Rare B Decays from the CDF Experiment

1. Introduction to B meson physics at CDF
2. The Discovery of the B_c meson
3. Other rare B meson decays
   - ψ and $\psi(2S)$ final states
   - $B \to \mu^+\mu^-$ and friends
4. Summary

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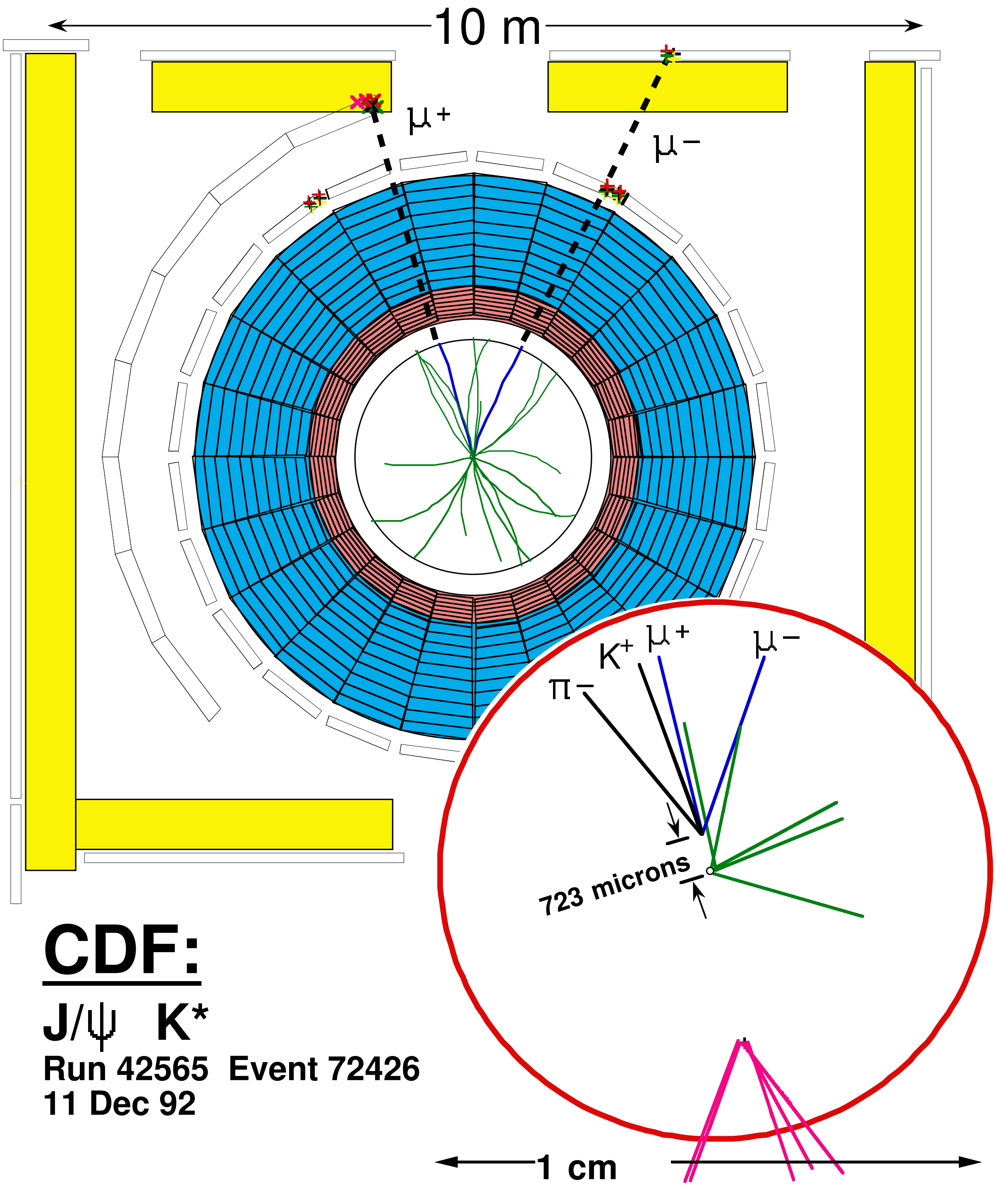
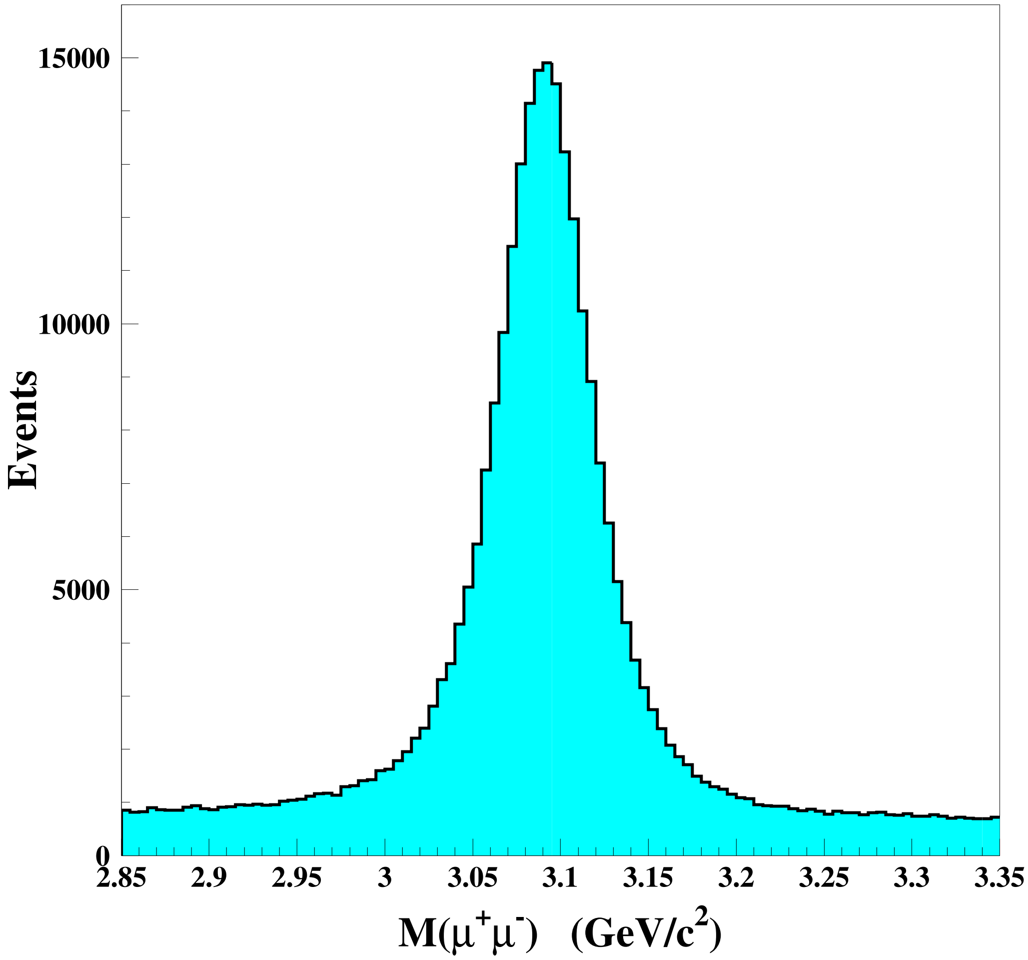
July 2, 1998

A Fully Reconstructed B Meson Decay in CDF

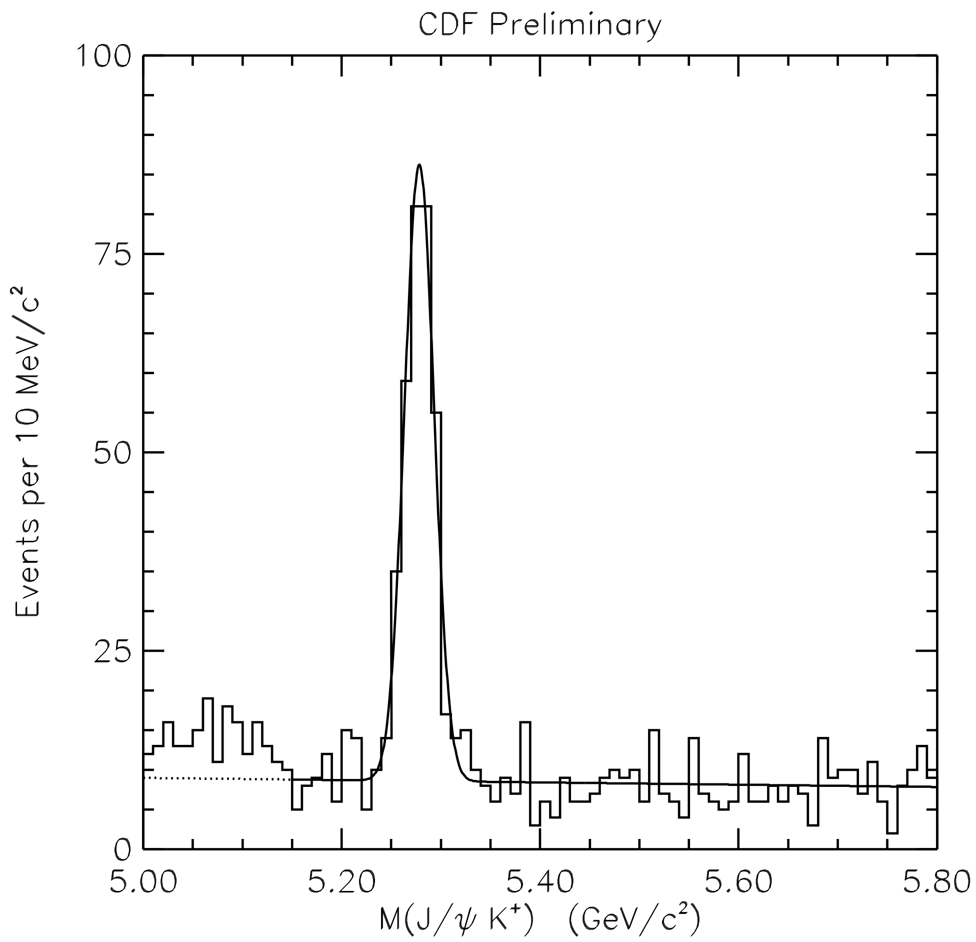


The CDF J/ψ Di-muon Sample



- Many B channels rely on di-muon trigger
- About 200 000 $\mu^+\mu^-$ candidates on small background

$\mathbf{J}/\psi\, K^{+}$ Fully Reconstructed Sample

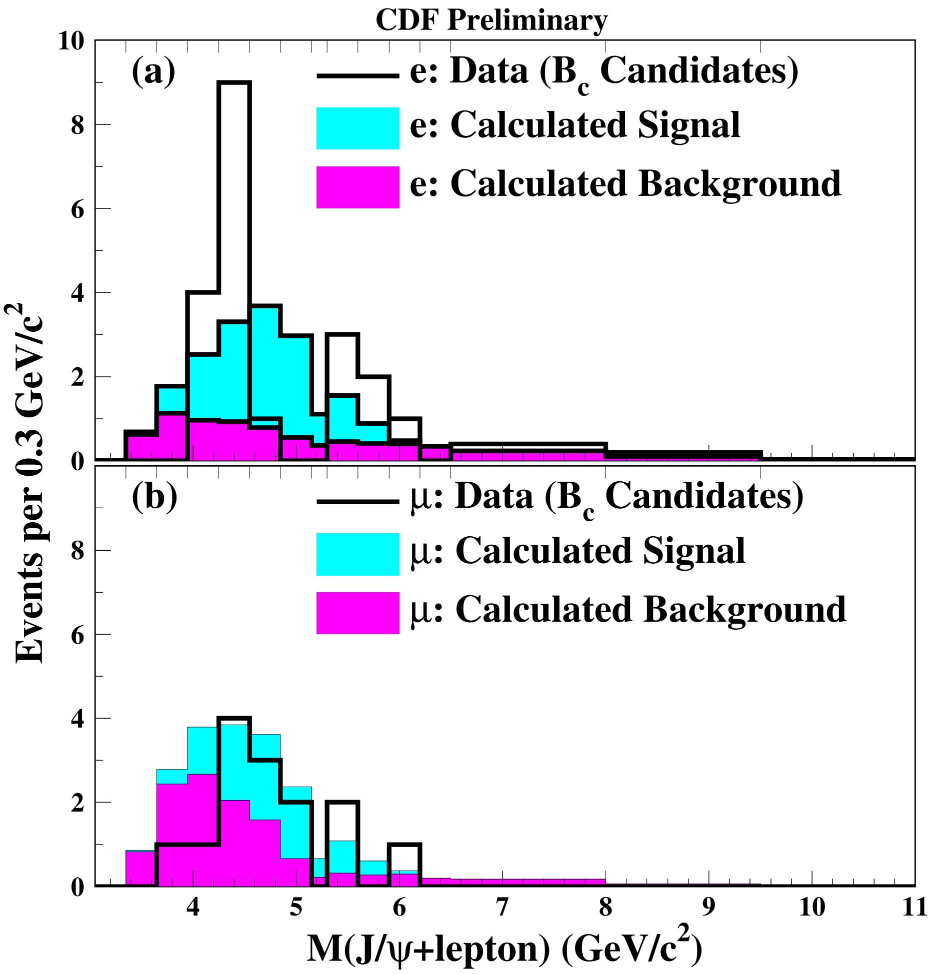


- Fully reconstruct large samples of B mesons
- About 300 fully reconstructed B^{+} mesons here
- Normalise rare B production to these to reduce uncertainties

$\boxed{\textbf{Search for the } B_c \textbf{ Meson}}$

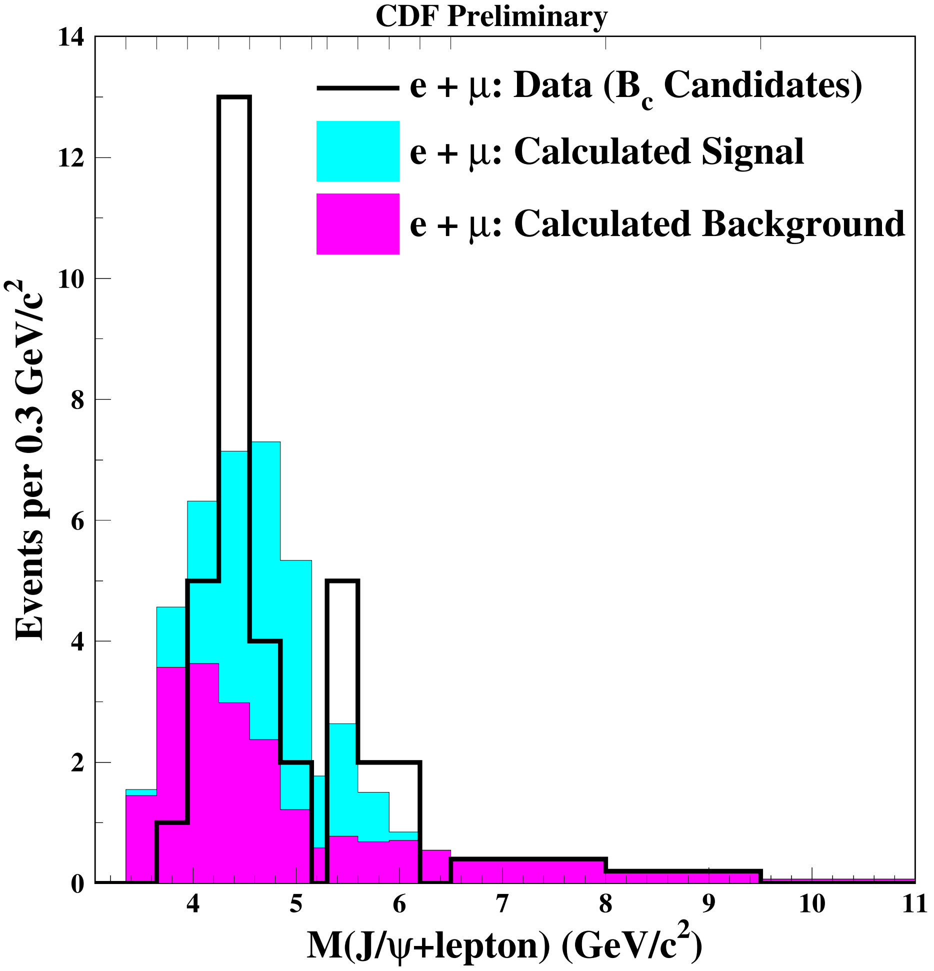
- Expected to be tightly bound $b\ c$ quark system
- Search in fully reconstructed final states
  - $J/\psi\,\pi$, ...
- Or in partially reconstructed final states
  - $J/\psi\, l\, \nu$
- Depending on binding energy mass should be
  - $M_{B_c} \approx m_b + m_c$
  - $\approx 4.8 + 1.5 = 6.3$ GeV/c^2
- Depending on model lifetime might be that of
  - c quark $\sim$ 0.3 ps
  - b quark $\sim$ 1.5 ps
  - somewhere in between ...

Fits to e and μ Samples



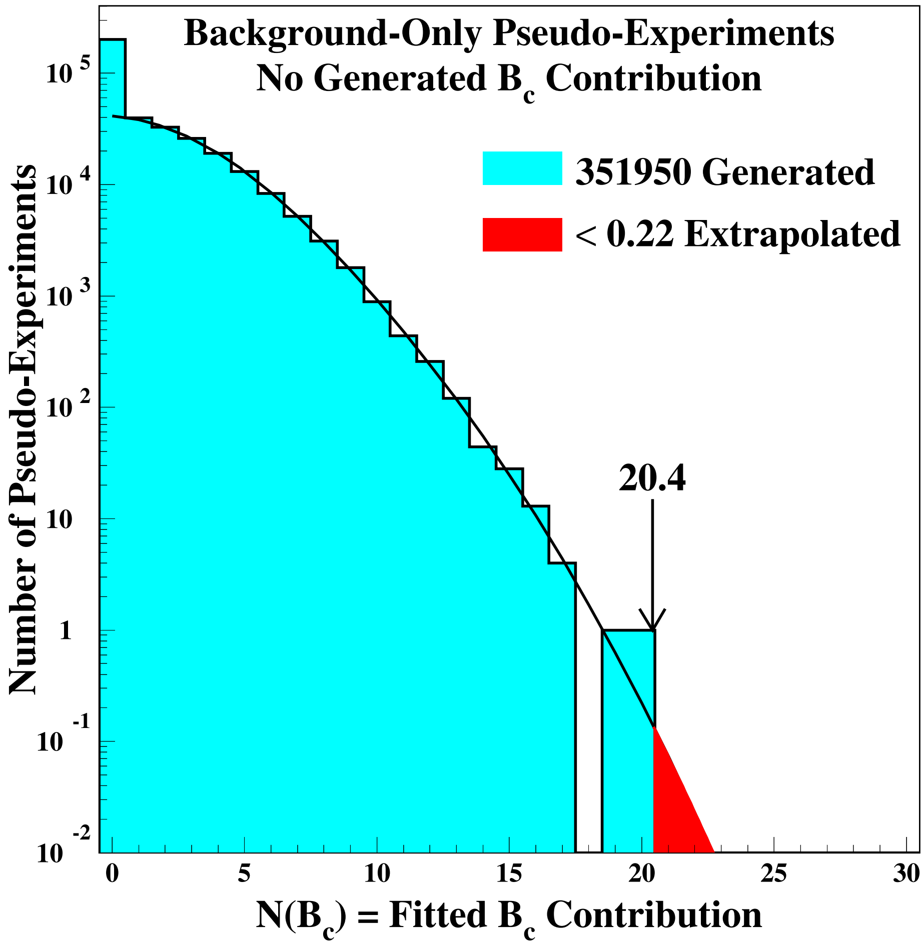
- Most of effort goes into quantifying background
  - Electrons: fakes, conversions
  - Muons: decay in flight, punch through
- Peak towards lower masses since from light B mesons

Combined Fit to e and μ



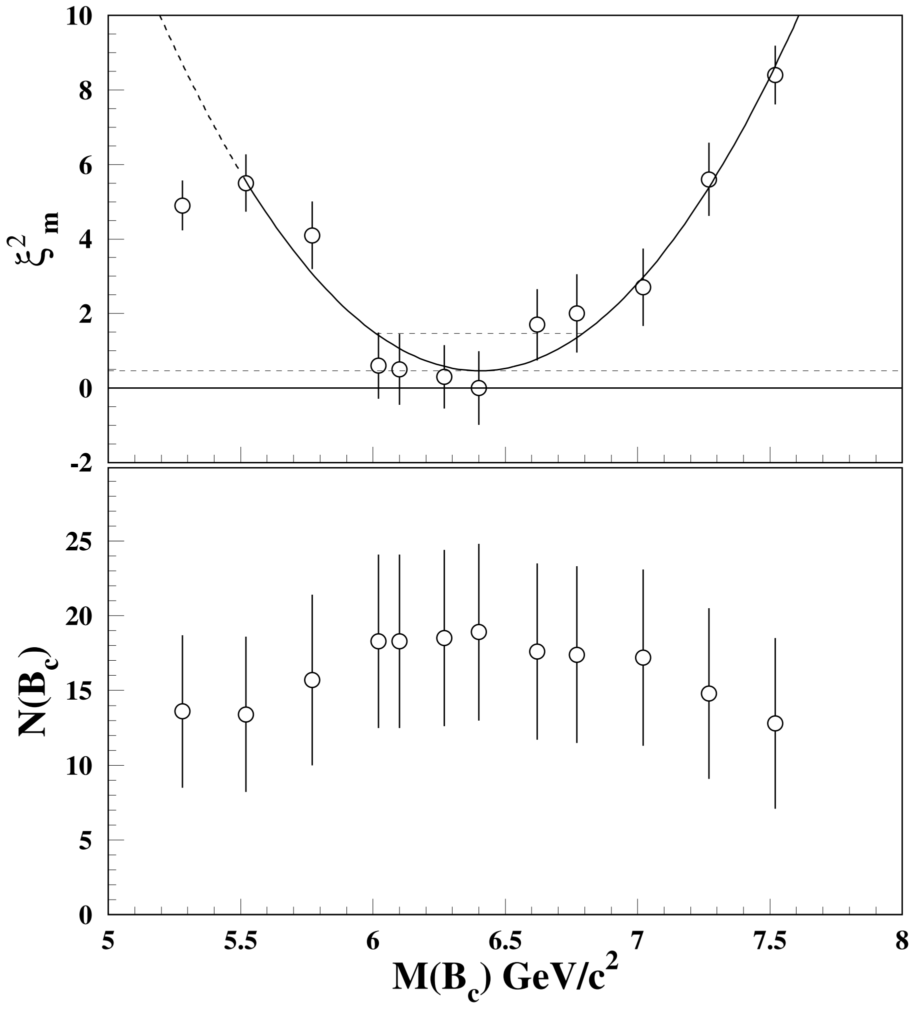
- Likelihood fit yields $20.4^{+6.2}_{-5.5}$ B_c candidates

Simulated Pseudo-Experiments



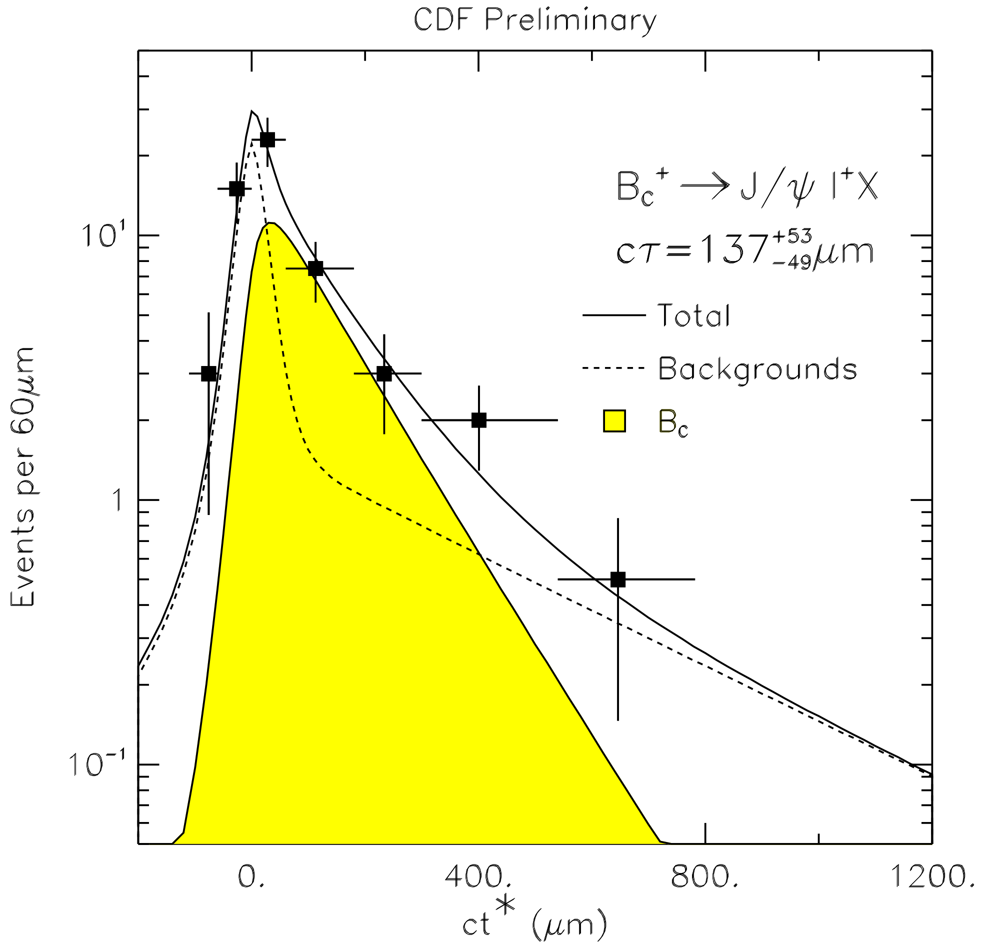
- No pseudo-experiments exceed 20.4 candidates
- Extrapolated Gaussian predicts less than one in 1.5 million
- Conclude significance $\approx 5\sigma$

Mass of the B_c Meson



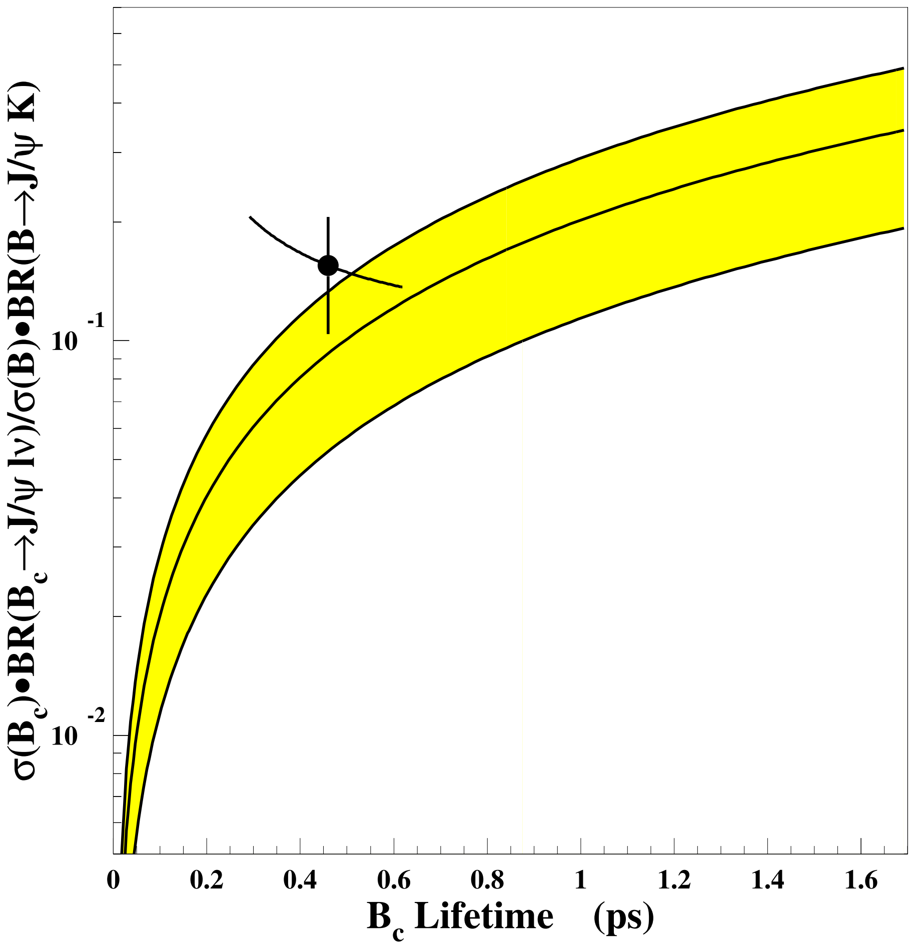
- Vary mass in simulation
- Make templates of $J/\psi\, l$ mass distribution
- Results in $m(B_c) = 6.4 \pm 0.4(stat.) \pm 0.1(sys.)$ GeV/c^2

Lifetime Fit to $J/\psi\, l$ Candidates



- Main backgrounds are
  - Prompt J/ψ mesons plus fake lepton
  - Light B mesons plus fake (or $\bar{B}$) lepton
- B_c is somewhere in between
  - $\tau(B_c) = 0.46 \pm 0.16 \pm 0.03$ ps
- Favours hypothesis that c quark decays independently/first

Production Rate vs. Lifetime



- Measure B_c production rate relative to B_u

  - $\mathcal{R} = \frac{\sigma(B_c)\cdot\mathcal{B}(B_c\rightarrow J/\psi\, l)}{\sigma(B)\cdot\mathcal{B}(B\rightarrow J/\psi\, K)}$
  - Significant uncertainties cancel (expt. & theory)

- Production rate vs lifetime (Theory Lusignoli 1991)

Comparison with Previous Results

Re-interpret previous results as limits on ratio measured by CDF

Experiment	Final State	$\mathcal{R}$
DELPHI	$J/\psi\,\pi$	$\leq$ 0.9 to 0.7
	$J/\psi\,l$	$\leq$ 0.5 to 0.4
	$J/\psi\pi\pi\pi$	≤ 1.5
OPAL	$J/\psi\,\pi$	≤ 0.6
	$J/\psi\,a_1$	≤ 0.3
	$J/\psi\,l$	≤ 0.4
ALEPH	$J/\psi\,\pi$	≤ 0.2
	$J/\psi\,l$	≤ 0.3
CDF	$J/\psi\,\pi$	$\leq$ 0.15 to 0.04
Current result	$J/\psi\,l$	$0.14 \pm 0.04 \pm 0.02$

- Submitted for publication in
  - Phys. Rev. Lett. (Fermilab-PUB-98-157-E)
  - Phys. Rev. **D** (Fermilab-PUB-98-121-E)

$\psi(2S)$ Branching Fractions

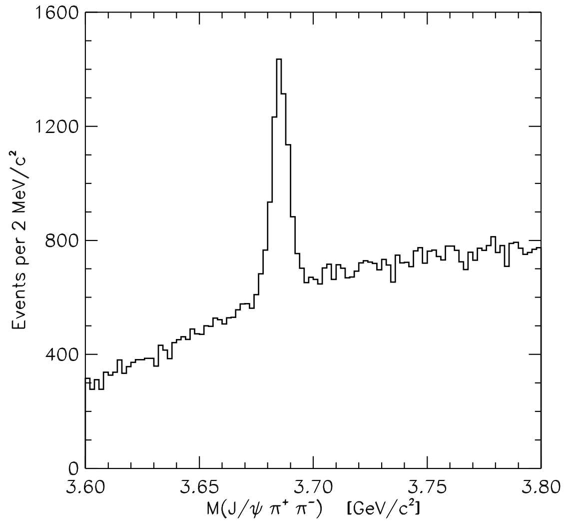
Recently finished measuring ratios

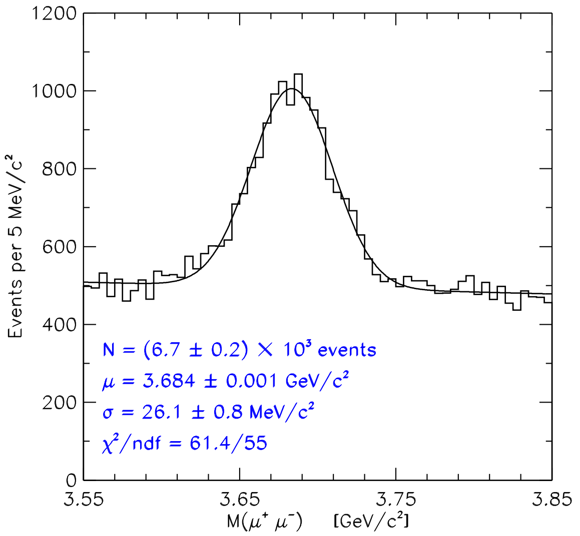
$$\frac{\mathcal{B}(B^+ \to \psi(2S)K^+)}{\mathcal{B}(B^+ \to J/\psi K^+)}$$

$$\frac{\mathcal{B}(B^0 \to \psi(2S)K^{*0})}{\mathcal{B}(B^0 \to J/\psi K^{*0})}$$

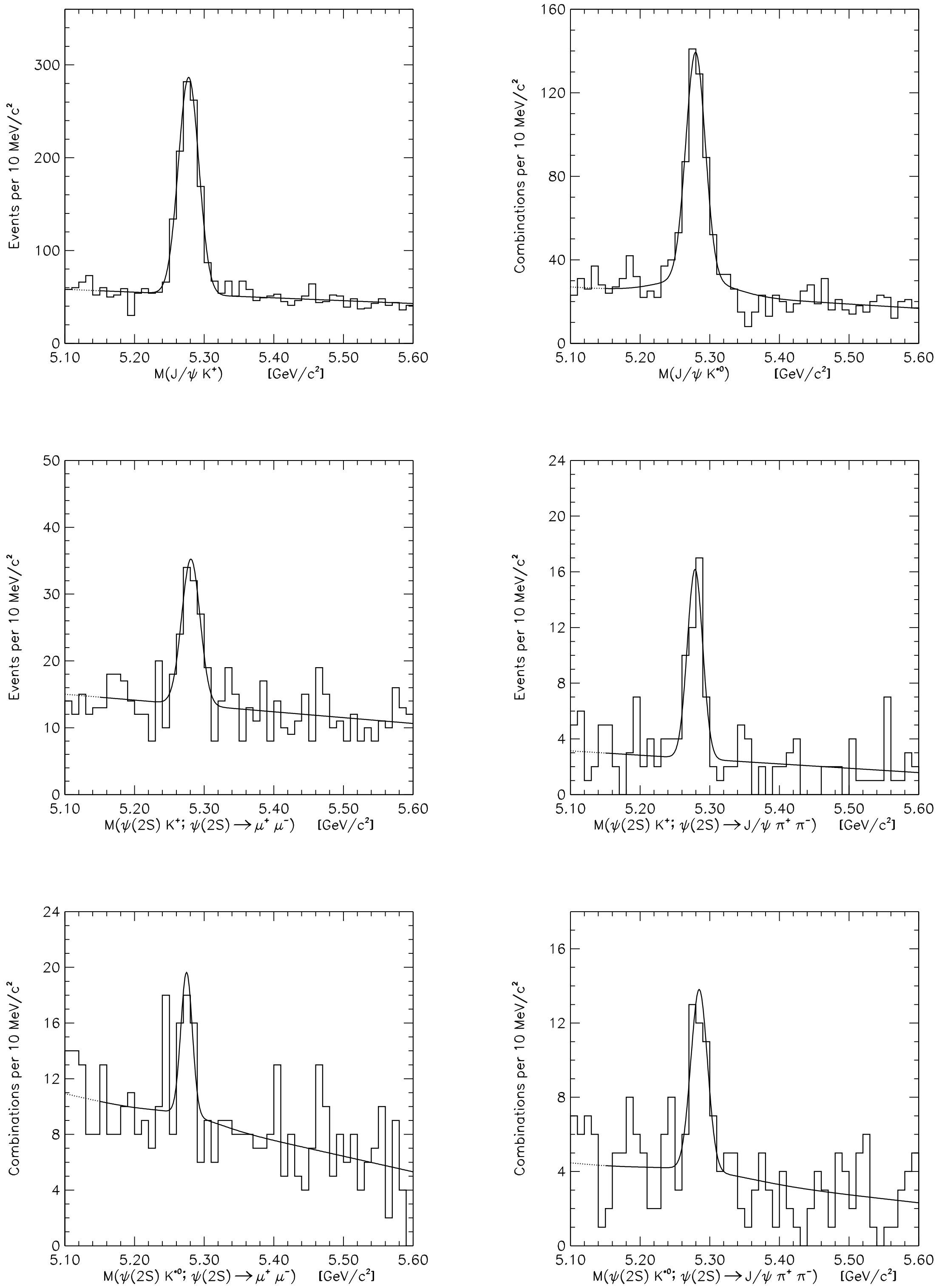
See clean inclusive $\psi(2S)$ signal

$\psi(2S) \to J/\psi\pi^+\pi^-$ and $\psi(2S) \to \mu^+\mu^-$



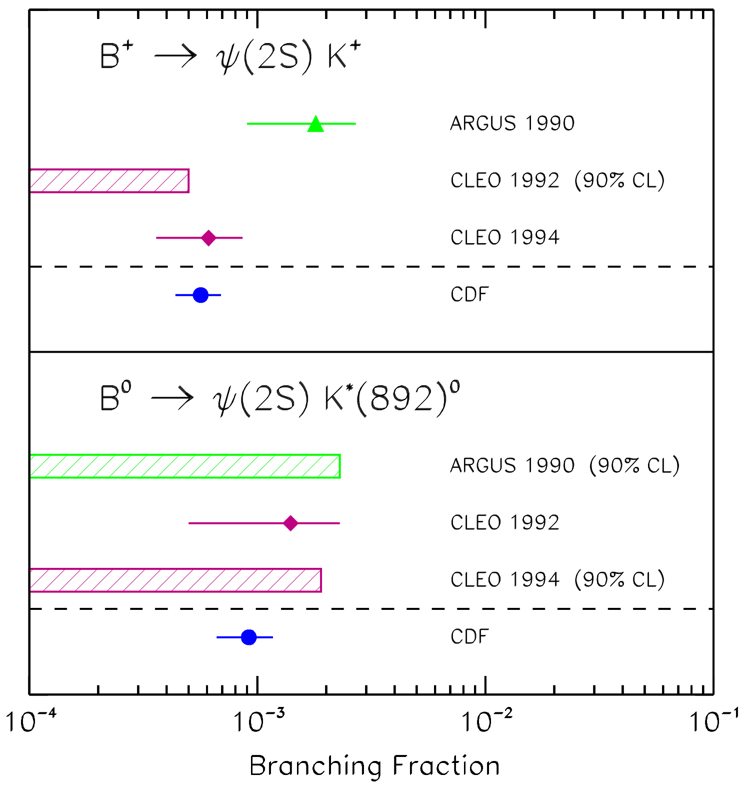


CDF $B \rightarrow \psi(2S)X$ Signals



Comparison with Other Measurements

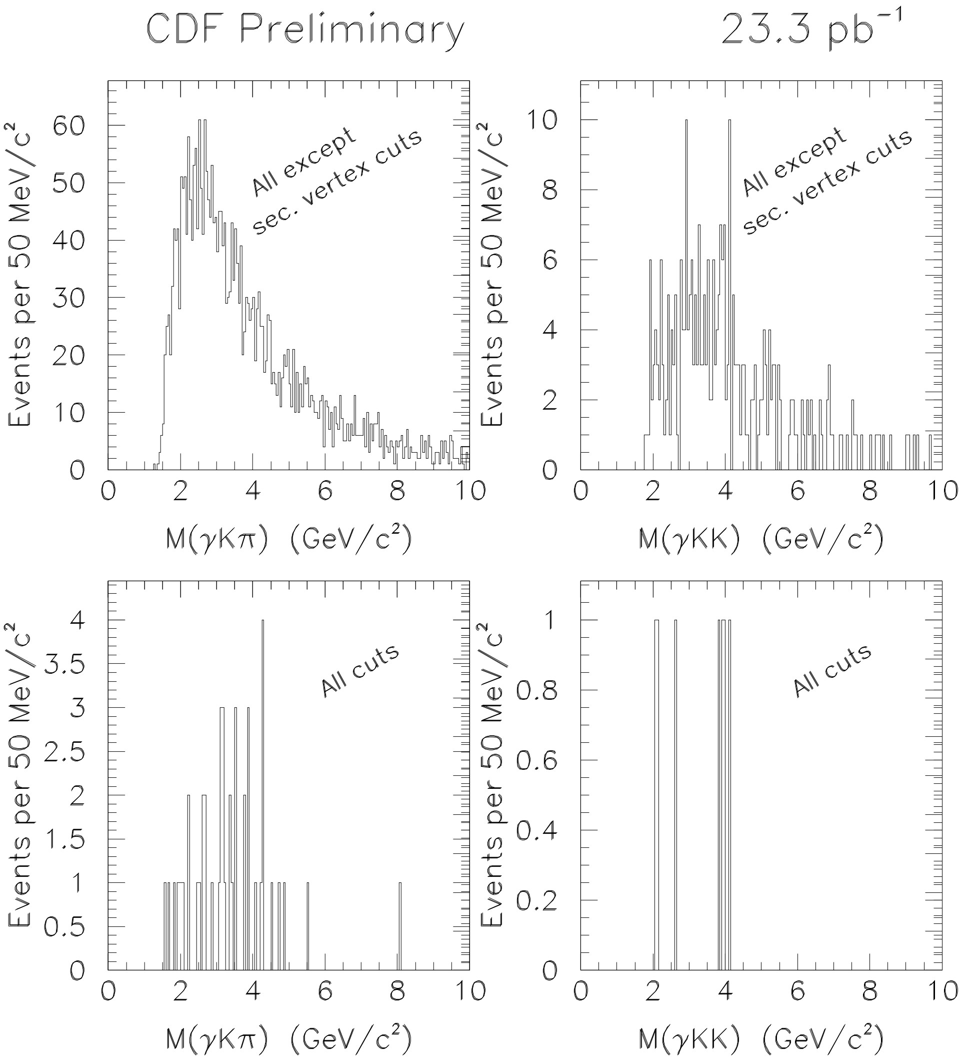
These results can be compared with CLEO results



- Now the world's best measurement.
- Accepted for publication in PRD.

Search for Electromagnetic Penguins

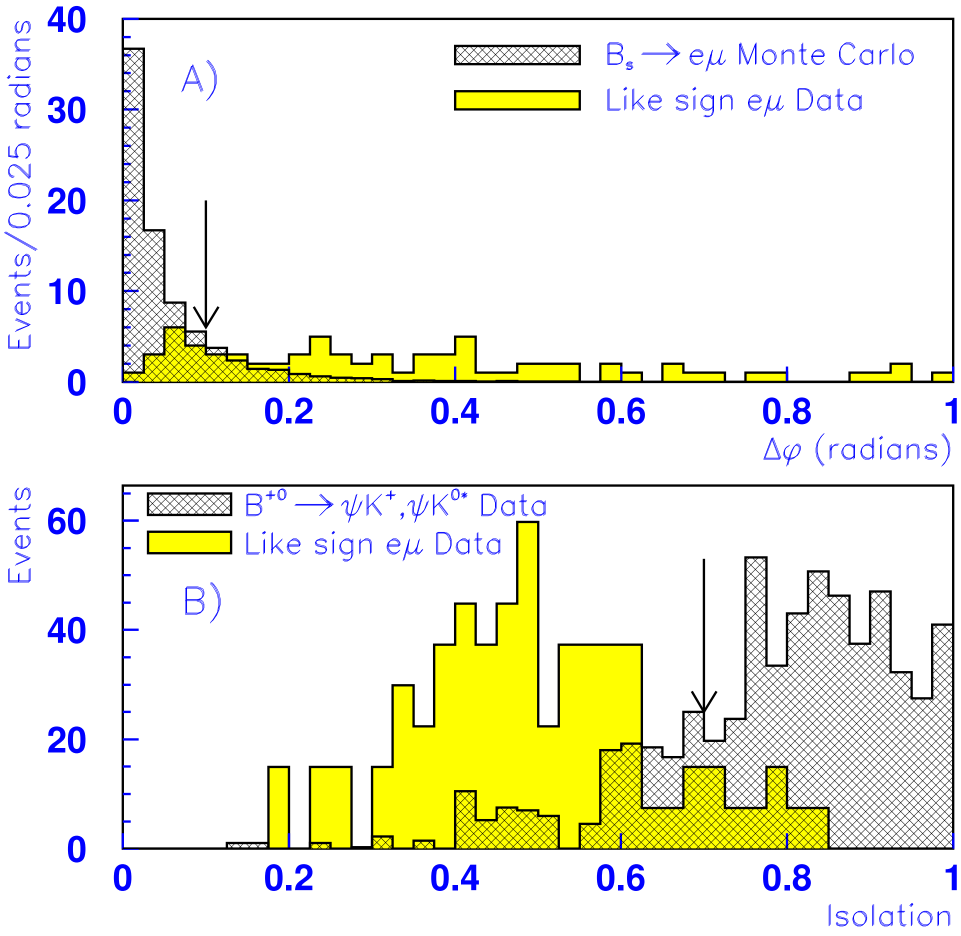
$B^0 \to K^{*0}\gamma$ $\qquad$ $B^0 \to \phi\gamma$



$\mathcal{B} \leq 2.9 \times 10^{-4}$ $\qquad$ $\mathcal{B} \leq 5.7 \times 10^{-4}$ $\quad$ $(95\% CL)$

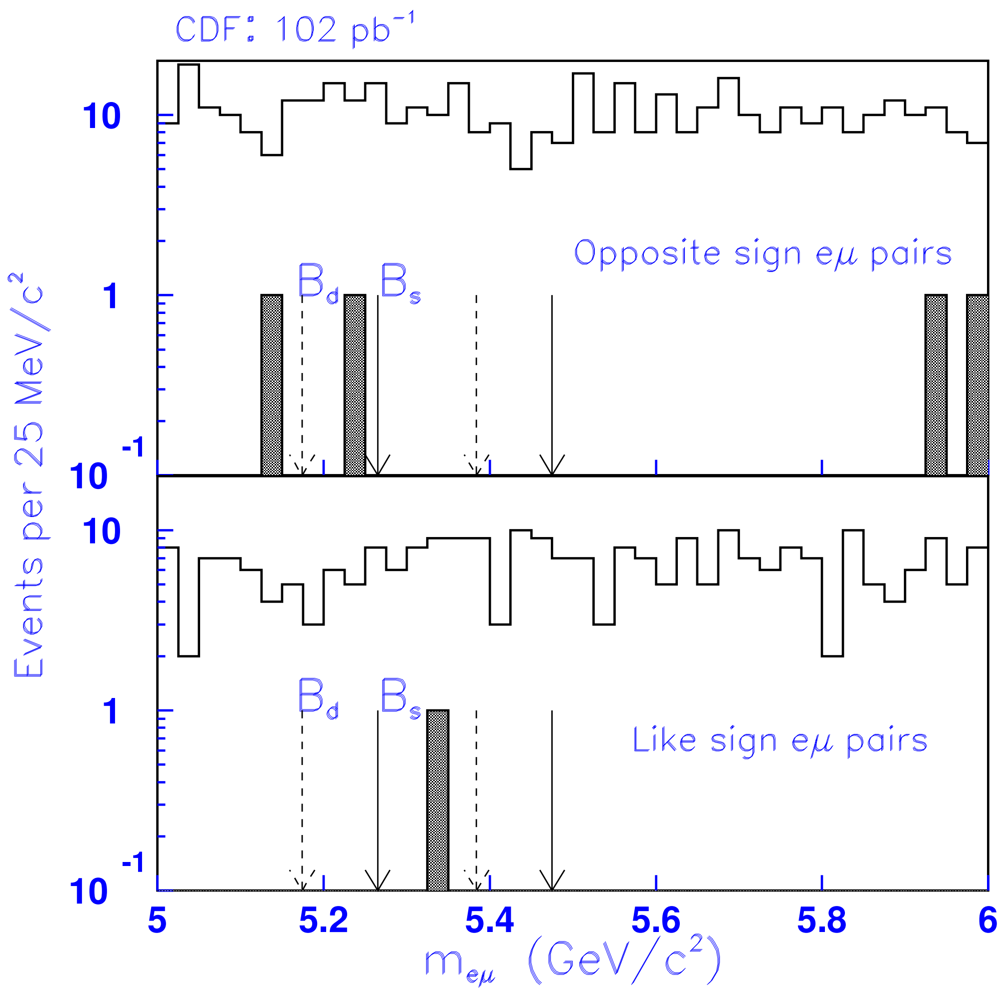
(CLEO observation of $\mathcal{B} \simeq 4 \times 10^{-5}$)

CDF Search for B to μe



- Usual cuts on long-lived B mesons ($c\tau > 100\mu$m)
- Decay direction parallel to p_t
- Real B mesons are more isolated than QCD background

Result of B to μe Search



- One candidate in B_d^0 mass window
- $\mathcal{B}(B_d^0 \to e^\pm \mu^\mp) < 4.4 \times 10^{-6} \quad (95\% CL)$
- $\mathcal{B}(B_s^0 \to e^\pm \mu^\mp) < 2.3 \times 10^{-5} \quad (95\% CL)$
- Can exclude Pati-Salam leptoquarks up to 19 TeV/c^2

Other Rare B Meson Decays

Limits on other rare B meson decay modes

Channel	Branching Fraction limit (95 %CL)
$B_d^0 \to \mu^+\mu^-$	8.6×10^{-7} (published)
$B_s^0 \to \mu^+\mu^-$	2.6×10^{-6} (published)
$B_d^0 \to \mu^\pm e^\mp$	4.4×10^{-6} (preliminary)
$B_s^0 \to \mu^\pm e^\mp$	2.3×10^{-5} (preliminary)
$B \to K^+\mu^+\mu^-$	5.4×10^{-6} $(90\% CL)$ (preliminary)
$B \to K^{*0}\mu^+\mu^-$	4.1×10^{-6} $(90\% CL)$ (preliminary)

Summary

- Hadron collider powerful tool for rare B meson searches
- B_c meson exists and properties measured
- We compete with CLEO on small $\mathcal{B}$ B modes (e.g. $\psi(2S)$)
- We don't, yet, see rare $B \to \mu^+\mu^-$ decays
- CDF-II should be sensitive to $B \to \mu^+\mu^- K^*$