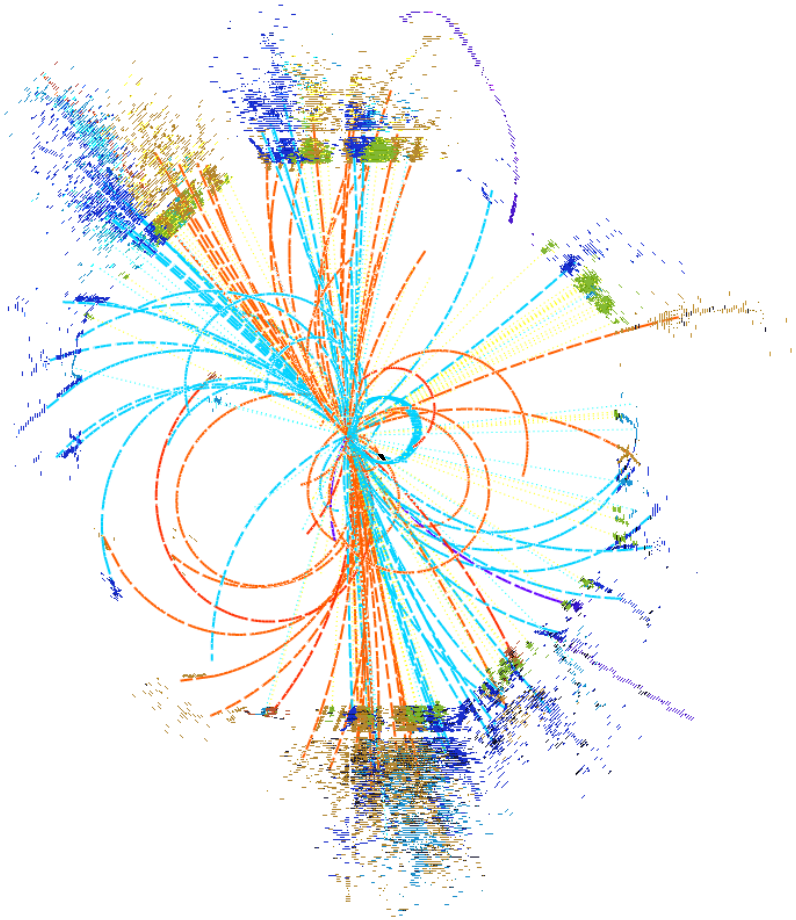
Overview of CLIC physics benchmark studies

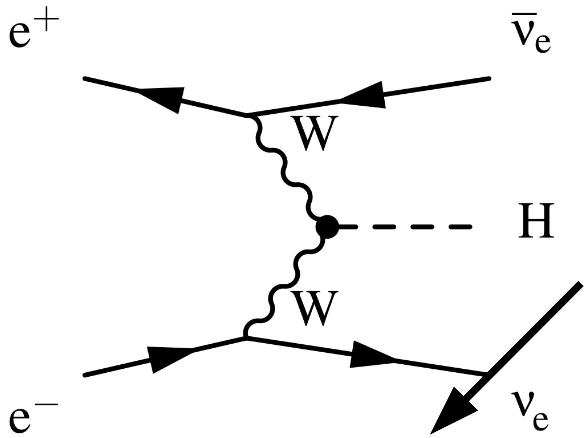
Philipp Roloff (CERN)



Collaboration meeting of the CLIC detector & physics study
CERN, 01/10/2013

Higgs physics

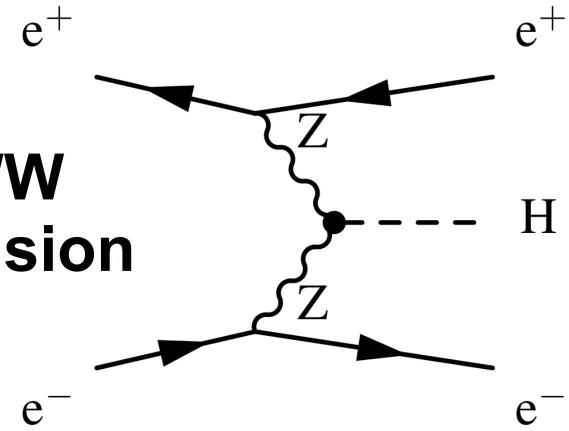
Reminder: Higgs production at CLIC

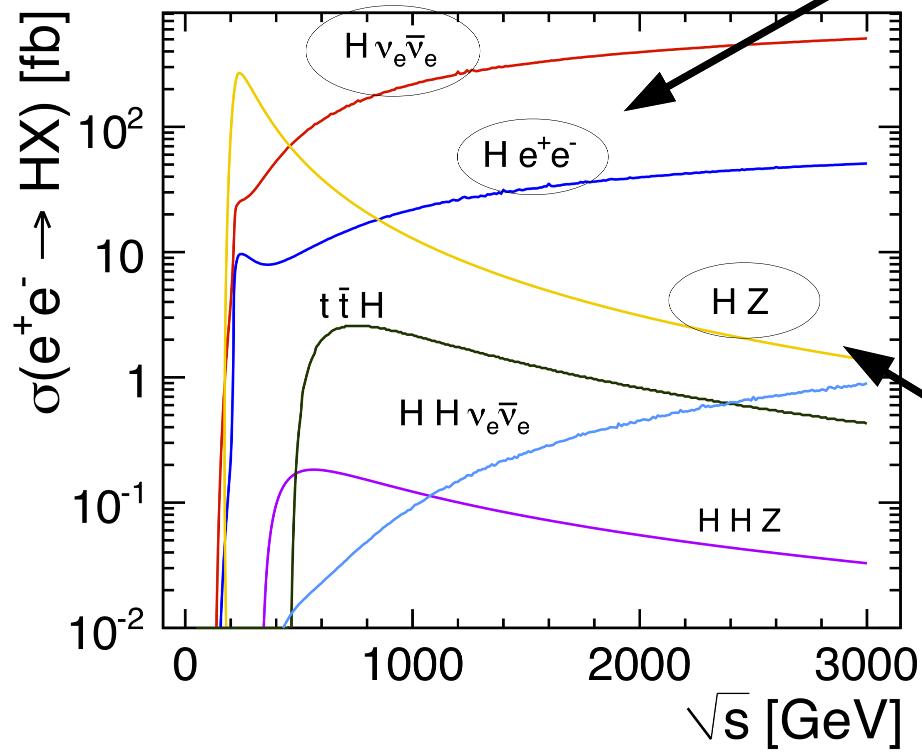


$\sigma \sim \log(s)$

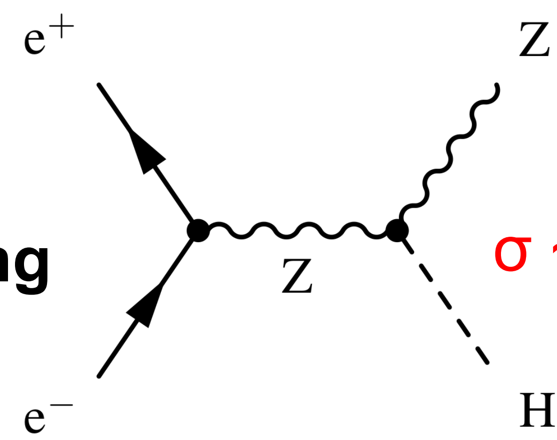
ZZ fusion

WW fusion



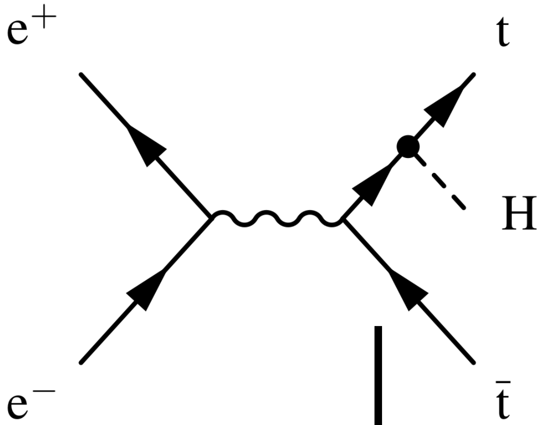


Higgs - strahlung

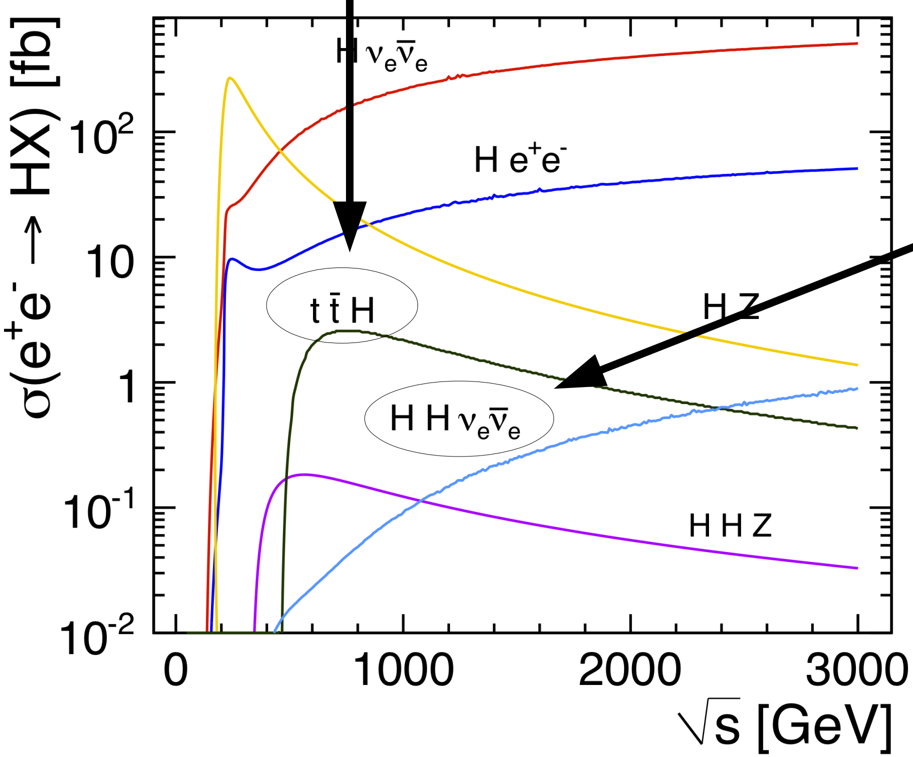


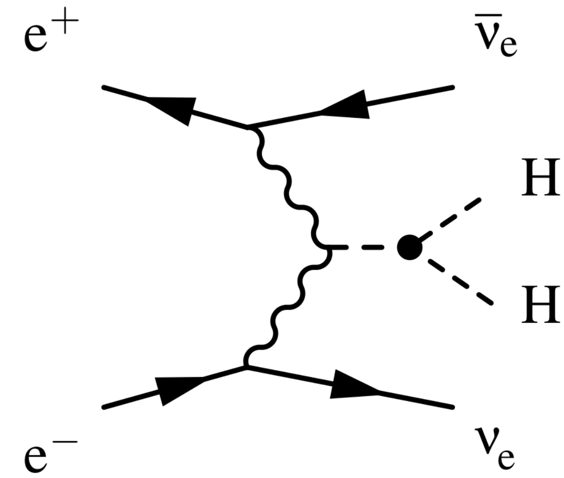
$\sigma \sim 1/s$

Reminder: Processes at higher energy

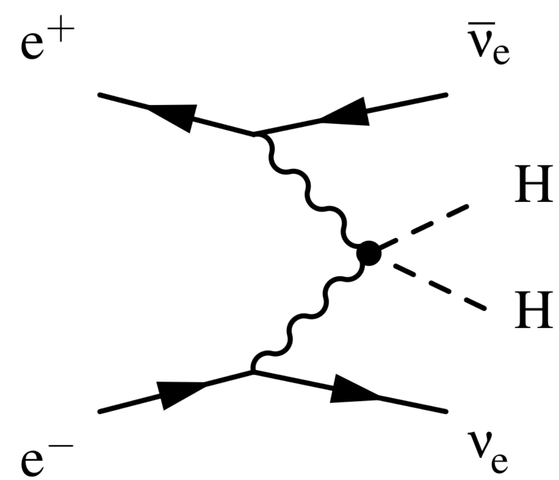


$t\bar{t}H$ production:
maximum at around 800 GeV





Double Higgs production:
requires high energy



Assumptions and numbers

Unpolarised cross sections for m_H = 125 GeV including ISR:

	350 GeV	1.4 TeV	3 TeV
$\sigma(e^+e^- \rightarrow ZH)$	134 fb	9 fb	2 fb
$\sigma(e^+e^- \rightarrow H\nu_e\bar{\nu}_e)$	52 fb	279 fb	479 fb
$\sigma(e^+e^- \rightarrow He^+e^-)$	7 fb	28 fb	49 fb

Numbers of events including ISR & Beam-strahlung:

	350 GeV	1.4 TeV	3 TeV
L_{int}	500 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	68'000	20'000	11'000
# $H\nu_e\bar{\nu}_e$ events	26'000	370'000	830'000
# He^+e^- events	3'700	37'000	84'000

Number of $e^+e^- \rightarrow H\nu\bar{\nu}$ events significantly enhanced with polarisation

Polarization	Enhancement factor	
$P(e^-) : P(e^+)$	$e^+e^- \rightarrow ZH$	$e^+e^- \rightarrow H\nu_e\bar{\nu}_e$
unpolarized	1.00	1.00
-80% : 0%	1.18	1.80
-80% : $+30\%$	1.48	2.34

List of benchmark studies I

1.) Simultaneous extraction of $H \rightarrow b\bar{b}$, $H \rightarrow c\bar{c}$ and $H \rightarrow gg$ at 350 GeV (Jan Strube, Victoria Martin, Jonatan Rosen, Marco Szalay) and 1.4 TeV (Tomas Lastovicka)

2.) Measurement of $H \rightarrow WW^*$ at 350 GeV and 1.4 TeV (and 3 TeV?)
(Mark Thomson: fully hadronic final state at 1.4 TeV and 3 TeV; Nigel Watson: qqlv final state, Mila Pandurovic: fully hadronic in HZ events at 350 GeV):
- At 1.4 TeV potential for absolute Higgs to W coupling

3.) ZZ-fusion at 1.4 TeV (and 3 TeV?)
(Aidan Robson, Dan Protopopescu, Tom Doherty, project student):
- Ratio of the ZZH to WWH couplings
- Potential for other coupling measurements

4.) Higgs to gamma+gamma (Christian Grefe) and Z+gamma (Eva Sicking) at 1.4 TeV

5.) Measurement of $H \rightarrow \tau^+\tau^-$ at 350 GeV, 1.4 TeV and 3 TeV (Astrid Münnich)

6.) Measurement of $H \rightarrow \mu^+\mu^-$ at 1.4 TeV
(Ivanka Bozovic-Jelisavcic, Gordana Milutinovic-Dumbelovic, Strahinja Lukic, Mila Pandurovic)

7.) Measurement of the top Yukawa coupling at 1.4 TeV
(Sophie Redford, Marcelo Vogel, Philipp Roloff)

List of benchmark studies II

8.) Measurement of the Higgs self-coupling at 1.4 and 3 TeV
(Tomas Lastovicka, Jan Strube (CLIC_SiD & CLIC_ILD)
+ MPI Munich (investigating potential of different analysis techniques in CLIC_ILD))

9.) Measurement of $H \rightarrow ZZ^*$ at 350 GeV and 1.4 TeV
(Gordana Milutinovic-Dumbelovic, with Z-decays qqqq and qqll)

10.) Model independent measurement of σ(HZ) using the recoil method with
$Z \rightarrow q\bar{q}$ at 350 GeV (Mark Thomson)

Uncovered topics (volunteers welcome):

- 350 GeV, WW fusion, Higgs decay to WW*
- 3 TeV, WW fusion, Higgs decay to gammagamma
- 3 TeV, WW fusion, Higgs decay to Zgamma

Current status: Snowmass white paper

Channel	Measurement	Observable	Statistical precision 350 GeV 500 fb^{-1}	1.4 TeV 1.5 ab^{-1}	3.0 TeV 2.0 ab^{-1}
ZH	Recoil mass distribution	m_H	120 MeV	–	–
ZH	$\sigma(HZ) \times BR(H \to \text{invisible})$	Γ_{inv}	tbd	–	–
ZH	$H \to b\bar{b}$ mass distribution	m_H	tbd	–	–
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	–	40 MeV*	33 MeV*
ZH	$\sigma(HZ) \times BR(Z \to \ell^+\ell^-)$	g^2_{HZZ}	4.2%	–	–
ZH	$\sigma(HZ) \times BR(H \to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	1%†	–	–
ZH	$\sigma(HZ) \times BR(H \to c\bar{c})$	$g^2_{HZZ}g^2_{Hcc}/\Gamma_H$	5%†	–	–
ZH	$\sigma(HZ) \times BR(H \to gg)$		6%†	–	–
ZH	$\sigma(HZ) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ}g^2_{H\tau\tau}/\Gamma_H$	5.7%	–	–
ZH	$\sigma(HZ) \times BR(H \to WW^*)$	$g^2_{HZZ}g^2_{HWW}/\Gamma_H$	2%†	–	–
ZH	$\sigma(HZ) \times BR(H \to ZZ^*)$	$g^2_{HZZ}g^2_{HZZ}/\Gamma_H$	tbd	–	–
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW}g^2_{Hbb}/\Gamma_H$	3%†	0.3%	0.2%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW}g^2_{Hcc}/\Gamma_H$	–	2.9%	2.7%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		–	1.8%	1.8%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-)$	$g^2_{HWW}g^2_{H\tau\tau}/\Gamma_H$	–	3.7%	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \mu^+\mu^-)$	$g^2_{HWW}g^2_{H\mu\mu}/\Gamma_H$	–	29%*	16%
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \gamma\gamma)$		–	15%*	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to Z\gamma)$		–	tbd	tbd
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*)$	g^4_{HWW}/Γ_H	tbd	1.1%*	0.8%*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to ZZ^*)$	$g^2_{HWW}g^2_{HZZ}/\Gamma_H$	–	3%†	2%†
He^+e^-	$\sigma(He^+e^-) \times BR(H \to b\bar{b})$	$g^2_{HZZ}g^2_{Hbb}/\Gamma_H$	–	1%†	0.7%†
$t\bar{t}H$	$\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$	$g^2_{Htt}g^2_{Hbb}/\Gamma_H$	–	8%	tbd
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	g_{HHWW}	–	7%*	3%*
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	λ	–	28%	16%
$HH\nu_e\bar{\nu}_e$	with -80% e^- polarization	λ	–	21%	12%

arXiv:1307.5288
final update:
01/10/2013
(yesterday)

†: estimate
*: preliminary

Several updates since the summer

Status reports from Higgs analyses

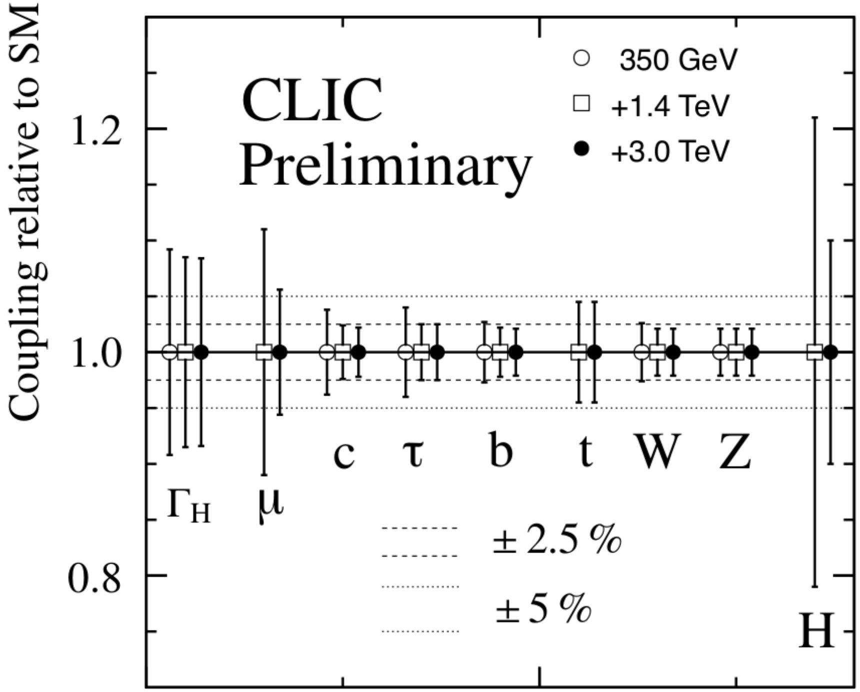
Tuesday morning:

Mark Thomson: $H \rightarrow WW^*$ at 1.4 TeV and nearly model-independent $HZ \rightarrow Hq\bar{q}$ at 350 GeV
Christian Grefe: $H \rightarrow \gamma\gamma$, $H \rightarrow Z\gamma$ at 1.4 TeV
Gordana Milutinovic-Dumbelovic: $H \rightarrow \mu^+\mu^-$ at 1.4 TeV

Wednesday morning:

Jan Strube: Higgs self-coupling at 1.4 and 3 TeV
Aidan Robson: ZZ-fusion at 1.4 TeV
Marcelo Vogel: $t\bar{t}H$ at 1.4 TeV

Combined analysis



Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+1.4 TeV +1.5 ab^{-1}	+3.0 TeV +2.0 ab^{-1}
m_H	120 MeV	30 MeV	20 MeV
Γ_H	9.2%	8.5%	8.4%
λ	–	21%	10%
g_{HZZ}	2.1%	2.1%	2.1%
g_{HWW}	2.6%	2.1%	2.1%
g_{Hbb}	2.7%	2.2%	2.1%
g_{Hcc}	3.8%	2.4%	2.2%
$g_{H\tau\tau}$	4.0%	2.5%	tbd
$g_{H\mu\mu}$	–	11%	5.6%
g_{Htt}	–	4.5%	tbd

- Fit to currently available results and a few estimates (see slide 8)
- Fully model-independent

Combined analysis II

Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+1.4 TeV +1.5 ab^{-1}	+3.0 TeV +2.0 ab^{-1}
$\Gamma_{\mathrm{H,model}}$	1.6%	0.29%	0.22%
κ_{HZZ}	0.49%	0.33%	0.24%
κ_{HWW}	1.5%	0.15%	0.11%
κ_{Hbb}	1.7%	0.33%	0.21%
κ_{Hcc}	3.1%	1.1%	0.75%
$\kappa_{\mathrm{H}\tau\tau}$	3.5%	1.4%	tbd
$\kappa_{\mathrm{H}\mu\mu}$	–	11%	5.2%
κ_{Htt}	–	4.0%	tbd
κ_{Hgg}	3.6%	0.79%	0.56%
$\kappa_{\mathrm{H}\gamma\gamma}$	–	5.5%	tbd

$$\kappa_i^2 = \frac{\Gamma_i}{\Gamma_i^{\mathrm{SM}}}$$

No invisible decays:

$$\Gamma_{\mathrm{H,model}} = \sum_i \kappa_i^2 \cdot BR_i^{\mathrm{SM}}$$

Sub-percent precisions at high energy

→ Results strongly dependent on fit assumptions

Next step: CLIC Higgs paper

Structure of the paper:

1.) Introduction
2.) Accelerator & detectors
3.) Monte Carlo generators, simulation and reconstruction tools
4.) Overview of Higgs production at CLIC
5.) Higgsstrahlung at 350 GeV
6.) Vector-boson fusion
7.) top Yukawa coupling
8.) Higgs self-coupling
9.) Higgs mass
10.) Combined analysis
11.) Summary and conclusions

Deadline: end of the year!

Ideas / plans for future studies

Precision EW measurements

- Triple and quartic gauge boson vertex corrections to $e^+e^- \to W^+W^- (\nu\bar{\nu}/e^+e^-)$

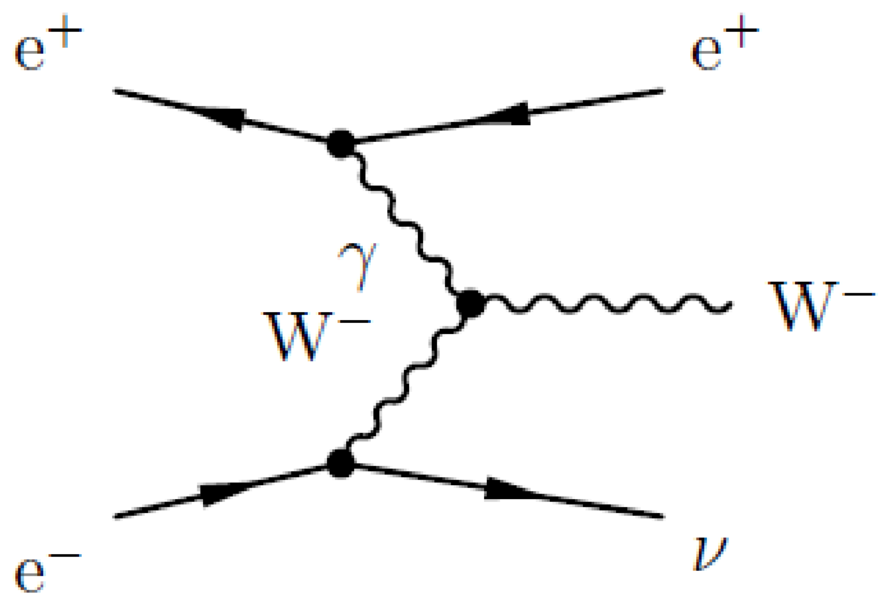
- Forward-backward and left-right asymmetries of fermion production to achieve precision measurements of $\sin^2\theta_f^{eff}$ at various energies

- W boson mass determination at high energy and high luminosity

- Total $e^+e^- \to f\bar{f}$ cross sections at high energy with various electron-positron polarisations in search of form-factor suppressions or enhancements

M_W from single W events

- Large samples of single W events produced at high-energy CLIC
- Potential for competitive measurement of M_W using $W^{\pm} \rightarrow q\bar{q}$
- Need full simulation study to understand the impact of systematic effects, i.e. the jet energy scale



$e^+e^- \rightarrow e^+W^-\nu$

	1.4 TeV	3 TeV
L_{int}	1500 fb^{-1}	2000 fb^{-1}
# eWv events	22.3 x 10^6	44.9 x 10^6
# eWv events, $W \rightarrow q\bar{q}$	15.0 x 10^6	30.3 x 10^6
# eWv events, $W \rightarrow q\bar{q}$, 20° < θ(q,$\bar{q}$) < 160°	8.9 x 10^6	15.4 x 10^6

Top physics

Study potential to use top quarks as probe for New Physics:

- Production asymmetries
- Couplings to γ, W and Z
- CP violation in top sector
- Flavour changing top decays

BSM physics

Mayor focus of CLIC physics at high energy!

• Model-independent searches for Dark Matter
→ see talk by J.J. Blaising

• Composite Higgs bosons → see talk by Roberto Contino

• Generalisation of higher-dimensional effective operator searches at the various CLIC energy stages

• Searches for weakly interacting exotic particles

• Searches for vectorlike particles charged under electroweak group

• Responding to theory guidance for New Physics that is compatible and explains LHC data in the future

How to get involved

Regular analysis meetings at CERN (every 2-3 weeks):

http://indico.cern.ch/categoryDisplay.py?categId=3222

Remote participation by webex is always possible!

If interested, please contact us:

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philipp.roloff@cern.ch

Summary

- CLIC physics benchmark studies are a very active area

- Contributions from many groups / individuals

- In the last few months we have focussed on Higgs physics

- Plan to finish the comprehensive paper on Higgs physics from 350 GeV to 3 TeV by the end of the year

Backup slides

CLIC energy stages

- CLIC will be implemented in stages: optimised running conditions over a wide energy range
- The energy stages are defined by physics with additional technical considerations

→ strategy can be adapted to discoveries at the LHC

Currently studied example scenario:

- **<u>Stage 1:</u>** 350/375 GeV, 500 fb^{-1}

HZ cross section, mass, $H\nu_e\bar{\nu}_e$ contribution sizeable, various branching rations, *top threshold scan*

- **<u>Stage 2:</u>** 1.4 TeV, 1.5 ab^{-1}

BSM physics, $t\bar{t}H$, Higgs self-coupling, rare Higgs decays

- **<u>Stage 3:</u>** 3 TeV, 2 ab^{-1}

BSM physics, $t\bar{t}H$, Higgs self-coupling, rare Higgs decays