Study of Higgs couplings measurements at muon collider

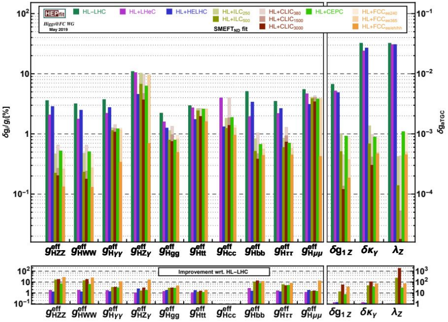
Laura Buonincontri (Università degli studi di Padova)

P. Andreetto, N. Bartosik, A. Bertolin, L. Sestini, M. Casarsa, F. Collamati, C. Curatolo, A. Ferrari, A. Ferrari, A. Gianelle, A. Mereghetti, N. Mokhov, M.Palmer, N. Pastrone, C. Riccardi, P. Sala, I. Vai

On behalf of the International Muon Collider Collaboration

106° Congresso Nazionale - Società Italiana di Fisica
14-18 Settembre 2020

Results performed so far on Higgs couplings to SM particles are in agreement with the SM predictions.



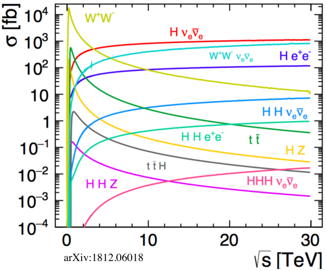
- One of the goal of future colliders is the measurement of Higgs couplings with SM particles with precision below the 1% precision scale.
- This would allow to reveal possible deviations from the SM.
- Muon Collider reaches not in table yet. Recent phenomenological study: sensitivity on $H \to WW$ coupling 0.073% (0.023%) and on $H \to ZZ$ 0.61% (0.21 %) for $\sqrt{s}$=10 TeV (30 TeV) and L=10 ab^{-1} (90 ab^{-1}). (see arXiv:2008.12204v1)

Higgs potential

After the electroweak symmetry breaking:

$$V = \frac{1}{2} m_h^2 h^2 + \lambda_3 v h^3 + \frac{\lambda_4}{4} h^4 \qquad \lambda_3^{SM} = \lambda_4^{SM} = \frac{m_H^2}{2v^2}$$

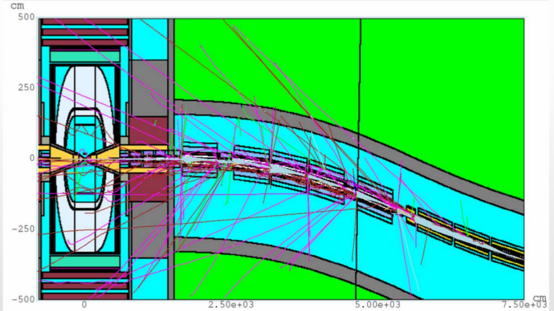
- $m_H = 125.10 \pm 0.14$ GeV;
- λ_3 and λ_4 never been measured so far.
- CLIC with 5 ab^{-1} at $\sqrt{s} = 3$ TeV can measure λ_3 with an uncertainty of -7% and +11% using HH events (arXiv:1901.05897v2).
- Sensitivity of FCC-hh to the measurement of λ_4 using HHH events, after full operations: -2 $< \lambda_4/\lambda_4^{SM} <$ +13 at 68% CL (arXiv:1909.09166).



- Muon collider is the ideal machine to study Higgs physics: high yields of single H, HH and HHH events are produced.
- Phenomenological studies: sensitivity of MC at 10 ab^{-1} and $\sqrt{s}$=10 TeV to the measurement of λ_3: 5.6%.
- Sensitivity of MC at 14 TeV with 33 ab^{-1} to the measurement of λ_4: 50%.
- In this presentation: study of the process $\mu^+\mu^- \to HH\nu\bar{\nu} \to b\bar{b}b\bar{b}\nu\bar{\nu}$ and evaluation of the sensitivity on its cross section

Detector challenges

In phenomenological studies detector performance is not taken into account. At a Muon Collider can be strongly limited by the Beam-Induced Background (BIB) if no mitigation strategies are applied.



- electrons, positrons and neutrinos from muons decay
- interactions with the machine and machine detector interface (MDI) can produce secondary particles (photons, neutrons or hadrons)
- First proposal to reduce the BIB at the detector: two tungsten cone-shaped nozzles
- From studies of beam-induced background at $\sqrt{s}$=1.5 TeV: photons (94%) and neutrons (4%), followed by electrons/positrons, charged hadrons and muons

Detector description

The effects of the beam-induced background on detector components have been studied with a full simulation.

Hadronic calorimeter (HCAL)
19 mm Fe absorber + scintillator (x 60)

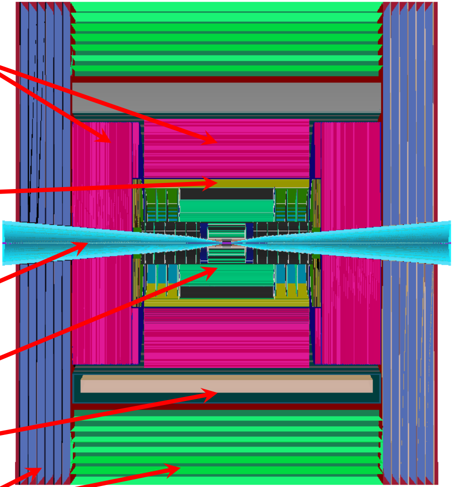
Electromagnetic calorimeter (ECAL)
1.9 mm W absorber + Si sensor x 40

Nozzles Optimized for $\sqrt{s}$=1.5 TeV

Tracker System

Superconducting solenoid (4T)

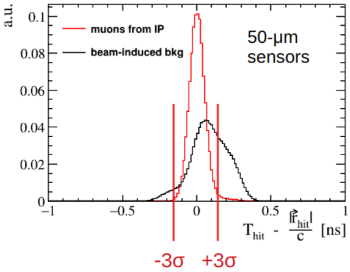
Muon Chambers

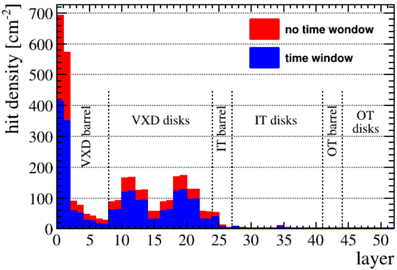


BIB reduction on detector components

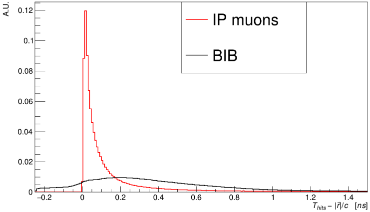
Tracker: large number of hits released by the beam-induced background particles in the innermost layers of the tracking system and vertex detector.

- Background particles have an arrival time distribution different from the signal.
- In this analysis: a time cut of 50 ps (100 ps) is assumed according to the thickness of sensors.





Calorimeter:

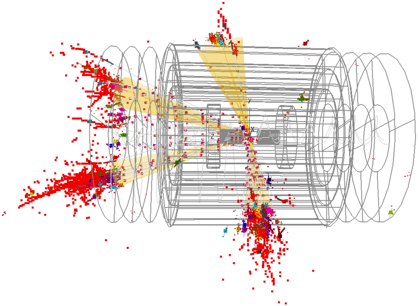


Double Higgs analysis

- The main effect of the BIB is to produce fake secondary vertices that leads to mis-tag. b-tagging efficiency in presence of the beam-induced background of the order of 60% with a mis-tag $< 1\%$ at 1.5 TeV (see 2020 JINST 15 P05001)
- b-tagging efficiencies are used for the 3 TeV analysis (conservative assumption)

The only relevant physics background considered is the inclusive $\mu^+\mu^- \rightarrow b\bar{b}b\bar{b}\nu\bar{\nu}$:

- one jet for each pair is required to be tagged: processes with jets in the final states different from the b quark are negligible; other physics background processes having b jets in final state have very low cross section



Signal and backgrounds are generated with WHIZARD.

- Event selection: N_{jets}>3 and minimum transverse momentum $p_T > 20$ GeV
- Jets paired by minimizing:

$$\sqrt{(m_{ij} - m_H)^2 + (m_{kl} - m_H)^2}$$

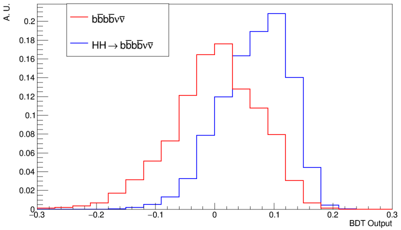
- Selection of the kinematic variables used to distinguish the signal and the physics background (m_{H_1},m_{H_2}, $\sum E_{jets}$, $\sum \vec{P}_T$, θ_{max})

Evaluation of the cross section uncertainty

- These variables are used to classify processes by using a Multivariate Analysis technique (Boosted Decision Tree)
- The sensitivity on the cross section is calculated by counting the number of signal and background events surviving preliminary cuts for different cuts on the output of the BDT:

$$\frac{\Delta\sigma}{\sigma} = \frac{\sqrt{S+B}}{S} \quad with \quad S = \sigma_{HH} \cdot BR(H \to b\bar{b})^2 \cdot L \cdot \epsilon_S \quad and \quad B = \sigma_{b\bar{b}b\bar{b}\nu\bar{\nu}} \cdot L \cdot \epsilon_B$$

- σ_{HH} double Higgs cross section, $\sigma_{b\bar{b}b\bar{b}\nu\bar{\nu}}$ is the $\mu^+\mu^- \to b\bar{b}b\bar{b}\nu\bar{\nu}$ cross section
- ϵ_S and ϵ_B are the selection efficiencies
- $L = 1.3\ ab^{-1}$ corresponds to four years of data taking at $\sqrt{s}$= 3 TeV



BDT_{Cut}	S	B	Significance	$\frac{\Delta\sigma}{\sigma}$
-0.06	67	618	2.52	0.40
-0.03	64	528	2.62	0.38
0	59	405	2.74	0.37
0.03	51	273	2.84	0.35
0.06	41	178	2.74	0.36
0.09	28	93	2.52	0.40
0.12	13	30	2.01	0.50

Conclusions and perspectives

- The Muon Collider is the dream machine for Higgs Physics
- With conservative assumptions we can already obtain good results on the uncertainty of the double Higgs cross section
- A lot of improvements can be obtained by performing a fit on the BDT, trying different classification variables and multivariate methods
- Full simulation studies to determine the Muon Collider Physics reach are ongoing (detector design and optimization, simulation of beam-induced background at $\sqrt{s}$=3 TeV,..)