ELETTRA - Operation & upgrade status, economy plan

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Outline:

- ❖ Introduction
- ❖ Energy saving plan
- ❖ Elettra status and statistics
- ❖ Short term developments
- ❖ Elettra 2.0
- ❖ Permanent magnet issues
- ❖ Into the 4th generation
- ❖ Conclusions

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources

www.elettra.eu

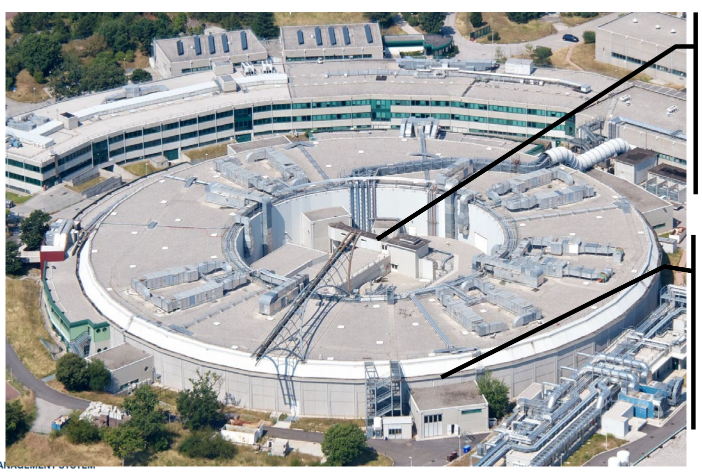
Elettra Sincrotrone Trieste

Elettra

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

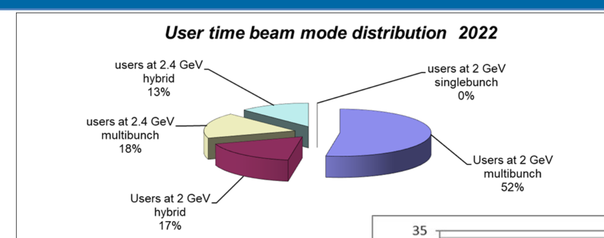
Operating modes for users (all in top-up since 2010):

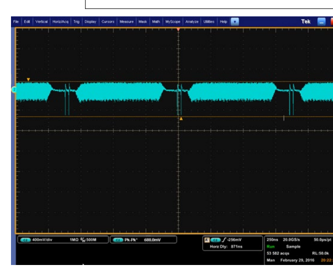
- Operates for about 6400 hours per year (24h, 7/7), 5016 hours reserved for users in 2 energies:
- 2.0 GeV, 7 nmrad, 310 mA for 75 % of users time with about 20 hours LT
- 2.4 GeV, 10 nmrad, 160 mA for 25 % of users time with about 33 hours LT
- 28 beamlines open to users– over 1000 user and user poposals / year
- Filling patterns: multi-bunch 95 % filling or hybrid, single bunch, few bunches or other multi-bunch fillings

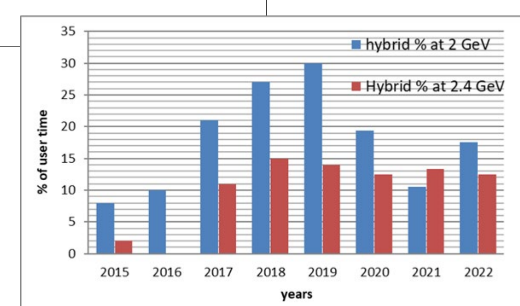


Linac + Booster (114 m)

Storage Ring (259 m)







Energy saving: Calendars

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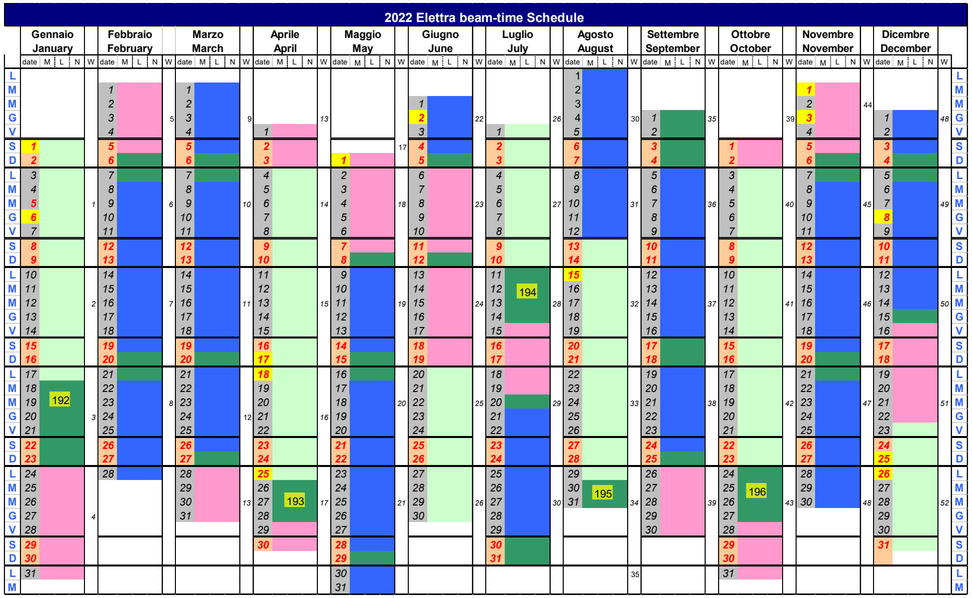
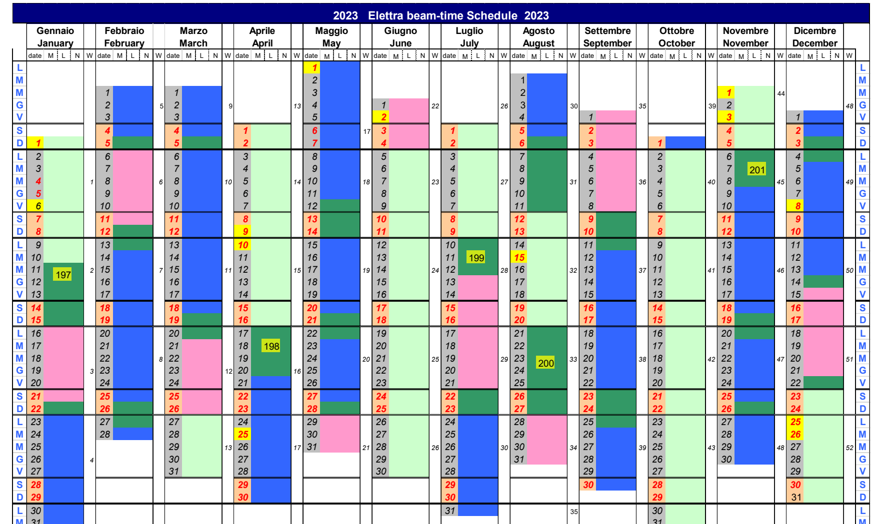
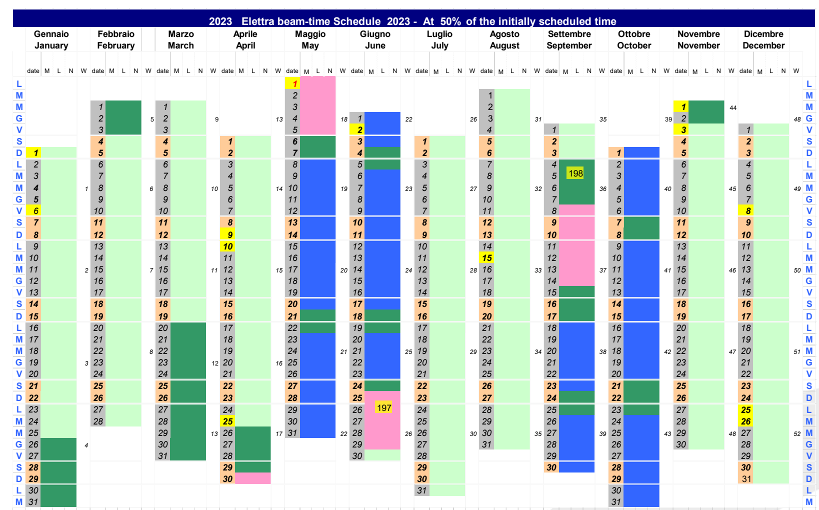
2022 user time 5016 h



2023 user time 4488 h

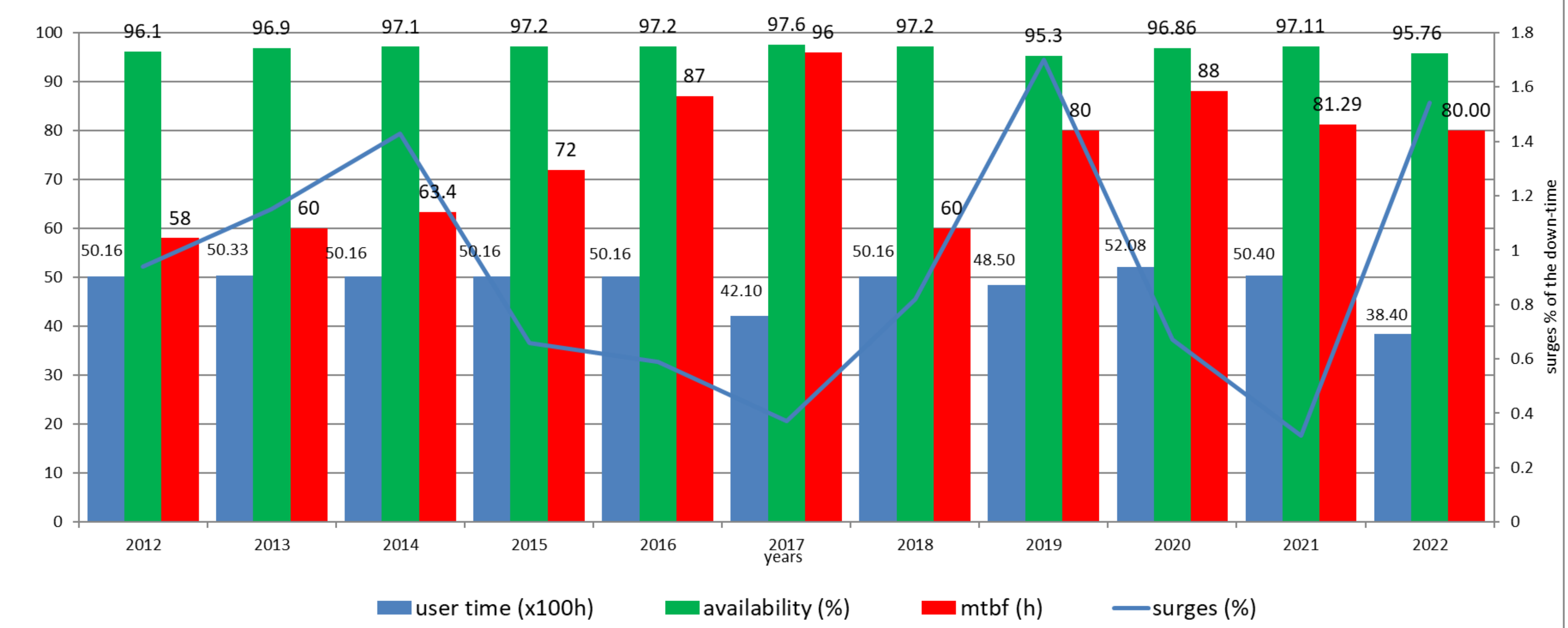


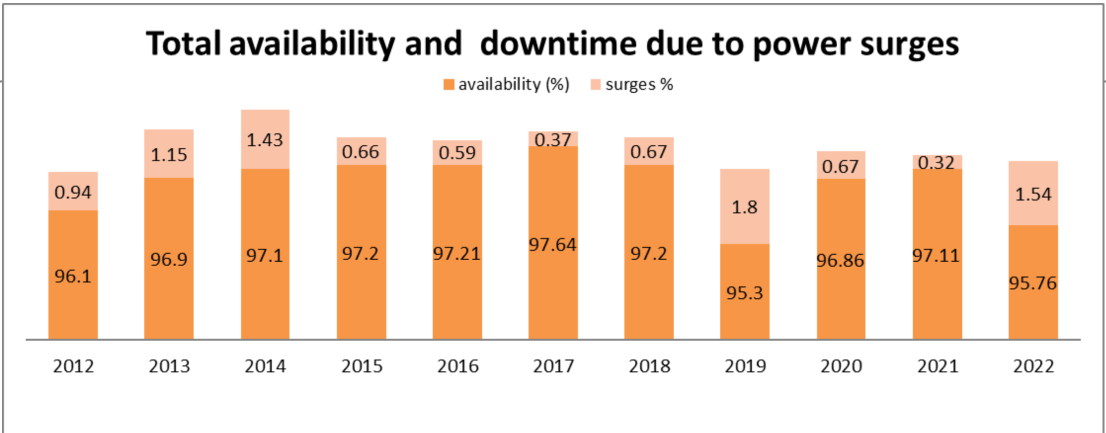
2023 user time 2304 h



Due to high energy costs we are reducing the run time of 2023 at 50% and use the spare personnel for works on Elettra 2.0

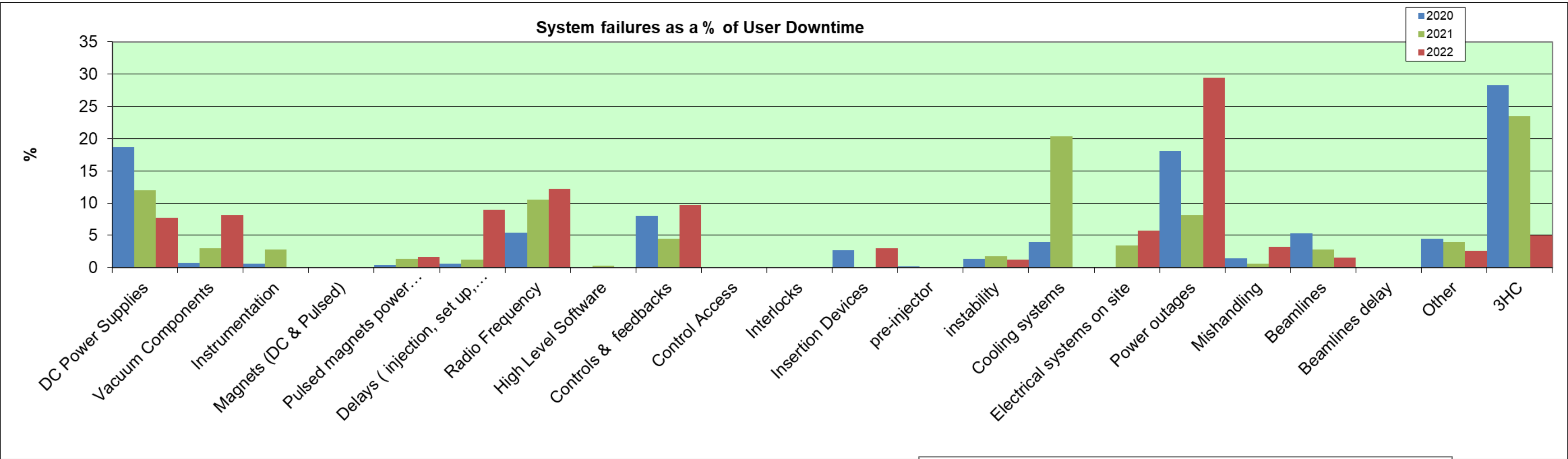
Uptime Statistics

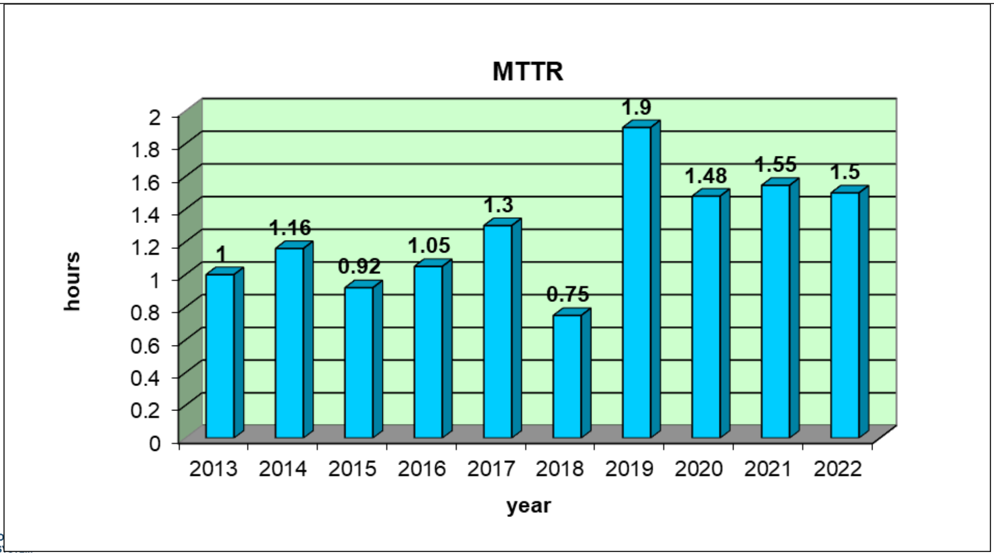


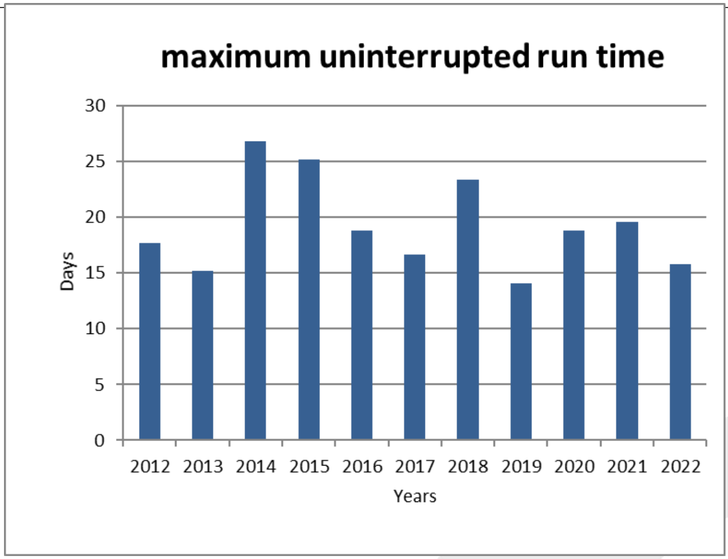


2022 statistics until October, still in run

System failures

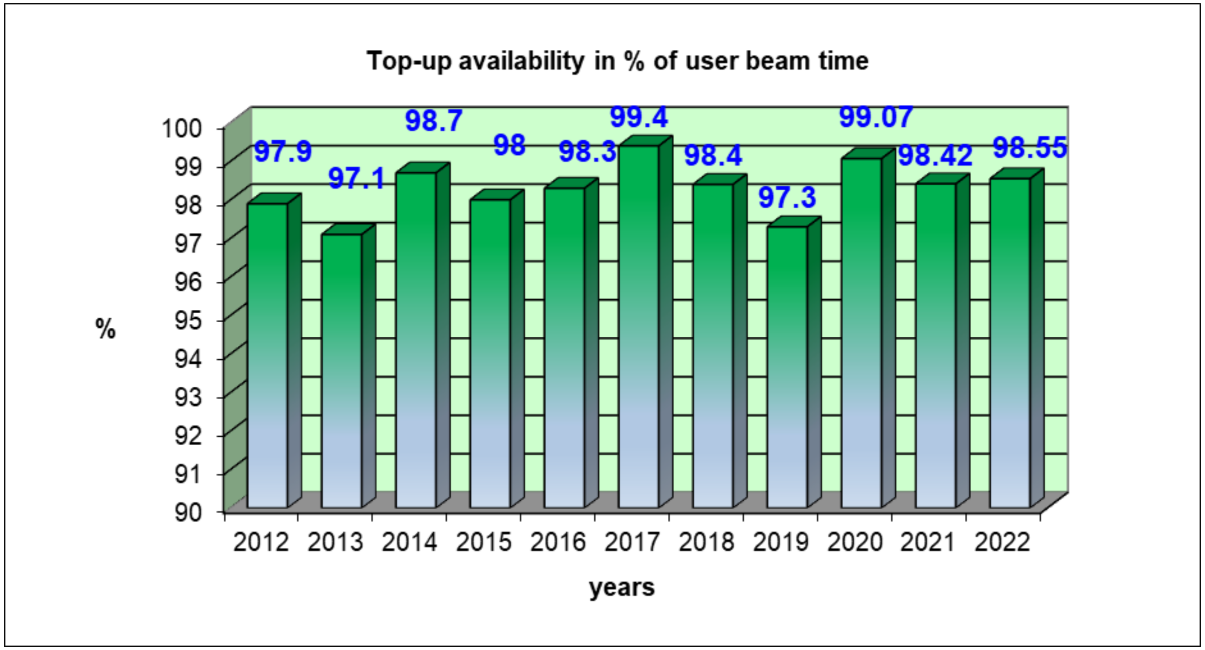






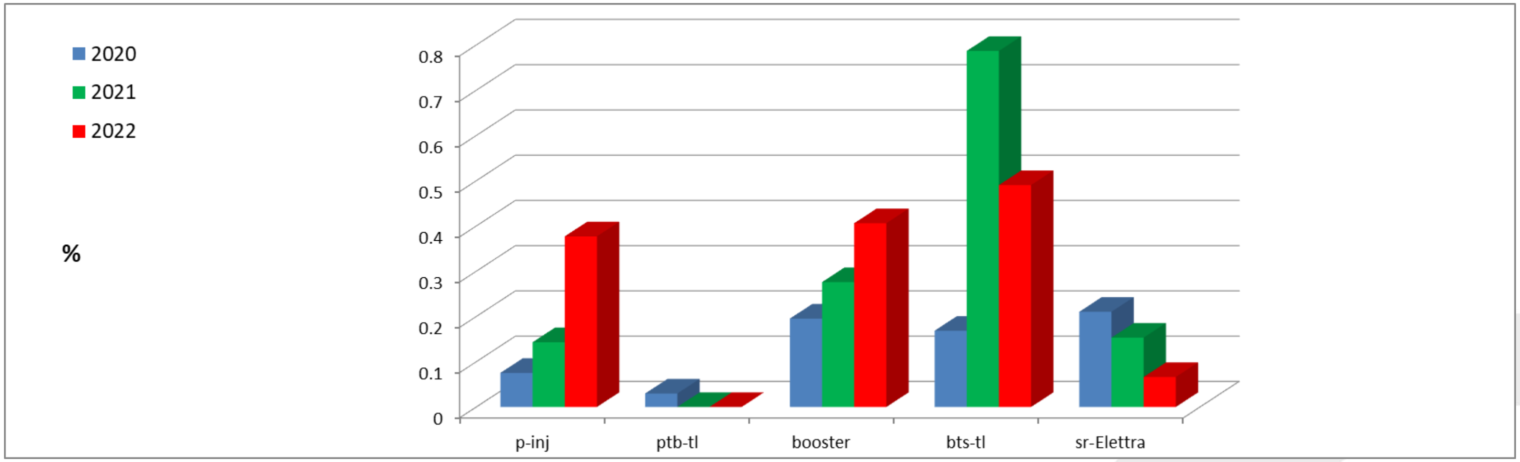
Top-up statistics

Every 5 min at 2 and 10 min at 2.4 GeV



During top-up systems run well and the top-up % of user beam-time is high. The remaining very few % is due to failures that, however, do not impact on the availability.

Distribution of Topup failures in % of user beam time due to various parts of the Accel. complex



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Present developments (also in view of Elettra 2.0)

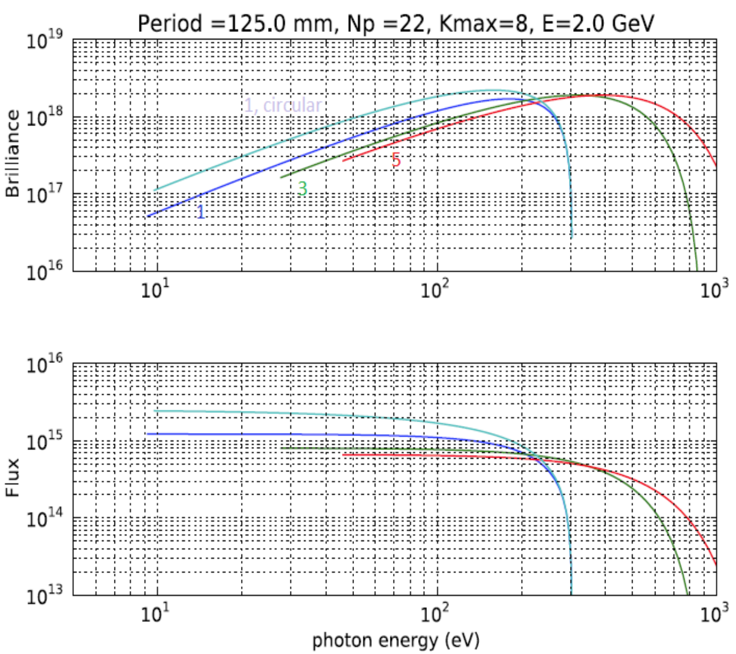
- Tunnel temperature stabilization -> better than ±0.5^{0}C
- Upgrade of the interlock system -> completed
- PS-controls upgrade -> completed
- RF upgrade (booster Solid State Amplifier) -> completed
- Replacement of all Elettra RF amplifiers with SS-> **2 already installed 2 more to go**
- Upgrade vacuum system electronics -> completed
- TMFB and LMBF upgrade -> completed
- Build new bpm electronics (detectors) -> 8 in construction and 200 in collaboration with external company
- Quench protection system -> in operation
- Complete realignment after 8 years (in parts for the past 1 1/2 years)->competed (revealed only 5 mm circumference change)
- Booster realignment -> in progress
- Series of Booster measurements and characterization-> in progress
- Injection system upgrade-> in progress

- Fixed gap undulators: There are 2, one single in Aloisa beamline and a double undulator for TwinMic -> in operation.
- Two new undulators (MOST project) *(ref: B. Diviacco)*

MOST Beam Line

All straight sections of Elettra are occupied but still there is demand for new insertion device based beam lines. An upgrade plan is developed which will merge the experiments running on the existing GasPhase and CiPo (Circular Polarization) beam-lines. Two new variable polarization undulators will be developed for this purpose, one for the lower (10÷200 eV) and one for the higher photon energies (80÷2000 eV), while the old electromagnetic elliptical wiggler serving CiPo will be dismissed. The installation is planed for 2023.

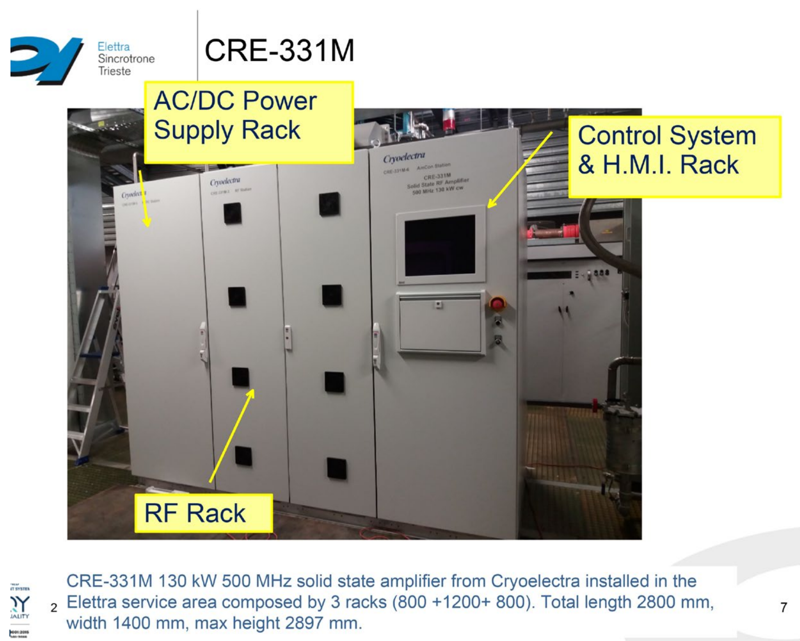
Low energy -> variable polarization APU (fixed gap)



Klystron-> SS replacement

CRE-331M 130 kW – 500 MHz amplifier (Manufacturer Cryoelectra GMbH)

Elettra uses 4 rf single cell cavities, 4 rf plants , 3 with klystrons and 1 with IOT. We are replacing them. Two SS amplifiers are already installed, two more in 2023



Elettra 2.0: final requirements

Although Elettra performs very well and is serving the user community with excellent results since 1994, in order to keep the light source competitive for synchrotron research and enable new science and new technology developments, a diffraction limited storage ring Elettra 2.0 is going to replace Elettra.

Main aspects

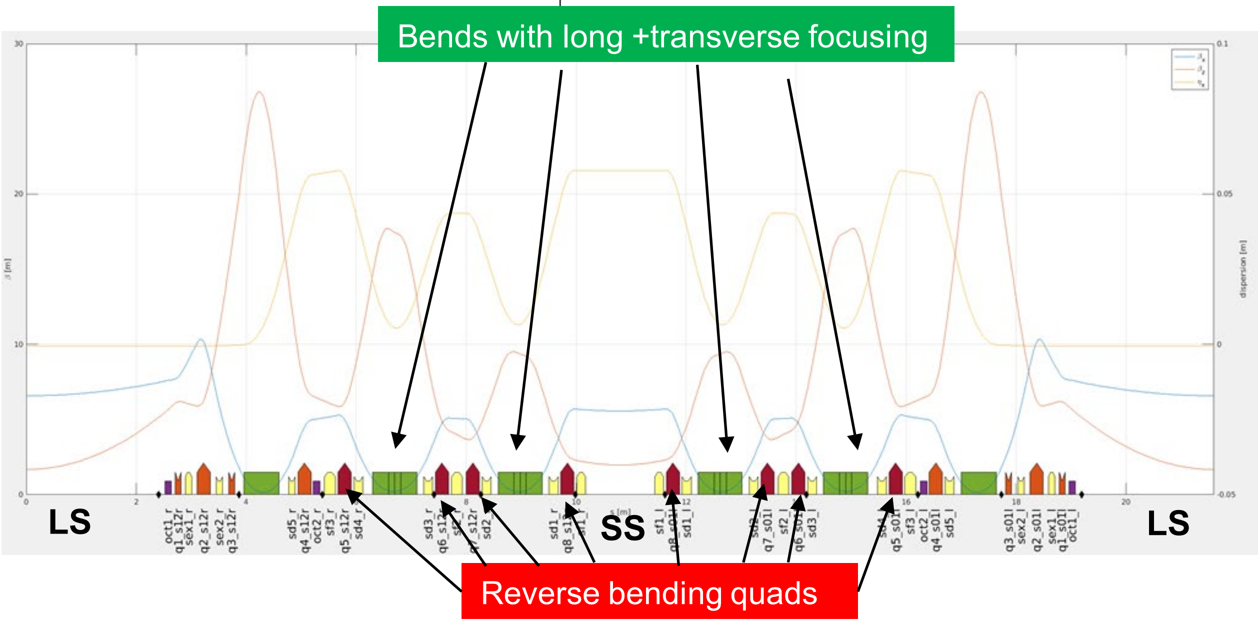
- ***Main operating energy 2.4 GeV (and only initially also at 2 GeV)***
- ***Reduce the horizontal equilibrium emittance***
- ***Increase the slots for insertion devices using some short straights***
- ***Let open the possibility for installing bunch compression scheme***
- ***Include super-bends (3 of 6T) and in-vacuum undulators*** **(3)**
- ***Preserve the time structure of the beam and upgrade the intensity to 400 mA***

Constraints

- *Keep the same building and the same ring circumference (259.2 m)*
- *Conserve the same source points in the long straights.*
- *Keep the present injection scheme and injection complex*
- *Minimize the downtime for installation and commissioning to about 18 months maximum.*

Elettra
Sincrotrone
Trieste

Elettra 2.0 lattice (S6BA-E)



The Emittance is 212 pm-rad at 2.4 GeV (1% coupling) i.e. 47 times reduction in emittance or about 7 or more times reduction in beam size compared with the actual Elettra.
At 2 GeV the emittance is 146 pm-rad.

- The lattice is 12-fold symmetric (24 arcs) with **LS=5.104 m and SS=1.26 m (from magnet to magnet)** this way the LSs coincide to those of the actual Elettra i.e. no radial shift of the IDs beam lines on the LSs.

The ratio between the circumference and the free space for IDs is 30%.
The available slots for IDs are 11 on LS and 5 on SS.

Seven sectors will keep their present arrangement in the ring (1,2,3,4,8,9,11)
12 beam lines will keep the same position/sector, 8 beam lines will be moved and 12 will be entirely new.

Total 32

The S6BA-E lattice and machine parameters

Although at the beginning Elettra 2.0 will operate in both energies the machine is optimized for 2.4 GeV

Circumference (m)	259.2	259.2
Energy (GeV)	2	2.4
Number of cells	12	12
Geometric emittance (pm-rad) 2% coupling	148	212
Horizontal tune	33.27	33.27
Vertical tune	9.14	9.14
Beta functions in the middle of straights (x, y) m	(6.3 , 1.7)	(6.3 , 1.7)
Horizontal natural chromaticity	-73	-73
Vertical natural chromaticity	-67	-67
Horizontal corrected chromaticity	+1	+1
Vertical corrected chromaticity	+1	+1
Momentum compaction	1.3e-004	1.3e-004
Energy loss per turn no IDs (keV)	217	450 (w SBs 486)
Energy spread	7.7e-004	9.3e-004
Jx	1.625	1.625
Jy	1.00	1.00
JE	1.376	1.376
Horizontal damping time (ms)	9.8	5.7
Vertical damping time (ms)	15.9	9.2
Longitudinal damping time (ms)	11.6	6.7
Dipole field (T)	<0.88 + 1.16T central	<1.03+1.46T central
Quadrupole gradient in dipole (T/m)	<19	<22
Quadrupole gradient (T/m)	<50	<60
Sextupole gradient (T/m²)	<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	1.7 , 5.7
Synchrotron frequency (kHz)	3.17 (@2MV)	2.86 (@2MV)

Parameter	Units	Elettra	Elettra 2.0 S6BA-E
Circumference	m	259.2	259.2
Energy	GeV	2.4	2.4
Horizontal bare emittance	pm rad	10000	212
Vertical emittance @1% coupling	pm rad	100	2.1
Beam size @ ID (σx,σy)	um	286 , 16	36 ,1.5
Beam size at short ID	um	400 , 25	64, 2.2
Beam size @ Bend (at z=0)	um	272, 27	8 , 6
Bunch length (zero current, 2 MV,1σ)	ps	22	5.4
Energy spread	ΔE/E %	0.095	0.11
Bending angle half achromat	degree	15	3.6 and 2x6.5+LG + 4x -0.40

Beam size and divergence

Energy 2.4 GeV	LS at 3% cpl	LS at 10% cpl	SS at 3% cpl	SS at 10% cpl
σx (um) /σ'x (urad)	36 /5.7	35/5.5	63/6	63/5.8
σy (um) /σ'y (urad)	3.2/1.9	5.7/3.4	3.5/1.8	6/3
Energy 2.0 GeV				
σx (um) /σ'x (urad)	30/4.8	29/4.6	53/5	52/4.8
σy (um) /σ'y (urad)	2.7/1.6	4.7/2.8	2.9/1.5	5.1/2.6

Some E2 characteristics

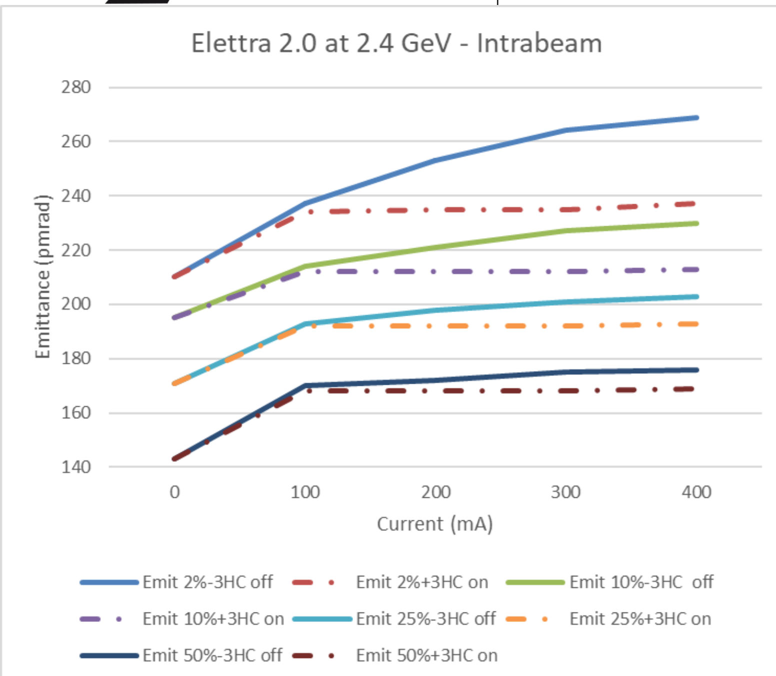
- The magnetic structure (S6BA-E lattice) consists of 12 identical achromats each containing
- **6 dipoles** with transverse gradient (4 with additional longitudinal focusing)
- **14 quadrupoles** of which 8 are shifted to give the necessary reverse bend angle (reverse bends)
- **20 sextupoles with embedded correctors** and **4 skew quadrupole coils** and
- **2 octupoles combined with embedded correctors**
- **2 octupoles combined with quadrupoles**
- **2 pure correctors**

The total number of magnets is 552. The multipoles are laminated.

- There are 168 corrector coils and 24 pure correctors, 168 BPMs with additional 3 dedicated to diagnostics and feedbacks. Slow and fast orbit correction systems will provide submicron orbit stability. For the fast correction (fast orbit feedback) additional coils will be used (from 46 to 72, under investigation, WIP)
- The dynamic aperture including all (errors, chambers, IDs) is about ±6 (±8 for the phase-1 optics) horizontally and ±2 mm (± 2.5 mm) vertically, permitting off axis injection with high efficiency especially in case of emittance swap in the booster (>95%).
- The 3D layout is completed and a mock-up is constructed. Minor adjustments are ongoing. Girders are defined 8 per achromat consisting of granite slabs long from 1.2 to 1.5 m, 0.6 m large and 0.3 m thick. Front-ends are defined. Prototyping is ongoing as well as discussions with potential manufacturers.
- The vacuum chamber will be rhomboidal with 20x30 mm external dimensions. Mainly out of copper (45% of its total length) with some parts in aluminum (20%) and stainless steel (35%). Most parts of the chamber (90%) will have 500 nm NEG.
- The Injection system will use 4 kickers as in Elettra and 2+1 septa. The emittance swap technique will be used if necessary. The injection system is almost specified we are in the process of fixing the final details

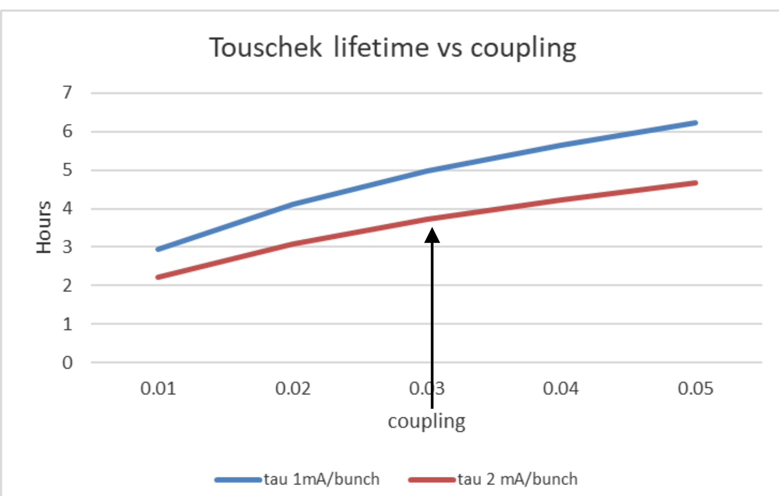
Intra-beam and Touschek effects

@ 400 mA

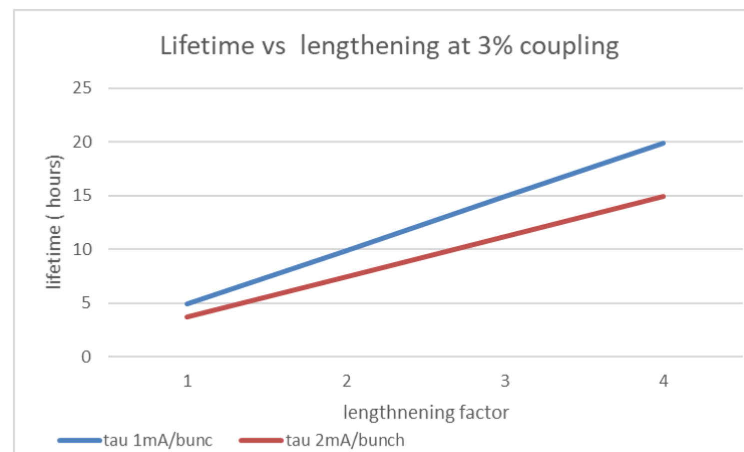


The intra-beam scattering without the effect of the third harmonic cavity will increase the emittance from 212 to 275 pm-rad (30% increase) while with the SUPER-3HC effect the emittance will increase to 235 pm-rad (increase at 11%).

Energy acceptance ±3.5% including errors and 1.8 MV



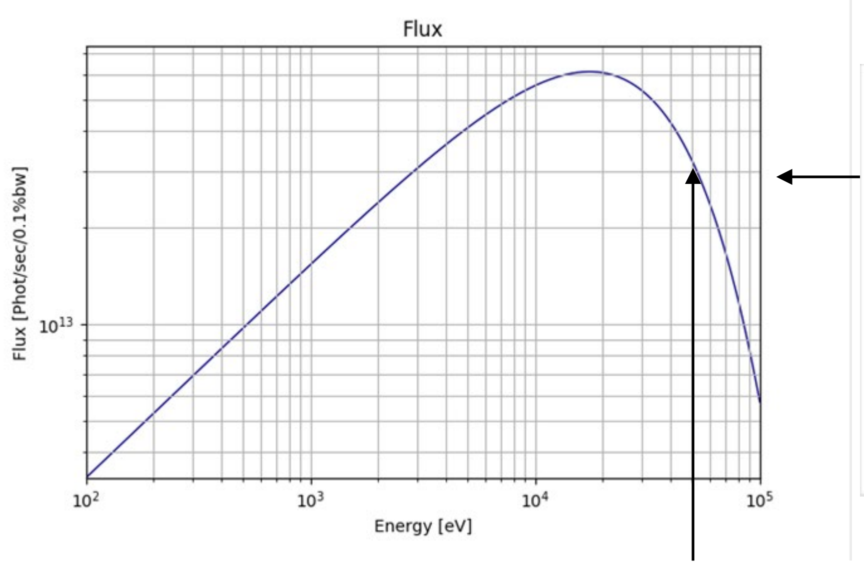
A 3% coupling seems reasonable. The results are without the 3HC effect. The minimum LT values are shown

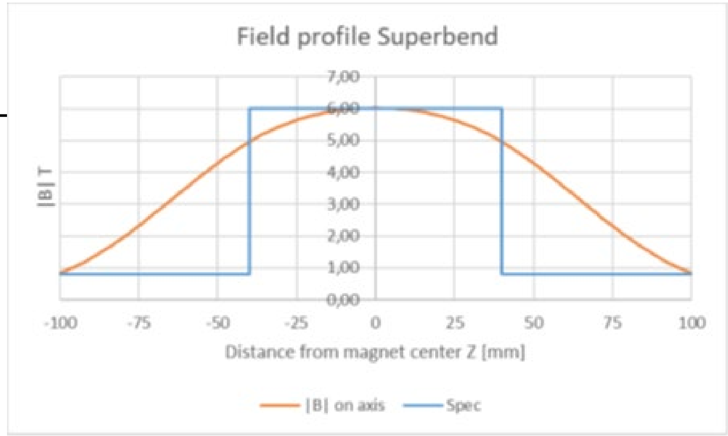


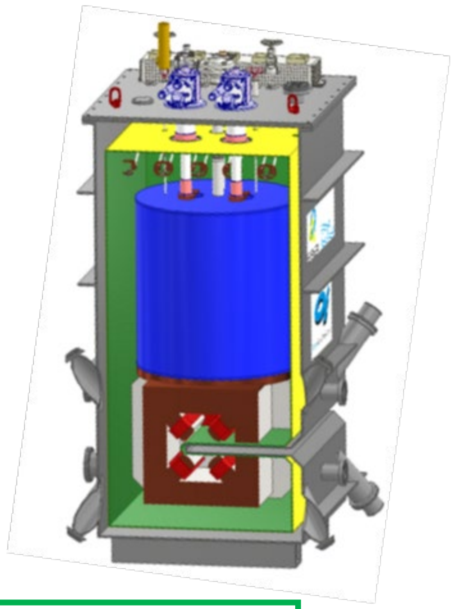
Including the 3HC effect the lifetime scales linearly with the bunch length.

Superconducting dipoles

Three beam lines at 35 and 50 keV and with flux above **10^{13} ph/sec** will be constructed and will be served by three 6 T SC-Dipoles to be installed after commissioning in sectors 4,8,12. First installation is expected in 2027.







- For the super-bends we opt for a C-shape magnet, technical specs at the end of 2022.
- In contact with companies in order to find the best proposal.
- There is also a MOU with PSI for many items including super-bends.

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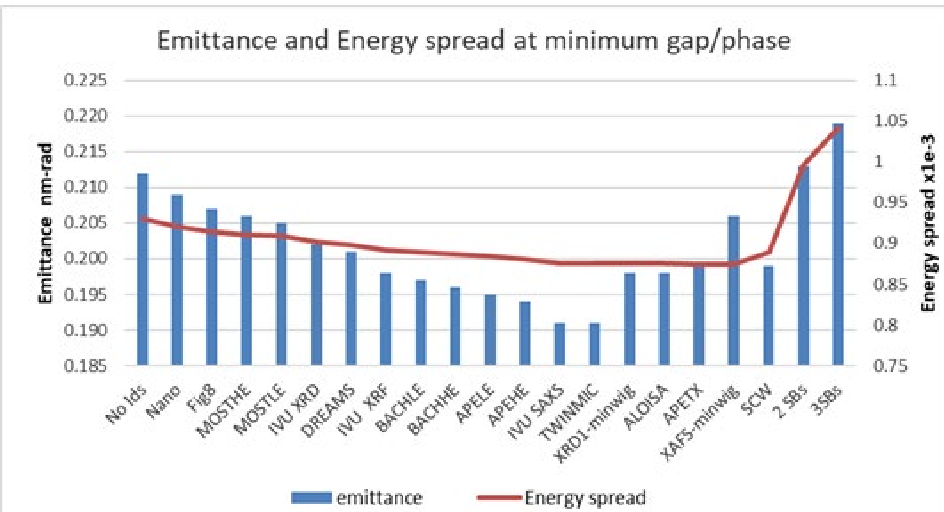
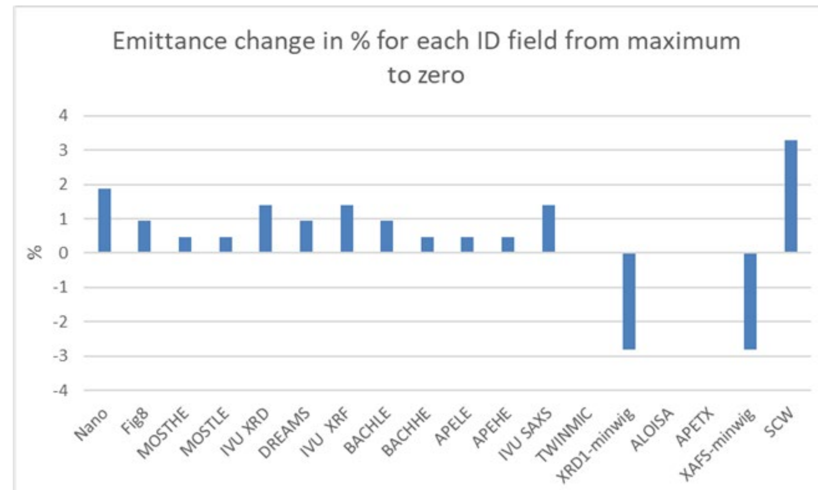
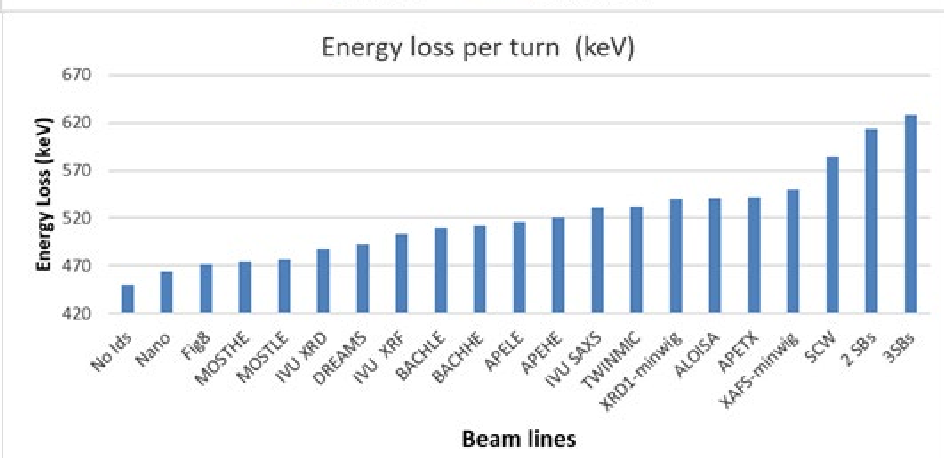
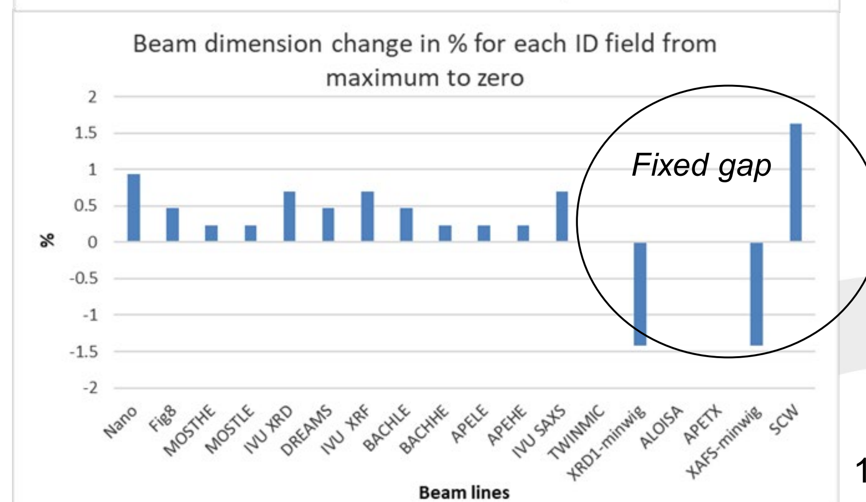
Emittance and beam size variation

All 11 long straight sections will be occupied, the section 2 is reserved for the deflecting RF cavities for achieving for some beamlines pulses as short as 1 ps (FWHM). Additionally 5 short straights will be occupied by IDs. When all insertion devices and SBs are included the emittance at 2.4 GeV reads 218 pm-rad and the energy loss due to radiation is 620 keV which for 400 mA translates to 248 kW radiation power. Moving any ID field for zero to maximum changes the beam dimension by less than 1%. However a feed back system is considered to take care of simultaneous field changes



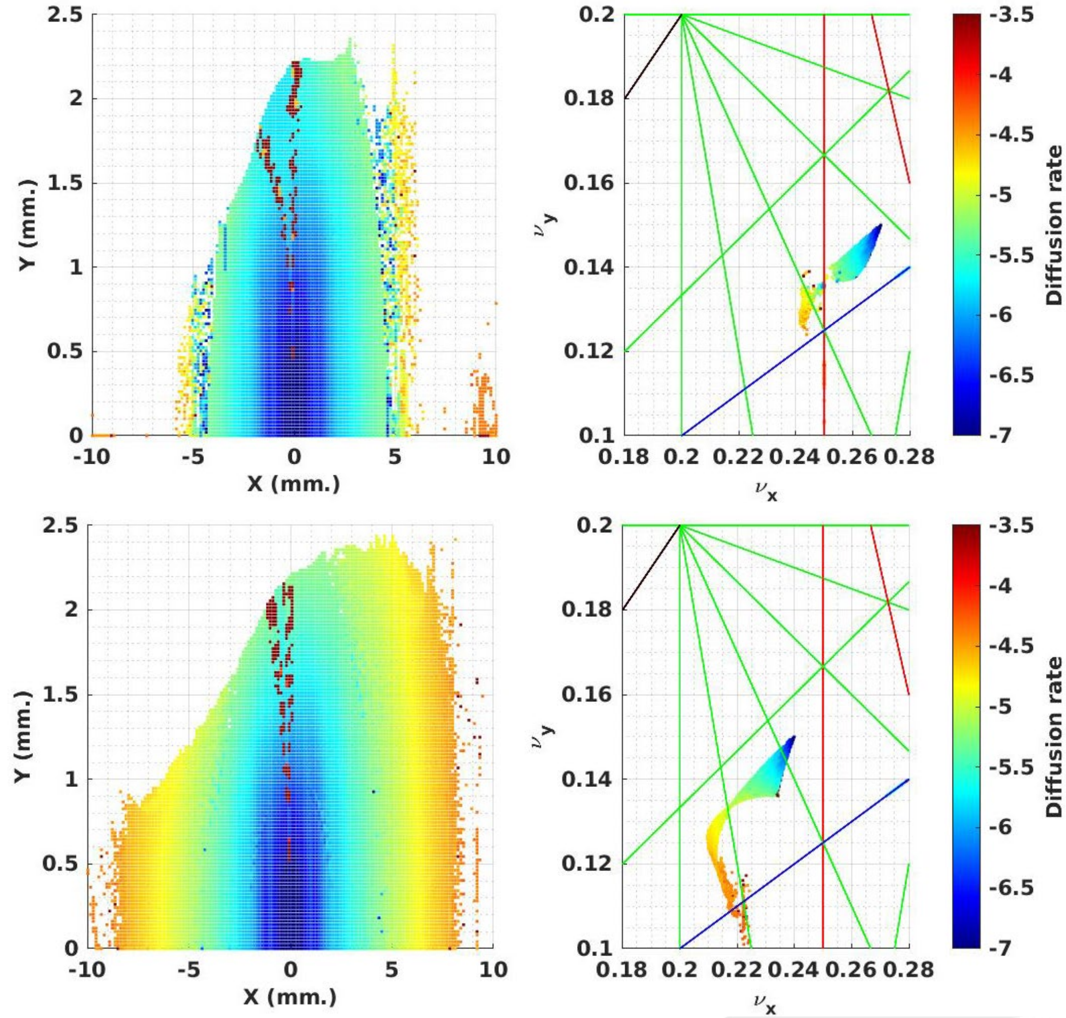




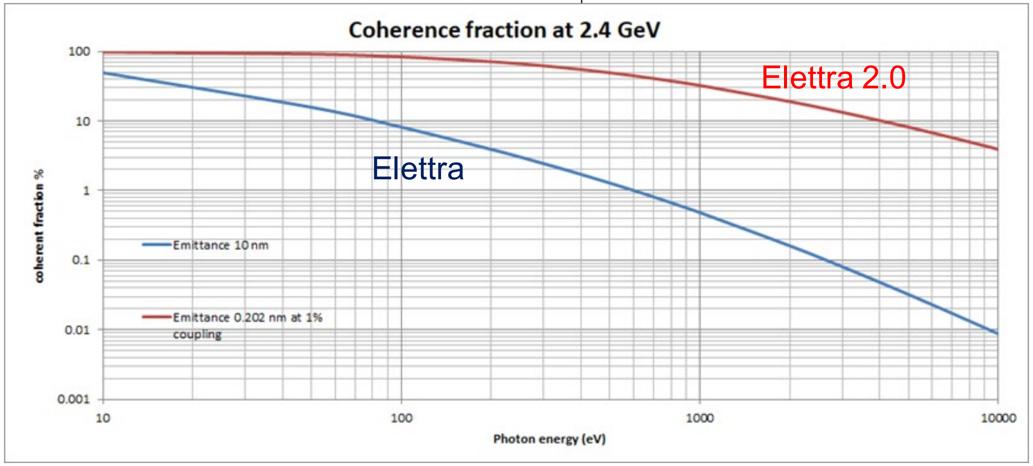


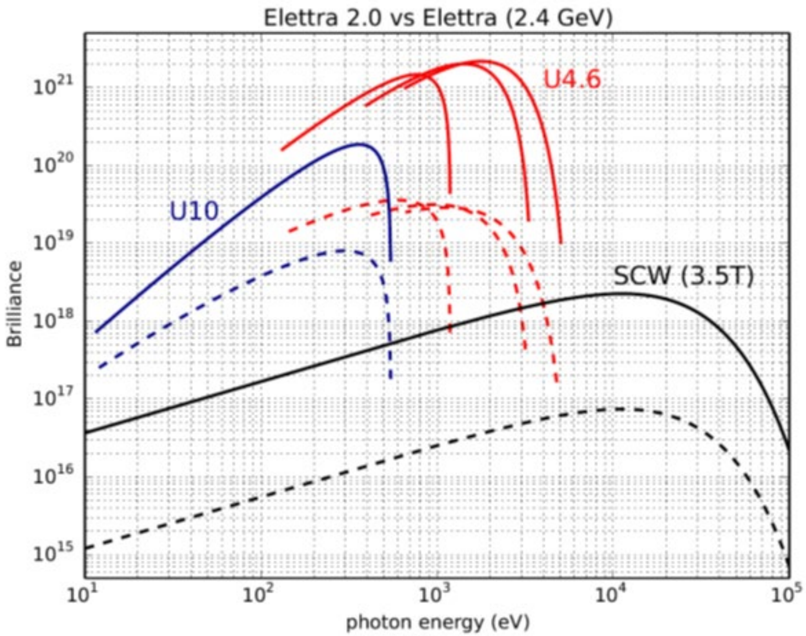
Impact of IDs on dynamics

- Impact of IDs on linear and nonlinear beam dynamics was studied using kick maps.
- For IDs which produce more than 5% beta beating local correction was applied.
- Some of IDs had strong dynamic octupole component which was causing reduction of dynamic aperture.
- Changing horizontal tune from 32.27 to 32.24 keeps tune footprint away from $4v_x$ and restore DA.
- Effect of IDs on machine with errors and correction is ongoing.
- Effect of measured field integrals is planed.

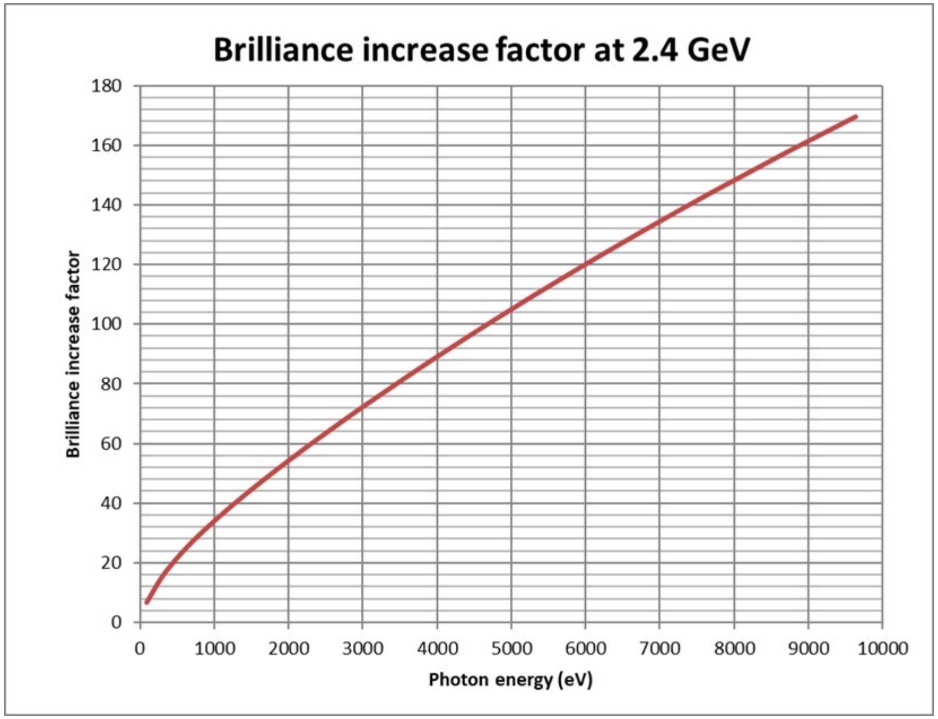


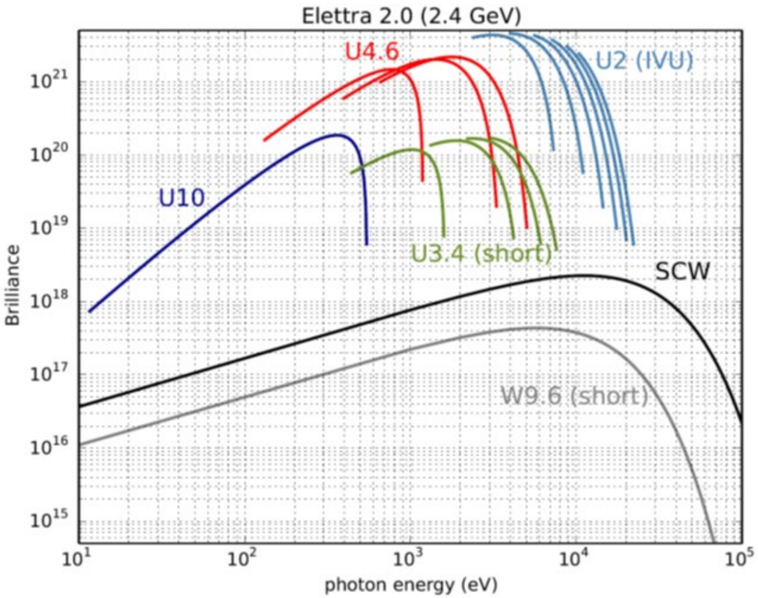
Ref. K. Manukyan





Solid lines refer to Elettra 2.0, dashed lines refer to Elettra





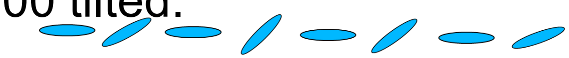
Short pulses

Elettra 2.0 naturally provides e-pulses of 19 ps fwhm at low intensities **(i.e. 0.25 mA /bunch, i.e. ~100 mA total)** due to its low momentum compaction ~ 10^{-4}

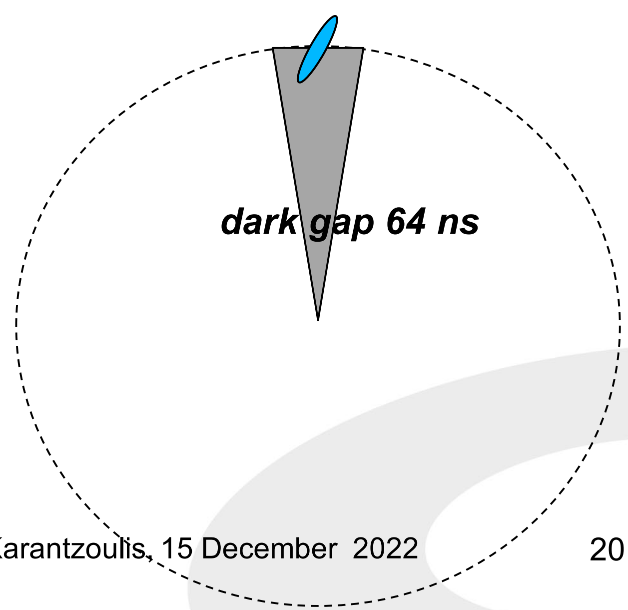
But using the deflecting cavities (crab) technology it can deliver shorter photon pulses that are particularly attractive for experiments requiring high repetition rate and low intensity

	Elettra 2.0 with crab
Pulse length fwhm	~1 ps
Flux at the sample (ph/s)	10^{8}-10^{10}
Photon energy (eV)	150-15000
Repetition rate (Hz)	1.156×10^{6}
Max range fine tuneability	> 100 eV
coherence	Transverse

A pair of deflecting cavities (3 and 3.25 GHz) deflect every other bunch thus we are going to have 200 regular and 200 tilted.



The regular bunches will have 2 mA each to achieve 400 mA target.



One possible operational scenario consists of one tilted bunch in the middle of a 64 ns dark gap with 2 mA to provide the short pulses.
This way all users can work simultaneously

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- **Δt(ps)** is the ***single shot*** pulse duration ***@ slit***

  Can be shortened by: machine optimization, not below 1 ps

  Can be lengthened by: larger flux, non-ideal optics multi-shot timing jitter

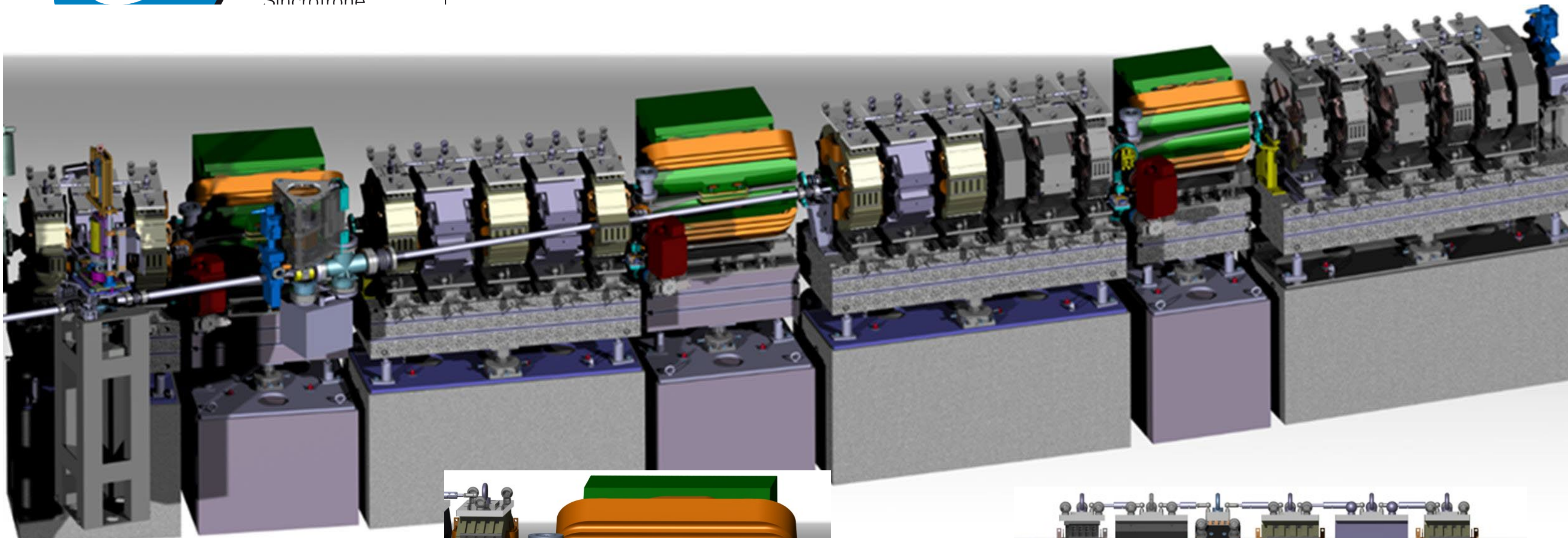
- **ΔF/F(%)** is relative to the ***SB emission @ ID***

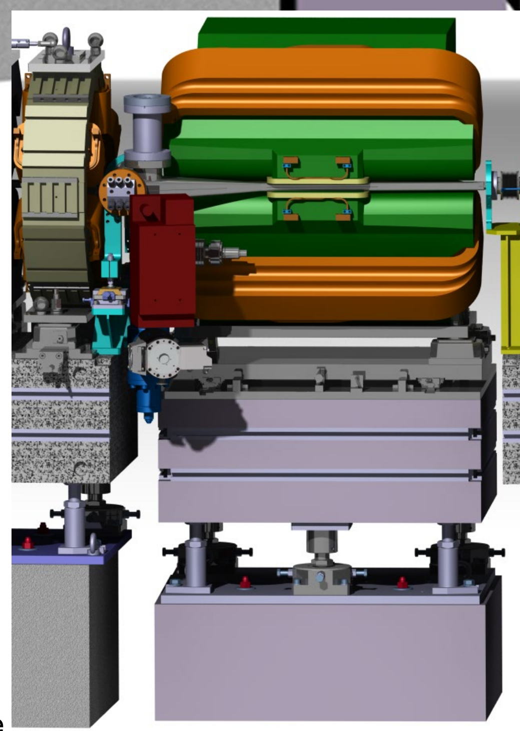
  It is ~2-fold larger if relative to the central cone emission

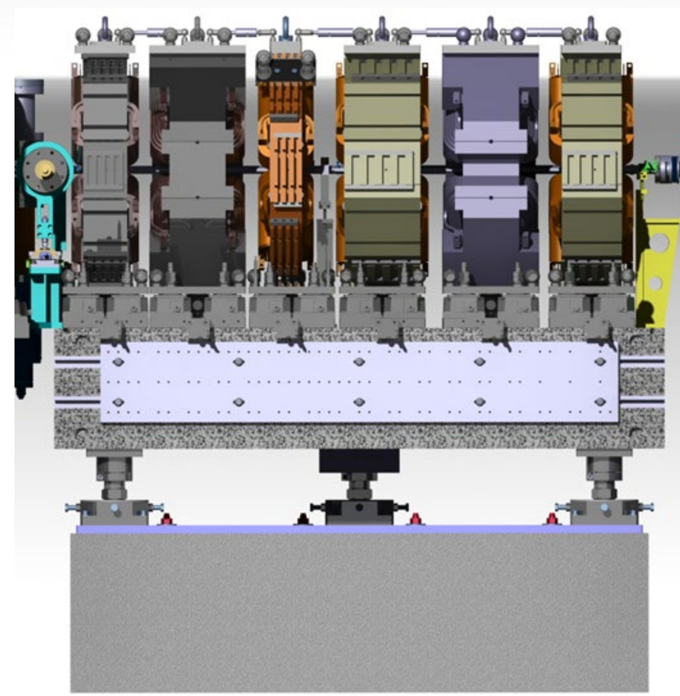
Beamline	LOWEST photon energy				HIGHEST photon energy			
	Δt_{FWHM} (ps)		ΔF/F (%)		Δt_{FWHM} (ps)		ΔF/F (%)	
	DR	HYB	DR	HYB	DR	HYB	DR	HYB
1.2 Nano-Spect	16	8	6	3	3	1.8	1.5	3
2.1 Twin-Mic	45	1.1	33	1.7	45	1	16	1.6
2.2 SuperESCA	-	-	-	-	-	-	-	-
3.2 Spectro-Micro	46	9.5	18	1.4	40	1.9	4	2.1
4.2 Most	20	20	13	4	2.9	4	1	6
5.1 XRD1	32	6	10	3	16	3	6	3
5.2 uXRD	10	1.4	4	3	17	0.8	3	2
6.1 XAS-mW	30	35	10	12	12	20	5	15
6.2 CDI	3.5	4	0.5	4	2.1	1.7	1	3
7.1 Aloisa	22	1.2	10	1.6	8	0.6	2	1.5
7.2 uXRF	6	1	1	2	7	0.8	1.8	2
8.2 Bach-VUV	18	7	9	4	2.8	1.5	1	3
9.2a APE-LE	35	7	13	2	15	1.6	3	2
9.2b APE-HE	22	2.8	4	2	6	1	1	2
10.2 HB-SAXS	2.3	1.1	1	2.5	1.9	1.1	1	2
11.1 APE-TX	15	0.8	1	1.5	7	0.8	2	2
11.2 SCW	40	10	15	2	26	5	7	2

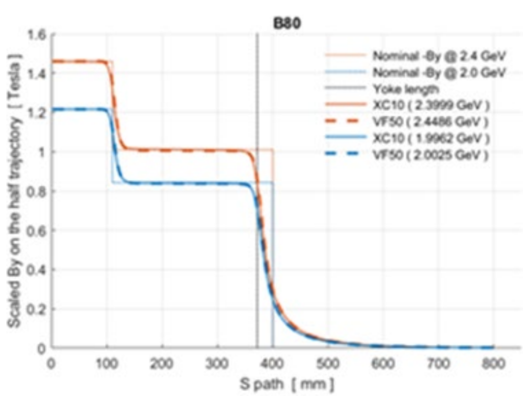
Ref: S. Di Mitri

Elettra 2.0 some views



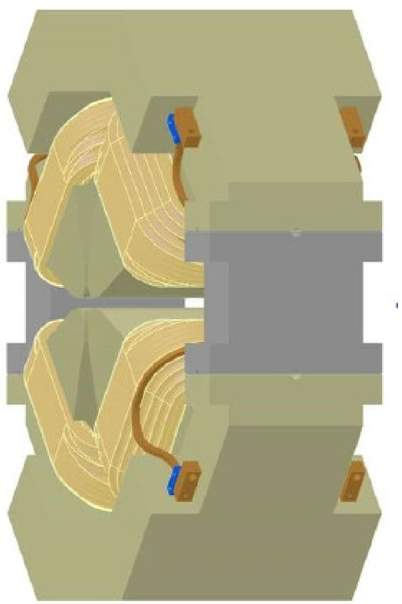


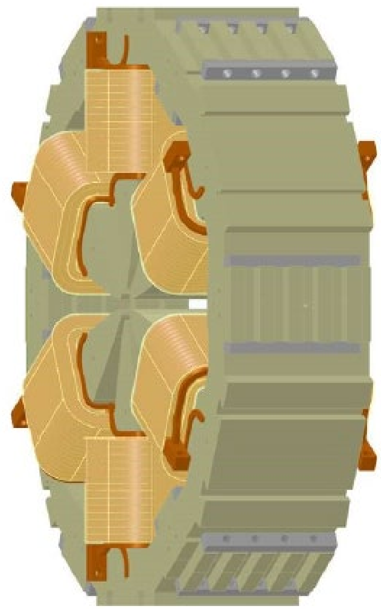




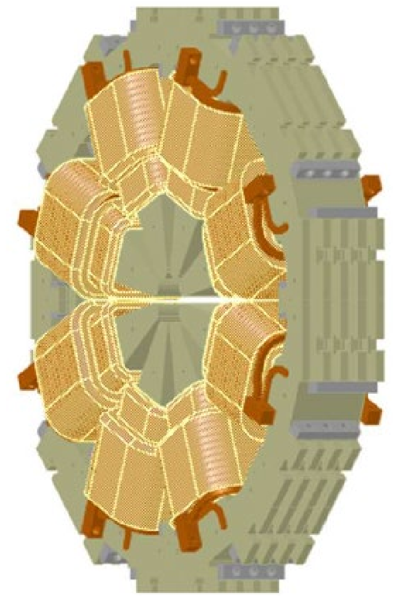
Elettra Sincrotrone Trieste

Magnets

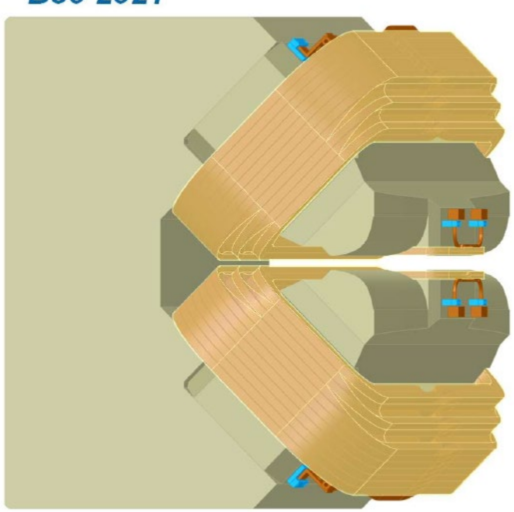


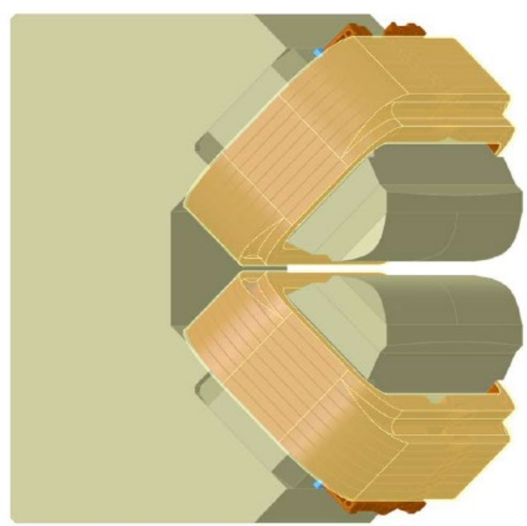


B64 2021



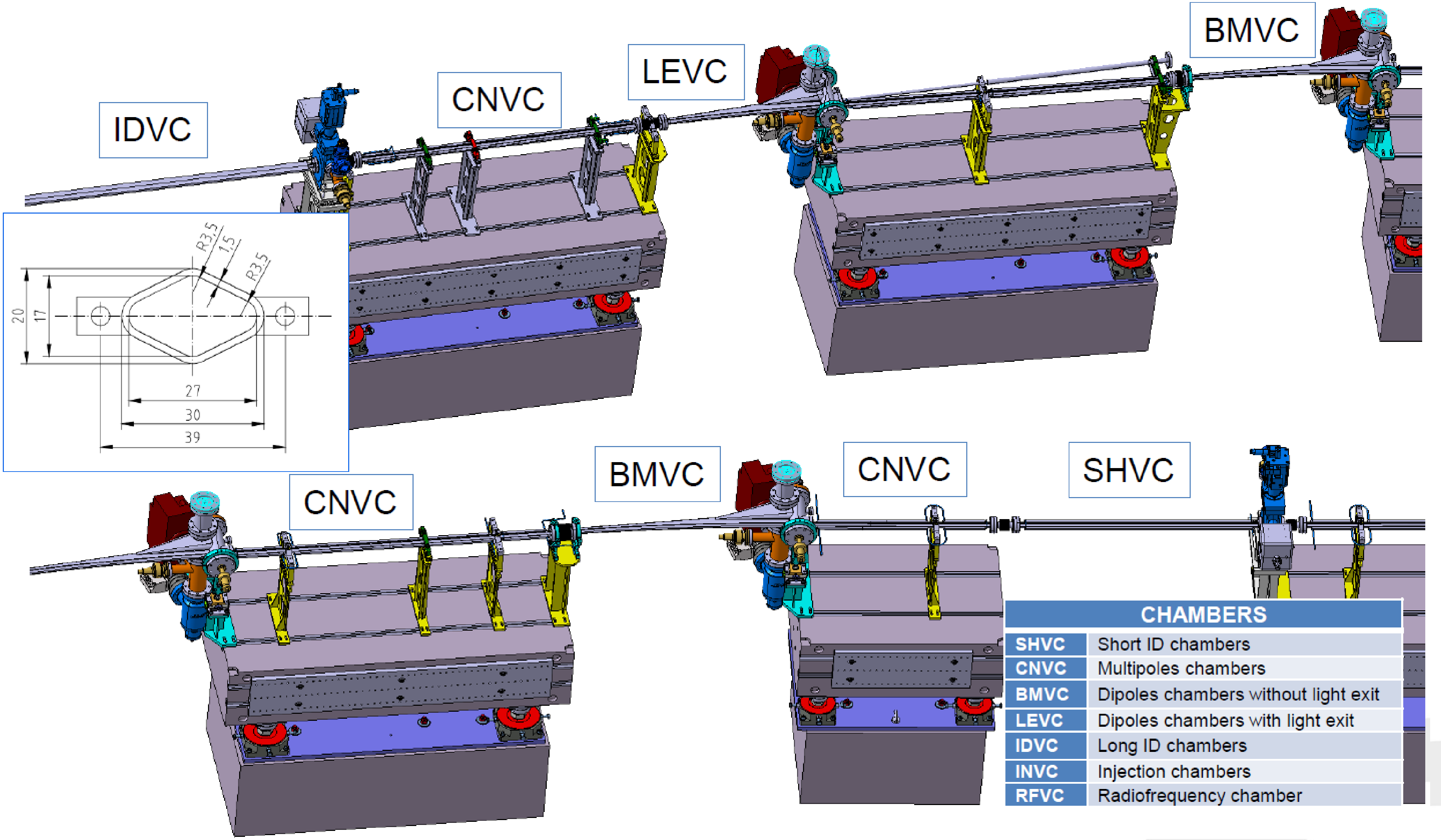
B80 2021





In the dipoles and quadrupoles the coils do not protrude
i.e. the useful space between magnets is not reduced by the coils

Types of vacuum chambers



CHAMBERS	
SHVC	Short ID chambers
CNVC	Multipoles chambers
BMVC	Dipoles chambers without light exit
LEVC	Dipoles chambers with light exit
IDVC	Long ID chambers
INVC	Injection chambers
RFVC	Radiofrequency chamber

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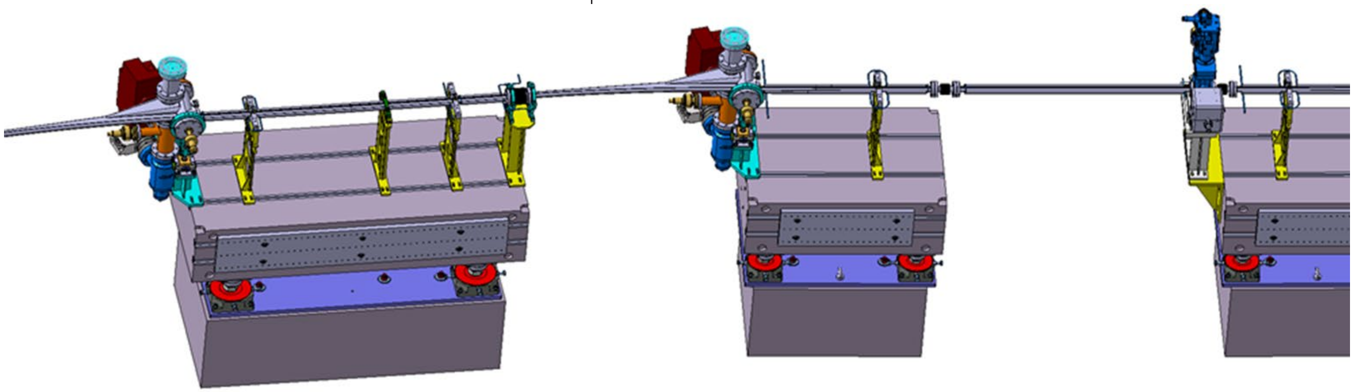
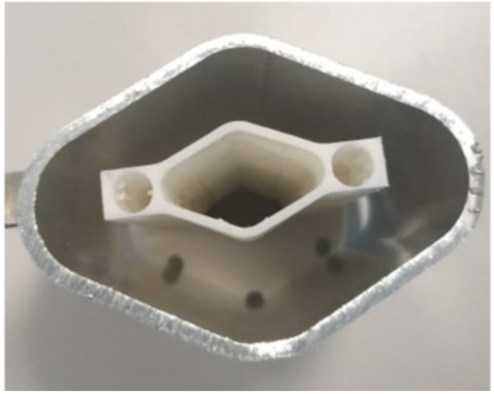
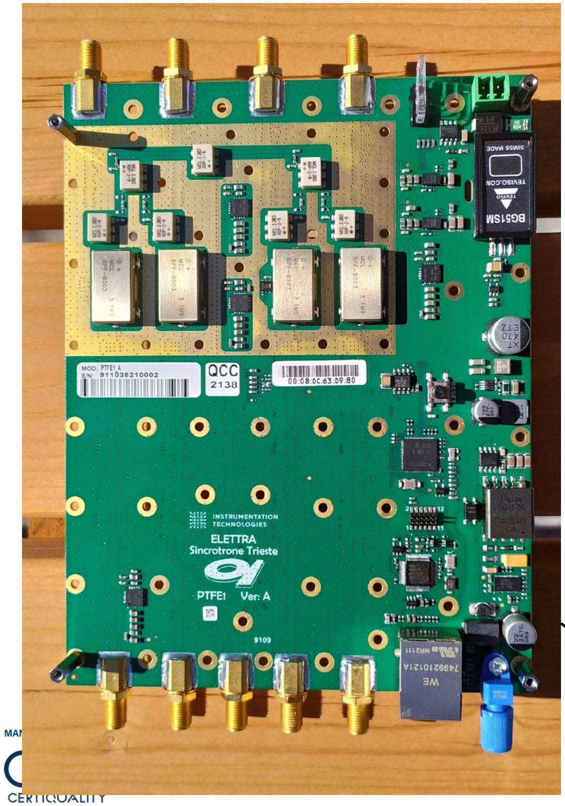
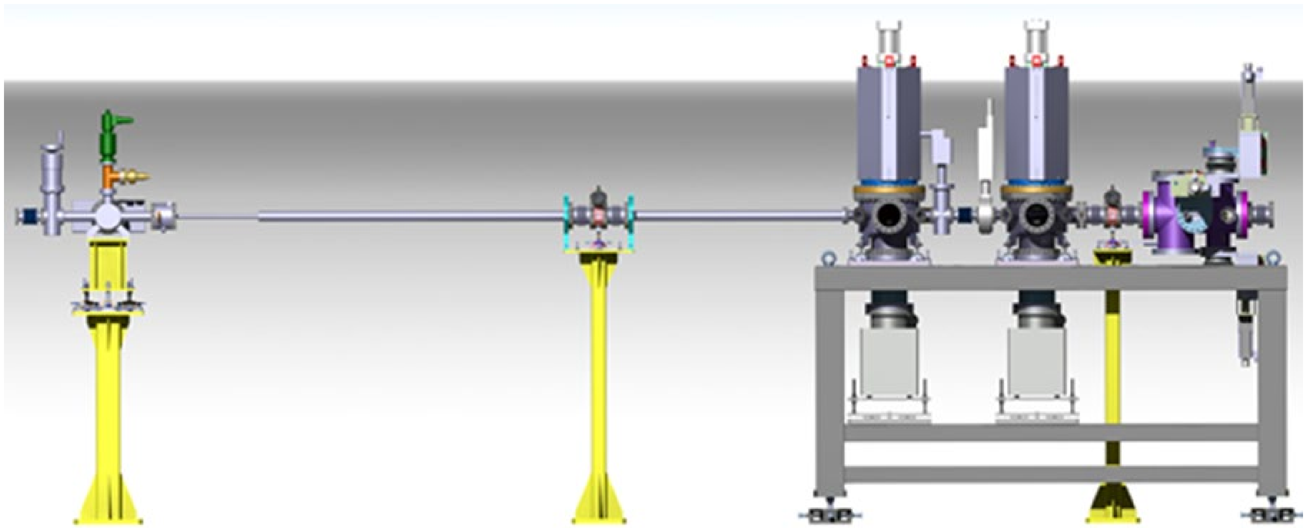
Vacuum chamber and Front Ends

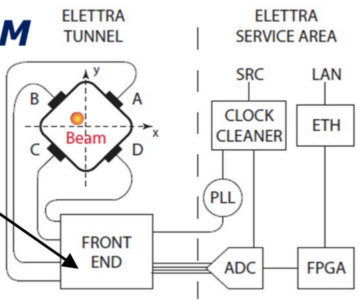








E²BPM



Elettra **E**lectron **B**eam **P**osition **M**onitor system

Elettra Sincrotrone Trieste

Energy issues

- ✓ Current Elettra functions for 75% of user time at 2 GeV 310 mA and for 25% of the user time at 2.4 GeV 160 mA. Total real power needed is 4 MW
- ✓ Elettra 2.0 will function mainly at 2.4 GeV with 400 mA and only initially at 2 GeV. Needed power 3.2 MW

Already there is a 20% saving in energy

- ✓ The power supplies of Elettra are 1.5 MW while the same of Elettra 2.0 are 0.35 MW

Do we really need permanent magnets?

YES

because energy issues will become very important in the future

PMs contribute also to higher beam stability but there are also issues to be solved (radiation, field stability vs. temperature)

VAriable Dipole for the Elettra Ring - VADER

- ***Main operating energy 2.4 GeV (and only initially at 2 GeV)***

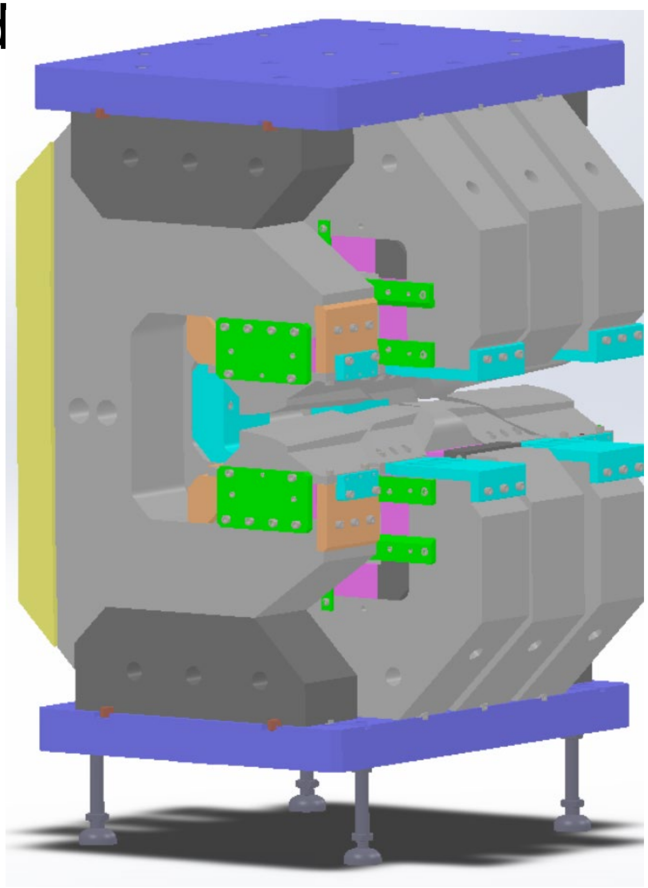
Thinking about future (Elettra 2.1) , we could replace the combined dipoles and maybe also other magnets, with permanent ones

- ✓ **Task 7.3** within I.FAST **WP7**: High Brightness Accelerators for Light Sources
- ✓ Partners and contact persons:

CERN	Ciemat – Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	Elettra Sincrotrone Trieste	KYMA
Y. Papaphilippou	F. Toral	E. Karantzoulis	R. Geometrante

VADER objectives

- ✓ **Specifications** of magnet used for **magnetic** and **mechanical** design, based on the experience already gained by CIEMAT.
- ✓ **Manufacturing** conducted by KYMA, a leading industrial partner in the magnet technologies for X-ray sources and, in particular, insertion devices.
- ✓ **Prototyping** and **acceptance** tests to shape **industrialization** procedure towards a series fabrication



Next step -> permanent anti-bend quads

VADER procedure

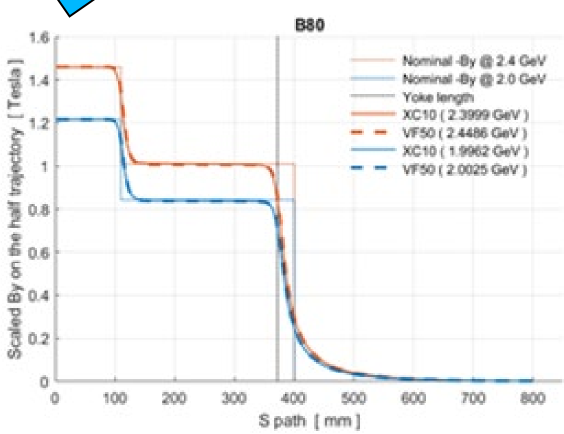
- ✓ Design to be modified/adapted to lattice for Elettra 2.0, in order to replace the **B80 electromagnets** (4/achromat for 12 achromats) with permanent magnets.
- ✓ **Optics** calculations for the storage ring S6BA-E cell, by replacing the dipoles with longitudinally varying field with an **optimized hyperbolic** field profile (as compared to the **step-like field** variation).

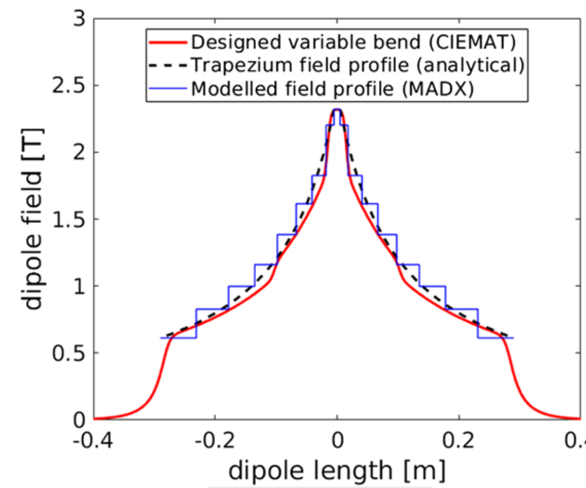
2.4 GeV	L1 T G=21T/m	L2 T G=0	L3 T G=21 T/m	Emittance pmrad
VH-LG	0.77 T	2.16	0.77	140
H-LG	0.92 T	1.78	0.92	150
M-LG	1.036 T	1.46	1.036	177

100 pm-rad

Additional 40% reduction (A. Poyet CERN)

B80

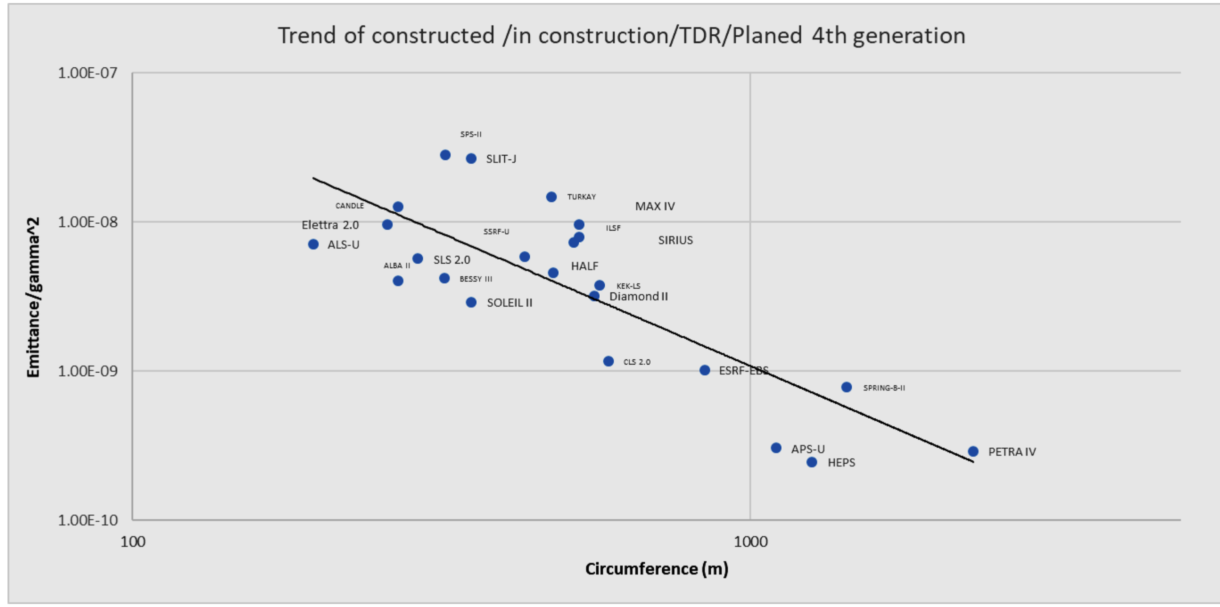


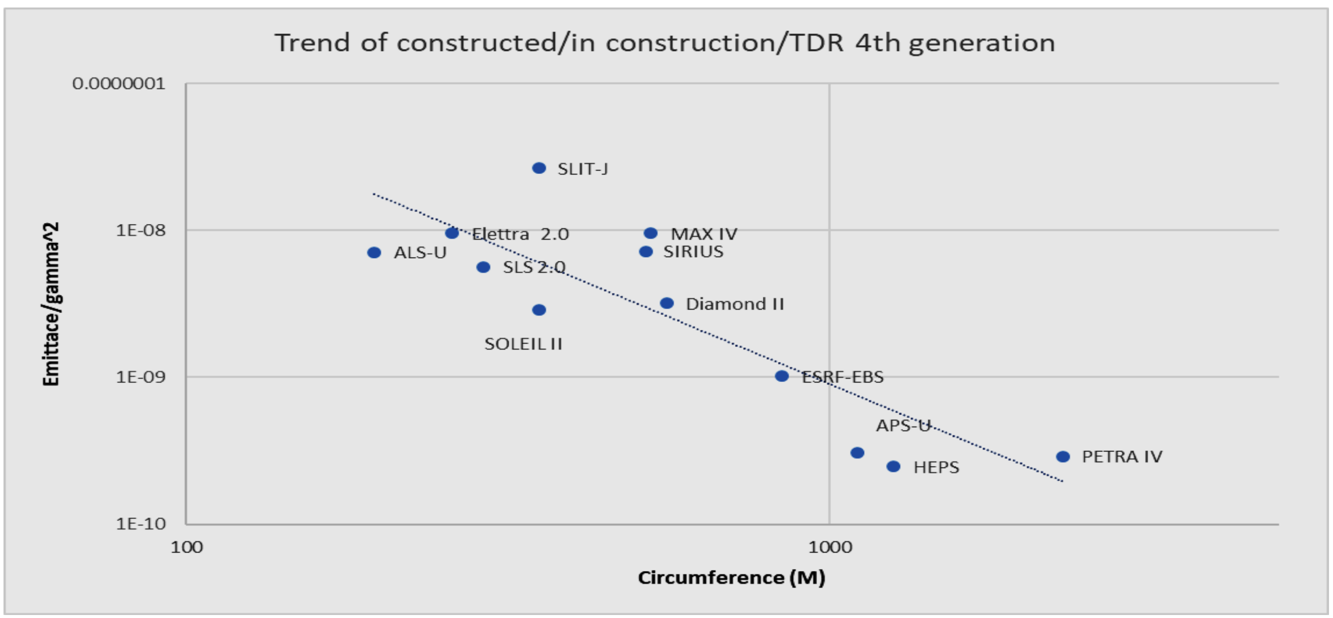


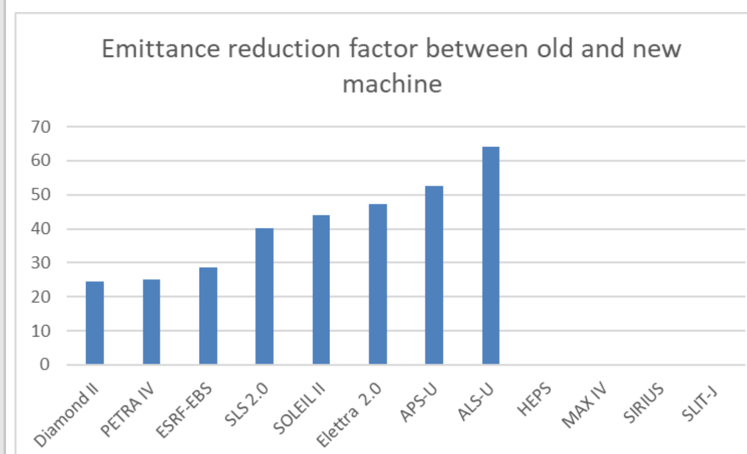
Info on 4th generation light sources

Elettra Sincrotrone Trieste

Facility	Country	Energy (GeV)	Lattice	Circumference (m)	emittance (pm-rad)	status
ALBA II	Spain	3	6BA	269	140	CDR
ALS-U	USA	2	9BA	196	109	construction
APS-U	USA	6	7BA	1104	42	construction
BESSY III	Germany	2.5	6BA	320	100	Study
CANDLE	Armenia	3	4BA	269	435	Study
CLS 2.0	Canada	3	9BA	590	40	Study
Diamond II	England	3.5	6BA	560	150	TDR
Elettra 2.0	Italy	2.4	6BA	259	212	construction
ESRF-EBS	France	6	7BA	844	140	operating
HALF	China	2.2	6BA	480	85	funded
HEPS	China	6	7BA	1260	34	construction
ILSF	Iran	3	5BA	528	275	Study
KEK-LS	Japan	3	8BA	571	130	Study
MAX IV	Sweeden	3	7BA	528	330	operating
PETRA IV	Germany	6	6BA	2304	40	TDR
SIRIUS	Brazil	3	5BA	518	250	operating
SLIT-J	Japan	3	4BA	354	920	construction
SLS 2.0	Switzerland	2.7	7BA	290	158	construction
SOLEIL II	France	2.75	7BA-4BA	354	84	TDR
SPRING-8-II	Japan	6	5BA	1435	108	Study& RD
SPS-II	Thailand	3	6BA	321	970	Study
SSRF-U	China	3	7BA	432	203	Study
TURKAY	Turkey	3	6BA	477	510	Study





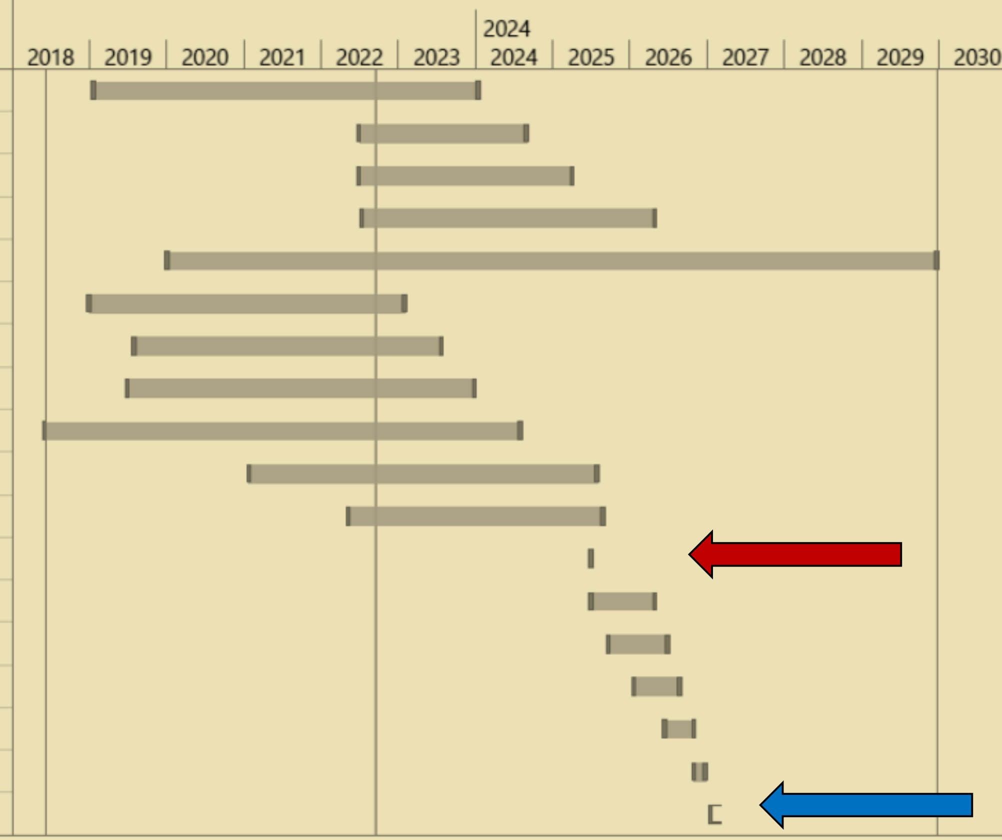


CERTIFIED MANAGEMENT SYSTEM
CERTIQUALITY
UNI EN ISO 9001:2015
UNI ISO 45001:2018

E2 Schedule

Elettra
Sincrotrone
Trieste

ID	Task Mode	Task Name	Duration	Start
1		Infrastructures upgrade	1300 days?	Wed 23/01/19
2		New Building (labs and store new)	566 days	Fri 01/07/22
3		RP Building (old machine storage)	718 days	Fri 01/07/22
4		Some Accelerator systems upgrade	992 days	Wed 13/07/22
5		Beam lines upgrade	2600.5 days?	Mon 06/01/20
6		Technical Design study	1066 days	Tue 01/01/19
7		Engineering Design	1040.5 days?	Thu 01/08/19
8		Prototyping	1175 days	Mon 01/07/19
9		Calls for tender	1605 days	Thu 07/06/18
10		Manufactoring construction and testing	1176 days?	Wed 27/01/21
11		Preparations and assembly	864 days?	Mon 09/05/22
12		End of user mode	1 day?	Wed 02/07/25
13		Ring decomissioning	215 days?	Thu 03/07/25
14		Installations	203 days?	Sun 21/09/25
15		Accelerator system tests /commissioning	153 days?	Fri 23/01/26
16		Ring and beamlines commissioning	100 days	Mon 15/06/26
17		Friendly users	39 days	Sat 31/10/26
18		Start user mode		Mon 11/01/27



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Elettra Sincrotrone Trieste

Summary

- Elettra, after 29 years of serving the synchrotron light community, is still running very well.
- The Elettra 2.0 project is fully financed
- The Elettra 2.0 configuration is fixed
- The first version of the Elettra 2.0 TDR made available in August 2021. The second version of the TDR made available April 2022. Upgrades and further developments will be incorporated as appendices.
- Remarkable progress has been made in almost all WPs of the Elettra 2.0 project (despite COVID-19).
- Elettra 2.0 will be up to 1000 times brighter and 60 times more coherent than the present Elettra.

Thank you for your attention