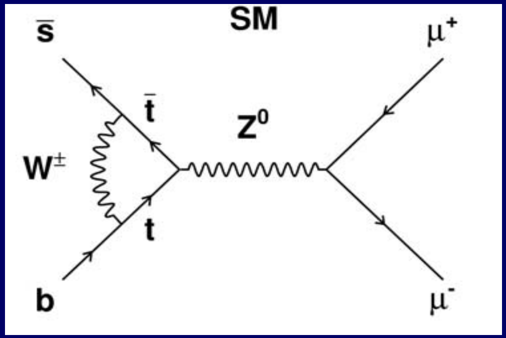
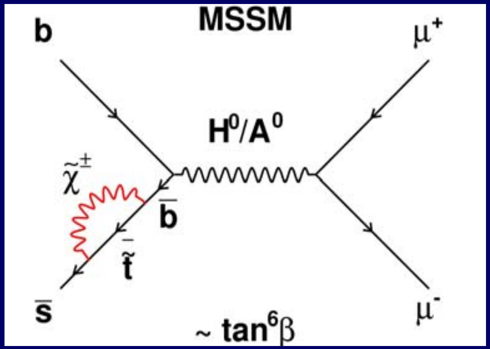
Search for $B_s \rightarrow \mu^+\mu^-$ decay at LHCb





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On behalf of the LHCb Collaboration

Lake Louise Winter Institute, February 19-24, 2007

Outline

- Motivation
- LHCb experimental conditions
- LHCb performance:
  - trigger
  - tracking
  - muon ID

- Backgrounds
- Event selection
- N-counting method
- LHCb prospects

$B_s \to \mu^+\mu^-$: motivation

Very rare decay → very sensitive to NP

♦ SM predictions* (including ΔMs measurement from CDF) :

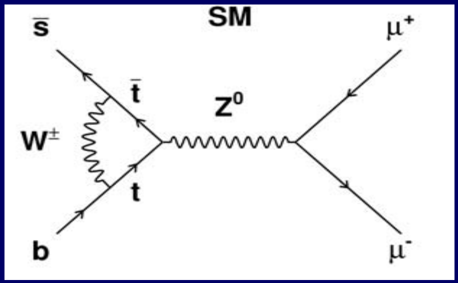
$BR(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$

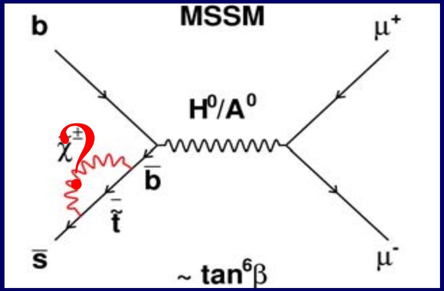
♦ Can be strongly enhanced in SUSY:

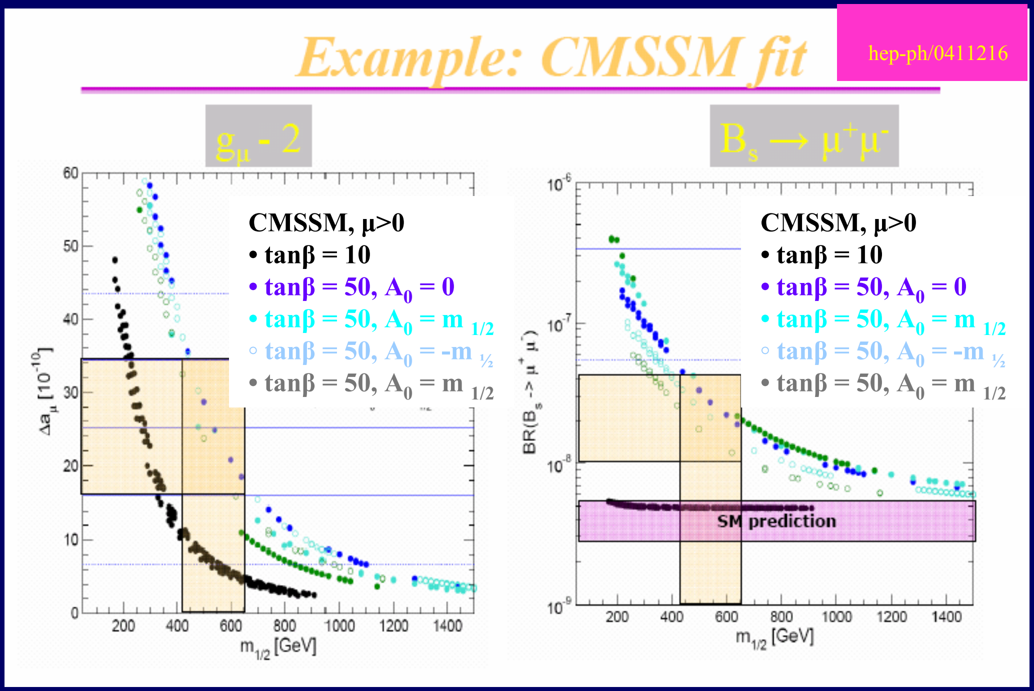
$BR(B_s \to \mu^+\mu^-) \propto \tan^6\beta$

♦ In the CMSSM the g_μ-2 and $BR(B_s \to \mu^+\mu^-)$ are computed as a function of gaugino mass for different tanβ values**.

♦ For high tanβ (tanβ~50) indications that gaugino mass is in the range 400-600 GeV →$Br(B_s \to \mu^+\mu^-)$ in the range $10^{-7} - 10^{-9}$







*A.J. Buras et al., Phys.Lett.B566 (2003) 115

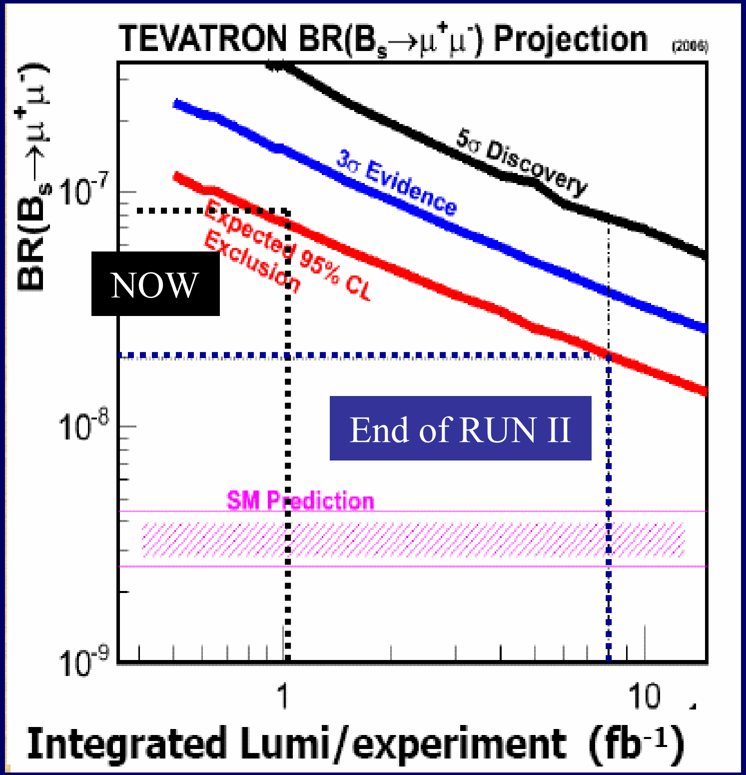
** J. Ellis et al., hep-ph/0411216

$B_s \to \mu^+\mu^-$: present experimental sensitivity

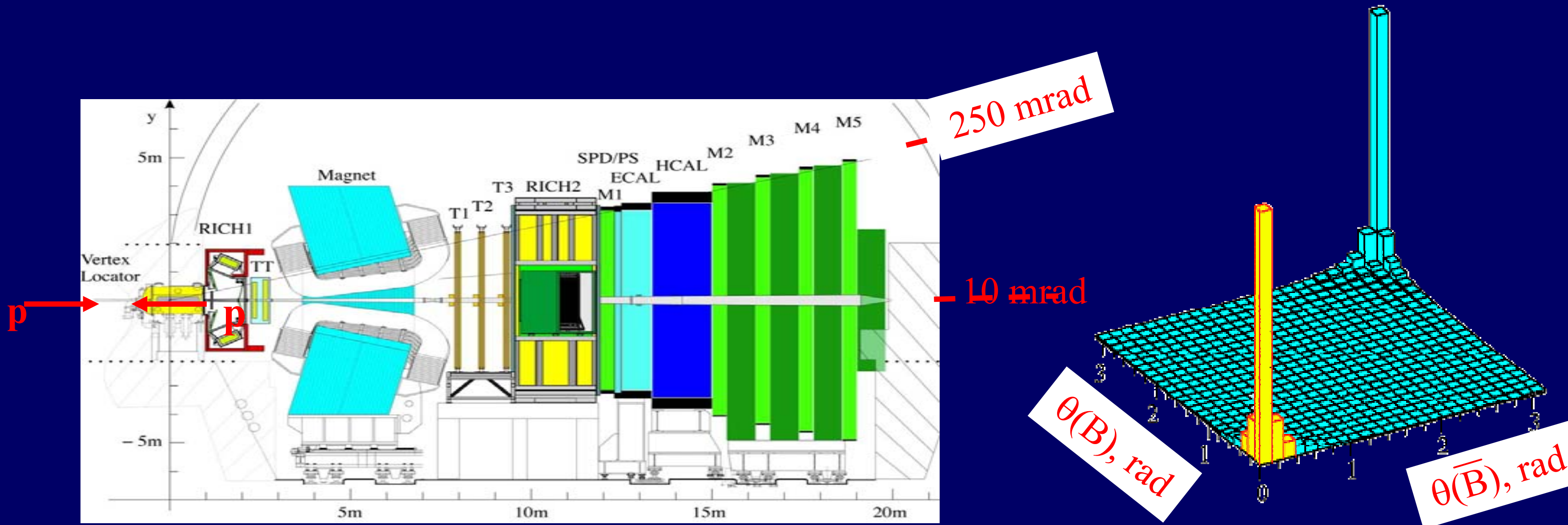
- Present experimental sensitivity:
  $BR(B_s \to \mu^+\mu^-) < 8 \cdot 10^{-8}$ @ 90% CL
  (CDF+D0 with 1 fb^{-1})

  $BR_{exp}/BR(SM) < 23$ @ 90% CL

- CDF+D0 projection with 8 fb^{-1}:
  $BR(B_s \to \mu^+\mu^-) < 2 \cdot 10^{-8}$ @ 90% CL
  (see M. Rescigno, CKM2006)



LHCb Experimental Conditions



Huge b's production:

- Luminosity 2 •10^{32} cm^{-2} s^{-1} → ~100 kHz bb @ ~10 MHz of visible interactions
- bb are produced backward/forward region → LHCb is one arm spectrometer
  - ~40 kHz in the acceptance $1.9<\eta<4.9$

Extremely low BR ($B_s \to \mu^+\mu^-$):

→ main issue is background rejection

$B_s \to \mu^+\mu^-$: key ingredients for sensitivity:

1) Very efficient trigger for the signal
2) Good mass resolution for background rejection
3) High μ-π and μ-K separation to minimize hadron misID

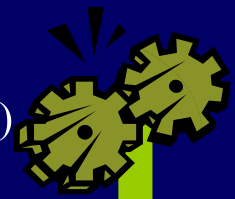
Relevant Trigger for $B_s \rightarrow \mu^+\mu^-$: the Muon Alley*

*General LHCb trigger description in V.Gibson's talk

b-content ~ 1%

~10 MHz

Number of visible interactions



L0 [hardware]:

Pt(μ)>1.1 GeV/c (with pileup veto)

OR

Pt(μμ)> 1.3 GeV (no pileup veto)

~200 kHz

HLT [software]:

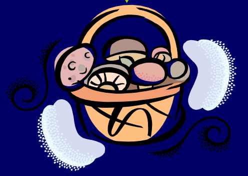
-Single muon line:

pt> 3GeV/c IPS>3

-di-muon line:

$M_{\mu\mu}$ > 2.5 GeV/c2 or

$M_{\mu\mu}$> 0.5 GeV/c2 and IP> 100 um



b-content ~ 60-70%

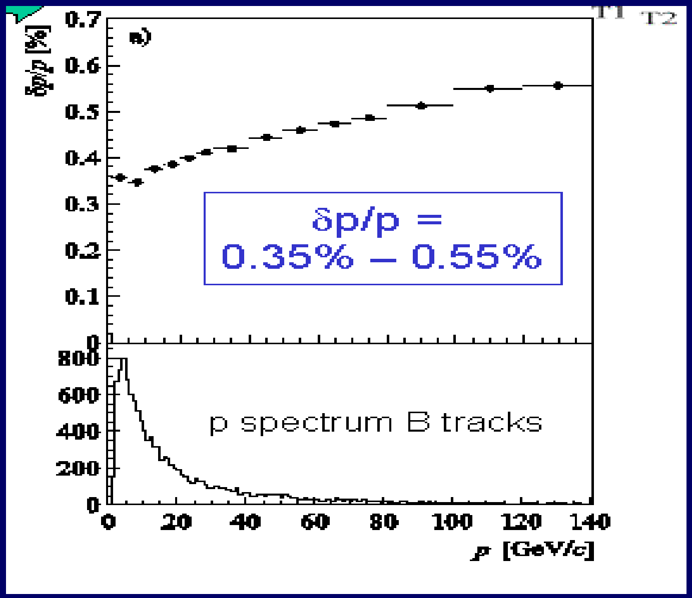
efficiency on Bs→ μ+μ- > 90%

~1.5 kHz

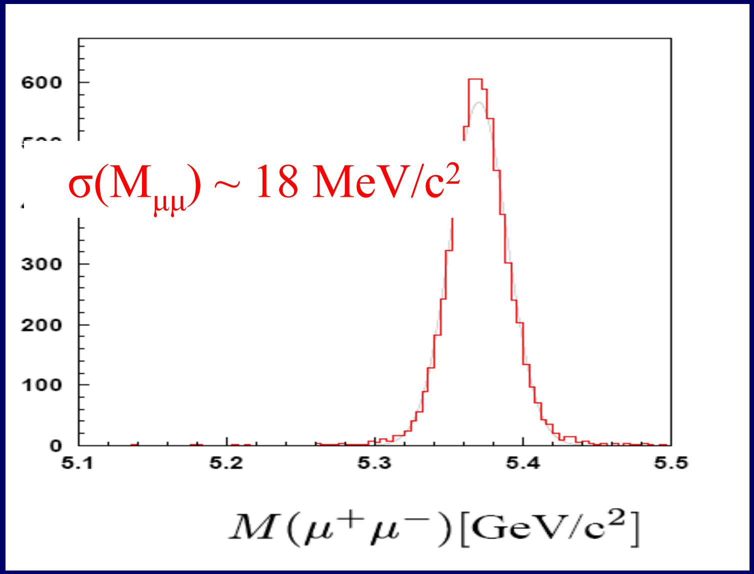
On Tape

LHCb Tracking performance

Momentum resolution:



Bs→μμ invariant mass:



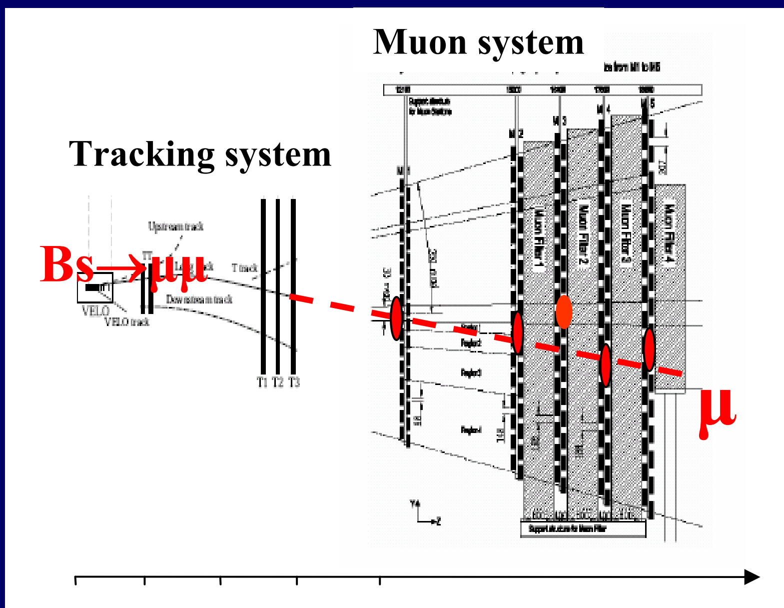
- Mass resolution defines the search window for signal;
- It is crucial to reduce background:
  - combinatorial background;
  - $B_{s,d} \rightarrow hh$ with one or two hadrons misidentified.

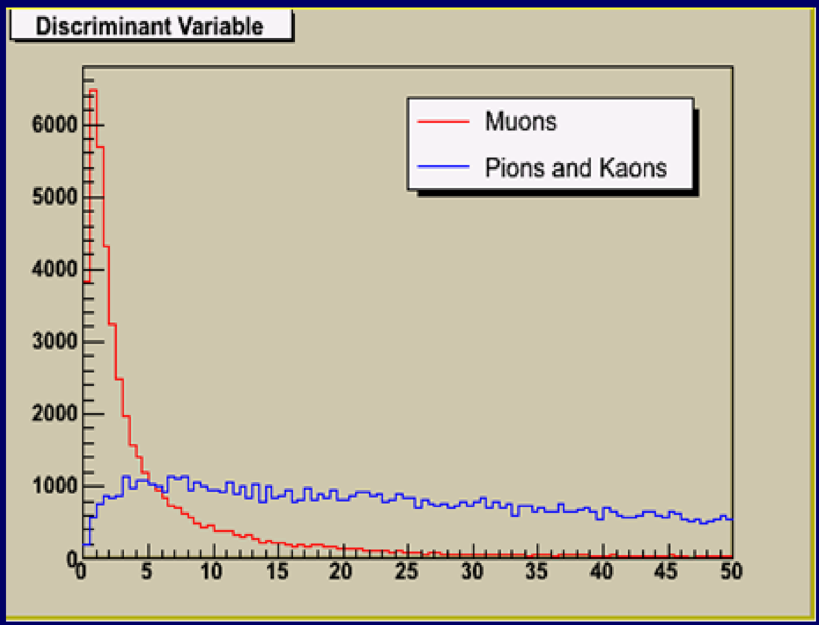
σ (LHCb) ~ 18 MeV/c^2
σ (CDF) ~ 25 MeV/c^2,
σ (ATLAS) ~ 84 MeV/c^2
σ (CMS) ~ 36 MeV/c^2

- Simulation shows that here LHCb has a clear advantage with respect ATLAS/CMS.

LHCb μ-ID performance (I)

Main discriminant variable for μ/π/K separation:
distance of the closest hit in the Muon Chambers to track extrapolation

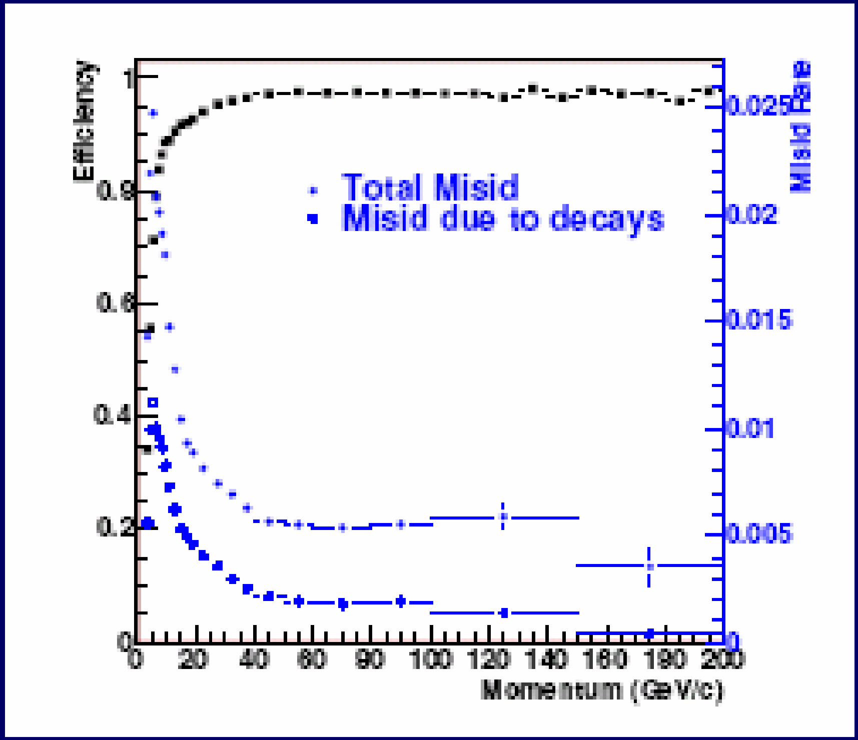




Distance of closest hit (pad unit)

- ♦ Minimum number of hits required in the Muon System as a function of momentum
- ♦ From distance of closest hit distribution build up the likelihoods for hypothesis test
- ♦ Evaluate the efficiency for μ/π/K as a function of the cut on the difference of likelihoods (DLL)

LHCb μ-ID performance (II)



Excellent nominal Muon ID performance:

for 95% muon efficiency, ~0.6% misID rate for pions from $B_d \rightarrow \pi\pi$

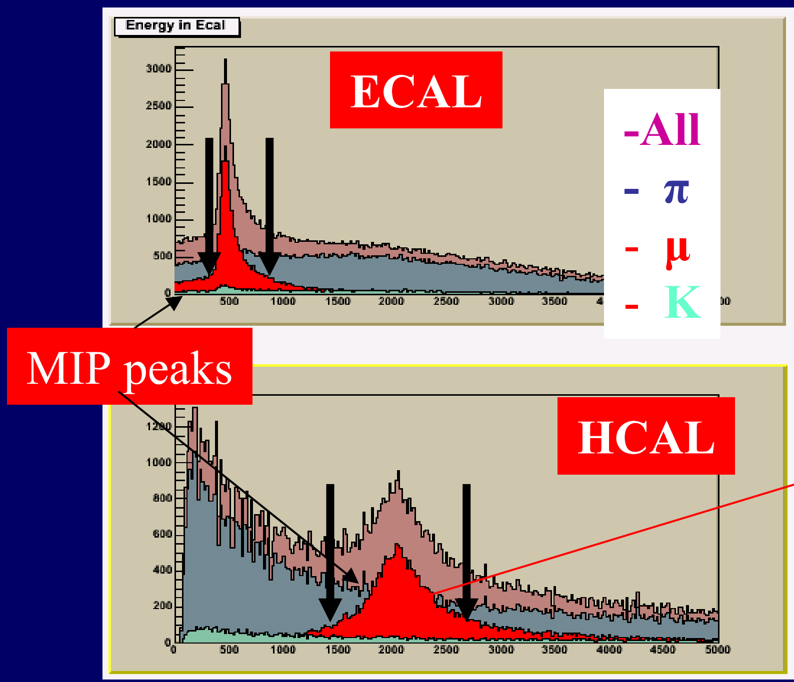
LHCb μ-ID performance (III)

Muon ID procedure can be fully and quickly calibrated with real data by using "almost" pure samples of:

→ muons identified through MIP signals in calorimeters

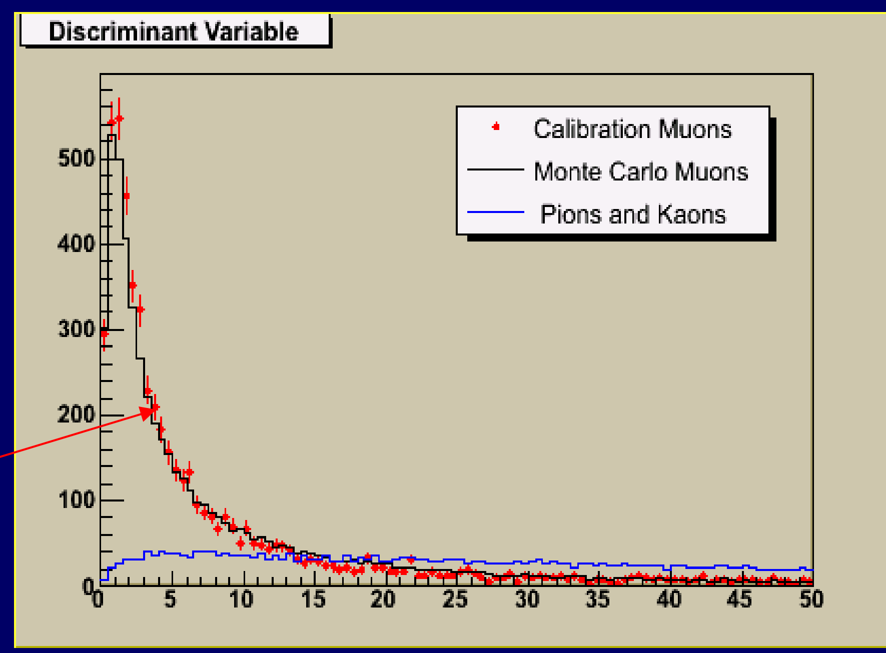
→ pions/kaons from the $D^{*+} \rightarrow D^0 (K^- \pi^+) \pi^+$

Energy released in ECAL/HCAL:



Energy (MeV)

Discriminant variable built with calibration muons:



Distance of closest hit

$B_s \to \mu^+\mu^-$: analysis strategy

1) Design a very efficient "soft selection" that removes the biggest amount of background with signal efficiency > 90%

2) Apply a "N-counting method":

→ identify some discriminant variables

→ divide the variables in N bins

→ evaluate the "expected" number of events for signal/background in each bin

→ compute confidence levels for observation and exclusion*:

BR exclusion @ 90% CL:

$$\text{Poisson}\,(N_{expected}^{S+B}(BR) \le N_{obs}) \,/\, \text{Poisson}(N_{expected}^{B} \le N_{obs}) = 10\%$$

3σ (5σ) sensitivity :

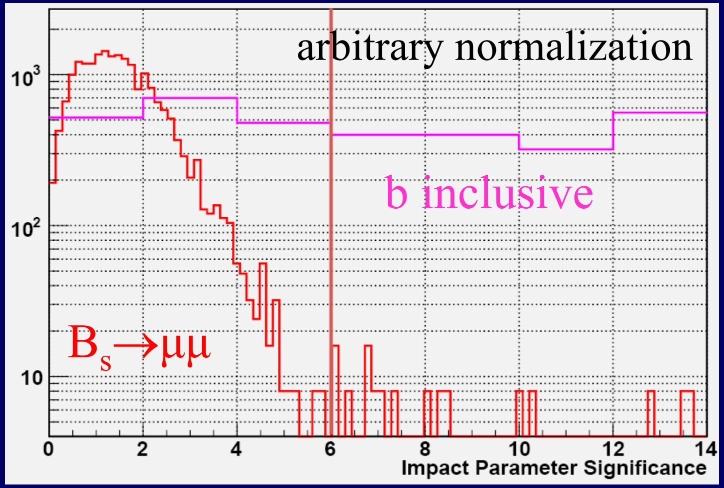
$$\text{Poisson}\,(N_{obs} \ge N_{expected}^{B}) = 1 - 3\sigma\,(5\sigma) = 2.7 \cdot 10^{-3}\ (5.7 \cdot 10^{-7})$$

* Same method used at LEP for Higgs searches, A..L.Read, CERN Yellow Report 2000-05

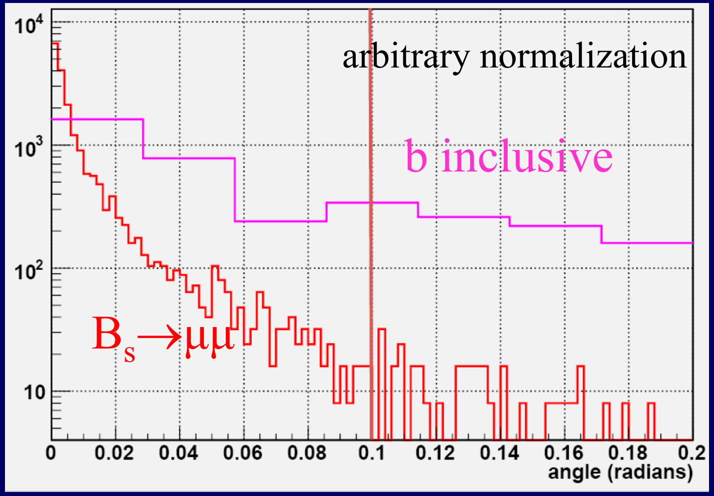
$B_s \to \mu^+\mu^-$: "soft selection"

- Two muons of opposite charge making a vertex with $\chi^2 < 14$
- Mass window around the Bs mass: ± 600 MeV/c^2
- Impact parameter significance of B: IP(B)/σ < 6
- Secondary vertex downstream wrt primary: Zsv- Zpv > 0
- Angle between B's decay length and $\vec{p}_{\mu\mu}$ < 0.1 rad

e.g: B's Impact Parameter significance:



Angle between decay length and $\vec{p}_{\mu\mu}$

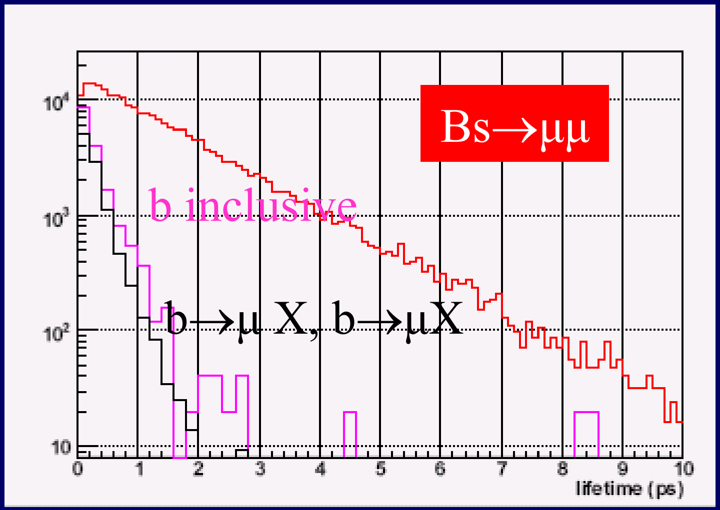


Very loose cuts on some relevant variables throw away most of combinatorics: overall efficiency: ε(signal) ~ 10 % (from soft selection 92%), ε (b inclusive) ~ 10^{-5}

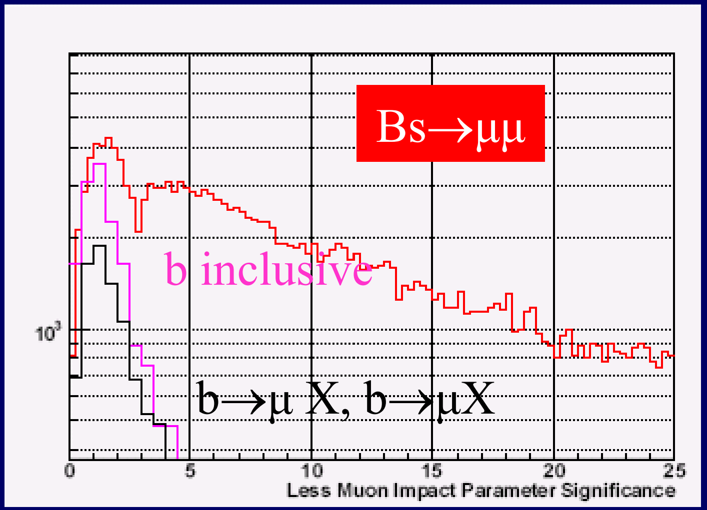
Background

After selection we expect in a mass window of ±60 MeV around the Bs peak
~35 signal events/ fb^{-1} and ~ 370 k background candidates/fb^{-1}
BUT
we still have many handles to separate signal from background:

E.g. B's lifetime distribution



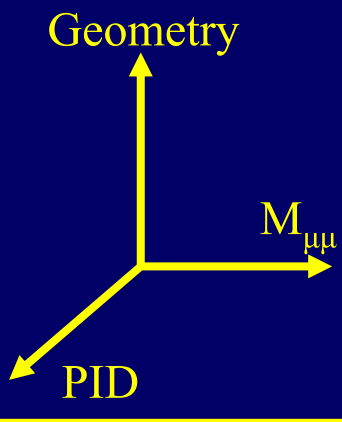
E.g. Lowest Muon Impact Parameter significance



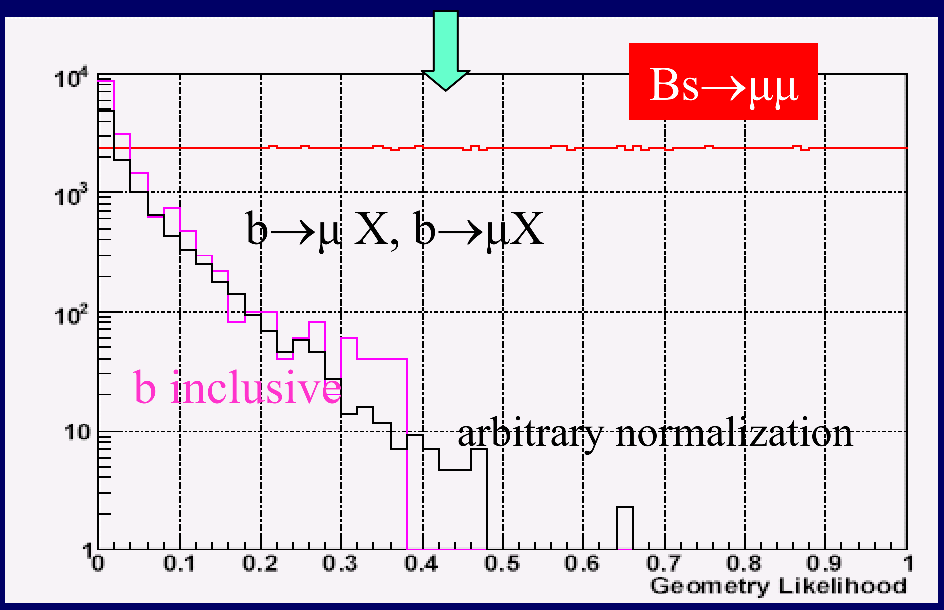
We choose do not apply further cuts BUT to combine variables in an optimal way in order to maximize sensitivity on the signal.

$B_s \rightarrow \mu^+\mu^-$: N-counting method

- Analysis in 3D Phase Space:
  - •Geometrical Likelihood [0,1]
    - → combines all informations from “geometry”
  - •PID Likelihood [0,1]
    - → combines all informations from PID
  - •Invariant Mass distribution around B_s Peak [-60, 60] MeV



E.g.“Geometry” likelihood:



Input variables:

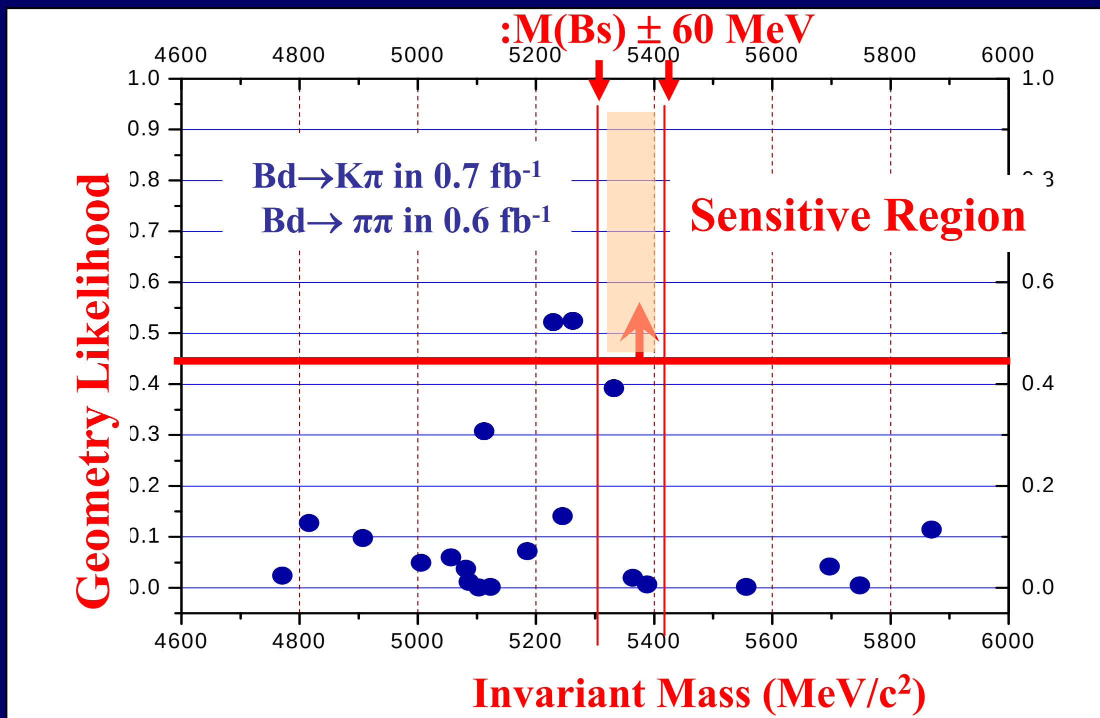
lifetime, muon minimum IPS,
Distance of closest approach between the two μ
Bs Impact parameter
Isolation from other possible vertices

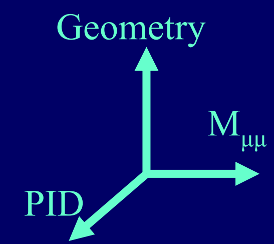
Geometry Likelihood:

- Input variables are combined in an optimal way in a single variable taking into account the correlations between them

Background from two-body modes: $B_{d,s} \rightarrow hh$

$B_d \rightarrow \pi\pi,\pi K$ background in the Geometry vs $M_{\mu\mu}$ plane





Most of the events come from 1 misID hadron + 1 μ from primary vertex

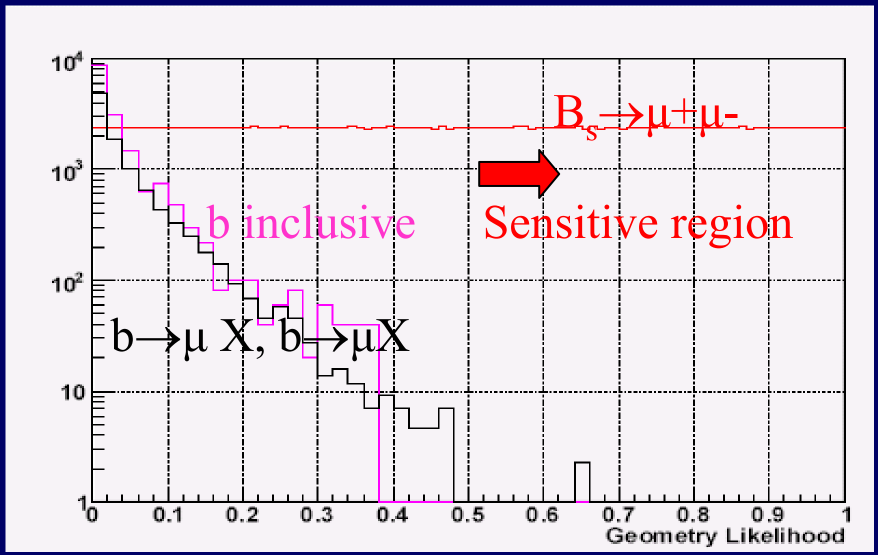
$B_d \rightarrow \pi\pi, K\pi$: 0 events in 0.7 fb^{-1} in sensitive region

$B_s \rightarrow \pi K, KK$: not enough MC statistics, rescaling from B_d results → 0.7 events/fb^{-1}

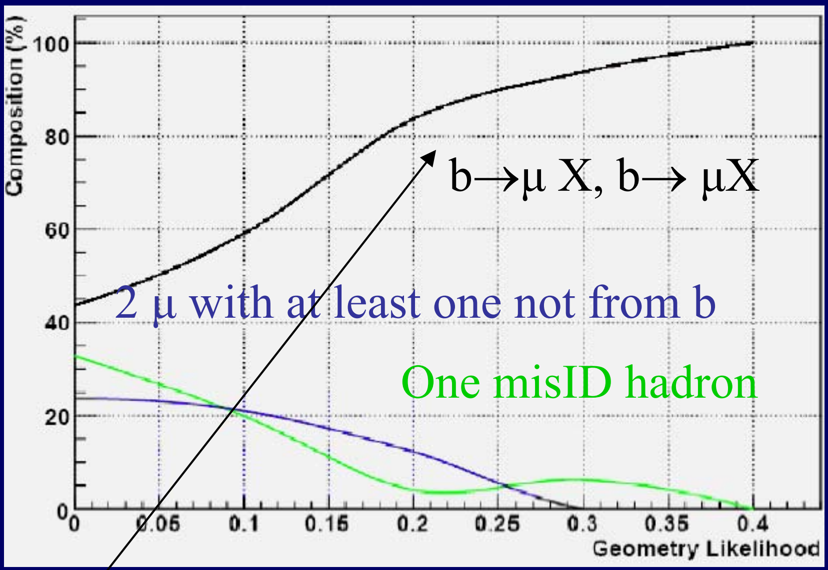
→ Background from 2 body modes seems to be fully negligible

Background Composition vs Geometry Likelihood

Geometry likelihood:



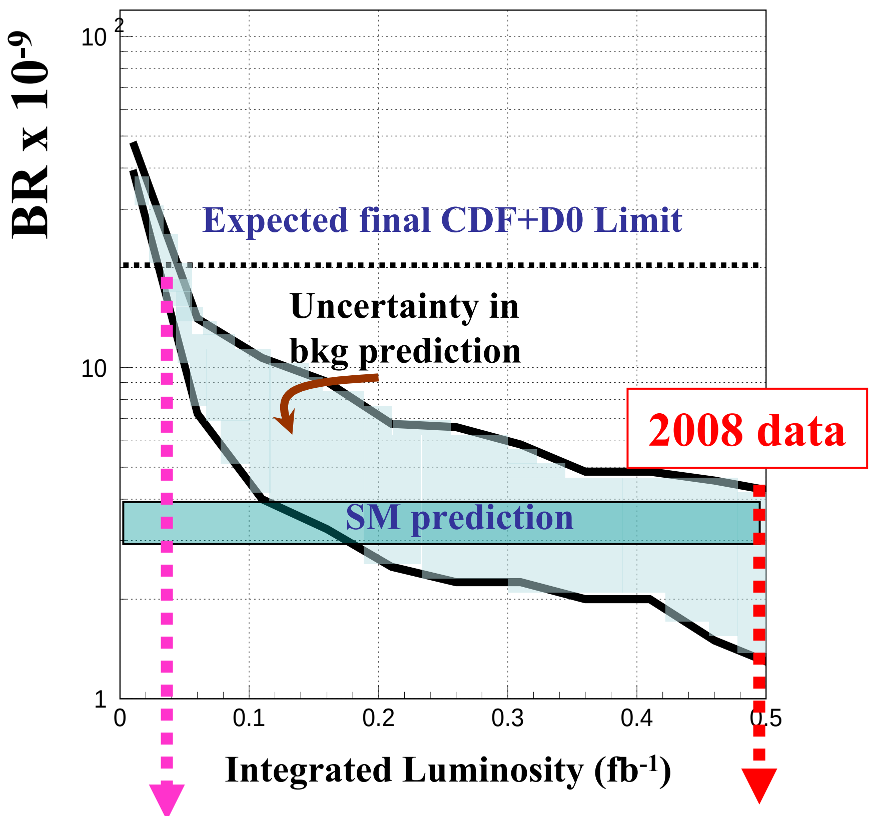
Background composition vs Geometry Likelihood:



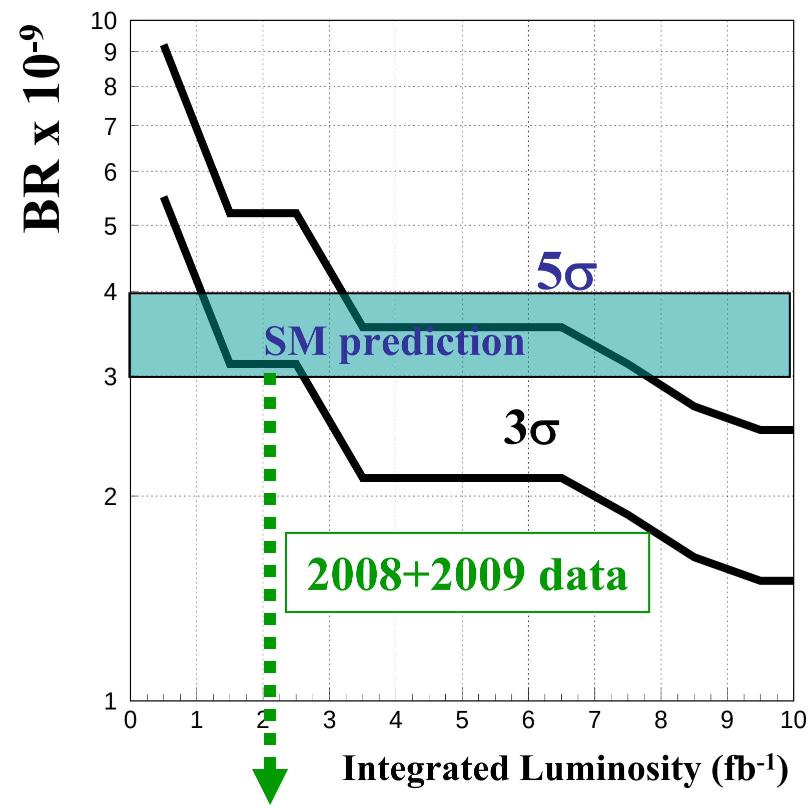
- Indications that main background in sensitive region is b→μ, b→μ
- But many bins empty due to poor Monte Carlo statistics
- To take into account for statistical uncertainty in the background prediction, the background expectation value in each bin is shifted upwards such that total number of background events has 90% probability to be below the sum of shifted value.

$B_s \to \mu^+\mu^-$: LHCb perspectives

Limit at 90% C.L.
(only bkg is observed)



LHCb Sensitivity
(signal+bkg is observed)



L ~0.05 fb^{-1}
Overtake CDF+D0

L~0.5 fb^{-1}
exclusion @ 90% CL
down to SM value

L~2 fb^{-1}:
3σ observation if SM value

Conclusions

♦ Simulation shows that LHCb has a big potential for the search of the $B_s \to \mu\mu$ decay….

~ 0.05 fb^{-1} we overtake the final CDF+D0 limit
~ 0.5 fb^{-1} we can exclude BR down to SM value (2008 data)
~ 2 fb^{-1} we can observe BR(SM) at 3 σ (2008-2009 data)

♦……to be realized in real life:

- working on way to extract performance (efficiencies, resolutions, purities) from data rather than MC, using control samples
- developing the analysis in all the steps

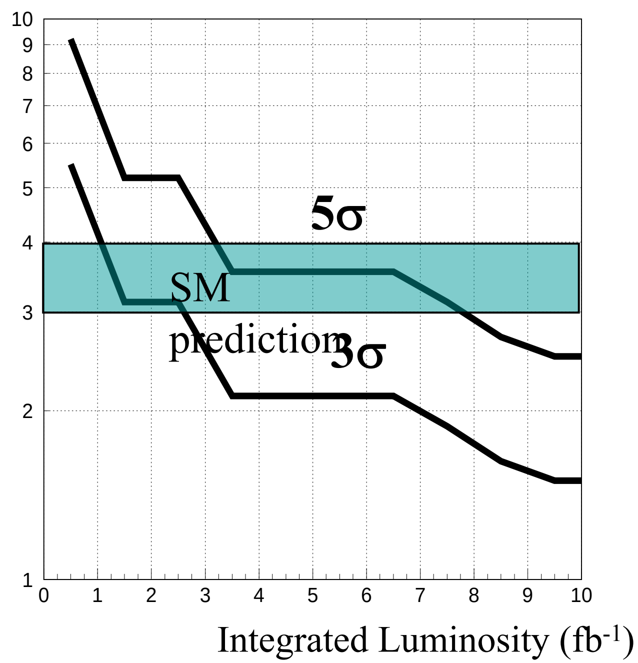
another 1 year to go until we demonstrate how this works with real data

Spares

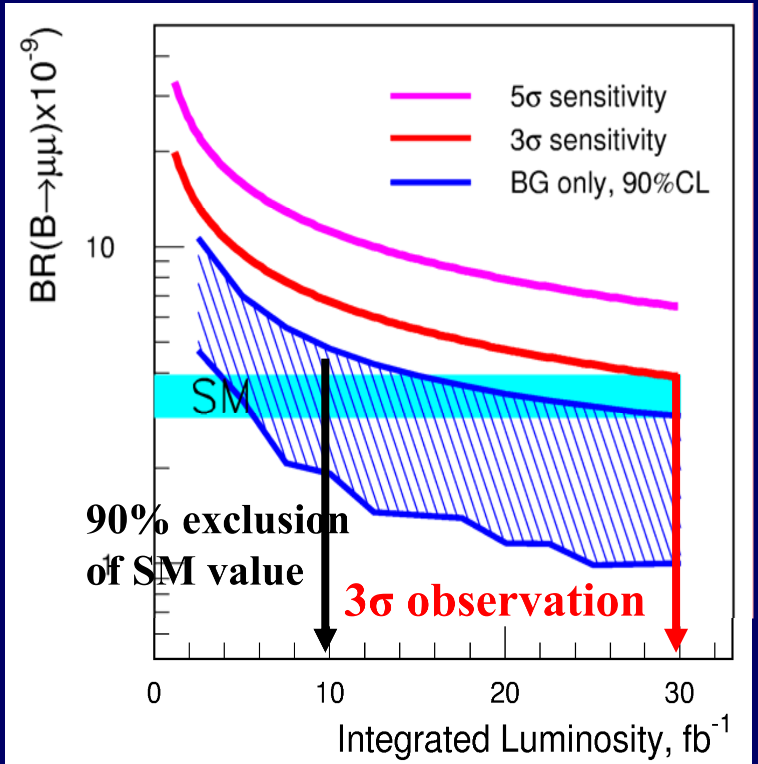
$B_s \rightarrow \mu^+\mu^-$: LHCb vs ATLAS/CMS

LHCb Sensitivity

(signal+bkg is observed)



ATLAS/CMS expectation



see Tomoto's talk at CKM 2006

→ 90% CL exclusion down to SM BR requires: 0.5 fb^{-1} for LHCb, ~ 10 fb^{-1} for ATLAS/CMS

→ 3σ sensitivity if BR(SM) requires: 2 fb^{-1} for LHCb and > 30 fb^{-1} for ATLAS/CMS

Counting vs N-Counting Method