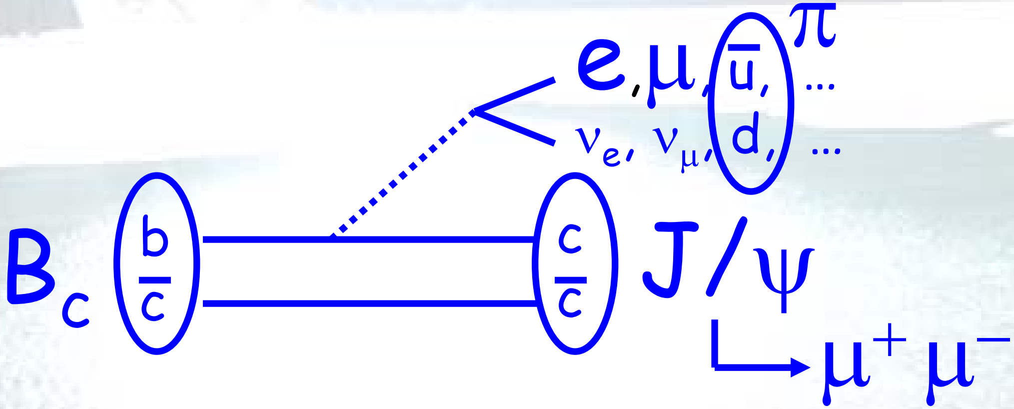
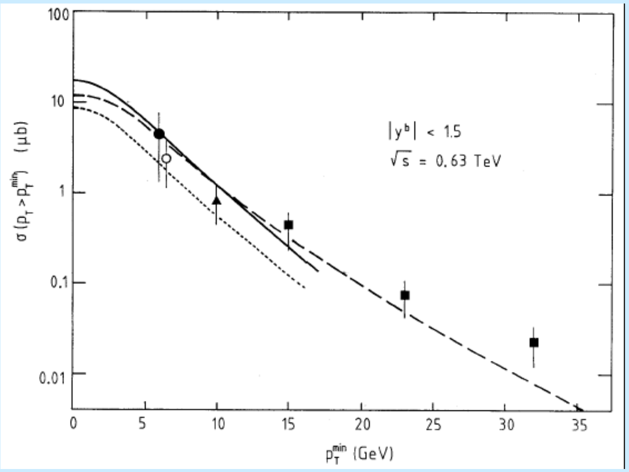
Bc at CDF



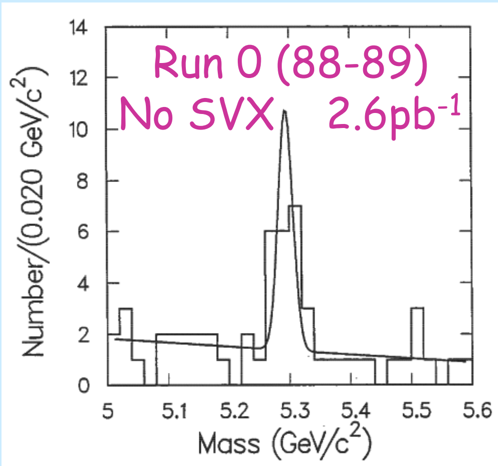
William Wester
Fermilab
for the CDF collaboration

Introduction

- B Physics at Hadron Colliders
  - UA1 cross section measurements
  - CDF fully reconstructed B->J/ψK$^{(*)}$



UA1 σ(b) in μ channel
PLB 213, 415 (1988)



CDF B_u->J/ψK
PRL 68, 3403 (1992)

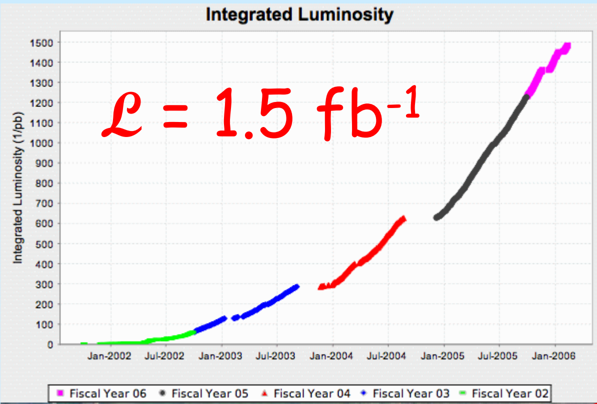
Since the 1980's …

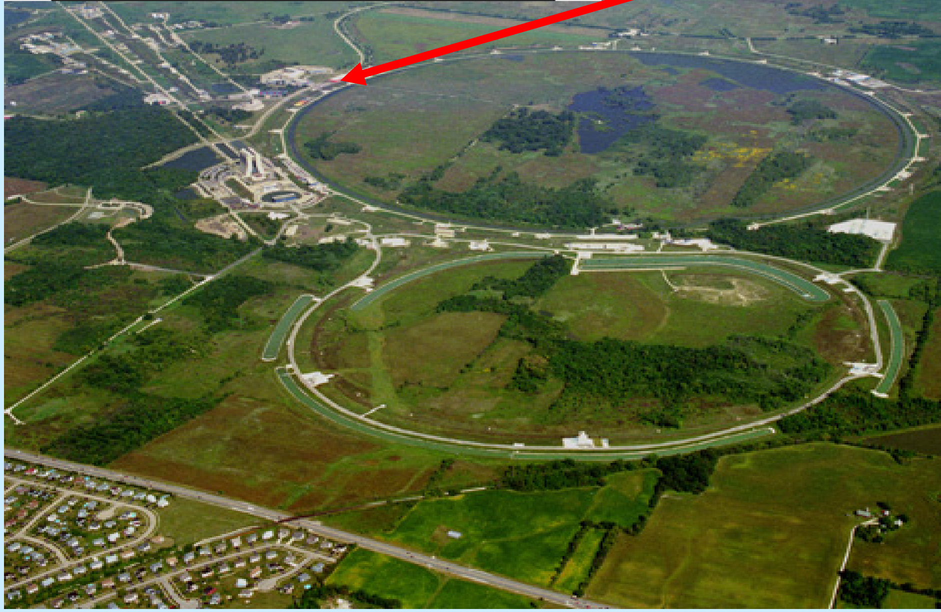
Advantages:
Large σ(b) x ℒ
All mesons and baryons
Triggerable: ℓ or J/ψ
Multipurpose detectors

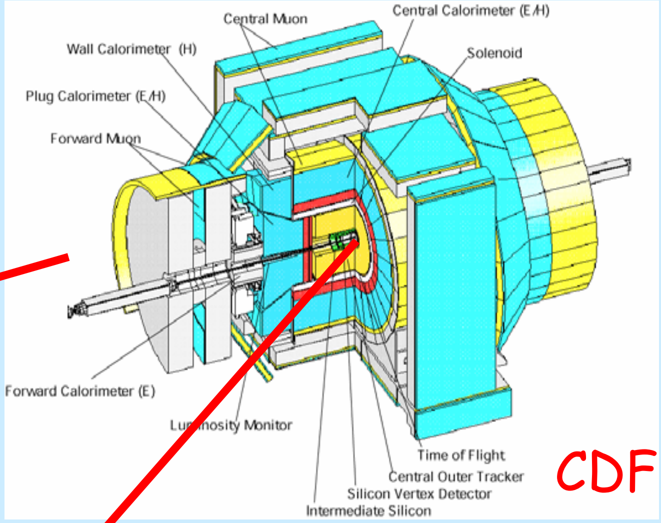
Disadvantages: (perceived)
High backgrounds
Limited acceptance
Small Lorentz boost
Unknown initial state

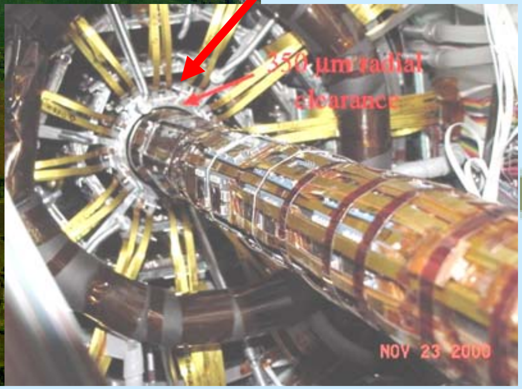
- Study of Bc highlights hadron collider advantages
  - Large cross section for producing triggerable low background decays not accessible at the B factories.

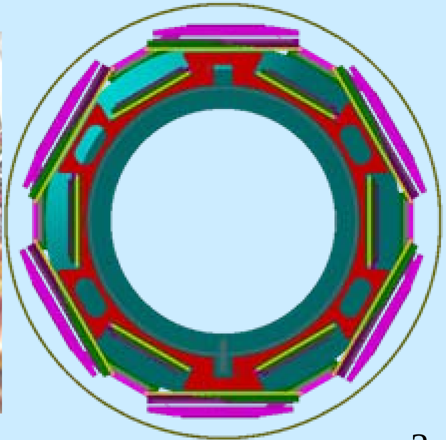
Tevatron and CDF in Run II







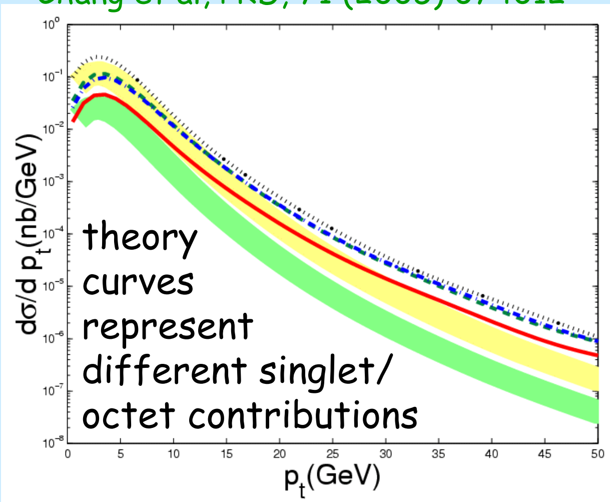




Bc properties

- Bc is a heavy-heavy system
  - Production: Factorization with two scales $M_b + M_c$ and contributions of color singlet / octet
    - Softer P_T distribution?
  - Decay: both b and c quarks can participate
    - Shorter *c-like* lifetime?
    - Large number of final state *BR*s.
  - Mass: new system for potential models and new lattice QCD calculations

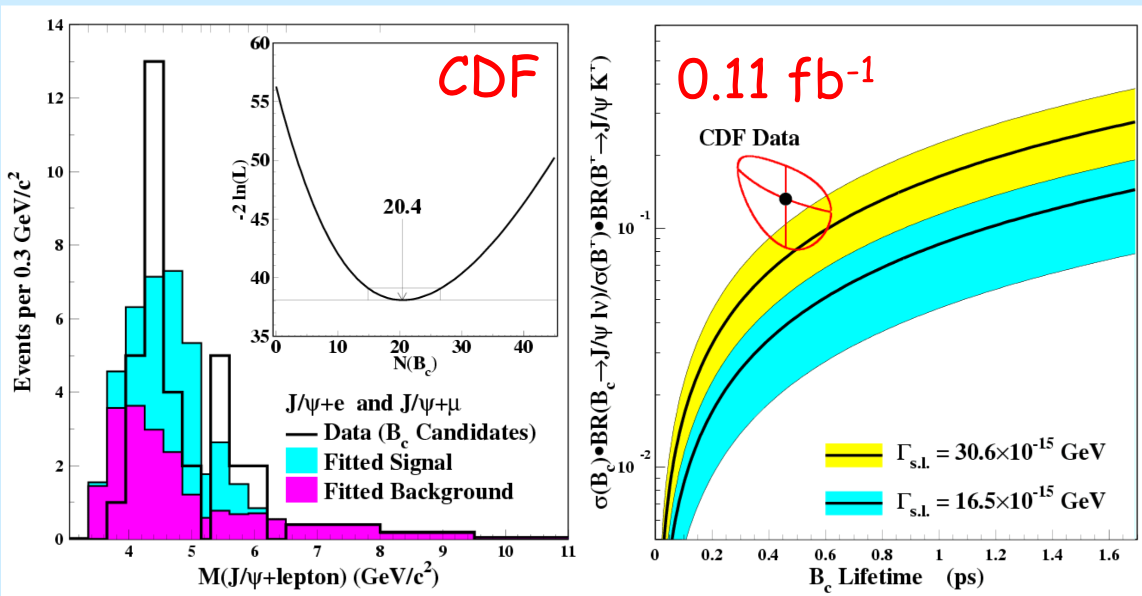
Chang et al, PRD, 71 (2005) 074012



- All aspects of the theoretical work require experimental measurement => happening now at the Tevatron

Bc in Run I ('91-'96)

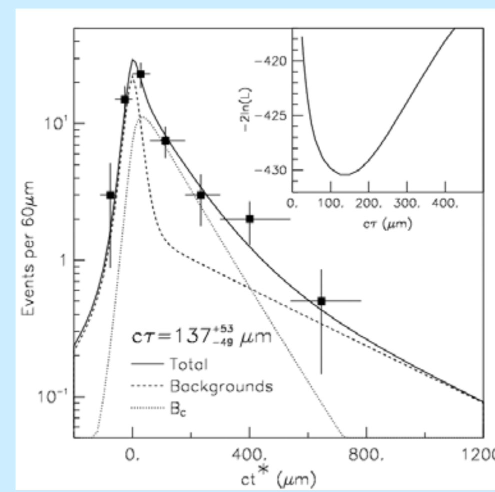
- A few candidate events at LEP and the CDF observation and measurements…



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

$M=6.4\pm0.39\pm0.13$ GeV

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



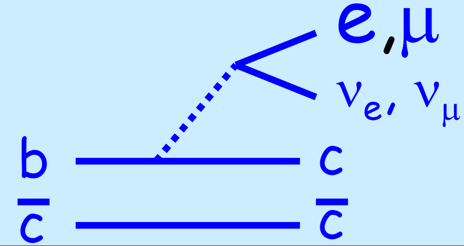
PRL 81, 2432 (1998) and PRD 58, 112004 (1998)

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

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

Note: assuming harder P_t spectrum in MC

Run II results: semi-leptonic decays

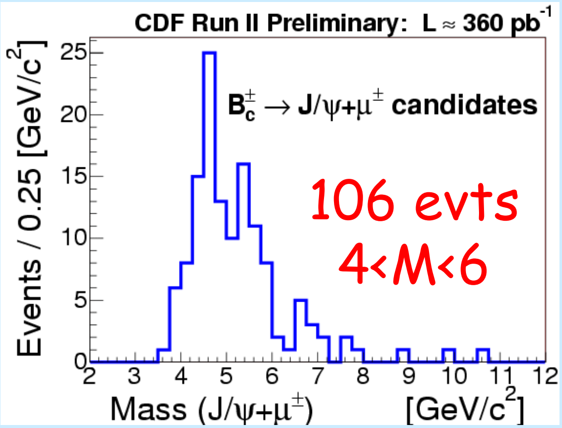


- B_c -> $J/\psi + \ell\nu$ with ℓ = e, μ
- Not fully reconstructed (missing ν)
- Understanding backgrounds are key
  - $b\bar{b}$ events with the J/ψ from b and ℓ from $\bar{b}$
  - Fake muons or fake electrons
  - Other backgrounds
- Study J/ψ+track and B_u->J/ψ K
- B_c is the excess above backgrounds
- Make measurements

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

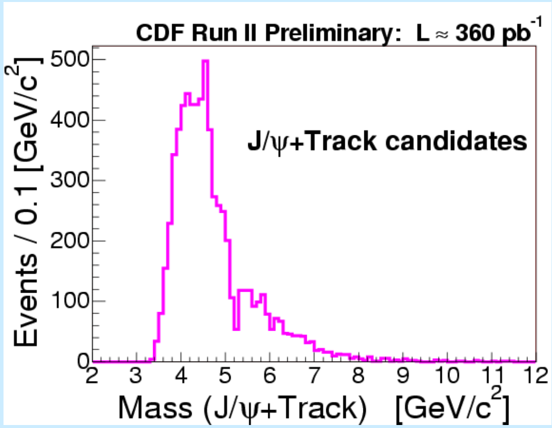
- Use 2.7M J/ψ's in 0.36 fb^{-1}
- Combine with third track with & w/o muon ID
  - P_T>3 GeV, $c\tau$ > 60μm, and $\Delta\phi(J/\psi\text{–trk})$ < 90 deg
- Use $B_u \to J/\psi K$ from data for normalization
- Use Monte Carlo of B_u and B_c for ε_{rel}
- Evaluate backgrounds in the data
  - Fake muons, $b\bar{b}$, fake J/ψ
- Estimate systematic uncertainties
- Fit data in 4-6 GeV for signal and backgrounds
  - Evaluate relative production of Bc to Bu

Fake muon background

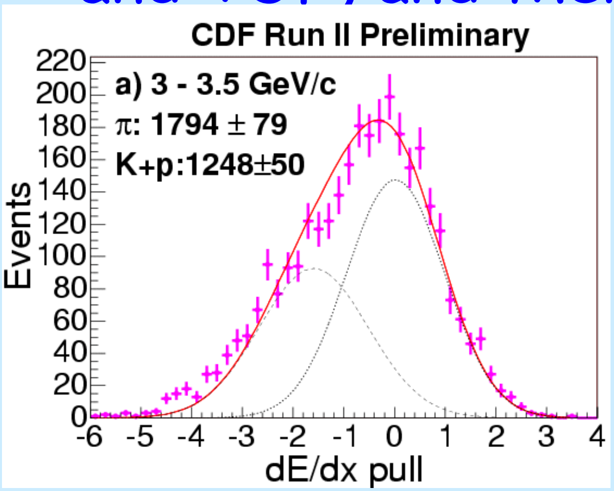


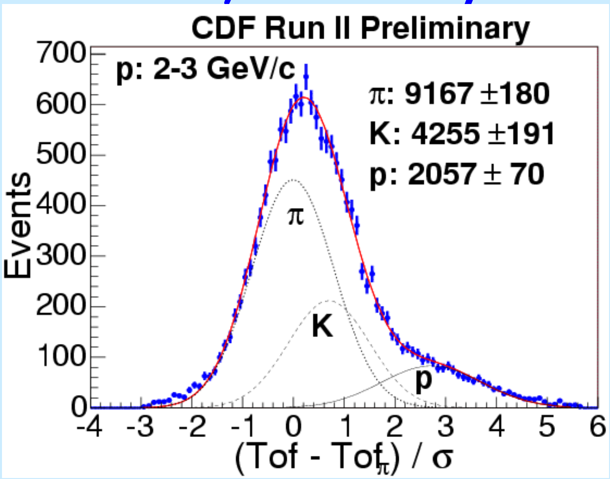
How many come from J/ψ+track where the track is a fake muon?

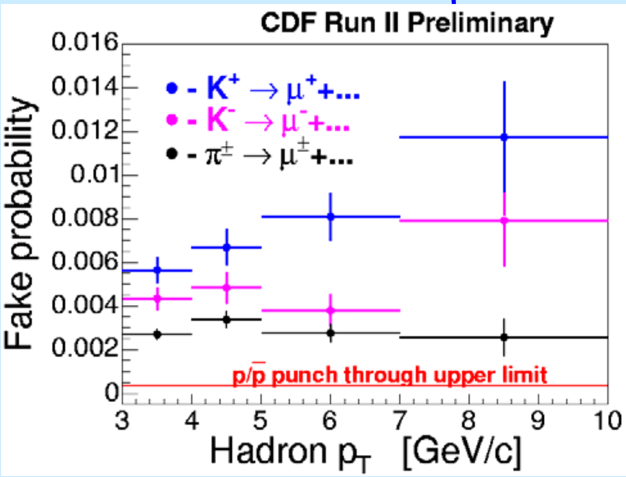
Fake muons primarily from decay in flight: 16.3±2.9 estimated in 4<M<6 GeV.



- Fake muons: determine π, K, p composition vs P_T (dE/dx and TOF) and then use D^*, Λ decays to find fakes vs P_T

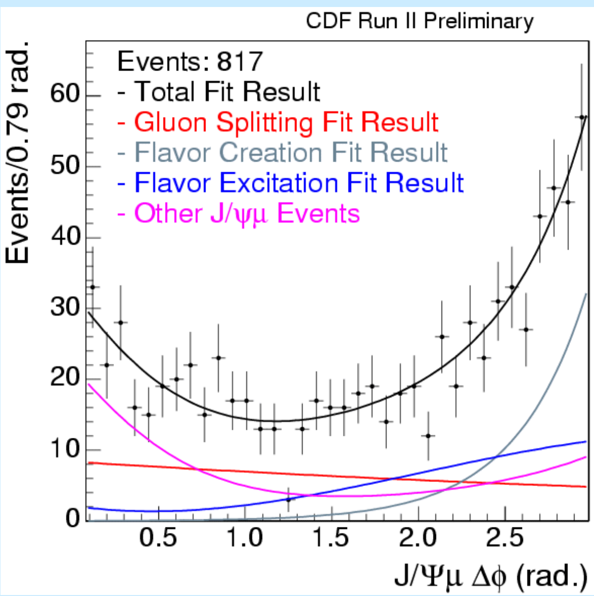


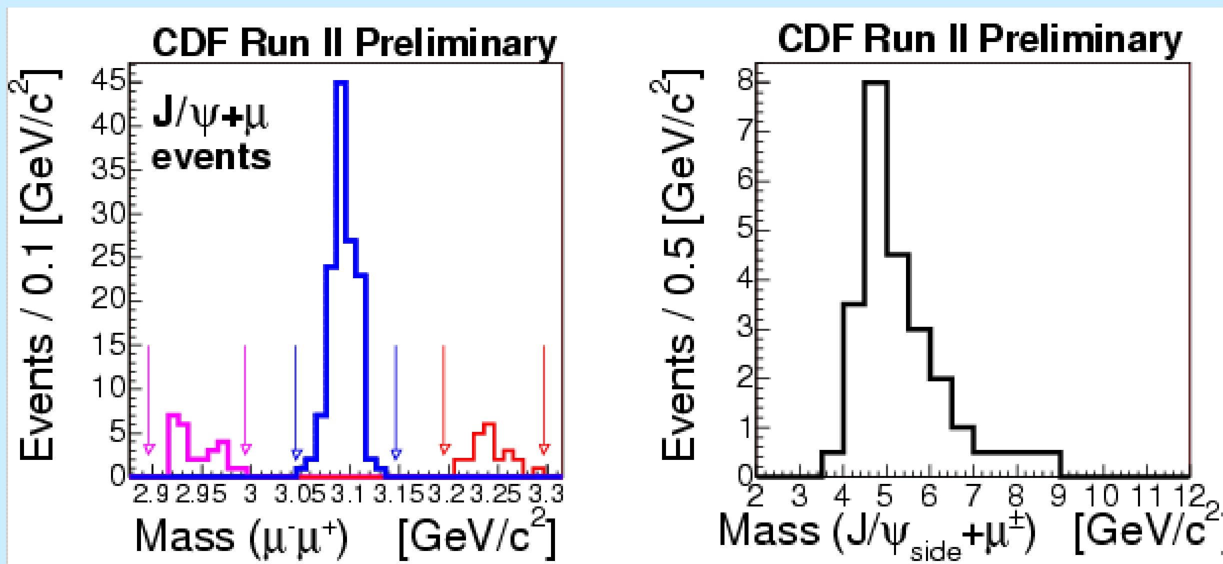




More backgrounds

- $b\bar{b}$ background from Pythia Monte Carlo normalized to B_u->$J/\psi K$ data using $\Delta\phi$ distributions (vary production)
- Fake J/ψ from J/ψ sidebands



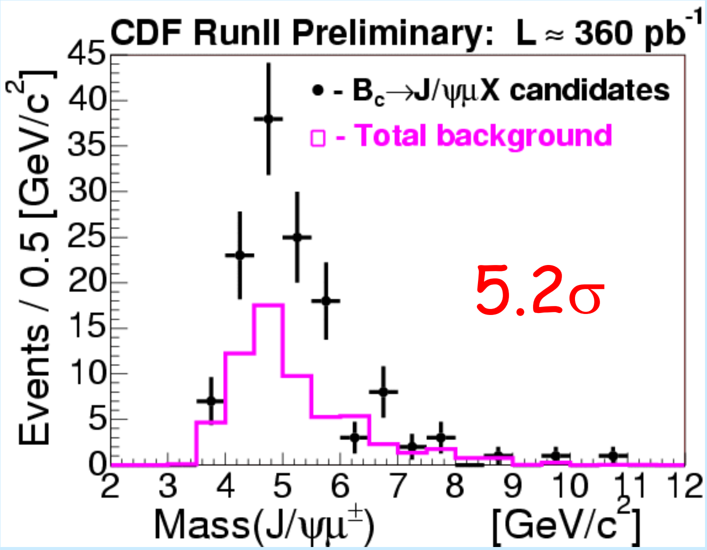


Backgrounds from the other b: 12.7±1.7 ±5.7 estimated in 4<M<6 GeV.

Backgrounds from fake J/ψ (no double counting): 19.0±3.0 estimated in 4<M<6 GeV.

Muon channel results

Mass window	3.0 – 4.0 GeV/c^2	4.0 – 6.0 GeV/c^2 (signal)	6.0 – 10.0 GeV/c^2
B_c candidates in mass window	7 ± 2.4	106 ± 10.3	19 ± 4.2
Fake muon background	3.9±0.7	16.3±2.9	2.2±0.4
BB background	$0.6 \pm 0.4 \pm 0.1$	$12.7 \pm 1.7 \pm 5.7$	$6.0 \pm 1.1 \pm 1.8$
Fake J/ψ background	0.5 ± 0.5	19.0 ± 3.0	5.0 ± 1.7
Fake μ from $(J/\psi_{side} + Trk)$	0.3±0.1	2.0±0.5	0.7±0.2
Total Background	4.7±0.9	46.0±7.3	12.5±2.7
Events above background	2.5±2.8	60.0±12.6	6.5±5.1



Use MC for relative efficiency for Bc and Bu along with Bu->J/ψK to obtain:

$$\frac{\sigma(B_c)\times B(B_c \to J/\psi \ell \nu)}{\sigma(B_u)\times B(B_u \to J/\psi K)} = 0.249 \pm 0.045 \pm 0.069 \pm^{0.082}_{0.033}$$

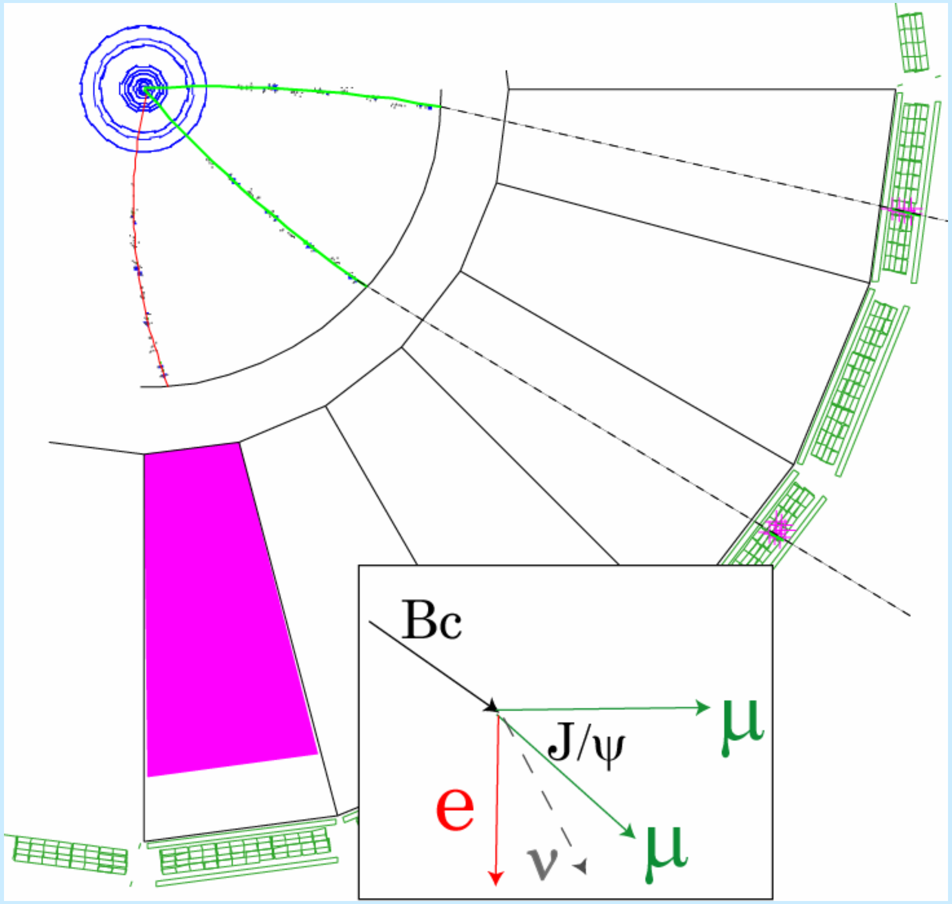
$P_T(B) > 4$ and $|y| < 1$

Other measurements from this sample are in preparation.

CDF Note: 7649

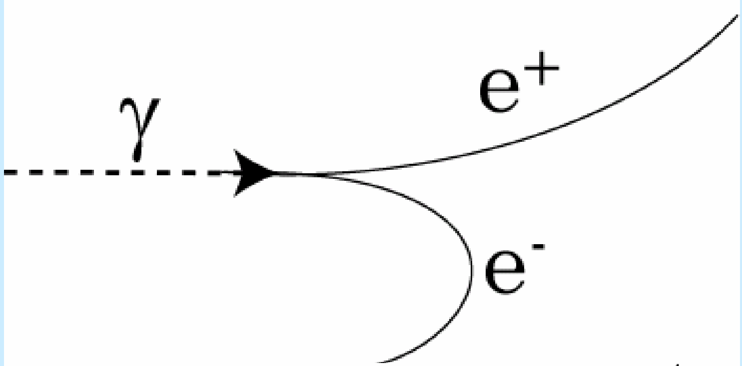
Bc -> J/ψ e X

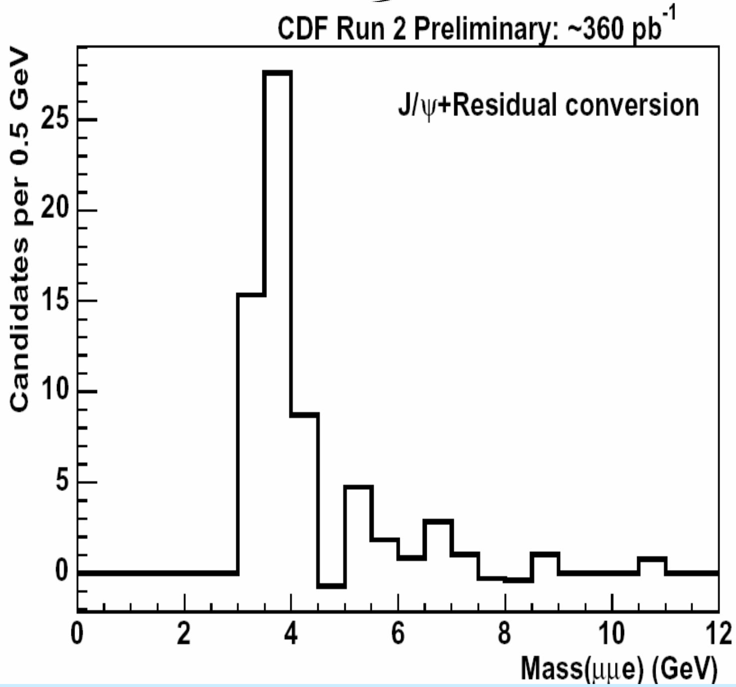
- Fake electron
  - Use J/ψ+track data
  - Estimate fake rate from data ($D^0 \rightarrow K\pi, \Lambda^0 \rightarrow p\pi$)
- Photon conversion
  - Use J/ψ+tagged conversion data
  - Conversion finding efficiency from MC
- $b\bar{b}$ background
  - $b \rightarrow J/\psi X$ and $\bar{b} \rightarrow eX$
  - PYTHIA $b\bar{b}$ Monte Carlo



Photon conversions

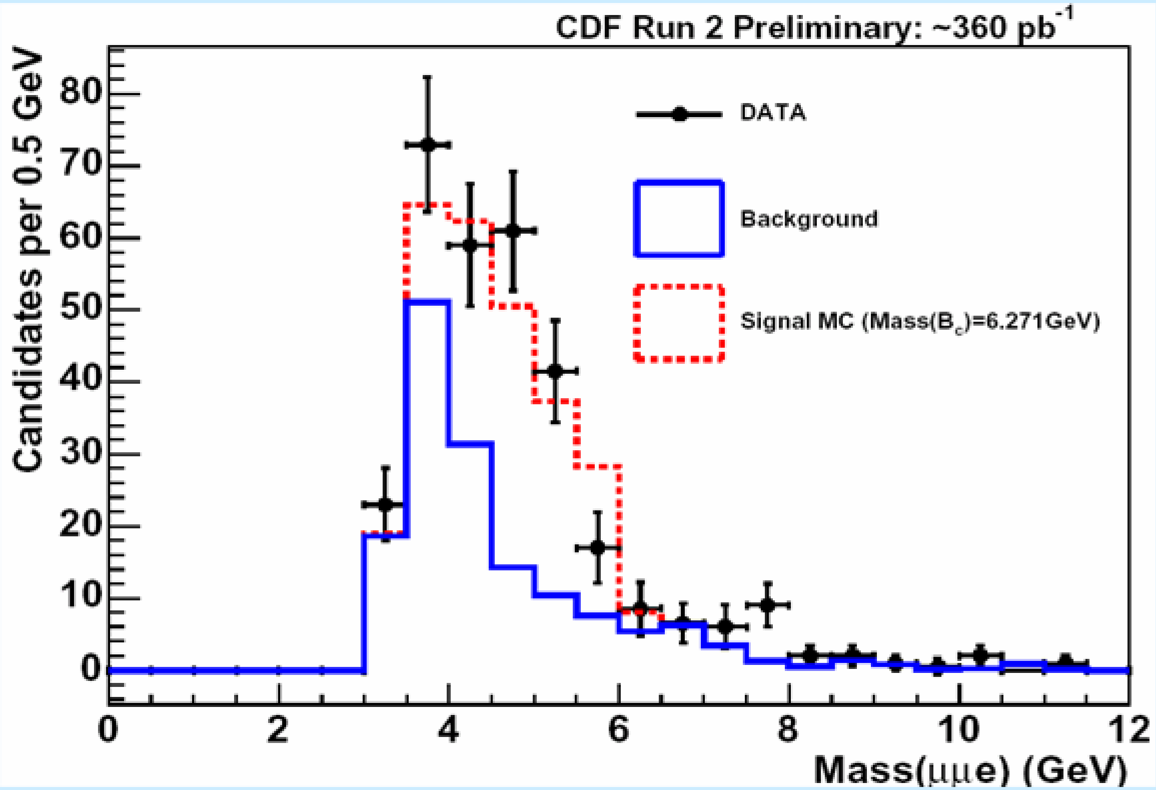
- Remove conversions by finding the partner track during the electron selection
- Evaluate the conversion finding efficiency from MC
- Calculate the residual conversion background as a function of M(J/ψe) using J/ψ+tagged conversions.
- Expected background
  - $14.54 \pm 4.38(\text{stat}) \pm 6.39\ (\text{syst})$





electron channel results

- Observed
  178.5±14.7 events
- Background
  63.6±4.9±13.6
- Excess
  114.9±15.5±13.6
- Significance
  5.9σ

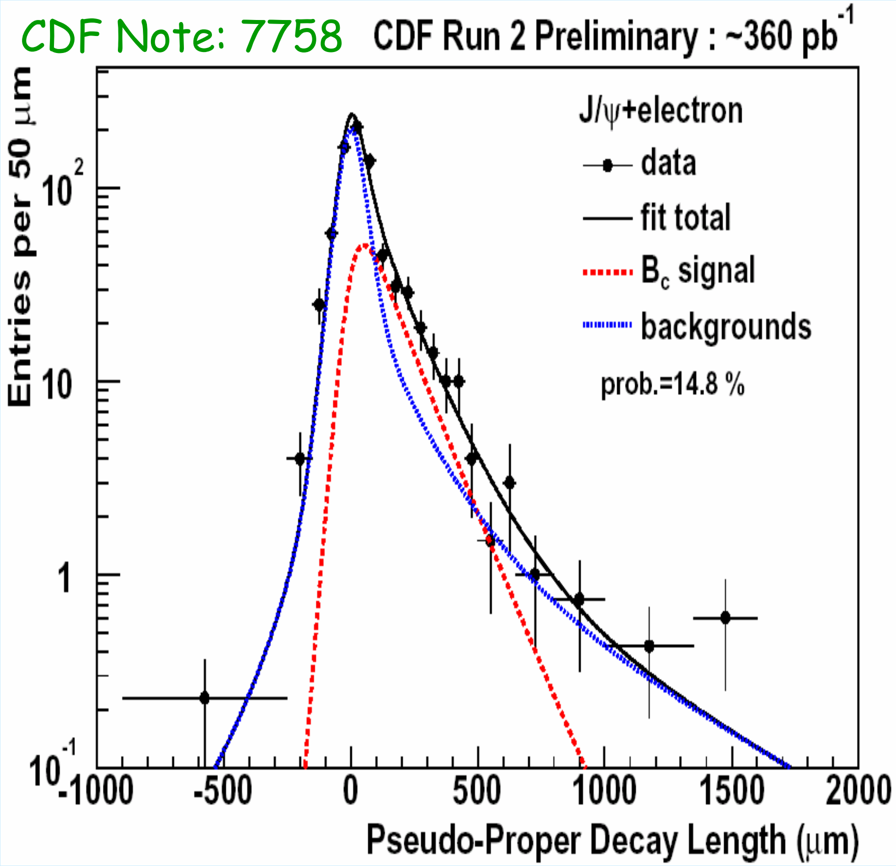


$$\frac{\sigma(B_c)\times \mathcal{B}(B_c \to J/\psi \ell \nu)}{\sigma(B_u)\times \mathcal{B}(B_u \to J/\psi K)} =$$

$P_T(B)>4$ and $|y| < 1$

0.282±0.038(stat.)±0.035(yield)±0.065(acceptance)

Bc lifetime



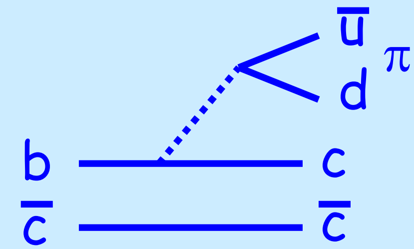
Systematic uncertainties

catalog	description	Fitted $c\tau$ (μm)	$\Delta c\tau$ (μm)
K-factor	$M(B_c) = 6.4, 6.2$ GeV	$140.4^{+21.7}_{-19.5}$, $143.0^{+22.0}_{-19.8}$	±1.7
K-factor	$\tau(B_c) = 0.5, 0.7$ ps	$141.9^{+21.9}_{-19.6}$	±0.2
K-factor	$H_b \to J/\psi X$ spectrum	$140.8^{+21.7}_{-19.5}$	±1.3
K-factor	Inclusive $J/\psi Xe\nu$	$140.5^{+21.7}_{-19.5}$	±1.6
K-factor	trigger simulation	$142.4^{+21.9}_{-19.7}$	±0.3
			K-factor sub-total $\Delta c\tau = \pm2.7$
$\mathcal{F}_{fake-e}$	Use J/ψ+trk shape directly	$140.6^{+21.5}_{-19.4}$	-1.5
$\mathcal{F}_{fake-J/\psi}$	use $J/\psi + e$ sideband	$136.0^{+24.8}_{-22.6}$	-6.1
$\mathcal{F}_{conv-e}$	Use tagged conv-e shape directly	$141.2^{+21.7}_{-19.5}$	-0.9
$\mathcal{F}_{conv-e}$	use J/ψ+conv-e sideband	$144.8^{+21.5}_{-19.3}$	$+2.7$
$\mathcal{F}_{b\bar{b}}$	use FE only	$150.2^{+17.5}_{-15.9}$	$+8.1$
$\mathcal{F}_{b\bar{b}}$	use GS only	$138.3^{+16.6}_{-15.0}$	-3.8
$\mathcal{F}_{b\bar{b}}$	No error scaling in MC	$140.9^{+21.6}_{-19.5}$	-1.2
			Background shapes sub-total $\Delta c\tau = (+8.5, -7.5)$
L_{xy} resolution	extra Gaussian/symmetric exponential	$137.0^{+21.9}_{-19.8}$, $136.5^{+21.9}_{-19.8}$	-5.6
L_{xy} resolution	Punzi effect	$137.3^{+22.1}_{-19.4}$	-4.8
L_{xy} resolution	silicon alignment		±1
			L_{xy} resolution sub-total $\Delta c\tau = (+1.0, -7.4)$
			Total systematic error $\Delta c\tau = (+9.0, -10.9)$

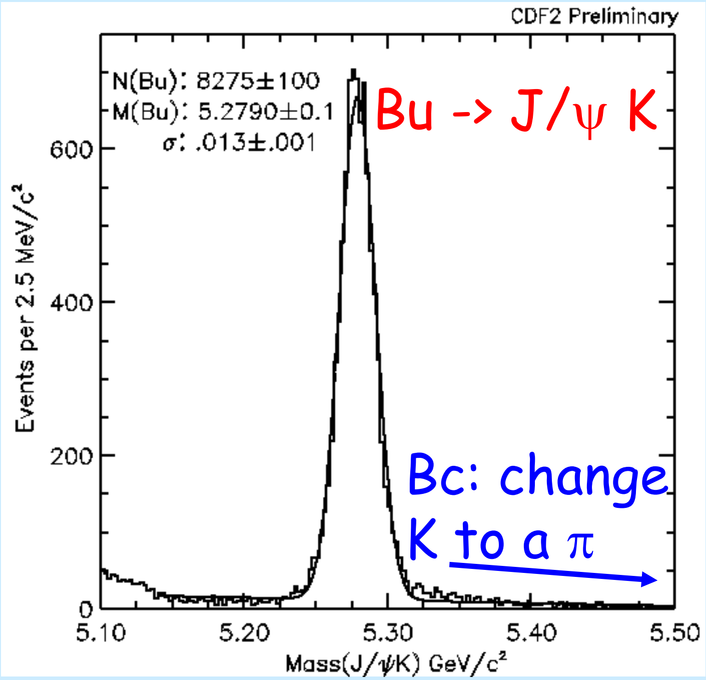
$c\tau(B_c)$ = 142.1 +21.9/-19.7(stat) ±10.0(syst) μm

$\tau(B_c)$ =0.474 +0.073/-0.066(stat) ±0.033(syst) ps

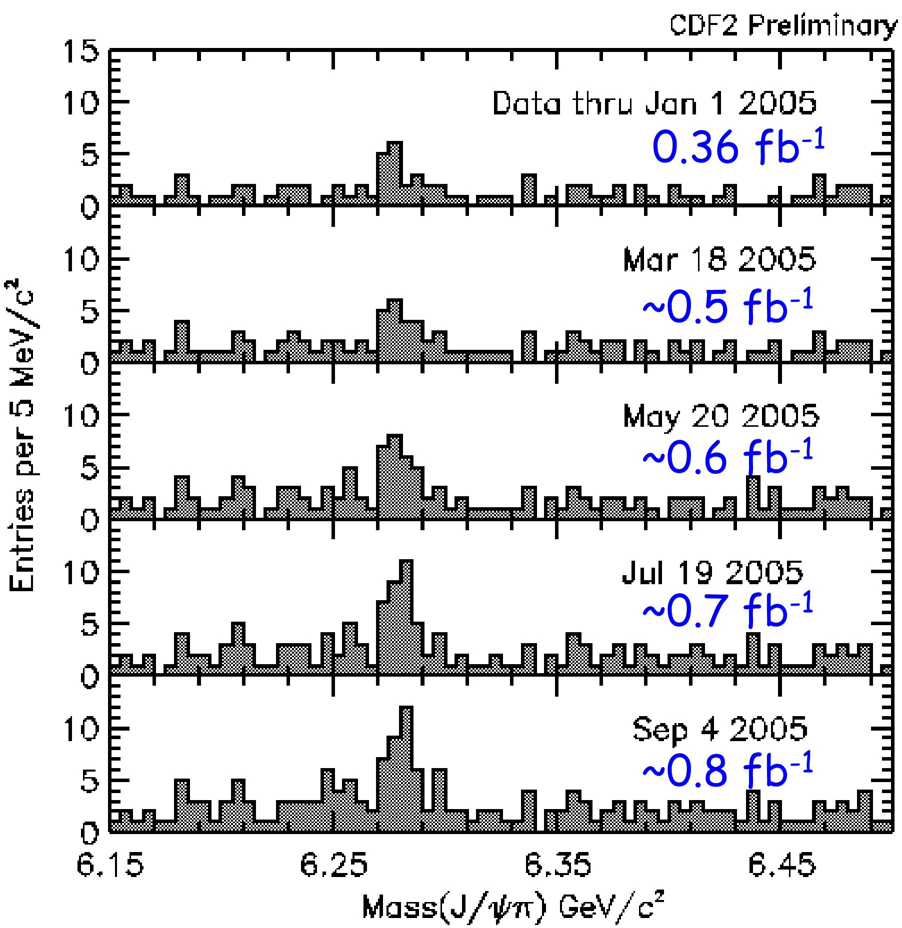
Bc -> J/ψ π

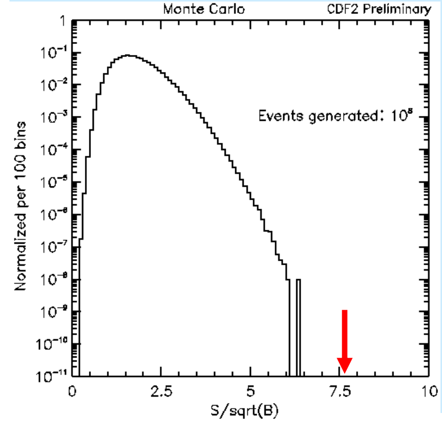


- Full reconstruction allows for precise mass measurement
- New analysis
  - Tune selection on the data: Bu -> J/ψ K reference decay
  - After approval, "open box".
  - Wait for events to become a significant excess
  - Measure properties of the Bc



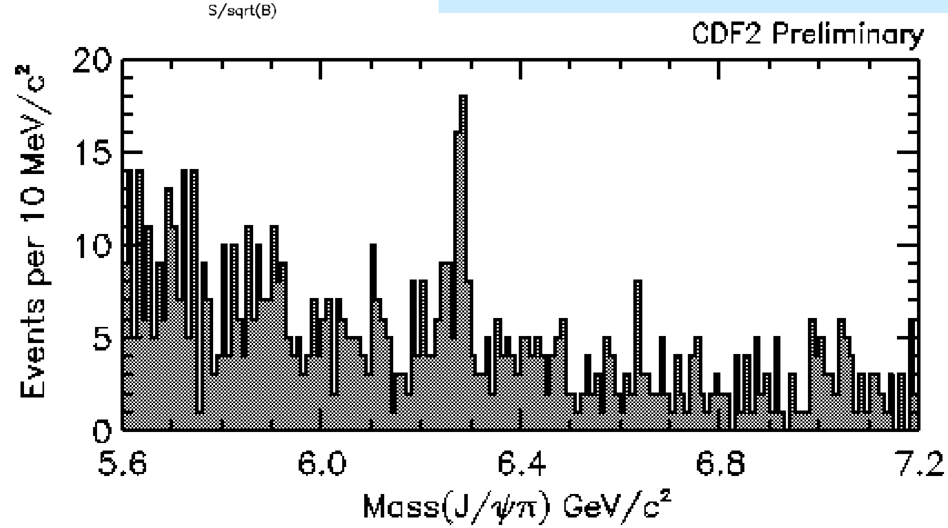
Bc -> J/ψ π





Num(events)$_{FIT}$= 38.9 sig 26.1 bkg between 6.24-6.3

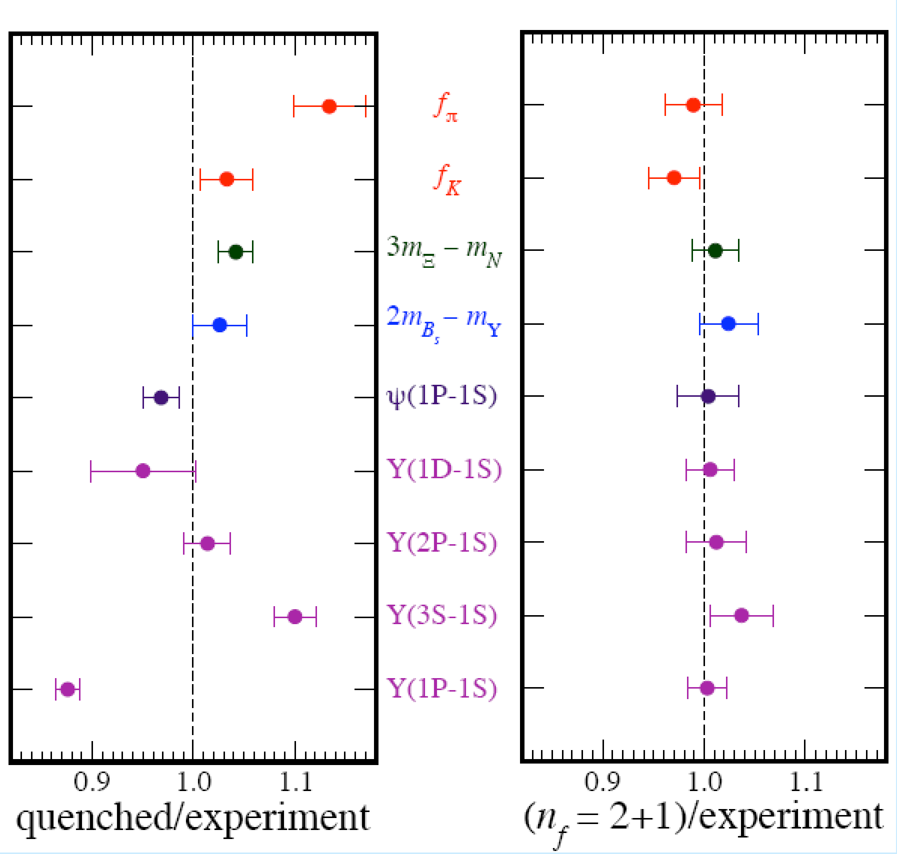
Significance > 6σ over search area

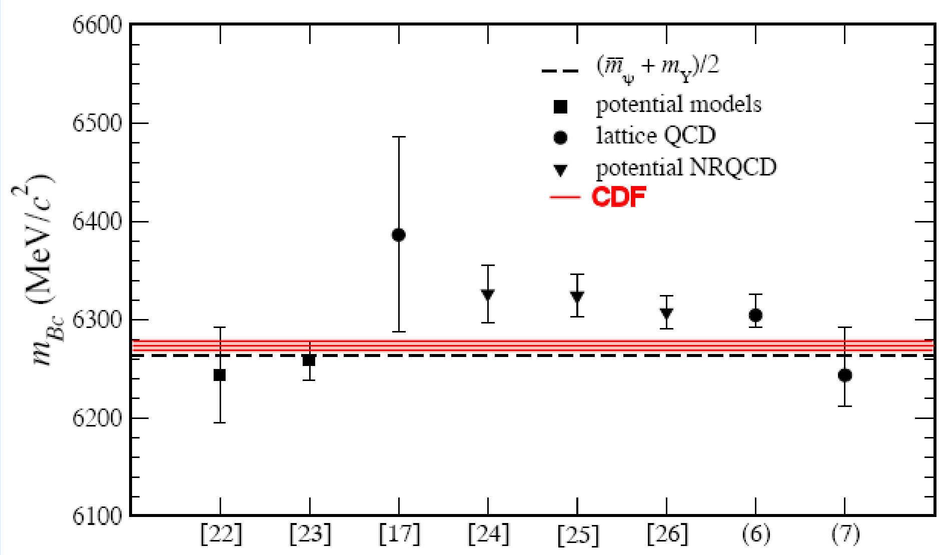


Mass(Bc) = 6275.2 +/- 4.3 +/- 2.3 MeV/c^2

Recent Lattice Calculations

- Lattice calculations that show good agreement with experiment were used to *predict* the mass of the Bc





$M(Bc)_{CDF} = 6275.2 \pm 4.3 \pm 2.3\ MeV/c^2$

$M(Bc)_{LAT} = 6304 \pm 12^{+18}_{-0}\ MeV/c^2$

PRL 94, 172001 (2005)

Summary and conclusions

- The study of the Bc is happening in Run II
- Semi-leptonic decays observed >5σ
  - $J/\psi\ \mu$ X and J/ψ e X
  - Precise lifetime measured
  - $\tau(B_c)$ =0.474 +0.073/-0.066(stat) ±0.033(syst) ps
- Fully reconstructed Bc -> $J/\psi\ \pi$ sample >6σ
  - Precision mass compared with theory
  - M(Bc) = 6275.2 +/- 4.3(stat) +/- 2.3(syst) MeV/c^2
- Bc at CDF is challenging theory