Physics potential for σ x BR($\mathrm{H} \rightarrow \mathrm{ZZ}^{*}$) measurement at CLIC

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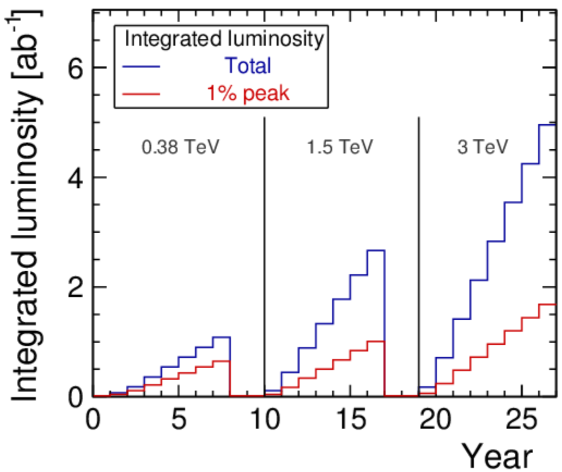
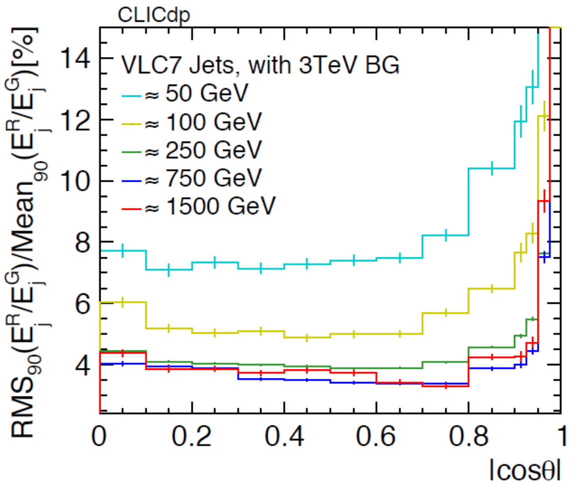
Overview

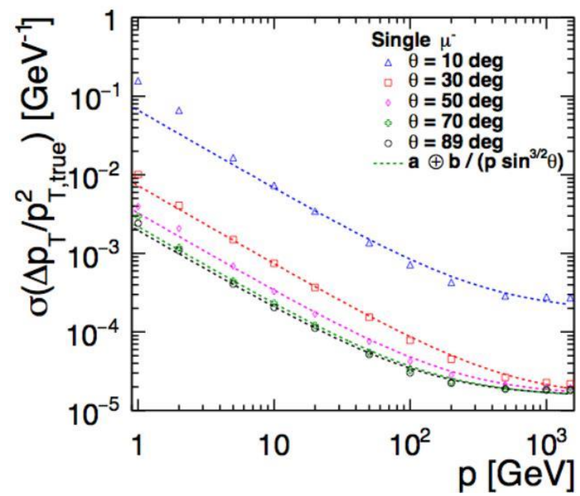
- Introduction to CLIC
- $H \rightarrow ZZ^{*}$ analyses at CLIC
- $H \rightarrow ZZ^{*}$ at 350 GeV
- Results
- Summary

Introduction to CLIC

- CLIC is a mature option for e^+e^- collider at CERN (Higgs factory and beyond)
- Energy staged from 380[1] (350) GeV up to 3 TeV
- Baseline ± 80 % electron polarization





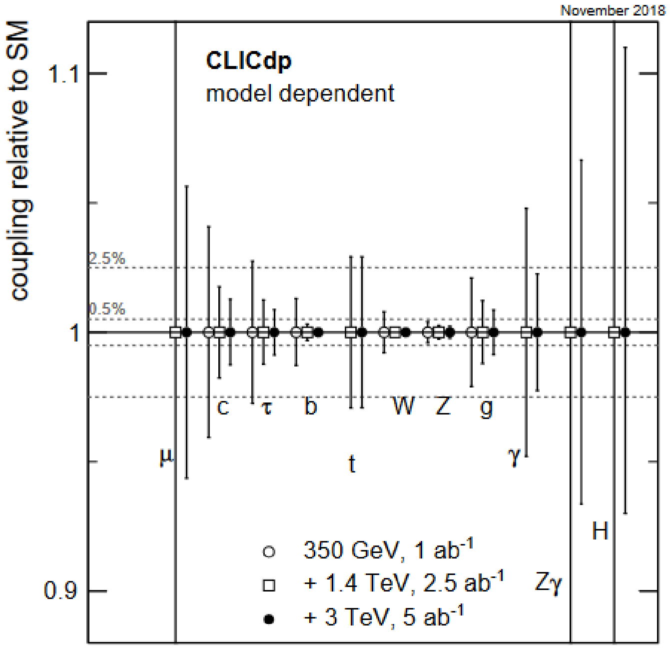


- Particle reconstruction and identification with Particle Flow Algorithm
- Jet energy resolution (3-5)%
- Efficient lepton identification and p_T measurement ($\Delta p_T/p_T^2$) ~ $2 \cdot 10^{-5}$ GeV^{-1}

Detector performance optimized to Higgs physics program

[1] 380 GeV option enables top quark measurements above the $t\bar{t}$ threshold.

Introduction to $H \rightarrow ZZ^*$ analyses

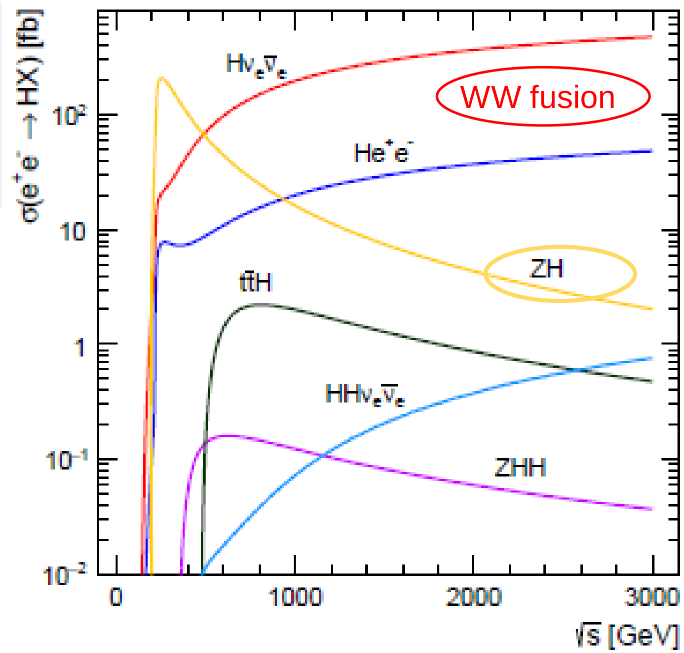


BR($H \rightarrow ZZ^*$) = 2.9%

BR($H \rightarrow ZZ^* \rightarrow q\bar{q}ll$) ≈ 0.4%

Target $\delta g_{HZZ} \lesssim 1\%$

Global fit enables utmost precision on g_{HZZ} using cumulative data from all energy stages



@ 350 GeV	@ 1.4 TeV	@ 3 TeV
$e^+e^- \rightarrow HZ, Z \rightarrow q\bar{q}$, $H \rightarrow ZZ^* \rightarrow q\bar{q}ll, (l = e^{\pm}, \mu^{\pm})$ $\mathcal{L}$ = 1 ab^{-1}, N_{evt} = 240	$e^+e^- \rightarrow H\nu\nu, H \rightarrow ZZ^* \rightarrow q\bar{q}ll$, $(l = e^{\pm}, \mu^{\pm}, \tau^{\pm})$ $\mathcal{L}$ = 1.5 ab^{-1} / *2.5 ab^{-1}* , N_{evt} ~ 1500 / *2500* *Updated luminosity staging [1]*	$e^+e^- \rightarrow H\nu\nu, H \rightarrow ZZ^* \rightarrow q\bar{q}ll, l = e^{\pm}, \mu^{\pm}$ $\mathcal{L}$ = 5 ab^{-1}, N_{evt} ~ 6000

[1] CLICdp-Note-2018-002

Overview of the method (all analyses)

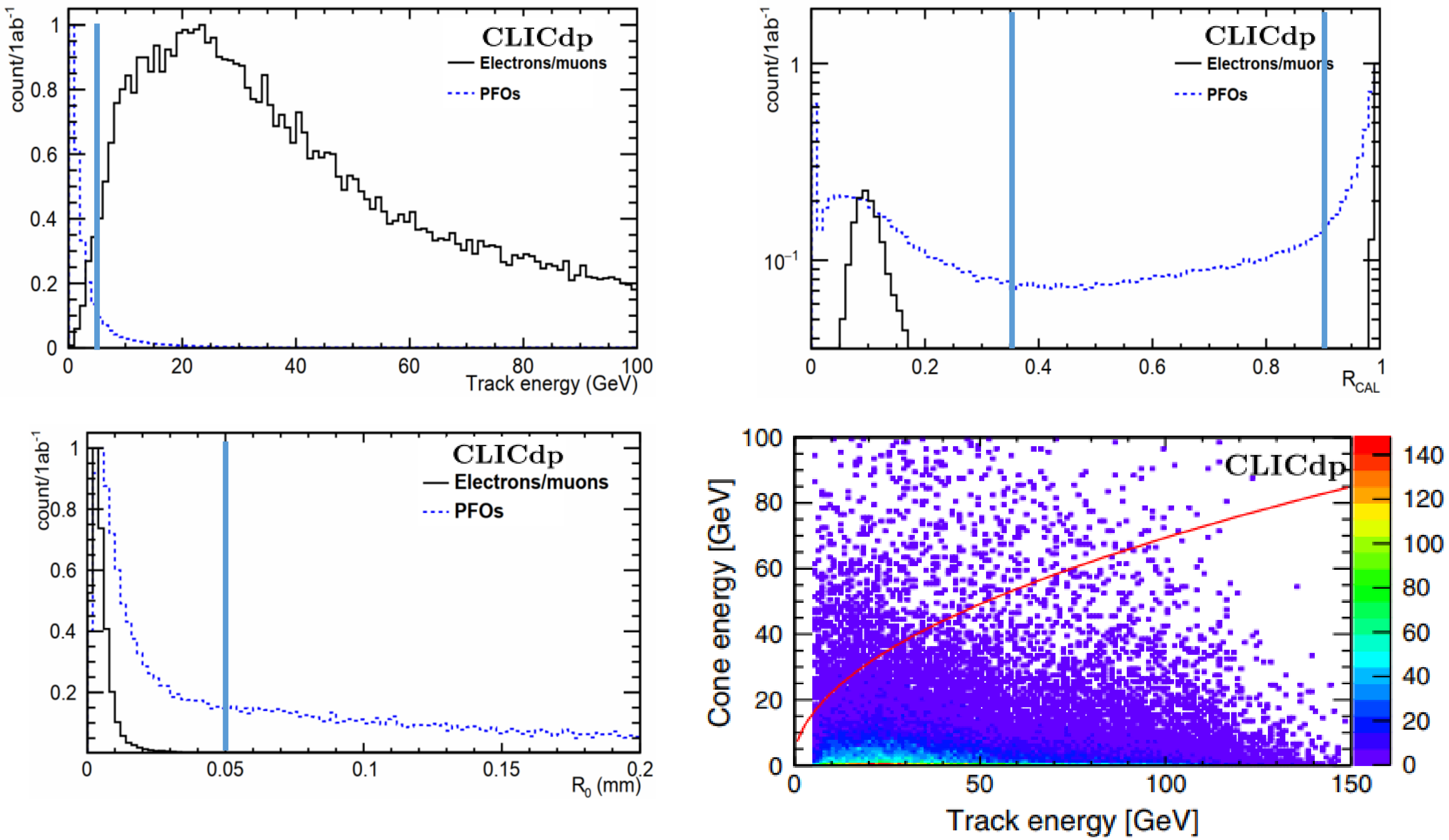
- **Lepton Isolation with Bremsstrahlung recovery**
  First the 2 isolated electrons or muons are found
- **Jet Reconstruction**
  Events are grouped in 4 (2) jets by k_T algorithm, with cone radius R = 1.1 (350 GeV) / 1 (1.4 TeV) / 0.7 (3 TeV)
- **LCFI Vertexing (heavy flavors)**
  Helps in separation of background processes containing b and c jets
- **Preselection (reduce large cross-section backgrounds)**
  Exactly 2 isolated leptons per event
- **MVA Selection**
  Maximizing statistical significance (S) of signal to background separation
- **Relative statistical uncertainty** of the ($\sigma \times$BR) observable is derived from the statistical significance

$H \rightarrow ZZ^*$ at 350 GeV

Signal	σ (fb)	N_{evt} @ 1 ab^{-1}
$e^+e^- \rightarrow HZ, Z \rightarrow q\bar{q}, H \rightarrow ZZ^*$, $ZZ^* \rightarrow q\bar{q}l^+l^-$ $(l = e, \mu)$	0.24	240
Background		N_{evt} **@ 1 ab^{-1} · 10^3**
$e^+e^- \rightarrow ZH, Z \rightarrow q\bar{q}, H \rightarrow$ others	7.0	7.0
$e^+e^- \rightarrow ZH, Z \rightarrow q\bar{q}, H \rightarrow WW \rightarrow q\bar{q}q\bar{q}$	10.5	10.5
$e^+e^- \rightarrow ZH, Z \rightarrow \mu^+\mu^-, H \rightarrow$ others	2.3	2.3
$e^+e^- \rightarrow ZH, Z \rightarrow e^+e^-, H \rightarrow$ others	2.3	2.3
$e^+e^- \rightarrow ZH, Z \rightarrow \mu^+\mu^-, H \rightarrow WW \rightarrow q\bar{q}q\bar{q}$	0.7	0.7
$e^+e^- \rightarrow ZH, Z \rightarrow e^+e^-, H \rightarrow WW \rightarrow q\bar{q}q\bar{q}$	0.7	0.7
$e^+e^- \rightarrow q\bar{q}q\bar{q}l^+l^-$	4.5	4.5
$e^+e^- \rightarrow q\bar{q}q\bar{q}$	5847	5800
$e^+e^- \rightarrow q\bar{q}l^+l^-$	1704	1700

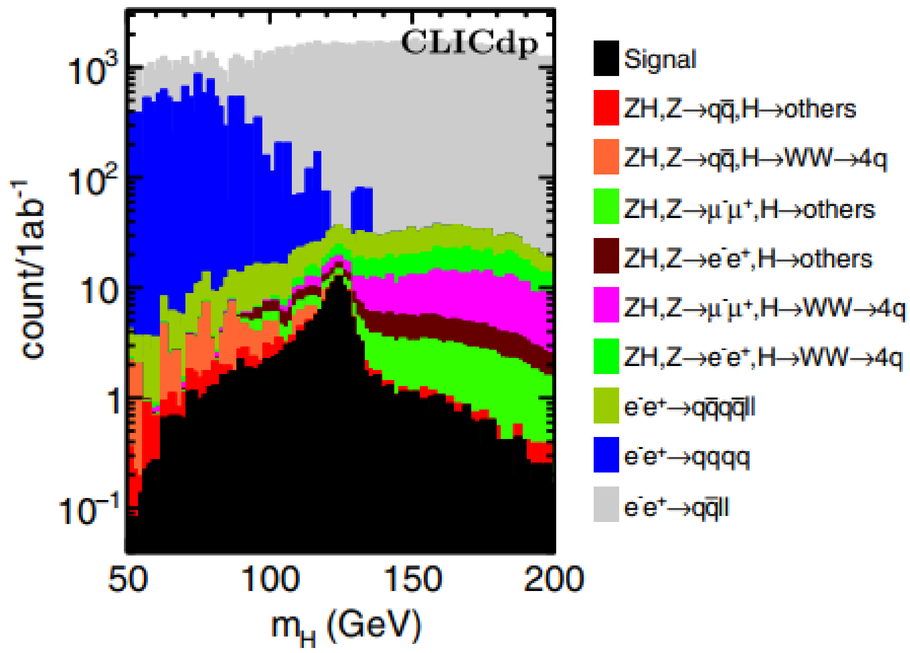
Preselection

- Several preselection criteria:
  - Track energy (E_{track}> 5 GeV),
  - Impact parameter (R_0 < 0.03 mm),
  - Energy deposited in calorimeters ($\frac{E_{ECAL}}{E_{ECAL}+E_{HCAL}}$ < 0.35 or > 0.9)
  - Lepton isolation curve ($E_{\text{cone}}^2 < 48\ \text{GeV} * E_{\text{track}} + 16\text{GeV}^2$)



Preselection efficiencies

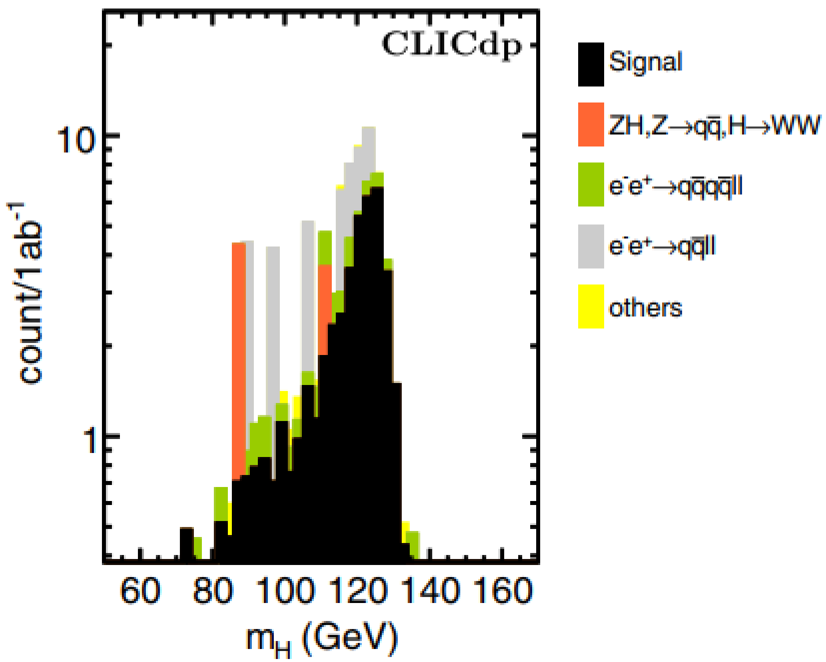
Background	ε_{presel} (%)
$e^+e^- \to ZH, Z \to q\bar{q}, H \to$ others	0.37
$e^+e^- \to ZH, Z \to q\bar{q}, H \to WW \to q\bar{q}q\bar{q}$	0.42
$e^+e^- \to ZH, Z \to \mu^+\mu^-, H \to$ others	61
$e^+e^- \to ZH, Z \to e^+e^-, H \to$ others	62
$e^+e^- \to ZH, Z \to \mu^+\mu^-, H \to WW \to q\bar{q}q\bar{q}$	59.6
$e^+e^- \to ZH, Z \to e^+e^-, H \to WW \to q\bar{q}q\bar{q}$	60.4
$e^+e^- \to q\bar{q}q\bar{q}l^+l^-$	21
$e^+e^- \to q\bar{q}q\bar{q}$	0.32
$e^+e^- \to q\bar{q}l^+l^-$	11.4

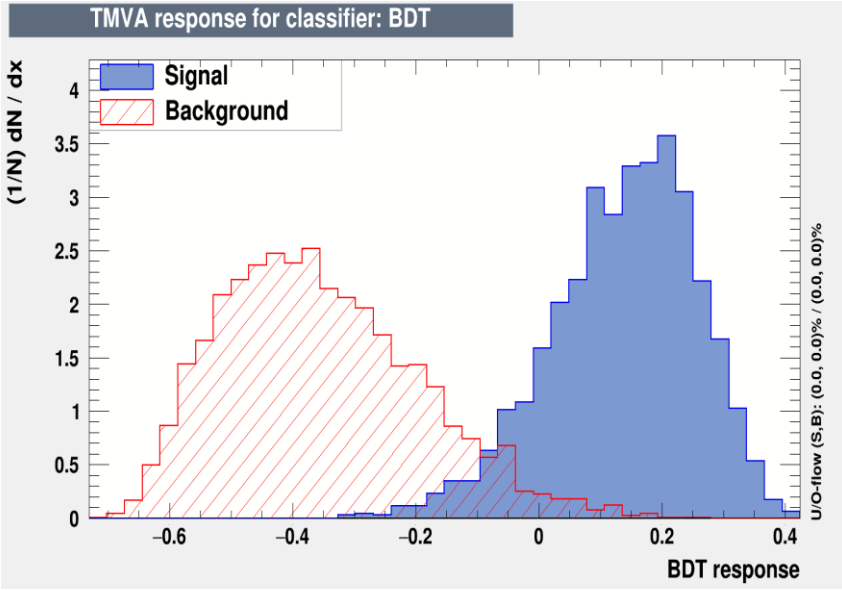


- Signal preselection efficiency: 77%
- Background rejection rate ≈ 97%

MVA

- MVA is employed with 17 sensitive observables (N_{PFO}, jet flavors, kinematic and event shape observables)
- The most sensitive observables: lepton energy, jet transition variable y_{23} and m_Z(primary)
- **BDT efficiency: 25%, Significance in application: 5, δ(σ×BR)=20%**





Results

Process	σ (fb)	N_{evt}	δ(σxBR) (%)
@ **350 GeV** [1] $e^+e^- \to HZ, Z \to q\bar{q}, H \to ZZ^*,$ $ZZ^* \to q\bar{q}l^+l^-$	0.240	240 @ 1 ab^{-1}	**20±2**
@ **1.4 TeV** [2] $e^+e^- \to H\nu\nu, H \to ZZ^*,$ $ZZ^* \to q\bar{q}l^+l^-$	0.995	1500 @ 1.5 ab^{-1}	**6±1** *4.3 ±0.4**
@ **3 TeV** [1] $e^+e^- \to H\nu\nu, H \to ZZ^*,$ $ZZ^* \to q\bar{q}l^+l^-$	1.130	6000 @ 5 ab^{-1}	**3.0±0.1**

- High-energy measurements are superior in statistical precision
- Statistical significance is affected by the presence of irreducible backgrounds, in particular when the signal cross-section is small(er)
- Left-handed electron beam polarization will additionally improve statistical precision of the high-energy measurements (1.4 TeV and 3 TeV) for a factor of 1.8 in cross-section of WW-fusion

[1] *N. Vukasinovic et al., Phys. Rev. D 105 (2022) 092008*
[2] *G. Milutinovic Dumbelovic, CERN-THESIS-2017-349 and CLIC Collaboration, Eur.Phys.J. C77 (2017) no.7, 475*
** Updated CLIC luminosity staging (scaled)*

Summary

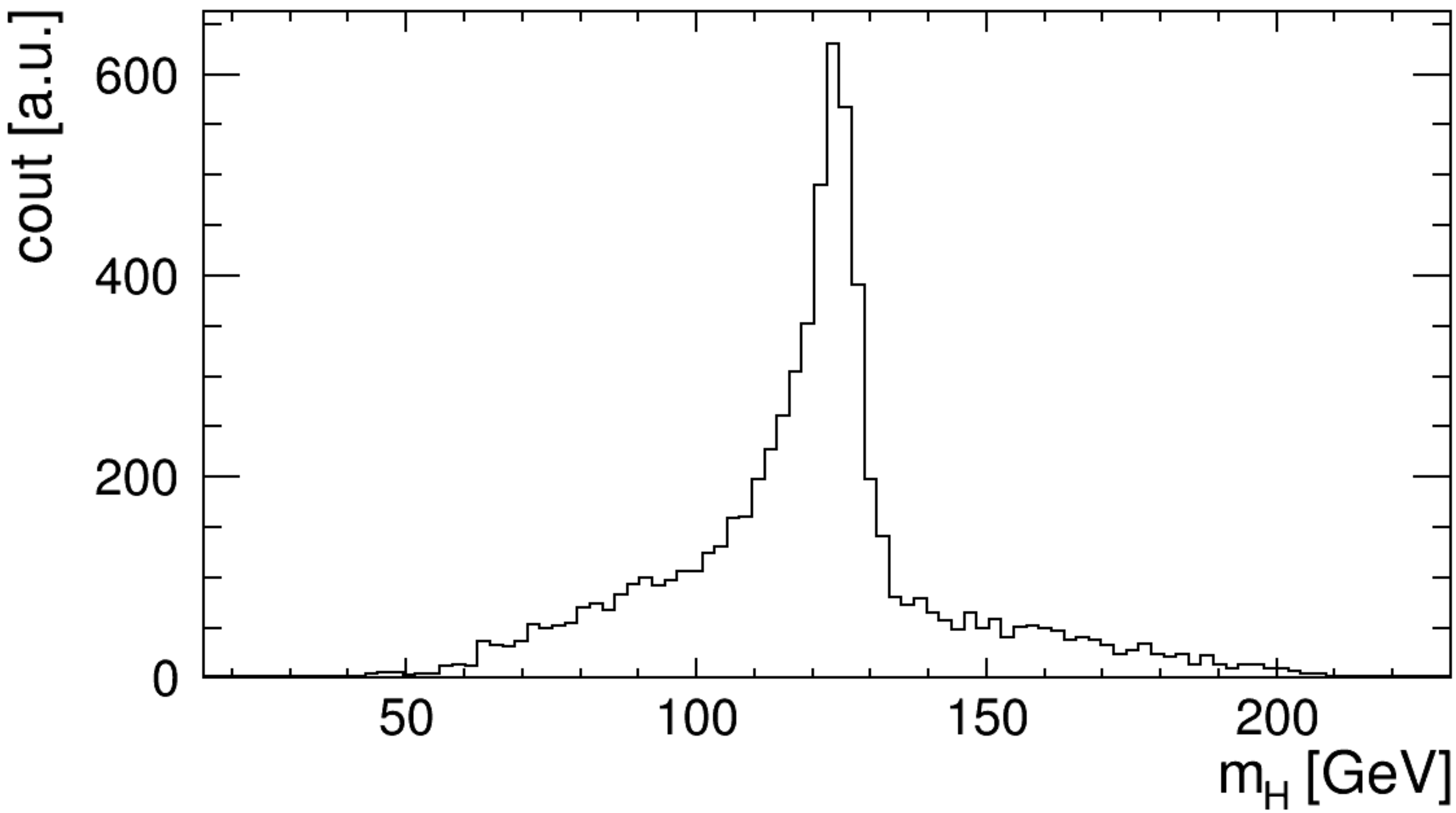
- $H \to ZZ^*$ decays in semileptonic final state are studied at all CLIC energies

- The most promising relative statistical precision *of order of a few percent on* $\sigma \times BR$ can be reached at higher center-of-mass energies (1.4 TeV and 3 TeV), due to a more abundant signal produced in WW-fusion.

  In addition, left-handed electron beam polarization can further improve the statistical precision.

- The utmost precision (several permille) on g_{HZZ} can be obtained in a global fit of cumulative data from all energy stages

BACKUP


cout [a.u.]
600
400
200
0
50
100
150
200
m_H [GeV]