Search for $H \rightarrow ZZ^* \rightarrow 4\mu$ at a Multi-TeV Muon Collider
ANGELA ZAZA (University of Bari and INFN)

**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 $H \rightarrow ZZ^* \rightarrow 4\mu$ 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 $Z \rightarrow \mu^+\mu^-$.

Signal and SM irreducible background processes are simulated with ILCSoft, without the BIB overlayed (computationally high demanding).
Search for $H \rightarrow ZZ^* \rightarrow 4\mu$ at a Multi-TeV Muon Collider

**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

**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.

ANGELA ZAZA (UNIVERSITY OF BARI AND INFN)
Search for $H \rightarrow ZZ^* \rightarrow 4\mu$ at a Multi-TeV Muon Collider

**ANALYSIS STRATEGY** → Discriminate signal from Standard Model (SM) irreducible background

**SM background**: $\mu^+\mu^- \rightarrow 4\mu \overline{\nu}\nu$

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.

---

*a* $D_0 (Z_0)$: transversal (longitudinal) impact parameter.
Search for $H \rightarrow ZZ^* \rightarrow 4\mu$ at a Multi-TeV Muon Collider

**RESULTS**

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

<table>
<thead>
<tr>
<th>$\sqrt{s} = 1.5$ TeV, L=500 fb$^{-1}$</th>
<th>$\sqrt{s} = 3$ TeV, L=1300 fb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal</strong> $\sigma = 9.136 \cdot 10^{-3}$ fb</td>
<td><strong>Signal</strong> $\sigma = 1.474 \cdot 10^{-2}$ fb</td>
</tr>
<tr>
<td><strong>SM background</strong> $\sigma = 9.175 \cdot 10^{-3}$ fb</td>
<td><strong>SM background</strong> $\sigma = 1.785 \cdot 10^{-2}$ fb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Events</th>
<th>Efficiency (%)</th>
<th>Events</th>
<th>Efficiency (%)</th>
<th>Events</th>
<th>Efficiency (%)</th>
<th>Events</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected</td>
<td>2.97±0.02</td>
<td>65.1±0.2</td>
<td>3.93±0.01</td>
<td>85.7±0.1</td>
<td>10.77±0.06</td>
<td>56.2±0.2</td>
<td>18.57±0.05</td>
</tr>
<tr>
<td>Higgs mass range [105,140] GeV</td>
<td>2.90±0.02</td>
<td>63.4±0.2</td>
<td>0.14±0.01</td>
<td>3.0±0.1</td>
<td>10.49±0.06</td>
<td>54.8±0.2</td>
<td>0.50±0.01</td>
</tr>
<tr>
<td>Scaled (BIB impact)</td>
<td>2.05±0.01</td>
<td>44.9±0.2</td>
<td>0.09±0.01</td>
<td>2.1±0.1</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**Future perspectives:**

- Include the $4e$ and $2e2\mu$ decay channels → improve the sensitivity to the HZZ coupling by a factor ~2.
- Study $H \rightarrow ZZ^* \rightarrow qql\ell$.
- Measure the expected sensitivity in ZZ fusion process: $\mu^+ \mu^- \rightarrow H \mu^+ \mu^-$. 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 $H \rightarrow ZZ^* \rightarrow 4\mu$.