Recent Results on Heavy Quarkonium from CDF Run II

1. J/Ψ Cross Sections
2. Properties of the X(3872)

QWG 3
Beijing, China
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Greg Feild
Yale University
The CDF Collaboration

Run I Quarkonium Measurements

J/ψ and $\psi(2S)$ production cross sections: PRL 79, 572 (1997)

Production of J/ψ from χ_c decays: PRL 79, 578 (1997)

J/ψ and $\psi(2S)$ polarization: PRL 85, 2886 (2000)

Υ cross sections and $\Upsilon(1S)$ polarization: PRL 88 161802 (2002)

Production of $\Upsilon(1S)$ from χ decays: PRL 84 2094 (2000)

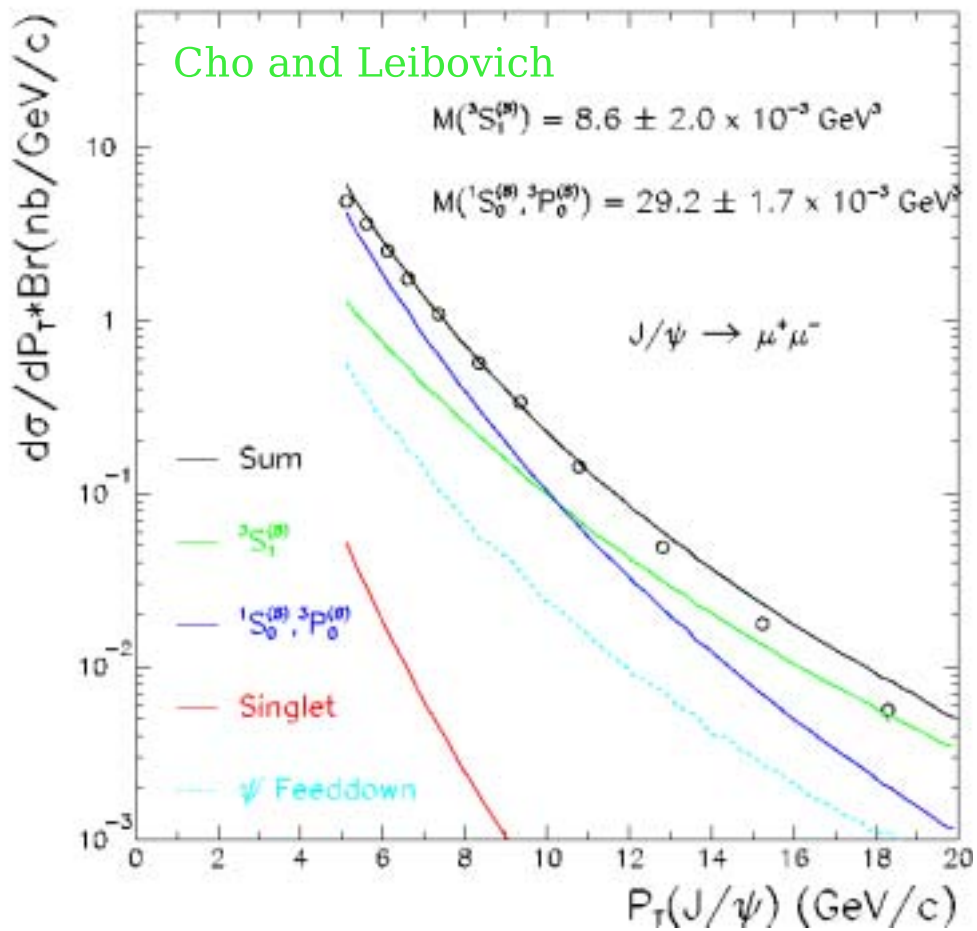
Forward J/ψ production cross section: PRD 66, 092001 (2002)

Run I Quarkonium Measurements

Color Singlet Model does not describe the CDF direct J/ψ cross section inspiring Color Octet Models

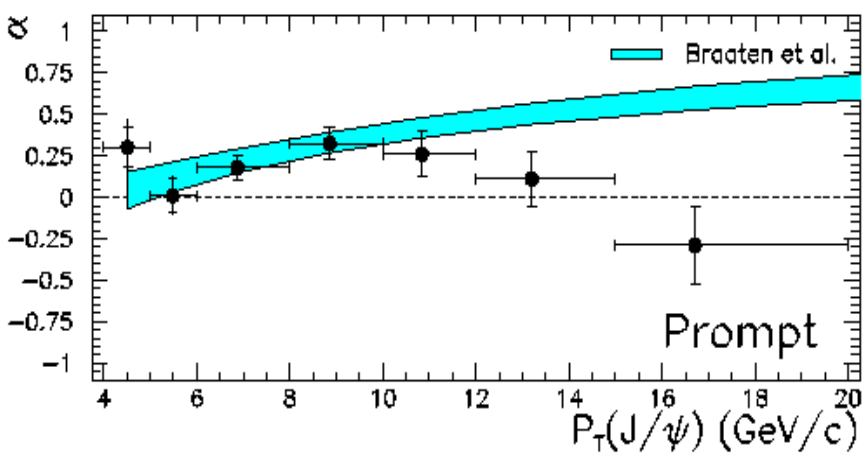
$L = 110\ pb^{-1}$

CDF Run I (1997)



Color octet contributions in NRQCD can fit the direct cross section but predict transverse polarization at high $p_T(J/\psi)$

CDF Run I



The CDF II Detector

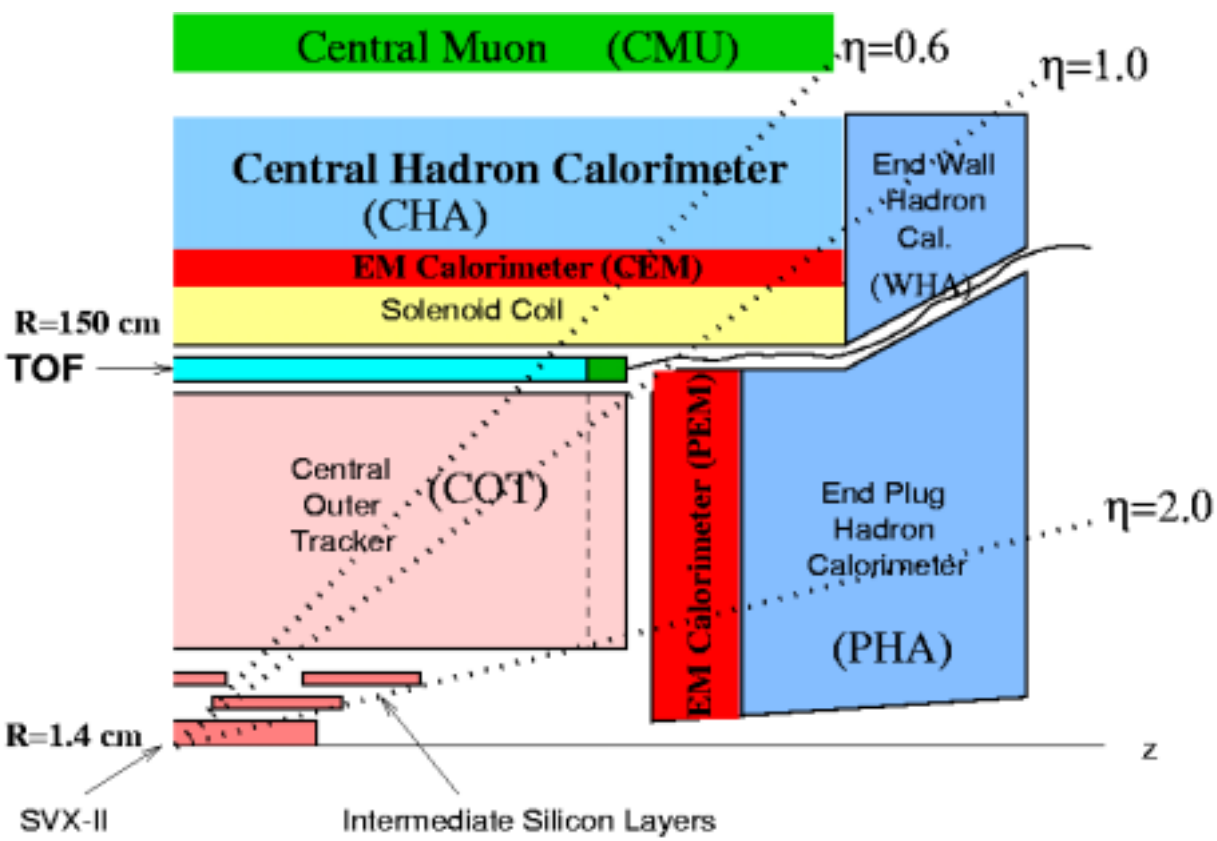
Location: Fermilab Tevatron

"All Purpose" Detector

$p\bar{p} \rightarrow X$; sqrt(s) = 1.96 TeV

total cross section ≈ 100 mb

$L \approx 5 \times 10^{31}\ cm^{-2}s^{-1}$



Central Muon Detector

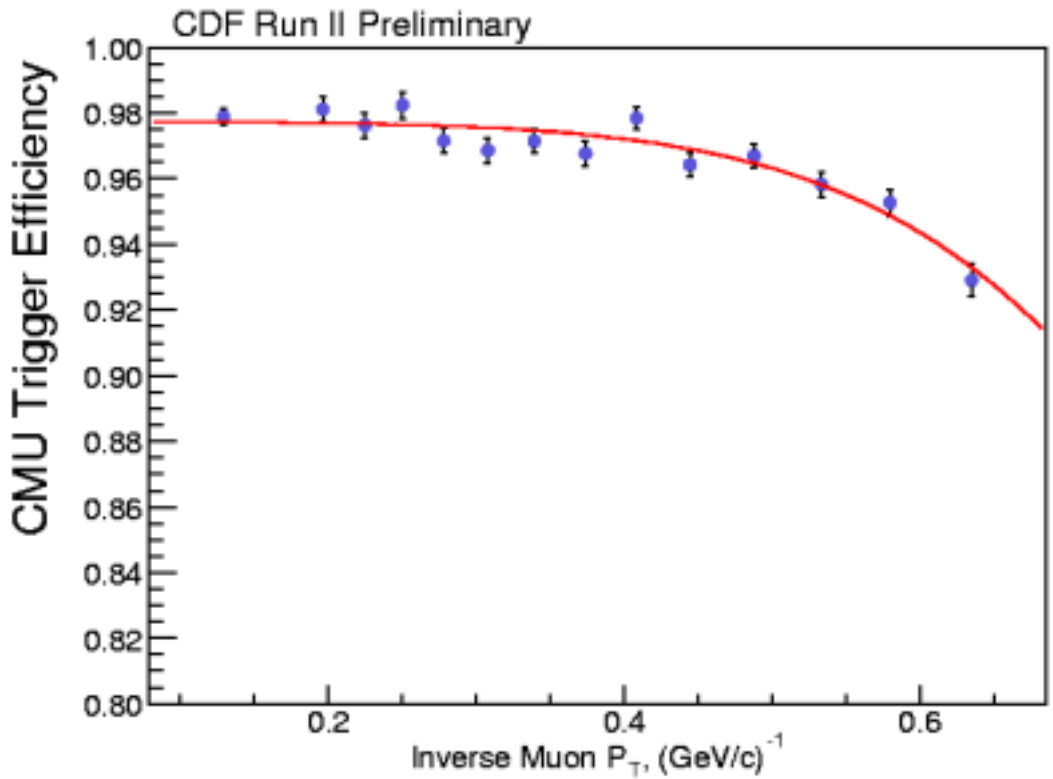
96 layer COT:
$\sigma(p_T)/p_T = 0.003p_T$

Si Vertex Detector:
8 Layers, 3-D tracking
$\sigma(d_0) \sim 20\ \mu m$

Run II Trigger

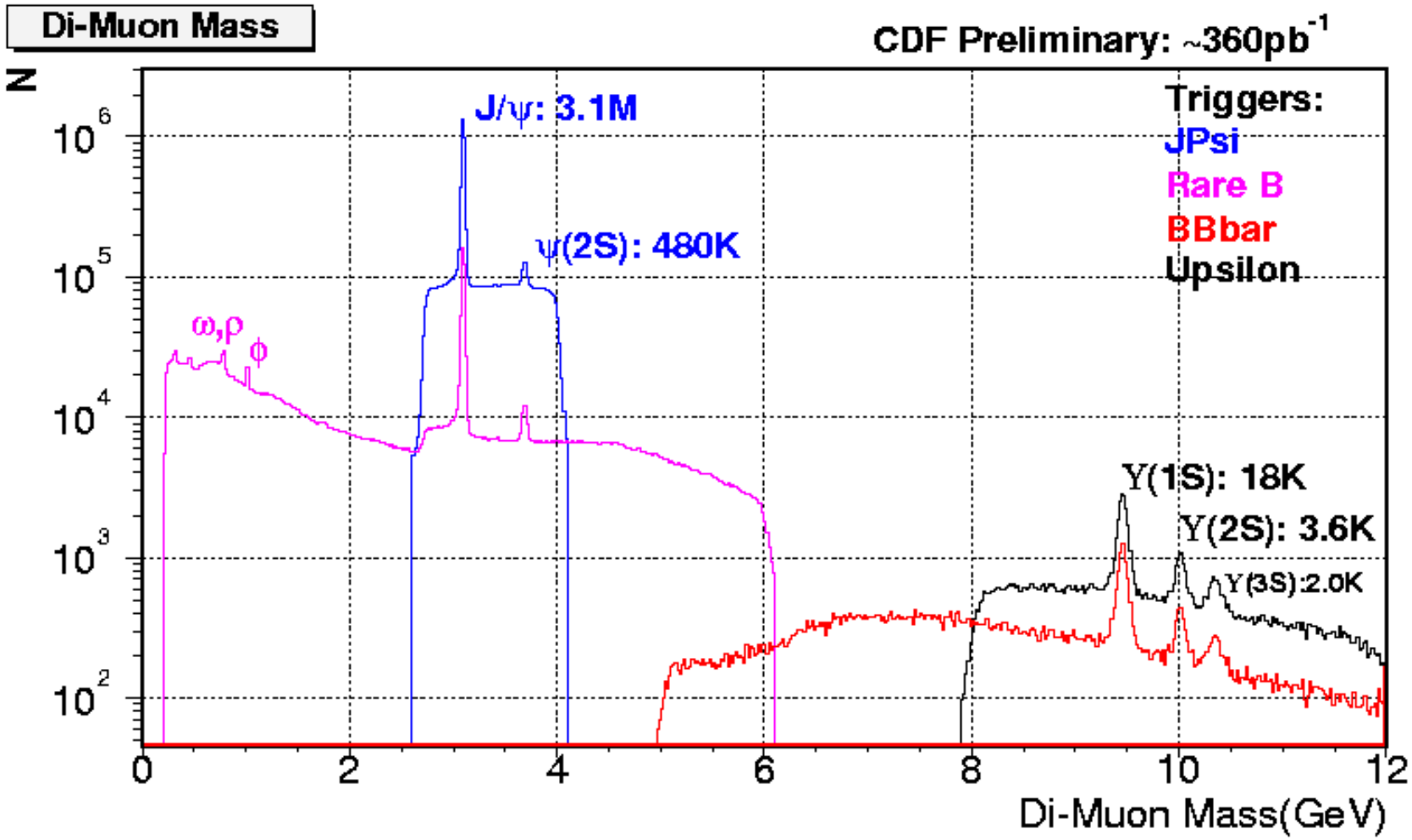
$pp \rightarrow [QQ]\ X \rightarrow \mu^+\mu^- X$

eXtremely Fast Tracker (XFT) at L1
92 % efficient at $p_T(\mu) > 1.5$ GeV/c
Plateau efficiency = 98 %



Run II Trigger Yields

$pp \rightarrow [QQ]\, X \rightarrow \mu^+\mu^- X$



J/Ψ Cross Sections in Run II

$L = 40\ pb^{-1}$

Kinematic selection cuts:

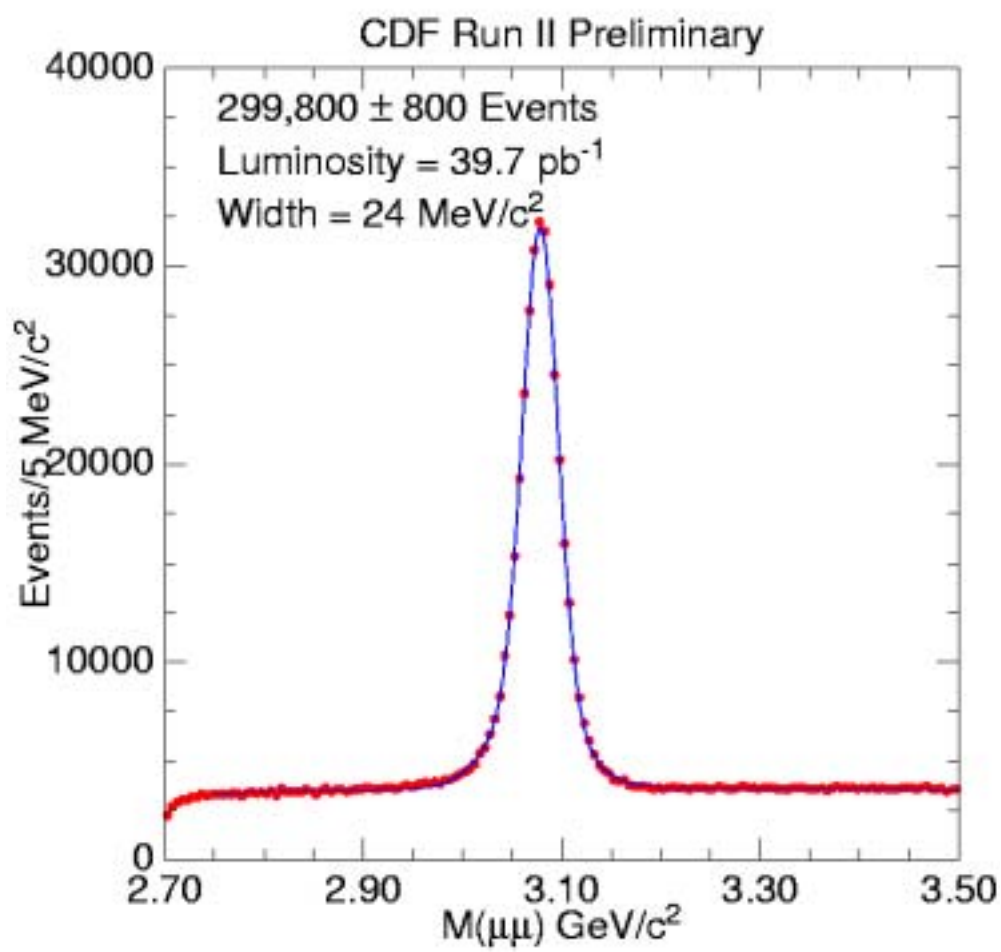
$J/\Psi \rightarrow \mu^+\mu^-$

$|\eta(\mu)| < 0.6$

$p_T(\mu) > 1.5$ GeV/c

$|y(J/\Psi)| < 0.6$

$0 < p_T(J/\Psi) < 20$ GeV/c

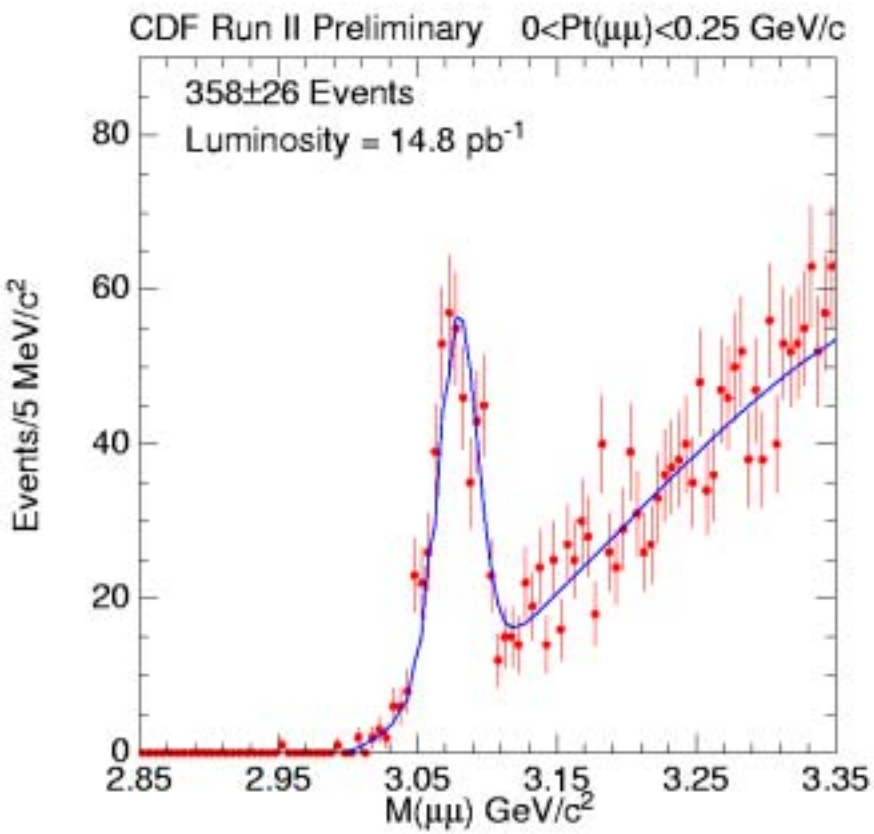


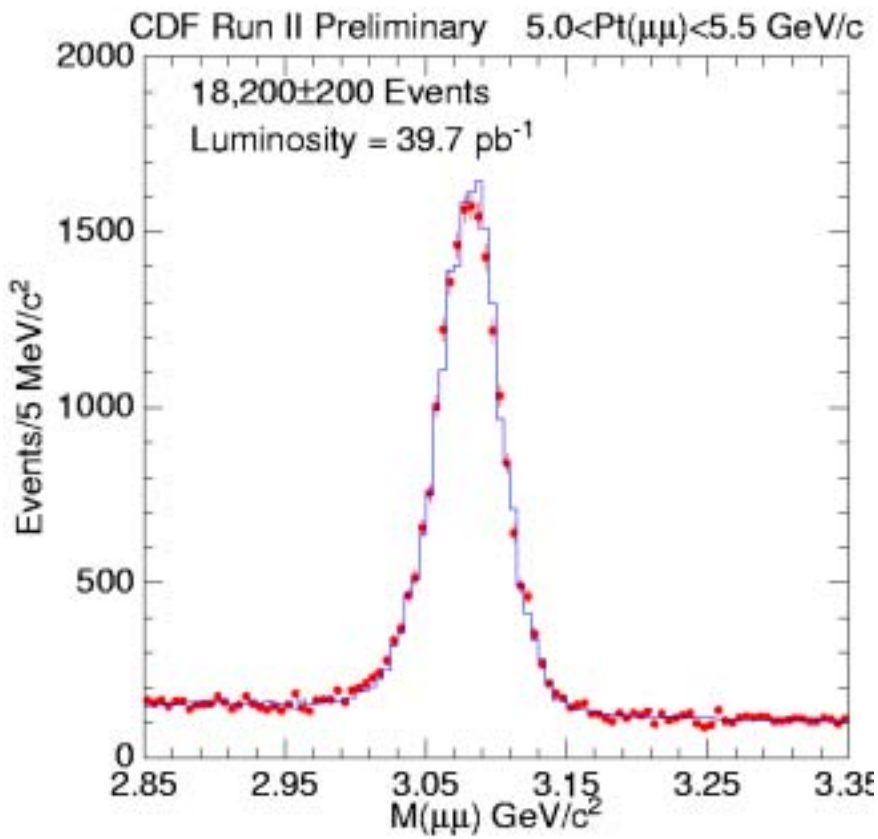
J/Ψ Cross Sections in Run II

$J/\Psi \rightarrow \mu^+\mu^-$

Count number of events in each p_T bin

Fit M(μμ) to MC template + polynomial

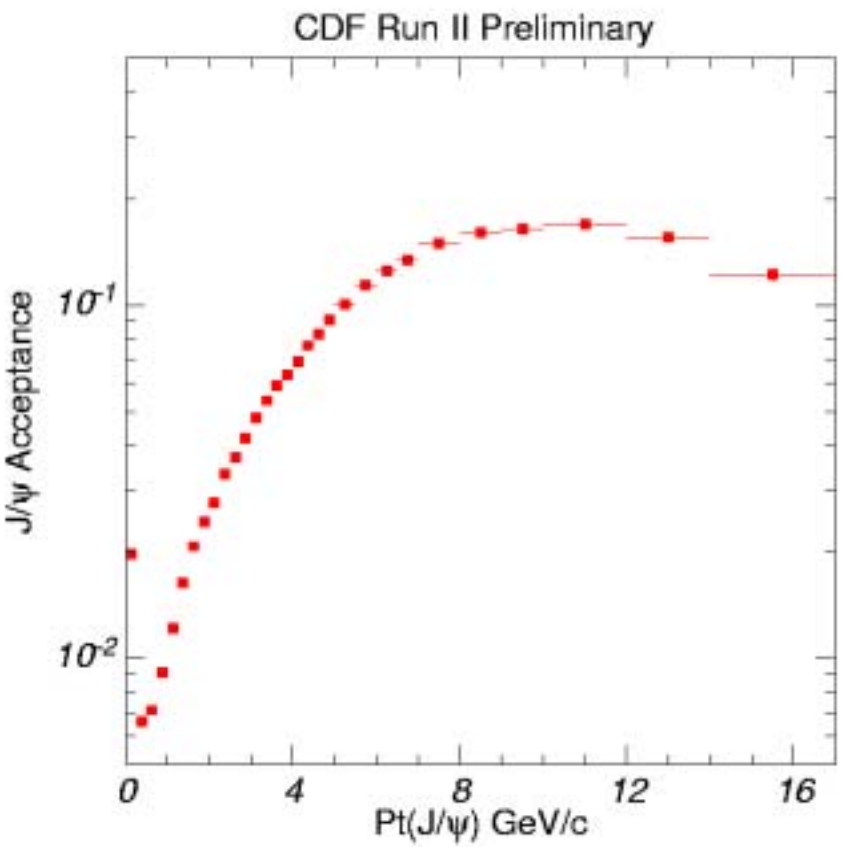


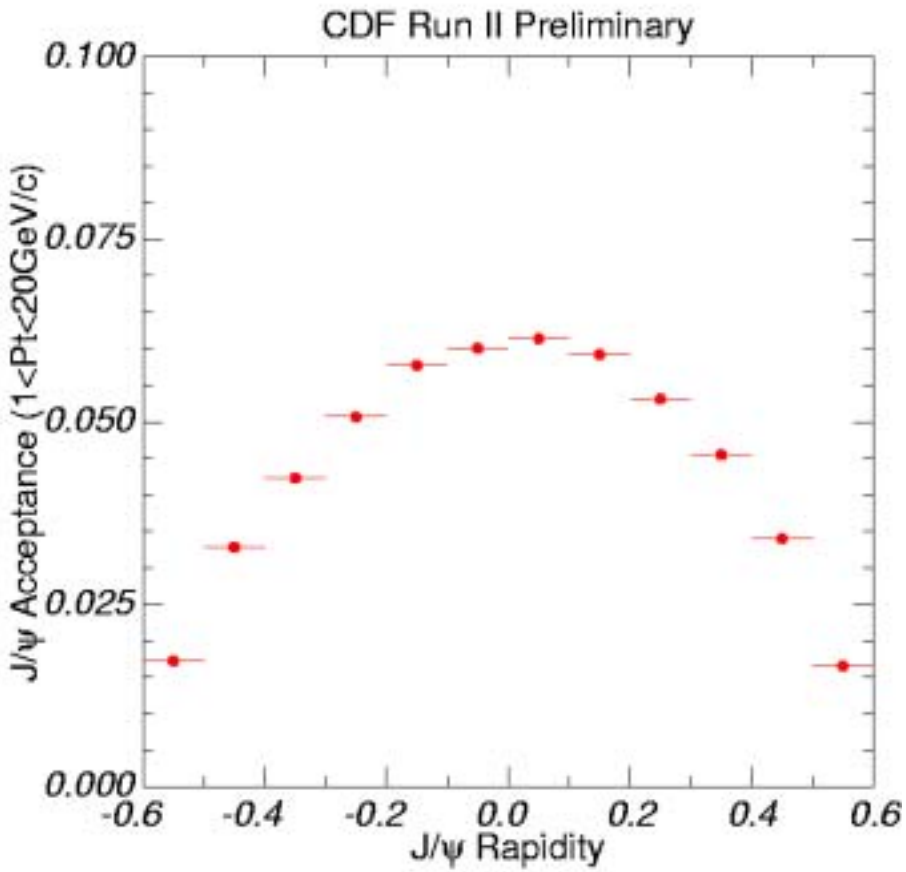


J/Ψ Cross Sections in Run II

$J/\Psi \rightarrow \mu^+\mu^-$

Compute detector acceptance: $A(p_T,y)$



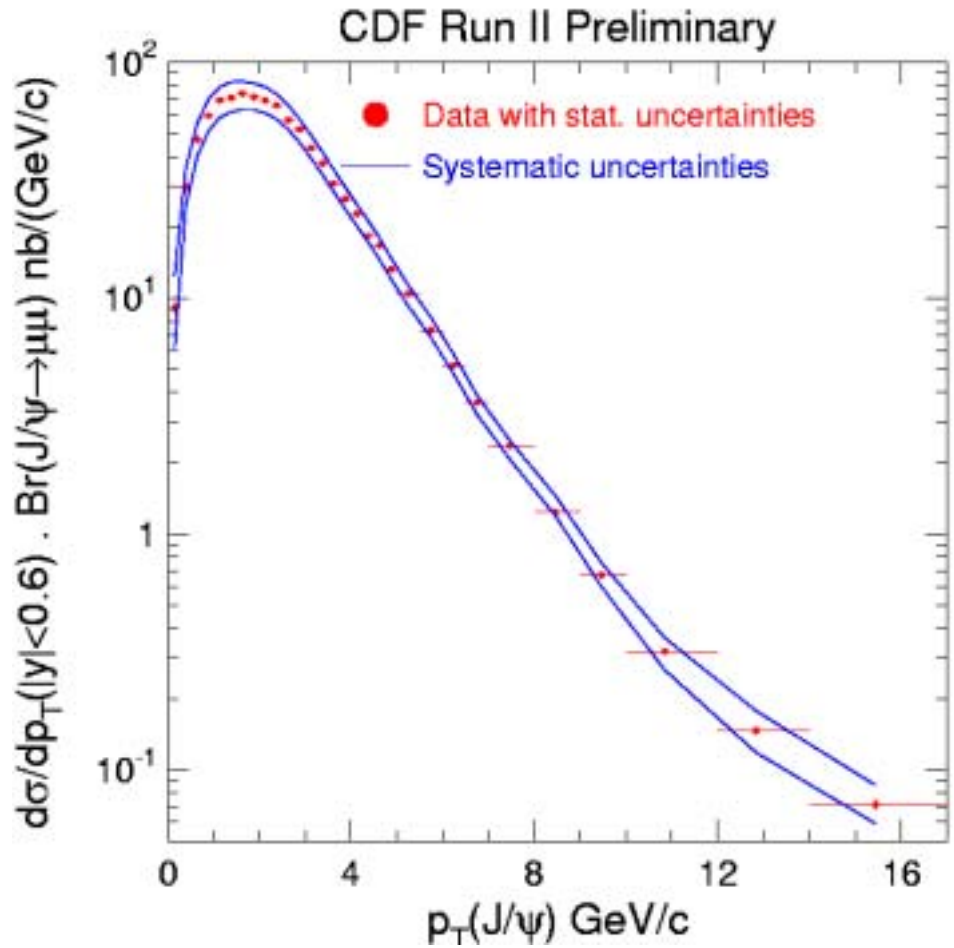


Inclusive J/Ψ Cross Section

L = 40 pb^{-1}

$J/\Psi \rightarrow \mu^+\mu^-$, $|y(J/\Psi)| < 0.6$

$0 < p_T(J/\Psi) < 20$ GeV/c



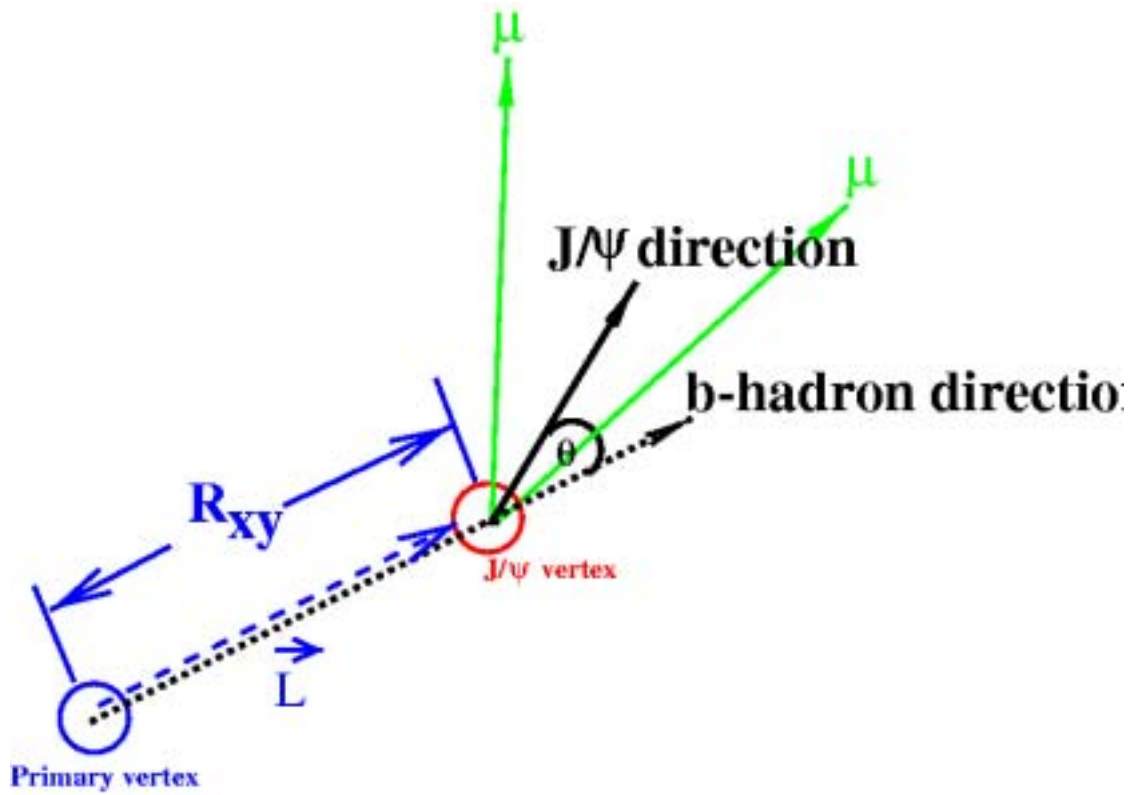
Integrate over p_T and correct for Br $(J/\psi \rightarrow \mu\mu)$ to obtain total cross section :

$\sigma(pp \rightarrow J/\psi\, X, |y(J/\psi)<0.6) = 4.08 \pm 0.02(\text{stat.}) \pm 0.60(\text{syst.})\ \mu b$

Separating J/Ψ from b-hadron decays

The inclusive J/ψ cross section includes contributions from:

- Direct production of J/ψ
- Decay of directly produced excited states (e.g. ψ(2S), χ_c)
- Decay of b-hadrons: $H_b \rightarrow J/\psi\ X$



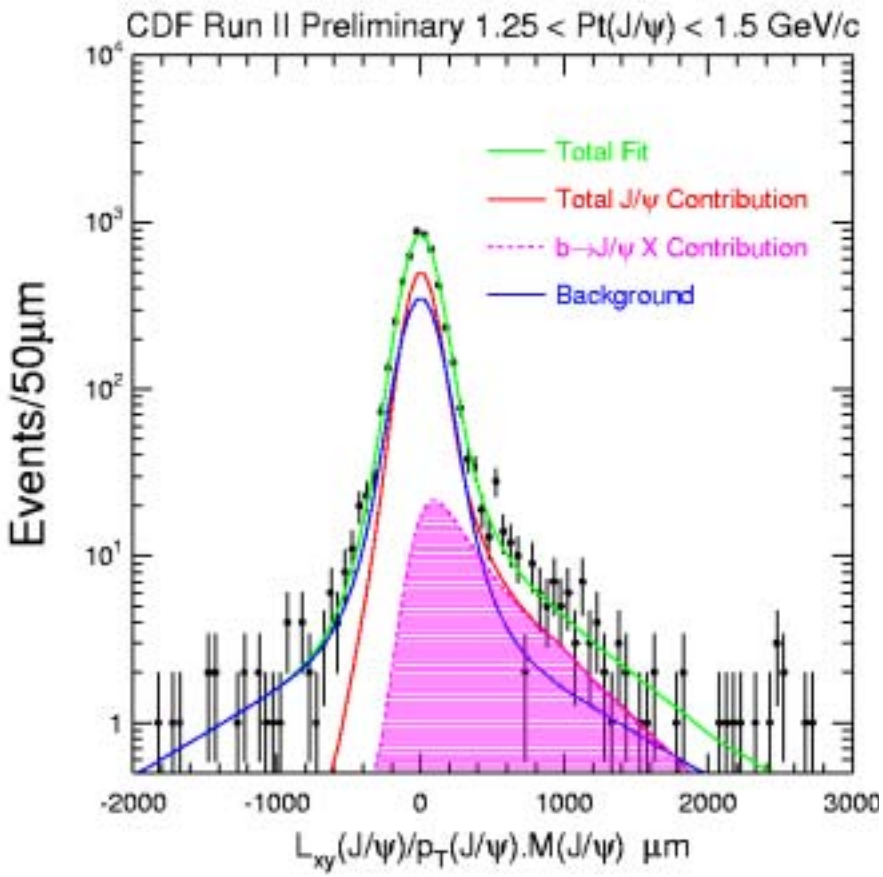
b-hadrons have long lifetimes so J/ψ events from $H_b \rightarrow J/\psi\ X$ will have a displaced vertex

J/Ψ from b-hadron decays

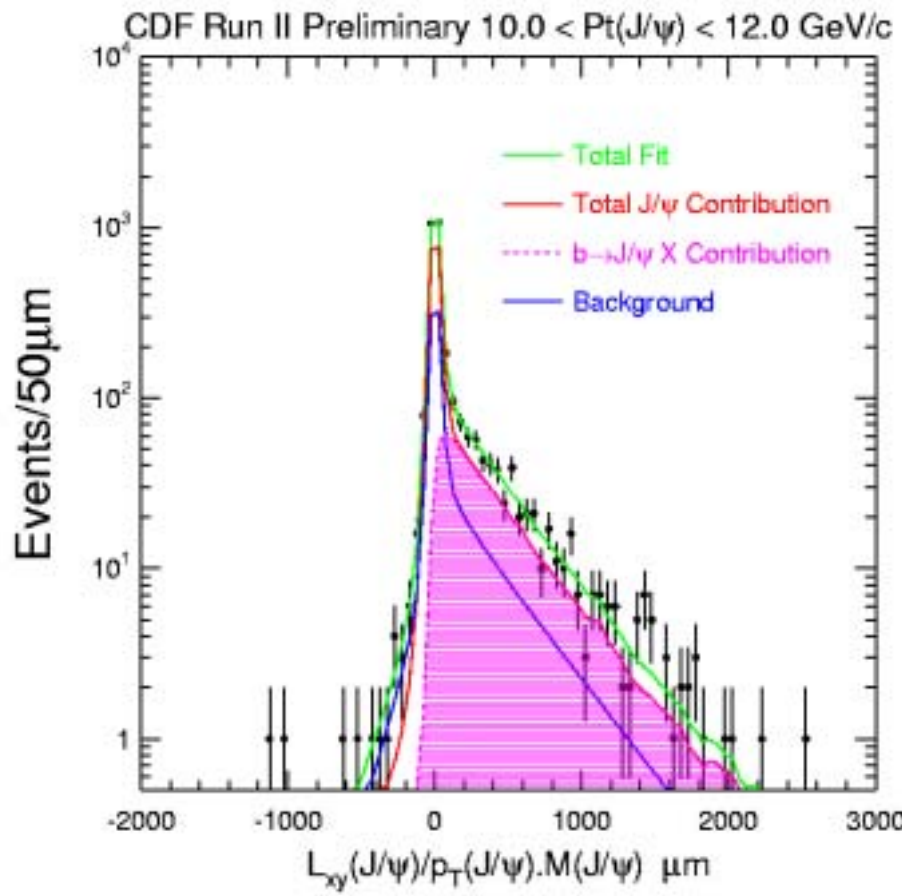
A maximum likelihood fit to L_{xy} is used to extract the b-fraction

Prompt J/ψ is fit to double Gaussian
$b \rightarrow J/\psi X$ shape is from MC template

$f_b = 9.7\%$

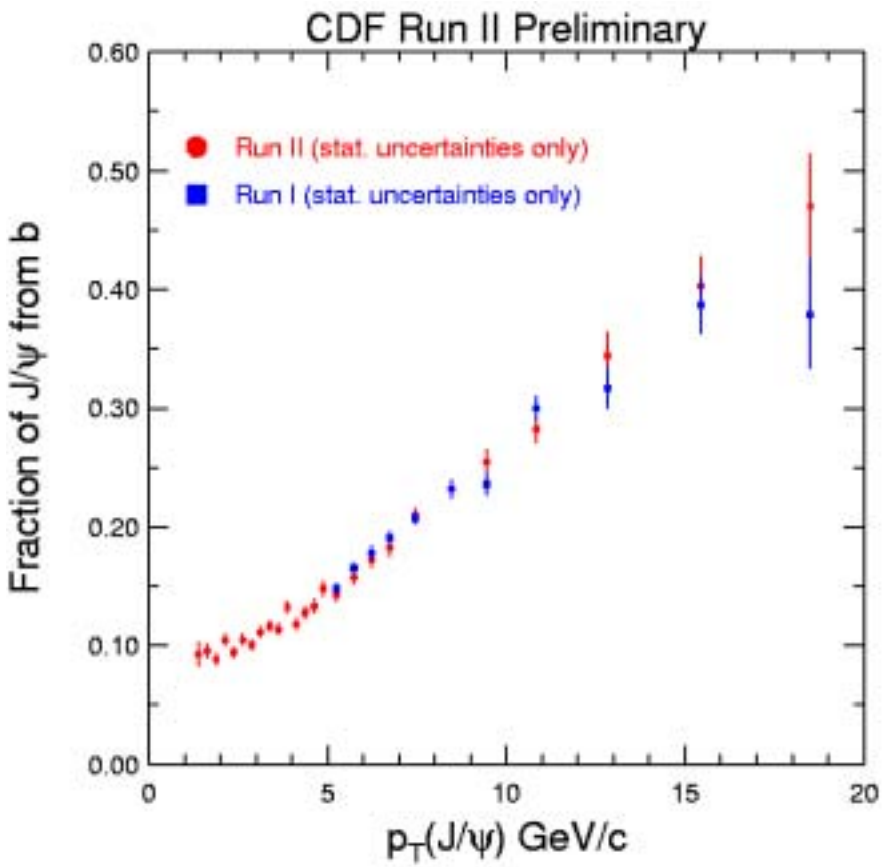


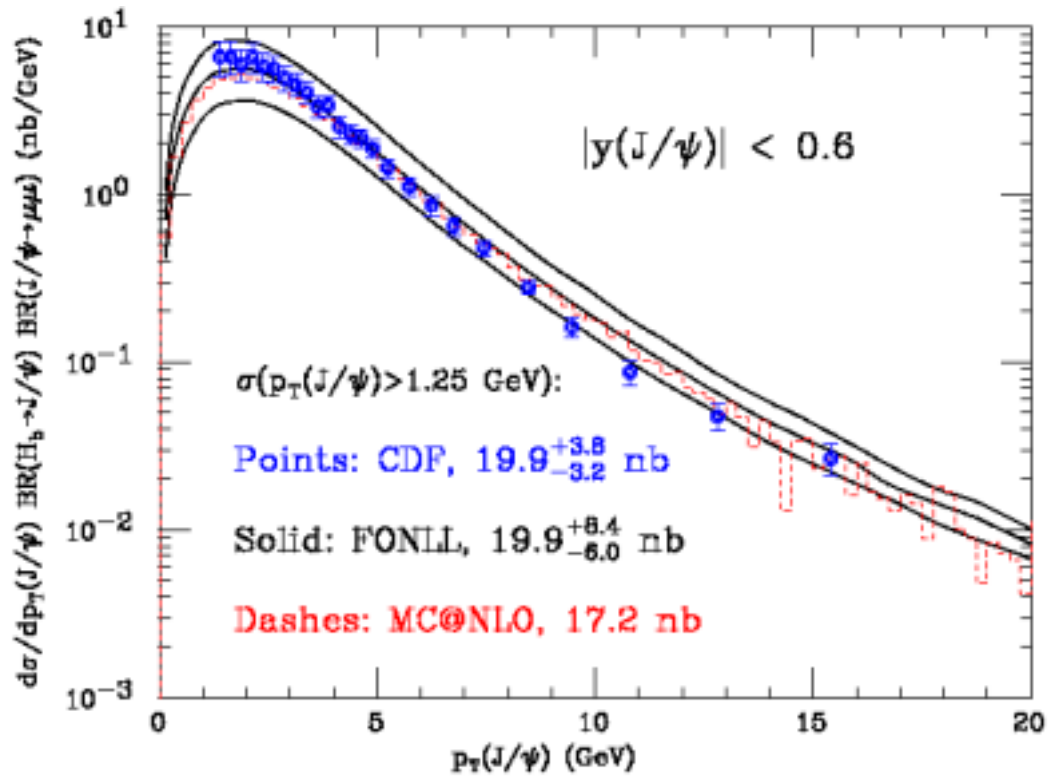
$f_b = 28\%$



J/Ψ Cross section from b decays

Obtained by multiplying the measured b-fractions with the inclusive J/ψ differential cross sections.



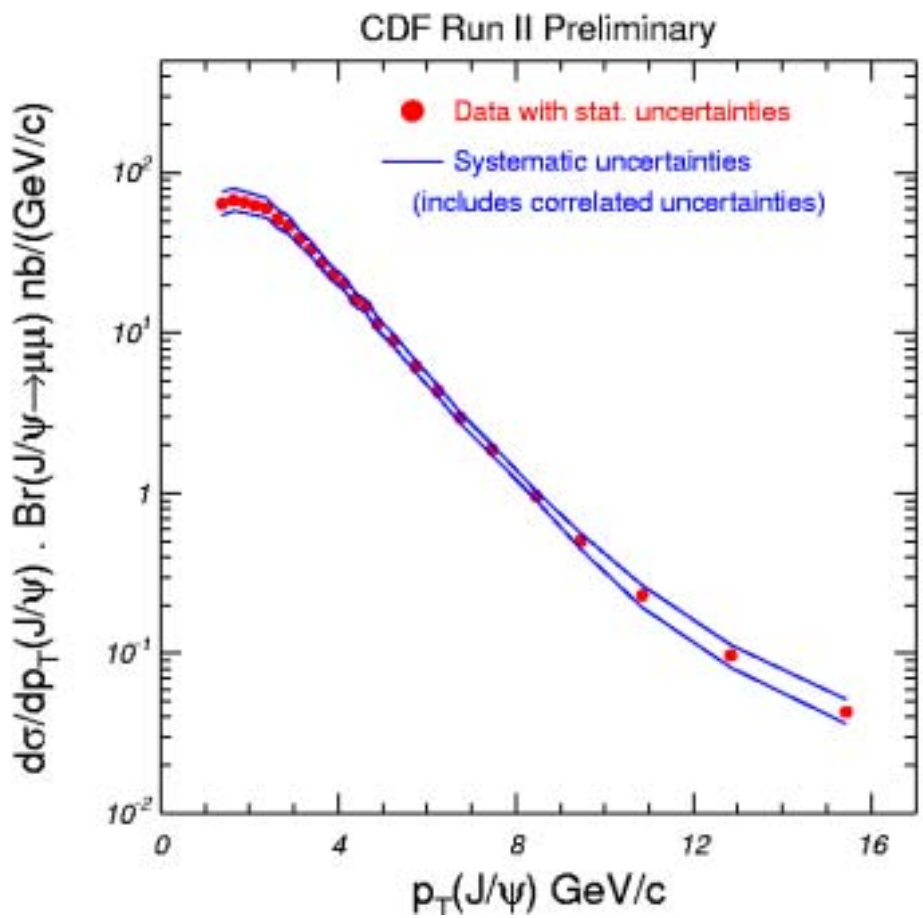


Theory: M. Cacciari et al. (Dec. 2003)

Prompt J/Ψ Cross section

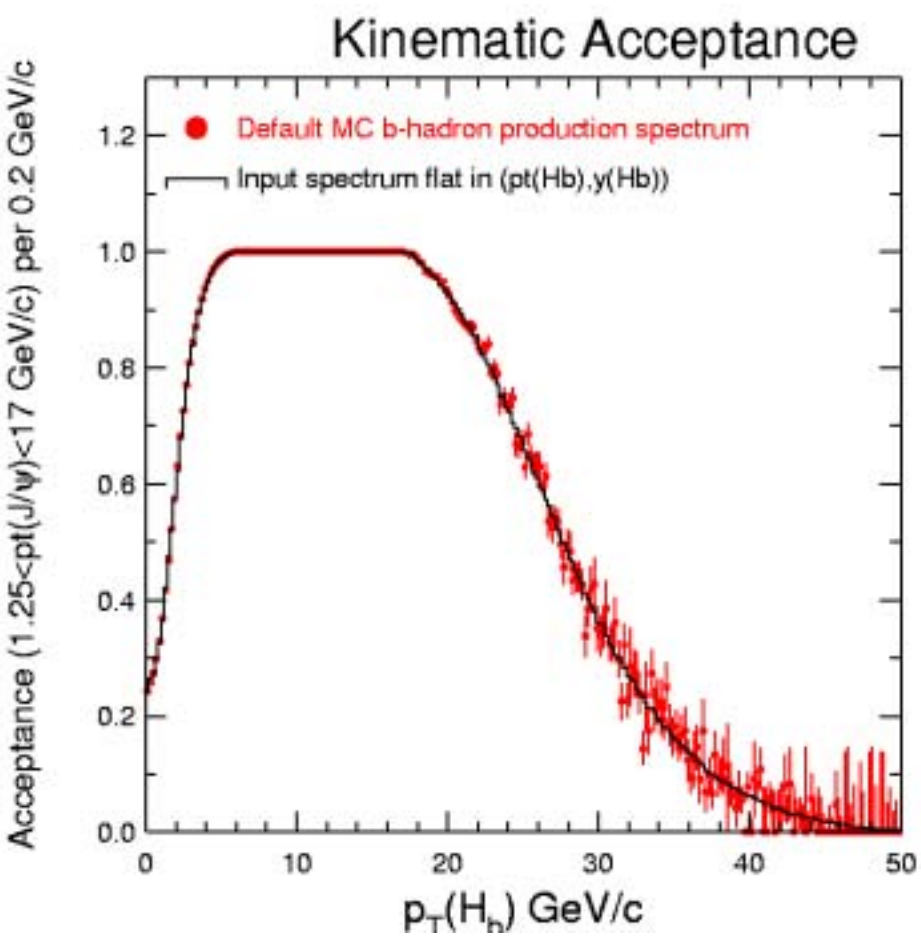
What remains after subtracting the b-hadron cross section from the inclusive cross section.

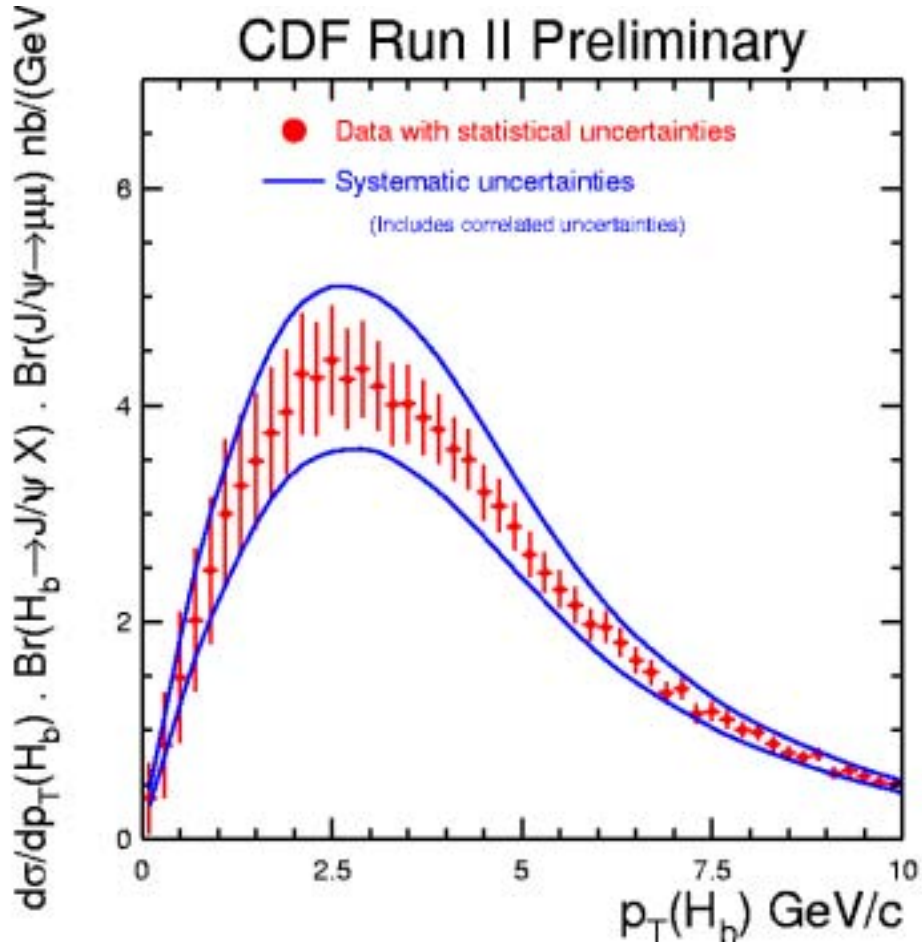
Note: Feed-down from directly produced excited states not removed



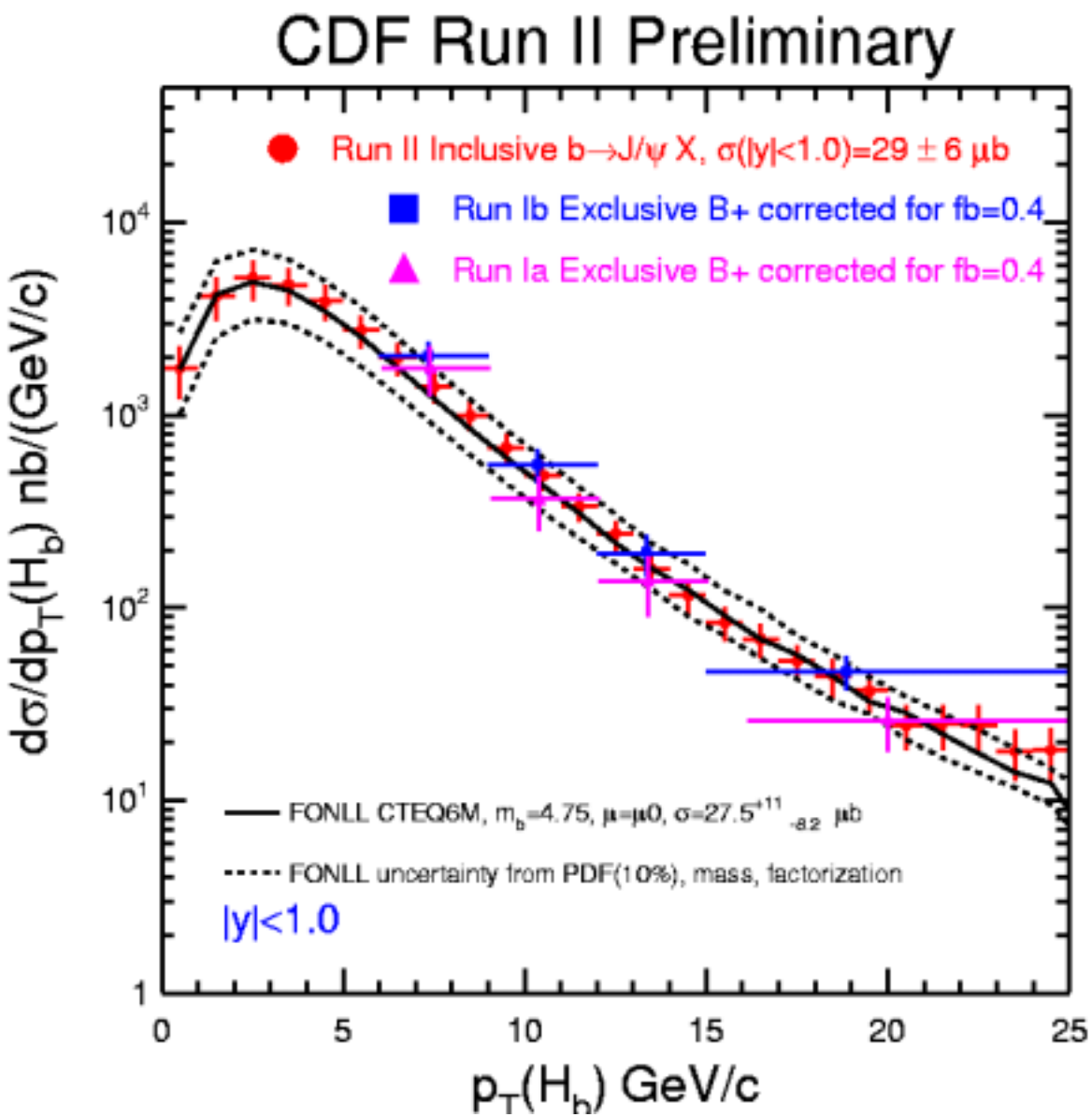
The inclusive H_b cross section

Extracted using MC model of $H_b \rightarrow J/\psi$ decays





Comparing Run I and Run II Results



$X(3872) \rightarrow J/\psi\ \pi^+\pi^-$

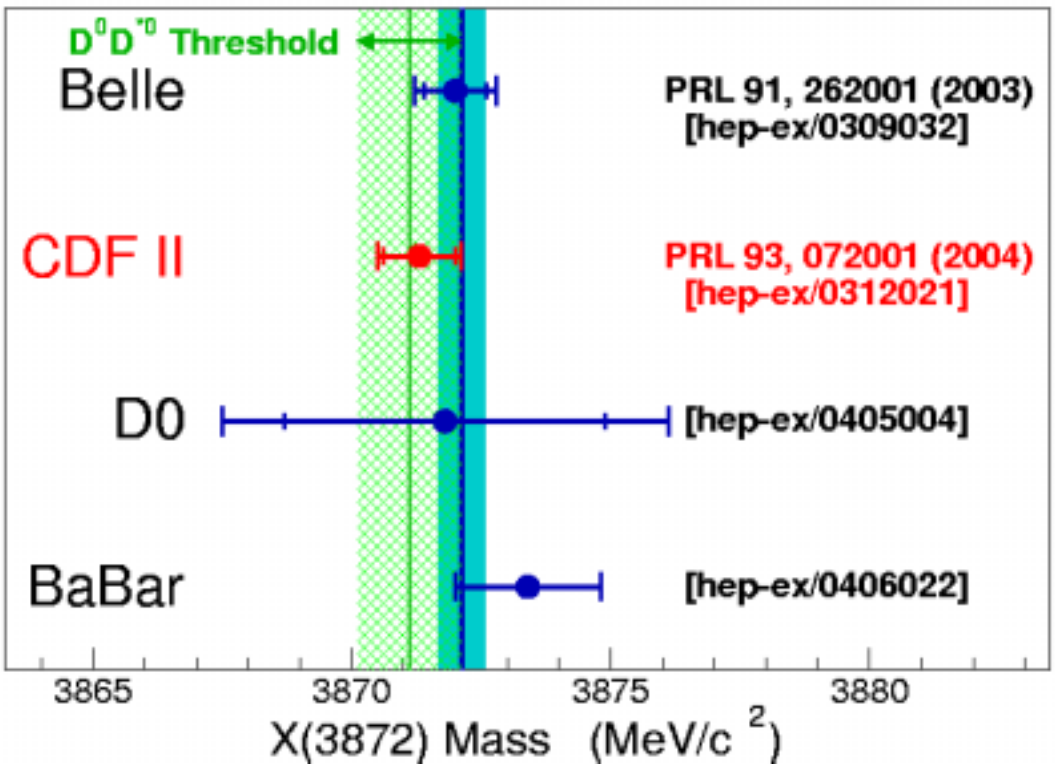
Observed, confirmed, and established

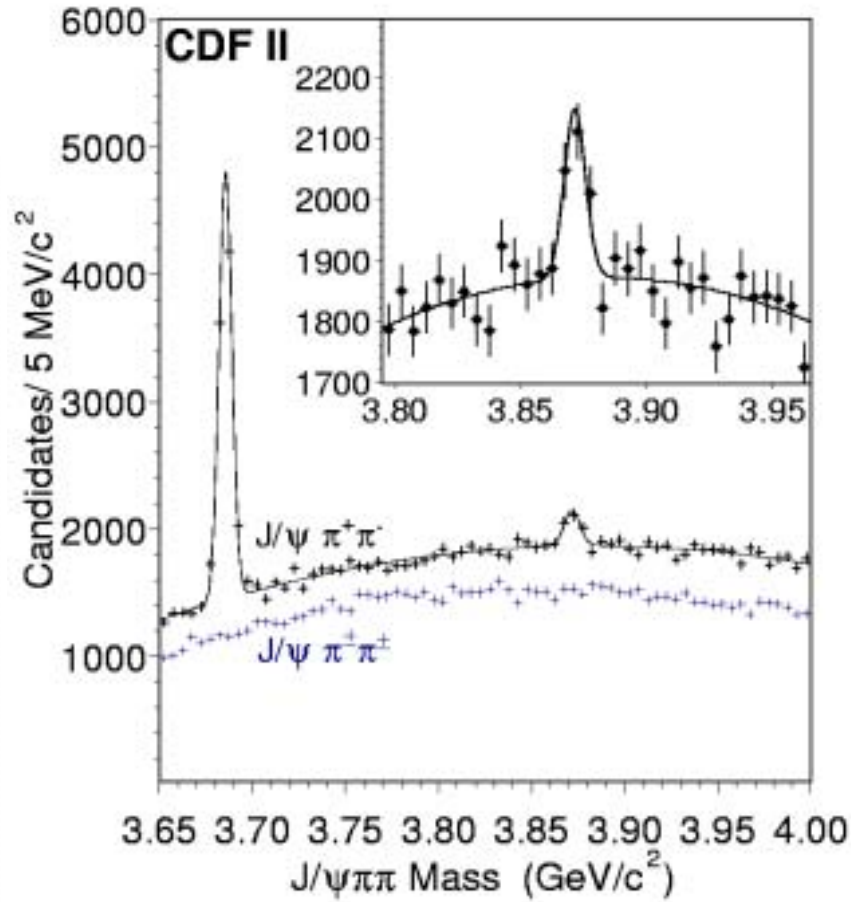
Is it charmonium or something else?

DD* bound state?

$p_T(J/\psi) > 4$ GeV/c

$P_T(\mu) > 400$ MeV/c





X(3872) Studies at CDF

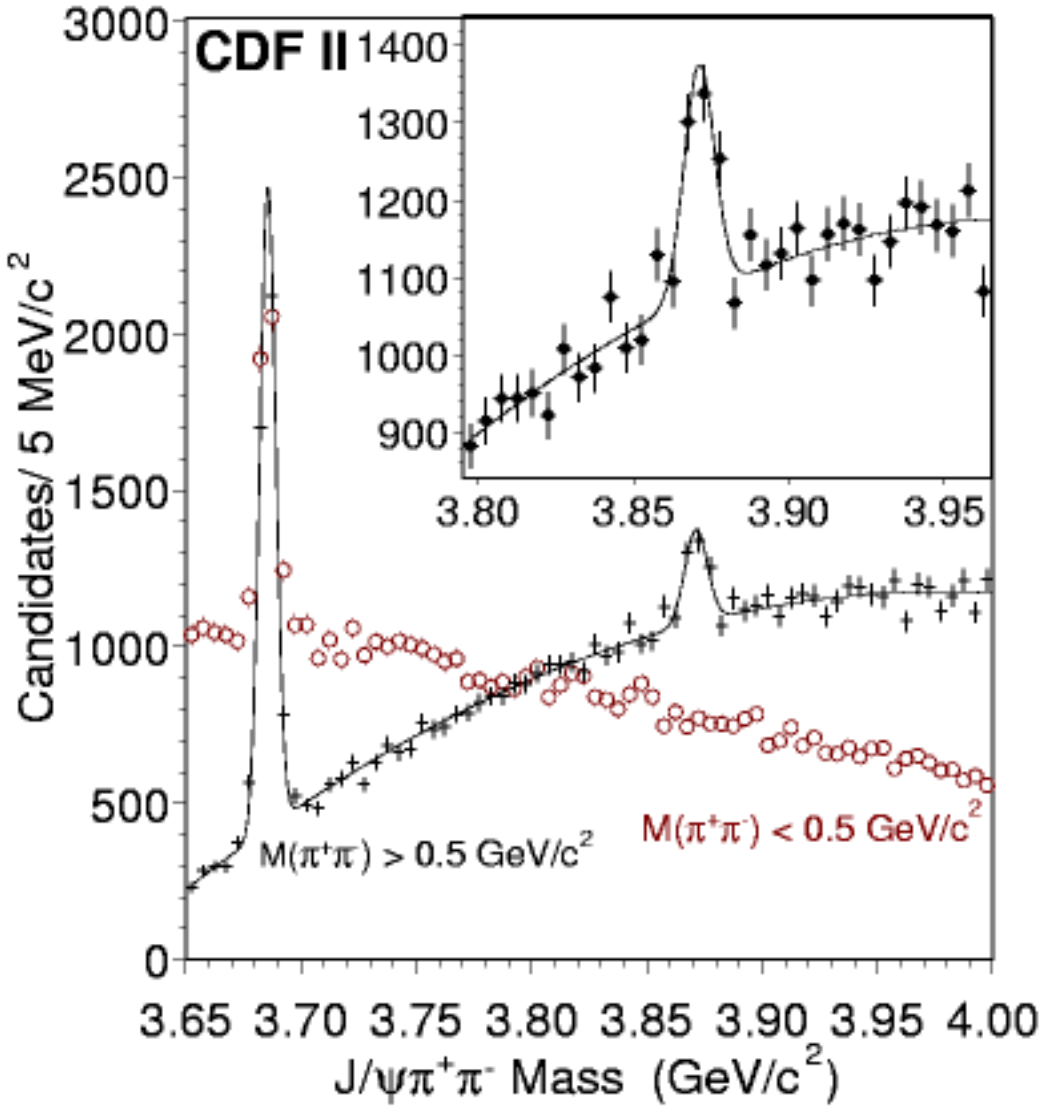
Belle results favors large M(ππ)

CDF splits sample into high an low M(ππ) regions

M(ππ) < 500 MeV/c^2: No observed signal

M(ππ) < 500 MeV/c^2: All signal ...

CDF currently studying M(ππ) distribution



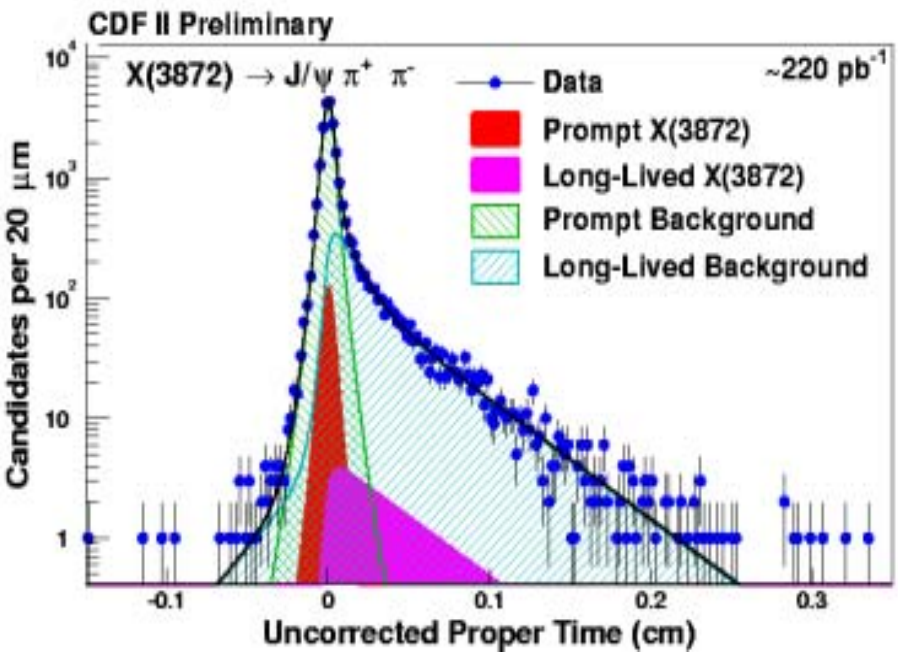
X Production: Prompt vs. b decays

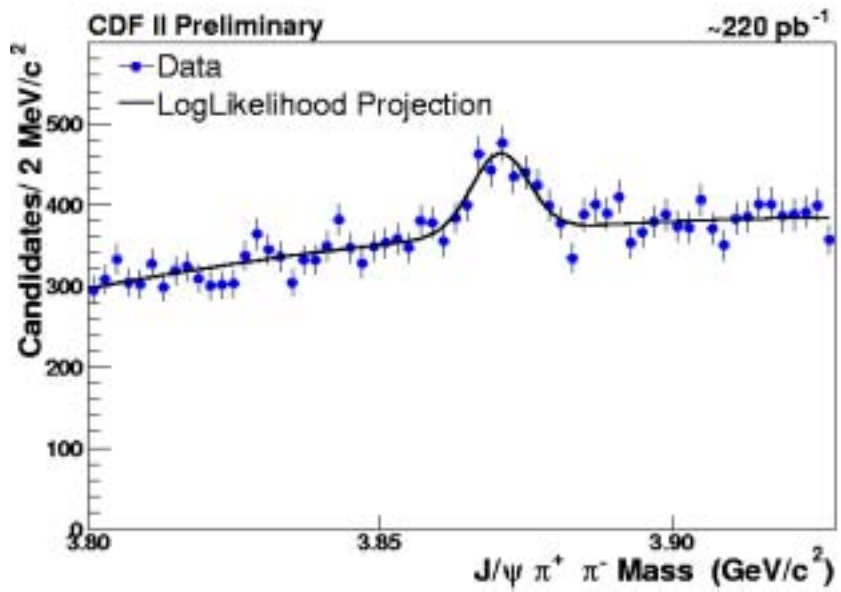
At Belle and BaBar all X(3872) comes from b decays

CDF: Fit for prompt and displaced fractions with simultaneous mass and $c\tau$ likelihood fit

Result: b-fraction = 16.1 ± 4.9(stat.) ± 2.0(syst.)%

Compare to $\psi(2S)$ b-fraction of ~ 28%





X Production at CDF: Summary

X production mostly prompt! Production mechanism appears similar to $\psi(2S)$

Plans for future study:

- $M(\pi\pi)$ distribution
- Relative production cross section to $\psi(2S)$
- Angular measurements

It would be nice to have theoretical production models to compare