H→γγ update @ 3 TeV

• AWG, 27 January 2020
Motivation for update

- 5000 pseudo-experiments have been performed with 5 ab^{-1} of data
- ... in order to simulate experimental determination of \( \sigma \times \text{BR}(H \rightarrow \gamma\gamma) \)
- ... motivated by paper publication
Old BDTG performance

- Best significance for BDTG > 0.68 → 7.9 % relative statistical uncertainty
- BDTG efficiency: 54%
- Total signal efficiency (BDTG + preselection): 38%
- Signal events remaining after preselection and MVA: 1790/5ab⁻¹
New BDTG performance

- di-photon invariant mass is excluded from MVA (to be fitted with PDFs)
- Best significance for BDTG > 0.32
- BDTG efficiency: 62%
- Total signal efficiency (BDTG + preselection): 42%
- Signal events remaining after preselection and MVA: 2060/5ab⁻¹
Higgs invariant mass distributions after preselection and MVA

\[ \delta \left( \sigma(H\nu\nu) \times BR(H\rightarrow\gamma\gamma) \right) = \frac{1/S}{N_s + N_B} = 12.1\% \]

<table>
<thead>
<tr>
<th>Results after MVA selection</th>
<th>5 ab(^{-1})</th>
<th>Signal Events</th>
<th>Background events</th>
<th>( \delta \left( \sigma(H\nu\nu) \times BR(H\gamma\gamma) \right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without polarization</td>
<td>2 062</td>
<td>60 327</td>
<td>12.1%</td>
<td></td>
</tr>
<tr>
<td>With polarization</td>
<td>3 052</td>
<td>80 284</td>
<td>9.5%</td>
<td></td>
</tr>
</tbody>
</table>

Polarization (new baseline) is conservatively taken to increase both signal and background cross-sections by a factor of 1.48. It improves statistical precision to 9.5%.  

5
Toy MC

- In order to estimate the statistical uncertainty, 5000 Toy Monte-Carlo experiments with 5ab⁻¹ of data were performed.
- Pseudo-data were obtained by randomly picking signal \( m_{\gamma\gamma} \) values from the fully simulated signal sample, while background \( m_{\gamma\gamma} \) values were randomly generated from the background PDF

\[
f(m_{\gamma\gamma}) = N_s \cdot f_s(m_{\gamma\gamma}) + N_b \cdot f_b(m_{\gamma\gamma})
\]
Signal Fit

Signal is fitted with two Gaussians \( f_{\text{flat}}, f_{\text{exp}} \):

\[
f_s = C \cdot f_{\text{exp}} + f_{\text{flat}}
\]

\[
f_{\text{flat}} \begin{cases} 
\exp \left( -\frac{(m_{YY}-m_H)^2}{2\sigma^2+\beta_L(m_{YY}-m_H)} \right) & m_{YY}<m_H \\
\exp \left( -\frac{(m_{YY}-m_H)^2}{2\sigma^2+\beta_R(m_{YY}-m_H)} \right) & m_{YY}>m_H
\end{cases}
\]

\[
f_{\text{exp}} \begin{cases} 
\exp \left( -\frac{(m_{YY}-m_H)^2}{2\sigma^2+\alpha_L|m_{YY}-m_H|} \right) & m_{YY}<m_H \\
\exp \left( -\frac{(m_{YY}-m_H)^2}{2\sigma^2+\alpha_R|m_{YY}-m_H|} \right) & m_{YY}>m_H
\end{cases}
\]
Background Fit

Function for background fit is combination of linear and exponential part:

\[ f_b = p_0 \cdot (p_1 e^{p_2 \cdot (m - m_H)} + (1 - p_1)) \]

\[ p_0 = 768 \pm 4.5 \]
\[ p_1 = 115 \pm 15 \]
\[ p_2 = 0.000158 \pm 0.000014 \]
Example of a pseudo-experiment

Distribution of the invariant mass, for the sum of the signal and background samples in one Toy MC experiment, together with the fit of the combined PDF model.
Pull distribution

- 1.4 TeV results by C. Greffe
- Estimates of statistical significance (green) include di-photon invariant mass $m_{\gamma\gamma}$ as a sensitive observable
- $m_{\gamma\gamma}$ is excluded in pseudo-experiments

<table>
<thead>
<tr>
<th></th>
<th>1.4 TeV CLIC 1.5 ab$^{-1}$/2ab$^{-1}$</th>
<th>1.4 TeV CLIC 1.5 ab$^{-1}$/2ab$^{-1}$ (50 Toy MC)</th>
<th>3 TeV CLIC 5 ab$^{-1}$</th>
<th>3 TeV CLIC 5 ab$^{-1}$ (5000 Toy MC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_s$</td>
<td>40 %</td>
<td>53.3 %</td>
<td>38 %</td>
<td>43.4 %</td>
</tr>
<tr>
<td>$\delta (\sigma \times BR)_{\text{unpolarized}}$</td>
<td>15%/13%</td>
<td>23 %/ 20 %</td>
<td>7.9 %</td>
<td>1.7 %</td>
</tr>
<tr>
<td>$\delta (\sigma \times BR)_{\text{polarized}}$</td>
<td>12.3%/10.7%</td>
<td>18.9 %/ 15.5%</td>
<td>6.5 %</td>
<td>1.4 %</td>
</tr>
</tbody>
</table>
List of systematic uncertainties – will be revised

- Taken from my presentation at ALPS19
- Integral luminosity uncertainty \( (10^{-3}) \rightarrow \) negligible
- Uncertainty of the luminosity spectrum (0.15%)
- *Relative uncertainty of the electron beam polarization (0.2%)*
- Uncertainty of the photon identification efficiency (1%)
- Photon energy resolution uncertainty (2% relative uncertainty of the sampling term) \( \rightarrow \) negligible

<table>
<thead>
<tr>
<th>Effect</th>
<th>Systematic Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity spectrum</td>
<td>0.15%</td>
</tr>
<tr>
<td>Beam polarization</td>
<td>0.1%</td>
</tr>
<tr>
<td>Photon identification</td>
<td>0.11%</td>
</tr>
<tr>
<td><strong>Total uncertainty</strong></td>
<td><strong>0.21%</strong></td>
</tr>
</tbody>
</table>
Summary

• Complete simulation of the analysis method to be employed at 3 TeV CLIC results in 1.7 % statistical dissipation of the counted number of signal events.
• Systematic uncertainties are preliminary estimated to be < 0.2 %
• Paper is planed to be submitted in February.
• I am grateful to colleagues from CLICdp AWG for their support and useful discussions
Backup
MVA Variables

• All background processes used for MVA training

TMVA is optimised with thirteen sensitive observables:

• Higgs candidate energy: $E(\gamma\gamma)$
• Higgs candidate transverse momentum: $p_T(\gamma\gamma)$
• Higgs candidate polar angle: $\theta(\gamma\gamma)$
• Cosine of the helicity angle: $\cos \theta_{\text{hel}}$
• *Photons transverse momenta: $p_T(\gamma_1)$ and $p_T(\gamma_2)$
• *Photons polar angle: $\theta(\gamma_1), \theta(\gamma_2)$
• *Photons energy: $E(\gamma_1), E(\gamma_2)$
• ECAL energy per event: $E_{\text{ECAL}}$
• HCAL energy per event: $E_{\text{HCAL}}$

* Photons are sorted by higher value, where $p_T(\gamma_1) > p_T(\gamma_2)$
The most sensitive observables ranked by TMVA:

- $p_T(\gamma_2)$
- Cosine of helicity angle
- Higgs candidate energy
Variables are sufficiently uncorrelated for MVA to perform
Higgs invariant mass distributions after MVA with invariant mass as variable

\[ \delta (\sigma(H\nu\nu) \times BR(H\gamma\gamma)) = \frac{1}{S} = \frac{\sqrt{N_s + N_b}}{N_s} = 7.9\% \]

### Results after MVA selection

<table>
<thead>
<tr>
<th>5 ab(^{-1})</th>
<th>Signal Events</th>
<th>Background events</th>
<th>(\delta (\sigma(H\nu\nu) \times BR(H\gamma\gamma)))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without polarizat ion</td>
<td>1 790</td>
<td>18 236</td>
<td>7.9 %</td>
</tr>
<tr>
<td>With polarizat ion</td>
<td>2 634</td>
<td>26 989</td>
<td>6.5 %</td>
</tr>
</tbody>
</table>

Conservatively taken to increase both signal and background cross-sections by a factor of 1.48, polarization improves the statistical precision to 6.5%