HH $\rightarrow$ bbZZ(4$\ell$) for FCC-hh studies

E. Fontanesi
L. Borgonovi, S. Braibant
University & INFN Bologna

FCC-hh physics analysis meeting
Thursday, 29 November 2018
OUTLINE

MC samples

Event selection

Signal strength

$\lambda$ studies
Signal events were generated for several values of $k_{\lambda}$ in the range [-1, 3] in step of 0.5.

- The **ttZZ background** is negligible.
- The contribution of the $4\ell +\text{jets}$ ($ZZ^*, Z^*Z^*, ZZ$) continuum was evaluated using a $\ell\ell\ell\ell\ell\ell$ ($\ell = e, \mu$) sample, generated with the $4\ell$ invariant mass in the range [100, 150] GeV and only heavy flavour partons (b/c). It is found to be negligible.
**Event selection**

**4ℓ analysis + 2 b-jet request**
- $|\eta| < 4$ & $p_T > 5$ (7) & iso < 0.7 GeV to identify a good muon (electron)

- $N(\ell) \geq 4$
- $N(\ell^+\ell^- \text{ pairs}) \geq 2$
- $M_{Z1} = [40, 120]$ GeV
- $M_{Z2} = [12, 120]$ GeV
- $N(\text{isolated } \ell') = 4$
- $p_T$ cuts on two $\ell$
- $M_{4\ell} = [120, 130]$ GeV
- $N(b\text{-jet}) = 2$
- $M_{bb} = [80, 130]$ GeV
- $\Delta R(bb) < 2$

![Graph showing the selection efficiency](image)

**FCC-hh Simulation (Delphes)**
- $\sqrt{s} = 100$ TeV
- $L = 30$ $ab^{-1}$

Selection efficiency ~15%
The invariant mass spectrum of the selected $4\ell$ was normalized to an integrated luminosity of $30 \text{ ab}^{-1}$:

<table>
<thead>
<tr>
<th>Process</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>HH</td>
<td>489</td>
</tr>
<tr>
<td>ttH</td>
<td>1162</td>
</tr>
<tr>
<td>$bb+gg(H)$</td>
<td>317</td>
</tr>
<tr>
<td>ZH</td>
<td>52</td>
</tr>
<tr>
<td>ttZ</td>
<td>179</td>
</tr>
</tbody>
</table>

The flat contribution of the $ttZ$ background has been added wrt the last version of the CDR.
COMBINE tool was used to perform the statistical analysis.

Three different scenarios for three different assumptions on the systematic uncertainties were considered: 
no systematics, 1%, 3%.

Expected precision on the signal strength $r$:

<table>
<thead>
<tr>
<th></th>
<th>No syst.</th>
<th>1%</th>
<th>3%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1\sigma$ (68% CL)</td>
<td>10%</td>
<td>11%</td>
<td>17%</td>
</tr>
<tr>
<td>$2\sigma$ (95% CL)</td>
<td>19%</td>
<td>21%</td>
<td>34%</td>
</tr>
<tr>
<td>Significance @95%CL[$\sigma$]</td>
<td>11.32</td>
<td>10.39</td>
<td>6.86</td>
</tr>
</tbody>
</table>
To estimate the sensitivity on $k_\lambda$, nine signal samples for different $k_\lambda$ values were generated:

-1, -0.5, 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0

Cross section from: https://github.com/FCC-hh-framework/EventProducer/blob/master/config/param_FCC.py#L772-L796

Approach to model anomalous $k_\lambda$ signals in COMBINE (counting experiment, $k_\lambda$ is a POI): yield parametrized vs $k_\lambda$ with quadratic function by fitting various $k_\lambda$ samples after the full selection.
Three different scenarios for three different assumptions on the systematic uncertainties were considered: 

- **no systematics**, 1%, 3%.

Expected precision on the self-coupling modifier $k_\lambda$:

<table>
<thead>
<tr>
<th></th>
<th>No syst.</th>
<th>1%</th>
<th>3%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1σ</td>
<td>14%</td>
<td>15%</td>
<td>24%</td>
</tr>
<tr>
<td>2σ</td>
<td>28%</td>
<td>31%</td>
<td>51%</td>
</tr>
</tbody>
</table>
Assuming a different detector configuration, for example a larger tracker and/or higher magnetic field and consequently a different request on the $p_T$ of muons and electrons, $p_T > 10$ GeV, the precision on the signal strength is not significantly affected.
Assuming a different detector configuration, for example a larger tracker and/or higher magnetic field and consequently a different request on the $p_T$ of muons and electrons, $p_T > 10$ GeV, the precision on the signal strength is not significantly affected.
A complete study of the $bbZZ(4\ell)$ channel in all the possible final states ($4\mu$, $4e$, $2e2\mu$, $4\ell$) has been performed.

The expected precision on the signal strength $r$ and on the Higgs self-coupling modifier $k_\lambda$ without systematics at 68% CL is:

\[ \delta r(\text{stat}) \approx 10\% \quad \delta k_\lambda(\text{stat}) \approx 14\% \]

The precision on $r$ and $k_\lambda$ is not significantly affected by varying the detector configuration as considered in this study.

Plots for the CDR - The four lepton invariant mass (without the inclusion of the ttZ background) and the negative log-likelihood on $k_\lambda$ in the $4\ell$ final state (also for two different detector assumptions) were included in the CDR as most relevant results.

An analysis note to include all the documentation and results will be completed before Christmas.