PERLE :
A Powerful ERL for Experiments at Orsay

On behalf of PERLE Collaboration

Walid Kaabi-LAL/CNRS

Introduction:

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.

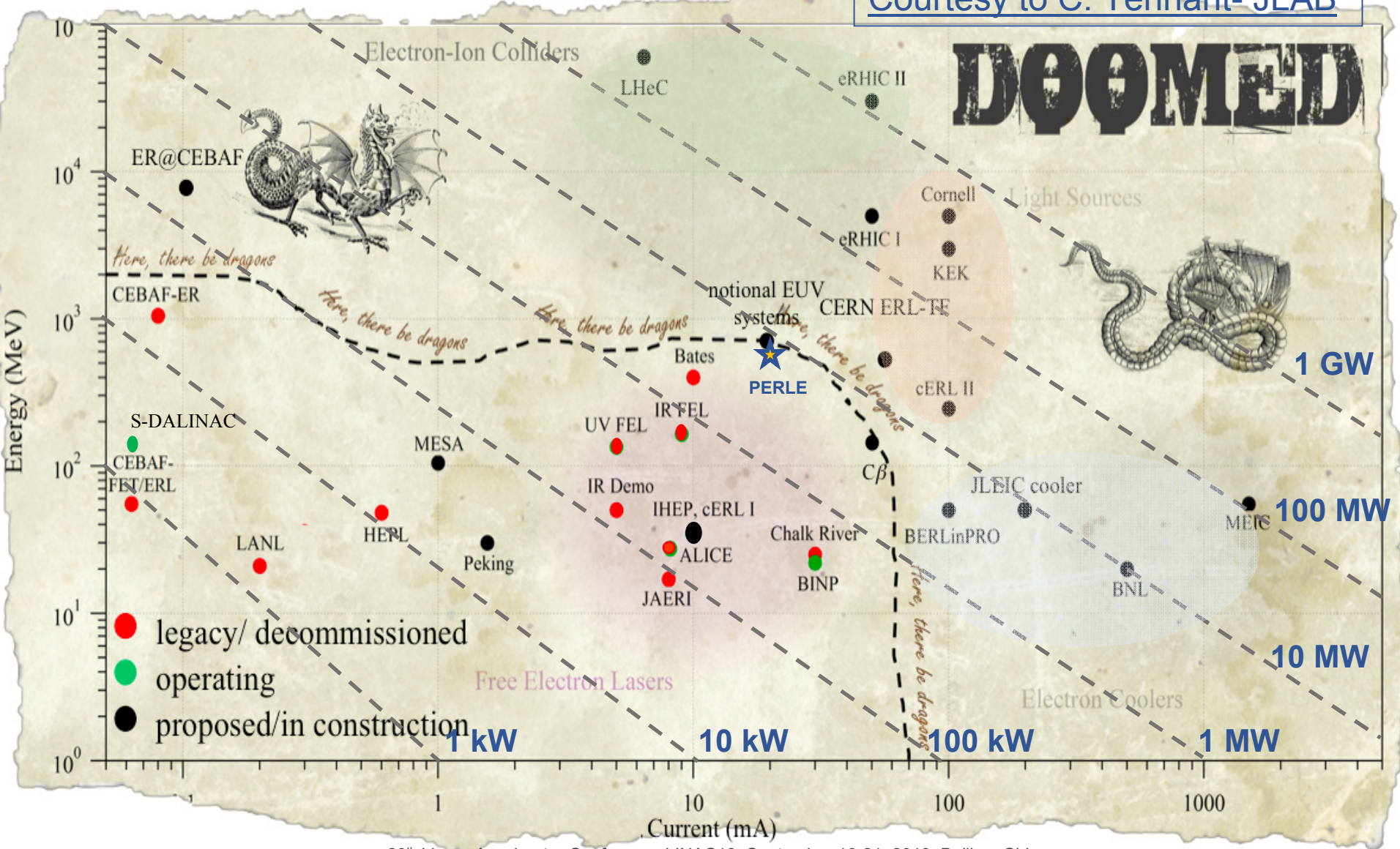
Particularly, design challenges and beam parameters are chosen to enable PERLE as the hub for technology development (especially on SRF) for the Large Hadron Electron Collider (LHeC) [1]:

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

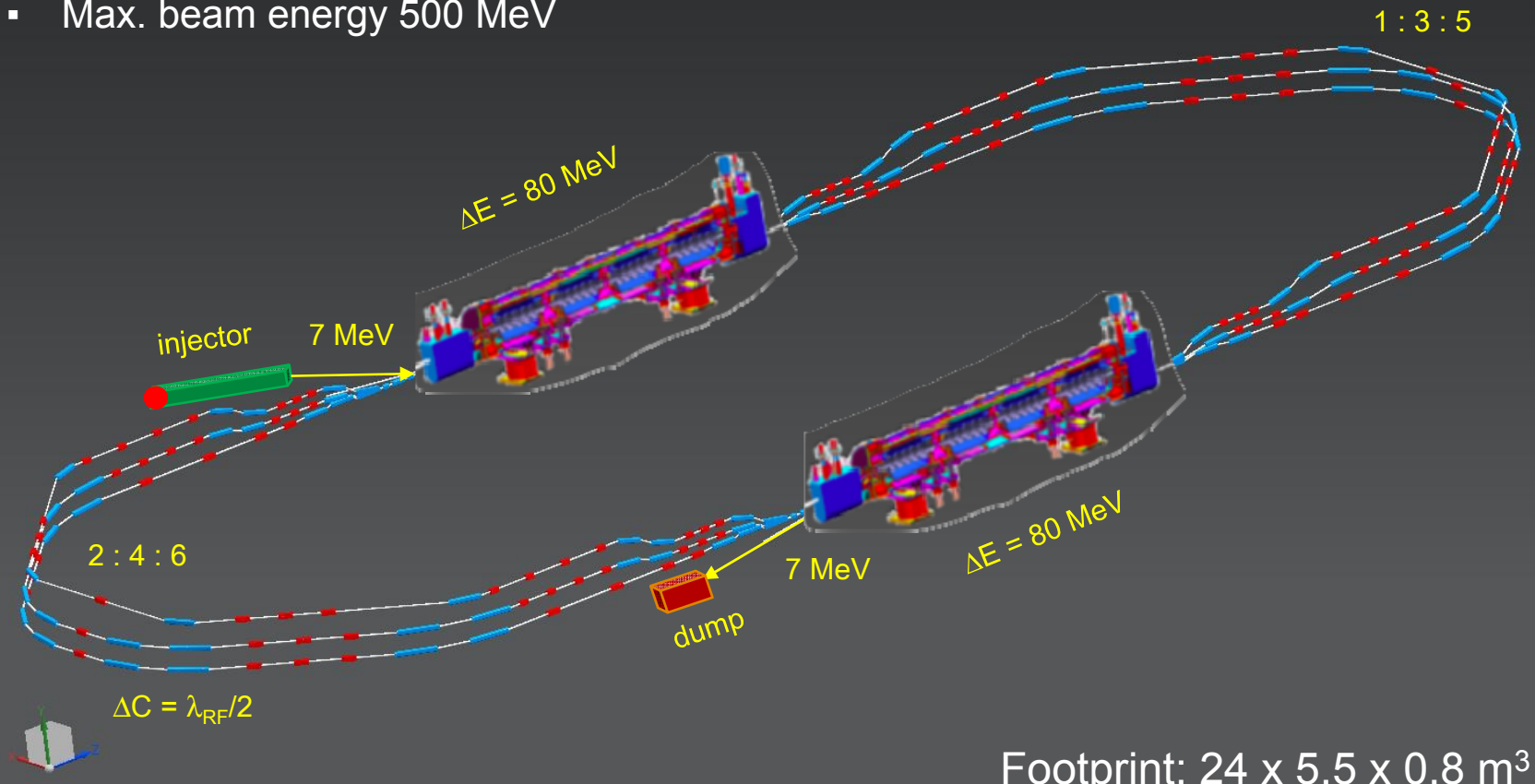
PERLE in the global landscape:

Courtesy to C. Tennant- JLAB



PERLE configuration:

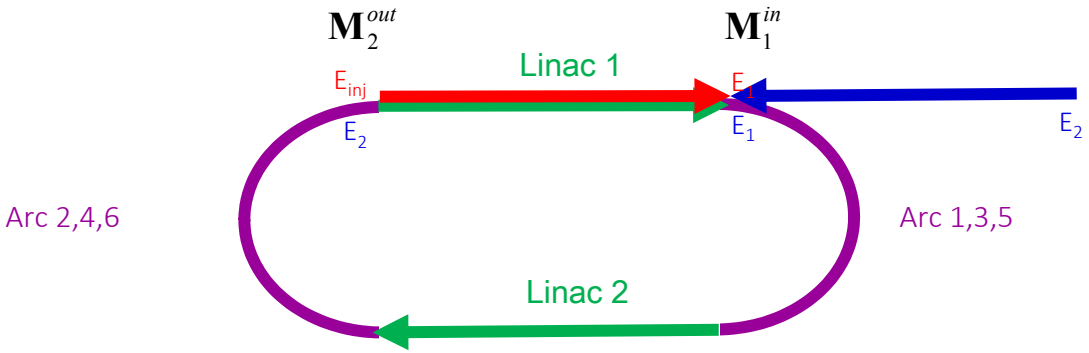
- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (160 MeV/turn)
- Max. beam energy 500 MeV



Footprint: 24 x 5.5 x 0.8 m^3

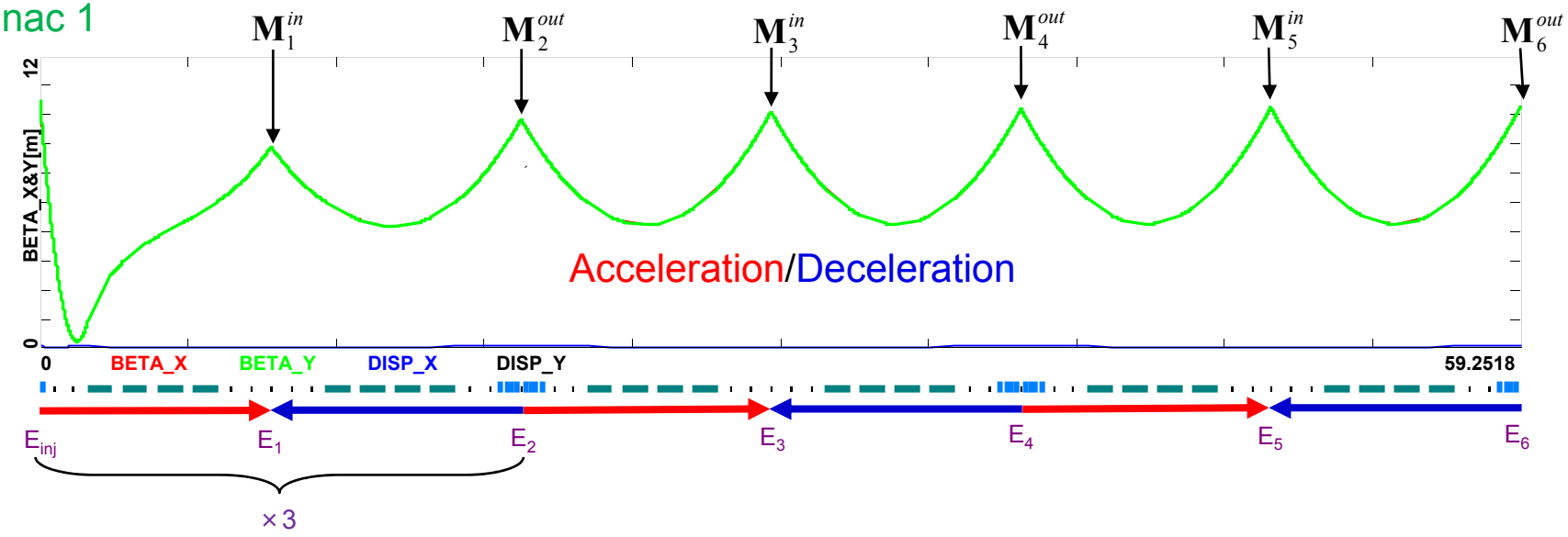
Multi-pass Energy Recovery optics:

Alex Bogacz-JLAB

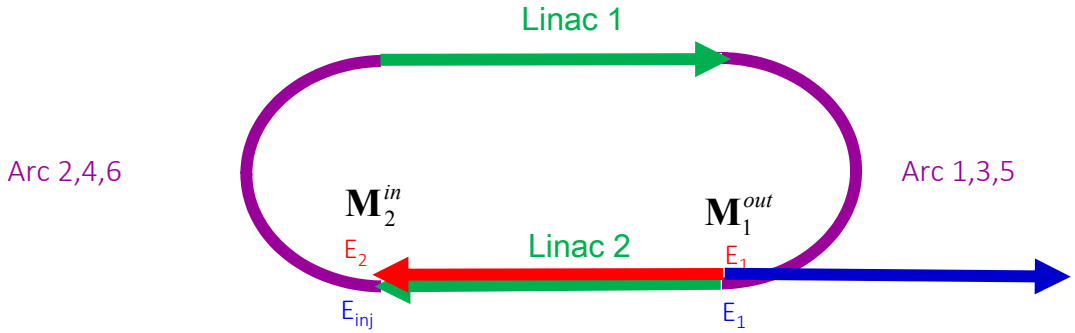


$$\mathbf{M} = \begin{bmatrix} \beta_x \\ -\alpha_x \\ \beta_y \\ -\alpha_y \end{bmatrix}$$

Linac 1



Multi-pass Energy Recovery optics:



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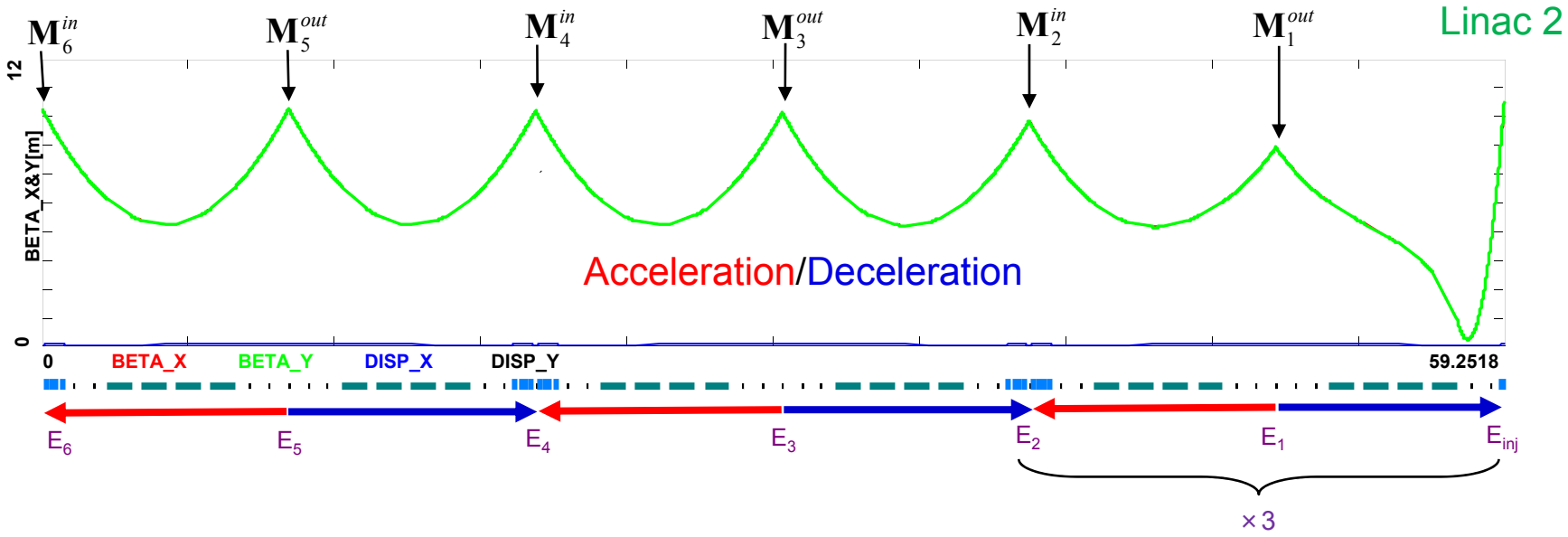
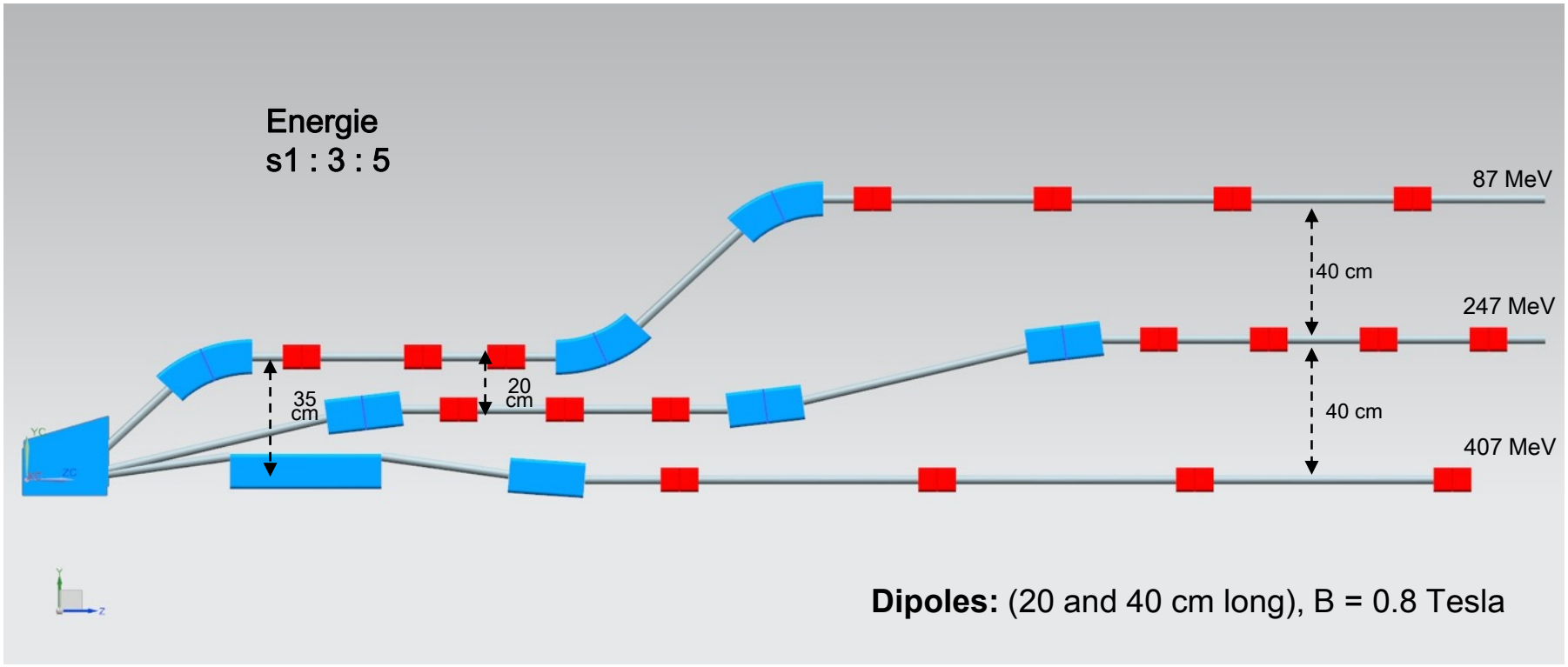
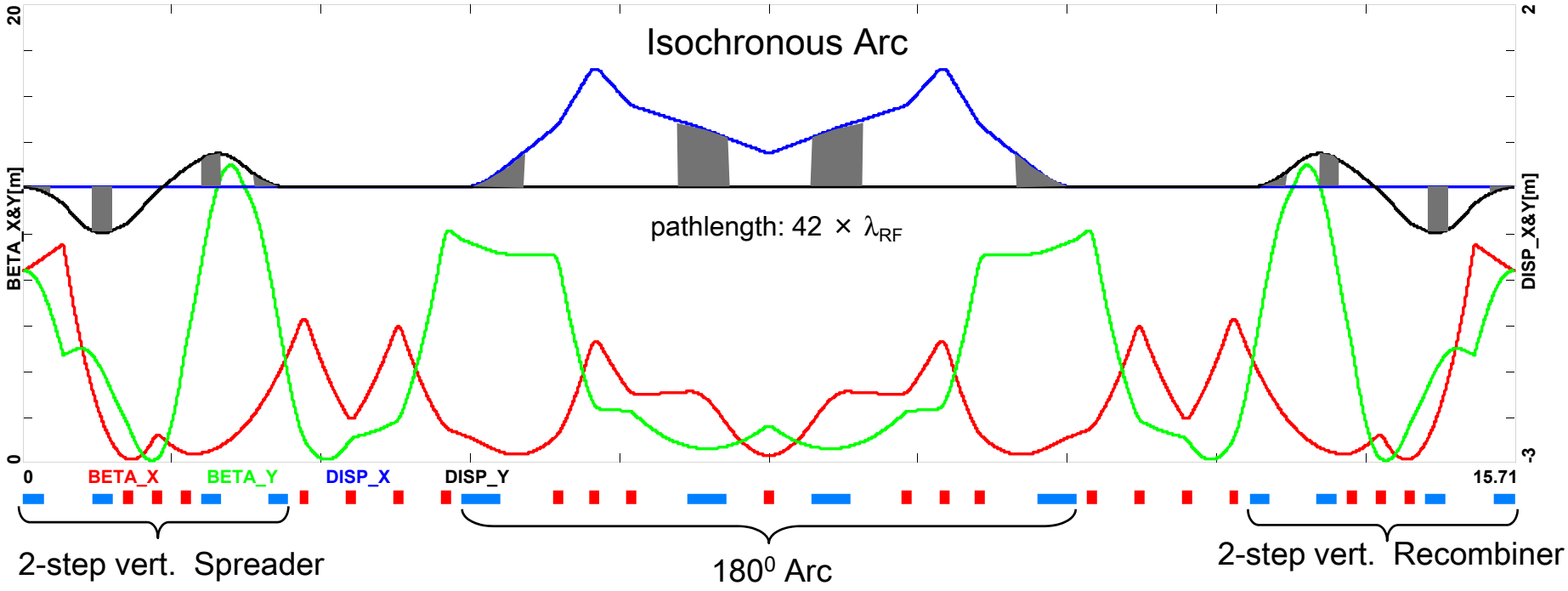


Switchyard- Vertical Separation of Arcs (1, 3, 5):



Arc optics, Arc 1 (71 MeV) as example:



Spr. dipoles:
4× 45⁰ bends
L = 20 cm
B = 9.5 kGauss

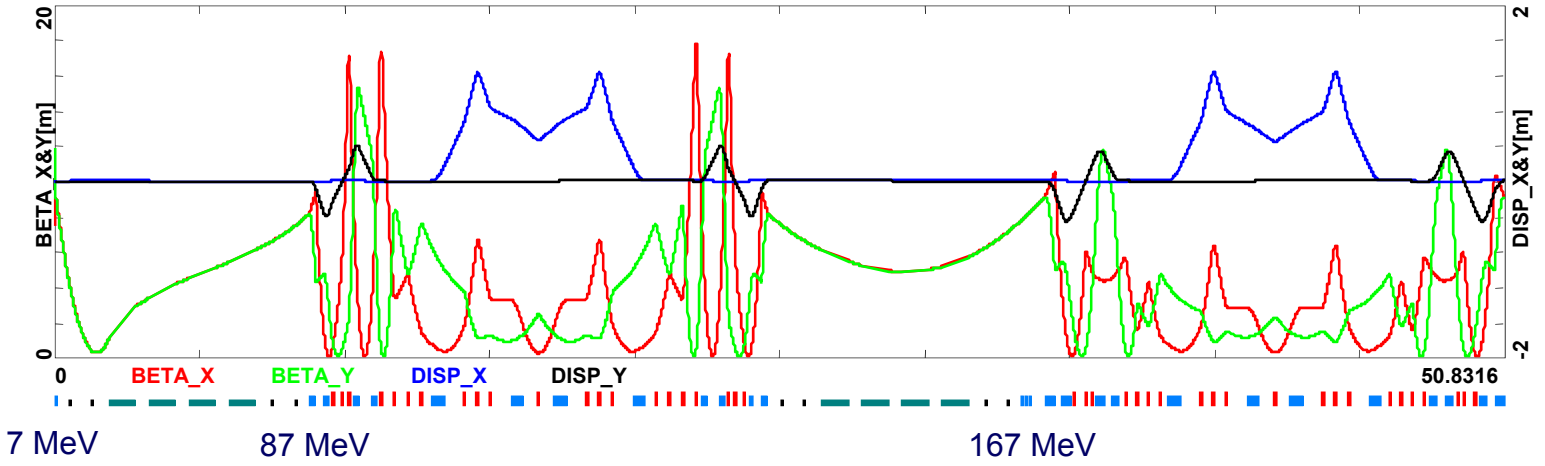
Arc dipoles :
4×45⁰ bends
L = 45.6 cm
B = 4.5 kGauss

Rec. dipoles:
4× 45⁰ bends
L = 20 cm
B = 9.5 kGauss

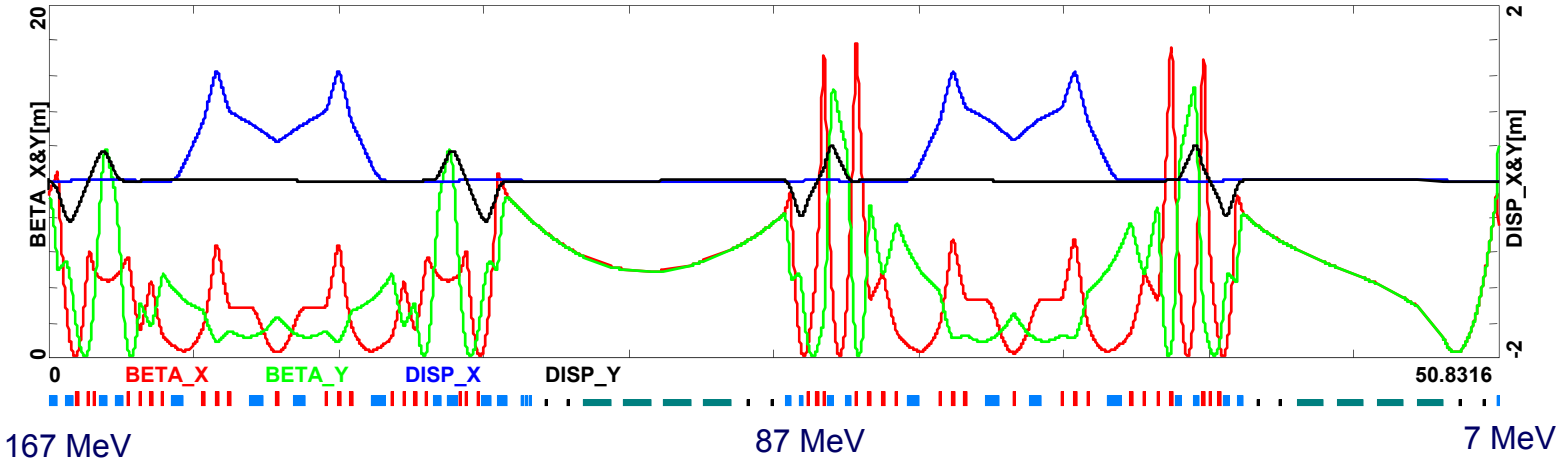
quads: L = 10 cm G ≤ 1 kGauss/cm

1 pass up + 1 pass down optics:

Pass-1 ‘up’

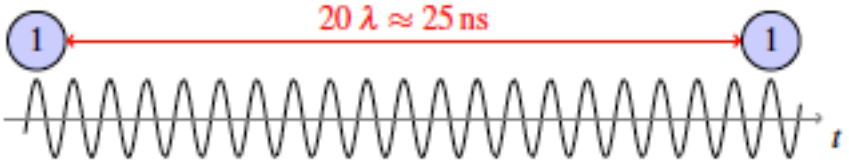


Pass-1 ‘down’



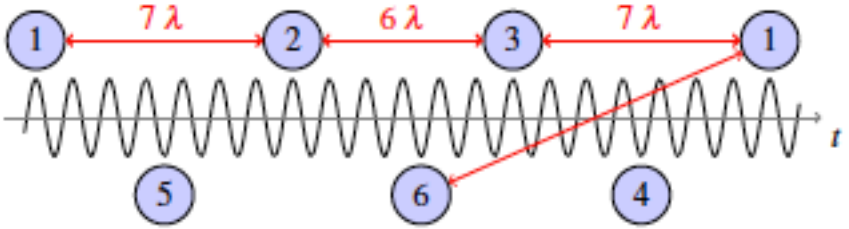
Bunch recombination pattern:

- 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	$n \times 20\lambda + 3.5\lambda$



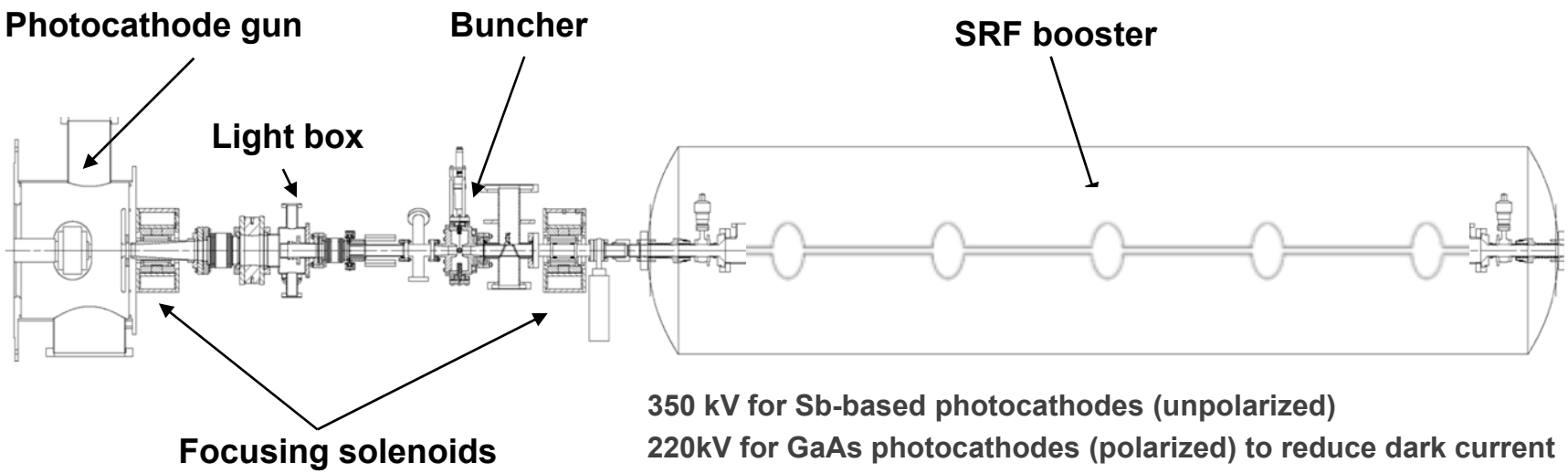
  - Maximize the distance between the lowest energy bunches (1 & 6): ovoid reducing the BBU threshold current due to the influence of HOMs kicks
  - Achieve a nearly constant bunch spacing: minimize collective effects

Electron source and injector:

Boris Militsyn & Benjamin Hounsell- Daresbury

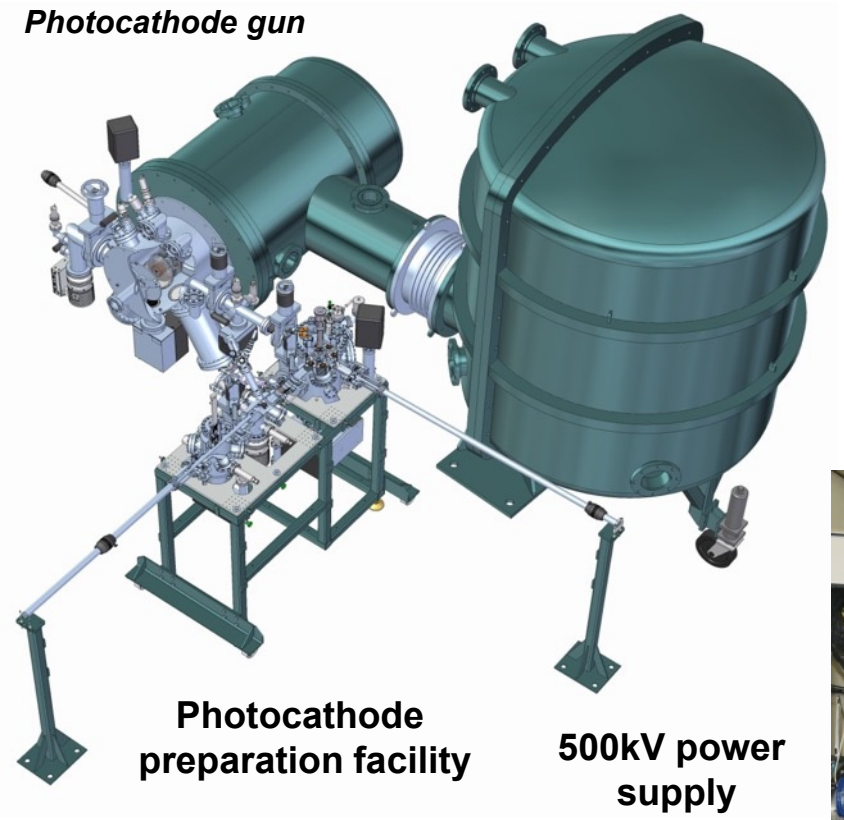
The PERLE injector consists of:

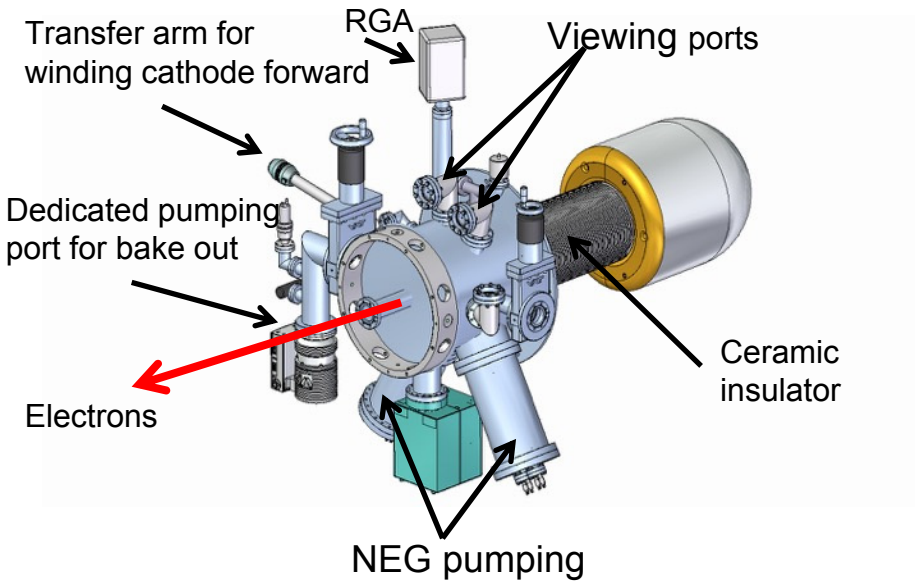
- The upgraded DC photoemission electron gun of ALICE.
- A bunching and focusing section: 401 MHz or 802 MHz normal conducting buncher cavity placed between two solenoid.
- A superconducting booster with 5 single cell 802 MHz cavities with individual control of the amplitudes and phases.
- Merger to transport the beam into the main LINAC,
- Beam diagnostics to be placed between components.

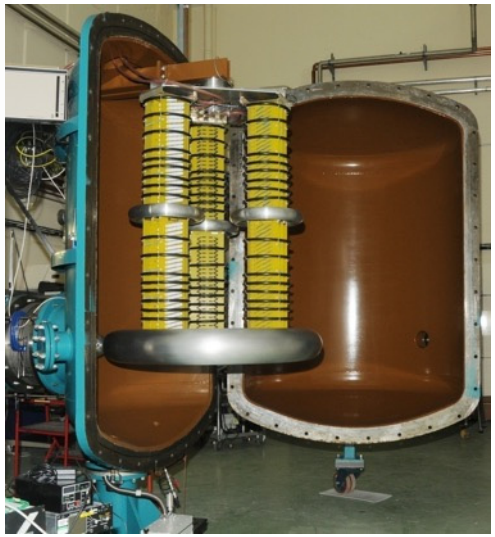


350 kV for Sb-based photocathodes (unpolarized)
220kV for GaAs photocathodes (polarized) to reduce dark current

Electron source and injector:







Electron source and injector:

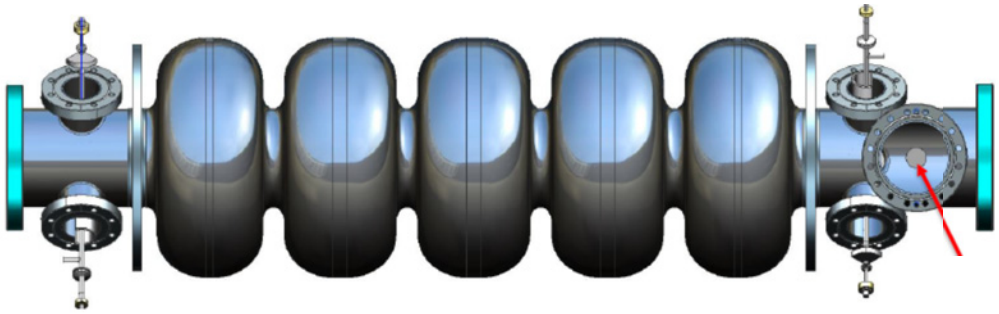
Ongoing studies at Daresbury for ALICE gun upgrade to operate at up to 500 pc:

- 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 (401 MHz or 802 MHz) in order to minimise emittance growth,
- Optimise beam transport from the gun to the booster to minimise transverse beam size and compensate emittance.

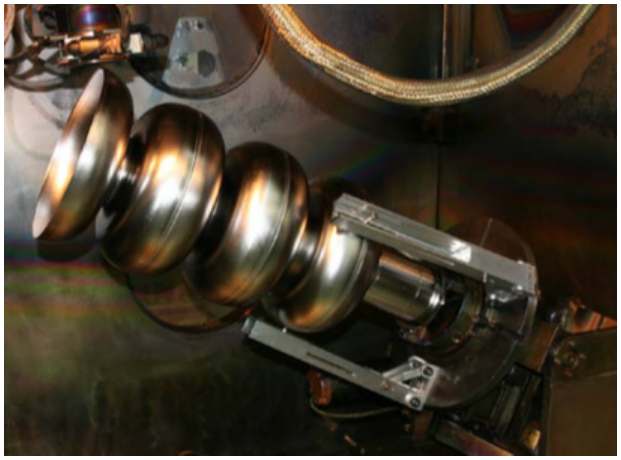
Main cavity parameters:

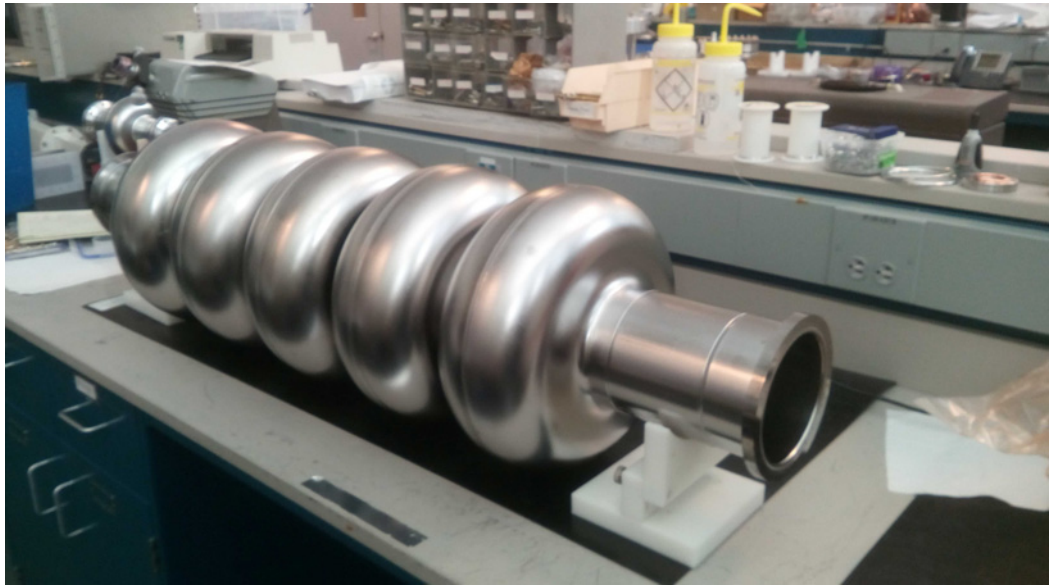
Frank Marhauser-JLAB

Parameter	Unit	Value
Frequency	MHz	801.58
Number of cells		5
Iris/tube ID	mm	130
L_{act}	mm	917.9
$R/Q = V_{eff}^{\wedge}/(\omega \cdot W)$	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



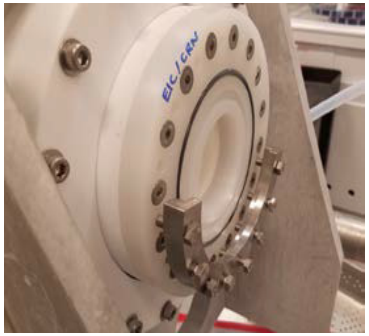
Cavity fabrication and test:

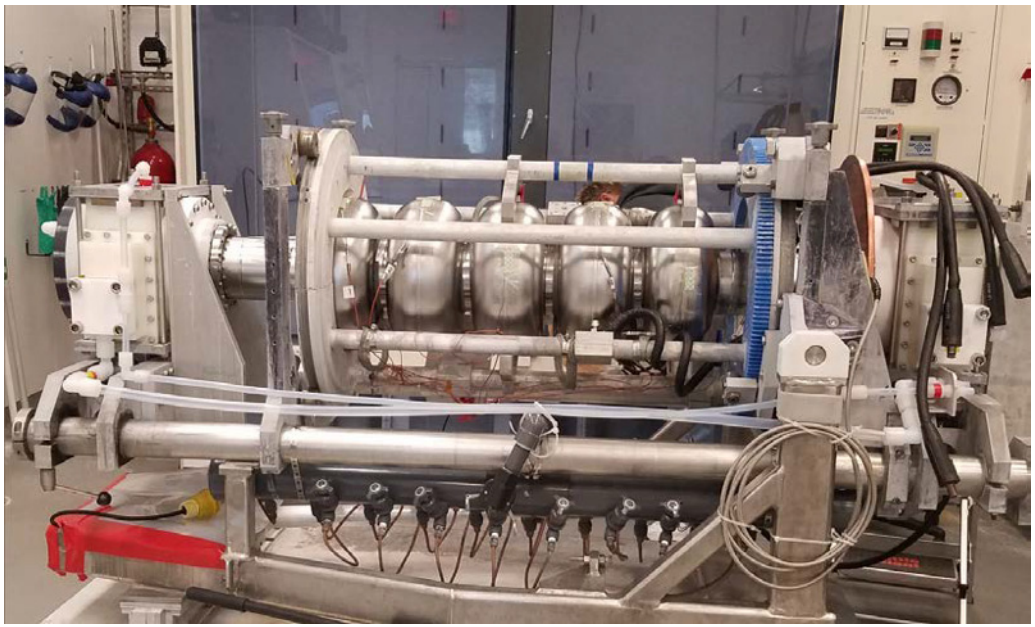


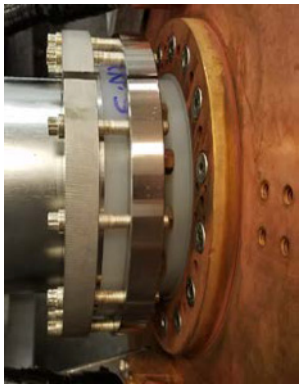


The first Nb 802 MHz 5-Cell cavity fabricated October 2017 at JLAB

Cavity fabrication and test:

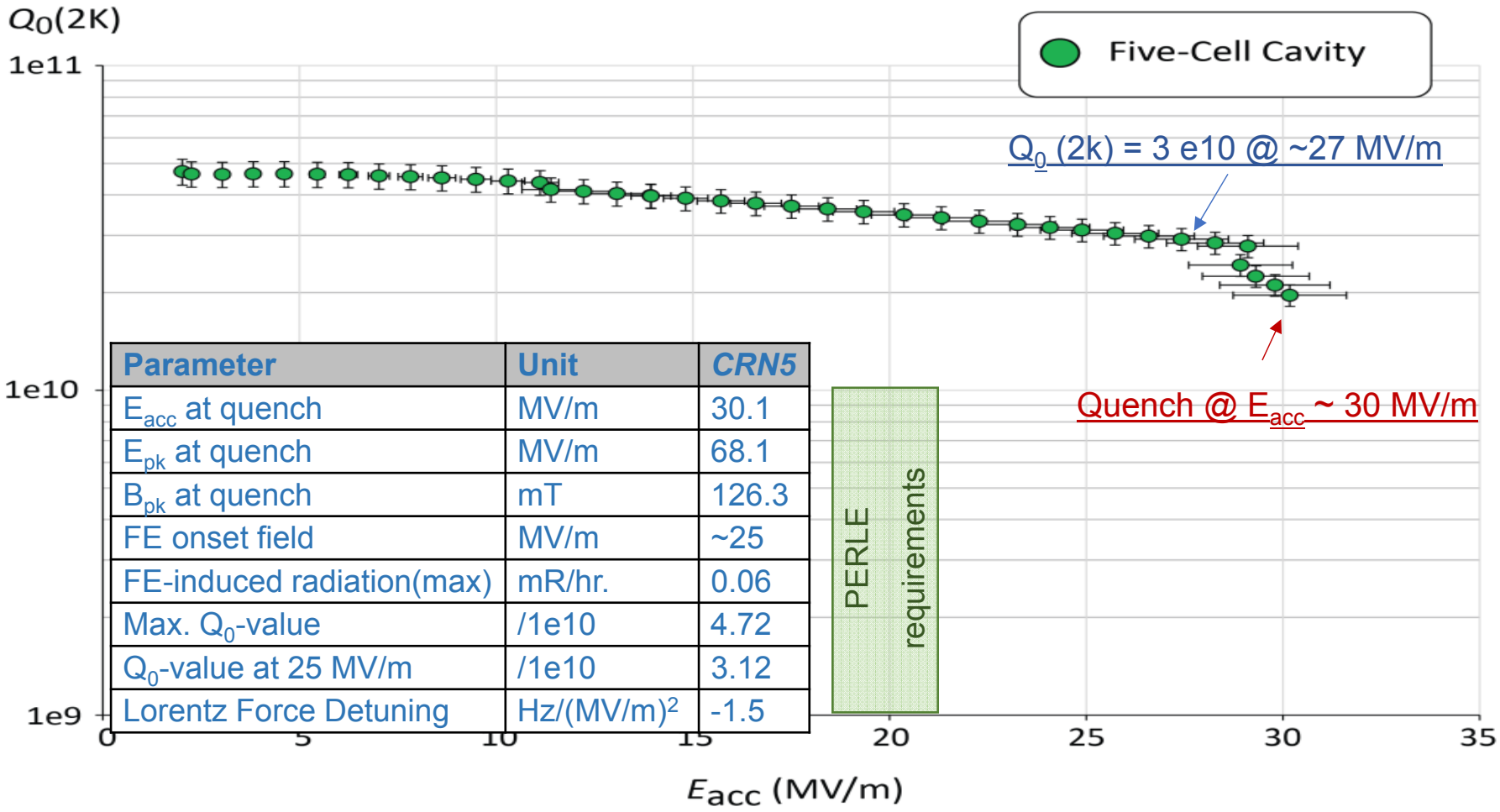






5-cell cavity successfully electropolished with new flange adapters

Cavity fabrication and test:



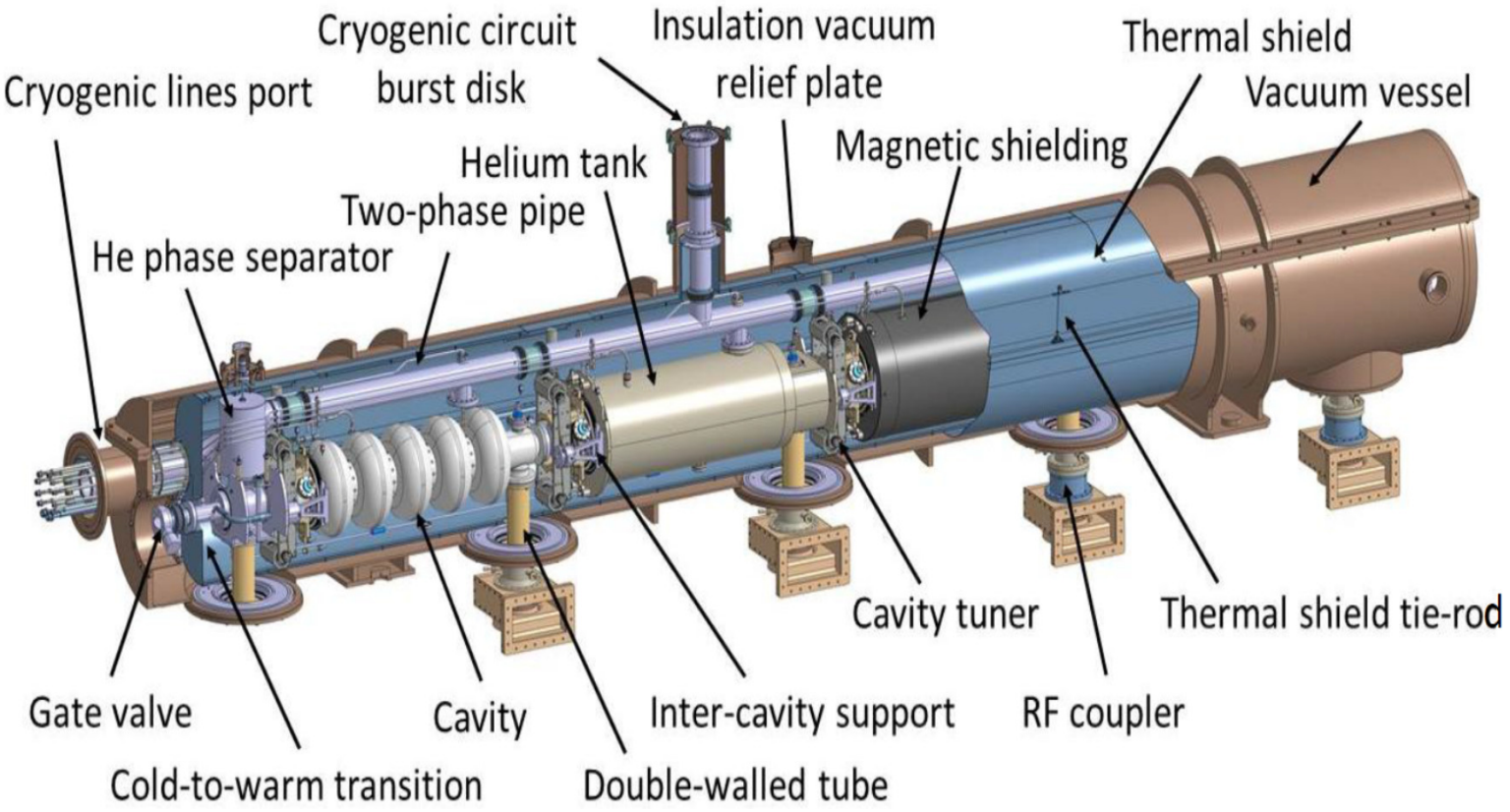
Parameter	Unit	*CRN5*
E_{acc} at quench	MV/m	30.1
E_{pk} at quench	MV/m	68.1
B_{pk} at quench	mT	126.3
FE onset field	MV/m	~25
FE-induced radiation(max)	mR/hr.	0.06
Max. Q_0-value	/1e10	4.72
Q_0-value at 25 MV/m	/1e10	3.12
Lorentz Force Detuning	Hz/(MV/m)^2	-1.5

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

Cryomodule design study:

Gilles Olivier-IPNo & Luca Dassa-CERN

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



SPL cryomodule: designed to integrate 4 elliptical 5-cells 704 MHz cavities

Cryomodule design study:

First results:

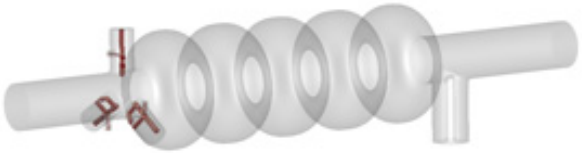
- Thermal and magnetic shielding are well sized for PERLE operation parameters,
- Input coupler designed for SPL cavity could be easily adapted to meet PERLE requirement,
- Space liberated due to cavity frequency difference give a margin for auxiliaries integration,

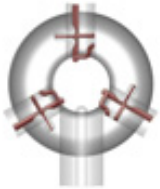
Pending issues:

- HOM study will define the design and the number of HOM couplers to be used → Will define the final decision to adapt the SPL cryomodule for PERLE or not.

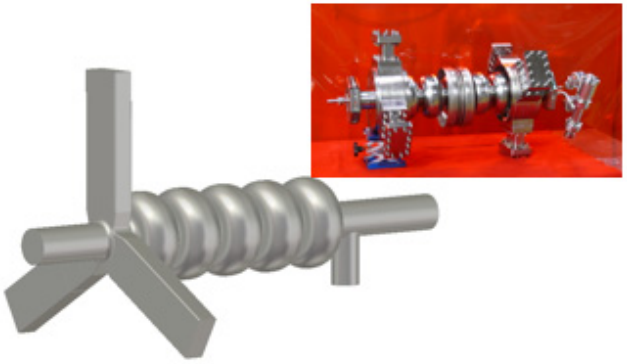
HOM studies

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

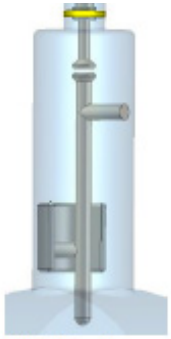




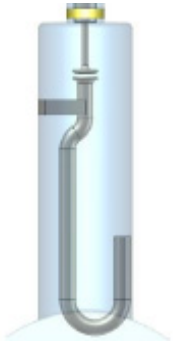
HOM 'Y' end-group with 3 coaxial couplers (here with scaled TESLA-type couplers)



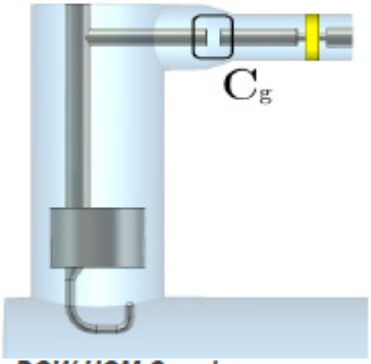
HOM 'Y' 'High Current' waveguide coupler end-group



LHC Probe-type



LHC Hook-type



DQW HOM Coupler

Next steps

• Formalize the collaboration in the coming months by signing the MoU between PERLE collaboration members. Interested lab/institutions are welcome to join!

• Draft the PERLE TDR by mid-July 2019.

• Parallel to the TDR writing, a prototyping activity on key components based on lab internal funds or in-kind contributions

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

• Define and set a list of key scientific cases for PERLE

- ERL Accelerator demonstrator
- Gamma ray beam generation
- Electron proton scattering
- Nuclear physics: electron diffusion on radioactive ion beams

Acknowledgments

Thanks to all the collaborators for their efforts and contributions to the success of PERLE project

BINP: E. Levichev, Y. Pupkov.

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CNRS- LAL: I.Chaikovska, A. Stocchi, C. Vallerand.

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STFC-Daresbury Laboratory: D. Angal-Kalinin, J. McKenzie, B. Militsyn, S. Smith, P. Williams.

University of Liverpool: B. Hounsell, M. Klein, U. Klein, P. Kostka, C. Welsch.

谢 谢!

Thank you for your attention

La jeune fille à la perle- J. Vermeer (1665)