Search for $B_s^0 \to \mu^+\mu^-$ at D0

EPS-HEP Conference
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Mark Williams, Indiana University

Searching for the SM?

$B_s^0 \rightarrow \mu^+\mu^-$ decay heavily suppressed in the standard model

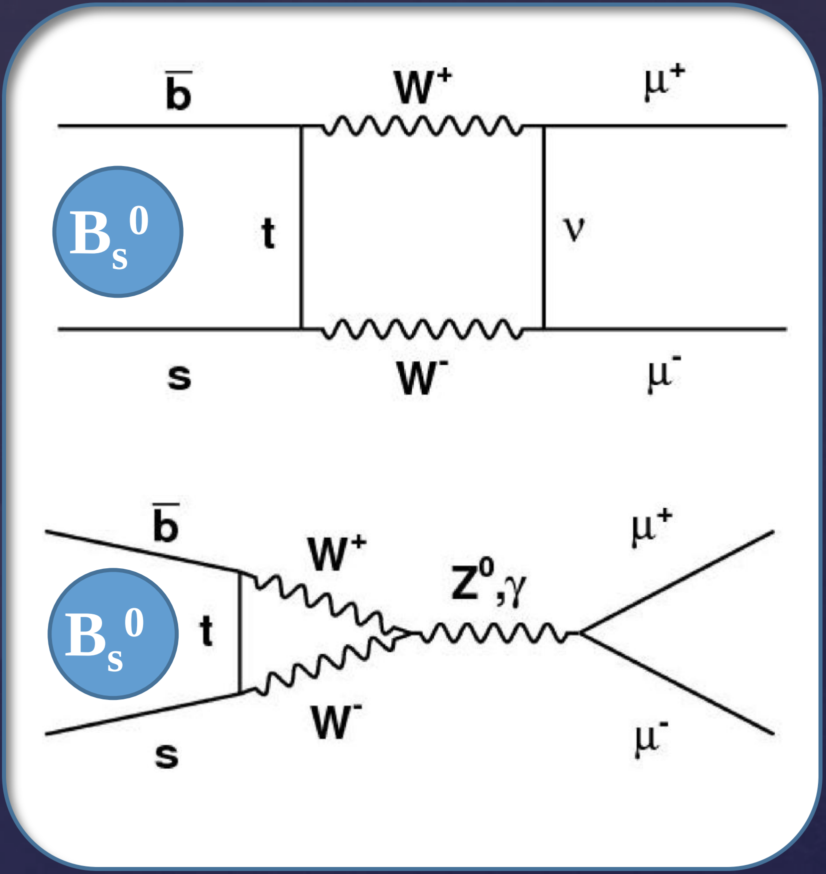
- Flavor Changing Neutral Current
- + Helicity suppressed

SM expectation:

$Br(B_s^0 \rightarrow \mu^+\mu^-) = (3.5 \pm 0.2) \times 10^{-9}$

BSM physics (e.g. SUSY) can significantly affect this decay $\Rightarrow$ new particles in loops

BR can be enhanced by several orders of magnitude, or even suppressed.



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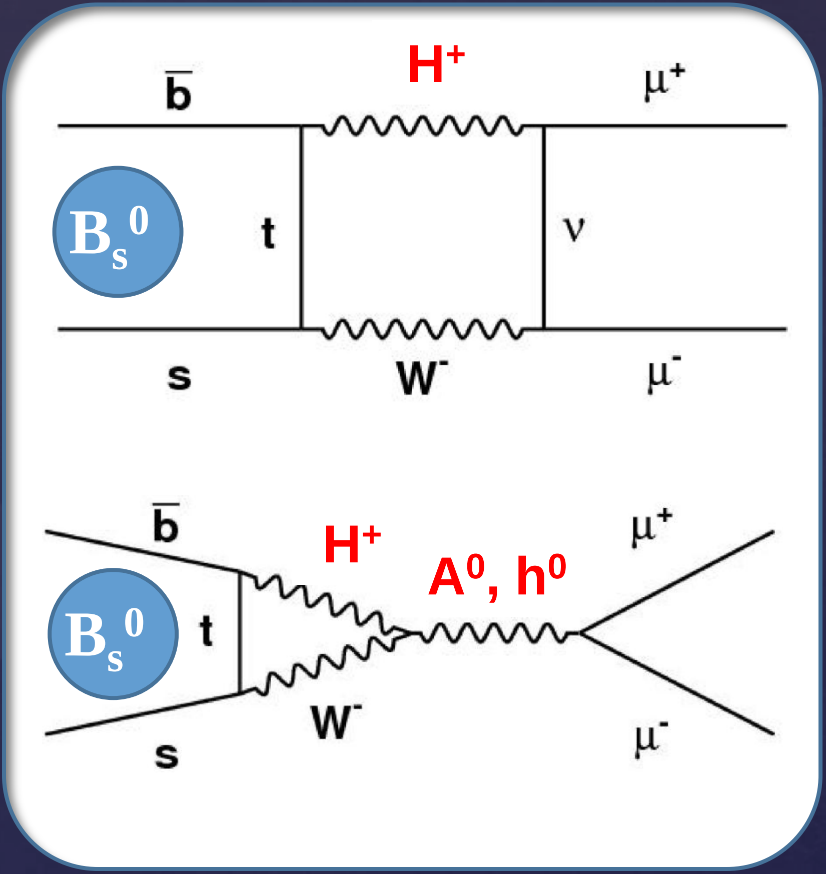
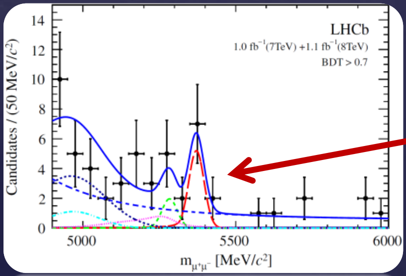
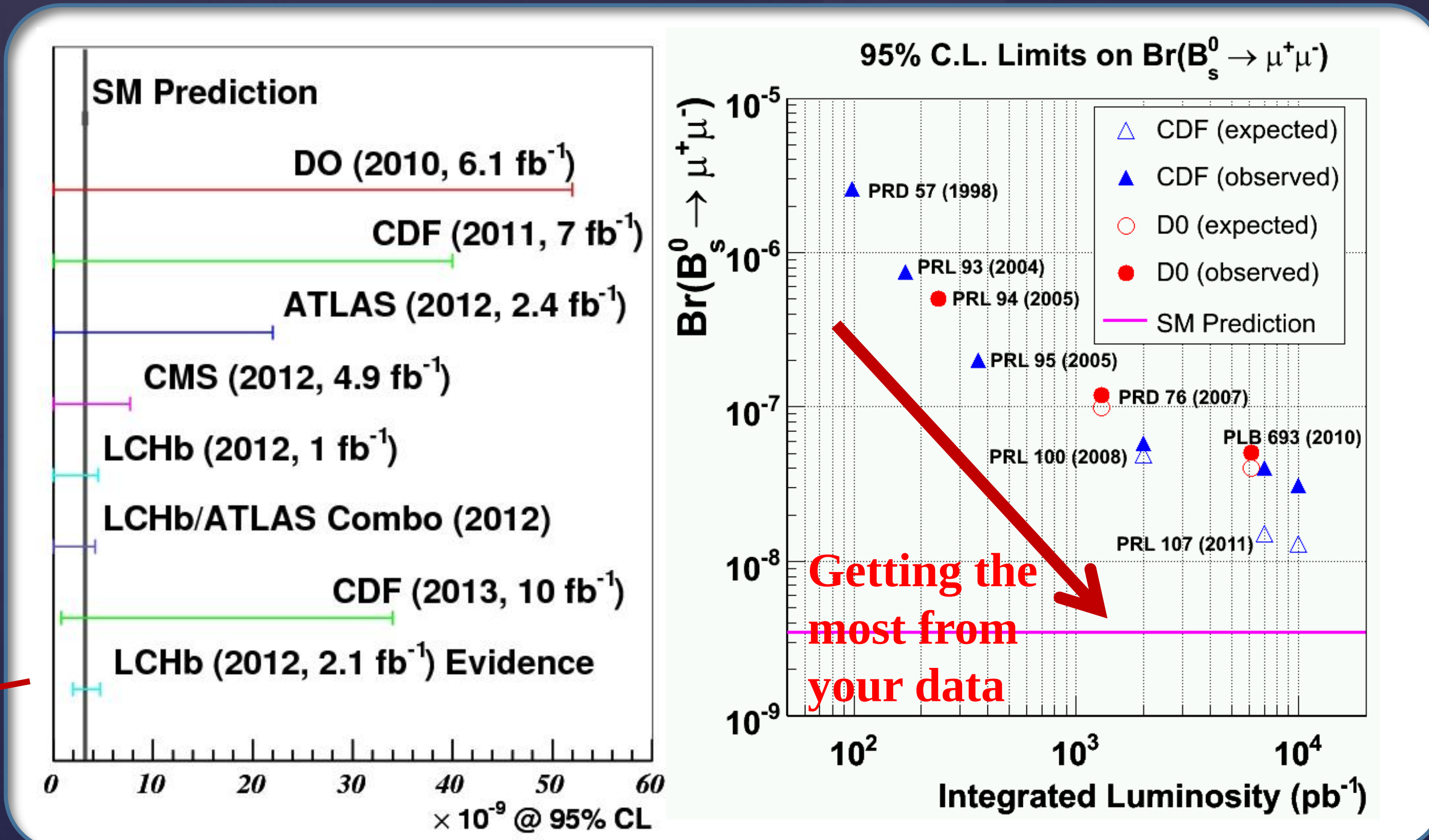


Experimental Status

- Long history of measurements from Tevatron and LHC
- Analyses progressively more advanced

LHCb reported 3σ evidence, consistent with SM rate (HCP, Nov 2012).
PRL 110 021801





Ingredients for Success

Aim 1: Maximise expected signal significance / sensitivity

- Understand backgrounds

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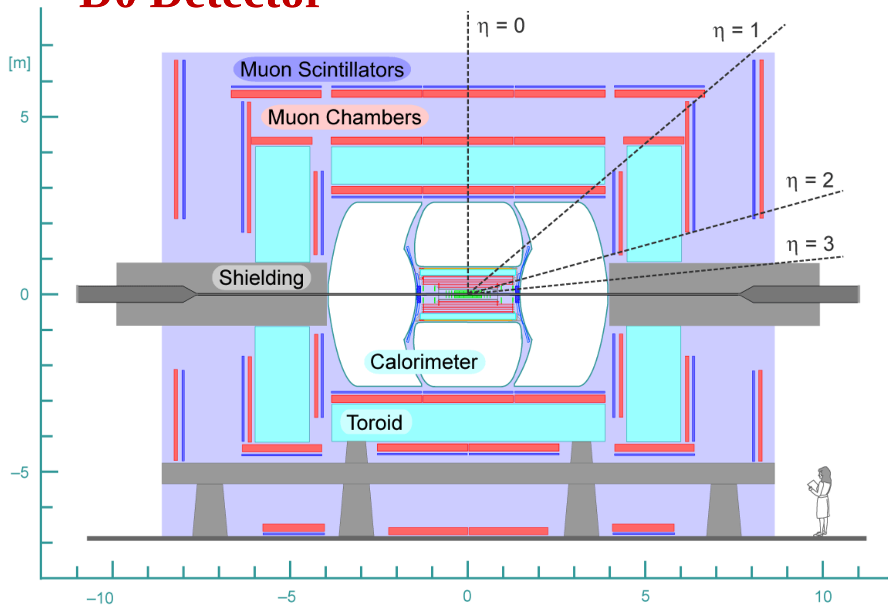
Thick **shielding** before muon system, & **independent magnetized tracking** – heavily suppresses hadronic punchthrough and decay-in-flight

⇒ Backgrounds dominated by real muons from b and c decay

D0 Detector



$p\bar{p}$ @ $\sqrt{s}$ = 1.96 TeV

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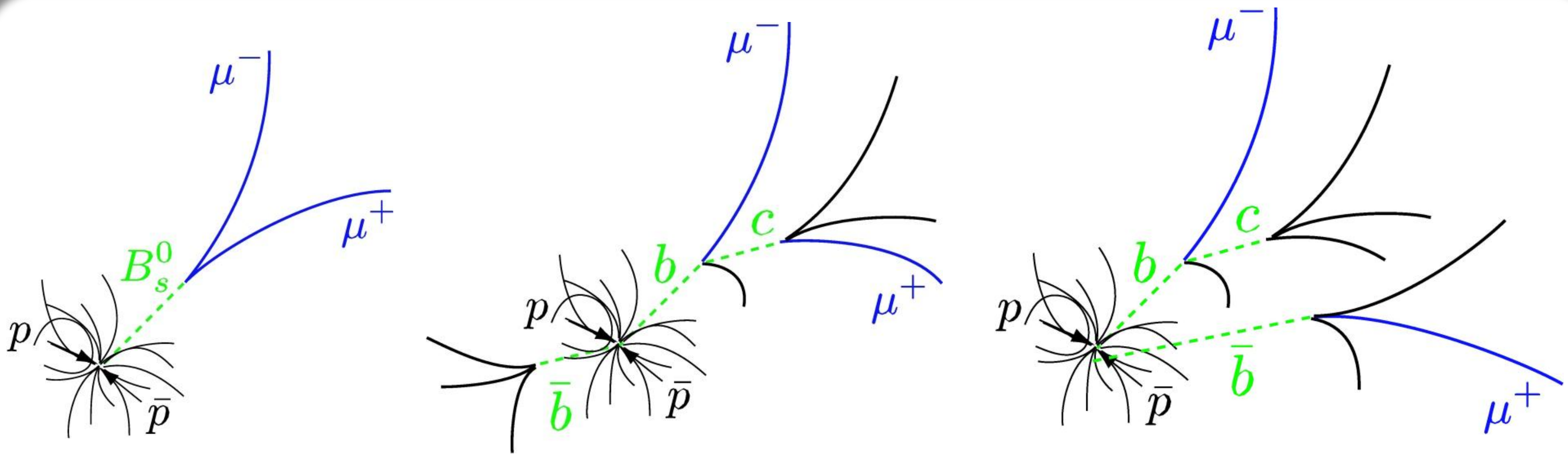

Signal **Sequential b→c decay** **Double b decay**

Design variables, and train MVA discriminants, based on known backgrounds

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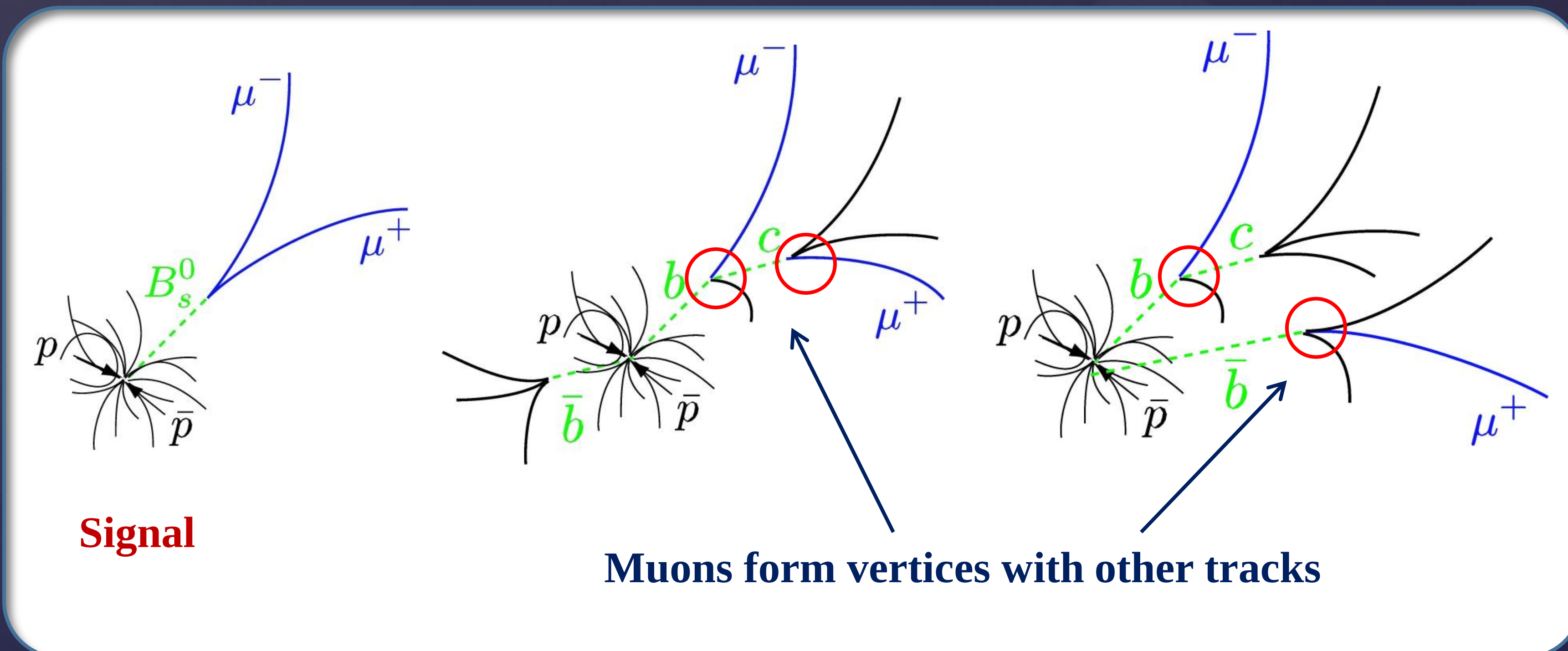

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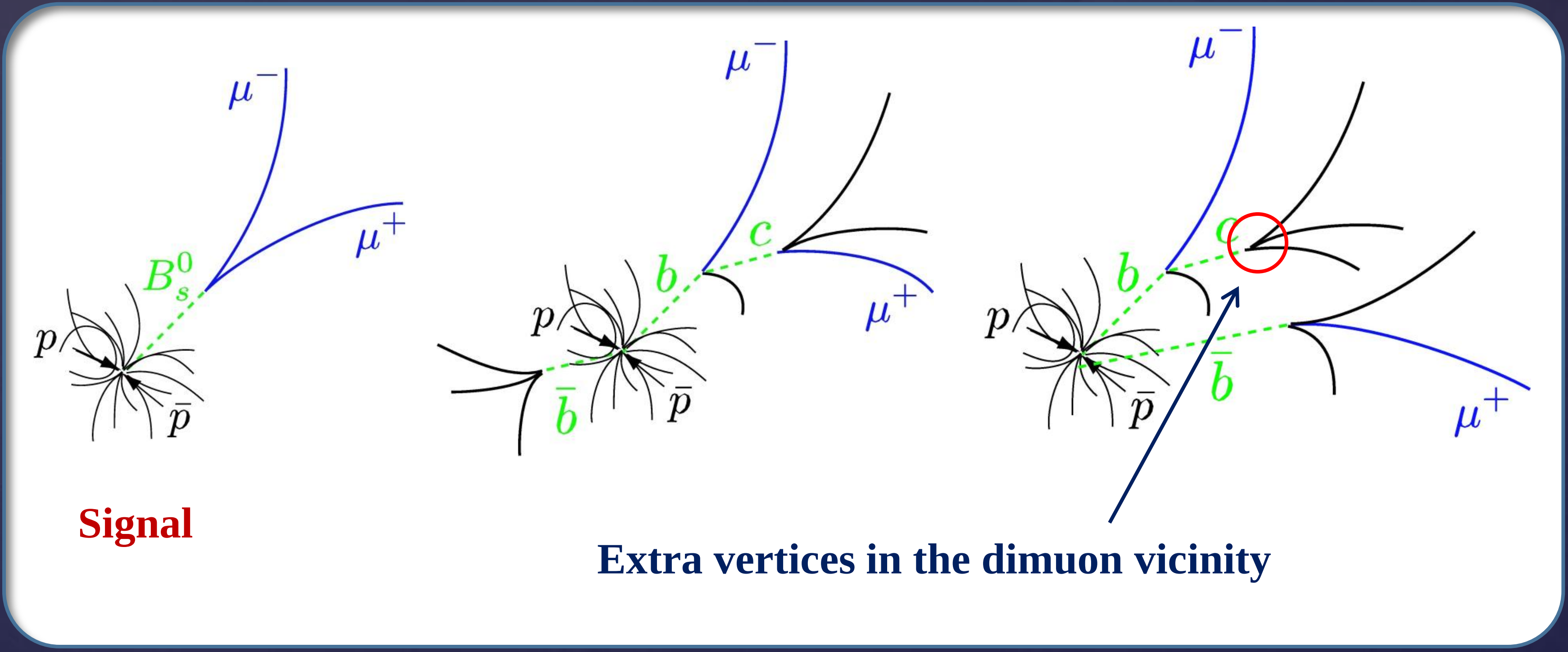

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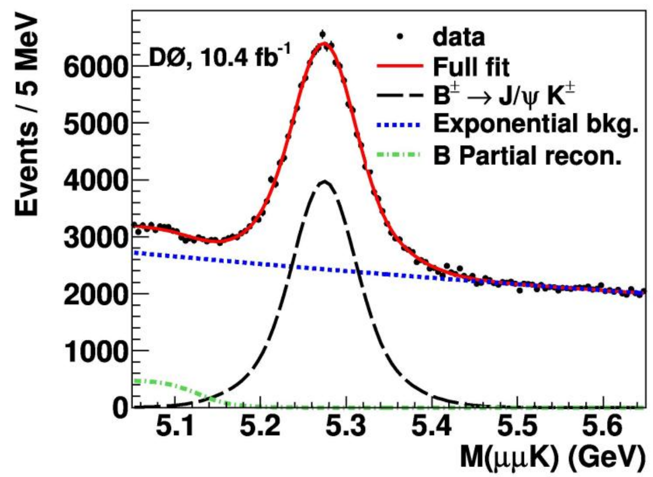
Use normalisation mode $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+\mu^- K^+$

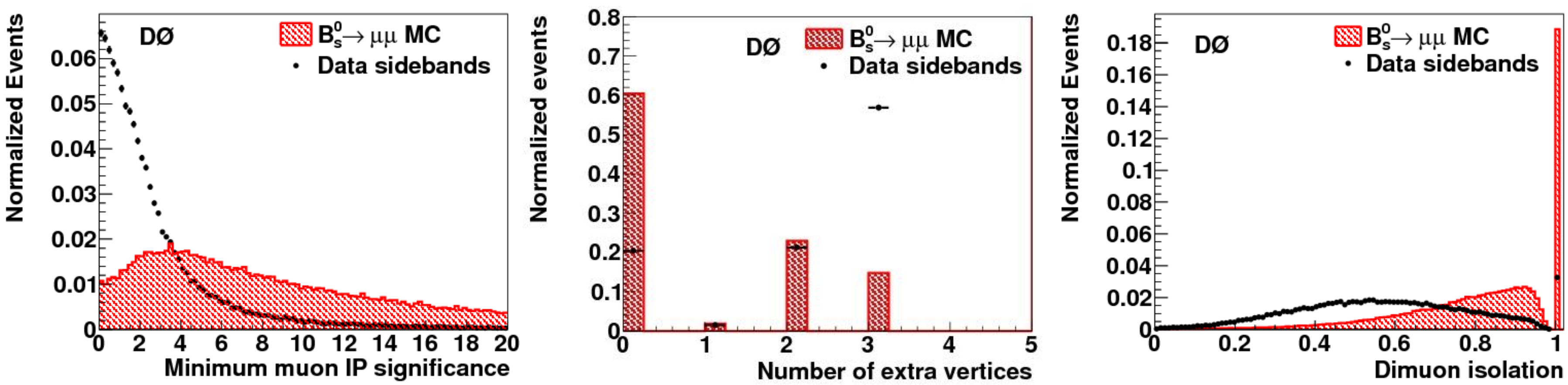
Determine BR($B_s^0 \rightarrow \mu\mu$) by comparing search results with B^+ yield

Many efficiency uncertainties cancel in the ratio (luminosity, trigger, muon ID…)



Event Selection

- Single and dimuon triggers
- Loose preselection (same muon requirements for signal and normalisation mode)
- Final selection uses **two BDTs**, one trained for each main background (30 variables)
- Innovative variables, including e.g. tertiary vertex information



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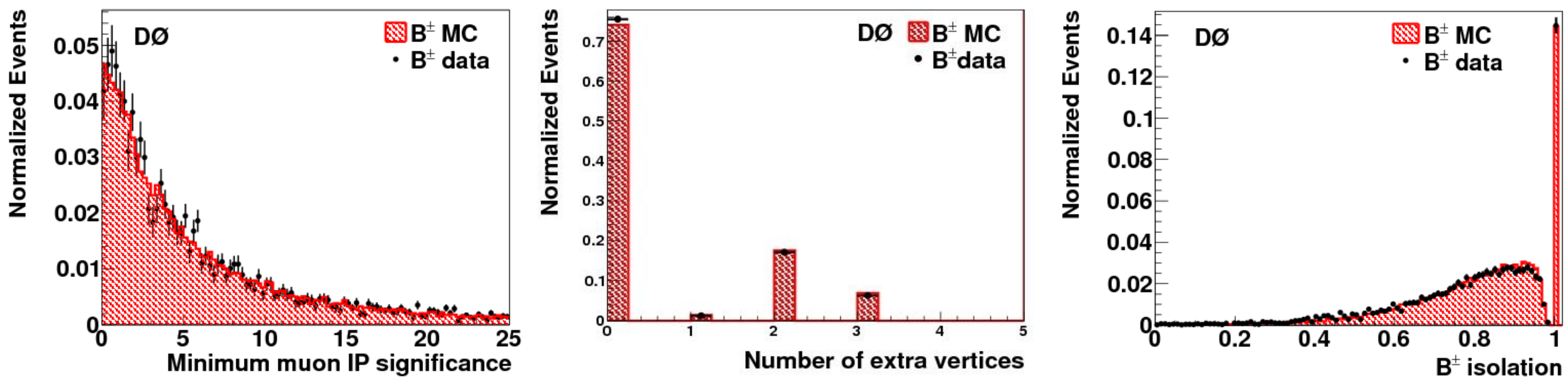
- **Verify MC performance using B^+ channel**



Single Event Sensitivity

SES = BR($B_s^0 \to \mu\mu$) which would give 1 signal event in the data, at preselection

Needed to **optimise BDT cuts**, and **convert results into BR** limit

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

Yield in normalisation channel

Ratio of efficiencies (from MC)

External constraints (PDG)

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⇒ **Crucial to trust signal model in MC**
All variables must be examined

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Yield in normalisation channel

Ratio of efficiencies (from MC)

External constraints (PDG)

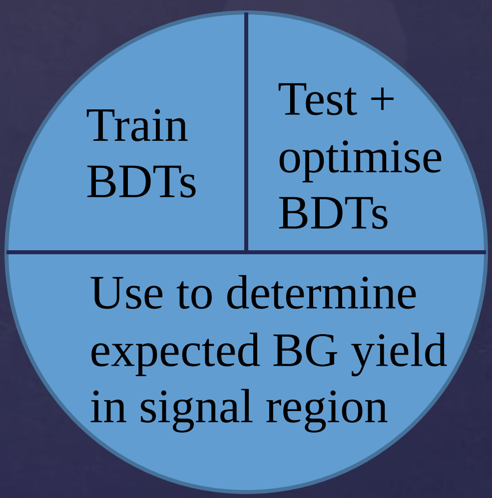
SES = 3.36 × 10^{-10}

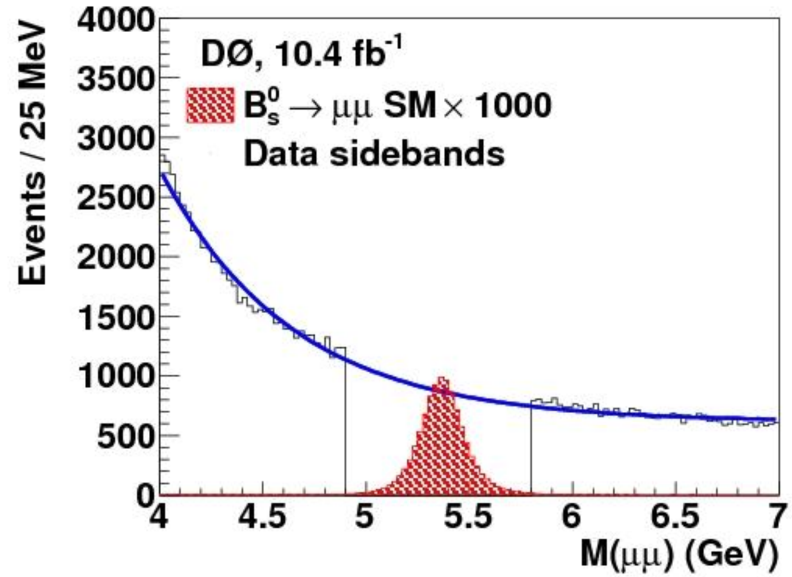
$\Rightarrow$ **10.4 ± 1.1** signal events expected, assuming SM BR *(before BDT cuts)*

Optimisation

Divide data into three orthogonal samples to train, optimise, and evaluate BDT performance

Training/testing samples further divided into high/low mass regions





σ(μμ) = 125 MeV

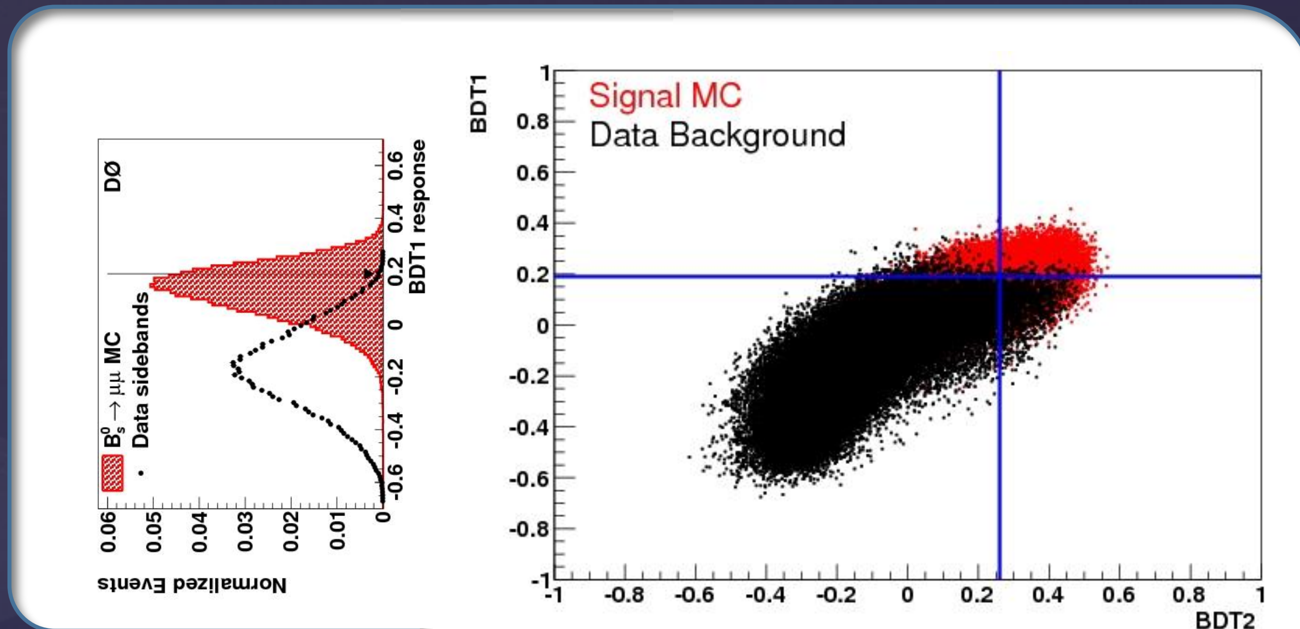
Blinded region: $4.9 < M_{\mu\mu} < 5.8$ GeV

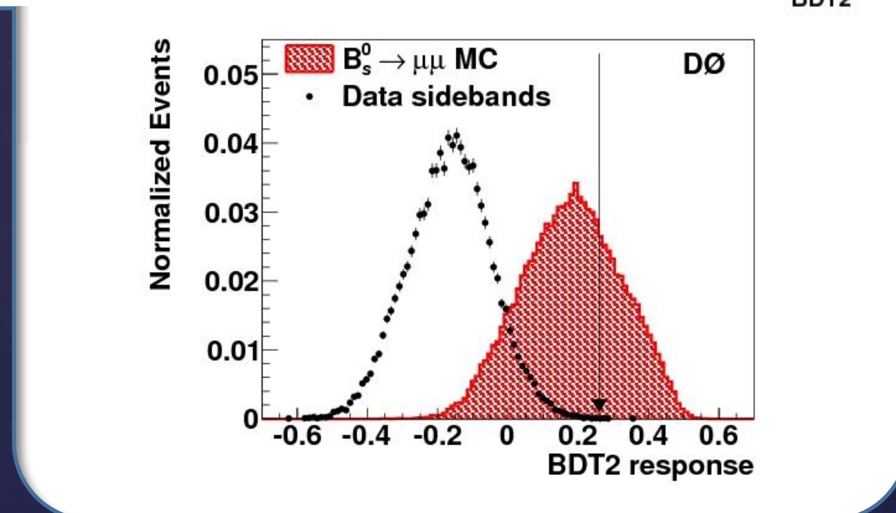
High-mass sideband: dominated by double-b decay – use to train dedicated BDT

Low-mass sideband: dominated by sequential decay – use to train second BDT

Optimisation

Apply cuts to both BDT output values – rectangle close to optimal shape in 2D distribution.





1) Coarse optimisation to maximise expected signal significance

2) Final cuts chosen to give best expected limit

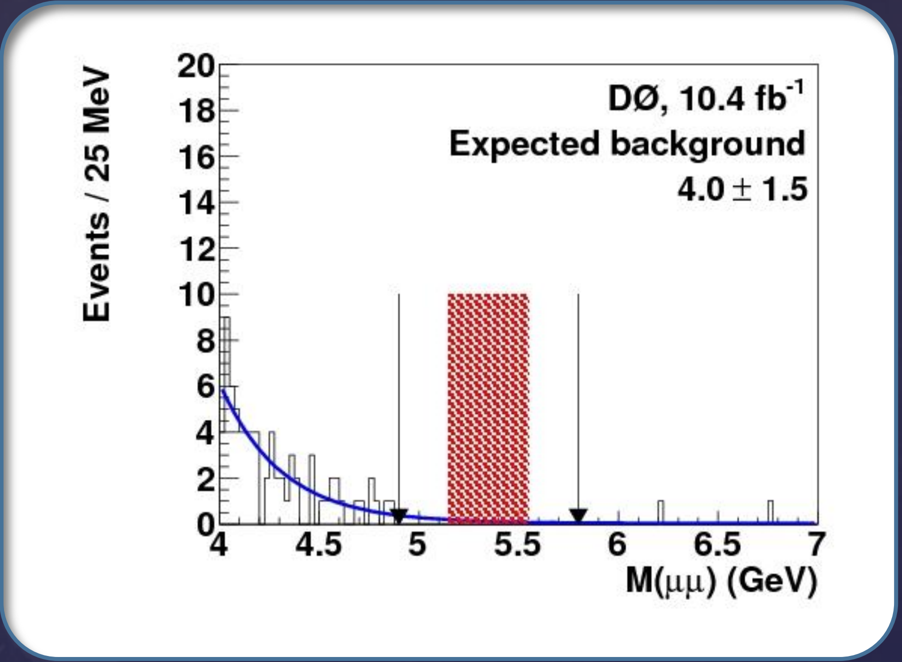
Expectations…

After applying all cuts, expected yields in signal region:

- **N(BG,μμ) = 4.0 ± 1.5**
- **N(BG, $B_s^0 \rightarrow K^+K^-$) = 0.3 ± 1.5**

(determined using K→μ 'fake rate' from B →μD^0X, suppressed by shielding)

- **N(SM $B_s^0 \rightarrow \mu^+\mu^-$) = 1.23 ± 0.13**



⇒ Expected limit: BR($B_s^0 \rightarrow \mu^+\mu^-$) < 23 × 10^{-9}

Modified frequentist approach [T. Junk, Nucl. Instrum. and Meth. in Phys. Res. A 434, 435 (1995).]

Results: Control Region

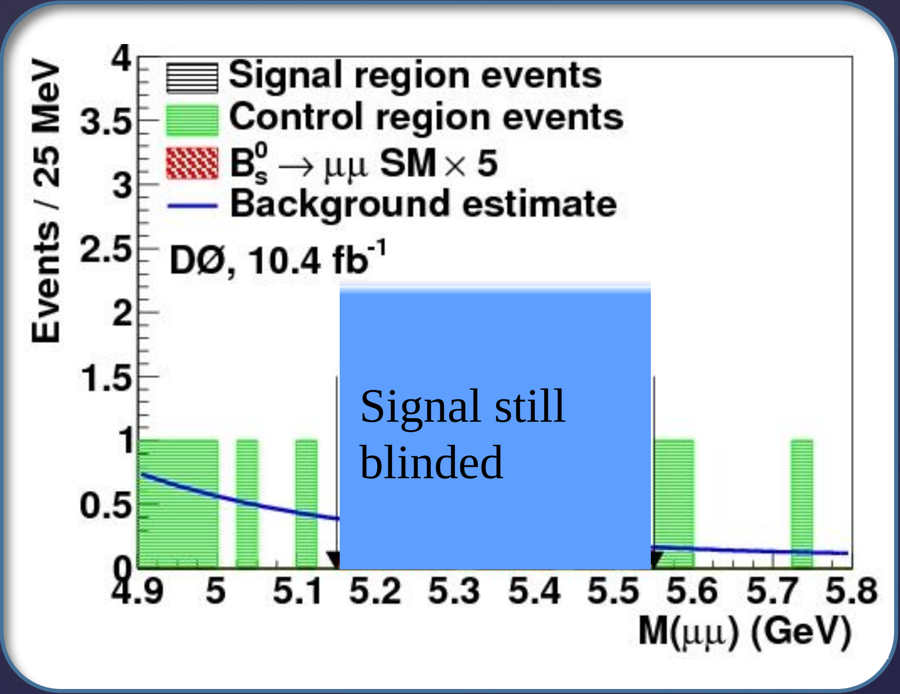
Blinded mass range contains ***control regions*** either side of signal window

Signal expectation negligible – allows test of method to estimate BG

Before full unblinding, compare expected and observed yields:

Expected: **6.7 ± 2.6 events**

Observed: **9 events**



⇒ BG consistent with expectations

Also tested high/low mass control regions individually

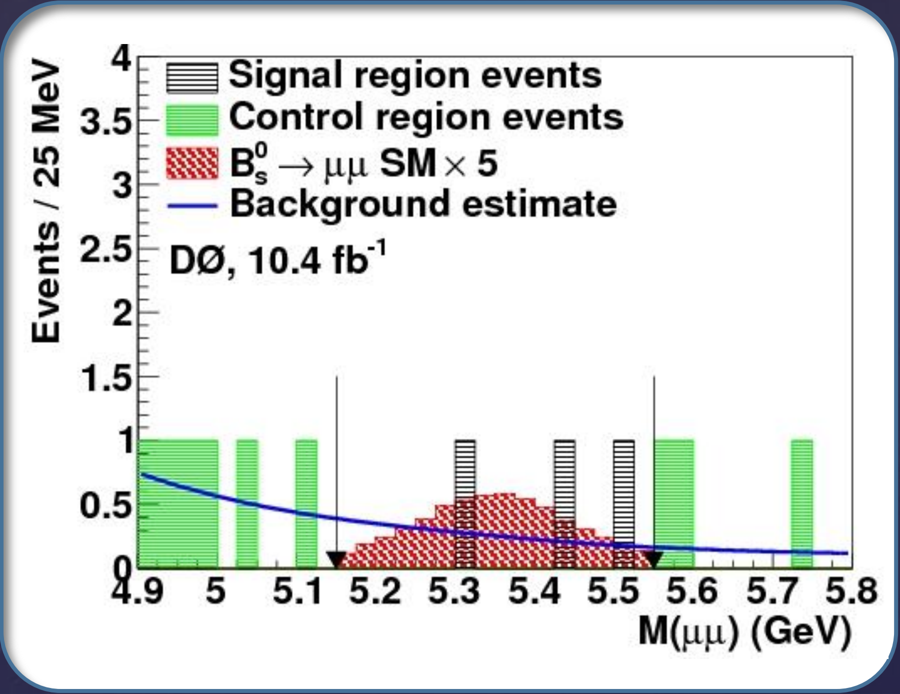
Results: Signal Region

In signal region:

Expected: **4.3 ± 1.6 BG events**

1.2 ± 0.1 SM signal events

Observed: **3 events**



Observed limit (95% C.L.):

$$\mathbf{BR(B_s^0 \rightarrow \mu^+\mu^-) < 15 \times 10^{-9}}$$

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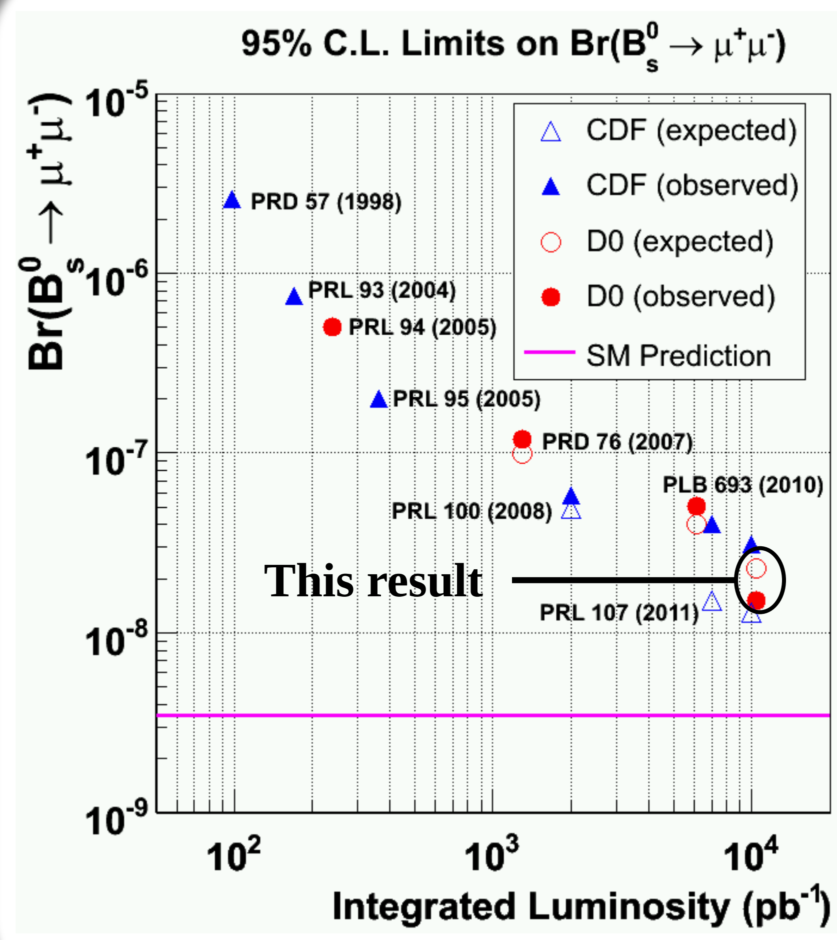
Best observed limit from Tevatron



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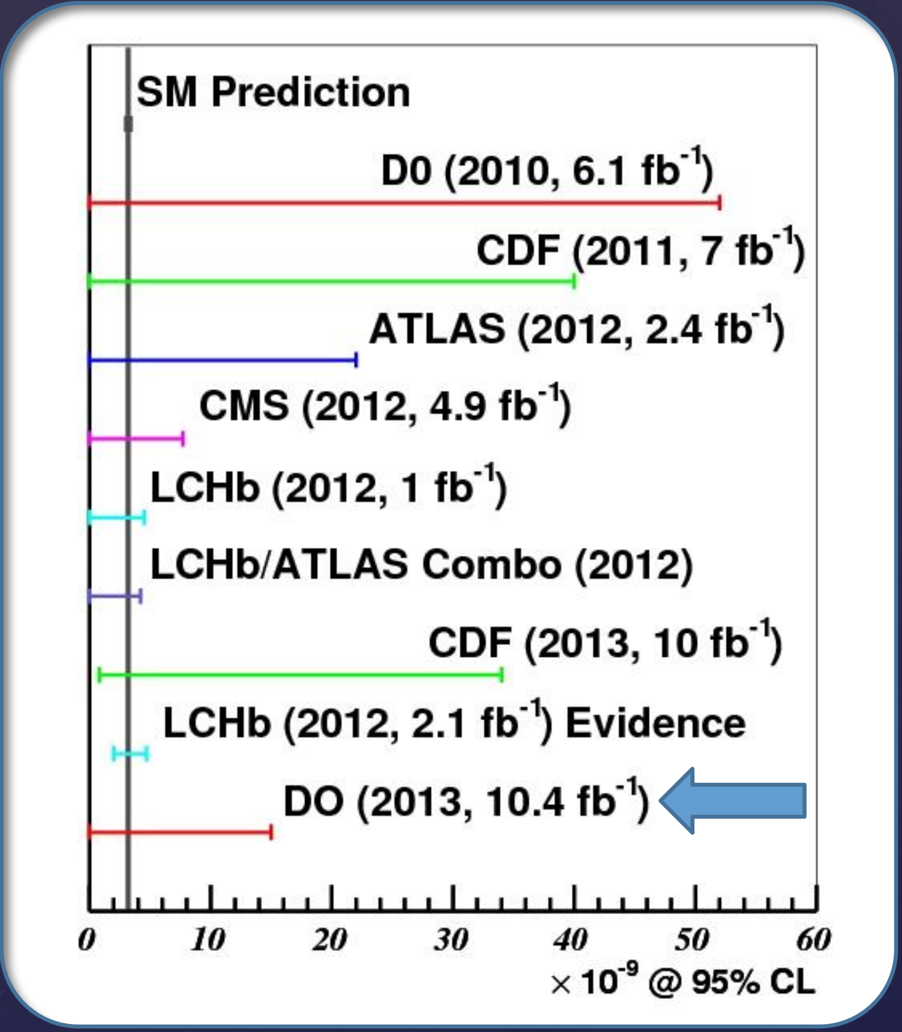


Best observed limit from Tevatron

Competitive, and consistent, with LHC results

Summary

Final word from D0 on this decay

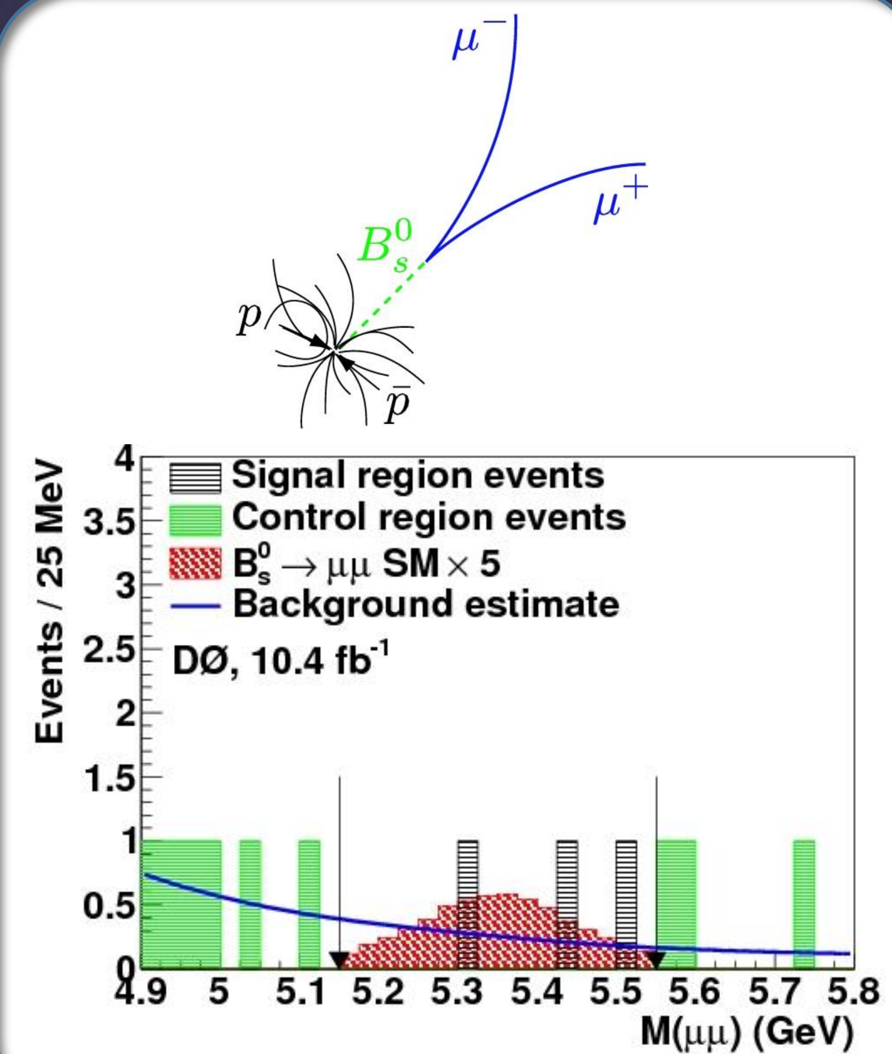
Significant effort to make the most of our data:

- Targeted BDTs for main backgrounds
- Novel tertiary vertexing variables

Set best Tevatron limit on the BR, in line with results from LHC.

$BR(B_s^0 \to \mu^+\mu^-) < 15 \times 10^{-9}$ @ 95% C.L.

PRD **87**, 072006 (2013)



Extra Material

Third Track Efficiency

Normalisation channel:

$B^+ \rightarrow J/\psi\, K^+ \rightarrow \mu\mu K^+$

has third track in addition to two muons;

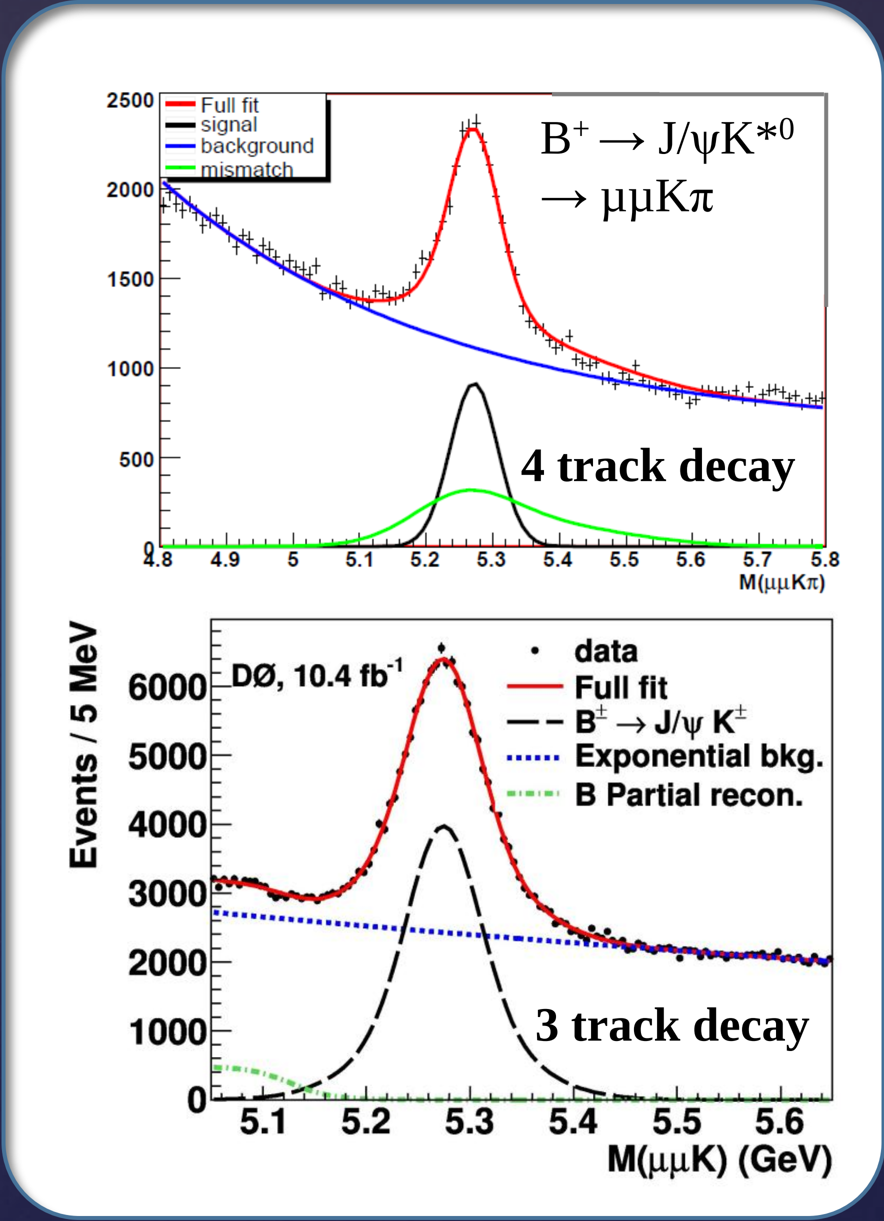
Important to compare tracking efficiency in MC and data, since this effect won't cancel in the ratio

Use **$B^+ \rightarrow J/\psi K^{*0} \rightarrow \mu\mu K\pi$**

to compare '4th track' efficiency in data/MC

Data/MC ratio is **0.88±0.06**

Correction applied for five separate data epochs



Expected vs Observed Yields

In signal region:

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1.2 ± 0.1 SM signal events

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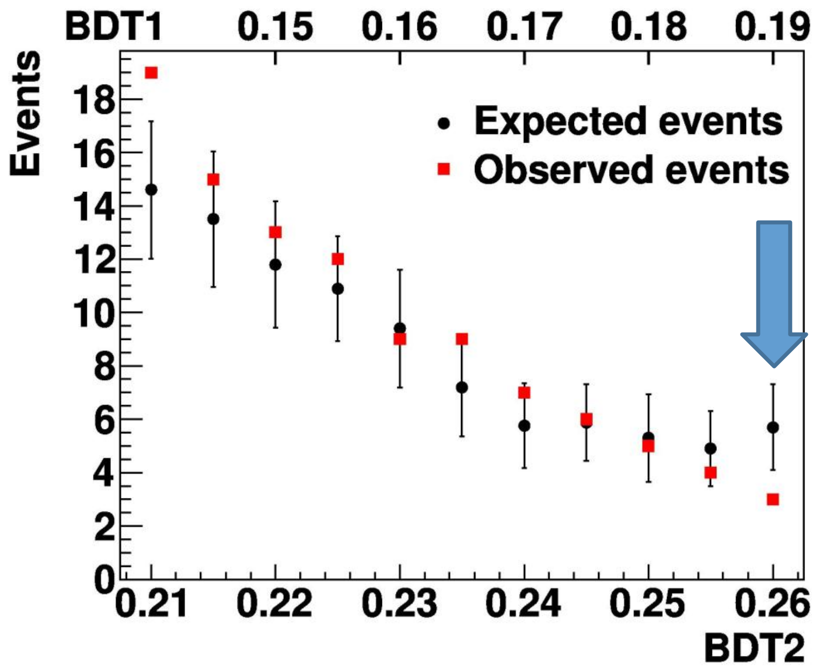

Observed yield consistent with expectations over broad range of BDT cuts – no systematic bias