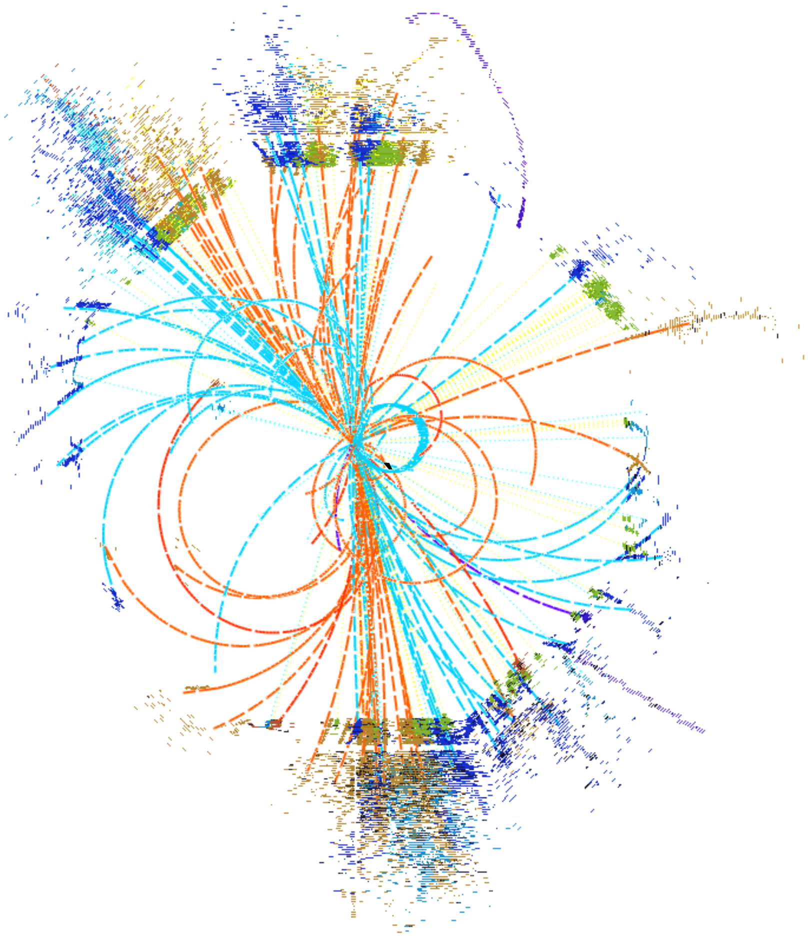
Prospects for precision Higgs physics at CLIC

Philipp Roloff (CERN)
on behalf of the CLIC detector and physics study



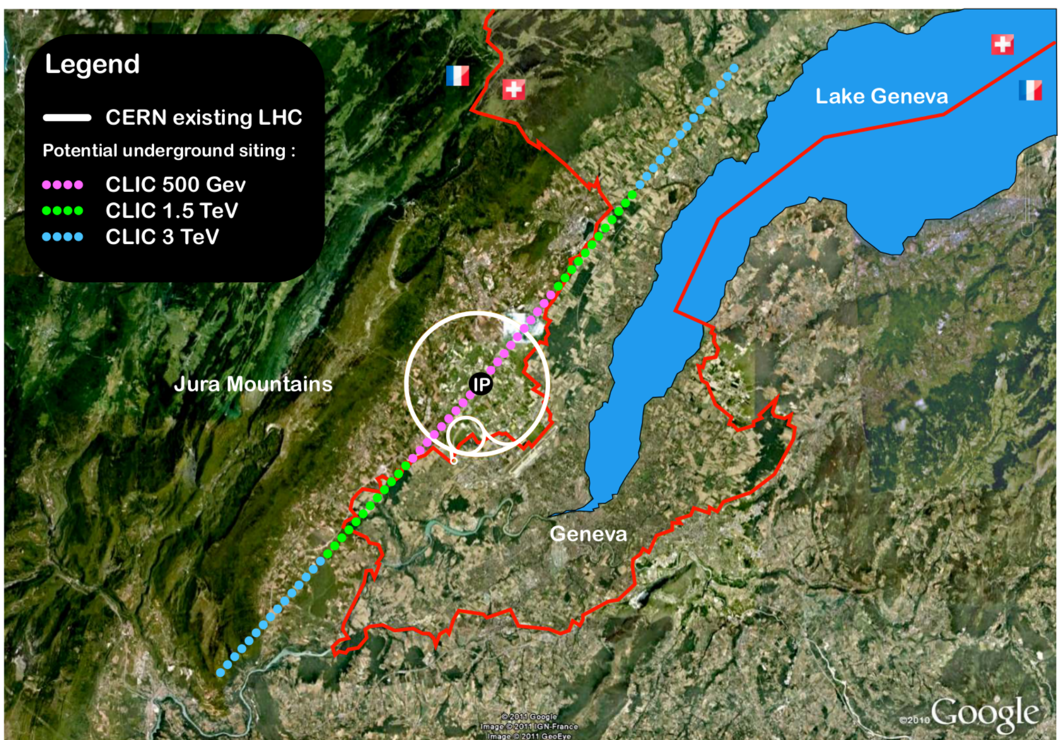
After the Discovery: Hunting for a Non-Standard Higgs Sector
Benasque, 14/04/2014

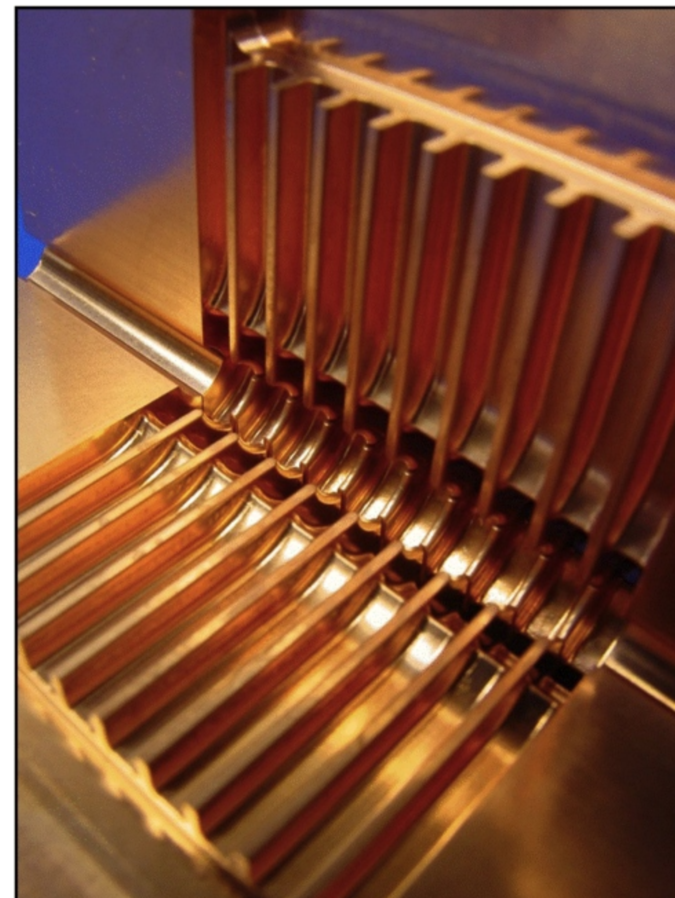
Introduction

The CLIC accelerator

CLIC is the only mature option for a multi-TeV future e^+e^- collider

- Based on 2-beam acceleration scheme
- Operated at room temperature
- Gradient: 100 MV/m
- Staged construction: ≈350 GeV up to 3 TeV
- High luminosity (a few 10^{34} $cm^{-2}s^{-1}$)





CLIC energy stages

CLIC would be implemented in stages:

- Optimised running conditions over a wide energy range
- The energy stages are defined by physics (with additional technical considerations)

→ The strategy can be adapted to discoveries at the LHC at 13/14 TeV

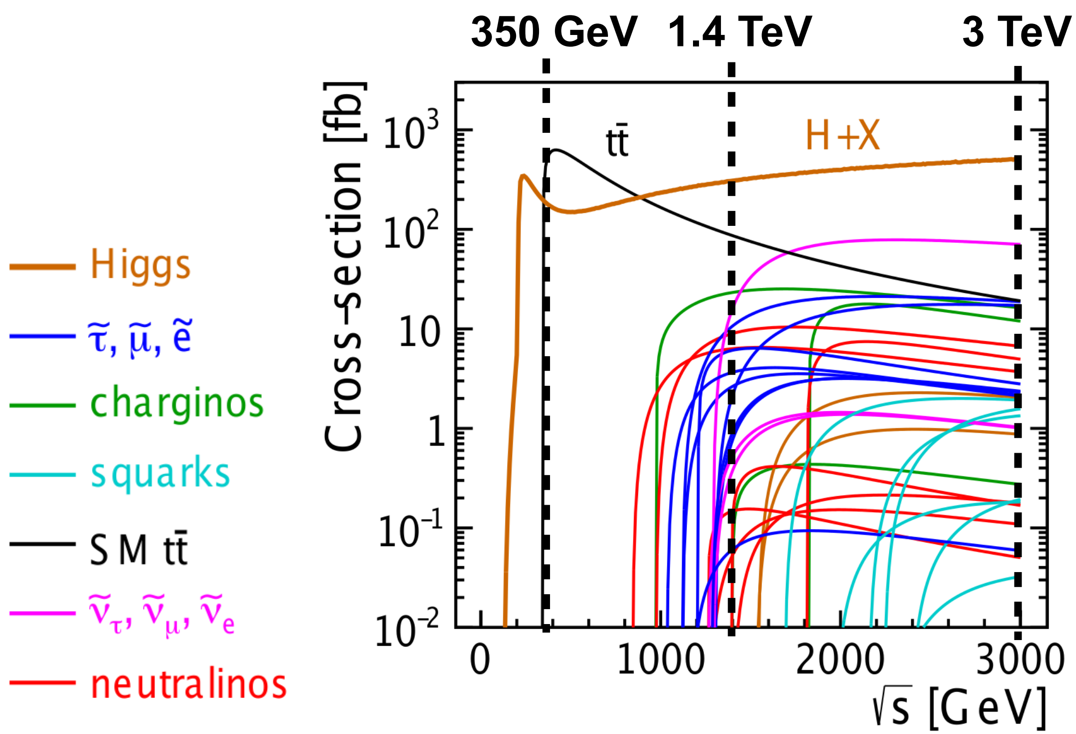
Currently studied example scenario:

- **Stage 1:** 350 / 375 GeV, 500 fb^{-1}
SM Higgs physics, $t\bar{t}$ threshold scan

- **Stage 2:** 1.4 TeV, 1.5 ab^{-1}
Targeted at BSM physics,
rare Higgs processes and decays

- **Stage 3:** 3 TeV, 2 ab^{-1}
Targeted at BSM physics,
rare Higgs processes and decays

(each stage corresponds to 4-5 years)

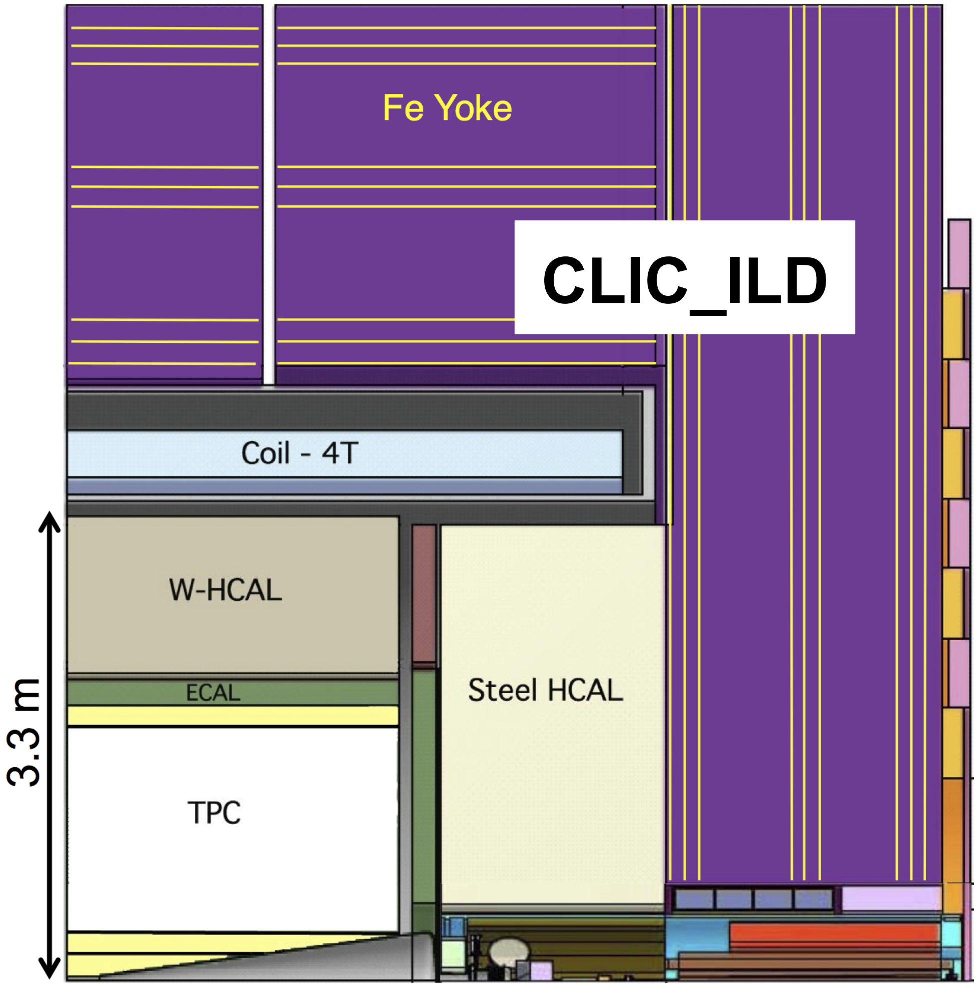


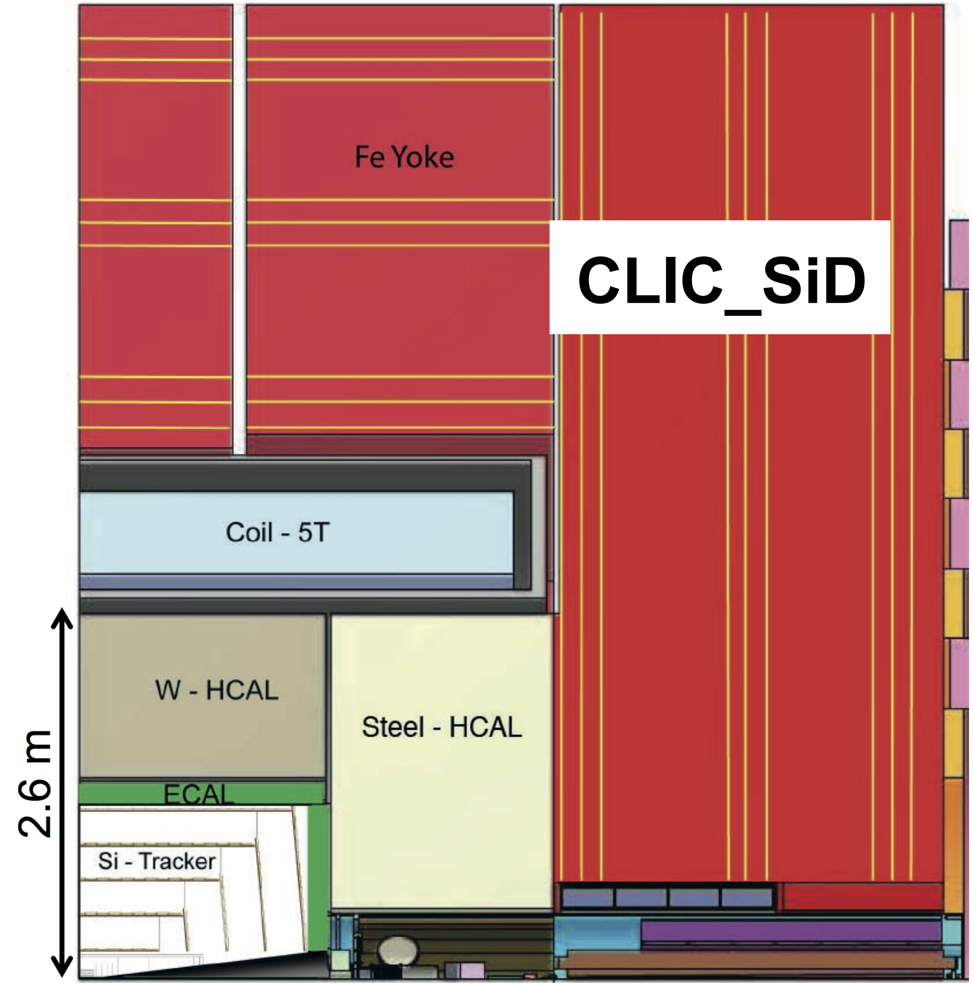
The CLIC detector and physics study

- Collaboration of 23 institutes from 16 countries
- CERN acts as host laboratory
- More information: http://clicdp.web.cern.ch/

CLIC detector concepts

Based on ILC concepts (ILD and SiD), adapted to CLIC conditions

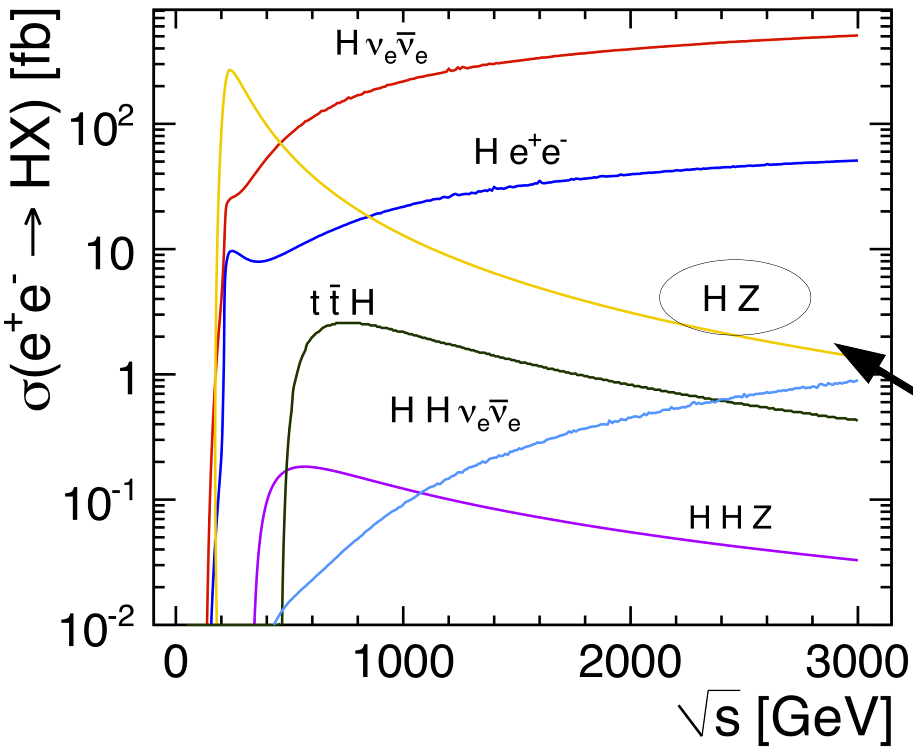




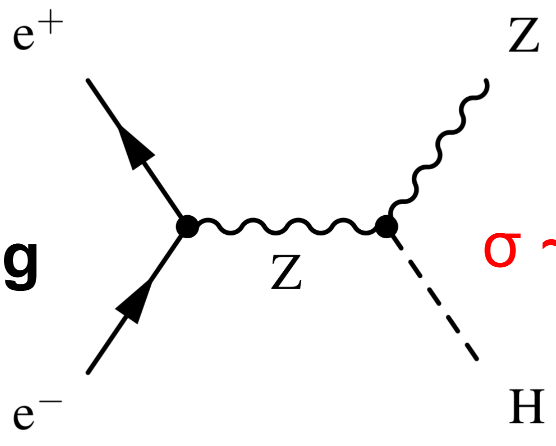
All benchmark studies are based on full detector simulations (Geant4)

SM-Higgs production at CLIC

Single Higgs production at CLIC

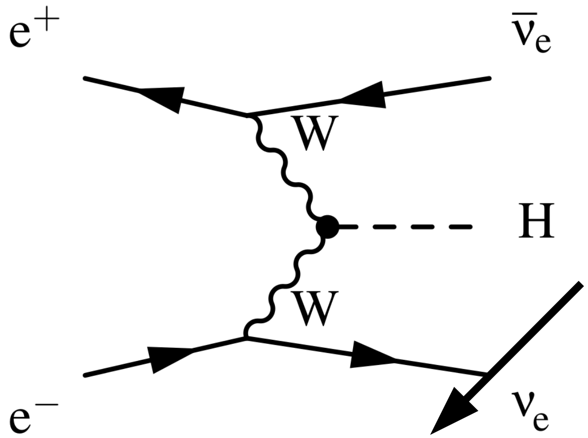


Higgs-strahlung



$\sigma \sim 1/s$

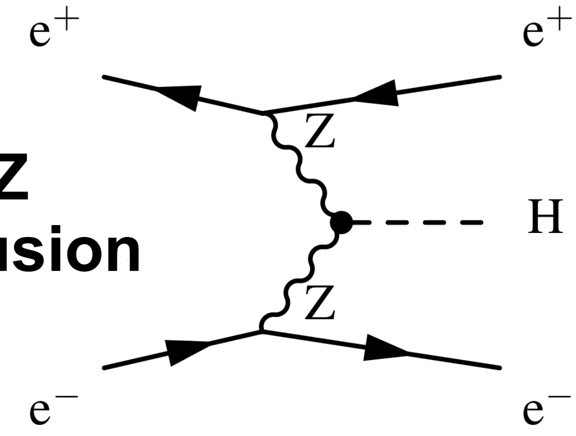
Single Higgs production at CLIC

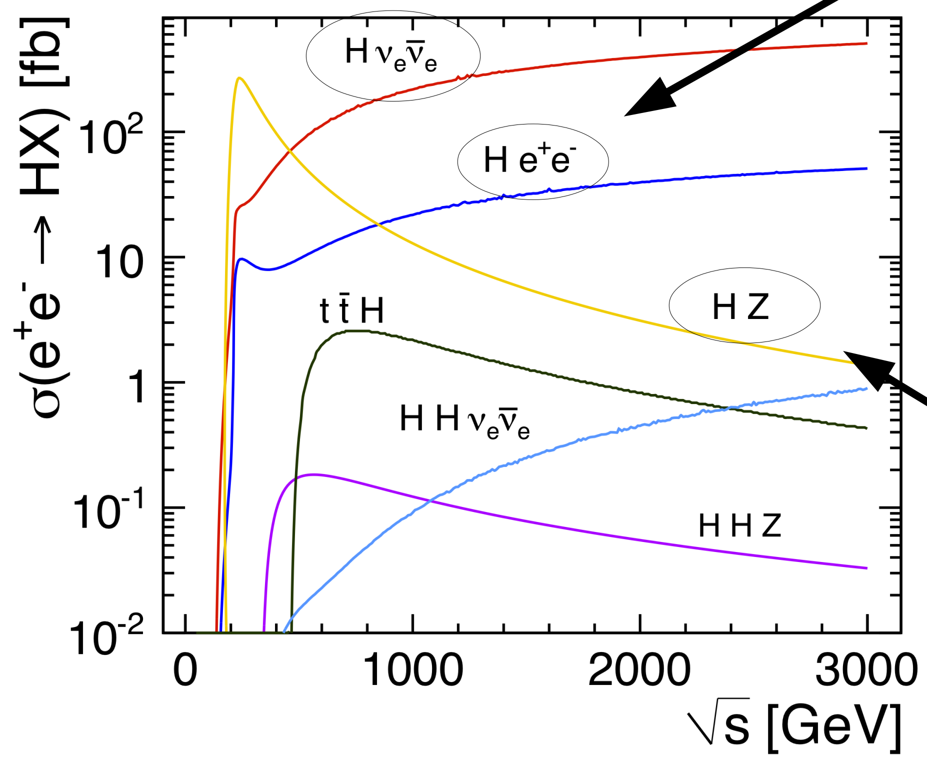


WW fusion

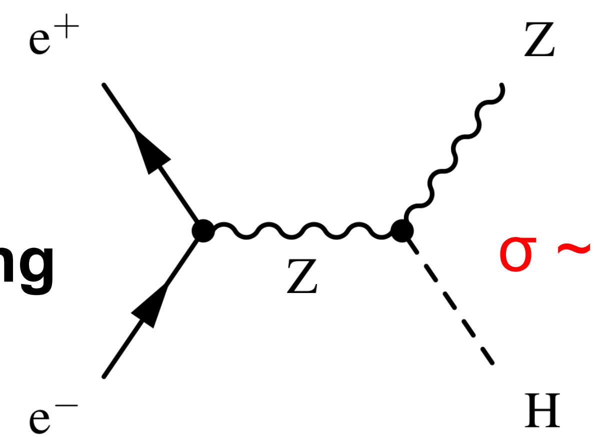
$\sigma \sim \log(s)$

ZZ fusion





Higgs-strahlung



$\sigma \sim 1/s$

Some numbers

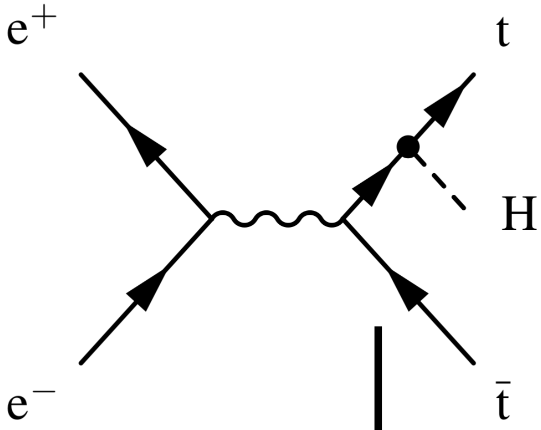
	350 GeV	1.4 TeV	3 TeV
L_{int}	500 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	68 000	20 000	11 000
# $H\nu_e\bar{\nu}_e$ events	26 000	370 000	830 000
# He^+e^- events	3 700	37 000	84 000

- Large samples of Higgs bosons produced at CLIC
- Already at 350 GeV far surpassing the number of W bosons at LEP

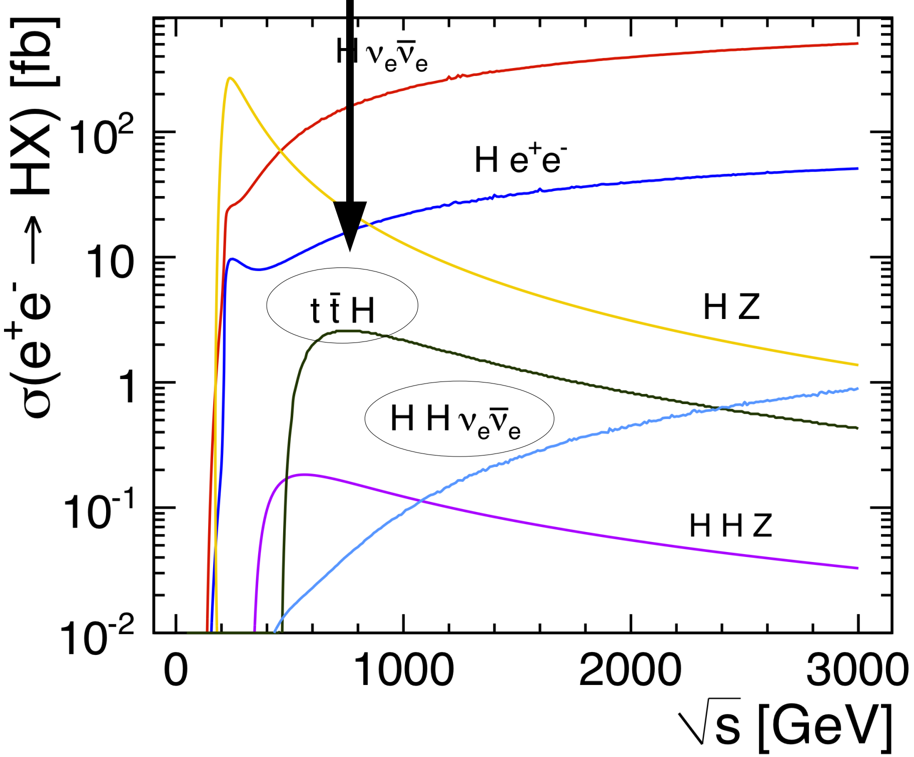
- Benchmark studies assume unpolarised beams
- CLIC foresees ±80% e^- polarisation (e^+ polarisation possible at lower level)

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

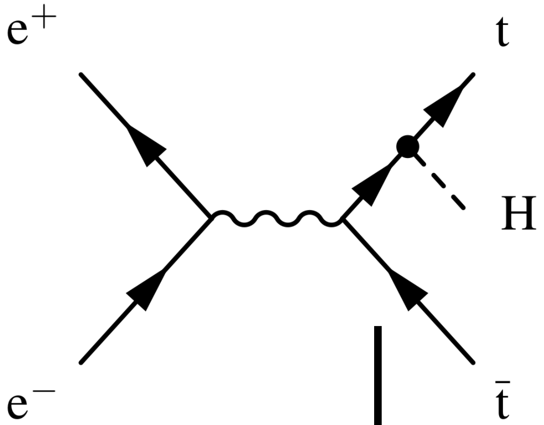
Processes at higher energy



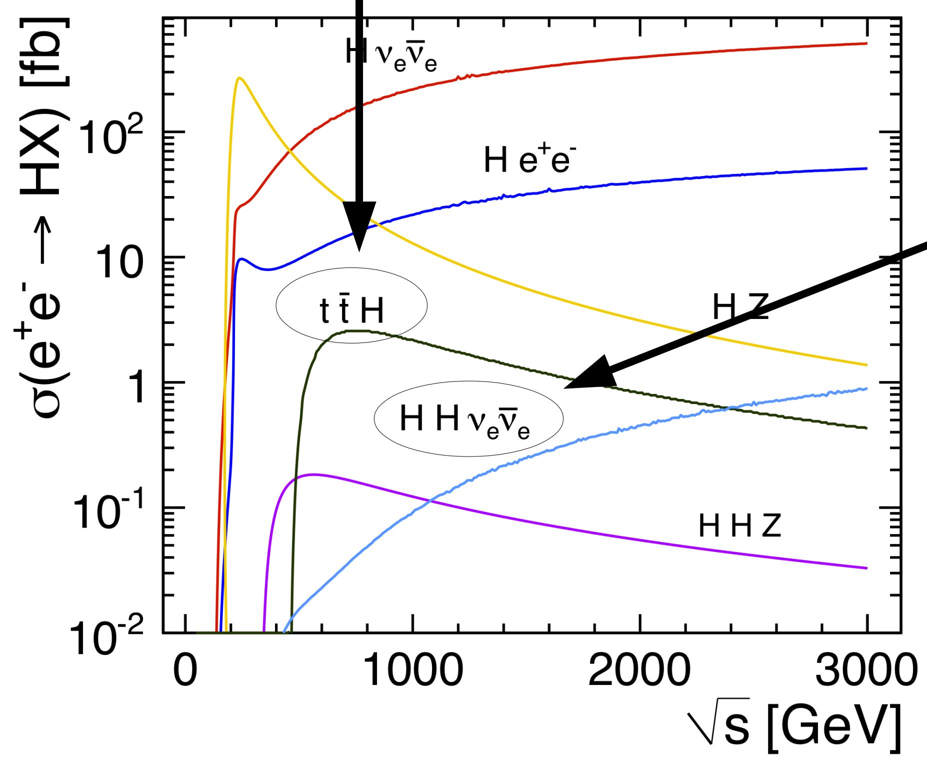
$t\bar{t}H$ production: maximum at around 800 GeV

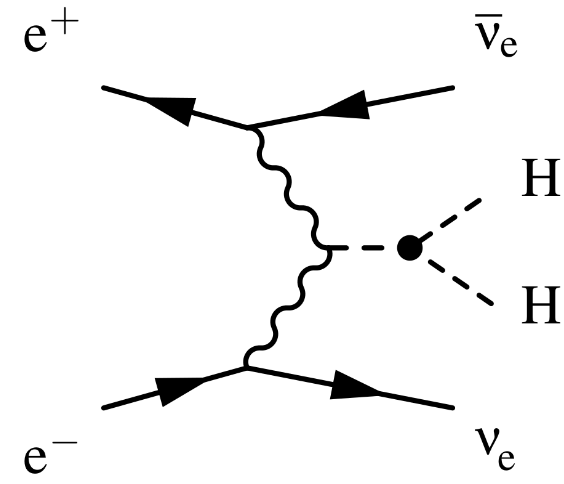


Processes at higher energy

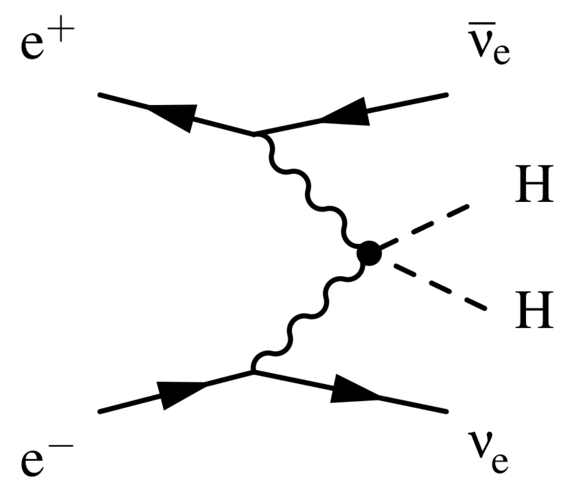


$t\bar{t}H$ production:
maximum at around 800 GeV





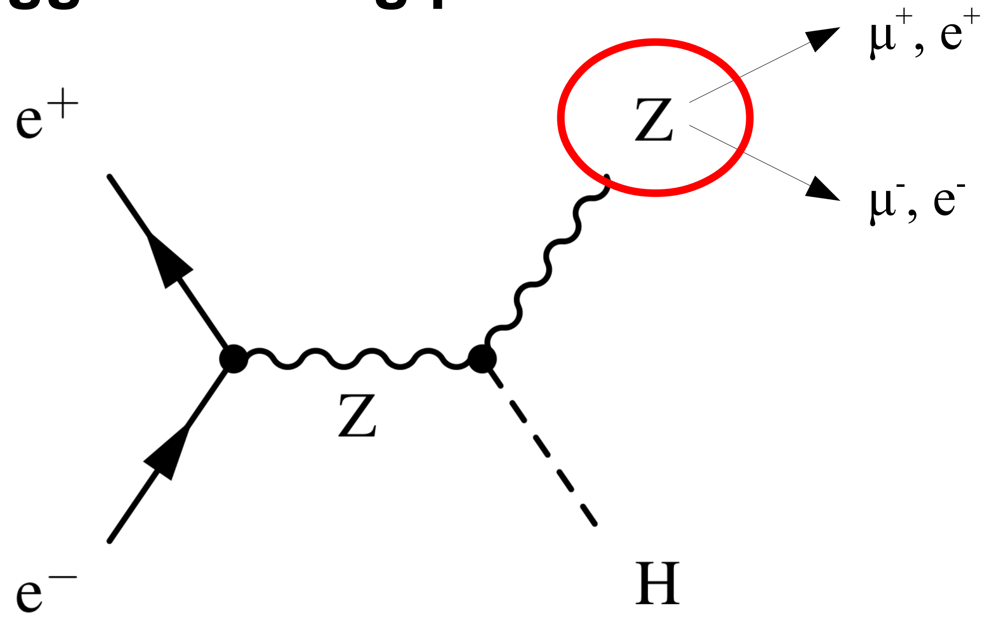
Double Higgs production:
requires high energy



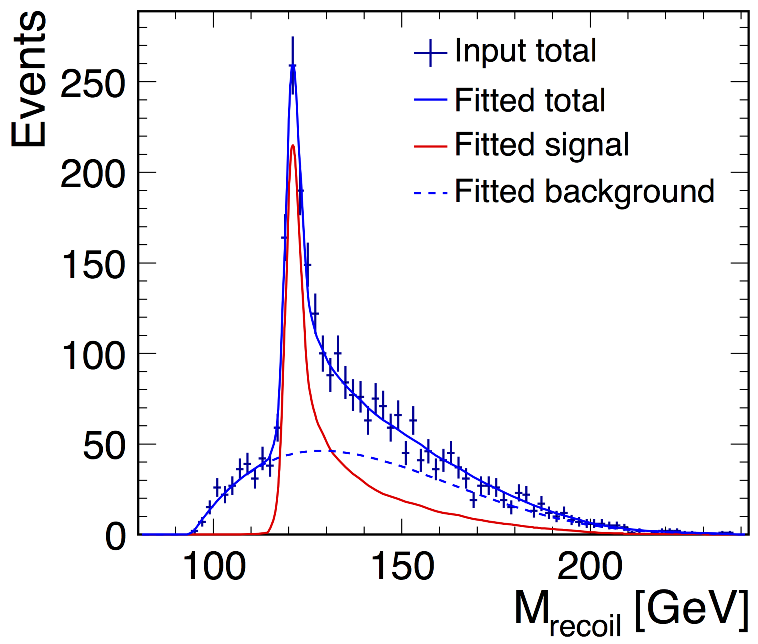
Results from full simulation studies

Higgsstrahlung at 350 GeV (1)

Higgsstrahlung process



$e^+e^+ \rightarrow ZH \rightarrow \mu^+\mu^-H$

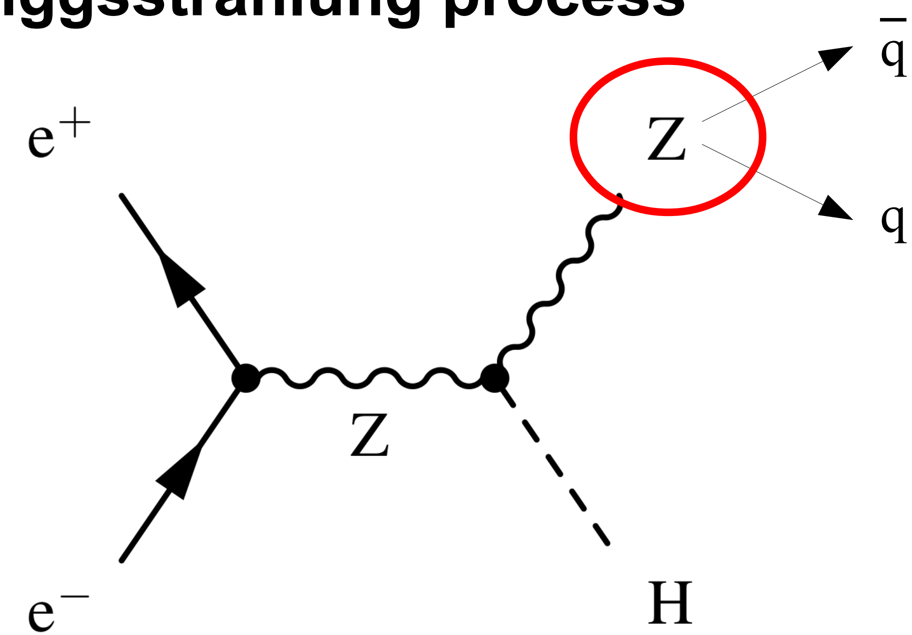


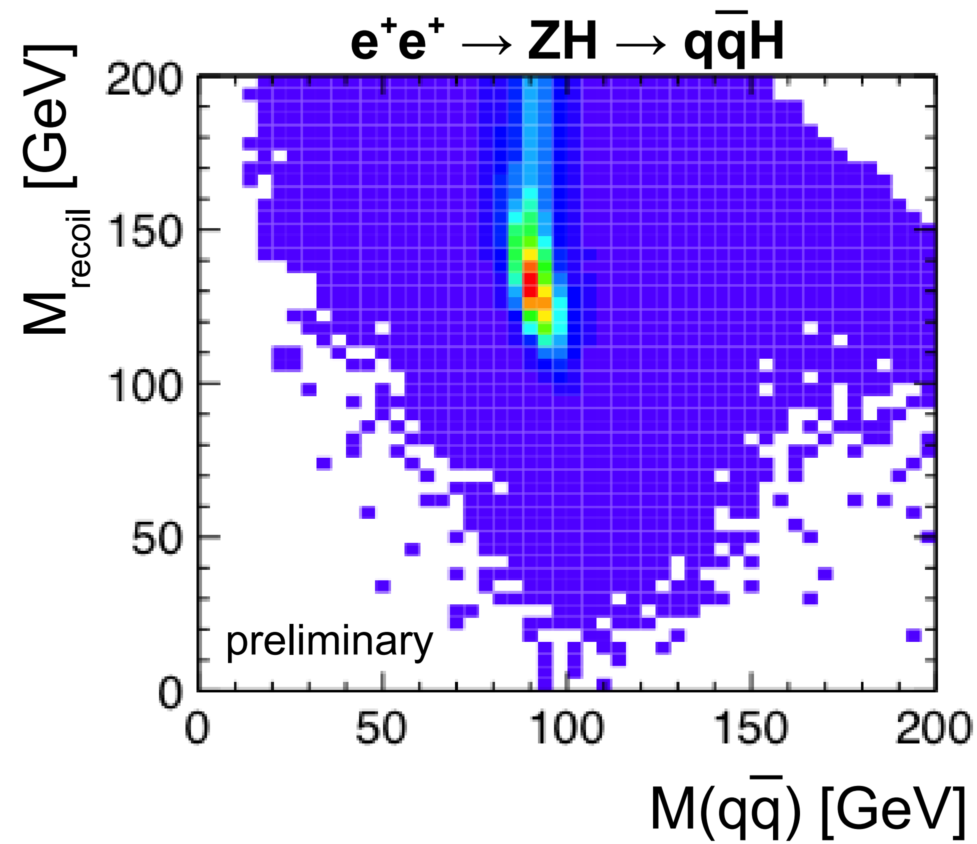
HZ events can be identified from Z recoil mass
→ model independent measurements of the g_{HZZ} coupling

$\Delta(\sigma_{HZ}) / \sigma_{HZ} \approx 4\% \rightarrow \Delta(g_{HZZ}) / g_{HZZ} \approx 2\%$ from $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$

Higgsstrahlung at 350 GeV (2)

Higgsstrahlung process

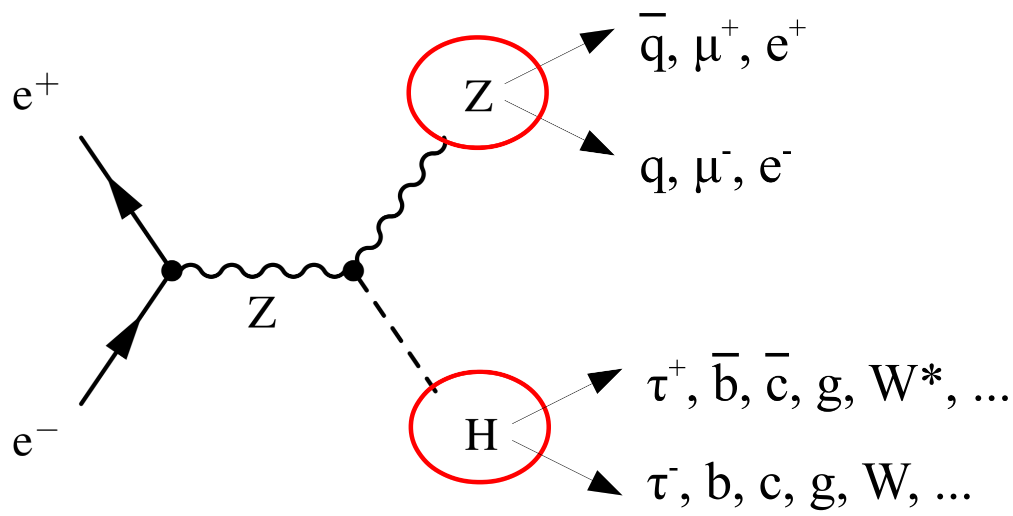




- Substantial improvement using hadronic Z decays
- Challenge: $Z \rightarrow q\bar{q}$ reconstruction may depend on Higgs decay mode
- Ongoing study: bias seems very small

$\Delta(\sigma_{HZ}) / \sigma_{HZ} \approx 2\% \rightarrow \Delta(g_{HZZ}) / g_{HZZ} \approx 1\%$ from hadronic Z decays

σ x BR measurements at 350 GeV



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

Assuming unpolarised beams

Extraction of Higgs couplings from all measurements → later

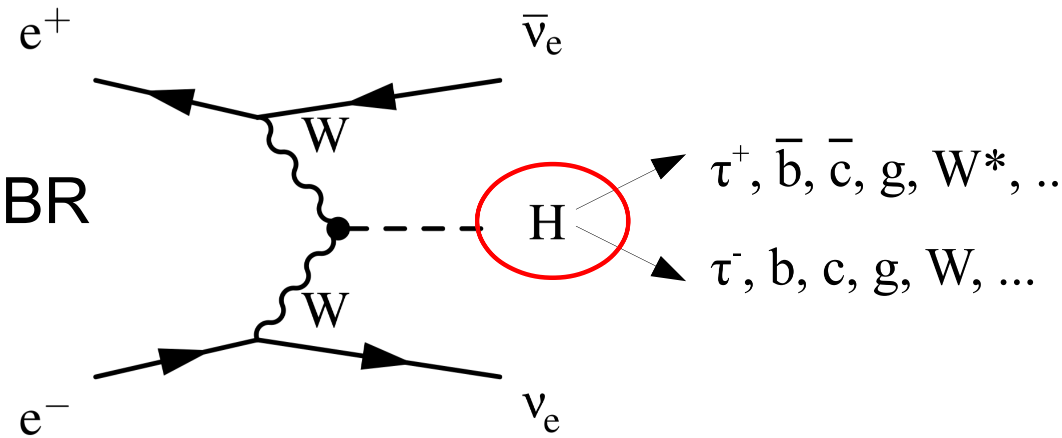
Measurements using $H\nu_e\bar{\nu}_e$ events

Large Higgs samples produced in WW fusion at high energy:

→ Precision measurements of σ x BR

→ Access to rarer decay modes

(examples on the following slides)



Measurement	Observable	Stat. precision (1.4 TeV)	Stat. precision (3 TeV)
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to \tau^+\tau^-)$	$g^2_{HWW} g^2_{H\tau\tau} / \Gamma_H$	3.7%	tbd
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb} / \Gamma_H$	0.3%	0.2%
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc} / \Gamma_H$	2.9%	2.7%
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to gg)$		1.8%	1.8%
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to \mu^+\mu^-)$	$g^2_{HWW} g^2_{H\mu\mu} / \Gamma_H$	29%	16%
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to \gamma\gamma)$		15% (preliminary)	tbd
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to ZZ^*)$	$g^2_{HWW} g^2_{HZZ} / \Gamma_H$	3% (estimated)	2% (estimated)
$\sigma(H\nu_e\bar{\nu}_e)$ x $BR(H \to WW^*)$	g^4_{HWW} / Γ_H	1.1% (preliminary)	0.8% (preliminary)

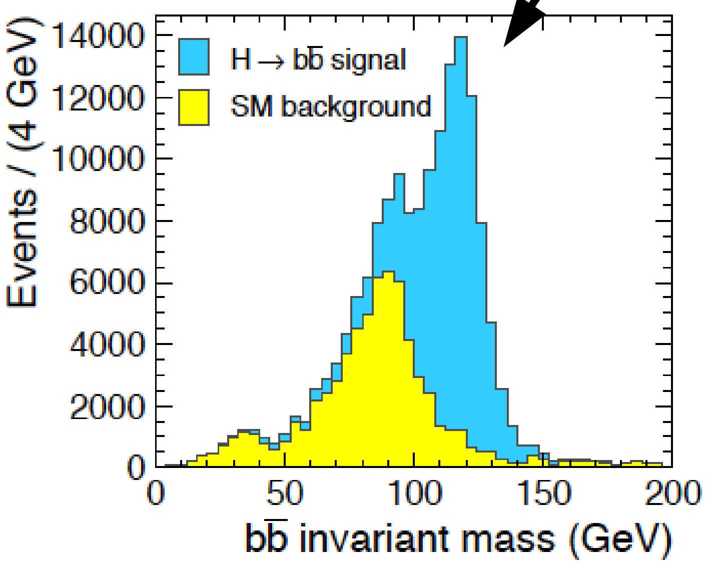
Assuming unpolarised beams

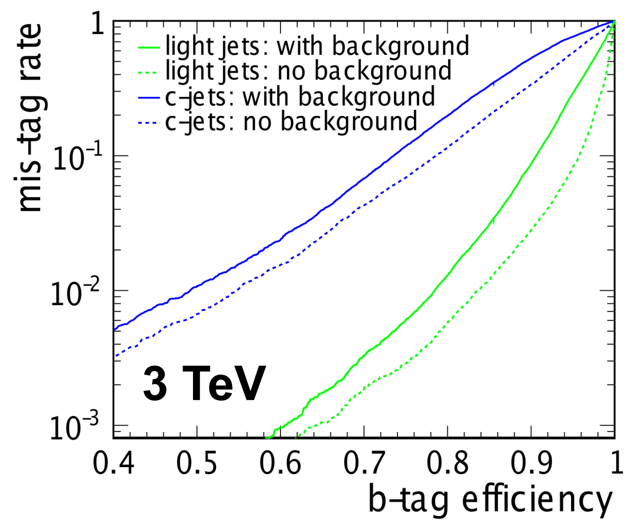
Precision measurements

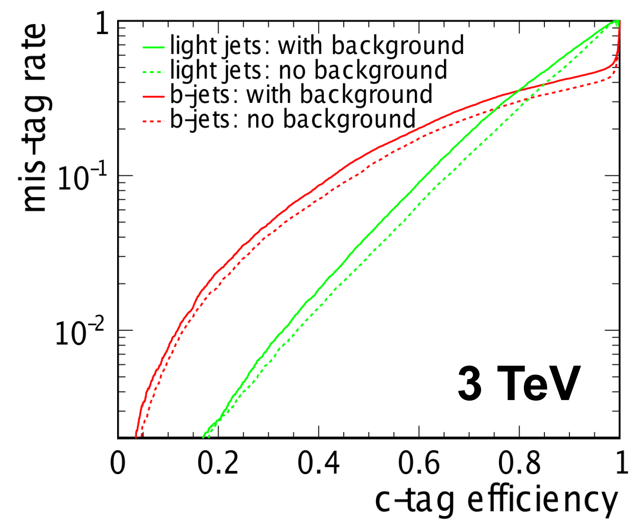
H → $b\bar{b}$/$c\bar{c}$/gg:

- Separation of the different hadronic final states using precise flavour tagging
- H → $c\bar{c}$ and gg impossible at hadron colliders
- In addition, the Higgs mass can be extracted from the H → $b\bar{b}$ invariant mass distribution (±40MeV at 1.4 TeV, ±33MeV at 3 TeV)

Measurement	1.4 TeV	3 TeV
$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	±0.3%	±0.2%
$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	±2.9%	±2.7%
$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$	±1.8%	±1.8%







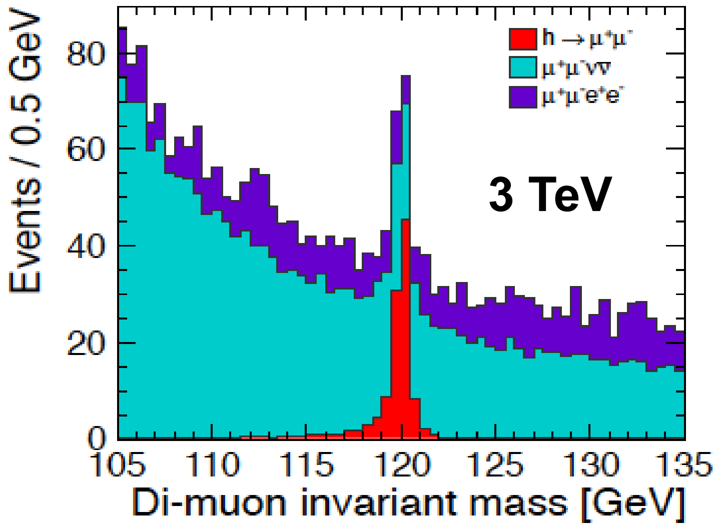
Rare decays

$\sigma(H\nu_e\bar{\nu}_e)$ x BR(H → $\mu^+\mu^-$):

- Very small BR (≈ 0.022%)
- Requires precision tracking

±29% at 1.4 TeV

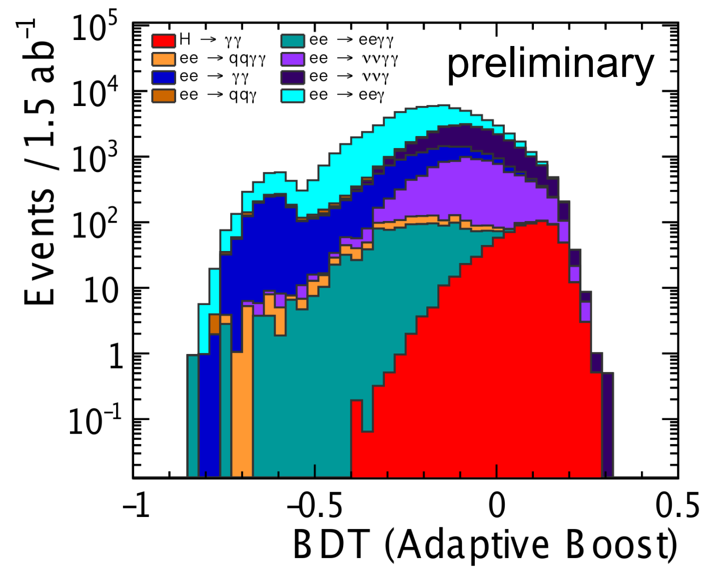
±16% at 3 TeV



$\sigma(H\nu_e\bar{\nu}_e)$ x BR(H → γγ):

- BR(H→γγ) ≈ 0.23%

±15% at 1.4 TeV



$\sigma(H\nu_e\bar{\nu}_e)$ x BR(H → Zγ):

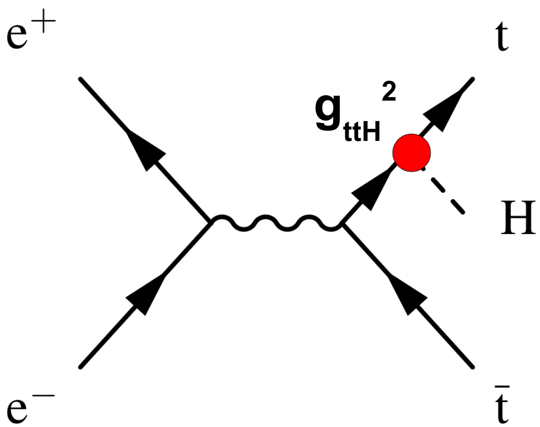
- BR(H→Zγ) ≈ 0.16%
- Hadronic Z decays usable

(in contrast to hadron colliders)

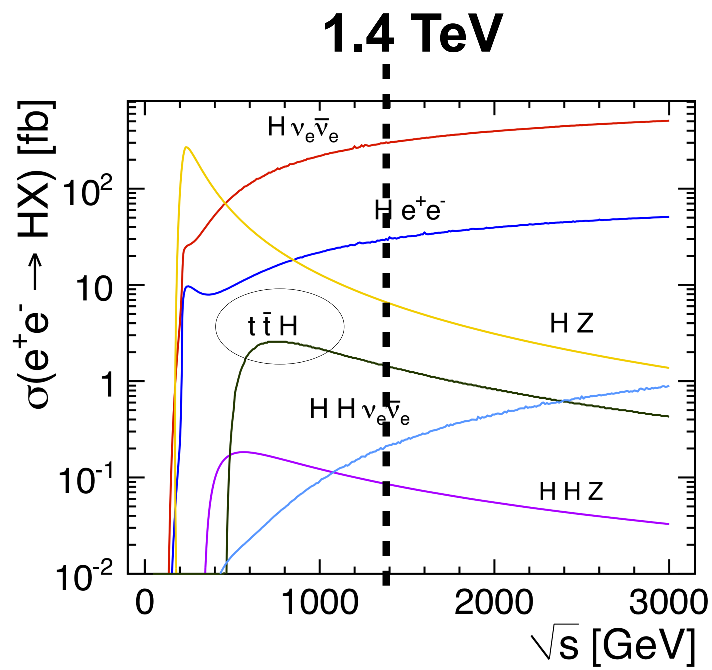
- Analysis ongoing

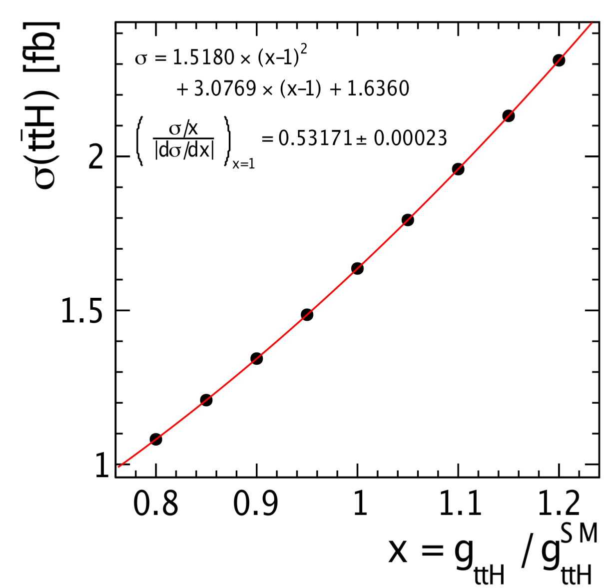
Processes at high energy

The $t\bar{t}H$ final state at 1.4 TeV (1)



→ The $t\bar{t}h$ cross section is directly sensitive to the top Yukawa coupling g_{ttH}





$$\frac{\Delta g_{ttH}}{g_{ttH}} = 0.53 \frac{\Delta\sigma}{\sigma}$$

(small deviation from 0.5 due to Higgsstrahlung contribution)

CLICdp-Note-2014-001

The $t\bar{t}H$ final state at 1.4 TeV (2)

Investigated final states:

"*6 jets*": $t(\rightarrow qqb)\bar{t}(\rightarrow l\nu\bar{b})H(\rightarrow b\bar{b})$

"*8 jets*": $t(\rightarrow qqb)\bar{t}(\rightarrow qq\bar{b})H(\rightarrow b\bar{b})$

→ Four b-quarks in the final state

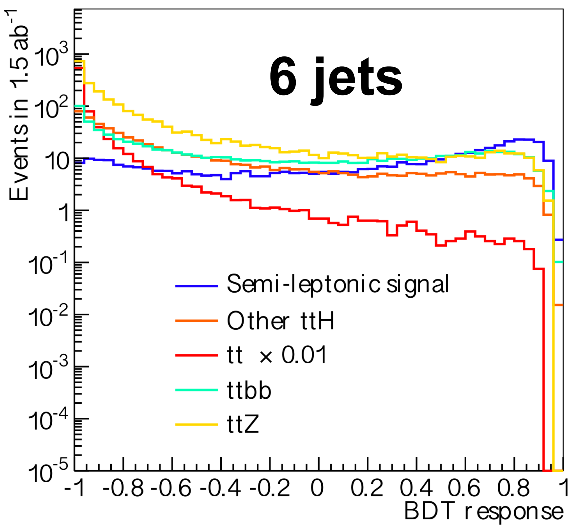
Various detector challenges:

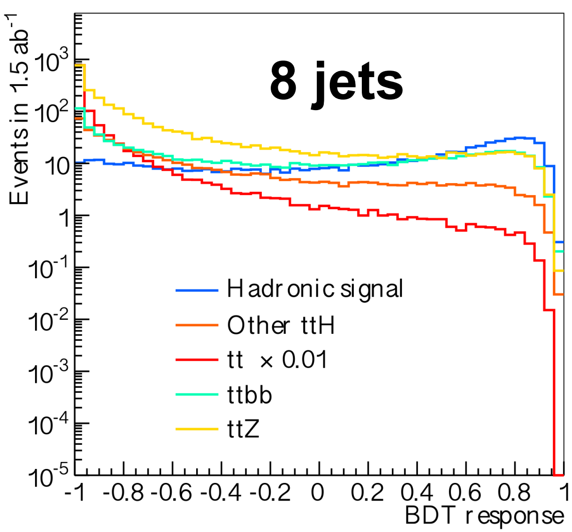
- jet clustering in complex final states
- flavour tagging
- identification of high-energy leptons
- missing energy reconstruction

Combination of both final states:

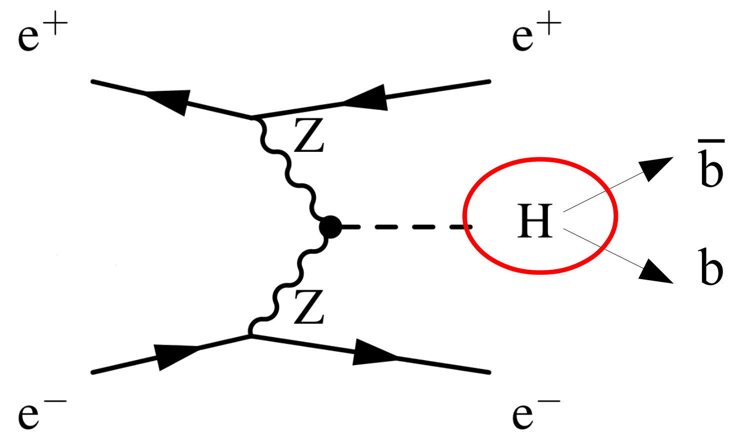
$\Delta\sigma(t\bar{t}H) / \sigma(t\bar{t}H) = 8.1\%$

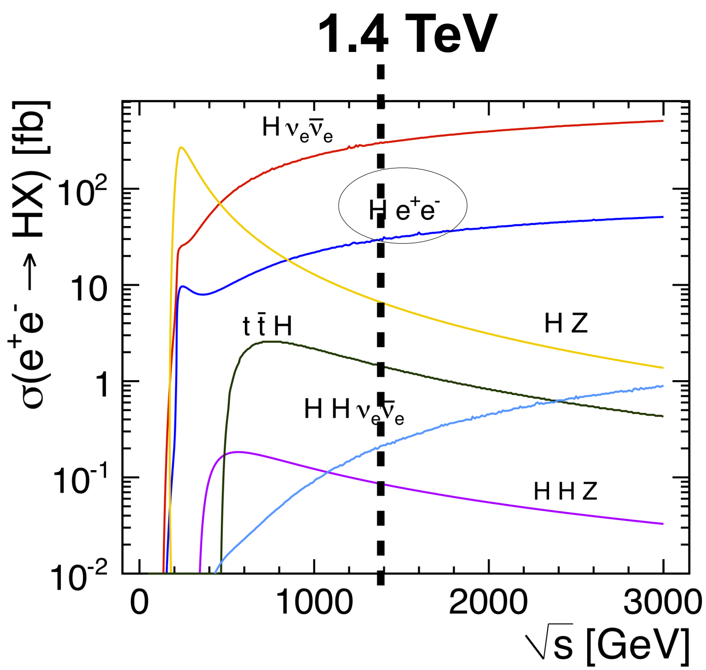
→ $\Delta g_{ttH} / \sigma_{ttH} = 4.3\%$





Higgs production in ZZ fusion





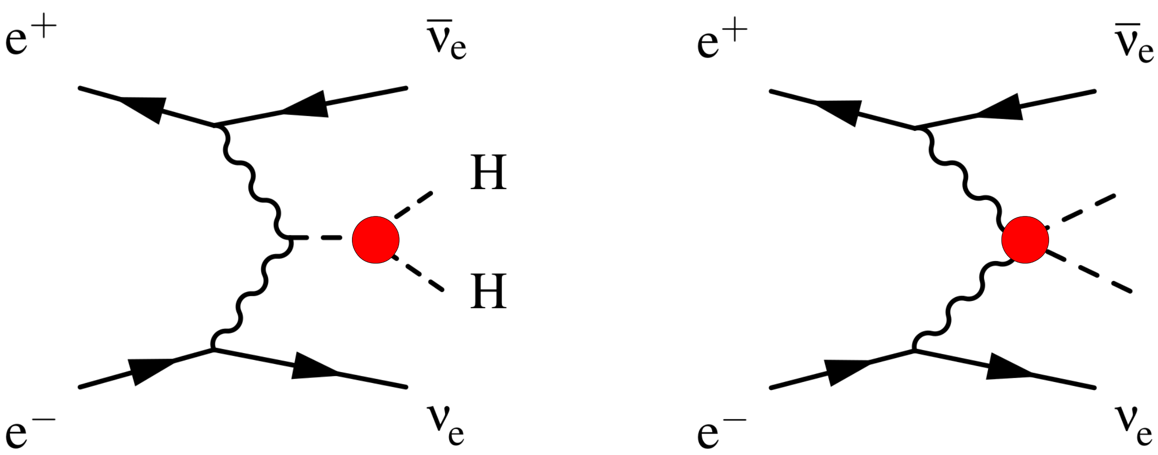
- Measurement of $\sigma(He^+e^-)$ x BR($H \to b\bar{b}$) with 1% precision

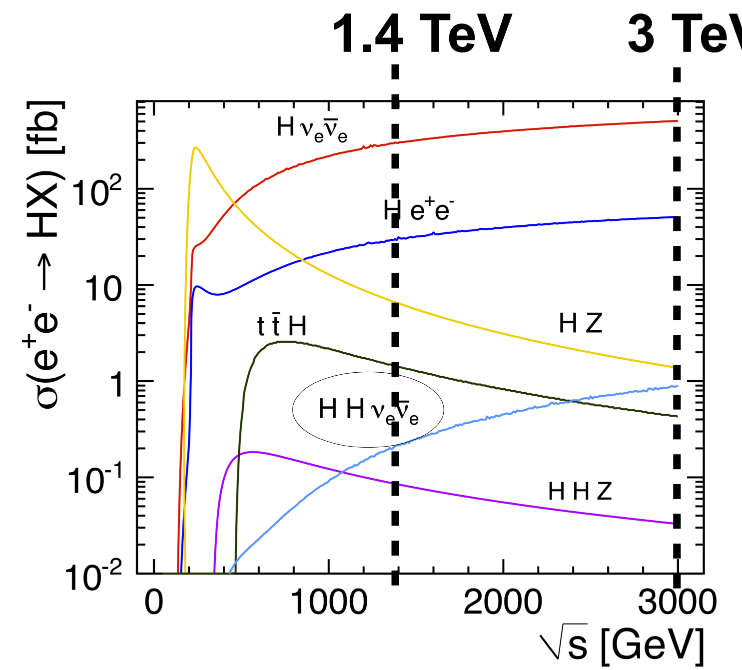
- Alternatively:

$$\frac{\sigma(He^+e^-) \times BR(H \to b\bar{b})}{\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})}$$

→ Precise determination of the ratio g_{HZZ} / g_{HWW}
(many systematic effects cancel in the ratio)

Double Higgs production at high energy (1)



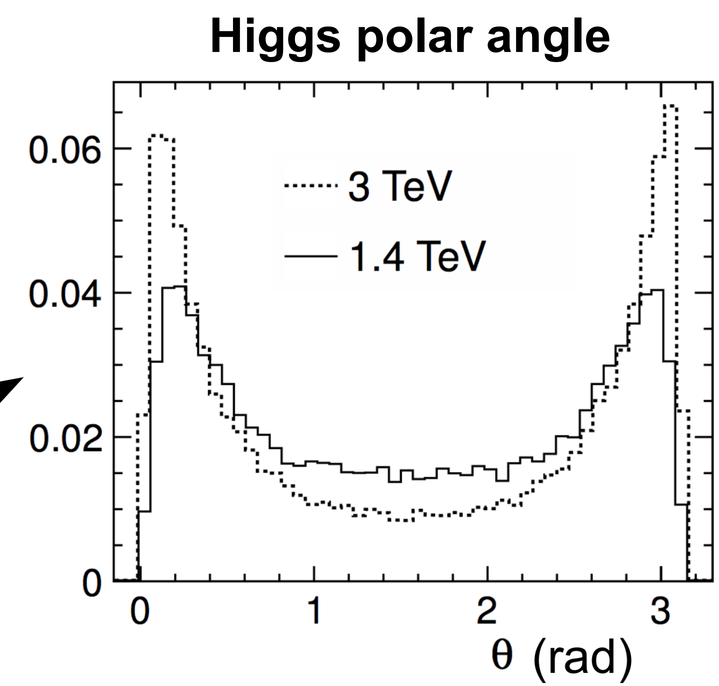


- The $HH\nu_e\bar{\nu}_e$ cross section is sensitive to the Higgs self coupling, λ, and the quartic HHWW coupling

- Only 225 (1200) $e^+e^- \rightarrow HH\nu_e\bar{\nu}_e$ events at 1.4 (3) TeV
→ high energy and luminosity crucial

Double Higgs production at high energy (2)

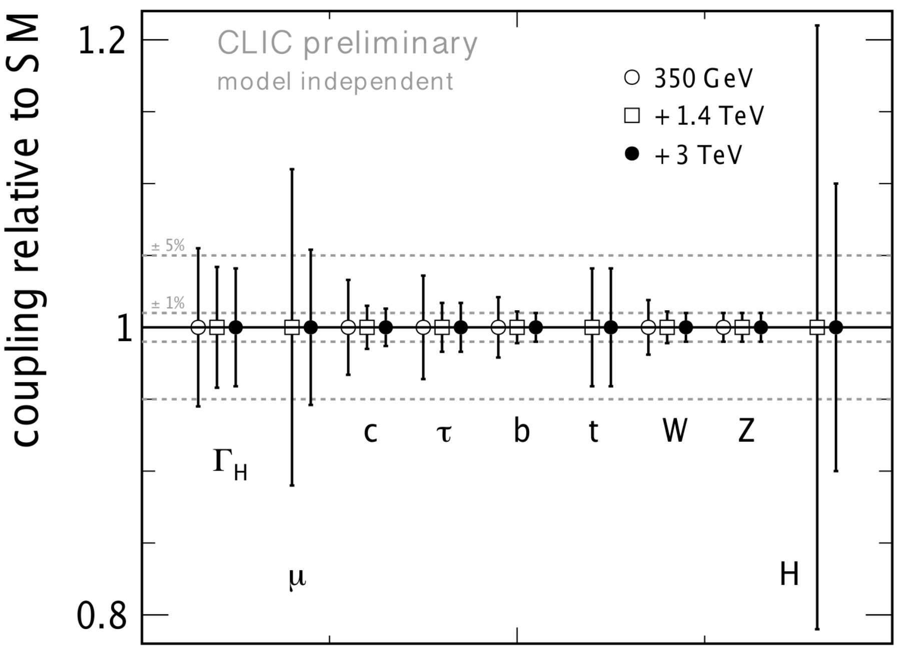
- HH→b$\bar{b}$b$\bar{b}$ events are selected in the current analysis
- Will perform studies for other final states, e.g. HH→b$\bar{b}$WW* in the future
→ Improvement expected
- Detector challenge: forward jet reconstruction



Measurement	1.4 TeV	3 TeV
$\Delta(g_{HHWW})$	7% (preliminary)	3% (preliminary)
$\Delta(\lambda)$	28%	16%
$\Delta(\lambda)$ for $P(e^-)$ = -80%	21%	12%

Combined analysis

Fully model-independent analysis

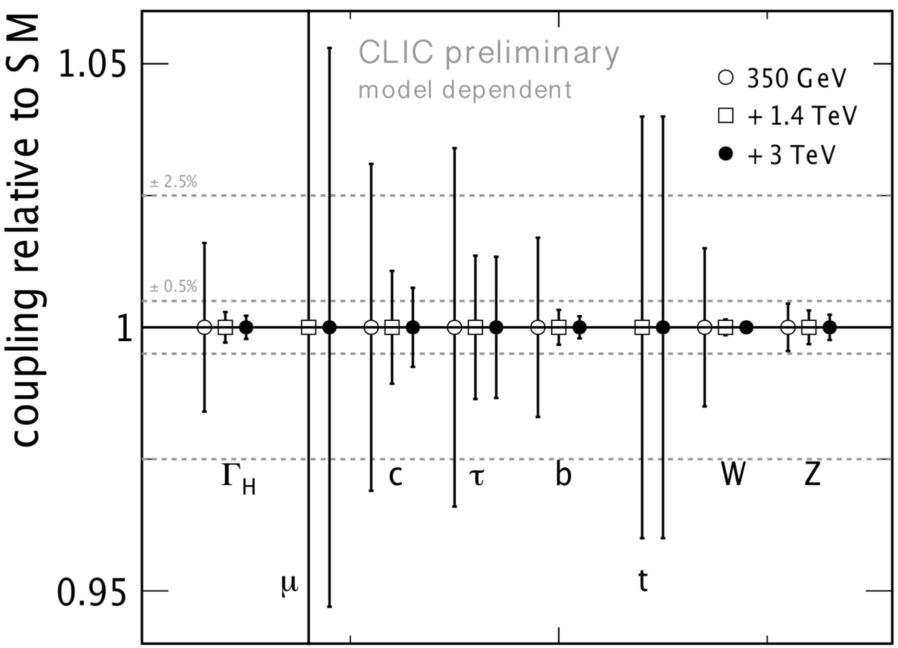


Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+ 1.4 TeV +1.5 ab^{-1}	+3.0 TeV +2.0 ab^{-1}
m_H	120.00 MeV	30.00 MeV	20.00 MeV
λ	–	21.00%	10.00%
Γ_H [%]	5.47	4.23	4.11
g_{HZZ} [%]	1.00	1.00	1.00
g_{HWW} [%]	1.87	1.05	1.03
g_{Hbb} [%]	2.06	1.11	1.05
g_{Hcc} [%]	3.28	1.50	1.26
g_{Htt} [%]	–	4.15	4.13
$g_{H\tau\tau}$ [%]	3.55	1.68	1.64
$g_{H\mu\mu}$ [%]	–	11.03	5.37
g_{Hgg} [%]	3.67	1.29	1.15
$g_{H\gamma\gamma}$ [%]	–	5.60	5.59

-80% electron polarisation at 1.4 and 3 TeV

- Fit to results shown on the previous slides
- Fully model-independent, only possible at a lepton collider
- All results limited by 1% from σ(HZ) measurement
- Higgs width is extracted with 5.5% - 4% precision

Analysis similar to LHC experiments



Parameter	Measurement precision		
	350 GeV 500 fb^{-1}	+ 1.4 TeV $+1.5\ \mathrm{ab}^{-1}$	+3.0 TeV $+2.0\ \mathrm{ab}^{-1}$
$\Gamma_{\mathrm{H,model}}$ [%]	1.62	0.29	0.22
κ_{HZZ} [%]	0.45	0.32	0.24
κ_{HWW} [%]	1.53	0.15	0.11
κ_{Hbb} [%]	1.69	0.33	0.21
κ_{Hcc} [%]	3.07	1.07	0.75
κ_{Htt} [%]	–	4.01	4.00
$\kappa_{\mathrm{H\tau\tau}}$ [%]	3.44	1.36	1.34
$\kappa_{\mathrm{H\mu\mu}}$ [%]	–	10.98	5.27
κ_{Hgg} [%]	3.62	0.79	0.56
$\kappa_{\mathrm{H\gamma\gamma}}$ [%]	–	5.52	5.51

-80% electron polarisation at 1.4 and 3 TeV

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

No invisible decays:

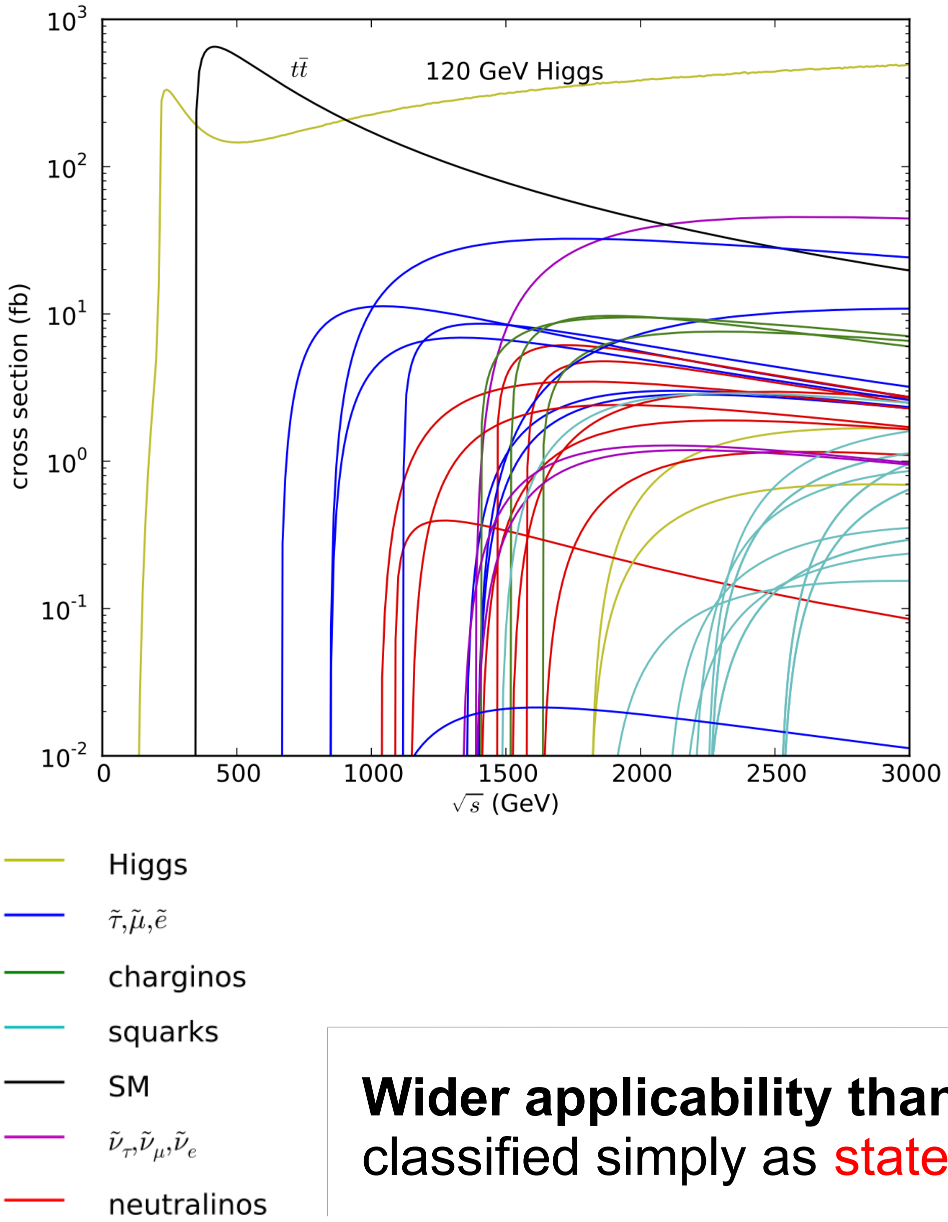
$$\Gamma_{\mathrm{H,model}} = \sum_i \kappa_i^2 \cdot BR_i^{\mathrm{SM}}$$

Sub-percent precisions at high energy

→ Results strongly dependent on fit assumptions

Heavy Higgs production

Heavy Higgs bosons at 3 TeV (1)



CLIC CDR SUSY model 1:

m(A) = 902.6 GeV
$m(H^0)$ = 902.4 GeV
$m(H^\pm)$ = 906.3 GeV

$BR(H^\pm \rightarrow t\bar{b}) = 82\%$
$BR(H^0 \rightarrow b\bar{b}) = 82\%$
$BR(A \rightarrow b\bar{b}) = 82\%$

Wider applicability than only SUSY: Reconstructed particles can be classified simply as states of given mass, spin and quantum numbers

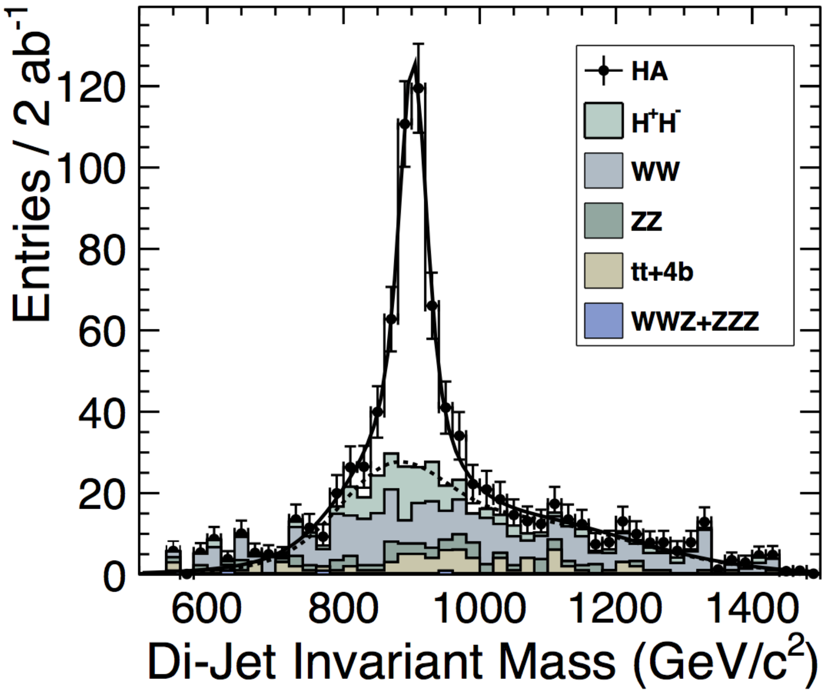
Heavy Higgs bosons at 3 TeV (2)

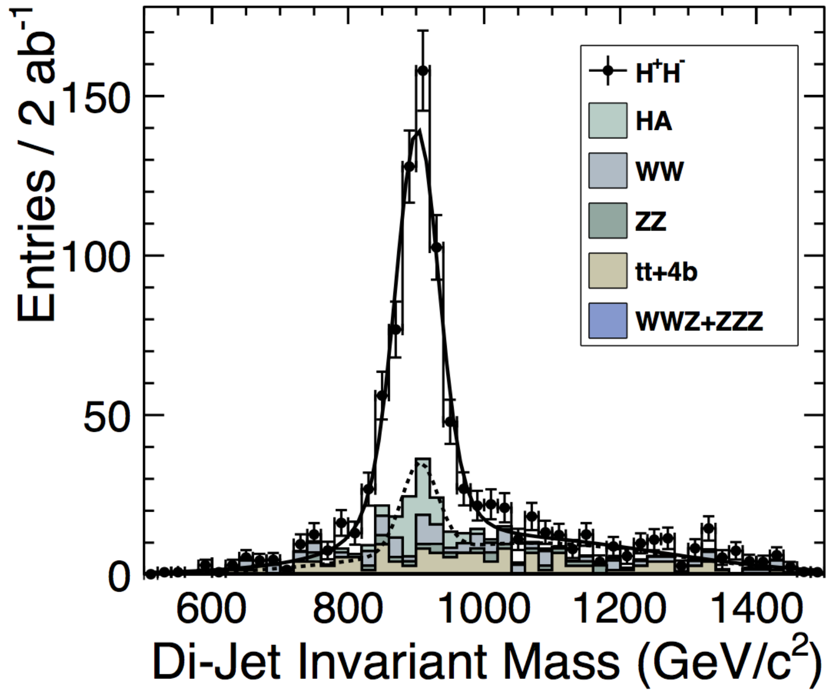
Reconstructed processes:

$e^+e^- \rightarrow HA \rightarrow b\bar{b}b\bar{b}$

$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$

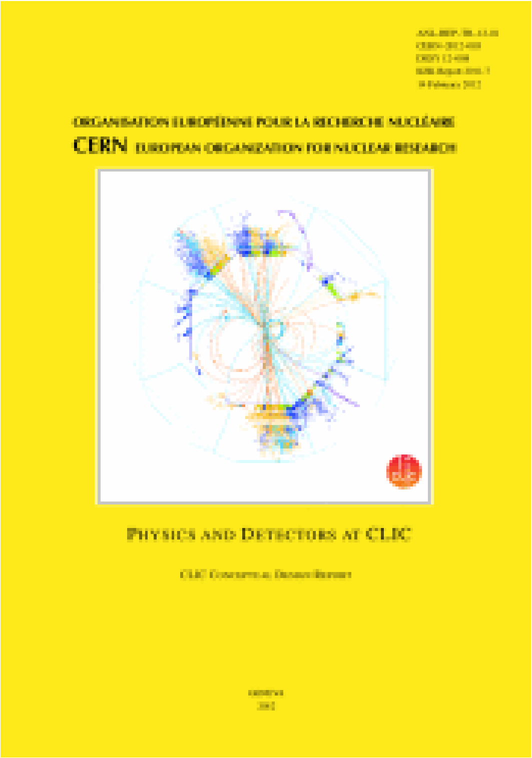
Complex final states

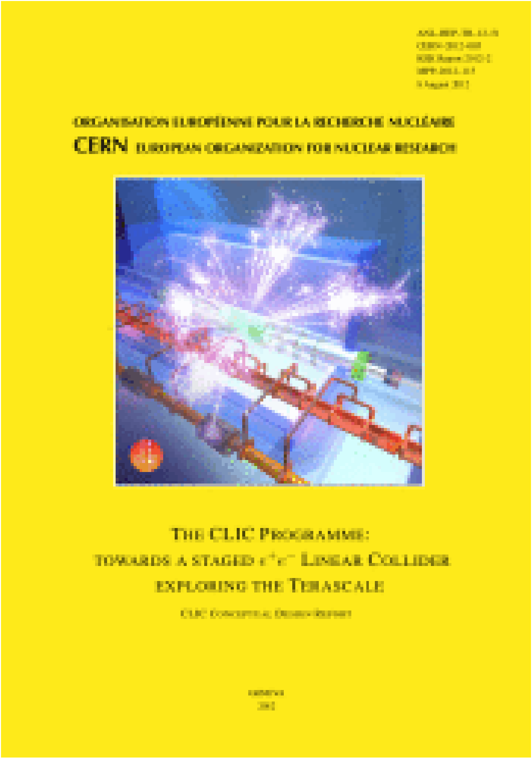




Accuracy of the heavy Higgs mass measurements: ≈ 0.3%

If you wish to learn more...






Physics at the CLIC e^+e^- Linear Collider

Input to the Snowmass process 2013

October 1, 2013

This paper summarizes the physics potential of the CLIC high-energy e^+e^- linear collider. It provides input to the Snowmass 2013 process for the energy-frontier working groups on The Higgs Boson (HE1), Precision Study of Electroweak Interactions (HE2), Fully Understanding the Top Quark (HE3), as well as The Path Beyond the Standard Model – New Particles, Forces, and Dimensions (HE4). It is accompanied by a paper describing the CLIC accelerator study, submitted to the Frontier Capabilities group of the Snowmass process [1].

The CLIC Detector and Physics Study

arXiv:1307.5288v3 [hep-ex] 30 Sep 2013

CLIC Conceptual Design Report (CDR) Vol. 2:
Physics and Detectors (mostly at 3 TeV)

arXiv:1202.5940

CLIC CDR Vol. 3:
Staged construction, SUSY at 1.4 TeV

arXiv:1209.2543

Snowmass white paper:
Most of the Higgs studies

arXiv:1307.5288
(last update: 01/10/2013)

Summary and conclusions

- The first stage of a CLIC collider at 350 GeV provides precise determinations of the absolute values of many Higgs boson couplings

- Subsequent high-energy running, here assumed at 1.4 and 3 TeV, improves the precision of many observables significantly and gives access to rare Higgs decays

- High-energy CLIC operation provides the potential to measure the trilinear Higgs self-coupling at the 10% level

- Combined fits to all measurements at 350 GeV, 350 GeV + 1.4 TeV and 350 GeV + 1.4 TeV + 3 TeV were performed to extract the Higgs couplings and width simultaneously

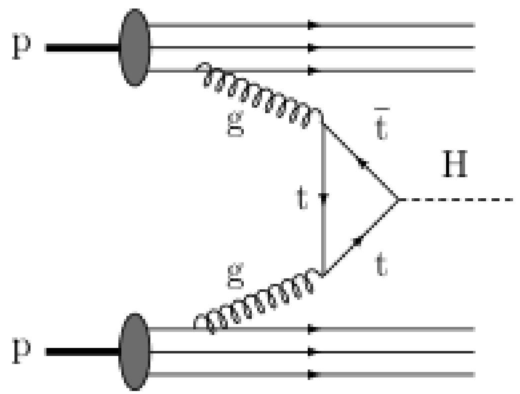
- A comprehensive paper on (SM-)Higgs physics at CLIC is in preparation

- Measurement of heavy Higgs boson masses with O(1%) precision, sensitivity up to the kinematic limit of $\approx \sqrt{s} / 2$

Backup slides

Comparison to hadron colliders

Hadron colliders:



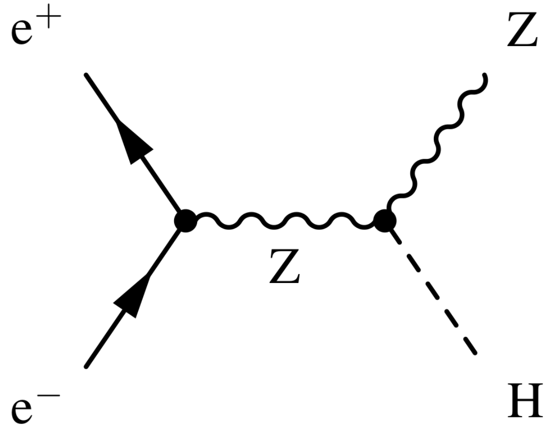
- **Proton is compound object**
  → Initial state unknown
  → Limits achievable precision

- **High-energy circular colliders possible**

- **High rates of QCD backgrounds**
  → Complex triggers
  → High levels of radiation

- **High cross sections for coloured states**

e^+e^- colliders:



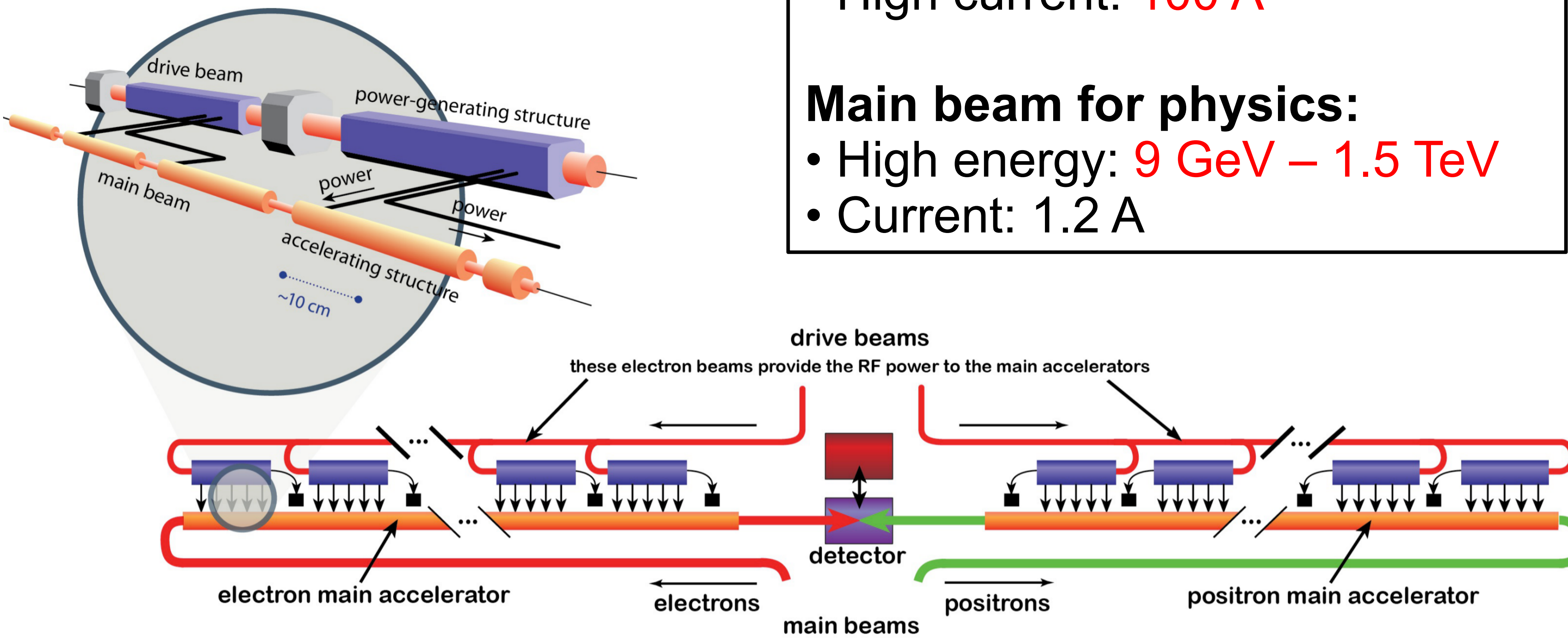
- **e^+e^- are pointlike**
  → Initial state well-defined (energy, polarisation)
  → High-precision measurements

- **High energies require linear colliders**

- **Clean experimental environment**
  → Trigger-less readout
  → Low radiation levels

- **Well suited for electroweak states**

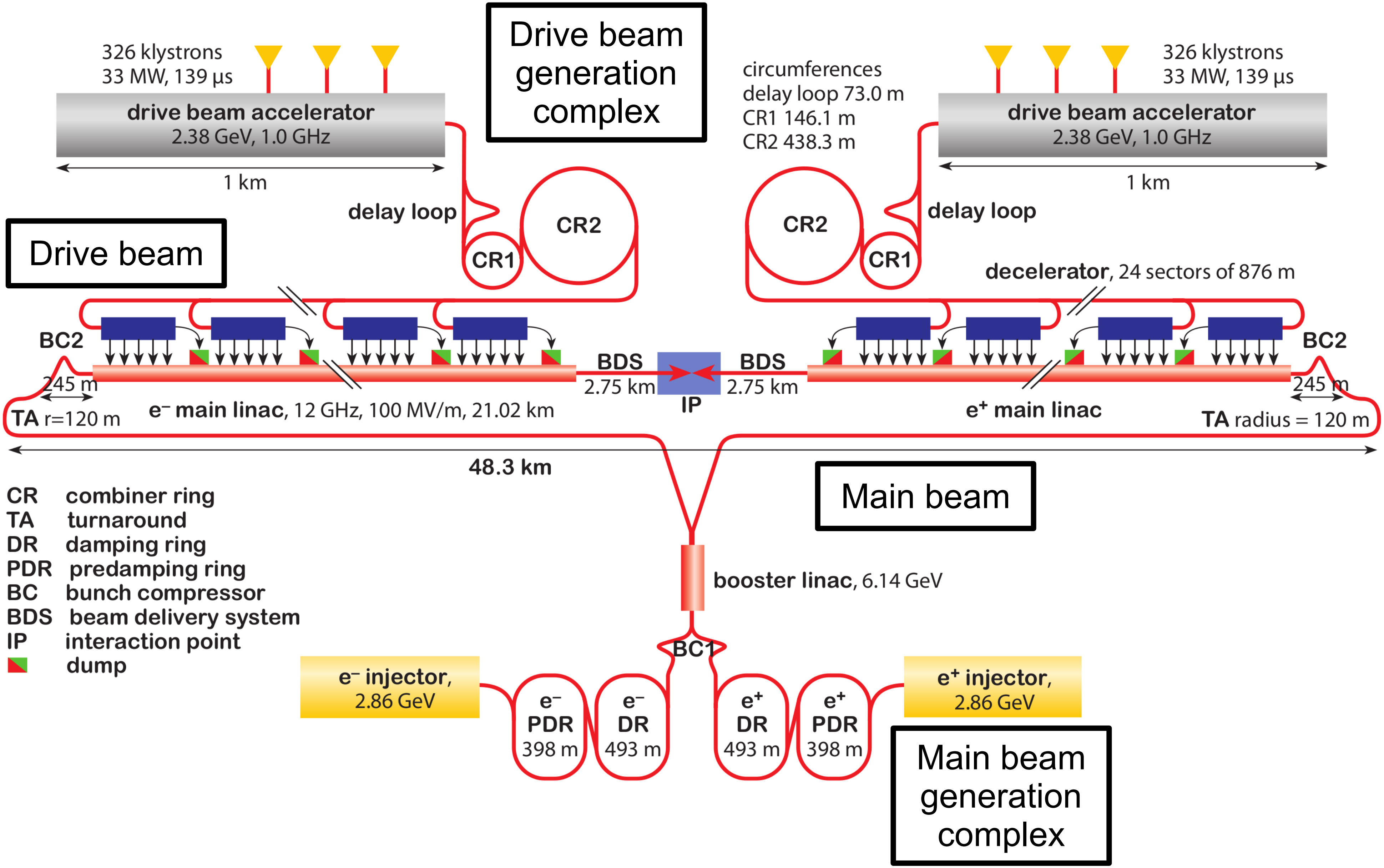
2-beam acceleration scheme



Drive beam supplies RF power:
- 12 GHz bunch structure
- Low energy:
2.4 GeV – 240 MeV
- High current: 100 A

Main beam for physics:
- High energy: 9 GeV – 1.5 TeV
- Current: 1.2 A

CLIC accelerator complex (3 TeV)

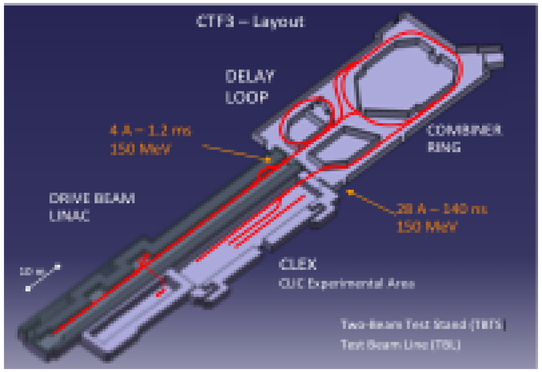


CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

CLIC project time line

2013-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



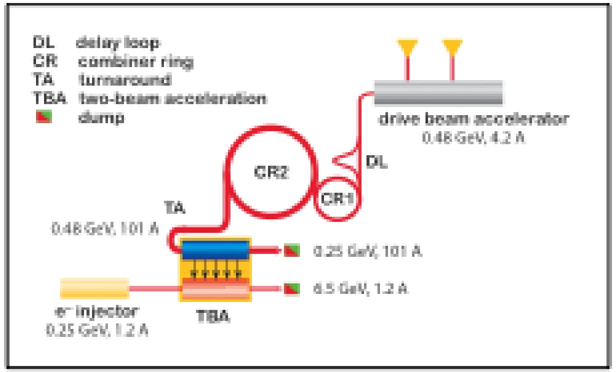
2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

4-5 year Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



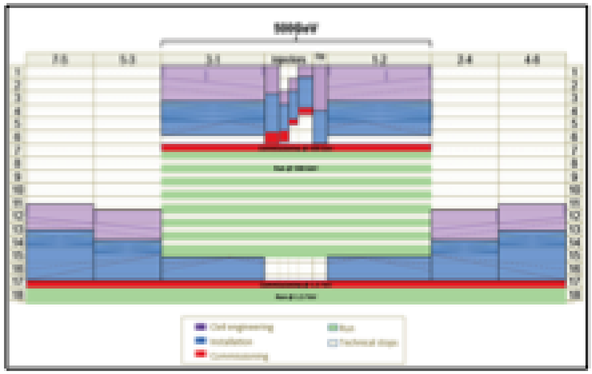
2024-25 Construction Start

Ready for full construction and main tunnel excavation.

Construction Phase

Stage 1 construction of CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



Commissioning

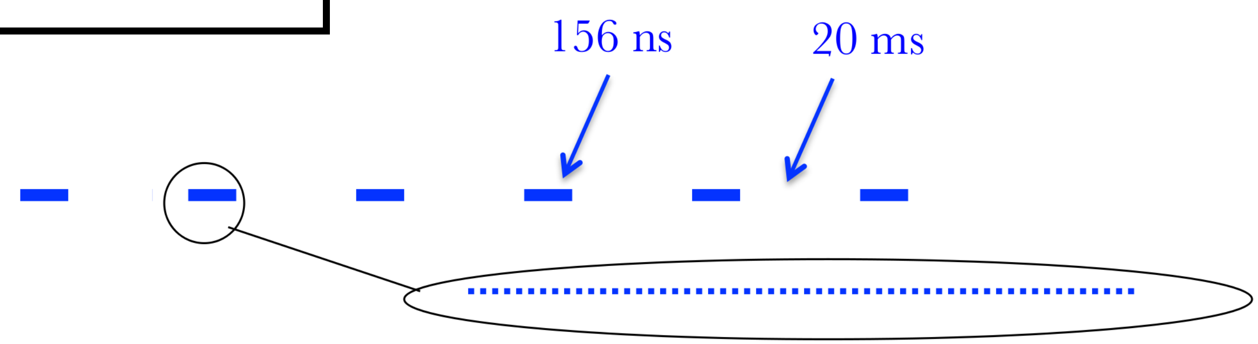
Becoming ready for data-taking as the LHC programme reaches completion.

Selected CLIC parameters

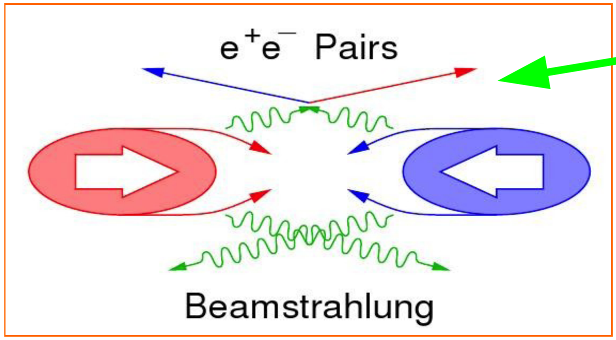
	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	$5.9 \cdot 10^{34}$
Bunch separation	0.5 ns
#Bunches / train	312
Train duration	156 ns
Train rep. rate	50 Hz
Crossing angle	20 mrad
Particles / bunch	$3.72 \cdot 10^{9}$
σ_x/σ_y (nm)	≈ 45 / 1
σ_z (μm)	44

Drive timing requirements for CLIC detector

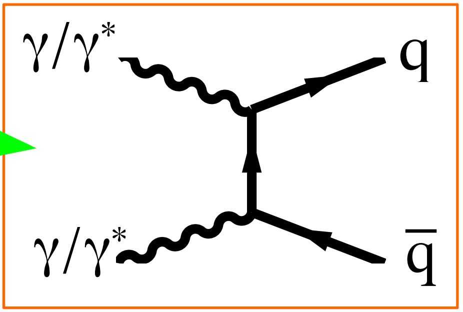
Very small beam profile at the interaction point



CLIC: trains at 50 Hz, 1 train = 312 bunches, 0.5 ns apart

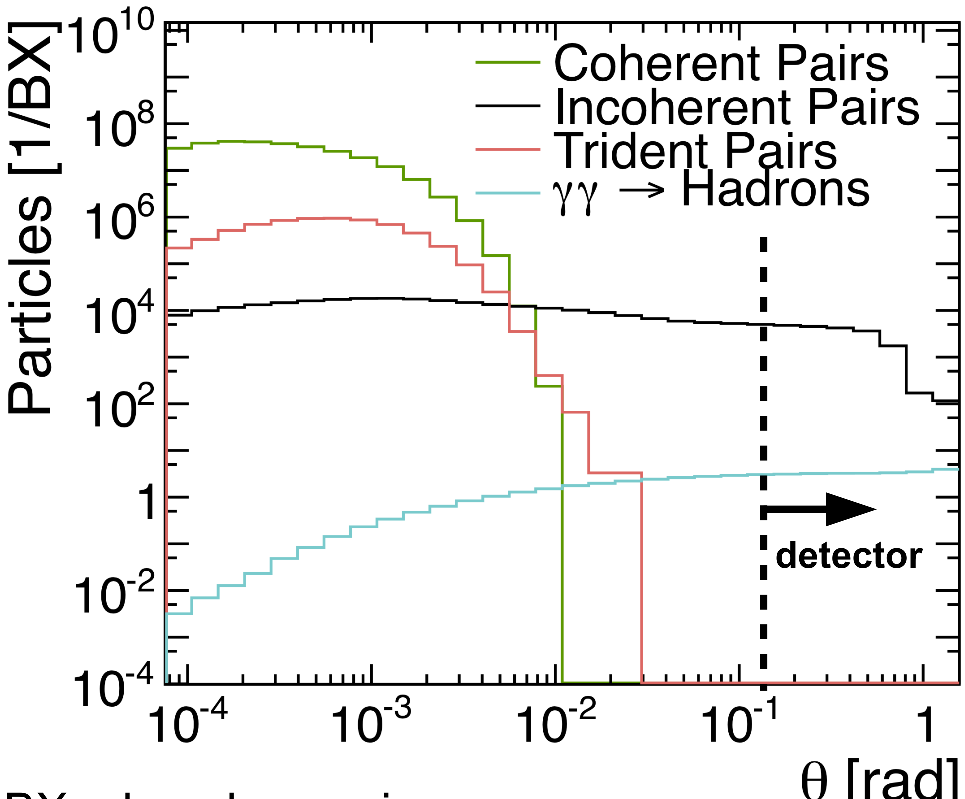


- e^+e^- pairs
- γγ → hadrons



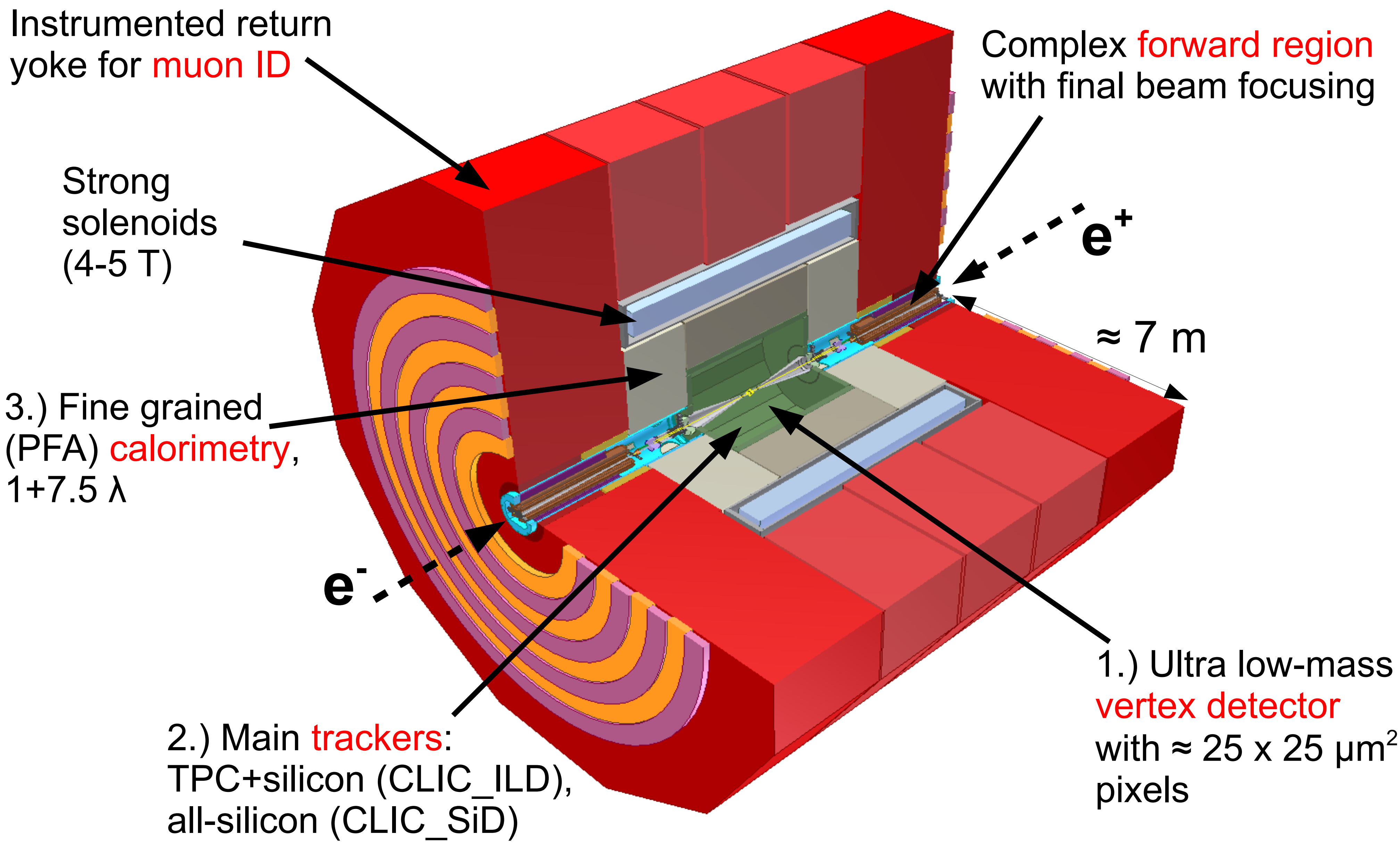
Coherent e^+e^- pairs:
$7 \cdot 10^8$ per BX, very forward
Incoherent e^+e^- pairs:
$3 \cdot 10^5$ per BX, rather forward
→ Detector design issue
(high occupancies)

γγ → hadrons
- "Only" 3.2 events per BX at 3 TeV
- Main background
in calorimeters and trackers
→ Impact on physics



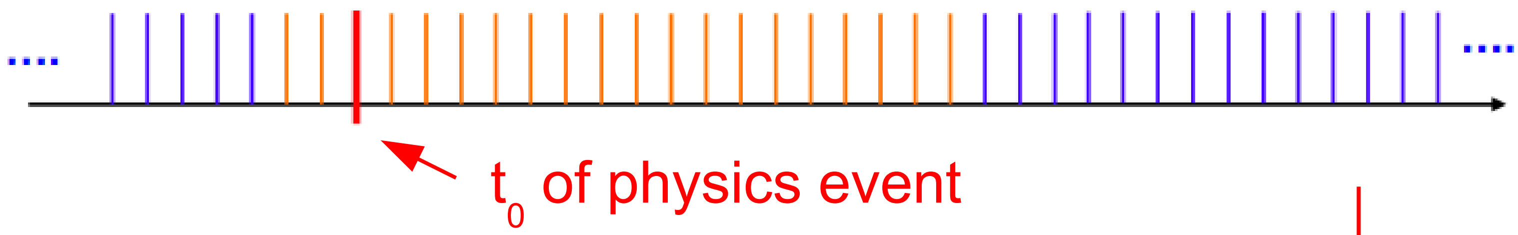
BX = bunch crossing

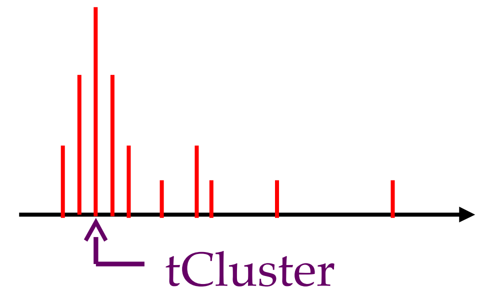
CLIC detector concepts



Background suppression

Triggerless readout of full bunch train:





1.) **Identify t_0 of physics event in offline event filter**

- Define reconstruction window around t_0
- All hits and tracks in this window are passed to the reconstruction

→ Physics objects with precise p_T and cluster time information

2.) **Apply cluster-based timing cuts**

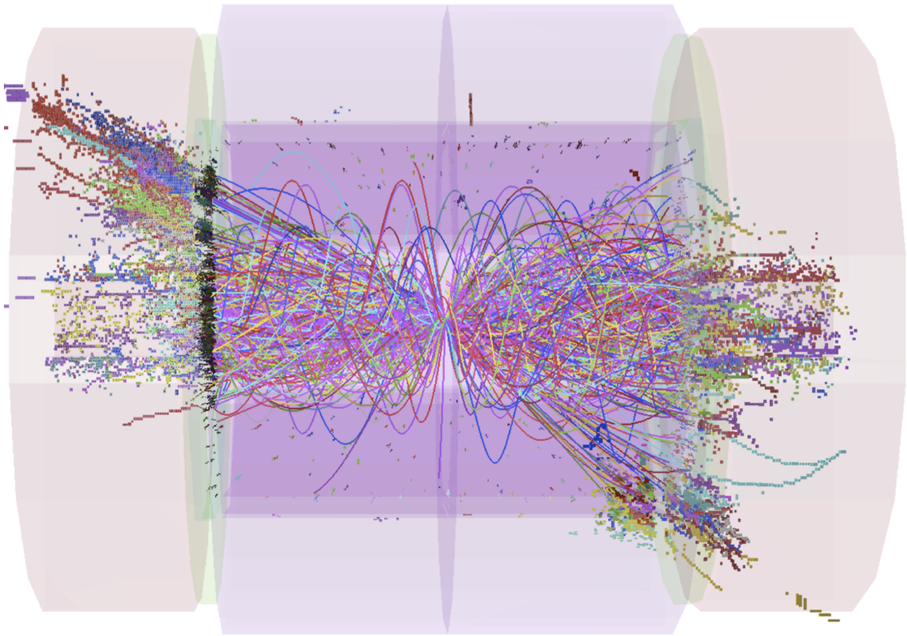
- Cuts depend on particle-type, p_T and detector region

→ Protects physics objects at high p_T

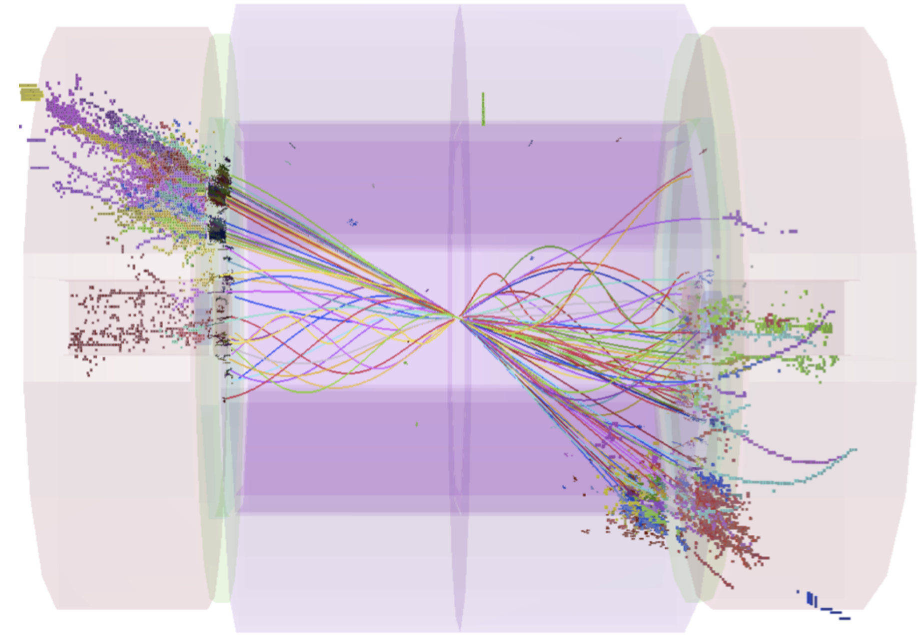
In addition: hadron-collider type jet algorithms (FastJet)

Impact of the timing cuts

$e^+e^- \rightarrow t\bar{t}$ at 3 TeV with background from $\gamma\gamma \rightarrow$ hadrons overlaid



1.2 TeV background
in the reconstruction window

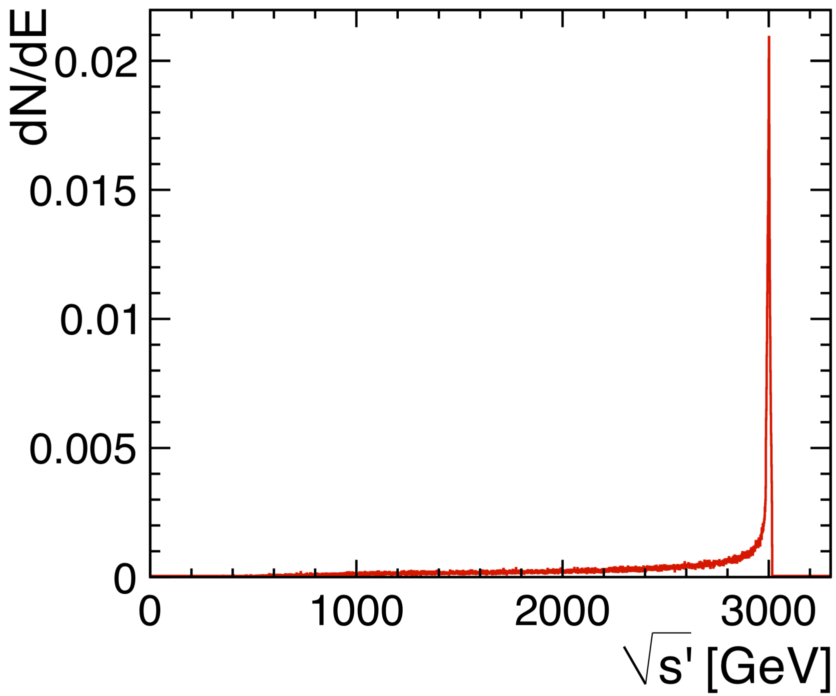


100 GeV background
after timing cuts

Physics studies are based on Geant4 simulations including pile-up from $\gamma\gamma \rightarrow$ hadrons

Luminosity spectrum

Significant energy loss at the interaction point due to Beamstrahlung



Full luminosity: $L = 5.9 \cdot 10^{34}\ cm^{-2}s^{-1}$
In the most energetic 1%:
("peak luminosity") $L_{0.01} = 2.0 \cdot 10^{34}\ cm^{-2}s^{-1}$

Most physics processes are studies well above the production threshold
→ Profit from (almost) full luminosity

$$\sqrt{s'} = \sqrt{4 \cdot E_1 \cdot E_2}$$

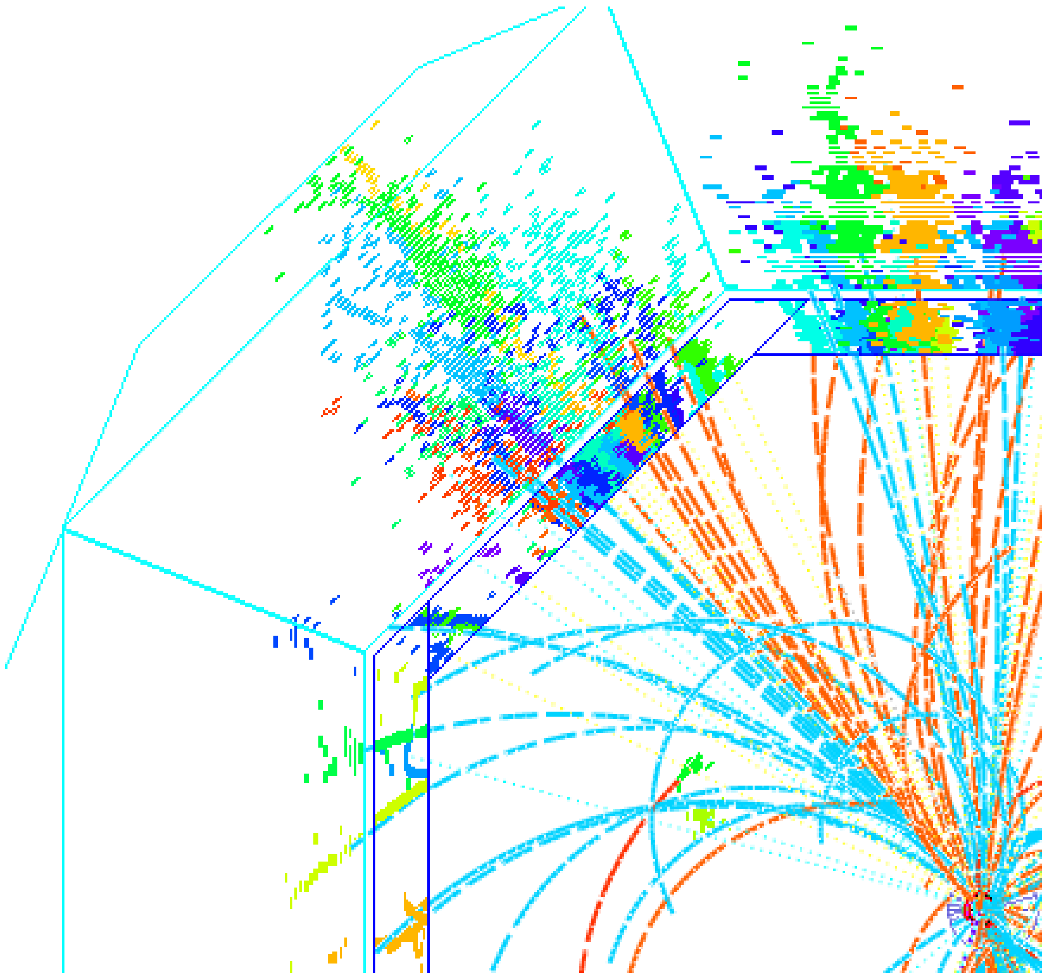
Calorimetry and PFA

Detector design driven by jet energy resolution and background rejection
→ Fine-grained calorimetry + particle flow analysis (PFA)

What is PFA?
Typical jet composition:
- 60% charged particles
- 30% photons
- 10% neutral hadrons

Always use the best available measurement:
- charged particles
→ tracking detectors: ☺ ☺
- photons → ECAL: ☺
- neutrals → HCAL: ☹

Hardware and software!



Challenges in CLIC (LC) detector R&D

These requirements lead to the following challenges:

Vertex and tracker

- Very high granularity
- Dense integration of functionalities including ≈10 ns time-stamping
- Super light materials
- Low-power design & power pulsing
- Air cooling

ultra-light

Calorimetry

- Fine segmentation in R, Φ and Z
- Time resolution ≈1 ns
- Ultra-compact active layers
- Pushing integration to the limits
- Power pulsing

ultra-heavy and compact

Comparison CLIC and LHC detector

CLIC detector:

High precision
- Jet energy resolution

→ fine-grained calorimetry
- Momentum resolution
- Impact parameter resolution

Pileup of beam-induced backgrounds
- High background rates, medium energies
- High occupancies
- Can not use vertex separation
- Need very precise timing (1 ns, 10 ns)

"No" issue of radiation damage (10^{-4} LHC)
- Except small forward calorimeters

Beam crossing "sporadic"

No trigger, read-out full 156 ns train

LHC detector:

Medium-high precision
- Very precise ECAL (CMS)
- Very precise muon tracking (ATLAS)

Pileup of minimum-bias events
- High background rates, high energies
- High occupancies
- Can use separation in Z
- Need precise time-stamping (25 ns)

Severe challenge of radiation damage

Continuous beam crossings

Trigger needed for huge data reduction

Physics aims → detector needs

- **Momentum resolution**
(e.g. Higgs recoil mass, H → $\mu^+\mu^-$, leptons from BSM processes)

$$\frac{\sigma(p_T)}{p_T^2} \sim 2\times10^{-5}\,GeV^{-1}$$

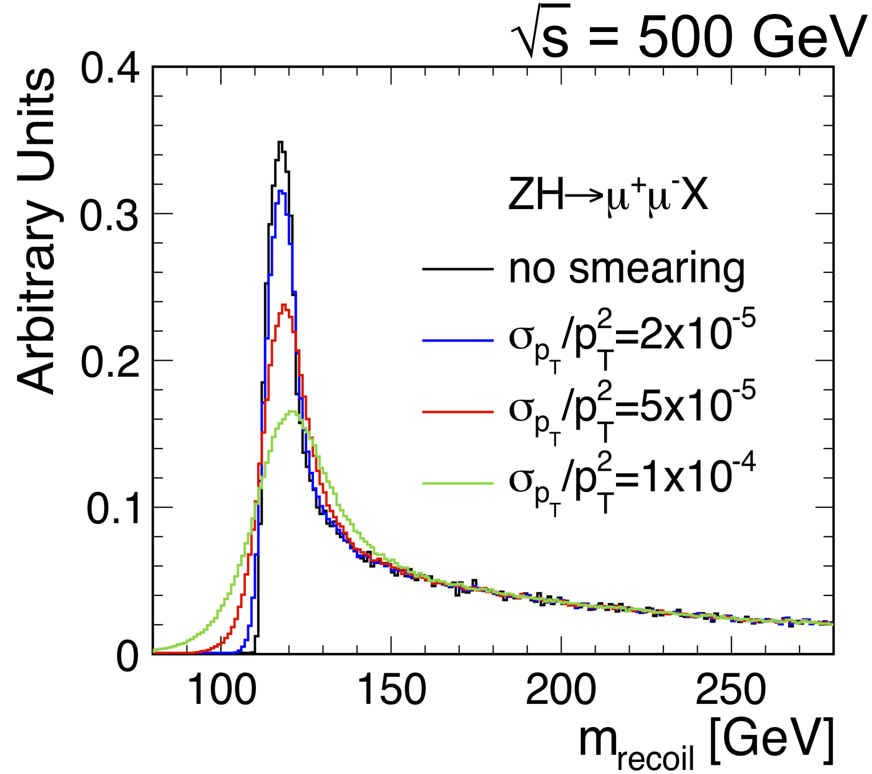
- **Jet energy resolution**
(e.g. W/Z/h separation)

$$\frac{\sigma(E)}{E} \sim 3.5-5\%\ for\ E=1000-50\,GeV$$

- **Impact parameter resolution**
(b/c tagging, e.g. Higgs couplings)

$$\sigma(d_0)=\sqrt{a^2+b^2\cdot GeV^2/(p^2\sin^3\theta)},\ a\approx5\,\mu m,\ b\approx15\,\mu m$$

- **Lepton identification, very forward electron tagging**



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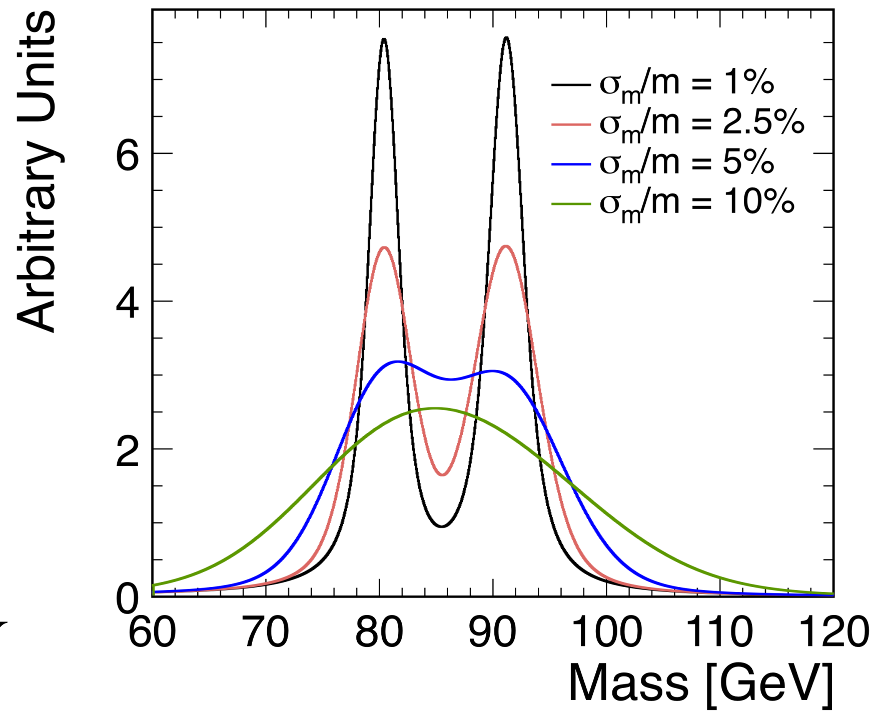

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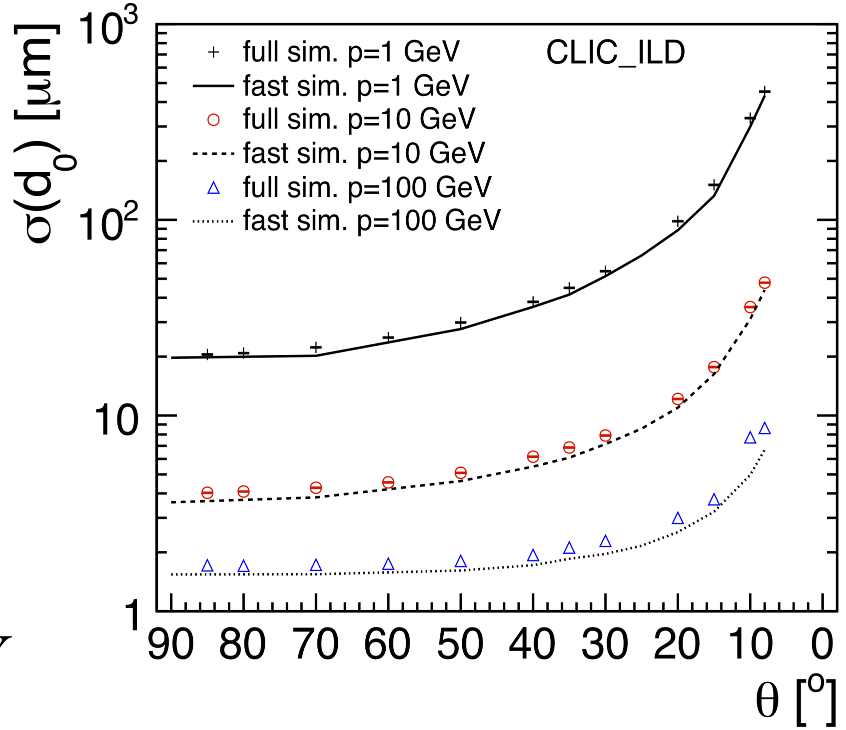

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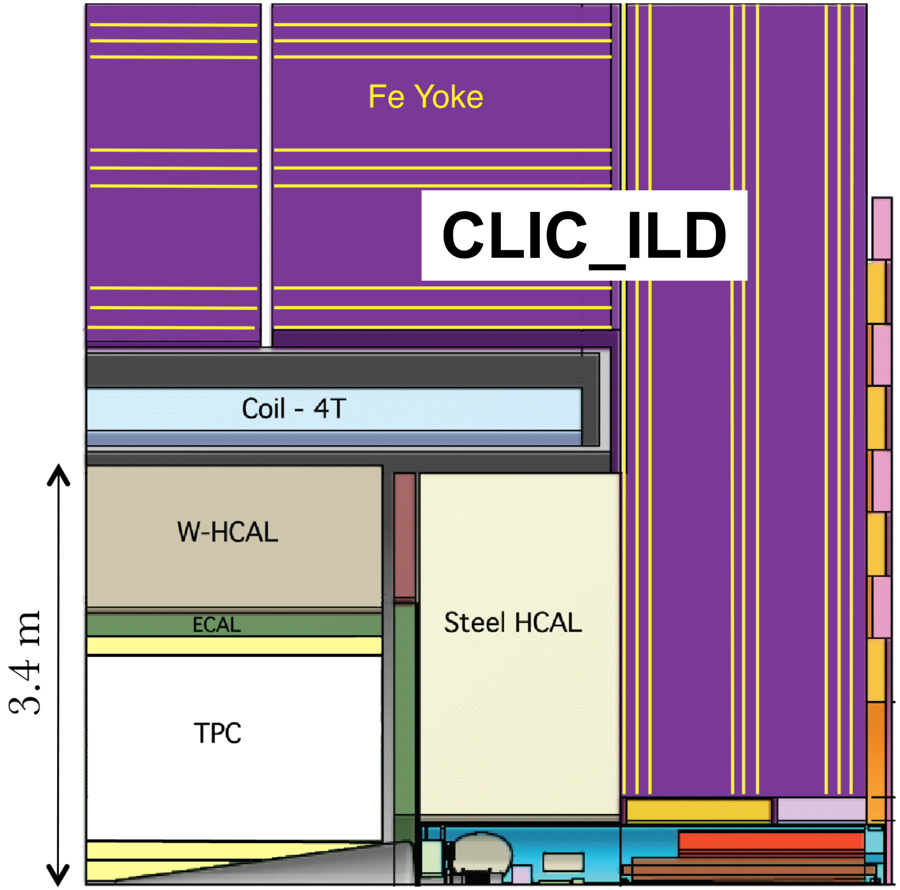
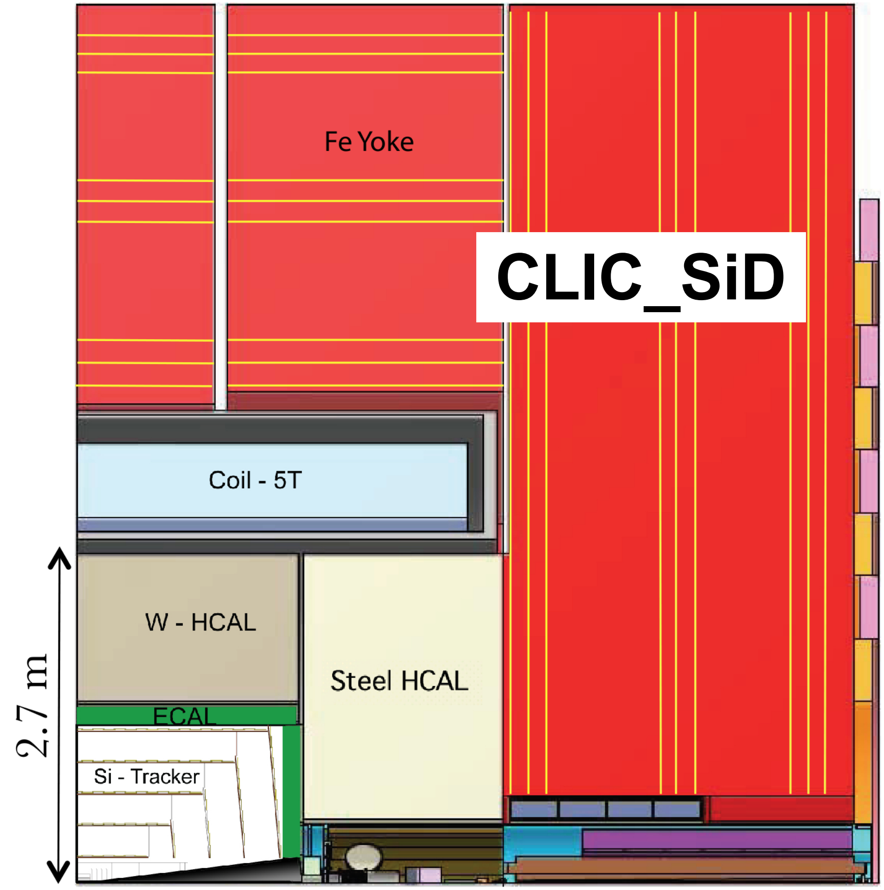
- **Lepton identification, very forward electron tagging**

CLIC detector concepts

Based on ILC designs, adapted and optimised to the CLIC conditions:

- Denser HCAL in the barrel (Tungsten, 7.5 λ)
- Redesign of the vertex and forward detectors (backgrounds)
- Precise timing capabilities of most subdetectors





Physics studies are based on Geant4 simulations including pile-up from γγ → hadrons

Time windows and hit resolutions

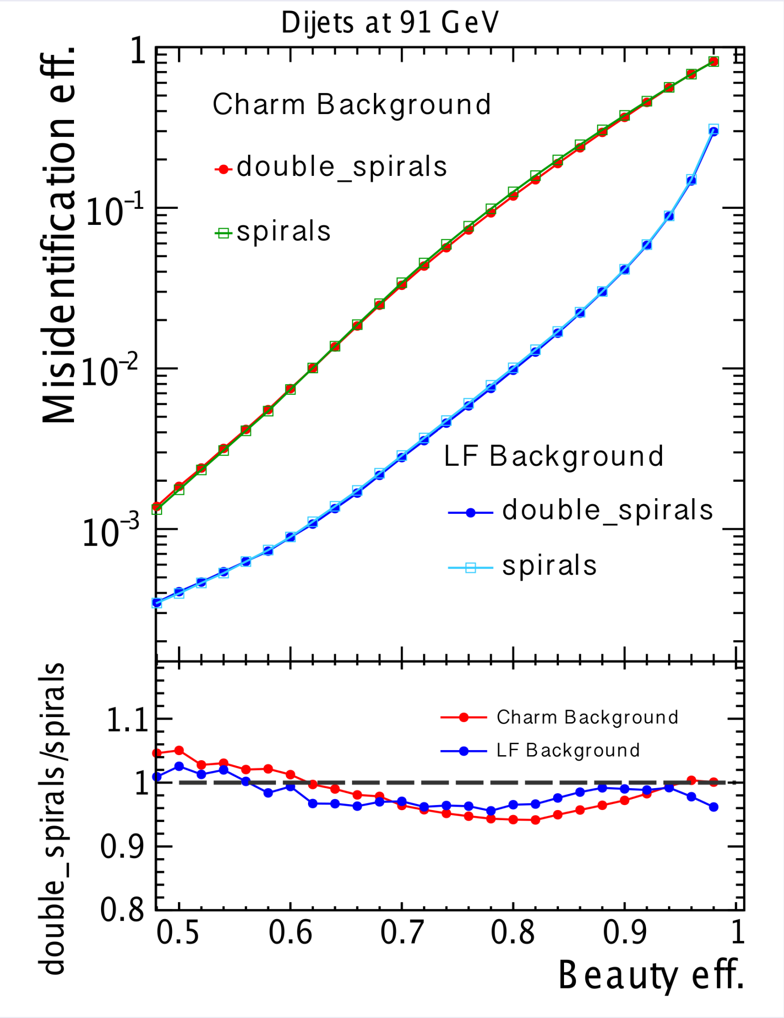
Used in the reconstruction software for CDR simulations:

Subdetector	Reconstruction window	hit resolution
ECAL	10 ns	1 ns
HCAL Endcaps	10 ns	1 ns
HCAL Barrel	100 ns	1 ns
Silicon Detectors	10 ns	$10/\sqrt{12}$ ns
TPC	entire bunch train	n/a

- CLIC hardware requirements
- Achievable in the calorimeters with a sampling every ≈ 25 ns

B-tagging performance

Dijets at 91 GeV



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

†: estimate
*: preliminary