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Study of $B_s \to \mu^+\mu^-$ rare decay: Analysis improvements for the upper limit extraction

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Summary. — The $B_s^0 \to \mu^+\mu^-$ is a flavor changing neutral current process highly suppressed at Standard Model (SM) tree level but it can still occur by loops. Particles expected in beyond SM theory can give contributions which change the SM Branching Ratio ($\mathcal{BR}_{SM} = 3.23 \pm 0.27 \times 10^{-9}$ (Buras A. J., *Acta Phys. Pol. B*, **41** (2010) 2487)). The current value of the Upper Limit (UL) set by ATLAS Collaboration with an integrated luminosity of $2.4\,\text{fb}^{-1}$ collected at 7 TeV is $\mathcal{BR} < 2.2 \times 10^{-8}$ at 95% CL. In this study we present two improvements on UL procedure: SWAP technique and Unbinned Likelihood.

PACS 13.20.He – Decays of bottom mesons.
PACS 14.40.Nd – Bottom mesons.
PACS 14.60.Ef – Muons.

1. – Standard analysis

The analysis fulcrum is the comparison between expected background and signal events and observed ones. The numbers of signal events is $N_{\mu^+\mu^-} = \mathcal{L}\cdot\alpha\cdot\epsilon\cdot\sigma\cdot\mathcal{BR}_{\mu^+\mu^-}$ [1]. To reduce the uncertainties ($\mathcal{L}$ and σ), the $\mathcal{BR}$ can be rewritten using the reference channel $B^\pm \to J/\psi K^\pm \to \mu^+\mu^-$ as

$$(1)\qquad \mathcal{BR}(B_s^0 \to \mu^+\mu^-) = \mathcal{BR}(B^\pm \to J/\psi K^\pm \to \mu^+\mu^-)\frac{\alpha_{B^\pm}}{\alpha_{B\mu^+\mu^-}} \cdot \frac{\epsilon_{B^\pm}}{\epsilon_{B\mu^+\mu^-}} \cdot \frac{f_u}{f_s} \cdot \frac{1}{N_{B^\pm}} = \mathcal{SES}\, N_{\mu^+\mu^-},$$

where $\mathcal{SES}$, *Single Event Sensitivity*, is the $\mathcal{BR}$ that would give 1 observed event in the experiment. Analysis type is *blind*: mass invariant range is divided in three regions: Sidebands (SBs), Grey Areas (GAs) and Signal Region (SR); this last zone is blinded during the estimation of the expected background in SR through the events that fall in the SBs. After kinematic cuts [1], the events observed in SBs are divided in ODD and EVEN subsets. One used for cut optimization an BDT training, the other one for UL

TABLE I. – *Expected UL at 95% CL, in ODD, EVEN and SWAP case.*

Statistic $2.4\,\text{fb}^{-1}$	Expected UL 95% CL EVEN $\mathcal{BR}$ (10^{-8})	Expected UL 95% CL ODD $\mathcal{BR}$ (10^{-8})	Expected UL 95% CL SWAP $\mathcal{BR}$ (10^{-8})
×2	2.08	1.96	1.91
×10	0.85	0.93	0.82

TABLE II. – *ODD and EVEN Expected UL at 95% CL, for Unbinned and Counting Likelihood.*

Likelihood	Expected ODD UL 95% CL	Expected EVEN UL 95% CL
Counting	$\mathcal{BR} < 1.64 \times 10^{-8}$	$\mathcal{BR} < 2.54 \times 10^{-8}$
Unbinned	$\mathcal{BR} < 1.53 \times 10^{-8}$	$\mathcal{BR} < 2.19 \times 10^{-8}$

extraction. Finally the blind zone is opened, observed events are compared with the estimations and UL is extracted with CL_s method using a counting likelihood.

2. – Improvements

2·1. *SWAP Technique*. – The use of only half part of events avoids problems of bias in the analysis but increases the systematic uncertainties. To minimize these we have proposed the SWAP technique. The likelihood is rewritten as consisting in two weighted parts: a first for ODD events optimized on EVEN part, a second one for inverted case. The results obtained for the expected UL (number of event in SR and expected background one in SR are supposed equal) with simulation of two and ten times the integrated luminosity of $2.4\,\text{fb}^{-1}$ (corresponding to approximately full 2011 and 2011+2012 statistics), are shown in table I.

2·2. *Likelihood based on fit to mass shape: Unbinned Likelihood*. – The second stronger improvement is a change in the likelihood form, passing form a counting to an Unbinned Likelihood. PDFs chosen are a Gaussian centered on B_s mass value for signal and a first degree polynomial for background. The UL expected for $4.9\,\text{fb}^{-1}$ data sample is shown in table II where the improvement is evident.

REFERENCES

[1] ATLAS COLLABORATION, *Phys. Lett. B*, **713** (2012) 387.