Linear colliders

Outline

- LC general considerations
- ILC - in Japan
- CLIC - at CERN
- Brief: C^3 and HALHF, energy recovery options
- LC at CERN, consider ILC technology as starting point, ESPP inputs

Steinar Stapnes – CERN

Nov 8th - 2024

Strategies, past and future

ESPP update 2018-19:
- Higgs factory next – project studies
- FCC feasibility study
- R&D on technologies and projects

Snowmass 2021-23 provided(s) an opportunity for formulating new ideas, updated reports, overviews and summaries – for the US and worldwide.
Many ideas, from mature to concepts.

Report of the Snowmass'21
Collider Implementation Task Force

Thomas Roser (chair)[1], Reinhard Brinkmann[2], Sarah Cousineau[3], Dmitri Denisov[1], Spencer Gessner[4], Steve Gourlay[5], Philippe Lebrun[6], Meenakshi Narain[7], Katsunobu Oide[8], Tor Raubenheimer[4], John Seeman[4], Vladimir Shiltsev[9], Jim Strait[9], Marlene Turner[5], and Lian-Tao Wang[10]

[1]Brookhaven National Laboratory, Upton, NY 11973, USA
[2]DESY, 22607 Hamburg, Germany
[3]Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA
[4]SLAC National Laboratory, Menlo Park, CA 94025, USA
[5]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[6]ESI Archamps, 74160 Archamps, France
[7]Brown University, Providence, RI, 02912, USA
[8]KEK, Tsukuba, Ibaraki 305-0801, Japan
[9]Fermi National Accelerator Laboratory, Batavia, IL 60510, USA
[10]University of Chicago, Chicago, IL 60637, USA

August 15, 2022

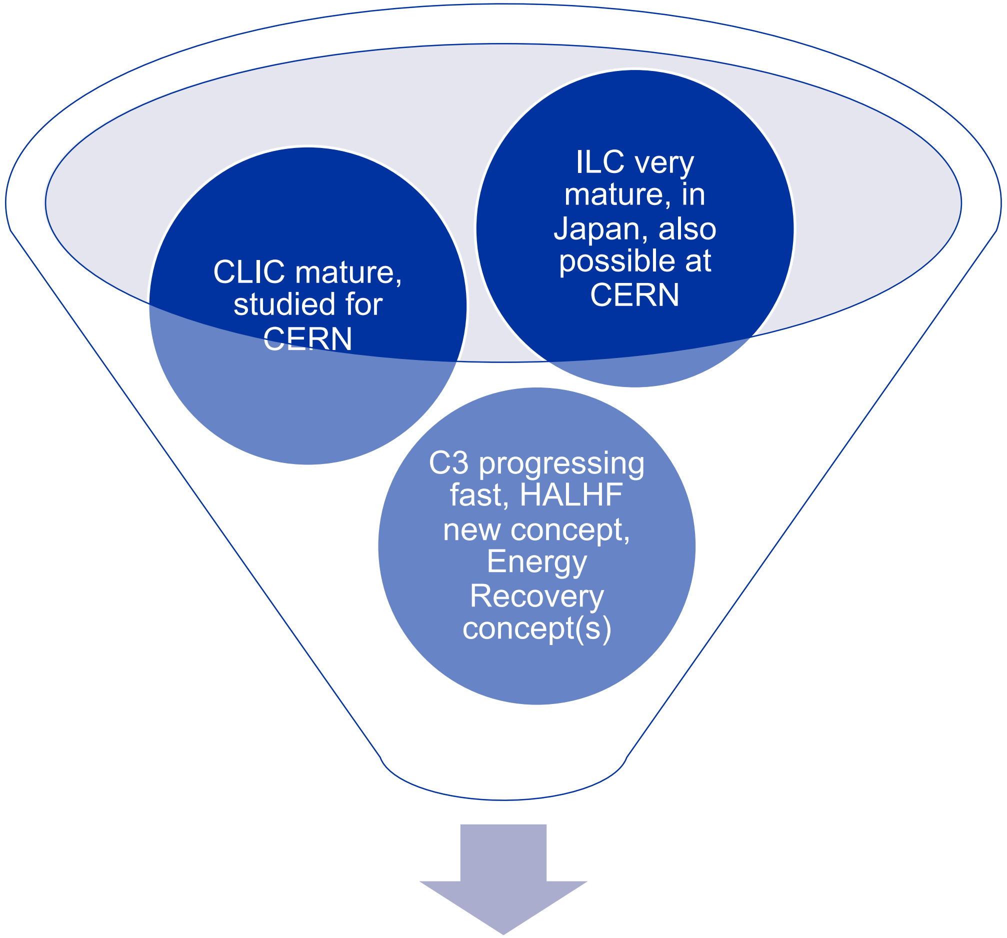
Abstract

The Snowmass'21 Implementation Task Force has been established to evaluate the proposed future accelerator projects for performance, technology readiness, schedule, cost, and environmental impact. Corresponding metrics has been developed for uniform comparison of the proposals ranging from Higgs/EW factories to multi-TeV lepton, hadron and ep collider facilities, based on traditional and advanced acceleration technologies. This report documents the metrics and processes, and presents evaluations of future colliders performed by Implementation Task Force.

https://arxiv.org/pdf/2208.06030.pdf

Proposal Name (c.m.e. in TeV)	Collider Design Status	Lowest TRL Category	Technical Validation Requirement	Cost Reduction Scope	Performance Achievability	Overall Risk Tier
FCCee-0.24	II					1
CEPC-0.24	II					1
ILC-0.25	I					1
CCC-0.25	III					2
CLIC-0.38	II					1
CERC-0.24	III					2
ReLiC-0.24	V					2
ERLC-0.24	V					2
XCC-0.125	IV					2
MC-0.13	III					3
ILC-3	IV					2
CCC-3	IV					2
CLIC-3	II					1
ReLiC-3	IV					3
MC-3	III					3
LWFA-LC 1-3	IV					4
PWFA-LC 1-3	IV					4
SWFA-LC 1-3	IV					4
MC 10-14	IV					3
LWFA-LC-15	V					4
PWFA-LC-15	V					4
SWFA-LC-15	V					4
FCChh-100	II					3
SPPC-125	III					3
Coll.Sea-500	V					4

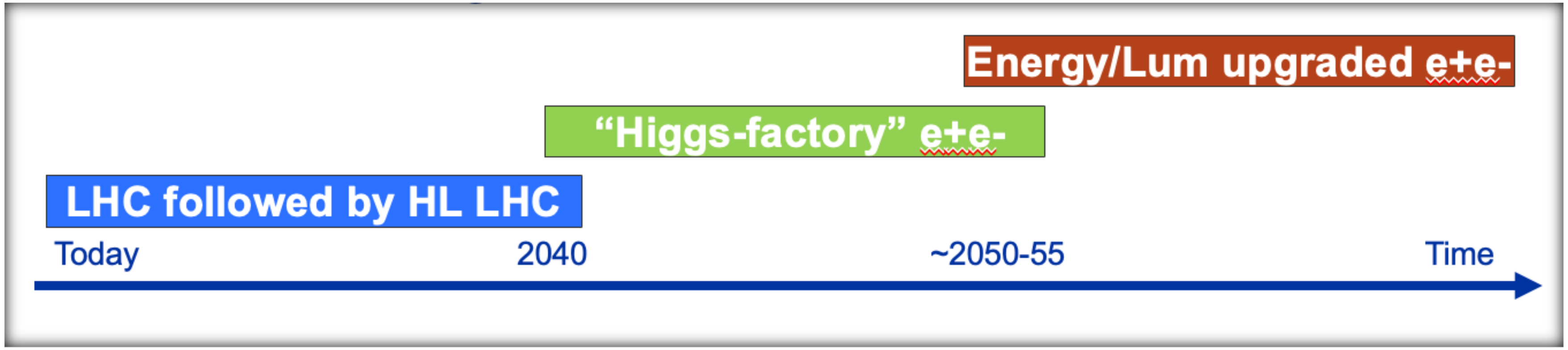
The challenge for the EPSS update:



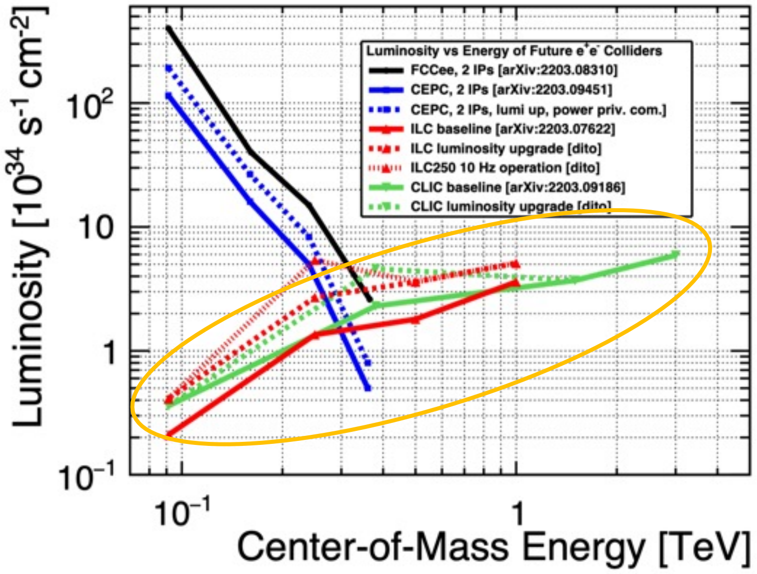
LC at CERN

Reminder: a LC can be upgraded in length and technology

LC general considerations - reminder



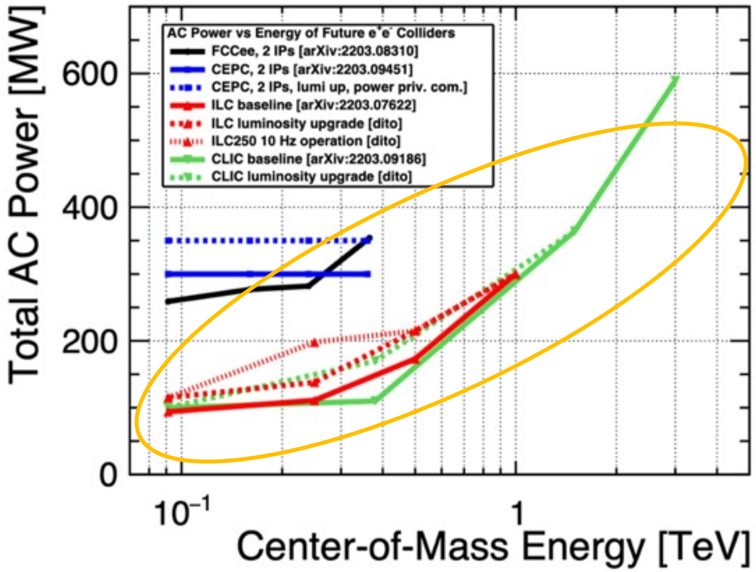
Start with mature technology, can expand in length and/or technology



Increased luminosity with energy, e.g. 1-3 x 10^{34} cm^{-2}s^{-1} for Higgs factories at 250 GeV, 6 x 10^{34} at 3 TeV.

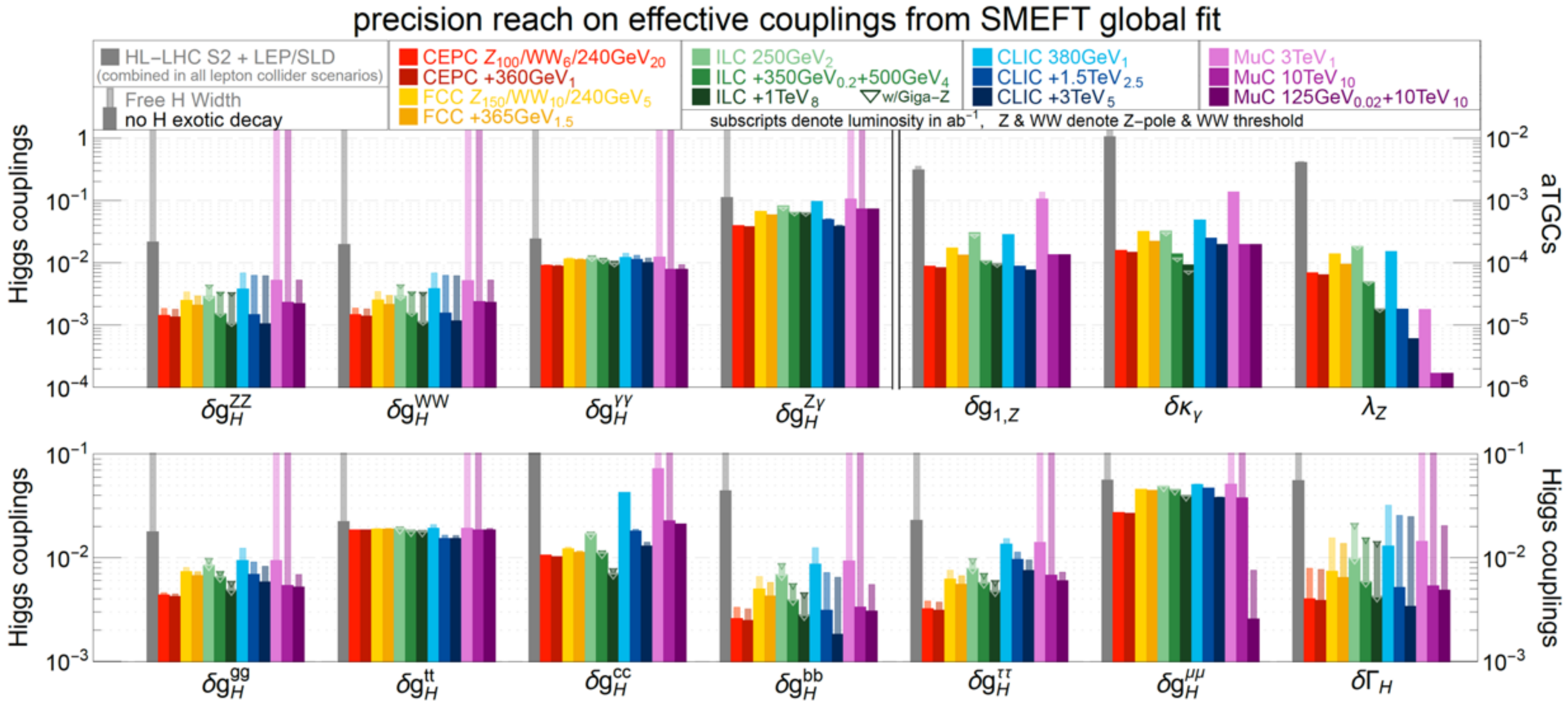
Higher energies "natural" – 3 TeV studied (for CLIC), but many TeVs challenging:

- Power increases with energy and luminosity
- Reach up to 50km
- Higher energy means smaller beams and increasingly important beam-beam effects.



LC physics opportunities - reminder

arXiv:2206.08326



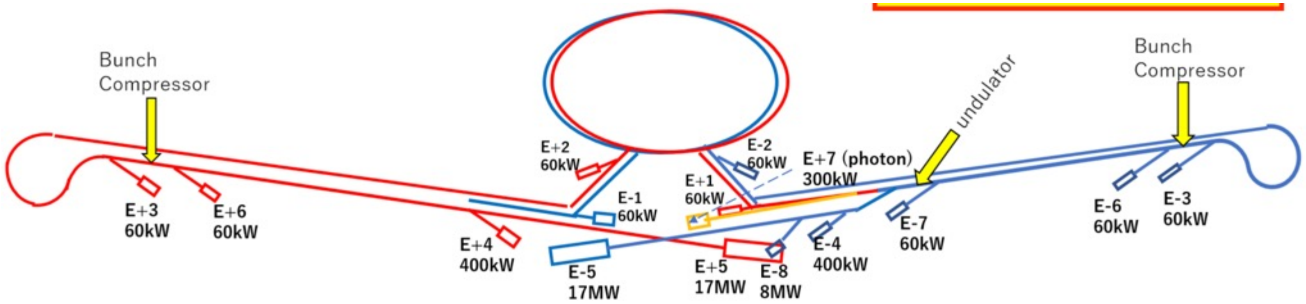
e+e- colliders show very comparable performance for standard Higgs program, despite quite different assumed integrated luminosities => longitudinal beam polarization an important factor for LCs

- several couplings at few-0.1% level: Z, W, g, b, τ
- some more at ~1%: γ, c

A physics-driven, polarised operating scenario for a Linear Collider

- **250 GeV, ~2ab-1:**
  - precision Higgs mass and total ZH cross-section
  - Higgs -> invisible (Dark Sector portal)
  - basic ffbar and WW program
  - optional: WW threshold scan
- **Z pole, few billion Z's: EWPOs 10-100x better than today**
- **350 GeV, 200 fb-1:**
  - precision top mass from threshold scan
- **500…600 GeV, 4 ab-1:**
  - Higgs self-coupling in ZHH
  - top quark ew couplings
  - top Yukawa coupling incl CP structure
  - improved Higgs, WW and ffbar
  - probe Higgsinos up to ~300 GeV
  - probe Heavy Neutral Leptons up to ~600 GeV
- **800…1000 GeV, 8 ab-1:**
  - Higgs self-coupling in VBF
  - further improvements in tt, ff, WW, ….
  - probe Higgsinos up to ~500 GeV
  - probe Heavy Neutral Leptons up to ~1000 GeV
  - searches, searches, searches, …

Beyond collider:
- ILCX – e.g. beam-dump experiments, dark sector physics, light dark matter, strong QED (ILCX workshop)
- Test and R&D beams for detector and accelerator studies



Higgs Factory Detector Concepts

Key requirements from Higgs physics:

- **p_t resolution** (total ZH x-section)
  $\sigma(1/p_t) = 2 \times 10^{-5}\ \mathrm{GeV}^{-1} \oplus 1 \times 10^{-3} / (p_t \sin^{1/2}\theta)$
- **vertexing** ($H \to bb/cc/\tau\tau$)
  $\sigma(d_0) < 5 \oplus 10 / (p[\mathrm{GeV}] \sin^{3/2}\theta)\ \mu m$
- **jet energy resolution** ($H \to$ invisible) 3-4%
- **hermeticity** ($H \to$ invis, BSM) θ_{min} = 5 mrad
  (FCCee: ~50mrad)

Determine to key features of the **detector**:

- **low mass tracker:**
  eg VTX: 0.15% rad. length / layer)
- **calorimeters**
  - **highly granular,** optimised for particle flow
  - or dual readout, LAr, …

≈ CMS / 40

≈ CMS / 4

≈ ATLAS / 2

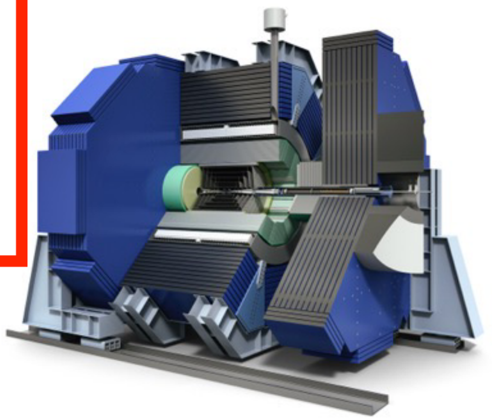
≈ ATLAS / 3

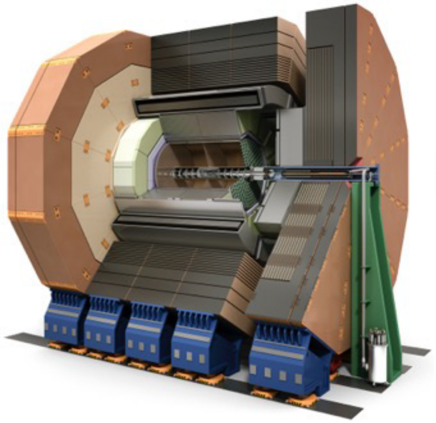
For LCs, bunches inside trains

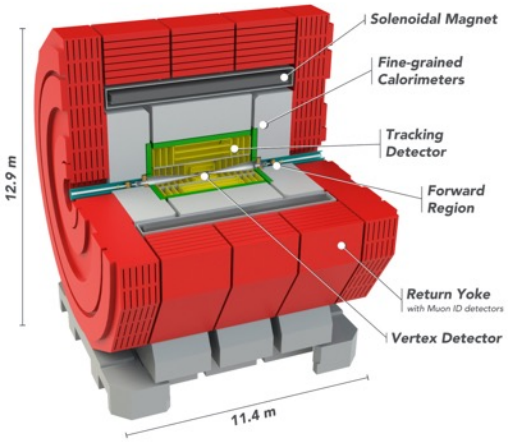
- at ILC: Δt_b = 554 ns; f_{rep} = 5 -10 Hz
- at CLIC: Δt_b = 0.5 ns; f_{rep} = 50-100 Hz

The lower collision rate enables

- passive cooling only => low material budget
- triggerless operation

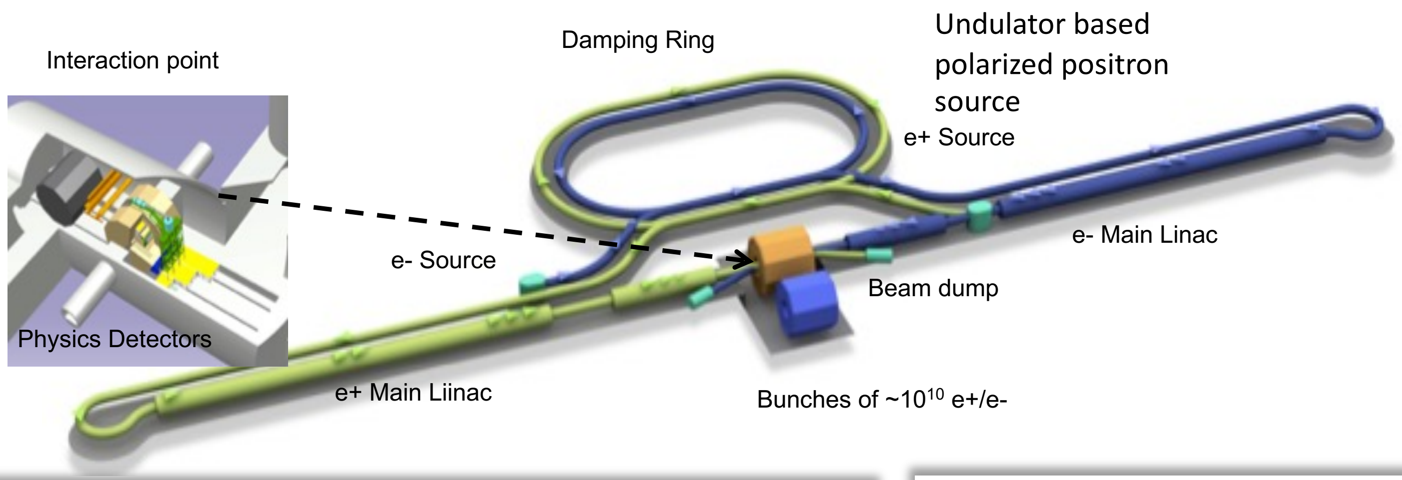


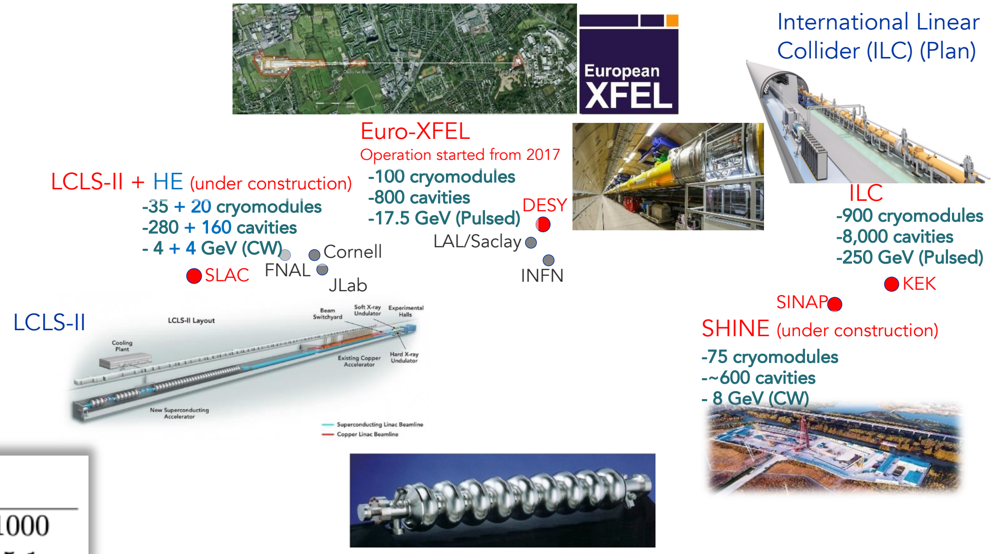




ILC – general updates and implementation in Japan

The ILC250 accelerator facility





Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_z^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_x^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_y^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	128	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Parameters and plans for luminosity and energy upgrades are available, including information about relevant SCRF R&D for such upgrades at (Snowmass input)

Some recent ILC developments - I

SRF	WPP	1	Cavity production	√		√	√	√			√	√	√				√	√	√		√	√		√	√	
	WPP	2	CM design	√				√				√			√	√	√	√	√			√		√	√	
	WPP	3	Crab cavity			√	√							√					√			√	√		√	√
Sources	WPP	4	E-source			√						√							√		√			√		
	WPP	6	Undulator target				√												√	√			√			
	WPP	7	Undulator focusing				√												√	√			√			
	WPP	8	E-driven target	√		√												√	√							
	WPP	9	E-driven focusing	√														√	√							
	WPP	10	E-driven capture	√															√					√		
	WPP	11	Target replacement	√																						
Nano-beams	WPP	12	DR System design	√	√				√	√		√							√				√	√		
	WPP	14	DR Injection/extraction	√					√										√				√	√		
	WPP	15	Final focus	√			√		√		√							√			√			√		
	WPP	16	Final doublet	√	√													√								
	WPP	17	Main dump	√			√					√														

Above: ILC Technology Network (ITN), interest/capability matrix from 28 labs/universities

WPP	1	Cavity production
WPP	2	CM design
WPP	3	Crab cavity
WPP	4	E- source
WPP	6	Undulator target
WPP	7	Undulator focusing
WPP	8	E-driven target
WPP	9	E-driven focusing
WPP	10	E-driven capture
WPP	11	Target replacement
WPP	12	DR System design
WPP	14	DR Injection/extraction
WPP	15	Final focus
WPP	16	Final doublet
WPP	17	Main dump

Promoting the technological development of the International Linear Collider: Twenty-eight research institutes participated in the ITN Information Meeting

Topics

2023/11/16

European ITN studies are distributed over five main activity areas:

ML related tasks
- SRF and ML elements: Cavities and Cryo Module, Crab-cavities, ML quads and cold BPMs (INFN, CEA, DESY, CERN, IJCLAB, UK, CIEMAT, IFIC)

Sources
- Pulsed magnet and wheel/target (Uni.H, DESY, CERN)

Damping Ring including kickers
- Low Emittance Rings (UK)

ATF activities, final focus and nanobeams
- ATS and MDI (UK, DESY, IJCLAB, CERN, IFIC)

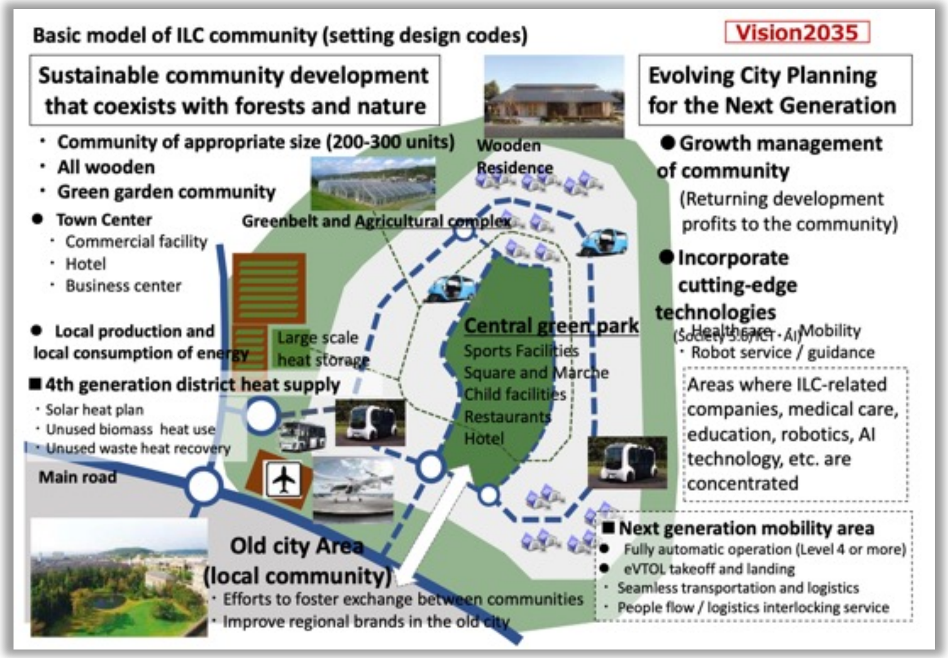
Implementation
- Dump, CE, Cryo – follow up efforts at CERN
- Sustainability, Life Cycle Assessment (CERN, DESY, CEA, UK groups)
- EAJADE started (EU funding) (DESY, UK, CEA, CNRS, IFIC, INFN, UHH, CERN)

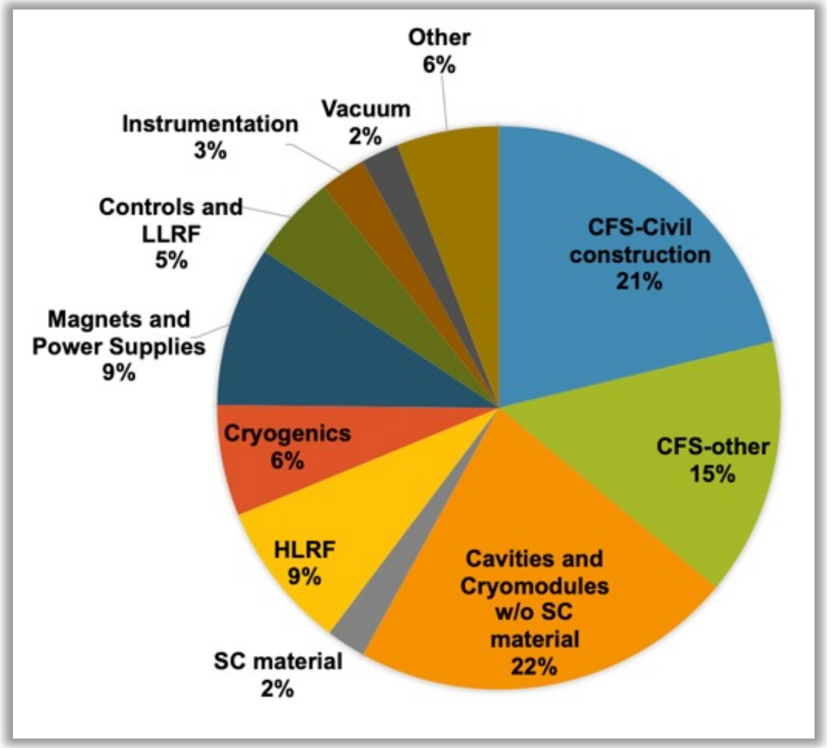
Some recent ILC developments - II

Re-evaluate CFS costs for ILC in Japan
- Mountainous site -> mostly sloped access tunnels
- CE based on NATM tunnelling method (blast and spayed concrete)

Includes design updates from TDR/ILC-250
- Some tunnel and cavern extensions for latest acc. and utility designs

Re-evaluated to 2024 National Cost Estimating Standards



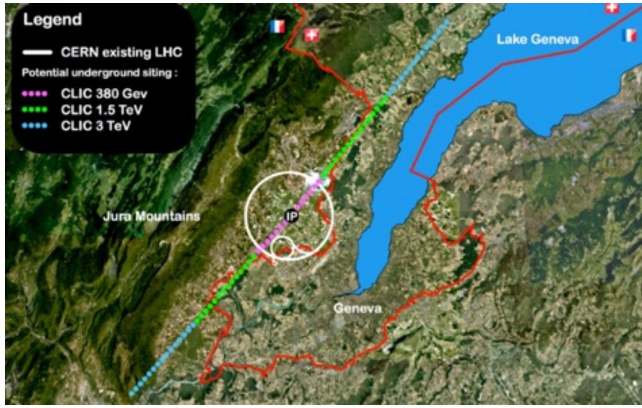


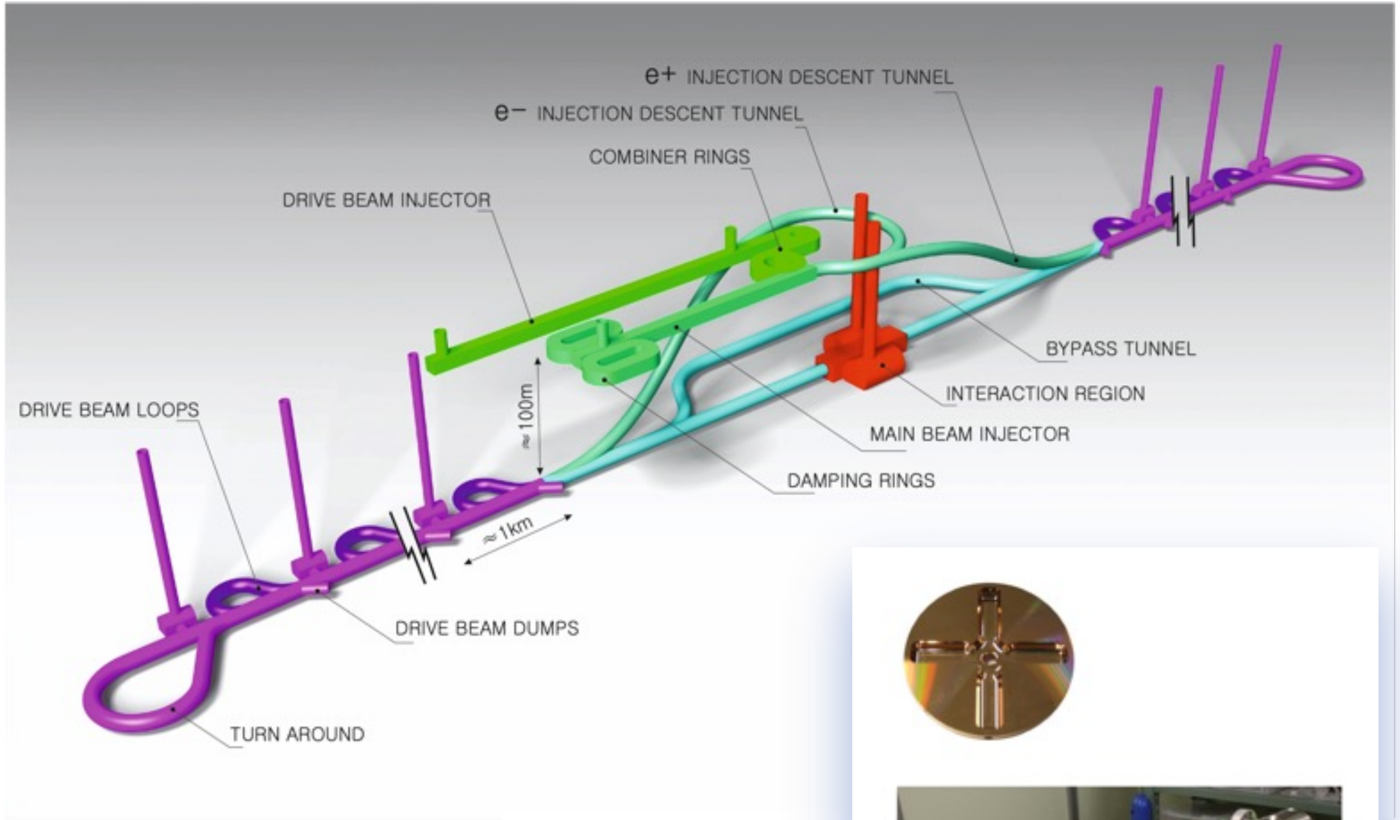
Cost matrix, updating SCRF and CFS (~75%), escalation and currency updates for the rest (~25%)

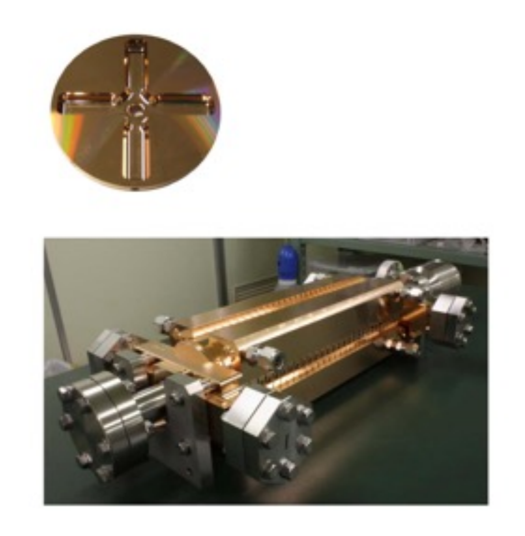
The ILC implementation is extensively studies in Japan, civil engineering, integration locally, environmental impacts, etc

CLIC at CERN

The Compact Linear Collider (CLIC)







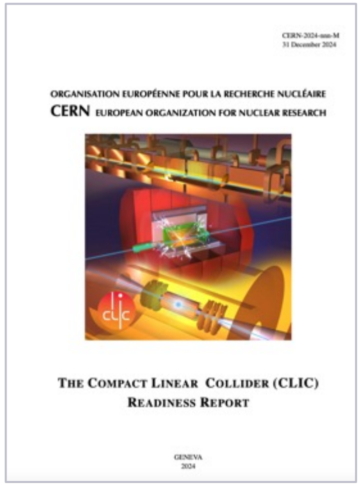
Accelerating structure prototype for CLIC: 12 GHz (L~25 cm), 100 MV/m

- **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) presented in previous ESPP updates
- 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.

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.


CERN-2024-nnn-M
31 December 2024

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

THE COMPACT LINEAR COLLIDER (CLIC)
READINESS REPORT

GENEVA
2024

However, several important changes:

- Energy scales: 380 GeV and 1.5 TeV with one drivebeam
- Consider also 100 Hz running at 250 GeV (i.e. two parallel experiments, two BDSs)
- 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 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 – 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, power update for 380 GeV: LINK

The CLIC ESPP update - II

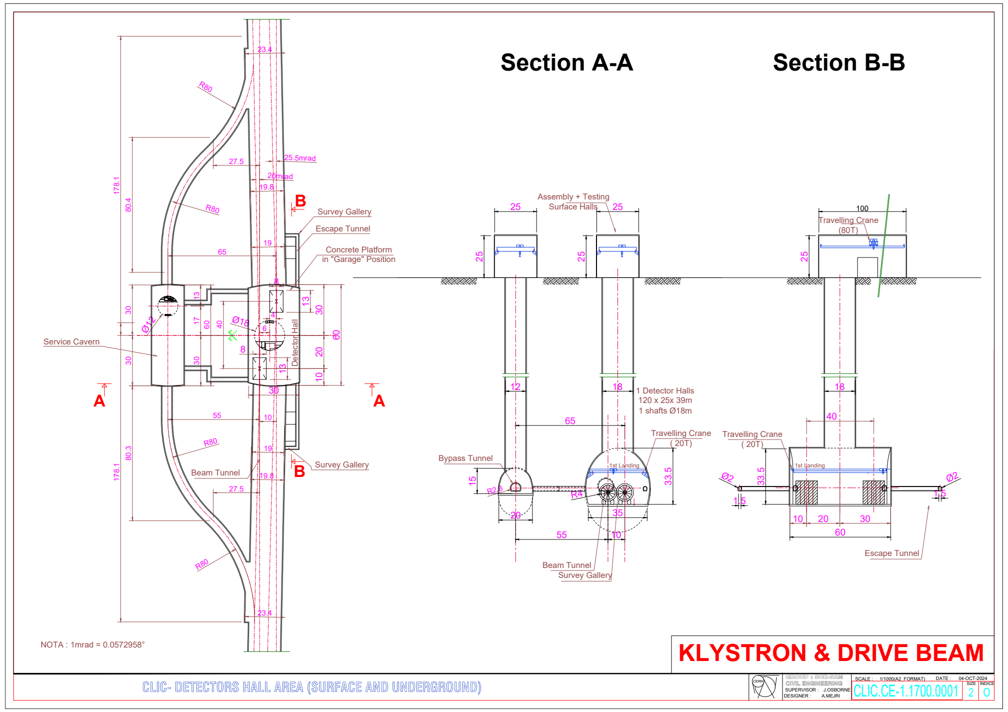
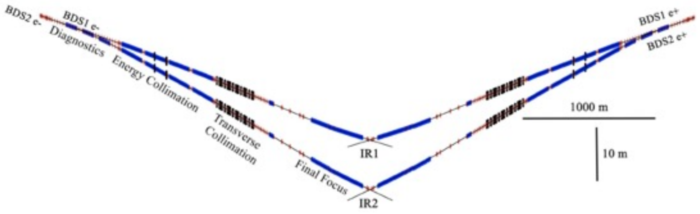


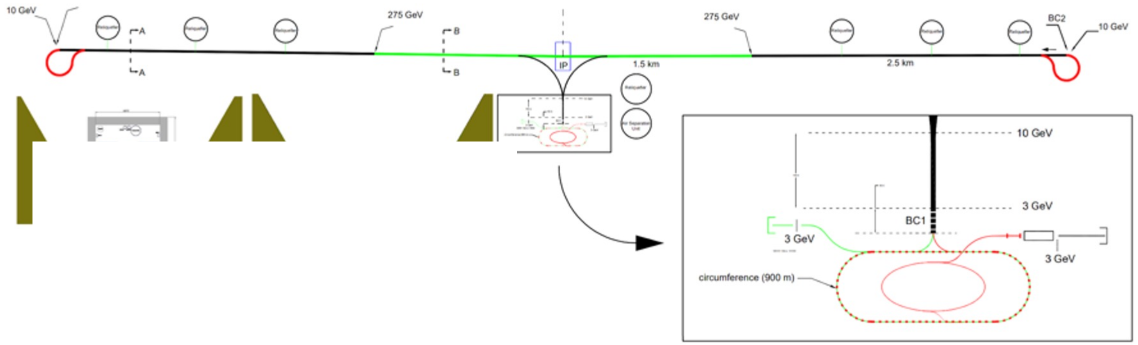
Table 1.1: Key parameters of the CLIC energy stages.

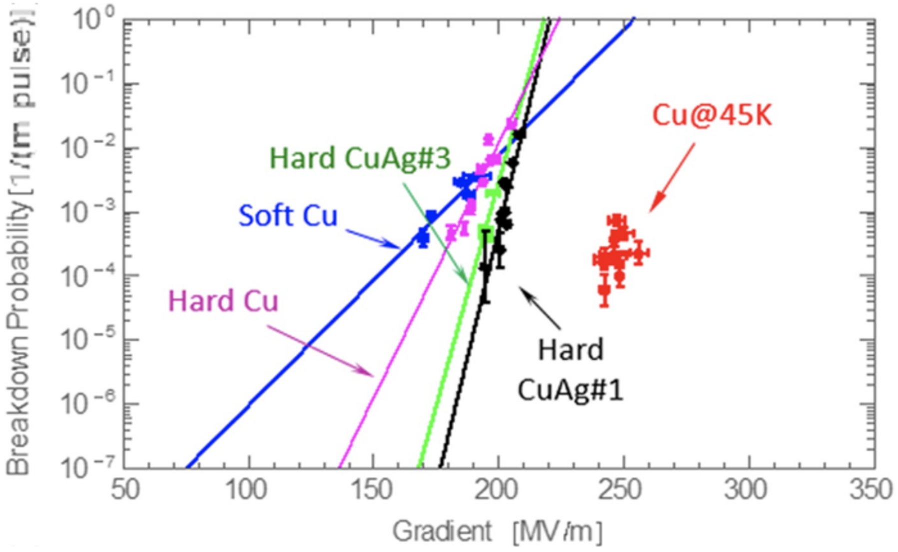
Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,\mathrm{cm^{-2}s^{-1}}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,\mathrm{cm^{-2}s^{-1}}$	1.3	1.4	2
Total int. lum. per year	$\mathrm{fb^{-1}}$	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



C3 and other options

C^3 Accelerator Complex





Cahill, A. D., et al. *PRAB* 21.10 (2018): 102002.

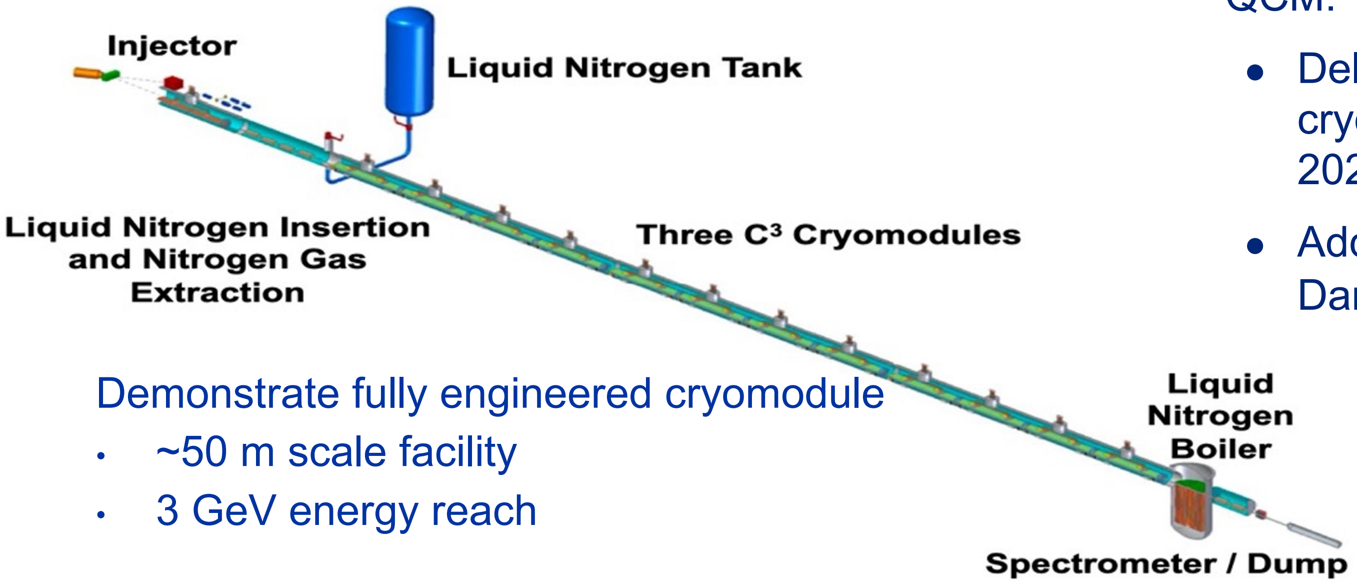
8 km footprint for 250/550 GeV CoM ⟹ 70/120 MeV/m
Large portions of accelerator complex compatible between LC technologies

- Beam delivery / IP modified from ILC (1.5 km for 550 GeV CoM), compatible w/ ILC-like detector
- Damping rings and injectors to be optimized with CLIC as baseline

Snowmass paper:
https://arxiv.org/pdf/2203.07646.pdf

Scenario	C^3 -250	C^3 -550	C^3 -250 s.u.	C^3 -550 s.u.
Luminosity [x10^{34}]	1.3	2.4	1.3	2.4
Gradient [MeV/m]	70	120	70	120
Effective Gradient [MeV/m]	63	108	63	108
Length [km]	8	8	8	8
Num. Bunches per Train	133	75	266	150
Train Rep. Rate [Hz]	120	120	60	60
Bunch Spacing [ns]	5.26	3.5	2.65	1.65
Bunch Charge [nC]	1	1	1	1
Crossing Angle [rad]	0.014	0.014	0.014	0.014
Single Beam Power [MW]	2	2.45	2	2.45
Site Power [MW]	~150	~175	~110	~125

C^3 recent developments and immediate plans

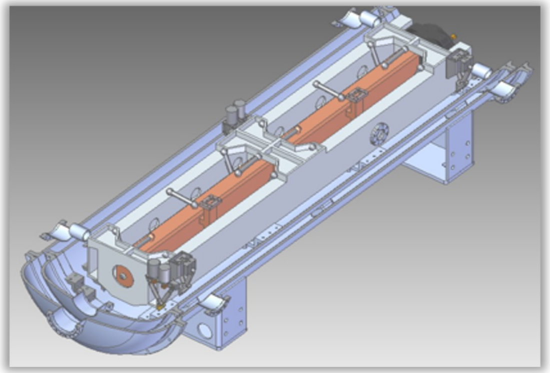


Demonstrate fully engineered cryomodule

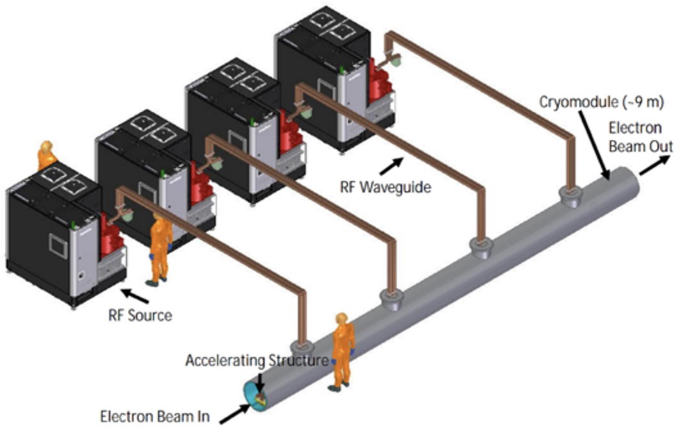
- ~50 m scale facility
- 3 GeV energy reach

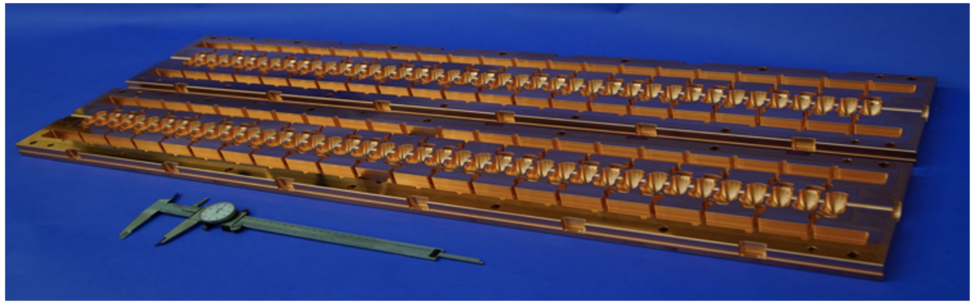
QCM:

- Delivery of prototype quarter cryomodule (QCM) expected Fall 2024
- Address Gradient, Vibrations, Damping, Alignment, Cryo, etc

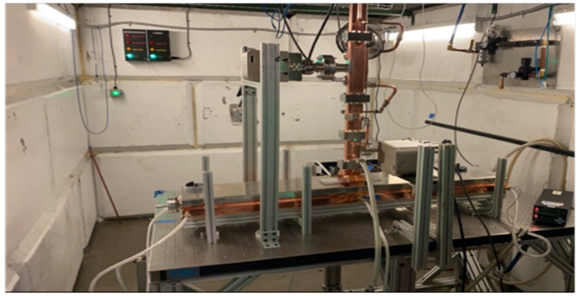


C^3 Main Linac Cryomodule
9 m (600 MeV/ 1 GeV)



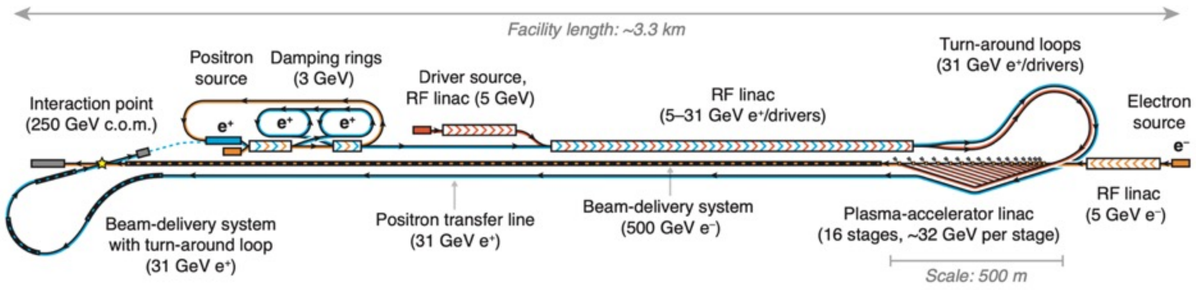


C^3 Prototype One Meter Structure



High power Test at Radiabeam

HALHF: A Hybrid, Asymmetric, Linear Higgs Factory



Source: **Foster, D'Arcy & Lindstrøm**, preprint at arXiv:2303.10150 (2023)

> Overall length: ~3.3 km ⇒ **fits in ~any major particle-physics lab**

> Length dominated by e⁻ beam-delivery system

New concept, aiming for pre-CDR (LINK)

- 500 GeV for electrons with plasma acceleration
- 31 GeV positrons with RF based linac, used also to provide electron drivebeam for the plasma acceleration
- Reach 250 GeV collision energy, luminosity 10^{34}

Asymmetric technologies, energies and bunch charges

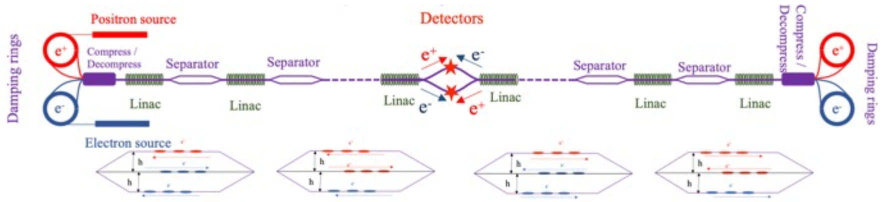
Small footprint, lower cost

Several key plasma acc. challenges:
Multi-staging, emittances, energy spread, stabilities, spin polarisation preservation, efficiencies, rep rate, plasma cell cooling and more

Conventional beam(s) challenges:
Positron production, damping rings, RF linac, beam delivery system

Experimental challenges with asymmetric beams

Energy recovery options, potentially very large luminosities but early stage of development



Twin LC with energy recovery

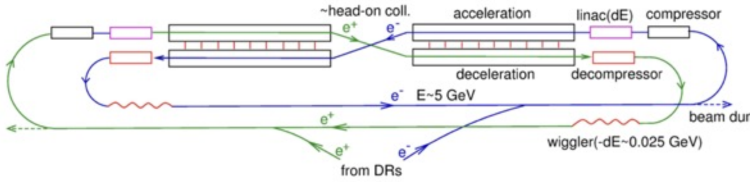


Figure 3-10. *Conceptual layout of the ERLC.*

LC "vision"
Also as option at CERN

An adaptable e+e- LC facility at CERN

A LC facility can be extended in length for higher energies, using the same or improved versions of the same technology, e.g. as suggested for ILC, CLIC, C3 and HALHF.

- It is also possible and realistic to change to more performant (usually higher gradient) technologies in an upgrade, e.g. from ILC to CLIC or C3, maybe even plasma and energy recovery based solutions

- The physics at higher energies – Higgs sector and extended models with increased reach and precision, top in detail well above threshold, searches and hopefully new physics – will open for a very exciting long term e+e- programme

- Such a programme can run in parallel with future hadron and/or muon colliders that can be developed, optimised and implemented as their key technologies mature

- It keep options open, provides flexibility, encourages and motivates R&D across a broad range of technologies and potential future colliders/accelerator/detector technologies

ESPP inputs – I

General goals for LCs :

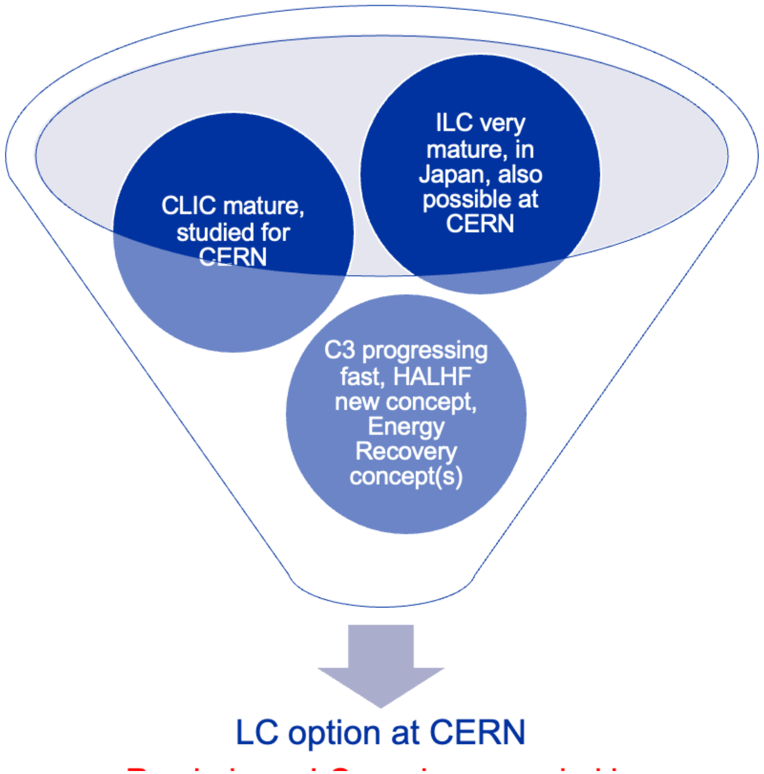
- See physics opportunities on page 5
- Lower cost to get to Higgs and top than a circular machine
- Power similar to LHC, or lower
- Footprint similar to LHC, CE cost risks therefore manageable
- Does not determine footprint of future energy frontier machines (hadrons and muon), and it has its own upgrade opportunities.

Higgs factory focussed studies	**Project input (the traditional way)** **See earlier slides**
ILC	ILC in Japan (JAHEP/ILC-Japan and IDT)
CLIC	CLIC at CERN
C3	Project study, focus on next phase
HALHF	Project concept, pre-CDR
Energy recovery	Project concepts and plans

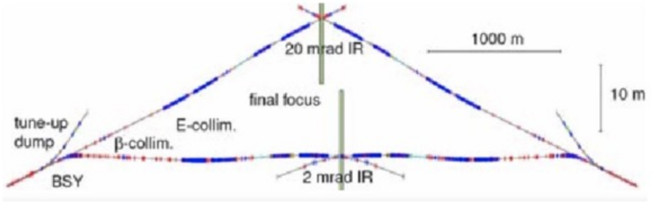
ESPP inputs – II

For a LC at CERN, what would be favoured option to start with – keeping in mind technology changes can be envisaged ?

The challenge for the EPSS update:



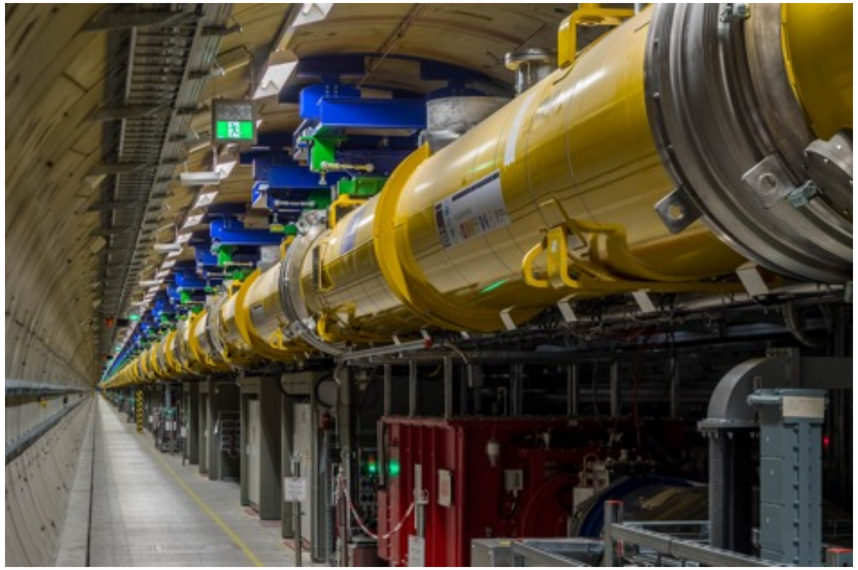
New approach for this ESPP (facility and community approach) – with three key inputs to the ESPP
Common LC physics paper covering from 90 GeV to 1000 GeV or even above. Include also non collider programme (see slide 5). Serves also the projects on previous page.
Starting with ILC technology, look at energy and luminosity extension options with improved SFR, or CLIC, C3, plasma and Energy Recovery technologies
Implementation of the above at CERN in footprint studied for CLIC (and ILC back in the TDR days), with two BDS, and experimental area at Prevessin, and considerations of upgrade options.



ESPP inputs – III

Why SRF as starting point ?

- Very detailed and mature technical design and industrialisation, several FEL linacs build and being operated.
- Can be upgraded in Energy and Luminosity.
- Worldwide interest in technology.
- Large technology interest in Europe (EUXFEL and several other projects), and leading industries in Europe.
  - Could it be exploited to reduce load on CERN during the HL period (lab support outside for cryomodules for example) ?
  - Can this be turned into schedule advancement ?



Cost and Personnel estimates – Higgs factories

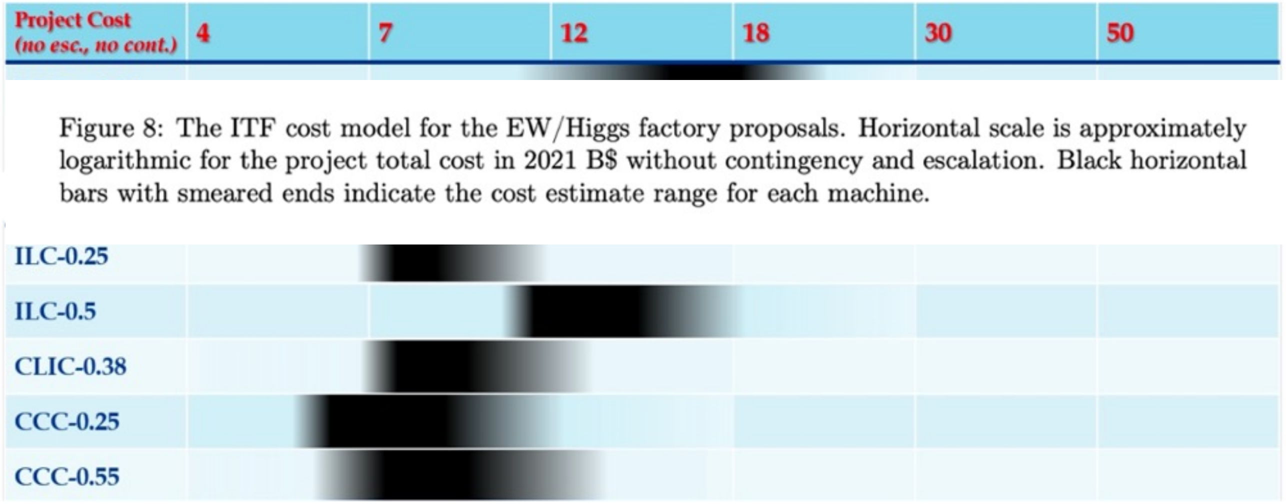


Figure 8: The ITF cost model for the EW/Higgs factory proposals. Horizontal scale is approximately logarithmic for the project total cost in 2021 B$ without contingency and escalation. Black horizontal bars with smeared ends indicate the cost estimate range for each machine.

These estimates from the Snowmass process includes personnel costs (usually kept separate in European project estimates, e.g. ILC and CLIC). Typically ~2 M$ on top.

Interesting to note that FCC-ee 250 estimated with this method at is 14-18 B$, in reasonably good agreement with FCC-ee mid term report.

Costs for ILC and CLIC (and others) are currently being re-costed and updated to 2023-24, including currency changes and price escalations. We will see if they also agree reasonably well with the Snowmass estimates shown above.

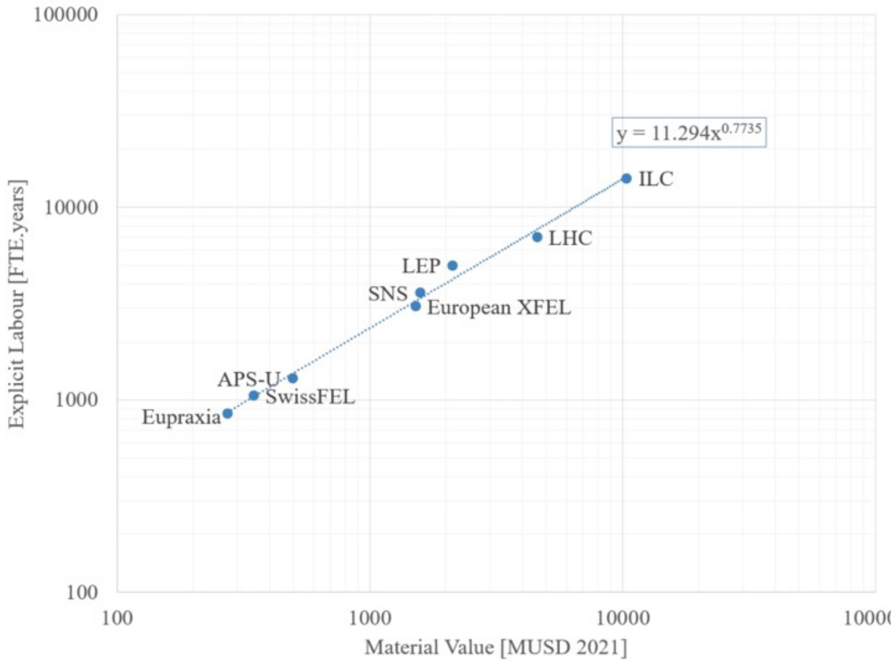


Figure 5: Explicit labor for several large accelerator projects vs. project value.

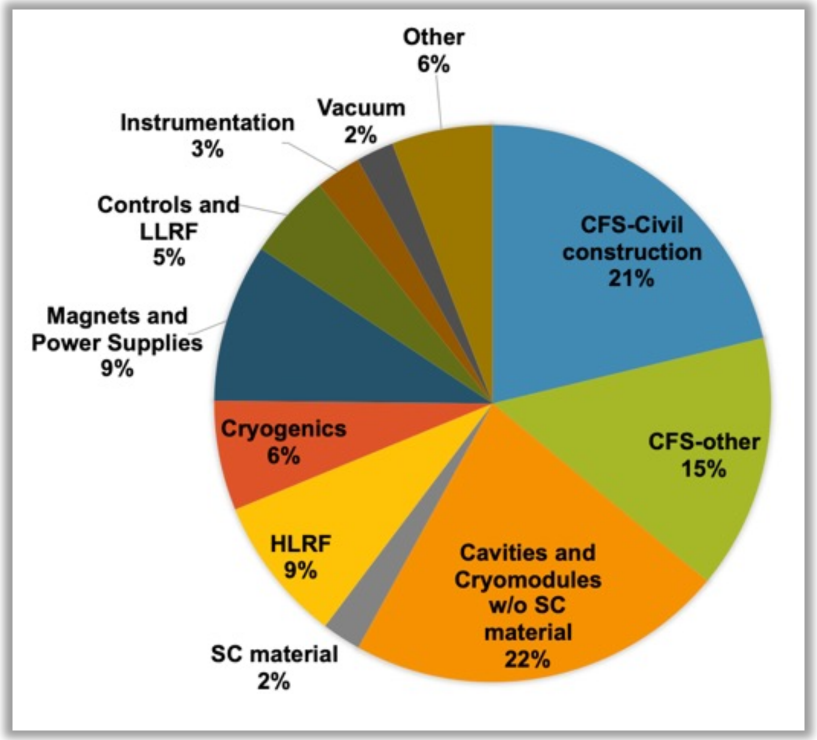
One FTEy estimated to 200kUS$.

Costs

Cost exercises and international reviews:

- ILC TDR 2012-13, 500 GeV primarily (LINK)
- CLIC CDR 2012-13, 3 TeV primarily and 500 GeV (LINK)
- ILC in Japan 2017-18, 250 GeV, reviewed within LCC (LINK)
- CLIC PiP 2018, 380 GeV primarily (LINK)

Updates and reviews underway (e.g. scheduled in December for ILC costs)



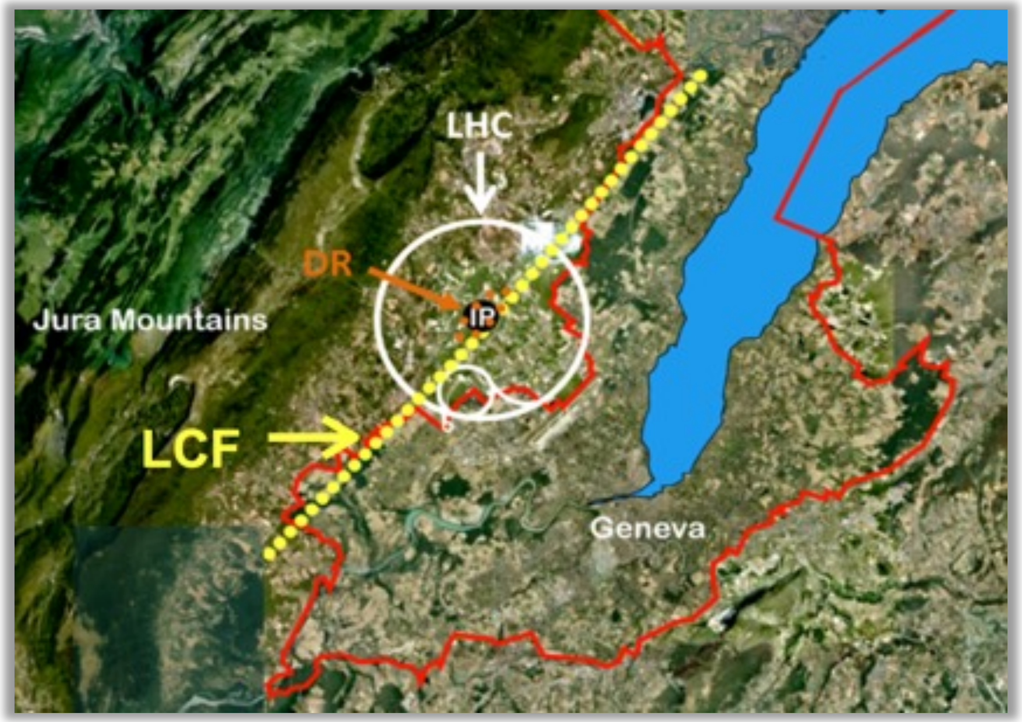
For the ESPP – concerning starting with ILC at CERN:

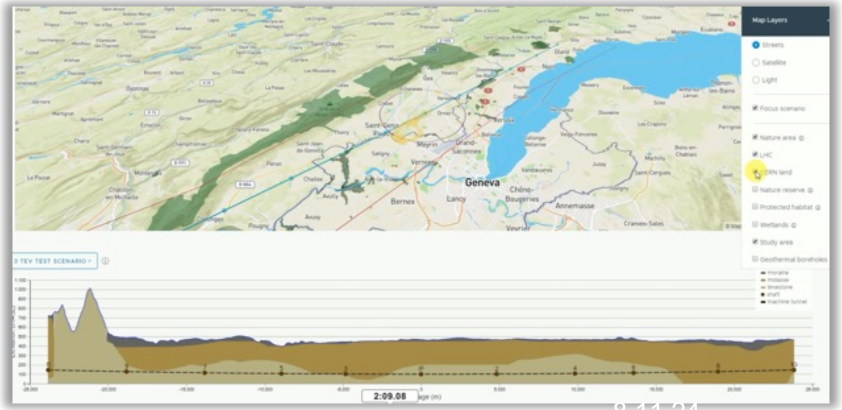
- Updated: ILC in Japan with updated technology results, updated CFS (CE and conv. systems, SCRF) – discussed on slide 10
- CERN implementation: CE costs based on CLIC and other CERN projects, same main linac footprint, change in number of shafts, add larger underground DR, remove drivebeam CE and turn arounds, slightly different BDS dimensions and cavern sizes

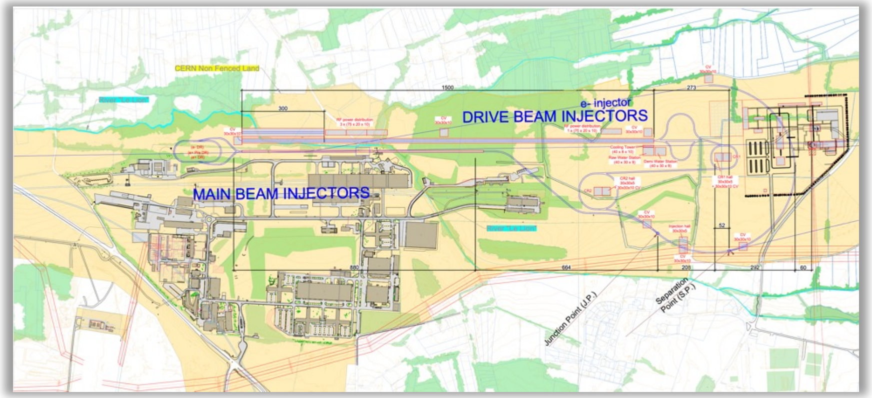
Civil Engineering

CE studies for LC at CERN:

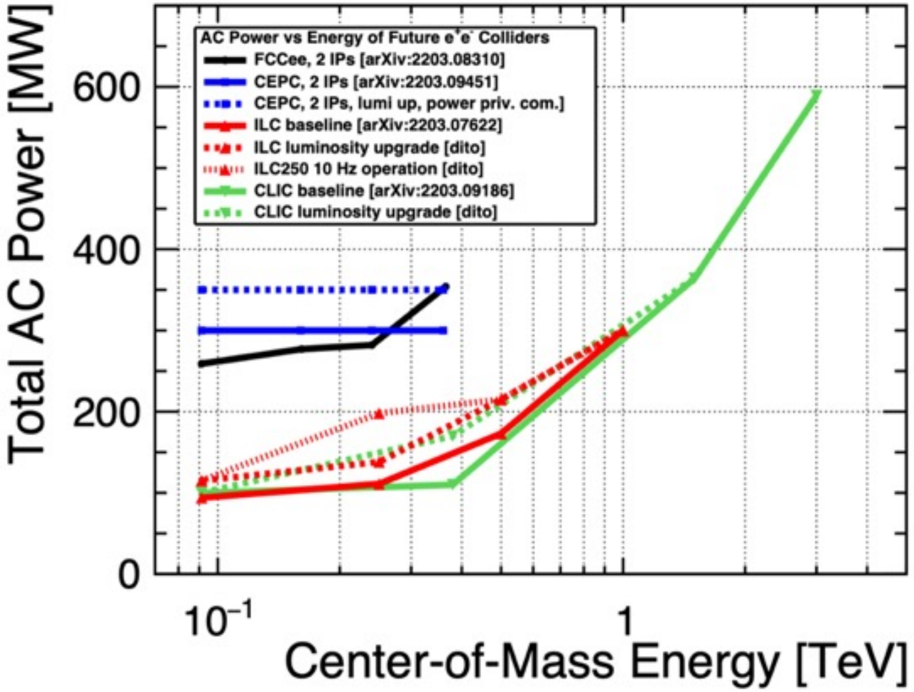
- CLIC, up to 3 TeV. Contract with Amberg Engineering for CDR in 2012-2013.
- ILC up 1 TeV. Contract with Amberg for the TDR in 2012-13.
- CLIC up to 3 TeV, TOT (layout tool) with ARUP, for Project Implementation Report 2018
- Update on-going, ILC up to 500 GeV, CLIC to 1.5 TeV, in both cases ~30km, using Geoprofiler layout tool
- Injectors and experimental areas on Prevessin site ("CERN land")







Power and energy

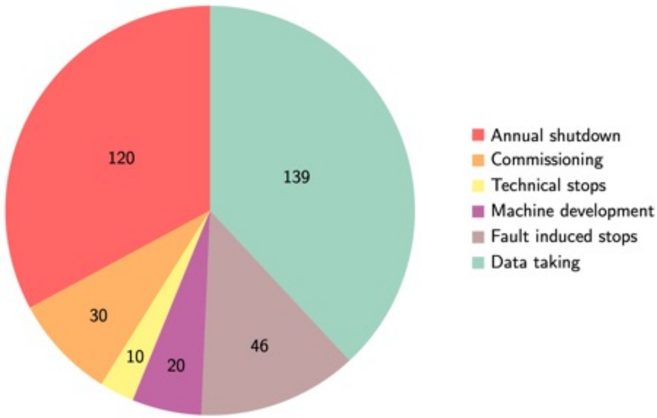


Power at 250-380 GeV in the 100-150 MW range for the projects above

With a running scenario on the right this corresponds to 0.6-0.8 TWh annually

CERN is currently consuming 1.2 – 1.3 TWh annually

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



Includes studies of overall designs optimisation to reduce power, SRF cavities (grad,Q), cryo efficiency, RF power system (klystrons, modulators, components), RF to beam efficiencies, permanent magnets, operation when power is abundant, heat recovery, nanobeam and more.
Recent overview (LINK)

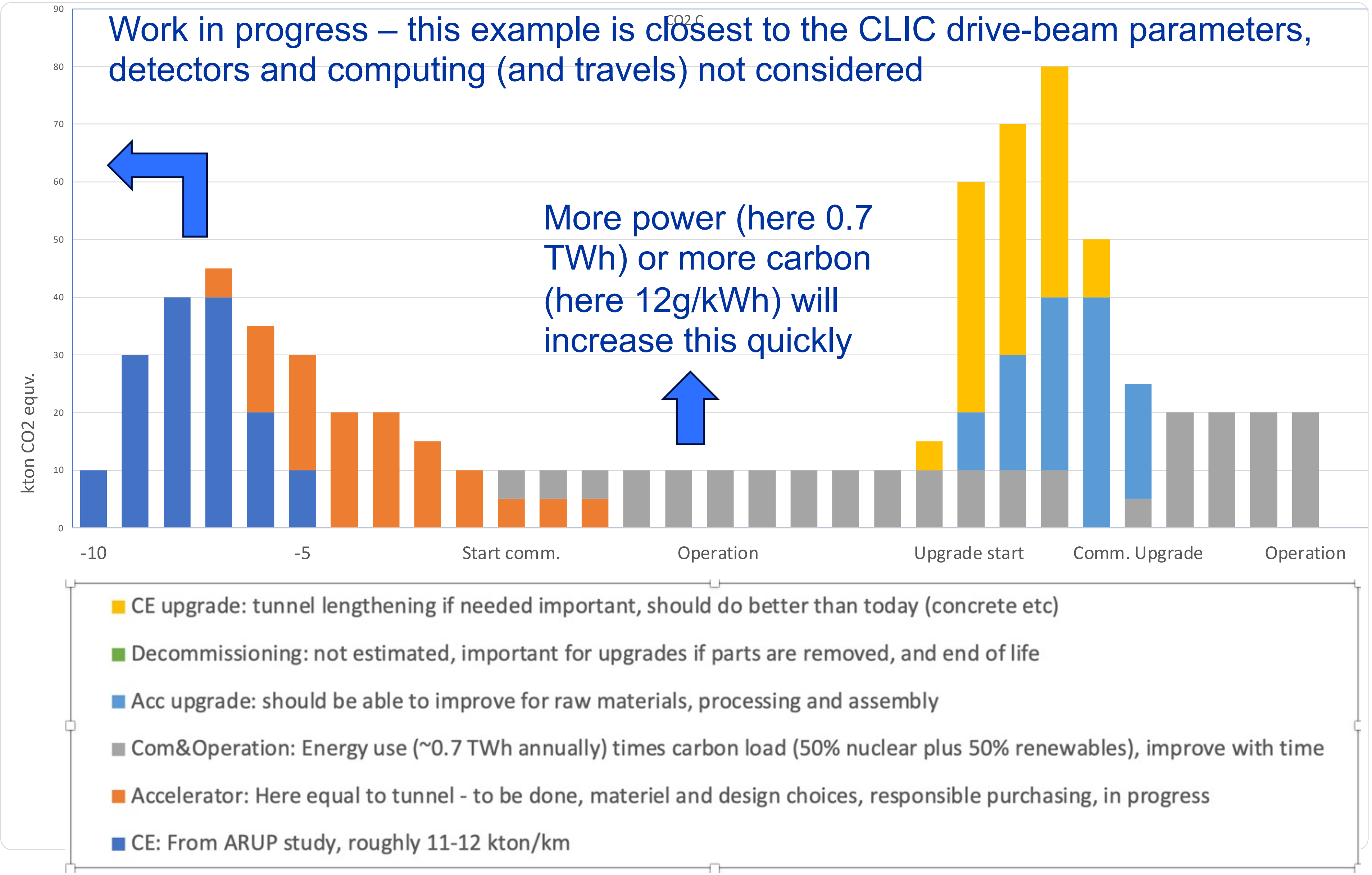
Towards Carbon Accounting with LCA

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

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 part will be higher



Some additional points

- US participates fully in ILC IDT WGs and costing, increased US engagement in ITN highly welcome
- Ongoing collaborative work within C3 (US led) including common studies CLIC-C3-ILC, HALHF (Energy Recovery concepts)
- LC vision activities ongoing including US, extended meeting at CERN 8-10.1.2025 to prepare ESPP inputs: https://indico.cern.ch/event/1471891/overview

Thanks – most of the slides/information from:

S.Michizono, B.List, IDT and ILC colleagues
CLIC team
J.List, A.Robson
E.Nanni and the C^3 team
The HALHF team
ARUP
The Snowmass Implementation Task Force (names on page 2, chair T.Roser)
many more

home.cern