Measurement of Higgs couplings and mass in e^+e^- collisions at 350 GeV, 1.4 TeV and 3 TeV CLIC

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on behalf of the CLIC Detector and Physics Study

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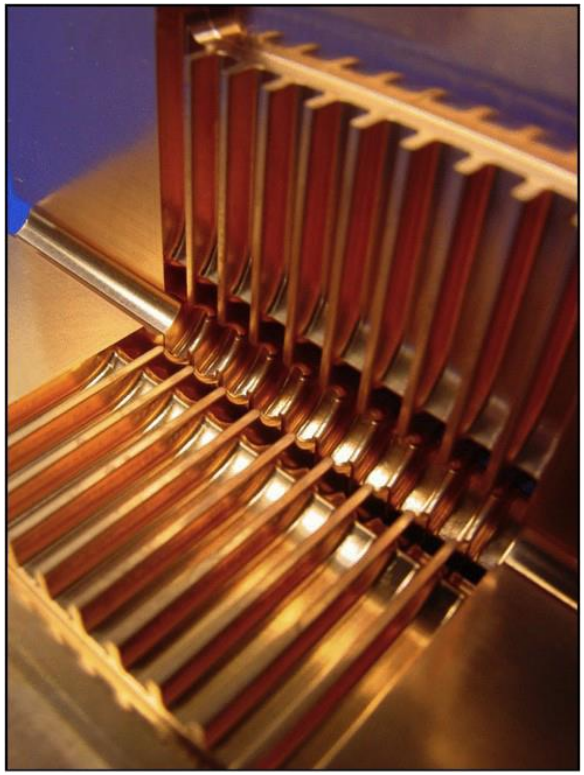
CLIC Environment

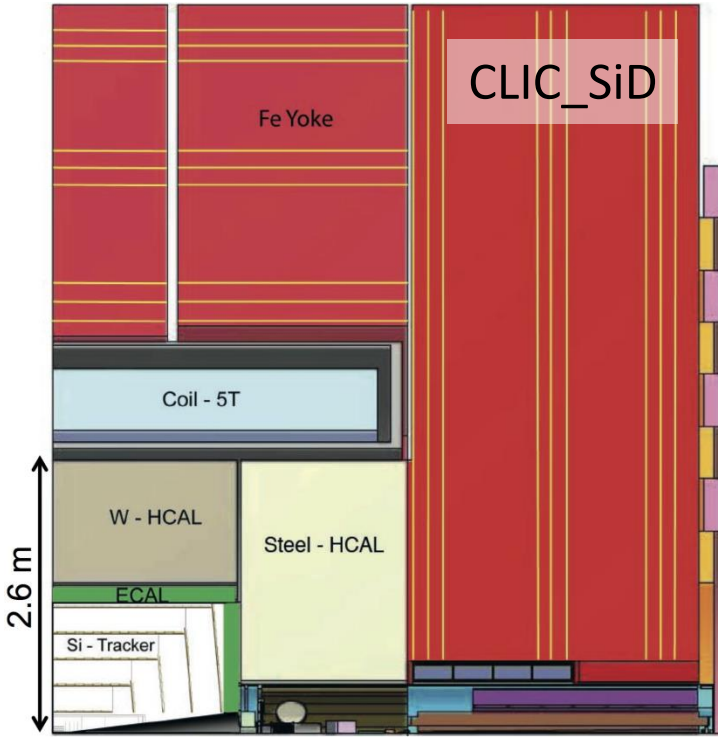
Center of mass energy	350 GeV	1.4 TeV	3 TeV
Bunch spacing		0.5 ns	
Bunches per train	354	312	312
γγ → hadrons per BX	0.3	1.3	3.2

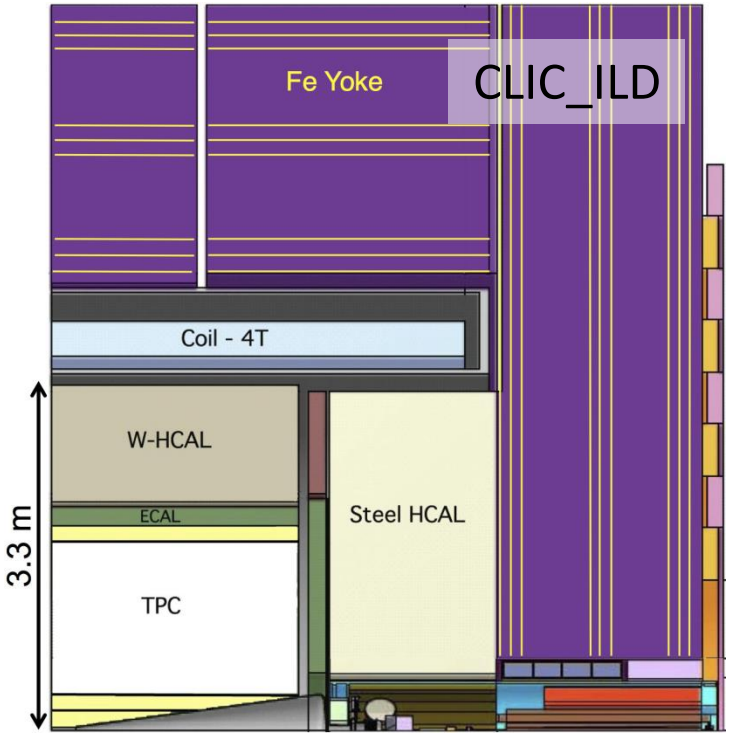
- Multi-staged approach
  - 350 GeV stage motivated by better luminosity and sizeable WW fusion cross section.
- CLIC will be operated at room temperature
- 100 MV/m gradient enabling multi-TeV CME
- Effective methods for beam-induced background suppression established
  - 10ns readout window (100ns for HCAL)
  - LHC-style jet reconstruction with FastJet



CLIC Detectors

- Two detector concepts: CLIC_SiD and CLIC_ILD
  - Based on SiD and ILD detector concepts for ILC, adapted to CLIC environment.
  - Full simulation and reconstruction of events, beam induced background overlaid.
  - Particle Flow Algorithm calorimetry.





CLIC Detectors and Physics Study

http://lcd.web.cern.ch/lcd/Home/MoC.html

Pre-collaboration based on Memorandum of Cooperation (MoC).

CERN acts as a host laboratory.

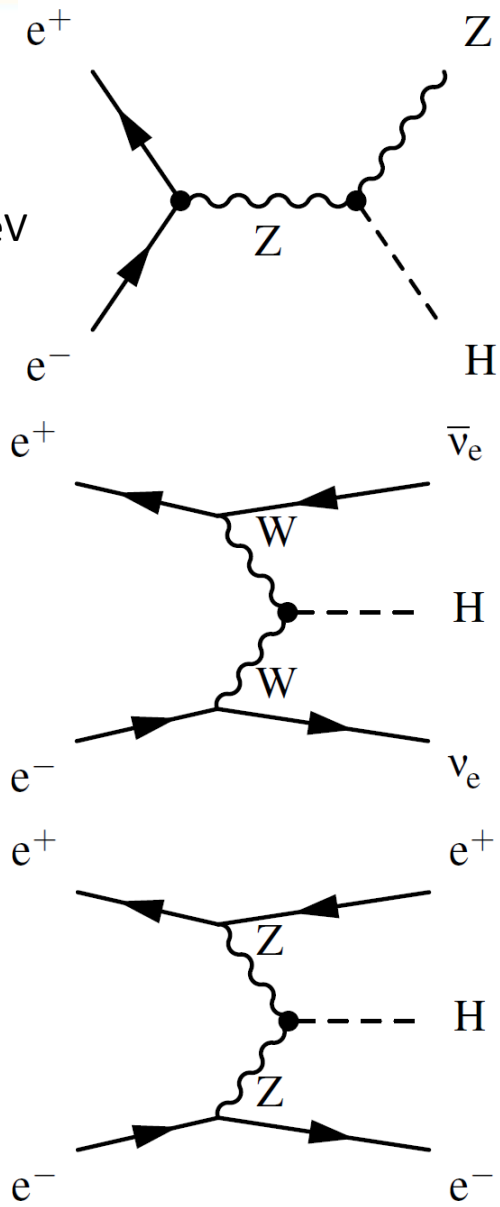
17 institutes from 14 countries – more contributors are welcome.

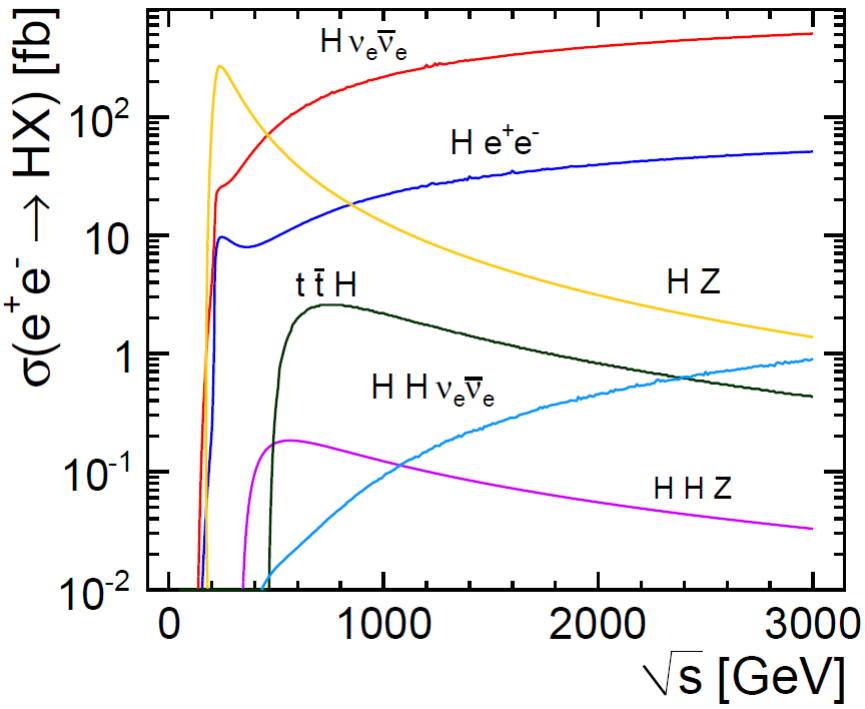
Higgs Production at CLIC

Higgs-strahlung
dominates below 500 GeV

WW fusion
dominats above 1 TeV
highest cross section

ZZ fusion
10x smaller than WW





	350 GeV	1.4 TeV	3 TeV
$e^+e^-\to HZ$	134 fb	9fb	2fb
$e^+e^-\to H\nu\bar{\nu}$	52 fb	279 fb	479 fb
$e^+e^-\to He^+e^-$	7 fb	28 fb	49 fb

Unpolarised cross sections
$H\nu\bar{\nu}$ signal increased by a factor of 1.8 (2.34) for
P(e-) = -80% (P(e-) = -80%, P(e+) = 30%)

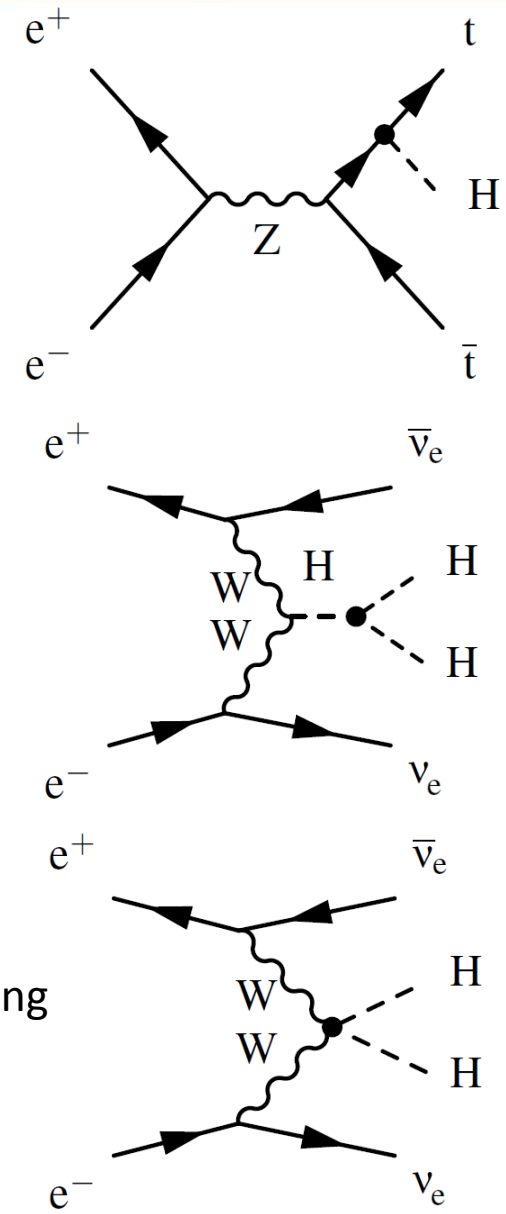
Double Higgs and ttH Production at CLIC

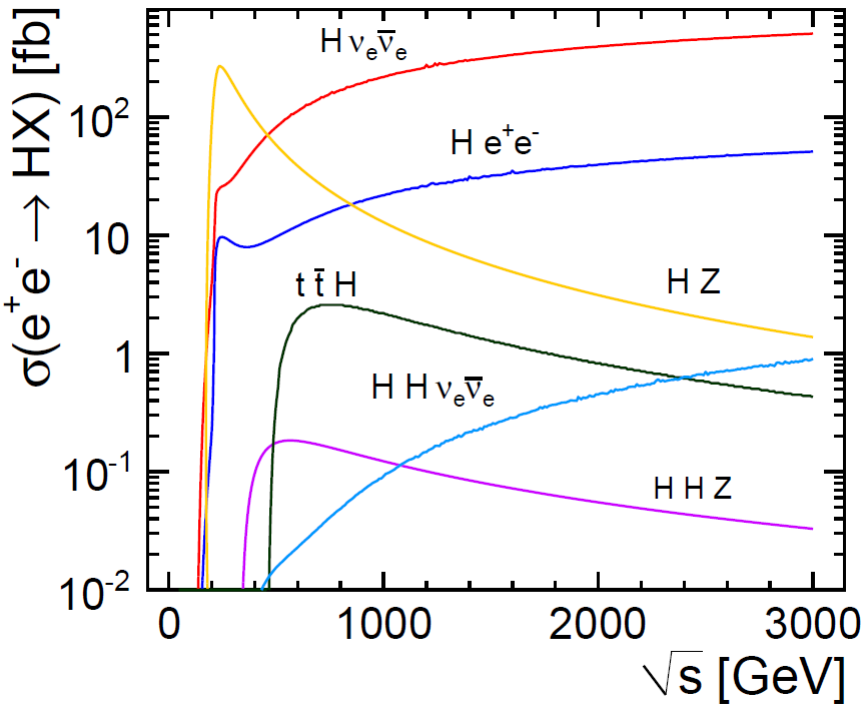
ttH production

Double Higgs production

Higgs self-coupling

Quartic HHWW coupling





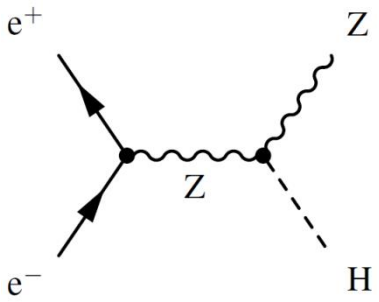
	1.4 TeV	3 TeV
$e^+e^-\to t\bar{t}H$	1.6 fb	
$e^+e^-\to HH\nu\bar{\nu}$	0.164 fb	0.63 fb

Unpolarised cross sections
HHνν̄ signal increased by a factor of 1.8 (2.34) for
P(e-) = -80% (P(e-) = -80%, P(e+) = 30%)

Measurements at 350 GeV (500 fb^{-1})

- Higgs-strahlung events enable Higgs mass reconstruction from Z recoil mass.
  - Model independent measurement of m_H and g_{HZZ}

$\Delta(m_H) \approx 120$ MeV

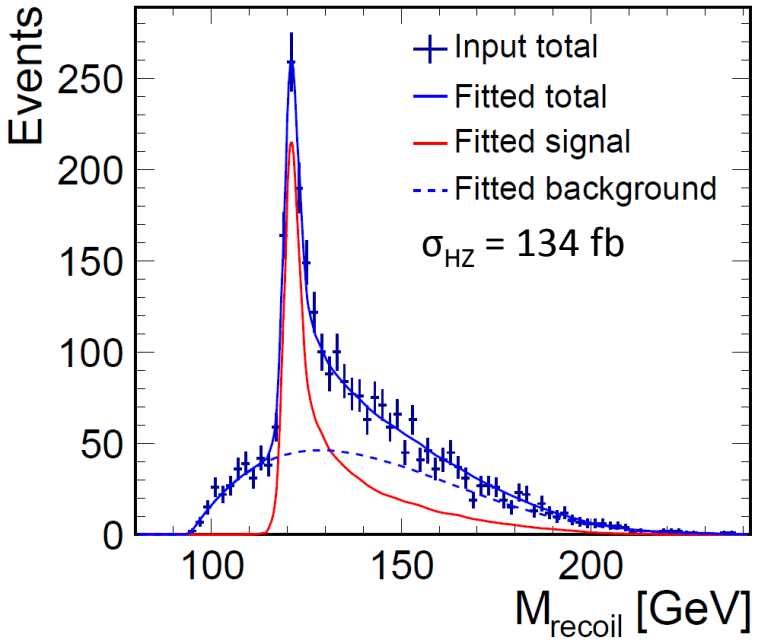


  - Higgs branching ratio analyses

Measurement	Observable	Stat. precision
$\sigma(HZ) \times BR(H\to\tau^+\tau^-)$	$g^2_{HZZ}g^2_{H\tau\tau}/\Gamma_H$	5.7%
$\sigma(HZ) \times BR(Z\to l^+l^-)$	g^2_{HZZ}	4.2%
$\sigma(HZ) \times BR(H\to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	1% †
$\sigma(HZ) \times BR(H\to c\bar{c})$	$g^2_{HZZ}g^2_{Hcc}/\Gamma_H$	5% †
$\sigma(HZ) \times BR(H\to gg)$		6% †
$\sigma(HZ) \times BR(H\to WW^*)$	$g^2_{HZZ}g^2_{HWW}/\Gamma_H$	2% †
$\sigma(H\nu\bar{\nu}) \times BR(H\to b\bar{b})$	$g^2_{HWW}g^2_{Hbb}/\Gamma_H$	3% †

† analysis ongoing, result estimated

$e^+e^-\to HZ, Z\to\mu^+\mu^-$



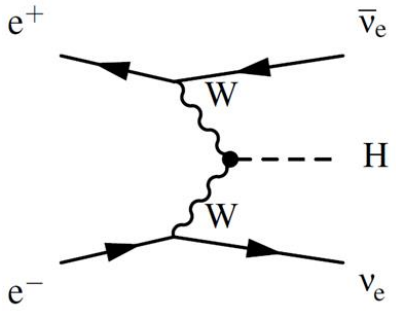
MEASUREMENTS AT 1.4 TEV (1.5 ab^{-1})

- Higgs measurements (mostly) in Hν$\bar{\nu}$ channel (279 fb):

Measurement	Observable	Stat. precision
σ(Hν$\bar{\nu}$) x BR(H→τ$^+$τ$^-$)	$g^2_{HWW} g^2_{H\tau\tau}/\Gamma_H$	3.7%
σ(Hν$\bar{\nu}$) x BR(H→μ$^+$μ$^-$)	$g^2_{HWW} g^2_{H\mu\mu}/\Gamma_H$	28% (prel.)
σ(Hν$\bar{\nu}$) x BR(H→b$\bar{b}$)	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	0.3%
σ(Hν$\bar{\nu}$) x BR(H→c$\bar{c}$)	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	2.9%
σ(Hν$\bar{\nu}$) x BR(H→gg)		1.8%
σ(Hν$\bar{\nu}$) x BR(H→γγ)		15% (prel.)
σ(Hν$\bar{\nu}$) x BR(H→Zγ)		tbd
σ(Hν$\bar{\nu}$) x BR(H→ZZ*)	$g^2_{HWW} g^2_{HZZ}/\Gamma_H$	3% †
σ(Hν$\bar{\nu}$) x BR(H→WW*)	g^4_{HWW}/Γ_H	1% †
σ(He$^+$e$^-$) x BR(H→b$\bar{b}$)	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	1% †

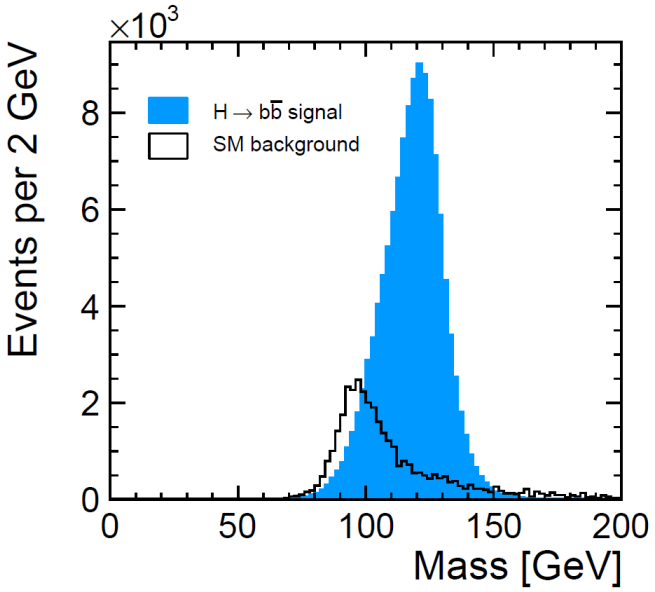
assuming unpolarized beams

† analysis ongoing, result estimated



Δ(m_H) ≈ 40 MeV

Estimated from Higgs mass distribution in H→b$\bar{b}$.



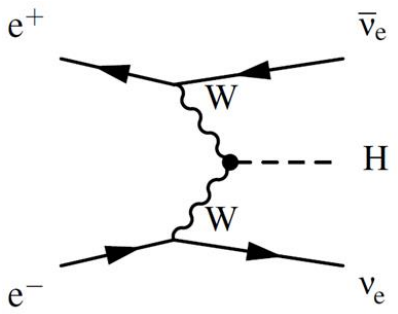
MEASUREMENTS AT 3 TEV (2ab^{-1})

- Large Higgs cross section: 479 fb corresponds to 830k Higgses (including beam spectrum)

Measurement	Observable	Stat. precision
$\sigma(H\nu\bar{\nu}) \times BR(H\to\tau^+\tau^-)$	$g^2_{HWW}\, g^2_{H\tau\tau}/\Gamma_H$	tbd
$\sigma(H\nu\bar{\nu}) \times BR(H\to\mu^+\mu^-)$	$g^2_{HWW}\, g^2_{H\mu\mu}/\Gamma_H$	16%
$\sigma(H\nu\bar{\nu}) \times BR(H\to b\bar{b})$	$g^2_{HWW}\, g^2_{Hbb}/\Gamma_H$	0.2%
$\sigma(H\nu\bar{\nu}) \times BR(H\to c\bar{c})$	$g^2_{HWW}\, g^2_{Hcc}/\Gamma_H$	2.7%
$\sigma(H\nu\bar{\nu}) \times BR(H\to gg)$		1.8%
$\sigma(H\nu\bar{\nu}) \times BR(H\to\gamma\gamma)$		tbd
$\sigma(H\nu\bar{\nu}) \times BR(H\to Z\gamma)$		tbd
$\sigma(H\nu\bar{\nu}) \times BR(H\to ZZ^*)$	$g^2_{HWW}\, g^2_{HZZ}/\Gamma_H$	2% †
$\sigma(H\nu\bar{\nu}) \times BR(H\to WW^*)$	g^4_{HWW}/Γ_H	0.7% †
$\sigma(He^+e^-) \times BR(H\to b\bar{b})$	$g^2_{HZZ}\, g^2_{Hbb}/\Gamma_H$	0.7% †

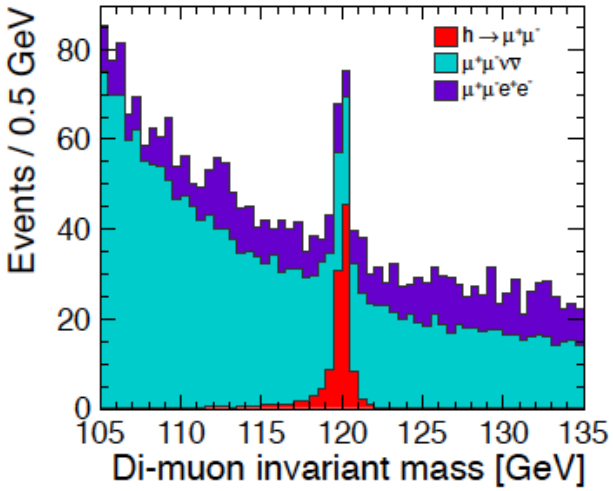
assuming unpolarized beams

† analysis ongoing, result estimated



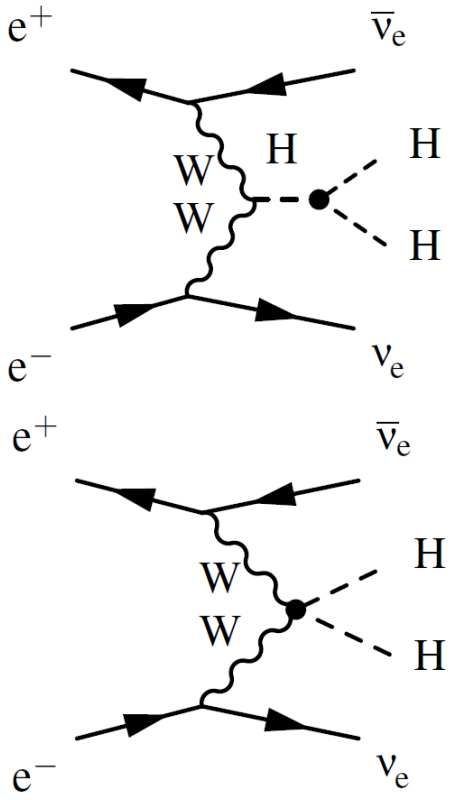
$\Delta(m_H) \approx 33$ MeV

Estimated from Higgs mass distribution in $H\to b\bar{b}$.



Double Higgs production at 1.4 TeV and 3 TeV

- The HHνν̄ cross section is sensitive to
  - Higgs self-coupling λ
  - Higgs quartic coupling g_{HHWW}
- Small cross section process
  - 0.164 fb (0.63 fb) at 1.4 TeV (3 TeV)
  - Requires large luminosity, large CM Energy



	1.4 TeV	3 TeV
$\Delta(g_{HHWW})$	7% (prel.)	3% (prel.)
$\Delta(\lambda)$	28%	16%
$\Delta(\lambda)$, $P(e^-) = -80\%$	21% †	12% †

Results for m_H = 120 GeV, analyses for m_H = 126 GeV are ongoing.

ttH Final State Measurements at 1.4 TeV

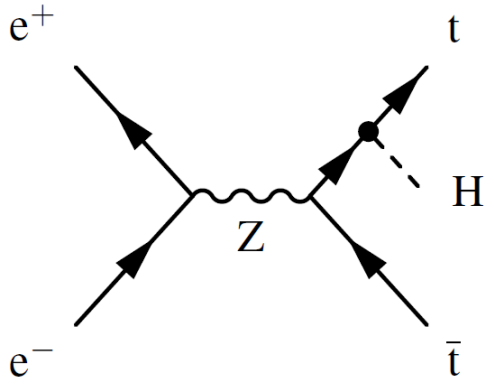
- The ttH cross section is sensitive to Top Yukawa coupling g_{ttH}
- The following final states were analysed
  - 6 jets: t(→qqb) t̄(→lνb̄) H(→bb̄)

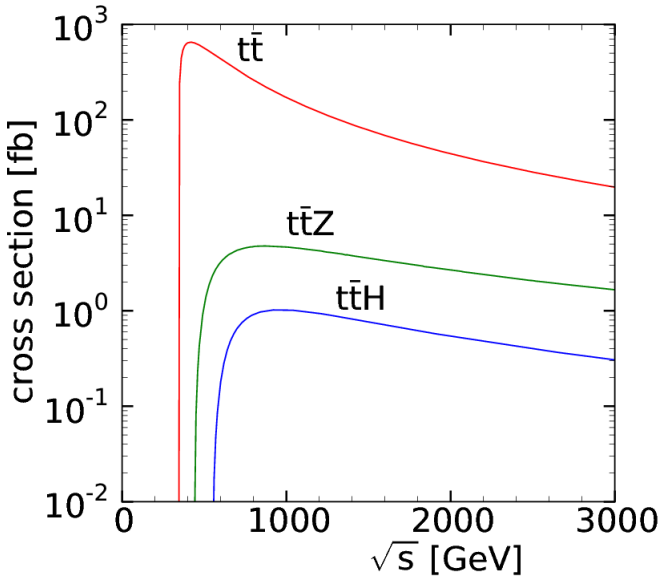
    Δ(σ(ttH)) ≈ 16% (preliminary)

    unpolarised beams assumed
  - 8 jets: t(→qqb) t̄(→qqb̄) H(→bb̄)

    ongoing, expected to be more precise

Yukawa coupling will be extracted from a combined fit to both decay channels.





SUMMARY

- The first CLIC stage at √s = 350 GeV will provide precision measurements of absolute values of various Higgs couplings.
- Running at √s = 1.4 TeV and √s = 3 TeV will open door to rare Higgs decays at the top of significantly improving many precision measurements from previous stages.
- High energy CLIC has a potential to pin down the value of trilinear Higgs self-coupling to 10% level.
- A combined fit is being done at CLIC to all measurements at 350 GeV, 350 GeV + 1.4 TeV and 350 GeV + 1.4 TeV + 3 TeV to extract the Higgs couplings and width.