Charm Physics at the Tevatron

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(For the CDF and D0 collaborations)

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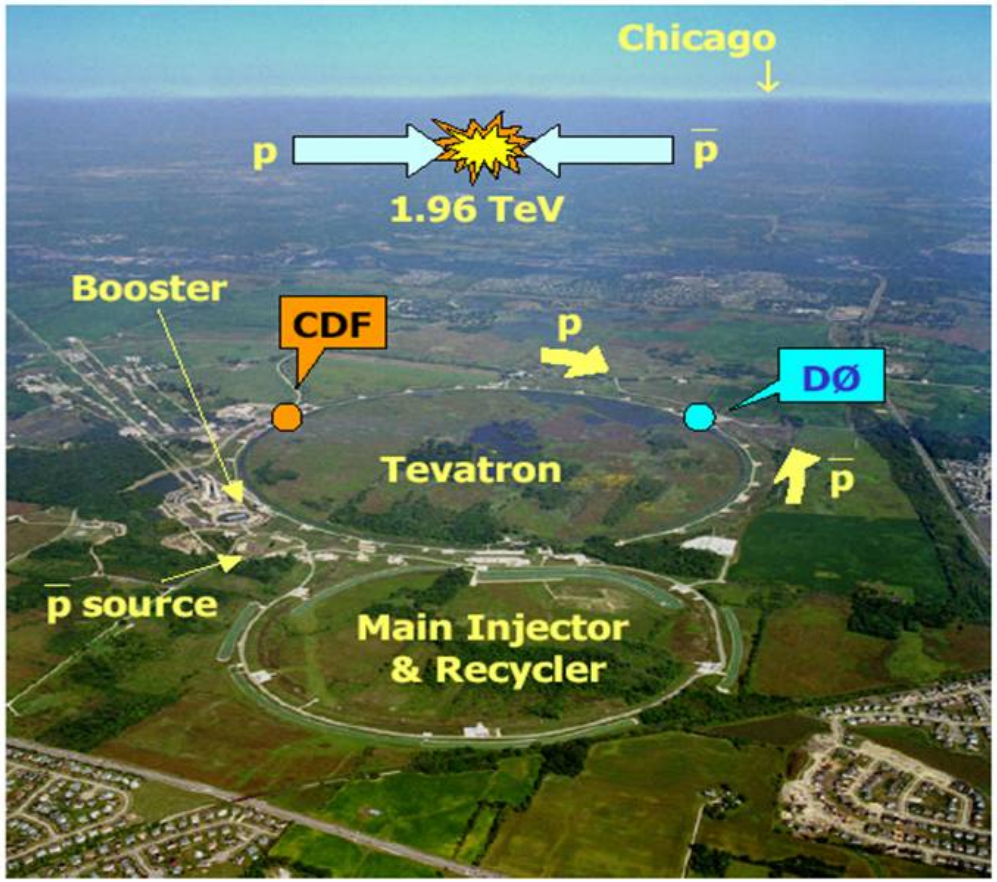
Outline

- The Tevatron
- The CDF and D0 Detectors
- Triggers for B/Charm
  - Silicon Vertex Tracker (SVT)
  - Triggers at D0 and CDF
- Cross Sections
  - J/ψ Cross Section
  - Direct Charm Cross Section
- CP Violation in D's
- Rare Decay: Search for FCNC
- Spectroscopy
  - χ_c Observation
  - Exotic D_s search
  - Confirmation of X(3872)
- Outlook

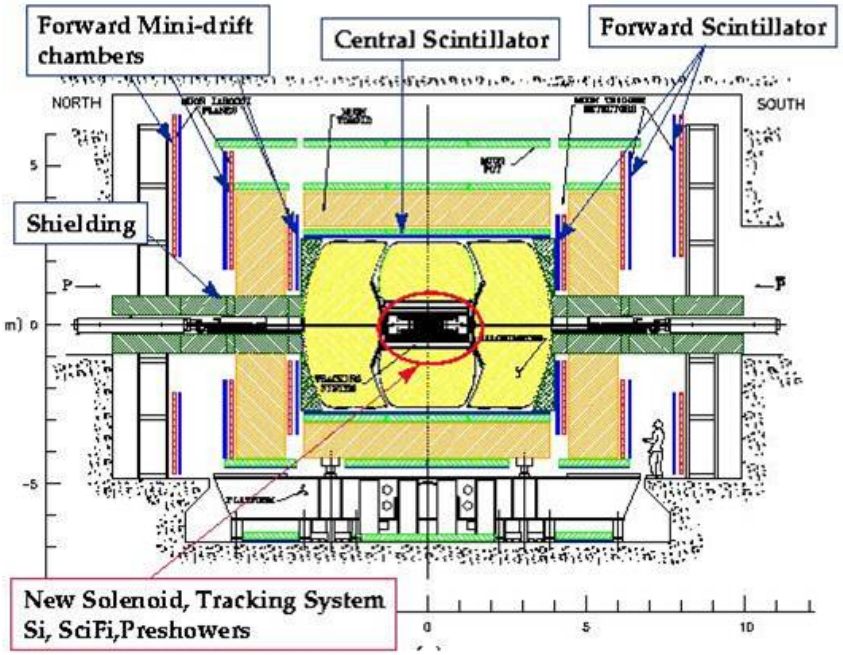
The Tevatron

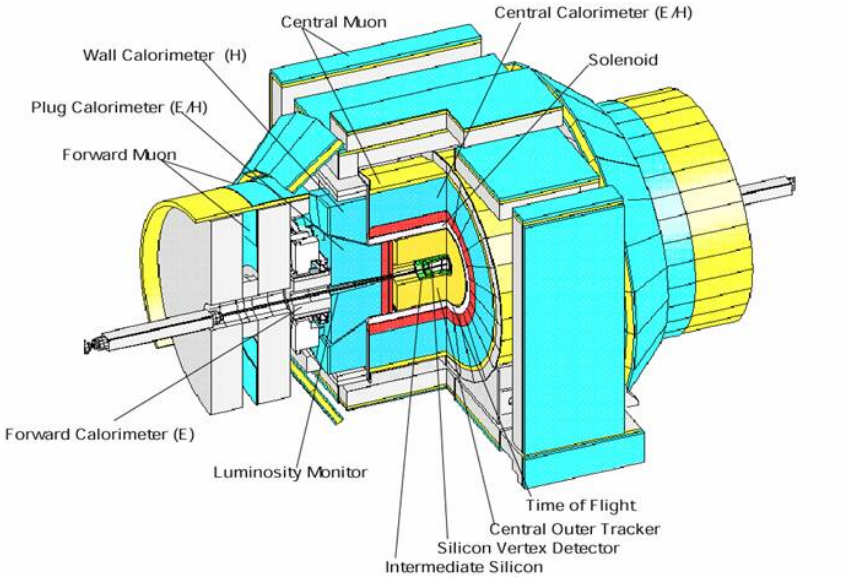


- # of bunches increased: 6X6(3500 ns) to 36X36(396ns)
- Peak Luminosity:
  - 0.16 x $10^{32}\ cm^{-2}s^{-1}$ (Run I)
  - 0.8 x $10^{32}\ cm^{-2}s^{-1}$ (Run II) by 2005
  - (Record: 0.52) (Run II)
  - 2-4 x $10^{32}\ cm^{-2}s^{-1}$ (before LHC)
- Int. Luminosity:
  - $\sim$ 2 fb^{-1} by 2005 (Run II)
  - 330 pb^{-1} delivered
  - 220 pb^{-1} to tape
  - 6-9 fb^{-1} before LHC (Run II)

The CDF and D0 Detectors

- Both Detectors
  - silicon vertex detector (New for D0)
  - solenoid (New for D0)
  - central tracking
  - high rate trigger/DAQ system
  - calorimeter & muon systems

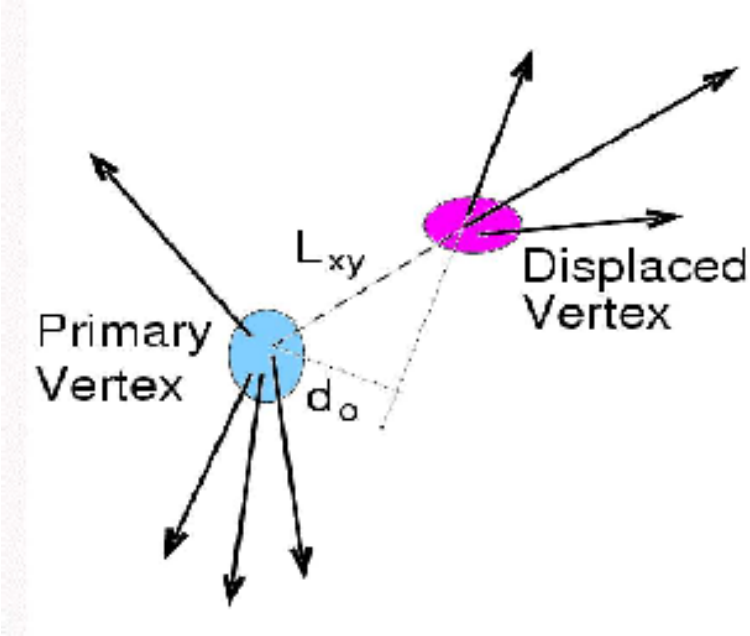




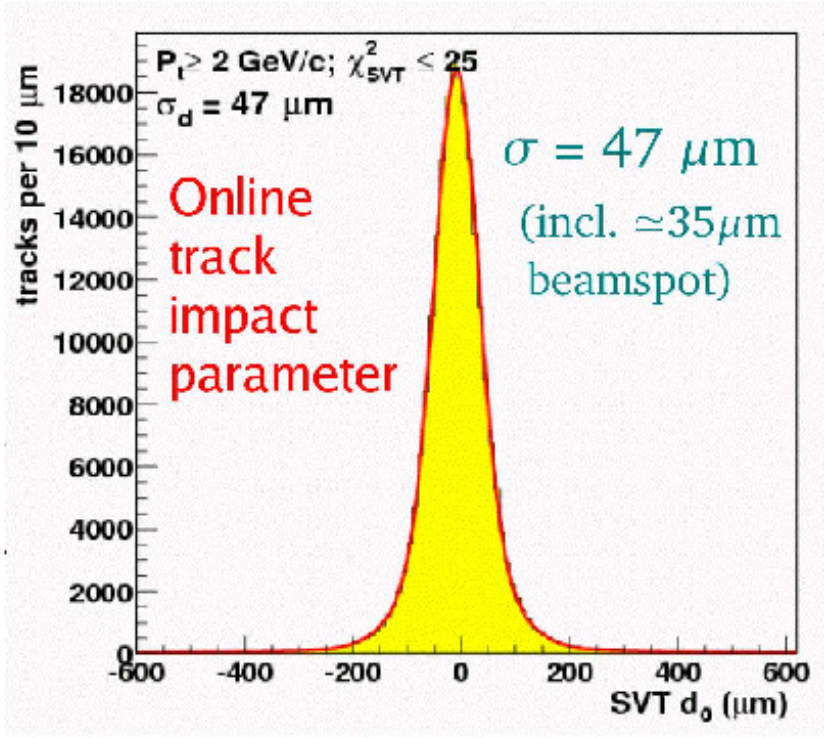
- D0 Detector
  - Excellent electron & muon ID
  - Excellent track acceptance
- CDF Detector
  - Silicon vertex trigger
  - Particle ID (TOF and dE/dx)
  - Excellent mass resolution

Triggers: Revolutionary Silicon Vertex Tracker(SVT)

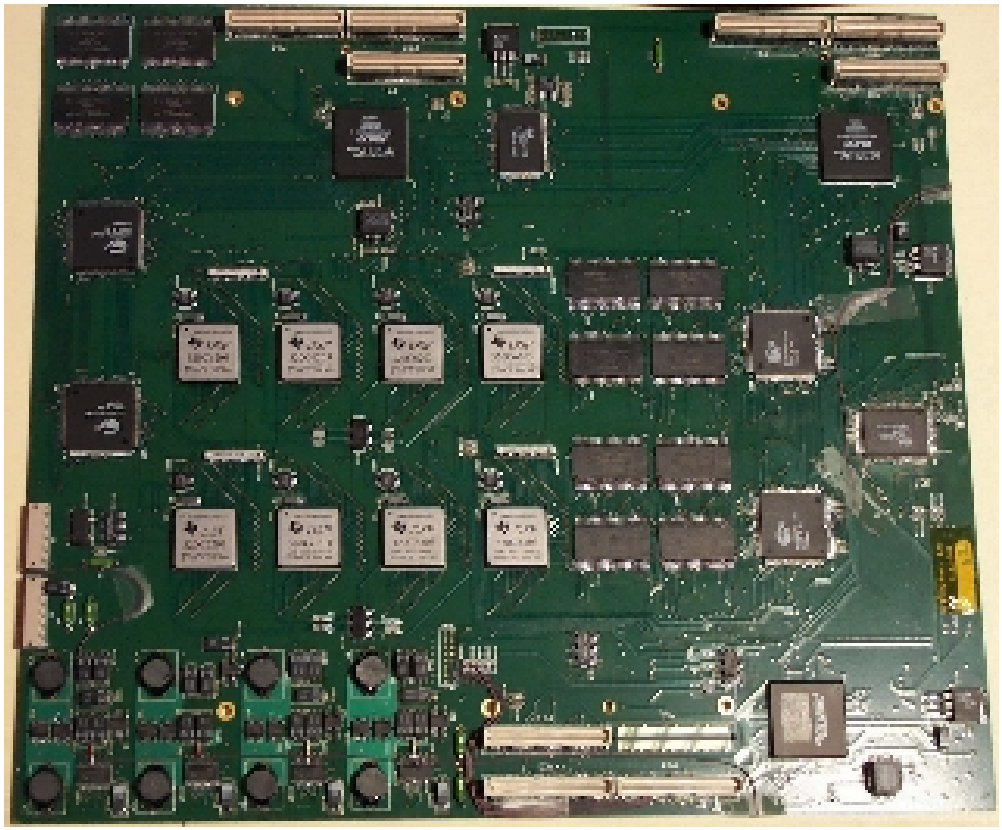
- Never had hadronic B trigger at Hadron collider (challenging background, high rate)
- Seeded by L1 drift chamber trigger tracks, VME boards find & fit in a 15 μs pipeline, with offline accuracy.
- Significantly reduce L2 trigger rate



- Increase physics sensitivity
  - CDF as "Charm Factory"
  - Hadronic B trigger. $B \rightarrow hh$, $B_s \rightarrow D_s\pi$
  - Higgs/new particles decaying into b/c quarks



The D0 Silicon Track Trigger

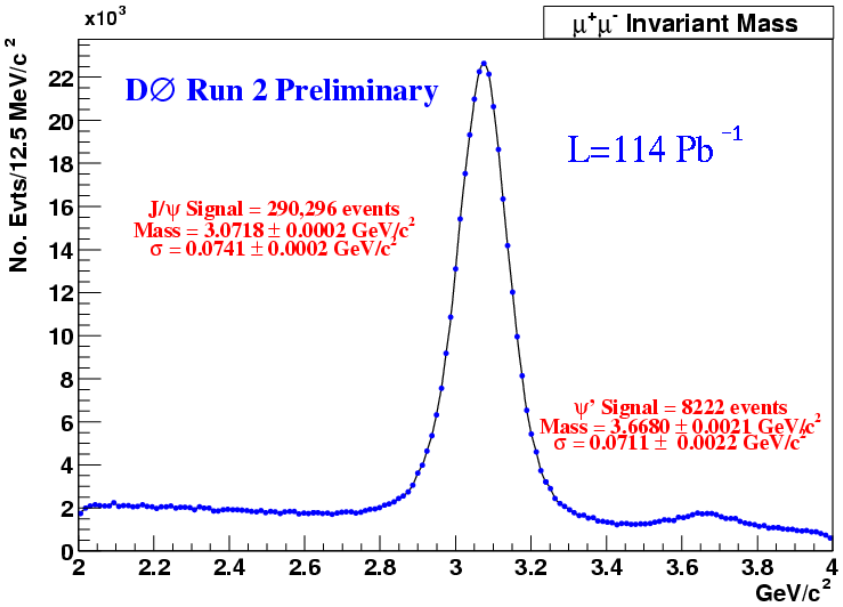


- D0 Track Fit card

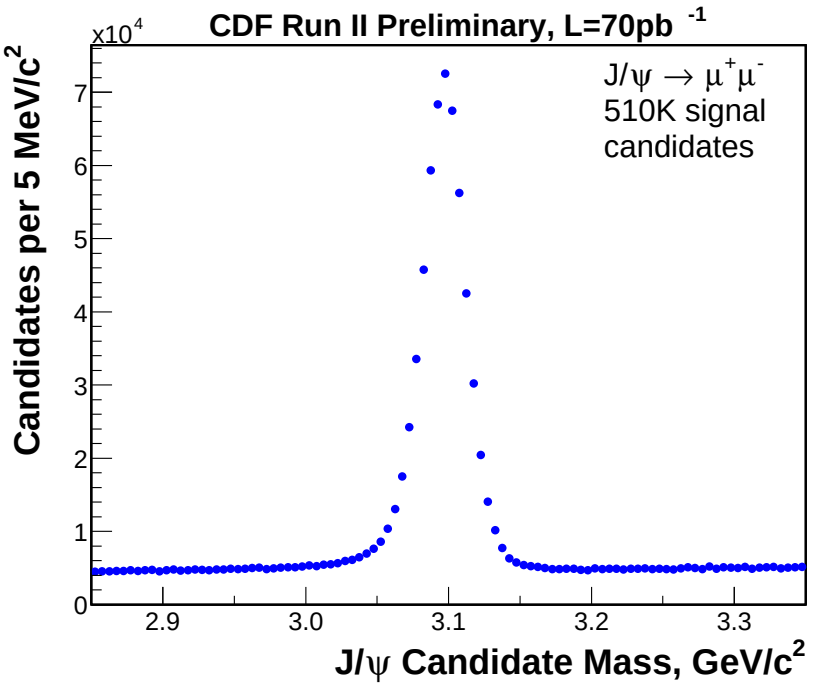
- Fully built
- In the final commissioning states
- Expect to take data shortly after the shutdown

Triggers for B/Charm Physics

- D0 Di-muon-Trigger
  - $J/\psi \rightarrow \mu\mu$
  - Two μ ($|\eta| < 2$)
  - $p_T > 2 - 4$ GeV, η dependent

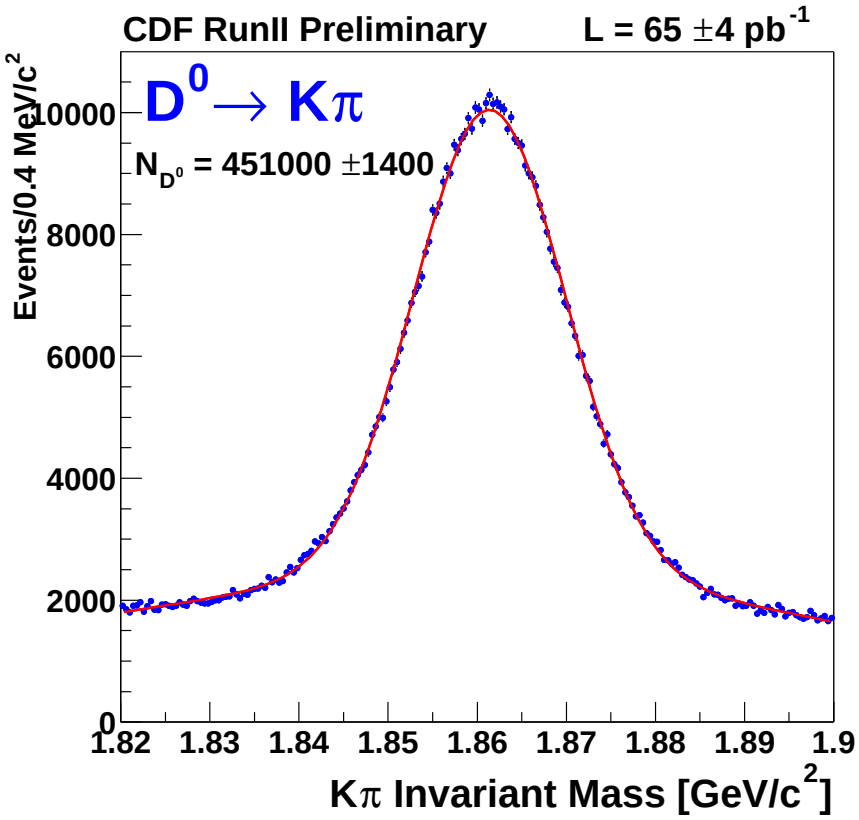


- CDF Di-muon-Trigger
  - $J/\psi \rightarrow \mu\mu$
  - Two central μ ($|\eta| < 1.0$)
  - $p_T > 1.5$ GeV



Triggers for B/Charm Physics

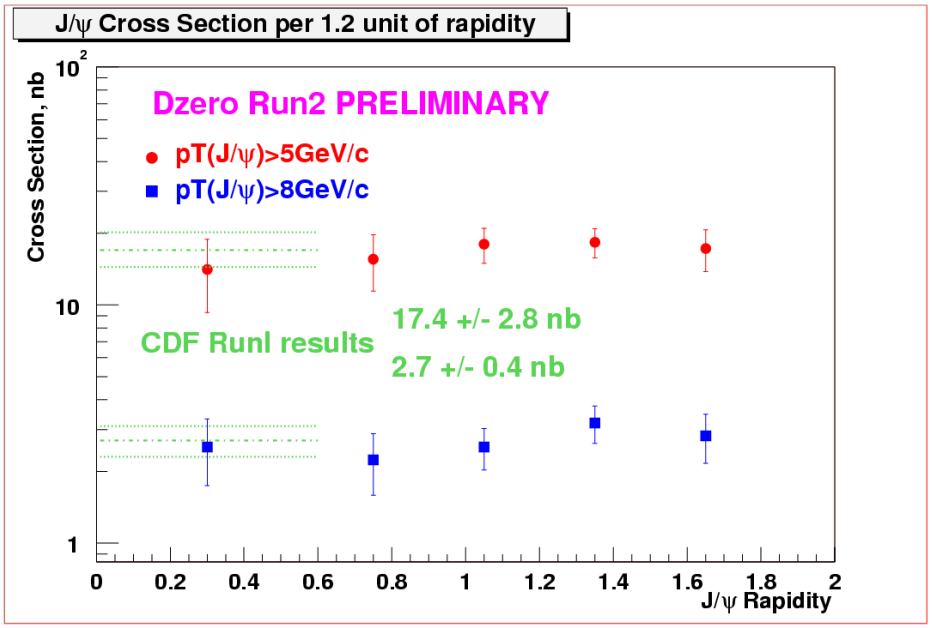
- CDF Two-Track-Trigger(TTT)
  - Hadronic Decays
  - two displaced tracks
  - $p_T > 2$ GeV, $d_0 > 100\mu m$
  - $\Sigma p_T > 5.5$ GeV
- Large sample: D^0, D_s, D*...



Cross Section: Introduction and D0 J/ψ Cross Section

Introduction:

- Run I meas., Orders of magnitude larger than Color singlet
- New ingredients from theorists
  - Gluon fragmentation important
  - Color octet contribution important...
  - Agree better than 50%



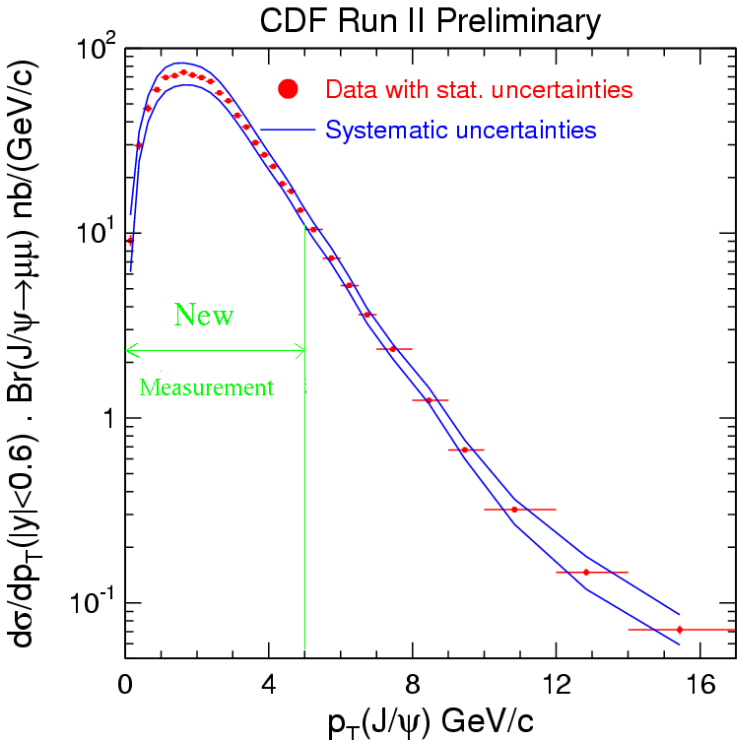
- D0 J/ψ $|\eta|$ reach of 1.8, σ vs J/ψ $|\eta|$
- CDF $p_T(J/\psi)$ down to 0, σ vs J/ψ p_T
- D0+CDF: Whole picture!

- Dimuon triggers, 4.7 pb^{-1} of data
- Two p_T ranges
- $\sim$ Overall 30% systematic uncertainty
- Agree with D0 Run I and CDF Run I

Cross Section: CDF and D0 J/ψ Cross Section

- di-muon trigger, 39.7 pb^{-1} of data
- cover whole J/ψ p_T range
- Total and diff. incl. cross section (nb)

$\sigma(p\bar{p} \to J/\psi, |y| < 0.6) * Br(J/\psi \to \mu\mu) = 240 \pm 1 \pm 30$



- σ includes direct, feed down, B decays
- For $p_T > 5$ GeV, similar to Run I

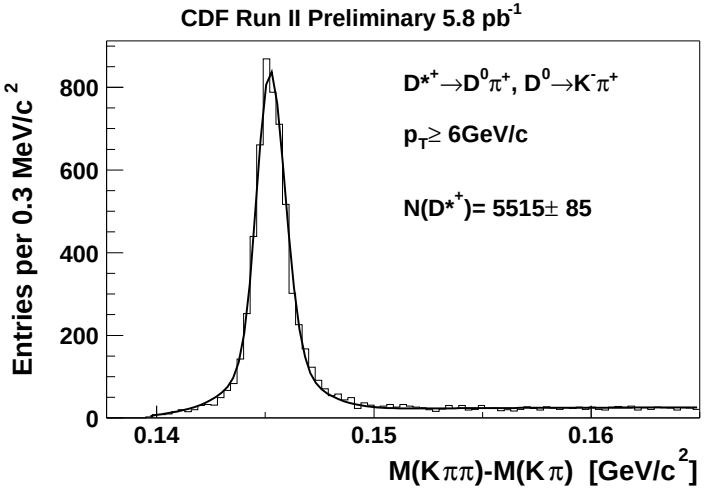
  $\sigma = 20.8 \pm 0.4 \pm^{+3.1}_{-3.5}$, Run II

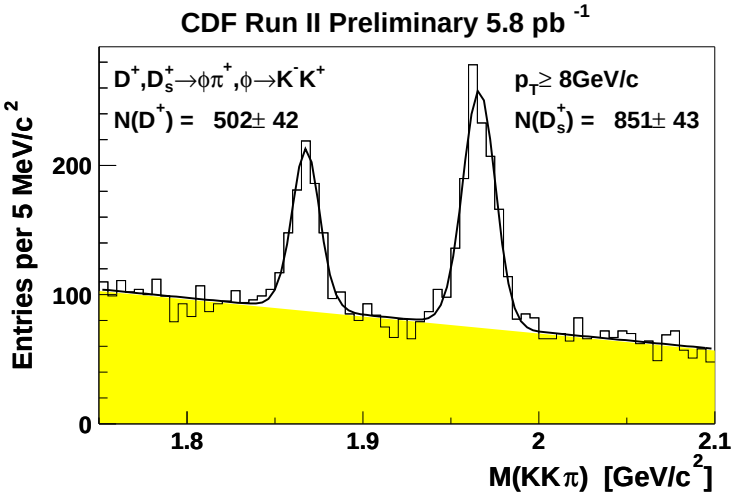
  $\sigma = 17.4 \pm 0.1 \pm^{+2.6}_{-2.8}$, Run I

- "Lifetime" distribution to extract B fraction (See Petros's talk)
- prospective measurements(D0+CDF):
  - $\psi(2s)$ cleaner(prompt/secondary)
  - high p_T, $p_T^2 >> m^2$ theoretically reliable
  - polarization, high p_T–Run I discrepancy
  - $\Upsilon(1S, 2S, 3S)$ Cross section/polarization
  - χ_c Cross section

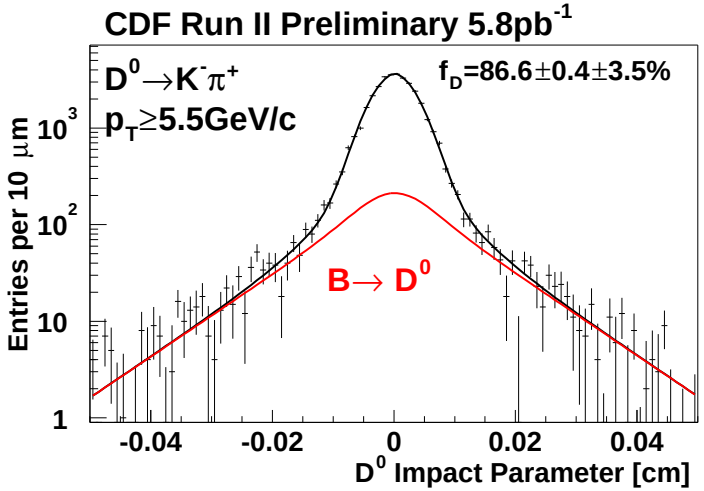
Cross Section: CDF Charm Cross Section

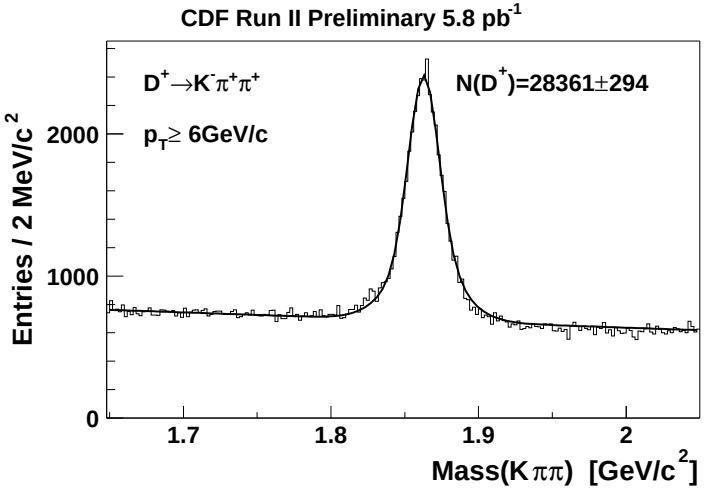
- two track trigger– charm "factory".
- direct or from b decay



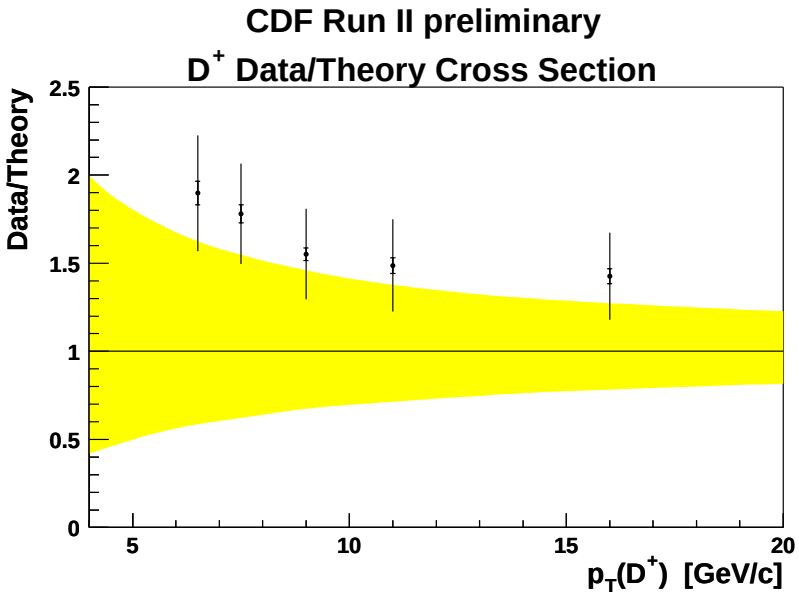


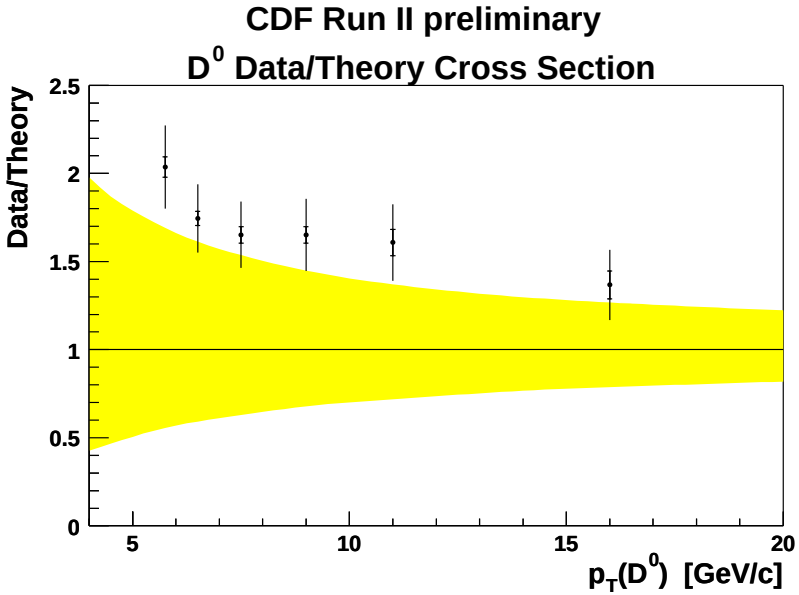
- direct fraction from impact parameter

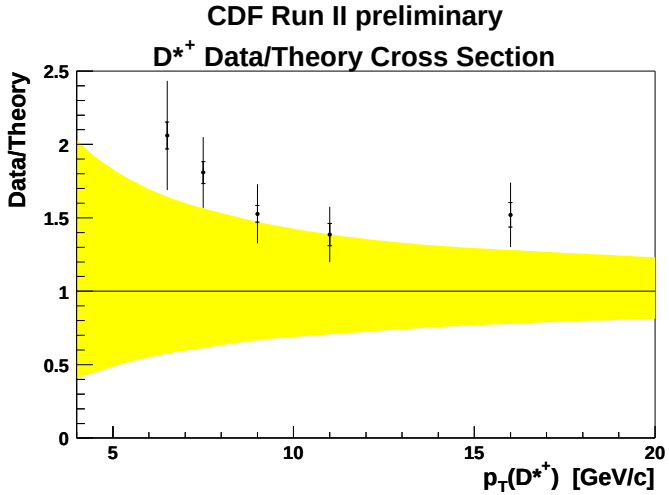




Cross Section: CDF Charm Cross Section







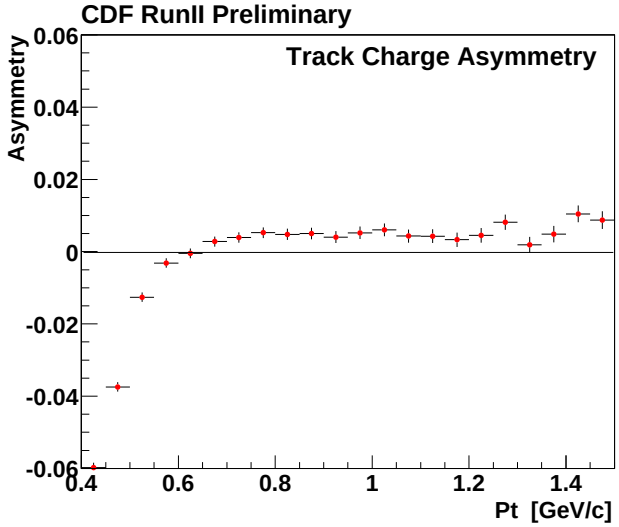
CTEQ6M PDF
m_c =1.5 GeV
Fragm. Func:
from ALEPH
Renom. & fact. scale
$m_T = (m_c^2 + p_T^2)^{1/2}$
Uncertainty:
vary scale: 0.5 to 2

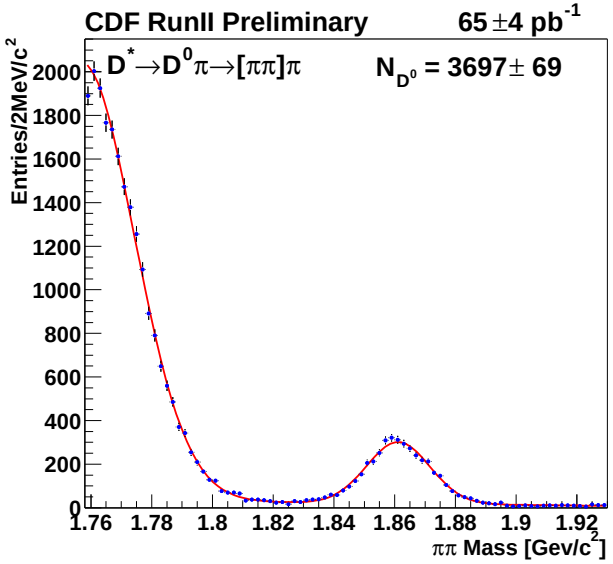
- $\sigma(D^0, p_T > 5.5\text{GeV}) = 13.3 \pm 0.2 \pm 1.5 \mu b$
- $\sigma(D^{*+}, p_T > 6\text{GeV}) = 5.2 \pm 0.1 \pm 0.8 \mu b$
- $\sigma(D^+, p_T > 6\text{GeV}) = 4.3 \pm 0.1 \pm 0.7 \mu b$
- $\sigma(D_s^+, p_T > 8\text{GeV}) = 0.75 \pm 0.05 \pm 0.22 \mu b$

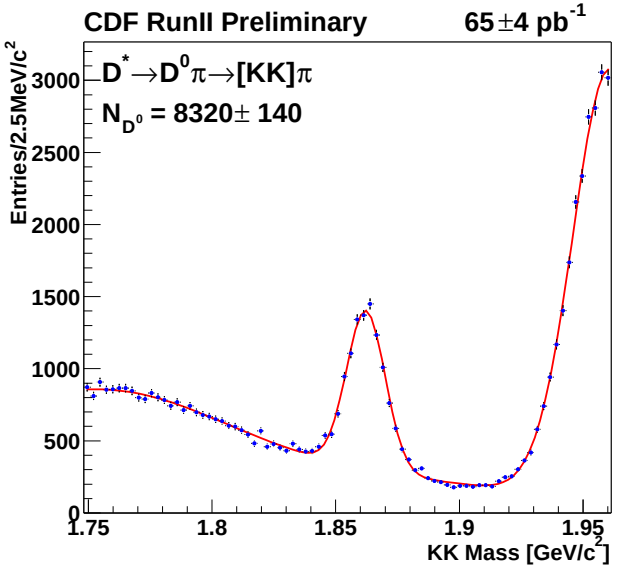
- Measurements higher than FONLL prediction by M. Cacciari, P. Nason. JHEP 0309, 006(2003)
- Agree within uncertainties

CP violation: CDF Cabbibo suppressed D decay

- CPV asy. for $D^0 \to KK(\pi\pi)$
- Tag–soft π, $D^{*+} \to D^0\pi^+$, $D^{*-} \to \bar{D}^0\pi^-$
- correction–intrinsic detector charge asymmetry



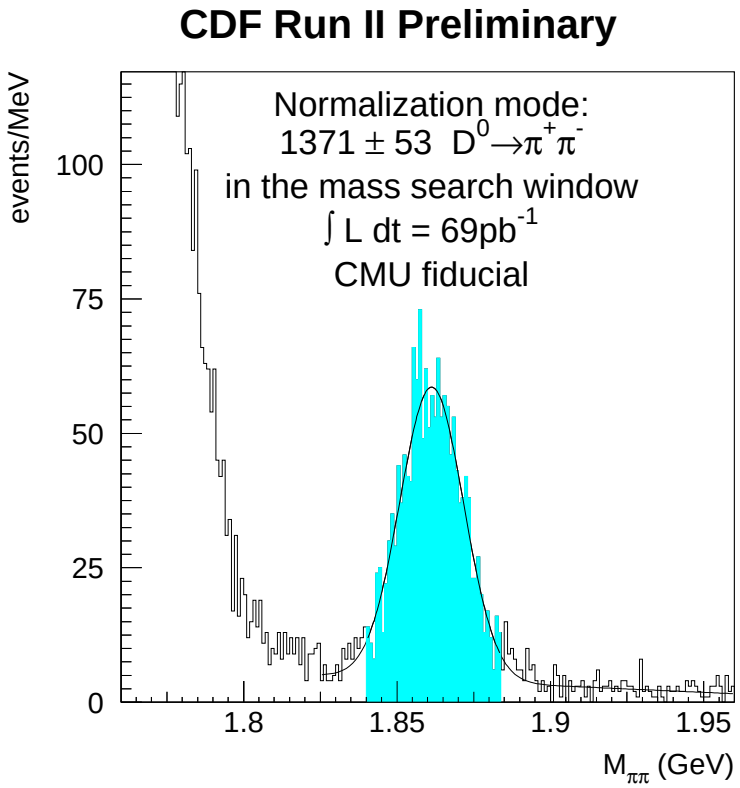


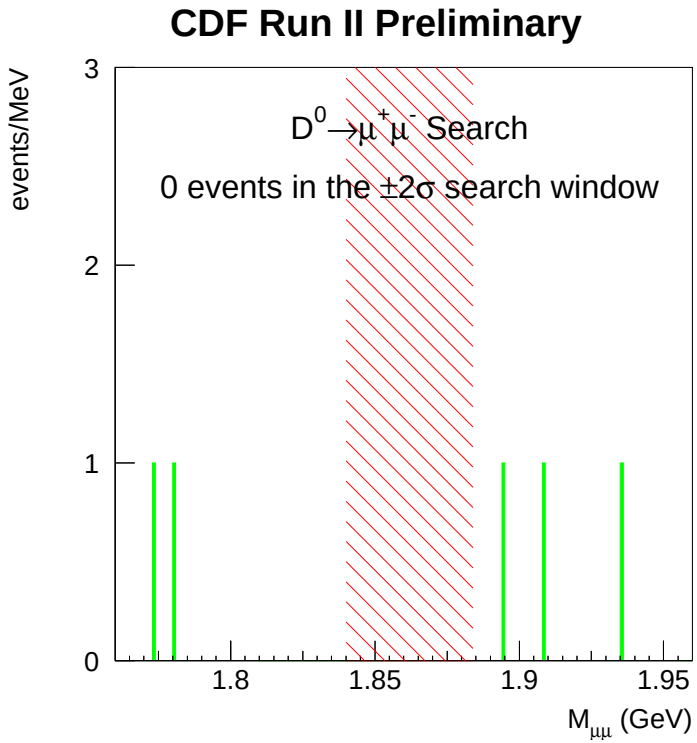


- $\frac{\Gamma(D^0\to KK)}{\Gamma(D^0\to K\pi)} = 9.38 \pm 0.18 \pm 0.10\%$
  FOCUS 2003: $9.93 \pm 0.14 \pm 0.14\%$
- $\frac{\Gamma(D^0\to \pi\pi)}{\Gamma(D^0\to K\pi)} = 3.686 \pm 0.076 \pm 0.036\%$
  FOCUS 2003: $3.53 \pm 0.12 \pm 0.06\%$
- $\mathcal{A}(D^0 \to KK) = 2.0 \pm 1.7 \pm 0.6\%$, $0.5 \pm 1.6\%$(PDG)
- $\mathcal{A}(D^0 \to \pi\pi) = 3.0 \pm 1.9 \pm 0.6\%$, $0.5 \pm 1.6\%$(PDG)

Rare Decay: FCNC $D^0 \to \mu\mu$

- BR($D^0 \to \mu^+\mu^-$) $\simeq 3\times 10^{-13}$(SM)
- BR to $3 \sim 4 \times 10^{-6}$, R-parity violating SUSY
- $D^{*+} \to D^0\pi^+$ to reduce background
- Normalize to $D^0 \to \pi^+\pi^-$, 69 pb^{-1} from TTT

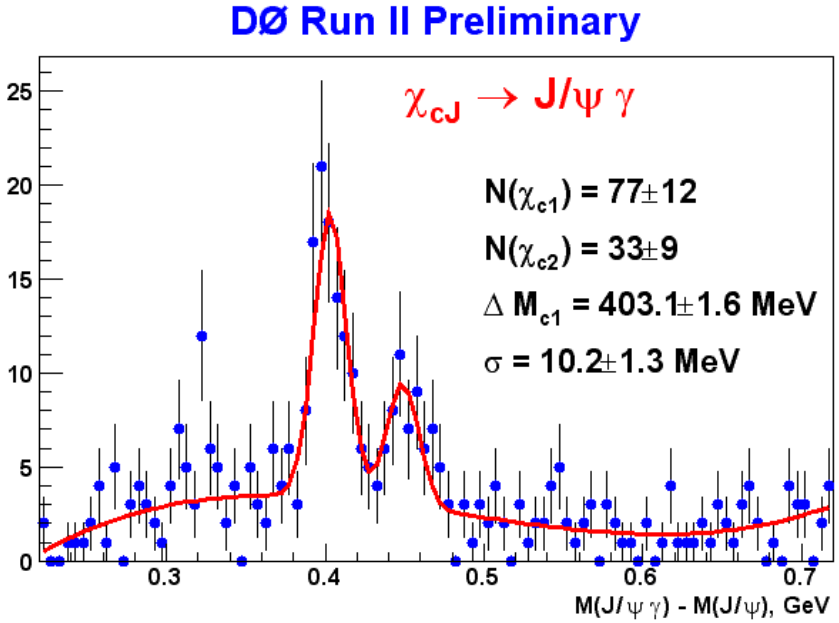




- 1.8 ± 0.7 background events expected
- open blind box, 0 signal observed
- $\frac{\mathcal{B}(D^0\to\mu\mu)}{\mathcal{B}(D^0\to\pi\pi)} = \frac{N_{CL}^{upper}(D^0\to\mu\mu)}{N(D^0\to\pi\pi)} \times \frac{\epsilon(D^0\to\pi\pi)}{\epsilon(D^0\to\mu\mu)}$
- BR($D^0 \to \mu^+\mu^-$) $\leq 2.4 \times 10^{-6}$ at 90% CL
- PDG: BR ($D^0 \to \mu^+\mu^-$) $\leq 4.1 \times 10^{-6}$

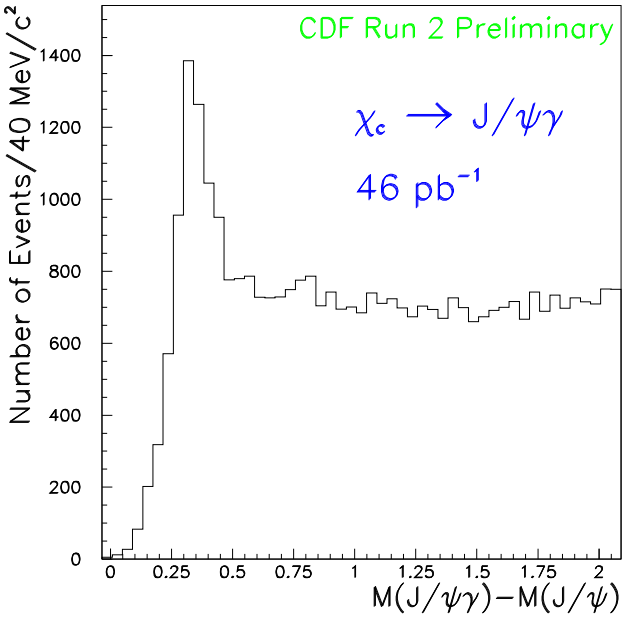
Spectroscopy: observation of χ_c states

- D0 χ_c states via conversion:



- Interesting physics: BR, Cross Section
- di-muon trigger, 114 pb^{-1}
- J/ψ mass window 200 MeV
- γ recon through conversion–e^+e^- pairs
- $p_T(\gamma)>$ 1 GeV

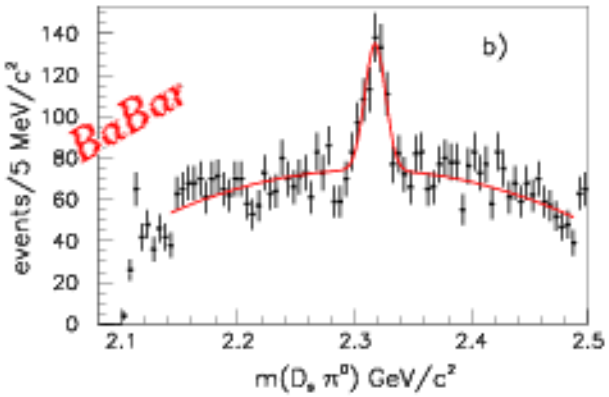
- CDF χ_c states via calorimeter:



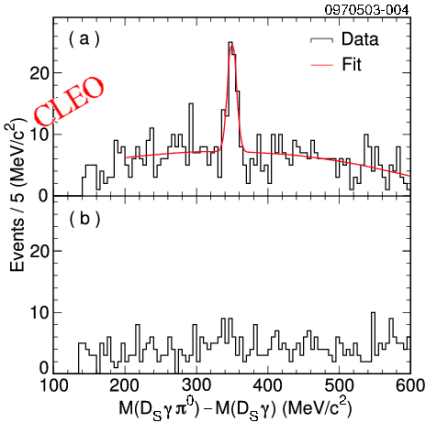
- Interesting physics: Cross Section
- di-muon trigger, 46 pb^{-1}
- $p_T(\mu) > 2$ GeV, J/ψ mass window 80 MeV
- $E_T(\gamma) > 1$ GeV, γ through calorimeter
- $\sigma(B \rightarrow \chi_c X)$ study in progress

Spectroscopy: Search for Exotics

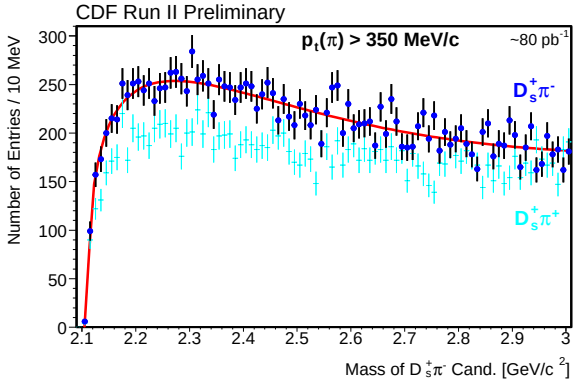
- $D^*_{sJ}(2317)^+ \to D_s^+\pi^0$ (BaBar, Apr.) :
  - Mass not match expectation for nomal D_s^{**}
  - Models wrong or something else?



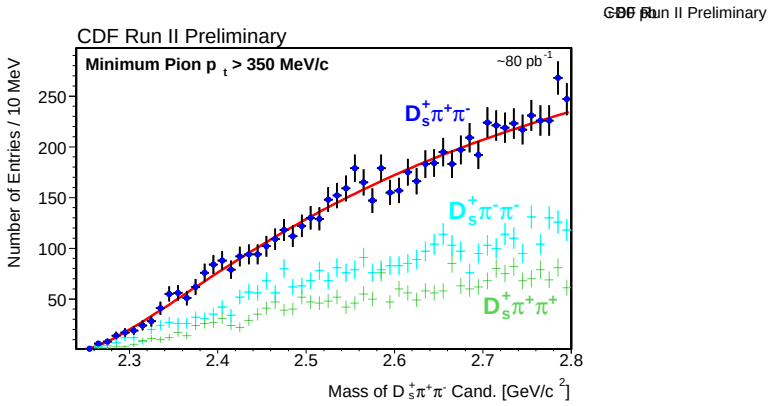
- $D_{sJ}(2463)^+ \to D_s^{*+}\pi^0$ (CLEO) :



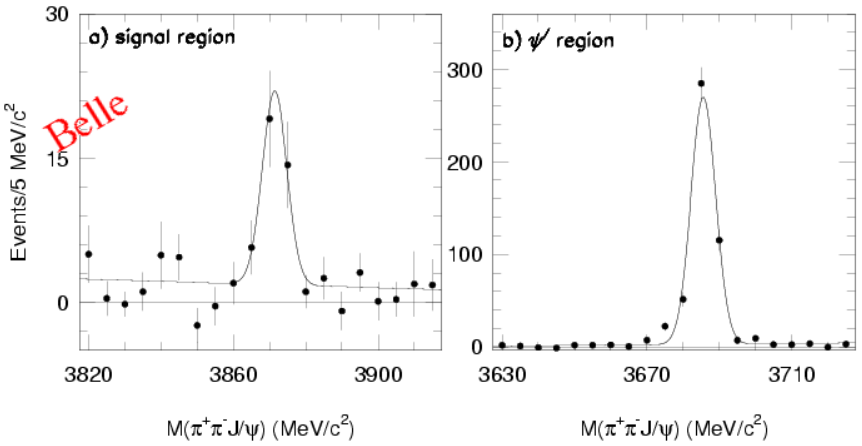
- CDF Search through $D_s^+\pi^-$, $D_s^+\pi^+\pi^-$:
  - If exotic, may have analog states like $D_s^+\pi^-$



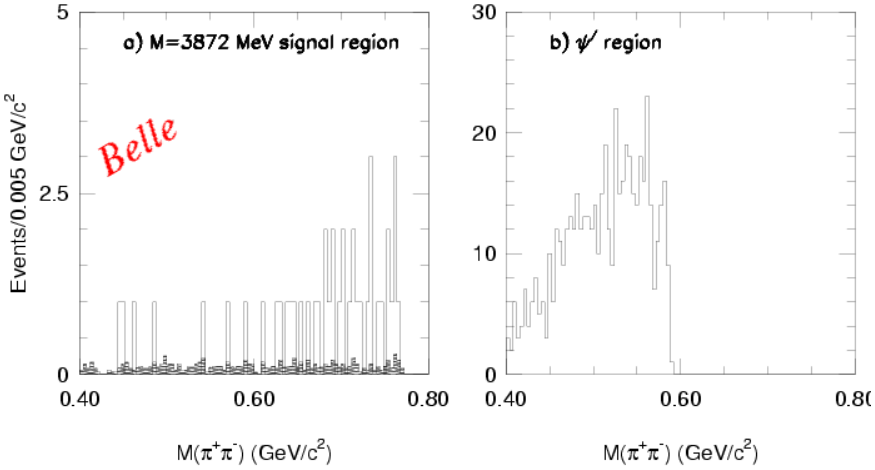
- No Signal Seen in $D_s^+\pi^-$, $D_s^+\pi^+\pi^-$:
  - $D_s\pi^+\pi^-$ allowed if 1^+; forbidden if 0^+
  - if $D^*_{sJ}(2317)$ is the lightest D_s^{**}



Spectroscopy: Confirmation of new 3872 state to $J/\psi\pi^+\pi^-$



- New narrow state – Belle (Aug. 10)
- Using exclusive $B^+ \to J/\psi\pi^+\pi^-K^+$
- A new Charmonium? or something else?



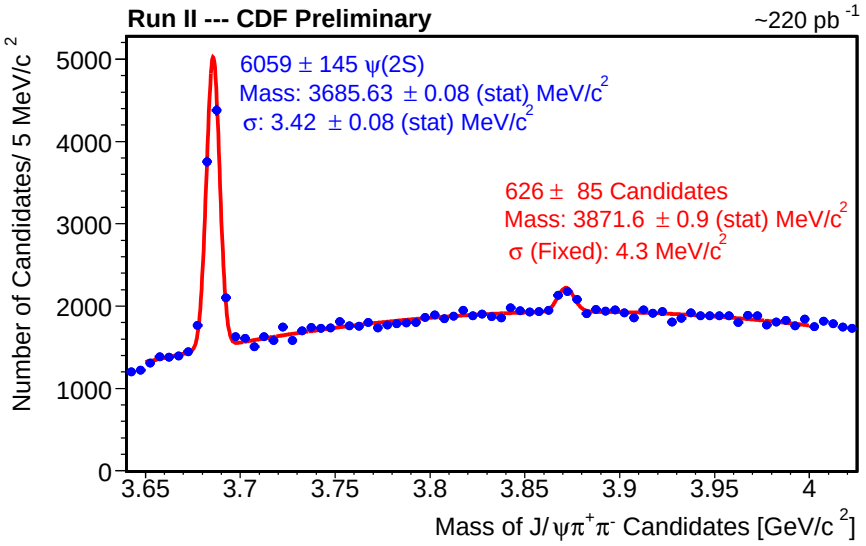
- First Confirmation of Belle's result
- Info. on production mechanisms

- ∼2M $J/\psi(220\ pb^{-1})$ at CDF
- Challenging combin. background
- Use inclusive $J/\psi\pi^+\pi^-X$

- CDF Strategies:
  - minimum p_T's
  - good silicon tracks
  - only tracks in fixed cone
  - optimize $\psi(2s) \to J/\psi\pi^+\pi^-$

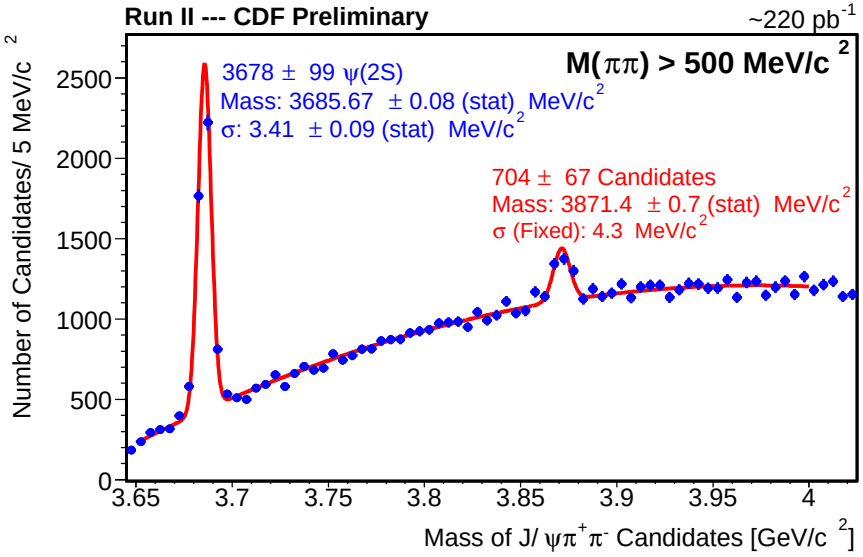
Spectroscopy: Confirmation of new 3872 state to $J/\psi\pi^+\pi^-$

- $\sim$ 600 candidates around 3870 MeV
- Width fixed from $\psi(2S)$ extrapolation
- $M(\pi\pi)$ Cut, Motiv.$\rightarrow$Belle's $M(\pi\pi)$



- After $M(\pi\pi)$ cut, $\sim$ 11 σ Signal
- $M = 3871.4 \pm 0.7 \pm 0.4$ MeV

  Belle: $3872.0 \pm 0.6 \pm 0.5$ MeV

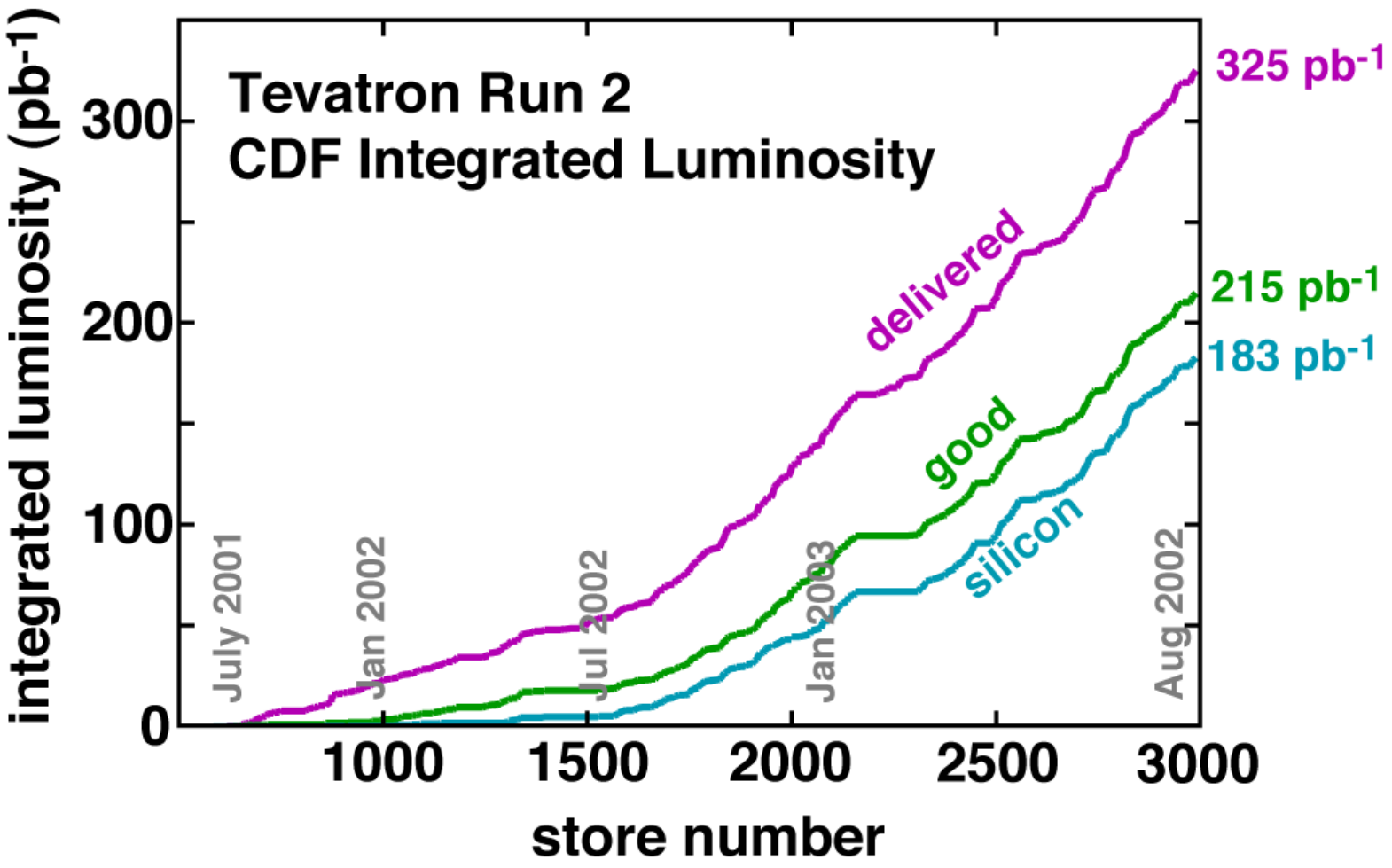


- Good agreement, CDF $\longleftrightarrow$ Belle
- Studies in Progress :
  - Charmonium/ $D\bar{D}^*$ molecule/ X?
  - Large CDF rate $\rightarrow$ Charmonium?
  - $M(\pi\pi)$ Distribution, $J/\psi\rho$ decay?
  - Prompt/Long lived (Stat. limited)?
  - Angular Distribution(Background)?
  - D0 study in progress

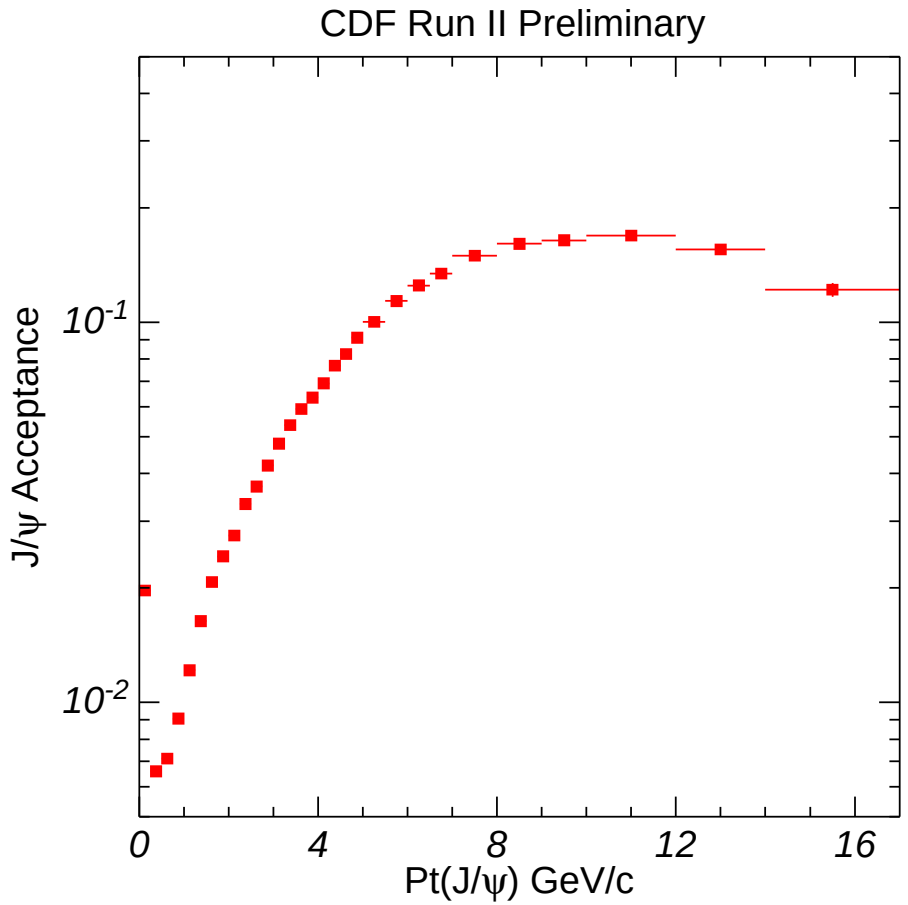
Outlook

- Yield estimate in 220 pb^{-1}
  - D0 $\sim$ 1M J/ψ , CDF $\sim$ 2M J/ψ
  - CDF $\sim$ 300k Tagged D^0 from D^*
  - CDF $\sim$ 900k $D^+ \to K^-\pi^+\pi^+$
- Cross section:
  - D0+CDF: Cross section/ Polarization–J/ψ, ψ', Υ, χ_c,...
  - CDF: $c\bar{c}$ correlations
- D^0 mixing(CDF):
  - $\Delta\Gamma$: $D^0 \to \pi^+\pi^-$ vs $D^0 \to K^-\pi^+$
  - wrong sign $D^0 \to K^+\pi^-$
- Direct CP violation(CDF):
  - Update $D^0 \to \pi^+\pi^-$, $D^0 \to K^+K^-$
  - New channel $D^+ \to \pi^+\pi^+\pi^-$
- FCNC(D0+CDF):
  - Update $D^0 \to \mu^+\mu^-$
  - New channel $D^+ \to \pi^+\mu^+\mu^-$
- Spectroscopy:
  - CDF: More Studies on X(3872)
  - D0+CDF: More Searches...

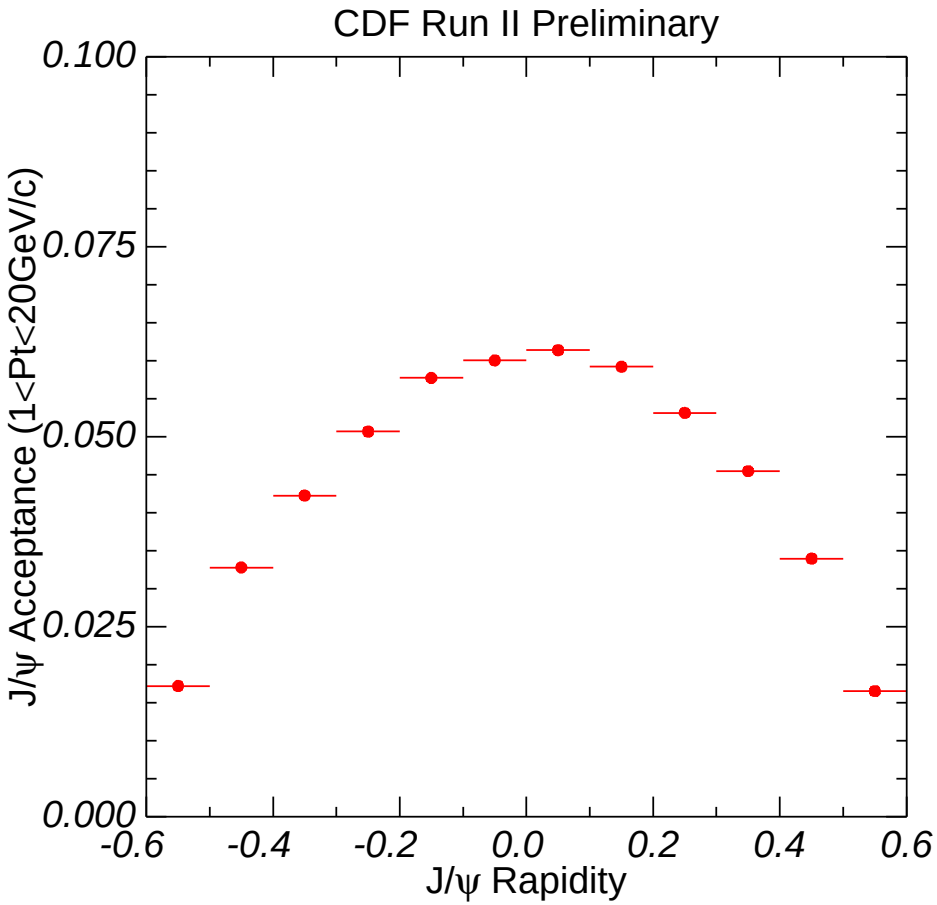
Backup 1


Tevatron Run 2
CDF Integrated Luminosity
integrated luminosity (pb-1)
store number
0
100
200
300
1000
1500
2000
2500
3000
July 2001
Jan 2002
Jul 2002
Jan 2003
Aug 2002
delivered
good
silicon
325 pb-1
215 pb-1
183 pb-1

Backup 2


CDF Run II Preliminary
J/ψ Acceptance
10^{-1}
10^{-2}
0
4
8
12
16
Pt(J/ψ) GeV/c

Backup 3


CDF Run II Preliminary
0.100
0.075
0.050
0.025
0.000
J/ψ Acceptance (1<Pt<20GeV/c)
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
J/ψ Rapidity