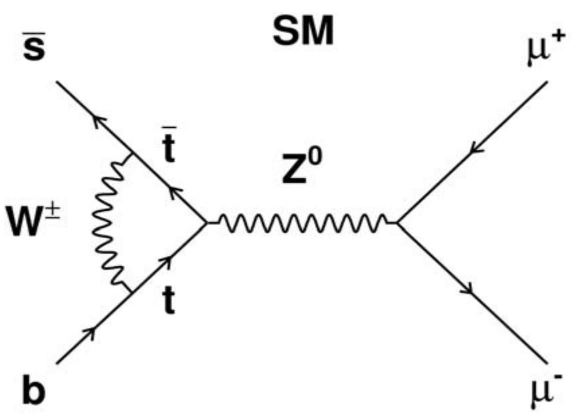
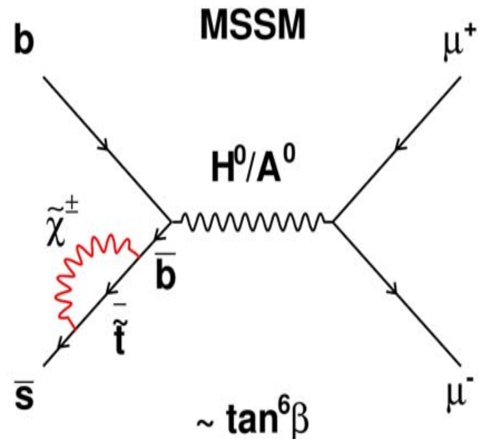
Search for the decay $B_s \to \mu^+\mu^-$ at LHCb





Frederic Teubert

CERN, PH Department

on behalf of the LHCb collaboration

Outline

I. Motivation

II. LHCb Performance:

Experimental Conditions

Trigger

Tracking and μ-ID

III. Backgrounds

Inclusive $b\bar{b}$ /$b \rightarrow \mu^- X$, $\bar{b} \rightarrow \mu^+ X$

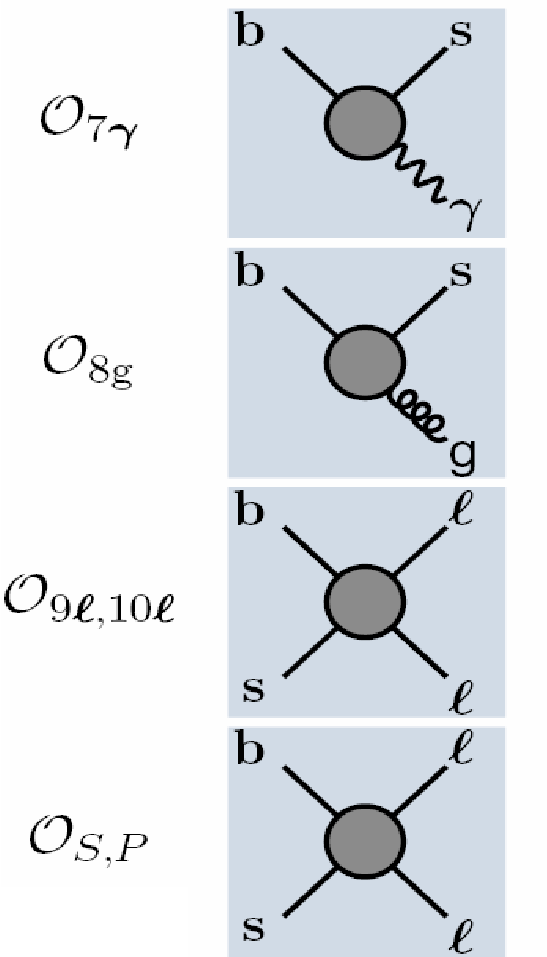
IV. Selection

Geometry, μ-ID, Invariant Mass

V. Statistical Method

VI. LHCb Prospects

b→s *Transitions & OPE…*



Describe *b→s* transitions by an effective Hamiltonian

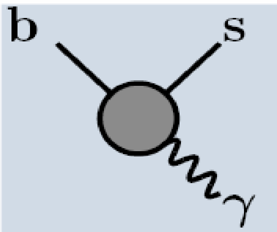
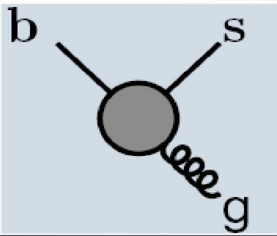
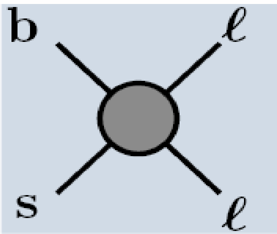
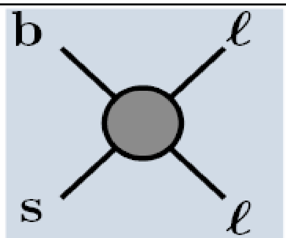
$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm ts}^* V_{\rm tb} \sum_{i=1}^{10} C_i(\mu)\mathcal{O}_i(\mu)$$

- **Long Distance:**
  - **Operators O_i**
- **Short Distance:**
  - **Wilson coef. C_i**

New physics shows up as modified C_i,
(or as new operators)

From G. Hiller [hep-ph/0308180]

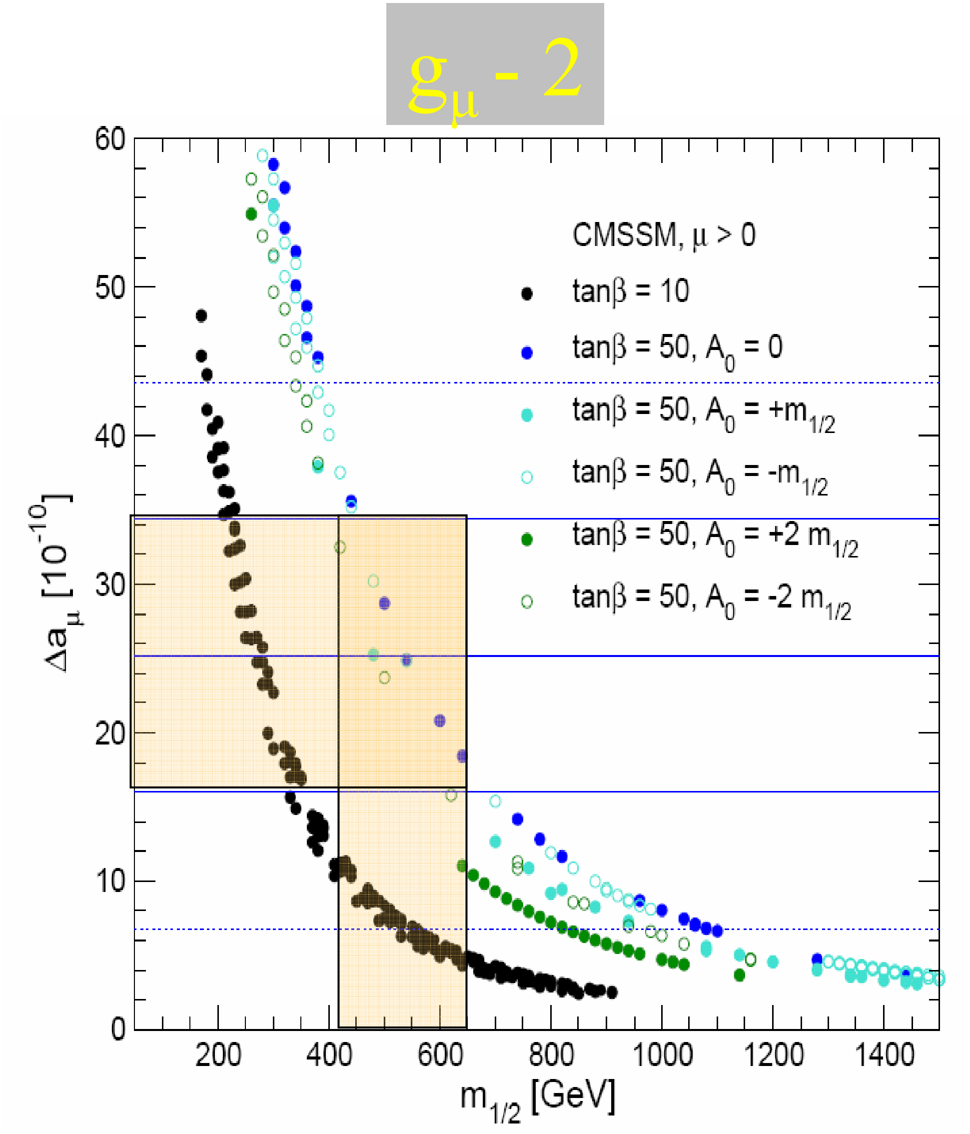
Operators & Observables

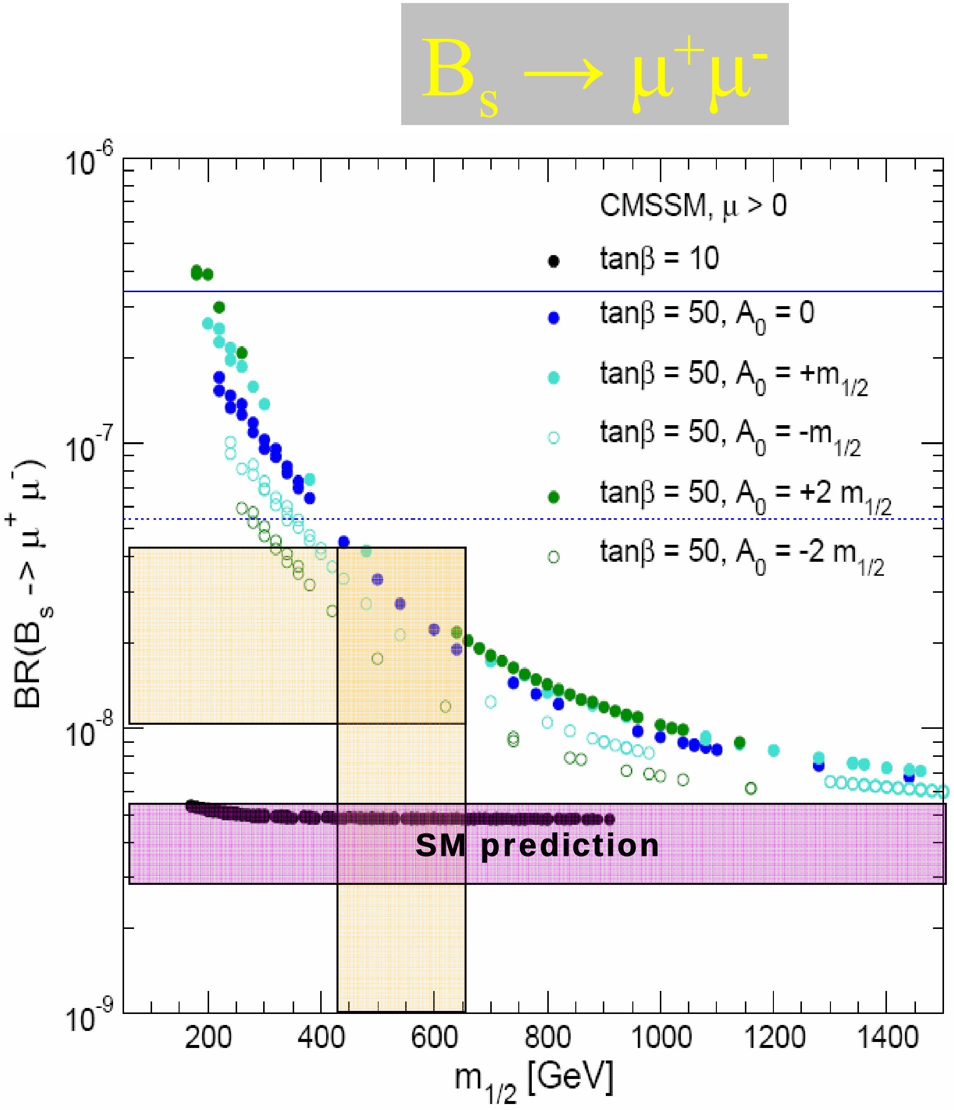
		magnitude	phase	helicity flip $\mathcal{O}'_i$
$\mathcal{O}_{7\gamma}$		$b \to s\gamma$	$a_{CP}(b \to s\gamma)$	$\Lambda_b \to \Lambda\gamma$ $B \to (K^* \to K\pi)\ell^+\ell^-$ $B \to (K^{**} \to K\pi\pi)\gamma$
$\mathcal{O}_{8g}$		$b \to s\gamma$ $B \to X_c$	$a_{CP}(b \to s\gamma)$ $B \to K\phi$	$\Lambda_b \to \Lambda\phi$ $B \to K^*\phi$
$\mathcal{O}_{9\ell,10\ell}$		$b \to se^+e^-$	$A_{FB}(b \to s\ell^+\ell^-)$	$B \to (K^* \to K\pi)\ell^+\ell^-$
$\mathcal{O}_{S,P}$		$B_{d,s} \to \mu^+\mu^-$	$B_{d,s} \to \tau^+\tau^-$	$b \to s\tau^+\tau^-$

From G. Hiller [hep-ph/0308180]

Example: CMSSM fit

hep-ph/0604180





Experimental Status

CDF preliminary @95% C.L.:

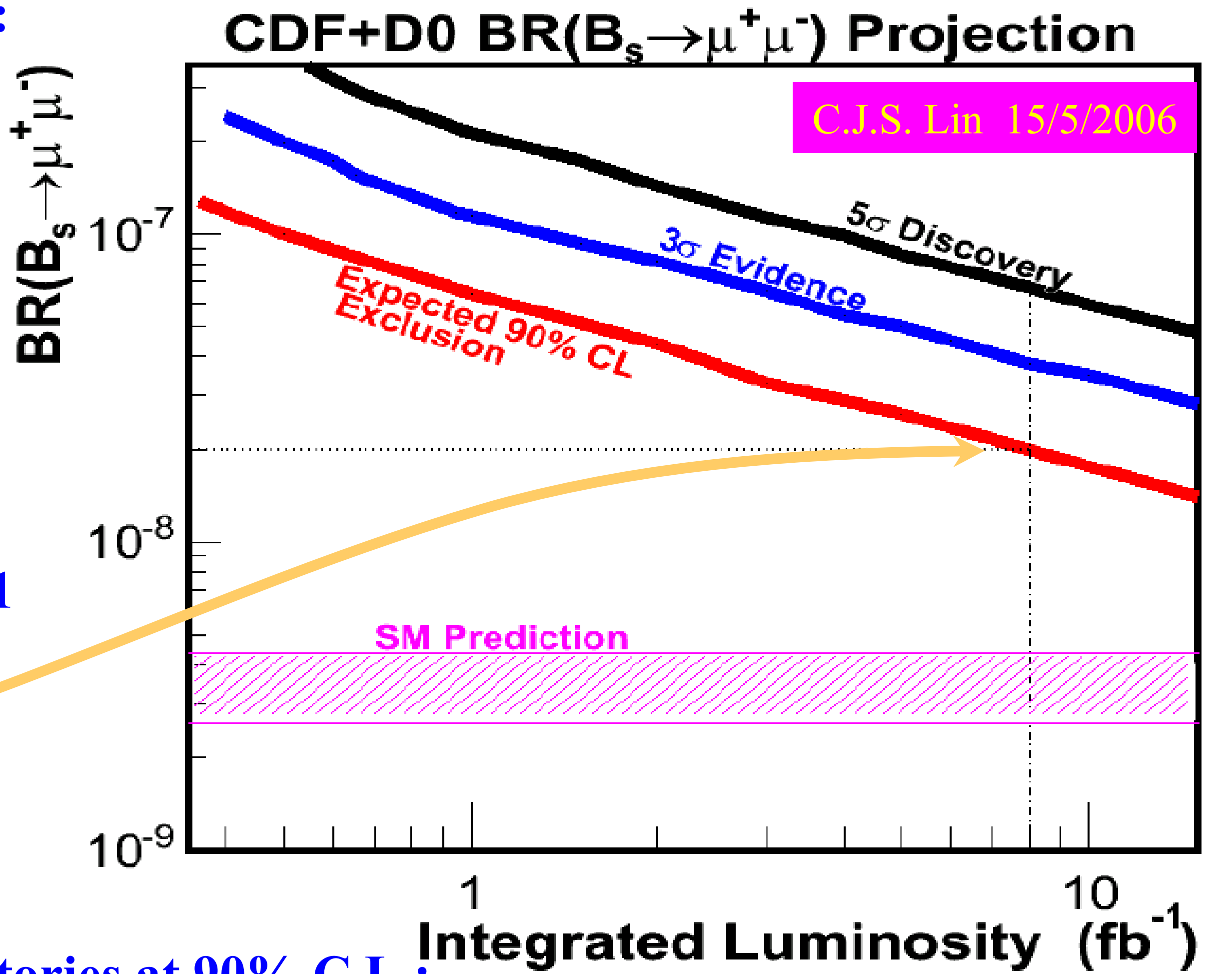
BR($B_s \to \mu^+\mu^-$) < 1.0×10^{-7}
BR($B_d \to \mu^+\mu^-$) < 3.0×10^{-8}

D0 preliminary @95% C.L :

BR($B_s \to \mu^+\mu^-$) < 4.0×10^{-7}

CDF+D0 combination at 8 fb-1 expects @90% C.L :

BR($B_s \to \mu^+\mu^-$) < 2.0×10^{-8}

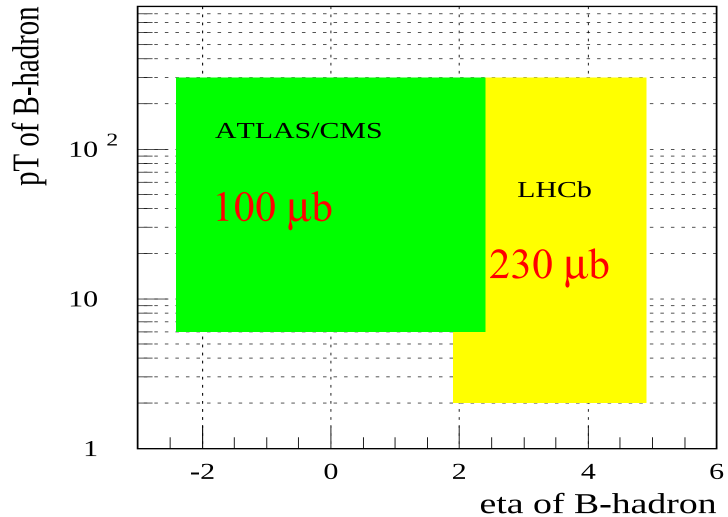


Limits on $B_d \to \mu^+\mu^-$ from B-factories at 90% C.L.:

BABAR < 6.1×10^{-8} **BELLE < 1.6×10^{-7}**

LHCb Experimental Conditions

- **LHCb:**
  - **Designed to maximize B acceptance (within cost and space constraints)**
  - **Forward spectrometer, $1.9 < \eta < 4.9$**
    - more b hadrons produced at low angles
    - single arm OK since bb pairs produced correlated in space
  - **Rely on much softer, lower p_T triggers, than ATLAS/CMS Efficient also for purely hadronic B decays**

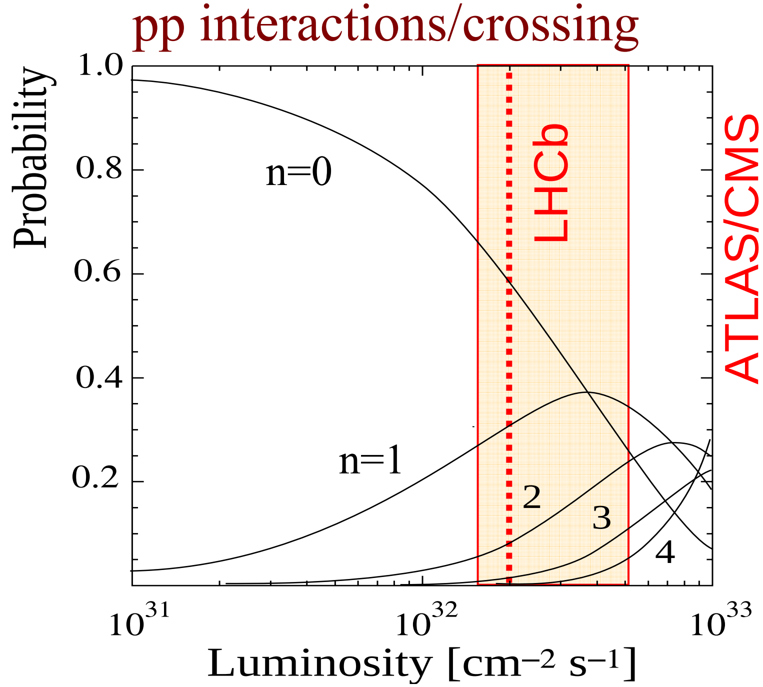


- **Pileup:**
  - **number of inelastic pp interactions in a bunch crossing is Poisson-distributed with mean $n = L\sigma_{inel}/f$**

    L = instantaneous Luminosity

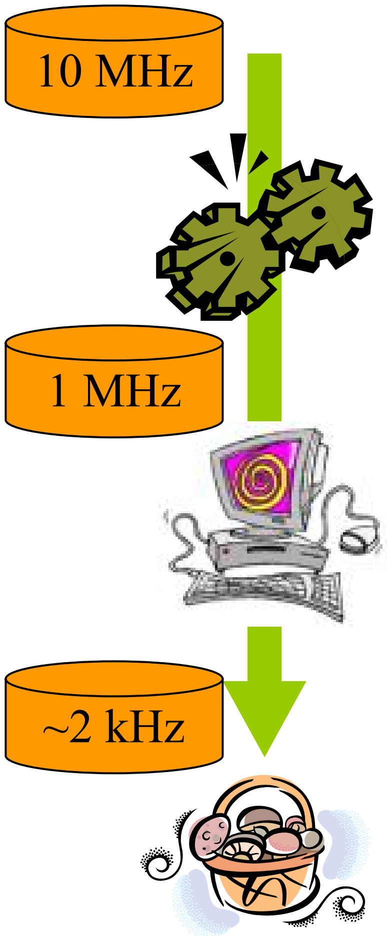
    σ_{inel} = 80 mb

    f=non-empty crossing rate (f = 30 MHz)



- **Luminosity L tuneable by adjusting beam focus**
  - **Choose to run at <L> ~ 2×10^{32} cm^{-2}s^{-1} (max. 5×10^{32} cm^{-2}s^{-1})**
    - Clean environment (n = 0.5)
    - Less radiation damage
      - LHCb 8mm from beam, ATLAS 5 cm, CMS 4 cm
    - Will be available from 1st physics run

LHCb Trigger



Visible collisions
L = 2 10^{32} cm^{-2} s^{-1}

L0: [hardware]
high Pt particles
calorimeter + muons
4 μs latency

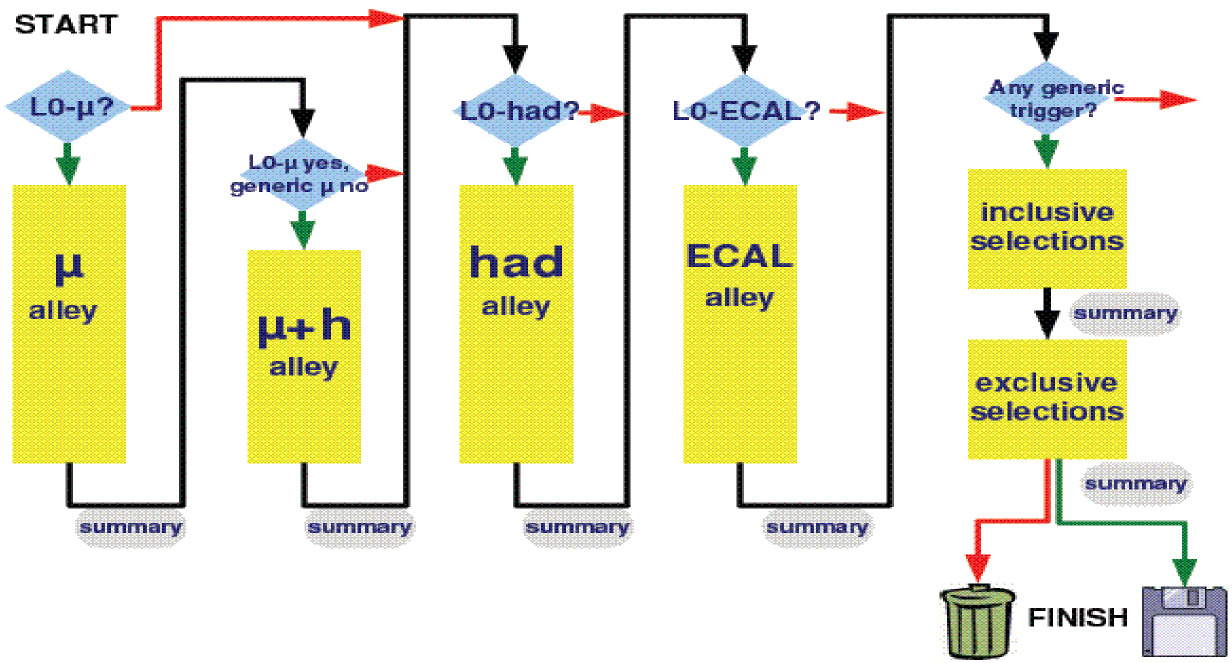
HLT [software]
1 MHz readout
~1800 nodes farm

On tape:
Exclusive selections
Inclusive streams

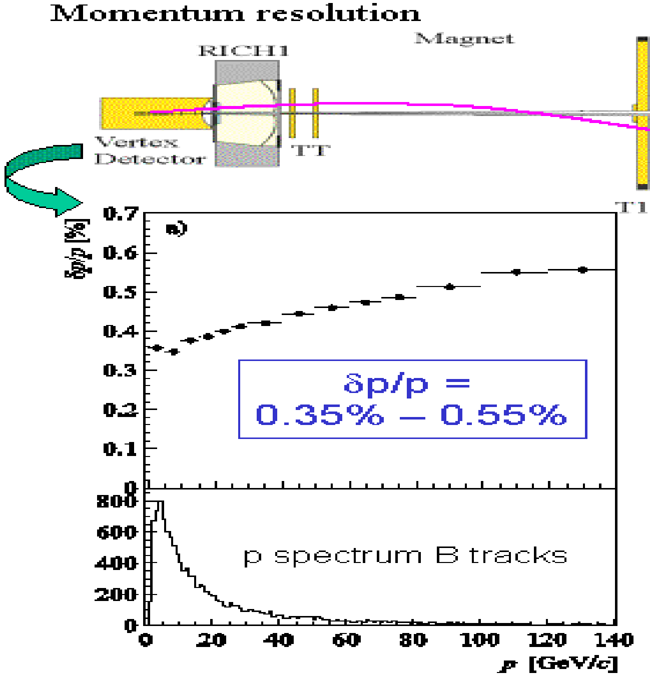
Relevant triggers for $B_s \to \mu^+\mu^-$:

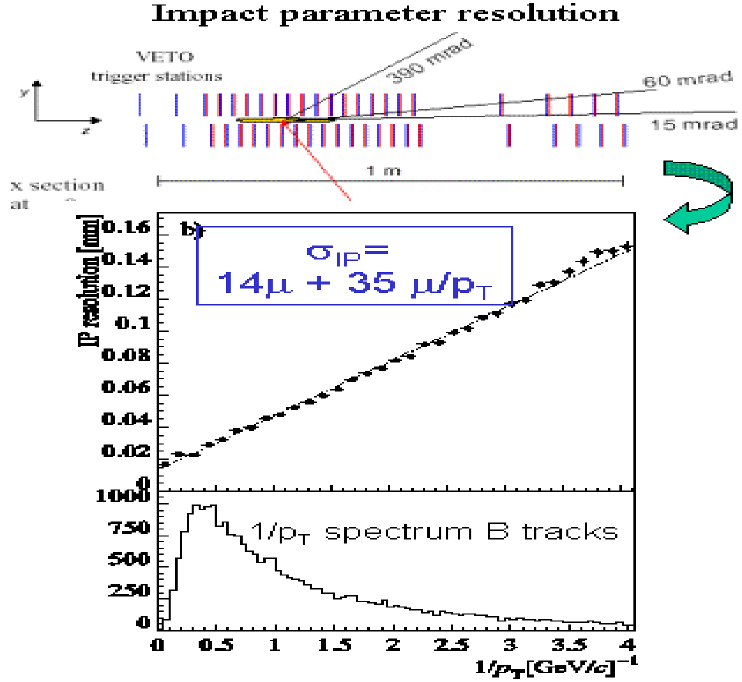
L0-μ: **$P_T(\mu)$>1.1 GeV (110 kHz)**
or $\sum P_T(\mu\mu)$>1.3 GeV (145 kHz) (override Pileup!).

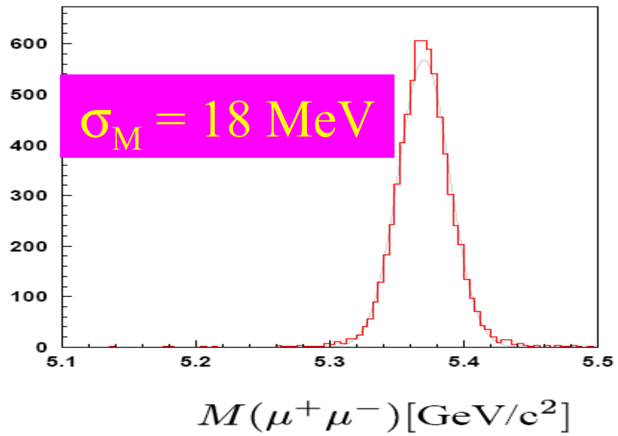
HLT-μ: **$P_T(\mu)$>3 GeV and IP(μ)>3σ (850 Hz)**
or M(μμ)>2.5 GeV and χ^2_{vertex}<20 (660 Hz).

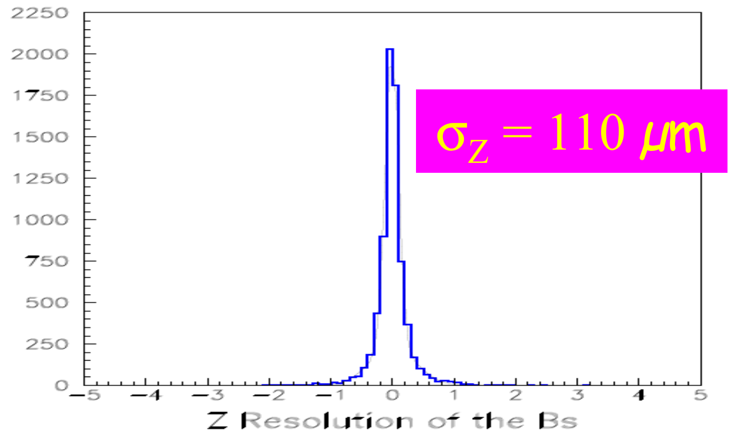


LHCb Tracking Performance



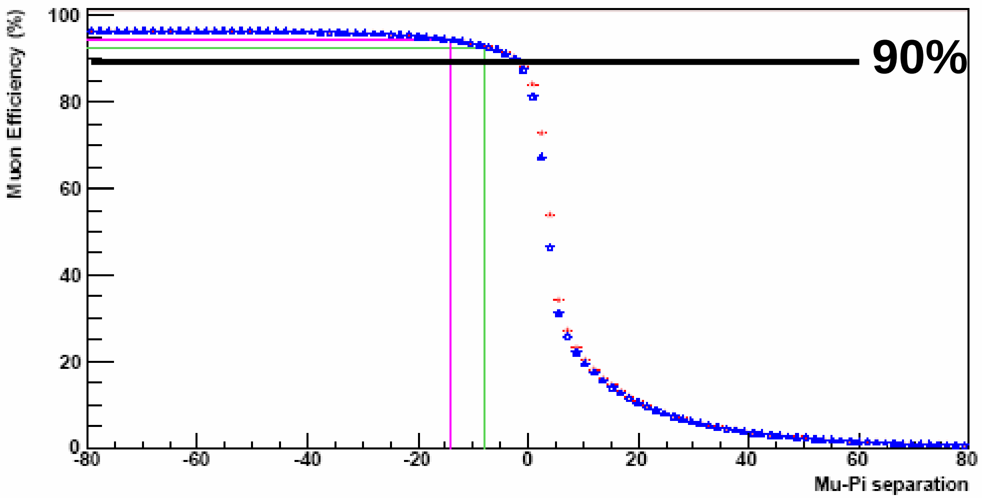




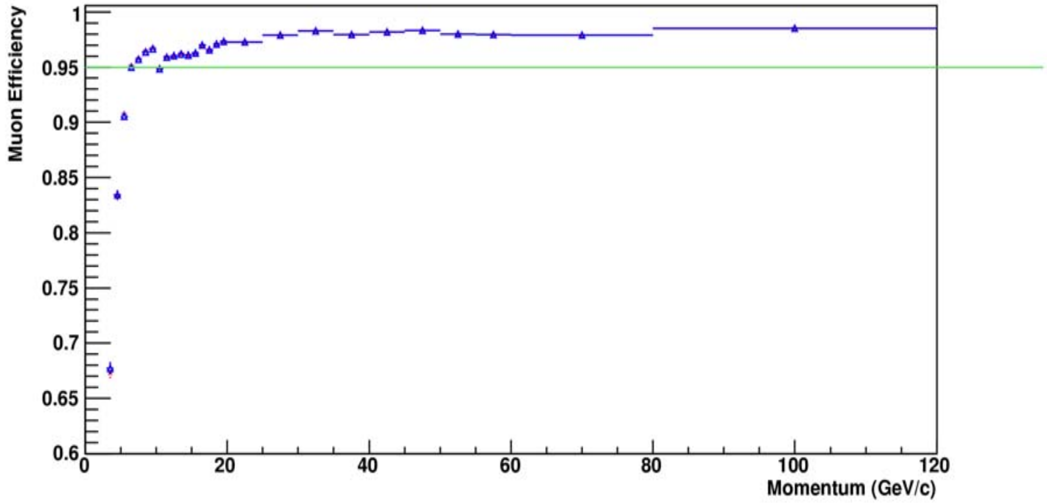


LHCb μ-ID Performance

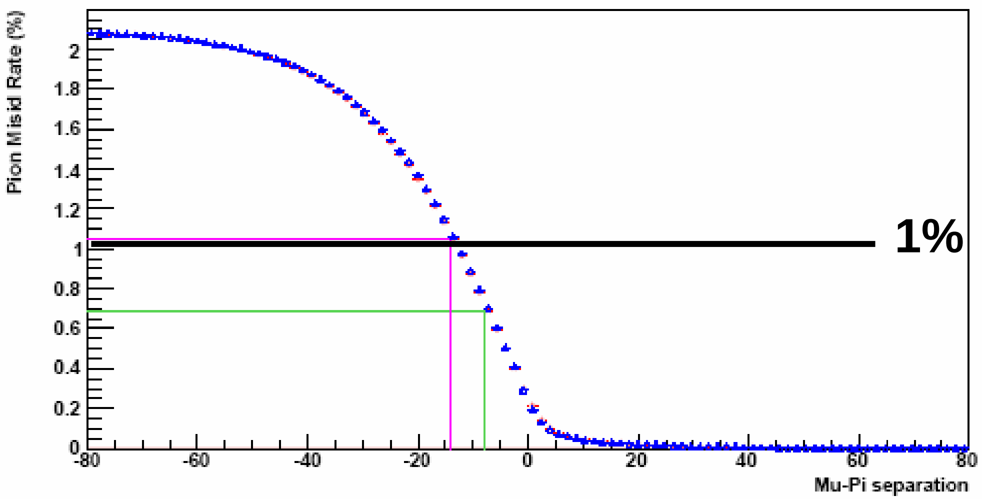
Muon ID efficiency (%) vs μ-π DLL cut



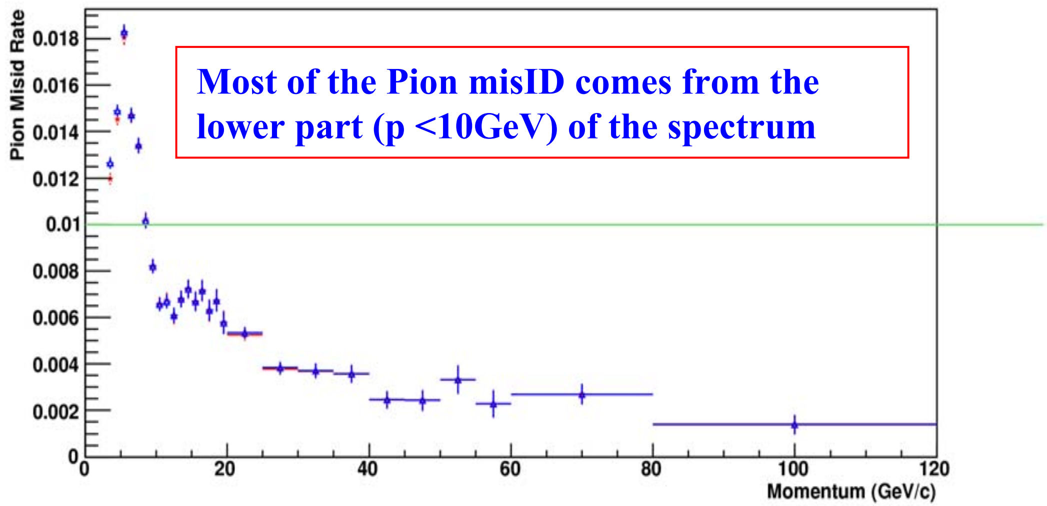
Muon ID efficiency (%) vs p (GeV)



Pion mis ID efficiency (%) vs μ-π DLL cut



Pion mis ID efficiency (%) vs p (GeV)

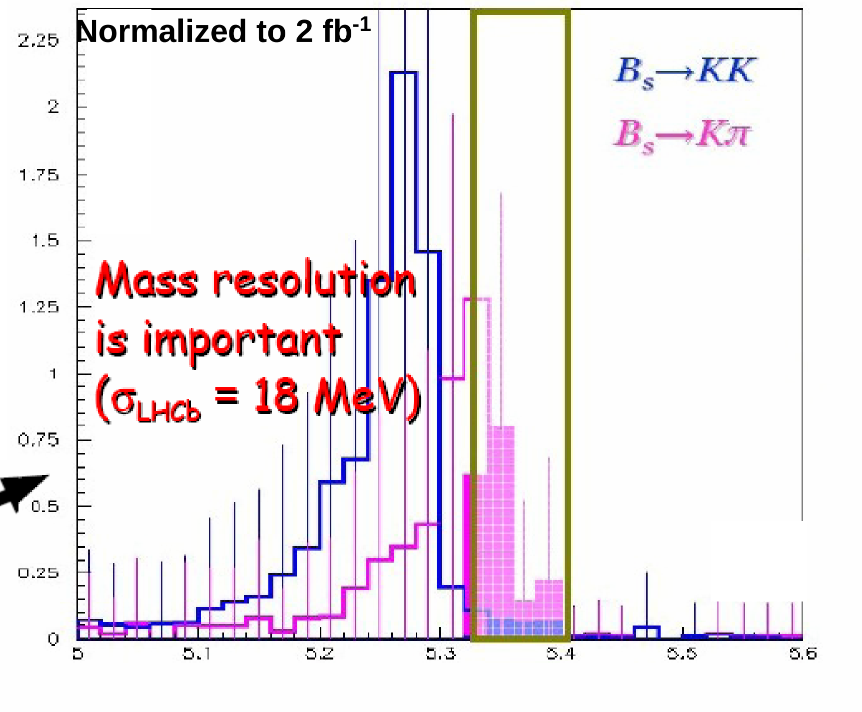


$B_s \to \mu^+\mu^-$: π & K Misidentification

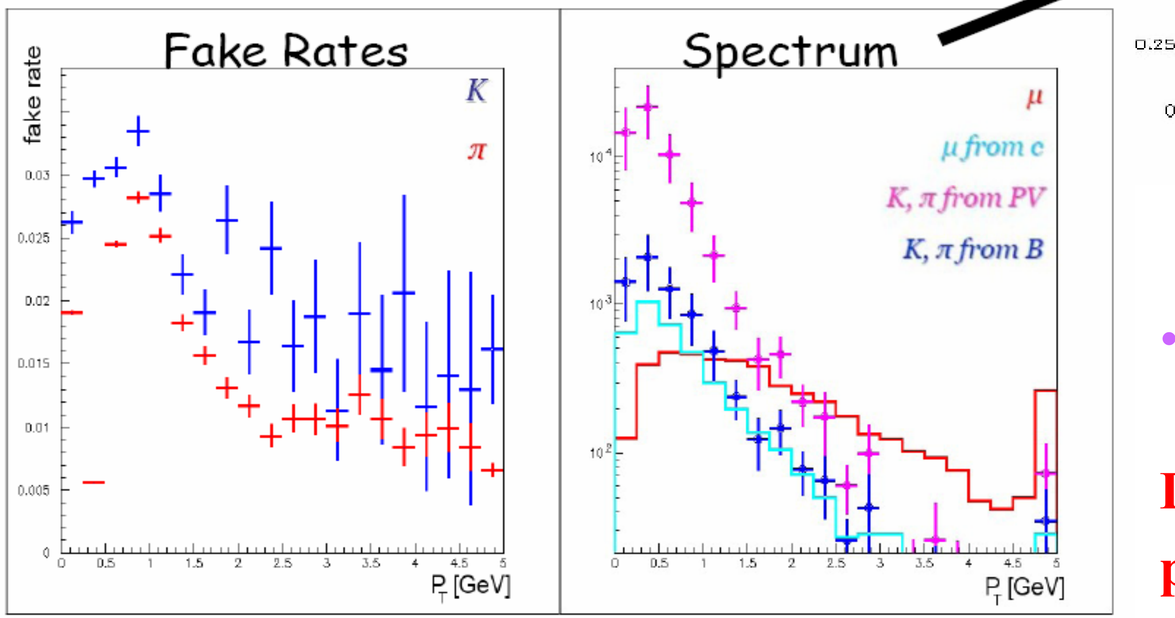
- **Two body modes:**
  - **Eg. Br($B_s \to K\pi$) = 5x10^{-6}**

➔Misid rate: need better than O(1%)

  - **Fake rate: 5x10^{-6} (1%)^2=0.5x10^{-9}**



$B^0_s \to hh$ background at LHCb, Kirill Voronchev



- **O(1) event per fb^{-1} in a 2σ mass window**

Does not seem to be a major problem at LHCb

LHCb Background Simulation

- Extremely low Br → the issue is Background
- Several sources of background:

1. Combinatorial with muons originated mainly from b(c) decays.
2. Misidentified hadrons.
3. Exclusive decays with very small BR or exotic decays. Many of them are not included in the standard MC generators.

- LHCb approach is to use full PYTHIA+GEANT simulation:
  - 1. and 2. are studied with ~33M events (~7min at LHCb) where a pair of $b\bar{b}$ are produced (inclusive b sample), and ~10M $b \to \mu^- X$, $\bar{b} \to \mu^+ X$ (~5h at LHCb). Hence, background predictions are very much limited by the amount of statistics we can generate.
  - 3. is under study with channels like: $B_c^+ \to J/\psi\ (\mu^+\mu^-)\ \mu^+\ \nu$, $B^0_{s(d)} \to \mu^+\mu^-\gamma$, $B^0 \to \mu^+\mu^-\pi^0$, $B^0 \to \mu^+\pi^-\nu$, …

Selection

LHCb-2003-165 public note:

- no events $M_{\mu\mu} > 4$ GeV passed cuts out of 11M $b\bar{b}\rightarrow$inclusive and 10M $b\bar{b}\rightarrow\mu X$ background
- signal cuts:
  - $p_T^{\mu} > 1.3$ GeV
  - $IP/\sigma_{Bs} < 3.5$
  - vertex $\chi^2 < 4$
  - $(Z_{sec} - Z_{prim})/\sigma > 29$
  - $p_T^{Bs} > 3$ GeV

channel (2 fb^{-1})	N^{sel}_{year}	B/S
$B_s^0 \rightarrow \mu^+\mu^-$	17.2 ± 0.3	
inclusive $b\bar{b}$	[0;9.6k]	[0;442]
$b \rightarrow \mu^- X; \bar{b} \rightarrow \mu^+ X$	[0;125]	[0;5.7]

New approach:

Avoid cuts on P_T → inefficiency && bias in background

Use geometry: pointing & Isolation.

Design a very efficient pre-selection, and weigh each event by its likelihood ratio on the relevant distributions.

Pre-Selection:

- Mass window: ±600 MeV
- Vertex $\chi^2 < 14$
- Bs Impact Parameter Significance < 6
- Z (SV – PV) > 0
- pointing angle < 0.1 radians
- Soft μID required for both particles (ε_μ~95%, ε_π~1.0%)

At this level of pre-selection:

N($B_s \rightarrow \mu^+\mu^-$) (SM) ~ 35 per fb^{-1}

N(inclusive $b\bar{b}$) ~ 10M per fb^{-1}

N($b \rightarrow \mu^- X$, $\bar{b} \rightarrow \mu^+ X$) ~ 1M per fb^{-1}

Likelihood Variables

Geometry

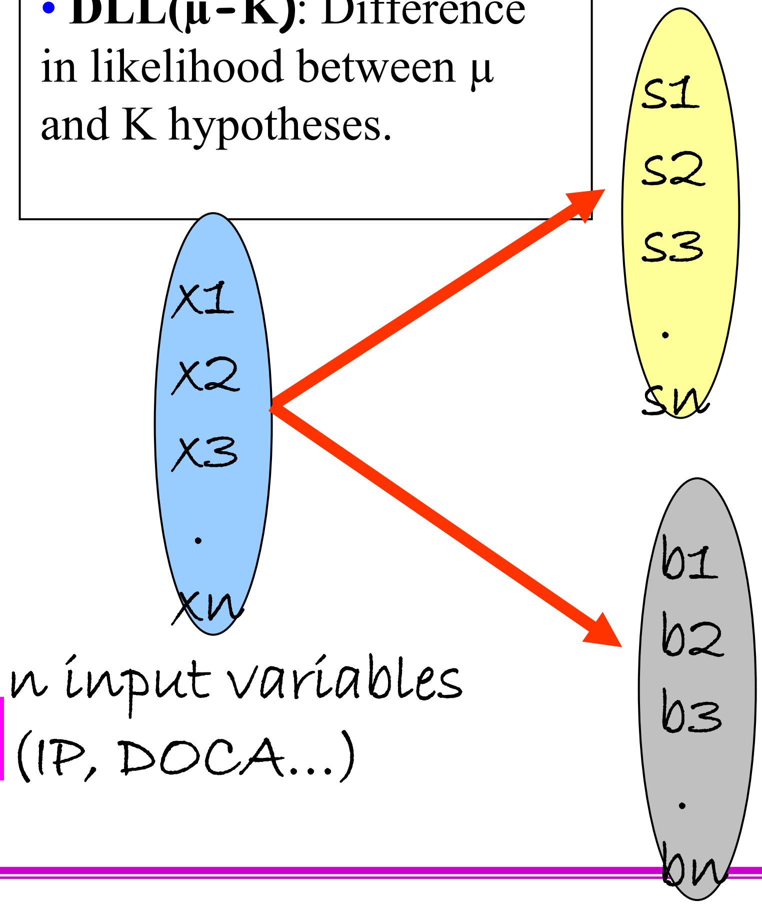
- **lifetime**: Similar to distance of flight, but uncorrelated with boost
- **muon IPS:** (less IPS – μ)
- **DOCA**: distance of closest approach between two μ-candidates.
- **Bs Impact Parameter**
- **Isolation:** Look for alternative vertices that are compatible with the cand.

PID

- **DLL(μ-π)**: Difference in likelihood between μ and π hypotheses.
- **DLL(μ-K)**: Difference in likelihood between μ and K hypotheses.

Invariant Mass

- **Invariant Mass**



→n variables which, for signal, are independent and Gaussian.

$\rightarrow \chi^2_S = \Sigma\, s_i^2$

→ same, but for background

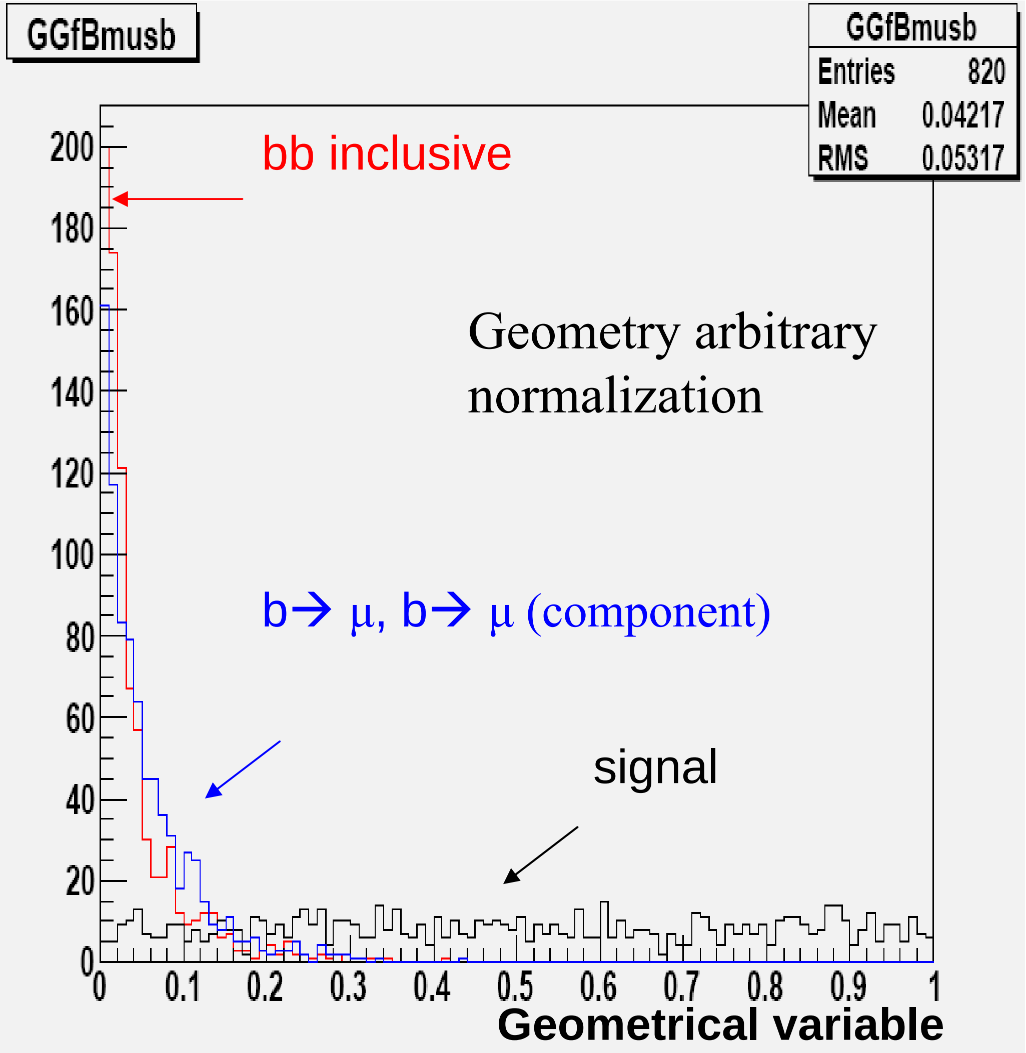
$\rightarrow \chi^2_B = \Sigma\, b_i^2$

$$\chi^2 = \chi^2_S - \chi^2_B$$

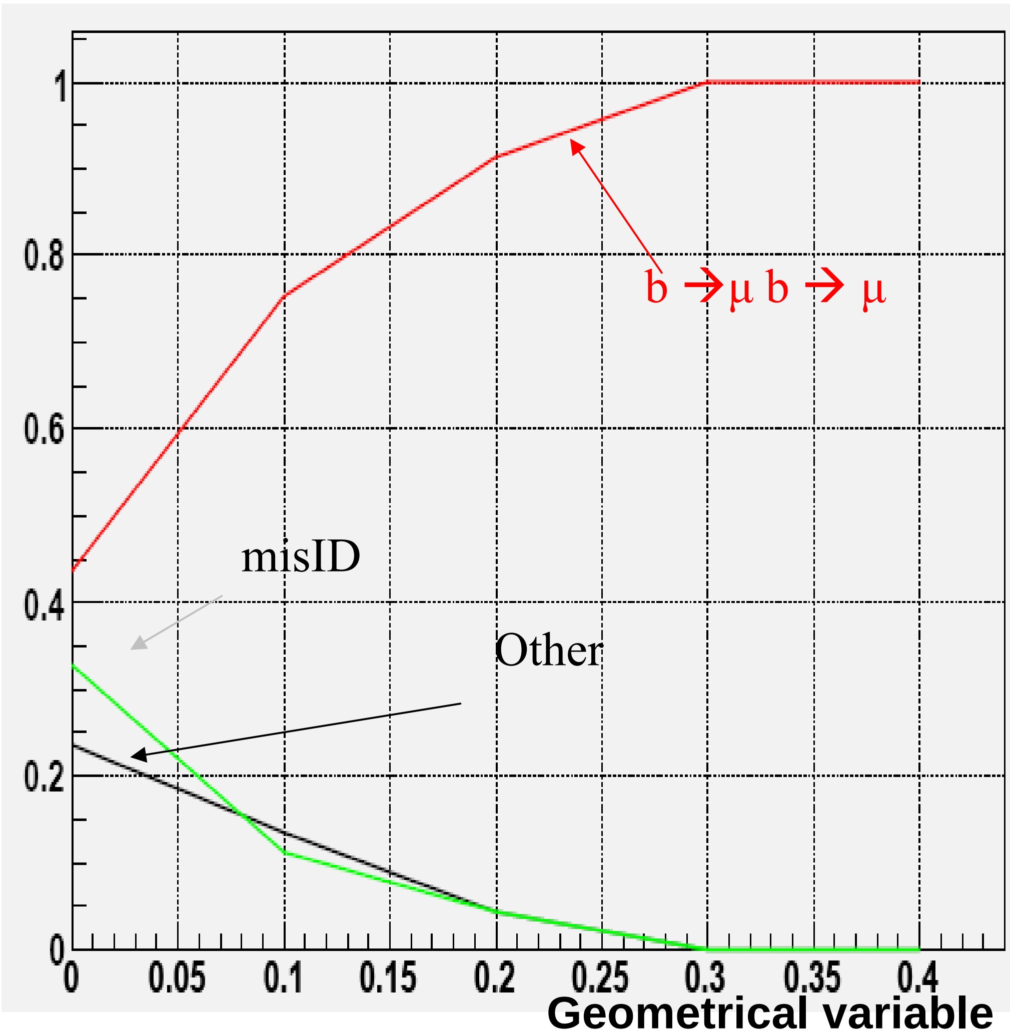
And made it uniform for signal (→flat distribution)

A very similar method is described by Dean Karlen, *Computers in Physics Vol 12, N.4, Jul/Aug 1998*

Background Composition



Fraction of background components in $b\bar{b}$ inclusive sample



- ***$b \to \mu^- X$ $\bar{b} \to \mu^+ X$ is the main source of background in sensitive region!!***

Background Estimation

Each distribution (Geometry, PID and Invariant Mass) is divided in several bins.

The $b \rightarrow \mu^- X$, $\bar{b} \rightarrow \mu^+ X$ sample is used to compute the background expected in each 3D bin.

However, due to the limited MC statistics (remember ~few hours of LHCb running), there are many bins with very little (or zero) background expected. To account for the statistical error, every background prediction is shifted upwards such that the total number of background events has a 90% probability to be below this value.

Notice that when LHC starts running the evaluation of the background level from the side bands and control channels will not suffer from statistics!

For example, as illustration, if a cut like (Geometry) > 0.7 was applied:

$N(B_s \rightarrow \mu^+\mu^-)$ (SM)		10.5	per fb^{-1}
$N(b \rightarrow \mu^- X, b \rightarrow \mu^+ X)$	$\subset$	[0,62.5]	per fb^{-1}

Remember, no cut is applied other than the pre-selection. Each bin has two estimates for the background $\subset$ [nominal, 90% upper limit].

Statistical Method

Computing CLs

Reference: A.L.Read, CERN Yellow Report 2000-005 (see searches for the Higgs boson at LEP)

For each bin:

si = expected signal events in bin
bi = expected bkg. events in bin
di = measured events in bin

$$X_i = \frac{Poisson\,(d_i, <d_i> = s_i + b_i)}{Poisson\,(d_i, <d_i> = b_i)}$$

For a configuration {Xi}:

$$X = \prod_i^N X_i$$

$$CL_{s+b} = P_{s+b}(X \le X^{OBSERVED})$$

$$CL_b = P_b(X \le X^{OBSERVED})$$

$CL_{s+b} = CL_b * CL_s$

CLs = CLs+b/CLb → A CLs for each BR hypothesis and luminosity.

BR exclusion at 90 % if CLs(BR) ≤ 10 %

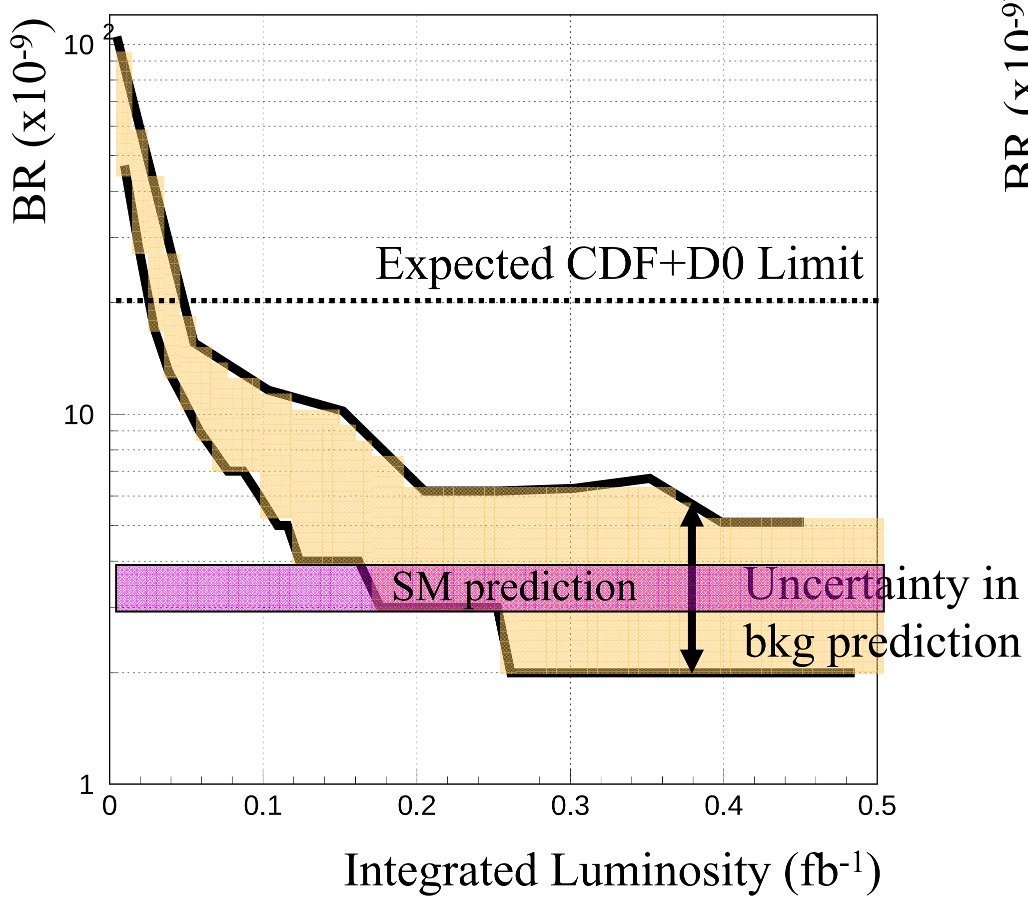
BR sensitivity at 3σ if 1-CLb(BR) ≤ 2.7x10^{-3}

BR sensitivity at 5σ if 1-CLb(BR) ≤ 5.7x10^{-7}

LHCb Prospects

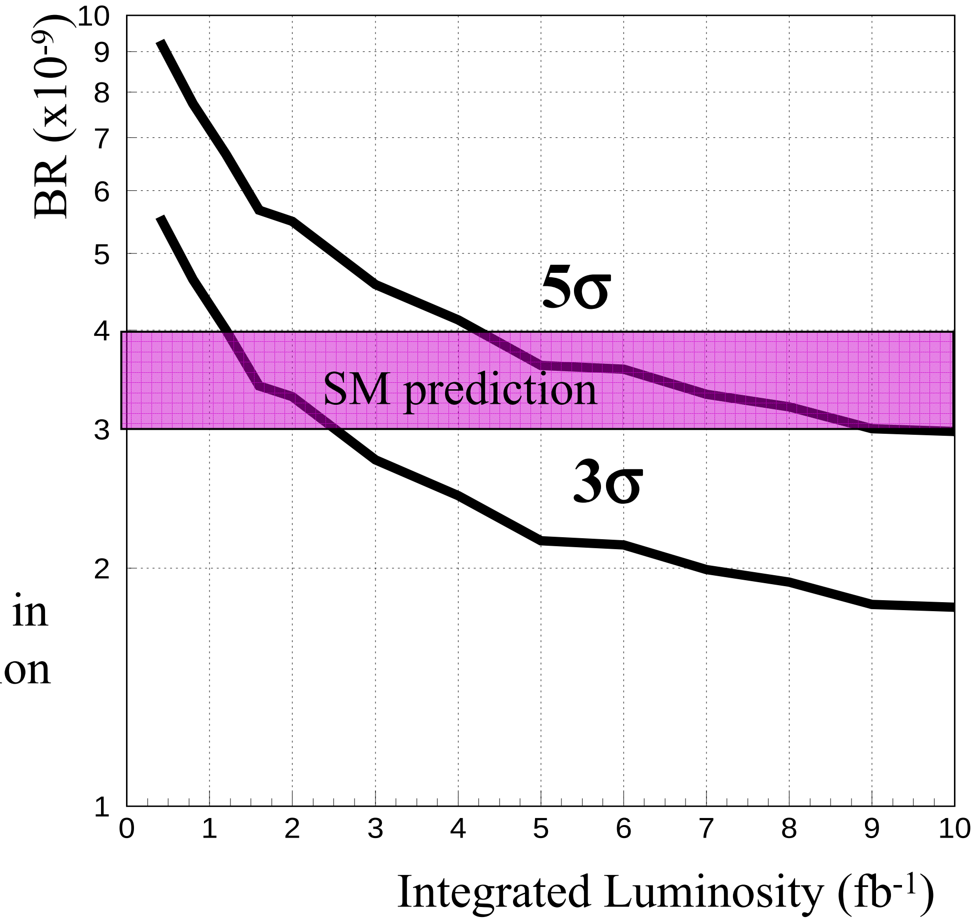
Limit at 90% C.L.

(only bkg is observed)



LHCb Sensitivity

(signal+bkg is observed)



Background is assumed to be dominated by combinations of $b \rightarrow \mu^- X$ $b \rightarrow \mu^+ X$ events.

Conclusions

The excellent tracking and μ-id performance expected at LHCb makes possible to handle the background expected. The di-muon trigger ensures a high efficiency to select $B_s \rightarrow \mu^+\mu^-$ events.

Of course, the challenge is to achieve this performance with real LHC data.

LHCb has the potential to exclude BR between 10^{-8} and the SM prediction already with the luminosity expected in 2008 (~0.5 fb^{-1}).

LHCb has the potential to claim a 3σ (5σ) observation (discovery) of the SM prediction with ~2 fb^{-1} (~6 fb^{-1}) of integrated luminosity.

We all are certainly eager to see the first LHC collisions at 14 TeV...