CERN Accelerator School – FELs and ERLs

Case Study: Case 1 / Group 2

Goal: **Design a high repetition FEL at a wavelength of 13.5 nm with an average power of more than 2 kW**

Case Study Group 2

Group 2		
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Introduction

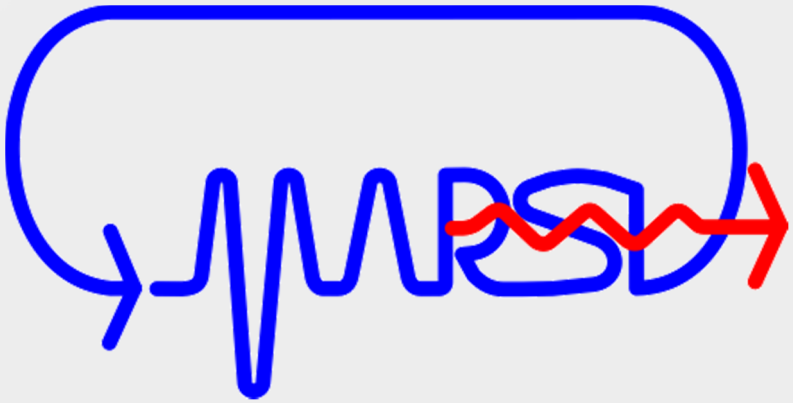
1. Background: To generate the fine structures in micro chips with lithorgraphy it requires a coherent light source and a mask for the fabrication of wafers. More average power results in faster fabrication. It should be at least above 1 kW because otherwise alternative solution exists.
2. The VUV FEL at a wavelength of 13.5 nm with an average power of more than 2 kW requires around 1 MW of average CW electron beam power (ρ_{FEL} ~ 0.2%).
3. Because of high required average electron beam power and CW operation an ERL based FEL with superconducting LINAC is proposed to reduce the dumped beam energy to an acceptable level.
4. The FEL undulator is chosen to be planar type vriable (20 mm) gap and 30 mm period, close by design to LCLS and FLASH/E-XFEL ones.
5. The ERL design is mainly based on bERLinPro and JAEA projects.

The Name

Multi-kW **A**dvanced EUV **R**adiation **S**ource

project

"MARS"

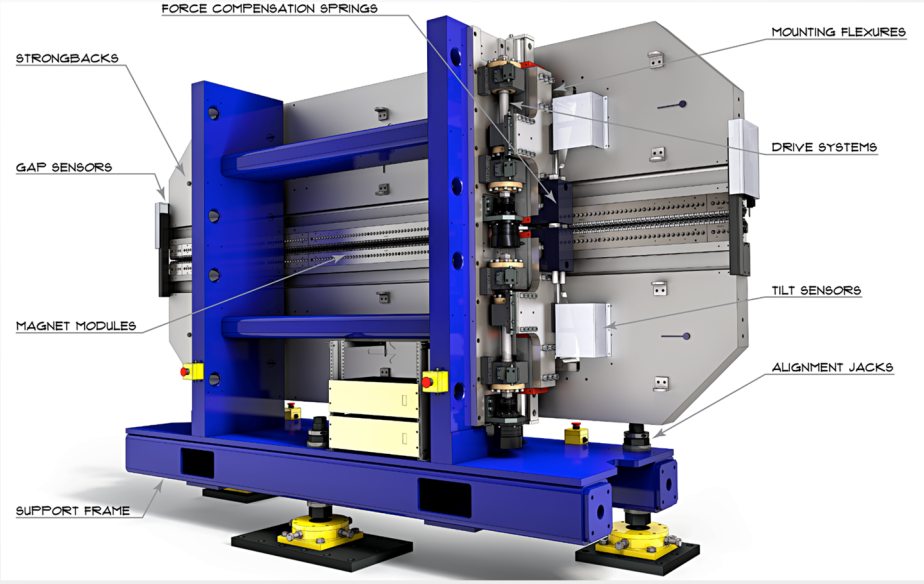


FEL Parameters

Power gain model used:	Xie		Input data set:	FLASH1	
Beam parameters:					
Beam Energy [GeV] :	0.60	Norm. Emittance [mm mrad]:	1.0	Energy Spread [MeV] :	0.15
Bunch charge [nC] :	0.2	Peak Current [kA] :	2	Beam Power [TW] :	1.2
Beam size [mu] :	50.413	bunch length [mu] :	11.968	#Bunches/sec. :	50000
Undulator parameters:	Type :	Hybrid with NdFeB	Geometry :	planar	
Period [mm] :	30	K-rms parameter :	0.487	Length [m] :	15
Peak field [T] :	0.246	Gap [mm] :	20.059	Bessel factor J0-J1 :	0.95
FODO period [m] :	1	Quadrupole gradient [T/m] :	10	Quadrupole Length [m] :	0.15
Quadrupole focal length [m] :	1.332	Average beta-function [m] :	2.979	beta_max/beta_min :	1.38
Radiation parameters:					
Radiation wavelength [nm] :	13.507	Photon Energy [eV] :	91.825		
finalize					
1D rho parameter (Bonifacio) :	0.002598	1D gain length [m] :	0.53		
3D rho parameter :	0.002042	**3D gain length [m] :**	**0.675**	**Saturation length [m] :**	**13.83**
Shotnoise power [W]:	34.935	**Saturation power [GW] :**	**3.082**	Power at undulator exit [GW] :	3.071
Electrons per wavelength:	562792	Effective Energy spread :	0.021	Diffraction parameter :	4.1
Spotsize at exit (FWHM) [mu] :	118.71	Divergence (FWHM) [murad]:	50.21	Bandwidth (FWHM) [%] :	0.48
Pulse duration (FWHM) [fs] :	47	Photons per Pulse :	0.105E14	Autocorrelation time [fs] :	6.22
Peak Flux [#/sec] :	2.098E26	Peak Brilliance* :	4.6E30	Pulse Energy [mJ] :	0.154
Average Flux [#/sec] :	0.493E18	Average Brilliance* :	10.81E21		
SR Energy loss [MeV] :	0.0002	SR Energy spread [MeV] :	0		

3 × 5 m long undulators

Undulator Parameters



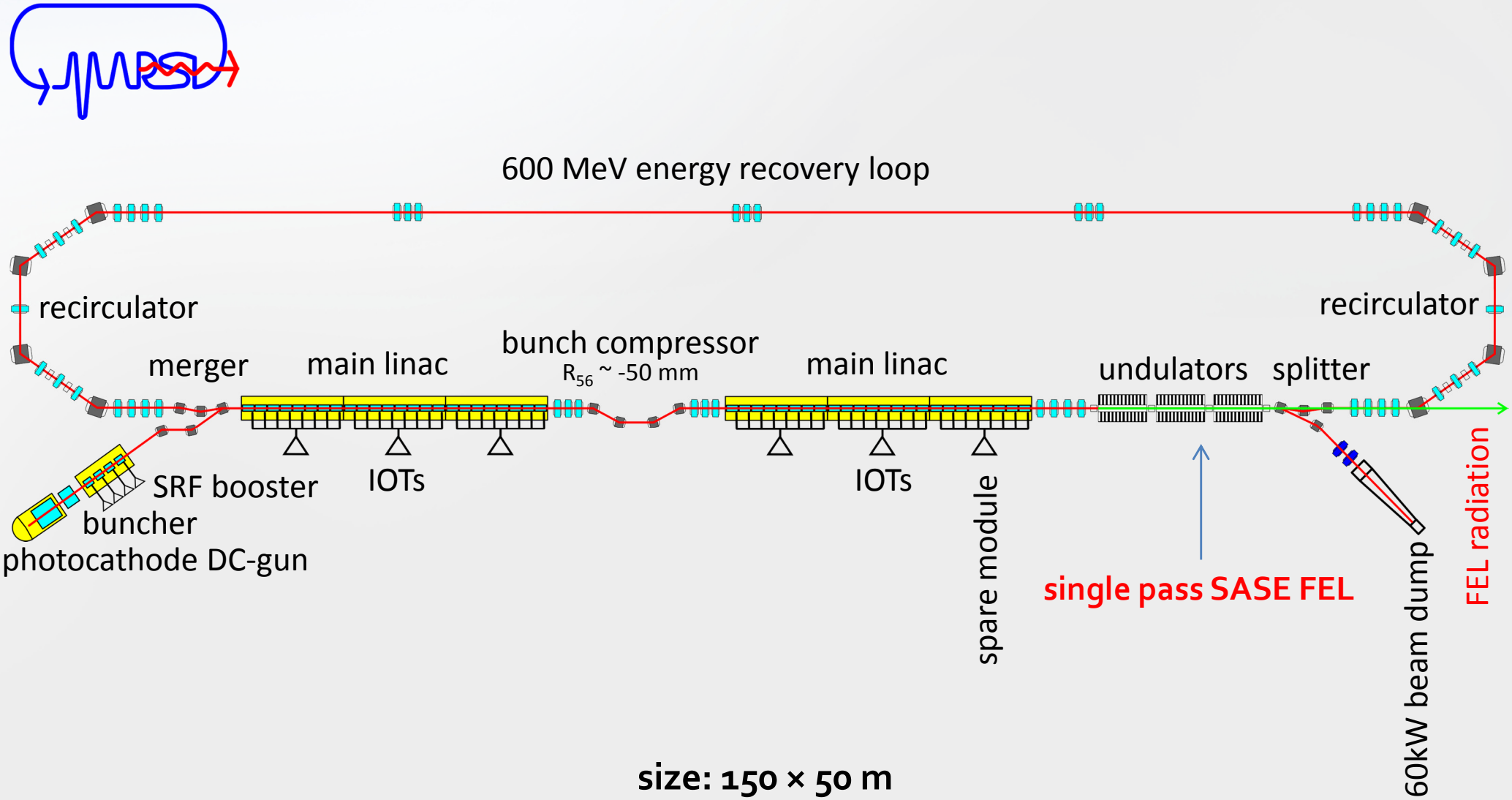
LCLS-II type undulator

D. Arbelaez, LBNL

parameter	value
geometry	planar
type	hybrid / variable gap
permanent magnets type	NdFeB / SmCo optional*
period [mm]	30
gap [mm]	20
peak magnetic field [T]	0.246
K-rms parameter	0.487
ρ parameter (3D)	0.002
saturation length [m]	13.8
length [m]	3 × 5 = 15
beam energy [MeV]	600
radiation wavelength [nm]	13.5
average FEL radiation power [kW]	1 .. 12

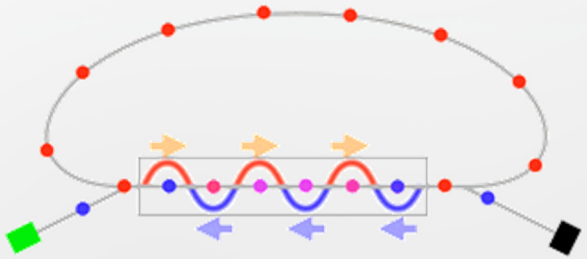
*to consider for increased life time with the radiation expose.

ERL based FEL Layout



size: 150 × 50 m

ERL Parameters

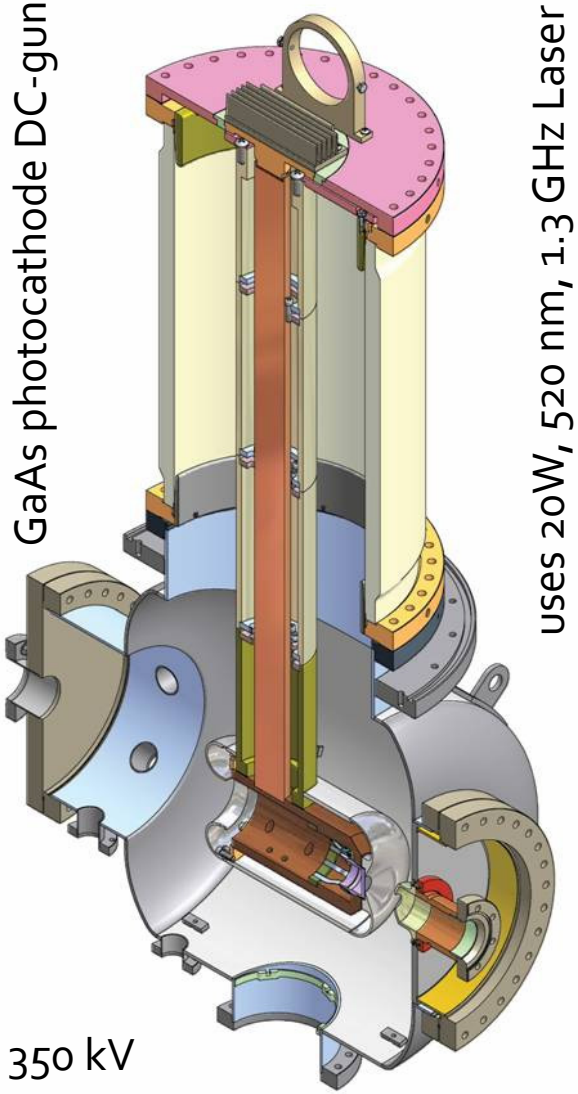


single pass recirculation layout

parameter	value
beam energy [MeV]	600
beam current [mA]	1 .. 10
bunch charge [pC]	20 .. 200
beam average power [MW]	0.6 .. 6.0
repetition rate [MHz]	50
normalized emittance [µm·rad]	1.0
bunch transversal size at undulator [µm]	50
bunch length at undulator [µm]	12
DC-gun energy [MeV]	0.35
booster energy [MeV]	6.0
main linac energy [MeV]	600
SRF module energy [MeV]	120
SRF modules number	5 + 1 spare
IOT RF power [kW]	80
converted FEL radiation [kW]	1 .. 12

ERL Injector

GaAs photocathode DC-gun

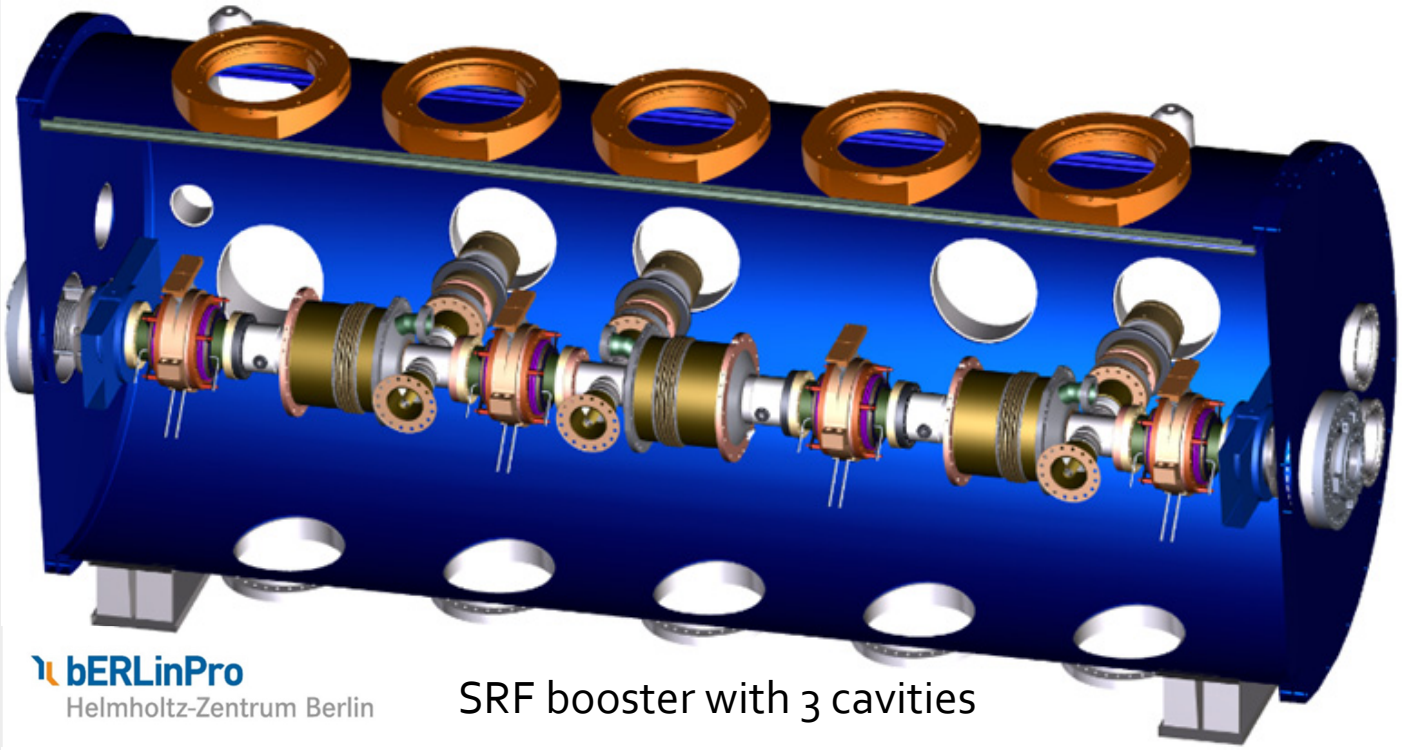


uses 20W, 520 nm, 1.3 GHz Laser

350 kV

CW operation needs a DC-gun, as a proven technology.
Needed parameters reached at Cornell and KEK.

Cornell / bERLinPro SRF booster 4 x 2cell SRF cavities 6MeV



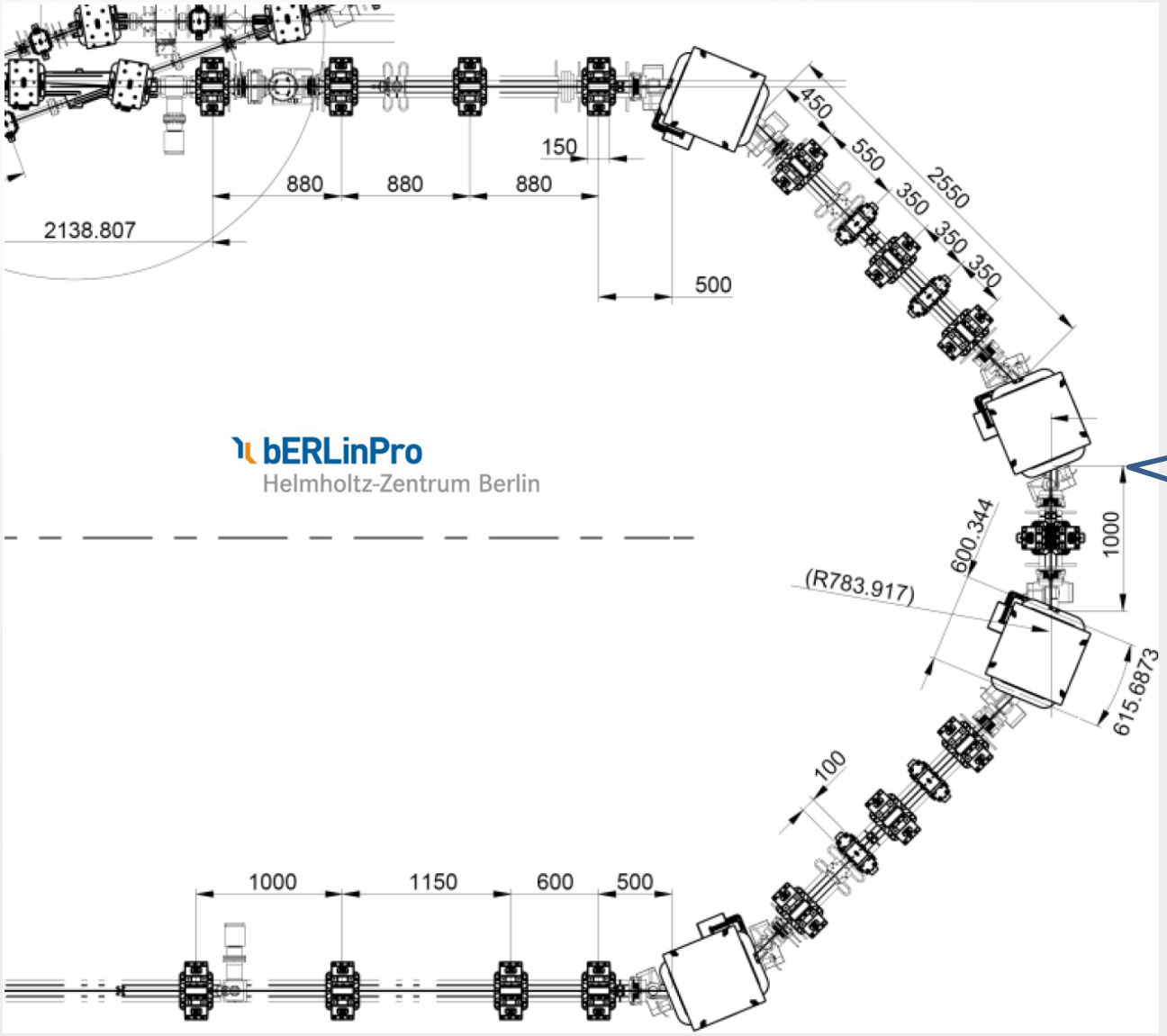
SRF booster with 3 cavities

ERL main linac

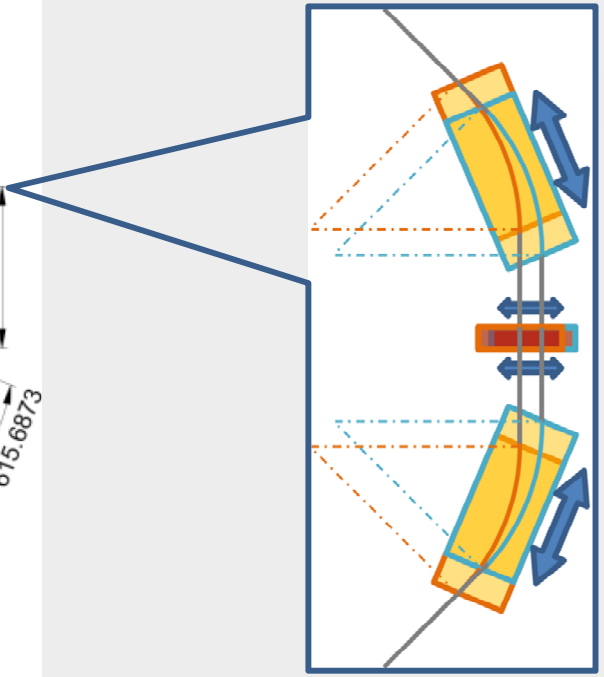
- accelerating module: 8 cavities / 120 MeV
- main LINAC: 5 (+ 1 spare) modules / 600 MeV
- accelerating cavity: bERLinPro type 7-cell
- RF power source: 80 kW IOT per module
- cryogenics: 1 kW at 1.8 K (LHe)
- LINAC length: 6 × 10 = 60 m

7-cell SRF cavity 20 MV/m, 17 MeV, operating temperature: 1.8 K
strong HOM damping design to cope with a BBU effect.

ERL Recirculator Arcs



Layout from bERLinPro Project:
bend-achromat / adjustable

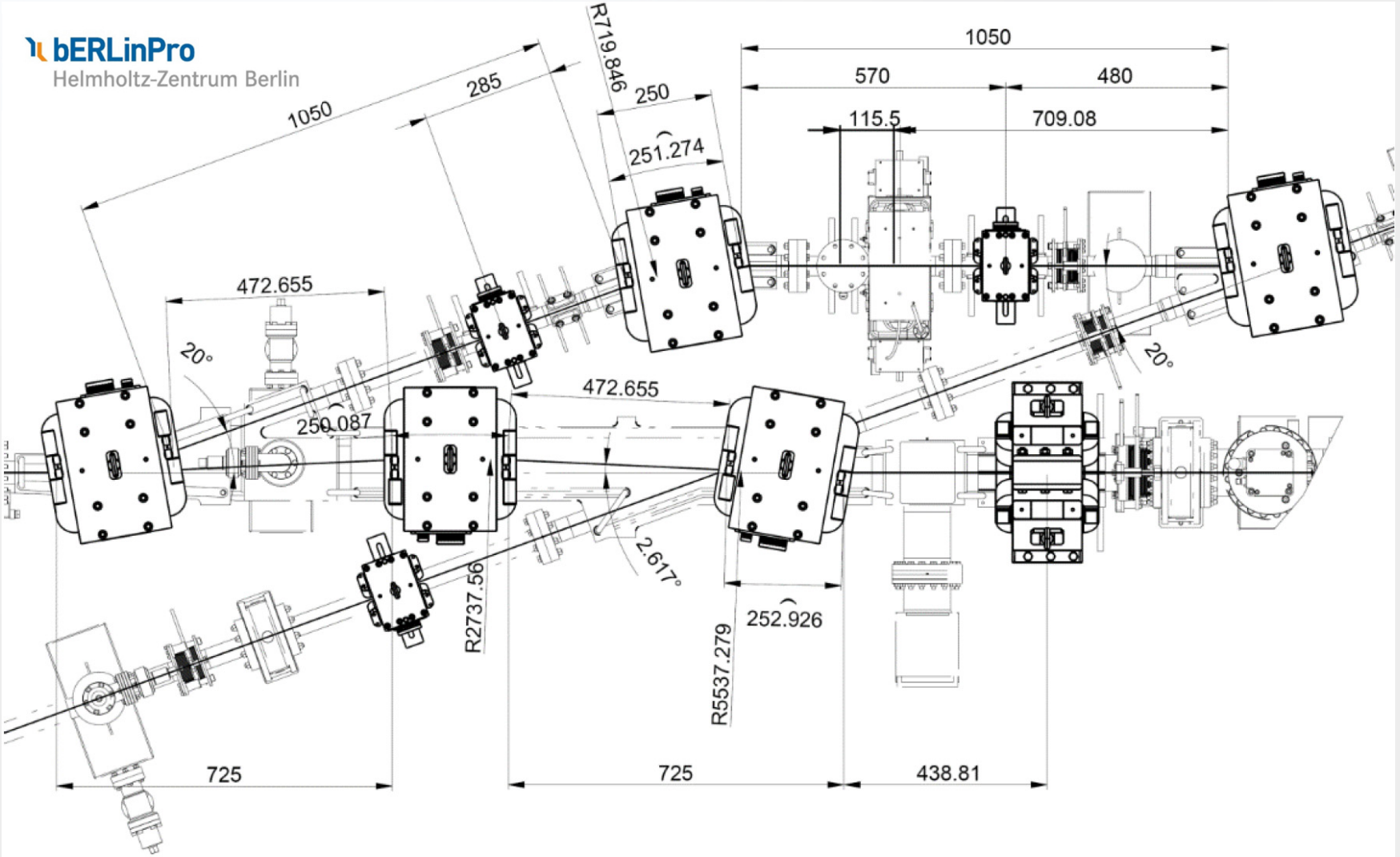


arc beam path adjustment

$L_{recirculator} = (n+½)\cdot c/f_{RF}$

ERL Merger

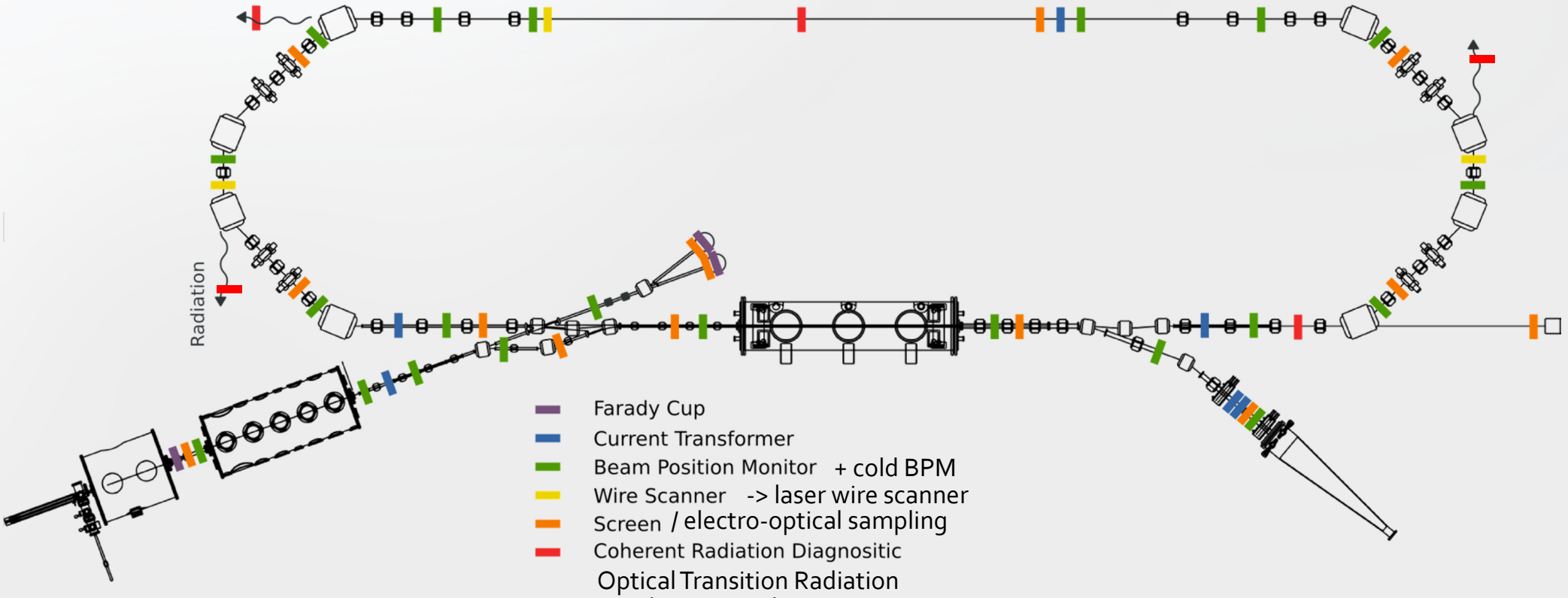
Layout from bERLinPro Project: dog-leg type, needs 6 / 600 MeV merging



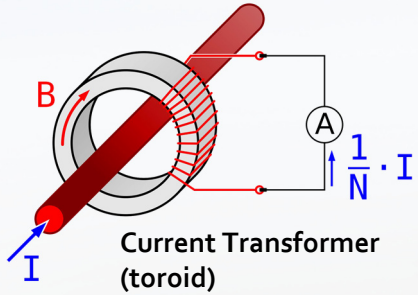
ERL Diagnostics

bERLinPro
Helmholtz-Zentrum Berlin

Layout from bERLinPro Project

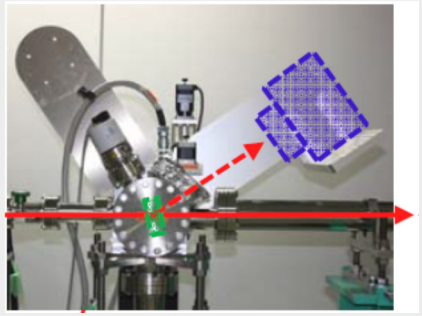


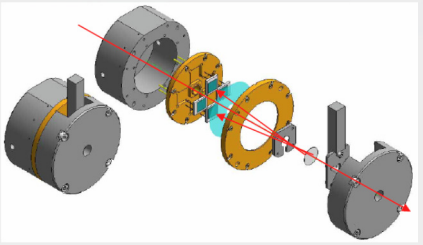
FEL-ERL Diagnostics Summary

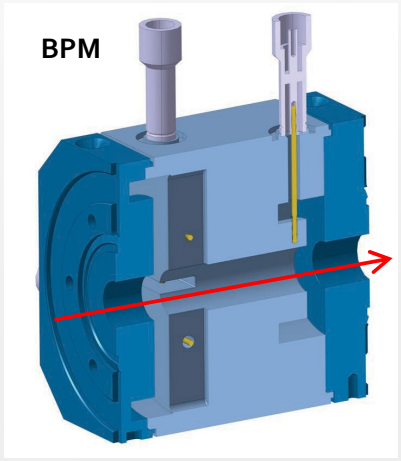


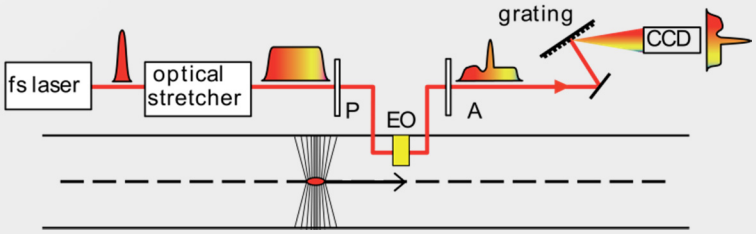
Current Transformer (toroid)

electron beam	photon beam
Farady Cup	Wave Length Monitor
Current Transformer	Pulse Energy Monitor
Beam Position Monitor	Screen Monitor
Laser Wire Scanner	Gas Monitor Detector
Screen	
Electro-Optical Sampling	
Optical Transition Radiation	
Synchrotron Light Monitor	
Beam Arrival Monitor	


Wave Length Monitor

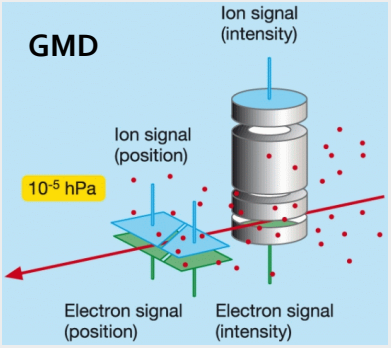

Pulse Energy Monitor

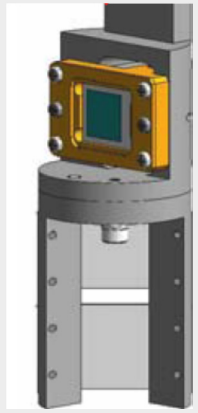




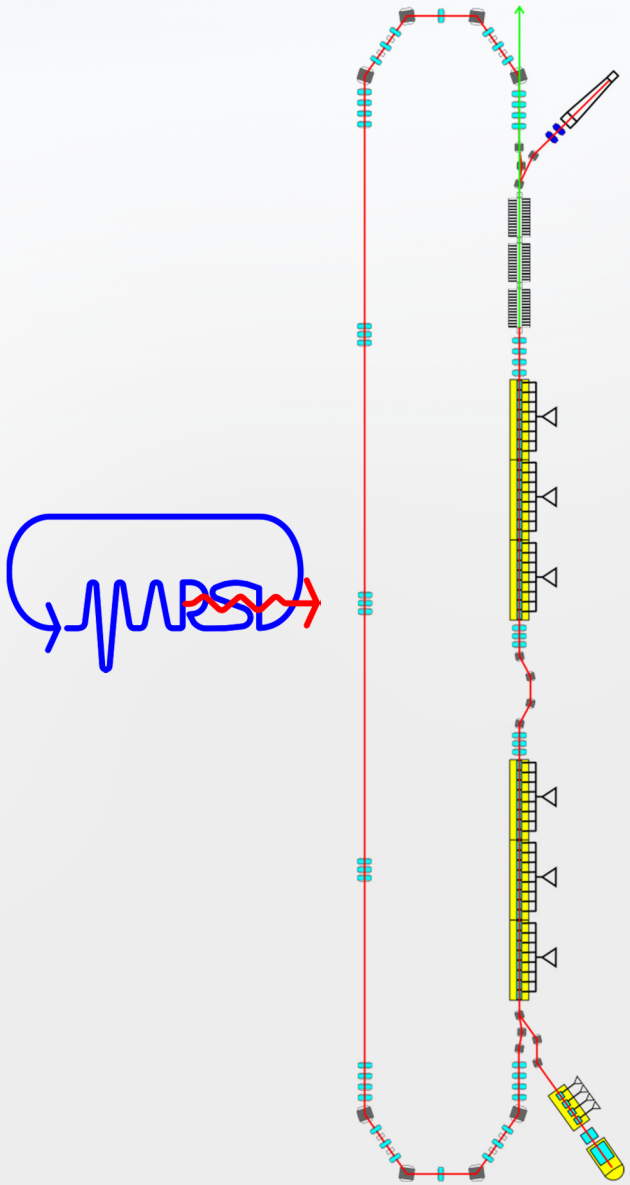
Electro-Optical Sampling


Beam Arrival Monitor




Screen Monitor

Cost Estimation



position	cost [M€]
Building 150×50×15 m³	20
shielding iron/concrete 10^4 t	1.2
air conditioning facility	1.0
water cooling facility	1.0
primary & indoor substation facility	1.3
He gas refrigerator facility 1.8 K 1 kW	14
SRF accelerator module	1.0
Undulators	1.5
accelerator facility 10 mA 600 MeV	30
EUV FEL facility (EUVL)	5
Total Construction Cost	**76**
Operation Cost (1 year)	
electricity 0.25€/kWh	6

Summary

1. Extreme ultraviolet lithography (also known as EUV or EUVL) is a next-generation lithography technology using an extreme ultraviolet (EUV) wavelength, currently expected to be 13.5 nm.
2. 13.5 nm 10 kW average power range 600 MeV 10 mA ERL based high repetition FEL EUV radiation source "**MARS**" is proposed.
3. Proposed facility design is mainly based on proved and already available and tested solutions with accent on the reliability.
4. Facility upgrade options may include the energy upgrade up to 750 MeV using the spare SRF accelerating module and up to 1.5 GeV with a possible double-pass ERL layout, which would allow to reach 10 and 1 nm radiation wavelength ranges respectively, with some undulators adjustments or upgrades. An average current upgrade up to 50 .. 100 mA is another option, implemented technology cutting edge is 100 mA and this is being currenly tested in several labs.

References

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