Higgs production at CLIC

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Overview

- Why we need to study Higgs boson properties
- CLIC as a Higgs factory
- CLIC potential for Higgs boson measurements
- What do I do for CLIC

Why we need to study Higgs boson properties

- So far Higgs boson is SM like particle.
- Nature of the Higgs boson is not yet completely explored.
- We have to know is Higgs boson SM particle or not!
- In some BSM models Higgs is part of the Two-Higgs-Doublet, which contains five Higgs bosons: three neutral Higgs bosons (two CP-even and one CP-odd) and two charged Higgs bosons.
- Higgs may be a composite particle.
- Extended Higgs boson sector can lead to deviations in the Higgs boson-fermion/boson couplings w.r.t. the Standard Model predictions.
- Precision measurements of Higgs properties at future colliders will provide sensitive tests to possible new physics.

CLIC as a Higgs factory

Compact Linear Collider

- The Compact Linear Collider (CLIC) is an option for a future multi-TeV high-luminosity linear e^+e^- collider.
- It is based on a two-beam acceleration technique providing accelerating gradients up to 100 MV/m.

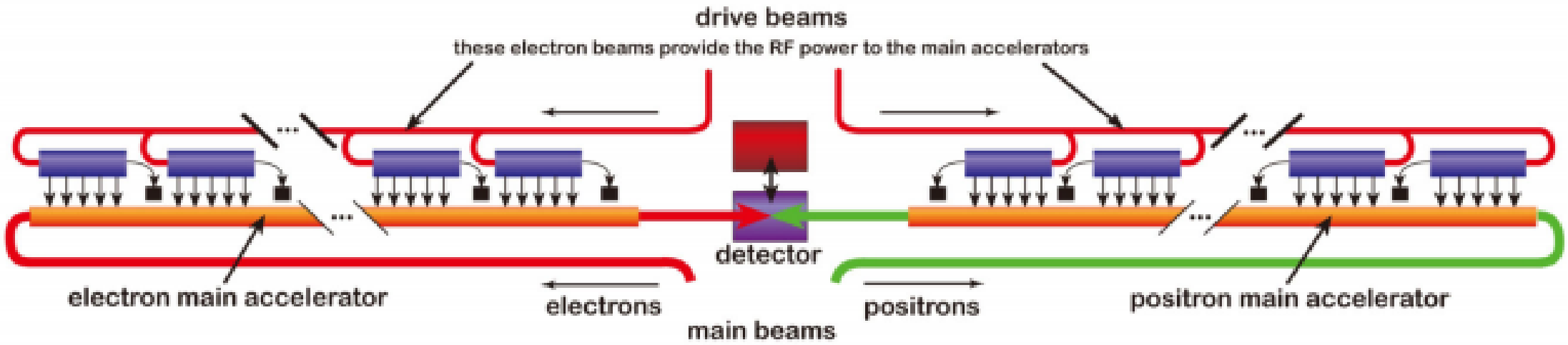


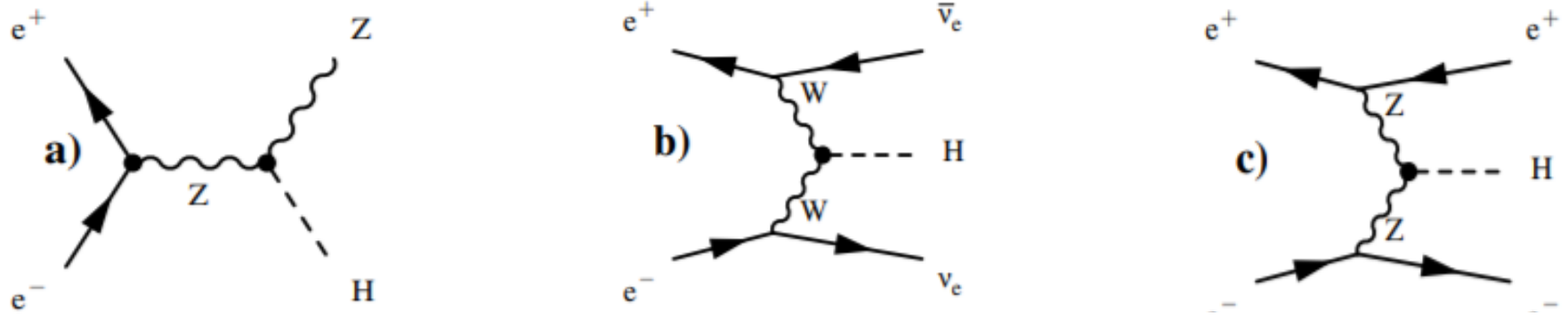
Figure is taken from CLIC CDR

CLIC as a Higgs factory

Energy staging

- CLIC will run at three energy stages: $\sqrt{s}$ = 350 GeV, 1.4 TeV and 3 TeV.
- Main Higgs production processes are:

a) Higgsstrahlung, b) WW-fusion, c) ZZ-fusion.



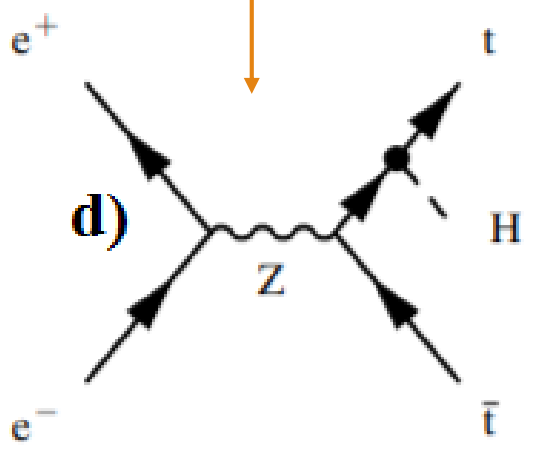
$\sqrt{s}$	$\mathscr{L}_{int}$	N_{ZH}	$N_{H\nu_e\bar{\nu}_e}$	$N_{He^+e^-}$
350 GeV	500 fb^{-1}	68,000	17,000	3,700
1.4 TeV	1.5 ab^{-1}	20,000	370,000	37,000
3 TeV	2 ab^{-1}	11,000	830,000	84,000

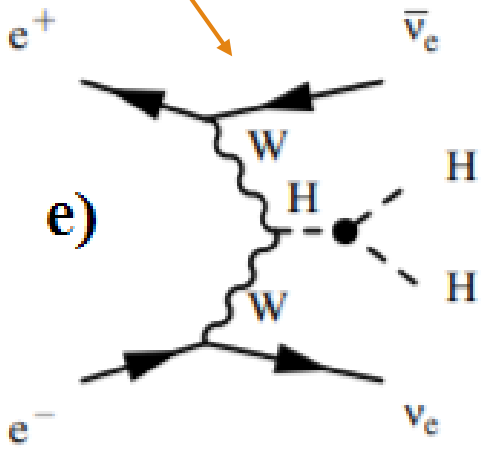
Table1: Integrated luminosity and Higgs production statistics at each energy stage with unpolarised beams (taken from Higgs paper)

Higgs production at CLIC

Specific Higgs production processes

- Some of the specific Higgs production processes such as Higgs production in conjunction with a pair of top quarks (d) and double Higgs production (e), are of particular importance to determine top Yukawa coupling or the Higgs trilinear self-coupling λ.



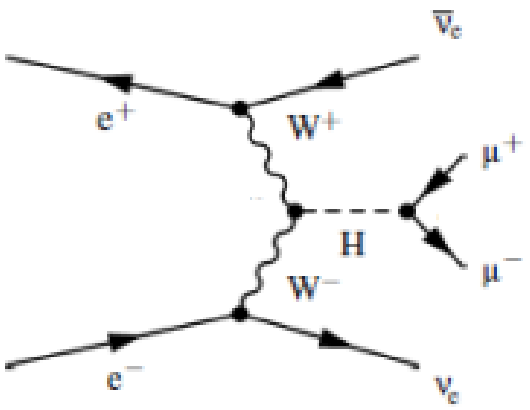


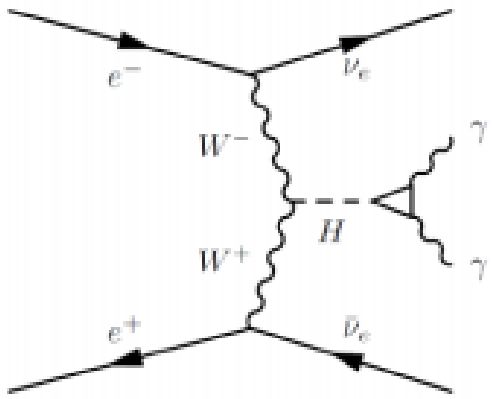
Higgs production at CLIC

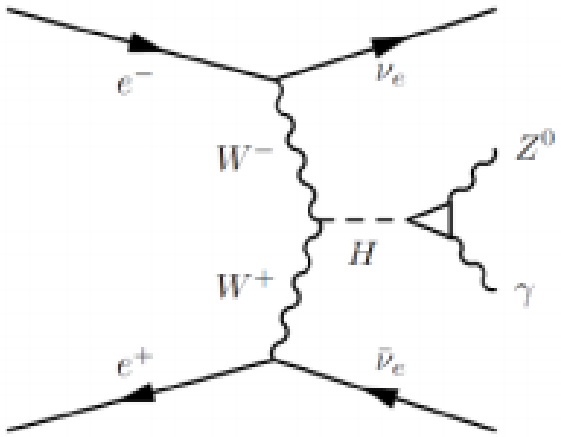
Rare Higgs decays

- At higher energy stages the high cross-section of the Higgs production through WW-fusion and large integral luminosities enable the access to the rare Higgs decay processes:

  $H \rightarrow \mu\mu$ (BR~ 0.021%), $H \rightarrow \gamma\gamma$ (BR~ 0.23%) and $H \rightarrow Z\gamma$ (BR~ 0.16%).







Higgs measurements at $\sqrt{s}$ = 350 GeV

- Recoil mass analysis provide measurement of the total ZH production cross section and a model-independent measurement of the absolute Higgs coupling to Z boson, g_{HZZ}.
  - The recoil mass measurement from $Z \to q\bar{q}$ enables a direct search for possible Higgs decays to invisible final states.
- Such a model-independent measurement is unique to a lepton (fermion-antifermion) collider.
- Operation at $\sqrt{s} \approx 350$ GeV enables the precision top mass measurement at the production threshold (Δm_t ~ 15 MeV)$_{stat}$.
- Measurements of the $\sigma\,(ZH)\ x\ BR(H \to X)$ provide determination of the Higgs couplings and the total Higgs decay width.

Parameter	Relative precision 350 GeV
g_{HZZ} (from combined $Z \to q\bar{q}$ and $Z \to l\bar{l}$ decay channels)	0.8 %
g_{HWW}	1.4 %
g_{Htt}	-
Γ_{invis}/Γ_H	< 1 %
Γ_H	6.7 %

Results are taken from Higgs paper

Higgs measurements above $\sqrt{s}$ = 1 TeV

- Above $\sqrt{s}$ > 1 TeV, relative couplings of the Higgs boson to the W and Z bosons can be determined at the $\mathcal{O}$(1 %) level. These measurements provide a strong test of the SM (i.e. of the Higgs compositness).

- Operation above at $\sqrt{s}$ > 1 TeV also enables a determination of the top Yukawa coupling g_{Htt}.

- Precision measurement of the Higgs boson self-coupling λ is a key tool to access the Higgs potential ($V(\phi) = \mu^2\phi^\dagger\phi + \lambda\left(\phi^\dagger\phi\right)^2$).

Parameter	Relative precision
	Above 1 TeV
g_{HWW}	0.9 %
g_{Htt}	4.2 %
λ	< 20 %
Γ_H	< 3.7 %

Results are taken from Higgs paper

CLIC potentials for Higgs measurements

- Measurements at $\sqrt{s}$ = 350 GeV allow determination of the absolute values of the Higgs boson couplings with fermions and bosons through the Higgsstrahlung, in a model-independent way.
- Measurements at $\sqrt{s}$ = 1.4 TeV allow the discovery of new physics phenomena and access to additional Higgs and top-quark properties.
- Measurements at $\sqrt{s}$ = 3 TeV improve statistical precision of the measured variables at the lower energy stages and allow access to the Higgs self-coupling and rare Higgs decays.
- The ultimate statistical precision is reached in the global fit of data from all the energy stages.

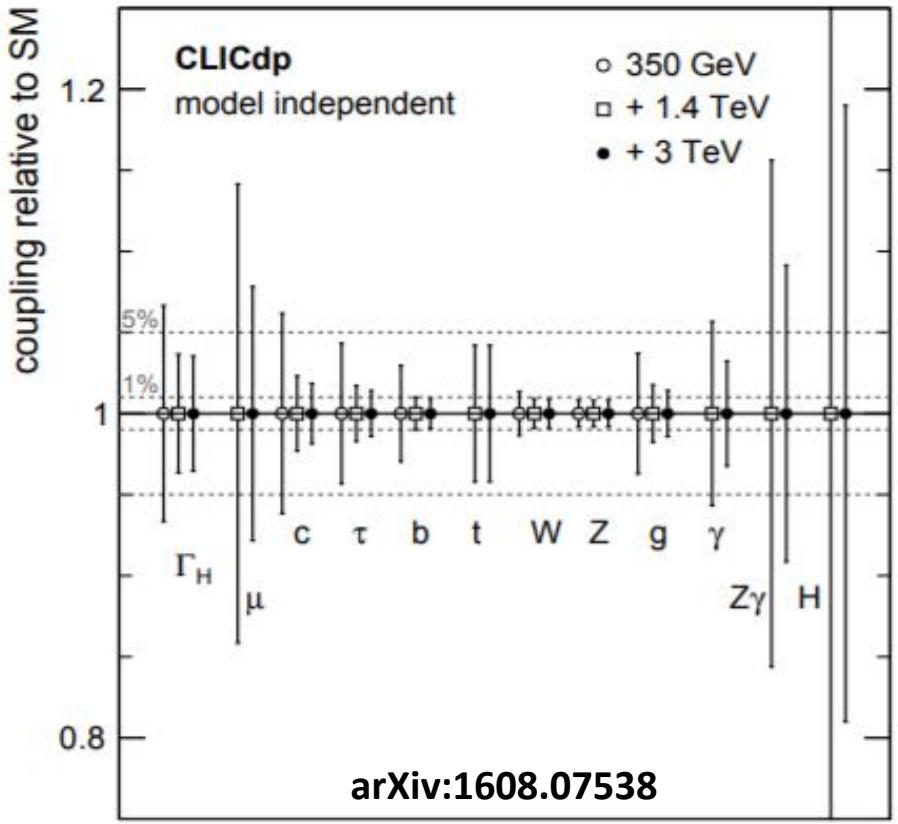
CLIC potentials for Higgs measurements

Combined fit results – model independent fit

- A combined fit of all measurements allows for a model independent extraction of the Higgs couplings and Higgs total width on the percent level.

- Most of the couplings (except top and rare decays) can be determined at the percent level.

- Statistical precision of the measurements is determined by the precision with which the g_{HZZ} coupling is measured in the recoil measurement.

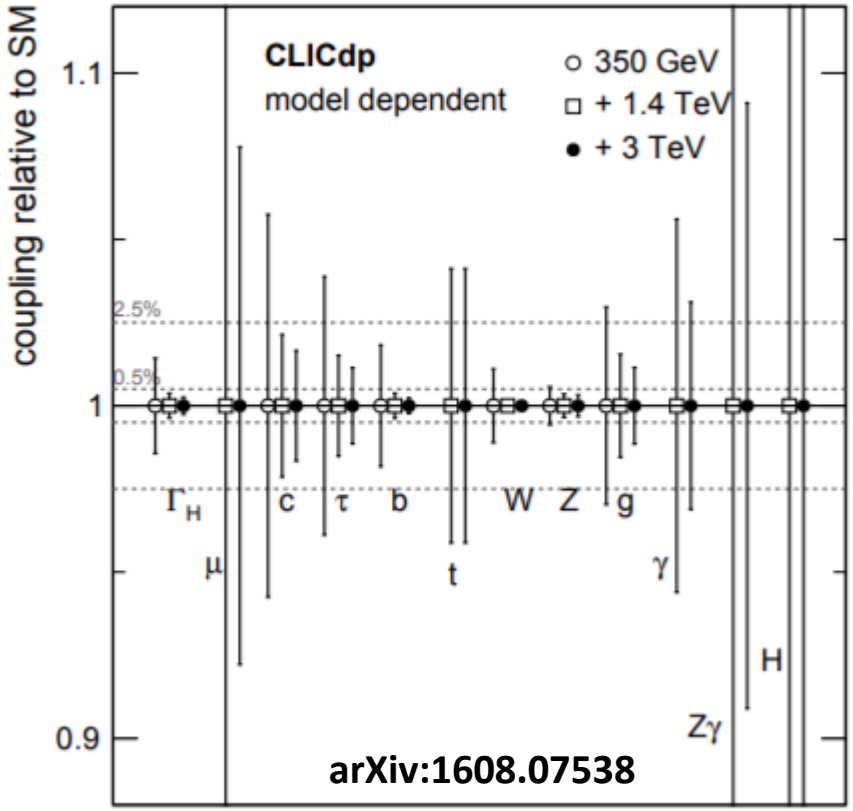


CLIC potentials for Higgs measurements

Combined fit results – model dependent fit

- Statistical precision can be even more improved if the total Higgs width is constrained by the Standard Model branching ratios (no invisible decays allowed).

- This approach allows direct comparison the between experiments using the same method (i.e. LHC, HL-LHC).
- CLIC sensitivity is significantly better than HL-LHC for most of the Higgs couplings (couplings to c, b, W, Z, and g, the self-coupling and the Higgs total decay width).
- The couplings to μ, τ, t, γ, and Zγ are at a similar level of sensitivity at both CLIC and HL-LHC.



CLIC potentials for Higgs measurements

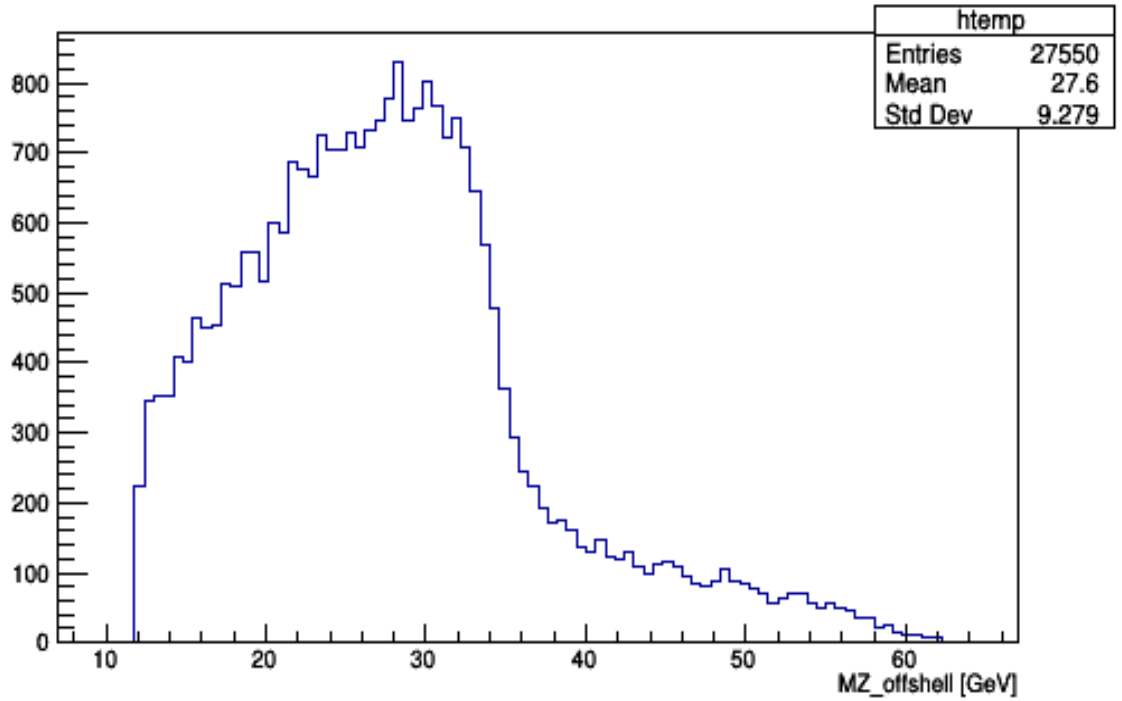
My personal contribution

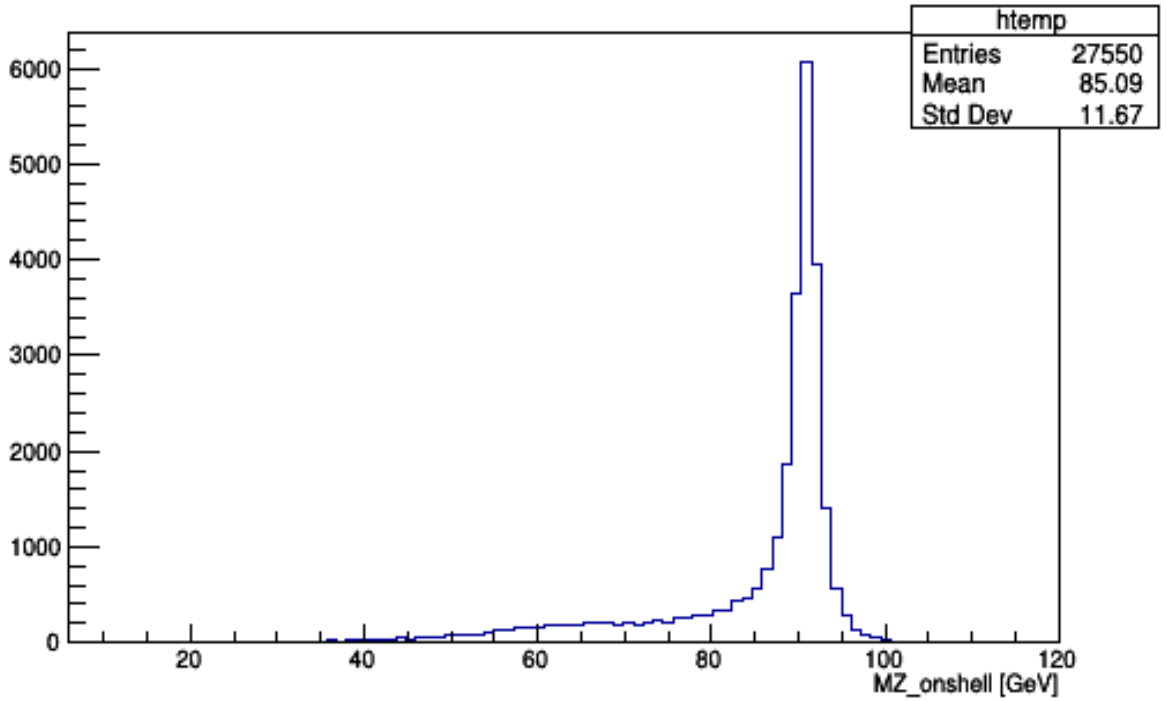
- My study is dealing with the measurement of the Higgsstrahlung cross section times $H \rightarrow ZZ^*$ branching ratio ($\sigma\ (ZH) x\ BR(H \rightarrow ZZ^*)$) at 350 GeV.
- So far CLIC uses this result from ILC.
- My task is to get this result, because it is needed to complete the list of observables to be measured at CLIC, necessary for estimation of the contribution of dimension-6 operators to the cross sections, in the Effective Field Theory approach (SM EFT).
- In this way new physics contribution can be probed up to the scale of $\mathcal{O}$(10 TeV).

CLIC potentials for Higgs measurements

My personal contribution

- On the pictures is presented Z boson off-shell and on-shell mass reconstructed from MC samples with ~ 197000 Higgsstahlung events, out of which are 27550 semileptonic Z decay events.





Conclusion

Higgs precision physics is mandatory for new physics.

Thank you for your attention!