Observation of a Narrow State Decaying to $J/\psi\pi^+\pi^-$ in CDF

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Representing the CDF Collaboration

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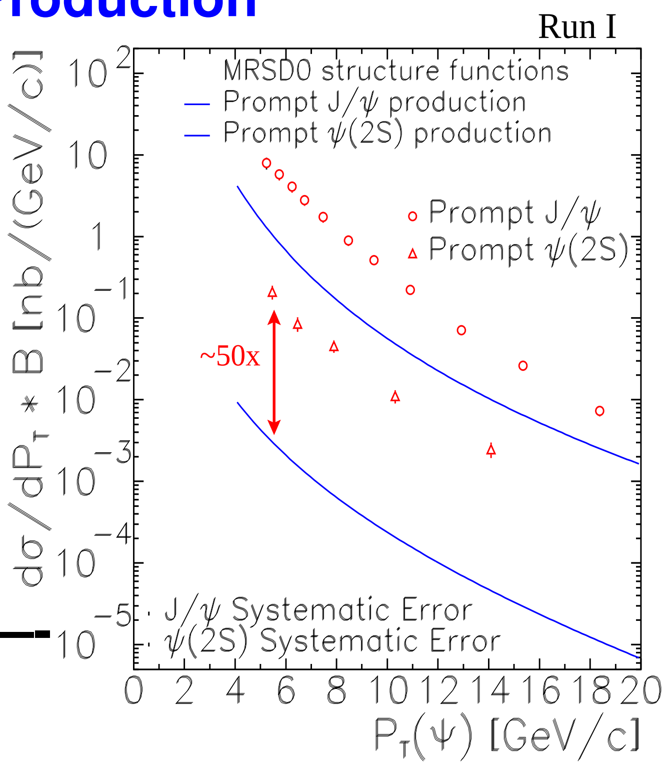
- **A Tevatron Reminder**
- **The CDF Detector in Run II**
- **Search for Narrow States in $J/\psi\pi\pi$**
  - **Selection**
  - **$J/\psi\pi\pi$ Mass Distribution**
  - **$M(\pi\pi)$ Characteristics**
  - **Signal Significance**
  - **Mass Measurement**
- **Summary and Work in Progress**

Quarkonia At the Tevatron

- **Historically Main Focus: Production**
  —*"CDF Crisis" in Mid-90's:*
  $\sim 50\times$ *Too Many Prompt* ψ*'s*

  $\longrightarrow$ *Experimental Impetus for "Color Octet" etc. . .*

- **A Few Run-I Forays Into Spectroscopy**
  — Limited Opportunities —



The Tevatron Contrast:

The Good:

- **Not limited to States Conventionally Accessible in e^+e^-**
- **Large Production Cross Sections**

The Bad:

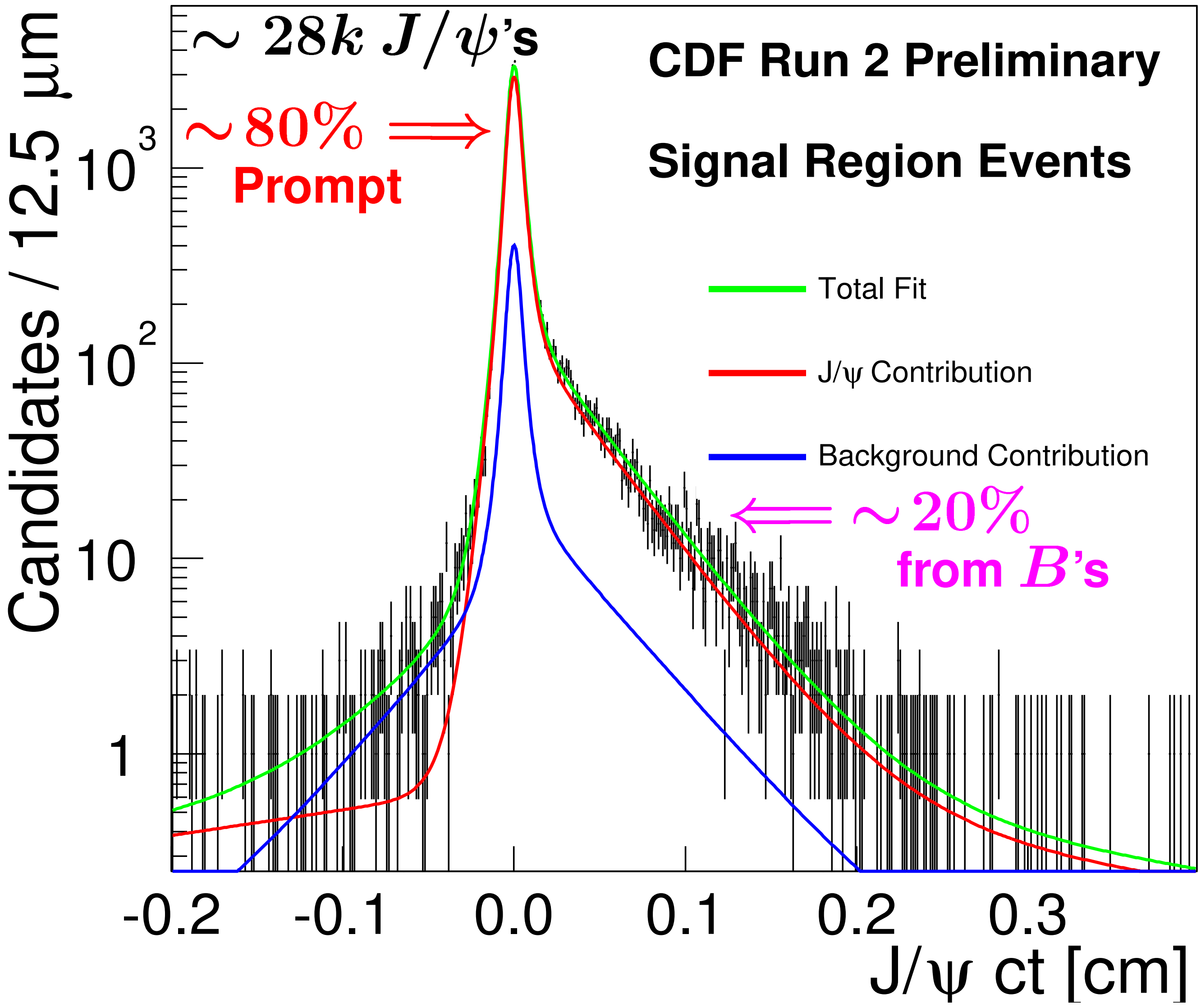
- **High Rates $\longrightarrow$ Requires Very Selective Triggers**
  Total X-Section $\sim 1000\times > \sigma(B)$

And The Ugly:

- **Messy Environment with Large Combinatorics**

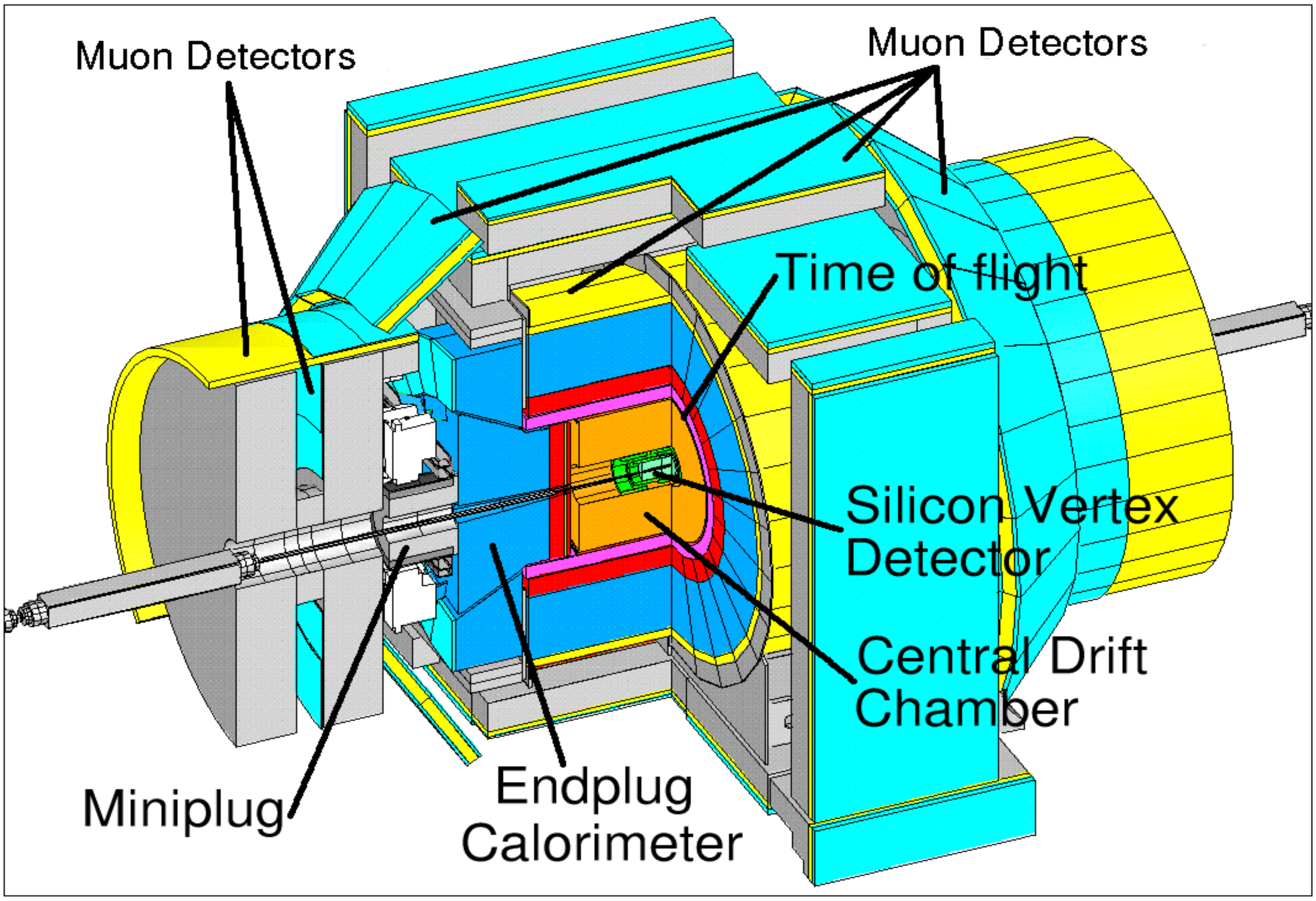
The Look of Charmonia at the Tevatron

- Classic Example: J/ψ's
- Mix of Prompt & $B \to \psi X$



- Note: Fraction of Prompt Depends Upon
  Species & Kinematics
- Good Si-Vertex Detector is Key!
- Now Have Many More: Nearly 2M $J/\psi \to \mu\mu$

CDF In Run II



- **Upgraded CDF Detector**
  - **Expanded μ Coverage & Lower Thresholds**
    $\Longrightarrow$ **More J/ψ's**
  - **Displaced Track Trigger**
    $\Longrightarrow$ **Liberated from Leptonic Myopia**
- **More Data!**
  - **Physics Data Since Spring 2002**
  - **Now $> 2\times$ Run I Samples**
    $\Longrightarrow$ **New Opportunties Opening Up**

Hunt For Charmonia via $J/\psi\pi^+\pi^-$

- Belle Announced New Narrow State at Lepton-Photon 03
- Seen in B Decays Around 3872 MeV
- Belle Conjecture May NOT be Charmonium
- Observed $J/\psi\pi^+\pi^-$ Mode Suited to CDF
- Always Fun to Find New States
- Can We Confirm?
  - Belle's Claim Impressive;
    But Confirmation Always Desired
  - Information on Production Mechanisms
    $\longrightarrow$ Insight to State's True Nature
  - Possibly Measure Other Characteristics
    Belle's Sample Small — Takes Time to Grow

The Tevatron Challenge

- **Backgrounds...** Backgrounds... Backgrounds...
- J/ψ Signal Quite Clean
- But J/ψ Plus 2 Tracks Rampant!

— Need Combinatorics Killers —

Strategies:

- Minimum p_T Reqirements
- Only Tracks Within Fixed Cone
- Limited Number of Candidates/Event

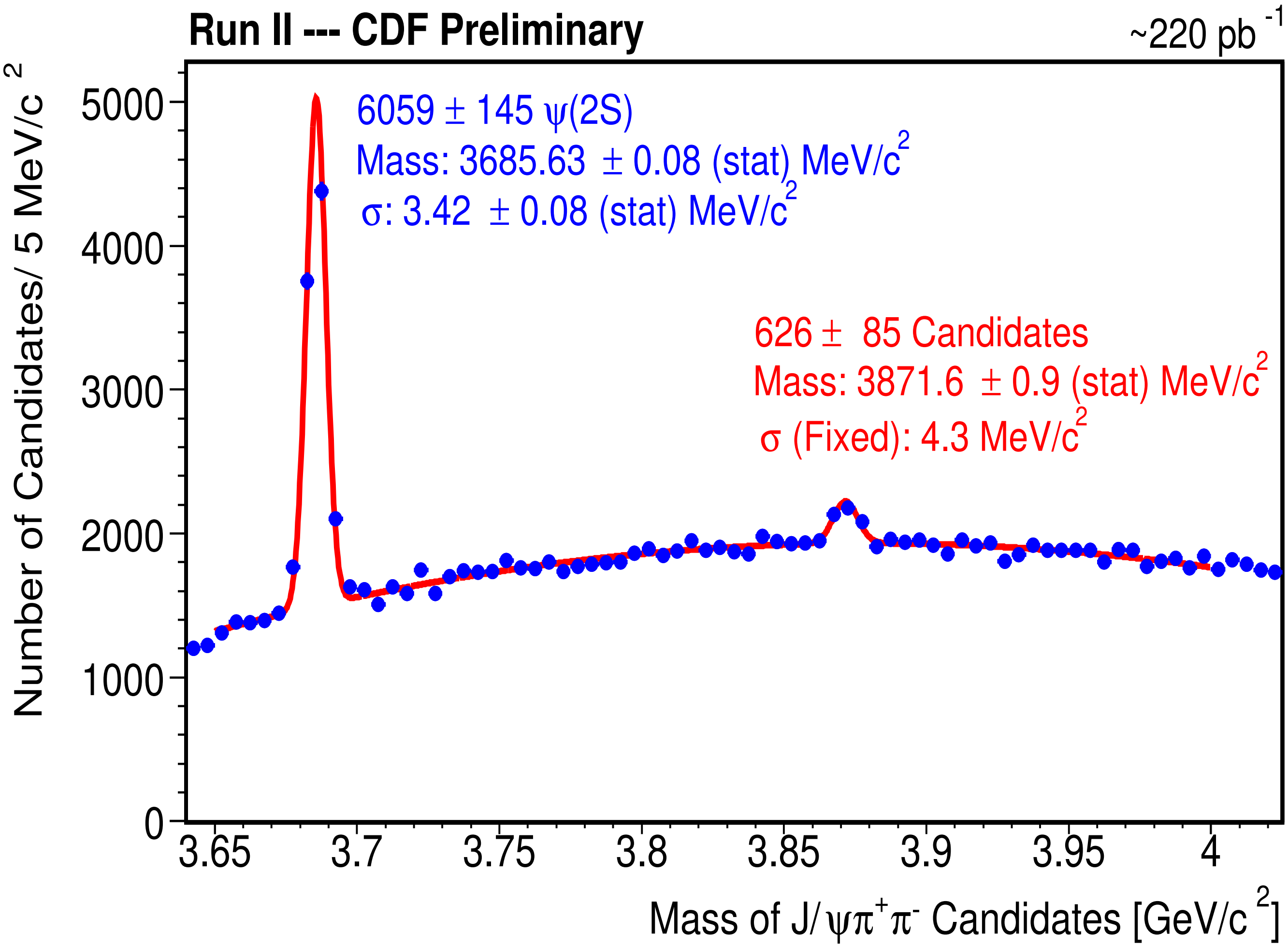
Key Off $\psi(2S) \to J/\psi\pi^+\pi^-$ to Optimize Cuts:

- Minimum Si-Hits & Drift Chamber Hits
- Max Number of Candidates/Event
- $|M(\mu^+\mu^-) - M(J/\psi)| < 60$ MeV
- χ^2 Cuts on J/ψ & $J/\psi\pi^+\pi^-$ Fits
- $p_T(\pi) > 400$ MeV & $p_T(\psi) > 4$ GeV
- $J/\psi\pi^+\pi^-$ Decay Distance $> -3\sigma$
- $\Delta R([J/\psi\pi^+\pi^-] - [\pi]) < 0.7$

Where: $$\Delta R = \sqrt{(\underset{\substack{\Uparrow \\ \text{Azimuthal Angles}}}{\Delta\phi})^2 + (\underset{\substack{\Uparrow \\ \text{Pseudorapidity}}}{\Delta\eta})^2}$$

$J/\psi\pi^+\pi^-$ Mass Distribution:

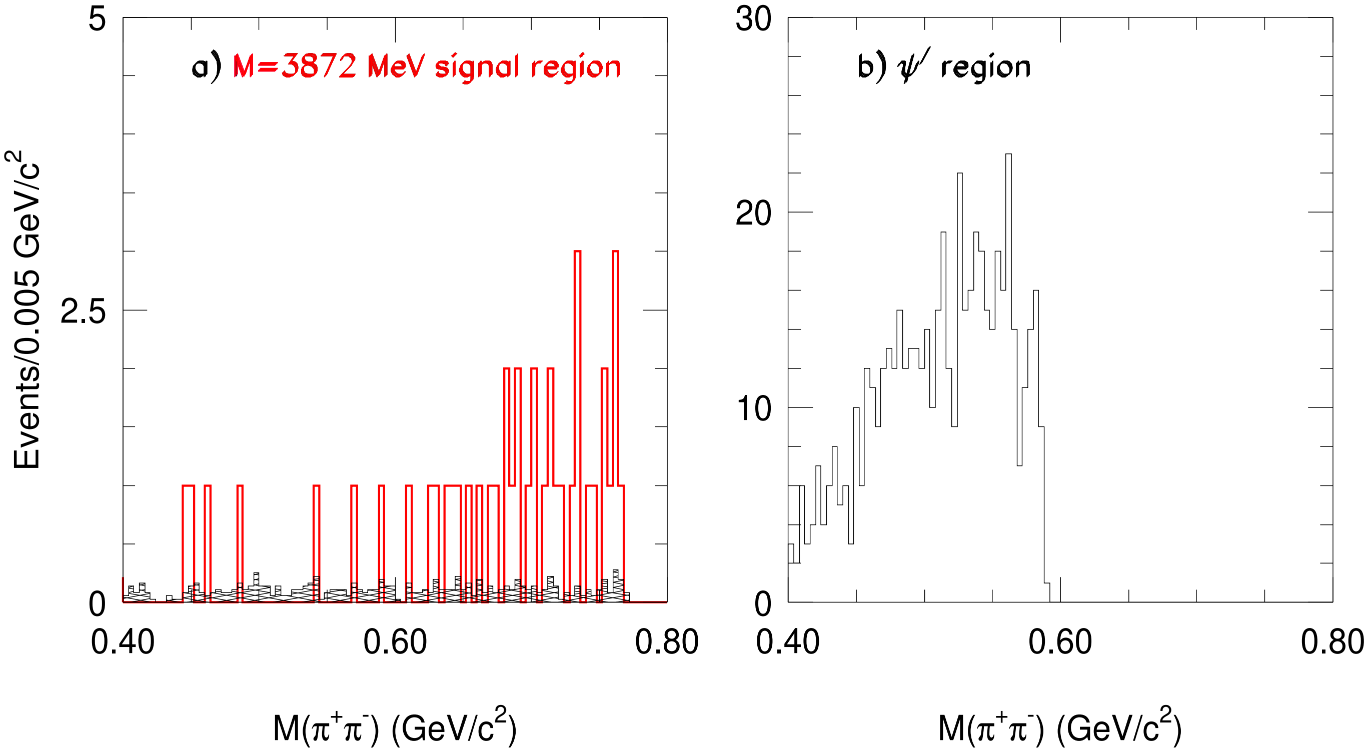
- Use ~ 220 pb^{-1} Run II Data



- Prominent $\psi(2S)$ Peak (6k Candidates)
- Relatively Loose Cuts
  $\longrightarrow$ Still Large Background
- Significant Peak Around 3870
  ~ 600 Candidate Excess!!
- Width Fixed Based on $\psi(2S)$ Extrapolation
  Helps Stabilize Yield — No Effect on Mass

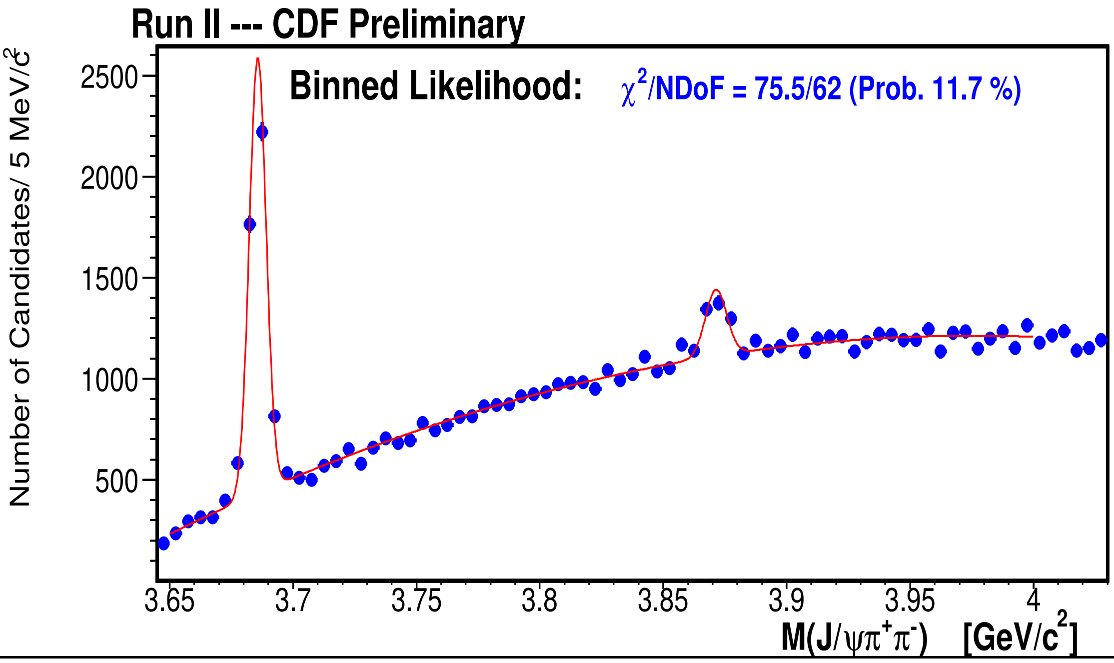
More $J/\psi\pi^+\pi^-$ Mass:

Belle Di-Pion Mass:



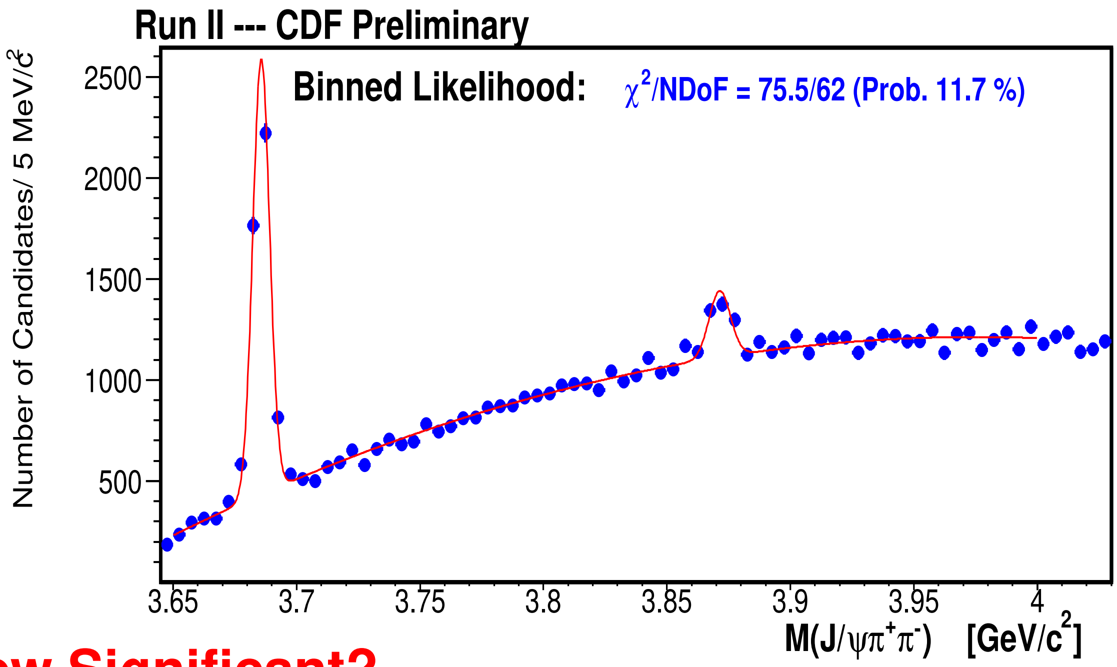
$\Longrightarrow$ **Belle Signal Favors Large $\pi\pi$ Mass** $\Longleftarrow$

$\Longrightarrow$ **Demand $M(\pi\pi) > 0.5$ to Improve Signal**

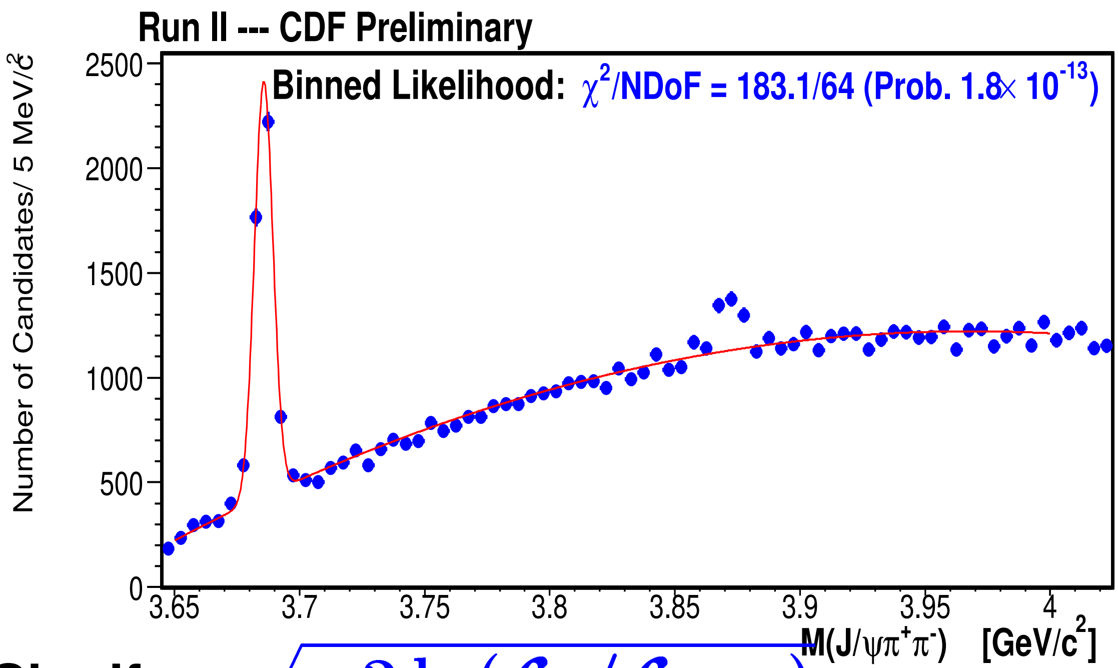


Imposing $M(\pi\pi) > 0.5$ GeV Cut:

- **Relatively Loose: Kills Backgrnd & Keeps ψ'**



- **How Significant?**
  - **Compare Log-Likelihood Fit With/Without**

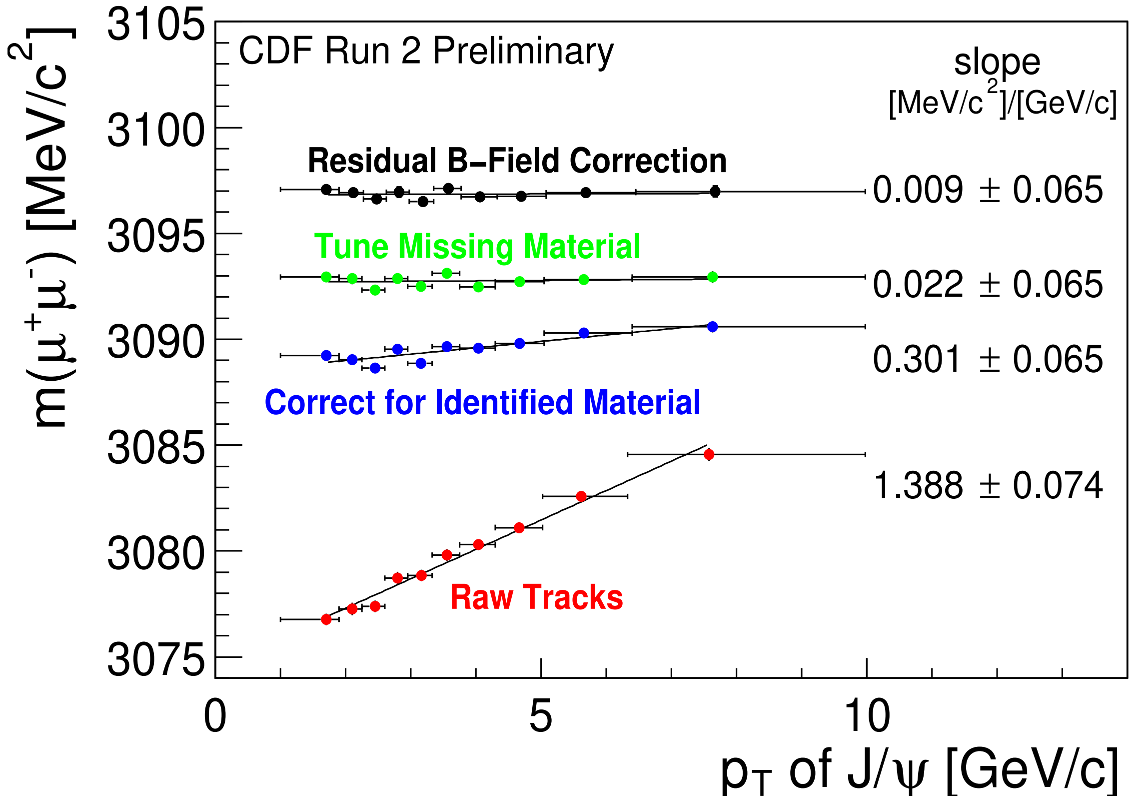


  - **Signif** $= \sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{max})}$

$$= \boxed{10.9\,\sigma}$$

Mass Measurement:

- **Calibrate Using Large J/ψ Sample**
- **E.G.: Energy-Loss & B-Field:**

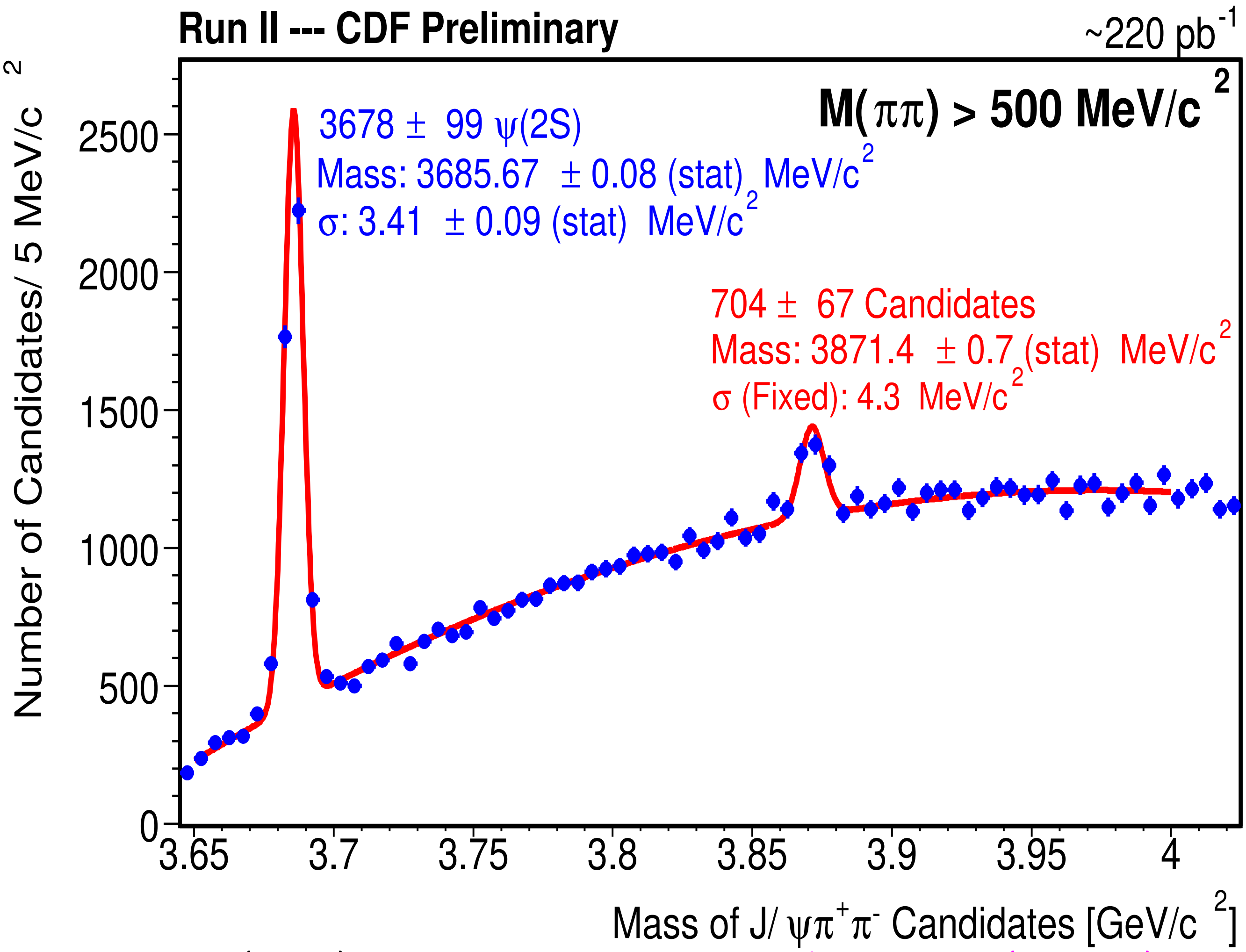


- **CDF Already Has Several Precision Masses**
  - $M(B^+) = 5279.32 \pm 0.68 \pm 0.94$
  - $M(B^0) = 5280.30 \pm 0.92 \pm 0.96$
  - $M(B_s) = 5365.50 \pm 1.29 \pm 0.94$

    (*Publication Being Prepared*)
  - $\Delta M(D_s\text{-}D^+) = 99.41 \pm 0.38 \pm 0.21$

    (*Accepted for Publication*)
- **CDF Calibration Well Established**

- Use More Significant $M(\pi\pi)$ Cut Distribution
- Model Background by Quadratic Polynomial

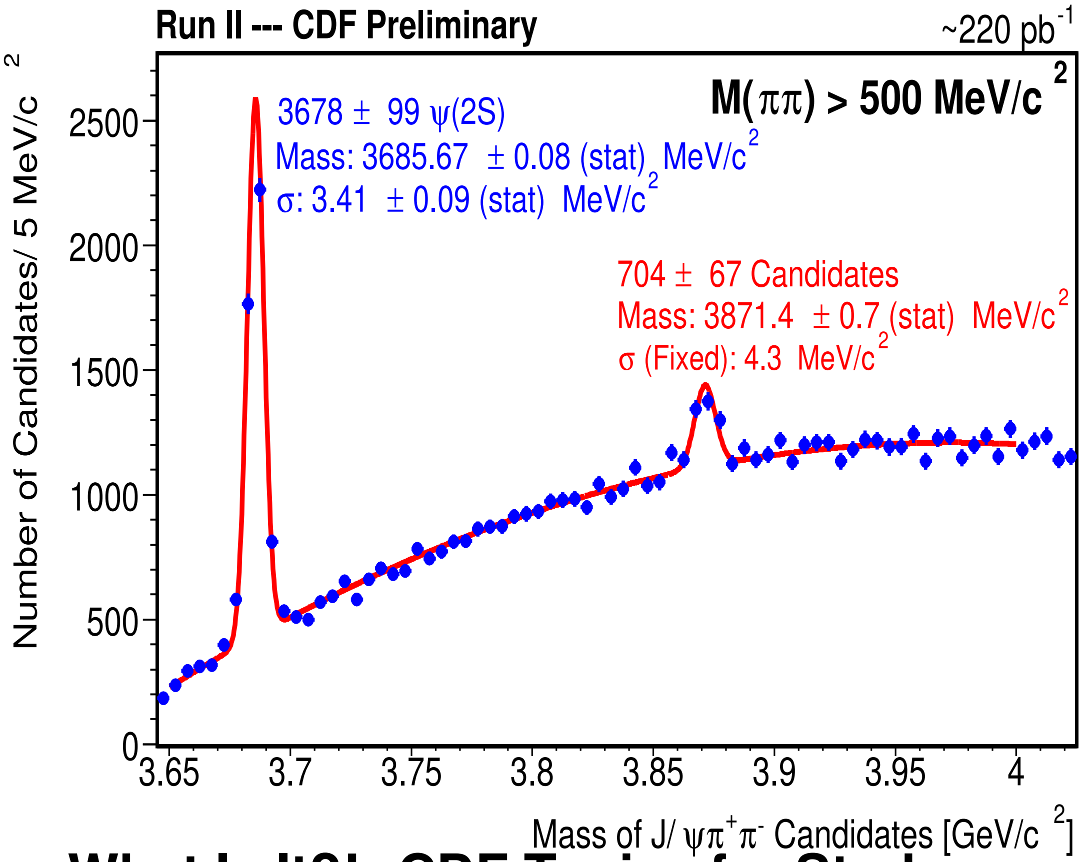


- Fit: $M(2S) \quad = 3685.67 \pm 0.08\,(stat)$
- Fit: $M(3870) \quad = 3871.4 \ \pm 0.7 \ \ (stat)$
- Use $\psi(2S)$ to Gauge Systematics: 0.4 MeV
- Negligible: Width, Backgrnd Shape, Binning...

$$\boxed{M = 3871.4 \pm 0.7\,(stat) \pm 0.4\,(sys)}$$

$J/\psi\pi^+\pi^-$ Summary:

- **Observe $\sim 11\sigma$ Signal in $J/\psi\pi^+\pi^-$**
- $M = \boxed{3871.4 \pm 0.7\,(stat) \pm 0.4\,(sys)}$
- **Very Close to Belle & Similar Errors:**
  $3872.0 \pm 0.6\,(stat) \pm 0.5\,(sys)$



- **What Is It?! CDF Topics for Study:**
  - $M(\pi\pi)$ **Distribution**:
    Expect Can Do Significant Measurement
  - **Prompt vs Long-Lived Production**:
    Statistically Challenging
  - **Angular Analyses**: **Unknown?**