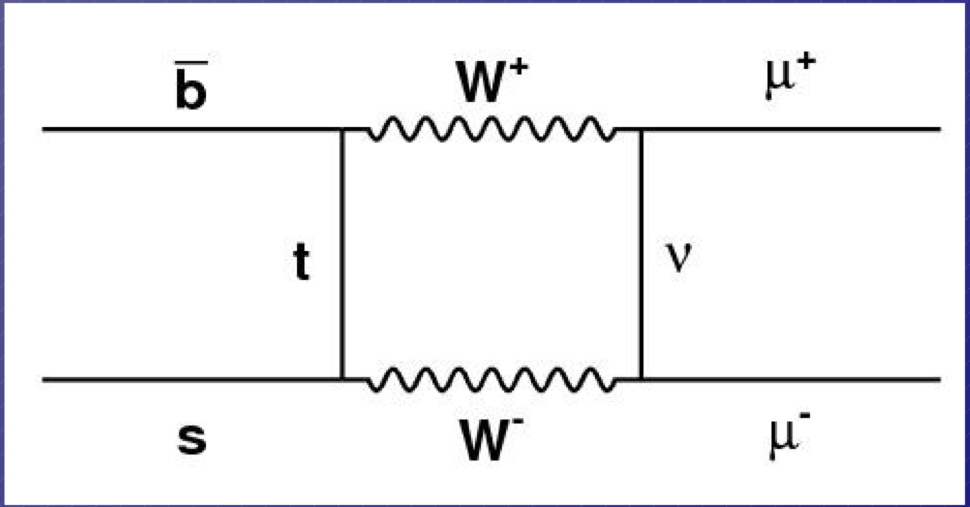
Search for the decay $B_s \to \mu\mu$ at D0

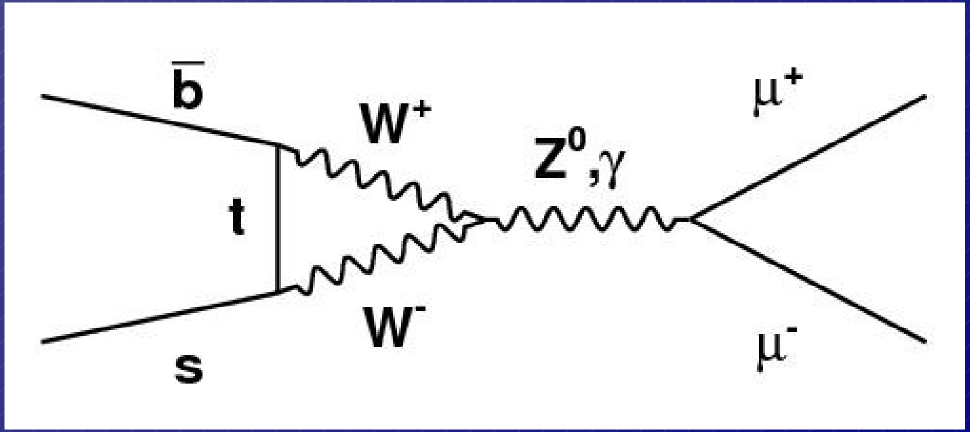
Marj Corcoran for the D0 collaboration
DPF August 2013

Search for the decay $B_s \rightarrow \mu\mu$

This process is highly suppressed in the SM

- FCNC
- Helicity suppressed





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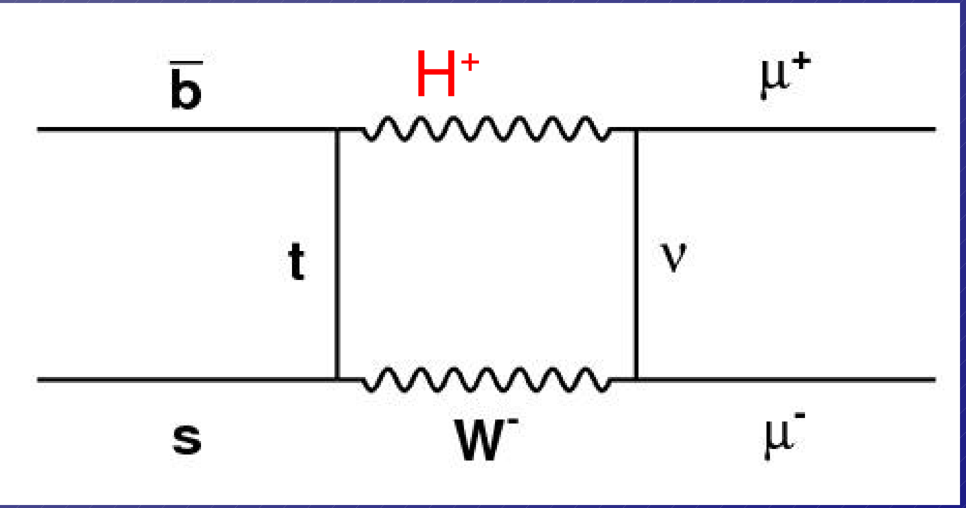
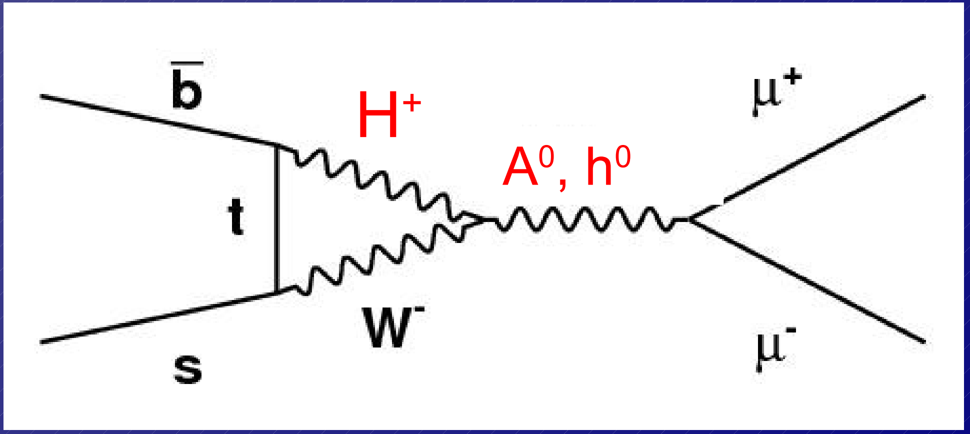


Expected BR is $3.5 \pm 0.2 \times 10^{-9}$

But almost every BSM scenario can enhance this decay rate.

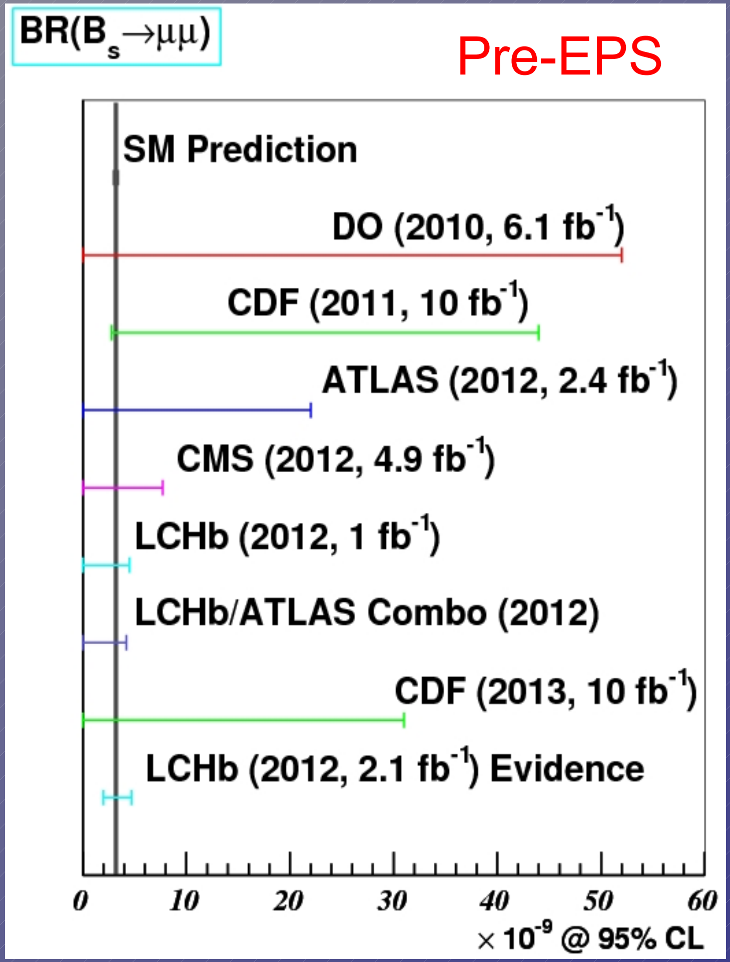
Some models suppress it further.

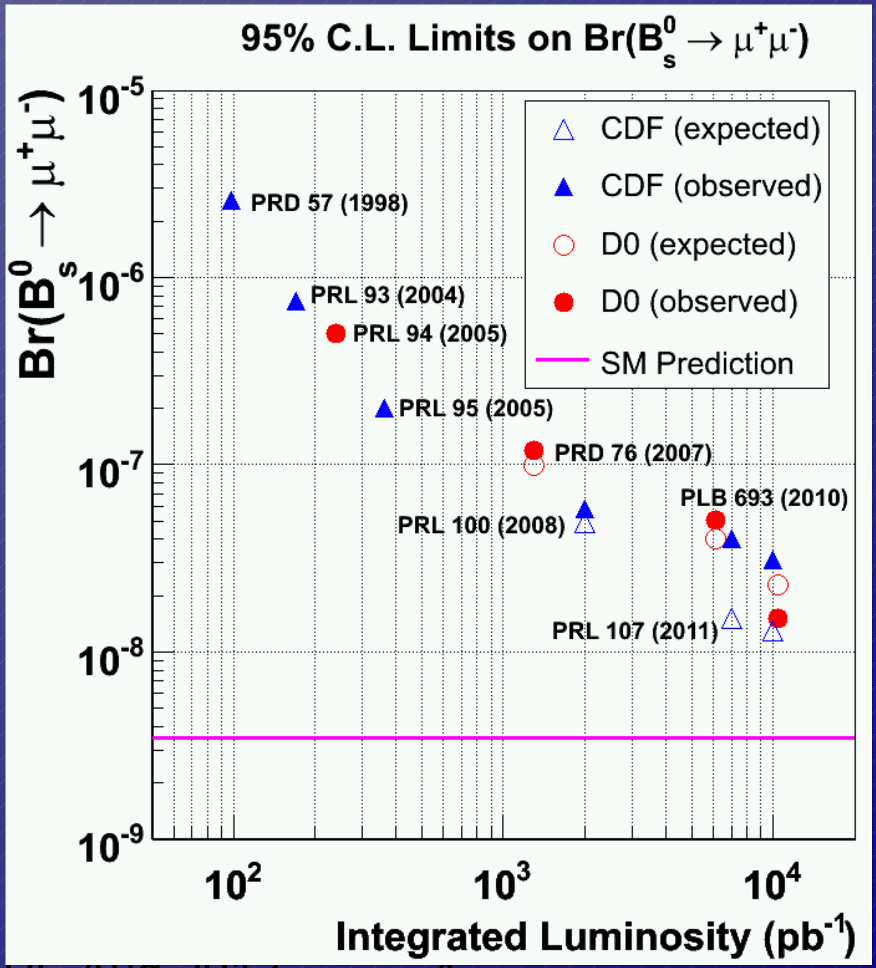


A promising place to look for new physics!

Search for the decay $B_s \to \mu\mu$

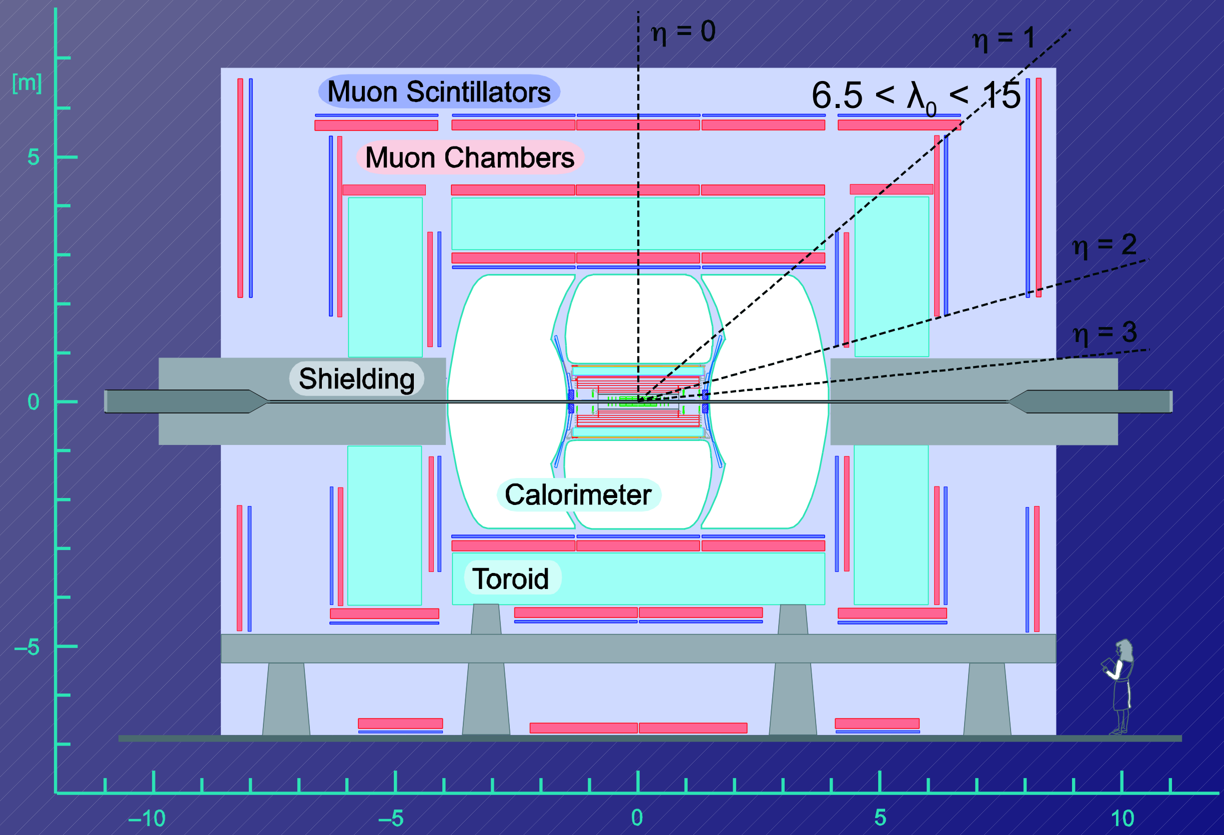
There is a long history of searches for this decay, at the Tevatron and earlier. This is the final result from D0.





The D0 detector

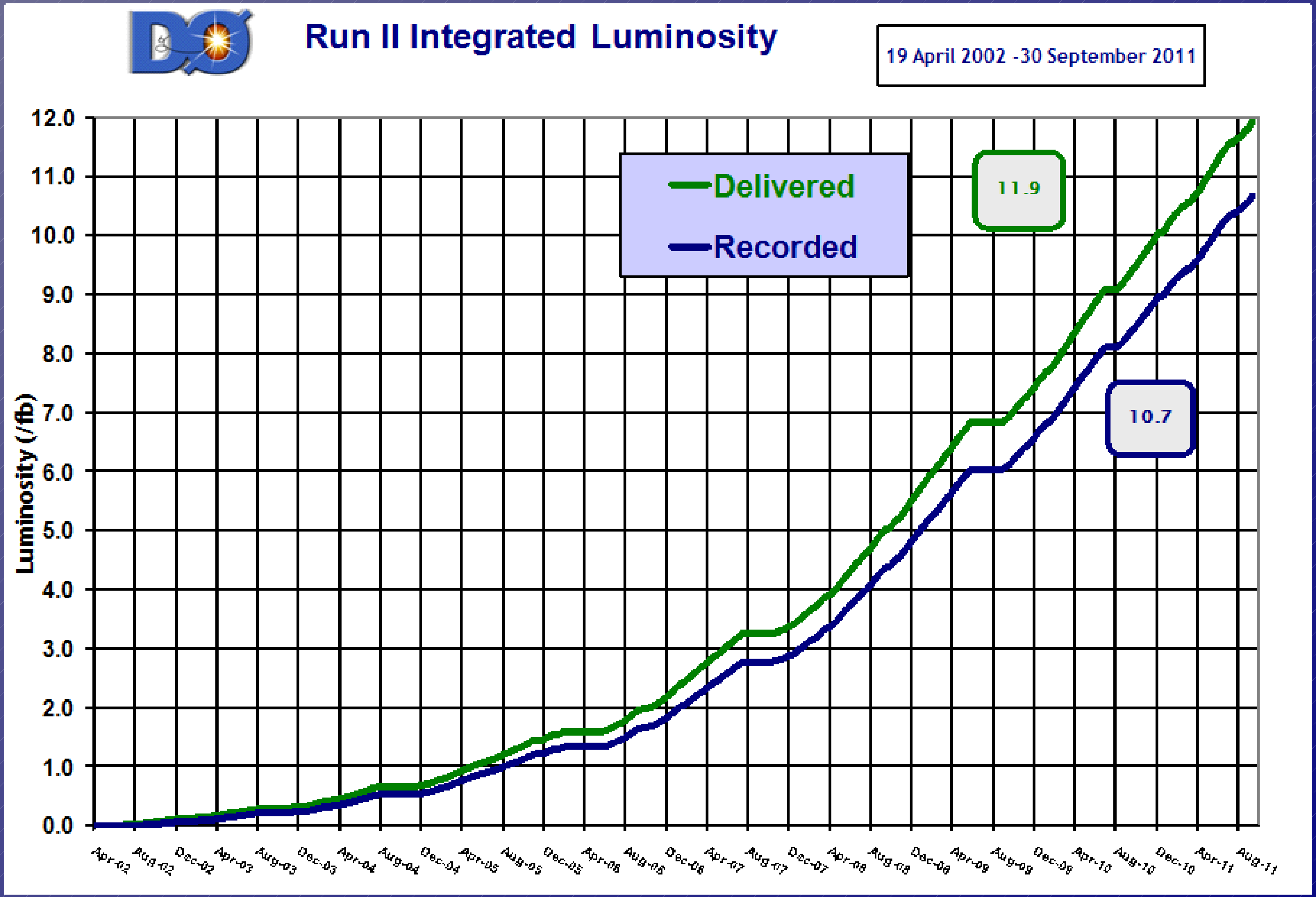
The D0 detector is especially well-suited to final states with muons, due to the large coverage of the muon system ($|\eta|<2$) and the large number of interactions lengths in our calorimeter and muon system.



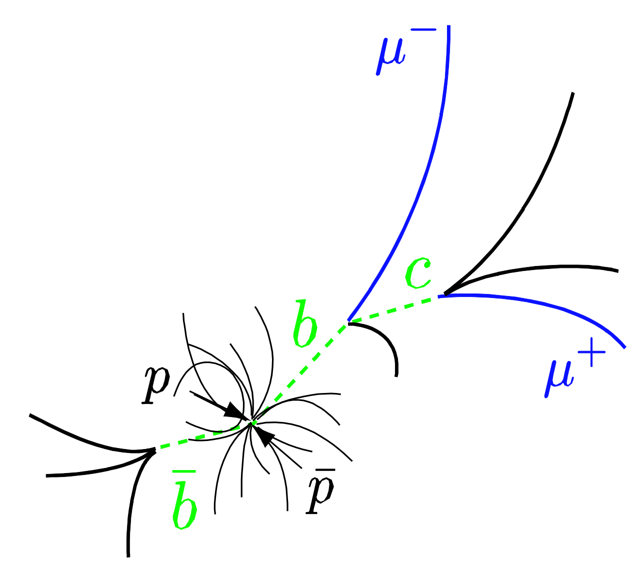
Tevatron data set

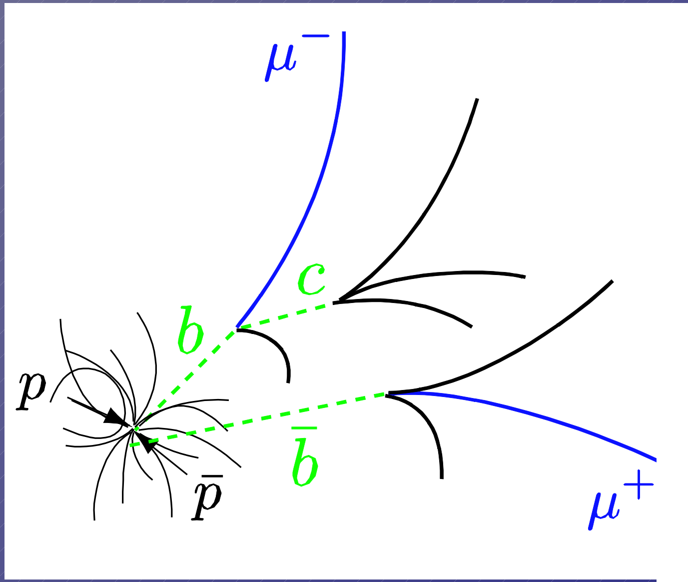
This result represents the full D0 RunII dataset 10.4 fb^{-1}.

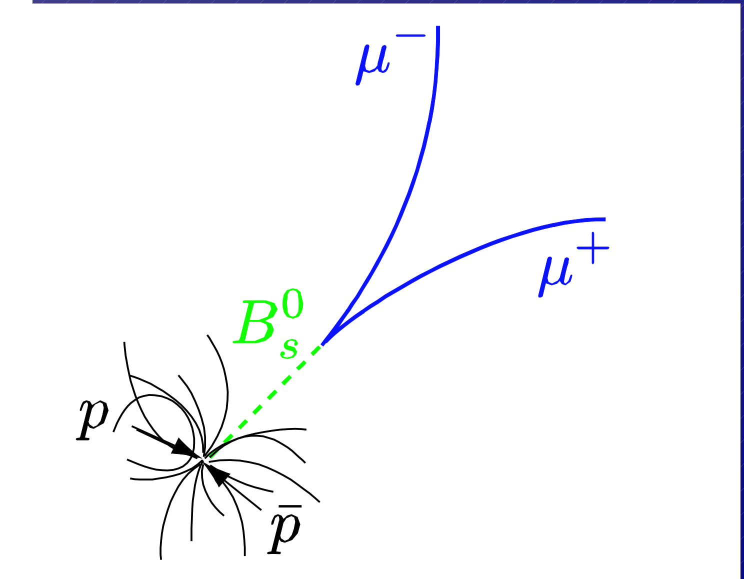
Thanks to Tevatron operations!



Search for the decay $B_s \to \mu\mu$







Understanding the background is the key

There are two main sources of background
- sequential decays
- double-b decays

Signal

Analysis overview

Blind analysis

- Total dimuon mass range studied was 4.0-7.0 GeV
- The mass range 4.9 to 5.8 GeV was blinded.
- The signal region was 5.15 to 5.55 GeV, the rest a control region

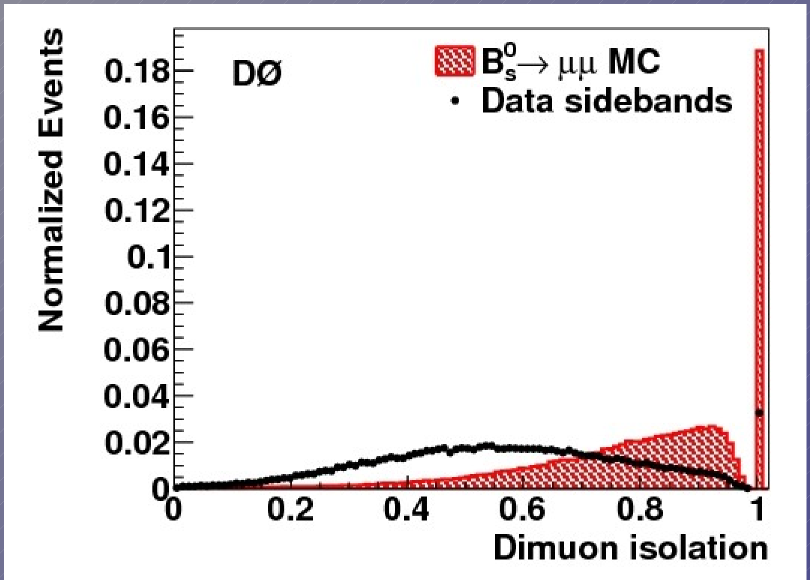
Understand the background as thoroughly as possible.

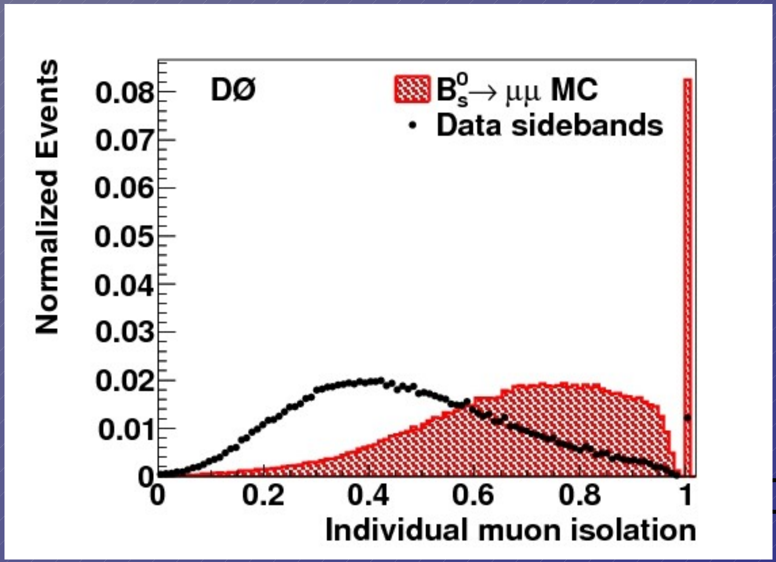
Use a multivariate method (we used a Boosted Decision Tree from TMVA). Signal MC and data side bands used for training.

The normalization mode $B^{\pm} \rightarrow J/\psi K^{\pm}$ was used to determine the number of $B_s \rightarrow \mu\mu$ decays expected.

Estimate signal and background, confirm with the control region first.

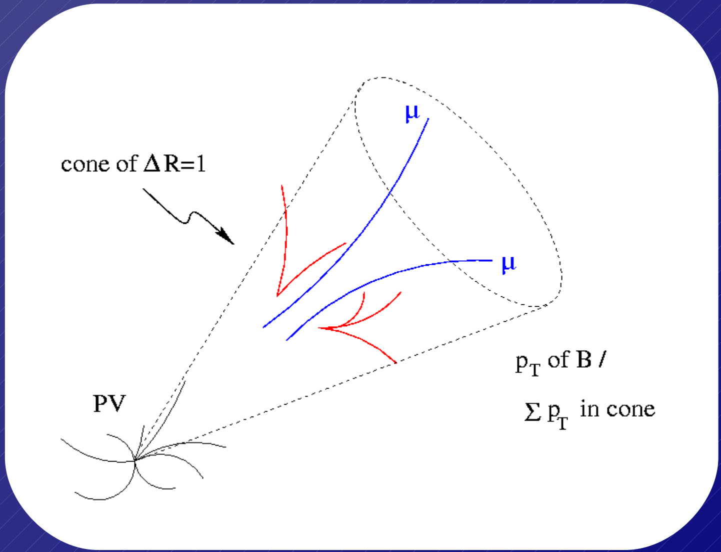
Some standard tools



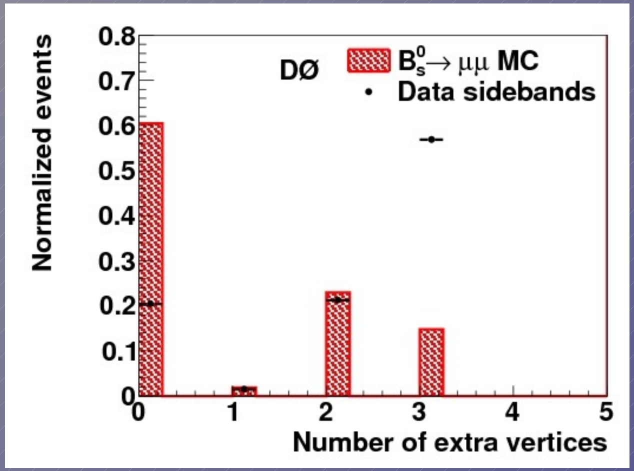


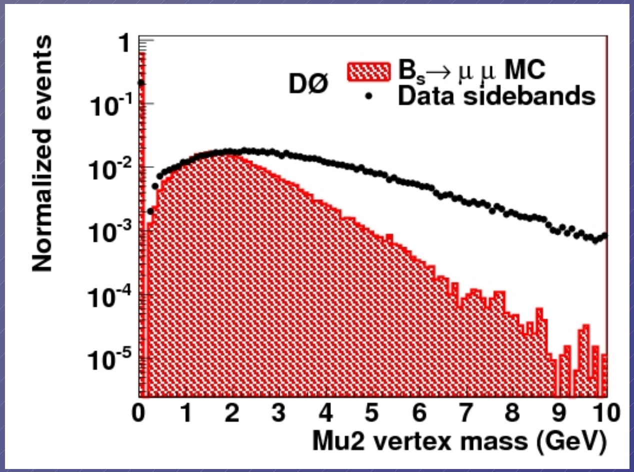
Dimuon isolation

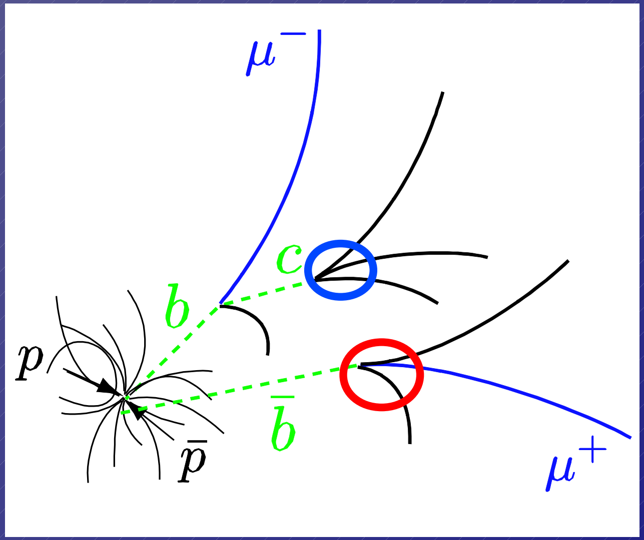
We also look at the isolation cone around each muon individually.



Some not-so-standard tools







Search for vertices with one of the muons and other nearby tracks

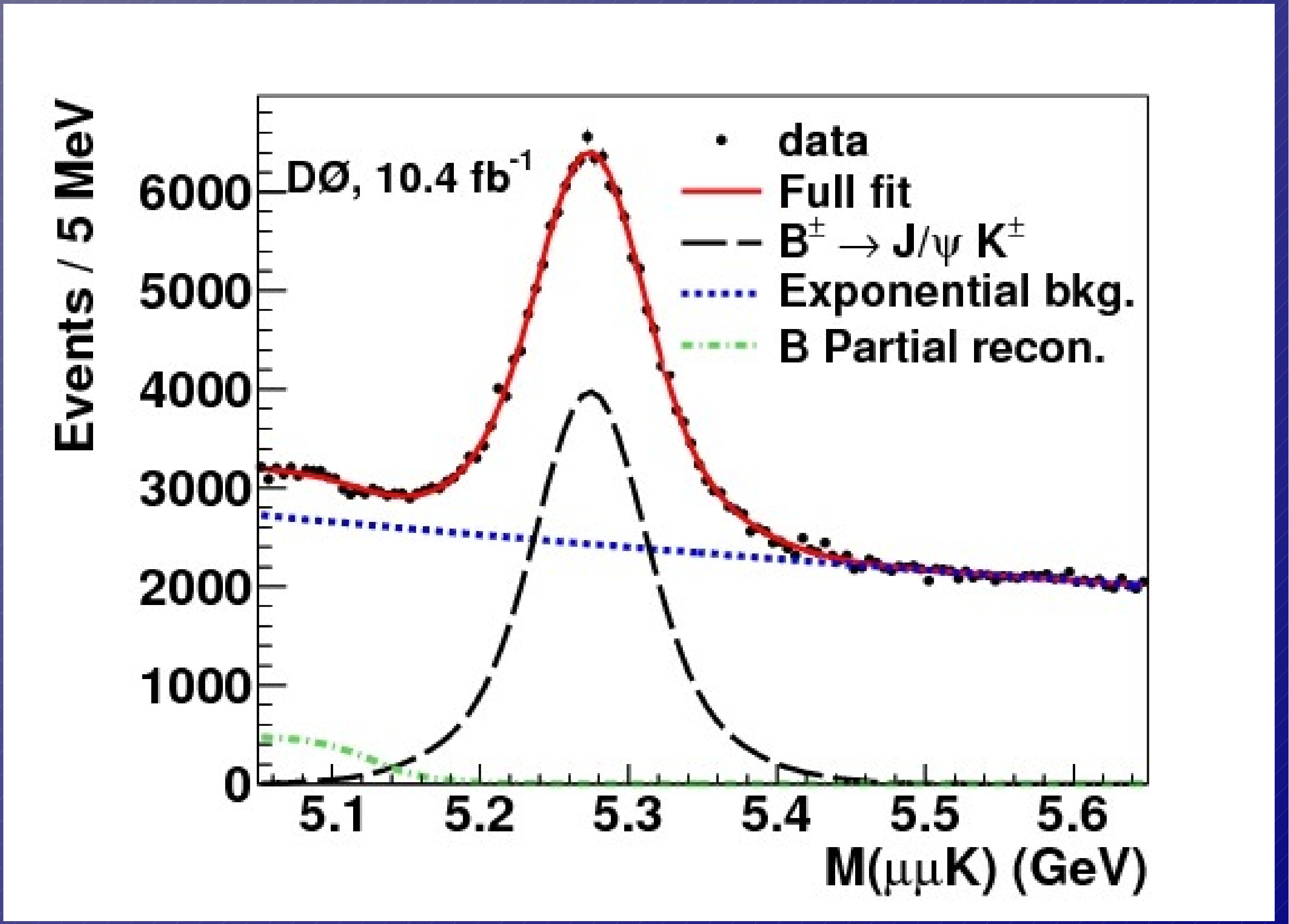
Search for additional vertices close to the dimuon vertex

Normalization Mode

Normalization mode is $B^{\pm} \rightarrow J/\psi\ K^{\pm}$ with $J/\psi \rightarrow \mu\mu$

We reconstruct about 85K such decays.

Used to determine sensitivity as well as validate Monte Carlo



Single Event Sensitivity

$$\mathrm{SES} = \frac{1}{N(B^{\pm})} \times \frac{\epsilon(B^{\pm})}{\epsilon(B_s^0)} \frac{f(b \to B^{\pm})}{f(b \to B_s^0)} \times \mathcal{B}(B^{\pm} \to J/\psi K^{\pm}) \times \mathcal{B}(J/\psi \to \mu^+\mu^-)$$

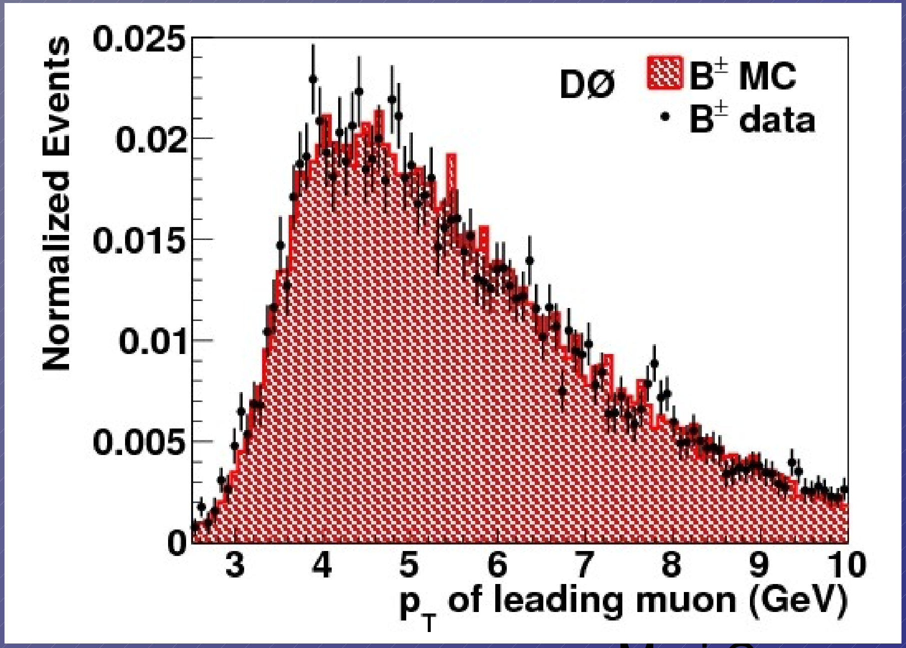
The single event sensitivity is the BR at which we expect one event in the dataset.

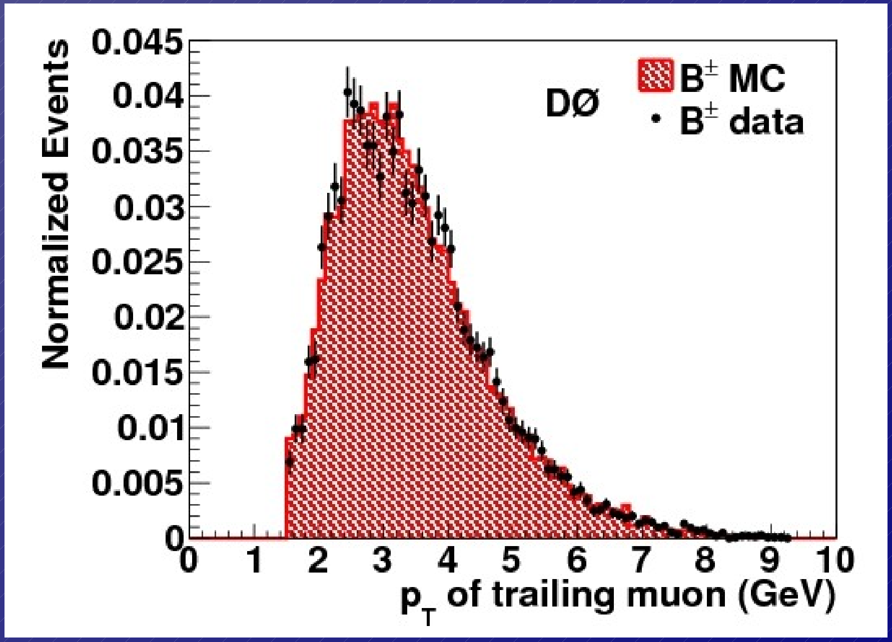
Ingredients are:
Number of $B^{\pm}$ decays seen
Efficiency ratio
Fragmentation fraction ratio
Branching ratios

We expect 10.4 ± 1.1 signal events in our dataset before BDT cuts, at the SM branching ratio

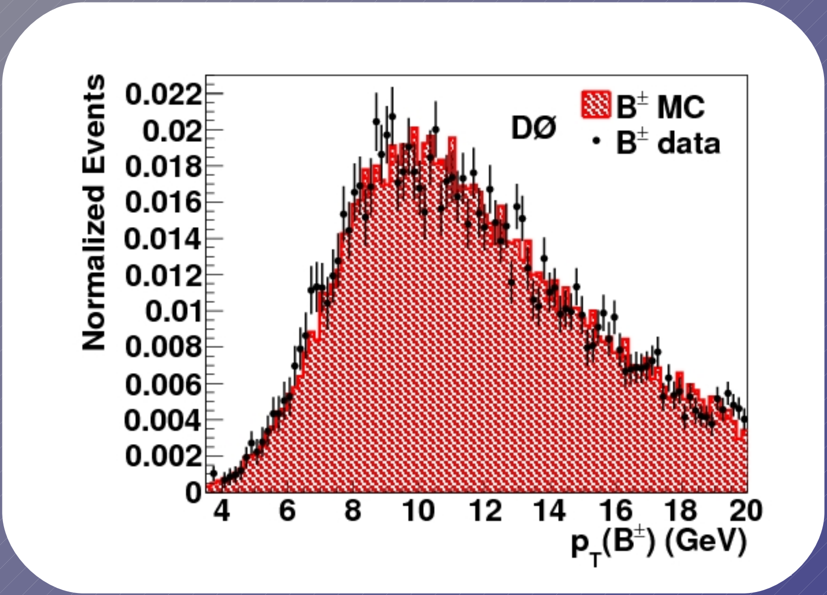
Monte Carlo trigger corrections

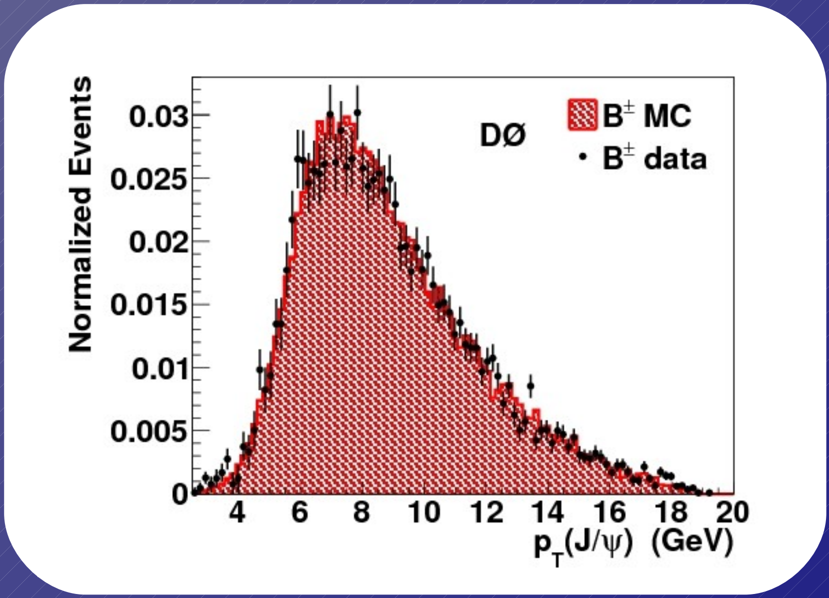
The triggers are single and dimuon triggers which are not modeled in the Monte Carlo. The MC muon p_T distributions must be weighted to correct for the trigger. Normalization mode is used to determine the weights and to validate the procedure.

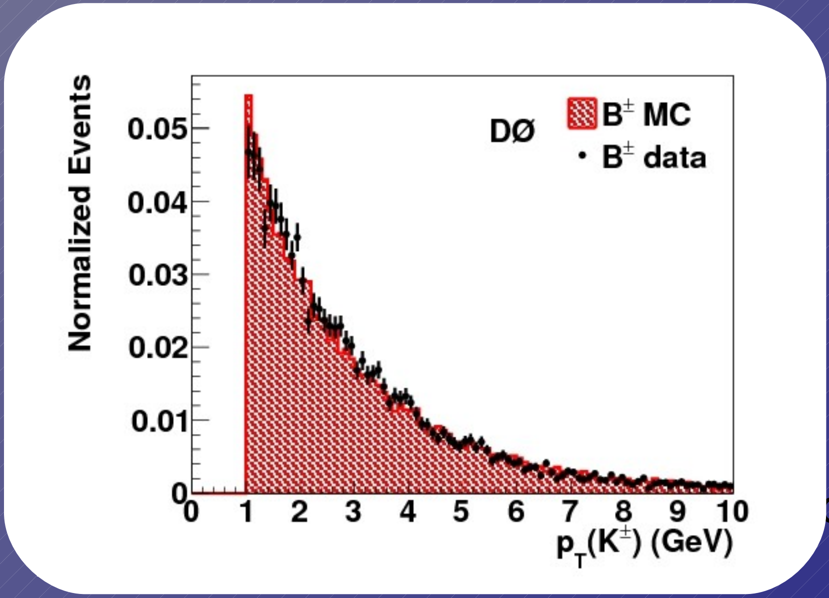




Monte Carlo Validation

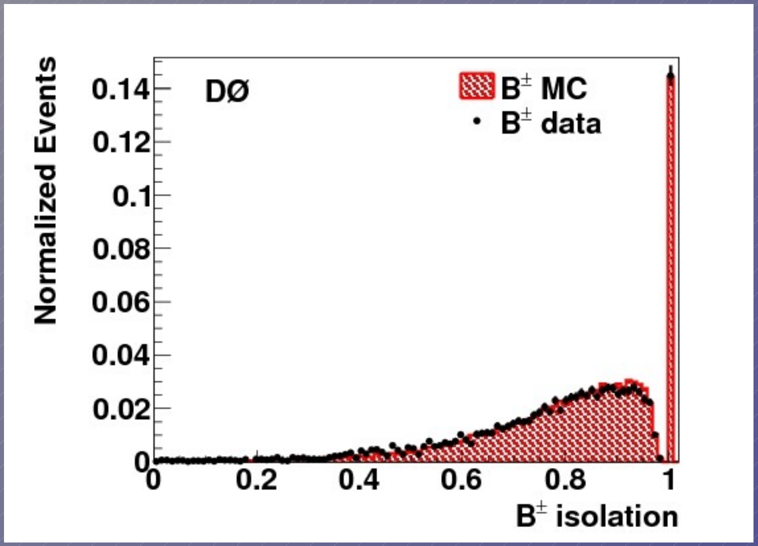


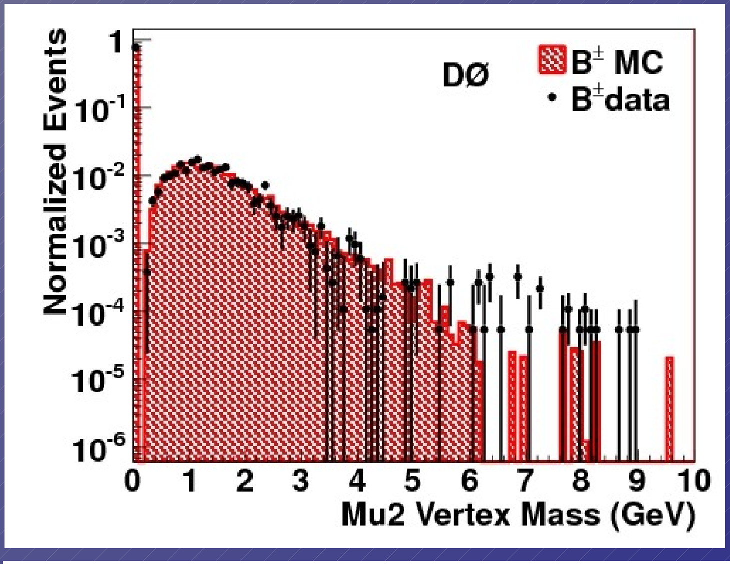


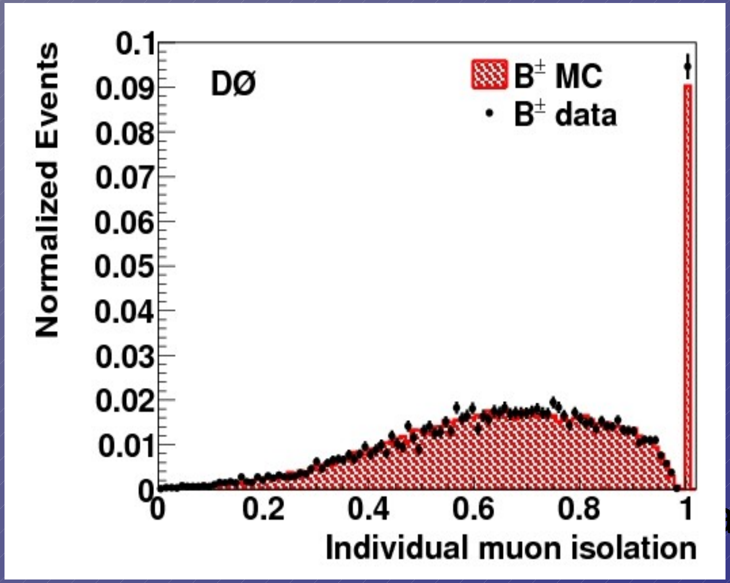


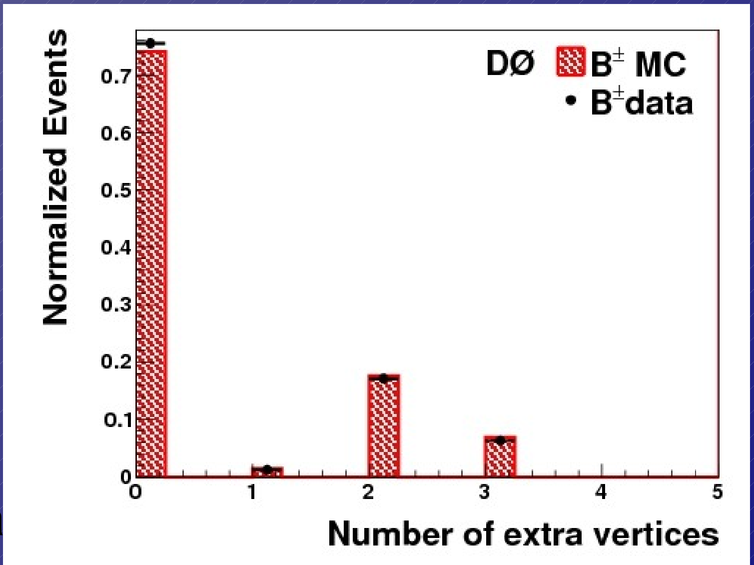
After the trigger correction, other momentum distributions agree well

Monte Carlo Validation





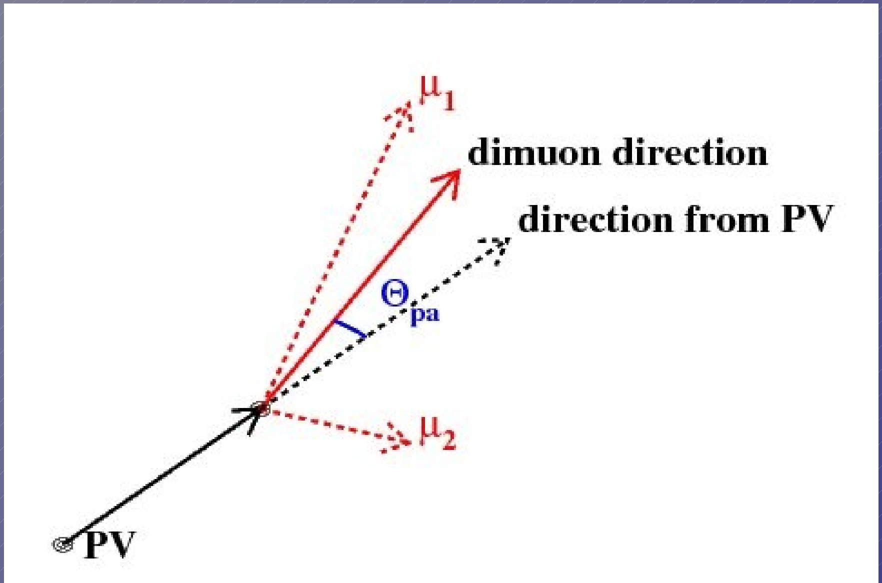


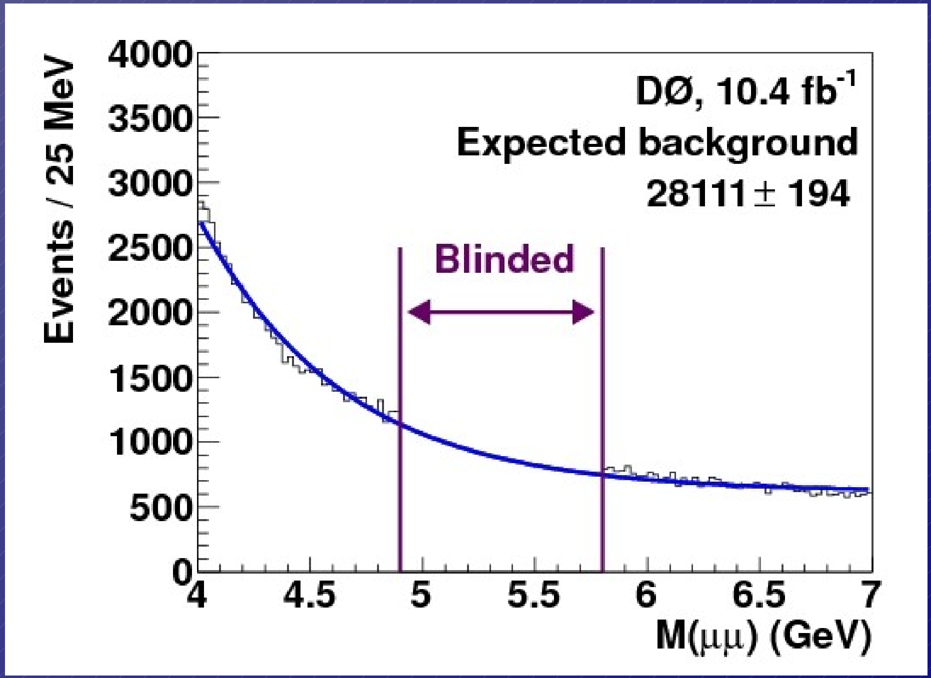


We checked all the variables used in the BDT for agreement between data and MC in the normalization mode

Boosted Decision Tree

Preselection cuts before training removed 96% of background and retained 78% of signal.





Cosine of 2D pointing angle Θ_{pa}>0.95

Cosine of 3D pointing angle Θ_{pa}>0.9

Dimuon p_T > 5 GeV

After preselection cuts, before BDT cuts

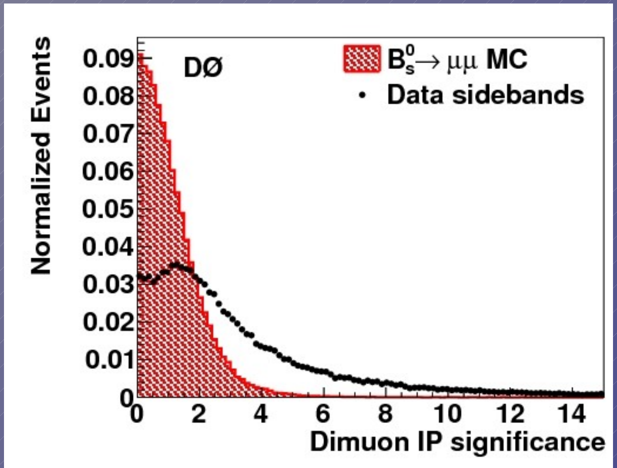
BDT details

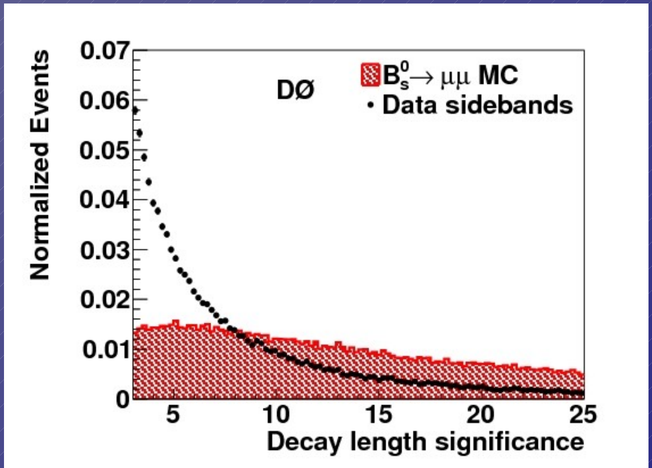
We used 30 variables—kinematic plus isolation-type variables.
Data sidebands used for background, signal MC for signal.
We trained two BDTs—one for sequential decays, which dominate the low mass sidebands, and one for double B decays, which dominate the high-mass sidebands.

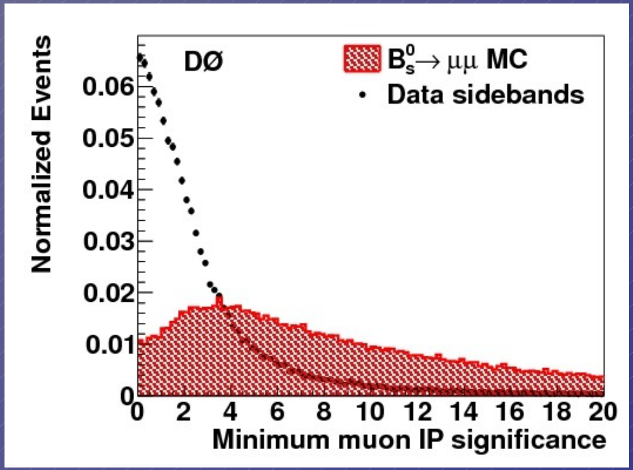
Three data subsamples A, B, C

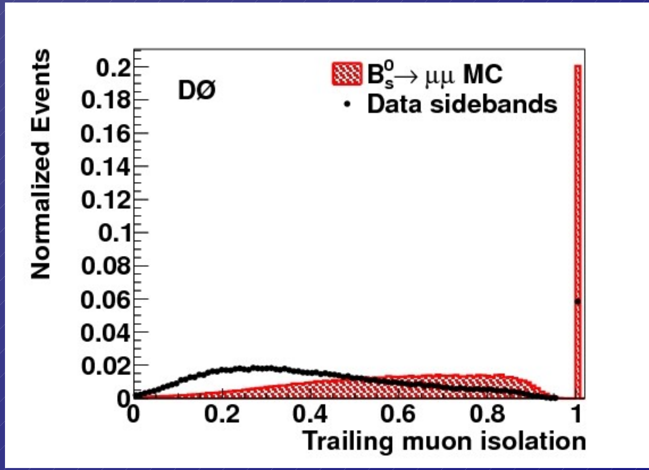
A used to train (25%)
B used to optimize location of cuts (25%)
C used to estimate background in control/signal region (50%)

Examples of variables used in BDT

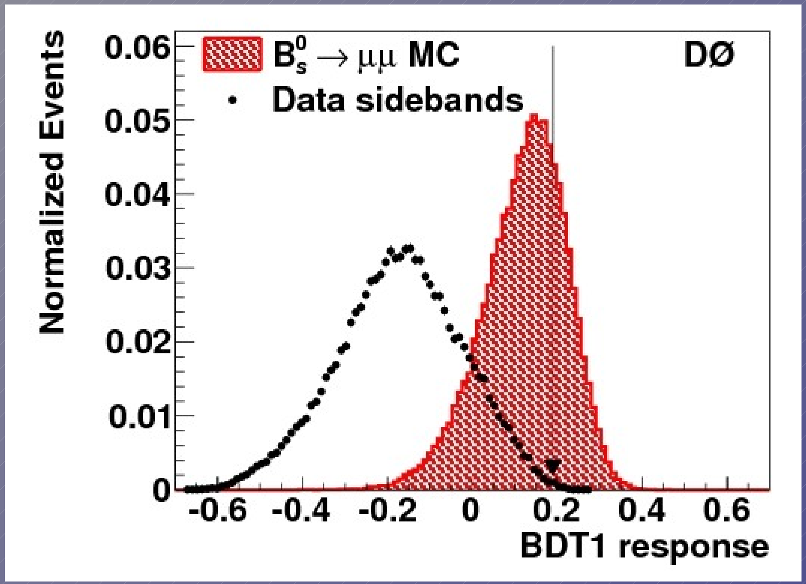


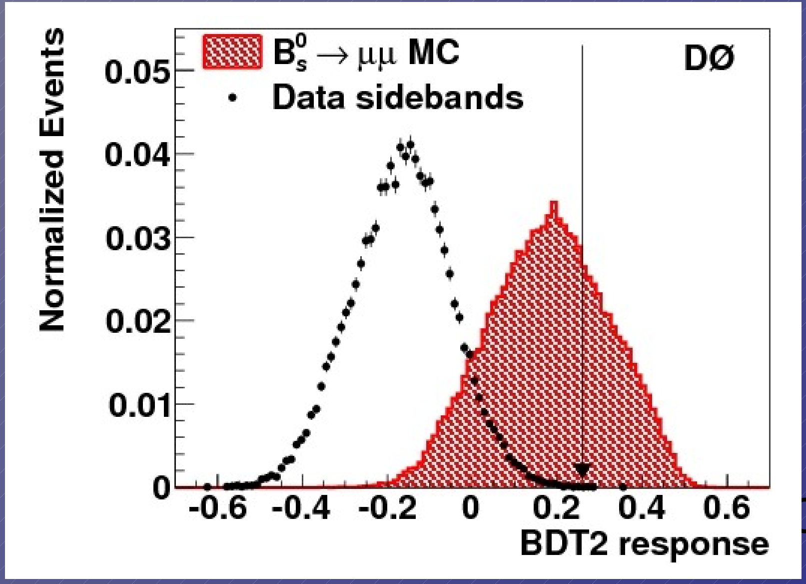


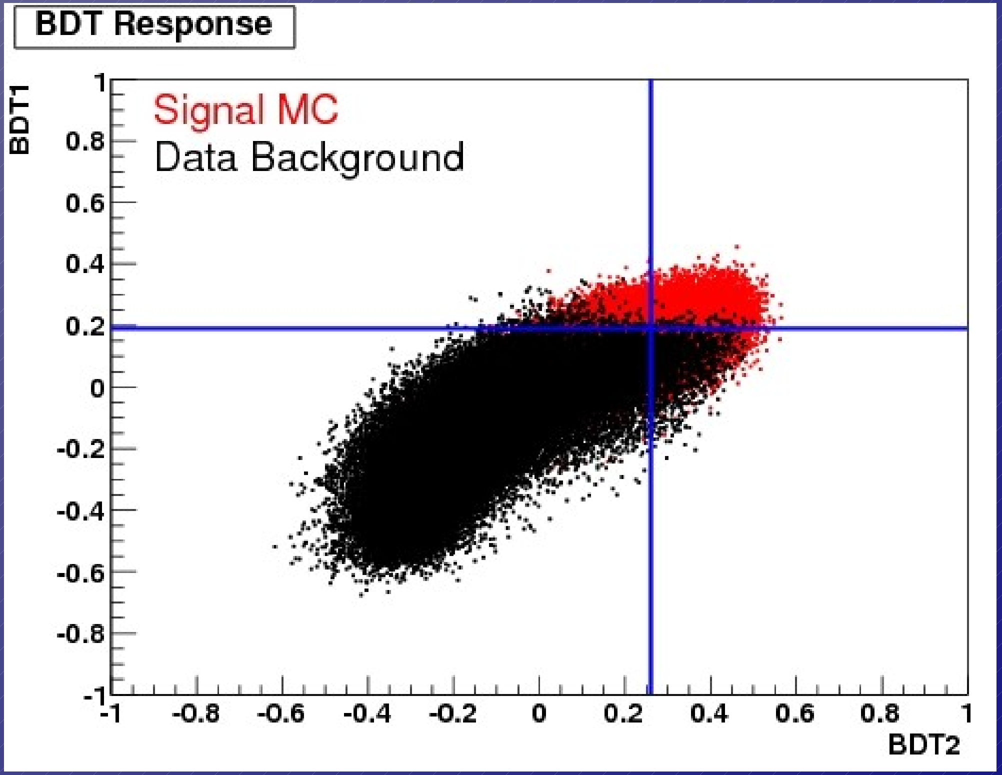




BDT response







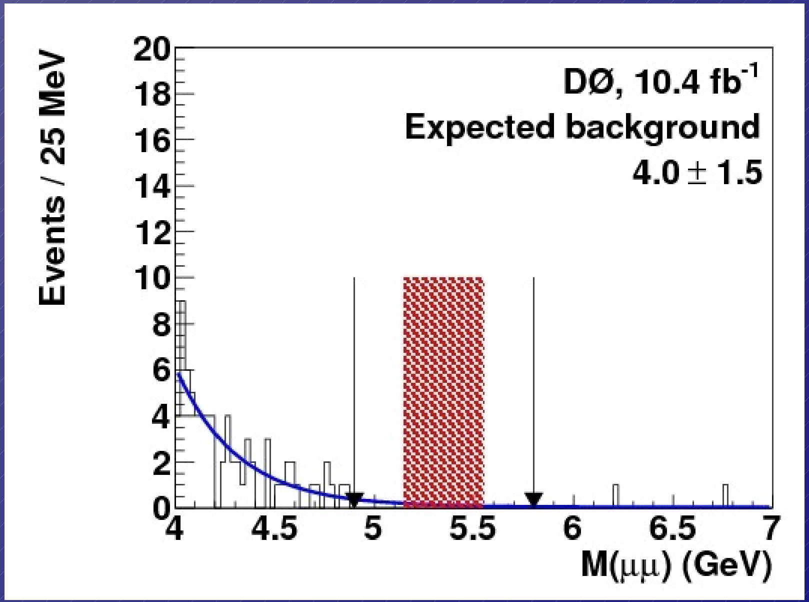
Trained two BDTs, one for sequential decays (BDT1), one for double B decays (BDT2)

Final background estimate

There are also backgrounds from
B_d and $B_s \rightarrow hh$ where h is a K or π.
D0's excellent muon system helps us here, the background from these decays is 0.28 ± 0.11 events.

After the BDT cuts our expected signal is 1.23 ± 0.13 events

Total expected background is 4.3 ± 1.6 events, giving an expected limit of
23 x 10^{-9} (CL_s method)

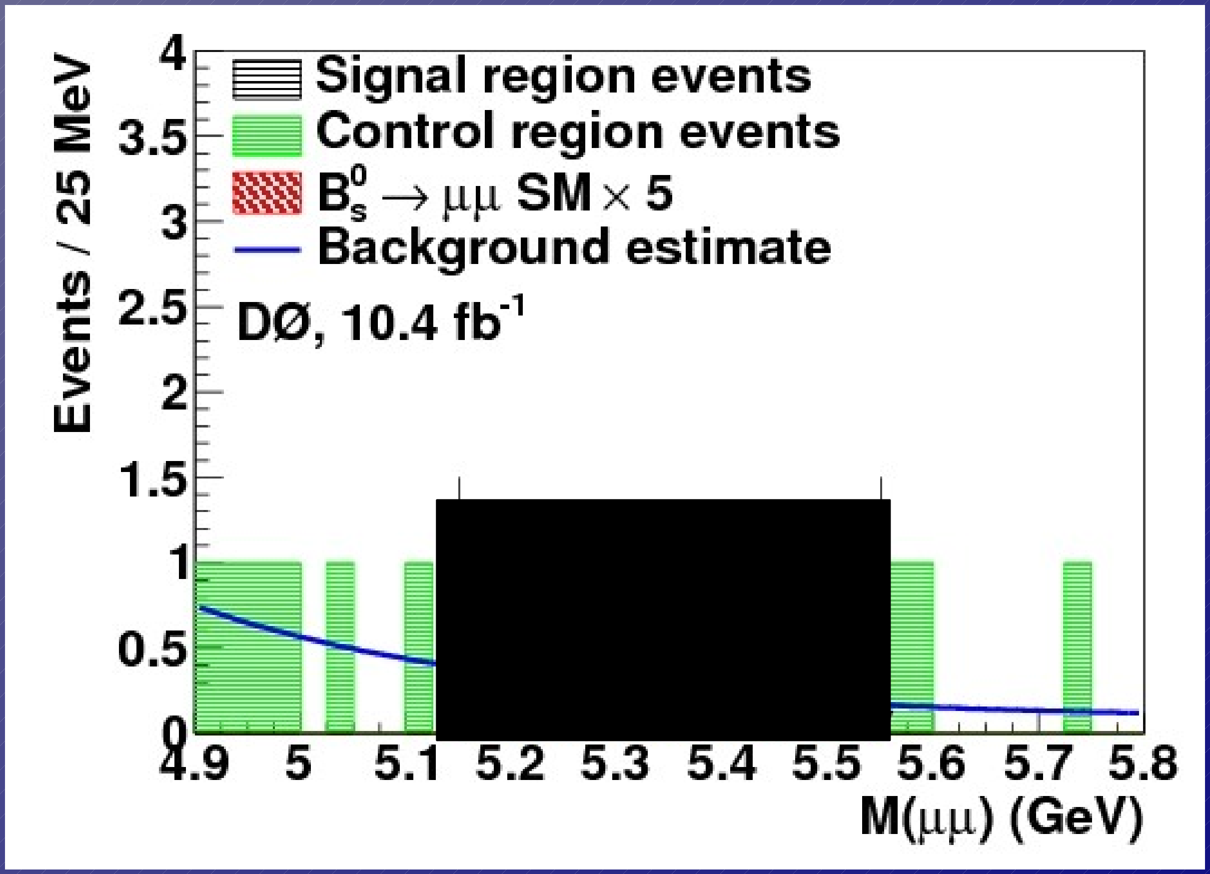


Time to unblind!

We first opened the control region, to be sure the observation fit expectations .

We saw nine events, consistent with the expected number, 6.7± 2.6 events.

So proceed opening the signal region

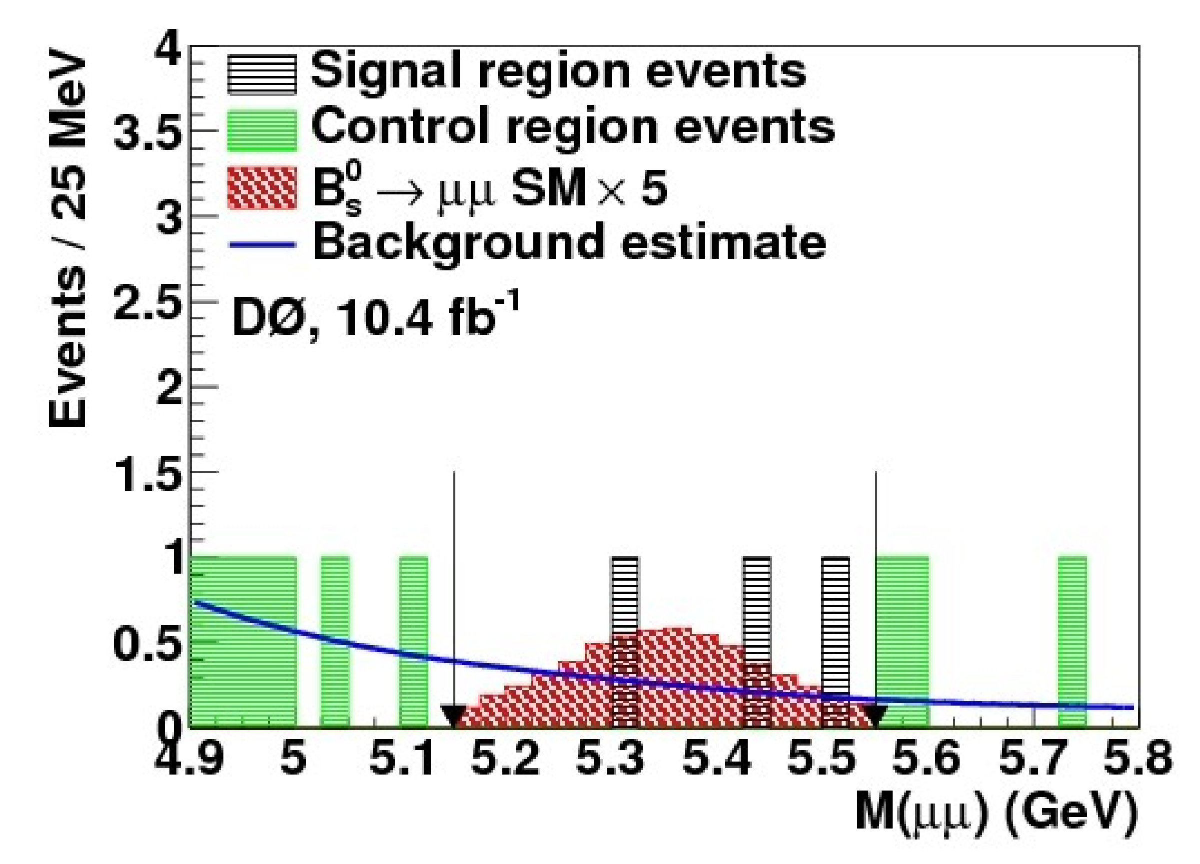


Final unblinding

We see three events, a slight fluctuation downward giving us a slightly more stringent limit thanexpected

BR(Bs $\rightarrow \mu\ \mu$) < 15 x 10^{-9}
at 95% CL

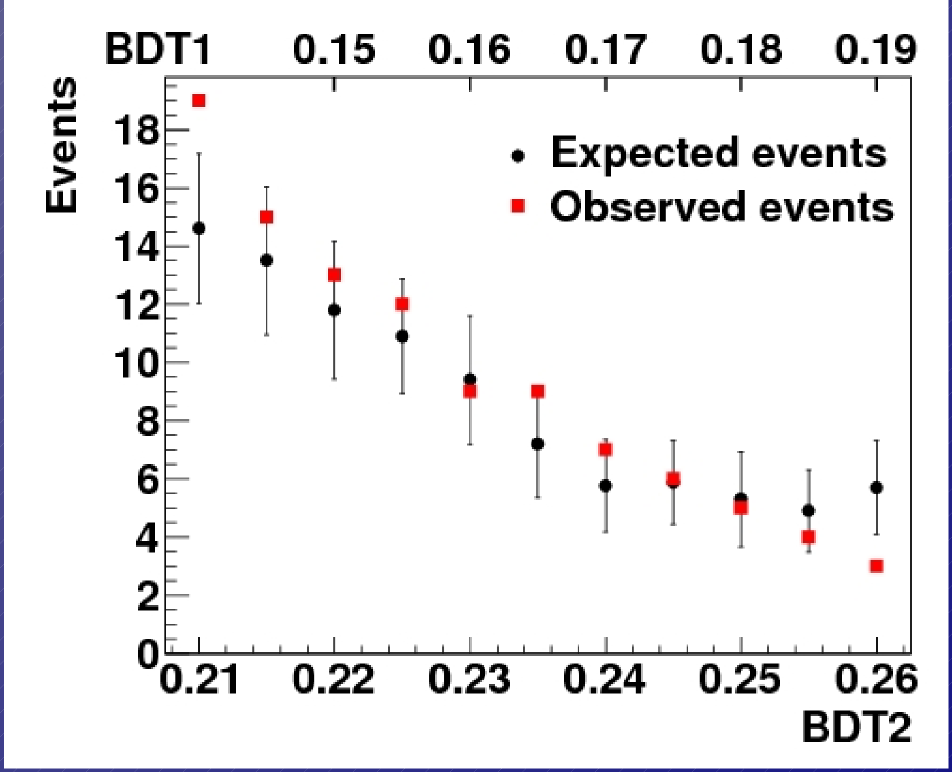
Published in Feb. 2013:
Phys. Rev. D87, 072006 (2013)



Cross checks

One of several cross-checks done after the unblinding.

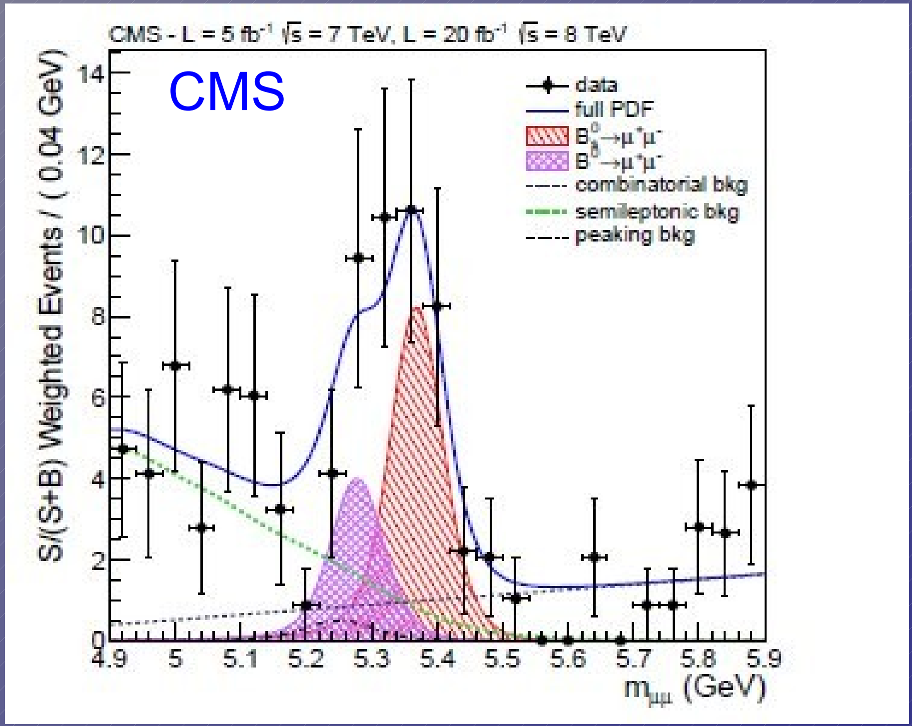
The BDT cuts were relaxed symmetrically, and the expected and observed number of events compared.

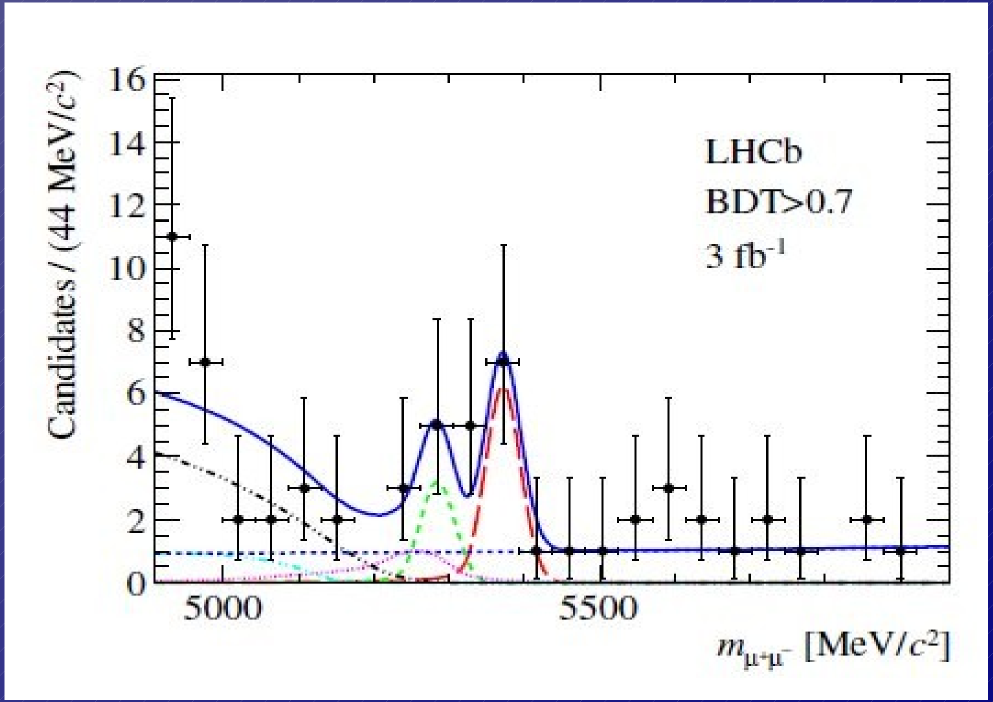


New results presented at EPS

At EPS Atlas presented a limit the same as D0, 15 x 10^{-9} (Atlas-conf-2013-076).

Both CMS and LHCb showed results with > 4σ evidence, with BR values in good agreement with the SM.





arXiv:1307.5025v2

arXiv:1307.5024v1

What have we learned ?

Another search for physics beyond the SM comes up empty, and the SM triumphs again.

There is a slight excess of $B_d \rightarrow \mu\ \mu$. Maybe we will see something new in an unexpected place?

At D0, we made the most of our data and obtained the best Tevatron limit.

Congratulations to CMS and LHCb for reaching the summit!