PROCEEDINGS OF SCIENCE

Prospects for the measurement of $\sigma_H \times BR(H \rightarrow \mu\mu)$ at a 3-TeV muon collider

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The muon collider is one of the most attractive projects for the next generation colliders, capable of providing leptonic collisions at the energies of several TeV. The first study about the muon collider prospects for the measurement of the Higgs boson production cross section σ_H times the branching ratio for the Higgs boson decay to a pair of muons $BR(H \rightarrow \mu\mu)$ is presented. The analysis is performed considering a 3-TeV muon collider and assuming an integrated luminosity of 1 ab^{-1}. This study is performed with a full simulation of the muon collider detector. It is shown that the expected number of signal events in the di-muon system invariant mass range from 105 to 145 GeV is 25.8 ± 9.9. The sensitivity on the measurement of $\sigma_H \times BR(H \rightarrow \mu\mu)$ is estimated to be 38%.

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1. Introduction

The discovery of the Higgs boson at the Large Hadron Collider (LHC), in 2012 [1, 2], opened a new era of research in particle physics, aimed at measuring its properties. In particular, the measurement of the Higgs boson couplings provides a strong test of the Standard Model (SM) and an indirect probe to possible new physics scenarios. So far, only the couplings of the Higgs boson to the vector bosons and the third-generation fermions of the SM have been measured, which turned out to be in agreement with the prediction of the SM [3, 4]. On the other hand, the couplings to the first and second-generation fermions of the SM and the Higgs boson self-couplings, are still to be observed. In addition, all the searches for new physics carried out at the LHC to date suggest the absence of new physics signals at the TeV scale.

Whether it is to carry out precision measurements or to explore the new energy frontier in the multi-TeV energy range, hardly within the reaches of the LHC, the construction of a new collider will be required [5]. The muon collider, among the projects currently under study for the next generation of particle accelerators, represents a unique machine, which has the capability to provide leptonic collisions at energies of several TeV [6]. A multi-TeV muon collider will produce huge samples of Higgs bosons that will allow the determination of the Higgs boson properties with unprecedented precision, including its couplings to the lighter sectors of the SM and its trilinear and quartic self-couplings.

This work provides the first estimate of the muon collider reach on the measurement of the $H \to \mu\mu$ decay, one of the rarest Higgs boson decays that represents the gateway to the determination of the Higgs boson coupling to the second generation fermions.

2. Analysis strategy

This analysis is carried out considering a 3-TeV muon collider and assuming an integrated luminosity of 1 ab^{-1}. At a 3-TeV muon collider, the Higgs boson production is dominated by the WW-fusion, followed by the ZZ-fusion. Accordingly, the signal processes considered are the channels $\mu^+\mu^- \to H\nu_\mu\bar{\nu}_\mu$ ($H \to \mu^+\mu^-$) and $\mu^+\mu^- \to H\mu^+\mu^-$ ($H \to \mu^+\mu^-$). The backgrounds considered are the processes with the same final states as the signals, and also a background via $t\bar{t}$ pair production in the s-channel: $\mu^+\mu^- \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$, $\mu^+\mu^- \to \mu^+\mu^-\mu^+\mu^-$ and $\mu^+\mu^- \to t\bar{t} \to W^+W^-b\bar{b}$ ($W^\pm \to \mu^\pm\nu_\mu[\bar{\nu}_\mu]$). The signal and background samples are processed with a full simulation of the the muon collider detector and reconstructed using the Muon Collider Software [7].

A preselection is performed before the event classification. The event preselection has the purpose of identifying the events of interest as well as to suppress part of the low-energy background. The preselection requirements are provided in Table 1, and a stack of the distributions of the di-muon system invariant mass ($m_{\mu\mu}$) of the preselected events for the signal and background processes is shown in Figure 1.

The event classification is carried out using two multivariate classifiers based on a boosted decision tree (BDT). Each one of the two classifiers is trained independently to discriminate the signal against one of the two main backgrounds (i.e. the backgrounds from $\mu^+\mu^- \to \mu^+\mu^-\nu_\mu\bar{\nu}_\mu$ and $\mu^+\mu^- \to \mu^+\mu^-\mu^+\mu^-$). Then, the event selection is performed with the implementation of a double cut, which is applied to the classification scores obtained from the application of the classifiers

Preselection requirements
Two opposite-charge muons
$10° < \theta_\mu < 170°$
$105 < m_{\mu\mu} < 145$ GeV
$p_T(\mu^\pm) > 5$ GeV
$p_T(\mu^+\mu^-) > 30$ GeV
$p_T(\mu^+) + p_T(\mu^-) > 50$ GeV

Table 1: Summary of the preselection requirements, where θ is the polar angle and p_T the transverse momentum.

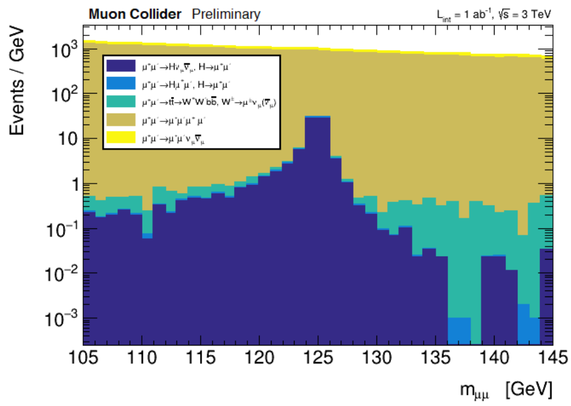

Figure 1: Stack of the distributions of $m_{\mu\mu}$ for the preselected signal and background events.

to the preselected events, in such a way as to select the events that are successfully discriminated against one of the two main backgrounds. The expected number of selected events is provided in Table 2, for each signal and background process, and the stack of the reconstructed $m_{\mu\mu}$ distributions of the selected events is shown in Figure 2. The total signal selection efficiency results to be $\epsilon_S = 0.2667 \pm 0.007$.

Process	Expected events with $105 < m_{\mu\mu} < 145$ GeV
$\mu^+\mu^- \to H\nu_\mu\bar{\nu}_\mu$, $H \to \mu^+\mu^-$	24.2
$\mu^+\mu^- \to H\mu^+\mu^-$, $H \to \mu^+\mu^-$	1.6
$\mu^+\mu^- \to \mu^+\mu^-\nu\bar{\nu}_\mu$	636.5
$\mu^+\mu^- \to \mu^+\mu^-\mu^+\mu^-$	476.4
$\mu^+\mu^- \to t\bar{t} \to W^+W^-b\bar{b}$, $W^\pm \to \mu^\pm\nu_\mu(\bar{\nu}_\mu)$	1.1

Table 2: Expected number of selected events in the invariant mass range from 105 to 145 GeV.

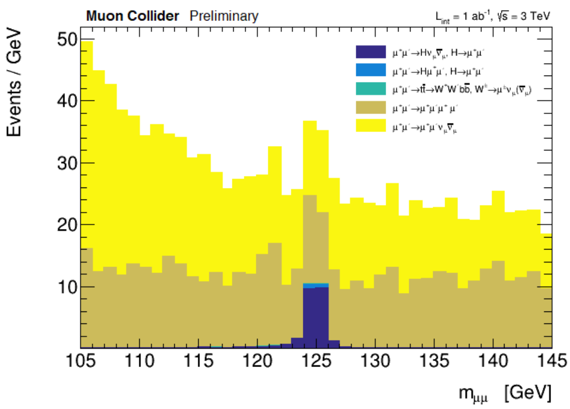

Figure 2: Stack of the $m_{\mu\mu}$ distributions for the selected signal and background events.

3. Results

The quantity $\sigma_H \times BR(H \to \mu\mu)$ is determined from:

$$\sigma_H \times BR(H \to \mu\mu) = \frac{N_S}{L_{int} \cdot \epsilon_S}, \tag{1}$$

where N_S is the number of signal events in the range $105 < m_{\mu\mu} < 145$ GeV, L_{int} the assumed integrated luminosity and ϵ_S the total signal selection efficiency. The uncertainty on $\sigma_H \times BR(H \to$

$\mu\mu$) is dominated by the statistical uncertainty on N_S, which is taken as an estimate of the sensitivity of the measurement. The number of signal events is extracted with an extended unbinned maximum likelihood fit to the $m_{\mu\mu}$ distribution with the function $f(m_{\mu\mu}) = N_S \cdot f_S(m_{\mu\mu}) + N_B \cdot f_B(m_{\mu\mu})$, where N_S and N_B are taken as the free parameters of the fit (N_B is the number of background events) and f_S and f_B are respectively the signal and background probability density functions, which are modeled in independent Monte Carlo samples. The statistical uncertainty on N_S, σ_{N_S}, is estimated as the root mean square (RMS) of the distribution of 10000 values of N_S that are extracted from the $m_{\mu\mu}$ distribution of 10000 simulated pseudo-experiments. As a result, for a 3-TeV muon collider, the expected number of signal events in the $m_{\mu\mu}$ range from 105 to 145 GeV is expected to be $\langle N_S \rangle = 25.8 \pm 9.9$ for a dataset corresponding to an integrated luminosity of 1 ab^{-1}. Accordingly, the relative uncertainty on N_S is estimated as

$$\frac{\sigma_{N_S}}{\langle N_S \rangle} = 38\% \tag{2}$$

and is taken as the estimate of the sensitivity on the measurement of $\sigma_H \times BR(H \to \mu\mu)$.

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