Recent Quarkonium results from CDF

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(on behalf of the CDF Collaboration)

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Measurement of the $B_c^+ \to J/\psi\, \mu^+ \nu$ relative cross section using the complete CDF dataset

$$\text{Ratio} \quad \frac{\sigma\left(B_c^+\right) \cdot Br\left(B_c^+ \to J/\psi\, \mu^+ \nu\right)}{\sigma\left(B^+\right) \cdot Br\left(B^+ \to J/\psi\, K^+\right)}$$

for $p\bar{p}$ interactions at $\sqrt{s}$ = 1.96 TeV

using the full RunII dataset: (8.7 ± 0.5) fb^{-1}

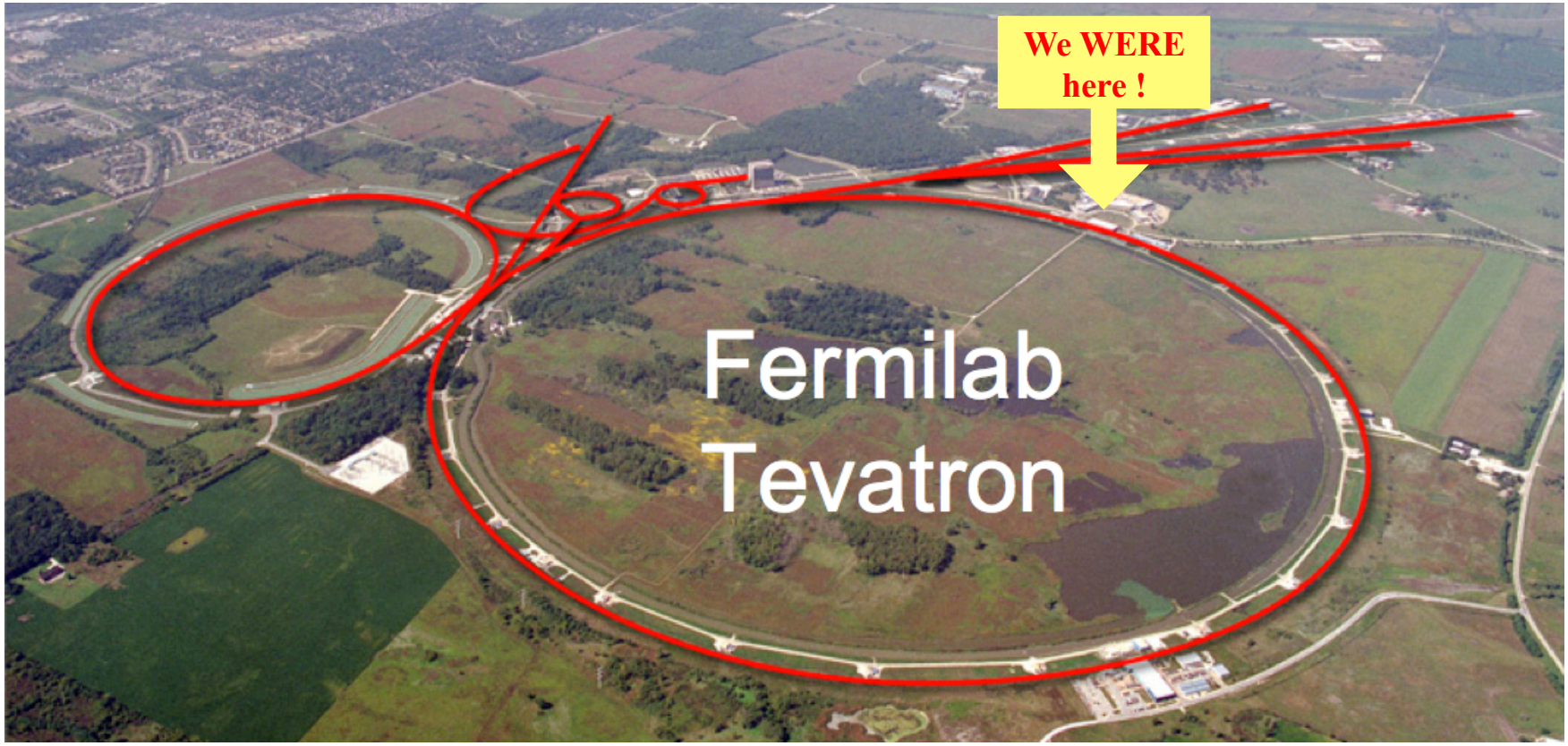
Motivations

Why is B_c^+ so interesting?

- most massive of the bottom-flavored mesons (apart from the bottomonium state $b\bar{b}$)
- 2 different "heavy" quarks are produced in one interaction
- major contributions to its decay:
  - $\bar{b} \to \bar{c}W^+$ final states like $J/\psi\pi$, $J/\psi\ell\nu$
  - $c \to sW^+$ final states like $B_s\pi$, $B_s\ell\nu$
  - $\bar{b}c \to W^+$ final states like DK , $\tau\nu_\tau$
- observed by CDF in RunI: $B_c^+ \to J/\psi\ell^+X$

  Phys. Rev. Lett. **81**, 2432 (1998)
  Phys. Rev. D **58**, 112004 (1998)

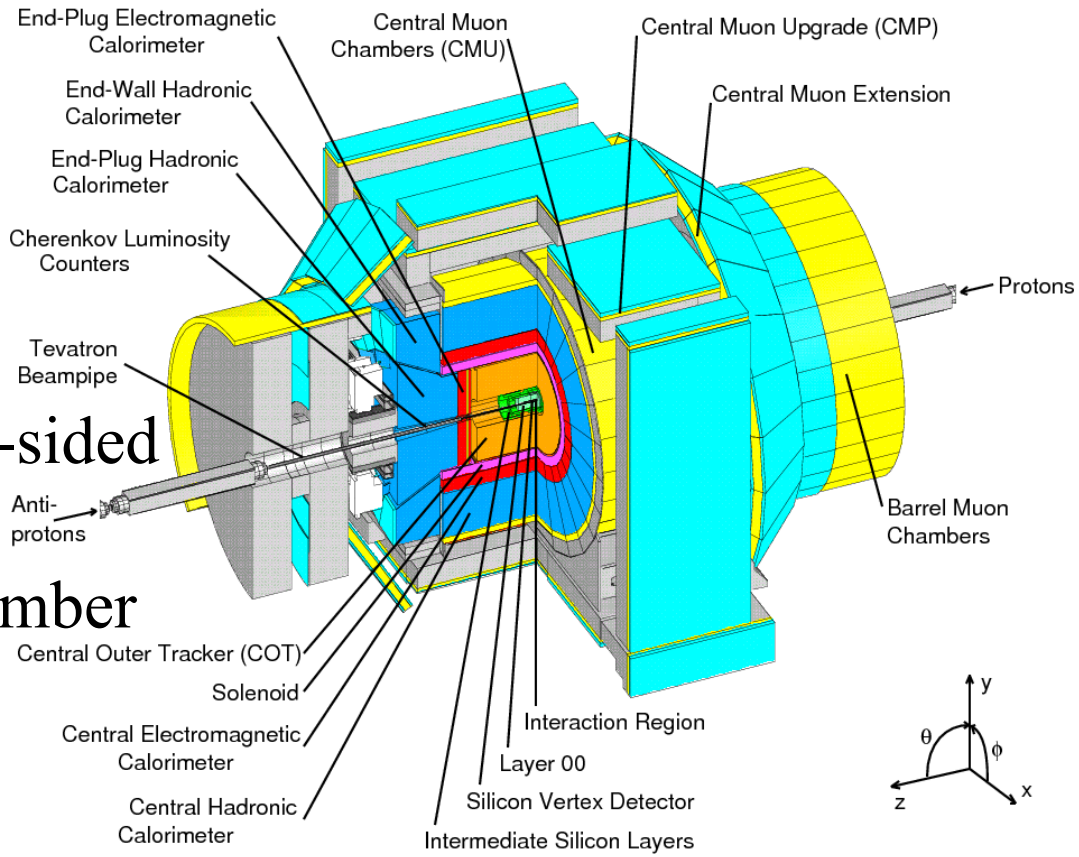
CDF @ Fermilab



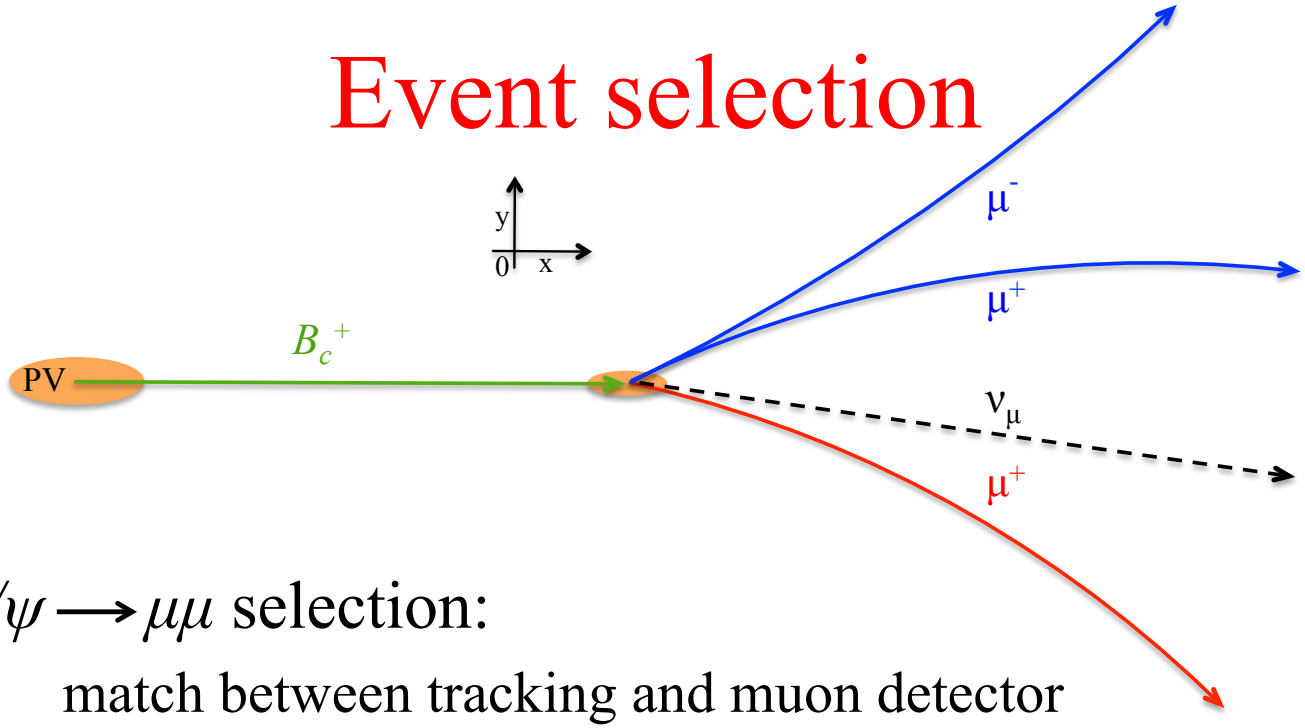
CDF detector

For this analysis:

- Trigger:
  - muon chambers
- 3D tracking:
  - 7 layers of double-sided silicon strips
  - 96 layers drift chamber
- Data:
  - 8.7 fb^{-1} in RunII
  - collected by the $J/\psi \longrightarrow \mu\mu$ trigger



Event selection



- $J/\psi \longrightarrow \mu\mu$ selection:

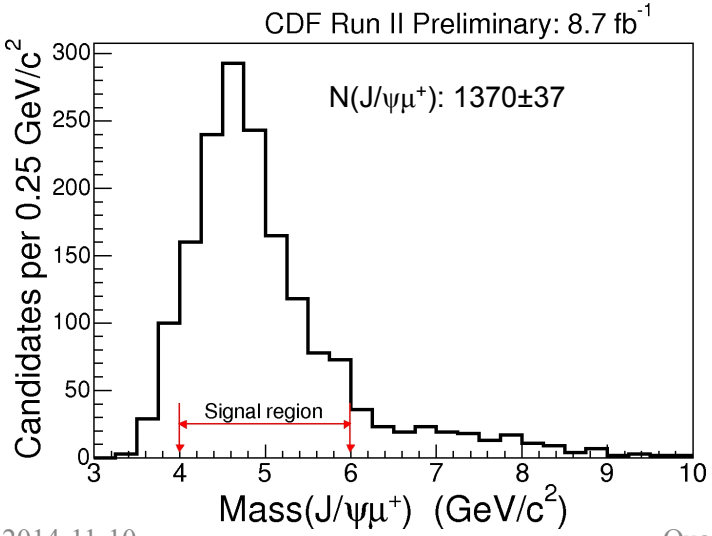
  match between tracking and muon detector

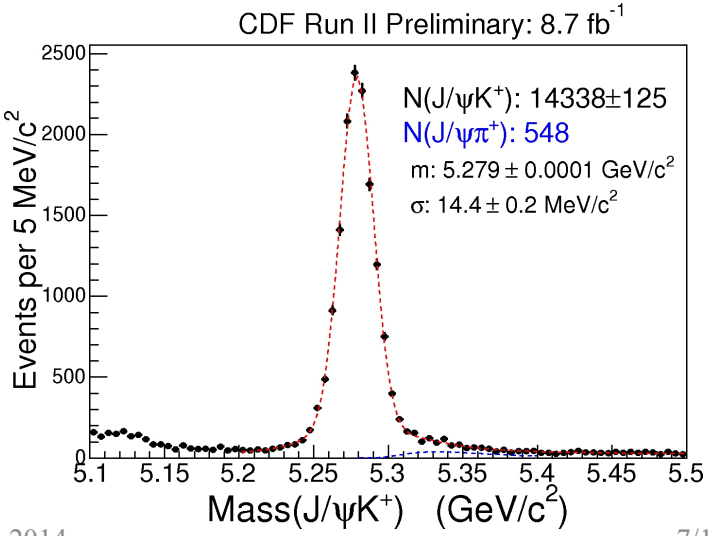
  - reconstructed track with $p_T > 1.5$ GeV/c
  - segment in the muon chambers

- We make a candidate with the J/ψ and a 3rd track:
  - a K^+ for a B^+ decay
  - a μ^+ for a B_c^+ decay

Event selection

- We define the B_c^+ signal region to be between 4 and 6 GeV/c^2
- B_c^+ off-signal regions are used as a cross check of the background prediction (they contain < 10% of the B_c^+ signal)
- The Cabibbo Suppressed contribution to the *J/ψ-K* invariant mass is fixed to 3.83 % [Phys. Rev. D **85**, 091105 (2012)]



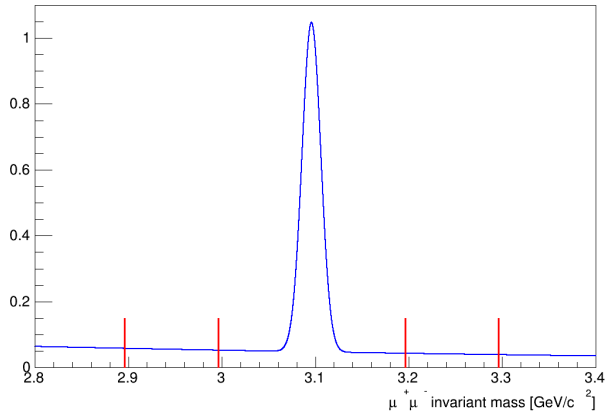


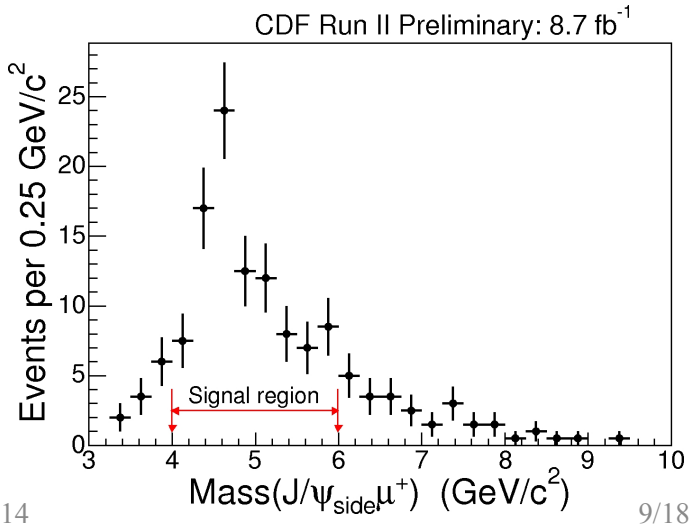
B_c^+ backgrounds

- Misidentified J/ψ
- Misidentified 3rd μ
- $b\bar{b}$ backgroud
- Other B_c^+ decays

Misidentified J/ψ - B_c^+ background

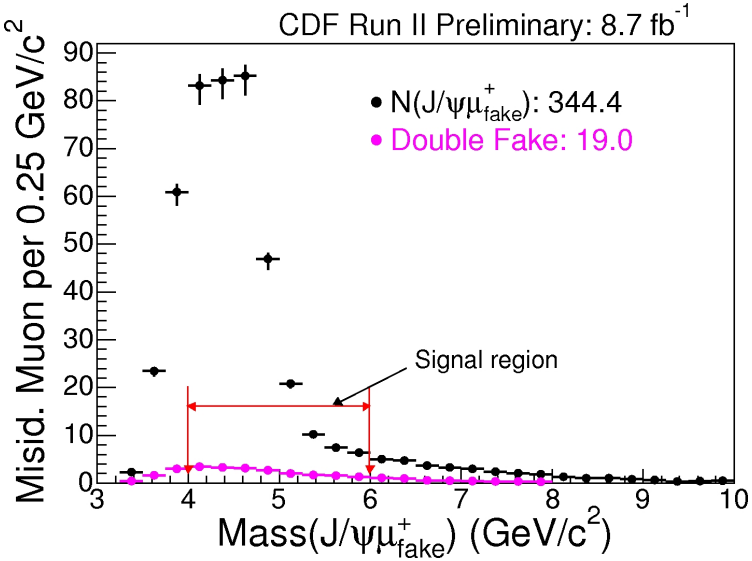
- We select the sidebands regions of the $\mu\mu$ invariant mass of the J/ψ candidates
- We add a 3rd muon
- 96.5 ± 6.9 (stat) events in the signal region





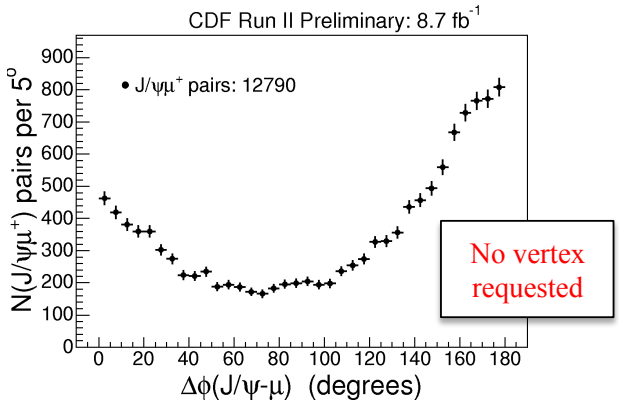
Misidentified μ - B_c^+ background

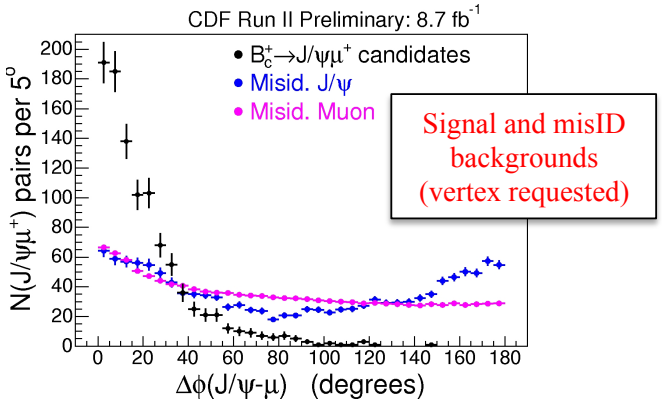
- Reconstruct *J/ψ* + *track* system
- The 3rd track, assumed to be a real μ, might be:
  - a real μ coming from a K or a π decay-in-flight
  - a fake μ due to a K or a π punch-through
  - a fake μ due to a p punch-through
- We assess the first two probabilities using real K and π tagged from a D^* sample
- p punch-through probability is measured from a Λ^0 sample
- Assess K, π and p fractions in our data using *dE/dx* and *ToF* information
- A small fraction of events comes from misID *J/ψ* AND misID μ; they are removed to avoid double counting



$b\bar{b}$ - B_c^+ background

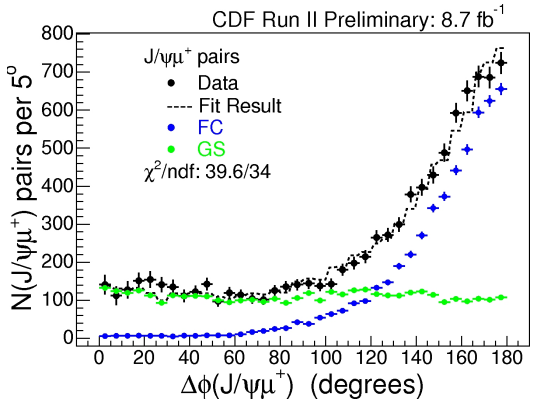
- When it happens ?
  - J/ψ produced by a b hadron
  - 3rd μ produced by a $\bar{b}$ hadron
- How we assess it ?
  - Pythia MC simulation
  - We remove the requirement that the $J/\psi\mu^+$ must come from the same vertex
  - We look at the $\Delta\phi$ distributions of the whole data sample
  - We subtract signal and non $b\bar{b}$ background components (with the vertexing requirement)

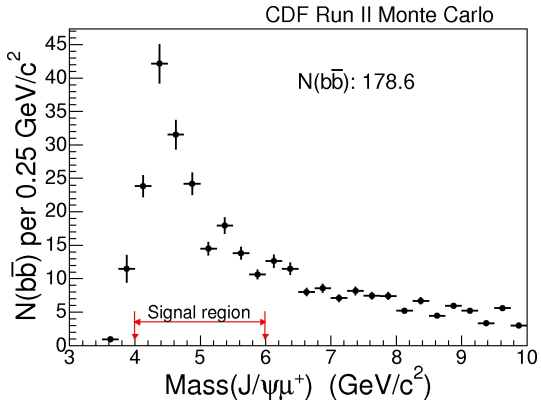




$b\bar{b}$ - B_c^+ background

- what's left is due to QCD background
- we get the shapes of the involved QCD processes (Flavor Creation and Gluon Splitting)
- we fit them to the subtracted $\Delta\phi$ distribution to measure their normalization in our sample
- 178.6 ± 12.4 (stat) ± 5.8 (sys) events in the signal region



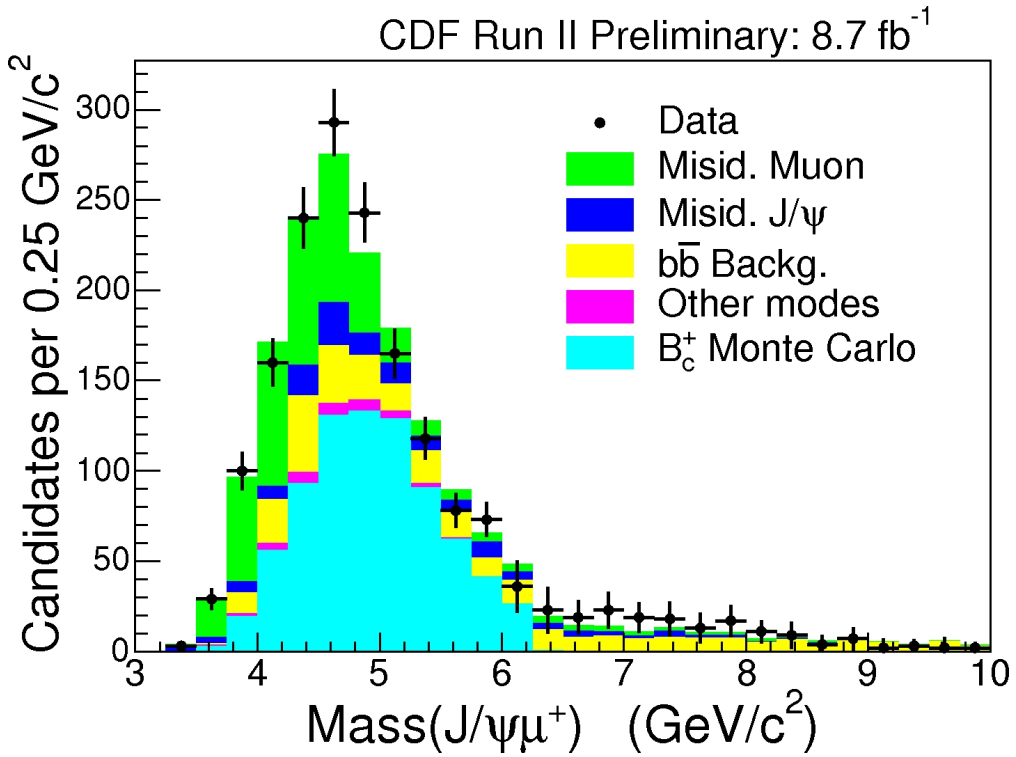


Other B_c^+ decays - B_c^+ background

- The remaining 3μ background may still have contributions from other B_c^+ decay modes:
  - $\psi(2S)[J/\psi X]\mu^+\nu$
  - $J/\psi\tau^+[\mu\nu]\nu$
- They're small but non-zero
- Using a MC simulation of 11 decay modes that may end-up in the 3μ system we measure it to be 3.9% in the signal region

B_c^+ yield

B_c^+ candidates	1370±37.0
Misidentified J/ψ	96.5±6.9
Misidentified Muon	344.4
Double Fake	-19.0
$b\bar{b}$ Background	178.6±12.4
Other decay modes	30.0±0.2
Total background	630.5 ± 14.2
B_c^+	739.5±39.6



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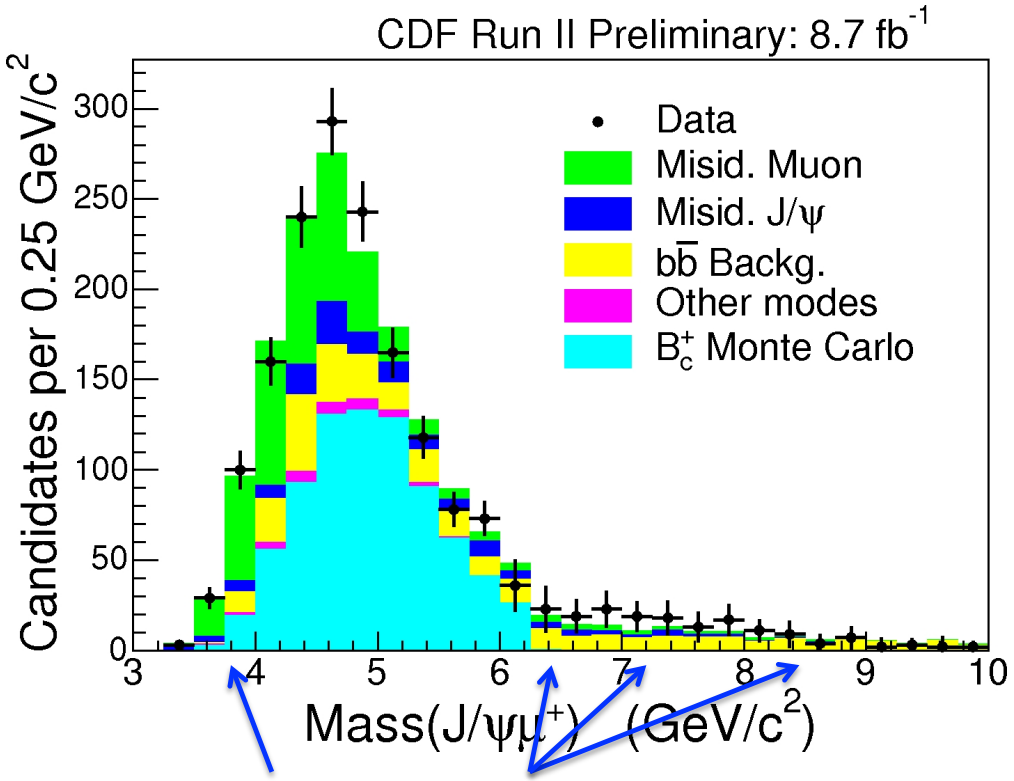
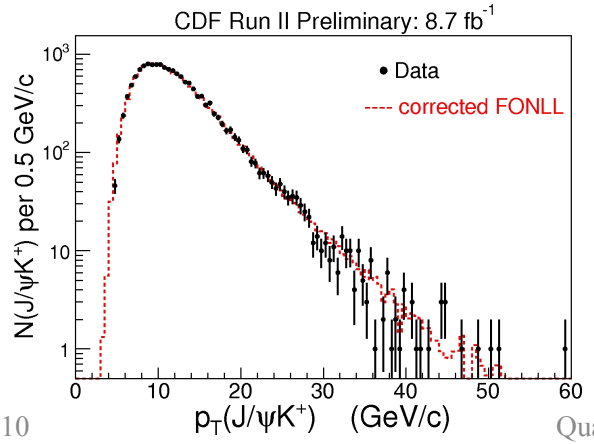


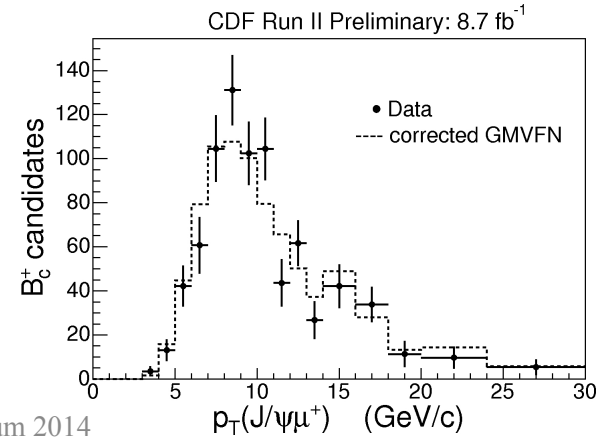
Good agreement of the backgrounds in the off-signal regions

Relative efficiency

$$\frac{\sigma\left(B_c^+\right)\cdot Br\left(B_c^+ \to J/\psi\,\mu^+\nu\right)}{\sigma\left(B^+\right)\cdot Br\left(B^+ \to J/\psi\,K^+\right)} = \frac{N_{B_c^+}}{N_{B^+}}\cdot\varepsilon_{rel} = \frac{N_{B_c^+}}{N_{B^+}}\cdot\frac{\varepsilon_{B^+}}{\varepsilon_{B_c^+}\cdot\varepsilon_{\mu}}$$

- $\varepsilon_{\mu} = 0.962 \pm 0.007$ (stat) $\pm$ 0.021 (sys) from data
- The two ε_B are measured from MC simulations (geometric eff + acceptance)
- Trigger and tracking drop out in the ratio of efficiencies
- MC p_T spectra are reweighted so selected MC events match p_T of data
- $\varepsilon_{rel} = 4.093 \pm 0.038$ (stat)





Systematic uncertainties

B_c^+ background	Systematic uncertainty
Misidentified J/ψ	not used
Misidentified Muon	$^{+9.6}_{-16.5}$
Double fake	$^{+0.5}_{-0.9}$
$b\bar{b}$ background	± 5.8
Other decay modes	± 16.3
Total events	$^{+19.8}_{-23.9}$

	$\Delta\epsilon_{rel}$
B_c^+ lifetime	$^{+0.134}_{-0.147}$
B_c^+ spectrum	$^{+0.356}_{-0.303}$
B^+ spectrum	± 0.055
XFT	± 0.070
CMUP efficiency	$^{+0.092}_{-0.087}$
Total systematics	$^{+0.401}_{-0.359}$

	$\Delta\frac{\sigma(B_c^+)BR(B_c^+\to J/\psi\mu^+\nu)}{\sigma(B^+)BR(B^+\to J/\psi K^+)}$
B_c^+ background	$^{+0.0057}_{-0.0068}$
$\Delta\epsilon_{rel}$	$^{+0.0207}_{-0.0185}$
Total systematics	$^{+0.0214}_{-0.0197}$

Cross section results

- *We have performed a measurement of the ratio* $\frac{\sigma\left(B_c^+\right)\cdot Br\left(B_c^+ \to J/\psi\,\mu^+\nu\right)}{\sigma\left(B^+\right)\cdot Br\left(B^+ \to J/\psi\,K^+\right)}$ *using the complete CDF dataset (8.7 fb^{-1}).*
- *We have identified 1370 ± 37 candidates including an estimated background of 630.5 ± 14.2 events.*
- *We obtain:*

$$\frac{\sigma\left(B_c^+\right)\cdot Br\left(B_c^+ \to J/\psi\,\mu^+\nu\right)}{\sigma\left(B^+\right)\cdot Br\left(B^+ \to J/\psi\,K^+\right)} = 0.211 \pm 0.012\,(stat)\,{}^{+0.021}_{-0.020}\,(sys)$$

- *The result is given for:*
  - $p\bar{p}$ *interactions at* $\sqrt{s}$ *= 1.96 TeV*
  - $p_T > 6$ *GeV/c*
  - $|y| < 0.6$

Backup

Event selection stability

- Since the luminosity increases over the time of data taking, we expect that our yields vary vs time
- How stable the ratio of the yields is vs time ?
- It's flat over the whole data taking