Roadmap on Energy Recovery Linacs

5 Energy-Recovery Linacs

Editor: M. Klein[b]

Panel members: M. Klein[b,] (Chair), A. Hutton[a] (Co-Chair), D. Angal-Kalinin[c], K. Aulenbacher[d], A. Bogacz[a], G. Hoffstaetter[e,f], E. Jensen[g], W. Kaabi[h], D. Kayran[f], J. Knobloch[i], B. Kuske[i], F. Marhauser[a], N. Pietralla[j], O. Tanaka[k], C. Vaccarezza[l], N. Vinokurov[m], P. Williams[c], F. Zimmermann[g]*

Associated members: G. Burt[n], M. Bruker[a], P. Evtushenko[o], B. Militsyn[c], A. Neumann[i], [incomplete 29.10.]

Sub-Panel on CERC and ERLC: A. Hutton[a] (Chair), C. Adolphsen[p], O. Brüning[g], R. Brinkmann[q], M. Klein[b], S. Nagaitsev[r], P. Williams[c], A. Yamamoto[k], K. Yokoya[k] F. Zimmermann[g]

Max Klein, Andrew Hutton

in conjunction with Interim Report and our presentations to the LDG 30.9. + 12.10.21

LDG Meeting, November 2nd, 2021

Long Write-Up on ERLs
For publication end of 21 to accompany ERL roadmap
~ 250 pages, ~50 authors

The Development of Energy Recovery Linacs

Contents

R&D Goals and Motivation as described in roadmap 28.10.

-- Sustainability: Limitation of power consumption despite orders of magnitude higher luminosity need in electron based colliders

-- The near term 10 MW, 2K program: 100 mA currents, Niobium SRF at optimum frequency, Q_0 3 10^{10} to 10^{11} , beam based

- **Next step in ERL technology**
- **Crucial development for Europe to stay as recognised partner for US, Russia and Japan**
- **Technology base for decision on LHeC and FCC-eh, 802 MHz cryomodule demonstrator for FCC-ee feasibility**
- **Low energy particle and nuclear physics: nuclear photonics, exotic isotope spectroscopy, elastic ep (p radius, weak i.a.), dark photons**
- **Industrial applications such as Photolithography at nm scale, FELs (low and high E), inverse gamma sources, pico-second Xray sources**

-- The longer term 4.4K program: R&D for power economy, comparable to high field magnet and high gradient plasma programs

- **Next generation ERL technology: power (heat transfer) efficiency enhanced by factor of three: 300 → 100 MW**
- **Enabling a 500 GeV 10^{36} $cm^{-2}s^{-1}$ luminosity ERL based linear collider for per cent measurement of Higgs self-coupling [backup]**
- **Transfer of superconducting RF technology to smaller labs → revitalisation of the field and its industrial base**

-- Boost European technology + Physics attraction : ERL, its impact and applications

3-fold Roadmap Structure (executive summary)

The ERL roadmap presented here rests upon three major, interrelated elements:

A) **Facilities in progress**, including crucial technological developments and operational experience. These comprise sDALINAC (Darmstadt, Germany), MESA (Mainz, Germany) + cBETA (Cornell, US), cERL (KEK, Japan) and the normal-conducting, lower-frequency Recuperator facility (Novosibirsk, Russia);

B) **A key technology R&D program** focused on high-current electron sources and high-power SRF technology and operation in the years ahead. Next generation ERLs lead to the major goal of being able to operate at 4.4 K cryogenic temperature [4] with high Q_0, and also including higher-order mode damping at high temperature, dual-axis cavity developments and novel means for high-current ERL diagnostics and beam instrumentation to deal with effects such as beam break-up or RF transients;

C) **New ERL facilities** in preparation for reaching higher currents and electron beam energies at minimum power consumption. These are, in Europe, bERLinPRO (Berlin, Germany) with the goal to operate a 100 mA, 1.3 GHz facility, and PERLE (hosted by IJCLab Orsay, France), as the first multi-turn, high-power, 802 MHz facility with novel physics applications. In the coming years, the US will explore ERL operation near 10 GeV with CEBAF5 (Jefferson Lab, Newport News) and develop the challenging 100 mA electron cooler for hadron beams at the EIC (BNL, Brookhaven).

[4] The 4.4 K R&D program, hosted by the SRF panel, would also allow universities to adopt small superconducting accelerators for inverse Compton back-scattering, FELs, isotope production, etc. Apart from the societal aspect, this would provide a steady product line for SRF cavity and cryomodule production by industry, which would in turn benefit future HEP colliders.

First presented to LDG 30.9.21

5.5 State of the art and Facility plans—Roadmap Part A

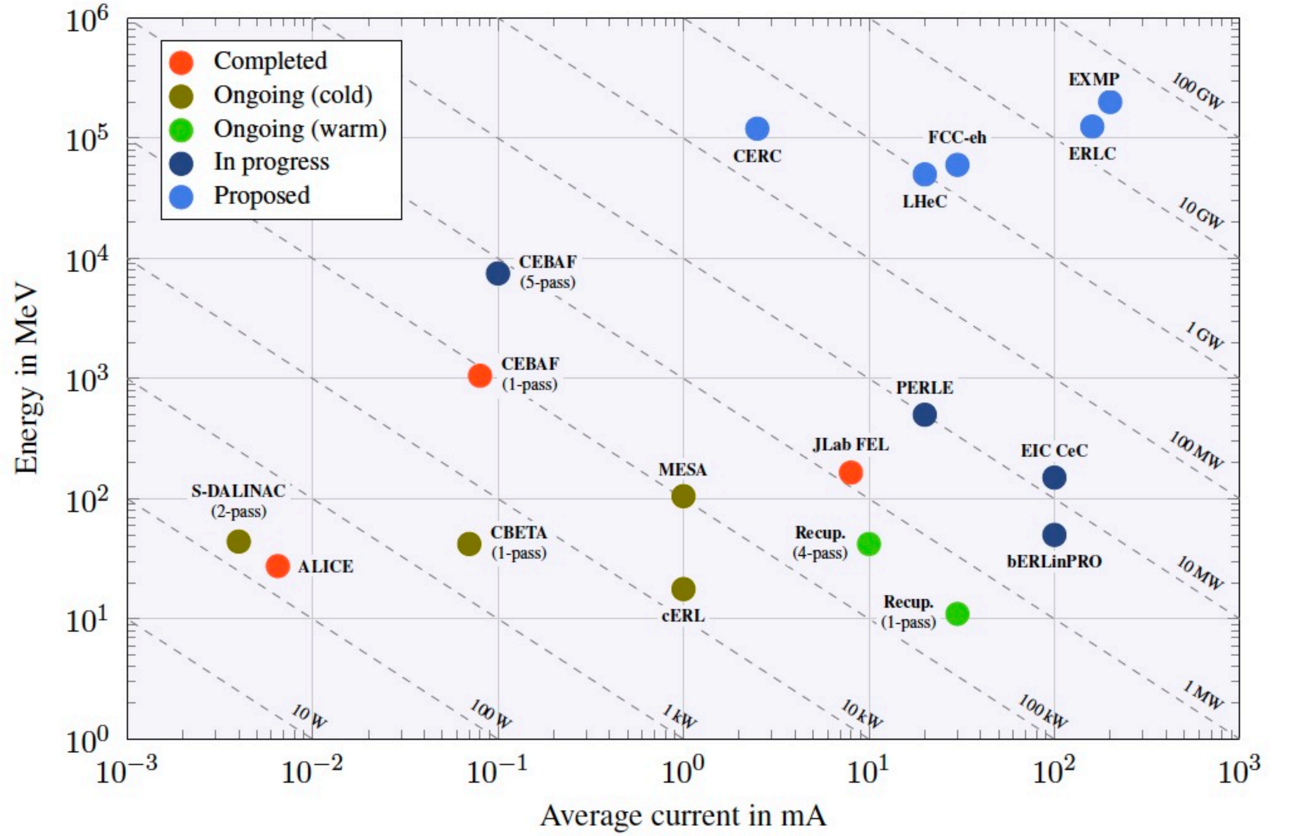


Fig. 5.1: Electron energy E vs. electron source current I for classes of past, present and possible future ERL facilities as are introduced in the text. Dashed diagonal lines are equi-power lines, $P[\mathrm{kW}] = E[\mathrm{MeV}] \cdot I[\mathrm{mA}]$. A brief account of the ERL history is presented in Sect. 5.2.1.

A challenging international ERL development program (no roadmap resource required).

Ongoing/forthcoming facilities

Training, operation **S-DALINAC - Darmstadt**

In August 2021, S-DALINAC was successfully operated in a twice-recirculating ERL mode. Full energy-recovery efficiencies of up to 81.8 % had been measured for beam currents of up to 8 µA at a beam energy of 41 MeV. The beam load of the SRF cavities in the two situations— with the beam either being accelerated only once or being accelerated twice and decelerated once— resulted in the same beam load within measurement uncertainties. The measurements, thus, indicate complete energy recovery in the first deceleration passage through the main linac with an efficiency of 100 % within uncertainties.

Support EIC CeC **CBETA - Cornell**

After achieving all Key Performance Parameters of CBETA's NYSERDA-funded construction and commissioning phase, operation was interrupted in the spring of 2020. The accelerator is now available to test single-turn and multi-turn ERL technology. Especially tests for the 100 mA hadron-cooling ERL of the EIC are of interest, as several key design parameters of CBETA's main components match that future accelerator well.

Exps, polarised, HOM **MESA- Mainz** (from 2024)

It will represent a sustained infrastructure for such experiments but also be available for further research on ERLs for a long time to come. The civil construction for the new machine will be finalised in 2022. Following the installation and commissioning of the machine, first ERL tests are expected in 2025. External-beam experiments are expected to start somewhat earlier. The ERL

– **Improving the higher-order mode damping capabilities** of the cavities.

rents, HOM heating of the damping antennas will lead to a breakdown of superconductivity in the antenna and hence inhibit operation. This can be improved by coating the HOM antennas with layers of material with a high critical temperature, e.g. Nb_3Sn. The MESA research group has recently received funding to start corresponding investigations within a larger joint effort of German universities.

Industry, 10mA, Nb_3Sn **cERL – KEK** (50 years..)

– Realization of energy-recovery operation with 100 % efficiency at a beam current of 10 mA at cERL and the FEL light production experiment.
– Development of an irradiation line for industrial applications (carbon nanofibers, polymers, and asphalt production) based on the CW cERL operation.
– Realization of a high-efficiency, high-gradient Nb_3Sn accelerating cavity to produce a superconducting cryomodule based on the compact freezer. We are targeting a general-purpose compact superconducting accelerator system that that can be operated at universities, companies, hospitals,

90MHz, FEL **Recuperator – BINP** (warm)

The current of the Novosibirsk ERL is now limited by the electron gun. A new RF gun was built and tested recently [41]. It operates at a frequency of 90 MHz. An average beam current of more than 100 mA was achieved. In brief, the following work is planned for the next years:

– Installation of the RF gun in the injector, while the existing electrostatic gun will be kept there. The RF gun beamline has already been manufactured and assembled in the test setup. It includes an RF chopper for the beam from the electrostatic gun.

See roadmap and long write-up for much more info.

5.6 R&D objectives - Key technologies - ERL Roadmap Part B

5.6.2 SRF Technology and the 4.4 K Perspective

Near-Term 2 K Developments

p.155

- Operation at 20 MV/m with $Q_0 > 3\ 10^{10}$
- Extraction of HOM power from Helium bath
- Damping of HOMs to prevent beam break up
- Reduction of RF power via Fast Reactive Tuners (FRT)
- 100mA sources (SRF and DC photocathode)

p.156

Towards 4.4 K

A significant part of the power consumption of ERLs is related to the dynamic cavity load in CW operation, which can be estimated by

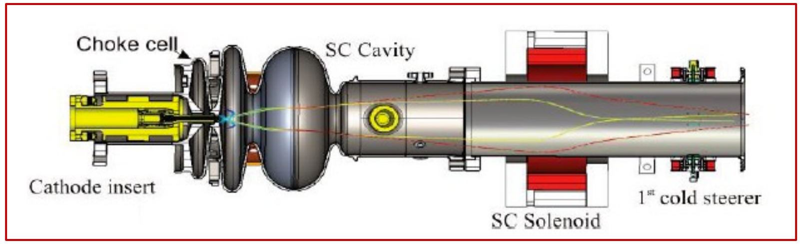
$$P = \frac{V_{\mathrm{acc}}^2}{(R/Q)\cdot Q_0}\cdot N_{\mathrm{cav}}\cdot \eta_T \qquad (5.1)$$

where V_{acc} is the acceleration of a cavity, R/Q the shunt impedance, Q_0 the cavity quality factor, N_{cav} the number of cavities and η_T the heat transfer, i.e. combined technical and Carnot, efficiency, which is proportional to the ratio of the cryo temperature, T, and its difference to room temperature, 300 K − T.

Boost cryogenic efficiency and chill cavities with cryocoolers, no lHe

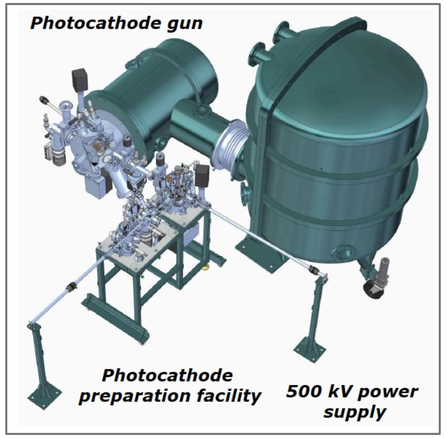
- Nb_3SN coating via vapour infusion, sputtering or ALD
- Evaluation of other superconductors as NbN, NbTiN, V3S
- Cavity tuners to avoid detachment of coating

5.6.1 High-Current Electron Sources



SRF elliptical cavity gun at bERLinPro: new 100mA module

ALICE (20mA) PERLE:



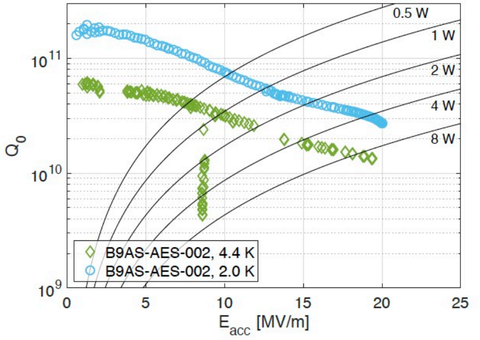


Fig. 13: Performance of 650 MHz single cell cavity B9AS-AES-002. The multipacting at 9 MV/m was processed during the test.

arXiv:2008.00599

In parallel: nitrogen diffusion and doping to reach 10^{11}

Roadmap integrates high current current source and 2K developments into the two facilities (part C):
bERLinPRO: 1.3 GHz, 100mA, 1-pass & PERLE: 802 MHz, 20mA, 3 passes

Roadmap: long term cavity R&D towards 4.4K: SRF Panel
ERL: full module in beam test (2030?) PERLE or bERLinPRO

R&D: HOM@hiT, Twins, Diagnostics

5.8.1 *Higher-order mode damping at high temperature*

Dynamic higher-order mode losses appear proportional to the beam intensity squared and to the number of cavities, which for ERLC reaches about 10^4. This dynamic load leads to a heat transfer related to a power "amplification" factor $\propto T/(300\,\mathrm{K} - T)$. The power requirement for compensating dynamic HOM losses is therefore the smaller the higher the temperature T is, as has been sketched in the key technology section 5.6. The diagram below summarises the sequence of steps and estimated effort for developing this area further.

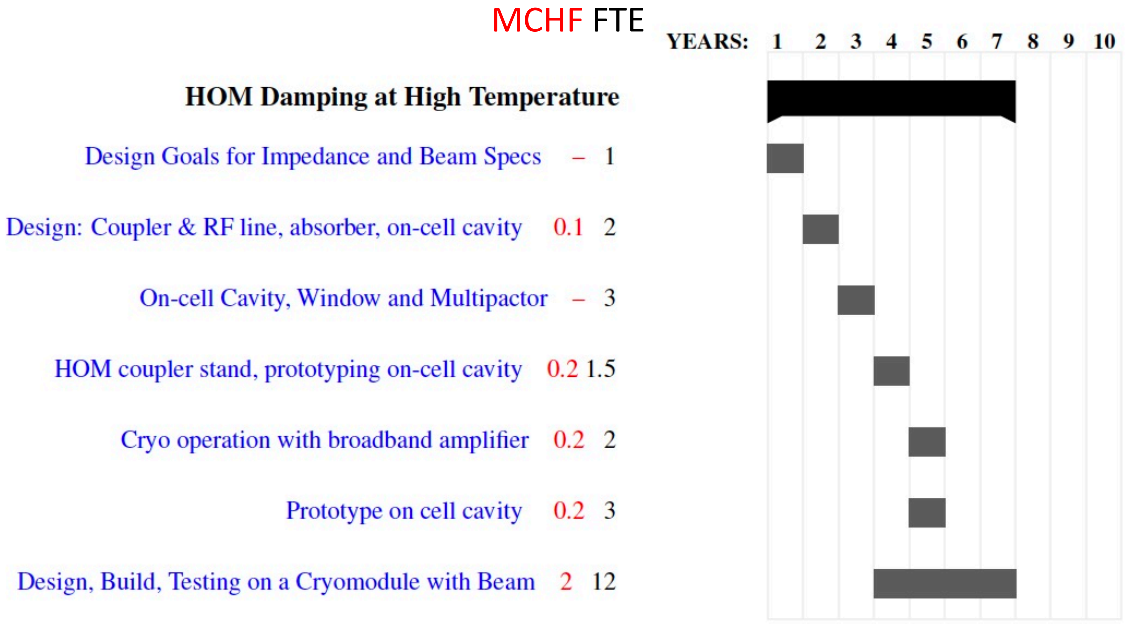


Chart 1: Development of HOM damping technology for high temperature. Funding 2.7 MCHF (red column) over 6 years, 24.5 FTEs (black). Year 1 for this development is chosen to be 2023 for giving time for interested laboratories to embark on it.

2.7 MCHF in 6 years

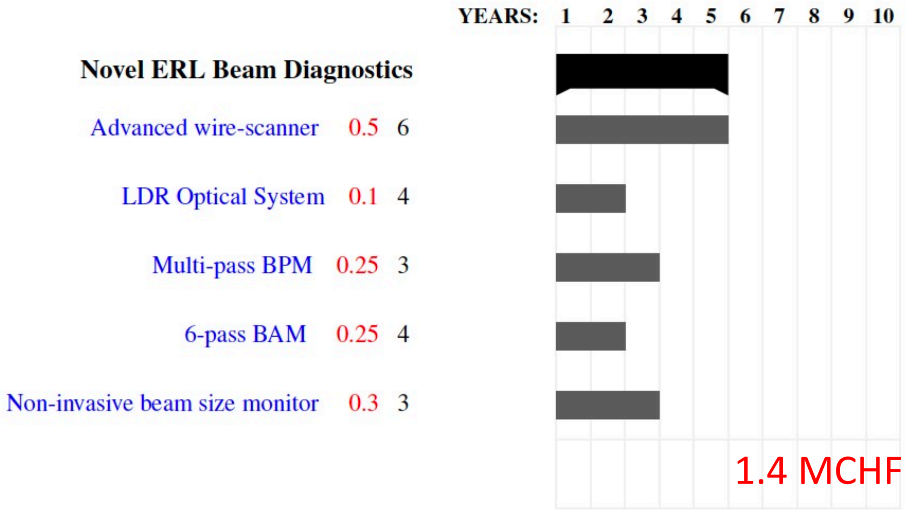
5.8.2 *Dual-axis cavity developments*

Twin-axis cavities are required when the accelerating and decelerating beams are traveling in opposite directions through long linacs. Initial developments have been done at JLab and the John Adams Institute a few years ago. For cost efficiency of a new generation e^+e^- linac, availability of high-Q_0 twin cavities is considered to be an important economy factor. The roadmap thus includes the design and production of a multi-cell twin cavity followed by a complete cryomodule.

3.5 MCHF in 6 years

Chart 2: Development of dual-axis cavity and cryomodule technology. Funding 3.5 MCHF (red column) over 6 years, 12.5 FTEs (black). Year 1 for this development is chosen to be 2023 for giving time for interested laboratories to embark on it.

5.8.5 *High-current operation and diagnostics*



1.4 MCHF in 5 years

Chart 5: Development plan for high current ERL beam diagnostics. Funding 1.4 MCHF (red column) over 5 years, 20 FTEs (black). Year 1 for this development is set to 2023 for interested parties to organise.

B

HOM damping to room T

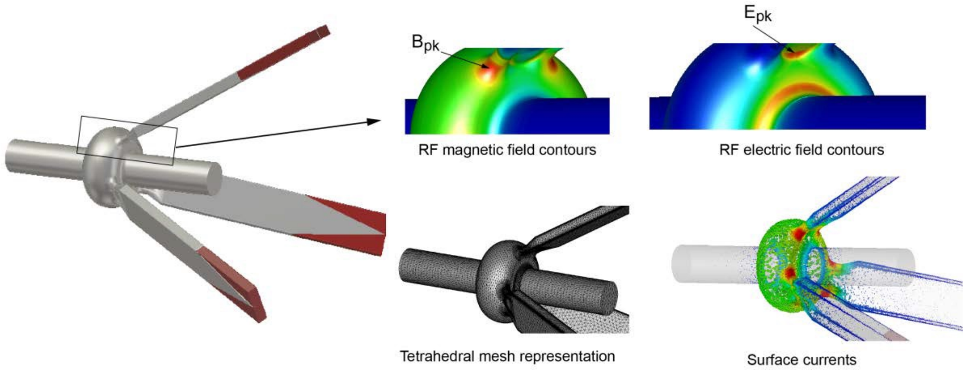
HOM power is usually extracted from the cavities and brought out to ~50K to reduce the thermal load

About 7% of the power is dissipated at 2K in the ILC

For high-current ERLs, this would be unacceptable

R&D Goal: >99% of HOM power transferred to room temperature

Possible technique: on-cell damping



Frank Marhauser: http://dx.doi.org/10.1088/1361-6668/aa6b8d

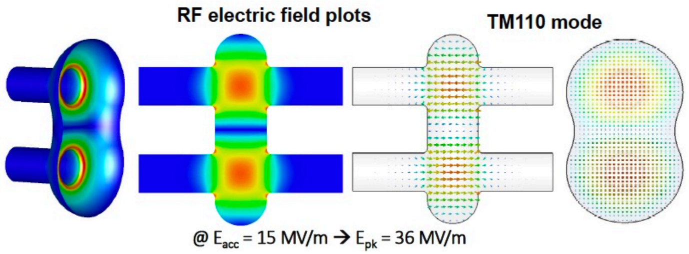
Input to roadmap being written, link to LHC:

Extract 1kW per HOM coupler at 400 MHz to warm via RF

Higher may need waveguide (Graeme Burt)

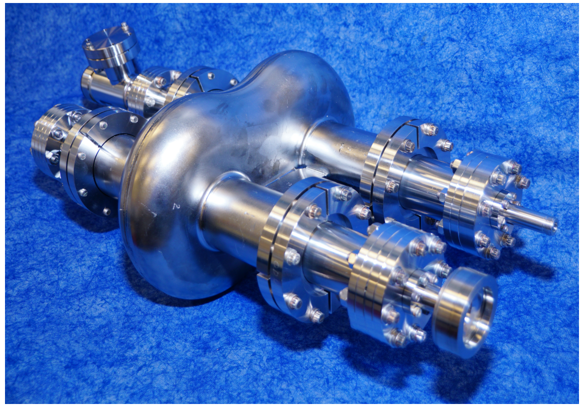
Twin Cavities

HyeKyoung Park
SRF2017 Lanzhou



"compatible with Nb_3SN vapor deposition process"

1.5 GHz twin axis Nb cavity



7-cell cavity in Al

H. Park, S. De Silva, J. Delayen, A. Hutton and F. Marhauser, "Development of a Superconducting Twin Axis Cavity, doi:10.18429/JACoW-LINAC2016-THPLR037.

V. Konoplev, K. Metodiev, A. J. Lancaster, G. Burt, R. Ainsworth and A. Seryi, "Experimental studies of 7-cell dual axis asymmetric cavity for energy recovery linac", Phys. Rev. Accel. Beams 20 (2017) no.10, 103501.

Reduce bbu, cost, ..: R&D for a decade for cryomodule

Experience at Jlab + Old Dominion U and John Adams + Cockcroft

bERLinPRO

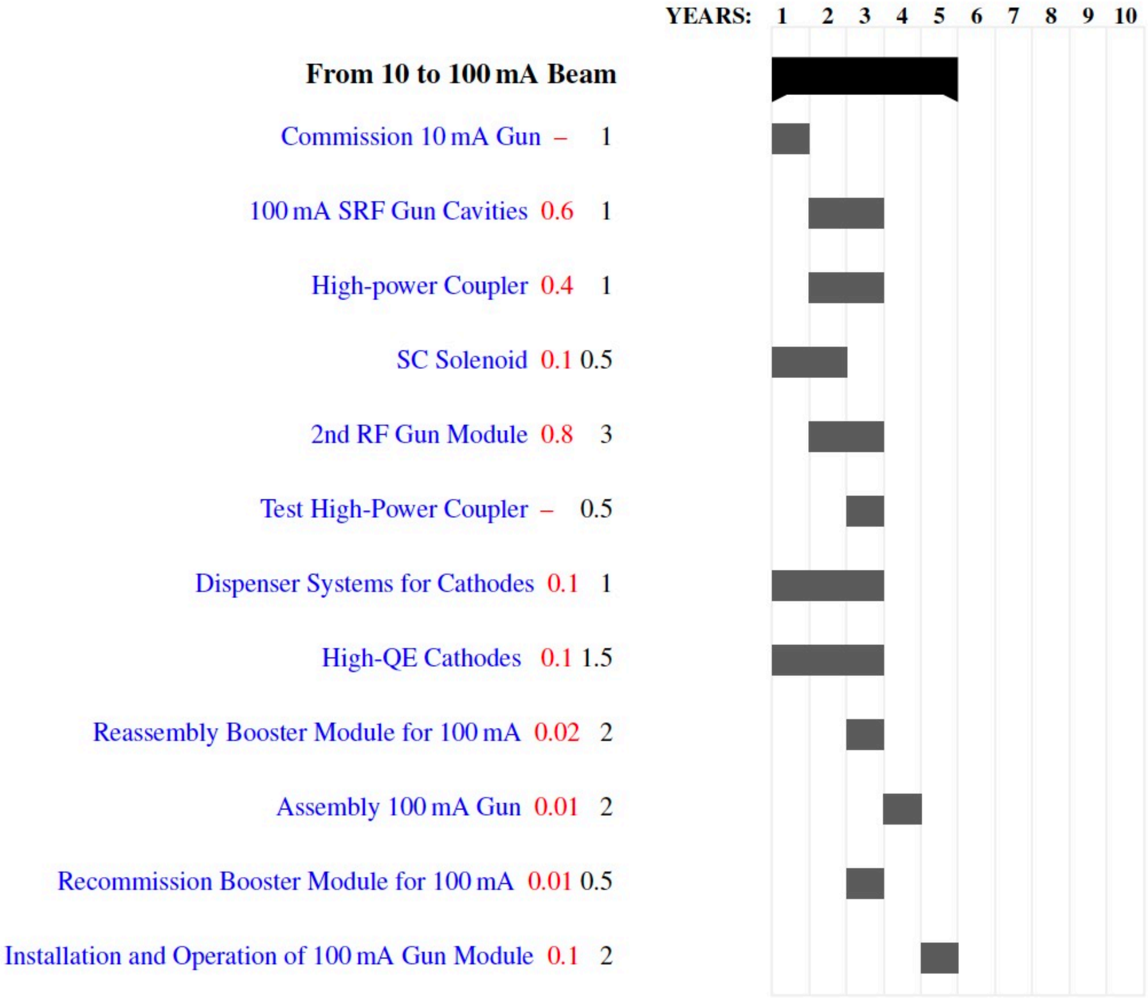


Chart 3a: Upgrade of bERLinPRO to 100 mA electron current operation. Funding 2.2 MCHF (red column) over 4 years, 16 FTEs (black). Year 1 for this development is 2022 for the program to succeed by 2025.

7.4 MCHF in 5 years

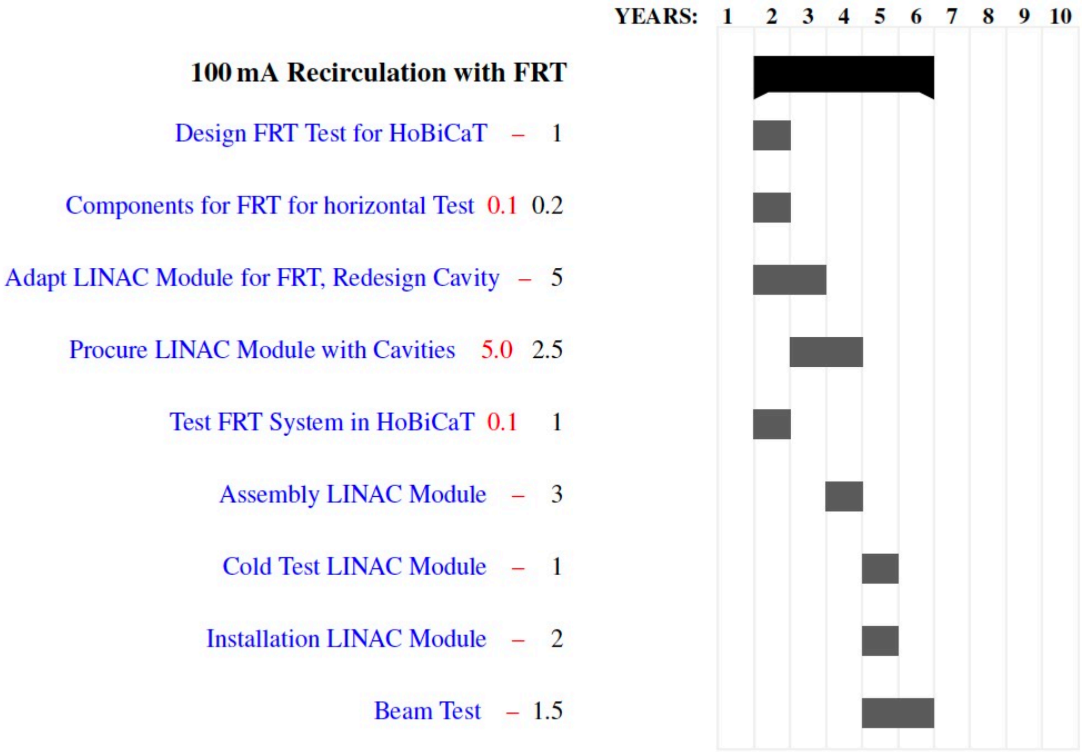


Chart 3b: Completion of bERLinPRO with a 1.3 GHz cavity-cryomodule. Funding 5.2 MCHF (red column) over 4 years, 17 FTEs (black). Year 1 for this development is 2023, a year after part a) started, for the program to succeed by 2025/6.

Goal: 10m A operation, 100 mA SRF gun, full, 1.3 GHz cavity cryostate module with FRT (CERN) by mid 20ies.
→ High current ERL operation (single pass) and study

PERLE

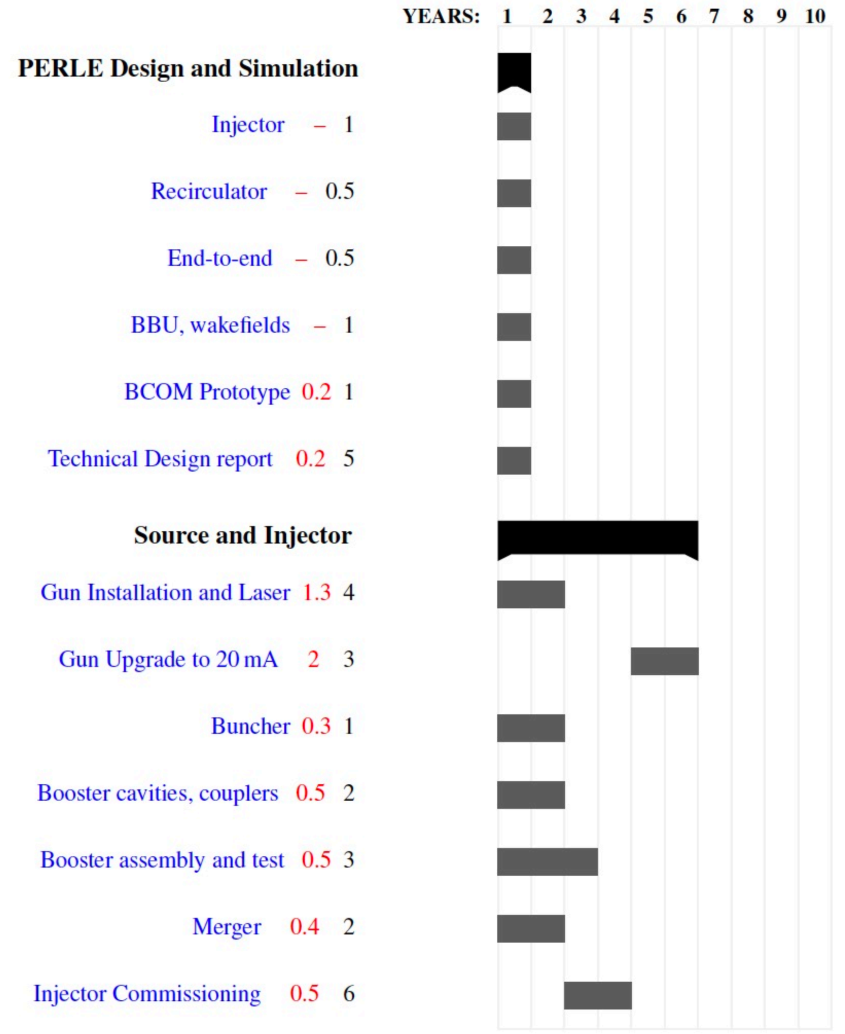


Chart 4a: The path to the PERLE technical design report and commissioning of the injector including the gun upgrade to full current. Funding 3.9 MCHF (red column) over 4 years plus 2 MCHF for the gun upgrade in the following two years, 27 FTEs (black). Year 1 for this development is 2022.

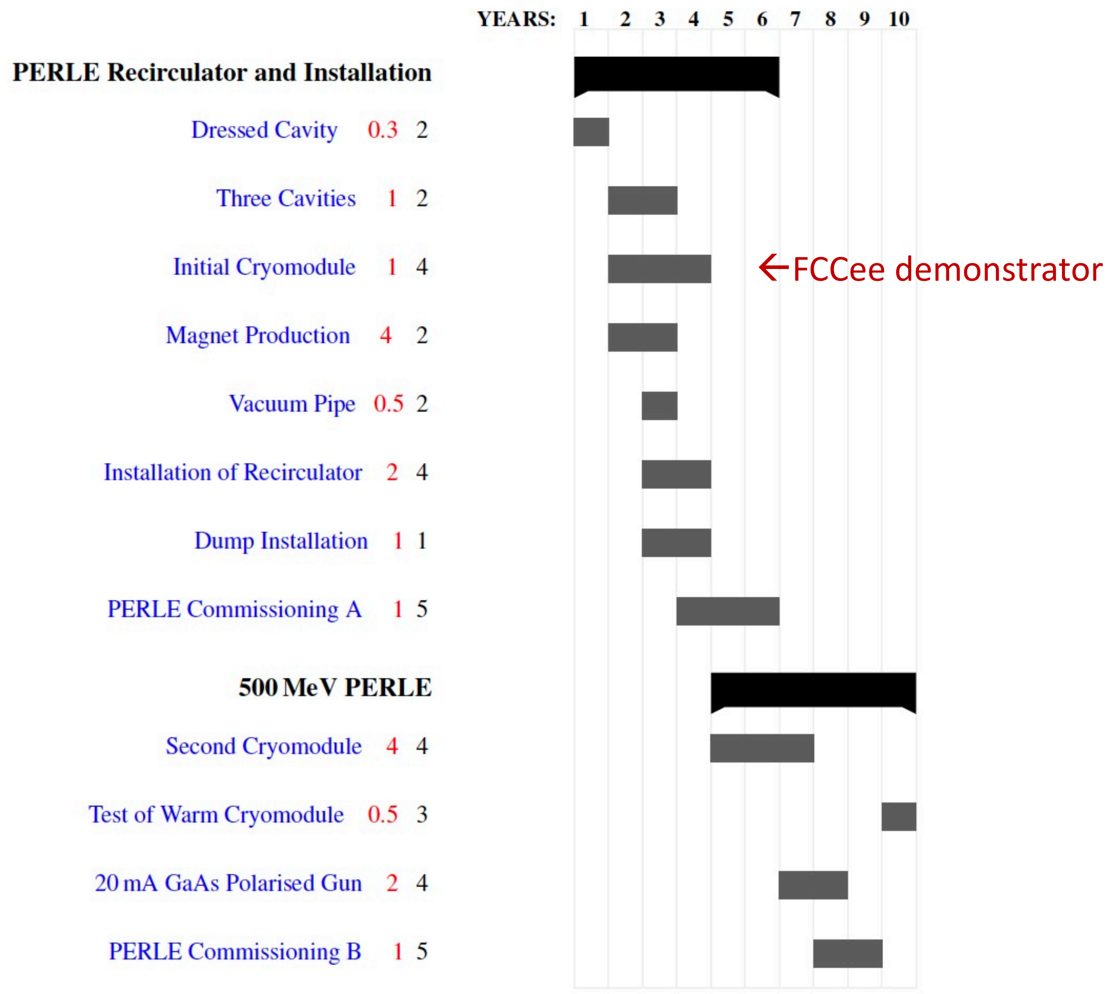


Chart 4b: PERLE completion in two steps, the 250 MeV phase with beam in the mid-twenties will be followed by the 500 MeV stage towards the end of the twenties. Funding of the first part 10.7 MCHF (red column) over 4 years, 22 FTEs (black), and 7.5 MCHF for the second part, 16 FTEs. Year 1 for this development is 2022 albeit the second part, as illustrated, begins only in 2026.

10 MW 3-pass operation in two steps; development of 802 MHz technology; physics and further R&D (4.4K)

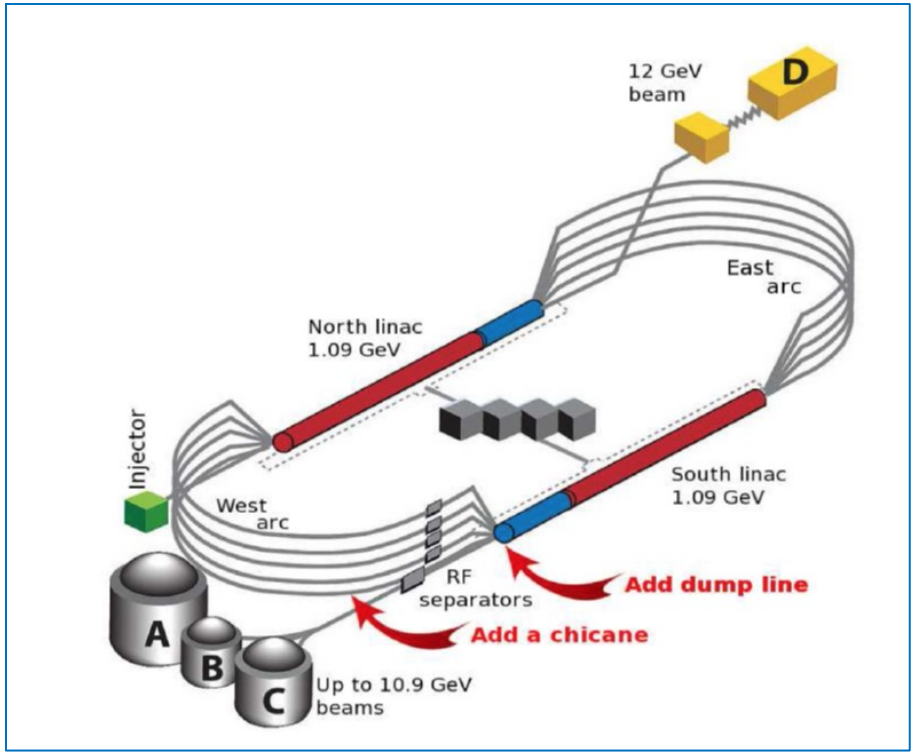
13.9 MCHF in 5 years

C

Two ERL facilities in progress in the US
Important for, but not part of this Roadmap

Electron Cooler for EIC

CEBAF 5 pass

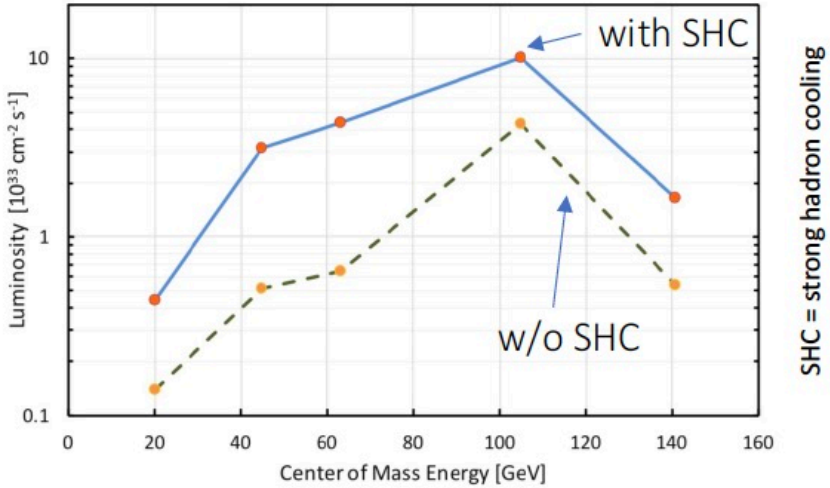


12 GeV (11 passes) beam to Hall D, 11 GeV to A,B,C

Experiment Run schedule for 2024
Important test of ERLs for high energy application

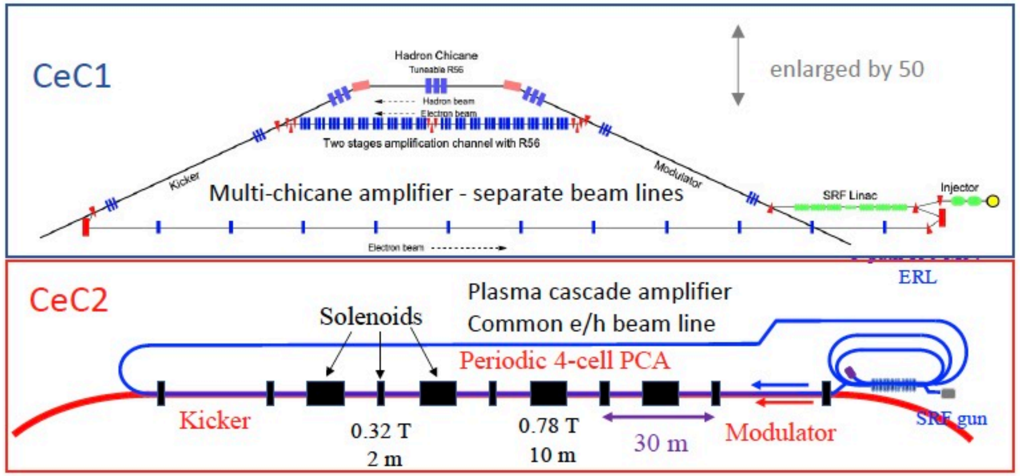
Decision expected with CD2

PRL **102,** 114801 (2009)
Derbenev, Litvinenko



L vs cms energy $\sqrt{s} = 2\sqrt{E_e E_p}$; HERA 319 GeV

Decision expected with CD2



0.4 (1.5) MeV DC gun, 100 mA I_e, 149 MeV : 15 MW. 1 (3) path facility

5.8.6 *Annual Investments*

The total investment corresponding to this roadmap is 43.1 MCHF for 10 years. This may be reduced to 37.1 MCHF if the polarised 20 mA gun and the 4.4 K 802 MHz cryomodule were postponed to beyond 2030 as these developments are clearly aspirational when projected to be available towards the end of this decade. The total cost of bERLinPRO and PERLE 250 MeV are 7.4 and 13.9 MCHF, respectively, for the coming 4 years, 2022 to 2025. Fig. 5.4 displays the annual spendings as a stacked histogram for PERLE (blue),bERLinPRO (grey) and basic R&D (green) as described. A substantial part of future ERL

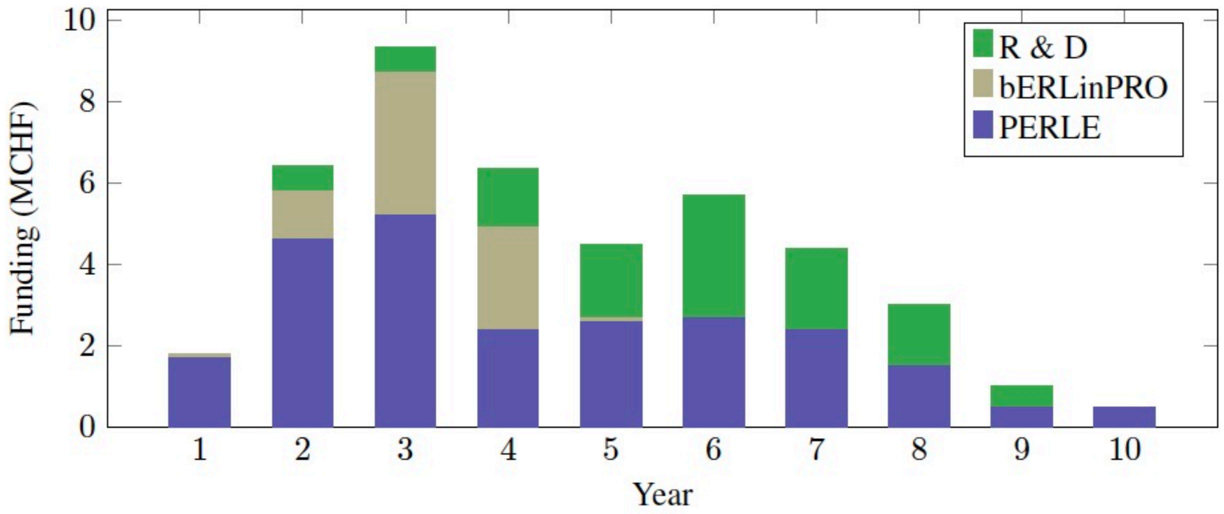


Fig. 5.4: Funding profile: annual spending in MCHF for the various parts of the ERL roadmap.

developments is covered by the existing or soon forthcoming (MESA) facilities and their development plans. The investments for 4.5 K base technology developments, such as sputtering and infusion as described in Sect. 5.6, are covered by the SRC roadmap. Until and including the year 2025, a total of 24 MCHF is required, composed of 13.9 MCHF for PERLE, 7.4 MCHF for bERLinPRO and 2.7 MCHF for R&D. The funding profile peaks for both facilities in 2024 which is due to the indeed ambitious schedule developed for providing high current ERL operation evidence in the mid twenties, when the European HEP strategy will be re-evaluated.

Total of 43.1 MCHF in 10 years

37.1 if less aspirational
(4.4K CM after 2030, no polarised gun for PERLE soon)

24 MCHF up to 2026

Modest wrt to collider cost.
Large for the poor.

The panel recommends the ERL Program as here presented for support :

Funding for coming 5 years:

< 5 MCHF / year
PERLE 2.8 M/y (besides IJCLab infrastructure)
bERLinPRO 1.5 M/y
R&D 0.6

as we tried to describe here. ERLs are one of the few ways for innovation of future accelerators, a technology with stringent advantages and the opportunity to eventually and experimentally lead particle physics indeed beyond its Standard Model. Their general physics and impact potential is outstanding. They are surely worth most sincere efforts.

Concluding sentences of roadmap

Acknowledgment

The authors most gratefully acknowledge information, insight and guidance they received in discussions with Roy Aleksan, Jean-Luc Biarotte, Phil Burrows, Dimitri Delikaris, Grigory Emereev, Eric Fauve, Rao Ganni, Frank Gerigk, Karl Jakobs, Vladimir Litvinenko, Maria Chamizo Llatas, Jan Lüning, Eugenio Nappi, Sam Posen, Guillaume Rosaz, Thomas Roser, Herwig Schopper, Mike Seidel, Alexander Starostenko, Valery Telnov [incomplete - 29.10]. They thank the members of the LDG group and especially its chair, Dave Newbold, for direction and support. They also thank the other panels for a pleasant cooperation.

Status: Draft still read by ERL Panel and authors: deadline 4.4. Updates Friday, very latest Monday 8.11.
Publication of Long Write-UP: tend of November (included long version of e^+e^- evaluation, facility tables..)

backup

Tentative Conclusions

From 30.9.

- What R&D needs to be done towards future facilities? What are the priorities? *)

  Priority is the 10 MW frontier: bERLinPRO fully equipped and PERLE 250 MeV, both by ~2026
  → new generation of low energy experiments, technology for medium energy (50 GeV) ERL for ep, impact on industry and ERL itself
  Next generation of High Energy (> 100 GeV) electron accelerators (e^+e^-, HE FCC-eh) needs key technologies to be developed
  → Nb_3SN and 4.4 K (sputtering Europe/CERN, thin film rather US), high T HOM damping, high(er) current OP and diagnostics, Twin cavities

- How long might it take? What is the fastest technically limited schedule?

  A facilities are operational but have important programs, MESA (polarized) coming up; **B** beam by 2026; **C** 2032
  Note that A,B,C are all interlinked.

- How much will it cost?

  A operational facilities: sDALINAC, MESA in Europe, cBETA (US), Recuperator (Ru), cERL (J). European facilities basically covered
  B new facilities and their technology: bERLinPRO (m MEuro) and PERLE (nn MEuro – cost + time reduced by in kind components)
  C 4.4K and Nb_3SN (cost depends on technology chosen [m sputtering, n Sn vapor diffusion]); high T HOM damping (?); diagnostics (?); twin cavity (depends on whether there will be a European development –JAI?)

- What different options and trade-offs exist?

  The field, especially in Europe, needs funding, coordination and inclusion. The genuine sustainability development we have.

- What are the linkages between activities?

  A,B,C and developments at other places (e.g. HZ Rossendorf) are much interlinked. ERLs are global (missing China, so far)
  ERLs are required for high E+L ep, yy, e^+e^-, muon? colliders. Links exist to SRF, Plasma, Muons. Technology for FCC-ee, …

- What science can be done using demonstrators, or intermediate-scale facilities?

  Huge opportunities with very high intensity (PERLE = 1000 ELI) and small emittance: MESA (> 2024), PERLE (>2027)
  Weak interactions, dark matter, nuclear photonics through IGS, exotic isotope spectroscopy, …

*) Questions posed by Dave Newbold in ECFA Newsletter No 7 (28.9.21)

C

Key Technology R&D longer term

4.4K and Nb_3SN program

Motivation

Technology perspective (long recognized, envisaged applications in waste water treatment or medical isotope production)
increase T from 2K to 4.4K which makes technology widely accessible - leads to Nb_3Sn or other superconductor instead of pure Niobium
Nb: T_c 9K → high Q_0 and small heat dissipation [but few 10^8 at 4K]. Nb_3Sn: T_c 18 K potentially higher Q_0

HEP Collider perspective:
single pass electron energy accelerator in ERL mode with E > 100 GeV costs few 100 MW of cryopower, i.e. loose the energy recovery gain
4.4 K has 3 times better performance than 2K, lower frequency than ILC (not too low for size), higher Q_0
→ Then reach 500 GeV with 10^{36} $cm^{-2}s^{-1}$ and O(100) MW total power, the ERL design of **a next generation e^+e^- collider**

Requirements

4.4 K cryo-cavity technology for 600-800 MHz frequency. Aim at Q_0 ~ 5 10^{10} and gradients about 20 MV/m

Tri-Linear Higgs Coupling in e^+e^-

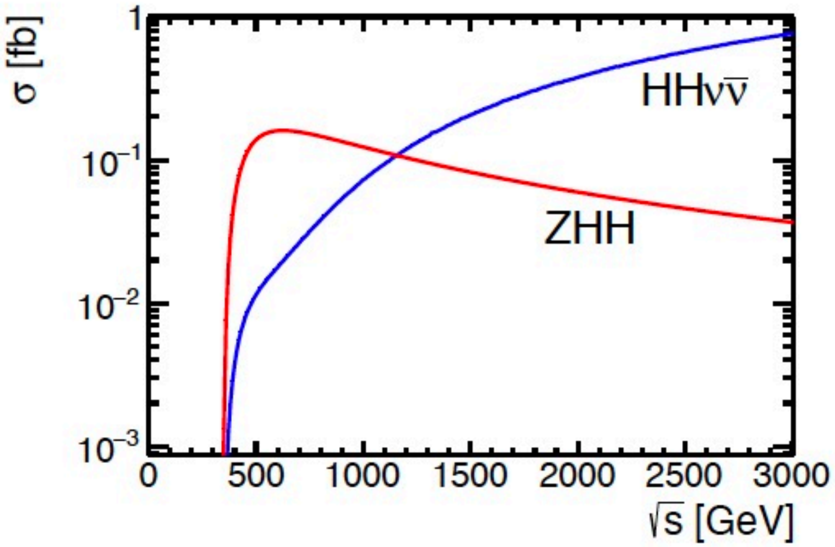


Fig. 1 Cross section as a function of centre-of-mass energy for $e^+e^- \to ZHH$ and $e^+e^- \to HH\nu\bar{\nu}$ production for a Higgs boson mass of $m_H = 126$ GeV. The values shown correspond to unpolarised beams including initial state radiation but not including the effect of beamstrahlung [16].

arXiv:1901.05897

CLIC: 1.4 TeV 2.5 ab^{-1} and 3 TeV 5 ab^{-1}
10% error on tri-linear H-HH coupling
[-29 - +67% for 1.4 TeV alone]

Kinematic limit of e e → Z H H : M(Z) + 2 M(H) = 341 GeV

ZHH unpolarised cross section maximum at 500 GeV: O(0.1) fb

O(10^{34}) $cm^{-2}s^{-1}$ luminosity gives 1 ab^{-1} in ten years: 100 events (A=1)

O(10^{36}) $cm^{-2}s^{-1}$ luminosity should produce 10 000 events → few %
and 300 fb * 100 ab^{-1} = 3 10^7 ZH events,
→ opens rare H decay channel programme in e^+e^-

This is a strong case for a next generation linear ee collider

Gradient 20*f MV/m: two 25/f km linacs:

It needs: Twin cavities, 4.5K, Nb_3SN, Q_0 towards 10^{11}

On CERC and ERLC: cf slides shown to LDG 8.9., subpanel report imminent: neither of the two concepts is ready to "just" replace the canonical FCC-ee or ILC designs → leads to a known R&D program.

LHeC: Poster at EPS by Kevin Andre

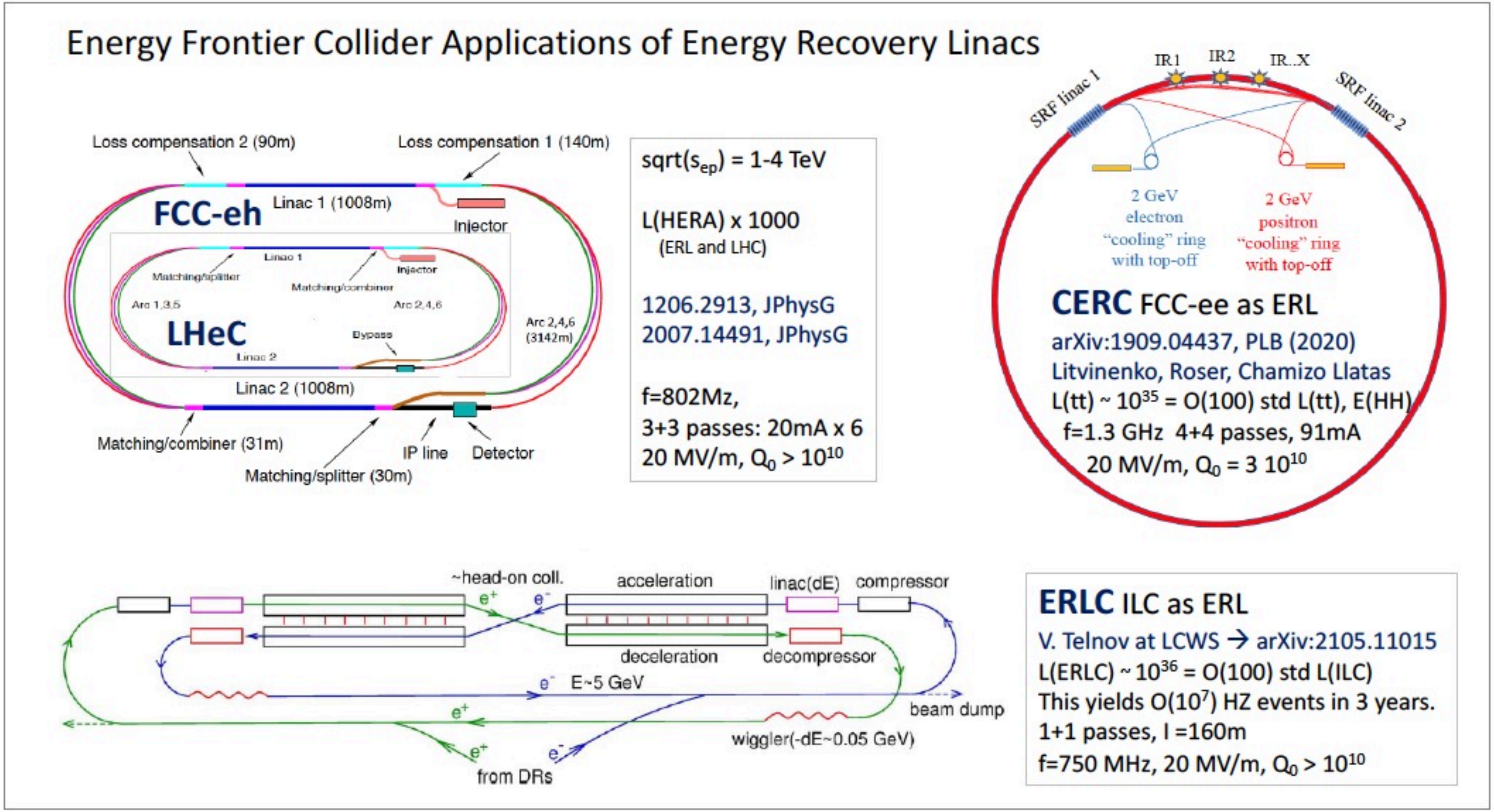


Figure 2: Sketch of possible future colliders based on ERLs: left top: LHeC and FCC-eh; right top: CERC; bottom: ERLC. For more information see the arXiv references displayed.

[from a report to LDG 5/21]

	163				Infusion				Module		Sputtering			
					5.971				10.809		5.543			
Year	Cost (MEUR)	Invest (MEUR)	FTE	FTE Cost (MEUR)	Sample recipe development	Vapor diffusion system readying	Single cell development	Multicell development	Proof of principle Test Module	Accelerator Motdule	Sample recipe development	Multicell Sputtering Setup	Single cell development	Multicell development
	22,3	11,1	69	11,2	0,5	3,4	0,7	1,4	3,8	7,0	1,3	1,5	1,1	1,7
1	4942	3475	9	1467										
2	3758	1150	16	2608										
3	3243	1450	11	1793			Single Cell cavities prove performance						Single Cell cavities prove performance	
4	1874,5	0	11,5	1874,5				Multicell cavities prove performance	Proof of principle test cryostat					
5	1467	0	9	1467										Multicell cavities prove performance
6	6222,5	5000	7,5	1222,5						Accelerator module operated (with beam?)				
7	815	0	5	815										

To SRF

Module

Task	Invest (TEUR)	FTE Total	FTE Cost (MI	Total cost	Proof of principle Test module	Accelerator module
	6.000	30	4.809	10.809	3.771	7.038
Test Module design work		4	652	652	1	
Test Module design work		4	652	652	1	
Procurement Test Module	1000	1	163	1163	1	
Installation Test Module		2	326	326	1	
"Test Module Testing"		2	326	326	1	
Design Accelerator Module		2,5	407,5	407,5		1
"Test Module Testing"		2	326	326	1	
Design Accelerator Module		2,5	407,5	407,5		1
"Test Module Testing"		2	326	326	1	
Procurement Accelerator Module	5000		0	5000		1
Assembly Accelerator module		2,5	407,5	407,5		1
SRF Testing Accelerator Module		2,5	407,5	407,5		1
Beam testing accelerator module		2,5	407,5	407,5		1