Elettra
Sincrotrone
Trieste

The Elettra 2.0 project: Challenges and Solutions

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on behalf of the Elettra team

Outline:

- Introduction
- Elettra 2.0 requirements
- S6BA-E
- Final Lattice
- Superbends
- Challenges
- Conclusions

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources

Elettra

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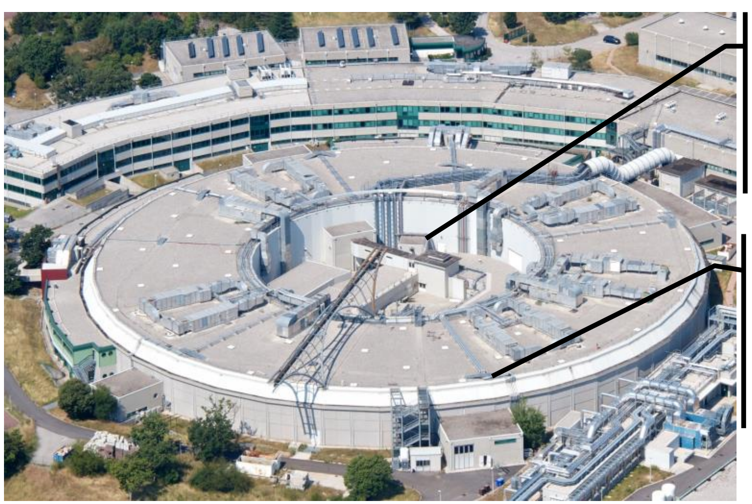
- First 3rd generation in Europe for “soft” x-rays (DBA lattice, 12 fold symmetry), commissioned in October 1993 and open to external users since 1994.

Operating modes for users (all in top-up since 2010):

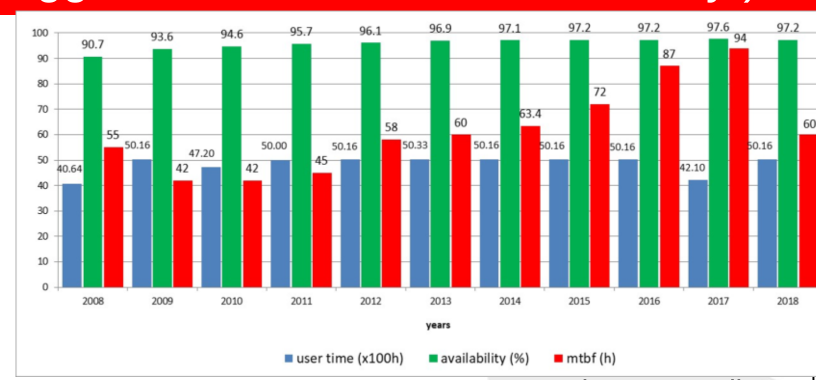
- Operates for about 6400 hours per year (24h, 7/7), 5016 hours reserved for users in 2 energies:
- 2.0 GeV, 7 nmrad, 310 mA for 75 % of users time
- 2.4 GeV, 10 nmrad, 160 mA for 25 % of users time
- 28 total, 27 operating beam lines – over 1000 user and user poposals / year
- Filling patterns: multi-bunch 95 % filling or hybrid, single bunch, few bunches or other multi-bunch fillings



Linac + Booster (114 m)

Storage Ring (259 m)

Exists also a **storage ring FEL** and we operate **super-conducting systems** (a 3.5 T wiggler and a third harmonic cavity)



Characteristics of the 4th generation

Some thought that the 4th generation were the FELs – but that is wrong. FELS are complimentary but do not have for the moment the hight repetition rate, reproducibility , stability and mainly can not simultaneously serve many beam lines.

A whole range of experiments requiring low intenstity to the sample and high repetition rate brought to the renaissance of SRs with the following characteristics:

- Higher brilliance -> i.e. smaller emittance
- Small photon beam size
- Small photon beam divergence
- Higher transverse coherence
- Cleaner spectral flux

Additionally there are requests for

- Short electron pulses (Time resolved)
- Round beams (full coupling)

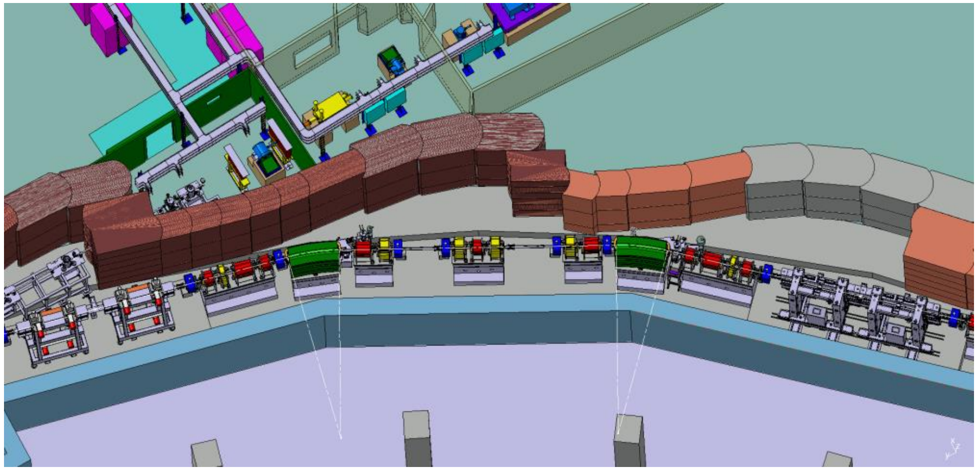
Elettra 2.0 initial and revised requirements

- Beam energy: 2 GeV
- Emittance: to be reduced by more than 1 order of magnitude
- Preserve the present intensities (400 mA) and the time structure of the beam
- Keep the same building and the same ring circumference (259-260 m)
- Existing ID beam lines and their position should be maintained
- Conserve space available for IDs: not less than that of Elettra
- Conserve the existing dipole beam lines
- Keep the present injection scheme and injection complex

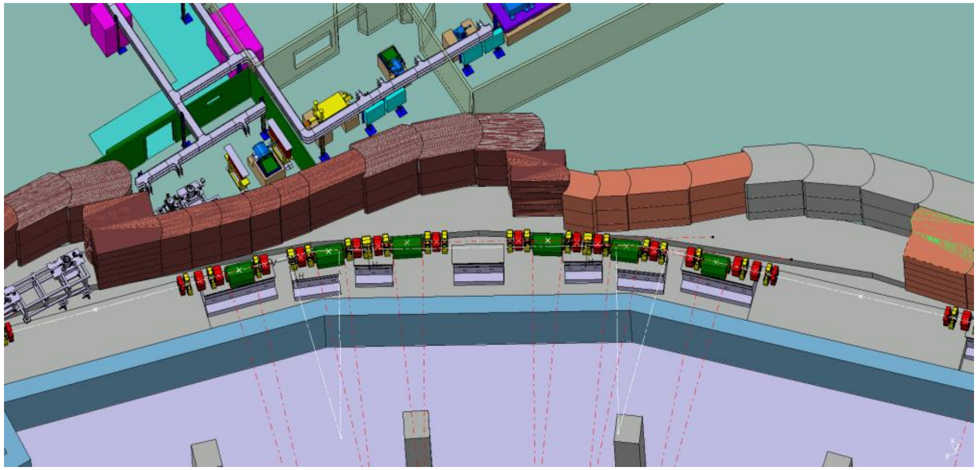
- ***Operating energy 2.0 and 2.4 GeV***
- Emittance: to be reduced by more than 1 order of magnitude
- ***<u>Increase the number of slots available for insertion devices</u>***
- ***New micro-spot in-vacuum undulator beamlines need to go on long straight sections***
- Keep the same building and the same ring circumference
- Preserve the present intensities and the time structure of the beam
- ***Leave open the possibility for installing bunch compression scheme***
- ***Include super-bends***
- Keep the present injection scheme and injection complex
- Minimize the downtime for installation and commissioning to less than 18 months

Elettra 2.0 Lattice in the tunnel

Best configuration that satisfied all initial requirements, including the free space for IDs is based on our symmetric six-bend achromat (S6BA).



Elettra

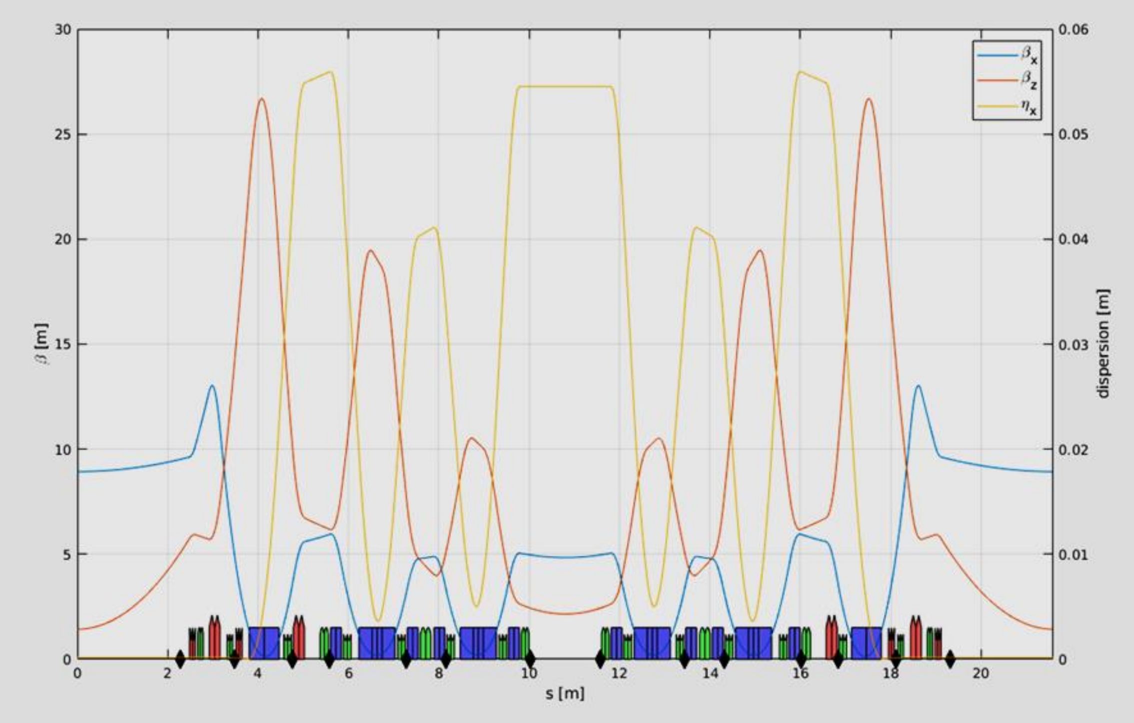


Elettra 2.0

Emittance at 2 GeV 0.25 nm-rad i.e. 28 x reduction from the actual machine

A preliminary but complete Conceptual Design Report was produced in January 2017 (https://www.elettra.eu/lightsources/elettra/elettra-2-0.html?showall=)

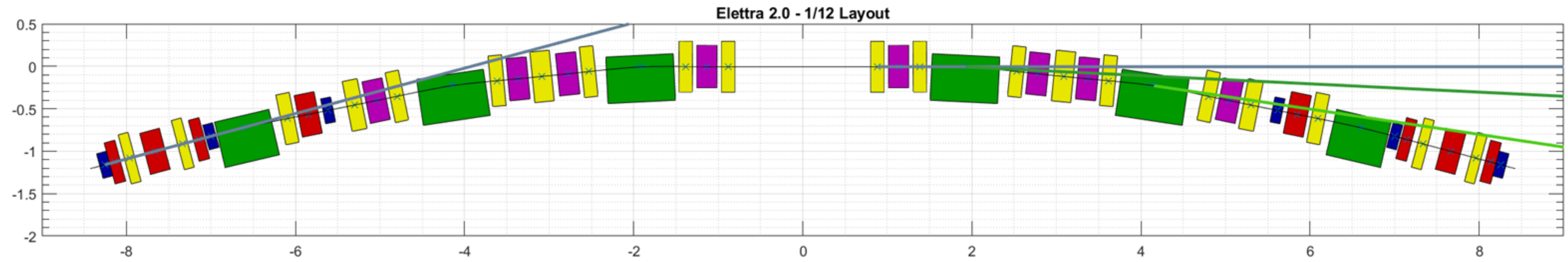
S6BA-E *(for the revised requirements)*



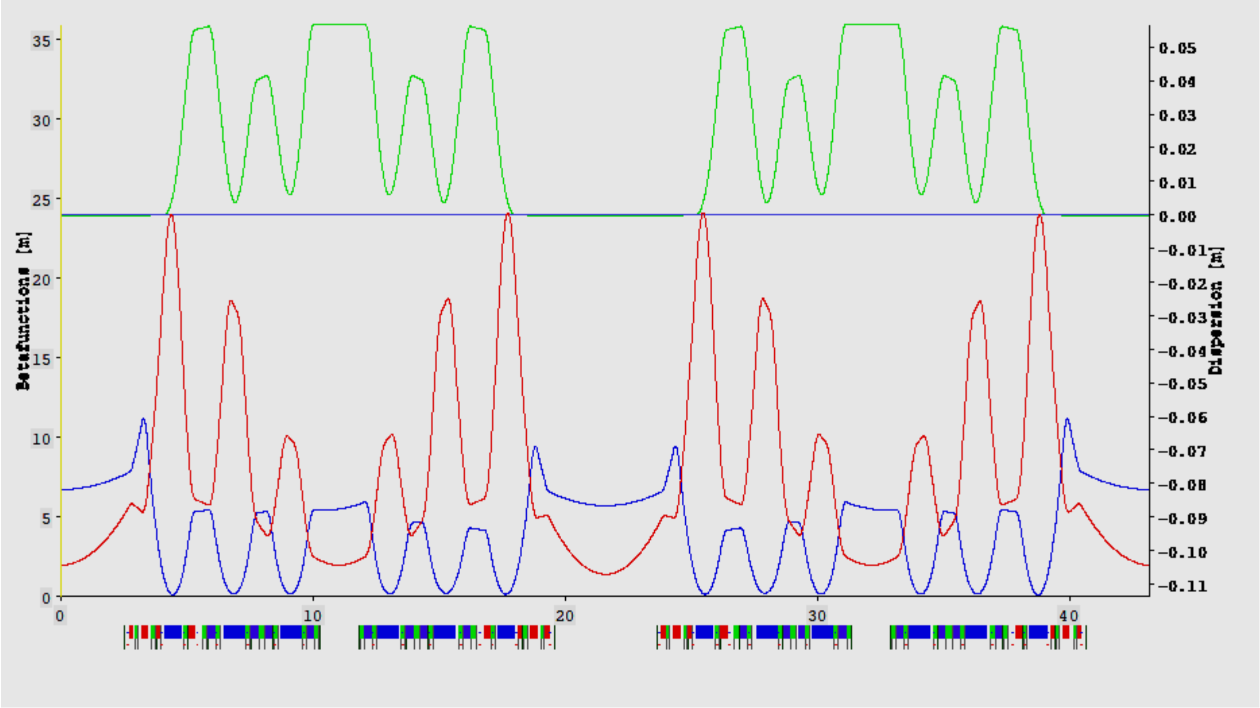
LG + quadrupole/dipole version:
Emittance 98 pm-rad (58 pm-rad if round) at 2 GeV or 140 pm-rad at 2.4 GeV (87 pm-rad if round)

Emittance reduction:
7/0.098=71
10/0.14=71

Free space for IDs (4.5 +1.55 m) 2 & 2.4 GeV



S6BA-E 4/5 matched options - Final



The desired final configuration finally is:

LS = 4.0 / 5.0 SS = 1.55 m with optic functions as matched as possible

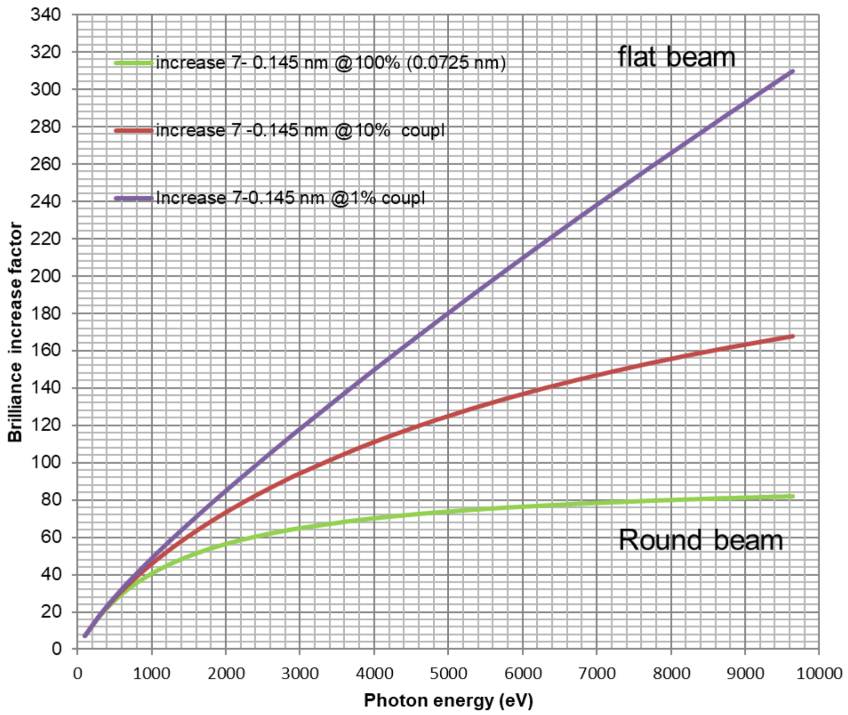
2.0 Gev	2%	10%	100%
Emit init	142	132	72
Emit final	235	185	103

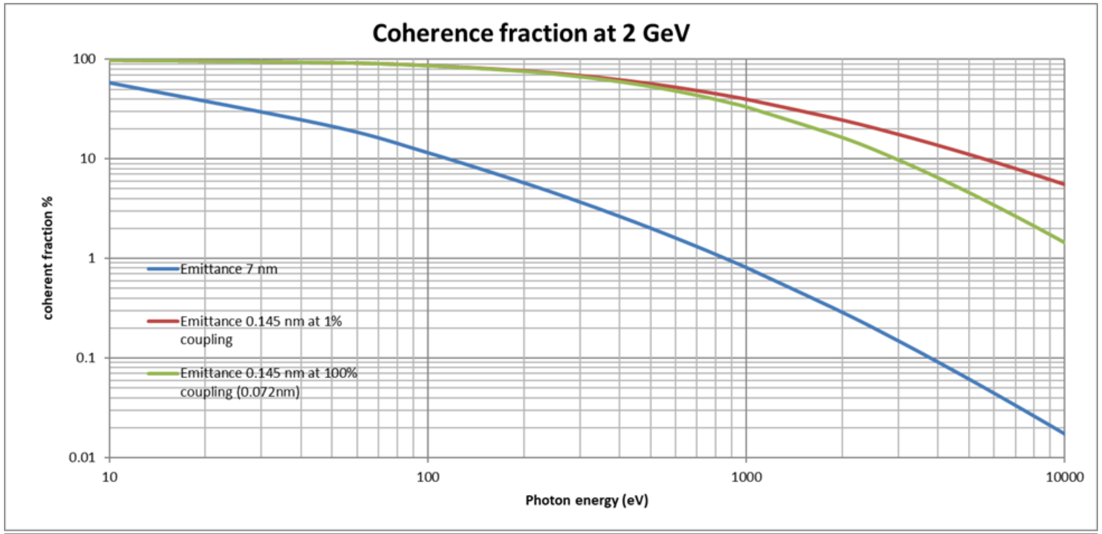
2.0 Gev	2%	10%	100%
σx (um)	30	28	21
σy (um)	2	4.6	11

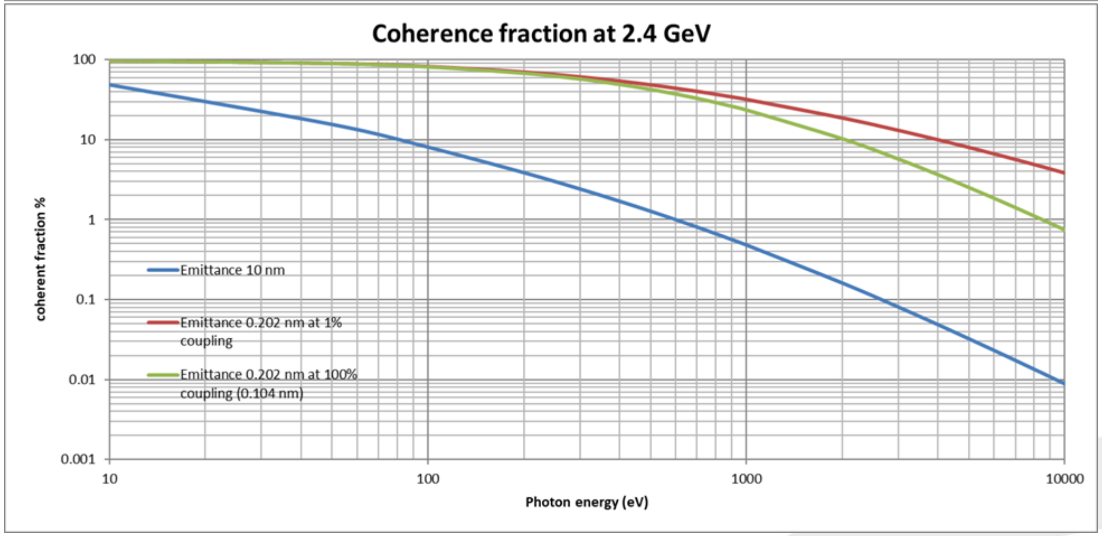
2.4 Gev	2%	10%	100%
Emit init	204	189	104
Emit final	230	206	130

2.4 Gev	2%	10%	100%
σx (um)	36	34	26
σx (um)	2.5	5.5	13

Brilliance increase factor and coherence







Short pulses

S6BA-E can provide e-bunch lengths with FWHM below 10 ps

Other methods being investigated:

1. Femtoslicing using 100 kHz or higher laser
2. Crabbing (S. *Zholents* - ANL collaboration)
3. Other exotic schemes
4. FERMI linac (?)

<u>Technology Involved:</u>

RF systems (mainly superconducting), Lasers, very fast electronics in the fs scale.

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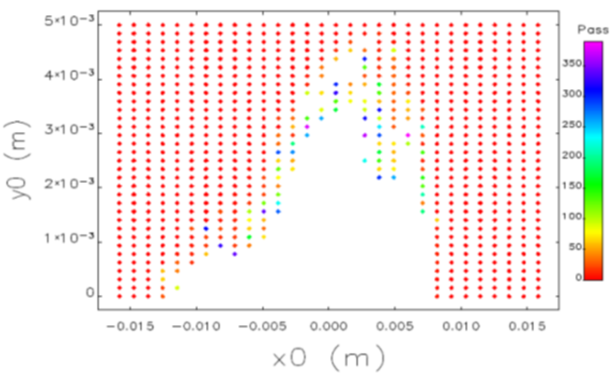
S6BA-E 4/5 Machine parameters



With rf on and some errors

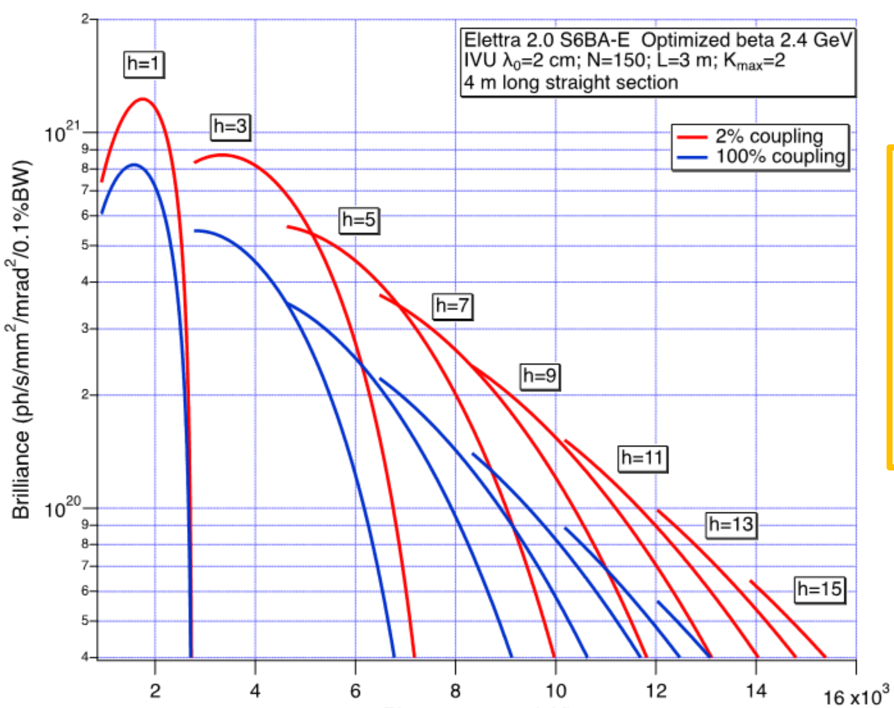
Circumference (m)	259.2	259.2
Energy (GeV)	2	2.4
Number of cells	12	12
Geometric emittance (nm-rad) 1% coupling	0.145	0.207
Horizontal tune	33.30	33.30
Vertical tune	9.4	9.4
Betatron function in the middle of straights (x, y) m	(6.7,2) (5.7,1.4)	(6.7,2) (5.7,1.4)
Horizontal natural chromaticity	-71	-71
Vertical natural chromaticity	-70	-70
Horizontal corrected chromaticity	+1	+1
Vertical corrected chromaticity	+1	+1
Momentum compaction	1e-004	1e-004
Energy loss per turn (no IDs) (keV)	237	492
Energy spread	8.26e-004	9.9e-004
Jx	1.595	1.595
Jy	1.00	1.00
JE	1.405	1.405
Horizontal damping time (ms)	9.13	5.3
Vertical damping time (ms)	14.57	8.4
Longitudinal damping time (ms)	10.37	6.0
Dipole field (T)	<0.8 + 1.5T central	<1 +1.8T central
Quadrupole gradient in dipole (T/m)	<19	<22
Quadrupole gradient (T/m)	<50	<60
Sextupole gradient (T/m^2)	<3500	<4000
RF frequency (MHz)	499.654	499.654
Beam revolution frequency (MHz)	1.1566	1.1566
Harmonic number	432	432
Orbital period (ns)	864.6	864.6
Bucket length (ns)	2	2
Natural bunch length (mm, ps)	1.3 , 4.3	1.8 , 5.8
Synchrotron frequency (kHz)	3.02 (@2MV)	2.73 (@2MV)

New beam lines
(see also S. Lizzit talk)

Elettra 2.0 will have three new micro-spot beam lines that the present machine can not support:

- All three will require a flux of 10^{14} ph/s at the source and are: the μXRD, the μXRF and HB-SAXS beam lines with different specifications in terms of spot size and photon energy range. (spot sizes 10x10 and 1x1 um)

- Such beam lines may require low-gap, in-vacuum undulators. Simulations show that undulators with K_{max}=2 and 20 mm period at 2.4 GeV (150 periods) will provide the 7^{th}, 9^{th}, 11^{th} and 13^{th} harmonics with the required flux and energy range.



Most of the existing beam lines will be shifted and updated. This is a trementous amount of work that with the present personel cannot be handled. Needed outsourcing.

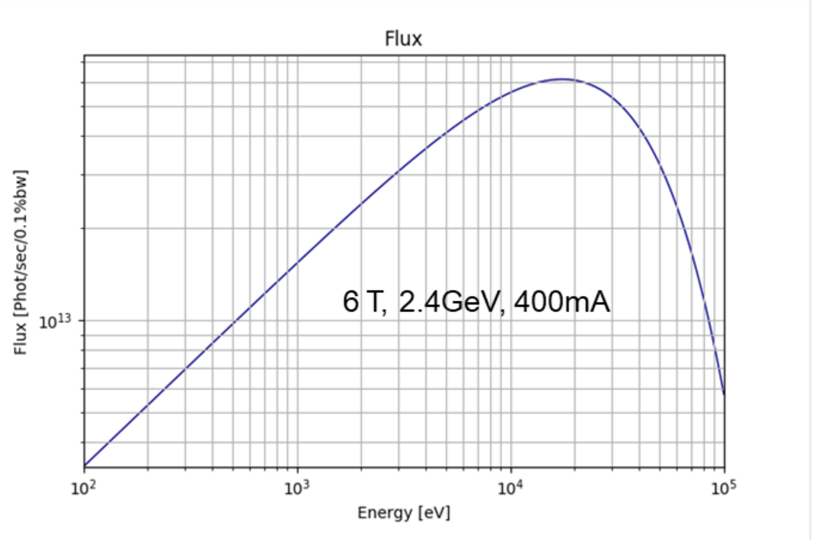
Superbends

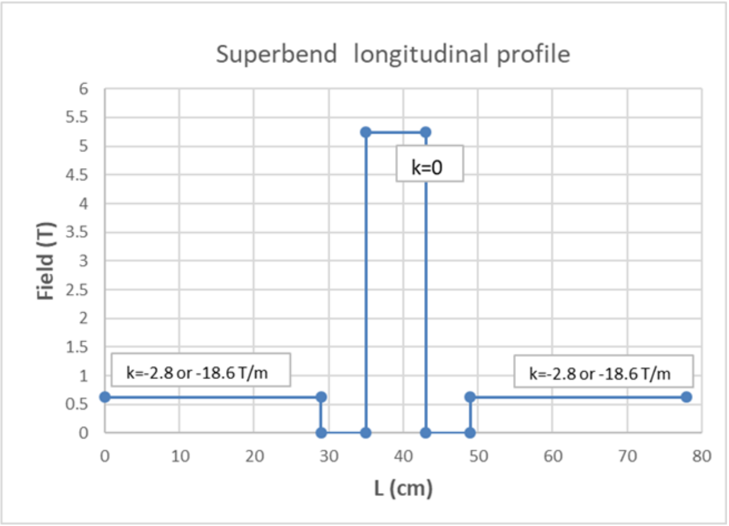
- ✓ The new hard X-ray imaging beamline **SYRMEP Life Science** will require a flux at the source of at least **10^{13} ph/sec at 50 keV**.
- ✓ The new hard X-ray imaging beamline **SYRMEP Materials Science** will require a similar flux at the source of at least **10^{13} ph/sec at 50 keV**.
- ✓ One of the proposed new beam lines for absorption/x-ray fluorescence (evolution of the XAFS and XRF BLs) will require ~ **35 keV with a flux of 10^{13} ph/sec** that can be easily provided with a super-bend of 3.5 T.
- ✓ Therefore at the current state of the analysis of the BLs plan in the new machine, we will need to include three super-bends of at least 5.5 T.

Technology Involved:

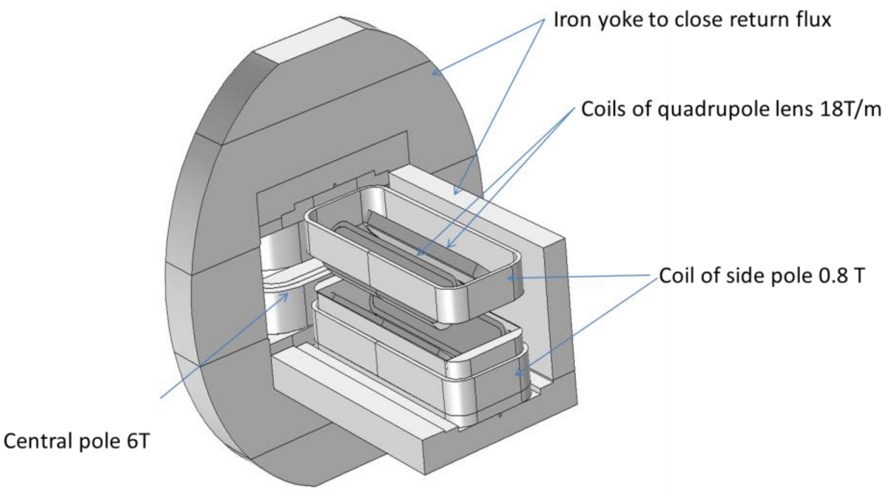
Superconducting systems (magnets , cryostats, coolers, pumps etc.)

Super-bend magnet

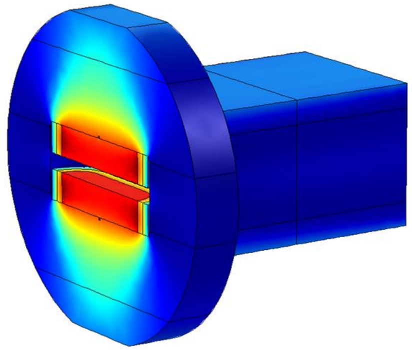




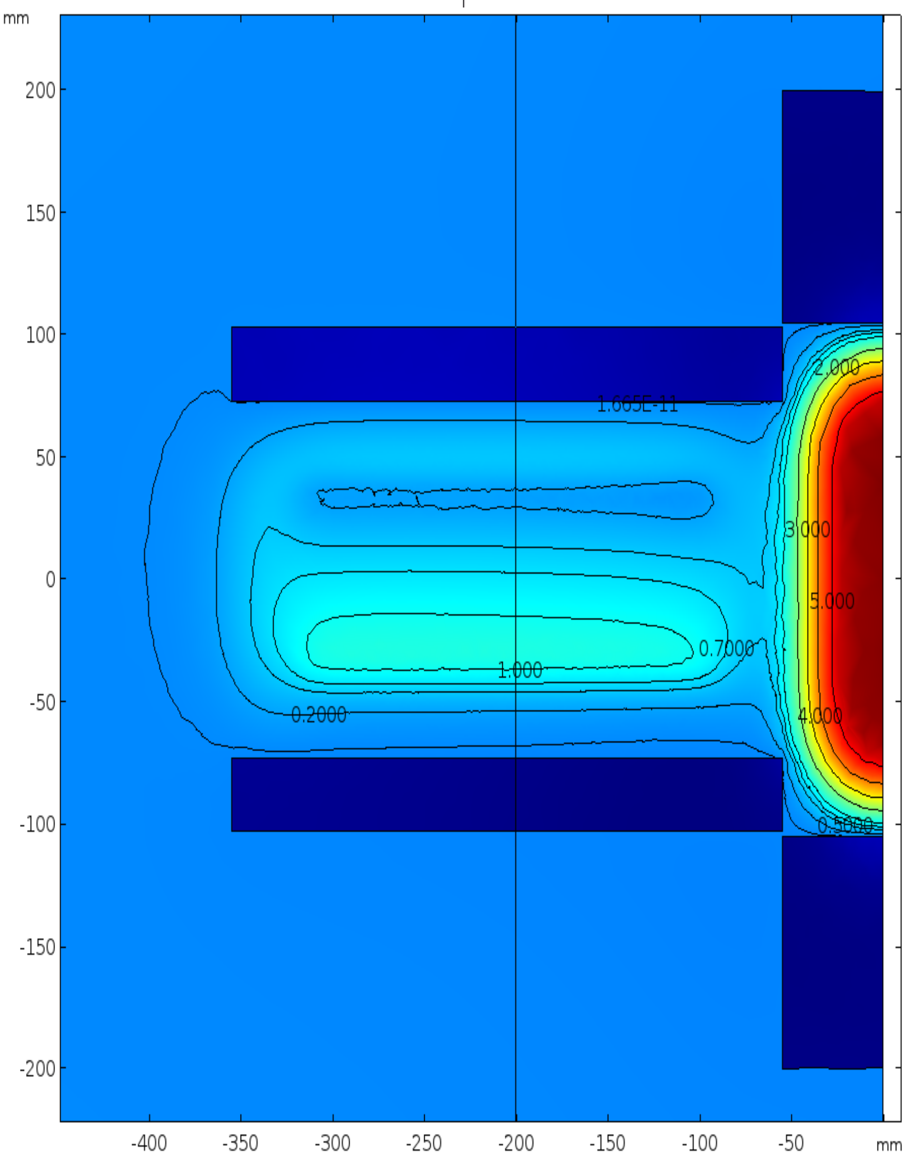
This profile has the minimum impact on the lattice

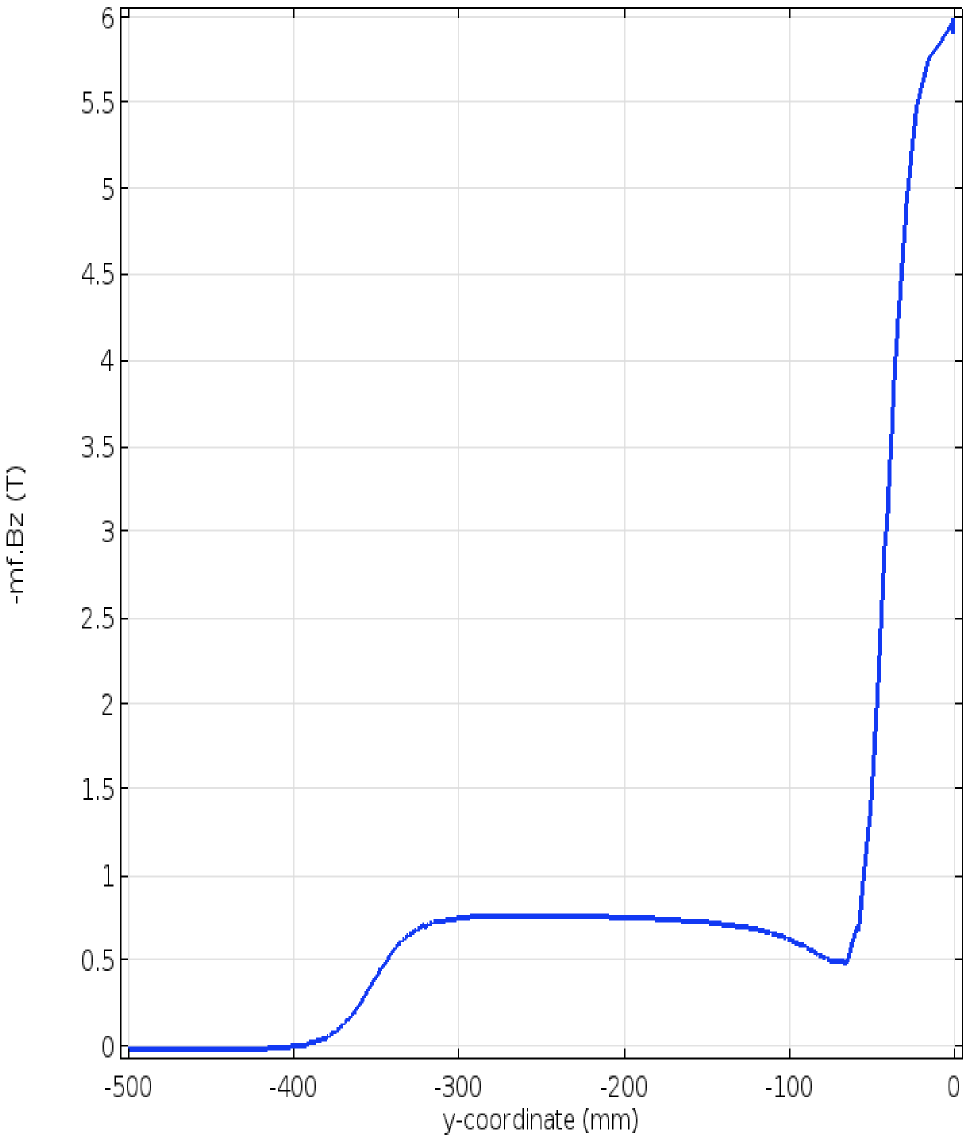


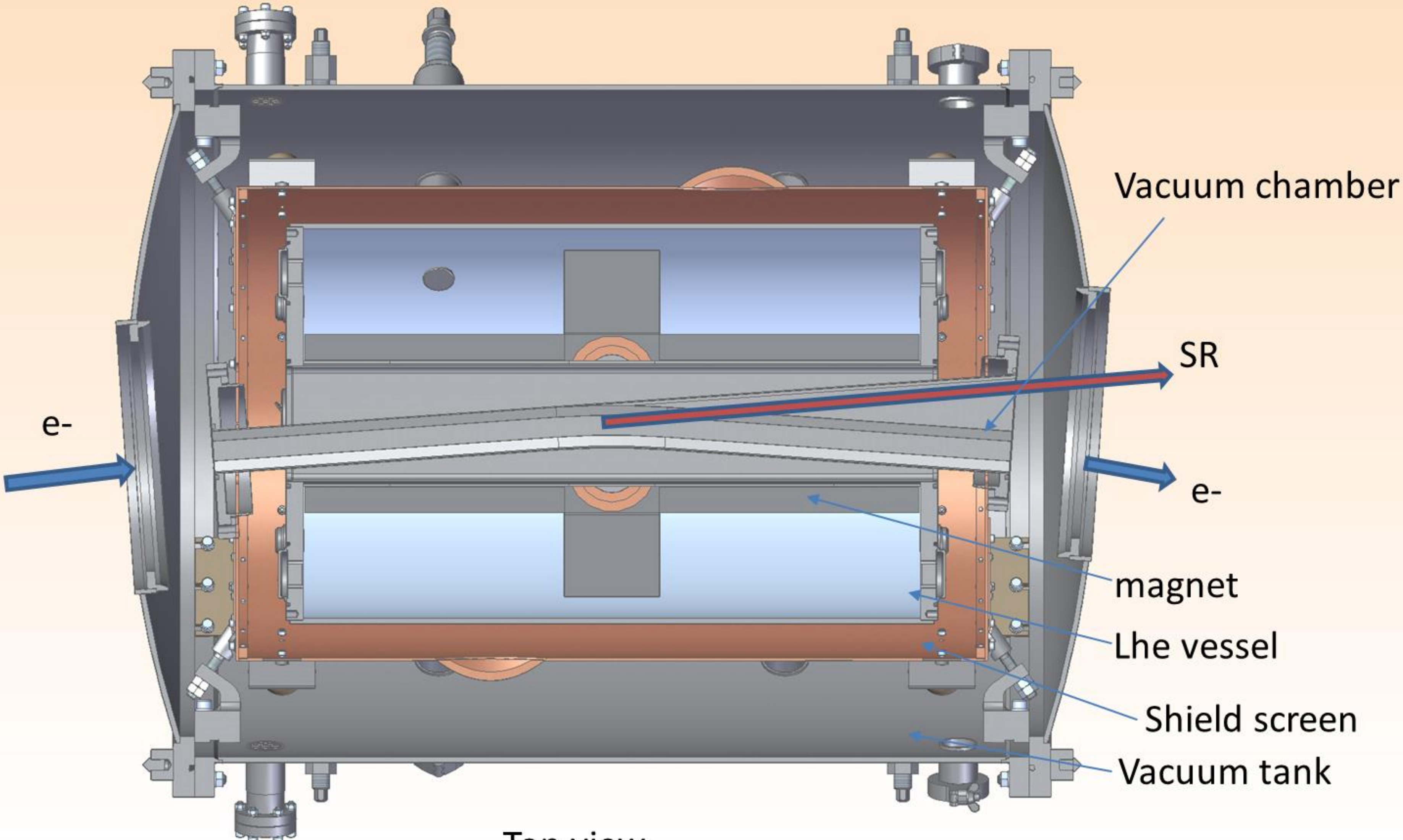
Simulations by N. Mezentsev (BINP -Novosibirsk)



Vertical Bz field component distribution






Vacuum chamber
SR
e-
e-
magnet
Lhe vessel
Shield screen
Vacuum tank

Top view

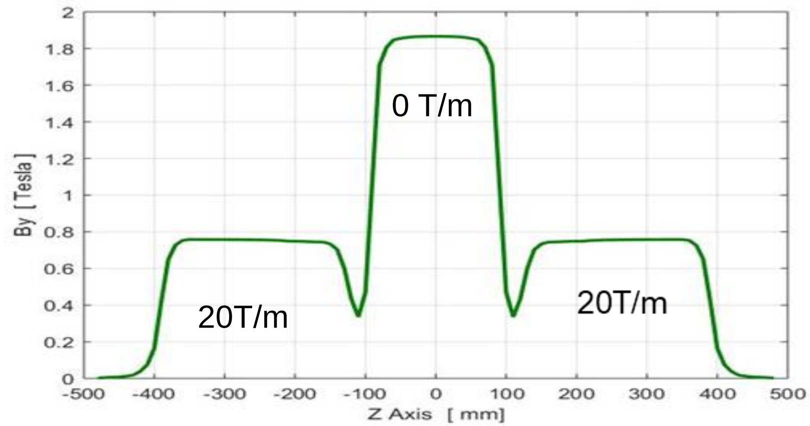
Challenges of the DLSR

- To squeeze the lattice the dipoles have very strong gradients. Also stronger gradient quadrupoles are needed .
- Sextupole strengths / second order chromaticities increase with number of the dipoles (N_d).
- The dynamic aperture reduces like $1/N_d$
- Optimizing for reduced emittance leads to smaller dispersion and larger chromaticity needing stronger sextupoles. Stronger sextupoles lead to problems related to non linear dynamics meaning difficulty in injecting and reduced lifetimes.
- Lattice becomes very sensitive to errors (field and alignment)
- Intra magnet space gets smaller
- Vacuum chamber diameters must become smaller for efficient magnets
- Extracting radiation becomes a problem also due to smaller bending angles as N_d increases

Challenges in Accelerator engineering

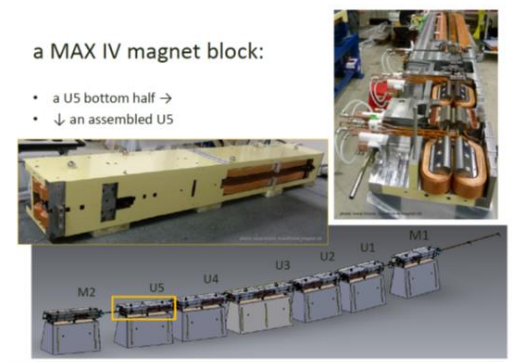
Magnets High gradient and high precision required -> Challenge for Engineers. New materials may be used (Fe-Co vacoflux) and combination of permanent and electro-magnets. Longitudinal and transverse gradient magnets impose challenges in design and realization. EU finances projects for innovation through TIARA e ARIES.

Quadruple gradient	
MAX IV has	40 T/m
ESRF – Diamond-II	100 T/m
Spring8-II	80 T/m
HEPS	80 T/m
τ USR	90 T/m
Elettra 2.0	35 T/m
Quadrupoles in dipoles	
MAX IV has	9 T/m
Elettra 2.0	18T/m
ESRF – Diamond-II	30 T/m
HEPS	40 T/m
HEPS in antibends	66 T/m
Sextupoles	
MAX IV has	4400 T/m^2
Elettra 2.0	4000 T/m^2
ESRF-Diamond || -τUSR	7000 T/m^2
Spring-8 II	13000 T/m^2
HEPS	5300 T/m^2



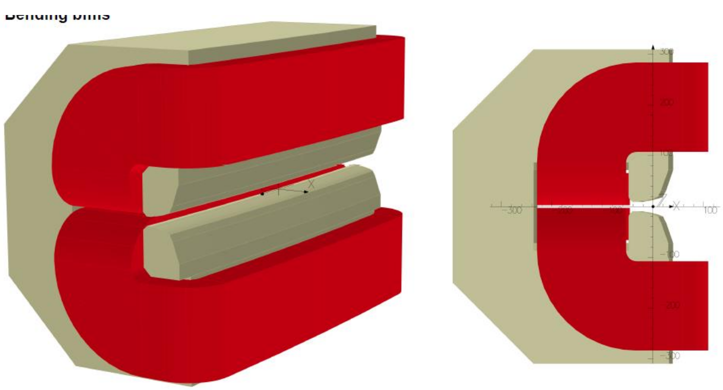
Longitudinal and transverse gradient dipole

For comparisson the 3rd generation had gradients of 3-5 T/m in the dipoles < 20 T/m in quads and < 500 T/m^2 in sextupoles

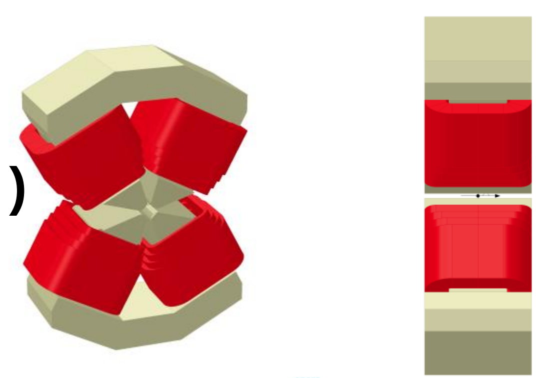


Some Elettra 2.0 Magnets

The short intra-magnet available space led us to design magnets with Lm≈Lp (max 10 mm difference). A quadrupole prototype is under construction at CERN



24 TG dipoles
48 TG and LG dipoles
192 Quadrupoles
240 sextupoles (combined)
48 pure correctors

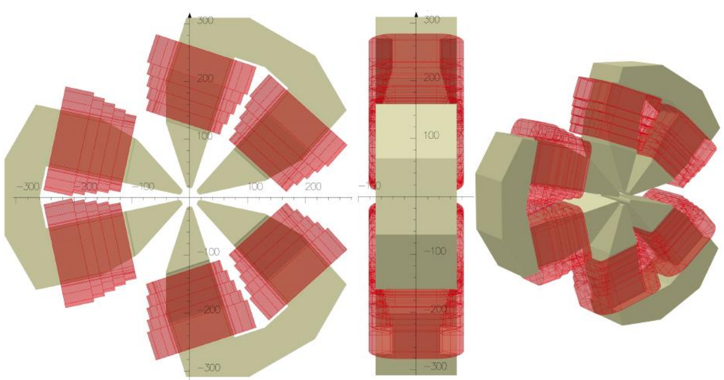


The bending integrated quadrupole component is done by only the pole profile geometry. In order to optimize space and performances, different coil and frame geometries are evaluated. Space between the pole terminations will be employed in order to obtain the requested frame stiff.

The quadrupole designs were developed with the vacuum chamber in order to resolve all the possible transversal interferences (beam lines). Asymmetric poles geometry has been opted.

The sextupole magnets have the higher design issue. The transversal interferences between coils and vacuum chamber are resolved.

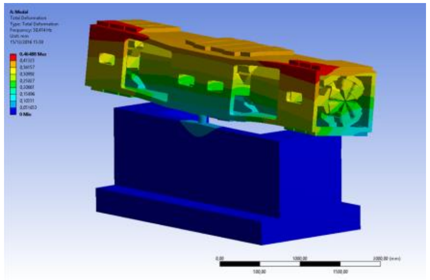
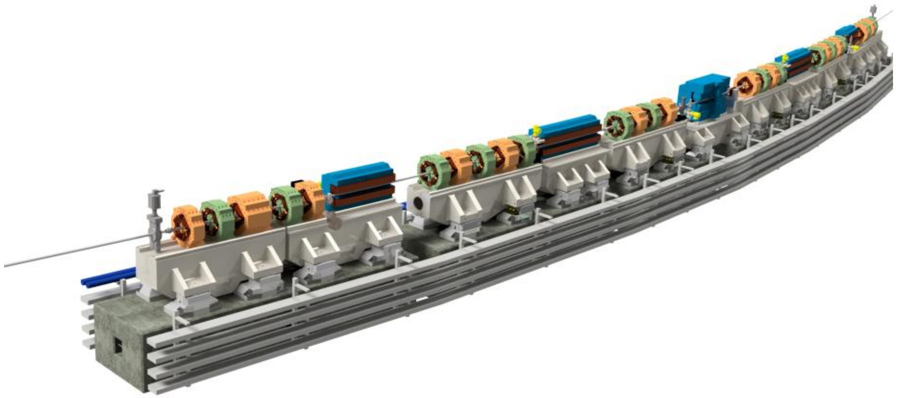
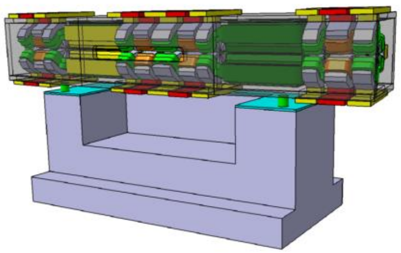
Ref. D. Castronovo (Opera)



Accelerator engineering

Space:
Space between magnets (hard edge) < 10 cm
MAX IV   7.5 cm
Elettra 2.0 varies, smaller 6 cm larger 18 cm
Items must be preassembled on the girder

Girders: Precision girder machining (20 um over 3-5 m). Special design to keep stably thin magnets. Vibrational analysis very important.

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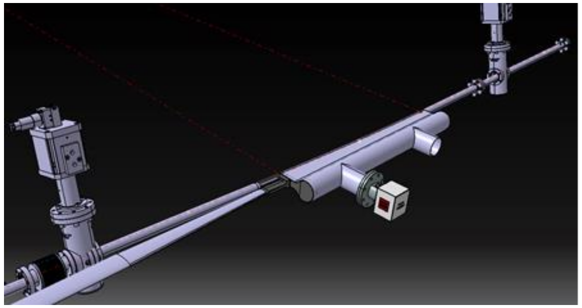
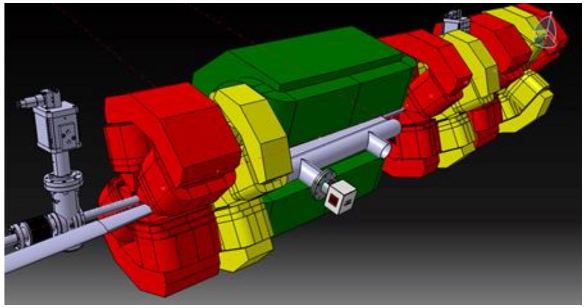
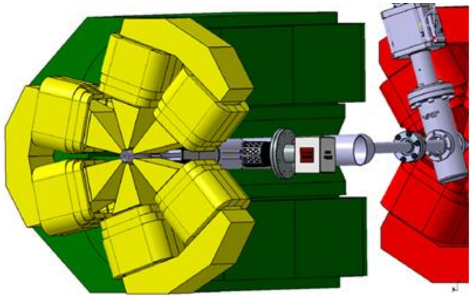
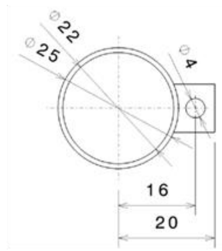
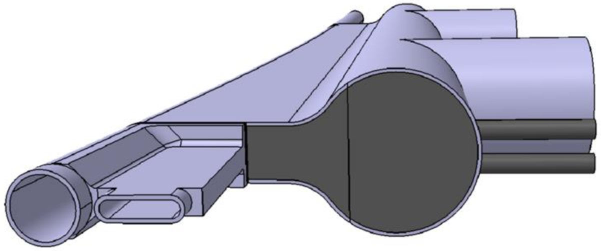
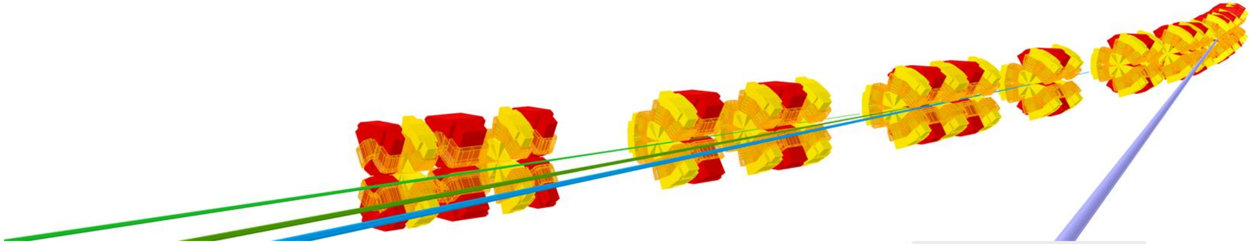
Accelerator engineering

Vacuum chamber: Apertures = 20-26 mm diameter in some places even 10 mm
MAX IV inner diam. 22 mm
Elettra 2.0 22 mm
Complex geometries, smaller diameter with NEG, cooling of the chambers..

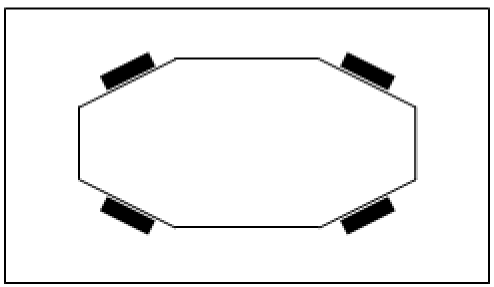
Radiation extraction: due to small bending angles for MBAs this might be a problem, carefull design and control needed, special modification of magnet poles possible.

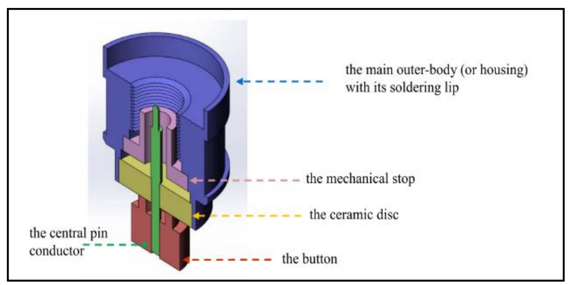



Accelerator engineering

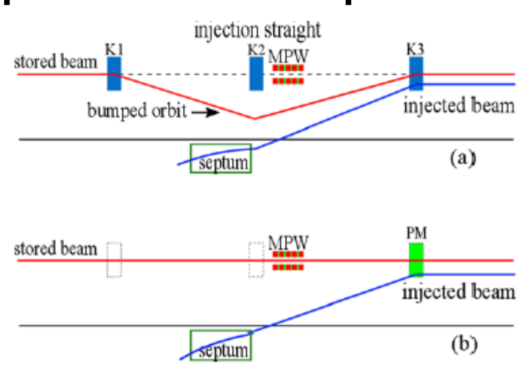
<u>Alignment:</u> challenging, 10-20 microns from magnet to magnet

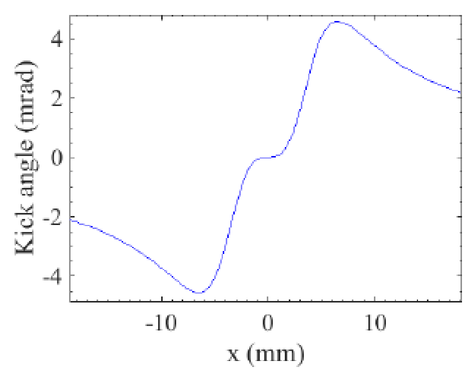
<u>Instrumentation:</u> BPMs incorporated on the vacuum chamber, detectors that can measure the 10% of the beam dimension for beams with vertical dimension of the order of a micron.

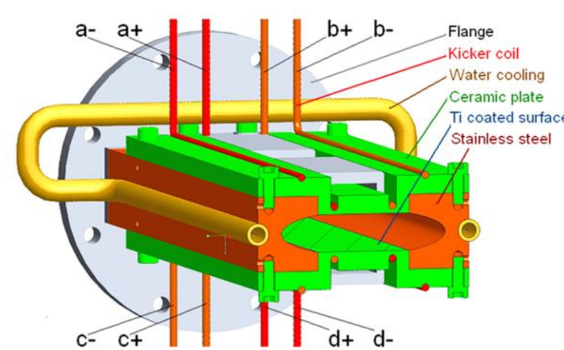




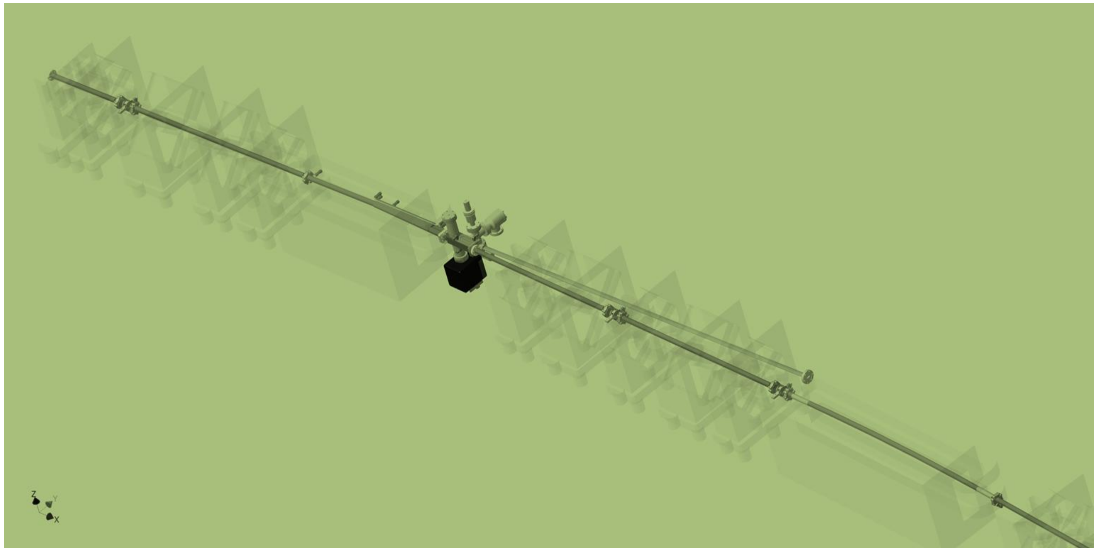
<u>Injection:</u> Due to the reduced dynamic apperture new schemes like pulsed multipoles may be used







Vacuum system: Inovative solutions are needed. Smaller, more efficient pumps, NEG technology (achieved NEG at <10 mm beam pipe diameter)



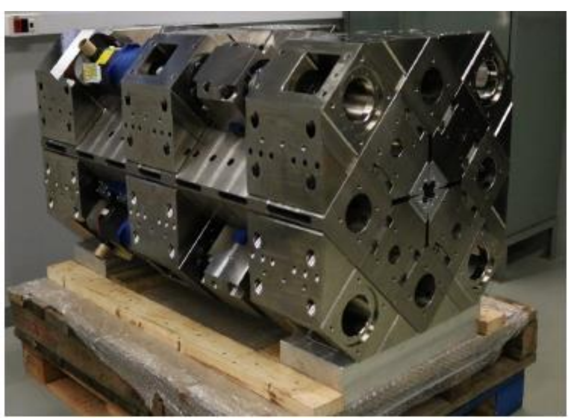
Power supplies: Here things get simpler since the trend is most likely modular, each magnet with its own PS. (Elettra 2.0 about 840 PS)

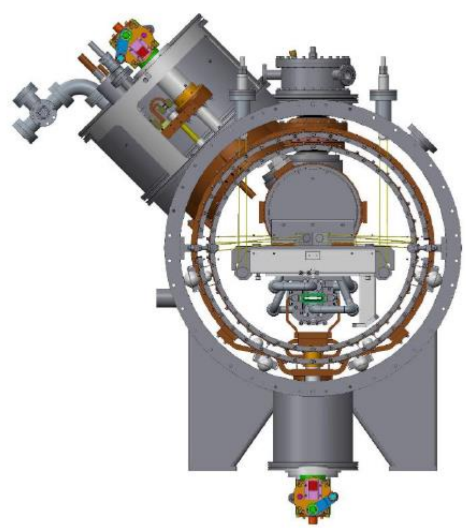
Controlls: Orbit feedbacks that can stabilise beams with dimensions with submicron dimensions. Strong multibunch feedbacks that have to fight the increased wall impedance.

Insertion Devices:

Although in the DLSR thought that wigglers are not needed wigglers will be in use but there is no any big change forseen on the present designs.
Instead a large variaty of new undulators will take advantage of the DLSR characteristics, like smaller diameter vacuum chambers (DELTA undulators). At the same time are coming the superconducting and the cryogenic in-vacuum undulators.

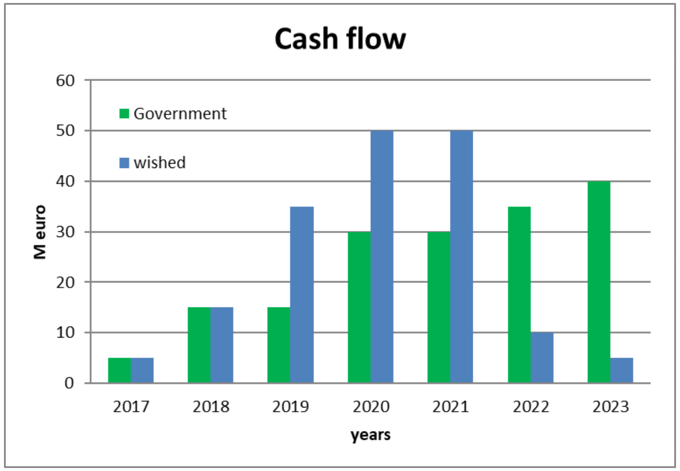
Other varieties (polarizing) are the fixed gap (APU) , APPLE II and various combinations to reduce the thermal load especially for beam lines requiring lower photon energy i.e. bellow 50 eV



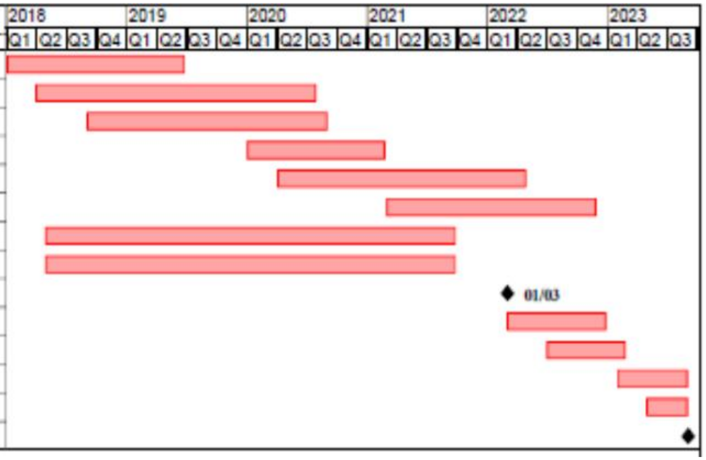


Preliminary schedule

Schedule according to the wished cash flow

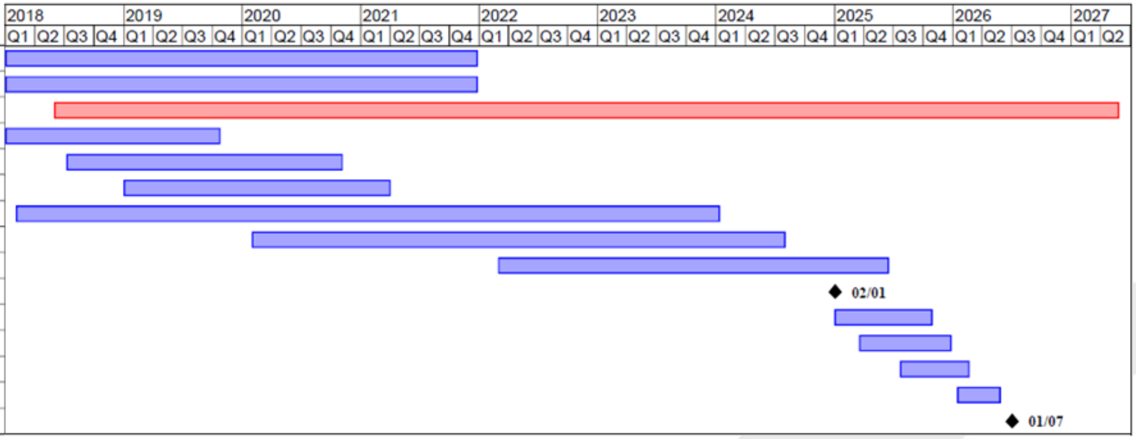


		Name	Durati...	Start	Finish	P...	R...
1		Technical design study	390 ...	01/01/18...	28/06/19...		
2		Engineering Design	610 ...	02/04/18...	31/07/20...		
3		Prototyping	524 ...	01/09/18...	03/09/20...		
4		Calls for tender	303 ...	01/01/20...	26/02/21...		
5		Manufactoring construction and t...	542 ...	02/04/20...	29/04/22...		
6		Preparation and assembly	458 ...	01/03/21...	30/11/22...		
7		Infrastructures upgrade	892 ...	01/05/18...	29/09/21...		
8		Beam Lines upgrade	892 ...	01/05/18...	29/09/21...		
9		End user mode	1 day?	01/03/22...	01/03/22...		
10		decommissioning	219 ...	01/03/22...	30/12/22...		
11		Installation	173 ...	01/07/22...	28/02/23...		
12		Accelerator tests/ commissioning	153 ...	01/02/23...	01/09/23...		
13		Beam line commissioning	90 d...	01/05/23...	01/09/23...		
14		Start Elettra2.0 user mode	1 day?	04/09/23...	04/09/23...		



Schedule according to the gov proposed cash flow

		Name	Duration	Start	Finish
1		Infrastructures upgrade and spaces	1.043 days?	01/01/18 8.00	29/12/21 17.00
2		Some Accelerator systems upgrade	1.043 days?	01/01/18 8.00	29/12/21 17.00
3		Beam lines upgrade	2.348 days?	01/06/18 8.00	01/06/27 17.00
4		Technical Design study	475 days?	01/01/18 8.00	25/10/19 17.00
5		Engineering Design	610 days?	09/07/18 8.00	06/11/20 17.00
6		Prototyping	589 days?	01/01/19 8.00	02/04/21 17.00
7		Calls for tender	1.552 days?	05/02/18 8.00	16/01/24 17.00
8		Manufactoring construction and testing	1.176 days?	03/02/20 8.00	05/08/24 17.00
9		Preparations and assembly	864 days?	01/03/22 8.00	20/06/25 17.00
10		End of user mode	1 day?	02/01/25 8.00	02/01/25 17.00
11		Ring decomissioning	215 days?	03/01/25 8.00	30/10/25 17.00
12		Installations	203 days?	21/03/25 8.00	30/12/25 17.00
13		Accelerator system tests /commissioning	153 days?	23/07/25 8.00	20/02/26 17.00
14		Beam lines commissioning	97 days?	15/01/26 8.00	29/05/26 17.00
15		Elettra 2.0 user mode	1 day?	01/07/26 8.00	01/07/26 17.00



Conclusions

- The S6BA-E with alternating 4 and 5 m long straights is the lattice that fits most requirements keeping the same circumference as Elettra. This version works for both 2 and 2.4 GeV.
- However it is more demanding from the engineering point of view.
- The preliminary version of the Elettra 2.0 conceptual design report (CDR), focused on the S6BA option at 2.0 GeV is available since 2017.
- Many sections of the available CDR will not need to be changed, but the TDR to be prepared will focus on the selected option of the S6BA-E lattice.
- The budget of 170 M€ (including the beam lines) has been approved by the Italian Gov. According to a preliminary schedule the beam will be back for users in 2026 (after 14 months of dark time).
- The funding profile will obviously determine the final scheduling.
- The new generation SRs are quite challenging and will offer many opportunities (financial and technological) to the industry


Thank you for your attention