Towards a novel ERL Facility - PERLE at Orsay

Max Klein

for the PERLE Collaboration
Achille Stocchi and Walid Kaabi (Orsay)

based on the CDR [→] and the TDR kickoff meeting held in February 2017 at Orsay

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

FCC Week Berlin 1.6.2017

PERLE

Powerful Energy Recovery Linac for Experiments

Conceptual Design Report

to be published in J.Phys.G

arXiv:1705.08783v1 [physics.acc-ph]

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 Intention

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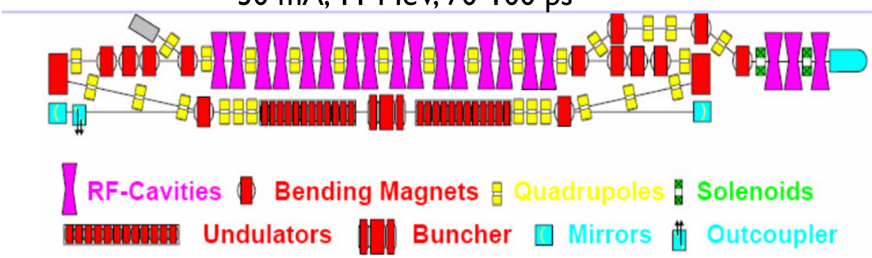
Authors of the CDR, but many further colleagues attended the TDR kickoff

The CDR is an expression of interest in: ERL, low energy electron and photon physics, technology development (high quality SCRF), development of the LHeC/FCC-eh etc

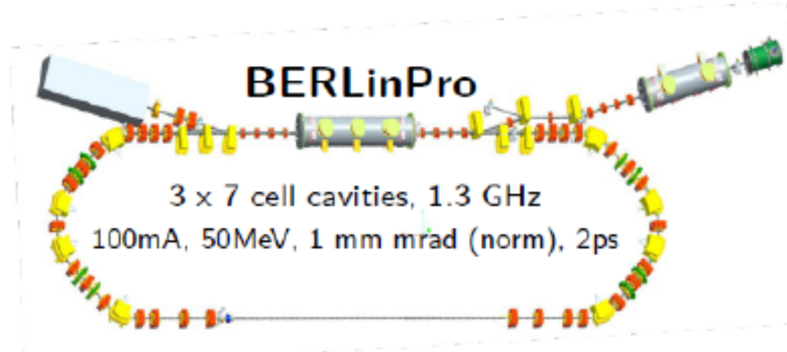
It is considered to be a technical facility first but has the potential to become a major user physics and technology development facility then with unique parameters, such as the orders of magnitude increased photon beam intensity wrt ELI now.

Other Facilities

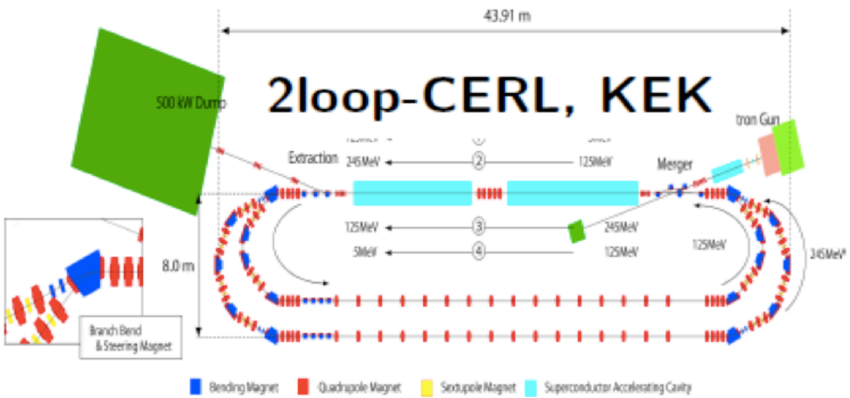
Normal Conducting 180 MHz + DC Gun
30 mA, 11 MeV, 70-100 ps



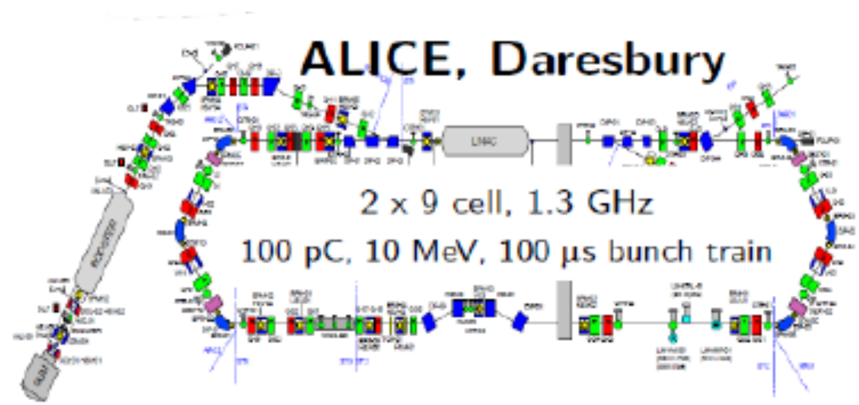
BINP, Novosibirsk



+D: MESA at Mainz and S-Dalinac Darmstadt



9 cell, 1.3 GHz cavities, 4 modules
77 pC, 245 MeV, 1-3 ps



Also: **CEBAF** (single pass, 5 GeV, ..

CBETA (50mA, 3 pass, FFAG, 1.3GHz)

Strong possibilities for collaboration (ERL workshop 19-23.6.2017 at CERN, E Jensen et al)

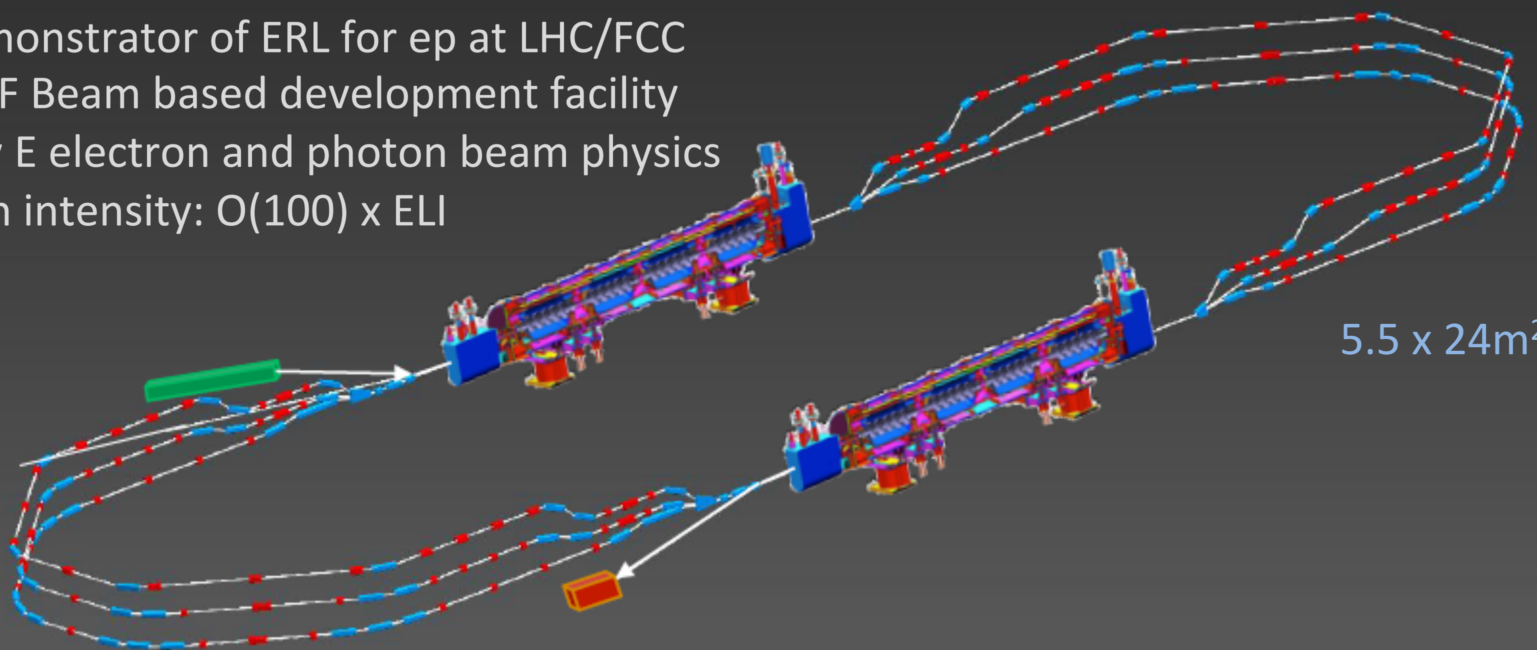
Powerful ERL for Experiments (ep,γp): PERLE at Orsay

title

PERLE at Orsay (LAL/INP) Collaboration: BINP, CERN, Daresbury/Liverpool, Jlab, Orsay +

3 turns, 2 Linacs, 400 MeV, 15mA, 802 MHz, Energy Recovery Linac facility

-Demonstrator of ERL for ep at LHC/FCC
-SCRF Beam based development facility
-Low E electron and photon beam physics
-High intensity: O(100) x ELI



CDR to appear in J Phys G [arXiv:1705. 08783]

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

A.Bogacz

Energy Recovery – Green Accelerators

M Tigner Nuovo Cimento 1.6.1965

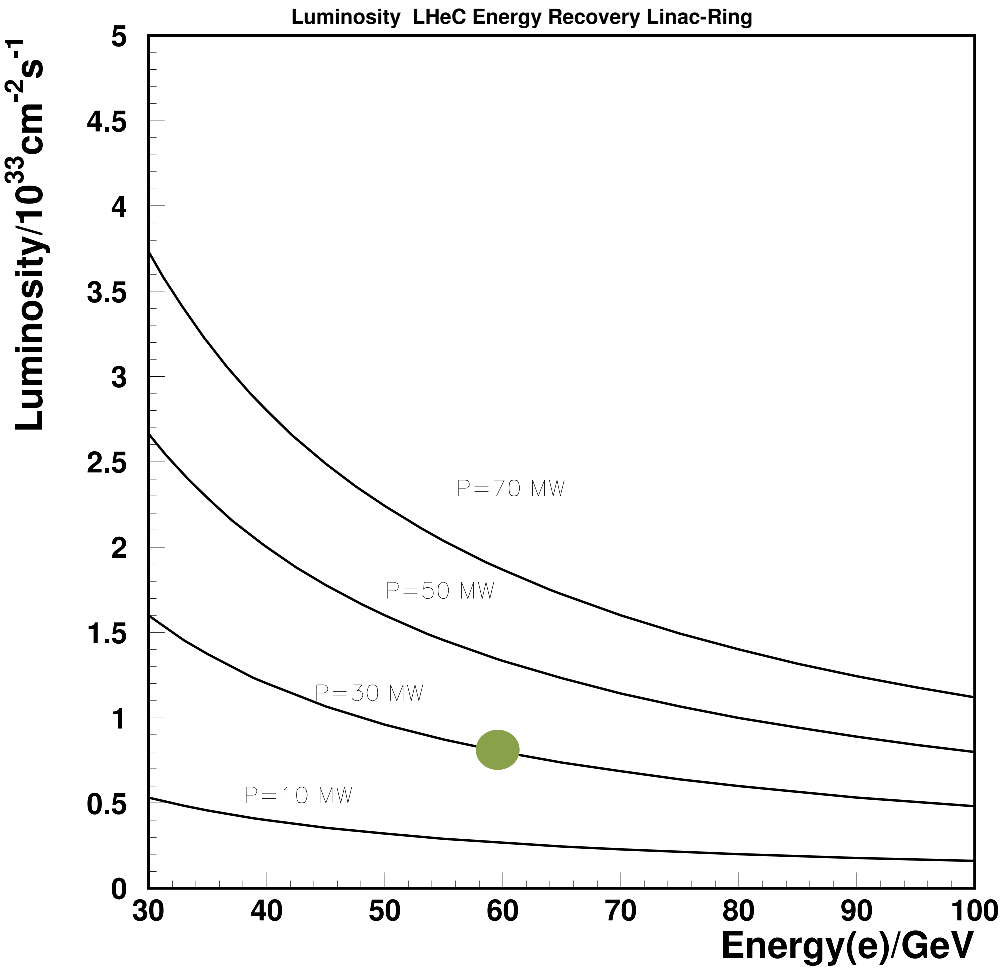
$$L = \frac{N_e N_p f \gamma_p}{4\pi \epsilon_p \beta^*}$$

$$I_e = e N_e f = \frac{P}{E_e}$$

High luminosity needs nearly GW of power P, for 60 GeV energy E

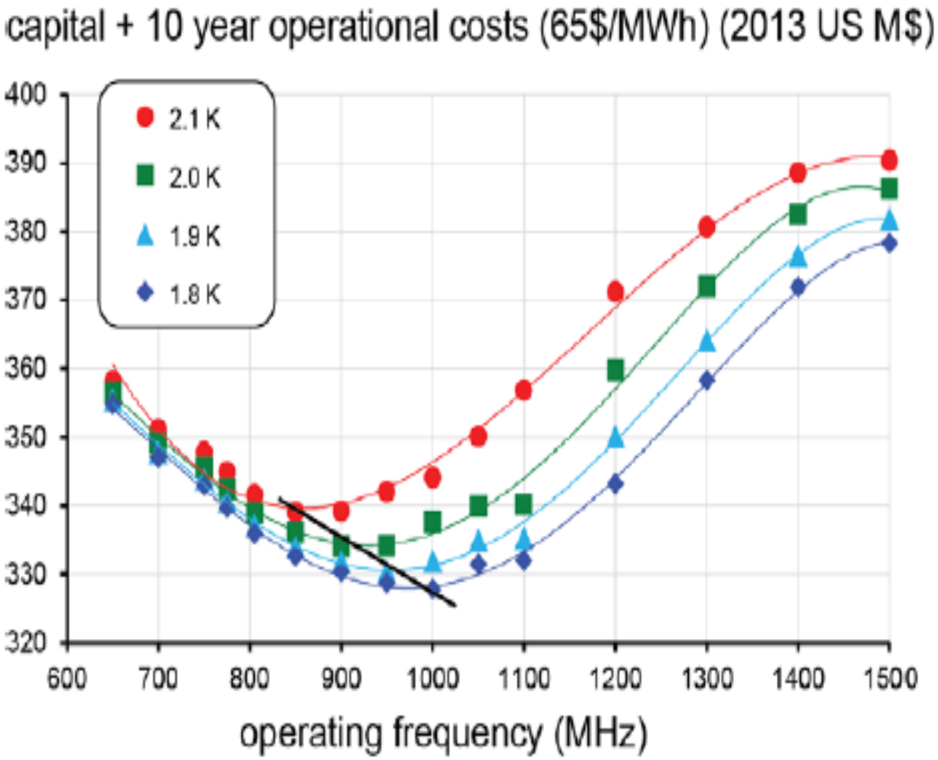
This can only be achieved with efficient energy recovery technique

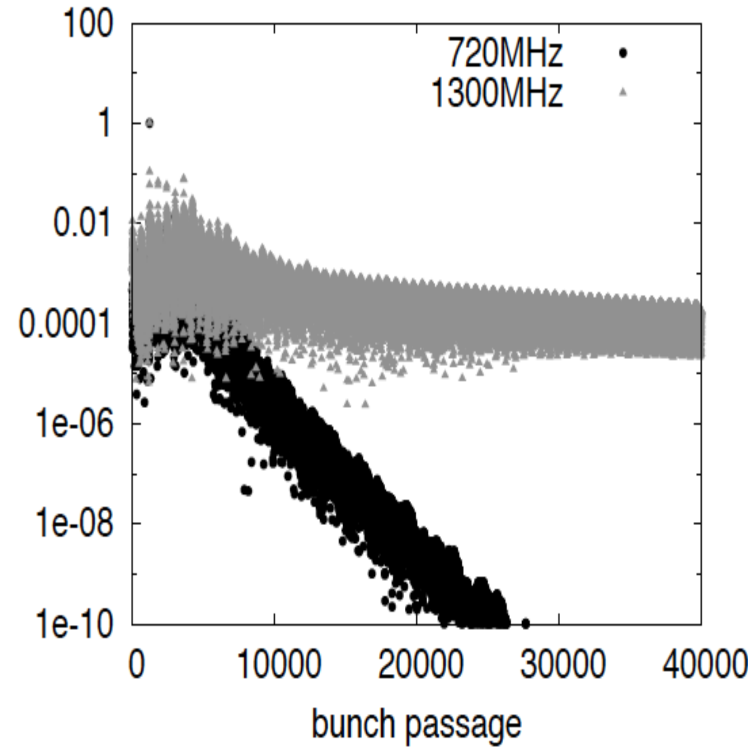
$P = P_0 /(1-\varepsilon)$ ERL efficiency



CDR of LHeC: Goal now is 10^{34} could NOT pay for power and not realise high lumi w/o ERL

Frequency Choice





Cost, dynamic heat losses, resistance, Q_0… point to f < 1 GHz (F Marhauser, Orsay 2/17)

Beam beam interactions unstable for f > 1 GHz (D Schule, D Pellegrini March 2013)

Compatibility with LHC: **Decision for 802 MHz** (E Jensen CI Workshop 1/2015, FM input)

Programme	Frequencies
CERN frequencies (SPS, LHC, L4, FCC)	200.4 MHz, 352.2 MHz, 400.8 MHz, 704.4 MHz, 801.6 MHz
ILC, E-XFEL, LCLS-II, CBETA …	1,300 MHz
PIP-II	325 MHz, 650 MHz
ESS	352.2 MHz, 704.4 MHz
eRHIC	647.7 MHz
JLAB MEIC	953 MHz
JAERI	500 MHz

E Jensen: use flexibility of laser driven photocathode → sub-harmonics: test of various cavities

… are there common sub-harmonics?

PERLE

- … I found 2 common (approximate) interesting sub-harmonics:
- f_0 =10.835 MHz:

Harmonic	Frequency
30	325 MHz
37	401 MHz
39	422 MHz
46	499 MHz
60	650 MHz
65	704 MHz
74	802 MHz
88	953 MHz
120	1,300 MHz

- f_0 =12.146 MHz:

Harmonic	Frequency
29	352 MHz
33	401 MHz
58	704 MHz
66	802 MHz
107	1,300 MHz

Many other technical applications: beam tests of quench behaviour (CDR), detector test …

Technical Mission Summary for LHeC:

-high current (25mA / 0.7nC) multi-turn (3) ERL operation

-Energy recovery efficiency

-SRF LLRF feedback and control

-Failure scenarios and transients in multi turn ERL operation

-Beam stability (Beam Breakup and filling schemes)

-Demonstration / specification of required HOM damping

-Transverse / longitudinal stability for bunch passage @ high energy

-Beam halo formation and dump-line acceptance

-Beam instrumentation (minimum requirements)

-Build up operational experience

-Source and injector validation

O Bruening at PERLE TDR Kickofff meeting at Orsay 2/17: **Much more than a demonstration**

ep Physics with PERLE – proton radius

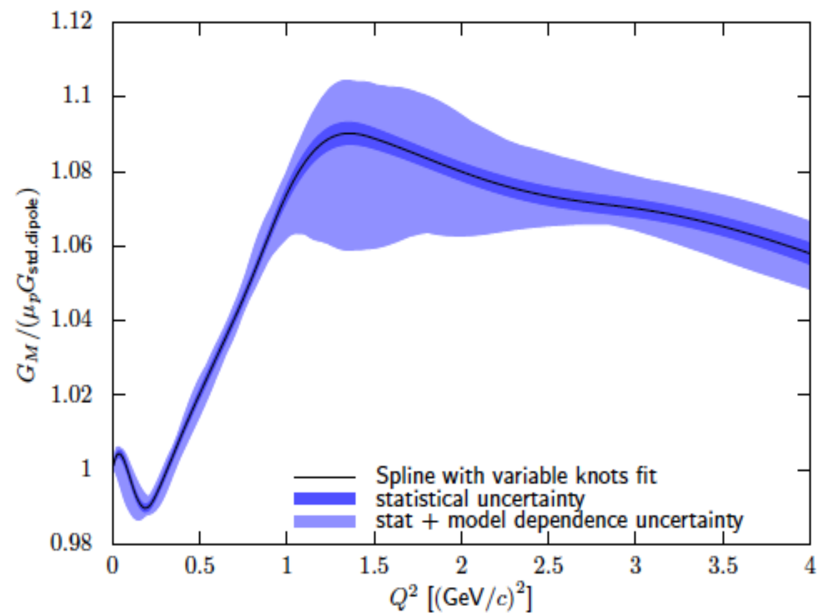
$$Q^2 = \frac{2ME^2(1-\cos\theta)}{M+E(1-\cos\theta)} \qquad E' = \frac{E}{1+\frac{E}{M}(1-\cos\theta)}$$

elastic ep → ep

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{[E(1-\cos\theta)]^2}\cdot\cos^2\frac{\theta}{2}\cdot\frac{1}{1+\frac{E}{M}(1-\cos\theta)}\cdot f(G_E,G_M,\theta)$$

$$f(G_E,G_M,\theta) = \frac{G_E^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2\tan^2\frac{\theta}{2}$$

CDR



Jan Bernauer

p radius from Q^2 dependence of G, Q^2=0

- thin target (gas jet), high current
- angular scan with different E_e < 400MeV
- electric and magnetic radius
- h.o. QED corrections

Further ep Physics with PERLE

$\sin^2\Theta_W$

Measurement of electroweak asymmetries (charge and polarisation)
Weak neutral current quark couplings [cf MK, T Riemann PL85B(79)385]

Confinement scale QCD

escape traditional, thick targets. It is thus possible to measure the reactions $\gamma p \to \pi^0 p, \pi^+ n$, $\gamma n \to \pi^0 n, \pi^- p$ and $\gamma D \to \pi^0 D$. Coherent π^0 production in D and ^3He measure relative signs of the $\gamma p \to \pi^0 p, \gamma n \to \pi^0 n$ amplitudes.

Such an experiment requires beam energies of 300 MeV or more. Depending on the

Dark photons

$e^- p \to e^- pA'(\to e^- pe^+ e^-)$

new "dark" Abelian forces with a new dark gauge field A'

Higher luminosity than DarkLight (Jlab)

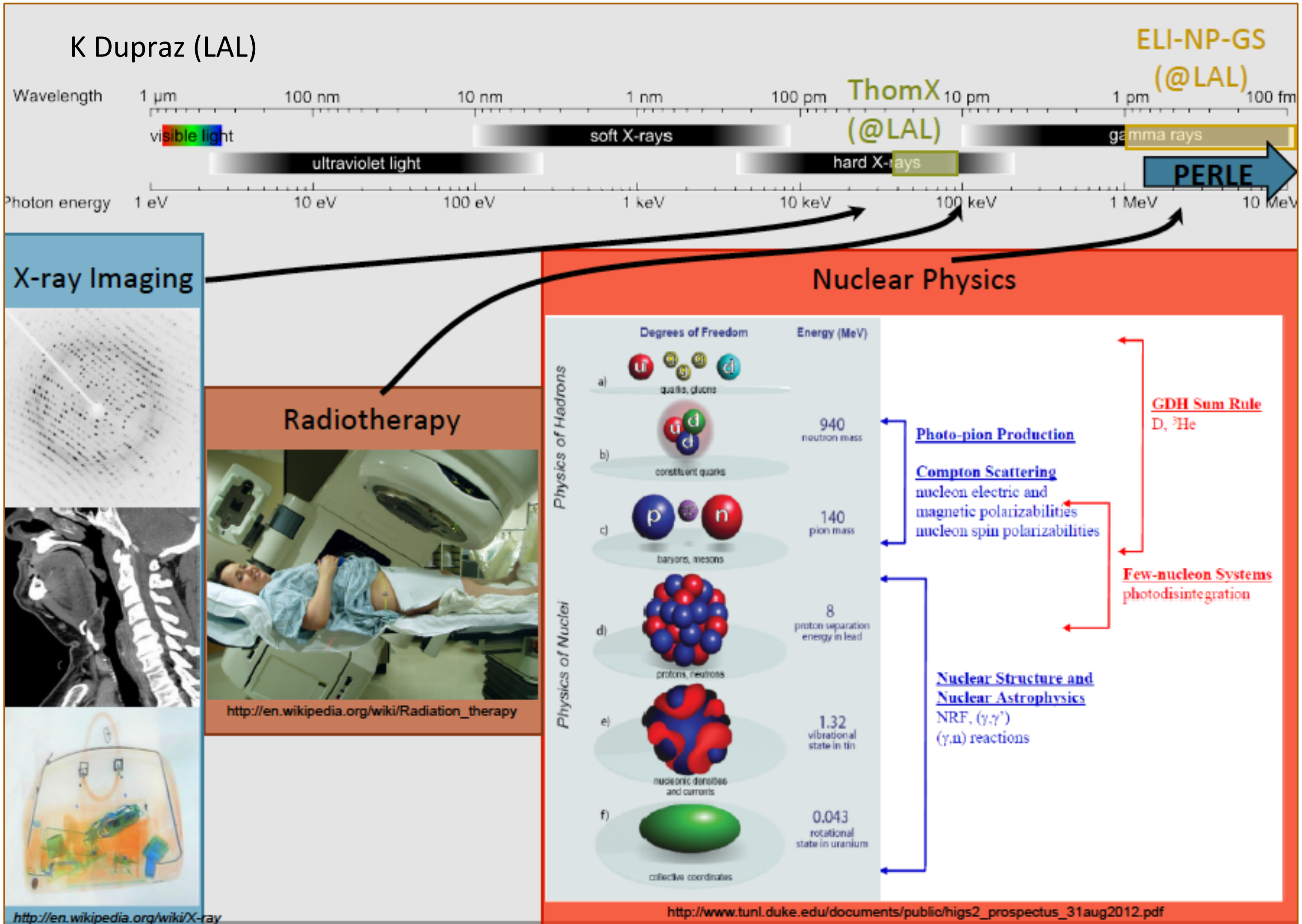
cf CDR

Electron-proton physics: high current, polarisation, positrons, energy > 300 MeV

PERLE Photon Physics (Compton Backscattering)

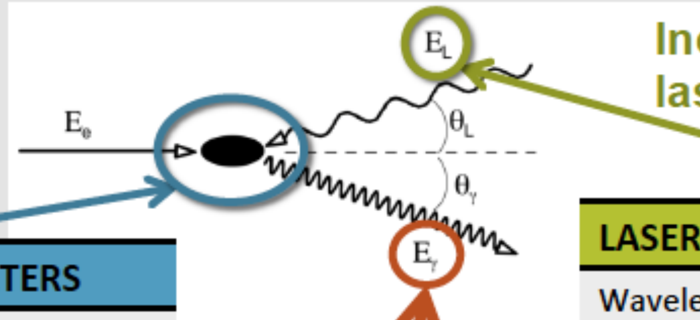
CDR: Photonuclear reactions, Nuclear Structure, Neutrino Physics, Nuclear Astrophysics
→ High energy, high intensity (100-1000 x ELI) – next generation photon physics facility

N Pietralla (TU Darmstadt)



Gamma beams at the PERLE Facility

Incident electron beam



Incident laser beam

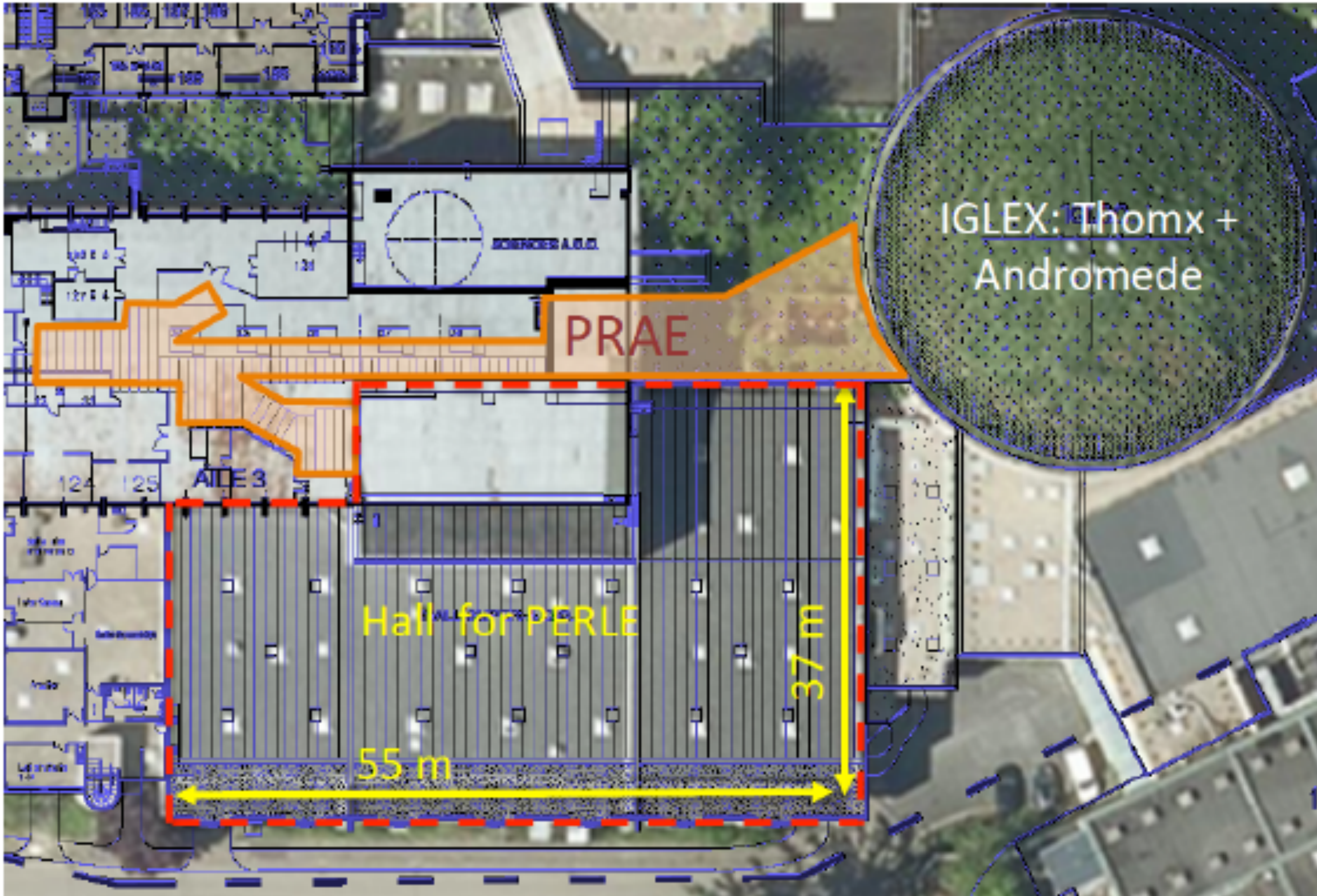
ELECTRON BEAM PARAMETERS	
Energy	900 MeV
Charge	320 pC
Bunch Spacing	25 ns
Spot size	30 um
Norm. Trans. Emittance	5 um
Energy Spread	0.1 %

LASER BEAM PARAMETERS	
Wavelength	515 nm - 1030 nm
Average Power	300kW - 600 kW (can be increased R&D)
Pulse length	3 ps (can be reduced)
Pulse energy	7.5mJ - 15 mJ
Spot size	30 µm (can be reduced)
Bandwidth	0.02 %

GAMMA BEAM PARAMETERS (for λ=515nm)	
Energy	30 MeV
Spectral density	$9*10^4$ ph/s/eV
Bandwidth	< 5%
Flux within FWHM bdw	$7*10^{10}$ ph/s (total flux 9*10^12)
ph/e^- within FWHM bdw	10^{-6}
Peak Brilliance	$3*10^{21}$ ph/s*mm^2*mrad^2 0.1%bdw

A. Valloni

Work in progress as electron energy will be 400 MeV and parameters evolve


IGLEX: Thomx +
Andromede
PRAE
AILE 3
Hall for PERLE
37 m
55 m

Hosting PERLE@Orsay:

Site description:

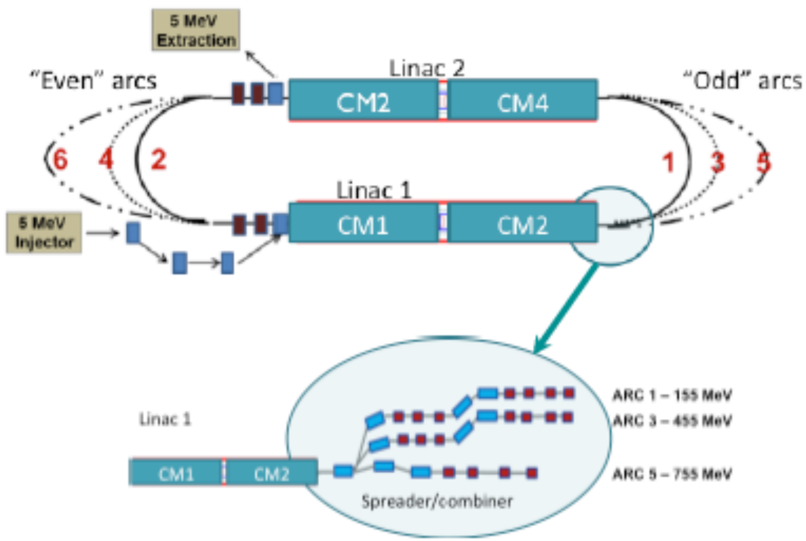
- The experimental hall is equipped with crane, electricity and partially shielded
- Water cooling circuit could be shared with other machines nearby.
- Possibility to install the RF source and power supplies in a different level than the accelerator
- A large area of ground have the required resistance 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.


8105


8105

Hosting PERLE@Orsay:

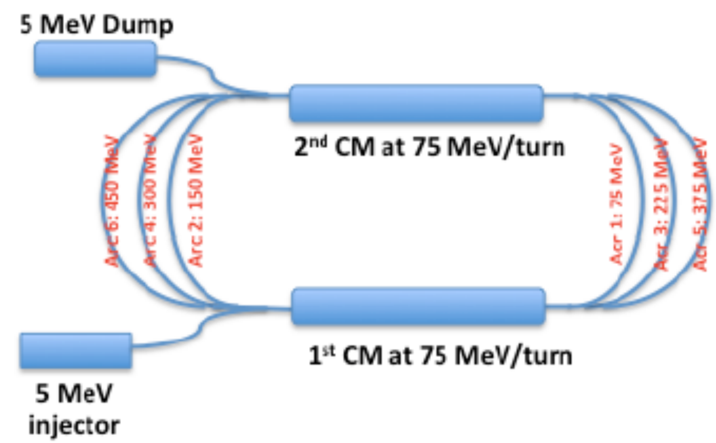
PERLE:



Target Parameter Values:

- Injection Energy: 5 MeV
- RF Frequency: 802 MHz.
- CW mode.
- Beam current: 6-15 mA.
- 4 CMs: 4 cavities (5 Cells) @ 15-20 MeV
  → ≈ 300 MeV/tour.
- 3 passes → ≈ 900 MeV.

PERLE@Orsay:



Target Parameter Values:

- Injection Energy: 5 MeV
- RF Frequency: 802 MHz.
- CW mode.
- Beam current: 6-15 mA.
- 2 CMs: 4 cavities (5 Cells) @ 15-20 MeV
  → ≈150 MeV/tour.
- 3 passes → ≈ 450 MeV.

Study of First Stage (single pass)

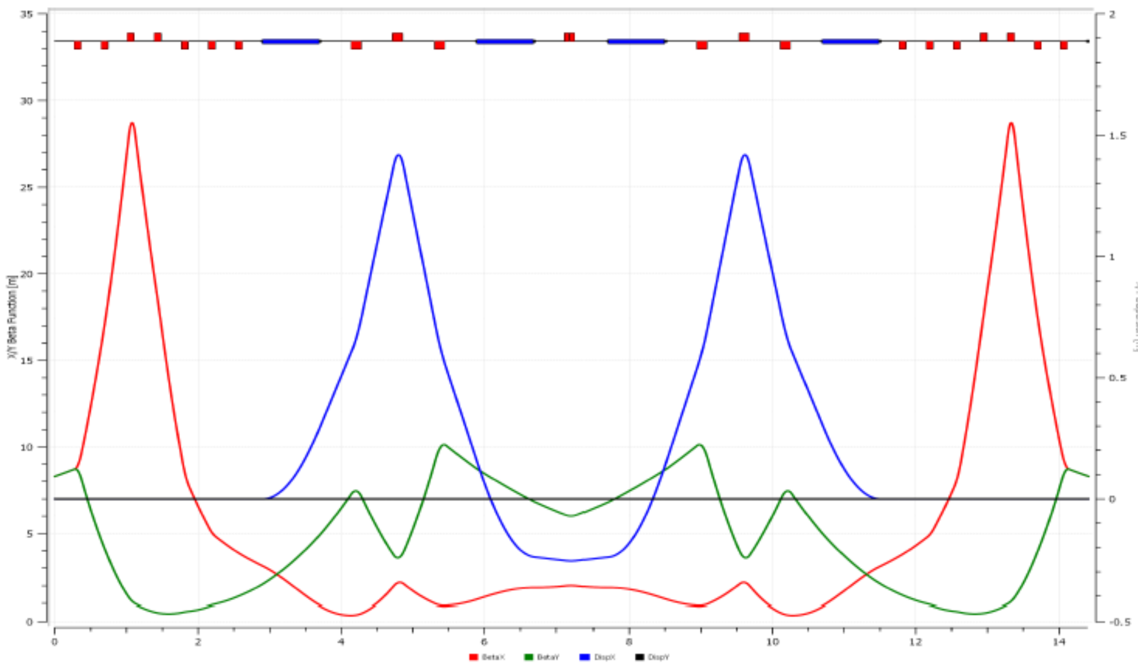
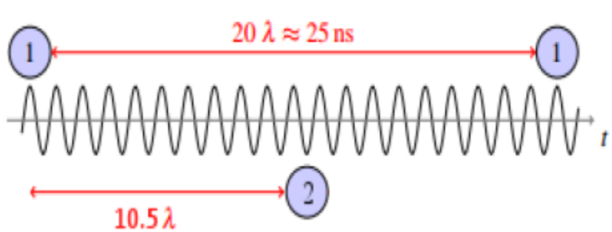


Figure 3.10: The lattice functions for the complete 80 MeV arc. β_x is given by the red line, β_y by the green line and the x dispersion by the blue line.



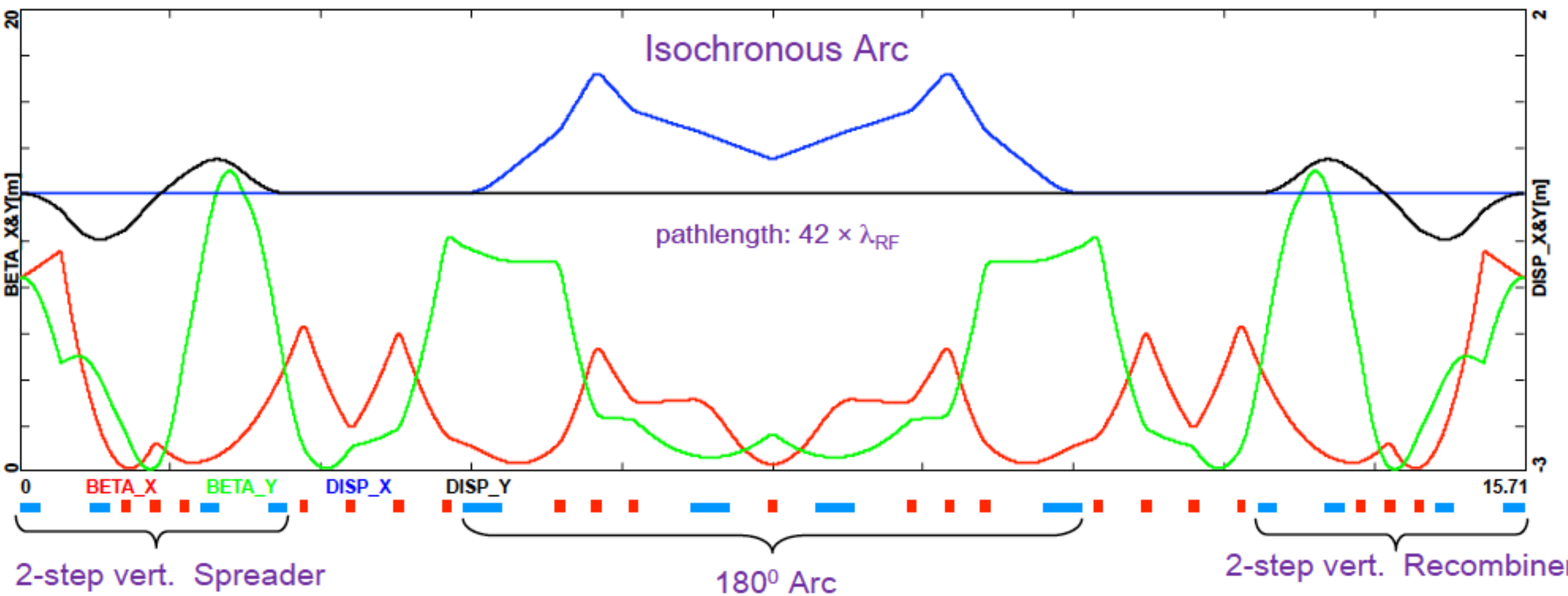
Independent design study: 6.2 x 20.9 m^2

Matched optics, momentum compaction

46 dipoles and quadrupoles

Linear Optics Study of PERLE, Ben Hounsell (Master Thesis 5/17) U Liverpool (MK and AB/AV)

PERLE 3 turn optics (80 MeV Arc)



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

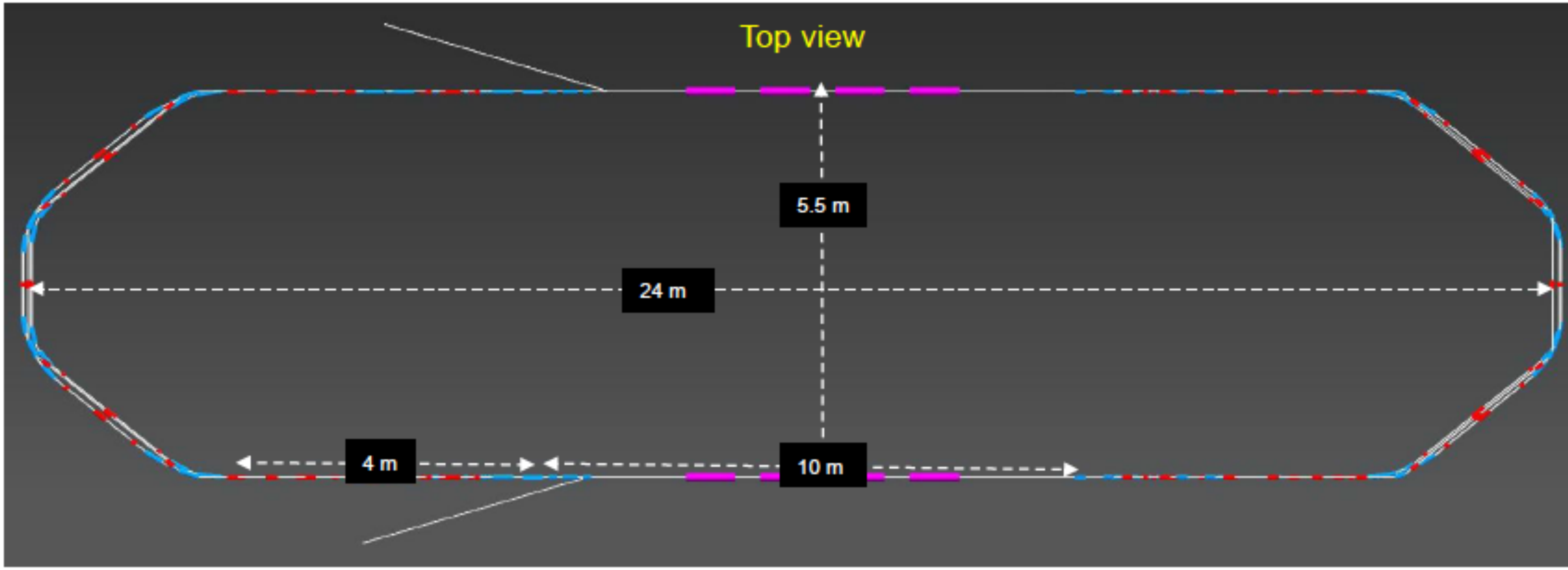
Rec. dipoles:
4× 45⁰ bends
L = 20 cm
B = 9.5 kGauss

quads: L = 10 cm G ≤ 1 kGauss/cm

A Bogacz (24.5.17)

70 Dipoles and **114 Quadrupoles** **footprint 22 x 5.5 m2**

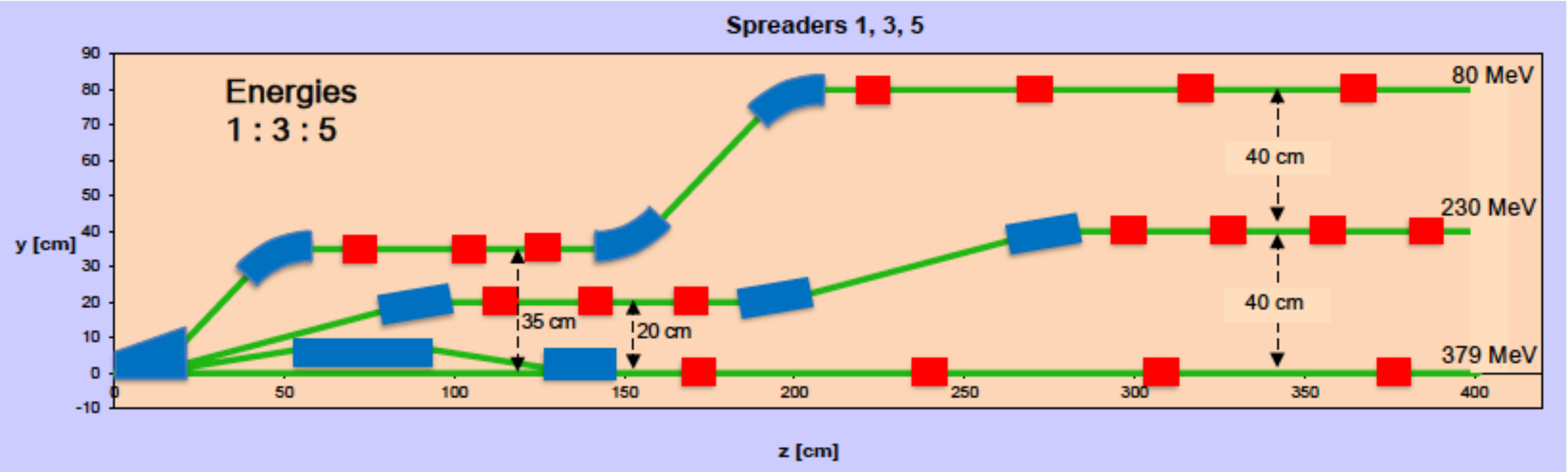
Footprint of PERLE@Orsay (tentative)

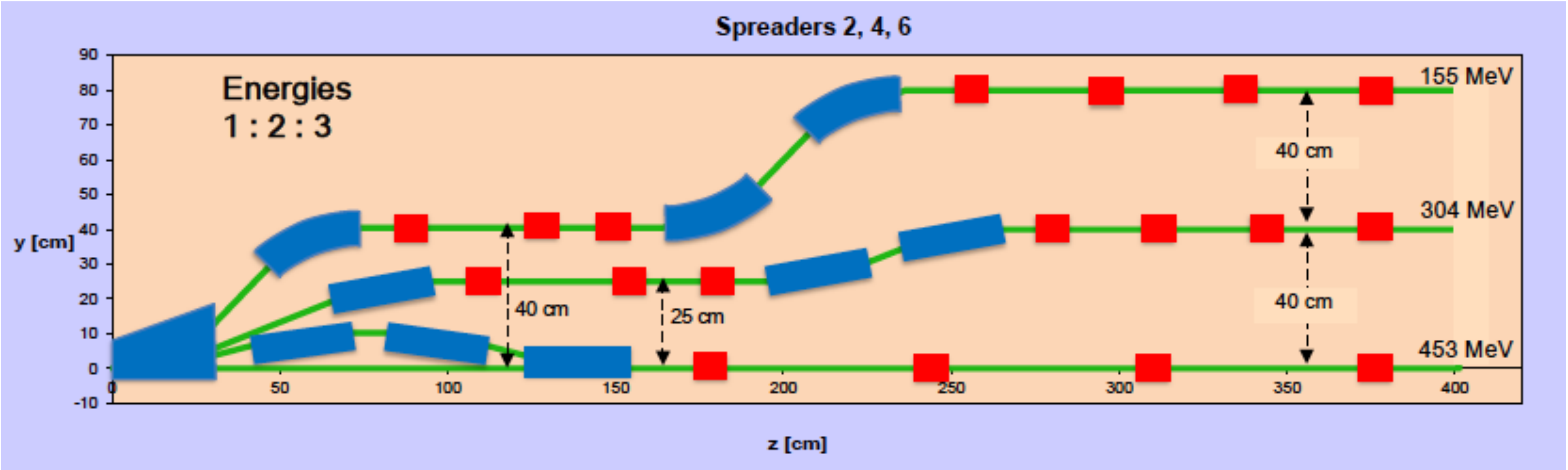


A. Bogacz (24.5.17)

5 x 2 cavities: 16.5 MeV/cavity (17.5/m) → 165 MeV per pass → 395 + 5 → E_e=400 MeV

Vertical Switchyards





A Bogacz (24.5.17)

PERLE Magnets

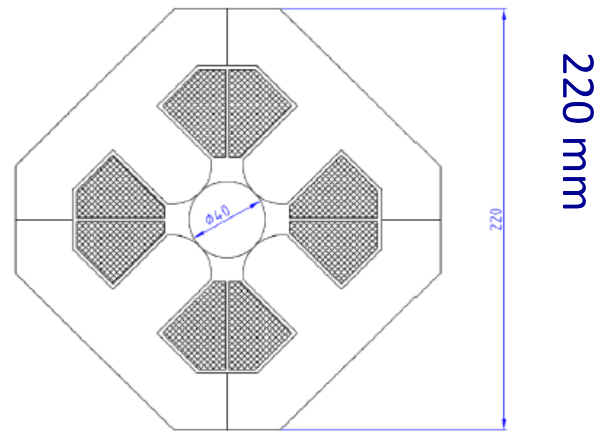
70 dipoles 0.45-1.29 T

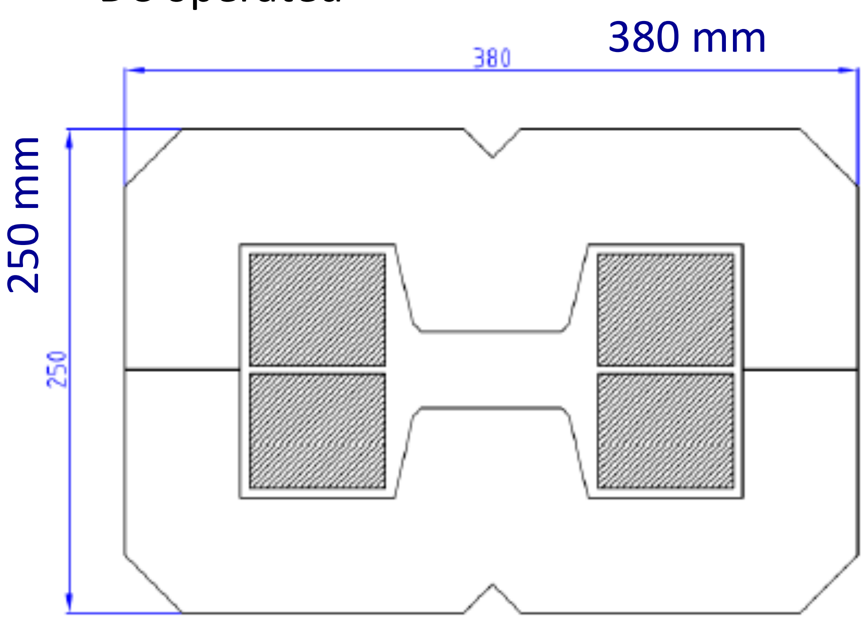
+- 20 mm aperture, l=200,300,400 mm

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

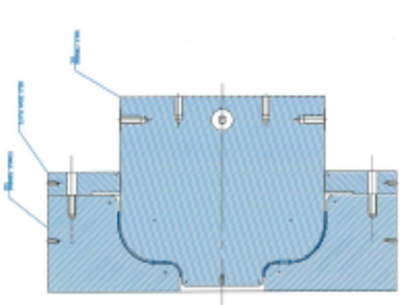
DC operated

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

802 MHz Cavity Fabrication Status

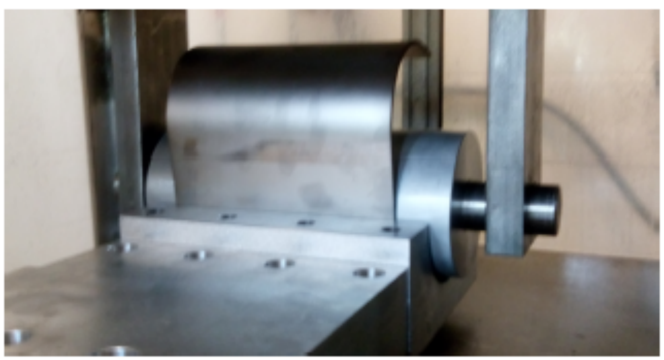
802 MHZ Nb and Cu prototype cavities progressing well

F. Marhauser
Status 05-25-2017

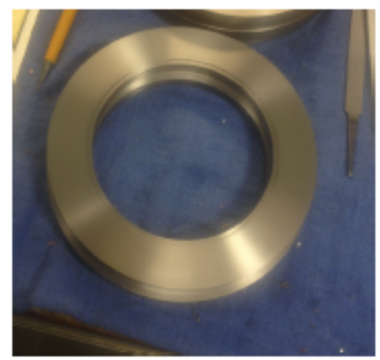


802 MHz deep-drawing die set and machining fixtures (completed)

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



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



NbTi flanges (completed)

RF test hardware for OD = 6.5" flanges available

Cryomodule requirements 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 !

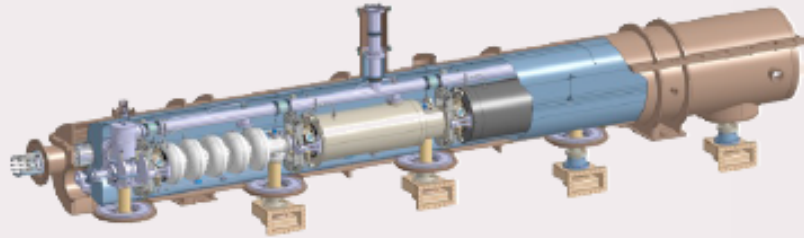
2. The aditionnal constraints coming from the cavities operated in the ERL mode and CW/high current operation mode:
    - High CW cryo loads
    - Low level of vibration, and damping of them
    - Excellent magnetic shielding (high Qo)
    - Accurate cavity alignment

Expertise on Cryomodules

SPL « Short cryomodule »

5-cells Elliptical
700 MHz, β = 1.0
X 4

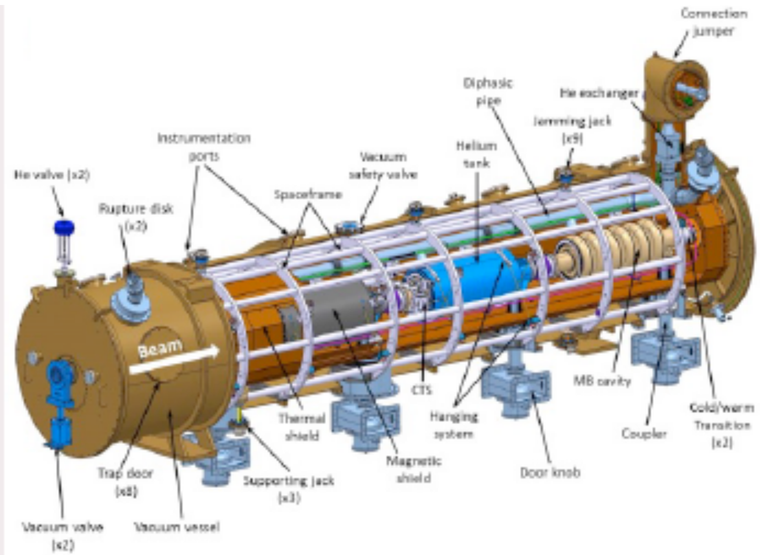
Full length top lid closure
Cold mass supported by power couplers



ESS Elliptical cryomodule(s)

5&6-cells Elliptical
700 MHz
β = 0.67 & 0.86
X 4

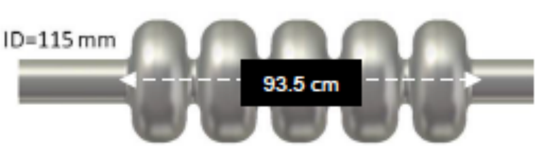
Side loading
Space frame

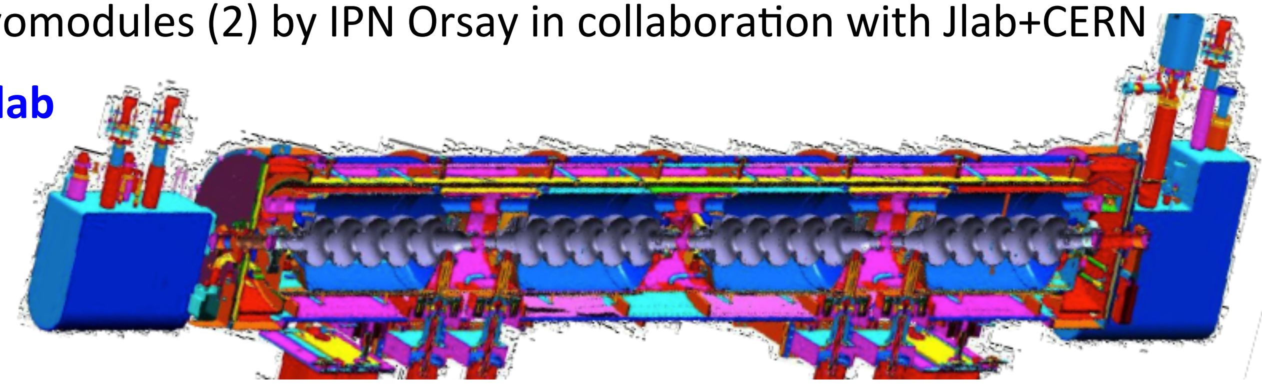


Plan for production of PERLE cryomodules (2) by IPN Orsay in collaboration with Jlab+CERN

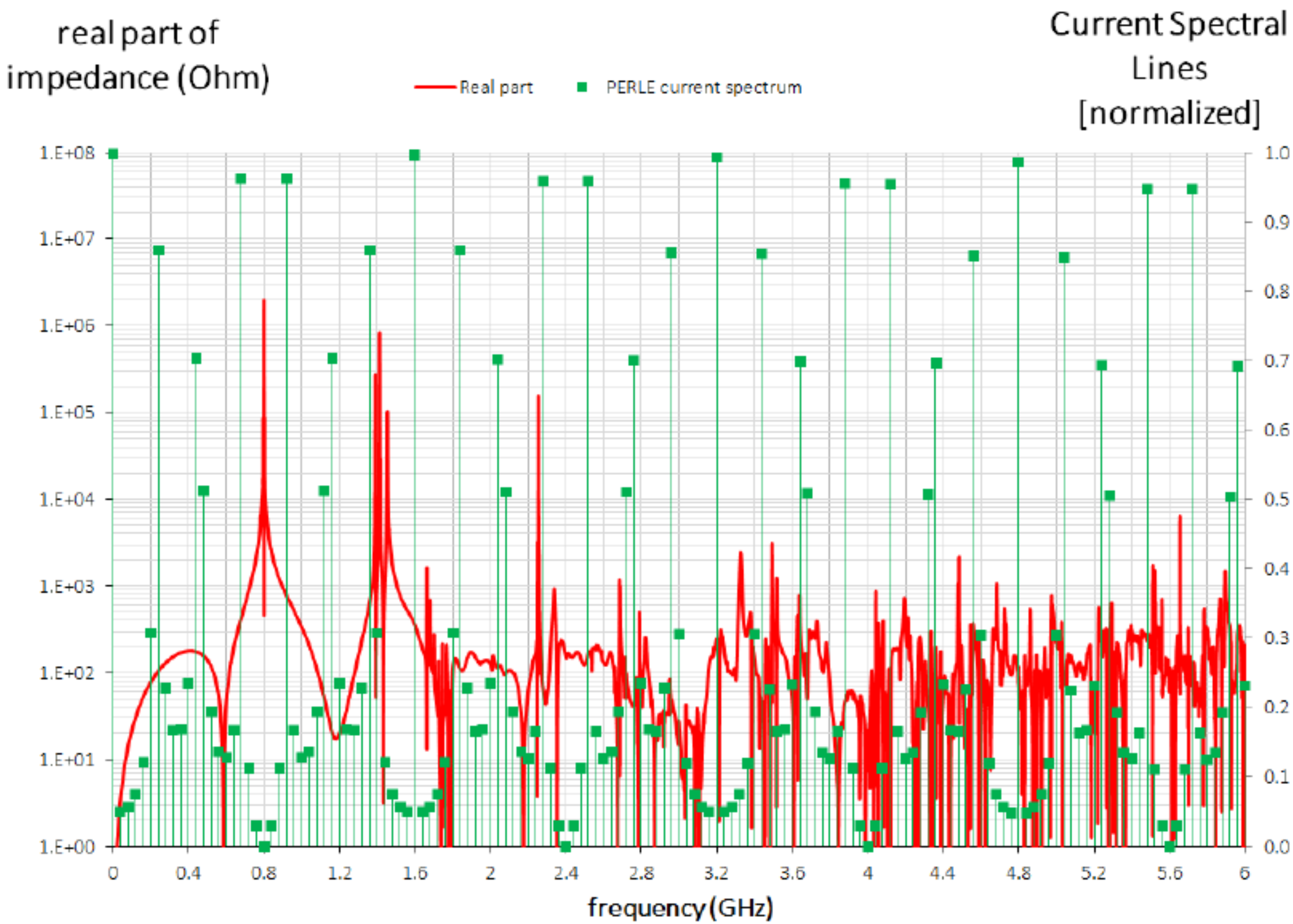
Jlab

SNS 805 MHz cryomodule





HOM Assessment



Impedance of cavities + oscillating modes (F Marhauser) ≠ Spectral content of PERLE beam (D Pellegrini)

Source

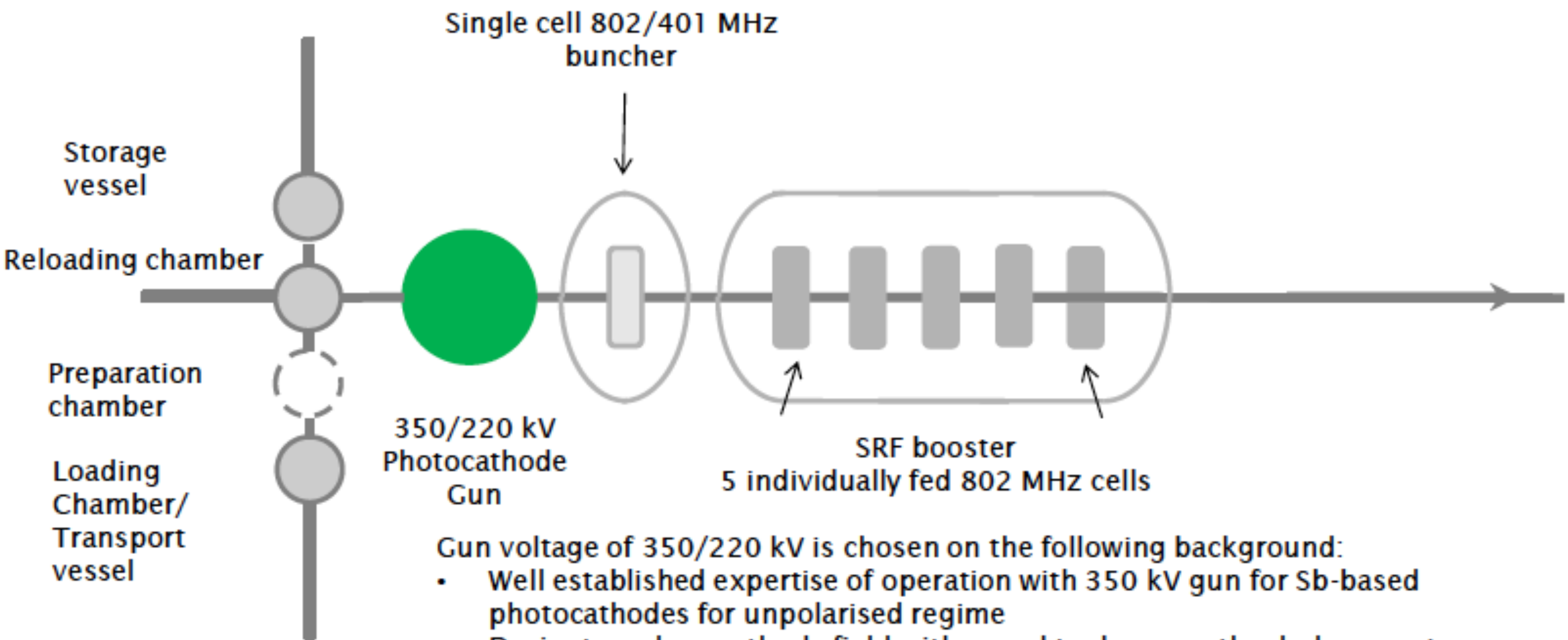
Material	Typical oper. λ	Work function	Observed Q.E.	Laser power for 20 mA	Observed max current	Obs. lifetime
Sb-based unpolarised	532 nm	1.5-1.9 eV	4-5%	4.7 W at Q.E.=1%	65 mA [Cornell]	Days rep.
GaAs-based polarised	780 nm	1.2 eV at NEA state	0.1-1.0%	31.8 W at Q.E.=0.1%	5-6 mA [JLAB]	Hours

Table 4.1: Characteristics of photocathode materials available for PERLE

← Boris Militsyn's home

GaAs photocathode preparation facility designed for 4GLS and ALICE gun upgrade.

General layout of the PERLE photoinjector



Gun voltage of 350/220 kV is chosen on the following background:

- Well established expertise of operation with 350 kV gun for Sb-based photocathodes for unpolarised regime
- Desire to reduce cathode field with a goal to decrease the dark current from GaAs type photocathodes which have low work function of 1.2 eV (polarised regime) leads to propose operation at lower voltage 220kV. As requirement to emittance is modest, high cathode field is not required.

Summary

CDR of PERLE

PERLE has the opportunity to be a clean-sheet globally optimised design for a new generation of high average power efficient ERL based machines, a novel testing ground for far reaching experiments with electron and photon beams of unique quality and, not least, to become a prime technical base for an electron beam upgrade of the LHC, i.e. a new generation of deep inelastic scattering experiments entailing the precision study of the Higgs boson and the exploration of new physics at TeV energies.

PERLE is a novel project and still to be established. It calls for and is open for a wide collaboration to make it a success for accelerator, particle and nuclear physics.
For the FCC developments at large it has a strong value as a test bed for SCRF development.

Special thanks to Erk Jensen, Achille Stocchi and many more people than I can list here.

No backup