Elettra
Sincrotrone
Trieste

Elettra Status and upgrades

Emanuel Karantzoulis
on behalf of the Elettra team

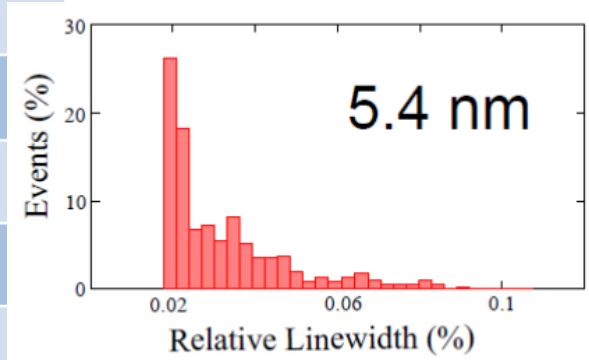
Outline:

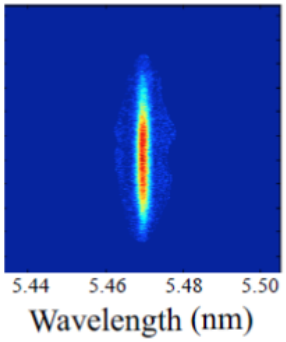
- Introduction
- Elettra status and statistics
- Short term developments
- Next upgrade: Elettra 2.0

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources

FERMI – electron/photon beam parameters

Parameter	Units	Value
Repetition rate	Hz	10 - 50
Bunch charge	pC	700
Peak current	A	700
Bunch length	ps	1.0
Energy	GeV	1.0 – 1.5
Energy spread	keV	100

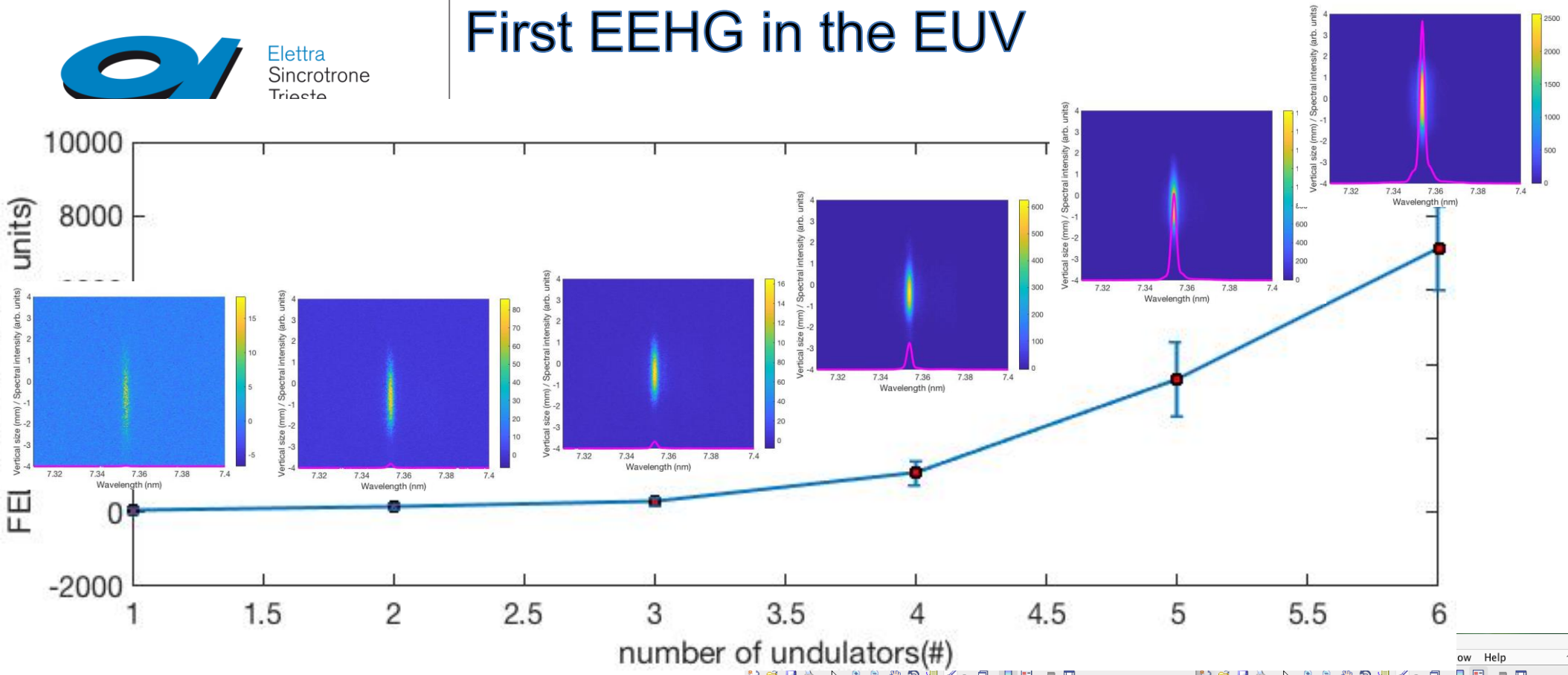




Parameters	Units	FEL-1	FEL-2
Wavelength range	nm	20 – 100	4 – 20
Photon energy	eV	62 – 12	62 – 310
Energy per pulse	μJ	50 – 300	10 – 100
Relative bandwidth (FWHM)	%	0.1	0.1
Pulse length	fs	50 – 100	30 – 70
Power fluctuations (rms)	%	10	30
Polarization		Hor/Vert/Circ	Hor/Vert/Circ

First EEHG in the EUV

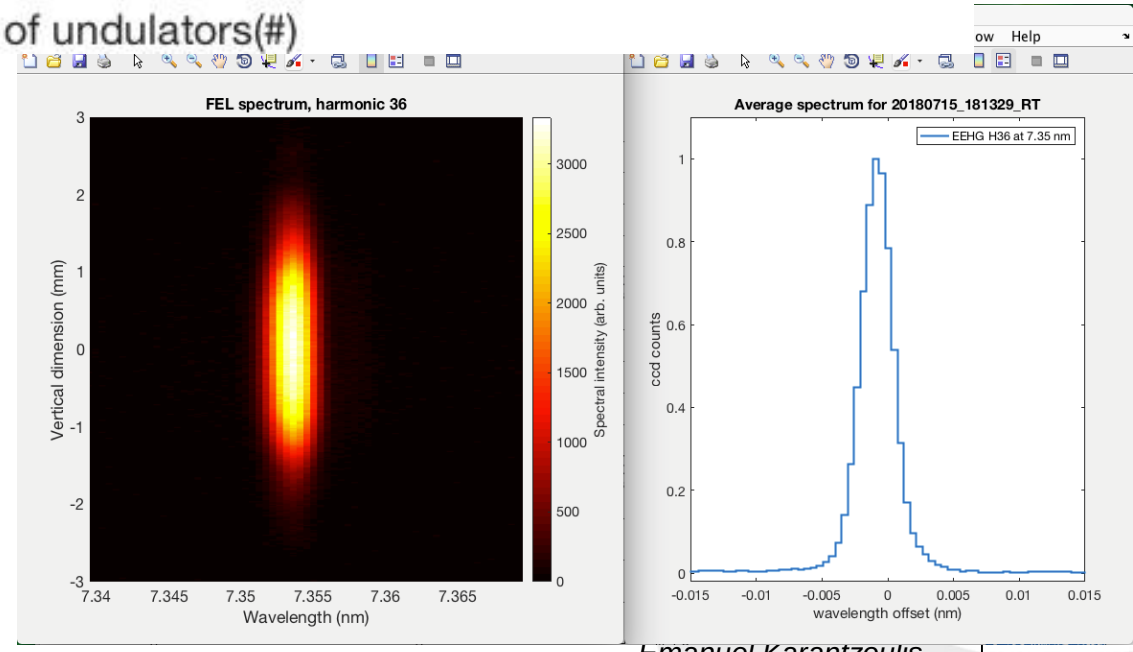
Elettra Sincrotrone Trieste



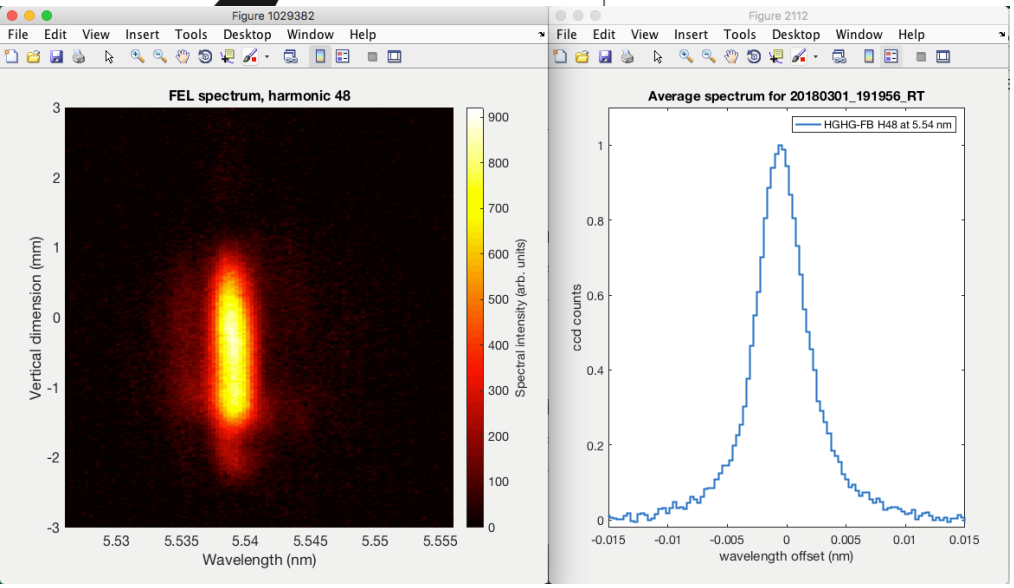
For the first time EEHG has been demonstrated

For the first time very stable FEL pulses at the Fourier limit have been produced.

Ref: M. Svandrlik

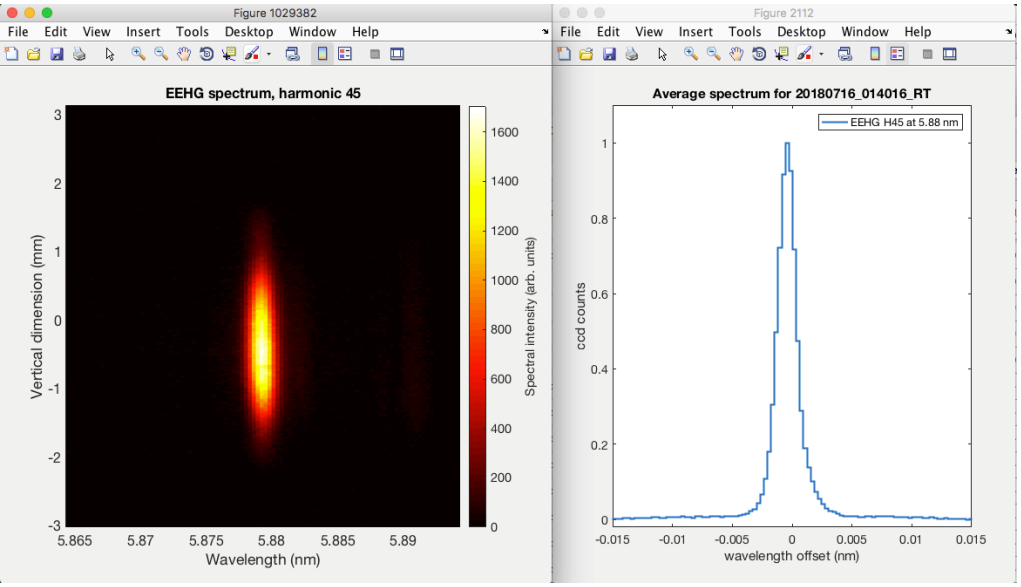


First EEHG in the soft – x ray

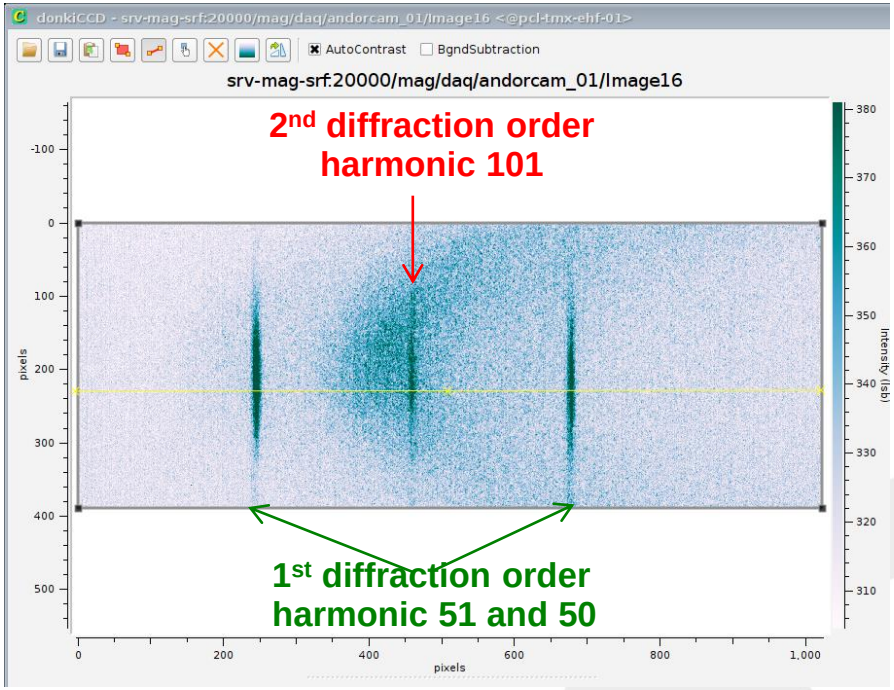


Even if not optimized for 5 nm the used setup has shown **improvement** for **5 nm** FEL using **EEHG** with **respect** to the standard **HGHG-FB**.

A clear signal of **coherent emission** at **harmonic 101** (2.6 nm) has been measured.

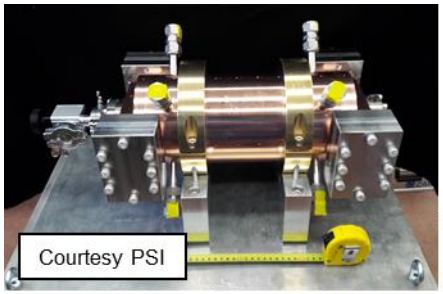


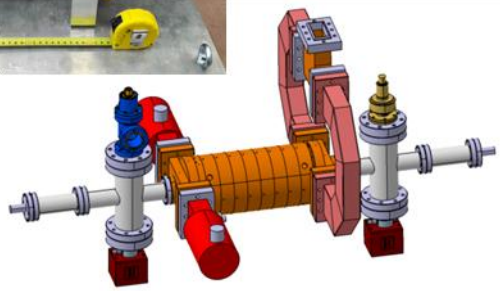
Ref: M. Svandrlik



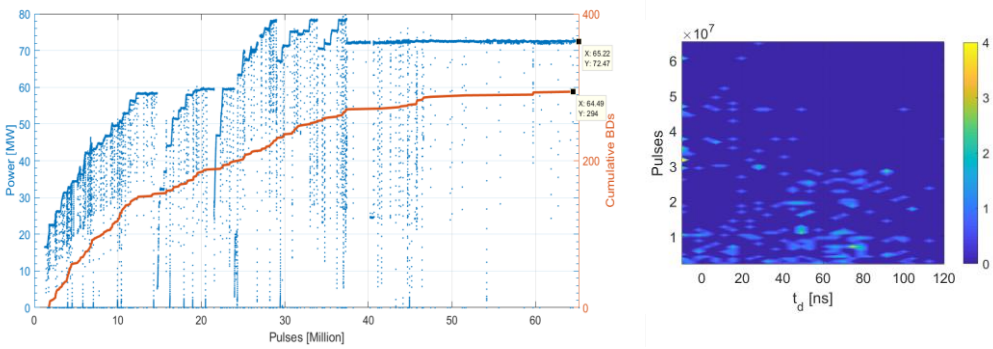
NEW ACCELERATING MODULE

- The new accelerating module will be comprised of two 3.2-m (approximately) long accelerating structures , for a reliable operation at **30 MV/m**.
- Each structure will be of the **constant-gradient type**.



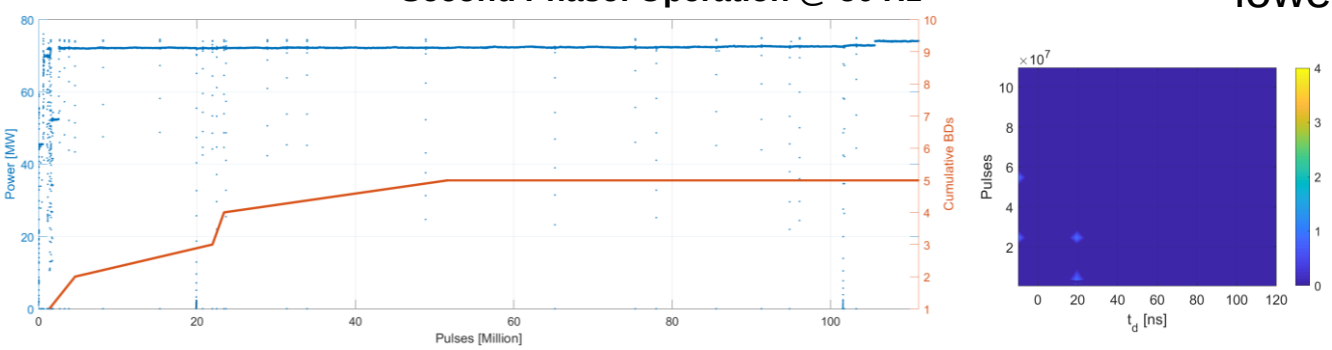


First Phase: Conditioning @ 10 Hz



History plot and breakdown localization during the conditioning phase at 10 Hz and the operation phase at 50 Hz

Second Phase: Operation @ 50 Hz



Ref: M. Svandrlik

Nominal operating values achieved for the short prototype (0.5 m), built by PSI

- RF Power: 72 MW (corresponding to a gradient of 30 MV/m)
- Pulse Length: 650 ns
- achieved BDR ≈$2\cdot10^{-8}$ bpp, lower than the required one

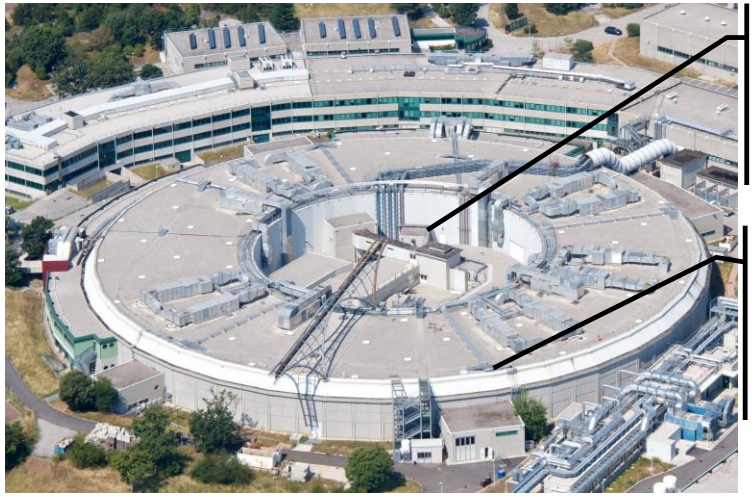
Next step is the production of a full module (two accelerating structures), to be tested in the FERMI Test Facility.

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.

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

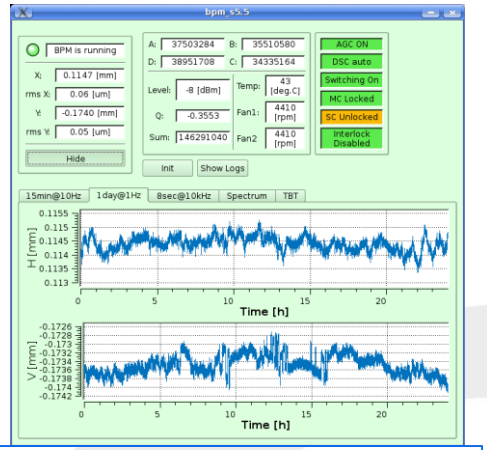
- Operates for about 6400 hours per year (24h, 7/7), 5016 hours reserved for users in 2 energies:
- 2.0 GeV, 7 nmrad, 310 mA for 75 % of users time
- 2.4 GeV, 10 nmrad, 160 mA for 25 % of users time
- 28 operating beam lines – over 1000 user and user poposals / year
- Filling patterns: multi-bunch 95 % 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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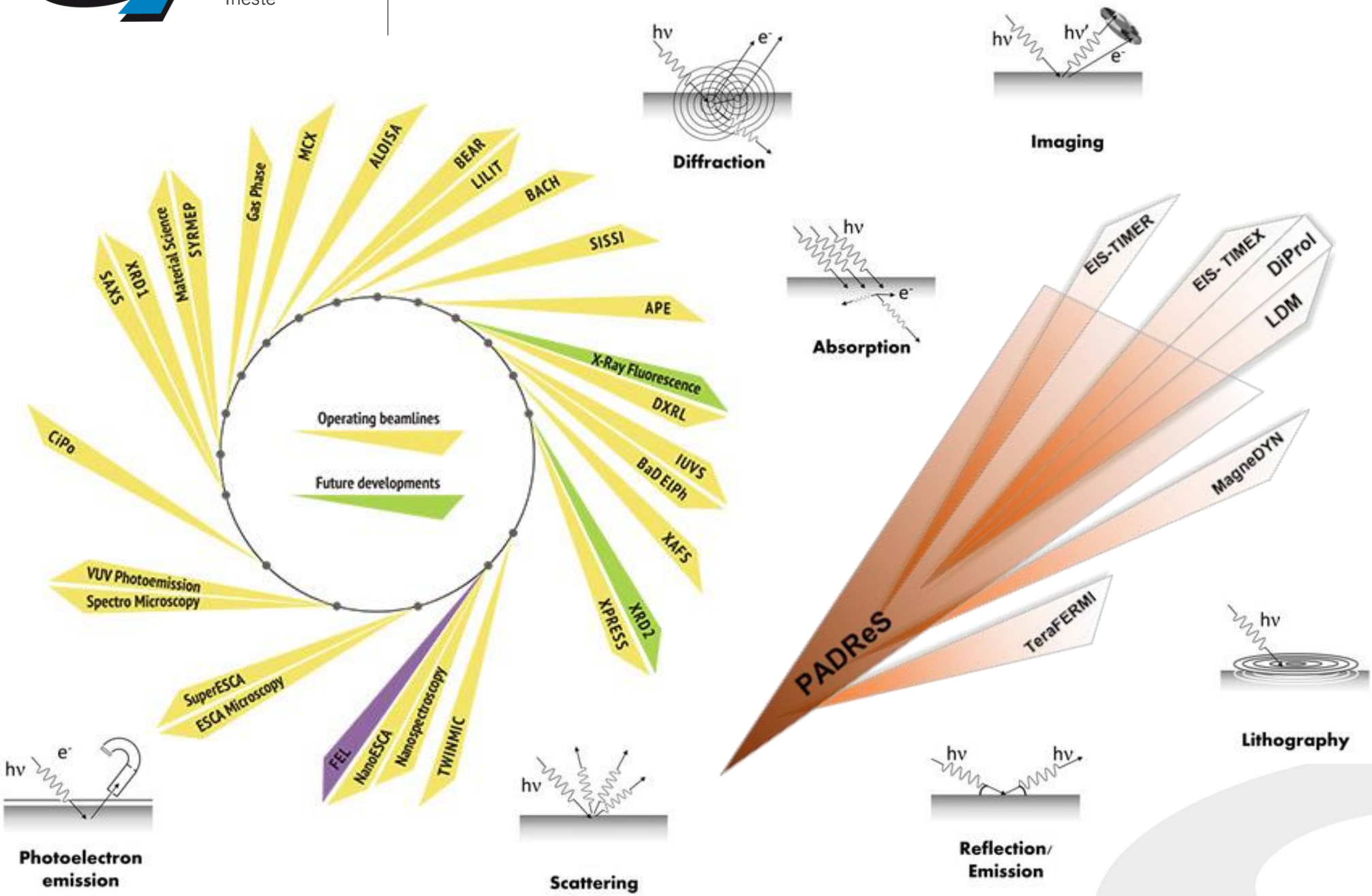
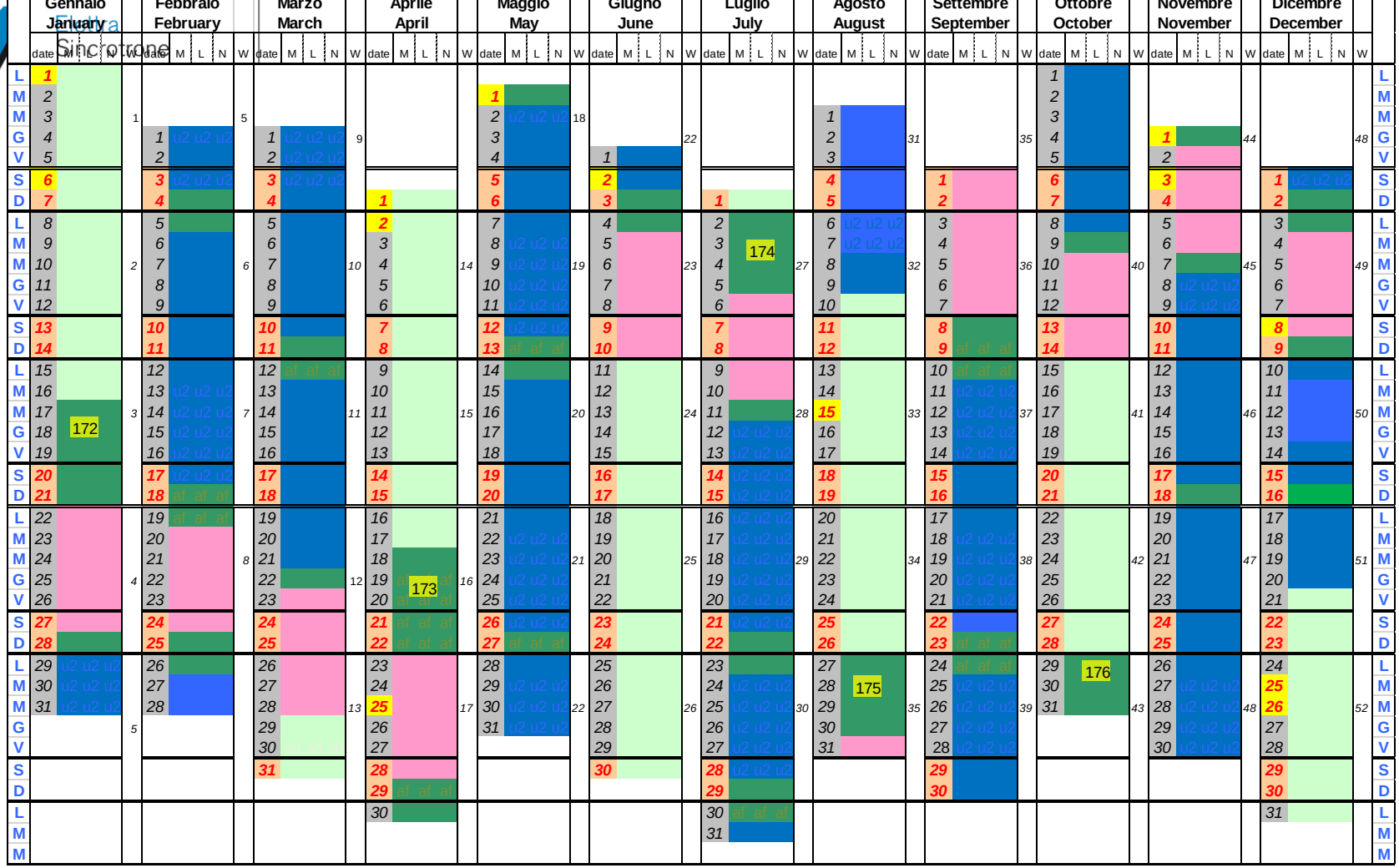
Beam lines 28 (+ 6 FERMI)



2018 Elettra Beam Time Calendar

Elettra Sincrotrone



STATISTICS

TOTAL SHIFTS	6384	Hours	72.9%	of the year
Users shifts	5016	Hours	78.6%	of total
Users at 2.0 GeV	3648	Hours	72.7%	of users
Users at 2.4 GeV	1368	Hours	27.3%	of users
SYRMEP dedicated shifts at 2.4 GeV	0	Hours	0.0%	of users
Accelerator Physics shifts + Accelerator service	1368	Hours	21.4%	of total
Shutdown	2376	Hours	27.1%	of the year
TOTAL shifts and shutdown	8760	Hours	365	days

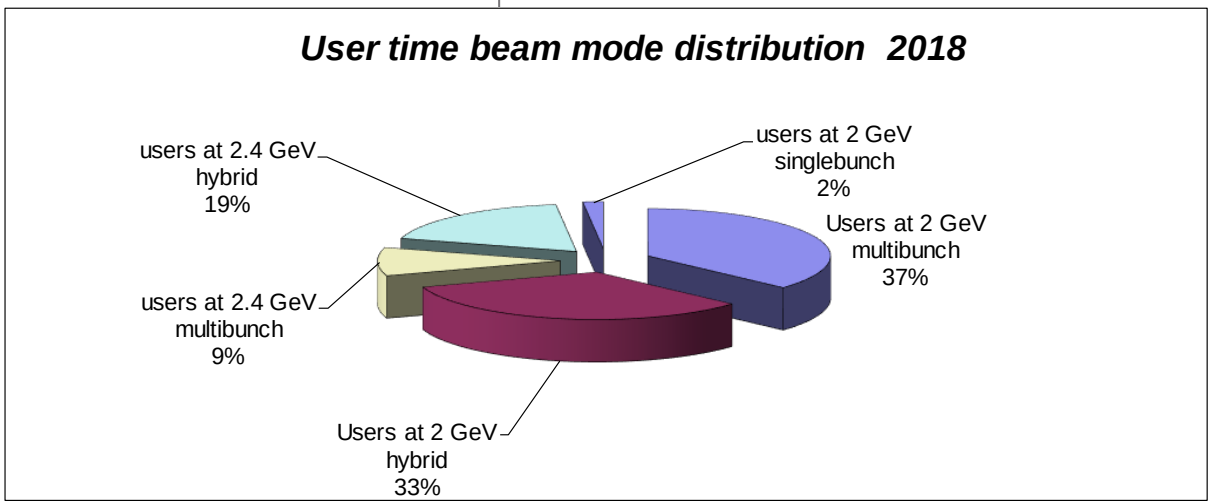
versioni: V1 17/03/17

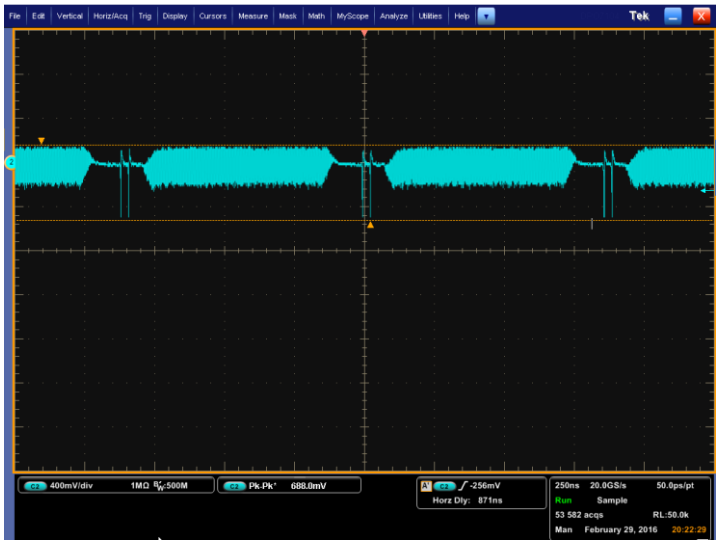
	Sabati	Domeniche
2.0GeV	24	12
2.4GeV	10	6
Tot	34	18
	3	19

	2	2.4 GeV	Total
users ore primo sem.	1632	696	2328
users ore secondo sem.	2016	672	2688
Users sum:	3648	1368	5016
Acc.Phys.			

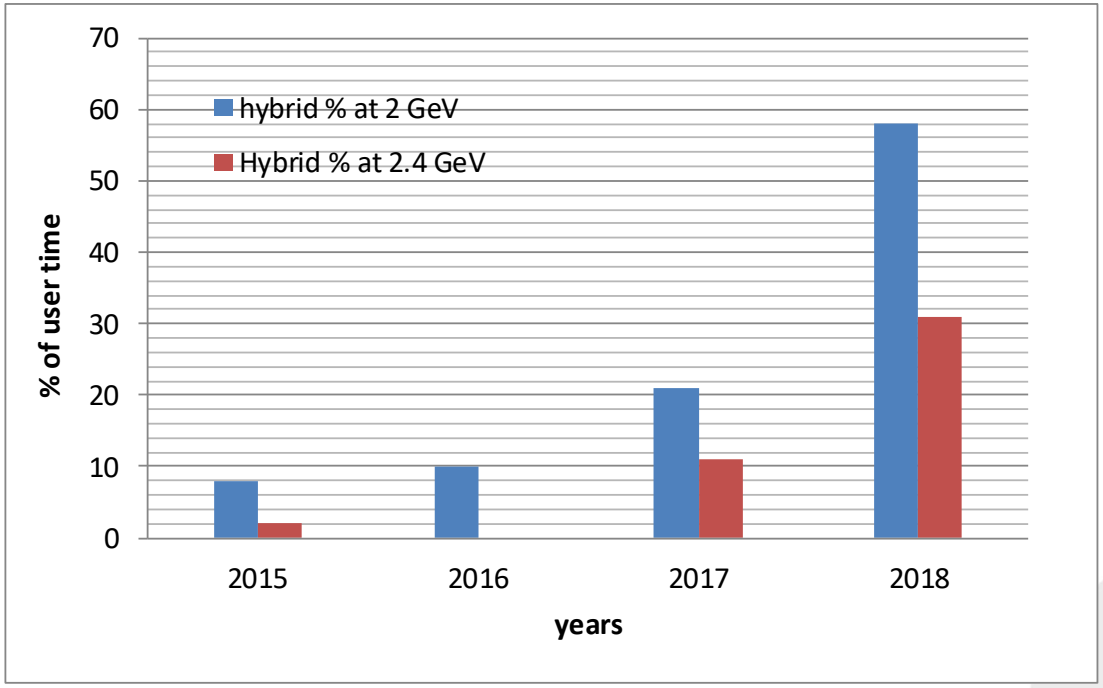
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2	72	408	456	0	648	48	384	216	432	192	528	264
2.4	144	120	144	144	0	144	120	24	168	120	120	120
AFIS	144	144	72	168	96	48	216	96	120	96	72	96
USERS	216	528	600	144	648	192	504	240	600	312	648	384
Tot	360	672	672	312	744	240	720	336	720	408	720	480

User time distribution





Increased interest for time resolved

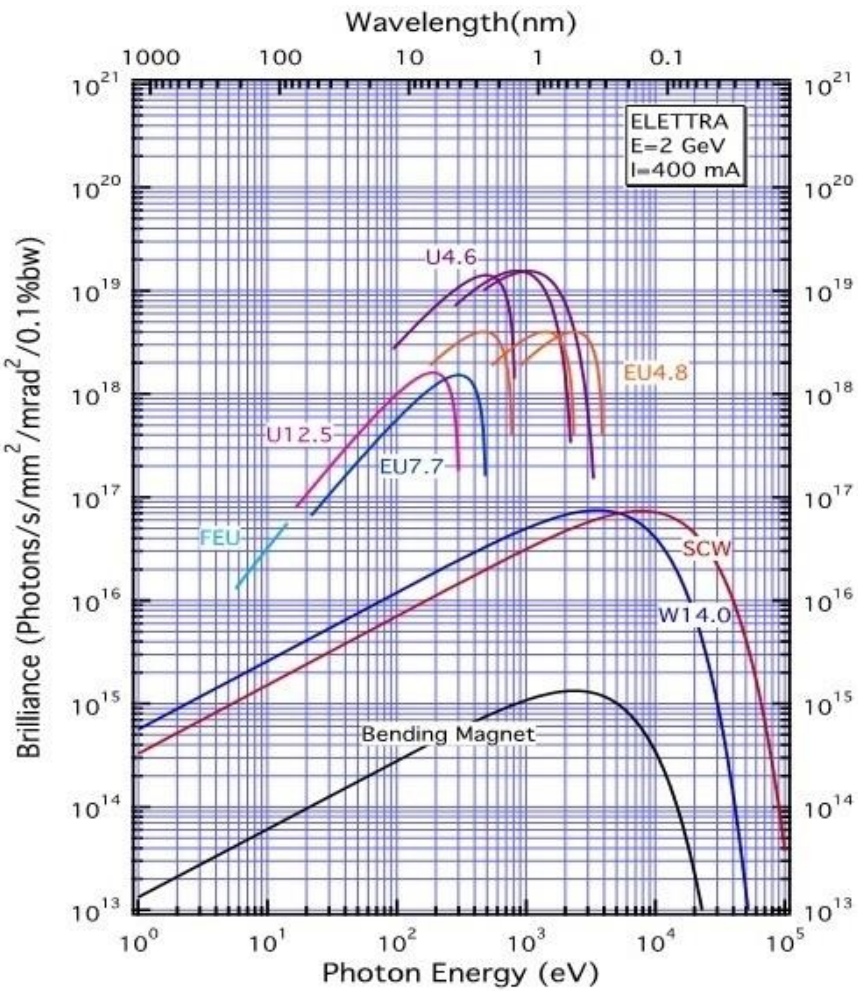


IDs and brilliance

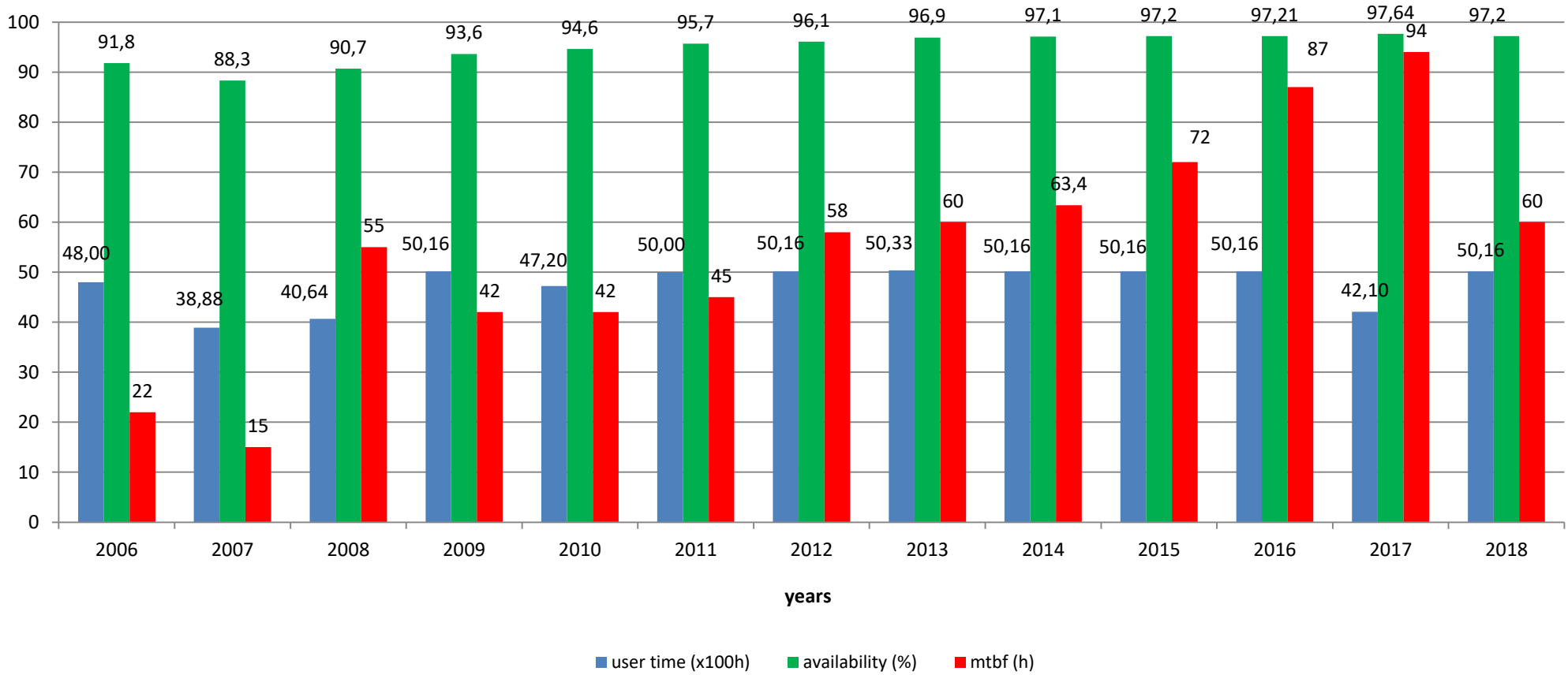
ID	type	section	Period (mm)	Nper	gap (mm)	status
U5.6	PM/Linear	12 short	56	18	23	operating
EU10.0	PM/Elliptical	1	100	20+20	13.5	operating
U4.6	PM/Linear	2	46	2 x 49	13.5	operating
U12.5	PM/Linear	3	125	3 x 12	32.0	operating
EEW	EM/Elliptical	4	212	16	18.0	operating
W14.0	HYB/Linear	5	140	3 x 9.5	22.0	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)

6 bending magnet source points serving 9 beam lines



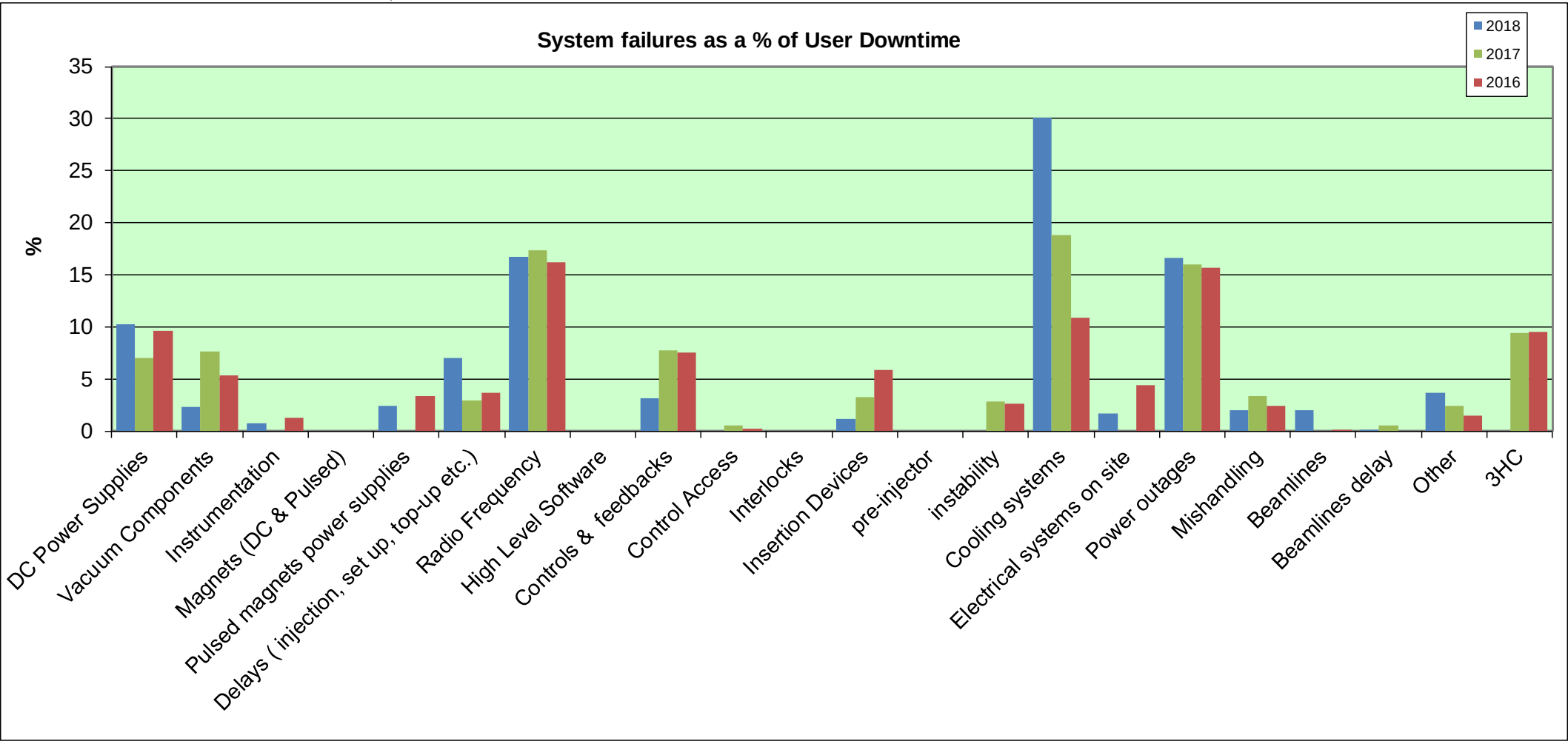
Uptime Statistics



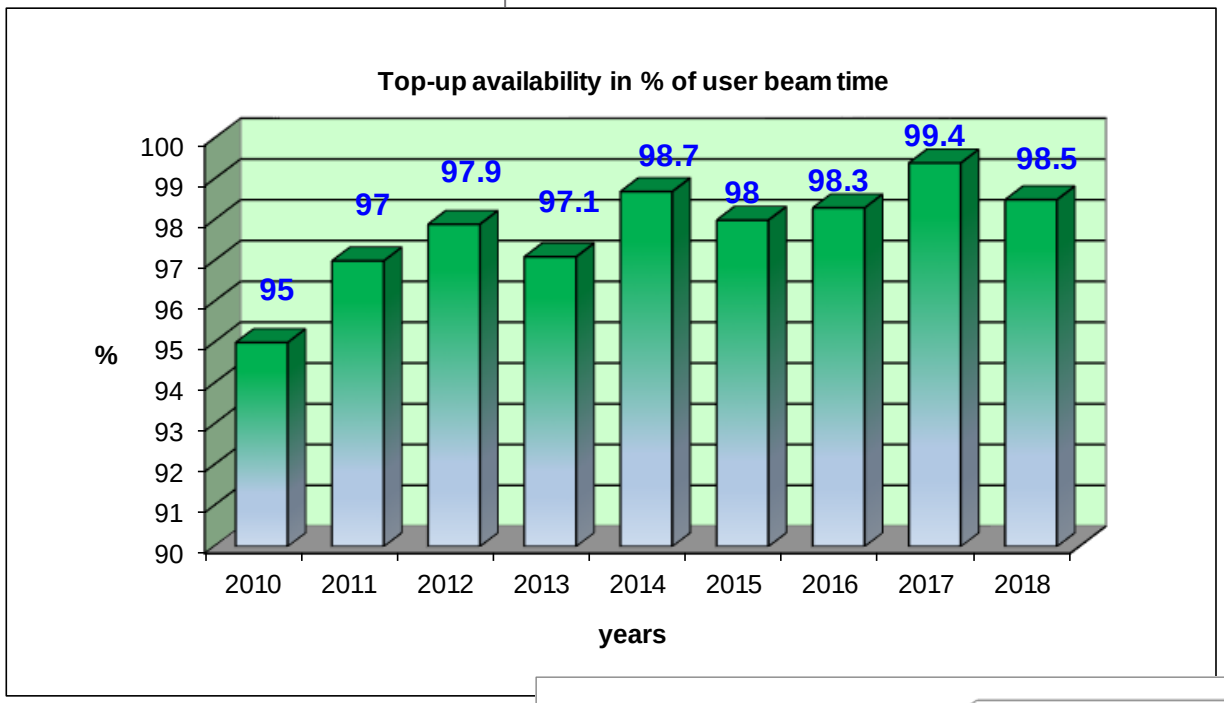
Statistics of 2018 at 80% of the total user time

No downtime due to the injectors

System failures

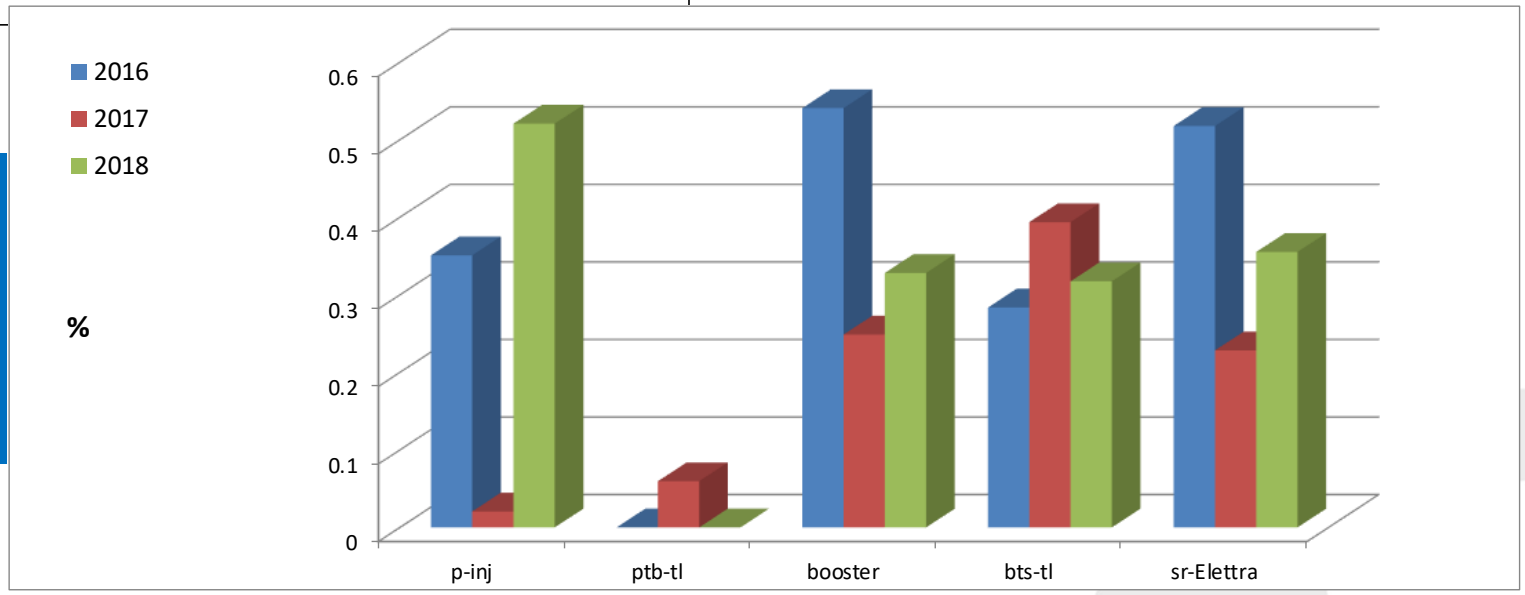


Top-up statistics



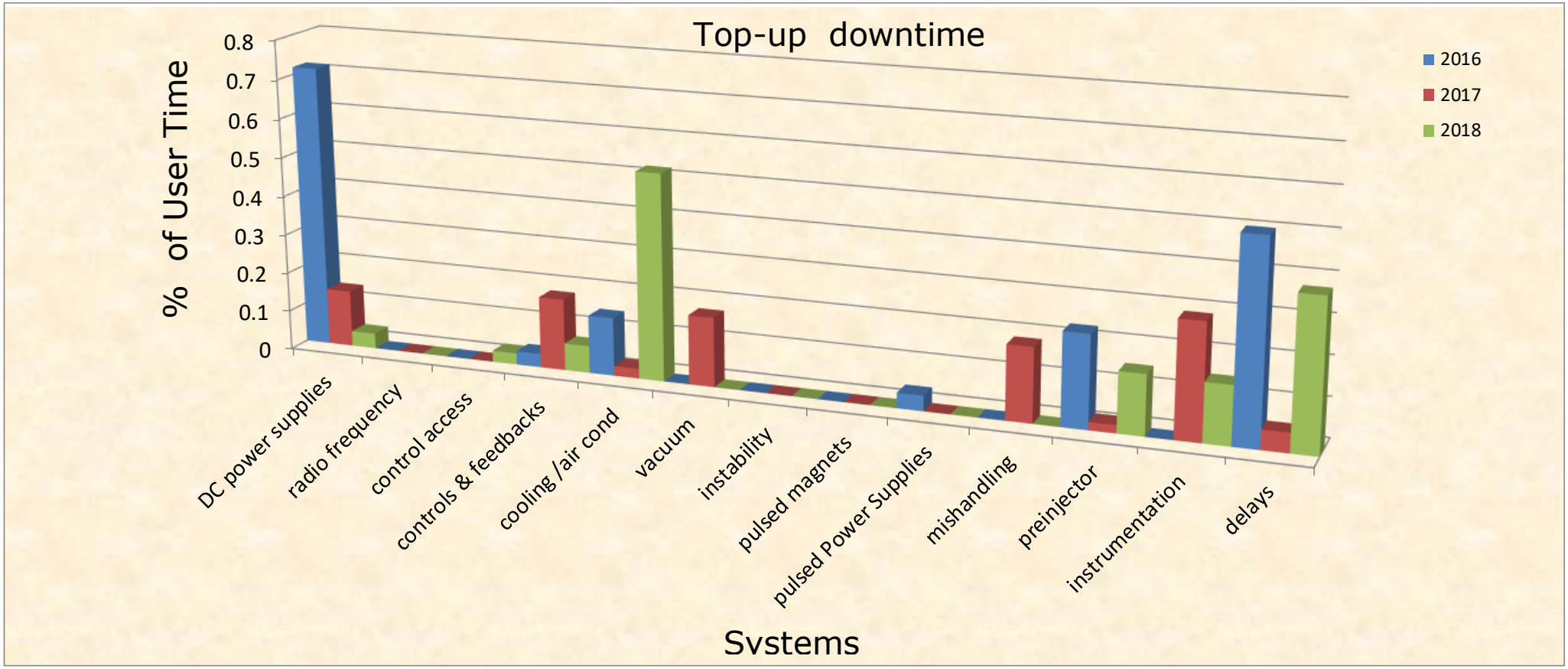
During top-up systems run well and the top-up % of user beam-time is high. The remaining ≤1.5% is due to failures that, however, do not impact on the availability.

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

Elettra present developments

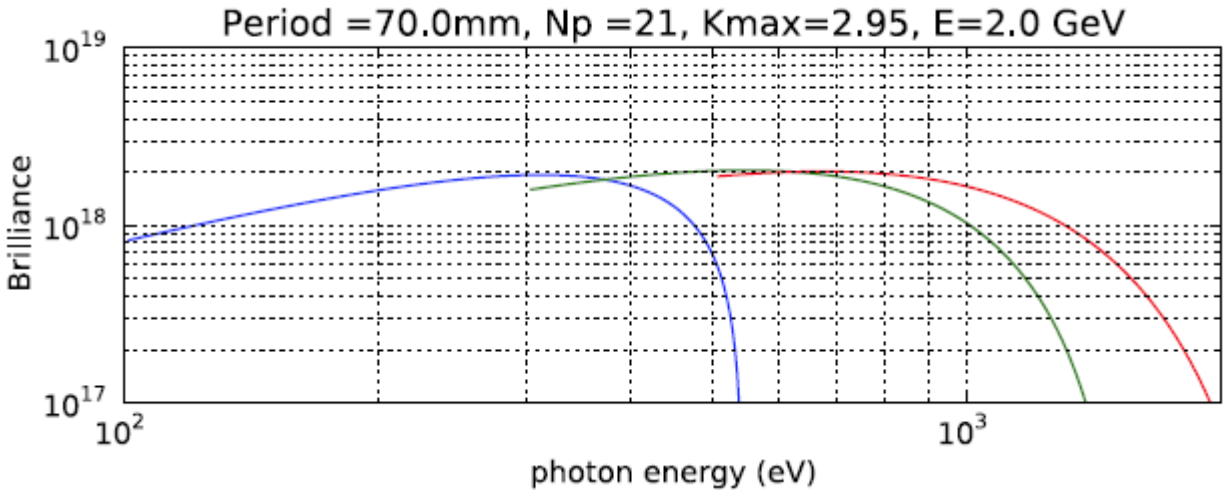
- ❑ Tunnel temperature stabilization -> better than $\pm 0.5^{0}$C
- ❑ Upgrade of the interlock system -> completed
- ❑ PS-controls upgrade -> finished
- ❑ RF upgrade (booster Solid State Amplifier) -> completed
- ❑ Upgrade vacuum system electronics -> completed
- ❑ Build new bpm electronics (detectors) -> tested with beam
- ❑ Quench protection system -> completed, in operation

❑ Fixed gap undulators -> the one constructed and installed in Elettra (Aloisa) performs very well

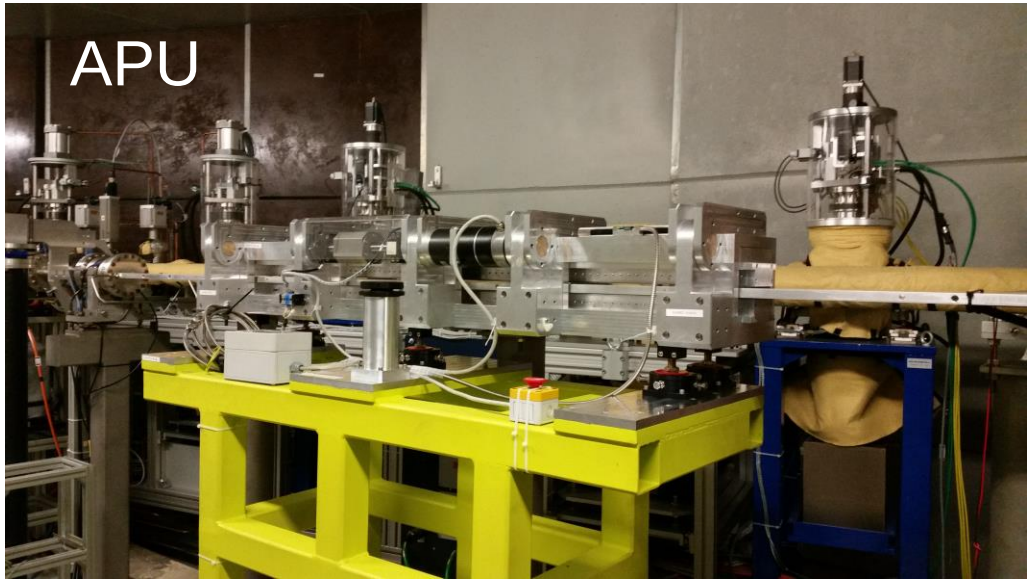
- ❑ A double fixed gap undulator for TwinMic in progress.
- ❑ Two new undulators (MOST project) *(B. Diviacco)*

Fixed gap undulator

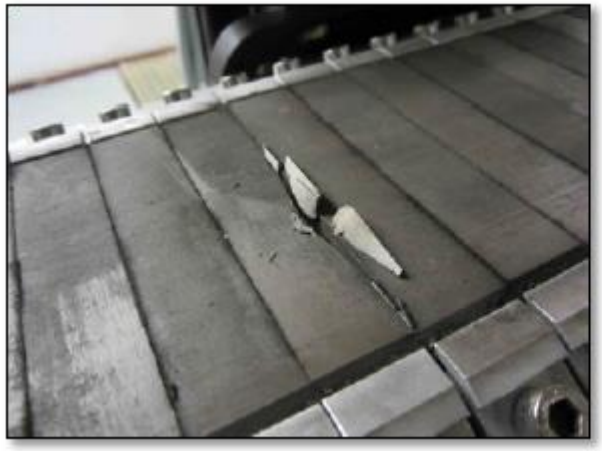
Installed for ALOISA beam line. Excellent performance and for operations almost “invisible”

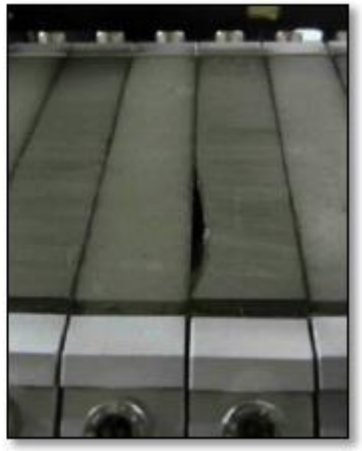


Ref: B. Diviacco



Original AGU: magnets from 1994
Material Neorem 450i uncoated

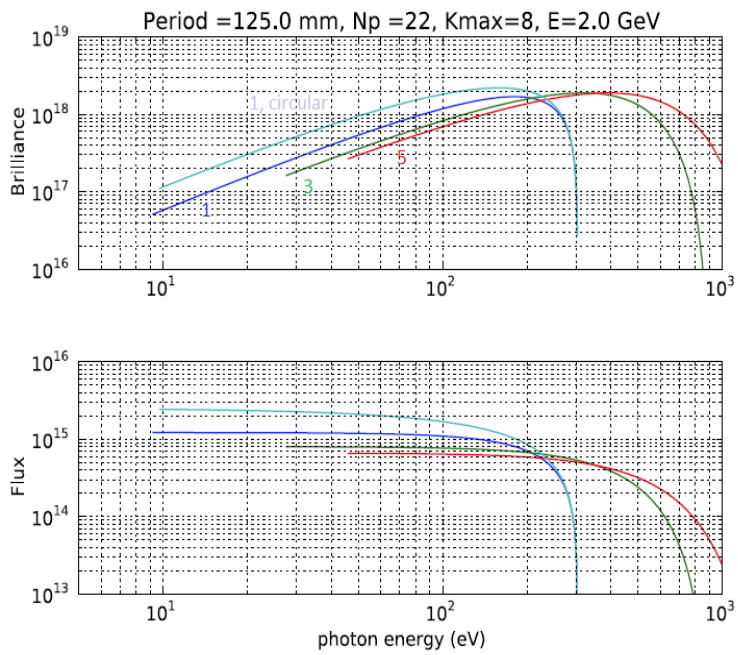




MOST Beam Line

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.

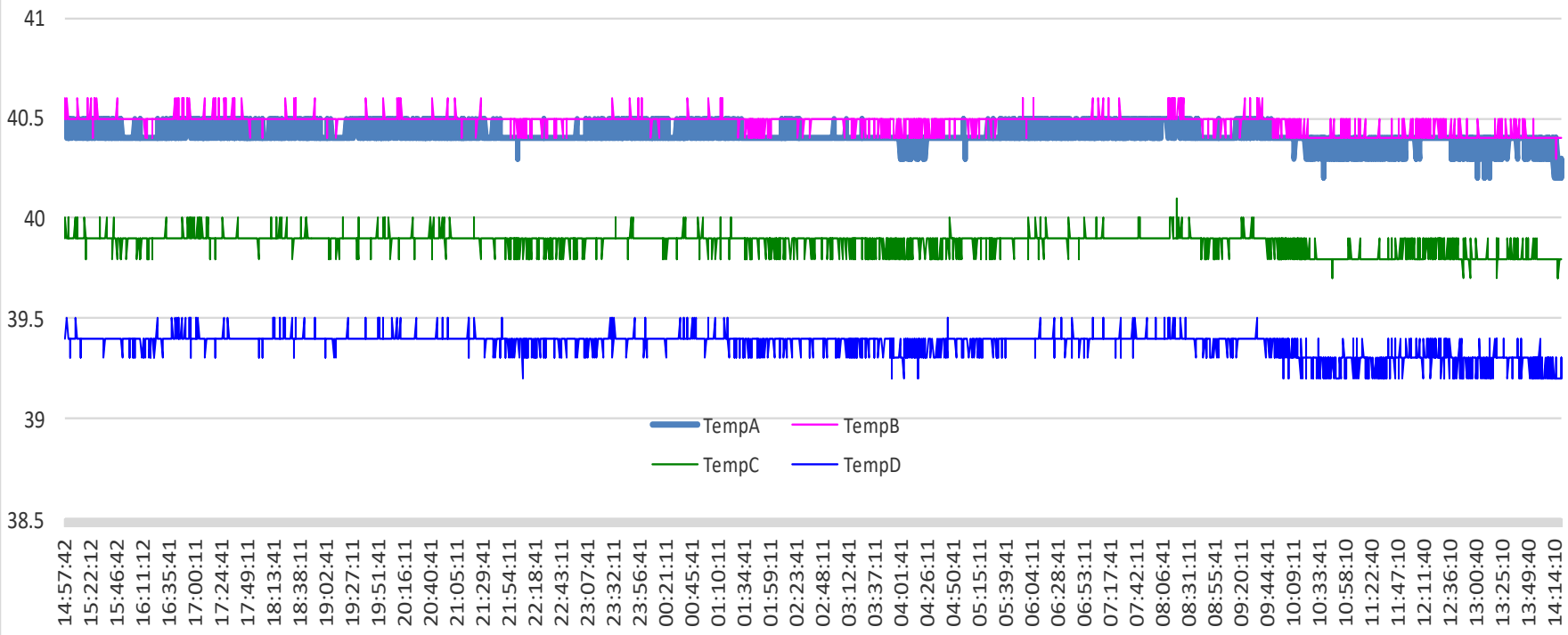
Low energy -> variable polarization APU (fixed gap)



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

Temperature Stability

The thermal stability of the tunnel is better than ±0.5^{0}C. As can be seen, the 24 h variations are < 0.4^{0}C PTP.



Measurements were taken form the continuous temperature monitoring of the electronics of E²BPM RF Front End.

E²BPM
Elettra Electron Beam Position Monitor system

Elettra Sincrotrone Trieste

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

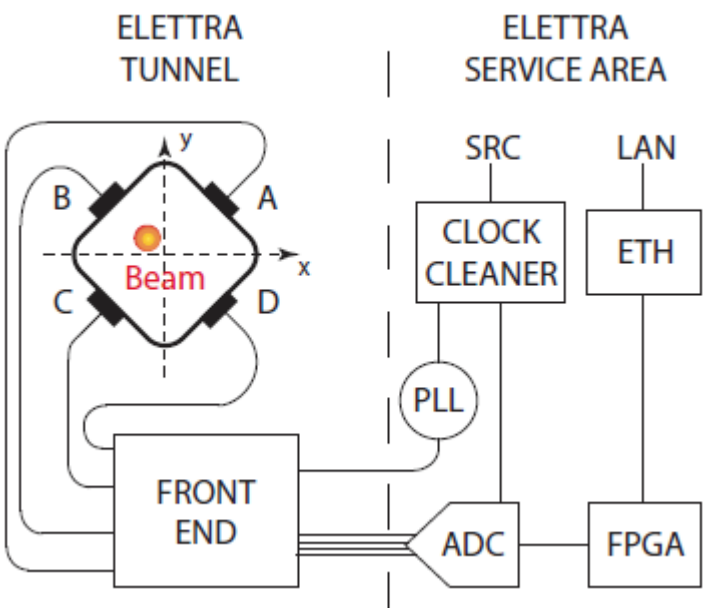
A NOVEL ELECTRON-BPM FRONT END WITH SUB-MICRON RESOLUTION BASED ON PILOT-TONE COMPENSATION: TEST RESULTS WITH BEAM

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.



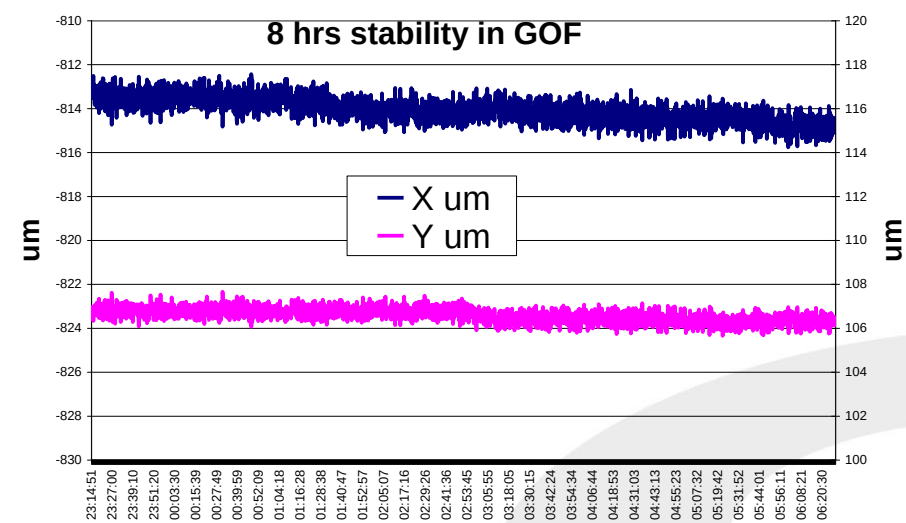
The Project will finish by end of 2018 aiming at a better and cheaper, than the existing, detector.

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

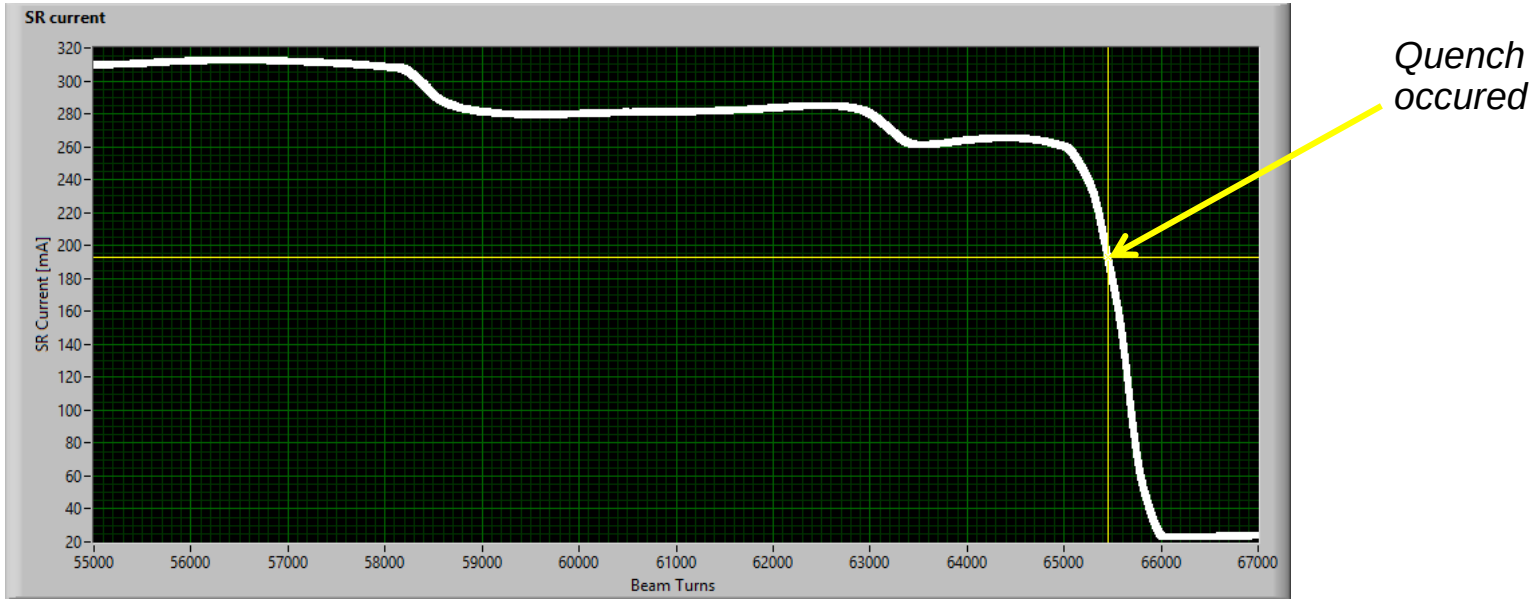
Direct measurement of the measurement quality



SCW Quench protection system

In the past Elettra suffered quenches mostly at 2.4 GeV when the fast rf-beam dump (orbit based) did non intervene timely as in the case of some quadrupole failures since there for many turns the orbit remained stable although there was a fast current loss. A system is developed that:

- ***Analyzes turn by turn the SR current***
- ***When the current loss rate exceeds a predefined value generates an alarm signal***
- ***if SCW is on, dumps the beam using an injection kicker on received alarm.***
- ***Logs all activity data.***

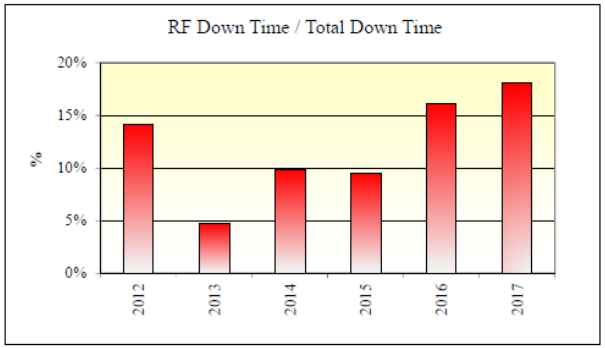


Beam current vs. turns recorded on 05-02-2018 when a quadrupole switched off and a micro-quench occurred; The protection system was in commissioning (kicker disconnected) ; The system would fire the beam at cursor turn.

Ref: A.Carniel S.Bassanese

Booster RF -> SSA

- ✓ CW 500 MHz 60 kW klystrons out of production, the 4 klystron amplifiers are old. Replacing started from the booster.
- ✓ SSA 18 kW 500 MHz in 6 modules

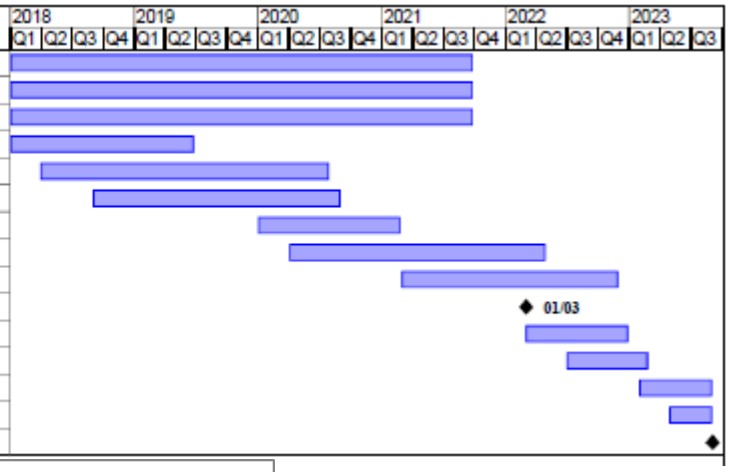


Ref. C. Pasotti

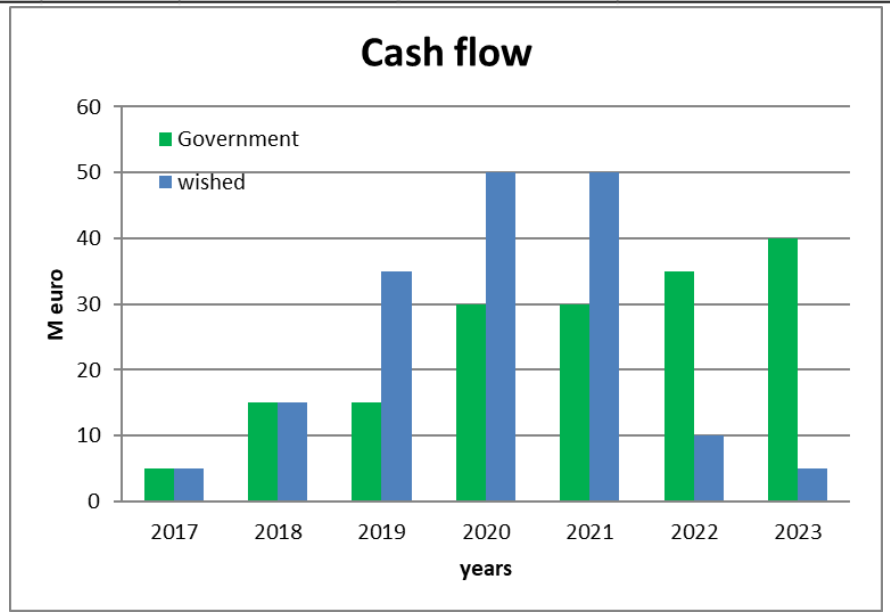
Elettra 2: Schedule (from CDR)

Elettra Sincrotrone Trieste

		Name	Duration	Start	Finish	Predecessors	Resource Names
1		Infrastructures upgrade ...	978 days?	01/01/18 8.00	29/09/21 17.00		
2		Accelerator systems up...	978 days?	01/01/18 8.00	29/09/21 17.00		
3		Beam lines upgrade	978 days?	01/01/18 8.00	29/09/21 17.00		
4		technical Design study	390 days?	01/01/18 8.00	28/06/19 17.00		
5		Engineering Design	610 days?	02/04/18 8.00	31/07/20 17.00		
6		Prototyping	524 days?	01/09/18 8.00	03/09/20 17.00		
7		Calls for tender	303 days?	01/01/20 8.00	26/02/21 17.00		
8		Manufactoring construct...	542 days?	02/04/20 8.00	29/04/22 17.00		
9		Preparations and asse...	458 days?	01/03/21 8.00	30/11/22 17.00		
10		End of user mode	1 day?	01/03/22 8.00	01/03/22 17.00		
11		Ring decomissioning	219 days?	01/03/22 8.00	30/12/22 17.00		
12		Installations	173 days?	01/07/22 8.00	28/02/23 17.00		
13		Accelerator system test...	153 days?	01/02/23 8.00	01/09/23 17.00		
14		Beam lines commissio...	90 days?	01/05/23 8.00	01/09/23 17.00		
15		Elettra 2.0 user mode	1 day?	04/09/23 8.00	04/09/23 17.00		



BUT



Alternative schedule is needed to follow the real cash flow, this may shift the date of operation for users by about 2.5 years

Already started: Elettra 2.0 projects to be used also for Elettra

Systems	Meuro (VAT excluded)
SSA for all 4 RF plants of Elettra	3
Additional spaces (laboratories as indicated in the CDR)	5.0
Super bends	0.5 (one)
TMFB + LMFB upgrades	0.5 - 0.8
Spare gun	0.2 - 0.5
Refurbishing cooling rack of pre-injector / Pre- injector chopper	0.1
Double ID	0.2
New corrector power supplies	0.8
Beam lines new control system (30 BLs only equipments)	2
New bpm detectors	0.7
IDs control system refurbishing	0.5
Diagnostic line from booster for equipment tests	0.15
Total	13.65 -14.25

In progress | In preparation

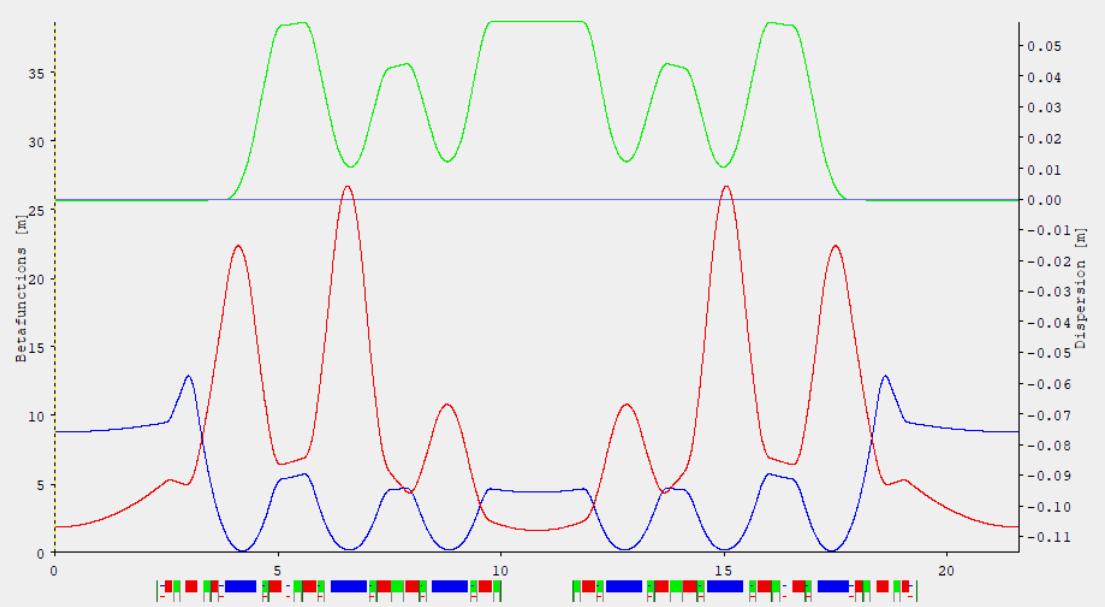
S6BA "basic" Lattice

Current version:

Emittance 0.25 nm-rad (0.15 if round beam) 169 keV/turn

Dipoles are simple electromagnets at 0.8 T

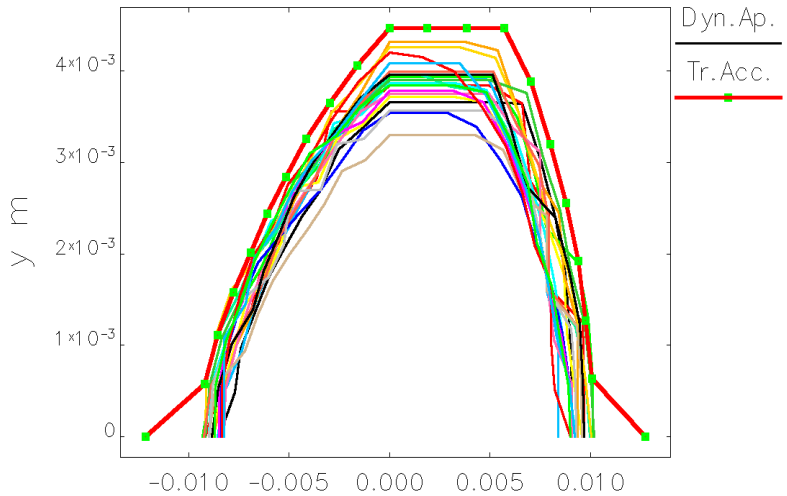
No Longitudinal Gradient in the dipoles



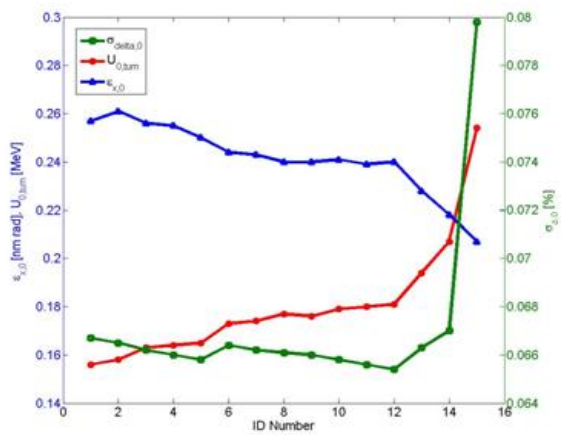
Free space for IDs (4.5 + 1.8 m)

Circumference (m)	~ 259.2
Energy (GeV)	2
Number of cells	12
Geometric emittance (nm-rad)	0.25
Horizontal tune	33.10 - 33.30
Vertical tune	9.2
Betatron function in the middle of straights (x, y) m	(9.5,3.2)
Horizontal natural chromaticity	-76
Vertical natural chromaticity	-52
Horizontal corrected chromaticity	+1
Vertical corrected chromaticity	+1
Momentum compaction	3.44e-004
Energy loss per turn (with no IDs) (keV)	156
Energy spread	6.67e-004
Jx	1.52
Jy	1.00
JE	1.48
Horizontal damping time (ms)	14.8
Vertical damping time (ms)	22.9
Longitudinal damping time (ms)	15.0
Dipole field (T)	<0.8
Quadrupole gradient in dipole (T/m)	<15
Quadrupole gradient (T/m)	<50
Sextupole gradient (T/m^2)	<3500
RF frequency (MHz)	499.654
Beam revolution frequency (MHz)	1.1566
Harmonic number	432
Orbital period (ns)	864.6
Bucket length (ns)	2
Natural bunch length (mm, ps)	2.0 , 6.5
Synchrotron frequency (kHz)	5.6 (@2MV)

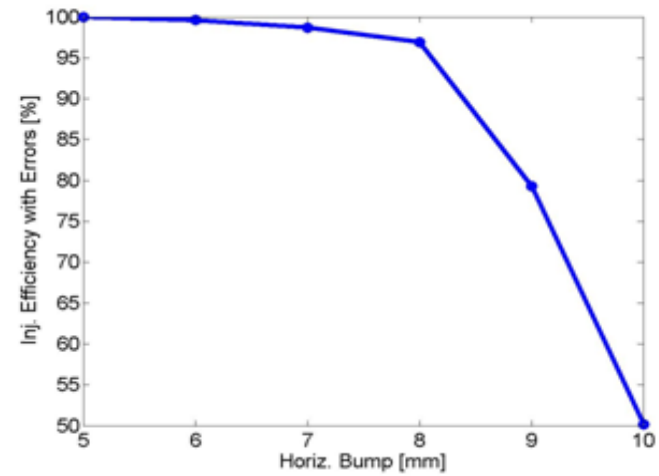
S6BA: DA with errors and IDs



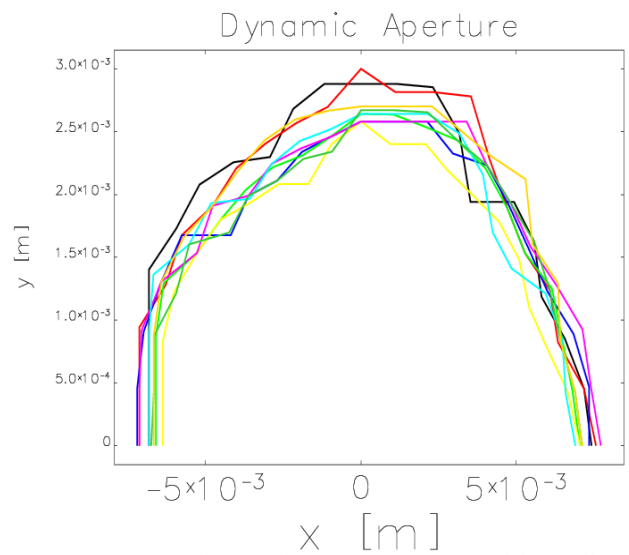
Dynamic aperture for the bare lattice, and in the presence of machine errors plus corrections, for 20 independent error seeds



Emittance, energy spread and energy loss per turn versus the number of insertion devices at minimum gap / max phase



Injection efficiency versus the horizontal beam bump amplitude



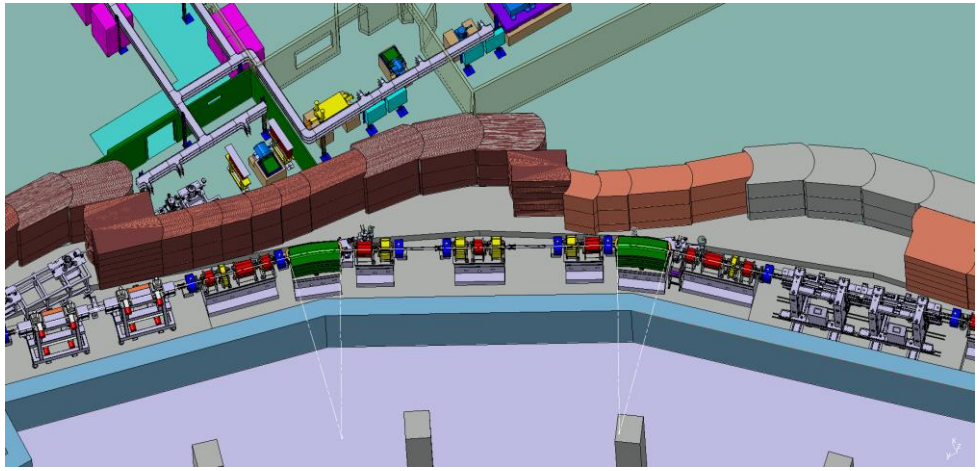
On-energy dynamic aperture with all IDs at functioning settings with alignment errors and the induced optical asymmetries. The wiggler is set to 3.5 T.

Other facts for S6BA "basic"

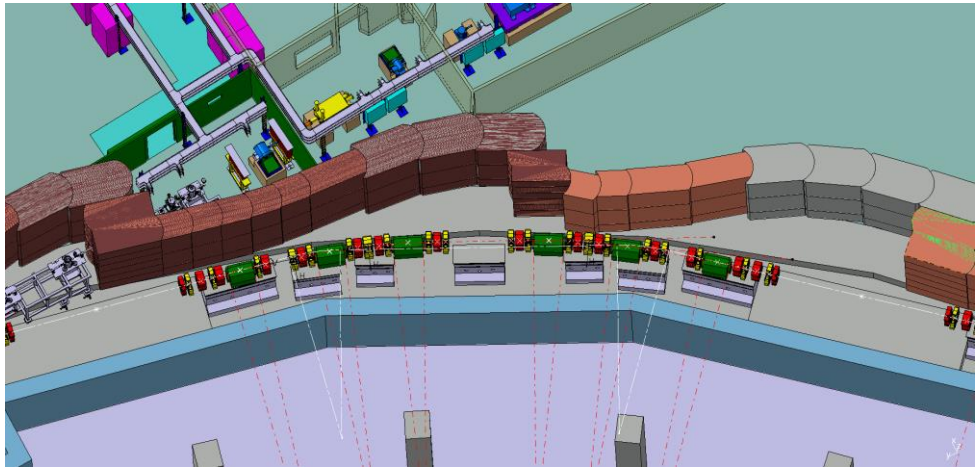
- ✓ Including errors and the existing IDs the dynamic aperture is ±7 mm horizontally and ± 2.5 mm vertically. This aperture permits off axis injection with an efficiency of more than 95%
- ✓ Lifetime is 6 hours at 2 GeV and with the third harmonic cavity (3HC, bunch lengthening) will be 18 h.
- ✓ Intra-beam scattering increases the emittance by 60% at 400 mA at 1% coupling however using the 3HC the effect is reduced down to 35%. At 2% coupling the numbers are 43 and 20% respectively.
- ✓ Vacuum chamber best compromise (considering also the magnet power) seems to be a circular cross section with 25 mm external diameter. For the long straight sections the current vertical dimension of 9 mm is assumed. Material stainless steel and aluminium.
- ✓ The impedances of the low gap chambers and the rf transitions dominate. Estimated 230 kohm/m for both planes. Microwave threshold 0.6 mA for a bunch length of 5 ps (1σ).

Elettra 2.0 Lattice in the tunnel

Best configuration up to now, satisfying all requirements, including the free space for IDs is based on our special six-bend achromat (S6BA).



Elettra



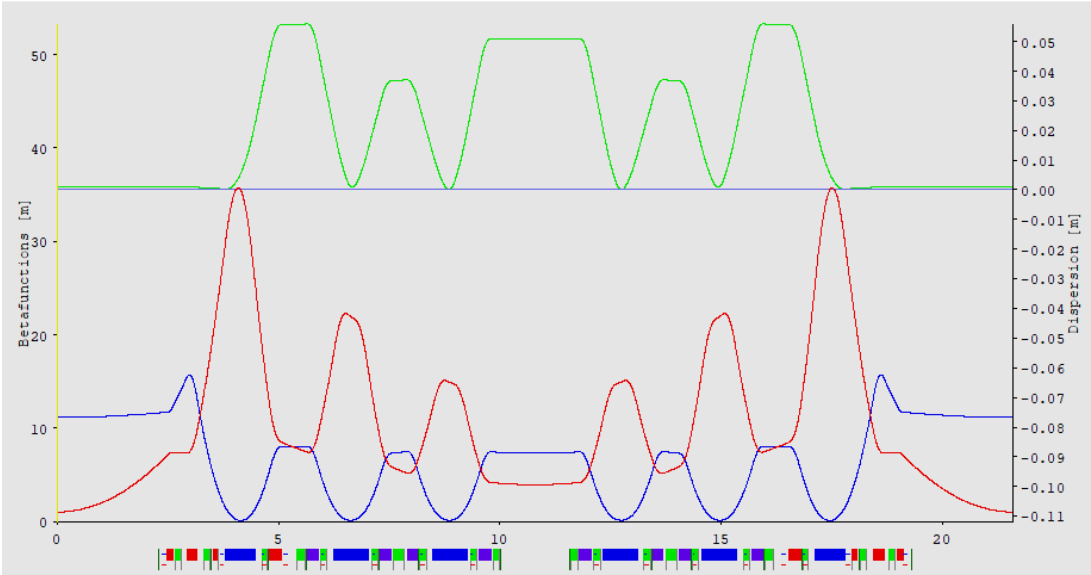
Elettra 2.0

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

Revised requirements

- ***Operating energy 2.0 and 2.4 GeV***
- ***Reduce the horizontal equilibrium emittance at least one order of magnitude***
- Maintain the existing ID beam lines
- Maintain the existing dipole magnet beam-lines
- ***Increase 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
- Minimize the downtime for installation and commissioning to about 18 months

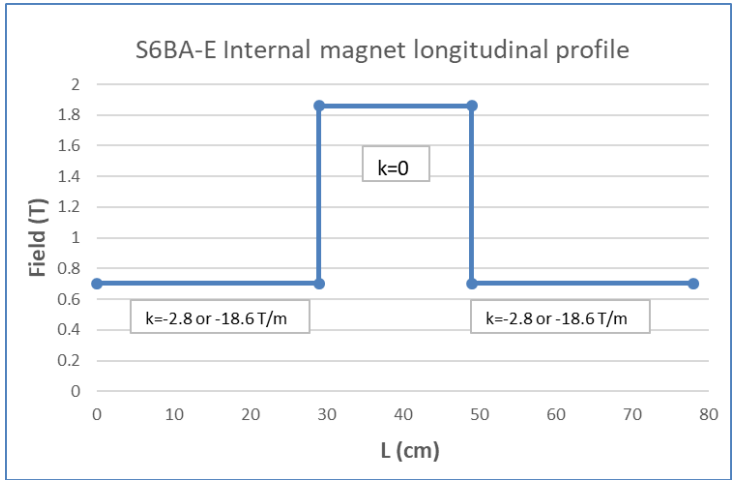
S6BA-E



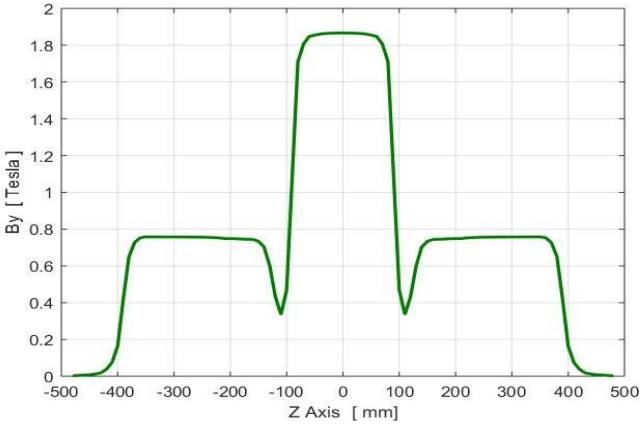
LG + dipole/quadrupoles version:

Emittance 0.098 nm-rad

(60 pmrad if round beam) at 2 GeV or 0.14 nmrad at 2.4 GeV



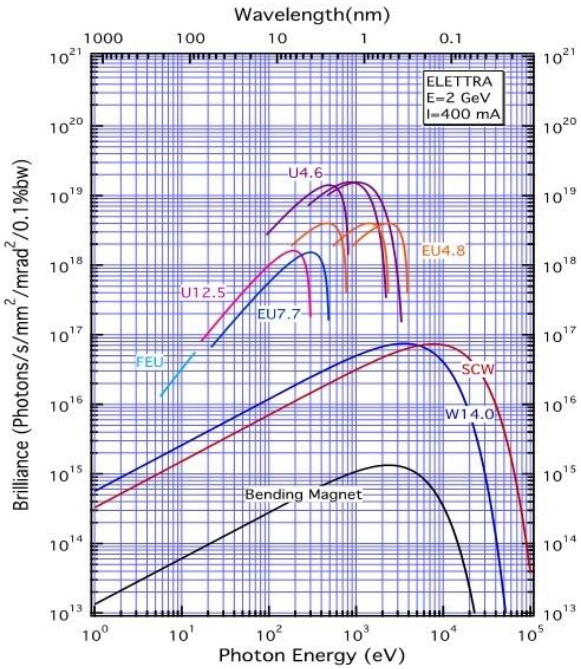
With its momentum compaction in the range of 10^{-5} short bunches at low intensity can be provided without adjusting the optics.

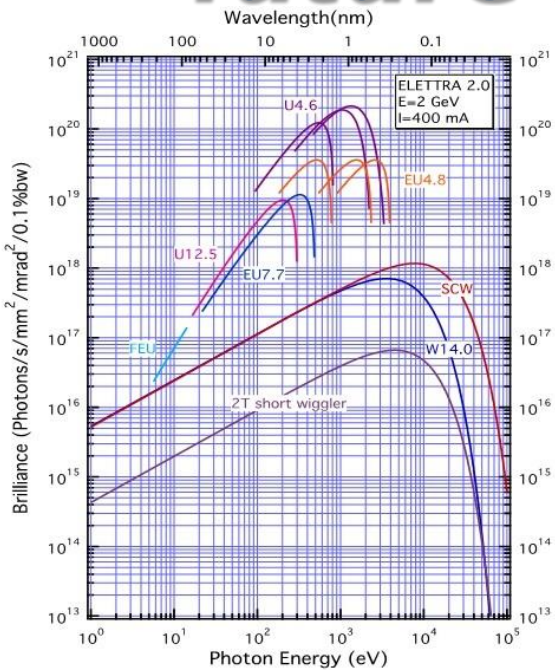


Comparison of Versions

Parameter	Units	Elettra	Elettra 2.0 S4BA	Elettra 2.0 S6BA	Elettra 2.0 S6BA-E
Circumference	m	259.2	259.2	259.2	259.2
Energy	GeV	2	2	2	2
Horizontal bare emittance	pm rad	7000	730	250	98
Vertical emittance @1% coupling	pm rad	70	7.3	2.5	0.98
Beam size @ ID ($\sigma x,\sigma y$)	um	240 , 14	70 , 4.5	47 , 2.2	31 ,1.2
Beam size at short ID	um	340 , 21	62, 5.6	52 , 2.0	51, 1.8
Beam size @ Bend (at z=0)	um	227, 23	22.5 , 12.8	10 , 8	17 , 4
Bunch length (zero current, 2 MV,1σ)	ps	17	8.3	6.3	3.7
Energy spread	$\Delta E/E$ %	0.078	0.075	0.068	0.095
Lifetime at 2 MV, 400 mA and 4 nTorr N_2	h	8	7.5	6	7 +3HC
Bending angle half achromat	degree	15	5.6 and 9.4	3.6 and 2x5.7	3.6 and 2x5.7 with LG

Brilliance with existing and future IDs (S6BA)



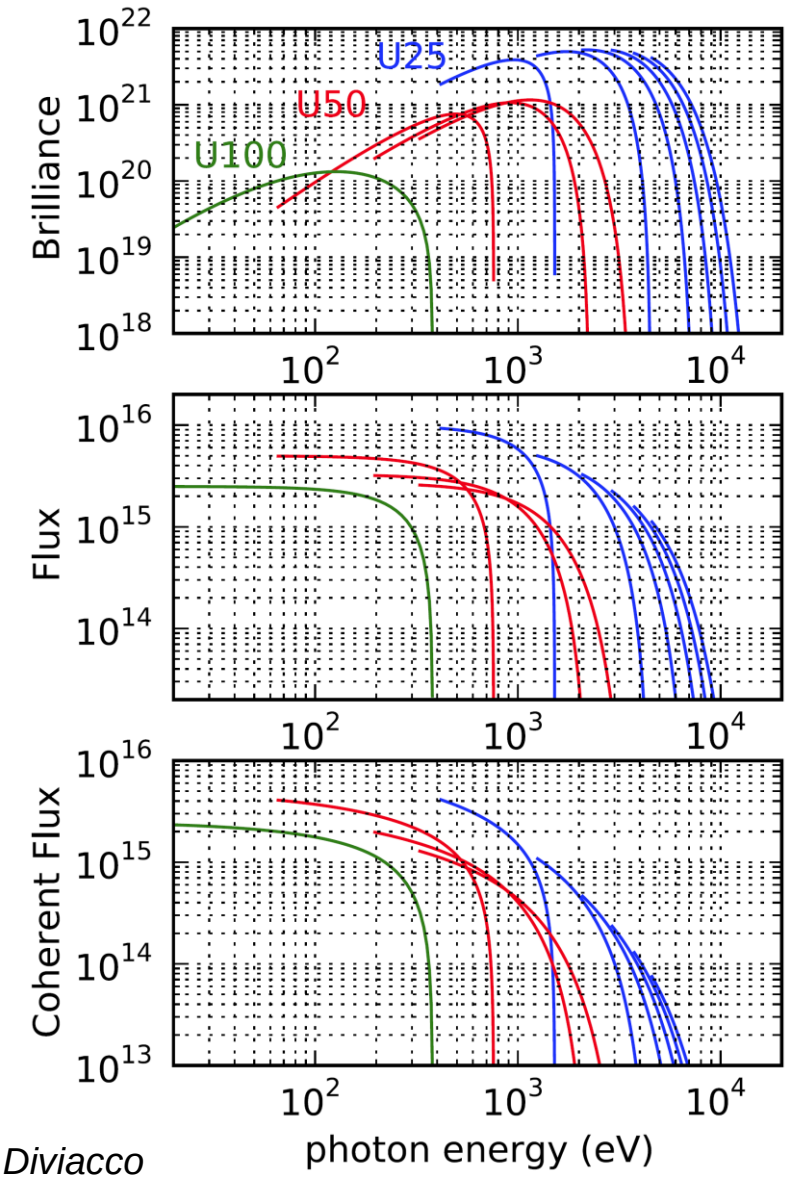


Performance in case of three well matched hypothetical insertion devices (brilliance, flux and coherent flux):

U100 *period = 100 mm,*
N_{per} = 45, K_{max} = 9,

U50 *period = 50 mm,*
N_{per} = 90, K_{max} = 4.5,

U25 *period = 25 mm,*
N_{per} = 180, K_{max} = 2.3



Ref: B. Diviacco

Elettra Sincrotrone Trieste

Summary

- Elettra is running well although is 25 year old, many small projects contribute to this including replacement of old / obsolete hardware.
- The Elettra 2.0 project has been approved and financed by the Italian government.
- Analysis is under way to find the best machine combining at best all user requirements. To this regrouping and/or excluding beam lines is also in discussion.
- There are 2 candidate lattices S6BA and S4BA. The S6BA-E may be the closest to the various requirements for Elettra 2.0 however it is more demanding from the engineering point of view.
- The final decision is expected soon
- The 1.0 version of the Elettra 2.0 conceptual design report (CDR) is available since 2017.
- Whatever the decision will be, most parts of the CDR need not change

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

ESRF	4
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	1
SOLEIL	1
DIAMOND	1

Elettra
Sincrotrone
Trieste