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LHeC and FCC-eh Workshop

PERLE @ Orsay: Introduction and Status

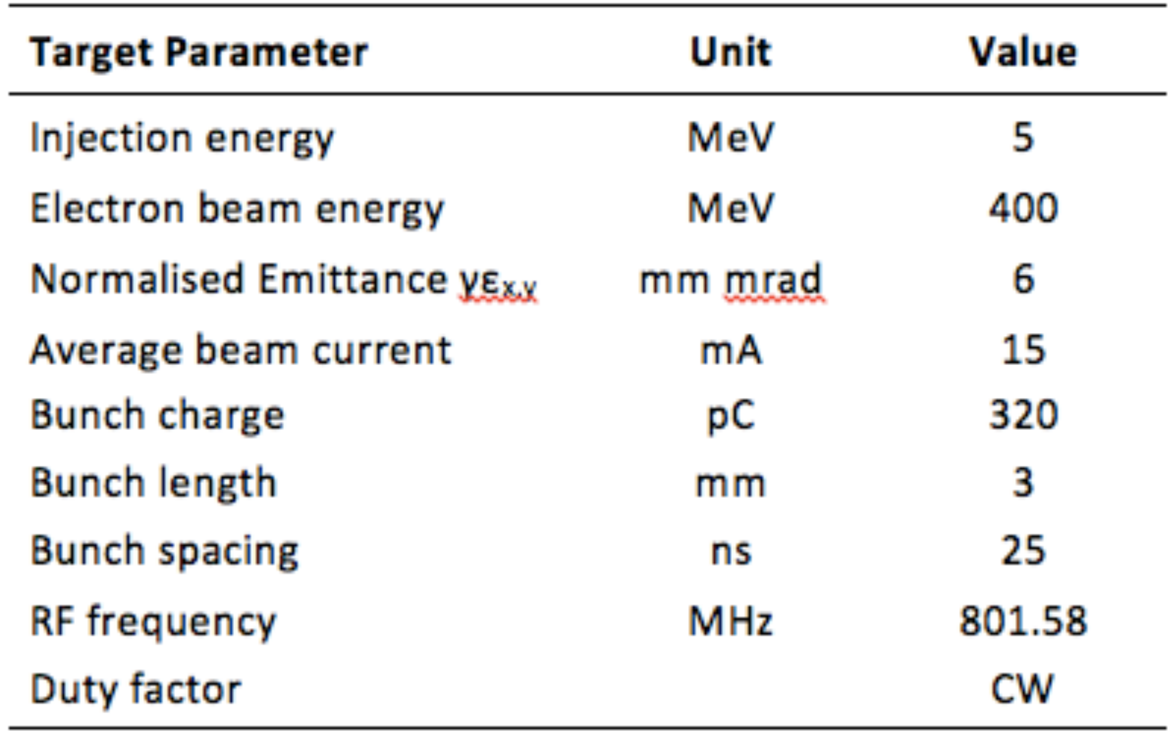
Walid Kaabi-LAL/CNRS

CERN, September 11th 2017

Introduction:

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

The Orsay realization of PERLE (Called PERLE@Orsay) is a smaller version (400 MeV) with the same design challenges and the same beam parameters:

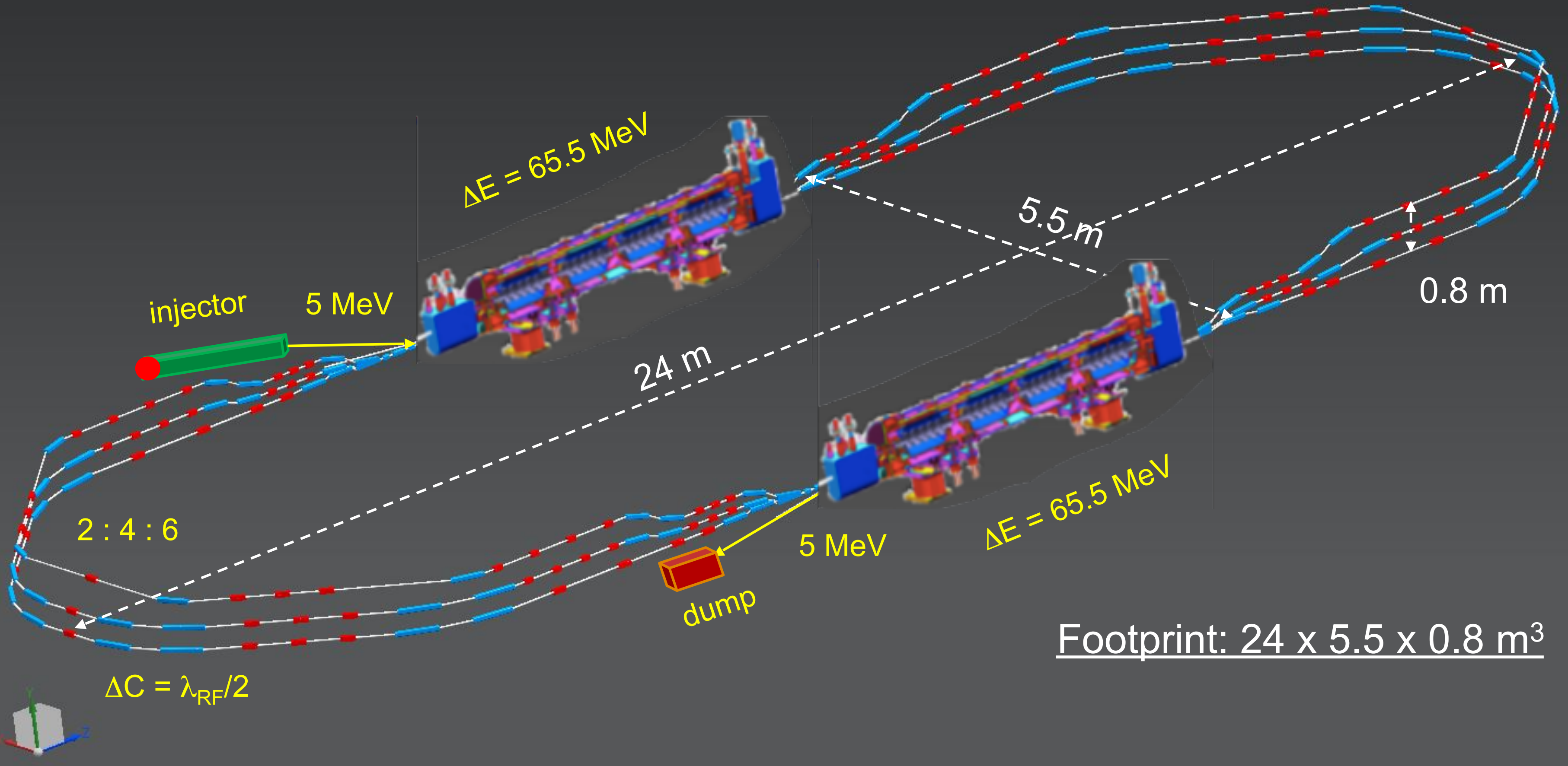


Target Parameter	Unit	Value
Injection energy	MeV	5
Electron beam energy	MeV	400
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	15
Bunch charge	pC	320
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE@Orsay:

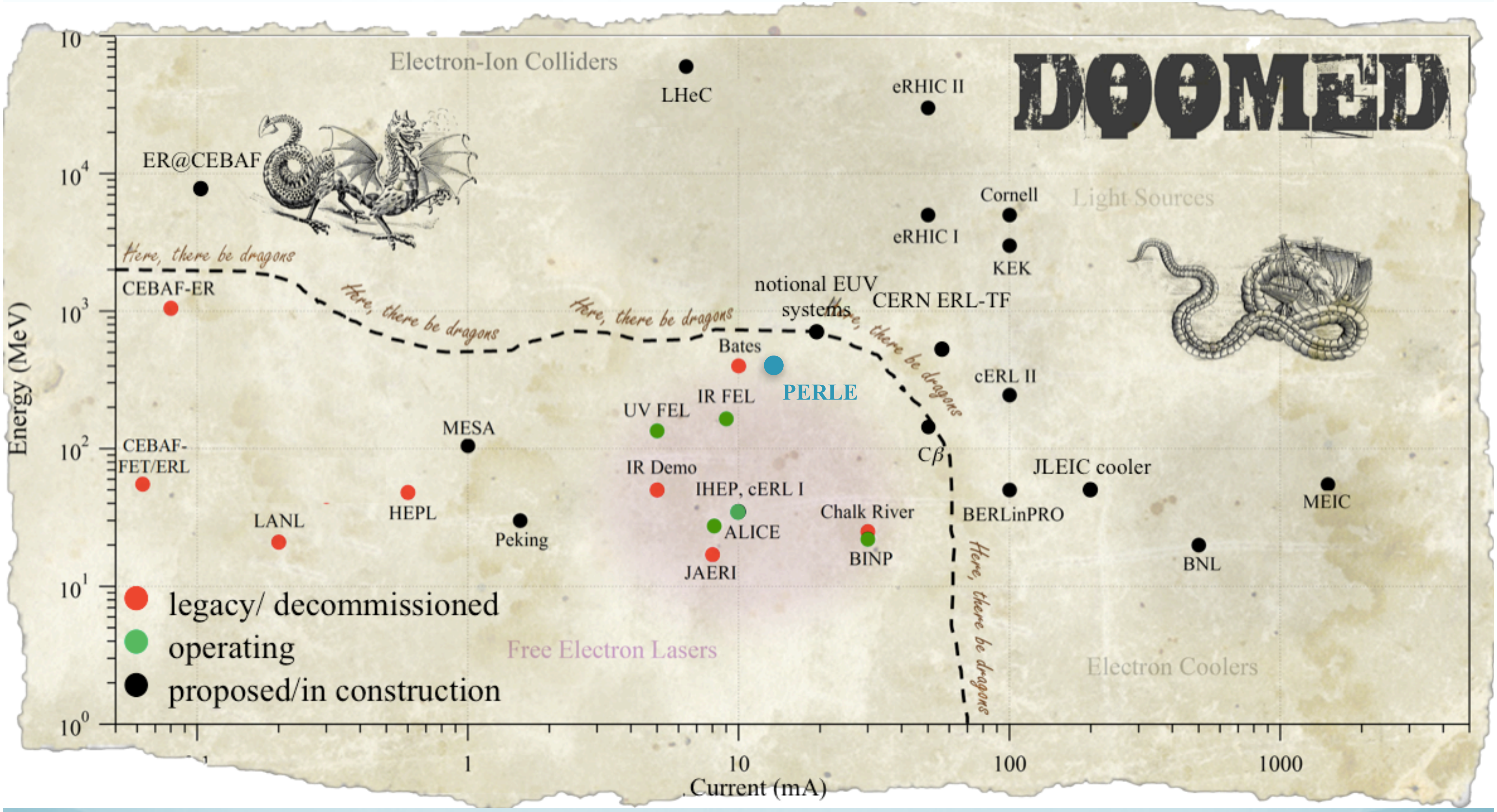
Courtesy to A. Bogacz

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (131 MeV/turn)
- Max. beam energy 400 MeV



Footprint: 24 x 5.5 x 0.8 m^3

PERLE@Orsay in the global landscape:



Courtesy to Chris Tennant

PERLE: An ERL at Orsay

Why an ERL?

- Accelerator R&D at its best.
- Compact accelerator with high performances that need smaller investment (site area, cryogenic plant, RF source…)
- A clever concept that allow energy saving: a key word for future machine construction.

Why @ Orsay?

- Involvement of local accelerator experts around an ambitious project.
- Opportunity to host the first superconductive R&D facility in Paris-Saclay campus.
- Develop and acquire expertise in design and operation of ERL.

Why PERLE?

- The opportunity to work within an international collaboration with expert in ERL design and operation.
- Technical challenges imposed by the machine design:
  - Multi-turn recirculation,
  - High current operation,
  - New SRF cavities & cryomodules to be tested with beam,
  - beam stability (intensity, position and size) in acceleration and deceleration phases,
  - Injector versatility,
- A unique technology test bed to explore and validate the key design choices for future larger machine.
- Compact but powerful machine that could provide electron beam for low energy physics experiment, intense Compton generation or FEL radiation to light source users.

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 PERLE @ Orsay workshop in February 23-24th 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.
- Next step will be the redaction of PERLE Technical Design Report (TDR).

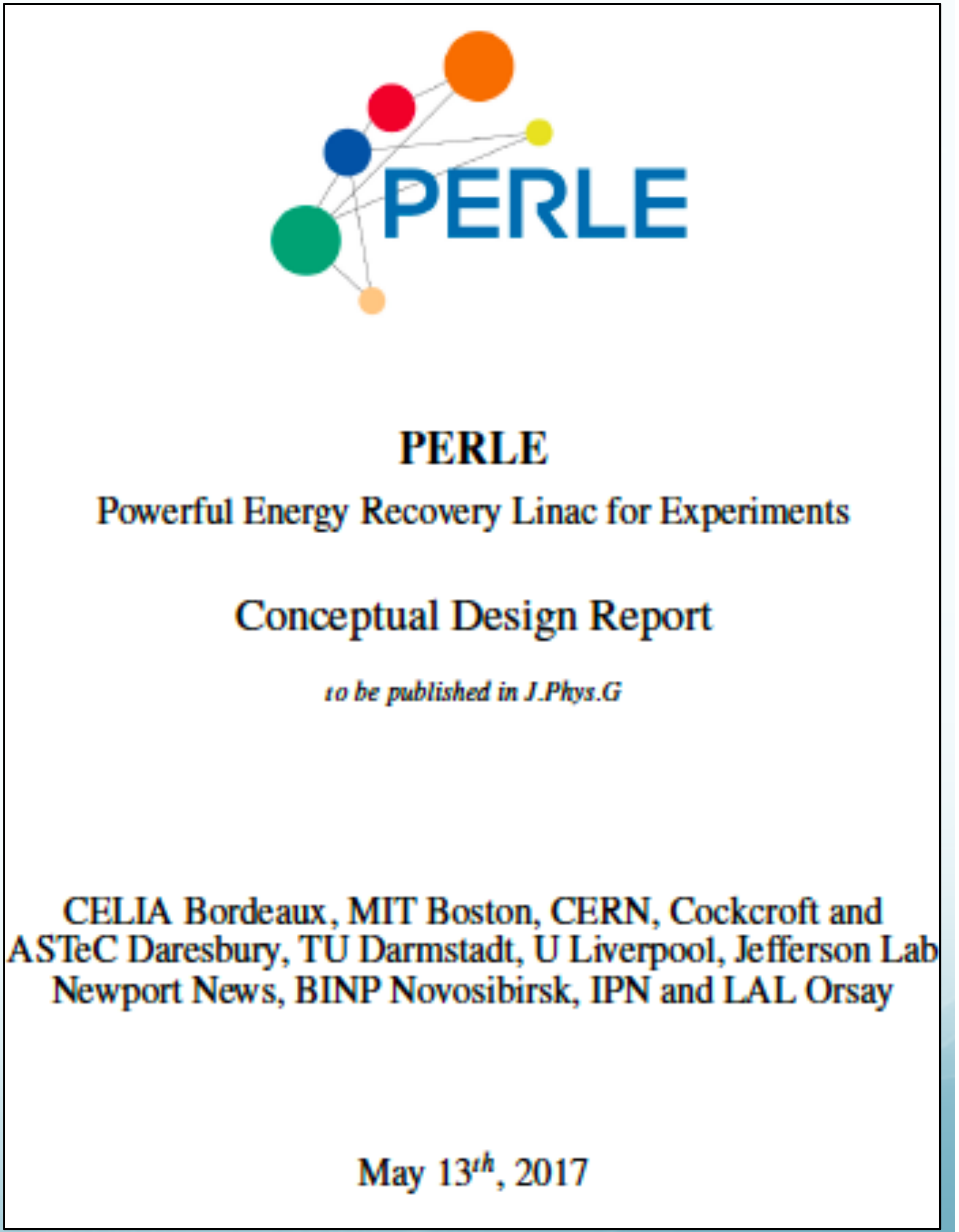
PERLE collaboration:

For more details:

- the PERLE CDR [arXiv:1705. 08783] →
- the indico site of PERLE Workshop held in February 2017 at Orsay

↓

https://indico.lal.in2p3.fr/event/3428/



PERLE

PERLE

Powerful Energy Recovery Linac for Experiments

Conceptual Design Report

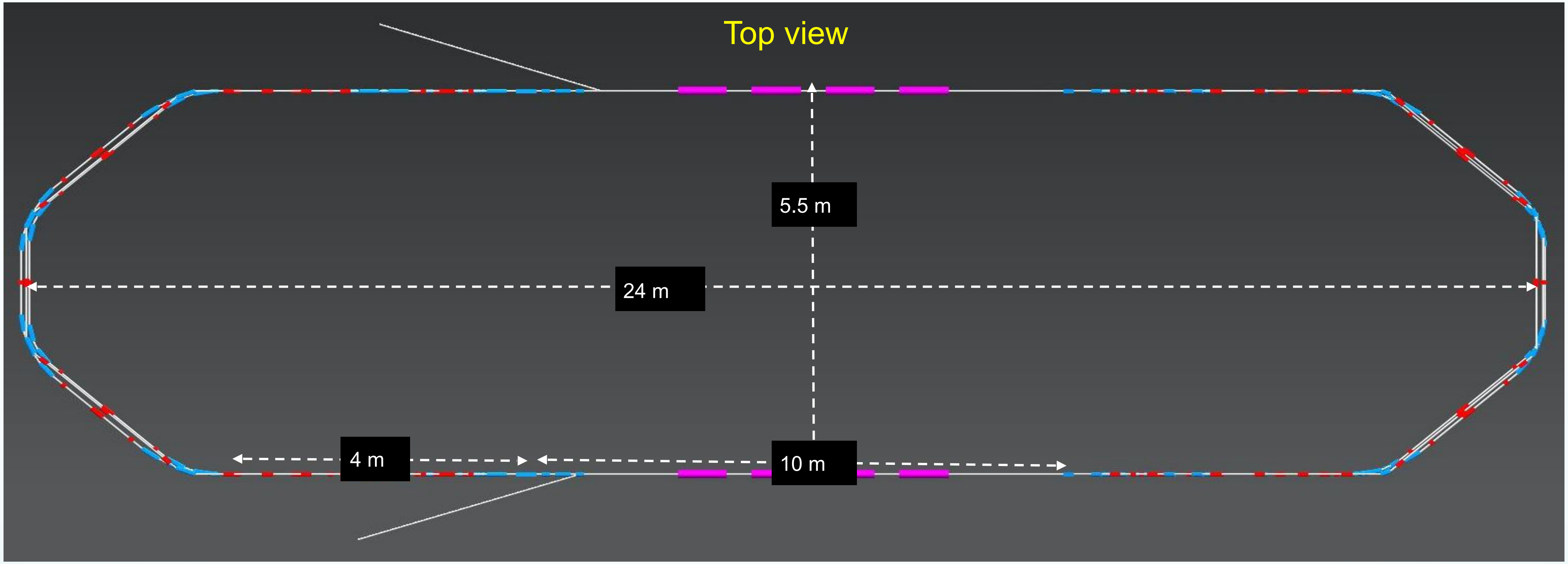
to be published in J.Phys.G

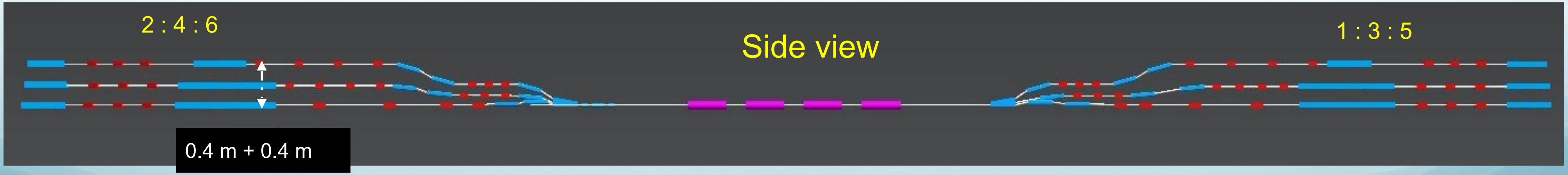
CELIA Bordeaux, MIT Boston, CERN, Cockcroft and ASTeC Daresbury, TU Darmstadt, U Liverpool, Jefferson Lab Newport News, BINP Novosibirsk, IPN and LAL Orsay

May 13th, 2017

PERLE Layout:

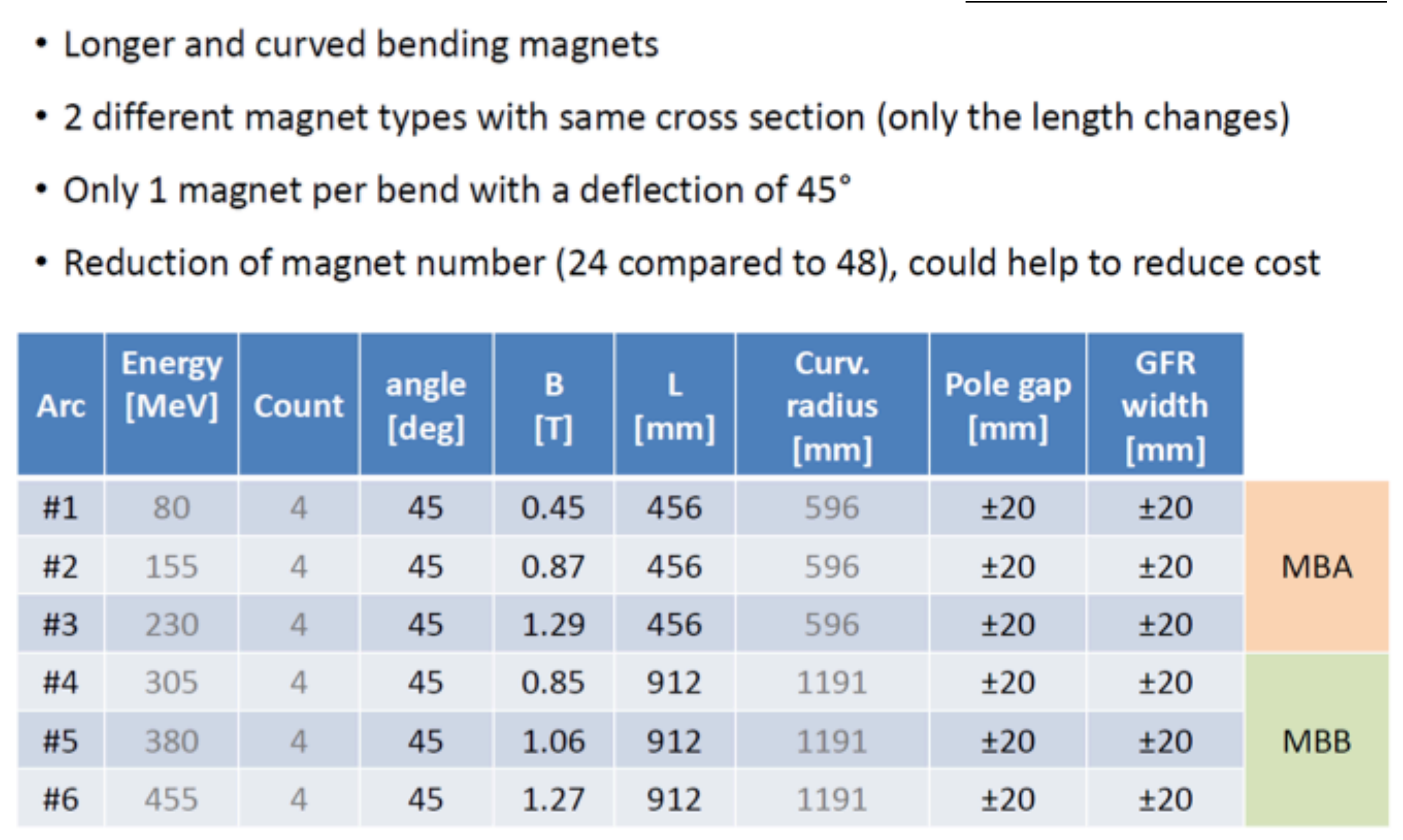
Alex Bogacz





Cost-effective magnet solution:

Pierre-Alexandre Thonet



- Longer and curved bending magnets
- 2 different magnet types with same cross section (only the length changes)
- Only 1 magnet per bend with a deflection of 45°
- Reduction of magnet number (24 compared to 48), could help to reduce cost

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):

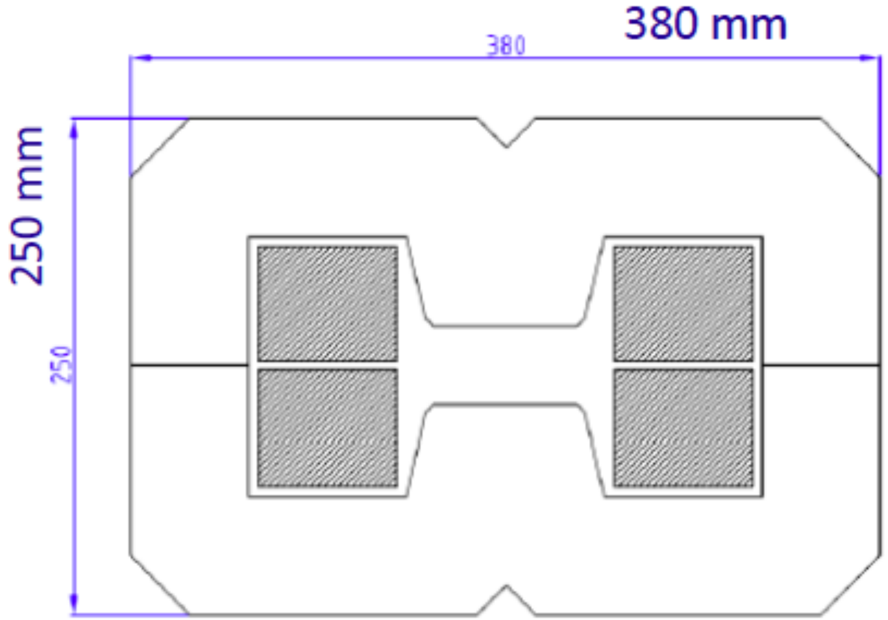
70 dipoles 0.45-1.29 T

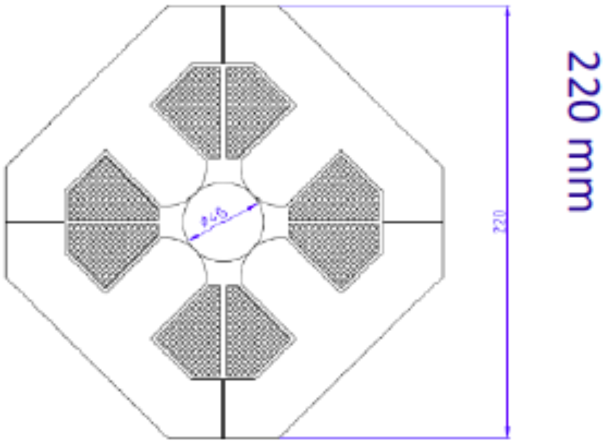
+- 20 mm aperture, l=200,300,400 mm

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

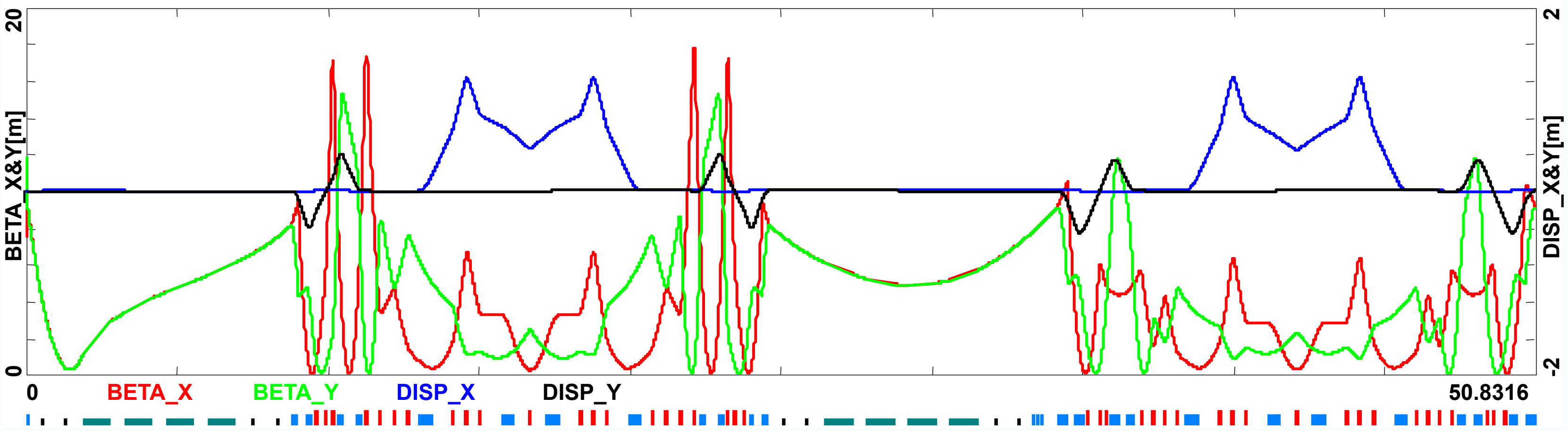
DC operated

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

1 pass up + 1 pass down optics:

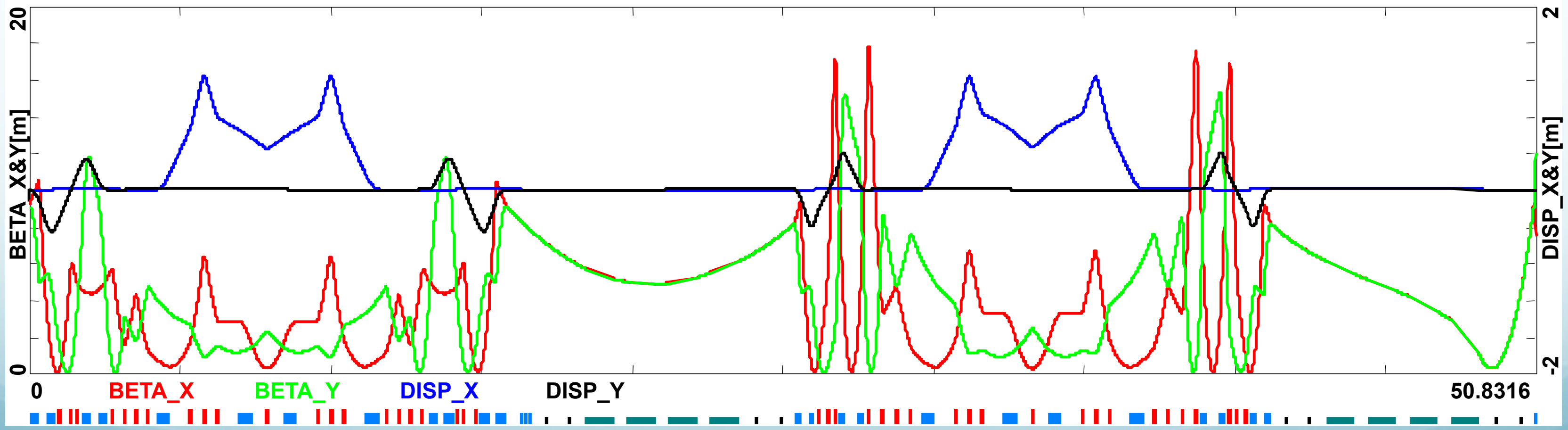
More details in tomorrow’s A. Bogacz presentation

Pass-1 ‘up’



5 MeV
71 MeV
137 MeV

Pass-1 ‘down’

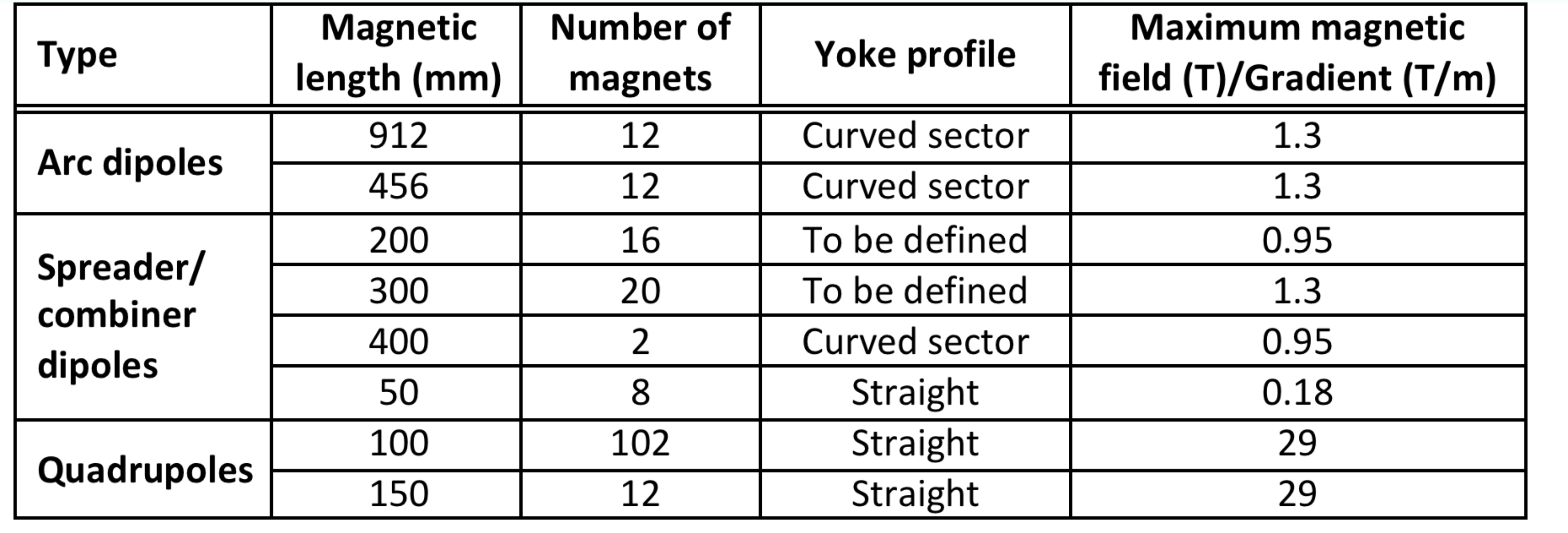


137 MeV
71 MeV
5 MeV

Magnets inventory:

C. Vallerand, P.A. Thonet & A. Milanese

Summary of magnetic element features



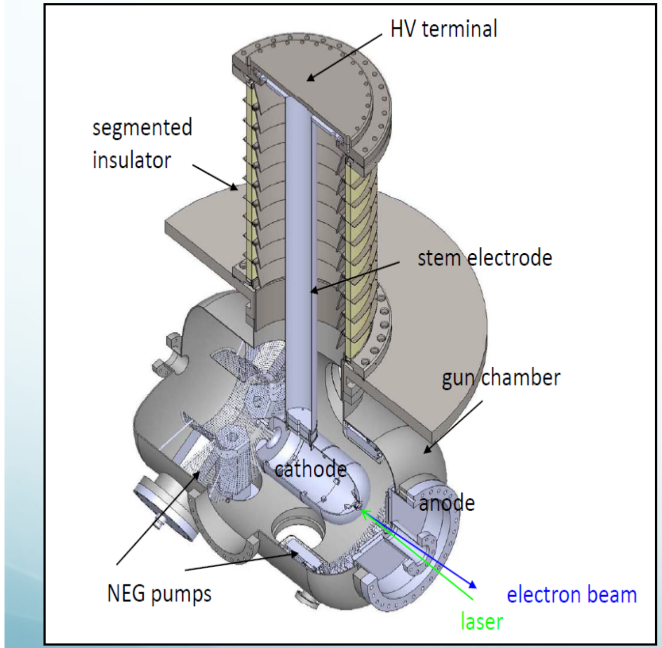
Type	Magnetic length (mm)	Number of magnets	Yoke profile	Maximum magnetic field (T)/Gradient (T/m)
Arc dipoles	912	12	Curved sector	1.3
	456	12	Curved sector	1.3
Spreader/ combiner dipoles	200	16	To be defined	0.95
	300	20	To be defined	1.3
	400	2	Curved sector	0.95
	50	8	Straight	0.18
Quadrupoles	100	102	Straight	29
	150	12	Straight	29

Bends: **70**
Quads: **114**

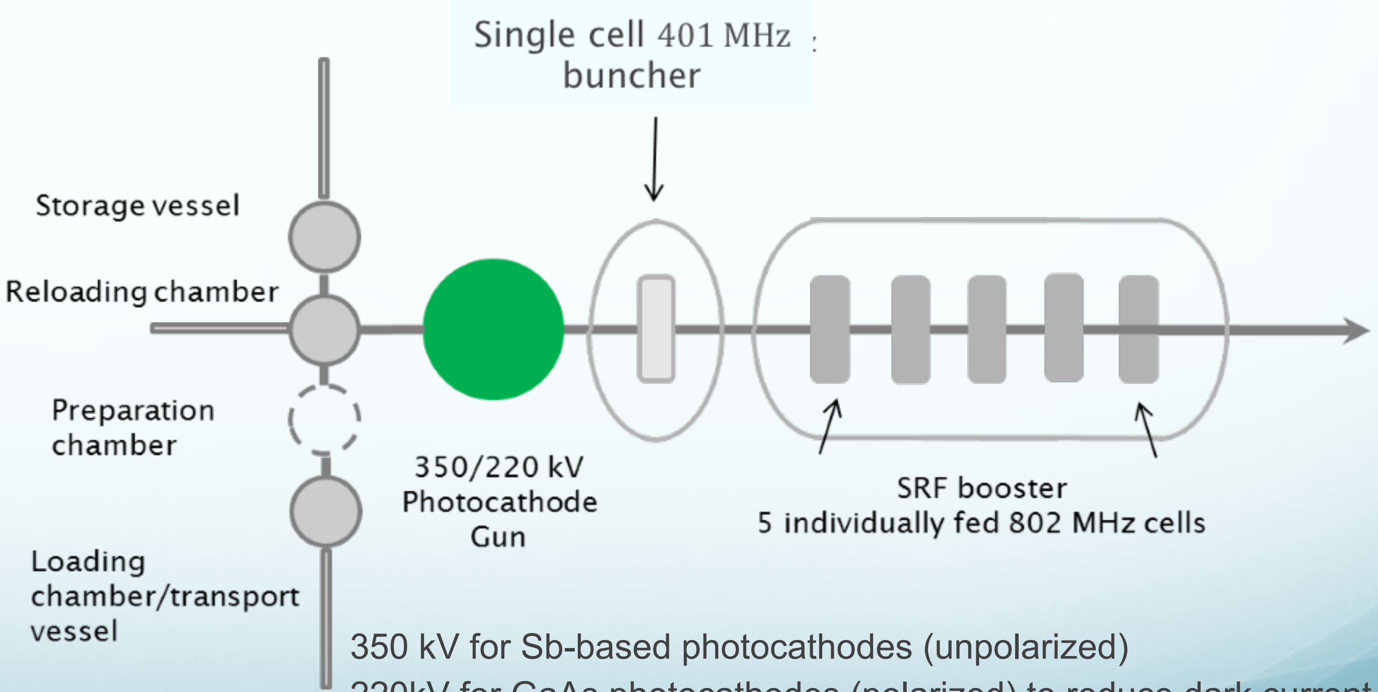
Electron source and injector:

Boris Militsyn

- Preferred concept: Photocathodes, DC Gun, single cell buncher and SRF accelerator (booster),
- Laser allows flexible bunching sequence,
- Nominal repetition rate 40.1 MHz (20th sub-harmonic of 801.56 MHz),
- Nominal bunch charge: 2.34 10^9 e- = 375 pC → 375 pC x 40 MHz = 15 mA.



DC Gun



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

Injector versatility:

Erk Jensen

One purpose of PERLE is to test SRF cavities/cryomodules with beam.

→ Thanks to the flexibility of laser pulse driven photocathode, sub-harmonics are used to test different frequencies with PERLE beam. Two interesting sub harmonics are found:

$f_0 = 10.835$ MHz

Harmonic	Frequency (MHz)
30	325
37	401
39	422
46	499
60	650
65	704
74	802
88	953
120	1300

$f_0 = 12.146$ MHz

Harmonic	Frequency (MHz)
29	352
33	401
58	704
66	802
107	1300

Injector versatility:

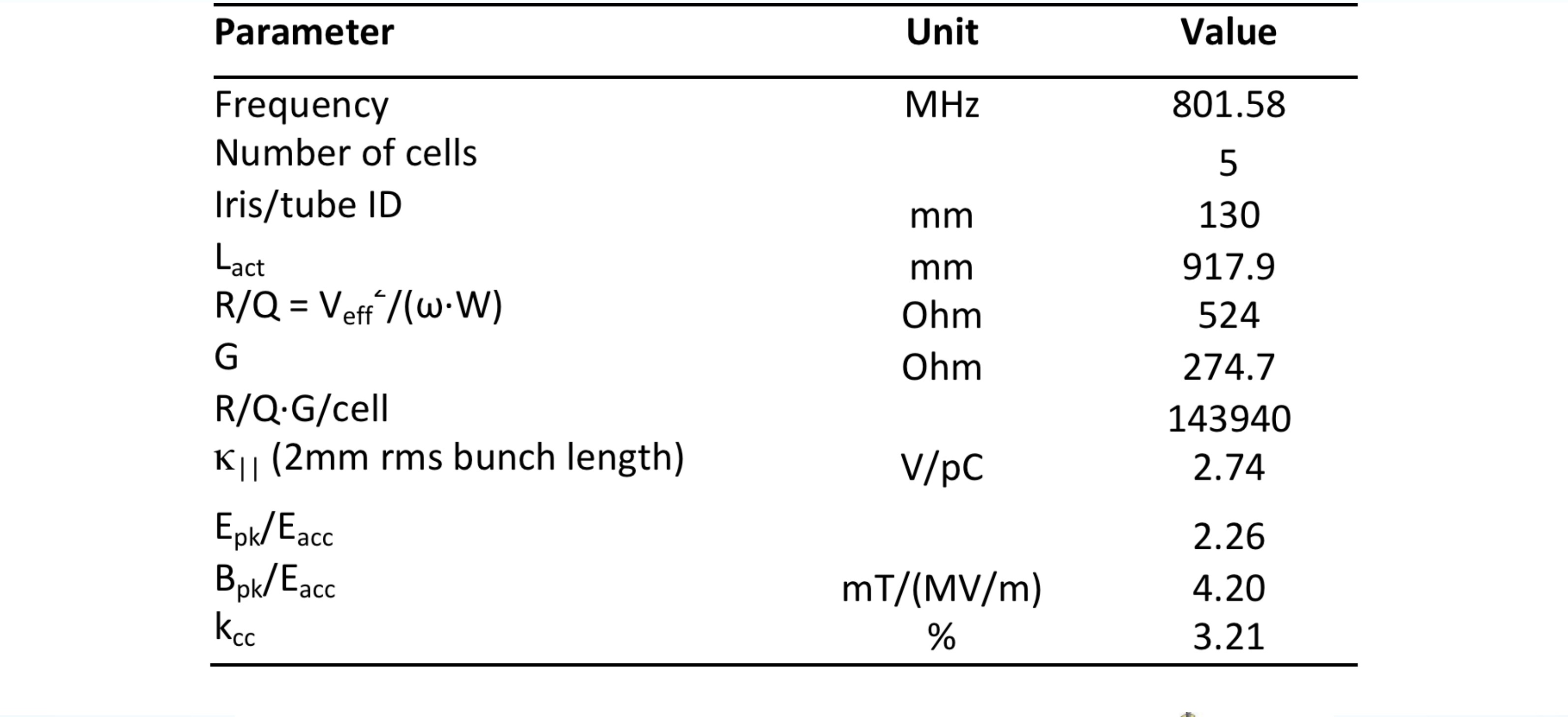
@ CERN

Programme	Frequency (MHz)
LHC, spare and more	401 MHz
LHC upgrade	200 MHz, 802 MHz
HIE-ISOLDE	101 MHz
HL-LHC crab cavities	401 MHz
Linac 4 (NC)	352 MHz
SPL (ESS)	704 MHz
LHeC, FCC-he	802 MHz
FCC-ee, FCC-hh	401 MHz & 802 MHz

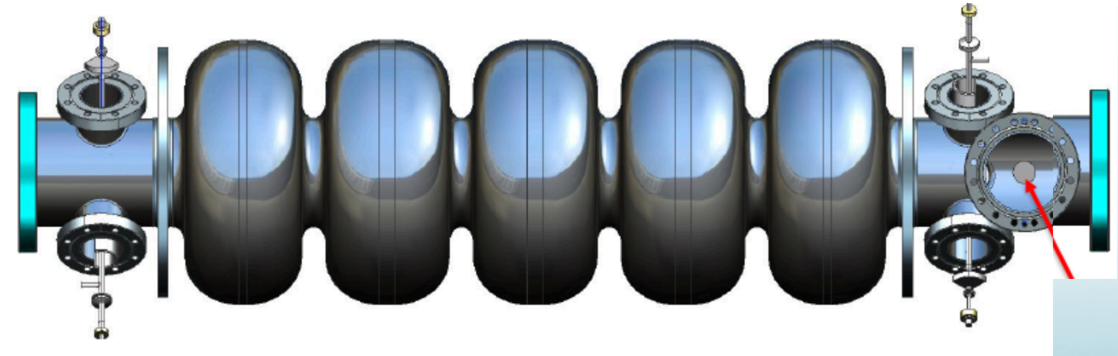
International

Programme	Frequency (MHz)
ILC, X-FEL, LCLS-2, CBETA, CERL, MESA…	1,300 MHz
PIP-II	650 MHz
SNS	805 MHz
PERLE	802 MHz
ESS	352 MHz, 704 MHz
eRHIC	422 MHz
JLAB MEIC	953 MHz
JAERI	500 MHz

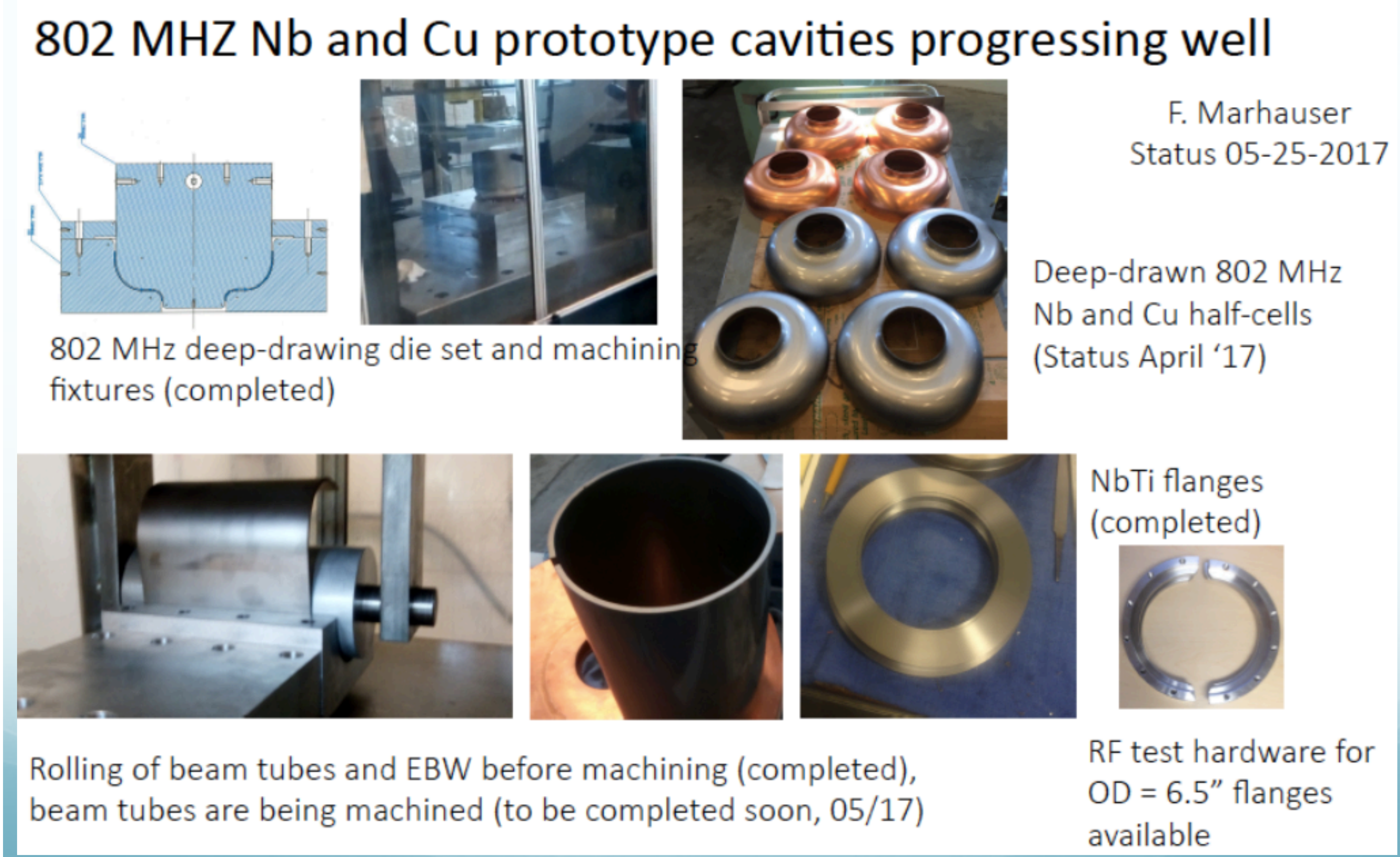
Main cavity parameters



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 status:



802 MHZ Nb and Cu prototype cavities progressing well

F. Marhauser
Status 05-25-2017

802 MHz deep-drawing die set and machining fixtures (completed)

Deep-drawn 802 MHz Nb and Cu half-cells (Status April '17)

NbTi flanges (completed)

Rolling of beam tubes and EBW before machining (completed), beam tubes are being machined (to be completed soon, 05/17)

RF test hardware for OD = 6.5" flanges available

Cryomodule requirement for PERLE:

Several cryomodule requirements could be listed for PERLE, and some of them are very challenging. They are of two types:

1. The classical challenges imposed by SRF:
   - Limit as much as possible heat transfer
   - Take into account all mechanical constraints
   - Design allowing an easy assembly procedure
   - … and as usual, optimize for cost !

2. The additional constraints coming from the cavities operated in the ERL mode and CW/high current operation mode:
   - High CW cryo loads
   - Low level of vibration, and damping of them
   - Excellent magnetic shielding (high Q_0)
   - Accurate cavity alignment

Sébastien Bousson

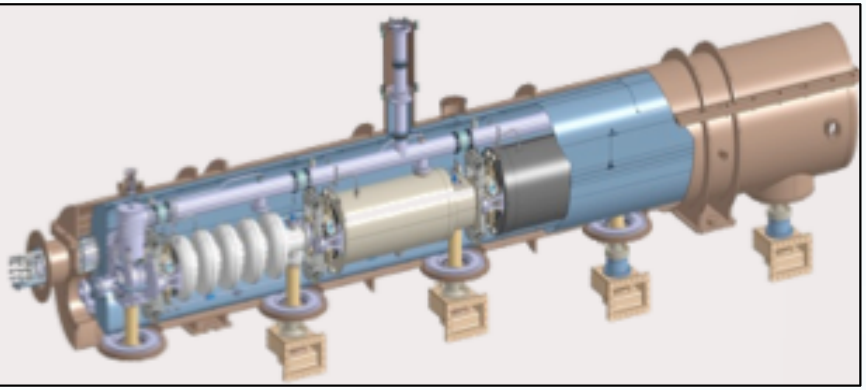
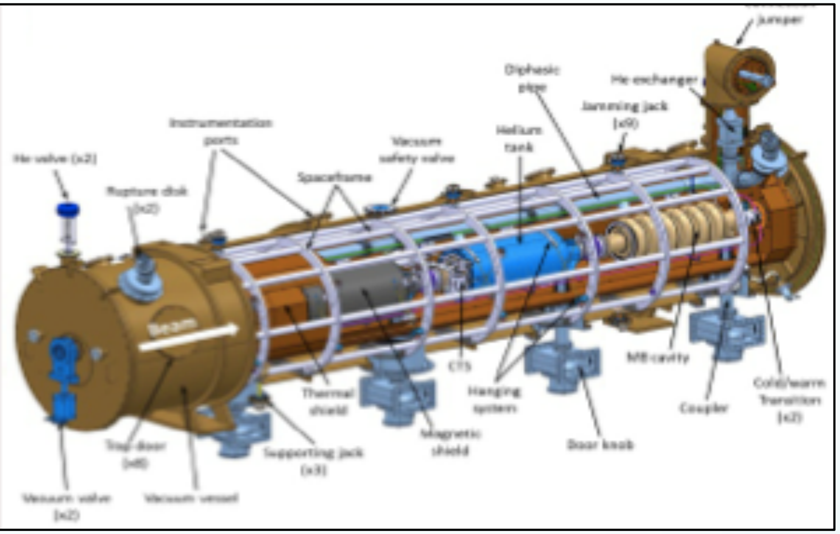
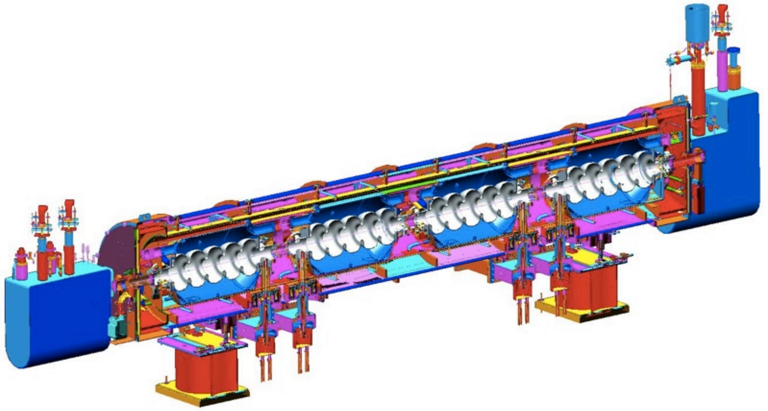
Specific constraints in PERLE cryomodule:

High cryo loads generated by the CW mode and high current operation

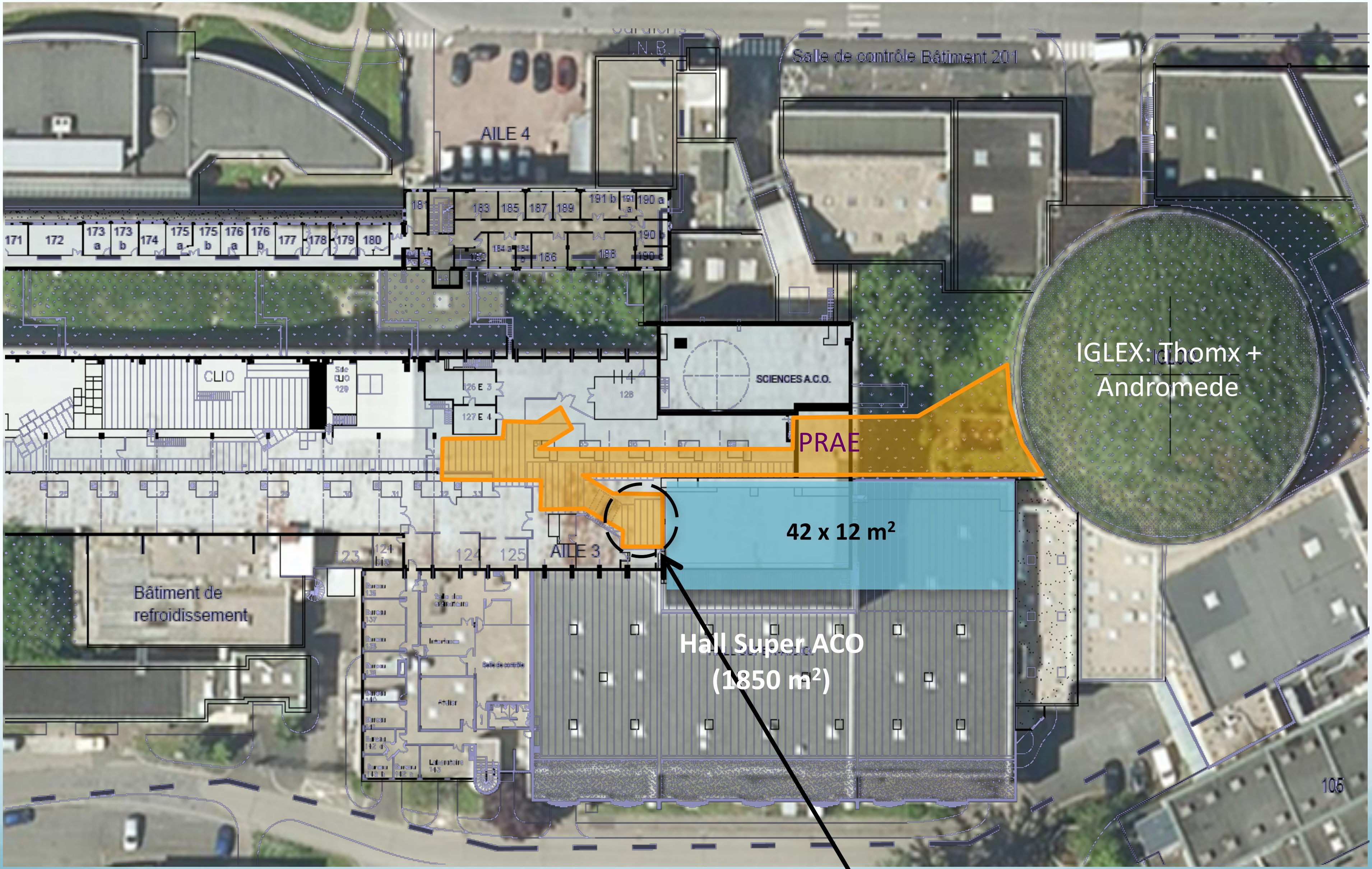
→ A large number of significant dynamic heat loads in an operation mode where dynamic loads are >> static loads

  - Cavity
  - HOM load
  - CW input couplers

- Design question/optimization points to find for cryostat/cryoplant: cryo load
  - Thermal shield temperature optimum
  - How to efficiently extract HOM power? at what T°?
  - Cryo load varies a lot between RF on/off : cryoplant flexibility is required
  - Cavity optimum operating temperature: cost vs cavity performances vs helium bath stability
  - How to cool the cavities (series/parallel) in order to insure “magnetic hygiene” (really an issue for high Q_0 @ 802 MHz ?)

SPL « Short cryomodule »	5-cells Elliptical 700 MHz, β = 1.0	Full length top lid closure Cold mass supported by power couplers	
ESS Elliptical cryomodule	5&6-cells Elliptical 700 MHz $\beta = 0.67$ & 0.86	Side loading Space frame	
SNS Cryomodule	5-cells elliptical 805 MHz	Side loading Space frame	

Site to host PERLE:



Possible use of a 2nd levels for RF source and power supplies installation

Site to host PERLE:

Site description:

- The experimental hall is equipped with crane, electricity and is partially shielded
- Water cooling circuit could be shared with other machines nearby.
- Possibility to install the RF source and power supplies in a different level than the accelerator
- A large area of ground have the required resistance to allow installation of PERLE.
- A control room that overlooks the hall could be used for PERLE.
- No Cryogenic plant around, has to be built.
- Space available for experiments.
- Support for the infrastructure is fully assured.

Next steps…

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

- Beam Dynamics
- Lattice and optics
- Electron source and injection
- Cavities, HOM study and cryomodule design and tests
- Magnets and power supplies
- Beam dumps
- RF power source
- Cryogenics
- Beam instrumentations
- LLRF
- Control software system
- Shielding and safety system

Thank you for your attention!