CLIC sensitivity to measure $\sigma_{H\nu\nu} \times BR\ (H\rightarrow\gamma\gamma)$ at 3 TeV center-of-mass energy

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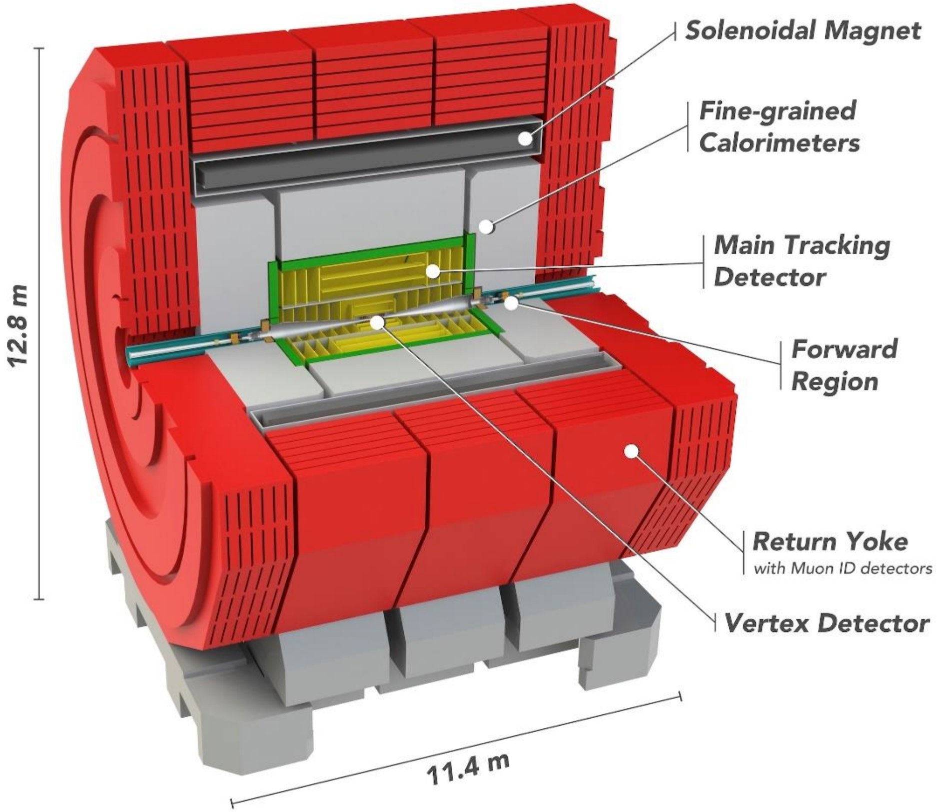
Compact LInear Collider - CLIC

- CLIC is a TeV scale e^+e^- linear collider
- Several energy stages: 380 GeV($1ab^{-1}$),1.5 TeV ($2.5ab^{-1}$) and 3 TeV ($5ab^{-1}$)
- Modular, upgradeable, site length 11 – 50 km

- All-silicon low mass vertex and tracking detectors
- High-granularity calorimeters
- 4T superconducting solenoid
- Muon detectors within return yoke
- **Optimized for Particle Flow reconstruction**

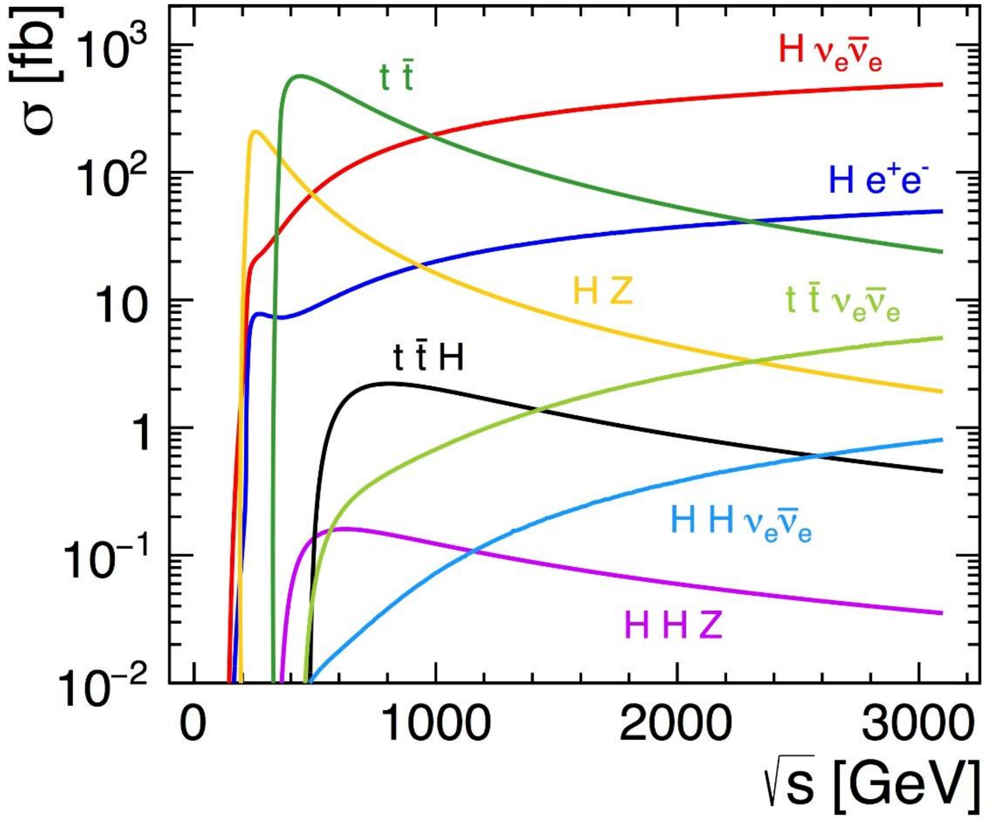
CLIC_ILD detector model used in the analysis whit TPC as a central tracker



CLICdet

Higgs production at CLIC

- CLIC as a Higgs factory:
    - $1.6 \cdot 10^5$ Higgs at 380 GeV
    - $\sim 10^6$ Higgs per higher energy stage
- Top threshold scan, model-independent Higgs measurements in the Higgsstrahlung
- Excellent sensitivity at higher energies to BSM physics, top and Higgs measurements



Production cross section as a function of center-of-mass energy for the main Higgs boson production processes at an e+e− collider

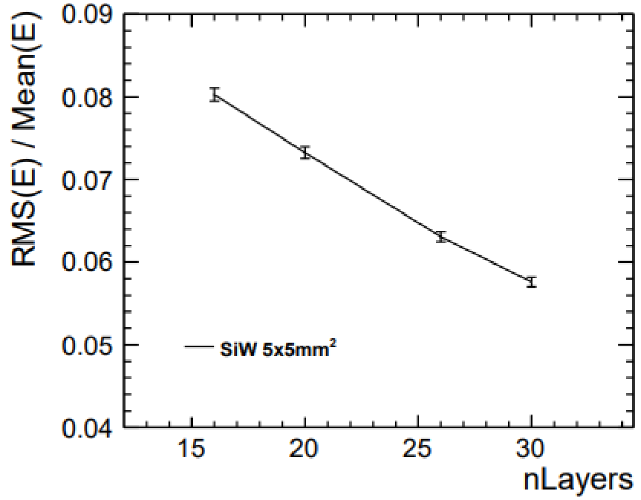
- WW-fusion dominates Higgs production at the energies above 500 GeV
- Electron polarisation: polarization -80%:+80%, where runtime will be 4:1 with -80% electron polarisation.
- This effectively increases the Higgs production cross-section for a factor of 1.48

$H \rightarrow \gamma\gamma$

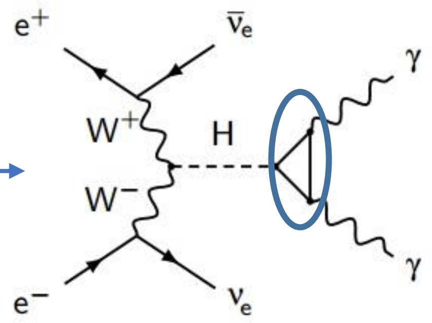
- One of the channels at LHC where Higgs boson was discovered
- High-granularity of ECAL → High efficiency of photon reconstruction, good energy resolution
- Higgs boson is coupled to photons via loop diagram and thus it is sensitive to eventual contribution of BSM physics through precision measurement of coupling $g_{H\gamma\gamma}$

- WW fusion dominant H production process at 3 TeV
- σ ($H\nu\nu$) at 3 TeV is 415 fb
- $BR(H\rightarrow\gamma\gamma)$ is 0.23%
- σ $(H\nu\nu)xBR(H\rightarrow\gamma\gamma)$ ≈0.95 fb
- $N_{signal} \approx 4750 evt/5ab^{-1}$

Silicon-tungsten ECAL energy resolution for 10 GeV photons (in the barrel)



10 GeV photons



Simulation details

- Assuming m_H = 126 GeV, $5ab^{-1}$
- Signal and background simulation: WHIZARD v1.95, including ISR and BS and realistic luminosity spectrum.
- Polarization is conservatively taken as a scaling factor for signal and background.
- Particle interaction with the CLIC_ILD detector is fully simulated.
- Hadronic background from BS is overlaid in the digitization phase.
- Photons are reconstructed using PandoraPFA v02-04-00 photon processor.

Generator Level Cuts:

- Applied to reduce CPU time
- On high cross-section backgrounds ($ee \rightarrow \gamma\gamma$, $ee \rightarrow ee\gamma$, $ee \rightarrow ee\gamma\gamma$, $ee \rightarrow \nu\nu\gamma$, $ee \rightarrow \nu\nu\gamma\gamma$):
  - At least two photons per event with event with p_T > 10 GeV and $5° < \theta_\gamma < 175°$
  - At least one Higgs candidate with 100 GeV < $M_{\gamma\gamma}$ < 150 GeV

Signal and background processes

Process	σ (fb)	Expected events at $5ab^{-1}$	Events Simulated
σ(hνν) × BR(h→γγ)	0.95	4750	24 550
ee→γγ	867	$4.25 \cdot 10^6$	29 900
ee→eeγ	185 392	$927 \cdot 10^6$	$3 \cdot 10^6$
ee→eeγγ	4 245	$21 \cdot 10^6$	144 900
ee→ννγ	16 806	$82.5 \cdot 10^6$	194 900
ee→ννγγ	2 616	$13 \cdot 10^6$	155 500
ee→qqγ*	584	$3 \cdot 10^6$	$1.2 \cdot 10^6$
ee→qqγγ*	72	360 000	299 600

*Process without generator level cuts

Method of the analysis

- Higgs candidate definition
  - Identify two Higgs photons without variables to be used later in MVA
- Preselection
  - Reduction of the high cross-section backgrounds
- Separation of signal with MVA
  - Signal to background separation with the maximal statistical significance S

- Observable to measure: σ ($H\nu\nu$) x $BR(H\to\gamma\gamma)$; $g_{H\gamma\gamma}$ will be derived from a global fit
- Relative statistical uncertainty of the measurement: δ (σ ($H\nu\nu$) x $BR(H\to\gamma\gamma)$) = 1/S

Higgs candidate definition

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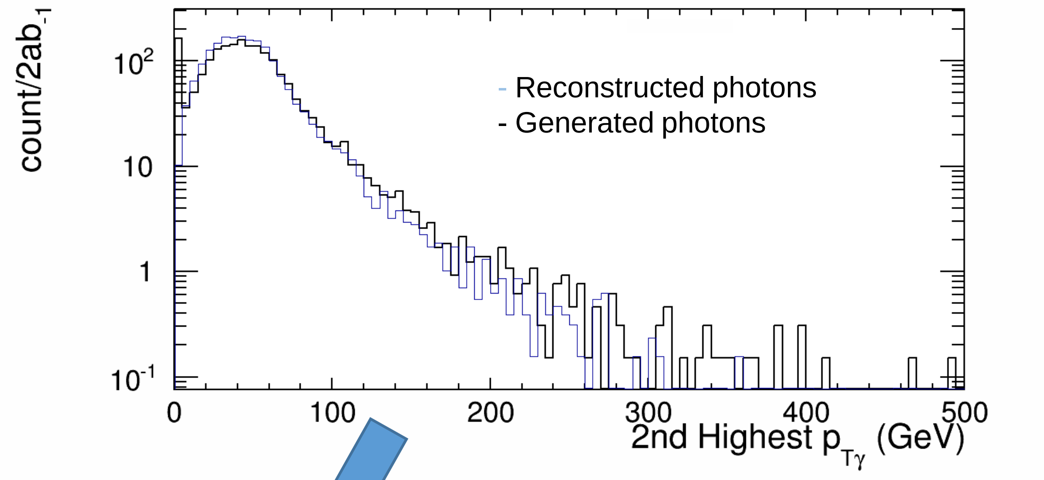
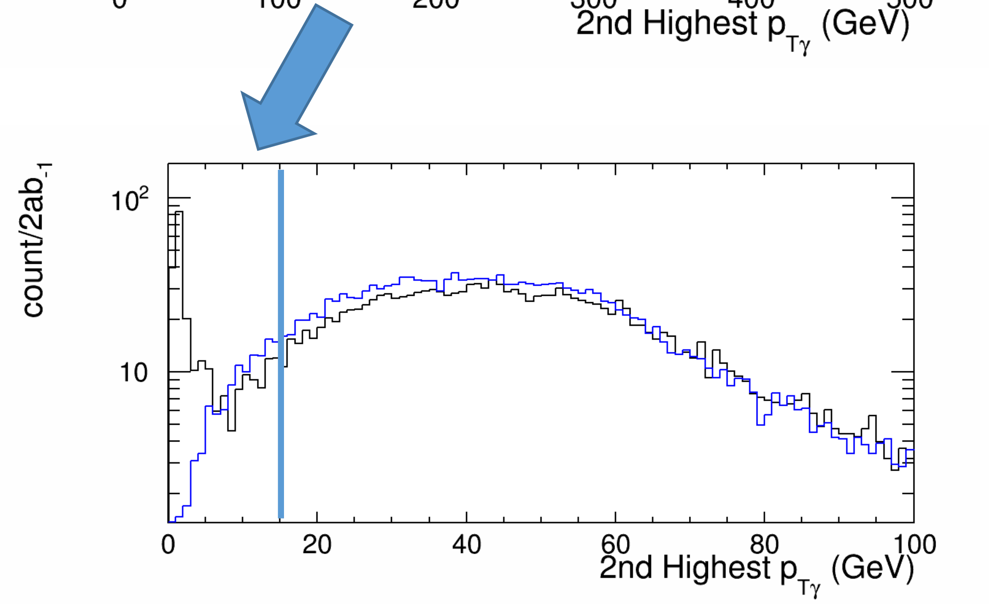
Signal

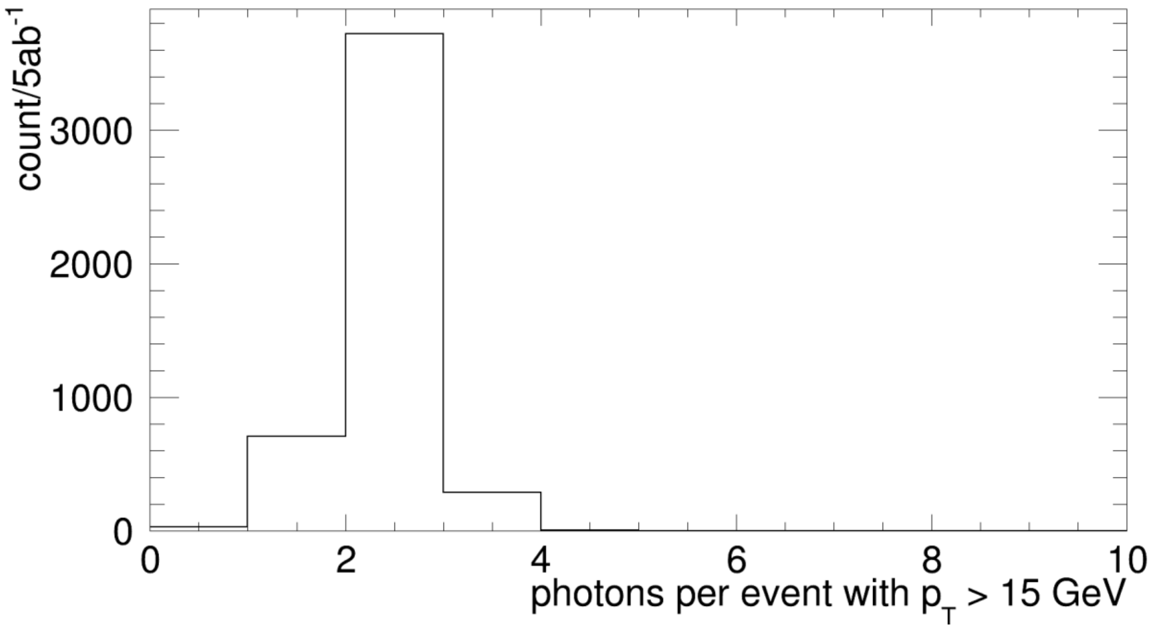




- Exactly 2 isolated photons with p_T > 15 GeV
  - Removing photons from ISR and machine background photons.
  - Signal loss: 14.8%
- Photon isolation - E < 20 GeV within 14 mrad cone around the photon.
  - Reduces effective cross-section of background processes with FSR
  - 23% background rejection. Signal loss < 0.1%

Higgs candidate definition: signal efficiency

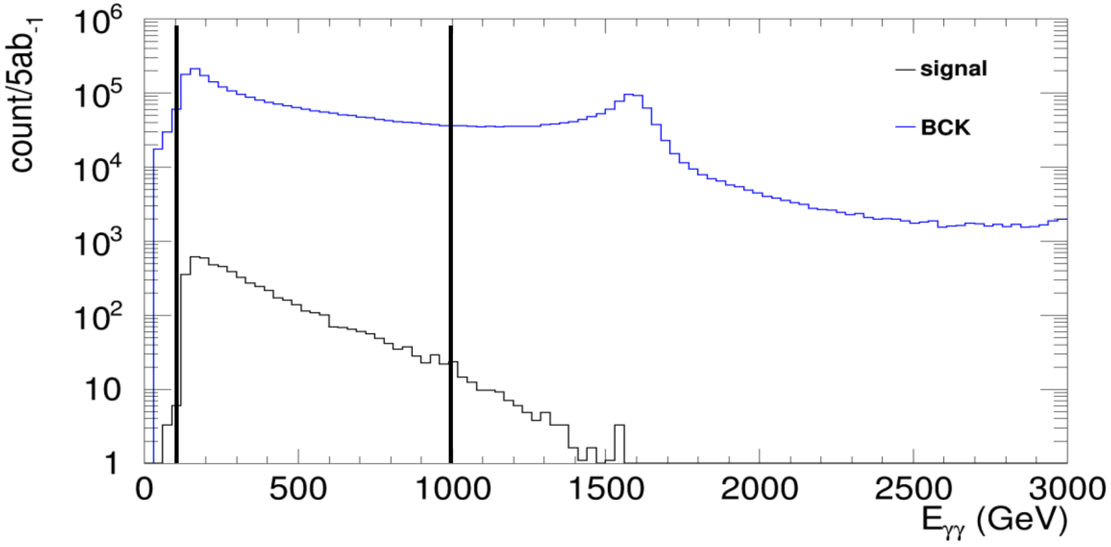
- 14.8 % events with less then 2 photons
- 7.5 % events with 3 or more photons.
- Signal efficiency is 77.7 % by definition of the Higgs candidate.

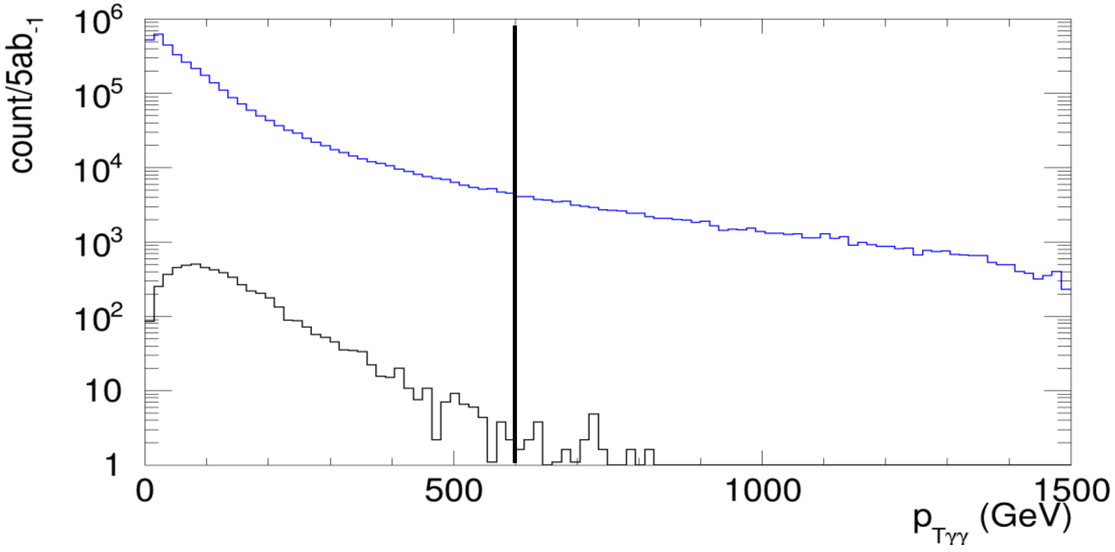


Preselection variables

Preselection:

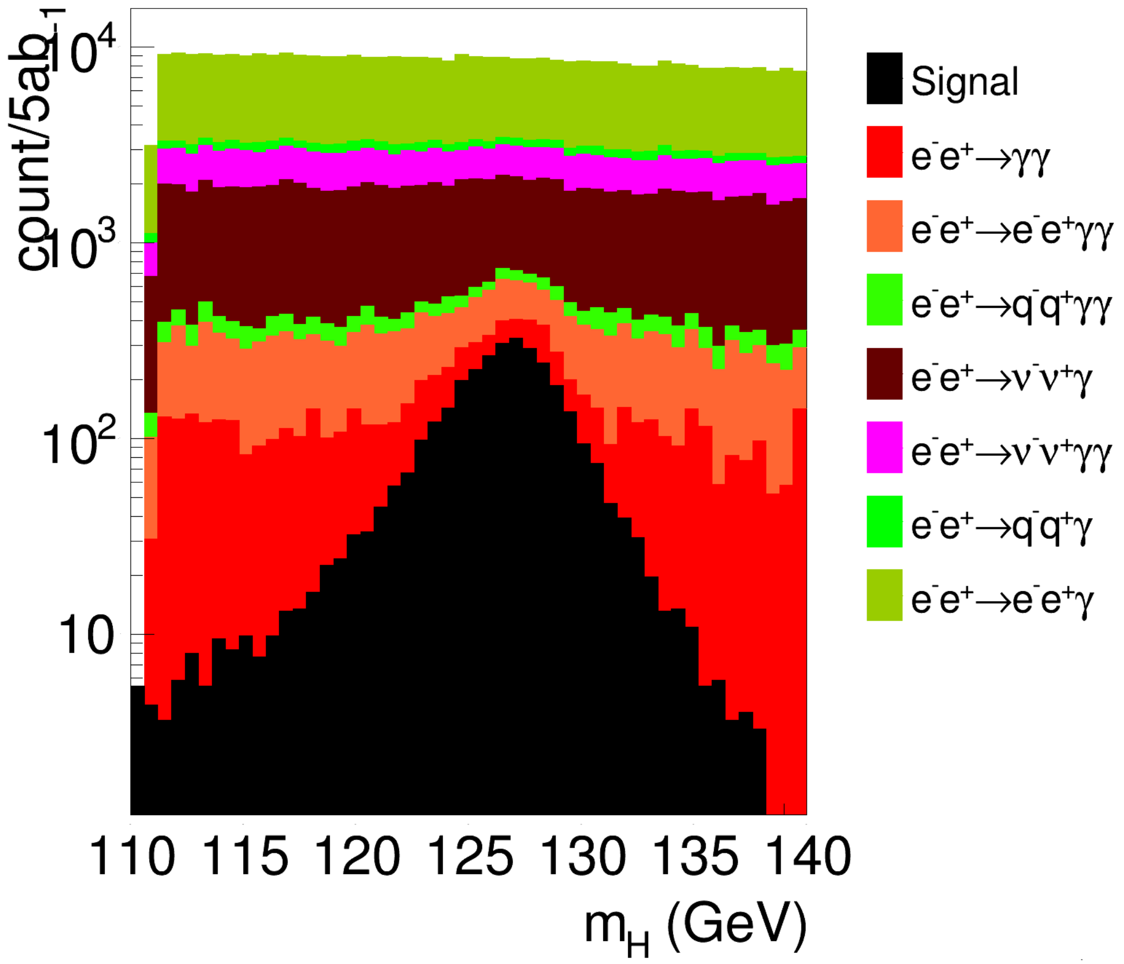
- Two isolated photons (Higgs candidate)
- Candidate energy: 100 GeV < E (γγ) < 1000 GeV
- Candidate transverse momentum: 20 GeV< p_T (γγ) < 600 GeV
- Candidate invariant mass: 110 GeV < M (γγ) < 140 GeV





Preselection

- Preselection efficiency: 70%.
- Background is reduced by a factor of 1000.
- Signal to background ratio (N_s/N_b) is $7.8 \cdot 10^{-3}$ after preselection.



MVA variables

- All background processes used for MVA training

TMVA is optimised with thirteen sensitive observables:

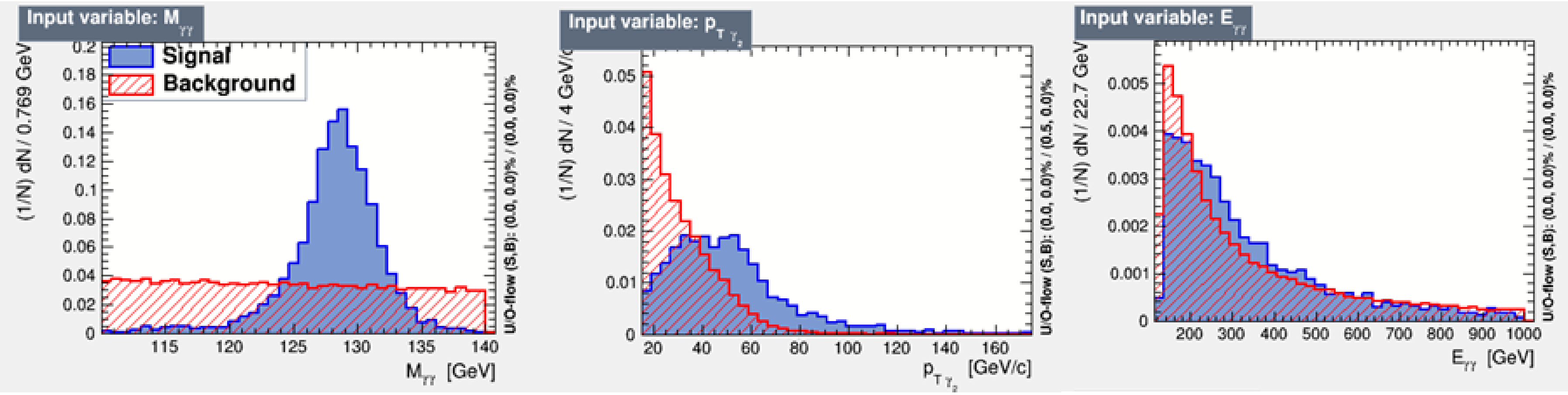
- Higgs candidate mass : M ($\gamma\gamma$)
- Higgs candidate energy: E ($\gamma\gamma$)
- Higgs candidate transverse momentum: p_T ($\gamma\gamma$)
- Higgs candidate polar angle: θ ($\gamma\gamma$)
- Cosine of the helicity angle: cos θ_{hel}
- *Photons transverse momenta: p_T (γ_1) and p_T (γ_2)
- *Photons polar angle: θ (γ_1), θ (γ_2)
- *Photons energy: $E(\gamma_1)$, $E(\gamma_2)$
- ECAL energy per event :E_{ECAL}
- HCAL energy per event: E_{HCAL}

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

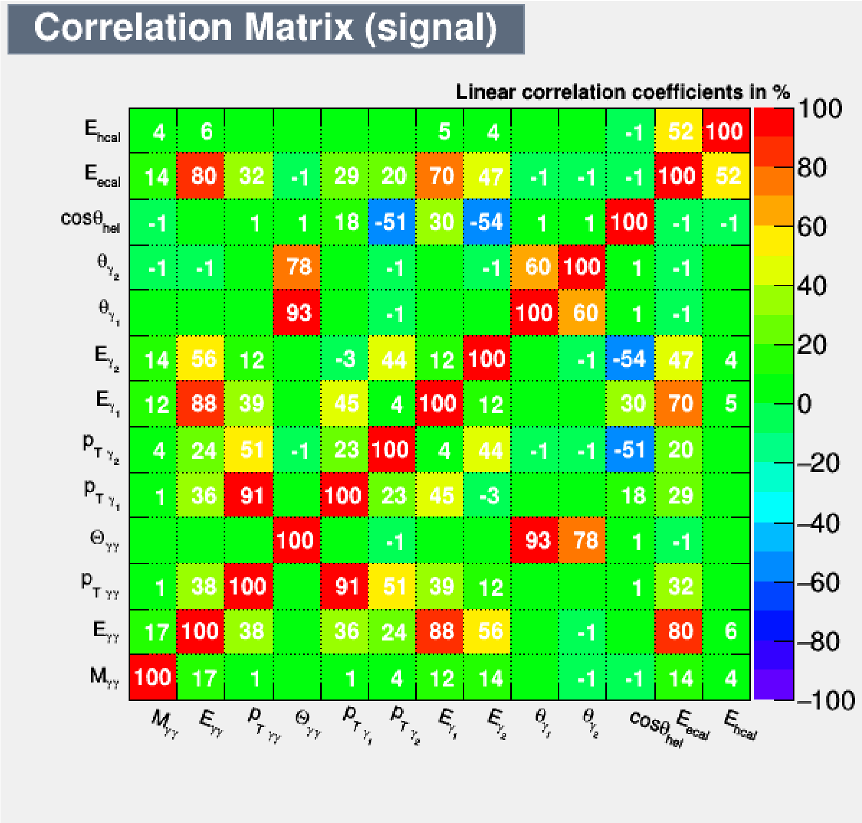
MVA variables II

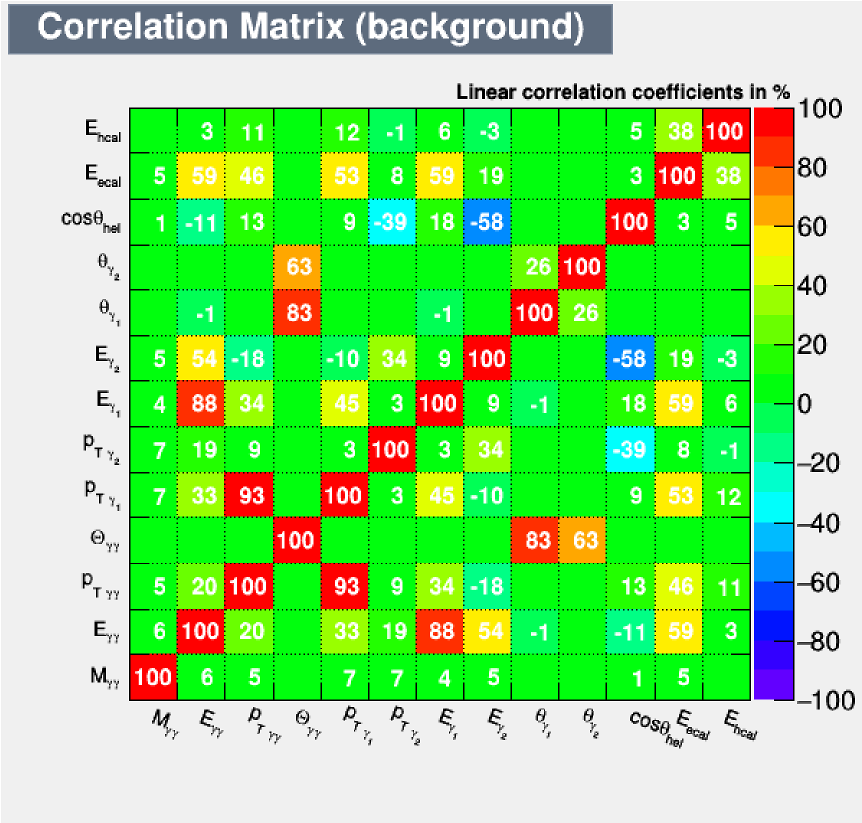
The most sensitive observables ranked by TMVA:

- Higgs candidate mass
- p_T (γ_2)
- Higgs candidate energy



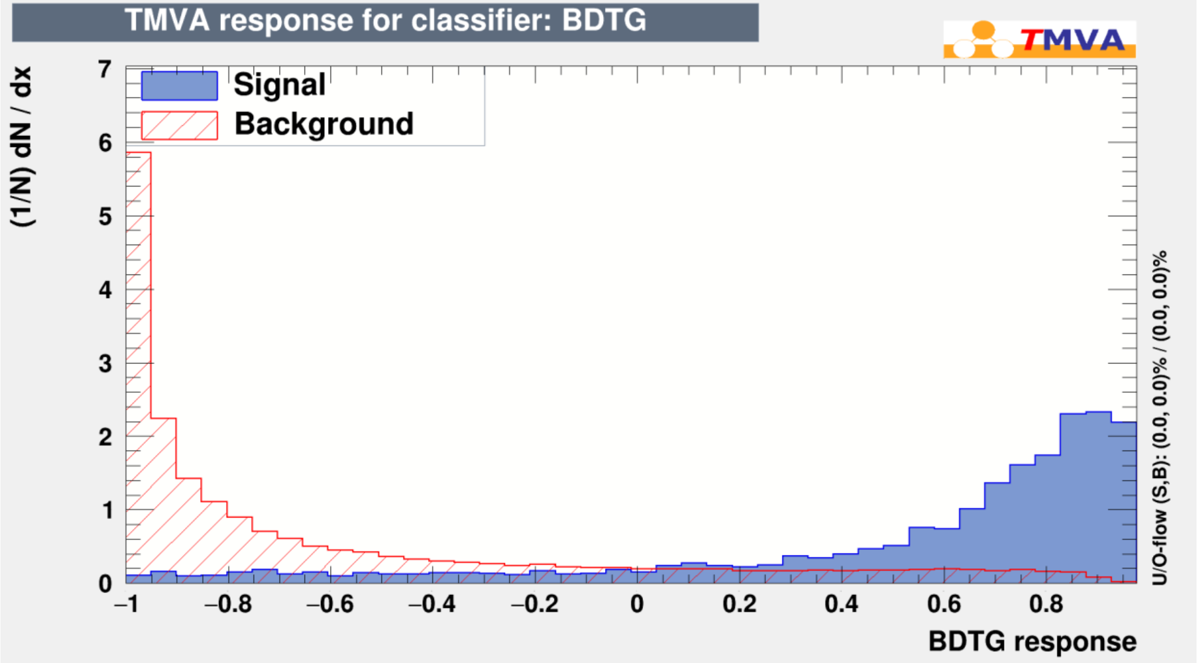
Correlations matrices

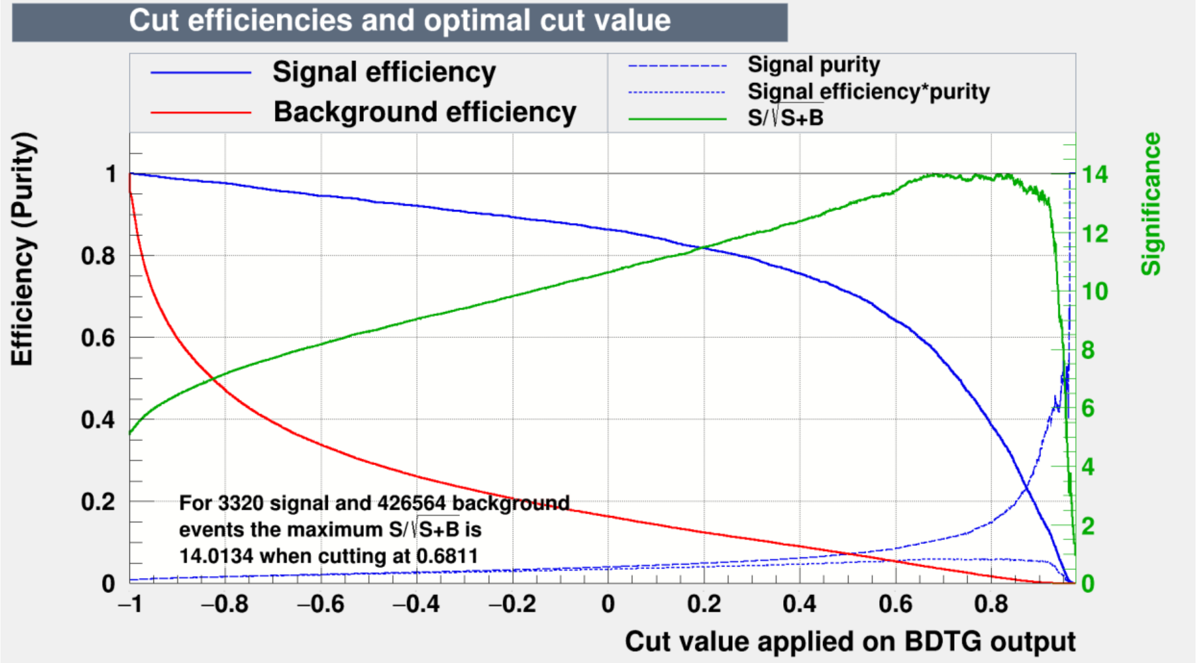




Variables are sufficiently uncorrelated for MVA to perform

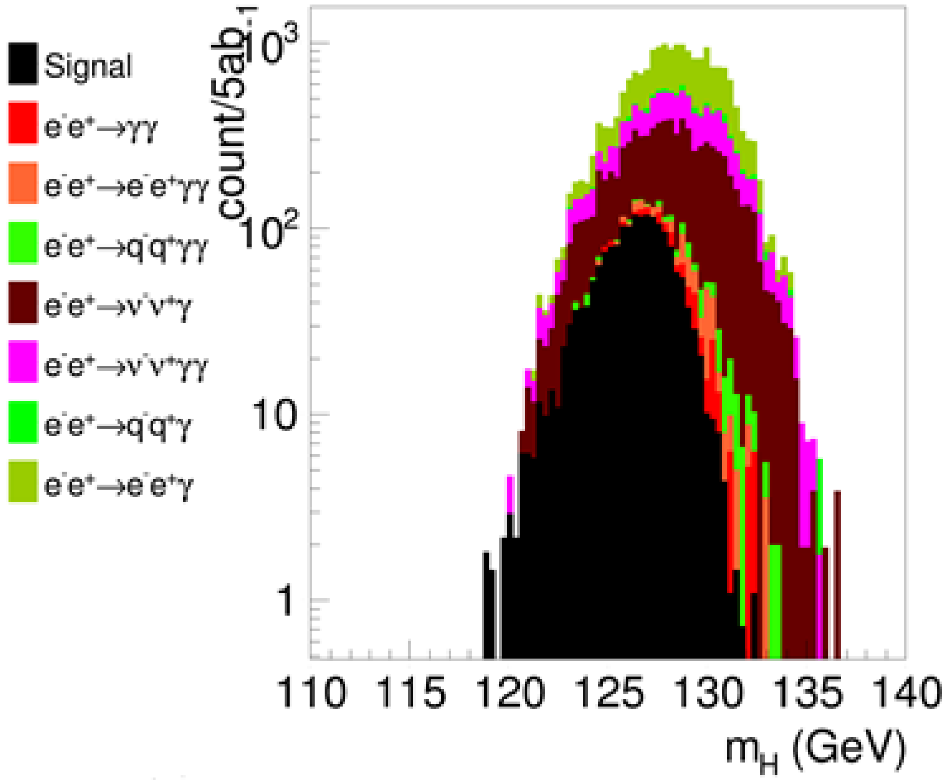
BDTG performance





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

Higgs invariant mass distributions after MVA



$N_s/N_b = 9.8 \cdot 10^{-2}$

Remain backgrounds after MVA are either from photon + E_{miss} processes (ee→ννγ, ee→ννγγ) or from the high cross-section ee→eeγ

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

Impact of polarization

Results after MVA selection			
5 ab^{-1}	Signal Events	Background events	δ (σ(H$\nu\nu$) × 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%

Concluding remarks

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- The highest energy operation at CLIC enables $\sigma(H\nu\nu) x BR(H \rightarrow \gamma\gamma)$ measurement with the relative statistical uncertainties of 7.9% and ultimately with 6.5% including electron-beam polarization.
- All relevant physics and background processes are fully simulated, as well as the response of the CLIC_ILD detector.
- Systematic uncertainties (luminosity spectrum, uncertainty of the photon identification efficiency, uncertainty of the photon energy resolution, etc.) are estimated to much smaller than the statistical one.

This analysis was part of my PhD thesis and the corresponding paper is in preparation.

Back Up

List of systematic uncertainties

- 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

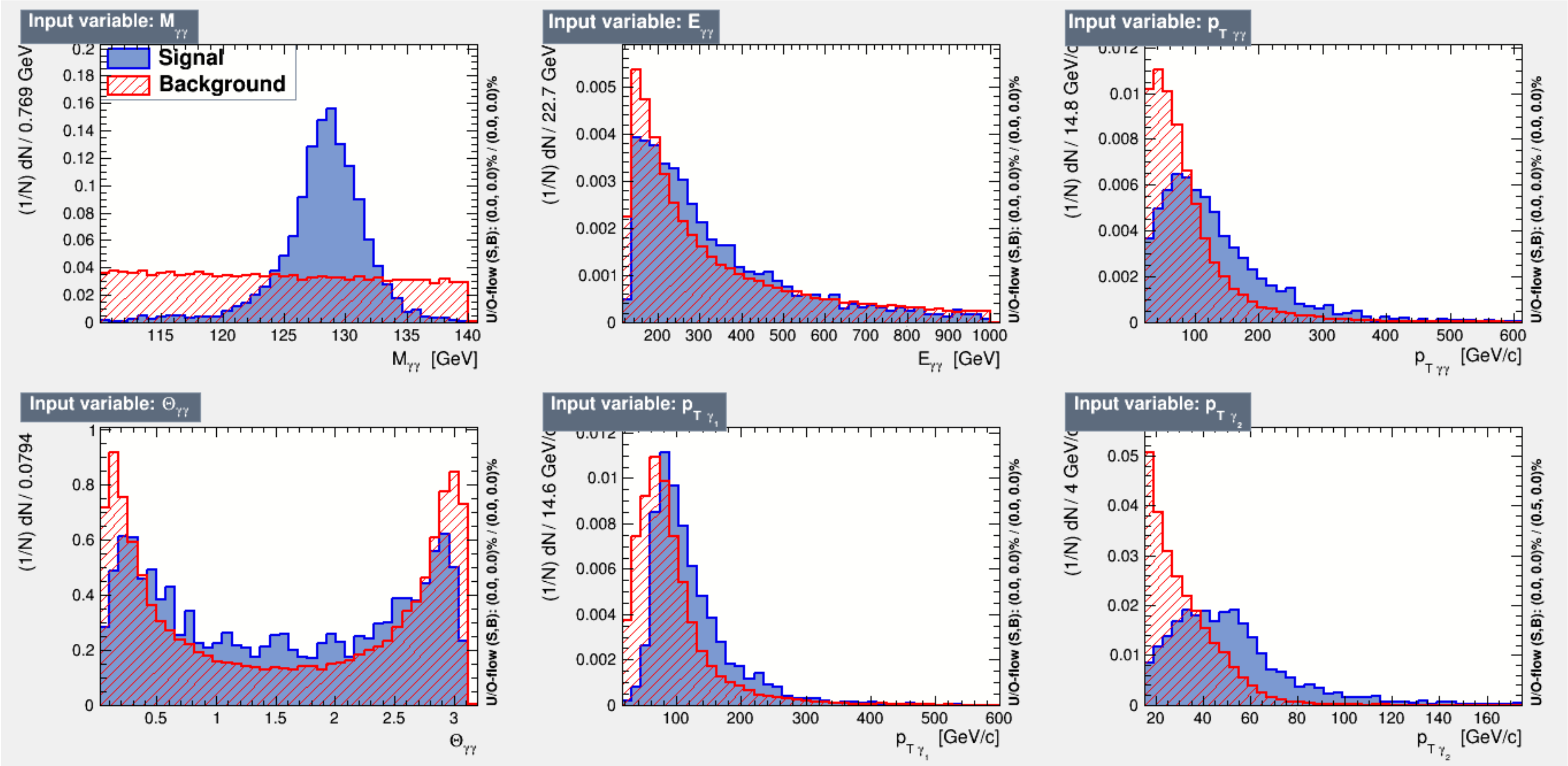
Effect	Systematic Uncertainty
Luminosity spectrum	0.15%
Beam polarization	0.1%
Photon identification	0.11%
Total uncertainty	**0.21%**

Event samples

Process ($5ab^{-1}$)	Events after preselection	Preselection efficiency (%)	Events after MVA	Total selection efficiency (%)
$ee\to\gamma\gamma$	4 540	0.1	173	0.004
$ee\to ee\gamma$	272 570	0.03	7 718	0.00008
$ee\to ee\gamma\gamma$	10 605	0.05	241	0.001
$ee\to\nu\nu\gamma$	73 155	0.09	5 847	0.007
$ee\to\nu\nu\gamma\gamma$	47 283	0.04	3 636	0.03
$ee\to qq\gamma$	14 538	0.5	444	0.015
$ee\to qq\gamma\gamma$	3 873	1	175	0.05
$H\nu\nu$	3 320	70	1790	38

- Statistical precision of the result is limited by the signal statistics and by the presence of irreducible or high cross-section backgrounds

Distributions of MVA variables



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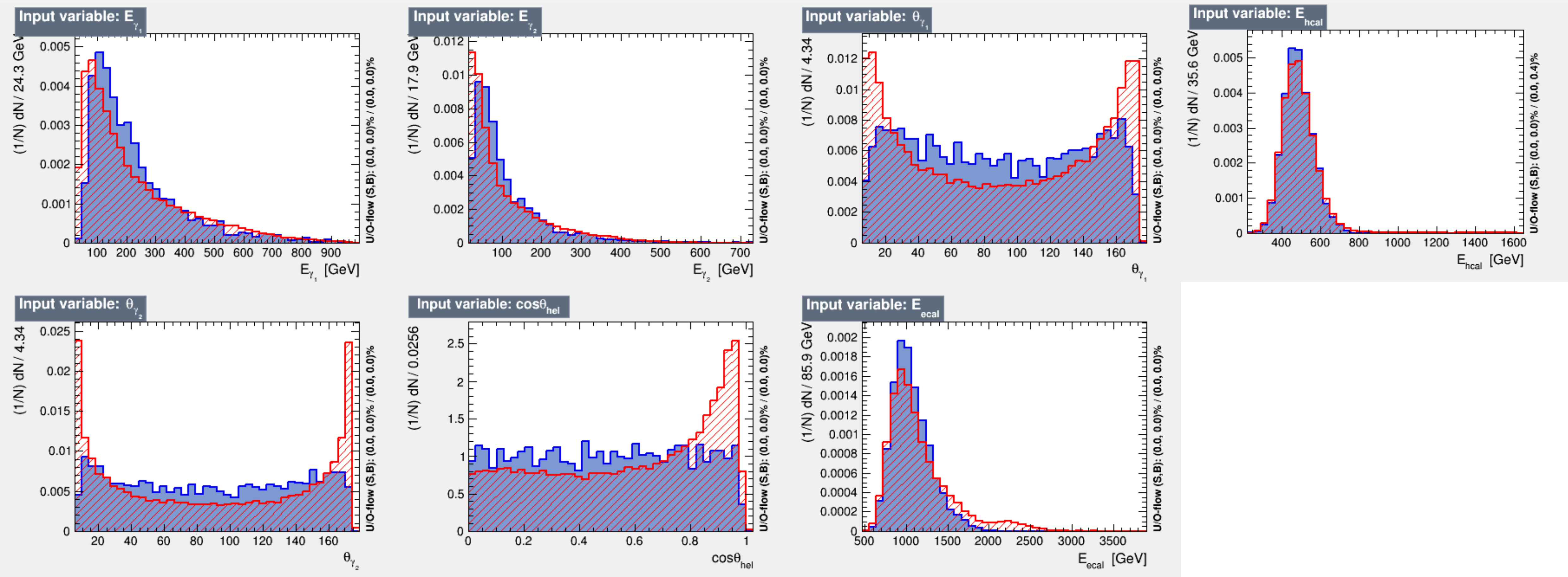
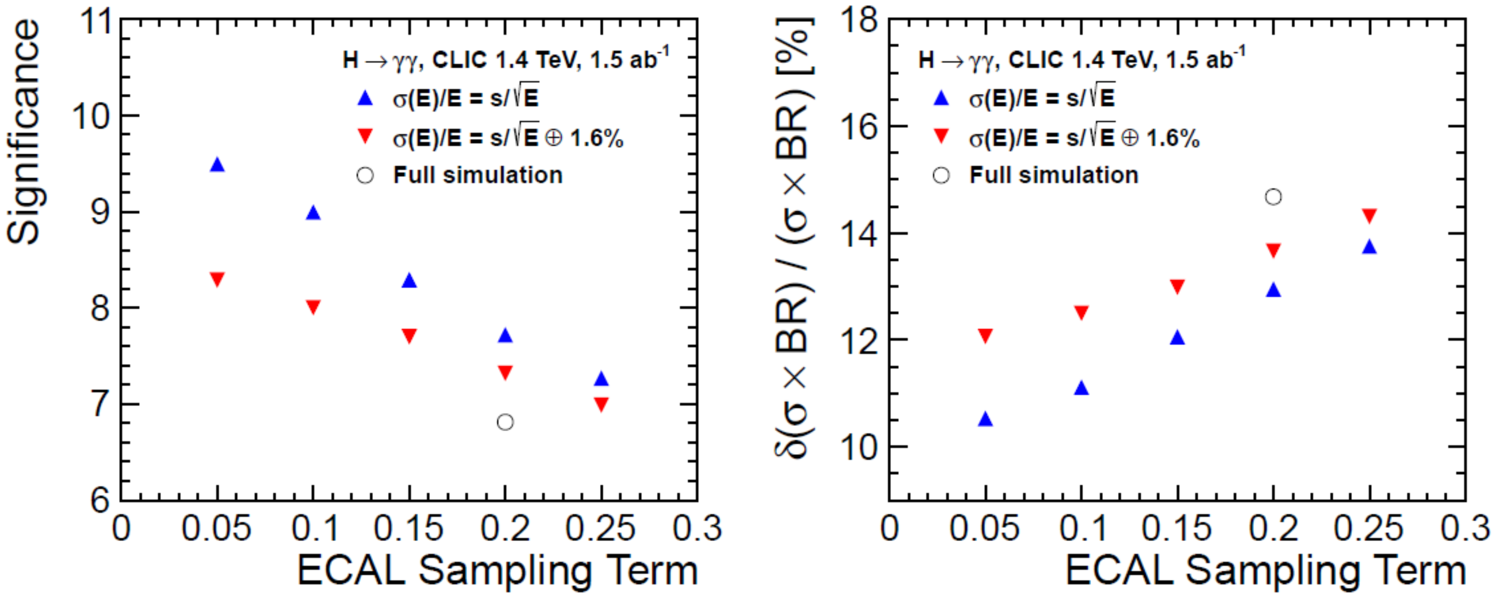


Dependence on ECAL Resolution in fast simulation at CLIC at 1.4 TeV

- Differences due to non-Gaussian tails and non-linearity in full simulation
- Improvement of sampling term 20% → 5%:
  rel. stat. uncertainty: 13.7% → 12.1% (with constant term)
  rel. stat. uncertainty: 12.9% → 10.5% (no constant term)



Credit: C. Grefe