Draft Delivery Plan - Roadmap on Energy Recovery Linacs

Max Klein   Andrew Hutton

For the ERL Roadmap Panel,

Deepa Angal-Kalinin (STFC Daresbury), Kurt Aulenbacher (Mainz), Alex Bogacz (Jlab), Georg Hoffstaetter (Cornell/BNL), Andrew Hutton (Co-Chair, Jlab), Erk Jensen (CERN), Walid Kaabi (IJCLab Orsay), Max Klein (Chair, Liverpool), Bettina Kuske (HZB Berlin), Frank Marhauser (Jlab), Dmitry Kayran (BNL), Jens Knobloch (HZB Berlin), Olga Tanaka (KEK), Norbert Pietralla (TU Darmstadt), Cristina Vaccarezza (INFN Frascati), Nikolay Vinokurov (BINP Novosibirsk), Peter Williams (STFC Daresbury), Frank Zimmermann (CERN)

Delivery Plan + Charts

In conjunction with Interim report and our presentation to the LDG 30.9.21.

the e^+e^- ERL Sub-Panel,

Chris Adolphsen (SLAC)   Reinhard Brinkmann (DESY)   Oliver Brüning (CERN)
Andrew Hutton (Jefferson Lab) – Chair   Sergei Nagaitsev (Fermilab)
Max Klein (Liverpool) Peter Williams (STFC, Daresbury) , Akira Yamamoto (KEK)
Kaoru Yokoya (KEK)   Frank Zimmermann (CERN)

and with invaluable help of many further colleagues to appear as co-authors

Following a 56 year old idea with the technology of today and tomorrow:

M Tigner A Possible Apparatus for Electron Clashing-Beam Experiments, N.Cim 10(1965)1228

LDG Roadmap Meeting – CERN/hybrid, 12.10.2021

ERL Roadmap - Delivery Plan

A – Facilities in progress including technology developments
[sDALINAC, MESA + cBETA, cERL, Recuperator]

B – New Facilities – towards high current and power
[bERLinPRO , PERLE multi-turn + CEBAF5, eCooler]

C – Key Technology R&D Program – next generation ERLs

As presented to LDG 30.9.

Remarks on ERL and Future HEP Colliders

Low Energy Physics

Applications

Facilities (part A of Roadmap)

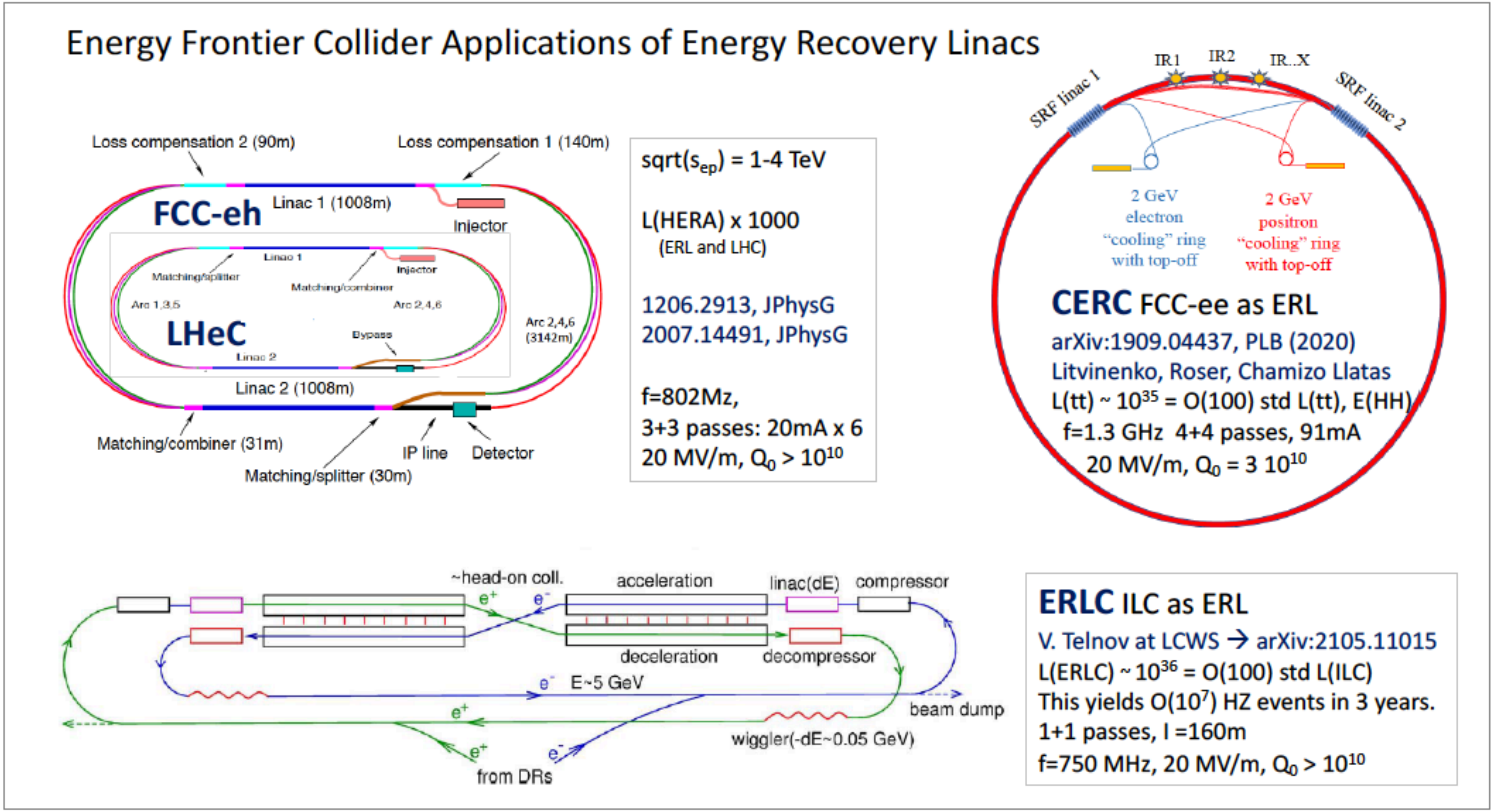


Figure 2: Sketch of possible future colliders based on ERLs: left top: LHeC and FCC-eh; right top: CERC; bottom: ERLC. For more information see the arXiv references displayed.

[from a report to LDG 5/21]

Report on CERC and ERLC

Overall Conclusions

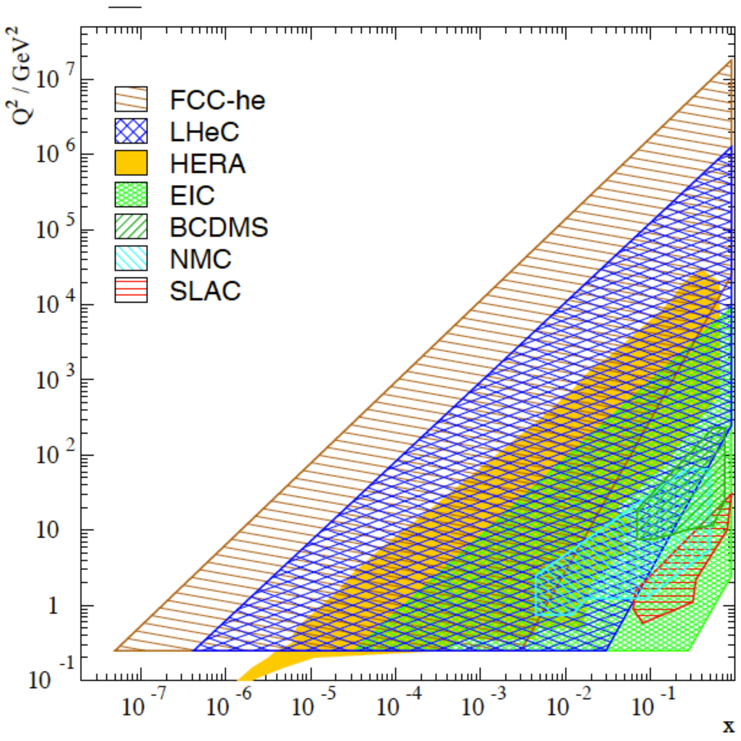
The sub-Panel was presented with two, extremely interesting ideas to evaluate. While neither is ready to be adopted now, they point to the future in different ways. The CERC aims for multiple passes in a tunnel with an extremely large bending radius to minimize the synchrotron radiation loss. The ERLC proposes a single acceleration and deceleration, separating the two beams by using twin-axis cavities. Both of these ideas provide an indication of the variety of different ERL layouts that might be developed in the future.

A particularly interesting prospect is to design an energy efficient, ultra-high luminosity ERL-based electron-positron collider at 500 GeV, which would enable the exploration of the Higgs vacuum potential with a measurement of the tri-linear Higgs coupling in e+e-.

The most important R&D activity that would make this kind of development viable is to be able to operate at 4.5K with high Q_0. We strongly recommend R&D on this topic as it 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.

A 5-pages report drafted and agreed by sub-Panel – out for factual check to the authors and for comments to Panel
Include in Roadmap report and (possibly and extended version) as an Appendix in the ERL long write-up

Remarks on ERL based Colliders (eh, muons)



Energy frontier DIS has been part of HEP and is necessary for going beyond the SM. The EIC has obviously a different role.

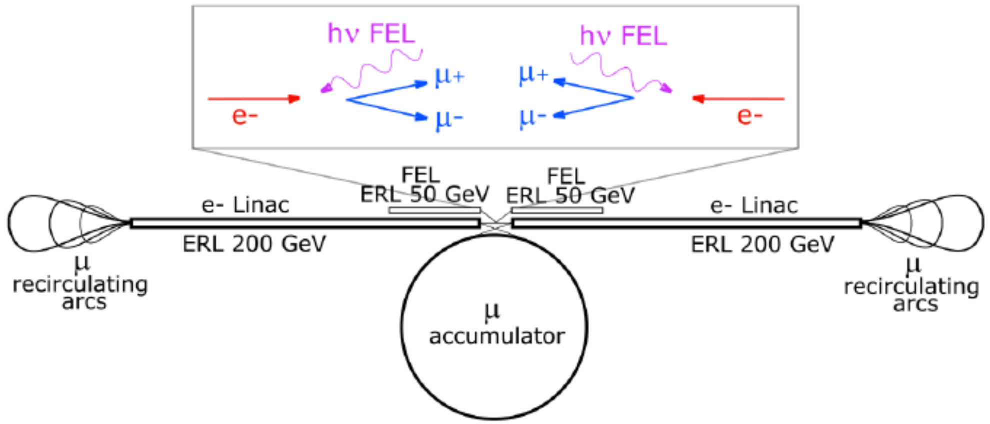
LHeC and FCC-eh are partners of LHC and FCC. The **cleanest high resolution telescopes world can build.** Rechecking the power economy of LHeC (100MW).

ERL technology concept of LHeC has wide range of HEP applications: yy collider, FCCee injector, HE XFEL →

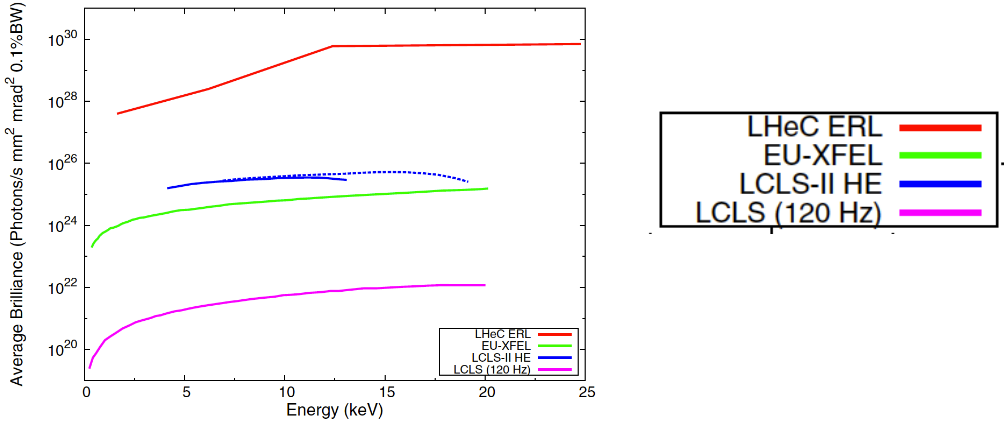
GeV muon beams with picometer-class emittance from electron-photon collisions

C. Curatolo[1,2] and L. Serafini[3]

arXiv:2106.03255



Bright Ångstrom and picometer free electron laser based on the Large Hadron electron Collider energy recovery linac

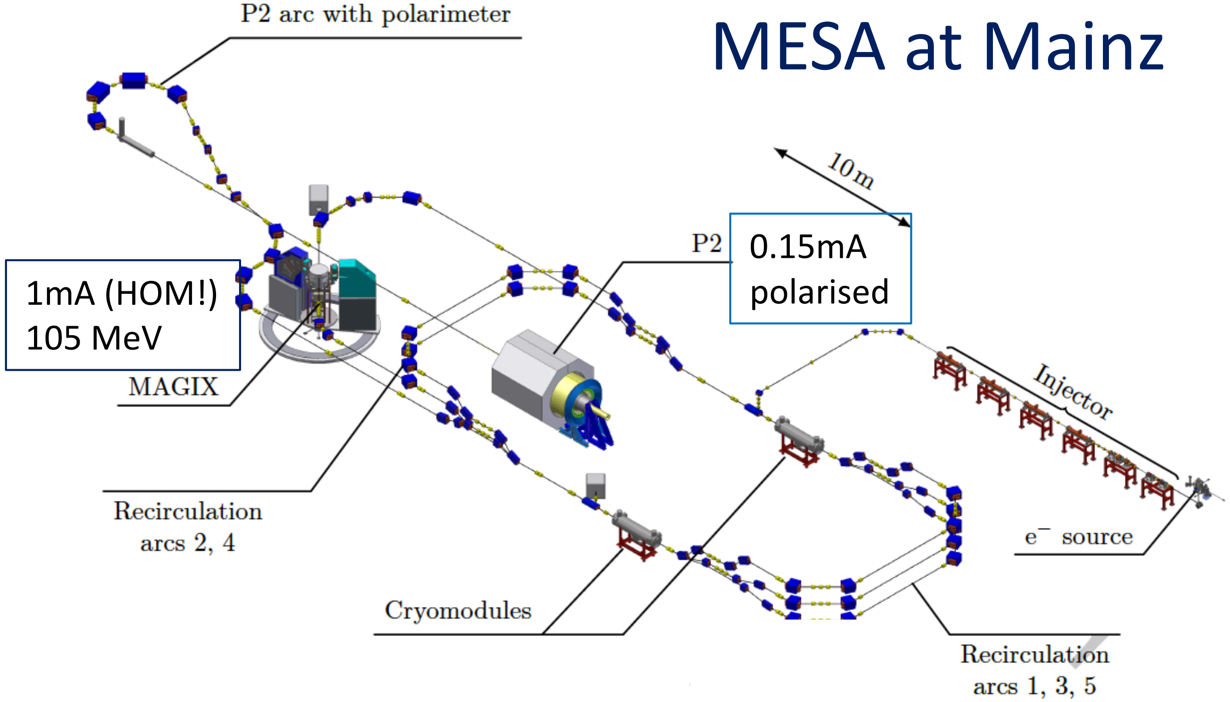


PHYSICAL REVIEW ACCELERATORS AND BEAMS **24**, 100701 (2021)

Low Energy Physics with ERLs

Three examples from Long Write-UP

MESA at Mainz

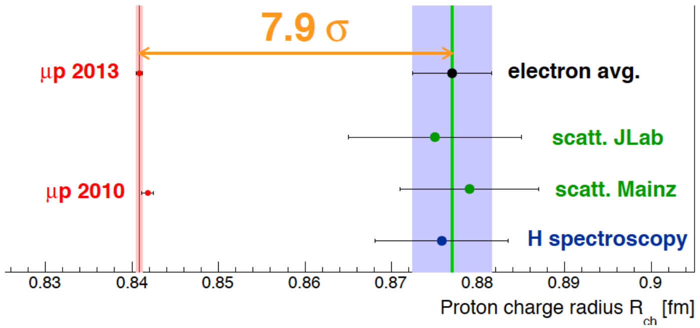


- 1.3 GHz, two ELBE type cryomodules, up to 3 passes
- New building, beam by 2024
- Polarimetry to 0.5% precision
- Current upgrade (unpolarised to 10 mA)

P2 – external target $\sin^2\Theta$, w/o energy recovery ("EB")
MAGIX – gas jet internal target, dark photons, p radius ("ER")

doi:10.18429/JACoW-ERL2019-MOCOXBS05

Proton Radius Puzzle [role for high intensity ERL, Jan Bernauer ERL Symposium 6/21



AMBER (CERN), MUSE (PSI), PRAD (Jlab), ULQ2 (Tohoku), Mainz .. ??

Nuclear Photonics [inverse γ's: L(PERLE) = O(10^3) L(ELI)]

Photonuclear reactions - from basic research to applications

A. Zilges[1], D. L. Balabanski[2], J. Isaak[3], N. Pietralla[3]

June 17, 2021, to appear

also: IGS: nuclear security, novel medical isotope research

Electrons Probing Exotic Nuclei

New field, pioneering: SCRIT@RIKEN, PRL 118, 2017
PERLE 500 MeV, 20mA, DESTIN project at Orsay
Outlook: eRI facility at GANIL (Caen, F) 200mA, ~2040

Applications for roadmap and in long write-up: 4 major examples

Three major features: Linac brightness at storage ring powers, Dump at injection, GW class beams unaffordable otherwise

The industrial process of producing semiconductor chips comprises the placing of electronic components of nanometre scale onto a substrate or wafer via photolithography

To advance this technology to a few nm dimension, the FEL must be driven by a superconducting ERL

An ERL with electron beam energy of about 1 GeV would enable multi-kW production of EUV

ERLs might well reach into the EUV market, which in 2020 was 400B Euro, following initial surveys and design studies undertaken by industry

Andrew Hutton at ERL symposium

Cryogenics is ¼ of capital cost → 4.4 K for applications!

Picosecond x-ray source with high (15 T) field magnet(s) on 1-GeV ERL. This option could intensify ERL activity, transforming, for example, test facility PERLE or ERL projects for x-ray lithography FEL, to unique user facility (storage rings can not provide so short x-ray pulses, and linacs can not provide average intensity).

Nikolay Vinokurov Talk at ERL Panel 15.7.21

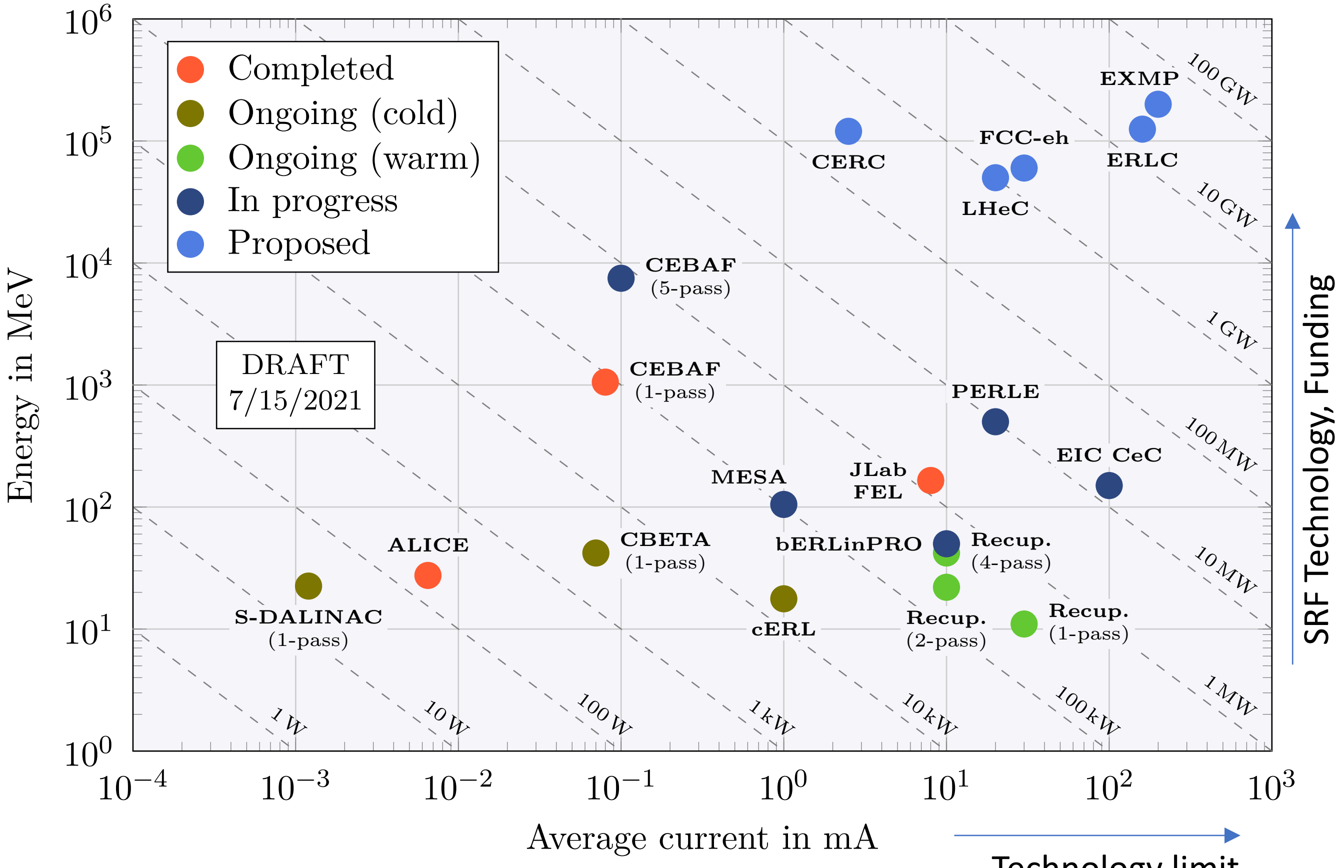
Sub-ps periodic X ray pulses for time resolved experiments → a 4th example for applications

Peter Williams at ERL Symposium June 6. 2021 - Free Electron Lasers and Inverse Compton Sources

A

Facilities

Electron beam energy [MeV] vs current [mA]



Notice: 10 MW frontier. Energy > 100 GeV needs 4.4K

Next ERL workshop will be held at Cornell (BNL, Jlab) 21-24. June 22

Current and coming activities [from Interim ERL report 7/21]

Text being extended, but rely and refer to long write up

- S-DALINAC (TU Darmstadt)
  - Establishment of a multi-turn SRF-ERL with high transmission (up to 70 MeV and 20 µA);
  - Quantification of phase-slippage effects in multi-cell-cavity ERLs and countermeasures;
  - Characterisation of potential operating points of individually recirculating ERLs.
- MESA
  - Improving electron beam polarimetry to an accuracy of $dP/P \leq 0.5\,\%$ in order to support the first physics measurements of electroweak observables, possibly including Hydro-Moeller polarimeter;
  - Installing a second photo-source at the MESA injector with the potential to provide bunch charges > 10 pC with good beam quality;
  - Improving the cavity higher-order mode (HOM) damping capabilities, for instance by coating of the HOM antennas by layers of material with a high critical temperature.
- CBETA (Cornell)
  - Improve transmission, which includes investigating better optics solutions;
  - Developing improved diagnostics for the decelerating passes;
  - Reducing halo by using a low-halo cathode, possibly in conjunction with beam collimation.
- cERL (KEK)
  - Development of a 10 kW-class powerful ERL-based EUV-FEL;
  - Realisation of 100 % energy-recovery operation with a beam current of 10 mA at cERL and FEL light production experiment;
  - Development of an irradiation line for industrial applications (carbon nanofibers, polymers and asphalt production) based on CW cERL operation;
  - Further, planning to develop a high-efficiency, high-gradient Nb_3Sn acceleration cavity to realise a superconducting cryomodule based on the compact freezer.
- Recuperator (BINP Novosibirsk)
  - The current of the Novosibirsk ERL is now limited by the electron gun. A new RF gun was built and tested recently. It operates at a frequency of 90 MHz. An average beam current of more than 100 mA was achieved;
  - Plans are to install this gun in the injector, while the existing electrostatic gun will be kept there. The RF gun beamline has already been manufactured and assembled on the test setup. The beam parameters were measured after the first bending magnet and at the beamline exit

ERL Roadmap - Delivery Charts

bERLinPRO

PERLE

Key Technologies

bERLinPRO

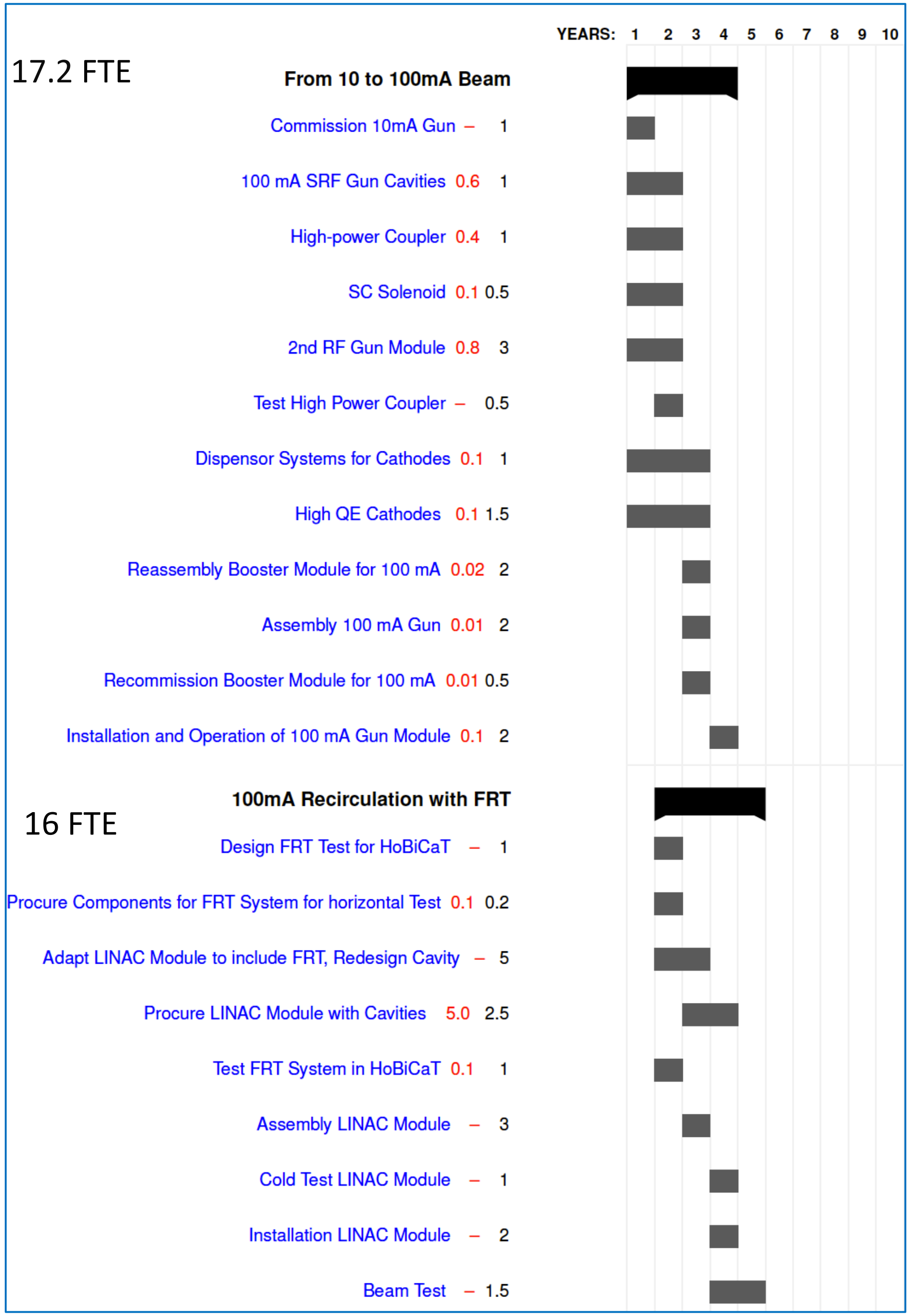
B

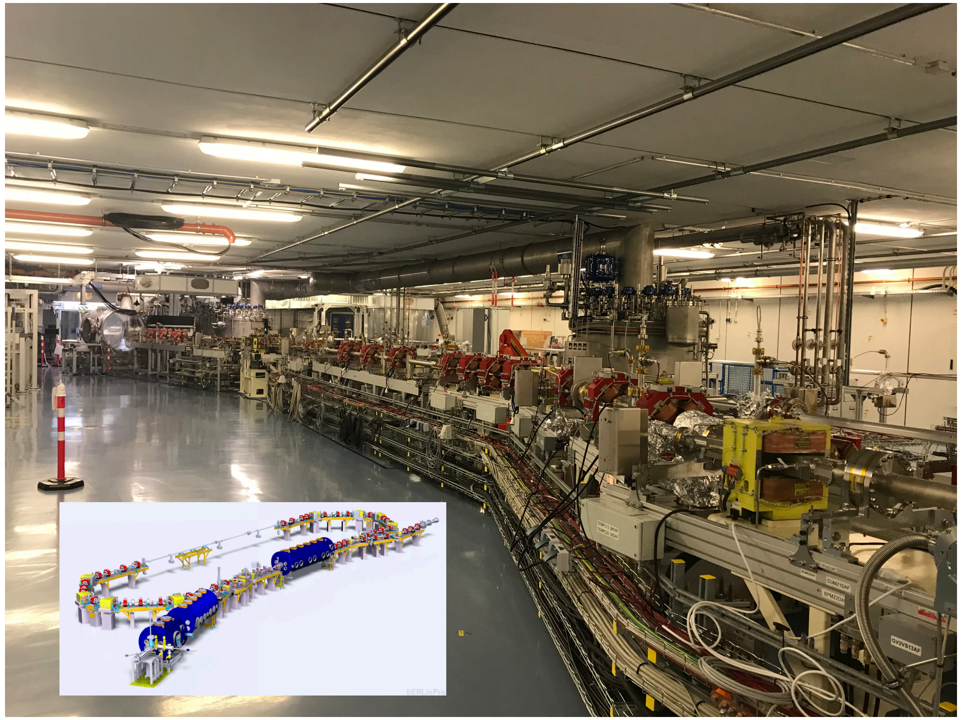
7.44 MCHF 33.2 FTE (2022-2025+)

5.2 MCHF 17.2 FTE

Y1= 2022

2.24 MCHF 16 FTE

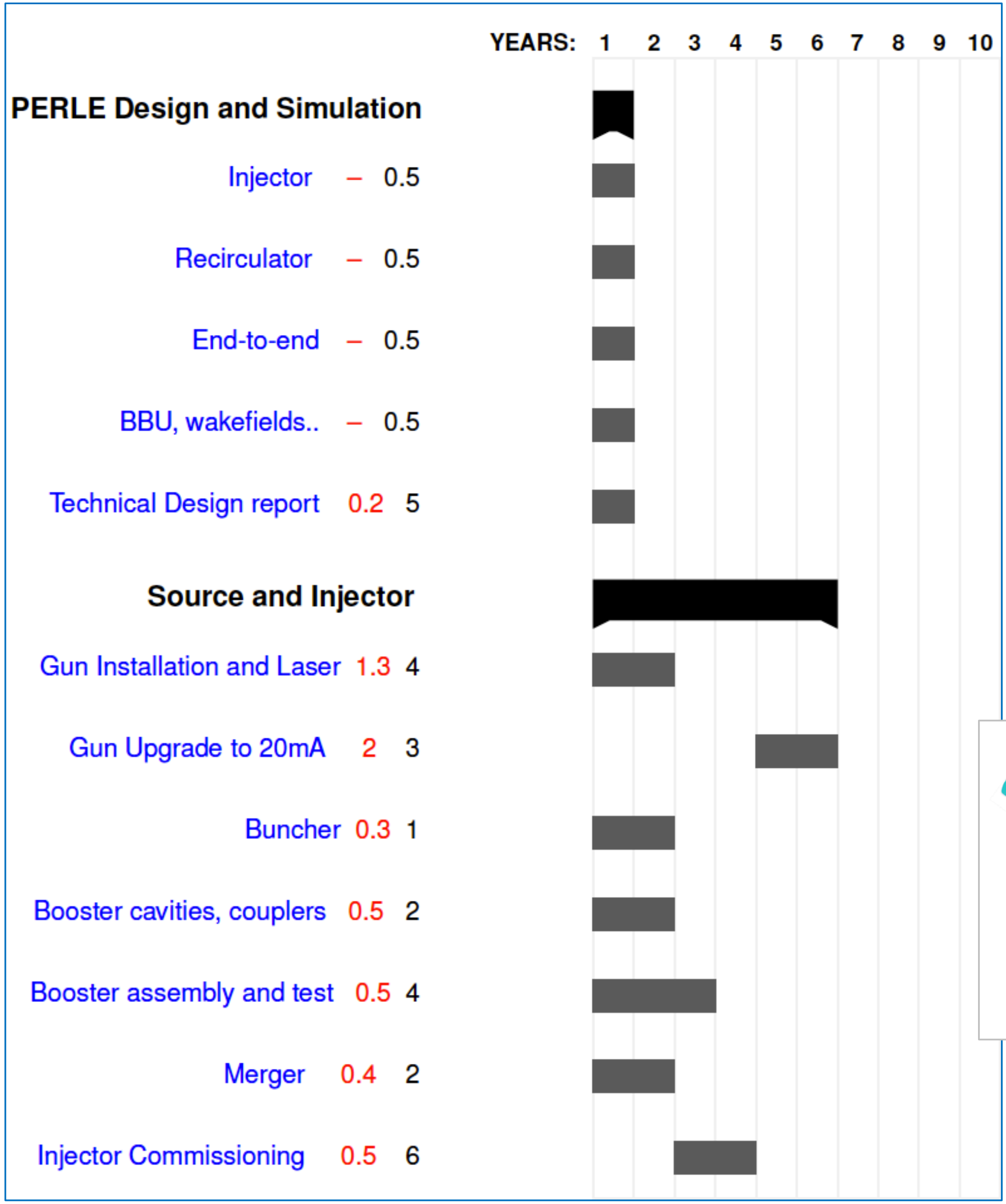




Jens Knobloch, Bettina Kuske, Axel Neumann (Berlin HZB)

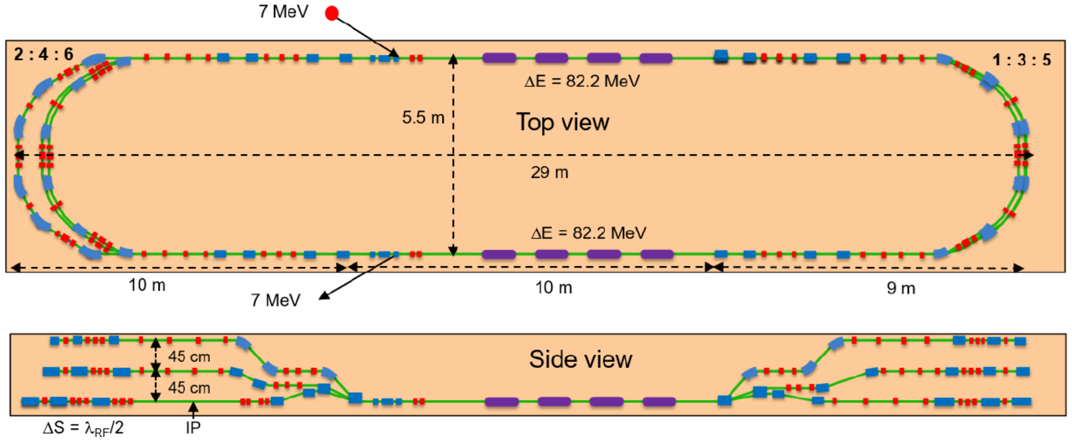
First ERL Facility to operate 100mA in single turn ERL with FRT control

A - Build SRF gun for 100 mA (currently power coupler limited)
B - Adding 1.3 GHz module, equipped with FRT, to complete facility.
→ R&D on stability, bbu, emittance preservation, beam loss, halo ..
→ Test of FRT concept in high current beam operation.

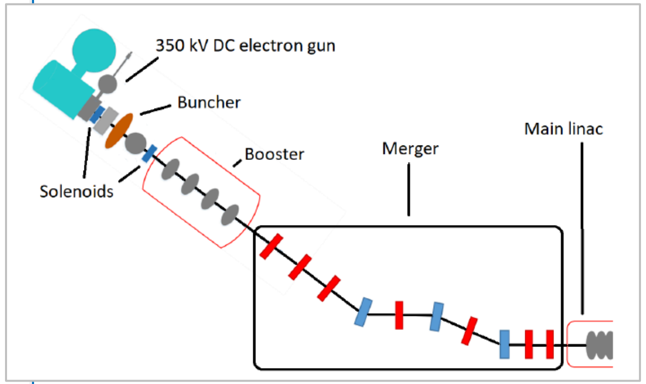


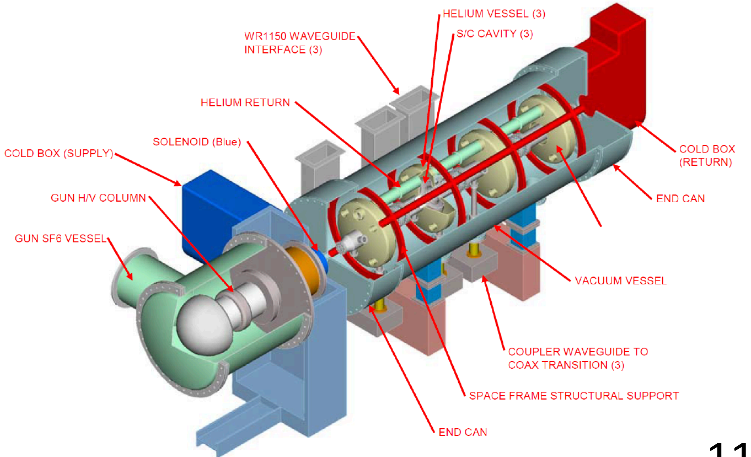
PERLE (design, TDR + injector)

B



CERN, Cornell, Daresbury, Jefferson Lab, Liverpool, Novosibirsk, IJCLab Orsay (Host) Collaboration, growing: Grenoble, GANIL +

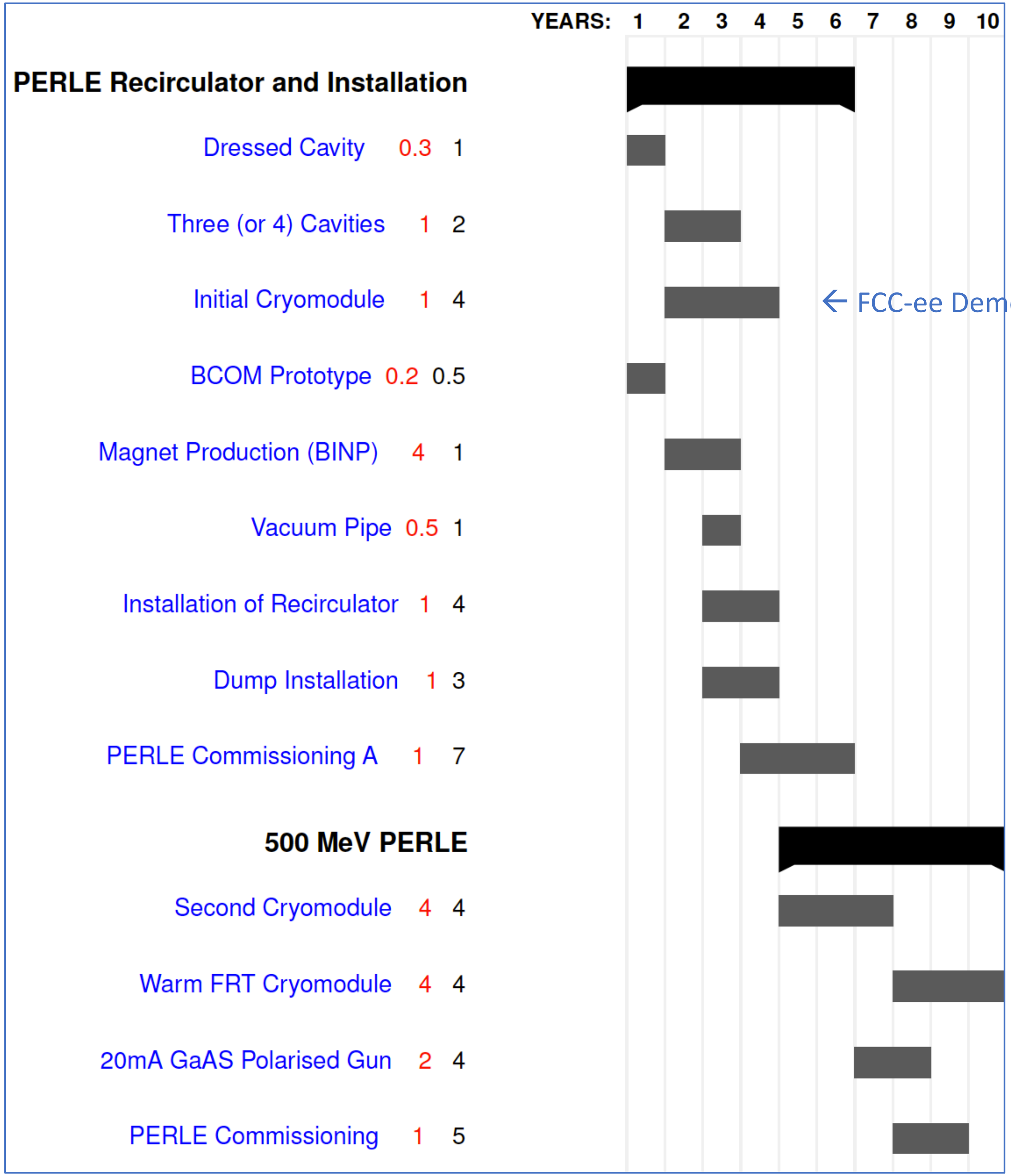




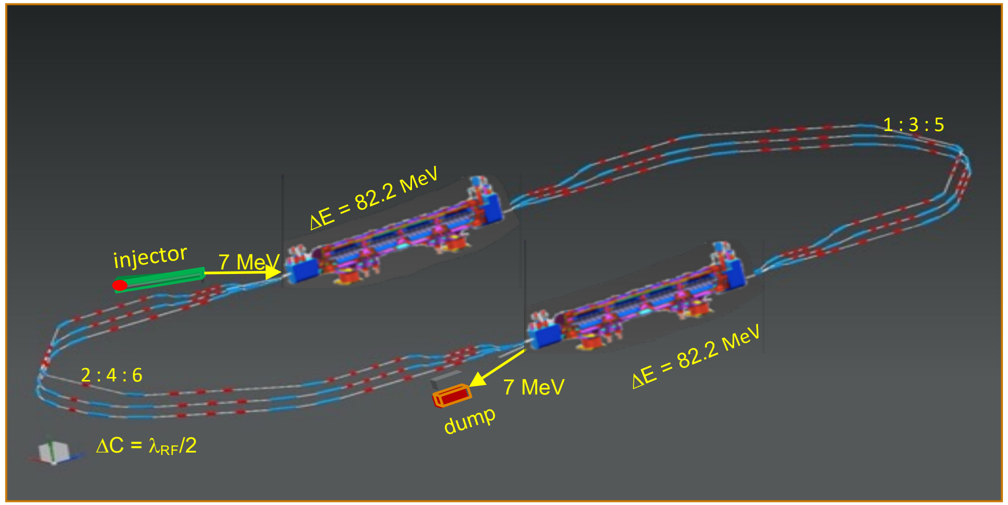
Cost assumes in-kind contribution of Booster (Jlab) and Linac (CERN, SPL) Modules

PERLE

B



← FCC-ee Demonstrator



The first high power, multi-turn ERL facility - R&D
Novel, 802 MHz technology development
High luminosity base for low energy experiments

250 MeV: 14 MCHF 52.5 FTE
t_0 = 2021 (Collaboration Agreement signed)

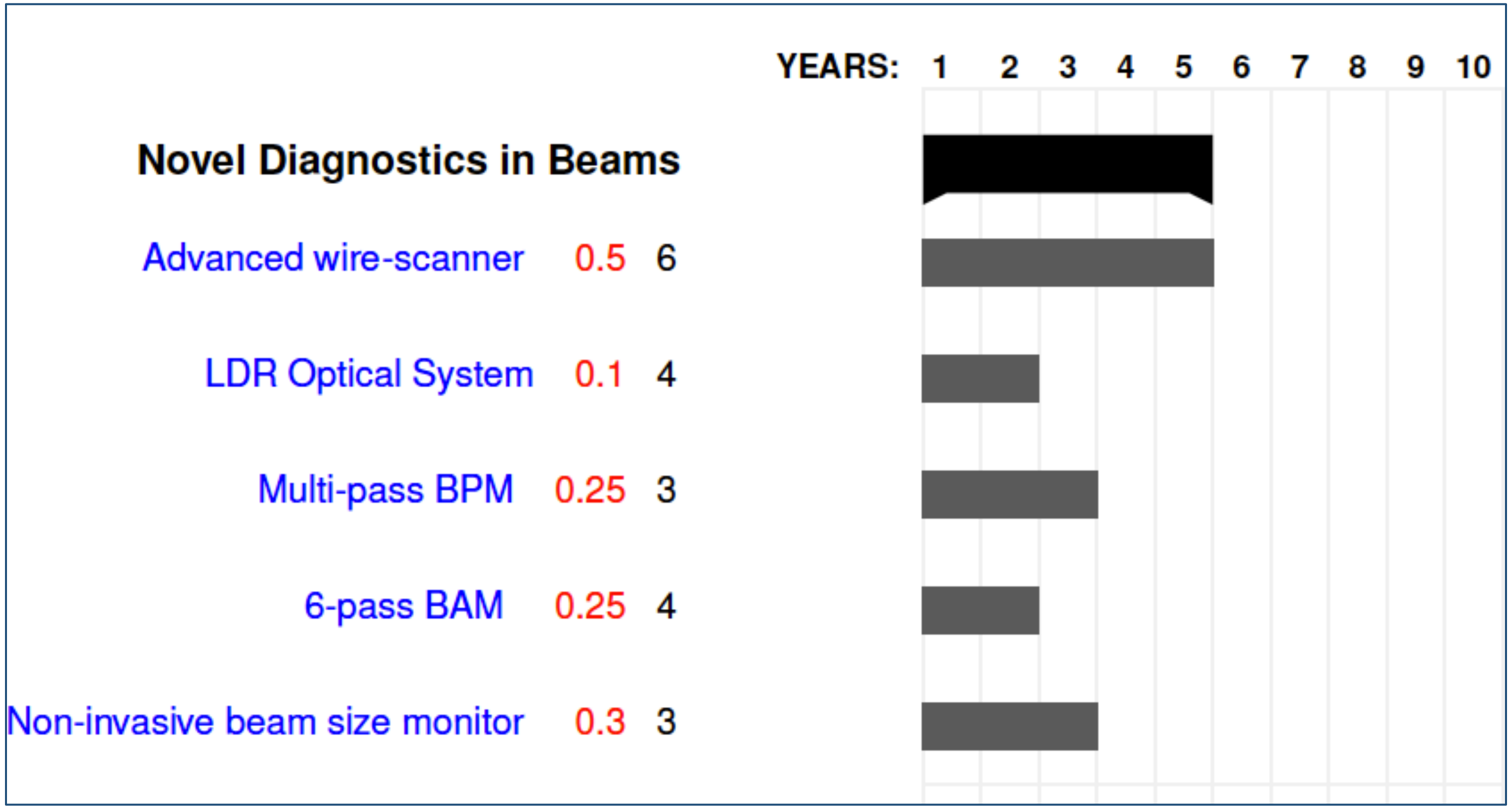
500 MeV: 11 MCHF 17 FTE t_0 = 2025
Warm Cryomodule and GaAS "aspirational"

Diagnostics, Cryogenics, Power, Building.. by IJCLab
Estimated to be 10 MCHF plus 2-3 times FTE

Experiments here not included (~2028 onwards)

1.4 MCHF 20 FTE
Y1 various

Beam Instrumentation and Diagnostics



Pavel Evtushenko (Rossendorf)

Monitors beyond the state of the art

Crucial for high current operation

Y1 may be different for these items

Integration in Facilities to be discussed

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

From talk 30.9. for LDG

Sputtering technology

- Magnetron sputtering allows for good stoichiometry control
- Compatible with other substrates (e.g., Cu)
- Can be rapidly be adapted to other superconductors (e.g. NbTiN)
- So far only sample measurements (QPR)
- Europe (CERN and IFAST Collaboration) leading, some effort in USA.

CERN, Nb_3Sn deposited on copper, magnetron sputtering & HiPIMS
STFC Daresbury, Nb_3Sn on Cu and multilayers
INFN Legnaro, Nb_3Sn by dipping/annealing, by magnetron sputtering -

Single cell → multi-cell → module → industry

A decade of developments.
Very promising but demanding (cf backup)

Involves industrialization prospects etc.

Tentatively: propose with SRF (S Bousson et al) that the Nb_3Sn-4K development is treated as part of their program. Support sputtering and infusion in Europe. Interest in module is also motivated with the ERL long term perspective

Sputtering

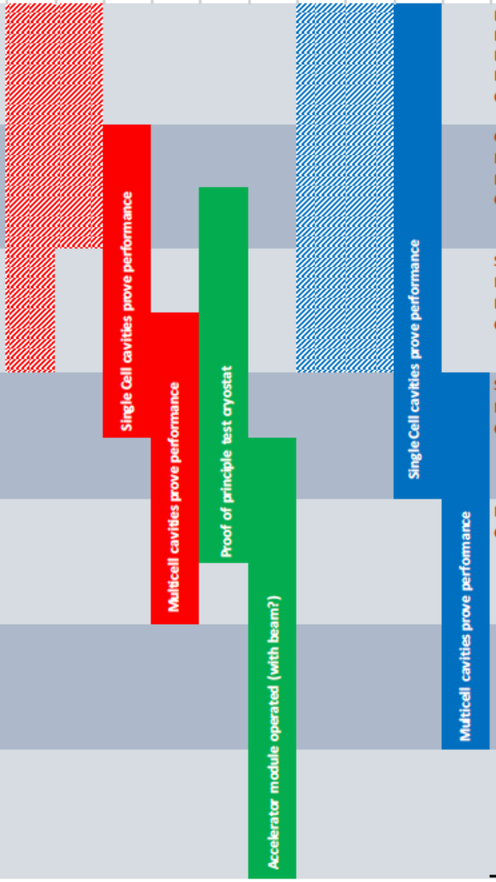
DRAFT 27.9.

Task	Invest (TEUR)	FTE Total	E Cost (MEU	Total cost	Sample recipe development	Multicell Sputtering Setup	Single cell development	Multicell development
	1.875	23	3.668	5.543	1.253	1.489	1.128	1.673
Produce 5 QPR Samples	75		0	75	1			
Produce RaSTA	200	1	163	363	1			
QPR Sample testing		1	163	163	1			
Sample production in IFAST		1	163	163	1			
6 GHz cavity testing in IFAST		1	163	163			1	
Design new multicell sputtering		1	163	163		1		
Sample production		2	326	326	1			
1.3 GHz cavity production to support IFAST		1	163	163			1	
Procure 5 copper single cell cavities	150		0	150			1	
Install multicell sputtering system	1000	1	163	1163		1		
RaSTA and QPR Sample Testing		1	163	163	1			
Cavity Testing		0,5	81,5	81,5			1	
Optimization of single cell coating		1	163	163			1	
Commission multicell sputtering system		1	163	163		1		
Procure 5 copper multicell cavities	450		0	450				1
RaSTA and QPR Sample Testing		0,5	81,5	81,5			1	
Cavity testing		0,5	81,5	81,5			1	
Single-cell/Multicell coating		2	326	326			0,5	0,5
Cavity testing		1	163	163			0,5	0,5
Multicell coating		2	326	326				1
Cavity Testing		1	163	163				1
Multicell coating		2	326	326				1
Cavity Testing		1	163	163				1

To SRF

Vapor infusion

					Infusion				Module		Sputtering			
	163				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										
4	1874,5	0	11,5	1874,5										
5	1467	0	9	1467										
6	6222,5	5000	7,5	1222,5										
7	815	0	5	815										



Task	Invest (TEUR)	FTE Total	FTE Cost (MI	Total cost	Sample recipe development	Readying vapor infusion furnace	Single cell development	Multicell development
	3.200	17	2.771	5.971	483	3.429	658	1.402
Procure vapor diffusion system	2125	3	489	2614		1		
Procure 5-10 single cell Nb cavities	250		0	250			1	
Procure 5-10 multicell Nb cavities	750		0	750				1
Produce 5 QPR Samples	75		0	75	1			
QPR Sample testing		1	163	163	1			
Commission vapor diffusion system (with US support)		3,5	570,5	570,5		1		
Prototype cavity testing ("learning the ropes")		1,5	244,5	244,5		1		
RaSTA and QPR Sample Testing		1	163	163	1			
Cavity Testing		0,5	81,5	81,5			1	
Single cell coating		1	163	163			1	
Multicell coating		1	163	163				1
RaSTA and QPR Sample Testing		0,5	81,5	81,5	1			
Cavity testing		0,5	81,5	81,5			0,5	0,5
Single-cell coating		0,5	81,5	81,5			1	
Multicell coating		1	163	163				1
Cavity testing		0,5	81,5	81,5			0,5	0,5
Multicell coating		1	163	163				1
Cavity testing		0,5	81,5	81,5				1

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
	163													
					Infusion				Module		Sputtering			
					5.971				10.809		5.543			
	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					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?)				Multicell cavities prove performance
7	815	0	5	815										

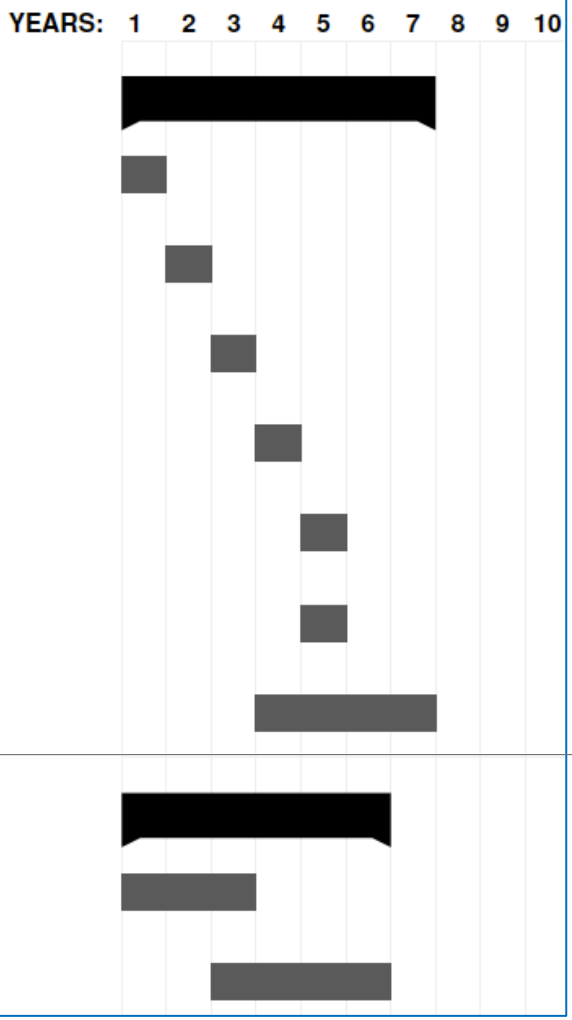
To SRF

Module

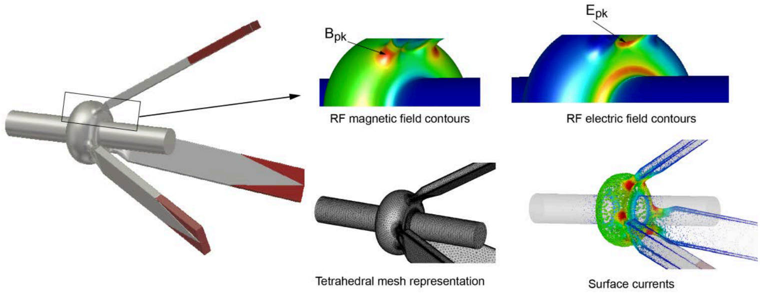
Task	Invest (TEUR)	FTE Total	FTE Cost (MI	Total cost	Proof of principle Test module	Accelerator module
	6.000	30	4.809	10.809	3.771	7.038
Test Module design work		4	652	652	1	
Test Module design work		4	652	652	1	
Procurement Test Module	1000	1	163	1163	1	
Installation Test Module		2	326	326	1	
"Test 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

HOM+Twin

2.7 MCHF 24.5 FTE Y1= 2022	**HOM Damping at High Temperature**	
Task	Cost	Duration
Design Goals for Impedance and Beam Specs	–	1
Design: Coupler & RF line, beamline absorber, on-cell cavity	0.1	2
On-cell Cavity, Window and Multipactor	–	3
HOM coupler conditioning stand, prototyping on-cell cavity	0.2	1.5
Operation in cryogenic environment with broadband amplifier	0.2	2
Prototype on cell cavity	0.2	3
Design, Build, Testing on a Cryomodule with Beam	2	12
3.5 MCHF 12.5 FTE Y1= 2024	**Twin Cavities**	
Single Multi-Cell Cavity	0.5	4.5
Dressed Multi-Cell Cavity in a Horizontal Cryostat	3	8

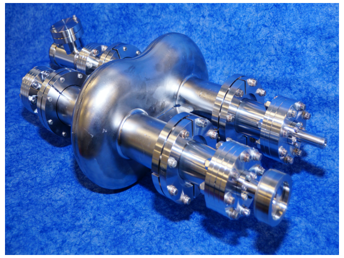


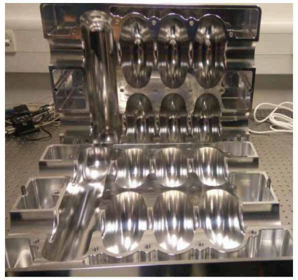
High ERL currents: large HOM load
Need >99% HOM transfer to room T
On-cell damping. SWELL?



CERN, Cockcroft/Lancaster, Rostock

Reduce BBU, Cost: 2K later 4.5 K





Lancaster/
Oxford (JAI)?

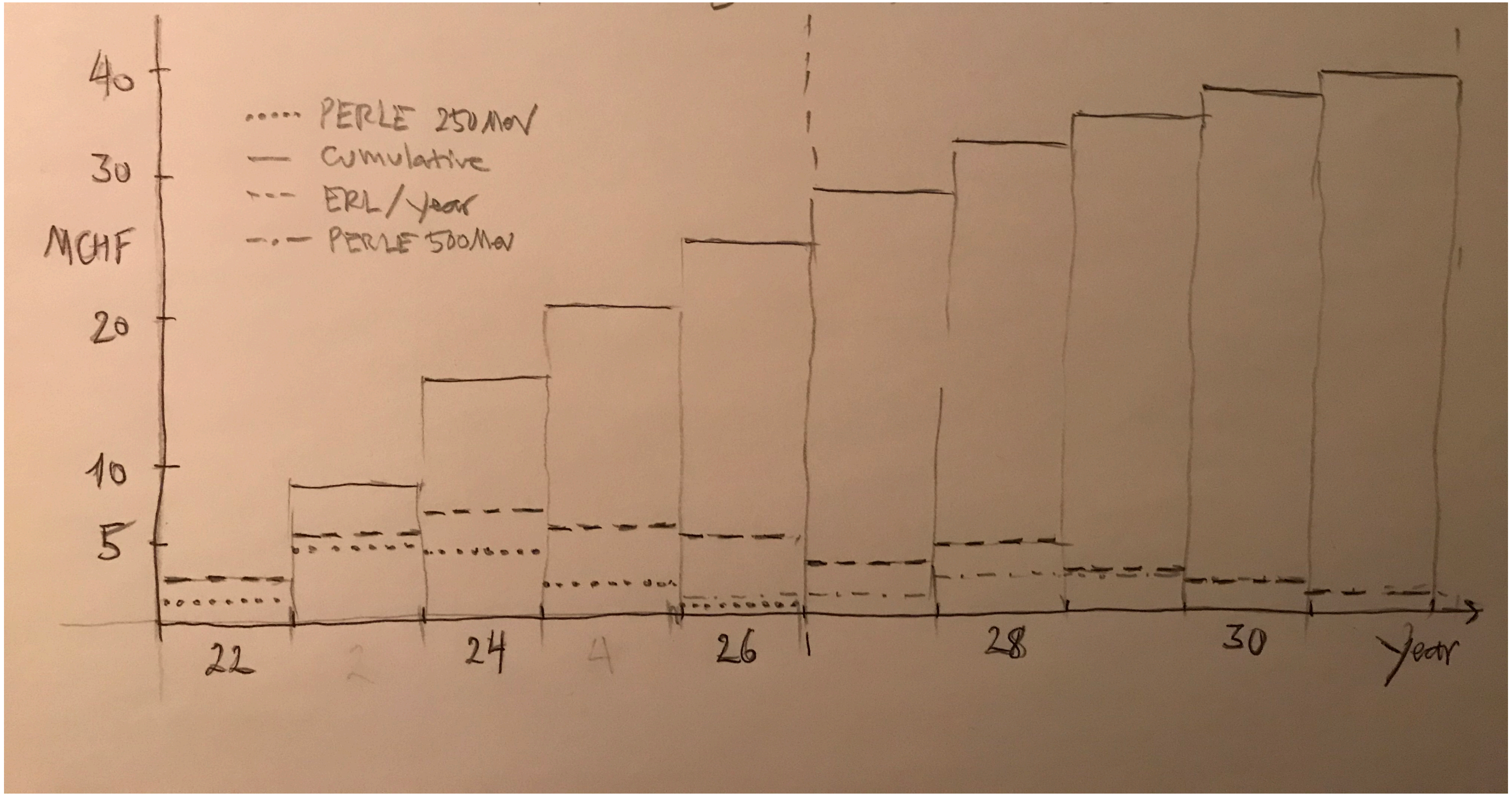
Graeme Burt (CI, Lancaster) Jean Delayen and Andrew Hutton (JLab)

ERL Funding Profile [bERLinPRO, PERLE, HOM-hiT, Twin Cavities] DRAFT 11.10.

A few MCHF per year for a decade with 2026/7 for realignment

No FTEs

Tentative



Builds on strong hostlab contributions and collaborative efforts. Few items as indicated above may reduce sum to ~ 32 MCHF

SUMMARY OF INTERIM REPORT

6.1 Executive summary of findings to date

The fundamental principles of energy recovery linacs (ERLs) have been successfully demonstrated across the globe. There can no longer be any doubt that an ERL can be built and achieve its goals. The panel has drafted a long write-up as an introduction to "The Development of Energy Recovery Linacs" and held an ERL Symposium . It is currently evaluating recent electron-positron collider ERL concepts and moves towards the development of a Roadmap on ERLs—to serve future colliders as well as low-energy particle and nuclear physics. ERLs promise a luminosity increase for physics applications by orders of magnitude at a power consumption comparable to classic, low-luminosity solutions, which is a necessary step towards the sustainability of high-energy physics, as interaction cross sections fall with rising energy. ERLs are also near utilisation in several industrial and other applications.

The novel high-energy ERL concepts targeted at energy-frontier electron-hadron, electron-positron and electron-photon colliders, as well as further physics and other applications, require the development of high-brightness electron guns and dedicated SRF technology as prime R&D objectives. Moreover, "it needs a facility comprising all essential features simultaneously: high current, multi-pass, optimised cavities and cryomodules and a physics-quality beam eventually for experiments" (Bob Rimmer).

Europe's next endeavours are MESA at Mainz, a polarised beam facility for experiments, bERLinPRO, an accelerator R&D facility at Berlin with the potential to reach 100 mA of electron current, and a dedicated high-power, multi-turn facility, PERLE at Orsay, which is being developed by a large international collaboration. Moderate investments, compared to other accelerator R&D projects, will be required to have this programme adequately supported. Globally, ERLs deserve coordinated cooperation, with the developments of high-current ERL facilities at BNL, BINP and KEK, with a forthcoming high-energy experiment at CEBAF as well as plans for next-generation facilities. High-current ERL operation causes major challenges, such as beam breakup instabilities or RF transients, requiring collaborative efforts across the various facilities. In summary, the panel notes with much interest that the ERL technology is close to its high-current and high-energy application, requiring dedicated and coordinated R&D efforts, with the stunning potential to revolutionise particle, nuclear and applied physics as well as key industry areas, at a time where caring for energy resources is a prime necessity for this planet, not least big science. ERLs are therefore primed for inclusion among the grand visions our field has been generating, and for dedication of adequate support to it for this unique potential to bear fruit.

A 3-FOLD INTERLINKED STRATEGY

A – Facilities in progress including technology developments
[sDALINAC, MESA + cBETA, cERL, Recuperator]

B – New Facilities – towards high current and power
[bERLinPRO , PERLE multi-turn + CEBAF5, eCooler]

C – Key Technology R&D Program – next generation ERLs

As presented to LDG 30.9.

Backup: summary from 30.9., in brief: **It is time for a next big step in ERLs and for Europe to be part of it**.

backup

Tentative Conclusions

Presented to LDG WS 30.9.21

- 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?

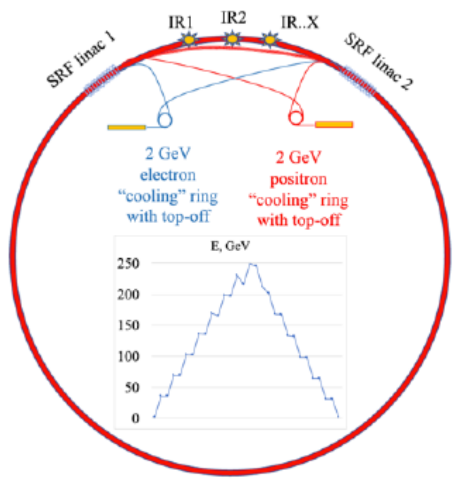
  Huge opportunities with very high intensity (PERLE = 1000 ELI) and small emittance: MESA (> 2024), PERLE (>2027)
  Weak interactions, dark matter, nuclear photonics through IGS, exotic isotope spectroscopy, …

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

A 5-pages report drafted and agreed by sub-Panel is/will now be out for factual check to the authors and for comments to Panel. Include in Roadmap report and (possibly an extended version) as an Appendix in the ERL long write-up

tentative

Figure 1 Possible Layout of the CERC

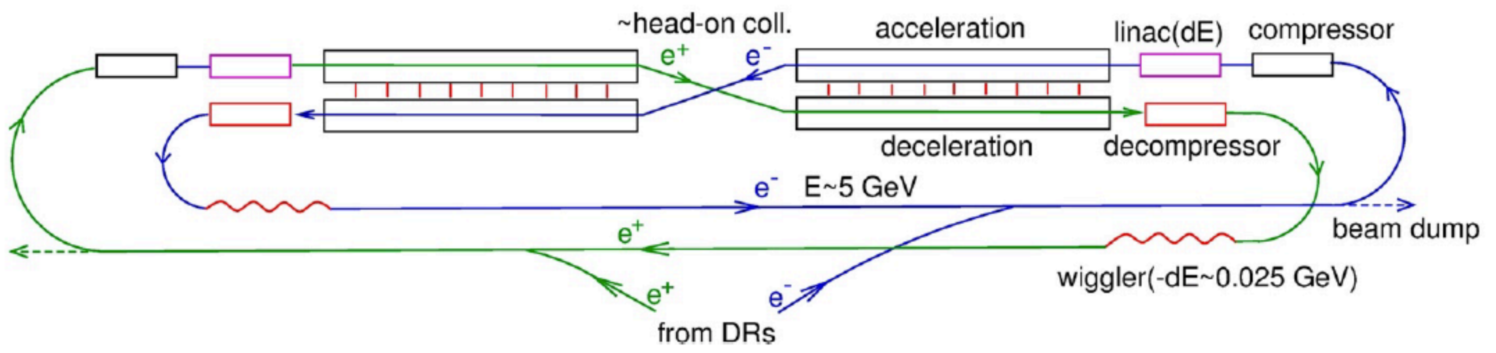


CERC Recommendations:

The sub-Panel supports the idea of designing a collider based on an ERL to reduce the energy footprint of the facility, and the CERC is an excellent first attempt. While the present proposal has several flaws due to the limited effort that the authors were able to devote to the design, the sub-Panel chose to look for ways that the design could be improved rather than focus on the problem areas.

1) We recommend the development of a self-consistent set of parameters with associated preliminary simulations to fully demonstrate that the idea is viable.
2) The bunch length is a critical parameter – too short and the beamsstrahlung becomes excessive; too long and the energy spread from the RF curvature becomes excessive. It will be necessary to carefully optimize the choice.
3) The energy requirements of the damping rings must be integrated in the design.
4) We recommend R&D on high Q_0 cavities operating at 4.5K, which would reduce both the cost and the power consumption.

Figure 2 Schematic Layout of the ERLC



ERLC Recommendations:

The sub-Panel approves the idea of designing a linear collider based on an ERL to reduce the energy footprint of the facility, and the ERLC is an excellent first attempt. The present proposal was developed by a single author and is therefore incomplete in many details. Therefore, the sub-Panel chose to look for ways that the design could be improved as part of a more detailed study.

1) We recommend a study of the new beam dynamics problems inherent in the integration of a linac and a damping ring.
2) We recommend R&D on high Q_0 cavities operating at 4.5K, which would reduce both the cost and the power consumption.
3) We recommend the development of twin aperture SRF cavities in common cryomodules.
4) If the ERLC is envisioned as an ILC Upgrade, then a list of the modifications to the ILC to accommodate a future ERL luminosity upgrade should be developed.

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

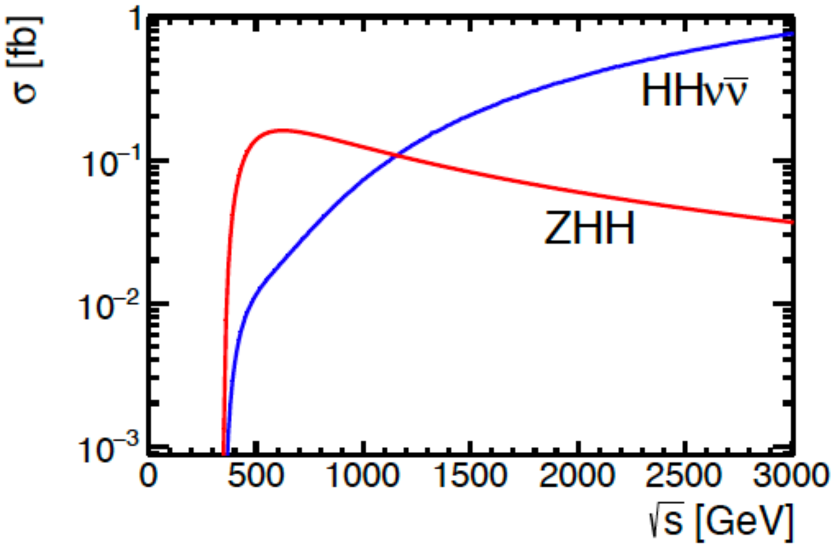


Fig. 1 Cross section as a function of centre-of-mass energy for $e^+e^- \to ZHH$ and $e^+e^- \to HH\nu\bar{\nu}$ production for a Higgs boson mass of $m_H = 126$ GeV. The values shown correspond to unpolarised beams including initial state radiation but not including the effect of beamstrahlung [16].

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^-

<u>This is a strong case for a next generation linear ee collider</u>

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.

C

Advances in Nb_3Sn superconducting radiofrequency cavities towards first practical accelerator applications

S. Posen[1a)], J. Lee[1,2], D.N. Seidman[2,3] A. Romanenko[1], B. Tennis[1], O. S. Melnychuk[1], D. A. Sergatskov[1]

[1]*Fermi National Accelerator Laboratory, Batavia, IL, 60510, USA*

[2]*Department of Materials Science and Engineering Northwestern University, Evanston, IL, 60208, USA*

[3]*Northwestern University Center for Atom-Probe Tomography (NUCAPT), Evanston, IL, 60208, USA*

arXiv:2008.00599 and many references therein

Single cell tests with gradient > 20 MV/m and high Q_0

1.3 GHz

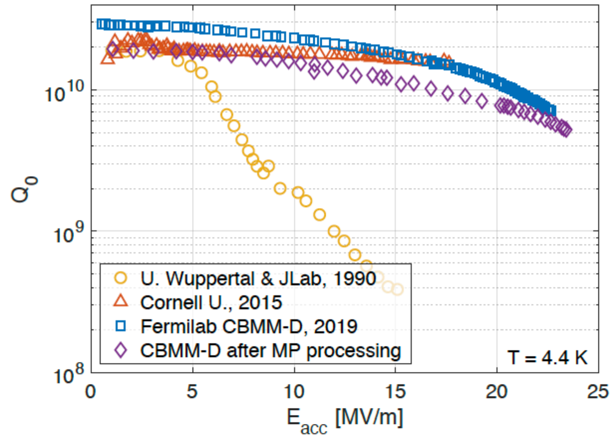


Fig. 12: Performance of 1.3 GHz single cell cavity CBMM-D before and after processing (top) and comparison to a selection of previous 1.3-1.5 GHz single cell cavities (data from [23], [32]) at 4.4 K (bottom).

650 MHz

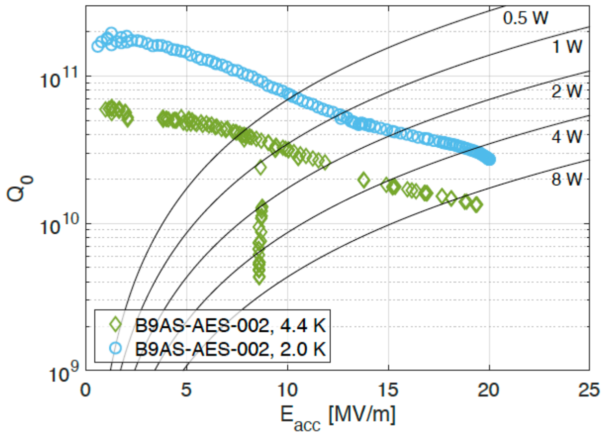


Fig. 13: Performance of 650 MHz single cell cavity B9AS-AES-002. The multipacting at 9 MV/m was processed during the test.

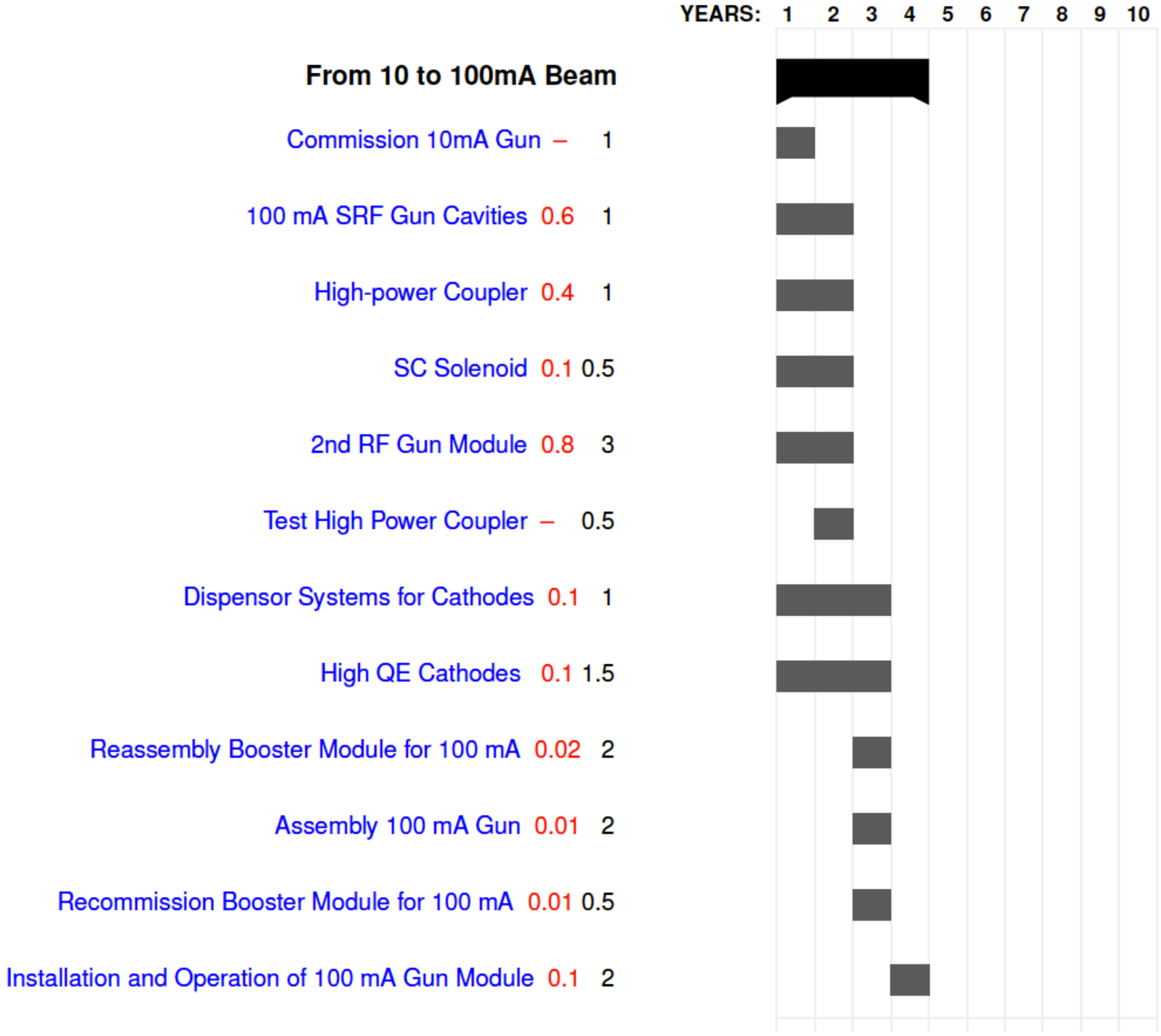
- The niobium cavity substrates were given electropolish treatment (as opposed to buffered chemical polish) to achieve a smooth surface prior to coating
- The niobium substrates were anodized to 30 V in ammonia prior to coating (recommended previously, e.g. [22] and [23])
- To encourage high vapor pressure, the Sn heater was driven with maximum power available (measured ~1300°C in thermocouples in heater coil, expect somewhere between 1200°C-1250°C in Sn crucible based on previous calibration)
- To encourage high vapor pressure, a relatively large crucible diameter was used (~15 mm or larger)
- To prevent condensation of Sn droplets on the surface due to a high vapor pressure in a closed volume, one or more ports of the cavity were kept open to the chamber (similar to the Cornell setup [1])
- The nucleation step was substantially modified, to have a rapid ramp to high temperatures ~1000°C – this will be discussed in detail below
- A nitrogen infusion step was added at the end of the coating process – this is also discussed in detail below

High end technology requiring long term expertise

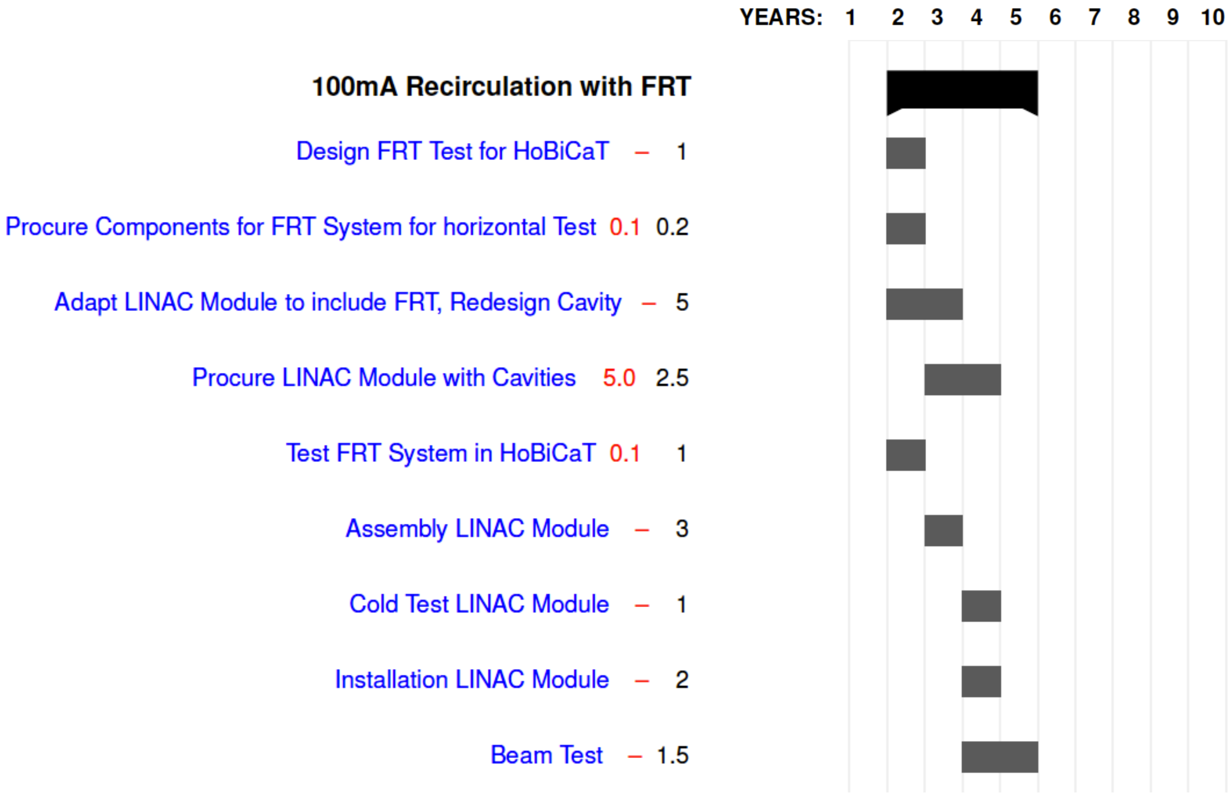
Sn Vapor diffusion: FNAL, JLab, Cornell. Not in EUK

bERLinPRO

7.44 MCHF 33.2 FTE



2.24 MCHF 16 FTE



5.2 MCHF 17.2 FTE