PERLE : Status and Plan

On behalf of PERLE Collaboration

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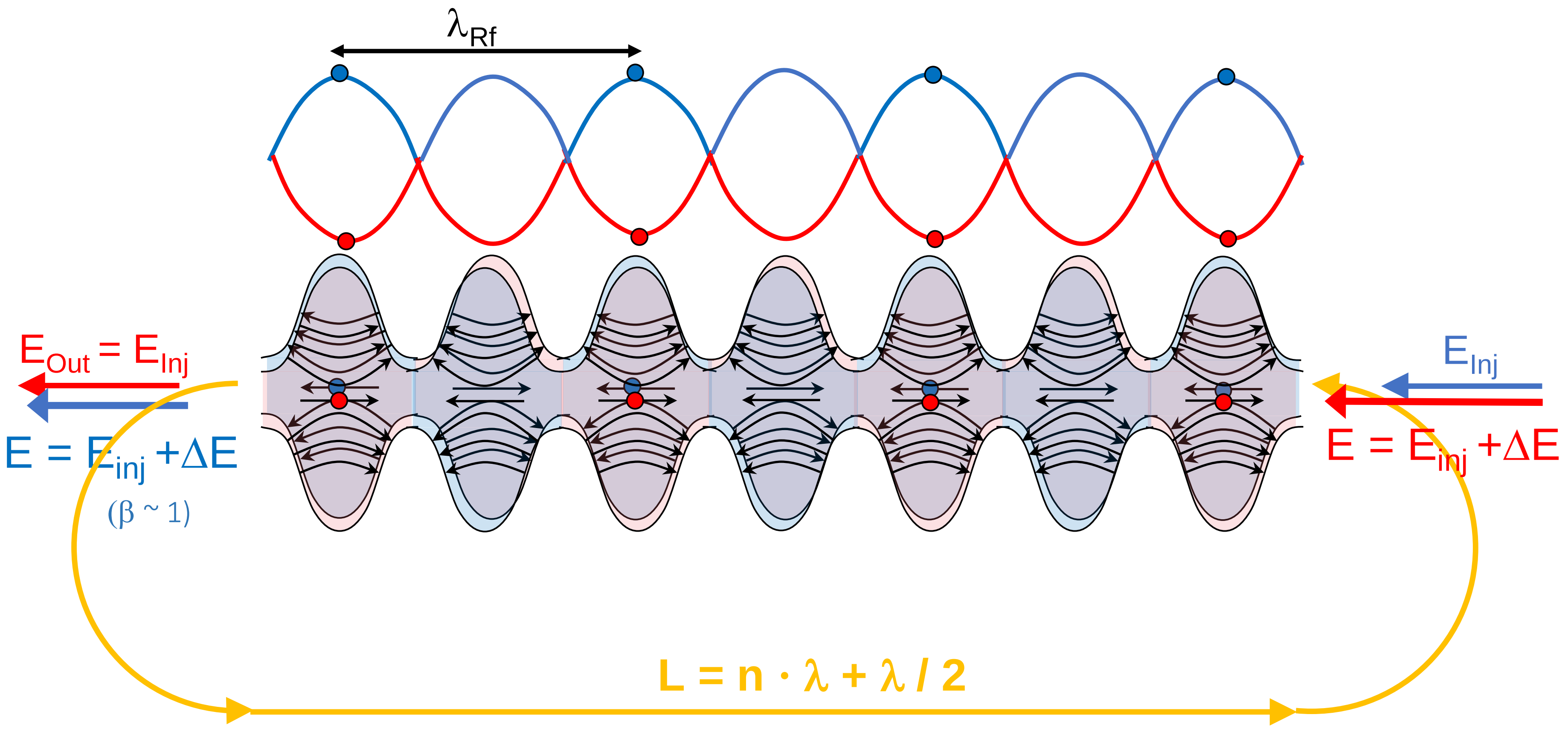
CERN
CNRS IN2P3 Les deux infinis
Jefferson Lab Thomas Jefferson National Accelerator Facility
Science & Technology Facilities Council
Budker Institute of Nuclear Physics
UNIVERSITY OF LIVERPOOL
PERLE

Introduction- Energy recovery in RF fields:



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

Introduction to PERLE:

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

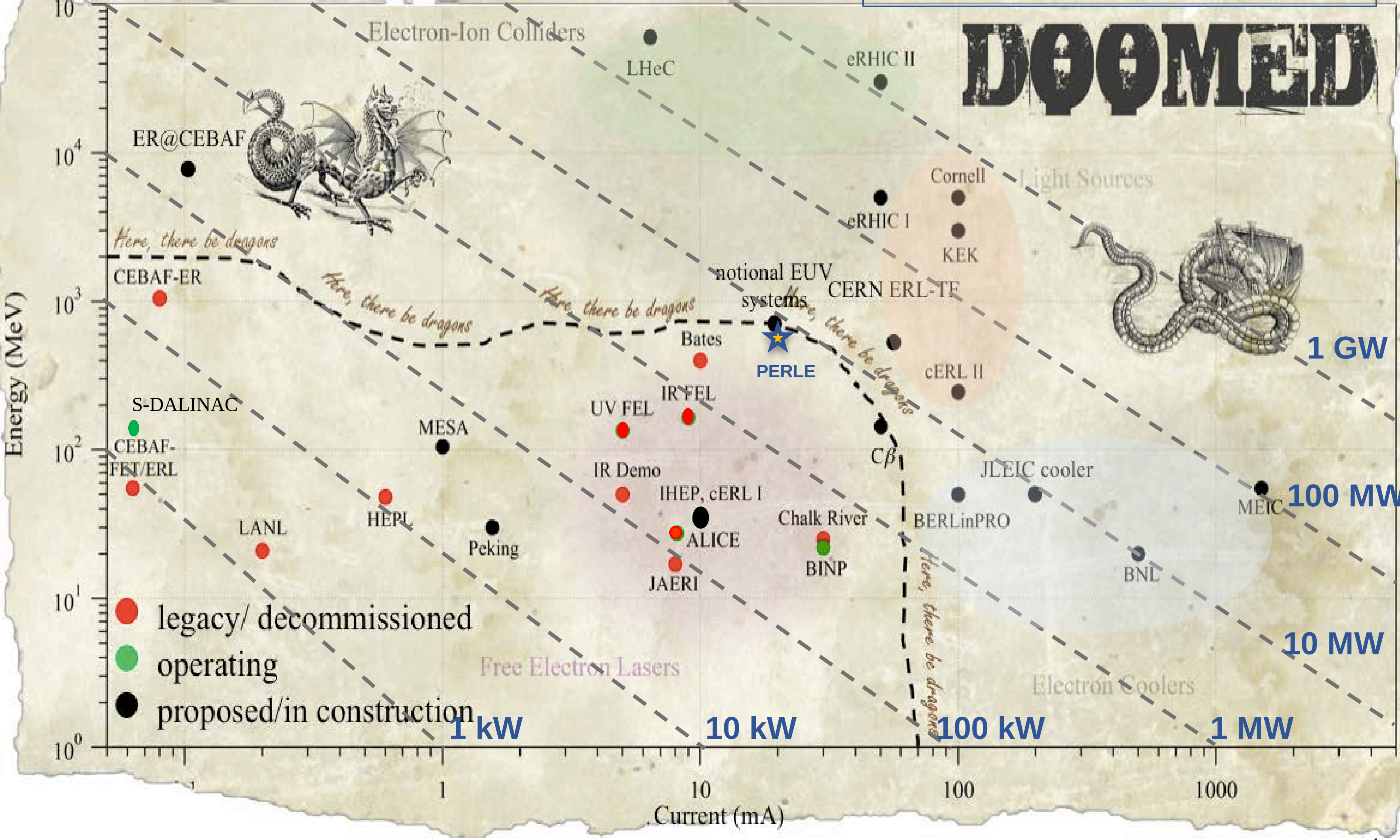
Particularly, design challenges and beam parameters are chosen to enable PERLE as the hub for technology development (especially on SRF) for the Large Hadron Electron Collider (LHeC) [1]:

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

[1] J.L. Abelleira Fernandez et al, " A Large Hadron Electron Collider at CERN: Report on the Physics and Design Concepts for Machine and Detector ", J.Phys. G39 (2012) 075001, arXiv:1206.2913

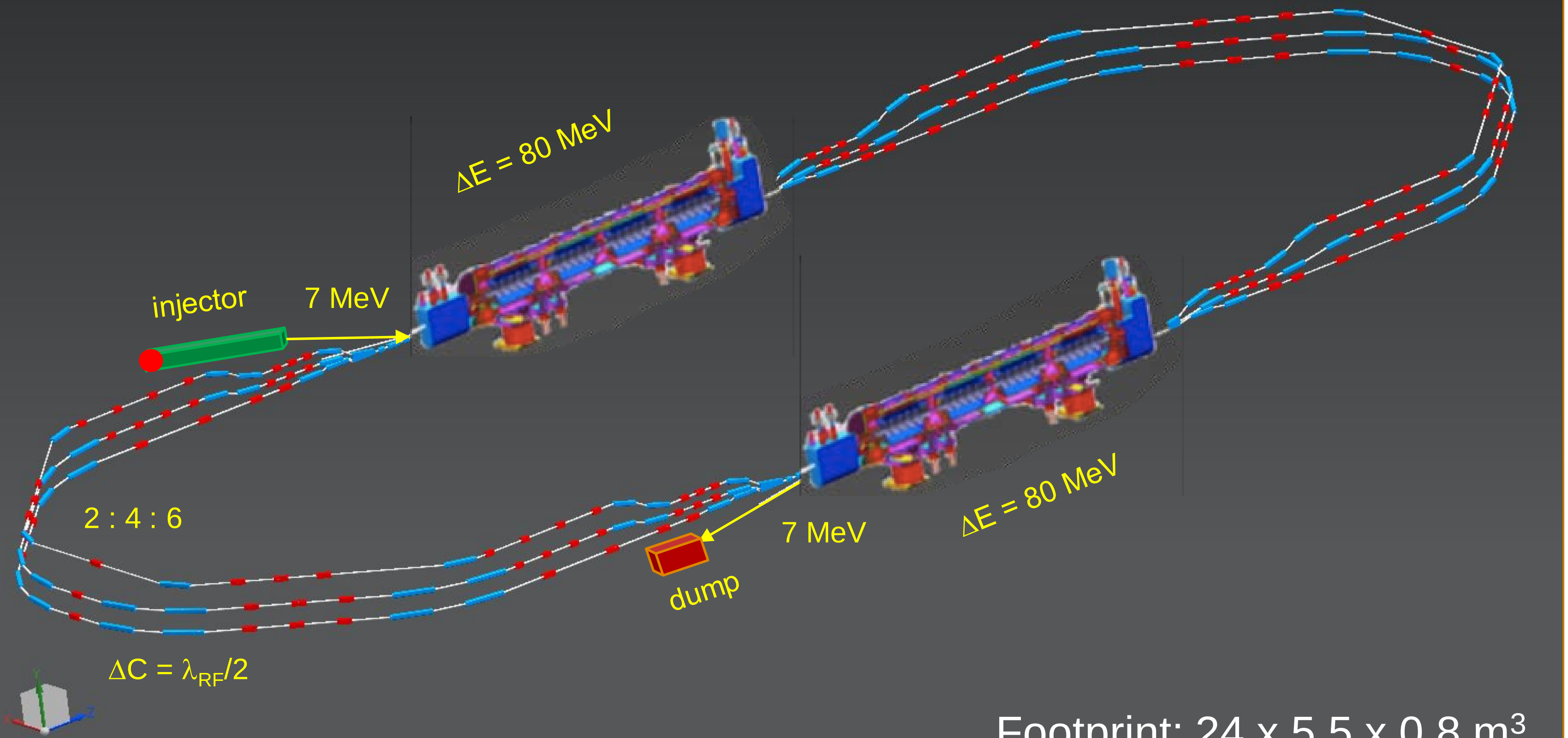
PERLE in the global landscape:

Courtesy to C. Tennant- JLAB



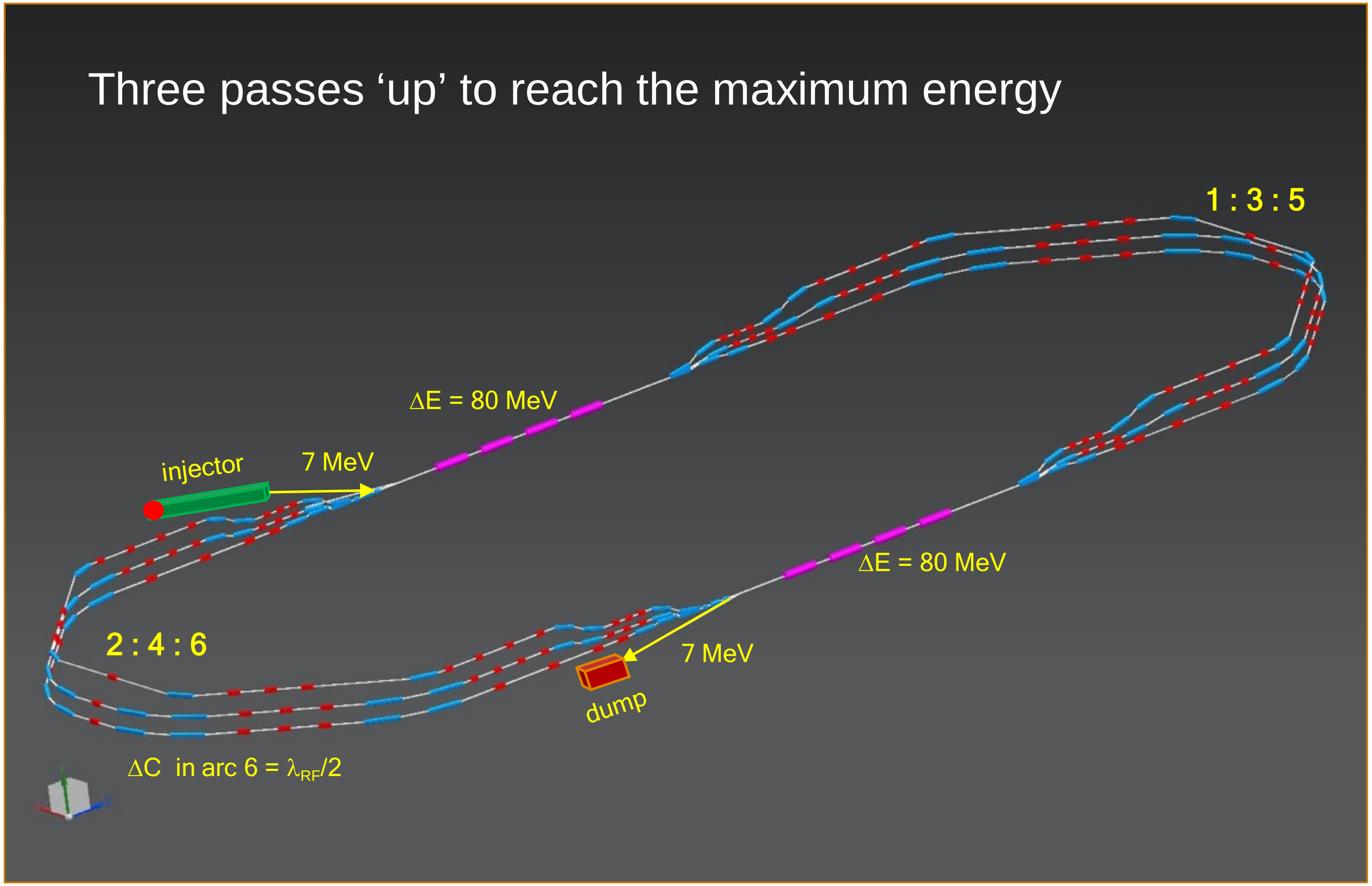
PERLE configuration:

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (160 MeV/turn)
- Max. beam energy 500 MeV

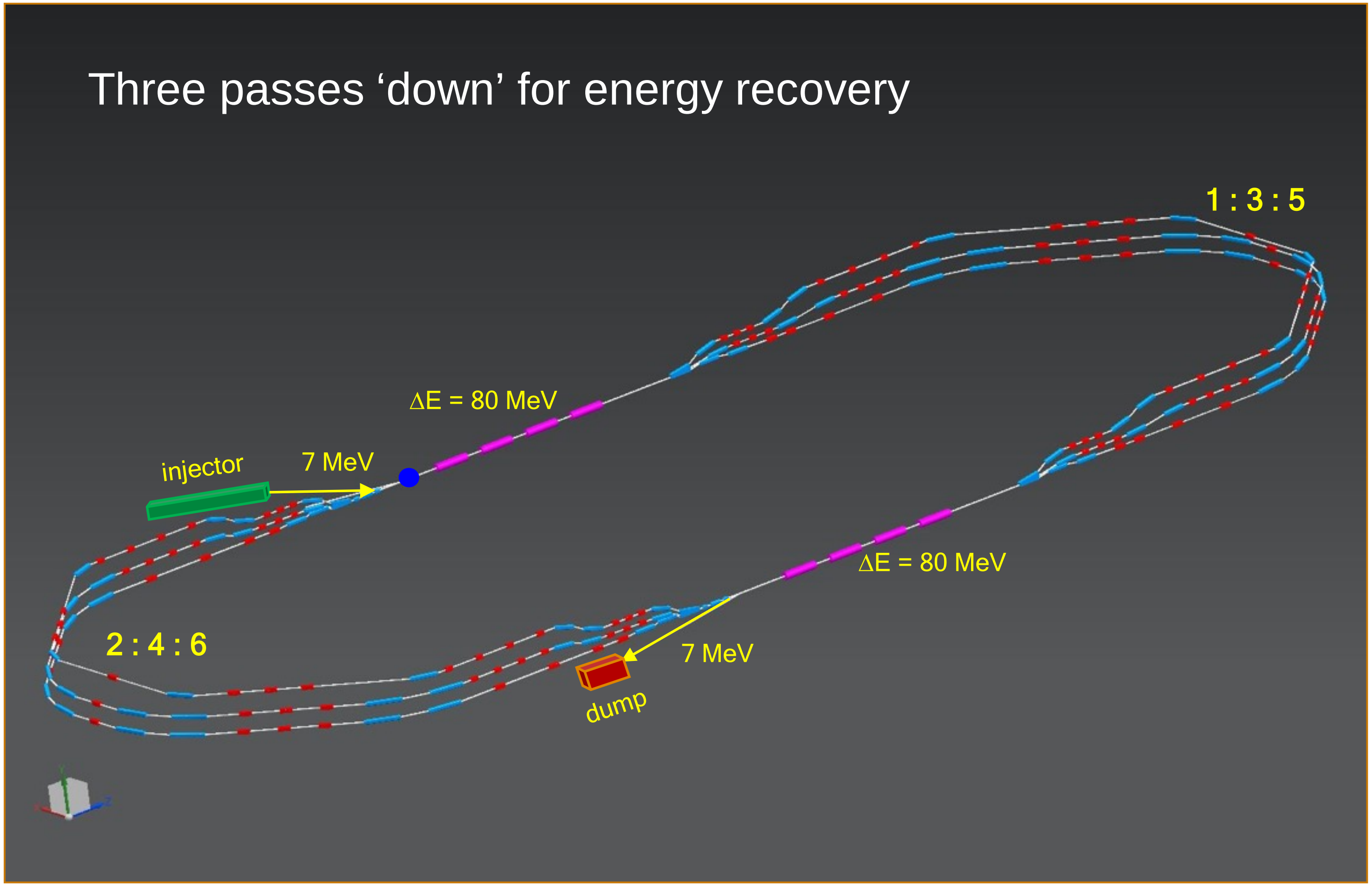


Footprint: 24 x 5.5 x 0.8 m^3

PERLE configuration:



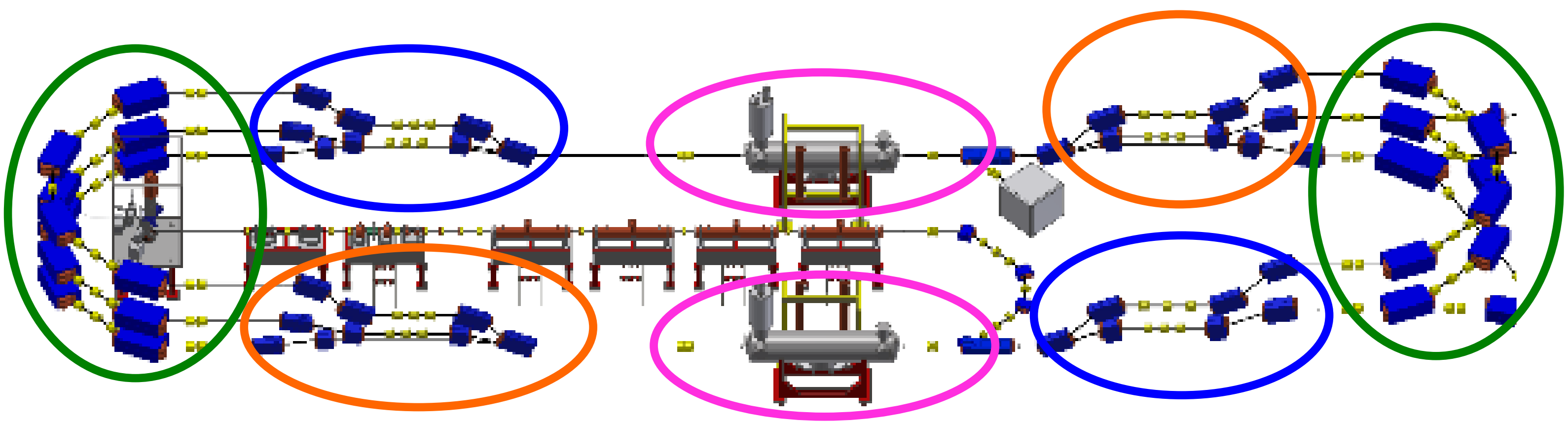
PERLE configuration:



PERLE transport optics:

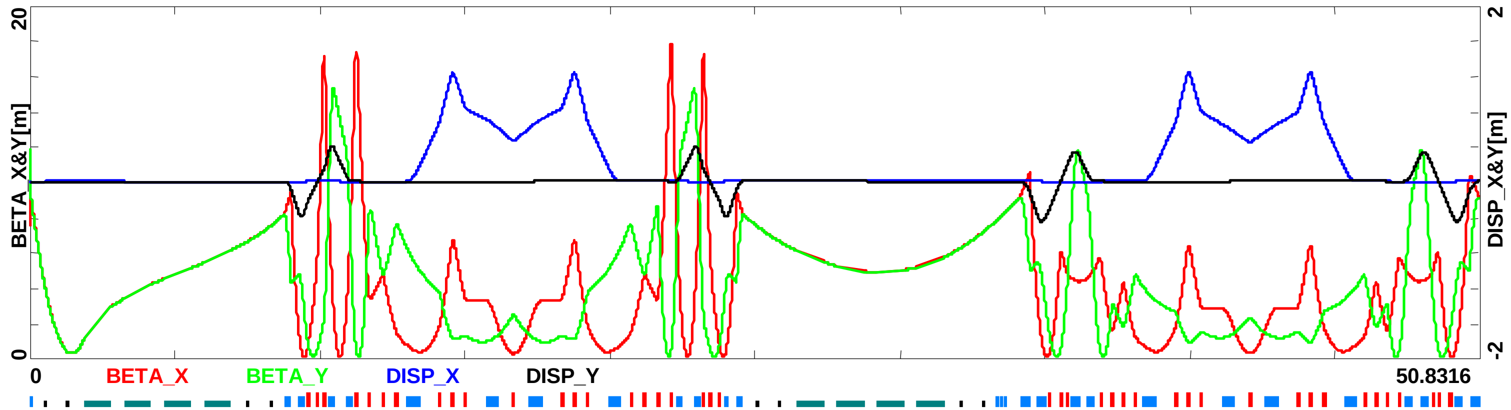
Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality. The design comprises different regions:

- **The Linac optics:** The focusing strength of the quadrupoles along the linac needs to be set to transport co-propagating beams of different energy and to support a large number of passes.
- **The Spreader optics:** The beams need to be directed into the appropriate energy dependent arc. Spreaders separate vertically beams and match optics functions to arcs.
- **The Arc optics:** Disturbing effects on beam space charge such us cumulative emittance and momentum growth have to be counteracted through a pertinent choice of the basic optics cell
- **The Re-combiner optics:** Re-combiners and spreader are mirror symmetric.



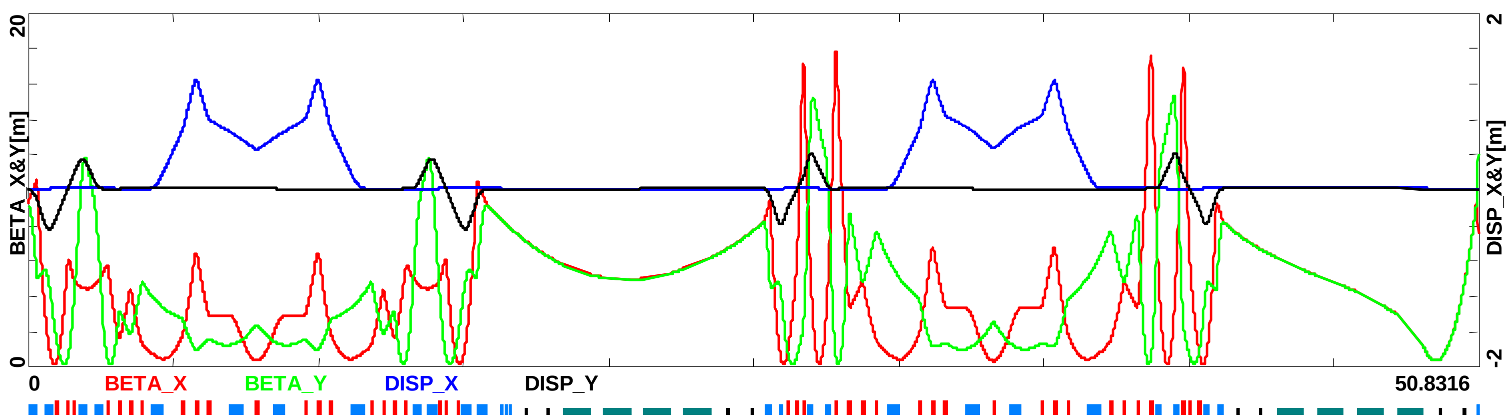
1 pass up + 1 pass down optics:

Pass-1 ‘up’



7 MeV 87 MeV 167 MeV

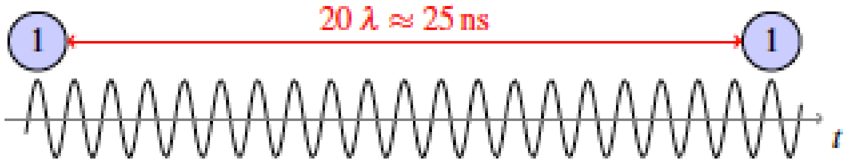
Pass-1 ‘down’



167 MeV 87 MeV 7 MeV

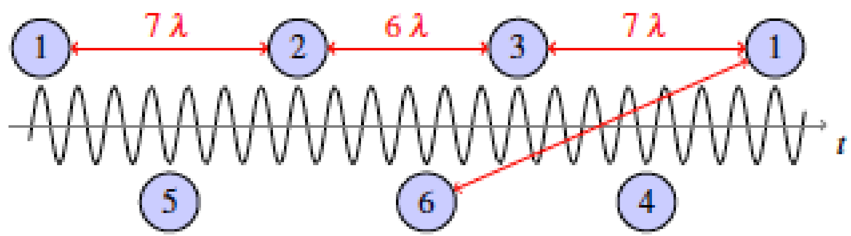
Bunch recombination pattern:

- Basic RF structure, without recirculation: Bunches are injected every 25 ns



- When recirculation occurs → bunches at different turns in the linacs:
  - Ovoid bunches in the same bucket
  - Recombination pattern adjusted by tuning returned arcs length of the required integer of λ

Turn number	Total pathlength
1	$n \times 20\lambda + 7\lambda$
2	$n \times 20\lambda + 6\lambda$
3	$n \times 20\lambda + 3.5\lambda$



- Maximize the distance between the lowest energy bunches (1 & 6): ovoid reducing the BBU threshold current due to the influence of HOMs kicks
- Achieve a nearly constant bunch spacing: minimize collective effects

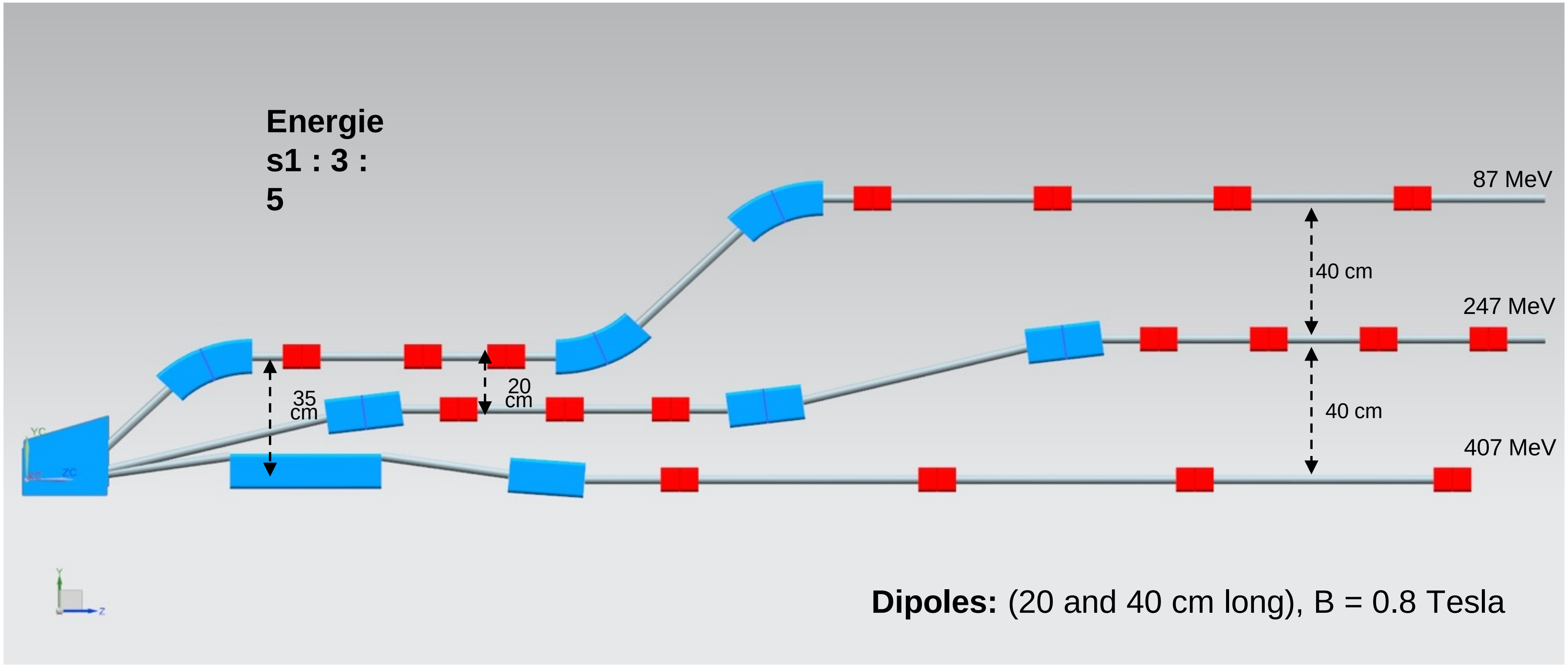
Cost-effective magnet solution:

Cynthia Vallerand (LAL) & Pierre Thonet (CERN)

- Iron-dominated resistive magnets preferred for improving tunability
- Magnet aperture of +/- 20 mm
- Current density of 7-8 A/mm2
- H design to reduce the magnet height for stacking
- Homogeneous field as low as possible due to the use of one power supply by arc
- Cost minimization with a design of the arc magnets coupled to studies of the power converters, the vacuum system and cooling as well as only one magnet per bend with a 45° deflection

Arc	Energy [MeV]	Count	angle [deg]	B [T]	L [mm]	Curv. radius [mm]	Pole gap [mm]	GFR width [mm]	
#1	80	4	45	0.45	456	596	±20	±20	MBA
#2	155	4	45	0.87	456	596	±20	±20	
#3	230	4	45	1.29	456	596	±20	±20	
#4	305	4	45	0.85	912	1191	±20	±20	MBB
#5	380	4	45	1.06	912	1191	±20	±20	
#6	455	4	45	1.27	912	1191	±20	±20	

Switchyard- Vertical Separation of Arcs (1, 3, 5):

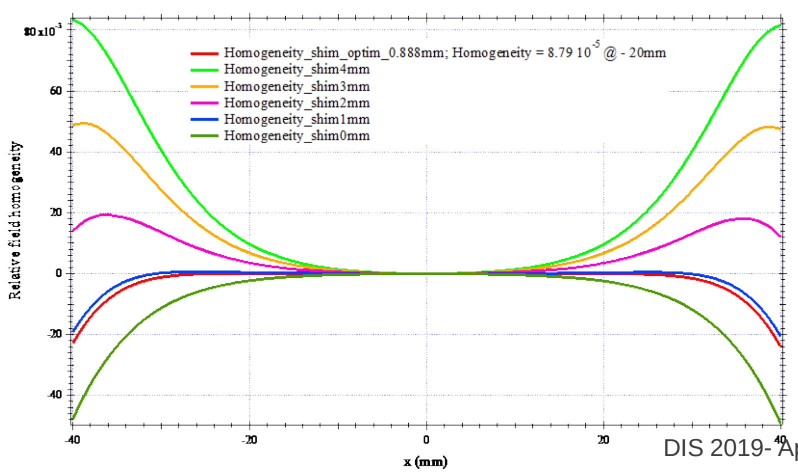


PERLE magnet design:

Simulations for magnet design optimization.
→ Main concern: magnet compactness configuration in spreaders and combiners: magnet saturation risk, cross-talk between magnets.

BINP- Novosibirsk will join the effort of magnet design & fabrication within a H2020 European programme: “CRIMLINplus”

3D Sin



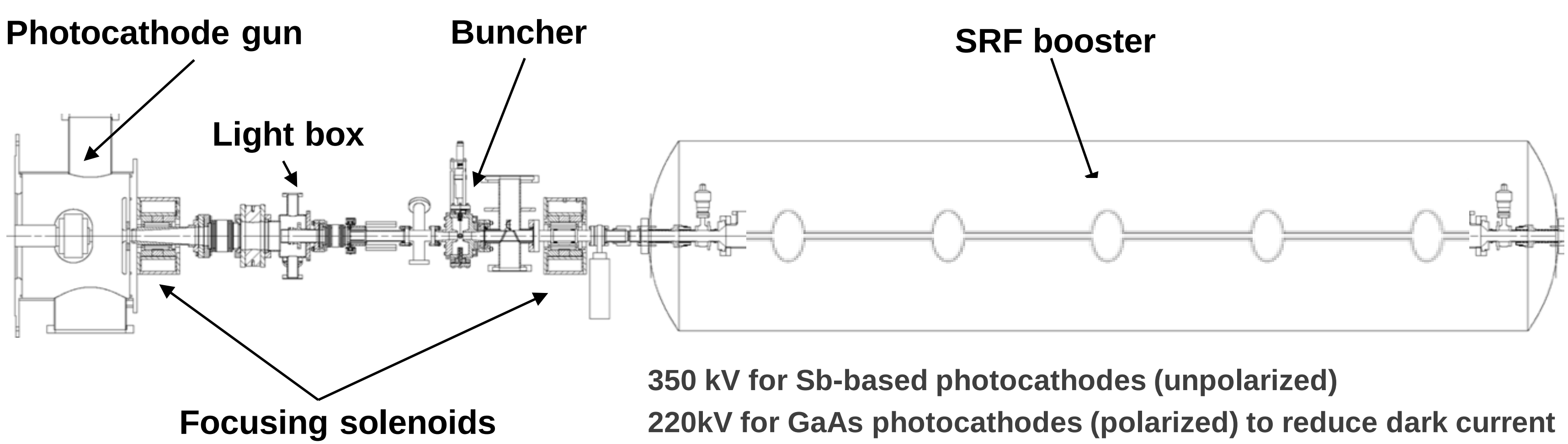
Bending magnets: field homogeneity with optimized shim of 8.8 10^{-5} at ± 20 mm (GFR), better than expected (5 10^{-4}).

Electron source and injector:

The PERLE injector consists of:

Boris Militsyn & Benjamin Hounsell- Daresbury

- The upgraded DC photoemission electron gun of ALICE: Need a new power supply and photocathode preparation chamber design.
- A bunching and focusing section: A normal conducting buncher cavity placed between two solenoid.
- A superconducting booster with 5 single cell 802 MHz cavities with individual control of the amplitudes and phases.
- Merger to transport the beam into the main LINAC,
- Beam diagnostics to be placed between components.



350 kV for Sb-based photocathodes (unpolarized)
220kV for GaAs photocathodes (polarized) to reduce dark current

Electron source and injector:

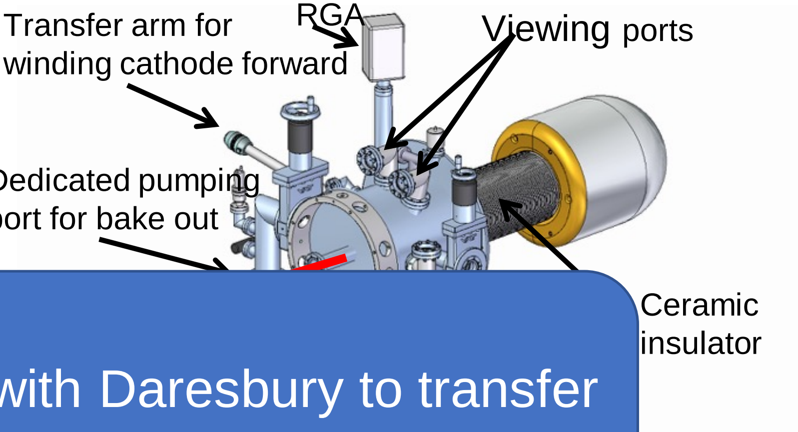
Studies on ALICE gun upgrade to operate at up to 500 pc (B. Hounsell PhD thesis):

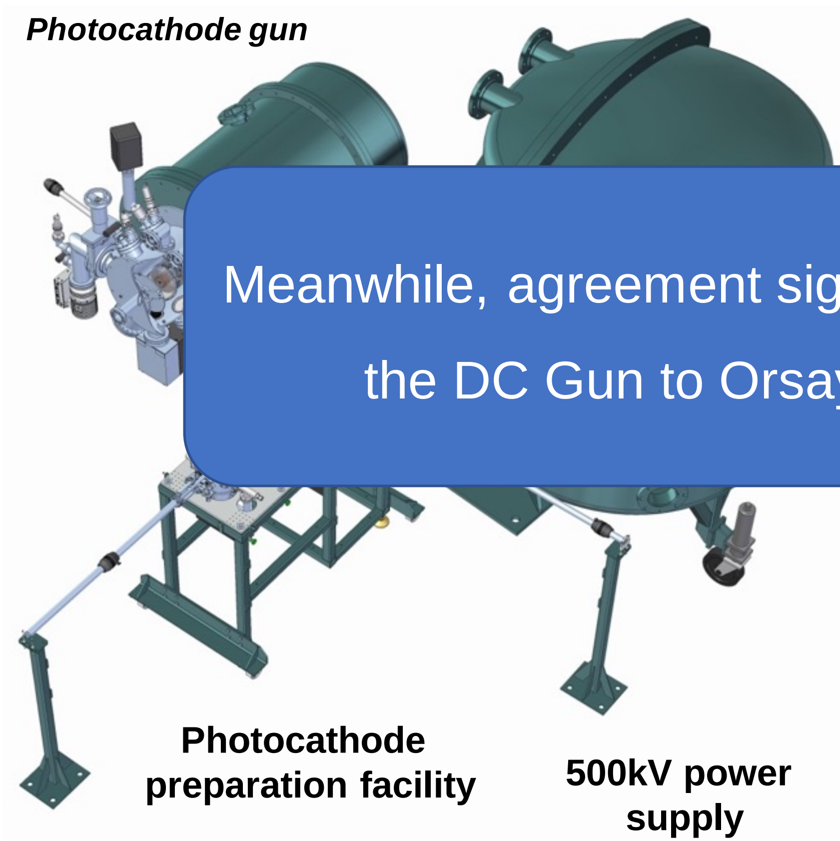
- ✓ Optimisation of the laser spot size, laser pulse length, cathode-anode gap and the cathode shape to preserve the emittance in the gun and first solenoid section and to reduce transverse beam size in the focusing and bunching section,
- ✓ Optimise the buncher frequency (**<u>401 MHz</u>** or 802 MHz) in order to minimise emittance growth,
- ✓ Optimise beam transport from the gun to the main Linac to minimise transverse beam size and compensate emittance.

Once the beam's parameters coming from the injector optimized (emittance, momentum spread, halo), we will be able to perform:

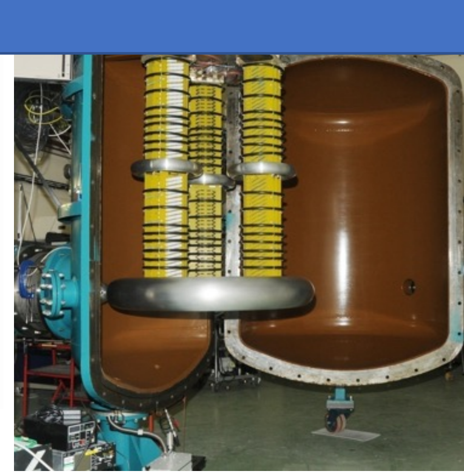
- ➢ A beta matching to the rest of PERLE starting with the first linac.
- ➢ A 'first ' end-to-end simulation: Tracking initial particle distribution, as defined by the injector and using magnet error tolerances would validate beam transport through the entire ERL complex.

Electron source and injector:





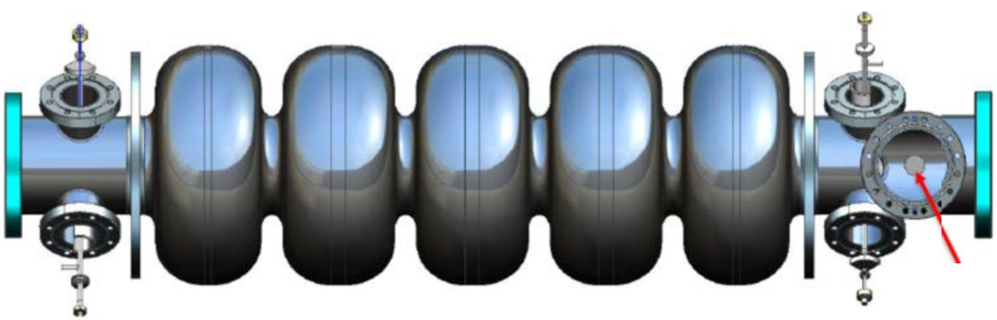
Meanwhile, agreement signed with Daresbury to transfer the DC Gun to Orsay in the upcoming weeks



Main cavity parameters:

Frank Marhauser-JLAB

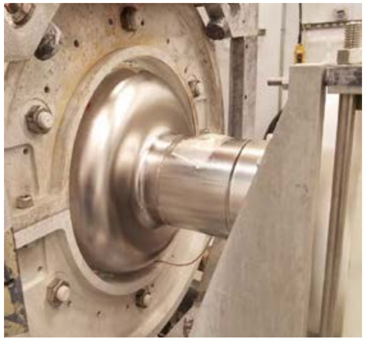
Parameter	Unit	Value
Frequency	MHz	801.58
Number of cells		5
Iris/tube ID	mm	130
L_{act}	mm	917.9
$R/Q = V_{eff}^{2}/(\omega \cdot W)$	Ohm	524
G	Ohm	274.7
R/Q·G/cell		143940
$\kappa_{\|\|}$ (2mm rms bunch length)	V/pC	2.74
E_{pk}/E_{acc}		2.26
B_{pk}/E_{acc}	mT/(MV/m)	4.20
k_{cc}	%	3.21

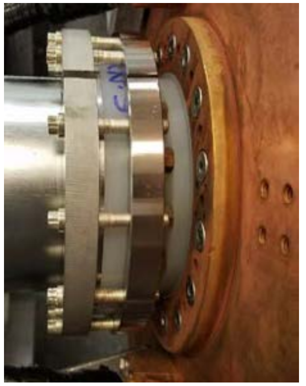


Cavity fabrication and test:

The first Nb 802 MHz 5-Cell cavity fabricated October 2017 at JLAB

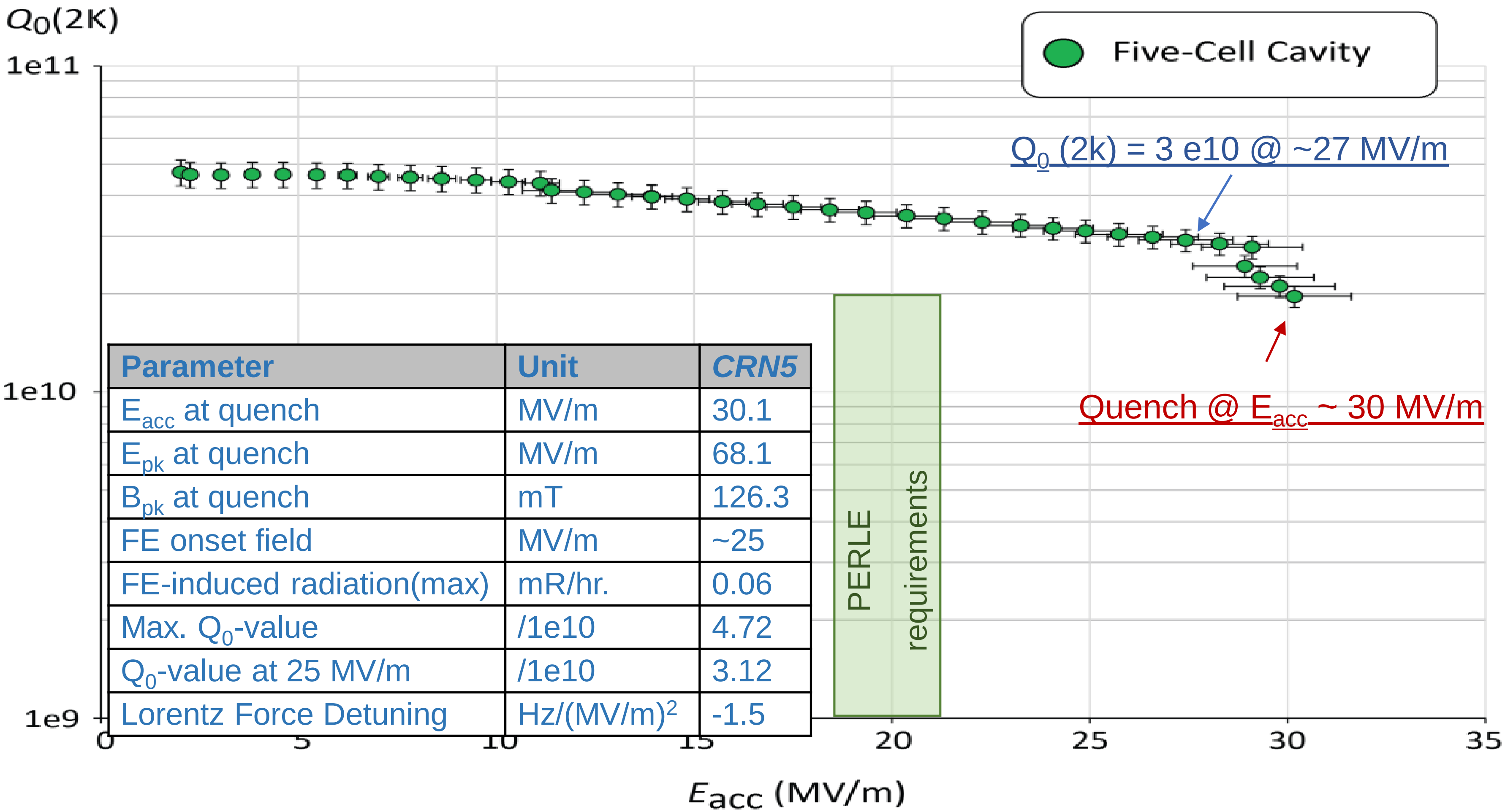
Cavity fabrication and test:





5-cell cavity successfully electropolished with new flange adapters

Cavity fabrication and test:

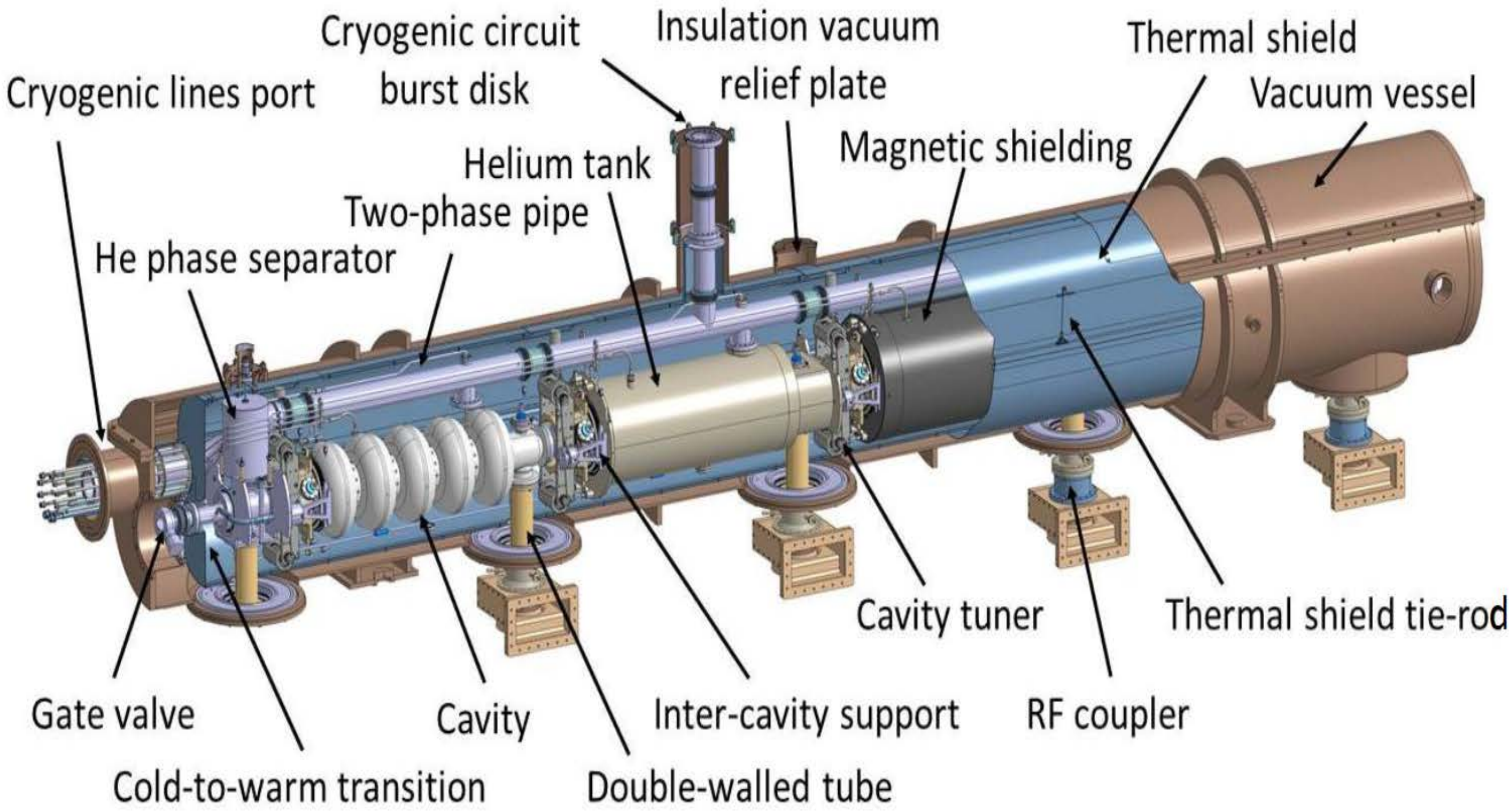


Parameter	Unit	*CRN5*
E_{acc} at quench	MV/m	30.1
E_{pk} at quench	MV/m	68.1
B_{pk} at quench	mT	126.3
FE onset field	MV/m	~25
FE-induced radiation(max)	mR/hr.	0.06
Max. Q_0-value	/1e10	4.72
Q_0-value at 25 MV/m	/1e10	3.12
Lorentz Force Detuning	$Hz/(MV/m)^2$	-1.5

For more details: F. Marhauser's talk in the FCC Week, April 2018, Amsterdam, Netherland

Cryomodule design study:

IPN-Orsay & CERN, started the study of the SPL cryomodule adaptation for PERLE.



<u>SPL cryomodule: designed to integrate 4 elliptical 5-cells 704 MHz cavities</u>

Cryomodule design study:

First results:

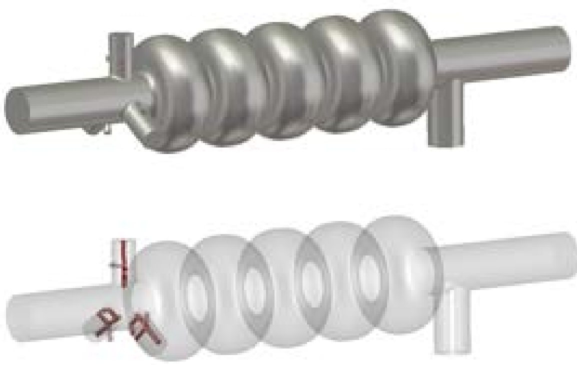
- ✓ Thermal and magnetic shielding were studied and found well sized for PERLE operation parameters,
- ✓ Input coupler designed for SPL cavity could be easily adapted to meet PERLE requirement, It needs slight mechanical modifications.
- ✓ Space liberated due to cavity frequency difference give a margin for auxiliaries integration,

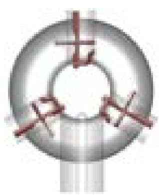
Pending issues:

- ➢ A review meeting dedicated to HOM couplers will be organized soon to decide on design and number of HOM couplers to be used for PERLE → Big impact on the decision to adapt the SPL cryomodule for PERLE or not.

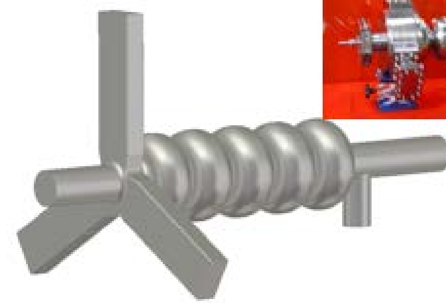
HOM studies

Several HOM coupler types were investigated for adaptation to the new cavity :



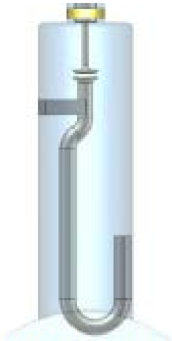


HOM 'Y' end-group with 3 coaxial couplers (here with scaled TESLA-type couplers)

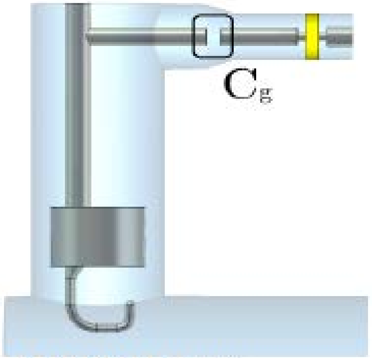


HOM 'Y' 'High Current' waveguide coupler end-group

LHC Probe-type



LHC Hook-type



DQW HOM Coupler

Other Highlights:

• A collaboration agreement was drafted and sent to the main PERLE collaboration members. Bilateral MoUs between some collaborators were also prepared and will be signed soon.

• PERLE collaboration drafted a document summarizing next technical steps toward PERLE study and construction. It was submitted with the LHeC document to the European strategy.

• In this document, we include a staging strategy allowing in phase 1 starting with a single cryomodule in the racetrack.

• The PERLE team at Orsay-France received the support of our institute (IN2P3-CNRS) by allowing annual budget and a post-doc position as a start (beam dynamics studies).

• A preliminary study on radiation security evaluation concluded that PERLE could not be classified as a “Basic Nuclear Infrastructure” according to French safety rules.

• A prototyping activity on key components is scheduled for the current project phase:

- ➢ Cavities and cryomodule (fully dressed cavities, cryomodule) within the 3 next years,
- ➢ Injector (upgrade of Alice injector)
- ➢ Magnets (build of prototype of each type)

Thank you for your attention!