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Feasibility study on the search for $H \to ZZ^* \to 4\mu$ at a muon collider

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Summary. — Among the hadron and lepton colliders proposed for the future of HEP, a multi-TeV muon collider currently represents the best candidate to probe the Higgs boson properties and, possibly, search for new physics. In this paper, a feasibility study on the search for $H \to ZZ^* \to 4\mu$ at a muon collider is briefly exposed. Signal and Standard Model (SM) irreducible background processes are studied in two center-of-mass energy scenarios, 1.5 and 3 TeV, in order to present a first estimate of the sensitivity of the Higgs boson coupling to Z bosons achievable at this facility. The impact of the machine background (BIB), due to the decay of beam muons, is evaluated in the 1.5 TeV scenario. This work also provides an evaluation of the muon system reconstruction performance.

1. – Introduction

In the last years, several studies have been conducted in order to compare the potential of future colliders in accessing not yet measured properties of the Higgs boson, *i.e.*, its coupling to second generation fermions and self-coupling. A multi-TeV muon collider appears as the ideal machine, since it would reach higher cross sections than a hadron collider and, at the same time, it would lose less synchrotron radiation than an electron-positron facility [1, 2]. The design of the Muon Collider has been initiated by the U.S. Muon Accelerator Program (MAP) [3] and it is currently under study. The detector system is typical of a multi-purpose experiment, with some specific components, as two shielding nozzles covering the beam-pipe, with an aperture of 10°, introduced in order to suppress the Beam Induced Background (BIB). At a multi-TeV muon collider, the Higgs boson would be produced mainly through Vector Boson Fusion (VBF) [1]. However, it would be extremely complicated to measure the Higgs coupling to Z bosons (g_{HZZ}) in a process $\mu^+\mu^- \to H\mu^+\mu^-$, where the Higgs boson is produced through ZZ fusion. Indeed, the final state muons, which represent the experimental signature of such a process, would be emitted very forward, out of the acceptance region. Therefore, $H \to ZZ^*$ represents the favoured process to access the g_{HZZ} coupling.

The search for $H \to ZZ^* \to 4\mu$ at a muon collider is investigated in two scenarios: $\sqrt{s} = 1.5\,\text{TeV}$ and $\sqrt{s} = 3\,\text{TeV}$, which correspond, respectively, to the integrated luminosities of $L = 500\,\text{fb}^{-1}$ and $L = 1300\,\text{fb}^{-1}$. Signal and SM irreducible background MC samples, generated respectively with Pythia8 [4] and MadGraph [5], are fully simulated and reconstructed with the software ILCSoft [6]. The simulated signal process is $\mu^+\mu^- \to H\nu_\mu\overline{\nu_\mu} \to ZZ^*\nu_\mu\overline{\nu_\mu} \to 4\mu\nu_\mu\overline{\nu_\mu}$, where the Higgs boson is produced through WW fusion, a dominant mechanism at a multi-TeV muon collider. The SM background includes all the processes with four muons and two neutrinos in the final state: $\mu^+\ \mu^- \to 4\mu\ \nu_\mu\ \overline{\nu_\mu}$.

In the following sections, the most important aspects of the study are illustrated. First, the muon reconstruction performance is evaluated. A dedicated study on track reconstruction is carried out in order to estimate the impact of the BIB in the 1.5 TeV scenario. Then, a multivariate analysis (MVA) is performed in order to suppress the SM background in the signal region. The relative precision expected on the g_{HZZ} coupling in the 4μ channel is finally computed.

2. – Muon reconstruction

At the Muon Collider, muon reconstruction is performed with Pandora Particle Flow Algorithms (PandoraPFA) [7], which combine hits collected and clustered in the calorimeter and tracks reconstructed essentially by means of the Conformal Tracking [8] and the Kalman filter [9] in the tracking system. The whole study on muon reconstruction performance, exposed in this section, is conducted by analyzing the four final state muons of the signal MC samples. The muon reconstruction efficiency and the transverse momentum (p_T) resolution are shown respectively in fig. 1(left) and (right) as a function of p_T. In order to provide more specific information about the reconstruction performance in different regions of the detector, three ranges of the polar angle θ are considered: 10°–20°, 20°–50°, 50°–90°. The reconstruction performance, which results in general very high, is found slightly degraded in the very forward region (10°–20°), since it is characterized by a transition between the detector layers of the tracking system.

Previous results do not take into account the impact of the BIB on muon reconstruction, because of the high demanding computational resources needed for a full event

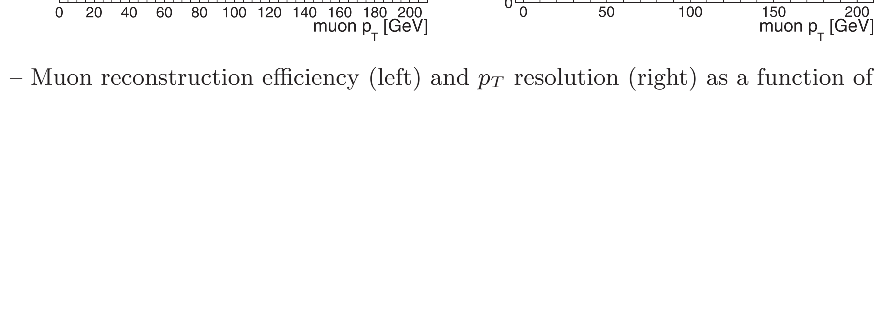

Fig. 1. – Muon reconstruction efficiency (left) and p_T resolution (right) as a function of p_T.

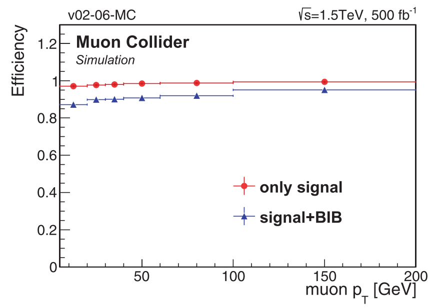

Fig. 2. – Track reconstruction efficiency *vs.* p_T, with and without the BIB overlay.

reconstruction with the overlay. However, a shortcut is used in order to evaluate a preliminary effect of the BIB on track reconstruction, which is the most affected step of the reconstruction chain. The result of this study is shown in fig. 2, where the track reconstruction efficiencies evaluated with and without the BIB overlay are compared.

3. – Analysis strategy and final results

The analysis strategy developed for this study is inspired to the search for $H \to ZZ^* \to 4l$ performed by the CMS collaboration [10] at LHC. Only events containing at least four good-quality final state muons with suitable electric charge are selected. In each of these events, two non overlapping Z candidates are built, sorted so that Z_1 corresponds to the muon pair with an invariant mass closest to the nominal value of the Z boson mass. ZZ candidates are then selected as explained in [11]. The mass distributions of the reconstructed Z_1 and Z_2 candidates are shown respectively in fig. 3 (left) and (right) for signal and SM background.

The Higgs candidate is reconstructed as the combination of the two selected Z candidates. An MVA analysis, based on angular distributions of the decay products of the Higgs boson, is carried out in order to discriminate the signal from its irreducible SM background. Figure 4 shows the Higgs candidate mass distribution, obtained at the end of the whole selection, for signal and SM background. The relative precision expected on the g_{HZZ} coupling is estimated, along with a projection of the effect of the BIB in the 1.5 TeV scenario. The g_{HZZ} coupling is expected to be measured with a relative precision

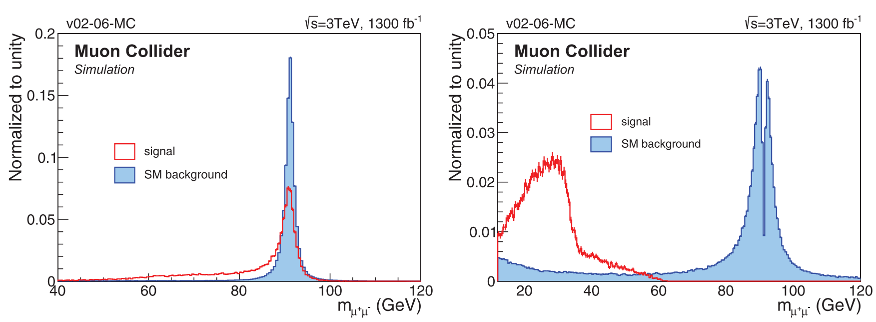

Fig. 3. – Z_1 (left) and Z_2 (right) mass distribution.

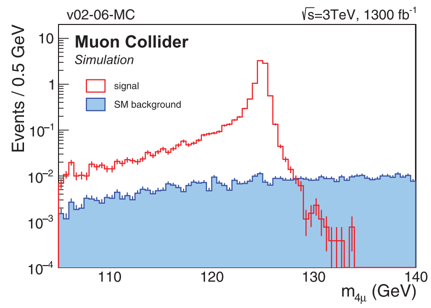

Fig. 4. – Higgs boson mass distribution normalized to cross section, luminosity and number of generated events.

of 30% in the 1.5 TeV scenario, which worsens up to the 36% if the BIB is considered. Better precision could be achieved for a muon collider operating at $\sqrt{s} = 3$ TeV. In this case, the g_{HZZ} coupling would be measured in the 4μ channel with a 16% precision. An overall factor 2 improvement on the relative precision is expected if 4l (l = e, μ) decay channel is considered.

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