LINEAR COLLIDER COLLABORATION

CLIC Accelerator Project: status and plans

Philip Burrows

John Adams Institute, Oxford University

and CERN

On behalf of the CLIC Collaborations

Thanks to all colleagues for materials

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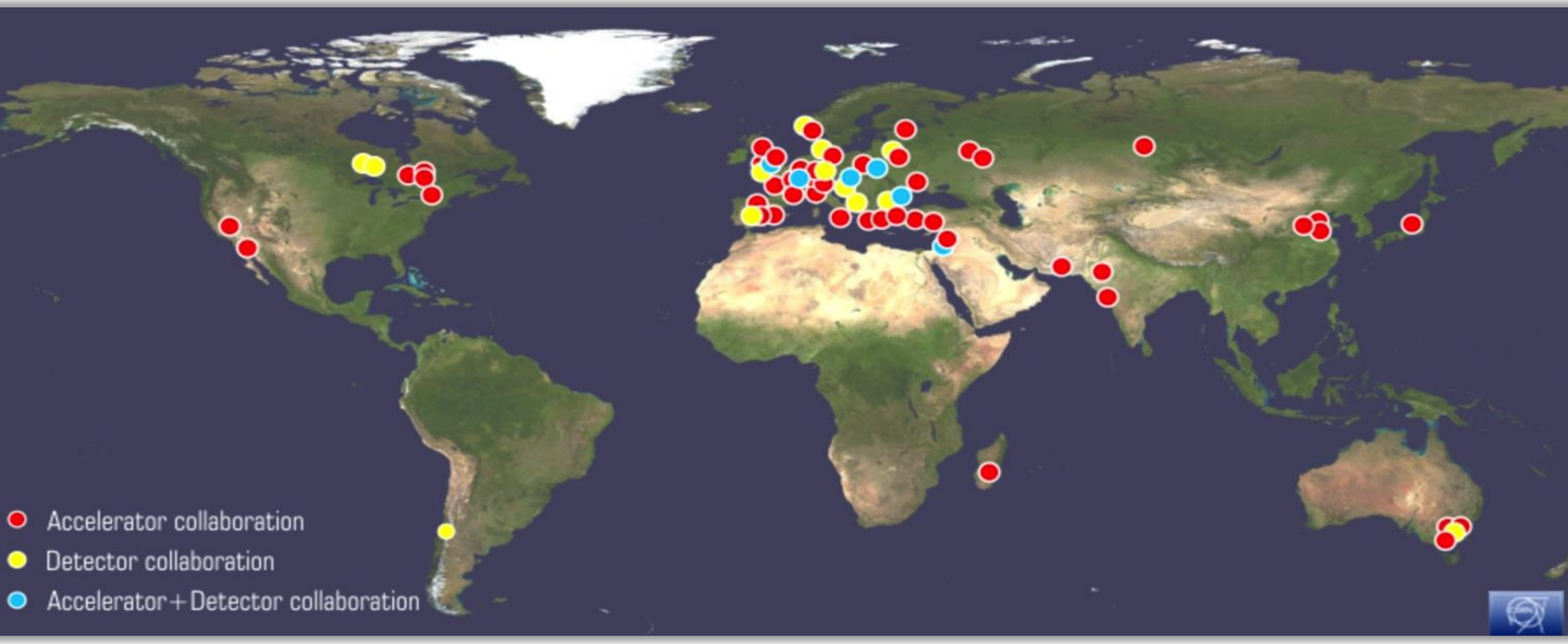
CLIC Collaborations

http://clic.cern/

CLIC accelerator collaboration
53 institutes from 31 countries

CLIC detector and physics (CLICdp)
30 institutes from 18 countries



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CLIC workshop January 2019

215 participants

Outline

- Reminder of inputs to European Strategy Update
- Brief overview of CLIC
- Project staging + updated run model
- Power
- Cost
- Schedule
- Next steps

Apologies for skipping many results + details

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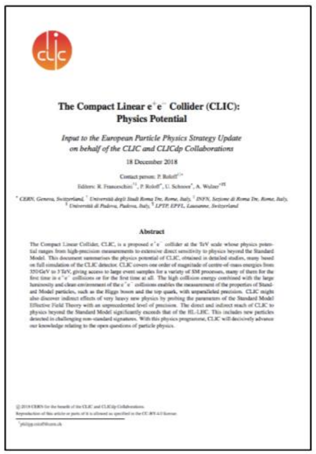
CLIC European Strategy Inputs


The Compact Linear e^+e^- Collider (CLIC): Accelerator and Detector

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

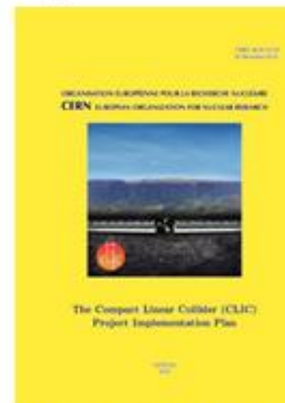

The Compact Linear e^+e^- Collider (CLIC): Physics Potential

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

CERN-2018-005-M

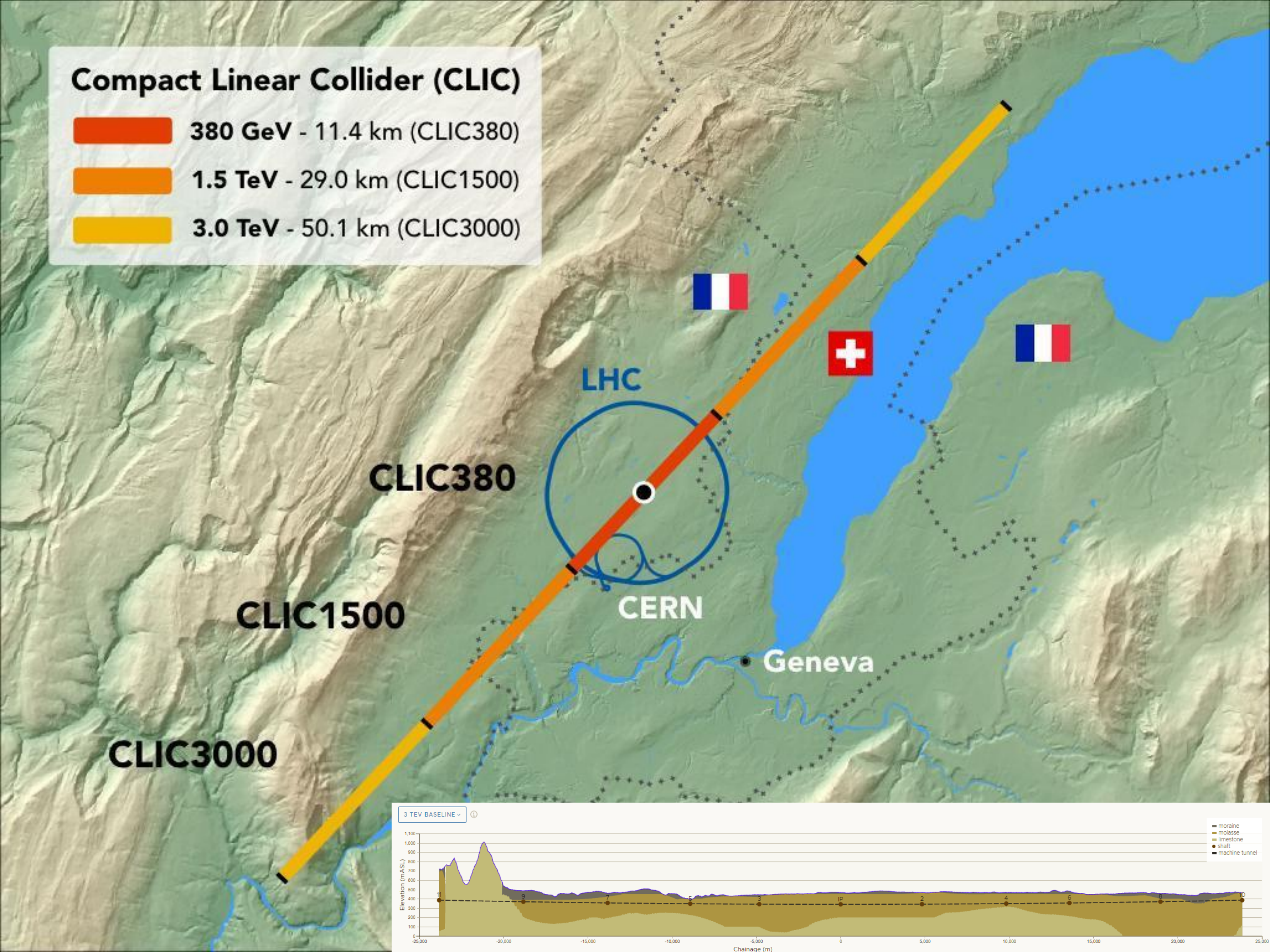
CERN-2018-009-M



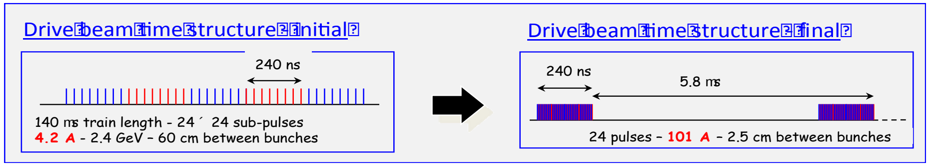
CERN-2018-010-M

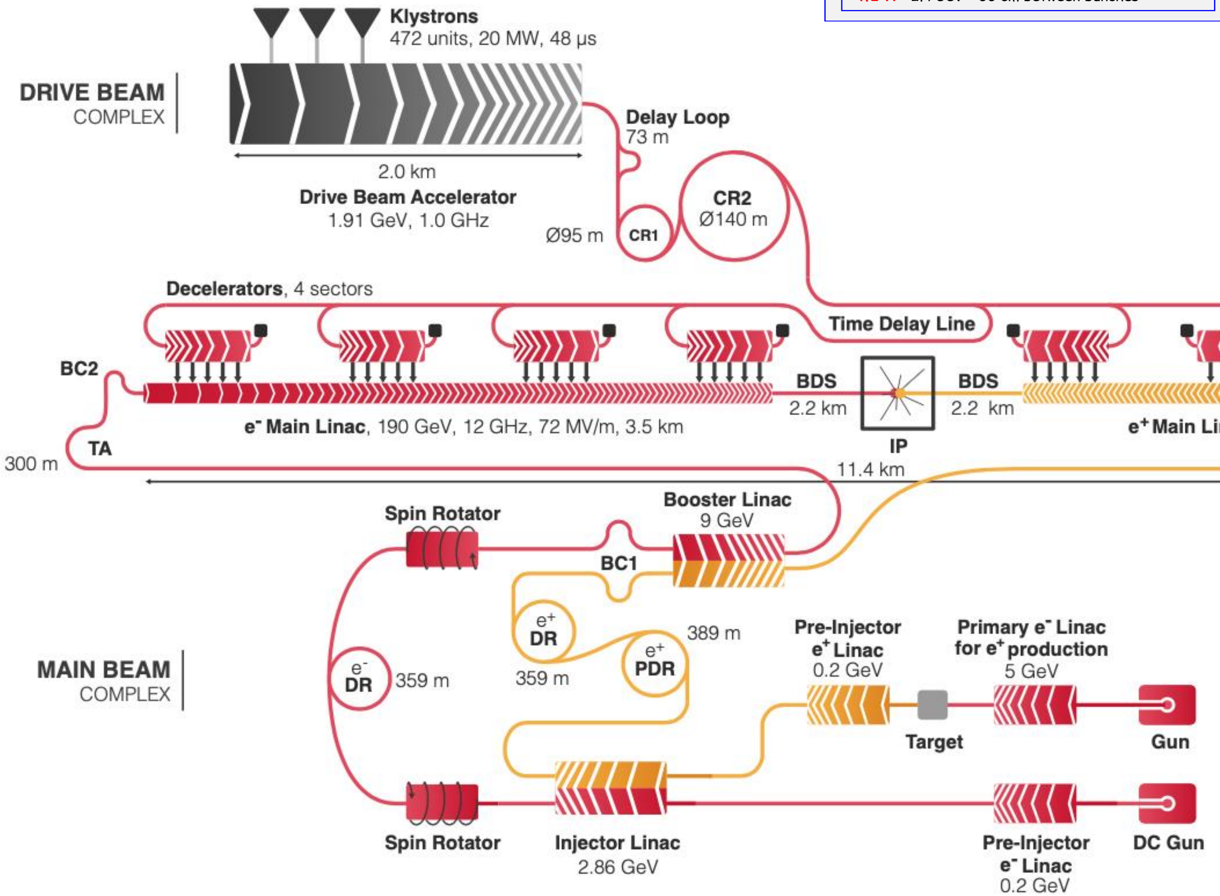
CERN-2019-001

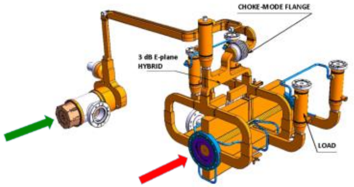
http://clic.cern/european-strategy


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
moraine
molasse
limestone
shaft
machine tunnel
Elevation (mASL)
Chainage (m)

CLIC 380 GeV layout





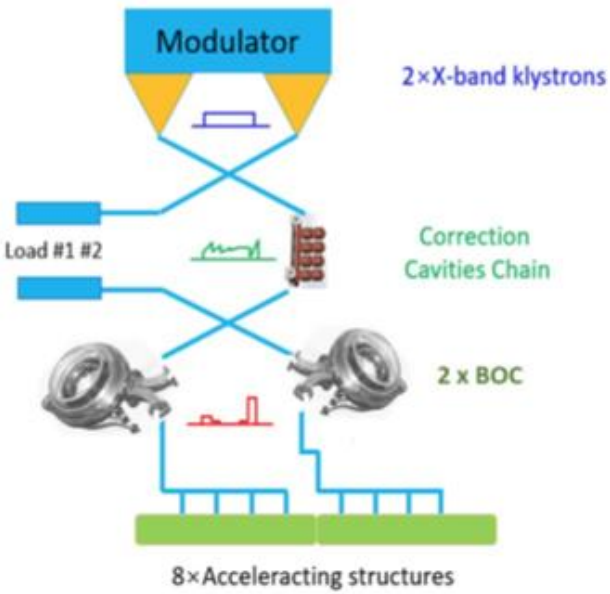


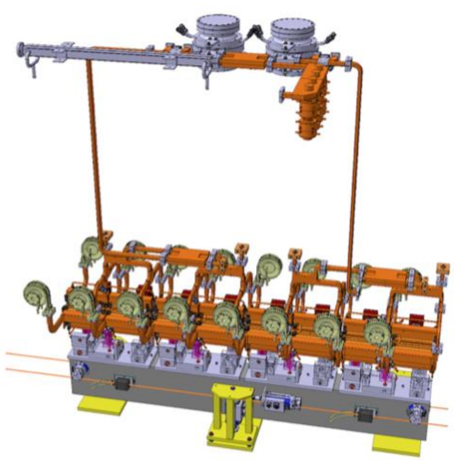
CAPTION

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

Baseline electron polarisation ±80%

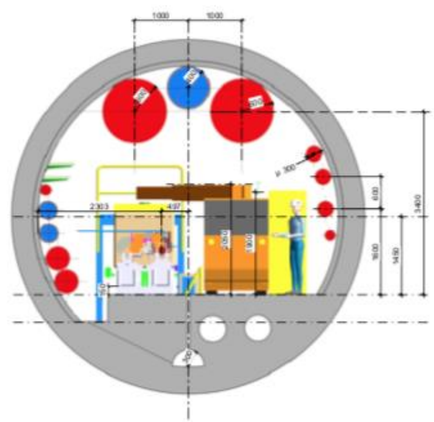
380 GeV klystron option





Replace drive-beam complex by local X-band RF power in tunnel

Simpler module, larger tunnel



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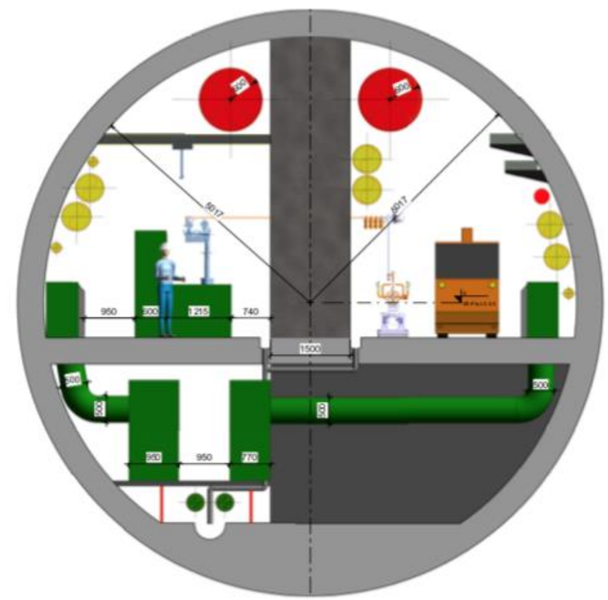

(b)

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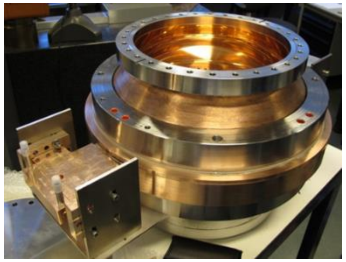
X-band RF test infrastructure

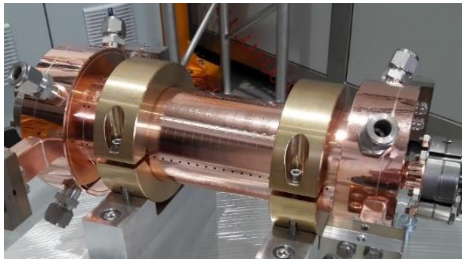
Modulator

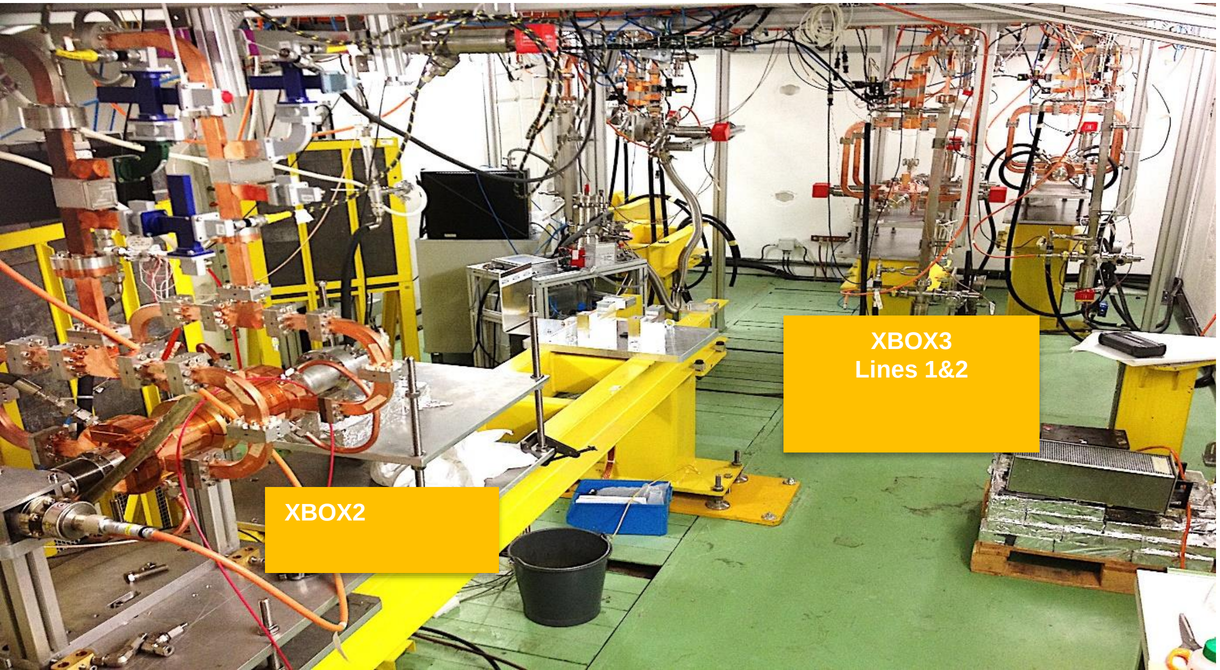
Klystron

Pulse compressor



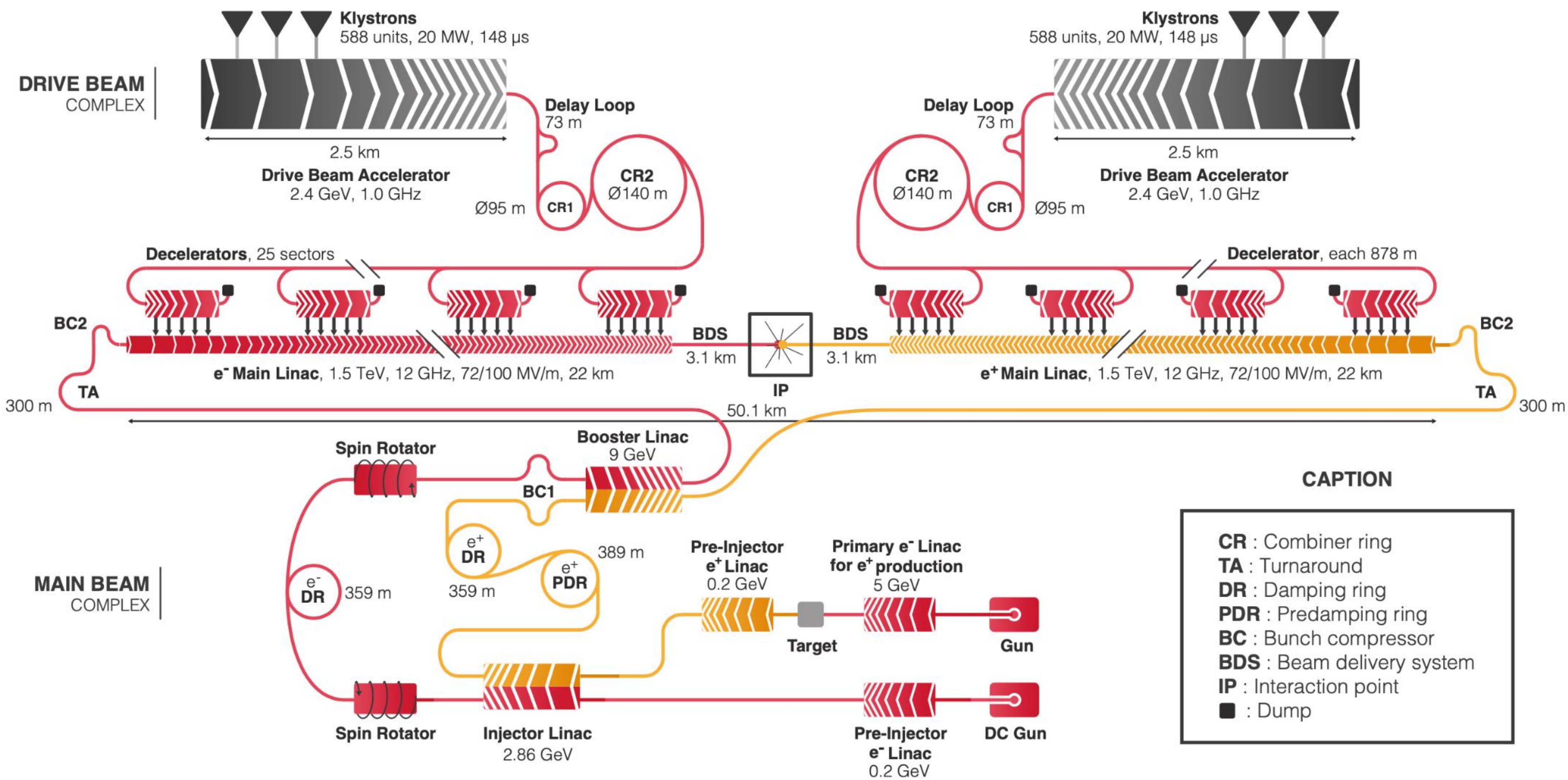
Accelerating structures





Assembled X-band systems in continuous operation at CERN

CLIC 3 TeV layout



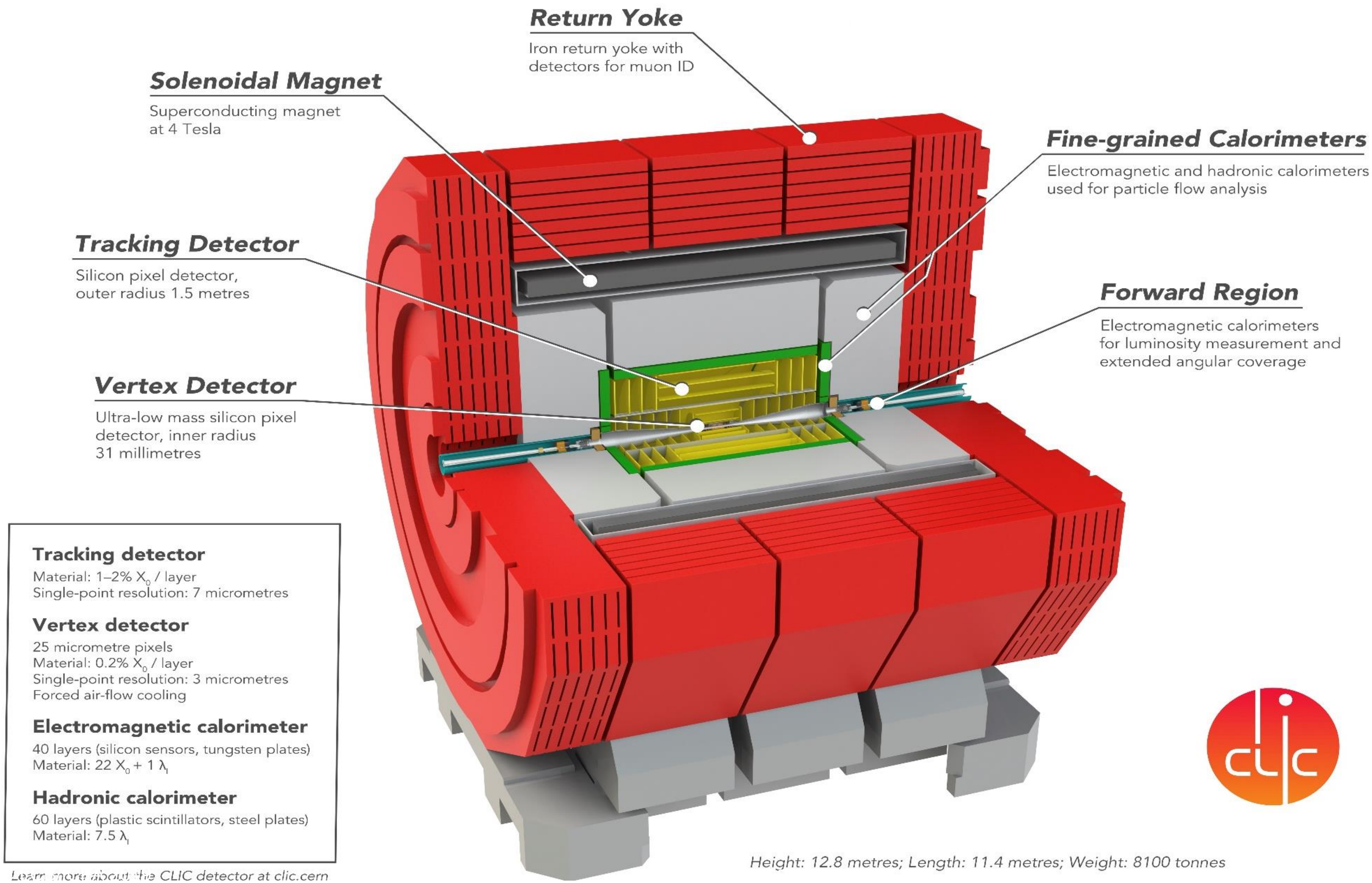
Baseline electron polarisation ±80%

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

CLIC detector

Mature CLICdet detector model; performance extensively validated:



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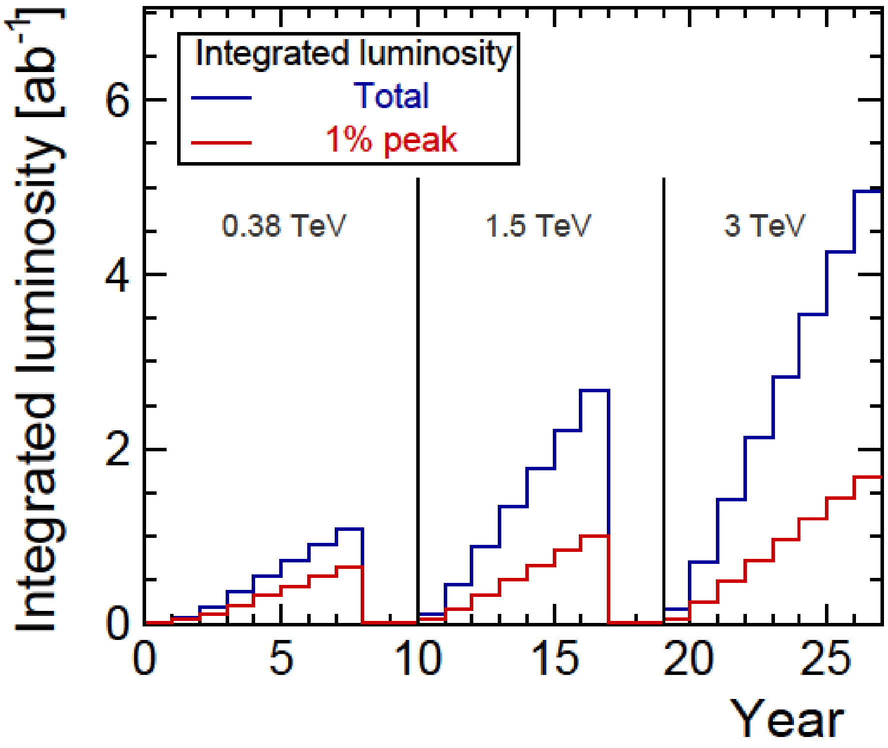
Luminosity staging baseline



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

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.

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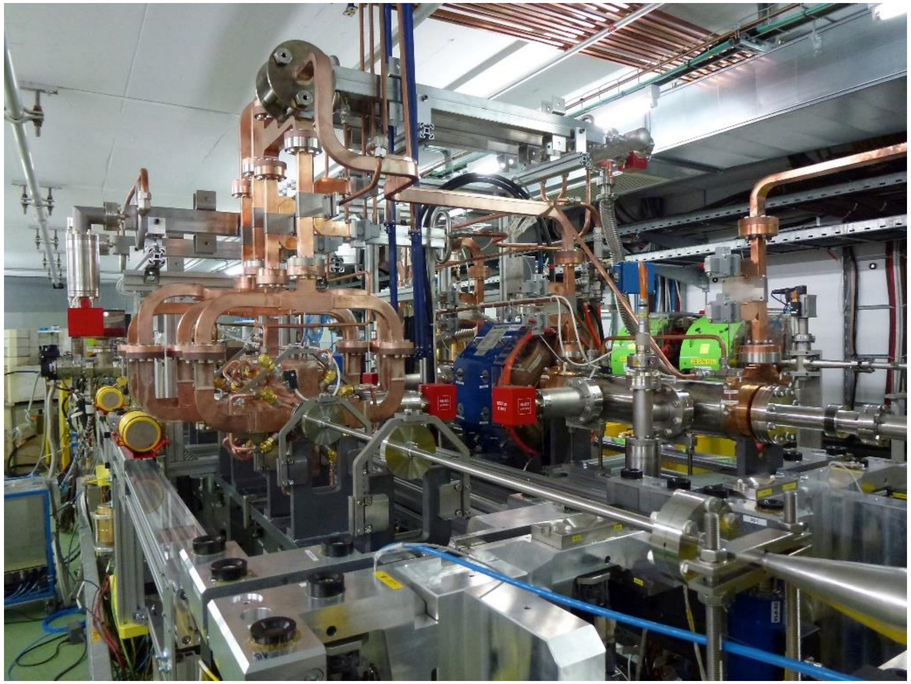
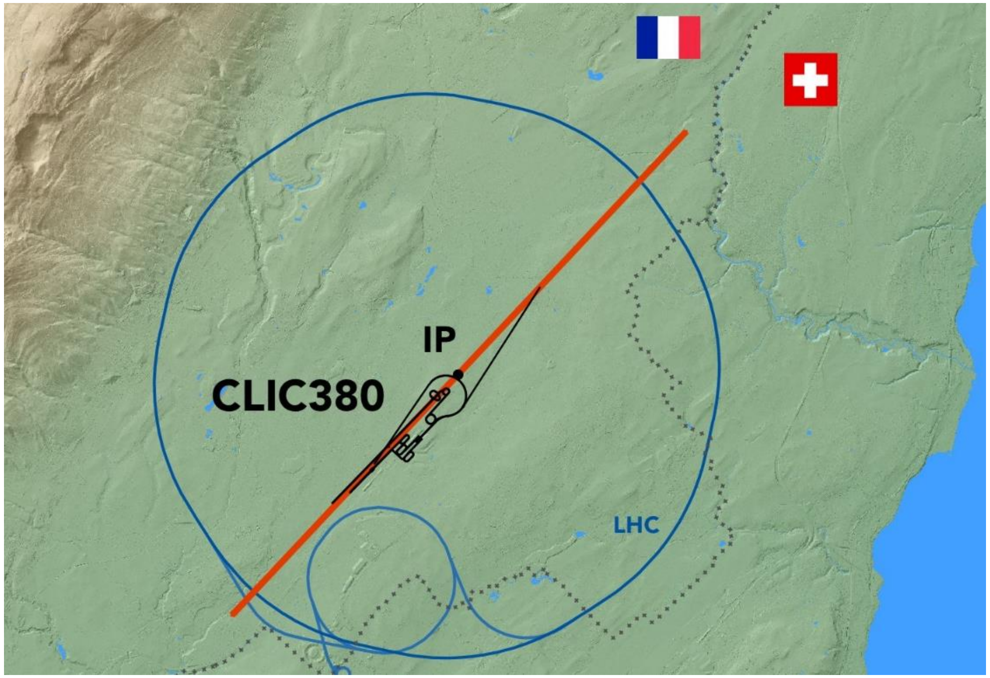
Status

Key technologies have been demonstrated
CLIC is now a mature project ready to move towards implementation
(see later for timeline)



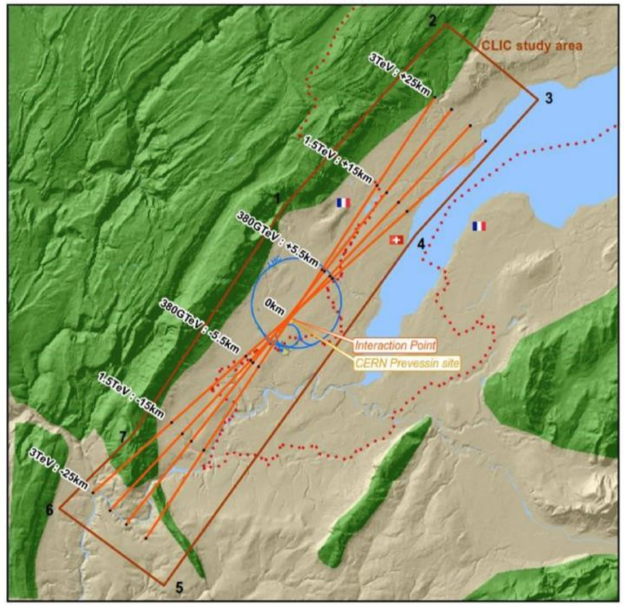


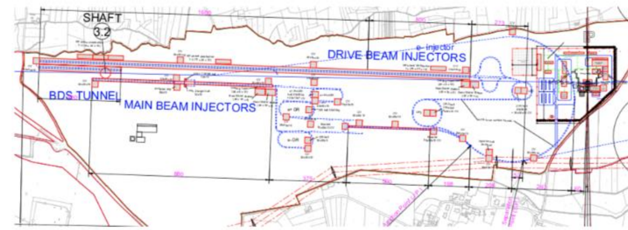
Civil Engineering and Infrastructure Studies

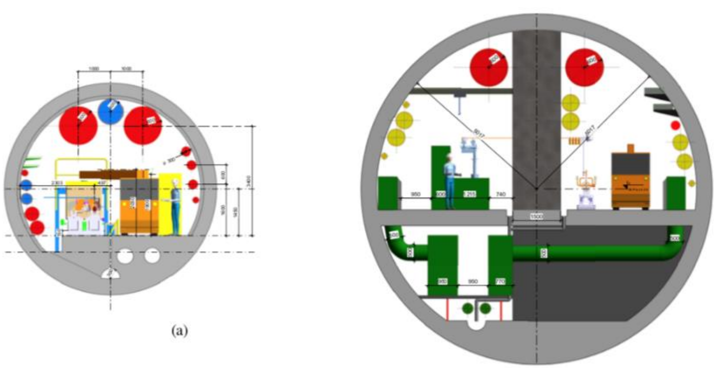
Important effort within:

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

Crucial for cost/power/schedule

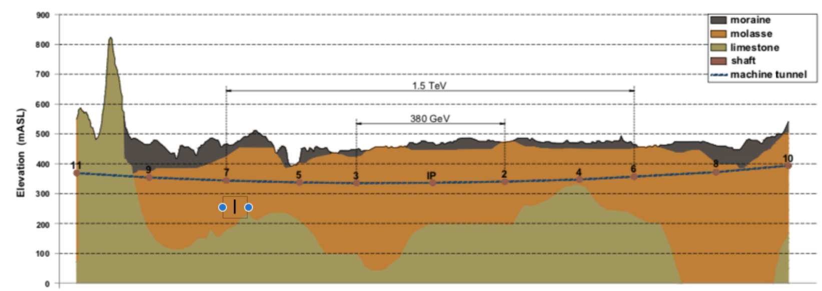






(a)

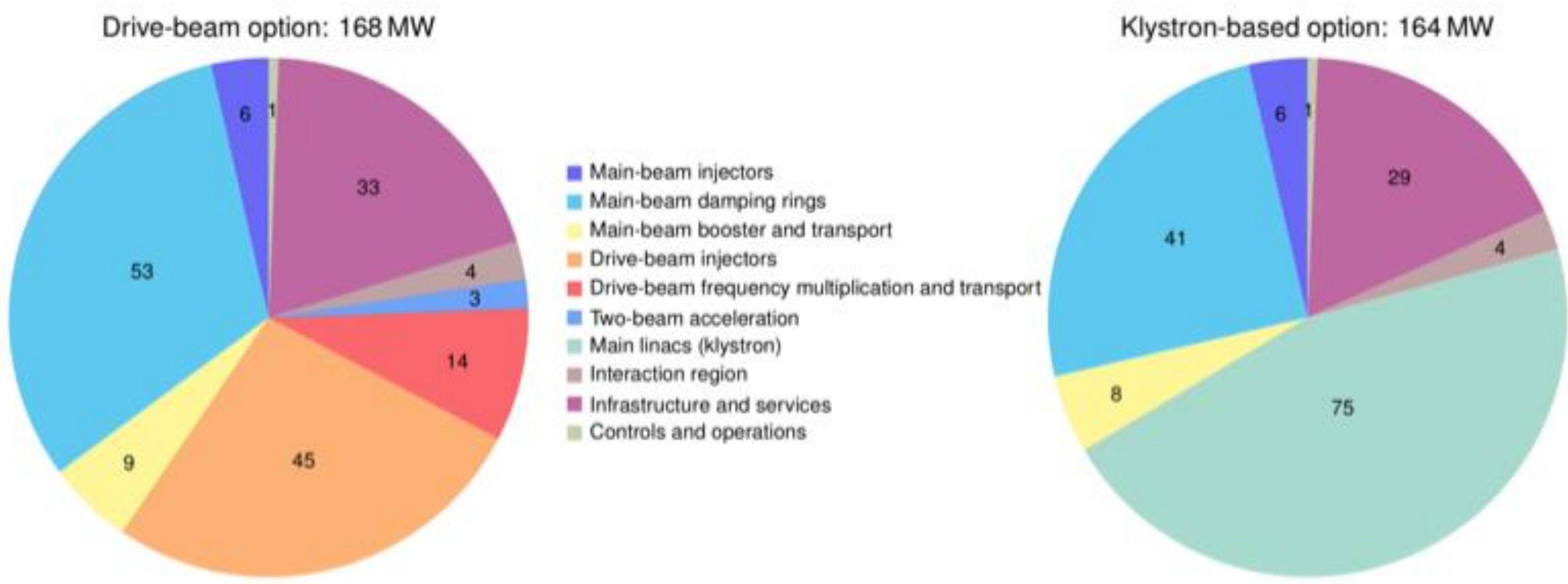
(b)



Power

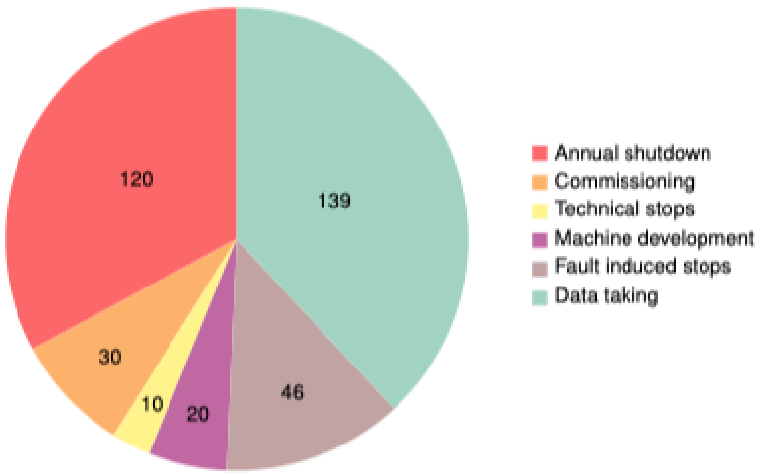
Power estimate bottom up (concentrating on 380 GeV systems)

- **Very large reductions since CDR, better estimates of nominal settings, much more optimised drive-beam complex and more efficient klystrons, injectors etc.**

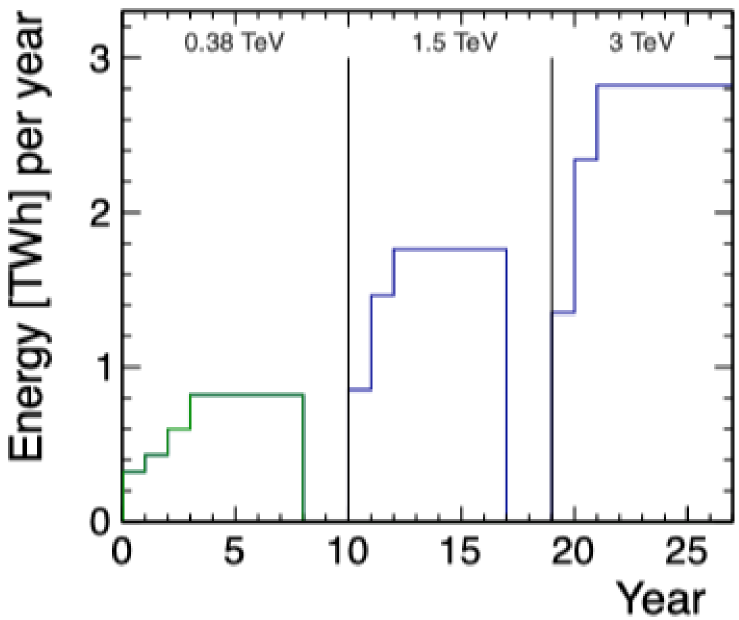


Further savings possible, main target damping ring RF
Will look also more closely at 1.5 and 3 TeV numbers next

Energy



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



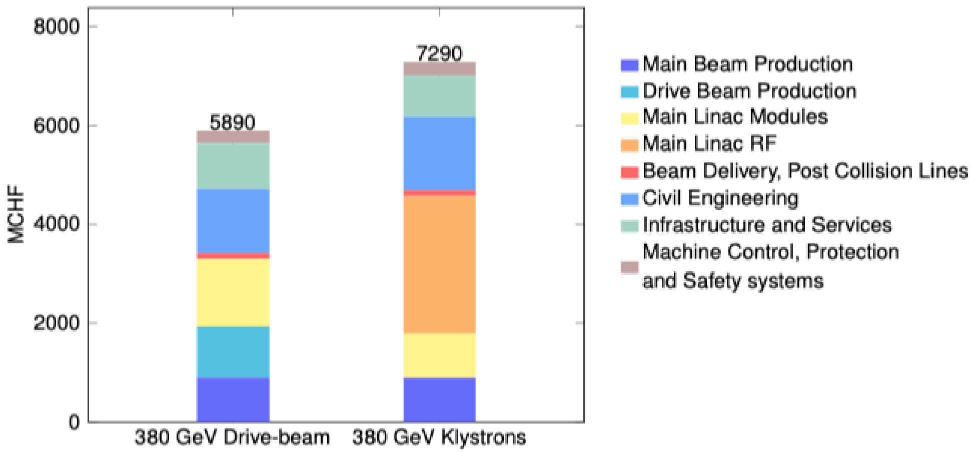
From running model and power estimates at various states – the energy consumption can be estimated

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

Cost – 380 GeV stage

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

- **Methods and costings validated at review on 7 November 2018 – 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.

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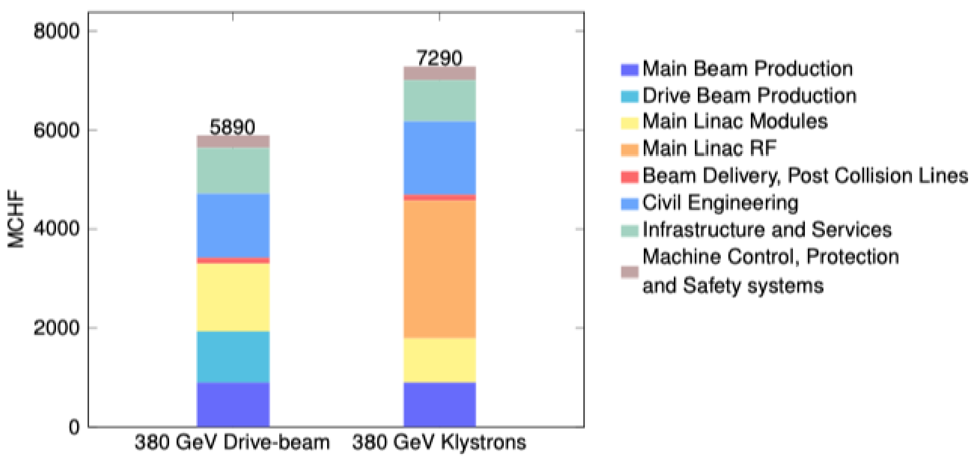

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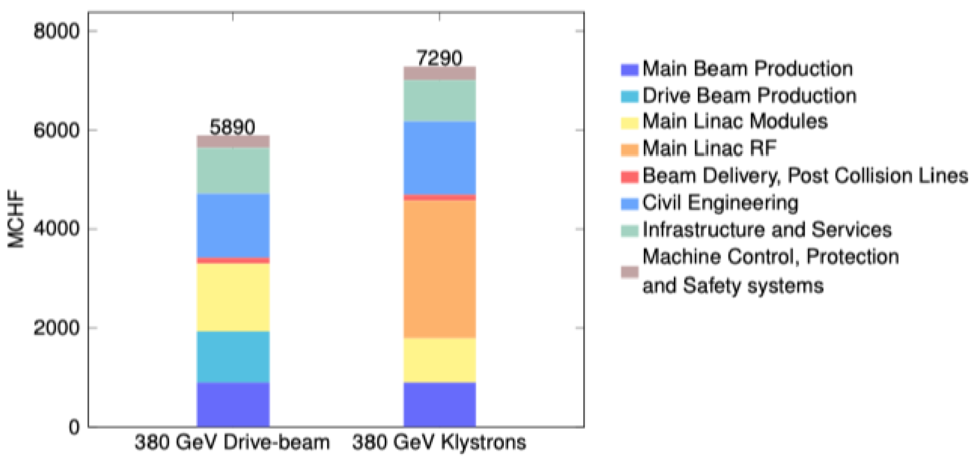

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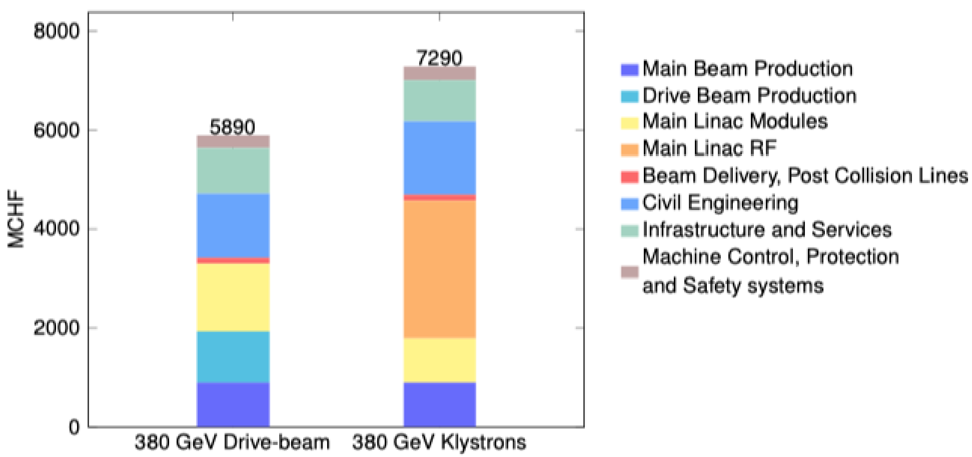

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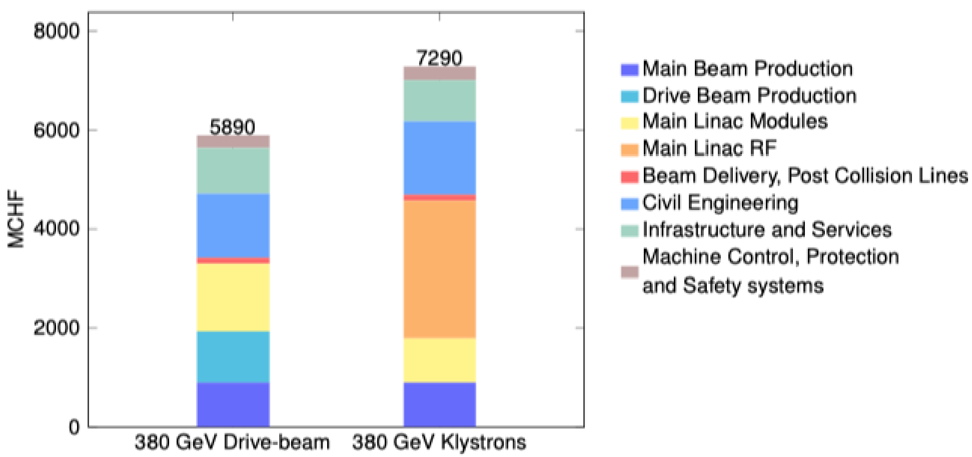

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Costs - II

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 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.

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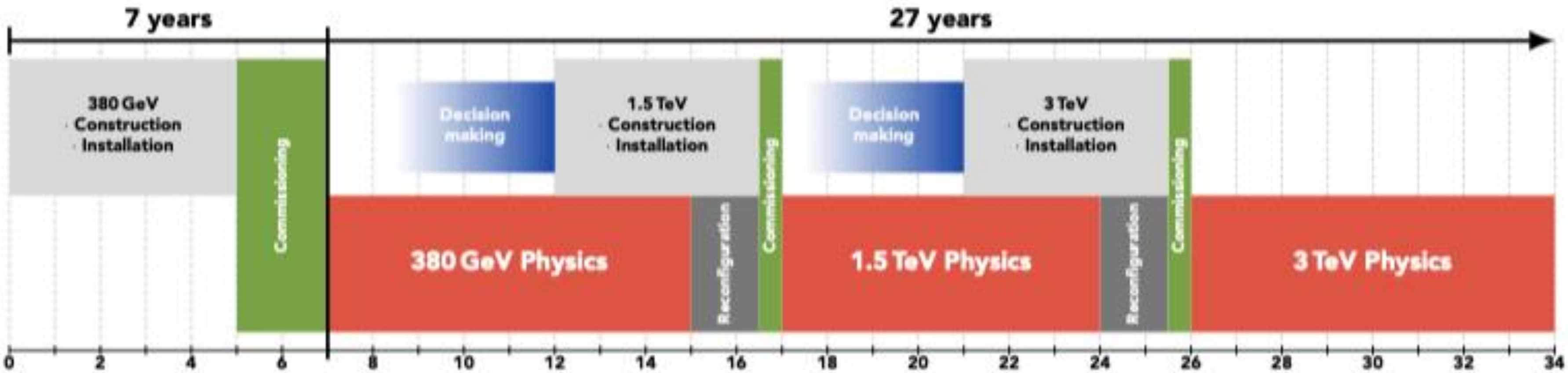
Schedule

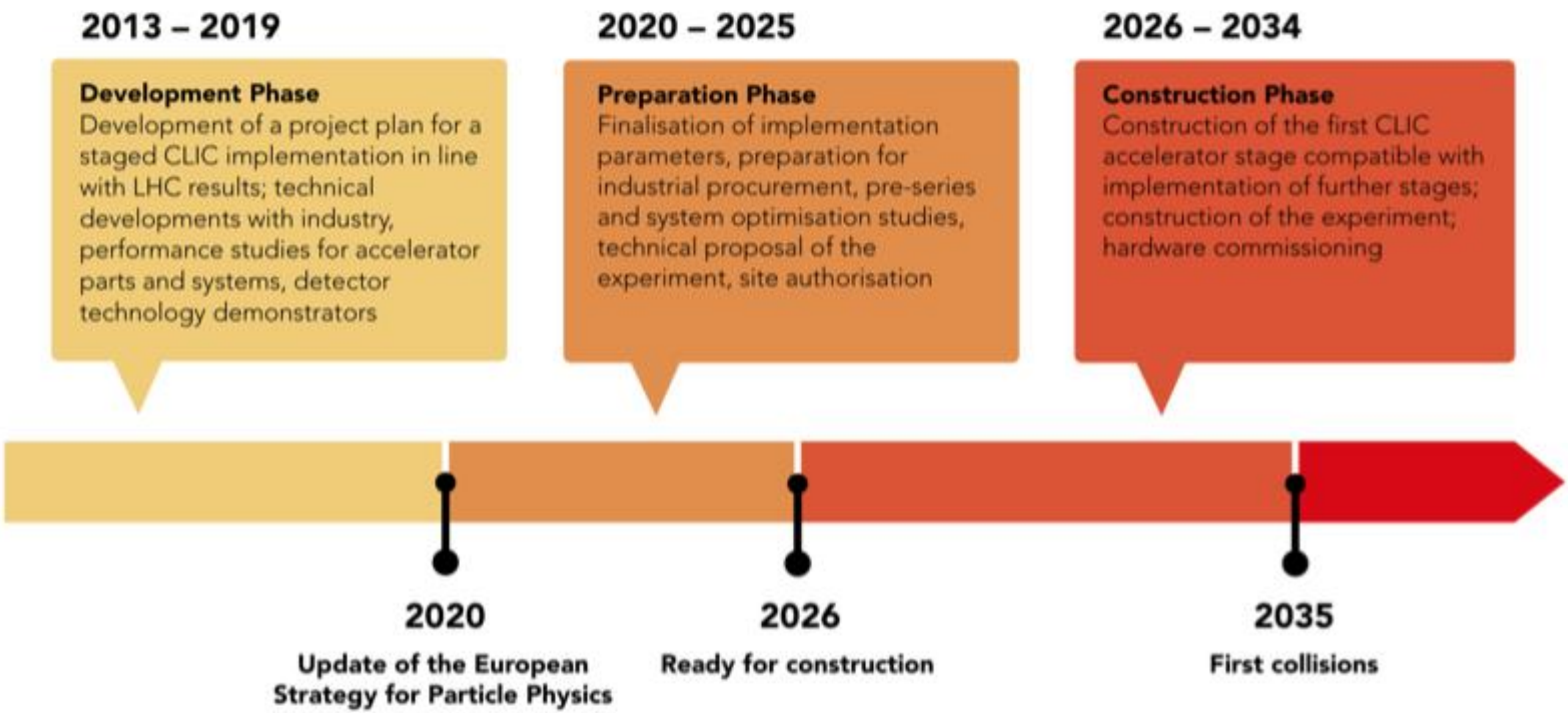


Construction + installation:	**5 years**
Commissioning:	**2 years**
380 GeV physics programme:	**8 years**
Additional energy stages:	**…**

Longer-term outlook

- A LC infrastructure offers possibility to re-use tunnel/infrastructure, injectors, drive-beams, etc. for major energy upgrades with new technologies
- 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
- Working group for use of Novel Acceleration Technologies (NAT):
  plasma wakefield, dielectrics …
- The actual effective linac length might remain short (and hence possibly “cheap” and inter-changeable in a limited time)
  → long term perspective worth considering
- Short chapter in Project Implementation Plan

CLIC roadmap



Next phase 2020-25

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 t*enders*
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 NCRF technology

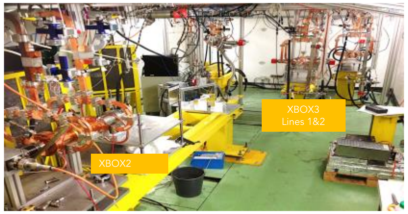
Prototype components

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

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

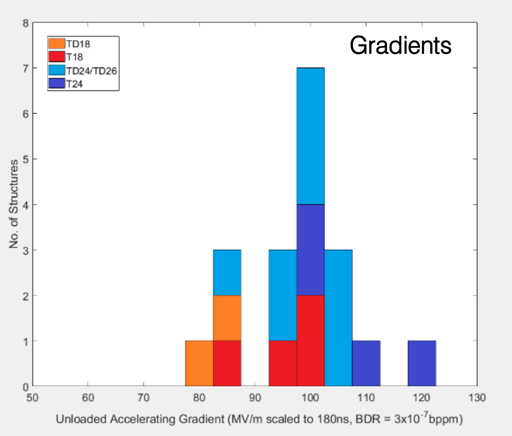
Systems and 100 MeV-range facilities

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



Normal-conducting, low- emittance GeV-range facilities

Operational
- SACLA
- SwissFEL

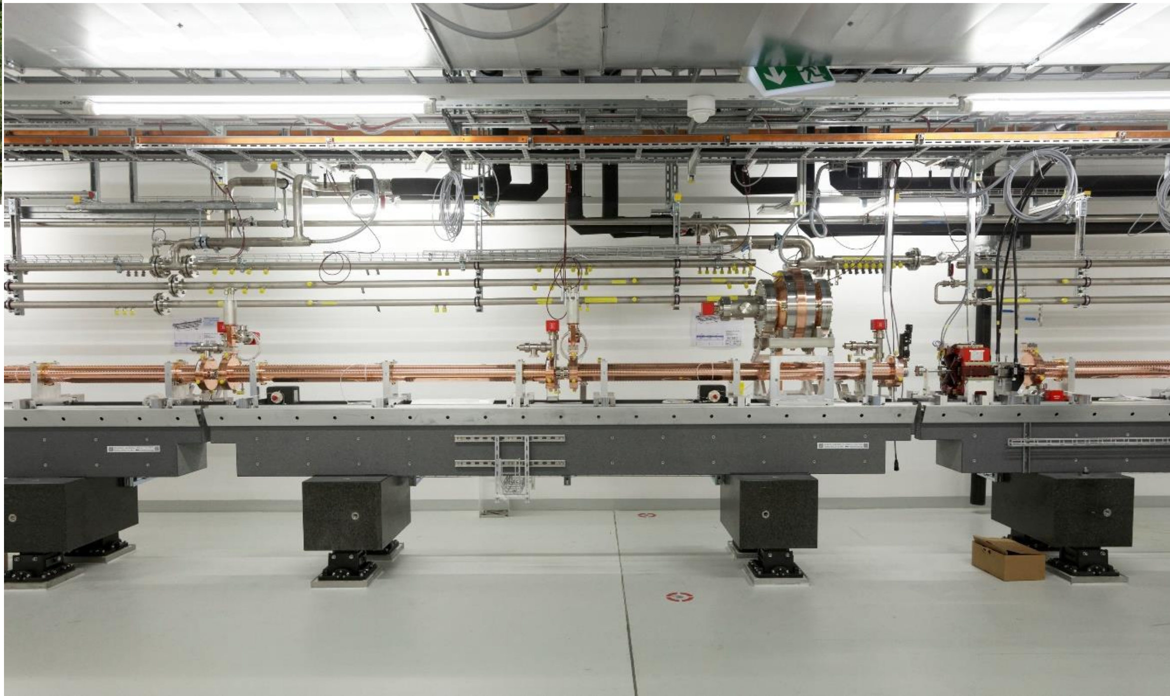


X-band GeV-range facilities

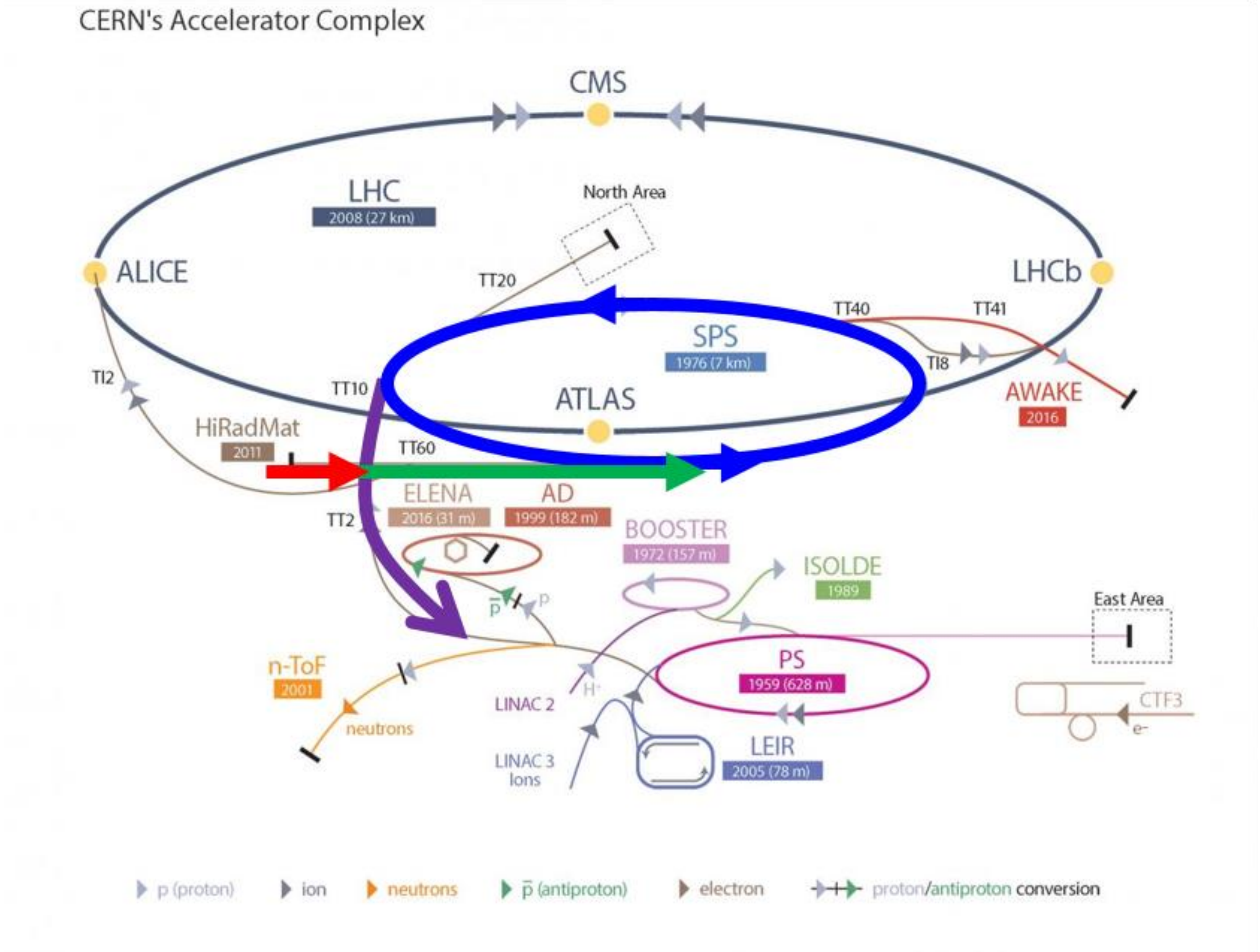
Planning:
- EU-Praxia
- eSPS
- CompactLight

SwissFEL

- **104 x 2m-long C-band structures (beam → 6 GeV @ 100 Hz)**
- **Similar um-level tolerances**
- **Length ~ 800 CLIC structures**



eSPS proposal



3.5GeV Linac

Transfer to SPS

Acceleration to in SPS

Extraction

Summary

- CLIC is now a mature project, ready for implementation
- Offers staged, flexible approach towards the energy frontier
- 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
- 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
- We are sharpening plans for preparation phase 2020-25

Following Granada

- **Looking at CLIC380 design margins:**

'perfect' machine > DR	**L = 4.3 10^{34}**
static imperfections only	**L = 3 10^{34}**
margins for static imperfections	**L = 1.9 10^{34}**
nominal luminosity goal	**L = 1.5 10^{34}**

- **Updating studies for running at Z-pole:**

CLIC380 linacs run @ Z	**L = 2.3 10^{32}**
linacs configured for Z running only	**L = 3.6 10^{33} (PRELIMINARY)**

- **Task force looking at doubling rep rate for CLIC380: 50 Hz → 100 Hz**
  - **double the luminosity**
  - **PRELIMINARY indications: power + ~50 MW, cost + ~5%**

- **Updating concept for gamma-gamma collisions**

Thanks to all CLIC collaborators for outstanding support

Backup slides

Key technical challenges

- **High-current drive beam bunched at 12 GHz**

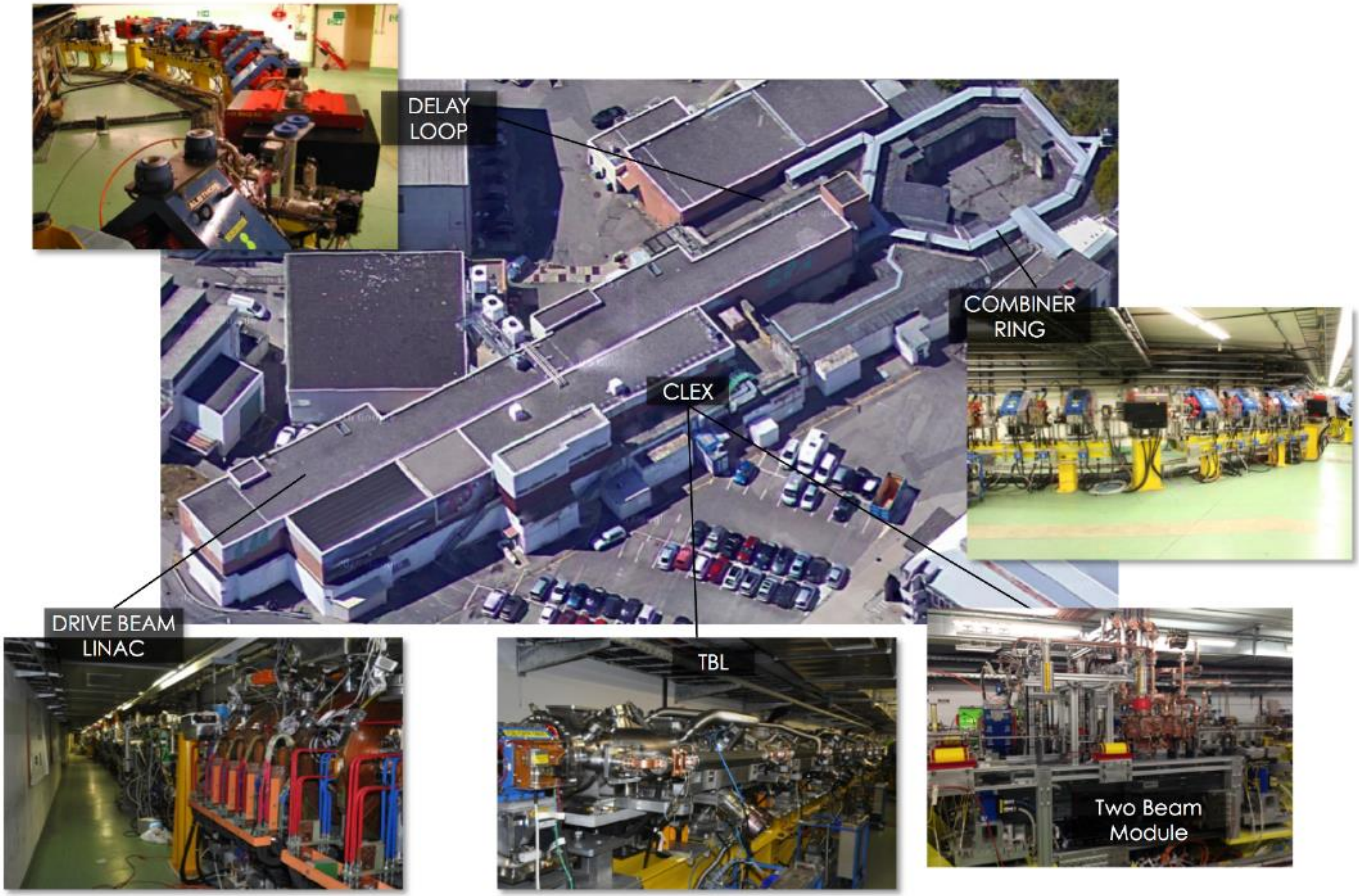
- **Power transfer + main-beam acceleration**

- **100 MV/m gradient in main-beam cavities**

- **Produce, transport + collide low-emittance beams**
- **System integration, engineering, cost, power …**

LINEAR COLLIDER COLLABORATION

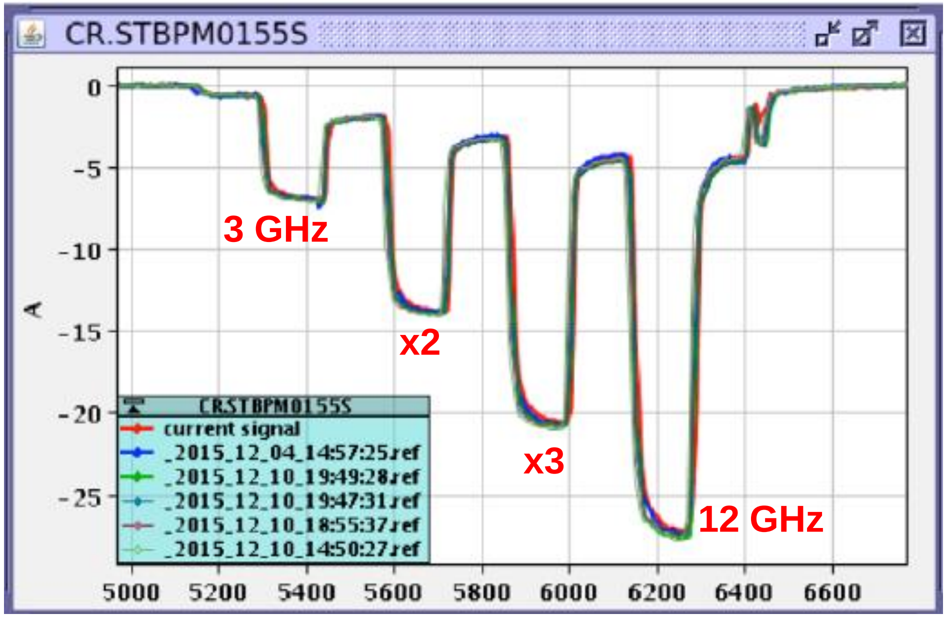
CLIC Test Facility (CTF3)



LINEAR COLLIDER COLLABORATION

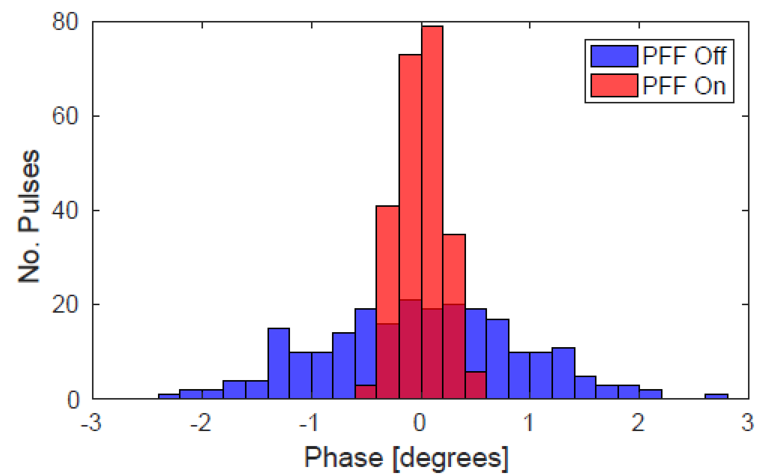
Status

- **Produced high-current drive beam bunched at 12 GHz**



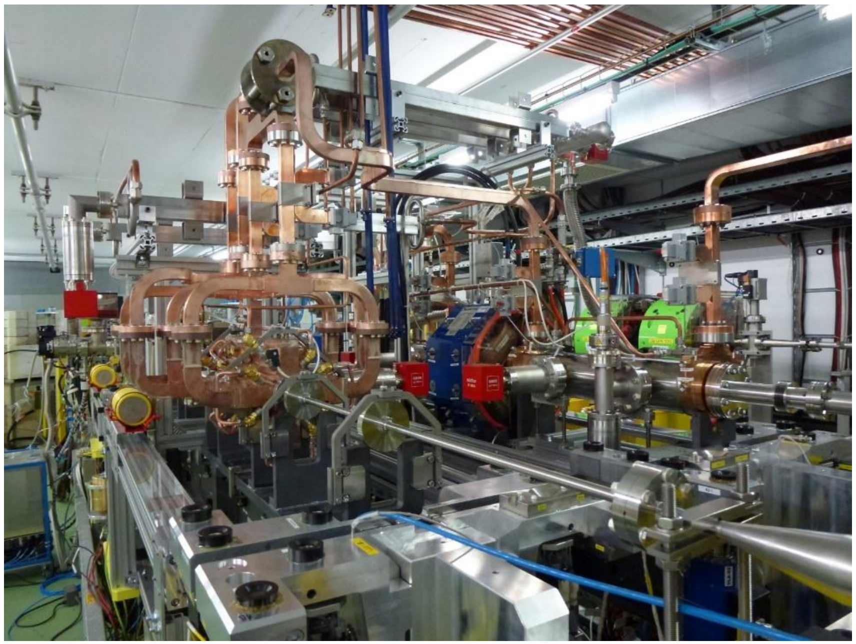
28A

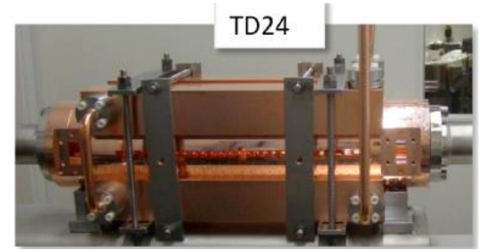
Arrival time stabilised to 50 fs



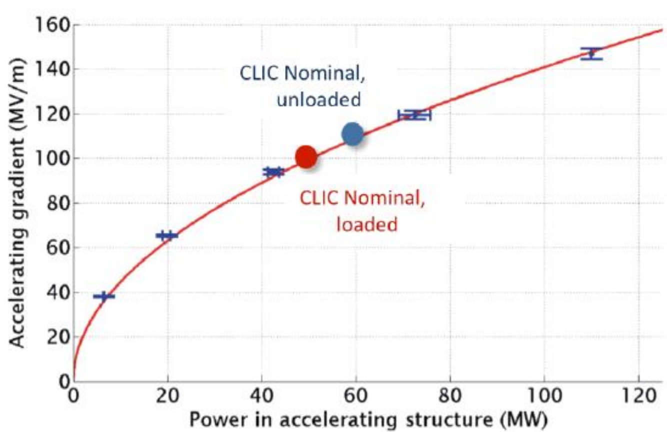
Status

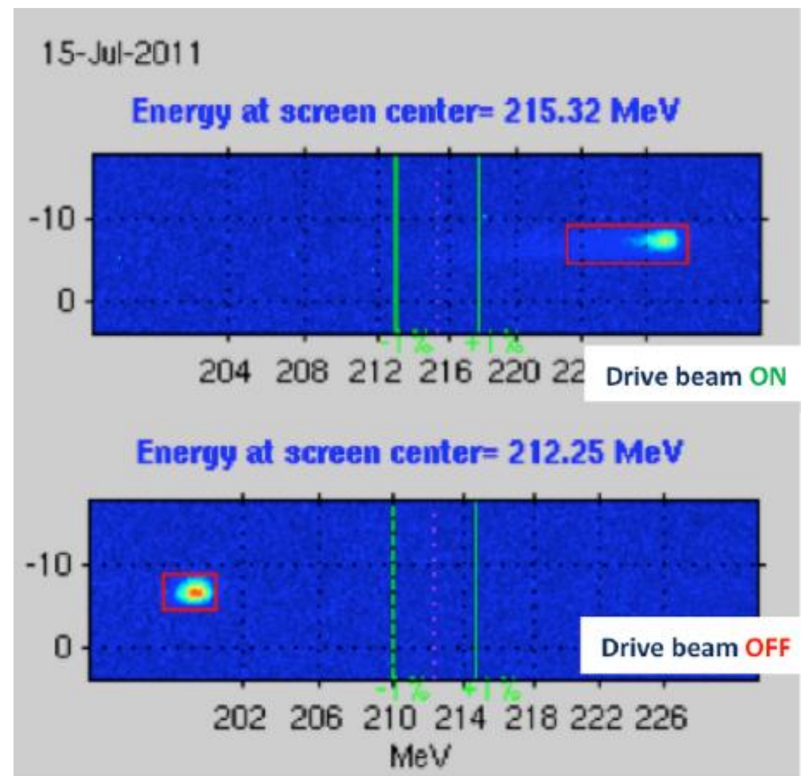
- **Demonstrated two-beam acceleration**





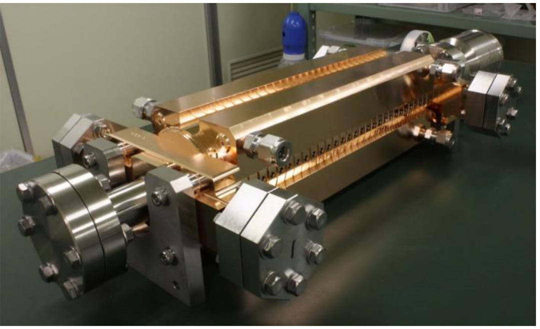
31 MeV = 145 MV/m

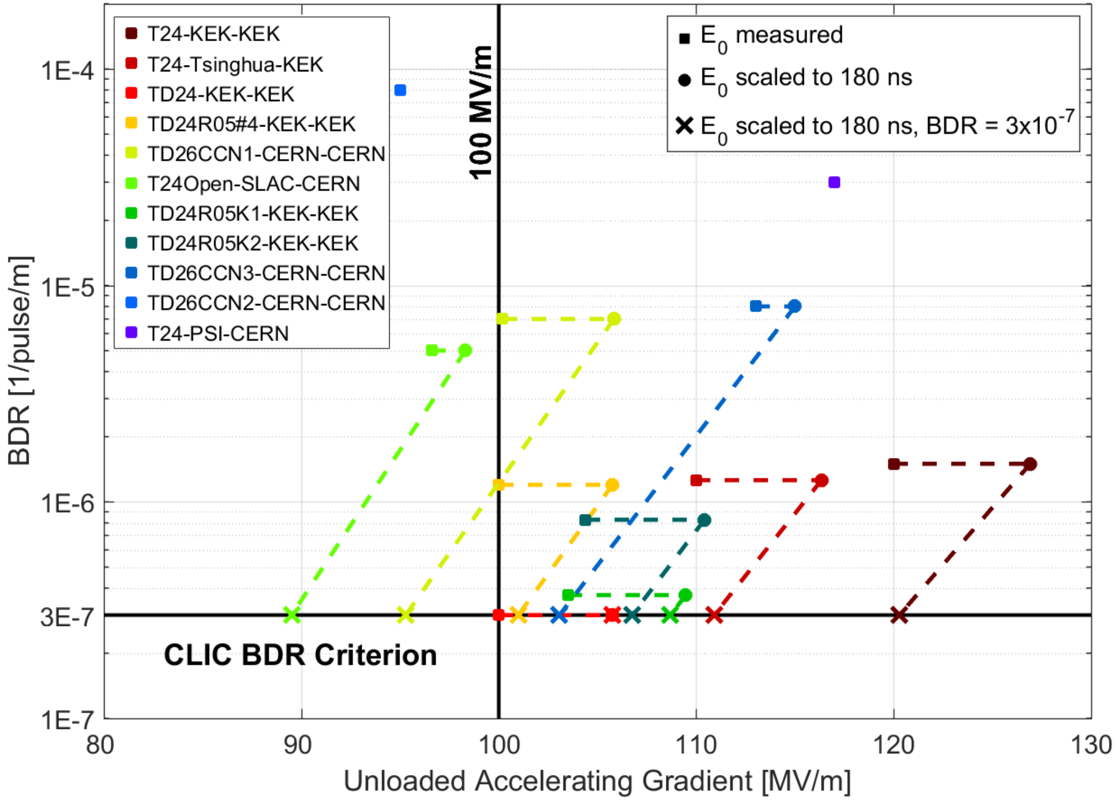


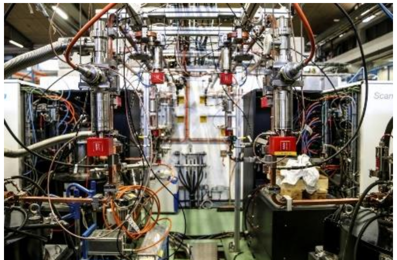


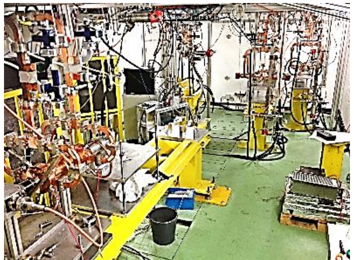
Status

- **Achieved 100 MV/m gradient in main-beam RF cavities**









Key technical challenges

- High-current drive beam bunched at 12 GHz ✔
- Power transfer + main-beam acceleration ✔
- 100 MV/m gradient in main-beam cavities ✔

→ Industrialisation of 12 GHz RF/structure technologies
→ Application to medium- and large-scale systems

Updated CLIC luminosity model

First-stage construction period ends with one year of beam commissioning with the whole machine before Lumi starts

Luminosity ramp-up:

380 GeV:	**10%, 30%, 60% then nominal L (same as ILC)**
1.5 TeV:	**25%, 75% then nominal L**
3 TeV:	**25%, 75% then nominal L**

Updated CLIC availability model

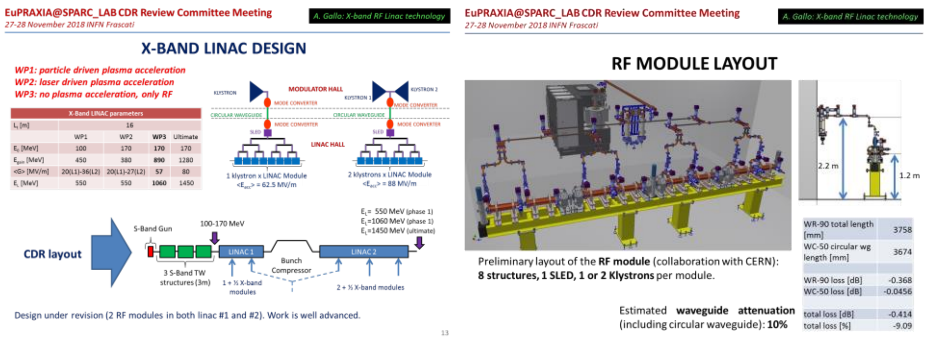
Task force study of LHC + modern light sources;

→ CLIC availability model common with FCCee

120 days	**winter shutdown (17 weeks)**
30 days	**commissioning**
20 days	**machine development**
10 days	**technical stops**
185 days	**physics @ 75% efficiency**
	→ 1.2 107 s** (c.f. ILC 1.6 10**7 s)

LINEAR COLLIDER COLLABORATION

EuPRAXIA@SPARC_LAB



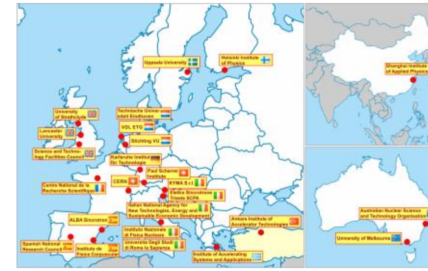
Compact

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.

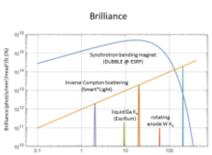
Based on advances in:

- Injectors
- X-band linac technology
- Undulators

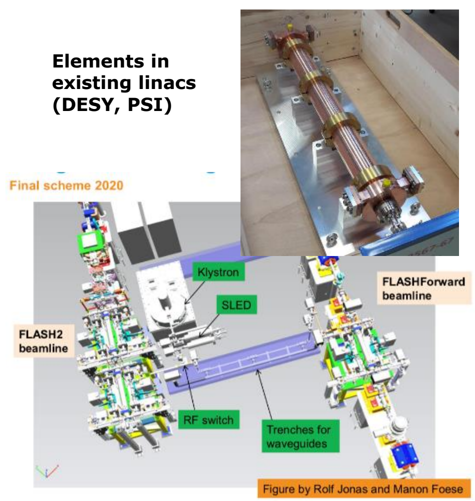


Inverse Compton Scattering Source - Smart*Light

Compact, highly monochromatic X-ray source.
Complementary to X-ray tube and synchrotron light source.
Applications in cultural heritage, material science, medical, etc.



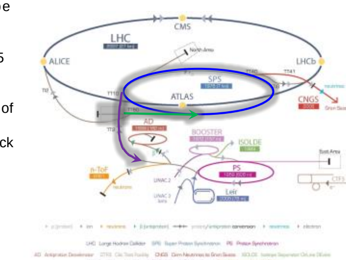
Elements in existing linacs (DESY, PSI)



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

Full project schedule