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

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**on behalf of the DØ collaboration**

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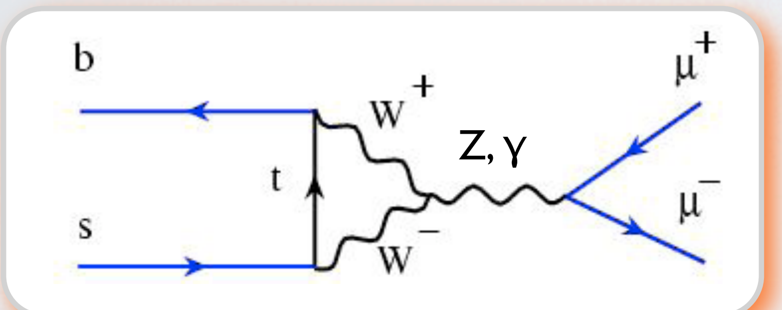
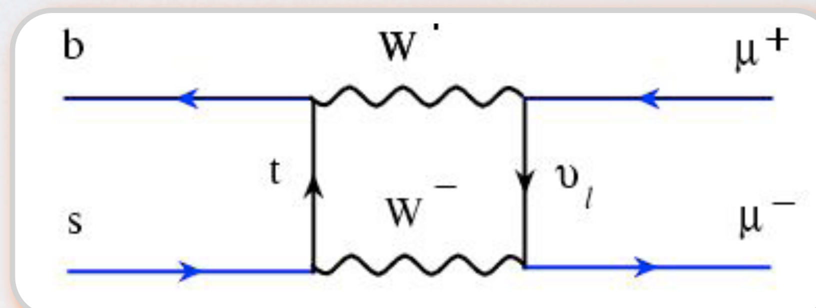
# motivation

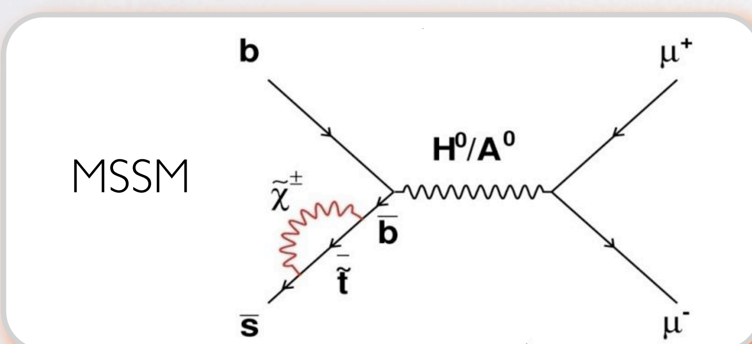
- FCNC processes have **very low rate in SM** and are well understood:

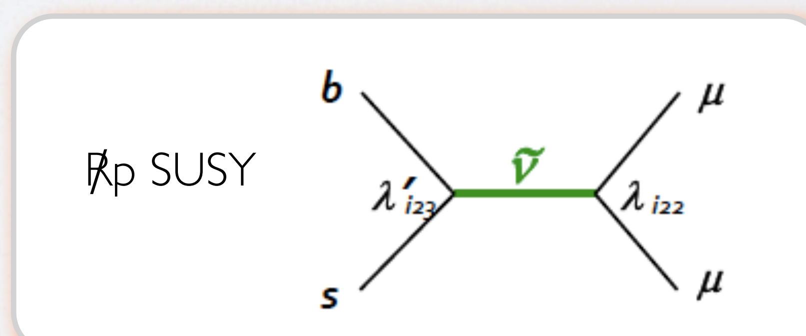
$$\mathscr{B}(B_s \to \mu^- \mu^+)_{SM} = (3.6 \pm 0.3)\text{x}10^{-9}$$ A.J. Buras, Prog.Theor.Phys.122:145-168,2009.




- whereas many Beyond SM theories predict enhancements.



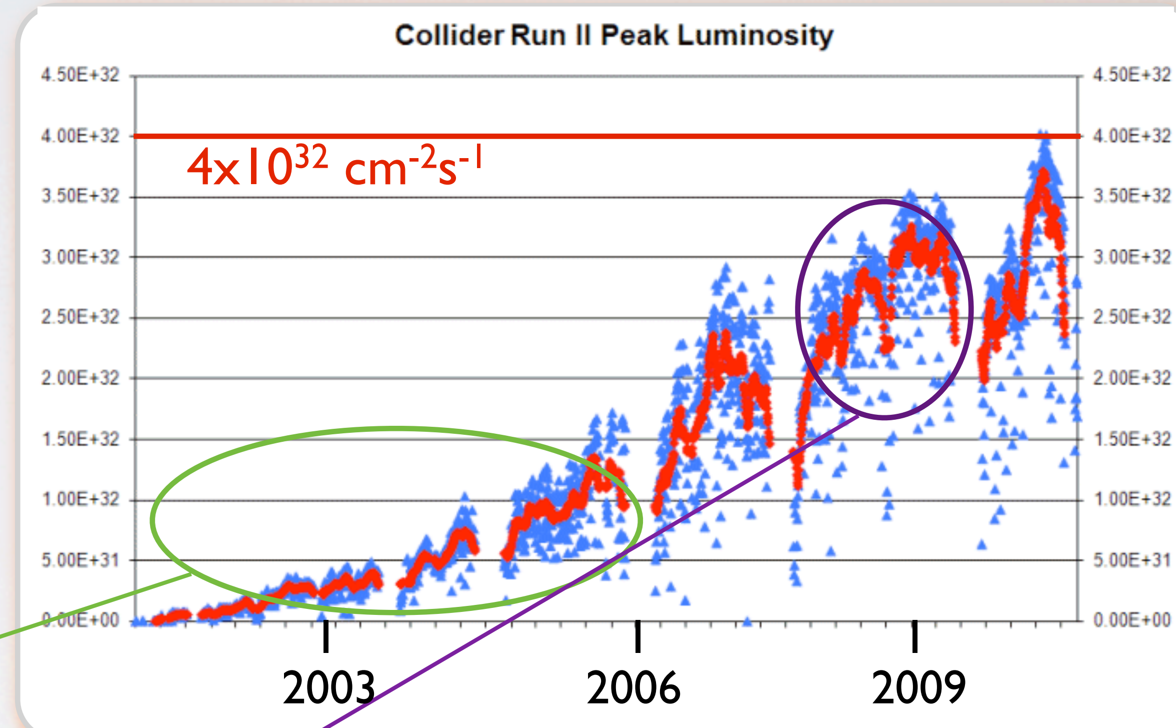

→ sensitivity to new physics

# previous measurements

- best current limit: $< 4.3\times10^{-8}$ (95% CL) by CDF with 3.7 $fb^{-1}$, preliminary
- DØ-Run II previous limits on $\mathcal{B}(B_s \to \mu^- \mu^+)$:
  - $< 5.0\times10^{-7}$ (95% CL) with 240 $pb^{-1}$ PRL 94, 071802 (2005)
  - $< 1.2\times10^{-7}$ (95% CL) with 1.3 $fb^{-1}$ PRD 76, 092001 (2007)
  - $< 9.3\times10^{-8}$ (95% CL) with 2 $fb^{-1}$ preliminary
  - $< 5.2\times10^{-8}$ (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.

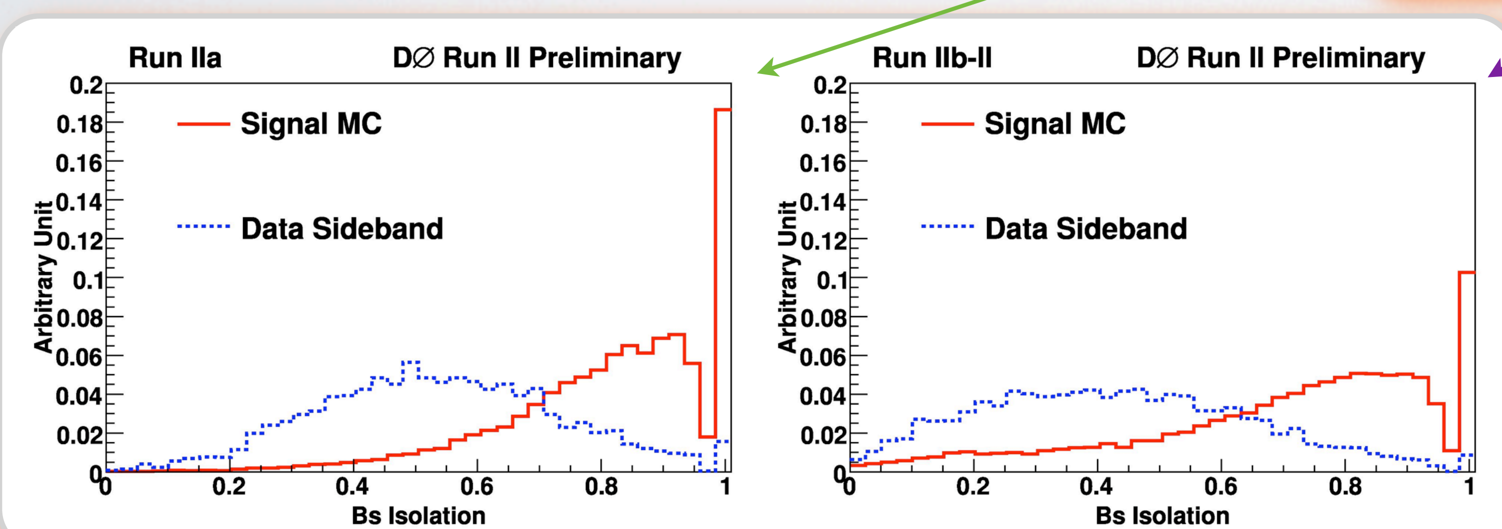



## Run II (since 2001):

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

## Tevatron offers:

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

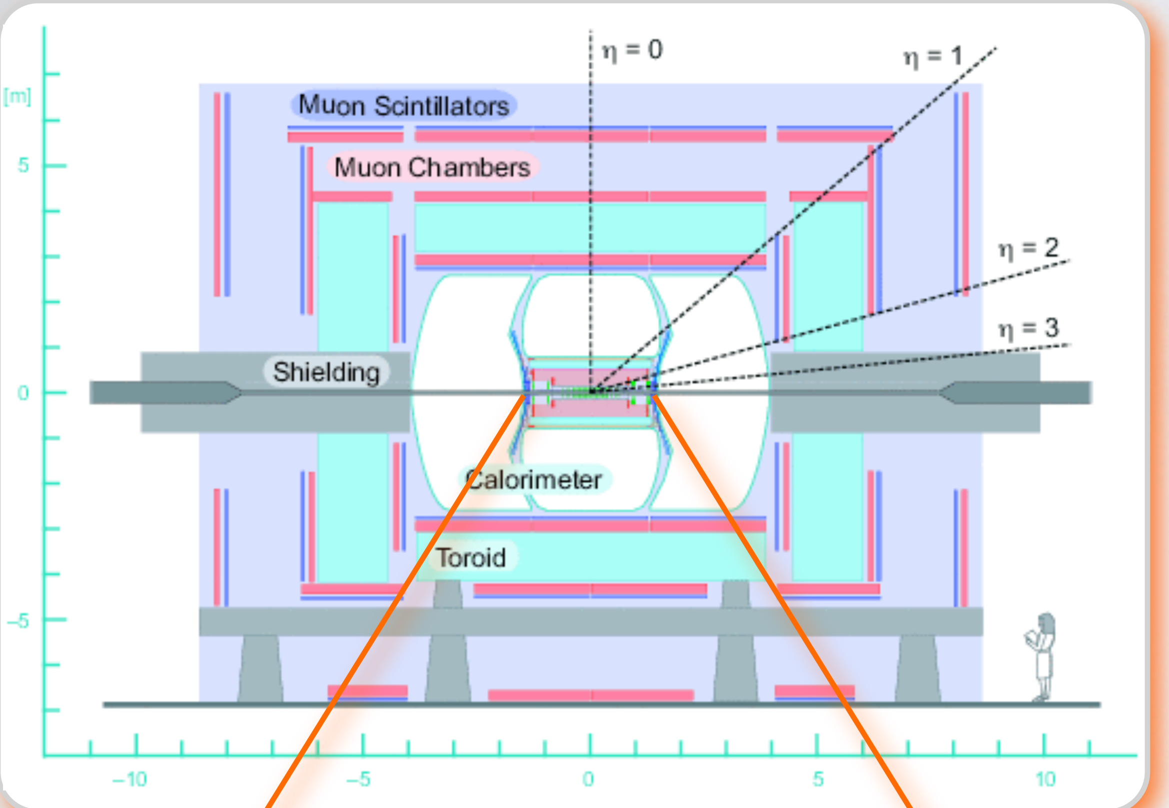


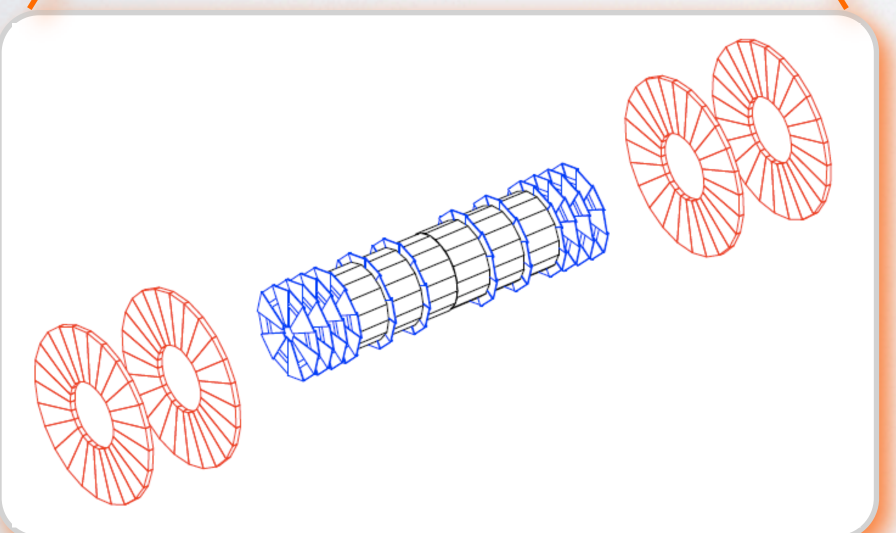

## But also:

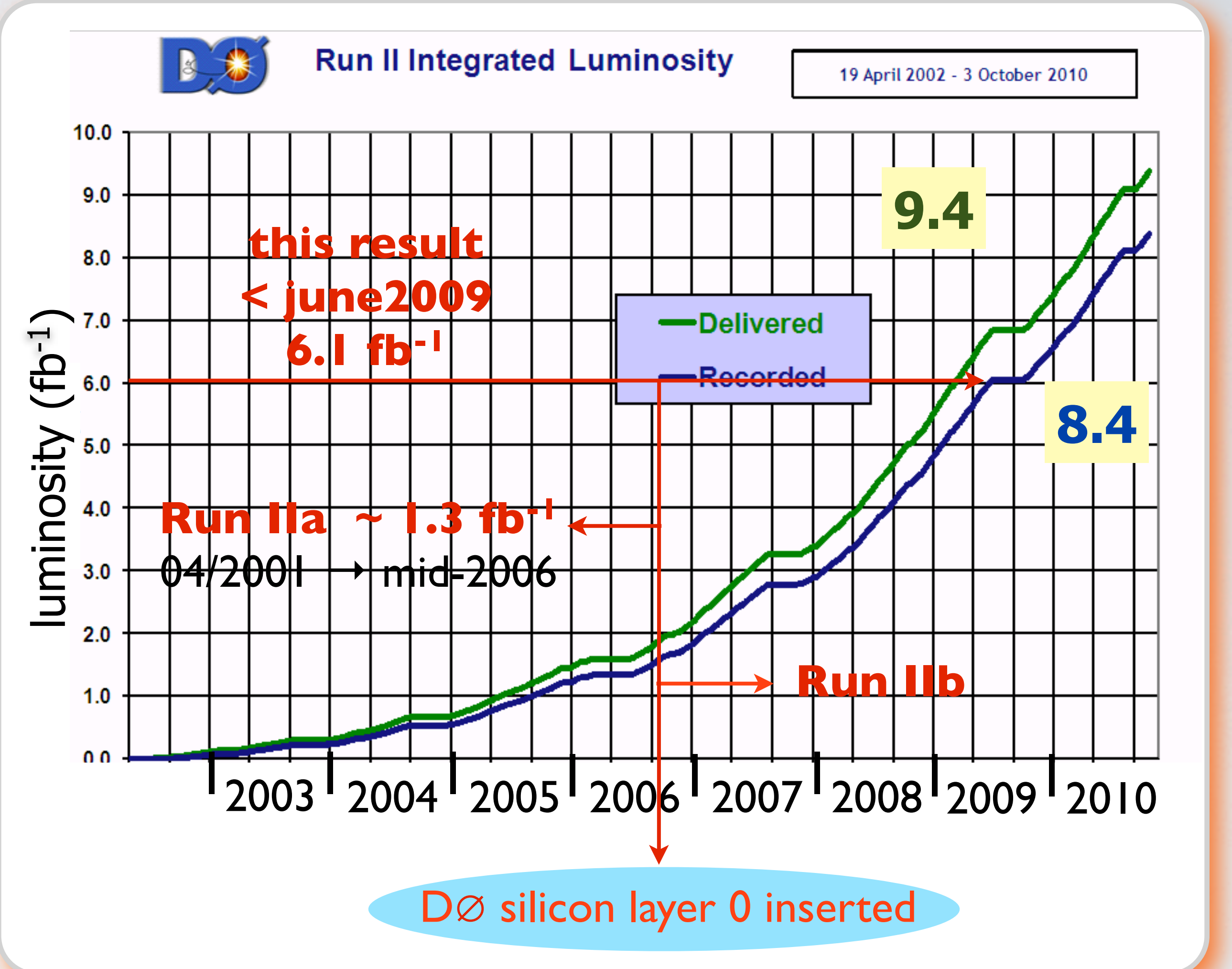
- huge background (> x1000),
- high track multiplicity environment.

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

# the D∅ detector






D∅'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

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

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.

# $B^+ \to J/\psi K^+$ calibration sample

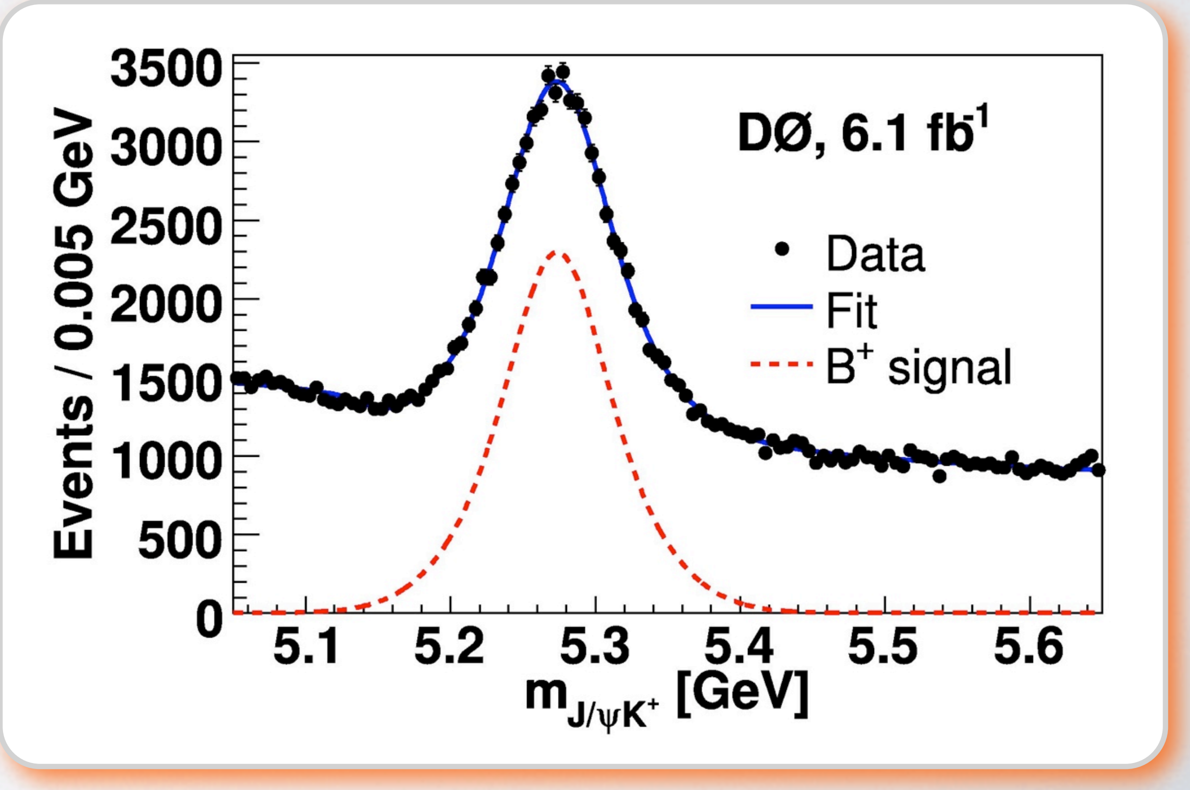
- preselection based on same sequential cuts as $B_s \to \mu\mu$:

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

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

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

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

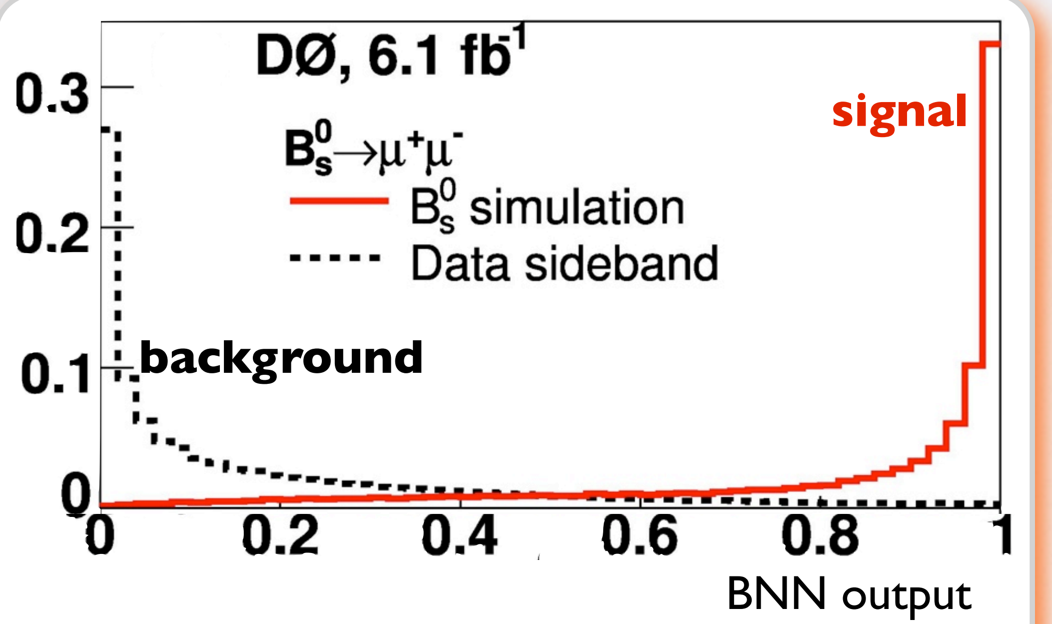


# $B_s \to \mu^+\mu^-$ improved selection

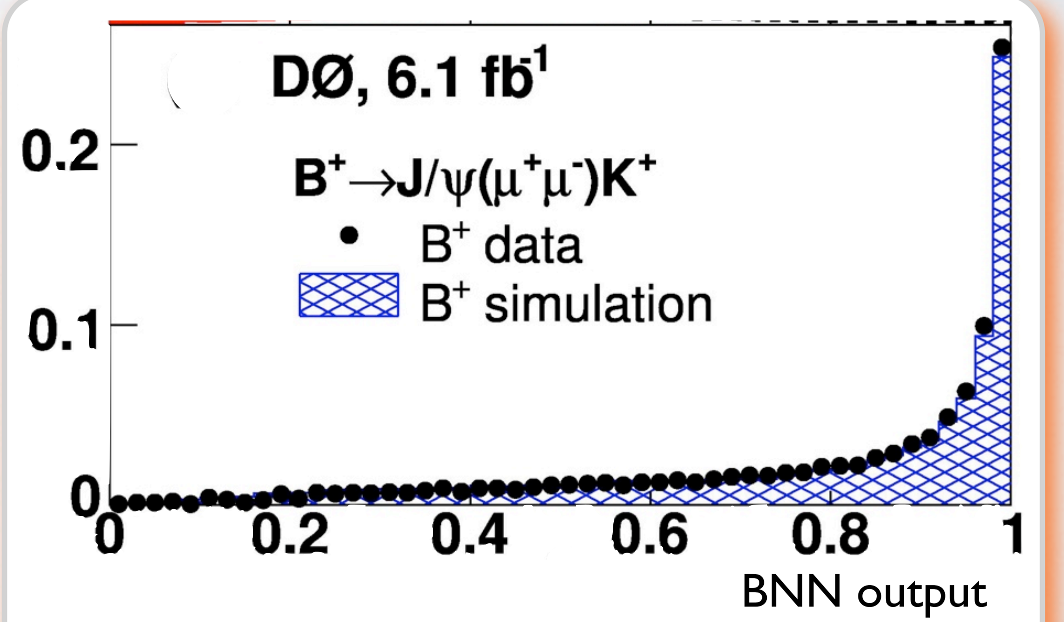
- further background rejection by using a Bayesian Neural Network built with 6 discriminating variables:

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

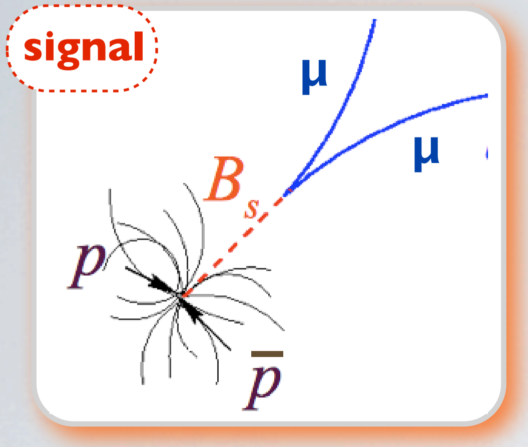
- unbiased selection optimization (data signal region blinded) based on simulated signal and mass sidebands data (4.5 to 5 GeV/$c^2$ and 5.8 to 6.5 GeV/$c^2$). Run IIa and Run IIb classifiers are trained separately.




signal / background discrimination



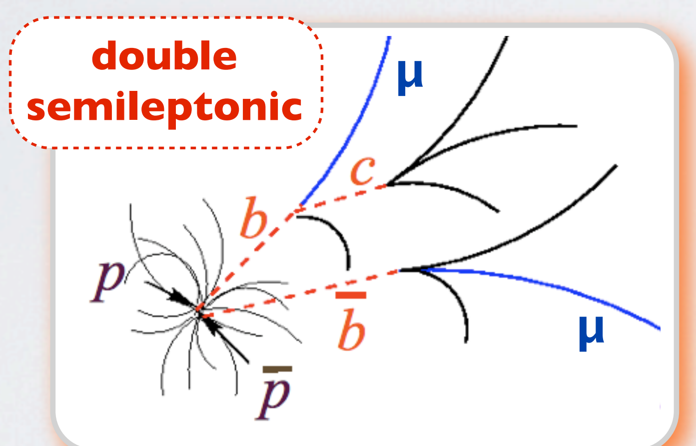

data / simulation agreement



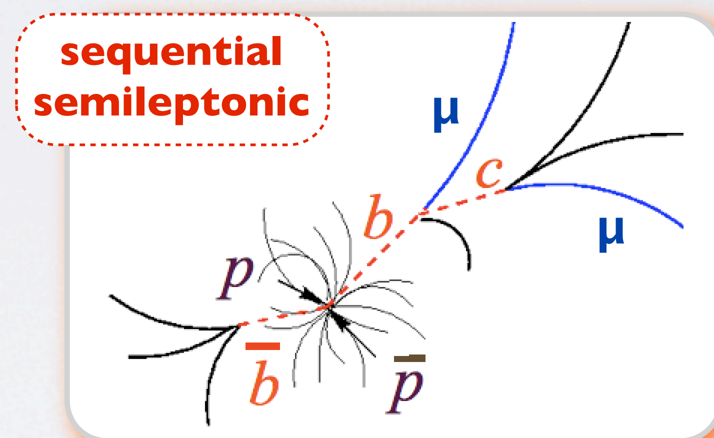

# background estimation

- **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.

# $B_s \to \mu^+\mu^-$ observation

- Observed yields in the signal region:

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

- Expected background:

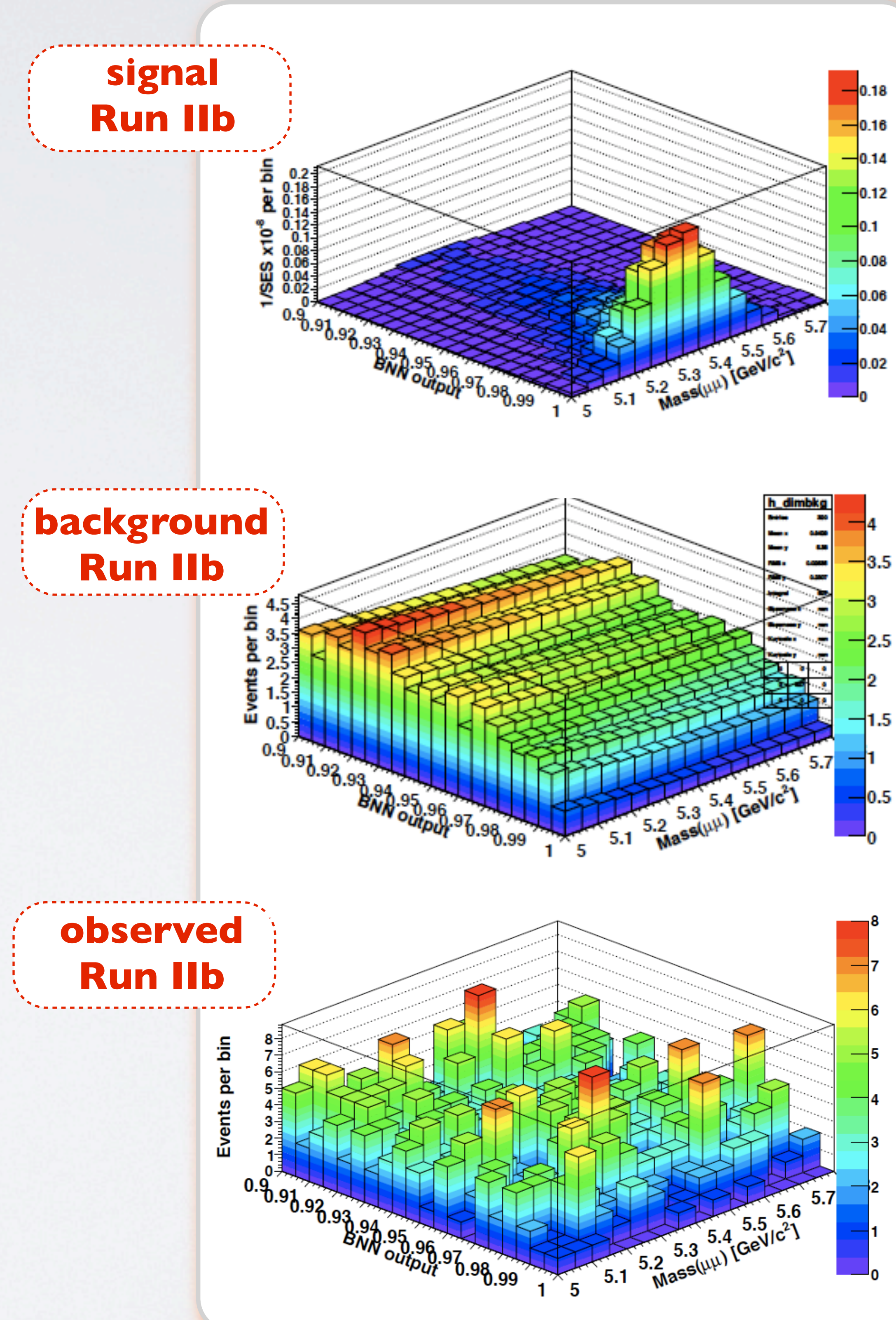
  Run IIa: **264 ± 13** events
  Run IIb: **827 ± 23** events

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

- SM expected $B_s \to \mu^+\mu^-$ 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 $m_{\mu\mu}$ vs. BNN output.



# $B_s \to \mu^+\mu^-$ limit extraction

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

| data | Run IIa | Run IIb |
|---|---|---|
| expected limit | $8.5\times10^{-8}$ | $8.2\times10^{-8}$ |
| observed limit | $4.6\times10^{-8}$ | $6.5\times10^{-8}$ |

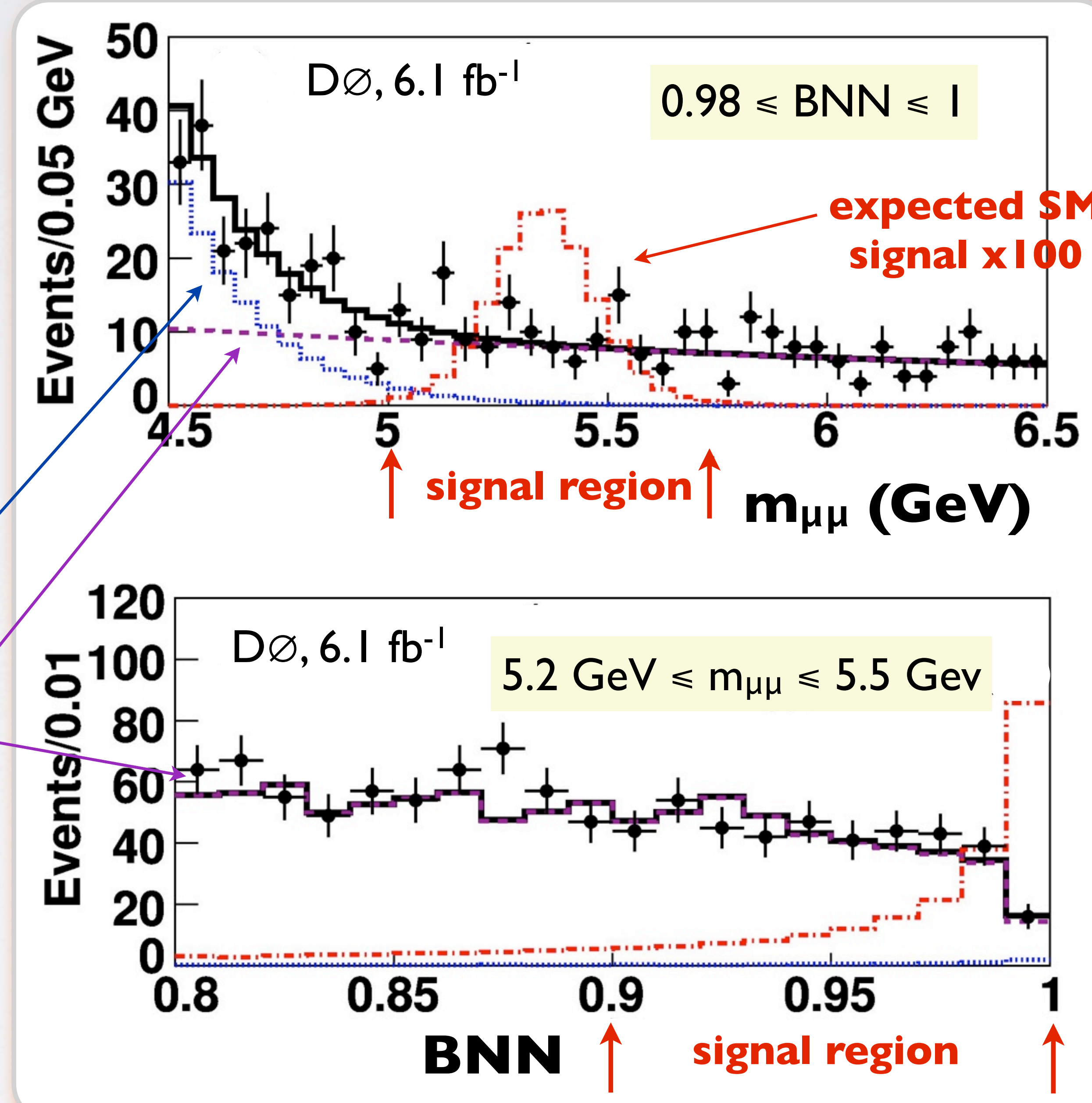
→ combined 95 % C.L. limit with $6.1\ fb^{-1}$ of DØ data:

$\mathcal{B}(B_s \to \mu^- \mu^+) < 5.1\times10^{-8}$

expected: $4.0\times10^{-8}$

sequential semileptonic

double semileptonic



# conclusion

- DØ reports a new limit on $B_s \to \mu\mu$. 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.

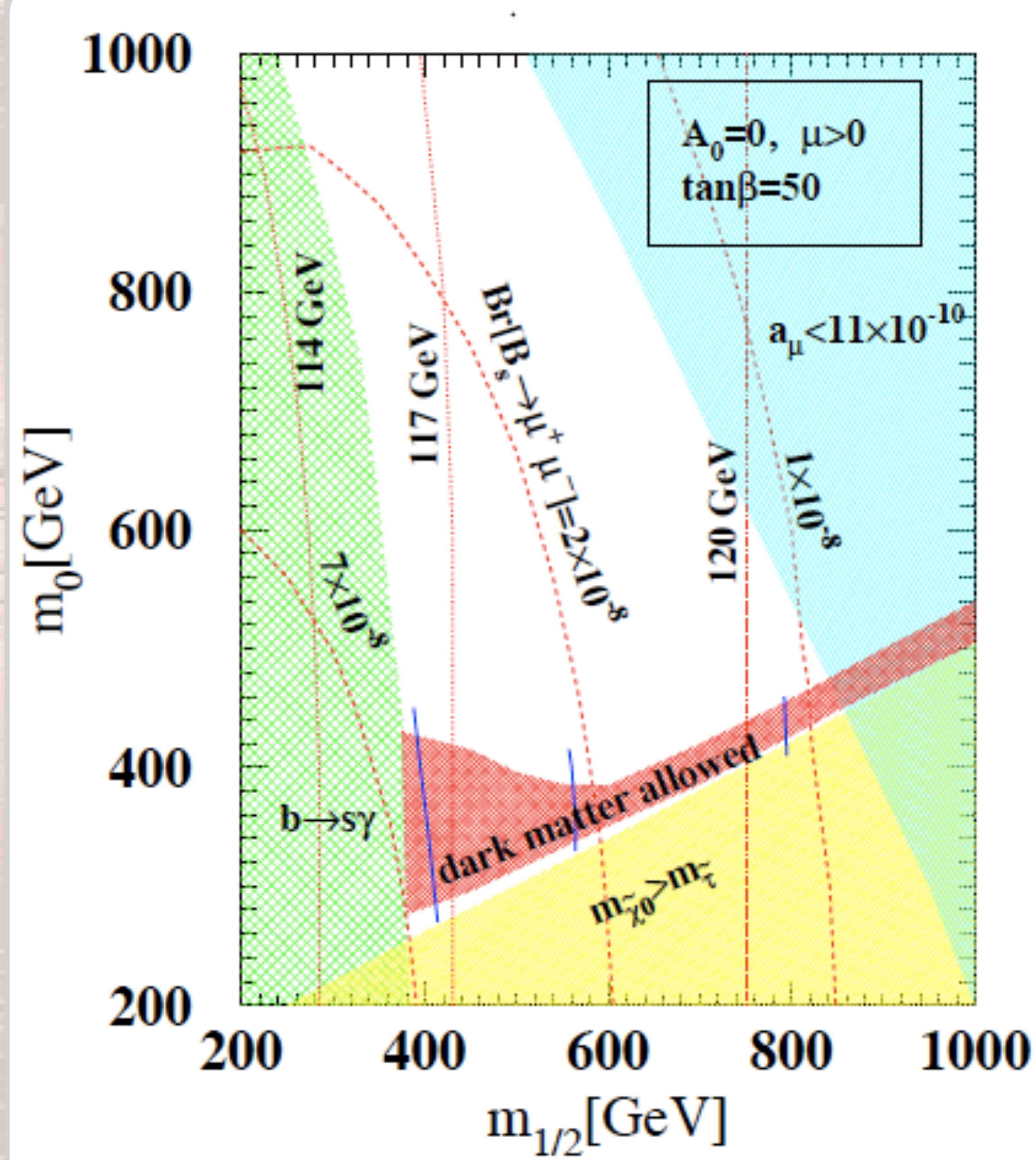
- **Expected limit scales better than 1/sqrt(N) due to improved analysis techniques.** This limit is 2.4x better than the previous published one:
  - 4.6 times more data,
  - 10% improvement originates in the analysis improvement:
    - gain in the muon yield,
    - not only counting events in signal 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.