



# Sensitivity analysis of the rare decay

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

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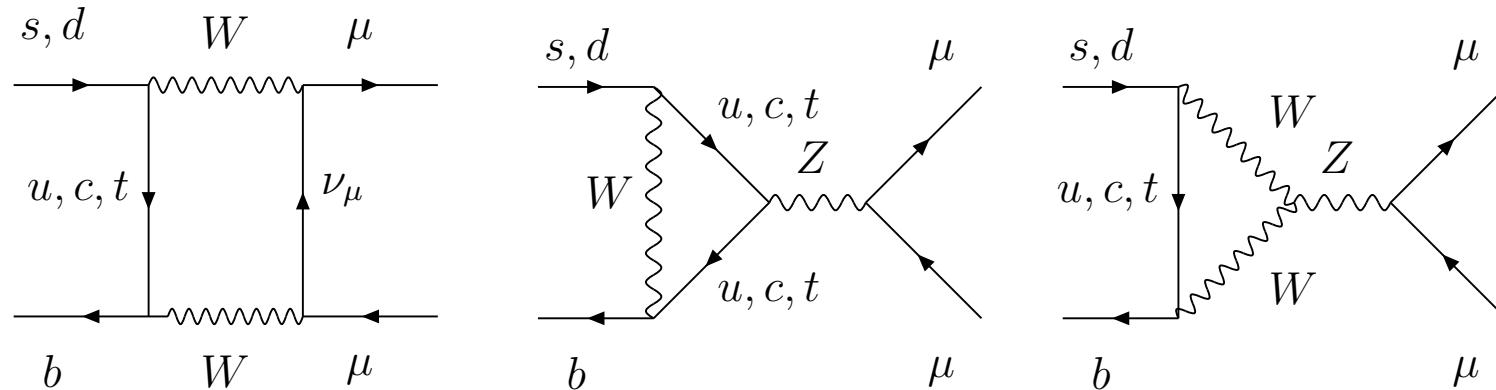
New Perspectives 2004  
4<sup>th</sup> June, 2004

- Theoretical Background
- DØ Experiment at the Tevatron
- Analysis procedure
- Preliminary results
- Conclusions and Outlook



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

Main contributing Standard Model diagrams



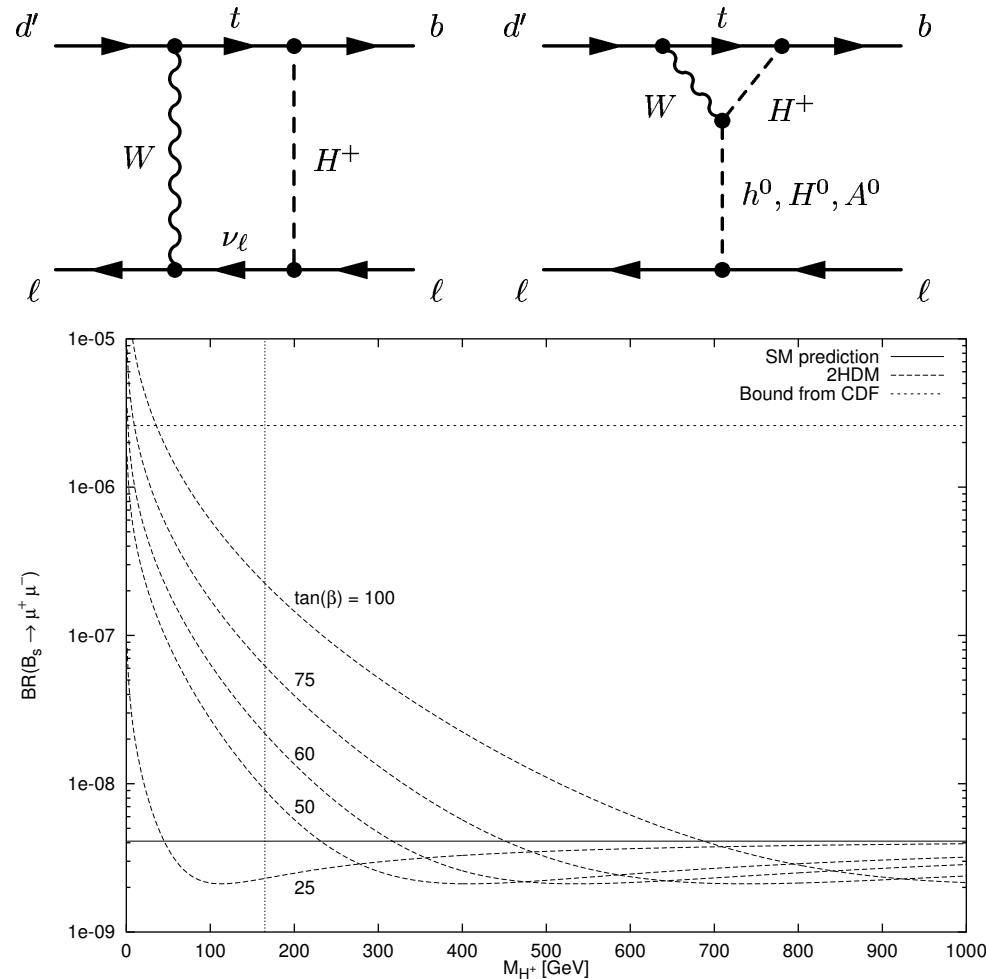
Theoretical predictions

	$BR(B_d \rightarrow l^+l^-)$	$BR(B_s \rightarrow l^+l^-)$
$l = \mu$	$(1.5 \pm 0.9) \cdot 10^{-10}$	$(3.4 \pm 0.5) \cdot 10^{-9}$
$l = \tau$	$(3.1 \pm 1.9) \cdot 10^{-8}$	$(7.4 \pm 1.9) \cdot 10^{-7}$

Experimental upper limits (at 90% (95%) confidence level)

	$BR(B_d \rightarrow l^+l^-)$	$BR(B_s \rightarrow l^+l^-)$
$l = \mu$	$< 1.5(1.9) \cdot 10^{-7}$	$< 5.8(7.5) \cdot 10^{-7}$
$l = \tau$	$< 2.5\%$	$< 5.0\%$

## $B_s \rightarrow \mu^+ \mu^-$ decay in SUSY (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  $b \rightarrow s\gamma$
- R parity violating models can give tree level contributions
- Mode is correlated to  $(g-2)$  in mSUGRA
- Also other models like e.g.  $MSO_{10}SM$  predict large enhancement  $\propto \tan^6\beta$



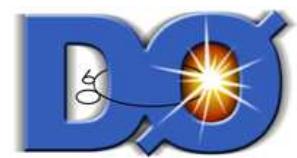
## B physics at the Tevatron

Why rare B physics at the Tevatron ?

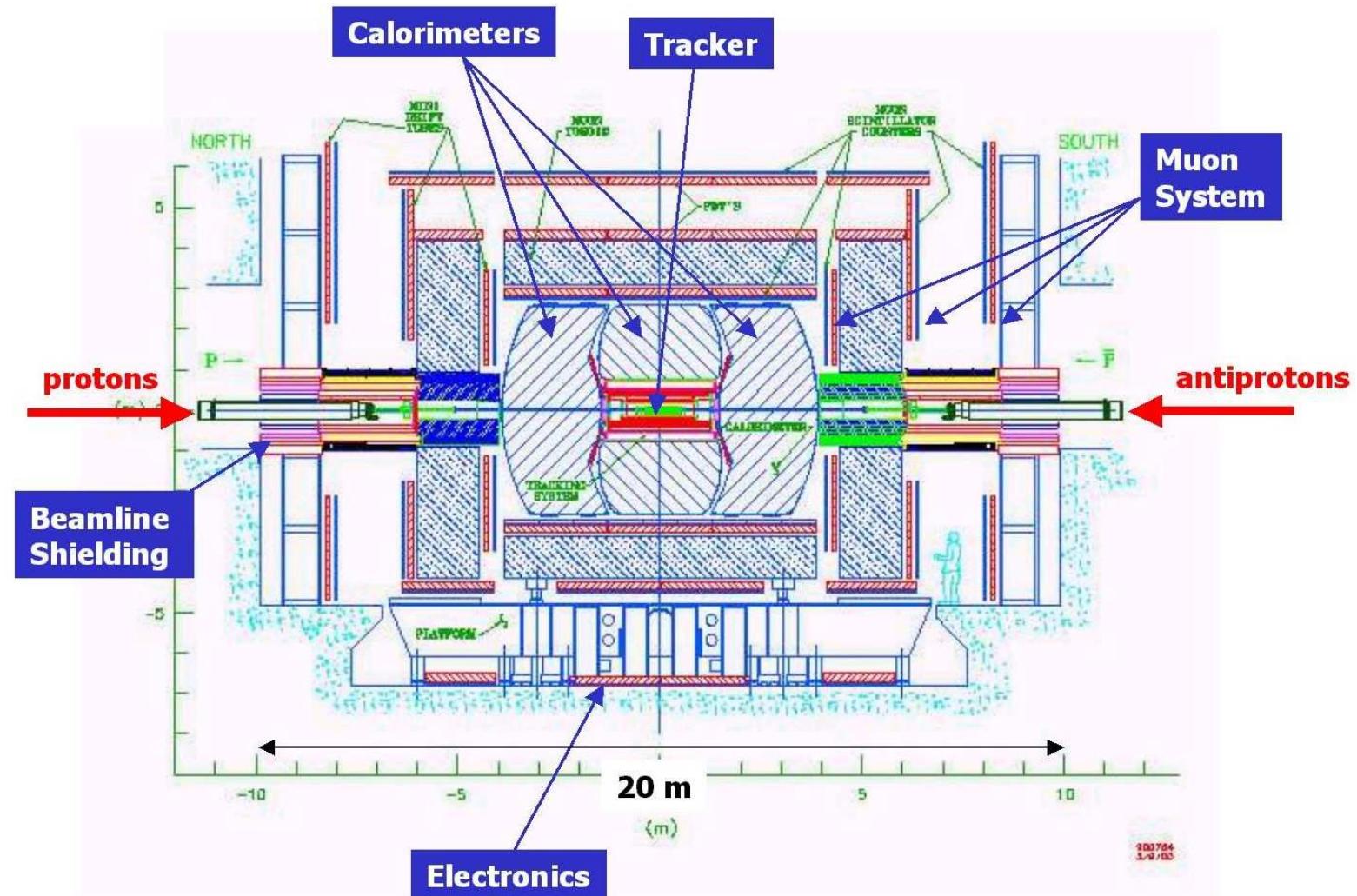
- Producing large numbers of  $b\bar{b}$  pairs
  - $\sigma(p\bar{p} \rightarrow b\bar{b}) = 150\mu\text{b}$  at 2 TeV
  - $\sigma(e^+e^- \rightarrow Z^0 \rightarrow b\bar{b}) = 7 \text{ nb}$
  - $\sigma(e^+e^- \rightarrow \Upsilon(4S) \rightarrow b\bar{b}) = 1 \text{ nb}$
- Expect  $10^{10} b\bar{b}$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

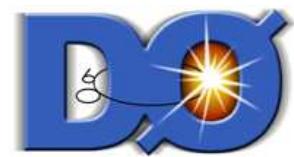
Key points for this analysis at DØ

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

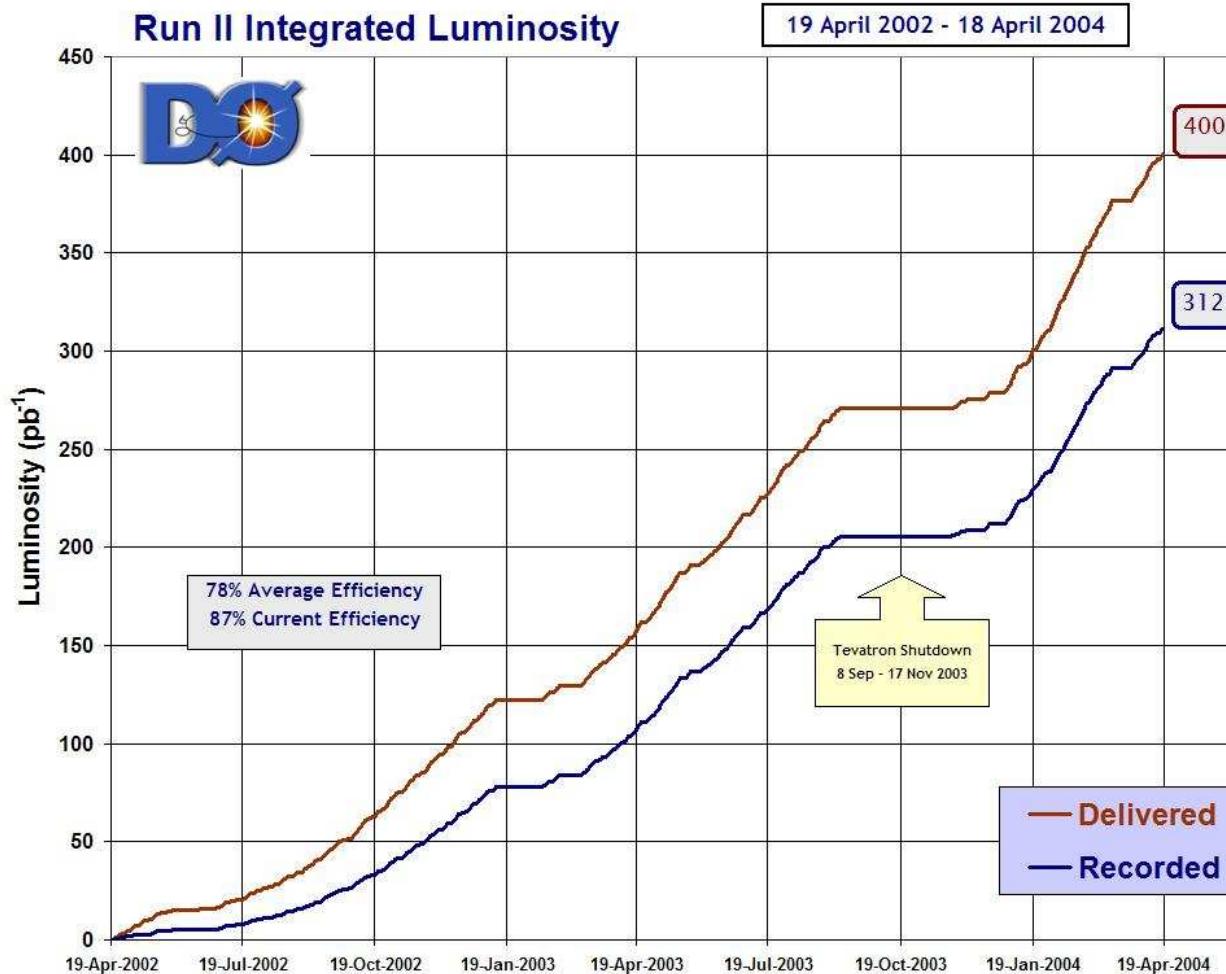


## D $\emptyset$ Detector

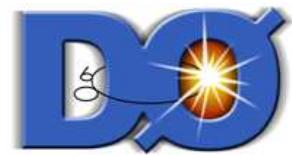




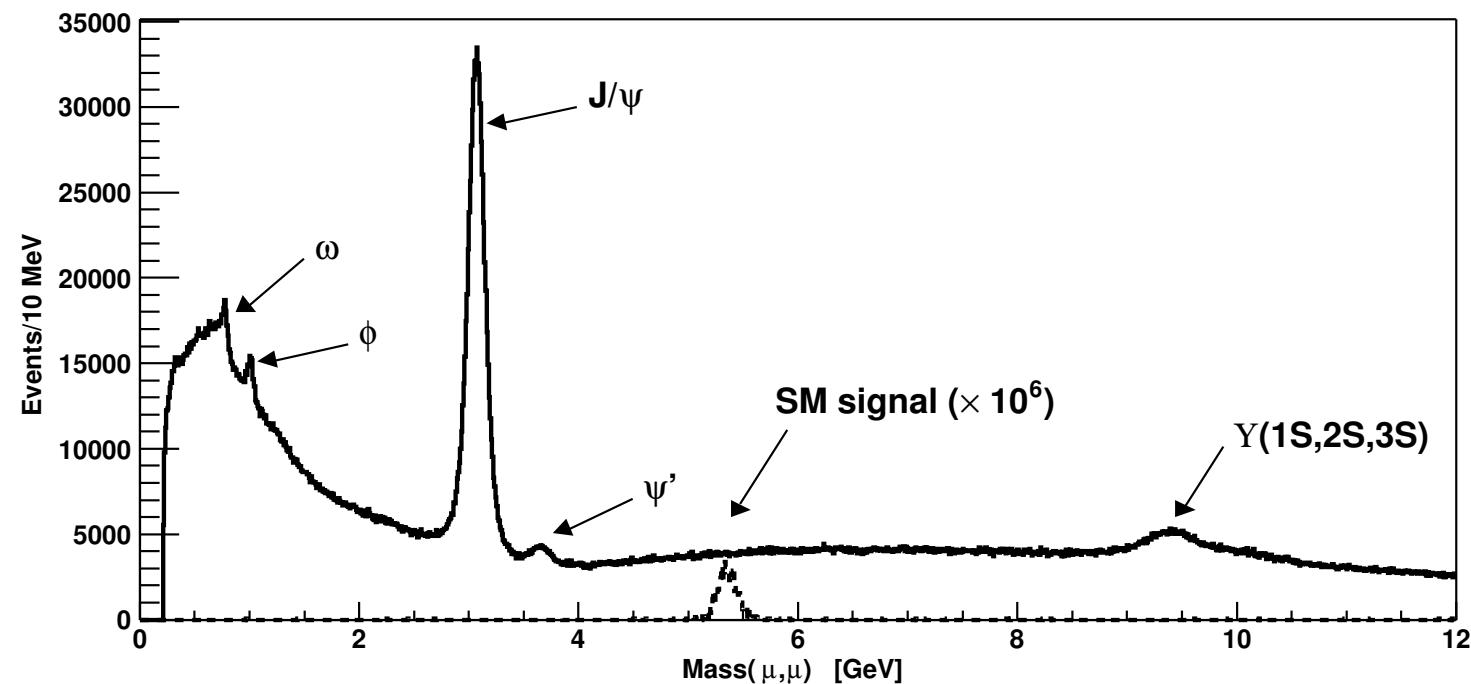
## Integrated Luminosity



Data of Trigger used till winter shutdown gives  $\approx 180\text{pb}^{-1}$



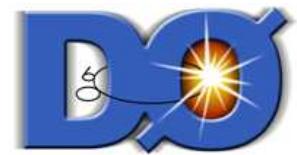
## DiMuon Data sample



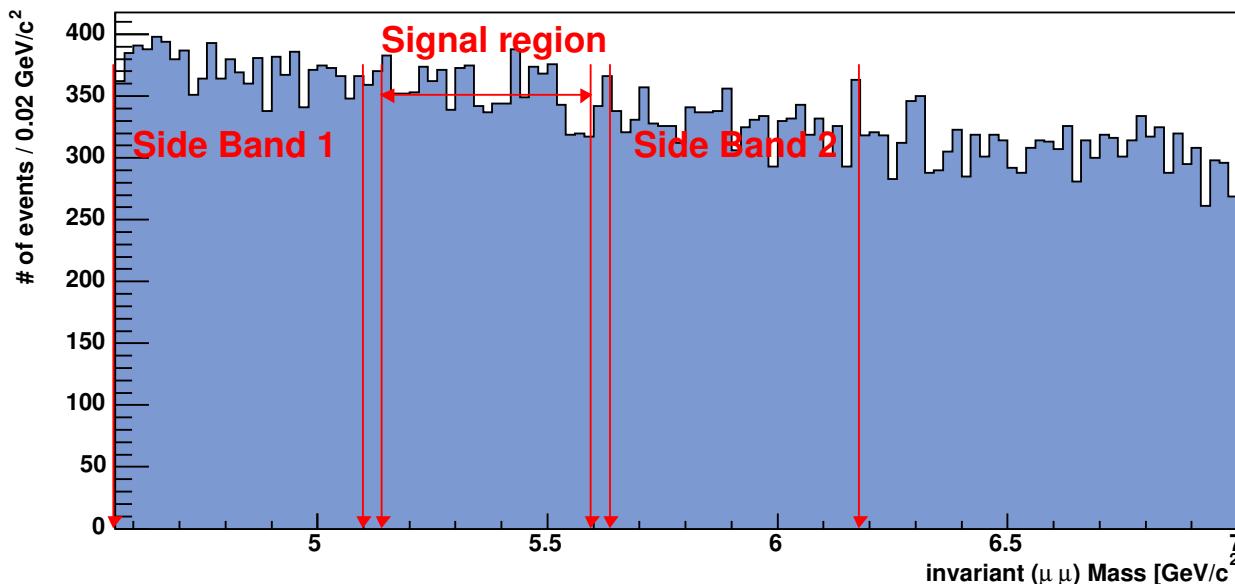


## Selection Cuts

- Cut on Mass region of DiMuon sample  $4.5 < m_{\mu\mu} < 7 \text{ GeV}$
- Two muons with a net charge of zero
- The triggered muons have reconstructed tracks in the tracker
  - at least 3 hits in the Silicon Tracker
  - at least 4 hits in the Fiber Tracker
- The  $\chi^2$  of the vertex fit is smaller than 10
- The measured  $p_T$  of the muons is greater than 2 GeV
- Both muons are at least of medium quality
- A minimum  $p_T$  of the  $B_s$  candidate of 5 GeV is required
- Cut on the significance of the transverse decay length  $\sigma(L_{xy}) < 150\mu\text{m}$

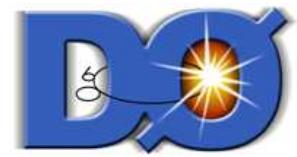


## Selection Cuts II



45k events remain after all these cuts in mass region ( $4.5 - 7 \text{ GeV}/c^2$ ) → use discriminating variables

- Opening angle between the vertex direction and the muon pair  
"Pointing consistency"
- Isolation of the muon pair
- Decay length



## Optimization procedure

- $\approx 80 pb^{-1}$  of Data have been used to optimize cuts
- Perform random grid search of the 3 discriminating variables  
(Use MC event properties as candidate cuts)
  - Signal region for MC is  $m_{B_s} \pm 3 \sigma$  ( $1\sigma = 90$  MeV) (same applies for Data)
  - Side Band 1 from 4.560 GeV to 5.100 GeV (540 MeV)
  - Side Band 2 from 5.640 GeV to 6.180 GeV (540 MeV)
- Keep signal region as a blind box
- Maximize sensitivity of searches for new signals

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

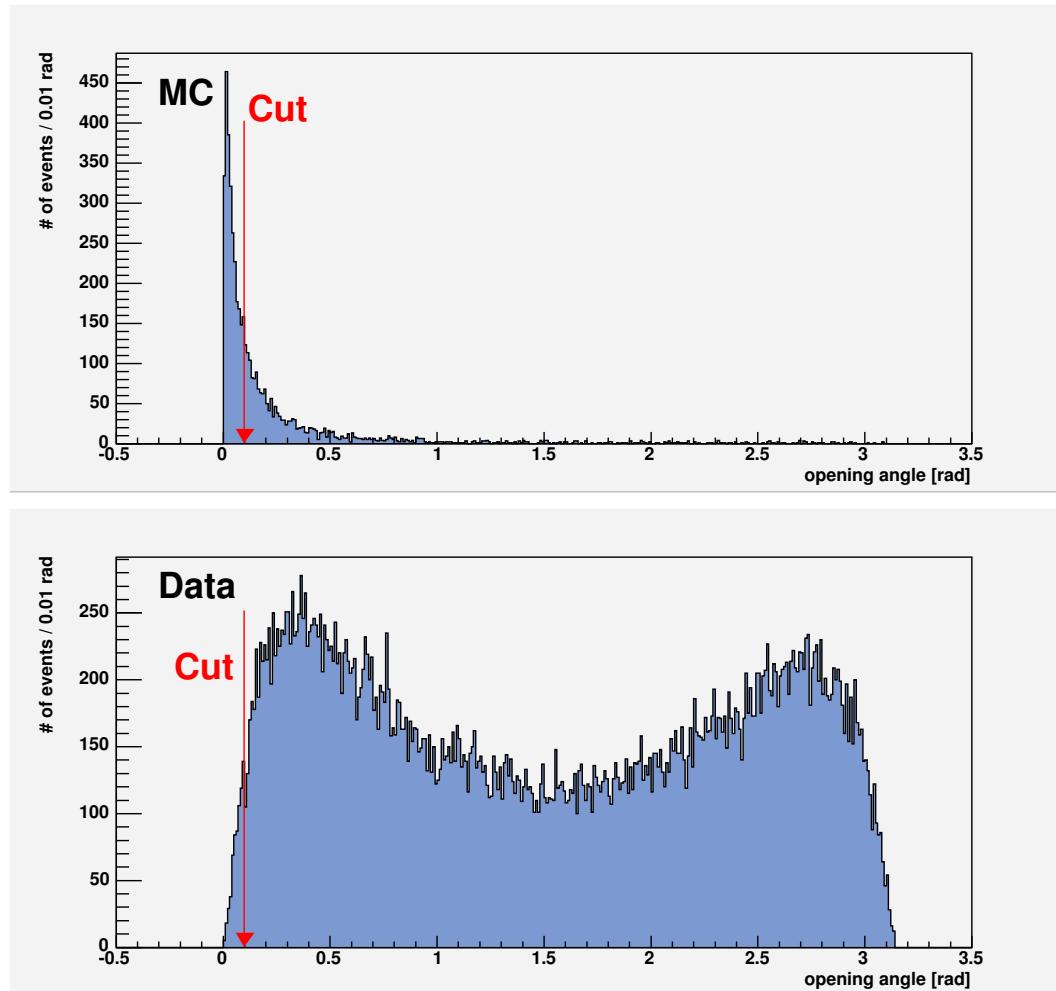
following the proposal from G. Punzi (physics/0308063 test of hypothesis and limits )

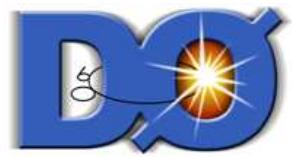
- define  $\alpha$  as significance of the test
  - $a$  is the number of sigmas for  $\alpha$   
(i.e 95%  $\rightarrow 2 \sigma \rightarrow a=2$ )
- $\epsilon_{\mu^+\mu^-}$  is the reconstruction efficiency for  $B_s \rightarrow \mu^+\mu^-$
- $B$  is the expected number of background events in signal region



## Discriminating variables I

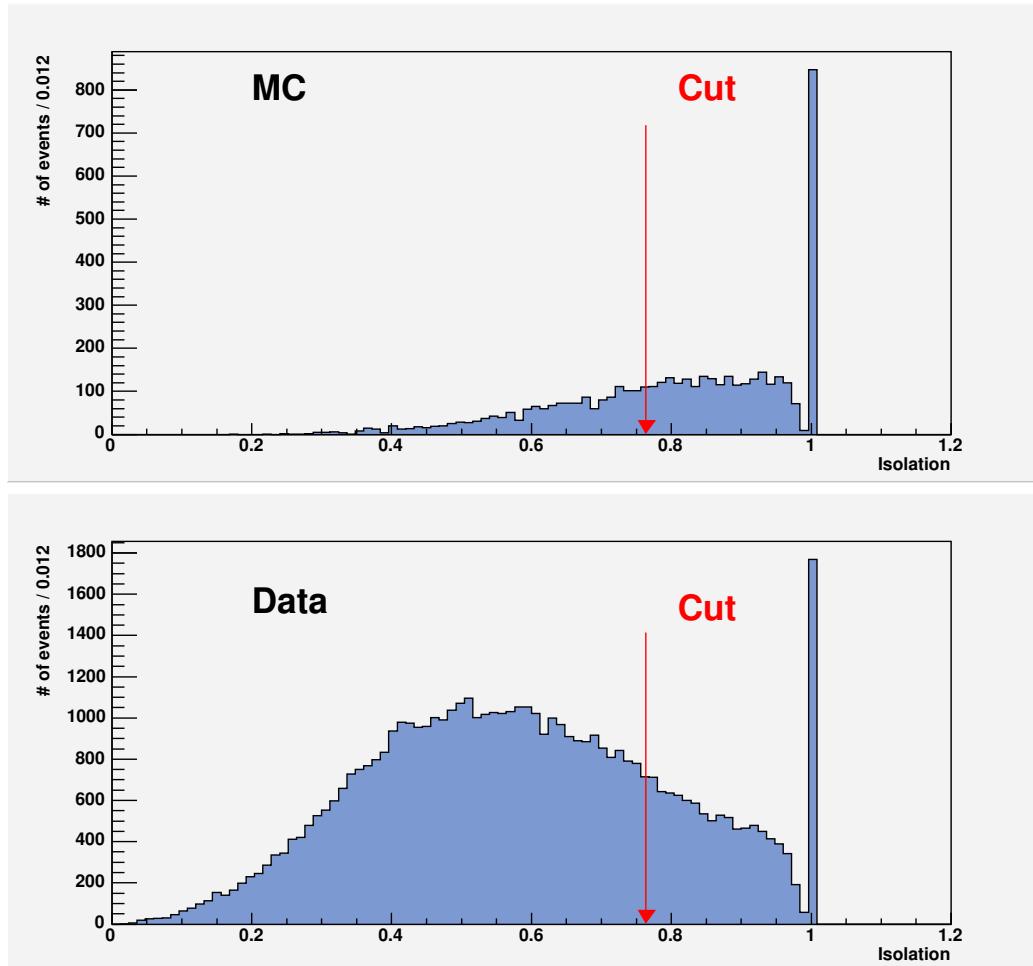
Opening angle  $\alpha < 0.103$  radians





## Discriminating variables II

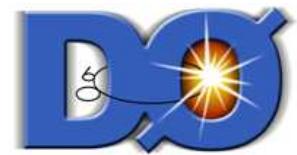
Isolation > 0.765



$$\text{ISO} = \frac{p_{B_s}}{p_{B_s} + \sum_{\text{allTracks}} p_{\Delta R \leq 1}}$$

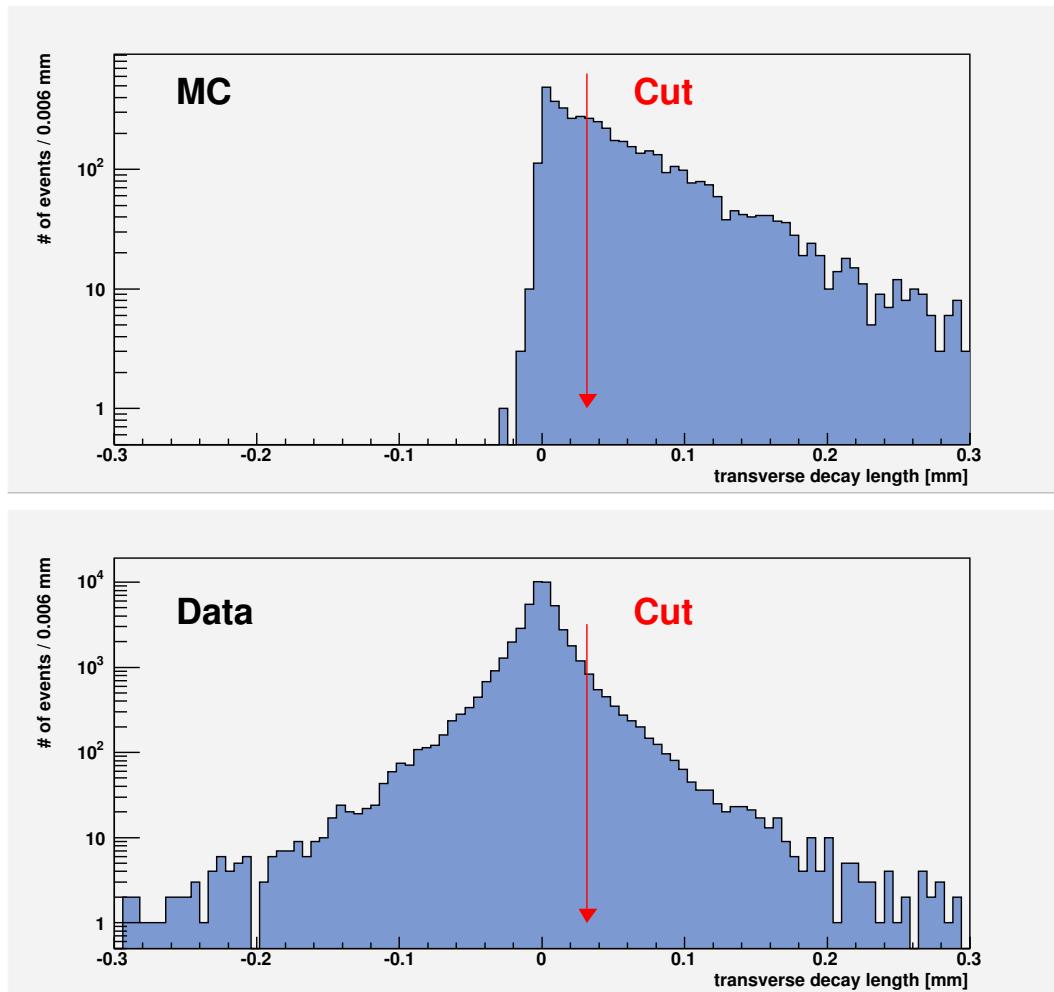
with

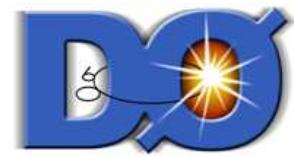
$$\Delta R = \sqrt{(\Delta\Phi)^2 + (\Delta\eta)^2} \leq 1$$



## Discriminating variables III

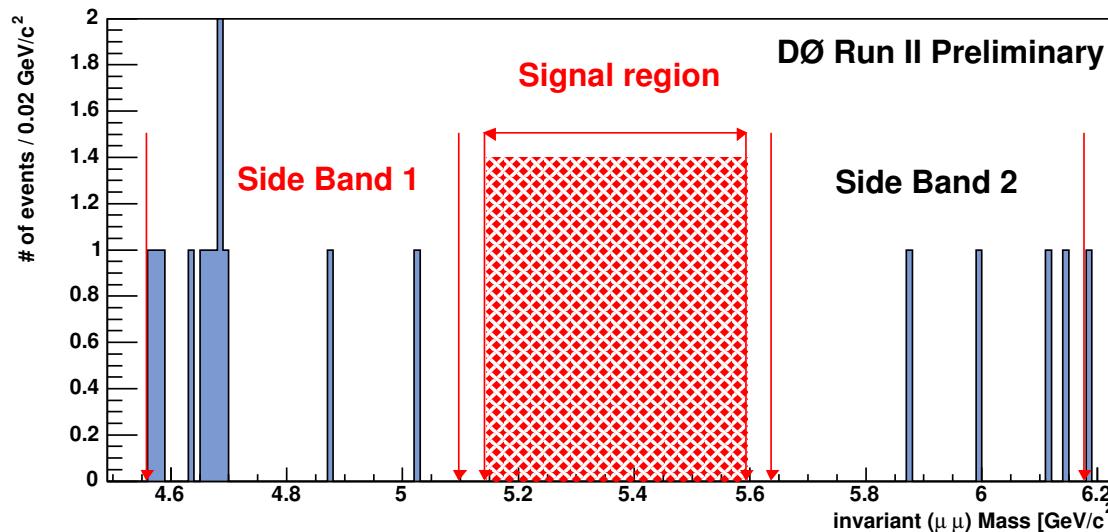
Transverse decay length  $> 0.033$  mm



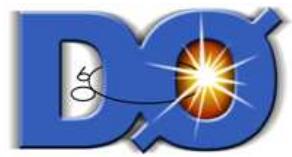


## Surviving events

Cut	MC efficiency [%]	Signal MC	ex. Background
Pointing angle	63.4	1142	$200 \pm 10$
Isolation	80.6	921	$46 \pm 4.5$
Decay length	66.7	615	$7.3 \pm 1.8$

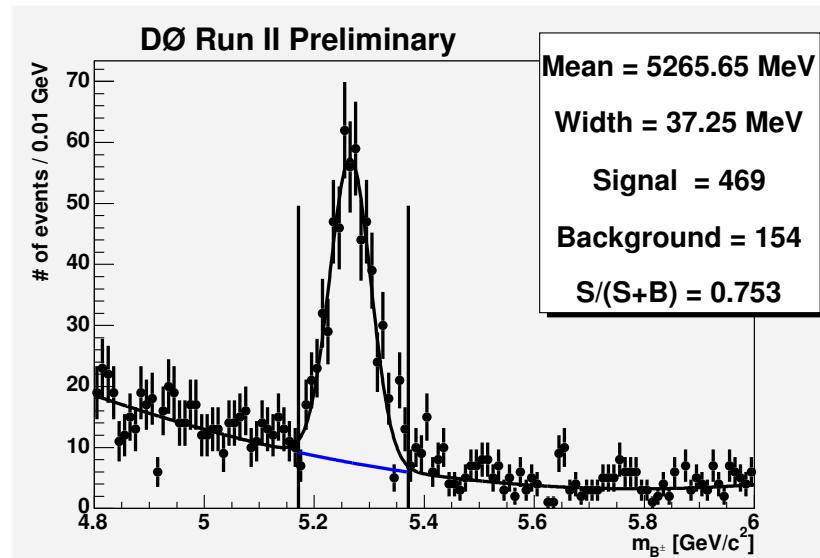


Box not opened!



## Normalizing channel $B^\pm \rightarrow J/\psi K^\pm$

- Use the decay of the  $J/\psi \rightarrow \mu\mu$  to cancel  $\mu\mu$  efficiencies  
(Apply same cuts to  $J/\psi$  like above.)
- Vertex an additional track to the  $J/\psi$
- Additional cuts on the Kaon and  $B^\pm$ 
  - Kaon pt of .9 GeV is required
  - $\chi^2$  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

$$N_{B^\pm} = 469 \pm 32$$



## Calculating the Sensitivity

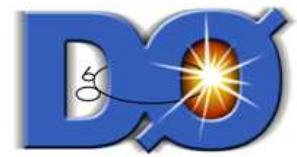
without opening the box

$$BR(B_s \rightarrow \mu^+ \mu^-) = \frac{N_{UL}(n_{obs}, n_B)}{N_{B^\pm}} \cdot \frac{\varepsilon_{\mu\mu K}}{\varepsilon_{\mu\mu}} \cdot \frac{b \rightarrow B^\pm}{b \rightarrow B_s} \cdot BR(B^\pm \rightarrow J/\psi K^\pm) \cdot BR(J/\psi \rightarrow \mu\mu)$$

- $N_{UL}(n_{obs}, n_B)$  is the Upper Limit calculated using the Feldman-Cousins method
- $N_{B^\pm}$  is the number of accepted  $B^\pm \rightarrow J/\psi K^\pm$  events  
 $N_{B^\pm} = 469 \pm 32$  events
- $\varepsilon_{\mu\mu}$  and  $\varepsilon_{\mu\mu K}$  are reconstruction efficiencies  
 $\varepsilon_{\mu\mu} = (5.58 \pm 0.21) \cdot 10^{-4}$  and  $\varepsilon_{\mu\mu K} = (4.33 \pm 0.17) \cdot 10^{-4}$
- Correction factor for fragmentation  $\frac{b \rightarrow B^\pm}{b \rightarrow B_s} = 3.91 \pm 0.72$  PDG

Expected average upper limit is calculated via

$$\langle BR(B_s \rightarrow \mu^+ \mu^-) \rangle = \sum_{n_{obs}=0}^{\infty} BR(n_{obs}, n_B) \cdot \frac{n_B^{n_{obs}}}{(n_{obs})!} \cdot \exp(-n_B)$$



## Preliminary Results RGS

$$\langle BR(B_s \rightarrow \mu^+ \mu^-) \rangle = 9.1 \cdot 10^{-7} \text{ at 95% CL}$$

Folding in the uncertainty of the background and the signal efficiency  
(MC integration with a gaussian background and efficiency as a log-normal distribution)

$$\langle BR(B_s \rightarrow \mu^+ \mu^-) \rangle = 1.0 \cdot 10^{-6} \text{ at 95% CL}$$

Relative systematic uncertainties to  $\langle BR(B_s \rightarrow \mu^+ \mu^-) \rangle$

Source	Relative Uncertainty [%]
$\mathcal{B}(B^\pm \rightarrow J/\psi K^\pm)$	4
$\mathcal{B}(J/\psi \rightarrow \mu\mu)$	2
$b \rightarrow B_s, b \rightarrow B^\pm$	15
MC stat for $B^\pm \rightarrow J/\psi K^\pm$	4
# of $B^\pm \rightarrow J/\psi K^\pm$	7
cut efficiency for $\alpha$	5



## Conclusions

- Expected average upper limit (statistical sensitivity) is  
 $\langle BR(B_s \rightarrow \mu^+ \mu^-) \rangle = 1.0 \cdot 10^{-6}$  at 95% CL
- The box has NOT been opened yet
  - Reoptimisation still in progress - testing other discriminating variables
  - Opening angle between muons
  - Isolation of muons individually
  - Optimizaztion of mass window
- More Data will be added