Rare leptonic B-decays simulation at ATLAS – the update

“Flavour in the era of the LHC, 4th meeting "
CERN, Tuesday 10 October 2006

N.Nikitine,
T.Buanes,
S.Sivoklokov,
M.Smizanska,
K.Toms

on behalf of the
ATLAS Collaboration

Introduction

Physics: $b \to d, s$ transitions (FCNC) are forbidden at the tree level in SM and occur at the lowest order through one-loop-diagrams "penguin" and "box".

Main points for study:

a) Good test of SM and its possible extensions;

b) Information of the long-distance QCD effects;

c) Determination of the $|V_{td}|$ and $|V_{ts}|$;

d) Some of rare decays can produce the BG to other rare decays.

BG for $B^0_{d,s} \to \mu^+\mu^-$ decays

In order to find physics beyond SM in rare muonic decays, we need to know <u>all possible SM BG</u>.

1. In ATLAS conditions the largest BG come from $b\bar{b}$ $(b\bar{b}b\bar{b}, b\bar{b}c\bar{c}) \to \mu\mu X$ processes, with muons originating mainly from semileptonic b(c) decays (so called combinatorial BG). This BG has always been taken into account when studying the discovery potential for rare B-decays at ATLAS.

Simulation with the <u>Final ATLAS detector</u> after the all cuts applied we have 7 signal events and 20 combinatorial BG events with 10 fb^{-1} of integral LHC luminosity.

BG for $B^0_{d,s} \to \mu^+\mu^-$ decays

2. Other important BG can be produced by decays with small branching ratios (rare decays) or exotic decays, which are not included in standard MC-generators and also by misidentification effects in detector.

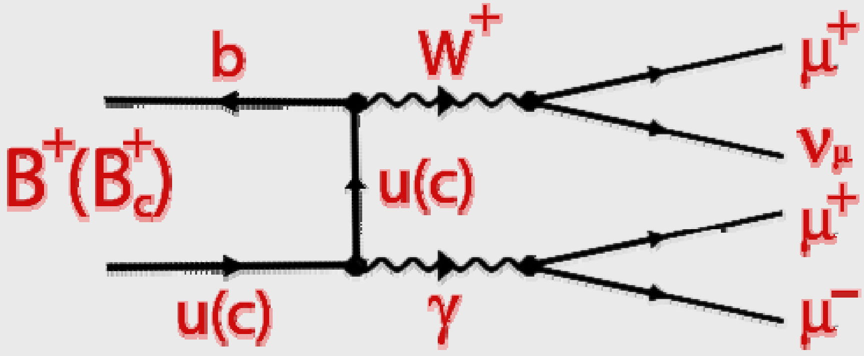
Without cuts, BG rates from exclusive decays and fake rates are both smaller than rates from the combinatoric BG. But after applying the signal selection cuts, the situation changes. Exclusive BG processes and the fake rates start to play a role because they have signatures very similar to $B^0_{d,s} \to \mu^+\mu^-$. The main noncombinatorial BG is presented in the following table.

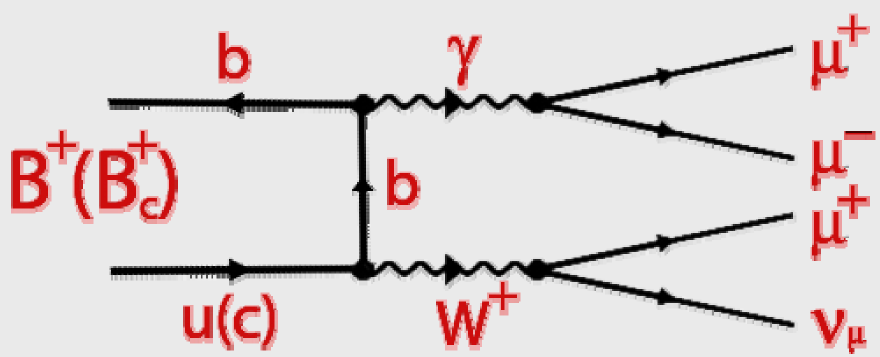
Review of the main noncombinatorial BG sources for muonic B-decays at ATLAS

BG process	Theoretical Br estimations	Effective Br in B-μμ signal space (ATLAS)
$B^0 \to \pi^- \mu^+ \nu_\mu$	$\sim 10^{-4}$	$\sim 5 \cdot 10^{-8}$ *)
$B^+ \to \mu^+\mu^- \ell^+\nu_\ell$	$< 5 \cdot 10^{-6}$	$< 5 \cdot 10^{-8}$
$B^+ \to (J/\psi \to \mu^+\mu^-)\ K^+$	$\sim 6 \cdot 10^{-5}$	$\sim 10^{-8}$ *)
Nonresonant $B_c \to \mu^+\mu^- \ell^+\nu_\ell$	$< 10^{-4}$	$< 10^{-8}$
$B_c \to (J/\psi \to \mu^+\mu^-)\ \mu^+\nu_\mu$	$\sim 5 \cdot 10^{-4}$	Study in progress
$B^0_d \to \pi^0 \mu^+\mu^-$	$\sim 2 \cdot 10^{-8}$	$\sim 10^{-10}$
$B^0_s \to \mu^+ \mu^- \gamma$	$\sim 2 \cdot 10^{-8}$	$\sim 10^{-10}$
$B^0_d \to K\pi, \pi\pi,\ B^0_s \to KK$	$2 \cdot 10^{-5}$	$< 10^{-9}$ *)
$B^0_s \to \mu^+ \nu_\mu\ \mu^- \nu_\mu$	$\sim 10^{-7}$	$\leq 10^{-9}$

*) convoluted by fake-muon probability using K/π full detector simulation.

1. Nonresonant four-leptonic decays $B^+ (B^+_c) \to \mu^+\mu^- \ell^+\nu_\ell$ as BG for $B^0_{d,s} \to \mu^+\mu^-$





Note: B-mass resolution of the ATLAS detector in $B \to \mu^+\mu^-$ - decays

$$\sigma_{B\to\mu+\mu-} \approx 80 \text{ MeV} .$$

Roughly: the nonresonant branching ratios is equal

$$Br(B^+ \to \mu^+\mu^- \ell^+\nu_\ell) \approx 5*10^{-6},$$

$$Br(B^+_c \to \mu^+\mu^- \ell^+\nu_\ell) \approx 8*10^{-5},$$

where $\ell^+ = \{e^+, \mu^+\}$. The theoretical descriptions of these decays are now in progress and will be completed before the LHC start. These decays should be independently measured in experiments

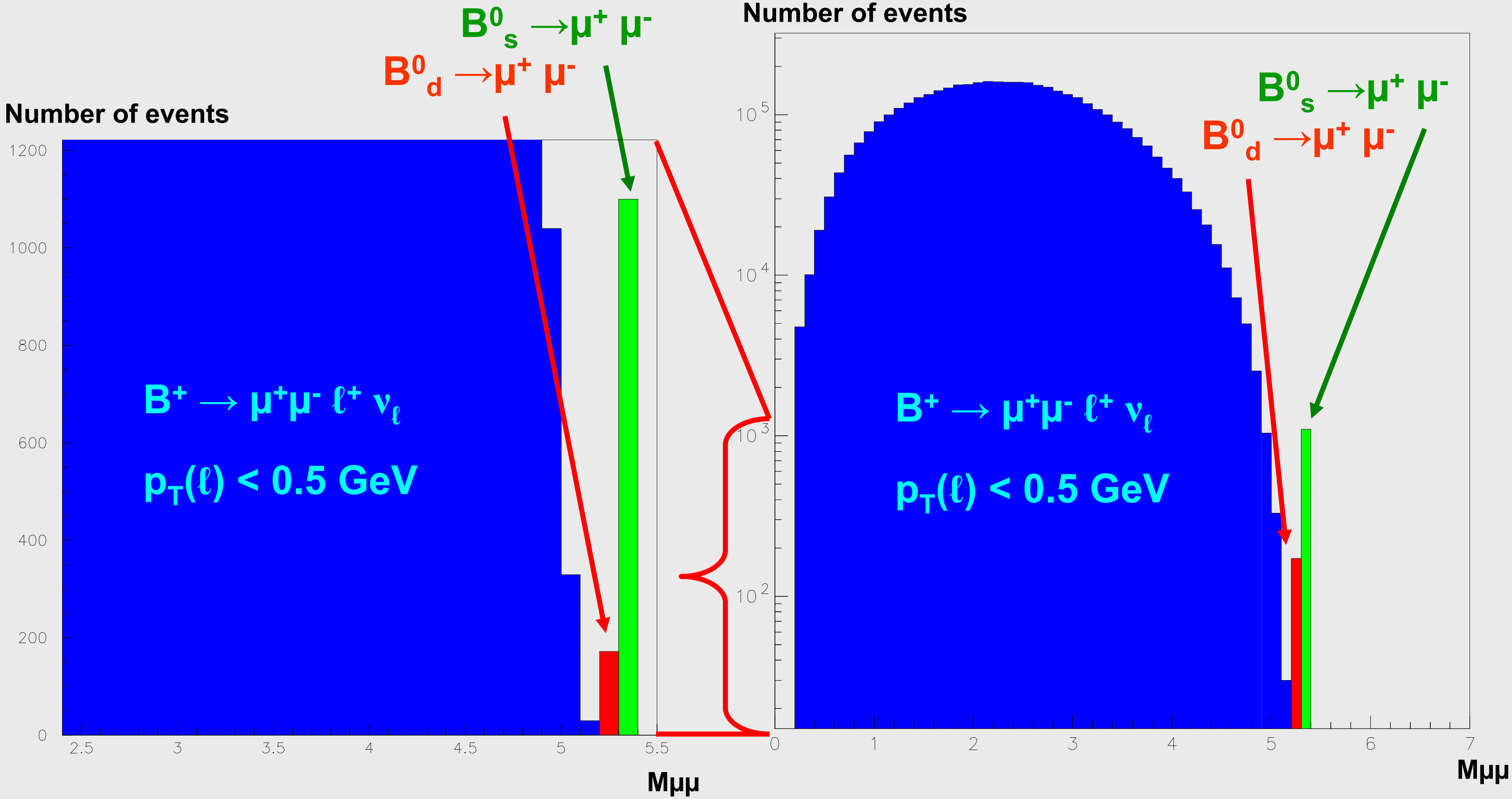
2. Nonresonant four-leptonic decays $B^+ (B^+_c) \to \mu^+\mu^- \ell^+\nu_\ell$ as BG for $B^0_{d,s}\to\mu^+\mu^-$

The decays with neutrino can be reduced using kinematical constraints (e.g. pointing to PV). However this methods will be limited. So the remaining background needs to be estimated.

If the p_T of one of the charged leptons is below the threshold for track reconstruction ($p_T(\ell \text{ or } \mu)<0.5$ GeV) then there are only two charged lepton tracks observed from the B-meson decay vertex and the invariant mass of the lepton pair is about the mass of the B-mesons.

At the LHC the four-leptonic nonresonant BG from B^+ is 25 to 40 times larger than BG from B^+_c in their common kinematical region. Beyond the end-kinematical point of B^+ - decay only the BG from B^+_c remains.

$B^+ \to \mu^+\mu^- \ell^+\nu_\ell$ as BG for $B^0_{d,s} \to \mu^+\mu^-$

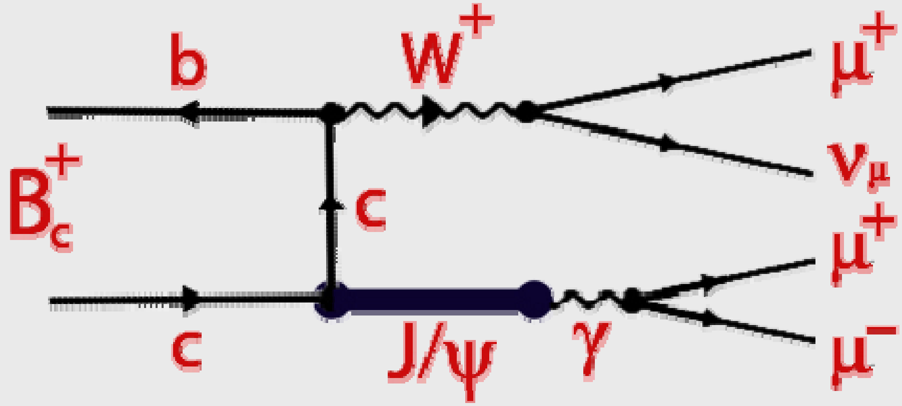


For muons in $M_{\mu\mu}$: $|\eta(\mu)| < 2.5$, $p_T(\mu) > 5$ (or 6) GeV.

The particle level phase space simulation of $B^0_d \to \mu^+ \mu^- \ell^+ \nu_\ell$

(<u>no cuts selecting μμ-pairs pointing to primary vertex applied yet!</u>).

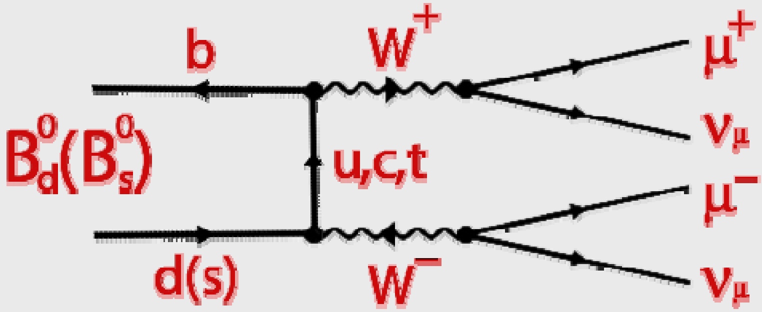
Resonant four-leptonic decay $B^+_c \to (J/\psi \to \mu^+\mu^-)\mu^+\nu_\mu$ as BG for $B^0_{d,s} \to \mu^+\mu^-$

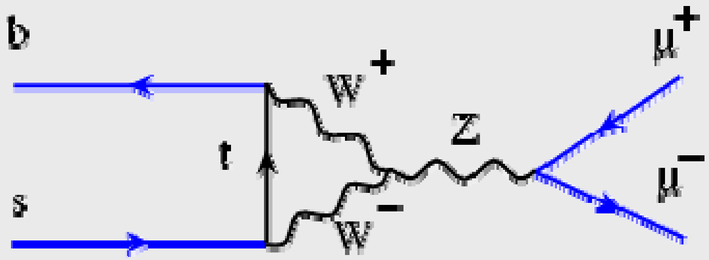


The effective Br of this channel when one of muons and neutrino is soft lies in the area 10^{-6} - 10^{-7}.

The full detector simulation is needed in order to understand if the masses of B^0_d and B^0_s - mesons are covered by the kinematical region of this decay.

Nonresonant four-leptonic decays of $B^0_{d,s}$ –mesons as BG for $B^0_{d,s} \to \mu^+\mu^-$





Unlike the $B^0_{d,s} \to \mu^+\mu^-$, the four-leptonic decays do not have loop-suppression, leading to the branching value approximately $\pi^2/16 \sim 6 \cdot 10^{-3}$.

Extracting the soft-neutrinos area from four-leptonic phase space should lower effective branching of four-leptonic decays 10^2 - 10^3 times. So this channel should be considered as a potential background.

Misidentification and fake rates - I

These backgrounds are determined by the probability of hadron-muon misidentification in the ATLAS detector. A typical value for the misidentification probability is approximately equal to 0.3-0.5% (in future estimations factor 1/200).

Two-body hadronic decay $Br(B^0_d \to K^+\pi^-) \approx 2 \cdot 10^{-5}$.

So the fake probability for $B^0 \to \mu^+\mu^-$ is equal to:

$$Br(B^0 \to K^+\pi^-) \cdot (1/200)^2 \approx 0.5 \cdot 10^{-9},$$

and nearly equal to $Br(B^0_s \to \mu^+\mu^-) \approx 3.5 \cdot 10^{-9}$.

Note: $B^0_{d,s} \to \pi^+\pi^-$, $B^0_s \to K^-\pi^+$, $B^0_{d,s} \to K^+K^-$, $\Lambda_b \to \pi p$.

Misidentification and fake rates - II

Two - body hadronic decay with soft muon in the final state:

$$Br(B^+ \to (J/\psi \to \mu^+\mu^-)K^+) \sim 10^{-3} \times 6 \cdot 10^{-2} \sim 6 \cdot 10^{-5} .$$

If we will take into account the K-μ misidentification, we get about 1/200 kaons misidentified as muons. In the case where the μ^+ from J/ψ decay has a $p_T < 0.5$ GeV, this muon is not detected by the Inner Detector (this assumption will add a suppression factor of 1/10 into the corresponding BG Br).

The effective fake probability for this case ~ 10^{-8} and can produce a significant BG $Br(B^0_s \to \mu^+\mu^-) \approx 3.5 \cdot 10^{-9}$.

Note: $B^+ \to$ and $B^+_c \to (J/\psi \to \mu^+\mu^-)\pi^+$, $B^+ \to (\psi' \to \mu^+\mu^-)K^+$.

Misidentification and fake rates-III

Semileptonic B-decay: $Br(B^0_d \rightarrow \pi^- \mu^+ \nu_\mu) \sim 10^{-4}$.

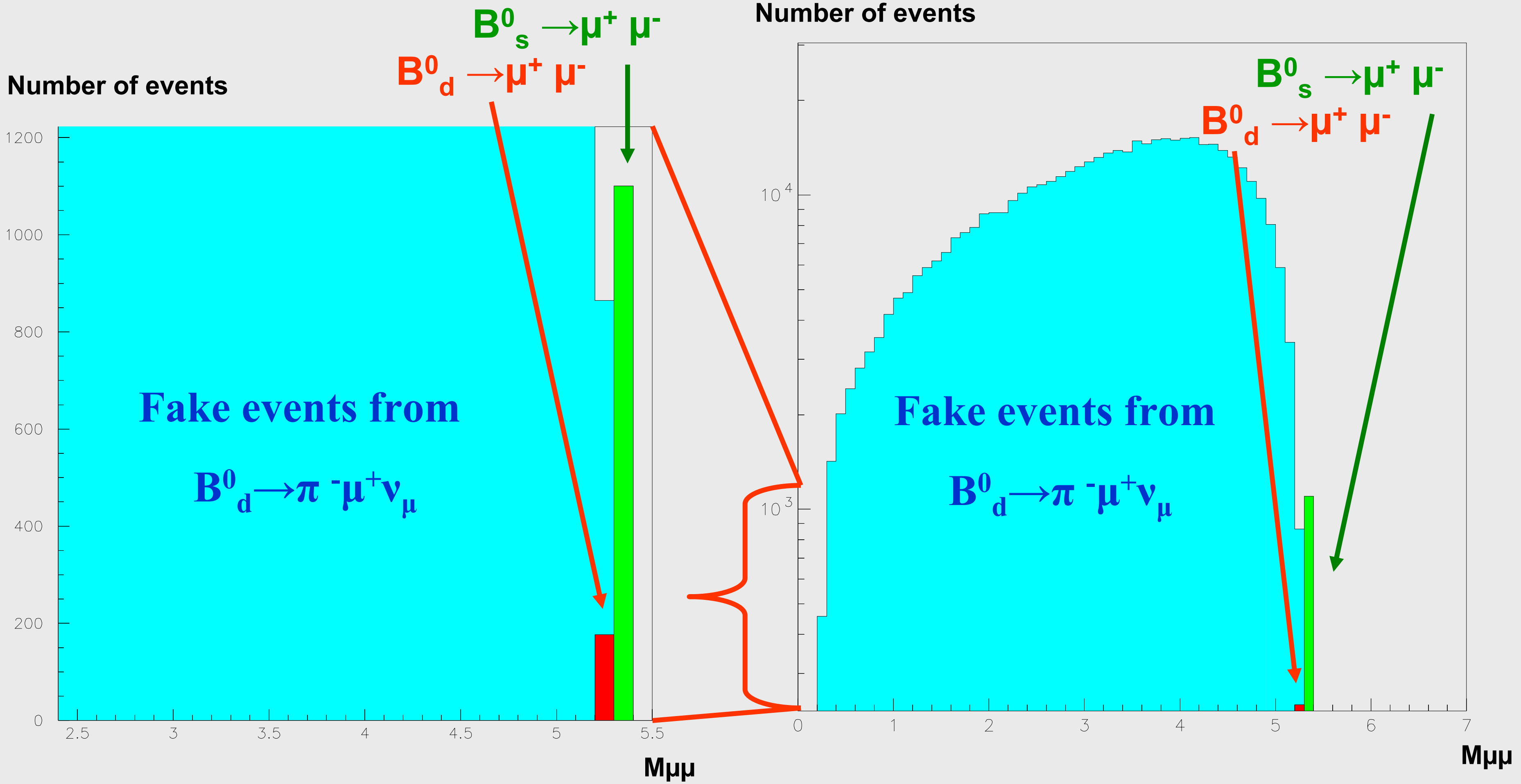
If we will take into account the π-μ misidentification, we get about one of 200 of pions misidentified as muon. Corresponding fake probability is roughly equal to:

$$Br(B^0_d \rightarrow \mu^- \mu^+ \nu_\mu) \bullet 1/200 \approx 0.5 \bullet 10^{-6}.$$

In order to estimate the fake probability for $B^0_{d,s} \rightarrow \mu^+ \mu^-$ we need to reduce this result by a factor of 10 corresponding to soft-neutrino phase space.

The effective probability rate for this case $\sim 5.0 \bullet 10^{-8}$ can produce a significant BG $Br(B^0_s \rightarrow \mu^+ \mu^-) \approx 3.5 \bullet 10^{-9}$.

Fake events from $B^0_d \to \pi^- \mu^+ \nu_\mu$

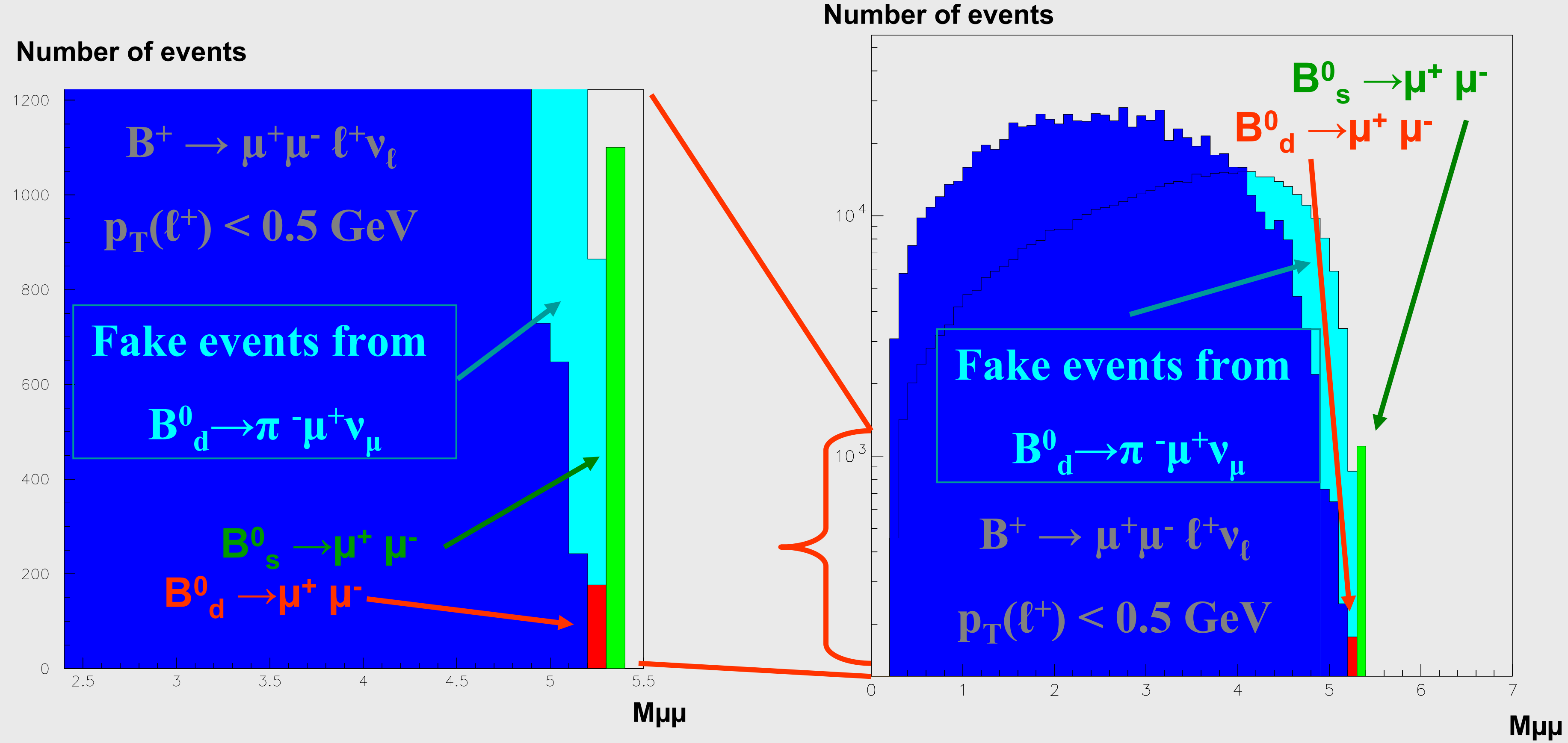


π-μ misidentification : $|\eta(\mu,\pi)| < 2.5$, $p_T(\mu,\pi) > 6$ and 5 GeV.

The particle level simulation of $B^0_d \to \pi^- \mu^+ \nu_\mu$ for SM

(no cuts selecting μμ-pairs pointing to primary vertex applied). 13

The comparison between fake events from $B^0_d \rightarrow \pi^- \mu^+ \nu_\mu$ and four-leptonic decays of B^+ - meson.



π-μ misidentification : $|\eta(\mu,\pi)| < 2.5$, $p_T(\mu,\pi) > 6$ and 5 GeV.

The particle level simulation of $B^0_d \rightarrow \pi^- \mu^+ \nu_\mu$ and $B^+ \rightarrow \mu^+\mu^- \ell^+\nu_\ell$ for SM (no cuts selecting μμ-pairs pointing to primary vertex applied).

Plans

I) The full detector simulation and reconstruction with misaligned geometry and pile-up for the following noncombinatorial BG:

a) Misidentification BG from $B^0_d \rightarrow \pi^- \mu^+ \nu_\mu$ decay;

b) Nonresonant four-leptonic decays $B^+ \rightarrow \mu^+ \mu^- \ell^+ \nu_\ell$;

c) Resonant $B^+_c \rightarrow (J/\psi \rightarrow \mu^+ \mu^-) \mu^+ \nu_\mu$ decay.

II) Fast detector simulation including the same trigger cuts for

a) Misidentification BG from two-body hadronic decays of B-mesons: $B \rightarrow \pi\pi$, $B \rightarrow K\pi$, $B \rightarrow KK$, $\Lambda_b \rightarrow \pi p$;

b) Nonresonant four-leptonic decays $B^+_c \rightarrow \mu^+ \mu^- \ell^+ \nu_\ell$.

CONCLUSIONS

1) **After applying of the signal selection cuts, the exclusive BG processes and the fake rates start to provide an essential contribution comparable to the combinatorial BG from $b\bar{b}(b\bar{b}b\bar{b}, b\bar{b}c\bar{c}) \to \mu\mu X$ processes.**

2) **The full detector simulation and reconstruction with misaligned geometry will be done for the fake BG from semileptonic $B^0_d \to \pi^- \mu^+ \nu_\mu$ decay, for four-leptonic nonresonant $B^+ \to \mu^+ \mu^- \ell^+ \nu_\ell$ and resonant $B^+_c \to (J/\psi \to \mu^+\mu^-)\, \mu^+ \nu_\mu$ decays.**

3) **All LHC experiments should collaborate in theoretically independent measurements of noncombinatorial BG!**