Spectroscopy and Rare Decays at CDF

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Outline

- Review of B physics at hadron collider
- B hadron spectroscopy
  → B^+, B^0, B_s, Λ_b, etc…
- $D^0 \rightarrow \mu^+\mu^-$ search
- $B_s \rightarrow \mu^+\mu^-$ search
- Summary

Related talks at the conference:

- Recent Results from CDF (R. Harr)
- Heavy Flavor Production and Cross Sections (C. Chen)
- B Lifetime Measurements at the Tevatron (D. Zieminska)
- CP Violation Prospects at the Tevatron (P. Maksimovic)
- Future Prospects on B Mixing (T. Miao)

B Physics at the Tevatron

- b production cross-section at the Tevatron is enormous:

  $\sigma(e^+e^-) \rightarrow b\bar{b}$: 1nb at $\Upsilon(4S)$

  7nb at Z^0 pole

  $\sigma(p\bar{p}) \rightarrow b\bar{b}$: ~ **50μb** at Tevatron

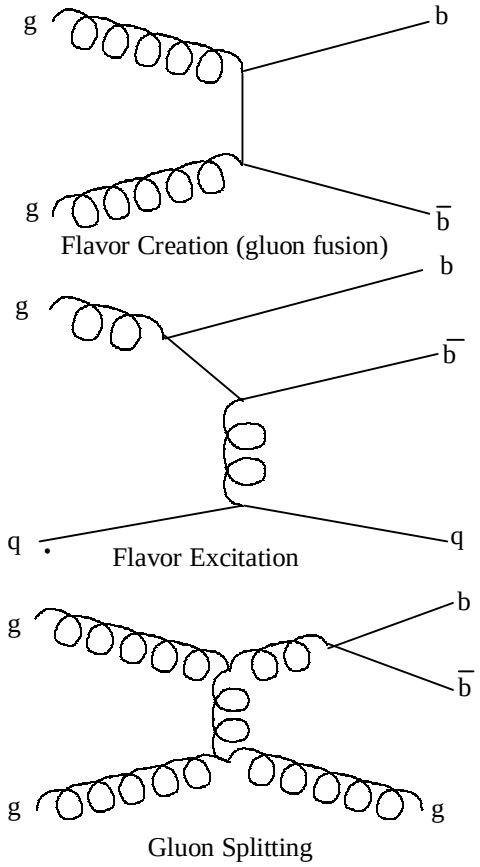
- Wide spectrum of B species are produced:

  B^+, B^0, B_s, B_c, Λ_b, etc…

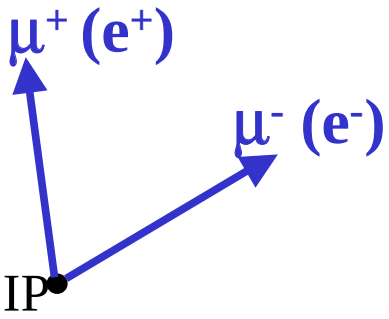
- However, inelastic cross-section at the Tevatron is x1000 larger ☹

  → High trigger efficiency and trigger bandwidth are the keys to success in hadron environment

b production mechanisms

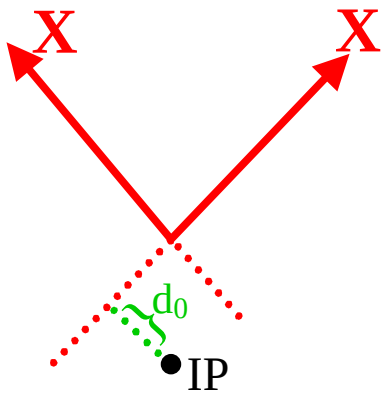


B Triggers at CDF



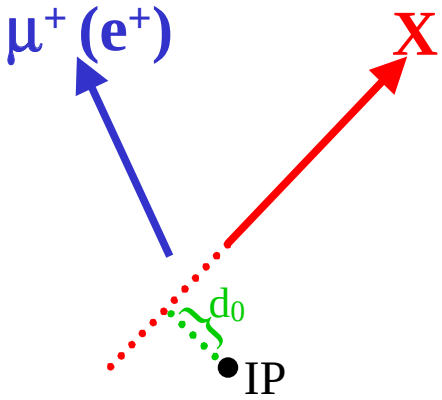
(1) Dimuon trigger:

For triggering on J/Ψ and rare B decays
Track pT threshold is lowered to 1.5GeV
(was 2GeV in RunI)



(2) Two-track trigger (SVT):

For triggering on hadronic B and charm decays. Both tracks are required to have an impact parameter $d_0 > 120\mu m$.
New trigger for RunII!!



(3) Lepton+Displaced Track(SVT):

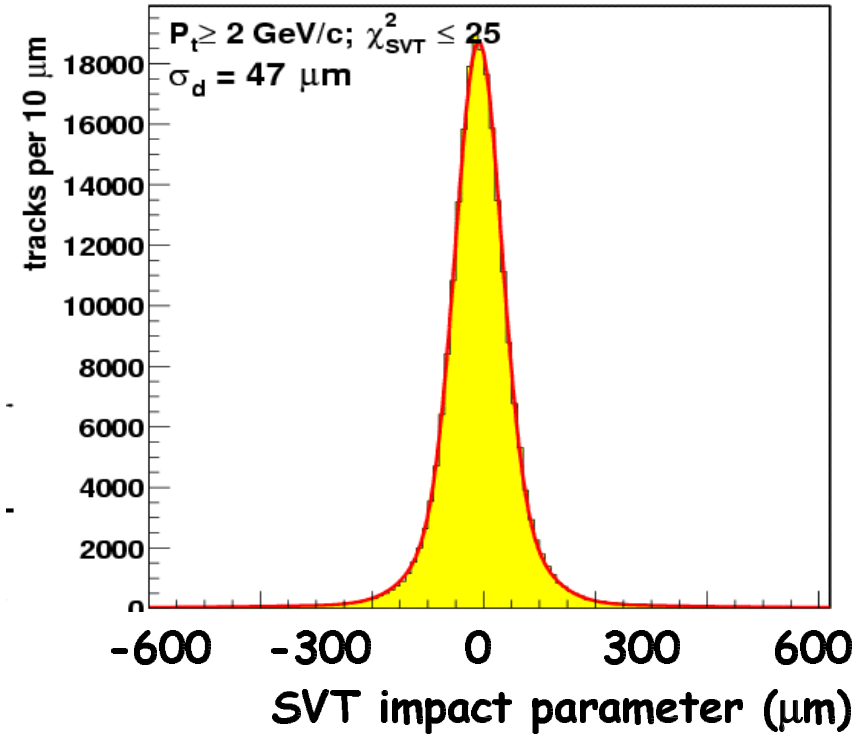
For triggering on semileptonic B decays.
New trigger for RunII!!

Silicon Vertex Tracker (SVT)

CDF is the first hadron collider experiment to be able to trigger on fully hadronic B events

Level-2 SVT Trigger

- SVT links drift chamber tracks from Level-1 with silicon hits to compute the impact parameter of the track.

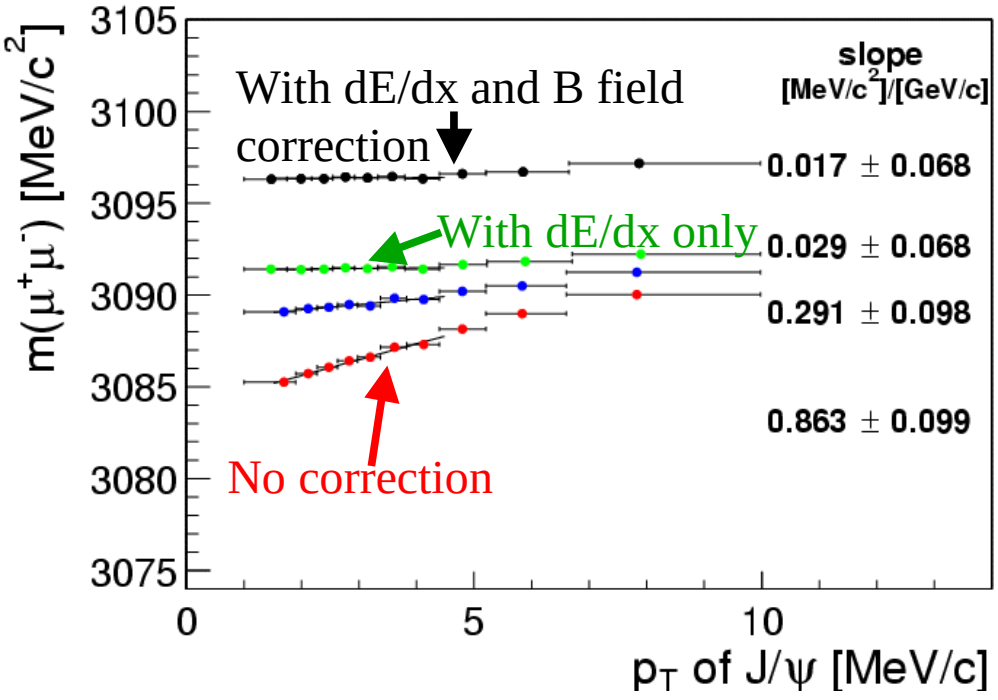


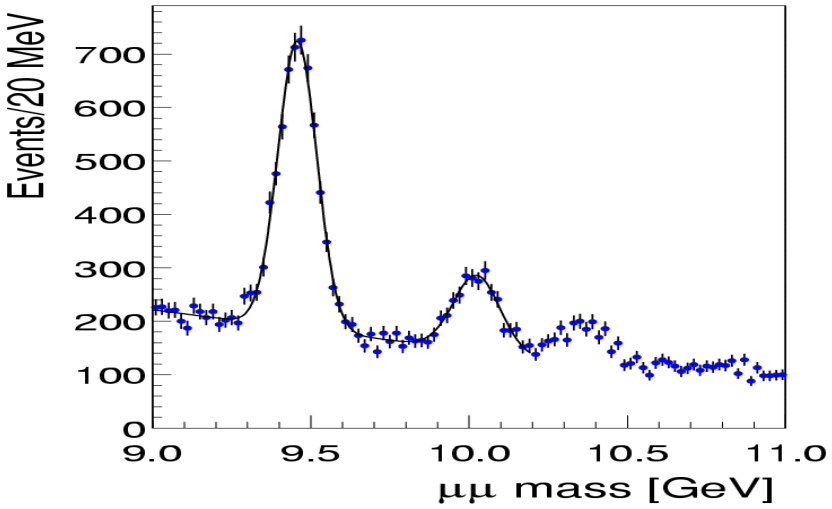
- SVT d0 resolution is ~ **47μm** (35μm beamline ⊕ 33μm resol).
- SVT revolutionized B and Charm physics at CDF.

Spectroscopy:Mass Scale Calibration

Calibration Momentum Scale of Tracks Using J/Ψ Sample:

- dE/dx correction→ tune GEANT material description to remove pT dependence on the J/Ψ mass,
- B field correction → apply magnetic field correction to shift the raw J/Ψ mass to the PDG value,
- Cross-checks → measure meson masses (Ks, D, ϒ, Ψ', etc…).





	CDF mass	PDG mass
Ψ'	3685.80 ± 0.12	3685.96 ± 0.09
ϒ(1S)	9461.1 ± 1.5	9460.30 ± 0.26

Spectroscopy: B Mass Measurements

- We have measured B hadron masses using fully reconstructed B→J/Ψ X decay modes

- CDF RunII preliminary results with ~80pb^{-1}:

  $m(B^0) = 5280.30 \pm 0.92 \pm 0.96$ MeV/c^2

  $m(B^+) = 5279.32 \pm 0.68 \pm 0.94$ MeV/c^2

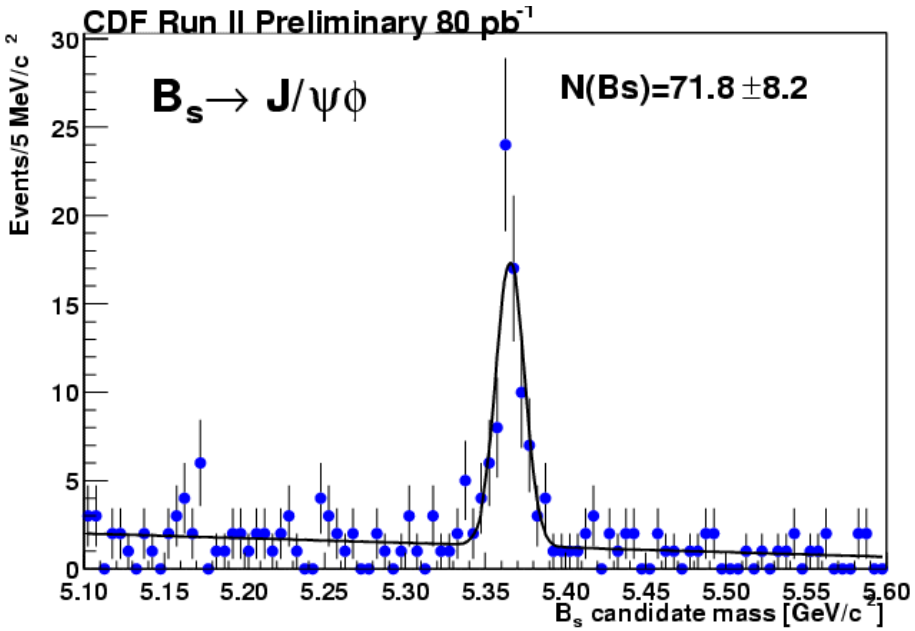
  CDF: $m(B_s) = 5365.5 \pm 1.6$ MeV/c^2

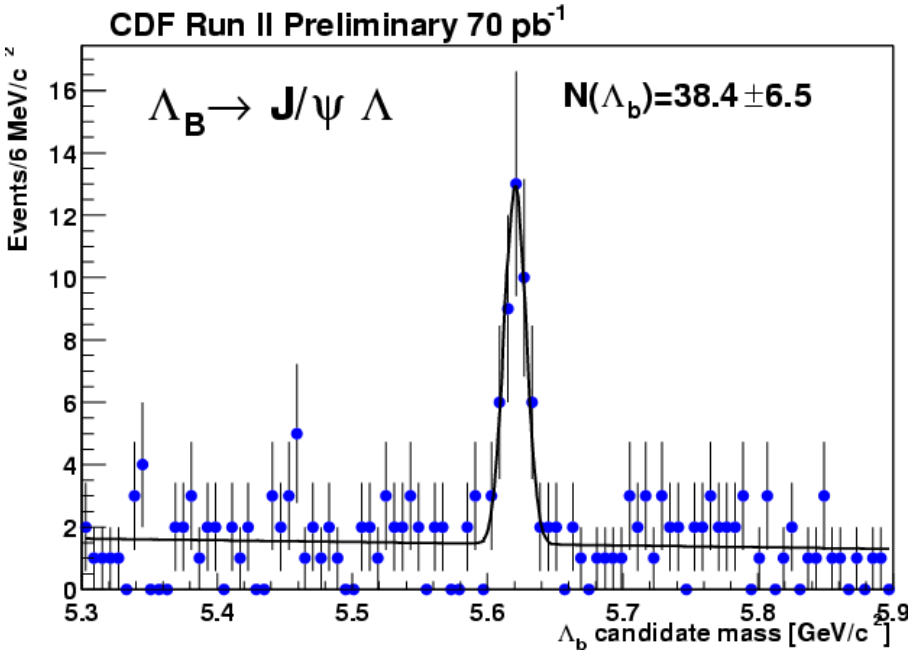
  PDG: $m(B_s) = 5369.6 \pm 2.4$ MeV/c^2

  CDF: $m(\Lambda_b) = 5620.4 \pm 2.0$ MeV/c^2

  PDG: $m(\Lambda_b) = 5624 \pm 9$ MeV/c^2

- CDF's B_s and Λ_b mass measurements are world's best!!!

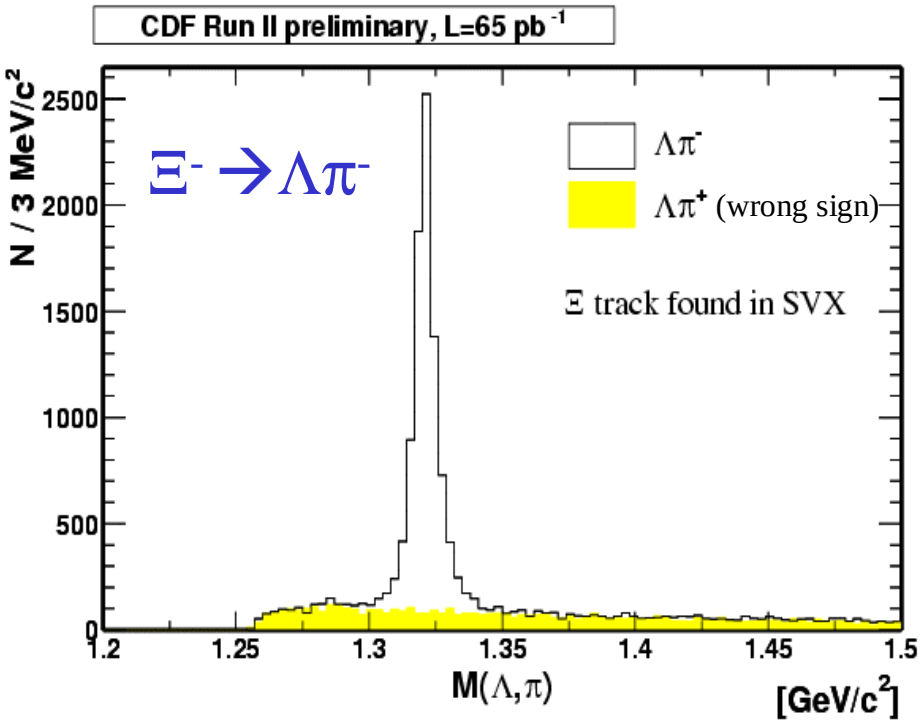


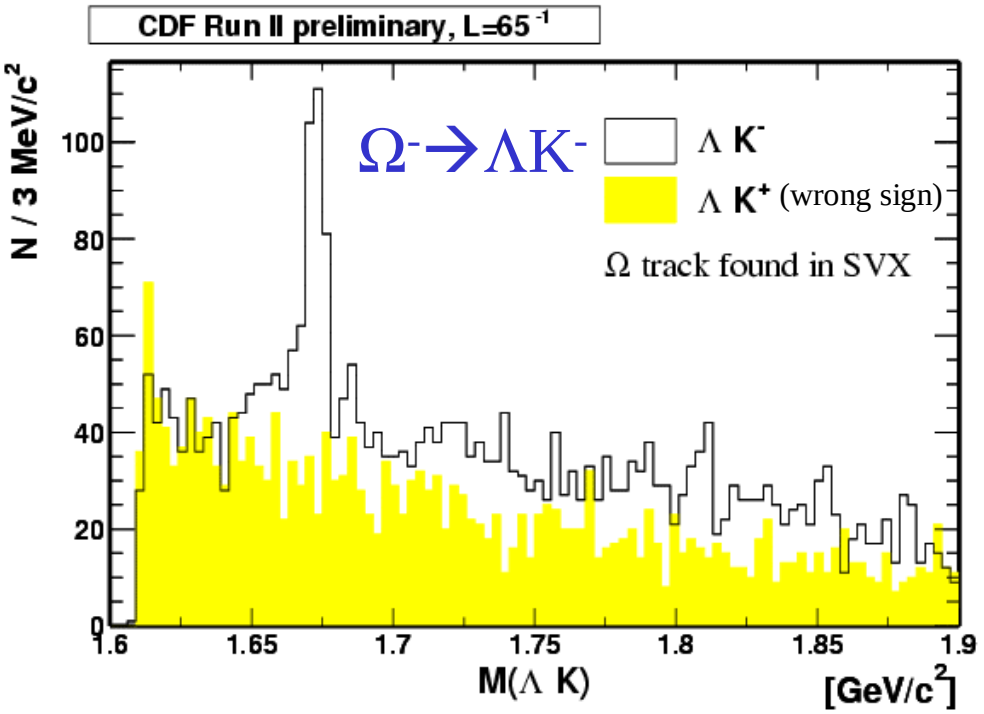


Spectroscopy: CDF Prospects

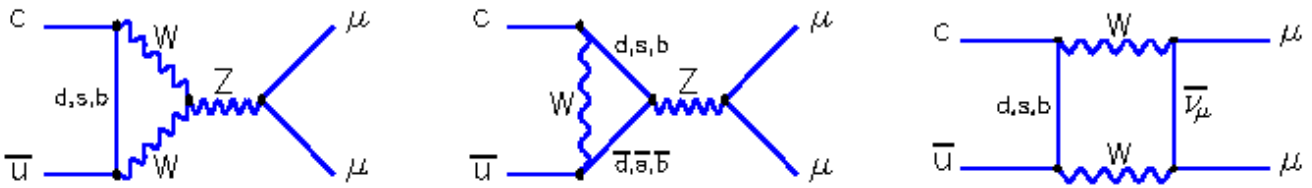
- Results presented used only a fraction of available data. With more data coming, the uncertainty on the mass measurements will continue to improve.
- Mass of other mesons (e.g. B_c) and baryons will be measured.
- Sneak preview: by tracking long lived charged hyperons through the silicon detector, we have obtained a very clean sample of Ξ^- and Ω^-.

→ **Next stop: Ξ_b and Ω_b**





$D^0 \rightarrow \mu\mu$ Search



- Standard Model expectation on the branching ratio is ~10^{-13}
- However, new physics (e.g. some R-parity violating SUSY Models) could enhance the branching to ~10^{-6} → window of opportunity to observe new physics

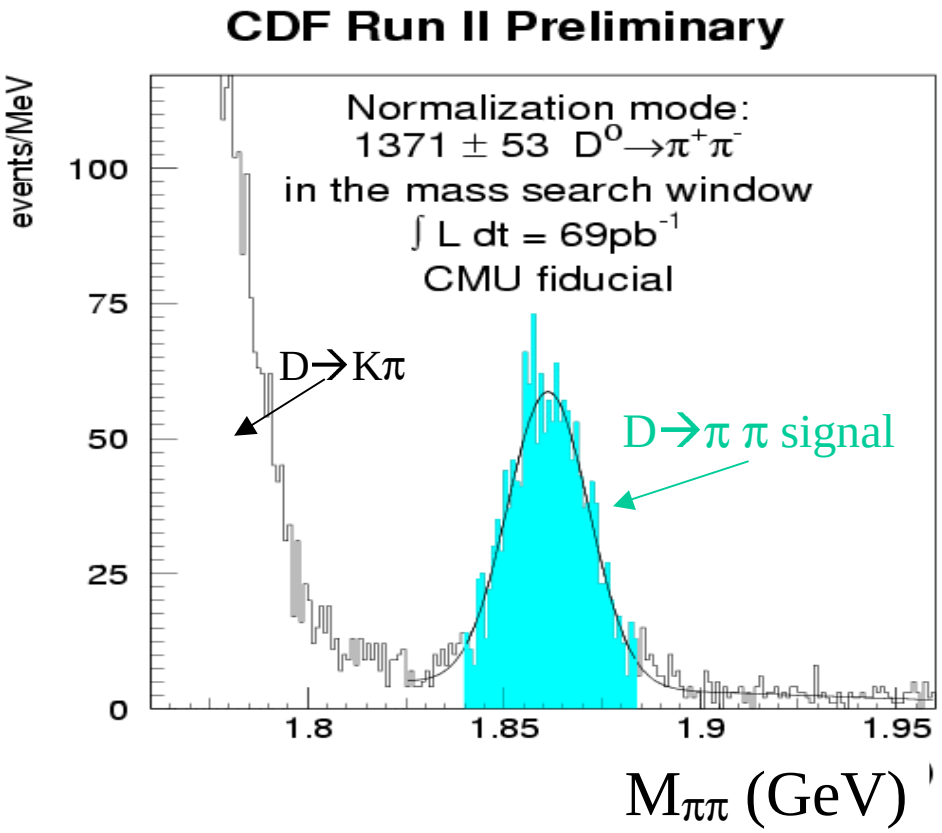
Analysis Approach:

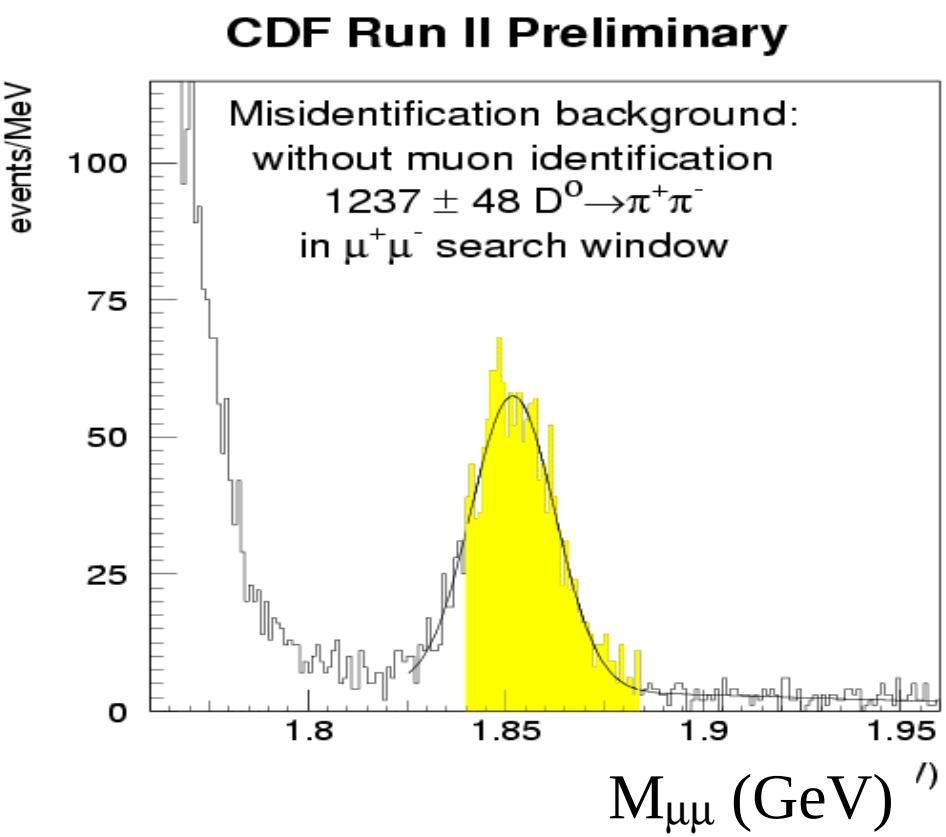
- Use data from the two-track (hadronic) trigger to search for $D^0 \rightarrow \mu\mu$ candidates
- The ideal normalization mode is $D^0 \rightarrow \pi\pi$. Similar decay topology as $D^0 \rightarrow \mu\mu$ and also comes through the same hadronic trigger path → trigger efficiency and acceptance cancel in the ratio!!

$$BR_{CL}(D^0 \rightarrow \mu^+\mu^-) \leq \frac{N_{CL}(D^0 \rightarrow \mu^+\mu^-)}{N(D^0 \rightarrow \pi^+\pi^-)} \cdot \frac{\varepsilon(D^0 \rightarrow \pi\pi)}{\varepsilon(D^0 \rightarrow \mu\mu)} \cdot BR(D^0 \rightarrow \pi^+\pi^-)$$

Reconstruction efficiency

$D^0 \rightarrow \mu\mu$ Search: Normalization

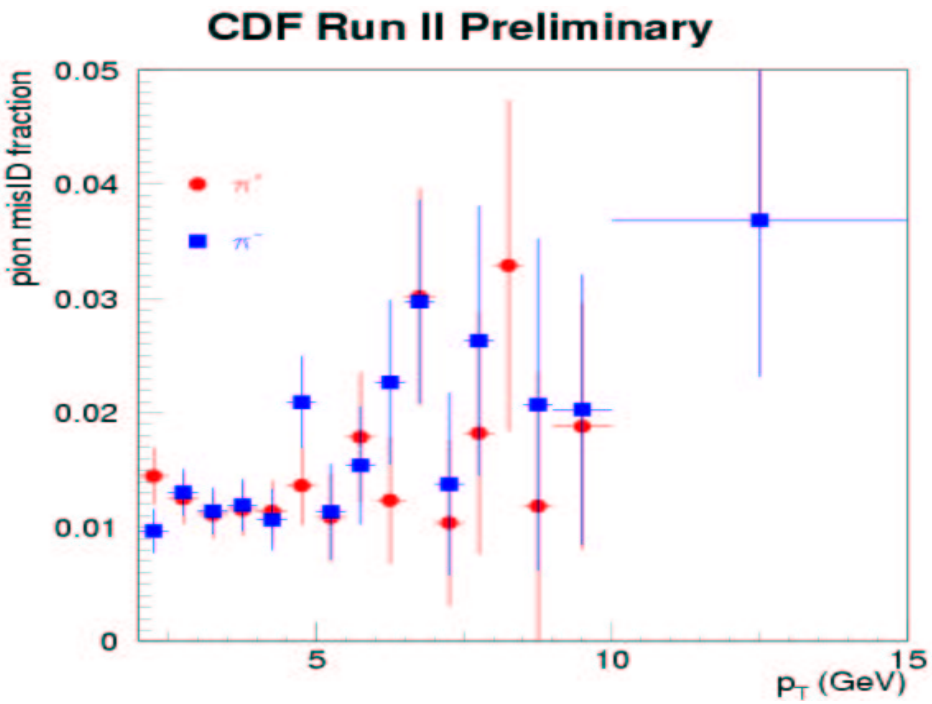


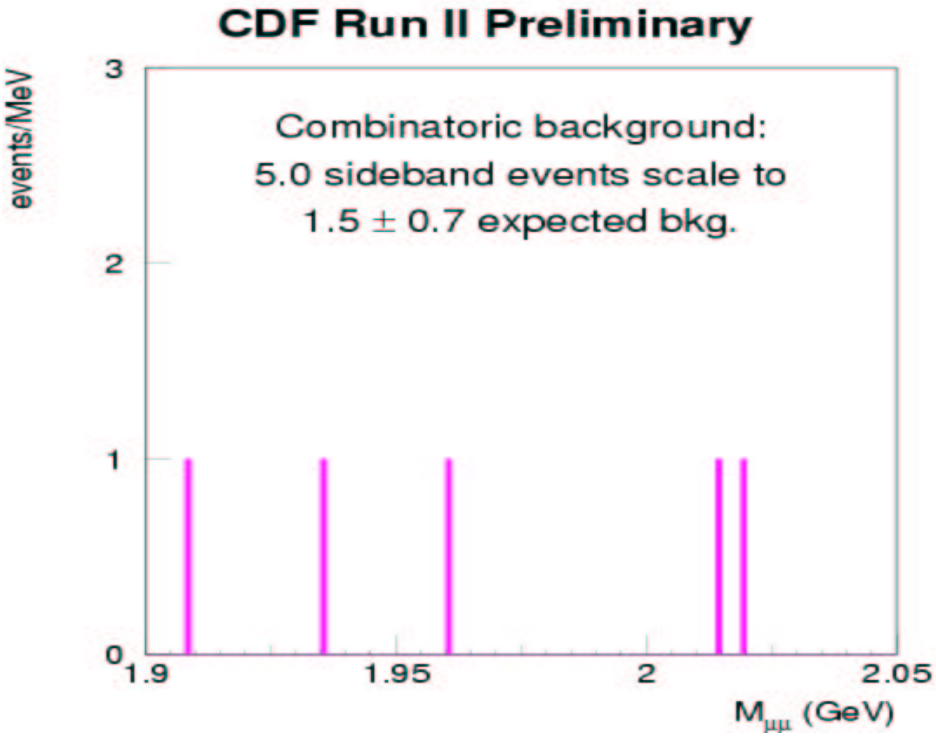


- Select D^0 from D* decay
- Clean $D^0 \rightarrow \pi\pi$ peak
- 1371 events in muon fiducial region

- $D^0 \rightarrow \pi\pi$ events almost completely overlaps with the $\mu\mu$ search window
- Need to have good understanding of $\pi \rightarrow \mu$ fake rate.

$D^0 \rightarrow \mu\mu$ Search: Background



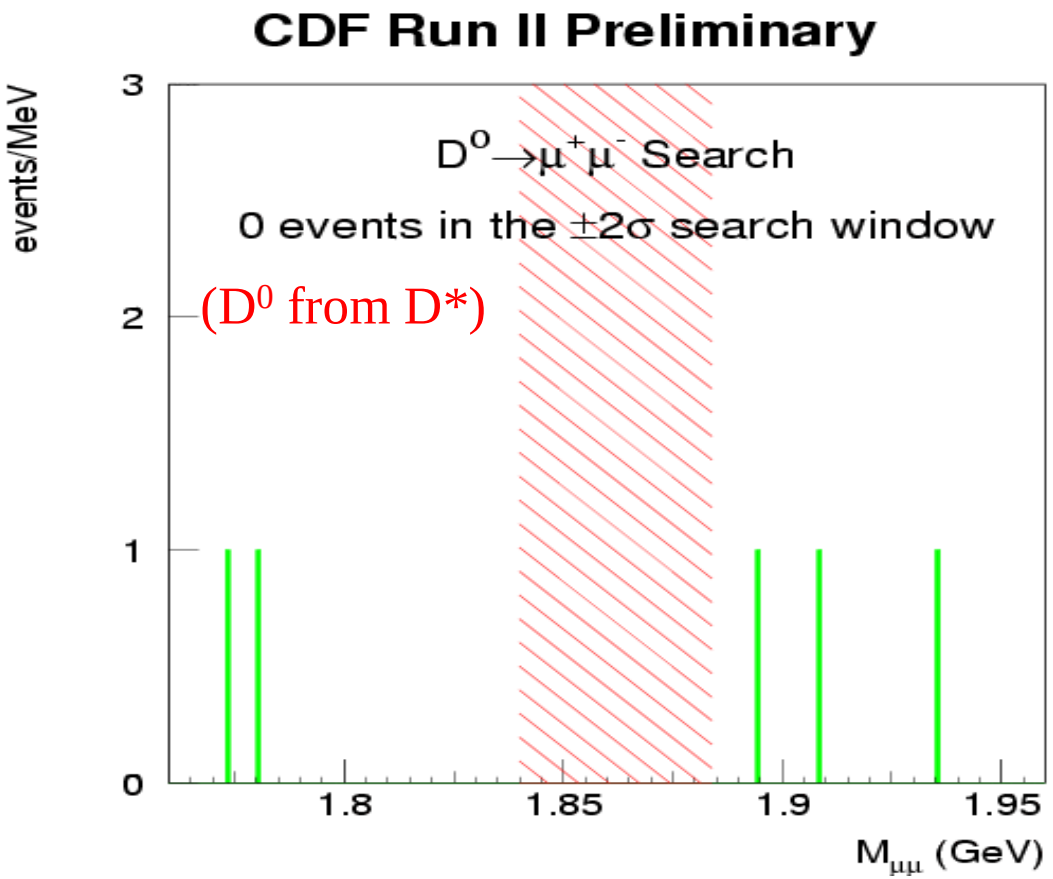


- Pion fake rate is measured from a sample of tagged D* events
- Fake background is determined from the # of $D^0 \rightarrow \pi\pi$ events reconstructed as $\mu\mu$ events times (pion misID)^2
- BKG(fake) = 0.3 ± 0.1 events

- Combinatoric background is determined from the high mass side-band region
- BKG(combinatoric)=1.5±0.7 events

Total expected background in $\mu\mu$ search window = 1.8 ± 0.7 events

$D^0 \rightarrow \mu\mu$ Search: Result



- 0 event in search window while expect 1.7 background events
- The upper limit is:
  $B(D^0 \rightarrow \mu\mu) < 2.5 \times 10^{-6}$ (90%CL)
  $B(D^0 \rightarrow \mu\mu) < 3.3 \times 10^{-6}$ (95%CL)
  (accepted by PRD Rapid Comm.)
- The limit is ~ x2 better than the previous published limit
- Future prospect:
  - Include more statistics and extend muon coverage,
  - Other interesting search modes:
    $D^+ \rightarrow \pi\mu\mu$, $D^+ \rightarrow K\mu\mu$,
    $D^0 \rightarrow \mu e$, etc…

$B_s \rightarrow \mu\mu$ Search

- FCNC is forbidden at the tree-level in the Standard Model. The expected branching ratio for $B_s \rightarrow \mu\mu$ is $\sim 10^{-9}$.

- Many SUSY Models predicts a large enhancement in the branching ratio ($\sim 10^{-6}$). The rate is proportional to $\tan(\beta)^6$.

If decay is observed soon → new physics
If decay is not seen → put a tight constraint on $\tan(\beta)$ and rule out some SUSY models

THIS IS A WIN-WIN SITUATION

- Theorists are very interested in the experimental progress of this analysis.

$B_s \rightarrow \mu\mu$ Search

$$BR(B_s \rightarrow \mu^+\mu^-) = \frac{N^{obs}_{90\%CL}}{\alpha \cdot \varepsilon \cdot \sigma_{Bs} \int Ldt}$$

Integrated luminosity

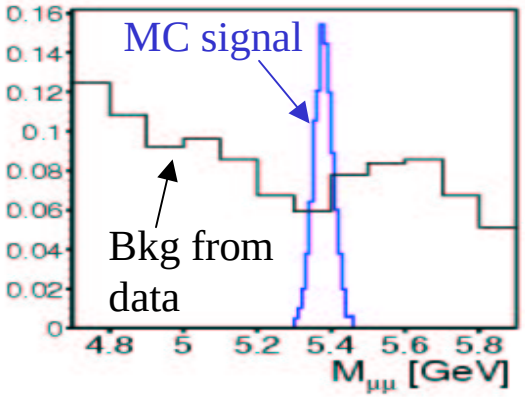
Geometric Acceptance

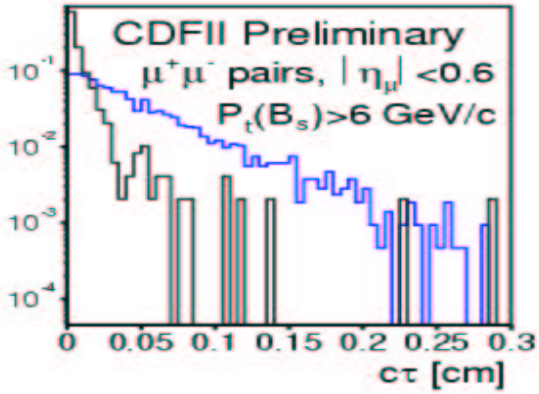
Trigger * reconstruction efficiencies

Bs cross-section

Discriminating variables :

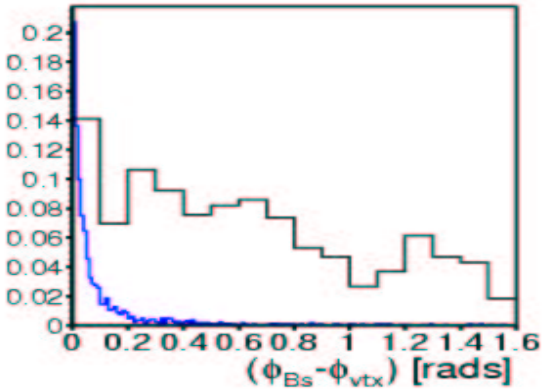
Dimuon Invariant mass

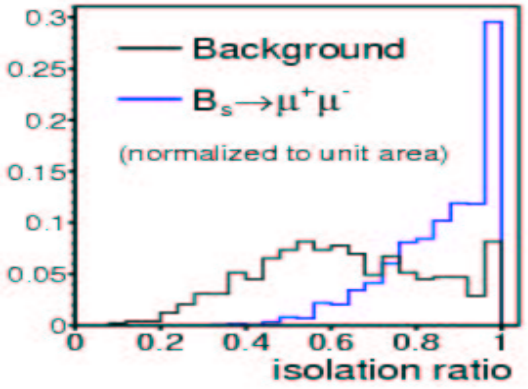




Proper lifetime ($c\tau$)

Angle between Bs momentum and vertex axis (from IP to Bs decay vertex)





Isolation:

$$\frac{pT(Bs)}{\sum_{\substack{Inside \\ cone}} pT(tracks) + pT(Bs)}$$

$B_s \rightarrow \mu\mu$ Search: Results

- It was a blind analysis
- Figure of merit for optimization:
  Expected 95% CL upper limit on the branching ratio

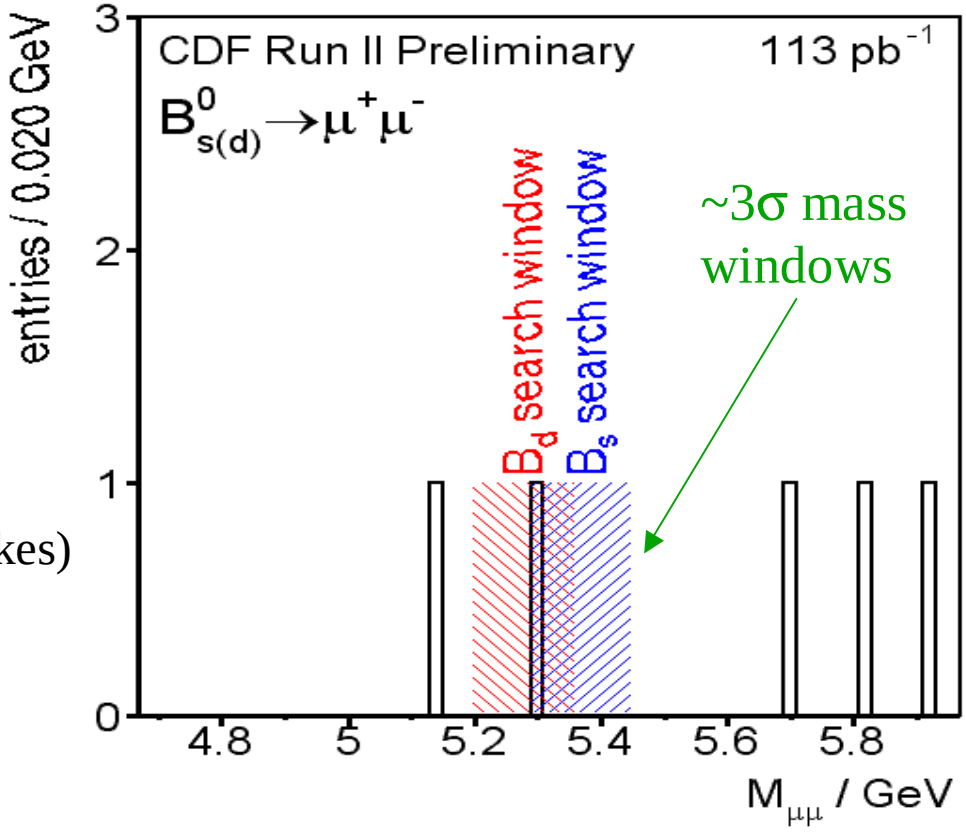
- 1 event observed in the search window with an expected background of 0.54 ± 0.2 events

(background is dominated by non-resonance fakes)

- The limit on the branching ratio:
  (based on 113pb-1 of data)

$Br(B_s \rightarrow \mu\mu) < 9.5\times10^{-7}$ @ 90% CL
$Br(B_s \rightarrow \mu\mu) < 1.2\times10^{-6}$ @ 95% CL

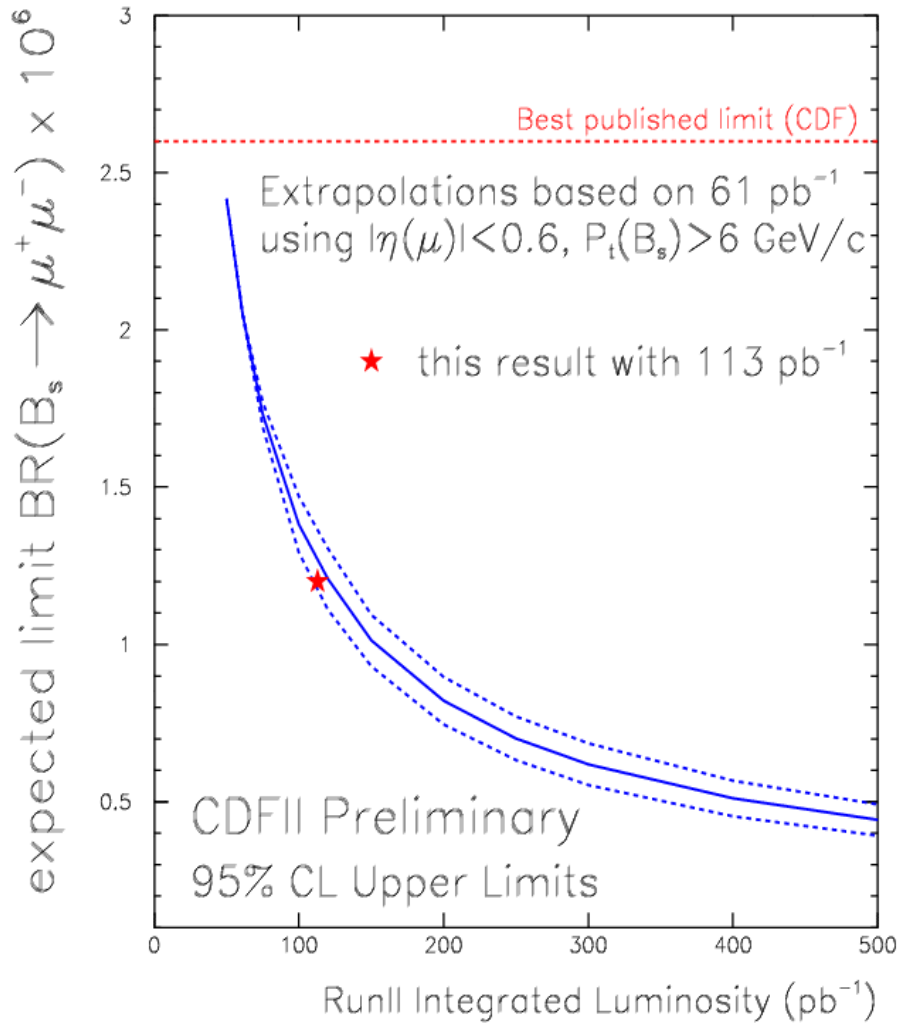
$Br(B_d \rightarrow \mu\mu) < 2.5\times10^{-7}$ @ 90% CL
$Br(B_d \rightarrow \mu\mu) < 3.1\times10^{-7}$ @ 95% CL



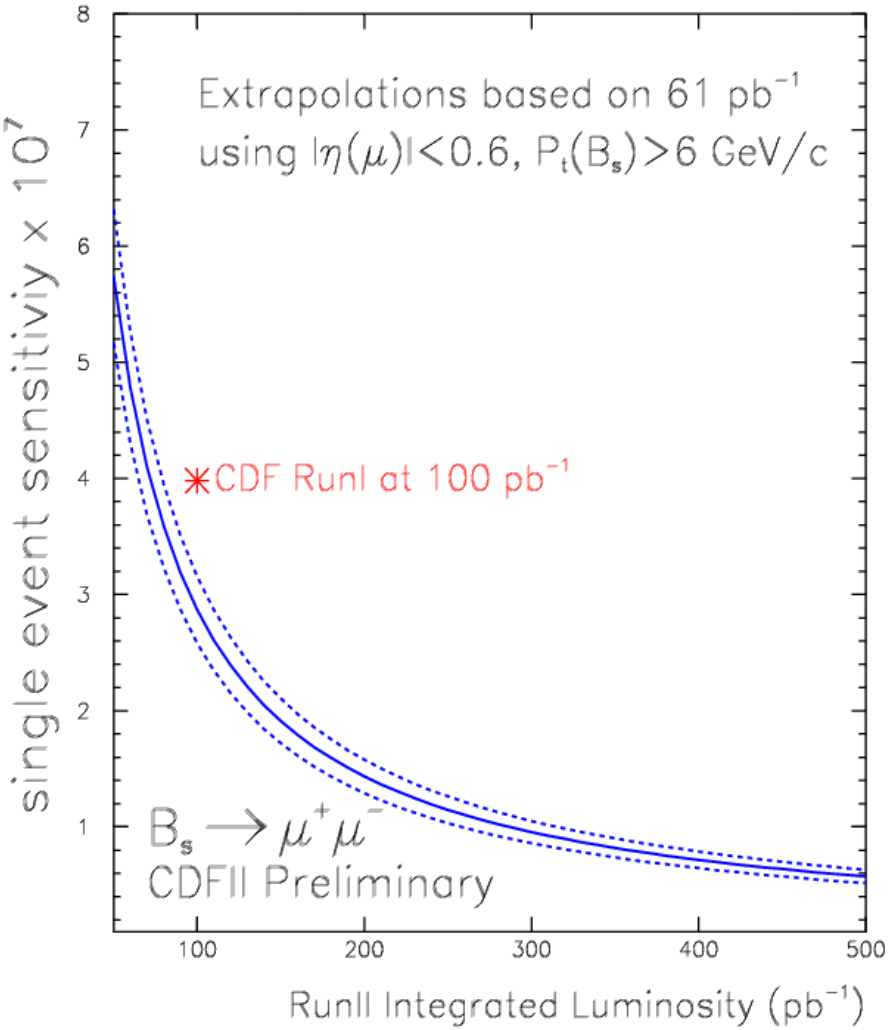
$B_s \rightarrow \mu\mu$ limit is a factor of 2 better than the published limit!!

$B_s \rightarrow \mu\mu$ Search: Projections

Expected Limit vs. Luminosity



Single Event Sensitivity vs. Luminosity



Summary

- CDF RunII has now accumulated over 200pb^{-1} of data (a factor of two larger than RunI). The results presented today are based on a fraction of available data. Updates with improved precision are on the way…

- CDF is back in the game of producing world class results.
  With more data coming, CDF will contribute to the physics community a wide spectrum of precision mass measurements.

- Bc was discovered in RunI via semileptonic channel. Search is on for the mass peak from Bc→ J/Ψ π in Run II.

- Bs and D^0→ μμ (and other rare decays) search will provide a window of opportunity to discover new physics. CDF will continue to be a major player in this arena.