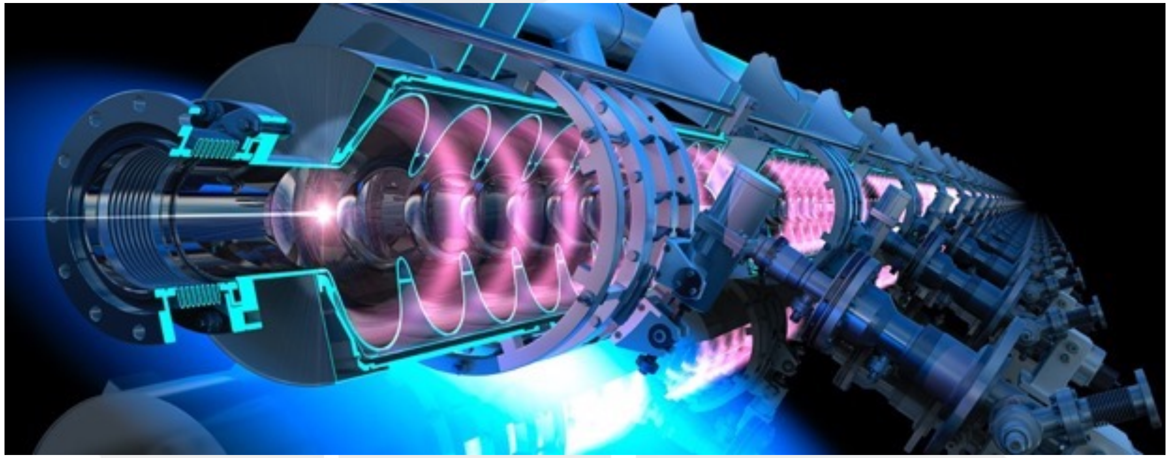
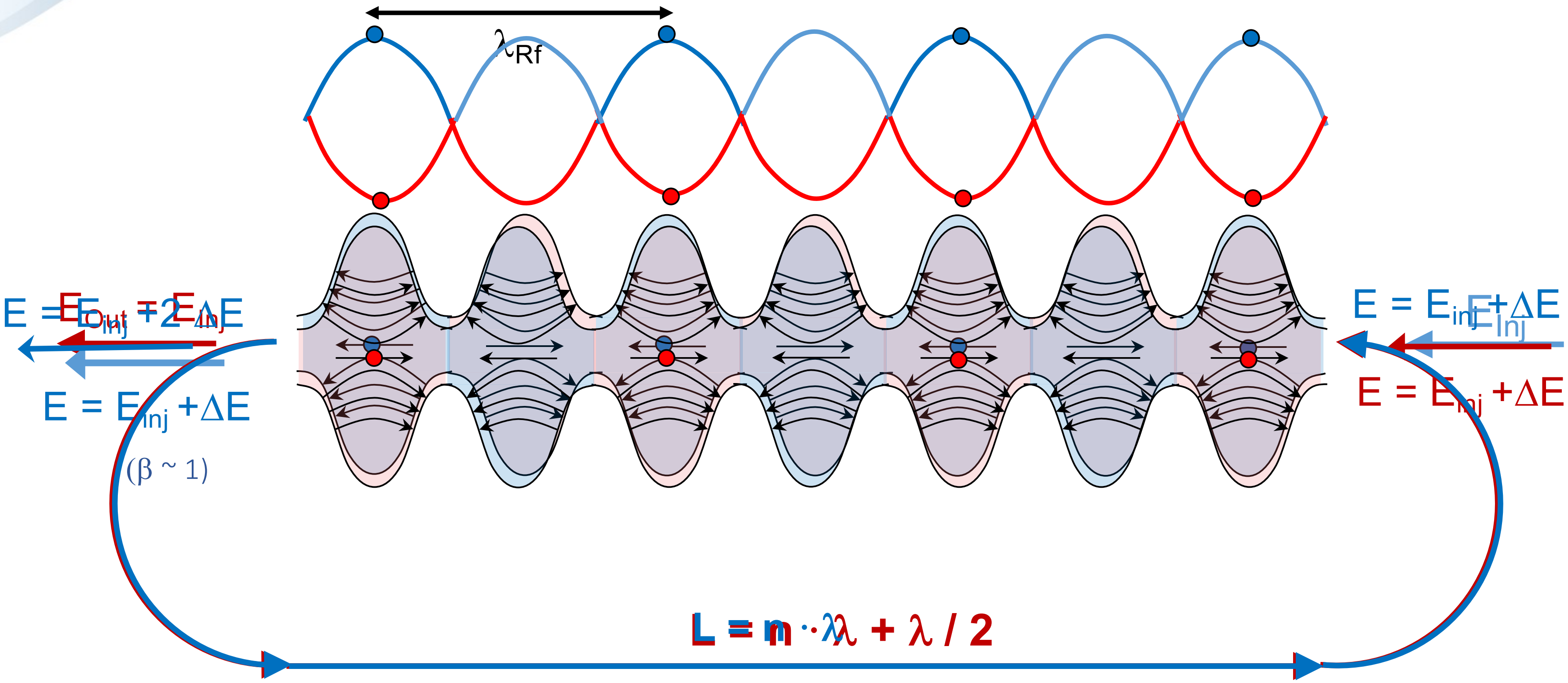
PERLE: A powerful Energy Recovery Linac @ Orsay



Walid Kaabi

09 Septembre 2021

Introduction- Energy Recovery in RF Fields

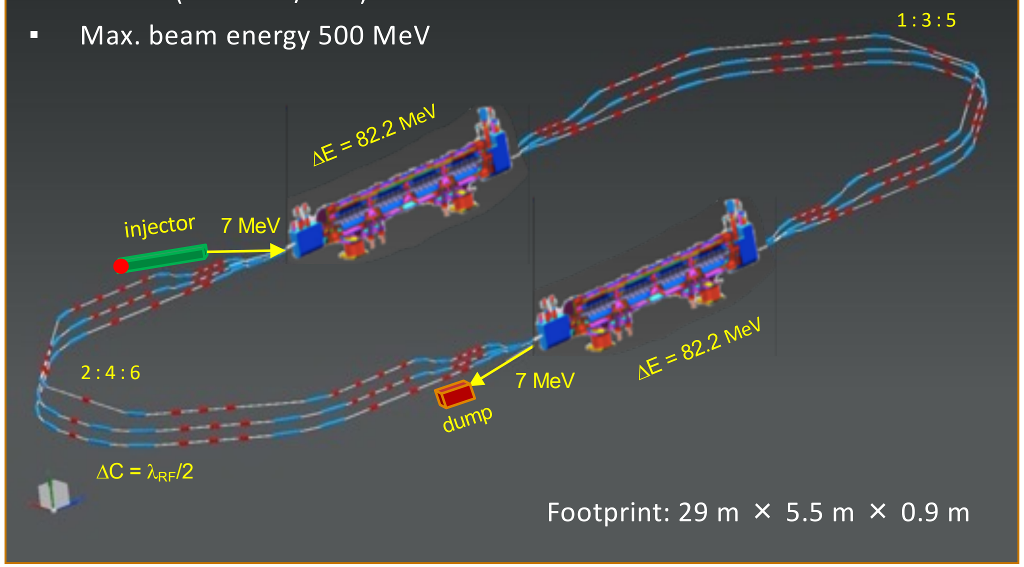


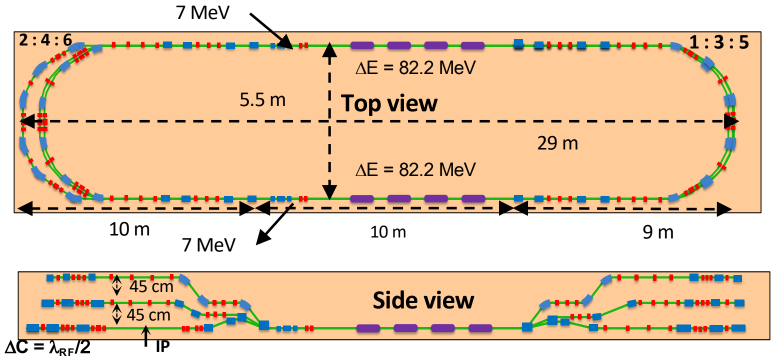
- Energy supply → acceleration
- Deceleration = “loss free” energy storage (in the beam) → Energy recovery

PERLE Configuration and Beam Parameters

PERLE: A proposed 3 turns ERL, based on SRF technology, to serve as testbed for studying, testing and validating a broad range of accelerator phenomena & technical choices for future ERL projects.

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (164 MeV/turn)
- Max. beam energy 500 MeV

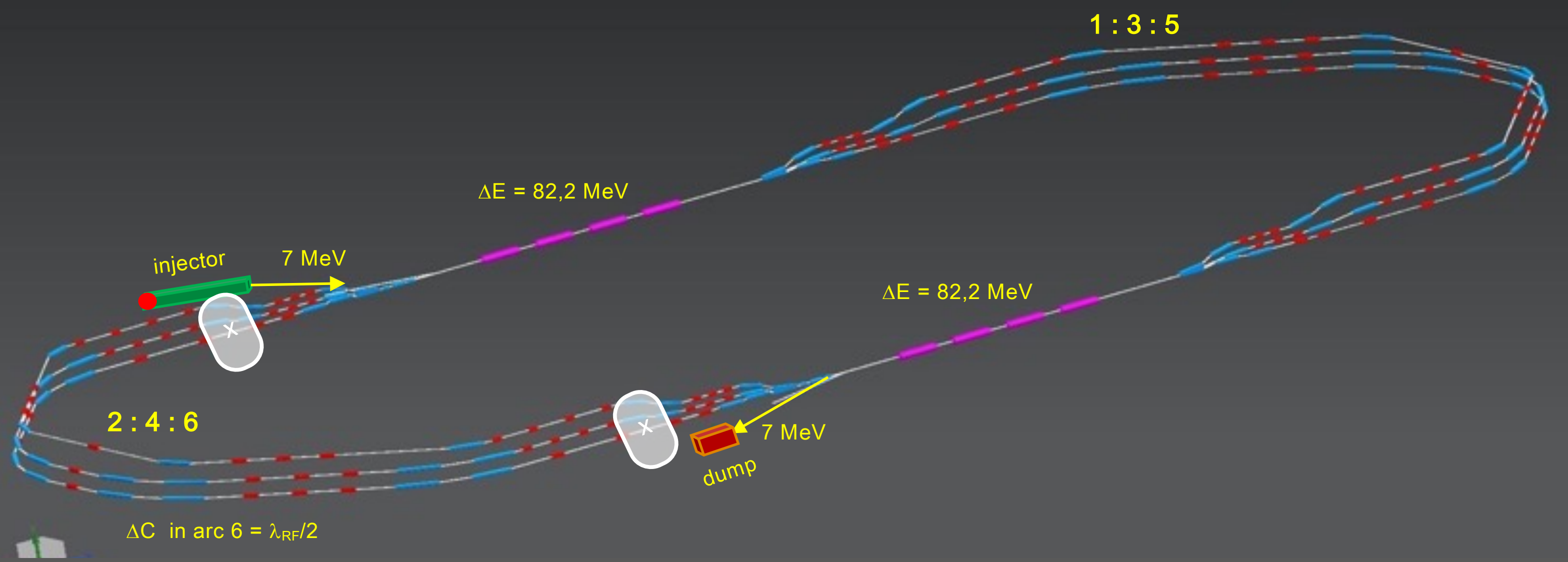




Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE Configuration

Three passes 'up' to reach the maximum energy

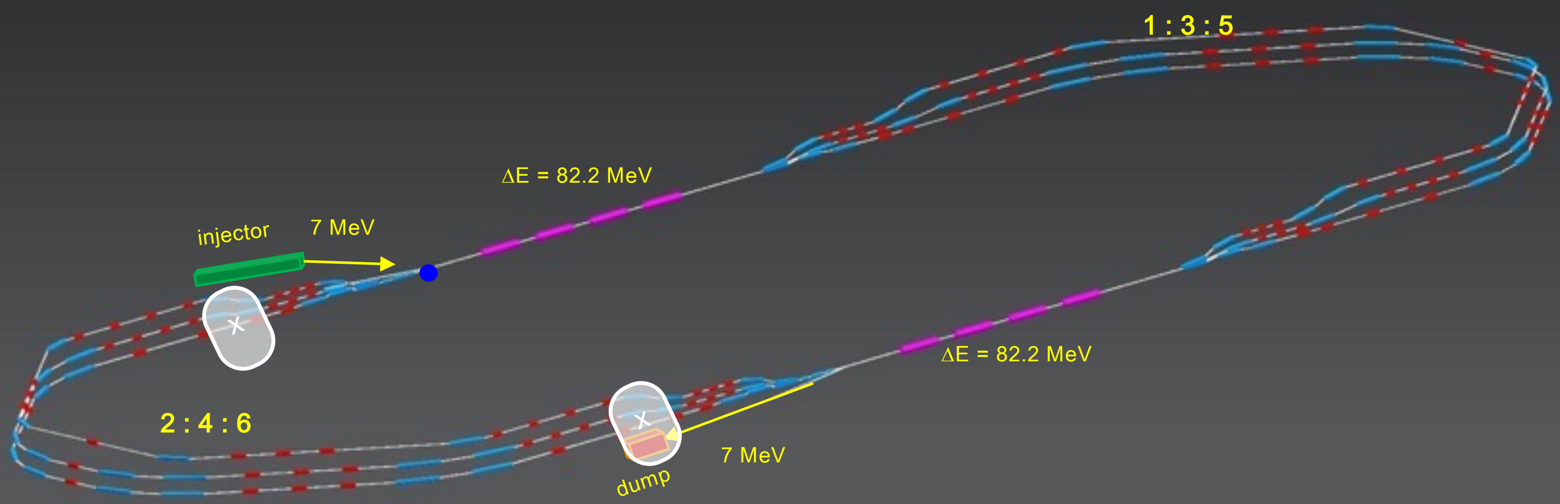


Electron beam at maximum energy could be used for:

- Elastic electron-proton scattering with polarised beam (Particle physics)
- Exploration of proton densities in exotic nuclei by electron scattering (Nuclear physics)
- Gamma ray production between 0.2 and 5 MeV (wide applications in Photo-nuclear physics),

PERLE Configuration

Three passes 'down' for energy recovery

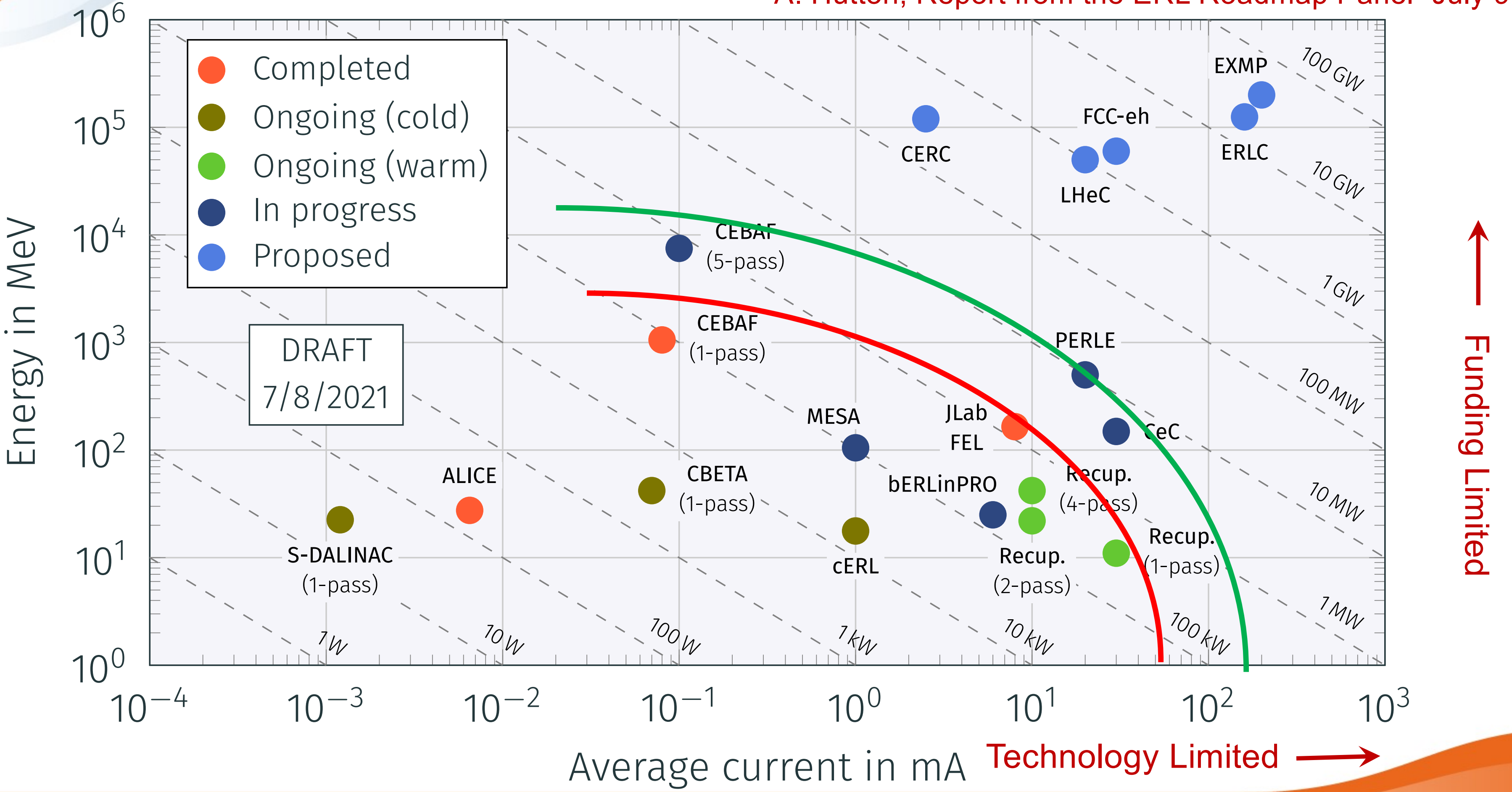


Several benefits from this manipulation:

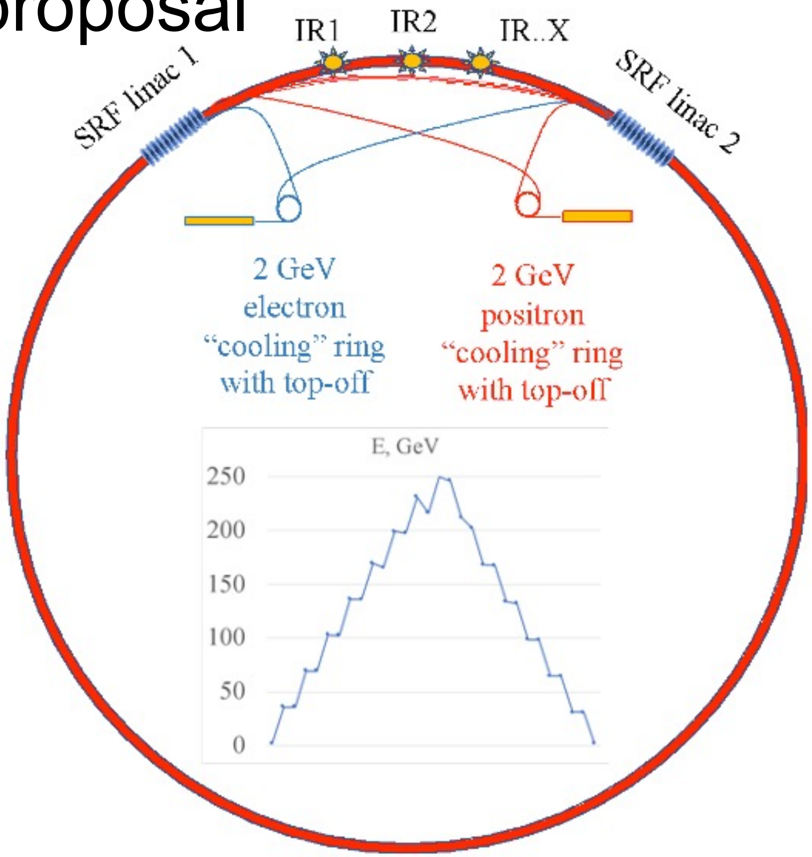
- The required RF power (and its capital cost and required electricity) is significantly reduced to that required to establish the cavity field and make up minor losses.
- The beam is constantly renewed: never reach equilibrium state --> provides flexibility to adapt beam properties for specific applications.
- The beam power that must be dissipated in the dump is reduced by a large factor.

PERLE in the Global ERL Landscape

A. Hutton, Report from the ERL Roadmap Panel- July 9, 2021



Circular Energy Recovery Collider Concept: CERC proposal



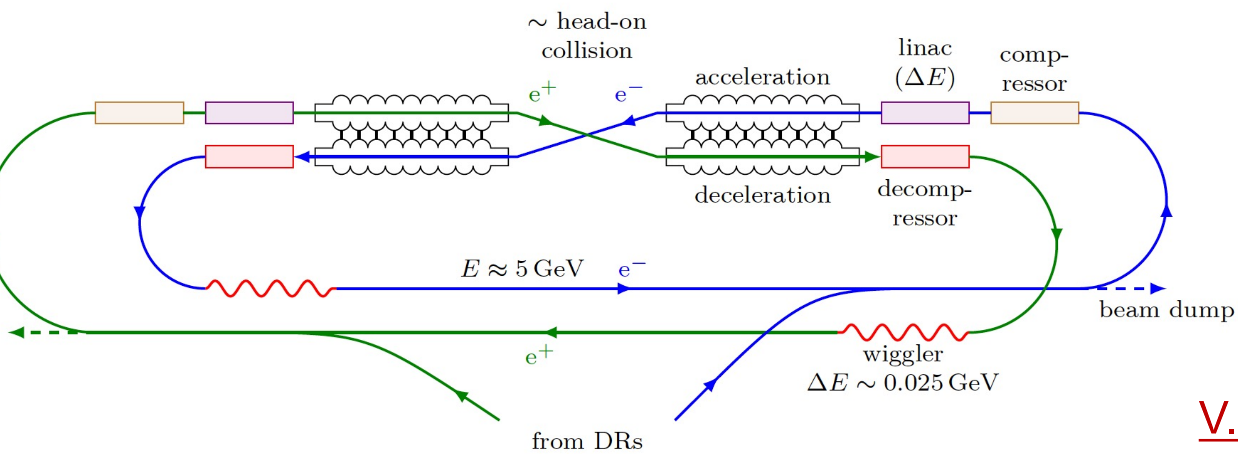
- Two 11 to 90 GeV SRF linacs in 4 pass configuration
- 1/3rd of power consumption as compared to circular collider
- CM Energy reach of 600 GeV in 100 km circumference tunnel
- Damping rings for emittance reduction and recycling of beams

https://arxiv.org/abs/1909.04437
Physics Letters B, 804 (2020) 135394

- Maximum Power of 300 MW per beam @ 120 GeV and 2.47 mA

V. Litvinenko BNL and Stony Brook University; T. Roser BNL; (

Energy Recovery Linear Collider Concept: ERLC proposal



V. Telnov proposal

- ERLC consists of two parallel superconducting linacs connected to each other with RF-couplers, so that the fields are equal at any time
  - One line is for acceleration, the other for deceleration.
- Damping is provided by wigglers (no damping rings) at the “return” energy about E~5 GeV
- The energy loss per turn δE/E~1/100
- Damping is needed to reduce the energy spread arising from collision of beams

Main challenges imposed by PERLE configuration

- **High current electron source operation: DC gun option chosen.**
- **Beam quality preservation with:**
  - Space charge (both transverse and longitudinal)
  - Coherent Synchrotron Radiation (CSR), microbunching and other collective effects
- **Power flow management and multiple beams undergoing common transport:**
  - Halo formation and control (development of new algorithme of control)
  - BBU and HOMs handling (new SRF development)
  - RF heating and mitigation of resistive wall
  - Development of specific diagnostics and measurement methods

The PERLE Collaboration

PERLE international collaboration leaded by IJCLab involves today:

CNRS IN2P3 Les deux infinis — CERN — University of Liverpool — Science & Technology Facilities Council — Cornell University, Founded A.D. 1865

Jefferson Lab, Thomas Jefferson National Accelerator Facility — Budker Institute of Nuclear Physics

- A Collaboration Agreement (CA) is now signed by all the partners.
- The collaboration aims at performing a technical detailed study of the PERLE facility and at preparing the ground at its construction and operation phase.
- The effort of the collaboration is currently focused on the work toward the publication of the PERLE Technical Design Report (TDR) by fall 2022.

PERLE Collaboration Agreement

Introduction

The efficient recovery of power to re-excite cavities from the used beam was proposed first for normal conductive facilities accelerating beams at rather low power. The major advances in superconducting RF technology and the consideration of multi-turn recirculation passages have paved the way to the "green" generation of high energy, high brightness, high current beams. Thus, Energy Recovery Linacs (ERL's) are now beginning to assert their potential as game changers in the field of accelerators and their applications. Their unique combination of bright linac-like beam quality, with high average current and extremely flexible time structure, unprecedented operating efficiency and compact footprint opens the door to previously unattainable performance regimes and applications.

PERLE is a compact three-pass ERL project based on SRF technology and targeting the 10 MW beam power range, with about 20 mA electron beam current and 500 MeV electron beam energy. The Conceptual Design Report was published in 2018[1]. The PERLE facility will primarily serve as a hub for the validation and exploration of a broad range of accelerator phenomena in an unexplored operational power regime serving for the development of ERL technology for future energy and intensity frontier machines. It will also host a new generation of nuclear and particle physics experiments. The PERLE facility is intended to be hosted by the CNRS-IN2P3 laboratory IJCLab (Orsay, France).

The present Collaboration Agreement defines the framework and steps of the collaborative effort towards the realization of this project.

1- Parties of the Collaboration Agreement

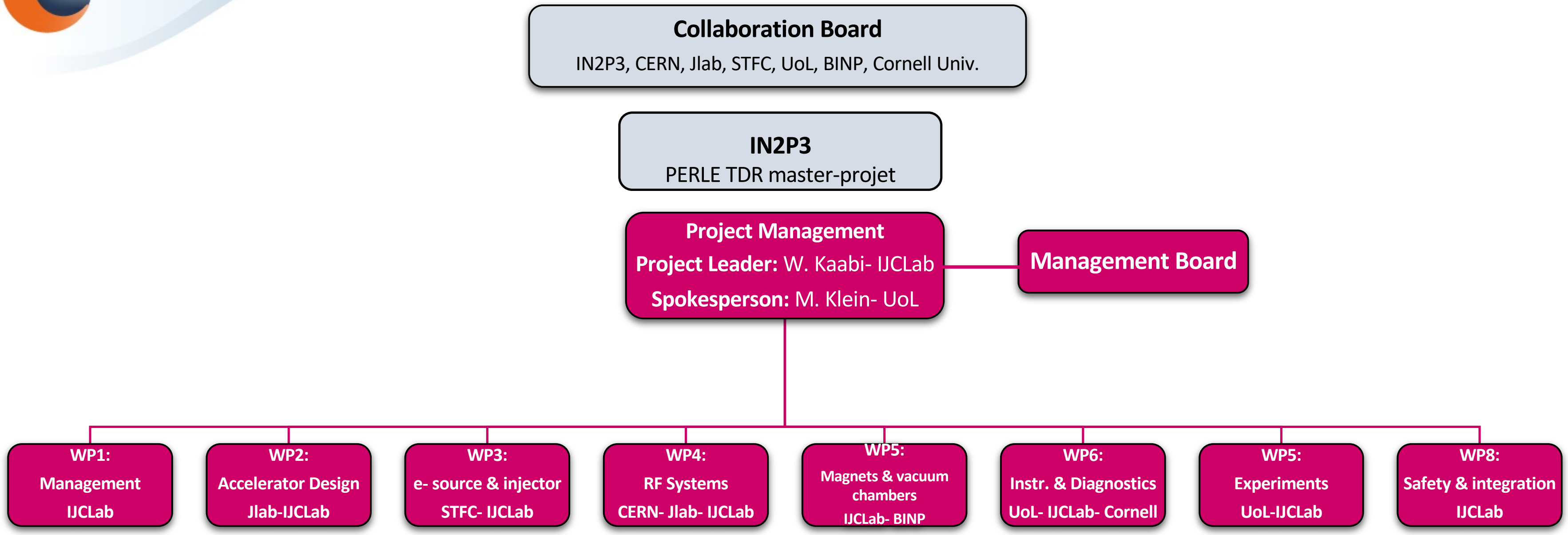
This Collaboration Agreement (CA) is signed between the member institutes (hereafter called "the Parties"). They form the PERLE collaboration to which this CA applies. The Parties are listed in Annex A.

The entry of new members into the collaboration is conditioned by a unanimous vote of Collaboration Board members (cf. Annex C).

[1] PERLE, Powerful Energy Recovery Linac for Experiments, CDR, J.Phys.G 45(2018)6, 065003, arXiv:1705.08783

PERLE Collaboration Agreement

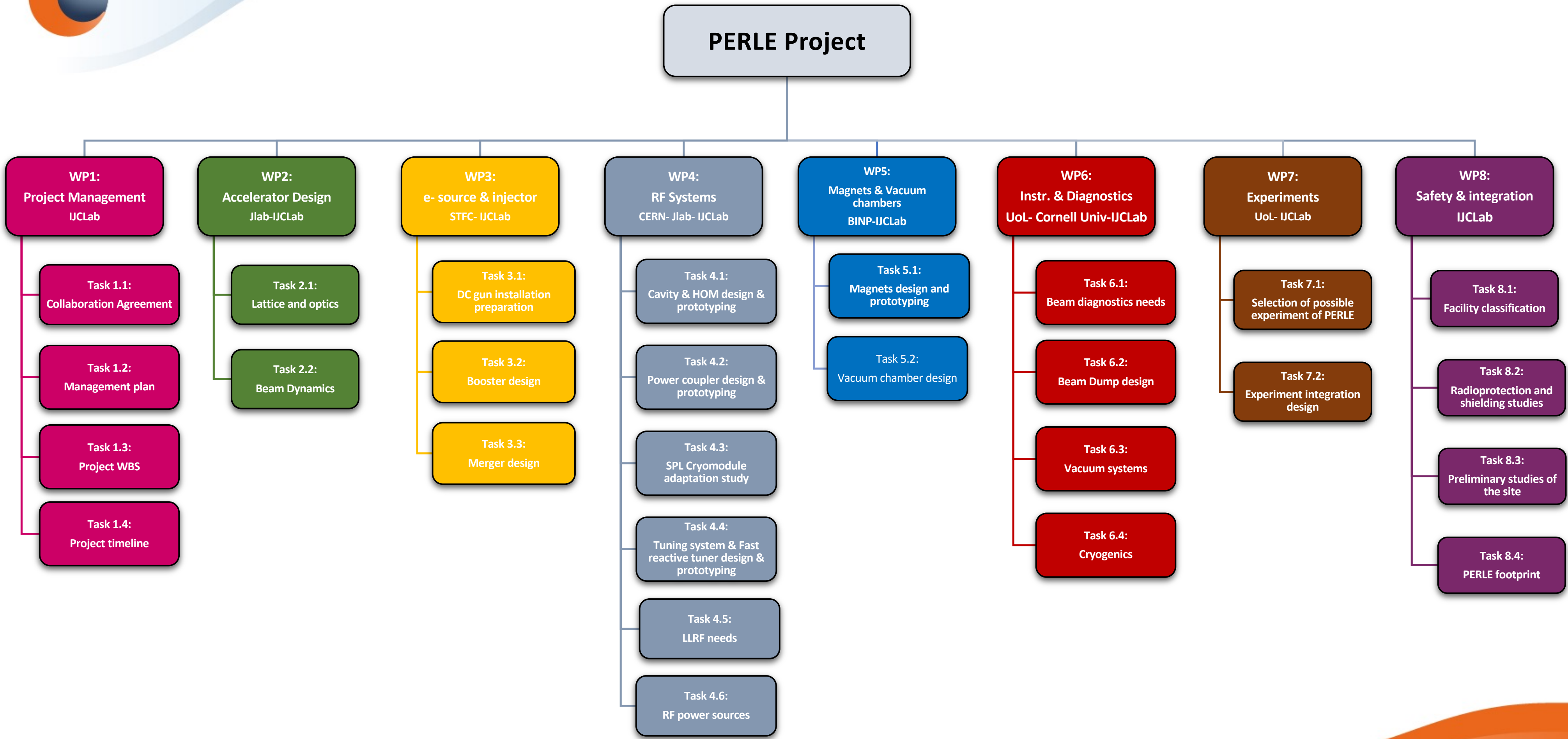
PERLE organisation



* **Collaboration Board:** consists of one representative of each Party signatory of the PERLE Collaboration Agreement, responsible for the science policy of the Collaboration. It oversees the progress made by the Project, reviews Parties' contributions estimates and ensures an efficient communication between the collaborators, providing a coherent communication channel and advice to the Project management.

** **Management Board**: Consists of the Project Leader, the Spokesperson and expert members from the collaboration partners. Its role is to assist the project leader in defining the project tasks and ensure the monitoring and execution of the tasks in their respective labs.

PERLE TDR Work Breakdown Structure (WBS)

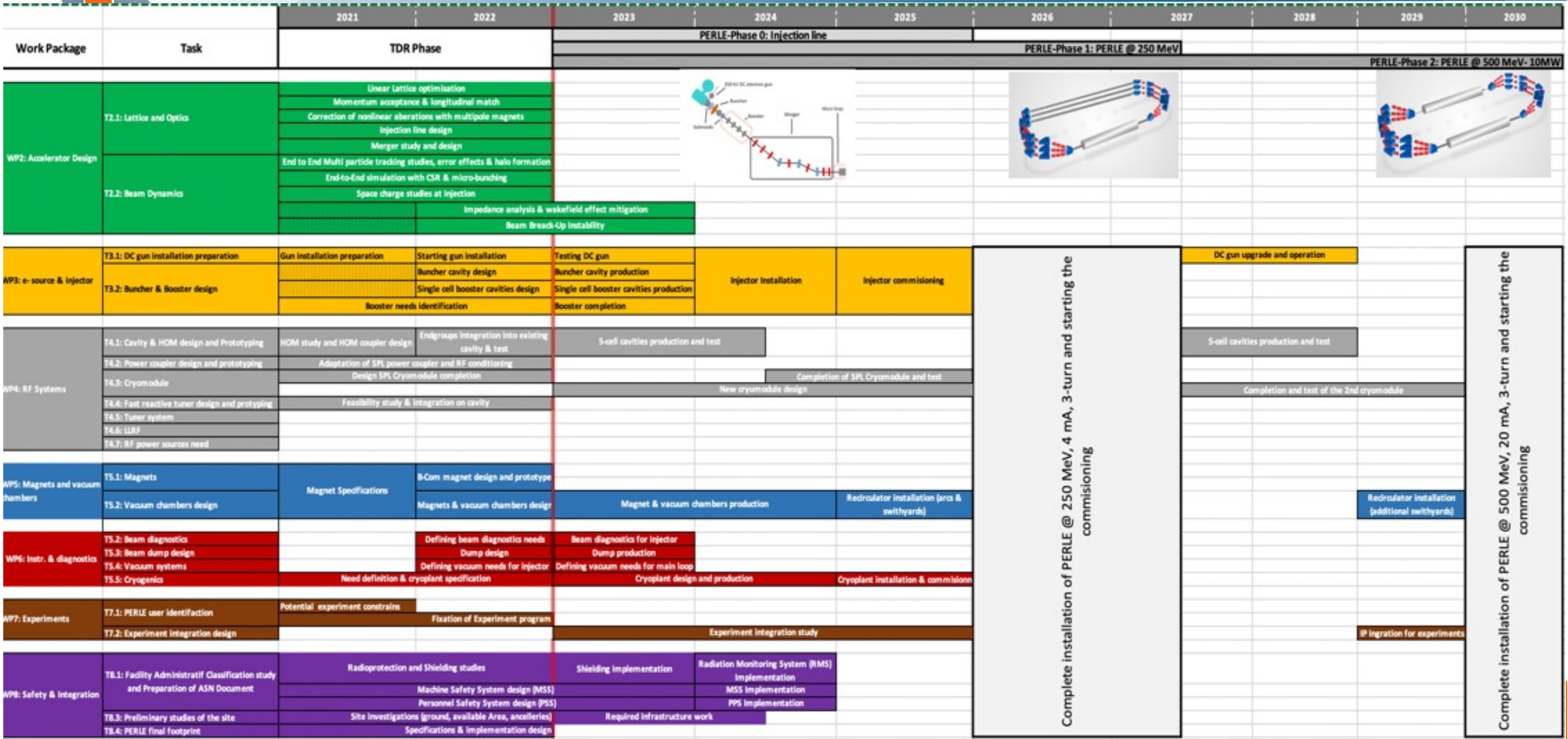


Toward PERLE Realisation

Given the challenges imposed by PERLE design and technical choices, we plan to go through two main phases toward PERLE realisation :

- A design and prototyping phase that ends with the PERLE TDR:
  - Study the main phenomena imposed by the challenging design choices (Lattice optimisation, BBU study, collective effects study, particle tracking studies, beam diagnostics development…)
  - Prototyping and test of the critical components (dressed cavity with HOM coupler(s), power coupler, B-Com dipoles…)
  - Design completion of the main sub-systems (booster, main cryomodule, DC gun upgrade…)
- Three staged construction, commissioning and exploitation phase, sketched as the following:

PERLE Timeline and Phases



Manpower Involvement and needs (TDR phase)

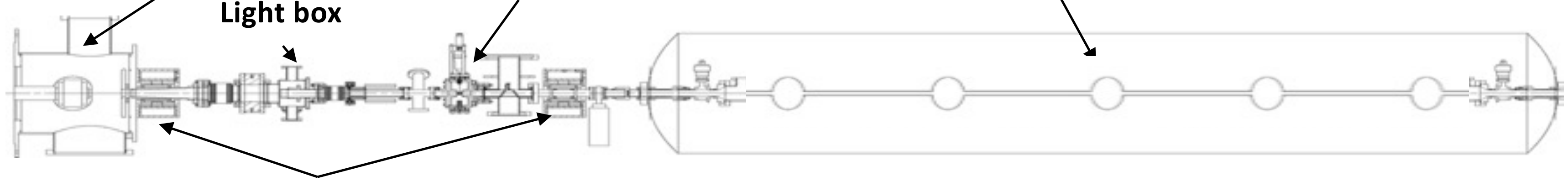
Work Package	Task	Available	Total needed	Comments	Starting period	End period
WP1: Management	T 1.1: Collaboration Agreement T1.2: Management Plan T1.3: WBS T1.4: Timeline	0.4	0.4	Support CeMAP needed for the upcoming 2 years		
WP2: Accelerator Design	T2.1: Lattice and Optics		0.6 *	* 2 years post-doc to be hired (funded by CREMLINplus: European program)	nov-21	31/10/2023
	T2.2: Beam Dynamics		1.4*			
			1**	** CR position asked for 2022 + Other IN2P3 labs support is under discussion (LPSC + Ganil)		
	T2.3: Magnet design and prototyping		0.3	Mecanical designer (FTE ratio to be discussed/confirmed with Pôle Ingénieurie)	S1 2022	
WP3: e- source & injector	T3.1: DC gun installation preparation		1	Pôle accélérateur staff + Other IN2P3 labs support under discussion (LPSC)	ASAP	
			TBD	Laser Expert (photocathode Laser)		
	T3.2: Booster design	0.5	0.5	PhD: Physical design of the booster		
			1	Mechanical designer (buncher + cavity + Cryomodule): FTE ratio to be discussed with Pôle Ingénie	S1 2022	
			1	RF designer	sept-21	
			TBD	Cryogenist (Cf. WP6)	S2 2021	
		0.5	0.5	PhD: Merger design and beam dynamics		
	T3.3: Merger design		0.3	Mechanical designer (FTE ratio to be discussed with Pôle Ingénieurie)	S1 2022	
WP4: RF Systems	T4.1: Cavity & HOM design and Prototyping T4.2: Power coupler design and prototyping T4.3: SPL Cryomodule adaptation	2.5	3.5	Available: Permanent staff + 1 PhD (2021-2024) + 1 post-doc (2021-2023) Requested: Mecanical designer (FTE ratio to be discussed/confirmed with Pôle Ingénieurie)	oct-21	
	T4.4: Fast reactive tuner design and protyping		TBD	Task fully undertaken by CERN --> Minimum local involvement needed (pôle Accélérateur)	TBD	
	T4.5: Tuner system		TBD	pôle accélérateur staff	TBD	
	T4.6: LLRF		TBD	To be discussed within the management board --> undertaken by CERN?	TBD	
	T4.7: RF power sources need		0.3	Pôle accélérateur staff	S1 2022	
WP5: Instr. & diagnostics	T5.1: Beam diagnostics needs		TBD	UoL and Cornell university will be involved in this task --> Local involvement needed (pôle Accélérateur)	sept-21	
	T5.2: Beam dump design		TBD	External expert identified for this task	S1 2022	
	T5.3: Vacuum systems		0.5	Vacuum expert from pôle accelerateur	S1 2022	
WP6: Cryogenics	Work in progress		TBD	Service Cryogénie	S2 2021	
WP7: Experiments	T7.1: PERLE user identifaction	0.2	0,2	Workshop organisation (2022)		
	T7.2: Experiment integration design					
WP8: Safety & integration	T8.1: Facility Administratif Classification (ASN)		TBD	SPR + external expertise	ASAP	
	T8.2: Radioprotection & shielding studies		TBD	Discussion ongoing with SPR service	S2 2021	
	T8.3: Preliminary studies of the site		TBD	Discussion ongoing with infrastructure	S2 2021	
	T8.4: PERLE footprint		TBD		S2 2021	
	Total	**4.1**	**> 12.5**			

PERLE Injection Line

Courtesy to B. Hounsell and B. Militsyn

It consist of:

- A DC photoemission electron gun (The ALICE DC gun to be upgraded).
- A bunching and focusing section: 401 MHz normal conducting buncher cavity placed between two solenoid.
- A superconducting booster with five 802 MHz cavities individually supplied and controlled on amplitudes and phases.
- Merger to transport the beam into the main LINAC,
- Beam diagnostics to be placed between components.



Photocathode laser choice:
Nd: YAG laser (532 nm) or Ti: Sapphire laser (400 nm).

Photocathodes choice:

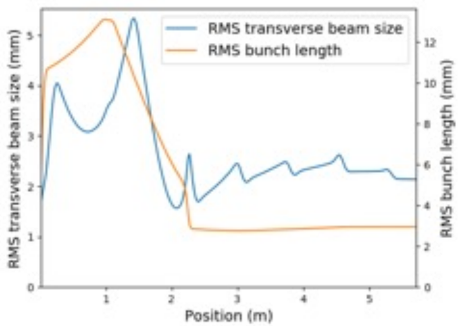
- **Sb-based photocathodes (unpolarized electrons) operated at 350 kV**
- **GaAs photocathodes (polarized electrons) operated at 220 kV**

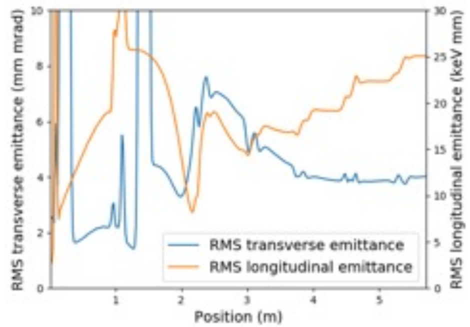
PERLE Injection Line

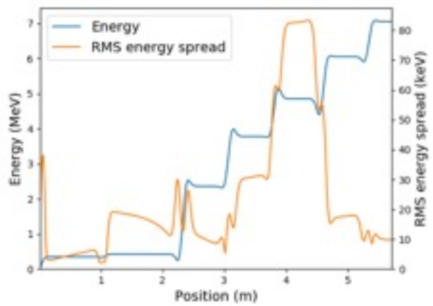
Achieved bunch parameters	
Transverse emittance/ mm mrad	4.0
Longitudinal emittance/ keV mm	25.1
Bunch length/ mm	3.0
Energy/ MeV	7.0

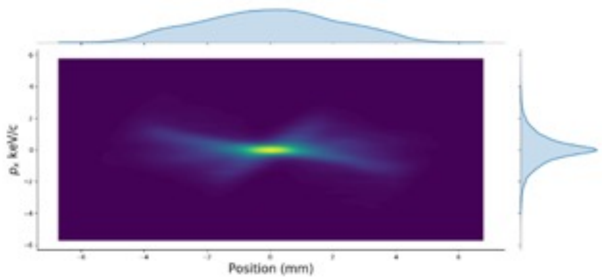
Electron source to booster exit optimisation:

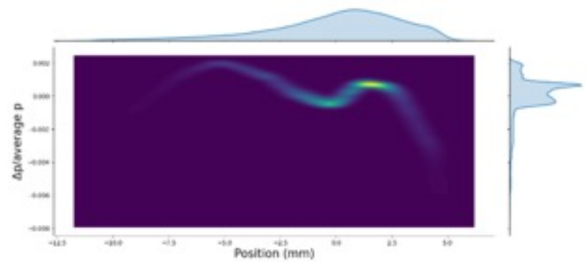
- The ALICE electron gun electrode geometry has been re-optimised for PERLE's new requirements.
- An optimisation with a 5 cavity booster linac, from the cathode to the booster exit, was done and meets the specification.
- If booster will be switched to a 4 cavity design, The tools for performing the re-optimisation are in place.



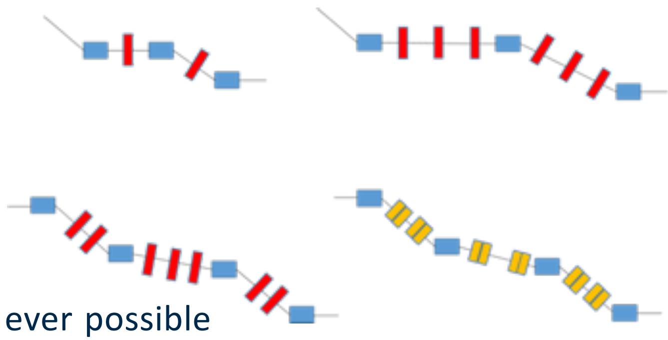


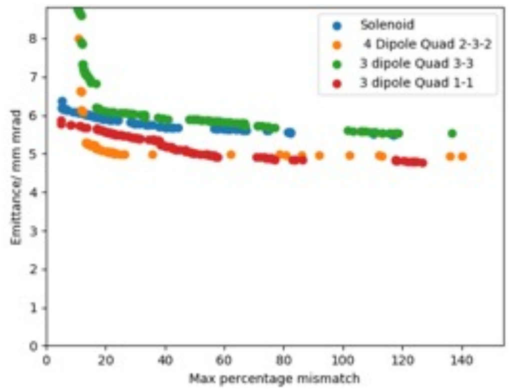




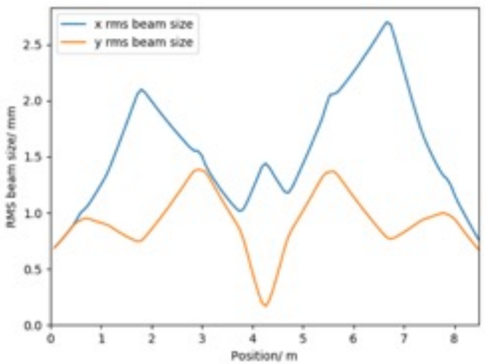


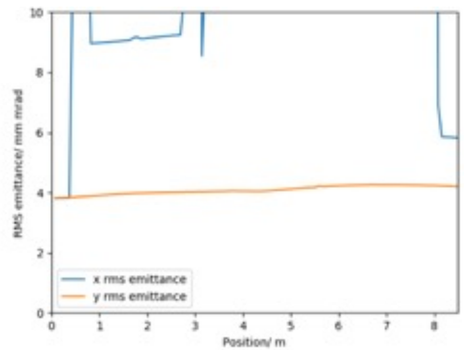
Merger tentative design:





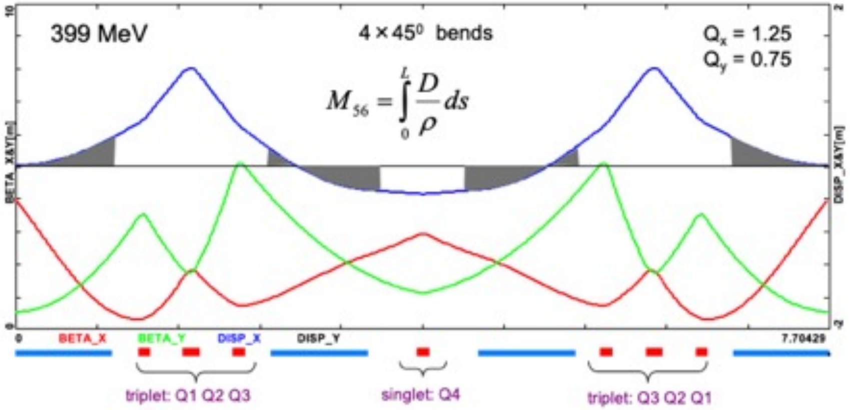
- Several merger schemes are investigated.
- Design philosophy: use adjustable elements where ever possible to keep as much flexibility in operation as possible and to avoid building an assumption about the amount of space charge force present into the physical system. possibility to operated with different bunch charges, bunch sizes, injection momentums
- Space charge is still significant and will need to be managed to prevent significant degradation to the emittance.
- 4 dipole schemes are currently being investigated as they have the potential to mitigate the effects of space charge on the dispersion and the consequent emittance growth.
- Implications of the current optimisation on the beam dynamics in the main lattice should be investigated or possibly modifying some of the requirements on the merger which might open up alternative schemes.

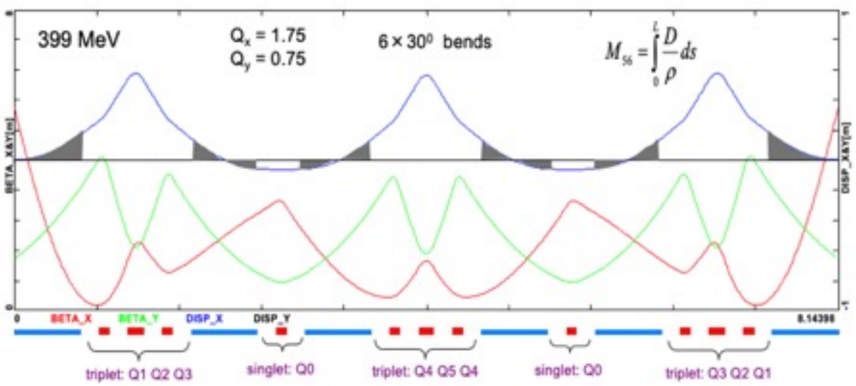


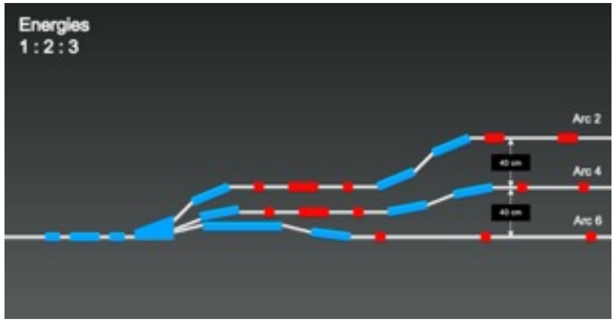


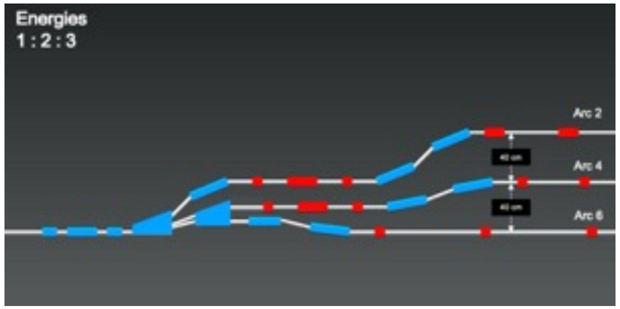
Lattice Design Optimisation

Courtesy to A. Bogacz and C. Vallerand

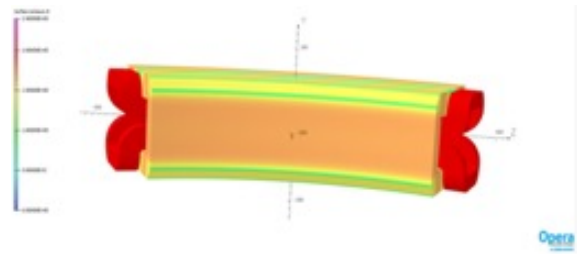


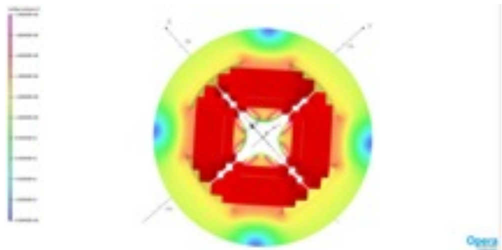






Design and prototyping of main **magnets for arcs and switchyards**

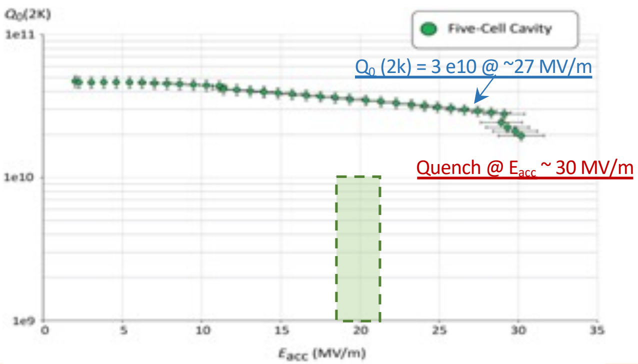




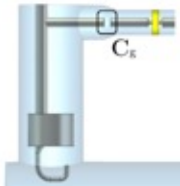
PERLE SRF System Development

Courtesy to F. Marhauser, N. Hu & G. Olivier

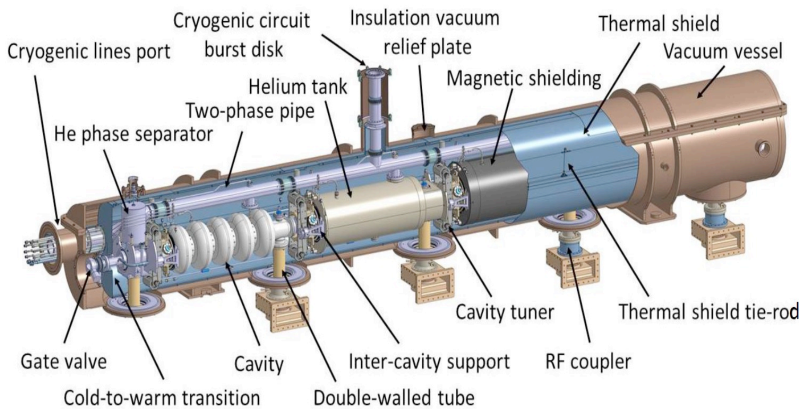
Design and prototyping of a full dressed SRF cavity: demonstration of level of SRF performance required in CW operation, high-average current environment, adequate damping of HOM.



HOM coupler study



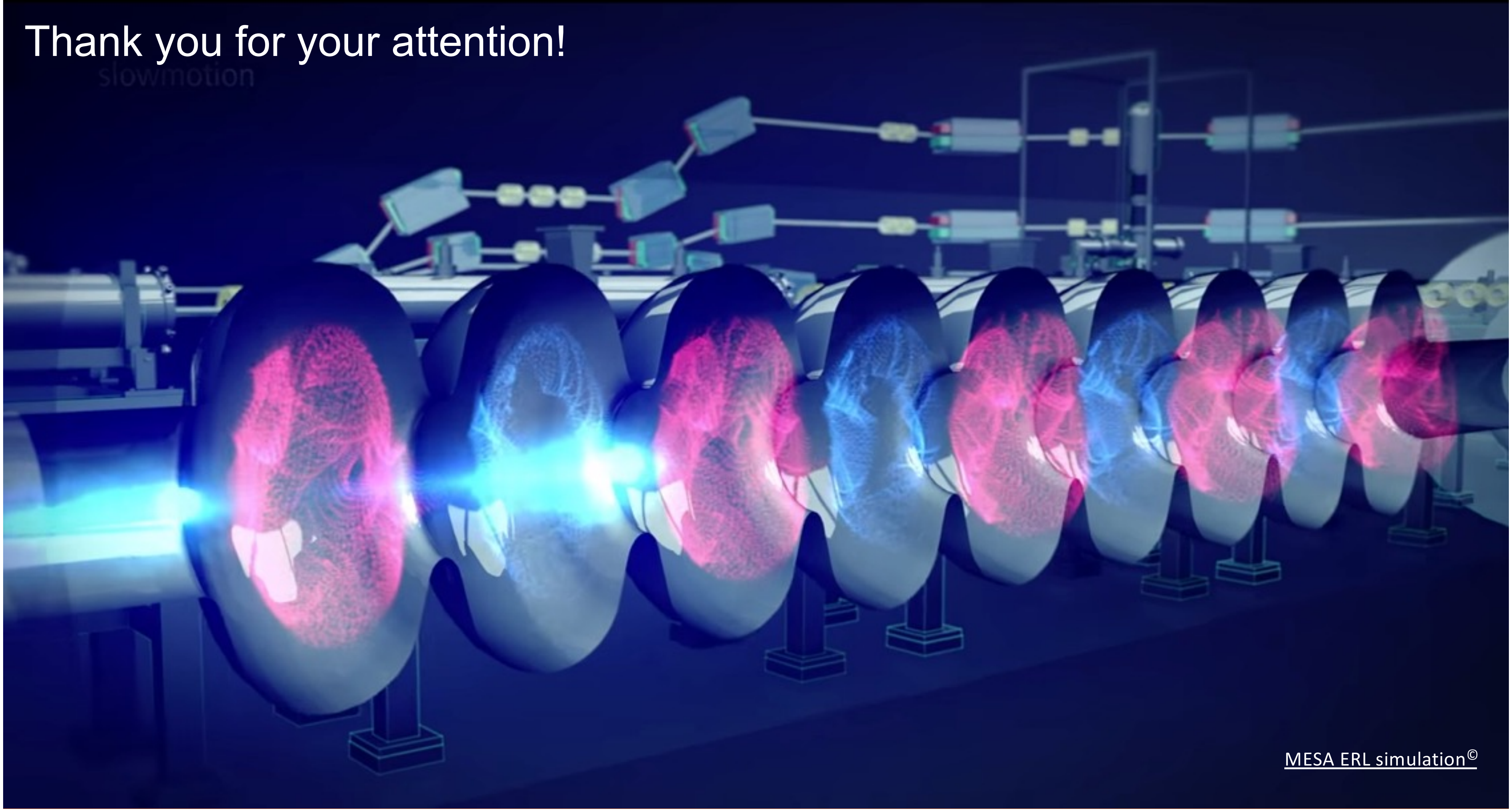
DQW HOM Coupler



Linac cryomodule design: **SPL cryomodule adaptation** to PERLE need, **complete design of a cryomodule** for PERLE later.

Design and prototyping of an input power coupler

Thank you for your attention!



MESA ERL simulation©

ERL- Scientific International Context

2020 Strategy Statements

European Strategy Update

3. High-priority future initiatives

Accelerator R&D is crucial to prepare the future collider programme

- The European particle physics community should develop an accelerator R&D roadmap focused on the critical technologies needed for future colliders, maintaining a beneficial link with other communities such as photon or neutron sources and fusion energy
- The roadmap should be established as soon as possible in close coordination between the National Laboratories and CERN
- A focused, mission-style approach should be launched for R&D on high-field magnets (16 T and beyond) including high-temperature superconductor (HTS) option to reach 20 T. CERN's engagement in this process would have a catalysing effect on related work being performed in the National Laboratories and research institutions
- The roadmap should also consider: R&D for an effective breakthrough in plasma acceleration schemes, an international design study for a muon collider and R&D on high-intensity, multi-turn energy-recovery linac (ERL) machines

b) Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. *The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.*

19/06/2020 CERN Council Open Session 18

H. Abramowicz, secretary of the European strategy update- June 2020

ERL- Scientific International Context

- CERN Council mandated the Laboratory Directors Group (LDG) to define and maintain a prioritised accelerator R&D roadmap towards future large-scale facilities for particle physics.

- The LDG suggested to invite expert panels to each of the areas and has very recently endorsed their tentative composition. Among the selected few key areas is the development of ERLs.

- IJCLab is represented in this ERL international expert panel (including US and Asia), to support this joint attempt for advancing the coordinated development of the ERL technology. The main task of this panel is to develop a roadmap for presentation to CERN Council, in December 2021.

ERL- Scientific National Context

Spiro Committee: Contribution to the future of GANIL:

Proposal of an electron-Radioactive Ions collision facility (e-RI) at GANIL:

- Option of a high current ERL as electron source is strongly supported.
- Preliminary investigations and analysis oriented the choice for a single tour, 100 mA (up to 200 mA), 500 MeV ERL.
- A key point in this facility is the ion capture efficiency: ***The more efficient the capture is, the less electron intensity is needed.***

→ Need of an intermediated step for an original ion trap R&D and test with a high performance electron machine: **Initiative DESTIN (DEep STructure Investigation of exotic Nuclei) @ Orsay coupler to PERLE facility**.