Measurement of B_c properties at CDF (mass, lifetime and cross section)

Turgun Nigmanov

University of Michigan and University of Pittsburgh, on behalf of CDF

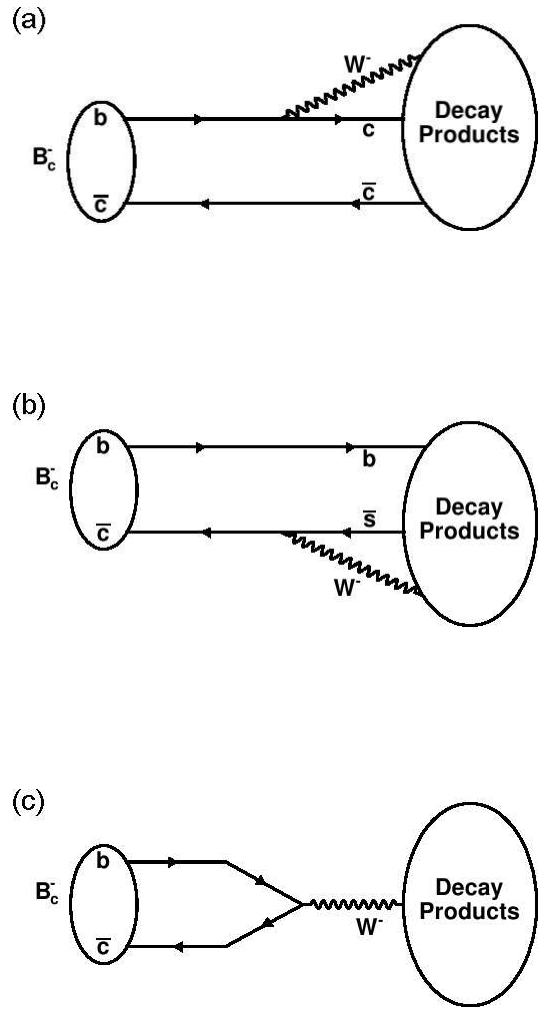
DPF 2009 WSU Detroit MI

July 26-31, 2009

introduction

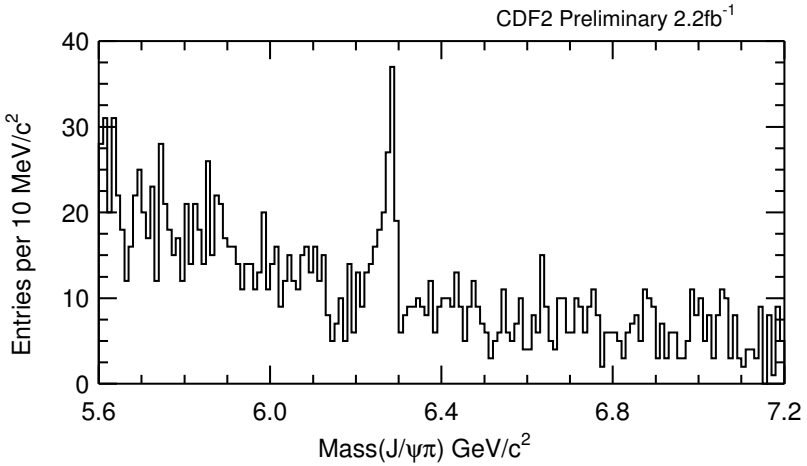
B_c^+ meson is composed of a $\bar{b}$ and c quarks

- Double heavy B_c^+ properties are interesting to compare with heavy-light mesons, such as B^+, B^0 or B_s^0
- Partial width from decays of either quark (a,b), or annihilation (c) make significant contribution to the total width:
  - predicted lifetime for B_c^+ is 0.55±0.15 ps (arXiv:hep-ph/0308214v1)
  - lifetimes of other B mesons are 3 times longer
- Rich spectroscopy. $B_c^+ \rightarrow J/\psi + \mu/e + \nu$ decay mode predicted to have a largest branching fraction:
  - used for lifetime and cross section measurements



B_c^+ mass measurements at CDF

- B_c^+ mass predictions:
  - nonrelativistic potential models: 6247-6286 MeV/c^2
  - lattice QCD calculations: 6304$\pm$12 MeV/c^2
- Precision measurements are needed to test these predictions
- B_c^+ is too heavy to be produced at e^+e^- colliders
- CDF has a capability to make most precise mass measurement of B_c^+ using hadronic decay mode: $B_c^+ \longrightarrow J/\psi\pi^+$



- Integrated luminosity: 2.2 fb^{-1}
- A signal: 108 $\pm$ 15 candidates
- m(B_c^+) = 6275.6 $\pm$ 2.9(stat) $\pm$ 2.5(syst) MeV/c^2
- Phys.Rev.Lett. 100,182002, 2008
- Studies are extended to higher luminosity

$c\tau$ and $\sigma(B_c)$ measurement concepts

Lifetime:

- Undetected ν lead to the missing momentum in B_c decays
- We measure a pseudo-decay length:

$$\text{ct}^* = \frac{M(B_c)L_{xy}(J/\psi+l)}{p_T(J/\psi+l)}$$

- Define K factor that relates ct of B_c system to ct*:

$$\text{Kct}^* = \text{ct, where ct} = \frac{mL_{xy}}{p_T}$$

- Obtain K distribution from Monte Carlo
- Write model for ct* in terms of B_c lifetime, cτ, and distributions of K, H(K):

$$F_{B_c}(ct^*,\sigma)=\sum_i H(K_i)\frac{K_i}{c\tau}e^{\frac{-K_i ct^*}{c\tau}}\theta(ct^*)\otimes G(\sigma)$$

where σ is an error of ct* in event-by-event base

Cross section:

- Perform measurements for both mesons: B_c and B^+ and calculate a ratio:

$$\frac{\sigma(B_c^+)*BR(B_c^+\to J/\psi+\mu^++\nu)}{\sigma(B^+)*BR(B^+\to J/\psi+K^+)} = \frac{N(B_c^+)}{N(B^+)}\times\epsilon_{rel}$$

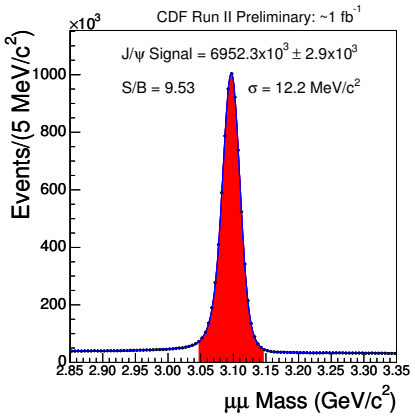
- Advantages:
  - $\sigma(B^+)$ and BR($B^+ \to J/\psi K^+$) are well measured
  - Most of uncertainties for $J/\psi \to \mu^+\mu^-$ and some for 3-rd track in $J\psi + Track$ system would be canceled
- For this analysis we use $B_c^+ \to J/\psi\mu^+\nu$ where selection cuts require a high quality third muon

Analysis overview

Reconstruct $J/\psi \to \mu^+\mu^-$ decays:

- Data: use an inclusive J/ψ trigger stream with integrated luminosity of 1 fb^{-1}
- Look for dimuons from $J/\psi \to \mu^+\mu^-$ within of $|\eta| < 1.0$

Dimuons from red area used as an input for both analysis



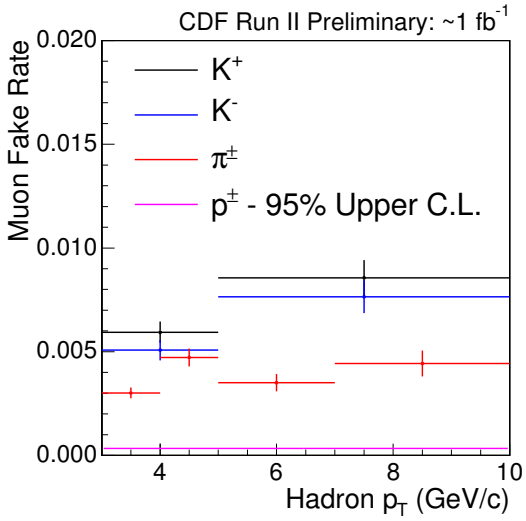
Reconstruct:

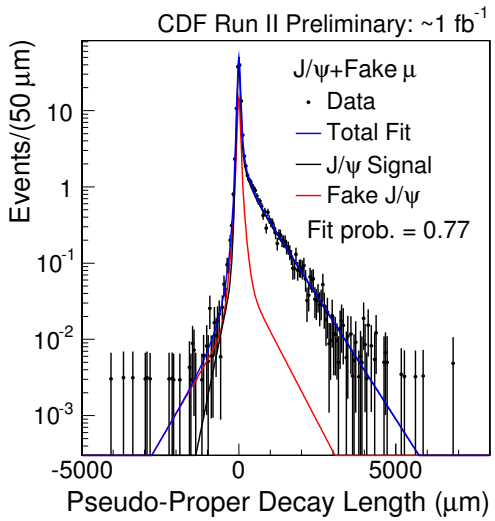
- $B^+ \to J/\psi + K^+$ (for both analysis: background normalization and ratio calculation)
- $B_c^+ \to J/\psi + l^+$ (where l either μ/e for lifetime and μ for cross section)

Backgrounds, common for both analysis:

- Misidentified J/ψ: continuum J/ψ background from $J/\psi + \mu/e$ system.
- Misidentified third muon: it can be caused by π or K hadrons due to decays-in-flight or punch through calorimetry and a steel absorber of 3.3 interaction lengths.
- $b\bar{b}$ background. The J/ψ and l^+ originate from different b jets in same event.

Backgrounds, continue





Left: probabilities to mimic a μ

- $D^{*+} \to D^o\pi^+ \to K^-\pi^+\pi^+$ for π and K
- $\Lambda^o \to p^+\pi^-$ for protons

Right: ct* model for misidentified third muon background

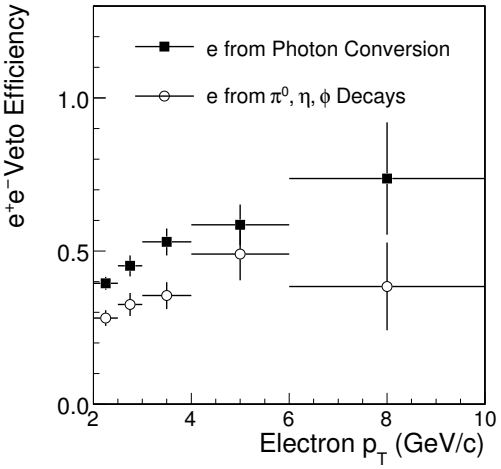
Backgrounds, specific for each analysis:	lifetime	cross section
Other modes of B_c^+ with 3μ in final state: $\psi(2S)\mu^+.. \to J/\psi\mu$	included	subtracted
Misidentified $e^\pm$ - if $\pi/K/\bar{p}$ satisfied $e^\pm$ likelihood (calorimeter)	yes	n/a
Residual conversion - electrons from γ-conversion or $\pi^o \to e^\pm$+...	yes	n/a
Prompt J/ψ - additional $J/\psi l^+$ that are not accounted above	yes	negligible

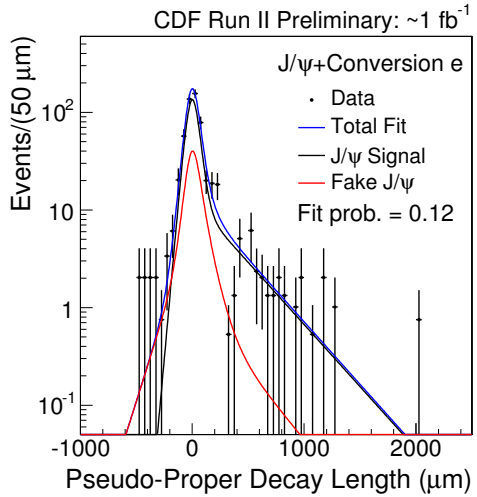
Systematic uncertainties for lifetime analysis

Apply veto if electron is part of e^+e^- pair.

Top: veto efficiency, determined with Pythia

Bottom: Fit ct* of reweighted veto events





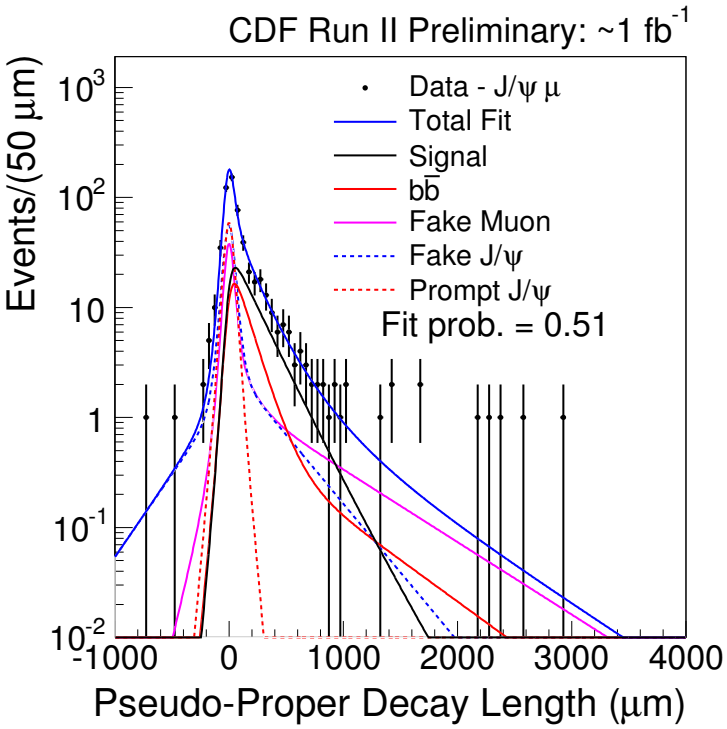
Lifetime systematic uncertainties:

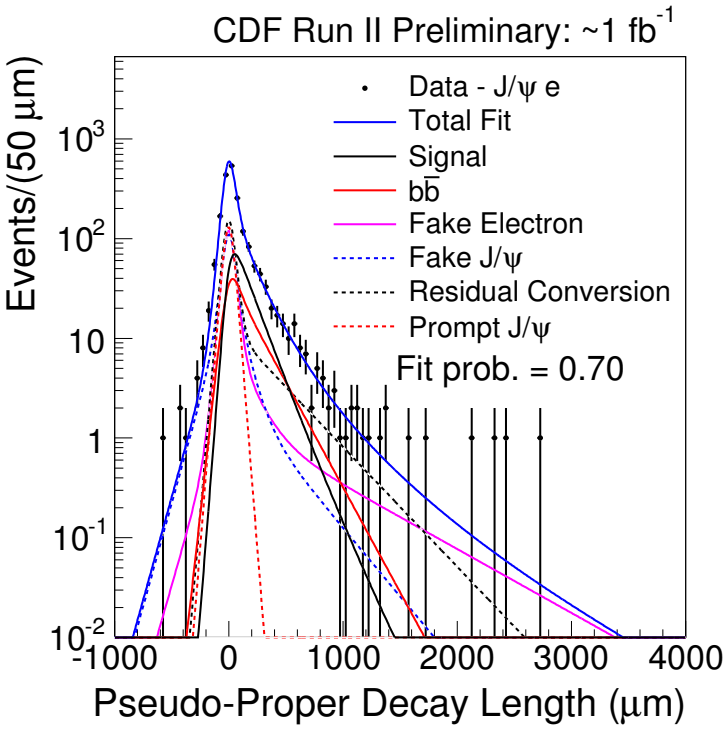
- Resolution function - choice of model for detector resolution: 3.8 μm
- Pythia model for $b\bar{b}$ background - relative contribution of QCD processes: 2.4 μm
- Vertex detector alignment - uncertainties in positions of silicon detectors: 2.0 μm
- e^+e^- veto efficiency - uncertainties related to modeling e^+e^- veto efficiencies: 1.5 μm
- B_c spectrum - variations of K factor distribution due to of variations in B_c production spectrum: 1.3 μm

Total uncertainty: $\pm$5.5 (syst) μm

B_c^+ lifetime fits

Background sizes were constrained to it's predicted values. Prompt J/ψ allowed to float.



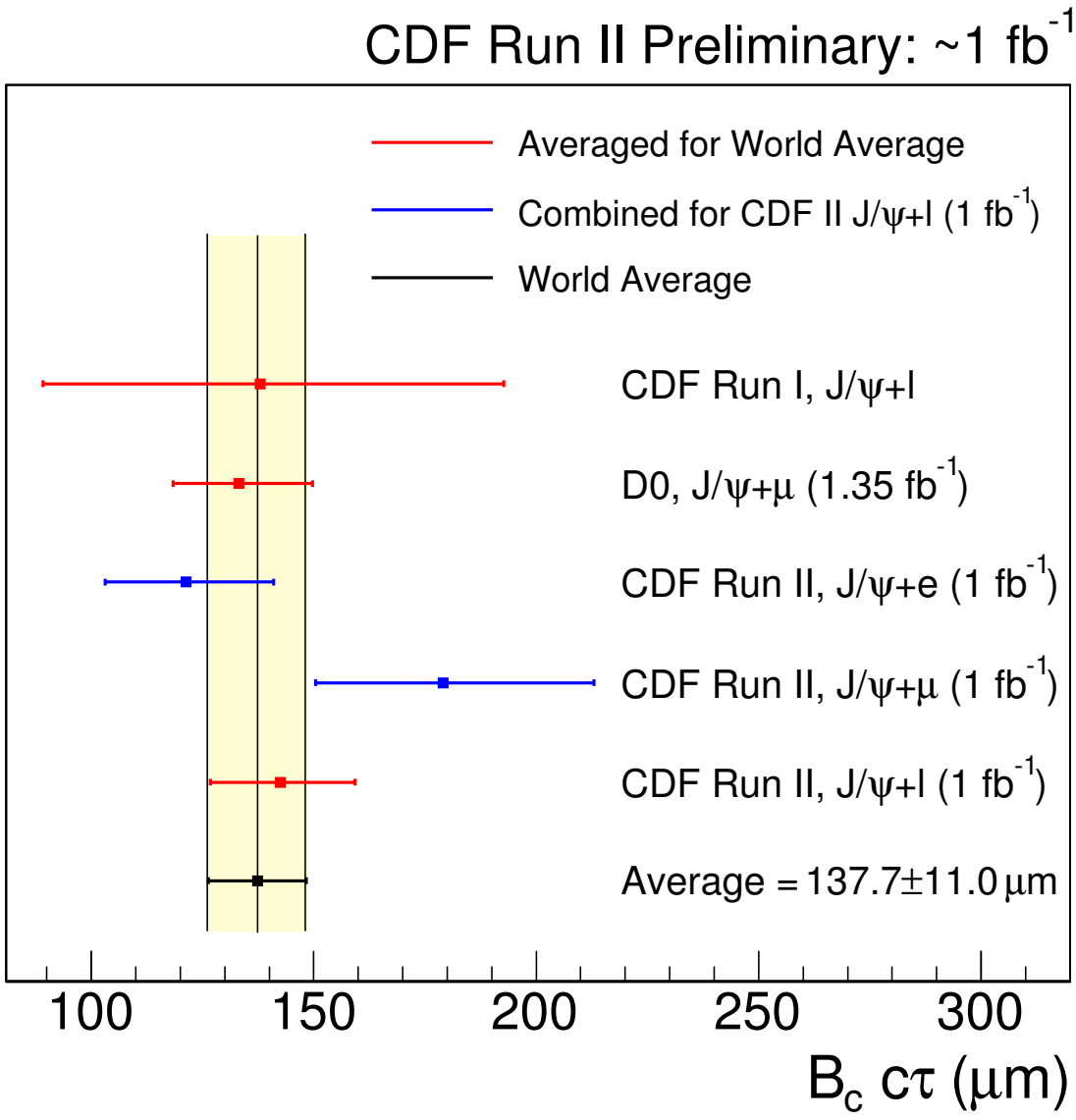


Fitted ct* for muon (on left) and electron (on right) channels.

$$c\tau_\mu = 179.1^{+32.6}_{-27.2}(stat)\mu m \qquad c\tau_e = 121.7^{+18.0}_{-16.3}(stat)\mu m$$

combined: $$c\tau(B_c^+) = 142.5^{+15.8}_{-14.8}(stat) \pm 5.5(syst)\mu m$$

Lifetime: comparison with other results

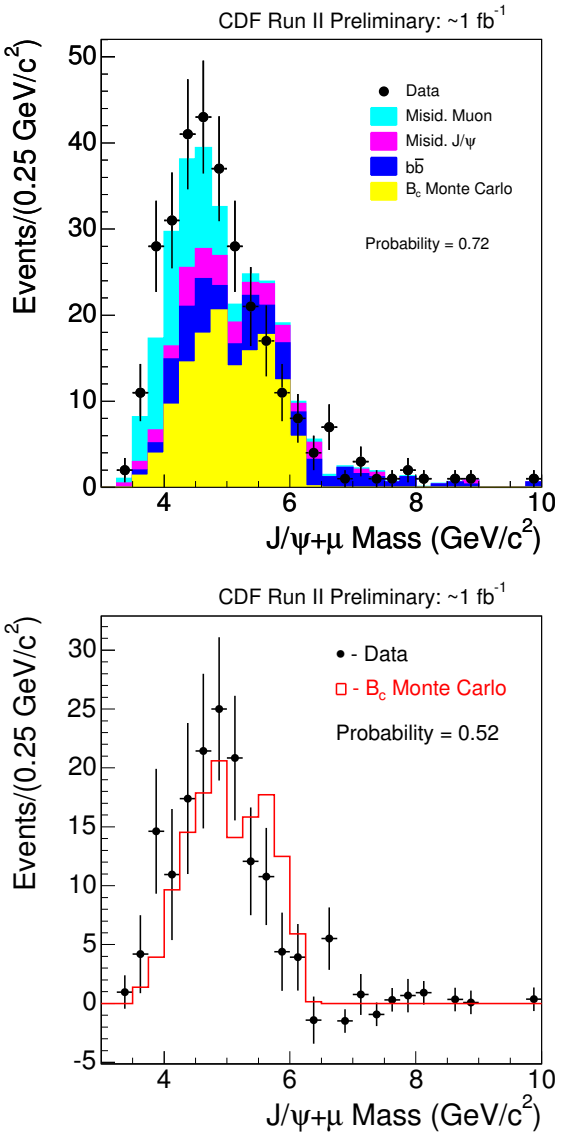


B_c^+ backgrounds for cross section

Backgrounds for $B_c^+ \to J/\psi\mu^+$ decays and B_c^+ excess with the $p_T(3\mu) > 4$ (6) GeV/c cuts.

	$p_T(B_c^+) > 4$ GeV/c	$p_T(B_c^+) > 6$ GeV/c
N(B_c^+) observed	229±15.1(stat)	214±14.6(stat)
Misidentified J/ψ	21.5±3.3(stat)	20.5±3.2(stat)
Misid. third muon	55.8±2.0(stat)	53.6±1.9(stat)
Doubly misidentified	-8.8±0.4(stat)	-7.5±0.3(stat)
$b\bar{b}$ background	37.7±7.3(st+sys)	35.4±7.0(st+sys)
Other decay modes	5.2±0.5(stat)	4.8±0.4(stat)
Total background	111.4±8.3(stat)	106.9±8.0(stat)
B_c^+ signal	$117.6 \pm 17.2(st)$	$107.1 \pm 16.7(st)$

Note: "Doubly misidentified" is a subsample of misid. J/ψ and misid. muon samples, it needs to be subtracted once to avoid double counting.



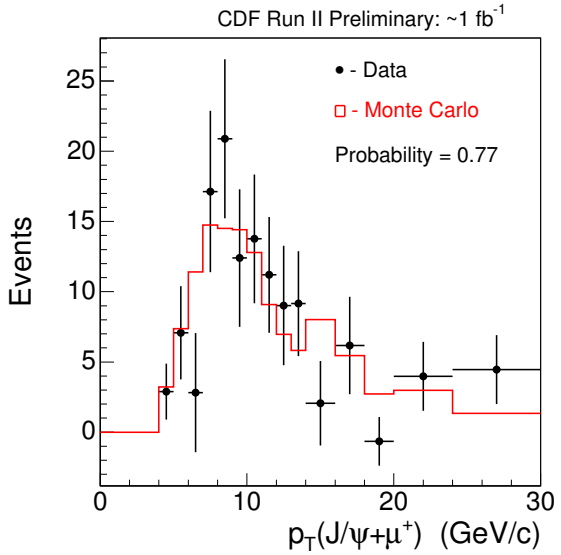
Upper plot: $B_c^+ \to J/\psi\mu^+$ candidates. Monte Carlo sample and backgrounds are superimposed. Lower: backgrounds are subtracted.

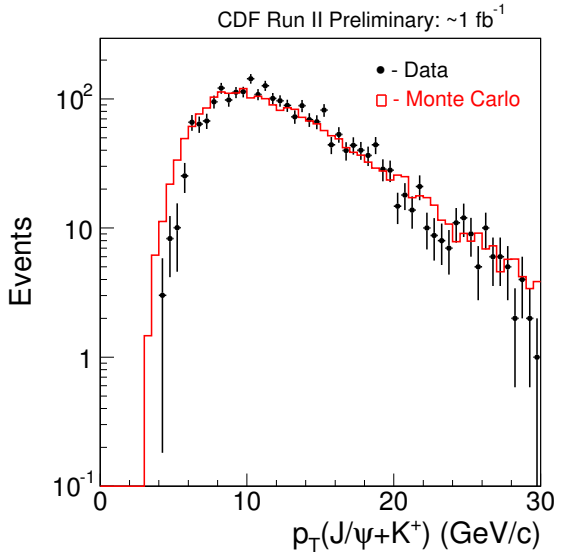
Relative efficiency, ϵ_{rel}

Relative efficiency $\epsilon_{rel} = \epsilon_{B^+}/\epsilon_{B_c^+}$

- MC simulations of $B_c^+ \to J/\psi\mu^+\nu$, $B_c^* \to B_c^+\gamma$ and $B^+ \to J/\psi K^+$ decays need as input:
  - p_T dependence of B_c^+ production spectrum, we used it from PRD 72,114009(2005)
  - p_T dependence of B^+ production spectrum, we used it as at JHEP07,033(2004), good agreement with CDF measurements

	$p_T(B) > 4$ GeV/c	$p_T(B) > 6$ GeV/c
$\epsilon_{B_c^+}$ (%)	0.0551	0.1232
ϵ_{B^+} (%)	0.3231	0.6005
ϵ_{rel}	5.867 ± 0.068(st)	4.873 ± 0.060(st)





B_c^+ systematic uncertainty for cross section

- Misidentified J/ψ: as this is derived from data, we do not assign a systematic uncertainty.
- Misidentified muon: we calculate the uncertainties by varying the proton fraction in the $J/\psi + track$ sample. This is a dominant source of uncertainty.
- $b\bar{b}$ background: we combine statistical and systematic uncertainties in the fit of the scale factors and their correlations. It included in the B_c^+ statistical uncertainty.
- Other decay modes: we calculate the uncertainty by varying the branching ratios of the non-exclusive $B_c^+ \rightarrow J/\psi + \mu^+ + X$ decays.

	$p_T(B) > 4$ GeV/c	$p_T(B) > 6$ GeV/c
Misidentified muon	± 5.7	± 5.5
Doubly misidentified	± 0.9	± 0.8
$b\bar{b}$ (illustration)	± 7.3 (st+sys)	± 7.0 (st+sys)
Other decay modes	$^{+6.0}_{-2.8}$	$^{+5.6}_{-2.5}$
Total	$^{+8.3}_{-6.4}$	$^{+7.9}_{-6.1}$

ϵ_{rel} systematic uncertainty for cross section

- B_c^+ lifetime: it was estimated by varying the B_c^+ lifetime within $\pm 14 \mu$m ($\sim 1\sigma$) relative to the nominal value
- B_c^+ spectrum: we estimate variations due to of three different theoretical approaches
- B^+ spectrum: re-weight the simulated spectrum below 10 GeV/c to bring it into agreement with the data
- μ,K simulation: re-weighting the transverse momentum of the kaon and muon according to the measured differences in data

	$p_T(B) > 4$ GeV/c	$p_T(B) > 6$ GeV/c
B_c^+ lifetime	$^{+0.393}_{-0.223}$	$^{+0.354}_{-0.160}$
B_c^+ spectrum	± 0.720	± 0.298
B^+ spectrum	± 0.340	± 0.161
μ,K simulation	± 0.192	± 0.160
ϵ_{rel} total systematics	$^{+0.554}_{-0.450} \pm 0.720$(spectrum)	$^{+0.420}_{-0.278} \pm 0.298$(spectrum)

B_c^+ to B^+ ratio results

	$p_T(B) > 4$ GeV/c	$p_T(B) > 6$ GeV/c
$N(B_c^+)$	117.6 ± 17.2(stat)$^{+8.3}_{-6.4}$(sys)	107.1 ± 16.7(stat)$^{+7.9}_{-6.1}$(sys)
$N(B^+)$	2333 ± 55(stat)	2299 ± 53(stat)
ϵ_{rel}	5.867 ± 0.068(stat) $^{+0.554}_{-0.450}$(sys)± 0.720(spectrum)	4.872 ± 0.060(stat) $^{+0.420}_{-0.278}$(sys)± 0.298(spectrum)
$\frac{N(B_c^+)}{N(B^+)} \times \epsilon_{rel}$	0.295 ± 0.040(stat) $^{+0.033}_{-0.026}$(sys)± 0.036(spectrum)	0.227 ± 0.033(stat) $^{+0.024}_{-0.017}$(sys)± 0.014(spectrum)

Previous CDF measurements:

	L, pb^{-1}	$p_T(B)$ value	$R = \frac{\sigma(B_c^+)\cdot BR(B_c^+ \to J/\psi + l^+ + \nu)}{\sigma(B^+)\cdot BR(B^+ \to J/\psi + K^+)}$
$Run\ I, e+\mu$	110	$p_T(B) > 6\ GeV/c$	$0.132^{+0.041}_{-0.037}$(st)± 0.031(sys)$^{+0.032}_{-0.020}$(lt)
$Run\ II, \mu$	360	$p_T(B) > 6\ GeV/c$	0.245 ± 0.045(st)± 0.066(sys)$^{+0.080}_{-0.032}$(lt)
$Run\ II, e$	360	$p_T(B) > 4\ GeV/c$	0.282 ± 0.038(st)± 0.035(y)± 0.065(a)

B_c^+ total cross section

Available quantities:

Predicted $BR(B_c^+ \to J/\psi + l^+ + \nu)$ = 2.07×10^{-2}, PRD 73 054024 (2006)

$BR(B^+ \to J/\psi + K^+)$ = $(1.007 \pm 0.035) \times 10^{-3}$ PDG, 2008

$\sigma(B^+)$ = 2.78 ± 0.24 μb for $p_T(B^+) > 6$ GeV/c by CDF PRD 75:012010,2007

Then we might calculate followings:

$\sigma(B_c^+) \cdot BR(B_c^+ \to J/\psi + l^+ + \nu) = 0.64 \pm 0.20 nb$ ($p_T(B_c^+) > 6$ GeV/c)

$\sigma(B_c^+) = \frac{0.227 \times 2.78 \mu b \times 1.007 \times 10^{-3}}{2.07 \times 10^{-2}}$ = $31 \pm 10\ nb$ ($p_T(B_c^+) > 6$ GeV/c)

Predicted $\sigma(B_c^+ + B_c^*)$:

	$\sqrt{s}$, TeV	$\lvert y \rvert$	p_T, GeV/c	$\sigma(B_c^+ + B_c^*)$
Chao-Hsi Chang[1]	1.96	< 0.6	> 4	$23.3\ nb$
Phys.Lett.B605(2005)311	1.8	< 1	> 6	$7.4 \pm 5.4\ nb$

[1] Chao-Hsi Chang, "Bc Production at Hadron Colliders" Sino-German Workshop, Sept. 20-23, 2006, DESY

conclusions

Prior to LHC data CDF is a major contributor to B_c^+ property studies:

- mass measurements

  m(B_c^+)=$6275.6 \pm 2.9(stat) \pm 2.5(syst)$ MeV/c^2, PRL 100,182002, 2008

- decay properties:

  $c\tau(B_c^+) = 142.5^{+15.8}_{-14.8}(stat) \pm 5.5(syst)\mu m$

- production properties (for $p_T(B) > 6$ GeV/c):
  - $\frac{\sigma(B_c^+)*BR(B_c^+ \to J/\psi+\mu^+ +\nu)}{\sigma(B^+)*BR(B^+ \to J/\psi+K^+)} = 0.227 \pm 0.033$(stat)$^{+0.024}_{-0.017}(sys)\pm 0.014$(spectrum)
  - $\sigma(B_c^+) \cdot BR(B_c^+ \to J/\psi + l^+ + \nu) = 0.64 \pm 0.20 nb$ (free from predictions)