Search for the Rare Decay $B_s \to \mu^+\mu^-$ with the DØ Experiment

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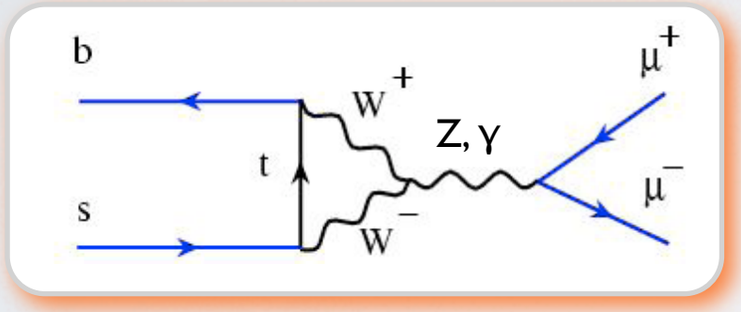
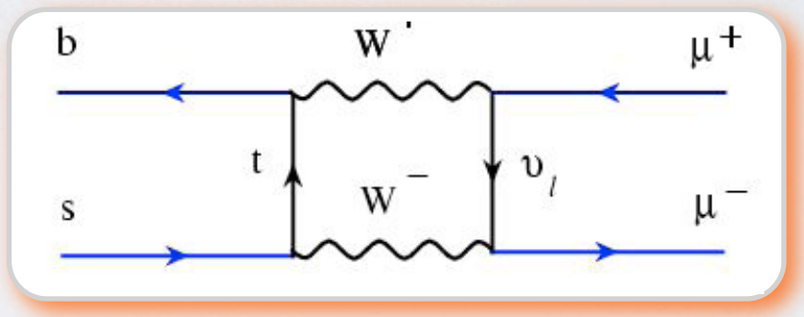
on behalf of the DØ collaboration

motivation

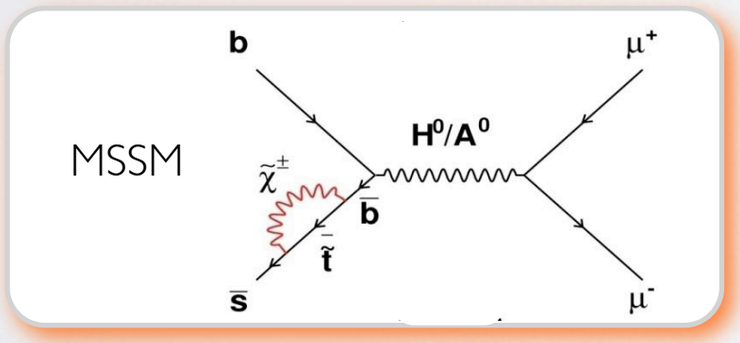
- FCNC processes have **very low rate in SM** and are well understood:

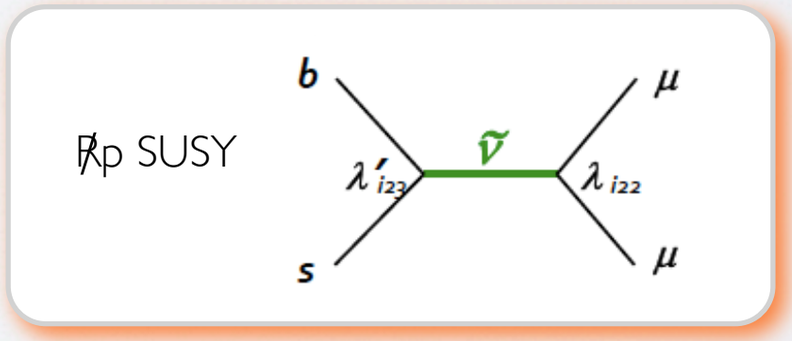
$\mathcal{B}(B_s \to \mu^- \mu^+)_{SM} = (3.6 \pm 0.3) \times 10^{-9}$ A.J. Buras, Prog.Theor.Phys.122:145-168,2009.





- whereas many Beyond SM theories predict enhancements.





→ sensitivity to new physics

previous measurements

- best current limit: $< 4.3 \times 10^{-8}$ (95% CL) by CDF with 3.7 fb^{-1}, preliminary
- DØ-Run II previous limits on $\mathcal{B}(B_s \rightarrow \mu^- \mu^+)$:
  - $< 5.0 \times 10^{-7}$ (95% CL) with 240 pb^{-1} PRL 94, 071802 (2005)
  - $< 1.2 \times 10^{-7}$ (95% CL) with 1.3 fb^{-1} PRD 76, 092001 (2007)
  - $< 9.3 \times 10^{-8}$ (95% CL) with 2 fb^{-1} preliminary
  - $< 5.2 \times 10^{-8}$ (95% CL) expected with 5 fb^{-1} preliminary
  - in this talk: observed limit obtained with **6.1 fb^{-1}** PLB 693, p. 539 (September 2010)

    Improved analysis technique and increased data set.

- predicted SM rate below experimental sensitivity: **still room for new physics** in this decay!

- predicted enhancements by many extensions of the SM bring this branching ratio close to its experimental bound: it could be observed soon!

experimental environment

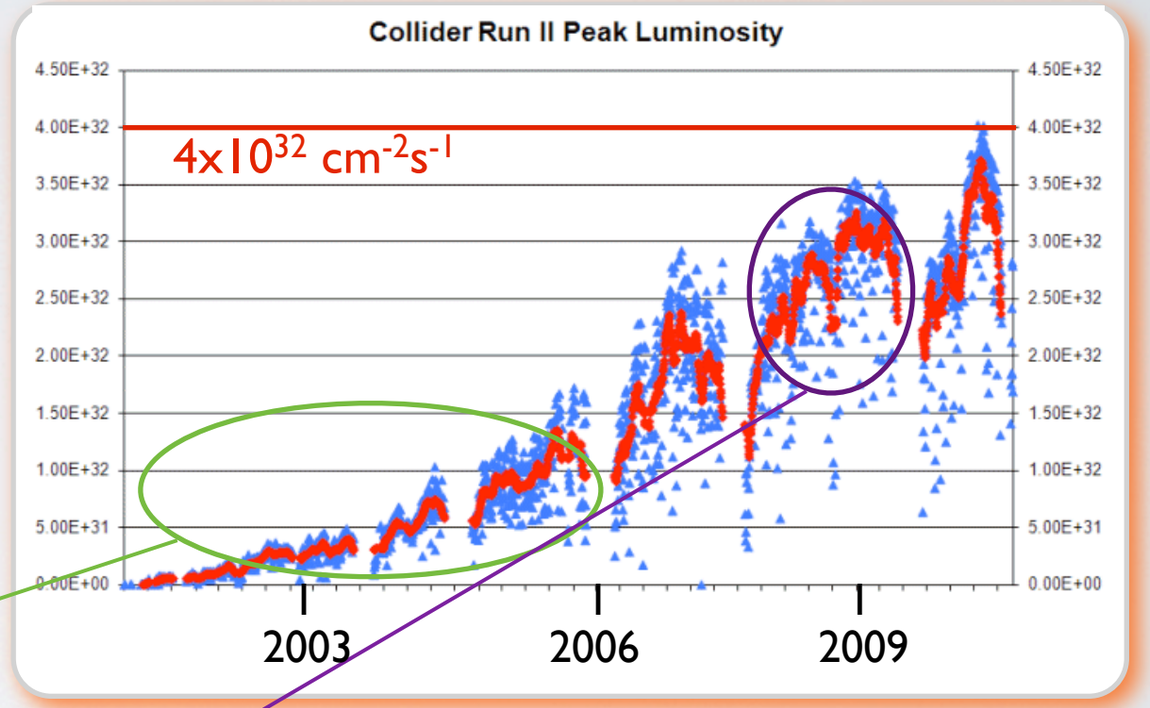
Data are produced by the $p\bar{p}$ Tevatron collider from Fermilab.

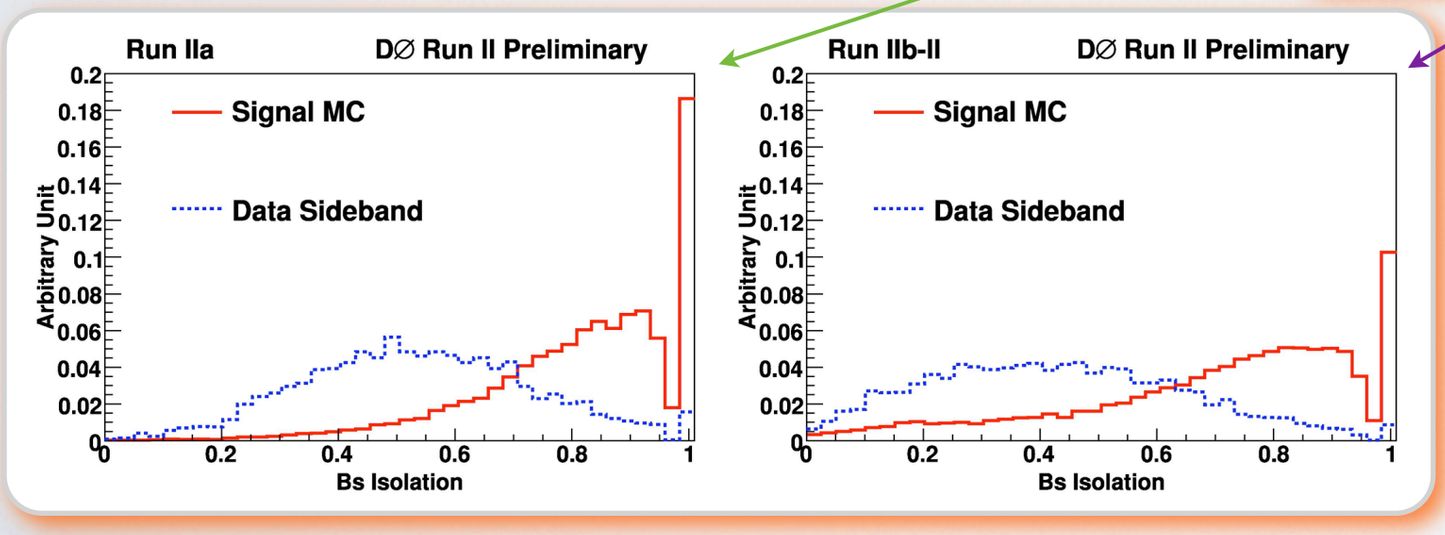
Run II (since 2001):

- $\sqrt{s} = 1.96$ Tev,
- inst. lumi ~ 3.5×10^{32} $cm^{-2}s^{-1}$,
- total lumi. > 9 fb^{-1} delivered.

Tevatron offers:

- large $b\bar{b}$ production rate,
  ~40×10^6 $b\bar{b}$ pairs/hour produced,
- unique opportunity to study B_s,
- high integrated luminosity.



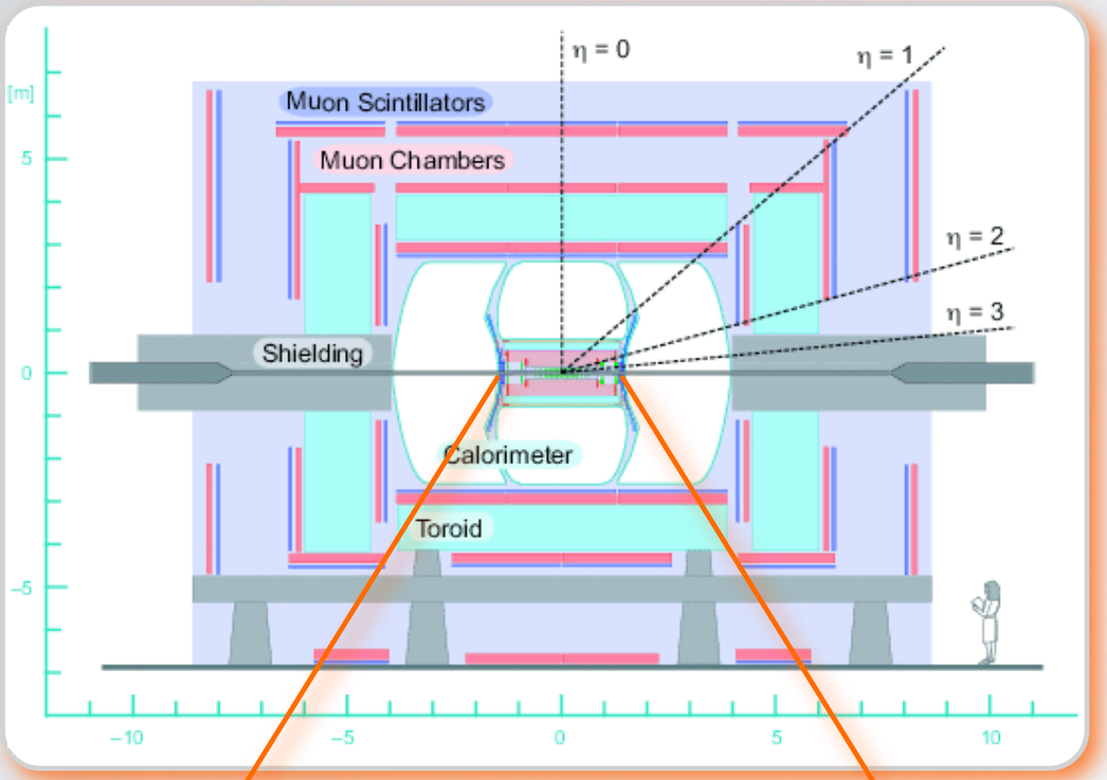


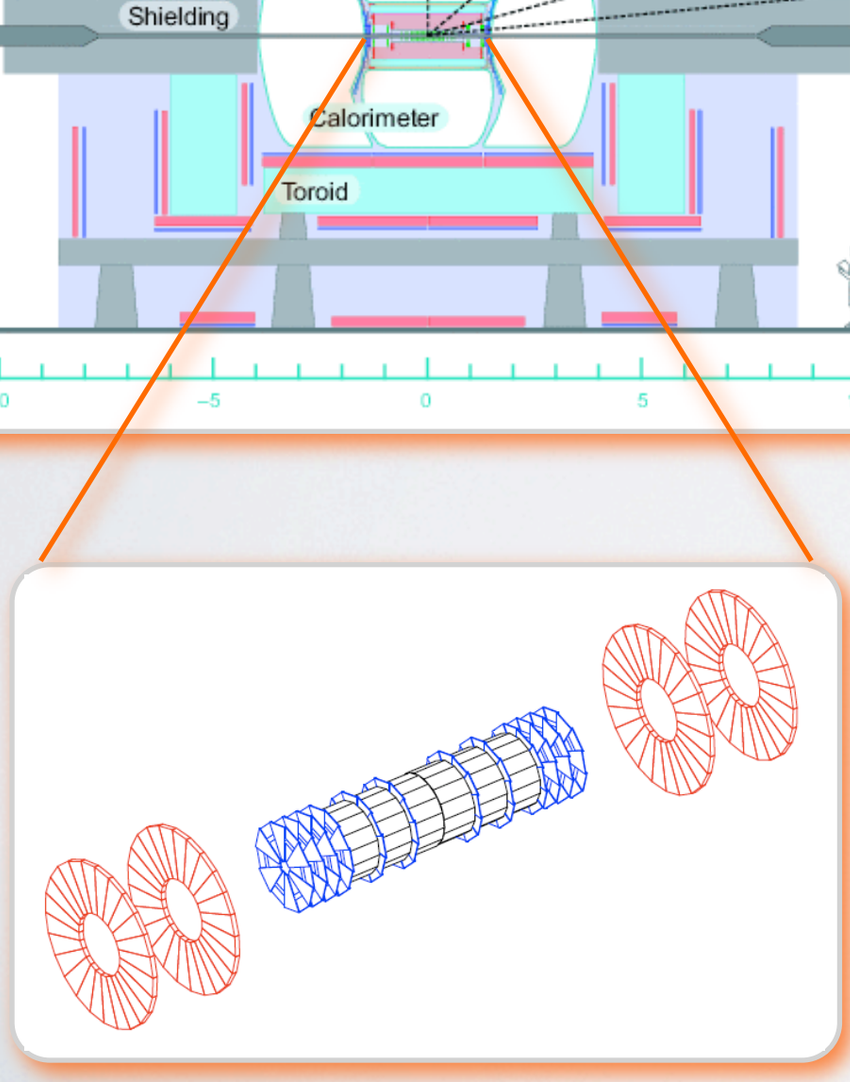
But also:

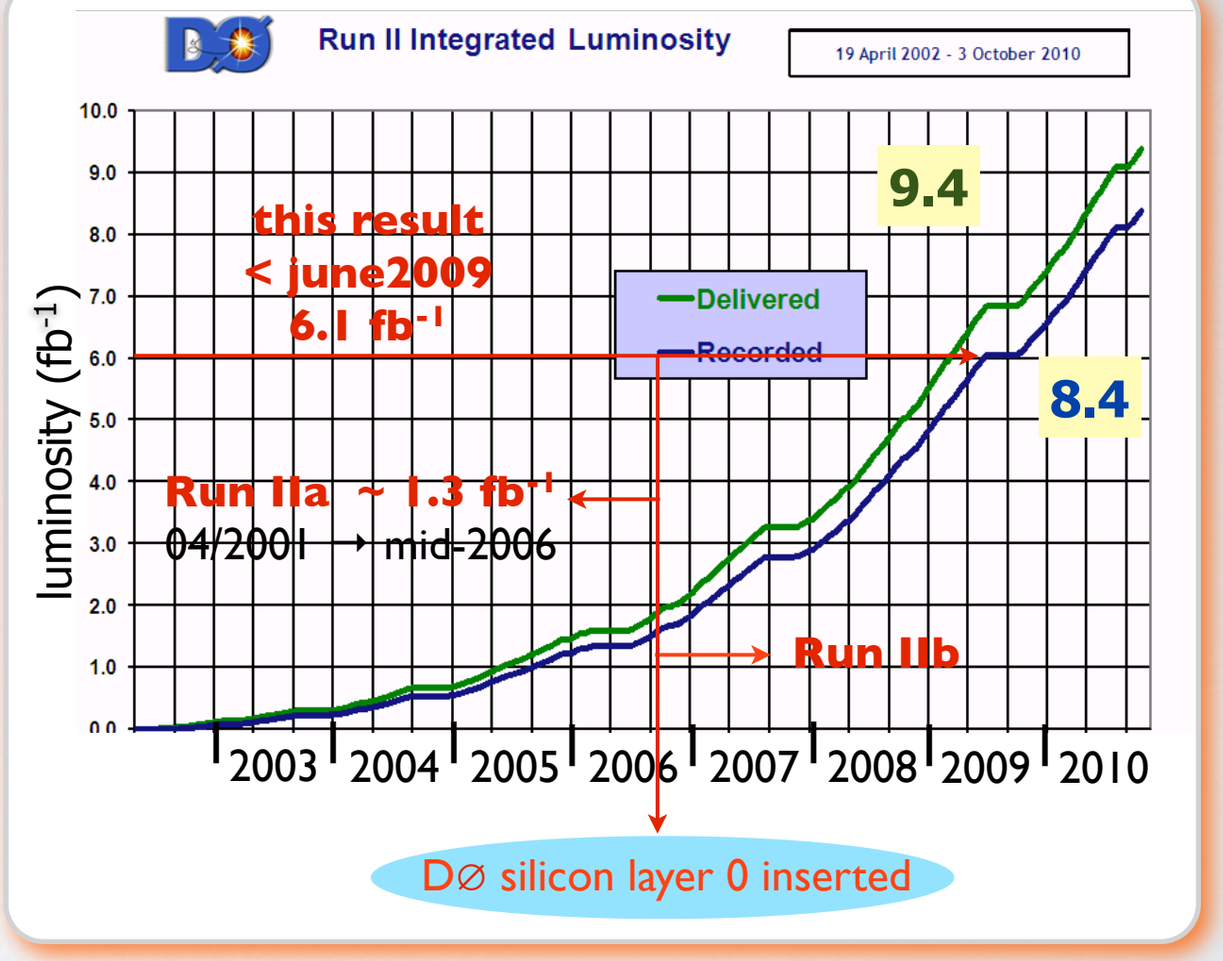
- huge background (> x1000),
- high track multiplicity environment.

→ underlying differences w.r.t. the instantaneous luminosity.

the DØ detector







DØ's major assets:

- very good data taking efficiency,
- **good muon** identification with **wide acceptance** ($|\eta| < 2$),
- highly **selective triggers** to cope with the high instantaneous luminosity.

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

$\mathcal{B}(B^0 \rightarrow \mu\mu) \sim 10^{-10}$:

- suppressed by $|V_{td}/V_{ts}|^2$,
- neglected.

correction for additional track from MC

$$\mathcal{B}(\mathbf{B_s^0} \rightarrow \mu\mu) = \frac{\mathbf{N(B_s \rightarrow \mu\mu)}}{\mathbf{N(B^+ \rightarrow J/\psi K^+)}} \times \frac{\varepsilon(\mathbf{B^+})}{\varepsilon(\mathbf{B_s^0})} \times \mathbf{f}\left(\frac{\mathbf{b \rightarrow B^+}}{\mathbf{b \rightarrow B_s^0}}\right) \times \mathcal{B}(\mathbf{B^+ \rightarrow J/\psi K^+, J/\psi \rightarrow \mu\mu})$$

PDG values: $f_s/f_d = 3.86 \pm 0.59$

normalization to observed $B^+ \rightarrow J/\psi K^+ \rightarrow \mu\mu K^+$ events:

- large and well-known B.R. = $(5.97 \pm 0.22) \times 10^{-5}$.
- same reconstruction & selection as $B_s \rightarrow \mu\mu$: efficiencies cancellation.

$B^+ \rightarrow J/\psi\, K^+$ calibration sample

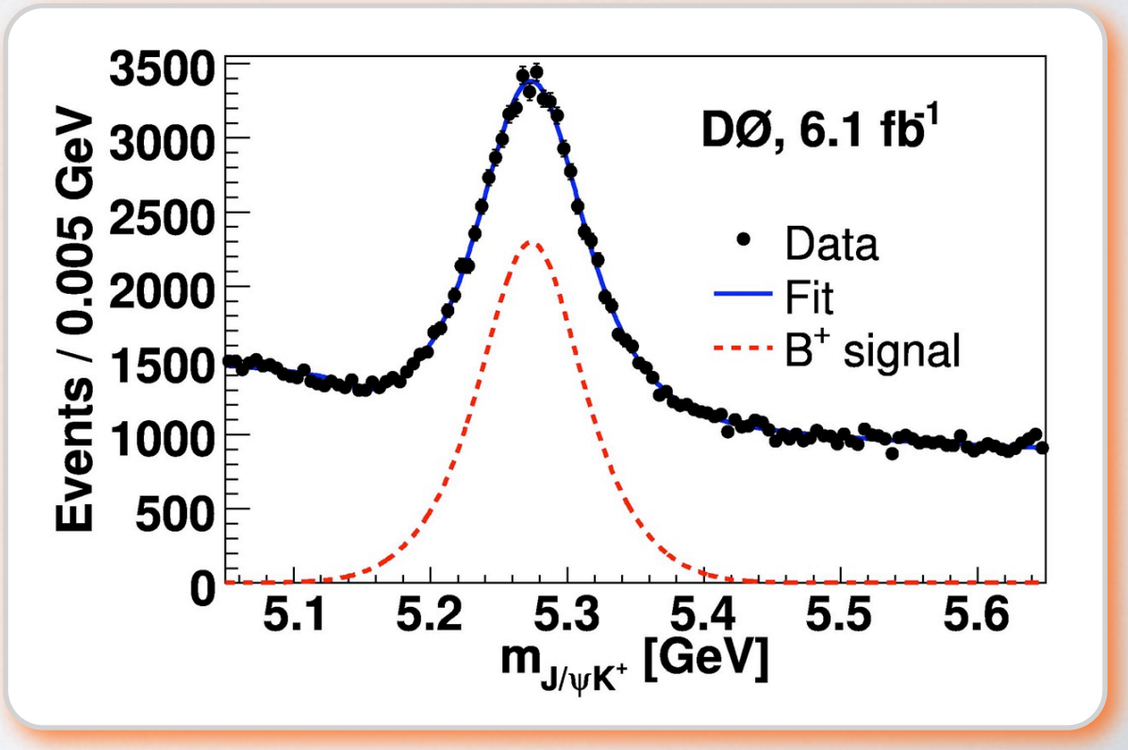
- preselection based on same sequential cuts as $B_s \rightarrow \mu\mu$:

  μ track selection, μ identification, $q(\mu\mu)$, $p_T(\mu)$, $L_{xy}(B)/\sigma_L$, $\chi^2(\text{vtx})$.

- efficiency to select one additional K track (w.r.t. $B_s \rightarrow \mu\mu$):
  - study of data/simulation agreement to estimate the systematics uncertainty using reconstructed $B^0 \rightarrow J/\psi K^{*0}$ with $K^{*0} \rightarrow K^+\pi^-$.

- background estimation under the B^+ mass peak:
  - shapes from simulation for the physical backgrounds $B^+ \rightarrow J/\psi\pi^+$ and $B^0 \rightarrow J/\psi K^{*0}$,
  - data sideband fit for the combinatorial background.

- observed number of $B^+ \rightarrow J/\psi K^+ \rightarrow \mu\mu K^+$:
  - Run IIa: **14340 ± 665** events,
  - Run IIb: **32463 ± 875** events.

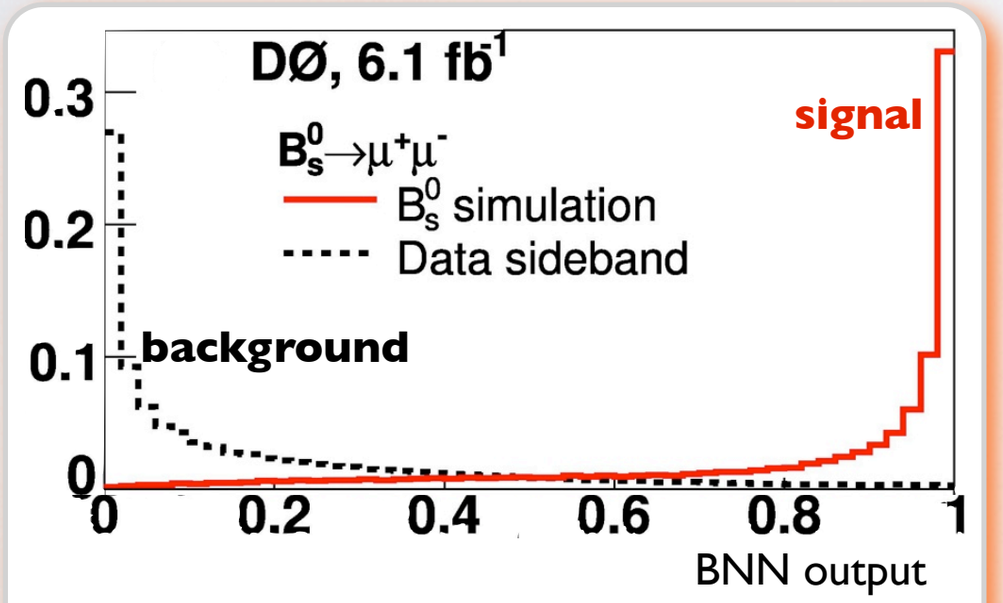


$B_s \rightarrow \mu^+\mu^-$ improved selection

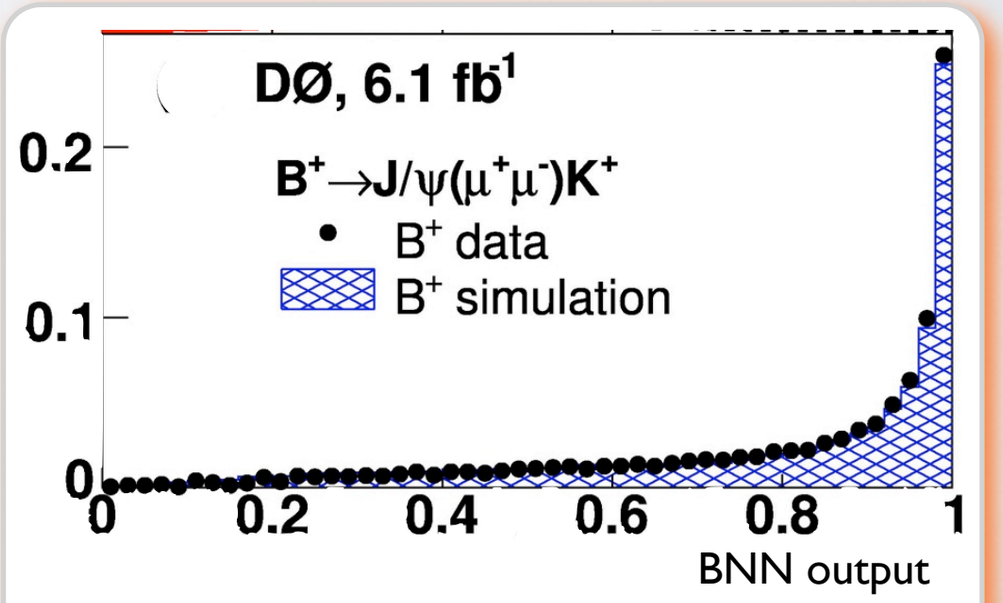
- further background rejection by using a Bayesian Neural Network built with 6 discriminating variables:

  min IP/$\sigma_{IP}(\mu)$ - pointing angle - χ_{vtx}^2 - L_{xy} (B)/σ_L - $p_T(B_s)$ - min $p_T(\mu)$.

- unbiased selection optimization (data signal region blinded) based on simulated signal and mass sidebands data (4.5 to 5 GeV/c^2 and 5.8 to 6.5 GeV/c^2).
Run IIa and Run IIb classifiers are trained separately.

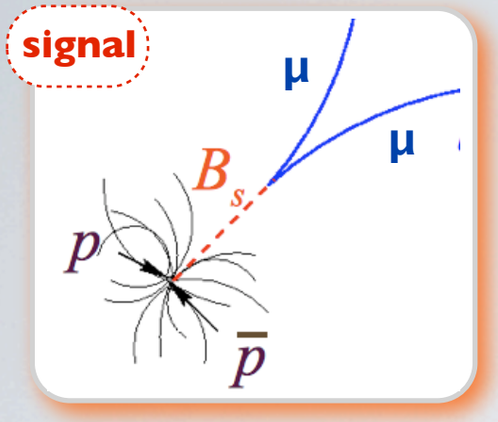


signal / background discrimination



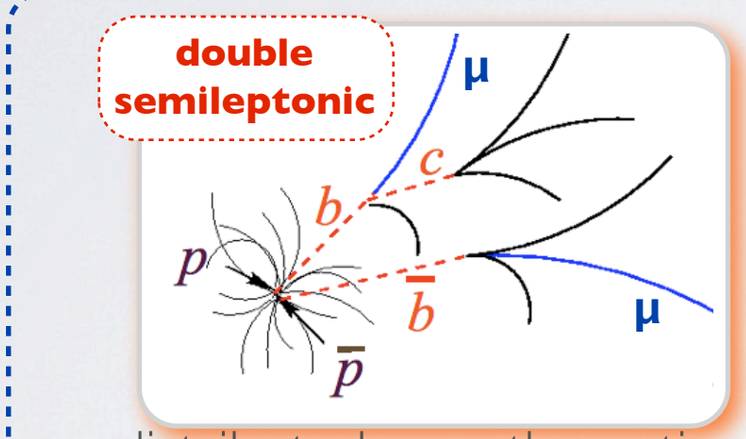
data / simulation agreement

background estimation

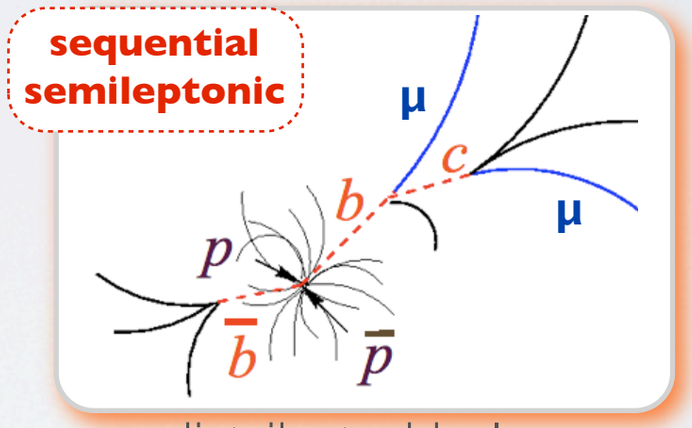


- Combinatorial background due to $b\bar{b}$ and $c\bar{c}$ semileptonic decays is dominant.

Estimated by fitting the data sidebands events, in each BNN bin ≥ 0.8, with shapes fixed from simulation for sequential and double semileptonic decays.



distributed over the entire invariant mass signal region



distributed below the B hadron mass

major background

- $B \rightarrow h^+h'^-$ contribution (with h = K or π) peaking in the B_s signal region, due to μ fake rate, is negligible.

Largest contribution is $B_s \rightarrow K^+K^-$: Run IIa : **0.13 ± 0.10** events expected

Run IIb : **0.36 ± 0.27** events in Run IIb.

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

- Observed yields in the signal region:

  Run IIa: **256** events
  Run IIb: **823** events

- Expected background:

  Run IIa: **264 ± 13** events
  Run IIb: **827 ± 23** events

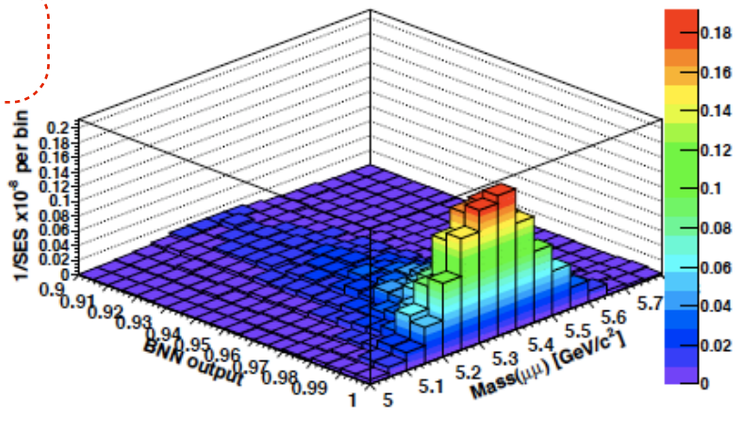
- Observed number of events is **compatible with the background expectation**.

- SM expected $B_s \rightarrow \mu^+\mu^-$ yields:

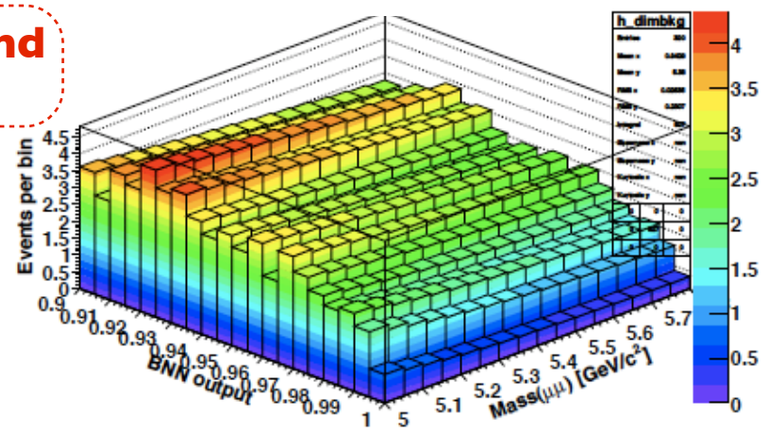
  Run IIa: **0.74 ± 0.17** events
  Run IIb: **1.95 ± 0.42** events

- **sensitivity improved** by dividing the signal region into several bins of **2D histograms** of mμμ vs. BNN output.

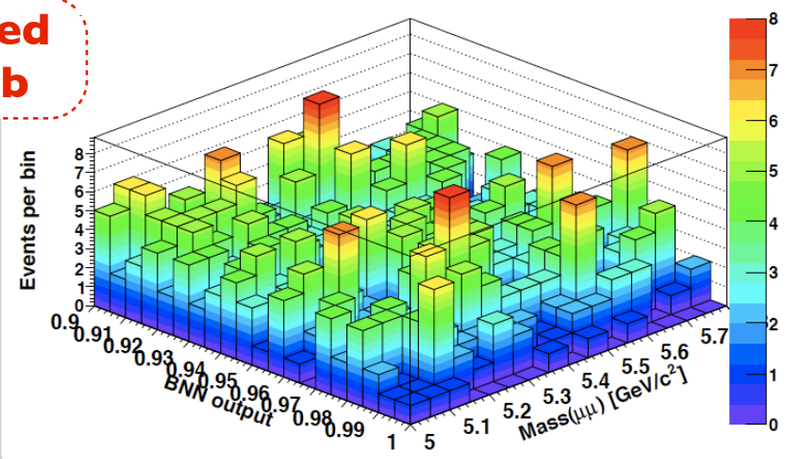
signal Run IIb



background Run IIb



observed Run IIb



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

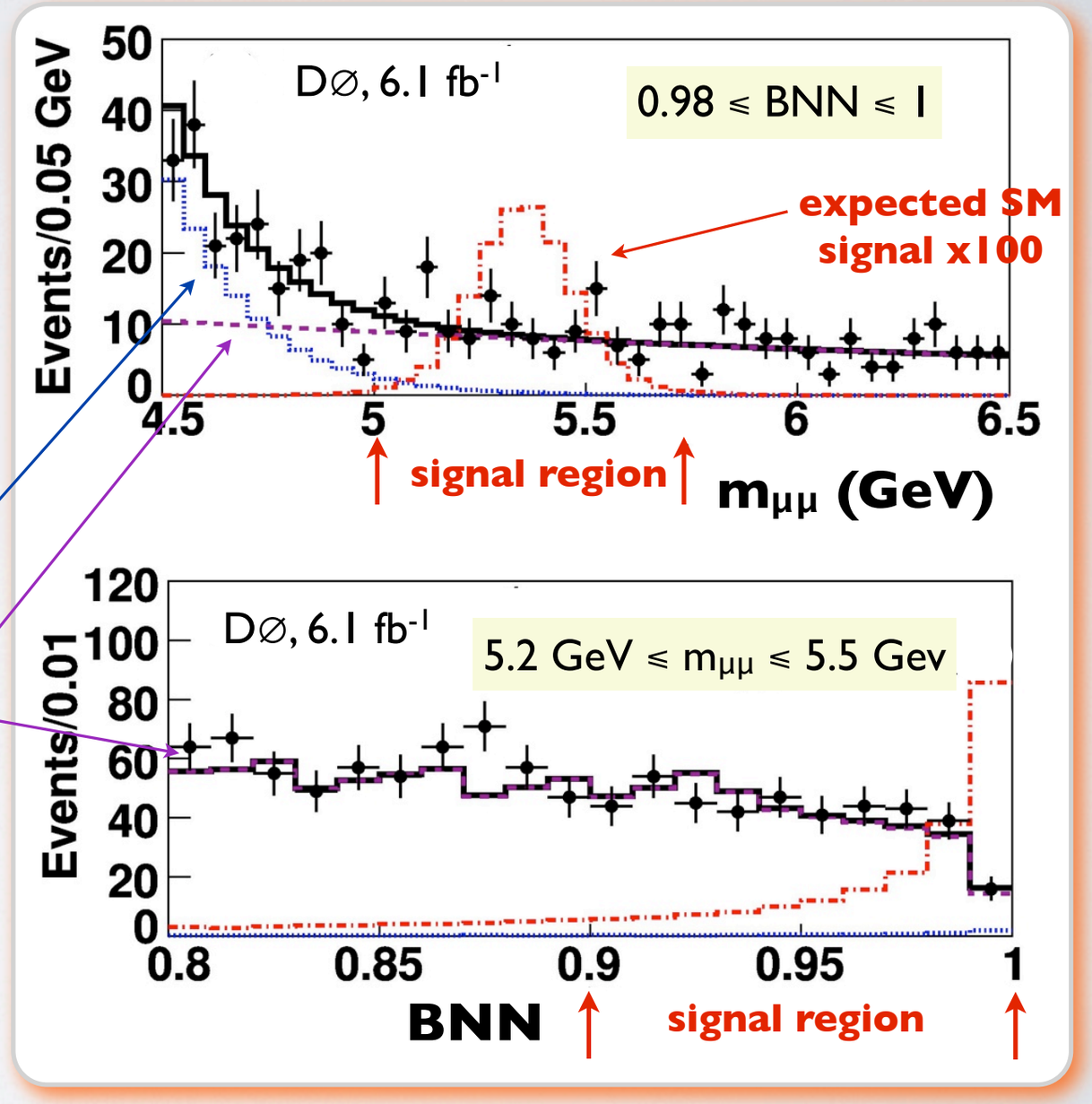
- the 95 % upper limits are calculated using the semi-Frequentist approach (CL_s):

data	Run IIa	Run IIb
expected limit	8.5×10^{-8}	4.6×10^{-8}
observed limit	8.2×10^{-8}	6.5×10^{-8}

→ combined 95 % C.L. limit with 6.1 fb^{-1} of DØ data:

$$\mathcal{B}(B_s \rightarrow \mu^- \mu^+) < 5.1 \times 10^{-8}$$

expected: 4.0×10^{-8}



conclusion

- DØ reports a new limit on $B_s \rightarrow \mu\mu$. This limit is the best published limit, it is at the same level of sensitivity than CDF's preliminary result.

- Very good performance from the Tevatron:
  - more than 6 fb^{-1} analysed in this measurement,
  - more than 8 fb^{-1} already stored,
  - twice as much data may be expected at the end of Tevatron RunII.

- **Expected limit scales better than 1/sqrt(N) due to improved analysis techniques.**

This limit is 2.4x better than the previous published one:

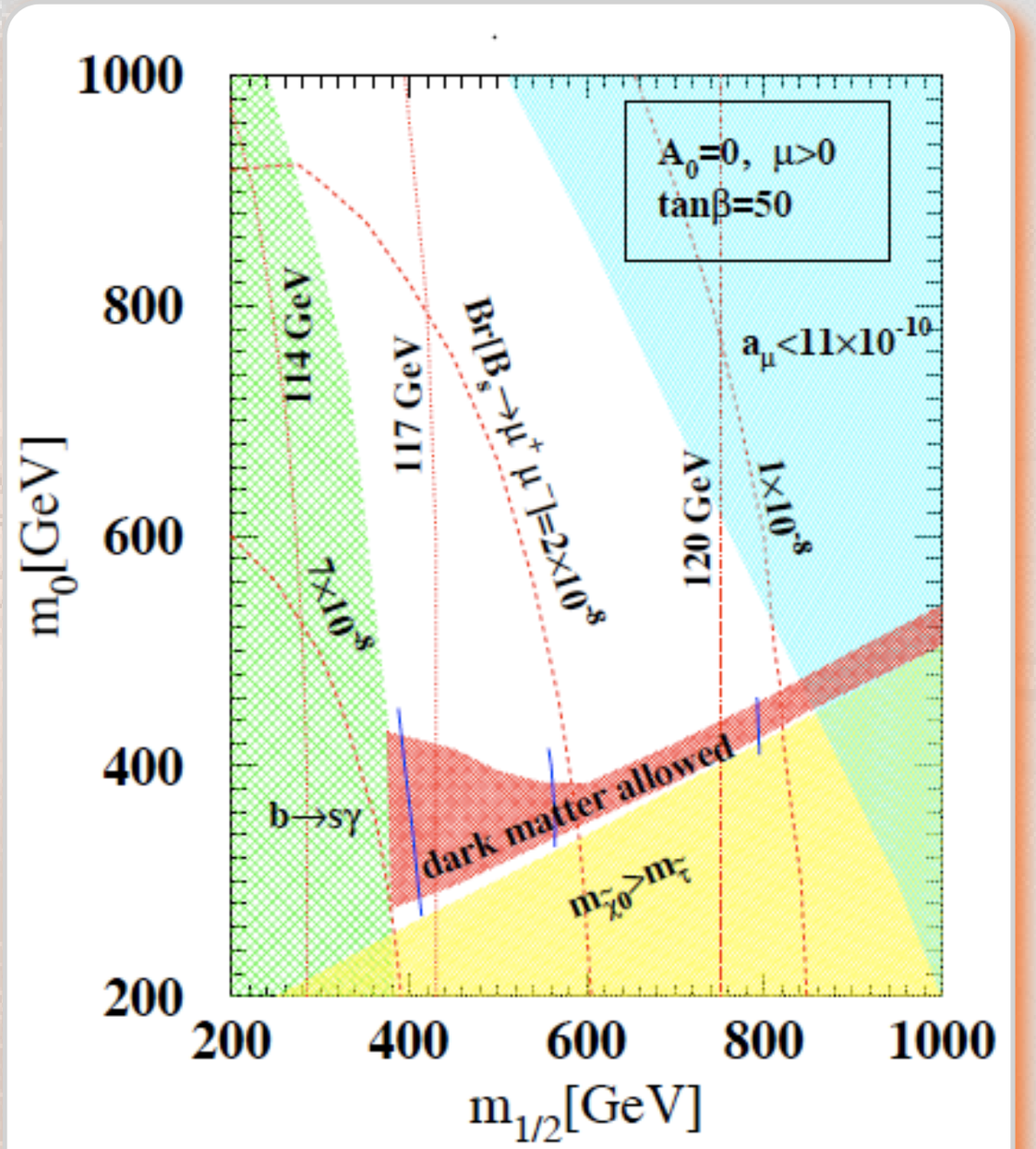
  - 4.6 times more data,
  - 10% improvement originates in the analysis improvement:
    - gain in the muon yield,
    - not only counting events in signal region but also using shape,
    - better background rejection.

and outlook

- Tevatron limits are only a factor 10 above the SM:
there is still room for new physics ☺.

- **Further significant reduction of theoretical parameter space** can be expected as more data are included.

- By end of 2011 LHCb will become competitive on this measurement.
We have to rapidly add data and combine DØ with CDF.



R. Arnowitt et. al., Phys.Lett.B538:121-129,2002.