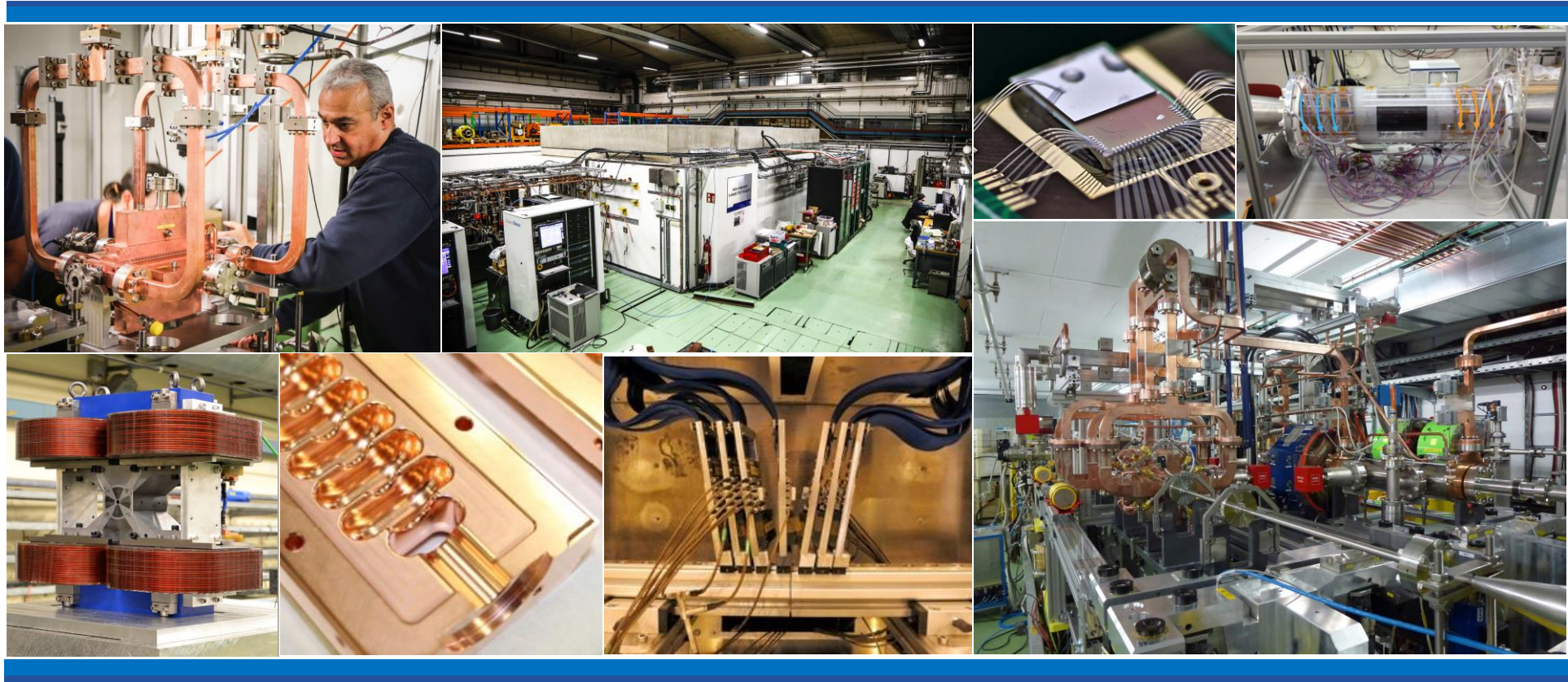


The CLIC project



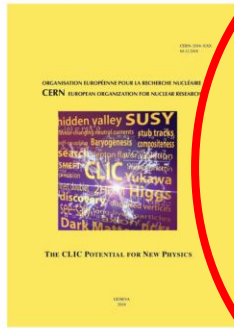
CLICdp collaboration meeting August 2019
Steinar Stapnes on behalf of CLIC



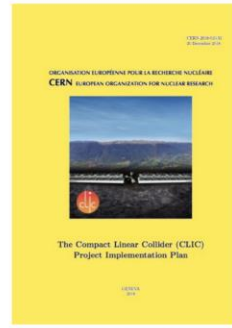
European Strategy Input



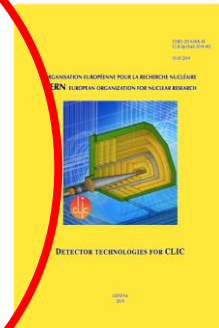
CERN-2018-005-M
<http://dx.doi.org/10.23731/CYRM-2018-002>



CERN-2018-009-M
<http://dx.doi.org/10.23731/CYRM-2018-003>



CERN-2018-010-M
<http://dx.doi.org/10.23731/CYRM-2018-004>



CERN-2019-001
<http://dx.doi.org/10.23731/CYRM-2019-001>

CLIC input to the European Strategy for Particle Physics Update 2018-2020

Formal European Strategy submissions

- **The Compact Linear e+e- Collider (CLIC): Accelerator and Detector** ([arXiv:1812.07987](https://arxiv.org/abs/1812.07987))
- **The Compact Linear e+e- Collider (CLIC): Physics Potential** ([arXiv:1812.07986](https://arxiv.org/abs/1812.07986))

Yellow Reports

- **CLIC 2018 Summary Report** ([CERN-2018-005-M](https://cds.cern.ch/record/2610000), [arXiv:1812.06018](https://arxiv.org/abs/1812.06018))
- **CLIC Project Implementation Plan** ([CERN-2018-010-M](https://cds.cern.ch/record/2610000), [arXiv:1903.08655](https://arxiv.org/abs/1903.08655))
- **The CLIC potential for new physics** ([CERN-2018-009-M](https://cds.cern.ch/record/2610000), [arXiv:1812.02093](https://arxiv.org/abs/1812.02093))
- **Detector technologies for CLIC** ([CERN-2019-001](https://cds.cern.ch/record/2610000), [arXiv:1905.02520](https://arxiv.org/abs/1905.02520))

Journal publications

- **Top-quark physics at the CLIC electron-positron linear collider** [In journal review] ([arXiv:1807.02441](https://arxiv.org/abs/1807.02441))
- **Higgs physics at the CLIC electron-positron linear collider** ([Journal](https://arxiv.org/abs/1608.07538), [arXiv:1608.07538](https://arxiv.org/abs/1608.07538))
 - Projections based on the analyses from this paper scaled to the latest assumptions on integrated luminosities can be found here: [CDS](https://cds.cern.ch/record/2610000), [arXiv](https://arxiv.org/abs/1807.02441).

CLICdp notes

- **Updated CLIC luminosity staging baseline and Higgs coupling prospects** ([CERN Document Server](https://cds.cern.ch/record/2610000), [arXiv:1812.01644](https://arxiv.org/abs/1812.01644))
- **CLICdet: The post-CDR CLIC detector model** ([CERN Document Server](https://cds.cern.ch/record/2610000))
- **A detector for CLIC: main parameters and performance** ([CERN Document Server](https://cds.cern.ch/record/2610000), [arXiv:1812.07337](https://arxiv.org/abs/1812.07337))

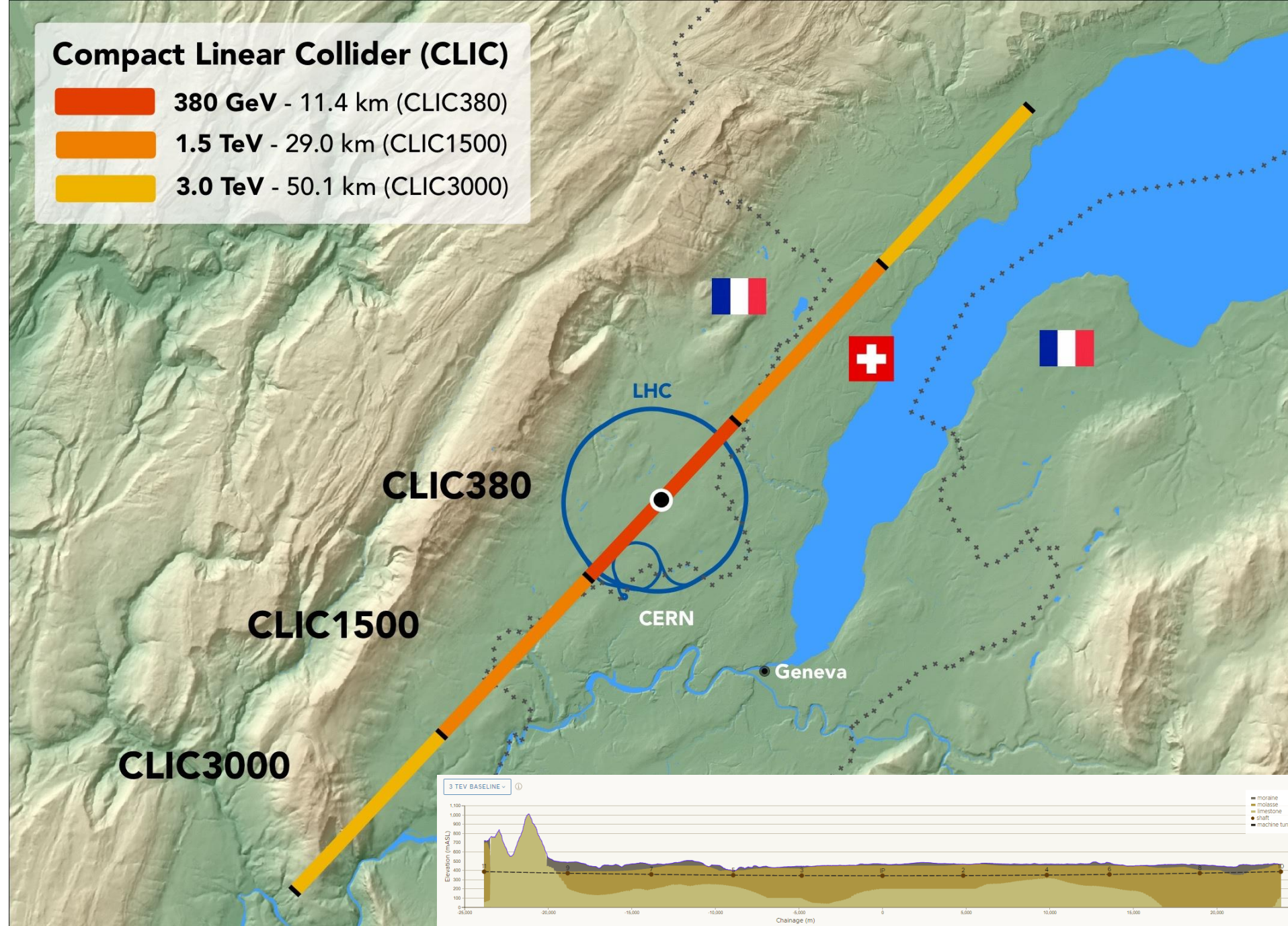


Link: <http://clic.cern/european-strategy>

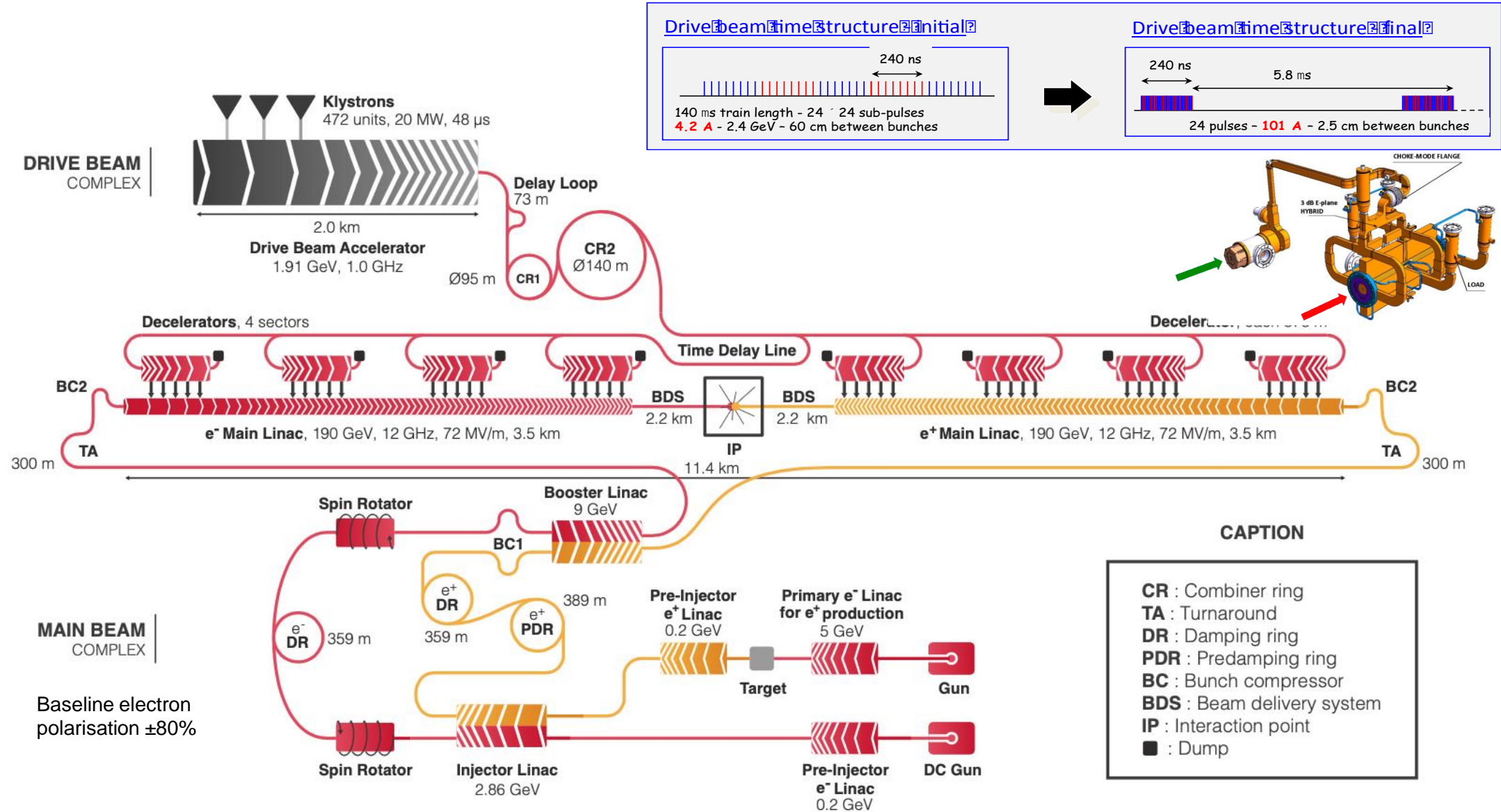


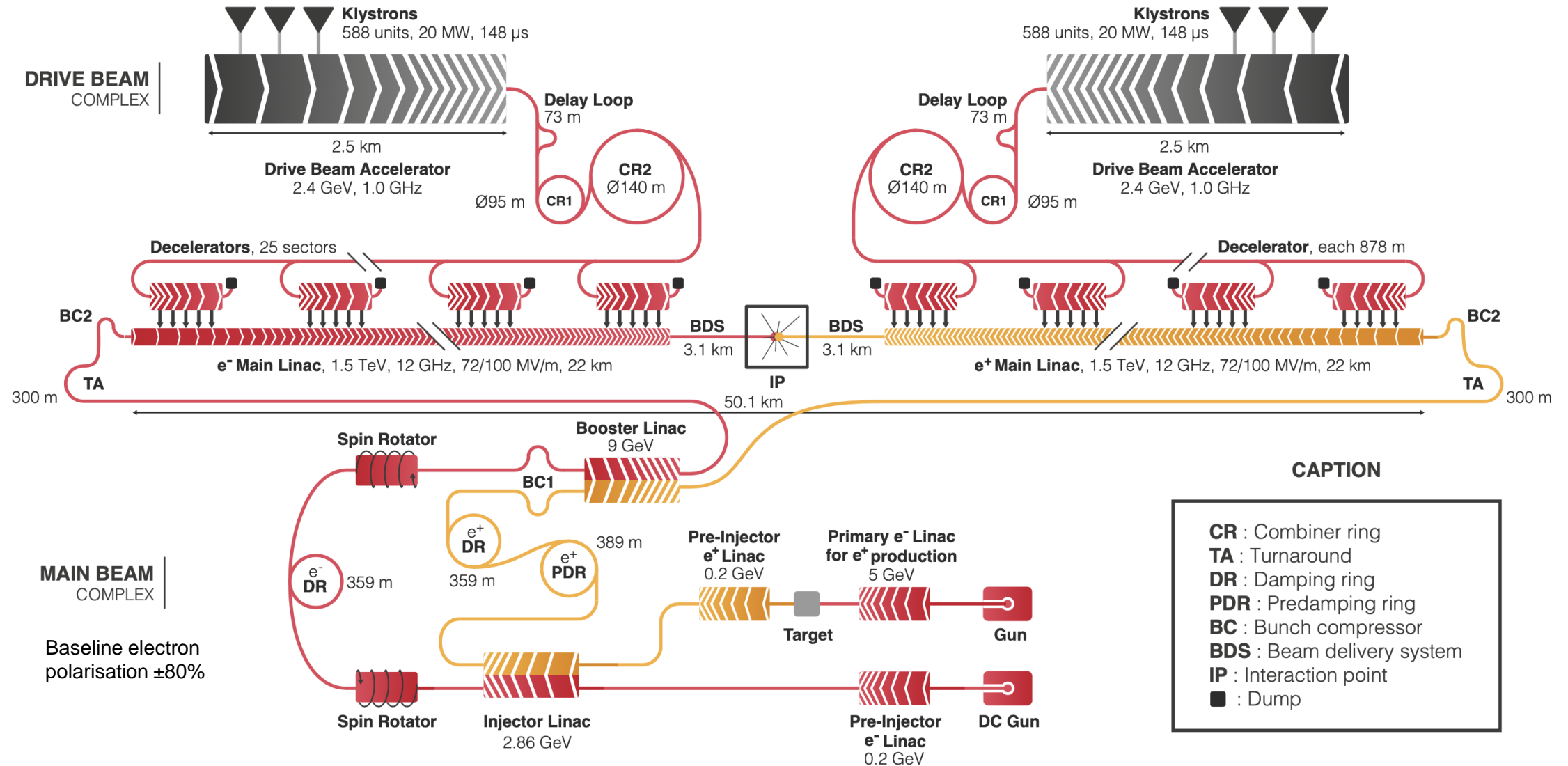
Compact Linear Collider (CLIC)

- 380 GeV - 11.4 km (CLIC380)
- 1.5 TeV - 29.0 km (CLIC1500)
- 3.0 TeV - 50.1 km (CLIC3000)



CLIC 380 GeV layout and power generation

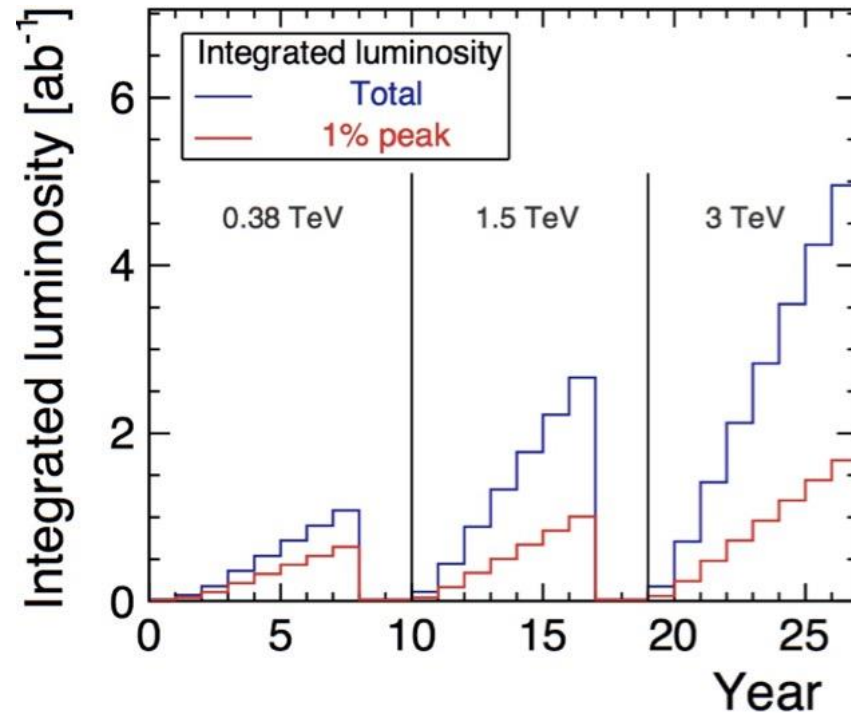




CLIC parameters

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	\sqrt{s}	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	\mathcal{L}	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	1.5	3.7	5.9
Luminosity above 99% of \sqrt{s}	$\mathcal{L}_{0.01}$	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	0.9	1.4	2
Total integrated luminosity per year	\mathcal{L}_{int}	fb^{-1}	180	444	708
Main linac tunnel length		km	11.4	29.0	50.1
Number of particles per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	μm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim 60/1.5$	$\sim 40/1$
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	900/20	660/20	660/20
Final RMS energy spread		%	0.35	0.35	0.35
Crossing angle (at IP)		mrad	16.5	20	20

Luminosity staging baseline



Stage	\sqrt{s} [TeV]	\mathcal{L}_{int} [ab $^{-1}$]	increased from
1	0.38 (and 0.35)	1.0	0.5+0.1ab $^{-1}$
2	1.5	2.5	1.5ab $^{-1}$
3	3.0	5.0	3ab $^{-1}$

Sensitivities updated for new
luminosity staging baseline

Baseline polarisation scenario adopted:
electron beam (−80%, +80%) polarised in ratio
(50:50) at \sqrt{s} =380GeV ; (80:20) at \sqrt{s} =1.5 and 3TeV

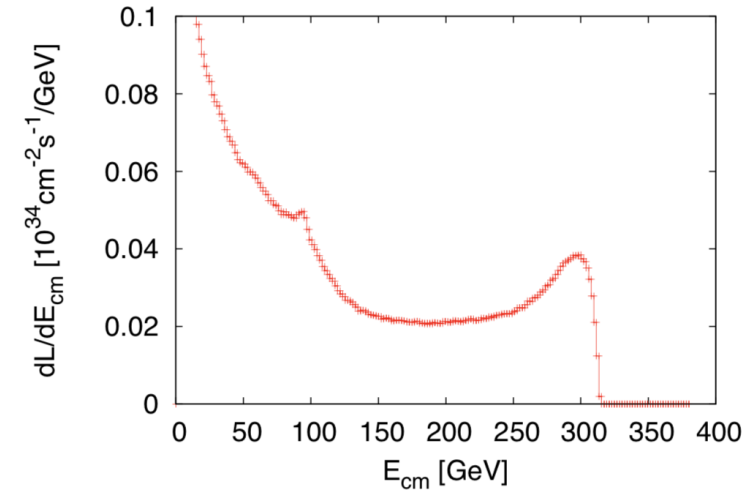
Staging and live-time assumptions following guidelines consistent with other future projects:
Machine Parameters and Projected Luminosity Performance of Proposed Future Colliders at CERN
[arXiv:1810.13022](https://arxiv.org/abs/1810.13022), Bordry et al.

Three questions:

- Z pole performance, $2.3 \times 10^{32} - 0.4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - The latter number when accelerator configured for Z running (either early or end of first stage)
- Gamma – Gamma spectrum (example)
- Luminosity margins and increases
 - Baseline includes estimates static and dynamic degradations from damping ring to IP: $1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, a “perfect” machine will give : $4.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, so significant possibilities for doing better
 - In addition: doubling the frequency (50 Hz to 100 Hz) would double the luminosity, at a cost of +50 MW and ~5% cost increase
- Note at: <http://cds.cern.ch/record/2687090> (in preparation)

Other points:

- Two detectors by push-pull, or doubling BDS (beam delivery system) possible ... the latter is costly (~15%) and the second collision point probably not useful at higher energies
- Overlap CLIC with FCC straight session ?





X-band NCRF technology

Prototype components

Laboratory with commercial

- Accelerating structures
- pulse compressors
- alignment
- stabilization
- etc.

Full commercial supply

- X-band klystrons
- solid state modulators
- etc.

Normal-conducting, low-emittance GeV-range facilities

Operational

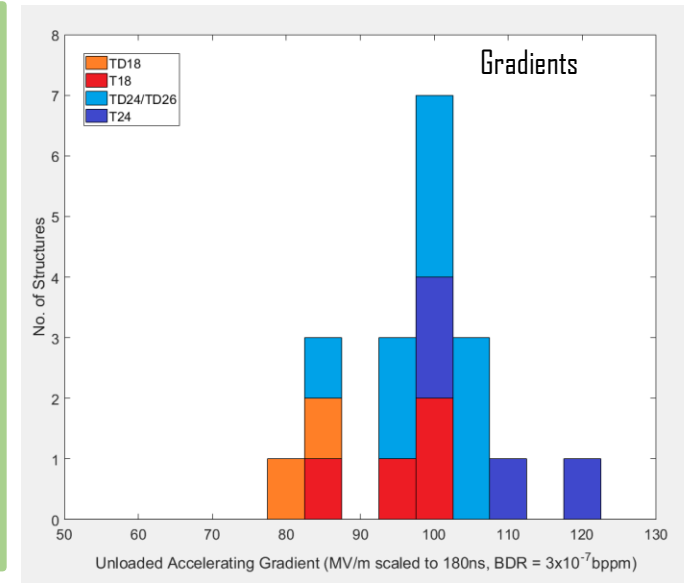
- SACLA
- SwissFEL

Swissfel: Specs similar, and reached



Systems and 100 MeV-range facilities

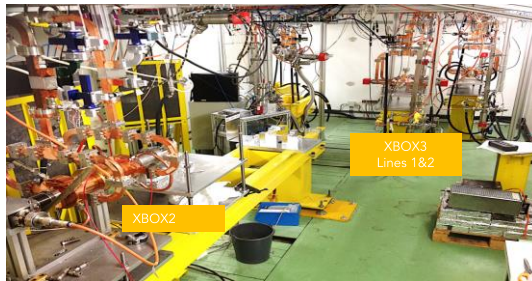
- XBoxes at CERN
- (NEXTEF KEK)
- Test stand at Tsinghua
- Frascati
- NLCTA SLAC
- Linearizers at Electra, PSI, Shanghai and Daresbury
- Deflectors at SLAC, Shanghai, PSI, DESY and Trieste
- NLCTA
- Smart*Light
- FLASH



X-band GeV-range facilities

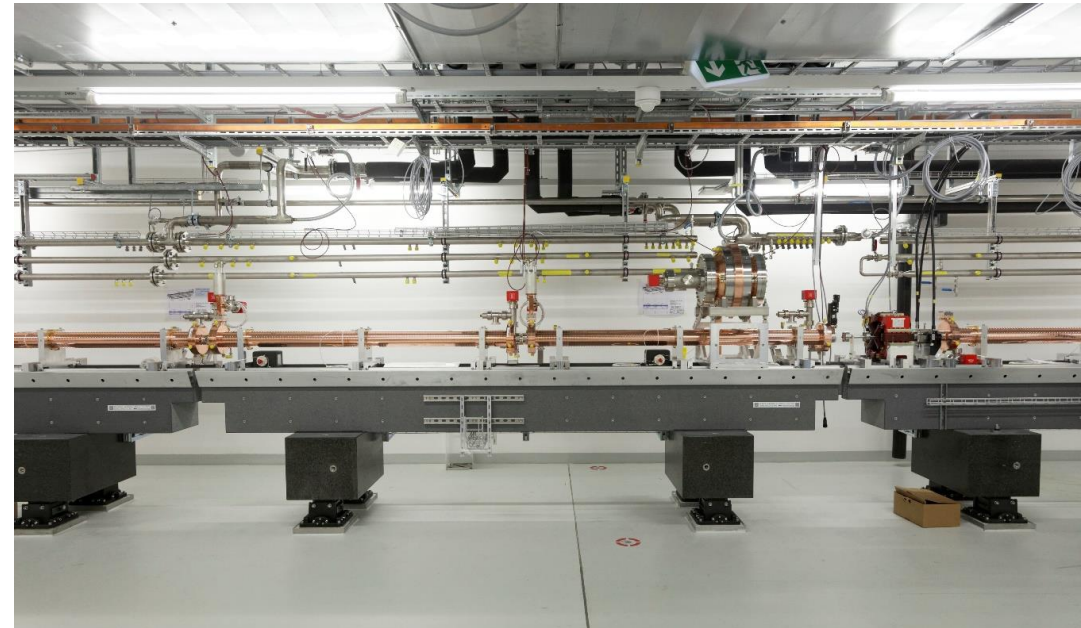
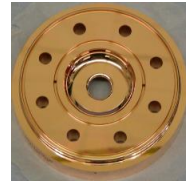
Planning:


- EU-Praxia
- eSPS
- CompactLight
- XARA






- 104 x 2m-long C-band structures (beam \rightarrow 6 GeV @ 100 Hz)
- Similar μm -level tolerances
- Length \sim 800 CLIC structures
- Being commissioned





EuPRAXIA@SPARC_LAB



EuPRAXIA@SPARC_LAB CDR Review Committee Meeting

27-28 November 2018 (HFN Present)

A. Gallor X-Band RF Linac technology

27-28 November 2018 (HFN Present)

A. Gallor X-Band RF Linac technology

27-28 November 2018 (HFN Present)

X-BAND LINAC DESIGN

WP1: particle driven plasma acceleration

WP2: laser driven plasma acceleration

WP3: no plasma acceleration, only RF

Linac	RF	RF2	RF3	Ultimate
E_{max} [MeV]	100	100	100	100
E_{min} [MeV]	450	100	100	100
RF [MHz]	2852.2 (SLED)	2852.2 (SLED)	2852.2 (SLED)	2852.2 (SLED)
E_{max} [MeV]	500	500	500	500

CDR layout

5-Band Gun

100-170 MeV

3.5-Band TW structures (2m)

1 + 1.5 k-band module

2 + 1.5 k-band modules

Design under revision (2 RF modules in both linac #1 and #2). Work is well advanced.

15

RF MODULE LAYOUT

2.2 m

3.2 m

W9-90 total length [mm]

3758

WC-50 circular w/g length [mm]

3674

W9-90 loss [dB]

-0.368

WC-50 loss [dB]

-0.0456

total loss [dB]

-0.414

total loss [%]

9.09

Preliminary layout of the RF module (collaboration with CERN):

8 structures, 1 SLED, 1 or 2 Klystrons per module.

Estimated waveguide attenuation (including circular waveguide): 10%

15

Upgrade proposal: XARA

• X-band Accelerator for Research and Applications

• The 4th CLARA linac is replaced by an X-band accelerating section to reach 1 GeV

• Novel FEL technology

• An EUV/soft x-ray FEL facility for ultra fast chemistry and biology, and a centre of accelerator R&D.

Gun

Linac1

Linac2

Linac3

Laser Heater

X-band Lineariser

Bunch Compressor

Spectrometer

Linac4

Linac5

Linac6

FEBE ~1GeV

~180 MeV

~1GeV

Trans. Def. Cavity

Diagnostics

Beamlines

Beam Dump

Science & Technology Facilities Council

UK Research and Innovation

Final scheme 2020

FLASH2 beamline

FLASHForward beamline

Klystron

SLED

RF switch

Trenches for waveguides

Figure by Rolf Jonas and Manon Foesé

CLIC

Compact

EU funded Design Study for a compact and low-cost XFEL.

Target: SwissFEL performance at half the cost, to bring XFELs to national and regional facilities.

Based on advances in:

• Injectors

• X-band linac technology

• Undulators

23 January 2019

CLIC week

W. Wuensch, CERN

8

Elements in existing linacs (DESY, PSI)

Figure by Rolf Jonas and Manon Foesé

Electrons at CERN, overview

Accelerator implementation at CERN of LDMX type of beam

• X-band based 70m LINAC to ~3.5 GeV in TT4-5

• Fill the SPS in 1-2s (bunches 5ns apart) via TT60

• Accelerate to ~16 GeV in the SPS

• Slow extraction to experiment in 10s as part of the SPS super-cycle

• Experiment(s) considered by bringing beam back on Meyrin site using TT10

Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

Acc. R&D interests (see later): Overlaps with CLIC next phase (klystron based), future ring studies, FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation, positrons and damping ring R&D

International Workshop on Breakdown Science and High Gradient Technology (HG2019)

More about these initiatives (June 2019):

<https://indico.cern.ch/event/766929/timetable/#all>

CLIC

Inverse Compton Scattering Source – Smart*Light

Compact, highly monochromatic X-ray source.

Complementary to X-ray tube and synchrotron light source.

Applications in cultural heritage, material science, medical, etc.

Brilliance

Synchrotron bending magnet (DUBBLE @ DESY)

Inverse Compton Scattering (Smart*Light)

Liquid K_α (Eichl)

rotating anode at K_{α}

Smart*Light project at Eindhoven University of technology

Karsten Strüger

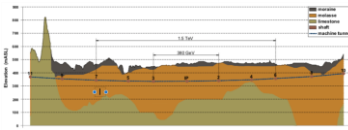
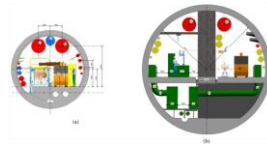
Jim Lütten

Peter Buitkens

Important effort within:

- Civil engineering
- Electrical systems
- Cooling and ventilation
- Transport, logistics and installation
- Safety, access and radiation protection systems

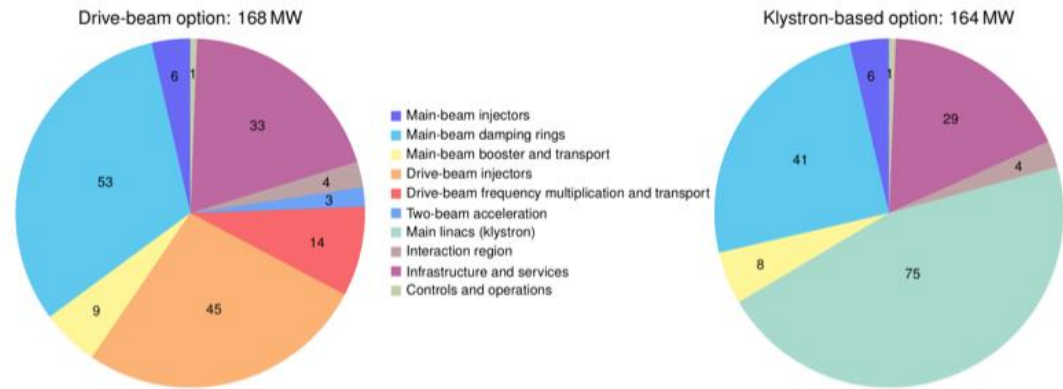
Crucial for cost/power/schedule



August 2019

Seinar Stappes

13



Power estimate bottom up (concentrating on 380 GeV systems)

- Very large reductions since CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimisation, etc

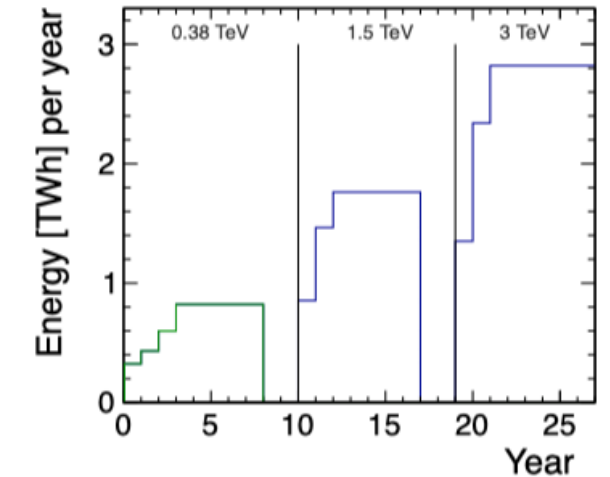
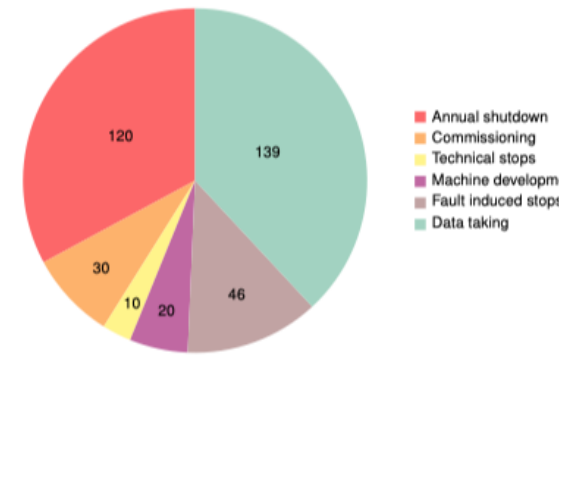
Further savings possible, main target damping ring RF

Will look also more closely at 1.5 and 3 TeV numbers next

Implementing CLIC



Collision Energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	168	25	9
1500	364	38	13
3000	589	46	17

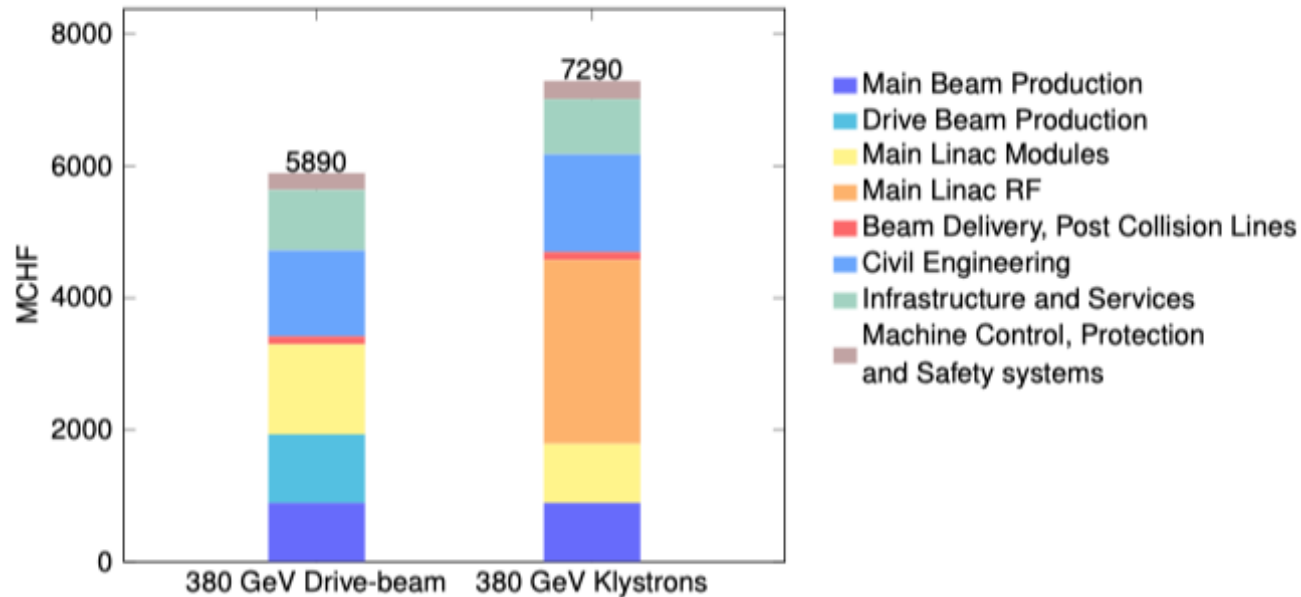


From running model and power estimates at various states – the energy consumption can be estimated

CERN is currently consuming ~1.2 TWh yearly (~90% in accelerators)

Machine has been re-costed bottom-up in 2017-18

- Methods and costings validated at review on 7 November – similar to LHC, ILC, CLIC CDR
- Technical uncertainty and commercial uncertainty estimated



Domain	Sub-Domain	Cost [MCHF]	
		Drive-Beam	Klystron
Main Beam Production	Injectors	175	175
	Damping Rings	309	309
	Beam Transport	409	409
Drive Beam Production	Injectors	584	—
	Frequency Multiplication	379	—
	Beam Transport	76	—
Main Linac Modules	Main Linac Modules	1329	895
	Post decelerators	37	—
Main Linac RF	Main Linac Xband RF	—	2788
Beam Delivery and Post Collision Lines	Beam Delivery Systems	52	52
	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
Civil Engineering	Civil Engineering	1300	1479
Infrastructure and Services	Electrical distribution	243	243
	Survey and Alignment	194	147
	Cooling and ventilation	443	410
	Transport / installation	38	36
Machine Control, Protection and Safety systems	Safety system	72	114
	Machine Control Infrastructure	146	131
	Machine Protection	14	8
	Access Safety & Control System	23	23
Total (rounded)		5890	7290

CLIC 380 GeV Drive-Beam based: 5890^{+1470}_{-1270} MCHF;

CLIC 380 GeV Klystron based: 7290^{+1800}_{-1540} MCHF.

Other cost estimates:

Construction:

- From 380 GeV to 1.5 TeV, add 5.1 BCHF (drive-beam RF upgrade and lengthening of ML)
- From 1.5 TeV to 3 TeV, add 7.3 BCHF (second drive-beam complex and lengthening of ML)
- Labour estimate: ~11500 FTE for the 380 GeV construction

Operation:

- 116 MCHF (see assumptions in box below)
- Energy costs
 - 1% for accelerator hardware parts (e.g. modules).
 - 3% for the RF systems, taking the limited lifetime of these parts into account.
 - 5% for cooling, ventilation and electrical infrastructures etc. (includes contract labour and consumables)

These replacement/operation costs represent 116 MCHF per year.

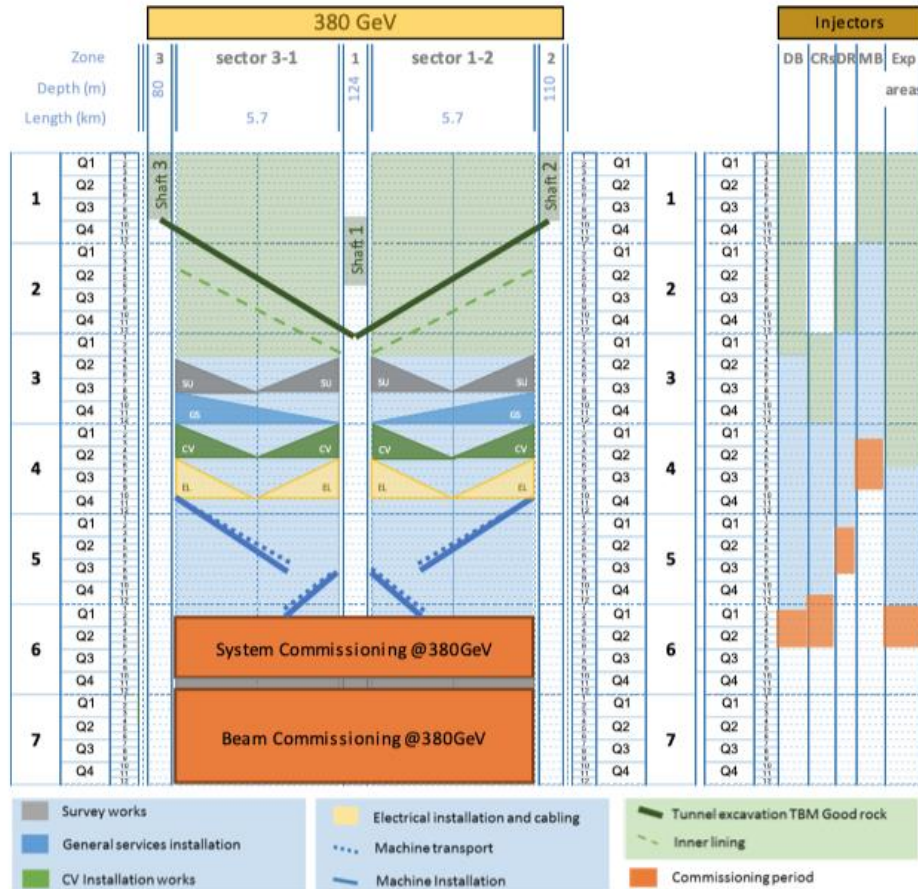


Schedule

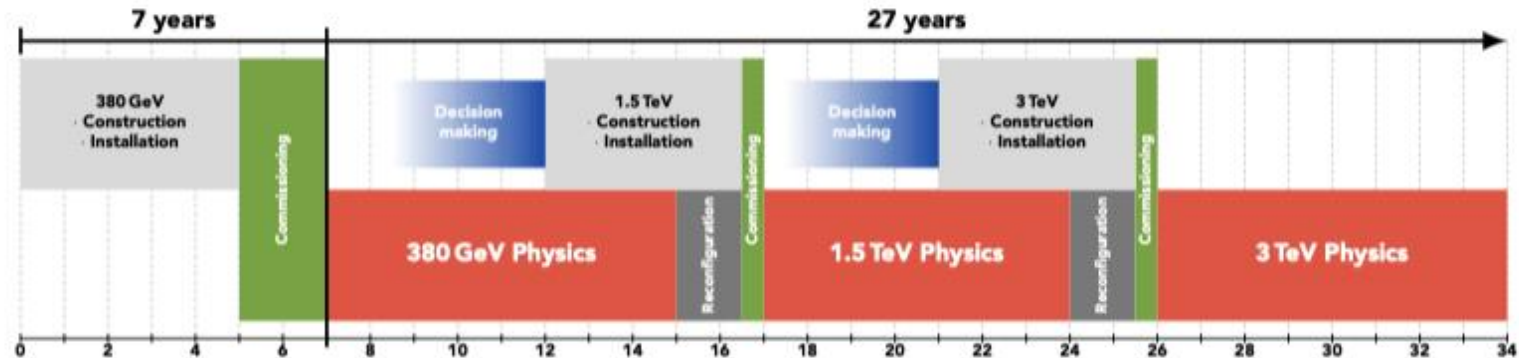
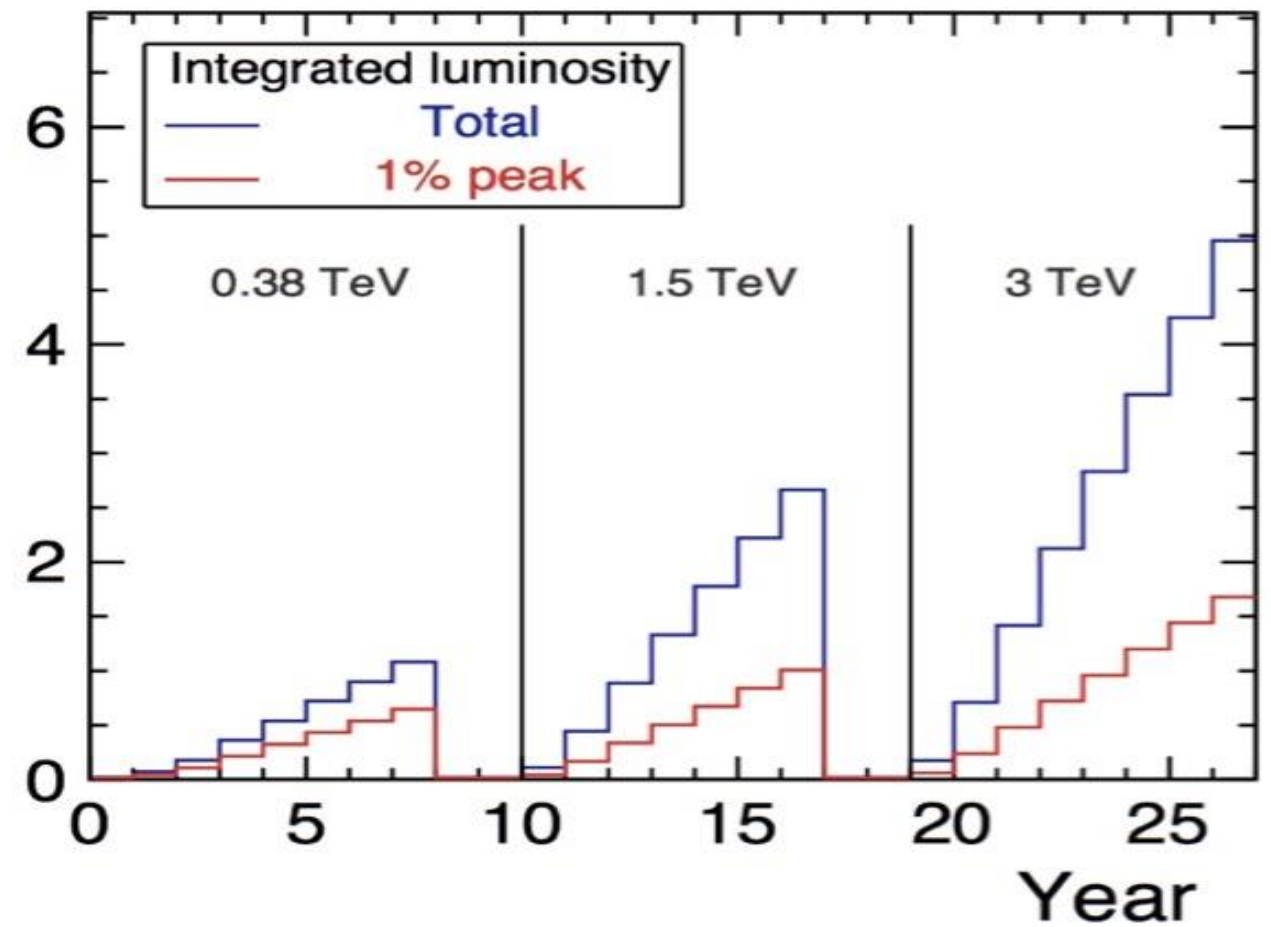
Updated schedule:

Construction + commissioning for 380 GeV: 7 yr

Full physics programme 27 yr



Integrated luminosity [ab^{-1}]



- Working group for use of Novel Acceleration Technologies (NAT) – plasma with various drivers, dielectrics, etc (short chapter in Project Implementation Plan document)
 - Physics and accelerator parameters (luminosity in particular)
 - Consider status of various studies
 - Key challenges beam-quality, positrons, energy efficiency for suitable luminosities
- Possible re-use of tunnel/infrastructure/drive-beams/injectors etc interesting for a LC infrastructure
- The fact the actual effective ML might remain short (and hence possibly “cheap” and inter-changeable in a limited time) makes this long term perspective worth considering
- Have not found any “constrains/guidance” from these very long term “hopes” that would impact the design of CLIC stages 1-3
 - CLIC is laser-straight and with a “reasonable” crossing angle likely to compatible with higher beam energies and the bunch separations needed for these technologies



Next phase



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

Activities 2020-2025

Design and parameters, final optimization and system verifications

Construction of pre-series of modules

Accelerator structures optimization and production of modules

X-band test facilities inside and outside CERN

Final parameters and design of magnets, instrumentation, alignment, stability, vacuum systems

Drive beam front end optimization to ~20 MeV and system tests

Detailed site design, impact studies, finalise infrastructure specifications

Purpose

Luminosity performance, risk, cost power reduction

Final technical design and industrial capabilities

Final design, industrial capabilities, conditioning

Needed for construction, further cost/power reduction

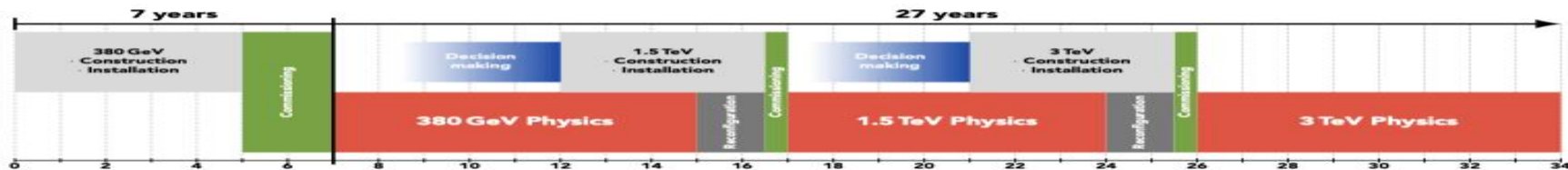
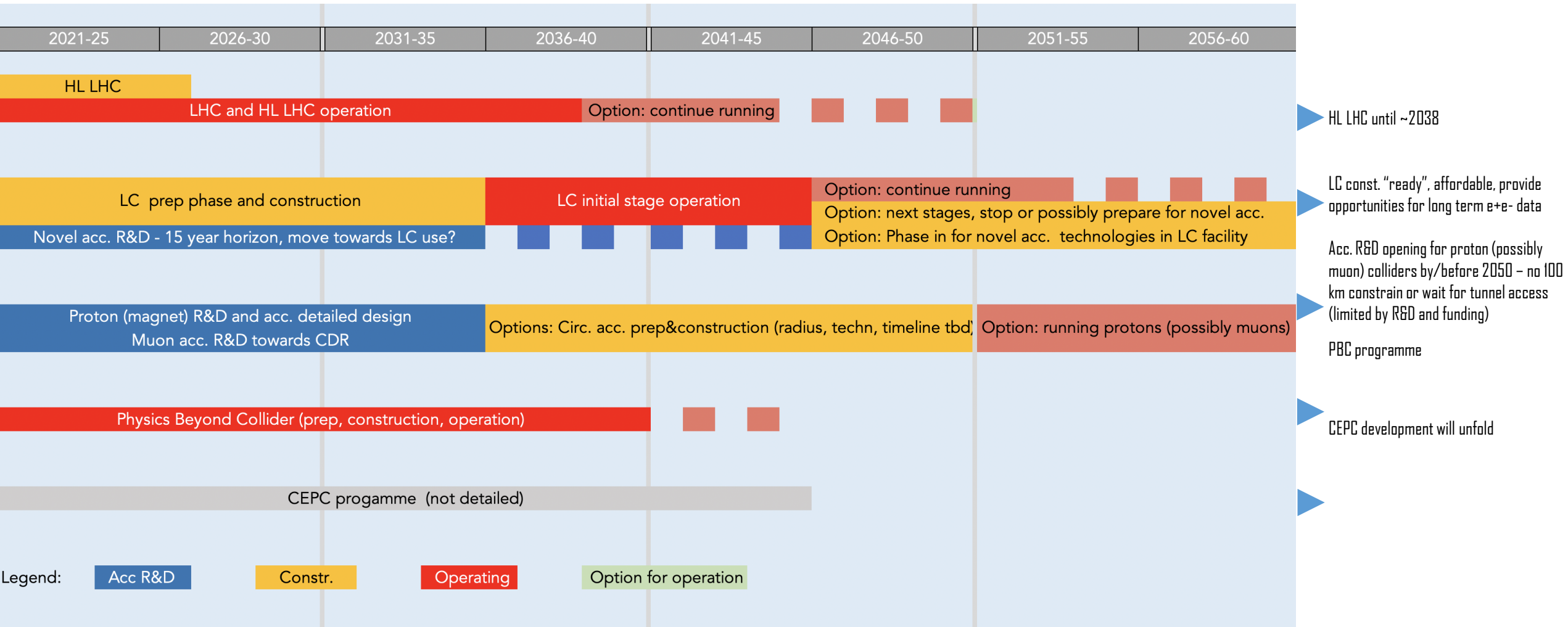
Luminosity performance, prepare for construction tenders

Drivebeam most critical parts, production preparation

Final CE and infrastructure parameters, permits, tenders



A linear collider as part of an overall strategy



Summary

- CLIC is now a mature project, ready for implementation
- The main accelerator technologies have been demonstrated
- The cost and implementation time are similar to LHC
- The physics case is broad and profound, and being further developed (in this meeting)
- The detector concept and detector technologies R&D are advanced (also in this meeting)
- The full project status has been presented in a series of Yellow Reports and other publications: <http://clic.cern/european-strategy>



Thanks to all providing material - and more generally ALL contributors to the CLIC ESPP input/background documents , from which this material is drawn