The X(3872) at CDF II

G. Bauer
(Representing the CDF II Collaboration)
Laboratory of Nuclear Science, Massachusetts Institute of Technology,
77 Massachusetts Avenue, Cambridge, MA 02139, USA

Last year’s X(3872) discovery was confirmed with the CDF II detector in \( \bar{p}p \) collisions. We measure its mass to be 3871.3±0.7±0.4 MeV/c\(^2\). The source of X-mesons in the large CDF sample is resolved by studying their vertex displacement. We find 16.1±4.9±2.0% of our X-sample comes from decays of \( b \)-hadrons, and the remainder from prompt sources: either direct production or by decay of (unknown) short-lived particles. The mix of production sources is similar to that observed for the \( \psi(2S) \) charmonium state.

\textit{Keywords:} X(3872); Charmonium.

At last year’s Lepton-Photon Symposium Belle announced discovery of a charm-omium-like state, \( X(3872) \), in \( B^+ \to K^+ J/\psi \pi^+ \pi^- \). CDF quickly confirmed \( X \to J/\psi \pi^+ \pi^- \). A natural interpretation of the X is the \( ^3D_2 \) of c\( \bar{c} \), but this is contrary to expectations. The \( ^3D_2 \) is thought to be significantly lighter (\( \sim 3830 \) MeV/c\(^2\)); and Belle failed to detect decays to \( \chi_{c1} \gamma \), which should be prominent for \( ^3D_2 \). More circumstantial is the expectation of a relatively flat dipion mass (\( M_{\pi\pi} \)) distribution for \( D \)-states, whereas Belle found high masses preferred—possibly consistent with the (isospin violating) decay to \( J/\psi \rho^0 \). These difficulties, coupled with the proximity of the \( X(3872) \) to the \( D_0^* D_0^* \)-threshold, prompted speculation that the \( X \) may be a \( D_0^* D_0^* \) “molecule.” Whether this is the case, or the \( X \) is “only” a \( c\bar{c} \)-state in conflict with current theoretical models, the \( X \) is an interesting object of study.

CDF II is a general purpose detector at Fermilab’s \( \bar{p}p \) collider. We use 220 pb\(^{-1}\) of \( \mu^+ \mu^- \) triggers, yielding a clean \( J/\psi \) sample. Aside from technical cuts, kinematic and spatial cuts suppress large backgrounds from \( J/\psi \)'s plus random tracks. The main cuts are: a maximum number of \( J/\psi \pi \pi \) candidates/event, \( p_T(J/\psi) > 4 \) GeV/c, \( p_T(\pi) > 400 \) MeV/c, and \( \Delta R = \sqrt{(\Delta \phi)^2 + (\Delta \eta)^2} < 0.7 \) for each pion, where \( \Delta \phi \) (\( \Delta \eta \)) is the azimuthal (pseudorapidity) difference of the pion with respect to the \( J/\psi \pi \). With these cuts a significant \( X \)-signal is revealed. Here, however, we show in Fig. 1 the results split up into \( M_{\pi\pi} < 500 \) and > 500 MeV/c\(^2\) subsamples. No \( X \)-signal is apparent for low \( M_{\pi\pi} \), supporting Belle’s observation of high-mass decays.

Using the high-\( M_{\pi\pi} \) sample, the \( X \)-mass is 3871.3 ± 0.7 ± 0.4 MeV/c\(^2\). Also shown in Fig. 1 are masses from other experiments, and the average compared to the \( D_0^* D_0^* \) threshold. The near equality helps fuel molecular-\( D_0^* D_0^* \) speculations.
From Belle’s observation, B-mesons are a significant source of X’s. This raises some questions: Is the CDF sample only from b-hadrons? If not, is direct X production different from charmonium? The technique of separating b-decay feeddown from prompt sources is well established. Since X-decay is not weak, it is too rapid to leave a displaced vertex. If, however, it is produced by a (boosted) b-decay, the X will be displaced due to the b-lifetime. We measure the transverse X-displacement, \( L_{xy} \), and convert it to an “uncorrected” proper-time: \( ct = M \cdot L_{xy}/p_T \). This is not the true proper-time of the b-decay because \( M \) and \( p_T \) are only for the \( J/\psi \pi^+ \pi^- \).

We use the same X-sample as above, but now impose additional cuts related to the Si-vertex tracker, mainly to demand \( \sigma(L_{xy}) < 125 \mu m \) and have good beamline information. The sample is reduced by \( \sim 15\% \). An unbinned likelihood fit is performed simultaneously over the \( ct \) and mass of the candidates. The signal is modeled by a Gaussian in mass; and for the \( ct \)-distribution, a resolution smeared exponential for the long-lived component and by the resolution function for the prompt. The background model uses a quadratic polynomial for mass, and resolution function for the prompt and three resolution smeared exponentials—one for the negative-\( ct \) tail and two for the positive. The resolution function consists of two Gaussians.

The fit for \( \psi(2S) \) is shown in Fig. 2 where 28.3\( \pm 1.0 \pm 0.7\% \) of signal is displaced, similar to Run I results. For \( X(3872) \), with \( M_{\pi\pi} > 500 \text{ MeV}/c^2 \), the fraction is 16.1\( \pm 4.9 \pm 2.0\% \) (Fig. 3)—a bit more than 2\( \sigma \) from the \( \psi(2S) \). These fractions agree with those obtained by simple sideband subtraction. They are, however, uncorrected for efficiency, and must be considered sample specific. The absence of a b-component is excluded at 3\( \sigma \) based on Monte Carlo “experiments.” Thus our X-sample is mainly prompt—presumably direct production—with a modest b-contribution.

It has been argued that all conventional \( c\bar{c} \) assignments for the \( X(3872) \) are

Fig. 1.  LEFT: The \( J/\psi \pi^+ \pi^- \) mass distribution for \( M_{\pi\pi} < 500 \) and \( > 500 \text{ MeV}/c^2 \) subsamples.  RIGHT: Summary of X-mass measurements compared to the \( D^*D^0 \) threshold.
Fig. 2. Projection of $\psi(2S)$ likelihood fit onto the uncorrected proper-time distribution for the full PDF, and its breakdown into signal (shaded) and background (hatched) classes. Signal and background are further separated into prompt and long-lived components. The projections are for candidates within $\pm 2.5\sigma$ of the $\psi(2S)$ mass in order to be reflective of its signal-to-background ratio. The fit actually spans the mass range 3640-3740 MeV/$c^2$.

Fig. 3. Projections of $X$-likelihood fit in mass (left), and uncorrected proper-time (right) as Fig. 2.

problematic. However, production of the $X$ appears, so far, quite similar to that of the $\psi(2S)$ in CDF. If it is indeed a “molecule,” there seems to be no dramatic penalty for producing such a fragile state in $\bar{p}p$ collisions. Although, more incisive comparisons require specific theoretical models for the production of exotic states. A recent analysis of $X$-production as a $1^{++}$ state may benefit from our results.

Studies of this mysterious state are continuing in CDF.

References

1. K. Abe et al. (Belle), contribution to Lepton-Photon [hep-ex/0308029], and reported in: T. Skwarnicki, 21st Int. Symp. On Lepton And Photon Interactions At High Energies, August 2003, Fermilab, Int. J. Mod. Phys. A19, 1030 (2004) [hep-ph/0311243].
2. S.-L. Choi et al. (Belle), Phys. Rev. Lett. 91, 262001 (2003).
3. D. Acosta et al. (CDF II), Phys. Rev. Lett. 93, 072001 (2004).
4. T.M. Yan, Phys. Rev. D 22, 1652 (1980).
5. An extensive list of literature on the $X(3872)$ can be found in the citations of Ref. 9.
6. R. Blair et al. (CDF II), FERMILAB-PUB-96-390-E (1996); and citations in Ref. 3.
7. F. Abe et al. (CDF), Phys. Rev. Lett. 79, 572 (1997).
8. S. Olsen (Belle), MESON 2004, Cracow, Poland, June 2004 [hep-ex/0407033].
9. E. Braaten [hep-ph/0408230].