[FJPPN-A_RD_29]
R&D toward next generation Energy Recovery Linacs

CNRS/IN2P3/IJCLab

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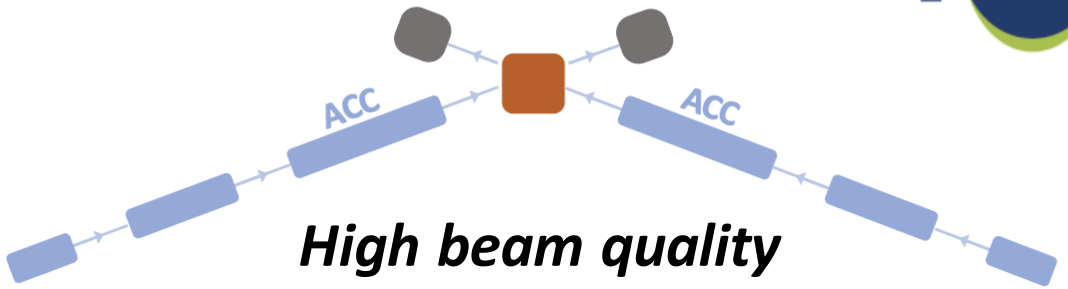
Outline

- Energy Recovery Linac and its potential and challenges
- Status and prospect of cERL (KEK/iCASA)
- Status and prospect of PERLE (IN2P3/IJCLab)
- Common interest 1: multi-turn beam dynamics
- Common interest 2: superconducting cavities
- Expected collaboration in 2024
  - KEK --> IJCLab: photocathode + DC gun commissioning
  - IJCLab --> KEK: ERL2024 workshop + participation in cERL operation
- Conclusion

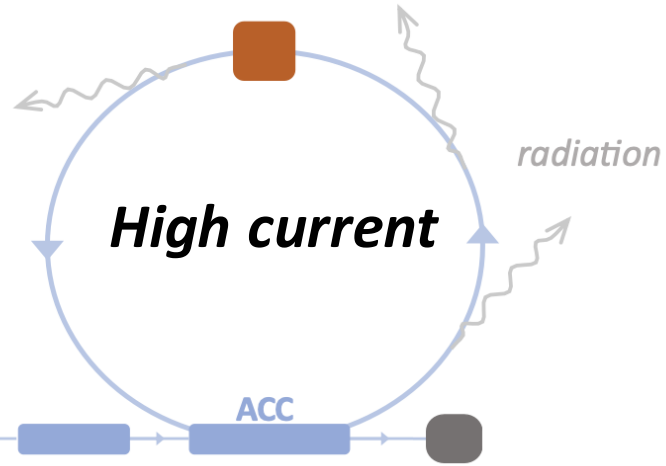
Toward more sustainable accelerators

Linear colliders



High beam quality

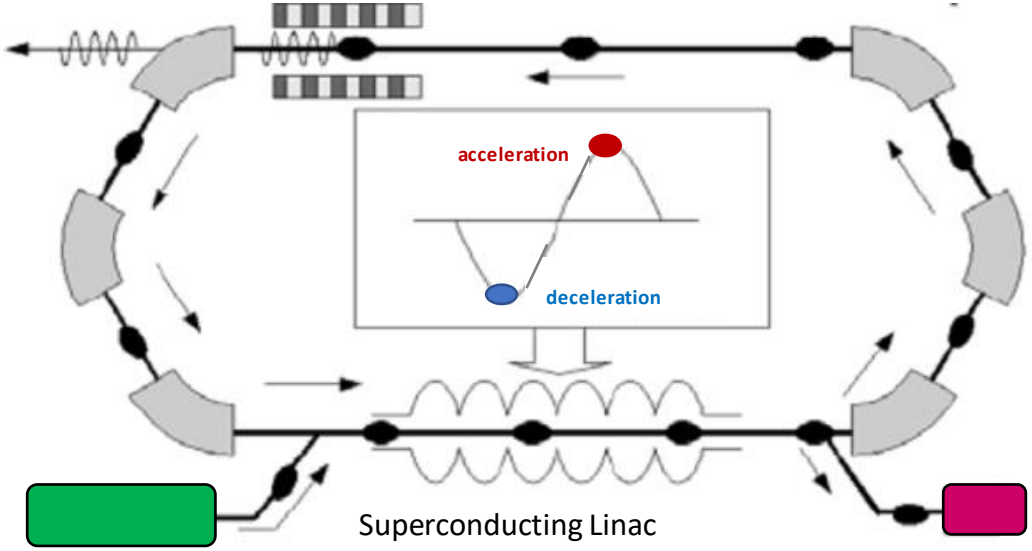
Circular colliders



Combine the advantages of linear and circular accelerators

Energy Recovery Linac

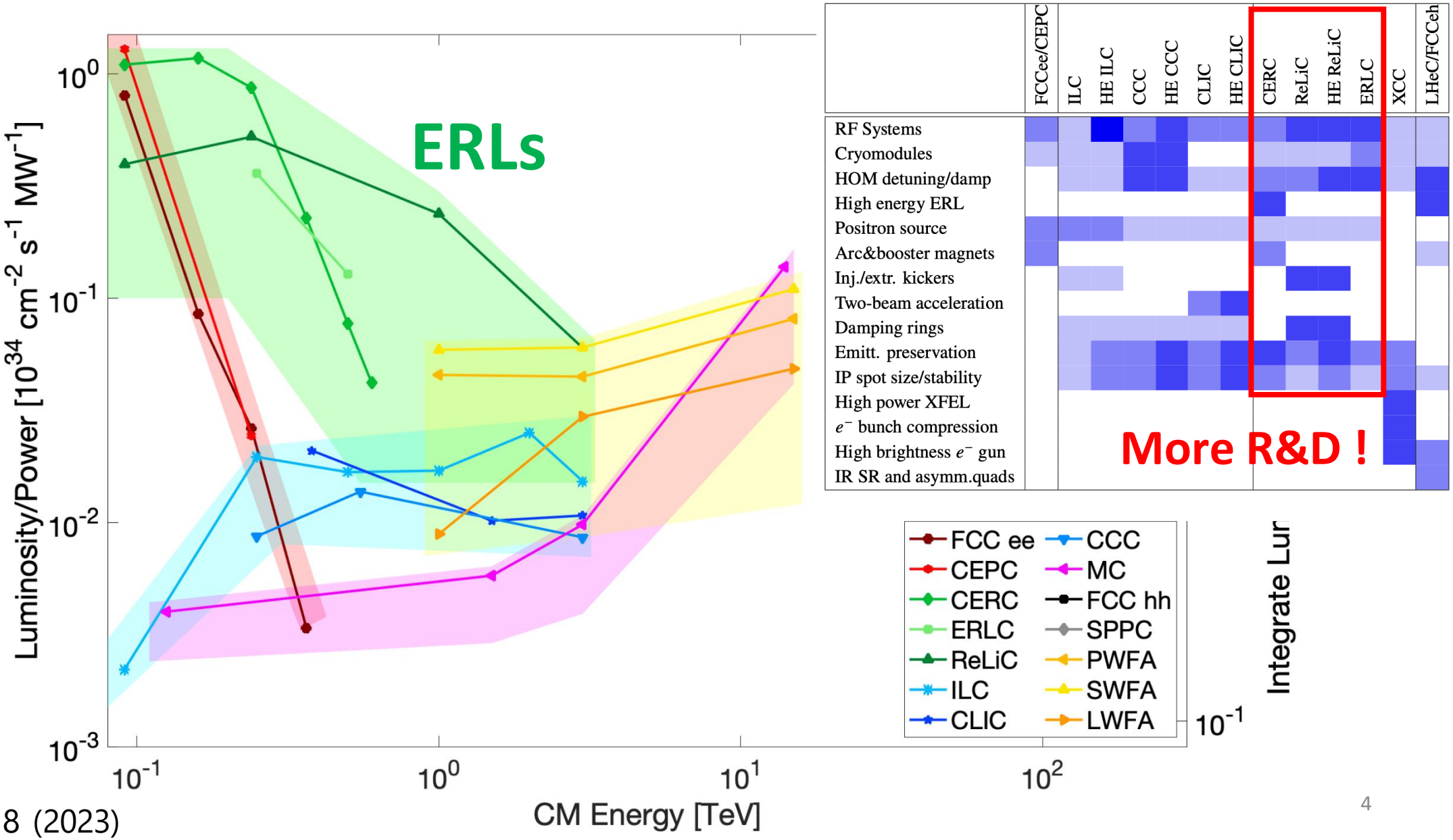
ERL Loop



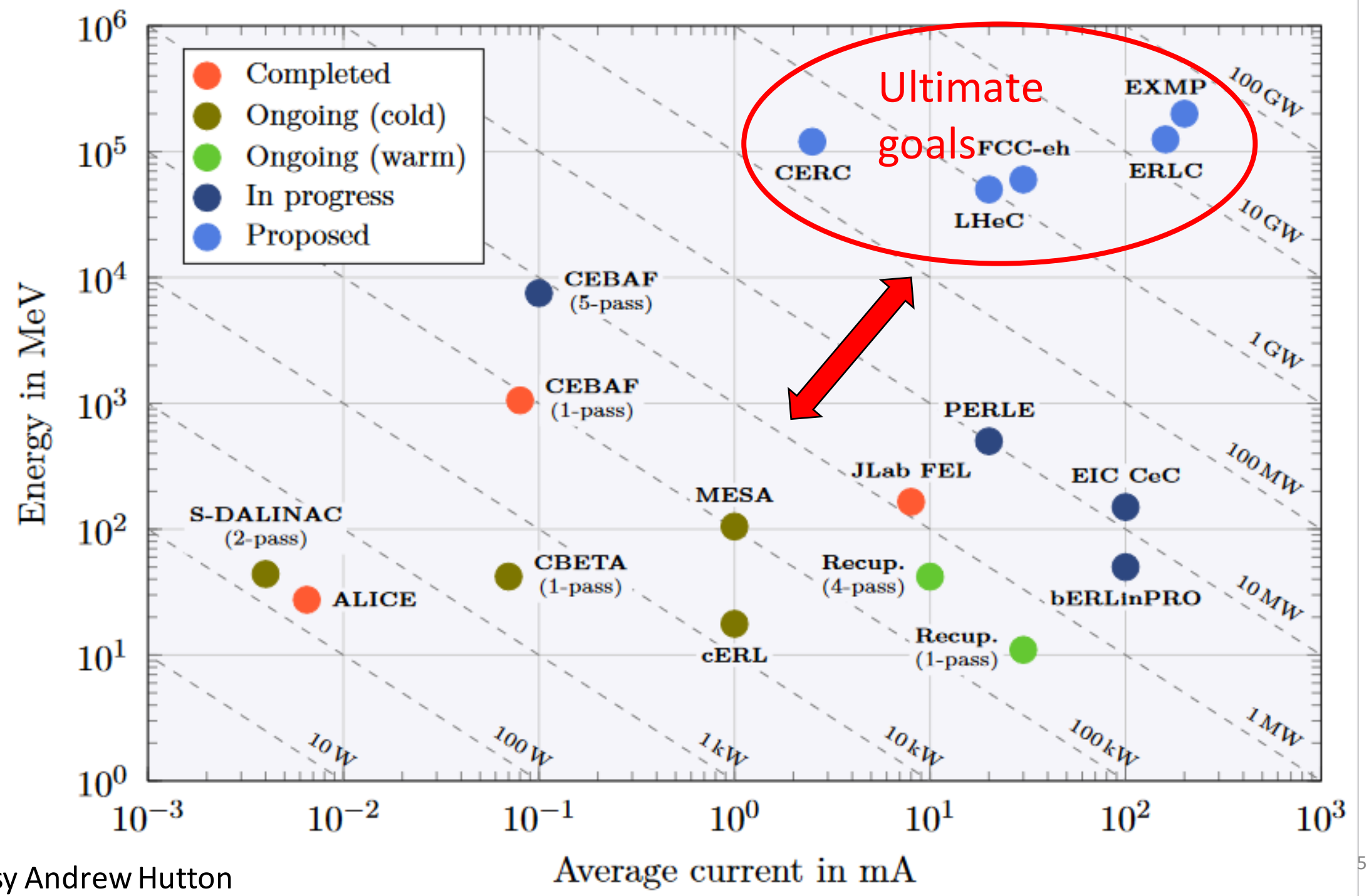
<u>Applications</u>

- Colliders
- FEL
- Nuclear physics

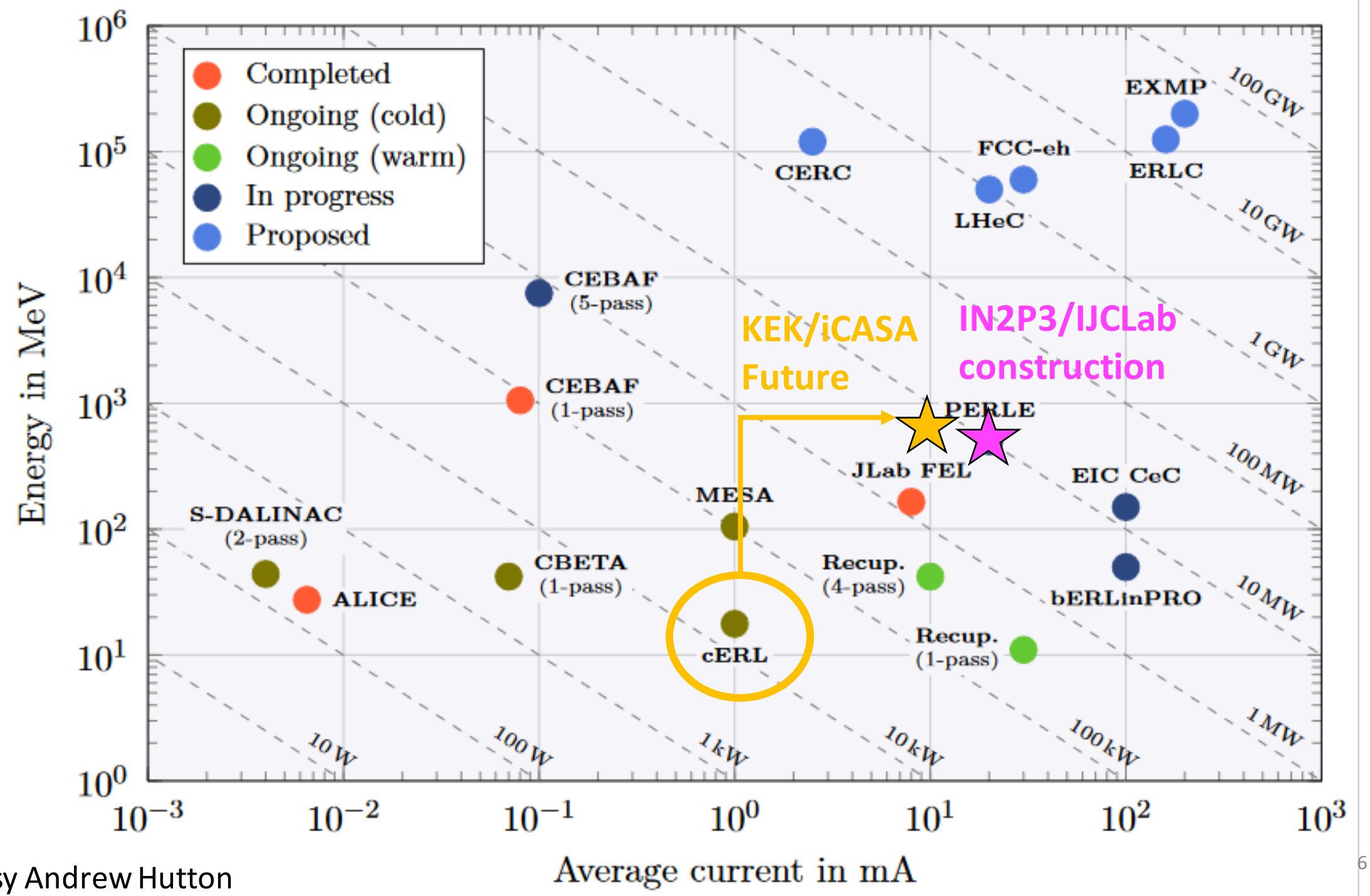
Example in colliders: case study in Snowmass



JINST 18 P05018 (2023)



Courtesy Andrew Hutton



Courtesy Andrew Hutton

Status of Compact ERL (cERL) in KEK

M. Akemoto *et al.*, Nucl. Instrum. Method A 877 p.197-219 (2018).

→ industrial applications

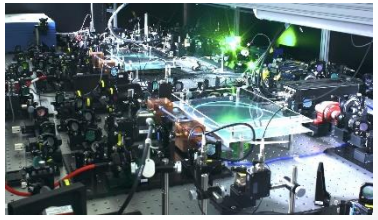
Circumference ~ 90m

Beam Dump

Main LINAC

1.3 GHz 9-cell SC cavity x 2 (8 MV/m)

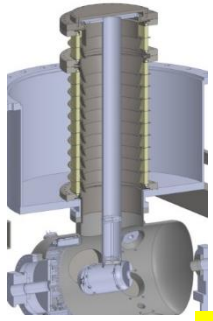
CW laser



Merger

Injector LINAC

2-cell SC cavity x 3 (7MV/m)



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Photocathode DC gun

500kV DC Gun (highest DC voltage in the world)

Operating parameters

Beam Energy	17.6 MeV
Injector Energy	3.0 – 5.0 MeV
E-Gun Energy	500 keV
Beam repetition	1.3 GHz
Average current	1 mA CW (max)
Bunch charge	60 pC/bunch (max)
Operation mode	CW or Burst

Future prospect of ERL activities in KEK/iCASA 1 mA → 10 mA

Towards Extreme-Ultraviolet (EUV)-FEL light source based on ERL

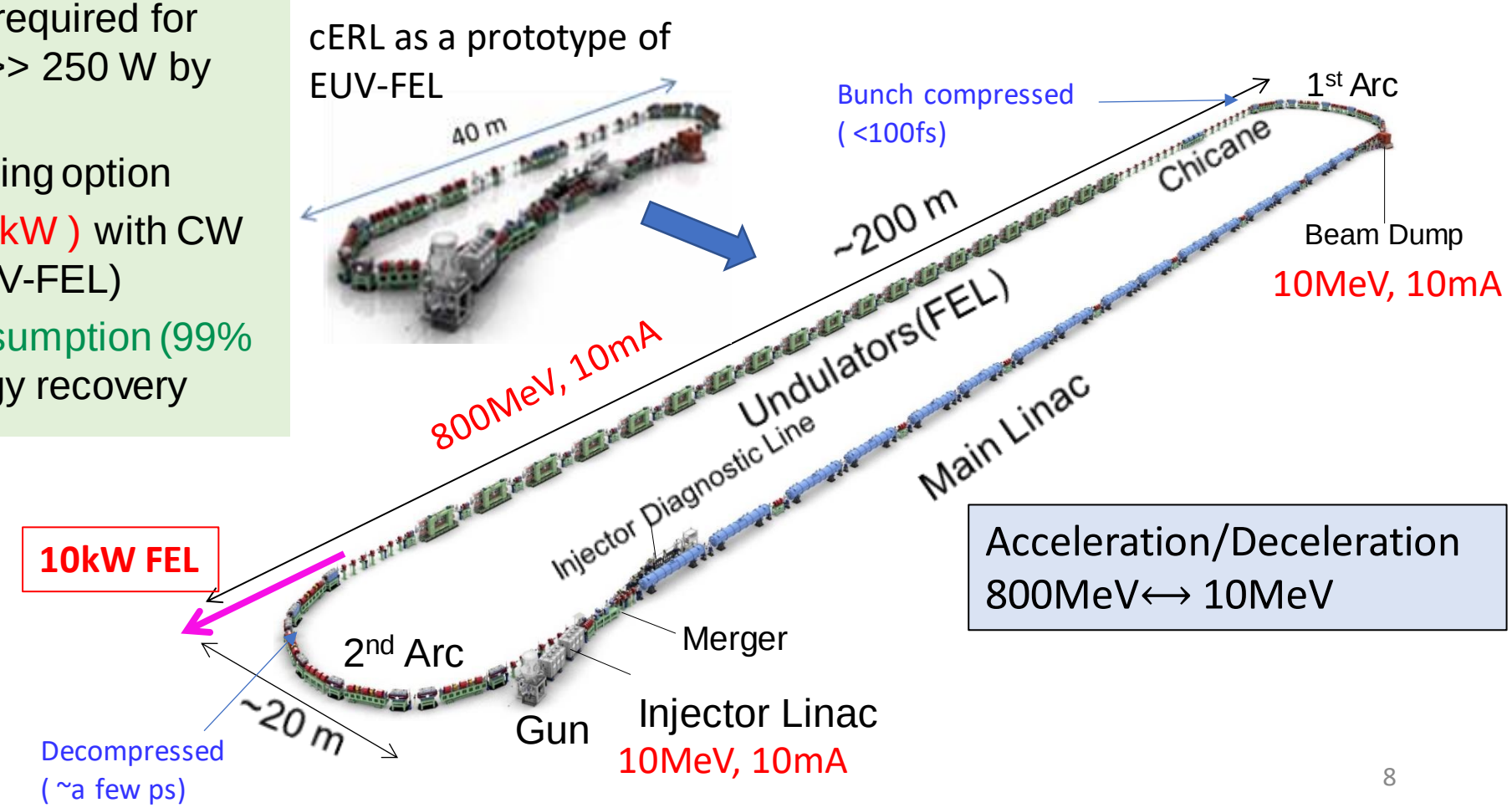
More than 10 mA Energy recovery and high brightness gun will be established in cERL beam operation with ERL-SASE-FEL.

10-kW class EUV sources are required for Next Generation Lithography (>> 250 W by Laser Produced Plasma)

→ ERL-FEL is the most promising option

- High EUV power (> 10 kW) with CW short pulses (SASE-EUV-FEL)
- Low electric power consumption (99% recycle) thanks to energy recovery

Parameters	Design
Beam energy	800 MeV
Beam current	10 mA



Acceleration/Deceleration
800MeV↔ 10MeV

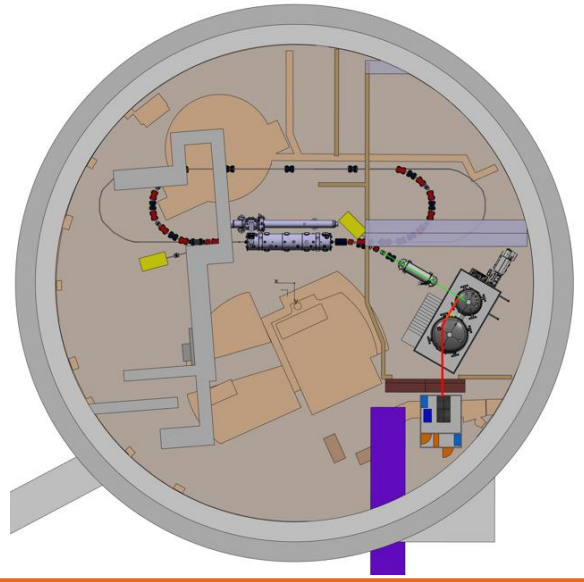
H, Kawata, et al, Journal of Micro/Nanopatterning, Materials, and Metrology 21(02) (2022)

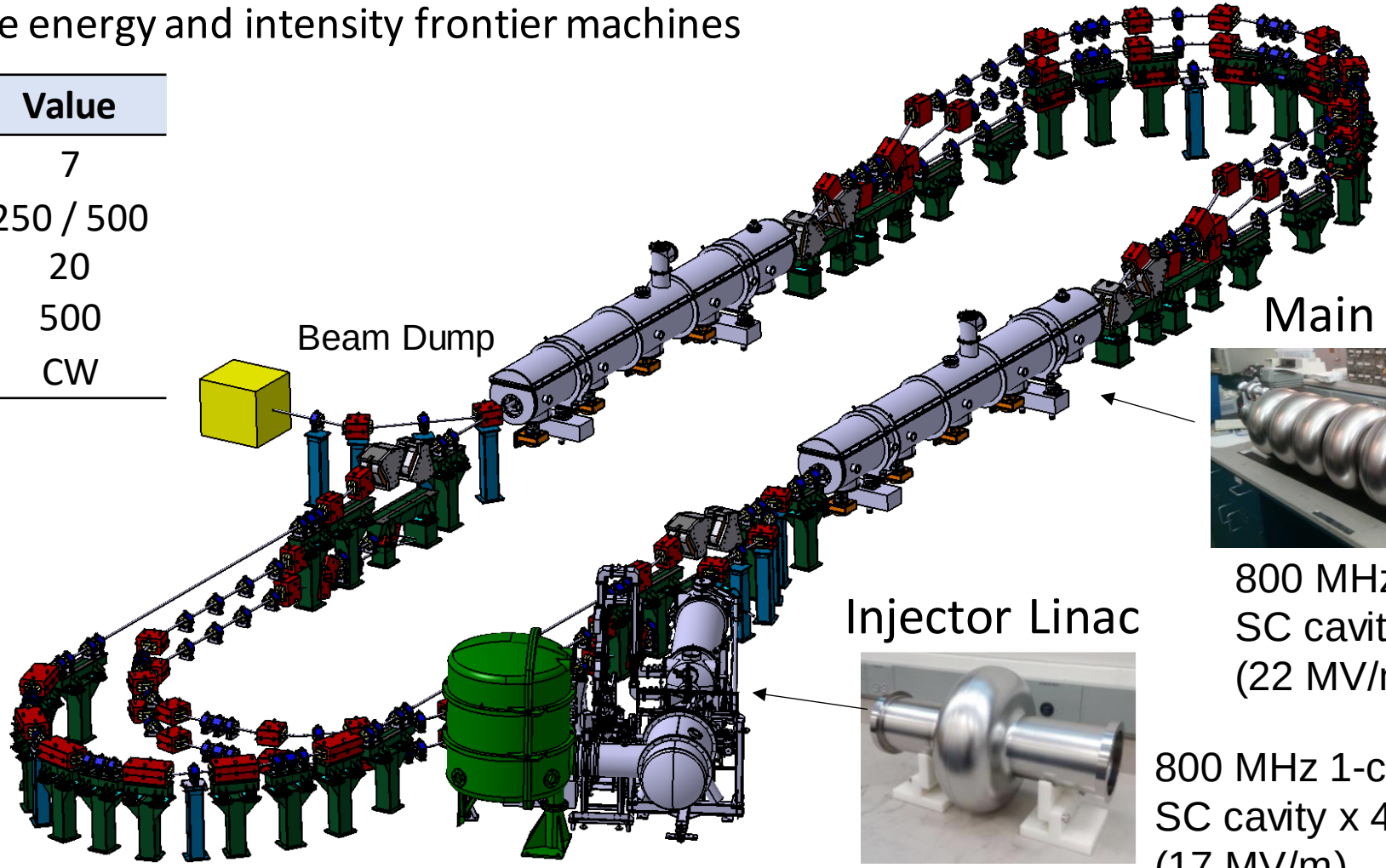
PERLE project at IN2P3/IJCLab

Ultimate goal of PERLE: first multi-turn ERL designed to operate at 10 MW (20 mA, 87→250→500 MeV)

→ A hub to explore a broad range of accelerator phenomena and to validate technical choices improving accelerators for future energy and intensity frontier machines

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	250 / 500
Average beam current	mA	20
Bunch charge	pC	500
Duty factor		CW





800 MHz 5-cell SC cavity x 4 (22 MV/m)

800 MHz 1-cell SC cavity x 4 (17 MV/m)

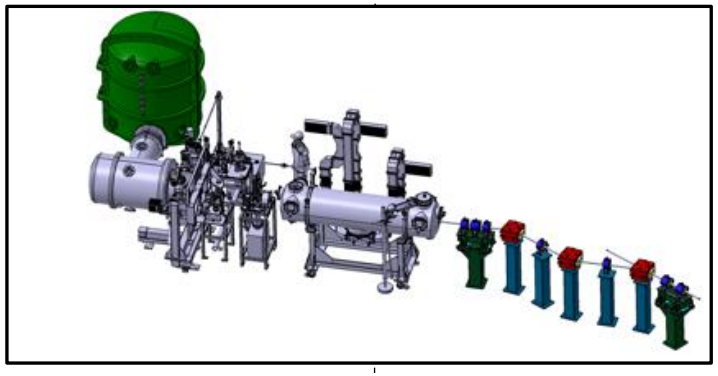
PERLE Timeline: phasing strategy

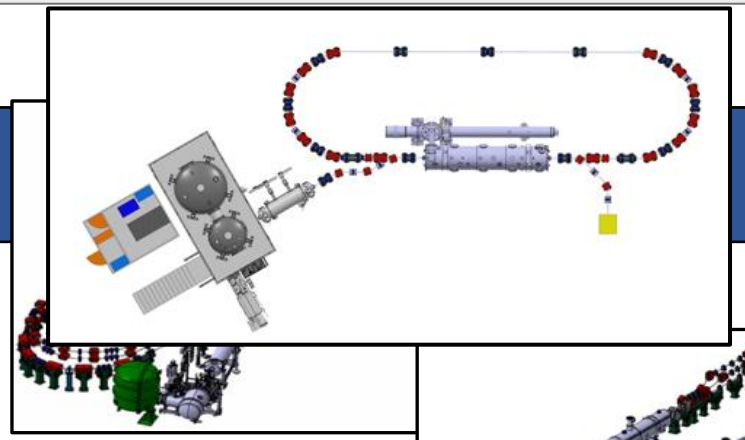
Prepare to Build phase (P2B): TDR and prototyping

Possible Single turn ERL phase under evaluation → Phase 1 to be extended to 2028

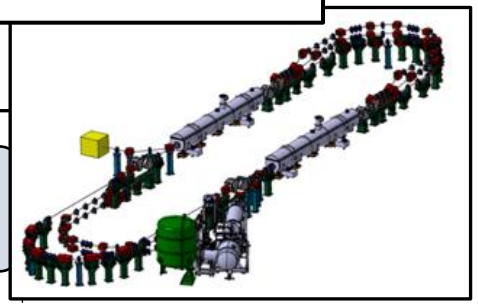
Installation phases

Phase 1: Injection line Installation





Phase 2: PERLE 250 MeV version

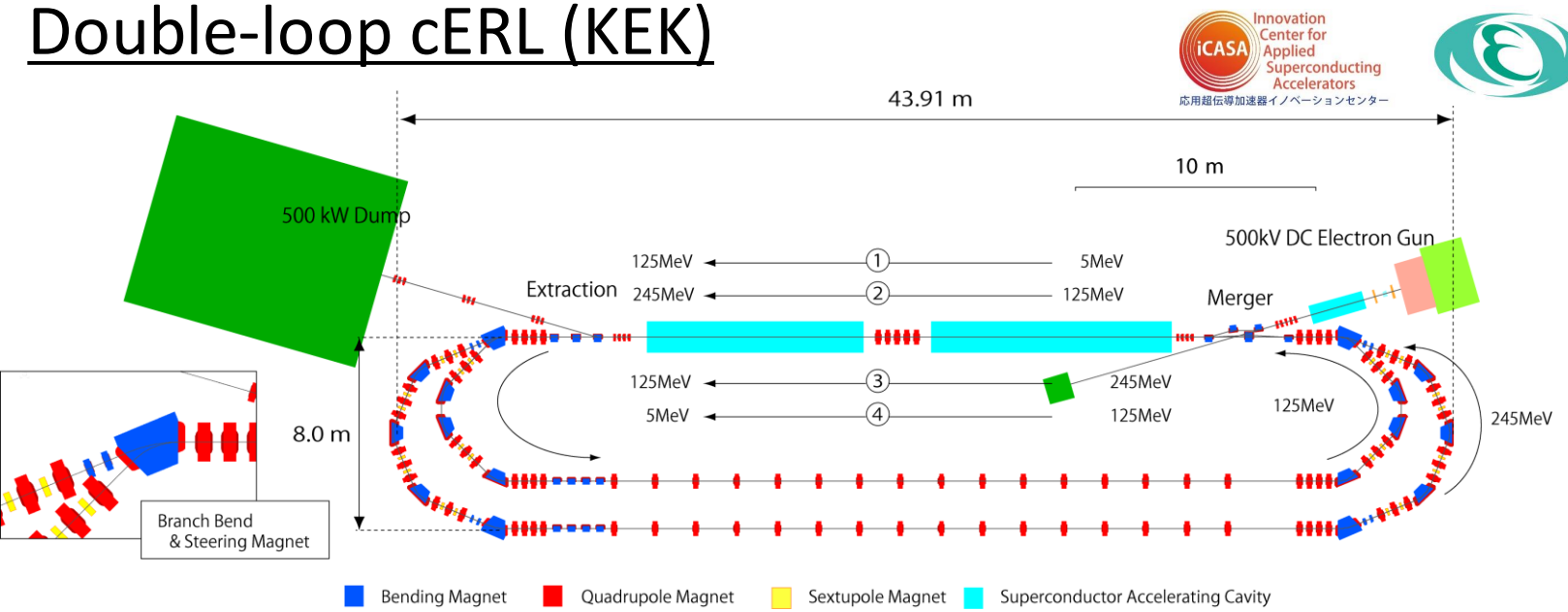


Phase 3: PERLE 500 MeV version

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031

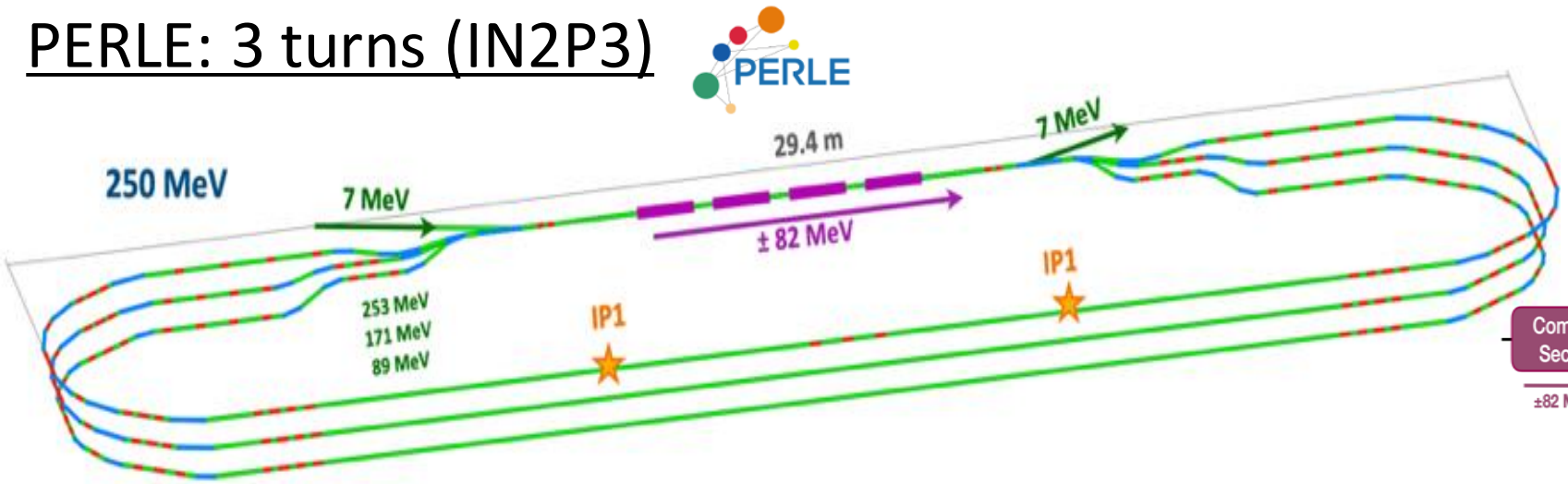
Common interest 1: multi-turn beam dynamics

Double-loop cERL (KEK)

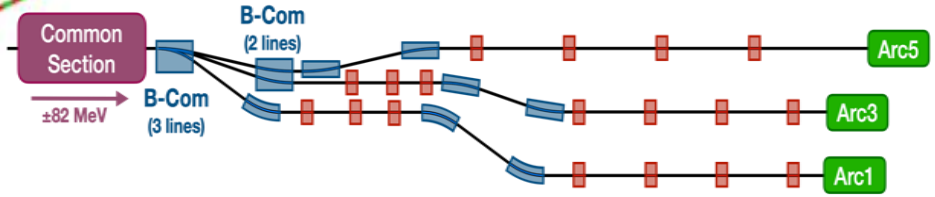


parameters	Unit	PERLE	cERL
Injection energy	MeV	7	5-10
beam energy	MeV	250	245
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6	< 1
Bunch charge	pC	500	77
Bunch length	ps	10	1-3

PERLE: 3 turns (IN2P3)

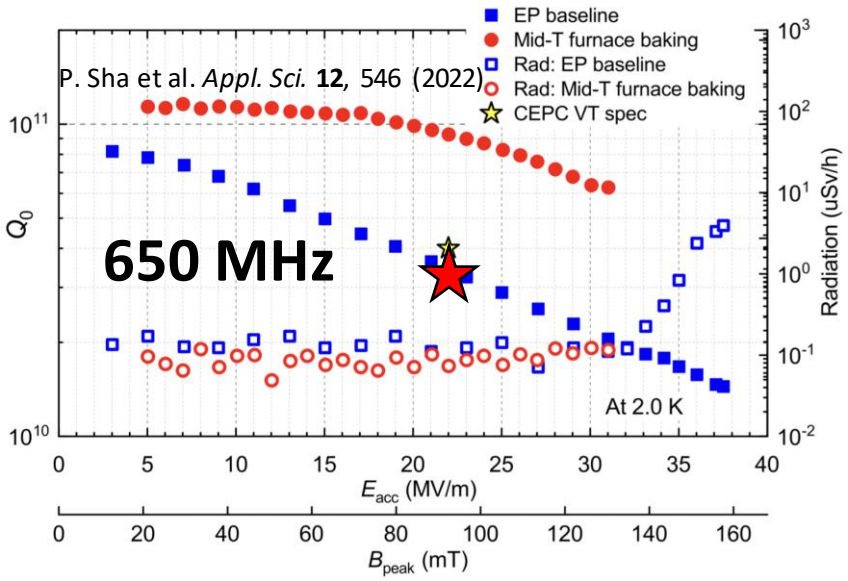


Clear technical synergy and complementarity for R&D

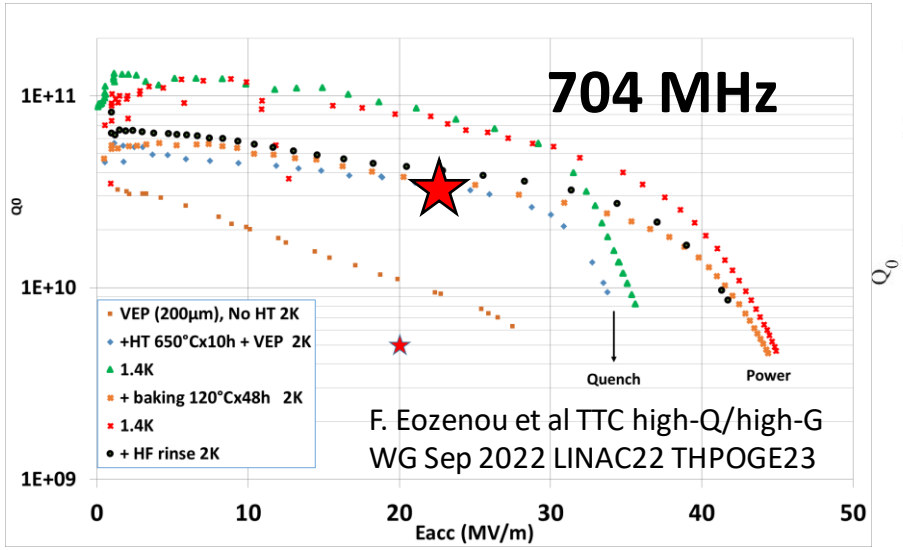


Common interest 2: high-Q/ high-G cavities

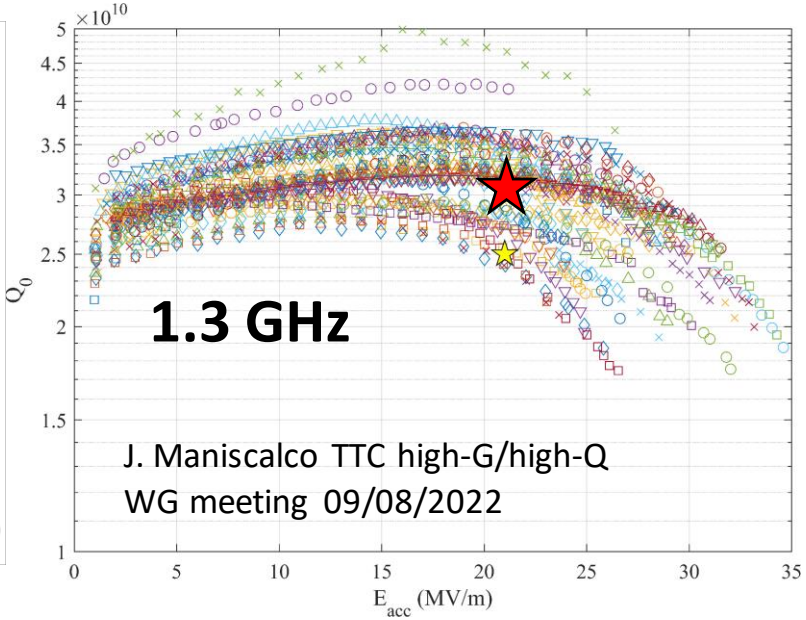
300C baking @ IHEP

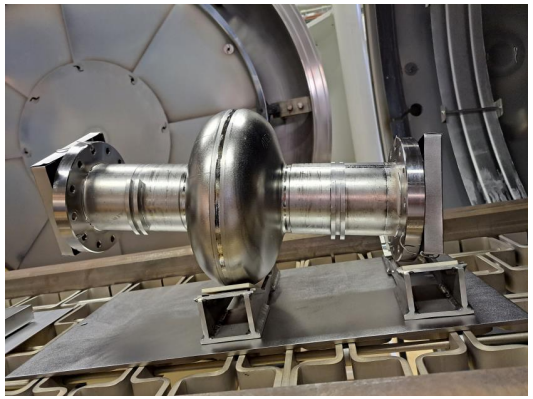


120C baking @ CEA-Saclay



2N0 doping at 800C @ LCLSII



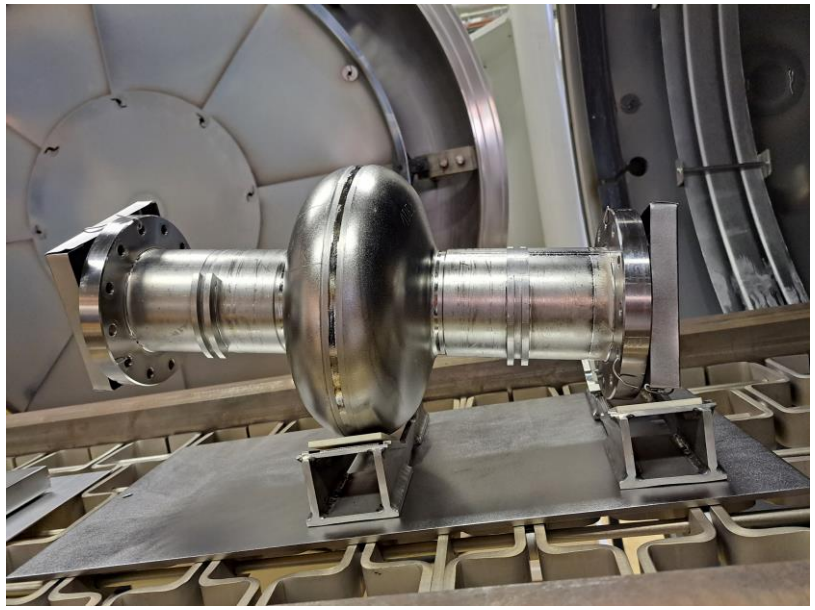


- 300C baking seems like the best option for PERLE
- 120C or 2-step baking for higher gradient
- General interest in SRF collaboration between KEK and IJCLab

→ Compare results in KEK, cold test, etc

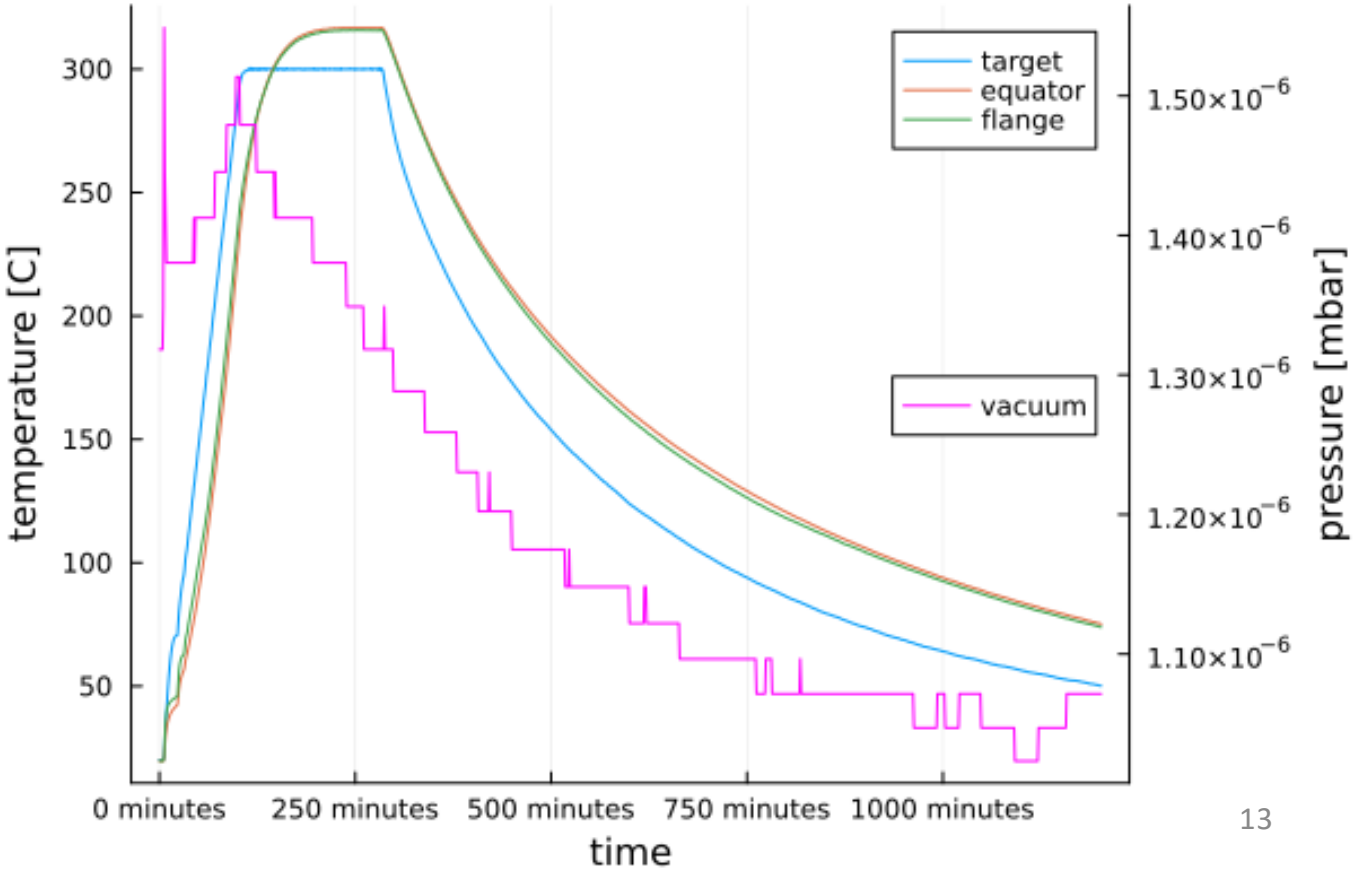
New

300C baking in IN2P3/IJCLab (April 2024)



- Vacuum furnace originally used for 600C annealing of ESS spoke cavities
- New experiments with DESY 1.3 GHz cavities

→ Compare results in KEK, cold test, etc



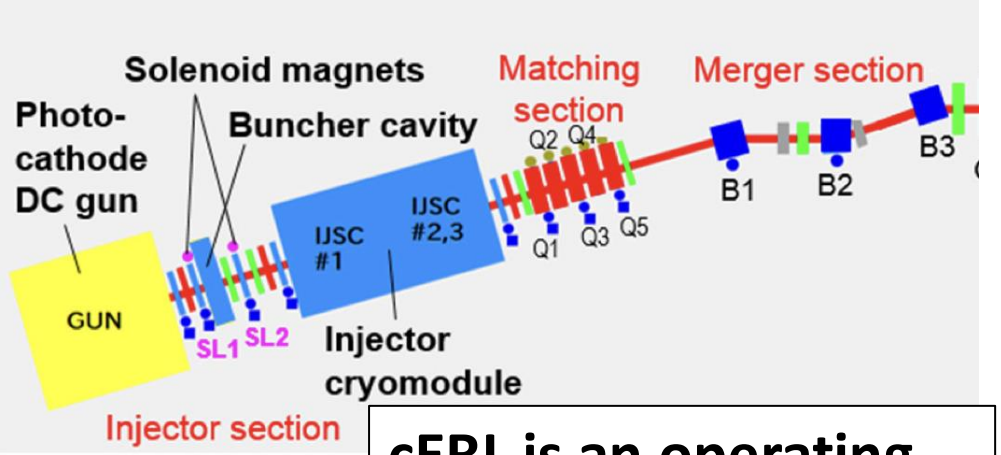
Plan of 2024: from IN2P3/IJCLab to KEK/iCASA

- Extended stay in KEK to join cERL operation after the workshop
- Co-funding

EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

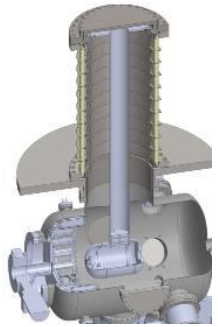
Plan of 2024: from KEK/iCASA to IN2P3/IJCLab

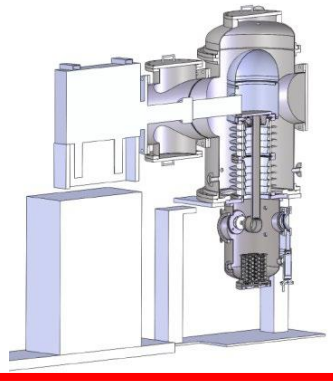
cERL Injector in ***operation***



cERL is an operating machine in KEK

Photocathode DC guns





- Practical experiences
- Lessons learned

PERLE injector under construction

HV tanks with HV columns & power supplies

Photocathode Production Facility

Conclusions

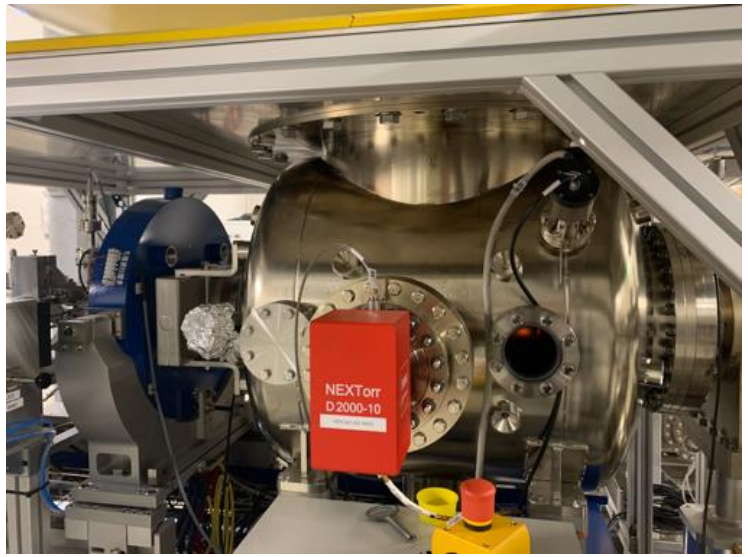
- Energy Recovery Linac is one of the possible options for future accelerator
  - Efficiency → improved sustainability
  - Still a lot of R&D subjects are lying in front of us
- KEK/iCASA and IN2P3/IJCLab are planning to develop next generation ERL
- Very strong technical synergy
  - KEK has developed and operated cERL as well as future projects (higher energy)
  - IJCLab is building PERLE
- Collaborations in beam dynamics and superconducting cavities
  - Multi-turn beam dynamics
  - High-Q/high-G bulk niobium cavities
- Sharing practical experiences
  - KEK → practical tips for photocathode DC gun, under construction at IJCLab
- ERL workshop in KEK in Sep 2024
  - Extended stay to join cERL operation

backup

PERLE e- Source

Collaboration IJCLab-LPSC & RI GmbH

Within a Collaboration Agreement for photoinjector R&D between IJCLab (IN2P3) and Research Instruments GmbH (RI), Hardware of lighthouse project (terminated) transferred to IJCLab for PERLE. The gun was commissioned and tested at high rep rate, at a limited bunch charge. It includes:



A DC Gun, Cornell design (400 pC, 50 MHz demonstrated), fully equipped (all pumps) in load-lock version

HV power supply suited for high bunch charge (designed for 40 mA, 450 kV)

A Photocathode Preparation Facility (PPF)