Searches for New Physics in the Flavour Sector

- Motivation
- Tevatron Detectors: CDF and D∅
- Results
- Conclusion

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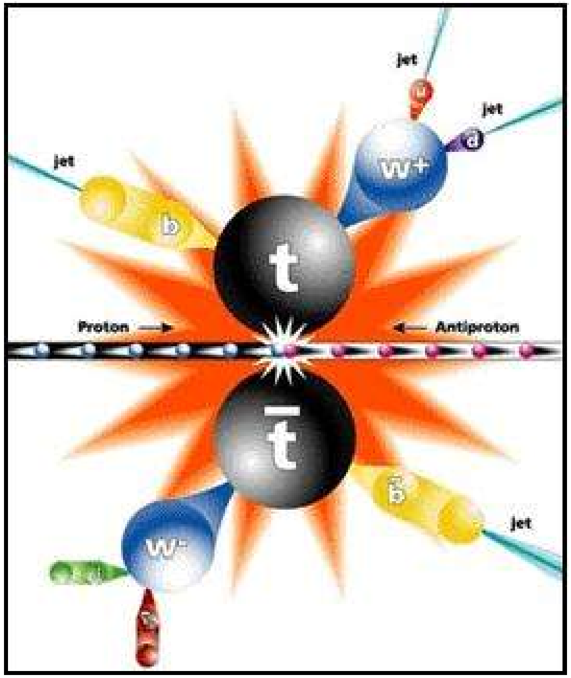
Searches For New Physics

- How do you search for new physics at a collider?
  - Direct searches for production of new particles
    - Particle-antipartical annihilation
    - Example: the top quark
  - Indirect searches for evidence of new particles
    - Within a complex decay new particles can occur virtually

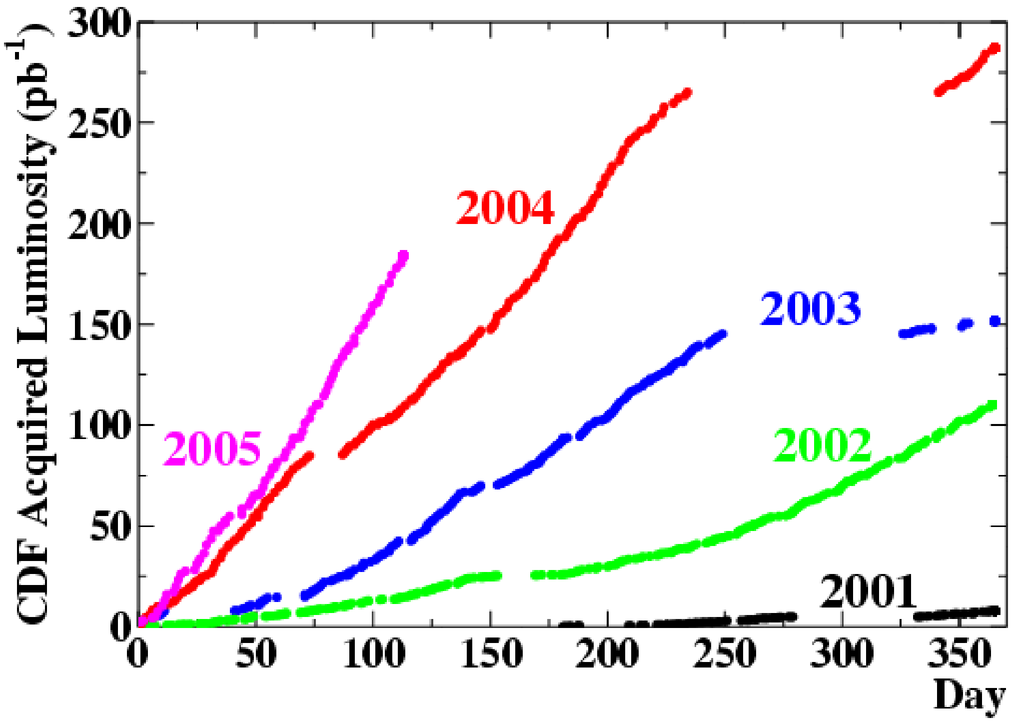


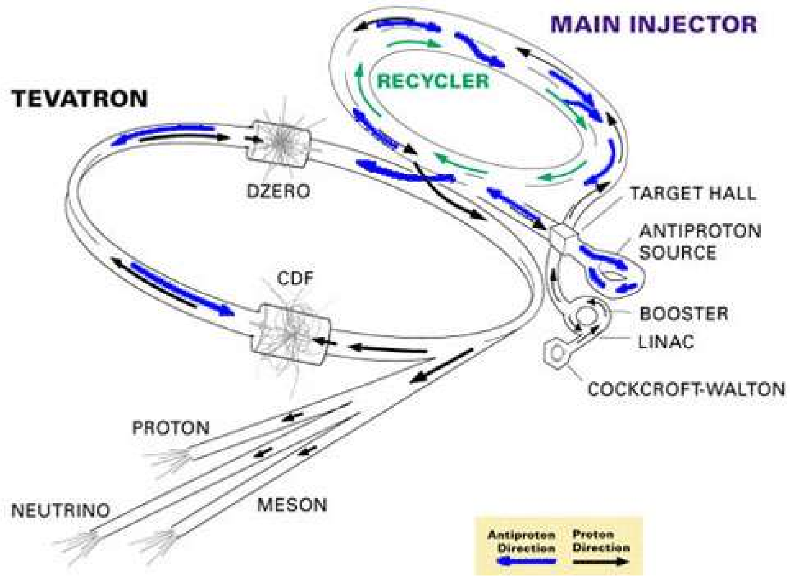
- Tevatron is at the energy frontier and a data volume frontier
  - So much data that we can look for some very unusual decays
- Where to look
  - Many weak decays of *B* hadrons are very low probability
  - Look for contributions from other low probability processes – Non Standard Model

A unique window of opportunity to find new physics before the LHC

Tevatron Performance

- 1.96TeV p$\bar{p}$ collider
  - Performance substantially improving each year
  - Record peak luminosity: $1.2 \times 10^{32} sec^{-1} cm^{-2}$
  - Expect 2x in 2005, 4-8fb^{-1} by 2009



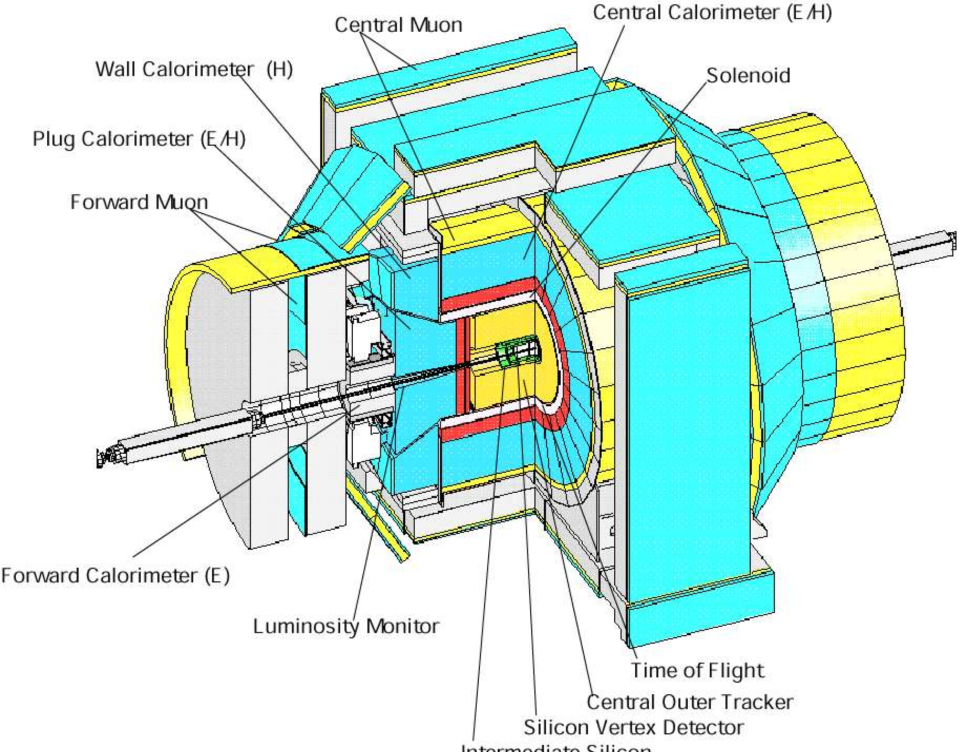


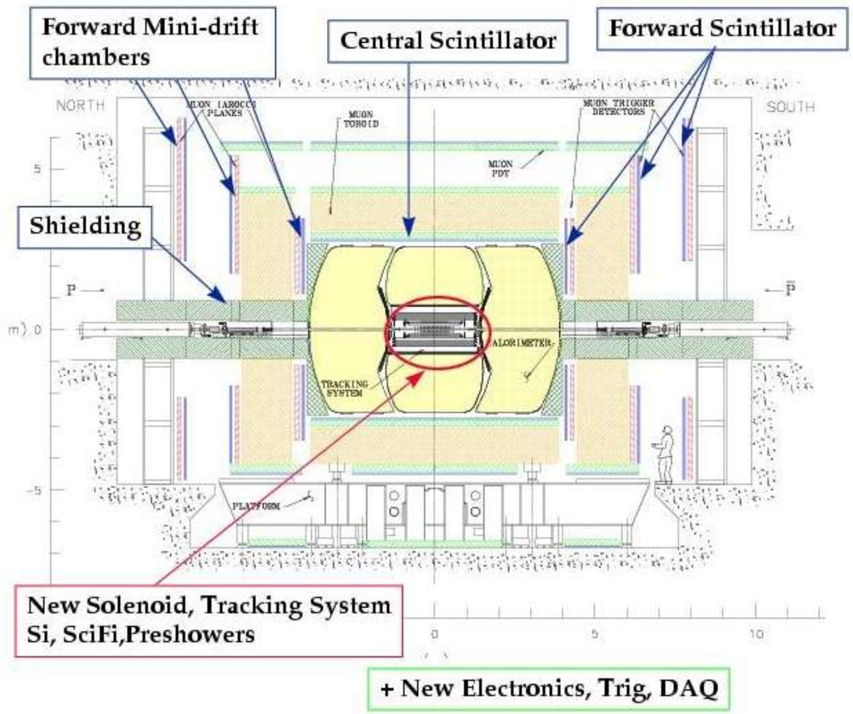
- Integrated Luminosity
  - Experiments have over 500pb^{-1} of good data
    - All critical systems operating including silicon
  - Analyses presented here use 180pb^{-1} to 450pb^{-1}

Tevatron likely to have 4x data in next 2 years

CDF & D∅ Detectors

- CDF: Silicon
  - $|\eta|<2$, 90cm long   **EXCELLENT TRACKING**
  - Silicon vertex trigger
- Drift Chamber(COT)
  - 96 layers between 44 and 132cm
- Triggered muon coverage $|\eta|<1.0$



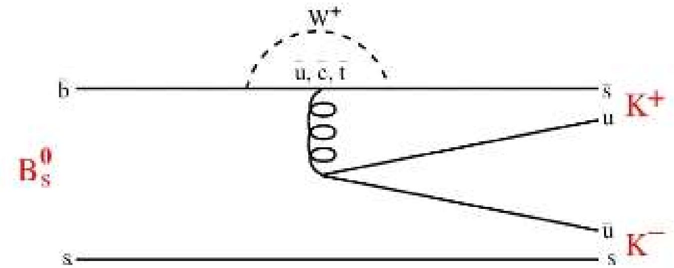


- D∅ Tracker
  - Scintillating fiber tracker and silicon
  - Triggered tracking to $|\eta|<2$
- Triggered muon coverage $|\eta|<2$

EXCELLENT MUON SYSTEM

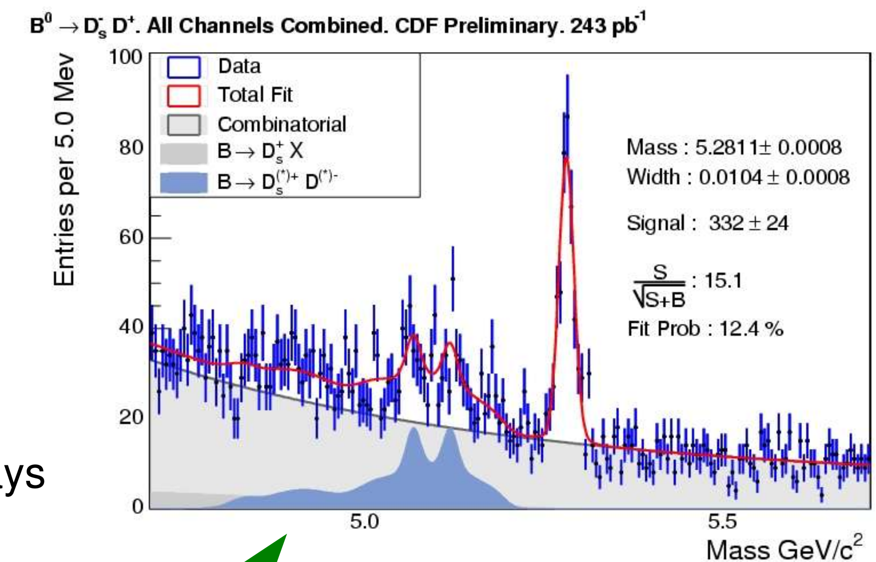
New Physics in $\Delta\Gamma_{Bs}$

- $\Delta\Gamma_{Bs}$: Width-lifetime difference for light/heavy eigenstate decays
- New physics contributions in penguin diagrams



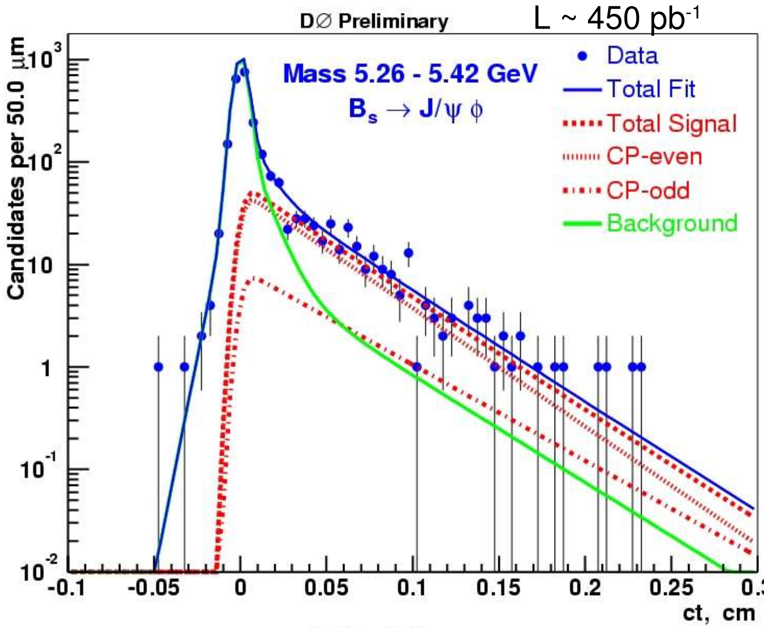
$$\Delta\Gamma_{B_s}^{(meas)} = \Delta\Gamma_{B_s}^{(CPcons)} \cos\left(\phi^{(SM)} + \phi^{(new\ physics)}\right)$$

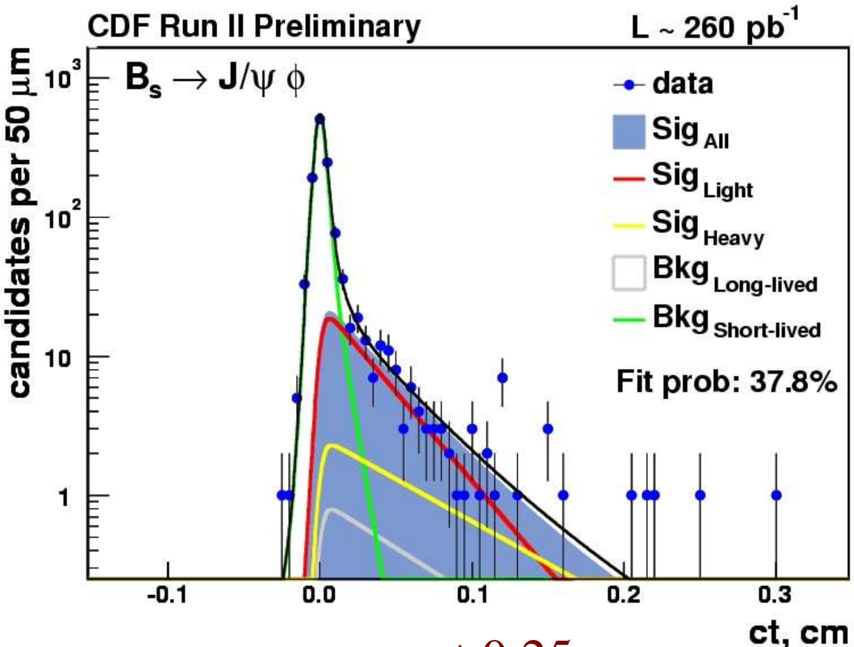
- Measurement possibilities
  - Directly measure two lifetimes in $B_s \to J/\psi\phi$
    - Lifetime and angular analysis
  - Measure lifetime in $B_s \to KK$
    - 97% CP even(short component)
    - In progress: disentangle $B_{(s,d)} \to hh$ decays
  - Measure the branching ratio of $B_s \to D_s D_s$
    - Pure CP even state
    - May account for most of the width difference
    - Observed first double charm decay in $B \to DD_s$

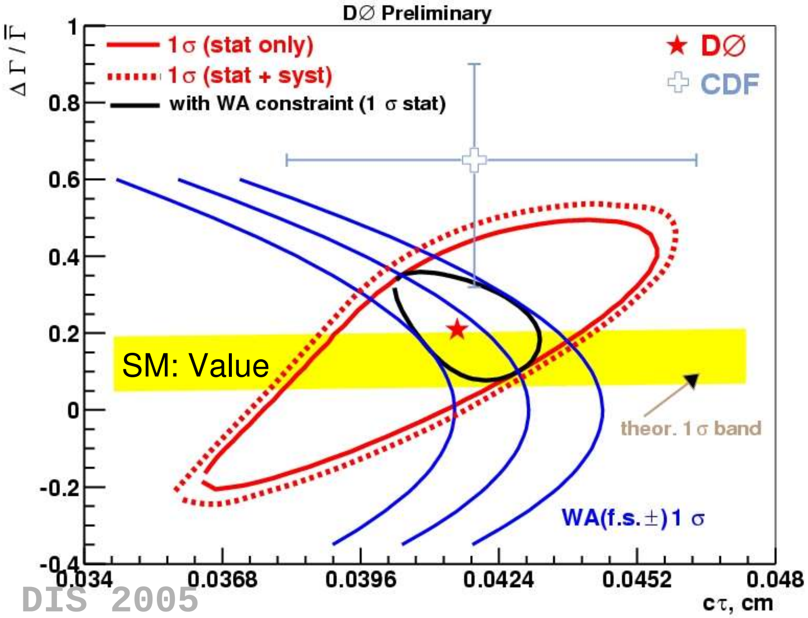


Many orthogonal methods to probe $\Delta\Gamma_{Bs}$

$\Delta\Gamma_{Bs}$ Results







$$\Delta\Gamma_{B_s}/\Gamma_{B_s} = 0.65^{+0.25}_{-0.33} \pm 0.01$$

CDF PRL 94 101803(2005)

$$\Delta\Gamma_{B_s}/\Gamma_{B_s} = 0.21^{+0.33}_{-0.45}(stat+sys)$$

D0 conf note 4557

SM: 0.12

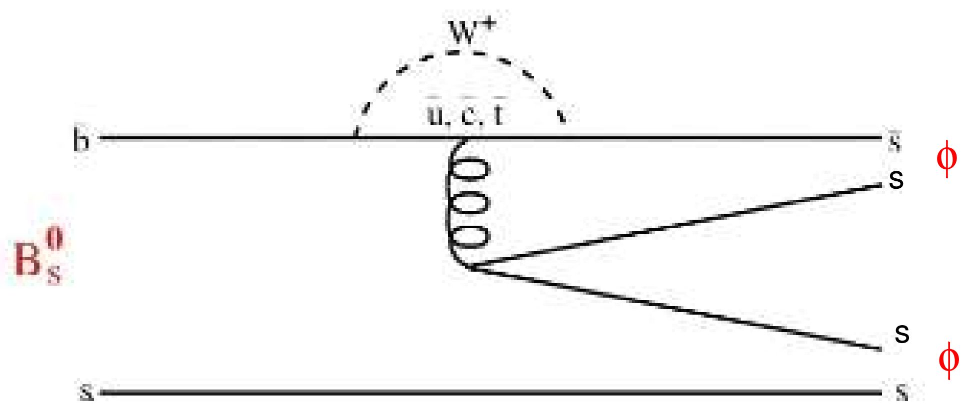
A. Lenz
hep-ex/0412007

New physics expectation was a lower value!

New Physics: Charmless B Decays

- CP Asymmetries: A_{CP}
  - Simplest case: A_{CP} in decay(Direct A_{CP}): difference in the decay rates of the CP eigenstates
  - Eigenstate decays identified by decay products or angular distributions
  - Can also occur in neutral meson decays with mixing

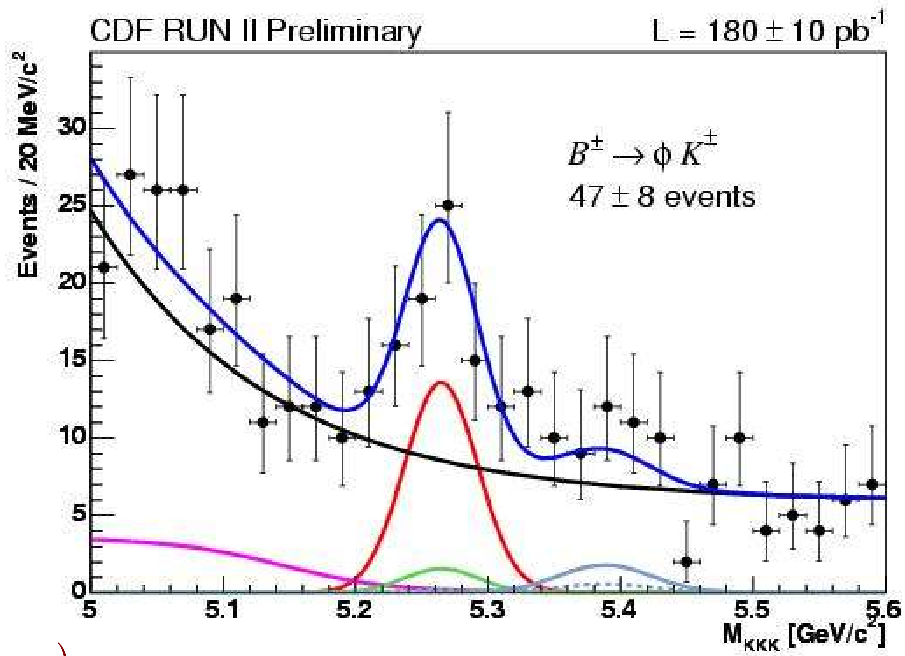
- Many charmless B decay modes are sensitive to A_{CP}
  - $B^+ \to \phi K^+$
    - SM A_{CP} rate expected to be small: Probe of new physics
  - $B_s \to \phi\phi$: Mixing and direct A_{cp}
    - Pure $b \to s$ penguin transition
    - BaBar/Belle: 3.7σ sin2β discrepancy penguin vs. charmonium decays
    - Vector Vector decay never observed before
  - $B_{s,d} \to hh$ $(h = K,\pi)$: $\bar{B}_d \to \pi^- K^+$ vs. $B_d \to \pi^+ K^-$



$B^+ \to \phi K^+$ Results

$$B^+ \to \phi K^+, \phi \to K^+ K^-$$

- Analysis Cuts
  - Momentum, lifetime and vertex cuts
  - $p_{TB} > 4.0$, $|d_{0B}|<100$ m, $L_{xy} > 350\mu m$
  - Results from likelihood fit to masses, dE/dx and helicity



- Results:

$$A_{CP}(B^+ \to \phi K^+) = -0.07 \pm 0.17(stat)^{+0.03}_{-0.02}(sys)$$

hep-ex/0502044

Babar result: $A_{CP} = 0.054 \pm 0.056(stat) \pm 0.012(sys)$

hep-ex/0408072

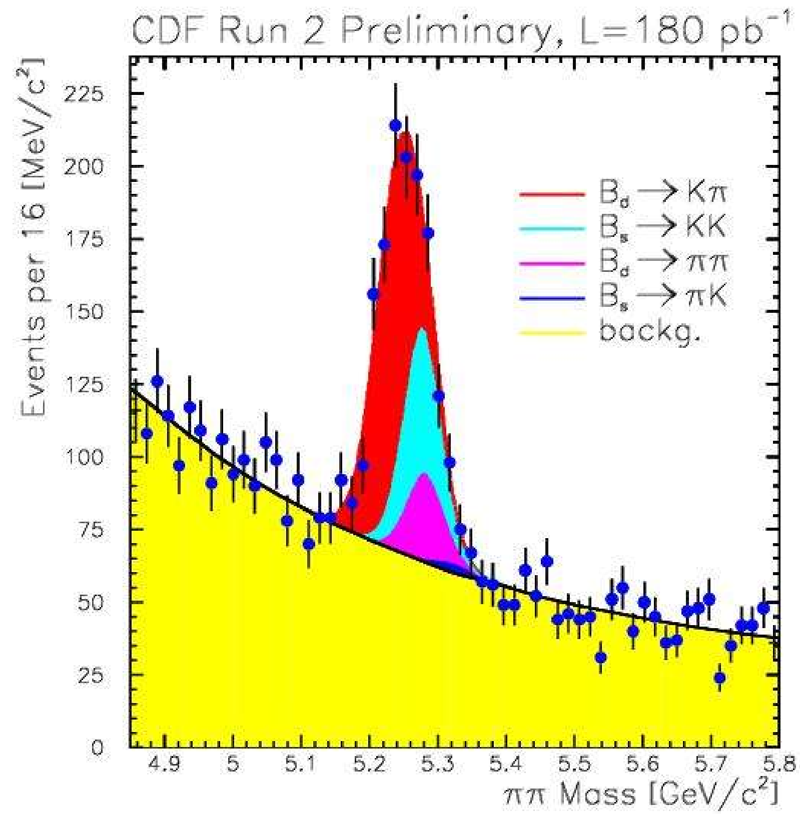
$$BF(B^+ \to \phi K^+) = (7.6 \pm 1.3(stat) \pm 0.6(sys)) \times 10^{-6}$$

HFAG: $(9.0 \pm 0.7) \times 10^{-6}$

- Signal
- Backgrounds
  - Combinatorial
  - Partially reconstructed *B* decays
  - $B \to f_0 K$
  - $B \to K^{*0}\pi$, $K\pi\pi$ (Cyan)

$B_{s,d} \to hh$ Results

- $B_{s,d} \to hh$ ($h = K,\pi$)
- Analysis Cuts
  - $\Sigma p_{T\pi} > 4.0$, $|d_{0B}|<80$ m, $L_{xy} > 300\mu m$
- Unbinned likelihood fit
  - $M_{\pi\pi}$, dE/dx, charge-momentum imbalance
  - Excellent mass resolution and high statistics samples for dE/dx calibration allow for small systematic errors



$$\frac{f_s \cdot BF(B_s \to K^{\pm} K^{\mp})}{f_d \cdot BF(B^0 \to K^{\pm} \pi^{\mp})} = 0.50 \pm 0.08(stat) \pm 0.09(sys)$$

$$A_{CP}(B^0 \to K^{\pm} \pi^{\mp}) = -0.04 \pm 0.08(stat) \pm 0.006(sys)$$

B^0	$\pi\pi$	134	15%
B^0	$K\pi$	509	57%
B_s	**KK**	**232**	**26%**
B_s	$K\pi$	18	2%

Babar result: 4.2σ

$$A_{CP} = -0.133 \pm 0.030(stat) \pm 0.009(sys)$$

hep-ex/0407057

Belle result: 3.9σ

$$A_{CP} = -0.101 \pm 0.025(stat) \pm 0.005(sys)$$

hep-ex/0408100

$B_s \rightarrow \phi\phi$ Results

$B_s \rightarrow \phi\,\phi\,,\ \phi \rightarrow K^+ K^-$

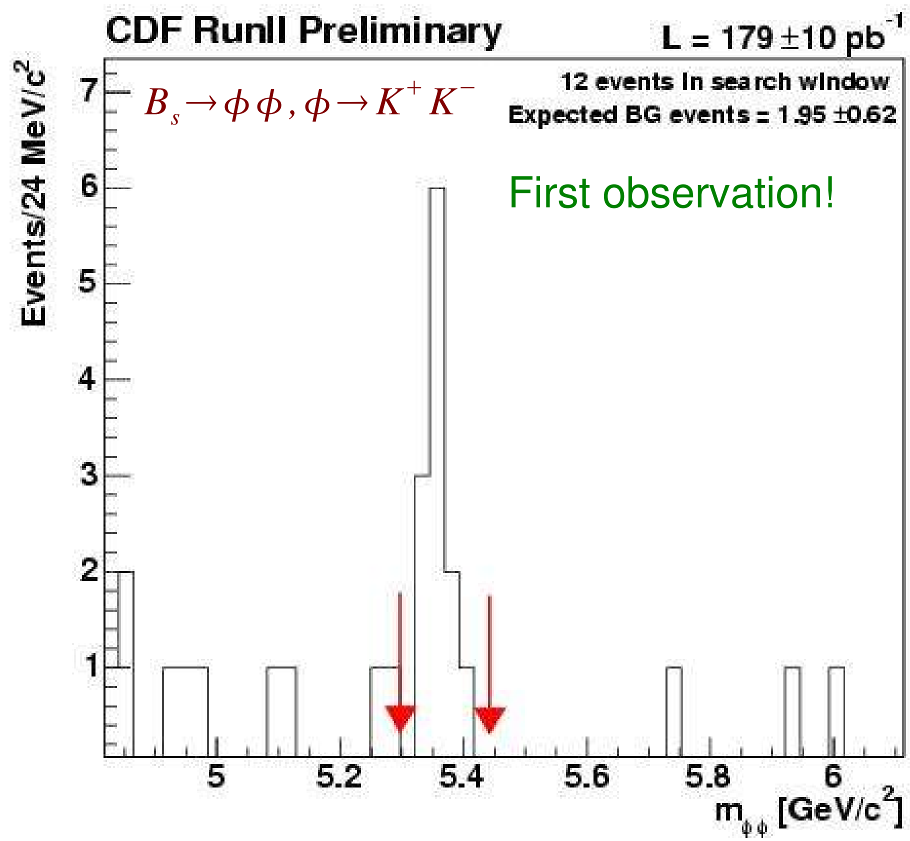
- Analysis Cuts
  - p_T > 2.5GeV/c, $|d_{0B}|$<80 m, L_{xy} > 350 m

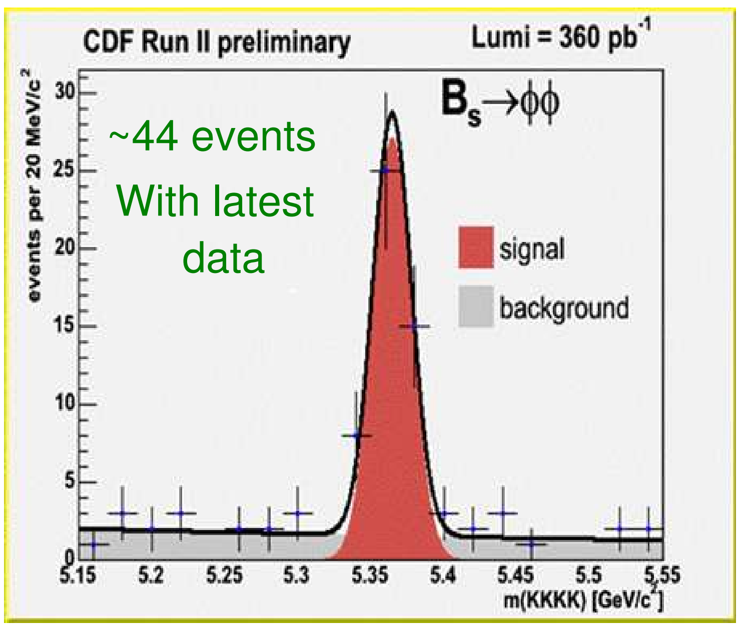
$$BF(B_s \rightarrow \phi\,\phi) =$$

$$1.4 \pm 0.6(stat) \pm 0.2(sys) \pm 0.5(norm) \times 10^{-5}$$

Th: $(1.79 - 3.68) \times 10^{-5}$

hep-ph/0309136, Li, Lu and Yang



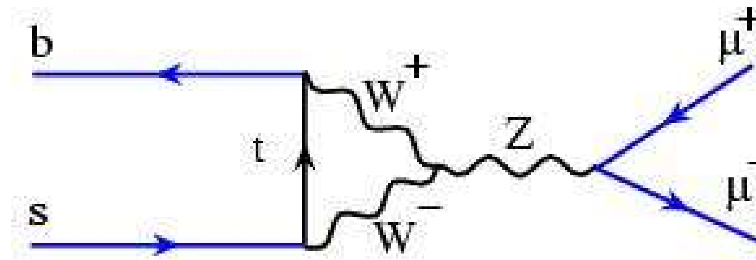


~4x as many events in 360pb^{-1}
polarization analysis in progress

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

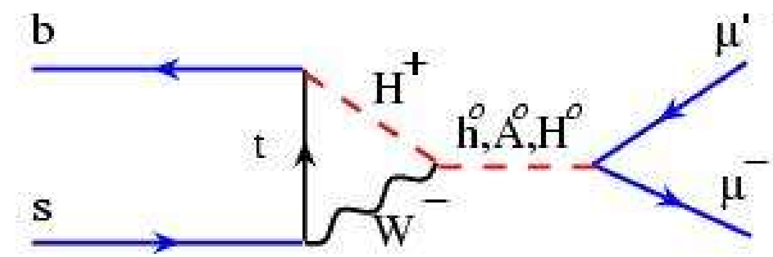
- Look at decays that are suppressed in the Standard Model: $B_{s(d)} \to \mu^+\mu^-$
  - Flavor changing neutral currents(FCNC) to leptons
    - No tree level decay in SM
    - Loop level transitions: suppressed
    - CKM , GIM and helicity(m_l/m_b): suppressed
    - SM: $BF(B_{s(d)} \to \mu^+\mu^-)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

G. Buchalla, A. Buras, Nucl. Phys. B398,285

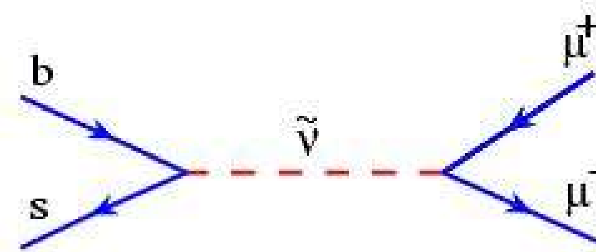


- New physics possibilities
  - Loop: MSSM: mSugra, Higgs Doublet
    - 3 orders of magnitude enhancement
    - Rate $\propto \tan^6\beta/(M_A)^4$

Babu and Kolda, Phys. Rev. Lett. 84, 228

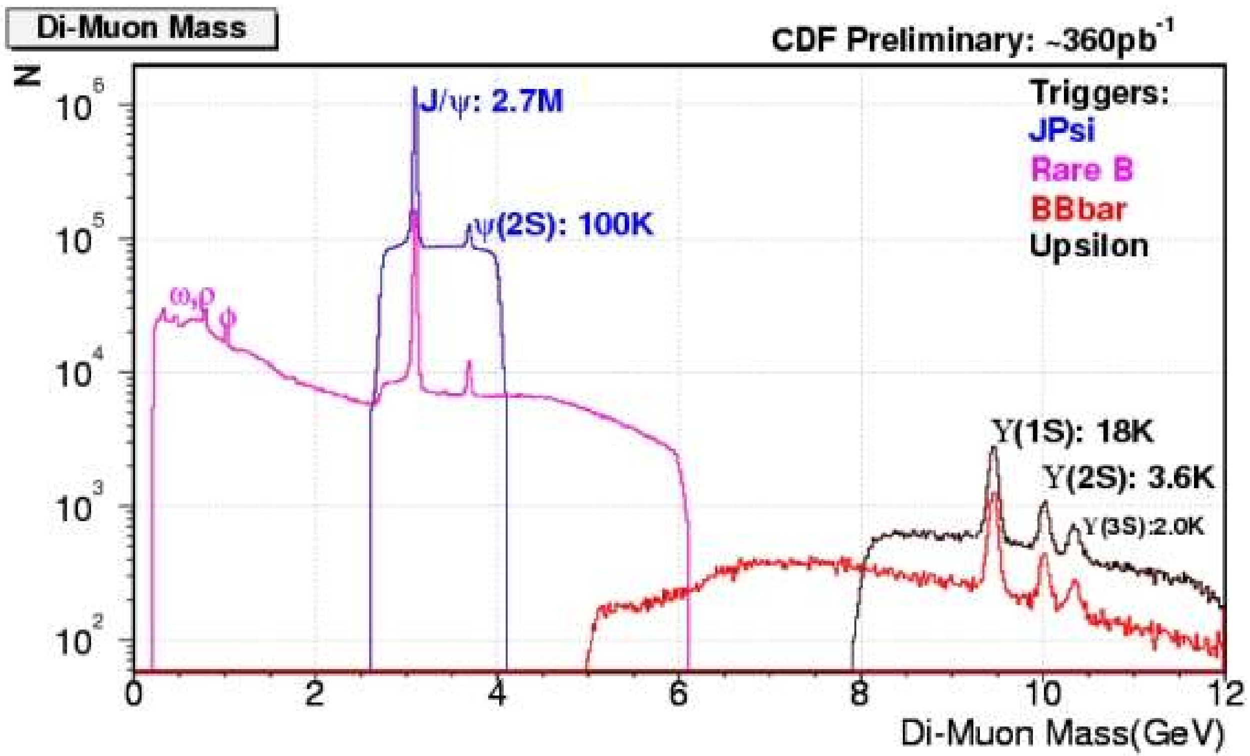


  - Tree: R-Parity violating SUSY



One of the best indirect search channels at the Tevatron

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



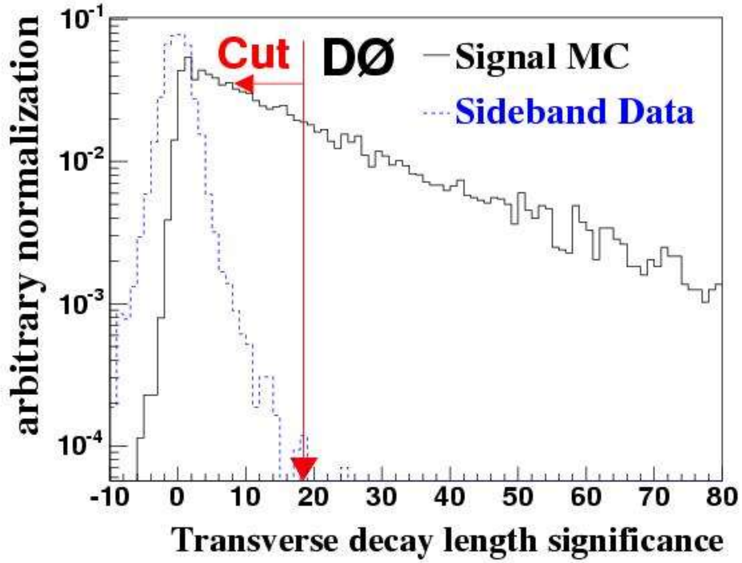
- Primary problem is large background at hadron colliders
  - Analysis and trigger cuts must effectively reduce the large background around $m_{Bs} = 5.37 GeV/c^2$ to find a possible handful of events
- BR 1000x SM rate results in ~200 events

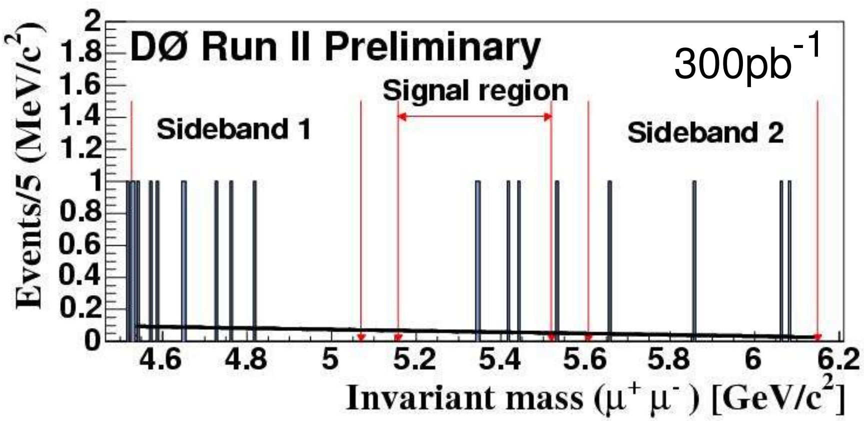
D0 Analysis and Results

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

$$BF(B_s \rightarrow \mu^+\mu^-) < 3.7\times10^{-7}\ 95\%\ \text{CL}$$

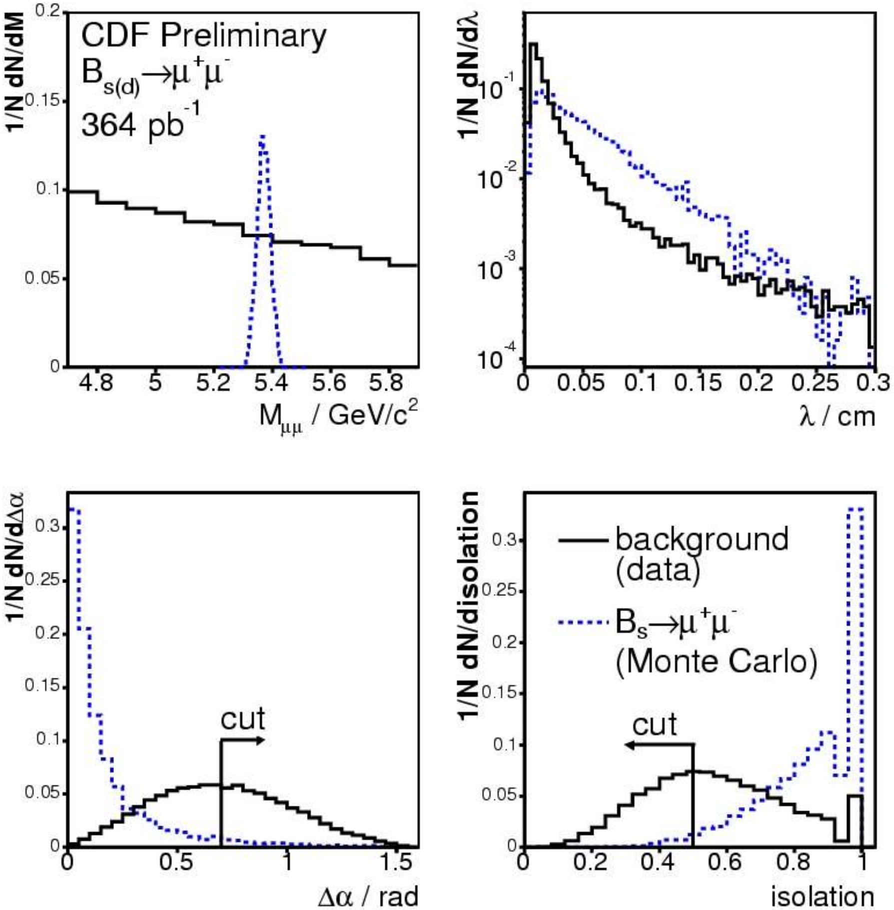
D0 Conference Note 4733, 300pb^{-1}





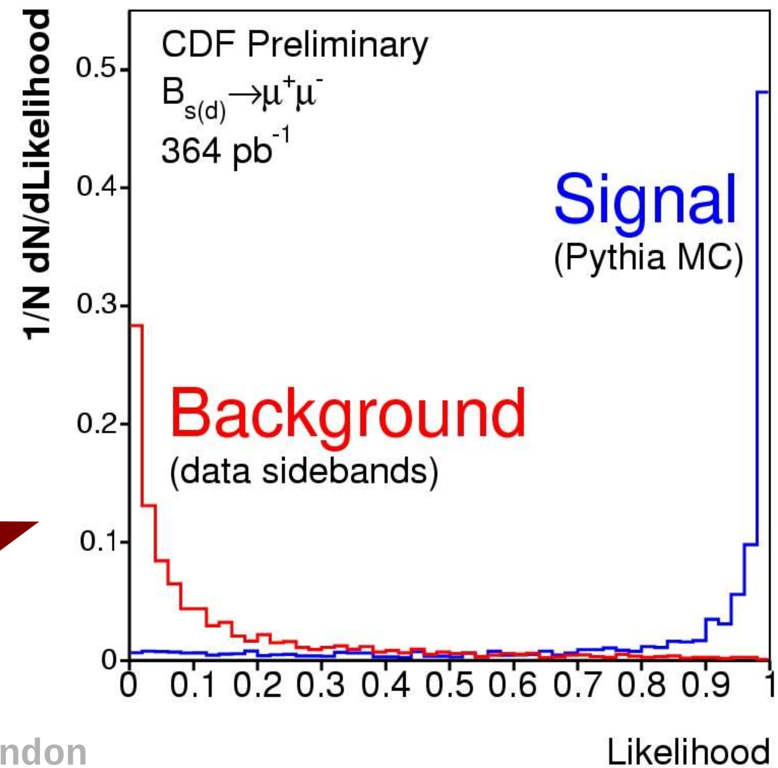
Expected background: 4.3 ± 1.2
Observe 4

CDF Discriminating Variables



- Mass $M_{\mu\mu}$: 2.5σ window: σ = 25MeV/c^2
- $\lambda = \exp(c\tau / c\tau_{Bs})$
- $\Delta\Phi$: $|\phi_B - \phi_{vtx}|$ in 3D
- Isolation: $p_{TB}/(\Sigma trk + p_{TB})$
- Use selection variables in likelihood ratio

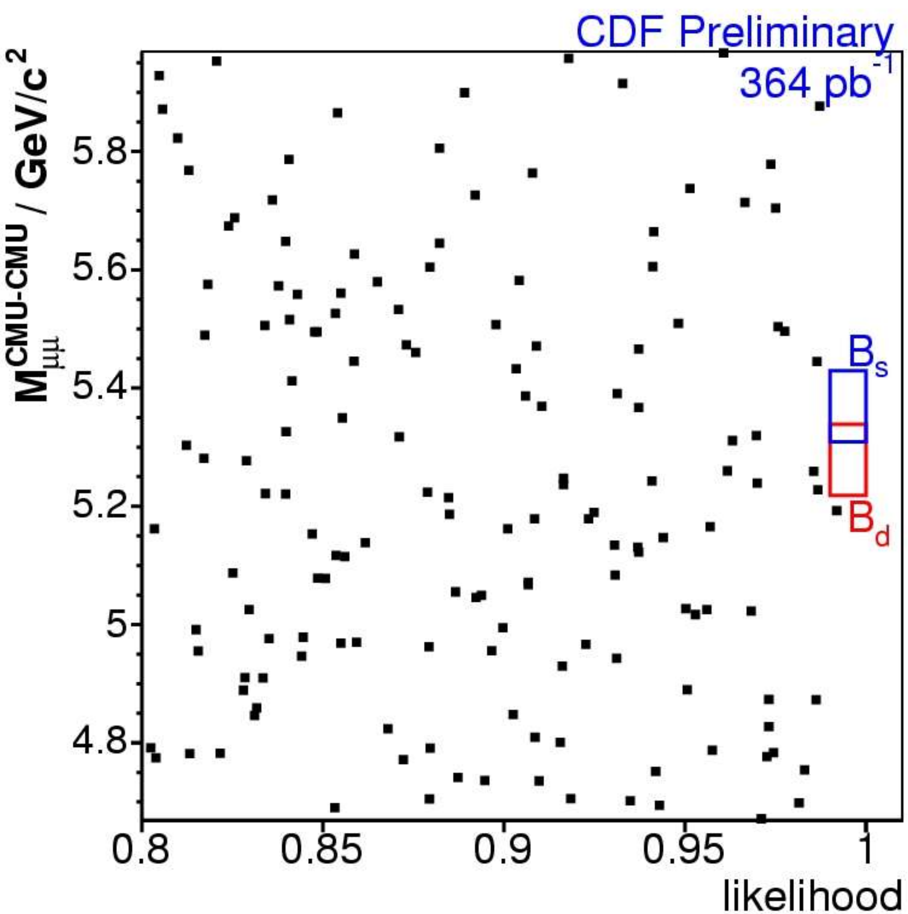
$$LH = \frac{\Pi_i P_s(x_i)}{\Pi_i P_s(x_i) + \Pi_i P_b(x_i)}$$



CDF $B_{s(d)} \to \mu\mu$ Results

- CDF $B_{s(d)} \to \mu^+\mu^-$ results
  - LH > 0.99
  - Expected backgrounds
    $B_{s(d)}$: 1.47 ± 0.18
  - Observe 0 events

World's best limits!



$$BF(B_s \to \mu^+\mu^-) < 2.0\times10^{-7}\ 95\%\ \mathrm{CL}$$

$$BF(B_d \to \mu^+\mu^-) < 4.9\times10^{-8}\ 95\%\ \mathrm{CL}$$

$$BF(B_s \to \mu^+\mu^-) < 3.7\times10^{-7}\ 95\%\ \mathrm{CI}$$

DØ Conf Note 4733, 300pb^{-1}

$$BF(B_d \to \mu^+\mu^-) < 8.3\times10^{-8}\ 90\%\ \mathrm{CL}$$

$$\mathrm{CDF:}\ < 3.8\times10^{-8}\ 90\%\ \mathrm{CL}$$

BaBar hep-ex/0408096, 111fb^{-1}

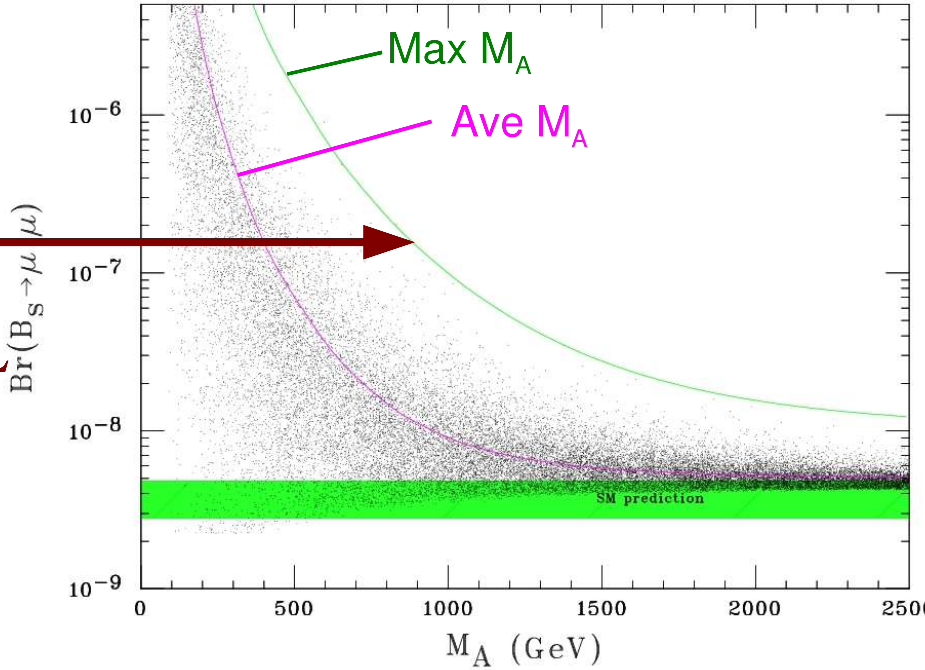
$B_s \rightarrow \mu\mu$: MSSM

- Combined $B_s \rightarrow \mu^+\mu^-$ result:

  Bayesian approach with a flat prior.
  Systematic errors on fs and
  BF($B^+ \rightarrow J/\psi K^+$) correlated.

$$BF(B_s \rightarrow \mu^+\mu^-) < 1.6\times10^{-7}\ 95\%\ \mathrm{CL}$$

- SM Prediction
  - SM: $BF(B_s \rightarrow \mu^+\mu^-) = 3.5\mathrm{x}10^{-9}$
  - No sensitivity for SM rate



Dedes, Huffman hep-ph/0407285,2004

- No strong SUSY:MSSM limits from $B_s \rightarrow \mu^+\mu^-$
  - Too many MSSM parameters
  - If $B_{s(d)} \rightarrow \mu^+\mu^-$ observed: M_A < 800GeV
  - $\tan\beta = 50$

Does limit specific SUSY models

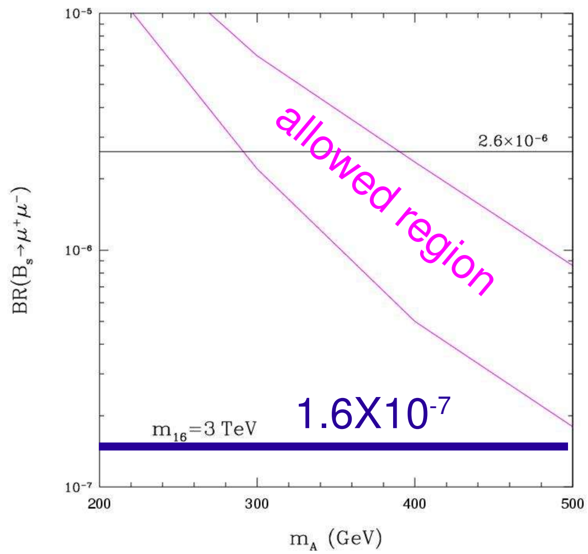
$B_s \to \mu\mu$: SUSY SO(10)

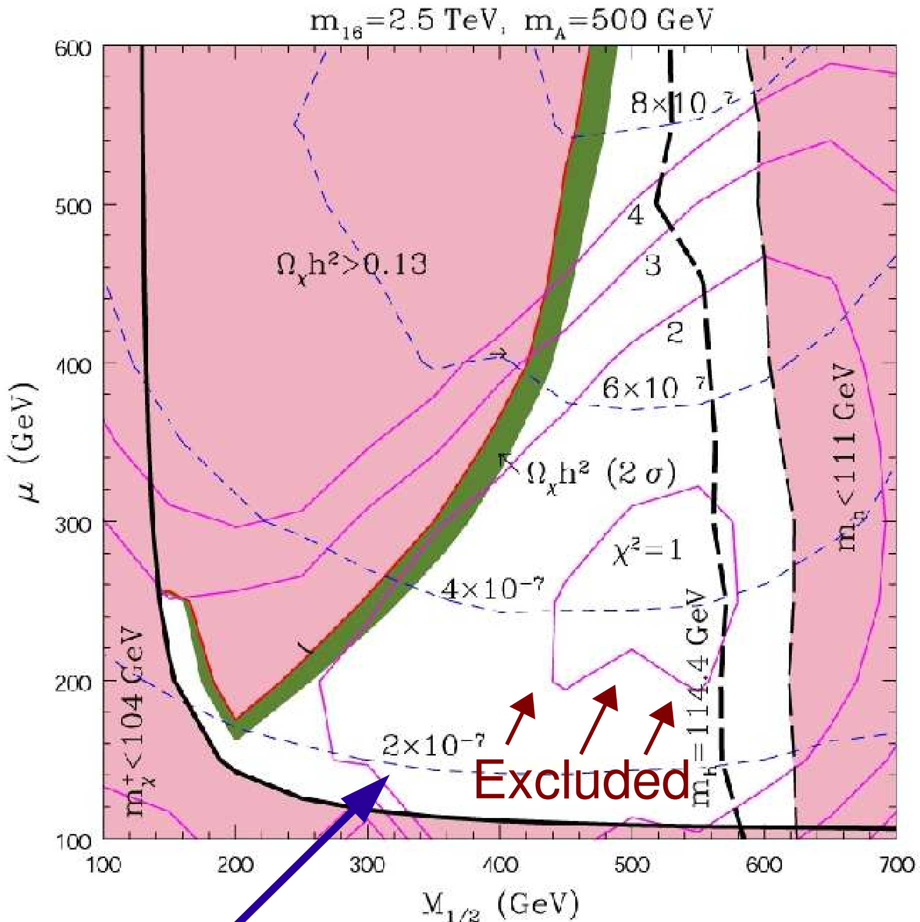
- Combined CDF/D∅ $B_s \to \mu^+\mu^-$ result:

$$BF(B_s \to \mu^+\mu^-) < 1.6\times10^{-7}\ 95\%\ \mathrm{CL}$$

- Can limit specific models
- Example SUSY SO(10)
  - Allows for massive neutrino
  - Relic density of cold dark matter

Dermisek, Raby, Roszkowski, Ruiz de Austri hep-ph/0304101 2003





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

Excludes scenarios where m_A is light and tanβ ~ 50: m_A > 500GeV/c^2

Conclusions

- Many posibilities to observe new physics in the flavour sector
- B_s part of the flavour sector particularly interesting at the Tevatron
- CDF observes a high $\Delta\Gamma_{Bs}$: 2σ
  DØ value is high/compatible with SM

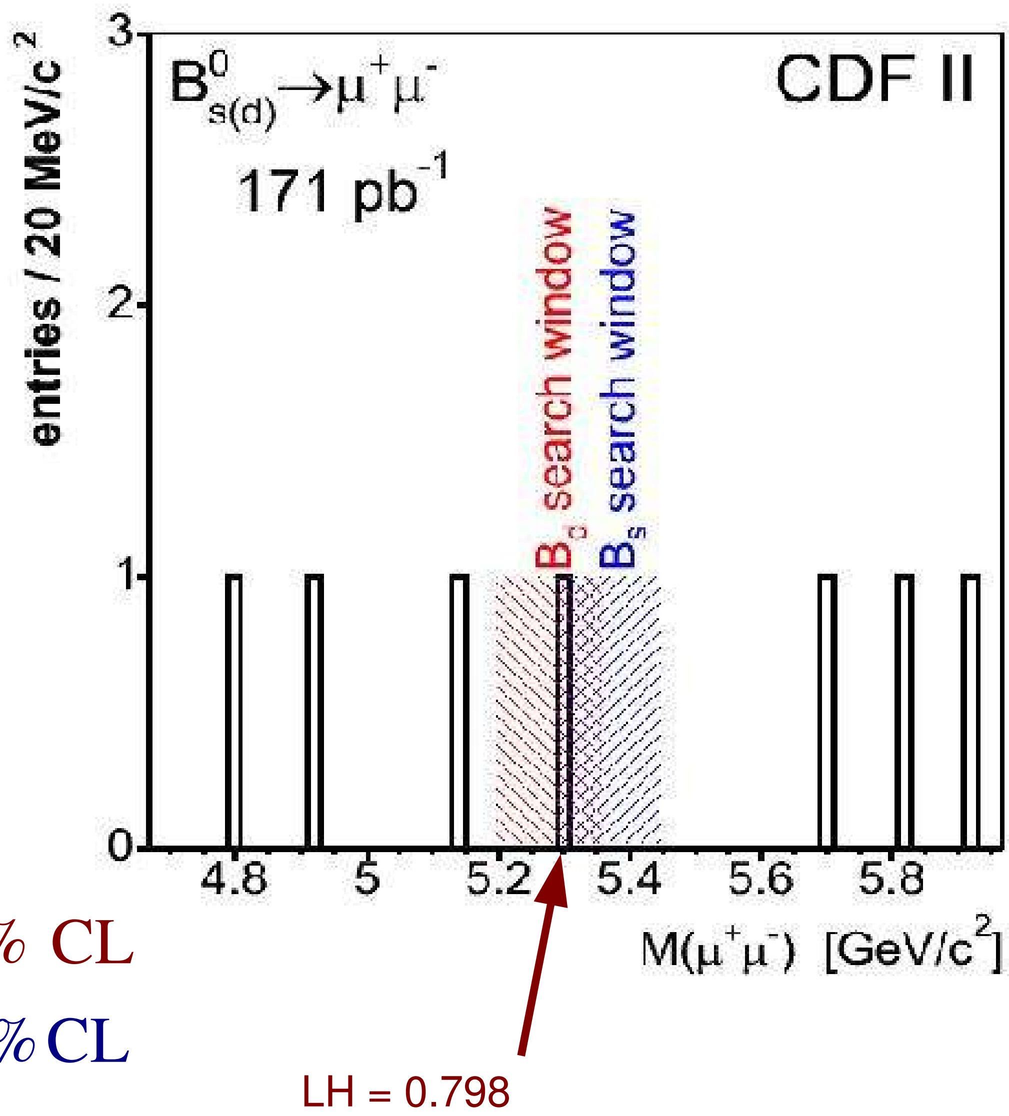
$$\text{CDF: } \Delta\Gamma_{B_s}/\Gamma_{B_s} = 0.71^{+0.24}_{-0.28} \pm 0.01$$
$$\text{D0: } \Delta\Gamma_{B_s}/\Gamma_{B_s} = 0.21^{+0.33}_{-0.45}$$

  - New physics would typically give a low value of $\Delta\Gamma_{Bs}$
  - Lifetimes in $B_s \to KK$ and $BR(B_s \to D_s D_s)$ next
- CDF has measured A_{cp} in several B modes
  - Systematic errors small - Data set now 4x used for original measuments. Should be competative with B factories and have B_s measurements soon
- CDF/DØ have improved $B_{s(d)} \to \mu^+\mu^-$ limits
  - Combined $B_s \to \mu^+\mu^-$ limit strongly restiricts the phase space of some new physics models
  - CDF $B_d \to \mu^+\mu^-$ result 2x lower than Babar limit

$$\text{CDF/D0: } BF(B_s \to \mu^+\mu^-) < 1.6\times10^{-7}\ 95\%\ \text{CL}$$
$$\text{CDF: } BF(B_d \to \mu^+\mu^-) < 4.9\times10^{-8}\ 95\%\ \text{CL}$$

$B_{s(d)} \to \mu\mu$ Results

- CDF $B_{s(d)} \to \mu^+\mu^-$ results
- $\alpha \times \varepsilon = 2.03 \pm 0.21\%$
  - Expected background $B_{s(d)}$: $1.05 \pm 0.30 (1.07 \pm 0.31)$
  - Expected limit: 5.9×10^{-7}
  - Observe 1 common event in the 3σ $B_{s(d)}$ mass windows



World's best limits(early 2004)

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

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

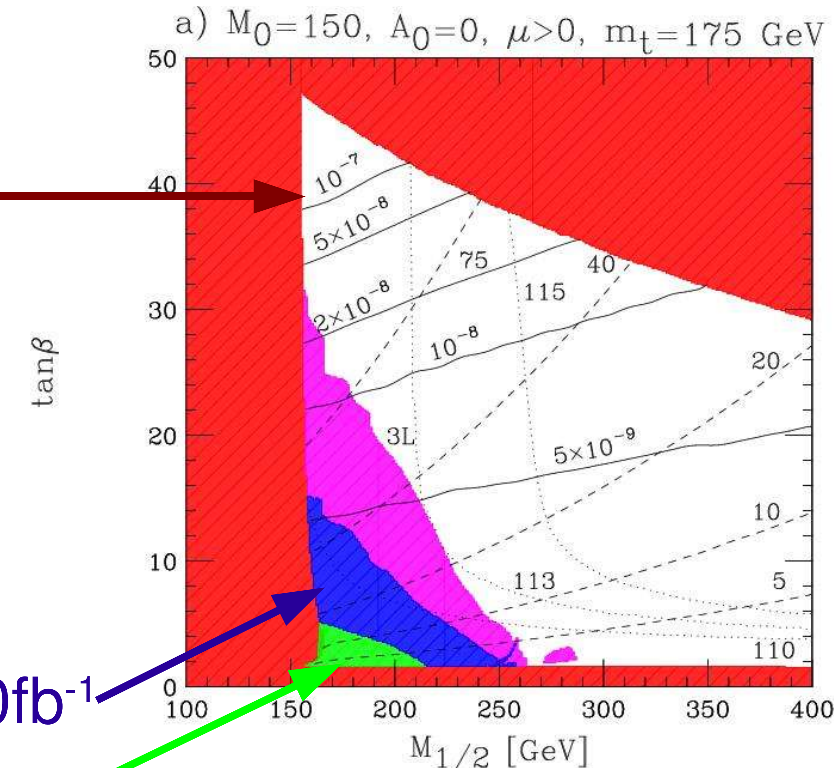
D. Acosta et al., PRL 93, 032001 2004

Physics Reach mSugra

- Combined CDF/D0 $B_s \to \mu^+\mu^-$ result:

$$BF(B_s \to \mu^+\mu^-) < 1.6\times10^{-7}\ 95\%\ \mathrm{CL}$$

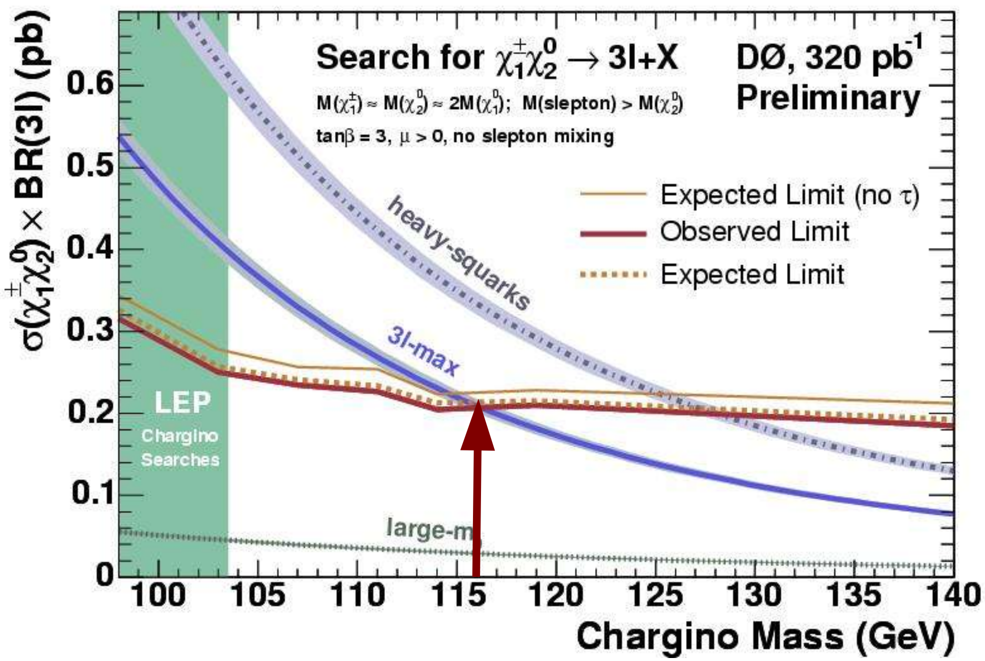
- D0 Chargino mass limit at 116GeV
- $M_{1/2}$ > 145GeV: ($M_{1/2}$~1.25M_{+})



10fb^{-1}

2fb^{-1}

Dedes, Dreiner, Nierste, Richardson
hep-ph/0207026,2002



- $B_s \to \mu^+\mu^-$ and Trilepton results:
  - Starting to limit mSugra in top left corner: bottom left soon