B_c Results from CDF II

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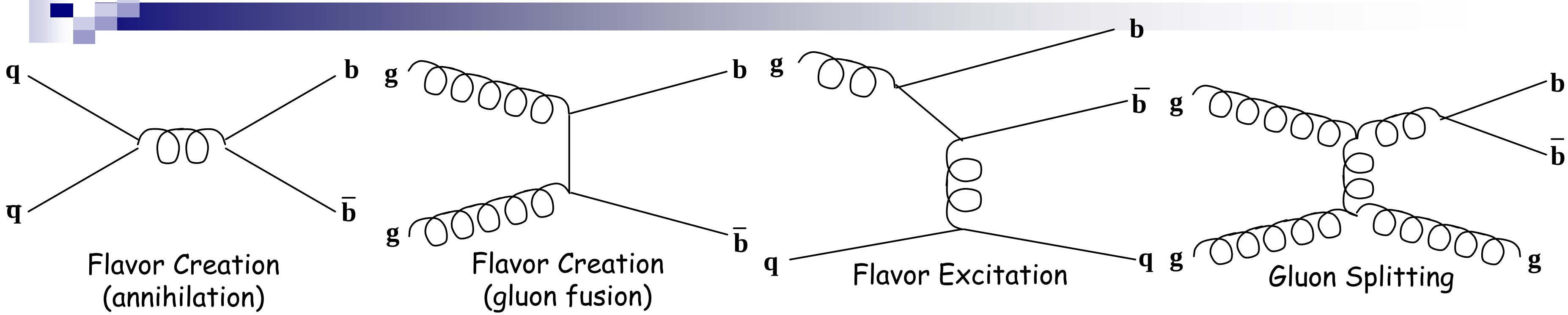
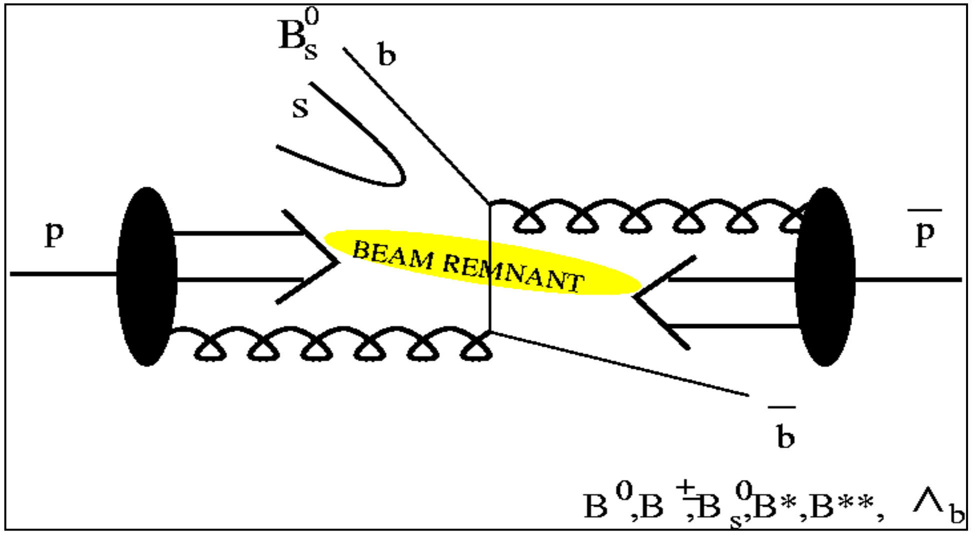
Heavy Flavor Physics at Tevatron





- Tevatron is a source of all B-hadron species, B_d, B_u, B_c, B_s and Λ_b
- $\sigma_b = 29.4 \pm 0.6 \pm 6.2\ \mu b\ (|\eta| < 1)$ (CDF)
- Huge cross-sections compared to the the B-factories but proportionally large backgrounds as well

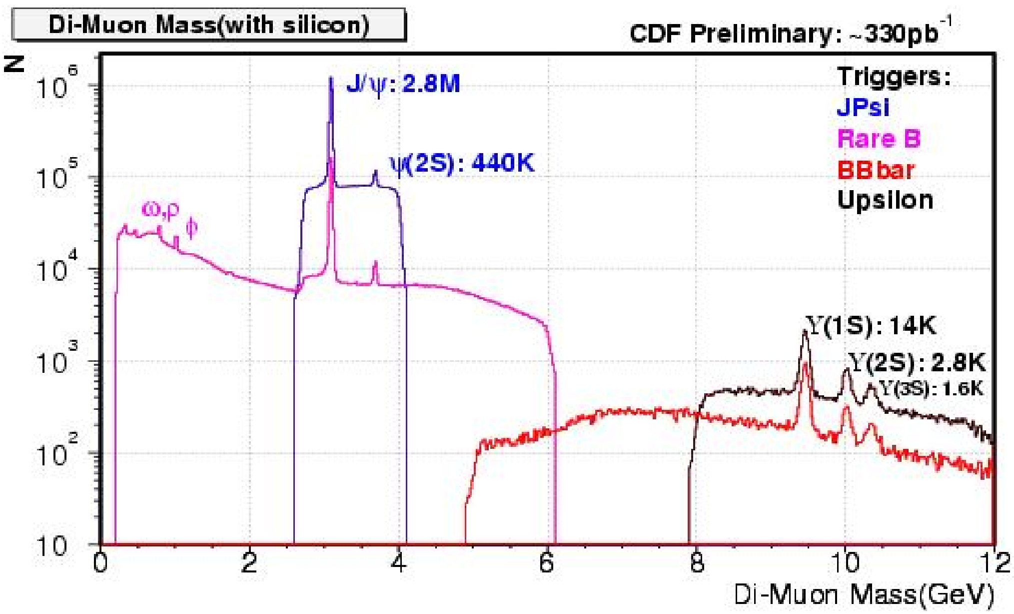
Since $\sigma(bb) \ll \sigma(pp)$ $\Rightarrow$ Events have to be selected with specific triggers

Trigger requirements: large bandwidth, background suppression, deadtimeless

Triggers for B_c Analyses

For Signal and Control Sample

- **Di-muon trigger**
  - p_T>1.5GeV, $|\eta|<0.6$
    p_T>2GeV, $0.6<|\eta|<1$
  - ϕ < 2.5° and Muon ID cuts
  - Yields higher than Run I (low p_T threshold, increased acceptance)



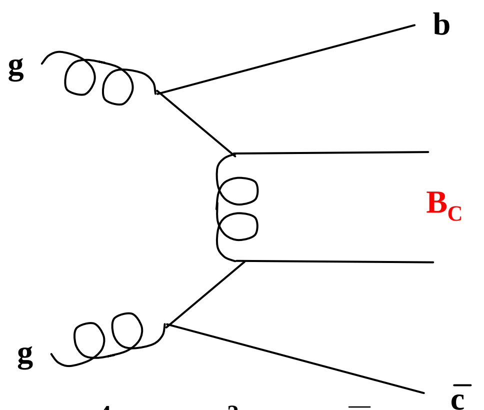
For particle ID studies

- **Two track trigger**
  - 2 opposite charged displaced tracks
  - p_T > 2 GeV, 120μm < |IP| < 1mm
  - $D^* \rightarrow D^0 \pi$, $\Lambda \rightarrow p \pi$

- **Single electron trigger**
  - A track matched to a central electron cluster
  - p_T > 8 GeV
  - $\gamma \rightarrow e e$

What is interesting about B_c

- The B_c is a ground state $\bar{b}c$ meson, first experimentally observed by CDF I (PRL 81, 1998). The measured mass is less precise than theoretical prediction.
  $\Rightarrow$ Test of lattice QCD and potential models
- Unlike quarkonia it carries flavor
  $\Rightarrow$ Probes heavy quark dynamics in new territories
- Spectroscopy of excited states
  $\Rightarrow$ Possible observation, test of models
- Production rate can shed light on fragmentation mechanism
  - Gluon fusion diagram dominant
  - Recent cross-section calculation 7.4 nb
    [Saleev et al, Phys. Lett. B605, 311 (2005)]

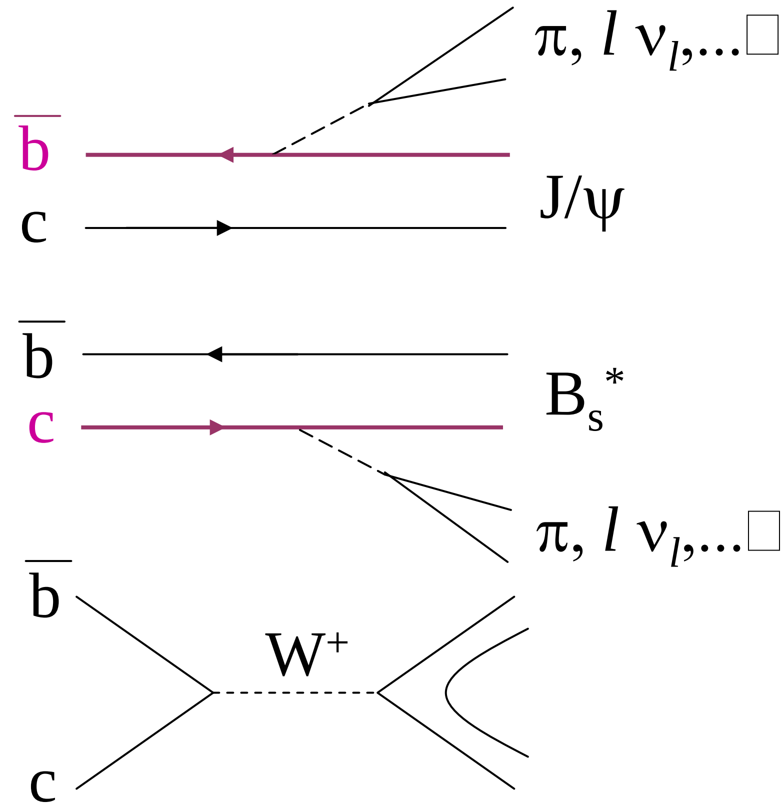


$O(\alpha_s^4) \approx 10^{-2} \times \sigma(b\bar{b})$

Interests in B_c *Continued..*

- No annihilation decay channel for $B_c \rightarrow$ hadrons via gluons

  $\Rightarrow$ **Only weak decays, large lifetime**



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

Long term...

- B_s produced from B_c decays
  $\Rightarrow$ Estimate B_c contribution to B_s lifetime and mixing
- B_c as a source of (lepton) tagged $B_s \Rightarrow B_s$ mixing
- *CP* asymmetry measurement in $\bar{D}^0 D_S^+$ decay mode

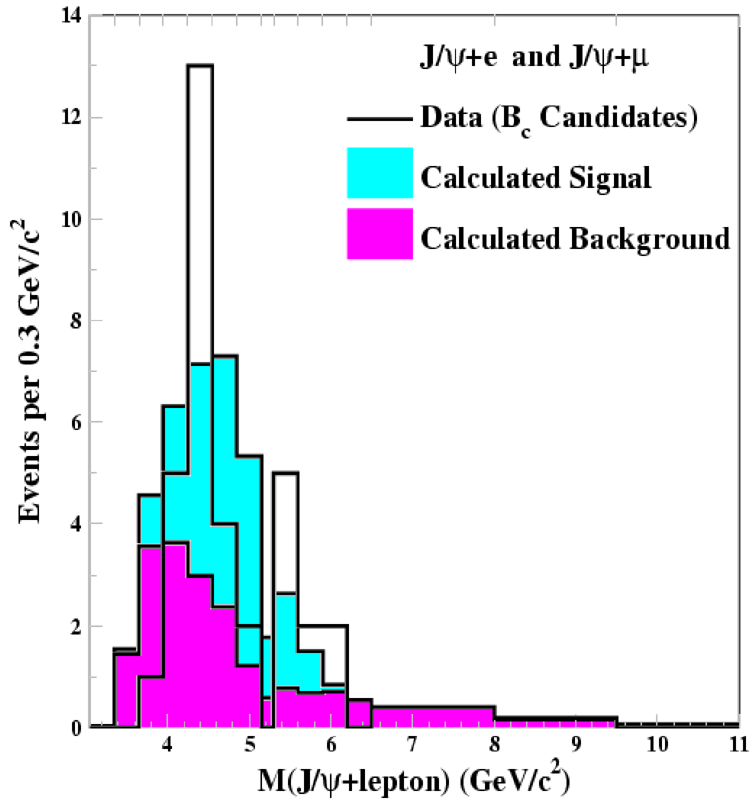
CDF Run I B_c Measurements

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

10.6 ± 2.3 background events

$L = 110\ pb^{-1}$

$pT(B_c) > 6$ GeV/c, $|\eta| < 0.6$



Mass: $(6.4 \pm 0.39 \pm 0.13)\ GeV/c^2$

PRL 81 n.12 (1998)

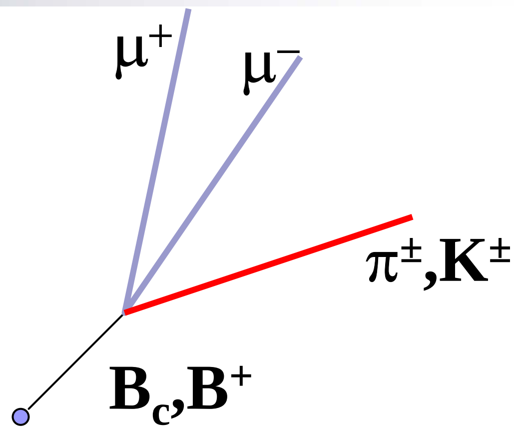
Lifetime: $(0.46\ ^{+0.18}_{-0.16} \pm 0.03)$ ps

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

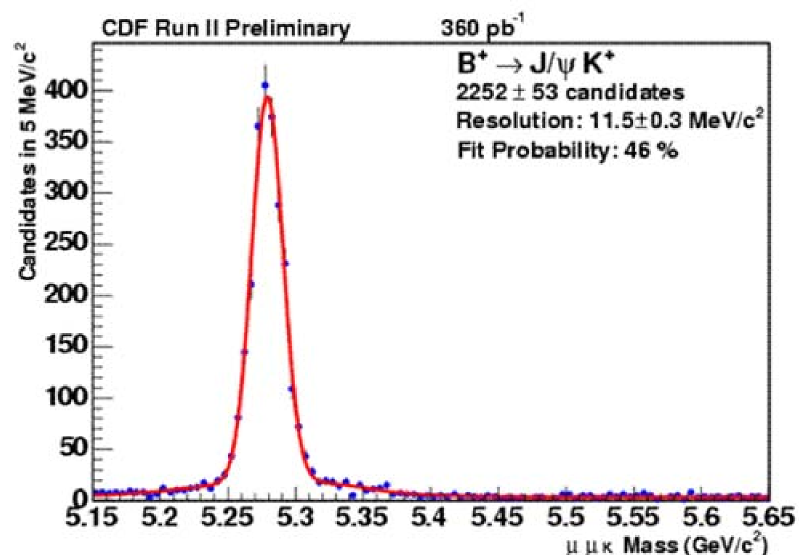
$B_c \rightarrow J/\psi\ \pi^{\pm}$ Search

- **Pros:**
  - Exclusive mode; Precise mass measurement possible
  - Same topology well known normalization mode: $B^+ \rightarrow J/\psi\ K^+$
- **Cons:**
  - B_c lifetime is shorter than light *b*-mesons (charm decay dominates)

    $\Rightarrow$ Need aggressive secondary vertex resolution
  - Expected signal > 10 times smaller than the signal in the semileptonic decay.



Primary vertex

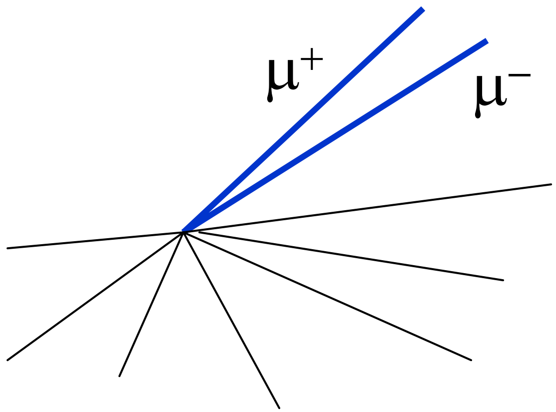


- **Analysis method:**
  - Reconstruct $\mu^+\mu^-$ vertex, **Constrain $\mu^+\mu^-$ to J/ψ mass**
  - Attach a **third track** w/ p_T threshold
  - Event-by-event primary vertex

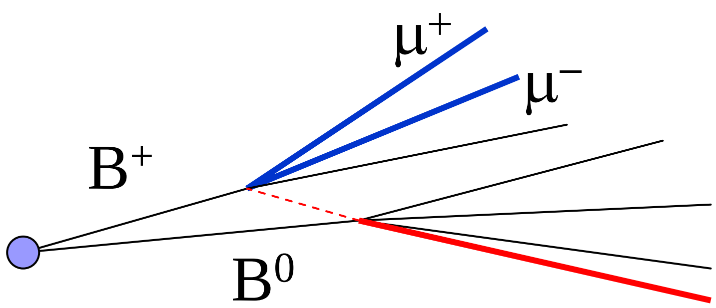
Cut Optimization

- **Blind analysis:**
  - Search range:
    $6.4 \pm 2\sigma$ = [5.6 to 7.2] GeV/c^2
  - Use MC for: optimizing cuts, estimate sensitivity, relative to B^+
- **Cut optimization:**
  - Score function: (for 3σ search)
    $$\Sigma = \frac{S}{1.5 + \sqrt{B}}$$
  - Signal from MC and background from data
  - Tight vertex requirements using 3D χ^2, 2D decay length significance, pointing angle, impact parameter etc.

Backgrounds



(Prompt J/Ψ + track from PV)



($b\bar{b}$ production from gluon splitting)

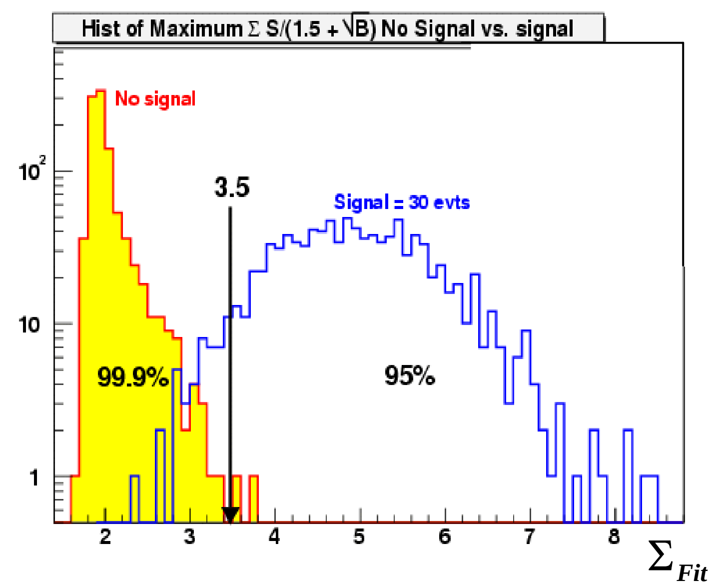
Peak Search Criteria

- **390** data events within mass range
- Expected signal:

$$S = \frac{\varepsilon_c}{\varepsilon_u} N_u R = 4 - 30\,\text{events}\;\;(c\tau \pm 1\sigma) \qquad \frac{\varepsilon_c}{\varepsilon_u} = 58.6 \pm 1.8\%\;\;(\text{from MC})$$

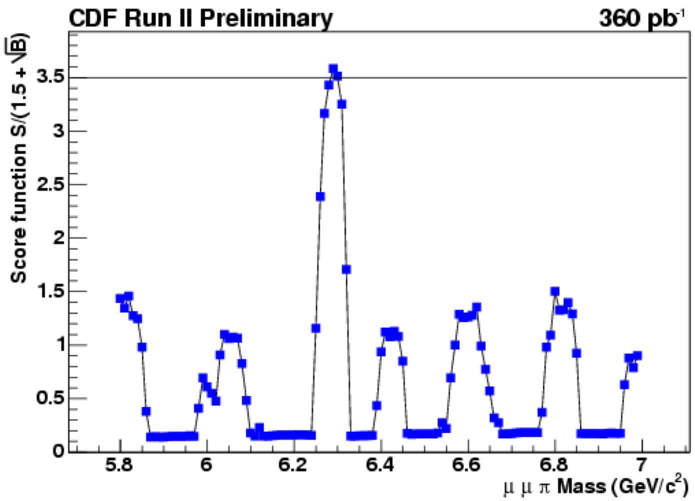
- Use Toy MC to determine criteria for seeing a significant peak:
  - Yellow: Toy MC with no signal, corresponding to 0.1% prob. of background fluctuation
  - Blue: Toy MC for N_{sig}=30 events

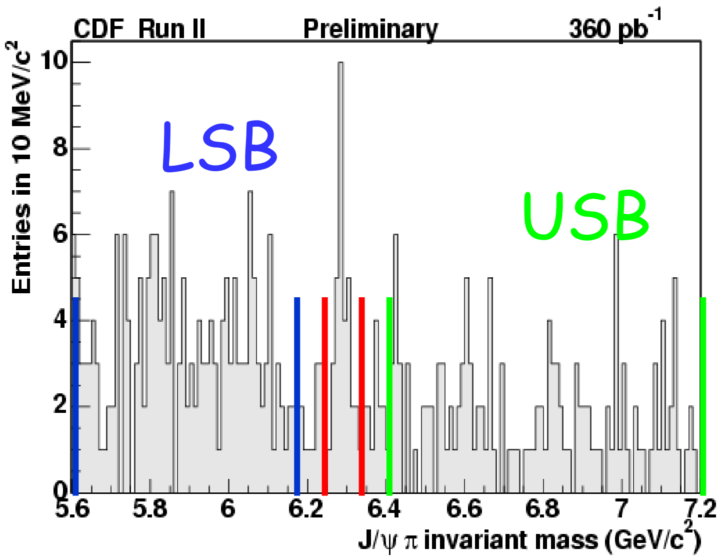
$\Rightarrow$ **Score function threshold: Σ > 3.5**



Peak Evaluation

- A sliding fit is performed in the search region and the score function is estimated. Σ_{max} = 3.6
- Probability for the background to give a peak at Σ_{max} = 3.6 is estimated from Toy MC as 0.27%.
- As a consistency check compare partially reconstructed B_c yield with that for B^+
  - Study impact parameter of the pion with J/Ψ vertex
  - **Yield difference between upper and lower sidebands consistent with B^+**

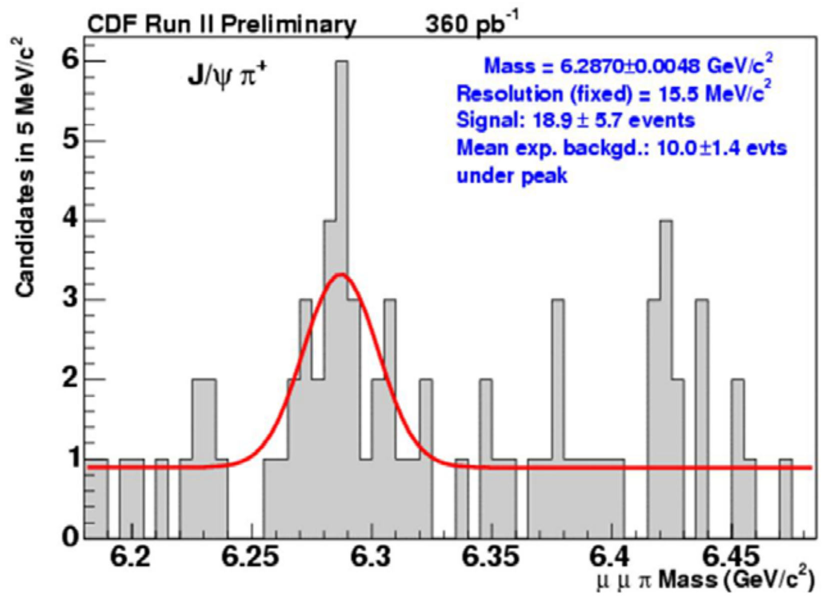


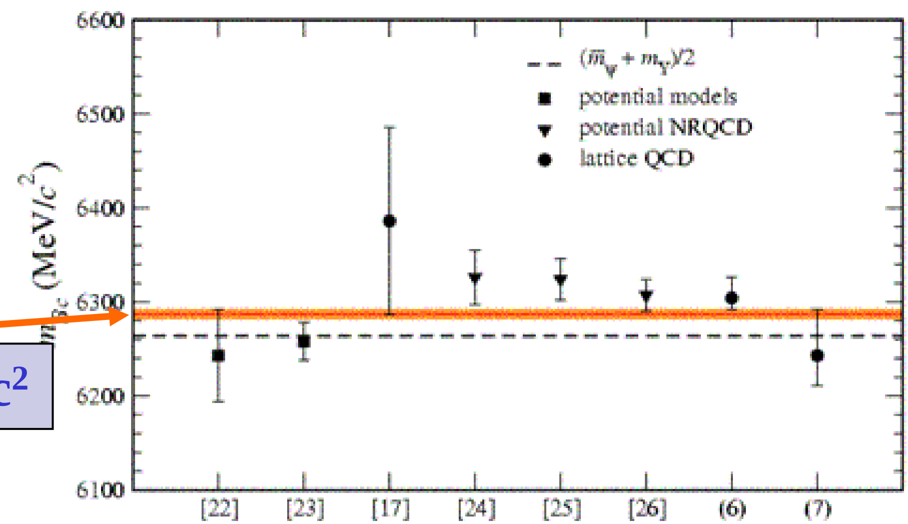


B_c Mass Measurement

- Unbinned likelihood fit w/ width fixed in 6.180 < M < 6.480

- **Sources of systematics:**
  - Background shape 0.8 MeV/c^2
  - Momentum scale 0.6
  - π/K dE/dx 0.2
  - Tracking 0.2
  - Δp_T 0.5
  - **Total 1.1 MeV/c^2**

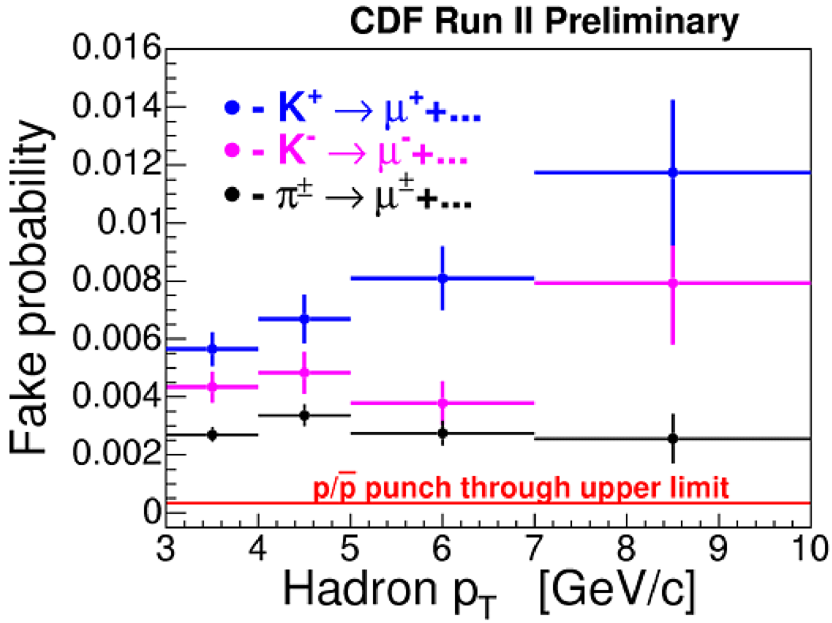




M(B_c) = (6287.0 ± 4.8$_{stat.}$ ± 1.1$_{syst.}$) MeV/c^2

$\sigma \times BR$ Ratio in $B_c \to J/\psi\ \mu\ \nu$

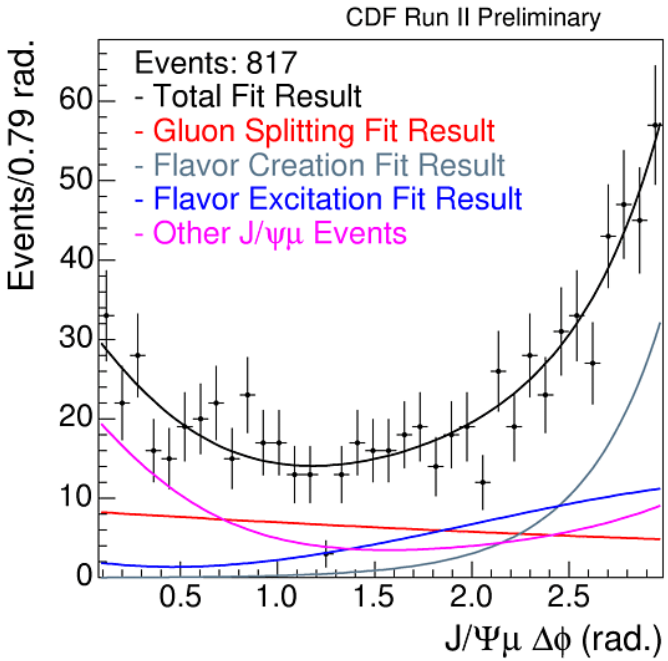
- Analysed ~360 pb^{-1}
- Normalization mode: $B^+ \to J/\psi\ K^+$
- Basic cuts:
  - Good muons: $\chi^2 < 9$
  - $|M(\mu\mu) - M(J/\psi)| < 50$ MeV
  - J/ψ mass constrained, Prob(χ^2)> 1%, $c\tau > 60\mu m$
  - Third muon $p_T > 3$ GeV
  - Remove $B^+ \to J/\psi\ K^+$ within $M_B \pm 50$ MeV
- **Backgrounds:**
  - **Fake muons from decay-in-flight of K, π, p**
    - Estimated by assigning muon probabilities to the third track, obtained from PID quantities, dE/dx and ToF



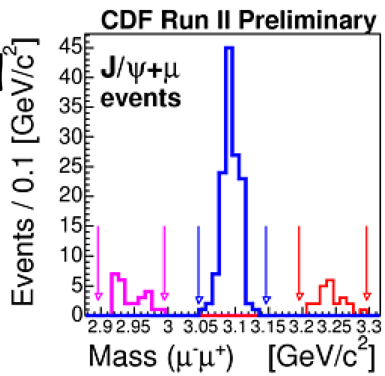
Predicted background: 16.3±2.9 events

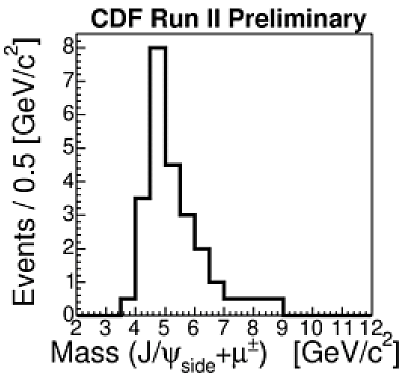
Background Predictions

- **From $b\bar{b}$ fragmentation**
  - Estimated relative contribution of QCD processes from a Pythia MC and compared to data
  - Predicted background:
    $12.7 \pm 1.7 \pm 5.7$ events

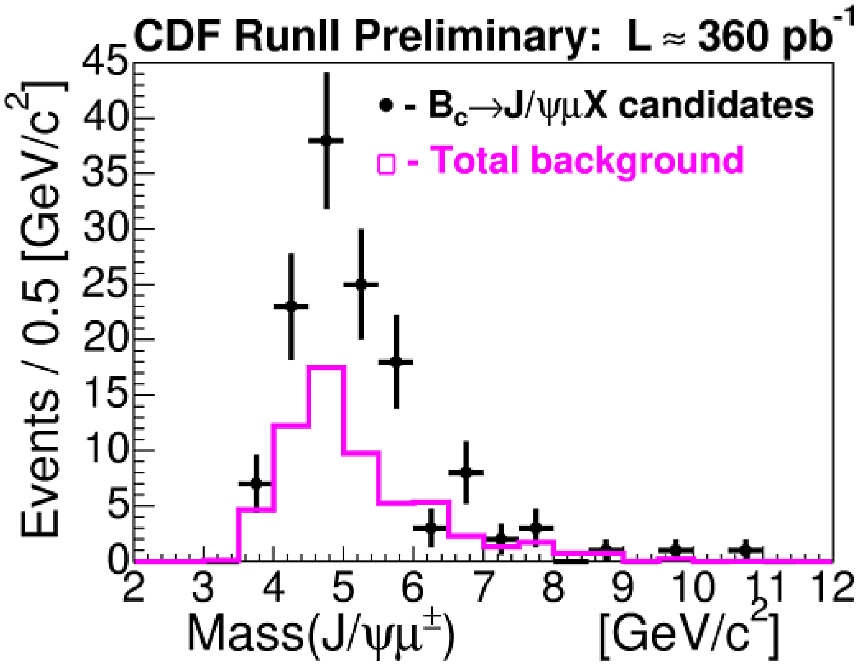


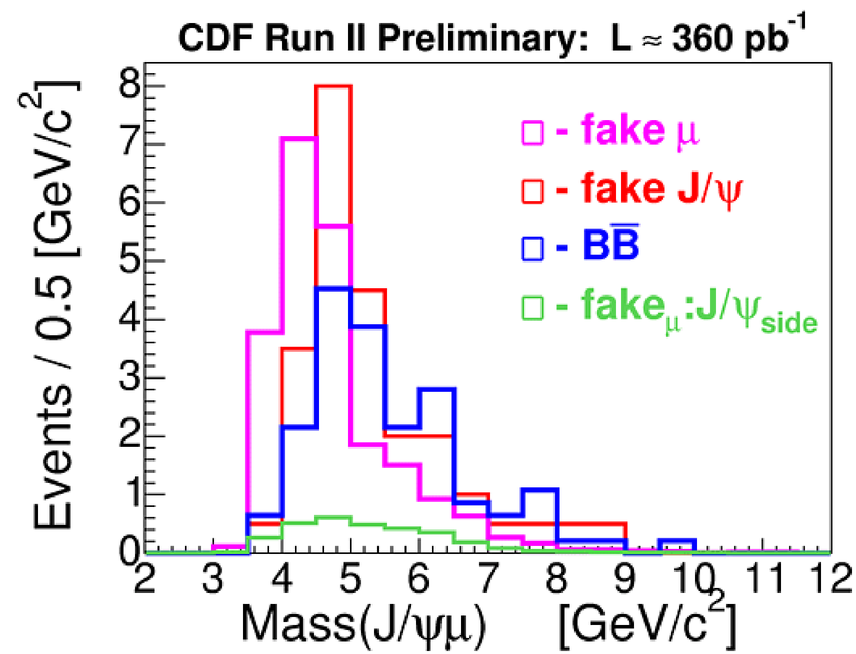
- **Fake J/ψ + a third muon**
  - Estimated by matching a third muon with events in J/ψ sidebands
  - Predicted background:
    19.0 ± 3.0 events





σ×BR Ratio Results





- Signal events: **60.0 ± 12.6**
- Background: **46.0 ± 7.3**
- Significance: **5.2σ**

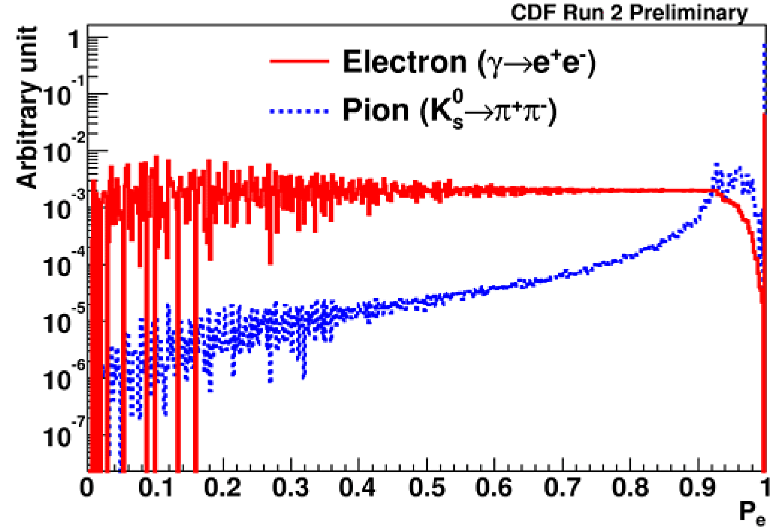
For $p_T(B_c) > 4$ GeV, $|\eta(B_c)| < 1$

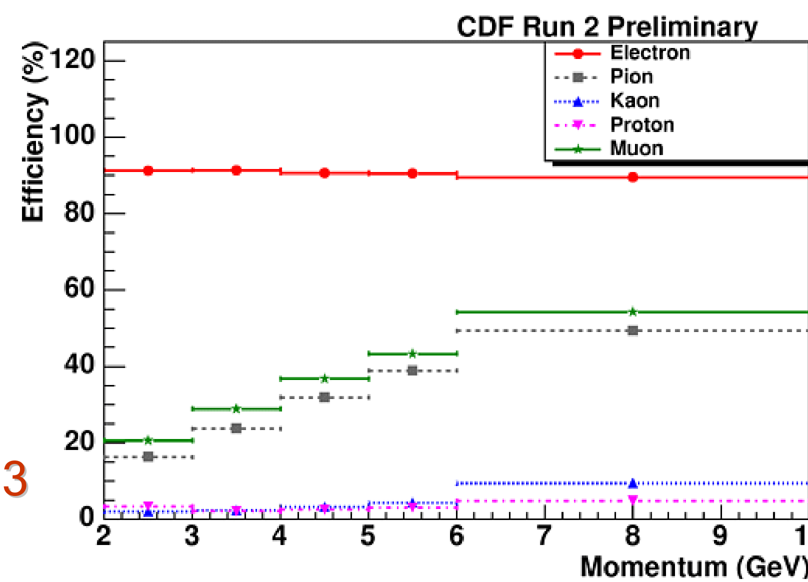
$$\frac{\sigma_{B_c} \cdot \mathrm{BR}(B_c \to J/\psi\mu\nu)}{\sigma_{B^\pm} \cdot BR(B^\pm \to J/\psi K^\pm)} = 0.249 \pm 0.045(stat.) \pm 0.107(syst.)$$

$\sigma \times BR$ Ratio in $B_c \rightarrow J/\psi\, e\, \nu$

- 360 pb-1 data,
  Normalization mode: $B^+ \rightarrow J/\psi K^+$
- **Basic cuts:**
  - Similar J/ψ selection as muon mode
  - Soft electron identification:
    - Good quality tracks, $p_T > 1$ GeV, matched to central strip chambers and EM calorimeter
    - Cut on a likelihood ratio variable constructed from 10 electromagnetic and tracking variables $P_e < 0.7$
    - Additional cut on specific ionization, dE/dx:

$$Z_e = \log\left(\frac{dE/dx_{measured}}{dE/dx_{predicted}}\right) \quad Z_e/\sigma_z > -1.3$$



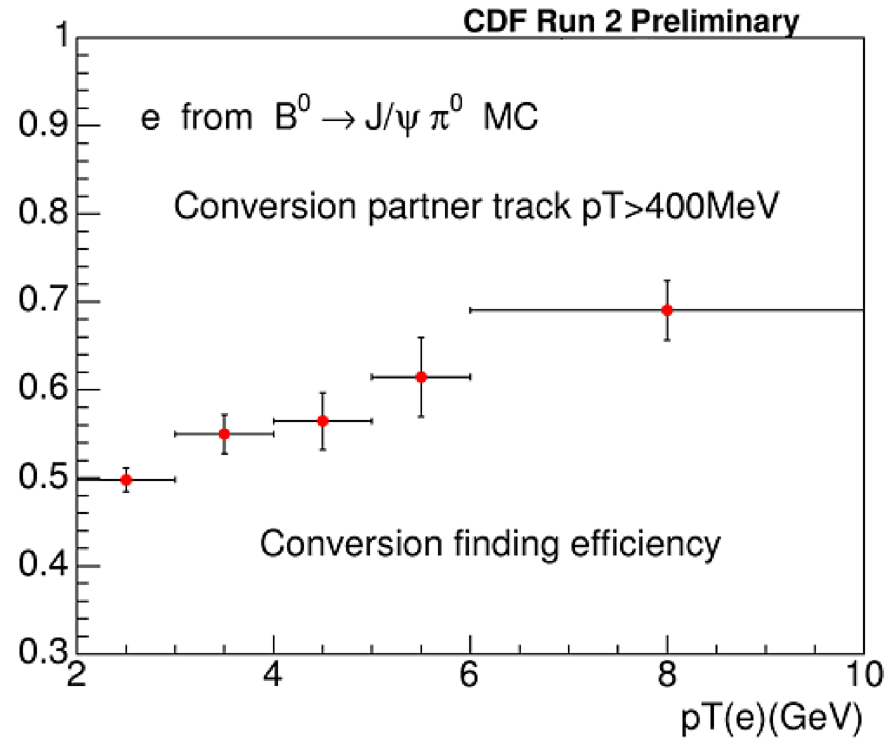


Backgrounds

- Fake electrons from decay-in-flight of K,π,p
- From $b\bar{b}$ fragmentation
- From fake J/ψ

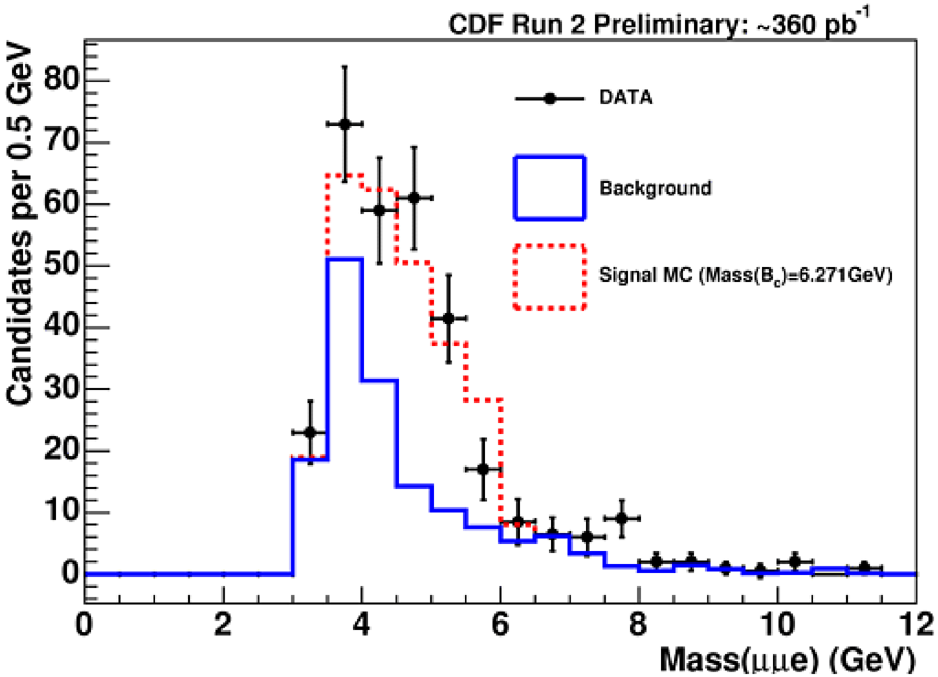
- Conversion electrons:
  - Removed during J/ψ e sample selection
  - Residual conversion electrons are found by pairing electron candidates with tracks, w/o electron requirement

$$N_{resid} = N_{conv} \times \frac{1-\varepsilon_{conv}}{\varepsilon_{conv}}$$



σ×BR Ratio Result

- Signal: 114.9 ± 15.5 ± 13.6
- Background: 63.6 ± 4.9 ± 13.6
- Significance: 5.9σ



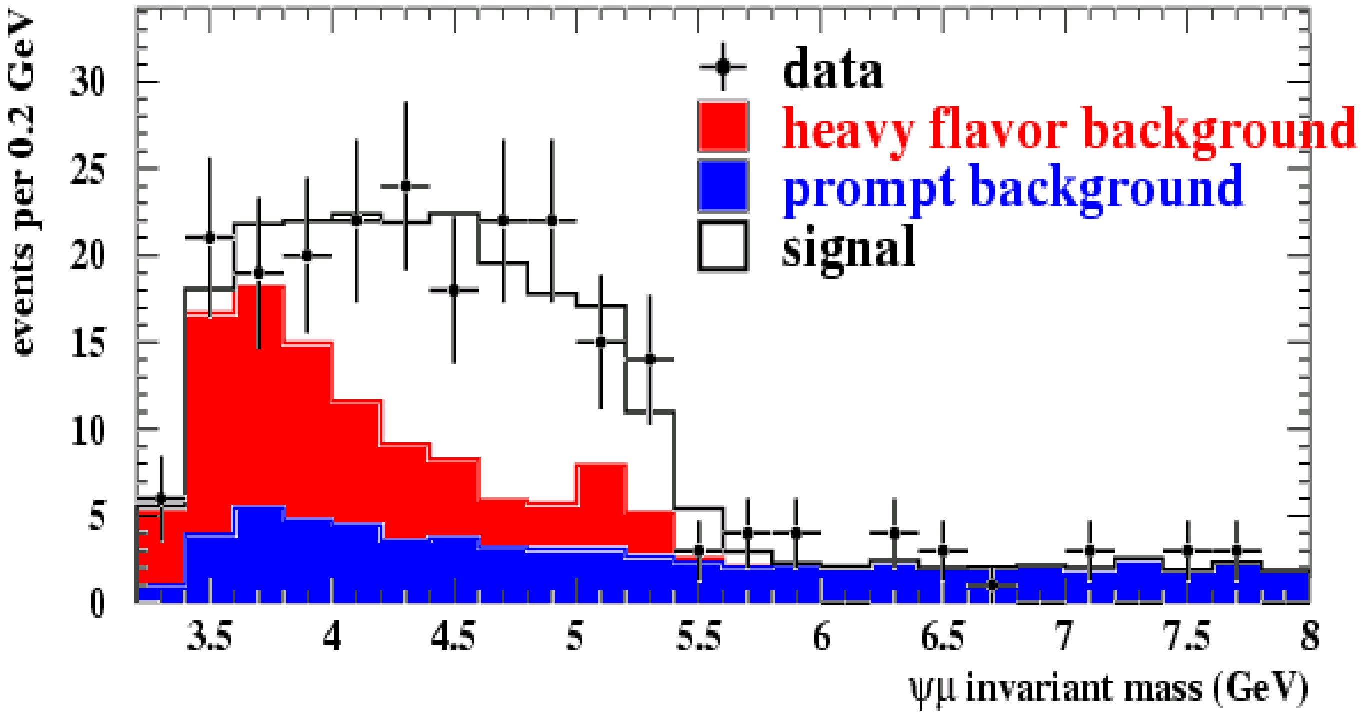
For $p_T(B_c) > 4$ GeV, $|\eta(B_c)| < 1$

$$\frac{\sigma_{B_c} \cdot \mathrm{BR}\left(B_c \to J/\psi e \nu\right)}{\sigma_{B^\pm} \cdot BR\left(B^\pm \to J/\psi K^\pm\right)} = 0.282 \pm 0.038(stat.) \pm 0.035(yield) \pm 0.065(acc.)$$

Summary

- A precise B_c mass measurement in $B_c \rightarrow J/\Psi\ \pi$ decay is in agreement with lattice QCD.
- σ*BR ratios of B_c measured in $Bc \rightarrow J/\Psi\ \mu,e\ \nu$ decays improve upon CDF Run I measurements.
- Update of mass and BR ratio measurements using high statistics (~ 1 fb^{-1}) are underway.
- Lifetime and other studies to follow..

Backup-1 DØ Run II (ICHEP2004)



$B_c \rightarrow J/\psi\ \mu\ \nu$:

95 ± 12 ± 11 signal events

L = 210 pb^{-1}

Lifetime: $(0.45^{+0.12}_{-0.10} \pm 0.12)$ ps
Mass: $(5.95^{+0.14}_{-0.13} \pm 0.34)$ GeV/c^2

Backup-2 Expected B_c Signal w.r.t B^+ data

Ratio of efficiencies in MC

Number of events in $B^+ \to J/\psi\ K^\pm$ data

$$S = \boxed{\frac{\varepsilon_c}{\varepsilon_u}} N_u \boxed{\frac{\sigma_c\, BR(B_c \to J/\psi\ \pi)}{\sigma_u\, BR(B_u \to J/\psi\ K)}}$$

"R"

define $$R_2 = \frac{\mathcal{BR}(B_c \to J/\psi\pi^\pm)}{\mathcal{BR}(B_c \to J/\psi l\nu)}$$

$$R = R_2 \times \frac{\sigma(B_c) \times \mathcal{BR}(B_c \to J/\psi l\nu)}{\sigma(B_u) \times \mathcal{BR}(B_u \to J/\psi K^\pm)}$$

To evaluate the expected signal we use CDF Run I measurement and one ratio of *BR*.

We know $$\frac{\sigma(B_c) \times \mathcal{BR}(B_c \to J/\psi l\nu)}{\sigma(B_u) \times \mathcal{BR}(B_u \to J/\psi K^\pm)} = 0.132 \pm 0.06$$ *From CDF Run-1*

All theoretical uncertainties are in the value of R_2