News on the CLIC physics potential

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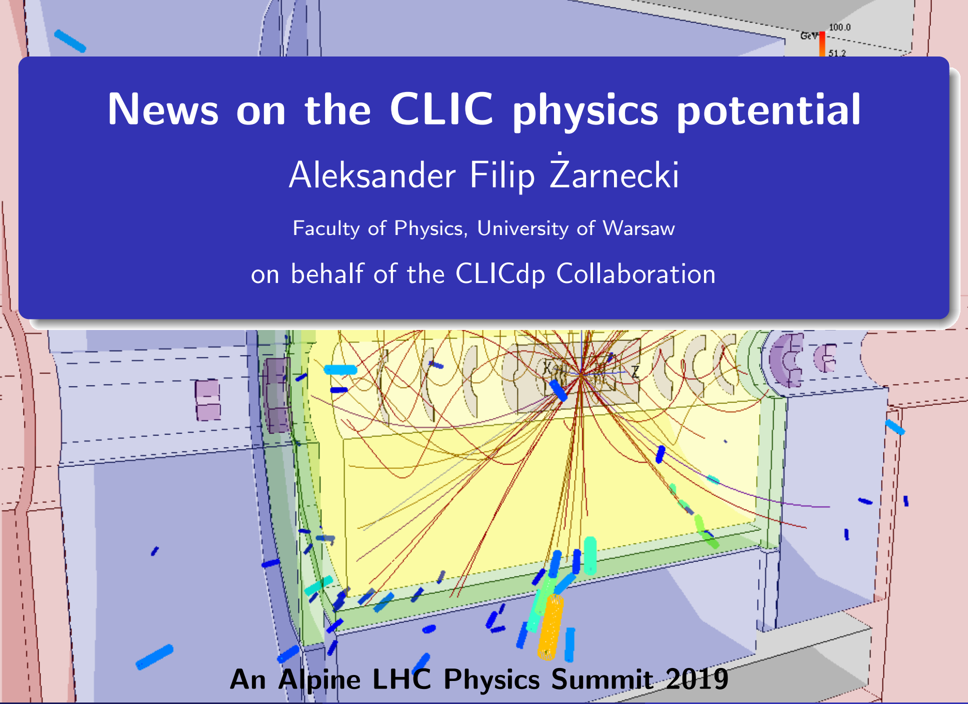
on behalf of the CLICdp Collaboration



An Alpine LHC Physics Summit 2019

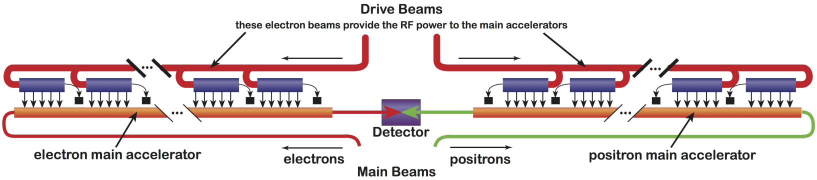
Outline

1. Introduction
2. Higgs physics
3. Top-quark physics
4. BSM physics
5. Conclusions

Focus on selected highlights and most recent studies

For more recent results see:
The CLIC potential for new physics, CERN-2018-009-M, arXiv:1812.02093

Compact LInear Collider



Conceptual Design (CDR) presented in 2012 CERN-2012-007

- high gradient, two-beam acceleration scheme
- staged implementation plan with energy from 380 GeV to 3 TeV
- footprint of 11 to 50 km
- e^- polarisation

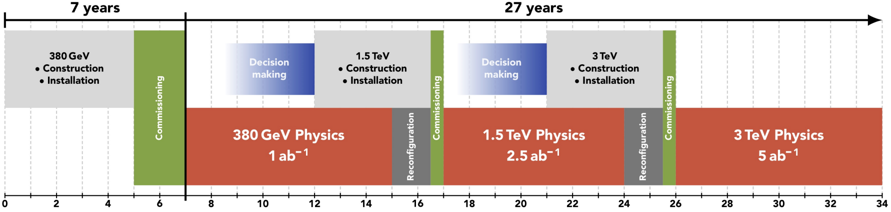
For details refer to arXiv:1812.07987

CLIC running scenario

new baseline: CERN-2018-005-M

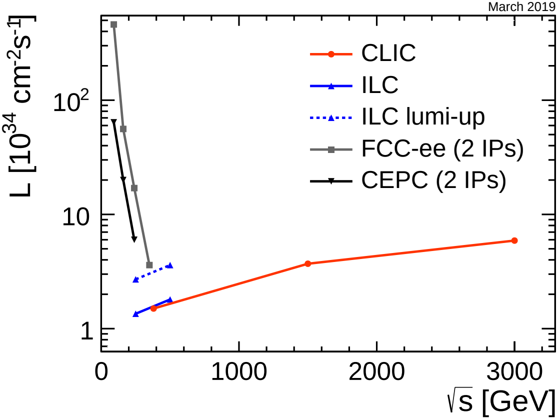
Three construction stages (each 7 to 8 years of running)
for an optimal exploitation of its physics potential

- $\sqrt{s} = 380$ GeV with $1\,\mathrm{ab}^{-1}$ including $100\ \mathrm{fb}^{-1}$ at $t\bar{t}$ threshold
  focus on precision SM studies, in particular Higgs and top-quark
- $\sqrt{s} = 1.5$ TeV with $2.5\,\mathrm{ab}^{-1}$
- $\sqrt{s} = 3$ TeV with $5\,\mathrm{ab}^{-1}$
  focus on direct and indirect BSM searches,
  but also additional Higgs boson and top-quark studies

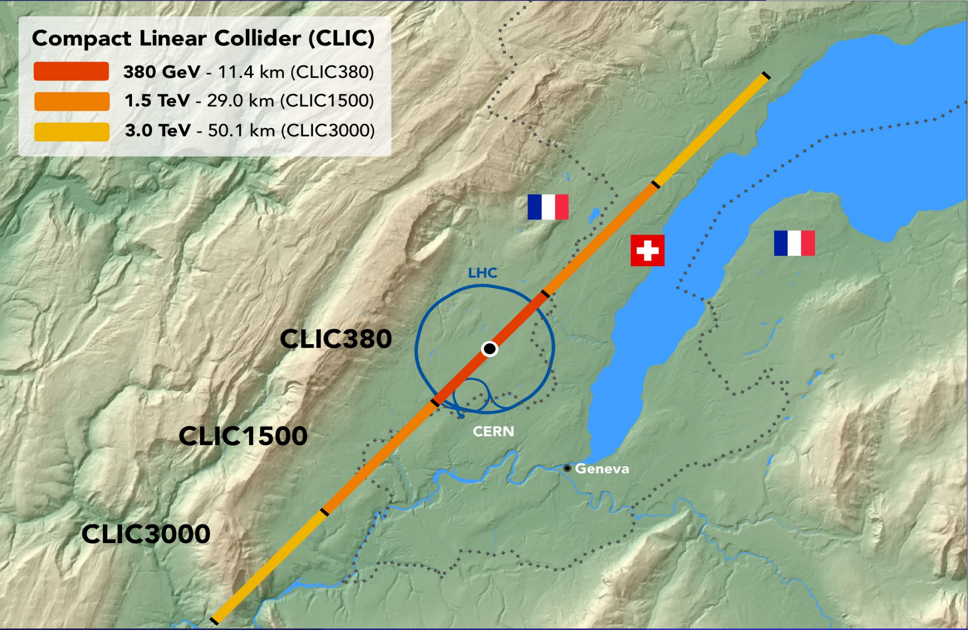


Comparison to other project

- Stage 1 luminosity "per IP" similar to FCC-ee
  with half the construction cost and half the power consumption
- The only e^+e^- project that can go into the TeV domain



Introduction



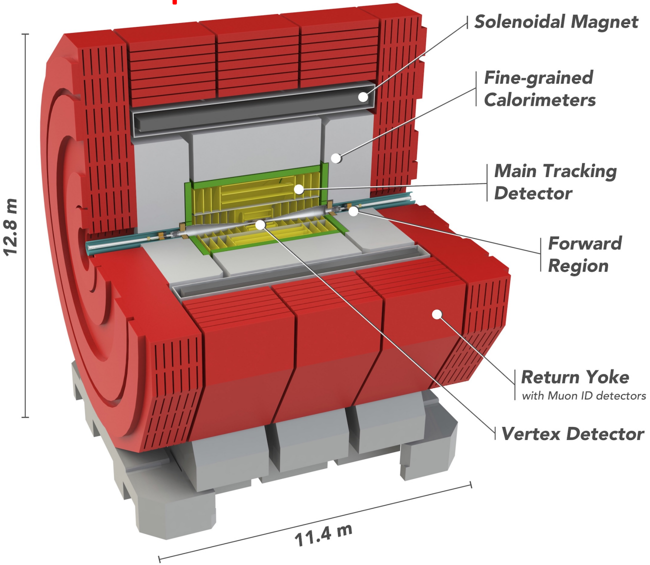
CLICdet: CLIC detector concept

Based on detailed simulation studies, detector R&D and beam tests.

Optimised for Particle Flow reconstruction

Full exploitation of physics potential from 380 GeV to 3 TeV

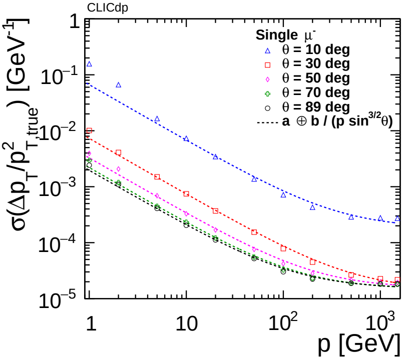
For details refer to arXiv:1812.07337



CLICdet performance

- Track momentum resolution:
  $\sigma_{1/p} < 5 \cdot 10^{-5}$ GeV^{-1}
  for high momentum tracks

p_T resolution for muons

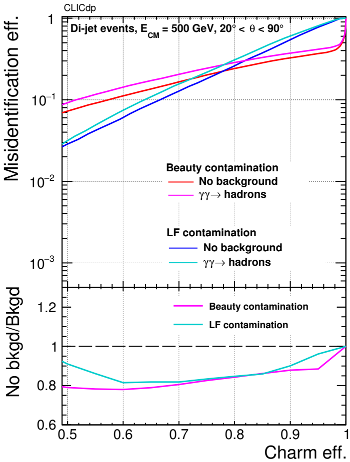


CLICdet performance

- Track momentum resolution:
  $\sigma_{1/p} < 5 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$
  for high momentum tracks
- Impact parameter resolution:

$$\sigma_d < 5\mu m \oplus 10\mu m\ \frac{1\ \mathrm{GeV}}{p\ \sin^{3/2}\Theta}$$

charm tagging performance



CLICdet performance

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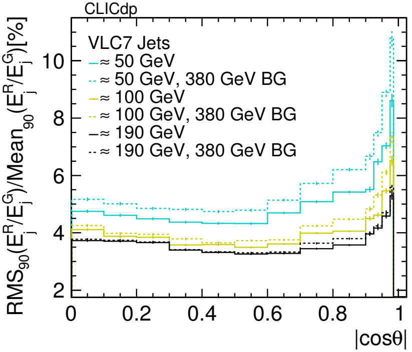
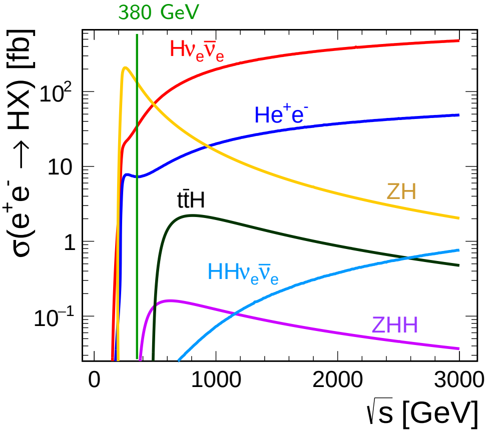
- Impact parameter resolution:
  $\sigma_d < 5\mu m \oplus 10\mu m \frac{1\ \mathrm{GeV}}{p\ \sin^{3/2}\Theta}$
- Jet energy resolution:
  $\sigma_E/E = 3 - 4\%$
  for high jet energies
- Hermecity:
  $\Theta_{min} = 5$ mrad

jet energy resolution

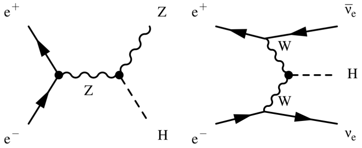


Higgs production

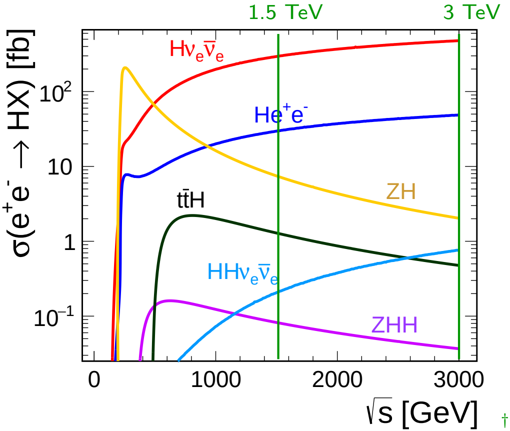


Precision Higgs couplings measurements at 380 GeV

Profit from combining two production channels:



Higgs production



Precision Higgs couplings measurements at 380 GeV

Even more Higgs bosons produced at TeV energies

- rare decay channels†
- top Yukawa coupling
- Higgs self-coupling

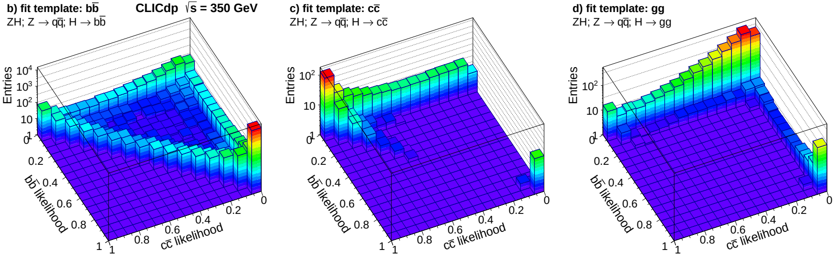
†see talk by Goran Kacarevic this afternoon

Higgs couplings

Eur. Phys. J. C 77 (2017) 475, arXiv:1608.07538

Recoil mass reconstruction in $e^+e^- \to ZH \Rightarrow$ unbiased selection

Clean environment $\Rightarrow$ unambiguous separation of different decay channels



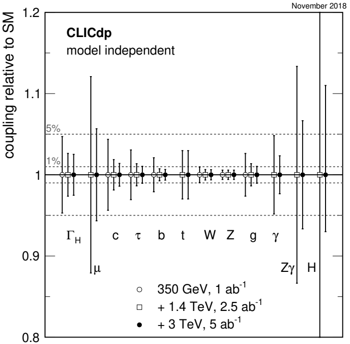
Prospects for direct measurement of $BR(H \to c\bar{c})$

Higgs couplings

Updated for new running scenario: arXiv:1812.01644

Precision of the Higgs couplings of the three-stage CLIC programme determined in a model-independent fit

Parameter	Relative precision		
	350 GeV 1 ab^{-1}	+ 1.4 TeV + 2.5 ab^{-1}	+ 3 TeV + 5 ab^{-1}
g_{HZZ}	0.6 %	0.6 %	0.6 %
g_{HWW}	1.0 %	0.6 %	0.6 %
g_{Hbb}	2.1 %	0.7 %	0.7 %
g_{Hcc}	4.4 %	1.9 %	1.4 %
$g_{H\tau\tau}$	3.1 %	1.4 %	1.0 %
$g_{H\mu\mu}$	−	12.1 %	5.7 %
g_{Htt}	−	3.0 %	3.0 %
$g^{\dagger}_{Hgg}$	2.6 %	1.4 %	1.0 %
$g^{\dagger}_{H\gamma\gamma}$	−	4.8 %	2.3 %
$g^{\dagger}_{HZ\gamma}$	−	13.3 %	6.7 %
Γ_H	4.7 %	2.6 %	2.5 %

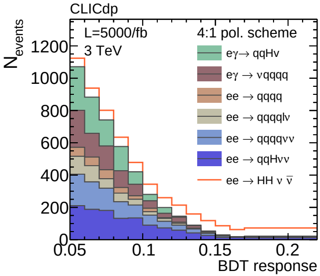


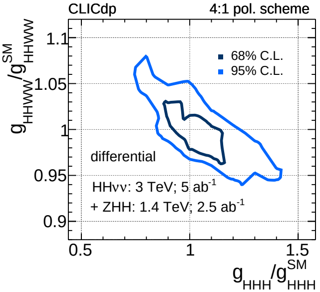
systematic or theoretical uncertainties not included

Higgs self-coupling

arXiv:1901.05897

Can be extracted from the measurement of double Higgs boson production at collision energies of $\sqrt{s} = 1.5$ and 3 TeV.





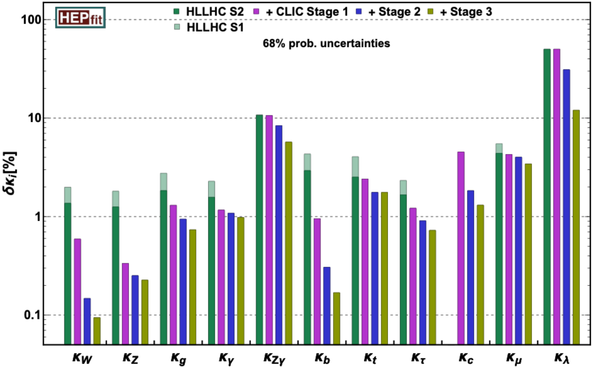
Trilinear Higgs self-coupling as well as the quartic HHWW coupling can be constrained.

Higgs couplings

CERN-2018-009-M, arXiv:1812.02093

CLIC sensitivity to the different Higgs boson couplings
compared with the HL-LHC projections

Model-dependent analysis

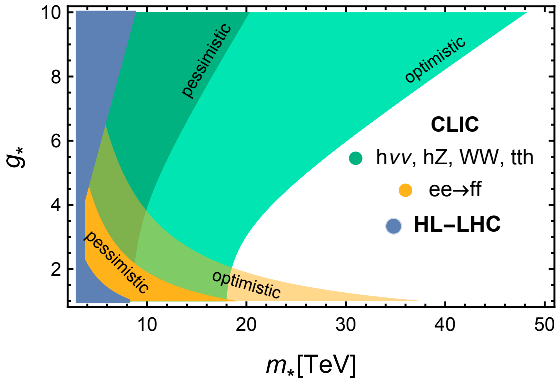


significant improvement already at the first energy stage

Looking for BSM effects

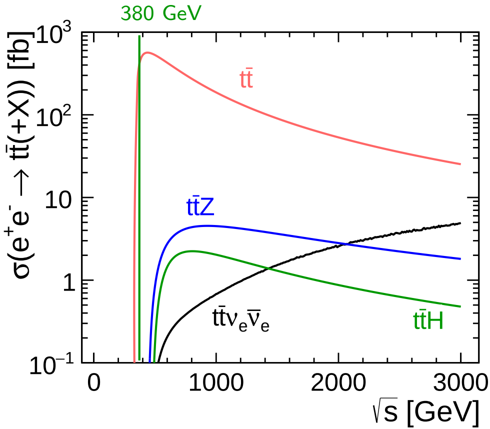
5σ discovery range for Higgs compositeness

compared to expected HL-LHC 2σ exclusions



New physics effects can be discovered via precision measurements at CLIC.

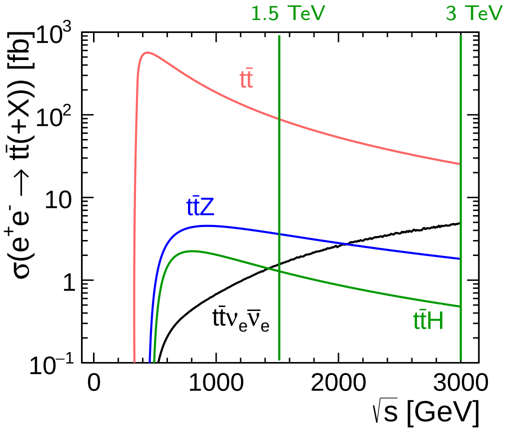
Processes of interest



Top pair-production at and above the threshold (380 GeV)

- top-quark mass
- electroweak couplings
- rare decays

Processes of interest



Top pair-production at and above the threshold (380 GeV)

- top-quark mass
- electroweak couplings
- rare decays

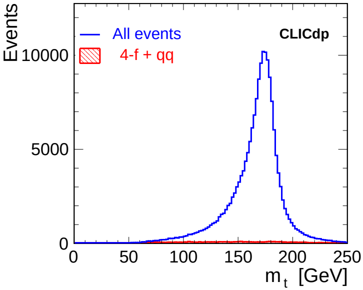
Additional processes open at high energies

- top Yukawa coupling
- CP properties
- BSM constraints

Top-quark mass

arXiv:1807.02441

Direct mass measurement from reconstruction of hadronic decays



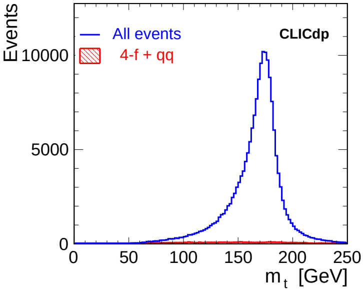
Statistical precision $\sim 30\,\mathrm{MeV}$

Large systematic effects (JES)
and theoretical uncertainties

Top-quark mass

arXiv:1807.02441

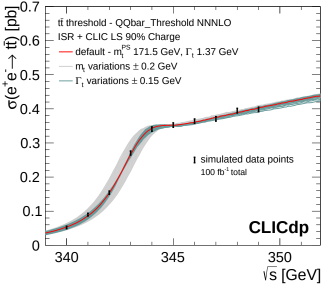
Direct mass measurement from reconstruction of hadronic decays



Statistical precision $\sim$ 30 MeV

Large systematic effects (JES) and theoretical uncertainties

Mass determination from the cross section scan at the threshold



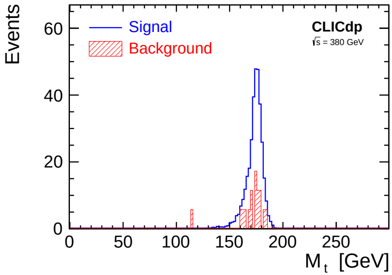
Statistical precision 20 – 30 MeV

Total systematic uncertainty
25 – 50 MeV (exp.) $\oplus$ 30 – 50 MeV (th.)

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

Reconstructed $c\gamma$ invariant mass after BDT selection



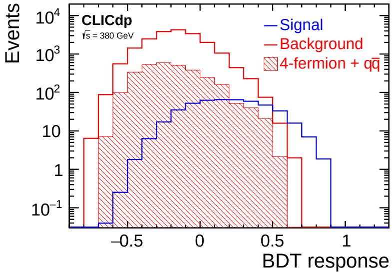
Limits expected for 1000 fb^{-1} collected at 380 GeV

$$BR(t \to c\gamma) < 2.6 \cdot 10^{-5}$$

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

Response distribution of the BDT for the $t \to cH$ selection



Limits expected for $1000\,fb^{-1}$ collected at 380 GeV

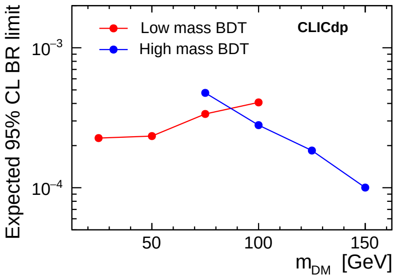
$$BR(t \to c\gamma) \quad < \quad 2.6 \cdot 10^{-5}$$

$$BR(t \to cH) \times BR(H \to b\bar{b}) \quad < \quad 8.8 \cdot 10^{-5}$$

FCNC top-quark decays

very strongly suppressed in SM (CKM+GIM)

95% C.L. limits on $BR(t \to c\not{E})$
as a function of DM particle mass



Limits expected for $1000\,fb^{-1}$
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$$BR(t \to c\gamma) \quad < \quad 2.6 \cdot 10^{-5}$$

$$BR(t \to cH) \times BR(H \to b\bar{b}) \quad < \quad 8.8 \cdot 10^{-5}$$

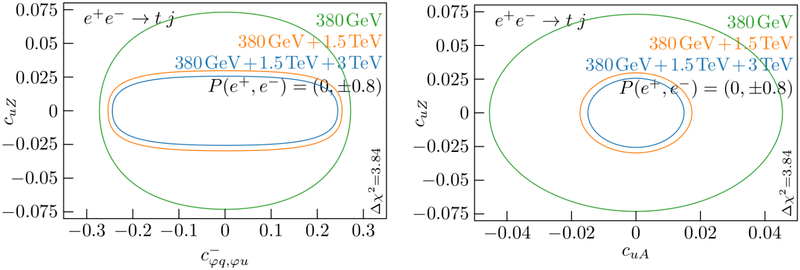
$$BR(t \to c\not{E}) \quad < \quad 1.0 - 3.4 \cdot 10^{-4}$$

FCNC top couplings

Can also be constrained from the measurement of single top production

Negligible SM contribution expected ⇒ clean BSM probe

Expected limits on Wilson coefficients perfect reconstruction, old running scenario

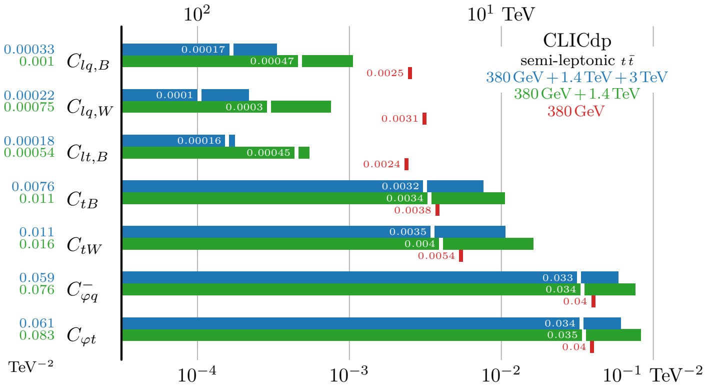


Indirect constraints comparable to direct ones for 380 GeV

Significant improvement for high energy running

Looking for BSM effects

Summary of the global EFT analysis of measurements involving top quark
Results based on statistically optimal observables



High energy CLIC can reach "new physics" scales in the 100 TeV range

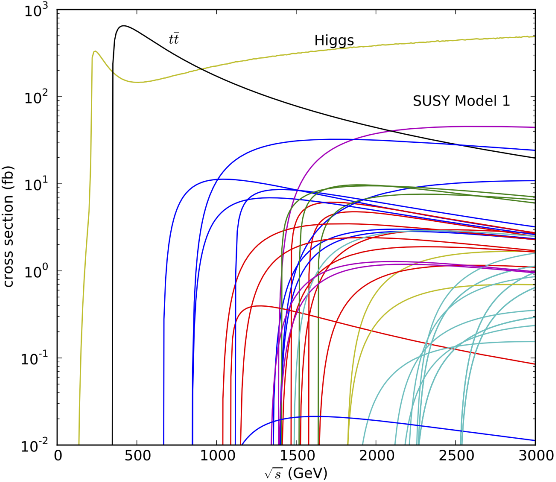
Main target for high energy CLIC stages

Strong limits expected at HL-LHC for many scenarios.

Complementary searches at CLIC:

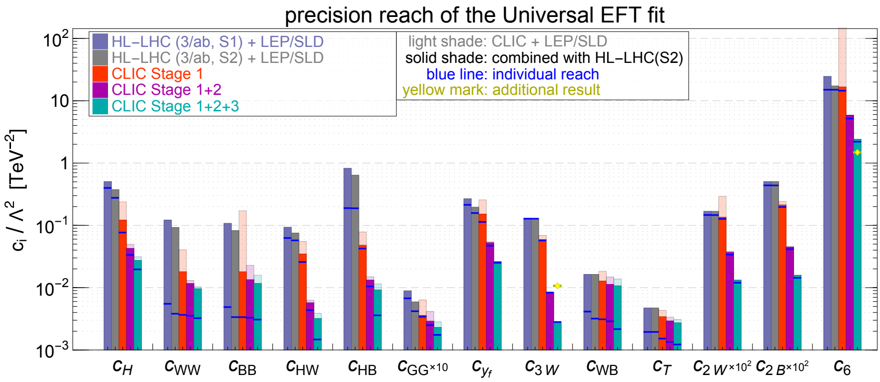
- direct searches
  models with weak couplings or soft signatures
- indirect searches
  high sensitivity

CLIC CDR



EFT analysis

Summary of the sensitivity to SM-EFT operators from a global analysis of CLIC's observables (Higgs, top-, boson- and fermion-pair production)

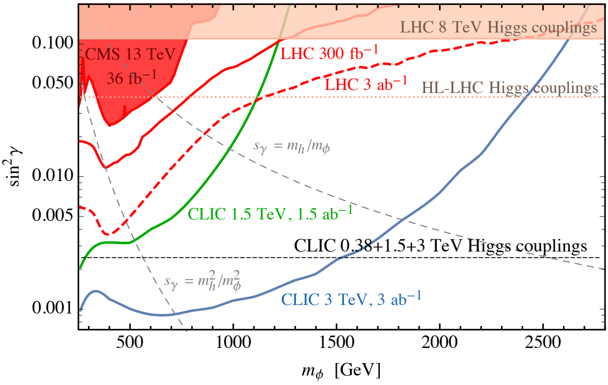


CLIC significantly increases the precision of BSM constraints

Direct searches

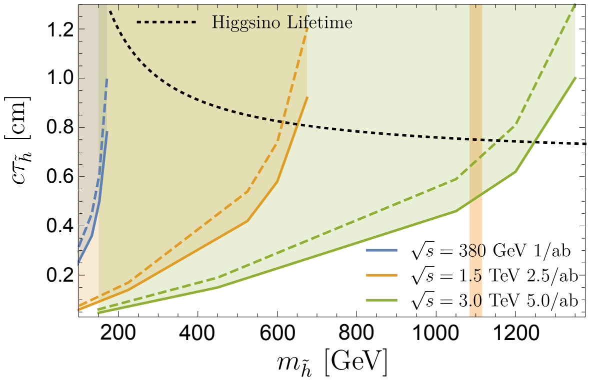
For many models, in particular those with exotic scalar sector or new Higgs bosons, CLIC direct and indirect reach can exceed that of HL-LHC.

Indirect and direct sensitivities to new heavy scalar singlets:



Direct searches

Search for dark matter production using "disappearing tracks" signature



high sensitivity thanks to precision tracking and low background conditions

Conclusions

CLIC

An attractive and cost-effective option for next large facility at CERN

The initial stage of CLIC: optimal for Higgs and top-quark measurements

- precise determination of top-quark mass and Higgs couplings
- stringent constraints on many BSM scenarios

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CLIC

An attractive and cost-effective option for next large facility at CERN

The initial stage of CLIC: optimal for Higgs and top-quark measurements

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- stringent constraints on many BSM scenarios

Subsequent CLIC stages:
higher energies, luminosities and cross sections (for many processes)

- significantly enhanced precision of SM measurements
- indirect BSM searches extending to 0(100) TeV scales
- direct searches for "new physics" up to the TeV scales
  complementary to those planned at HL-LHC

References

Formal European Strategy submissions

- The Compact Linear e^+e^- Collider (CLIC): Accelerator and Detector, arXiv:1812.07987
- The Compact Linear e^+e^- Collider (CLIC): Physics Potential, arXiv:1812.07986

Yellow Reports

- CLIC 2018 Summary Report, CERN-2018-005-M, arXiv:1812.06018
- CLIC Project Implementation Plan, CERN-2018-010-M, arXiv:1903.08655
- The CLIC potential for new physics, CERN-2018-009-M, arXiv:1812.02093

Journal publications

- Top-quark physics at the CLIC electron-positron linear collider arXiv:1807.02441
- Higgs physics at the CLIC electron-positron linear collider arXiv:1608.07538

Public CLICdp notes

- Updated CLIC luminosity staging baseline and Higgs coupling prospects arXiv:1812.01644
- CLICdet: The post-CDR CLIC detector model CLICdp-Note-2017-001
- A detector for CLIC: main parameters and performance arXiv:1812.07337
- Double Higgs boson production and Higgs self-coupling extraction... arXiv:1901.05897


stub tracks
self-coupling
Higgs
SMEFT
flavour-changing neutral currents
lepton flavor
baryogenesis
dark matter
discovery
inert doublet
BSM
2HDM
precision
photon

Thank you!

CLIC 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, pre-series and system optimisation studies, 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

2020
Update of the European Strategy for Particle Physics

2026
Ready for construction

2035
First collisions

CLICdp Collaboration