PERLE Facility: Status and Further Steps

On behalf of PERLE Collaboration

Walid Kaabi-LAL/CNRS

Introduction:

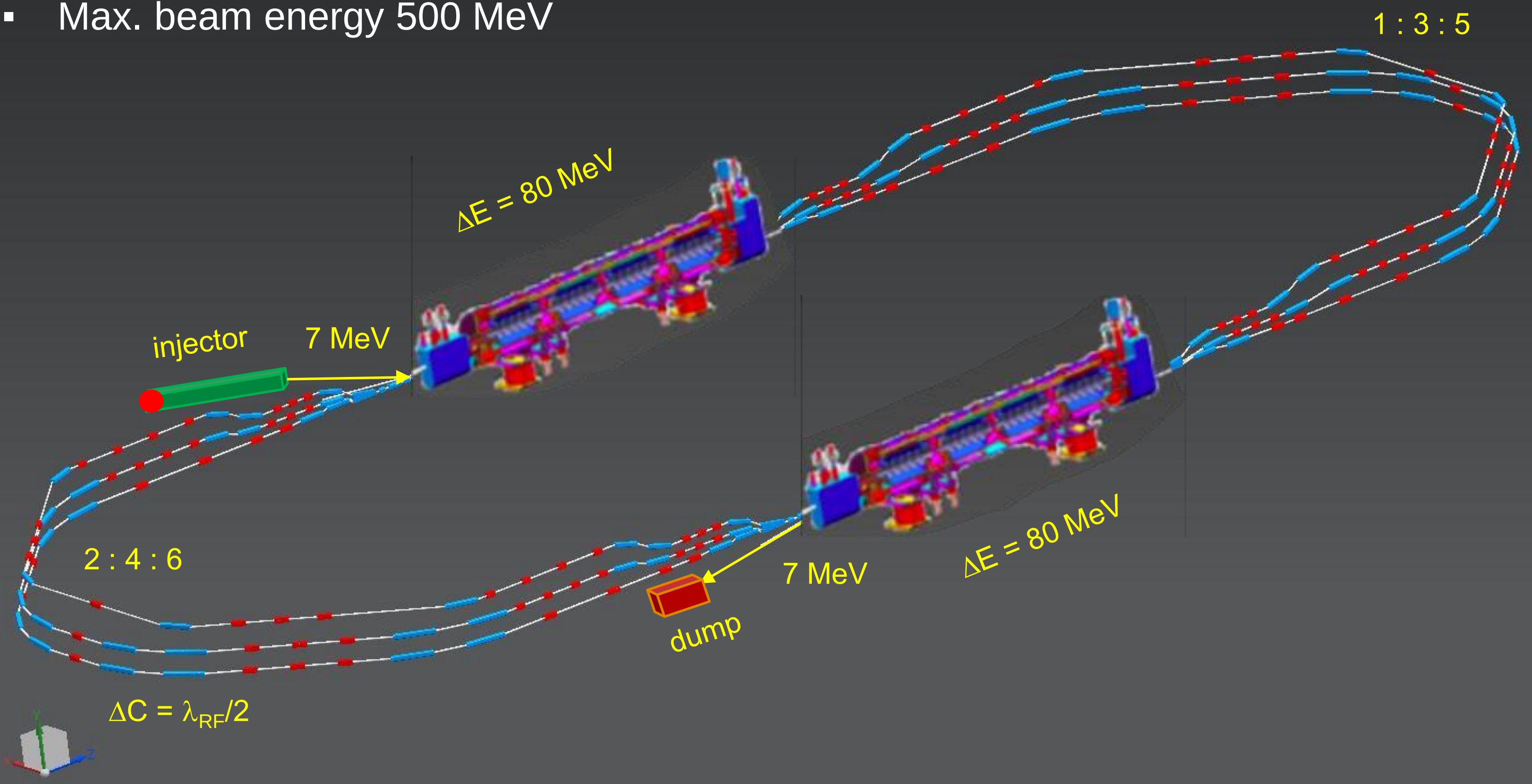
PERLE is a high current, multi-turn ERL facility (900 MeV), designed to study and validate main principles of the Large Hadron Electron Collider (LHeC: 60 GeV).

The Orsay realization of PERLE (Called PERLE@Orsay) is a smaller version (500 MeV) with the same design challenges and the same beam parameters:

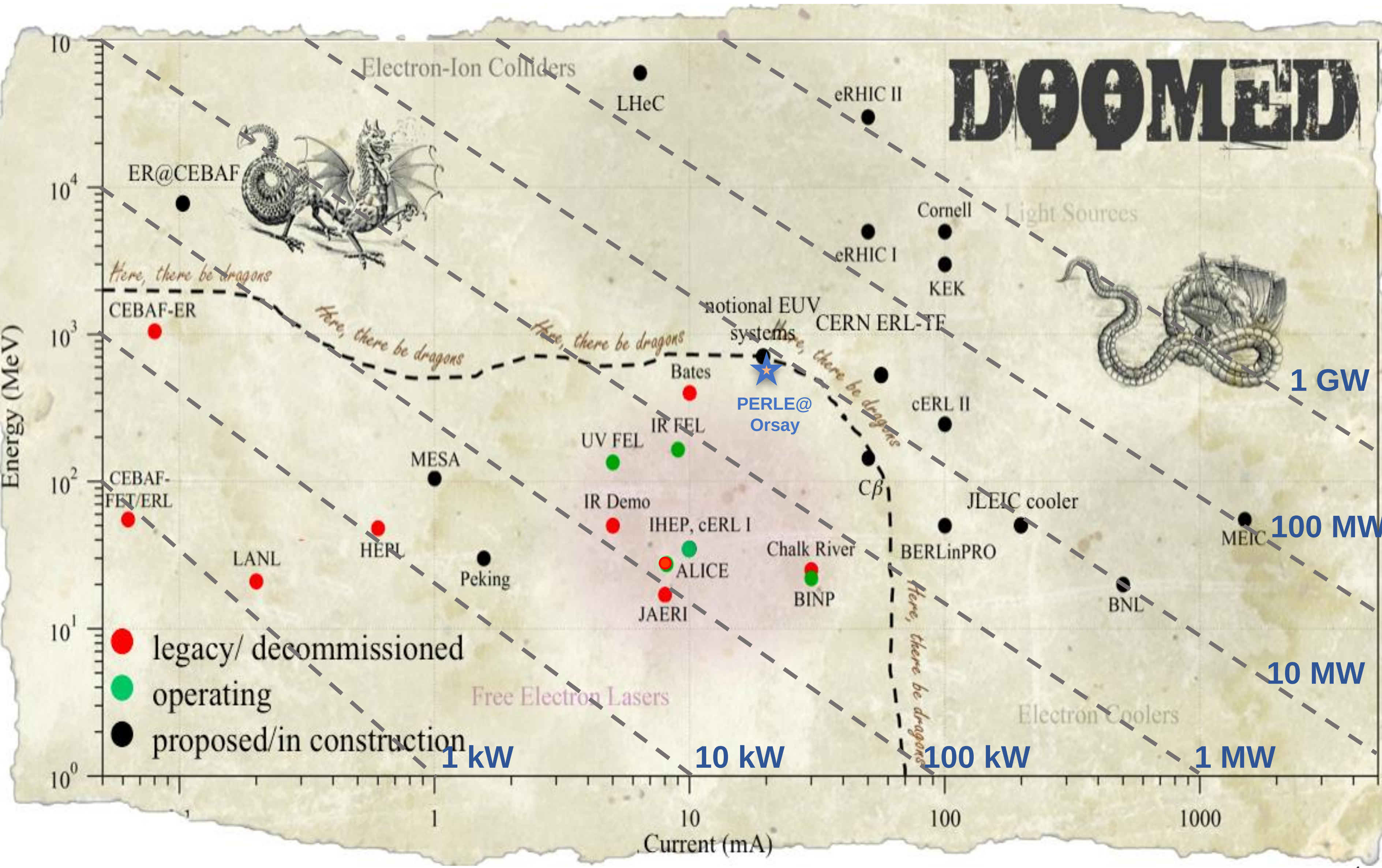
Target Parameter	**Unit**	**Value**
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE@Orsay configuration:

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



PERLE@Orsay in the global landscape:

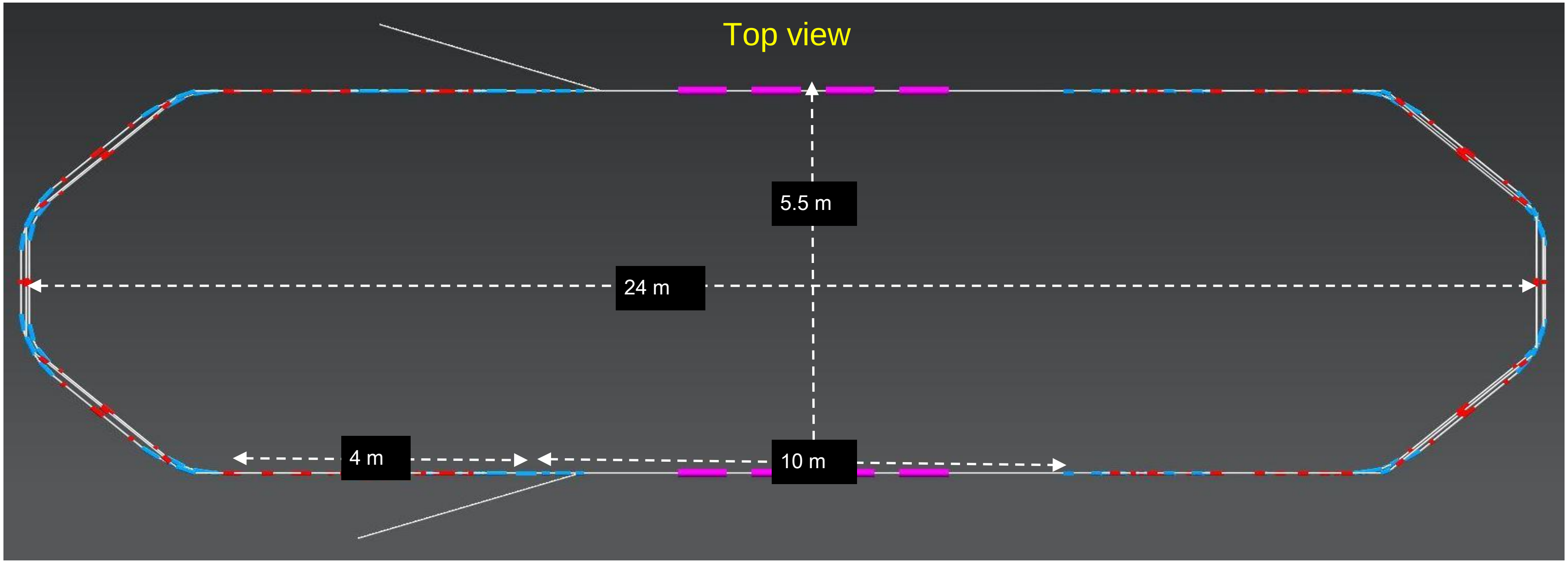


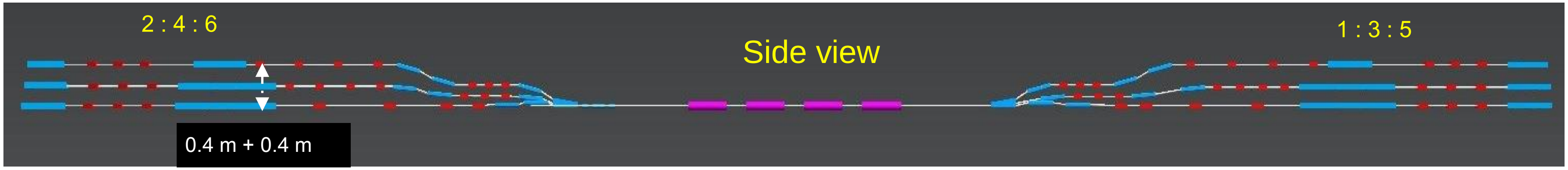
PERLE collaboration:

- The PERLE@Orsay collaboration includes today CERN, JLAB, ASTeC Daresbury, University of Liverpool, BINP, LAL and IPN Orsay.
- We are open to **new collaborators.**
- The collaboration signed the PERLE Conceptual Design Report (CDR) submitted for publication in J. Phys. G
- LAL organized the 1^{st} PERLE@Orsay workshop in February $23\text{-}24^{th}$ 2017.
- PERLE@Orsay was presented at ERL 2017 conference and meet a high interest of the community, supportive to see PERLE becoming a real project, with proposals of synergetic work with other ERLs in construction worldwide.
- First PERLE collaboration meeting was held at Daresbury, January $15\text{-}16^{th}$ 2018. Next one is foreseen at Orsay, on June 27-29th 2018 during the LHeC workshop (Electrons for LHC).
- Next step will be the redaction of PERLE Technical Design Report (TDR).

PERLE Layout:

Alex Bogacz- JLAB





Footprint: 24 x 5.5 x 0.8 m^3

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 height of magnet 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	

PERLE magnet design (dipoles and quadrupoles):

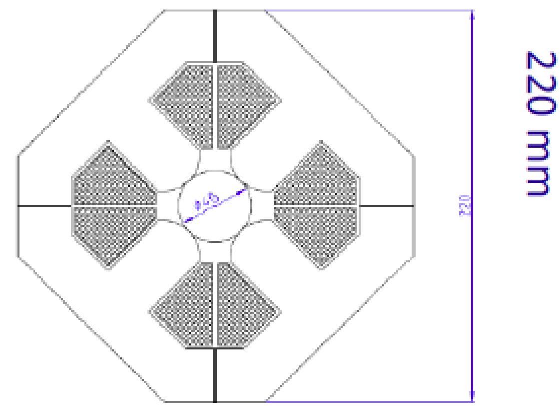
70 dipoles 0.45-1.29 T

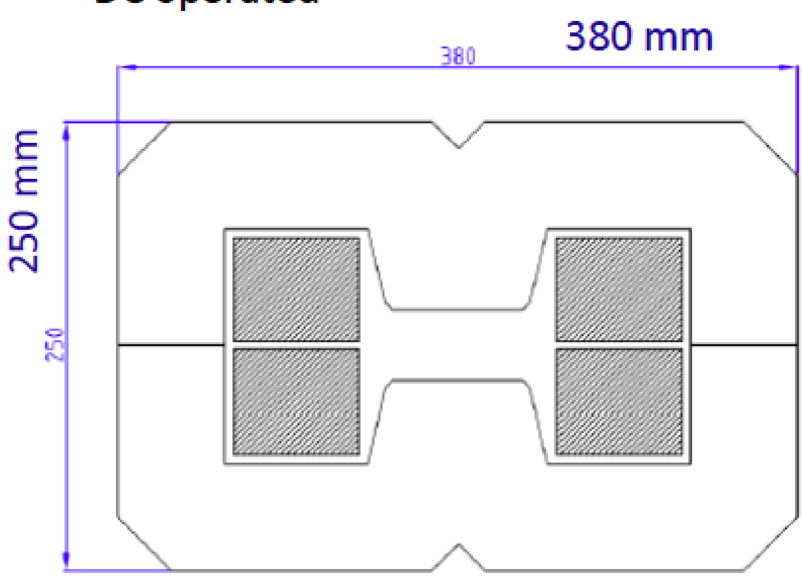
+- 20 mm aperture, l=200,300,400 mm

May be identical for hor+vert bend

7A/mm2 (in grey area) water cooled

DC operated





114 quadrupoles max 28T/m

Common aperture of 40mm all arcs

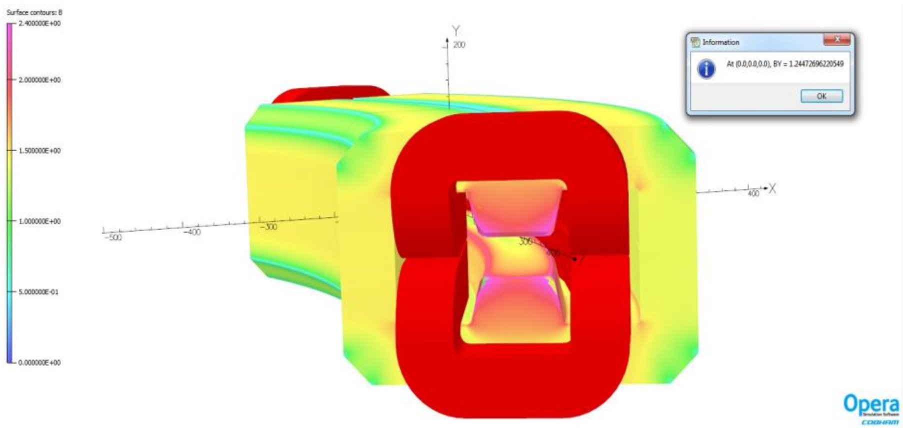
Two lengths: 100 and 150mm

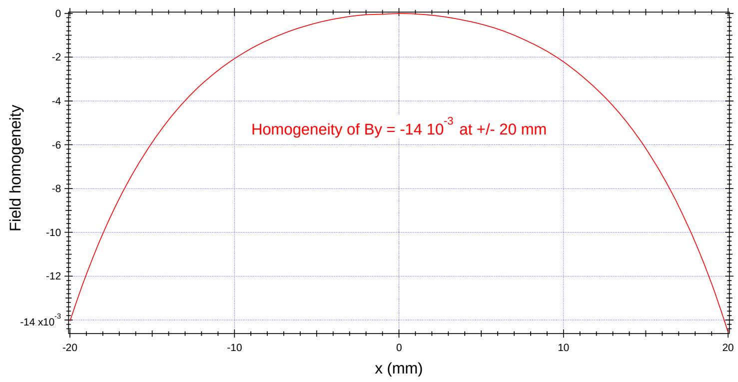
DC operated

P Thonet, A Milanese (CERN), C Vallerand (LAL), Y Pupkov (BINP)

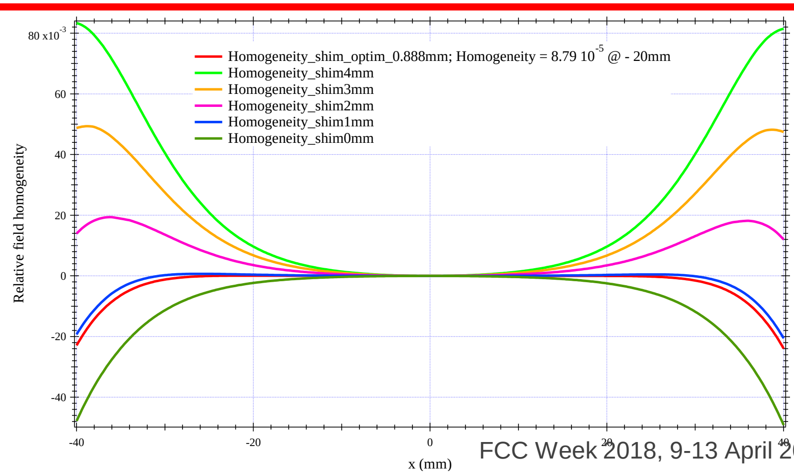
PERLE magnet design:

- 3D Simulation results from 2D design with bedstead coils





Value of vertical field at the center fulfill too requirements. We obtained with the same number of turns the same value but with a current density much lower than model with racetrack coil : **5.5A/mm2 instead of 7.8 A/mm.**

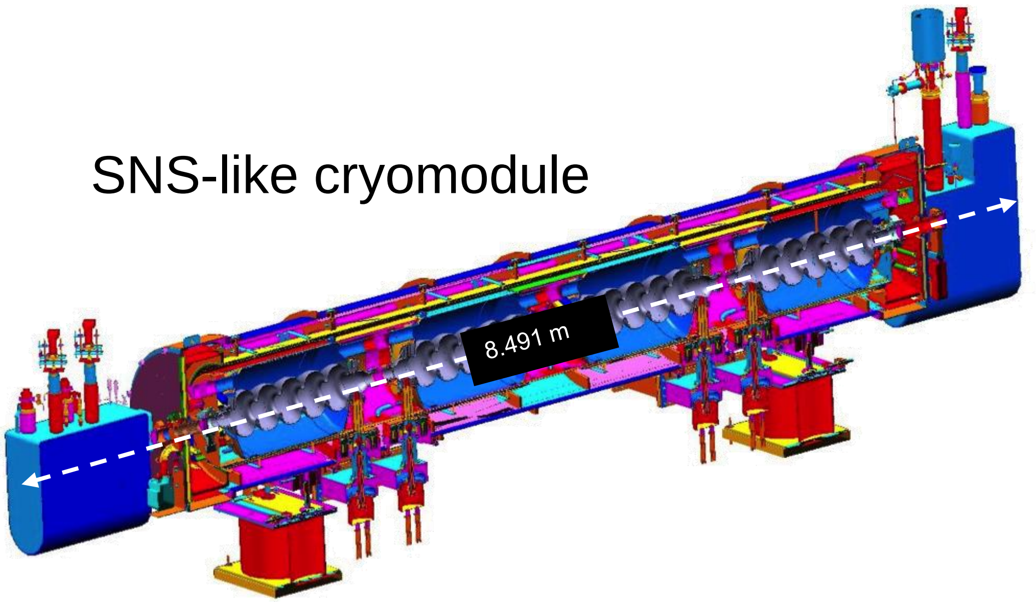


The field homogeneity with the optimized shim is 8.8 10^{-5} at ± 20 mm (GFR), better than expected (5 10^{-4}).

Linac, Cryomodule Layout:

Alex Bogacz- JLAB

SNS-like cryomodule



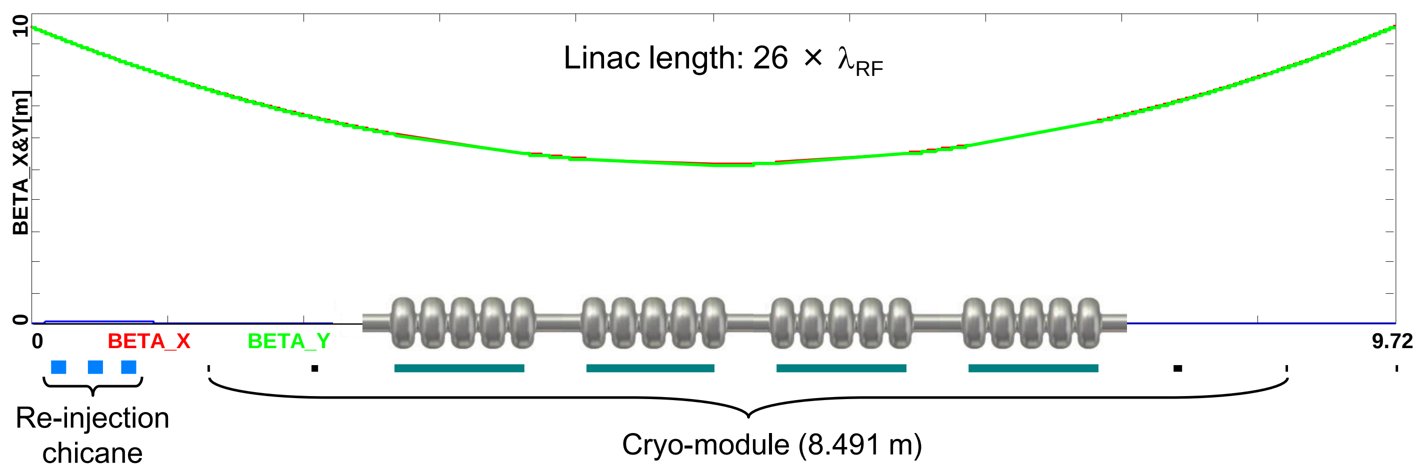
801.58 MHz RF, 5-cell cavity:

λ = 37.40 cm

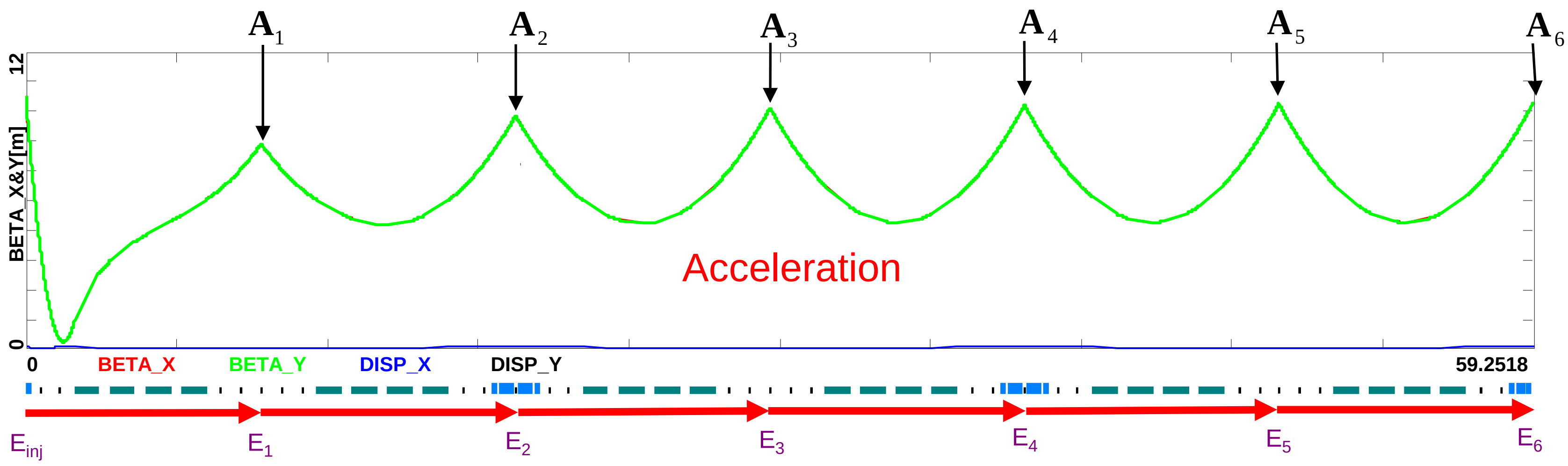
L_c = $5\lambda/2$ = 93.50 cm

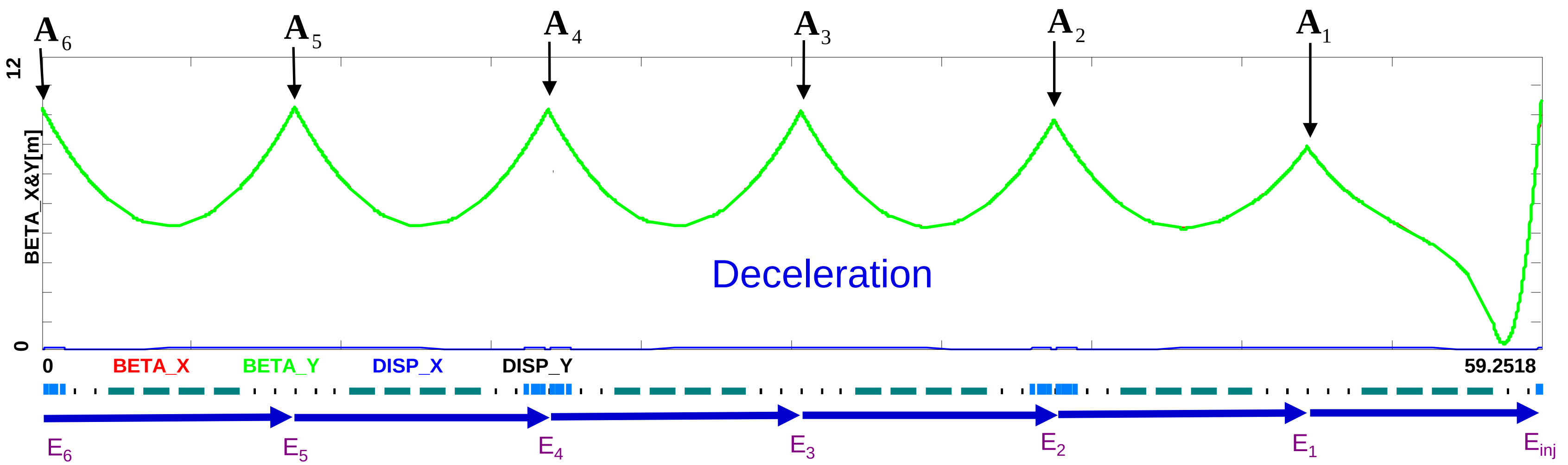
Grad = 21.4 MeV/m (20 MeV per cavity)

ΔE= 80 MeV per Cryo-module

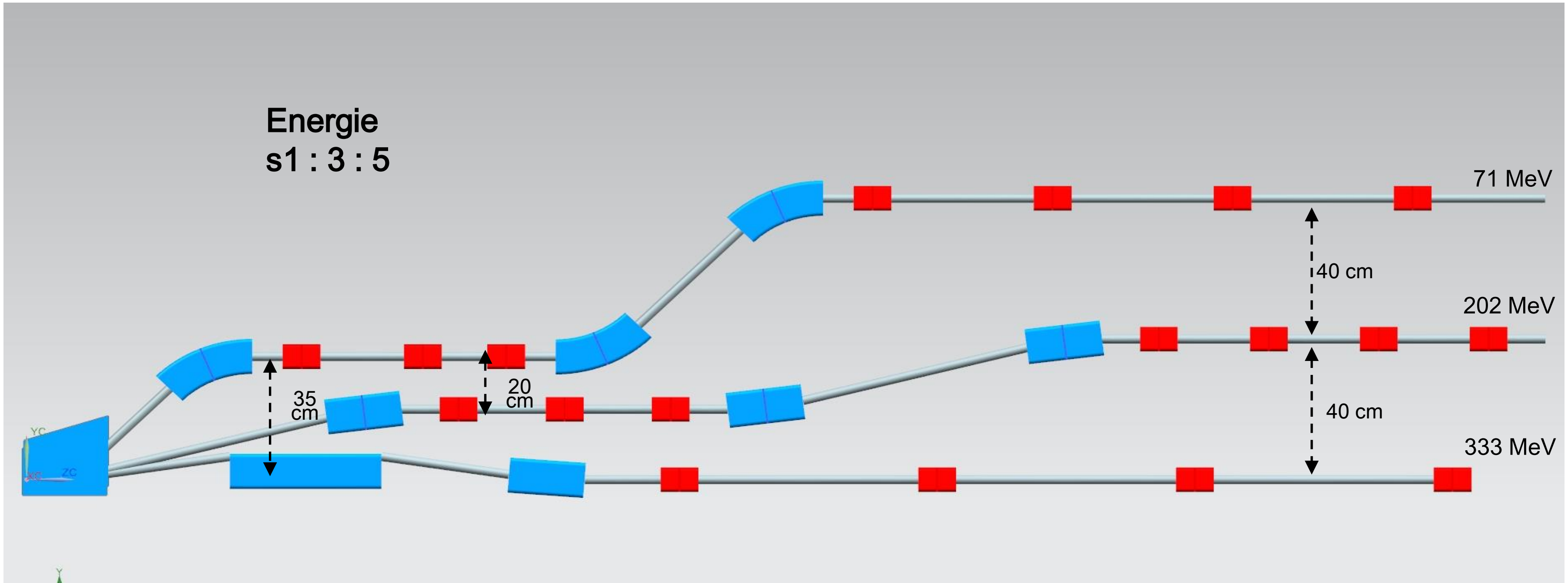


Multi-pass Energy Recovery optics:



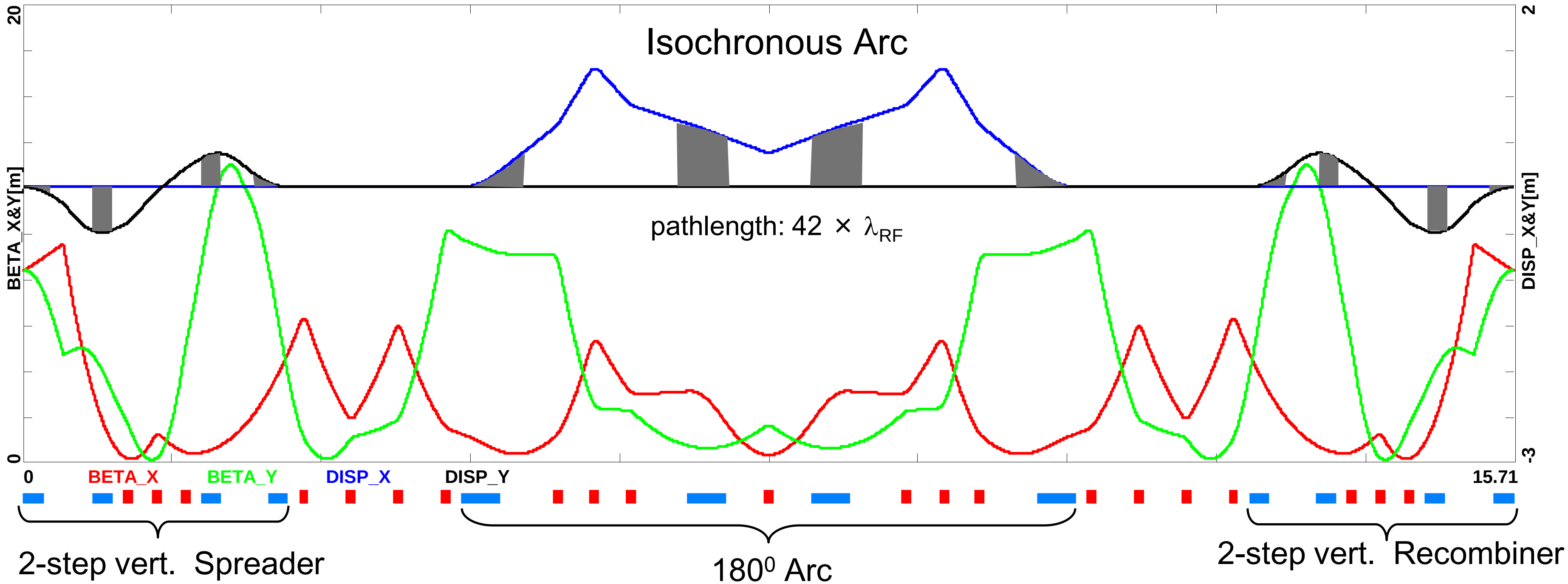


Switchyard- Vertical Separation of Arcs (1, 3, 5):



Dipoles: (20 and 40 cm long), B = 0.8 Tesla

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

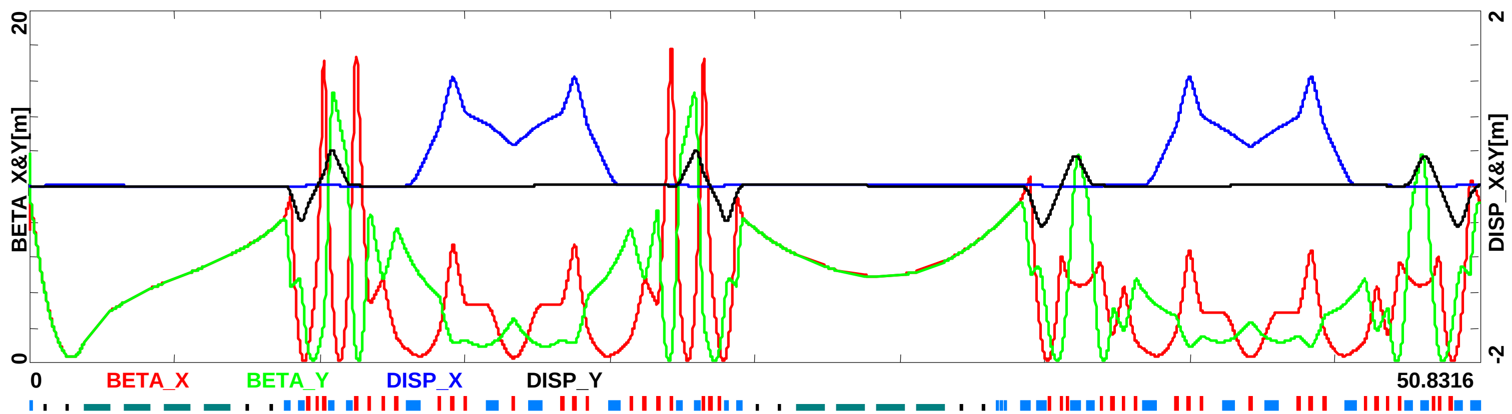
L = 20 cm

B = 9.5 kGauss

quads: L = 10 cm G ≤ 1 kGauss/cm

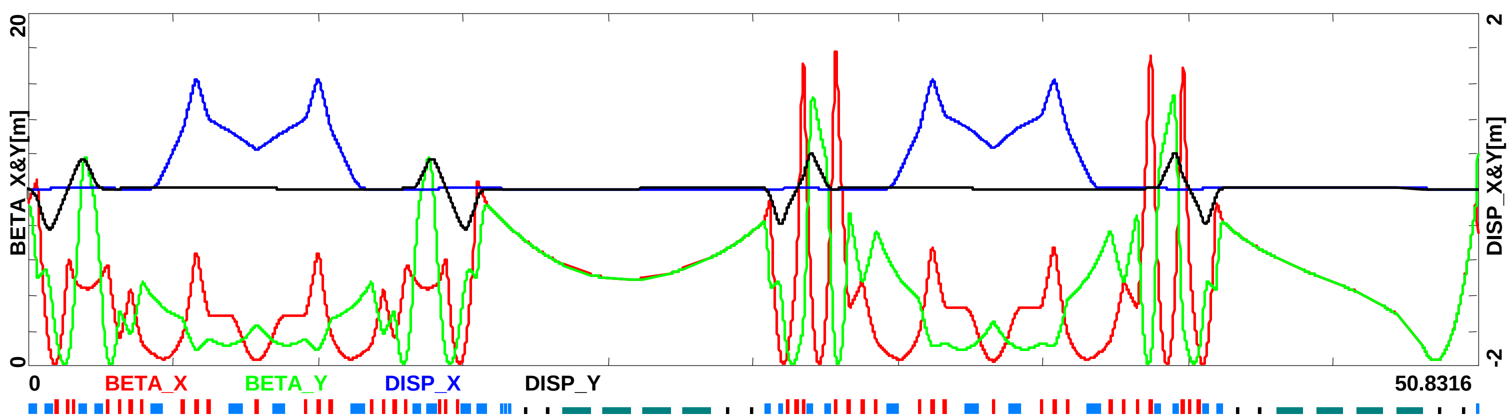
1 pass up + 1 pass down optics:

Pass-1 ‘up’



5 MeV 71 MeV 137 MeV

Pass-1 ‘down’

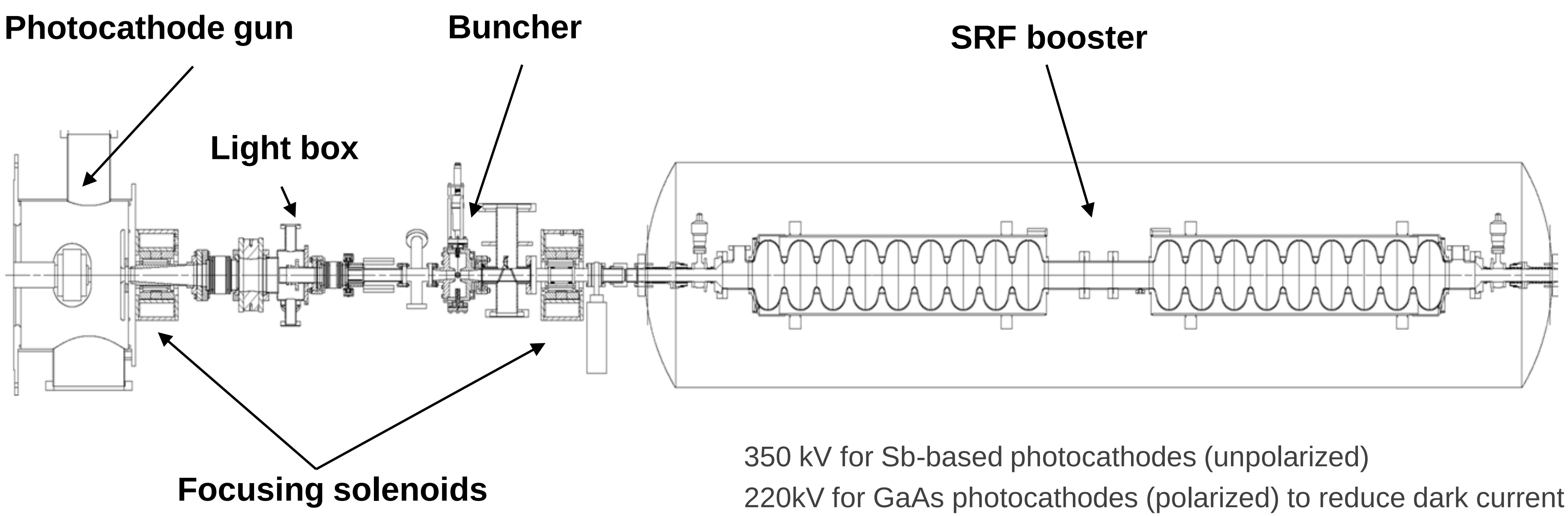


137 MeV 71 MeV 5 MeV

Electron source and injector:

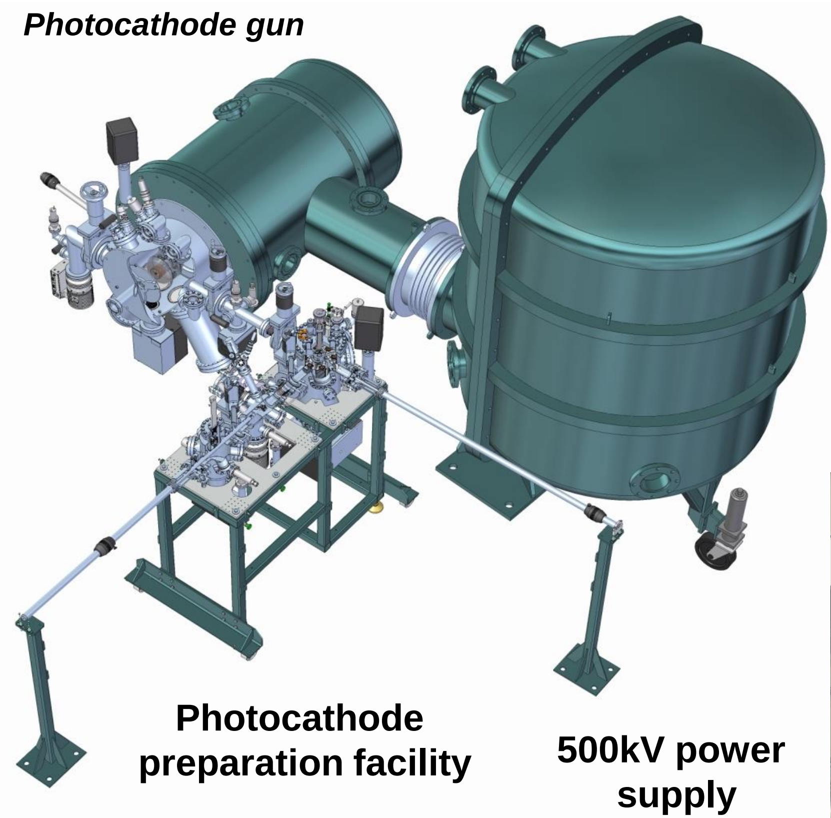
Boris Militsyn & Benjamin Hounsell- Daresbury

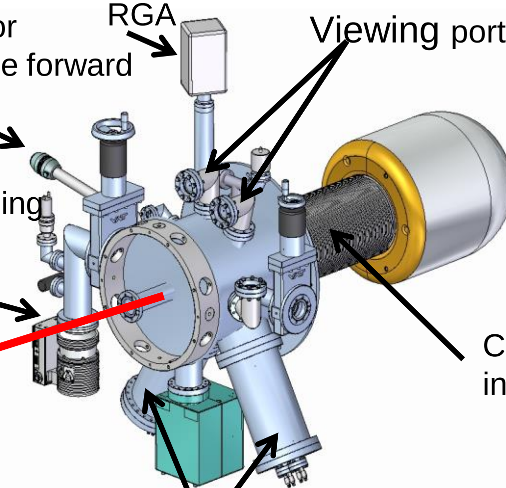
- Preferred concept: Photocathodes, DC Gun, single cell buncher and SRF accelerator (booster),
- Laser allows flexible bunching sequence,
- Nominal repetition rate 40.1 MHz (20^{th} sub-harmonic of 801.56 MHz),
- Nominal bunch charge: 3.12 10^9 e- = 500 pC → 500 pC x 40 MHz = 20 mA.



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

Electron source and injector:





Electron source and injector:

ASTeC/Cockcroft Institute:

Investigation operation of ALICE gun upgrade at up to 500 pc- Beam dynamic simulation

The goals of the simulations are:

- Optimisation of the laser pulse size (transverse and longitudinal) to minimise emittance of 500 pC beam delivered by the gun
- Choice of buncher frequency in order to minimize emittance growth
- Optimise beam transport from the gun to entrance of the booster to minimize transverse beam size and compensate emittance

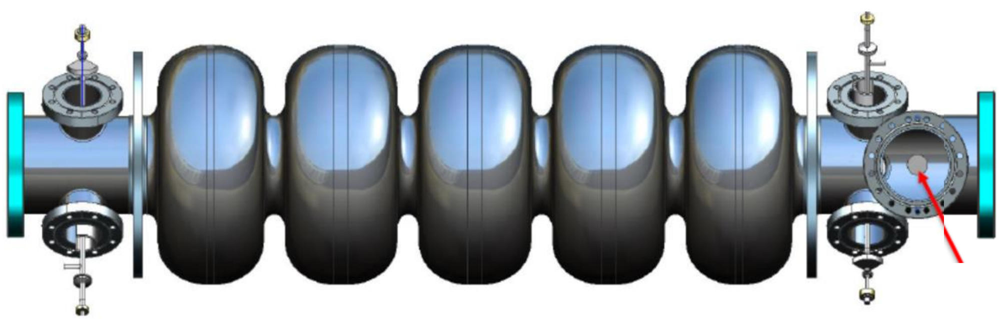
Current results:

- Beam dynamic simulation have been done at a bunch length of 28 ps delivered by existing ALICE laser with a pulse diameter of 8 mm
- 800 MHz normal conducting low-beta buncher cavity does not provide significant emittance growth
- Uncompensated beam emittance at the entrance of the booster is about 5.8 π·mm·mrad
- Maximum RMS beam diameter in the second solenoid is 8 mm. It may require adjustment of the gun optics to minimize it.

Main cavity parameters:

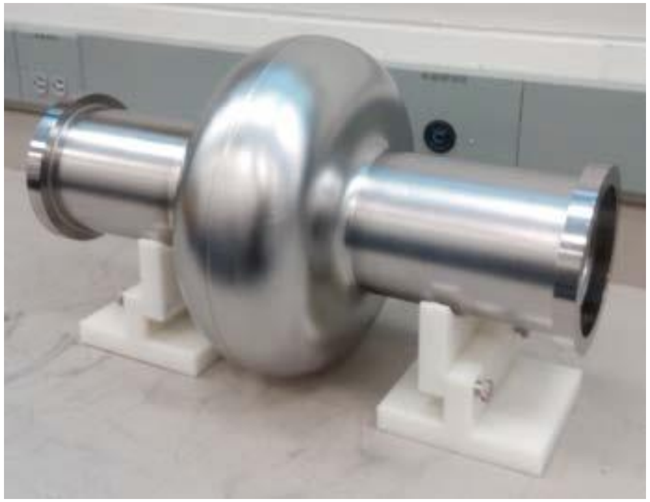
Frank Marhauser-JLAB

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:

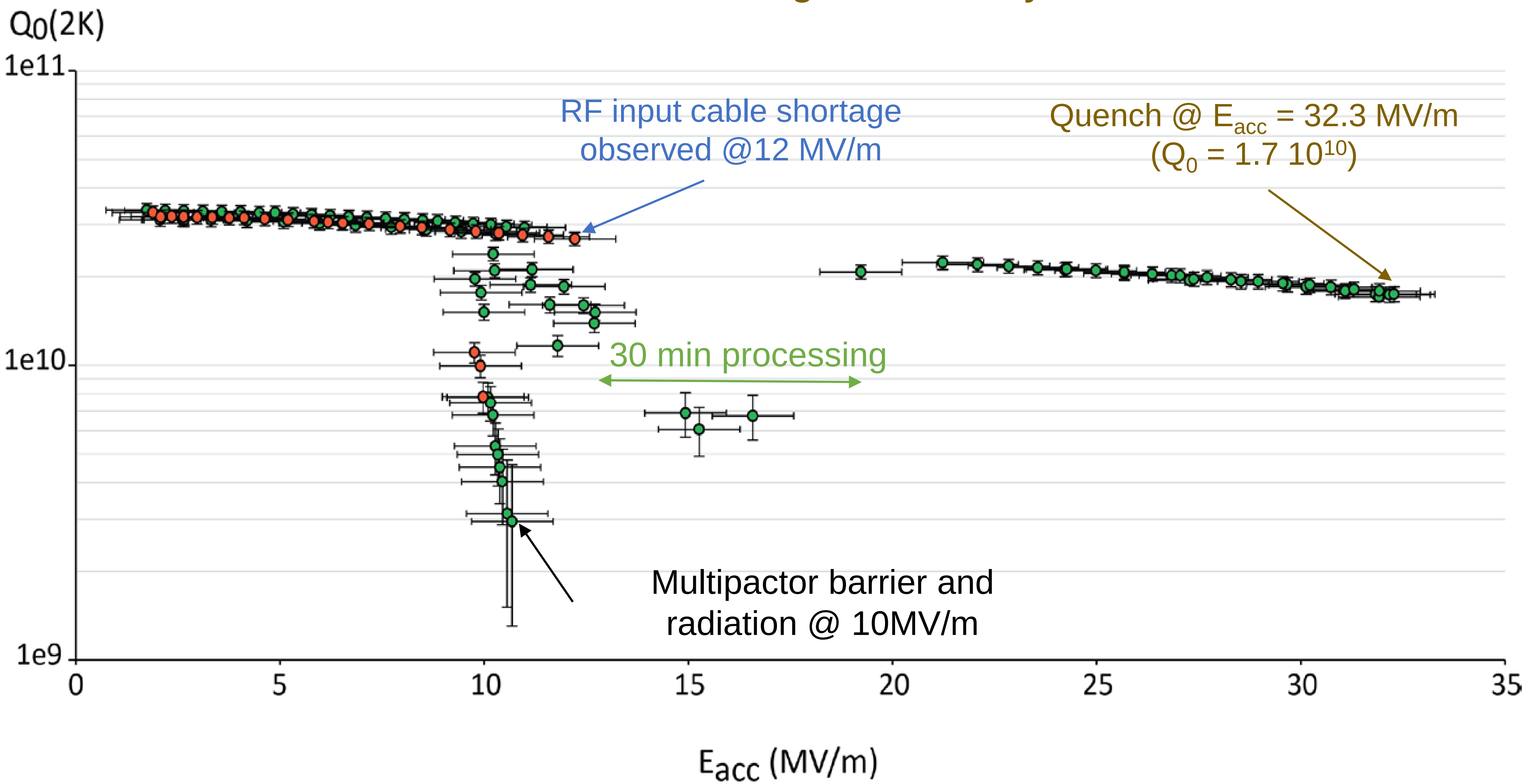
Single Cell:



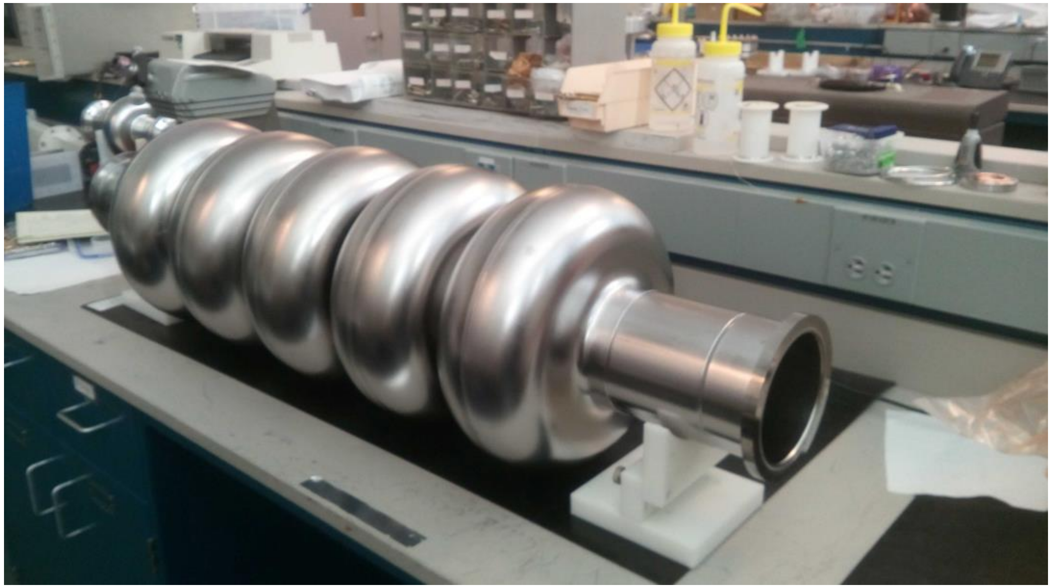
802 MHz Niobium single cell cavity has been completed in August' 17

Cavity fabrication and test:

- First test on single cell cavity
- Second test on single cell cavity

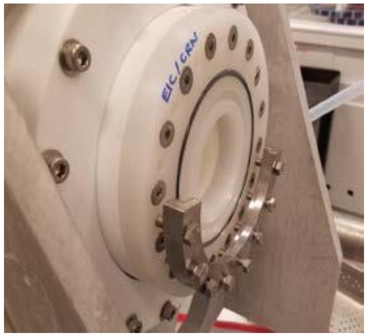


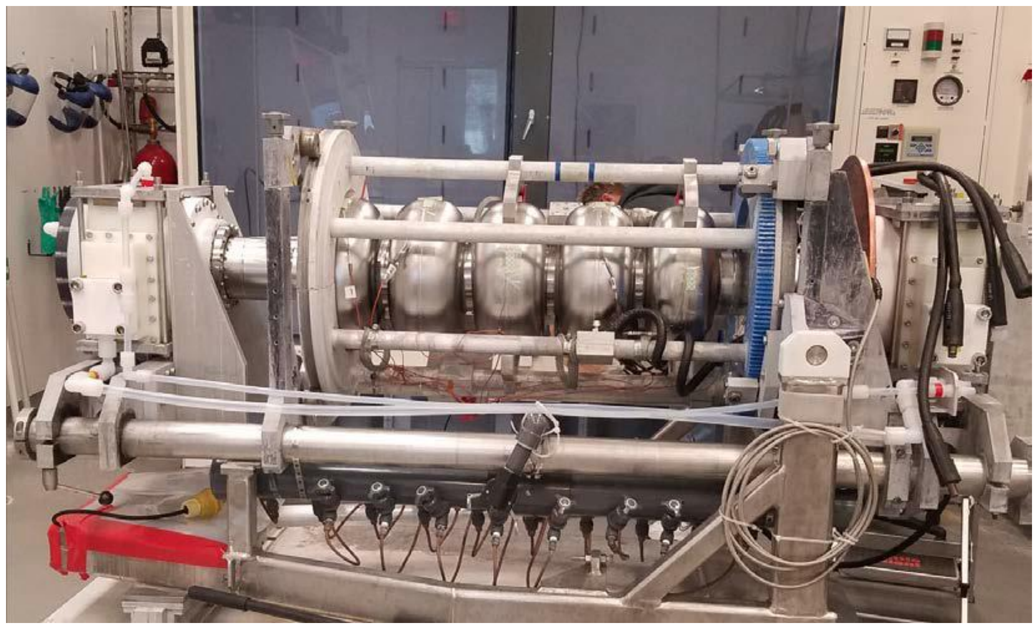
Cavity fabrication and test:



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

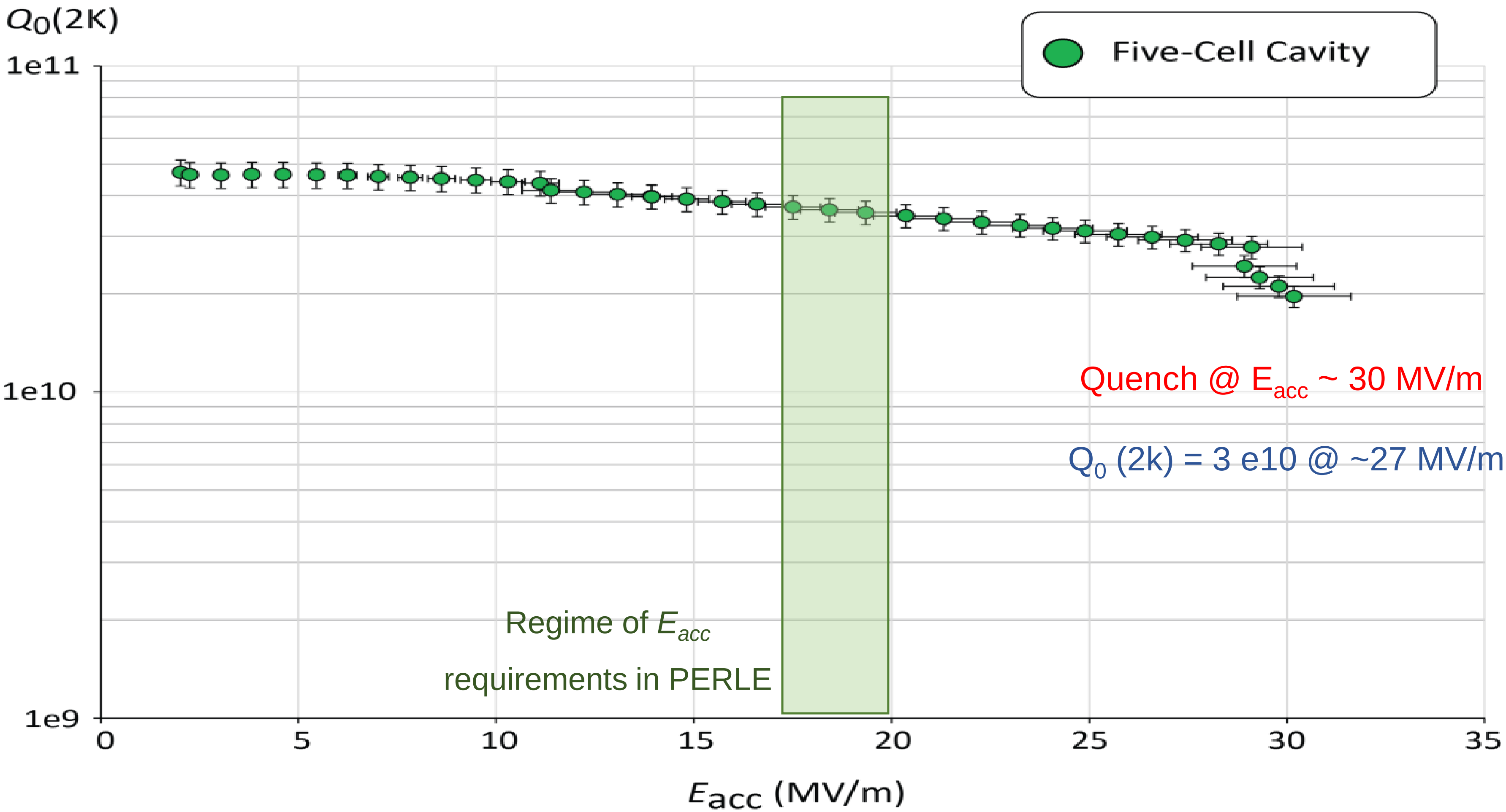
Cavity fabrication and test:





5-cell cavity successfully electropolished with new flange adapters

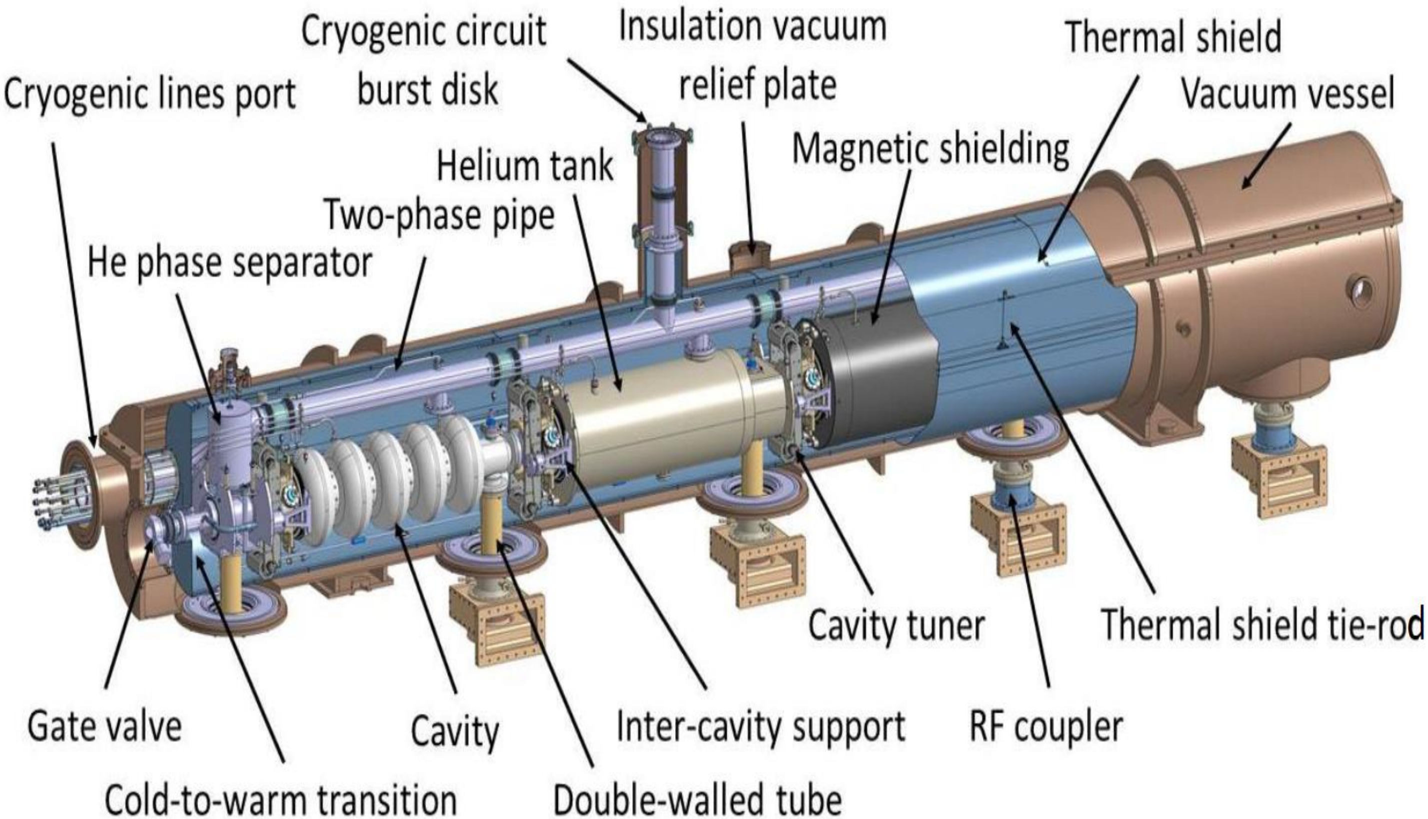
Cavity fabrication and test:



More details: F. Marhauser Talk- Tuesday, April 10

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:

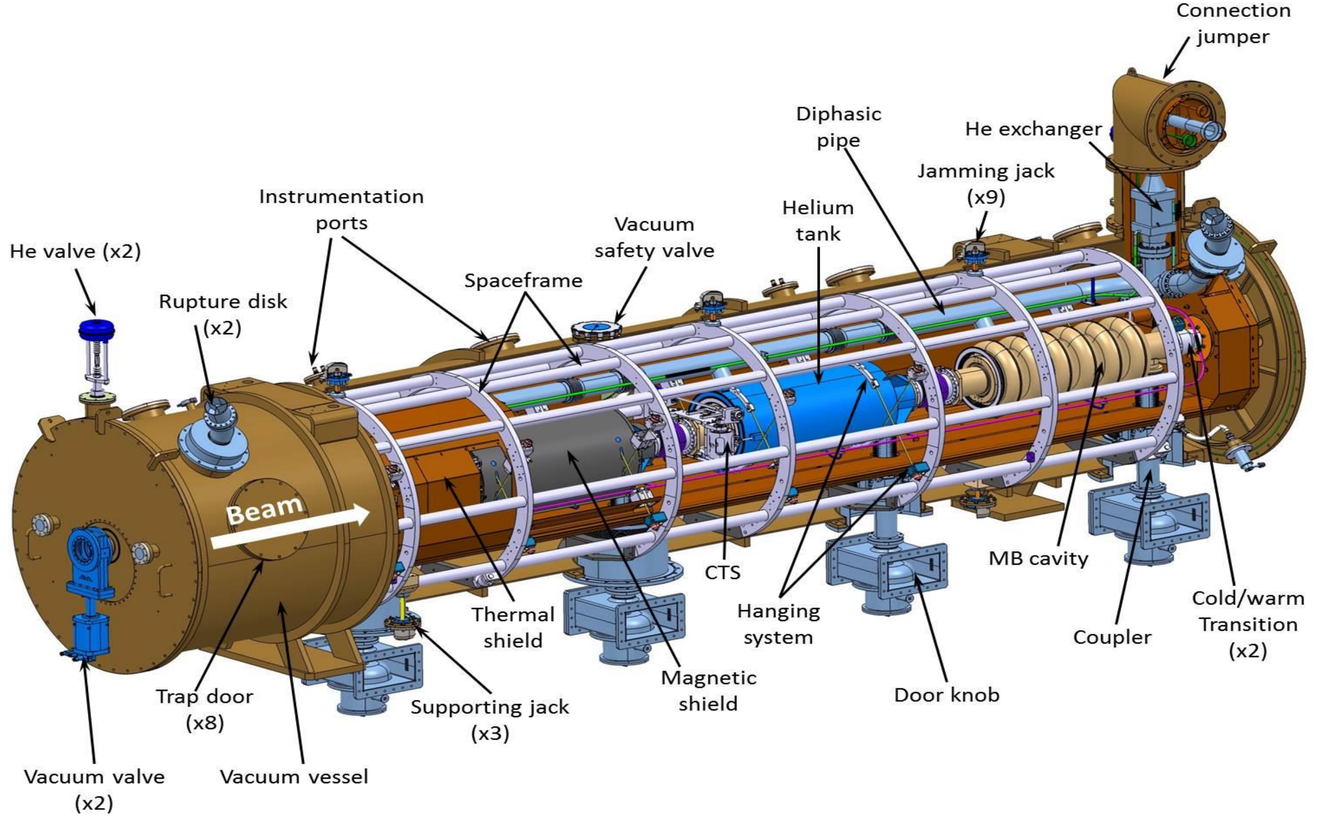
- Thermal and magnetic shielding are well sized for PERLE operation parameters,
- Input coupler designed for SPL cavity could be easily adapted for PERLE requirement,
- Space liberated due to cavity frequency difference give a margin for auxiliaries integration,

Pending issues:

- Find alternative solution to the beam line vacuum valve system,
- 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.

Cryomodule design study:

ESS cryomodule adaptation remain a possible solution for PERLE.



<u>ESS elliptical cryomodule general assembly view</u>

Next steps

Main goal:

to have a complete cryomodule assembled and ready for test in **3 years (Jan2018 – Dec2020)**

How ? → 2 stages:

P1: Prototype phase:

- Cavity: ongoing work on “naked” 5-cells (HOM study & BBU studies) + produce and test a complete cavity (cav#1)
- Couplers: design, produce and test 2 couplers (RF conditioning)
- Cryomodule: analyze the possibility to adapt SPL cryomodule to the 802 MHz PERLE cavity
- HOM design

→ In this first phase, all the design studies and test results of several components will be included in the TDR.

P2: series phase:

- 3 more cavities produced and tested
- Detailed design and fabrication of cryomodule
- 2 additional power coupler fabricated and tested
- All remaining HOM couplers produced
- 3 additional cold tuning system produced

→ Staging will allow to maintain the current dynamic within the collaboration and give time to think about a funding strategy.

Next steps

ASTeC/Cockcroft Institute:

Investigation possibility of using ALICE photo-injector as electron source for PERLE

- **350 kV photocathode gun**: Needs upgrade to operate with interchangeable Sb-based photocathodes. The upgrade was designed and many mechanical components have been delivered.
- Prototype of the **photocathode preparation system** for Sb-based photocathode has been designed.
- 500 kV 8 mA **gun power supply**: Could be used as it is with operational current of up to 5 mA. Operation with 20 mA requires upgrade.
- **Injector laser system:** Delivers 2.5 W 81.25 MHz 7 ps pulses in 532 nm. Laser may be used as such with high (more than 4%) QE photocathodes. Other laser components need upgrade as specified for low power train pulse operation.
- **Buncher and booster**: To be designed
- Use of the **gun solenoids** is under discussion as increase of the aperture may be required

Next steps

Important R&D effort still to be done in several fields:

- Linear lattice optimization and Initial magnet specifications
- Correction of nonlinear aberrations (geometric & chromatic) with multipole magnets
- Beam Dynamics (start to end simulation with synchrotron radiation, CSR and micro-bunching, Multi-particle tracking studies of halo formation
- Injection line/chicane design
- Space-charge studies at injection
- Final magnets and power supplies specifications
- Beam dumps optimization
- RF power source specification
- Cryogenics optimization
- Beam instrumentations
- LLRF
- Control software system
- Shielding and safety system

Electrons for the LHC
LHeC/FCCeh and PERLE
Workshop
June 27-29, 2018
LAL-Orsay, France
Bruno Mazoyer LAL Orsay 2018
Organising Committee:
Nestor Armesto (USC)
Oliver Brüning (CERN)
Walid Kaabi (LAL)
Uta Klein (Liverpool)
Zhiqing Zhang (LAL)
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Bruce Mellado (Wits)
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Georges Azuelos (Montreal)
Olaf Behnke (DESY)
Monica D'Onofrio (Liverpool)
Oliver Fischer (Karlsruhe)
Claire Gwenlan (Oxford)
Uta Klein (Liverpool)
Peter Kostka (Liverpool)
Masahiro Kuze (Tokyo)
Paul Newman (Birmingham)
Alessandro Polini (Bologna)
Fred Olness (Dallas)
Christian Schwanenberger (DESY)
Anna Stasto (Pennsylvania)
https://indico.cern.ch/event/698368/

Thank you for your attention!

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