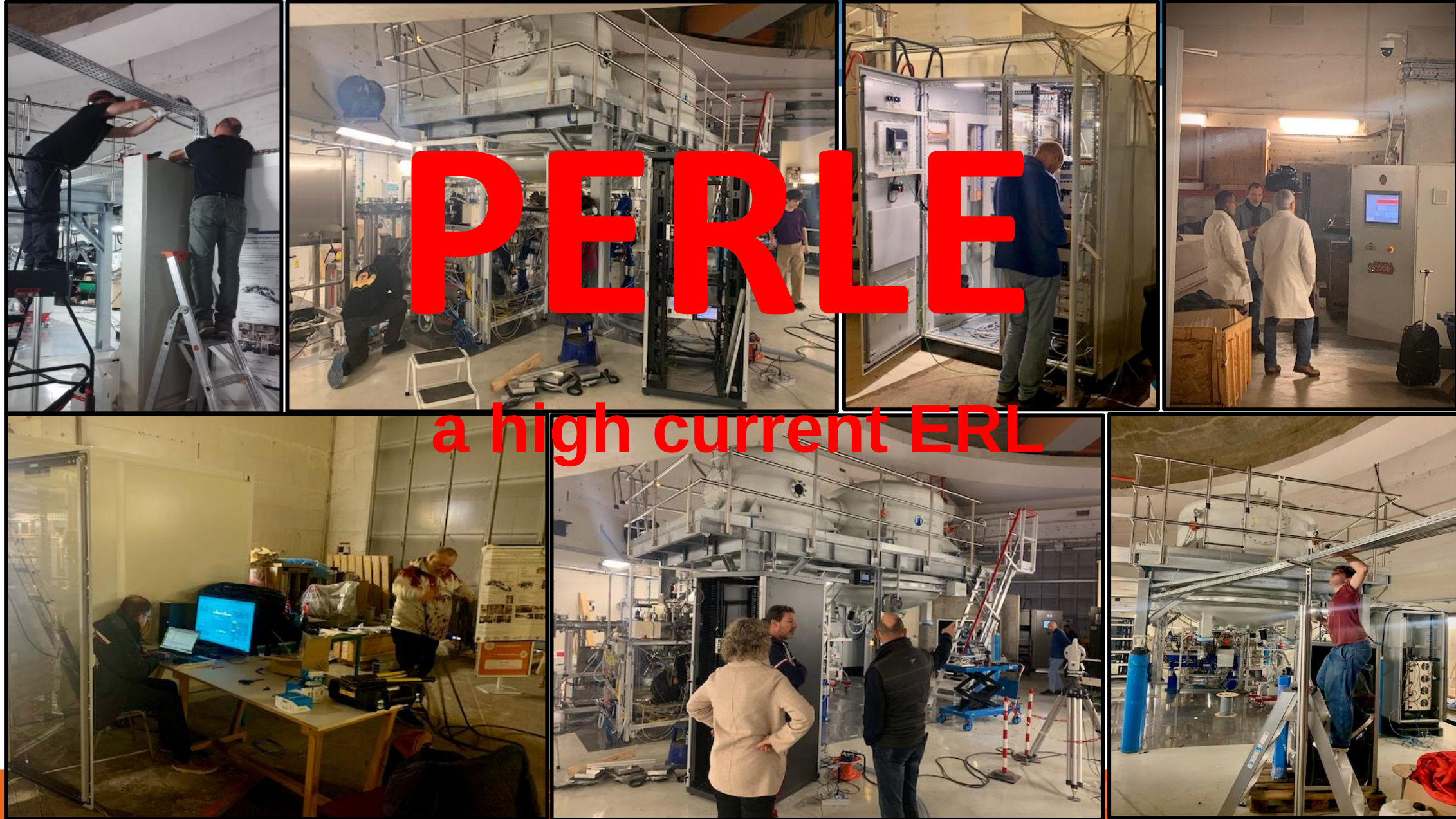
PERLE

a high current ERL

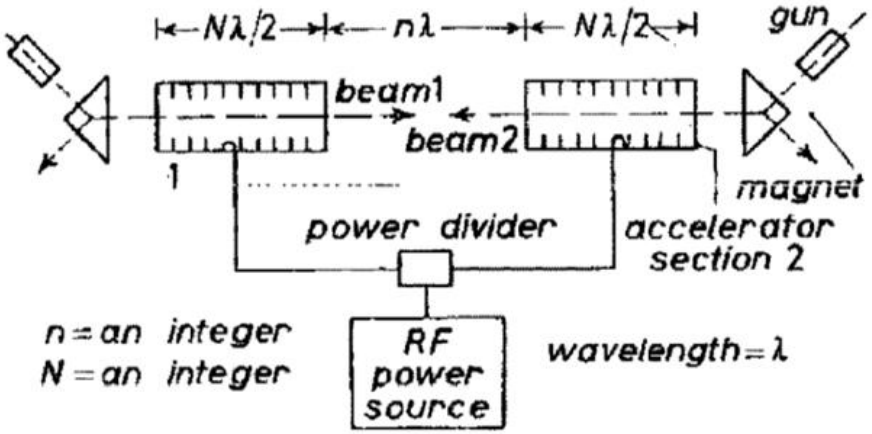
for future colliders (LHeC, FCC-ee)
and other applications

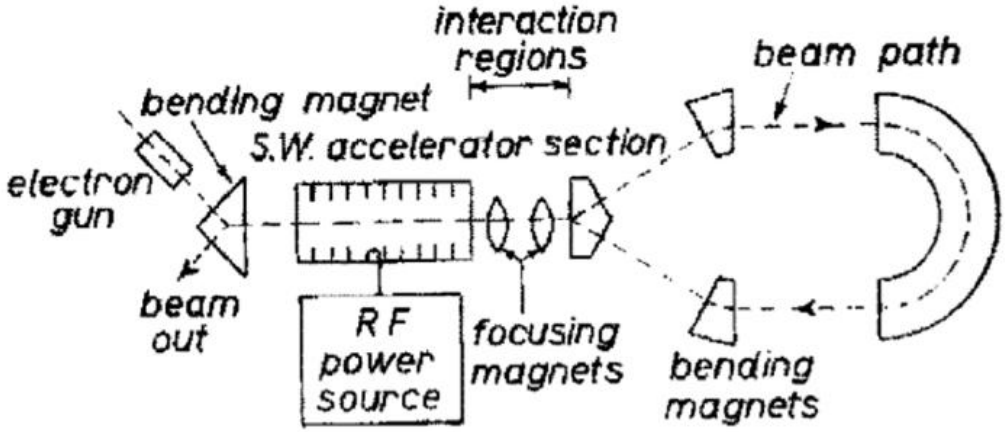
Achille Stocchi (IJCLab, CNRS, Université Paris-Saclay)
On behalf of PERLE Collaboration


PERLE
a high current ERL

ERL. The original Idea.

- ERL concept was proposed first in 1965 by Maury Tigner [1]



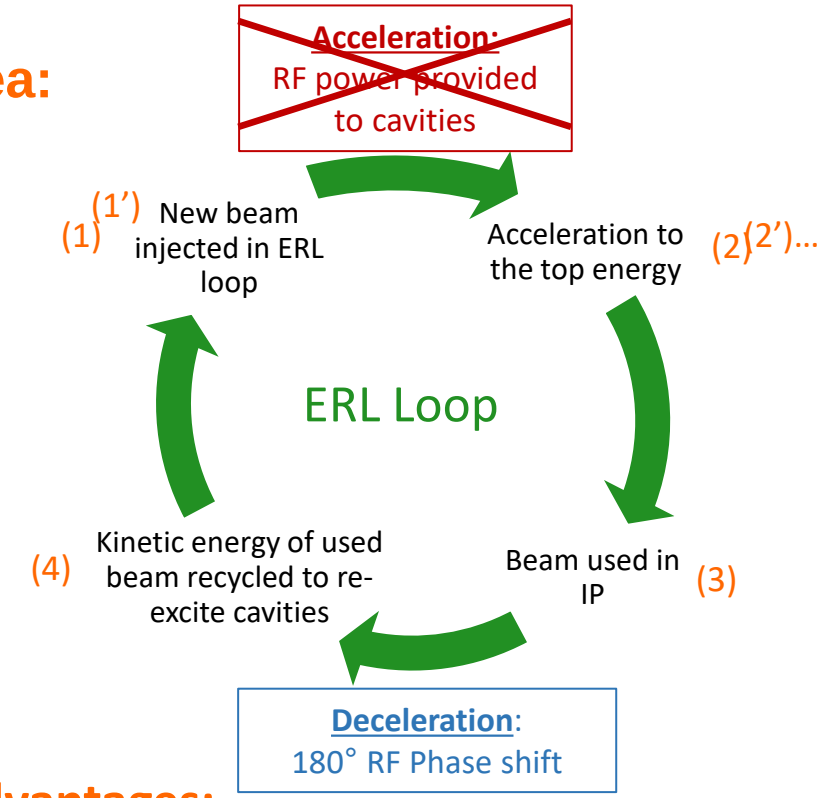


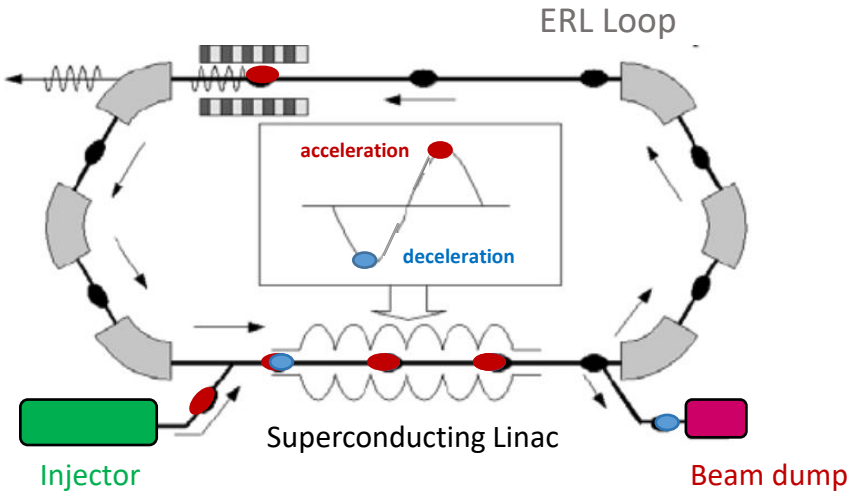
[1] M. Tigner: "A Possible Apparatus for Electron Clashing-Beam Experiments", Il Nuovo Cimento Series 10, Vol. 37, issue 3, pp 1228-1231,1 Giugno 1965

- First test was done at Stanford in 1986 (interesting concept for FELs, Compton light sources and high current electron cooler)
- Concept become only viable with recent advances in SRF technology.

Introduction- ERL Concept

The idea:





The benefits:

- Reduce accelerator power consumption
- Dumping the beam at injection power
- Fresh beam in IP with the same characteristics

More advantages:

- Linac-like beam quality with extremely flexible time structure
- High operating efficiency
- Multi-pass configuration: High average current carrying capability (no more RF power limit) + High average beam power in a compact machine

Which could be the use of ERL ?

It addresses the need **to reduce energy consumption** and enables the design of high-intensity accelerators for high-energy physics, nuclear physics, and other applications.

To go to high power has become possible thanks to the great progress on SRF technologies

One of the applications that has strongly renewed interest in ERLs is the LHeC project.

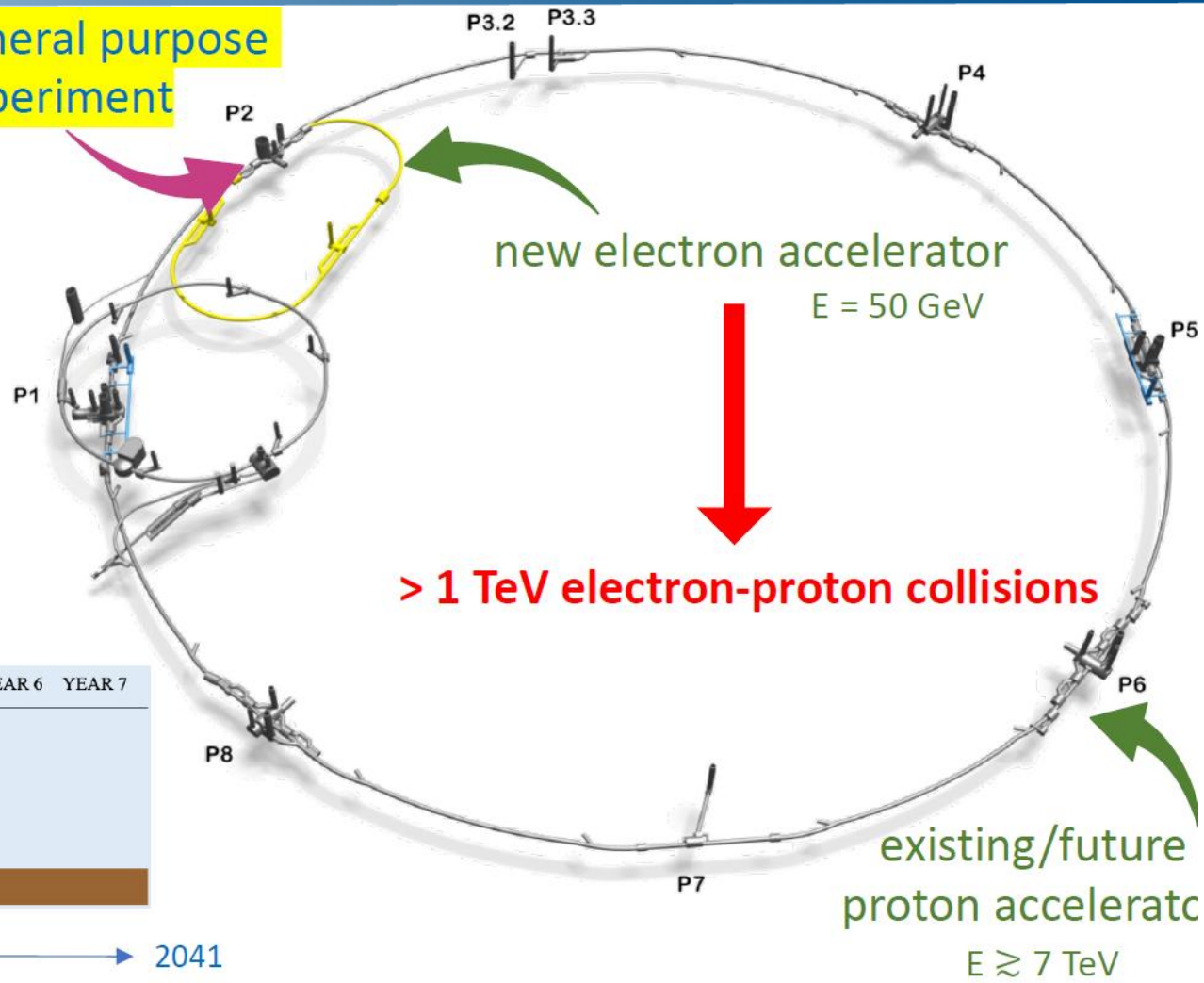
ERL-based machines can also play a key role in

- Testing SRF technologies for future accelerators, and above all FCC-ee
- nuclear physics, in particular through eN scattering;
- high-brightness photon sources via Compton scattering.

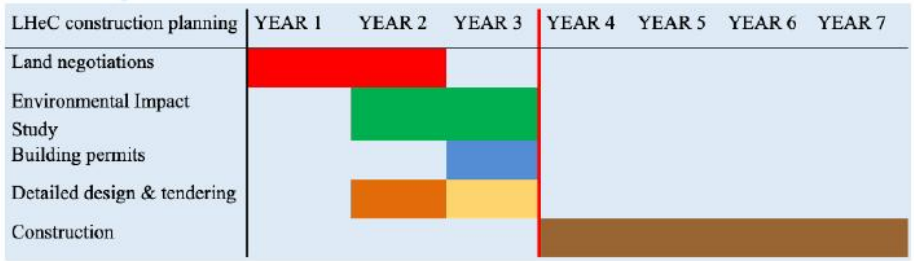
LHeC – parameters, timeline, resources, energy consumption

The LHeC project emerges as an impactful and feasible bridge between present and future major colliders at CERN

one general purpose experiment



800MHz, 20MV/m in CW, 6x25mA in SRF
ERL 3-turns, 50 GeV (1/3 of LHC circumference)
Start operation after HL-LHC (>2041)
Luminosity above 10^{34} $cm^{-2}s^{-1}$
6 years of operation, 1 ab^{-1} (e.g. 2043-2048)
120MW from HL-LHC + 100MW from e-beam



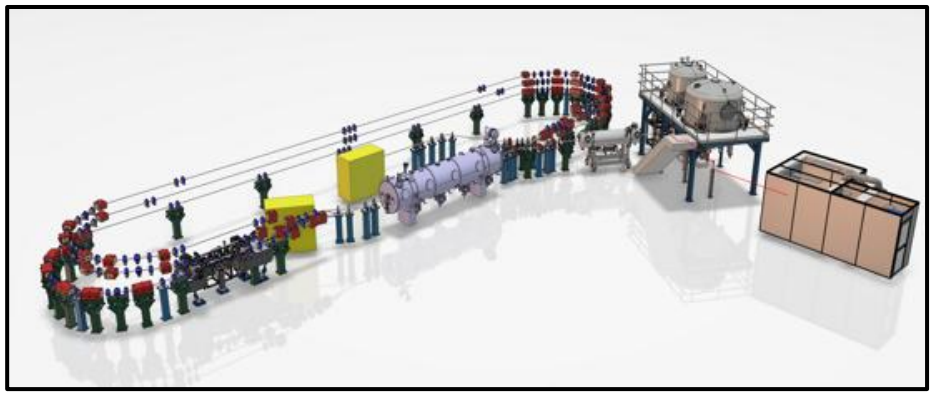
for example 2034 → 2041

PERLE as a demonstrator of LHeC

PERLE: A testbed to explore and validate a broad range of accelerator phenomena & technical choices on the **pathway to the LHeC and other new frontier machines realisation.**

Main challenges: Multi-turn, high bunch charge, high power energy recovery, …

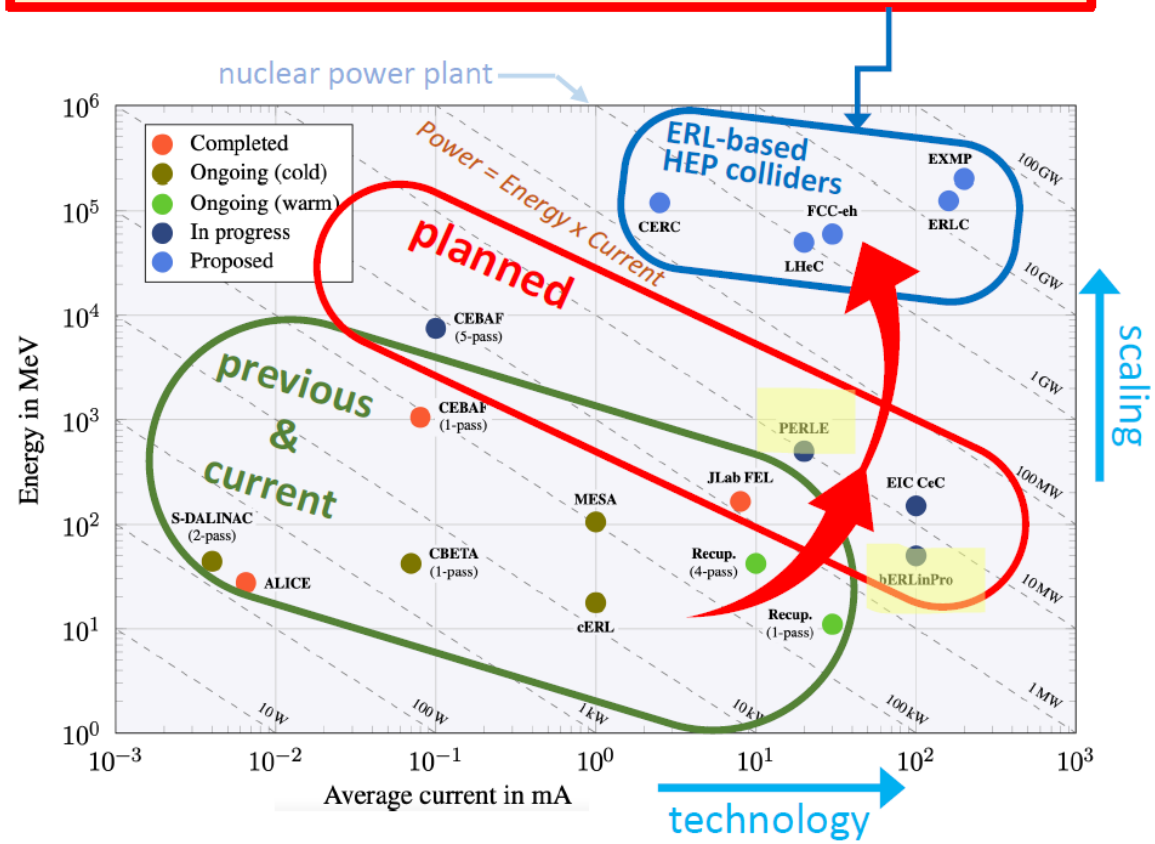
- 1 Linac (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (164 MeV/turn)
- Max. beam energy 250 MeV
- I = 20mA



Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	250
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE as a pioneering machine

ERL to enable high-power beams that would otherwise require one or more nuclear power plants



Future ERL-based Colliders

H, HH, ep/eA, muons, …

bERLinPro & PERLE

essential accelerator R&D labs with ambitions overlapping with those of the particle physics community

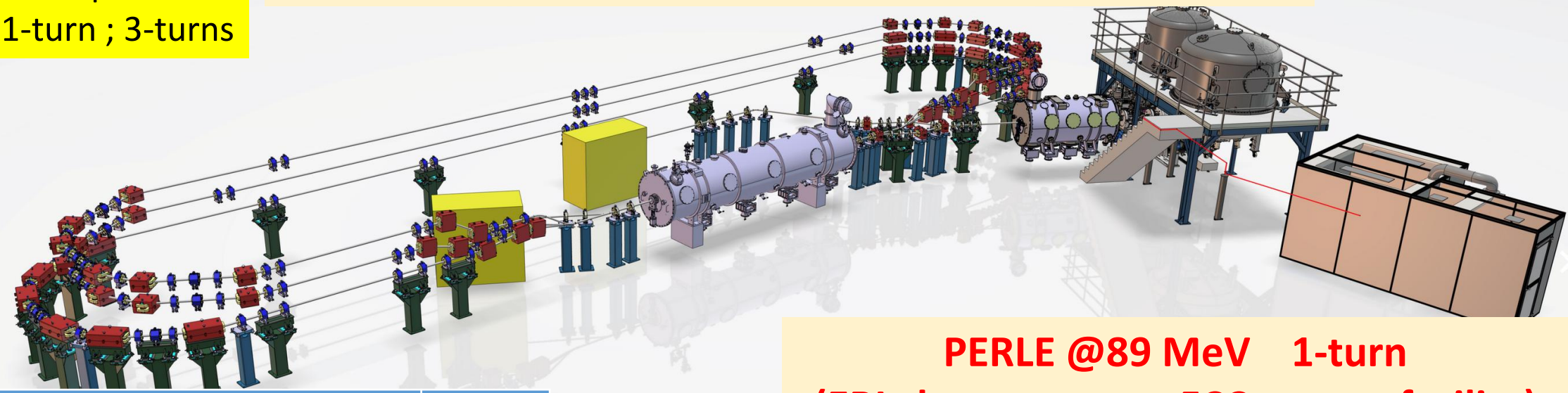
towards high power

Energy Recovery demonstrated

great achievements on all aspects and large research infrastructures based on Energy Recovery systems have been operated successfully

Two phases :
1-turn ; 3-turns

PERLE @250 MeV 3-turns (ERL demonstrator, LHeC)

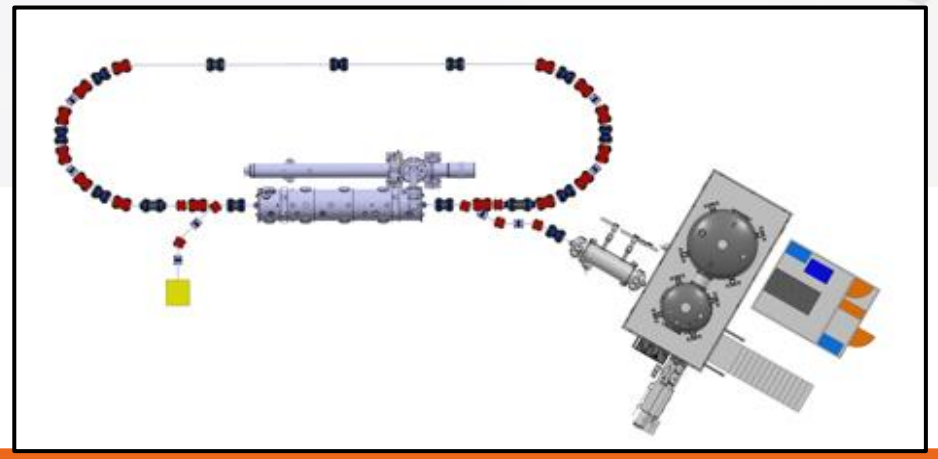


Parameters	Values
Injection Energy	7 MeV
Electron beam energy PHASE 1 (1-turn)	89 MeV
Electron beam energy PHASE 2 (3-turns)	250 MeV
Normalised Emittance $\gamma\varepsilon_{x,y}$	6 mm.mrad
Average beam current	20 mA
Bunch charge	500 pC
Bunch length	3 mm
Bunch spacing in injector	25 ns
RF frequency	802 MHz
Duty factor	CW

1,8MW
5MW

Same parameters as **LHeC**

PERLE @89 MeV 1-turn
(ERL demonstrator, FCC-ee test facility)



Accelerator Priorities in the ESPP 2026 : ERL/PERLE well positioned

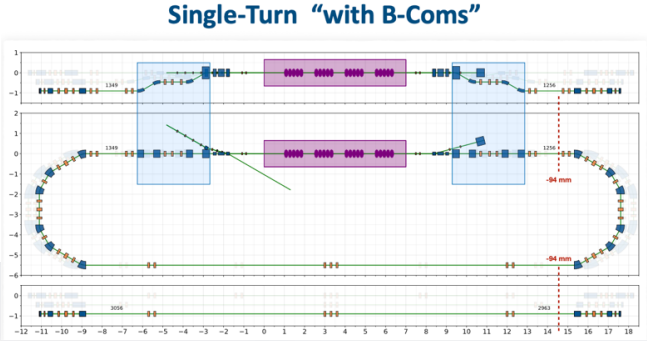
B. In order to realise the visionary plan presented, the highest priority must be the development and industrialisation of key technologies: advanced superconducting and normal-conducting RF structures, efficient RF power sources and accelerator-quality magnets in the 14–20 T range, including those based on high-temperature superconductors.

C. Demonstration of high-current multi-turn energy recovery in linacs constitutes an important step towards power-efficient lepton accelerators for a broad range of applications and should be pursued.

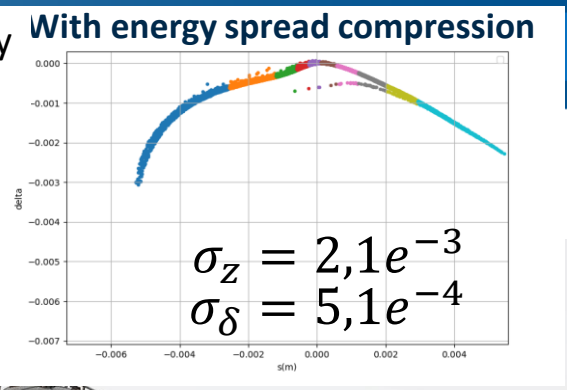
D. The longer-term development of advanced technologies, such as high-gradient wakefield acceleration and those underpinning bright muon beams, should be supported at an appropriate level. Synergies with the US initiative on muon collider R&D should be exploited.

PERLE is an International collaboration

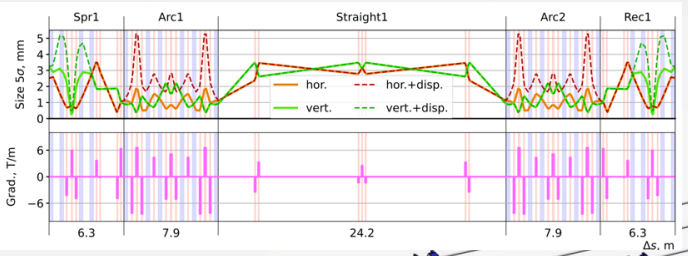
+ Contributions through iSAS of



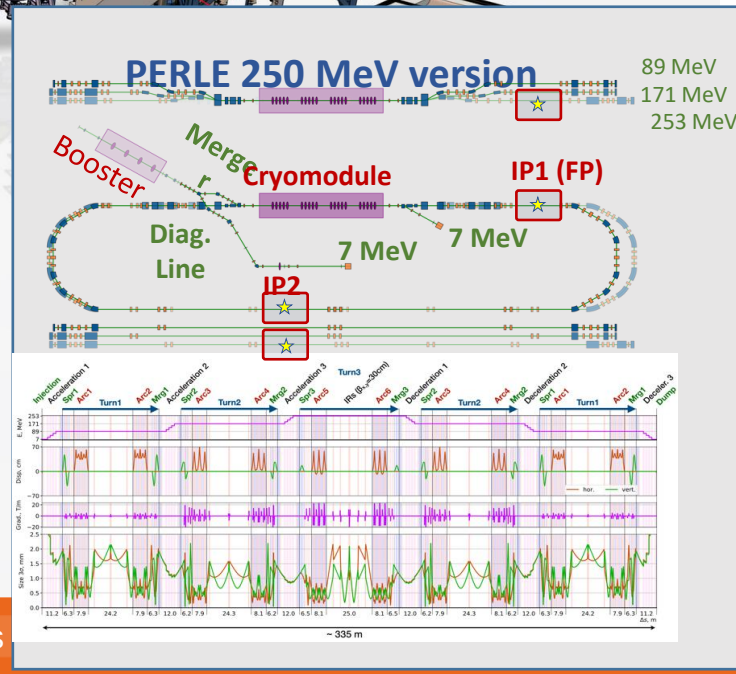
Longitudinal matching for energy spread compression at EP



Great progress
on beam dynamics
and on lattice design
1-turn 3-turns

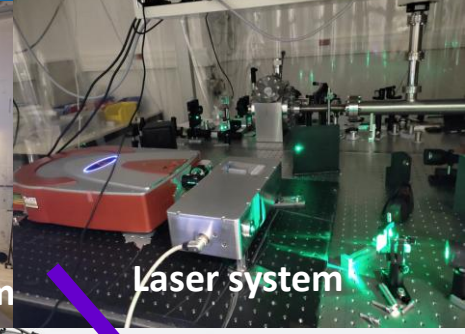


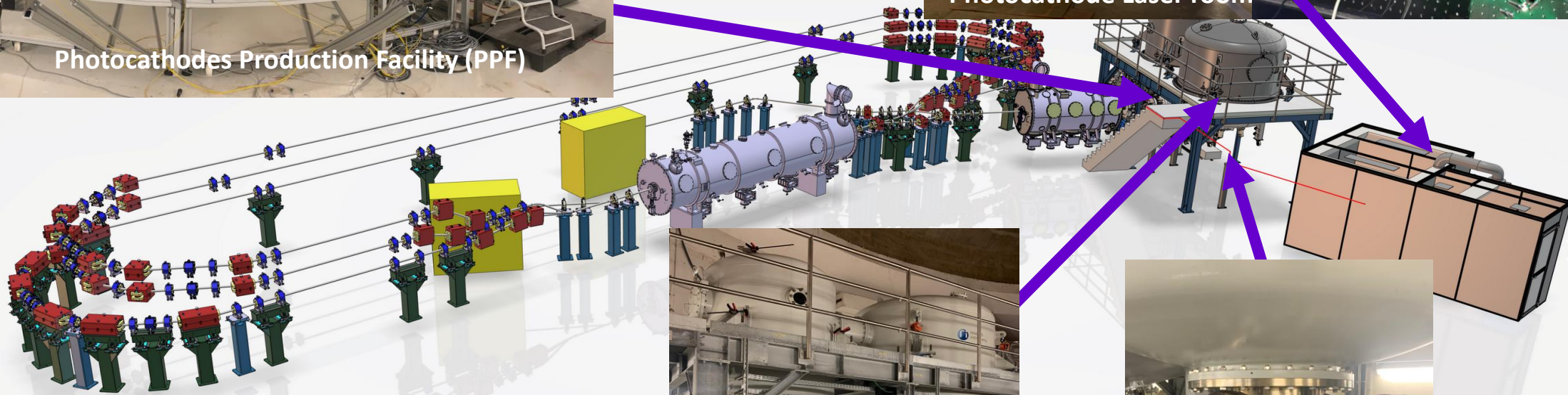
Effect of kickers correction
on magnet disalignements




Photocathodes Production Facility (PPF)


Photocathode Laser room


Laser system

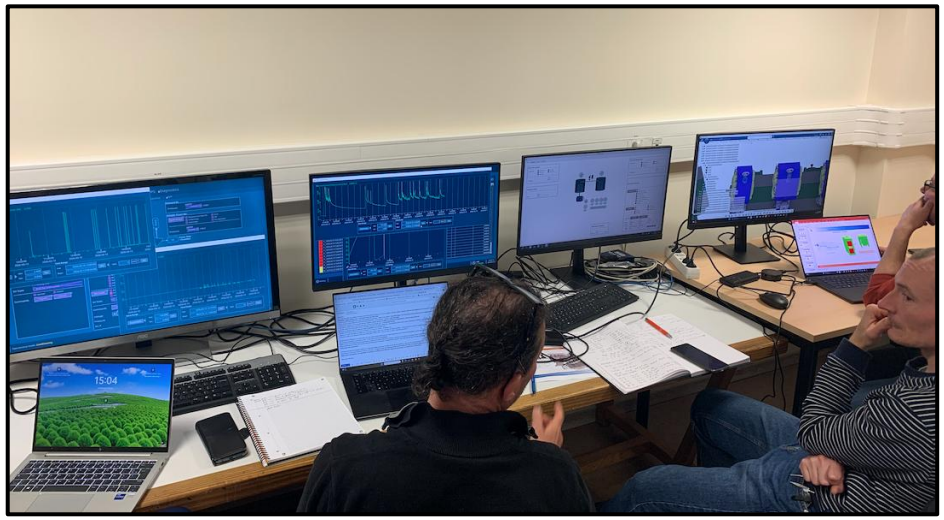


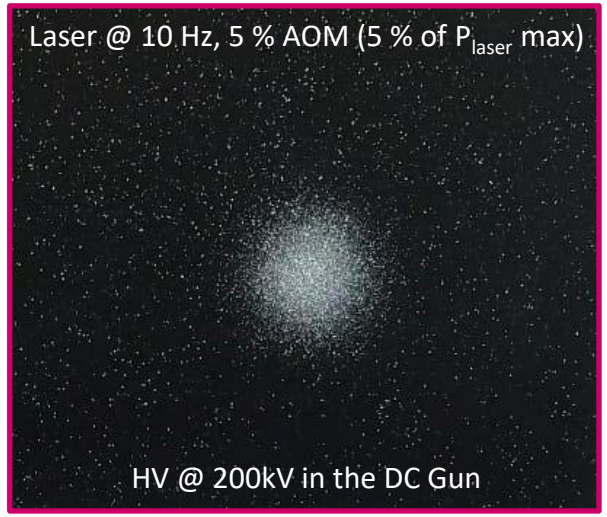

DC Gun & HV system

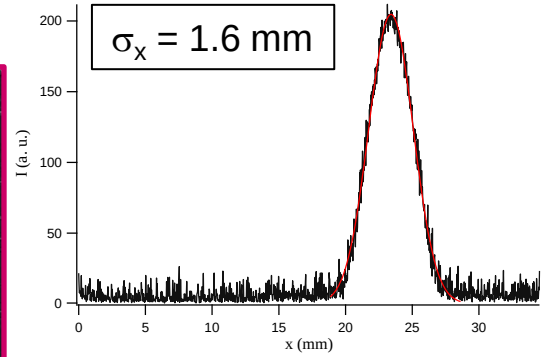

DC Gun

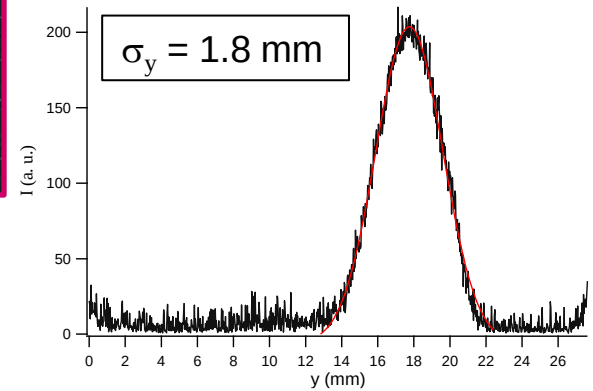
First Beam at the DC-Gun!

- May 07th 2026: **first photocathode** inserted in the gun with the **load-lock system**, QE= 5.2 % (Measured before insertion)
- May 11th 2026: **1st beam obtained!!**



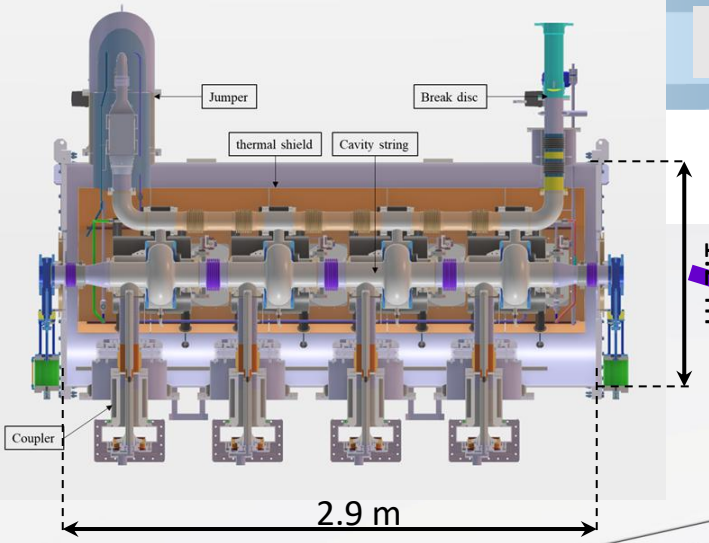


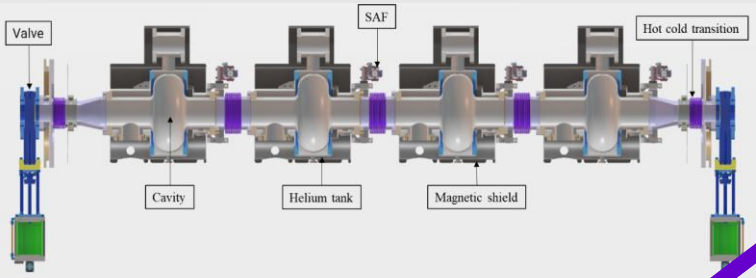


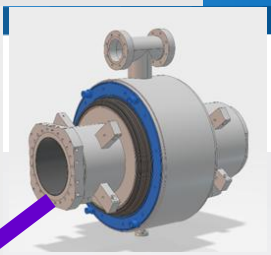


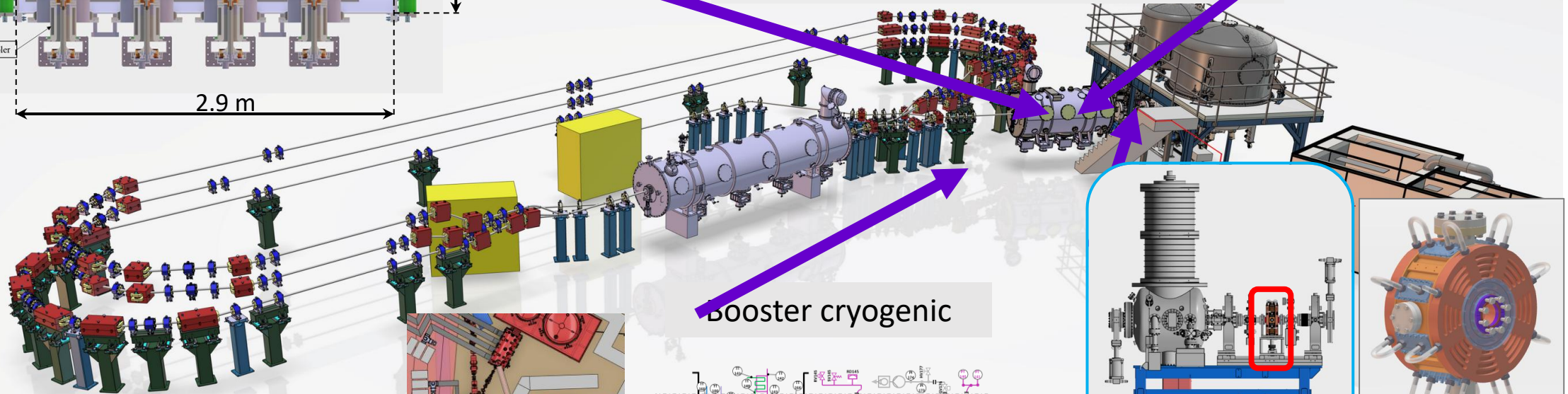
Since, other exited achievements were reached → Do not miss Maud's talk on Wednesday

Advancement for the signel cell cavity for booster + cryomodule

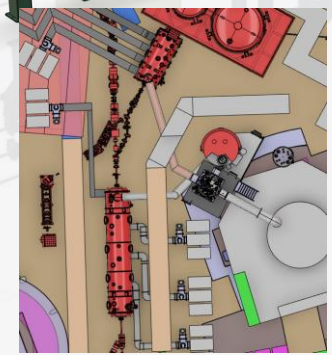


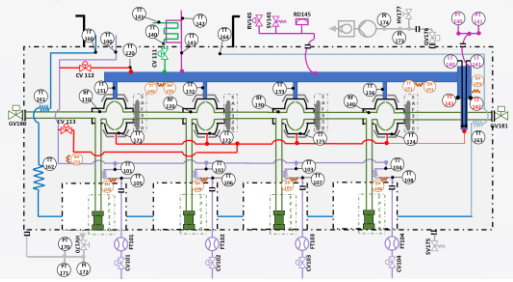






Booster cryogenic

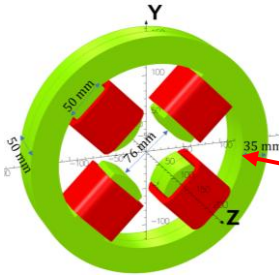




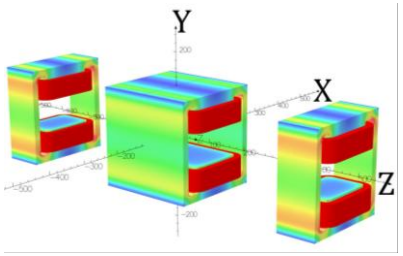
Techincal design for buncher !

Magnet design of PERLE almost completed

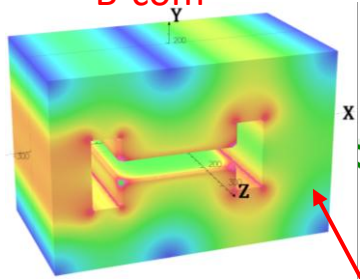
Q5-mgr/diag/com



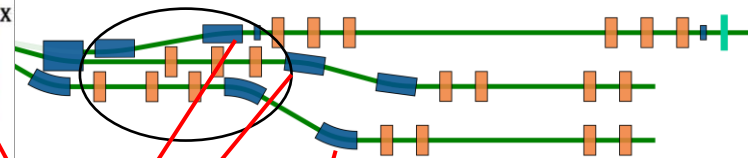
Merger



B-com

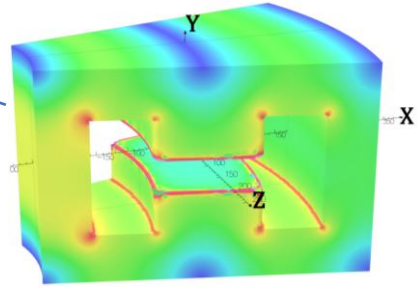


Horizontal field dipoles



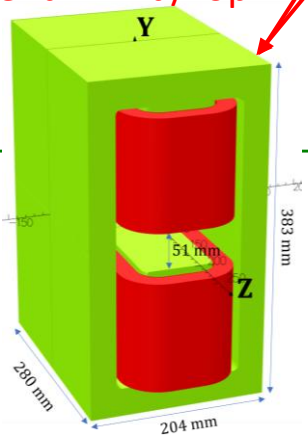
Inj/dmp chicane

Spreader

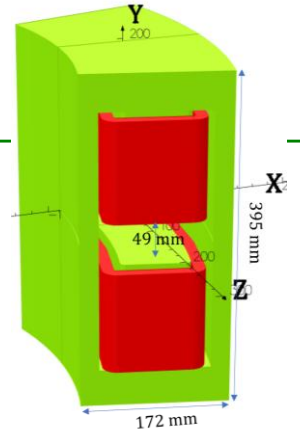


Arc dipole

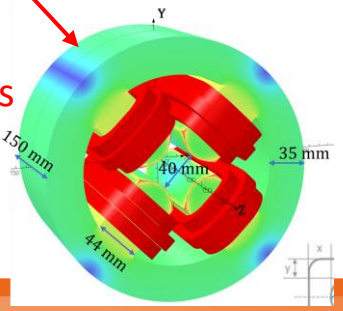
R-bend – Mid/Top

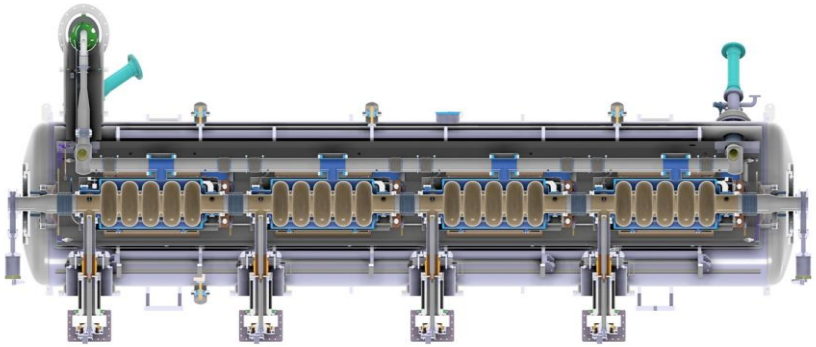


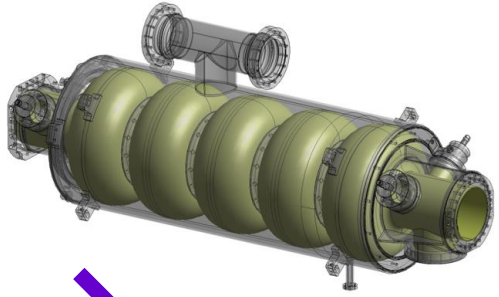
S-bend – Bot. turn

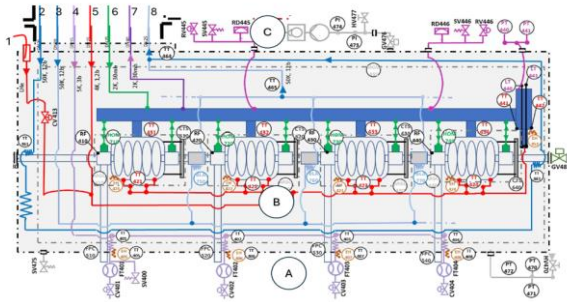


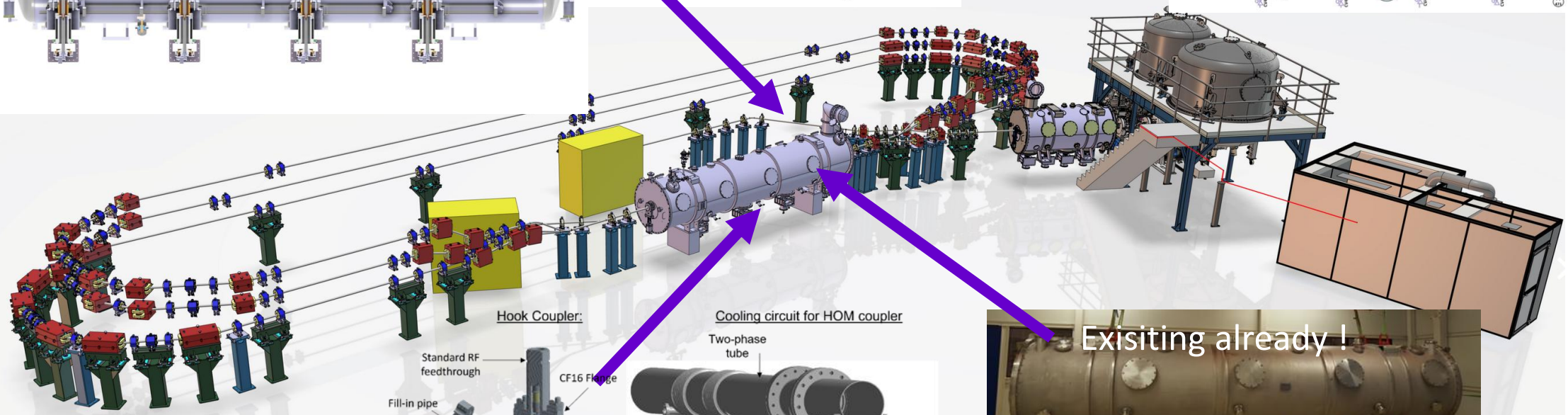
Q15 - Arcs



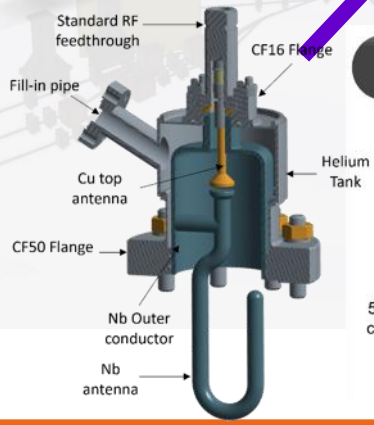




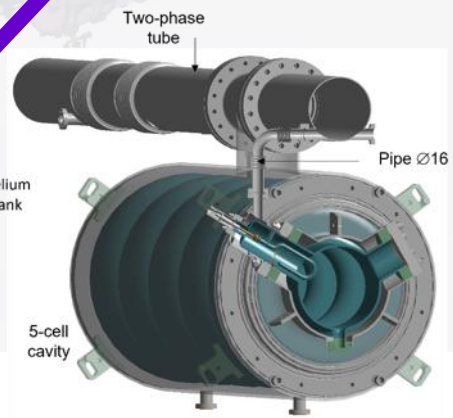


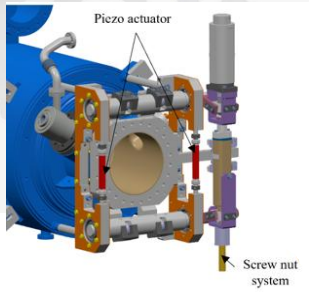


Hook Coupler:



Cooling circuit for HOM coupler







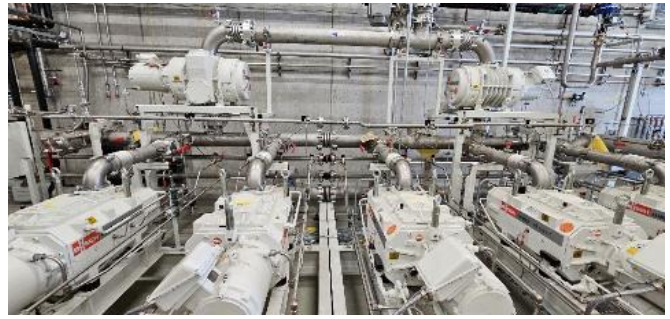


IN-KIND : News of the Collaboration:

- Signature of the Cooperation Agreement between IJCLab/LPSC and Helmholtz Zentrum Berlin (HZB) for the transfer of the Cryo-plant and related equipment and collaboration on SRF activities of mutual interest and activities related to ERLs.
- Technical detail discussions are ongoing for the Cryo-plant transfer (boxing, handing, transportation), responsibilities…

Cold Box





Helium pumping station for 2 K operation

Gas management panel



C&C cabinets



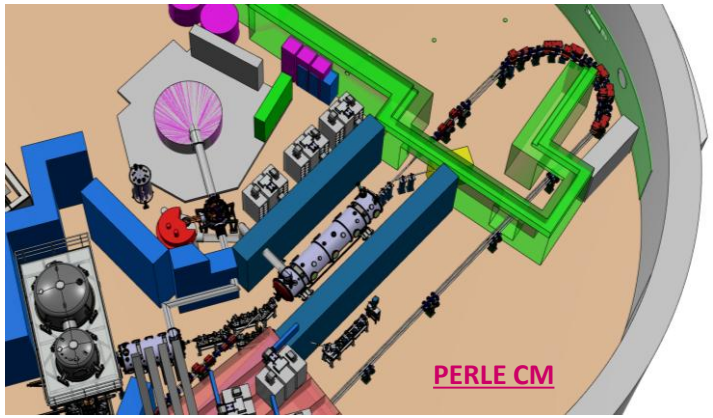


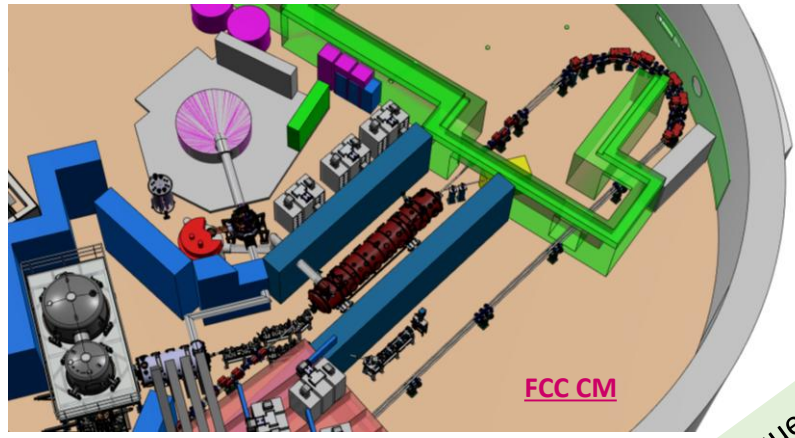
Cycle compressors

Collaboration with CERN and synergy with FCC-ee → PERLE as a FCC-ee test facility

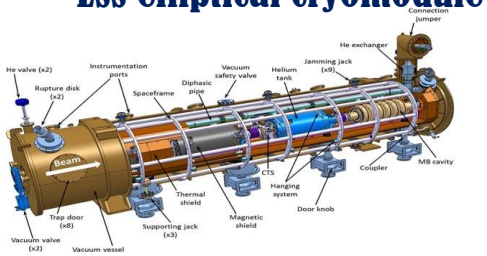
Synergies between PERLE and FCC:

- 800 MHz Cryomodule design for FCC,
- First test of FCC cryomodule with beam in PERLE (as soon as the FCC-ee cryomodule is ready it will be installed in PERLE)
- Development of high performance 800 MHz SRF cavities,
- Development of "cold" beam line absorbers
- Collaboration on RF power sources (installed in PERLE)

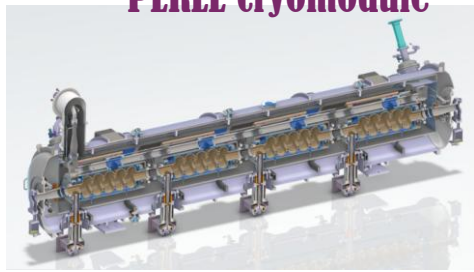




ESS elliptical cryomodule



PERLE cryomodule



FCC cryomodule



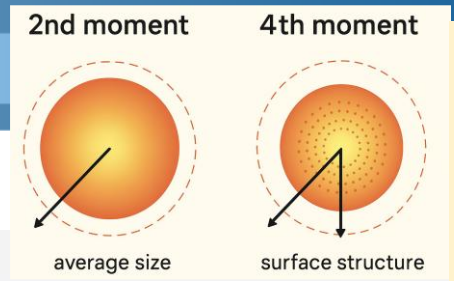
To be revisited if the frequency will be 600MHz instead of 800MHz

Inverse Campton scattering source @ PERLE



Imaging , Art history → Radiotherapy, Material science→ Nuclear Physics, Nuclear waste management

Implementation of DESTIN @ PERLE:



Electron scattering at low q
PERLE will be the only facility to provide electrons for low-q scattering on the rare isotopes nuclei

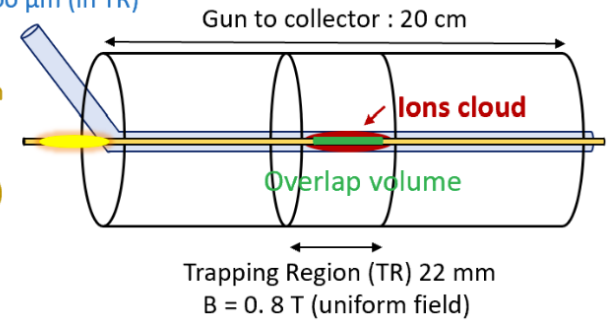
Interest even at 89 MeV
1-turn PERLE !



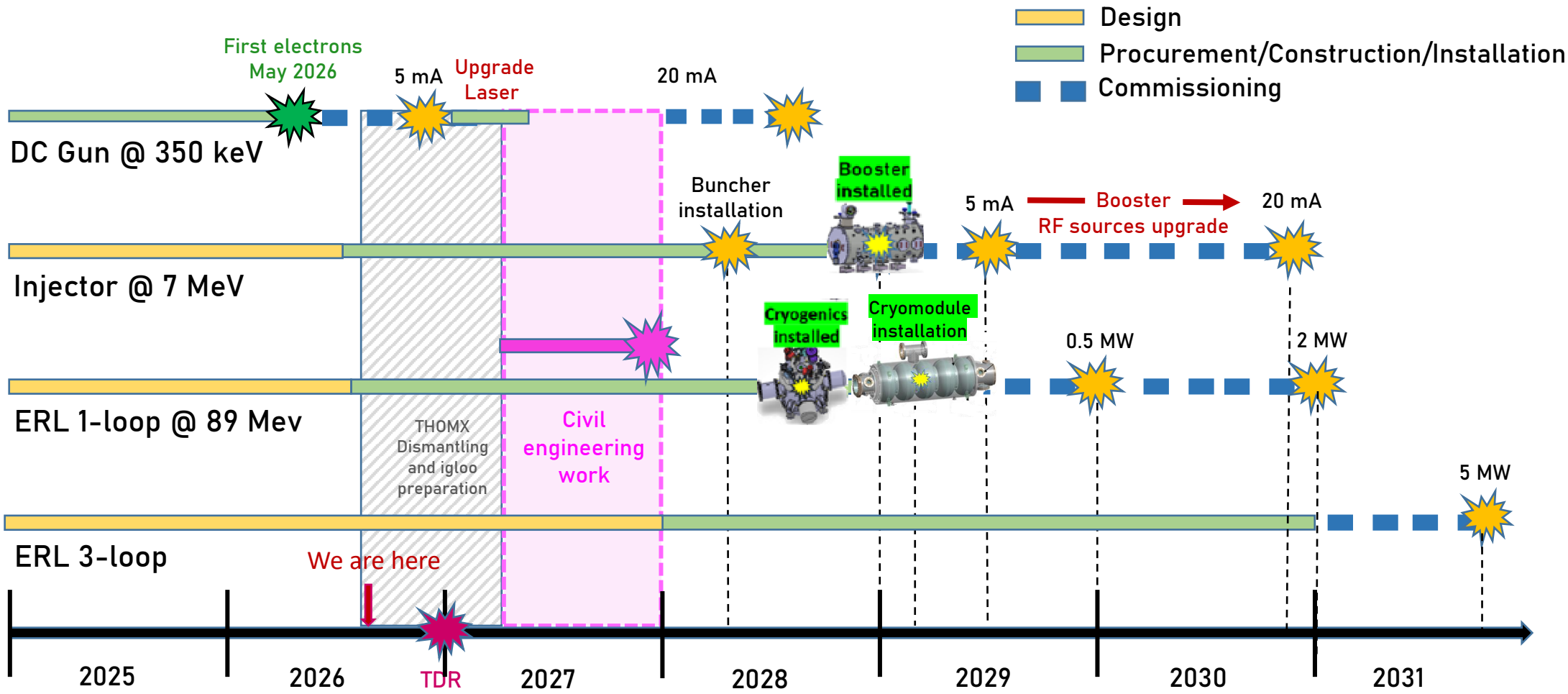


EBIT beam
keV electron beam
R ~ 100 µm (in TR)

PERLE
89 MeV e- beam
Bunch : 25 ns
I = 5 – 20 mA
R ~ 50µm in (TR)



PERLE global planning



Conclusions and Perspectives

PERLE explores **high-current, high-power ERL regime**

- for **LHeC**
- for a broad range of applications (**eN** pioneering and **Inverse Compton scattering experiments)**
- while supporting **sustainable SRF technology development** highly relevant **for FCC-ee**

It is a challenge and it remains to be demonstrated.

- **Significant progress has been made on PERLE** over the past years.
  - Installation of the DC gun and commissioning
  - Finalization of the designs of all other machine components
  - Procurement of some critical components have been already launched (ex. Linac cryomodule)
- Important **enlargement of the international collaboration**
- Project is well in track to do the first ERL demonstration (1-turn) before the end of the decade.