Production and Properties of X(3872) at CDF

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A brief $X(3872)$ history

- Belle announced discovery of $X(3872) \to J/\psi\pi^+\pi^-$ in Aug-03
  - $B \to X(3872)K^+$ candidates
  - $3872.0 \pm 0.6 \pm 0.5\,\mathrm{MeV/c^2}$
  - $\Gamma < 2.3\,\mathrm{MeV/c^2}$
  - Most of events in high $\pi\pi$-Masses
    $X \to J/\psi\rho \to J/\psi\pi^+\pi^-$?

- What is it?
  - Obvious choice: $^3D_2$ Charmonium?
  - Not seen in $\chi_1\gamma$ (Belle)
  - $M(X) \approx M(D^0D^{*0}) \Longrightarrow D\text{-}\overline{D^*}$ "Molecule"?

- **Sept-03: CDF confirmed**
  $X(3872) \to J/\psi\pi^+\pi^-$

$X(3872)$ has also been confirmed by D0 and BaBar experiments

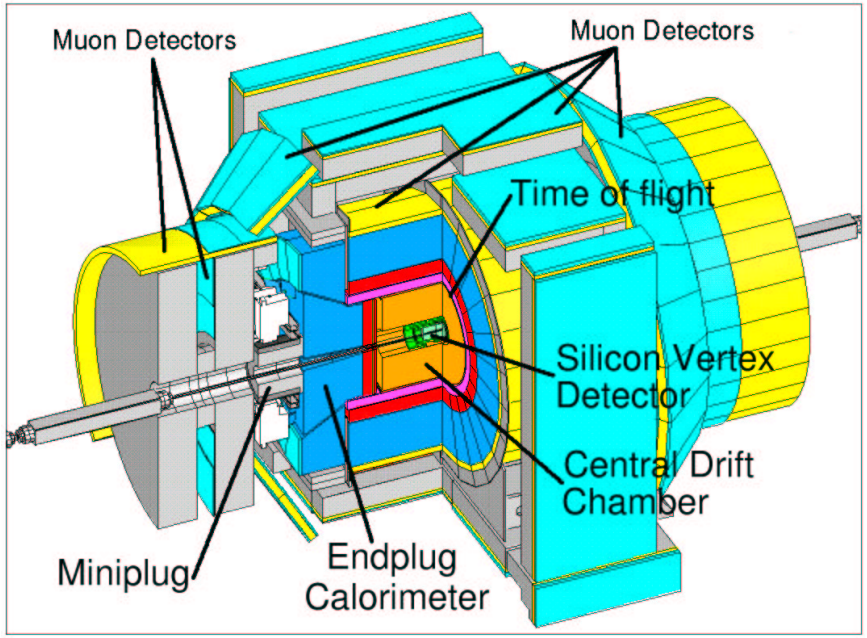
CDF capabilities

Exploit strong sides of the CDF experiment:

- Great momentum resolution
  - Can measure mass peaks down to ~ 2-3 MeV (e.g., $\Psi(2S)$)
- Precision tracking:
  - Good 3D vertexing: reduced backgrounds

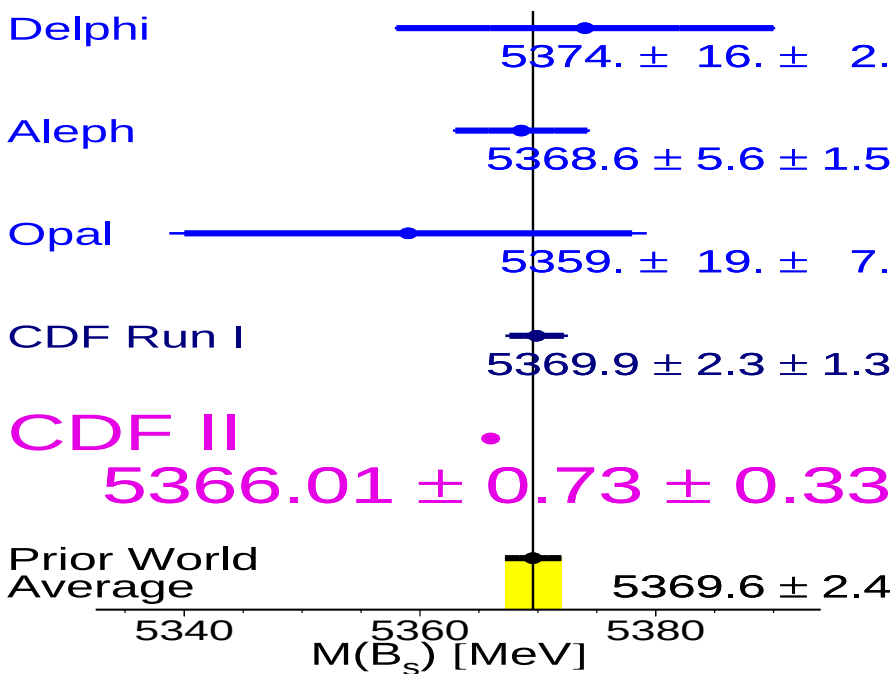
General purpose detector:

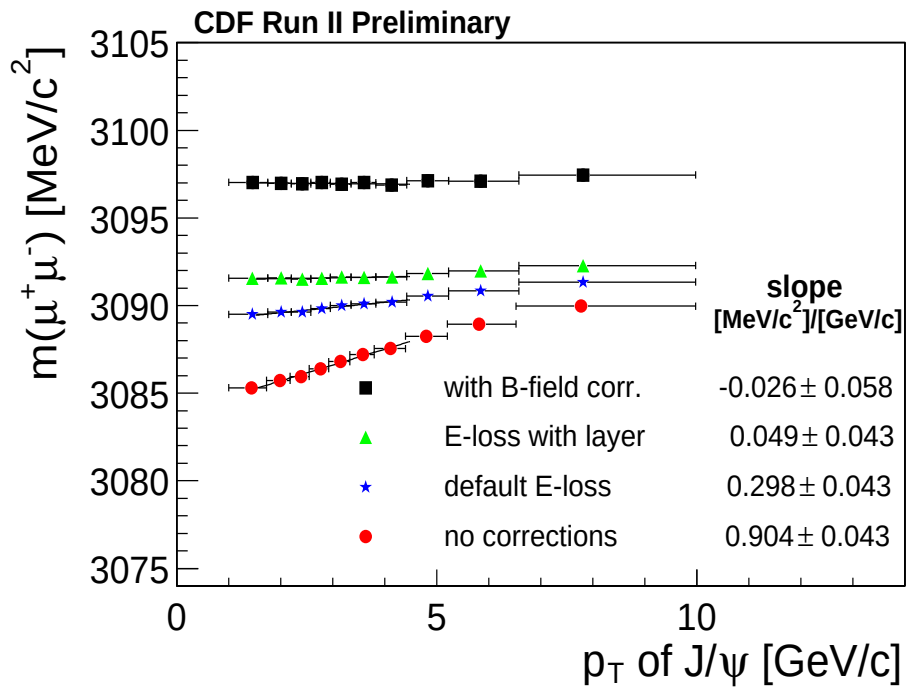
vertexing	SVX-II, ISL, L00
$\vec{P}$ measurements	COT
particle ID	TOF, COT
muons	muon system
electrons/photons	calorimeter system



CDF capabilities

Great momentum resolution and vertexing!

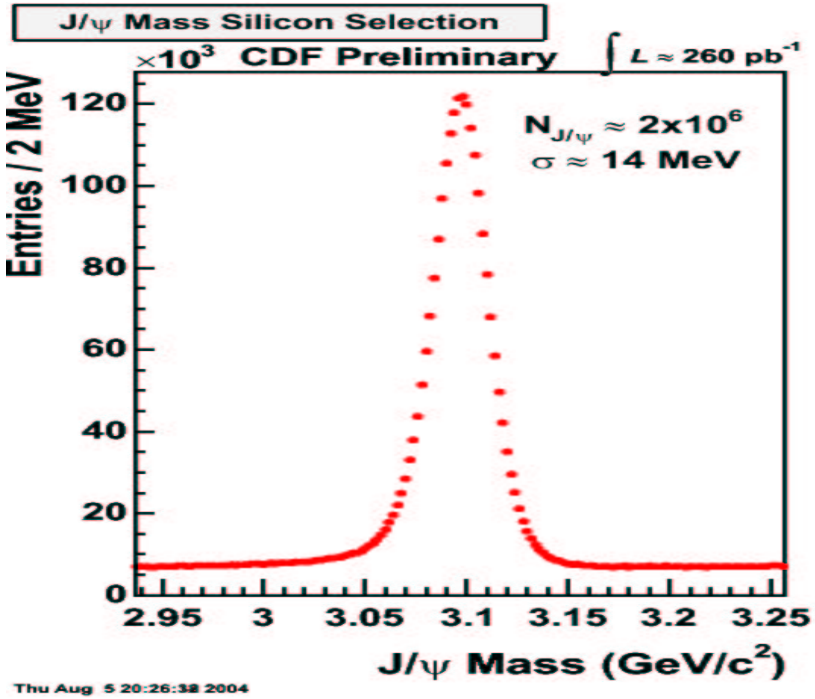


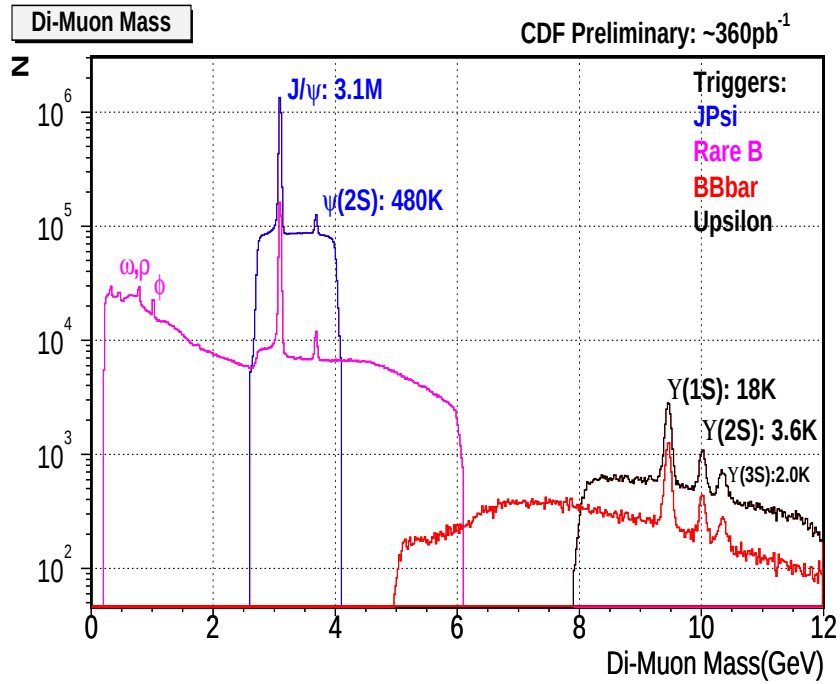


World best measurements on *B* hadron masses, very low systematic uncertainties!

Spectroscopy at CDF

- ALL B/D mesons are produced at the TeVatron: $D^{(**)}$, $B_{u,d}$, $B_{s,c}$, B^{**}, Λ_b, Ξ_b...
- Large signal X-Sections!
- But also huge backgrounds (x1000)... effective triggers are mandatory!:
  2μ (J/ψ) Trigger is used in this analysis
  - 2 tracks found in the COT that are matched to stubs in the muon chambers
  - P_t(track) > 1.5 GeV/c





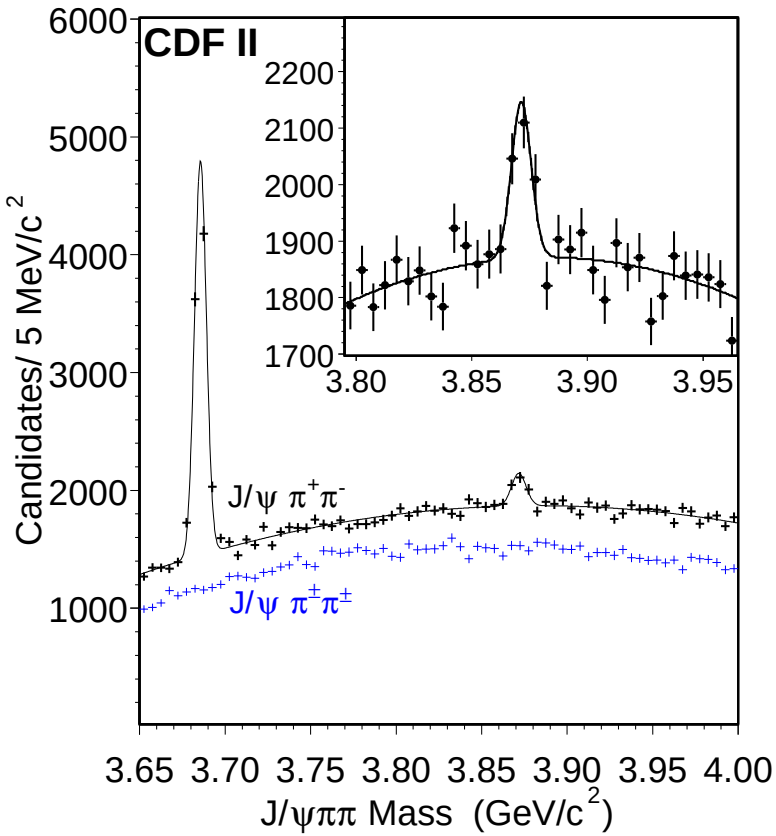
$X(3872)$ selection

Background suppression:

- Maximum number of $J/\psi\pi\pi$ candidates
- Track and vertex quality cuts
- $p_T(J/\psi) > 4$ GeV/c
- $p_T(\pi) > 400$ MeV/c
- $\Delta R(J/\psi - \pi) \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.7$

$\mathcal{L} \sim 220\ pb^{-1}$ $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$

- No $J/\psi\pi^{\pm}\pi^{\pm}$ bumps
- Large $\psi(2S)$ signal
- Small peak ~ 3872 MeV/c^2
- Large yield: $\sim 730 \pm 90$ X**'s**



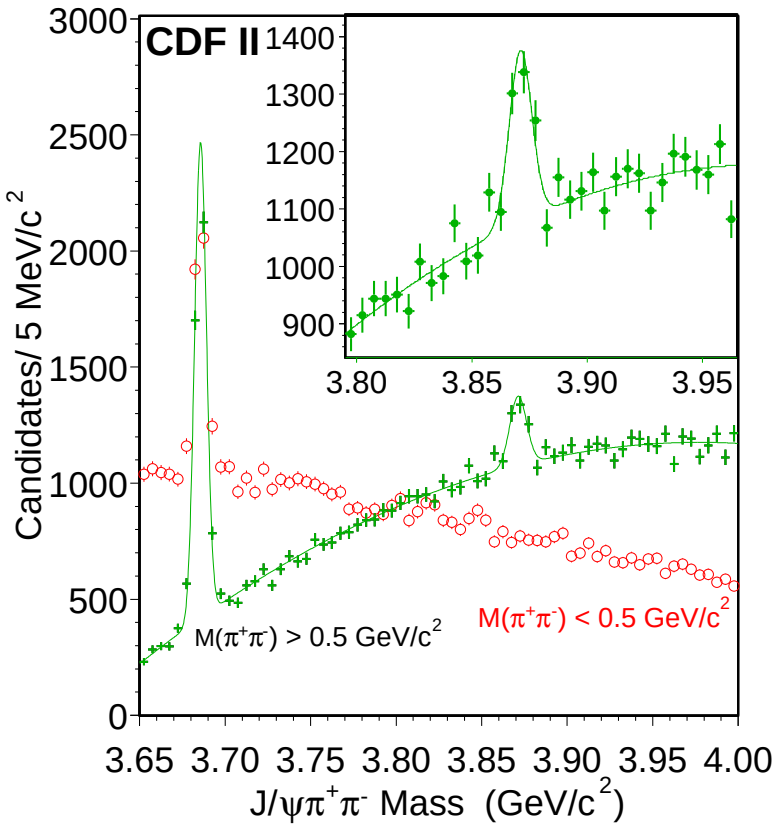
$X(3872)$ selection

Belle sees most of the X events at large $M(\pi\pi)$

$\longrightarrow$ Split sample

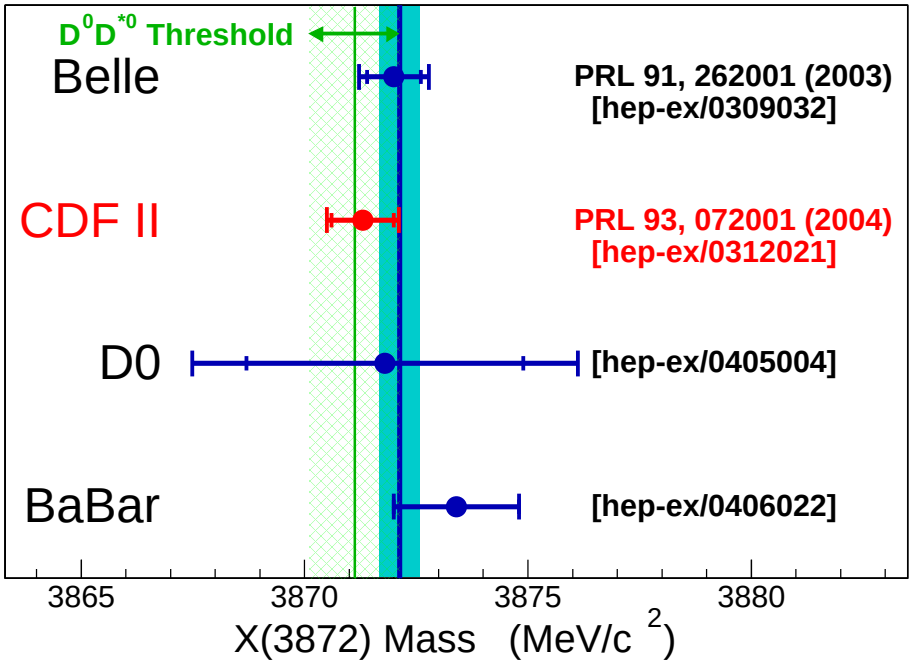
$<$ 500 MeV/c^2: ~ No signal

$>$ 500 MeV/c^2: ~ All signal



Measure X-Mass was next step...

X-Mass



$3871.3 \pm 0.7 \pm 0.4\ \mathrm{MeV}/c^2$

- $X(3872)$ right In D^0D^{*0} threshold region
  - DD^* bound state?
  - Mix of $c\bar{c}$ & DD^*?
  - Conventional $c\bar{c}$ with coupled channel (DD^*) effects?
  - . . . . . [*eg Quigg et al hep-ph/0401210*]
  - Simply coincidence??

$X(3872)$ Production

- Large CDF Signal: $\sim 6k$ $\psi(2S)$ vs ~ 700 $X(3872)$
- From Belle we know that $B \to X(3872)\ldots$ is a significant source
  $\Rightarrow$ Is "ALL" CDF signal from B's??
  …Any direct X-Production? How much?

$\Longrightarrow$ Does X-Production *look* like charmonium?? $\Longleftarrow$

- If X is DD^* $\longrightarrow$ very weakly bound
- Need model for Production, but naively:
  $\Rightarrow$ Cross-Section **penalty** for fragile states??

$\Longrightarrow$ X-Production could be completely different! $\Longleftarrow$

Prompt vs B-Production:

Standard technique to distinguish B from Non-B Production:

- Measure apparent "Lifetime" of $X(3872)$ [reminder: $\tau(X) = 0$!, $\tau(B) \sim 450 - 500\ \mu$m]
- Fit relative "Prompt" and "displaced" **fractions**

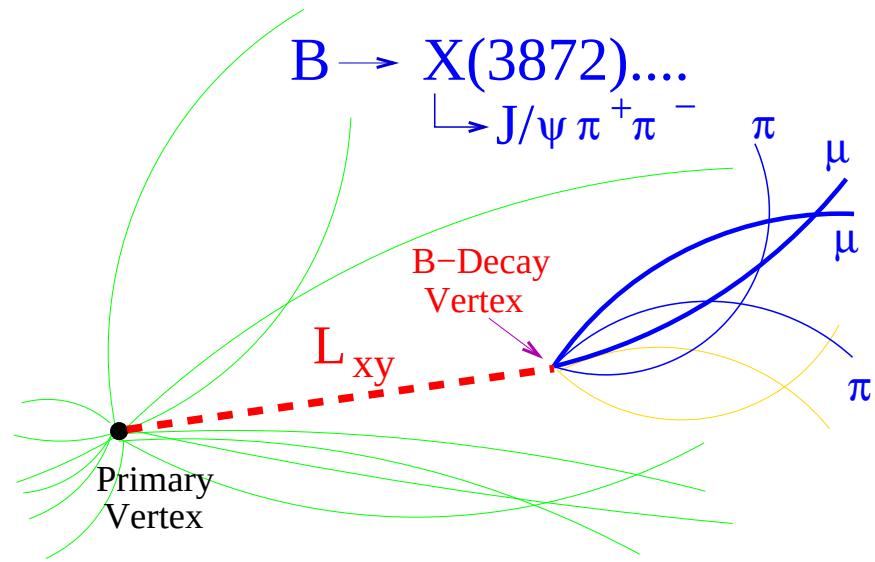
Details of the analysis:

- Measure displacement of vertex: L_{xy} vertex w.r.t. primary
- "Proper Time":

$$ct \equiv \frac{M(J/\psi\pi^+\pi^-)}{p_T(J/\psi\pi^+\pi^-)} L_{xy}$$

- Missing B decay products
  $\Longrightarrow$ NOT true ct
  $\Longrightarrow$ It does not matter!
- Unbinned Likelihood Fit:

$\rightarrow$ **Fraction of Displaced X's**



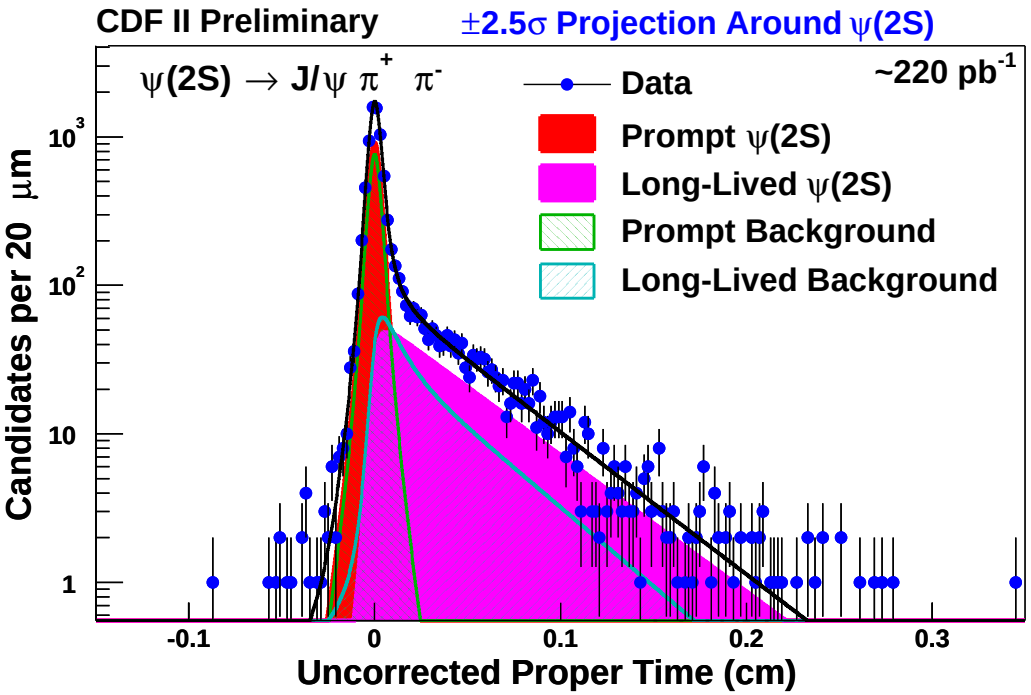
$\Longrightarrow$ Use same X sample: 220pb^{-1}

$\Longrightarrow$ + vertexing cuts (SVX, $\sigma(Vrtx)$,...): -15%

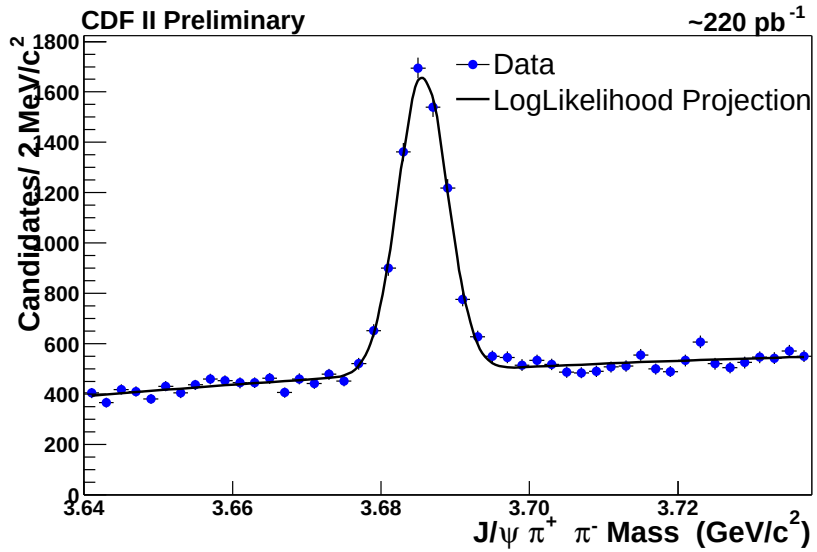
.....& $\psi(2S)$ a good reference signal...

Displaced fraction: $\psi(2S)$

Simultaneous *ct* and Mass Likelihood Fit:



Mass Projection:



⇐Proper-Time Model:

Prompt:
Res. Smeared Gaussian
Long-Lived:
Res. Smeared Exp.
Resolution: 2 Gaussians

Displaced $\psi(2S)$-Fraction:

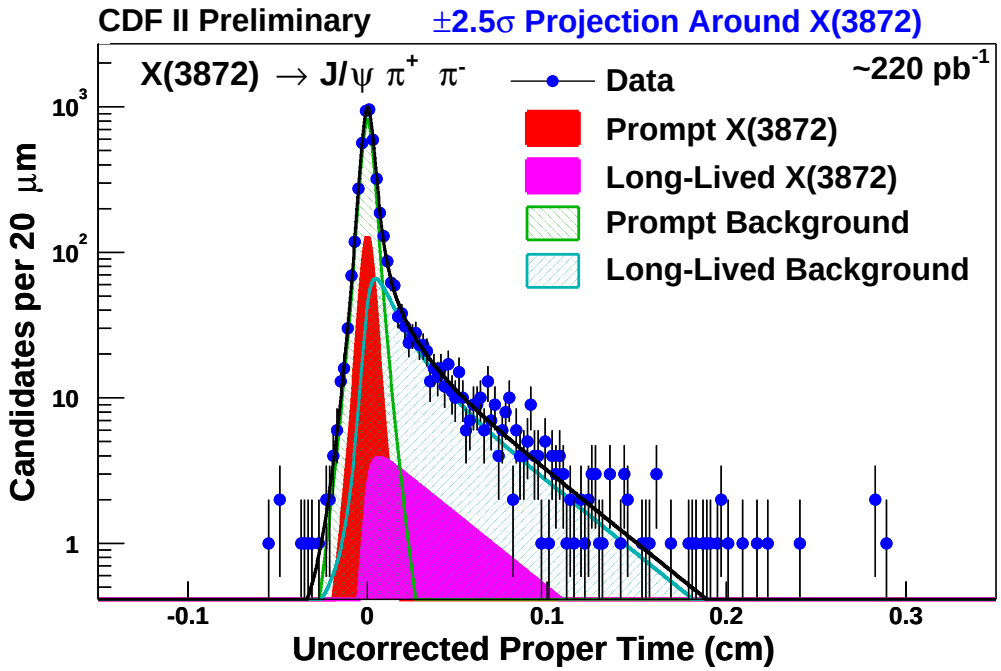
$$28.3 \pm 1.0 \pm 0.7\%$$

$\Rightarrow$ $\psi(2S)$ mostly PROMPT

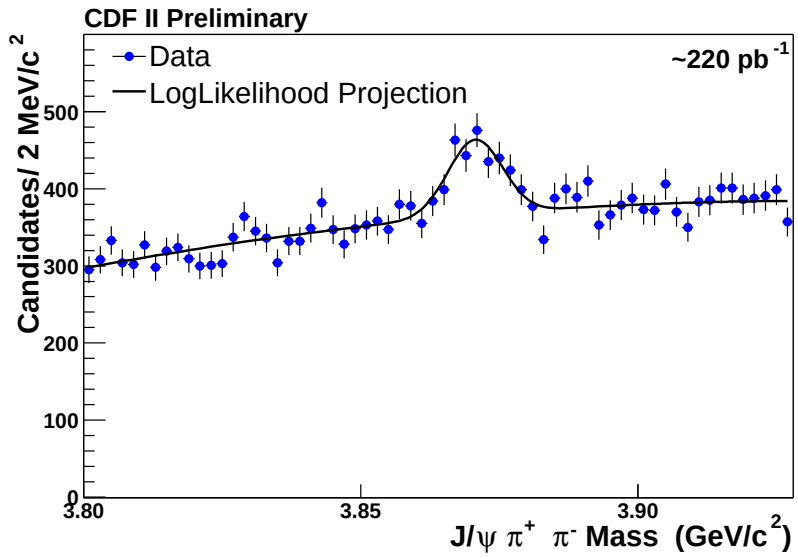
[Previously studied: CDF PRL**79**, 572 (1997)]

Displaced fraction: $X(3872)$

Same procedure for $X(3872)$. . . . . Use $M(\pi\pi) > 500$ MeV/c^2. . .



Mass Projection:

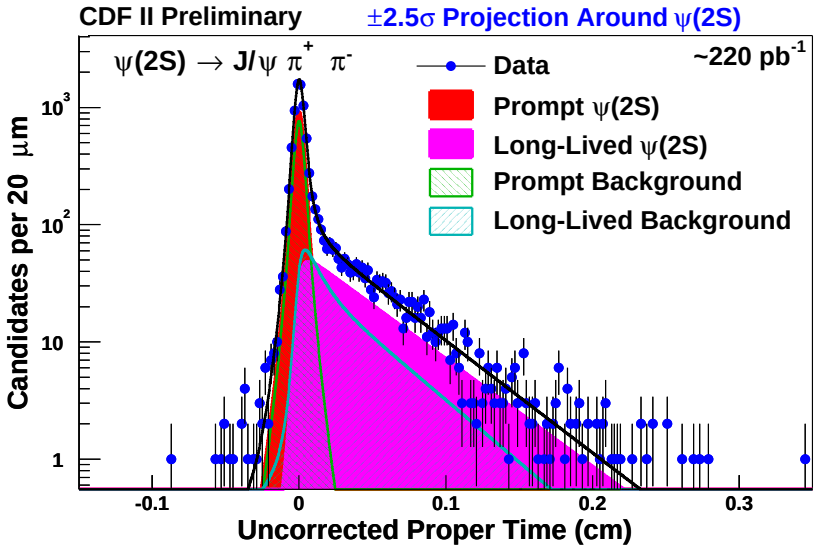


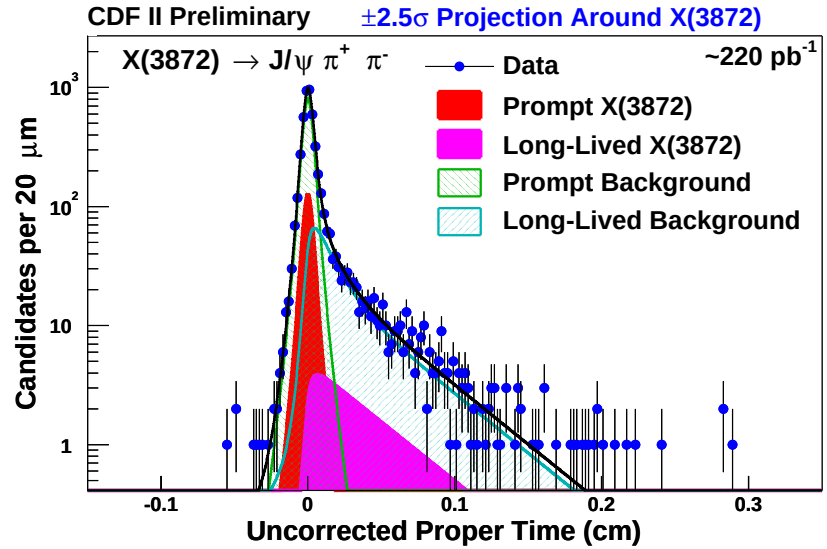
Displaced X-Fraction:

$$16.1 \pm 4.9\,(stat) \pm 2.0\,(syst)\%$$

$\Rightarrow$ **X is also mostly PROMPT!**

$\psi(2S)$ vs $X(3872)$ Likelihood Fit





	$\psi(2S)$	Parameter	$X(3872)$
Signal	4940 ± 110	Signal Yield	605 ± 91
	28.3 ± 1.0	Displaced Fraction	16.1 ± 4.9
	473 ± 13	"Lifetime" (μm)	439 ± 107
Background	0.4± 0.1	Frac of Neg Tail Bckgrnd (%)	0.3± 0.1
	6.6± 0.8	Frac of Pos Tail Bckgrnd (%)	10.3± 0.8
	18.8± 0.8	Frac of Long Pos Tail Bckgrnd (%)	13.0± 0.9
	301± 48	Neg Tail Lifetime (μm)	274± 53
	87± 17	Pos Tail Lifetime (μm)	116± 12
	409± 12	Long Pos Tail Lifetime (μm)	436± 17

Statistical Errors Only!

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Displaced fraction: systematics

Systematics breakdown:

Source	$\psi(2S)$	$X(3872)$	
Mass window	± 0.2	± 1.5	%
Fit model	± 0.3	*negligible*	%
Duplicates	± 0.6	± 1.3	%
Fit bias	*negligible*	± 0.4	%
Total	± 0.7	± 2.0	%

Systematics errors smaller than statistical errors

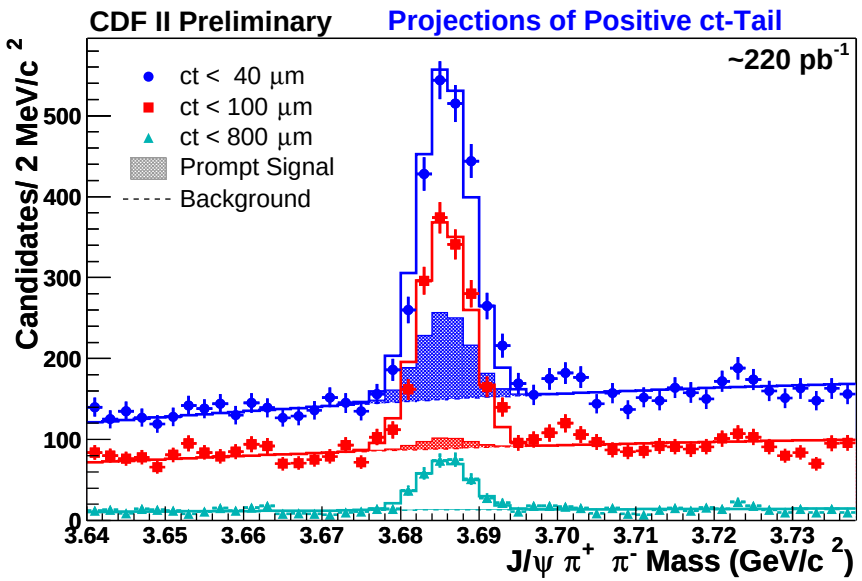
$B \to X(3872)$ … significance?

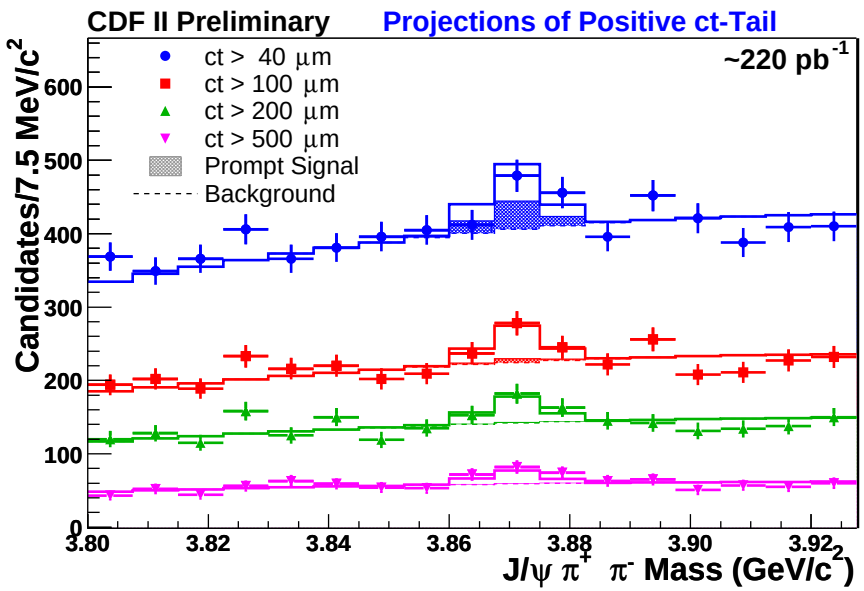
- From Belle: we know $B \to X$ … is significant
- we know now **Prompt dominates CDF signal**. . .

  But error on displaced fraction is not small. . . 16.1 ± 4.9(*stat*)%

  $\Longrightarrow$ Could it all be Prompt?
  - Naively: 16.1/4.9 $\to$ ~3.3σ Null Hypothesis Excluded
  - MC: NO B-Signal to fluctuate ≥ 16.1% is 3σ
  - Still. . . Good to take direct look at data. . .

    $\Longrightarrow$ Project Likelihood for high-*ct* Tails:





$\Longrightarrow$ Likelihood describes tails well

$\Longrightarrow$ ~ 3σ B-Component for X

Conclusions

- CDF Confirms $X \to J/\psi\pi^+\pi^-$ at Tevatron [PRL93, 072001 (2004)]
- $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2 $\approx$ Belle precision

- Confirm X favors high $M(\pi\pi)$
- X-Production in CDF:
  - Raw X-rate is substantial fraction of $\psi(2S)$
  - X Mostly PROMPT—Displaced X *vs* $\psi(2S)$:
    $16.1 \pm 4.9 \pm 2.0\%$ vs $28.3 \pm 1.0 \pm 0.7\%$ $\Rightarrow \Delta \sim 2\sigma$

    $\Longrightarrow$ X-Production *appears* similar to $\psi(2S)$ $\Longleftarrow$
  - It seems a little penalty for Prompt-X compared to $\psi(2S)$ Charmonium state*!*
    . . . . . Need specific production models to compare
    But no clear $c\bar{c}$ interpretations $\longleftarrow$ [Olsen hep-ex/0407033]

- More data & other topics are coming soon:
  $M(\pi\pi)$ distribution, angular measurements...