Elettra
Sincrotrone
Trieste

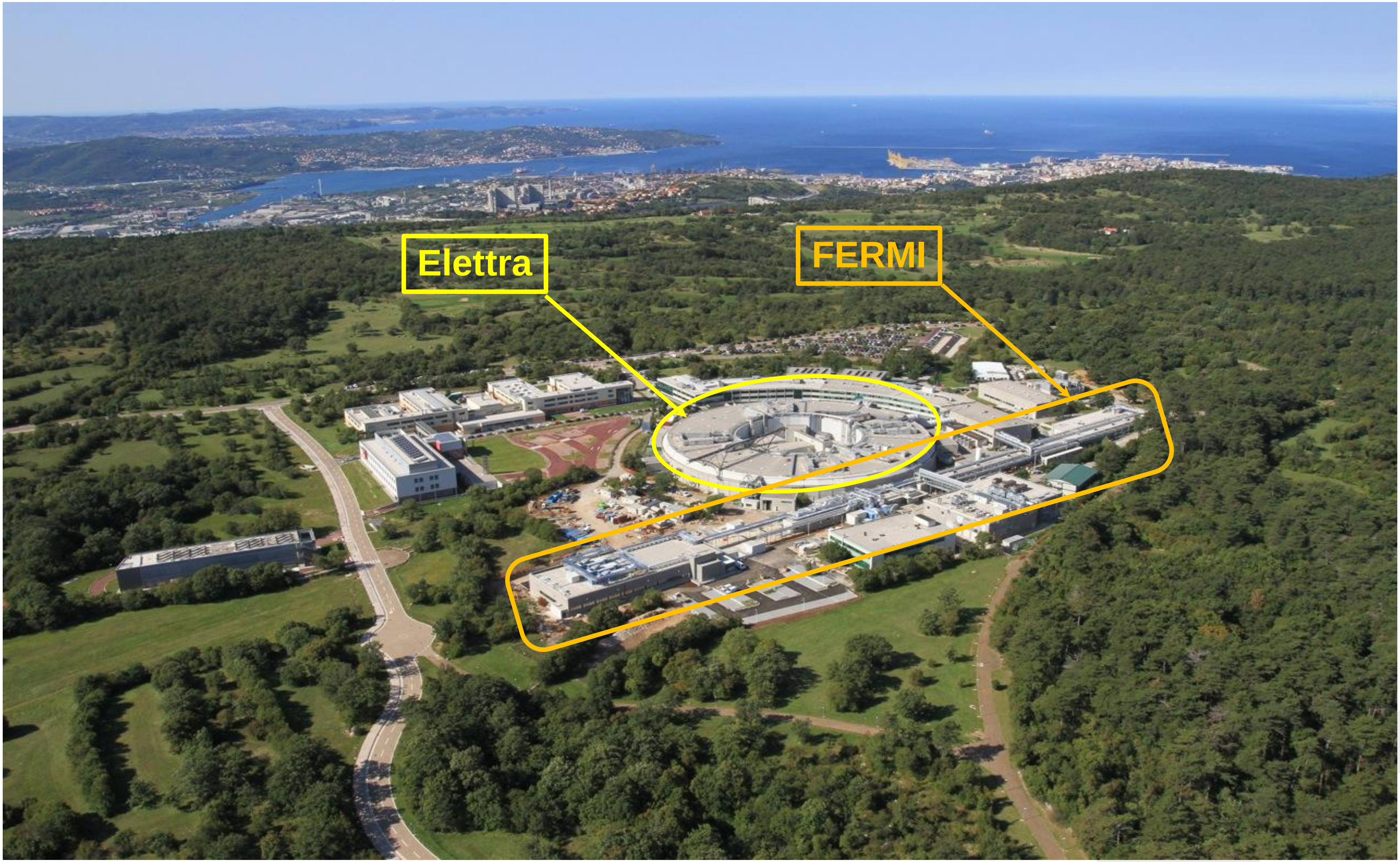
Elettra (and FERMI) Status and upgrades

Emanuel Karantzoulis

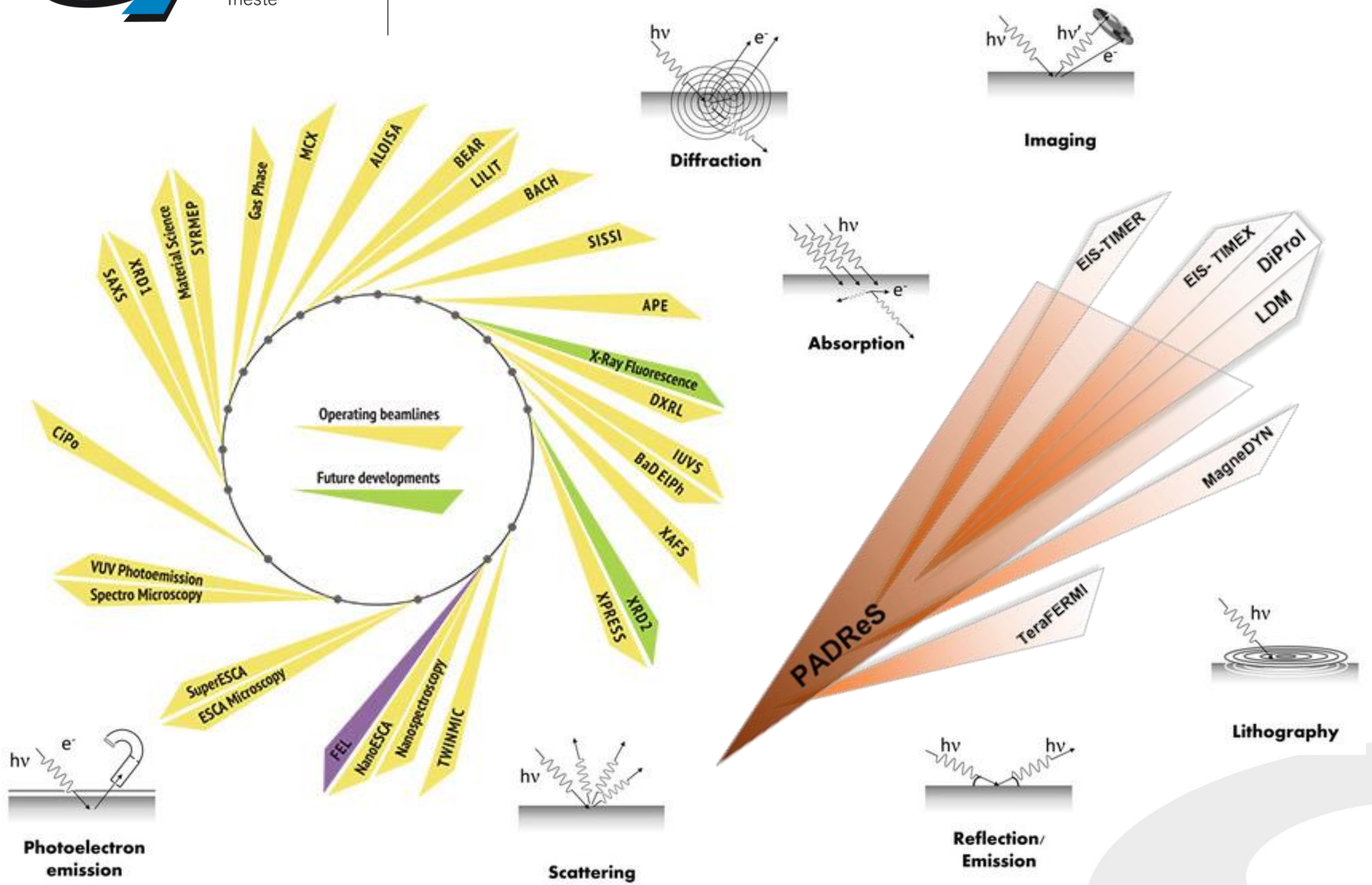
Outline:

- Introduction
- FERMI status and prospects
- Elettra status and statistics
- Short and mid term developments
- Future upgrade: Elettra 2.0

Elettra Sincrotrone Trieste in brief: 2 complementary Light Sources



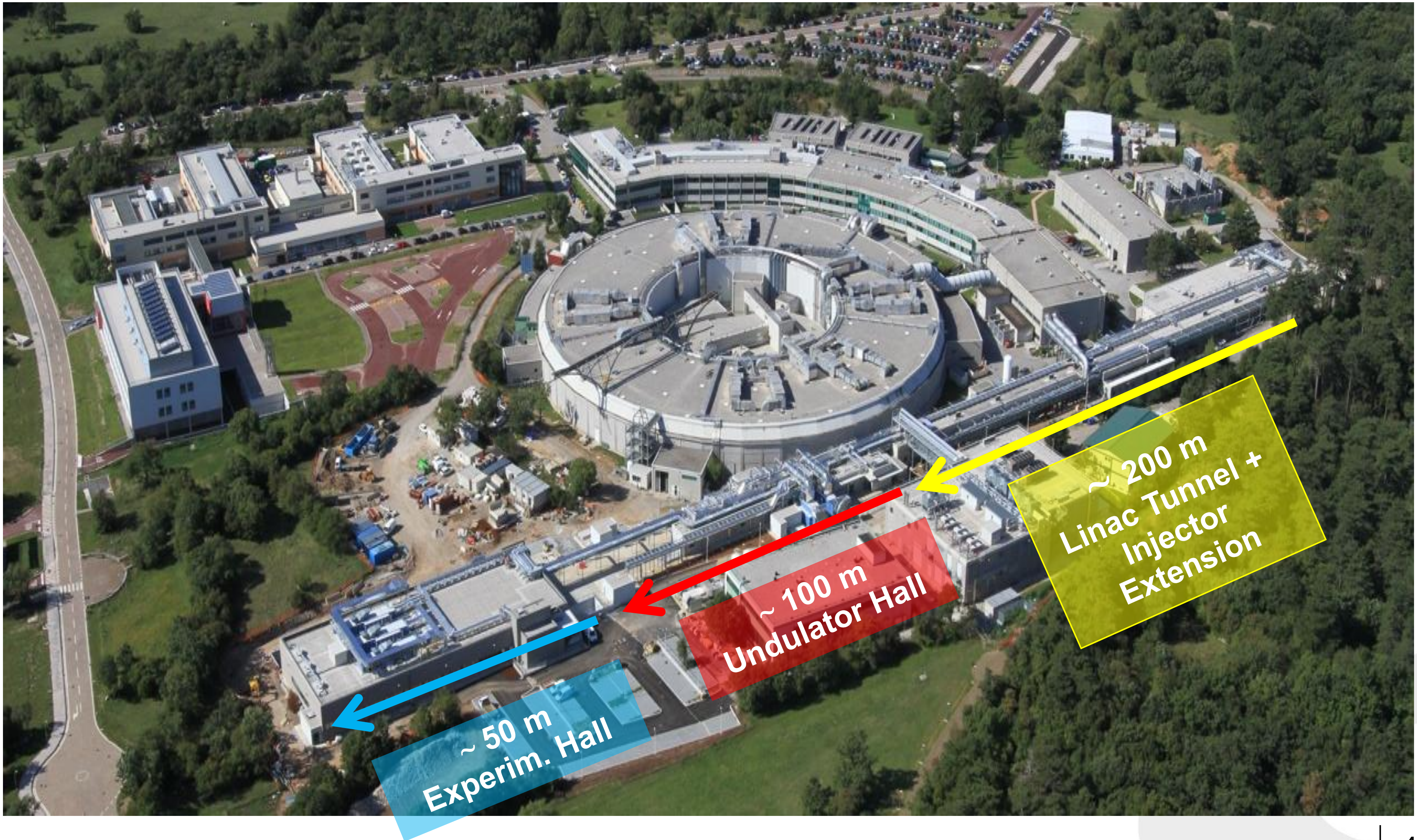
Beam lines 28 + 6



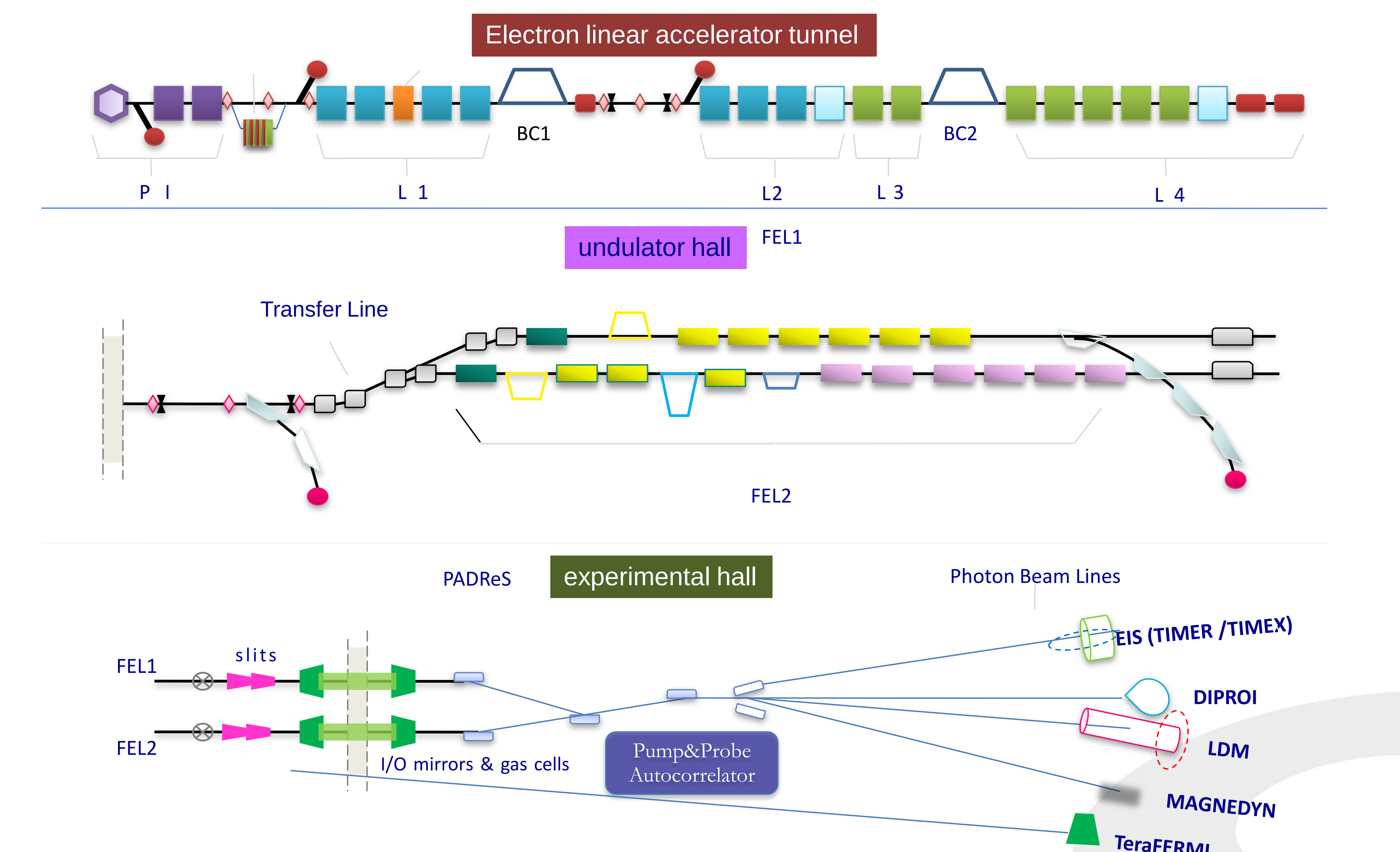
Elettra Sincrotrone Trieste

FERMI

- Seeded FEL (HGHG), 1.5 (1.8) GeV, 10 Hz (50 Hz) – First Lasing Dec.13, 2010
- Open to external users since 2012 (FEL-1) (100-20 nm, 12 - 62 eV) and 2015 (FEL-2) (20- 4 nm, 62 - 320 eV)



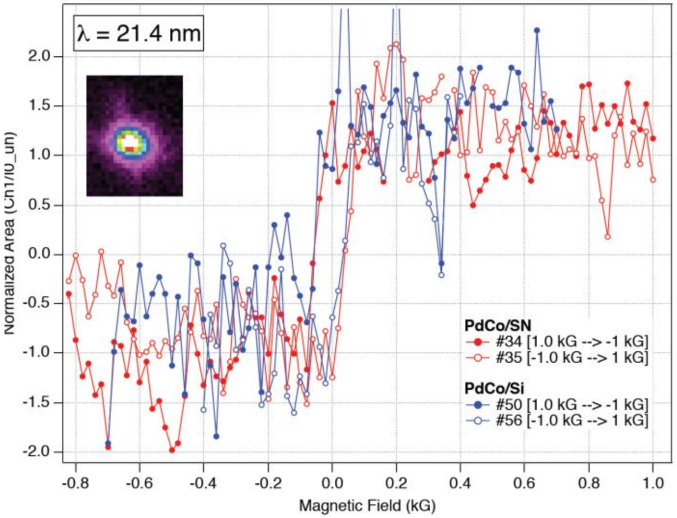
FERMI Layout



FERMI 2017 in a nutshell

courtesy M. Svandrlik

- ✓ **Two operation modes** are available for experiments:
  - Low and medium energy (below 1350 MeV, for **$\lambda > 5$ nm**) at **50 Hz**
  - High energy (up to 1550 MeV, for **$\lambda \leq 5$ nm**) at **10 Hz**
- ✓ FEL uptime for users in 2017 close to **90%**
- ✓ **MagneDyn** beamline commissioning started in October. The picture shows the first spectra taken, measuring the magnetic hysteresis of a 4 nm cobalt film deposited on a Si3N4 100 nm membrane.



- ✓ FERMI offer to users includes now **five** end stations connected to the FEL line, plus the TeraFERMI THz beamline and two table-top laser laboratories (T-ReX and CITIUS).
- ✓ **96 experiment proposals** submitted to VII call for proposals in October

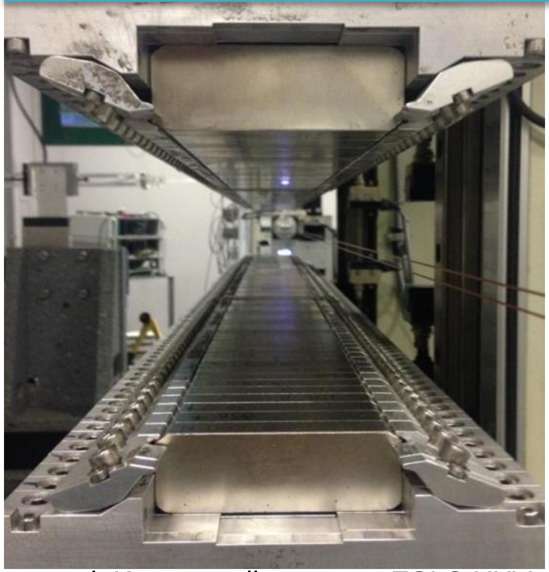
Future Developments

courtesy M. Svandrlik

✓ A number of research activities are ongoing with the goal of defining an upgrade plan for FERMI. Two highlights are:

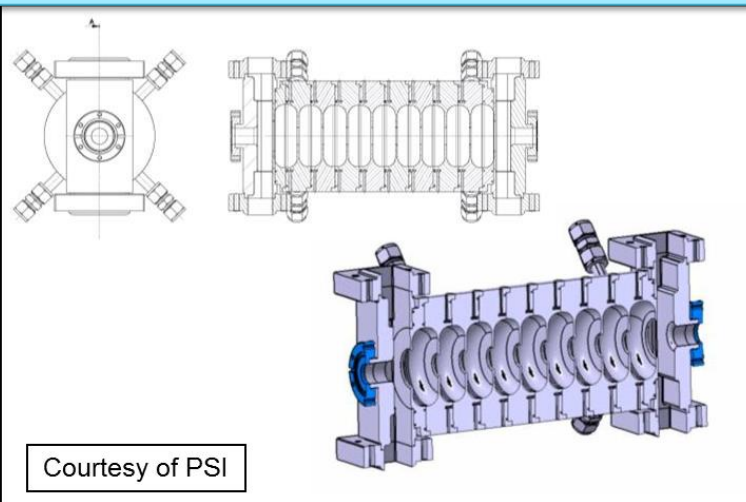
- The Echo Enabled Harmonic Generation experiment at **$\lambda \leq$ 5 nm**
- The design of new S-band accelerating structures, intended to replace the existing BTW sections, tailored for high gradient operation, low breakdown rates and low wakefield contribution.

EEHG experiment on FEL-2: May-August ‘18
Goal: **EEHG demonstration at short λ**
Refurbished U113 as 2nd Modulator



- Length: 1.5 m
- Period length: 11.3 cm
- Number of periods: 13
- Minimum gap: 10 mm
- Tuning range: 200-400 nm

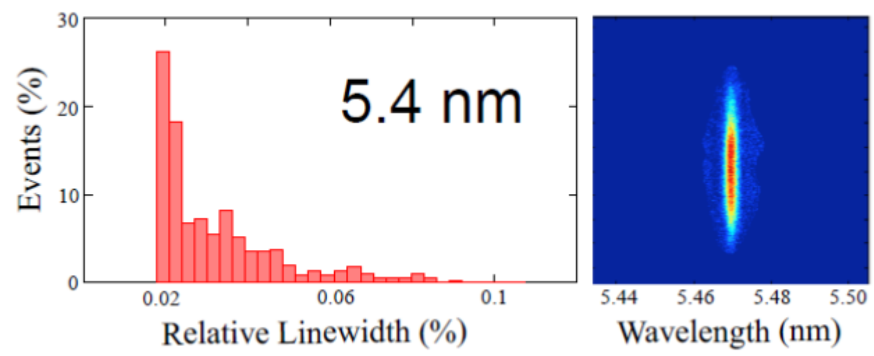
S-band protoype in development with PSI
Goal: gradient > **30 MV/m**
High Power test at Elettra next Spring



Courtesy of PSI

FERMI – electron/photon beam parameters

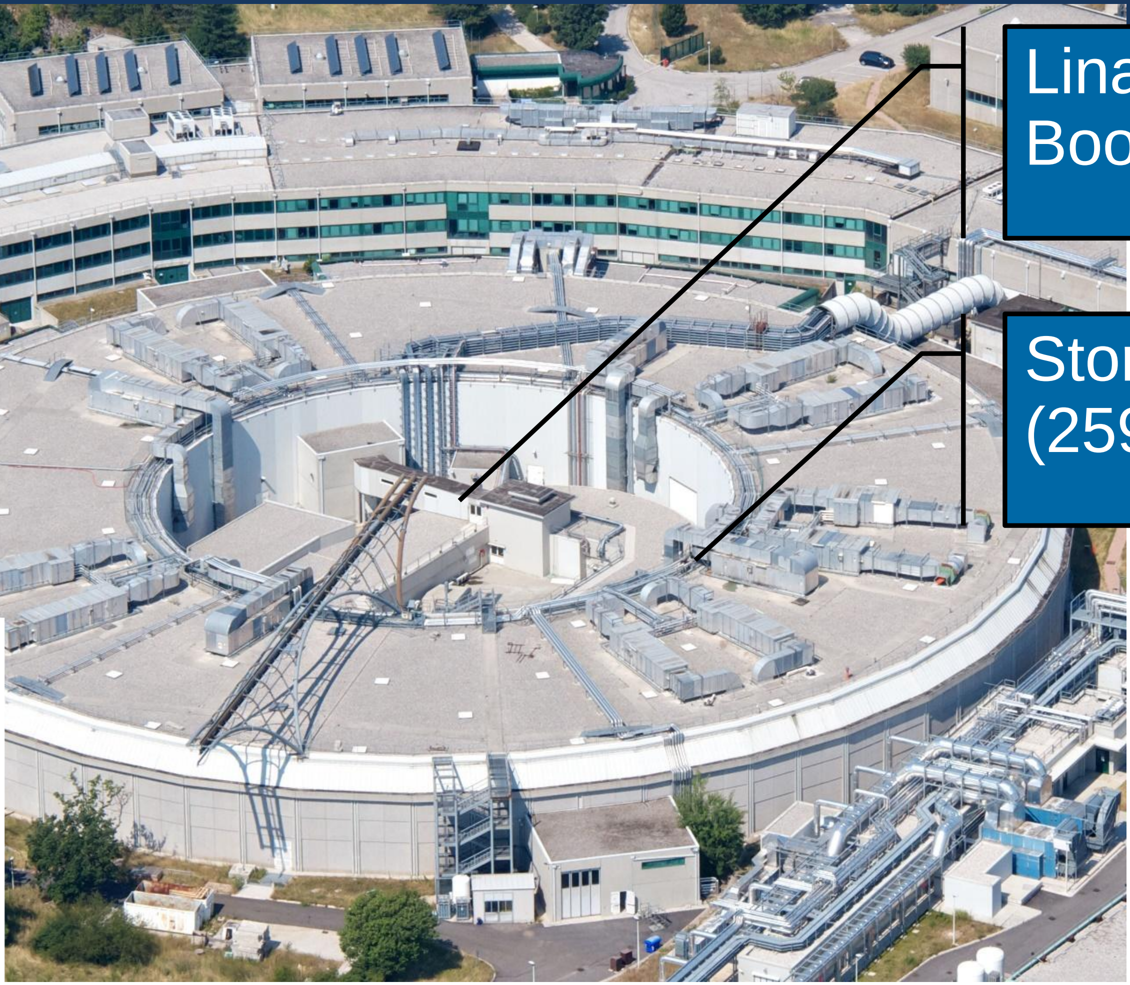
Parameter	Units	Value
Repetition rate	Hz	10 - 50
Bunch charge	pC	700
Peak current	A	700
Bunch length	ps	1.0
Energy	GeV	1.0 – 1.5
Energy spread	keV	100



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

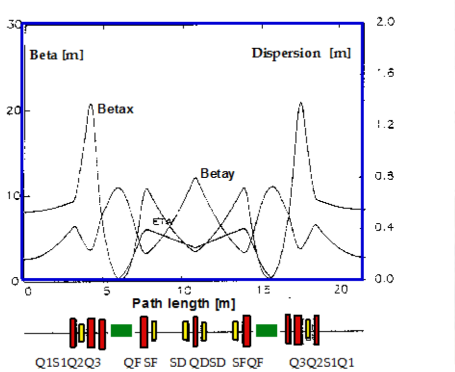
Elettra

- Third generation light source (DBA - 259.2 m) , open to external users since 1994
- The machine complex initially made of a 1 GeV linac and a storage ring operating at 2.0 (7nm-rad) and since 1998 also at 2.4 GeV, in 2008 built a full energy injector (2.5 GeV booster plus 100 MeV linac) and since 2010 operates in **top-up mode**.



Linac + Booster (114 m)

Storage Ring (259 m)

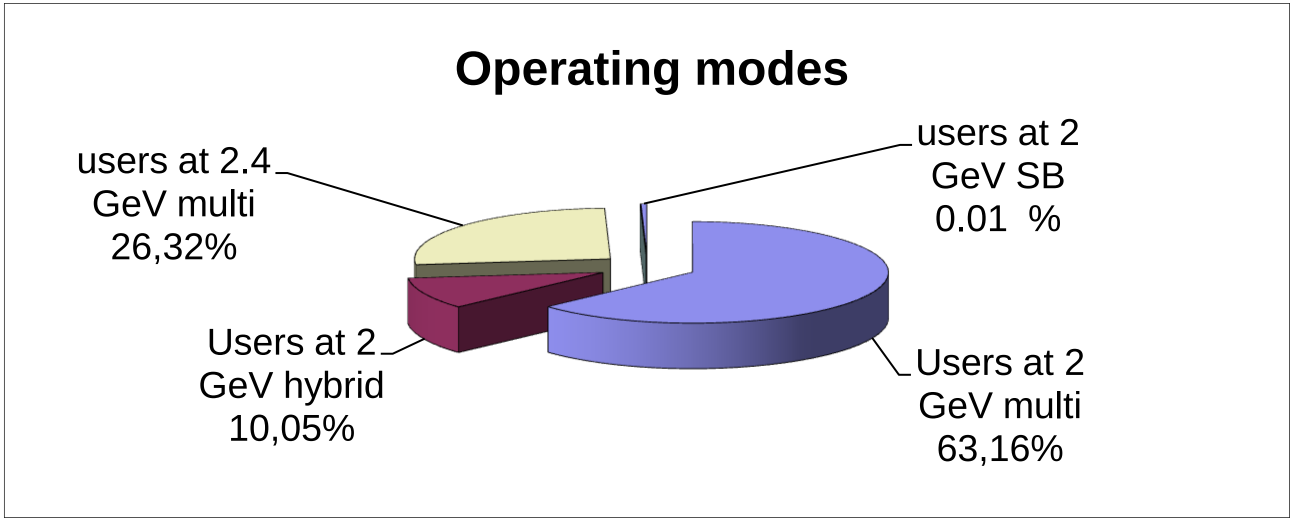


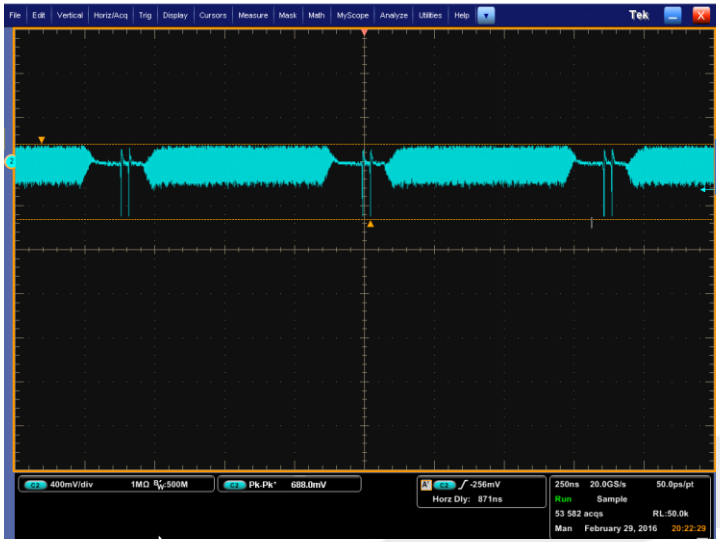
Operate also a **storage ring FEL** and **superconducting systems** (a 3.5 T wiggler and a third harmonic cavity)

Elettra in brief

Operating modes for users:

- Operates for 6400 hours per year (24h, 7/7), ≥ 5000 hours for users
- Top-up 2.0 GeV, 310 mA for 75 % of users time
- Top-up 2.4 GeV, 160 mA for 25 % of users time
- Filling patterns: multi-bunch 95 % filling or hybrid. Other filling patterns, as single bunch, few bunches or other multi-bunch fillings can be provided.
- 28 beam lines
- More than 900 proposals per year
- Oversubscription rate from 1.5 to 3 depending on the beamline.





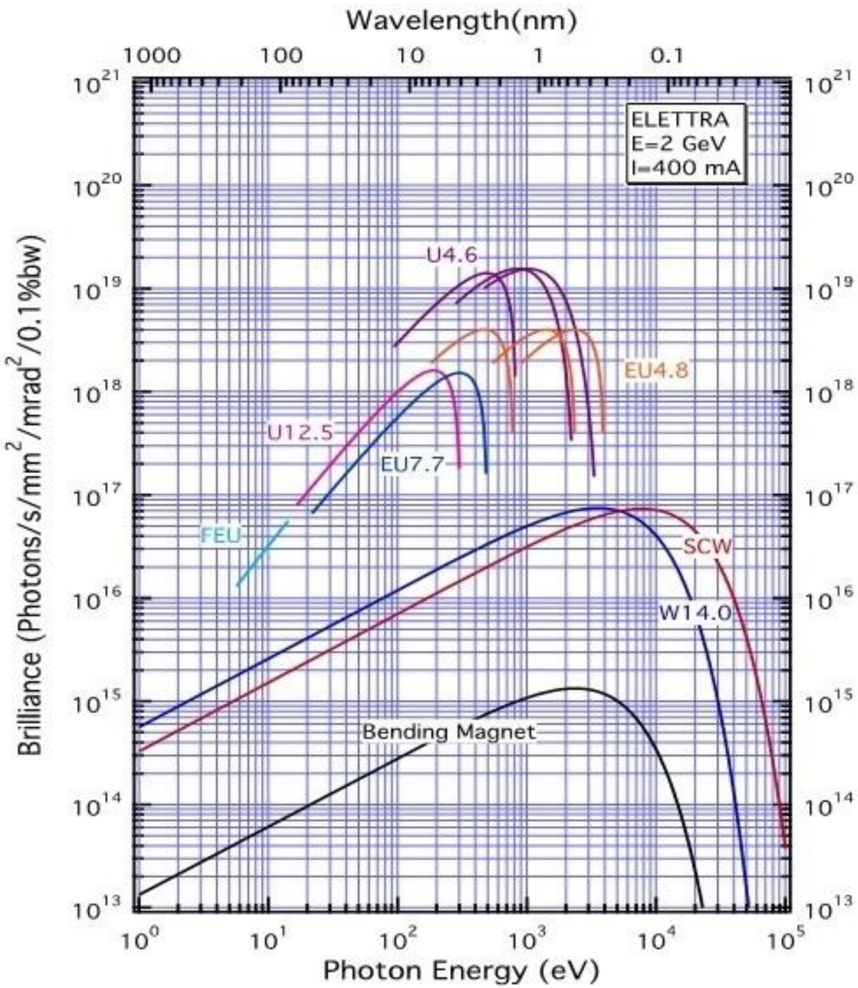
Lately high demand for time resolving

IDs and brilliance

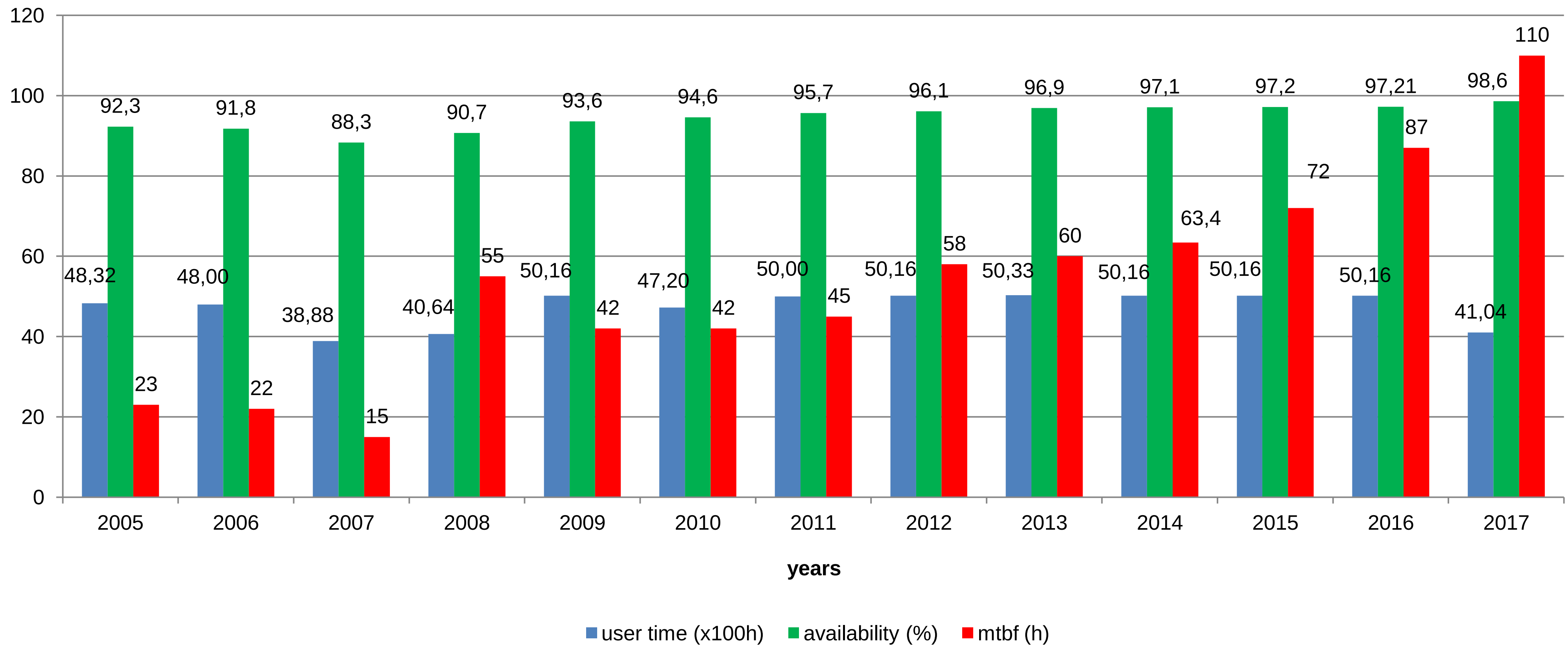
ID	type	section	Period (mm)	Nper	gap (mm)	status
U5.6	PM/Linear	12 short	56	18	23	operating
EU10.0	PM/Elliptical	1	100	20+20	13.5	operating
U4.6	PM/Linear	2	46	2 x 49	13.5	operating
U12.5	PM/Linear	3	125	3 x 12	32.0	operating
EEW	EM/Elliptical	4	212	16	18.0	operating
W14.0	HYB/Linear	5	140	3 x 9.5	22.0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

22 ID segments + 1 SCW -> 18 beam lines (planar, elliptical, canted, electromagnetic)

6 bending magnet source points serving 9 beam lines + 1 IR = 10 beam lines



Uptime Statistics



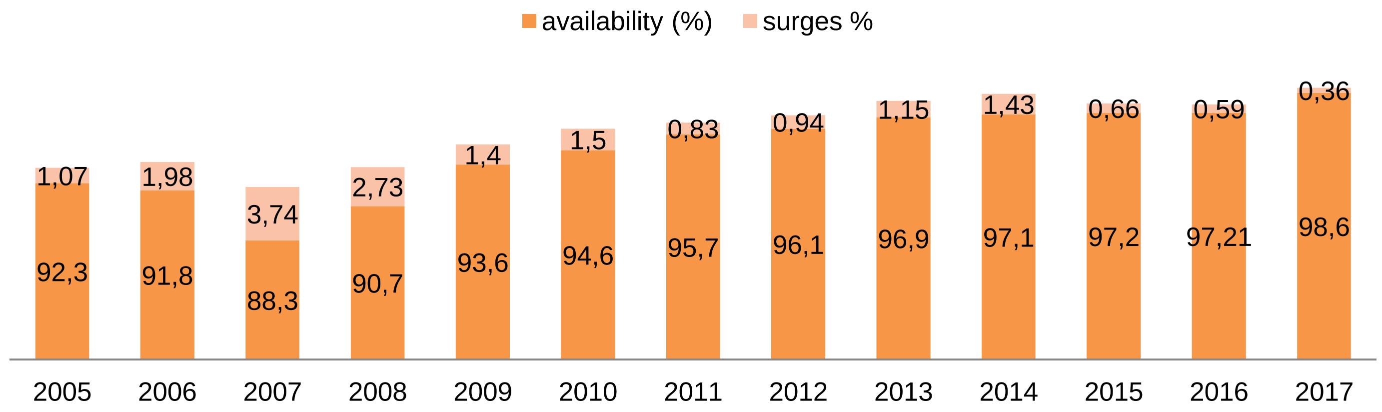
Maximum running without a beam dump: 603 hours , the average of maxima is about 300 hours

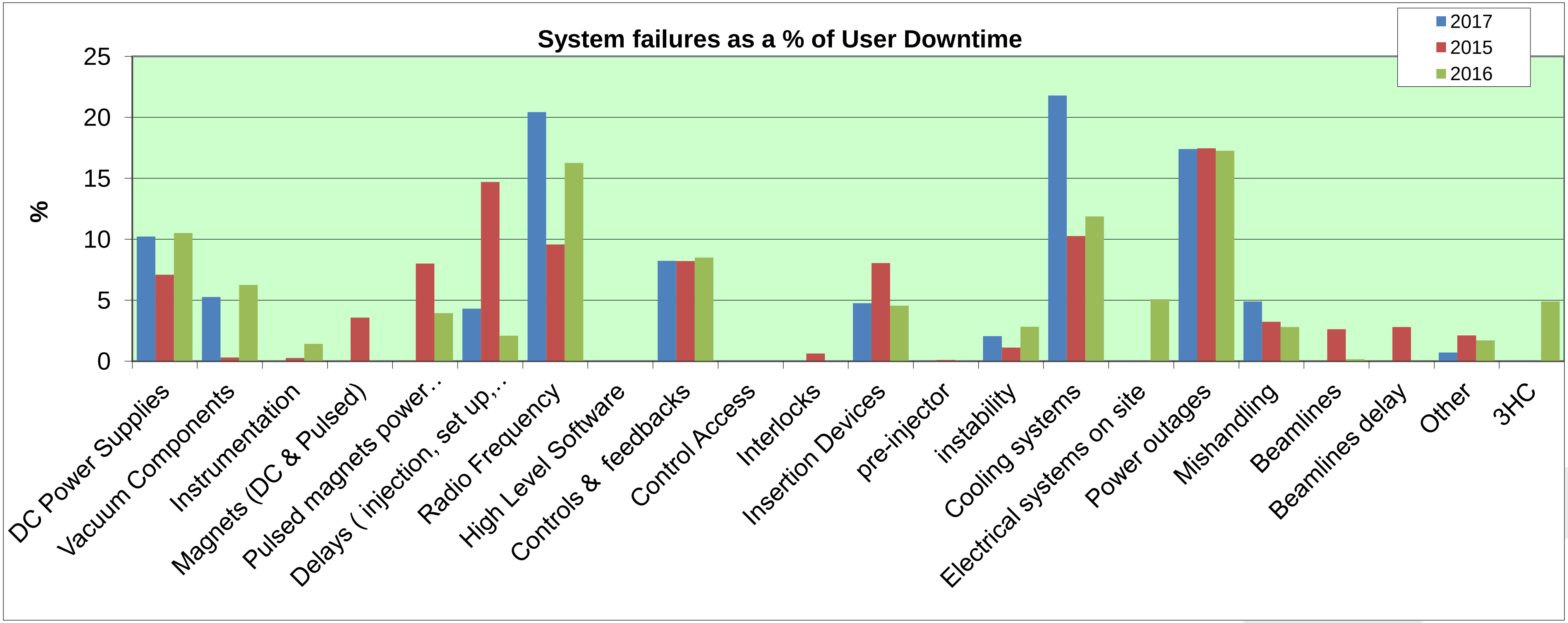
2017 data at 81.8% of total user run time

Mean fault duration ~ 1.0 hour

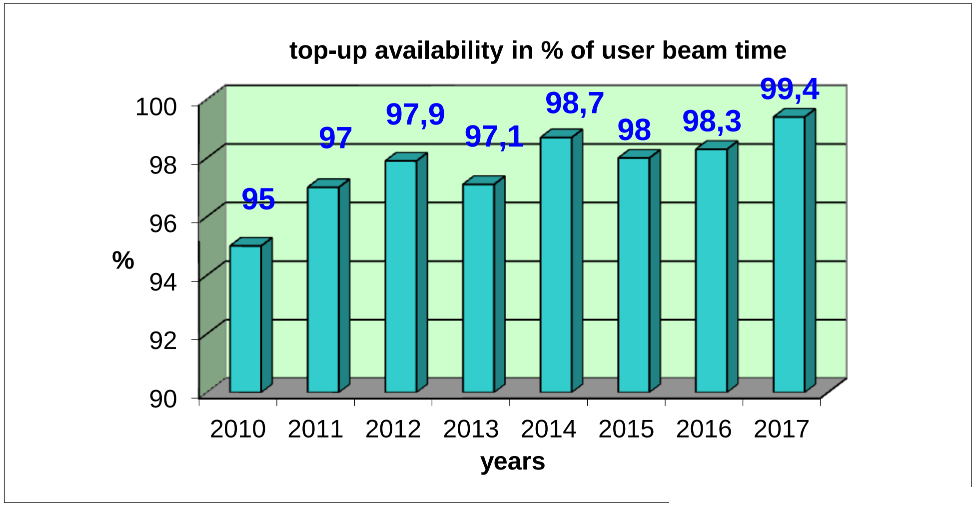
No downtime from the injectors

Total availability and downtime due to power surges



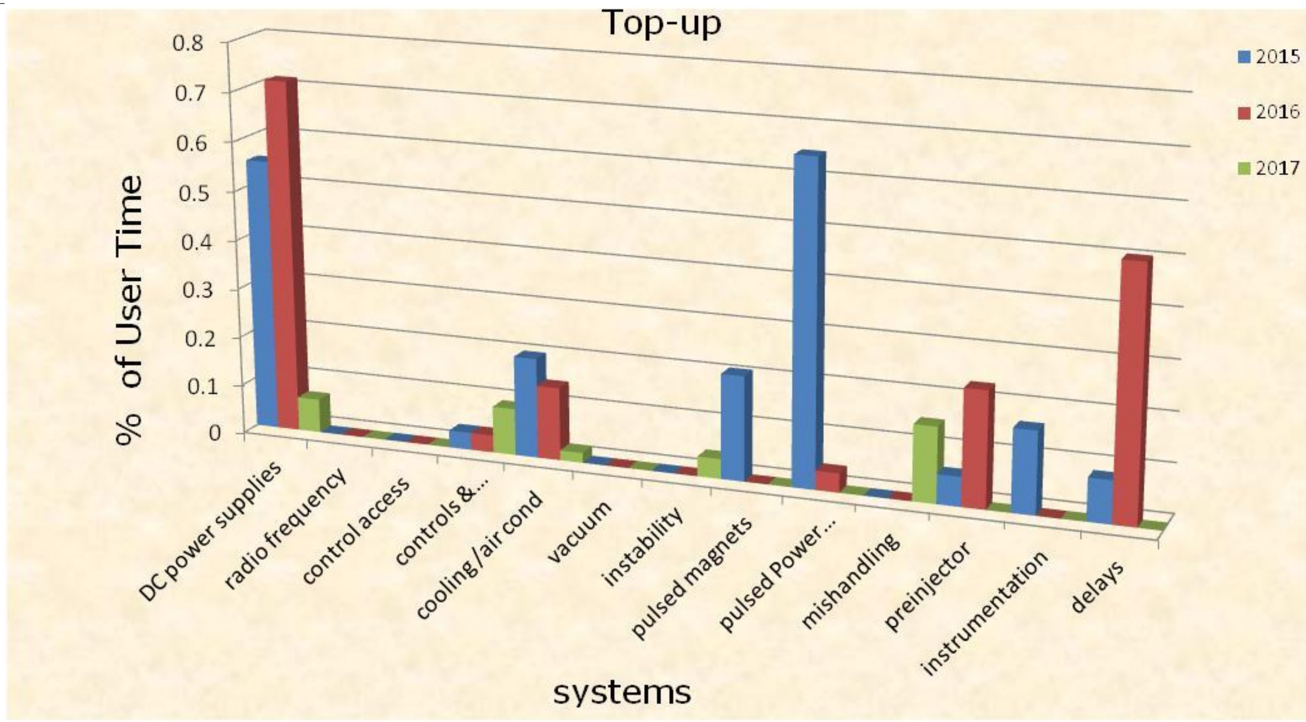


Top-up statistics



Electron orbit stability requirements meet most of the time provided that ambient temperature is within the defined limits, i.e., ± 0.5^0C
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).

System faults during top up down time.



Top-up down-time occurs when the intensity drops to less than 99.5% of the nominal.

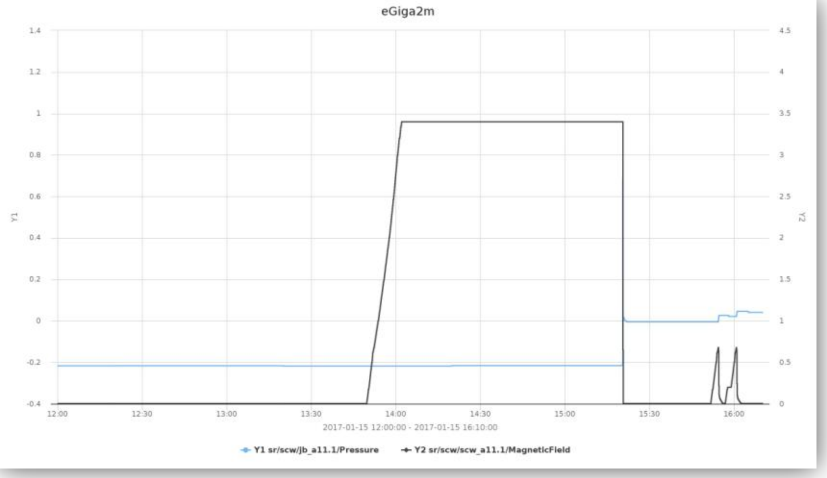
Pure down-time starts when intensity drops at 50% or less.

Some Problems

Problem 1. (minor) -> 2 beam lines inactive

On 15/1/2017 the superconducting wiggler after a quench could not exceed 0.63 T. The magnet suffered 12 quench in 2 years (3 at 2 GeV and 9 at 2.4 GeV). A quench protection system is developed and under tests.

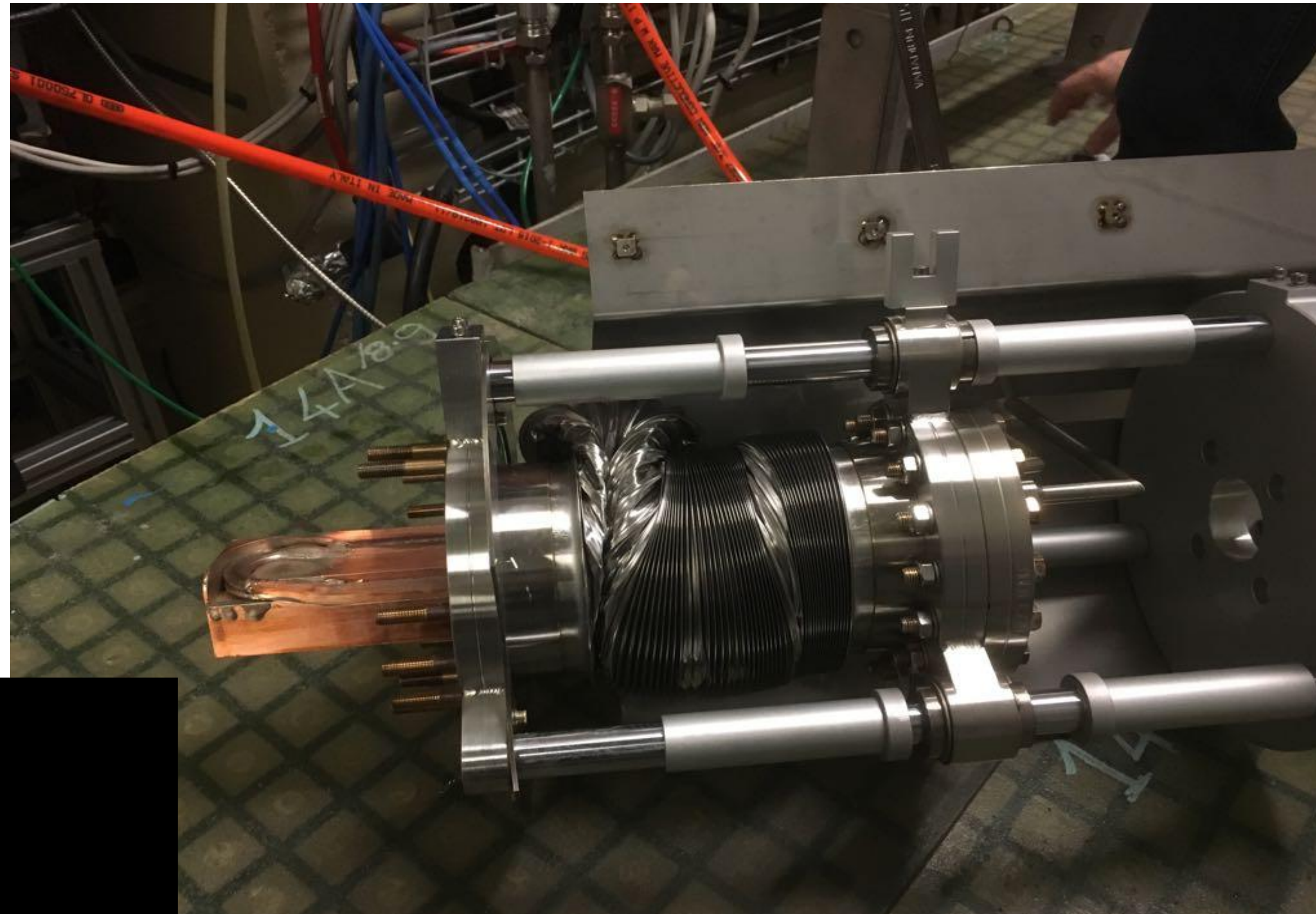
Until 7/2/2017 various tests performed indicated that the magnet is damaged. Two BINP experts came on 19/2 confirming that the magnet is damaged with most probably a short circuit. (the magnet was originally built in 2002 but remained unused until 2012 and damaged, BINP fixed the problem at that time with the occasion of the refurbishment of the cryostat in 2012 since the two relevant beam lines XRD2 and XPress were ready)



The magnet is rebuild by BINP and is expected to be assembled to the cryostat end of December 2017.

Problem 2 -> major flooding

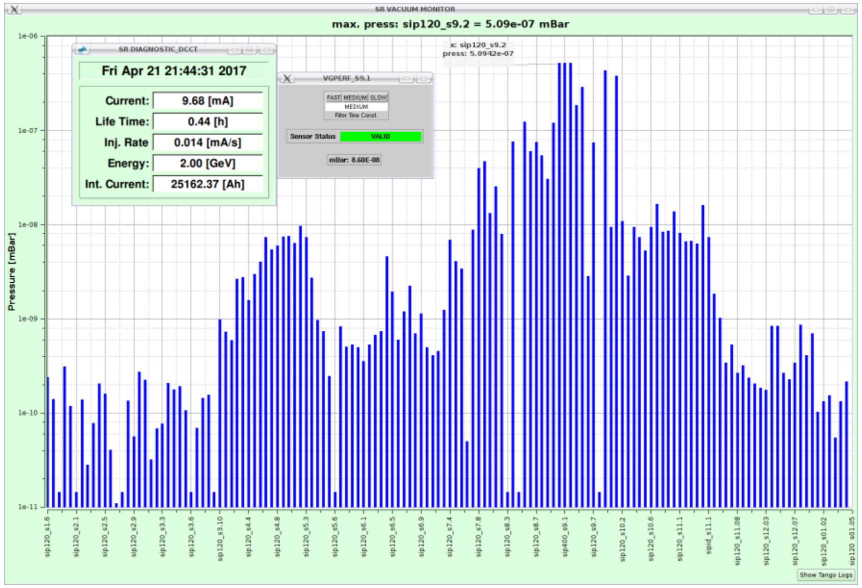
On 18/3 2017 suffered internal flooding due to a cooling tube blockage and a flow meter failure that did not trigger a beam dump



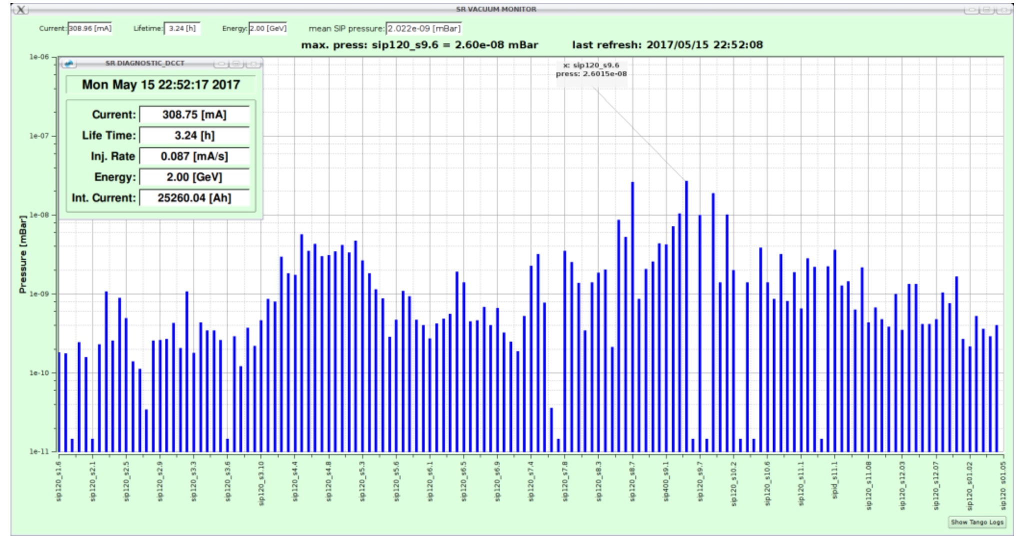
40 m of vacuum chamber flooded. The machine was repaired during the spring shutdown (1 month) and up in time for the next run (168, 20/4-11/6) but due to low lifetime (radiations) we decided to cancel the run for users and instead dedicate the run to vacuum conditioning.

Elettra Sincrotrone Trieste

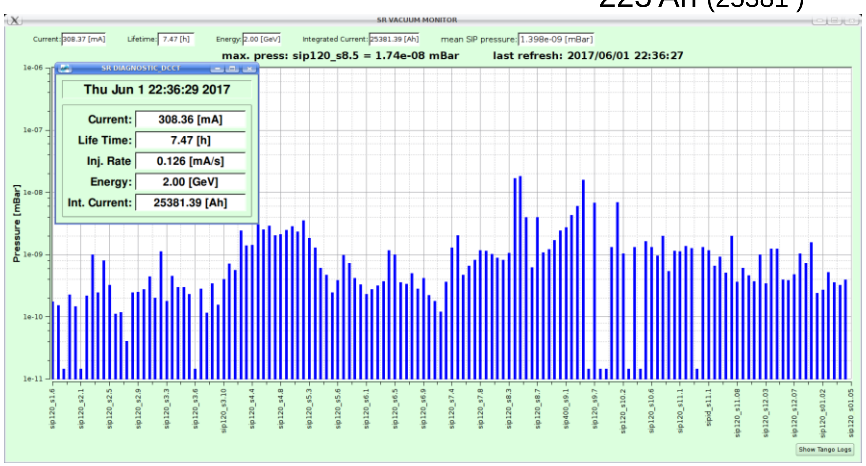
0 Ah *(25158)*



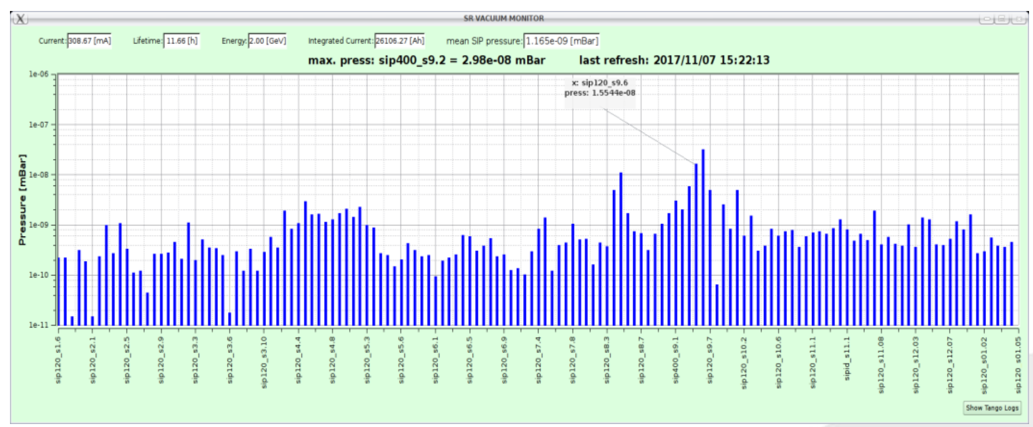
102 Ah *(25260)*



223 Ah (25381)



948 Ah (26106) **LT =12 h about 50% of the usual 24 h at 2 GeV 310 mA**



The above confirms what is already known: radiation conditioning is not efficient for water contamination. Changed all we could and had (spares), remaining parts will be changed during the winter shutdown

Elettra short and mid term developments

Elettra has been upgraded during the years to keep the performance competitive to the new light sources being built in the recent years. Some current upgrades include:

- ❑ RF upgrade (booster Solid State Amplifier)
- ❑ PS-controls upgrade
- ❑ Build new bpm electronics (detectors)
- ❑ Upgrade vacuum system electronics
- ❑ Fixed gap undulators

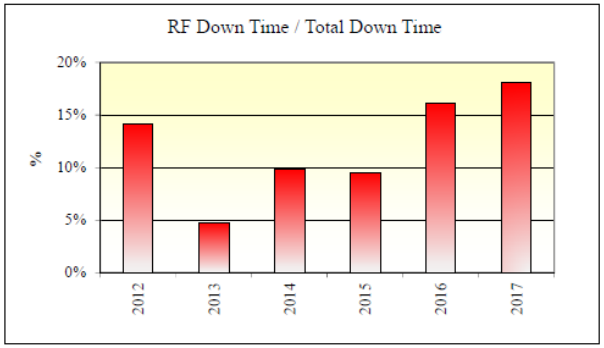
Studies perfomed to exploit the margins for other relatively low impact upgrades to extend the performance to the ultimate limits allowed by the present machine also in terms of operability and stability.

Some possibilities (and actualities) include :

- Increasing the energy to 2.5 GeV, 140 mA (reached 2.46 for more need additional PS)
- Reduction of the emittance, presently closest to the theoretical limit for a DBA, with DBC optics
- Low alpha optics for short bunches (coherent infrared – papers published)
- *Unifying space in the arcs, to integrate the two separated shorter straight section in a 2.5 m straight to provide possibilities for new insertion devices.*
- *Reduce the coupling by installing skew quadrupoles*

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

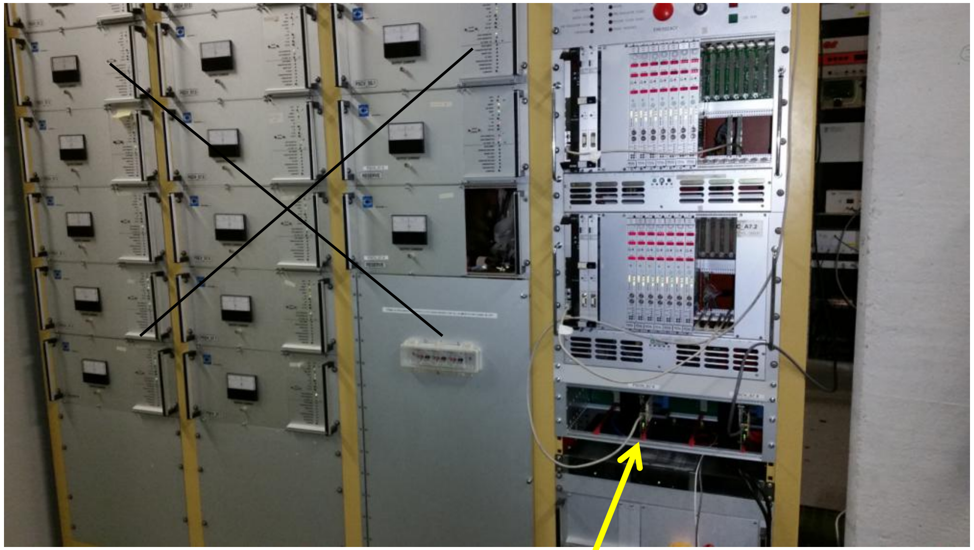
PS (controls) upgrade

- ✓ Almost all big PS have the new Beaglebone control system
- ✓ Some correctors have been replaced with the new ones, intent to replace all of them (2x82) soon (must be constructed) Already sold 4 to MAXIV, will be delivered about 180 to ESS.

old

new

old



new

Ref.
M Cautero , R. Visintini

New bpm detectors

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

First part done (DIAMOND expressed interest to collaborate)

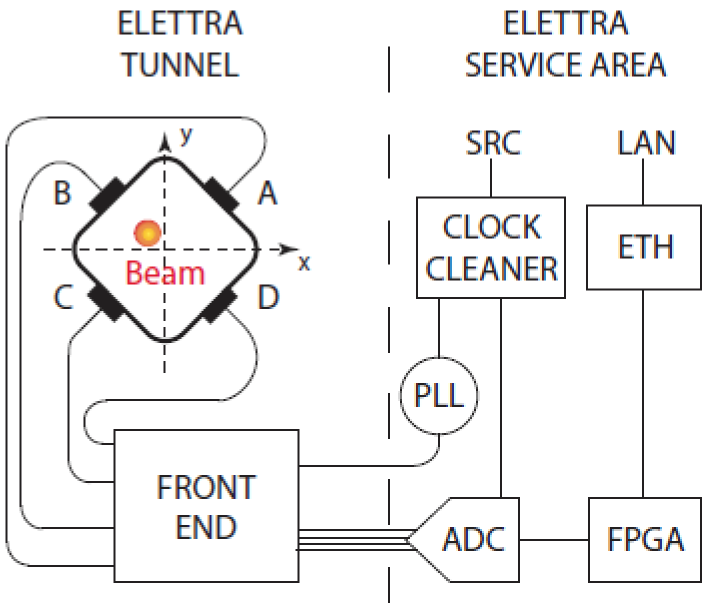
A NOVEL ELECTRON-BPM FRONT END WITH SUB-MICRON RESOLUTION BASED ON PILOT-TONE COMPENSATION: TEST RESULTS WITH BEAM

G. Brajnik, S. Carrato, University of Trieste

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

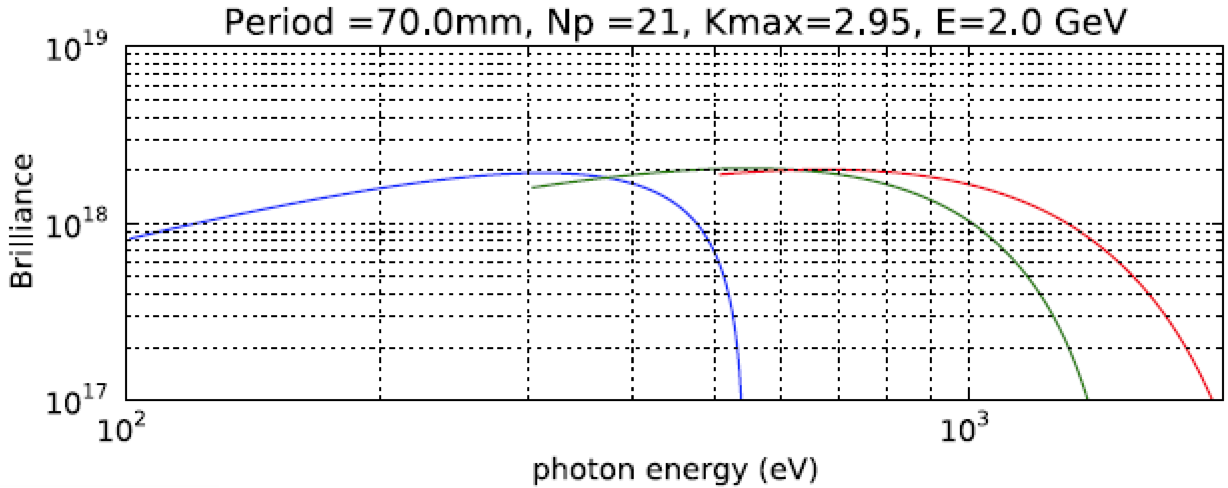
Proceedings of IBIC2016, Barcelona, Spain

Presented a 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.

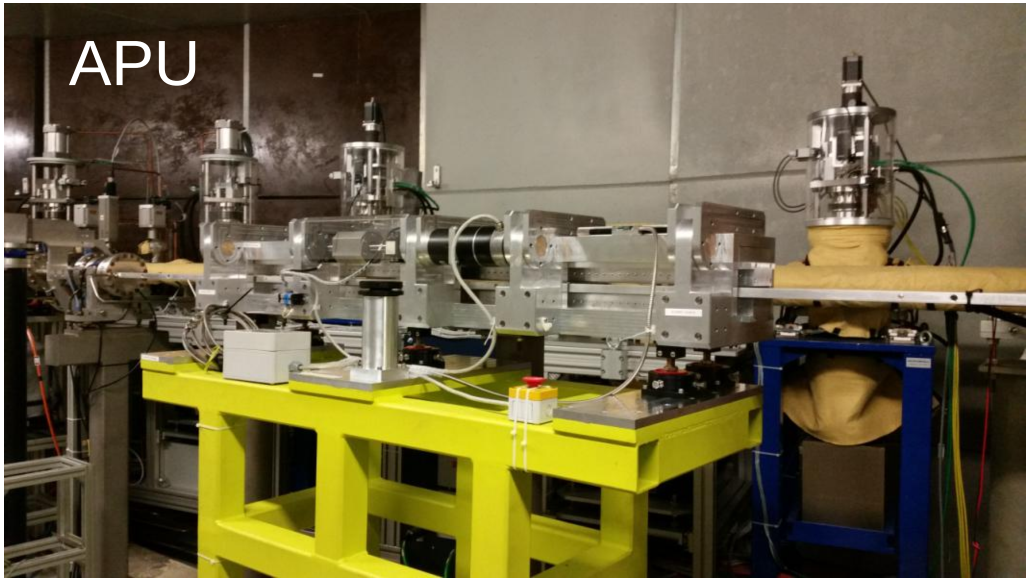


Fixed gap undulator

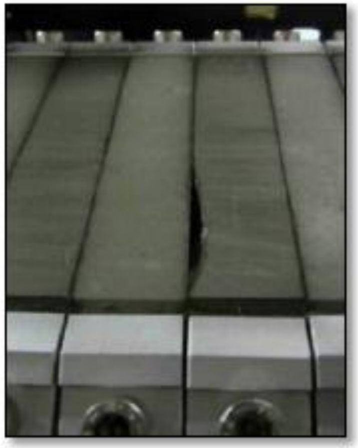
Installed for ALOISA beam line. Excellent performance and for operations almost "invisible"



Ref: B. Diviacco



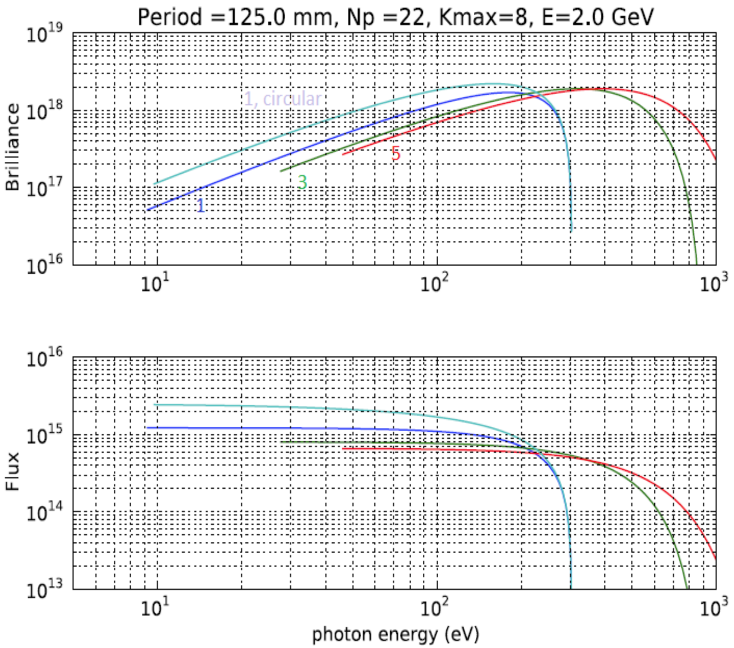
Original AGU: magnets from 1994
Material Neorem 450i uncoated



MOST Beam Line

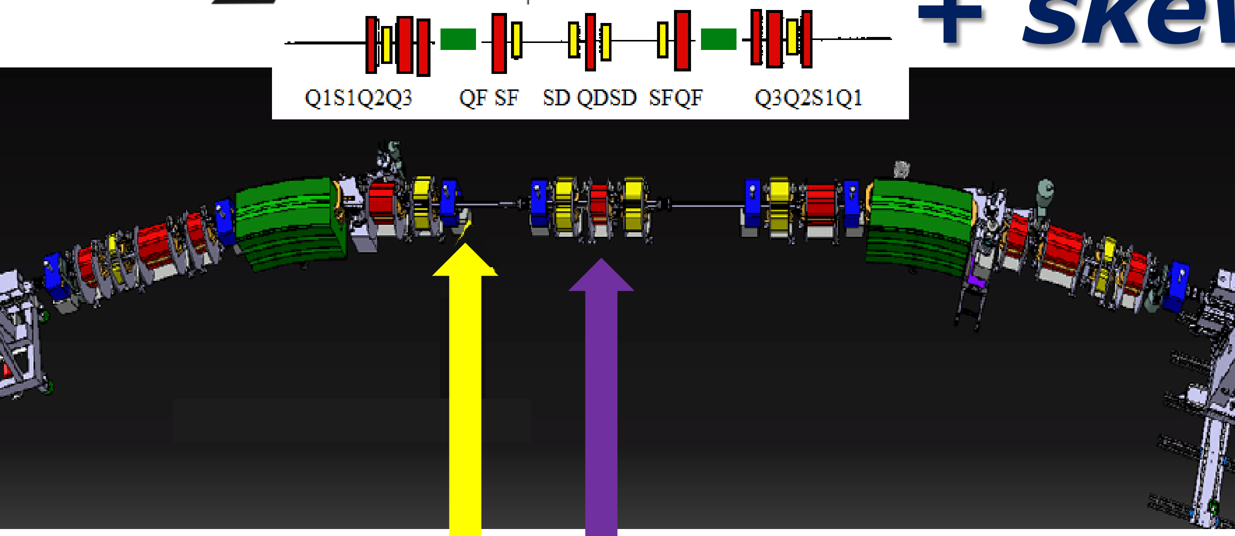
All straight sections of Elettra are occupied but still there is demand for new insertion device based beam lines. An upgrade plan is presently being developed which will merge the experiments running on the existing GasPhase and CiPo (Circular Polarization) beam-lines. Two new variable polarization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

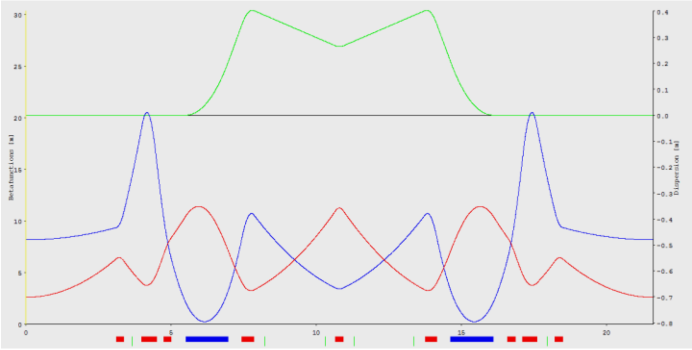
Unifying space in the arcs + skew quads



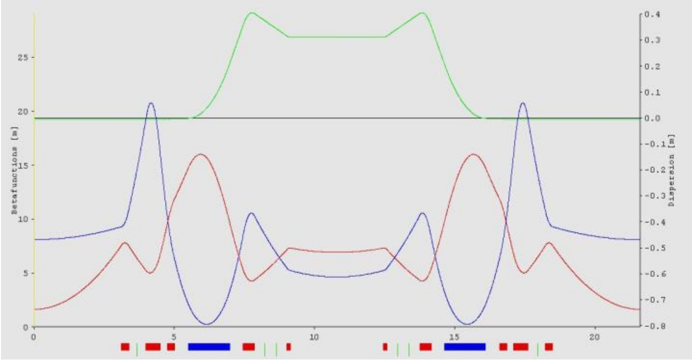
Room for skew quad, <0.3m

About 2.5 m unified free space can be gained (now are two separated 1 and 1.5) Need to build 2 quadrupoles / achromat

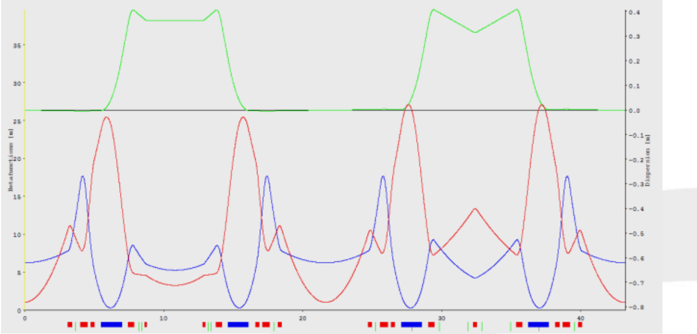
actual



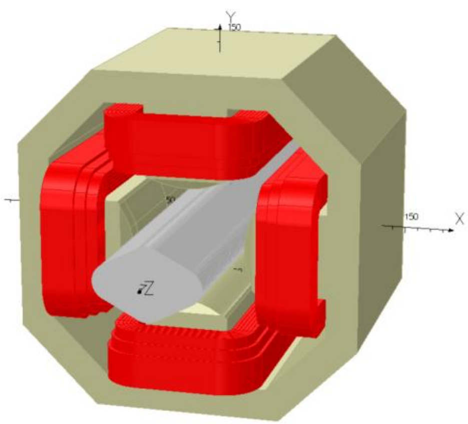
proposed



Same emittance, chromaticity etc.



Or for partial replacement (fully matched)



Magnetic design according to specification:

- physical length < 0.3 m
- integrated norm. strength $k_1 l < 0.015\ m^{-1}$
- bore diameter ≥ 85 m
- power supply at ≤ 20 A (30W)

Elettra 2.0

Based on latest trends in this field, i.e. next generation, ultimate light sources (ULS):

- Much higher brilliance (more than one order of magnitude at lower photon energies, e.g. 1 keV),
- High level of coherence in both planes (3rd generation sources have only high vertical coherence),
- Smaller spot size and divergence
- Higher flux and a variety of insertion devices.

A first version of the conceptual design for Elettra 2.0 based on the above is already available

Note: some of our users are not impressed / don't care and many are alarmed. Microscopy BLs seem happy.

Many don't care about emittance and coherence instead they ask for short pulses, high dipole fields and round beams.

Can a compromise be reached? To investigate it we organize the PHANGS workshop 4-5 Dec 2017 (https://www.elettra.eu/Conferences/2017/PHANGS/)

Elettra 2.0 requirements

- The requirements for the new machine have been developed based on the interaction with the users' community and considering costs optimization.
- A dedicated workshop on the future of Elettra was held in April 2014 to examine the various requirements

Design boundary conditions

Easier part

Beam energy: 2 GeV

Beam intensity: 400 mA

Emittance: to be reduced by more than 1 order of magnitude

Horizontal electron beam size: less than 60 µm

Conserve filling patterns: multibunch, hybrid, single bunch, few bunches

Keep the same building and the same ring circumference (259-260 m)

Existing ID beam lines and their position should be maintained

Free space available for IDs: not less than that of Elettra

Keep the existing bending magnets beam lines

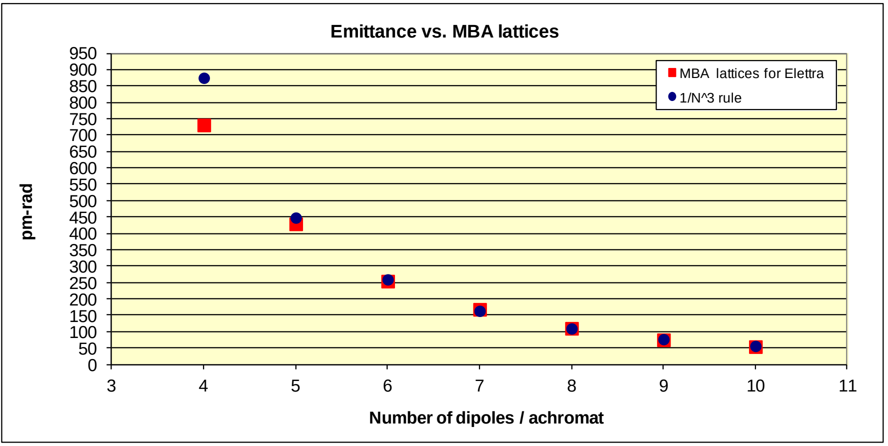
Use the existing injectors, that means off-axis injection

Minimize dark time

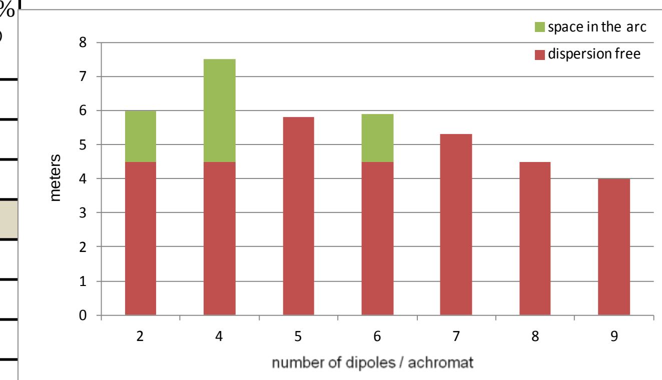
Tougher part

Elettra 2.0 Lattice quest

Elettra Sincrotrone Trieste



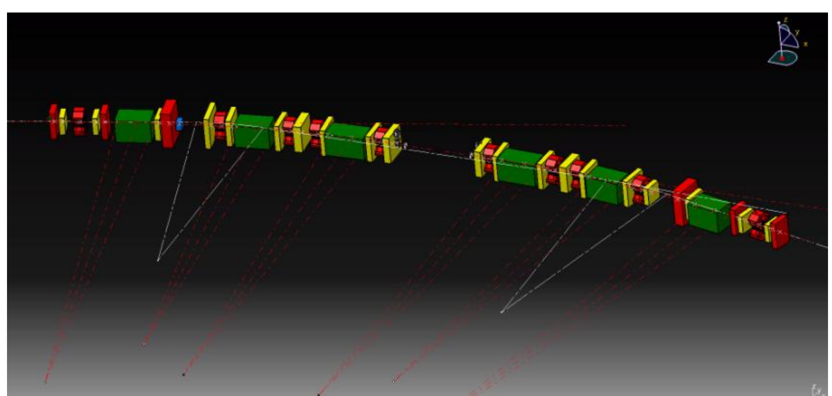
Number of dipoles / achromat	Emittance (nm-rad) @ 2 GeV	σ_x (μm) @ LS	σ_y (μm) @1% coupling @ LS
2	7	240	14
4	0.73	80	4.5
5	0.43	70	3
6	0.25	55	2.2
7	0.17	40	1.9
8	0.11	26	1.7
9	0.075	22	1.5
10	0.054	20	1.3



Best configuration up to now satisfying all requirements including large free space for IDs is based on a special six-bend achromat (S6BA). Versions that minimize interferences and induce minimal position shift of the dipole beam lines were examined. Possible new beam lines from central dipoles

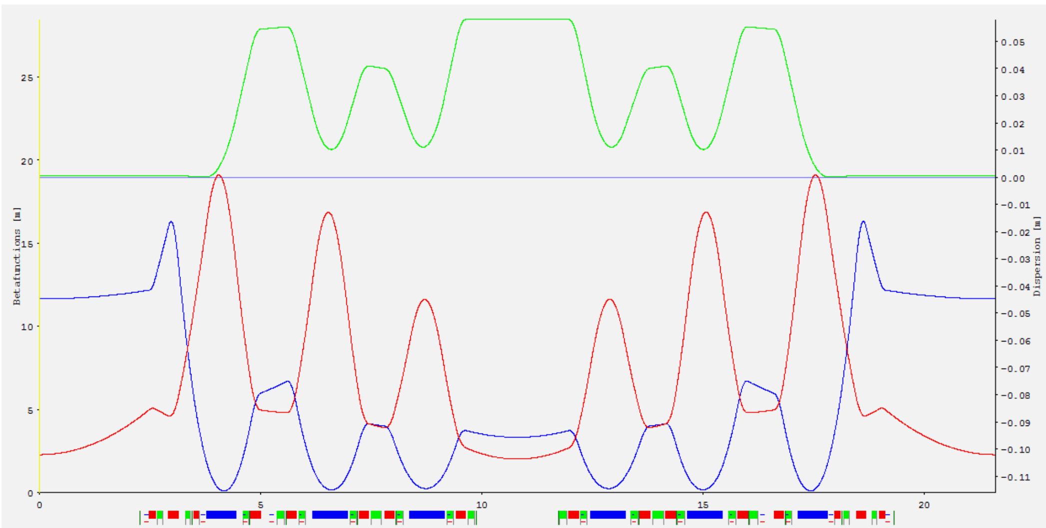
E. Karantzoulis,"Elettra 2.0 - The diffraction limited successor of Elettra", Nuclear Inst. and Methods in Physics Research, A 880 (2018) 158–165

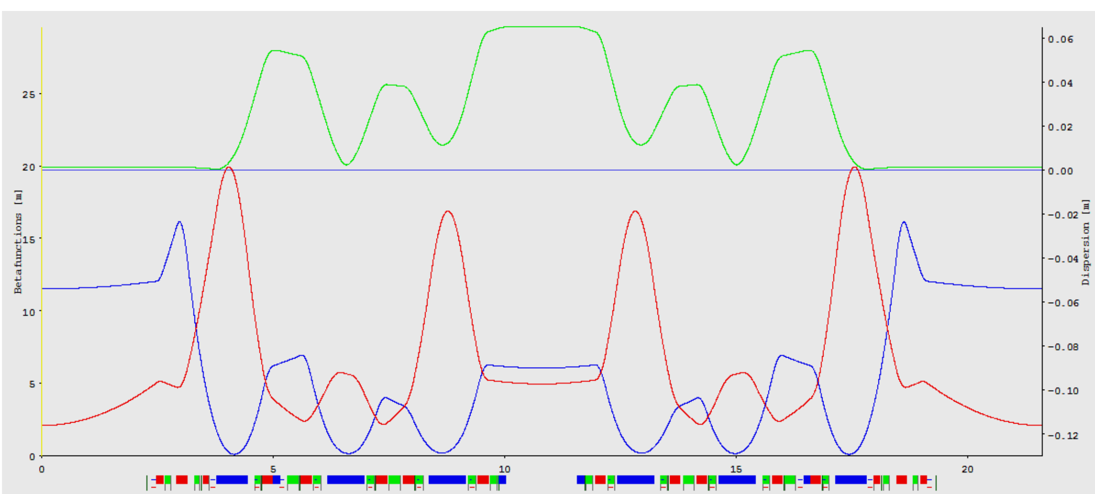
The S6BA arc



Latest version but maybe not final

Lattices



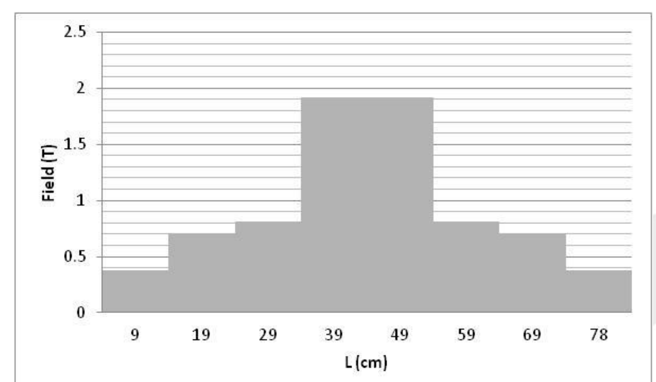


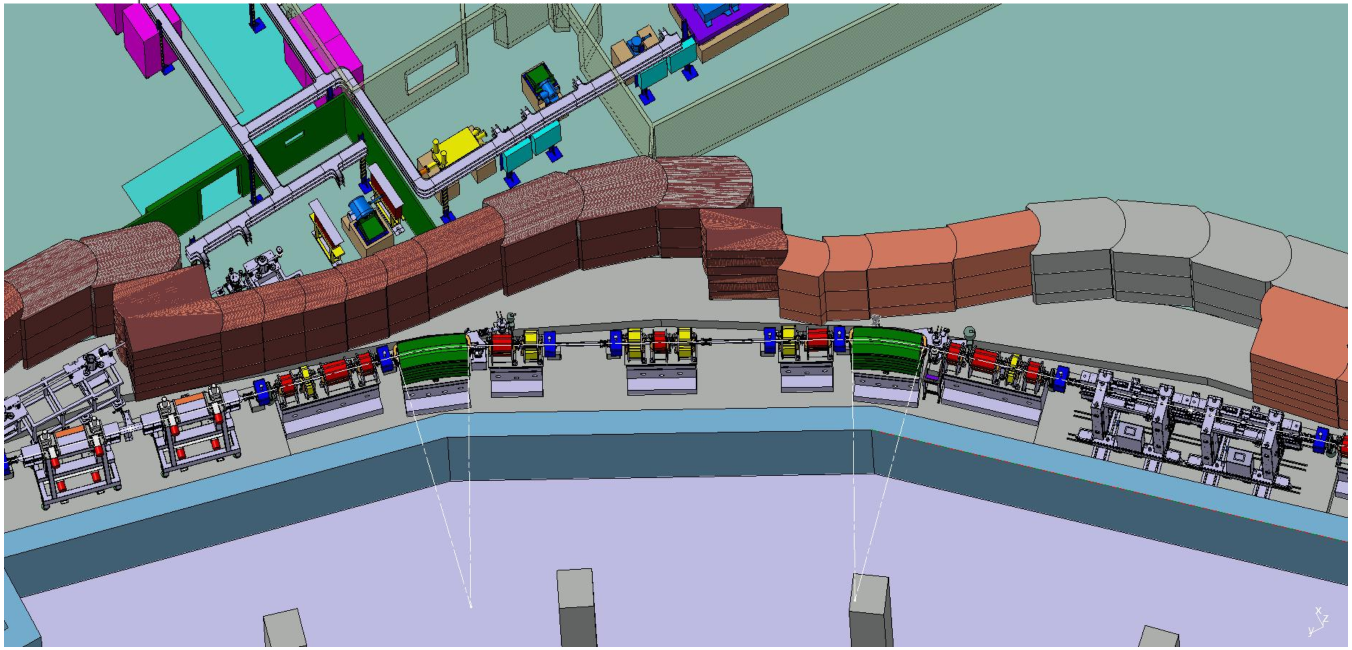
For graphics used "OPA version 3.39", PSI, 2014 by A. Streun

<u>Current version</u>:
Emittance 0.25 nm-rad
Dipoles electromagnets at 0.8 T
No Longitudinal Gradient (LG)
BUT Users ask for higher dipole fields

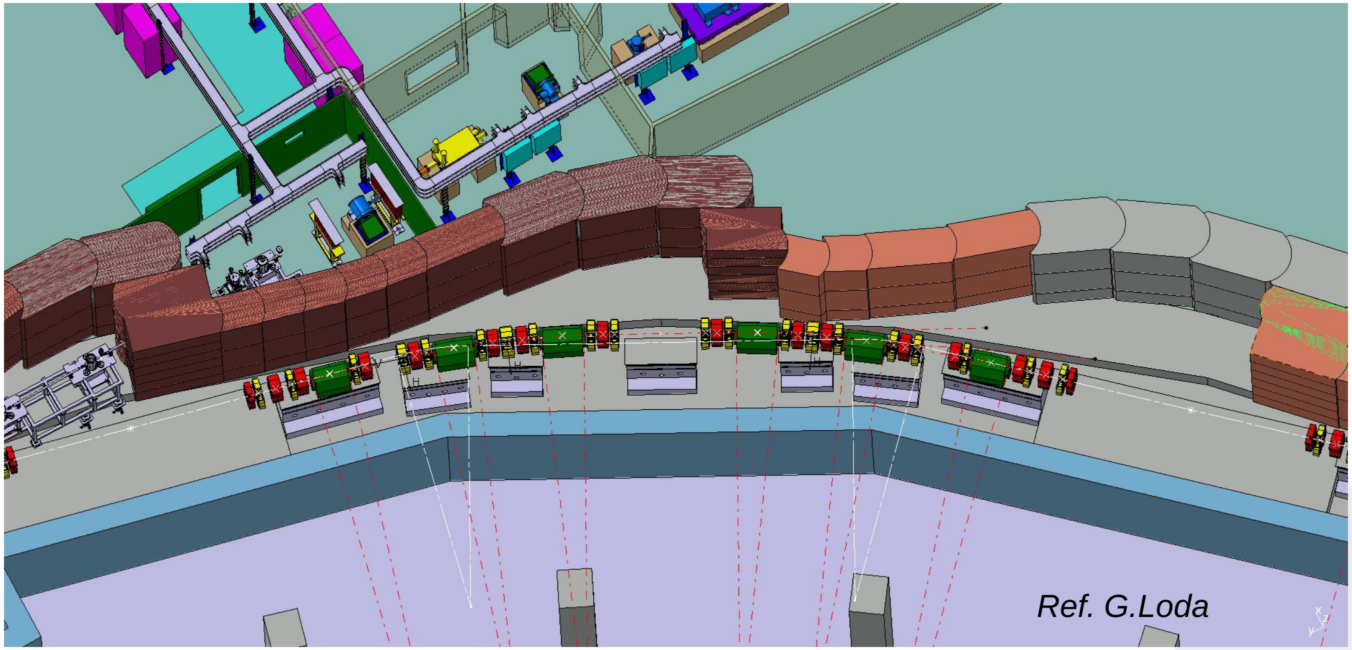
For round beams consider a ~57% reduction on both emittances

LG+anti-bend version:
Emittance 0.19 nm-rad
The 2 and 5 dipoles in LG.





Fits in the old tunnel



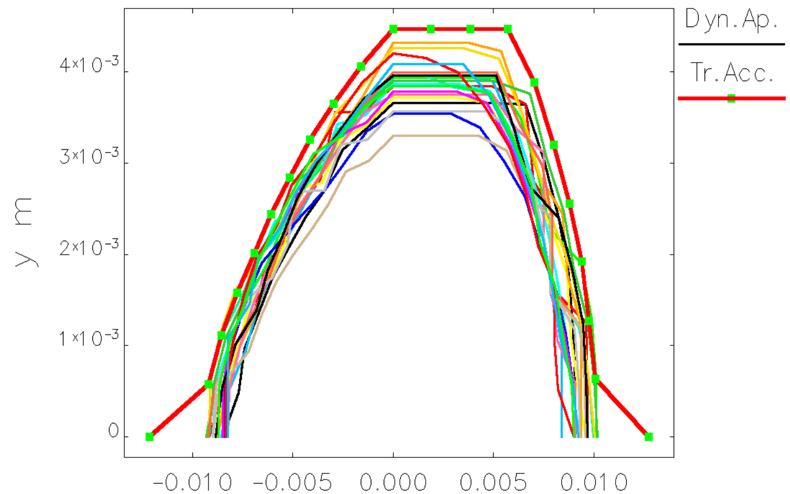
List of optics and rf functions and magnet errors

Circumference (m)	259.2
Energy (GeV)	2
Number of cells	12
Geometric emittance (nm-rad)	0.25
Horizontal tune	33.10
Vertical tune	9.19
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
Momentum compaction second order	3.60e-004
Energy loss per turn (with no IDs) (keV)	156
Energy spread	6.67e-004
Jx	1.52
Jy	1.00
Jdelta	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)	2.16 , 7.2
Synchrotron frequency (kHz)	5.23

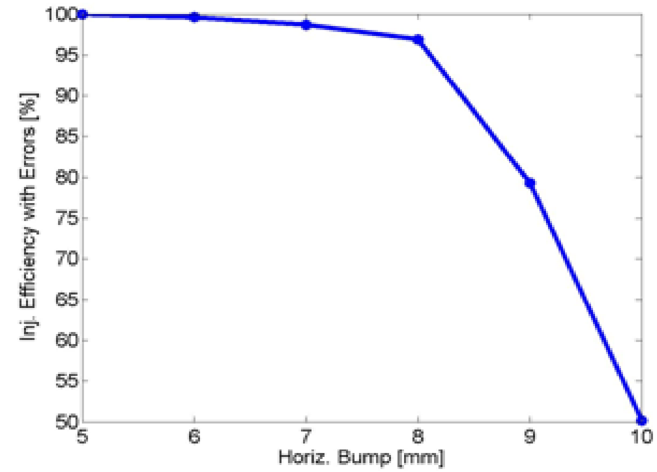
Element Type	Parameter	Value	Unit
Dipole	Δx	20	μm
	Δy	20	μm
	Δz	300	μm
	Roll angle	100	μrad
	ΔBl/Bl	0.01	%
Quadrupole	Δx	20	μm
	Δy	20	μm
	Δz	300	μm
	Roll angle	100	μrad
	ΔBl/Bl	0.01	%
Sextupole	Δx	20	μm
	Δy	20	μm
	Δz	300	μm
	Roll angle	100	μrad
	ΔBl/Bl	0.01	%
Corrector	Δz	20	μm
	Roll angle	100	μrad
BPM	Δx	20	μm
	Δy	20	μm
	Δz	300	μm
	Roll angle	100	μrad

DA with errors and IDs

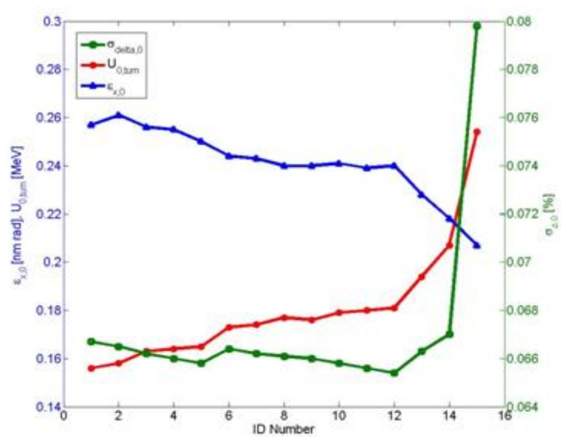
Elettra Sincrotrone Trieste



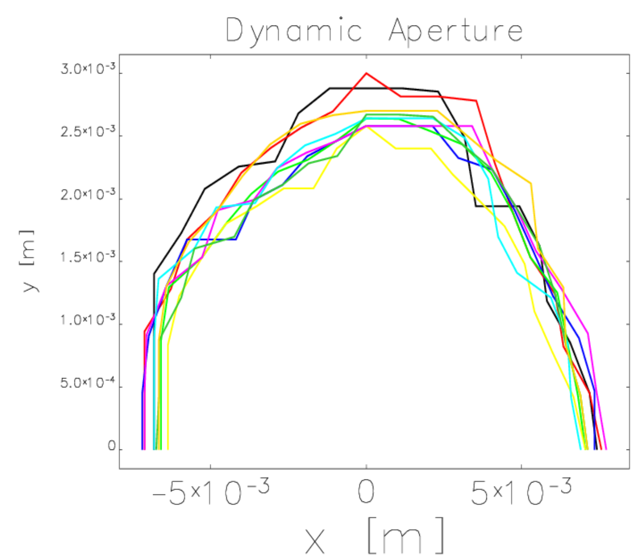
Dynamic aperture for the bare lattice, and in the presence of machine errors plus corrections, for 20 independent error seeds



Injection efficiency versus the horizontal beam bump amplitude



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

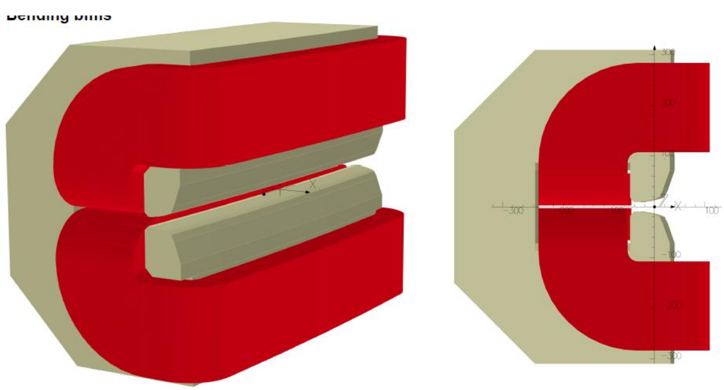


On-energy dynamic aperture with all IDs at functioning settings with alignment errors and the induced optical asymmetries. The wiggler is set to 3.5 T.

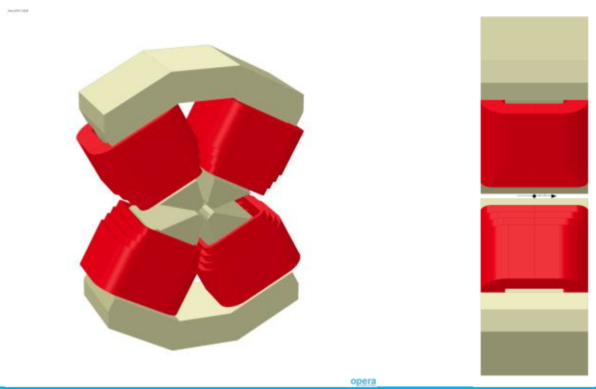
"elegant" runs ref. S. Di Mitri

Magnets

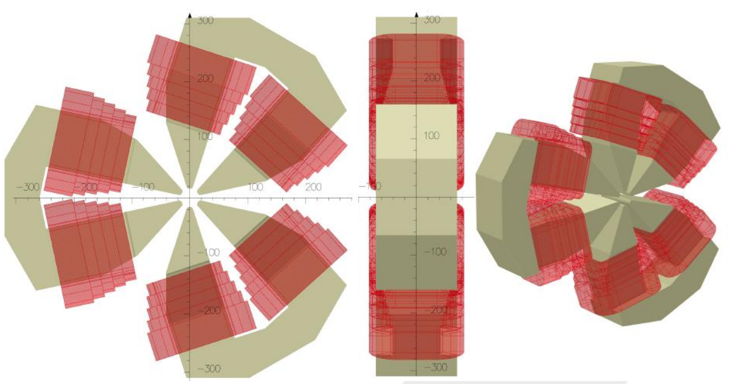
Almost final with Lm≈Lp (worst case 10 mm difference). Use of new materials such as Cobalt – Iron alloys will also be considered



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.



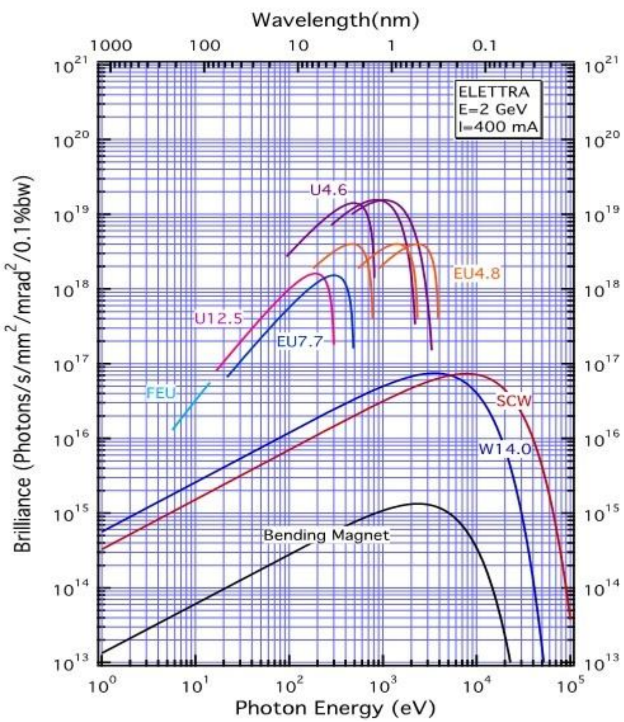
The sextupole magnets have the higher design issue. The transversal interferences between coils and vacuum chamber are resolved.

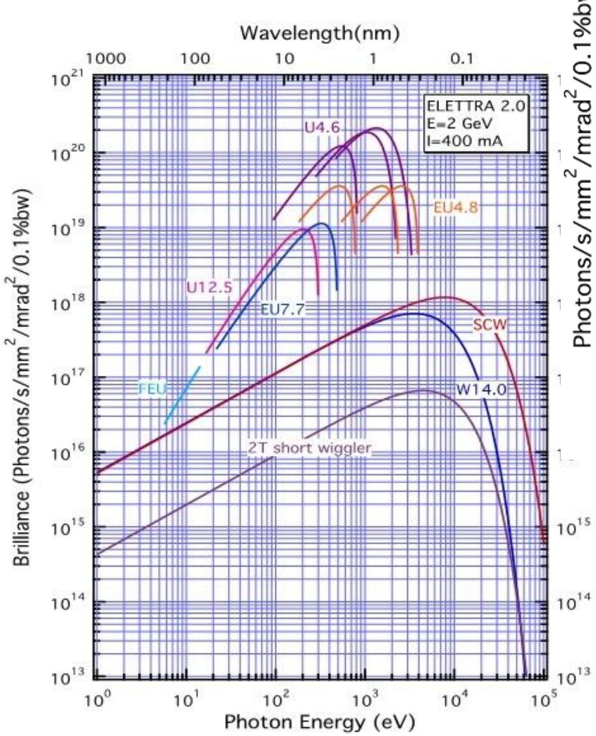
Ref. D. Castronovo (Opera)

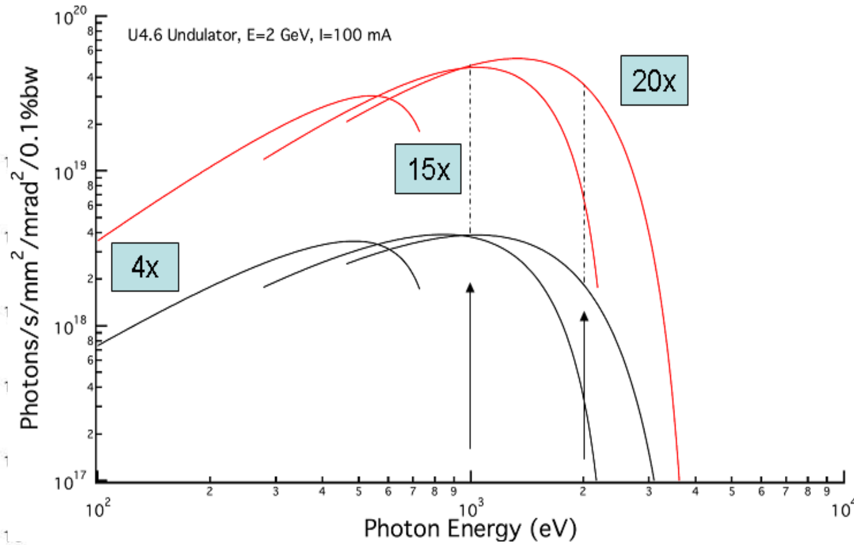
Elettra 2.0 brilliance

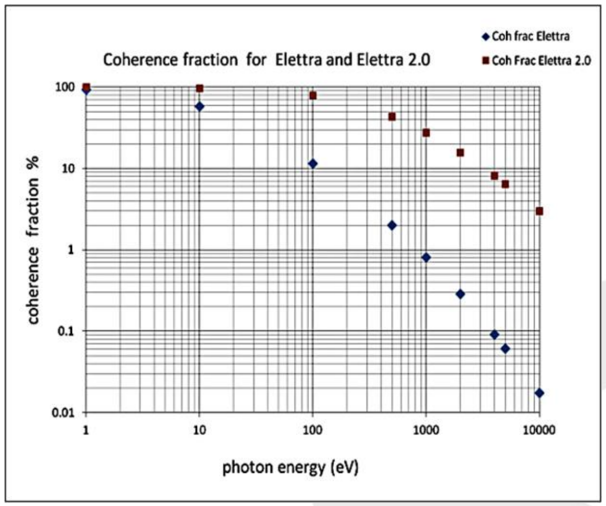
Assuming the existing IDs

Ref. B. Diviacco









Elettra and Elettra2.0

Parameter	Units	Elettra	Elettra2.0
Circumference	m	259.2	259.(2-8)
Energy	GeV	2 - 2.4	2
Horizontal emittance	pmrad	7000	230-280
Vertical emittance	pmrad	70 (1% coupl)	2.5
Beam size @ ID ($\sigma x, \sigma y$)	μm	245 , 14 (1% coupl)	43 , 3
Beam size at short ID	μm	350 , 22 (1% coupl)	45 , 3
Beam size @ Bend	μm	150, 28 (1% coupl)	17 , 7
Bunch length	ps	18 (100 with 3HC)	9 (70-100 with 3HC)
Energy spread	DE/E %	0.08	0.07
Bending angle half achromat	degree	15	3.6 and 2x5.7
Lattice		DBA	S6BA

Conclusions

- ✓ Elettra is running well although is 24 year old, many small projects contribute to this including replacement of old / obsolete hardware.
- ✓ The water flooding was mainly due to human negligence
- ✓ The first version of the conceptual design for Elettra 2.0 is available (Elettra 2.0 Technical Conceptual Design Report", ST/M-17/01, Elettra – Sincrotrone Trieste, internal document (2017)) Looking for money (170 Meuro including machine, infrastructures and beam lines)
- ✓ Many mid term possibilities also in discussion (for less money)

- ✓ FERMI@Elettra runs successfully giving unique opportunities to experimentalists.
- ✓ The EEHG will be tested soon.


Thank you for your attention

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

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	0
ALBA	1
SOLEIL	1
DIAMOND	1