Status Report of Measurement of the Higgs Couplings to Gauge Bosons at CLIC

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on behalf of the CLIC Detector and Physics Study

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Introduction

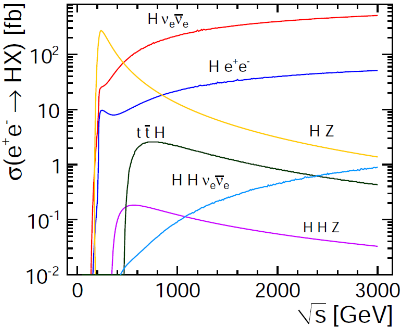
Motivation

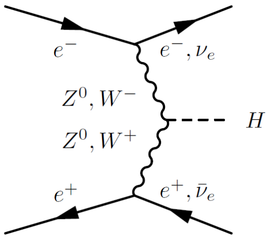
- The presented analyses are part of an ongoing effort to investigate the complete physics potential of a CLIC collider operated at various energies for measurements of the Standard Model Higgs boson properties
- Goal
  - Measurement of Higgs coupling to gauge bosons at CLIC
  - Measurement of the ratio of the H-to-W and H-to-Z couplings at CLIC
- Ongoing analyses
  - Higgs boson production in W^+W^--fusion
    (1) $H \rightarrow WW^*$ at 350 GeV and 1.4 TeV[1]
    (2) $H \rightarrow \gamma\gamma$ measured at 1.4 TeV[1]
    (3) $H \rightarrow Z^0\gamma$ measured at 1.4 TeV[1]
  - Higgs boson production in Z^0Z^0-fusion
    (4) $H \rightarrow b\bar{b}$ at 1.4 TeV[2]

[1] Analysis covered in this talk

[2] Analysis in progress but not presented here

Higgs Production in Vector Boson Fusion

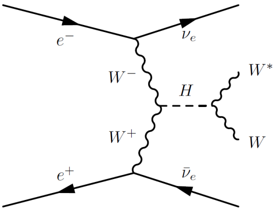




- Above $\sqrt{s} = 500\,\text{GeV}$, the W^+W^--fusion is the dominant H production channel
  - Possibility to study many Higgs decay channels including very rare channels
- The Z^0Z^0-fusion has an approximately 10 times lower cross section
  - Study this Higgs production channel in Higgs decay channels with large branching ratios

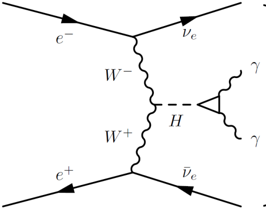
Higgs Production in W^+W^--Fusion

- Assuming Higgs mass of $M_H = 126\,\text{GeV}$
- Above $\sqrt{s} = 500\,\text{GeV}$, the W^+W^--fusion is the dominant Higgs production channel in e^+e^-collsions
- Higgs decay to bosons
  - Possibility to study $H \rightarrow WW^*$ with large statistics
  - Also rare Higgs decay channels can be studied, e. g. $H \rightarrow \gamma\gamma$, $H \rightarrow Z^0\gamma$



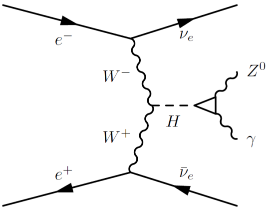
$H \rightarrow WW^*$

$BR_{H\rightarrow WW^*} = 23\%$



$H \rightarrow \gamma\gamma$

$BR_{H\rightarrow\gamma\gamma} = 0.23\%$

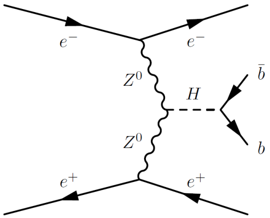


$H \rightarrow Z^0\gamma$

$BR_{H\rightarrow Z^0\gamma} = 0.16\%$

Higgs Production in Z^0Z^0-Fusion

- The Z^0Z^0-fusion has an approximately 10 times smaller cross section than the W^+W^--fusion at the same collision energy
  - Study this production channel in the most probable Higgs decay channel $H \to b\bar{b}$
- Comparison of $H \to b\bar{b}$ results between Z^0Z^0-fusion and W^+W^--fusion
  - Precise measurement of the ratio of the H-to-W and H-to-Z couplings, expected precision 0.5 % for $\sqrt{s} = 1.4$ TeV, 1.5 ab^{-1}

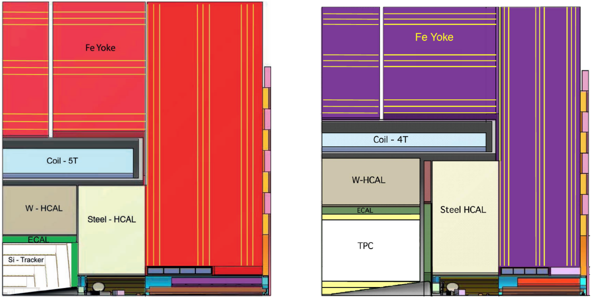


$H \to b\bar{b}$

$BR_{H\to b\bar{b}} = 56\%$

Detector Simulation and Reconstruction

- Full **CLIC_SiD** or **CLIC_ILD** detector simulation of signal and background events
  - Same software chain as used for the CLIC Conceptional Design Report
  - Full GEANT4 detector simulation
  - Overlay of $\gamma\gamma \rightarrow$ hadrons background
  - Full event reconstruction



- Integrated luminosity of 4-5 years data taking assuming no polarisation: e. g. $\sqrt{s} = 350$ GeV: 500 fb^{-1}, $\sqrt{s} = 1.4$ TeV: 1.5 ab^{-1}

Photon Reconstruction

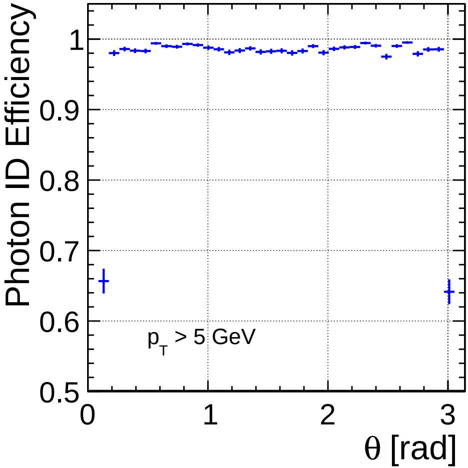
Photon Reconstruction Efficiency

- $H \rightarrow \gamma\gamma$ and $H \rightarrow Z^0\gamma$ analyses can be used to test the quality of the γ reconstruction in CLIC_SiD

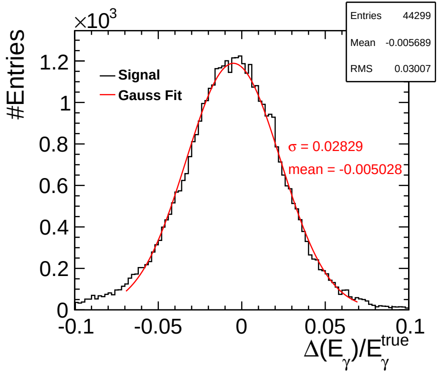
Photon Reconstruction Efficiency

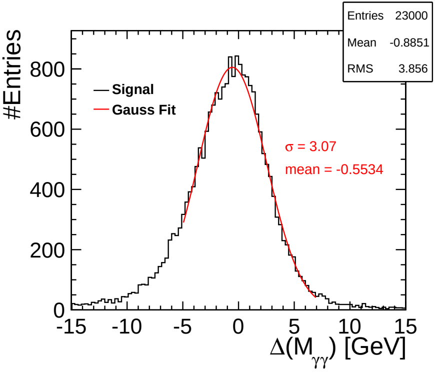
- $H \to \gamma\gamma$ and $H \to Z^0\gamma$ analyses can be used to test the quality of the γ reconstruction in CLIC_SiD

- Reconstruction ID efficiency of $H \to \gamma\gamma$ signal sample at 1.4 TeV
- Mean photon energy of signal sample $E_\gamma = 135$ GeV
- Reconstruction ID efficiency for photons with $p_T > 5$ GeV is roughly 98 %, descreasing towards forward direction



Energy and Mass Resolution in $H \to \gamma\gamma$

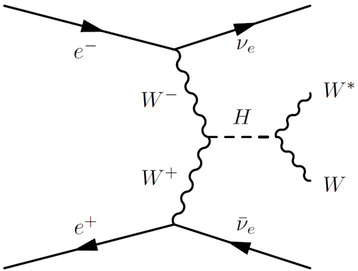




- Photon energy resolution and Higgs mass resolution for $H \to \gamma\gamma$ signal sample
- Mean photon energy of signal sample $E_\gamma = 135\,\text{GeV}$

$e^+e^- \rightarrow H\nu\bar{\nu}$; $H \rightarrow WW^*$

Signal Process $e^+e^- \to H\nu\bar{\nu}$; $H \to WW^*$



- $\sigma(e^+e^- \to H\nu\bar{\nu}) \approx 52\,\text{fb}$ for $\sqrt{s} = 350\,\text{GeV}$
  - $\text{BR}_{H\to WW^*} \approx 23\,\% \Rightarrow \sigma \times \text{BR} \approx 12\,\text{fb}$
  - $N_{\text{signal}} \approx 6000/500\,\text{fb}^{-1}$
- $\sigma(e^+e^- \to H\nu\bar{\nu}) \approx 244\,\text{fb}$ for $\sqrt{s} = 1.4\,\text{TeV}$
  - $\text{BR}_{H\to WW^*} \approx 23\,\% \Rightarrow \sigma \times \text{BR} \approx 56\,\text{fb}$
  - $N_{\text{signal}} \approx 84500/1.5\,\text{ab}^{-1}$

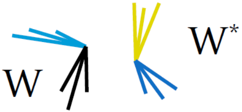
Signal and Background for $H \to WW^*$ Study

- Signal channel $H \to WW^*$:
  - Semileptonic final state
    $$\nu\bar{\nu}H \to \nu\bar{\nu}WW^* \to \nu\bar{\nu}q\bar{q}l\nu_l$$
  - Fully hadronic final state
    $$\nu\bar{\nu}H \to \nu\bar{\nu}WW^* \to \nu\bar{\nu}q\bar{q}q\bar{q}$$

- Relevant background channels:
  - 2 final state fermions l^+l^-, $q\bar{q}$
  - 4 final state fermions from W^+W^-, Z^0Z^0, $Z^0\nu\bar{\nu}$, and $Z^0e^+e^-$
  - 6 final state fermions from $Z^0W^+W^-$ and $t\bar{t}H$

$H \to WW^*$ - Fully Hadronic Final State

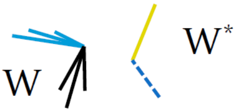
- Reconstruction
  - Jet reconstruction using fastjet, k_T-algorithm, exclusive mode (4-jets)
  - 3 pairwise combinations, assert that one pair comes from the on-shell W ($M_{\text{di-jet}} \approx M_W$)



- Signal/background classification using kinematic variables
  - Jet resolution parameters y_{ij} at which the event changes from a i-jet like topology to a j-jet like topology: y_{23}, y_{34}, y_{45}
  - Net p_z
  - Total multiplicity to sub-jet multiplicity
  - Inclusive/anti-b tags with 4 jets to reject Z bosons
  - Invariant mass hypothesis/χ^2 for di-jet $M_{\text{di-jet}} \approx M_W$ and 4-jet $M_{\text{4-jet}} \approx M_H$

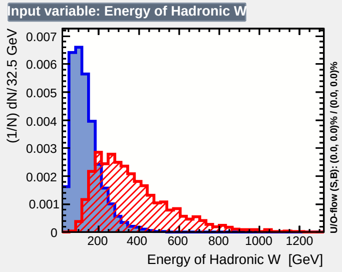
$H \rightarrow WW^*$ - Semi-Leptonic Final State

- Reconstruction
  - Identify charged lepton
  - Jet reconstruction of remainder particles using fastjet, k_T-algorithm, exclusive mode (2-jets)
  - Assert that di-jet mass comes from on-shell W or that the lepton energy is compatible with that expected from W decay



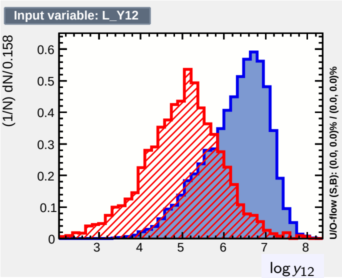
- Signal/background classification using kinematic variables
  - Energy of hadronic W
  - Jet resolution parameters y_{ij} at which the event changes from a i-jet like topology to a j-jet like topology: y_{12}, y_{23}, y_{34}
  - Thrust
  - Total multiplicity to sub-jet multiplicity for (forced into) di-jet system
  - Invariant mass hypothesis/χ^2 for di-jet $M_{\text{di-jet}} \approx M_W$
  - Transverse momentum $p_T(q\bar{q})$

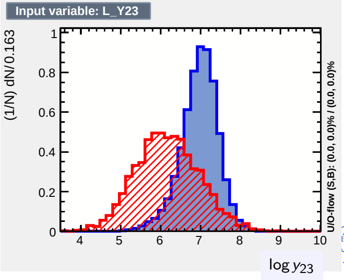
First Comparison of Signal and Background at 1.4 TeV



- Signal: $H \to WW^* \to q\bar{q} l \nu_l$
- Background: $q\bar{q}$

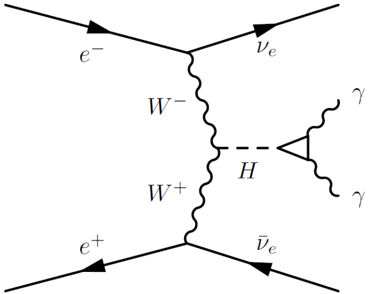
- Histograms normalized to same integral
- Next steps
  - Simulate and include all relevant background channels





$e^+e^- \to H\nu\bar{\nu}$; $H \to \gamma\gamma$

Signal Process $e^+e^- \to H\nu\bar{\nu}$; $H \to \gamma\gamma$



- $\sigma(e^+e^- \to H\nu\bar{\nu}) \approx 244\,\mathrm{fb}$ for $\sqrt{s} = 1.4\,\mathrm{TeV}$
- $\mathrm{BR}_{H\to\gamma\gamma} \approx 0.23\,\% \Rightarrow \sigma \times \mathrm{BR} \approx 0.56\,\mathrm{fb}$
- $N_{\mathrm{signal}} \approx 840/1.5\,\mathrm{ab}^{-1}$

Simulation of Background Samples for $H \to \gamma\gamma$

- Background can have very large cross sections
- Use generator level cuts to reduce required background samples for detector simulation

- Generator level cuts for $H \to \gamma\gamma$ analysis
  - At least two photons with $E > 10\,\text{GeV}$, $p_\text{T} > 5\,\text{GeV}$ and $5^\circ < \theta < 175^\circ$
  - At least one Higgs candidate with $110 < M(\gamma\gamma) < 140\,\text{GeV}$
  - No visible lepton or quark with $10^\circ < \theta < 170^\circ$

Relevant Background Samples for $H \to \gamma\gamma$

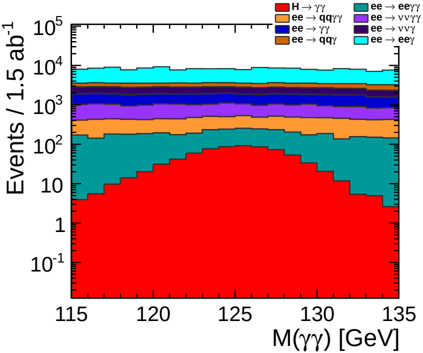
Process (- ISR)	σ[fb][3]	Events in 1.5 ab^{-1}
$e^+e^- \to \nu\bar{\nu}\gamma$	30	44000
$e^+e^- \to \nu\bar{\nu}\gamma\gamma$	17	26000
$e^+e^- \to \gamma\gamma$	27	41000
$e^+e^- \to e^+e^-\gamma$	290	430000
$e^+e^- \to e^+e^-\gamma\gamma$	13	19000
$e^+e^- \to q\bar{q}\gamma$	67	100000
$e^+e^- \to q\bar{q}\gamma\gamma$	17	25000

- Final state γ can also originate from ISR
- $e^\pm\gamma$ and $\gamma\gamma$ inital state processes are not relevant for this analysis

[3] after generator level cuts

Pre-Selection

- Use only reconstructed particles (PFO) that pass the default time selection cuts, reject out-of-time $\gamma\gamma \to$ hadrons backgrounds
  - Combined timing and transverse momentum cuts depending on the particle type, the transverse momentum, and the detector region
  - "Tight", "default", and "loose" timing cuts
- Use only reconstructed photons with $E > 15\,\text{GeV}$ and $p_T > 10\,\text{GeV}$
- Select two highest energy photons with $115 < M(\gamma\gamma) < 135\,\text{GeV}$ as Higgs candidate

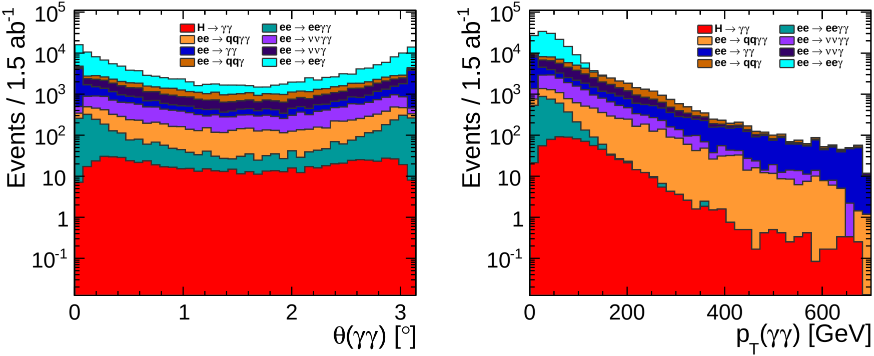


- Stacked histogram
- Contributions are normalized to the number of collected events (after pre-selection) recorded in 4 years of data taking corresponding to $1.5\,\text{ab}^{-1}$

Kinematic Variables

- Comparison of signal and background channels
  - Higgs candidate mass: $M(\gamma\gamma)$
  - Higgs candidate polar angle: $\theta(\gamma\gamma)$
  - Higgs candidate azimuthal angle: $\phi(\gamma\gamma)$
  - Higgs candidate transverse momentum: $p_{\mathrm{T}}(\gamma\gamma)$
  - Higgs candidate energy: $E(\gamma\gamma)$
  - Higgs candidate velocity: $\beta(\gamma\gamma)$
  - Scalar sum of transverse momenta: $\sum p_{\mathrm{T}} = p_{\mathrm{T},1} + p_{\mathrm{T},2}$
  - Angle between the photons: $\Delta\theta(\gamma\gamma)$
  - Total visible energy: E_{vis}

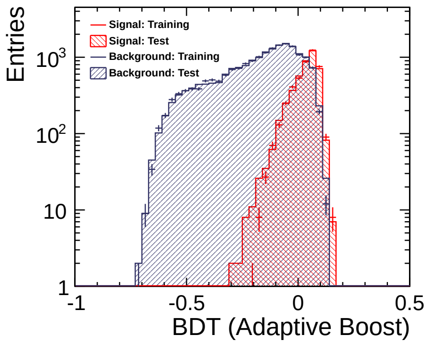
Comparison of Signal and Background

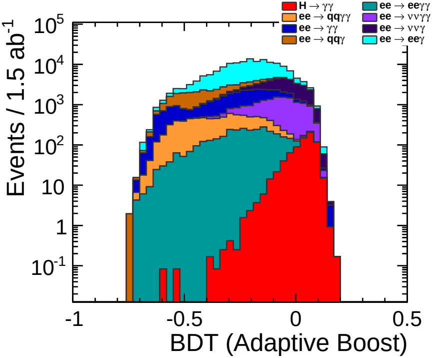


- Stacked histogram
- Contributions are normalized to the number of collected events (after pre-selection) recorded in 4 years of data taking corresponding to $1.5\,\mathrm{ab}^{-1}$

Multivariate Event Selection

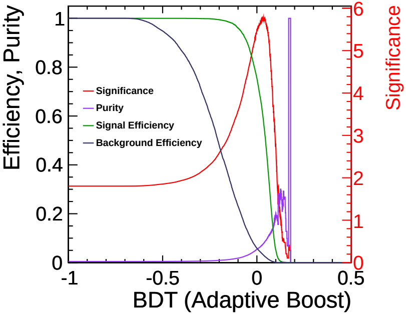
- Boosted decision trees (BDT) as implemented in TMVA are used for signal/background classification
- Several BDTs are tested for the $H \to \gamma\gamma$ analysis
- Here, adaptive boosting using 400 trees





Preliminary Results of $H \to \gamma\gamma$ Analysis

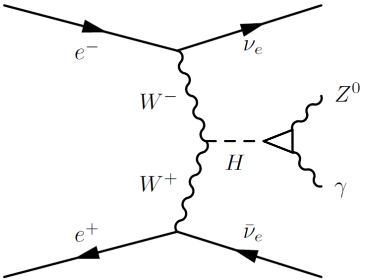
- Find BDT cut value at which significance is largest
  - Significance $= S/\sqrt{S+B}$
  - Purity $= S/(S+B)$
  - $S = \#$ of signal events, $B = \#$ of background events



- Preliminary results using adaptive boosting
  - Best significance: 5.8
  - Signal efficiency at best significance: 51 %
  - $\Rightarrow$ Uncertainty of measurement of $\sigma_{e^+e^- \to H\nu\bar{\nu}} \times \mathrm{BR}_{H \to \gamma\gamma} = 17\,\%$
- Ideas for improvement
  - Increase number of simulated events
  - Study additional variables in the multivariat analysis

$e^+e^- \to H\nu\bar{\nu}$; $H \to Z^0\gamma$

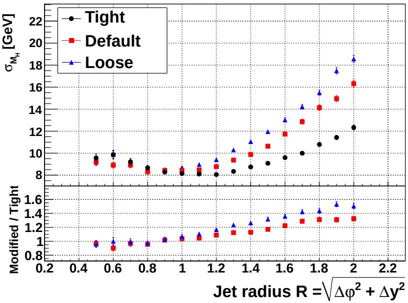
Signal Process $e^+e^- \to H\nu\bar{\nu}$; $H \to Z^0\gamma$



- $\sigma(e^+e^- \to H\nu\bar{\nu}) \approx 244\,\text{fb}$ for $\sqrt{s} = 1.4\,\text{TeV}$
- $\text{BR}_{H\to Z^0\gamma} \approx 0.16\,\% \Rightarrow \sigma \times \text{BR} \approx 0.39\,\text{fb}$
  - $\text{BR}_{Z^0\to q\bar{q}} \approx 69\,\%$ $\to N_{\text{signal}}(Z^0 \to q\bar{q}) \approx 408/1.5\,\text{ab}^{-1}$
  - $\text{BR}_{Z^0\to e^+e^-} \approx 3.4\,\%$ $\to N_{\text{signal}}(Z^0 \to e^+e^-) \approx 20/1.5\,\text{ab}^{-1}$
  - $\text{BR}_{Z^0\to \mu^+\mu^-} \approx 3.4\,\%$ $\to N_{\text{signal}}(Z^0 \to \mu^+\mu^-) \approx 20/1.5\,\text{ab}^{-1}$
  - Case $Z^0 \to \tau^+\tau^-$ not used in the following

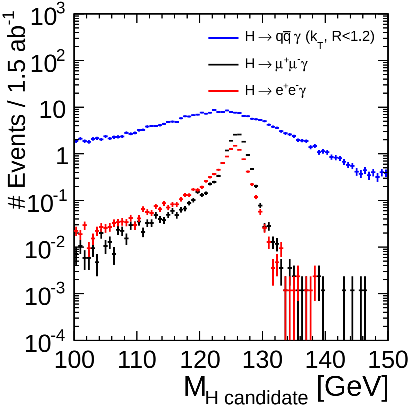
$H \rightarrow Z^0\gamma$ Reconstruction in Hadronic Case

- Signal reconstruction from hadrons in $\gamma\gamma \rightarrow$ hadrons background
- Reject out-of-time $\gamma\gamma \rightarrow$ hadrons background using timing cuts
  - Combined timing and transverse momentum cuts depending on the particle type, the transverse momentum, and the detector region
  - "Tight", "default", and "loose" timing cuts
- Jet reconstruction
  - fastjet, k_T-algorithm, exclusive mode (two jets)
  - Scan of $R = \sqrt{\Delta\varphi^2 + \Delta y^2}$ from 0.5 to 2.0



- "Tight" timing cut and jet radius of $R = 1.2$ give smallest width of reconstructed H peak

Signal $H \to Z^0\gamma$



- Applied "tight" timing cuts for all signal channels
- Jet reconstruction using fastjet, k_T-algorithm, exclusive mode (two jets), jet radius of $R < 1.2$

- Quark channel has largest branching ratio but broad mass peak
- μ and e channels have sharp mass peak but low branching ratio

Simulation of Background Samples for $H \to Z^0\gamma$

- Background channels can have very large cross sections
- Use generator level cuts to reduce required background samples for detector simulation

- Generator level cuts for $H \to Z^0\gamma$ analysis
  - At least one photon and two quarks or charged leptons with $E > 15\,\text{GeV}$, $p_T > 10\,\text{GeV}$ and $10^\circ < \theta < 170^\circ$
  - At least one Higgs candidate with $100 < M(Z^0\gamma) < 150\,\text{GeV}$

Relevant Background Channels e^+e^-

Process (- ISR)	σ[fb][4]	Events in 1.5 ab^{-1}
$e^+e^- \to \nu\bar{\nu}q\bar{q}\gamma$	-	-
$e^+e^- \to \nu\bar{\nu}q\bar{q}$	122	182000
$e^+e^- \to q\bar{q}$	4000[5]	5916000
$e^+e^- \to q\bar{q}q\bar{q}$	1328[5]	1995230
$e^+e^- \to \nu\bar{\nu}l^+l^-\gamma$	-	-
$e^+e^- \to \nu\bar{\nu}l^+l^-$	23	34000
$e^+e^- \to l^+l^-l^+l^-$	85	127000
$e^+e^- \to q\bar{q}l^+l^-\gamma$	-	-
$e^+e^- \to q\bar{q}l^+l^-$	97	147000

- Final state γ can also originate from ISR
- Processes with $e^+e^- \to 5$ final states and $e^\pm\gamma$ inital state processes in processing
- $\gamma\gamma$ intital state processes are not relevant for this analysis

[4] after generator level cuts

[5] w/o generator level cuts

Pre-Selection

- Use only reconstructed particles that pass the tight time selection cuts
- Use only reconstructed photons, jets, muons, and electrons of $E > 15$ GeV and $p_T > 10$ GeV
- Select events in which the photon of highest energy combined with the jet-pair or the two leptons of highest energy have an invariant mass of $100 < M(Z^0\gamma) < 150$ GeV

Kinematic Variables

- Comparison of signal and background channels
  - Mass of reconstructed H candidates and Z^0 candidates
  - Polar angle θ of H candidate
  - Transverse momentum p_T of H candidate
  - Energy E of H candidate
  - $\sum|\overrightarrow{p_\mathrm{T}}|$ of H candidate daughters
  - $\sum\overrightarrow{p_\mathrm{T}}$ of H candidate daughters

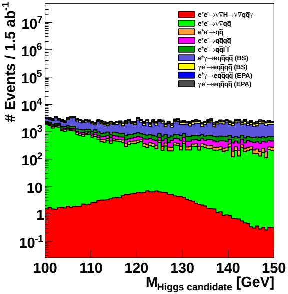
  - Event shapes: thrust, oblateness, sphericity, aplanarity of l^+l^- $(q\bar{q})$ and γ
  - Missing energy $\not{E}$ of l^+l^- $(q\bar{q})$ and γ
  - Missing transverse energy $\not{E}_\mathrm{T}$ of l^+l^- $(q\bar{q})$ and γ

  - Angle between vectors of Z^0 and γ
  - $\Delta\theta$ between Z^0 and γ
  - $\Delta\varphi$ between Z^0 and γ

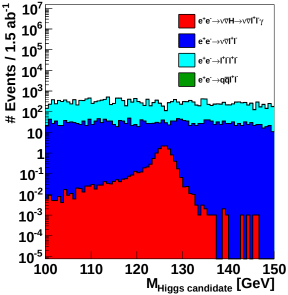
  - Visible energy excluding the reconstructed H candidate $E_\mathrm{vis} - E_H$
  - Particle multiplicity N

Comparison of Signal and Background: M_H

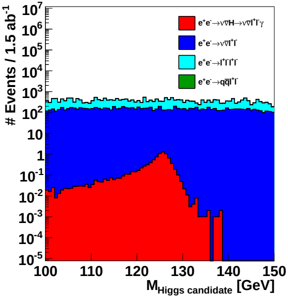
Jets



Muons

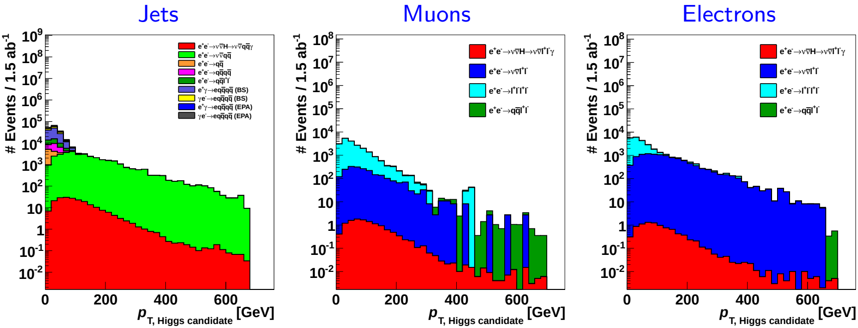


Electrons



- Stacked histogram
- Channels are scaled to number of events (after pre-selection) in $1.5\,\text{ab}^{-1}$
- Signal channels show H mass peak, background channels are flat
- Background channels dominate
- Next step:
    - Perform signal/background classification based on boosted decision trees as implemented in TMVA based on all kinematic variables

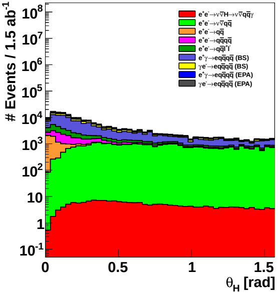
Comparison of Signal and Background: $p_{\mathrm{T},H}$



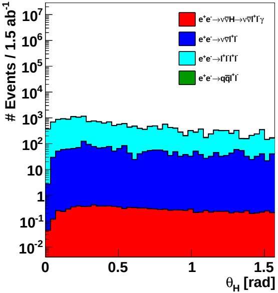
- Stacked histogram
- Channels are scaled to number of events (after pre-selection) in $1.5\,\mathrm{ab}^{-1}$
- Next step:
  - Perform signal/background classification based on boosted decision trees as implemented in TMVA based on all kinematic variables

Comparison of Signal and Background: θ_H

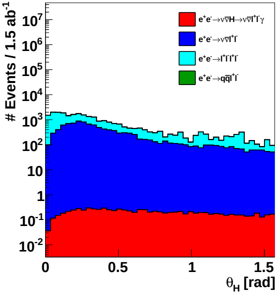
Jets



Muons



Electrons



- Stacked histogram
- Channels are scaled to number of events (after pre-selection) in $1.5\,\mathrm{ab}^{-1}$
- Next step:
  - Perform signal/background classification based on boosted decision trees as implemented in TMVA based on all kinematic variables

Summary: Higgs Couplings to Gauge Bosons at CLIC

- Higgs boson production in W^+W^--fusion

(1) $H \to WW^*$ at 350 GeV and 1.4 TeV
  - Analysis in progress
  - Study semi-leptonic final state and fully hadronic final state
  - Identify kinematic variables for signal/background classification
  - Simulate additional relevant background channels

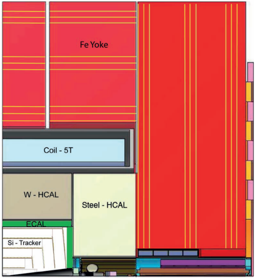
(2) $H \to \gamma\gamma$ measured at 1.4 TeV
  - Preliminary results: Uncertainty of measurement of $\sigma_{e^+e^- \to H\nu\bar{\nu}} \times \mathrm{BR}_{H\to\gamma\gamma}$ is 17 %
  - Towards final results:
    - Increase number of simulated events
    - Study additional kinematic variables for the multivariat analysis

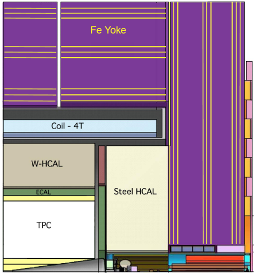
(3) $H \to Z^0\gamma$ measured at 1.4 TeV
  - Analysis in progress
  - Study quark, e, and μ channel
  - Identify kinematic variables for signal/background classification
  - Simulate additional relevant background channels

Backup

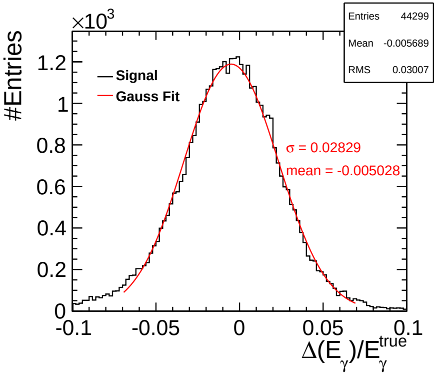
Detector Simulation and Reconstruction - Details

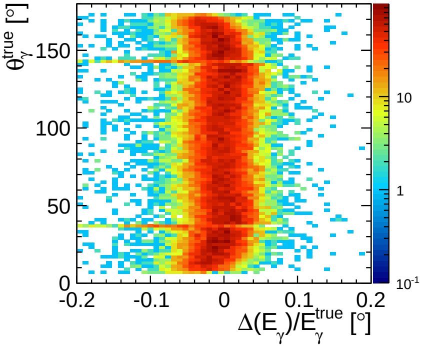
- Full **CLIC_SiD** or **CLIC_ILD** detector simulation of signal and background events
  - Assuming $M_H = 126\,\text{GeV}$
  - Event generation with WHIZARD v.1.95, including ISR and CLIC BS
  - Fragmentation using PYTHIA
  - Full simulation with SLIC v.2.9.8 in CLIC_SID_CDR and MOKKA v.0706P08 in CLIC_ILD_CDR both using GEANT4 v.9.3.2
  - Overlay of $\gamma\gamma \to$ hadrons background before digitization
  - Digitization and track reconstruction using `org.lcsim` and MARLIN
  - Particle flow reconstruction and particle identification using PANDORAPFA





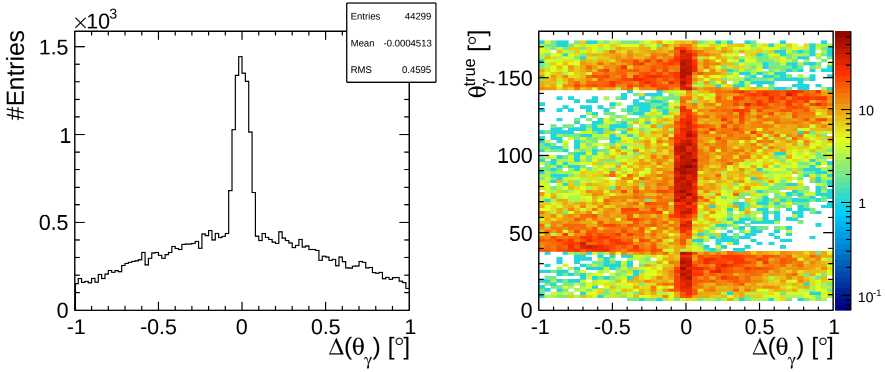
Photon Energy Resolution





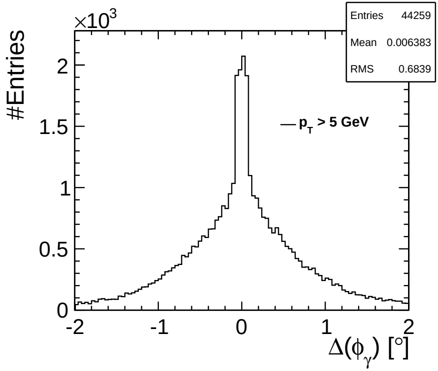
- $\Delta E_\gamma / E_\gamma$ follows a Gaussian distribution centered close to zero of a width of $\sigma = 0.02$
- Energy resolution is large in transition regions between central barrel and end caps

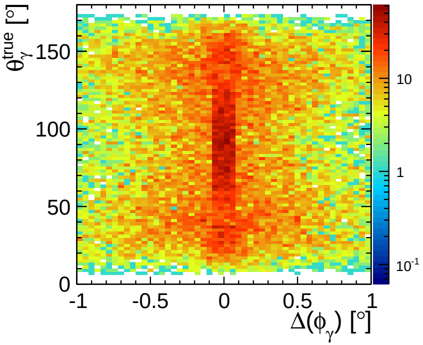
Photon Polar Angle Resolution



- Polar angle resolution shows a peak at zero on top of a rather flat background
- Polar angle resolution depends on the polar angle itself

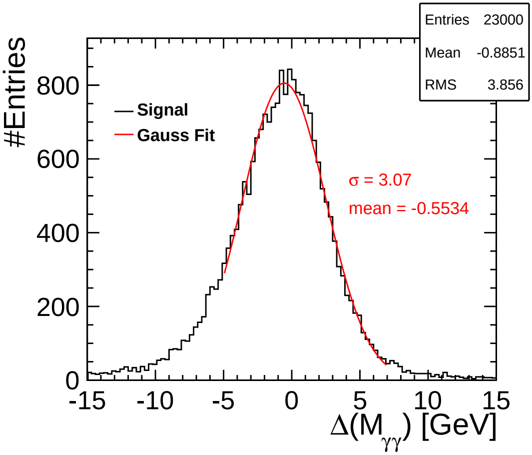
Photon Azimuthal Angle Resolution





- Azimuthal angle resolution shows a peak at zero followed by tails

Higgs Mass Resolution in $H \to \gamma\gamma$ Channel



- Higgs mass resolution from $H \to \gamma\gamma$ study
- $\Delta(M_{\gamma\gamma})$ follows a Gaussian distribution slightly shifted to negative values, mean $\approx -0.6\,\text{GeV}/c^2$, and with a width of $\sigma \approx 3\,\text{GeV}/c^2$

Variable Correlations: Signal and Background

Signal Correlations

	$M(\gamma\gamma)$	$\theta(\gamma\gamma)$	$\phi(\gamma\gamma)$	$p_T(\gamma\gamma)$	$E(\gamma\gamma)$	$\beta(\gamma\gamma)$	Σp_T	$\Delta\theta(\gamma\gamma)$	E_{vis}	E_{vis} - $E(\gamma\gamma)$
E_{vis} - $E(\gamma\gamma)$	-4								43	100
E_{vis}	-10	1	-1	45	90	69	46	-70	100	43
$\Delta\theta(\gamma\gamma)$	16		1	-44	-78	-85	-44	100	-70	
Σp_T		-1		94	51	43	100	-44	46	
$\beta(\gamma\gamma)$	-13			47	77	100	43	-85	69	
$E(\gamma\gamma)$	-9	1	-1	50	100	77	51	-78	90	
$p_T(\gamma\gamma)$	-3	-2		100	50	47	94	-44	45	
$\phi(\gamma\gamma)$	-3	1	100		-1			1	-1	
$\theta(\gamma\gamma)$	-1	100	1	-2	1		-1		1	
$M(\gamma\gamma)$	100	-1	-3	-3	-9	-13		16	-10	-4

Background Correlations

	$M(\gamma\gamma)$	$\theta(\gamma\gamma)$	$\phi(\gamma\gamma)$	$p_T(\gamma\gamma)$	$E(\gamma\gamma)$	$\beta(\gamma\gamma)$	Σp_T	$\Delta\theta(\gamma\gamma)$	E_{vis}	E_{vis} - $E(\gamma\gamma)$
E_{vis} - $E(\gamma\gamma)$	3	1		33	-2	4	28	5	88	100
E_{vis}	4			40	44	38	47	-33	100	88
$\Delta\theta(\gamma\gamma)$	5			-11	-81	-81	-39	100	-33	5
Σp_T	5		1	90	48	47	100	-39	47	28
$\beta(\gamma\gamma)$	-4			26	75	100	47	-81	38	4
$E(\gamma\gamma)$	2			23	100	75	48	-81	44	-2
$p_T(\gamma\gamma)$	2		1	100	23	26	90	-11	40	33
$\phi(\gamma\gamma)$		-4	100	1			1			
$\theta(\gamma\gamma)$		100	-4							1
$M(\gamma\gamma)$	100			2	2	-4	5	5	4	3

Relevant Background Channels $e^+\gamma$

Process (- ISR)	σ[fb]	Events in 1.5 ab^{-1}
γ from BS		
$e^+\gamma \to e^+ q\bar{q}\gamma$	-	
$e^+\gamma \to e^+ q\bar{q}$	-	-
$e^+\gamma \to e^+ q\bar{q}q\bar{q}$	1156	1736000
$e^+\gamma \to e^+ q\bar{q}\nu\bar{\nu}$	-	-
$e^+\gamma \to e^+ l^+ l^- \gamma$	-	-
$e^+\gamma \to e^+ l^+ l^-$	-	-
$e^+\gamma \to e^+ l^+ l^- q\bar{q}$	-	-
γ from EPA		
$e^+\gamma \to e^+ q\bar{q}\gamma$	-	-
$e^+\gamma \to e^+ q\bar{q}$	-	-
$e^+\gamma \to e^+ q\bar{q}q\bar{q}$	279	429000
$e^+\gamma \to e^+ q\bar{q}\nu\bar{\nu}$	-	-
$e^+\gamma \to e^+ l^+ l^- \gamma$	-	-
$e^+\gamma \to e^+ l^+ l^-$	-	-
$e^+\gamma \to e^+ l^+ l^- q\bar{q}$	-	-

Relevant Background Channels γe^-

Process (- ISR)	σ[fb]	Events in 1.5 ab^{-1}
γ from BS		
$\gamma e^- \to e^- q\bar{q}\gamma$	-	-
$\gamma e^- \to e^- q\bar{q}$	-	-
$\gamma e^- \to e^- q\bar{q}q\bar{q}$	1158	1737000
$\gamma e^- \to e^- q\bar{q}\nu\bar{\nu}$	-	-
$\gamma e^- \to e^- l^+l^-\gamma$	-	-
$\gamma e^- \to e^- l^+l^-$	-	-
$\gamma e^- \to e^- l^+l^- q\bar{q}$	-	-
γ from EPA		
$\gamma e^- \to e^- q\bar{q}\gamma$	-	-
$\gamma e^- \to e^- q\bar{q}$	-	-
$\gamma e^- \to e^- q\bar{q}q\bar{q}$	279	428000
$\gamma e^- \to e^- q\bar{q}\nu\bar{\nu}$	-	-
$\gamma e^- \to e^- l^+l^-\gamma$	-	-
$\gamma e^- \to e^- l^+l^-$	-	-
$\gamma e^- \to e^- l^+l^- q\bar{q}$	-	-