Searches for FCNC Decays $B_{s(d)} \rightarrow \mu^+\mu^-$

- Motivation
- Tevatron Detectors: CDF and D0
- Results
- Conclusion

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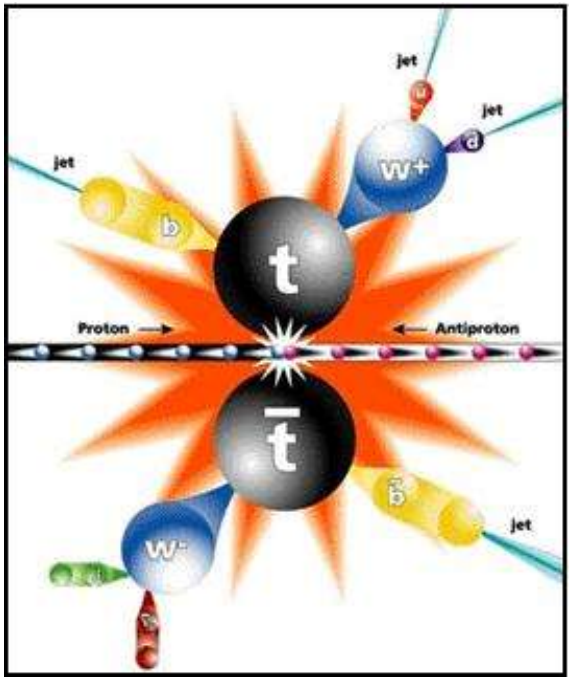
32nd International Conference on High Energy Physics 2004

Searches for New Physics

- How do you search for new physics at a collider?
  - Direct searches for production of new particles
    - Annihilation of two particles – available energy can contribute to formation of one or a pair of new particles
    - Last new particle found: the top quark
  - Indirect searches for evidence of new particles
    - Within a complex decay new particles can occur virtually
- Tevatron is at the energy frontier, but not in the sense that the LHC will be at the energy frontier
  Instead at a data volume frontier
  - Collecting so many physics events that we can search for some very unusual things
- Where to look
  - Many weak decay rates are very low probability
  - Can look for contributions to decay rates from other low probability processes – Non Standard Model



Excellent way to look for new physics before the LHC

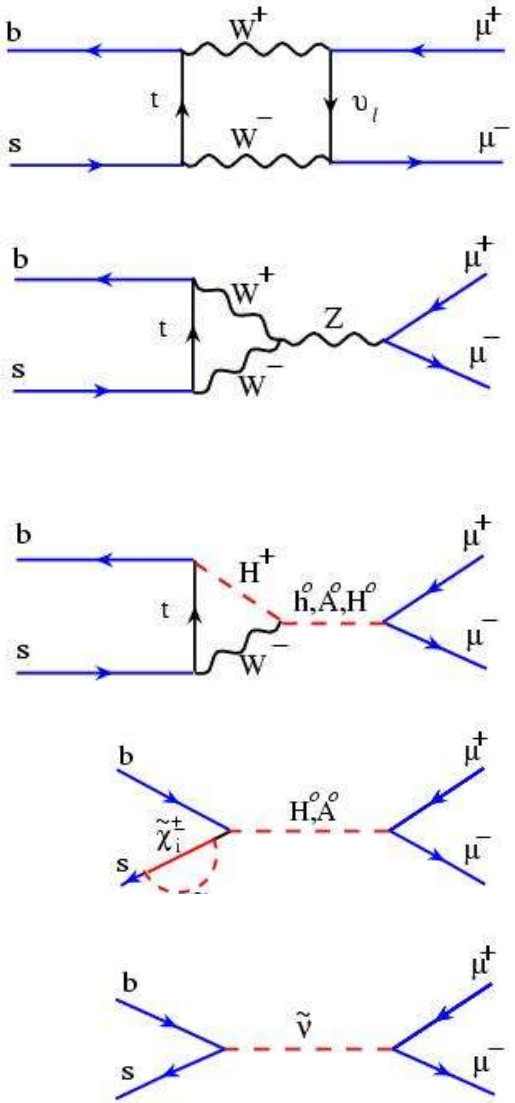
$B_s \rightarrow \mu\mu$: Beyond the SM

- Look at decays that are suppressed in the Standard Model: $B_{s(d)} \rightarrow \mu^+\mu^-$
  - Flavor changing neutral currents(FCNC) to leptons
    - No tree level decay in SM
    - Loop level transitions allowed though suppressed
    - CKM , GIM and helicity(m_l/m_b) suppressed
    - SM: $BF(B_{s(d)} \rightarrow \mu^+\mu^-) = 3.5\times10^{-9}(1.0\times10^{-10})$

      G. Buchalla, A. Buras, Nucl. Phys. B398,285
- New physics possibilities
  - Loop and tree level decays
  - Tree: Flavor violating models or R-Parity violating SUSY
  - Loop: MSSM: mSugra, Higgs Doublet
    - 3 orders of magnitude enhancement

      R. Arnowitt et al., Phys. Lett. B538,121
    - Rate $\propto \tan^6\beta$: can set lower limit if decay observed

      G. Kane et al., Hep-ph/0310042
  - One of the best indirect search channels at the Tevatron

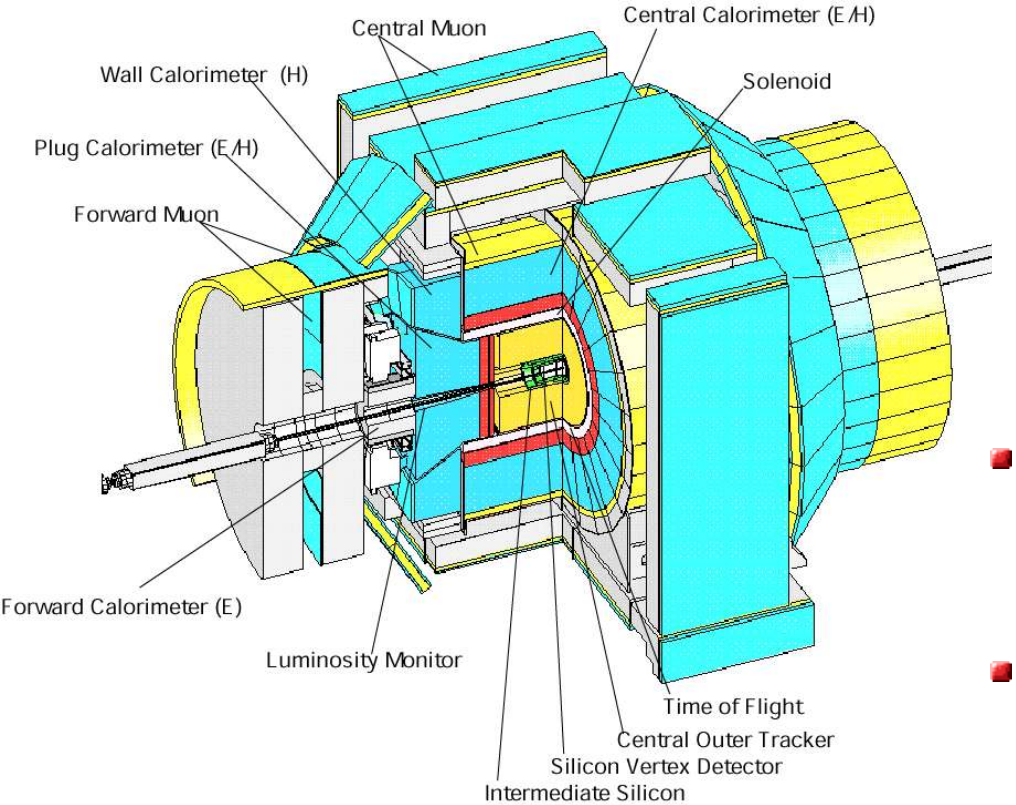


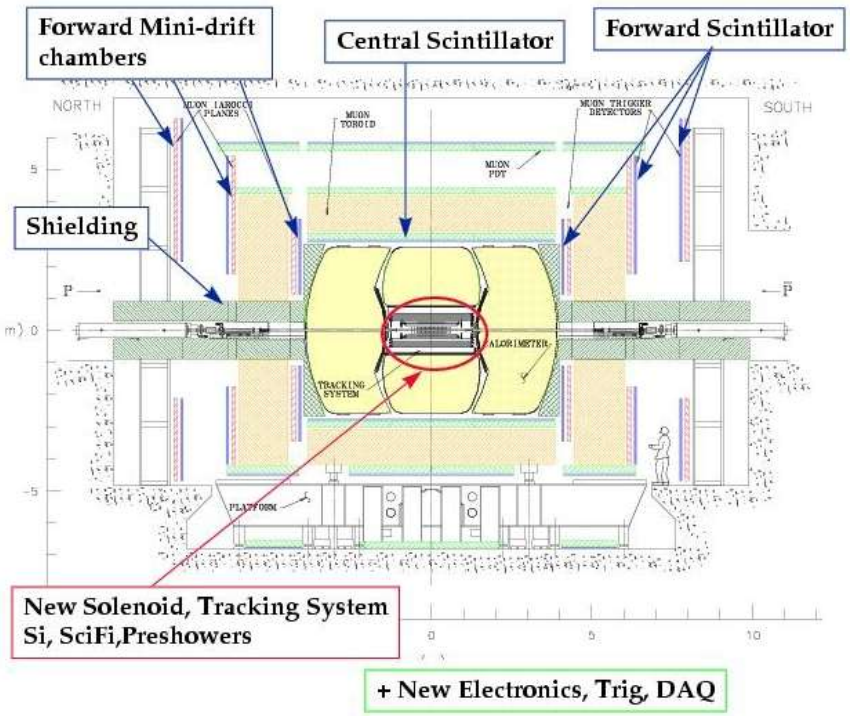
CDF & D0 Detectors

- CDF: Silicon

  EXCELLENT TRACKING

  - |η|<2, less coverage gaps, 90cm long
- Drift Chamber(COT)
  - 96 layers between 44 and 132cm
- Triggered muon coverage |η|<1.0

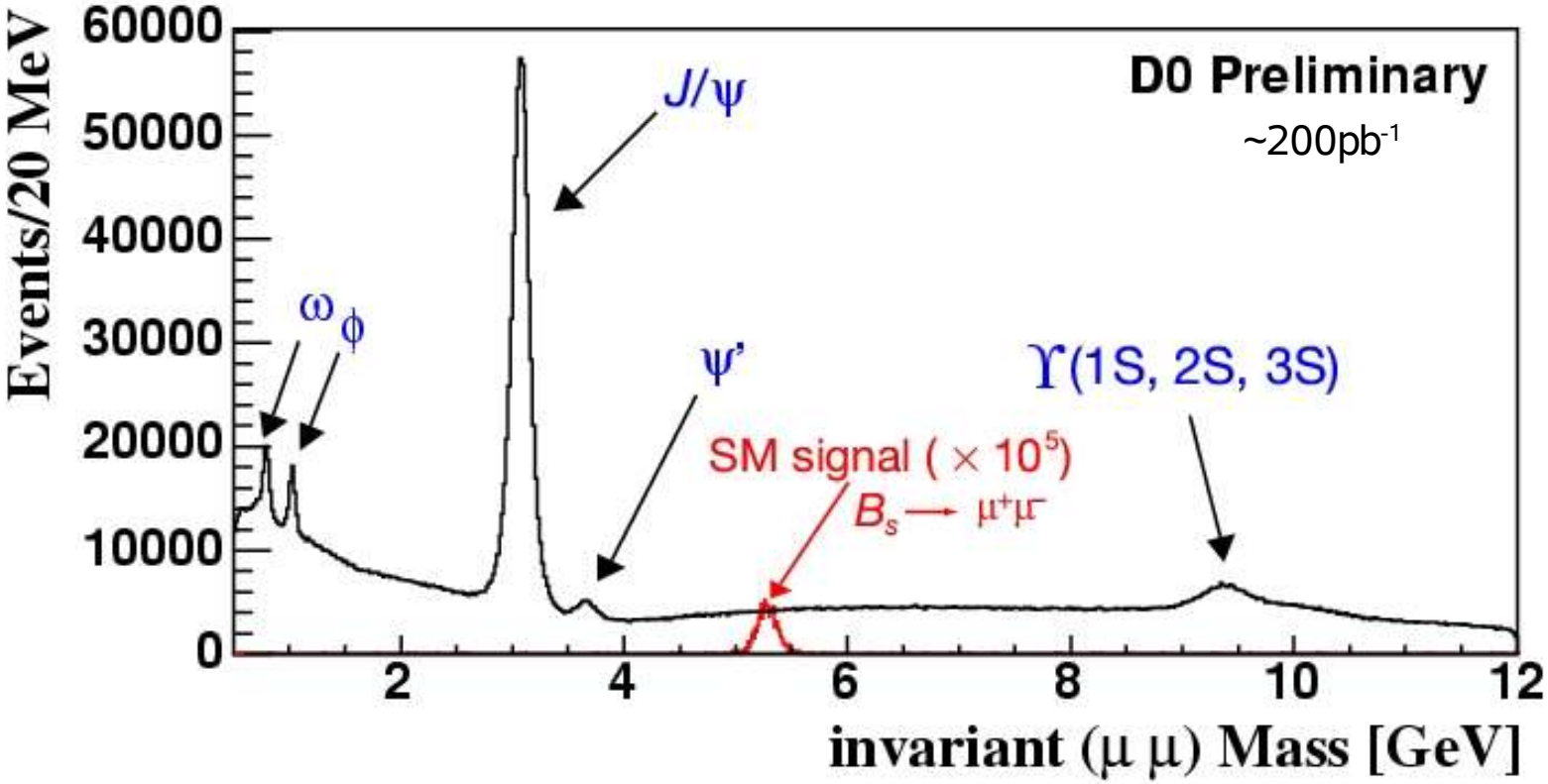




- D0 Tracker
  - Scintillating fiber tracker and silicon
  - Triggered tracking to |η|<2
- Triggered muon coverage |η|<2

  EXCELLENT MUON SYSTEM

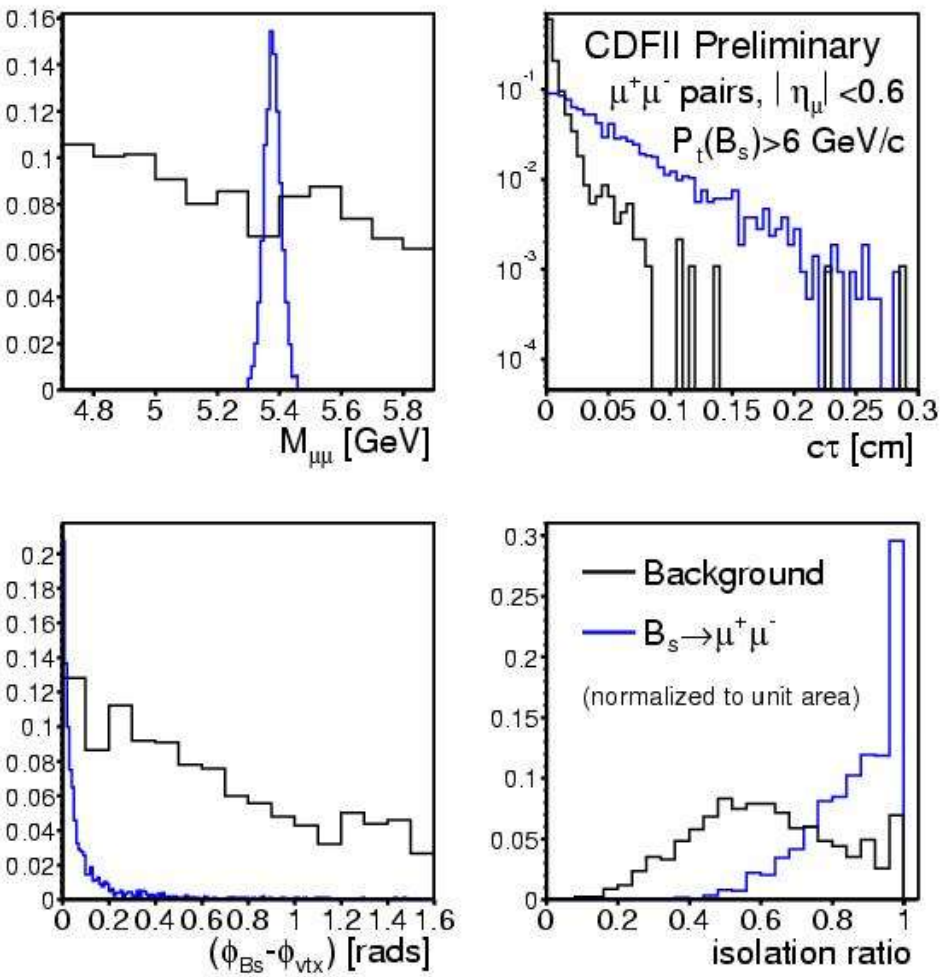
$B_s \to \mu\mu$: Experimental Challenge



- Primary problem is large background at hadron colliders
- Key elements of the analysis are determining the efficiency and rejection of discriminating variables and estimating the background level

CDF Analysis

- Cdf $B_{s(d)} \rightarrow \mu^+\mu^-$: Used blind analysis technique



- Used 4 primary discriminating variables
  - $c\tau$: $L_{xy} \cdot M/p_{TB} > 200\mu m$
  - $\Delta\Phi$: $|\phi_B - \phi_{vtx}| < 0.10$rad
  - Isolation: $p_{TB}/(\Sigma trk + p_{TB}) > 0.65$
  - Mass $M_{\mu\mu}$: choose 3σ window: $\sigma = 27 MeV/c^2$
- Optimization
  - Used simulated signal and data sidebands
  - Independent sets of cuts were factorized for optimization
    - Improves efficiency and background estimates
  - Background estimates were checked in same sign lepton and -$c\tau$ samples

CDF Results

- CDF $B_{s(d)} \to \mu^+\mu^-$ results
  - $\alpha \times \varepsilon = 2.03 \pm 0.21\%$
  - Expected background

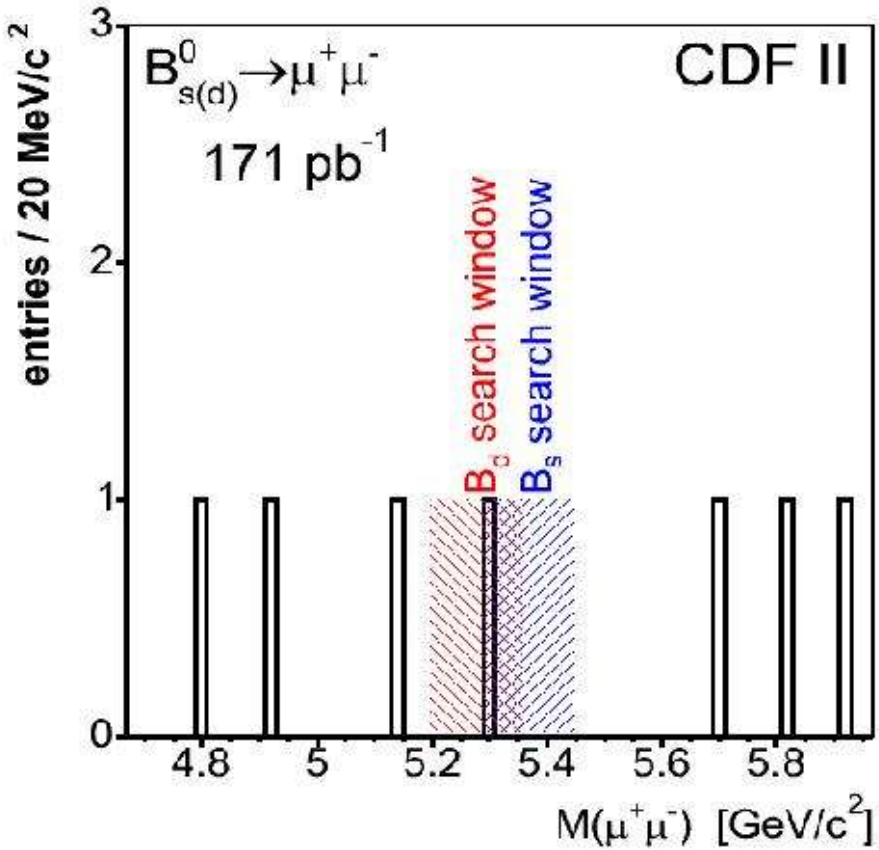
    $B_{s(d)}$: $1.05 \pm 0.30 (1.07 \pm 0.31)$
  - Observe 1 common event in 3σ $B_{s(d)}$ mass window which yields a limit of

$$BF(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

(4x more B_d produced than B_s)

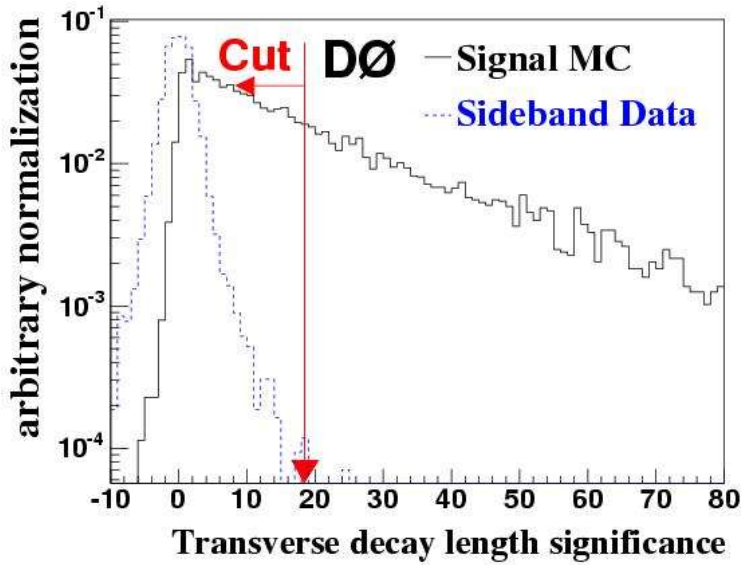
D. Acosta et al., PRL 93, 032001 2004

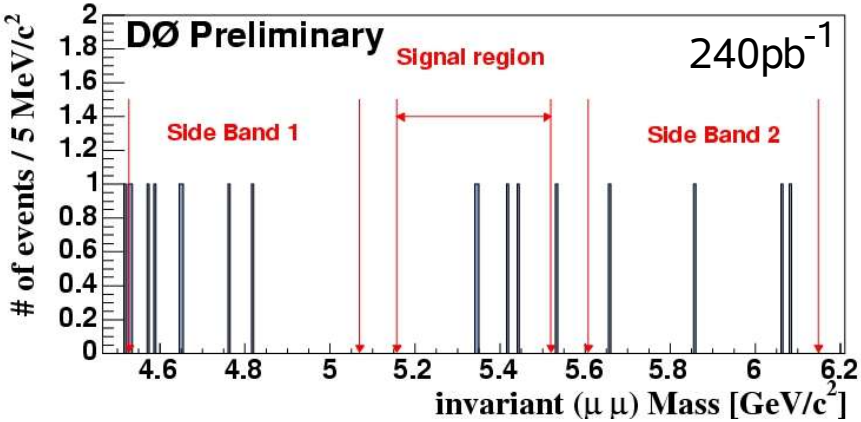


- Less than 1/3 of previous CDF limit: 20.0×10^{-7} 90% CL
- Competitive with Belle B_d results 1.6×10^{-7} (Likely updated soon)
  - Tevatron should be competitive in all $B \to X\ \mu^+\mu^-$ modes

D0 Analysis and Results

- 3 primary discriminating variables
  - L_{xy} Sig : $L_{xy} / \delta L_{xy} > 18.47$
  - $\Delta\Phi$: $\phi_B - \phi_{vtx} > 0.203$rad
  - Isolation: $p_{TB}/(\Sigma trk + p_{TB}) > 0.56$
- Choose 2σ mass window: $\sigma = 90 MeV/c^2$
- Optimization
  - Used simulated signal and data sidebands
  - Use random grid search of all cut combinations
- Relative normalization to $B^+ \rightarrow J/\psi K^+$
- D0 Result: Worlds best limit!





$$BF(B_s \rightarrow \mu^+ \mu^-) < 3.8 \times 10^{-7} \; 90\% \text{ CL}$$

D0 Conference Note 4514

35% better than CDF limit

Expected background: 3.7 ± 1.1
Observe 4

$B_s \to \mu\mu$: Physics Reach

D0 $B_s \to \mu^+\mu^-$ result: 240pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 3.8 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

CDF $B_{(s,d)} \to \mu^+\mu^-$ results: 171pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

Combined: Bayesian approach with a flat prior. Systematic error on fs correlated. Combination by M. Herndon

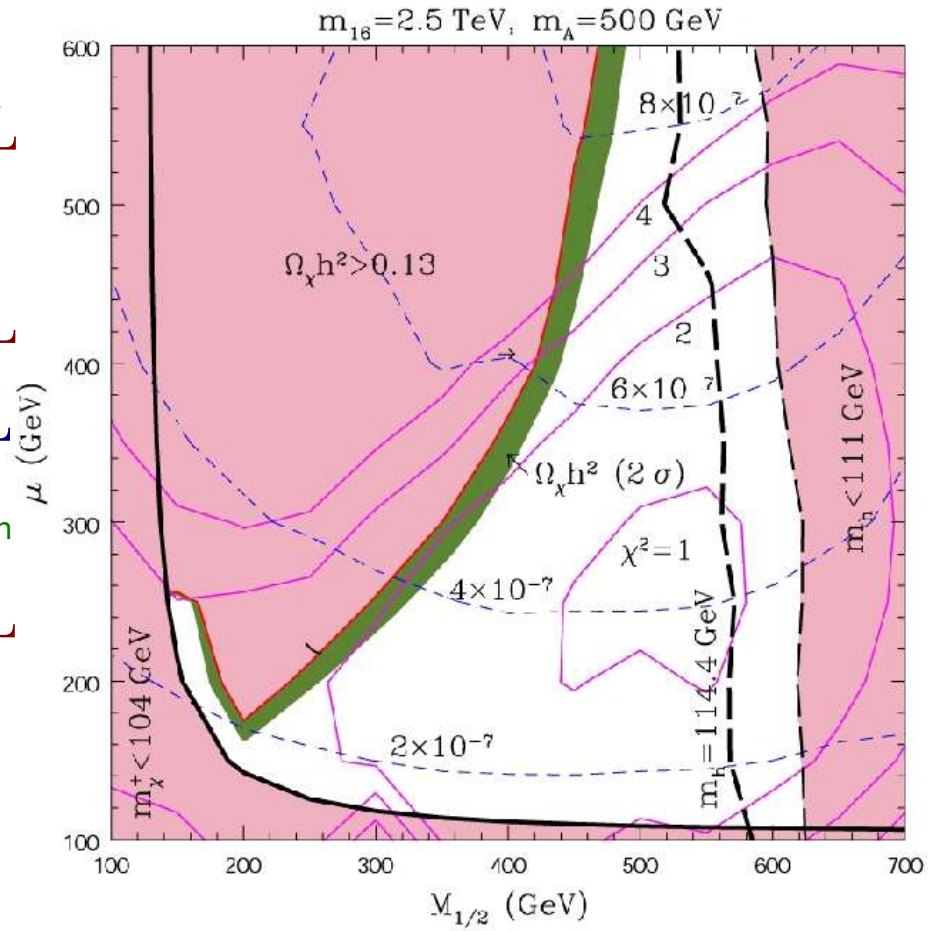
$$BF(B_s \to \mu^+\mu^-) < 2.7 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

SM predictions

$BF(B_{s(d)} \to \mu^+\mu^-)$ 3.5x10^{-9} (1.0x10^{-10})

- No sensitivity for SM decay rate

- BSM predictions Limiting many models
- Example SUSY S0(10)
  - Allows for massive neutrino
  - Accounts for relic density of cold dark matter



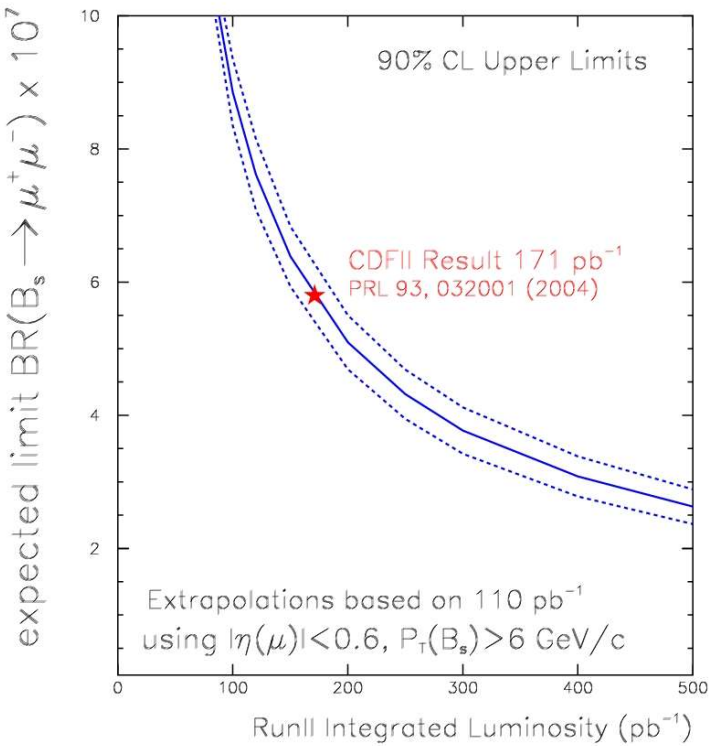
$BF\ B_s \to \mu^+\mu^-$: Dashed blue

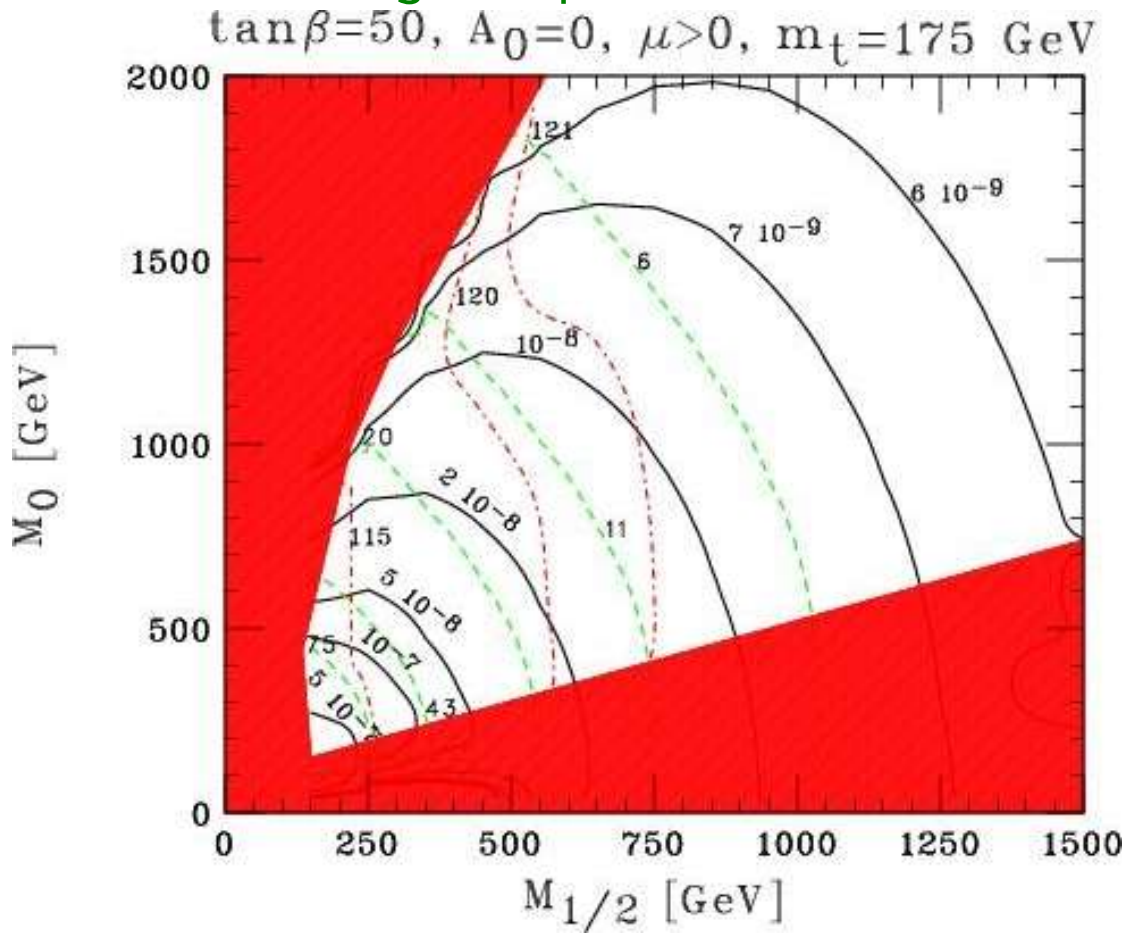
Excludes scenarios where M_A is light and tanβ ~ 50: M_A > 450GeV/c^2

R. Dermisek hep-ph/0304101,2003

$B_s \rightarrow \mu\mu$: Physics Reach

- In addition to limiting S0(10) models – starting to impact standard MSSM scenarios: mSugra
  - Solid black: $BF(B_s \rightarrow \mu^+\mu^-)$
  - Dashed green: $a_\mu = (g\text{-}2)_\mu/2$
  - Dashed red: Light Higgs Mass
  - Red areas: excluded





- Should be able to considerably increase sensitivity this year
  - Limit will start to intersect 115GeV Higgs contour

Conclusions

- Have set the worlds best limit on the decay $B_s \to \mu^+\mu^-$

D0 $B_s \to \mu^+\mu^-$ result

$$BF(B_s \to \mu^+\mu^-) < 3.8 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

CDF $B_{(s,d)} \to \mu^+\mu^-$ results

$$BF(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

Combined:

$$BF(B_s \to \mu^+\mu^-) < 2.7 \times 10^{-7}\ 90\%\ \mathrm{CL}$$

- Results on light B_d competitive with the B factories
- Limit excludes part of parameter space allowed by SO(10) models
- Will soon have sensitivity for interesting areas of mSugra parameter space
  - Tevatron experiments integrating large amounts of new data
  - New analysis techniques could improve sensitivity
  - CDF: Multivariate technique for primary analysis cuts, use of L00 with primary vertex finding, and include forward triggered muon coverage(CMX)

Backup: Limits

D0 $B_s \to \mu^+\mu^-$ result: 240pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 3.8\times10^{-7}\ 90\%\ \mathrm{CL}, \quad 4.6\times10^{-7}\ 95\%\ \mathrm{CL}$$

CDF $B_{(s,d)} \to \mu^+\mu^-$ results: 171pb^{-1}

$$BF(B_s \to \mu^+\mu^-) < 5.8\times10^{-7}\ 90\%\ \mathrm{CL}, \quad 7.5\times10^{-7}\ 95\%\ \mathrm{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 1.5\times10^{-7}\ 90\%\ \mathrm{CL}, \quad 1.9\times10^{-7}\ 95\%\ \mathrm{CL}$$

CDF $B_s \to \mu^+\mu^-$ results: using updated f_s (used by D0)

$$BF(B_s \to \mu^+\mu^-) < 5.4\times10^{-7}\ 90\%\ \mathrm{CL}, \quad 7.1\times10^{-7}\ 95\%\ \mathrm{CL}$$

Combined using updated f_s:

$$BF(B_s \to \mu^+\mu^-) < 2.7\times10^{-7}\ 90\%\ \mathrm{CL}, \quad 3.4\times10^{-7}\ 95\%\ \mathrm{CL}$$