The X(3872) in CDF II

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Representing the CDF II Collaboration

— DPF04 —

- Some X History
- Spectroscopy at CDF II
- CDF X-Confirmation
- $X(3872)$ Mass Measurement
- $X(3872)$ Production: Prompt *vs* B-Decay
- Summary

A Little $X(3872)$ History:

- Aug-03: Belle Annouced Discovery of $X(3872) \to J/\psi\pi^+\pi^-$
  > ~ 35 $B \to X(3872)\, K^+$ Candidates
  > $3872.0 \pm 0.6 \pm 0.5$ MeV/c^2
  > $\Gamma < 3.5$ MeV/c^2
  > Favors High $\pi\pi$-Masses

- What is it?
  > Obvious Choice: $^3D_2$ Charmonium?
  > . . . . . Too Light: $^3D_2 \sim 3810$-3840? [e.g. hep-ex/0401210]
  > . . . . . Not Seen in $\chi_1\gamma$ (Belle)
  > Curiously: $M(X) \approx M(D^0 D^{*0}) \Longrightarrow D$-$\overline{D^*}$ "Molecule" ?
  High-$M(\pi\pi) \Longrightarrow \rho$-Like? $\Longrightarrow$ Isospin Violating?

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

2003: **The Year of "Exotics"?**

. . . . . Pentaquarks, D_{sJ} States & $X(3872)$

Why Spectroscopy at CDF?

@Tev: $D^{(**)}, B_{u,d}, B_{s,c}, B^{**}, \Lambda_b, \Xi_b, \ldots$

@Tev: Large Signal X-Sections!

60 mb → Total Inelastic Cross−Section

÷ 5000x

⇐ But Large

⇐ Backgrnds!

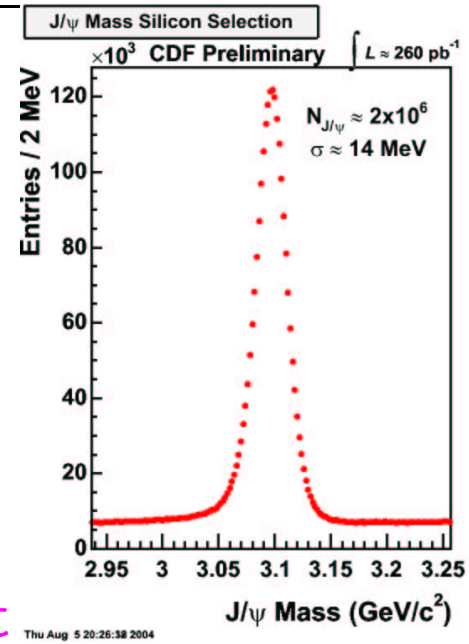
Live & Die By Trigger

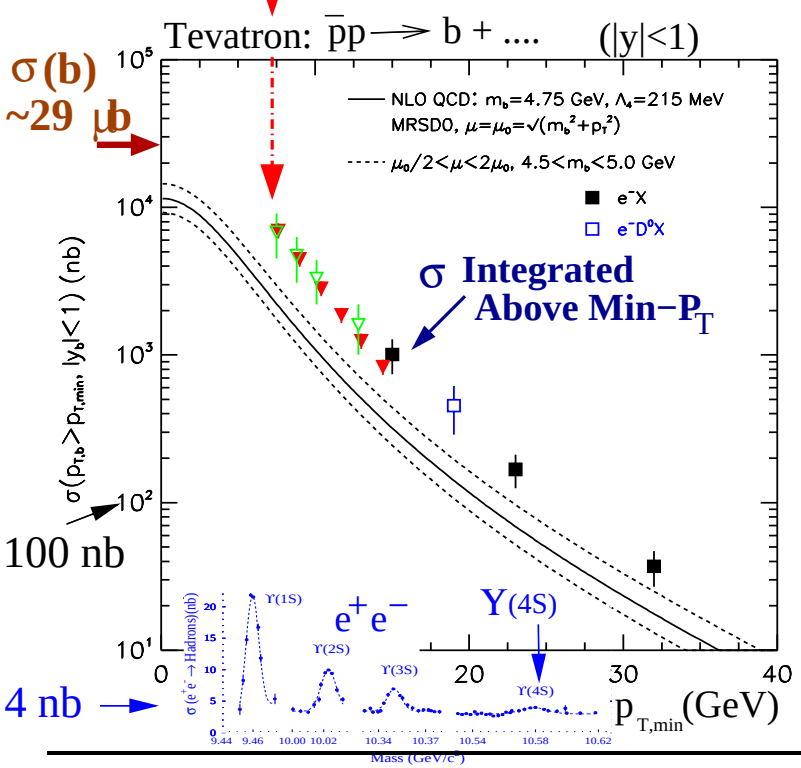
⇑ ⇑

@CDF: 2μ Trig

→Clean J/ψ Sample:

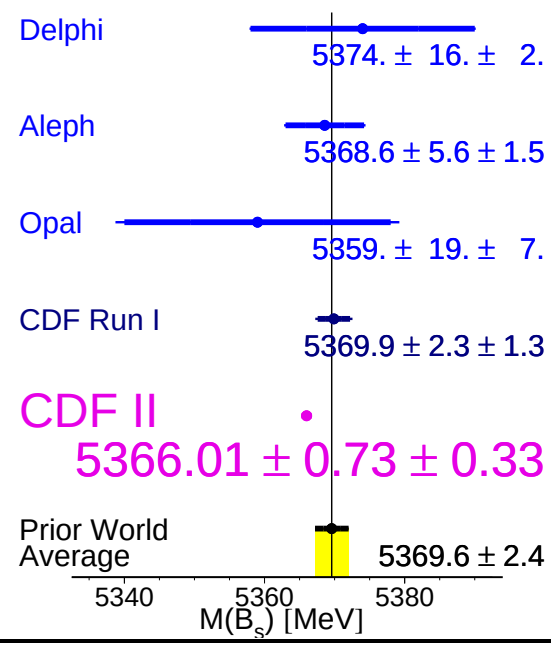
⇑





@CDF: Excellent Tracking ⇒ Sub-MeV Precision

e.g. B_s:



$X(3872) \to J/\psi\pi^+\pi^-$ in CDF:

Background Suppression:

- Max Number of $J/\psi\pi\pi$ Cand.
- Track and Vertex Quality Cuts
- $p_T(J/\psi) > 4$ GeV/c
- $p_T(\pi) > 400$ MeV/c
- $\Delta R(\pi) \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.7$

220 pb^{-1} $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$

$\Rightarrow$ No $J/\psi\pi^\pm\pi^\pm$ Bumps

$\Rightarrow$ Small Peak ~ 3872 MeV/c^2

$\Rightarrow$ Large Yield: $\sim 730 \pm 90$ X's

$\Rightarrow$ Belle: X-Favors Large $M(\pi\pi)$

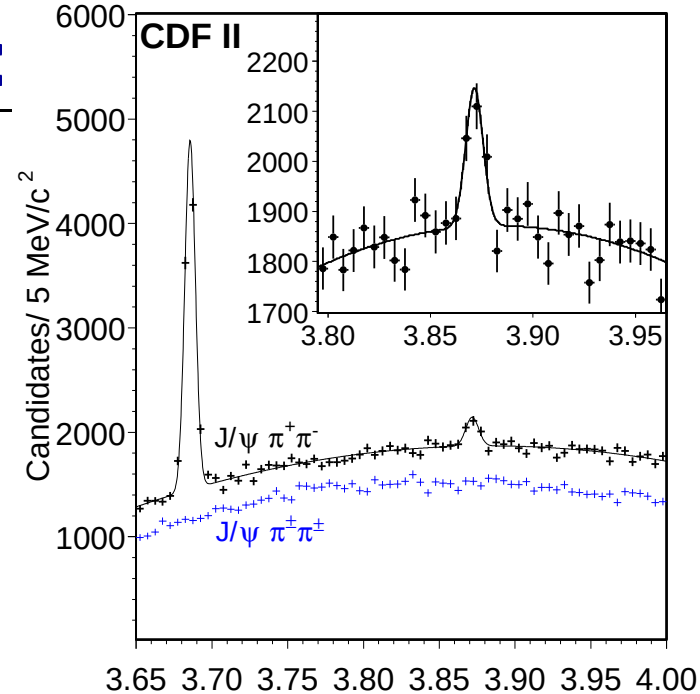
$\longrightarrow$ Split Sample

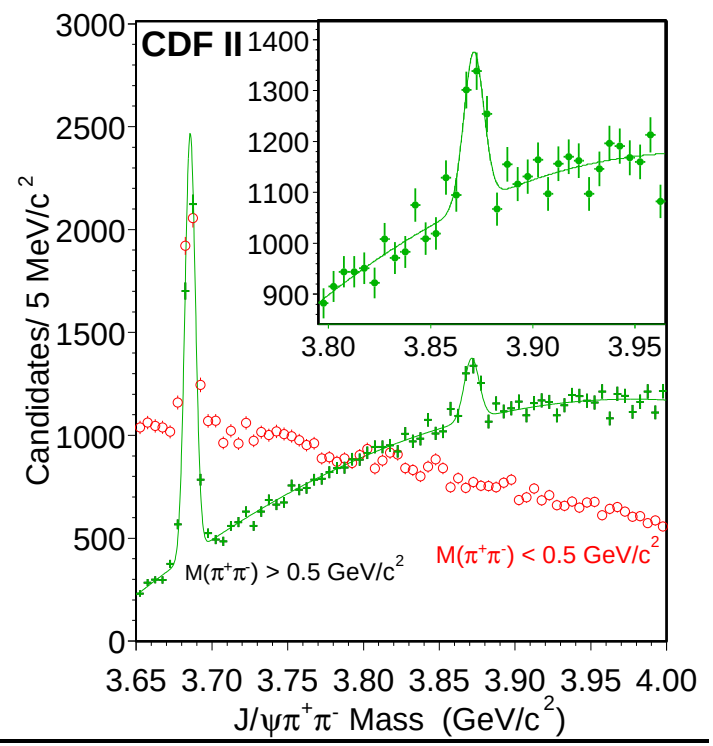
< 500 MeV/c^2: $\sim$No Signal

> 500 MeV/c^2: $\sim$All Signal

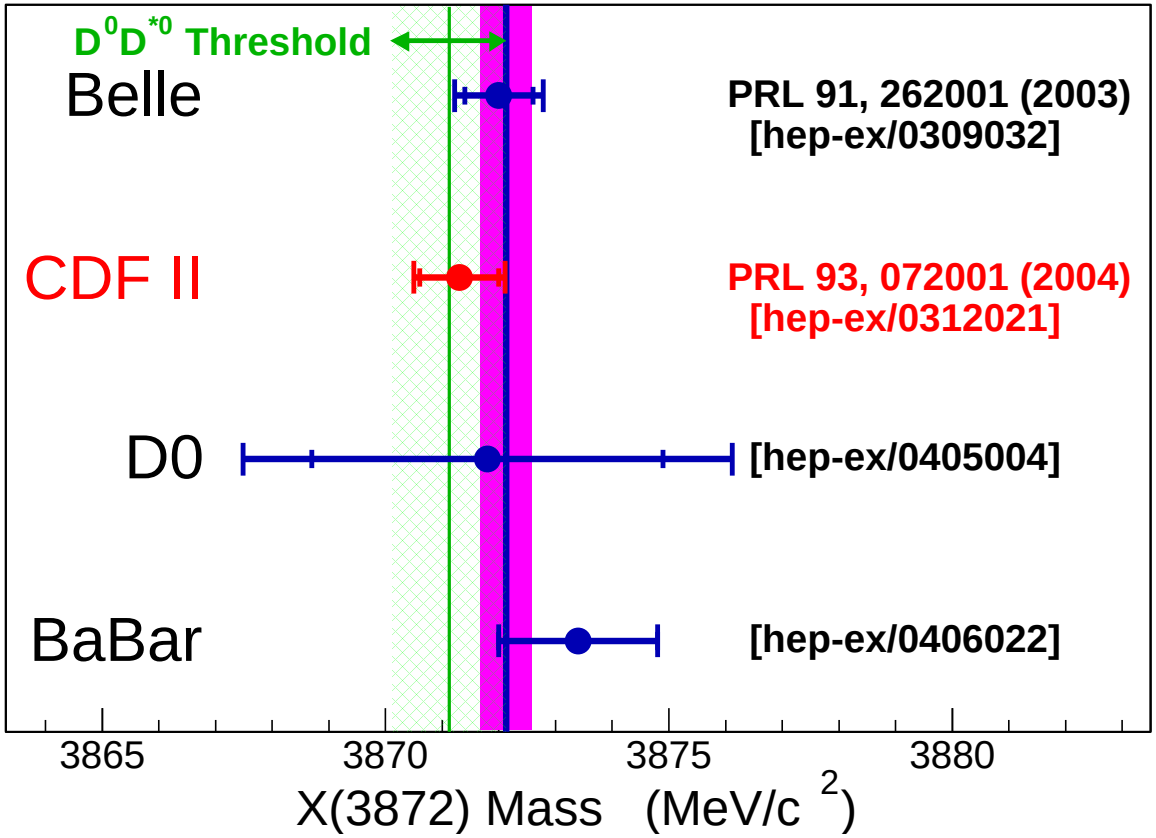
$\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$ $\Longrightarrow$

$\Rightarrow$ Measure X-Mass. . . . . .





X-Mass Summary:



$3871.3 \pm 0.7 \pm 0.4$ MeV/c^2

- $X(3872)$ Right In $D^0 D^{*0}$ Threshold Region
  - $\Rightarrow$ DD^* Bound State?
  - $\Rightarrow$ Mix of $c\bar{c}$ & DD^*?
  - $\Rightarrow$ Conventional $c\bar{c}$ With Coupled Channel (DD^*) Effects?
  - $\Rightarrow$ . . . . . [*eg Quigg et al hep-ph/0401210*]
  - $\Rightarrow$ Freak Coincidence??

$X(3872)$ Production:

- Large CDF Signal: $\sim 6k\ \psi(2S)$ vs $\sim 700\ X(3872)$
- From Belle: $B \to X(3872)\ldots$ Is 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 May Offer Insight Into Its Nature $\Longleftarrow$

Prompt *vs* B-Production:

Standard Technique to Distinguish B From Non-B Production:

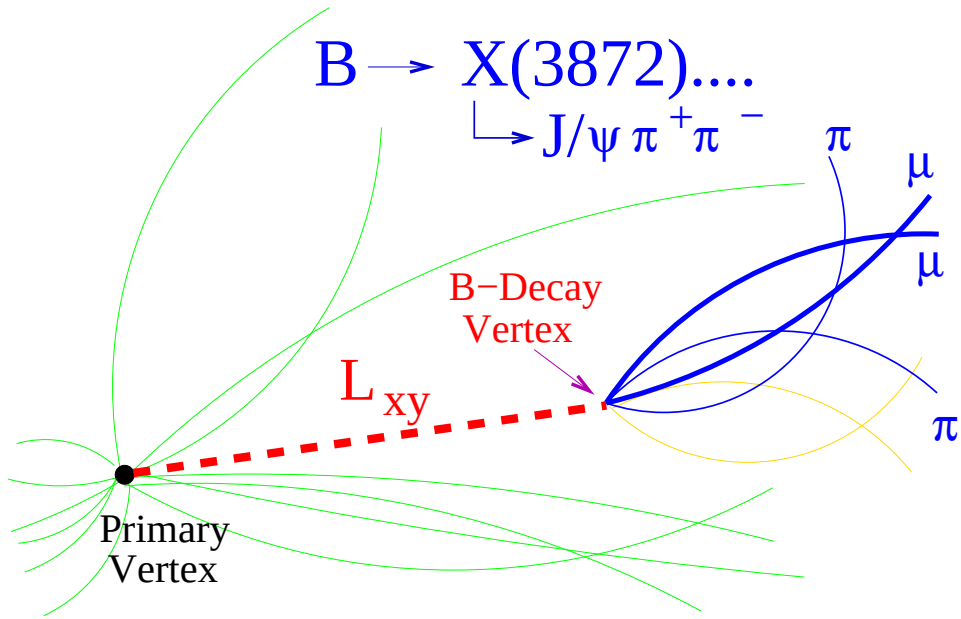
- Measure Apparent "Lifetime" of $X(3872)$ $[\tau(X) = 0\,!]$
- Fit Relative "Prompt" and "Displaced" **Fractions**

Details:

- Measure Displacement of Vertex: L_{xy}
- "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
  $\Longrightarrow$ Don't Care!
- Likelihood Fit:
  $\rightarrow$ **Fraction of Displaced X's**



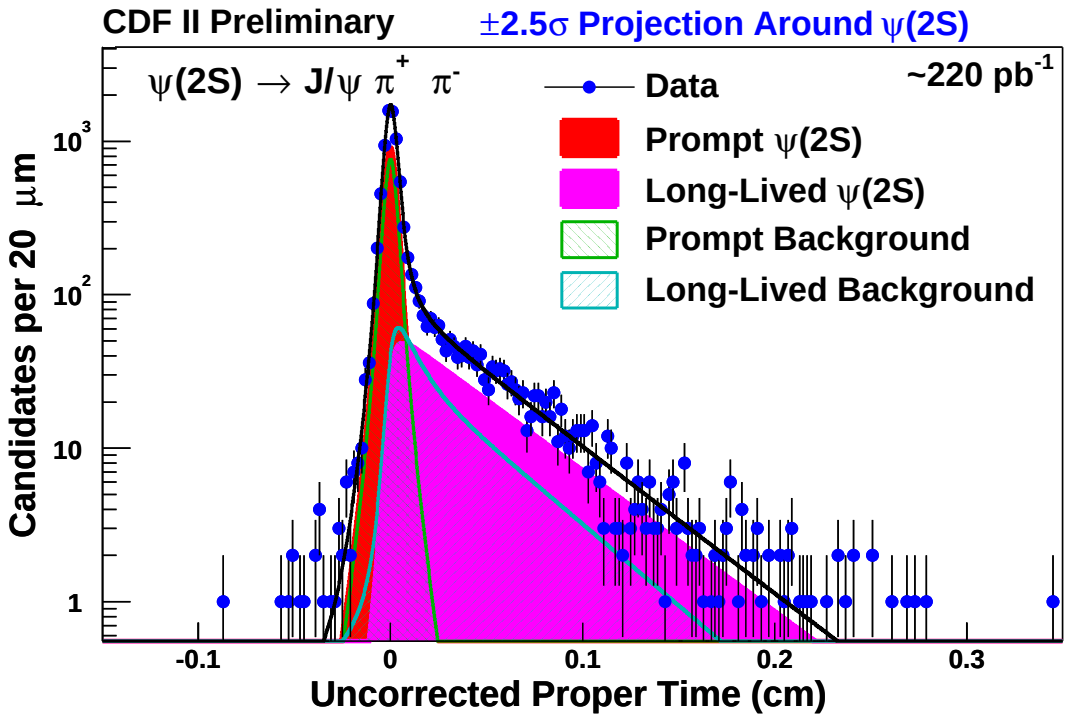
$\Longrightarrow$ Use Same X Sample: 220 pb^{-1}

$\Longrightarrow$ +Vertexing Cuts (SVX, $\sigma(Vrtx)$,. . .): -15%

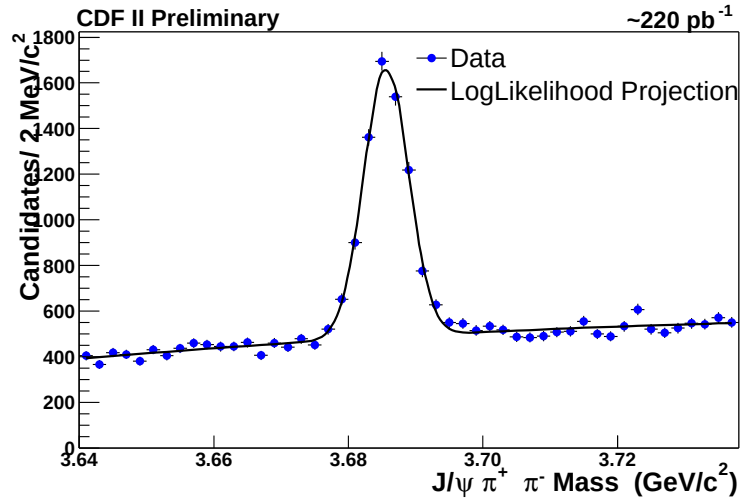
. . . . . & $\psi(2S)$ *a Good Reference Signal. . .*

Displaced Fraction: $\psi(2S)$

Simultaneous M & ct Likelihood Fit:



Mass Projection:



⇐Proper-Time Model:

Prompt:
Res. Smeared Gaussian

Long-Lived:
Res. Smeared Exp.

Resolution: 2 Gaussians

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

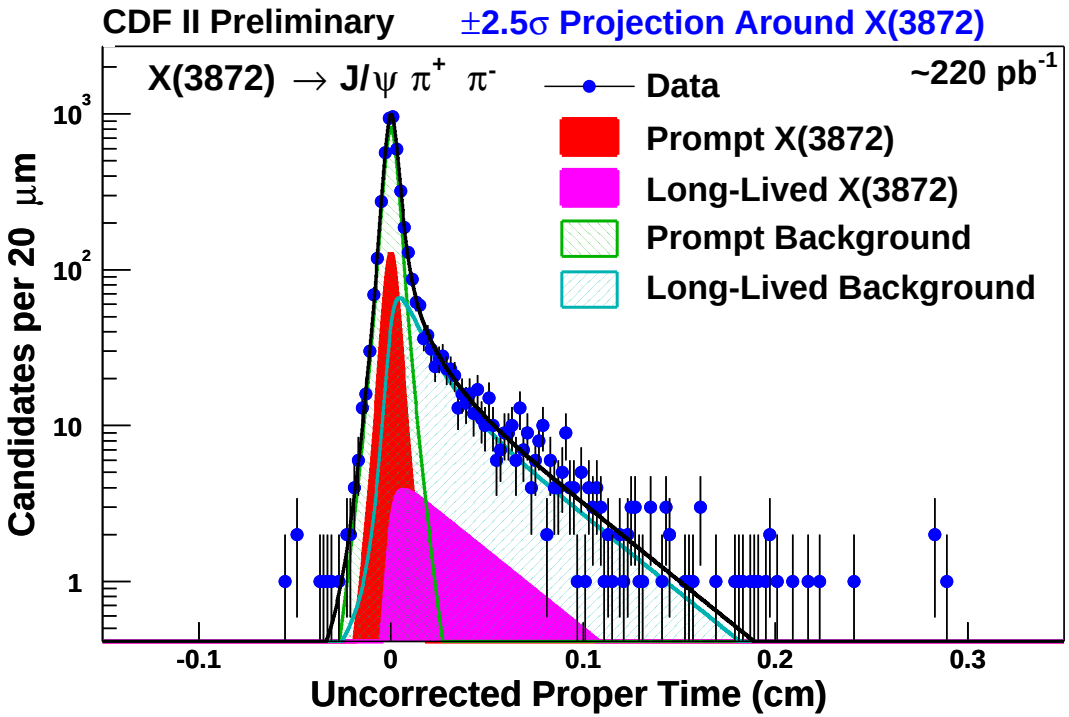
$$28.3 \pm 1.0 \pm 0.7\%$$

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

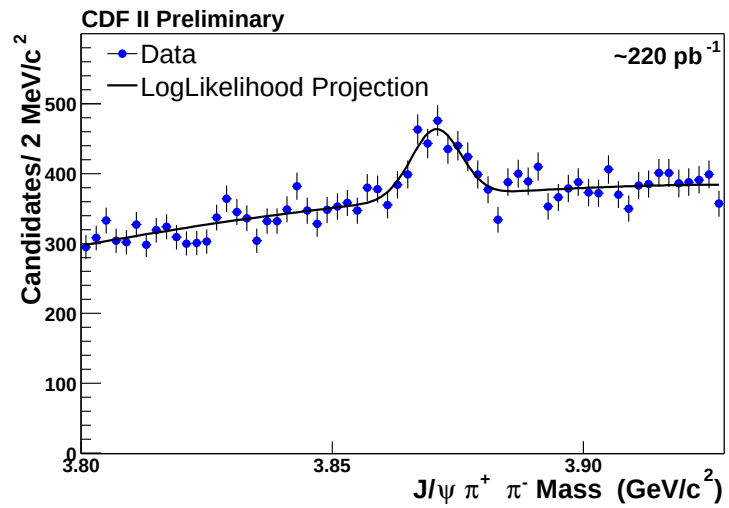
[Previously Studied: CDF PRL**79**, 572 (1997)]

Displaced Fraction: $X(3872)$

Same Procedure for $X(3872)$. . . . . Use $M(\pi\pi) > 500\,\mathrm{MeV}/c^2$. . .



Mass Projection:



Displaced X-Frac:

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

$\Rightarrow X$ **Mostly PROMPT!**

CDF X-Summary:

- Confirm $X \to J/\psi\pi^+\pi^-$ at Tevatron [PRL93, 072001 (2004)]
- $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2 $\approx$ Belle Precision
- X-Production in CDF: $\Leftarrow$Note: ****Sample Specific!****
  > 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 $\psi(2S)$ $\Longleftarrow$

$\Rightarrow$ Seems Little Penalty for Prompt-X Compared to $\psi(2S)$ Charmonium State*!*

. . . . . Need Specific Production Models to Compare

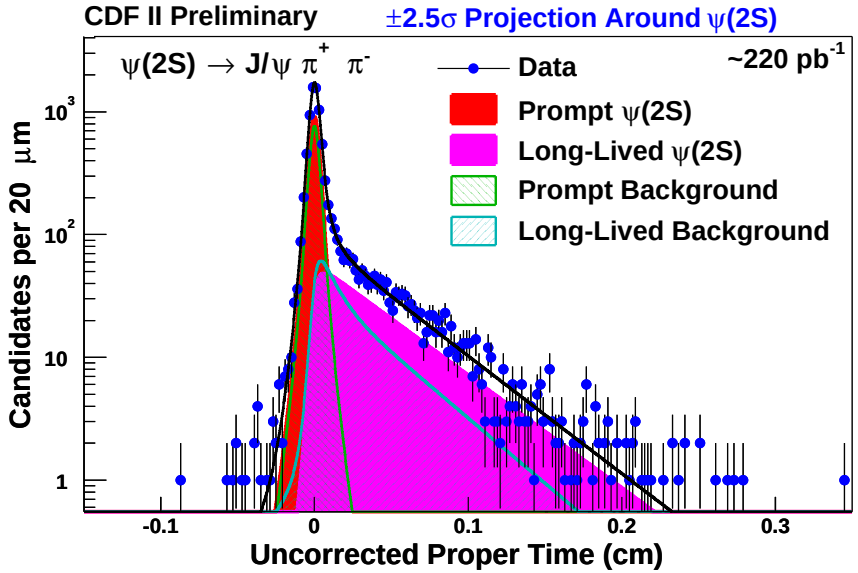
But No Clear $c\bar{c}$ Interpretations $\longleftarrow$ [Olsen hep-ex/0407033]

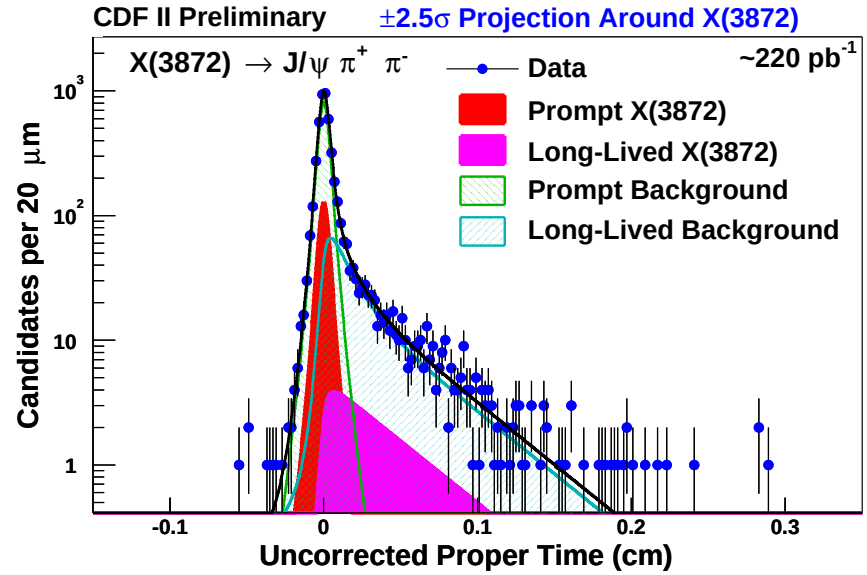
- More Data & Other Topics:
  $M(\pi\pi)$ Distribution, Angular Measurements,. . .

X-Mystery $\longrightarrow$ More Fun to Be Had

BACKUP SLIDES

$\psi(2S)$ vs $X(3872)$ Likeli-Fit:

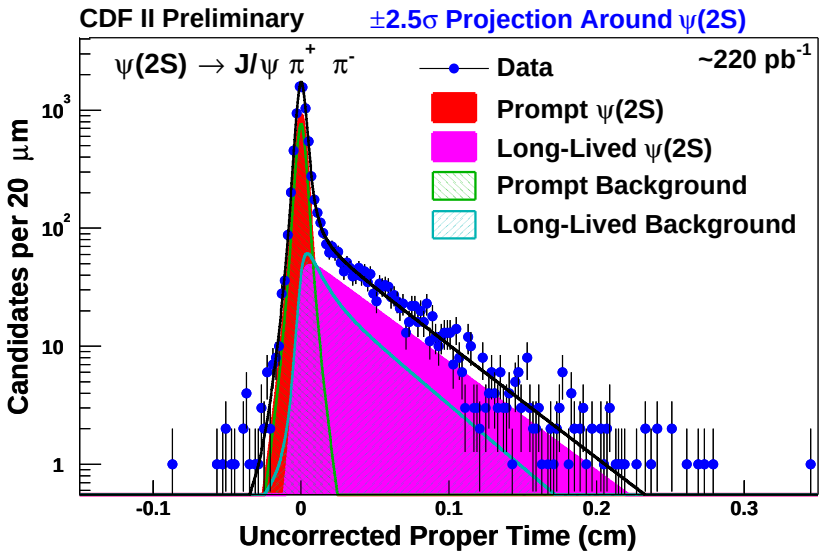


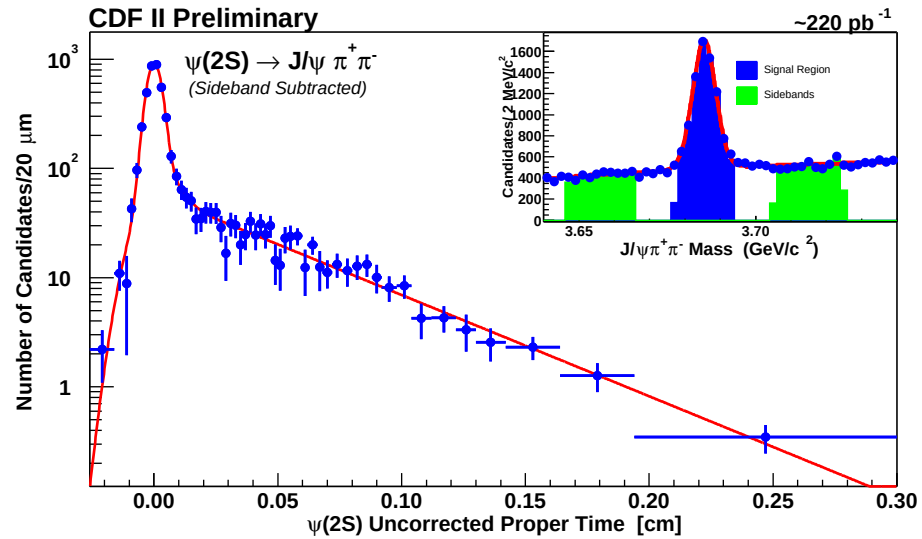


	$\psi(2S)$	Parameter	$X(3872)$
Signal	4940 ± 110	Signal Yield	605 ± 91
	28.3 ± 1.0	Displaced Fraction	16.1 ± 4.9
	473 ± 13	"Lifetime" (μm)	439 ± 107
Background	0.4 ± 0.1	Frac of Neg Tail Bckgrnd (%)	0.3 ± 0.1
	6.6 ± 0.8	Frac of Pos Tail Bckgrnd (%)	10.3 ± 0.8
	18.8 ± 0.8	Frac of Long Pos Tail Bckgrnd (%)	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!

$\psi(2S)$ Likelihood *vs* Sideband-Sub:

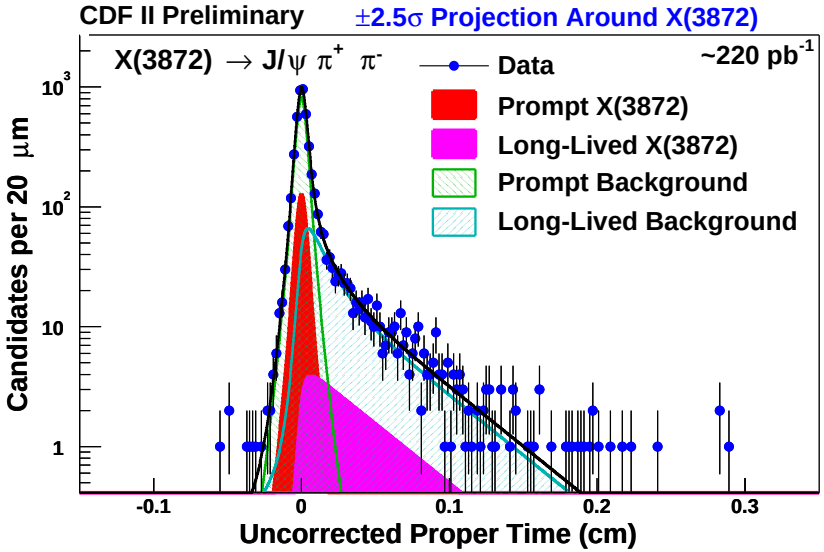


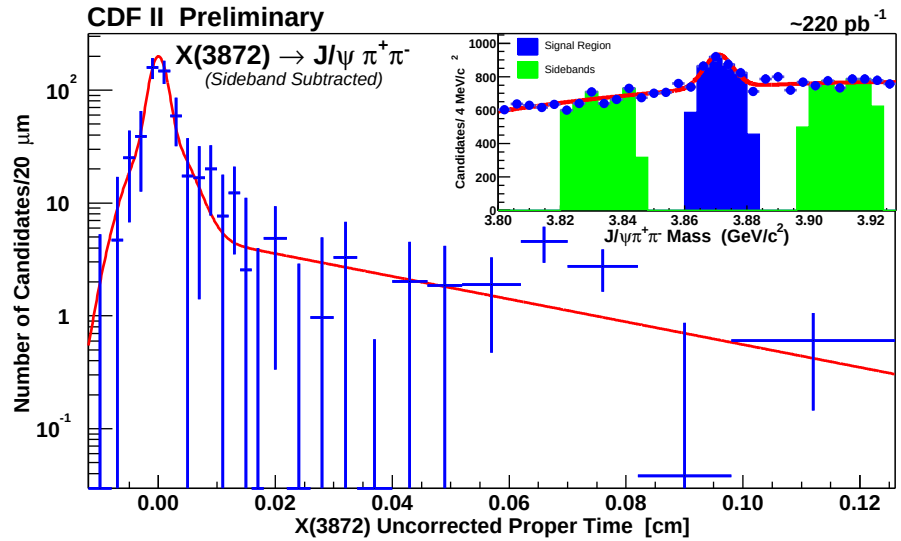


Likelihood	Parameter	Sideband-Sub
28.3 ± 1.0	Displaced Fraction	28.1 ± 1.1
473 ± 13	"Lifetime" (μm)	468 ± 19

Statistical Errors Only!

$X(3872)$ Likelihood *vs* Sideband-Sub:





Likelihood	Parameter	Sideband-Sub
16.1 ± 4.9	Displaced Fraction	20.9 ± 6.3
439 ± 107	"Lifetime" (μm)	431 ± 109

Statistical Errors Only!

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	%

$B \to X(3872)\ldots$ Significance:

- Belle: KNOW $B \to X\ldots$ is Significant
- Now KNOW **Prompt Dominates CDF Signal**...

  But Error on Displaced Fraction Not Small... $16.1 \pm 4.9(stat)\%$

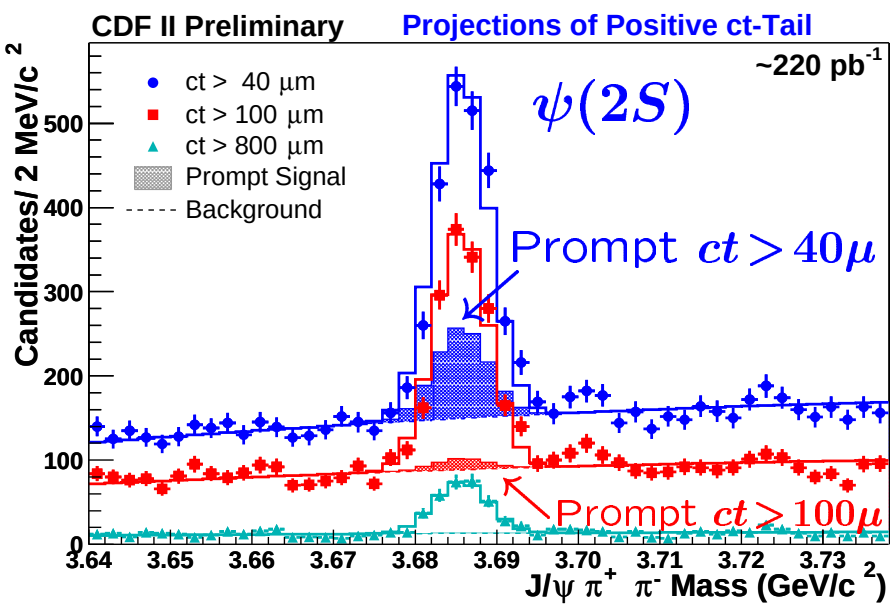
  $\Longrightarrow$ Could It "**ALL**" Be Prompt?

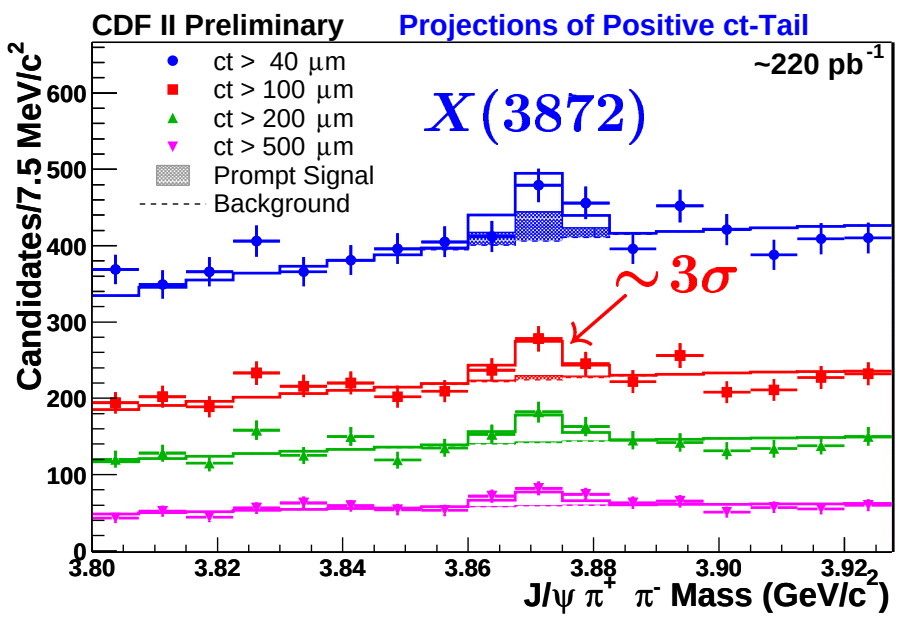
  > Naively: $16.1/4.9 \to \sim 3.3\sigma$ Null Hypothesis Excluded

  > MC: NO B-Signal to Fluctuate $\geq 16.1\%$ is 3σ

  > Still... Good to Take Direct Look at Data...

  $\Longrightarrow$ Project Likelihood for High-ct Tails:





$\Longrightarrow$ Likelihood Describes Tails Well

$\Longrightarrow$ Even Visually: $\sim 3\sigma$ B-Component for X!