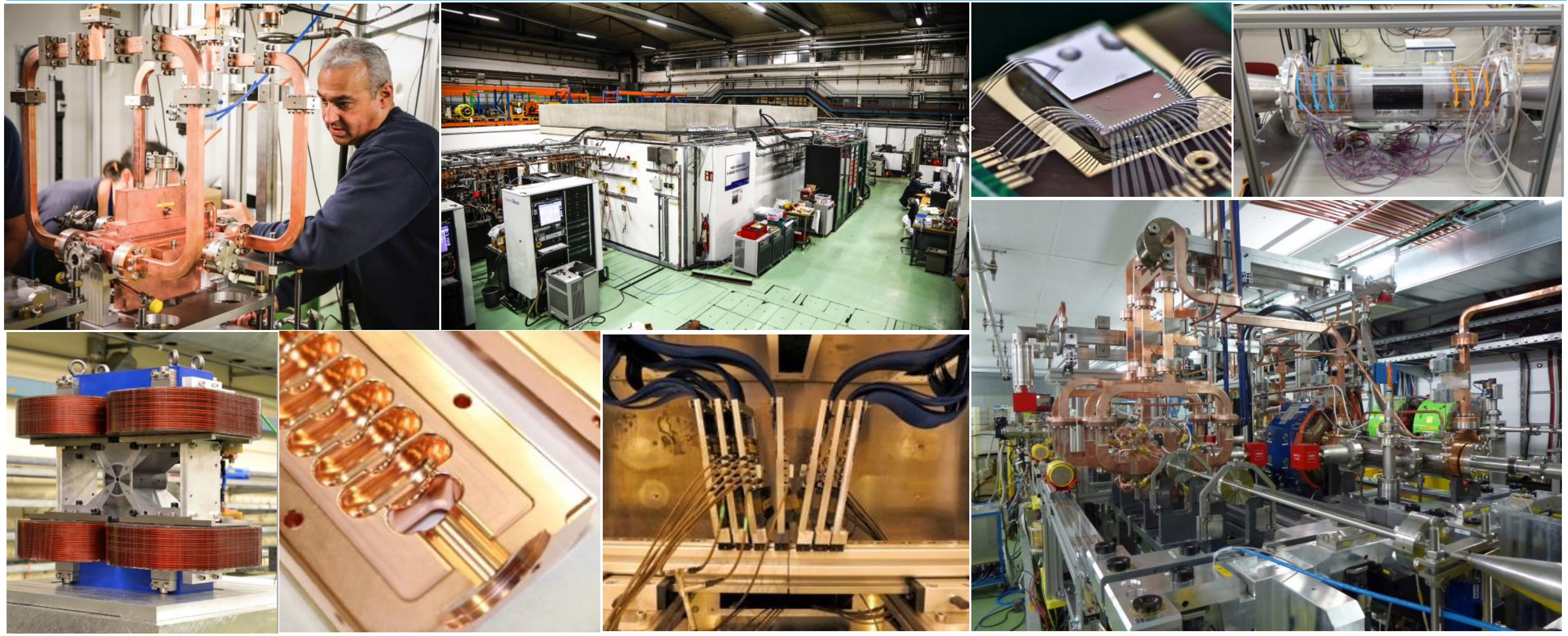
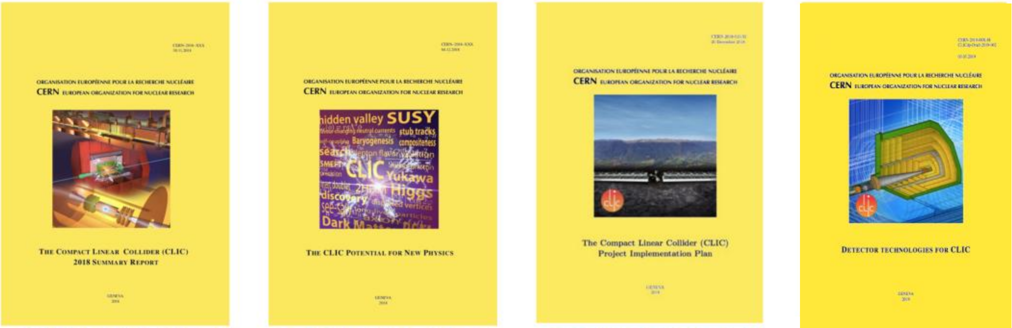
CLIC – next steps

Steinar Stapnes, CERN



Outline:
- The input to the European Strategy process
- Additional studies responding to questions raised in this process
- Next phase and an overall strategy for a LC

CLIC European Strategy Input



[CERN-2018-005-M](http://dx.doi.org/10.23731/CYRM-2018-002) http://dx.doi.org/10.23731/CYRM-2018-002

[CERN-2018-009-M](http://dx.doi.org/10.23731/CYRM-2018-003) http://dx.doi.org/10.23731/CYRM-2018-003

[CERN-2018-010-M](http://dx.doi.org/10.23731/CYRM-2018-004) http://dx.doi.org/10.23731/CYRM-2018-004

[CERN-2019-001](http://dx.doi.org/10.23731/CYRM-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)
- **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)
- **Detector technologies for CLIC** (CERN-2019-001, arXiv:1905.02520)

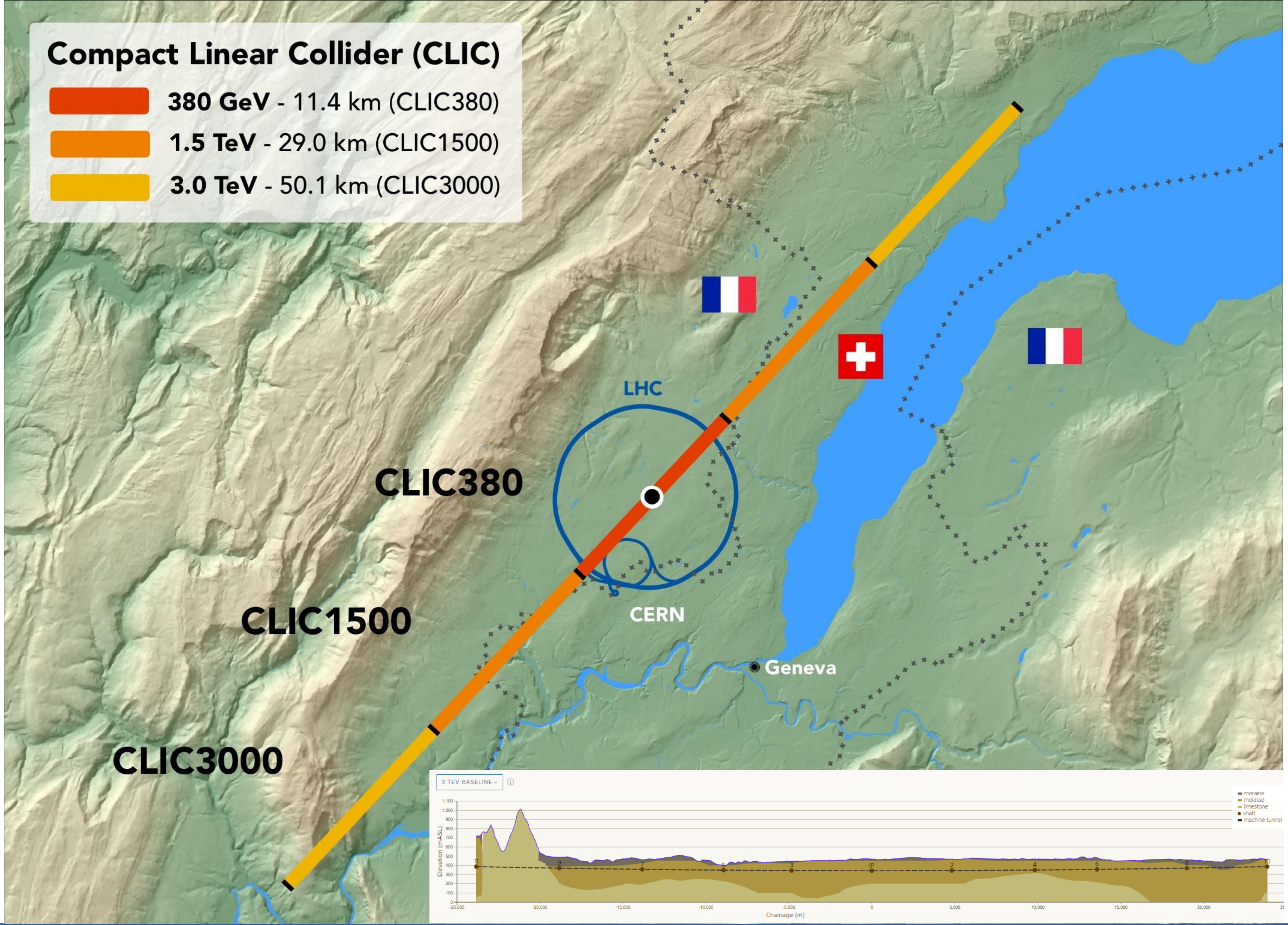
Journal publications

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

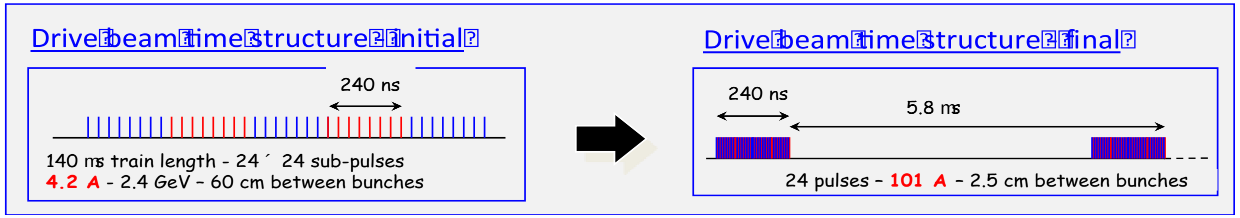
CLICdp notes

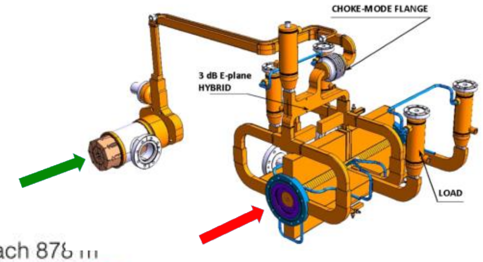
- **Updated CLIC luminosity staging baseline and Higgs coupling prospects** (CERN Document Server, arXiv:1812.01644)
- **CLICdet: The post-CDR CLIC detector model** (CERN Document Server)
- **A detector for CLIC: main parameters and performance** (CERN Document Server, arXiv:1812.07337)

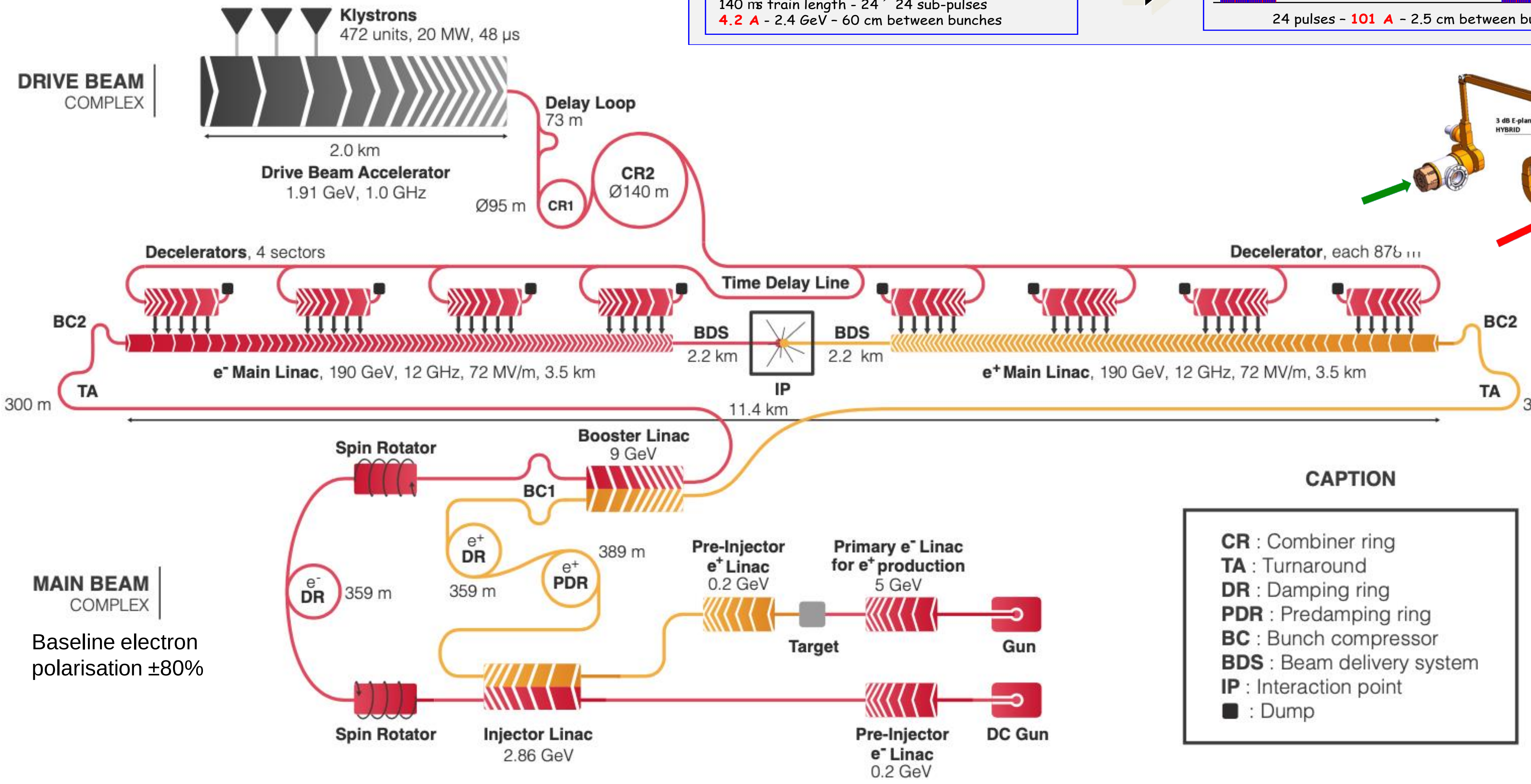
Link: http://clic.cern/european-strategy


Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
3 TEV BASELINE

CLIC 380 GeV layout and power generation







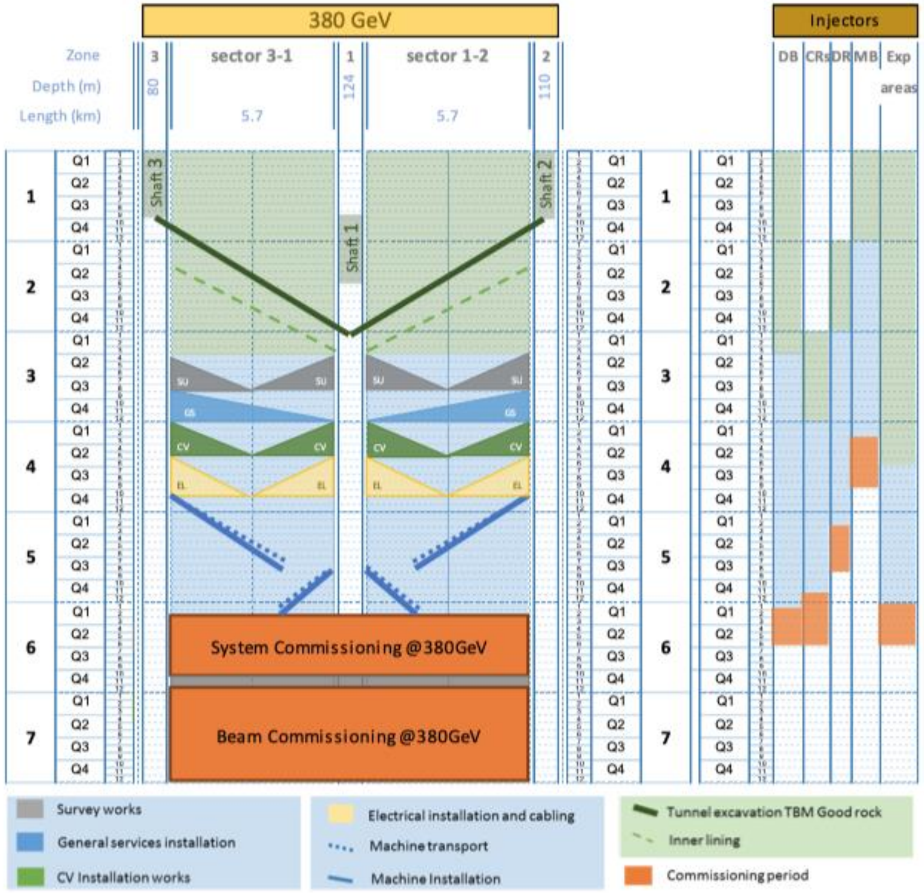
Baseline electron polarisation ±80%

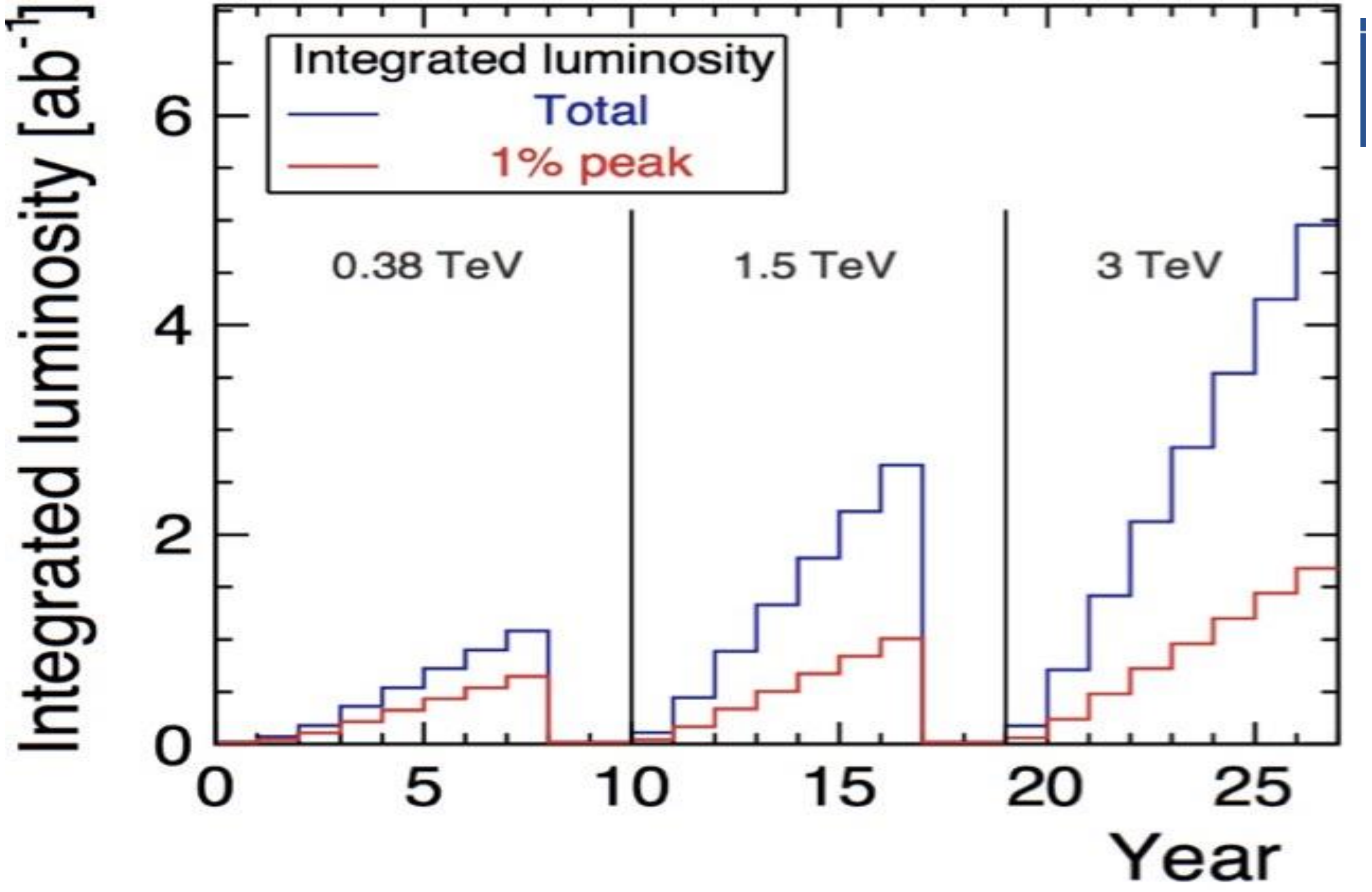
CLIC parameters

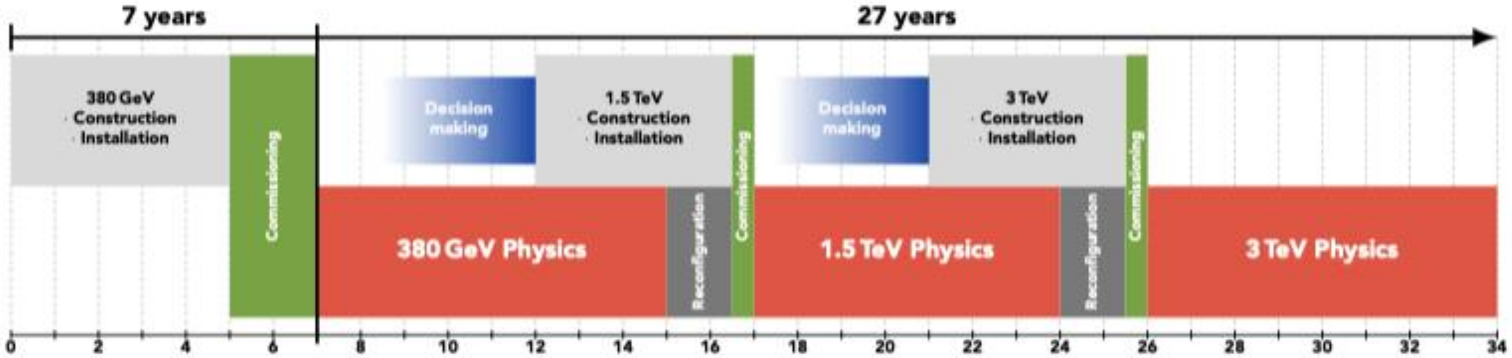
Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2} s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2} s^{-1}	0.9	1.4	2
Total integrated luminosity per year	$\mathscr{L}_{\text{int}}$	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

Schedule

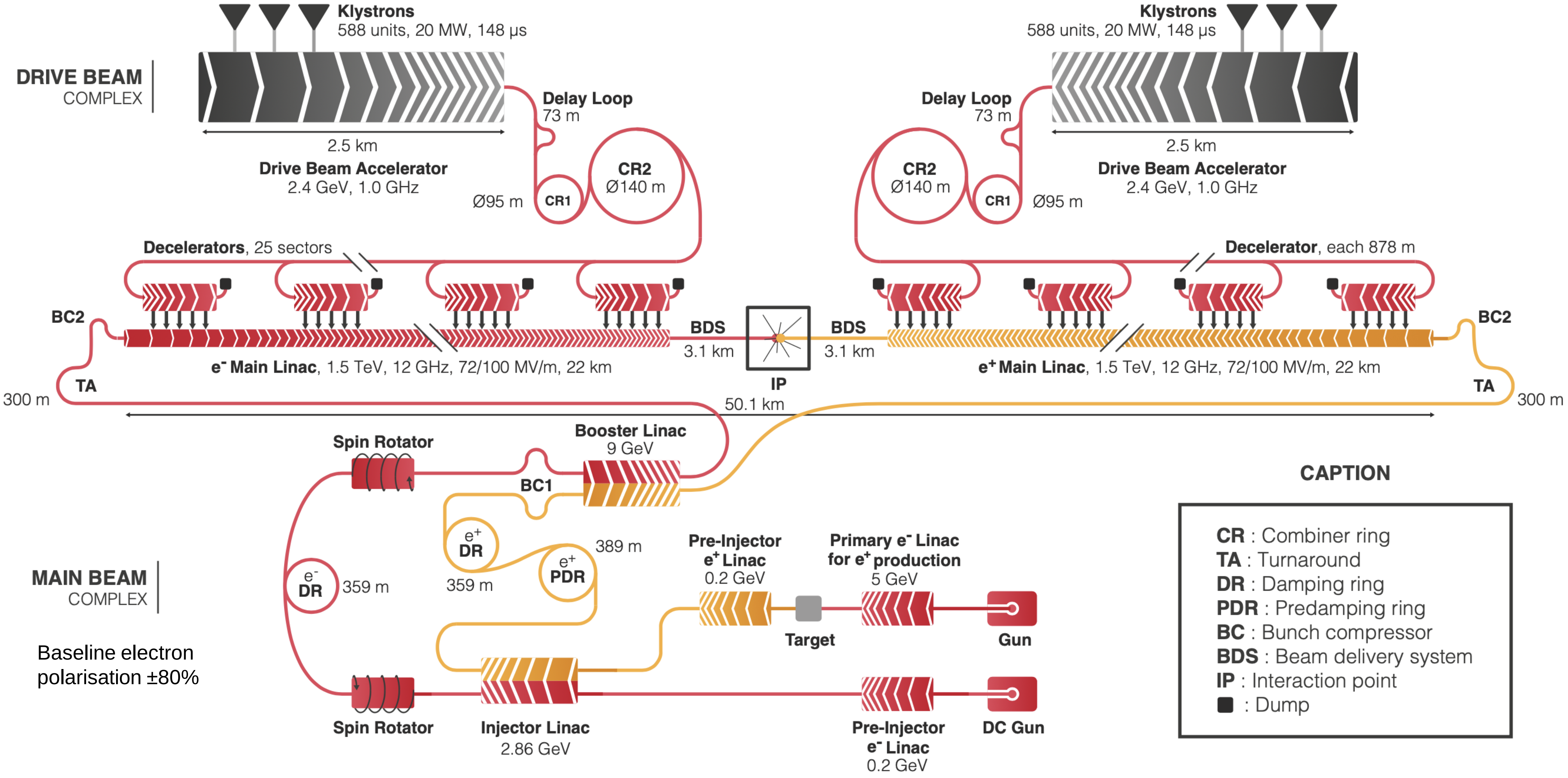
Updated schedule:
Construction + commissioning for 380 GeV: 7 yr
Full physics programme 27 yr







CLIC layout – 3TeV



Baseline electron polarisation ±80%

CAPTION

CR : Combiner ring
TA : Turnaround
DR : Damping ring
PDR : Predamping ring
BC : Bunch compressor
BDS : Beam delivery system
IP : Interaction point
■ : Dump

Looking forward

- Much more about the accelerator in Roberto Corsini's talk this afternoon (link)
- Additional questions about Z-pole performance, luminosity margin at 380 GeV – can it be increased, a the gamma-gamma spectrum addressed since Granada meeting, see next slide and talk of Andrea Latina tomorrow - link
- Then moving on the future plans (brief)

After Granada

Three questions:

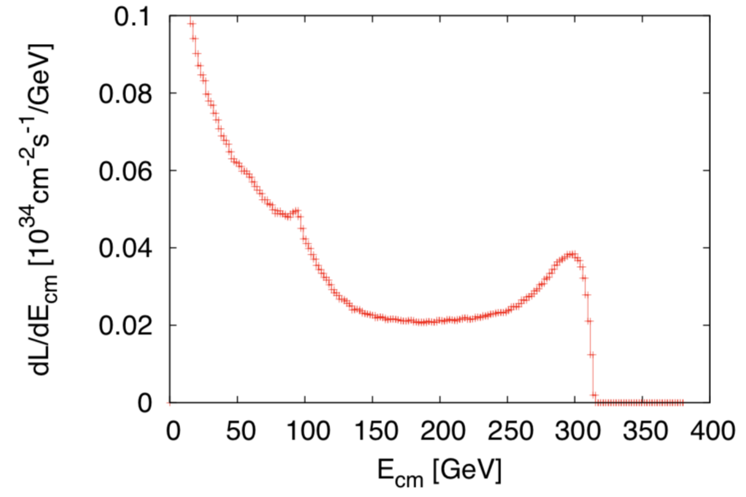
- Z pole performance, 2.3×10^{32} – 0.4×10^{34} cm^{-2} s^{-1}
  - The latter number when accelerator configured for Z running (either early or end of first stage)

- Gamma – Gamma spectrum (example)

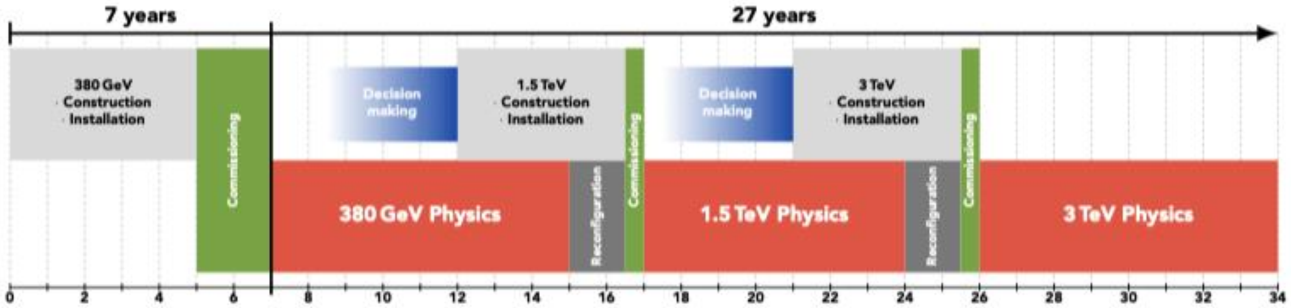
- Luminosity margins and increases
  - Baseline includes estimates static and dynamic degradations from damping ring to IP: 1.5×10^{34} cm^{-2} s^{-1}, a "perfect" machine will give : 4.3×10^{34} cm^{-2} s^{-1}, so significant possibilities for doing better

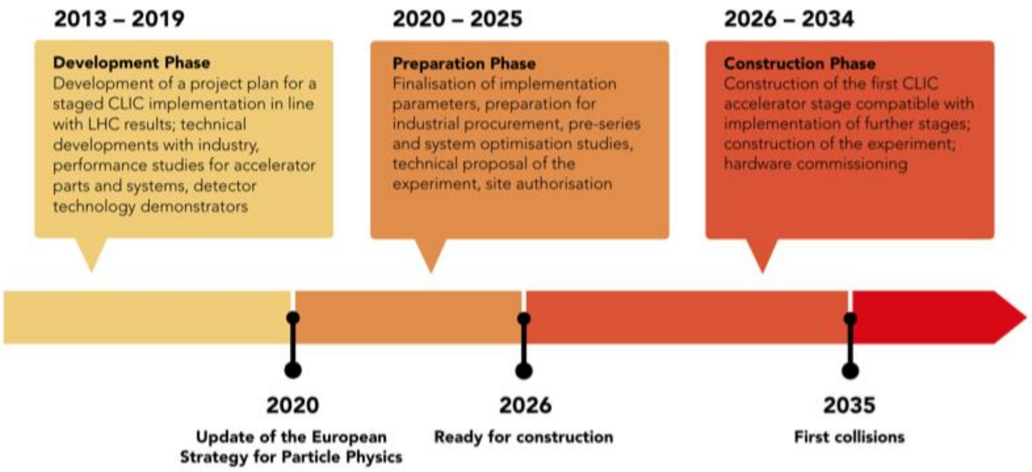
  - In addition: doubling the frequency (50 Hz to 100 Hz) would double the luminosity, at a cost of +50 MW and ~5% cost increase

- Note at: http://cds.cern.ch/record/2687090
- See talk tomorrow by Andrea Latina (link)



Next phase for CLIC





Activities 2020-2025	Purpose
Design and parameters, final optimization and system verifications	Luminosity performance, risk, cost power reduction
Construction of pre-series of modules	Final technical design and industrial capabilities
Accelerator structures optimization and production of modules	Final design, industrial capabilities, conditioning
X-band test facilities inside and outside CERN	Needed for construction, further cost/power reduction
Final parameters and design of magnets, instrumentation, alignment, stability, vacuum systems	Luminosity performance, prepare for construction *tenders*
Drive beam front end optimization to ~20 MeV and system tests	Drivebeam most critical parts, production preparation
Detailed site design, impact studies, finalise infrastructure specifications	Final CE and infrastructure parameters, permits, tenders

X-band technology and its use

(see talk of Walter Wuensch tomorrow (link))

Prototype components

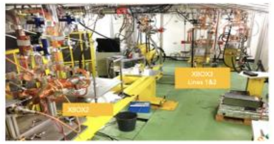
Laboratory with commercial
- Accelerating structures
- pulse compressors
- alignment
- stabilization
- etc.

Full commercial supply
- X-band klystrons
- solid state modulators
- etc.



Systems and 100 MeV-range facilities

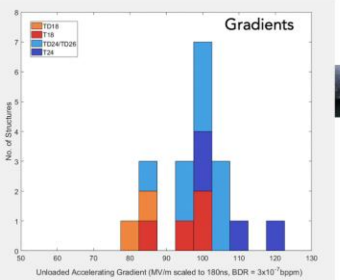
- XBoxes at CERN
- (NEXTEF KEK)
- Test stand at Tsinghua
- Frascati
- NLCTA SLAC
- Linearizers at Electra, PSI, Shanghai and Daresbury
- Deflectors at SLAC, Shanghai, PSI, DESY and Trieste
- NLCTA
- Smart*Light
- FLASH




Normal-conducting, low-emittance GeV-range facilities

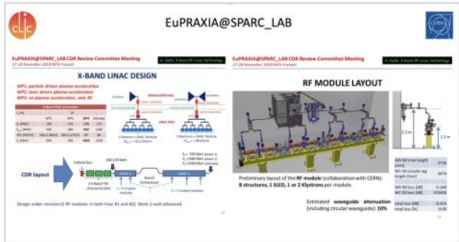
Operational
- SACLA
- SwissFEL

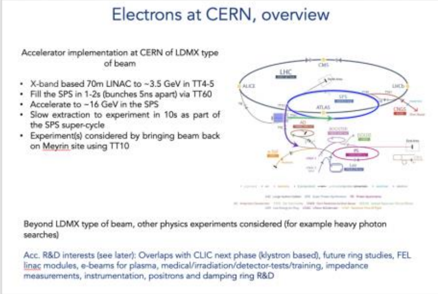
Swissfel: Specs similar, and reached

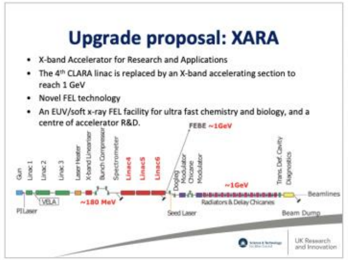


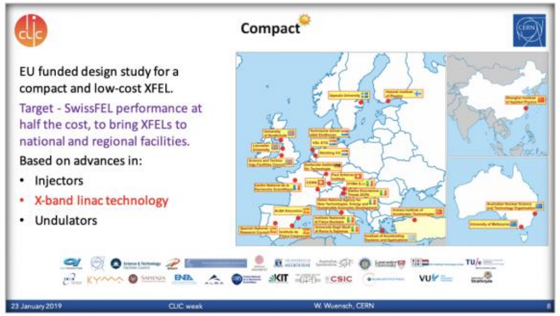
X-band GeV-range facilities

Planning:
- EU-Praxia
- eSPS
- CompactLight
- XARA



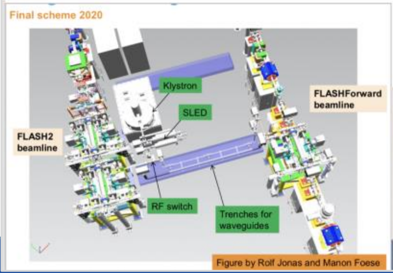




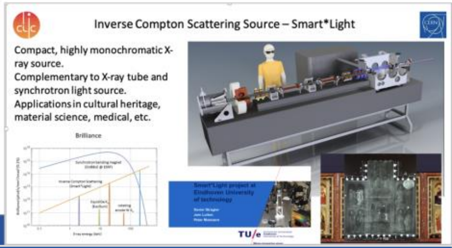


International Workshop on Breakdown Science and High Gradient Technology (HG2019)

More about these initiatives (June 2019): https://indico.cern.ch/event/766929/timetable/#all



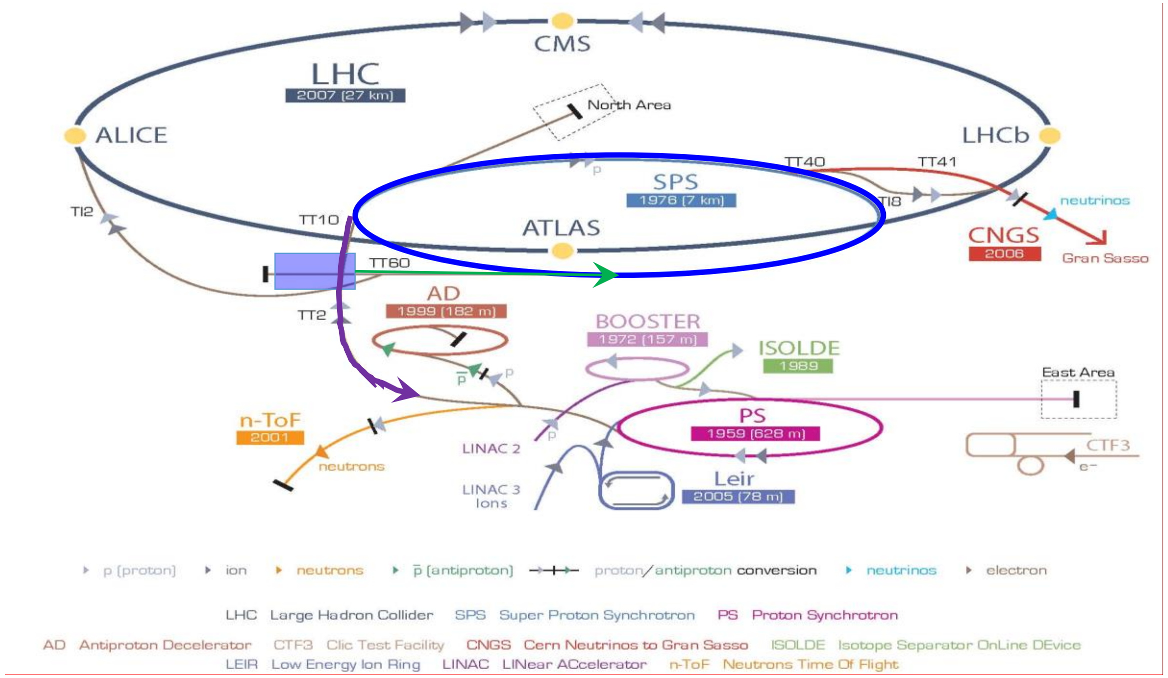
Elements in existing linacs (DESY, PSI)



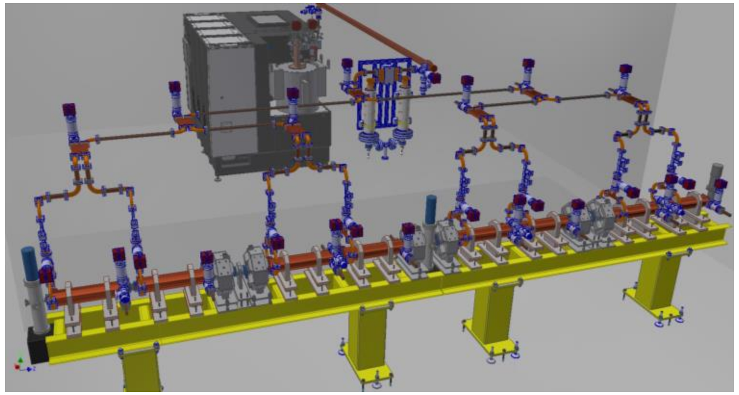
Electrons at CERN, overview

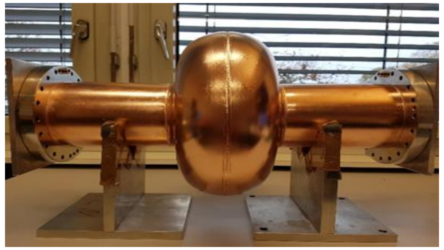
Accelerator implementation at CERN of electron beam for light dark matter searches (LDMX type) - part of Beyond Collider Physics programme

- 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



X-band linac and SC RF with FCC-ee relevance (800 MHz)

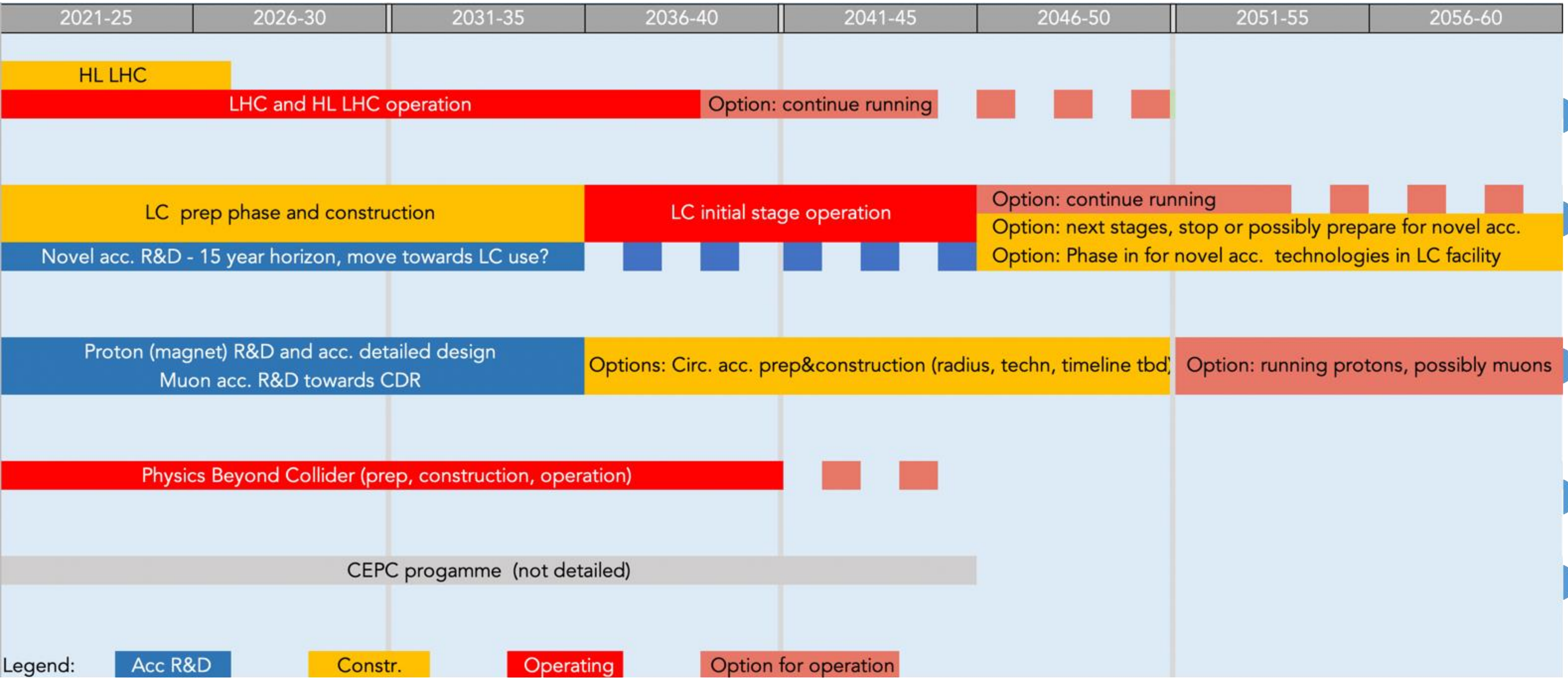




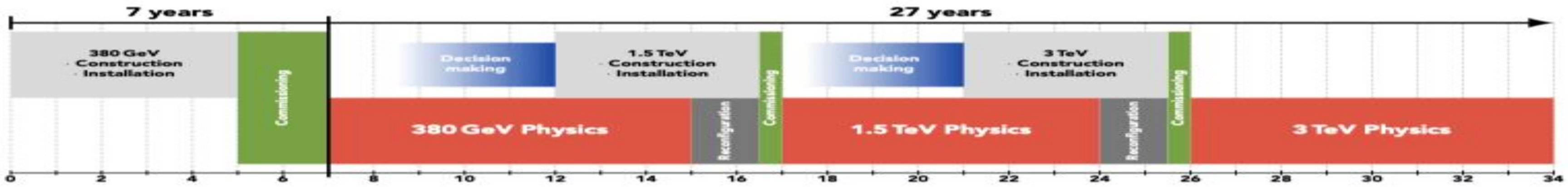
Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

Acc. R&D interests: 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

LC and beyond



- HL LHC until ~2038
- LC const. "ready", affordable, provide opportunities for long term e+e- data
- Acc. R&D opening for proton (possibly muon) colliders by/before 2050 – no 100 km constrain or wait for tunnel access (limited by R&D and funding)
- PBC programme
- CEPC development will unfold



Looong term future for a LC – NAT

- 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

Scenarios in the European Strategy

- With a view to update the European Strategy for Particle Physics, the Briefing Book compiled by the Physics Preparatory Group (PPG), based on the submitted inputs and the discussions during the Open Symposium in Granada, provides a summary of the present landscape in the field.

- It summarises the scientific aspirations, opportunities, as well as technical challenges. Revolving around future major colliders in Europe, at this stage, five scenarios are defined to initiate the discussions within the European Strategy Group (ESG).

CERN/ESG/05b
29 September 2019

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SUPPORTING NOTE FOR BRIEFING BOOK 2020

Towards an update of the European Strategy for Particle Physics

prepared by the Strategy Update Secretariat

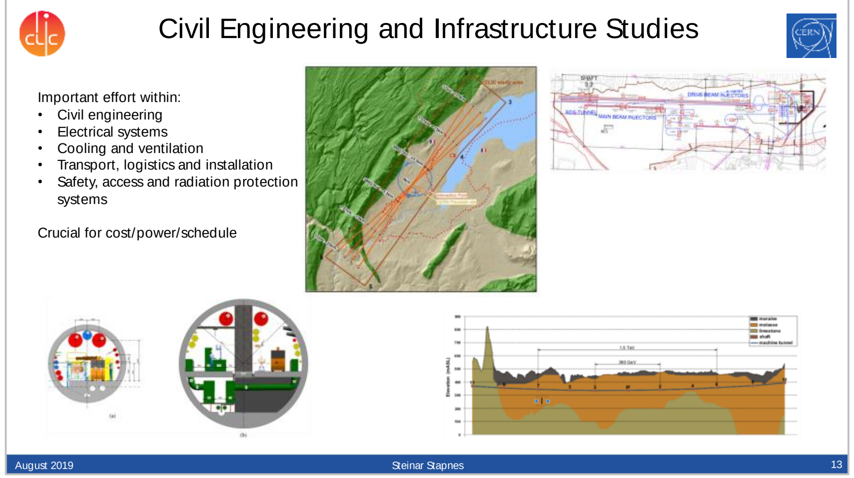
	2020-2040		2040-2060	2060-2080
			1st gen technology	2nd gen technology
CLIC-all	HL-LHC		**CLIC380-1500**	CLIC3000 / other tech
CLIC-FCC	HL-LHC		**CLIC380**	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC		**FCC-ee (90-365)**	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC		**LE-FCC-h/e/A (low-field magnets)**	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC	**+ LHeC**	**LHeC**	FCC-h/e/A (Adv HF magnets) / other tech

Summary

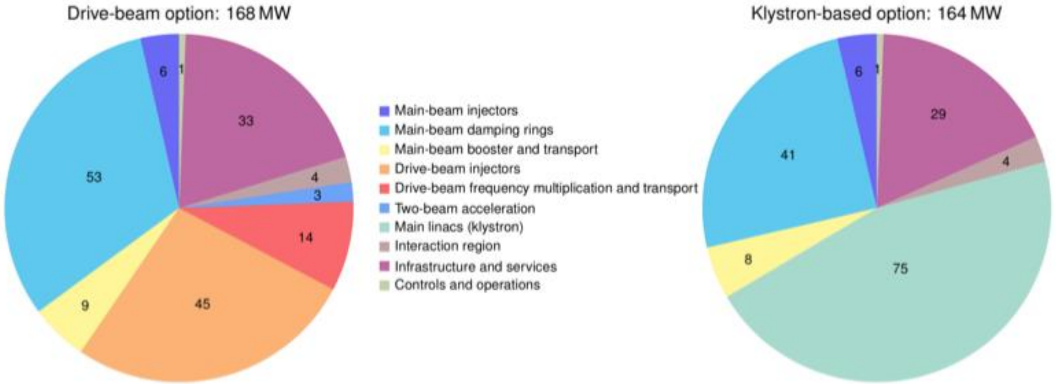
- CLIC is now a mature project, ready to move towards next phase preparing for a 380 GeV stage
- There is an consistent way forward with initial LC at “SM energies”, keeping the options open for future upgrades and/or circular accelerators further on
- The cost and implementation time for CLIC 380 are similar to LHC
- The physics case is broad and profound, and being further developed
- The detector concept and detector technologies R&D are advanced
- The full project status has been presented in a series of Yellow Reports and other publications: http://clic.cern/european-strategy

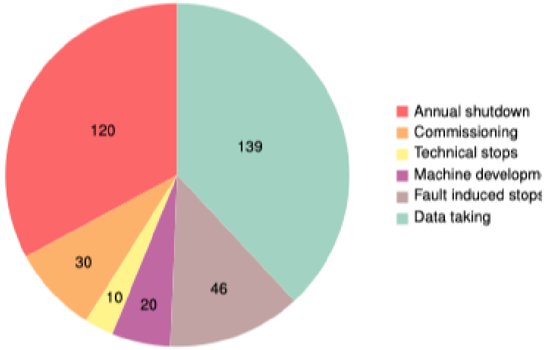
Picture from the CLIC week 2019,
Next year it will take place March 9-13 2020

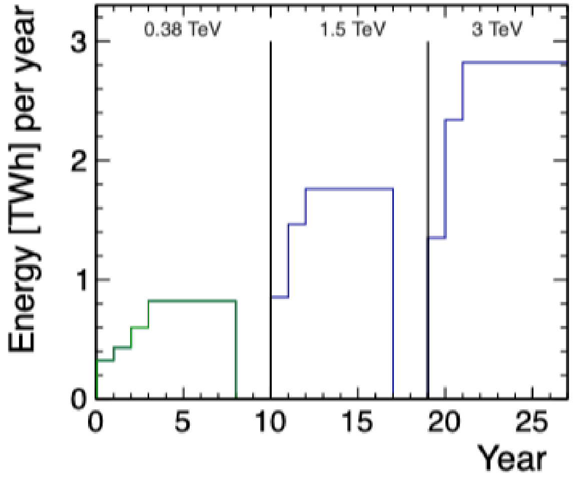
Implementing CLIC



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







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

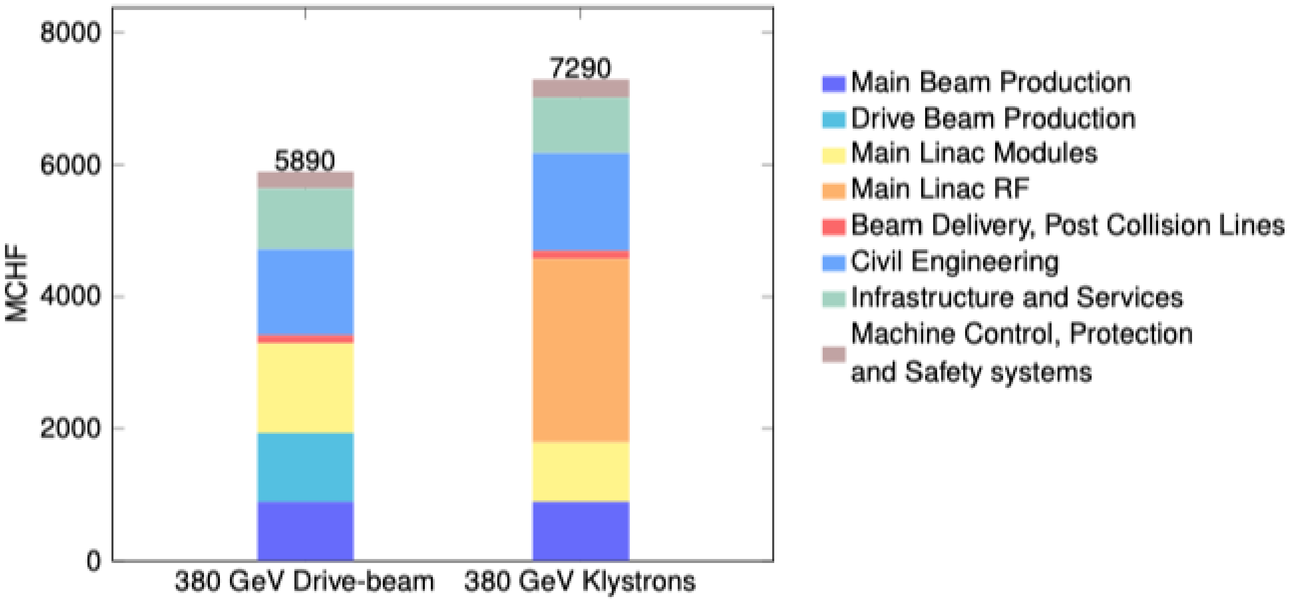
From running model and power estimates at various states – the energy consumption can be estimated

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

Cost - I

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	Cost [MCHF] 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.

Cost - II

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

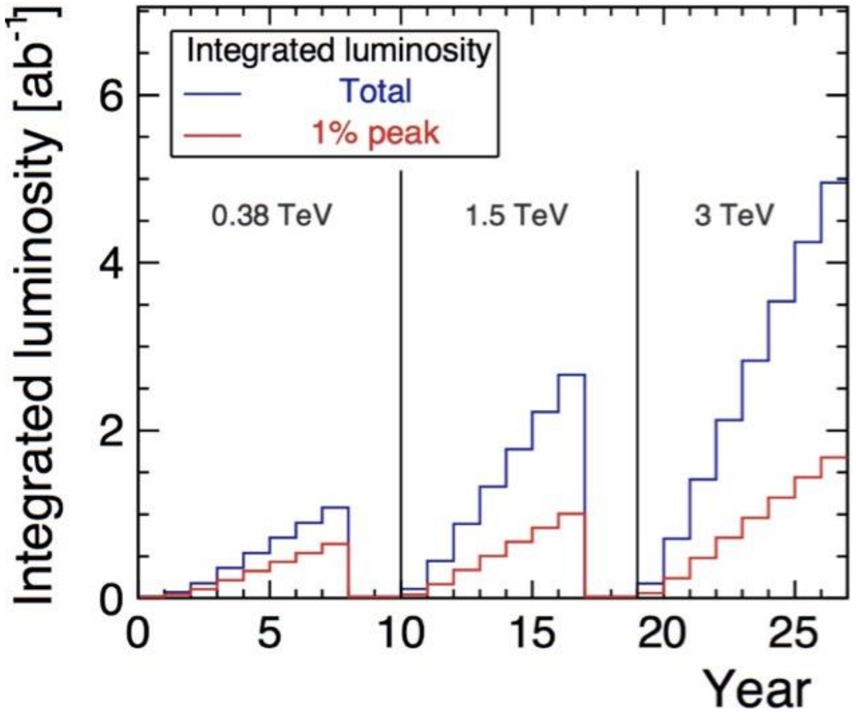
Operation:

- 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.

Luminosity staging baseline



Stage	$\sqrt{s}$ [TeV]	$\mathscr{L}_{\text{int}}$ [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 √s=380GeV ; (80:20) at √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, Bordry et al.

Prototype components

Laboratory with commercial
- Accelerating structures
- pulse compressors
- alignment
- stabilization
- etc.

Full commercial supply
- X-band klystrons
- solid state modulators
- etc.

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
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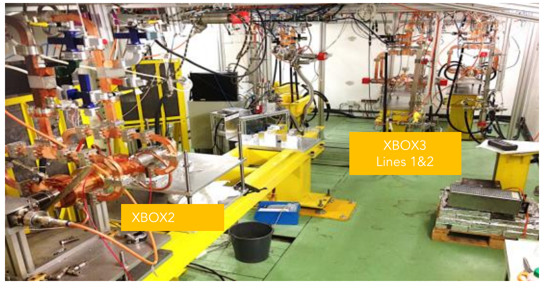
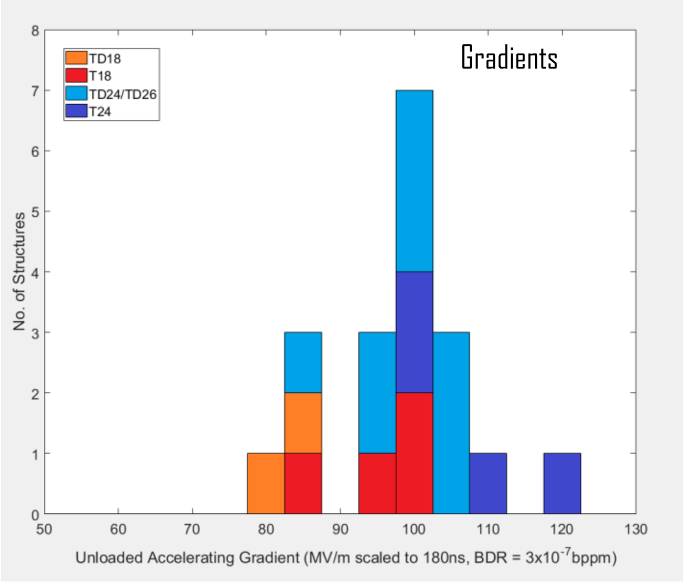
- Smart*Light
- FLASH



Normal-conducting, low- emittance GeV-range facilities

Operational
- SACLA
- SwissFEL

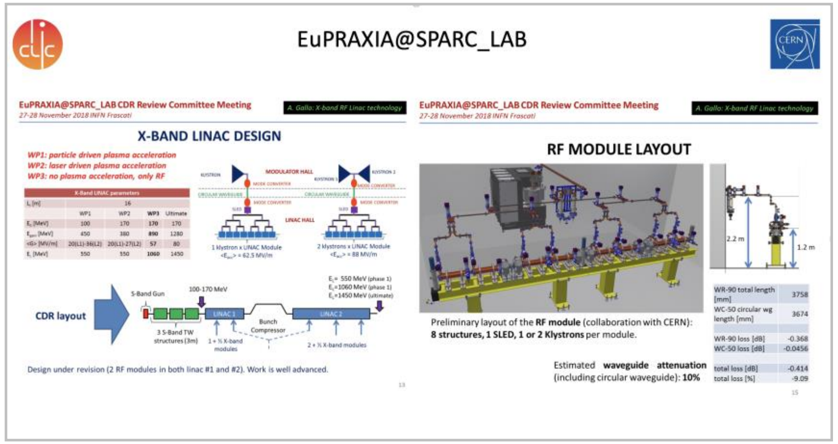
Swissfel: Specs similar, and reached



X-band GeV-range facilities

Planning:
- EU-Praxia
- eSPS
- CompactLight
- XARA

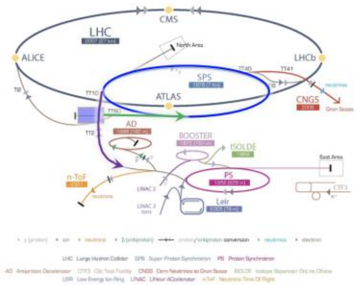
EuPRAXIA@SPARC_LAB



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

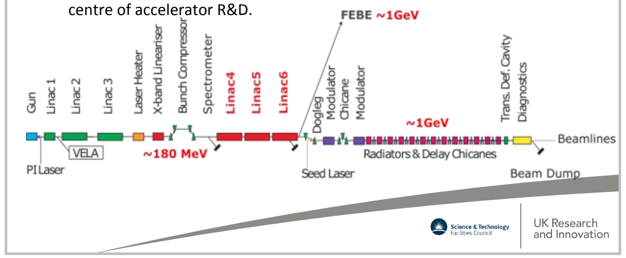


Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

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

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.



Science & Technology Facilities Council | UK Research and Innovation

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.

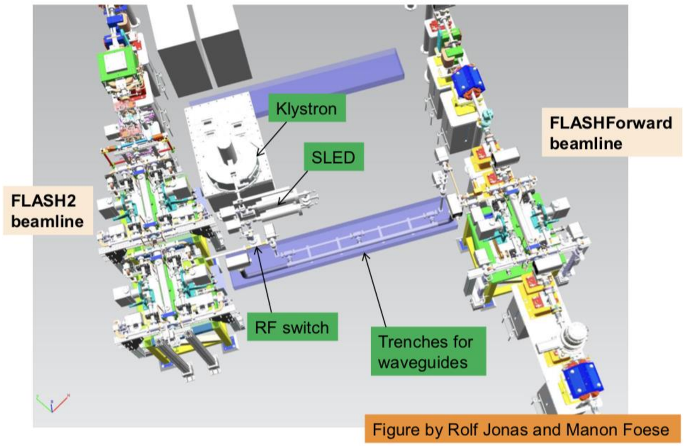
Based on advances in:

- Injectors
- X-band linac technology
- Undulators

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

More about these initiatives (June 2019):
https://indico.cern.ch/event/766929/timetable/#all

Final scheme 2020



Elements in existing linacs (DESY, PSI)

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.