The latter can be produced diffractively.

The photoproduction cross sections for these states have recently been estimated to be of the order of a nb for photon energies $E_\gamma \sim 20$–$25\,\text{GeV}$ [3]. The yields have been computed using a hypothetical detector setup based on the existing GlueX apparatus at Jefferson Lab [4]. Specifically, for a luminosity of $\sim 500\,\text{pb}^{-1}$/year and even with a conservative assumption about efficiency, one expects hundreds of events per year of data taking. While diffractive production of Y states benefits from higher energies, energies $E_\gamma \sim 20$–$25\,\text{GeV}$ are much more efficient in producing X and Z states.

A photoproduction facility will give an opportunity to study exotic states in exclusive reactions that are different from the ones where they have been seen so far. A spectroscopy program at the forthcoming Electron-Ion Collider is presently under consideration [5]. However, it is clear that a machine able to work at lower energies and with higher luminosity would be much more efficient in studying many of the $XYZP$ states. Such a facility could provide much needed insights into the nature of these intriguing resonances.

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