ATLAS Preparations for Precise Measurements of $B^0 \rightarrow \mu^+\mu^-$ Decays

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Outline

- B-physics in ATLAS
- ATLAS detector and the trigger system
- $B^0_s \rightarrow \mu^+\mu^-$ analysis strategy
  - Trigger and offline selection
  - Expected sensitivity
  - Study on backgrounds from other rare decay channels
- Conclusion

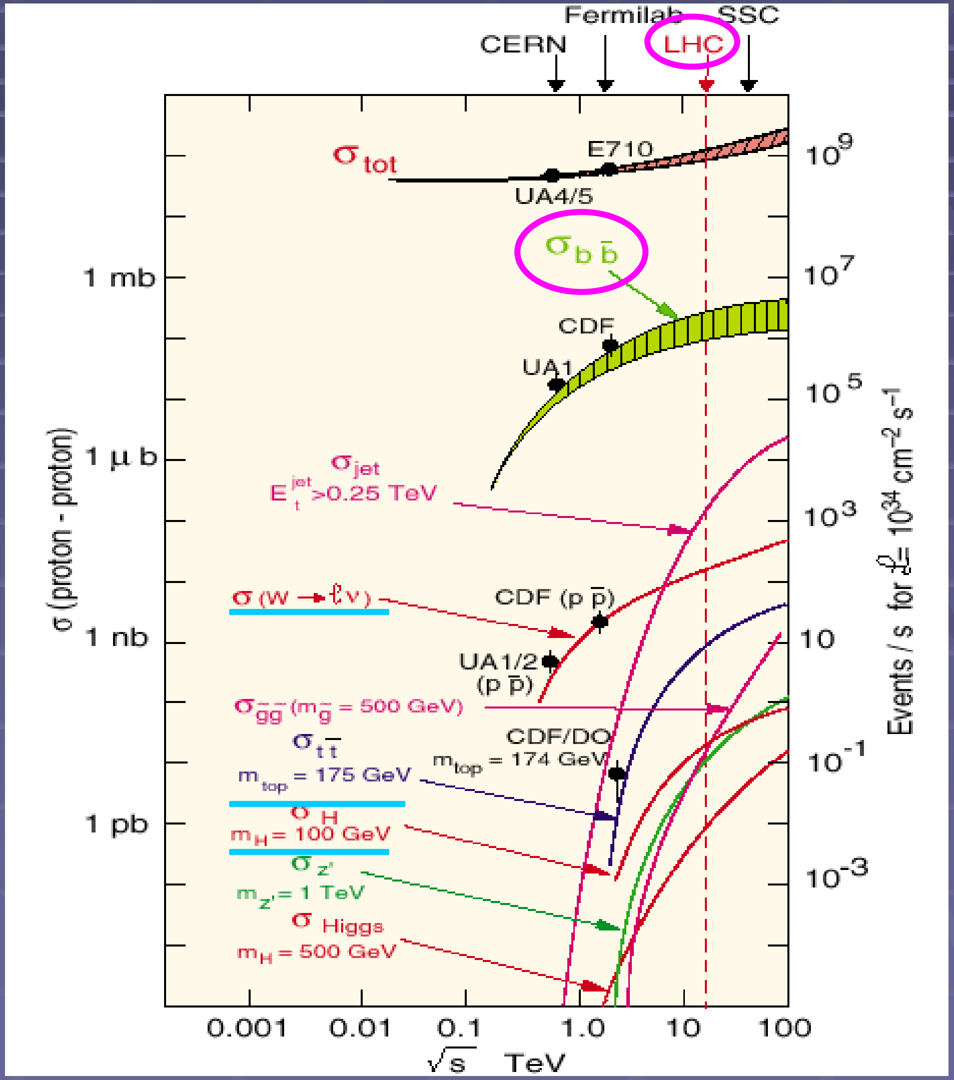
B-physics at ATLAS

- · Large production cross section. At the initial luminosity running. At $\mathcal{L}$~10^{33} $cm^{-2}s^{-1}$, 10^5 bb events/s is produced.
- · Large statistics sample which can be triggered efficiently gives excellent precision for B-physics.
- · The detector design is optimized for high-p_T events, while majority of B events are rather low-p_T.
- · <u>Trigger/tracking is a challenge.</u>

<u>B-physics at ATLAS</u>

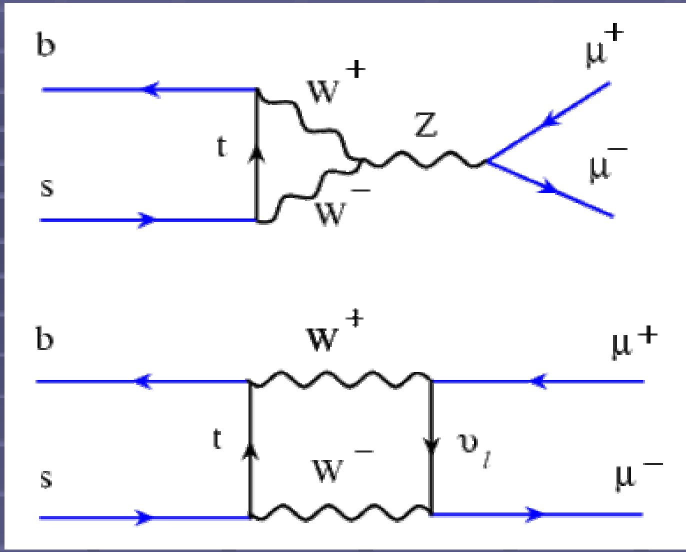
- Bs oscillation, Δm_s, ~~CP~~ in B_s mixing
- Rare B-decays
  - $B^0 \rightarrow \mu\mu$ ⟵ THIS TALK
  - Semi-leptonic decays
  - $\Lambda_b \rightarrow \Lambda\mu\mu$, $B \rightarrow K^* ll$ etc.

Cross sections of various processes



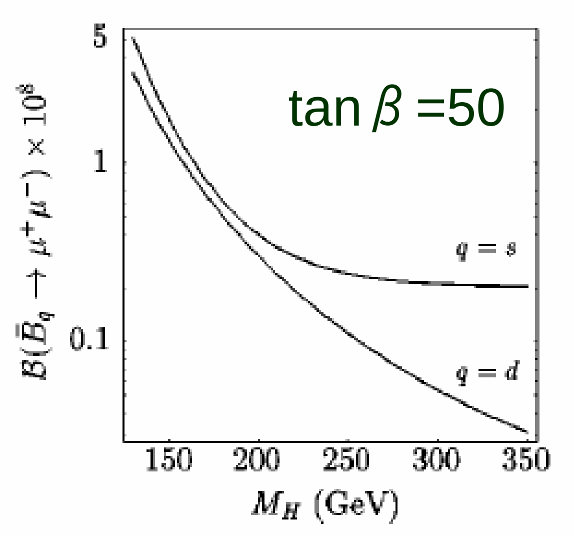
$B^0_{s(d)} \to \mu^+\mu^-$ decays

- Flavor changing neutral current (FCNC) is forbidden at tree level in Standard model. Lowest-order contribution from box and penguin diagrams and branching ratios are very small.
- In some scenarios for physics Beyond the Standard Model (BSM), the branching ratio may be larger than in the Standard Model.



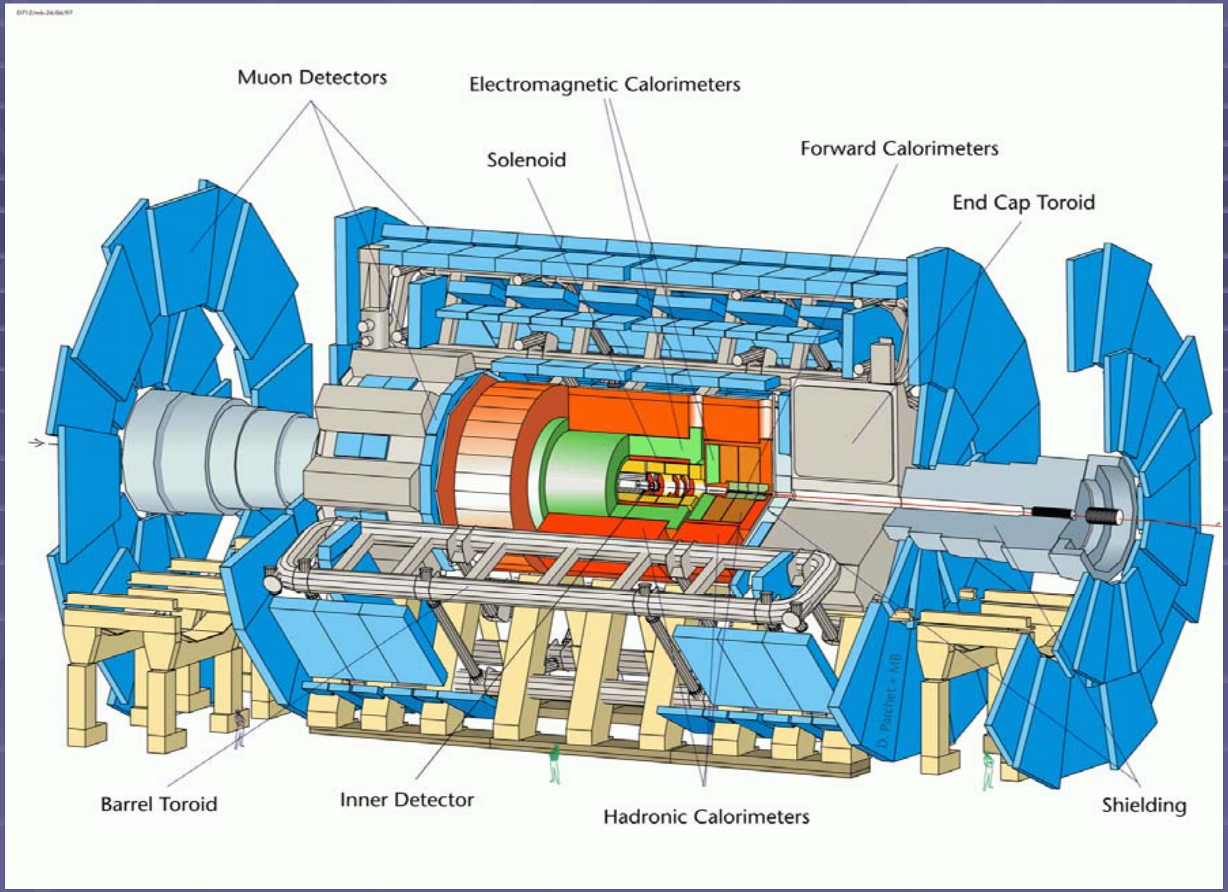
	SM prediction	upper limit
$Br(B^0_s \to \mu^+\mu^-)$	3.5×10^{-9}	$<8.0\times10^{-8}$(90% CL)
$Br(B^0_d \to \mu^+\mu^-)$	0.9×10^{-10}	$<2.2\times10^{-8}$(90%CL)

CDF ICHEP 2006
780 pb^{-1}



Bobeth et. al., PRD66 074021 (2002)

ATLAS experiment



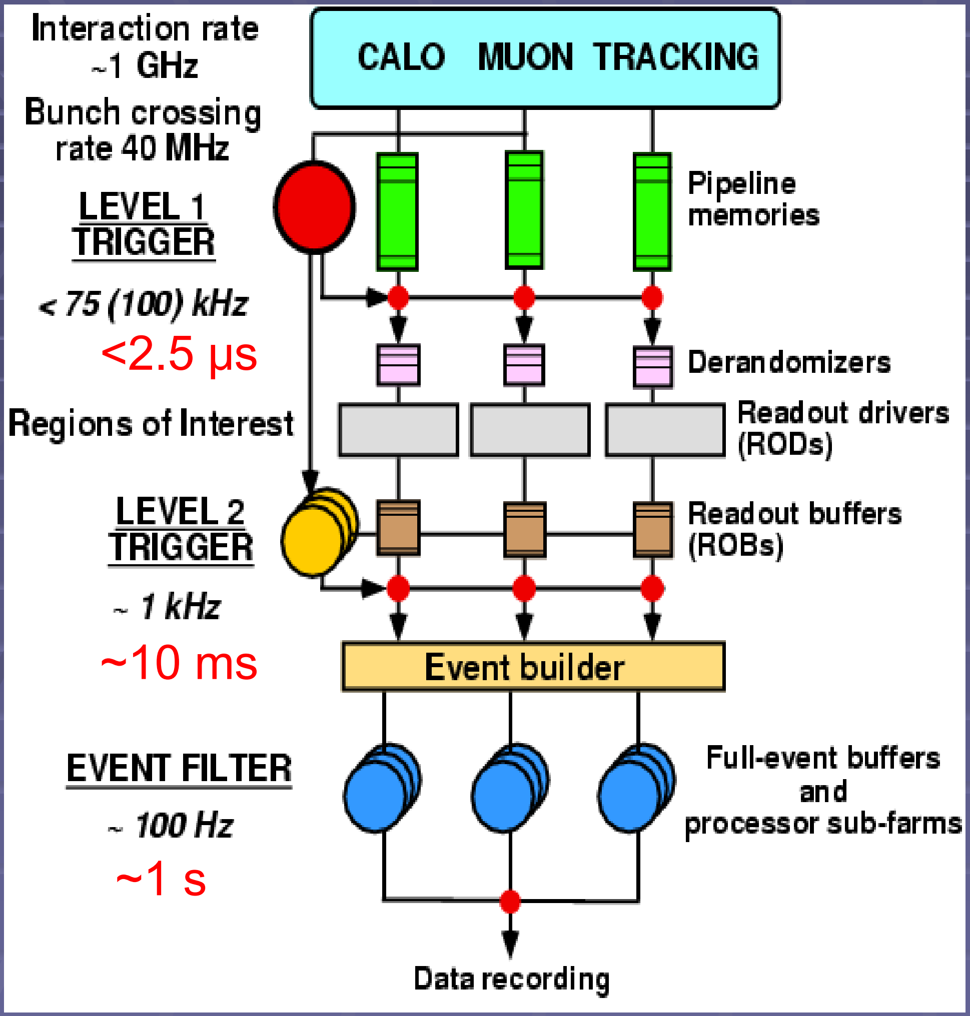
· 14 TeV pp collision
· 25 ns bunch crossing interval

Operation plan
-End of 2007:
900 GeV (commissioning)
$\mathcal{L}$~10^{29} $cm^{-2}s^{-1}$
-Starting summer 2008:
14 TeV
up to "initial luminosity" of
$\mathcal{L}$~10^{33} $cm^{-2}s^{-1}$

Muon system
· RPC (barrel) and TGC (endcap) for LVL1 trigger
· MDT for precise tracking in 0.5 T toroid field

Inner Detector
· Pixel, SCT, TRT in 2 T solenoid field

ATLAS Trigger



LVL1

Hardware trigger. Inputs from muon system and calorimeter

LVL2

Process only in the Regions of Interest (RoI) from LVL1.
Full granularity of data in RoI.
(typically ~2 % of data to access)
Data must be readout over network from the detector ReadOut System.

Event Filter (EF)

Full event available at the EF. But also, RoI seeded algorithm foreseen for some algorithms for performance.

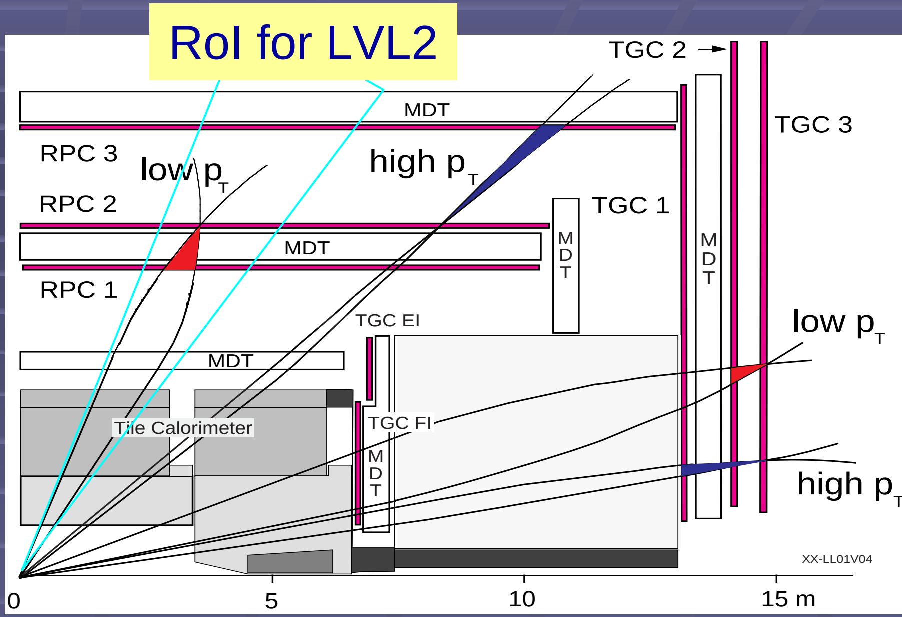
$B^0_s \rightarrow \mu^+\mu^-$ Analysis strategy

Trigger selection

- LVL1
  - $1 \times \mu(p_T > 6$ GeV) at very low luminosity runs at the beginning ($\sim 10^{31}$ $cm^{-2}s^{-1}$)
  - $2 \times \mu(p_T > 6$ GeV) at higher luminosity ($> 10^{33}$ $cm^{-2}s^{-1}$)
- LVL2
  - $2 \times \mu(p_T > 6$ GeV) with mass cut
  - Combining tracks in muon chamber and inner detector for π/K rejection (track/momentum matching). This RoI processing works within the LVL2 averaging processing time (<10 ms).
- EF
  - Further reduce the background rate using the reconstruction similar to the offline using the vertexing algorithm with looser cuts
  - The optimization of the thresholds are in development

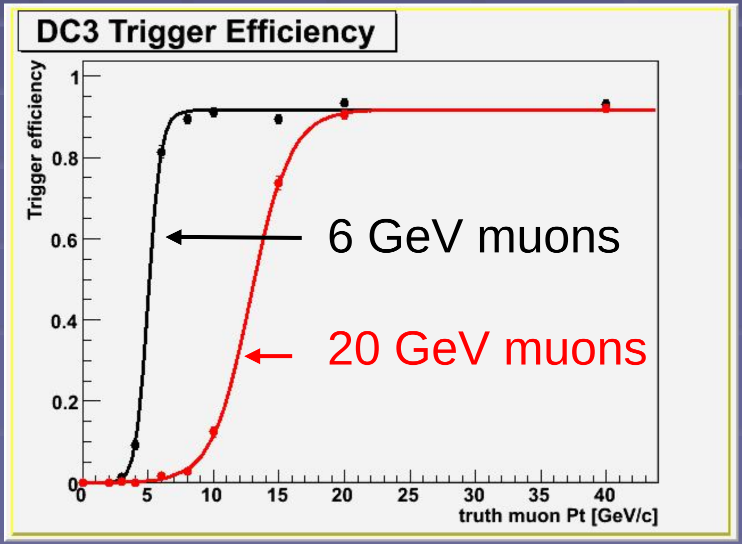
LVL1 muon trigger

- Selection of muons done by requiring a coincidence between different layers in a specified window
- The size of the window provides an effective p_T threshold
- The same idea is used in both barrel and endcap, but different technologies (RPC:barrel, TGC:endcap)



-System being optimized to reduce rate of fake dimuons when a single muon traverses more than one sector
-Understand contaminations of lower p_T muons

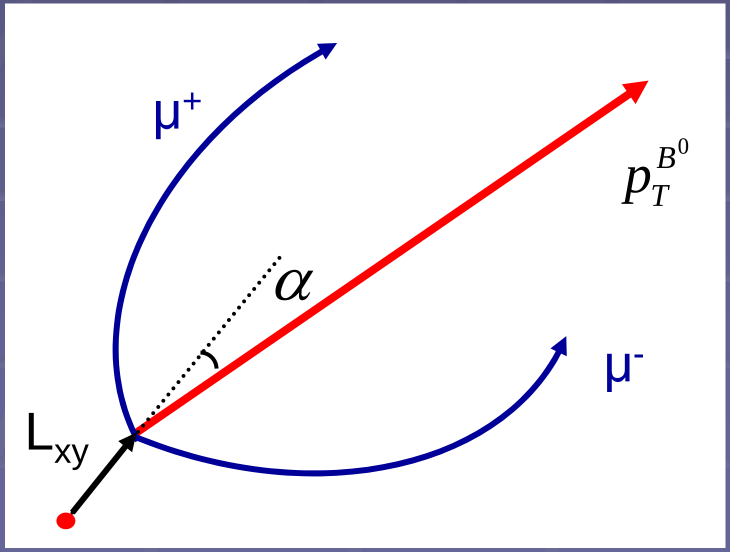
Efficiency curves for 6 and 20 GeV muons. (simulation)

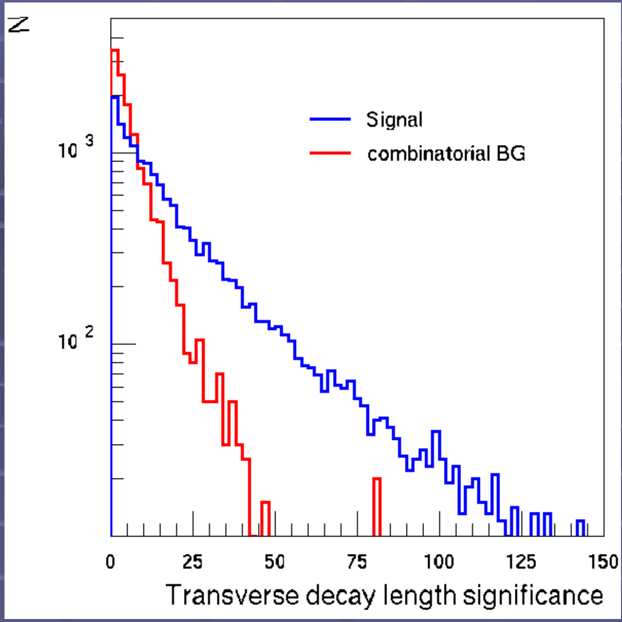


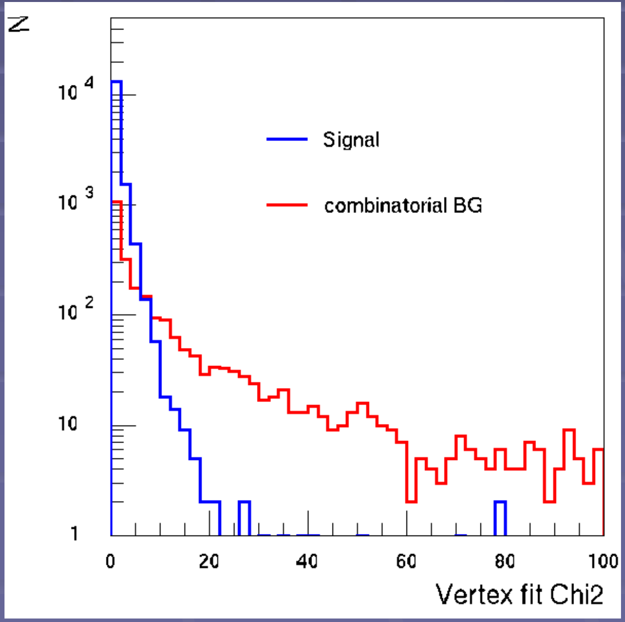
(Around 6 GeV is the lowest threshold we can achieve at LVL1)

Offline selection

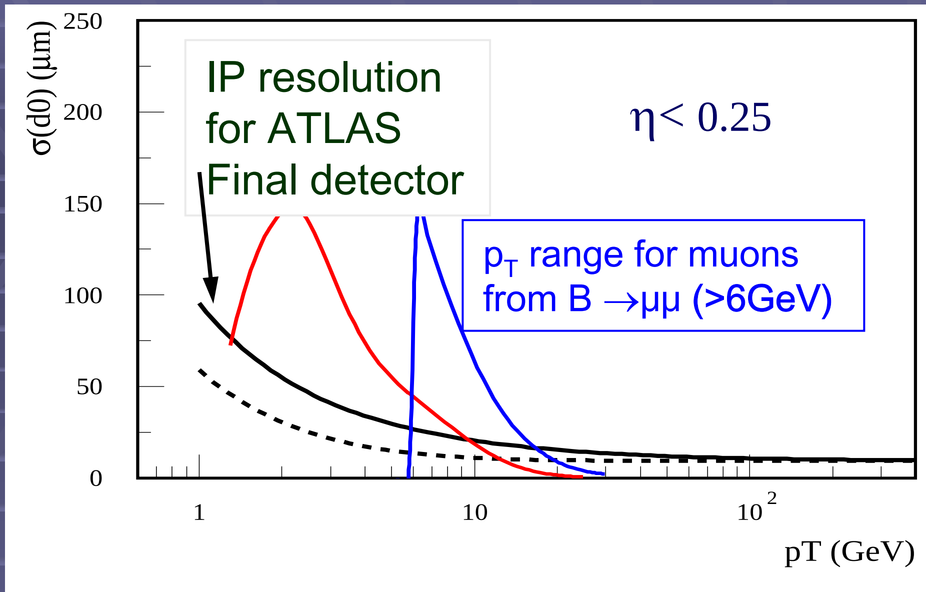
- Muon selection (p_T>6 GeV, |η|<2.5)
- $\Delta R_{\mu\mu}$<0.9
- Transverse decay length: $L_{xy}/\sigma(L_{xy})$>11
- Isolation: no charged track with p_T>0.8 GeV in cone <15 °
- Matching between the direction from the primary to secondary vertex and the the μμ–system momentum.
- $M_{\mu\mu}=M_{Bs}{}^{+140}{}_{-70}$ MeV





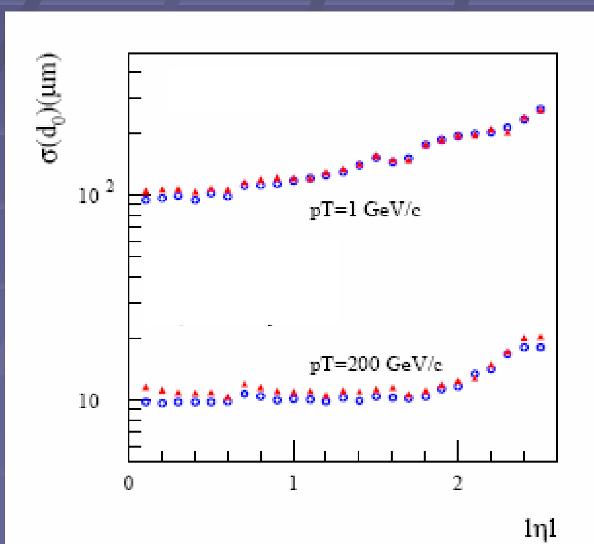


Impact parameter resolution

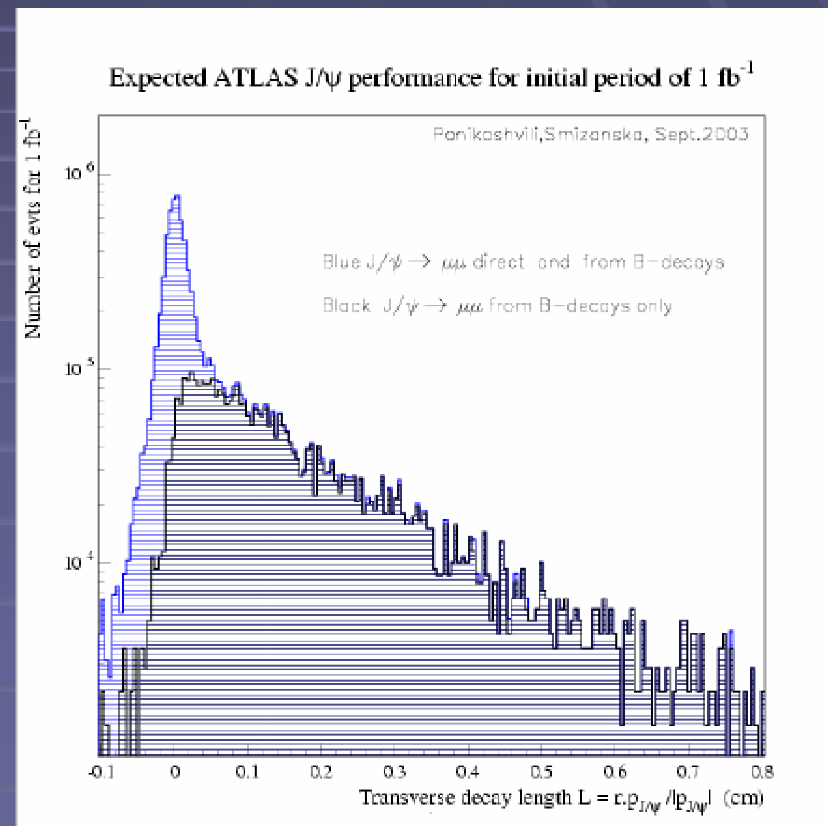


·Good impact parameter resolution for p_T>6 GeV.σ=25-70 (μm)

·Transverse decay length L_{xy}



Resolution almost flat in barrel region. Some degradation in the endcap.



Projected number of events

- B^0_s signal and background ($bb \rightarrow \mu\mu X$) with 10 fb^{-1} (1 year at initial luminosity)
- Signal generated assuming $Br(B^0_s \rightarrow \mu^+\mu^-)=3.5\times10^{-9}$
- Background sample: $bb \rightarrow \mu\mu X$ (PYTHIA) (combinatorial background)
- Large reduction of BG with secondary-vertex cut

	B^0_s signal	BG ($bb \rightarrow \mu\mu X$)
$p_T>6$ GeV, $\Delta R_{\mu\mu}<0.9$	50 events	6.0×10^6 events
$M_{\mu\mu}$ cut	0.77	2×10^{-2}
Isolation cut	0.36	5×10^{-2}
$L_{xy}/\sigma>11$, $\chi^2<15$	0.4	$<0.7\times10^{-4}$
All cuts	7	20±20

efficiency (applies to the $M_{\mu\mu}$ cut, isolation cut and L_{xy}/σ, χ^2 rows)

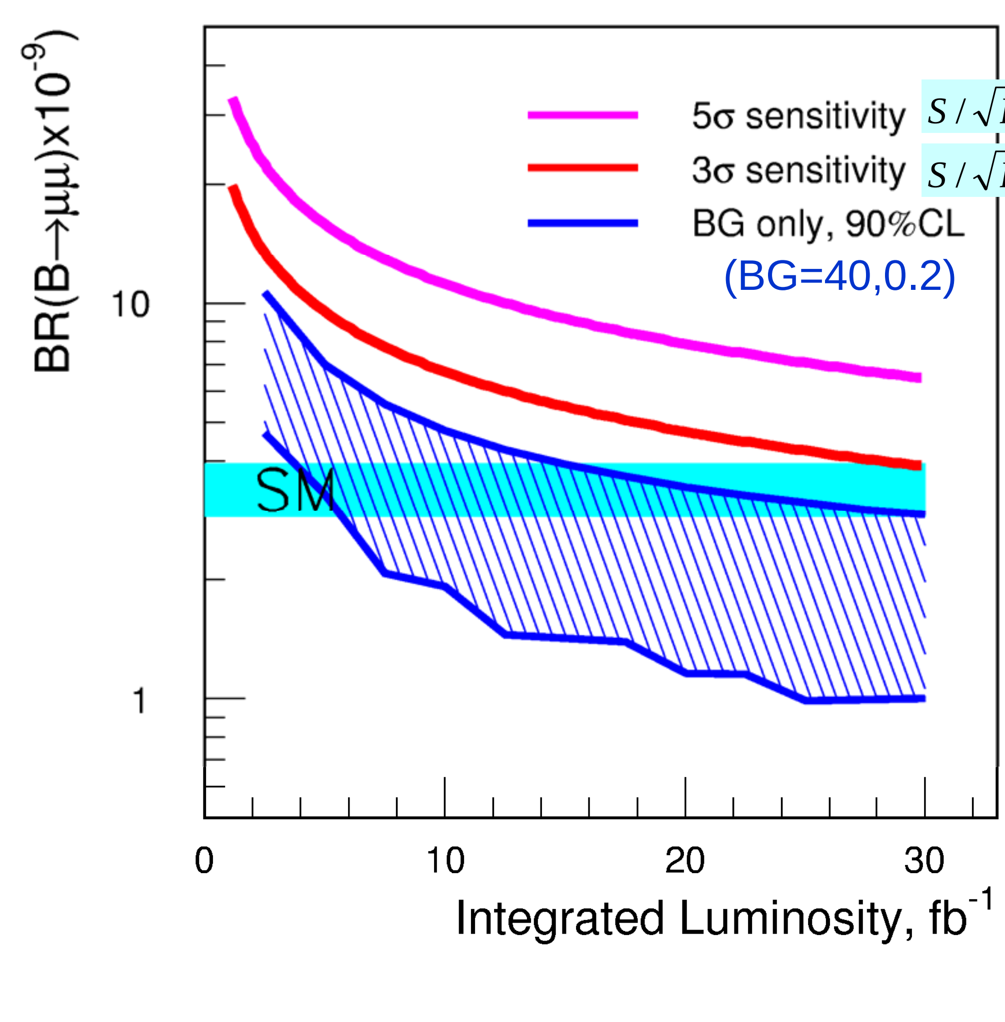
Projected upper limits

Expected signal/background for various integrated luminosity. Upper limit on $Br(B^0_s \to \mu^+\mu^-)$ based on S=7, B=20±20 at 10 fb^{-1}.

Bayesian estimate of the number of signal events

$$Br\left(B_s^0 \to \mu^+\mu^-\right) \le \frac{N\left(n, n_{bg}\right)}{2\sigma_{Bs} L \alpha \varepsilon_{total}}$$

- Number of events scaled to higher luminosities
- The projection of the sensitivity at higher luminosity includes large uncertainty from the limited MC statistics.
- ATLAS expects to reach the sensitivity of the level of SM prediction with 30 fb^{-1} (3 years of data taking)



$S/\sqrt{B}=5$

$S/\sqrt{B}=3$

Study of specific backgrounds

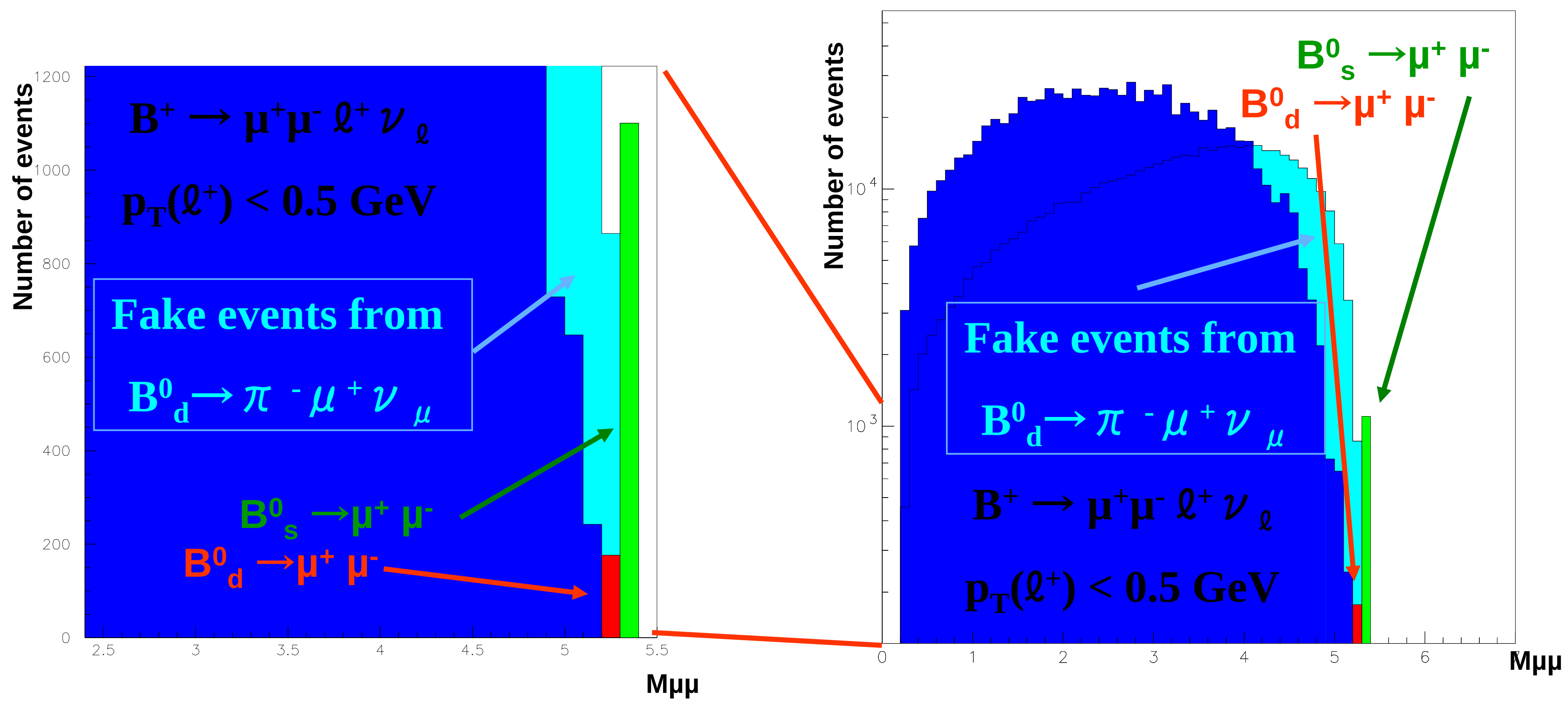
Motivation

In earlier studies, the main emphasis was on understanding the combinatorial BG (PYTHIA, bb→μμX). In view of the very high sensitivity, other rare decay processes might become a background to $B^0_s \to \mu\mu$ in addition to combinatorial backgrounds.

Precise measurements (branching ratio, distribution) from existing experiments would be very useful to understand all backgrounds.

BG process	Br	Effective Br in B→μμ signal region
$B^0 \to \pi^- \mu^+ \nu_\mu$	$\sim 10^{-4}$	$\sim 5 \bullet 10^{-8}$
$B^+ \to \mu^+\mu^- \ell^+ \nu_\ell$	$< 5 \bullet 10^{-6}$	$< 5 \bullet 10^{-8}$
$B_c \to \mu^+\mu^- \ell^+ \nu_\ell$	$< 10^{-4}$	$< 10^{-8}$
$B^0_d \to \pi^0 \mu^+\mu^-$	$\sim 2 \bullet 10^{-8}$	$\sim 10^{-10}$
$B^0_s \to \mu^+ \mu^- \gamma$	$\sim 2 \bullet 10^{-8}$	$\sim 10^{-10}$
$B_d \to K\pi$ $B_s \to KK$	$2 \bullet 10^{-5}$	$< 10^{-9}$

$B^0 \rightarrow \pi^+\mu^-\nu_\mu$ background



- $Br(B^+ \rightarrow \pi^+\mu^-\nu_\mu) \approx 10^{-4}$ compared to $Br(B^0_s \rightarrow \mu^+\mu^-)=3.5\times10^{-9}$.
- Taking into account the π/K→μ fake rate (0.1-0.5 %) and soft ν_μ phase space (~10 %), this channel may give non-negligible contribution (~5×10^{-8}).
- Currently, only generator-level study. No vertex pointing cut applied yet.
- Needs further investigation with full simulation.

Conclusion

- Large production cross section of bb pair at LHC allows to study $B^0_s \rightarrow \mu^+\mu^-$ decays with high sensitivity.
- Trigger: $1\times\mu6$ initially and $2\times\mu6$ at high luminosity

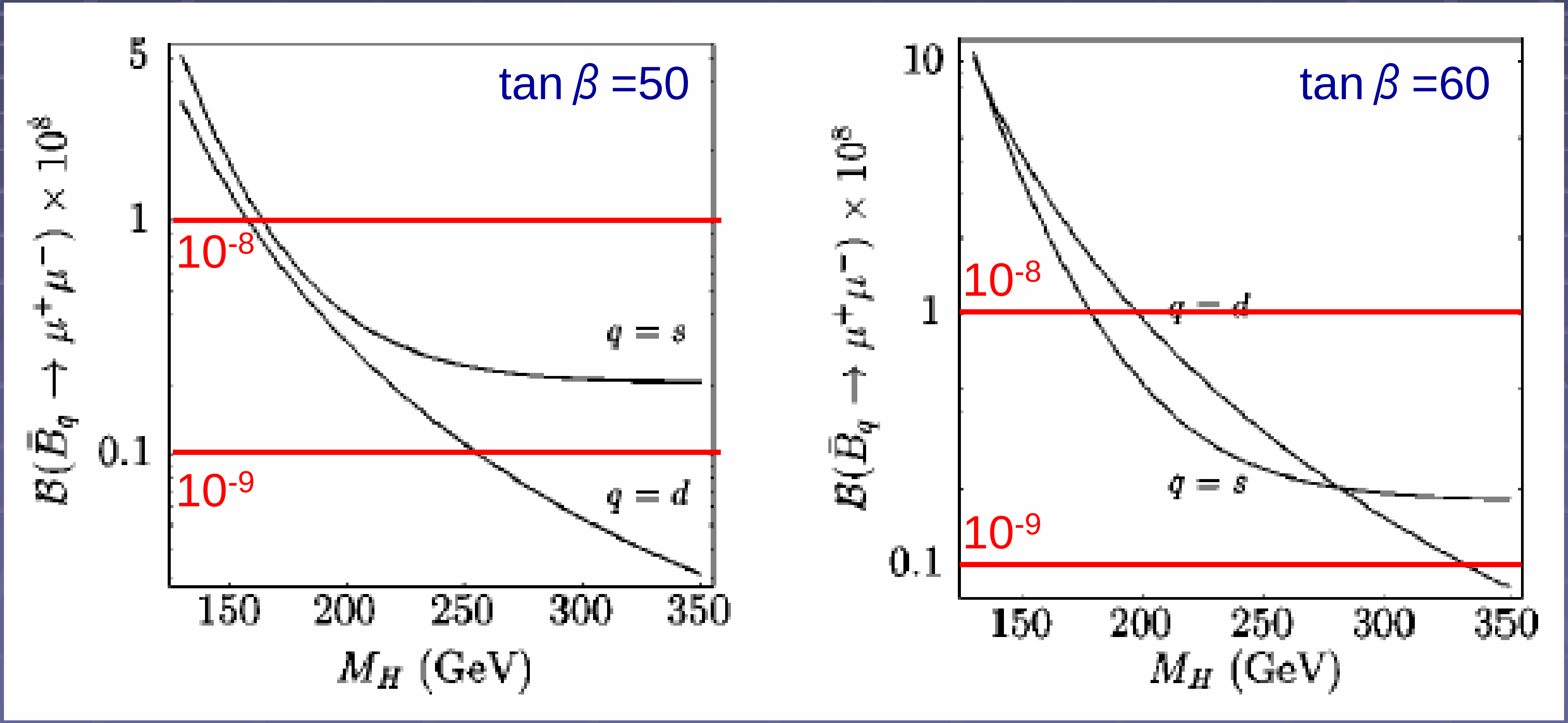
- ATLAS sensitivity to $B^0_s \rightarrow \mu^+\mu^-$ decay is expected to reach the level of SM prediction after 3 years of data taking
- $Br(B^0_s \rightarrow \mu^+\mu^-)$ measurement will continue at the nominal LHC luminosity ($10^{34}cm^{-2}s^{-1}$).

- At this sensitivity, backgrounds from other rare decay channels could become non-negligible. A study using the full simulation/reconstruction is under way.

BACKUP SLIDES

Sensitivity reach

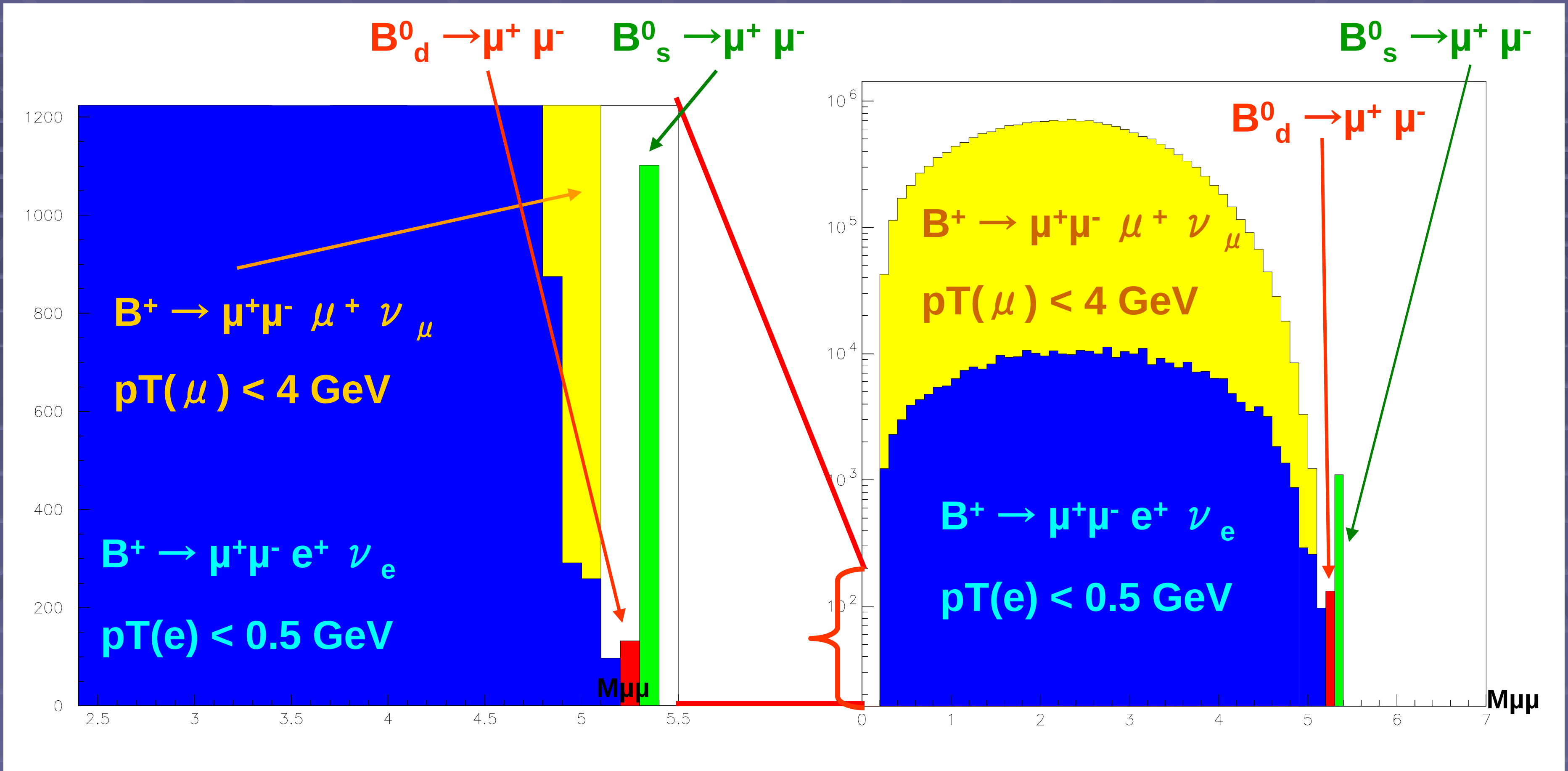
- ATLAS sensitivity after 1 year (10 fb-1) → $Br(B^0_s \to \mu^+\mu^-) < 1.4\times10^{-8}$
- (Standard model prediction: $Br(B^0_s \to \mu^+\mu^-) < 3.5\times10^{-9}$)
- ATLAS will study it beyond the initial luminosity phase.



Bobeth et. al., PRD66 074021 (2002)

Sensitivity reach down to possibly detecting a MSSM signal.

$B^+ \rightarrow \mu^+\mu^- l^+ \nu_l$, background



- $Br(B^+ \rightarrow \mu^+\mu^- \ell^+\nu_\ell) \approx 5*10^{-6}$ compared to $Br(B^0_s \rightarrow \mu^+\mu^-)=3.5\times10^{-9}$.
- Taking into account the soft $\ell^+\nu_\ell$ system, this channel may give a non-negligible contribution in the signal region.
- Currently, only generator level study. No vertex pointing cut applied yet.

Mass resolution