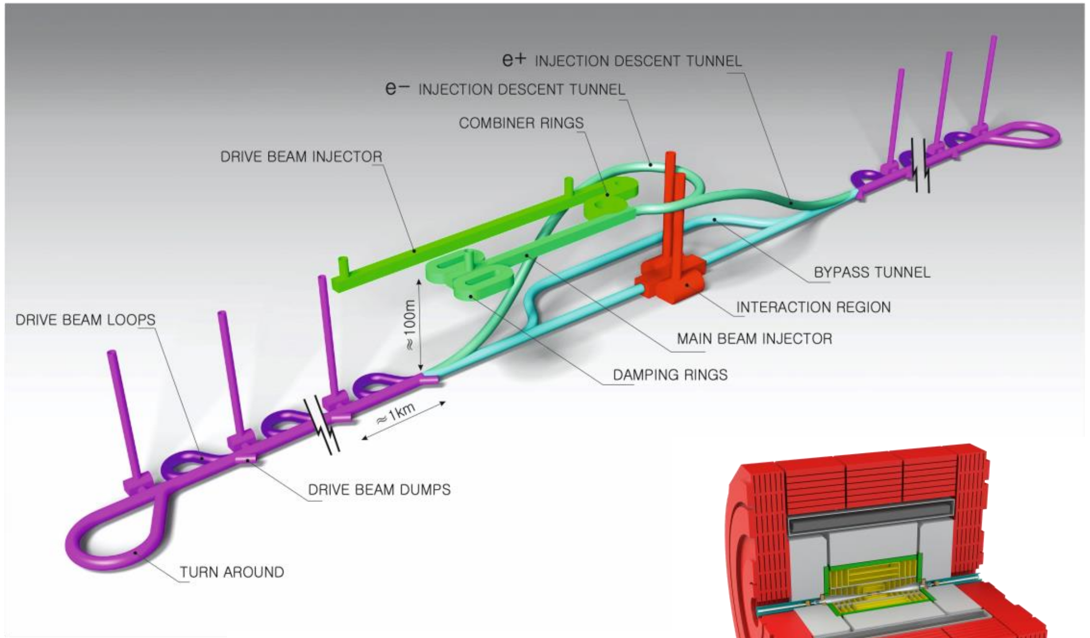
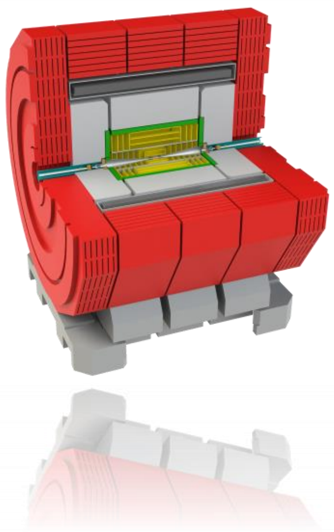
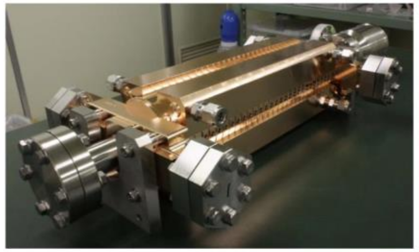
The Compact Linear Collider (CLIC)





Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)



- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20'500 structures at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision energies from 380 GeV (Higgs/top) up to 3 TeV (Energy Frontier)

- CDR in 2012 with focus on 3 TeV. Updated project overview documents in 2018 (Project Implementation Plan) with focus 380 GeV for Higgs and top.

- **Cost:** 5.9 BCHF for 380 GeV (stable wrt 2012)
- **Power:** 168 MW at 380 GeV (reduced wrt 2012), corresponding to 60% of CERN's energy consumption today

- Comprehensive **Detector and Physics** studies

15:50 → 16:05 **CLIC physics and detector activities**
Speaker: Aidan Robson (University of Glasgow (GB))

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 is a mature design/study

The CLIC accelerator studies are mature:

Optimised design for cost and power

Many tests in CTF3, FELs, lightsources and test-stands

Technical developments of “all” key elements

Resources

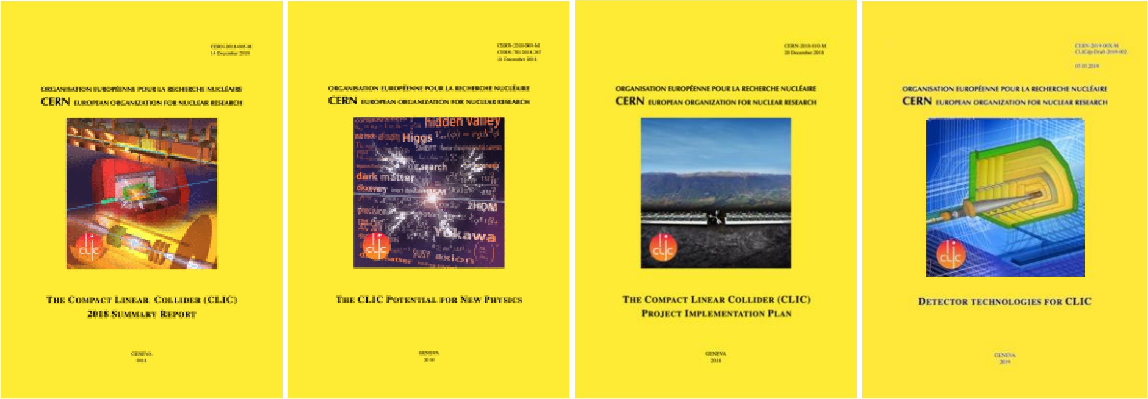
Available at:
clic.cern/european-strategy

3-volume CDR 2012

Updated Staging Baseline 2016

Two formal submissions to the ESPPU 2018

4 CERN Yellow Reports 2018



Details about the accelerator, detector R&D, physics studies for Higgs/top and BSM

Several LoIs have been submitted on behalf of CLIC and CLICdp to the Snowmass process:

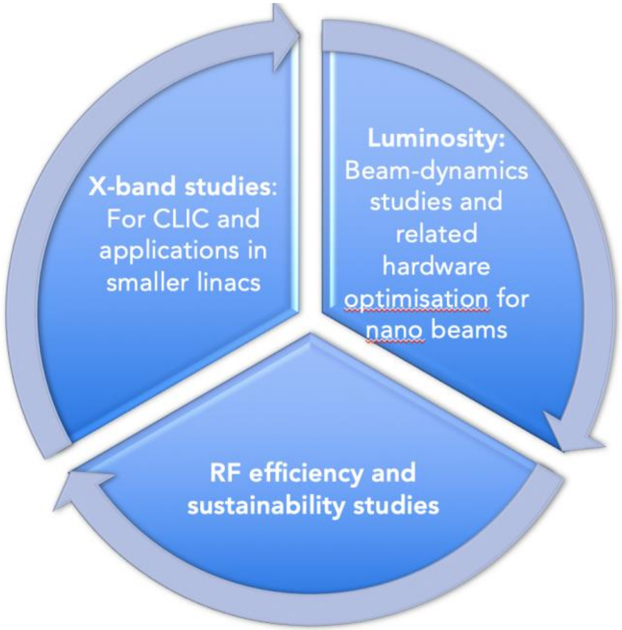
The CLIC accelerator study: Link
Beam-dynamics focused on very high energies: Link
The physics potential: Link
The detector: Link

CLIC Project Readiness 2025-26

Project Readiness Report as a step toward a TDR – for next ESPP
Assuming ESPP in 2026, Project Approval ~ 2028, Project (tunnel) construction can start in ~ 2030.

Focusing on:

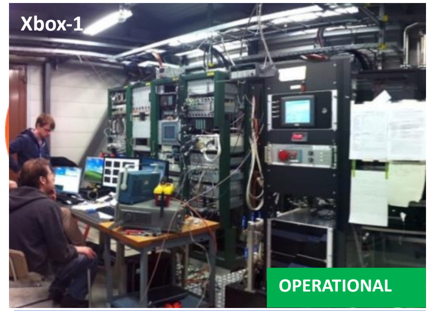
- The X-band technology readiness for the 380 GeV CLIC initial phase
- Optimizing the luminosity at 380 GeV
- Improving the power efficiency for both the initial phase and at high energies



Goals for these studies by ~2025:

- Improved 380 GeV parameters/performance/project plan
- Push multi-TeV options/parameters

X-band



CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz
Beam test capabilities

Ongoing test:
CPI2 repair validation and interferometry tests

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz

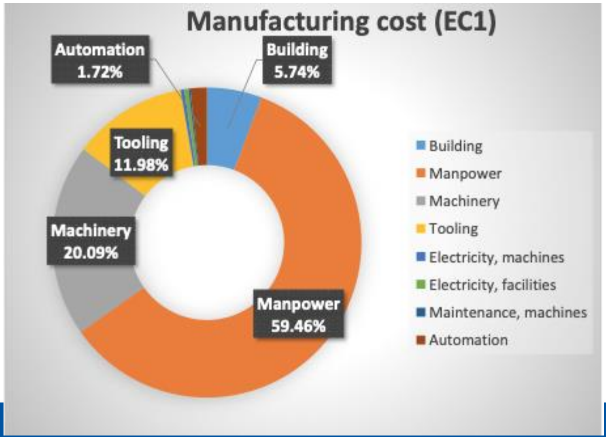
Ongoing test:
CLIC TD26 CLEX SuperStructure

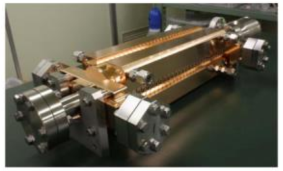
2x Toshiba 6MW 5us klystron
2x Scandinova Modulators
Rep Rate 400Hz

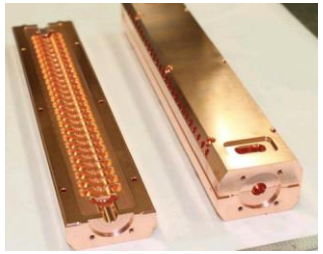
Ongoing test:
SARI X-band deflector
High power window

S-box (3GHz) also being set up again to test KT structure, PROBE and the new injector

Industrial questionnaire:
Based on the companies feedback, the preparation phase to the mass production could take about five years. Capacity clearly available.







Structures and components production programme to study designs, operation/conditioning, manufacturing, industry qualification/experience

EU projects: ARIES, I-FAST, new TNA

X-band

CPI 50MW 1.5u
Scandinova Mo
Rep Rate 50Hz
Beam test capa

Ongoing test:
CPI2 repair valid
interferometry te

S-box (3

Industrial
Based or
mass pro
available

09:00 → 09:15 **X-band design activities**

Speaker: Ping Wang (CERN)

09:20 → 09:35 **Xband structures and components**

Speaker: Pedro Morales Sanchez (Centro de Investigaciones Energéti cas Medioambientales y Tecnológicas (ES))

09:40 → 09:55 **X-Band Interferometry at Xbox1 and Xbox Status**

Speaker: Amelia Veronica Edwards (Lancaster University)

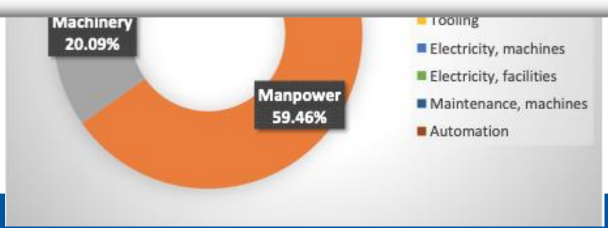
10:00 → 10:15 **Monte Carlo simulation of HG conditioning and operation**

Speaker: Lee Millar (CERN)

10:20 → 10:35 **Xband technology spread and societal impact**

Speaker: Anastasiya Magazinik (Helsinki Institute of Physics (FI))

me to study
industry

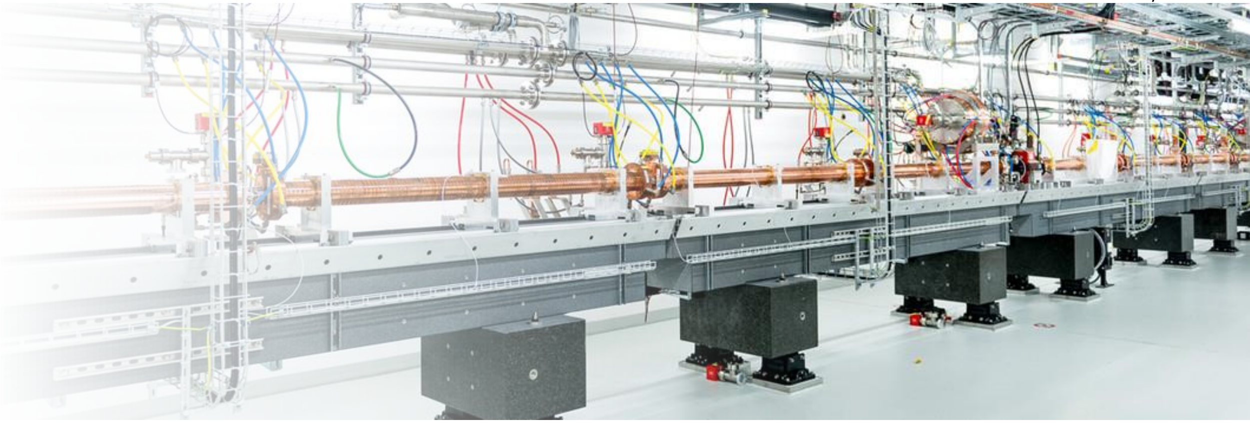


Use in smaller linacs (C and X-band)

SwissFEL: C-band linac

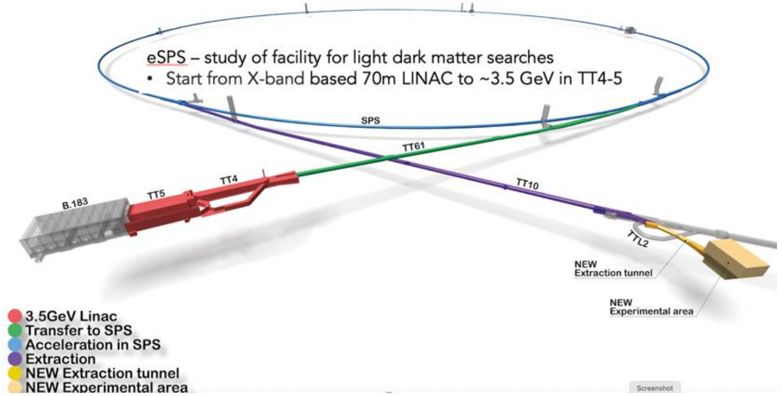
- 104 x 2 m-long C-band (5.7 GHz) structures (beam up to 6 GeV at 100 Hz)
- Similar μm-level tolerance
- Length ~ 800 CLIC structures
- Being commissioned
- X-band structures from PSI perform well

Photo: SwissFEL/PSI



26 academic and industrial partners: http://www.compactlight.eu/Main/HomePage

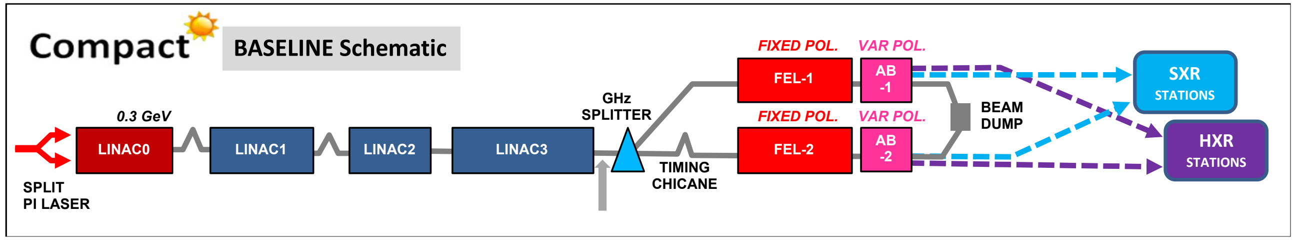
CompactLight Design Studies 2018-21 (link)
Compact FEL based on X-band technologies

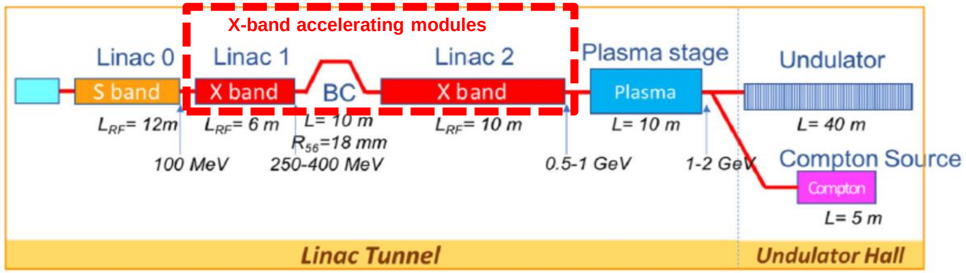


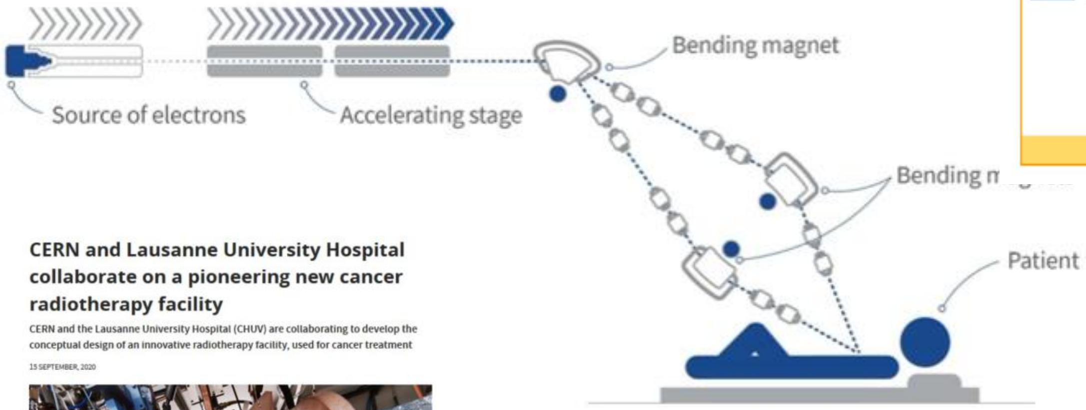
CERN: eSPS study (3.5 GeV X-band linac)

Applications – injector, X-band modules, RF

- CompactLight Design Studies 2018-21 (right)
- INFN 1 GeV linac
- Flash RT, at CHUV (see talk of M.Cirilli)
- “Design Studies” for ICS
- AERES, IFAST and TNA project



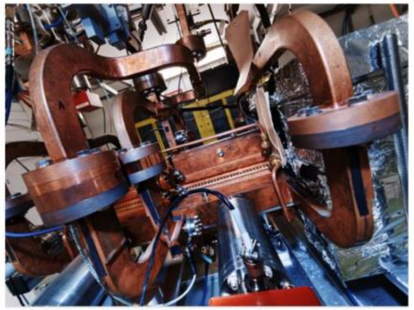


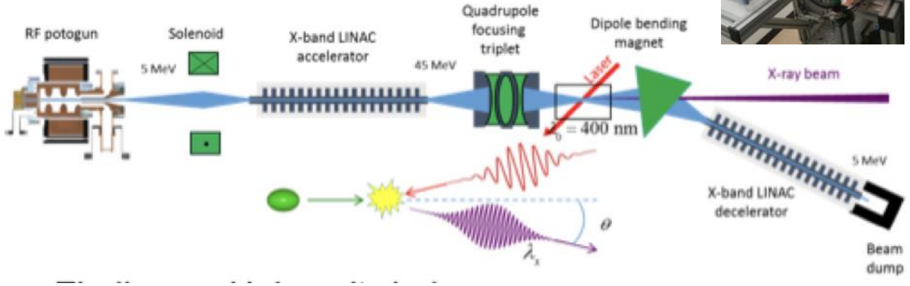


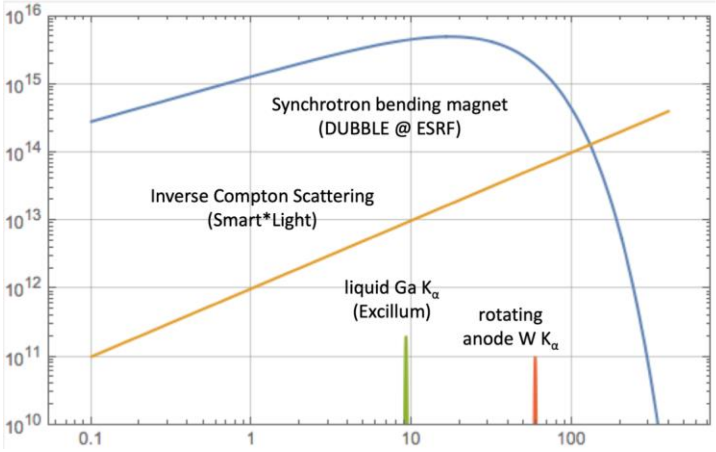
CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility

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







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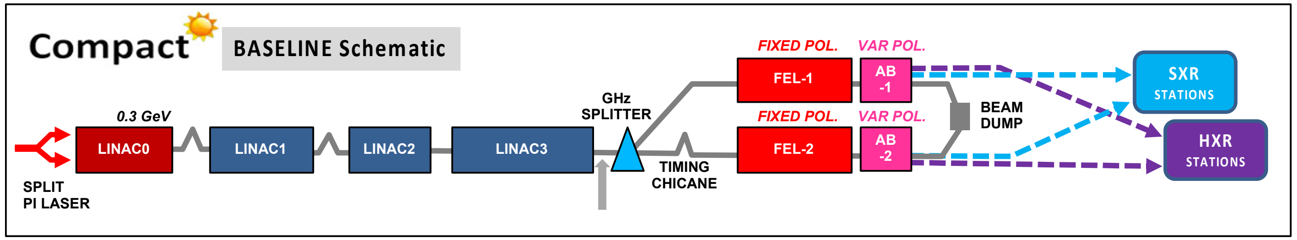
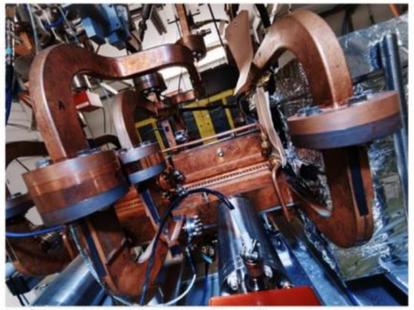


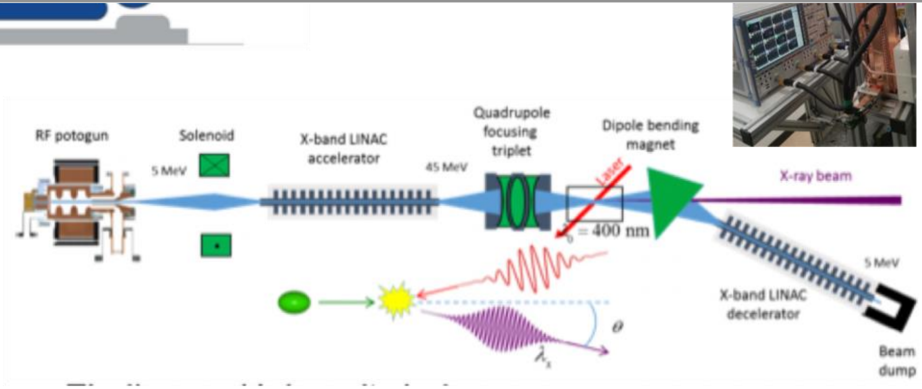
11:20 → 11:35 **CompactLight and ICS including new EU project ideas**

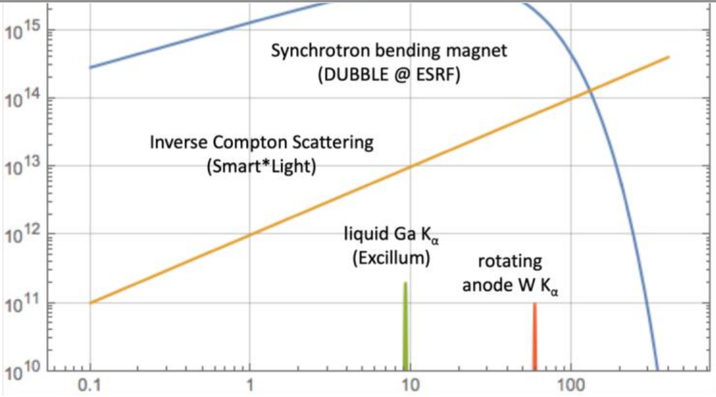
Speaker: Gerardo D'Auria (Elettra Trieste)

11:40 → 11:55 **X-band in linacs outside particle physics and “novel” R&D ideas for gradient and/or power-efficiency**

Speaker: Walter Wuensch (CERN)







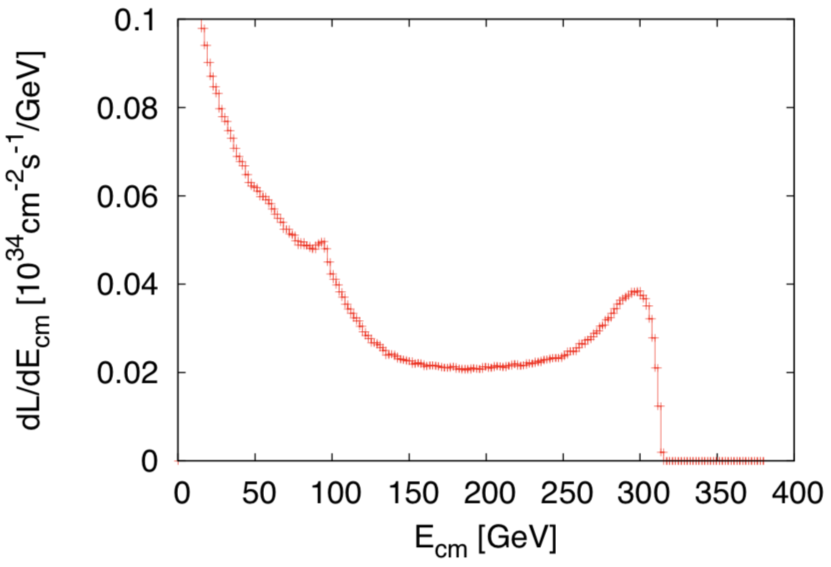
CLIC acc. studies – luminosities

Further work on luminosity performance, possible improvements and margins, operation at the Z-pole and gamma-gamma

- Z pole performance, 2.3×10^{32} – 0.4×10^{34} cm^{-2} s^{-1}
  - The latter number when accelerator configured for Z running (e.g. 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 upside
  - In addition: doubling the frequency (50 Hz to 100 Hz) would double the luminosity, at a cost of +50 MW and ~5% cost increase

  - **Studies cover from beam-dynamics to technical studies of the required performances of stability, alignment, instrumentation, magnets, BDS, final focus, injectors including positrons, damping rings – priority for next ESU**

- CLIC note and paper about these studies



Luminosity related

See talks in earlier PMs this year:
https://indico.cern.ch/event/1042101/contributions/4377679/attachments/2264162/3843869/CLIC_Project6.pdf (Daniel Schulte)

Positron studies(see for example talk by Hugo Bajas):
https://indico.cern.ch/event/995633/contributions/4270584/attachments/2209893/3739822/LCWS2021_H_Bajas.pdf

Nanobeam workshop (summary by Nuria Catalan):
https://indico.cern.ch/event/995633/contributions/4271717/attachments/2209497/3739115/NanobeamsWS_LCWS2021.pdf

14:30	→ 14:45	**Module and main linac studies** **Speaker**: Matthew John Capstick (CERN)
14:50	→ 15:10	**Coffee Break**
15:10	→ 15:25	**DR Longitudinally Variable Field Dipole: Assembly and Magnetic Measurements** **Speaker**: Manuel Dominguez (Centro de Investigaciones Energéti cas Medioambientales y Tecno)

Program and organization team

- Nuria Catalan-Lasheras
- Angeles Faus-Golfe
- Thibaut Lefevre
- Helene Mainaud-Durand
- Yannis Papaphilippou
- Nobuhiro Terunuma
- Alexia Augier
- Grace Fern Jackson

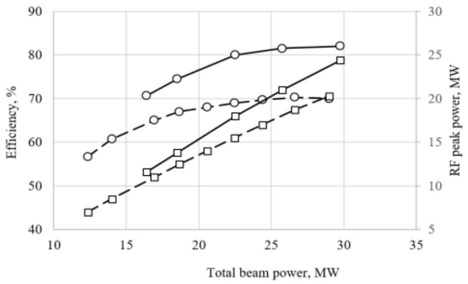
Tuesday 2 February 2021

Beam dynamics (Chair: N. Catalan-Lasheras)	Welcome and introduction	Steinar Stapnes
	Beam dynamics tolerances for Rings.	Yannis Papaphilippou
	Beam dynamics tolerances for FELs and Linear colliders.	Andrea Latina
	Jitter control and Feedback (IP, DB).	Philippe Burrows
Break		
Magnets (Chair: A. Faus-Golfe)	Permanent adjustable Magnets	Ben Shepard
	SC Low-beta magnets	Brett Parker
	High-field undulators/wigglers HTS	Daniel Schoerling
	Special magnets (ATF octupoles, skew sextupoles)	M. Modena
	High-field longitudinal gradient dipoles.	Manuel Dominguez
	Crab cavities	S. Verdu
RF/Injection/Extraction (Chair: T. Lefevre)	RF design for High-frequency systems for rings (including lo	Themis Mastoridis
	Injection systems and methods for ultra-low emittance rings	Masamitsu Aiba
	Power systems for low emmittance rings	Erk Jensen
	Wake-field monitors and wakefield mitigation.	Kyrre Ness Sjobaek
	Kicker design with tight kick tolerances and Pulsers with ultr	Mike Barnes
Break		
Instrumentation (Chair: H. Mainaud-Durand)	Overview on profile measurements of nano-beams.	Thibaut Lefevre
	Measuring nanometer beam size at final focus.	Toshiyuki Okugi
	High resolution cavity BPMS. From prototype to larger produ	Alexej Lyapin
	Non-invasive beam measurement using polarisation radiatio	Pavel Karataev
	X -band transverse deflection structure with variable polariz	Barbara Marchetti
	Measuring femtosecond bunches using Electro-optical techn	Serge Bielawski
Alignment and stability (Chair: Terunuma)	The PACMAN project results.	Helene Mainaud-Durand
	Structured laser beam for alignment.	Jean-Christoph Gayde
	Status MDI alignment.	Leonard Watrelot
	Development of low-cost alignment systems.	Mateusz Sosin
	Girder stability LAPP	Gael Balik
Break		
Vacuum and wrap-up (Chair: Y. Papaphilippou)	"Very thin" Non-Evaporable Getter coatings for particle acce	Pedro Costa Pinto
	Development of thin-walled copper electroformed vacuum c	Lucia Lain Amador
	Measuring conductivity of coated surfaces at high frequency.	Andrea Pasarelli
	Beam dynamics tolerances for next generation of accelerato	Daniel Schulte
	Workshop wrap-up	Nuria Catalan-Lasheras

Damping rings, radio-frequency, magnets, alignment, stabilization, Injection/extraction, vacuum and impedance, instrumentation

High Eff. Klystrons

L-band, X-band (for applications/collaborators and test-stands



Location: CERN Bldg: 112

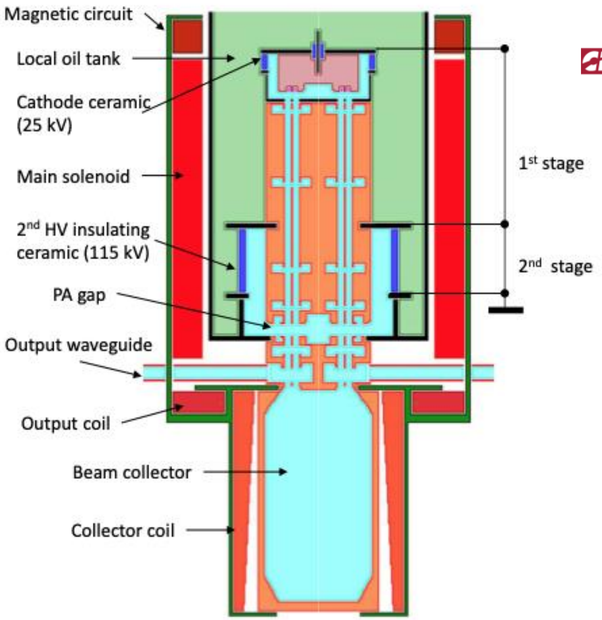
Drivebeam klystron: The klystron efficiency (circles) and the peak RF power (squares) simulated for the CLIC TS MBK (solid lines) and measured for the Canon MBK E37503 (dashed lines) vs total beam power. See more later.

Publication: https://ieeexplore.ieee.org/document/9115885

High Efficiency implementations:

- New small X-band klystron, ordered
- Large with CPI, work with INFN
- L-band two stage, design done, prototyping for FCC

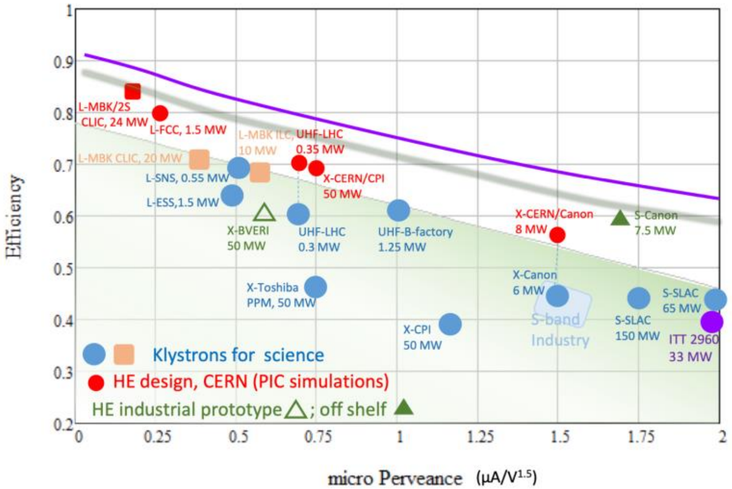
Also important, redesign of damping ring RF system (well underway) – no klystron development foreseen



High Efficiency X-band klystrons retrofit upgrades (in collaboration with CPI and Canon).

50 MW	VKX-8311A	HEX COM_M (CERN/CPI)
Voltage, kV	420	420
Current, A	322	204
Frequency, GHz	11.994	11.994
Peak power, MW	49	59
Sat. gain, dB	48	58
Efficiency, %	36.2	68 / KlyC
Life time, hours	30 000	85 000
Solenoidal magnetic field, T	0.6	0.35/0.6
RF circuit length, m	**0.32**	**0.32**

8-10 MW	E37113 at factory	HEX COM_M (CERN/Canon)
Voltage, kV	154	154
Current, A	93	90
Frequency, GHz	11.994	11.994
Peak power, MW	6.2	8.1
Sat. gain, dB	49	58
Efficiency, %	42	57/ FCI
Life time, hours	30 000	30 000
Solenoidal magnetic field, T	0.35	0.4
RF circuit length, m	**0.127**	**0.127**



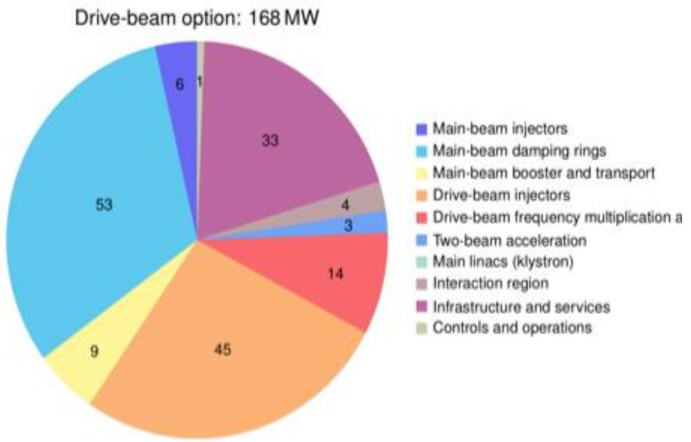
14:10 → 14:25 **Klystron developments for CLIC - Xband and L-band prospects**

Speaker: Igor Syratchev (CERN)

13:50 → 14:05 **CLIC power update**

Speaker: Alexej Grudiev (CERN)

Power and Energy



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 optimized, etc

Further savings possible, main target damping ring RF, L-band klystron (target 140-150 MW)

Energy consumption ~0.8 TWh yearly (target 0.7)
CERN is currently (when) running at 1.2 TWh (~90% in accelerators)

Design Optimisation:

The designs of CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost but also increasingly focussing on reducing power consumption.

Technical Developments:

Technical developments targeting reduced power consumptions at system level high efficiency klystrons, and super conducting and permanents magnets for damping rings and linacs.

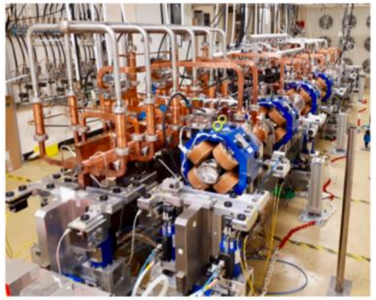
Running when energy is cheap:

CLIC is normal conduction, single pass, can change off-on-off quickly, at low power when not pulsed. Specify state-change (off-standby-on) times and power uses for each – see if clever scheduling using low cost periods, can reduce the energy bill

Renewable energy (carbon footprint):

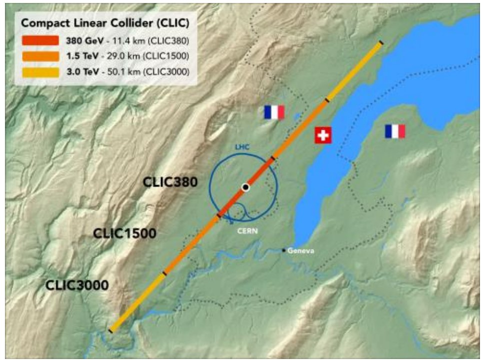
Is it possible to fully supply the annual electricity demand of the CLIC-380 by installing local wind and PV generators (this could be e.g. achieved by 330 MW-peak PV and 220 MW-peak wind generators, at a cost of slightly more than 10% of the CLIC 380 GeV cost)

CLIC can easily be extended



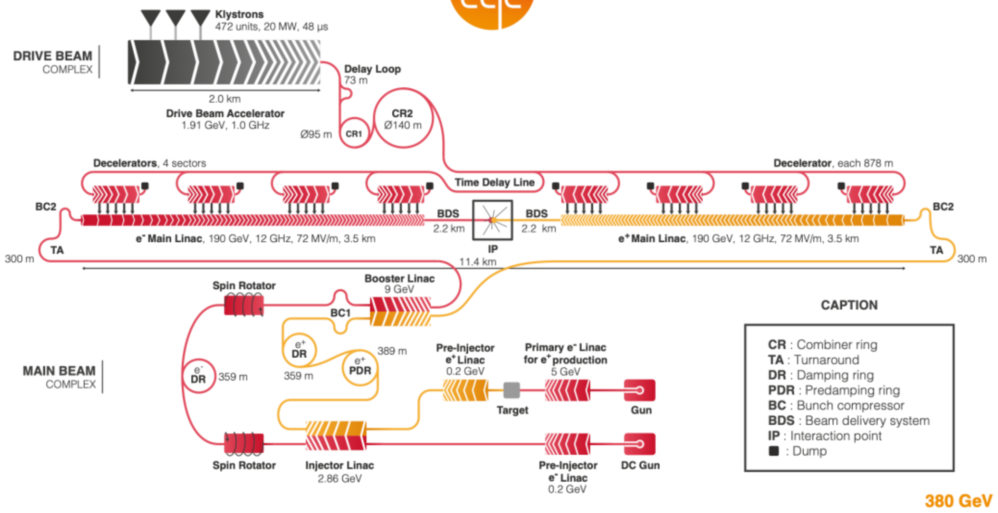
What are the critical elements:

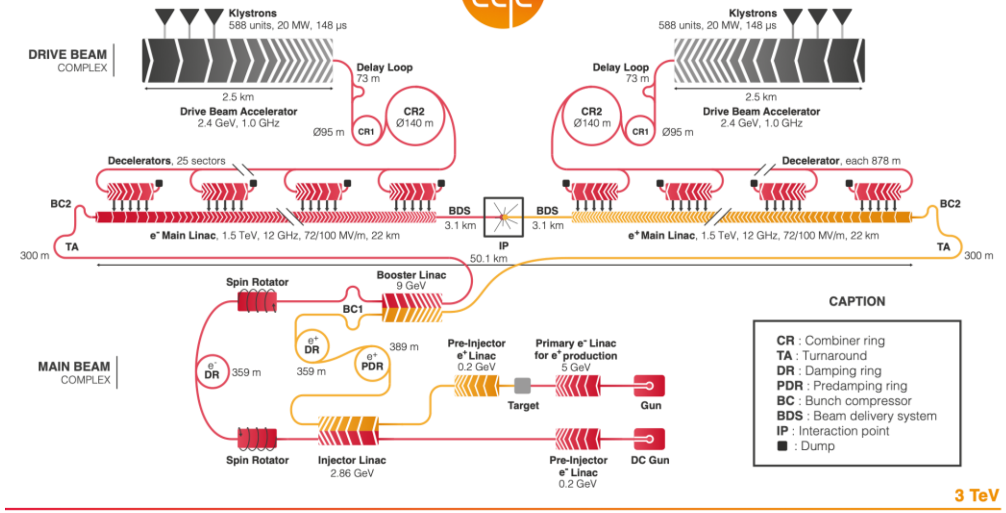
- Physics
- Gradient and power efficiency
- Costs



1. Drive beam accelerated to ~2 GeV using conventional klystrons
2. Intensity increased using a series of delay loops and combiner rings
3. Drive beam decelerated and produces high-RF
4. Feed high-RF to the less intense main beam using waveguides

Extend by extending main linacs, increase drivebeam pulse-length and power, and a second drivebeam to get to 3 TeV

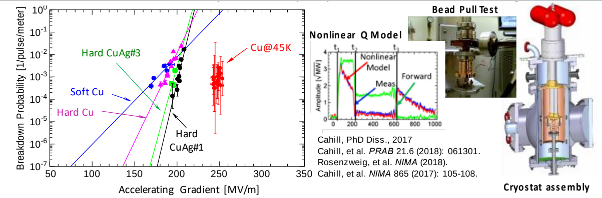




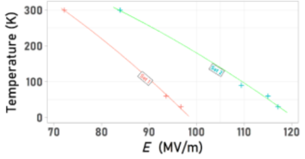
CLIC - Scheme of the Compact Linear Collider (CLIC)

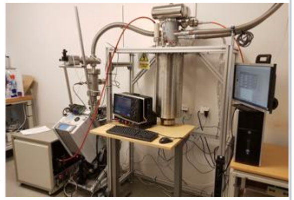
Pushing the RF technologies,

see talk of Walter already mentioned

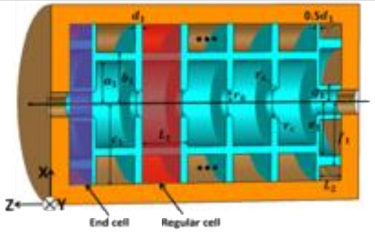


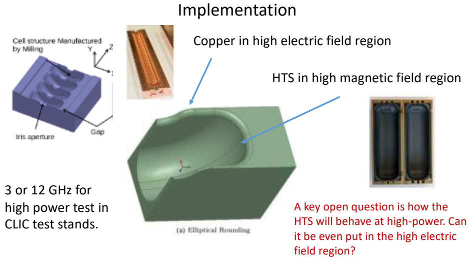
Cryo-cooled copper cavity, SLAC





Cryo-cooled copper pulsed dc electrodes, Uppsala/CERN





Cryogenic systems extended: Combining high-gradients in cryo-copper and high-temperature superconductors for high-efficiency and reduced peak RF power requirements.

And two more talks:

Muon collider towards multi-TeV energies (and technology links to LCs)
Daniel Schulte

CLEAR, touching on many CLIC and technology application studies
Luke Dyks

Monday, 13 December

13:30	→ 13:45	**Introductions, goals for 2025** **Speaker**: Steinar Stapnes (CERN)
13:50	→ 14:05	**CLIC power update** **Speaker**: Alexej Grudiev (CERN)
14:10	→ 14:25	**Klystron developments for CLIC - Xband and L-band prospects** **Speaker**: Igor Syratchev (CERN)
14:30	→ 14:45	**Module and main linac studies** **Speaker**: Matthew John Capstick (CERN)
14:50	→ 15:10	**Coffee Break**
15:10	→ 15:25	**DR Longitudinally Variable Field Dipole: Assembly and Magnetic Measurem** **Speaker**: Manuel Dominguez (Centro de Investigaciones Energéti cas Medioambientales y Tecno)
15:30	→ 15:45	**Muon collider studies and links to LC studies** **Speaker**: Daniel Schulte (CERN)
15:50	→ 16:05	**CLIC physics and detector activities** **Speaker**: Aidan Robson (University of Glasgow (GB))
16:10	→ 16:15	**AOB and end of session**

Tuesday, 14 Decemb

09:00	→ 09:15	**X-band design activities** **Speaker**: Ping Wang (CERN)
09:20	→ 09:35	**Xband structures and components** **Speaker**: Pedro Morales Sanchez (Centro de Investigaciones Energéti cas Medioambientale
09:40	→ 09:55	**X-Band Interferometry at Xbox1 and Xbox Status** **Speaker**: Amelia Veronica Edwards (Lancaster University)
10:00	→ 10:15	**Monte Carlo simulation of HG conditioning and operation** **Speaker**: Lee Millar (CERN)
10:20	→ 10:35	**Xband technology spread and societal impact** **Speaker**: Anastasiya Magazinik (Helsinki Institute of Physics (FI))
10:35	→ 11:00	**Coffee Break**
11:00	→ 11:15	**CLEAR Report** **Speaker**: Luke Aidan Dyks (University of Oxford)
11:20	→ 11:35	**CompactLight and ICS including new EU project ideas** **Speaker**: Gerardo D'Auria (Elettra Trieste)
11:40	→ 11:55	**X-band in linacs outside particle physics and "novel" R&D ideas for grad** **Speaker**: Walter Wuensch (CERN)
12:00	→ 12:05	**AOB and end of meeting** **Speaker**: Steinar Stapnes (CERN)