Search for $H \to ZZ^* \to 4\mu$ at a Multi-TeV Muon Collider

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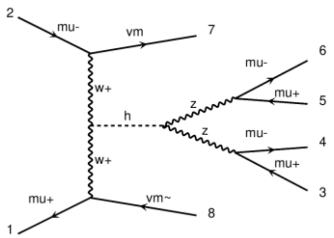
MUON COLLIDER:

Ideal machine to reach very high center-of-mass energies and luminosities by colliding elementary particles.

- **Potential:** probe the Higgs boson properties with a never reached precision.
- **Challenge:** mitigate the intense Beam Induced Background (BIB).

Feasibility study of the search for $H \to ZZ^* \to 4\mu$ at a **1.5** and **3-TeV** muon collider.

Higgs boson produced through WW fusion, dominant production process at a multi-TeV muon collider.

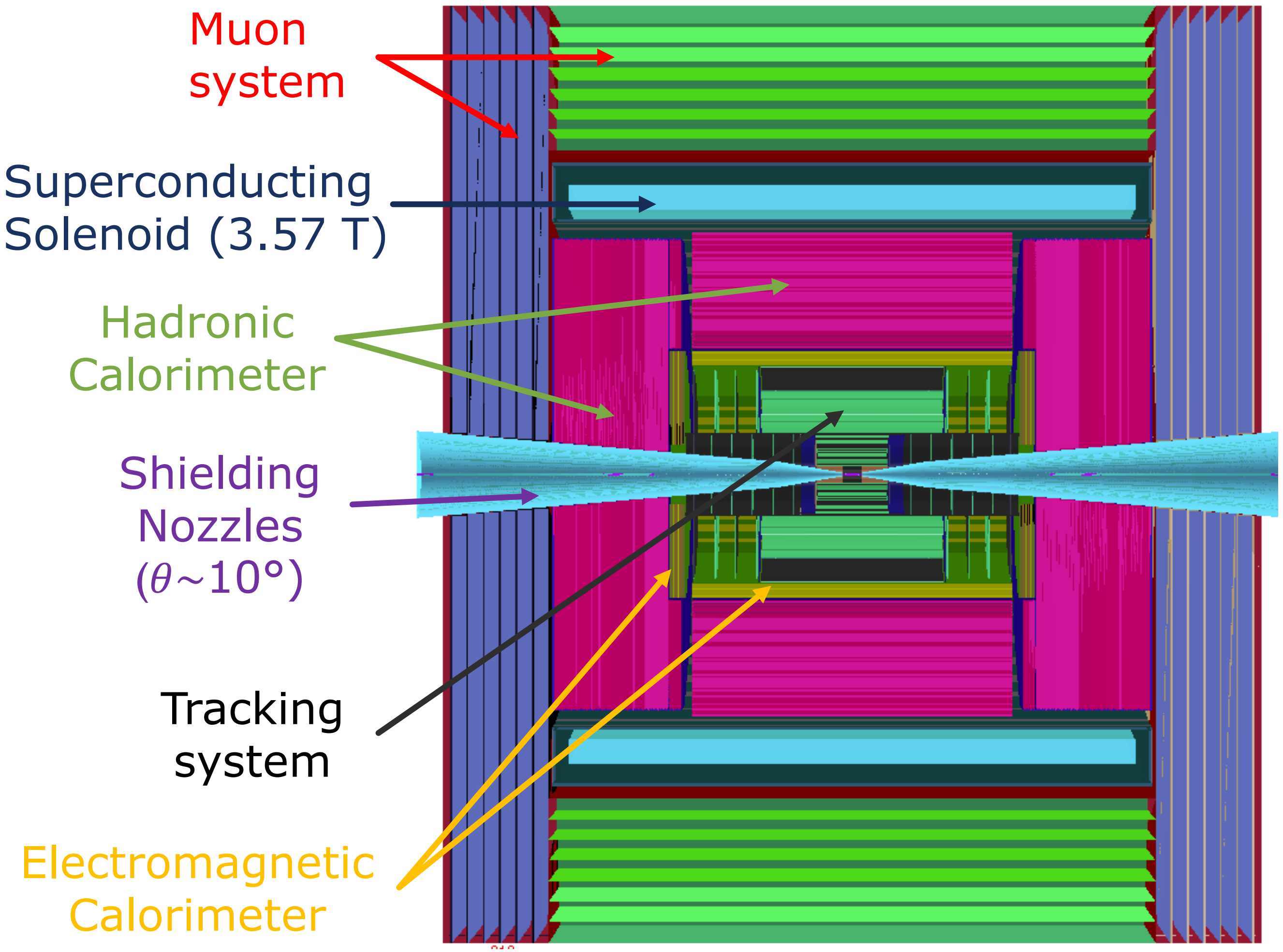


Goals:

- evaluate muon reconstruction performance;
- estimate the uncertainty on the Higgs boson coupling to Z bosons, in the specific channel $Z \to \mu^+\mu^-$.

Signal and SM irreducible background processes are simulated with ILCSoft, without the BIB overlayed (computationally high demanding).

DETECTOR



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MUON RECONSTRUCTION

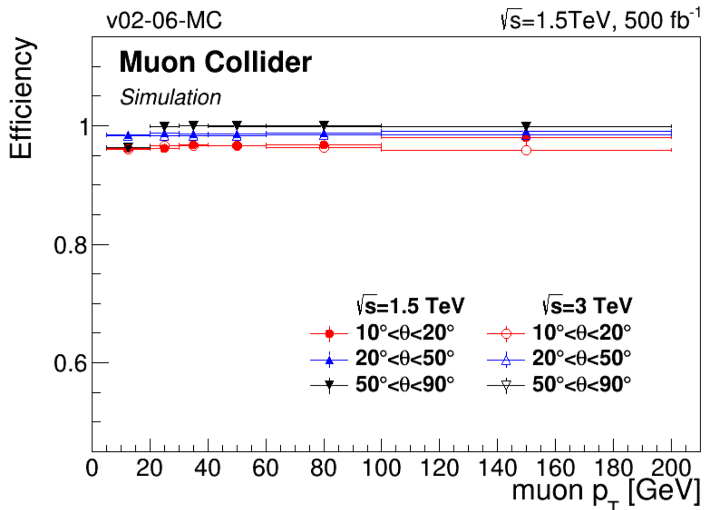
TRACK RECONSTRUCTION (only in the tracking system)

1. Conformal tracking: pattern recognition based on conformal mapping and cellular automata.
2. Kalman Filter for track fitting.

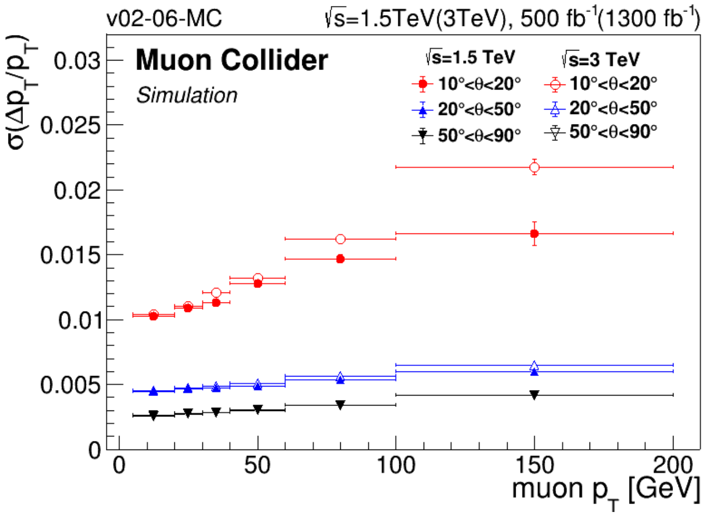
MUON RECONSTRUCTION with PandoraPFA

1. Inward projection: hits in the muon system clustered and matched with well reconstructed tracks.
2. Outward projection:
   - applied to all particles
   - Only hits in the calorimeter

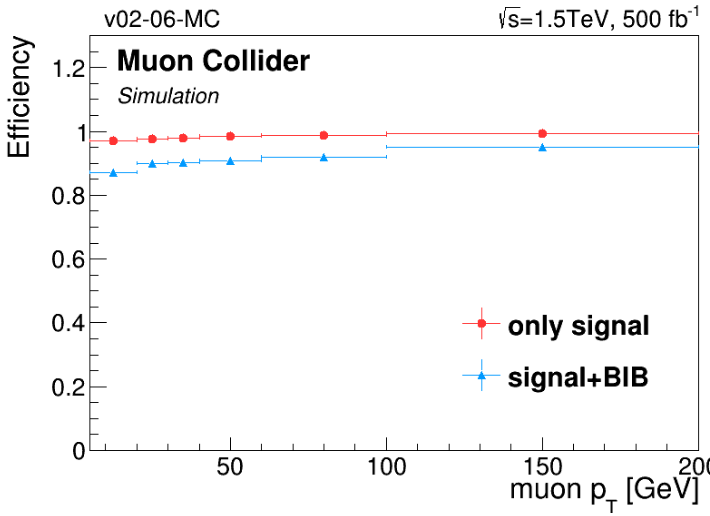
Muon reconstruction efficiency



Transverse momentum (p_T) resolution vs p_T



Impact of the **BIB** on **track reconstruction**



Shortcut for track reconstruction with BIB: consider only hits in narrow cones around simulated muons.

Impact of the BIB on final results: the number of reconstructed muons is scaled, according to the p_T, to the ratio between the track reconstruction efficiency evaluated with BIB overlay and the one evaluated without including it.

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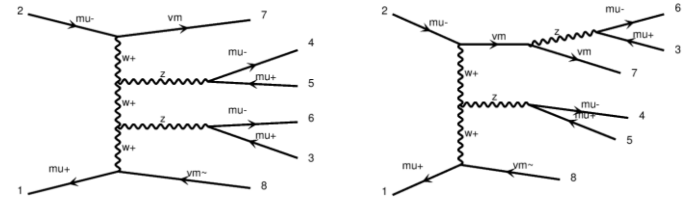
ANALYSIS STRATEGY (inspired to CMS) → Discriminate signal from Standard Model (SM) irreducible background

SM background : $\mu^+\mu^- \to 4\mu\,\overline{\nu_\mu}\,\nu_\mu$

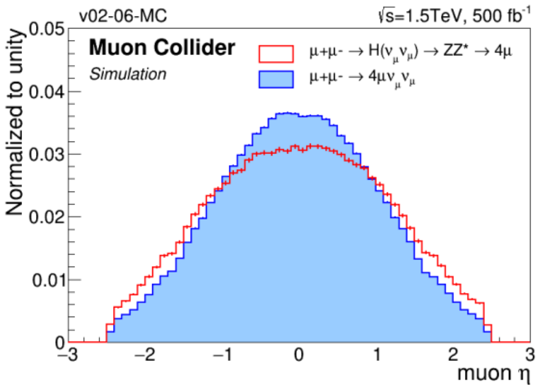


Optimized generation of signal-like events

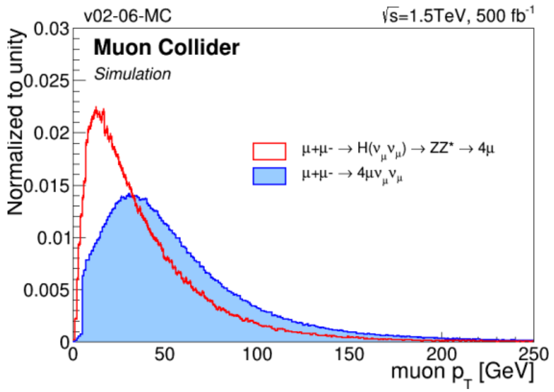
1. Selection of events with at least 4 well reconstructed muons ($p_T > 5$ GeV, $|\eta| < 2.5$, $D_0 < 2\,mm$, $Z_0 < 10\,mm$ *)
2. Selection of events with at least one ZZ candidate:
   - Z candidates: opposite charge muon pairs with $12 < m_{\mu^+\mu^-} < 120$ GeV
   - ZZ candidates: non-overlapping Z candidates
     Z_1: Z candidate with reconstructed mass closest to the nominal value
     Z_2: other Z candidate
     ZZ candidates are required to satisfy:
     - $\Delta R > 0.02\ \mu_i - \mu_j$
     - $p_{T,\mu_i} > 20$ GeV, $p_{T,\mu_j} > 10$ GeV
     - Z_1 mass > 40 GeV
     - $m_{4\mu} > 70$ GeV

   More than one ZZ candidate per event → the one with the Z_1 mass closest to the nominal value is chosen.

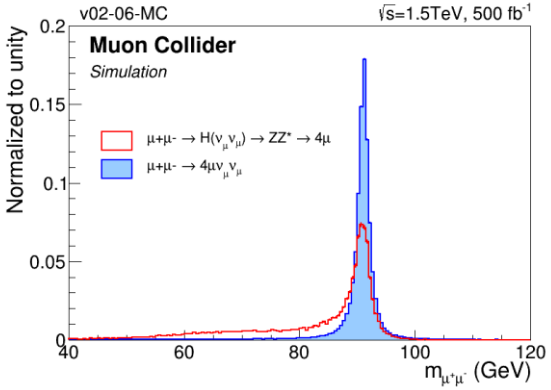
Muon pseudorapidity (η)



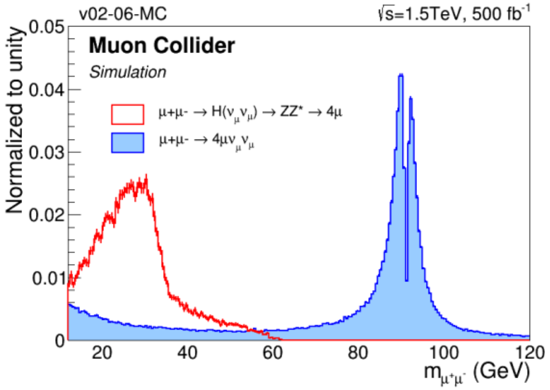
Muon p_T



Z_1 mass



Z_2 mass



*D_0 (Z_0) : transversal (longitudinal) impact parameter.

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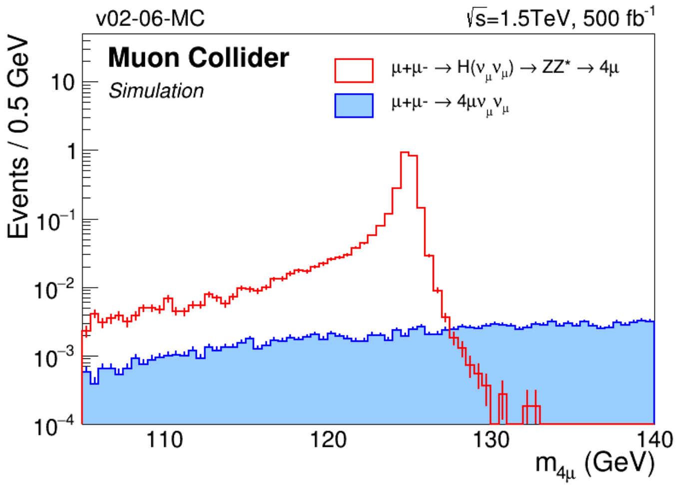
RESULTS

The number of events is scaled to cross section (σ), integrated luminosity (L) and number of generated events.

	$\sqrt{s} = 1.5$ TeV, L=500 fb^{-1}				$\sqrt{s} = 3$ TeV, L=1300 fb^{-1}			
	Signal $\sigma = 9.136 \cdot 10^{-3}$ fb		SM background $\sigma = 9.175 \cdot 10^{-3}$ fb		Signal $\sigma = 1.474 \cdot 10^{-2}$ fb		SM background $\sigma = 1.785 \cdot 10^{-2}$ fb	
	Events	Efficiency (%)	Events	Efficiency (%)	Events	Efficiency (%)	Events	Efficiency (%)
Selected	2.97±0.02	65.1±0.2	3.93±0.01	85.7±0.1	10.77±0.06	56.2±0.2	18.57±0.05	80.0±0.1
Higgs mass range [105,140] GeV	2.90±0.02	63.4±0.2	0.14±0.01	3.0±0.1	10.49±0.06	54.8±0.2	0.50±0.01	2.2±0.1
Scaled (BIB impact)	2.05±0.01	44.9±0.2	0.09±0.01	2.1±0.1	–	–	–	–

Higgs reconstructed mass



FINAL RESULTS

	$\sqrt{s} = 1.5$ TeV, L=500 fb^{-1}		$\sqrt{s} = 3$ TeV, L=1300 fb^{-1}	
	Significance	$\frac{\Delta g_{HZZ}}{g_{HZZ}}$ (%)	Significance	$\frac{\Delta g_{HZZ}}{g_{HZZ}}$ (%)
No BIB	3.61	**30.09**	6.85	**15.83**
BIB	3.08	35.75	–	–

Future perspectives:

- Include the $4e$ and $2e2\mu$ decay channels → improve the sensitivity to the HZZ coupling by a factor ~2.
- Study $\boldsymbol{H \to ZZ^* \to qqll}$.
- Measure the expected sensitivity in ZZ fusion process: $\mu^+ \mu^- \to H \mu^+ \mu^-$.
  Scattered muons difficult to detect →very challenging process to investigate
  proposed approach: extract the uncertainty on HZZ and HWW couplings from a two-bin likelihood fit of k_Z and k_W.

CONCLUSIONS:

- The study of the four final state muons allows to evaluate the muon reconstruction performance.
- The uncertainty on the HZZ coupling expected at a multi-TeV muon collider is measured for the first time in the channel $\boldsymbol{H \to ZZ^* \to 4\mu}$.