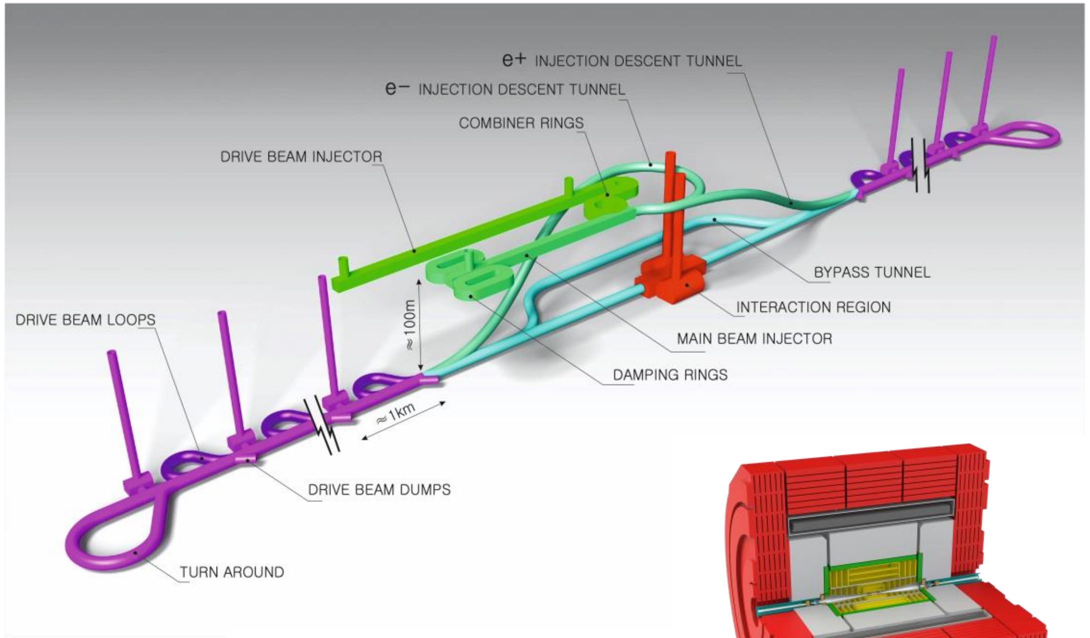
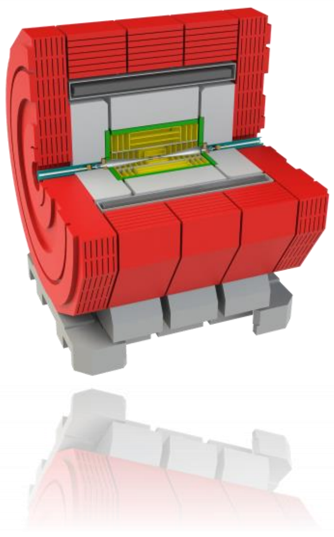
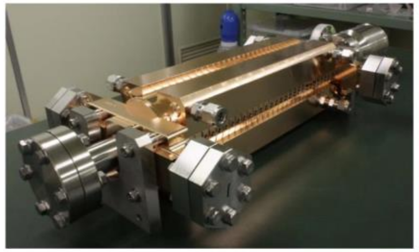
The Compact Linear Collider (CLIC)





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
- **Power/Energy:** 110 MW at 380 GeV (~0.6 TWh annually), corresponding to 50% of CERN’s energy consumption today

- Comprehensive **Detector and Physics** studies

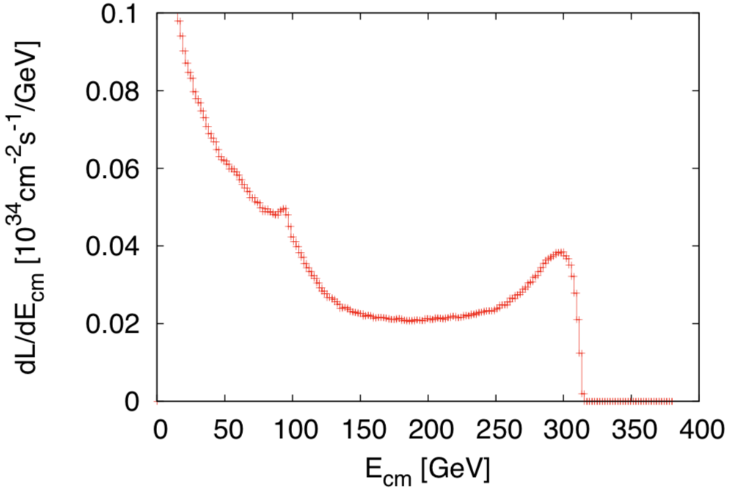
CLIC parameters

Table 1.1: Key parameters of the CLIC energy stages.

Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$	1.3	1.4	2
Total int. lum. per year	fb^{-1}	276	444	708
Main linac tunnel length	km	11.4	29.0	50.1
Nb. of particles per bunch	1×10^{9}	5.2	3.7	3.7
Bunch length	µm	70	44	44
IP beam size	nm	149/2.0	~60/1.5	~40/1
Final RMS energy spread	%	0.35	0.35	0.35
Crossing angle (at IP)	mrad	16.5	20	20

CLIC performance

- Luminosity margins and increases
  - Initial estimates of static and dynamic degradations from damping ring to IP gave: 1.5 x 10^{34} cm^{-2} s^{-1}
  - Simulations give 2.8 on average, and 90% of the machines above **2.3 x 10^{34} cm^{-2} s^{-1}**
  - A "perfect" machine will give : 4.3 x 10^{34} cm^{-2} s^{-1}
  - In addition: doubling the frequency (50 Hz to 100 Hz) would double the luminosity, at a cost of ~55% and ~5% power and cost increase
- Z pole performance, 2.3x10^{32} – 0.4x10^{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)



Power and Energy

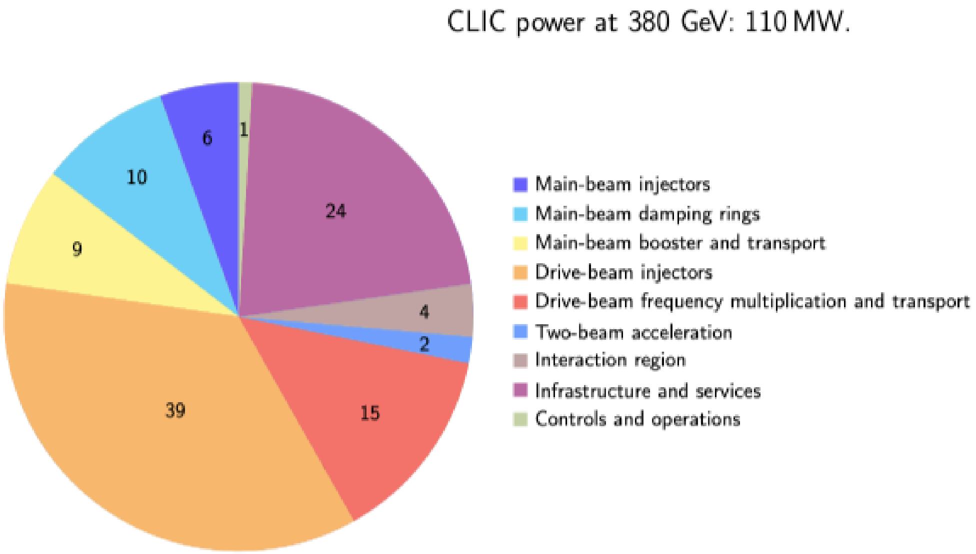


Fig. 4.8: Breakdown of power consumption between different domains of the CLIC accelerator in MW at a centre-of-mass energy of 380 GeV. The contributions add up to a total of 110 MW. (image credit: CLIC)

Table 4.2: Estimated power consumption of CLIC at the three centre-of-mass energy stages and for different operation modes. The 380 GeV numbers are for the drive-beam option and have been updated as described in Section 4.4, whereas the estimates for the higher energy stages are from [57].

Collision energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	110	25	9
1500	364	38	13
3000	589	46	17

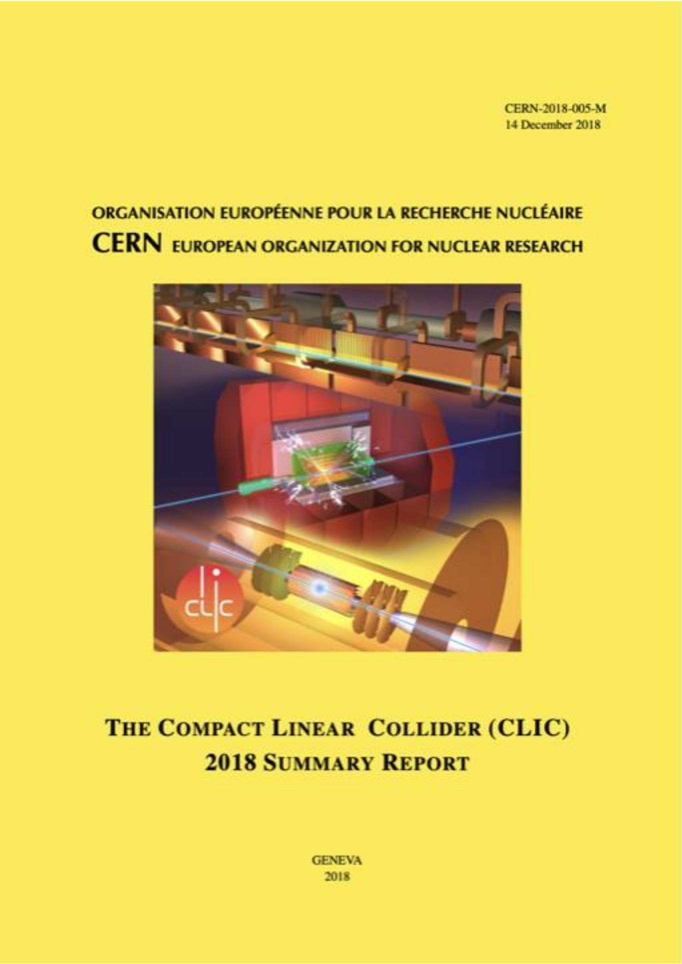
Power estimate bottom up (concentrating on 380 GeV systems)

- Very large reductions since the CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimized, main target damping ring RF significantly reduced, recent L-band klystron studies

Energy consumption ~0.6 TWh yearly, CERN is currently (when running) at 1.2 TWh (~90% in accelerators)

1.5 TeV and 3 TeV numbers still from the CDR (but included in the report), to be re-done the next ~2 years

Snowmass …. https://arxiv.org/abs/2203.09186



Broadly speaking:
"Updated accelerator part of Summary Report"

The CLIC project

O. Brunner[a], P. N. Burrows[b], S. Calatroni[a], N. Catalan Lasheras[a], R. Corsini[a], G. D'Auria[c], S. Doebert[a], A. Faus-Golfe[d], A. Grudiev[a], A. Latina[a], T. Lefevre[a], G. Mcmonagle[a], J. Osborne[a], Y. Papaphilippou[a], A. Robson[e], C. Rossi[a], R. Ruber[f], D. Schulte[a], S. Stapnes[a]*, I. Syratchev[a], W. Wuensch[a]

[a]CERN, Geneva, Switzerland, [b]John Adams Institute, University of Oxford, United Kingdom, [c]Elettra Sincrotrone Trieste, Italy, [d]IJCLab, Orsay, France, [e]University of Glasgow, United Kingdom, [f]Uppsala University, Sweden

April 4, 2022

Abstract

The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear e^+e^- collider under development by the CLIC accelerator collaboration, hosted by CERN. The CLIC accelerator has been optimised for three energy stages at centre-of-mass energies 380 GeV, 1.5 TeV and 3 TeV [21]. CLIC uses a novel two-beam acceleration technique, with normal-conducting accelerating structures operating in the range of 70 MV/m to 100 MV/m.

The report describes recent achievements in accelerator design, technology development, system tests and beam tests. Large-scale CLIC-specific beam tests have taken place, for example, at the CLIC Test Facility CTF3 at CERN [39], at the Accelerator Test Facility ATF2 at KEK [53, 67], at the FACET facility at SLAC [35] and at the FERMI facility in Trieste [36]. Crucial experience also emanates from the expanding field of Free Electron Laser (FEL) linacs and recent-generation light sources. Together, they demonstrate that all implications of the CLIC design parameters are well understood and reproducible in beam tests and prove that the CLIC performance goals are realistic. An alternative CLIC scenario for the first stage, where the accelerating structures are powered by X-band klystrons, is also under study. The implementation of CLIC near CERN has been investigated. Focusing on a staged approach starting at 380 GeV, this includes civil engineering aspects, electrical networks, cooling and ventilation, installation scheduling, transport, and safety aspects. All CLIC studies have put emphasis on optimising cost and energy efficiency, and the resulting power and cost estimates are reported. The report follows very closely the accelerator project description in the CLIC Summary Report for the European Particle Physics Strategy update 2018-19 [22].

Detailed studies of the physics potential and detector for CLIC, and R&D on detector technologies, have been carried out by the CLIC detector and physics (CLICdp) collaboration. CLIC provides excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors. The physics potential at the three energy stages has been explored in detail [2, 3, 17] and presented in submissions to the European Strategy Update process.

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

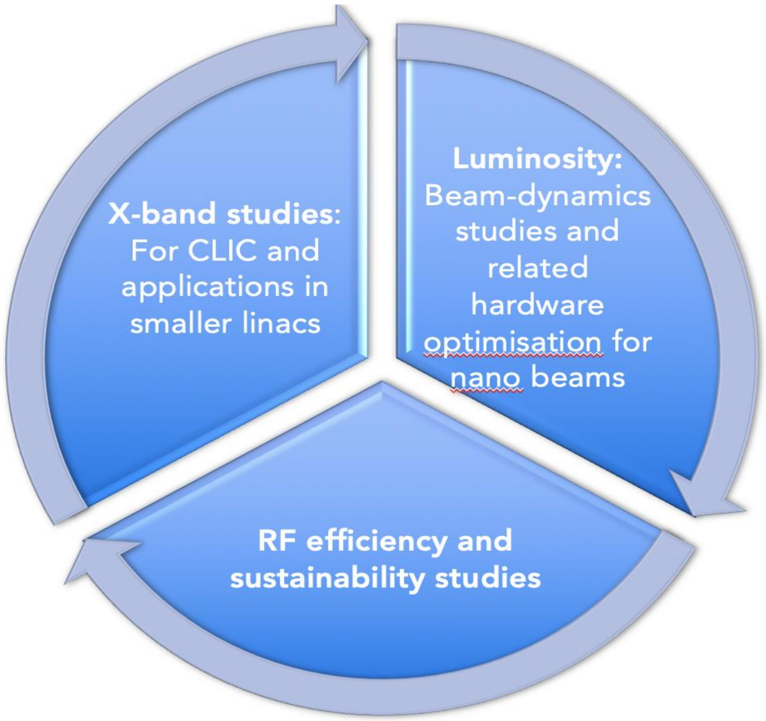
*Compiled and edited by the CLIC Accelerator Steering Group on behalf of the CLIC Accelerator Collaboration, corresponding author: steinar.stapnes@cern.ch

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



CLIC Project Readiness 2025-26

Goals for the studies by ~2025, key improvements:

- Luminosity numbers, covering beam-dynamics, nanobeam, and positrons - at all energies. Performance risk reduction, system level studies
  - Substantial progress already documented in Snowmass report and associated references, remains a focus for beamdynamics, nanobeam related technical developments and positron production studies
- Energy/power: 380 GeV well underway, 3 TeV to be done, L-band klystron efficiency
  - Also in Snowmass report for 380 GeV, documented in previous PM meeting by Alexej.
- Sustainability issues, more work on running/energy models and carbon footprint
  - Will show a couple of slides later, initial studied in PiP, just referred to briefly in Snowmass report
- X-band progress – for CLIC, smaller machines, industry availability, including RF network
  - Addressed by establishing improved baseline, CompactLight very important and many smaller setup (examples today)
  - No complete documentation in PiP or Snowmass report.
- R&D for higher energies, gradient, power, prospects beyond 3 TeV
  - See examples in previous PM, talk by Walter, links also to power, nanobeam and beamdynamics
- Cost update, only discuss changes wrt Project Implementation Plan in 2018
- Low cost klystron version – reoptimize for power, cost and fewer klystrons ?

CLIC: Study on Regenerative Energy Use

CLIC Study: consider 5 operating modes:

- Off (shutdown)
- Standby and intervention – scheduled or unscheduled
- Low power running (50% lumi)
- Full operation (note at that time assumed to need 200 MW, now reduced)

Study assumes target of 130 days of full operation equivalent running

Considers impact of various running strategies on energy costs

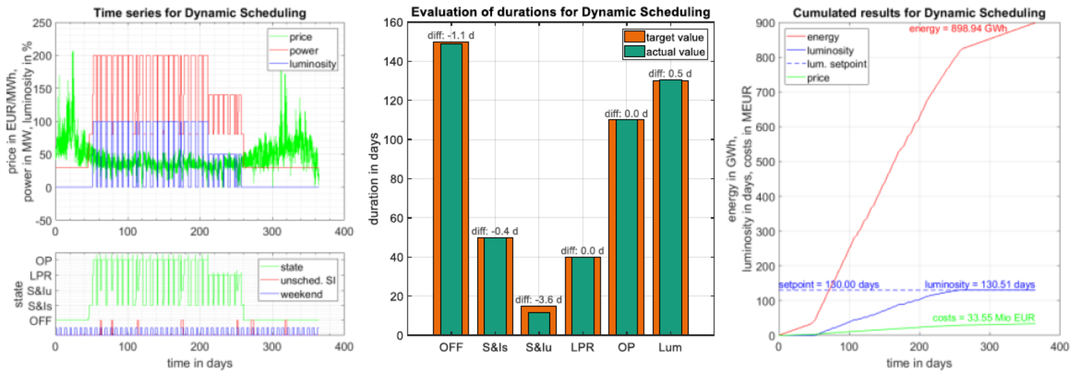


Figure 1-18: Example plots of a simulation run (left: time series, middle: bar graph with durations, right: cumulated times)

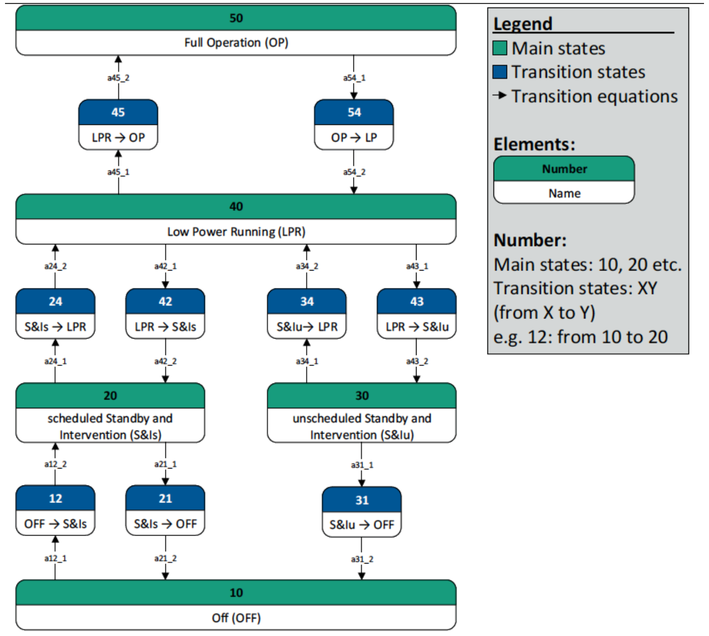


Figure 1-1: Schematic representation of the finite state machine

https://edms.cern.ch/document/2065162/1

Running on renewables

- It is possible to 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)
  - At the time of the study 200 MW was conservatively used, in reality only ~110 MW are needed
- Self-sufficiency during all times can not be reached and 54% of the time CLIC could run independently from public electricity supply with the portfolio simulated.
- About 1/3 of the generated PV and wind energy will be available to export to the public grid even after adjusting the load schedule of CLIC.
- However, the renewables are most efficient in summer, when prices are low

More information (link)

Other news

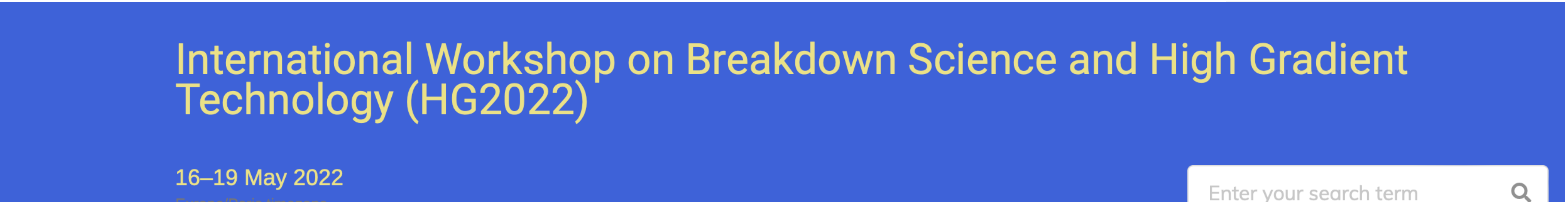
CERN budget planning for 2023 (and -2027) ongoing.

New EU project submissions (EUPRAXIA-PP, EAJADE, CREATE) with links to LC studies

CompactLight completed

Accepted abstracts for ICHEP and eeFACT22 in July and September

High Gradient Workshop next week: https://indico.cern.ch/event/1080222/



Today

13:30 → 13:45	**Introductions, goals for 2025** **Speaker**: Steinar Stapnes (CERN)	15m
13:50 → 14:05	**X-band status and plans in Melbourne** **Speaker**: Matteo Volpi (University of Melbourne (AU))	15m
14:10 → 14:25	**ATF2/3 planning and status** **Speaker**: Toshiyuki Okugi (KEK)	15m
14:30 → 14:45	**The ATF IP-BSM system** **Speaker**: Alexander Aryshev (KEK)	15m
14:50 → 15:05	**The PolariX TDS at PSI** **Speaker**: fabio marcellini (paul scherrer insitut)	15m
15:10 → 15:25	**IFAST X-band structure for CompactLight** **Speakers**: Gerardo D'Auria (Elettra Trieste), Markus Aicheler (Helsinki Institute of Physics (FI))	15m
15:30 → 15:45	**Coffee Break**	15m
15:45 → 16:00	**X-band energy spread minimizer** **Speaker**: Sergey Antipov (Deutsches Elektronen-Synchrotron DESY)	15m
16:05 → 16:20	**VBox status/operation/results/plans** **Speaker**: Nuria Fuster	15m
16:25 → 16:40	**Verification Experiment of Cherenkov Diffraction Radiation Theories at CLEAR Facility** **Speaker**: Kacper Lasocha (Jagiellonian University (PL))	15m
16:45 → 17:00	**Cavity BPM system and signal processing upgrades at CLEAR** **Speaker**: Alexey Lyapin (RHUL)	15m
17:05 → 17:20	**Medical applications in the CERN Linear Accelerator for Research** **Speaker**: Pierre Korysko (University of Oxford (GB))	15m
17:25 → 17:40	**C^3 and high gradient R&D** **Speaker**: Emilio Alessandro Nanni	15m
17:45 → 17:55	**AOB and close**	10m