Studies of the B_c meson at CDF

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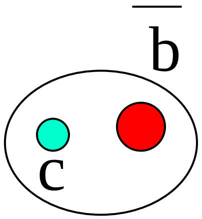
For the CDF Collaboration

What the B_c is

Heaviest ground state of two different quarks



$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix}$$

Lifetime too short to form mesons

$u\bar{b}$	$\bar{u}c$	$u\bar{s}$	$u\bar{d}$	$u\bar{u}$	B^+ D^0 K^+ π^+ (π^0,ρ..)
$d\bar{b}$	$\bar{d}c$	$d\bar{s}$	$d\bar{d}$		B^0 D^+ K^0 π^0
$s\bar{b}$	$\bar{s}c$	$s\bar{s}$			B_s D_s φ
$c\bar{b}$	$c\bar{c}$				**B_c** J/Ψ
$b\bar{b}$					Y

Observed by CDF run I in 1998, in semileptonic decays:

$$B_c^+ \to J/\psi\ \ell^+\ \nu\ X; \quad J/\psi \to \mu^+\mu^-$$

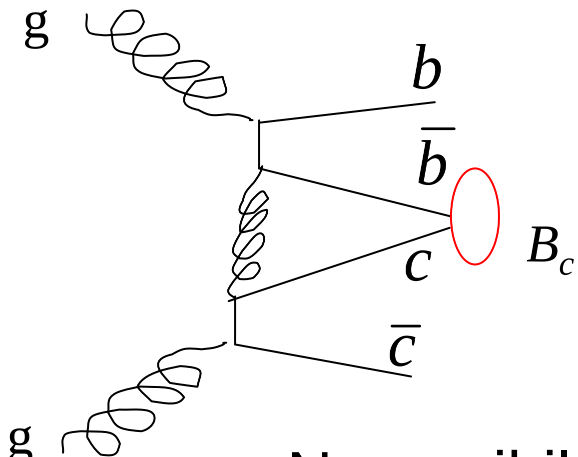
M=6.4±0.39±0.13 GeV

PRL 81, 2432 (1998) and PRD 58, 112004 (1998)

Production and decay

Latest cross section calculation: 7.4 nb

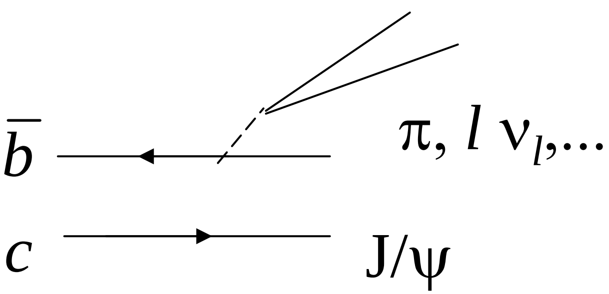
Phys. Lett. B605, 311 (2005)

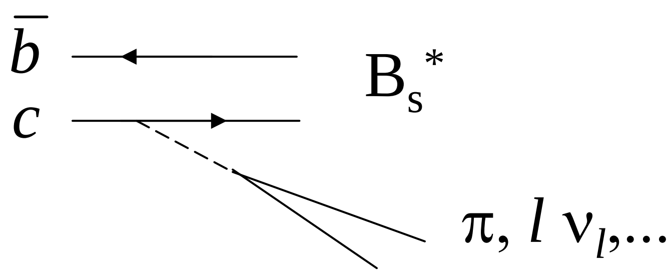


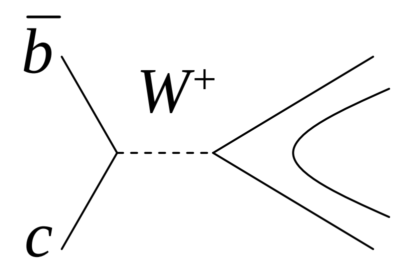
$$O(\alpha_s{}^4) \approx 10^{-3}\sigma(B^+)$$

No annihilation into gluons, only weak decays

$$\Gamma_{Bc} = \Gamma_b(\approx 25\%) + \Gamma_c(\approx 65\%) + \quad \Gamma_W$$



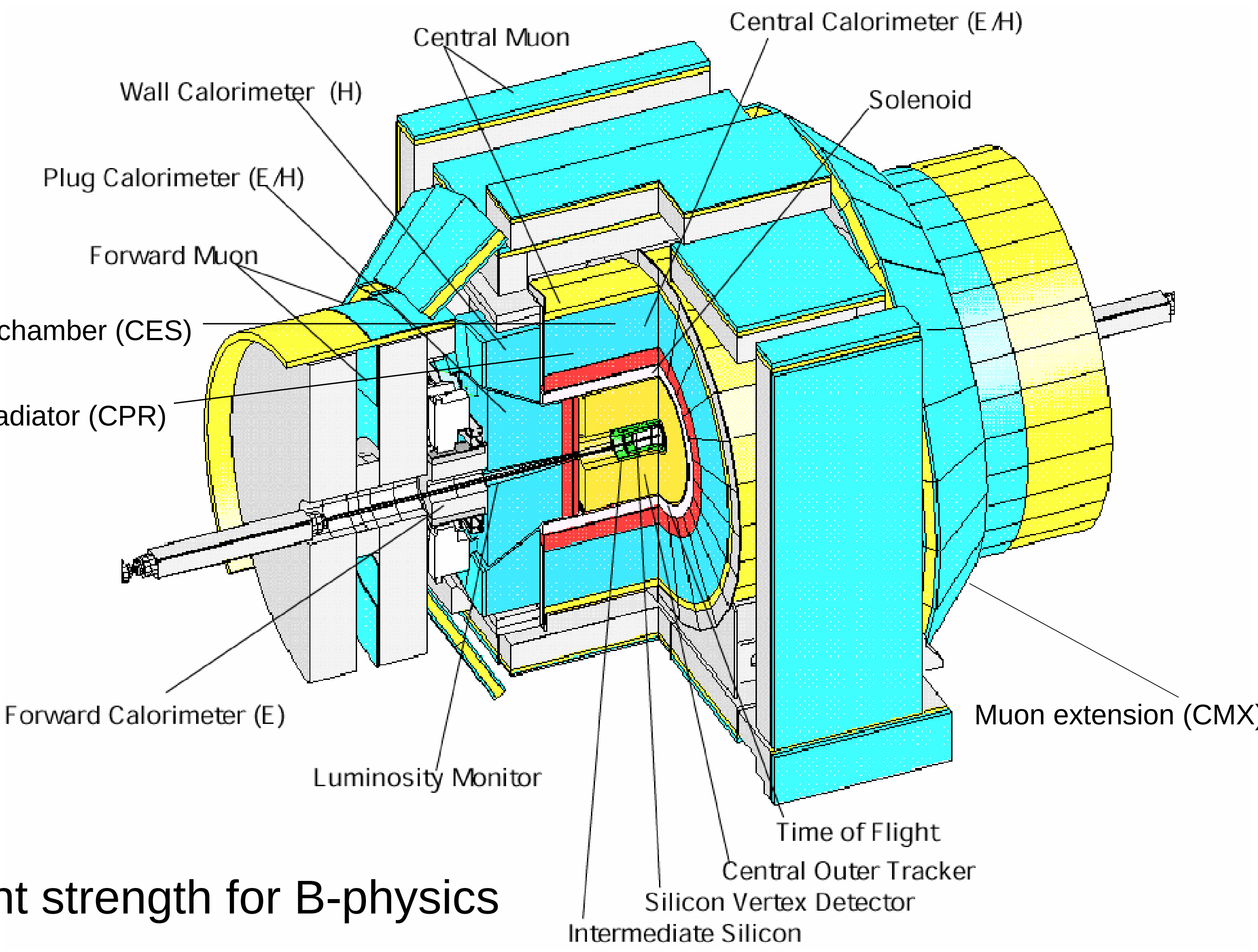




Interest of B_c

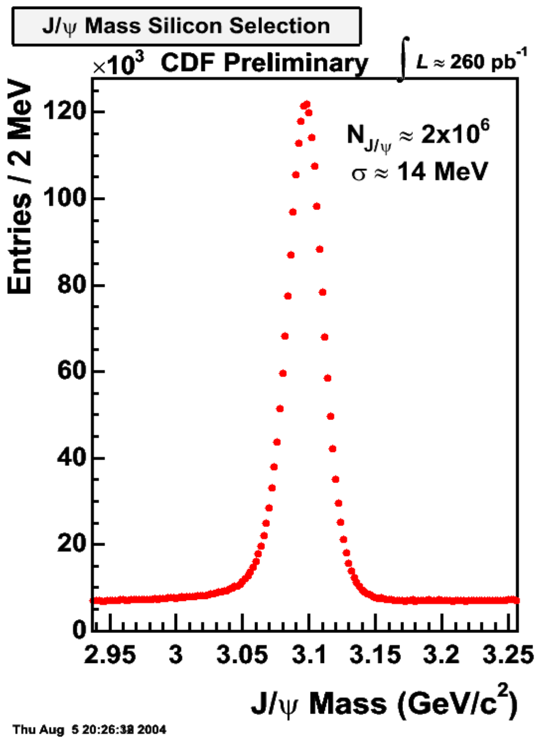
- Heavy-heavy meson: *v* and Λ_{QCD}/m_q as expansion parameters
- 2 spectator-model decays with comparable amplitude
- Special system for extraction of bare quark quantities (masses, mixing angles, …)
- Validation of theoretical models (lattice QCD, NR potential models)
- Other (B_s production, spectroscopy, …)

The CDF detector, run II



Excellent strength for B-physics

Triggers



Main trigger for signal and $B^{+} \rightarrow J/\psi\ K^{+}$ control sample:

•**Dimuon (J/ψ) trigger**: 2 opposite charge tracks matched to muon stubs and invariant mass around the J/ψ mass

For particle identification studies:

•**Two-tracks trigger**: 2 opposite charge tracks, with Pt>2 GeV/c, and impact parameter > 120 microns ($D^{0} \rightarrow K\pi$, $\Lambda \rightarrow p\pi$)

•**Single electron trigger**: Track with Pt>8 GeV matched to central electron cluster ($\gamma \rightarrow e^{+}e^{-}$)

Channels used in this analysis(360 pb^{-1})

- Semileptonic decays:

$$\left.\begin{array}{l} B_c \rightarrow J/\psi \ \ \mu \ \ \nu \\ B_c \rightarrow J/\psi \ \ e \ \ \nu \end{array}\right\} J/\psi \rightarrow \mu\mu$$

Pro: Larger branching fraction (O(2%))

Con: Need accurate estimate of background

- Fully reconstructed:

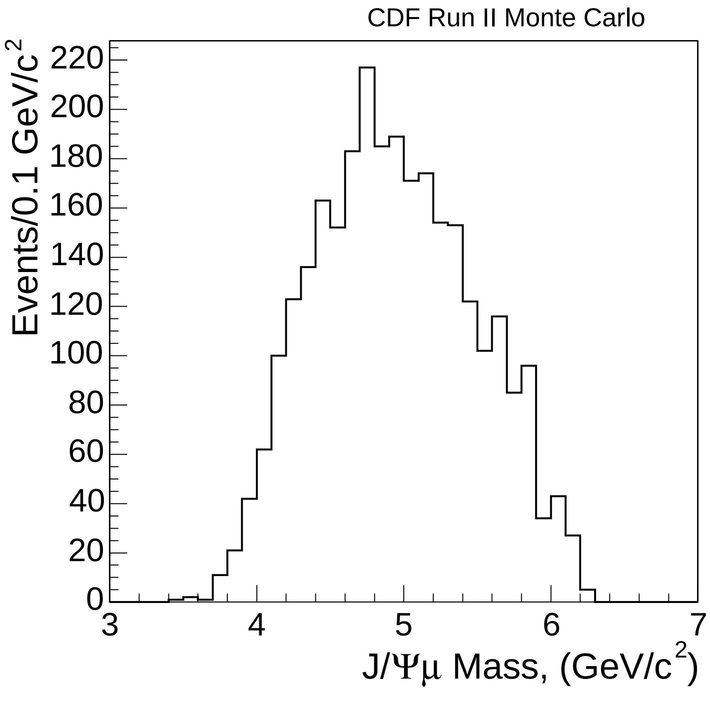
$$B_c \rightarrow J/\psi \ \ \pi, \quad J/\psi \rightarrow \mu\mu$$

Pro: Allows precise determination of the mass

Con: Lower rate

Semileptonic

Expected signal region: $M(J/\psi) < M(J/\psi + e, \mu) < M(B_c)$



Mass used to generate this distribution: 6.4 GeV

Search window defined between 4 and 6 GeV

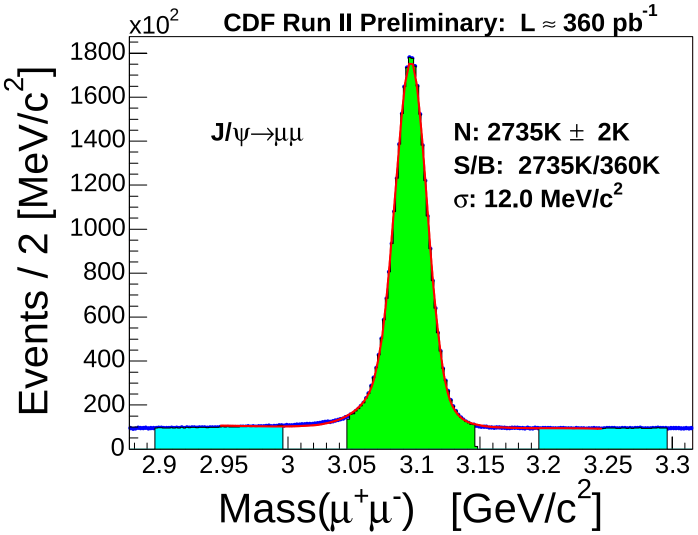
Backgrounds

- Fake muons/electrons from K/pi/p
- Conversion electrons
- $b\bar{b}, \quad b \to J/\psi + X, \quad \bar{b} \to e/\mu + X$
- Fake J/ψ :

  To estimate

  this contribution,

  sidebands are used

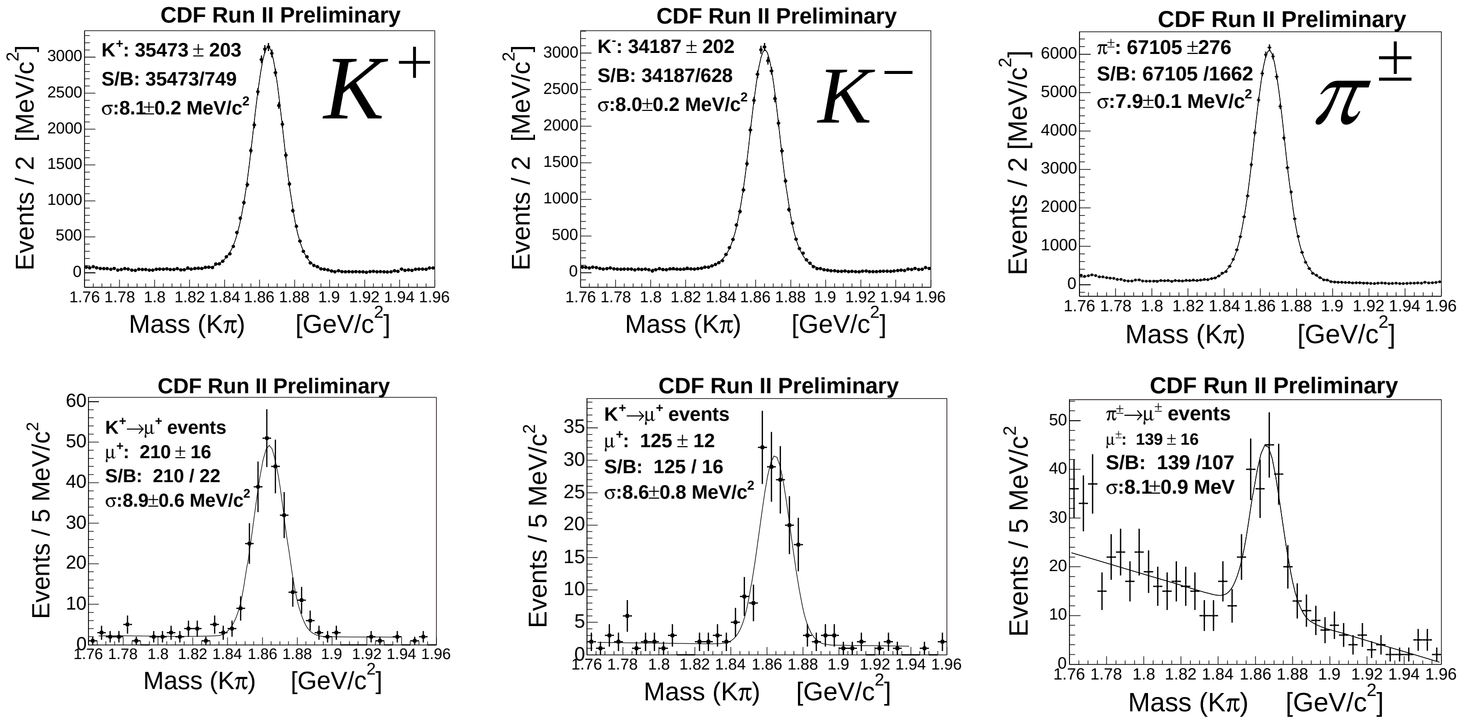


Fake muon/electron rate

From $D^* \to \pi^+ D^0 \to \pi^+ K^- \pi^+$ and $\Lambda \to p\pi$

Full sample

Identified As muons

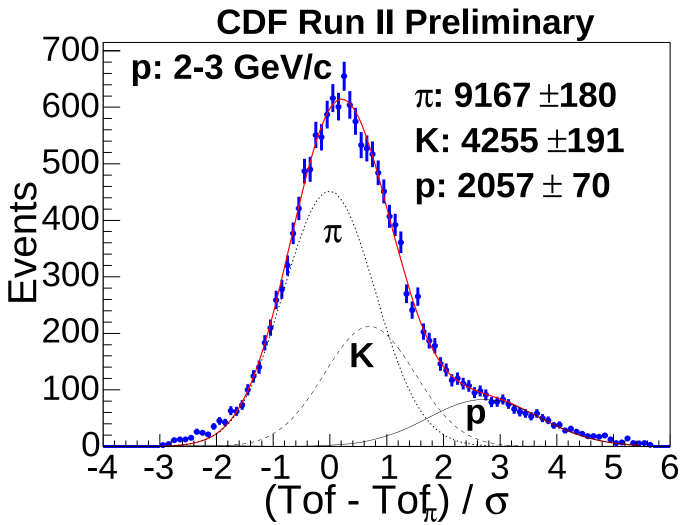


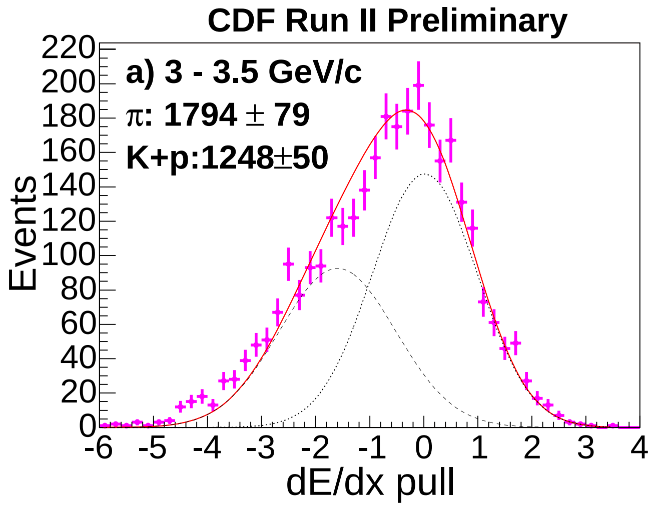
Similar procedure for electrons

The rate is then multiplied by the probability to have a K/pi/p in the sample

Fake muon/electron probability

The probability of the third track to be a pi/K/p is obtained from dE/dx and Time of Flight distributions for $J/\psi\ \mu$



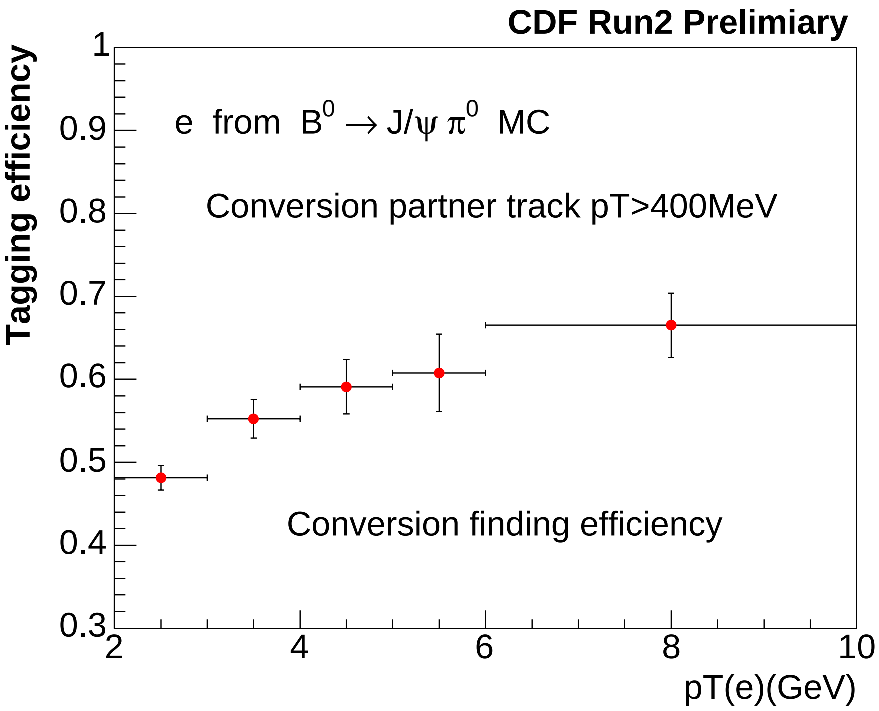


These fractions are extracted from Pythia MC and cross-checked with dE/dx distribution in the case of $J/\psi\ e$

Conversion electrons background

$$\gamma \rightarrow e\, e$$

•Get the conversion finding efficiency from MC (momentum dependence is important)
•Normalize total rate to data

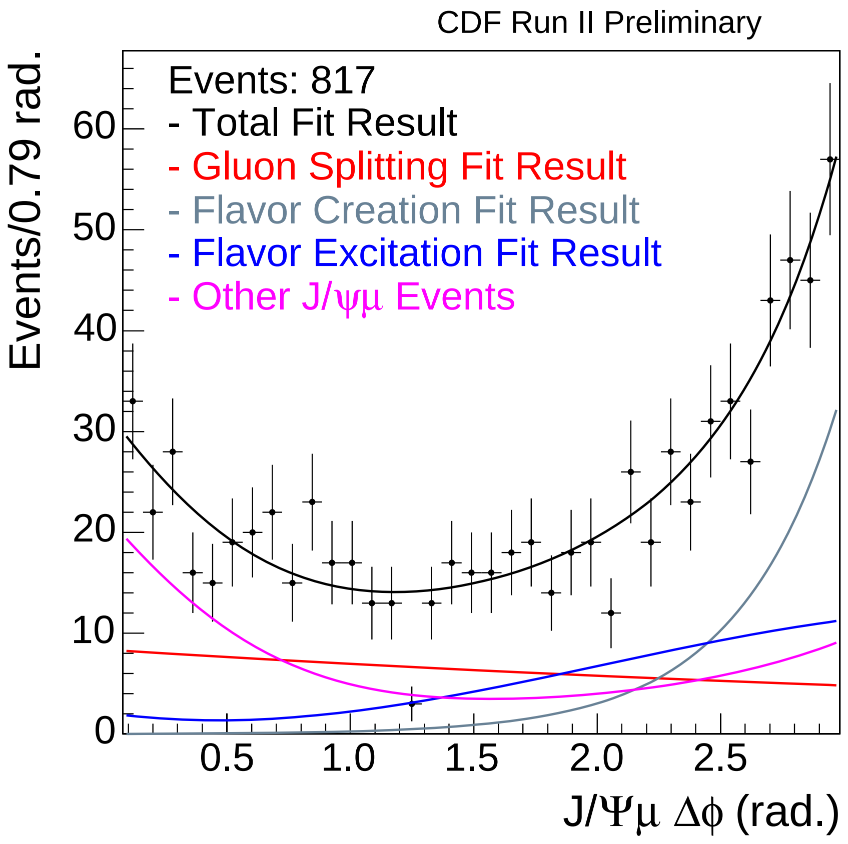


b-bbar background

Three processes:

- Flavour creation
- Gluon splitting
- Flavour excitation

Processes are simulated using Pythia MC, then normalized to data (B->J/psi K sample). Relative fractions are checked with data, by fitting the angle separation between J/psi and muon



Summary of backgrounds

	$B_c \to J/\psi\ \mu$	$B_c \to J/\psi\ e$
Fake μ/e	15.6±2.7	15.43±0.31
b-bbar	16.1±2.1±5.7	33.63±2.20
Conversions	----------	14.54±4.38
Fake J/psi	19.0±3.1	Negl.
Fake J/psi & μ	-2.0±0.5	---------
Total	48.7±7.4	63.6±4.9

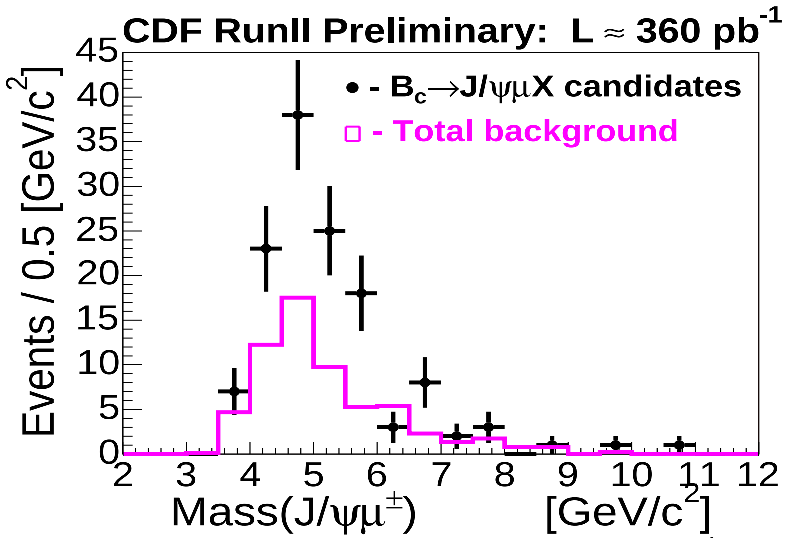
Final distributions

$$B_c \to J/\psi\ \mu$$

$\text{Background}: 46.0 \pm 7.3$

$\text{Signal events}: 60 \pm 13$

$\text{Significance}: 5.2\sigma$



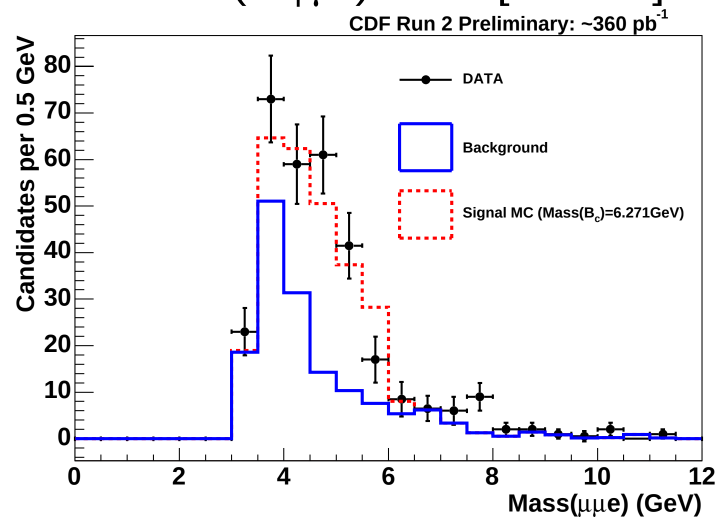
$$B_c \to J/\psi\ e$$

$\text{Background}: 63.6 \pm 4.9 \pm 13.6$

$\text{Signal events}: 115 \pm 16 \pm 14$

$\text{Significance}: 5.9\sigma$

(probability of background.
to fluctuate to signal)



Cross sections

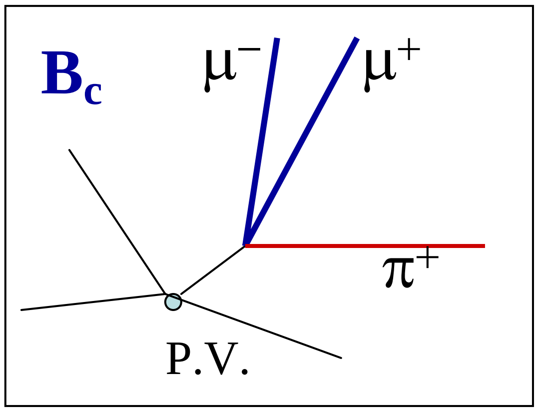
Pt(Bc)>4 GeV/c, |y(Bc)|<1

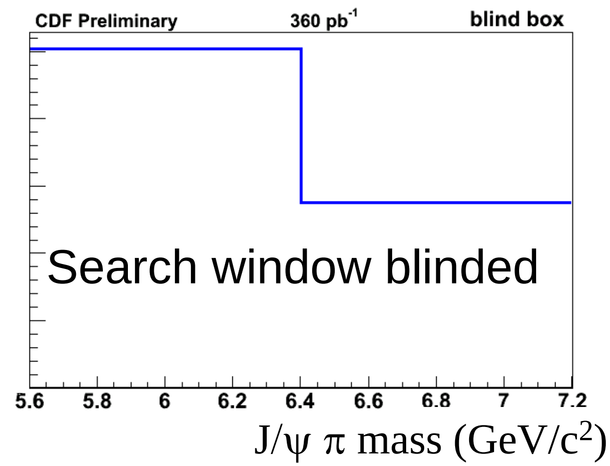
$$\frac{\sigma(B_c)\times BR(B_c \to J/\psi\ \mu)}{\sigma(B)\times BR(B \to J/\psi\ K)} = 0.249 \pm 0.045(\text{stat})^{+0.107}_{-0.076}(\text{syst})$$

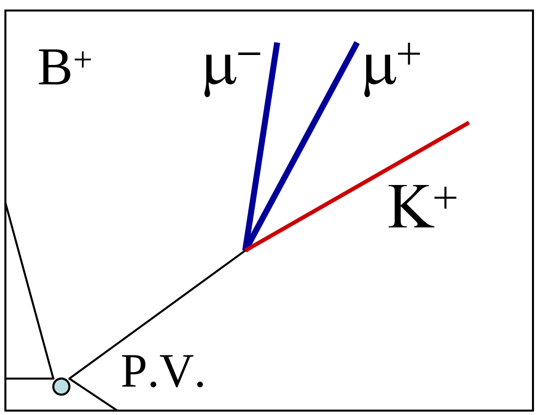
$$\frac{\sigma(B_c)\times BR(B_c \to J/\psi\ e)}{\sigma(B)\times BR(B \to J/\psi\ K)} = 0.282 \pm 0.038(\text{stat}) \pm 0.074(\text{syst})$$

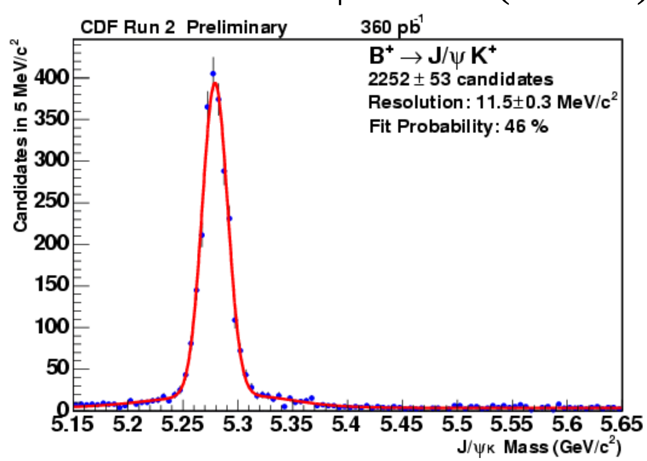
Fully reconstructed decay

Precise mass measurement, but due to low statistics, careful optimization of cuts is required. Signal region is blinded during optimization. Vertex cuts are critical





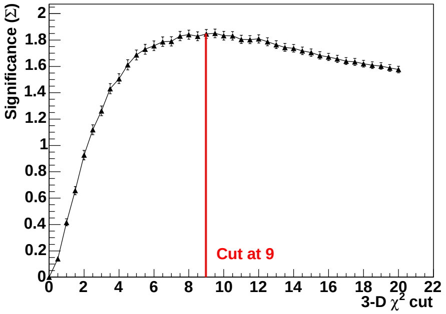




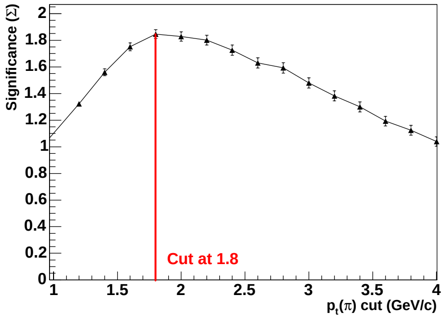
Cut optimization (blinded sample)

$$\Sigma = \frac{S}{1.5 + \sqrt{B}}$$

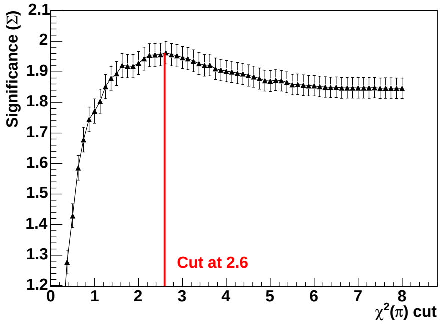
G. Punzi, PHYSTAT2003 and arXiv:physics/0308063



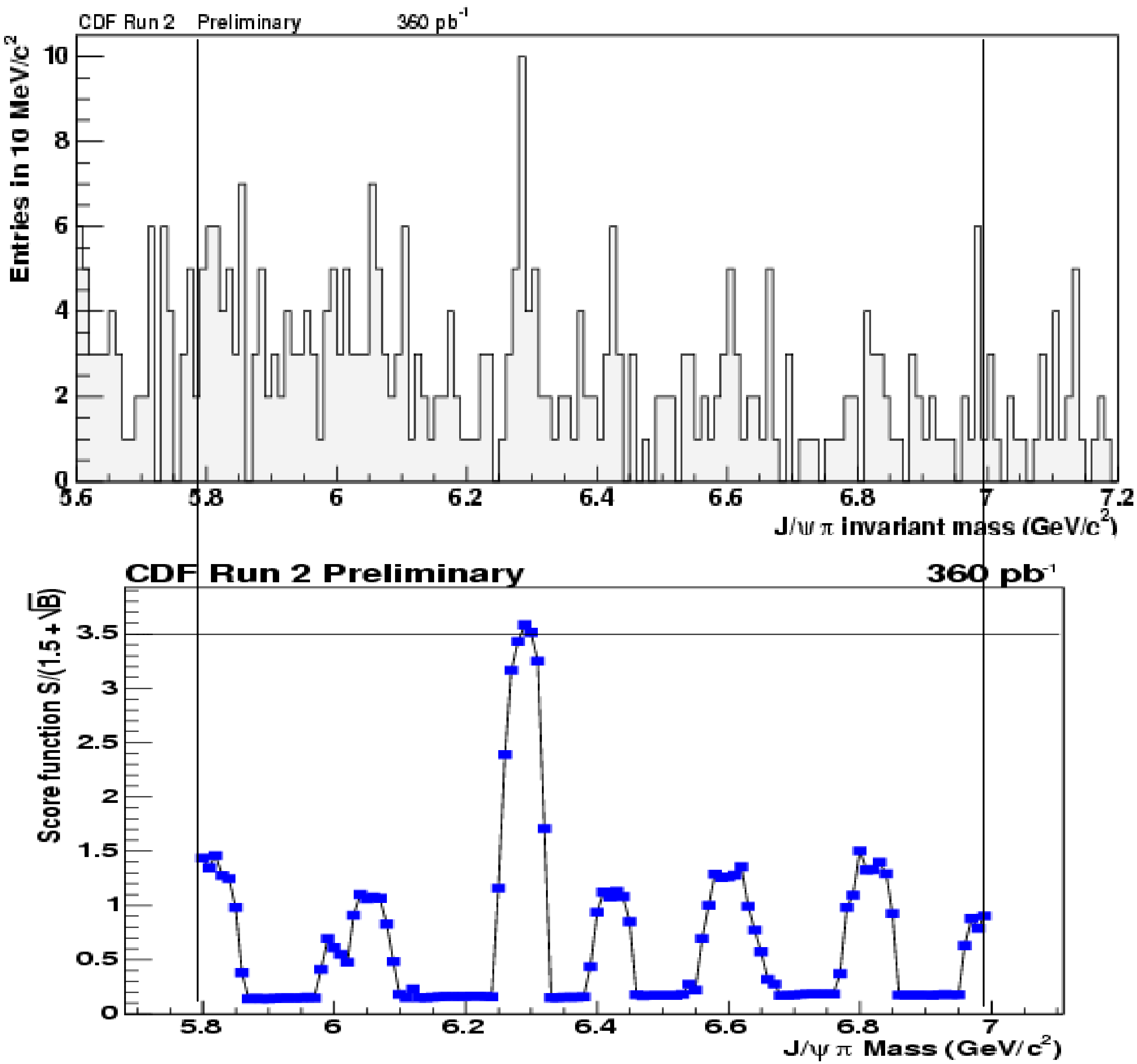
Σ is maximized, where **S**ignal is from MC and **B**ackground is the number of events in the blind search region



1. $p_T(\pi)$ > 1.8 GeV/c
2. $L_{xy}/\sigma(L_{xy})$ > 4.4 (significance of decay length)
3. χ^2(3D) < 9.0 (quality of the vertex fit)
4. $d_0(B_c)$ < 65 μm (impact parameter)
5. pointing angle < 0.4 radians (B_c direction of flight)
6. $\chi^2_{vtx}(\pi)$ < 2.6 (contrib. of π το vertex quality)
7. ct < 750 μm (B_c lifetime)



Significance evaluation



A sliding fit is performed in the search region and the significance Σ is estimated.
The probability of the background to give a peak with Σ=3.6 at any point in the window is estimated from toy MC as 0.27%

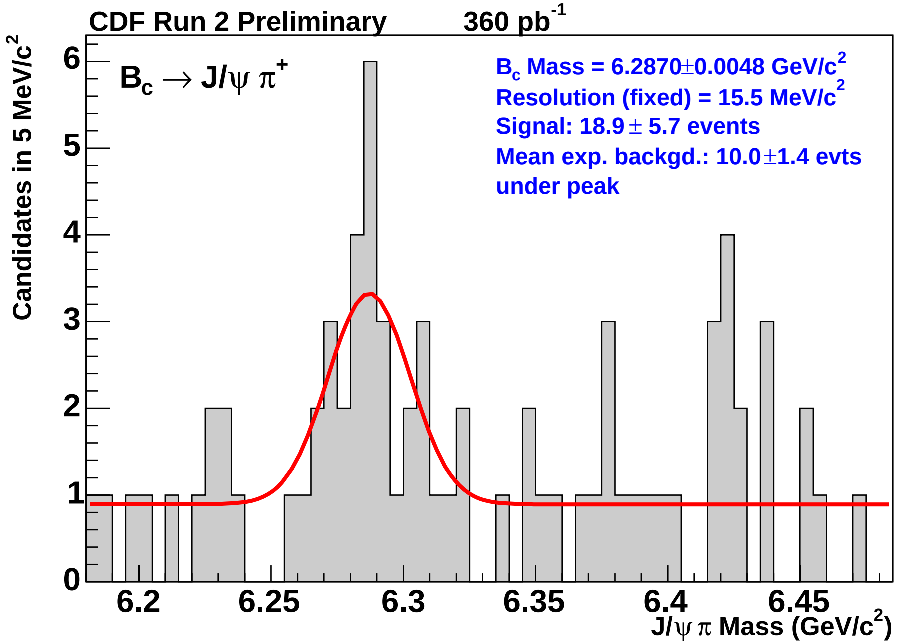
B_c mass

Unbinned likelihood fit.

Mass = 6287.0 ± 4.8(stat.) ± 1.1(syst.) MeV/c^2

Previous measurements:

CDF: 6.4±0.39±0.13 GeV -- D0: 5.95±0.13±0.34 GeV



Signal: 18.9±5.7

Background: 10.0±1.4

Systematics:

Background shape: 0.8 MeV

Momentum scale: 0.6 MeV

Pi/K dE/dx: 0.2 MeV

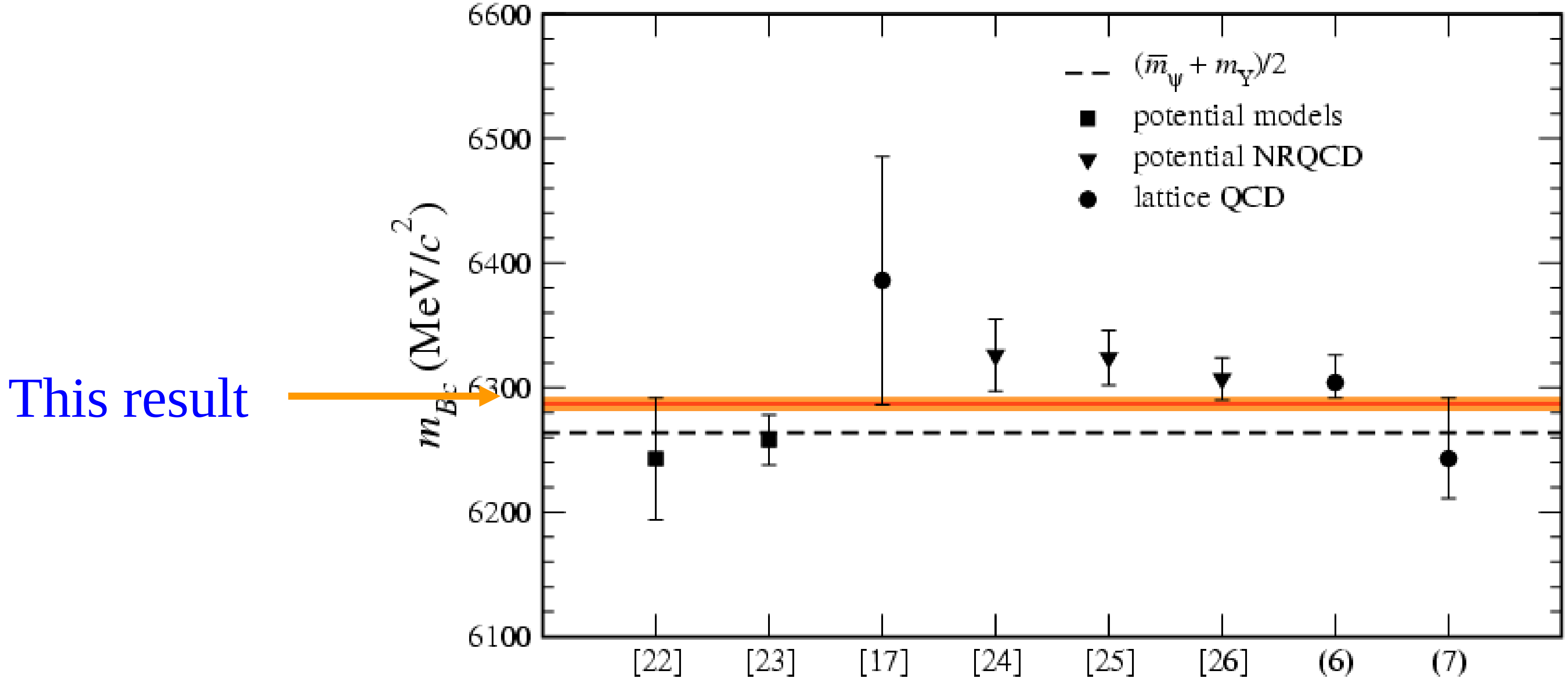
Tracking: 0.2 MeV

Bc Pt uncertainty: 0.5 MeV

Total: 1.1 MeV

Compared to theory

Allison et al., Phys rev. Lett. 94 (2005) 172001



Conclusion

360 pb^{-1} CDF new measurements:

$$\frac{\sigma(B_c)\times BR(B_c \to J/\psi\ \mu)}{\sigma(B)\times BR(B \to J/\psi\ K)} = 0.249 \pm 0.045(\text{stat})^{+0.107}_{-0.076}(\text{syst})$$

$$\frac{\sigma(B_c)\times BR(B_c \to J/\psi\ e)}{\sigma(B)\times BR(B \to J/\psi\ K)} = 0.282 \pm 0.038(\text{stat}) \pm 0.074(\text{syst})$$

Mass = 6287.0 ± 4.8(stat.) ± 1.1(syst.) MeV/c^2

compatible with theory and previous measurements

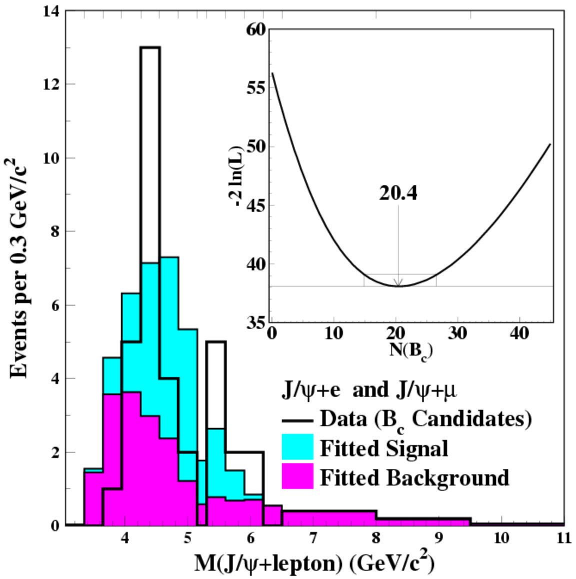
1 fb^{-1} of data recently achieved by Tevatron:
Update is on the way

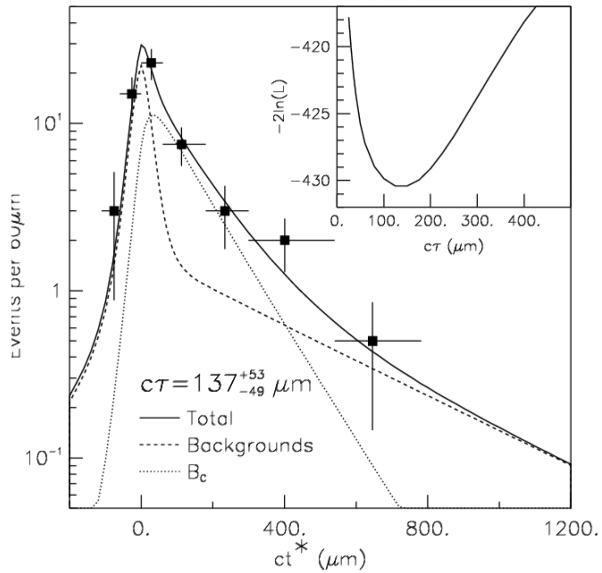
Back up slides

What we know (CDF I)

CDF run I observation ($J/\psi\ \mu\,\nu$):

PRL 81, 2432 (1998) and PRD 58, 112004 (1998)





$20.4^{+6.2}_{-5.5}$ signal events

M=6.4±0.39±0.13 GeV

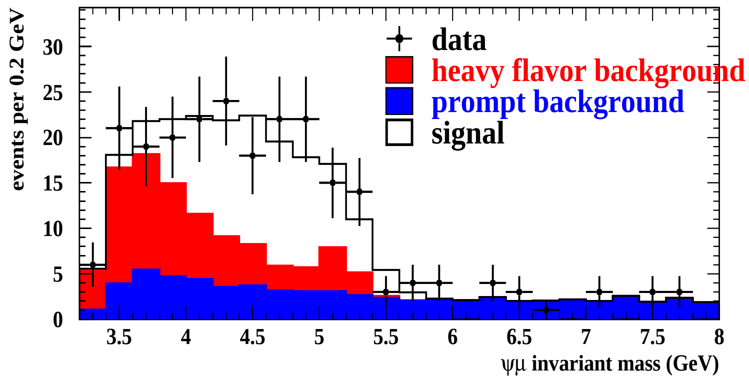
$c\tau = 0.46\ ^{+0.18}_{-0.16}\ 0.03$ ps

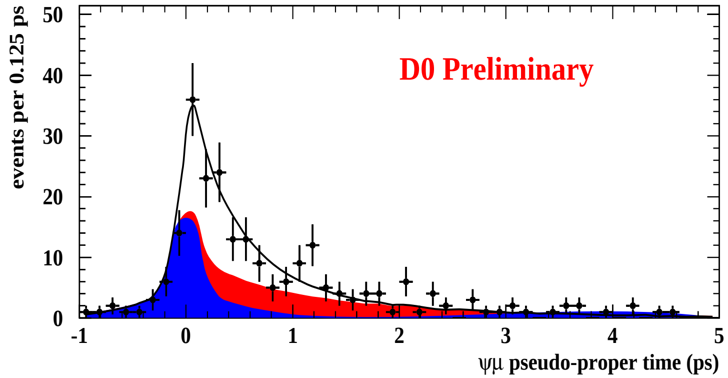
$$\frac{\sigma(B_c)\times \mathcal{B}(B_c \to J/\psi \ell \nu)}{\sigma(B_u)\times \mathcal{B}(B_u \to J/\psi K)} = 0.132^{+0.041}_{-0.037}\,(\mathrm{stat}) \pm 0.031\,(\mathrm{syst})\ ^{+0.032}_{-0.020}(c\tau)$$

($P_t(B)>6$ GeV/c $|\eta|<0.6$)

What we know (D0 II)

D0 run II measurement ($J/\psi\ \mu\ \nu$):





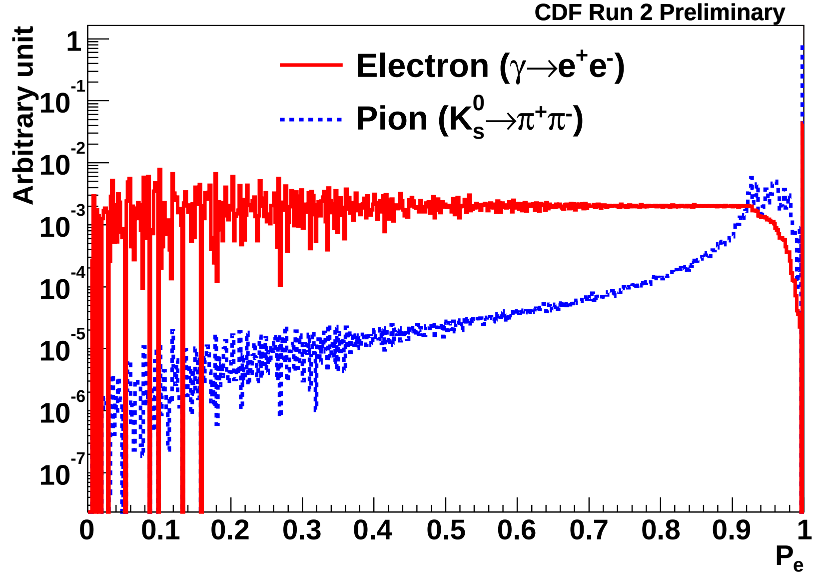
$95 \pm 12 \pm 11$ Candidates

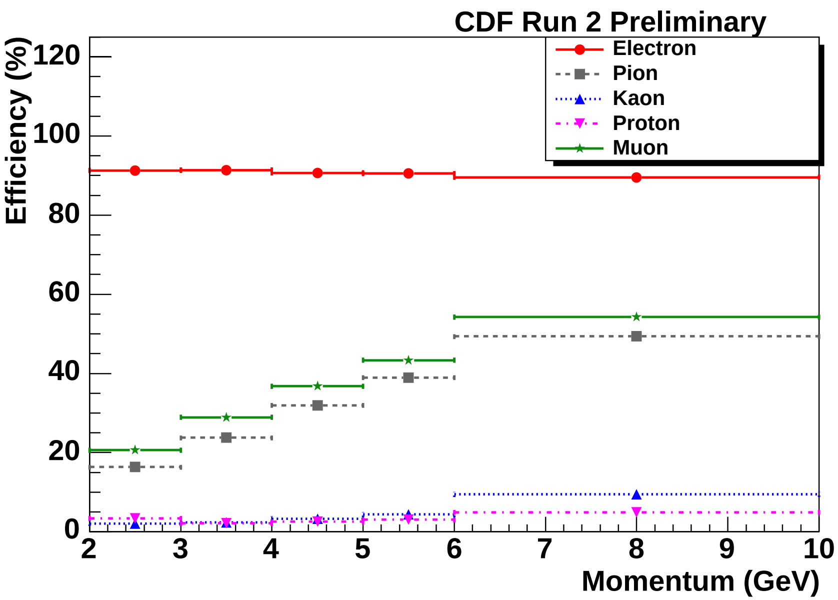
$$M = 5.95^{+0.14}_{-0.13} \pm 0.34\ Gev$$

$$c\tau = 0.448^{+0.123}_{-0.096} \pm 0.121\ ps$$

Electron identification

Cutting on a likelihood distribution function based on 10 electromagnetic and tracking variables (track matching, E_H/E_E, p/E, shower profile,…) $P_e<0.7$ (70% efficiency, independent on P_T)





Additional cut on specific energy loss dE/dx.