Fermilab FERMILAB-CONF-04-460-E CDF DECEMBER 2004

CDF/PUB/BOTTOM/PUBLIC/7390

Properties of the X(3872)

Guillelmo Gómez-Ceballos
(on behalf the CDF Collaboration)
Laboratory of Nuclear Science, Massachusetts Institute of Technology,
77 Massachusetts Avenue, Cambridge, MA 02139, USA

E-mail: ceballos@fnal.gov

Abstract. $X(3872)$ discovery was confirmed with the CDF II detector in $\bar{p}p$ collisions. We measure its mass to be $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2. The source of the X state in the large CDF sample is resolved by studying their vertex displacement. We find $16.1 \pm 4.9 \pm 2.0\%$ 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.

1. Introduction

At 2003's Lepton-Photon Symposium Belle announced discovery of a charmonium-like state, [1, 2] $X(3872)$, in $B^+ \to K^+ J/\psi\pi^+\pi^-$. CDF quickly confirmed $X \to J/\psi\pi^+\pi^-$ [3]. 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 (~ 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, [4] 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 $D^0\overline{D}^{*0}$-threshold, prompted speculation that the X may be a D^0-$\overline{D}^{*0}$ "molecule". Whether this is the case, or the X is "simply" a $c\bar{c}$-state in conflict with current theoretical models, the X is an interesting object of study [5].

2. Selection

CDF II [6] 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/ψ sample.

Technical cuts, kinematic and spatial cuts are applied to suppress large backgrounds from J/ψ'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 $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.7$ for each pion, where $\Delta\phi$ ($\Delta\eta$) is the azimuthal (pseudorapidity) difference of the pion with respect to the $J/\psi\pi\pi$. With these cuts a significant X-signal is revealed [3].

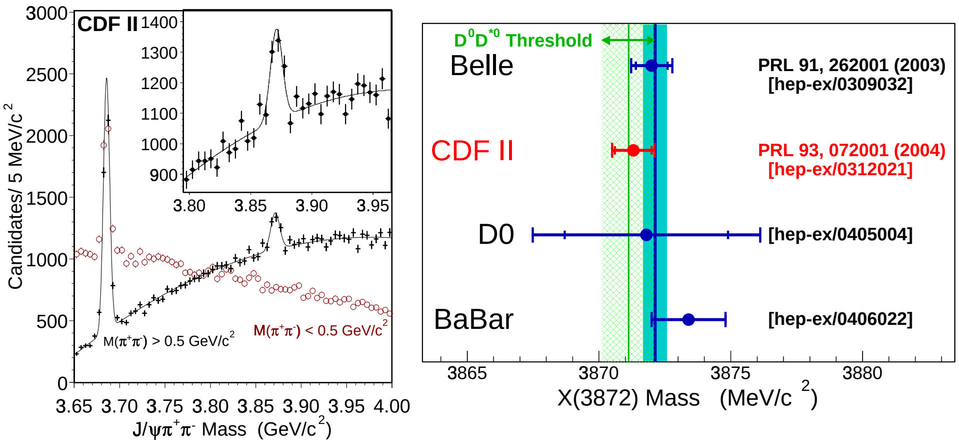


Figure 1. LEFT: The $J/\psi\pi^+\pi^-$ mass distribution for $M_{\pi\pi} < 500$ and > 500 MeV/c^2 subsamples. **RIGHT:** Summary of X-mass measurements compared to the $D^0\overline{D}^{*0}$ threshold.

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.

3. Mass measurement

Using the high-$M_{\pi\pi}$ sample, the X-mass is $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2. Also shown in Fig. 1 are masses from other experiments, and the average compared to the $D^0\overline{D}^{*0}$ threshold.

The near equality helps fuel molecular-$D^0\overline{D}^{*0}$ speculations.

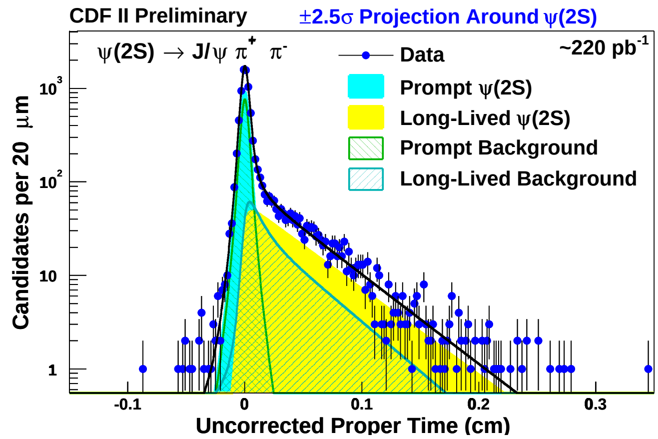
4. Long 'Lifetime' Fraction

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 [7]. 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 Silicon vertex tracker, mainly to demand $\sigma(L_{xy}) < 125\,\mu$m and have good beam line 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 [7]. For the $X(3872)$, with $M_{\pi\pi} > 500$ MeV/c^2, the fraction is $16.1 \pm 4.9 \pm 2.0\%$ (Fig. 3)—a bit more than 2σ 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 [7]. The *absence* of a b-component is excluded at 3σ based on Monte Carlo

Figure 2. Projection of $\psi(2S)$ likelihood fit onto the uncorrected proper-time distribution for the full probability distribution fraction, 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.



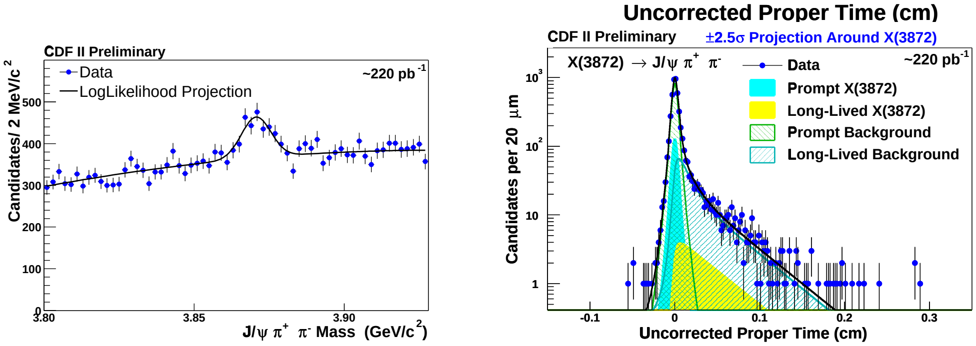


Figure 3. Projections of X-likelihood fit in mass (left), and uncorrected proper-time (right) as Fig. 2.

"experiments."

Thus our X-sample is mainly prompt—presumably direct production—with a modest b-contribution.

5. Conclusions

It has been argued that all conventional $c\bar{c}$ assignments for the $X(3872)$ are problematic [8]. 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 [9] may benefit from our results.

Studies of this mysterious state are continuing in CDF, and results on the $M(\pi\pi)$ distribution and angular measurements are expected to be shown soon.

[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].