CLIC physics potential

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on behalf of the CLICdp Collaboration

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Outline

- Introduction to Compact Linear Collider (CLIC)
- CLIC accelerator
- Detector requirements and design
- Physics at CLIC
  - Higgs physics
  - Physics of top quark
  - BSM physics
- Conclusions and summary

Compact Linear Collider Project CLIC

Motivation for e^+e^- colliders

- Precision measurement of the newly discovered Higgs boson
- Measurement of the properties of top quark with high precision
- Searches for physics beyond Standard model

Complimentarity to the LHC

- Initial state well known (energy, polarization)
- High energy e^+e^- colliders provide a experimental environment for precision measurements
- Equal sensitivity to electroweak and strongly interacting particles
- Clean experimental environment (almost QCD background free, triggerless readout, low radiation levels)

CLIC is one of the most mature options of the future e^+e^- colliders

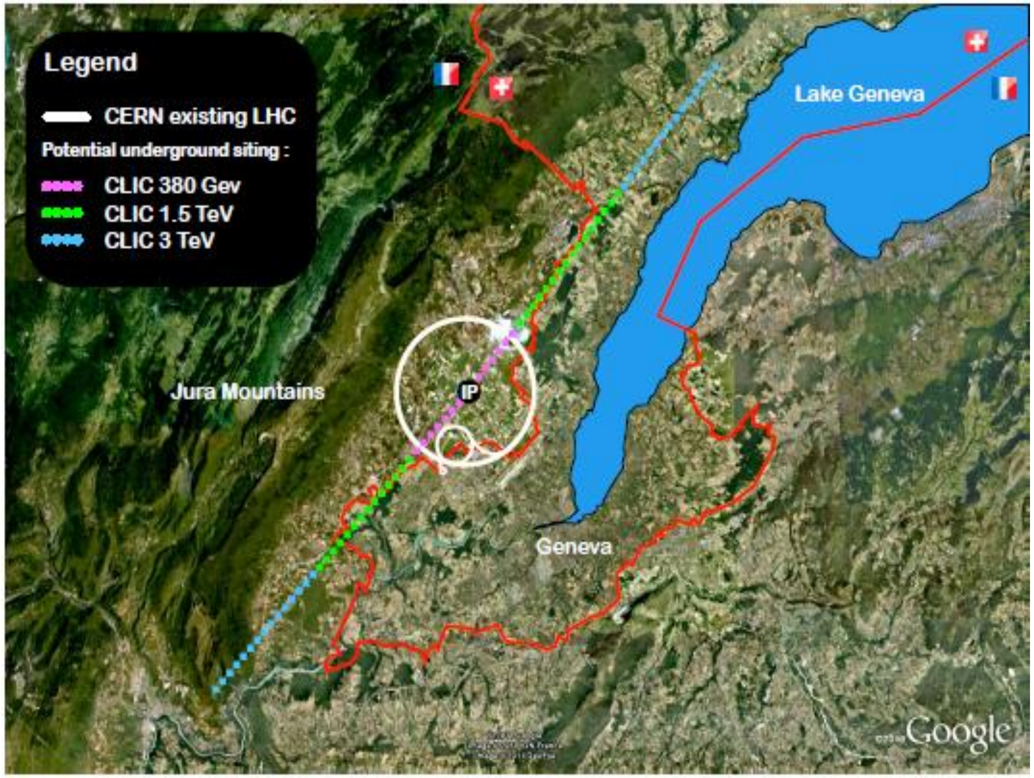
- Novel two-beam acceleration technique
- Rich physics program over a wide time span
- Staged construction with the ultimate energy reach of 3 TeV

CLIC staged implementation

Three center-of-mass energies: 350/380 GeV, 1.5 TeV, 3.0 TeV

- **Stages are defined by physics and technical considerations**
- **Optimization w.r.t. cost and sensitivity of the measurements**
- **Provides early start of physics: construction possible during physics run at the lower energy stage**
- **Stages adaptable to the LHC input**

$\sqrt{s}$	Accelerator length [km]	$\mathcal{L}_{int}$ [ab^{-1}]
380 GeV	11.4	0.5
1.5 TeV	29.0	1.5
3.0 TeV	50.1	3.0



- **High instantaneous luminosity at each stage: ~ 1.5 - 6 x10^{-34} cm^{-2} s^{-1}**

Accelerator technology

- Technology challenge: high energy and high luminosity
- Newly developed principle of particle acceleration: “Two-beam technique”

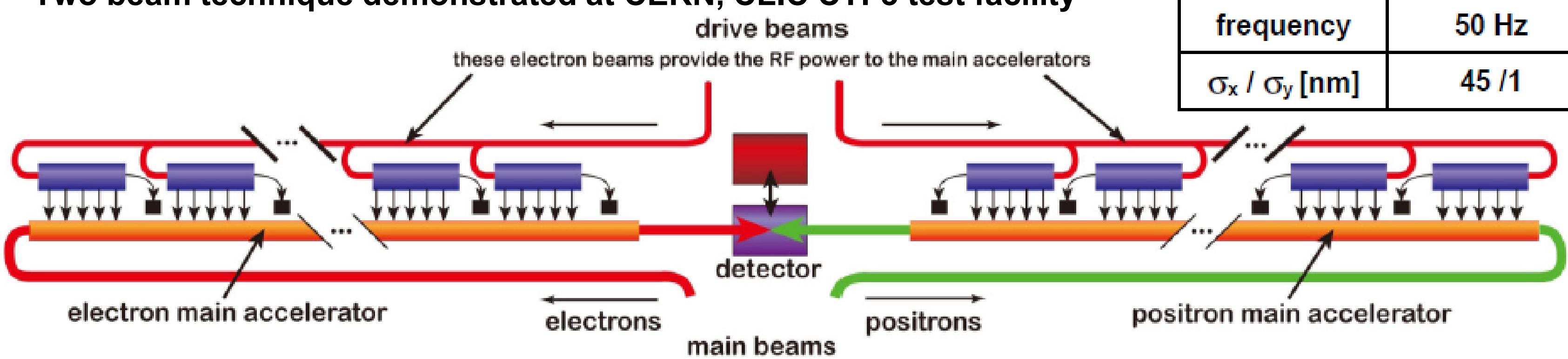
  Drive beam: high current (100 A), low energy (2.4 GeV -240 MeV), klystron acceleration

  Main beam: lower current (1.2 A), high energy (9 GeV-1.5 TeV)

  accelerated by the RF waves, produced by the deceleration of the drive beam in RF cavities
- High energy $\Rightarrow$ high accelerating gradient
- CLIC will be operating at high gradient level (100 MV/m)

  at the highest energy stage of 3 TeV
- Two beam technique demonstrated at CERN, CLIC CTF3 test facility

	3.0 TeV
$L[cm^{-2}s^{-1}]$	5.9×10^{-34}
BX/train	312
BX separation	0.5 ns
Train duration	156 ns
frequency	50 Hz
σ_x / σ_y [nm]	45 /1



CLIC working environment

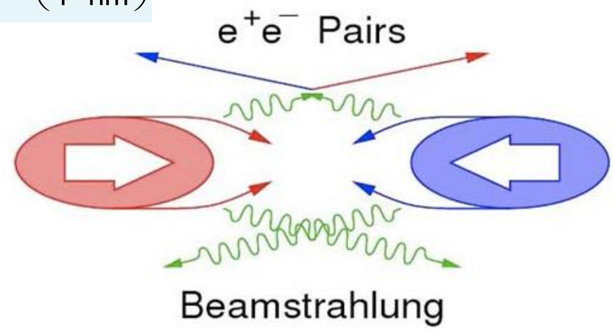
$$L = \frac{n_b N^2 f_{rep}}{4\pi\sigma_x\sigma_y}$$

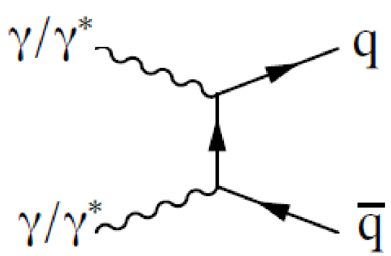
- CLIC challenge: high luminosity ⇒ small beam sizes at interaction point

$$\frac{\sigma_x}{\sigma_y} = \left(\frac{45\,\text{nm}}{1\;\;\text{nm}}\right)$$

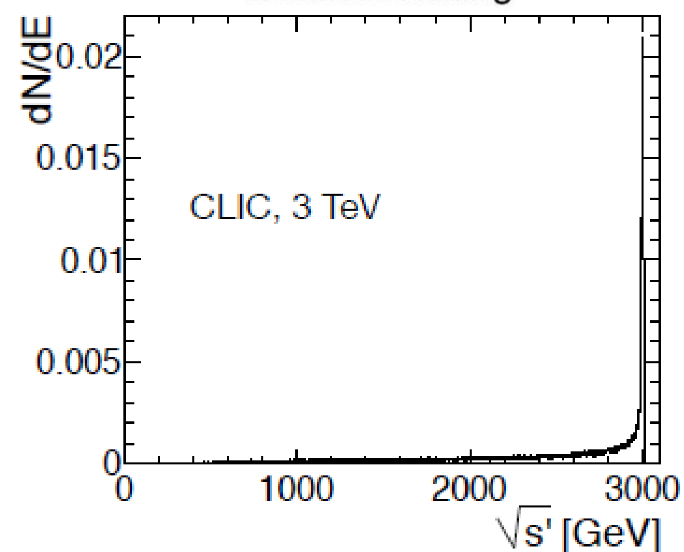
- Dense bunches ⇒ high electric field inside each bunch, which is influencing the particles in the opposite bunch
- This induces emission of radiation – beamstrahlung
- Beamstrahlung ⇒ important energy loses at the IP

  ⇒ distortion of the luminosity spectrum





$$\delta E \approx \frac{N^2}{(\sigma_x + \sigma_y)^2 \sigma_Z}$$



~35% in 1% of peak energy of 3TeV

- e^+e^- pairs – high doses deposited in the forward calorimeters
- γγ to hadrons = 3.2/bunch crossing at 3TeV – influences event reconstruction

Detector requirements

High precision measurements constrain the detector technologies and design

- **Jet energy resolution:** **Calorimeters**

  Benchmark: W/Z/H di-jet mass separation

$$\sigma_E/E \sim 3.5-5\%, \quad E > 100\ \mathrm{GeV}$$

- **Momentum resolution:** **Tracker**

  Benchmark: Higgs recoil mass measurements, $g^2_{H\mu\mu}$

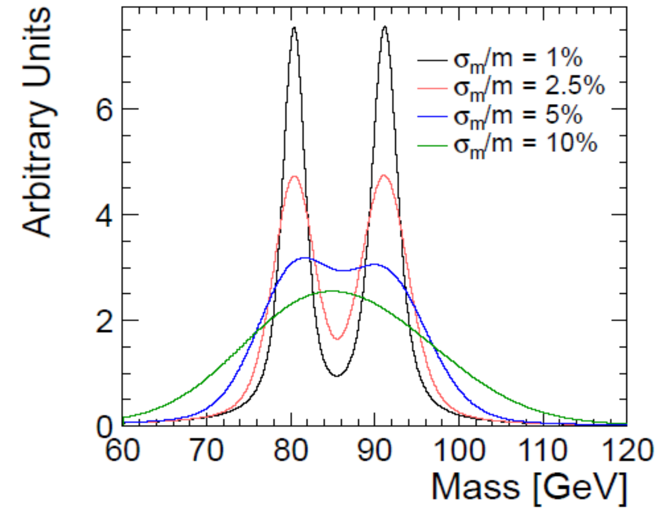
$$\sigma_{p_t}/p_t^2 \sim 2\times10^{-5}\ \mathrm{GeV}^{-1}$$

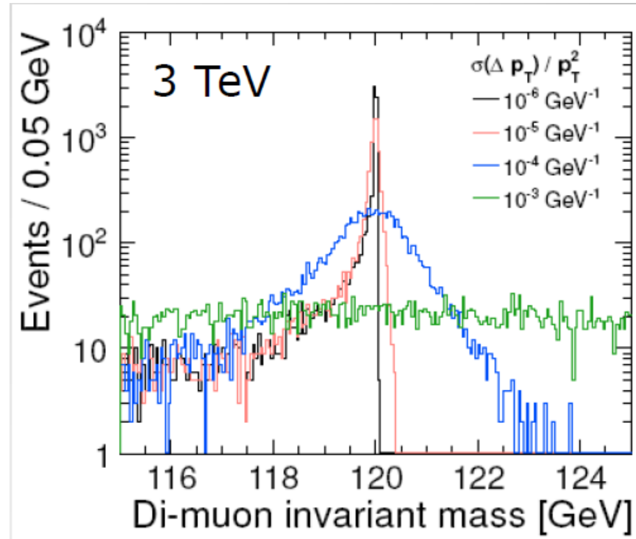
- **Impact parameter resolution:** **Vertex detector**

  Benchmark: flavor tagging – Higgs BF measurements

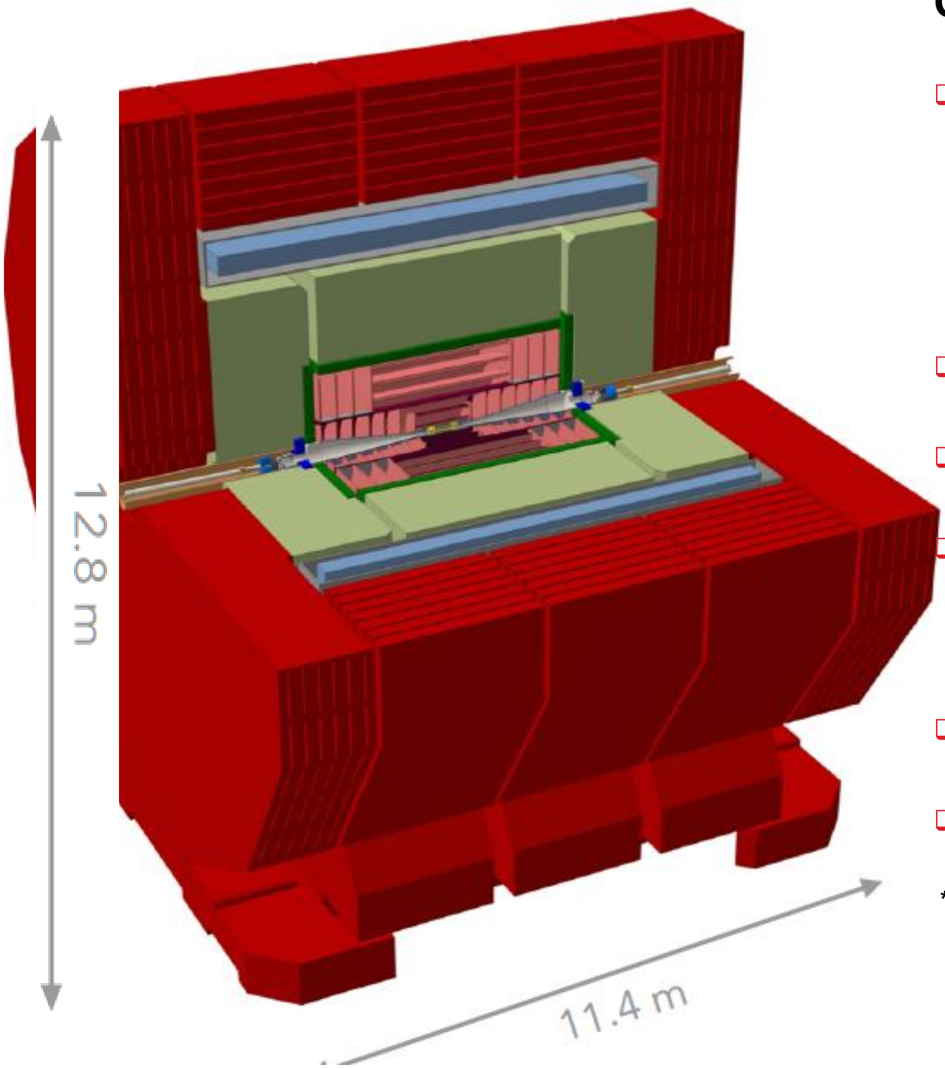
$$\sigma_{r\varphi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\mu m$$

- **Detector hermeticity - almost 4π solid angle coverage**





CLIC detector



Optimized detector model for CLIC:

- Forward region calorimeters:
  - Luminosity calorimeter
  - Beam calorimeter
- Ultra-low-mass Si-pixel ($2x10^9$) vertex detector
- Silicon tracker r=1.5 m , l = 4.6 m
- Fine grained calorimeters:
  - ECAL Si/W, HCAL Sc/Fe
- Superconducting solenoid B=4T
- Return iron yoke instrumented with muon chambers

*Final focusing (QD0) is outside the detector

CLIC physics program

Three construction stages are optimized for physics runs (each 5 to 7 years of running)

Each stage foresees high luminosities

Stage 1 380 GeV $0.5\ ab^{-1}$:

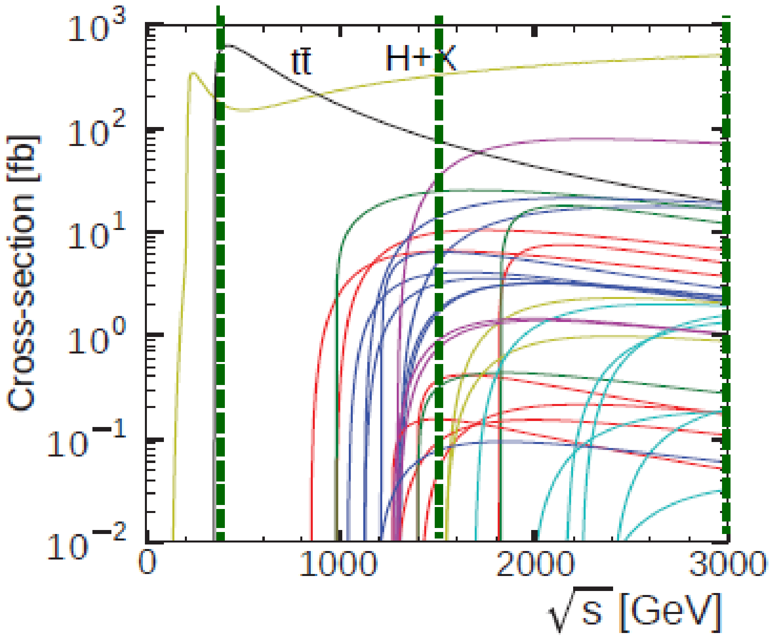
- Standard model Higgs physics measurement
- Top physics
- tt threshold scan dedicated run at ~350 GeV $100\ fb^{-1}$

Stage 2 1.5 TeV $1.5\ ab^{-1}$

- Targeted at BSM physics
- Top-Yukawa coupling ttH , Higgs self coupling
- Rare Higgs decays
- Top quark physics

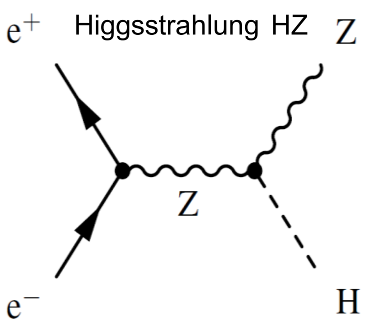
Stage 3 3 TeV $3.0\ ab^{-1}$

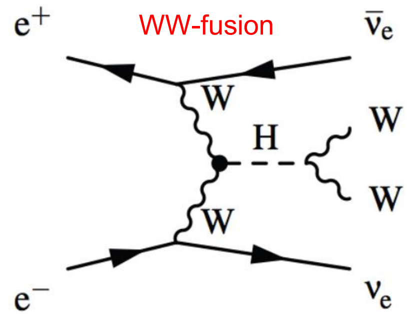
- BSM physics,
- Higgs self coupling
- Rare Higgs decays
- Top quark physics

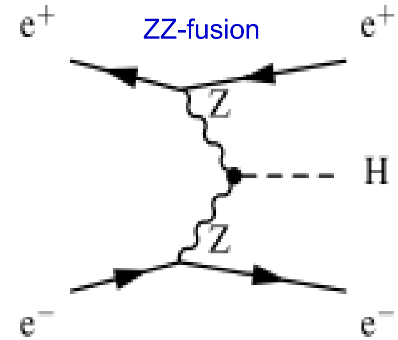


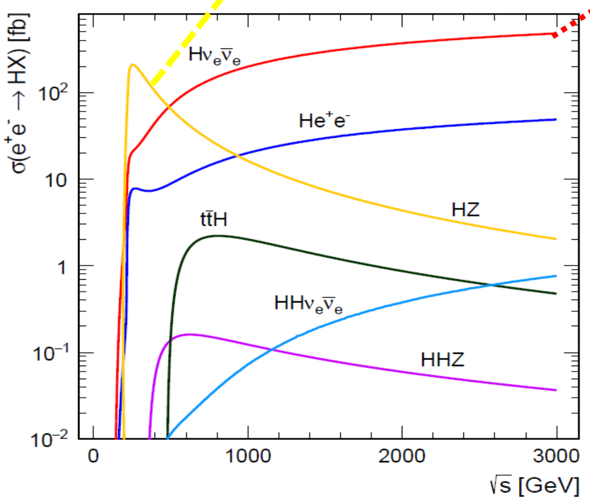
Higgs physics

- Measurement of the Higgs properties: mass, couplings (including self-coupling)
- Deviation from the predicted linearity of SM Higgs couplings could hint at new physics
- At lepton colliders the total Higgs decay width, Γ_H, is accessible







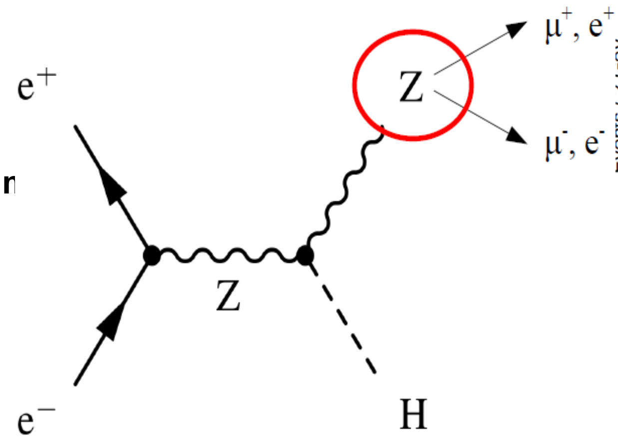


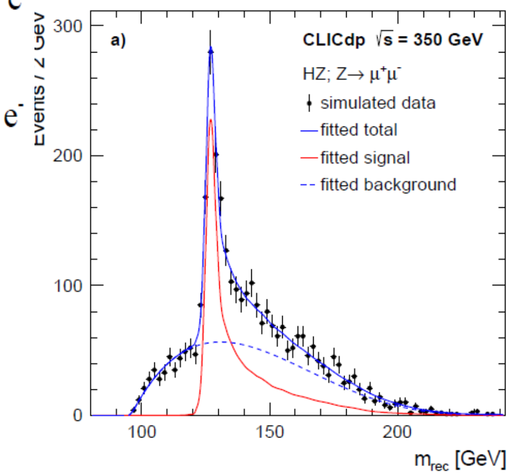
$\sqrt{s} =$	350 GeV	1.4 TeV	3 TeV
$\mathscr{L}_{int}$	500 fb^{-1}	1.5 ab^{-1}	2 ab^{-1}
# ZH events	68,000	20,000	11,000
# $H\nu_e\bar{\nu}_e$ events	17,000	370,000	830,000
# He^+e^- events	3,700	37,000	84,000

Previous CLIC staging scenario — no polarization

Model independent σ_{HZ} measurement

Higgsstrahlung – allows model independent measurement of the absolute g_{HZZ} coupling





$$\Delta m = 100\ MeV$$

$$m_{rec}^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$

$m_{l^+l^-} \Rightarrow$ tag Z boson

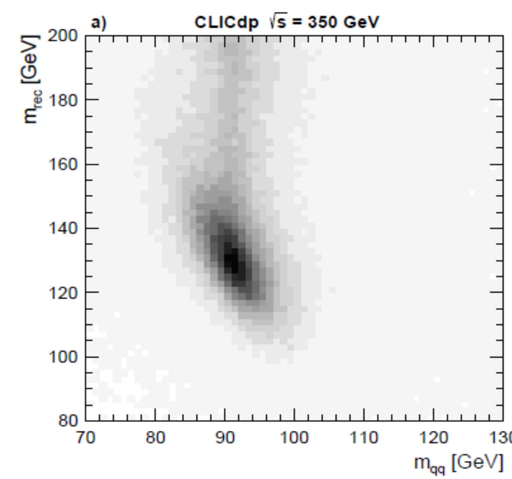
$m_{rec} \Rightarrow$ tag Higgs boson

$$\frac{\Delta(\sigma_{HZ})}{\sigma_{HZ}} \approx 3.8\% \rightarrow \frac{\Delta(g_{HZZ})}{g_{HZZ}} \approx 1.9\%$$

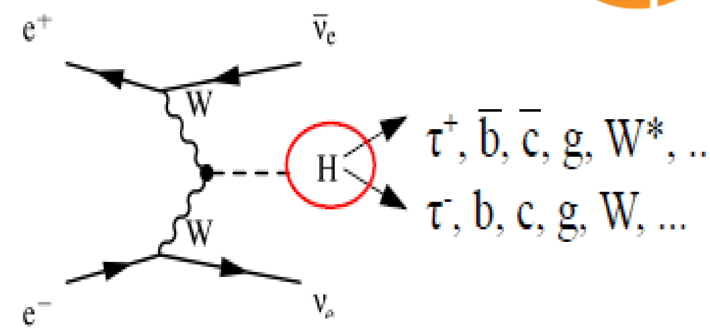
Using hadronic Z-qq decay (BF~70%), the combined uncertainty (leptonic and hadronic) :

$$\frac{\Delta(\sigma_{HZ})}{\sigma_{HZ}} \approx 1.65\% \rightarrow \frac{\Delta(g_{HZZ})}{g_{HZZ}} \approx 0.8\%$$

Analysis optimized to ensure the independence on Higgs decays



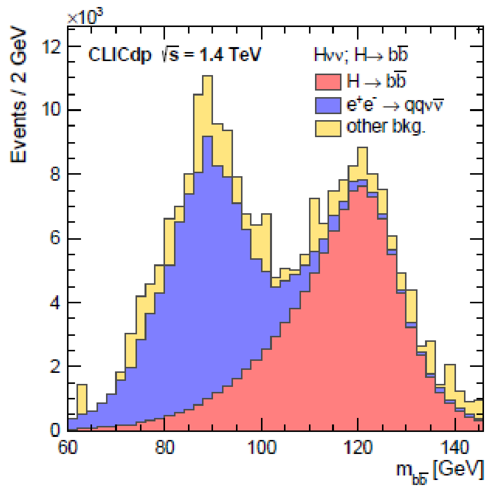
Higgs physics at high energies



The high cross-section of the WW-fusion process :

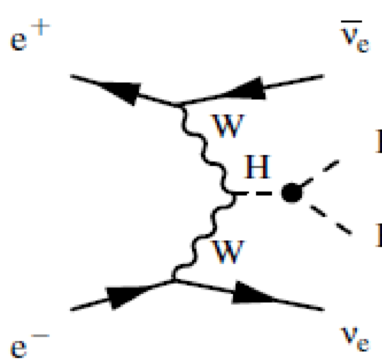
- **Increases the precision of Higgs couplings,**
- **Allows the coupling measurements of the rare decays,**

  $H \to \mu^+\mu^-, H \to Z\gamma, H \to \gamma\gamma$
- **And the determination of the invariant mass of Higgs boson with high precision** (Δm_H=32 MeV)

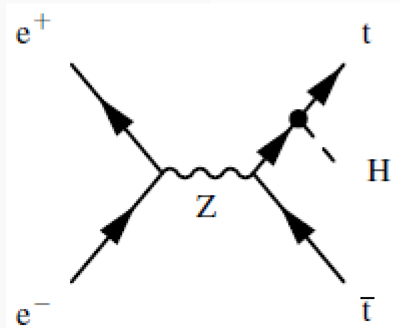


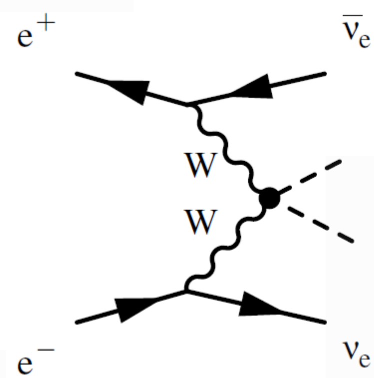
Higgs-self coupling : access to Higgs potential

$$V = \mu^2(\phi^+\phi) + \lambda(\phi^+\phi)^2 \Rightarrow \lambda = \frac{m_H^2}{V}$$



Top-Yukawa coupling





Quartic coupling g_{HHWW}

Measurement summary

Summary of CLIC Higgs studies

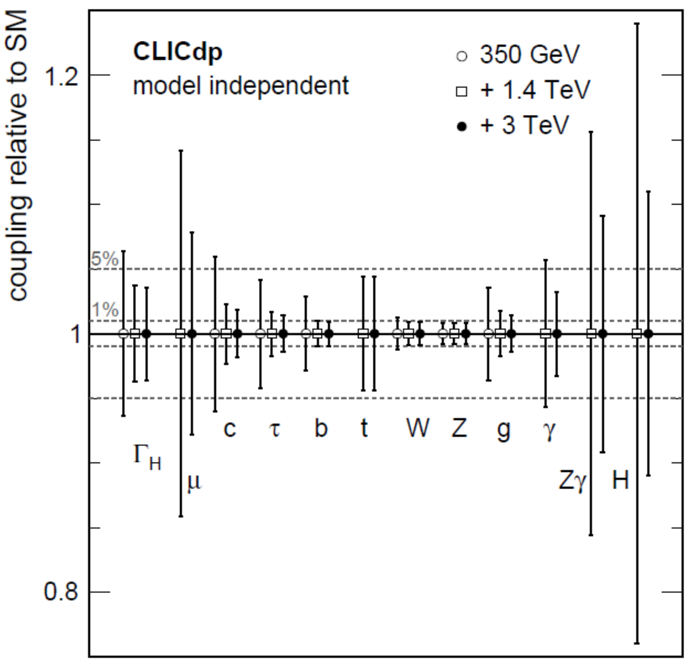
- 25 independent analyses done in full simulation including the beam-induced background overlay
- The results show expected statistical uncertainties for unpolarized beams

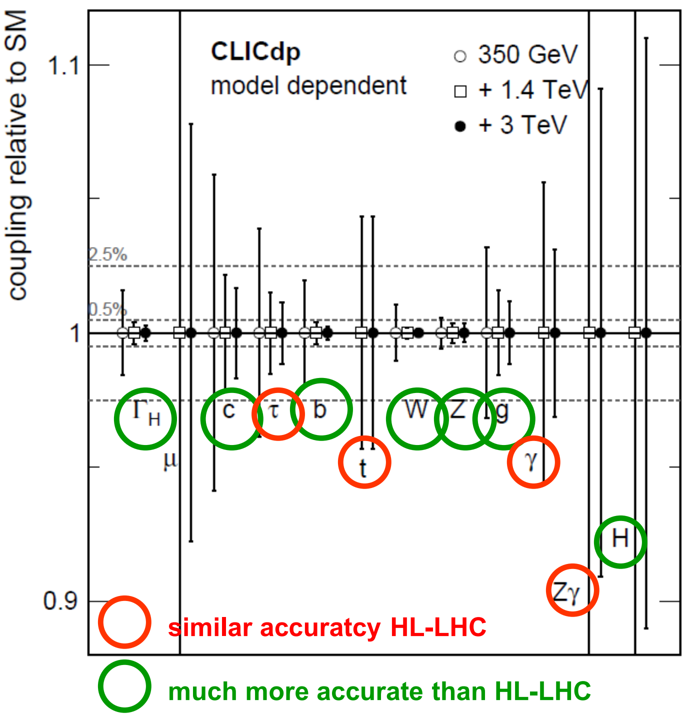
Channel	Measurement	Observable	Statistical precision 350 GeV 500 fb^{-1}
ZH	Recoil mass distribution	m_H	110 MeV
ZH	$\sigma(ZH) \times BR(H \to \text{invisible})$	Γ_{inv}	0.6 %
ZH	$\sigma(ZH) \times BR(Z \to l^+l^-)$	g^2_{HZZ}	3.8 %
ZH	$\sigma(ZH) \times BR(Z \to q\bar{q})$	g^2_{HZZ}	1.8 %
ZH	$\sigma(ZH) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	0.84 %
ZH	$\sigma(ZH) \times BR(H \to c\bar{c})$	$g^2_{HZZ} g^2_{Hcc}/\Gamma_H$	10.3 %
ZH	$\sigma(ZH) \times BR(H \to gg)$		4.5 %
ZH	$\sigma(ZH) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ} g^2_{H\tau\tau}/\Gamma_H$	6.2 %
ZH	$\sigma(ZH) \times BR(H \to WW^*)$	$g^2_{HZZ} g^2_{HWW}/\Gamma_H$	5.1 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	1.9 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	14.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		5.7 %

Channel	Measurement	Observable	Statistical precision 1.4 TeV 1.5 ab^{-1}	3 TeV 2.0 ab^{-1}
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	47 MeV	44 MeV
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	0.4 %	0.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	6.1 %	6.9 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		5.0 %	4.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-)$	$g^2_{HWW} g^2_{H\tau\tau}/\Gamma_H$	4.2 %	4.4 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \mu^+\mu^-)$	$g^2_{HWW} g^2_{H\mu\mu}/\Gamma_H$	38 %	25 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \gamma\gamma)$		15 %	10 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to Z\gamma)$		42 %	30 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*)$	g^4_{HWW}/Γ_H	1.0 %	0.7 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to ZZ^*)$	$g^2_{HWW} g^2_{HZZ}/\Gamma_H$	5.6 %	3.9 %*
He^+e^-	$\sigma(He^+e^-) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	1.8 %	2.3 %*
$t\bar{t}H$	$\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$	$g^2_{Htt} g^2_{Hbb}/\Gamma_H$	8.4 %	–
$HH\nu_e\bar{\nu}_e$	$\sigma(HH\nu_e\bar{\nu}_e)$	λ	32 %	16 %
$HH\nu_e\bar{\nu}_e$	with −80 % e^- polarisation	λ	24 %	12 %

Global fit

- The results of all studied Higgs production and decay channels, obtained at each energy stage, are combined in a global fit to extract absolute couplings and the total Higgs decay width
- Assumption: 80% electron polarization for 1.4 TeV and 3 TeV measurements
- Two types of fit applied:
  - Model independent: free parameters Γ_H and ten Higgs couplings
  - Model dependent: Γ_H constrained by the SM expectations ; no invisible Higgs decays





arXiv:1608.07538

Top physics

- Top quark couples most strongly with Higgs field $\Rightarrow$ closest insights to the electroweak symmetry breaking
- Loop contribution to the processes that can be studied with high precision shows sensitivity to BSM signals
- Uncertainty of the top mass, along with the uncertainty on the Higgs boson mass, is one of the key inputs to the studies of the SM vacuum stability

Dedicated measurements:

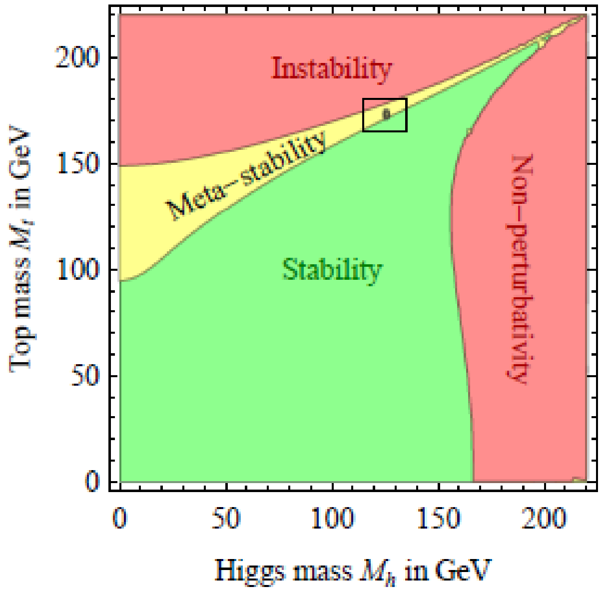
Top quark mass

- Top quark threshold scan
- Direct reconstruction

Top -Yukawa coupling

Probe of new physics

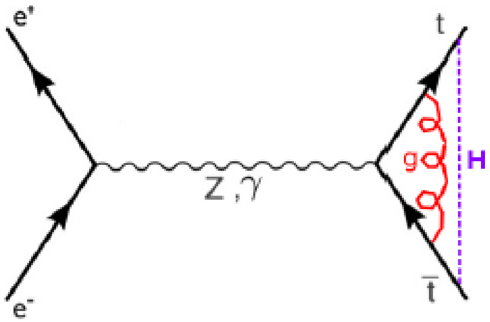
- Top quark electroweak couplings
- Top quark production asymmetries
- CP violation in top sector



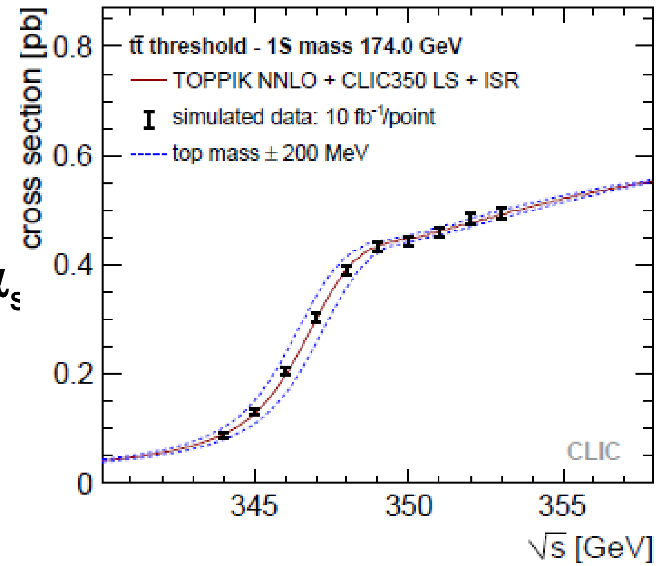
Degrasi et al. Arxiv 1205.6497v2

Top treshold scan

Resonant behavior of the cross-section near the production threshold bound tt state

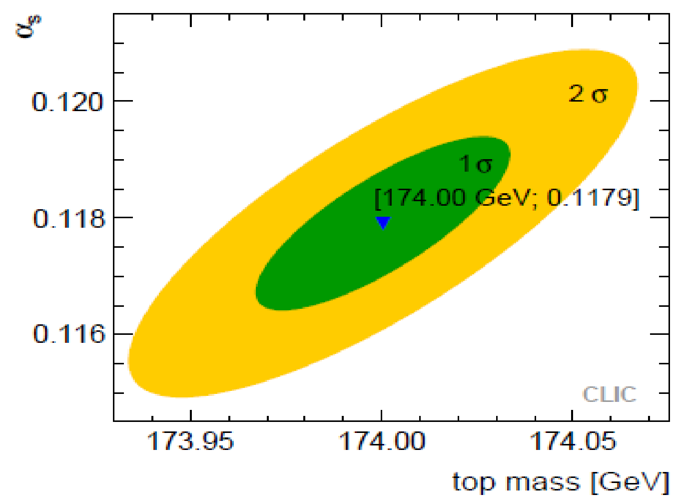


- Top quark mass m_t
- Top quark width Γ_t
- Strong coupling constant α_s
- Top-Yukawa coupling y_t



Dedicated run around threshold with 100 fb^{-1}

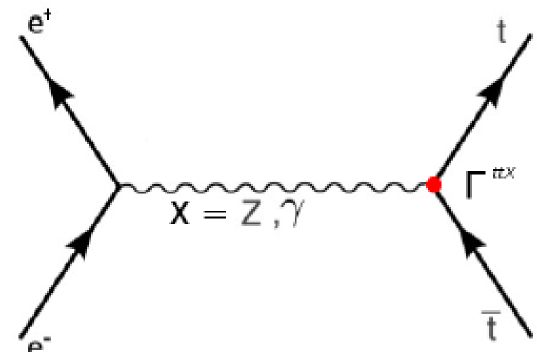
- Ten scan points, 1 GeV, 10 fb^{-1}
- m_t total uncertainty ~50 MeV (~30 MeV stat)



Top electroweak couplings

Top as a probe of New physics: top electroweak couplings

- At higher energy, main targets are the determination of the top quark couplings to Z boson and photon
- Vertices $tt\gamma$, ttZ – sensitivity to the deviation from the SM
- The contribution of Z or γ depend on beam polarization
- These vertices can be described via form factors ($\Rightarrow$couplings)

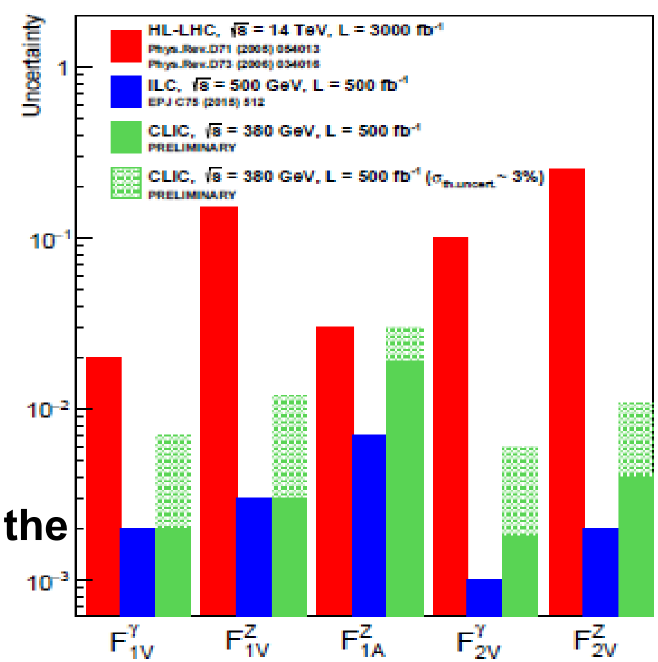


Determination of the couplings:

- Measurement of the cross-section
- Measure forward-backward asymmetry A_{FB}
- Measure left-right asymmetry A_{LR}

  for different polarizations

CP CONSERVING COUPLINGS



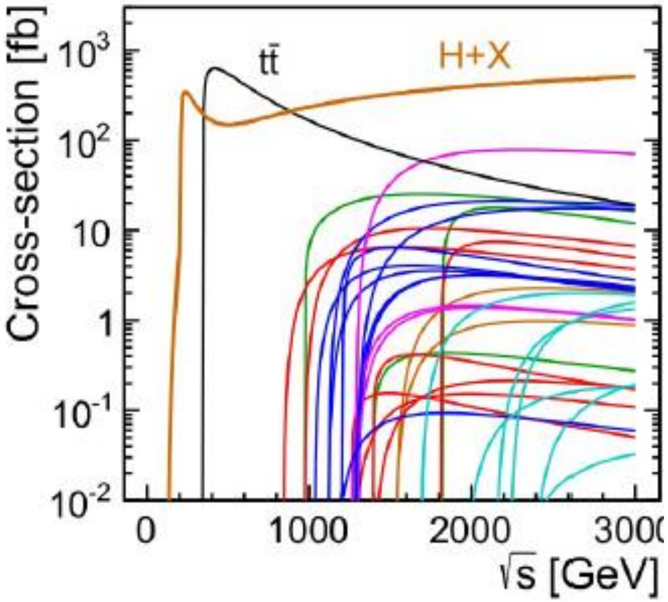
Results are significantly better than HL-LHC even for the first CLIC energy stage

BSM physics at CLIC

CLIC operating at high energy provides significant discovery potential for BSM physics

Direct searches of new particles

- Possible observation of the new phenomena
- Precision measurements of new particle properties
- Kinematic limit at the of 1.5 TeV



Indirect searches

- Precision measurements of sensitive observables reveal a signs of new physics, comparing to the SM expectations
- Kinematic limit is higher – several tens of TeV

Next slides: examples of some benchmark BSM studies

BSM physics: direct measurements

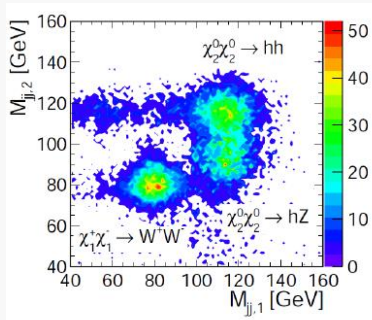
Reconstruction of the SUSY particles

Chargino and neutralino

Reconstruction

of W/Z/h in hadronic decays:

4 jets and missing energy



$e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$

$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to hh\,\tilde{\chi}_1^0\tilde{\chi}_1^0$ (82 %)

$e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to Zh\,\tilde{\chi}_1^0\tilde{\chi}_1^0$ (17 %)

Heavy Higgs bosons at 3 TeV

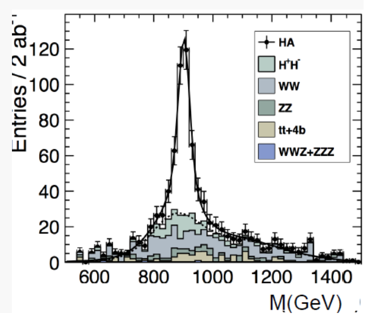
Reconstruction of four heavier Higgs degrees of freedom

$e^+e^- \longrightarrow H^0A$

$e^+e^- \longrightarrow H^+H^-$

Almost degenerate in mass

$\Delta m/m = 0.3$ %



$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Stat. uncertainty
3.0	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	$\tilde{\ell}$ mass	0.6%
				$\tilde{\chi}_1^0$ mass	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	0.3%
				$\tilde{\chi}_1^0$ mass	1.0%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	0.4%
				$\tilde{\chi}_1^\pm$ mass	0.6%
3.0	Chargino Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	1.1%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	1.5%
3.0	Squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	$\tilde{q}_R$ mass	0.52%
3.0	Heavy Higgs	$H^0A^0 \to b\bar{b}b\bar{b}$	I	H^0/A^0 mass	0.3%
		$H^+H^- \to t\bar{b}b\bar{t}$		$H^\pm$ mass	0.3%
1.4	Sleptons	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\ell}$ mass	0.1%
				$\tilde{\chi}_1^0$ mass	0.1%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\ell}$ mass	0.1%
				$\tilde{\chi}_1^0$ mass	0.1%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^-W^+W^-$		$\tilde{\ell}$ mass	2.5%
				$\tilde{\chi}_1^\pm$ mass	2.7%
1.4	Stau	$\tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\tau}_1$ mass	2.0%
1.4	Chargino Neutralino	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	III	$\tilde{\chi}_1^\pm$ mass	0.2%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0\, h/Z^0\, \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	0.1%

Masses of superpartners can be measured with ~1% up to a kinematic limit

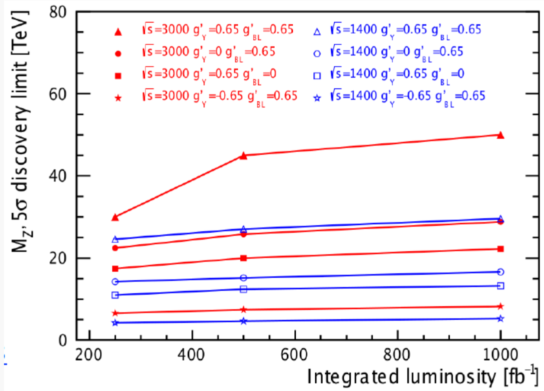
BSM physics: indirect measurements

Extended gauge theories, Z′:

- Hypothetical gauge boson
- Precision measurement of using polarized beams
- Compared to the SM predictions for cross-sections, A_{FB}, A_{LR}

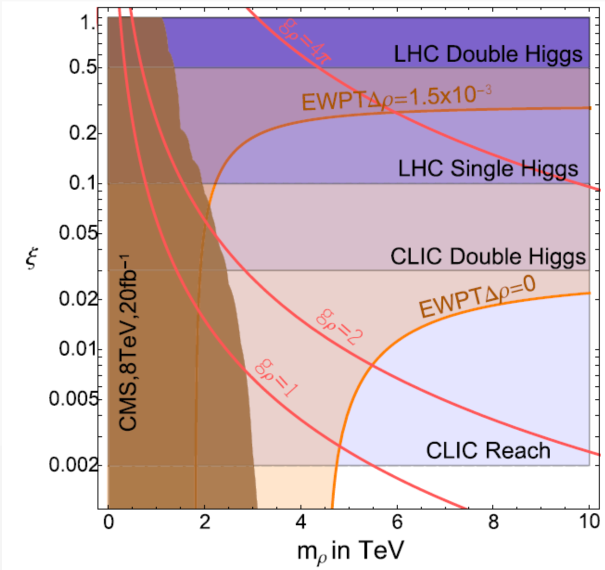
Minimal anomaly-free (AFZ') model :

- Discovery reach up to tens of TeV
- HL-LHC reaches ~8 TeV with 3 ab^{-1}



Composite Higgs:

- Higgs as a composite bound state of fermions
- m_ρ are the masses of vector resonances
- $4\pi f$ scale of compositness
- $\xi=(v/f)^2$ measures the strength of Higgs interactions



In AFZ' theory, sensitivity on the mass can reach several tens of TeV

Composite scale reaches up to 70 TeV

Conclusions

- CLIC is an attractive option for the future e^+e^- collider.
- Feasibility of the new acceleration technique based on a two-beam technology, with high gradient of 100 MV/m, is demonstrated.
- The CLIC detector is optimised to the benchmark physics processes.
- Performed physics studies show excellent potential of CLIC for precision measurements, as well as large discovery potential for physics beyond the Standard model.
- Close look to possible discoveries at LHC

The CLICdp Collaboration

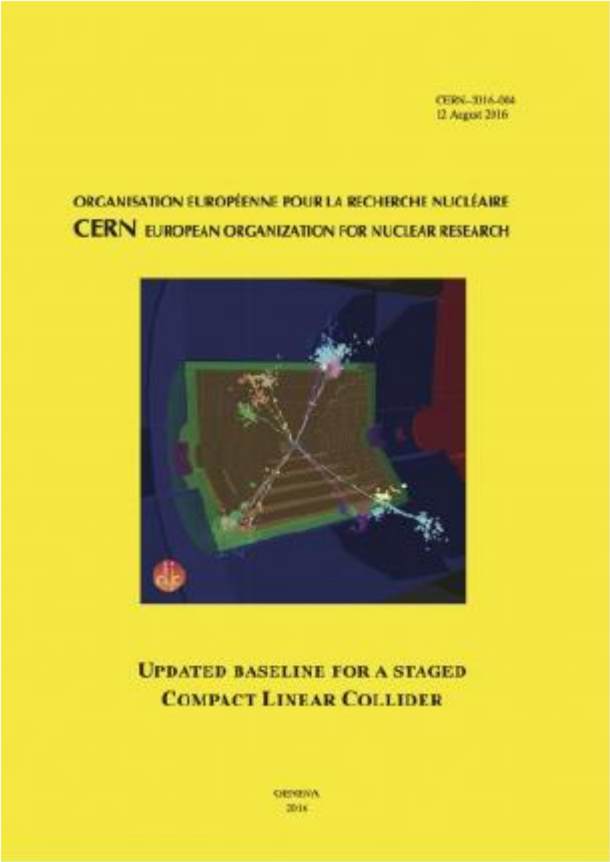
Australia	Australian Collaboration for Accelerator Science (ACAS)
Belarus	National Scientific and Educational Centre of Particle and High Energy Physics (NC PHEP), Belarusian State University, Minsk
Chile	Pontificia Universidad Católica de Chile, Santiago
Czech Republic	Institute of Physics, Academy of Sciences of the Czech Republic, Prague
Denmark	Department of Physics and Astronomy, Aarhus University
France	Laboratoire d'Annecy-le-Vieux de Physiques des Particules (LAPP), Annecy
Germany	Karlsruher Institut für Technologie (KIT), Institut für Prozessdatenverarbeitung und Elektronik (IPE)
Germany	Max-Planck-Institut für Physik, Munich
Israel	Department of Physics, Faculty of Exact Sciences, Tel Aviv University, Tel Aviv
Norway	Department of Physics and Technology, University of Bergen, Bergen
Poland	Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow
Poland	The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Cracow
Poland	University of Warsaw
Romania	Institute of Space Science
Russia	Joint Institute for Nuclear Research (JINR), Dubna
Serbia	Vinca Institute of Nuclear Sciences, Belgrade
Spain	Spanish Network for Future Linear Colliders
Switzerland	Département de Physique Nucléaire et Corpusculaire (DPNC), Geneva
United Kingdom	School of Physics and Astronomy of the University of Birmingham, Birmingham
United Kingdom	University of Bristol
United Kingdom	University of Cambridge, Cambridge
United Kingdom	University of Glasgow
United Kingdom	Department of Physics of the University of Liverpool, Liverpool
United Kingdom	University of Oxford, Oxford
USA	Argonne National Laboratory, High Energy Physics Division, Argonne
USA	Physics Department of the University of Michigan

- **Focus on CLIC physics and detector studies:**
- **Physics prospects and simulation studies**
- **Detector optimization (Research & Development) for the future Compact Linear Collider (CLIC)**
- **28 Institutes from 18 countries**
- **http://clicdp.web.cern.ch/**

New CLICdp publications

- Comprehensive Higgs physics paper http://arxiv.org/abs/1608.07538
- New baseline for a staged CLIC http://arxiv.org/abs/1608.07537


Higgs Physics at the CLIC Electron-Positron Linear Collider



Thank you !

BACKUP

CLIC Project timeline

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020-2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

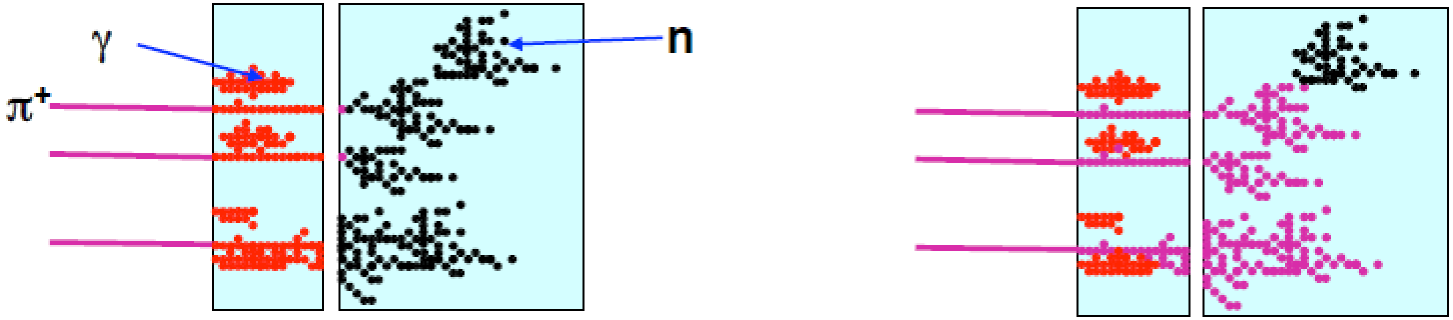
2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

Particle Flow Paradigm

- ★ Particle flow approach:
  - Try and measure energies of individual particles
  - Reduce dependence on intrinsically "poor" HCAL resolution

- ★ Idealised Particle Flow Calorimetry paradigm:
  - charged particles measured in tracker (essentially perfectly)
  - Photons in ECAL
  - Neutral hadrons (and ONLY neutral hadrons) in HCAL
  - Only 10 % of jet energy from HCAL ⇒ improved jet energy resolution



$E_{JET} = E_{ECAL} + E_{HCAL}$ ⇒ $E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$