Elettra Sincrotrone Trieste

Elettra Status and upgrades

Emanuel Karantzoulis
on behalf of the Elettra group

Outline:

- ❖ Introduction
- ❖ Elettra status and statistics
- ❖ Operating with covid-19
- ❖ Short term developments
- ❖ Next upgrade: Elettra 2.0
- ❖ Conclusions

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources

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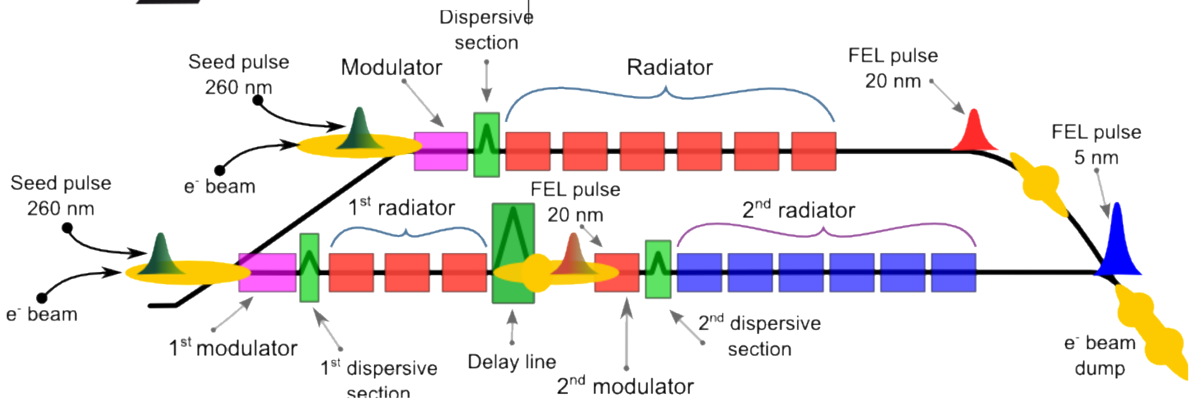
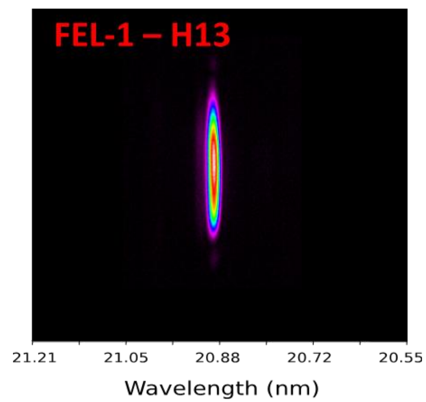
FERMI FELs: FEL-1 & FEL-2



FEL-1: **single** stage **HGHG** seeded by a **UV laser**

FEL-1 (Nat. Photon. **6**, 699 (2012))	
Tuning range	100-20 nm (12-60eV)
Relative bandwidth	1x10^{-3} (FWHM)
Pulse length	<100 fs
Pulse energy	20-100 µJ

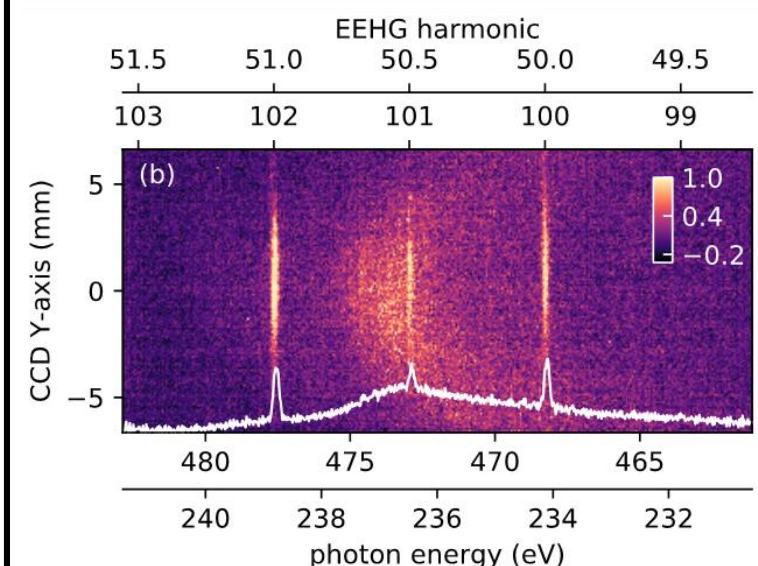


FEL-2: **double** cascade HGHG

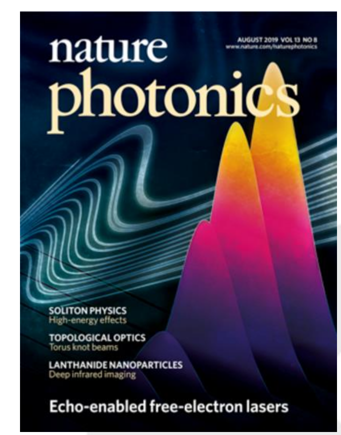
FEL-2 (Nat. Photon. **7**, 913 (2013), Journal of Synchrotron Radiation 22 (2015))	
Tuning range	20 - 4 nm (60 - 300eV)
Relative bandwidth	1x10^{-3} (FWHM)
Pulse length	~50 fs
Pulse energy	10-70µJ

Both FELs have APPLE-II undulators in the final radiator allowing **polarization control**.

Demonstration of EEHG with FEL-2



Clear evidence of coherent emission at harmonic 101 (2.6nm)



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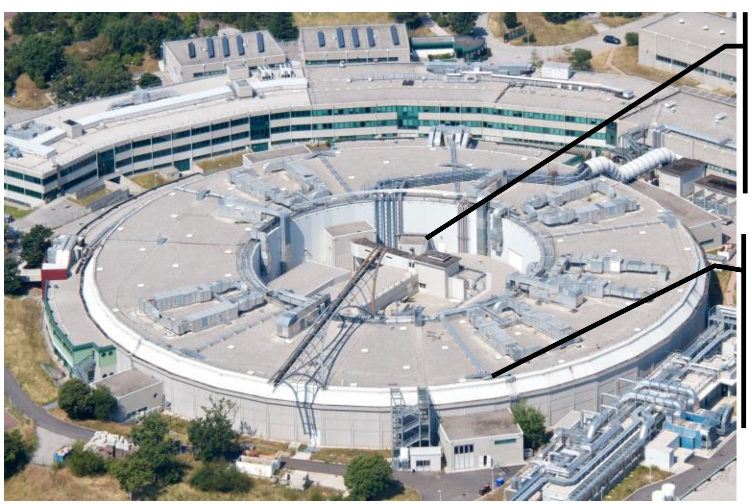
Elettra

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

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

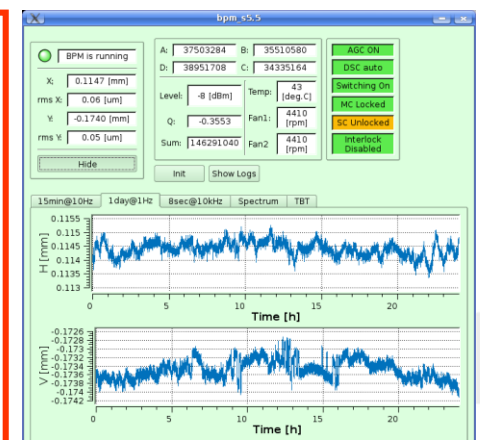
- Operates for about 6400 hours per year (24h, 7/7), 5016 hours reserved for users in 2 energies:
- 2.0 GeV, 7 nmrad, 310 mA for 75 % of users time with about 20 hours LT
- 2.4 GeV, 10 nmrad, 160 mA for 25 % of users time with about 33 hours LT
- 27 operating beam lines – over 1000 user and user poposals / 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)

Electron orbit stability requirements met most of the time provided that ambient temperature is within the defined limits, i.e., ± 0.5^{0}C Short term stability (< 24 hours) is < 10% of the electron beam size. Long term (>24 h) is ≤ ± 5 μm ptp (max value for >120 h).



H: 1.6 um V: 1 um

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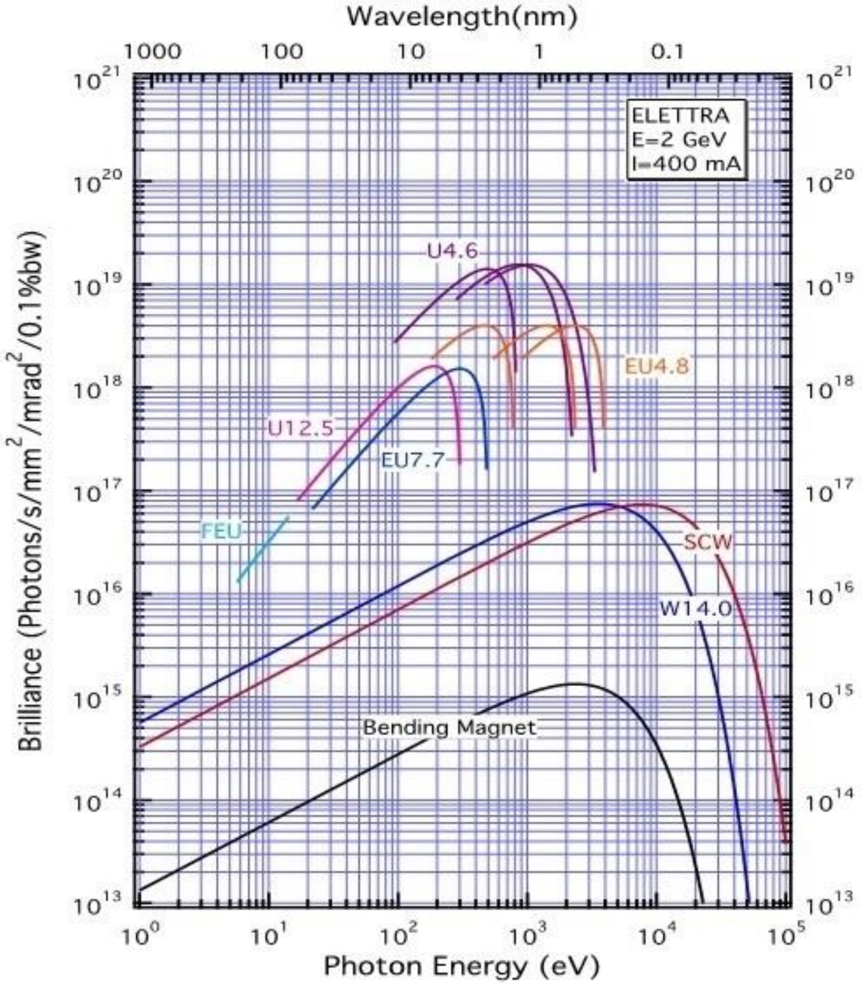
IDs and brilliance

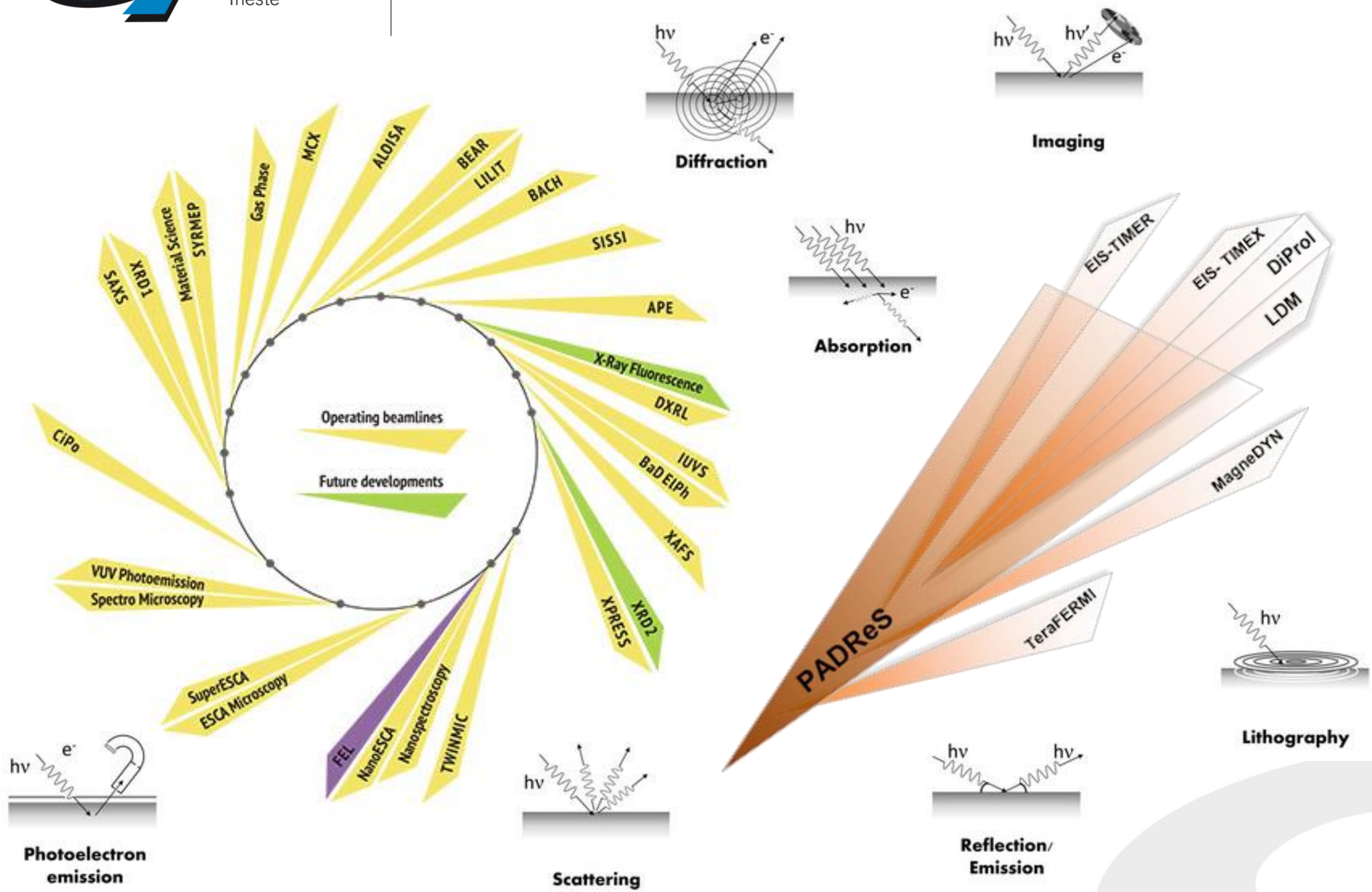
ID	type	section	Period (mm)	Nper	gap (mm)	status
U5.6	PM/Linear	12 short	56	18	23	operating ☆
EU10.0	PM/Elliptical	1	100	20+20	13.5	operating
U4.6	PM/Linear	2	46	2 x 49	13.5	operating
U12.5	PM/Linear	3	125	3 x 12	32.0	operating
EEW	EM/Elliptical	4	212	16	18.0	operating
W14.0	HYB/Linear	5	140	3 x 9.5	22.0	operating
U12.5	PM/Linear	6	125	3 x 12	29.0	operating
U8.0	PM/Linear	7	80	19	26.0	operating ☆
EU4.8	PM/Elliptical	8	48	44	19.0	operating
EU7.7	PM/Elliptical	8	77	28	19.0	operating
EU6.0	PM/Elliptical	9	60	36	19.0	operating
EU12.5	PM/Elliptical/QP	9	125	17	18.6	operating
FEU	PM/Figure-8	10	140	16+16	19.0	operating
SCW	SC/Linear	11	64	24.5	10.7	operating



21 ID PM segments + 1 SCW + 1 EM -> 19 beam lines: planar, elliptical, canted, electromagnetic, superconducting

6 bending magnet source points serving 9 beam lines

Beam lines 27+1 (+ 6 FERMI)



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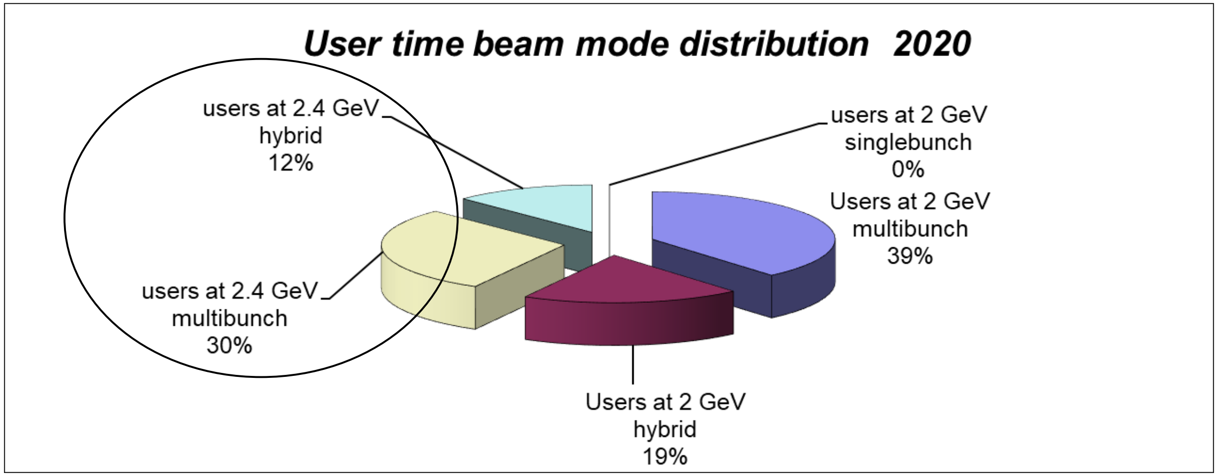
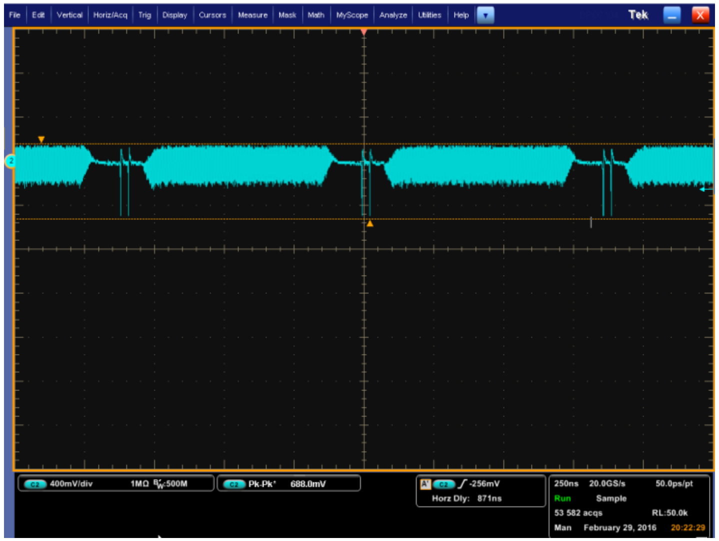
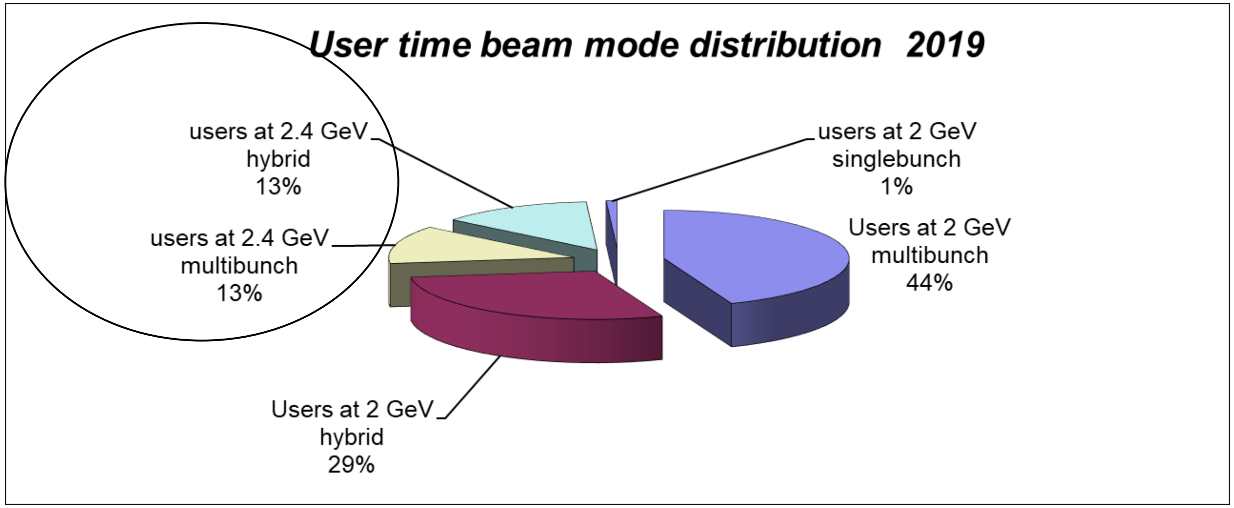
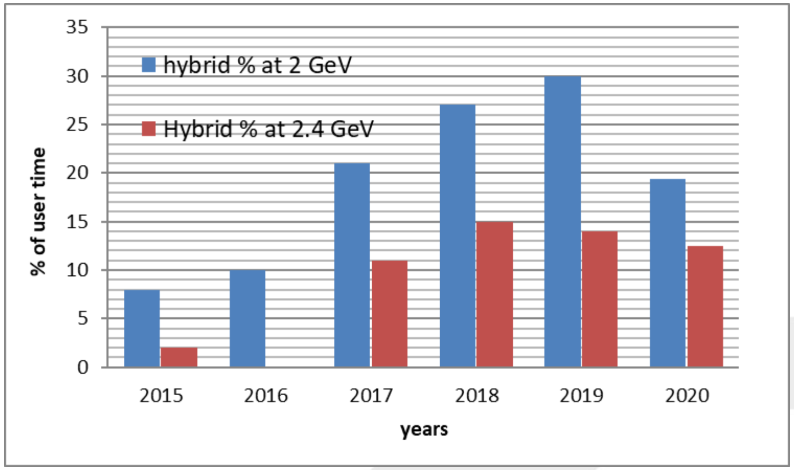
User time distribution



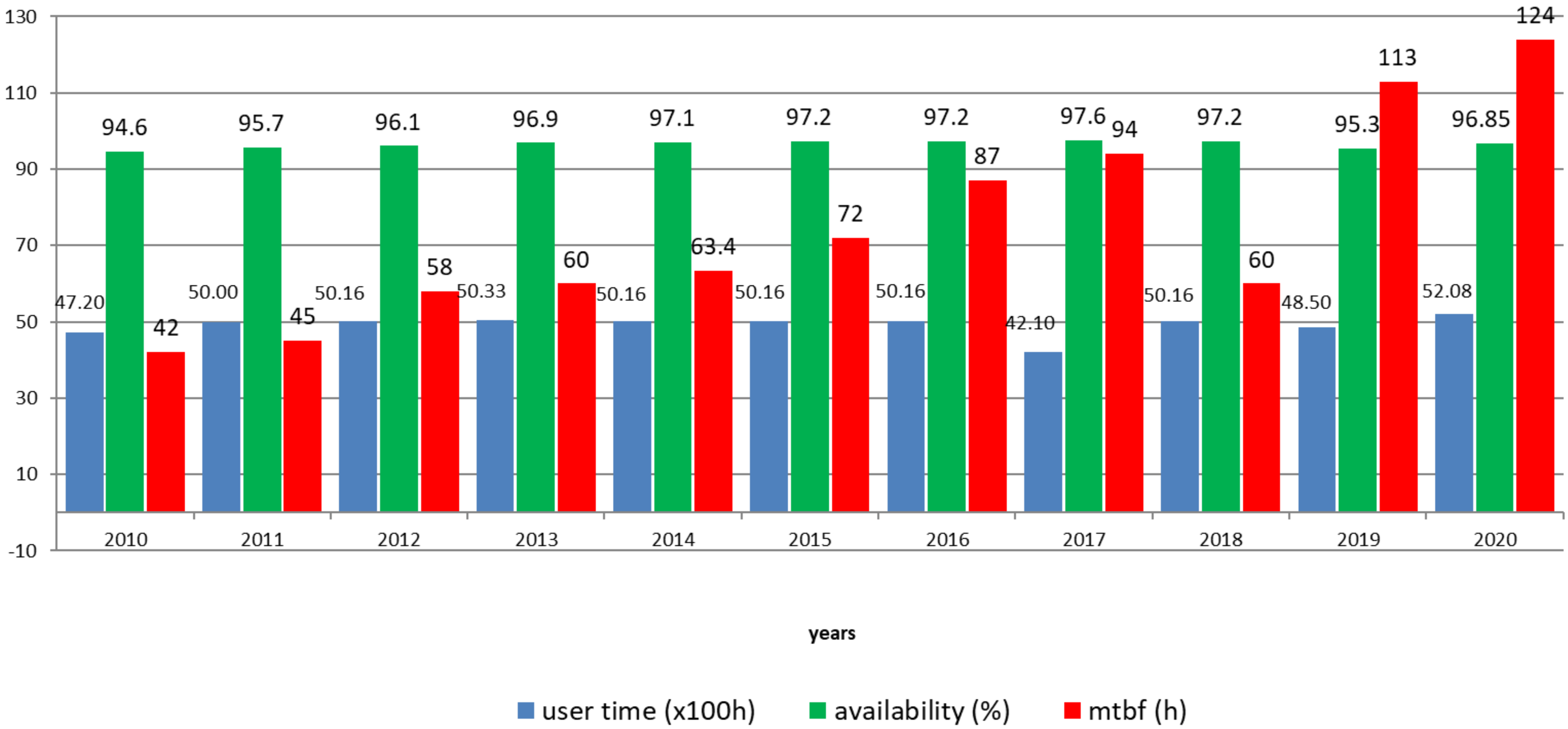




Time resolved distribution

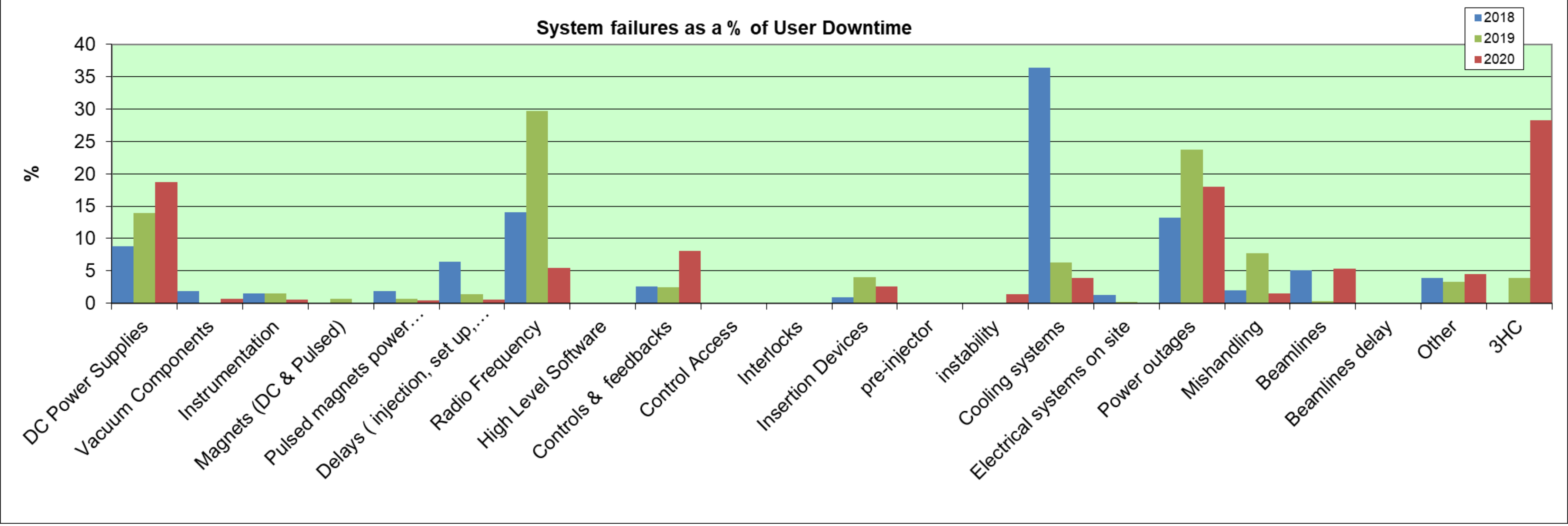


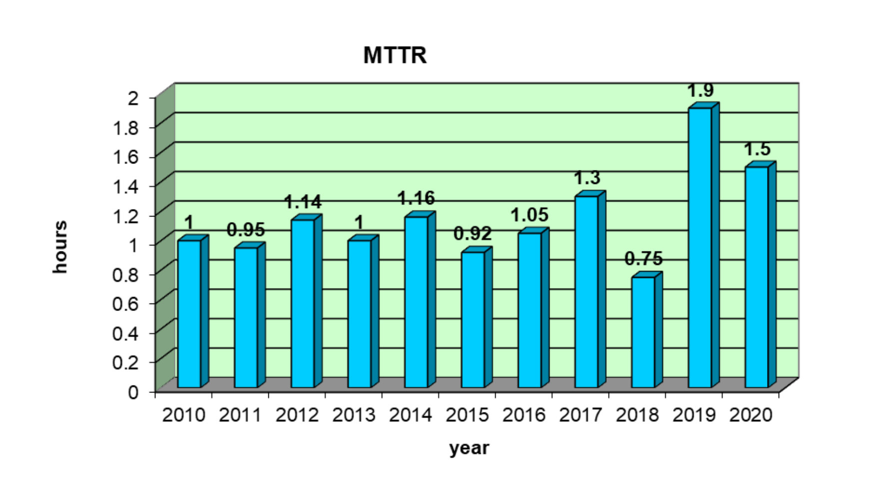
Uptime Statistics

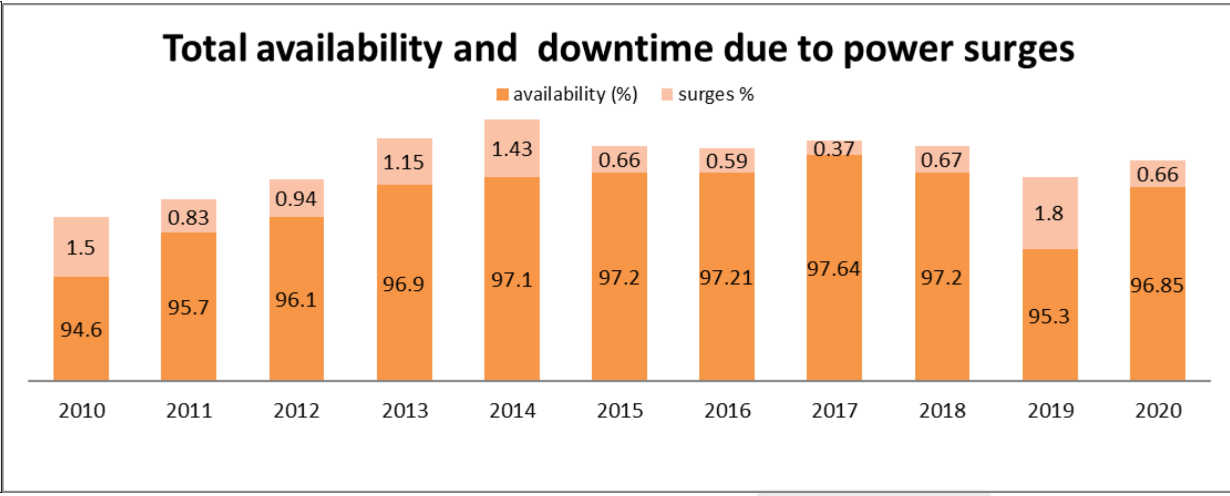


The availability includes all events, 2020 statistics for the 93% of the run time

System failures

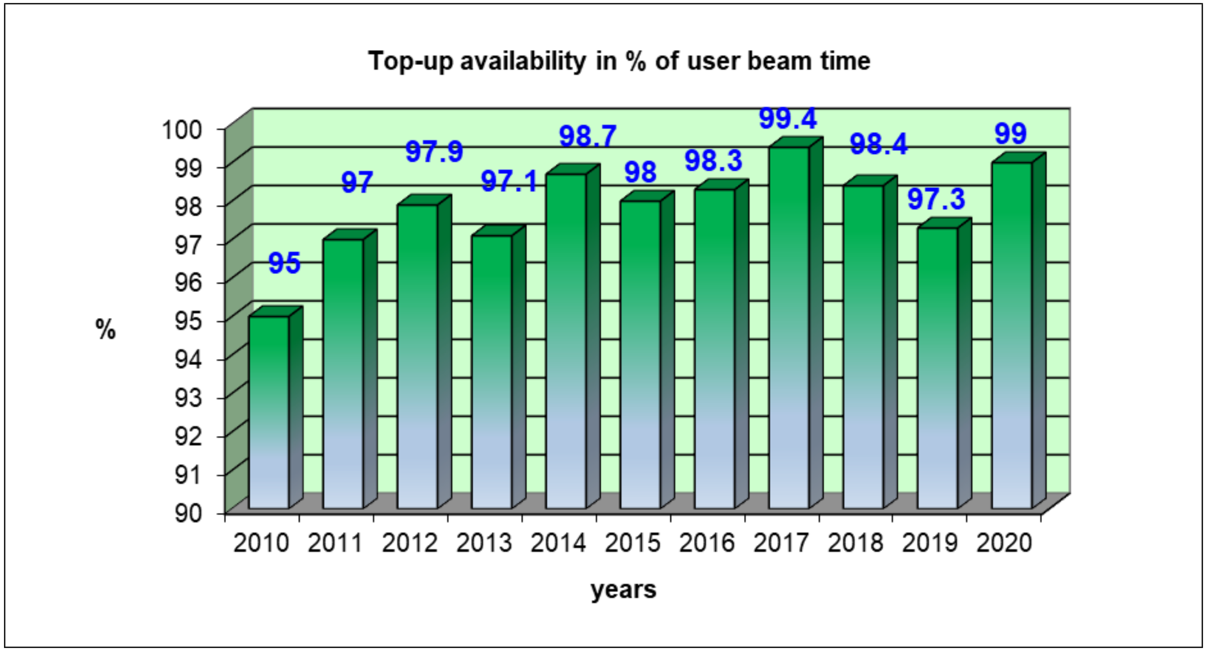






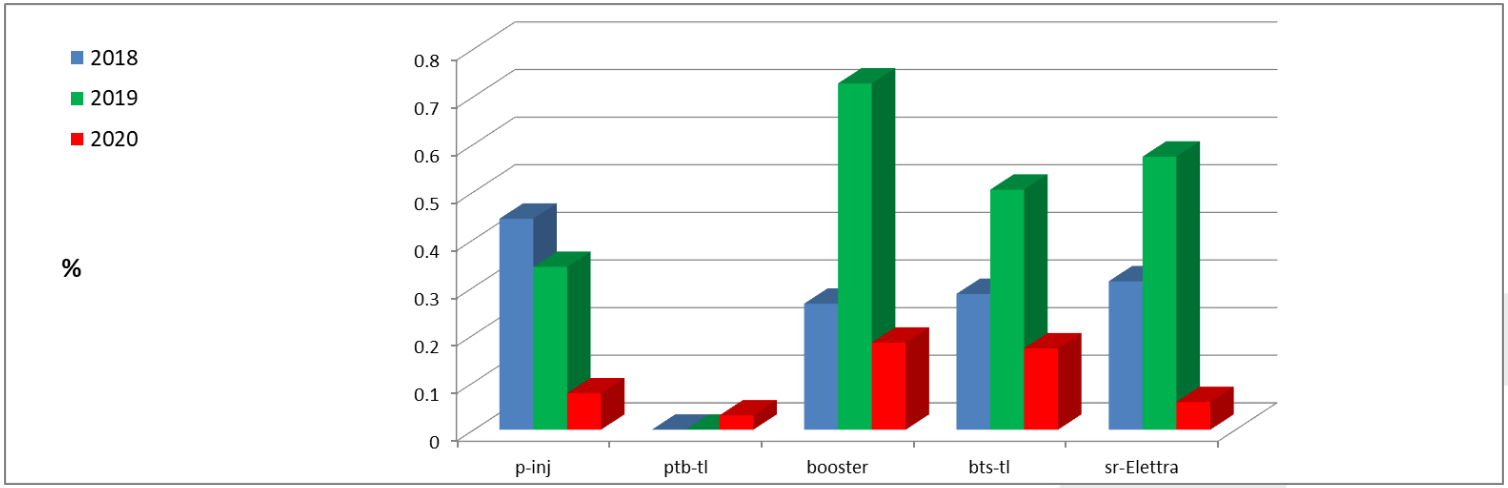
Top-up statistics

Every 5 min at 2 and 10 min at 2.4 GeV



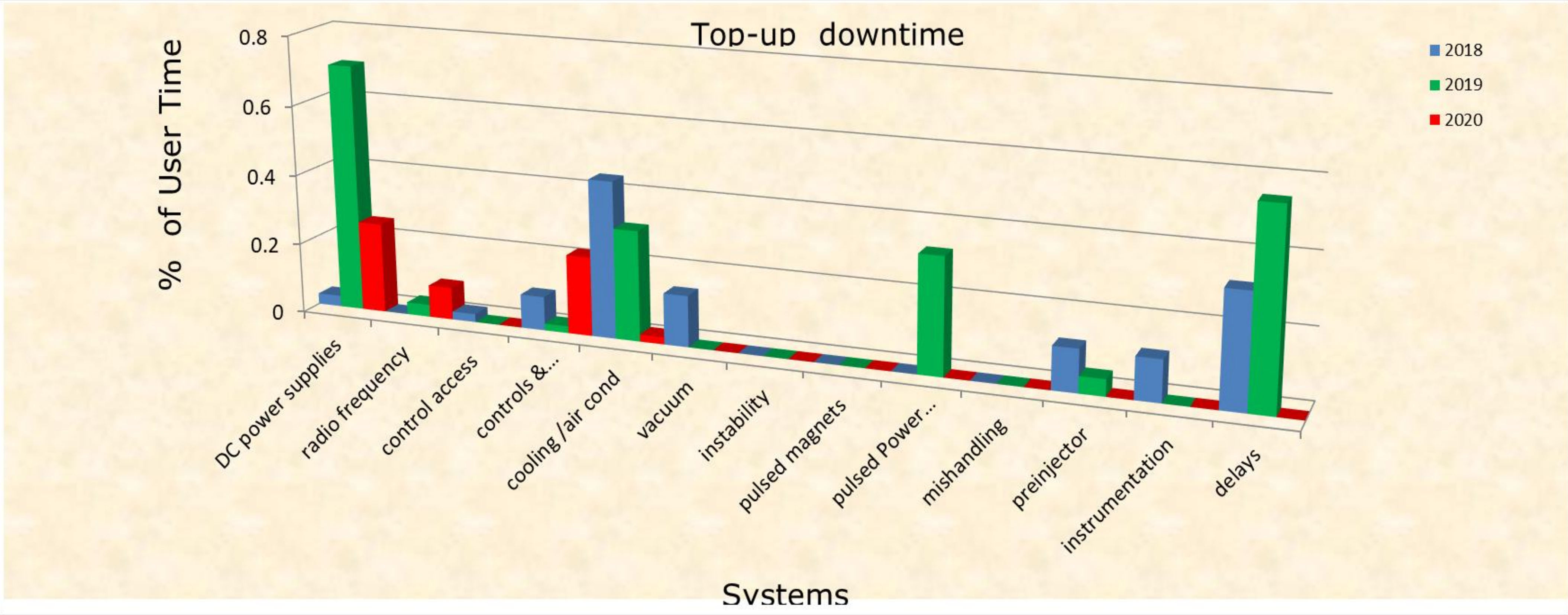
During top-up systems run well and the top-up % of user beam-time is high. The remaining very few % is due to failures that, however, do not impact on the availability.

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



Top-up downtime

considered when the intensity is less than 99.5% of the nominal



Note: the failures presented are not considered as downtime, BUT ***they can be considered (and therefore not shown here) if the intensity goes below 50% of the nominal.***

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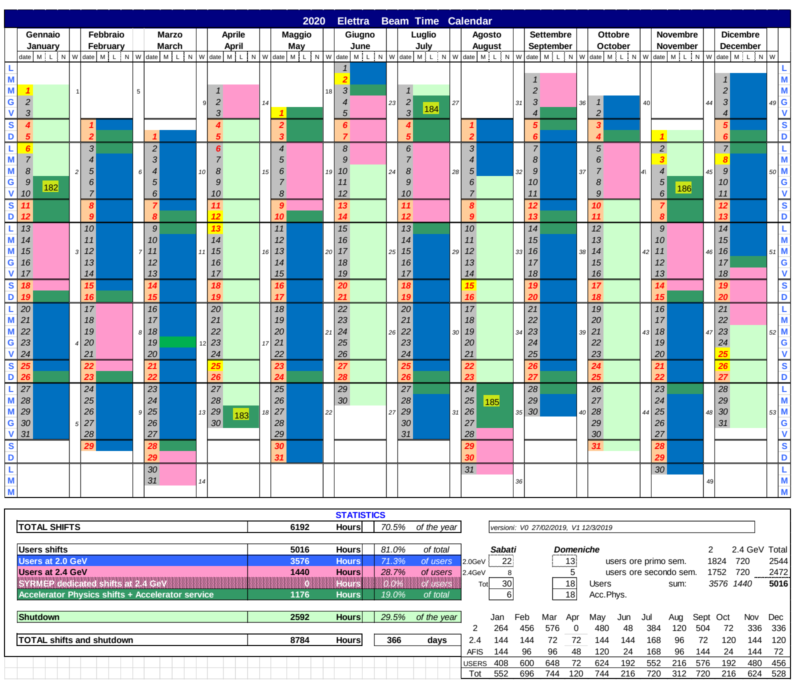
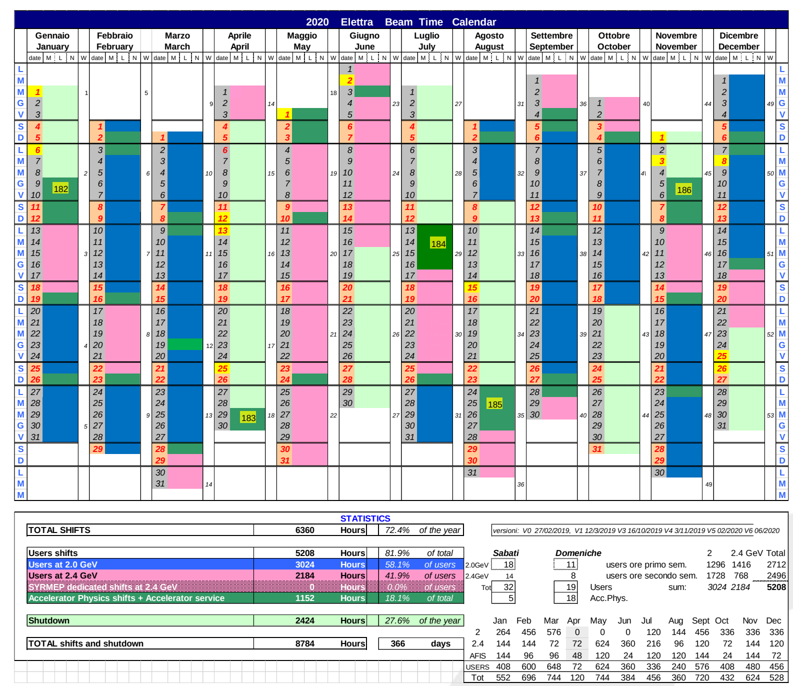
Operating with Covid-19

- ✓ The machine never stopped running
- ✓ Nobody got infected
- ✓ First lock down – 50% of beam lines were operating many experiments in remote (sample mail-in mode), with corona virus dedicated research
- ✓ Second lock down , all beam lines operating still many experiments in remote. (sample mail-in mode)
- ✓ Survey and feed back from users, 90% performed at least once in remote, in general satisfied but many experiments are postponed due to their complicated preparation.
- ✓ Smart Working (SW) at about 50% of the personnel
- ✓ Strick rules for being on site (mask, distance, one person per 15 sqm (office rotation) , sufficient ventilation, safety controls, procedures for entering into the site)
- ✓ *However due to lock down the machine itself suffered!!!*

The 3HC event

- ✓ Due to leak of a gasket in the compressor screw unit of the third harmonic cavity, (due to covid-19 could not be replaced by the technicians of air liquide) the 3HC cold box got contaminated and stopped functioning. Thus for a long time we had to run only a 2.4 GeV having 3HC worm and detuned since at that energy the 3HC does not contribute (at 2.4 GeV we run with 160 mA and the 3HC is passive).
- ✓ The problem was fixed after the first lockdown but this created calendar modification in the distribution of 2 and 2.4 GeV





Present developments in view of Elettra 2.0

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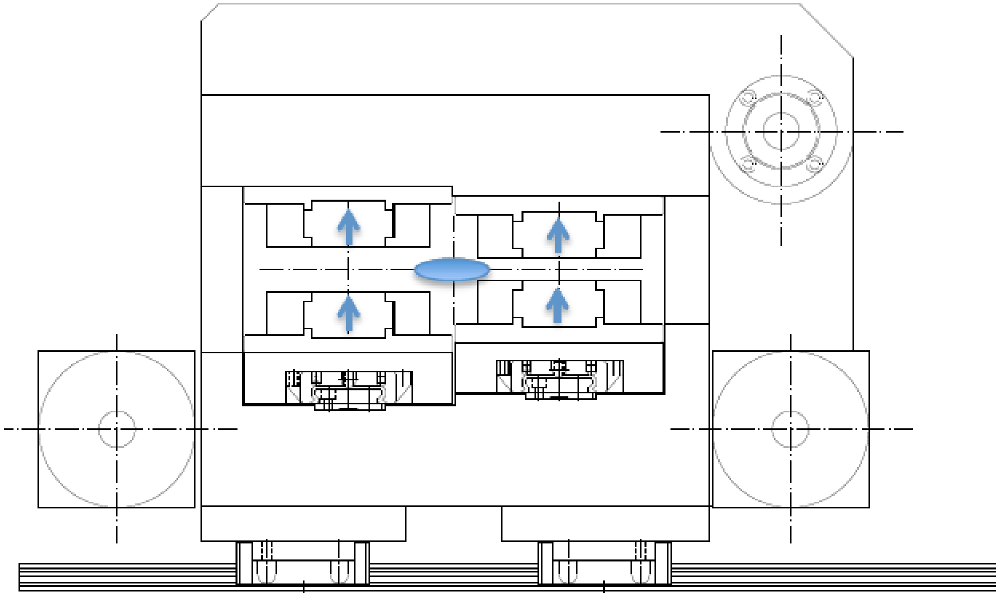
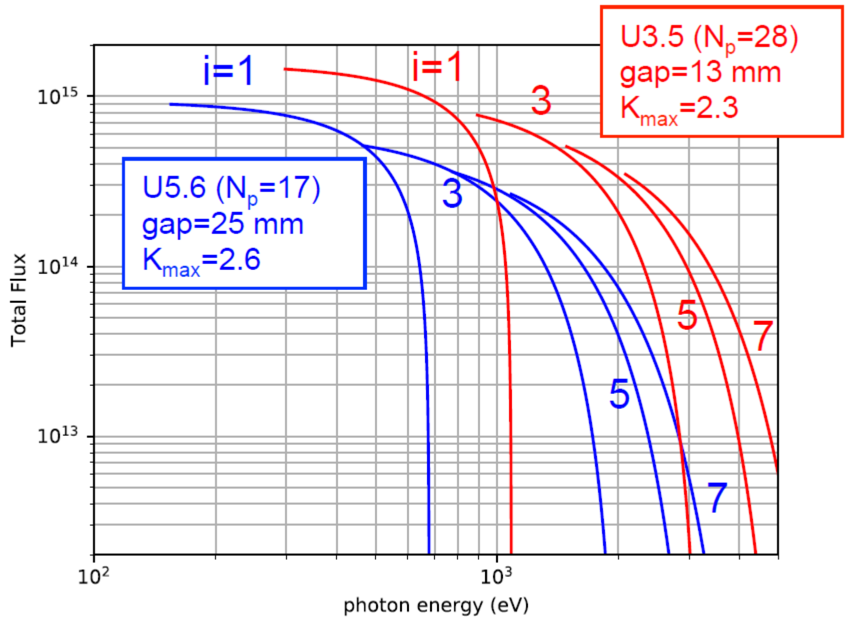
- Tunnel temperature stabilization -> better than ±0.5^{0}C
- Upgrade of the interlock system -> completed
- PS-controls upgrade -> finished
- RF upgrade (booster Solid State Amplifier) -> completed
- Replacement of all Elettra RF amplifiers with SS-> in progress
- Upgrade vacuum system electronics -> 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)
- 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)*

Double fixed gap undulator for TwinMic

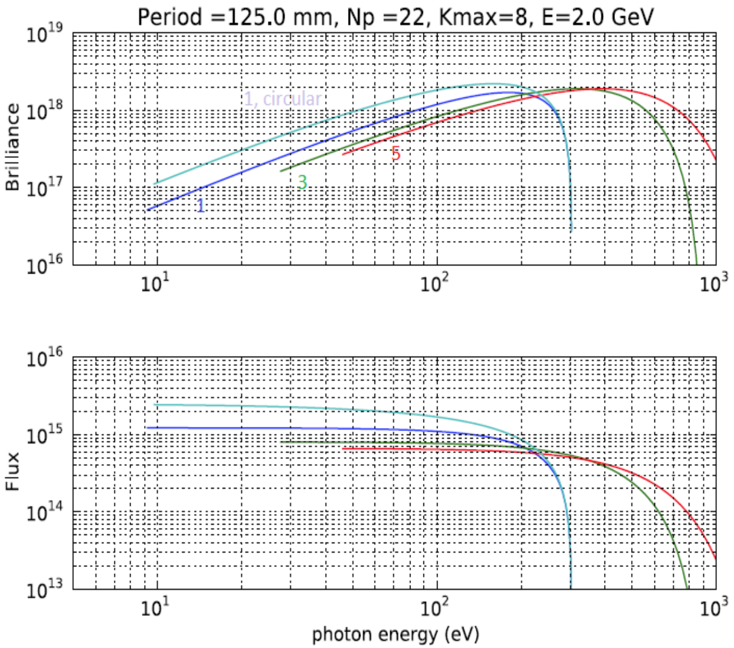




MOST Beam Line

All straight sections of Elettra are occupied but still there is demand for new insertion device based beam lines. An upgrade plan is presently being 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) VPU and one for the higher photon energies (80÷2000 eV), VGU while the old electromagnetic elliptical wiggler serving CiPo will be dismissed.

Low energy -> variable polarization VPU (fixed gap)



(http://www.kyma-undulators.eu/) is constructing the high energy one and expressed interest to construct the low energy one as well.

E²BPM
Elettra **E**lectron **B**eam **P**osition **M**onitor system

Elettra Sincrotrone Trieste

G.Brajnik, S. Bassanese, G. Cautero, S. Cleva, R. De Monte, M. Predonzani

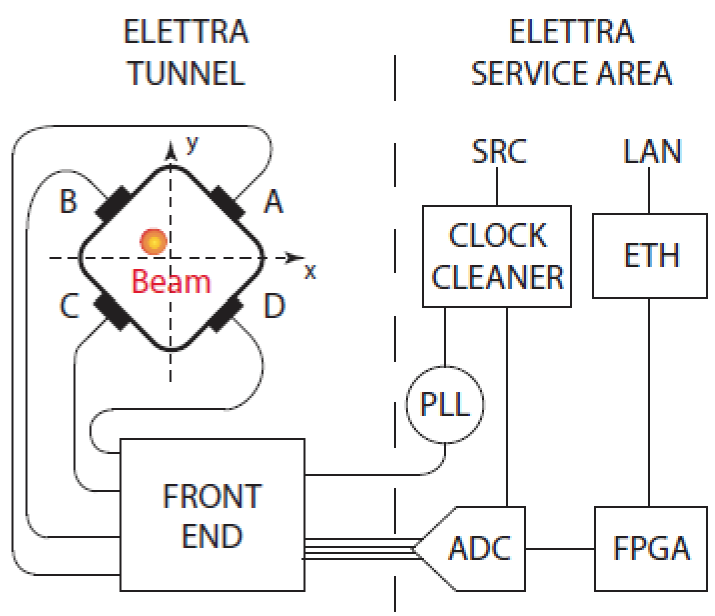
A NOVEL ELECTRON-BPM FRONT END WITH SUB-MICRON RESOLUTION BASED ON PILOT-TONE COMPENSATION: TEST RESULTS WITH BEAM

G. Brajnik, S. Carrato, University of Trieste

S. Bassanese, G. Cautero, R. De Monte, Elettra-Sincrotrone Trieste

Proceedings of IBIC-2016, Barcelona, Spain

Novel and original four-channel-front end developed for a beam position monitor (BPM) system. It is demonstrated for **the first time the continuous calibration** of the system by using **a pilot tone for both beam current dependency and thermal drift compensation**, completely eliminating the need for thermoregulation.



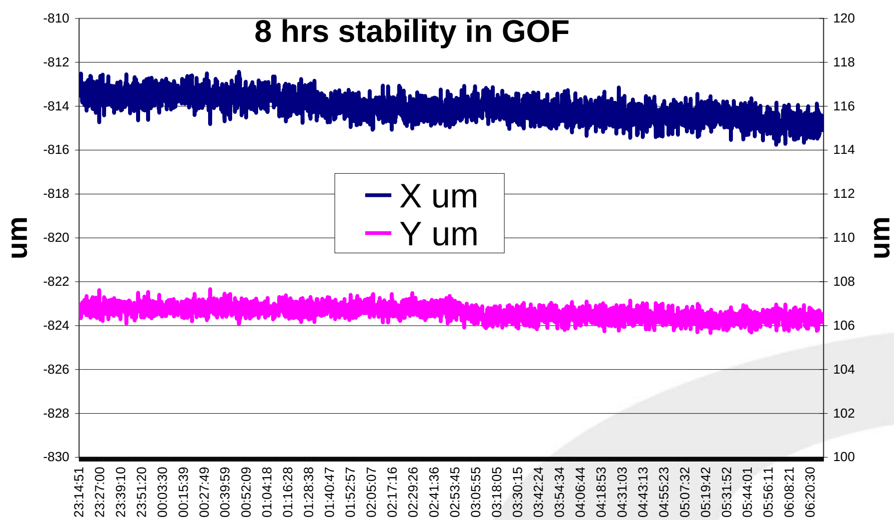
Direct measurement of the measurement quality

The Project will finish by end of 2018 aiming at a better and cheaper, than the existing, detector.

A prototype of the new ***E²BPM*** has been successfully tested and used in Elettra machine in **real** environment within a control system and Global Orbit Feedback replacing one old BPM electronics. The **measured "on field"** performances for ***E²BPM*** with 20 mm gap chamber are based on "pilot tone" compensation:

Resolution: 200 nm

8hrs stability: < 300nm

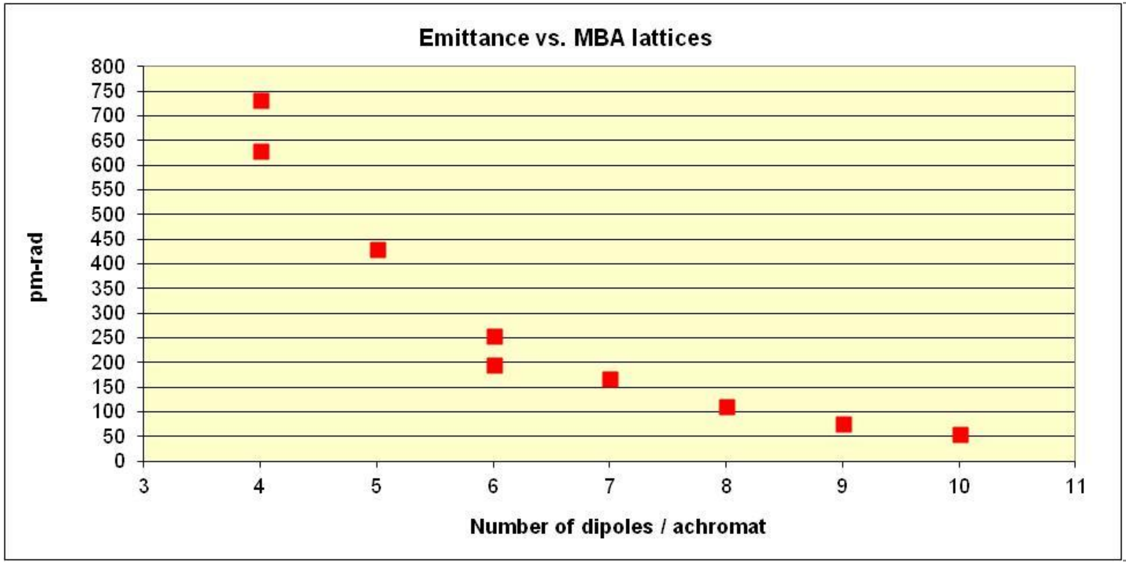


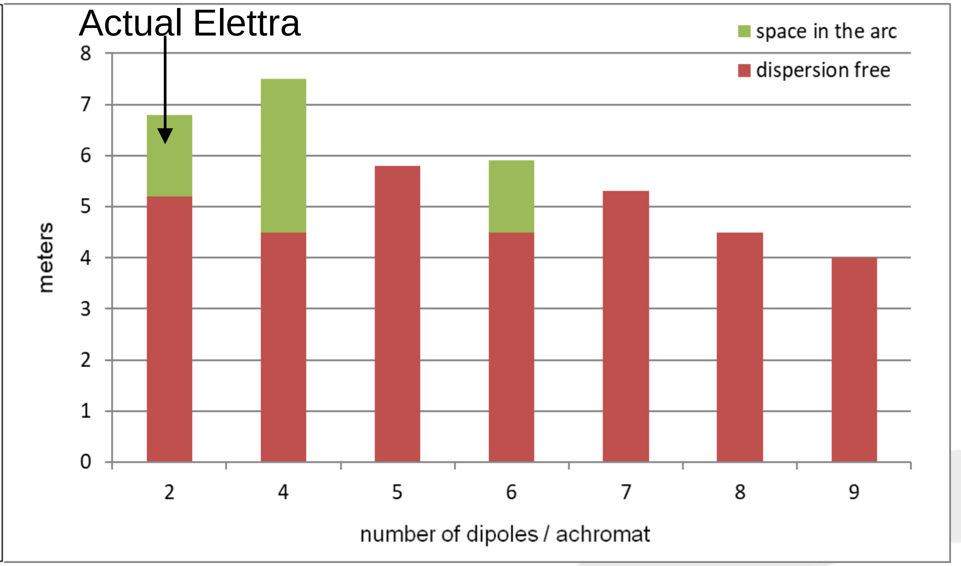
Elettra 2.0 - Introduction

The first dedicated workshop on the future of Elettra was held in April 2014 to examine the various scenarios however since 2012 I started thinking of the new machine. The requirements for the new machine were based on the interaction with the users' community beam line scientists and considering cost optimization.

At that time it was demanded (amongst other) the following

- Keep the same building, circumference.
- Energy at 2 GeV
- **Reduce the bare emittance by more than one order of magnitude**
- **Conserve the available slots and free space for IDs**

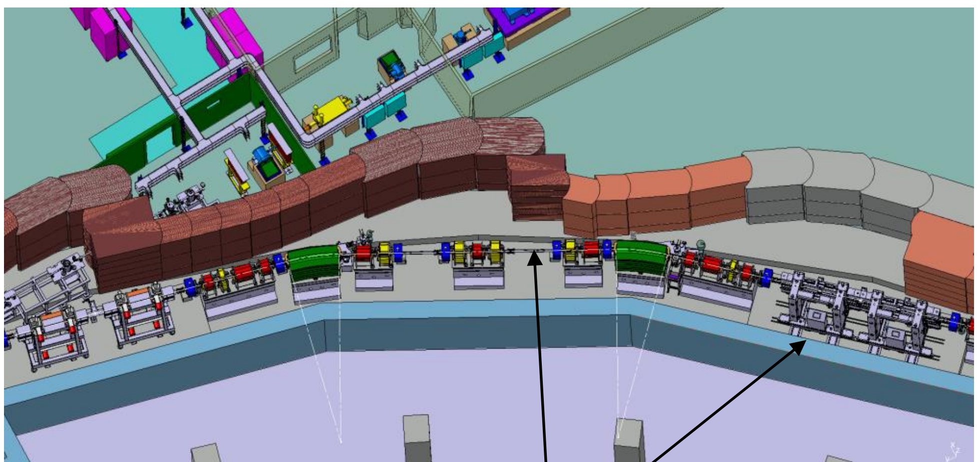




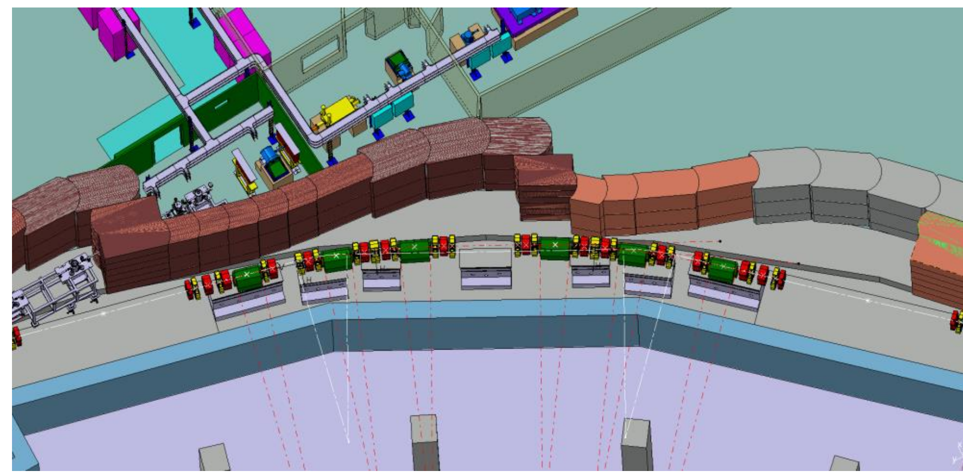
The obvious choice is a 6 BA lattice

Almost but not quite done

Best configuration that satisfied the initial requirements, mainly Energy 2 GeV, Emittance less than an order of magnitude, at least same number of slots for IDs, was based on a symmetric six-bend achromat **S6BA** that gave an emittance of 250 pm-rad at 2 GeV.



Elettra



Elettra 2.0

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

But further requirements forced us seek better but more difficult solutions

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Elettra 2.0 revised and final requirements

After a few more workshops and discussion with users and beam line scientists :

- ***Operating energy 2.4 GeV (and for sometime at 2 GeV)***
- ***Reduce the horizontal equilibrium emittance at least one order of magnitude***
- Conserve the existing ID beam lines in LongStraights at the same position
- Conserve the existing dipole magnet beam-lines
- ***Conserve the slots available for insertion devices***
- Preserve the present intensities and the time structure of the beam
- ***Let open the possibility for installing bunch compression scheme***
- ***Include super-bends and in-vacuum undulators***
- Keep the present injection scheme and injection complex
- Keep the same building and the same ring circumference (259.2 m)
- Minimize the downtime for installation and commissioning to about 18 months maximum.

The S6BA-E Lattice

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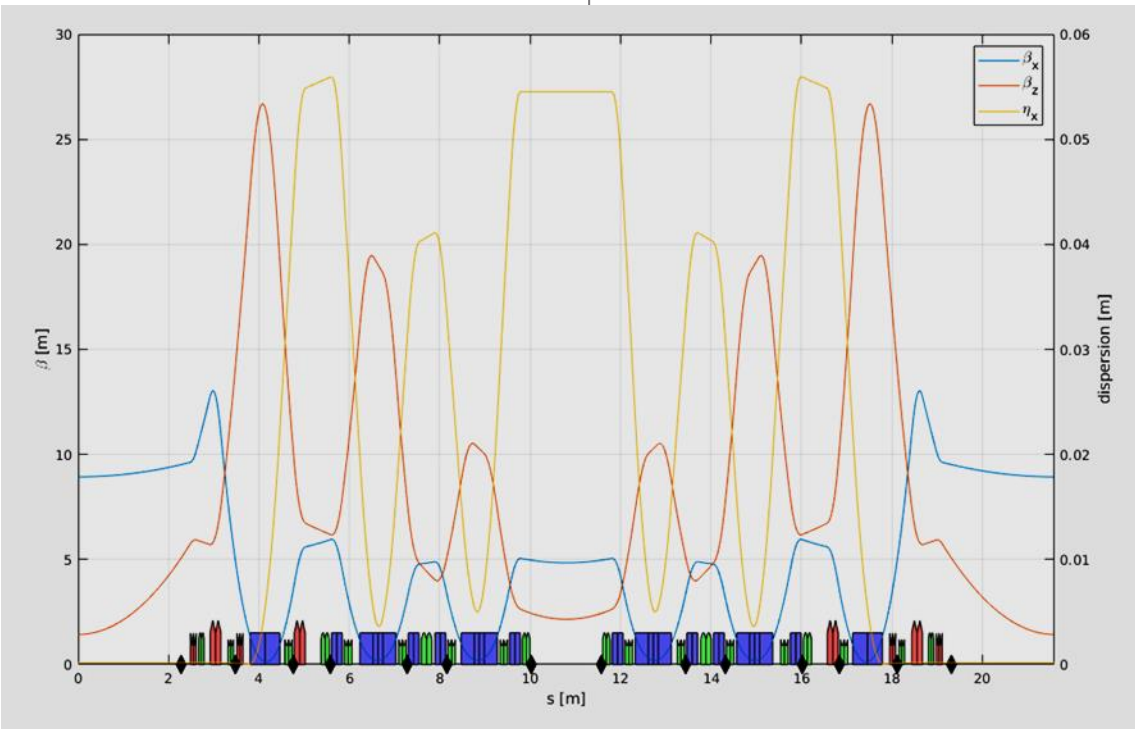


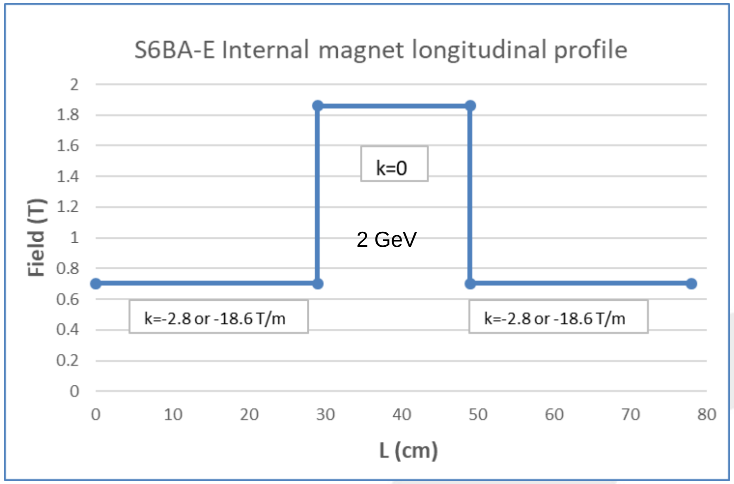
This upgraded version uses 8 reverse-bends/achromat and 4 longitudinal + transverse gradient dipoles/achromat.
Conserves the free space required for IDs while the gradients on the quadrupoles are reasonable

Emittance 98 pm-rad (58 pm-rad at full coupling) at 2 GeV and 140 pm-rad at 2.4 GeV (87 pm-rad at full coupling)

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

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

S6BA-E can provide e-bunch lengths with FWHM below 10 ps
due to its low momentum compaction 1 10^{-4}



Field choice for the Longitudinal Gradient Dipoles

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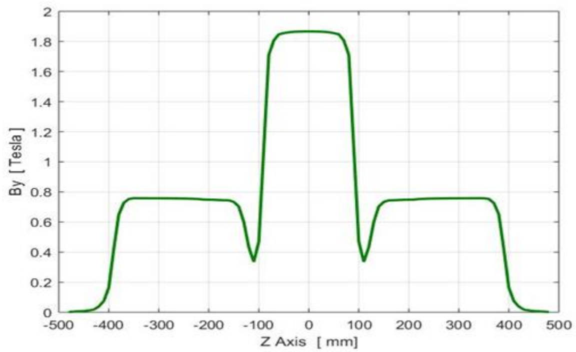
✓ The LG dipoles have a quite important transverse gradient in the lateral parts of the magnet where the field is lower.



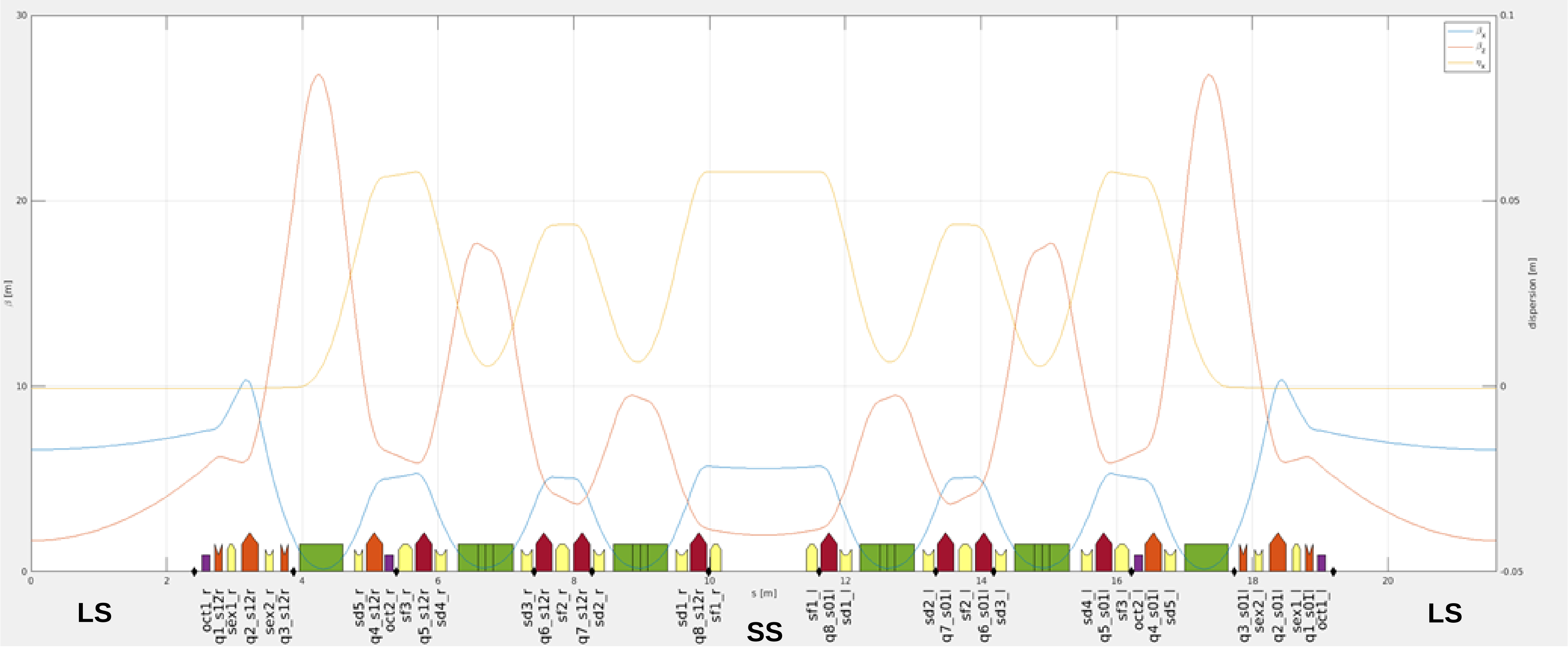
2.4 GeV	L1 T G=21T/m	L2 T G=0	L3 T G=21 T/m	Emittance pmrad
VH-LG	0.77 T	2.16	0.77	140
H-LG	0.92 T	1.78	0.92	150
M-LG	1.036 T	1.46	1.036	177

After adjusting the horizonal beta function to about 5.7 m from the originally set at 9 m (that is also the value for the actual Elettra)

Emittance reduction by a factor of 48 i.e. at 2 GeV 147 and at 2.4 GeV 212 pm-rad.

2.4 GeV	L1 G=21T/m	L2 G=0	L3 G=21 T/m	Emittance pmrad
All H-LG	0.92 T	1.78	0.92 T	200
All M-LG	1.036 T	**1.46** T	1.036 T	212
Half H and M				204
All M-LG with only the necessary HLS and instead VH_LG				210 208

Final S6BA-E optics (Frozen)



The lattice is 12-fold symmetric (24 arcs) and is invariant under relative length changes of the LS and SS.
Choosing **LS=4.94 m and SS=1.17 m (from magnet to magnet)** the LSs coincide to those of the actual Elettra i.e. no radial shift of the beam lines using IDs on the LSs

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

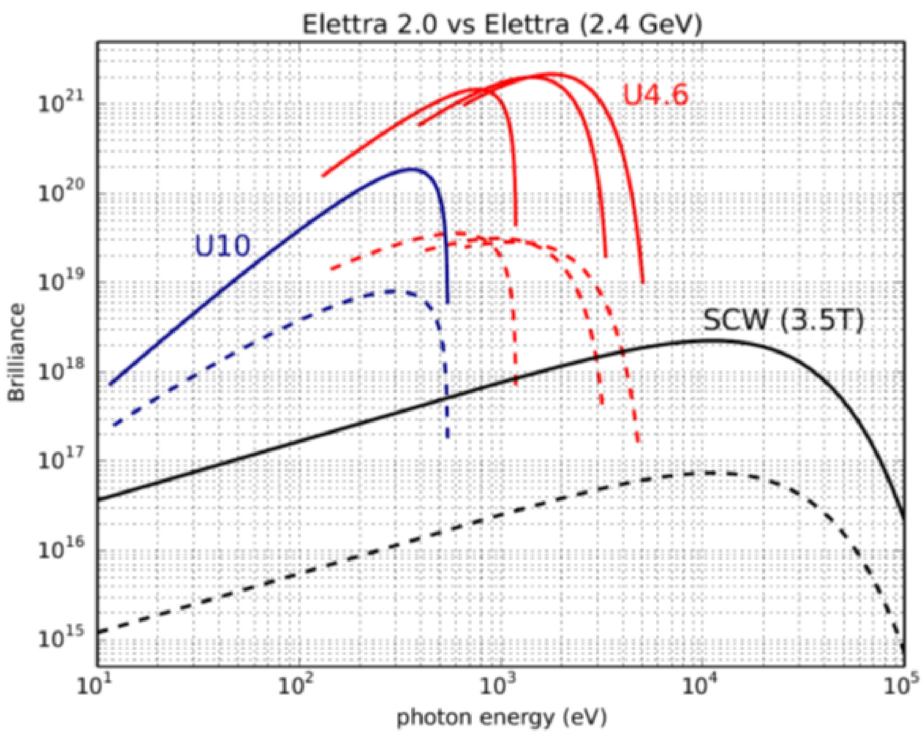
Beam lines

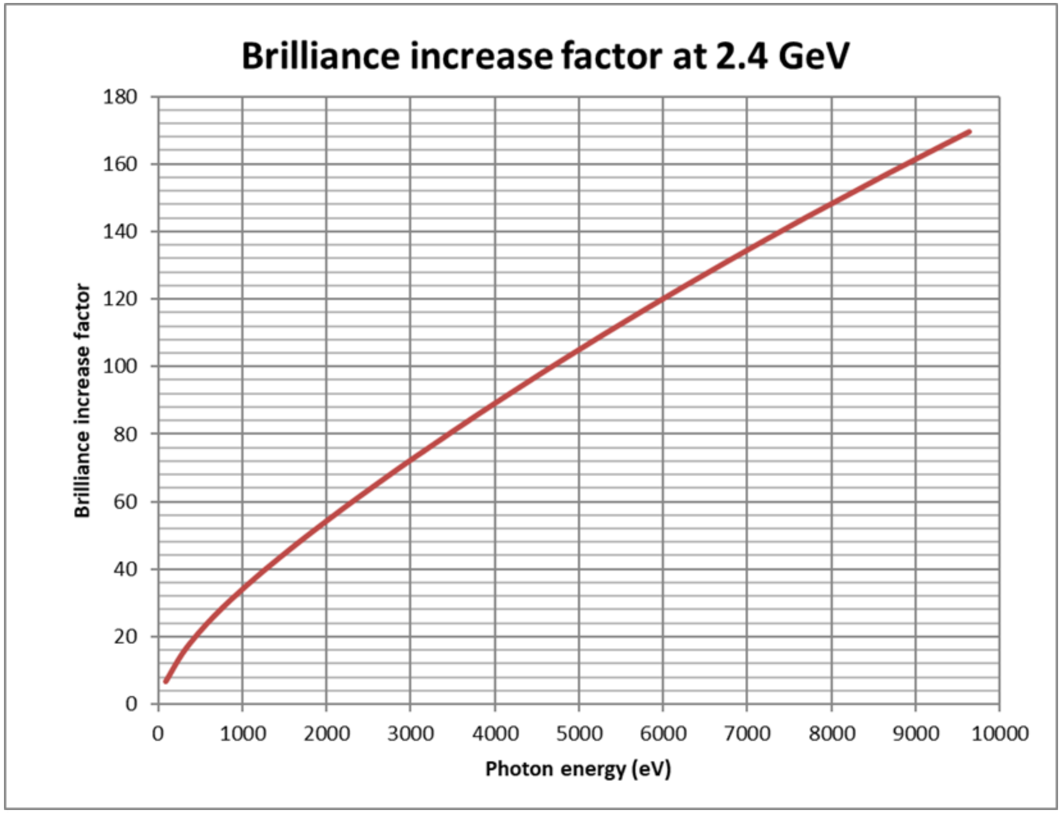
Insertion devices

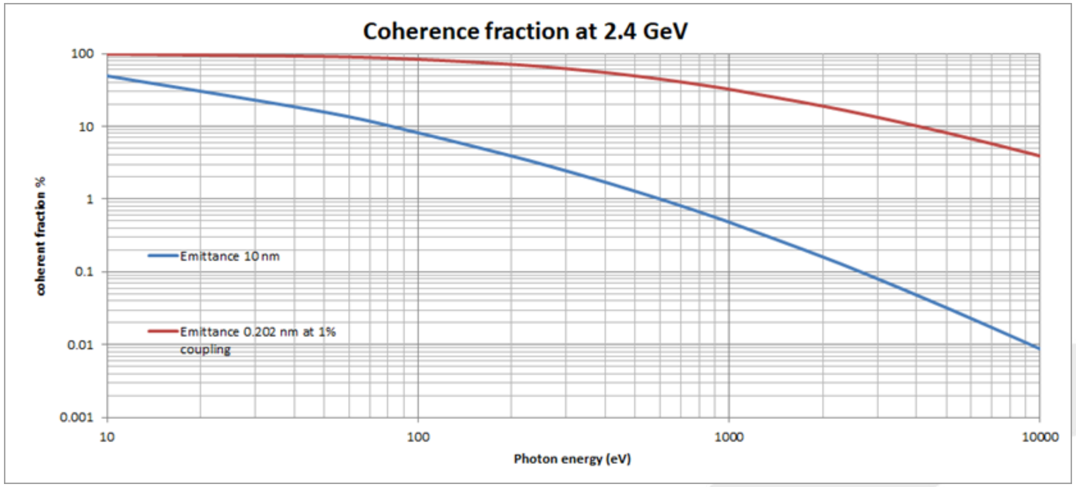
BL long sect.	Machine long sect.	BL short sect.	Short sect. free for BL	Machine short sect.	BL on BM	BM free for BL	BL: beamlines	hν-range	source	length (m)	period (cm) ; field (T)
				1.1		1.1 (BM)**					
1.2							Nanospectr/NanoESCA	20*-1500 eV	Ellipt. Und.	2x2	10 ; 1
	(in case of Crab Cavities)		2.1	available for machine in absence of crab cavities			Twin Mic/SESCA (with Crab Cav in 2.2)	130-4000 eV	AdjustPhase Und. (linear h)	0.80	5.6 ; 0.5
2.2	2.2 (Crab Cavities)						Twin Mic/SESCA (in absence of crab cavities)	130-4000 eV	Lin. Pol. Und. (linear h)	2x2.0	4.6;0.9
				3.1 (RF)	3.1 (BM)		DXRL	5-10 keV	Bending Magnet		;1.4
3.2							Spectroμ/BaDElPh	6.7*-200 eV	Figure8 Und. (linear h/v)	2x2.2	14 ; 0.75/0.14
		4.1		4.1 (RF)		4.1 (BM)					
4.2							MOST	12.6*-1500 eV	Ellipt. Und.	HE 1.5 LE 1.5	HE 5;0.85 LE 1.32;0.64
		5.1					XRD1	4-21 keV	miniWiggler	0.80	10 ; 1.8
5.2	Machine***						μXRD	4-15 keV	InVacuum Und.	3.00	2 ; 1
				6.1	6.1 (SB)		XAFS1/MAIA	4-60 keV	SuperBend (6T)		; 6
6.2							DReaMS/ESCAμ	330-4000 eV	Ellipt. Und.	2x2	4.4 ; 0.6
				7.1 (RF)	7.1 (BM)		BEAR/MatSci	10*-1500 eV	Bending Magnet		; 1.4
7.2	Machine***						μXRF	2-15 keV	InVacuum Und.	3.00	2 ; 1
		8.1					ALOISA/NAP-XPS	60*-1500 eV	AdjustPhase Und. (linear h)	0.80	8 ; 0.5
8.2							BACH/VUV	20*-1500 eV	Ellipt. Und.	HE 2,LE 2	HE 4.8;0.6 LE 7.7;0.9
				9.1 (RF)	9.1 (BM)		SISSI	IR	Bending Magnet		;1.4
9.2							APE LE/HE	13*-1500 eV	Ellipt. Und.	HE 2.16, LE 2.125	HE 6;0.78 LE 12.5;0.77
		10.1					APE-TX	2-7 keV	Ellipt. Und.	0.80	3.4 ; 0.7
10.2	Machine***						HB-SAXS	5-15 keV	InVacuum Und.	3.00	2 ; 1
		11.1					XAFS-mW	3-15 keV	miniWiggler	0.80	10 ; 1.8
11.2	3HC						SAXS/MCX/Xpress	9-35 keV	SCW	1.57	6.4 ; 3.5
				12.1	12.1 (SB)		SYRMEP-LS	4-60 keV	SuperBend (6T)		;6
	12.2 (Injection)										

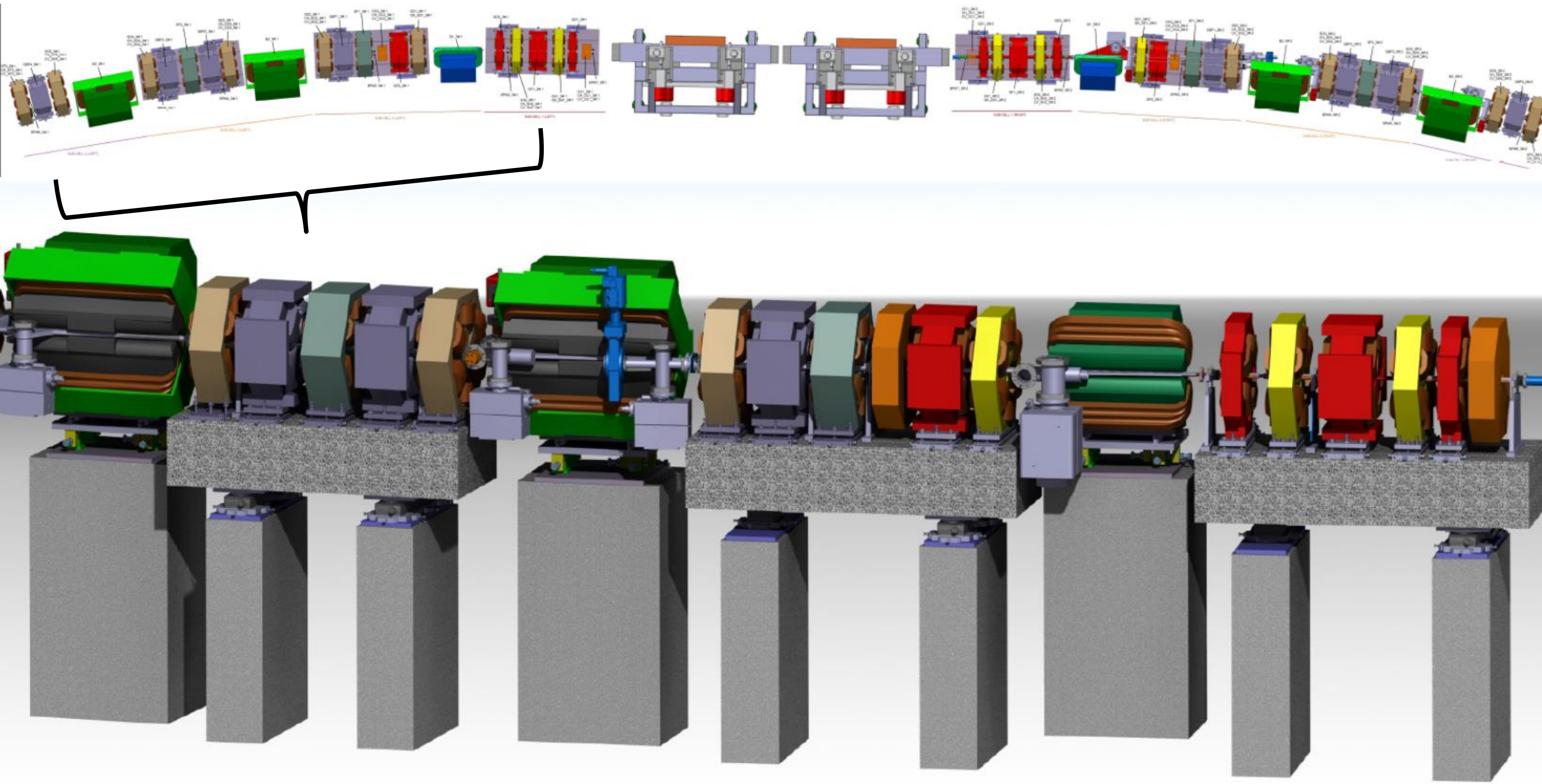
31 beam lines (Elettra actual has 28 beam lines) of which:
2 from super-bends (6T), 2 mini-wigglers, 3 IVU (new micro-spot beam lines) and 1 CDI.
The micro-spot and CDI the present machine cannot support.

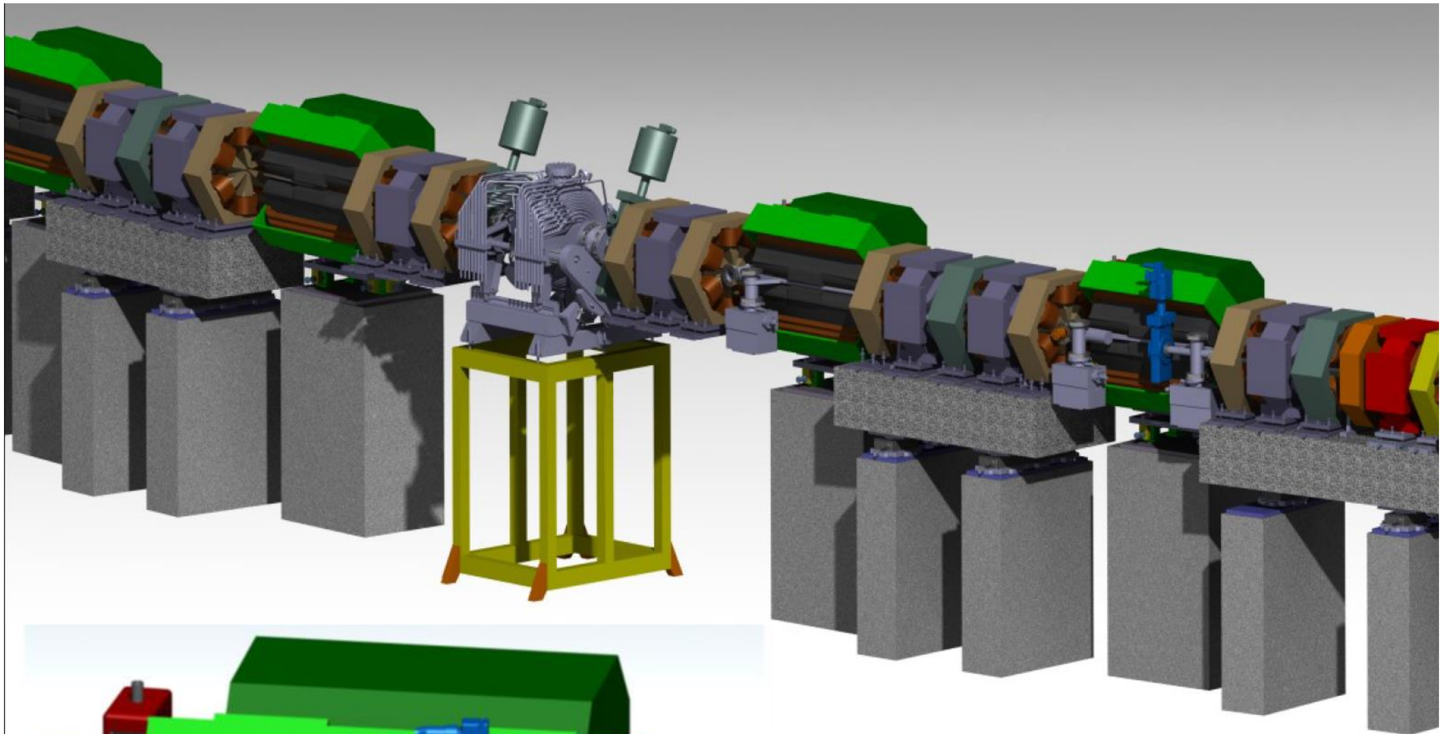
Elettra
Sincrotrone
Trieste

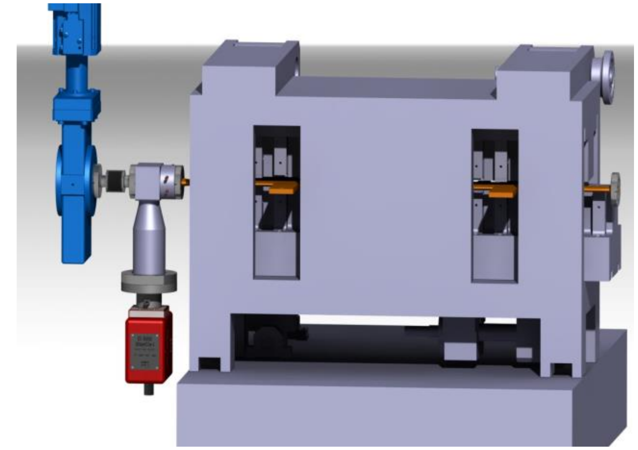


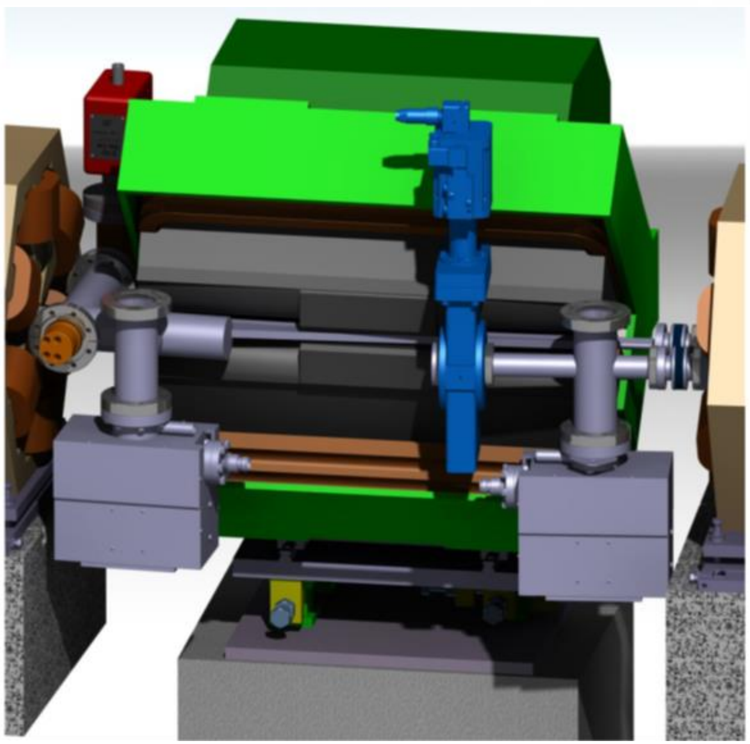


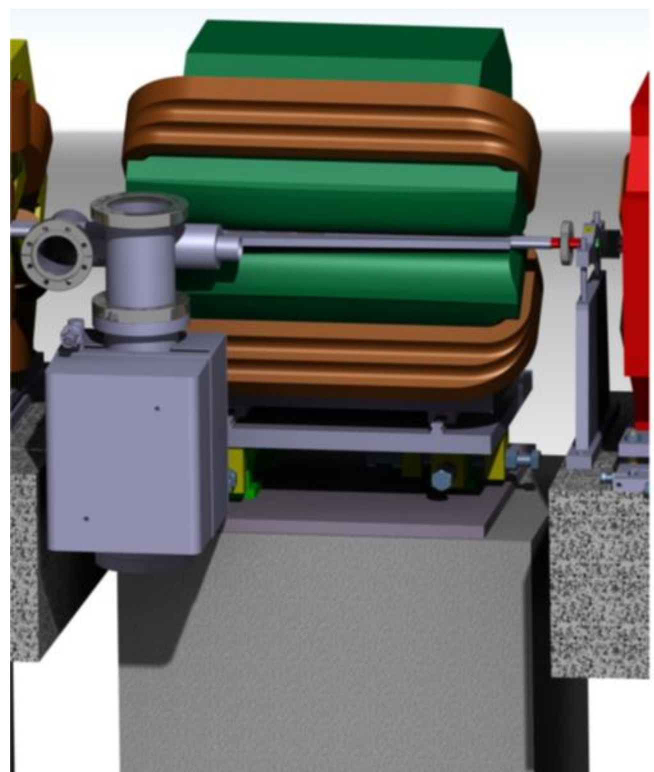


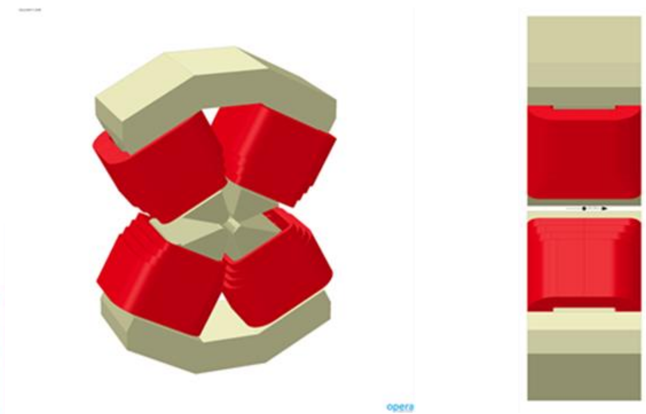


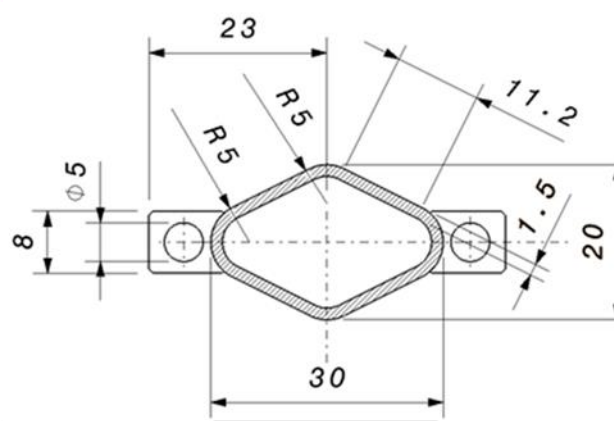











23
R5
R5
11.2
Φ5
8
1.5
20
30

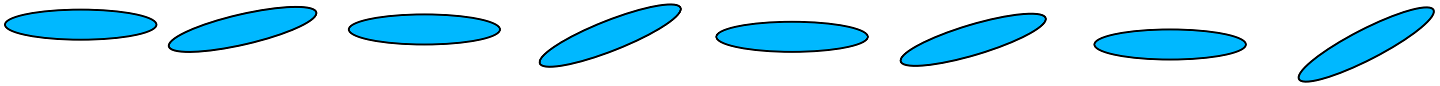
Machine parameters

Elettra

Circumference (m)	259.2	259.2
Energy (GeV)	2	2.4
Number of cells	12	12
Geometric emittance (pm-rad) 2% coupling	147	212
Horizontal tune	33.29	33.29
Vertical tune	9.18	9.18
Beta functions in the middle of straights (x, y) m	(5.7 , 1.6)	(5.7 , 1.6)
Horizontal natural chromaticity	-71	-71
Vertical natural chromaticity	-68	-68
Horizontal corrected chromaticity	+1	+1
Vertical corrected chromaticity	+1	+1
Momentum compaction	1.2e-004	1.2e-004
Energy loss per turn no IDs (keV)	220	457 (w SBs 486)
Energy spread	7.8e-004	9.3e-004
Jx	1.598	1.66
Jy	1.00	1.00
JE	1.402	1.34
Horizontal damping time (ms)	9.45	5.46
Vertical damping time (ms)	15.67	9.08
Longitudinal damping time (ms)	9.45	6.78
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/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	1.7 , 5.7
Synchrotron frequency (kHz)	3.17 (@2MV)	2.86 (@2MV)

Very short photon pulses via deflecting (crab) cavities

ANL-SLAC - Elettra collaboration



200 buckets straight and 200 tilted. Four (4) oblique can be filled with 2 mA each. The pulse length depends on the beam line slit opening, whether there is drift or imaging optics and differs at each beam line position.

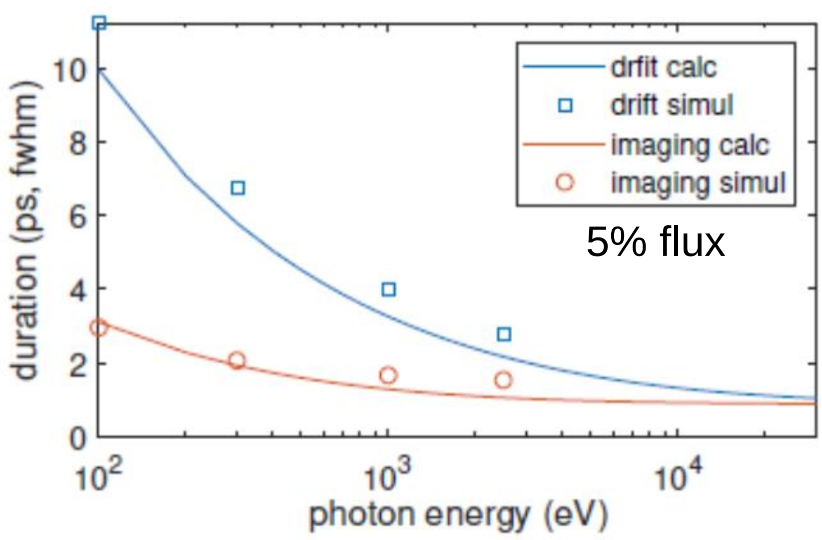
The tilted bunches will give:

The FWHM pulse duration for the imaging optics case, assuming photon energy of a 2.5 keV.

Beamline Sector	fwhm/5% (ps)	fwhm/10% (ps)	fwhm/15% (ps)	fwhm/20% (ps)
12	1.54	2.42	3.39	4.41
1	7.31	7.52	7.89	8.35
2	1.55	2.42	3.39	4.42
3	4.45	4.86	5.42	6.12
4	1.59	2.44	3.41	4.42
5	2.94	3.47	4.22	5.09
6	1.53	2.40	3.38	4.41
7	2.17	2.85	3.73	4.66
8	1.64	2.47	3.42	4.44
9	2.46	3.06	3.88	4.79
10	3.62	3.96	4.60	5.42
11	4.92	5.28	5.78	6.48

The FWHM pulse duration for the imaging optics case for the dipole beamlines at 6.9 keV

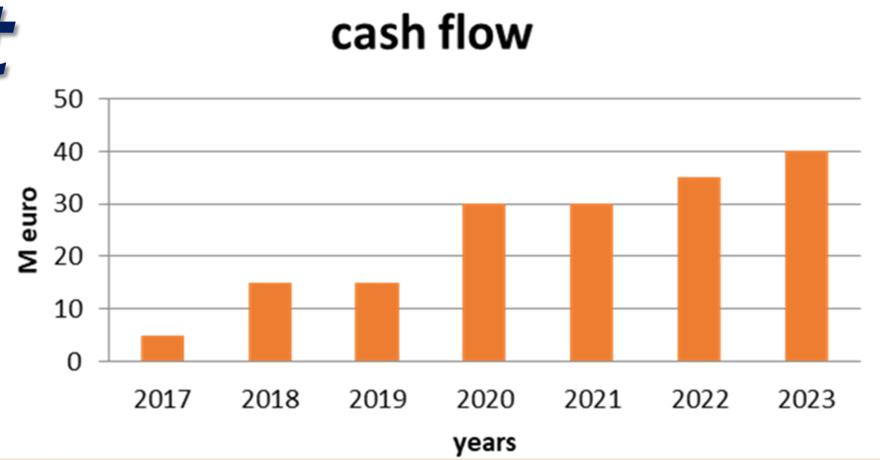
Beamline	fwhm/5% (ps)	fwhm/10% (ps)	fwhm/15% (ps)	fwhm/20% (ps)
DB	1.35	2.30	3.30	4.35



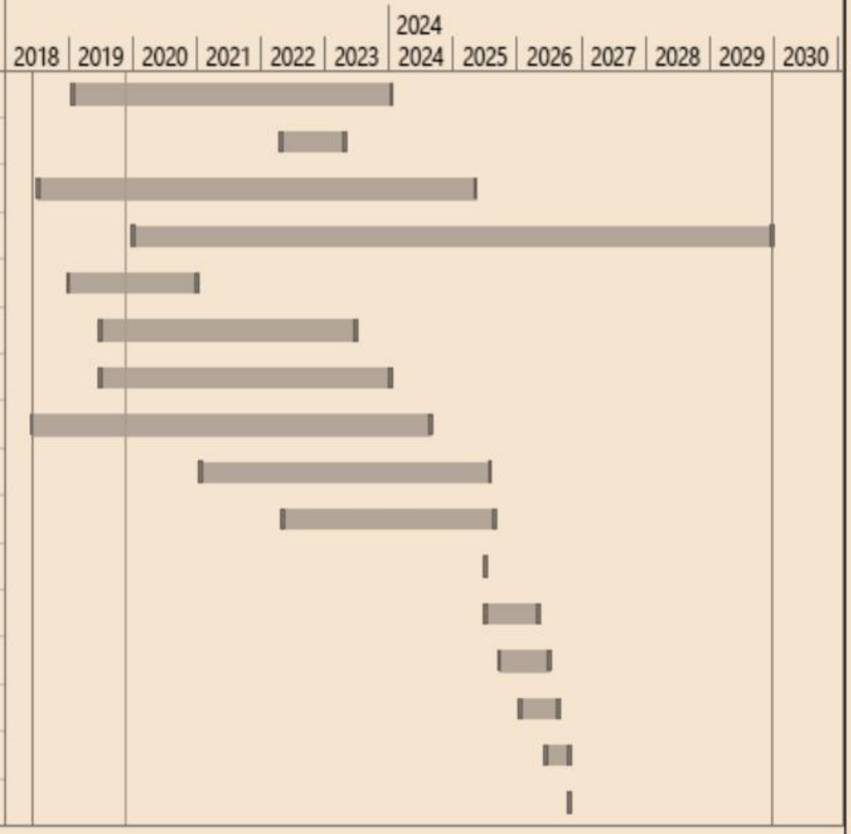
X. Huang and A. Zholents: (ANL-SLAC) - Elettra collaboration

The Project

Is approved, financed and running (but does not include the deflecting cavities part)



ID	Ta Mo	Task Name	Duration	Start	Finish
1		Infrastructures upgrade	1300 days?	Wed 23/01/19	Tue 16/01/24
2		New building costruction	260 days?	Sun 01/05/22	Thu 27/04/23
3		Some Accelerator systems upgrade	1780.5 days?	Fri 13/07/18	Fri 09/05/25
4		Beam lines upgrade	2600.5 days?	Mon 06/01/20	Mon 24/12/29
5		Technical Design study	524 days?	Tue 01/01/19	Fri 01/01/21
6		Engineering Design	1040.5 days?	Mon 01/07/19	Mon 26/06/23
7		Prototyping	1184 days?	Mon 01/07/19	Thu 11/01/24
8		Calls for tender	1621 days?	Thu 07/06/18	Thu 22/08/24
9		Manufactoring construction and testing	1176 days?	Wed 27/01/21	Wed 30/07/25
10		Preparations and assembly	864 days?	Mon 09/05/22	Thu 28/08/25
11		End of user mode	1 day?	Wed 02/07/25	Wed 02/07/25
12		Ring decomissioning	215 days?	Thu 03/07/25	Wed 29/04/26
13		Installations	203 days?	Sun 21/09/25	Tue 30/06/26
14		Accelerator system tests /commissioning	153 days?	Fri 23/01/26	Tue 25/08/26
15		Ring commissioning with beam lines	97 days?	Mon 15/06/26	Tue 27/10/26
16		Elettra 2.0 user mode	1 day?	Fri 30/10/26	Fri 30/10/26



Summary

- Elettra is running well although is 27 year old, many small projects contribute to this including replacement of old / obsolete hardware.
- The final lattice is the S6BA-E with 12-fold symmetry and will operate mainly at 2.4 GeV (and for some time also at 2 GeV) since a notable shift to tender, high and very high photon energies has been decided.
- The chosen lattice is more demanding but for the moment we don't see major showstoppers from the engineering point of view. The up to now analysis gives us very encouraging results.
- The crab cavity option may give an up to 60 times reduction of the short pulse for some beam lines compared to the standard hybrid mode being valid for all beam lines. It does not deteriorate the machine emittance or has any other serious implications.
- The first draft of the TDR will be ready by the end of 2020 however the upgrade of the experimental instrumentation and the construction of a new auxiliary building has already been started.
- New personnel employment started (https://www.elettra.eu/about/careers.html)

Elettra
Sincrotrone
Trieste

Next ESLS?

1	1993	ESLS	ESRF
2	1994	ESLS II	ESRF
3	1995	ESLS III	Daresbury
4	1996	ESLS IV	ELETRA
5	1997	ESLS V	MAX-lab
6	1998	ESLS VI	DELTA
7	1999	ESLS VII	BESSY
8	2000	ESLS VIII	LURE
9	2001	ESLS IX	ANKA
10	2002	ESLS X	SLS
11	2003	ESLS XI	ESRF
12	2004	ESLS XII	Desy
13	2005	ESLS XIII	ALBA
14	2006	ESLS XIV	SOLEIL
15	2007	ESLS XV	Diamond
16	2008	ESLS XVI	Daresbury
17	2009	ESLS XVII	DESY
18	2010	ESLS XVIII	ELETRA
19	2011	ESLS XIX	ISA
20	2012	ESLS XX	BESSY
21	2013	ESLS XXI	ANKA
22	2014	ESLS XXII	ESRF
23	2015	ESLS XXIII	SLS
24	2016	ESLS XXIV	Max-Lab
25	2017	ESLS XXV	DELTA
26	2018	ESLS XXVI	SOLARIS
27	2019	ESLS XXVII	ALBA
28	**2020**	**ESLS XXVIII**	**ESRF**

ESRF	5
DARESBURY	2
ELETTRA	2
MAX-Lab	2
DELTA	2
BESSY	2
LURE	1
ANKA	2
SLS	2
DESY	2
ISA-AARHUS	1
SOLARIS	1
ALBA	2
SOLEIL	1
DIAMOND	1