$H \rightarrow \gamma\gamma$ 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 σ x BR (H→γγ)
- ... motivated by paper publication

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

MEASUREMENT OF THE HIGGS BRANCHING RATIO BR($H \to \gamma\gamma$) AT 3 TeV CLIC*

G. Kačarević[a,1], I. Božović-Jelisavčić[a,1], N. Vukašinović[1], T. Agatonović-Jovin[1], M. Radulović[2], J. Stefanović[2], P. Roloff[3]

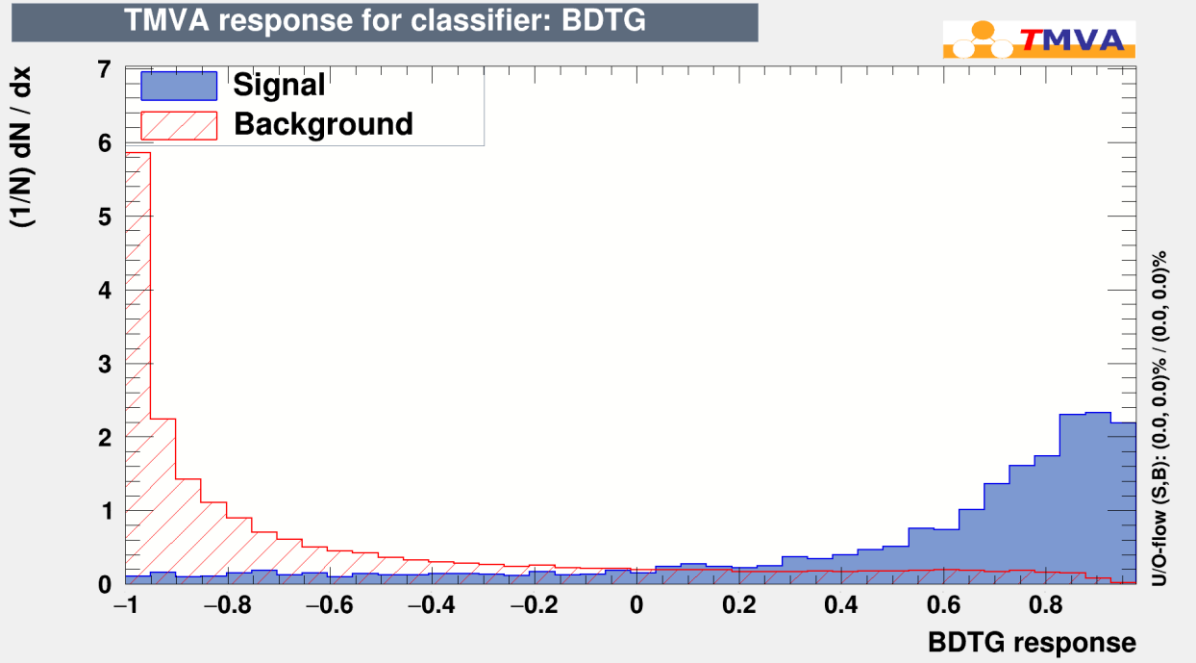
[1]Vinca Institute of Nuclear Sciences, University of Belgrade, Mike Petrovića Alasa 12-14, Belgrade, Serbia
[2]Faculty of Science, University of Kragujevac, Radoja Domanovića 12, Kragujevac, Serbia
[3]CERN, CH-1211 Geneva 23, Switzerland

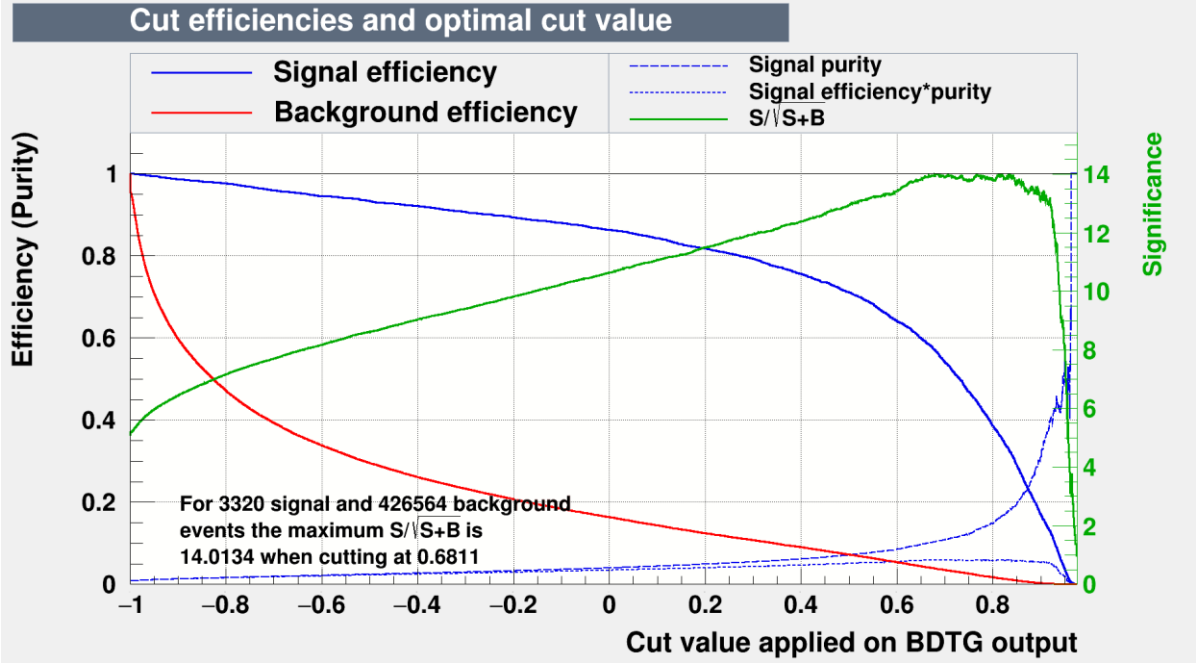
Received: date / Accepted: date

Abstract In this paper we address a potential of 3 TeV Compact Linear Collider (CLIC) to measure to measure the Standard Model Higgs boson decay to two photons. Photons are created in a loop exchange of heavy particles, either from the Standard Model (SM) or beyond. Any deviation of the effective $H \to \gamma\gamma$ branching ratio and consequently of the Higgs to photon coupling, may indicate a New Physics. The Higgs decay to two photons is thus an interesting probe of the Higgs sector, both at the running and future experiments. Similar study has been performed at 1.4 TeV CLIC, where statistical uncertainty is calculated to be 15 % for integrated luminostity of 1.5 ab^{-1} with unpolarized beams.

The study is performed using a full simulation of the detector for CLIC and by considering all relevant physics and beam-induced processes in the full reconstruction chain. Measurement is performed on 5000 samples of pseudo-data and relative statistical uncertainty is determined from the pull distribution. It is shown that the Higgs production cross-section in W^+W^- fusion times branching ratio BR($H \to \gamma\gamma$) can be measured with a relative statistical accuracy of 1.7 %, assuming integrated luminosity of 5 ab^{-1} with unpolarized beams.

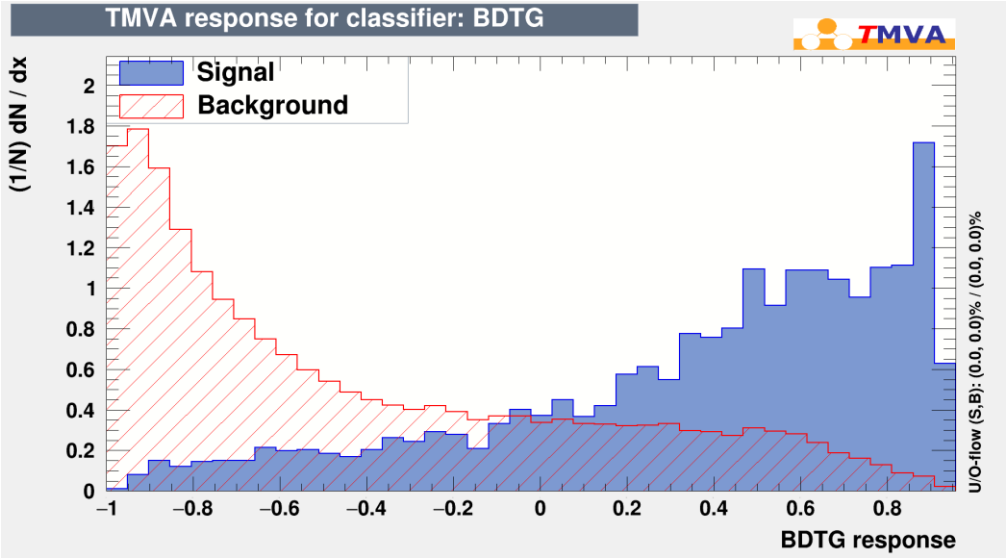
Old BDTG performance

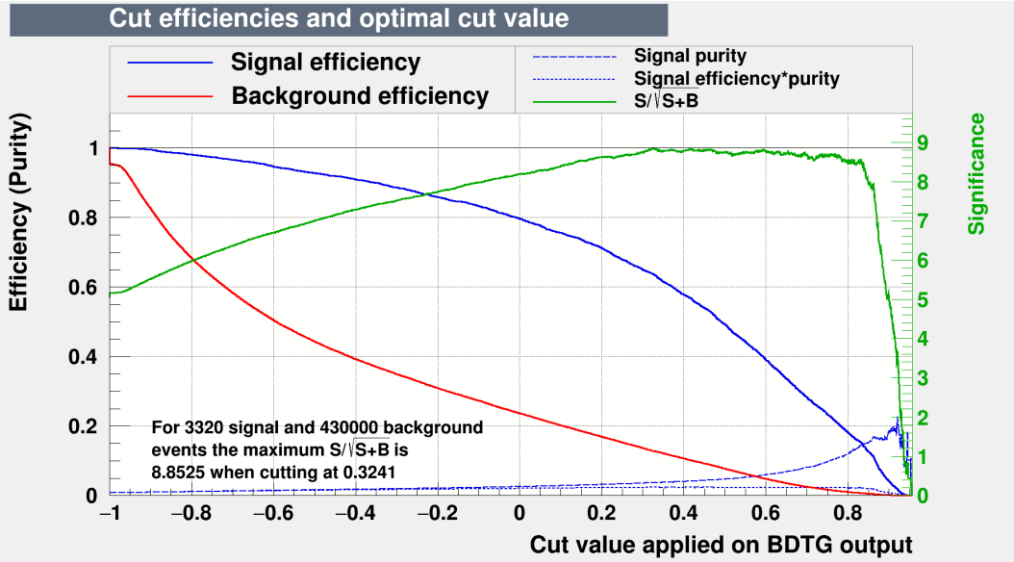




- Best significance for BDTG > 0.68 → 7.9 % relative statistical uncertainty
- BDTG efficiency: 54%
- Total signal efficiency (BDTG + preselection): 38%
- Signal events remaining after preselection and MVA: 1790/5ab^{-1}

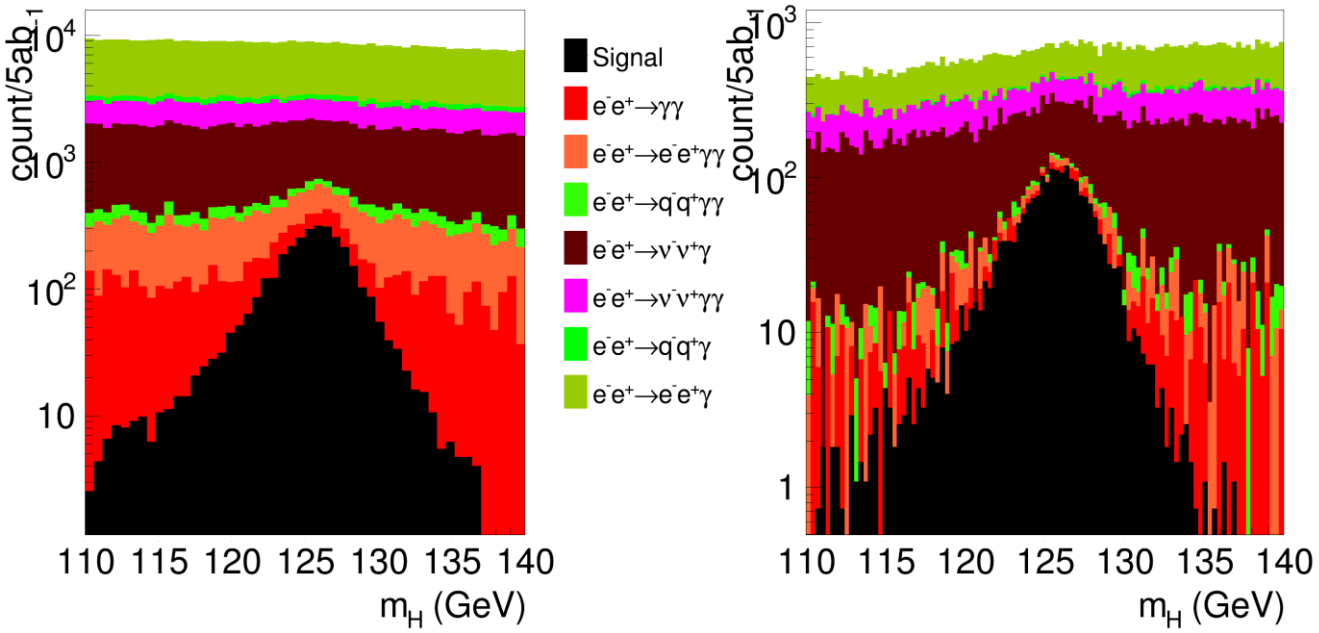
New BDTG performance





- 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



$\delta\,(\sigma(H\nu\nu) \times BR(H\to\gamma\gamma)) = 1/S = \frac{\sqrt{N_S+N_b}}{N_S} = 12.1\%$

Results after MVA selection			
5 ab^{-1}	Signal Events	Background events	$\delta\,(\sigma(H\nu\nu) \times BR(H\gamma\gamma))$
Without polarization	2 062	60 327	12.1%
With polarization	3 052	80 284	9.5%

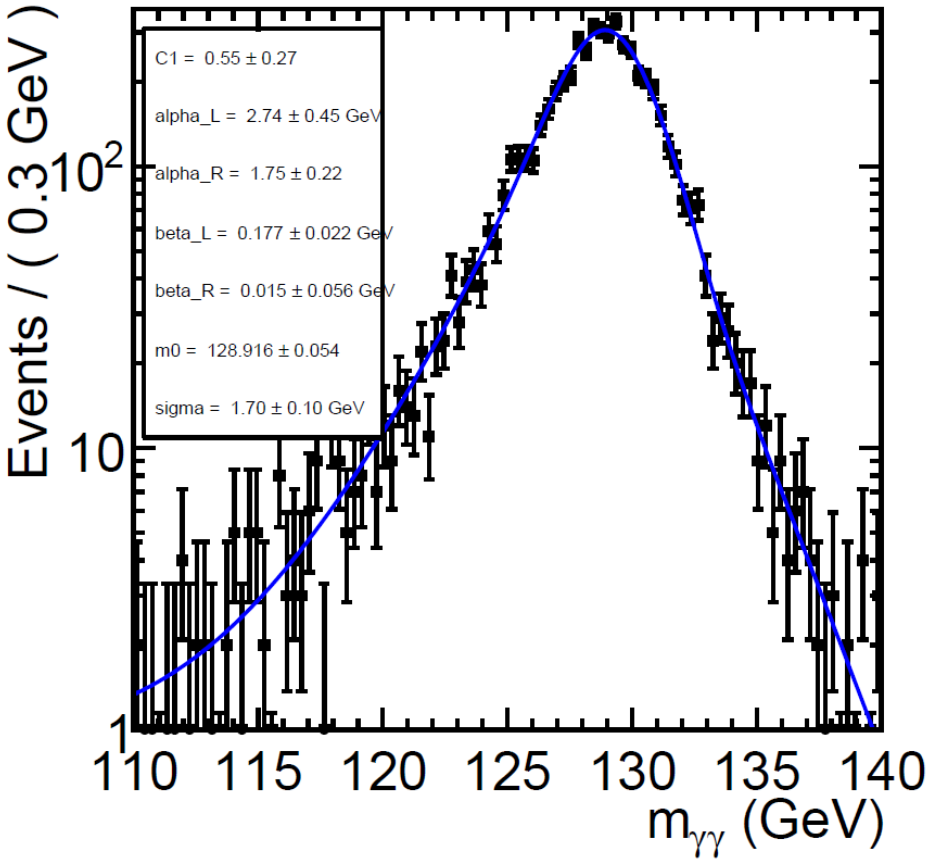
Polarization (new baseline) is conservatively taken to increase both signal and background cross-sections by a factor of 1.48. It improves statistical precision to 9.5%.

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



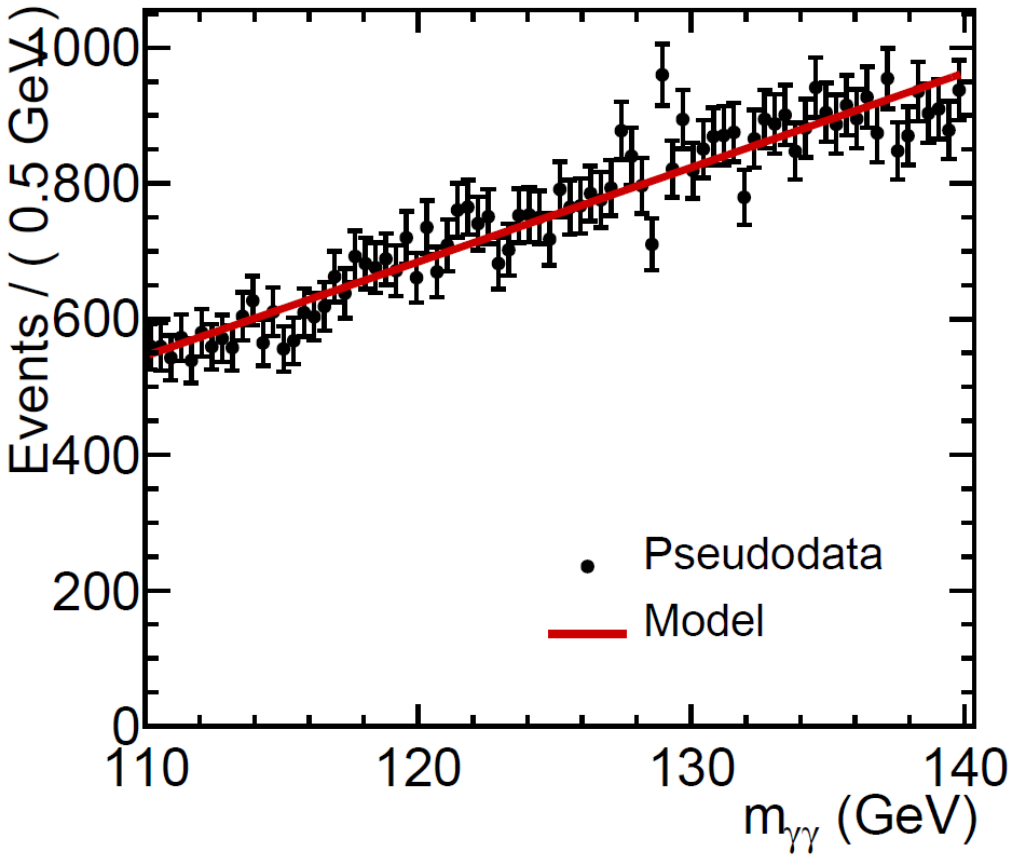
Signal is fitted with two Gaussians (f_{flat}, f_{exp}):

$f_s = C \cdot f_{exp} + f_{flat}$

$$f_{flat} \begin{cases} e^{-\frac{(m_{\gamma\gamma}-m_H)^2}{2\sigma^2+\beta_L\cdot(m_{\gamma\gamma}-m_H)^2}} & m_{\gamma\gamma} < m_H \\ e^{-\frac{(m_{\gamma\gamma}-m_H)^2}{2\sigma^2+\beta_R\cdot(m_{\gamma\gamma}-m_H)^2}} & m_{\gamma\gamma} > m_H \end{cases}$$

$$f_{exp} = \begin{cases} e^{-\frac{(m_{\gamma\gamma}-m_H)^2}{2\sigma^2+\alpha_L\cdot|m_{\gamma\gamma}-m_H|}} & m_{\gamma\gamma} < m_H \\ e^{-\frac{(m_{\gamma\gamma}-m_H)^2}{2\sigma^2+\alpha_R\cdot|m_{\gamma\gamma}-m_H|}} & m_{\gamma\gamma} > m_H \end{cases}$$

Background Fit

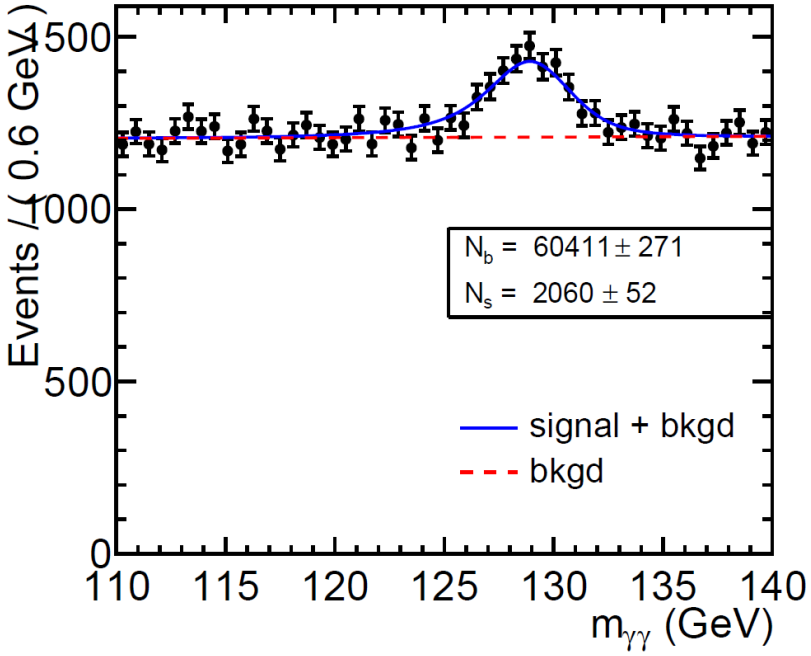


Function for background fit is combination of linear and exponential part:

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

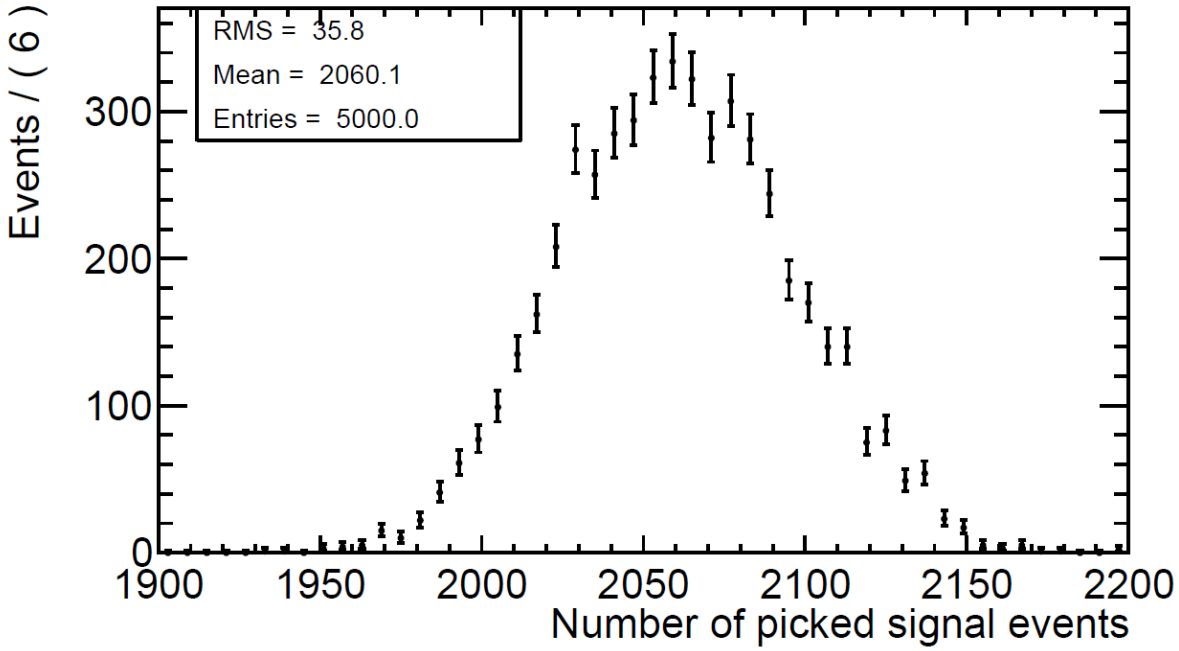
p_0 = 768 +- 4.5
p_1 = 115 +- 15
p_2 = 0.000158 +- 0.000014

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

	1.4 TeV CLIC 1.5 ab^{-1}/2ab^{-1}	**1.4 TeV CLIC 1.5 ab^{-1}/2ab^{-1} (50 Toy MC)**	**3 TeV CLIC 5 ab^{-1}**	**3 TeV CLIC 5 ab^{-1} (5000 Toy MC)**
ε_s	40 %	53.3 %	38 %	43.4 %
δ (σ x BR)$_{unpolarized}$	15%/13%	23 %/ 20 %	7.9 %	1.7 %
δ (σ x BR)$_{polarized}$	12.3%/10.7%	18.9 %/ 15.5%	6.5 %	1.4 %

List of systematic uncertainties – will be revised

- Taken from my presentation at ALPS19
- Integral luminosity uncertainty (10^{-3}) → negligible
- Uncertainty of the luminosty 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) → negligible

Effect	Systematic Uncertainty
Luminosity spectrum	0.15%
Beam polarization	0.1%
Photon identification	0.11%
Total uncertainty	**0.21%**

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

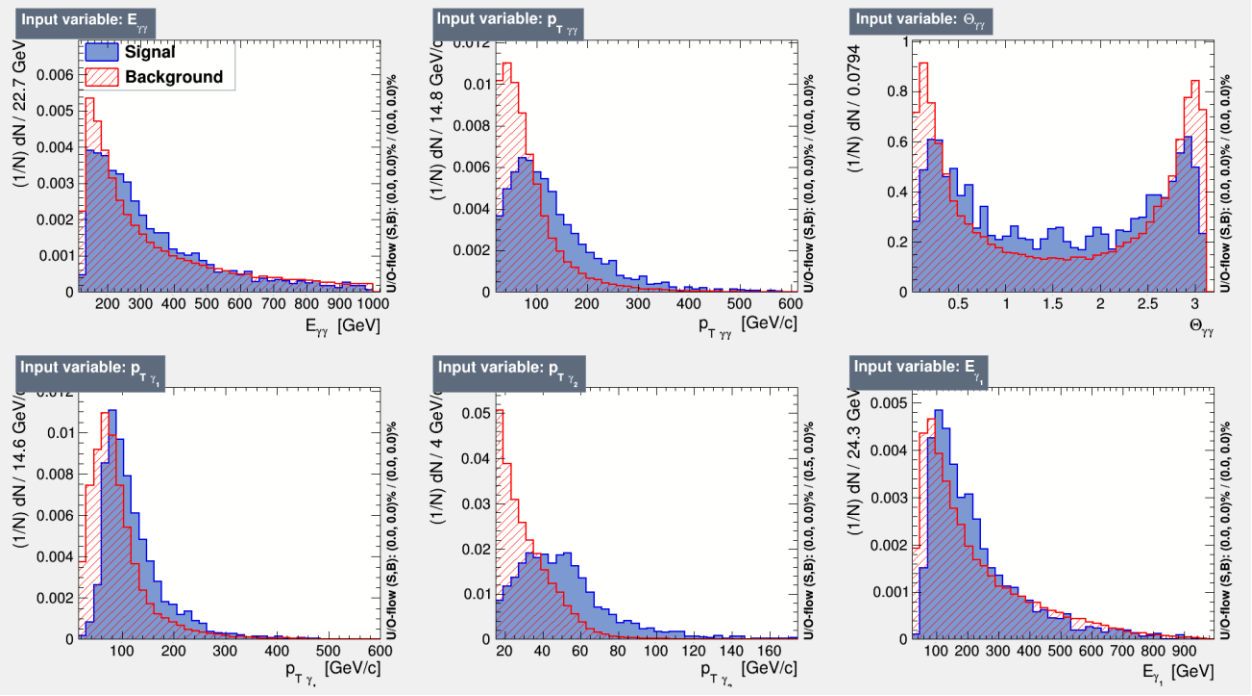
- All background processes used for MVA training

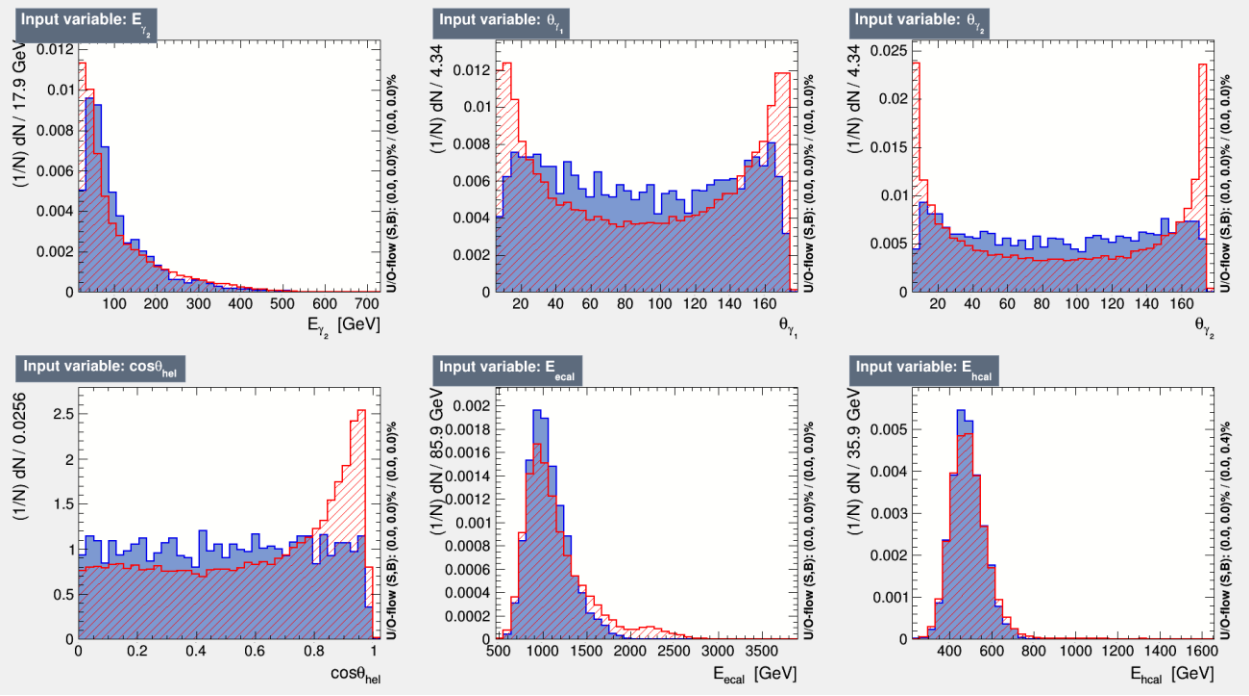
TMVA is optimised with thirteen sensitive observables:

- Higgs candidate energy: E ($\gamma\gamma$)
- Higgs candidate transverse momentum: p_T ($\gamma\gamma$)
- Higgs candidate polar angle: θ ($\gamma\gamma$)
- Cosine of the helicity angle: cos θ_{hel}
- *Photons transverse momenta: p_T (γ_1) and p_T (γ_2)
- *Photons polar angle: θ (γ_1), θ (γ_2)
- *Photons energy: E(γ_1), E(γ_2)
- ECAL energy per event :E_{ECAL}
- HCAL energy per event: E_{HCAL}

** Photons are sorted by higher value, where $p_T(\gamma_1) > p_T(\gamma_2)$*

MVA Variables II

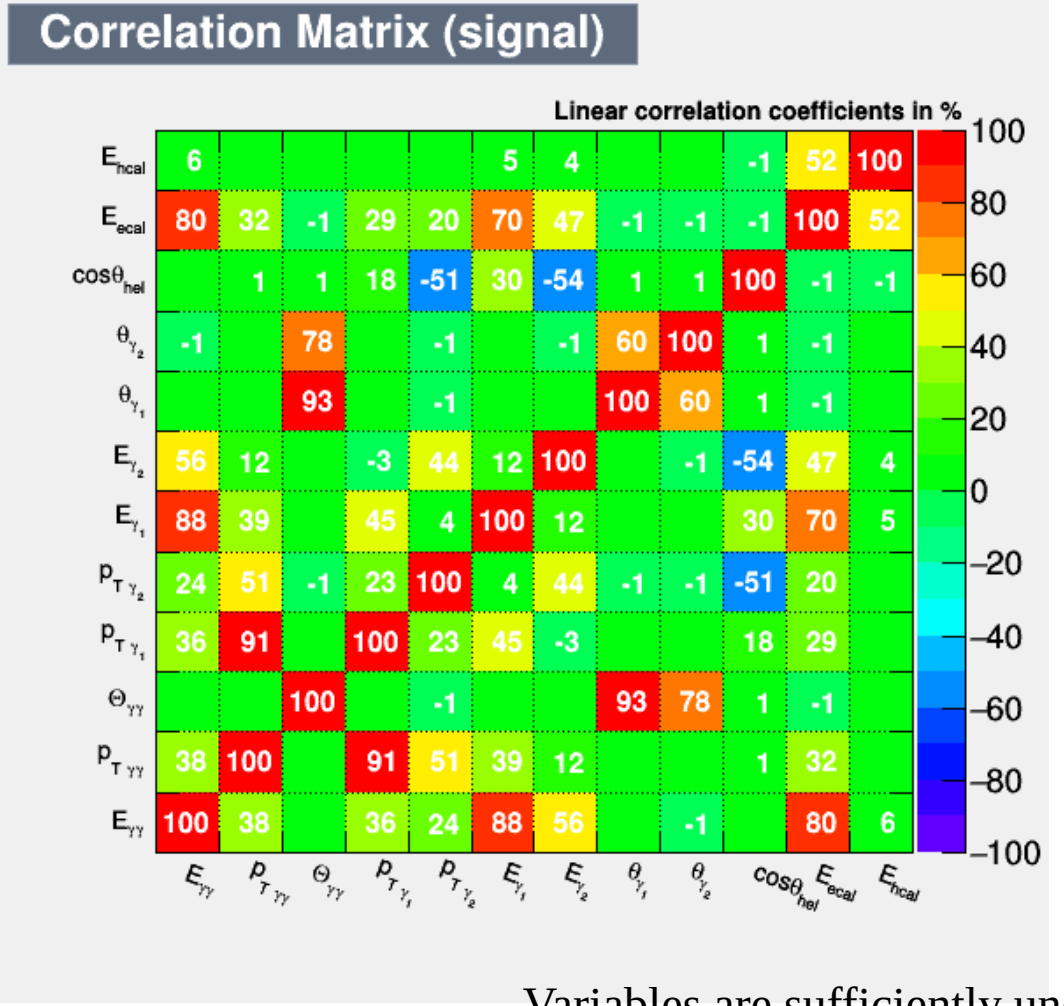


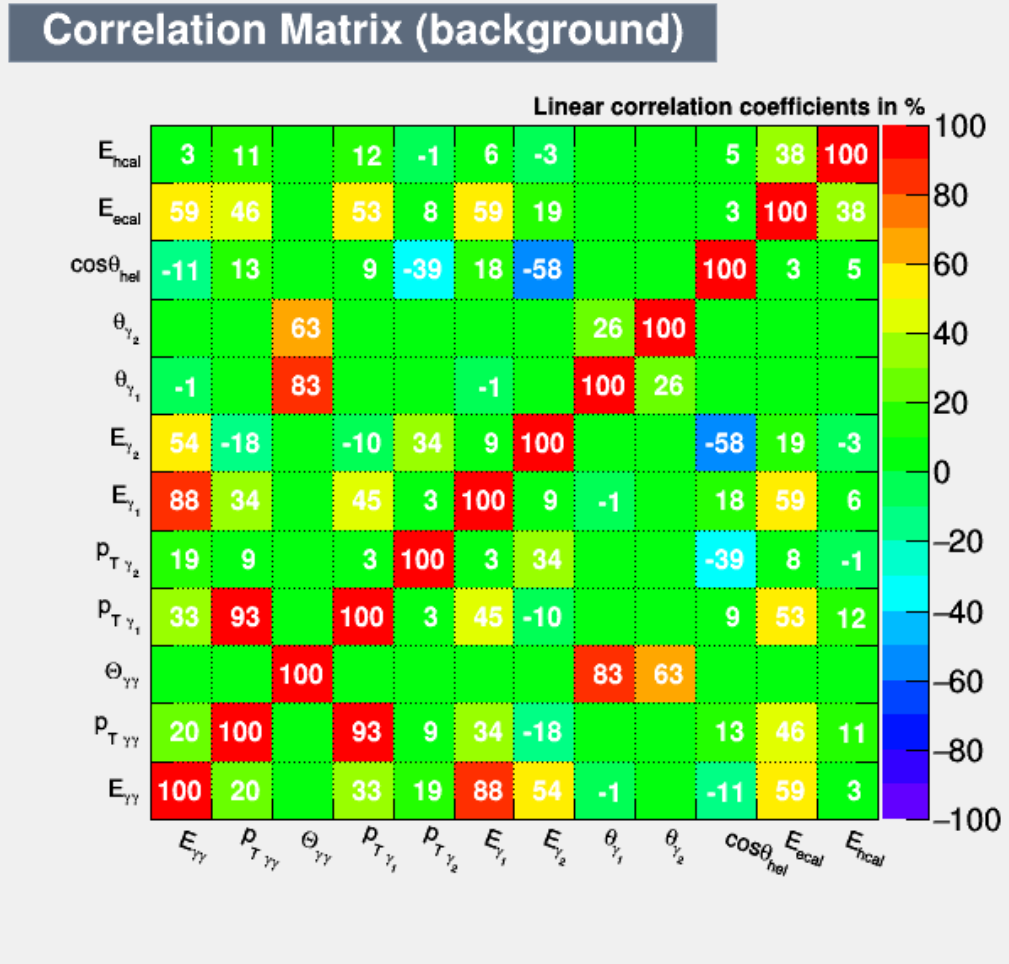


The most sensitive observables ranked by TMVA:

- p_T (γ_2)
- Cosine of helicity angle
- Higgs candidate energy

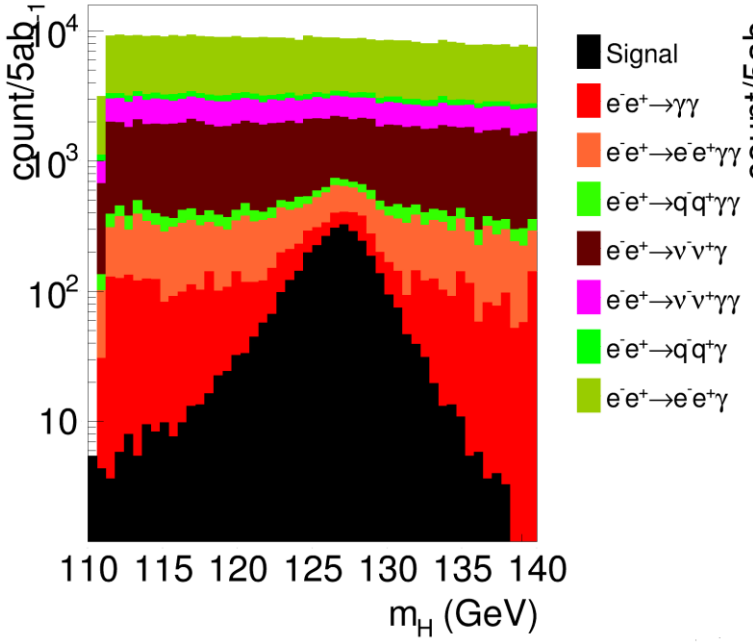
Correlation matrices

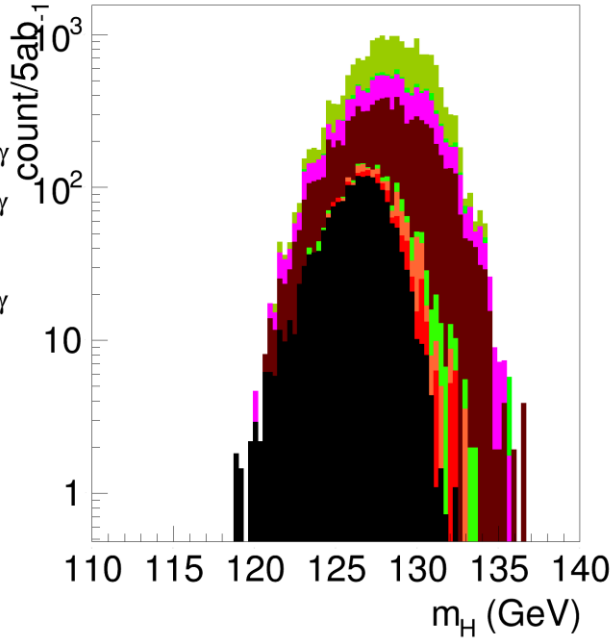




Variables are sufficiently uncorrelated for MVA to perform

Higgs invariant mass distributions after MVA with invariant mass as variable





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

Results after MVA selection			
5 ab^{-1}	Signal Events	Background events	$\delta\,(\sigma(H\nu\nu) \times BR(H\gamma\gamma))$
Without polarization	1 790	18 236	7.9 %
With polarization	2 634	26 989	6.5 %

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