Search for rare B decays at the Tevatron

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DPF Riverside
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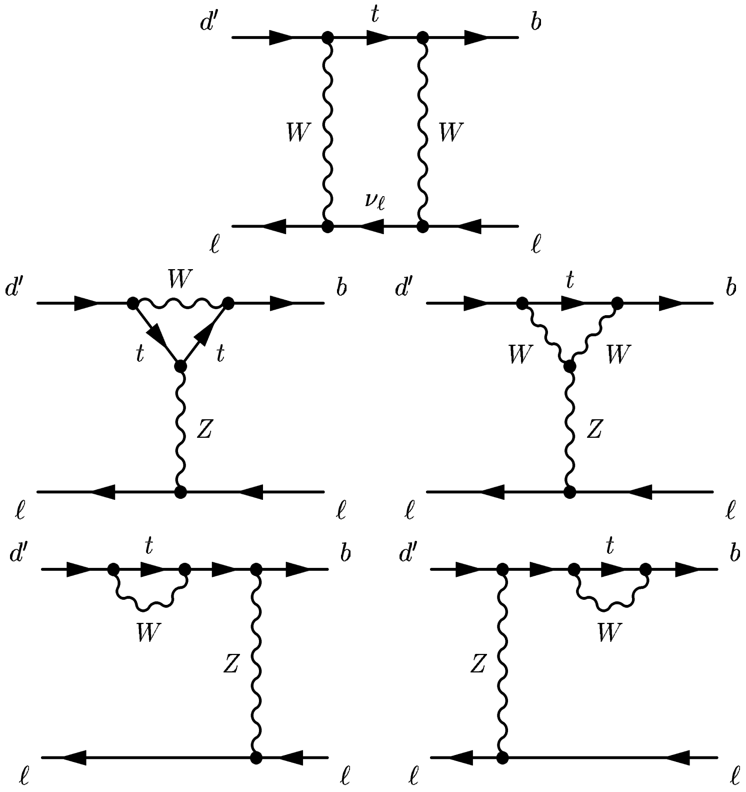
- Theoretical introduction
- Analysis procedure
- Results and conclusions

Introduction to the $B_{d,s} \rightarrow l^+l^-$ decay I (SM)



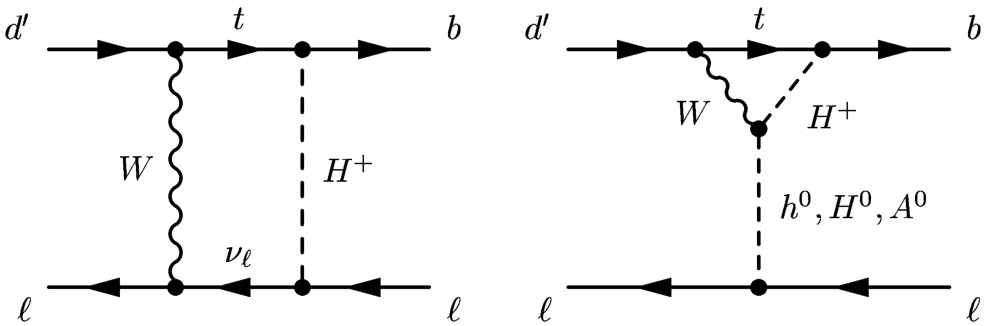
SM predictions

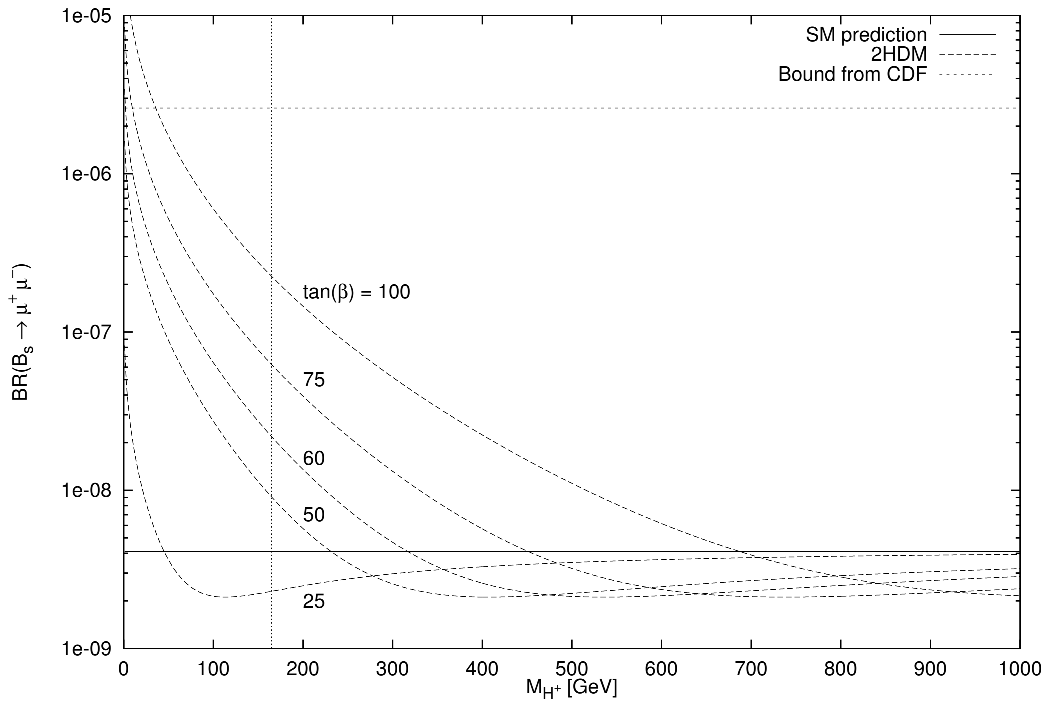
	$BR(B_d \rightarrow l^+l^-)$	$BR(B_s \rightarrow l^+l^-)$
$l = e$	$(3.4\pm2.3)\cdot10^{-15}$	$(8.0\pm3.5)\cdot10^{-14}$
$l = \mu$	$(1.5\pm0.9)\cdot10^{-10}$	$(3.4\pm0.5)\cdot10^{-9}$
$l = \tau$	$(3.1\pm1.9)\cdot10^{-8}$	$(7.4\pm1.9)\cdot10^{-7}$

Experimental upper limits at 90% (95%) CL

	$BR(B_d \rightarrow l^+l^-)$	$BR(B_s \rightarrow l^+l^-)$
$l = e$	$< 5.9\cdot10^{-6}$	$< 5.4\cdot10^{-5}$
$l = \mu$	$< 1.5(1.9)\cdot10^{-7}$	$< 5.8(7.5)\cdot10^{-7}$
$l = \tau$	$< 2.5\%$	$< 5.0\%$

$B_s \to \mu^+\mu^-$ decay in the Two Higgs-Doublet Model



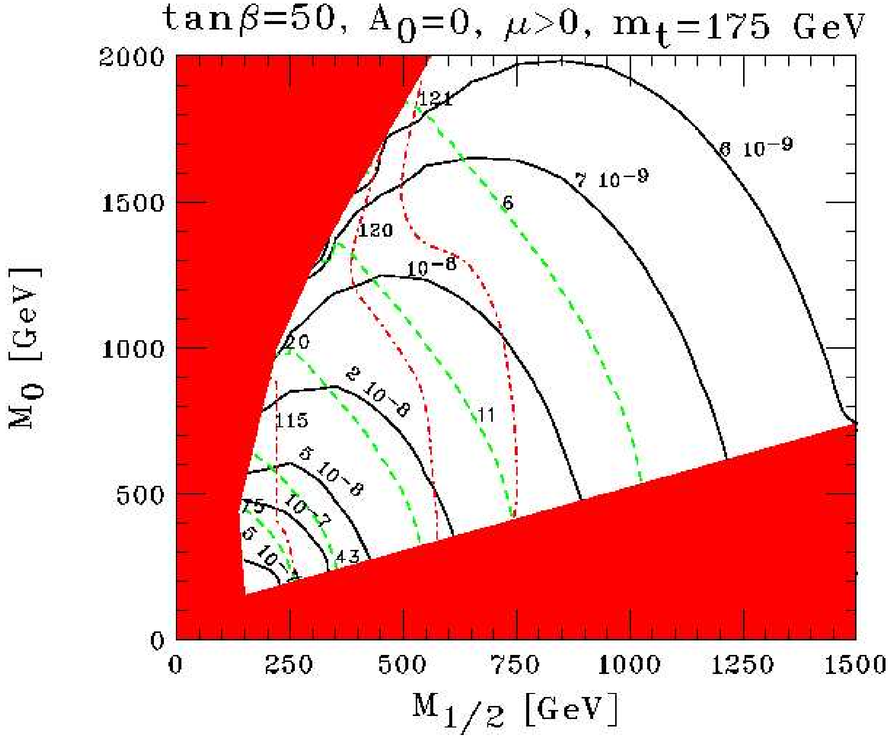


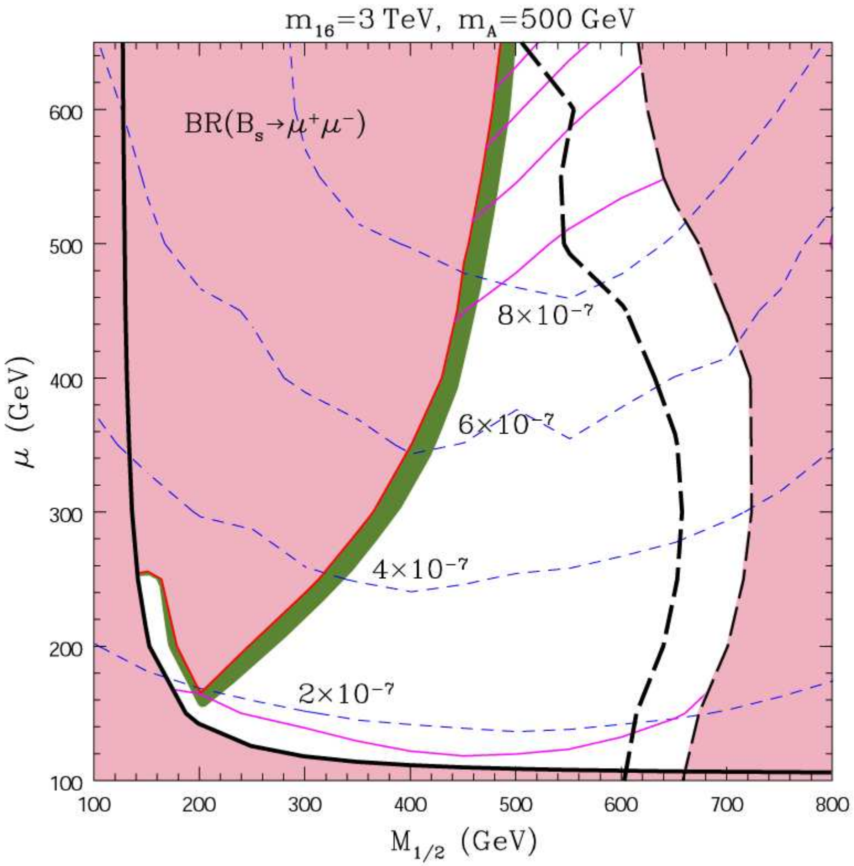
- Parameters of the neutral Higgs sector cancel out
- Branching fraction depends only on charged Higgs mass and $\tan\beta$
- Branching fraction increases like $\tan^4\beta$ ($\tan^6\beta$) in 2HDM (MSSM).
- Mode is complementary to $b \to s\gamma$
- R parity violating models can give tree level contributions

$B_s \to \mu^+\mu^-$ in other extensions to the SM

SO(10) symmetry breaking model

The MSuGra Model

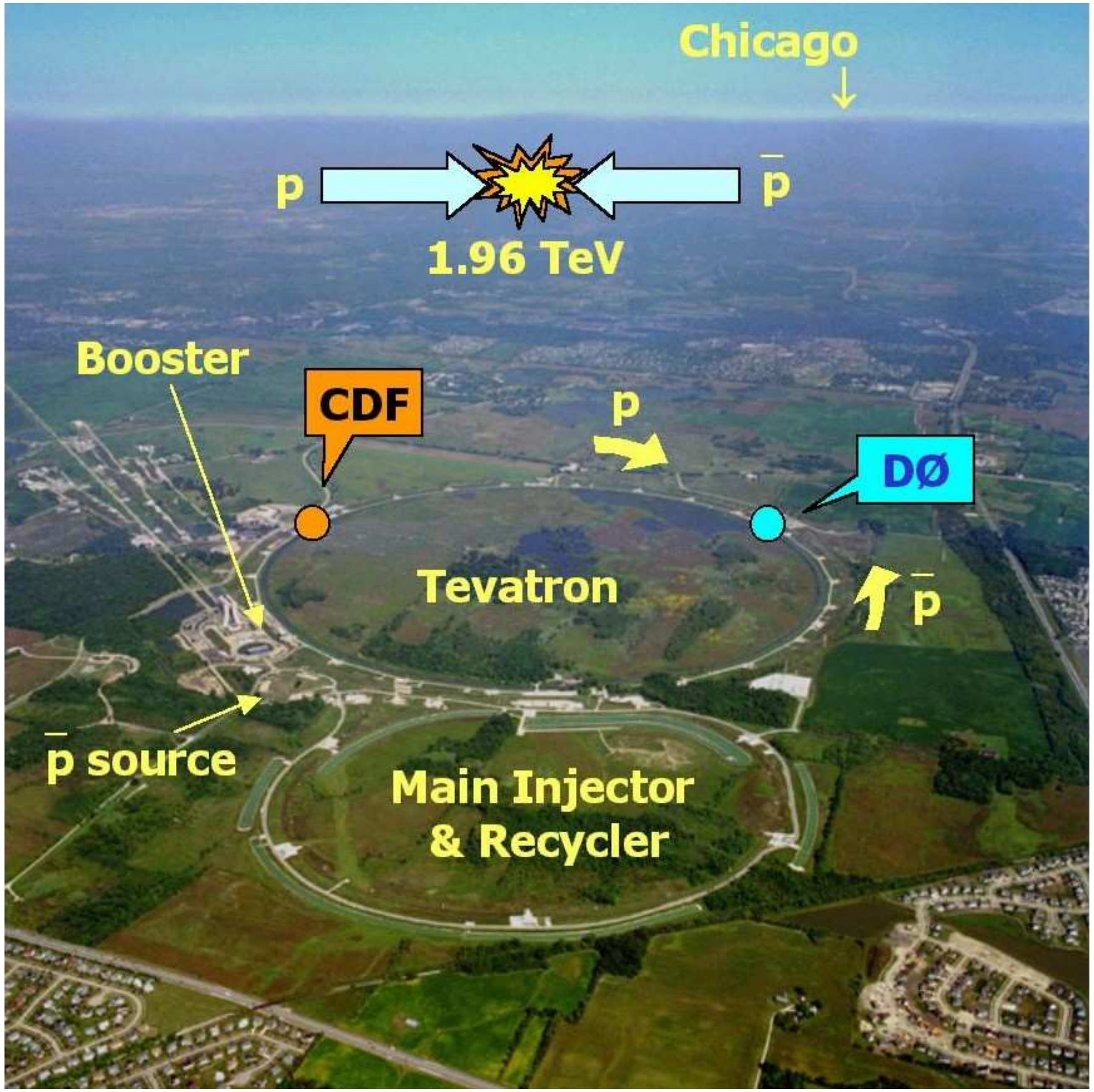




Mode is correlated to (g-2)

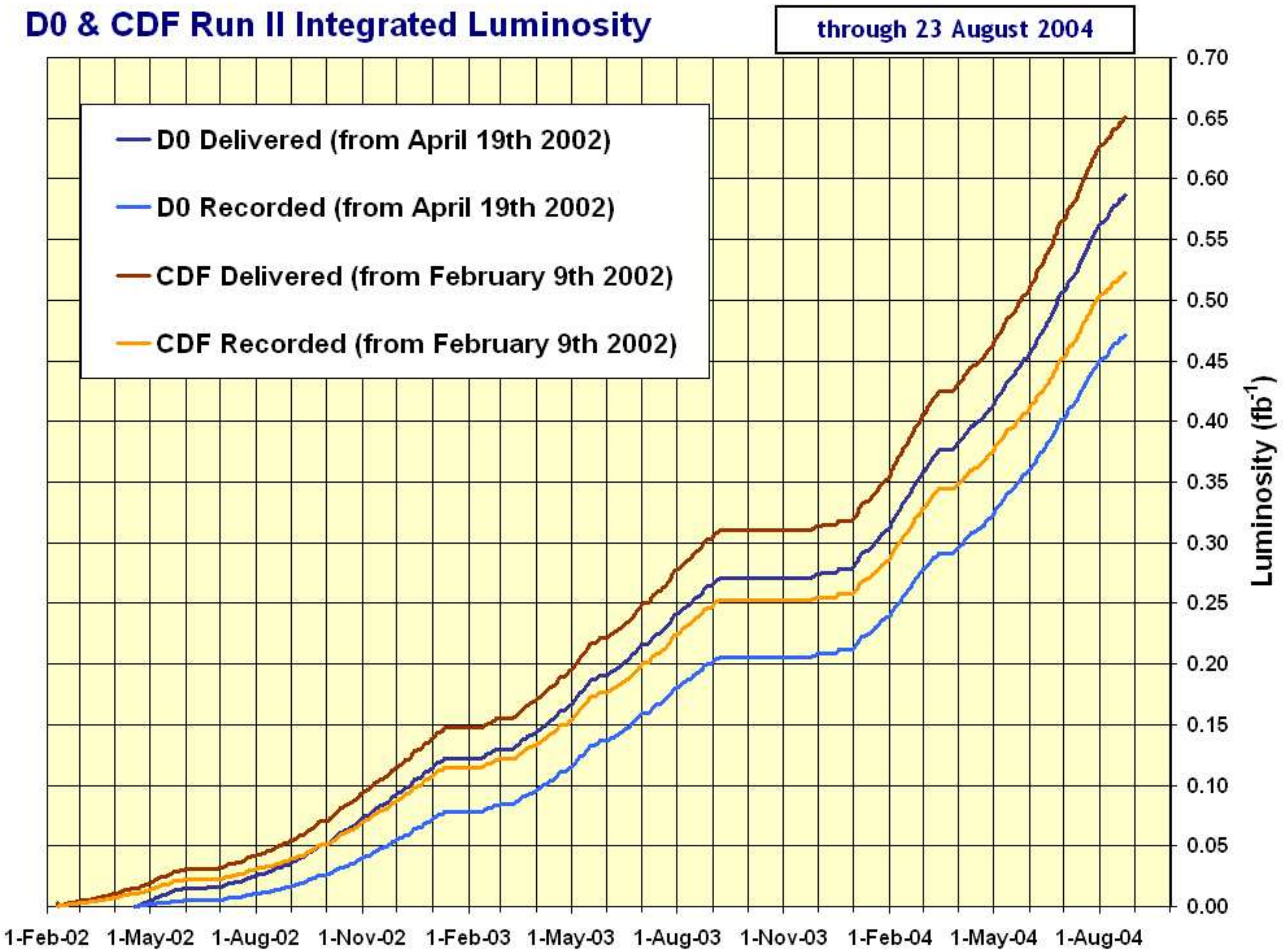
Model predict large enhancement $\propto \tan^6 \beta$

The Fermilab Tevatron Collider



- New main injector and antiproton recycler
- Increase number of bunches ($6 \times 6 \rightarrow 36 \times 36$)
- Reduce bunch spacing ($3.5\mu s \rightarrow$ 396ns)
- Increase beam energy 900 $\rightarrow$ 980 GeV (increase x-sections e.g. top production by 30-40 %)
- Projected integrated luminosity per experiment:
  - ≈ 2 fb^{-1} 2006
  - ≈ 8 fb^{-1} 2009
- Highest luminosity so far $1.03 \cdot 10^{32}$ cm^{-2} s^{-1}
- Nearly 0.5 fb^{-1} on tape per experiment
- Data taking efficiency: 85-90 %

Integrated Luminosity



CDF used 171pb^{-1} and DØ used 240pb^{-1} for this analysis
1 billion events recorded at DØ as of August 2nd

Why rare B physics at the Tevatron ?

- Producing large numbers of $b\bar{b}$ pairs
  - $\sigma(p\bar{p} \to b\bar{b}) = 150\mu$b at 2 TeV
  - $\sigma(e^+e^- \to Z^0 \to b\bar{b}) = 7$ nb
  - $\sigma(e^+e^- \to \Upsilon(4S) \to b\bar{b}) = 1$ nb
- Expect 10^{10} $b\bar{b}$ pairs pairs/year at $4 \cdot 10^{31} cm^{-2}s^{-1}$
  - fragmenting into all B-species: $B_d, B_u, B_s, \Lambda_b, \ldots$
- Exploring the B_s sector

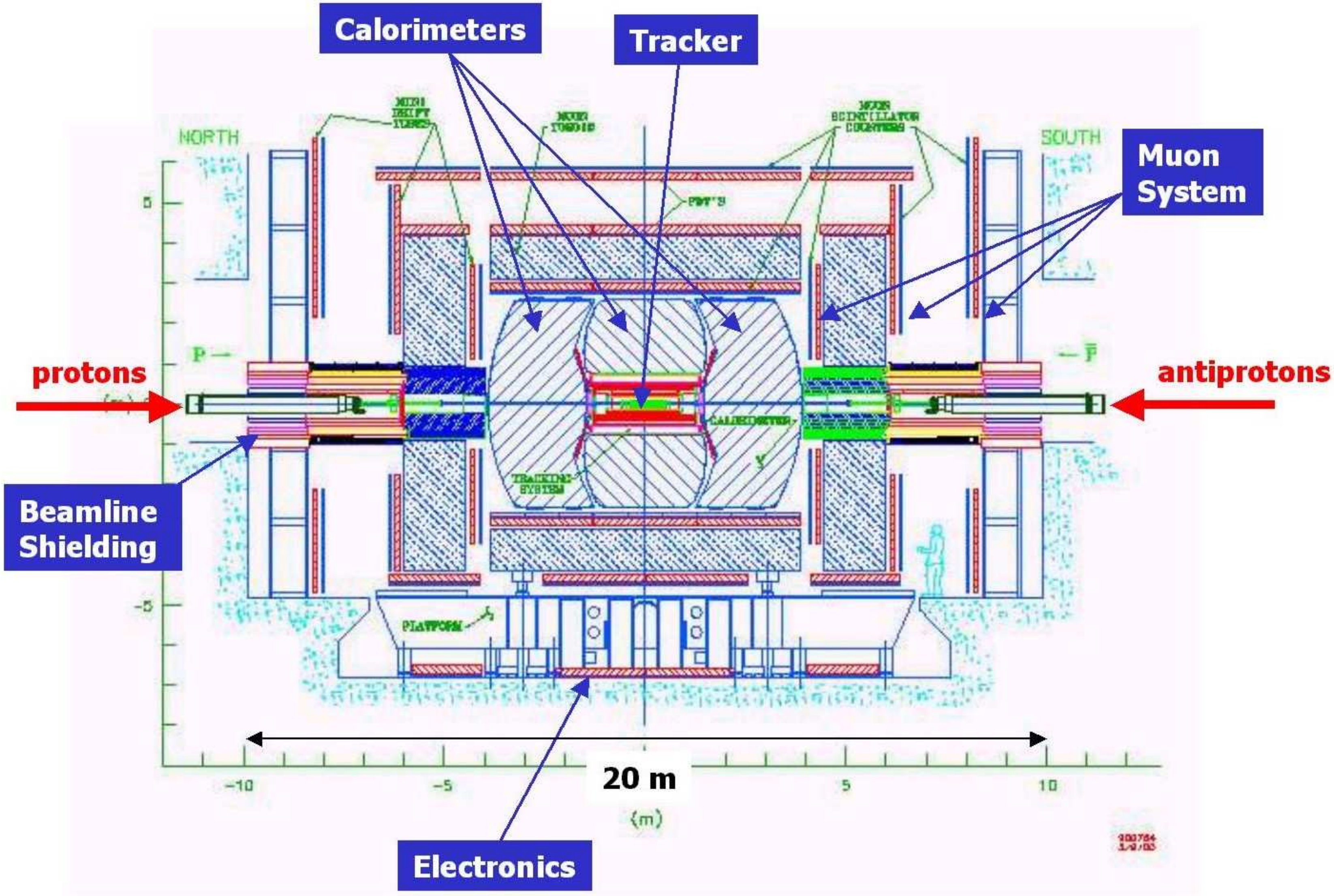
Con's

- QCD background overwhelming
- efficient trigger and reliable tracking necessary
- soft pt spectrum, smaller boost than LEP

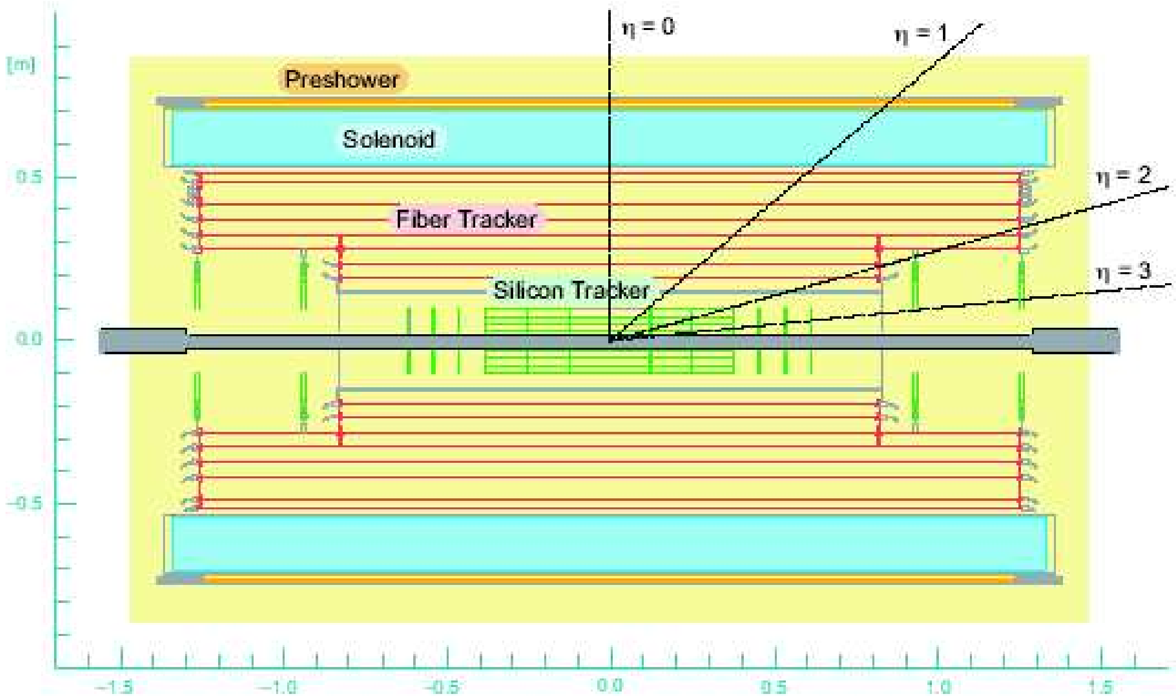
Key points for this analysis

- Muon system
- Muon trigger (single and dimuon triggers)
- Silicon Vertex + Tracker

The DØ detector

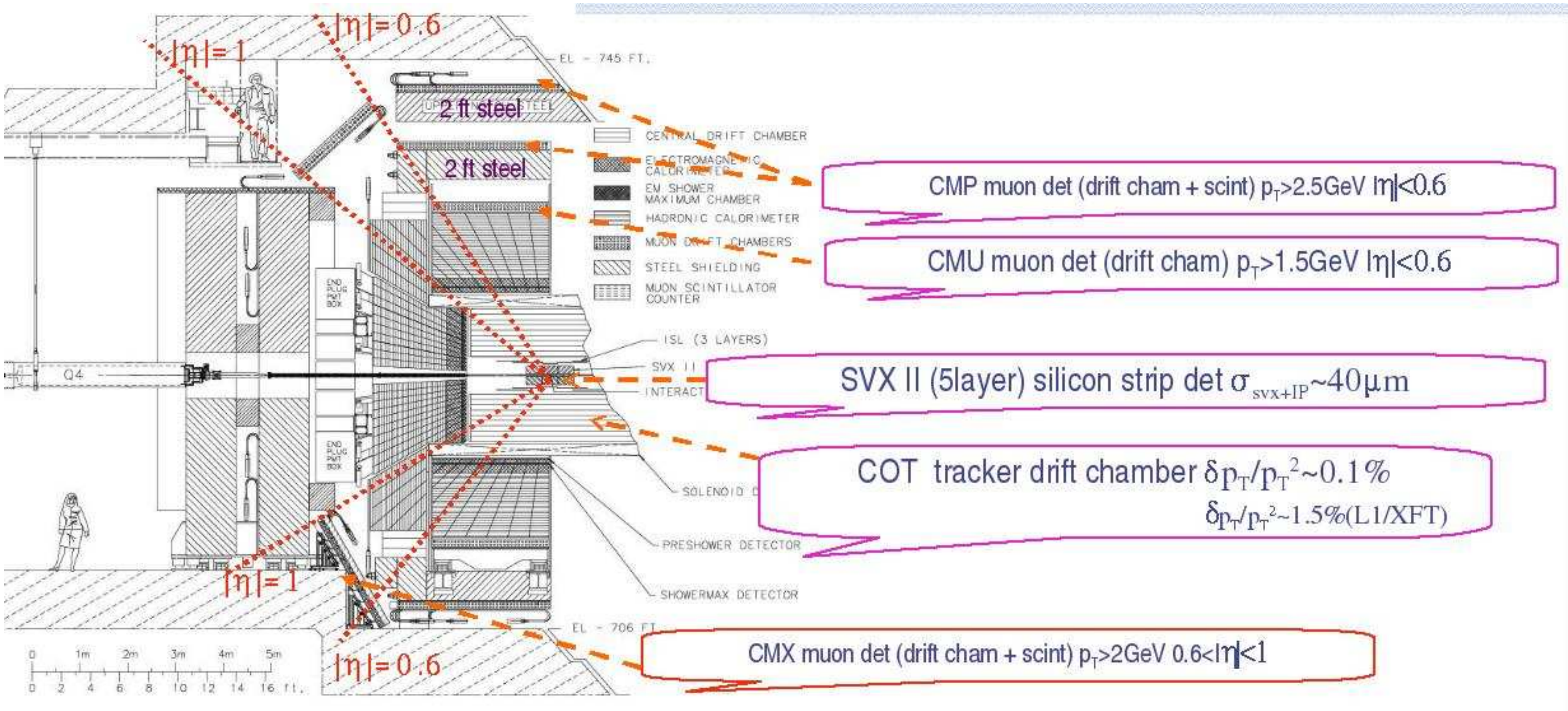


DØ Tracking region



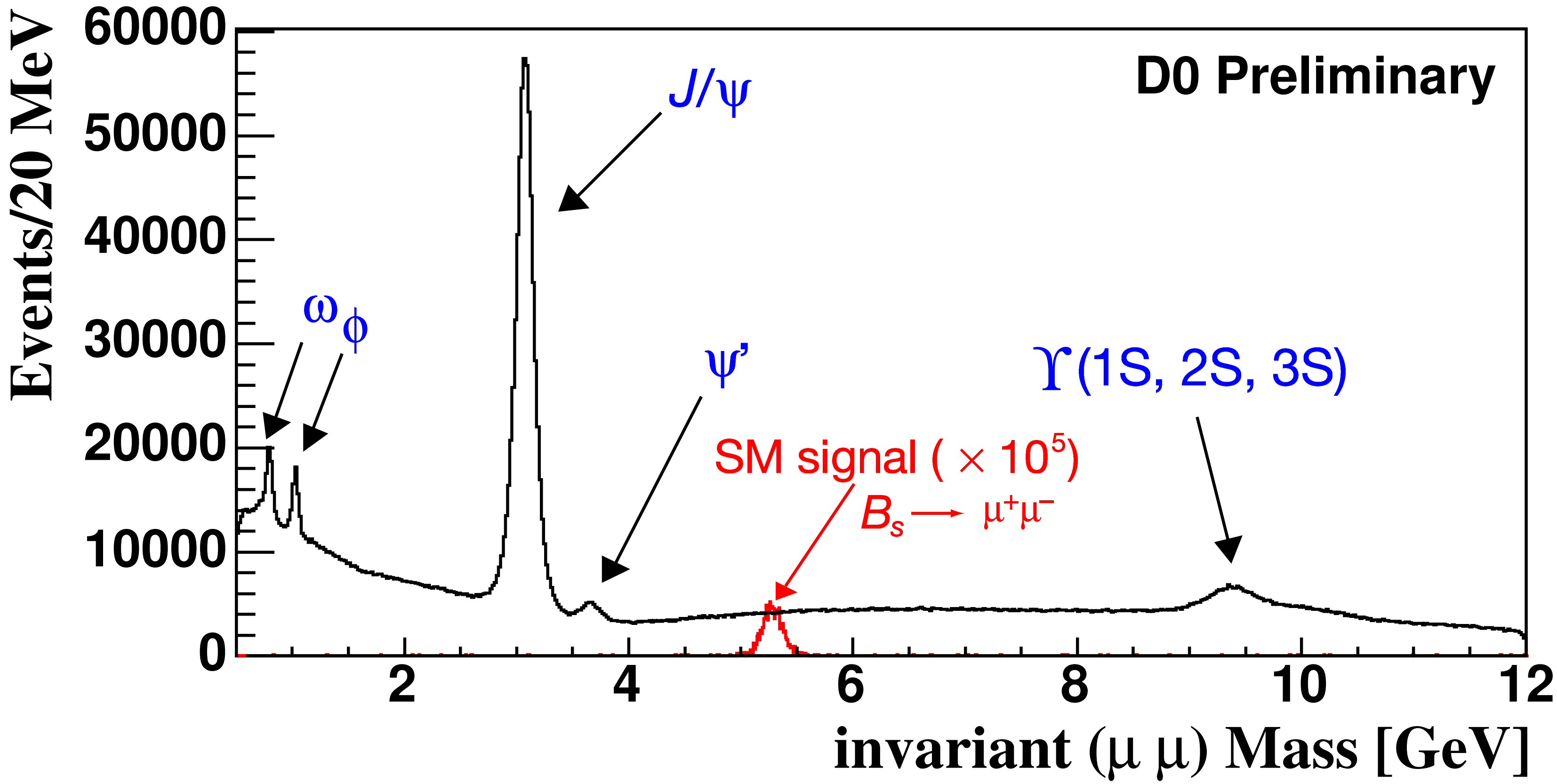
- Silicon Detector
  + 6 barrels w/ 4 layers silicon sensors
  + large external area disk at the end
- Fiber Tracker
  + scintillating fiber ∅ 0.82 mm
  + 8 layer axial and stereo
  + R/O through VLPC in LHe
- Superconduction Solenoid (2 Tesla)
- tracking/vertexing up to $|\eta| < 3$

The CDF-II detector



- Upgraded silicon vertex detector (SVX) and faster tracking drift chambers
- New scintillating tile end-plug calorimeter
- Increased muon eta-phi coverage
- New scintillator time of flight system

DØ dimuon sample



- Signal region in DØ is $m_{B_s^{D\emptyset}} \pm 2\sigma = 5.160 < m_{B_s} < 5.520$ GeV$/c^2$ ($m_{B_s^{D\emptyset}} = m_{B_s^{PDG}}$-30MeV; $1\sigma = 90$ MeV)
- Signal region in CDF is $5.169 < m_{B_s} < 5.469$ GeV$/c^2$ (covering B_s and B_d)

Selection Cuts

DØ

- Normalize to the $B^+ \to J/\psi K^+$ decay
- Cut on Mass region of DiMuon sample $4.5 < m_{\mu\mu} < 7$ GeV/c^2
- Two good muons with a net charge of zero and p_T greater than 2.5 GeV
- The triggered muons have reconstructed tracks in the tracker
- Good reconstructed vertex
- A minimum p_T of the B_s candidate of 5 GeV is required
- Cut on the uncertainty of the transverse decay length $\sigma(L_{xy}) < 150\mu m$

38k events remain

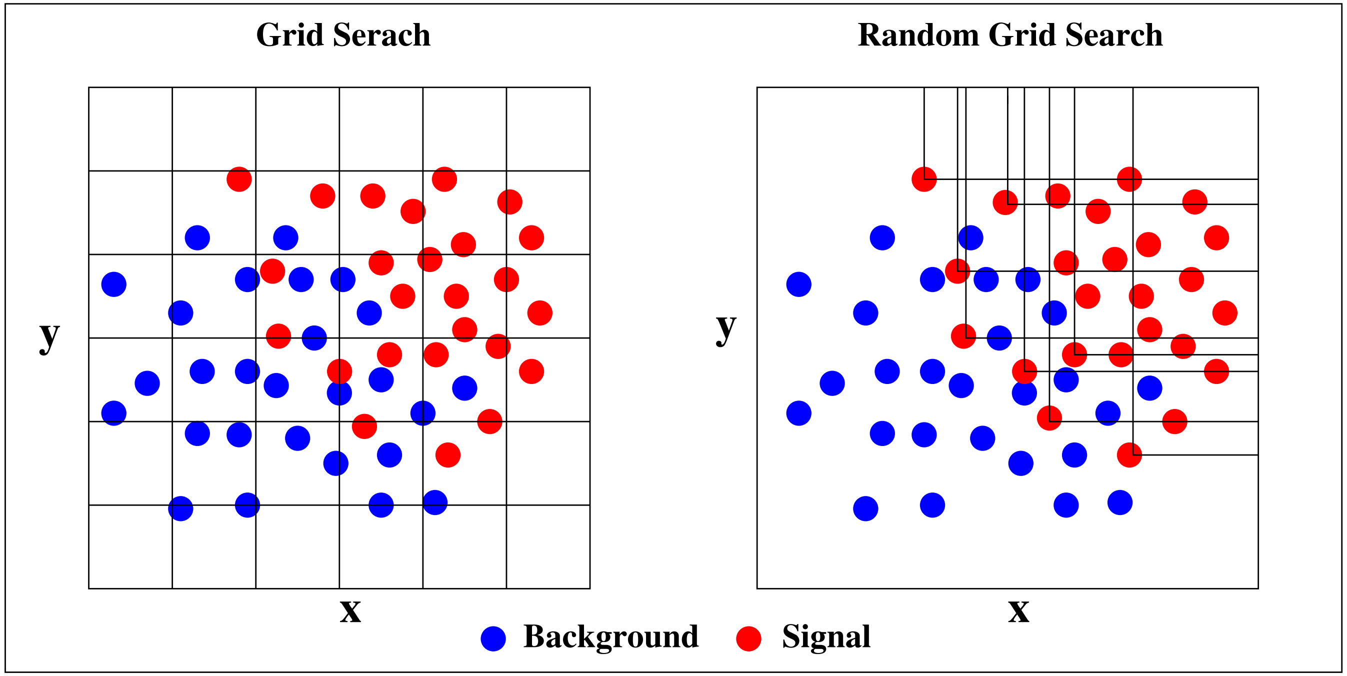
CDF

- Normalize to the RunI measured B cross section
  $\sigma_{B_s} = 0.9\mu b$ for $p_T(B_s) > 6$ GeV/c, $|y| < 1$
  use this as a basline selection
- Require dimuon trigger (2.7 $< M_{\mu\mu} <$ 6.0 GeV/c^2)
  different threshold on muon p_T 1.5 - 3 GeV, analysis cut is $>$ 2 GeV
- Standard track, vertex and muon selection

2940 events remain

Optimization procedure

- DØ used $\approx 80pb^{-1}$ of data to optimize cuts
- DØ performed random grid search of the 3 discriminating variables
- CDF performed grid search of the 3 discriminating variables (100 combinations)



- ⊕ Opening angle between the vertex direction and the muon pair "Pointing consistency"
- ⊕ DØ : Decay length significance ($c\tau/\sigma c\tau$), CDF: $c\tau$ of B_s candidate
- ⊕ Isolation of the muon pair

Optimization procedure II

- Keep signal region as a blind box

DØ

- Maximize sensitivity of searches for new signals

$$\frac{\epsilon_{\mu^+\mu^-}}{a/2+\sqrt{B}}$$

following G. Punzi (physics/0308063 test of hypothesis and limits)

– $\epsilon_{\mu^+\mu^-}$ is the reconstruction efficiency for $B_S \rightarrow \mu^+\mu^-$

– B is the expected number of background events in signal region

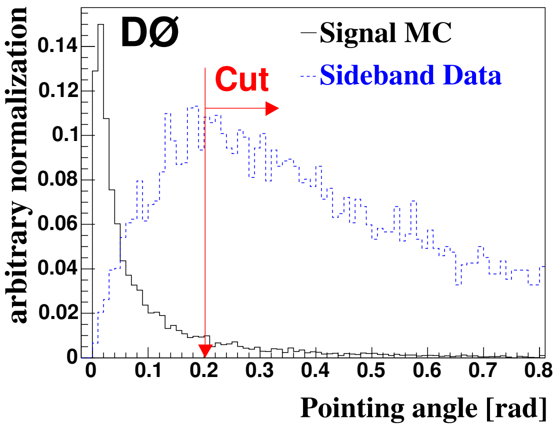
– define α as significance of the test
  a is the number of sigmas for α(i.e 95% $\rightarrow$ 2 σ $\rightarrow$ a=2)

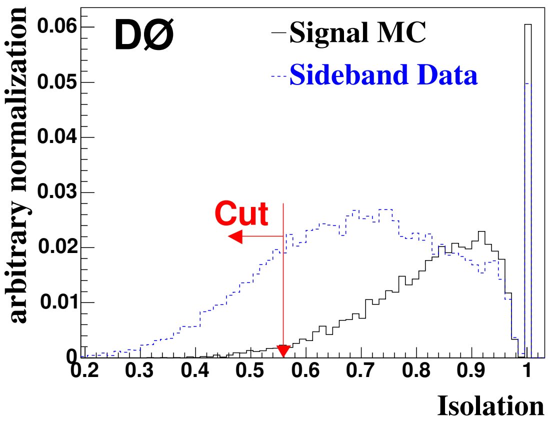
CDF

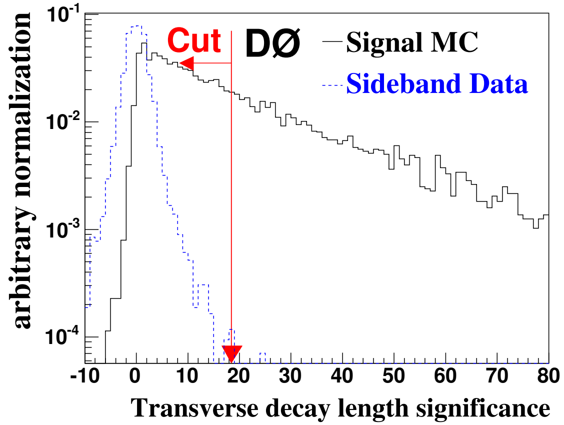
- Maximize to get the best expected limit

$$< BR(B_s \rightarrow \mu^+\mu^-) >= \frac{\sum_n N(n|n_{back}) \cdot P(n|n_{back})}{2 \cdot \sigma_{B_s}\alpha \cdot \cdot \varepsilon_{total} \cdot \int \mathcal{L}dt}$$

DØ : Discriminating variables - Optimization results







Pointing angle
$\alpha < 0.203$ radians

Isolation > 0.56

Transverse decay length significance > 18.47

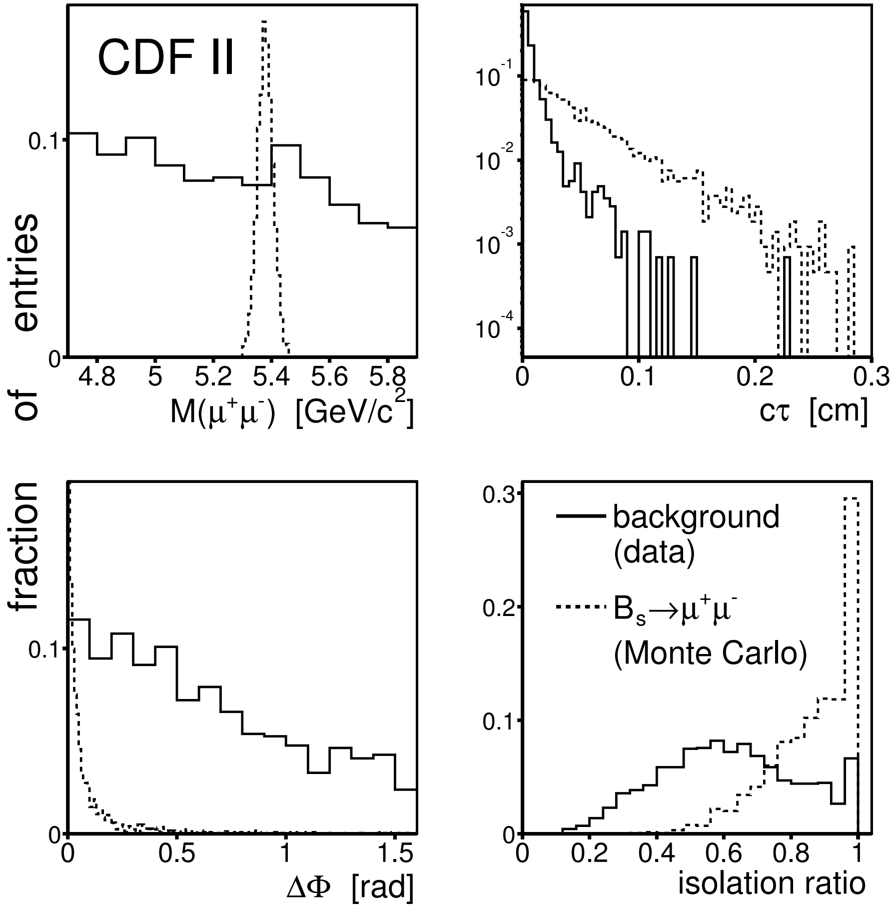
$$\mathrm{Iso} = \frac{p_{B_s}}{p_{B_s} + \sum_{\mathrm{allTracks}\Delta R \leq 1} p}$$

with

$$\Delta R = \sqrt{(\Delta\Phi)^2 + (\Delta\eta)^2} \leq 1$$

Expect 3.7±1.1 background events in 240pb^{-1}

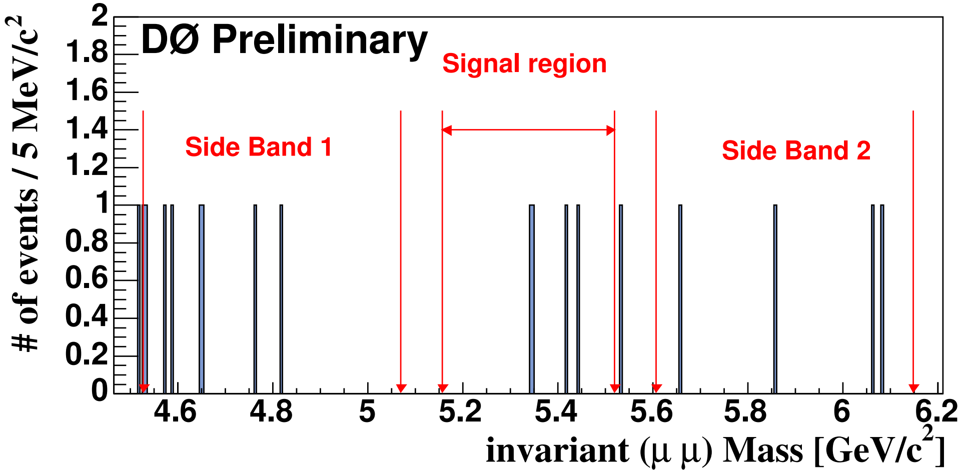
CDF: Discriminating variables - Optimization results

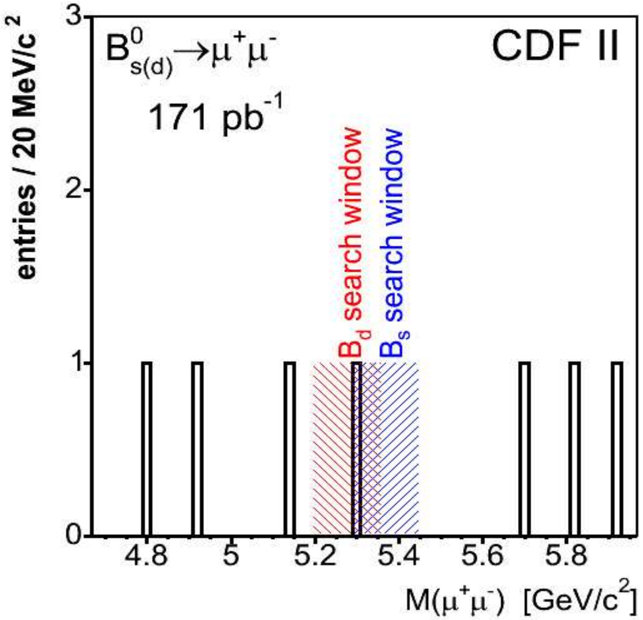


- $M_{\mu\mu} = M_{B_s} \pm$ 80 MeV/c^2 (resolution from MC is 27 MeV/c^2)
- c$\tau = L_{xy} \cdot \frac{M}{p_T(B)}$ >200 mm
- $\Delta\Phi = \phi(pTB) - \phi(vtx)$ >0.1 rad
- $Iso = \frac{p_T(B)}{p_T(B)+\sum_{R<1} p_T(tracks)} > 0.65$

Expect 1.1±0.3 background events in 171pb^{-1}

Unblinding the signal region





DØ

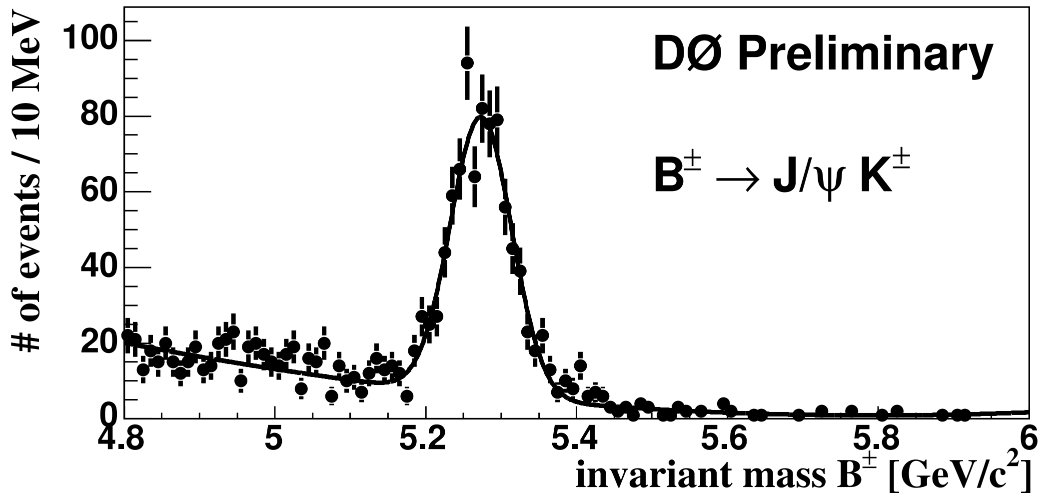
Observed 4 events while expecting 3.7±1.1 background events from the sidebands

CDF

Observed 1 event while expecting 1.1±0.3 background events
(in overlapping B_s and B_d mass region)

Normalizing channel $B^{\pm} \to J/\psi K^{\pm}$

- Use the decay of the $J/\psi \to \mu\mu$ to cancel $\mu\mu$ efficiencies (Apply same cuts to J/ψ like above.)
- Vertex an additional track to the J/ψ
- Additional cuts on the Kaon and $B^{\pm}$
  - Kaon pt of .9 Gev is required
  - χ^2 of the vertex fit contribution not more than 10, together not more than 20
  - Collinearity of .9 is required



Fit of a gaussian with a quadratic background

$N_{B^{\pm}} = 741 \pm 31 \pm 22$

DØ : Calculating the upper Limit

$$\mathcal{B}(B_s \to \mu^+\mu^-) \leq \frac{N_{UL}(n_{obs}, n_B)}{N_{B^\pm}} \cdot \frac{\epsilon^{B^\pm}_{\mu\mu K}}{\epsilon^{B_s}_{\mu\mu}} \cdot \frac{\mathcal{B}(B^\pm \to J/\psi K^\pm) \cdot \mathcal{B}(J/\psi \to \mu\mu)}{\frac{f_{b\to B_s}}{f_{b\to B_{u,d}}} + R \cdot \frac{\epsilon^{B_d}_{\mu\mu}}{\epsilon^{B_s}_{\mu\mu}}}$$

- $N_{UL}(n_{obs}, n_B)$ is the Upper Limit calculated using the Feldman-Cousins method
  4 events observed and 3.7 $\pm$1.1 background expected, N_{UL}=6.82
  (including systematic uncertainties via MC integration)
- $N_{B^\pm}$ is the number of accepted $B^\pm \to J/\psi K^\pm$ events
  $N_{B^\pm} = 741 \pm 31 \pm 22$ events
- $\varepsilon_{\mu\mu}$ and $\varepsilon_{\mu\mu K}$ are reconstruction efficiencies
  $\varepsilon_{\mu\mu K}/\varepsilon_{\mu\mu} = 0.229 \pm 0.008 \pm 0.014$
- Correction factor for fragmentation $f_{b\to B_s}/f_{b\to B_{u,d}} = 0.270 \pm 0.034$ PDG
- Assume no B_d contribution i.e. R=0 due to its suppression by $|V_{td}/V_{ts}|^2$
  valid in all MFV models

$\mathcal{B}(B_s \to \mu^+\mu^-) \leq 4.6 \cdot 10^{-7} (3.8 \cdot 10^{-7})$ at 95% (90%) C.L.

Using a Bayesian approach:
$\mathcal{B}(B_s \to \mu^+\mu^-) \leq 4.7 \cdot 10^{-7} (3.8 \cdot 10^{-7})$ at 95% (90%) C.L.

CDF: Calculating the upper Limit

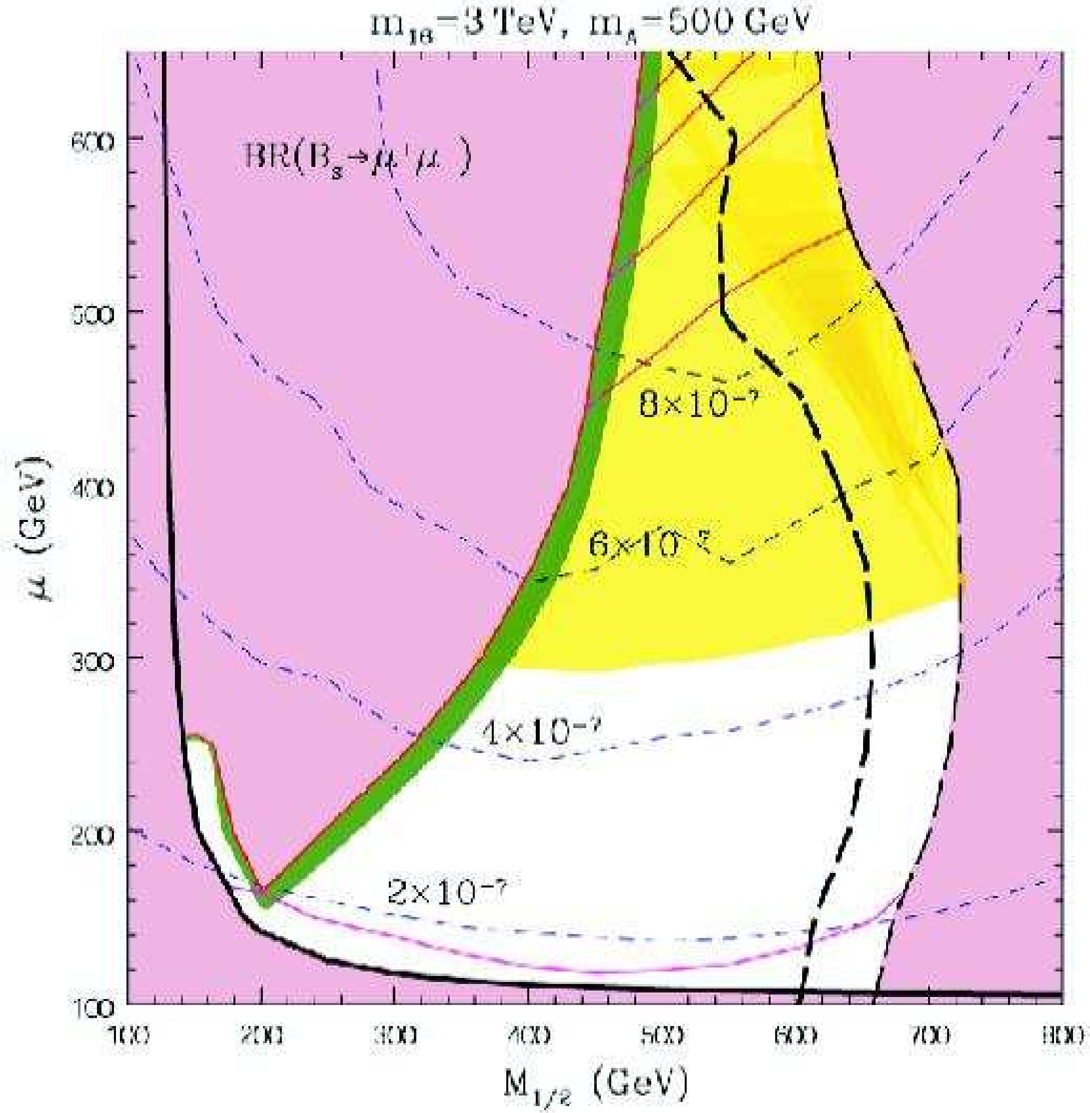
$$\mathcal{B}(B_s \to \mu^+\mu^-) \leq \frac{\sum_n N(n, n_{back})}{2 \cdot \sigma_{B_s} \cdot \alpha \cdot \varepsilon_{total} \cdot \int \mathcal{L}dt}$$

- $N(n, n_{back})$ is the number of candidates
  estimated using a Bayesian approach and including the associated uncertainties
  1 event observed and 1.1 $\pm$0.3 background expected
- σB_s= 0.9μb measured by CDF in RunI
- $\alpha \cdot \varepsilon_{total}$ = 2.0$\pm$0.2%
- $\int \mathcal{L}dt$ = 171 pb^{-1}

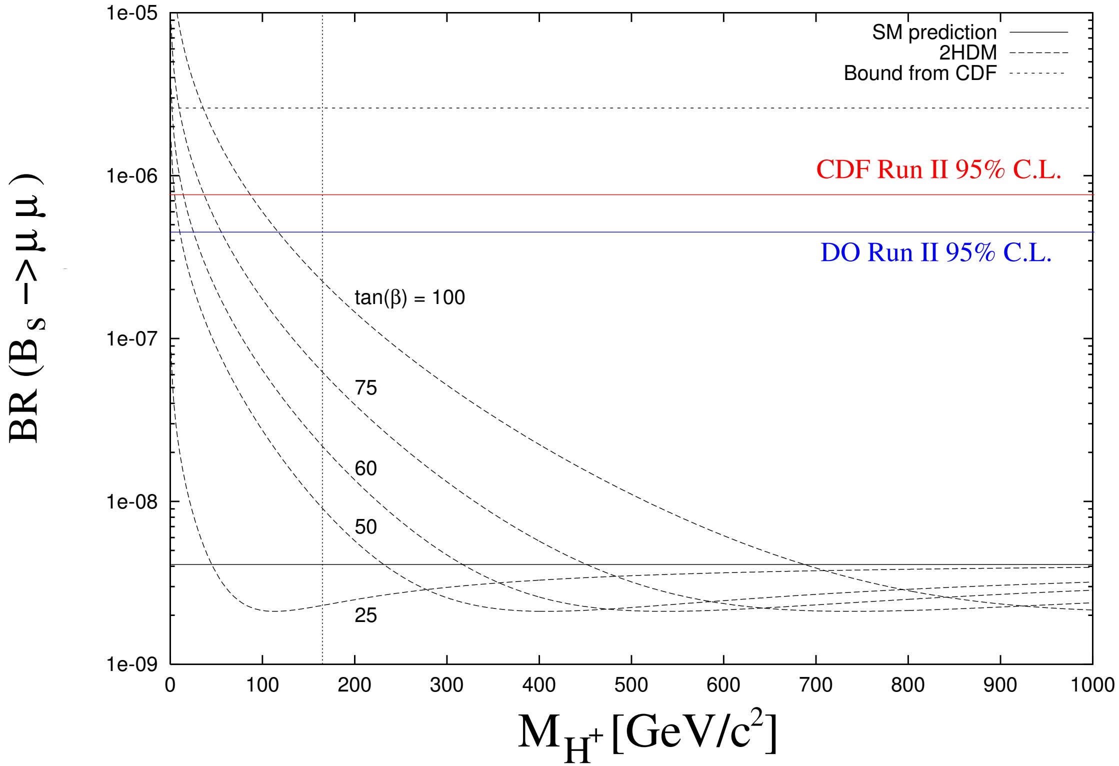
$\mathcal{B}(B_s \to \mu^+\mu^-) \leq 7.5 \cdot 10^{-7}(5.8 \cdot 10^{-7})$ at 95% (90%) C.L.
$\mathcal{B}(B_d \to \mu^+\mu^-) \leq 1.9 \cdot 10^{-7}(1.5 \cdot 10^{-7})$ at 95% (90%) C.L.

Conclusions

- New upper limits on B_s and B_d (CDF only) have been presented
  - CDF: upper limits are
    $\mathcal{B}(B_s \to \mu^+\mu^-) \leq 7.5 \cdot 10^{-7}(5.8 \cdot 10^{-7})$ at 95% (90%) C.L.
    $\mathcal{B}(B_d \to \mu^+\mu^-) \leq 1.9 \cdot 10^{-7}(1.5 \cdot 10^{-7})$ at 95% (90%) C.L.
    published in Phys Rev Lett 93, 032001 (2004)
    Result improved the B_s RunI limit by a factor of 3 and the B_d limit slightly
  - DØ : upper limit is
    $BR(B_s \to \mu^+\mu^-) \ \leq 4.6 \cdot 10^{-7}$ $(3.8 \cdot 10^{-7})$at 95% (90%)CL
    Paper draft is waiting for collaboration approval
    The most stringent result at the moment for the B_s
- Both experiments continue to increase their data samples ...



Dermisek et al hep-ph/0304101


SM prediction
2HDM
Bound from CDF
CDF Run II 95% C.L.
DO Run II 95% C.L.
tan(β) = 100
75
60
50
25
1e-05
1e-06
1e-07
1e-08
1e-09
0
100
200
300
400
500
600
700
800
900
1000
BR (B s -> μ μ)
M H+ [GeV/c2]

Backup slides

DØ : Relative systematic uncertainties to $BR \to \mu^+\mu^-)$

Source	Relative Uncertainty [%]
$\epsilon^{B^\pm}_{\mu\mu K}/\epsilon^{B_s}_{\mu\mu}$	6.9
# of $B^\pm \to J/\psi K^\pm$	5.1
$\mathcal{B}(B^\pm \to J/\psi K^\pm)$	4.0
$\mathcal{B}(J/\psi \to \mu\mu)$	1.7
$f_{b\to B_s}/f_{b\to B^\pm}$	12.7
Background uncertainty	29.7

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