Measurement of the Higgs branching ratio BR ($H \to \gamma\gamma$) at 3 TeV CLIC

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on behalf of CLICdp Collaboration

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Overview

- CLIC Detector
- Higgs to di-photon decays at future colliders
- $H \rightarrow \gamma\gamma$ @ 3 TeV CLIC
- Method of the analysis
- Results
- Summary

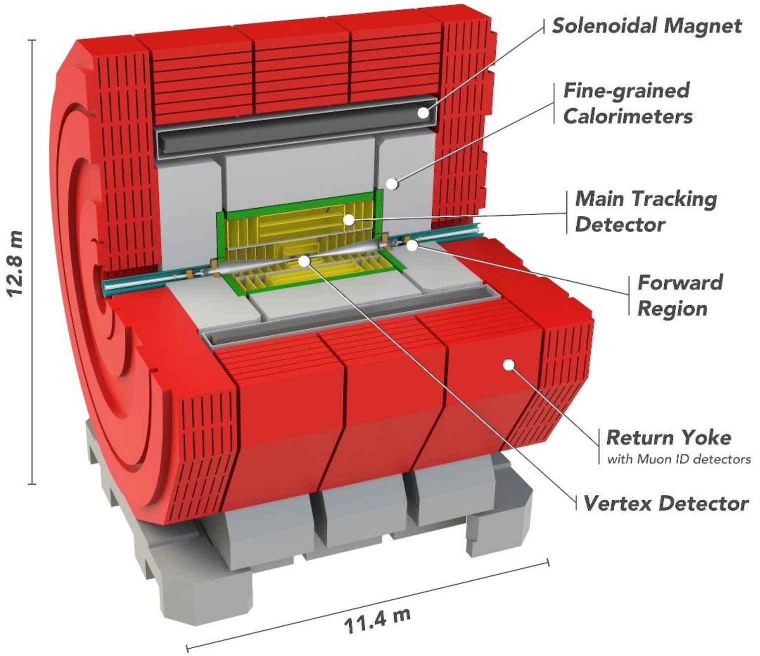
CLIC Detector

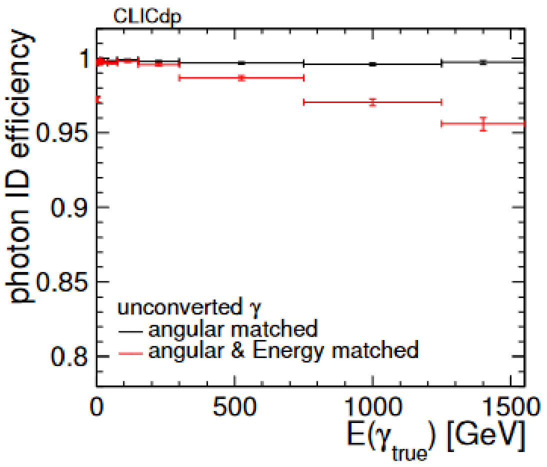
Mature lepton-collider project aiming for multi-TeV energies that can explore SM and BSM physics. Ready to be built already in 2026.

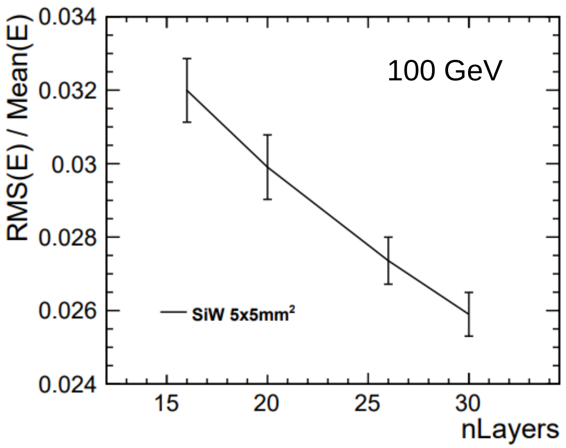
- 4T superconducting solenoid
- All-silicon low mass vertex and tracking detectors
- High-granularity calorimetry inside magnetic field
- **Optimized for Particle Flow reconstruction**
- Excellent performance of photon identification and reconstruction*
  - Photon identification efficiency ~ 99%
  - Photon energy resolution of 2%-3% due to optimized ECAL sampling term

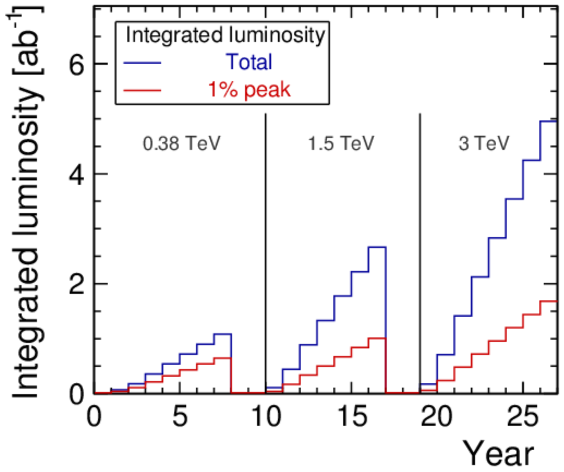
*Analysis is done with the CLIC_ILD [CDR], but the above holds

- CLIC is a Higgs factory:
  - ~$3.3 \cdot 10^6$ Higgs bosons at 3 TeV
  - $4.5 \cdot 10^6$ Higgs bosons in all stages (with polarization)
- High Higgs production x-section at higher energy stages enables access to rare decays ($H \to \mu\mu$, $H \to Z\gamma$, $H \to \gamma\gamma$)
- Staged approach enables combination of individual measurements in a global fit (model independent /dependent, EFT)









CLICdet: The post-CDR CLIC detector model

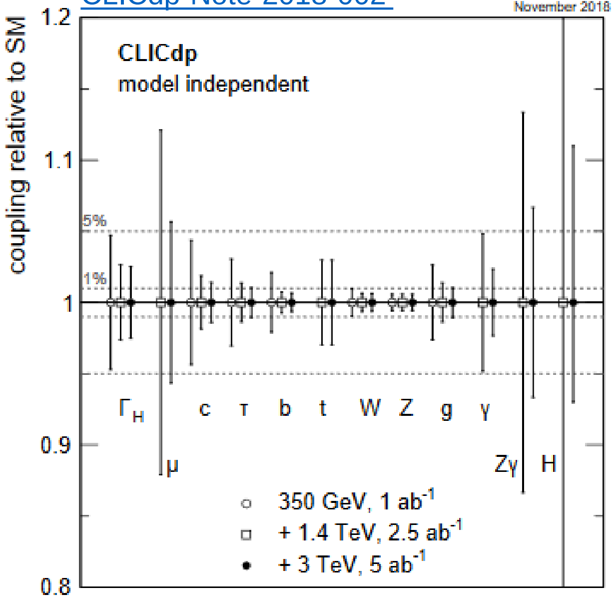
Higgs to di-photon decays at future colliders

ATLAS-CONF-2018-028

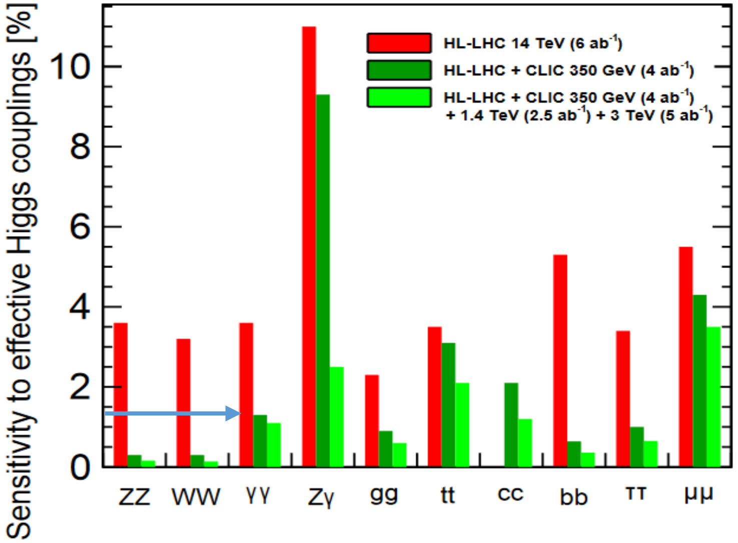
State-of-the-art from LHC: Combined production at ATLAS,13 TeV, 80 fb^{-1}
$\sigma \times BR = (60.4 \pm 6.1\ (stat.) \pm 6.0\ (exp.) \pm 0.3\ (theo.))$ fb

All future e+e- project nicely complements HL-LHC results, improving precision of $g_{H\gamma\gamma}$ coupling down to 1%

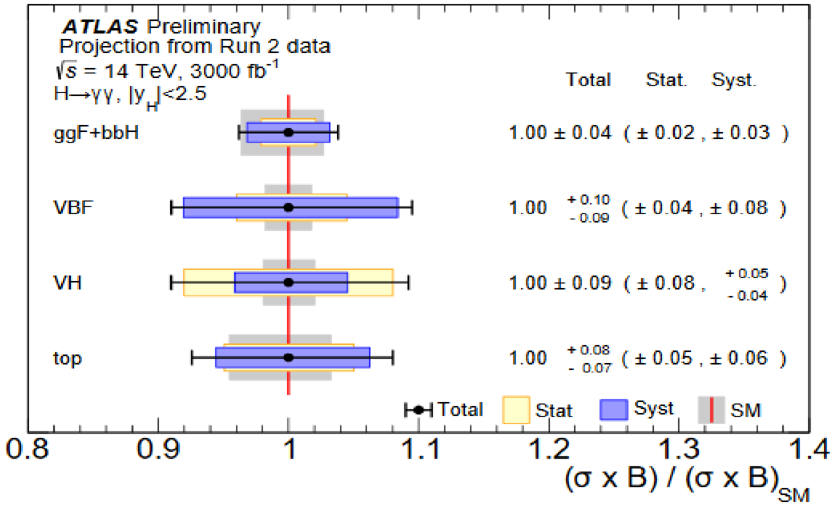
CLICdp-Note-2018-002



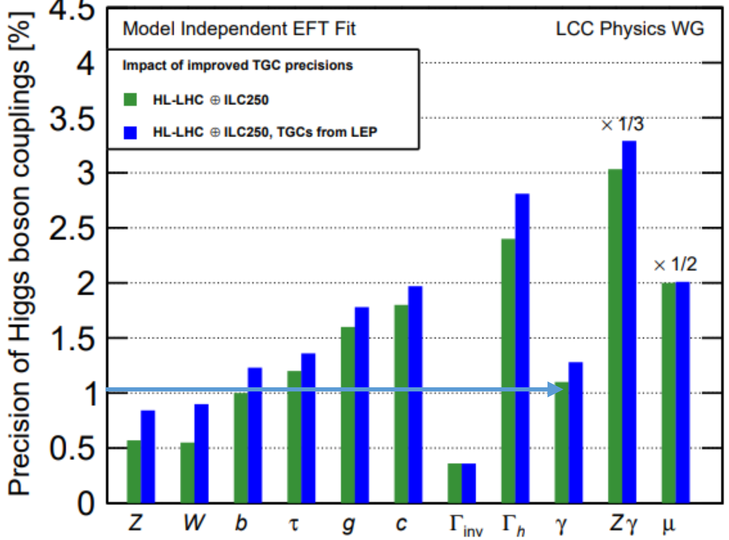
CLICdp-Note-2020-001



CERN-LPCC-2018-04



The ILC-A Global Project, arXiv:……..

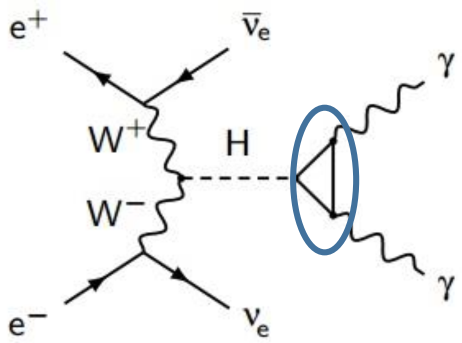


FCCee,

Coupling	FCC-ee 240 GeV (in %)	+FCC-ee at 365 GeV (in %)	+HL-LHC (in %)
δg_{HZZ}	0.25	0.22	0.21
δg_{HWW}	1.3	0.47	0.44
δg_{Hbb}	1.4	0.68	0.58
δg_{Hcc}	1.8	1.23	1.20
δg_{Hgg}	1.7	1.03	0.83
$\delta g_{H\tau\tau}$	1.4	0.8	0.71
$\delta g_{H\mu\mu}$	9.6	8.6	3.4
$\delta g_{H\gamma\gamma}$	4.7	3.8	1.3
δg_{Htt}			3.3
$\delta \Gamma_H$	2.8	1.56	1.3

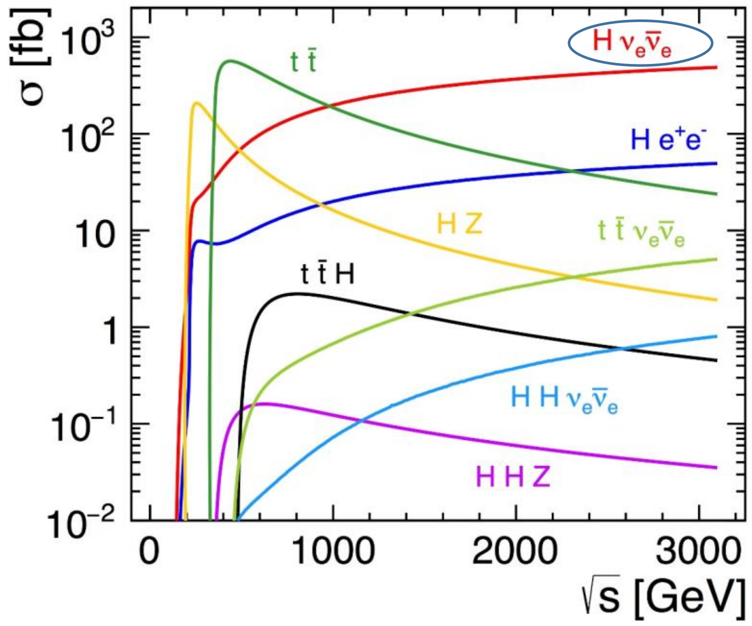
• H→γγ analysis @ 3 TeV CLIC

- Higgs boson is coupled to photons at the loop level and thus it is sensitive to eventual contribution of BSM physics through exchange of new heavy particles
- Benchmark channel for ECAL performance at LHC



- At 3 TeV CLIC there was no full simulation result on BR(H→γγ) measurement available, only estimate based on luminosity scaling of 1.4 TeV measurement

- WW-fusion dominates Higgs production at the energies above 500 GeV
- Production cross-section can be increased by a factor of 1.48, by electron-beam polarization (-80%):(+80%), with 4:1 runtime



- σ (Hνν) at 3 TeV is 415 fb
- BR(H→γγ) is 0.23%
- σ (Hνν)xBR(H→γγ) ≈0.95 fb
- $N_{signal} \approx 4750$evt/5ab^{-1}

Signal and background processes

Process	$\sigma_{effecive}$ (fb)	No. evt*, 5 ab^{-1}	No. evt. simulated
$\sigma(h\nu\nu) \times BR(h\to\gamma\gamma)$	0.95	4750	24 550
$e^+e^-\to\gamma\gamma$	19	$9.5 \cdot 10^5$	$3.0 \cdot 10^4$
$e^+e^-\to e^+e^-\gamma$	797	$4 \cdot 10^6$	$3.0 \cdot 10^6$
$e^+e^-\to e^+e^-\gamma\gamma$	56	$2.8 \cdot 10^5$	$1.5 \cdot 10^5$
$e^+e^-\to\nu\nu\gamma$	47	$2.4 \cdot 10^5$	$2.0 \cdot 10^5$
$e^+e^-\to\nu\nu\gamma\gamma$	49	$2.5 \cdot 10^5$	$1.6 \cdot 10^5$
$e^+e^-\to qq\gamma$	363	$1.9\cdot 10^6$	$1.2 \cdot 10^6$
$e^+e^-\to qq\gamma\gamma$	59	$3.0\cdot 10^5$	$3.0 \cdot 10^5$

All processes are produced with generator level cuts to reduce CPU time, requiring, among others 100 GeV < $M_{\gamma\gamma}$< 150 GeV

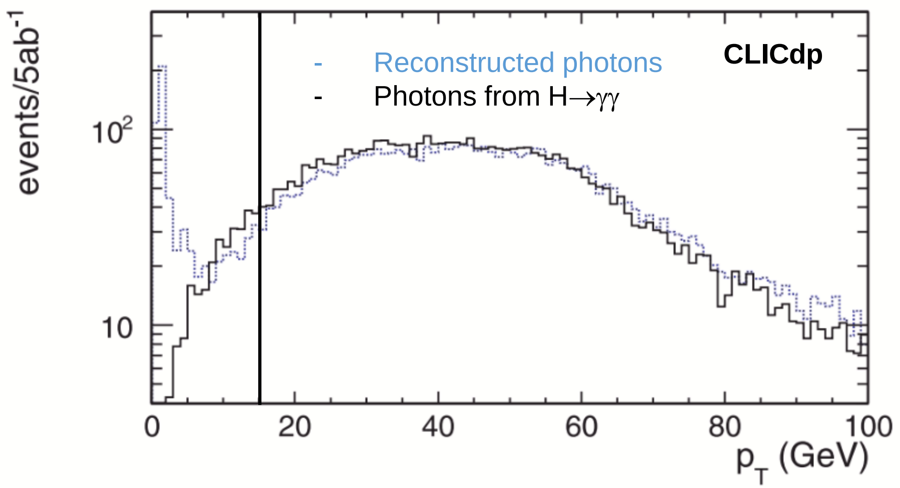
Method of the analysis

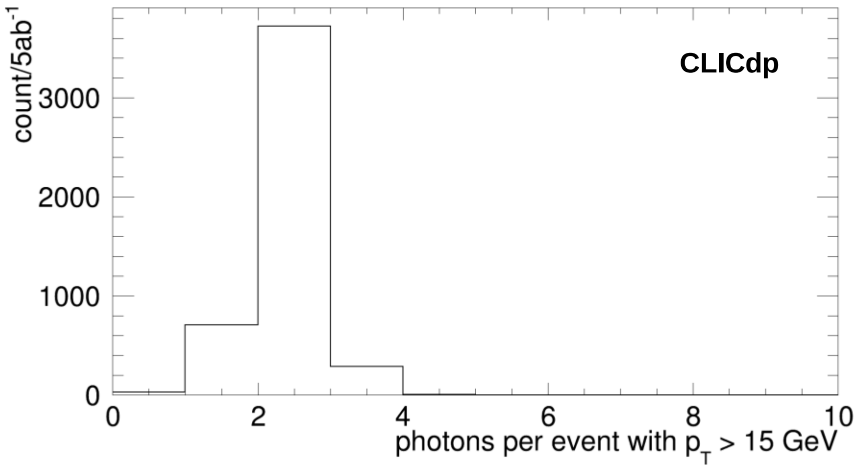
- **Observable** to measure $\sigma(H\nu\nu) \times BR(H \to \gamma\gamma) \sim N_S$
- **Number of signal events** N_S will be determined from selected experimental data (or pseudo-data)
- **Higgs candidate definition -** isolate and identify two Higgs candidate photons
- **Preselection -** reduction of the high cross-section background
- **MVA selection -** signal to background separation with optimised statistical significance S
- **PDF functions (**f_s and f_b) - mathematical description of signal and background
- **Pseudo-experiment** - combined fit of di photon invariant mass distribution: $f(m_{\gamma\gamma}) = N_s \cdot f_s(m_{\gamma\gamma}) + N_b \cdot f_b(m_{\gamma\gamma})$
- **5000 Toy-MC experiments** - pull distribution
- **Relative statistical uncertainty of the measurement** - RMS of the pull distribution

Higgs candidate definition

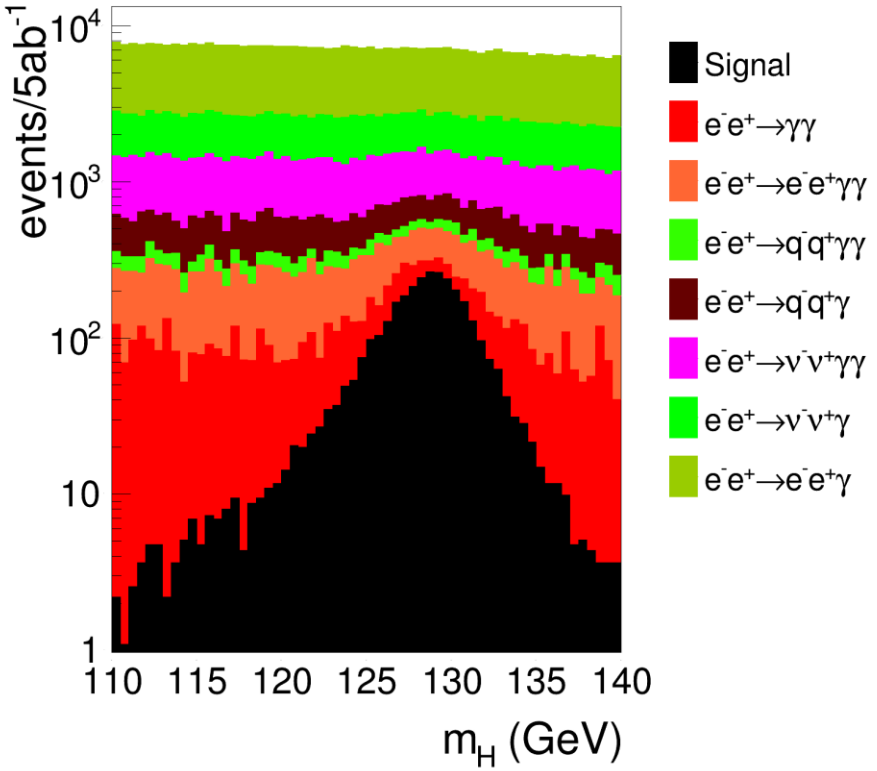
- Photon isolation: 14 mrad cone energy < 20GeV
  - Reduces background processes with FSR
  - 23% background rejection. Signal loss < 0.1%
- p_T > 15 GeV
  - Removing photons from ISR and Beamstrahrlung
- Exactly 2 isolated photons – 77.7% of reconstructed signal events
  - 14.8% events with one photon reconstructed (6% below barrel region,…)
  - 7.5% of events with 3 or more reconstructed photons

Signal efficiency is ~77.7 % by definition of the Higgs candidate.

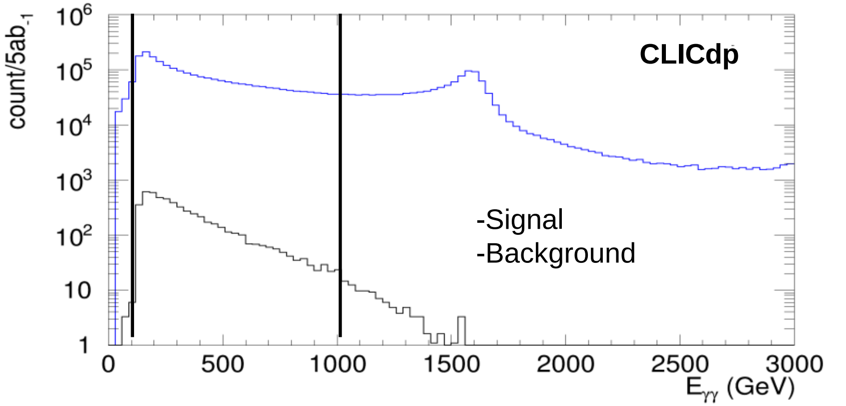


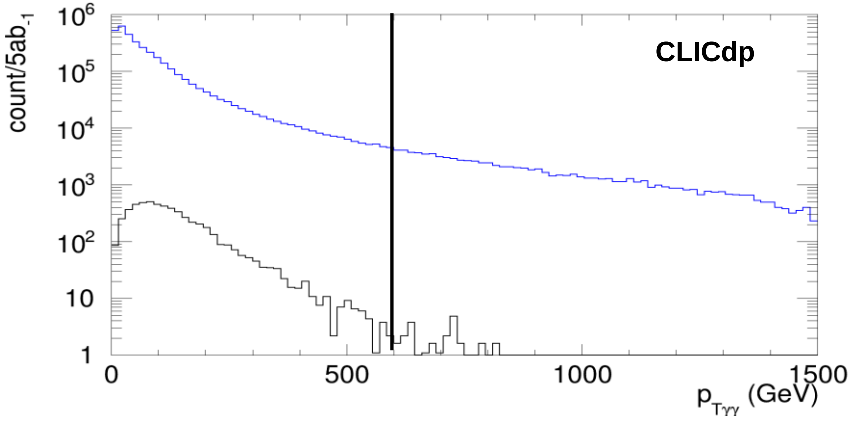


Preselection



- 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



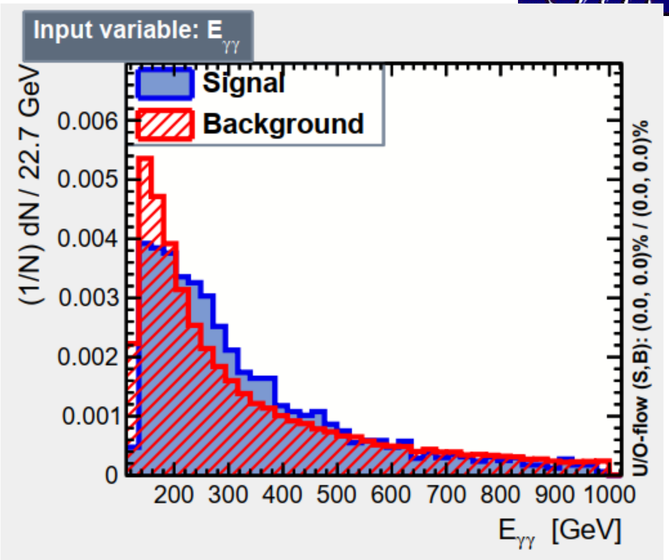


- Preselection efficiency: 70%
- Background is reduced by a factor of 1000
- Signal to background ratio (N_s/N_b) is $7.8 \cdot 10^{-3}$ after preselection

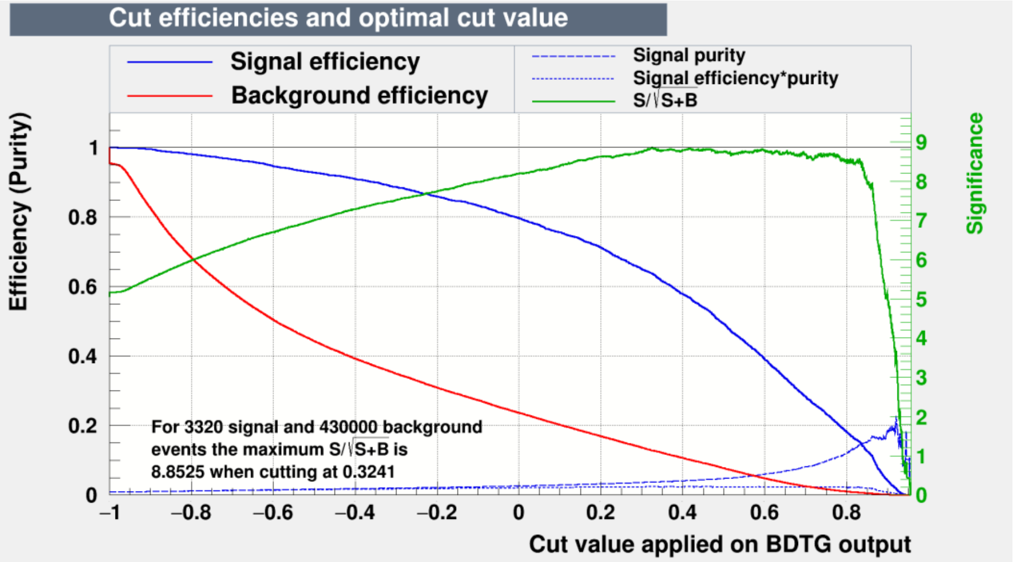
MVA variables and performance

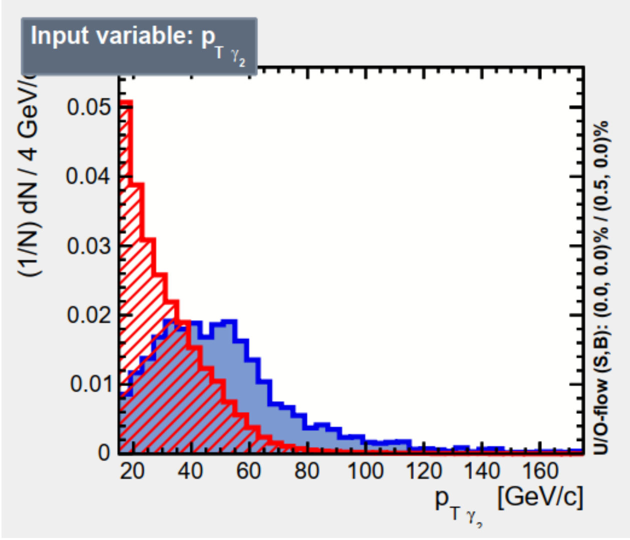
- 13 sensitive observables: E $(\gamma\gamma)$, p_T $(\gamma\gamma)$, θ $(\gamma\gamma)$, cos θ_{hel}, *p_T (γ_1) ,*p_T (γ_2), *θ (γ_1), *θ (γ_2),*E(γ_1), *E(γ_2), E_{ECAL}, E_{HCAL}

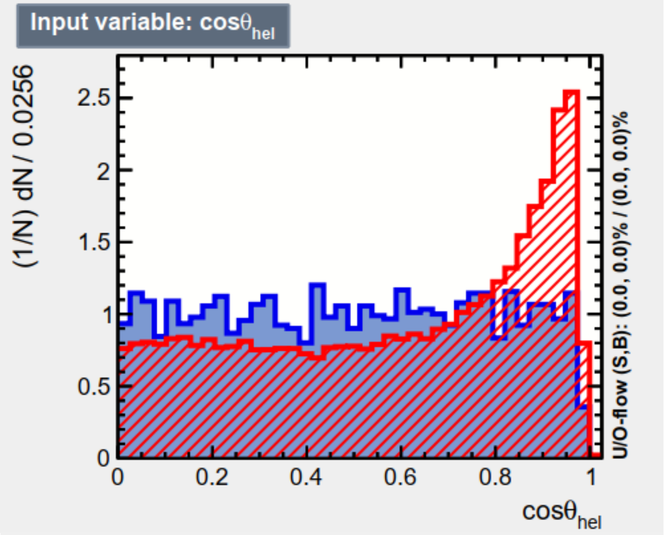
  ** Photons are sorted by higher value, where $p_T(\gamma_1) > p_T(\gamma_2)$*



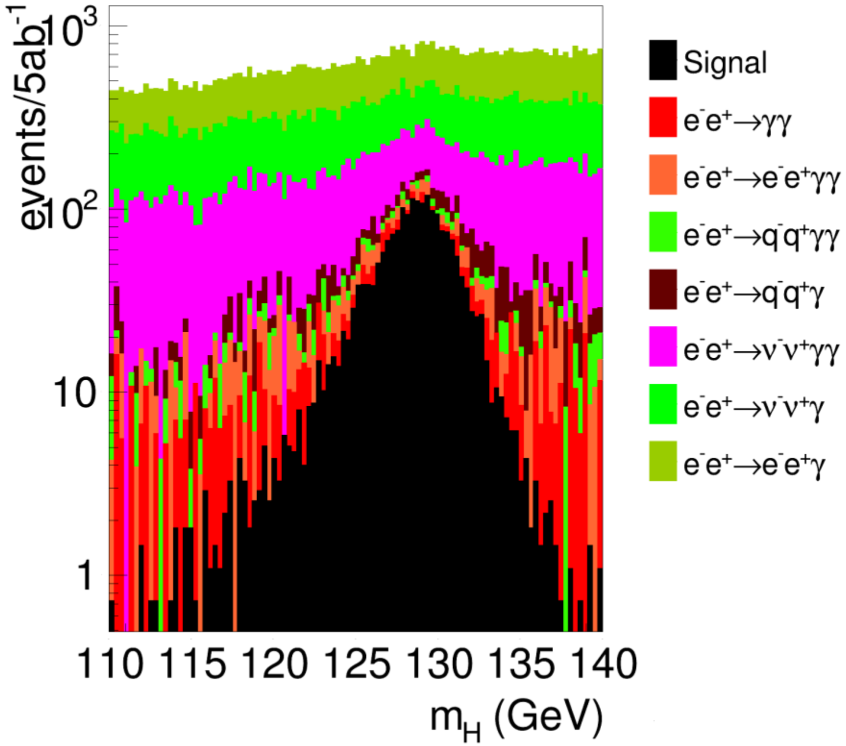
Best significance for BDTG > 0.32
BDTG efficiency: 62%







MVA results



Results after MVA selection			
5 ab^{-1}	Signal Events	Background events	Significance
Without polarization	2 062	60 327	8.3

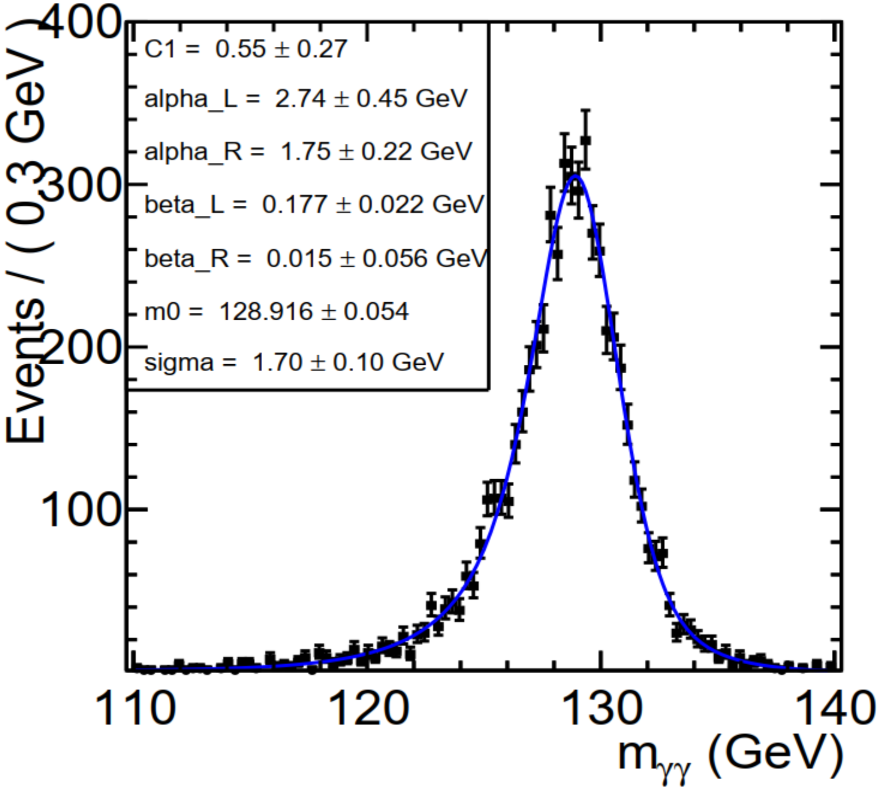
Total signal efficiency (BDTG + preselection): 43%

No. of signal evt. after preselection and MVA: 2062/5ab^{-1}

Polarization will increases cross-sections for signal and background by a factor of 1.48

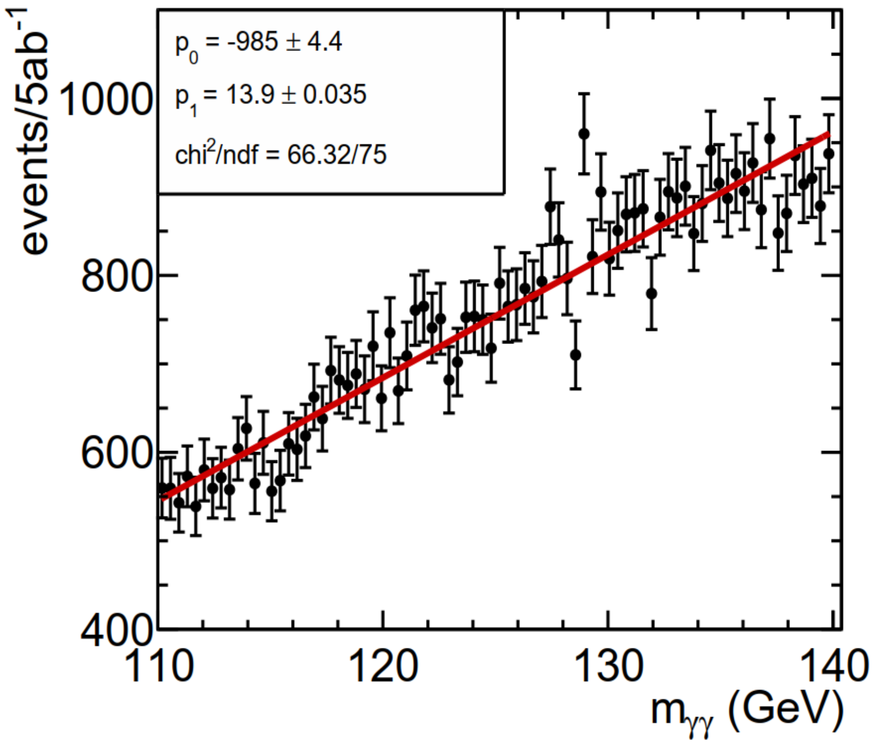
PDF functions

$f_s = C_1 \cdot f_{exp} + f_{flat}$



Signal

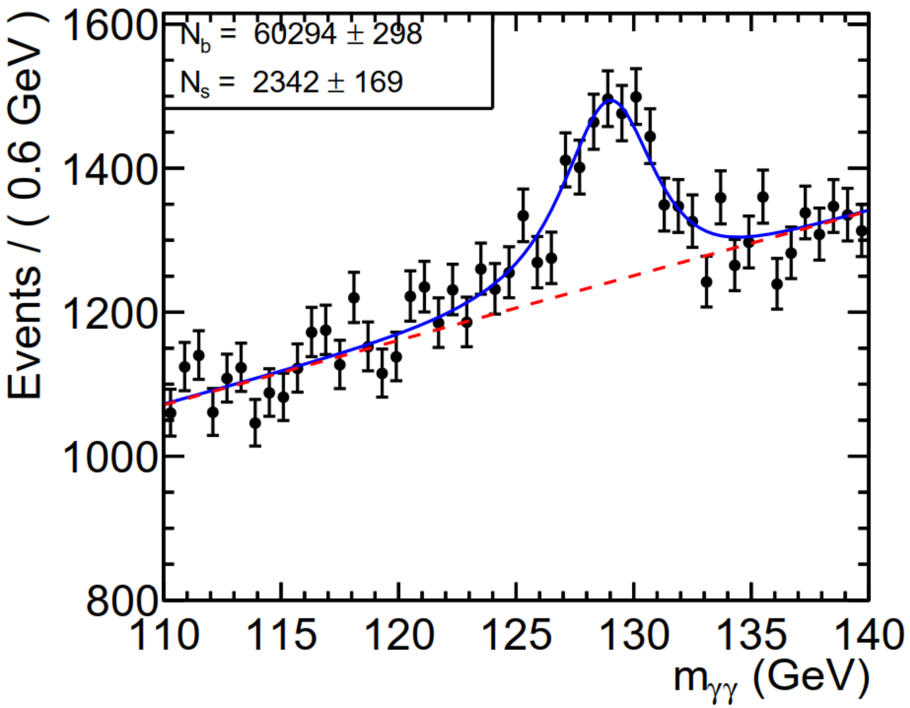
$f_b = p_0 + p_1 \cdot x$

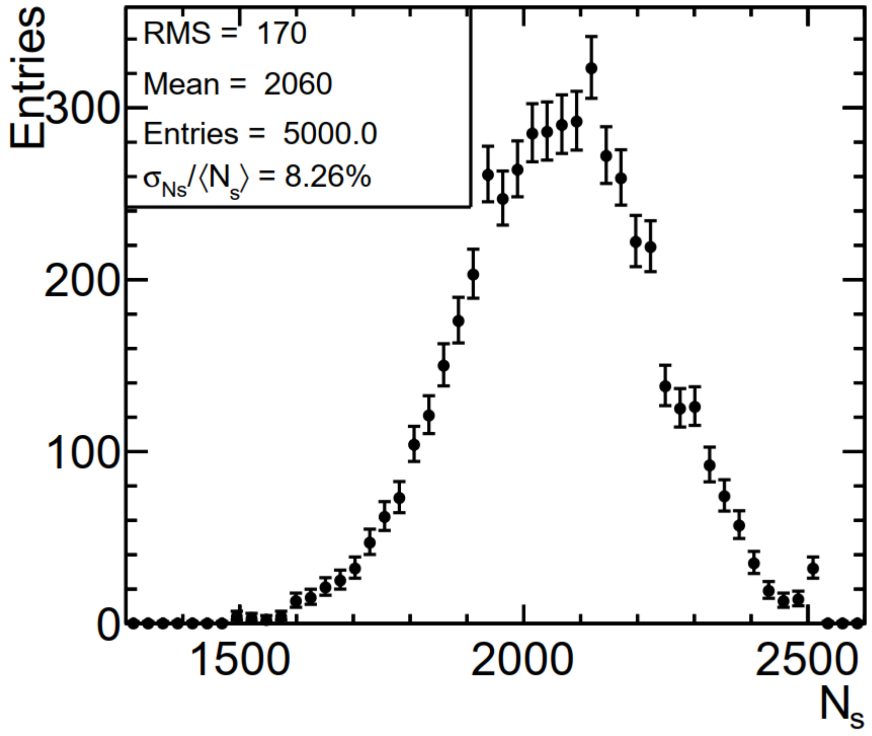


Background

Toy MC experiments

$$f(m_{\gamma\gamma}) = N_s \cdot f_s(m_{\gamma\gamma}) + N_b \cdot f_b(m_{\gamma\gamma})$$





Pull distribution from 5000 Toy MC experiments

Uncertainties of the measurement

3 TeV CLIC 5 ab^{-1} (5000 Toy MC)	Preliminary
Signal selection efficiency ε_s	43 %
δ (σ x BR)$_{stat.}$	**8.3 %**

Effect	Systematic Uncertainty
1) Uncertainty of the luminosity spectrum reconstruction	0.15%
2) Uncertainty of the integrated luminosity	<1%
3) Uncertainty of photon identification efficiency	2%
4) Photon energy resolution	negligible
Total systematic uncertainty	**2.2%**

Considered systematic effects

1. Luminosity spectrum [arxiv.org/abs/1608.07538]
2. Integrated luminosity uncertainty of <1% [arxiv.org/abs/1006.2539]
3. Uncertainty of photon identification efficiency (1%) [CLICdp-Note-2018-005.pdf]
4. 2% relative uncertainty of the sampling term [CLICdp-Note-2017-001.pdf] → uncertainty of photon energy resolution of ~40 MeV

Authors intend to publish paper that is currently under Collaboration review. In this sense, presented results are preliminary.

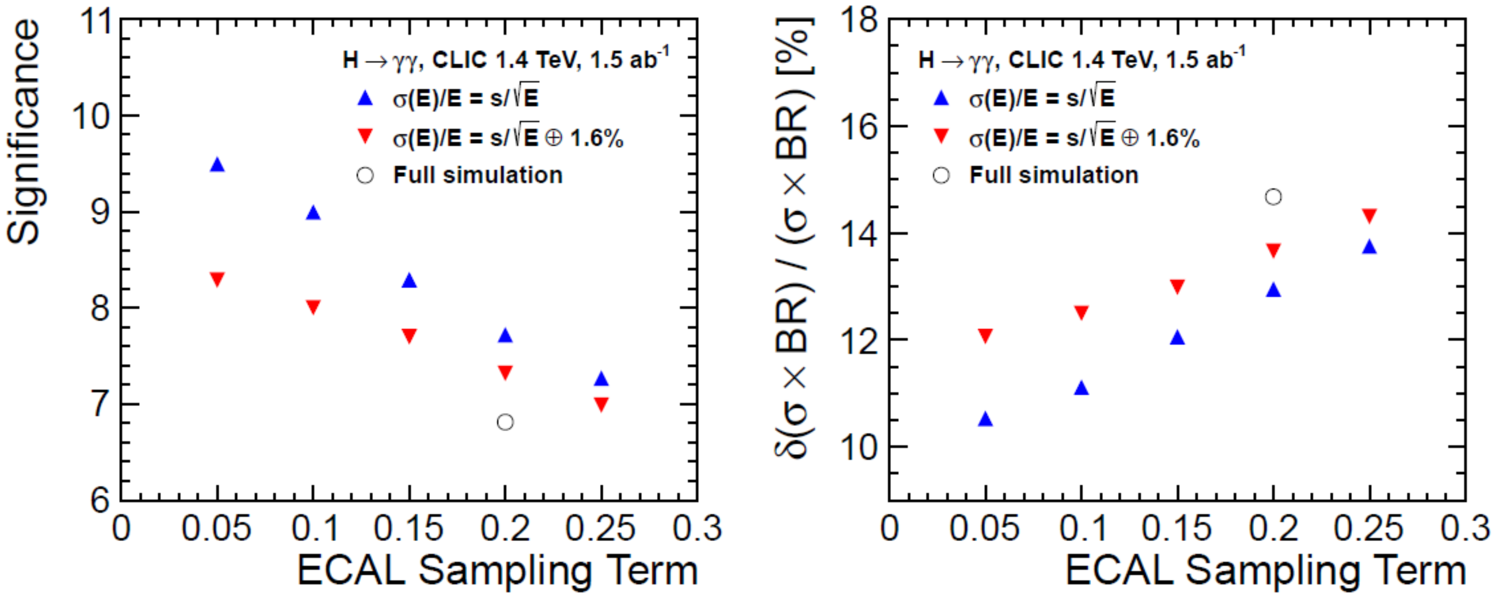
Summary

- Realistic simulation of experimental measurement of $\sigma(H\nu\nu)\times BR(H\rightarrow\gamma\gamma)$ at 3 TeV CLIC
- 5 ab^{-1} of simulated data with 8.3 % statistical dissipation of the counted number of signal events
- Systematic uncertainty is estimated to be 2.2%, dominantly originating from uncertainty of photon identification efficiencyThis results completes set of individual CLIC $\sigma(H\nu\nu)\times BR(H\rightarrow\gamma\gamma)$ measurements at energies above 1 TeV

Back up

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

Higgs to di-photon decays at colliders