International Journal of Modern Physics A

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 $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2. The source of X-mesons in the large CDF sample is resolved by studying their vertex displacement. We find $16.1 \pm 4.9 \pm 2.0\%$ 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.

Keywords: X(3872); Charmonium.

At last year'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 "only" a $c\bar{c}$ state in conflict with current theoretical models, the X is an interesting object of study.[5]

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. Aside from technical cuts, kinematic and spatial cuts 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] 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 $3871.3 \pm 0.7 \pm 0.4$ 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.

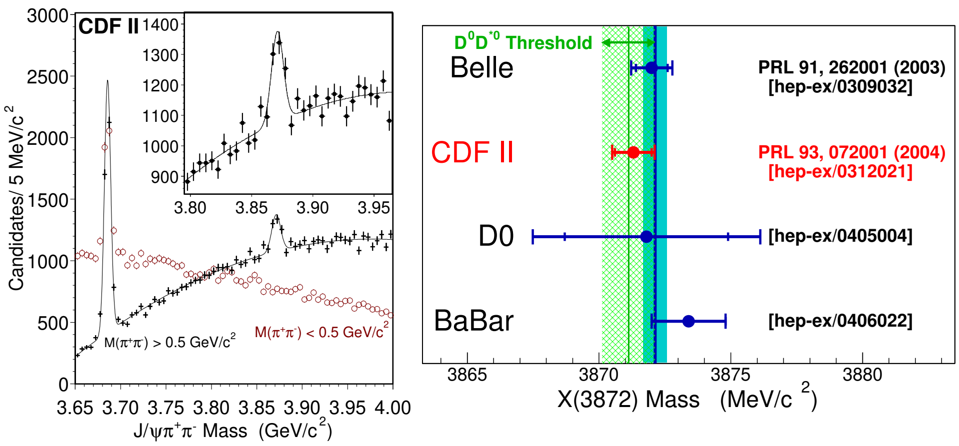

Fig. 1. **LEFT:** The $J/\psi\pi^+\pi^-$ mass distribution for $M_{\pi\pi} < 500$ and > 500 MeV/c^2 subsamples. **RIGHT:** Summary of X-mass measurements compared to the $D^0\overline{D}^{*0}$ threshold.

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 *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±1.0±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±4.9±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 "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

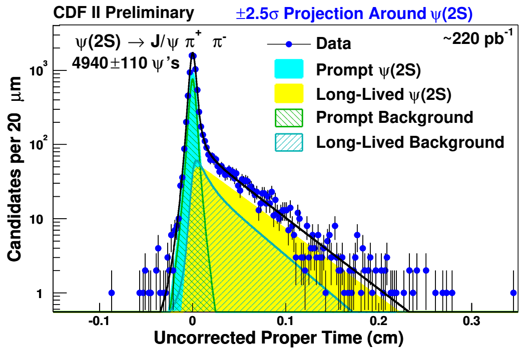

Fig. 2. Projection of $\psi(2S)$ likelihood fit onto the uncorrected proper-time distribution for the full PDF, and its breakdown into signal (shaded) and background (hatched) classes. Signal and background are further separated into prompt and long-lived components. The projections are for candidates 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.

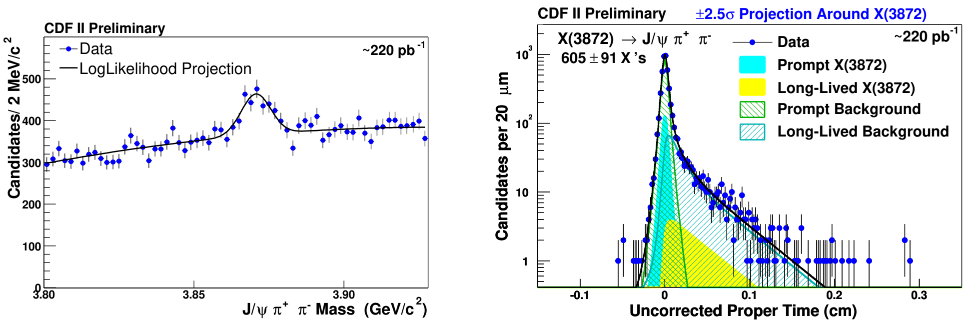

Fig. 3. Projections of X-likelihood fit in mass (left), and uncorrected proper-time (right) as Fig. 2.

problematic.[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.

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