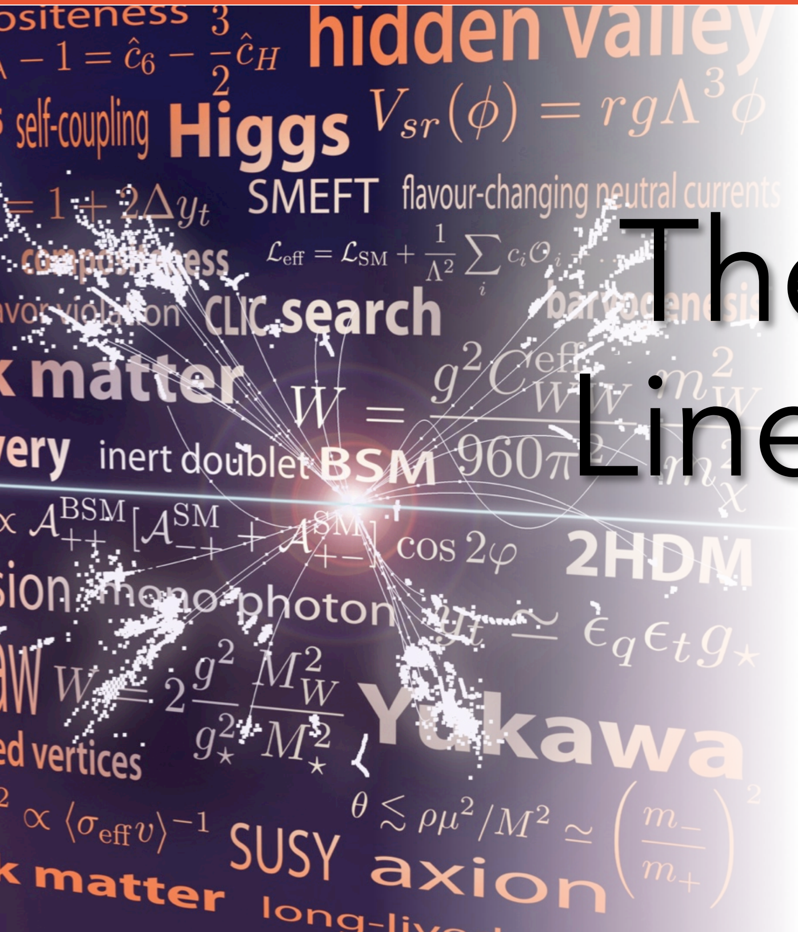
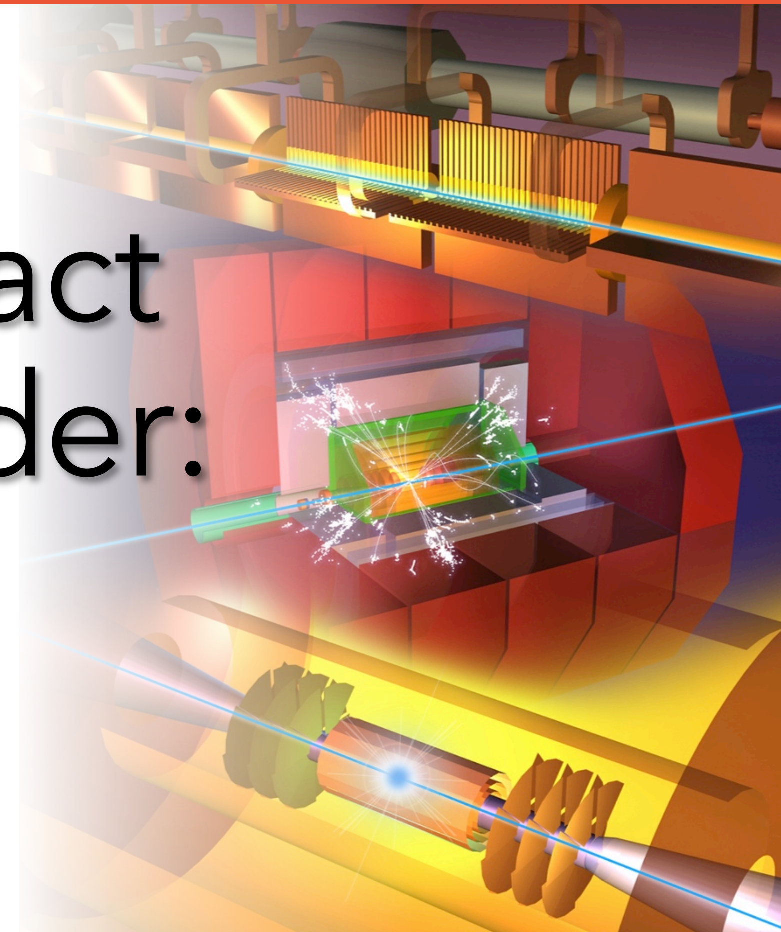


The Compact Linear Collider: CLIC

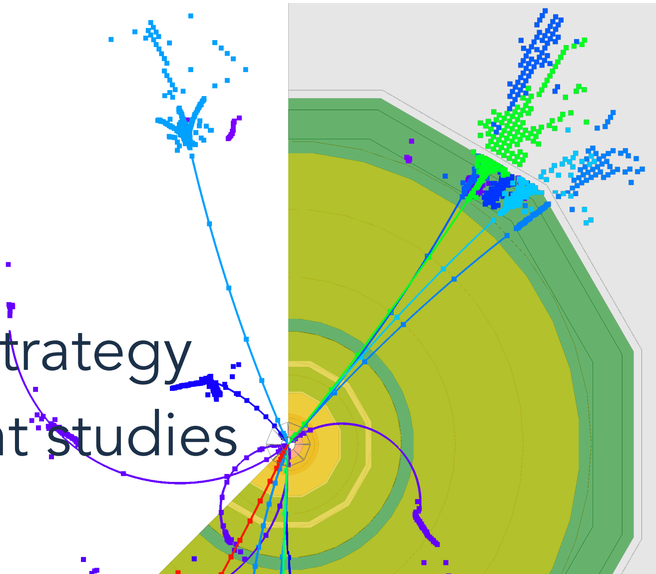


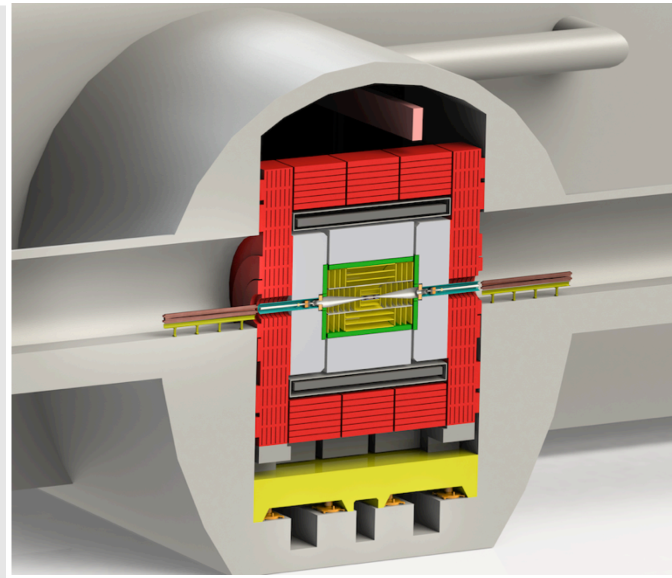
Spanish Future Collider Network, 7 October 2020

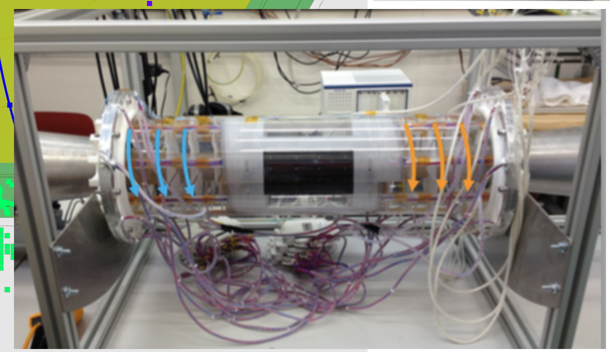
Aidan Robson, University of Glasgow

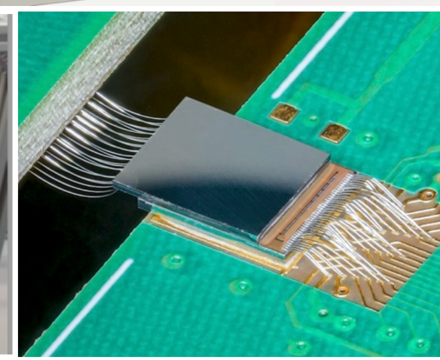
CLIC

- Project overview
- Status after European Strategy
- Physics reach and recent studies
- Outlook









Compact Linear Collider:
e^+e^- collisions up to 3TeV
http://clic.cern/

Collaborations

http://clic.cern/

CLIC accelerator collaboration

~60 institutes from 28 countries

including CELLS-ALBA (Barcelona), CIEMAT (Madrid), CSIC-UV (Valencia)

CLIC accelerator studies:

- CLIC accelerator design and development
- (Construction and operation of CLIC Test Facility, CTF3)

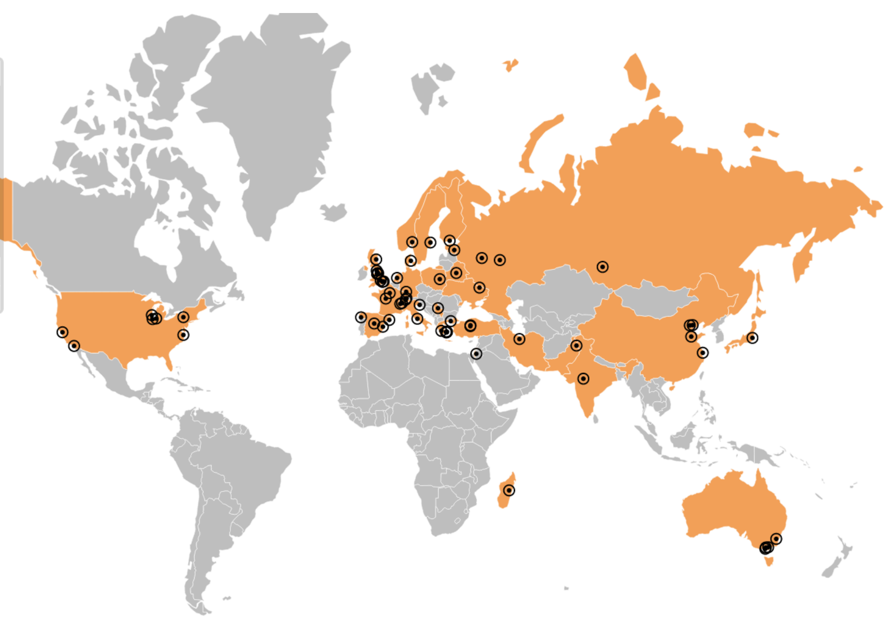
CLIC detector and physics (CLICdp)

30 institutes from 18 countries

Spanish Network including Valencia and Cantabria

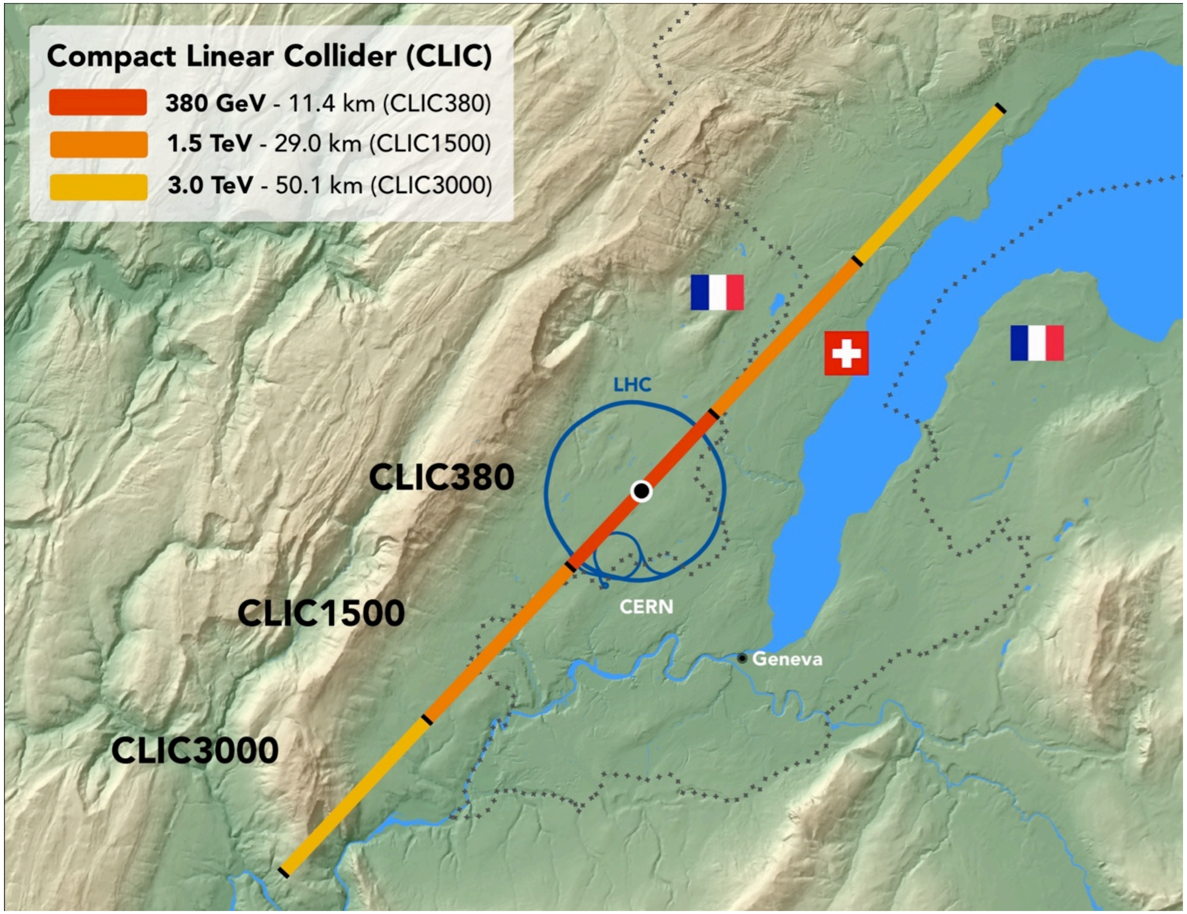
Focus of CLIC-specific studies on:

- Physics prospects & simulation studies
- Detector optimization + R&D for CLIC



The Compact Linear Collider

- A high-luminosity, multi-TeV electron–positron collider
- Planned for construction at CERN in three energy stages:



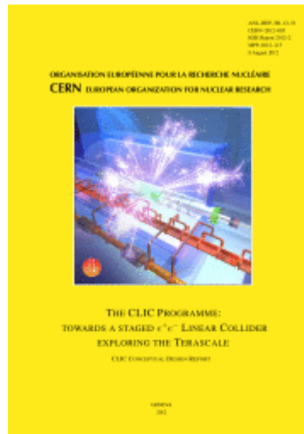
- 380GeV, focusing on precision Higgs boson and top-quark physics
- 1.5 and 3TeV, expanding Higgs and top studies including Higgs self-coupling, and opening higher direct and indirect sensitivity to Beyond Standard Model (BSM)
- Nominal physics programme lasts for 25–30 years; approvable in stages
- Benefit of linear machine: length/energy staging plan can be updated in response to developing physics landscape

CLIC History

◆ 3-volume CDR 2012

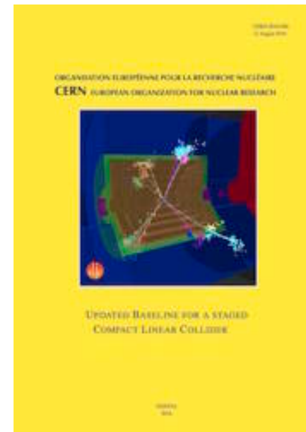
Accelerator

Physics & Detectors



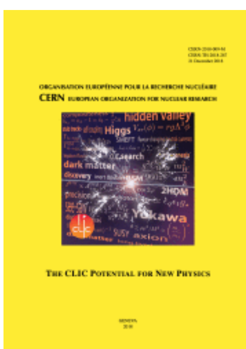
Strategy & Implementation

Updated Staging Baseline 2016

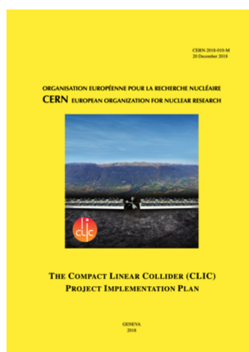


◆ 4 Yellow Reports 2018

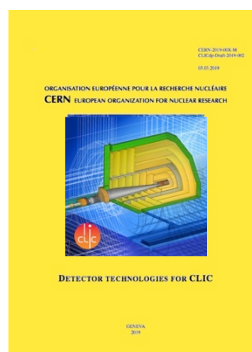
Summary Report



Physics Potential



Project Implementation



Detector Technologies

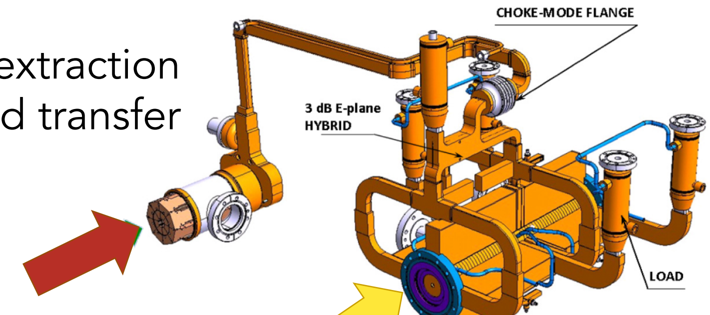
http://clic.cern/european-strategy

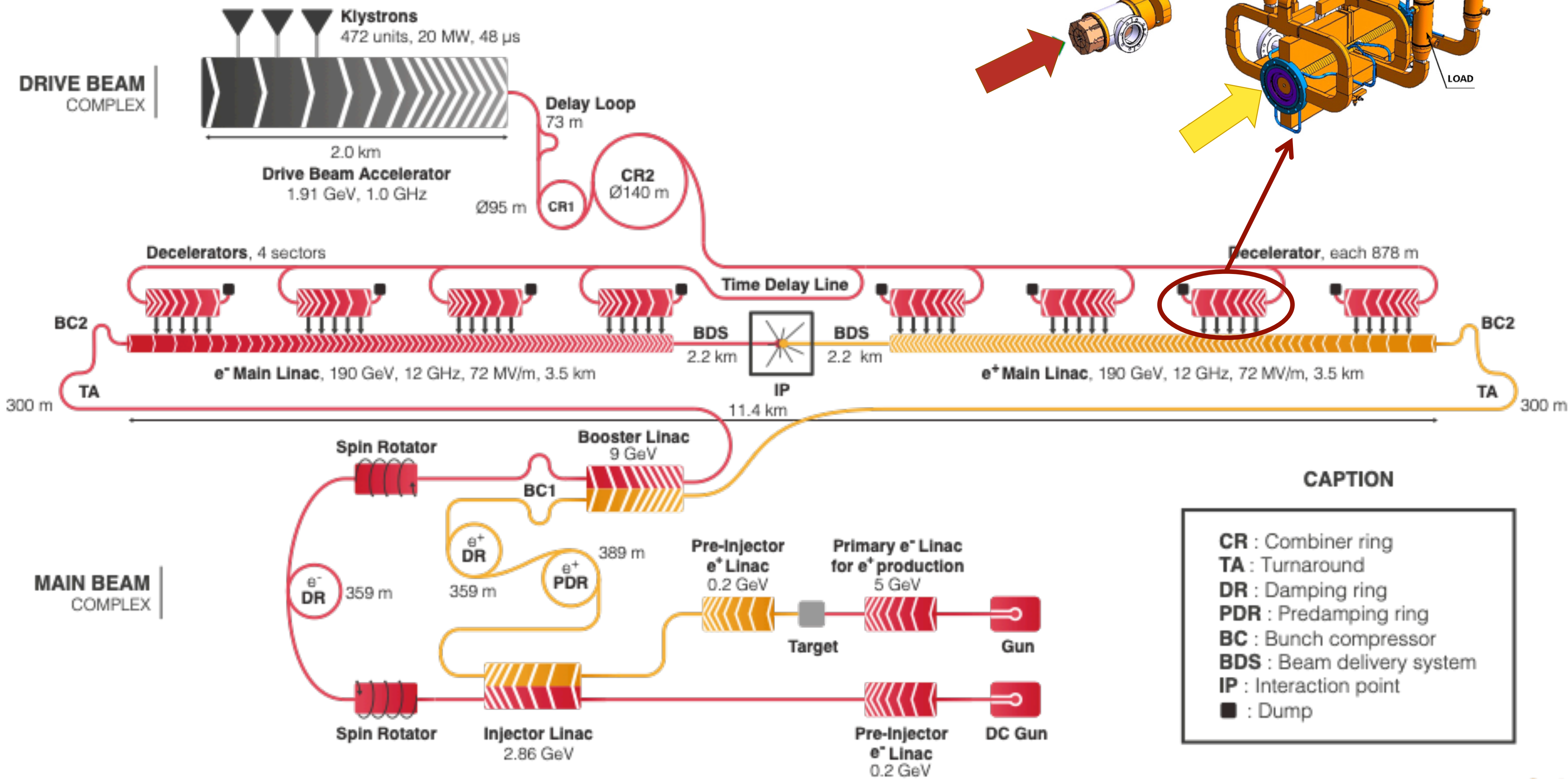
◆ CLIC is now a mature project – technical timeline gives readiness for construction starting ~2026, with first collisions ~2035

CLIC at 380GeV

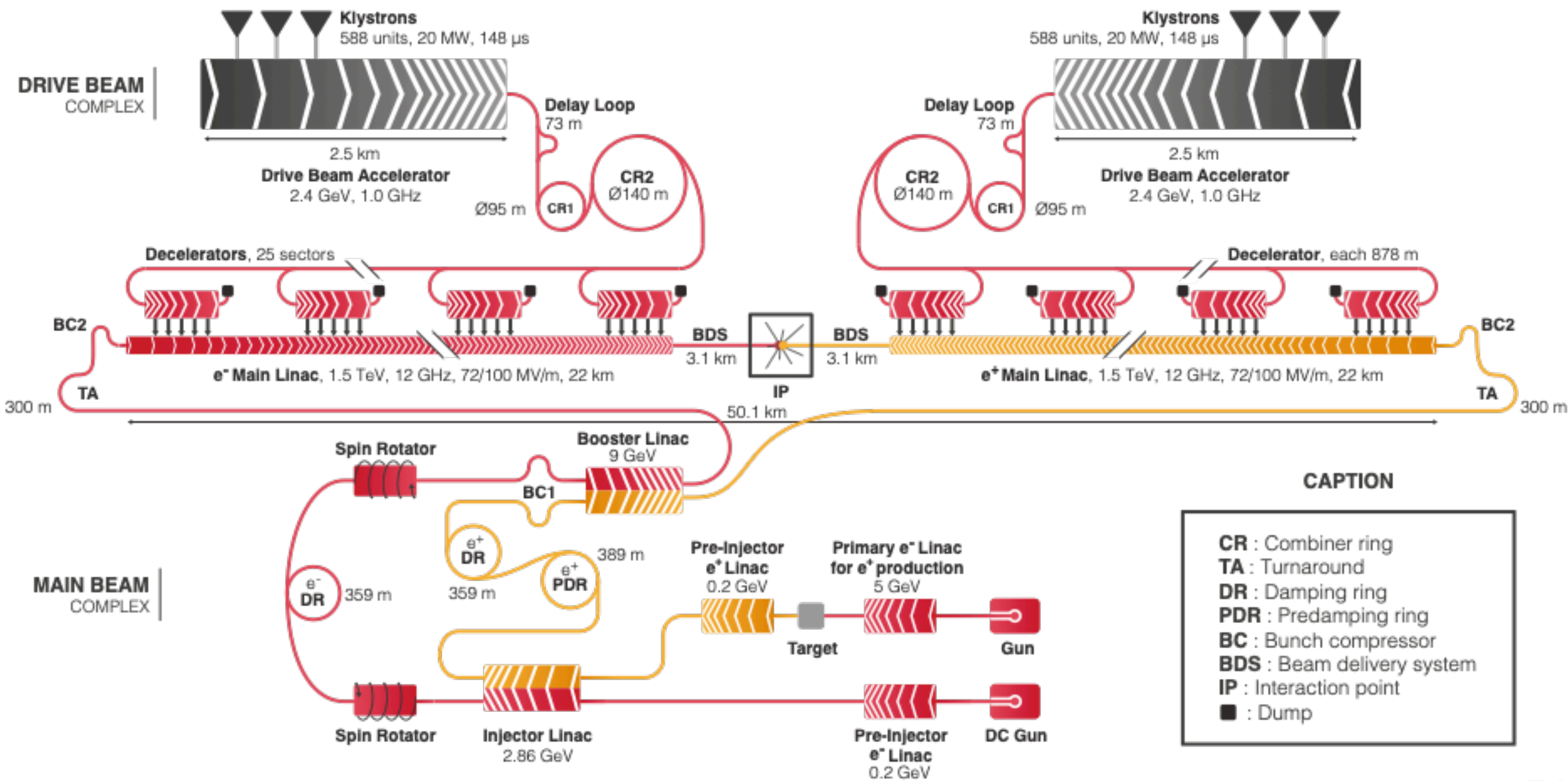
- Two-beam acceleration scheme

Power extraction and transfer





CLIC at 3TeV

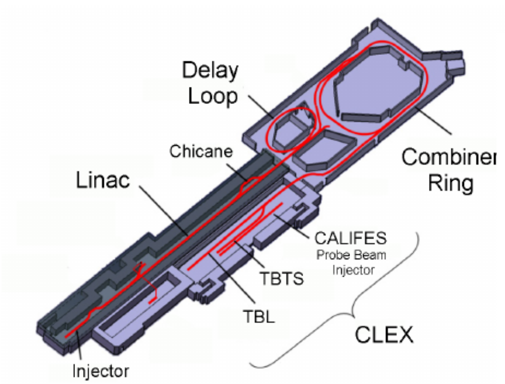


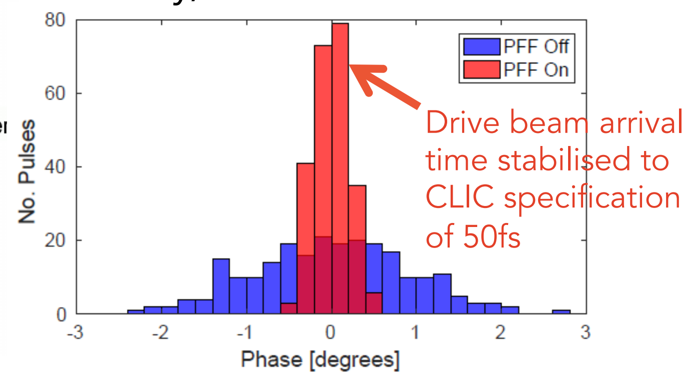
Klystrons
588 units, 20 MW, 148 μs
DRIVE BEAM
COMPLEX
2.5 km
Drive Beam Accelerator
2.4 GeV, 1.0 GHz
Delay Loop
73 m
CR1
Ø95 m
CR2
Ø140 m
Decelerators, 25 sectors
Decelerator, each 878 m
BC2
TA
300 m
e⁻ Main Linac, 1.5 TeV, 12 GHz, 72/100 MV/m, 22 km
e⁺ Main Linac, 1.5 TeV, 12 GHz, 72/100 MV/m, 22 km
BDS
3.1 km
IP
50.1 km
MAIN BEAM
COMPLEX
Spin Rotator
Booster Linac
9 GeV
BC1
e⁺ DR
e⁺ PDR
389 m
359 m
e⁻ DR
Pre-Injector
e⁺ Linac
0.2 GeV
Primary e⁻ Linac
for e⁺ production
5 GeV
Target
Gun
Injector Linac
2.86 GeV
Pre-Injector
e⁻ Linac
0.2 GeV
DC Gun
CAPTION
CR : Combiner ring
TA : Turnaround
DR : Damping ring
PDR : Predamping ring
BC : Bunch compressor
BDS : Beam delivery system
IP : Interaction point
■ : Dump

Accelerator challenges

High-current drive beam bunched at 12 GHz

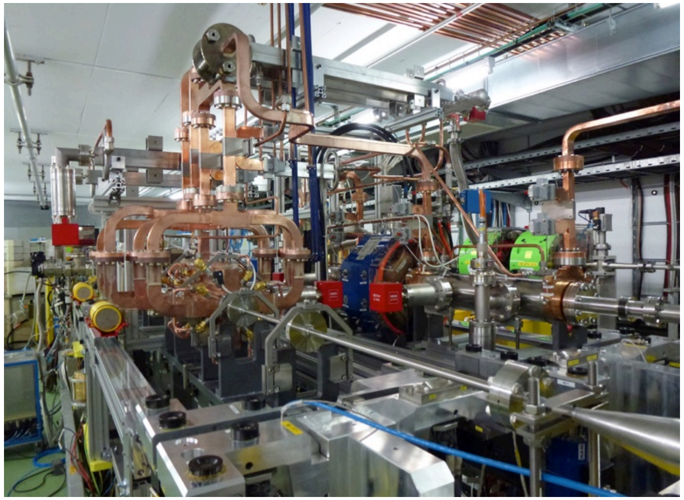
Produced at CLIC Test Facility CTF3, now the 'CERN Linear Electron Accelerator for Research' facility, CLEAR





Power transfer + main-beam acceleration

Demonstrated 2-beam acceleration



~100 MV/m gradient in main-beam cavities

Achieved in structures produced by different sources

Alignment & stability

The CLIC strategy:

- Alignment; vibration damping; good beam measurement and feedback
- Tests in small accelerators of equipment and algorithms (FACET at Stanford, ATF2 at KEK, CTF3, Light-sources)

–> Key accelerator technologies have been demonstrated

For more on accelerator, see talk from Steinar Stapnes at June joint Snowmass AF/EF session: https://indico.fnal.gov/event/43871/

CLIC status after European Strategy

- European Strategy for Particle Physics was updated in June after a several-year process:
– prioritises an electron–positron Higgs factory as the next collider
– articulates the ambition to operate a proton–proton collider at the highest achievable energy
– mandates a technical and financial feasibility study for a 100TeV collider
– mandates intensified accelerator R&D, including on high-gradient structures

- Over the next 5 years CERN will continue the investment in R&D for key technologies related to CLIC

–> CLIC is maintained so that if in 2026 the feasibility study is not conclusive for FCC then CLIC could be implemented in an expeditious way.

- CLIC is the least-expensive Higgs factory proposed for construction in Europe, and leads to unique physics potential at high energy running

CLIC status after European Strategy

ECFA

European Committee for Future Accelerators

ECFA Newsletter 5 (August 2020)

Initial views on the European Strategy implementation

by Fabiola Gianotti (CERN Director-General)

The 2020 update of the European Strategy for Particle Physics (ESPP) provides a realistic and prudent approach to setting ambitious and visionary scientific objectives. It lays the foundations for a bright future for particle physics in Europe, within the global context of the field.

Implementation of the ESPP has started at CERN, and a few examples are listed below. The full exploitation of the LHC, including the high-luminosity upgrades, remains CERN's highest priority. Accelerator R&D studies are being reinforced, in particular in the domain of superconducting high-field magnets. The feasibility study for the FCC (Future Circular Collider), which should be completed by the next Strategy update, will focus on the tunnel (high-risk zones, environmental aspects, etc.) and on the main technologies for the e^+e^- and pp colliders. To maintain CLIC as an option for a future collider, as recommended by the ESPP, resources will be allocated to continue work on key accelerator technologies. An effort on muon colliders is starting with the goal of addressing the main challenges (neutrino background, muon source and cooling, accelerator and collider rings, etc.) and of developing the design of a demonstrator by the next ESPP update. Physics Beyond Colliders activities will be strengthened. Work at the Neutrino Platform continues, in support of the European community involved in long-baseline projects in the US and Japan. A Quantum Technology Initiative has been launched at CERN, in collaboration with similar efforts in CERN's Member States and beyond, to develop innovative computing technologies for future projects.

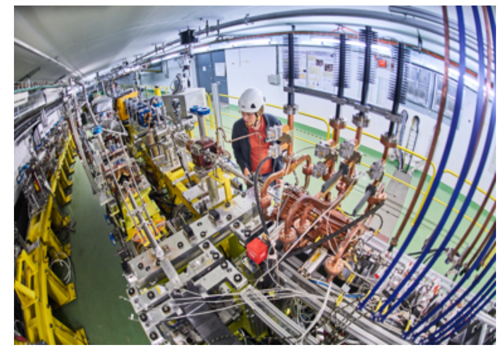
The ESPP is the result of two years of intense and successful efforts by our community to prepare and discuss high-quality scientific and other input. Similarly, its implementation will require the work, dedication and enthusiasm of the full community.

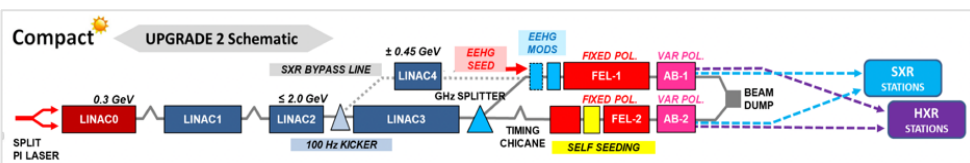
https://cds.cern.ch/record/2729018

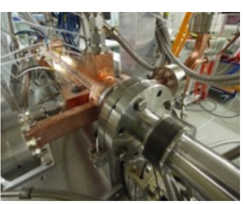
CLIC studies 2021–25

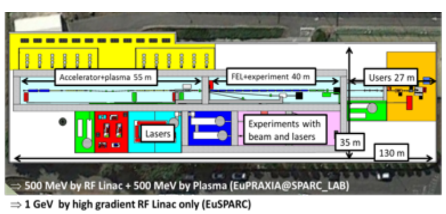
X-band technology:
- Design and manufacturing of X-band structures and components
- Study structures breakdown limits and optimization, operation and conditioning
- Baseline verification and explore new ideas
- Assembly and industry qualification
- Structures for applications, FELs, medical, etc

Technical and experimental studies, design and parameters:
- Module studies (see some targets for development below)
- Beamdynamics and parameters: Nanobeams (focus on beam-delivery), pushing multi TeV region (parameters and beam structure vs energy efficiency)
- Tests in CLEAR (wakefields, instrumentation) and other facilities (e.g. ATF2)
- High efficiency klystrons
- Injector studies suitable for X-band linacs (coll. with Frascati)









Application of X-band technology (examples):
- A compact FEL (CompactLight: EU Design Study 2018-21)
- Compact Medical linacs (proton and electrons)
- Inverse Compton Scattering Source (SmartLight)
- Linearizers and deflectors in FELs (PSI, DESY, more)
- 1 GeV X-band linac at LNF
- eSPS for light dark matter searches (within the PBC-project)

CLIC in the news

- ## FLASH therapy

15 Sept. 2020

https://home.cern/news/news/knowledge-sharing/cern-and-lausanne-university-hospital-collaborate-pioneering-new-cancer

https://physicsworld.com/a/cern-accelerator-technology-to-underpin-flash-radiotherapy-facility/

CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility

CERN and the Lausanne University Hospital (CHUV) are collaborating to develop the conceptual design of an innovative radiotherapy facility, used for cancer treatment

15 SEPTEMBER, 2020

physicsworld | Magazine | Latest

RADIOTHERAPY | RESEARCH UPDATE

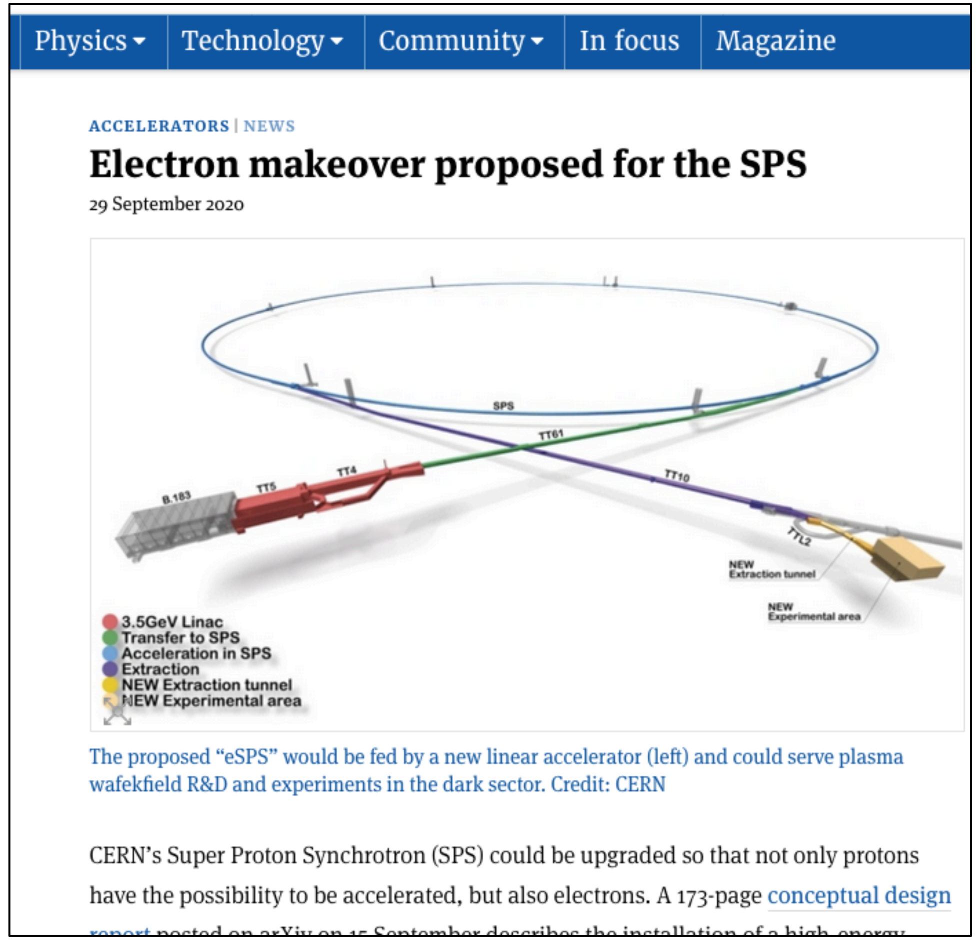
CERN accelerator technology to underpin FLASH radiotherapy facility

17 Sep 2020 Tami Freeman

- ## eSPS proposal

29 Sept. 2020

https://cerncourier.com/a/electron-makeover-proposed-for-the-sps/



Physics | Technology | Community | In focus | Magazine

ACCELERATORS | NEWS

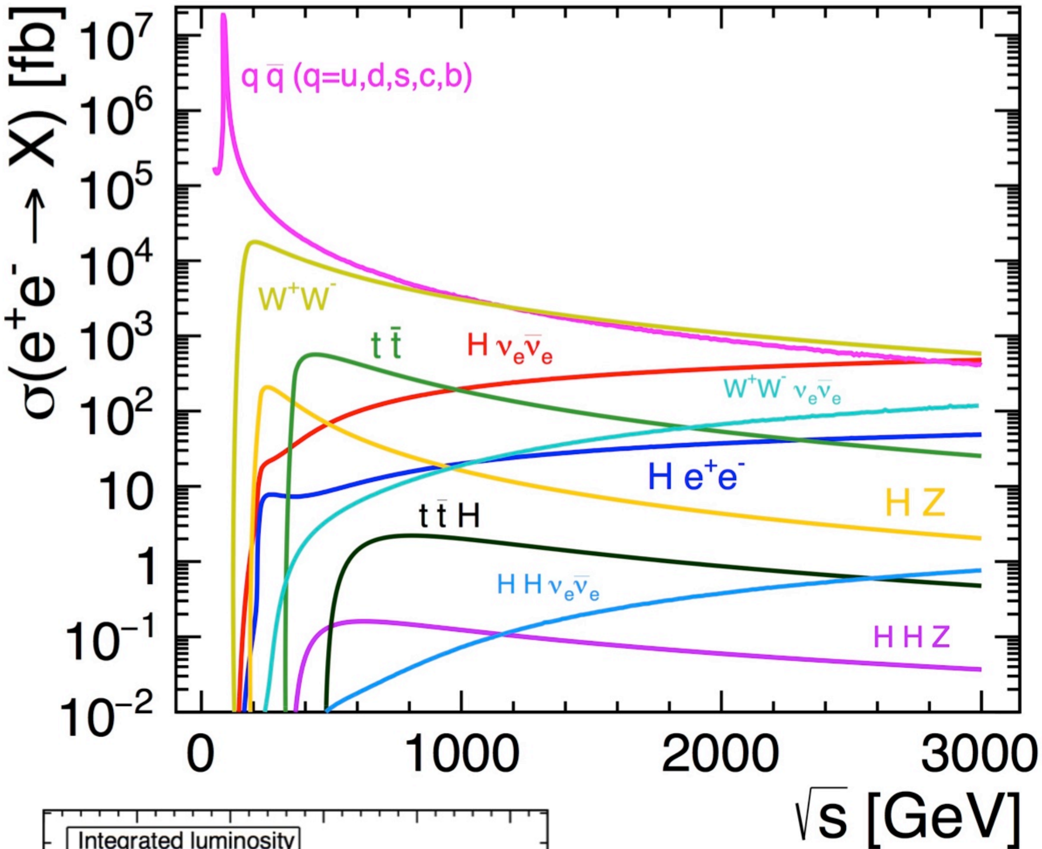
Electron makeover proposed for the SPS

29 September 2020

The proposed "eSPS" would be fed by a new linear accelerator (left) and could serve plasma wakefield R&D and experiments in the dark sector. Credit: CERN

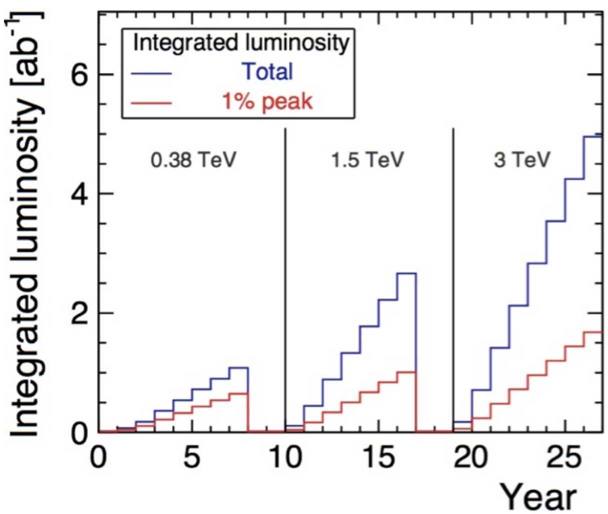
CERN's Super Proton Synchrotron (SPS) could be upgraded so that not only protons have the possibility to be accelerated, but also electrons. A 173-page conceptual design

Physics processes and staging



- 2-fermion production e.g. $q\bar{q}$
- WW production
- Higgsstrahlung (HZ):
  – best at 240–380 GeV: "Higgs factory"
- $t\bar{t}$ threshold: 350 GeV
- $t\bar{t}$ continuum: >365 GeV
- Double Higgsstrahlung (HHZ):
  – cross-section maximum ~600 GeV
- Single and double Higgs in WW fusion ($H\nu_e\bar{\nu}_e$ and $HH\nu_e\bar{\nu}_e$):
  – cross-section rises with energy
- Direct searches for new particles:
  highest possible energy

–> Best explored in several energy stages



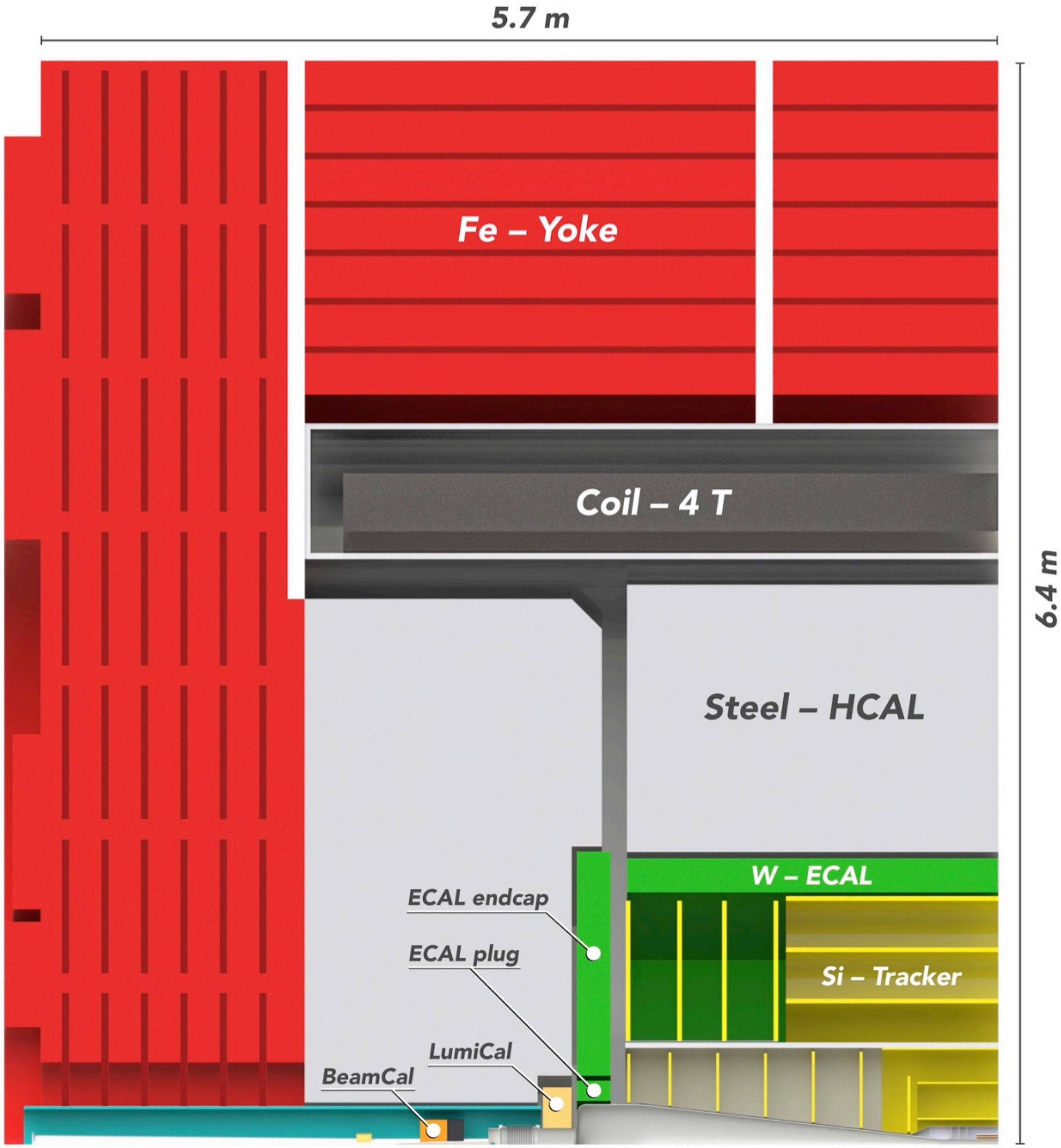
Stage	$\sqrt{s}$ [TeV]	$\mathscr{L}_{int}$ [ab^{-1}]
1	0.38 (and 0.35)	1.0
2	1.5	2.5
3	3.0	5.0

Polarised electron beam (–80%, +80%)

Ratio (50:50) at $\sqrt{s}$=380GeV ; (80:20) at $\sqrt{s}$=1.5 and 3TeV

Baseline staging scenario emphasis is on getting to multi-TeV collisions quickly

CLIC Detector Concept



Essential characteristics:

- B-field: 4T
- Vertex detector with 3 double layers
- Silicon tracking system: 1.5m radius
- ECAL with 40 layers (22 X_0)
- HCAL with 60 layers (7.5 λ)

Precise timing for background suppression (bunch crossings 0.5ns apart)

- ~10ns hit time-stamping in tracking
- 1ns accuracy for calorimeter hits

CLICdp-Note-2017-001
arXiv:1812.07337

+ Dedicated detector R&D programme, particularly on Vertex & Tracking

Vertex and Tracking R&D

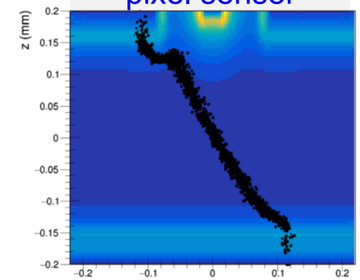
Stringent requirements for CLIC vertex & tracker detectors inspired broad and integrated technology R&D programme

Benefit from rapid progress in Si industry and synergies with HL-LHC

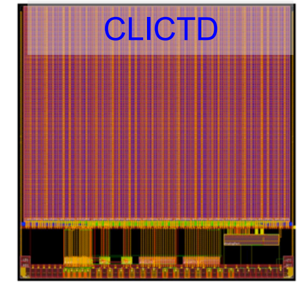
Highlights:

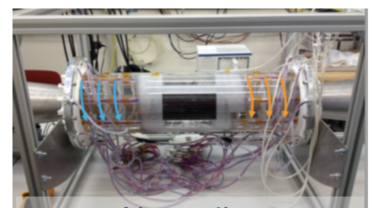
- Full efficiency obtained from hybrid assemblies of 50µm thin sensors that satisfy CLIC time-stamping requirements
- Sensor design with enhanced charge-sharing is underway to reach required spatial resolution with thin sensors
- Good progress towards reducing detector mass with active-edge sensors and through-Si interconnects
- Promising results from fully integrated technologies; CLIC-specific fully integrated designs underway (CLICTD, CLIPS)
- Developed advanced simulation/analysis tools for detector performance optimisation
- Feasibility of power-pulsing demonstrated; power consumption specification met
- Feasibility of air cooling demonstrated in simulation & full vertex detector mockup

Allpix[2] simulation of HV-CMOS pixel sensor



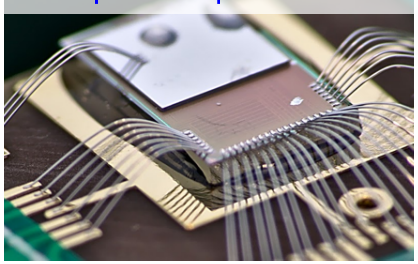
CLICTD



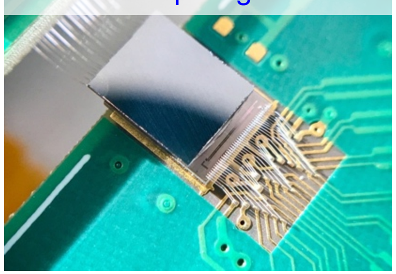


Air cooling

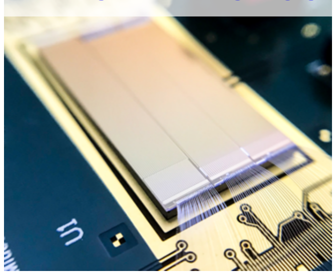
CLICpix + 50 µm sensor



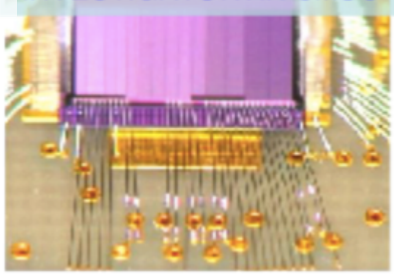
C3PD+CLICpix2 glue ass.



ATLASPIX HV-CMOS



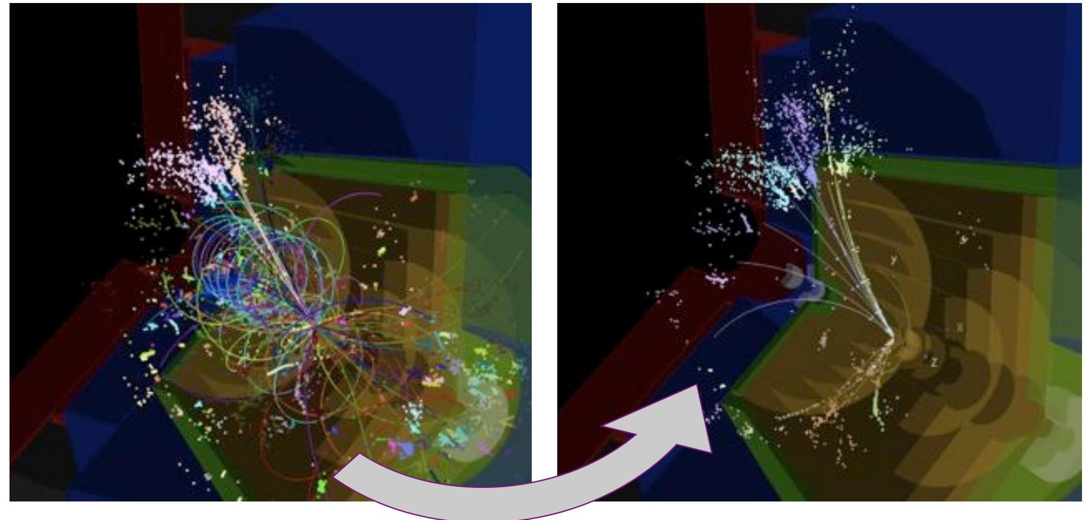
INVESTIGATOR HR-CMOS

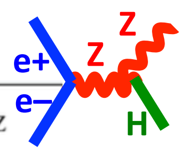


Cracow SOI

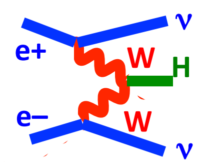
Higgs coupling sensitivity

- Extensive set of full GEANT-based simulation studies including beam backgrounds done for Higgs sector
- Full simulation: imaging calorimetry allows e.g. H->bb/cc/gg separation
- Model-independent coupling extraction
  arXiv:1812.01644
  based on Eur. Phys. J. C 77, 475 (2017)
- Sensitivities used as input for EFT fits


timing/momentum cuts



Channel	Measurement	Observable	Statistical precision 350 GeV $1\,ab^{-1}$
ZH	Recoil mass distribution	m_H	78 MeV
ZH	$\sigma(ZH) \times BR(H \to \text{invisible})$	Γ_{inv}	0.4 %
ZH	$\sigma(ZH) \times BR(Z \to l^+l^-)$	g^2_{HZZ}	2.7 %
ZH	$\sigma(ZH) \times BR(Z \to q\bar{q})$	g^2_{HZZ}	1.3 %
ZH	$\sigma(ZH) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	0.61 %
ZH	$\sigma(ZH) \times BR(H \to c\bar{c})$	$g^2_{HZZ} g^2_{Hcc}/\Gamma_H$	10 %
ZH	$\sigma(ZH) \times BR(H \to gg)$		4.3 %
ZH	$\sigma(ZH) \times BR(H \to \tau^+\tau^-)$	$g^2_{HZZ} g^2_{H\tau\tau}/\Gamma_H$	4.4 %
ZH	$\sigma(ZH) \times BR(H \to WW^*)$	$g^2_{HZZ} g^2_{HWW}/\Gamma_H$	3.6 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	1.3 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	18 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		7.2 %



Many channels studied

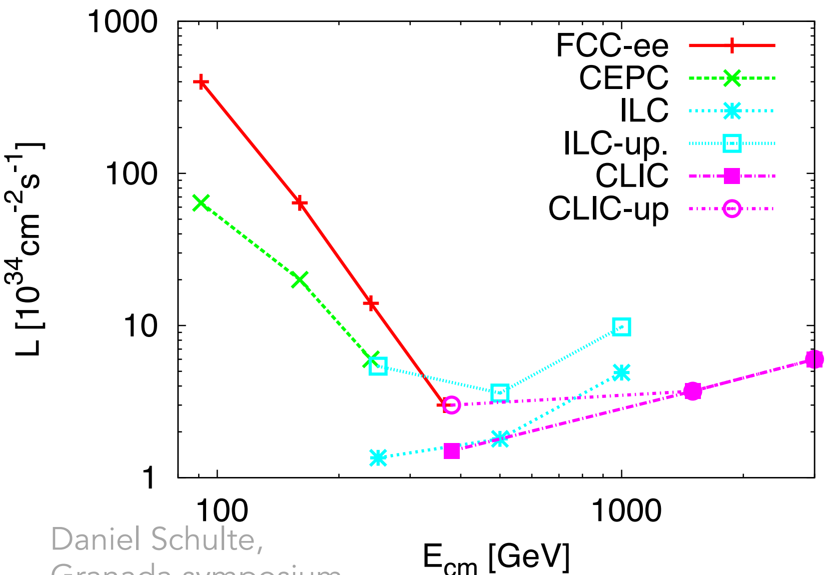
Channel	Measurement	Observable	Statistical precision 1.4 TeV $2.5\,ab^{-1}$	Statistical precision 3 TeV $5.0\,ab^{-1}$
$H\nu_e\bar{\nu}_e$	$H \to b\bar{b}$ mass distribution	m_H	36 MeV	28 MeV
ZH	$\sigma(ZH) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	2.6 %†	4.3 %†
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to b\bar{b})$	$g^2_{HWW} g^2_{Hbb}/\Gamma_H$	0.3 %	0.2 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to c\bar{c})$	$g^2_{HWW} g^2_{Hcc}/\Gamma_H$	4.7 %	4.4 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to gg)$		3.9 %	2.7 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-)$	$g^2_{HWW} g^2_{H\tau\tau}/\Gamma_H$	3.3 %	2.8 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \mu^+\mu^-)$	$g^2_{HWW} g^2_{H\mu\mu}/\Gamma_H$	29 %	16 %
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \gamma\gamma)$		12 %	6 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to Z\gamma)$		33 %	19 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to WW^*)$	g^4_{HWW}/Γ_H	0.8 %	0.4 %*
$H\nu_e\bar{\nu}_e$	$\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to ZZ^*)$	$g^2_{HWW} g^2_{HZZ}/\Gamma_H$	4.3 %	2.5 %*
He^+e^-	$\sigma(He^+e^-) \times BR(H \to b\bar{b})$	$g^2_{HZZ} g^2_{Hbb}/\Gamma_H$	1.4 %	1.5 %*
$t\bar{t}H$	$\sigma(t\bar{t}H) \times BR(H \to b\bar{b})$	$g^2_{Htt} g^2_{Hbb}/\Gamma_H$	5.7 %	–

(These precisions are for unpolarised beams; baseline is on slide 11) † : fast simulation *: extrapolated from 1.4TeV

Alternative run scenario

- To illustrate the flexibility of the run-plan: two modifications with respect to the baseline staging:
- **Doubling bunch train repetition rate at initial stage from 50Hz to 100 Hz**
  –> modest increase in cost (~5%) and power (from 170MW to 220MW)
  CERN-ACC-2019-0051
- **Increasing initial stage from 8 to 13 years**

–> Integrated luminosity at 380GeV increases from 1ab^{-1} to 4ab^{-1}



Daniel Schulte, Granada symposium

	Benchmark	HL-LHC	HL-LHC + CLIC 380 ($4\,ab^{-1}$) (CLIC longer first stage)	HL-LHC + CLIC 380 ($1\,ab^{-1}$) + 1500 ($2.5\,ab^{-1}$) (CLIC baseline)	HL-LHC + FCC-ee 240	HL-LHC + FCC-ee 365
$g_{HZZ}^{eff}[\%]$	SMEFT$_{ND}$	3.6	0.3	0.2	0.5	0.3
$g_{HWW}^{eff}[\%]$	SMEFT$_{ND}$	3.2	0.3	0.2	0.5	0.3
$g_{H\gamma\gamma}^{eff}[\%]$	SMEFT$_{ND}$	3.6	1.3	1.3	1.3	1.2
$g_{HZ\gamma}^{eff}[\%]$	SMEFT$_{ND}$	11.	9.3	4.6	9.8	9.3
$g_{Hgg}^{eff}[\%]$	SMEFT$_{ND}$	2.3	0.9	1.0	1.0	0.8
$g_{Htt}^{eff}[\%]$	SMEFT$_{ND}$	3.5	3.1	2.2	3.1	3.1
$g_{Hcc}^{eff}[\%]$	SMEFT$_{ND}$	–	2.1	1.8	1.4	1.2
$g_{Hbb}^{eff}[\%]$	SMEFT$_{ND}$	5.3	0.6	0.4	0.7	0.6
$g_{H\tau\tau}^{eff}[\%]$	SMEFT$_{ND}$	3.4	1.0	0.9	0.7	0.6
$g_{H\mu\mu}^{eff}[\%]$	SMEFT$_{ND}$	5.5	4.3	4.1	4.	3.8
$\delta g_{1Z}[\times 10^2]$	SMEFT$_{ND}$	0.66	0.027	0.013	0.085	0.036
$\delta \kappa_\gamma[\times 10^2]$	SMEFT$_{ND}$	3.2	0.032	0.044	0.086	0.049
$\lambda_Z[\times 10^2]$	SMEFT$_{ND}$	3.2	0.022	0.005	0.1	0.051

From arXiv: 2001.05278

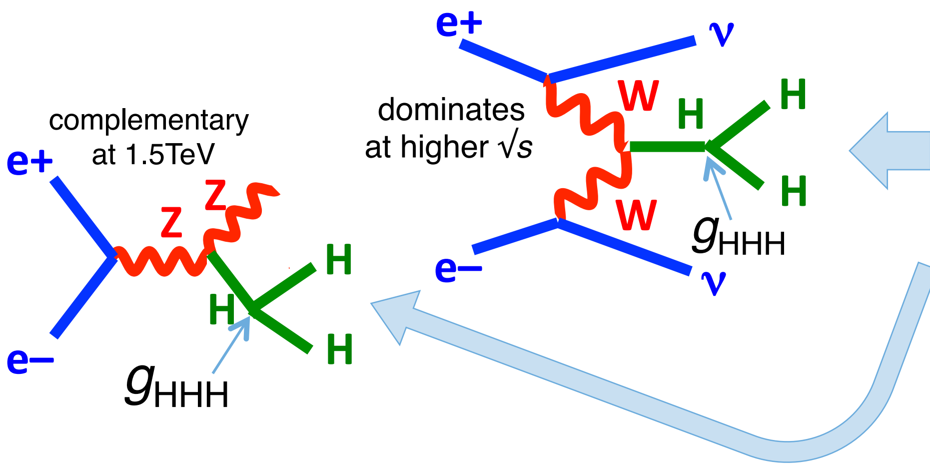
From European Strategy Briefing Book

- Either scenario (longer 1st stage, or baseline 1st+2nd stage) very competitive
- Proposed e+e– colliders give similar Higgs performance at the initial stage "Higgs Factory"

–> look at what is unique to CLIC

Higgs self-coupling, and ZH at 3TeV

◆ High-energy running gives direct access to Higgs self-coupling



	1.4TeV	3TeV
$\sigma(HH\nu_e\bar{\nu}_e)$	>3σ EVIDENCE $\frac{\Delta\sigma}{\sigma}$ = 28%	>5σ OBSERVATION $\frac{\Delta\sigma}{\sigma}$ = 7.3%
σ(ZHH)	3.3σ EVIDENCE	2.4σ EVIDENCE
g_{HHH}/g_{HHH}^{SM}	1.4TeV: –34%, +36% rate-only analysis	1.4 + 3TeV: **–8%, +11%** differential analysis

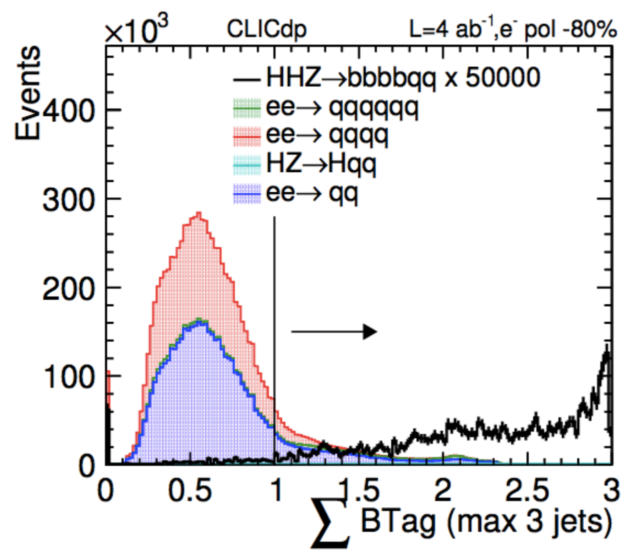
◆ Direct access to two processes that behave differently with non-SM values of self-coupling

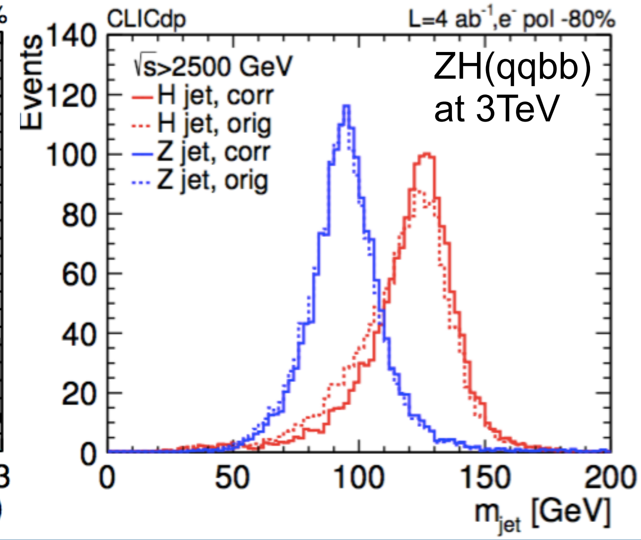
arXiv:1901.05897 updated with new full-sim ZHH study

◆ Recently-completed high-energy studies

ZHH and ZH(qqbb) at 3 TeV to confirm fast simulation / extrapolation
- use of jet substructure
- first use of b-tagging in boosted Higgs decays at CLIC

Also ongoing in full simulation: WW production ; H rare decays H->ZZ at high energy

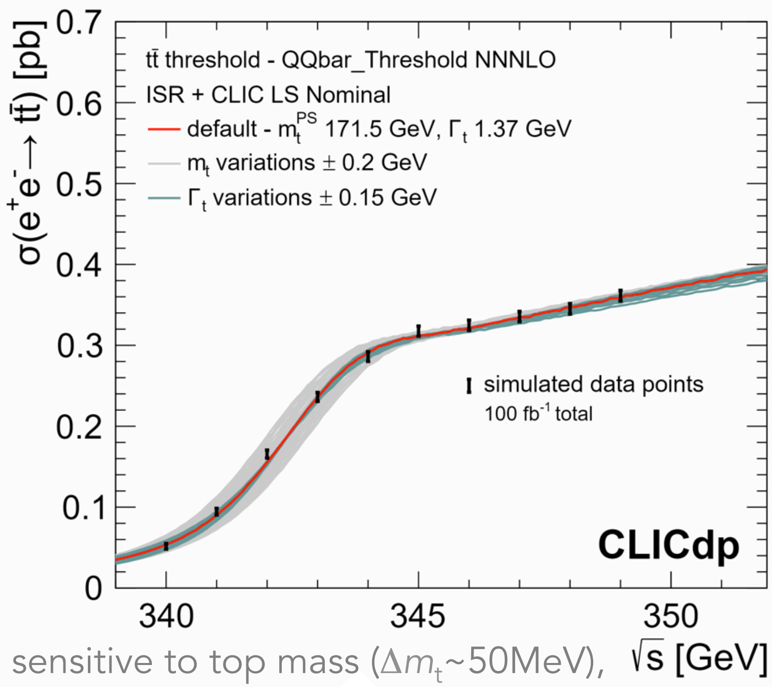




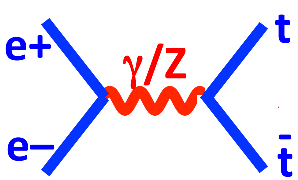
Top-quark physics

- **CLIC is unique among e+e– colliders by accessing top-quark physics from the initial energy stage**

Threshold scan:



sensitive to top mass (Δm_t~50MeV), width, couplings



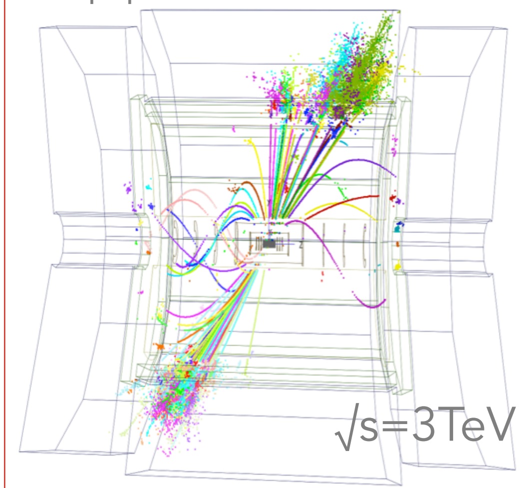
Electron beam polarisation provides new observables

Top-quark physics at CLIC: JHEP11 (2019) 003

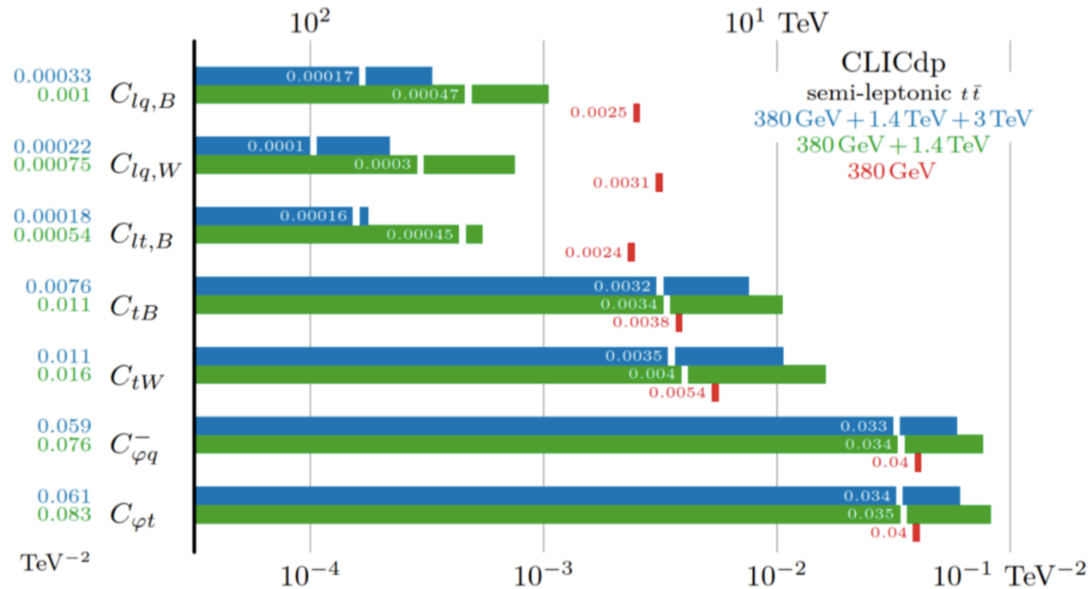
Pair production:

- Top cross-sections, both polarisations ~1%
- Top forward-backward asymmetries ~3–4%
- Statistically optimal observables for top EWK couplings; more than one energy stage allows global fit

First study of boosted top production in e^+e^-

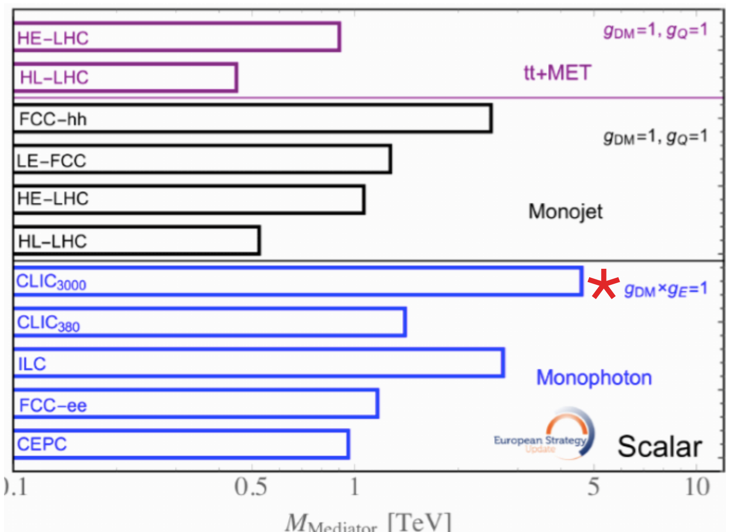


$e^+e^- \to t\bar{t} \to q\bar{q}q\bar{q}b\bar{b}$



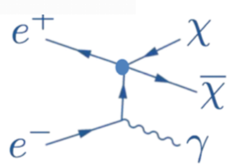
BSM direct searches

◆ Examples of recent search studies for European Strategy:



- **Dark matter:**

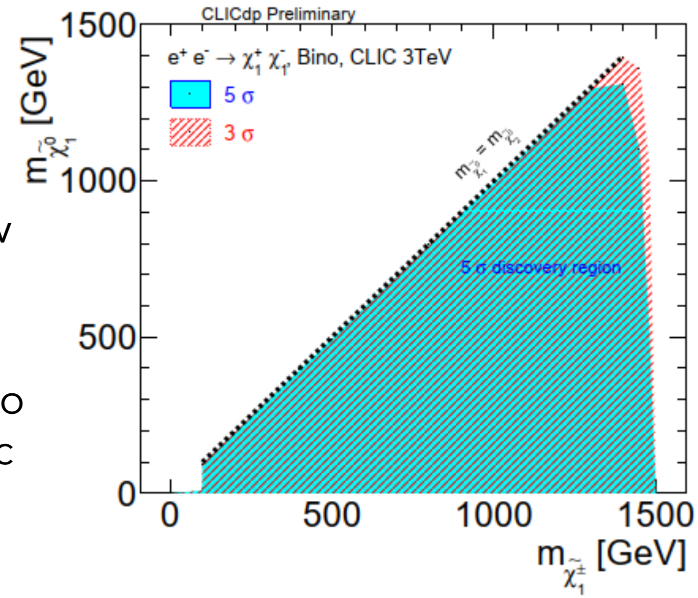
Searching for simplified model dark matter scalar mediator using mono-photon signature –> higher mass reach



- **SUSY signatures:**

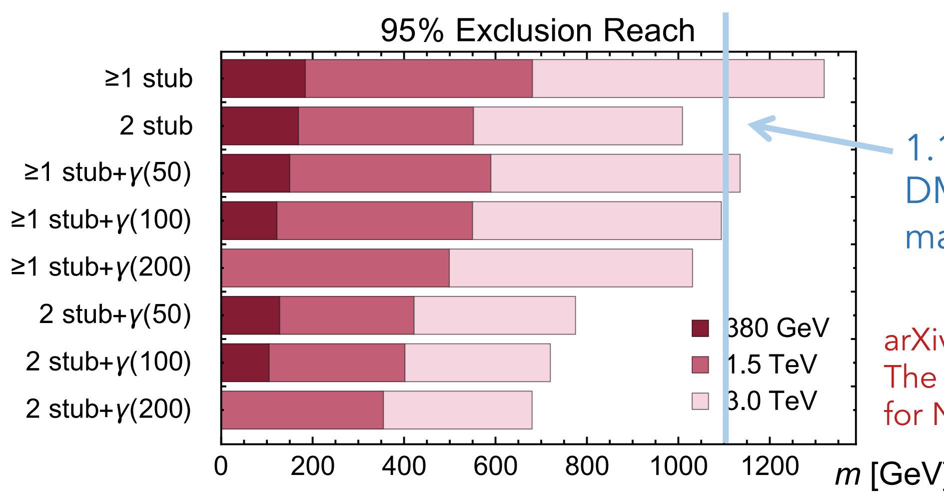
$e^+e^- \to \chi_1^+ \chi_1^-$
with $\chi_1^\pm \to \chi_1^0 W^\pm$
and $W^+W^- \to qqqq$
or $W^+W^- \to e^-\mu^+\nu\nu$
or $e^+\mu^-\nu\nu$

Scan of parameter space in R-parity conserving scenario –> larger kinematic coverage; difficult to access at LHC



- **Higgsino:**

With other superpartners decoupled:
$\chi^\pm$ slightly heavier than χ^0 ; $\chi^\pm \to \pi^\pm\chi^0$
leaving 'disappearing track' signature



1.1TeV for DM relic mass density

arXiv:1812.02093 The CLIC Potential for New Physics

BSM effects through global EFT fits

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i$$

Standard Model

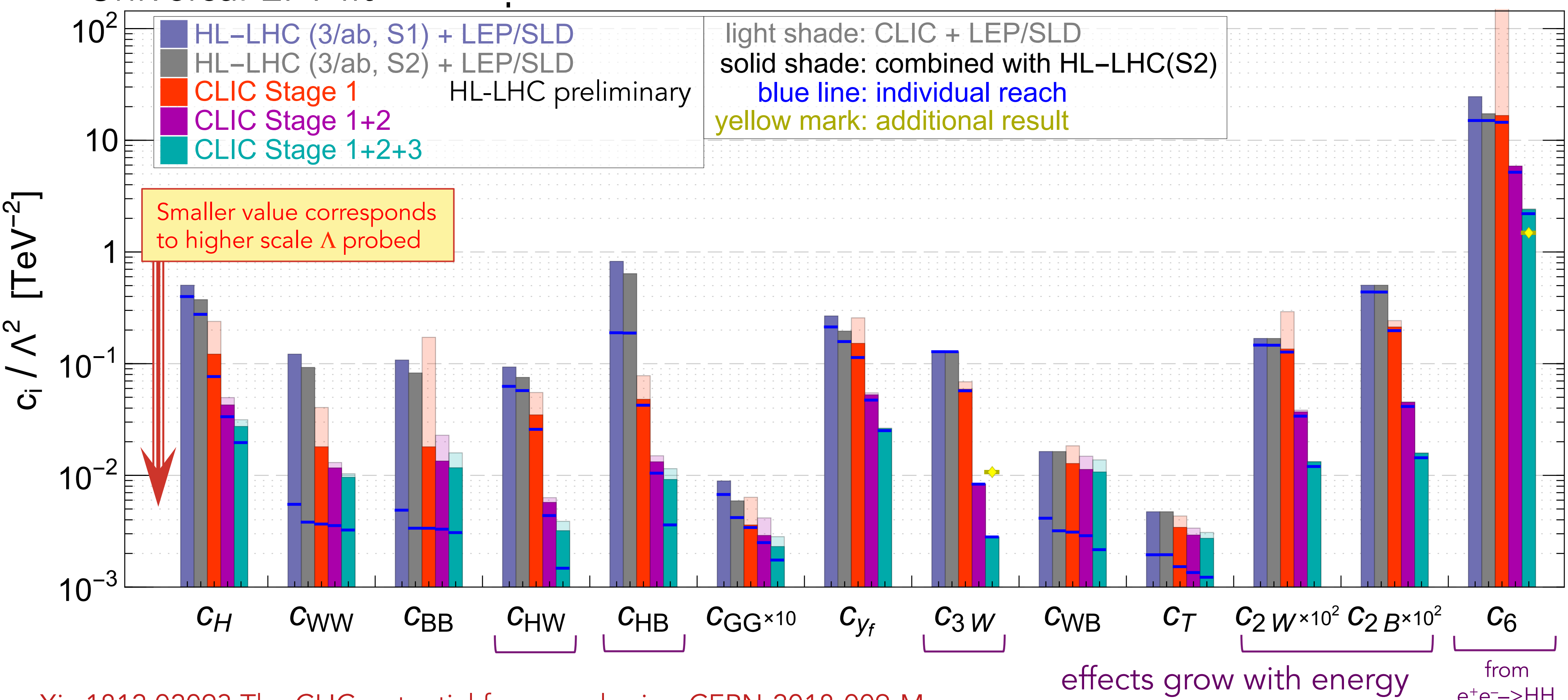
Scale of new decoupled physics

Dimension-6 operators

Includes CLIC measurements of:
- Higgs
- Top
- WW
- $e^+e^- \to f\bar{f}$

Strongly benefits from high-energy running

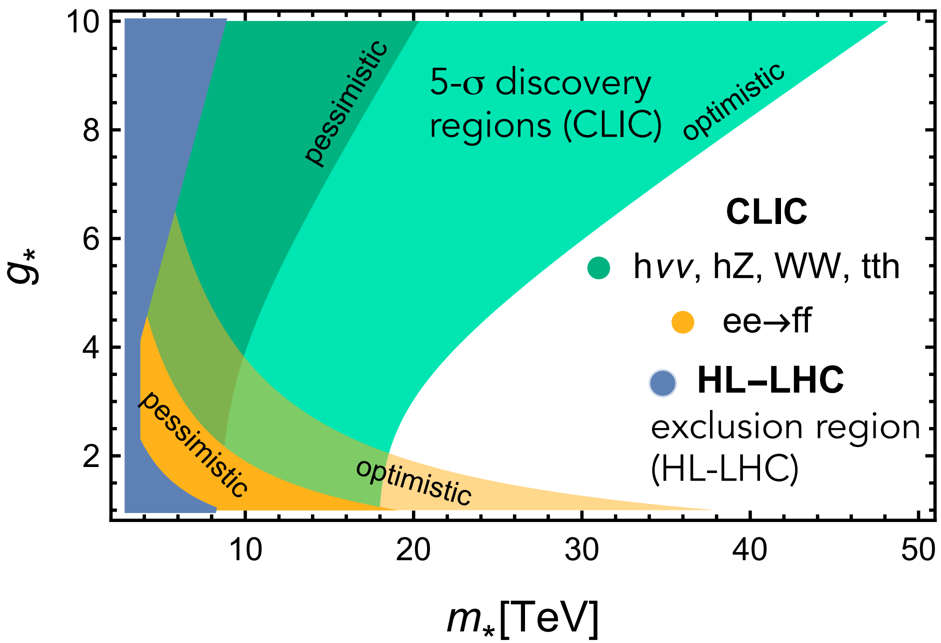
Universal EFT fit



arXiv:1812.02093 The CLIC potential for new physics, CERN-2018-009-M

BSM indirect searches

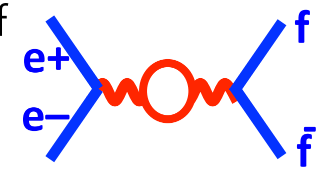
- Composite Higgs (or top) would appear through SM-EFT operators – translate EFT limits into characteristic coupling strength g_* of composite sector and mass m_*



CLIC can ***discover*** compositeness up to ~10TeV compositeness scale (~30 – ~50TeV in favourable conditions) – above what HL-LHC can ***exclude***

- Precision measurements e.g.

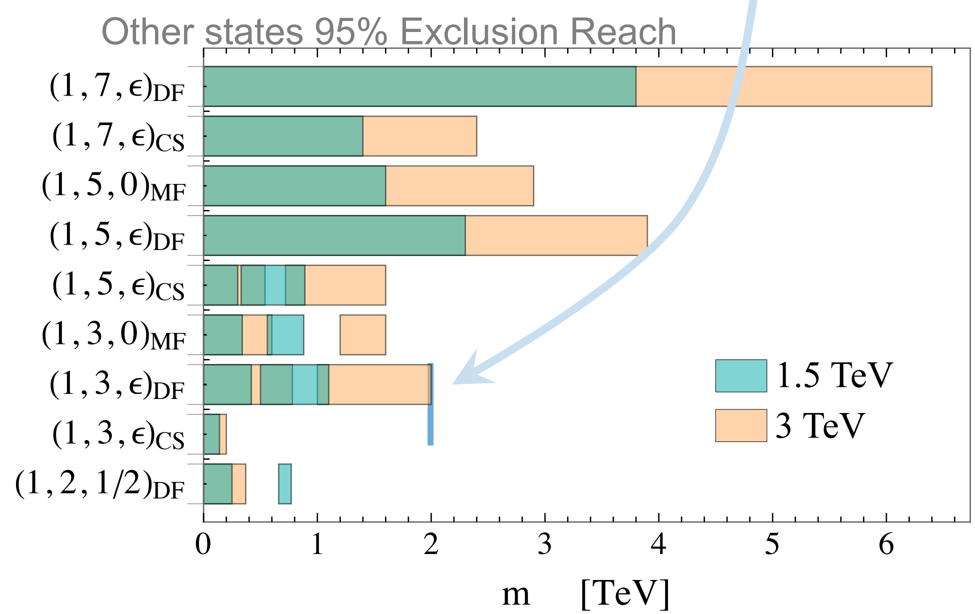
$d\sigma/d(\cos\theta)$ in e^+e^- -> $f\bar{f}$



can be sensitive to new states –> excluded mass ranges

arXiv:1810.10993 - Di Luzio, Gröber, Panico

e.g. for *n*=3 Dirac fermion, *m*=2TeV saturates DM relic mass density: can be excluded by CLIC

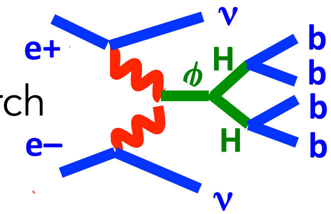


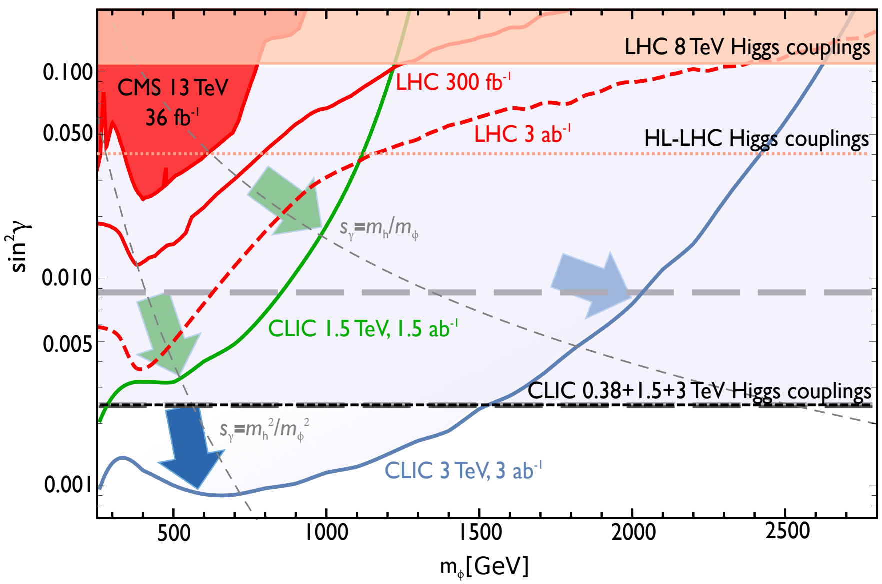
DF=Dirac Fermion, MF=Majorana Fermion, CS=Complex Scalar
SU(3)xSU(2)xU(1) representation; different *n*-tuplet multiplicities

arXiv:1812.02093 The CLIC Potential for New Physics

Interpretations and full programme

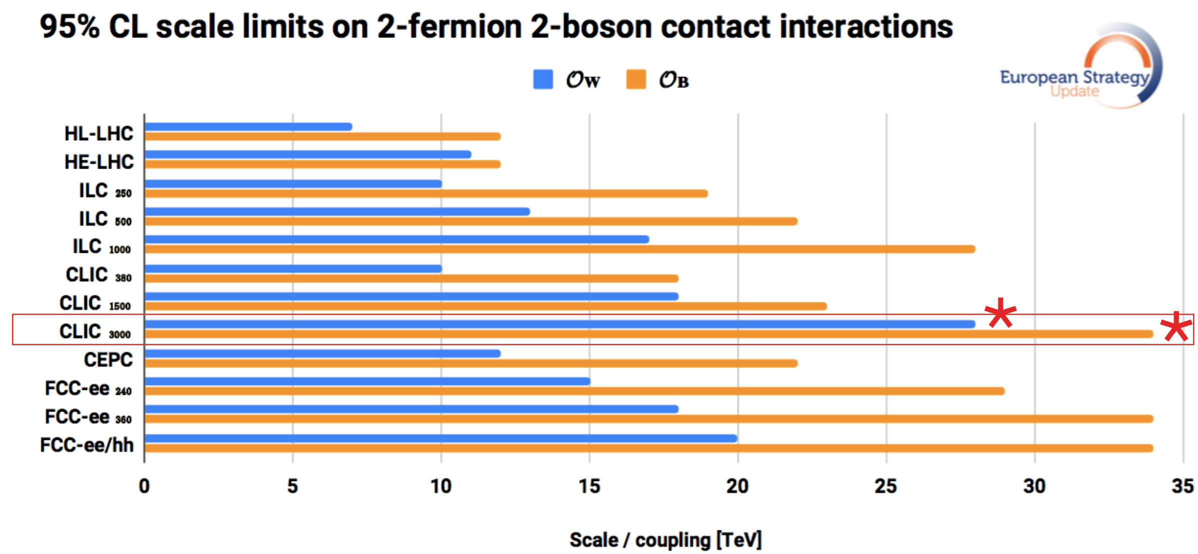
- Higgs + heavy singlet: Complementarity of direct search and indirect constraints





Precision Higgs couplings and self-coupling
Precision electroweak and top-quark analysis
Sensitivity to BSM effects in the SMEFT
Higgs and top compositeness
Baryogenesis
Direct discoveries of new particles
Extra Higgs boson searches
Dark matter searches
Lepton and flavour violation
Neutrino properties
Hidden sector searches
Exotic Higgs boson decays

- Contact interactions interpretations

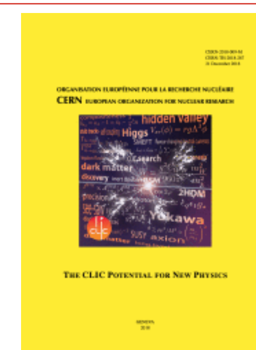


CLIC reaches ~28TeV in O_W, ~34TeV in O_B

Many more studies in CERN Yellow Report:

The CLIC Potential for New Physics (250 pages)

arXiv:1812.02093 CERN-2018-009-M



Ongoing physics studies

- Accelerator R&D continues –> CLIC physics remains very relevant
- Growing interest in high-energy lepton collisions:

  –> CLIC is by far the most advanced TeV-scale lepton collider considered, and the only one where detailed physics studies have been done.

- Particular areas of focus beyond Higgs physics:

  – importance of top-quark physics in e+e–
  – importance of several energy stages in e+e–
  – direct searches, in particular for elusive signatures
  – further and novel ways of constraining NP from precision measurements
  – importance of beam polarisation
  – new BSM scenarios of particular relevance to multi-TeV lepton collisions

–> look at your favourite model at CLIC energies
–> if new benchmark models are defined, e.g. during US Snowmass exercise, then please help obtain sensitivities for them!

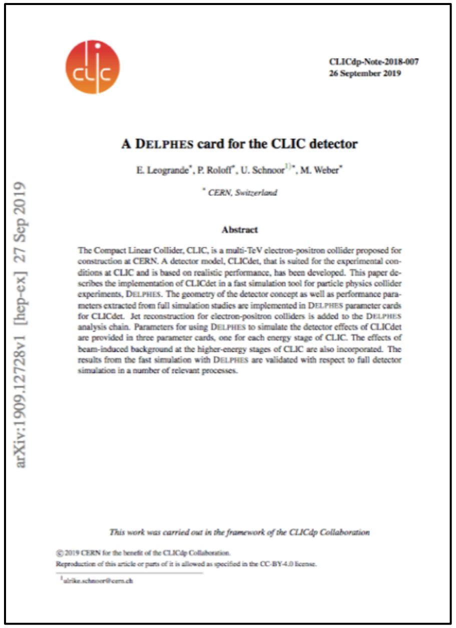
Tools for CLIC sensitivity studies

- A Delphes card for the CLICdet detector model is well-documented and has already been extensively used:

  Whizard settings for CLIC:
  https://gitlab.cern.ch/CLICdp/DetectorSoftware/clic-whizard2-settings

  CLICdet Delphes card description and validation:
  https://arxiv.org/abs/1909.12728

  Further information on the use of the CLICdet Delphes card can be found here:
  https://twiki.cern.ch/twiki/bin/view/CLIC/CLICdetDelphesInstructions


arXiv:1909.12728v1 [hep-ex] 27 Sep 2019

CLICdp-Note-2018-007
26 September 2019

A DELPHES card for the CLIC detector

E. Leogrande*, P. Roloff*, U. Schnoor[1]*, M. Weber*

* CERN, Switzerland

Abstract

The Compact Linear Collider, CLIC, is a multi-TeV electron-positron collider proposed for construction at CERN. A detector model, CLICdet, that is suited for the experimental conditions at CLIC and is based on realistic performance, has been developed. This paper describes the implementation of CLICdet in a fast simulation tool for particle physics collider experiments, DELPHES. The geometry of the detector concept as well as performance parameters extracted from full simulation studies are implemented in DELPHES parameter cards for CLICdet. Jet reconstruction for electron-positron colliders is added to the DELPHES analysis chain. Parameters for using DELPHES to simulate the detector effects of CLICdet are provided in three parameter cards, one for each energy stage of CLIC. The effects of beam-induced background at the higher-energy stages of CLIC are also incorporated. The results from the fast simulation with DELPHES are validated with respect to full detector simulation in a number of relevant processes.

This work was carried out in the framework of the CLICdp Collaboration

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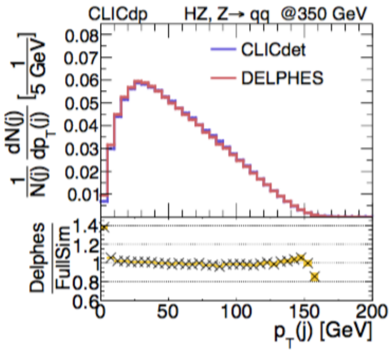
[1] ulrike.schnoor@cern.ch

  - b-tagging working points
  - jet reconstruction choices
  - etc.

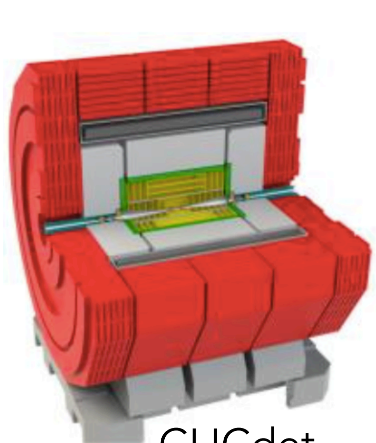


Delphes jet p_T validation in HZ events

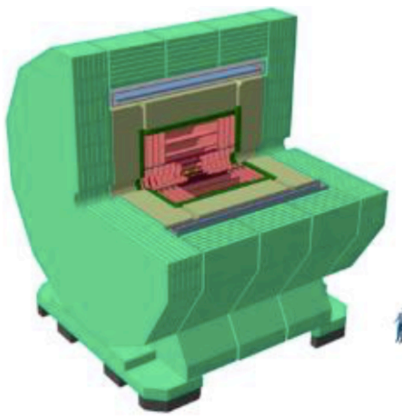
- If you are interested in using the full simulation or have questions on Whizard and Delphes for CLICdet, you are very welcome to contact us:
  clicdp-snowmass-samples-contacts@cern.ch

Exploiting synergies

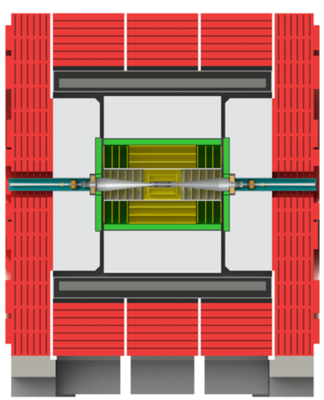
Priority: focusing on project synergies



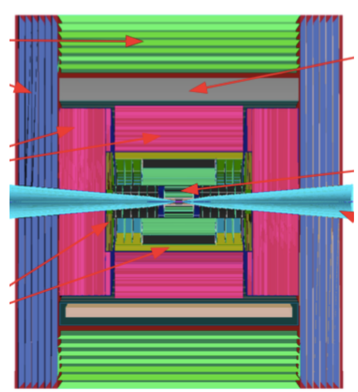
CLICdet



CLICdet adapted for FCC-ee



CLICdet



CLICdet adapted for muon collider

– detector concepts and software tools

Detector	Collider	SW name	SW status	SW future
ILD	ILC	iLCSoft	Full sim/reco	
SiD	ILC	iLCSoft	Full sim/reco	
CLICdet	CLIC	iLCSoft	Full sim/reco	
CLD	FCC-ee	iLCSoft	Full sim/reco	Key4hep
IDEA	FCC-ee	FCC-SW	Fast sim/reco	
IDEA	CEPC	FCC-SW	Fast sim/reco	
CEPCbaseline	CEPC	iLCSoft branch-off	Full sim/reco	

–> all moving to common framework

CLIC perspective

- CLIC is a mature project, ready to provide a Higgs factory and subsequent multi-TeV lepton machine
  - precision measurements
  - sensitivity to elusive signatures
  - extended energy/mass reach
- CERN is continuing investment in CLIC accelerator R&D for the next 5 years
- So far, CLIC has provided the most detailed studies for high-energy lepton collisions, where interest is increasing
- You are strongly encouraged to continue exploring synergies in accelerator technology, detector technologies, and physics studies, among the different collider options and to contribute to CLIC!

Thank you!

Backup

Snowmass21

LoIs submitted:

- on the accelerator:
https://www.snowmass21.org/docs/files/summaries/AF/SNOWMASS21-AF4_AF3-EF0_EF0-177.pdf
- the physics potential:
https://www.snowmass21.org/docs/files/summaries/EF/SNOWMASS21-EF0_EF0_CLICphysics-170.pdf
- and the detector:
https://www.snowmass21.org/docs/files/summaries/IF/SNOWMASS21-IF3_IF6_Mathieu_Benoit-188.pdf

The Compact Linear e^+e^- Collider (CLIC) Snowmass 2021 LoI: Physics Potential

Contact person: A. Robson[1)*]

, R. Franceschini[†‡], L. Linssen[§], P. Roloff[§], U. Schnoor[§], A. Wulzer[§¶], A.F. Żarnecki[‖]

On behalf of the CLIC and CLICdp Collaborations

[*] *University of Glasgow, Glasgow, Scotland,* [†] *Università degli Studi Roma Tre, Rome, Italy,* [‡] *INFN Sezione di Roma Tre, Rome, Italy,* [§] *CERN, Geneva, Switzerland,* [¶] *LPTP, EPFL, Lausanne, Switzerland,* [‖] *University of Warsaw, Warsaw, Poland*

Abstract

By providing e^+e^- collisions over the broad energy range 380 GeV to 3 TeV, the Compact Linear Collider (CLIC) provides excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors. We strongly encourage the full consideration of multi-TeV lepton collisions as part of the Snowmass 2021 process.

Energy Frontier Topical Groups:
- ■ (EF01) EW Physics: Higgs Boson properties and couplings
- ■ (EF02) EW Physics: Higgs Boson as a portal to new physics
- ■ (EF03) EW Physics: Heavy flavor and top quark physics
- ■ (EF04) EW Physics: EW Precision Physics and constraining new physics
- □ (EF05) QCD and strong interactions: Precision QCD
- □ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
- □ (EF07) QCD and strong interactions: Heavy Ions
- ■ (EF08) BSM: Model-specific explorations
- ■ (EF09) BSM: More general explorations
- ■ (EF10) BSM: Dark Matter at colliders

31/8/2020

Detector optimisation and detector technology R&D for the CLIC detector and for the CLD detector of FCC-ee

Snowmass21 Letter of Interest

Mathieu Benoit[1a], Dominik Dannheim[b], Philipp Roloff[b], Andre Sailer[b]
[a] Brookhaven National Laboratory, USA, [b] CERN, Geneva, Switzerland

on behalf of the CLICdp collaboration and of the CLD detector study

Introduction:

The recent update of the European Strategy for Particle Physics allocates its highest priority to a future electron-positron Higgs factory. This conclusion is motivated by a number of physics arguments, such as precision Higgs physics, top-quark physics, electroweak observables and a broad scope for other precision measurements. Four high-energy electron-positron colliders have been proposed for construction. Linear colliders offer the advantage of reaching very high energies, up to 1 TeV for the ILC and up to 3 TeV for CLIC, while circular colliders, FCC-ee and CEPC, offer unprecedented luminosities at the 91 GeV Z-peak. Both linear and circular colliders can operate at energies close to the highest Higgs and top-antitop production cross sections. The ILC and CEPC are proposed for construction in Asia (Japan, China), while CLIC [1] and FCC-ee [2] are proposed for construction in Europe (CERN). In light of the European Strategy, CERN is continuing to invest in the key CLIC accelerator technologies while in parallel carrying out a feasibility study for FCC.

The CLICdp collaboration[2] has developed the CLICdet [3] detector concept and is actively engaged in the corresponding detector technology development. The CLICdet development has strongly benefitted from an integrated effort on detector optimisation studies, full simulation software development and relevant hardware R&D. In recent years, members of the CLICdp collaboration and the FCC collaboration have adapted the CLIC detector concept for operation at FCC-ee. The resulting CLD [4] concept was scaled from the CLICdet concept, taking FCC-ee experimental conditions and design constraints into account. The CLD detector was optimised in view of the FCC-ee Higgs and top physics energy stages (250 GeV – 365 GeV) and its performance was validated.

The Compact Linear Collider (CLIC) Snowmass 2021 LoI

A.Robson (University of Glasgow), P.N.Burrows (University of Oxford), D.Schulte and S.Stapnes (CERN)*

Introduction
The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear e^+e^- collider under development by the CLIC accelerator collaboration [1]. The CLIC accelerator has been optimised for three energy stages at centre-of-mass energies 380 GeV, 1.5 TeV and 3 TeV [2].

Detailed studies of the physics potential and detector for CLIC, and R&D on detector technologies, are carried out by the CLIC detector and physics (CLICdp) collaboration [1]. CLIC provides excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors.

The CLIC accelerator, detector studies and physics potential are documented in detail at: http://clic.cern/european-strategy.

CLIC layout
A schematic overview of the accelerator configuration for the first energy stage is shown in Figure 1. To reach multi-TeV collision energies in an acceptable site length and at affordable cost, the main linacs use normal conducting X-band accelerating structures; these achieve a high accelerating gradient of 100 MV/m. For the first energy stage, a lower gradient of 72 MV/m is the optimum to achieve the luminosity goal, which requires a larger beam current than at higher energies.

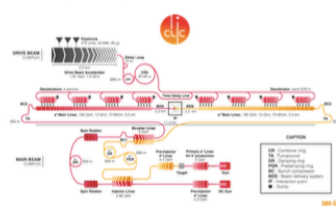


Figure 1. Schematic layout of the CLIC complex at 380 GeV.

intensity pulses that are distributed alongside the main linac, where they release the stored energy in power extraction and transfer structures (PETS) in the form of short RF power pulses, transferred via waveguides into the accelerating structures. This concept strongly reduces the cost and power consumption compared with powering the structures directly by klystrons.

The upgrade to higher energies is done by lengthening the main linacs. While the upgrade to 1.5 TeV can be done by increasing the energy and pulse length of the primary drive-beam, a second drive-beam complex must be added for the upgrade to 3 TeV.

An alternative design for the 380 GeV stage has been studied, in which the main linac accelerating structures are directly powered by klystrons. The further stages will also in this case be drive-beam based.

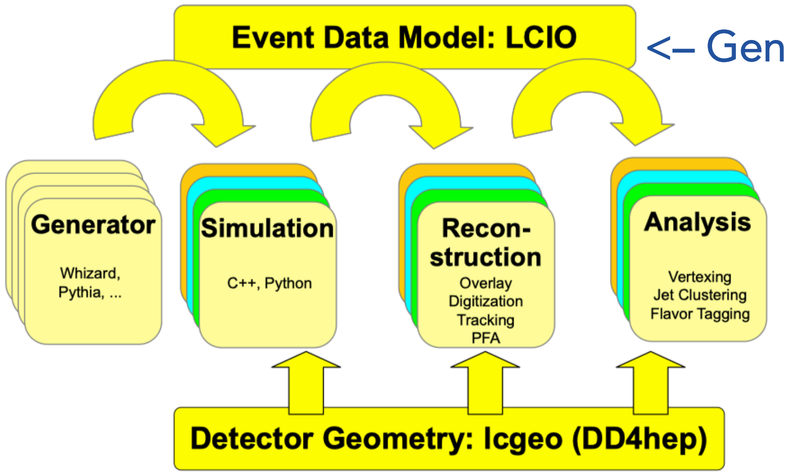
Parameter overview
The parameters for the three energy stages of CLIC are given in Table I. The baseline plan for operating CLIC results in an integrated luminosity per year equivalent to operating at full luminosity for 1.2×10^7 s [3]. Foreseeing 8, 7 and 8 years of running at 380, 1500 and 3000 GeV respectively, and a luminosity ramp up for the first years at each stage, integrated luminosities of 1.0, 2.5 and 5.0 ab^{-1} are reached for the three stages.

CLIC provides ±80% longitudinal electron polarisation and proposes a sharing between the two polarisation states at each energy stage for optimal physics reach [4].

Luminosity margins and performance
In order to achieve high luminosity, CLIC requires very small beam sizes at the collision point, as listed in Table I. Recent studies have explored the margins and possibilities for increasing the luminosity, operation at the Z-pole and gamma-gamma collisions [5].

The vertical emittance and consequently the luminosity are to a large extent determined by imperfections in the accelerator complex. Significant margin has been added to the known effects to enhance the robustness of the design; without imperfections a factor three higher luminosity would be reached at 380 GeV [6]. At this energy also the repetition rate of the facility, and consequently luminosity,

Simulation/Reconstruction



<– Generic SW structure for detector optimisation and physics studies

Now	Future
iLCSoft	Key4hep
Marlin framework	GAUDI framework
LCIO event data model	EDM4hep/PODIO event data model

Detector	Collider	SW name	SW status	SW future
ILD	ILC	iLCSoft	Full sim/reco	
SiD	ILC	iLCSoft	Full sim/reco	
CLICdet	CLIC	iLCSoft	Full sim/reco	
CLD	FCC-ee	iLCSoft	Full sim/reco	Key4hep
IDEA	FCC-ee	FCC-SW	Fast sim/reco	
IDEA	CEPC	FCC-SW	Fast sim/reco	
CEPCbaseline	CEPC	iLCSoft branch-off	Full sim/reco	

Recommendation:

use iLCSoft now

and

join Key4hep development

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