Search for $B_s \rightarrow \mu^+\mu^-$

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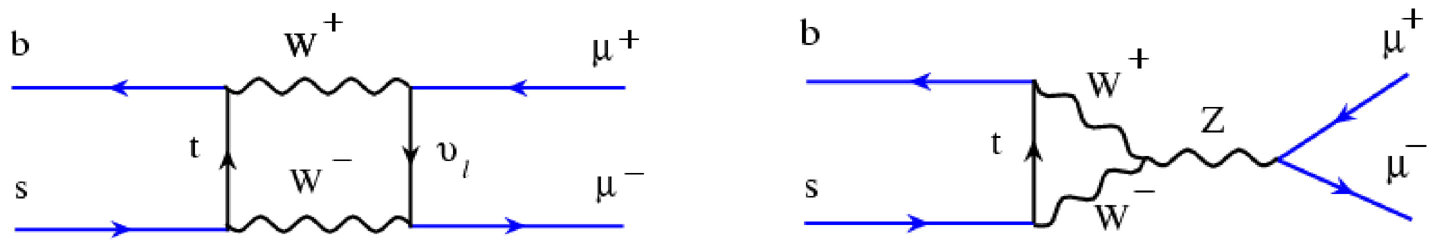
Outline

- Overall motivations
- $B_{d,s} \rightarrow \mu^+\mu^-$ Search strategy at CDF and D0
- Impact of current results on some SUSY models
- CDF+D0 projection
- Some thoughts on LHC

Introduction

- In the Standard Model, the FCNC decay of B →$\mu^+\mu^-$ is heavily suppressed



SM prediction → $BR(B_s \rightarrow \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$

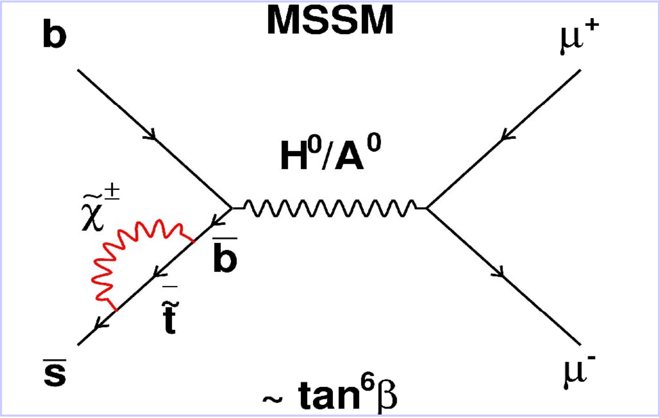
(Buchalla & Buras, Misiak & Urban)

- SM prediction is below the sensitivity of current experiments (CDF+D0): SM → Expect to see 0 events at the Tevatron

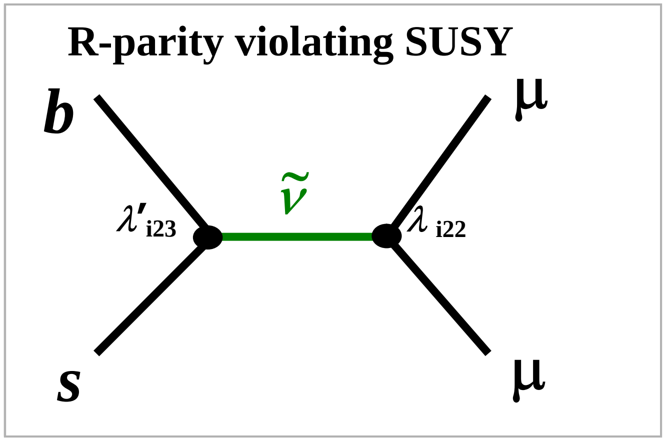
Any signal would indicate new physics!!

BEYOND STANDARD MODEL

- In many SUSY models, the BR could be enhanced by many orders of magnitude:



- For examples:
  - MSSM: Br(B→μμ) is proportional to $\tan^6\beta$. BR could be as large as ~100 times the SM prediction
  - Tree level diagram is allowed in R-parity violating (RPV) SUSY models. Possible to observe decay even for low value of tanβ.



- In context of mSUGRA, Br(B→μμ) search complements direct SUSY searches: (A. Dedes et al, hep-ph/0207026)

  Low tan(β) → observation of trilepton events

  Large tan(β) → observation of Br(B→μμ)

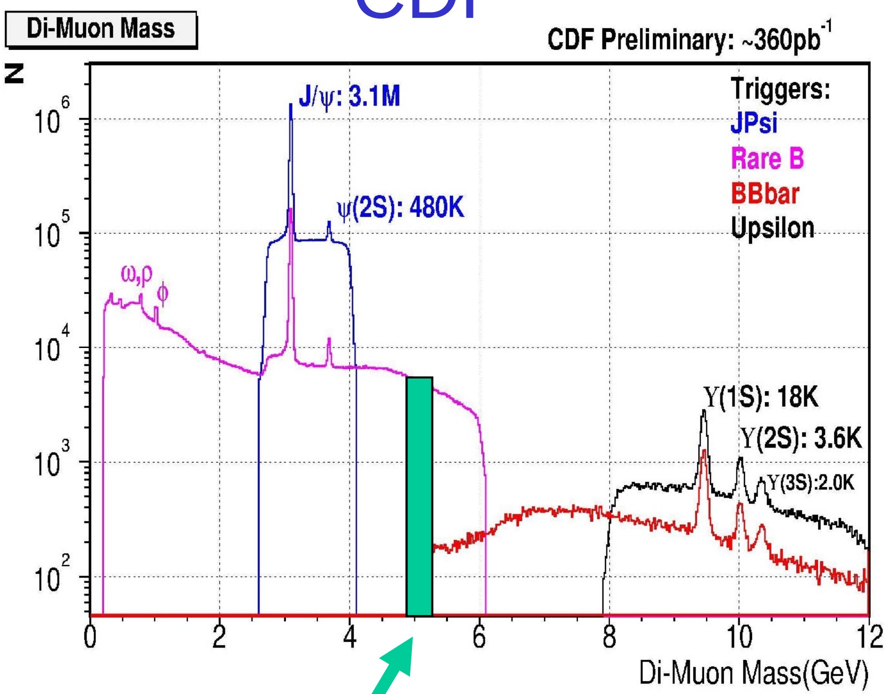
Data Sample

- Both CDF (~360pb^{-1}) and D0 (~300pb^{-1}) use di-muon trigger sample for the search

  Trigger is a vital part of this analysis

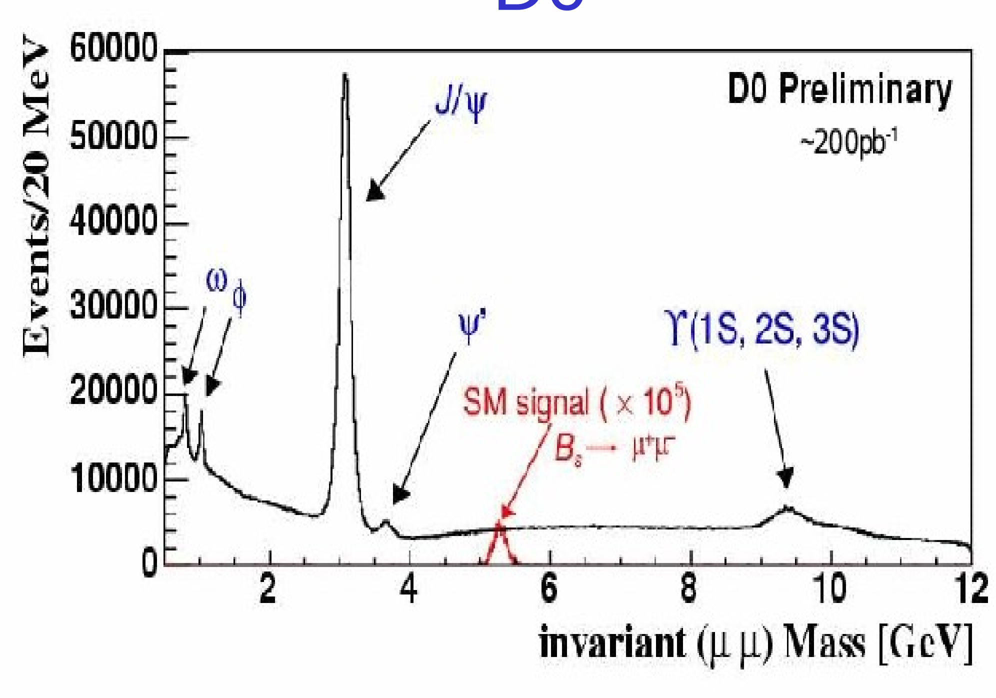
- Combinatorial background from the raw sample is enormous

CDF



Search region

D0



Ingredients of the Analysis

Overall picture:

- Reconstructing di-muon events in the B mass window
- Measure the branching ratio or set a limit

  Normalized to B→J/ψ K decays

$$BR(B_s \to \mu^+\mu^-) = \frac{N_{Bs}}{\alpha_{Bs}\cdot\varepsilon_{Bs}^{total}}\frac{\alpha_{B+}\cdot\varepsilon_{B+}^{total}}{N_{B+}}\frac{f_u}{f_s}BR(B^+ \to \psi K^+)BR(\psi \to \mu^+\mu^-)$$

Key elements in the analysis:

- Construct discriminant to select B_s signal and suppress bkg
  - CDF → Likelihood ratio discriminant
  - D0 → Cut based analysis
- understanding the background
- accurately measure the acceptance and efficiency ratios

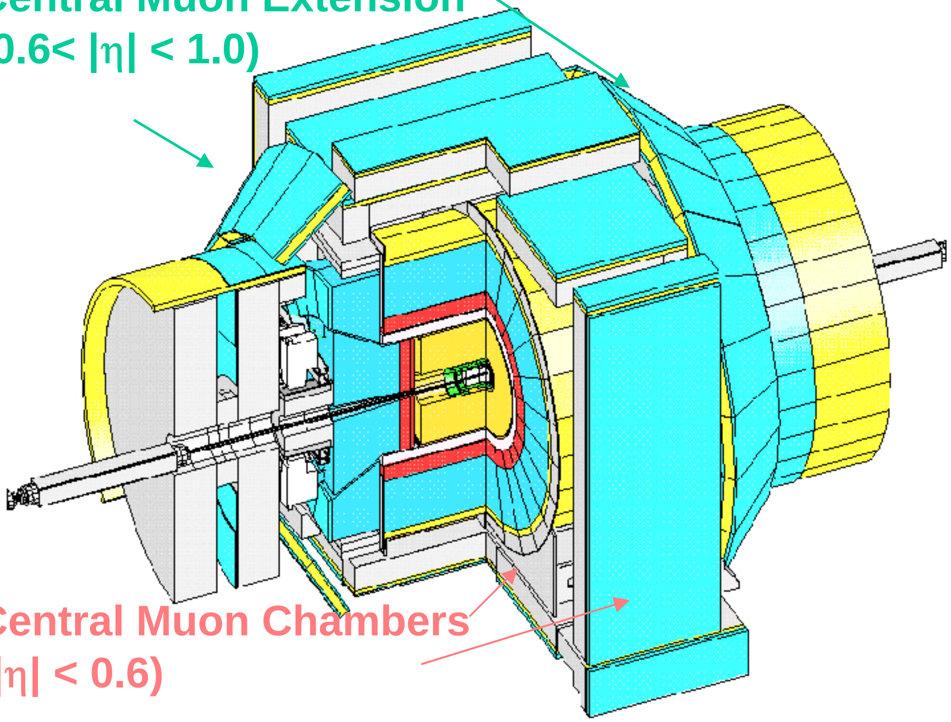
Analysis optimization (figure of merit):

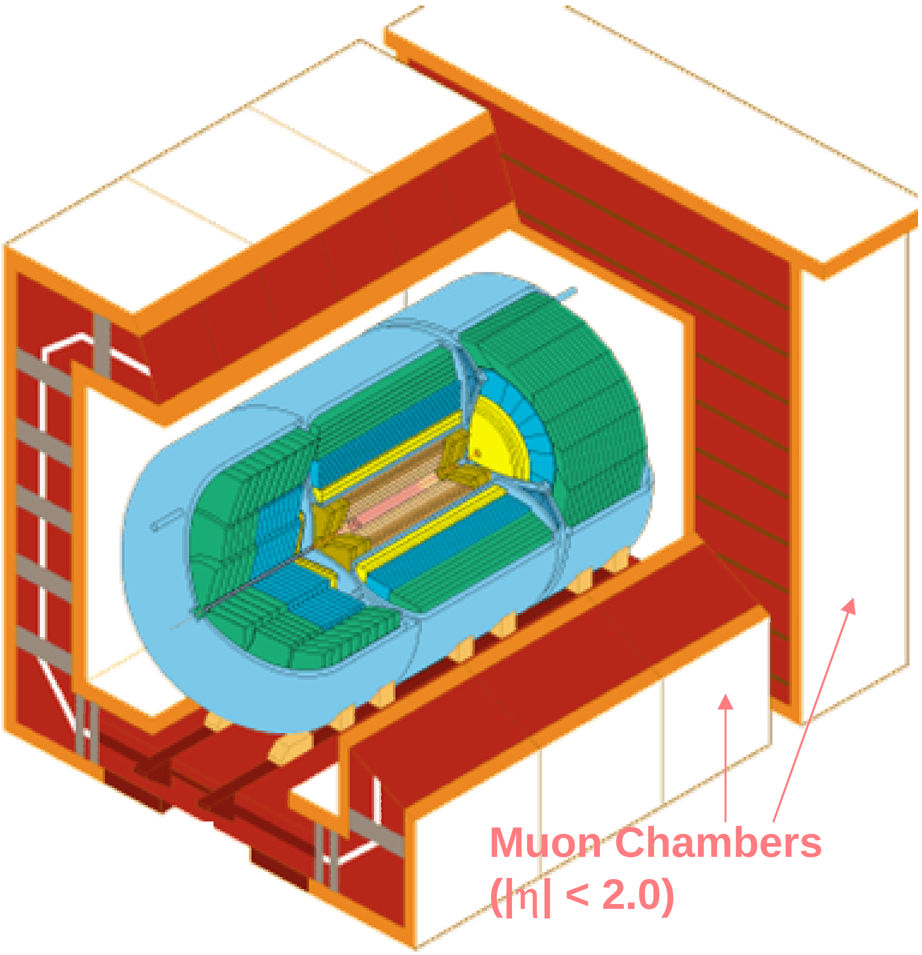
CDF → expected 90% C.L. upper limit

D0 → S/(1+sqrt(B))

CDF

D0

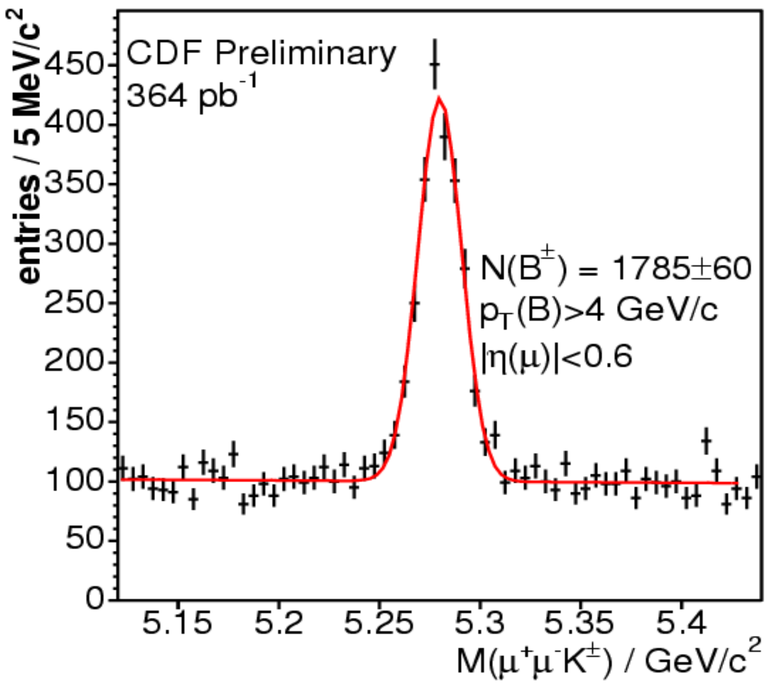




GOOD MUON COVERAGE HELPS!!!

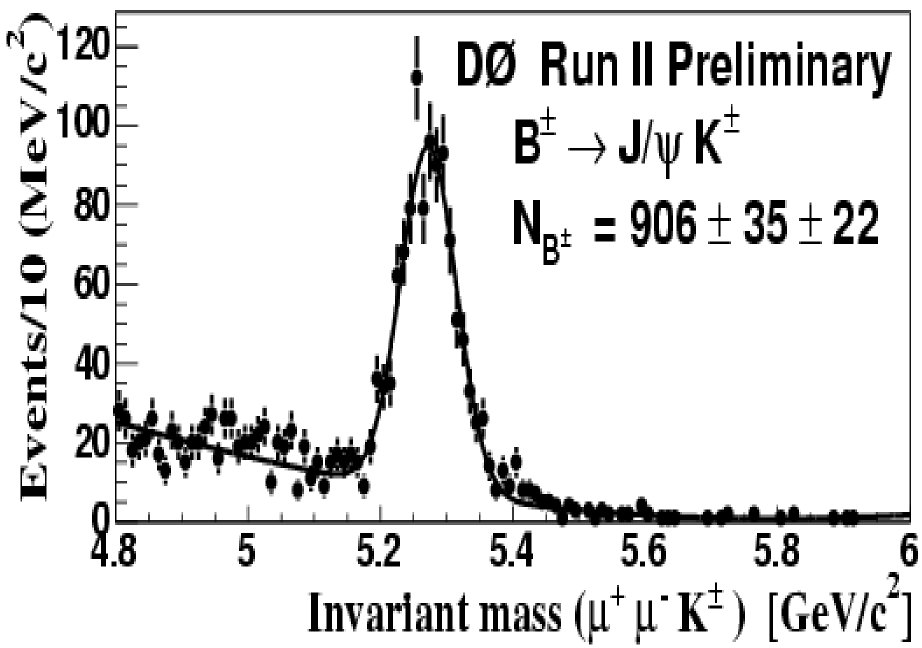
Reconstruct Normalization Mode ($B^+ \rightarrow J/\psi\ K^+$)

CDF



central-central muons

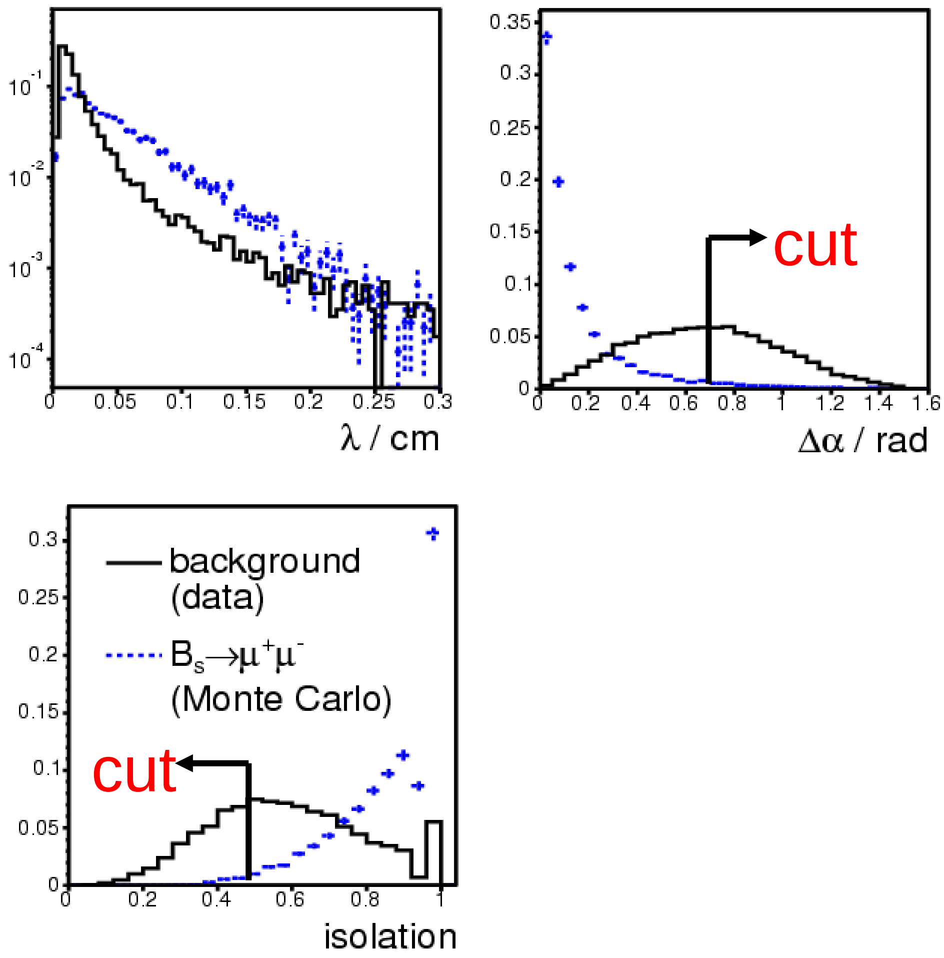
D0



GOOD MASS RESOLUTION HELPS!!!

B → μμ Optimization (CDF)

- **Chosen three primary discriminating variables:**



- **proper decay length (λ)**

$$\lambda = \frac{c L_{3D} M_{vtx}}{\left|\vec{p}(B)\right|}$$

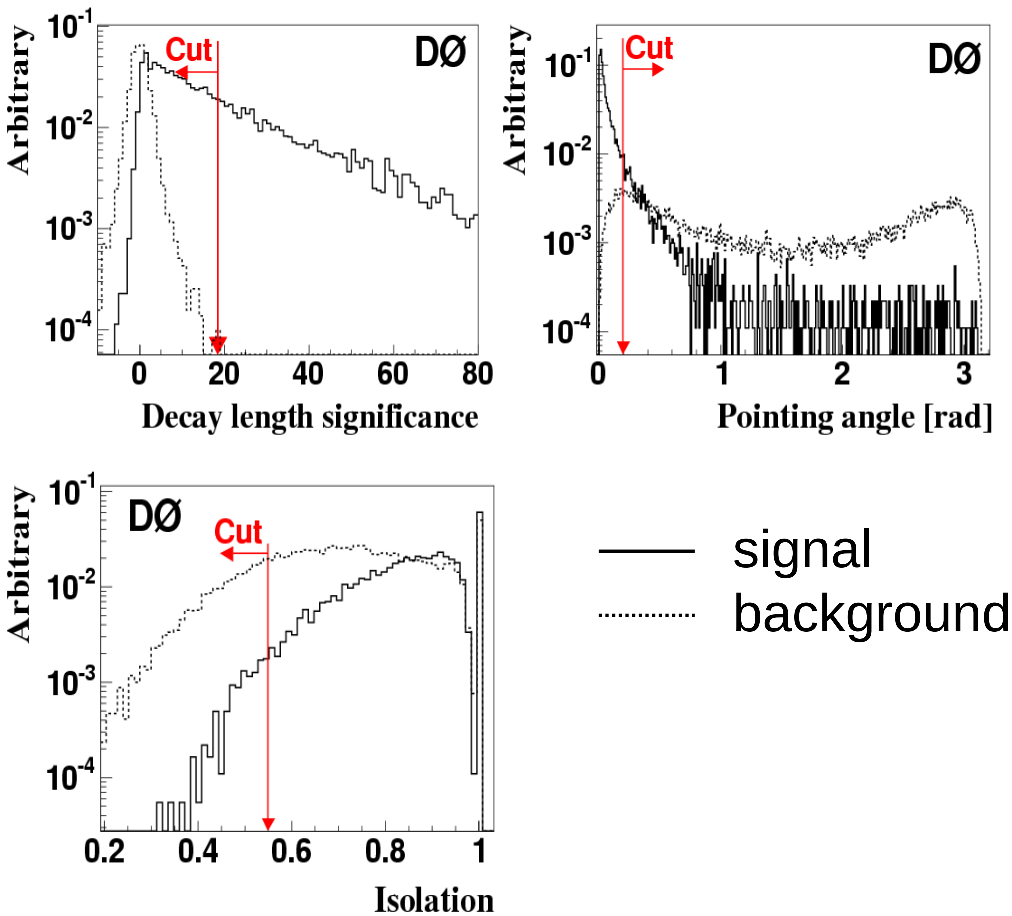
- **Pointing (Δα) $|\phi_B - \phi_{vtx}|$**

- **Isolation (Iso)**

$$Iso = \frac{p_T(B)}{p_T(B) + \sum_i p_T^i(\Delta R_i < 1.0)}$$

B → μμ Optimization (D0)

- Similar three primary discriminating variables



- D0 use 2d lifetime variables instead of 3d
- Optimize using MC for signal, data sidebands for background
- Random grid search, optimizing for ~ S/(1+sqrt(B))

Likelihood Ratio Discriminant (CDF)

- First iteration of analysis used standard cuts optimization
- Second iteration uses the more powerful likelihood discriminant

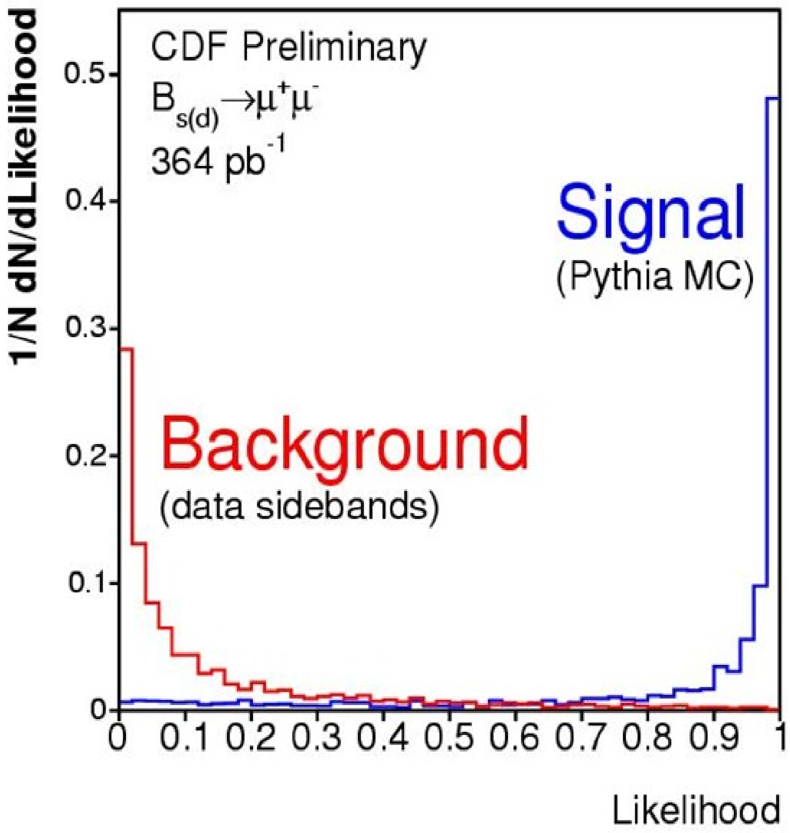
$$L = \frac{\prod_i P_{sig}(x_i)}{\prod_i P_{sig}(x_i) + \prod_i P_{bkg}(x_i)}$$

- i: index over all discriminating variables
- $P_{sig/bkg}(x_i)$: probability for event to be signal / background for a given measured x_i

- Obtain probably density functions of variables using
  - background: Data sidebands
  - signal: Pythia Monte Carlo sample

Optimization (CDF)

Likelihood ratio discriminant:

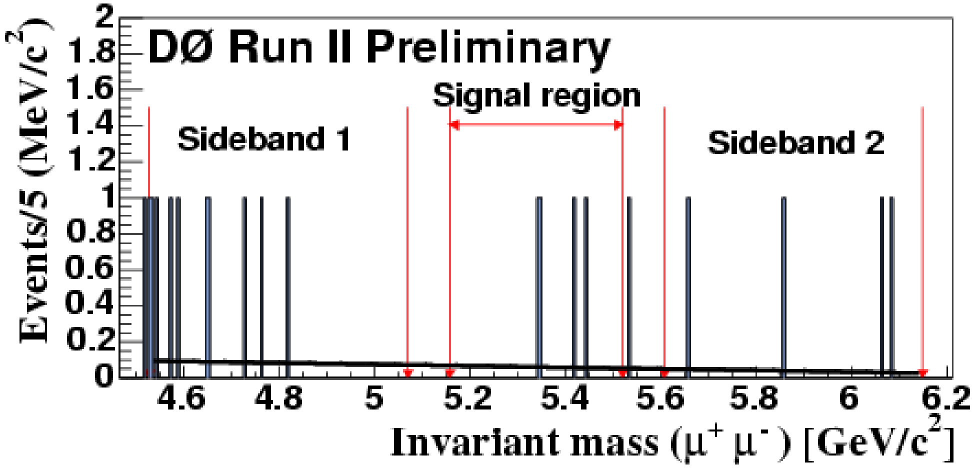


Optimize likelihood and $p_t(B)$ for best 90% C.L. limit

- **Bayesian approach**
- **consider statistical and systematic errors**
- **Assume $1fb^{-1}$ integrated luminosity**

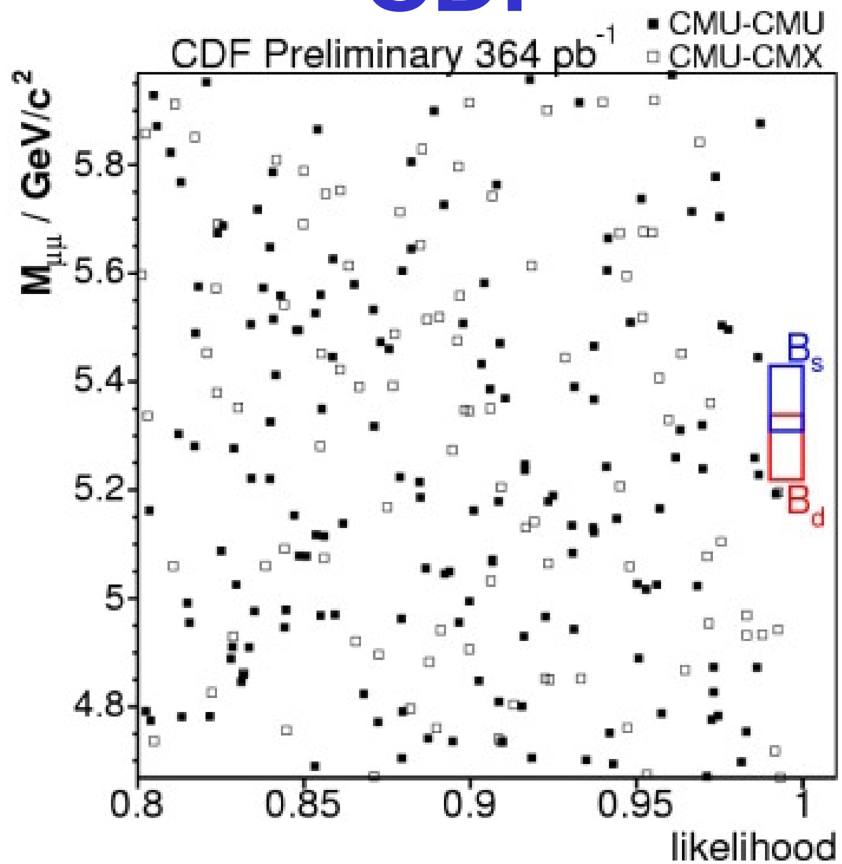
Results

D0



- Expected background: 4.3 ± 1.2
- Observed: 4

CDF



- Expected background: 1.5 ± 0.2
- Observed: 0

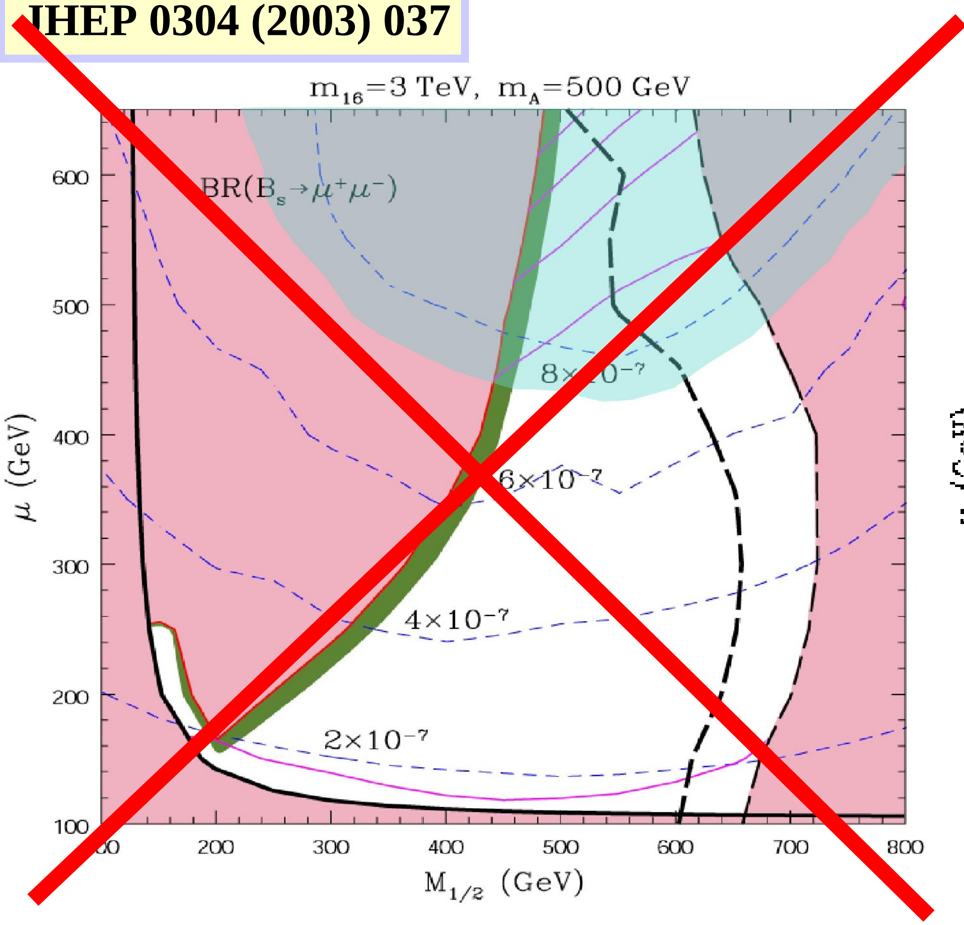
CDF and D0 Combined:

$BR(B_s \rightarrow \mu\mu) < 1.2\times10^{-7}$ @ 90% CL
$< 1.5\times10^{-7}$ @ 95% CL

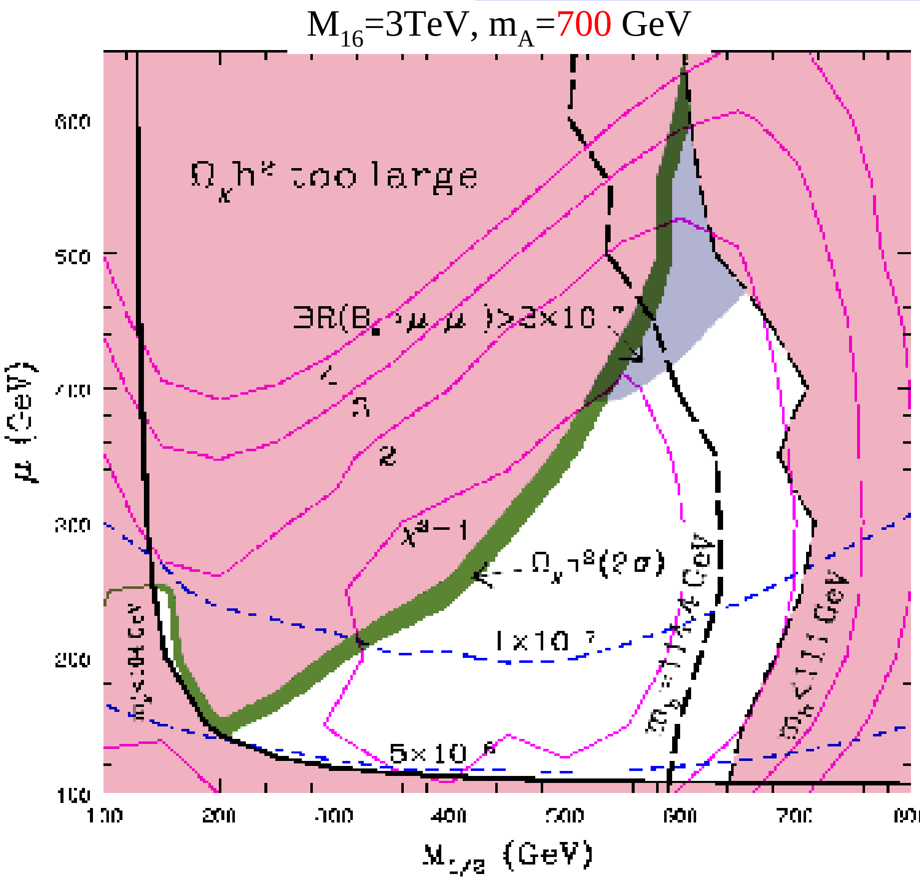
$BR(B_d \rightarrow \mu\mu) < 3.2\times10^{-8}$ @ 90% CL
$< 4.0\times10^{-8}$ @ 95% CL

SO(10) Grand Unification Model

R. Dermisek *et al.*, JHEP 0304 (2003) 037



R. Dermisek *et al.*, hep-ph/0507233 (2005)



Red regions are excluded by either theory or experiments

Green region is the WMAP preferred region

Blue dashed line is the Br(Bs→μμ) contour

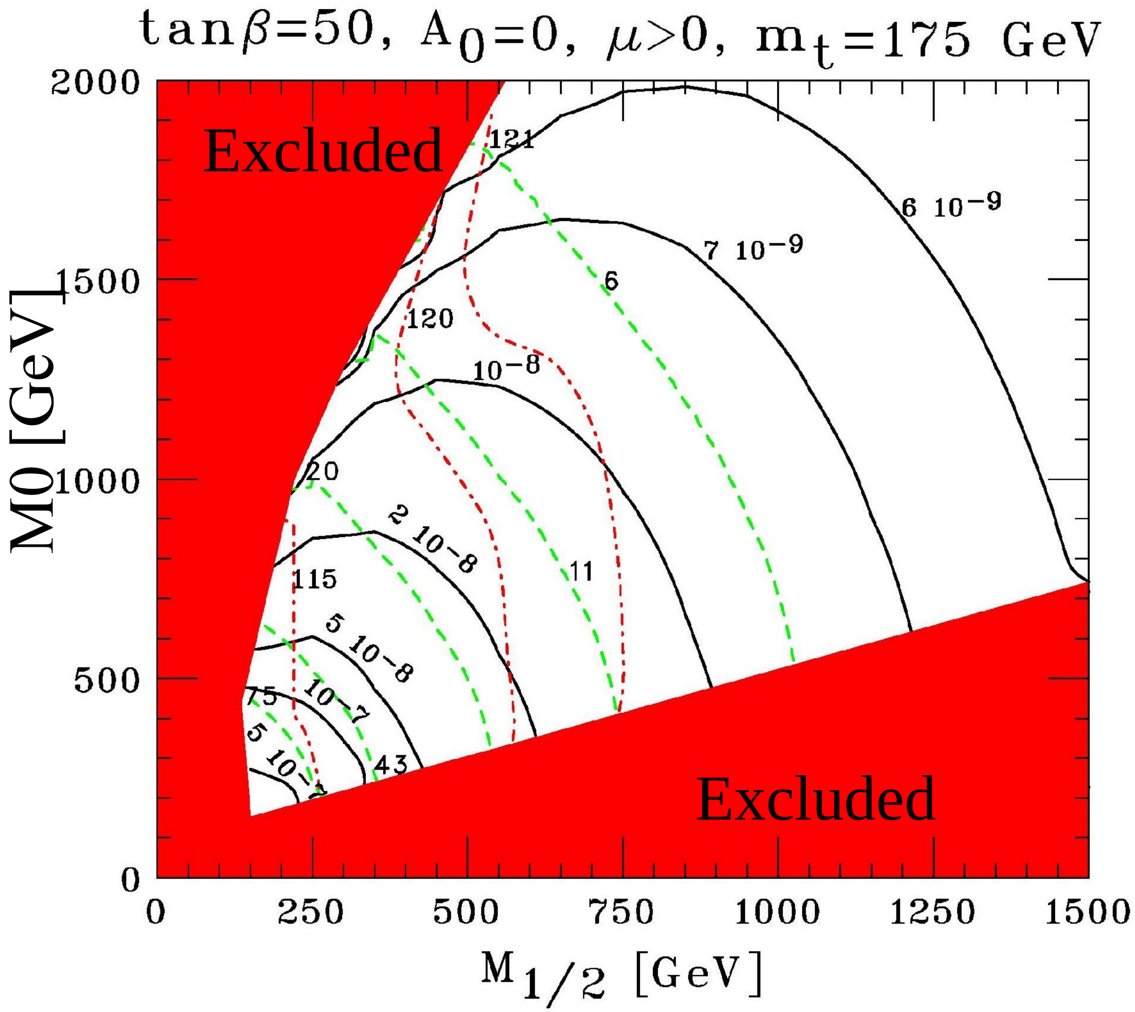
Light blue region excluded by old Bs→μμ analysis

tan(β)~50 constrained by unification of Yukawa couplings

mSUGRA M0 vs $M_{1/2}$

Dedes, Dreiner, Nierste, PRL 87(2001) 251804

- For m_h~115GeV implies $10^{-8} < Br(B_s \rightarrow \mu\mu) < 3\times10^{-7}$



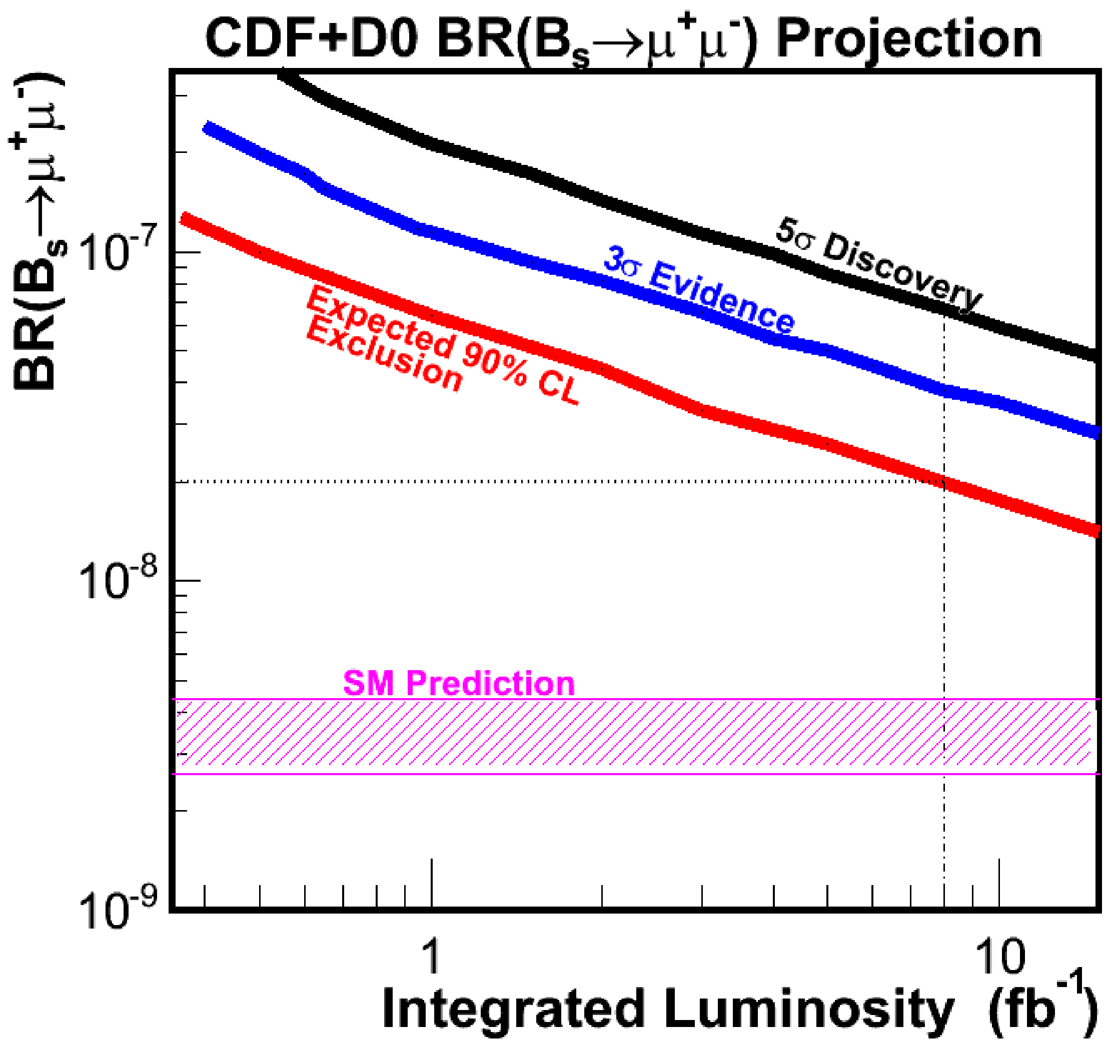
Solid red = excluded by theory or experiment

Dashed red line = light Higgs mass (m_h)

Dashed green line = (δa_μ)susy (in units of 10^{-10})

Black line = $Br(B_s \rightarrow \mu\mu)$

TEVATRON REACH on $B_s \rightarrow \mu\mu$



Can push down to Low 10^{-8} region

Still a factor of 10 from SM value

Some Thoughts on LHC

- Still a window of opportunity for discovery at the Tevatron. However, LHC will sweep the measurement.
- Maintaining a healthy B physics trigger will be a challenge at the LHC. It's all too easy to raise pT threshold and/or prescale B triggers when trigger rate is high.
- Not clear to me how reliable is the background estimate in various LHC $B_s \rightarrow \mu\mu$ projections. Don't be surprised if your background turns out to be x10 higher.
- Similar search strategy as Tevatron can probably be adopted at LHC. May require additional discriminating variables or more sophisticated approach (e.g. NN) to suppress bkg.

Remaining Thoughts on LHC

- B→hh (where h=kaon,pion) will be an issue at LHC. Will need to have a detailed understanding of muon fake rates.

- Some efficiencies may have to be estimated from Monte Carlo (e.g. isolation cut)→ need a reliable LHC MC.

- Looking forward to the first physics (hopefully surprises) from the LHC!!

Backup Slides

Background estimate (CDF)

	LH cut	CMU-CMU pred	CMU-CMU obsv	CMU-CMX pred	CMU-CMX obsv
OS-	>0.50	236+/-4	235	172+/-3	168
	>0.90	37+/-1	32	33+/-1	36
	>0.99	2.8+/-0.2	2	3.6+/-0.2	3
SS+	>0.50	2.3+/-0.2	0	2.8+/-0.3	3
	>0.90	0.25+/-0.03	0	0.44+/-0.04	0
	>0.99	<0.10	0	<0.10	0
SS-	>0.50	2.7+/-0.2	1	3.7+/-0.3	4
	>0.90	0.35+/-0.03	0	0.63+/-0.06	0
	>0.99	<0.10	0	<0.10	0
FM+	>0.50	84+/-2	84	21+/-1	19
	>0.90	14.2+/-0.4	10	3.9+/-0.2	3
	>0.99	1.0+/-0.1	2	0.41+/-0.03	0

1.) OS- : opposite-charge dimuon, $\lambda < 0$

2.) SS+ : same-charge dimuon, $\lambda > 0$

3.) SS- : same-charge dimuon, $\lambda < 0$

4.) FM : fake muon sample (at least one leg failed muon stub chi2 cut)