



CLIC status

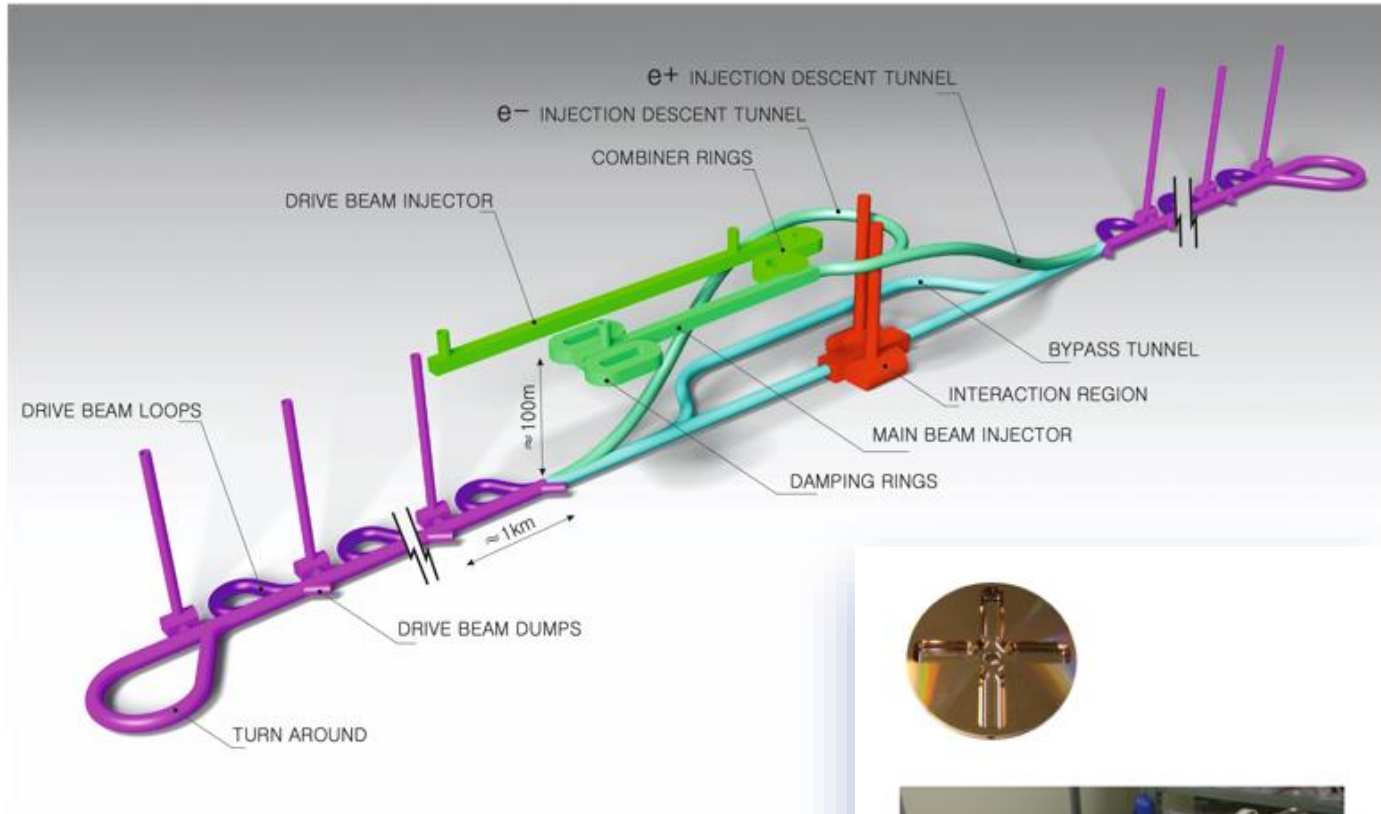
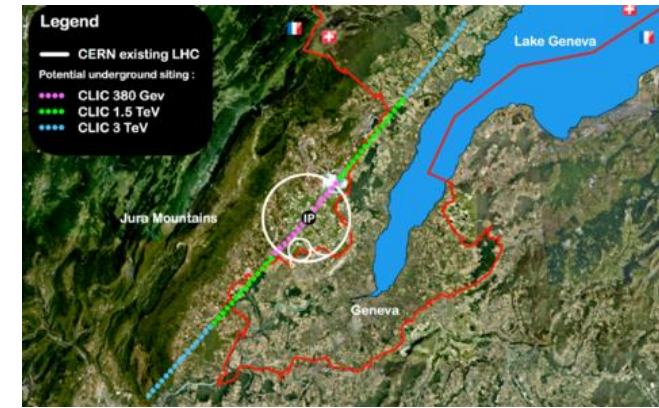
Outline

- CLIC parameter overview
- Recent and ongoing activities
- ESPP planning
- Schedules, Costs, Power and Sustainability

Steinar Stapnes, CERN

LC vision meeting, CERN - 10.1.2025

The Compact Linear Collider (CLIC)

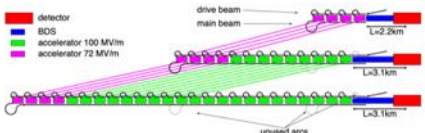
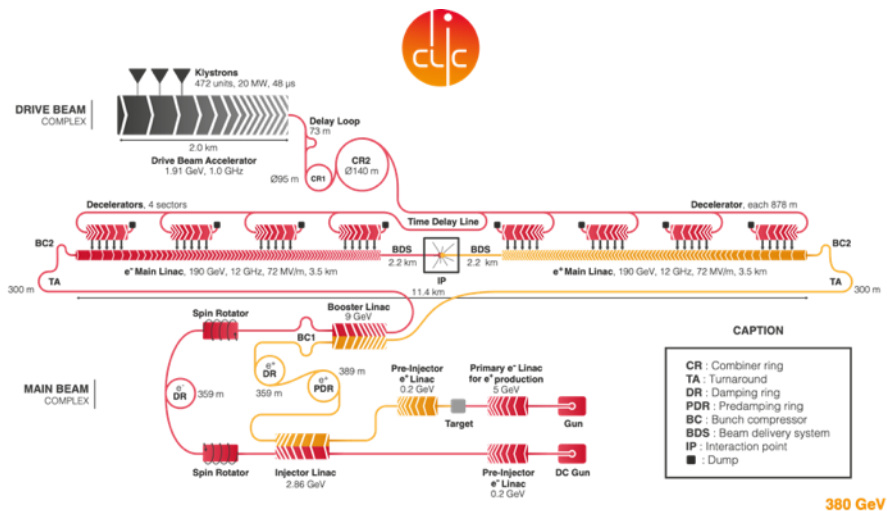


Accelerating structure prototype for CLIC: 12 GHz (L~25 cm), 100 MV/m



- **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.
- **Project Implementation Plan in 2018** with focus on 380 GeV for Higgs and top.

CLIC from 380 GeV to 3 TeV



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

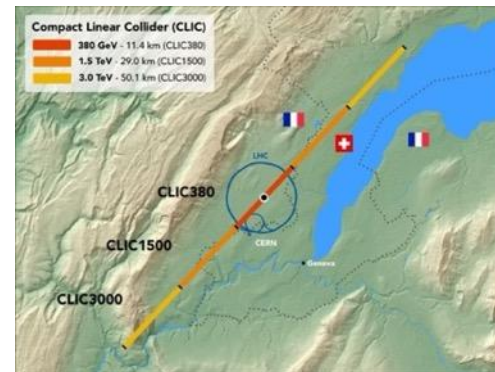
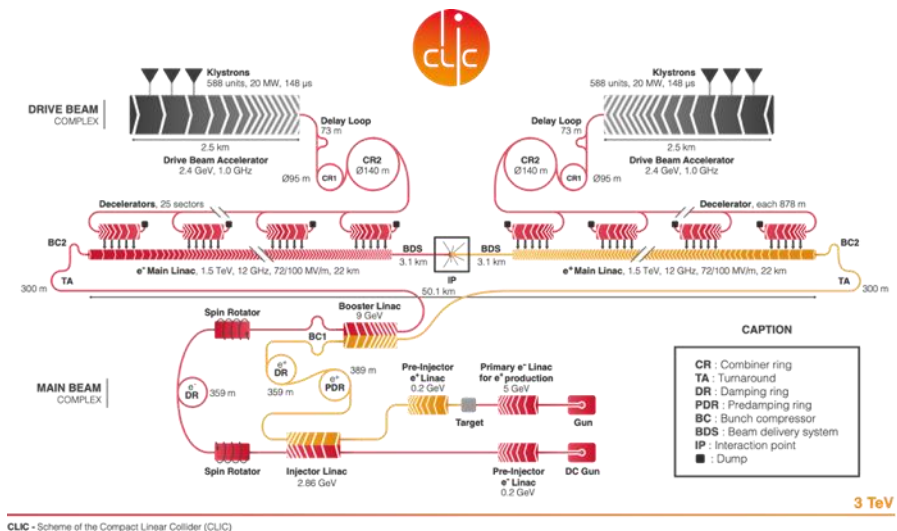


Table 1.1: Key parameters of the CLIC energy stages.

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	$1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	2.3	3.7	5.9
Lum. above 99% of \sqrt{s}	$1 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$	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 is heavily prototyped



The CLIC accelerator studies are mature:

- Optimised design for cost and power
- Many tests in CTF3, FELs, light-sources and test-stands
- Technical developments of “all” key elements

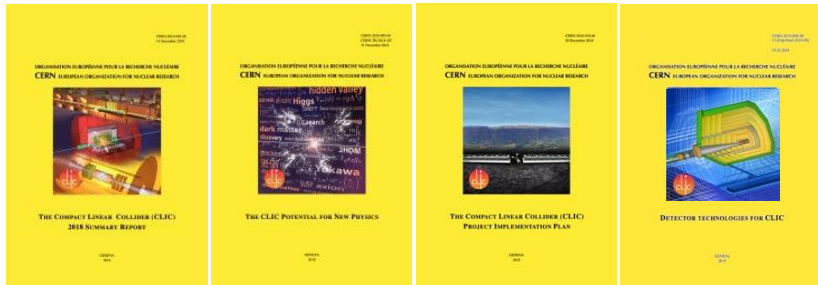
Status reports and studies

3-volume CDR 2012

Updated Staging Baseline 2016



4 CERN Yellow Reports 2018



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

Available at:
clic.cern/european-strategy



CLIC status and plans

Two formal submissions to the ESPPU 2018



Several Lols were 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](#)

Snowmass white paper (most recent overview):

<https://arxiv.org/abs/2203.09186>

Broadly speaking: “Updated accelerator part of 2018 Summary Report”

The CLIC project

O. Brunner¹, P. N. Burrows², S. Calatroni³, N. Catalan Lasheras⁴, R. Corsini⁵, G. D'Auria⁶, S. Doebert⁷, A. Faas-Galle⁸, A. Gouliou⁹, A. Lattini¹⁰, T. Lefevre¹¹, G. Micromaglio¹², J. Osborne¹³, Y. Papanthiopoulos¹⁴, A. Robson¹⁵, C. Rossi¹⁶, R. Ruber¹⁷, D. Schulte¹⁸, S. Stagnone¹⁹, I. Syrtchev²⁰, W. Wuensch²¹

¹CERN, Geneva, Switzerland, ²John Adams Institute, University of Oxford, United Kingdom, ³Elettra Sincrotrone Trieste, Italy, ⁴CLICLab, Orsay, France, ⁵University of Glasgow, United Kingdom, ⁶Uppsala 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 [1]. 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 [2], at the Accelerator Test Facility ATF2 at KEK [3, 4], at the FACET facility at SLAC [5] and at the FERMI facility in Trieste [6]. Crucial experience also emanates from the expanding field of Free Electron Laser (FEL) lines and revent-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 [2]. 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 [7, 8, 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)

²¹Compiled and edited by the CLIC Accelerator Steering Group on behalf of the CLIC Accelerator Collaboration, corresponding author: stagnone@cern.ch

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** ([Journal](#) , [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](#))

The key documents
for 2018 ESSP:

<https://clic.cern/european-strategy>

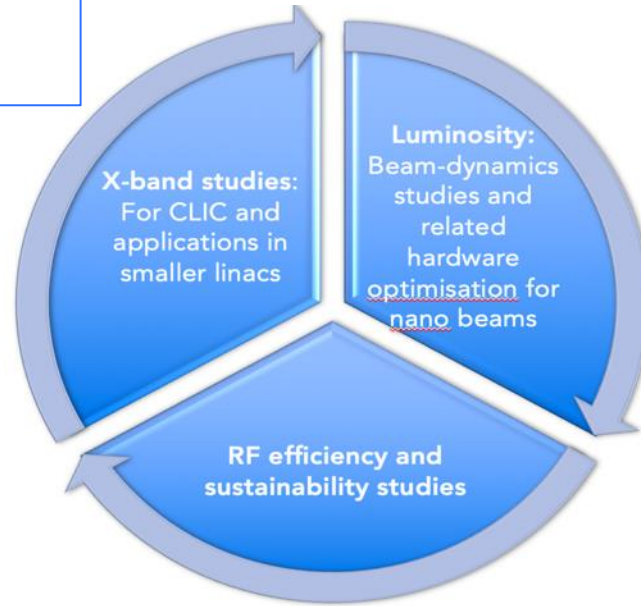
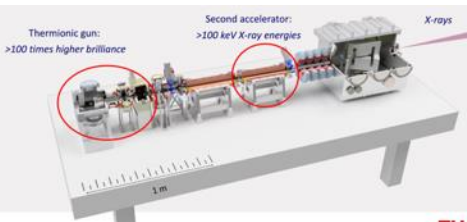
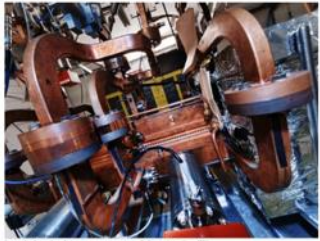
On-going and recent CLIC studies

The X-band technology readiness for the 380 GeV CLIC initial phase - manufacturability and developments driven by use in small compact accelerators for industrial experience (see examples in the following slides)



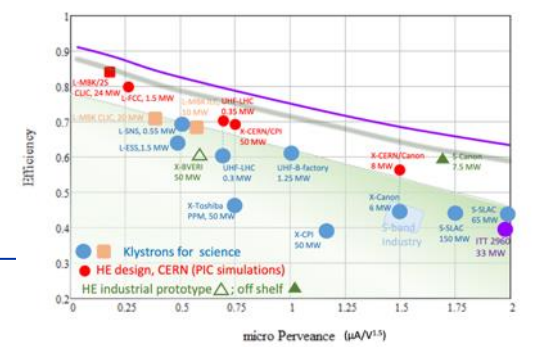
CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility

CERN and the Lausanne University Hospital (CHUV) are collaborating to develop the conceptual designs of an innovative radiotherapy facility, used for cancer treatment



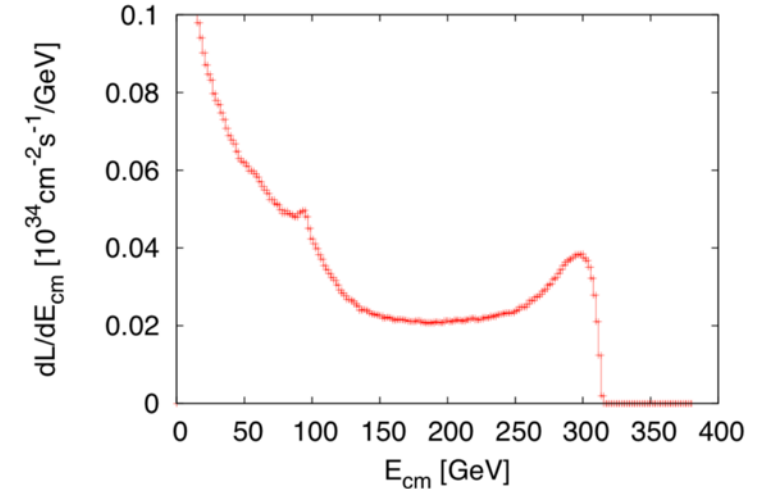
Optimizing the luminosity at 380 GeV at $2.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ – already implemented for Snowmass paper, further work to provide margins will continue (HW and SW)

Improving the **power efficiency** for both the initial phase (already in Snowmass report) and at high energies, including more **general sustainability studies** (in many cases done together with ILC – see later)



Luminosities studies 2019-22, and continued

- Luminosity margins and increases
 - Initial estimates of static and dynamic degradations from damping ring to IP gave: $1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - Simulations give 2.8 on average, and 90% of the machines above **$2.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$**
 - A “perfect” machine will give : $4.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - 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, $2.3 \times 10^{32} - 0.4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
 - The latter number when accelerator configured for Z running (e.g. early or end of first stage)
- Gamma – Gamma collision luminosity spectrum on the right (example with 190 GeV e-beams)



These numbers are already included (but 100 Hz only mentioned in passing, not in tables) in the Snowmass report 2021. See link of previous slides.

The CLIC project
 O. Brunner¹, P. N. Burrows², S. Calatroni³, N. Catalan Lachenaie⁴, R. Corsini⁵, G. D'Auria⁶, S. Doberst⁷, A. Faas-Gold⁸, A. Grudnev⁹, A. Latina¹⁰, T. Lefevre¹¹, G. Memonoglu¹², J. Osborne¹³, Y. Papaphilippou¹⁴, A. Robson¹⁵, C. Rossi¹⁶, B. Ruber¹⁷, D. Schulte¹⁸, S. Shapiro¹⁹, I. Syrotzke²⁰, W. Wornatke²¹
¹CERN, Geneva, Switzerland, ²John Adams Institute, University of Oxford, United Kingdom, ³Elektron Sincrotrone Trieste, Italy, ⁴ICLab, Orsay, France, ⁵University of Glasgow, United Kingdom, ⁶Uppsala University, Sweden
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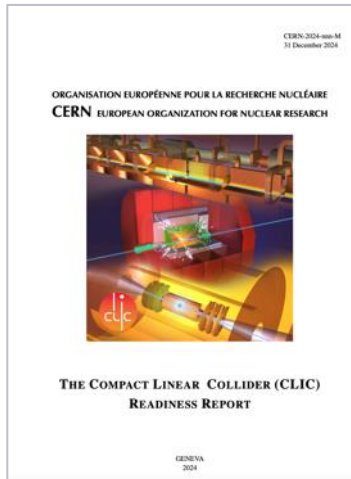
Now look towards the ESPP and CLIC parameters
to be presented there

The CLIC ESPP update – I

Guidelines:

Preparing “Project Readiness Report” as a step toward a TDR

Assuming ESPP in ~ 2025-6, Project Approval ~ 2028, Project (tunnel) construction can start in ~ 2030.



Several important changes:

- Energy scales: 380 GeV and 1.5 TeV with one drivebeam
- Present 100 Hz running at 250 GeV and 380 GeV (i.e. two parallel experiments, two BDSs) – some increased cost and increased power wrt to one IP
- New run plan, 10+10 year for two stages (380 -> 1500 GeV) – with ramp-ups
- Several updates on parameters (injectors, damping rings, drive-beam) based on new designs, results and prototyping (e.g. klystrons, magnets) - however no fundamental changes beyond staying at one drivebeam
- Technology use examples, including more on use of them in other projects (e.g. alignment, instrumentation, X-band RF is small linacs)
- Update costing and power – interplay between inflation and CHF
- Life Cycle Assessments
- More detailed prep phase planning (next 5-7 years)

Project summary for Snowmass already include some of these changes, i.e. luminosity improvements, 100 Hz study is mentioned, the power is updated for 380 GeV: [LINK](#)

The CLIC ESPP update - II

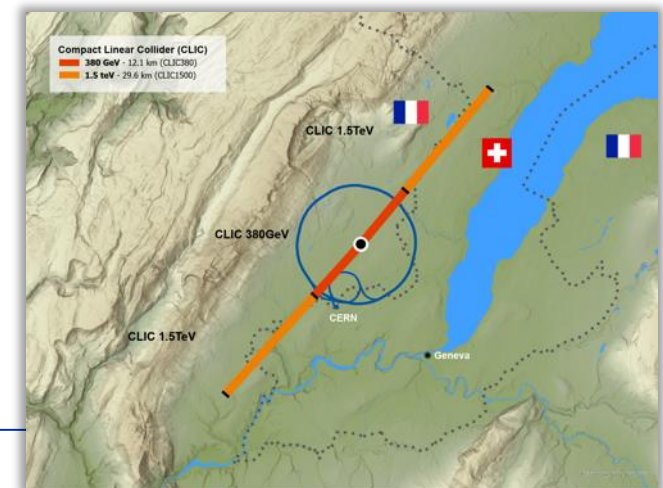
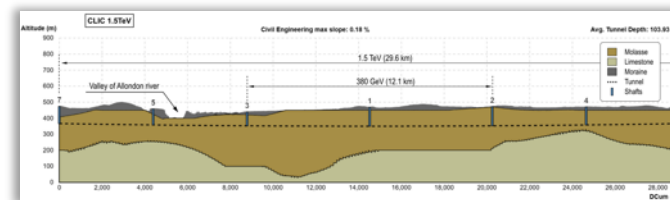
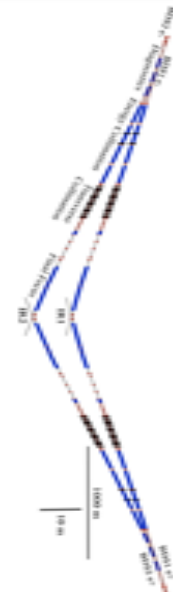
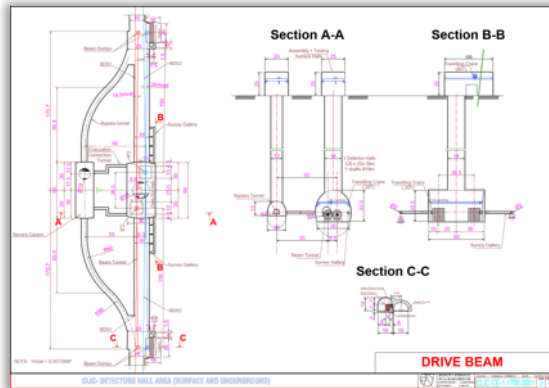
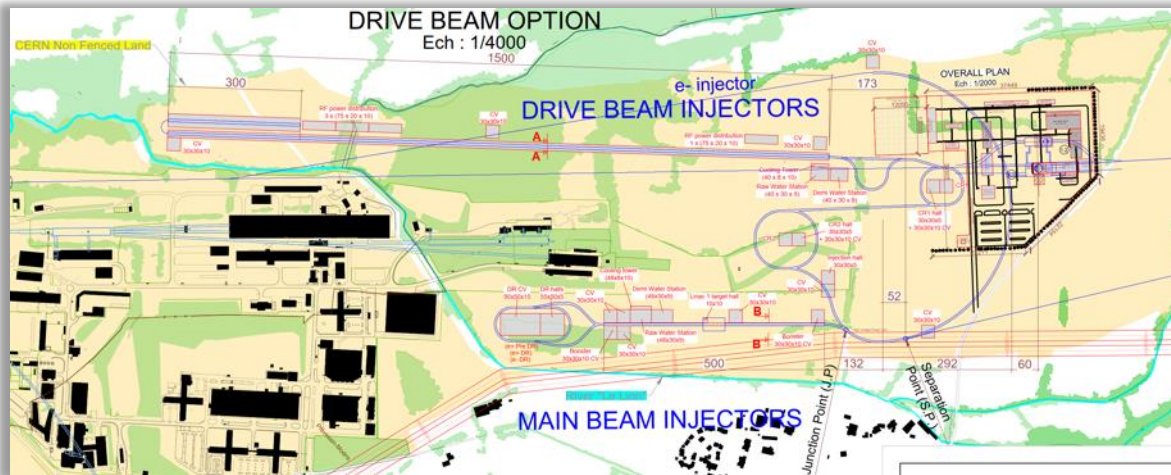
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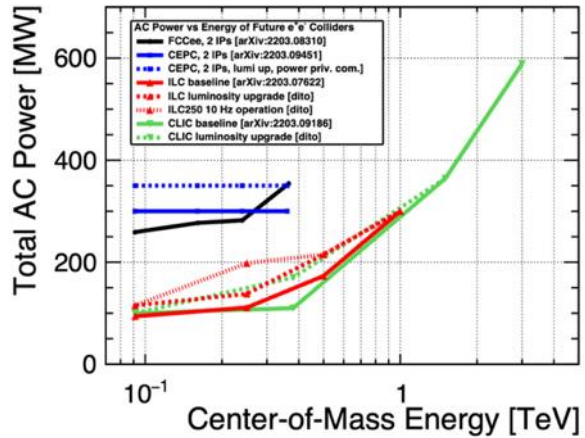
Add:

- 250 GeV parameters
- 100 Hz running for both 250 and 380 GeV

3 TeV: refer to earlier reports



Power and energy



Power estimate bottom up (concentrating on 380 GeV systems)

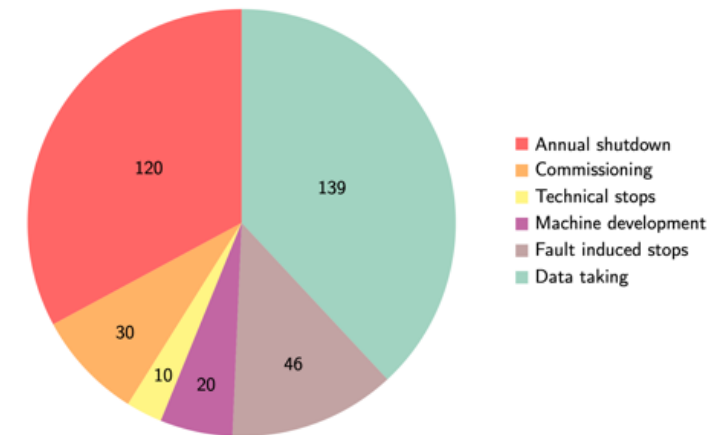
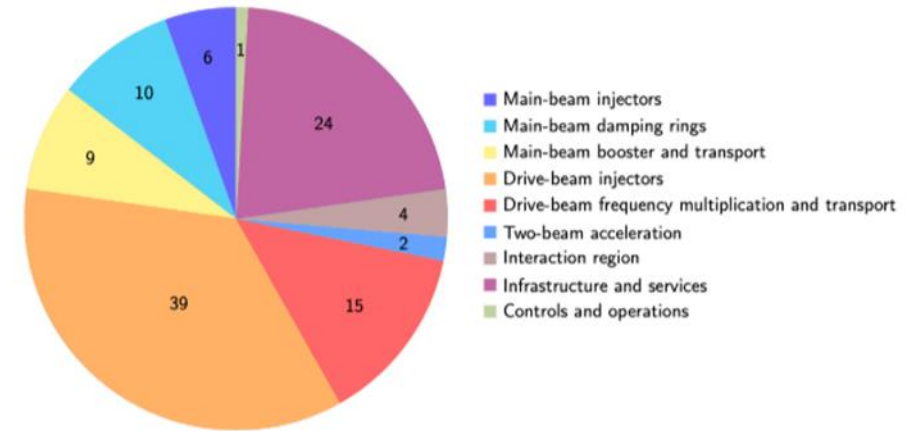
- Very large reductions since the CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimized, main target damping ring RF significantly reduced, recent L-band klystron studies

CERN “standard” running scenario used to convert to annual energy use

Energy consumption ~0.6 TWh yearly, CERN is currently at 1.2-1.3 TWh (~90% in accelerators)

1.5 TeV (and 3 TeV) numbers still from the CDR, being re-done. Aim to be around ~300 MW at 1.5 TeV. For these energies the savings of high efficiency klystrons, DR RF redesign or permanent magnets not included, so numbers will be reduced

CLIC power at 380 GeV: 110 MW.



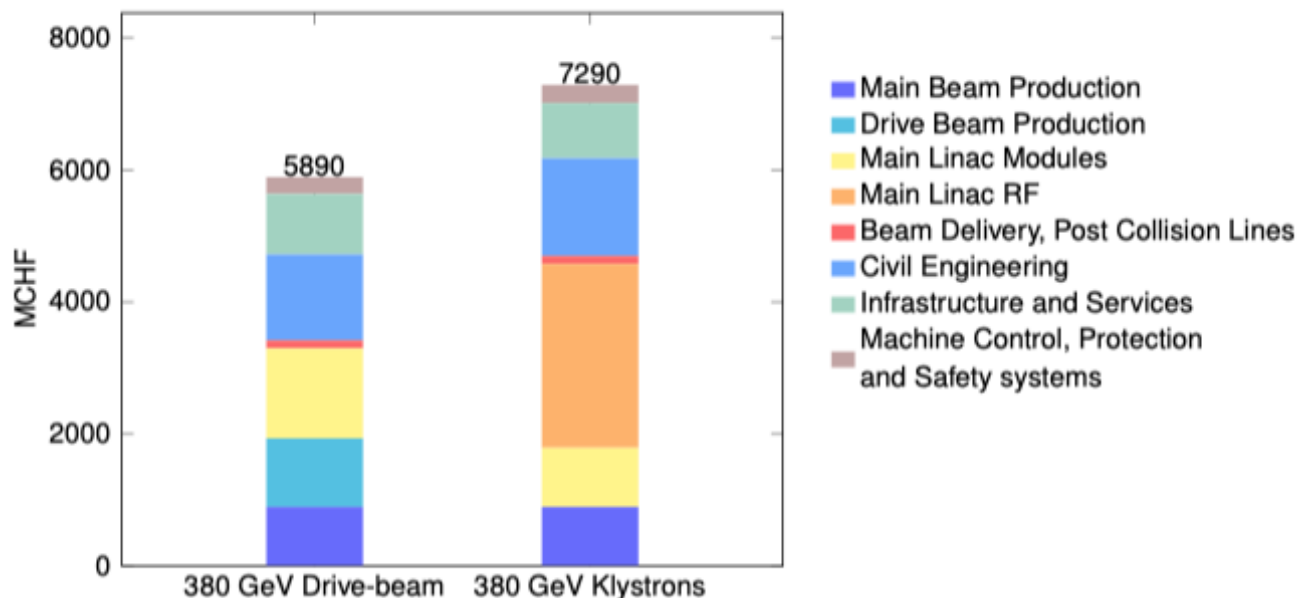
Cost – I (currently being updated)

Cost exercises and international reviews:

- CLIC CDR 2012-13, 3 TeV primarily and 500 GeV ([LINK](#))
- CLIC PiP 2018, 380 GeV primarily ([LINK](#))

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	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 Systems	52	52
Beam Delivery and Post Collision Lines	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
	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 (will update 1.5 TeV, labor and operation)

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)

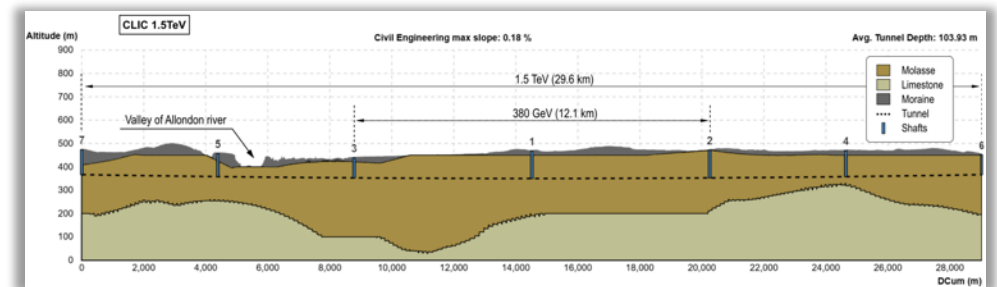
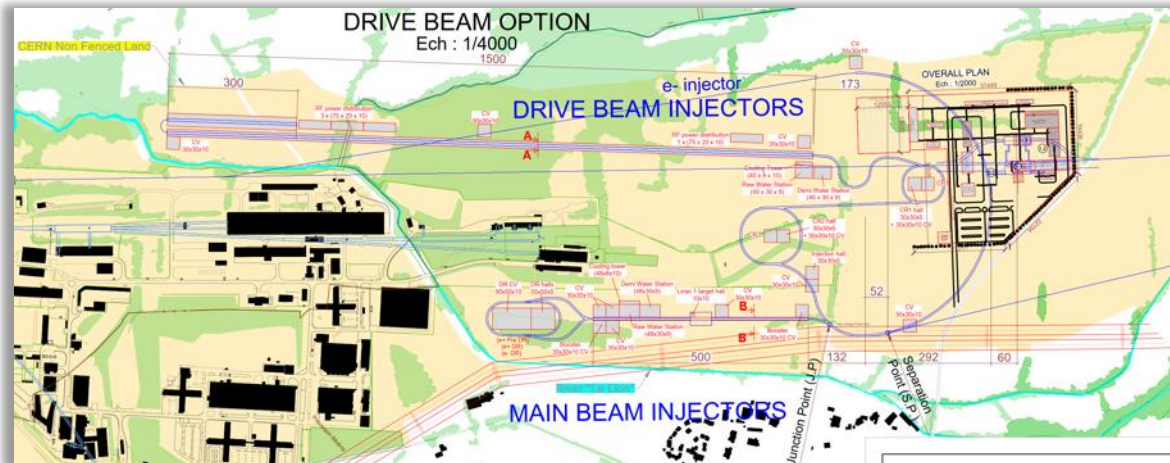
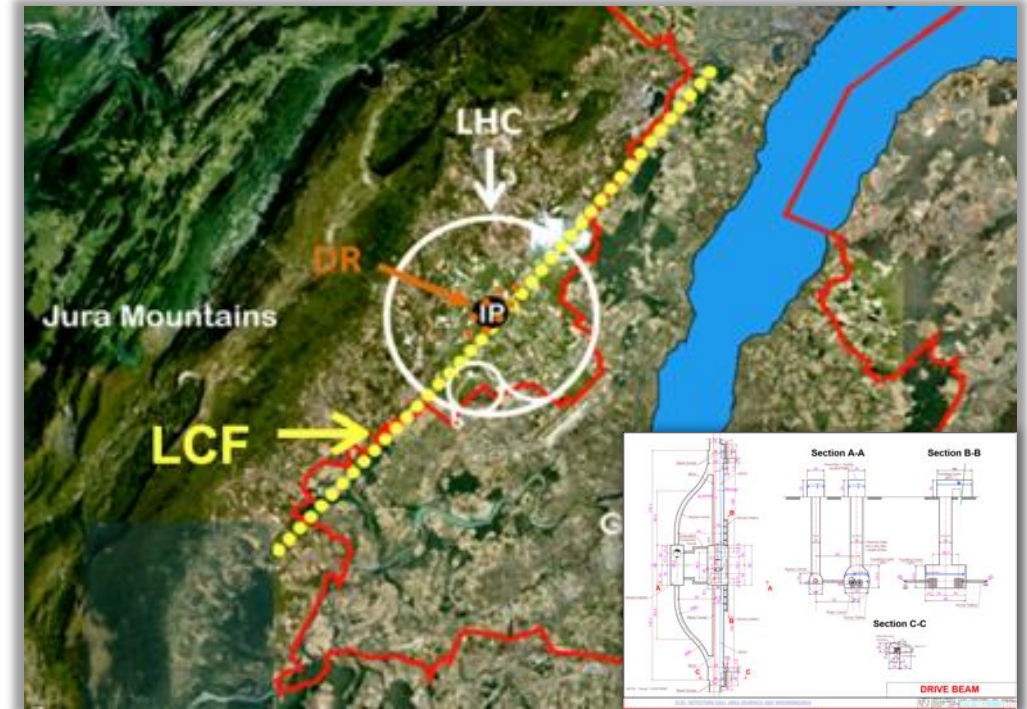
These replacement/operation costs represent 116 MCHF per year.

Civil Engineering

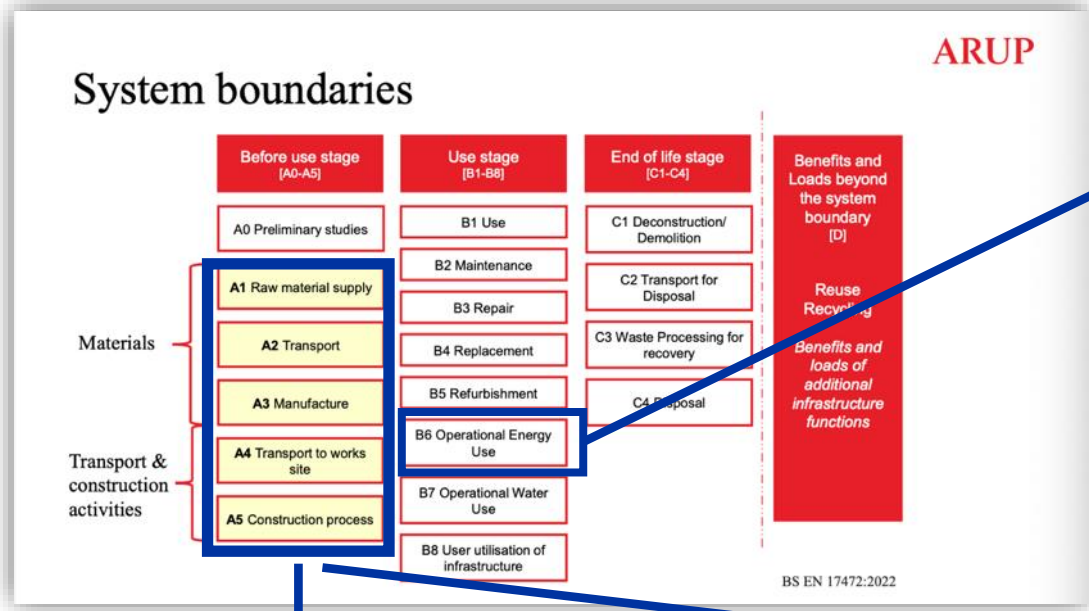
CE studies for LC at CERN:

- CLIC, up to 3 TeV. Contract with Amberg Engineering for CDR in 2012-2013.
- ILC up to 1 TeV at CERN. Contract with Amberg for the TDR in 2012-13.
- CLIC up to 3 TeV, TOT (layout tool) with ARUP, for Project Implementation Report 2018
- Update on-going, CLIC to 1.5 TeV, ILC to 550 GeV, in both cases ~30km, using Geoprofiler layout tool
- Injectors and experimental areas on Preveessin site (“CERN land”)

See talk of John & Edward in a moment



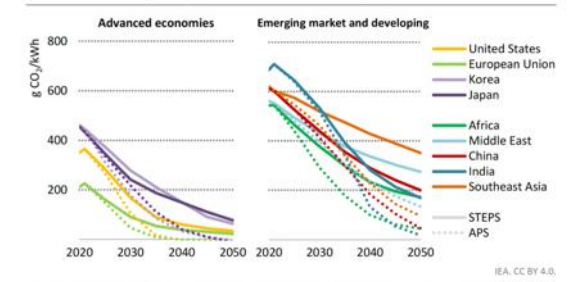
Sustainability: Life Cycle Assessment (LCA)



What is the carbon intensity of energy in ~2050 (operation):

- 50% nuclear and 50% renewable give ~10-15g/kWh, to optimistic ?
- France summer-months are today ~40g/kWh
- Reductions predicted ([LINK](#))

Figure 6.14 > Average CO₂ intensity of electricity generation for selected regions by scenario, 2020-2050

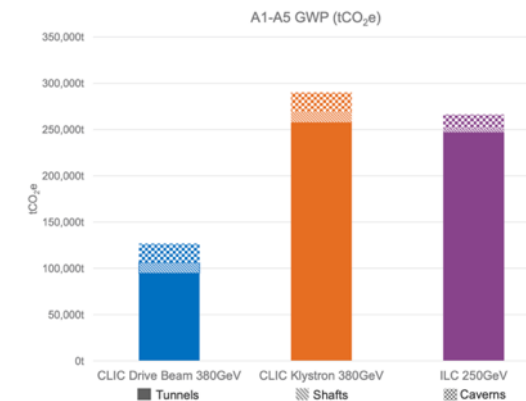
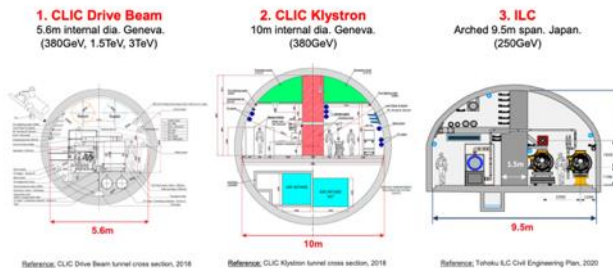


CO₂ intensity of electricity generation varies widely today, but all regions see a decline in future years and many have declared net zero emissions ambitions by around 2050

LCA report for **Civil Engineering**: [LINK](#)

Addressing the Civil Engineering impact

Linear Collider Options



Next working on the machine parts, on top of the CE estimate

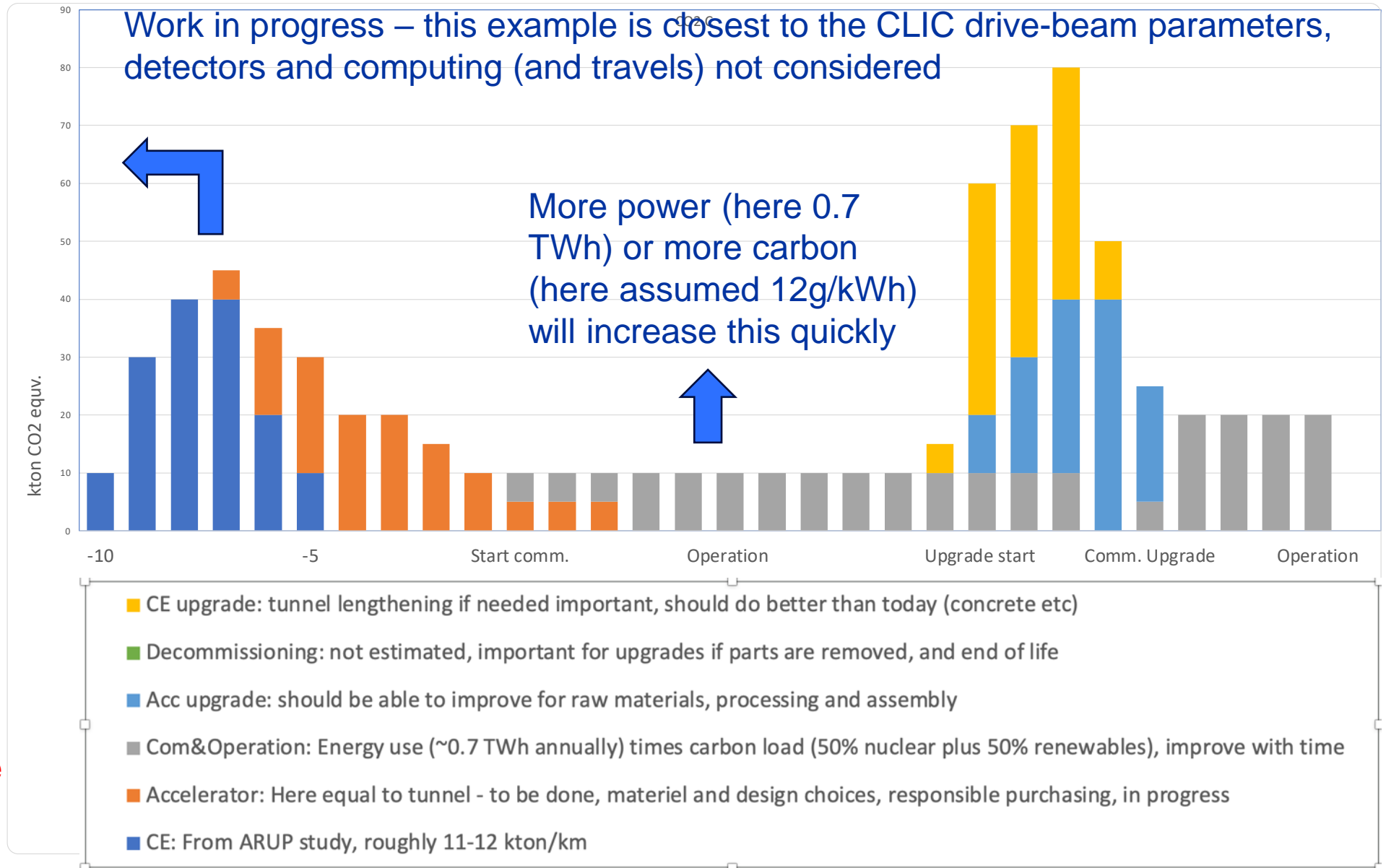
Towards Carbon Accounting with LCA

- example for CLIC, also (being) done for ILC, C3, HALHF, FCC -

This plot (blue part) is for 11 km of tunnel, scales with length, injectors will add to this

Next working on machine parts (orange), here assumed hardware and infrastructure = equal civil engineering impact.

Most likely this is optimistic, i.e. orange and light blue parts will be higher



CLIC for the ESPP update

Preparing “Project Readiness Report” as a step toward a TDR

Several important changes compared earlier CLIC versions presented in 2018 and for Snowmass:

- Energy scales: 380 GeV and 1.5 TeV with one drive-beam, 100 Hz running with two Ips
Intermediate energy scales possible
- Several updates on parameters (injectors, damping rings, drive-beam) based on new designs, results and prototyping (e.g. klystrons, magnets) - however no major changes
- Technology results updates, including more on use of them in other projects (e.g. alignment, instrumentation, X-band RF is small linacs)
- Update costing and power – for costing interplay between inflation and CHF exchanges – and for example power at 1.5 TeV
- LCAs covered, Technical Readiness Levels also
- More on next steps (prep phase)



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