Report on Elettra

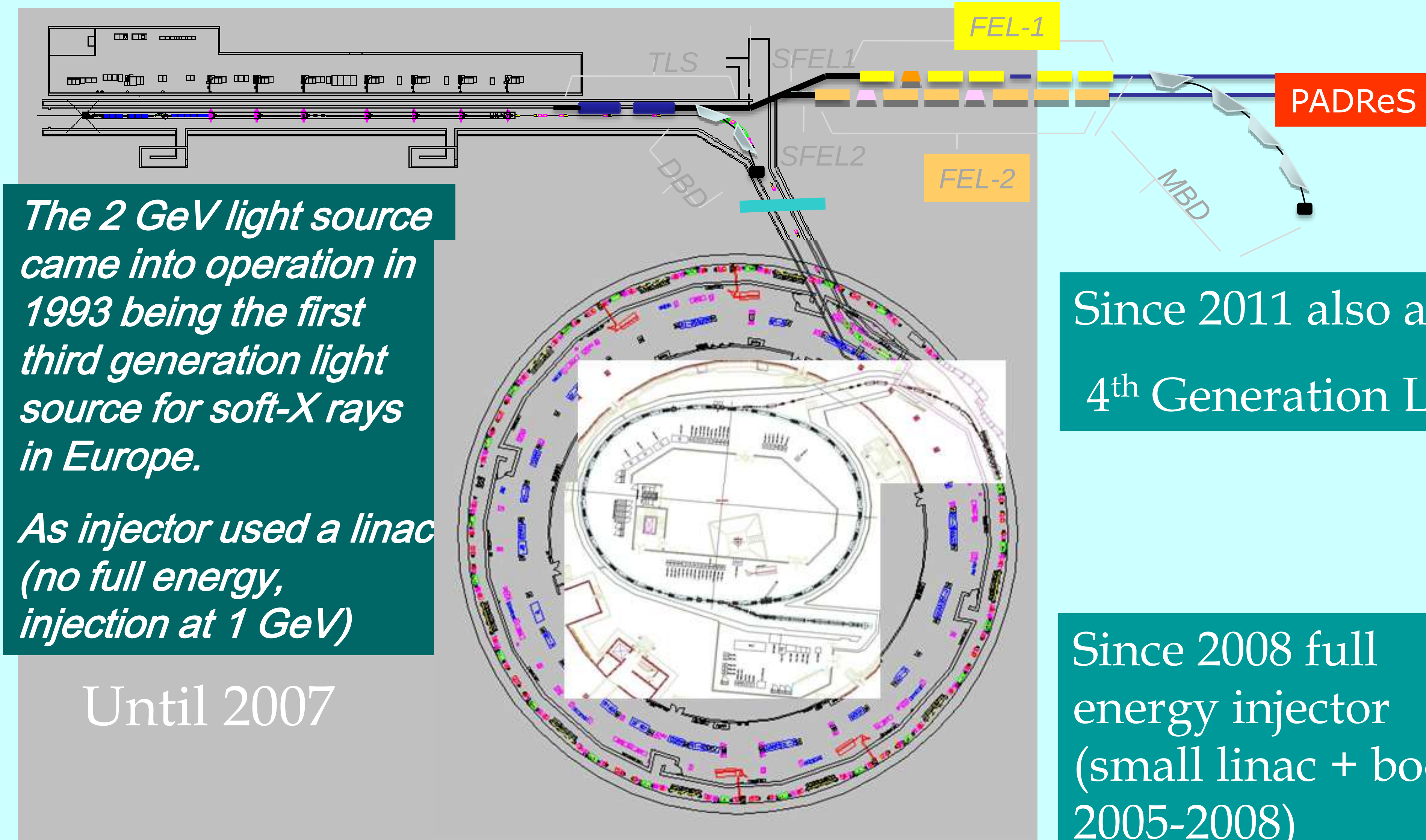
Emanuel Karantzoulis

on behalf of the Elettra Team

Outline

1. Introduction Elettra and FERMI@ELettra
2. Elettra and its Injector
3. How Elettra Operates
4. Top Up
5. Performance & statistics
6. Upgrade projects

Elettra complex



The 2 GeV light source came into operation in 1993 being the first third generation light source for soft-X rays in Europe.

As injector used a linac (no full energy, injection at 1 GeV)

Until 2007

Since 2011 also a

4th Generation LS

Since 2008 full energy injector (small linac + booster 2005-2008)

The accelerators

Elettra consists of:

- 2.4 GeV third generation light source
- 2.5 GeV Booster
- 100 MeV conventional linac
- 26 beam lines (including a SR-FEL) + 2 in construction

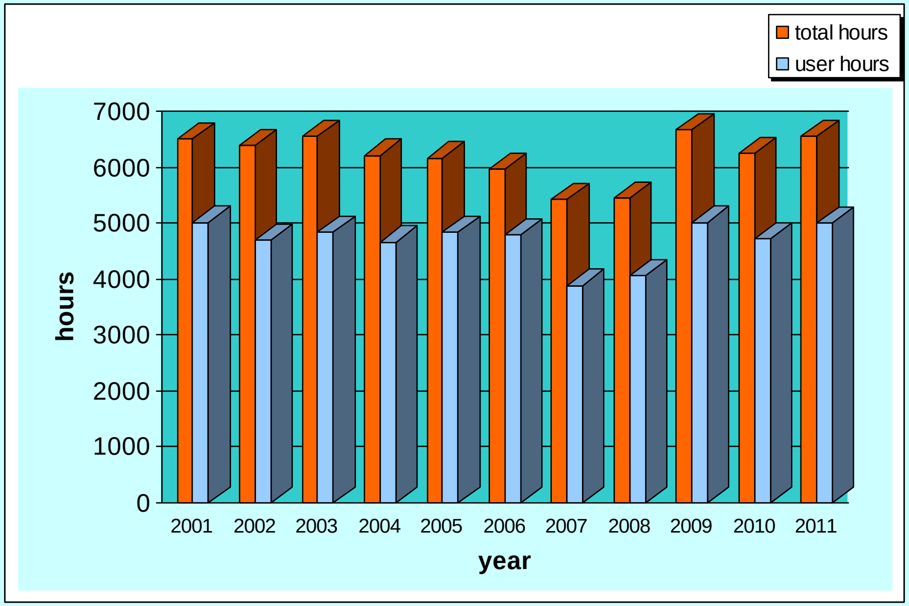
FERMI@Elettra consists of:

- 1.2 -1.8 GeV conventional S / X band linac with photon injector
- a double x120 m e- beam transport line + undulators
- 3 beam lines in construction

Some numbers from the lab

- 450 persons (330 (238+92) +120)
- 750 proposals/year (only Elettra)
- 1000 users / year (only Elettra)
- Many publications on scientific magazines (>150/year)
- SR-FEL 10 Phys. Rev. Letters

Elettra functions 24 hours/day and dedicates 5000 h/year to the users



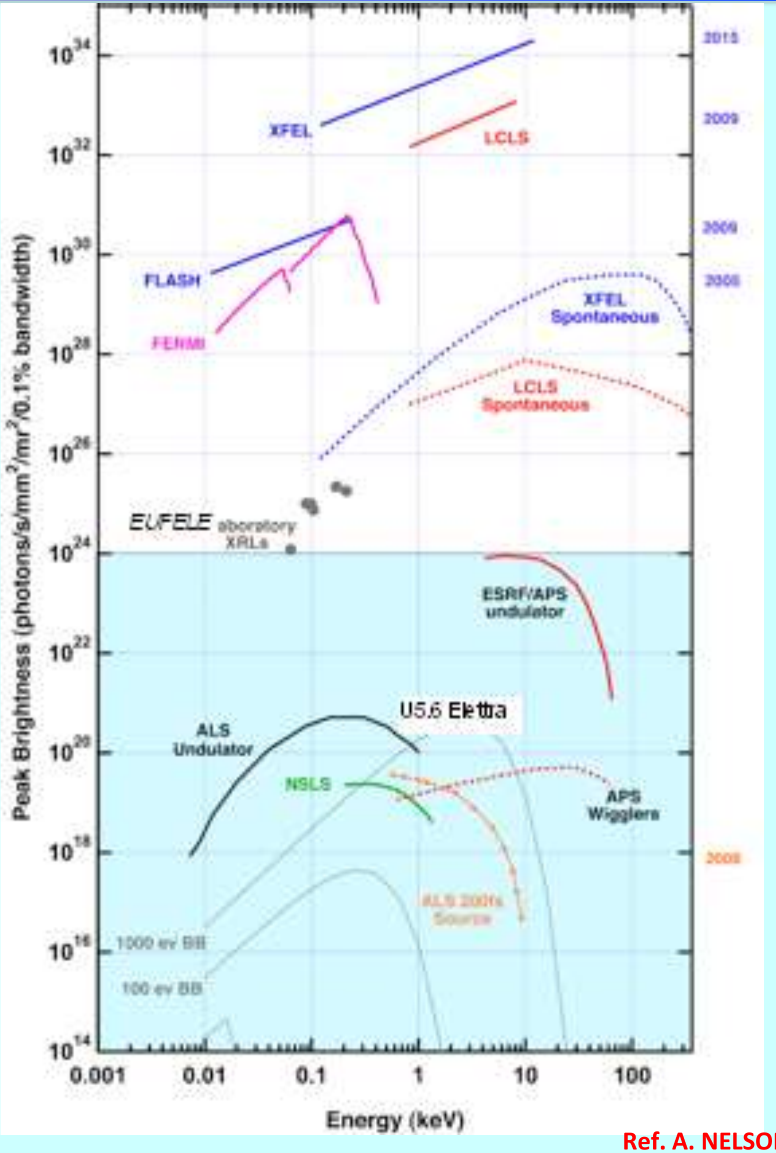
FERMI main features

FERMI@Elettra single-pass FEL user-facility.

Two separate FEL amplifiers will cover the spectral range from 100 nm (12eV) to 4 nm (320 eV).

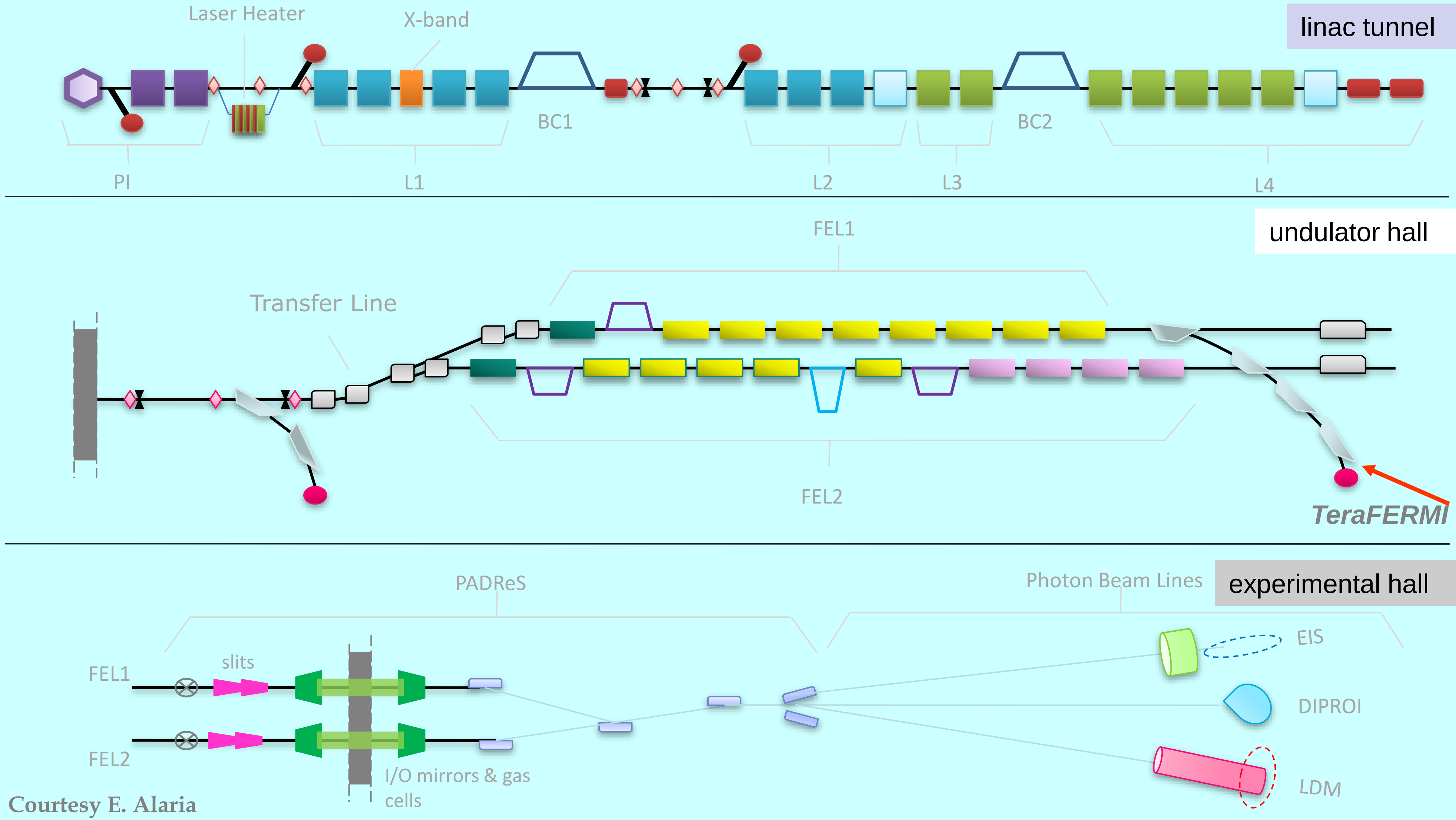
The two FEL’s will provide users with ~100fs photon pulses with unique characteristics.

❑ <u>high peak power</u>	0.3 – GW’s range
❑ <u>short temporal structure</u>	sub-ps to 10 fs time scale
❑ <u>tunable wavelength</u>	APPLE II-type undulators
❑ <u>variable polarization</u>	horizontal/circular/vertical
❑ seeded harmonic cascade	longitud. and transv. coherence



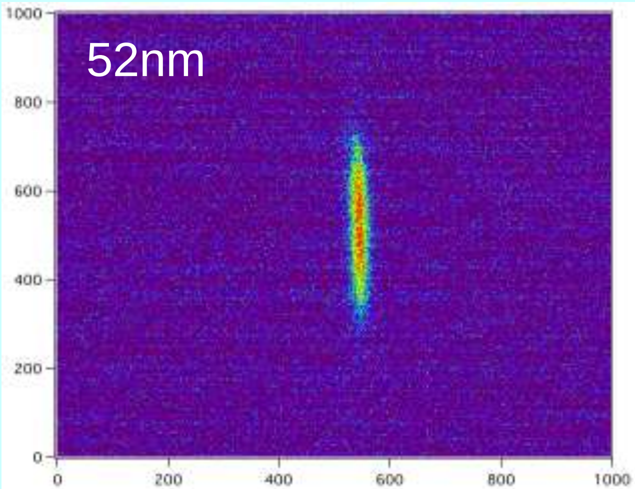
Ref. A. NELSON

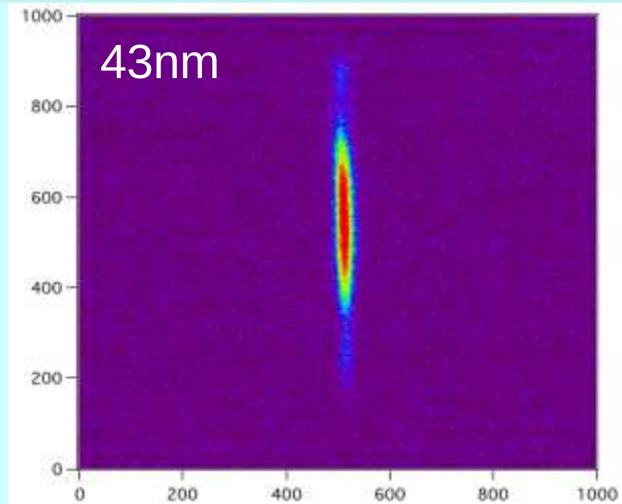
FERMI Layout

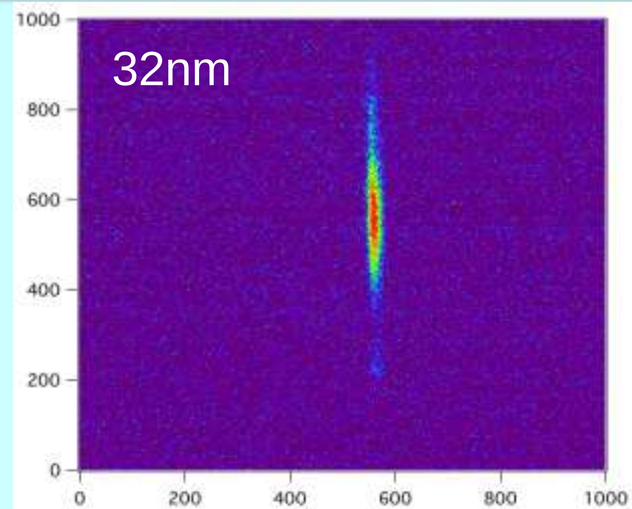


Courtesy E. Alaria

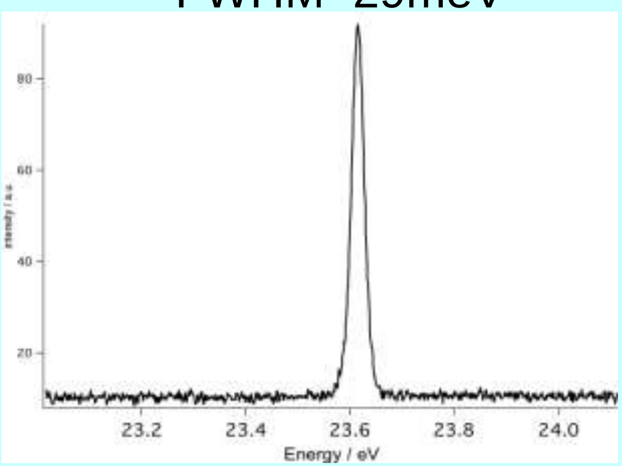
Measured HGHG seeded-FEL spectrum



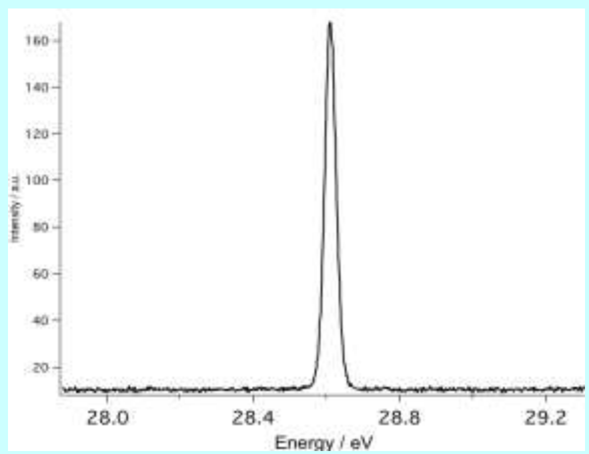




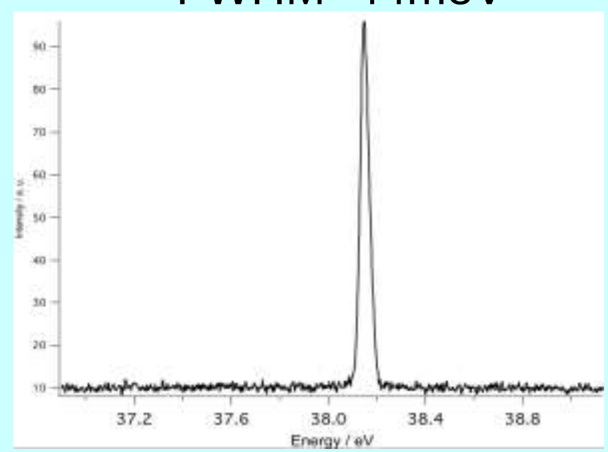
FWHM~29meV



FWHM~33meV



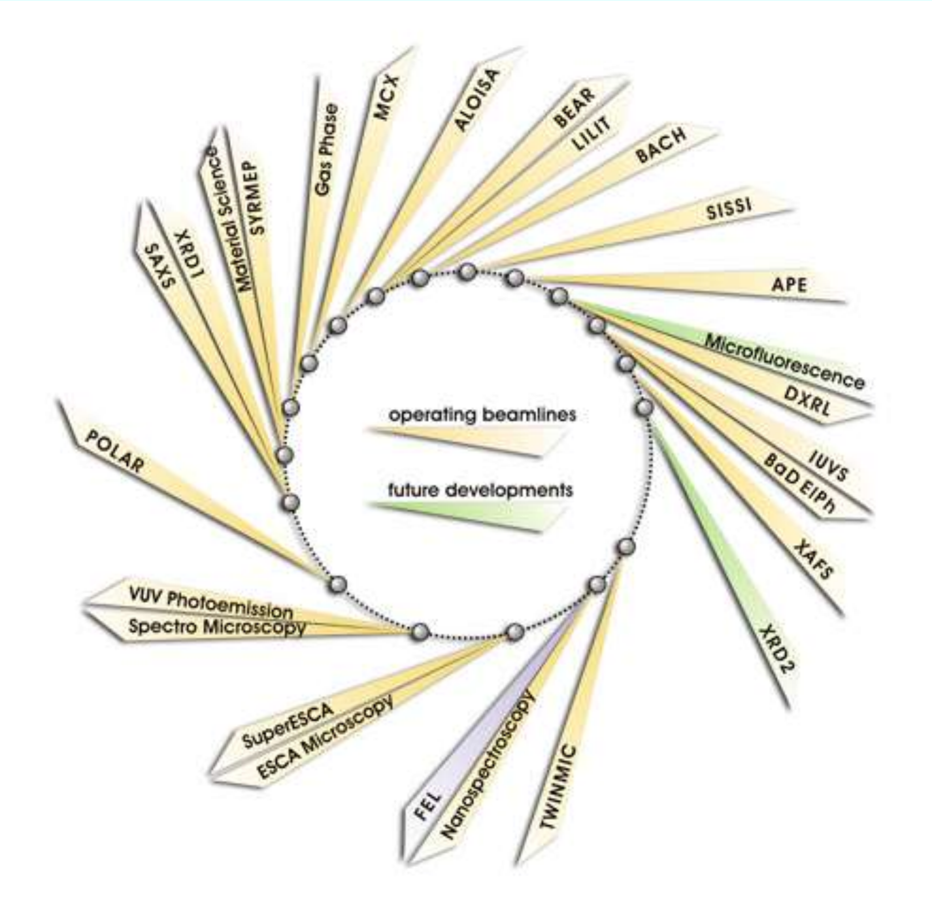
FWHM~44meV



* Single shot spectrum

REF: M. Zangrando, C. Svetina, G. Penco

Elettra beam lines



26 beam lines

of which major upgrades

XRD1

SuperESCA

***SR-FEL** (2 GeV , currently 1.8 GeV and 130 nm)*

2 under construction

Microflurescence

XRD2

Beam Lines

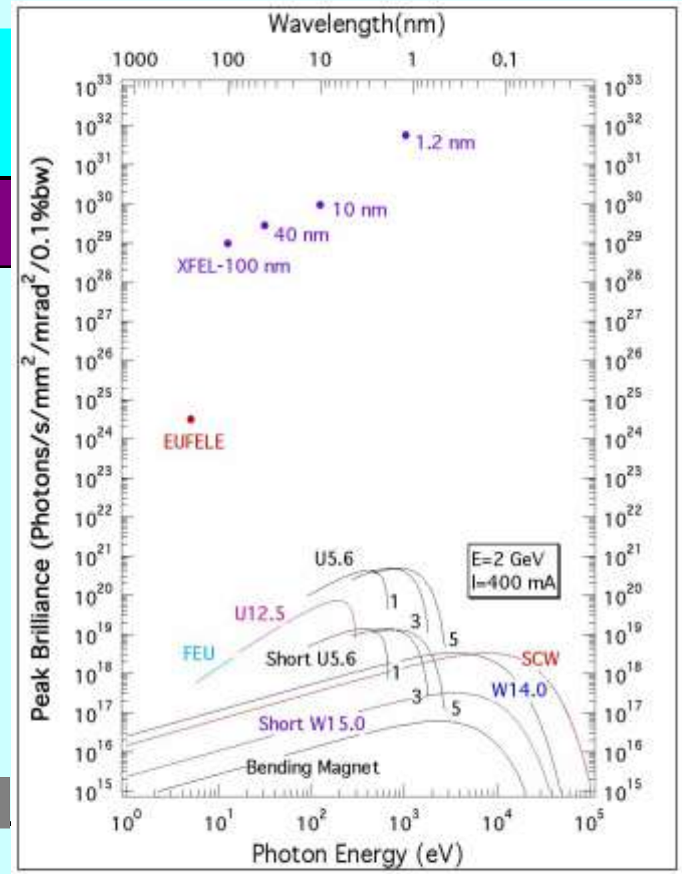
22 ID segments + 1 SCW installed

6 bending magnet source points serving 8 beam lines + 1 IR

ID	type	section	Period (mm)	Nper	gap (mm)	status
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	refurbishing

PM = Permanent Magnet, HYB = Hybrid, EM = Electromagnetic,
SCW = Superconducting, QP = Quasi-Periodic

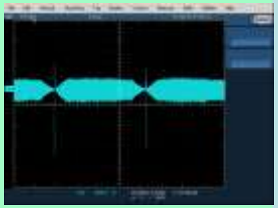
Brightness of ELETTRA Photon Sources



Operating modes

Top-up at both 2 GeV (310 mA) & 2.4 GeV (150 mA)

- 2 GeV multibunch / small demand for single bunch / more demand for hybrid (75% of user time)
- 2.4 GeV multibunch / hybrid (25% of user time)



- 1-1.8 GeV SR-FEL single, 4-bunch (at 1.8 GeV - 130 nm)
- 0.8-1.0 GeV 4 bunch, CSR also for pump-probe experiments (use accel. physics time 25% of total)

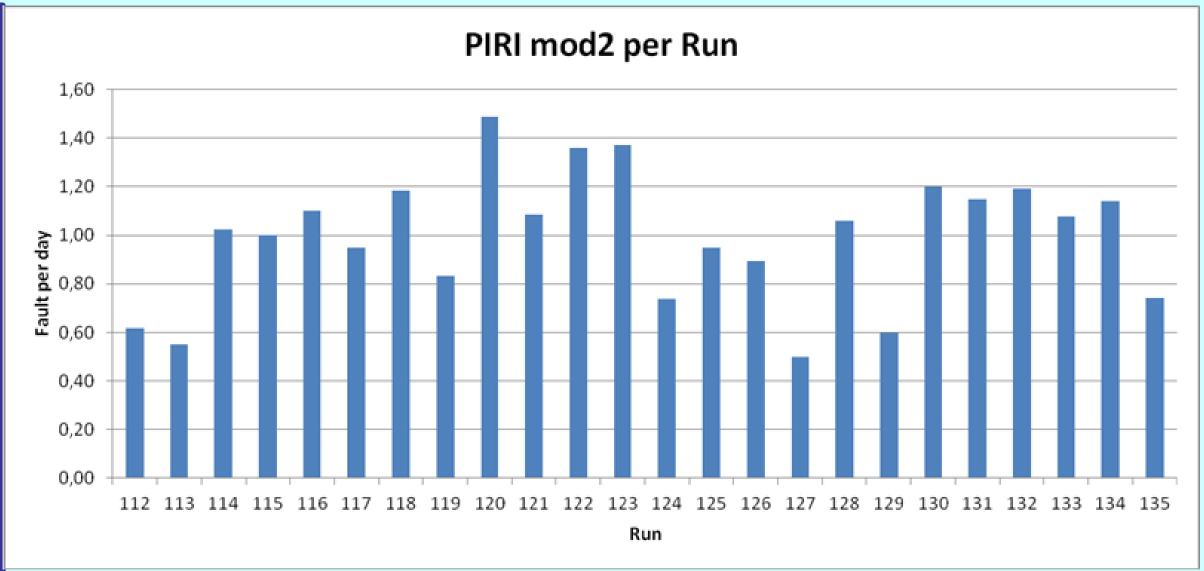
Fully software controlled. Operators intervene only in case of problems

Users are allowed to change gaps, but not e-beam position/angle

Pre-injector & Booster

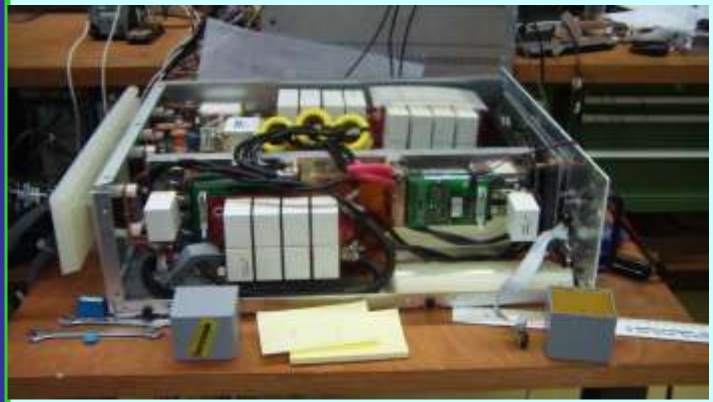
The pre-injector performance is acceptable

- There is redundancy
- Effort on water/ambient temp stability
- Klystron discharges



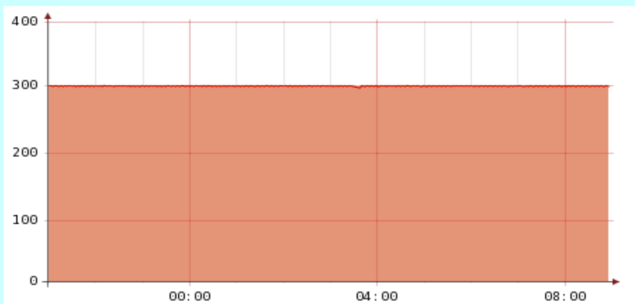
Booster operates at full cycle (2.5 GeV) and at 2 Hz rep. rate. Full energy injection in Elettra at any energy and with any filling mode (multi-bunch , single- or few-bunch)

- Gaining know-how on the power supplies; able to repair them without external help
- Home made modules, redesigning control boards

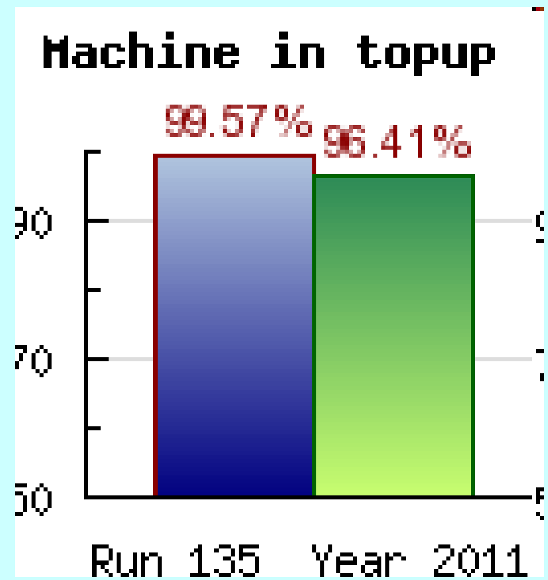


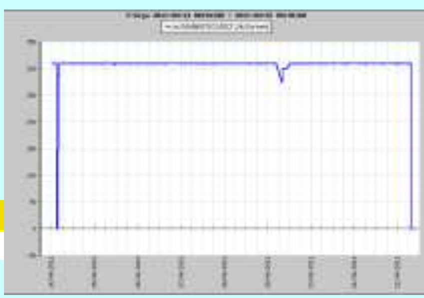
Operating in top-up

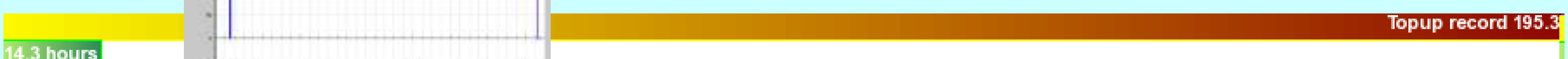
- Top-up is the usual operating mode at both main operating energies for Elettra users.
- Top-up at 1.5 and 1.8 GeV, but only for accel. Physics studies



Top-up statistics are continuously monitored



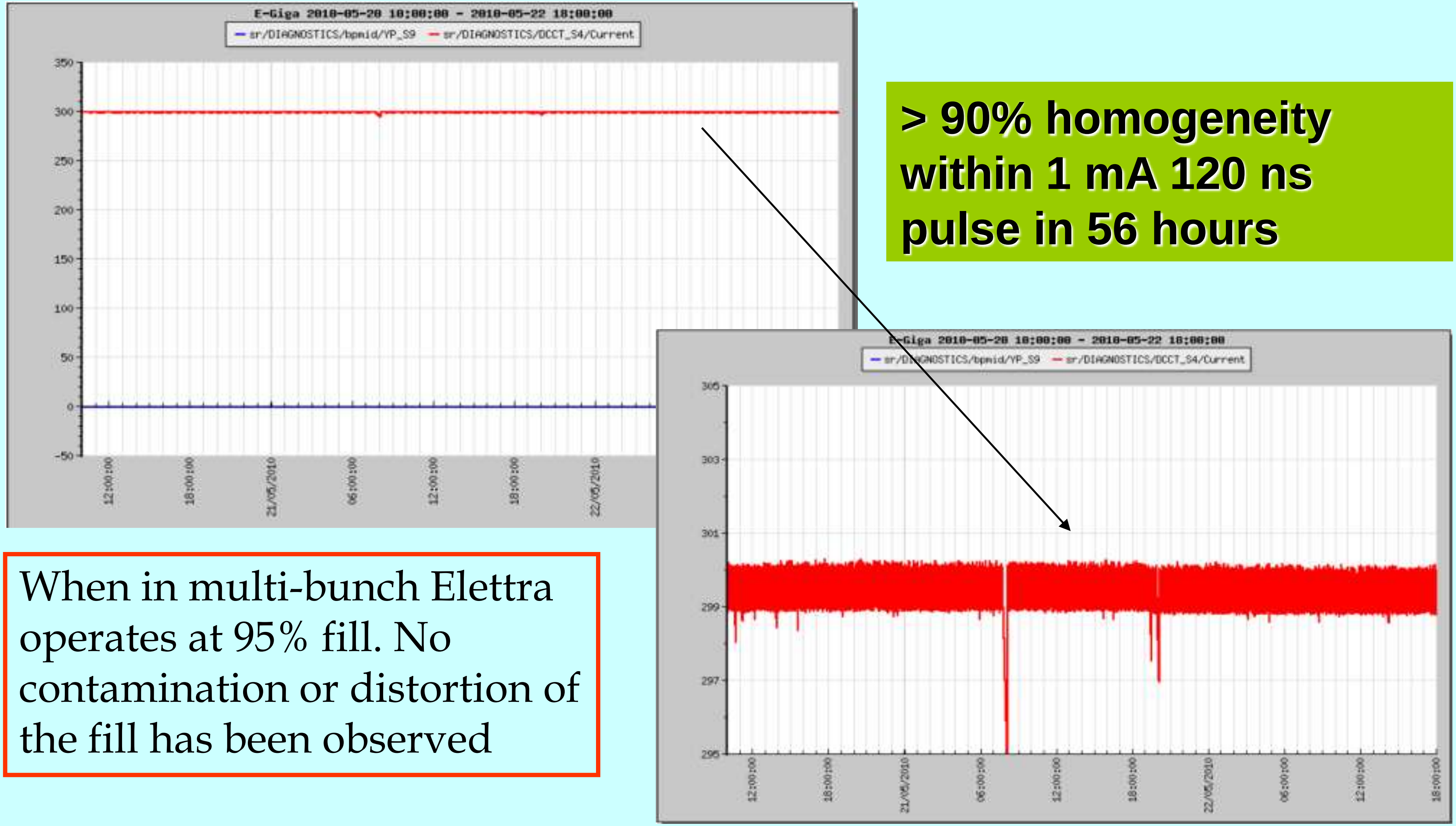




Top-up details

- Fixed current mode (1mA) every 6 min at 2 GeV , 20 min at 2.4 GeV in about 20 pulses at 2 Hz
- Multi-bunch fill of 120 ns pulse from booster, >90 % homogeneity and no contamination of the fill in the SR
- Fast dcct already installed will allow bunch-to-bunch fill for hybrid operations refilling also the single bunch.
- Total current loss budget 10 (5 at 2.4 GeV) mA /hour. This allows efficiencies in the range 100 - 60% otherwise blocks top-up for the rest of the hour (seldom)
- Each beamline is interlocked with dosimeters; above a certain radiation level the beamline is blocked for 4 hours (never happened)
- Upon request gating and additional interface boards are provided. To date only 2 beamlines are making use of it

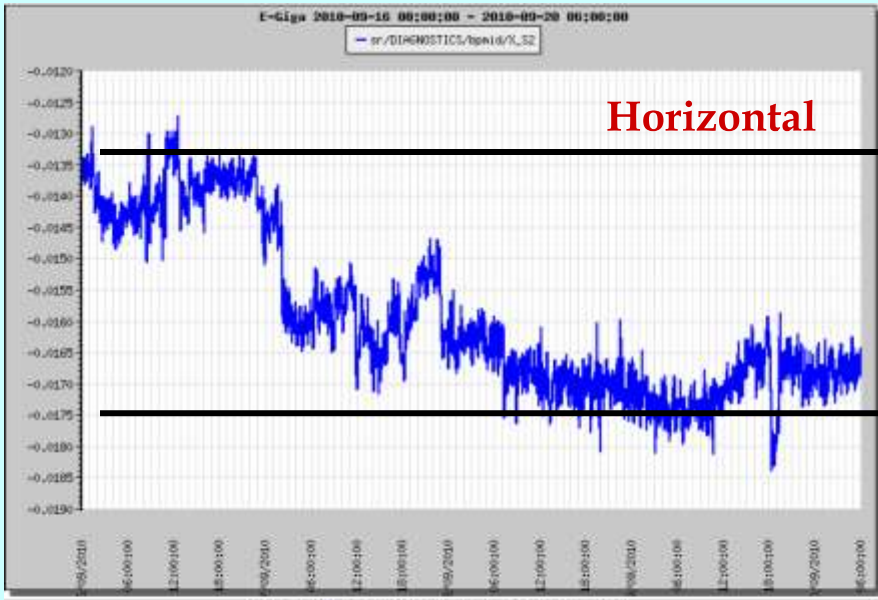
Systems stability during top-up

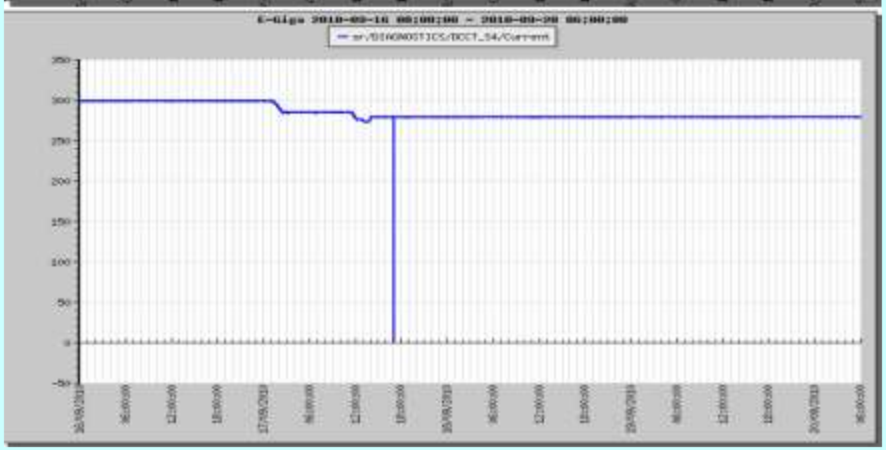


> 90% homogeneity within 1 mA 120 ns pulse in 56 hours

When in multi-bunch Elettra operates at 95% fill. No contamination or distortion of the fill has been observed

Long term orbit stability

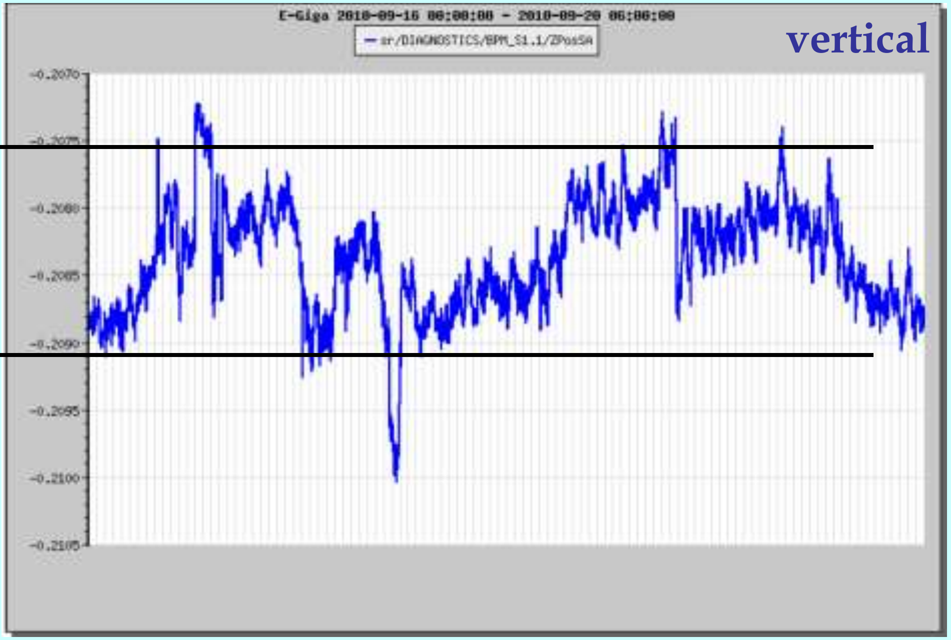




Long-term stability: In about 100 h a 4 μm horizontal and 1.5 μm vertical ptp measured

4 μm

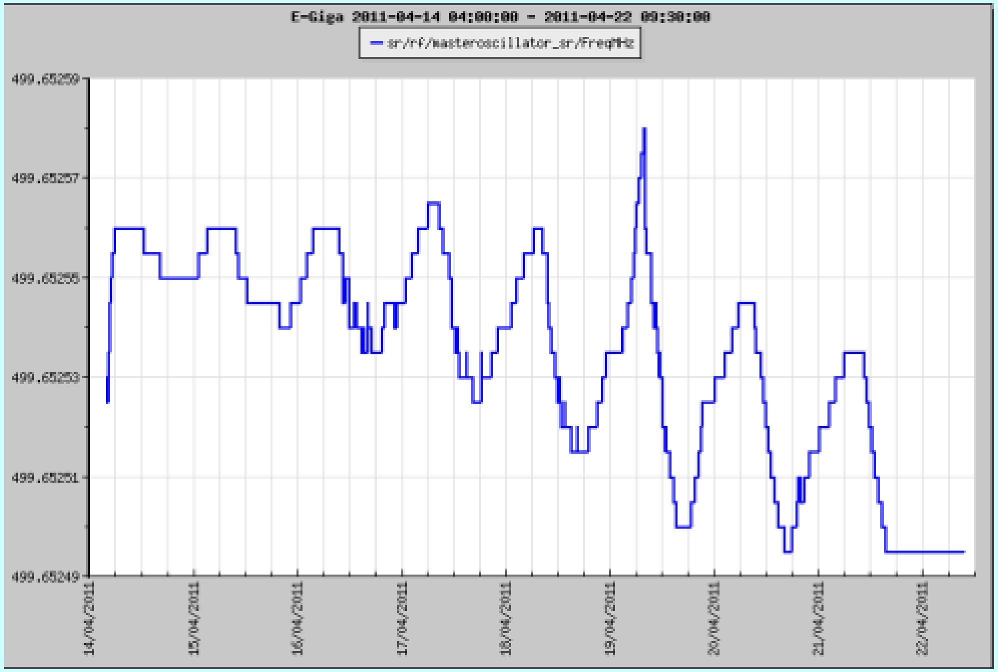
1.5 μm

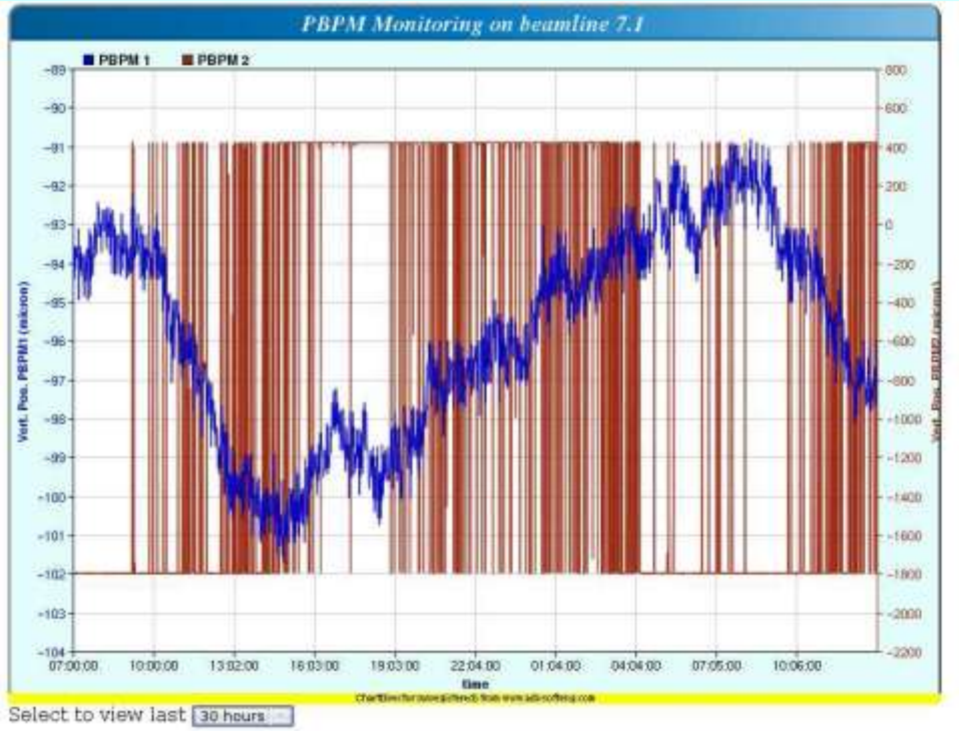


from 16/9/2010 00:00 to 20/9/2010 06:00

day - night temperature gradient

Occasionally when there is a big temp gradient between day and night the e-orbit follows a day night thermal pattern. The feedback changes the frequency to keep the mean horizontal orbit at zero

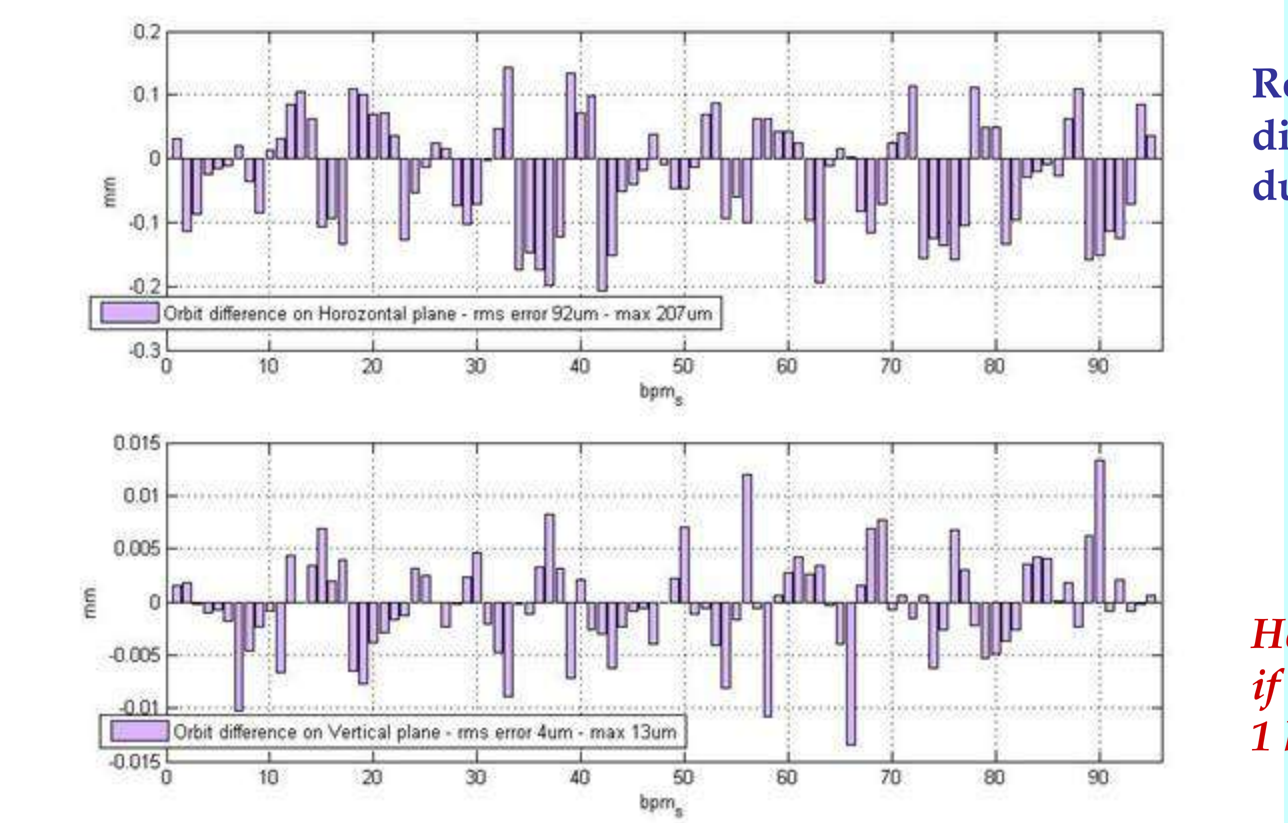




$$\frac{\Delta C}{C} \propto \frac{\Delta f}{f}$$ About 50 Hz corresponding to 26 um in C

Reproducibility

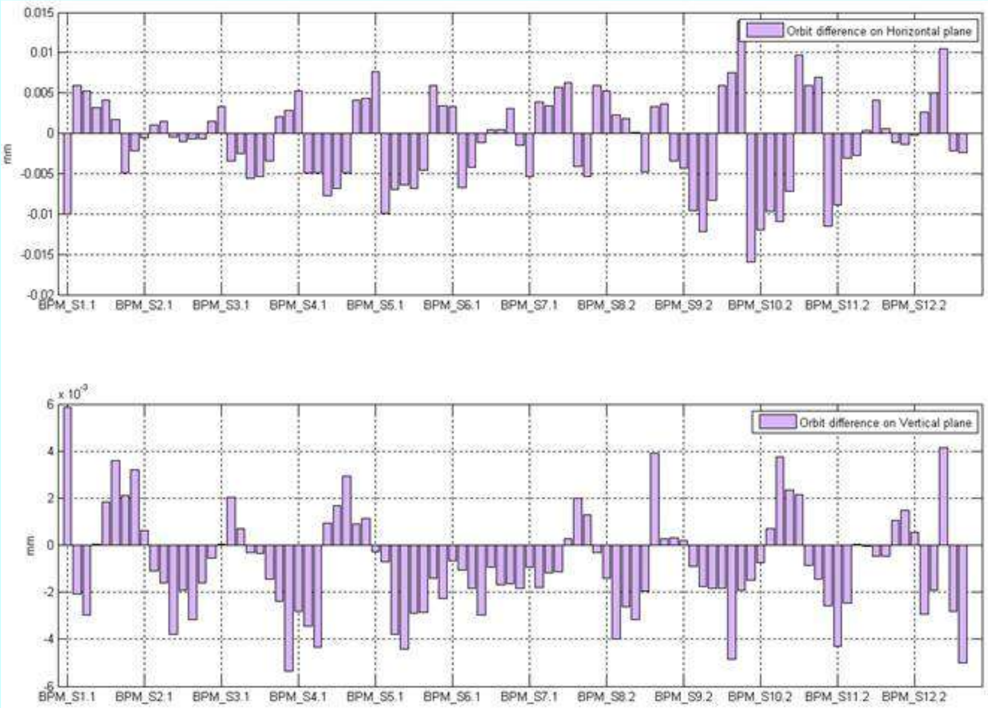
Reproducibility mainly depends on thermal equilibrium. Machine (vacuum chamber) need some time after refill to arrive at the previous position settings

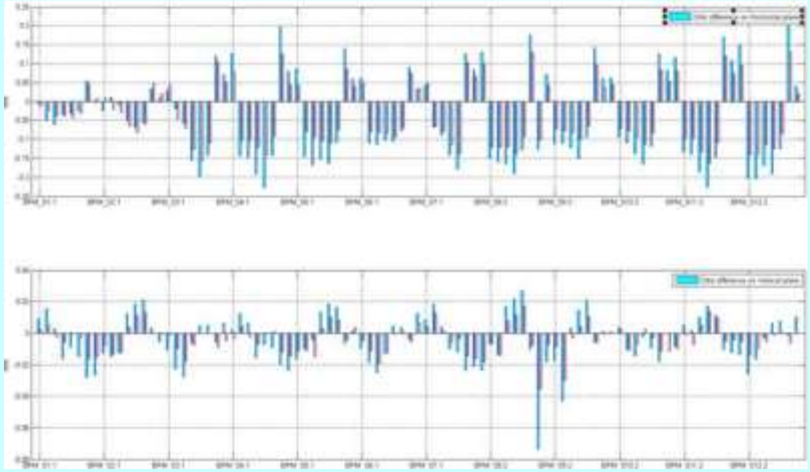


Re-inject after 10 min (temperature difference 20° C) from a beam-dump to 310 mA

	H [um]	V [um]
Rms	92	4
max	207	13

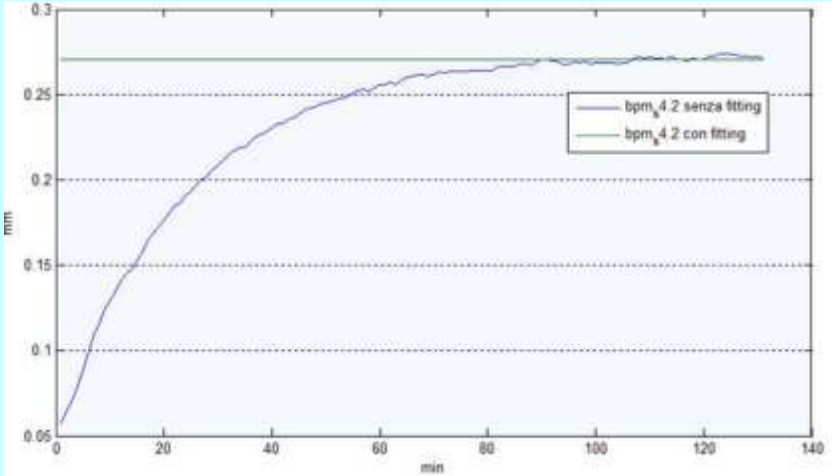
Horizontal difference can be 0.5 mm if the machine left without beam for 1 hour





The deformation always follows the same pattern

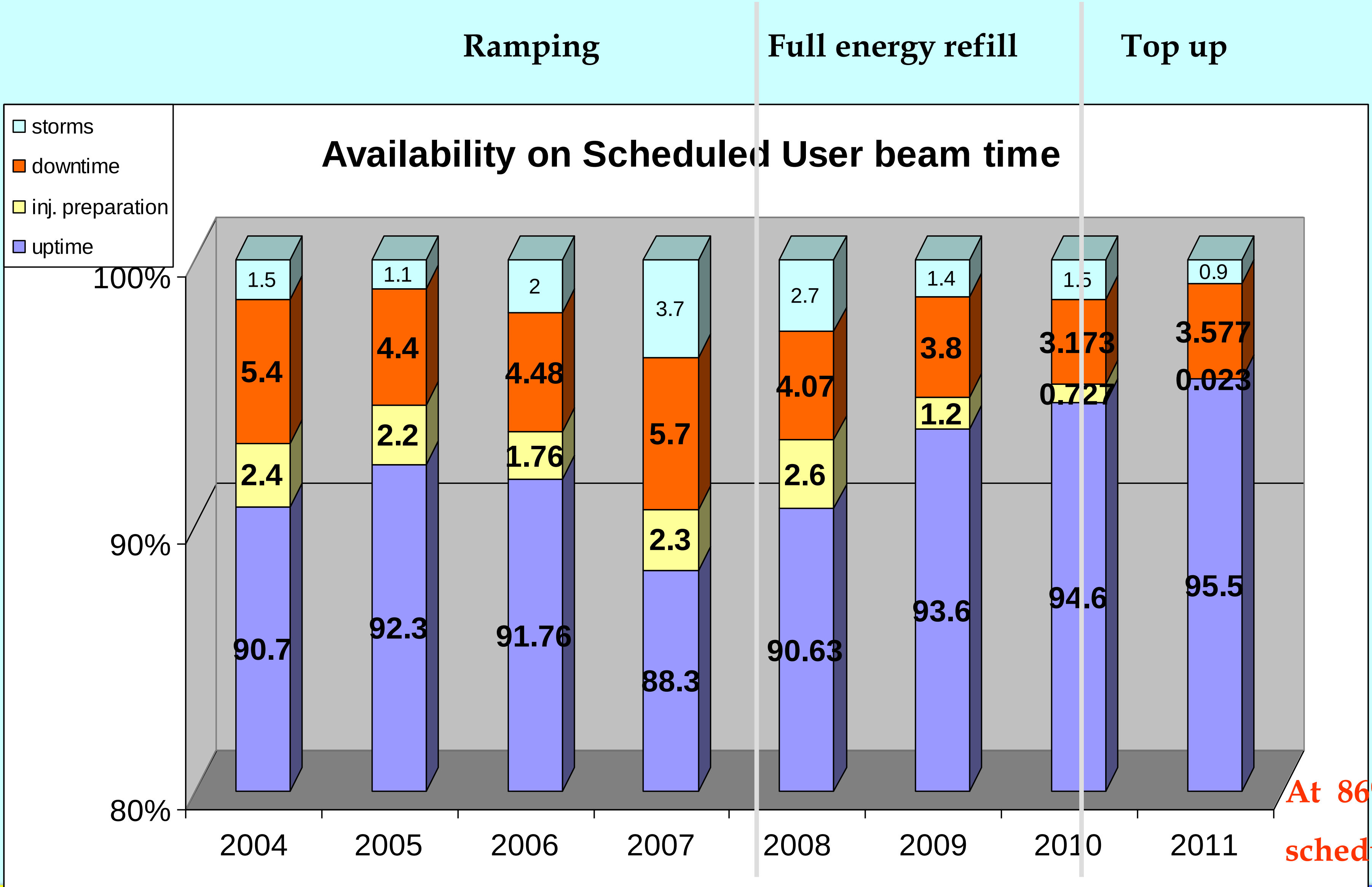
Comparing many orbits in thermal equilibrium (no feed-backs) obtain 10 microns rms difference



Courtesy S. Krecic

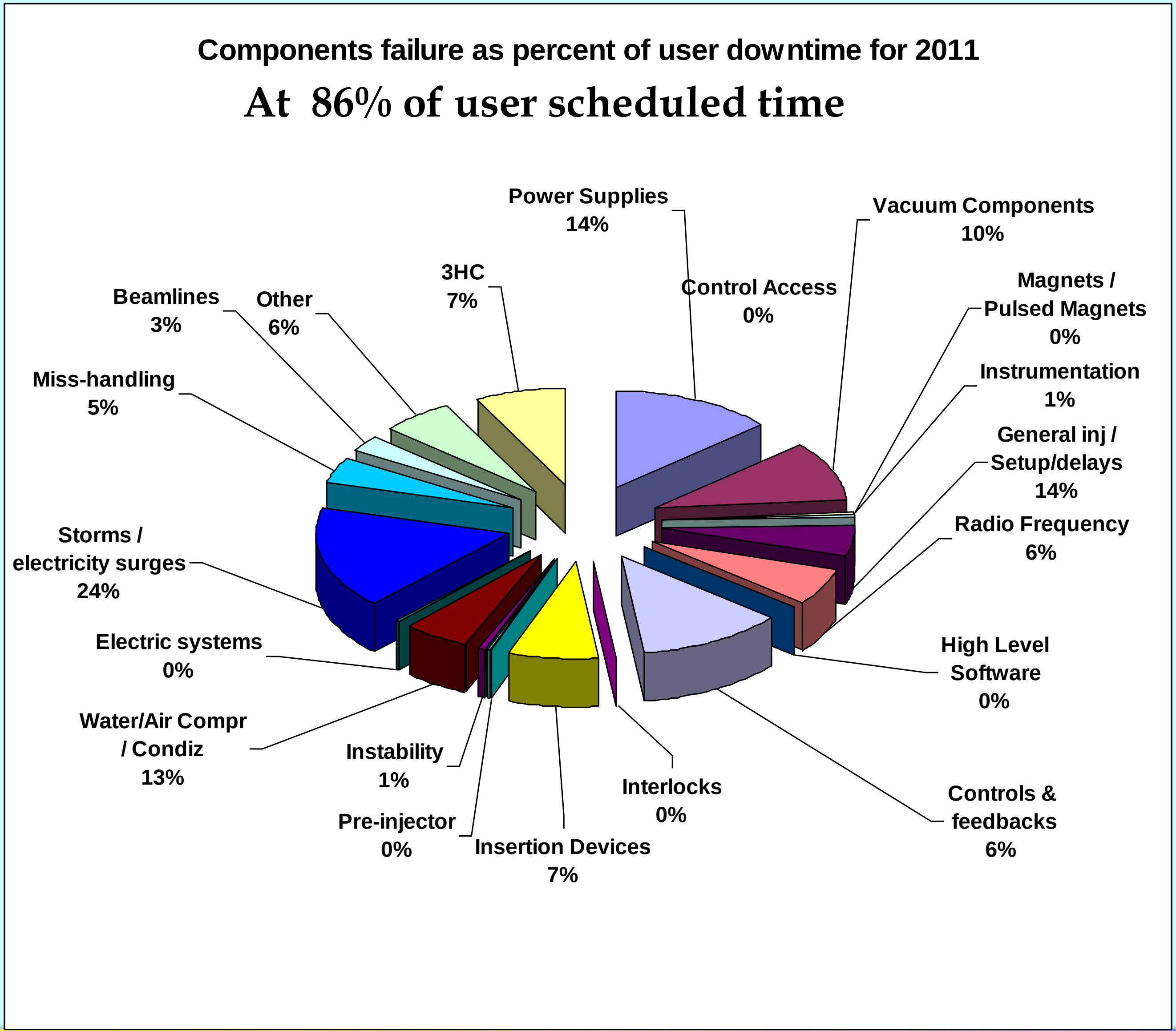
bpm value during thermal drift towards its equilibrium value vs. time

Operating Performance (User Mode)



At 86% of user scheduled time

Systems user downtime distribution



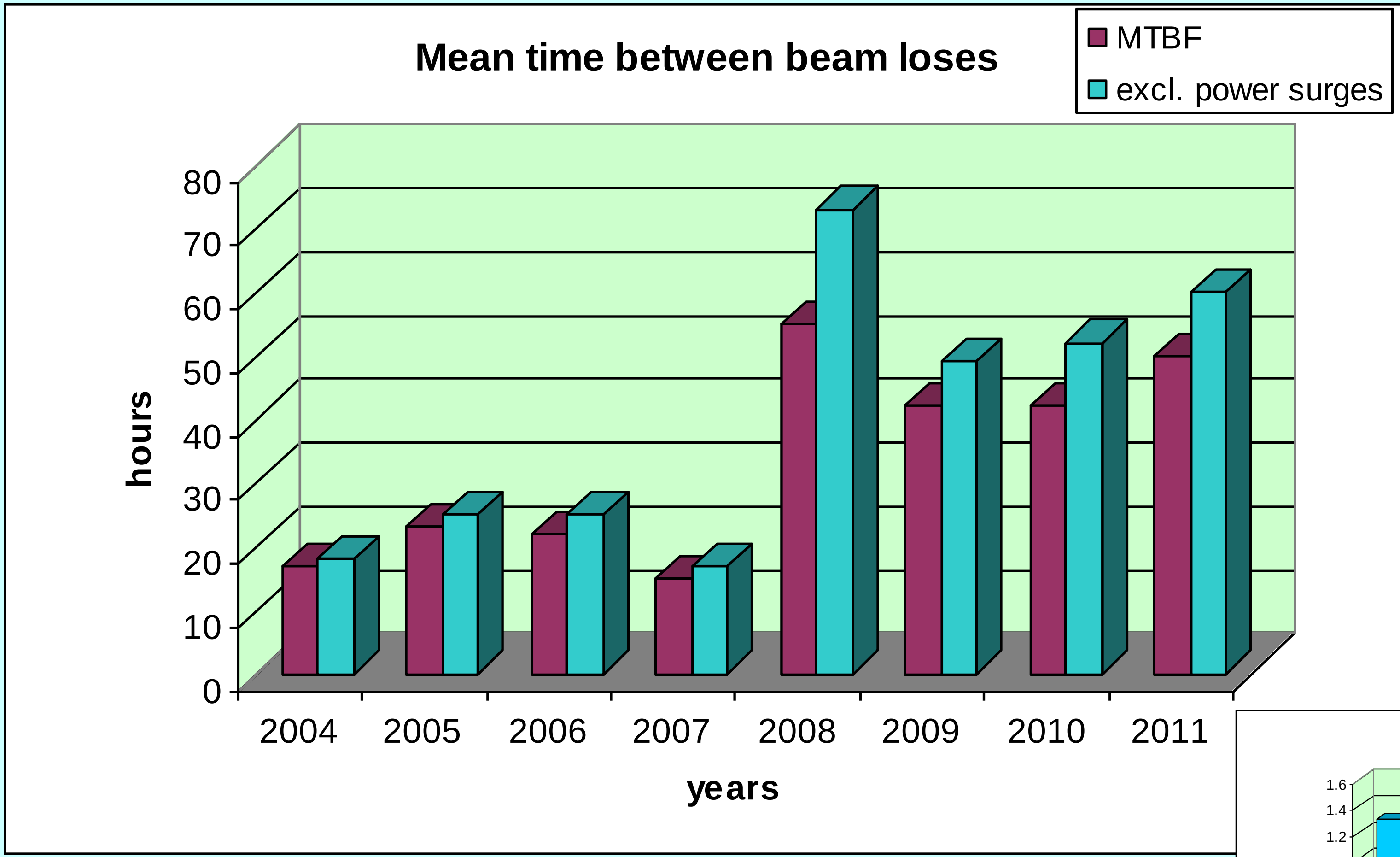
Observed (components) fatigue. Note the failure equipartition

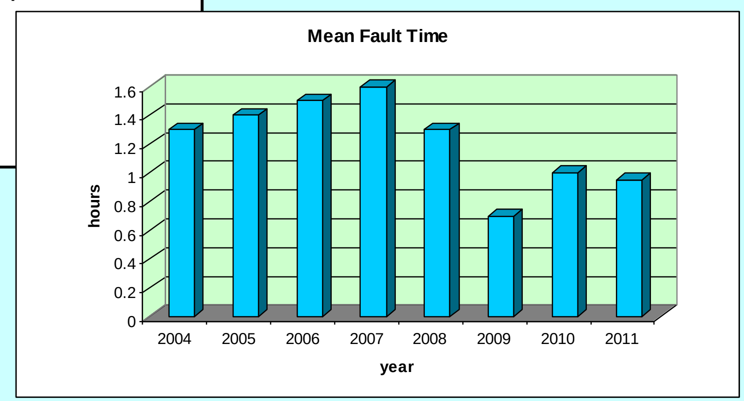
Suffered from the cryogenic systems

Some power supplies (dust problems)

Encoders and electronics of some IDs

TMFB and controls


Mean time between beam loses
MTBF
excl. power surges
hours
80
70
60
50
40
30
20
10
0
2004
2005
2006
2007
2008
2009
2010
2011
years


Mean Fault Time
hours
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2004
2005
2006
2007
2008
2009
2010
2011
year

Stability and other systems

Elettra has 4 rf single cell cavites installed in the dispersive regions, temp controlled to minimize multibunch instabilities. Three systems work on klystrons and one on IOTs

For longitudinal stability and high lifetime a third harmonic cavity (at 1.5 GHz) is used

Feedbacks: Use 2 transverse (H+V); there is also a longitudinal (but never operated).

For orbit stability after refill a HLS program sets the orbit at its value and then a fast orbit FB (GOF) keeps the positions as set.

Additional: *feed forward orbit correctors for IDs, Tune feedback, Mean H-orbit feed back*

Projects update

Actual

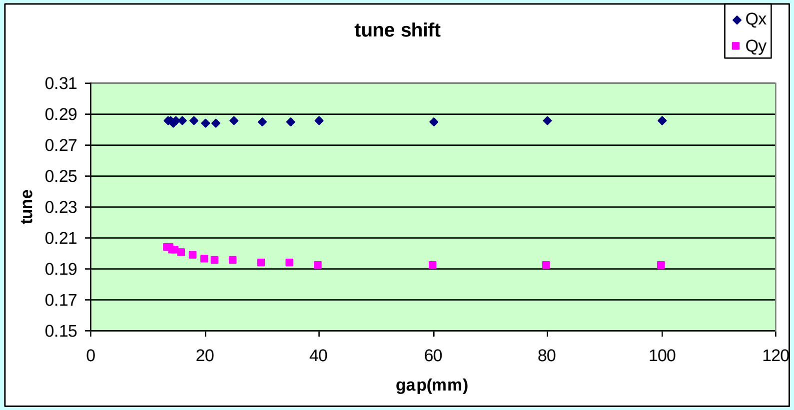
- New undulator (KYMA) for SuperESCA √
- Low-profile vacuum chambers √
- Storage ring realignment √
- BBA √
- 8th corrector
- Superconducting wiggler
- *Ambient temperature stabilization* - *tough*
- Cooling of 24 hot bpms -> intensity increase
- Photon bpm
- PS 300 A module
- Beam damp exhaustive diagnostics
- Control rooms unification and system upgrade

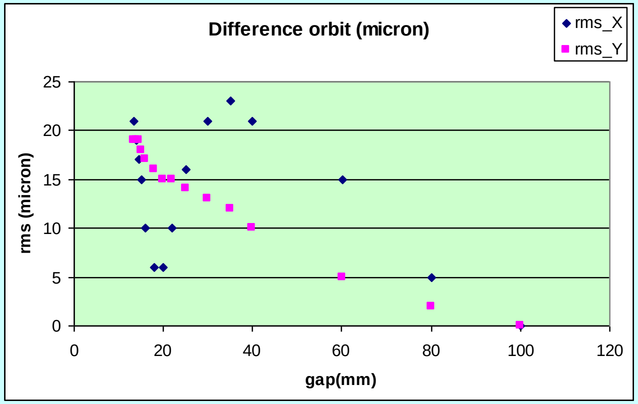
In progress / near future

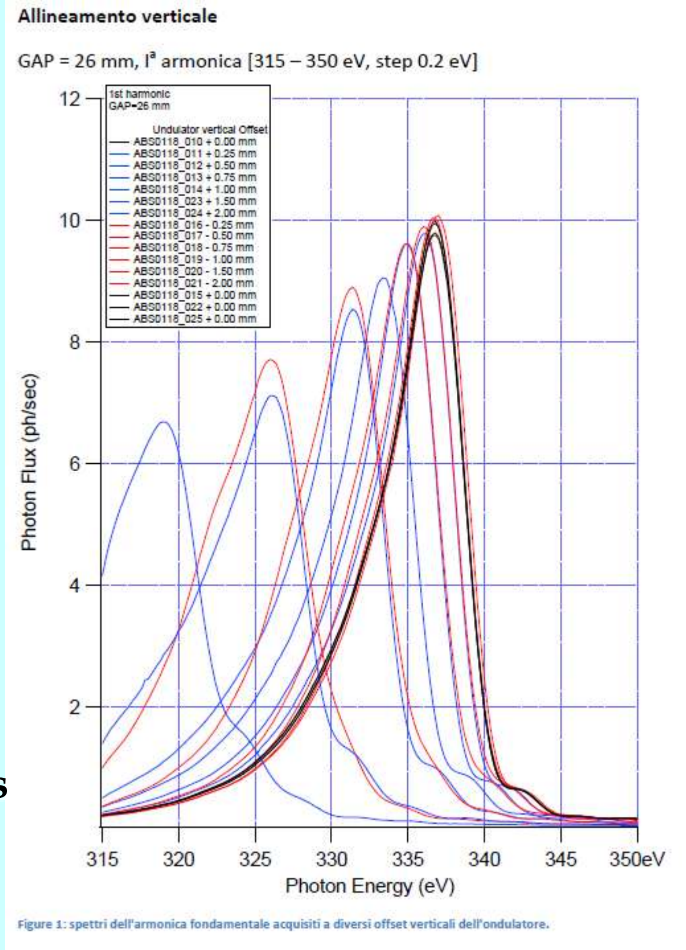
- ***Low alpha optics***
- ***In vacuum undulators***
- ***Super- bends***
- ***Skew multipoles***

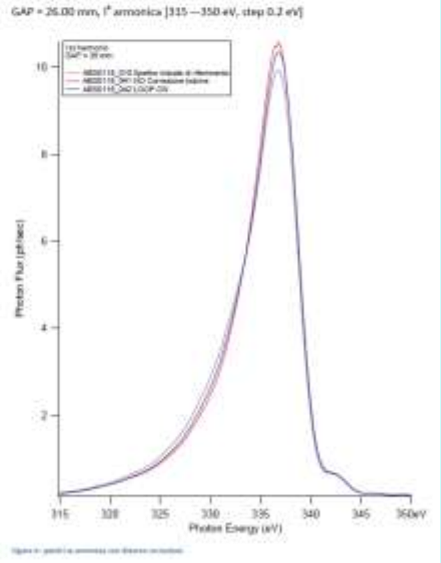
SuperESCA new undulator

U5.6	KYMA U4.6
PM/Linear NdFeB	PM/Linear NdFeB
56.36mm	46.00 mm
3x27	2x49
0.693 T	0.928 T
19.5 mm	13.5 mm
90-1000 eV	90 -2000 eV









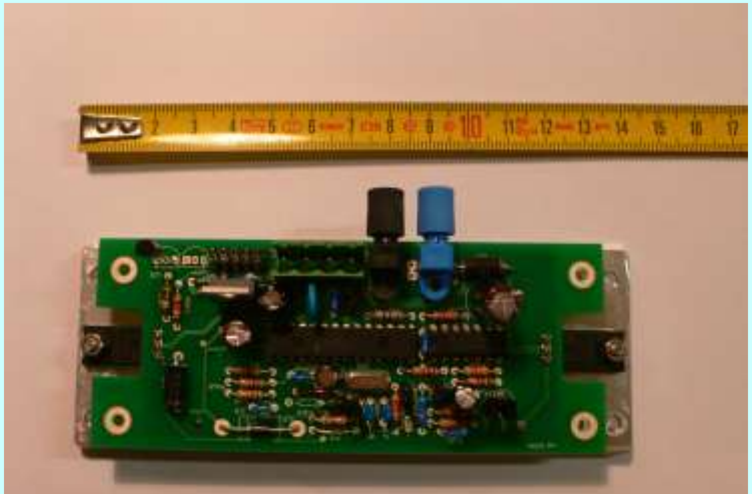
Orbit distortion and tune measurements performed with excellent results: Max orbit error 20 μm rms whereas the max tune shift by 13.5 mm gap was 0.011 (value theory 0.009)

Courtesy B. Diviacco, S. Lizzit

Re-Alignment

- Full magnet realignment completed (±0.1 mm) and bpms aligned to (±1 mm)
- All 108 shunt BBA modules used for beam based alignment.
- All beamlines successfully realigned to zero

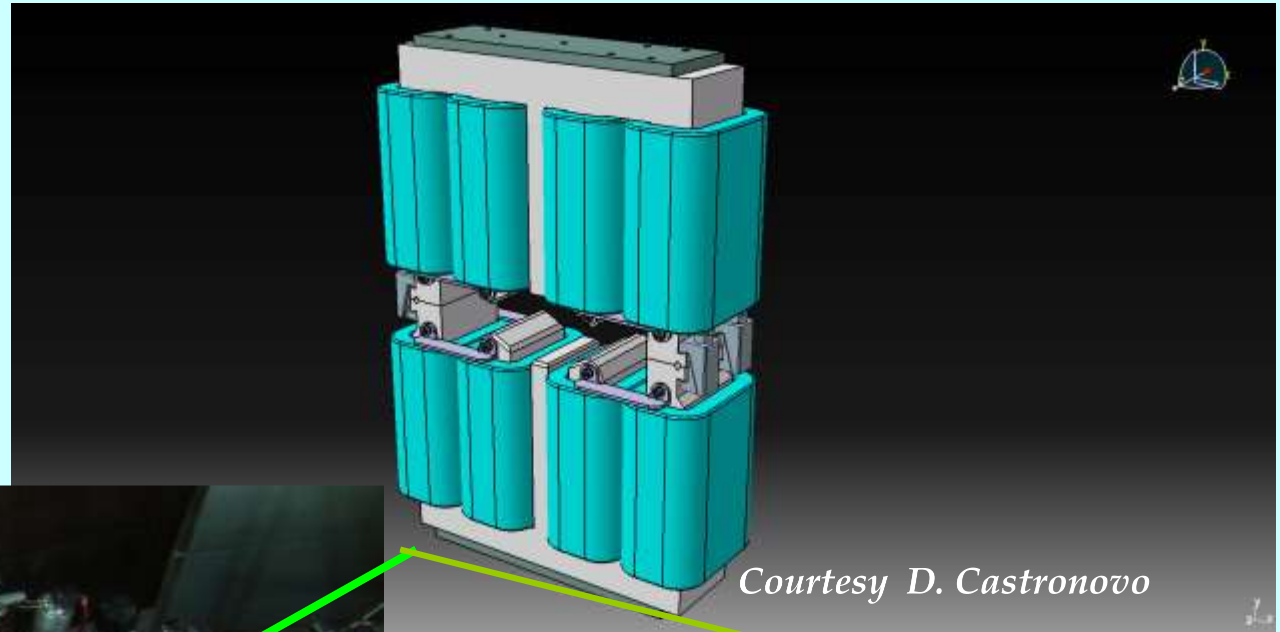
Electron orbit (absolute) <0.35 mm rms horizontal and <0.2 mm rms vertical with correctors strength of 2 A rms horizontal (12%) and 0.8 A rms vertical (5%) (max. allowed 16 A)



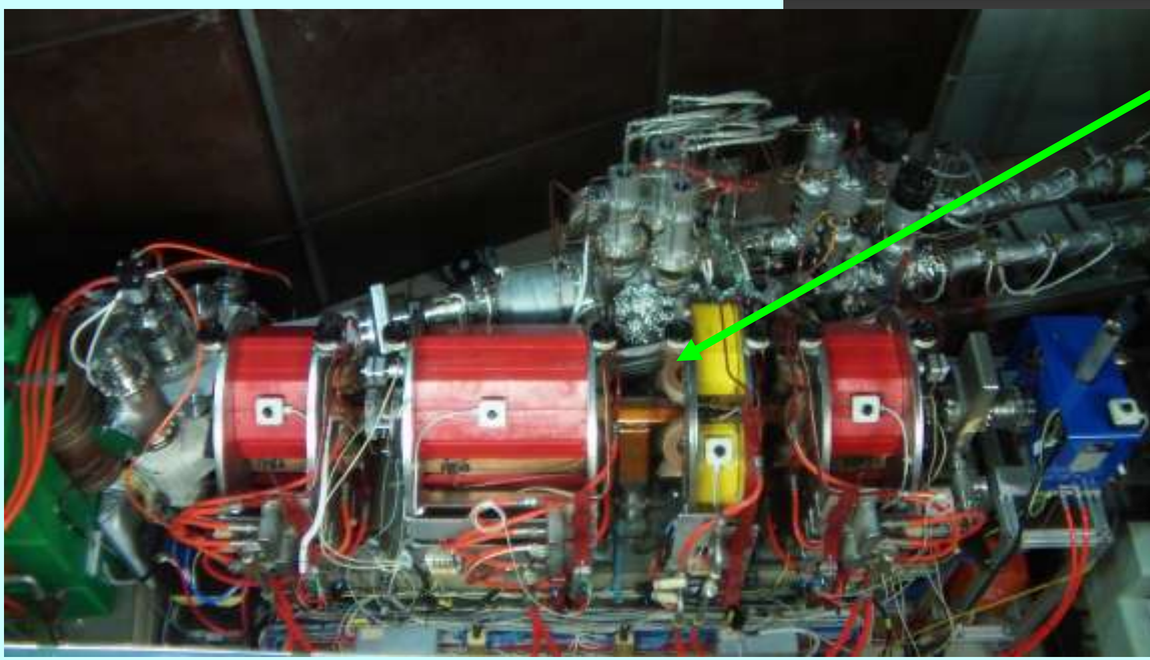
A. Carniel

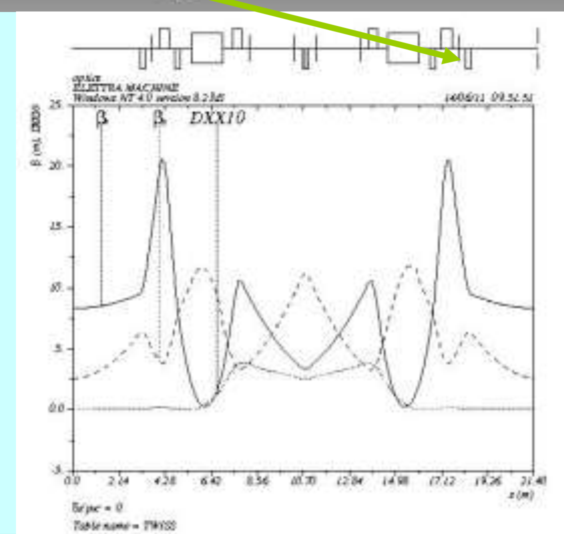
8th corrector/section

- Magnet in construction
- Changing the vacuum chamber



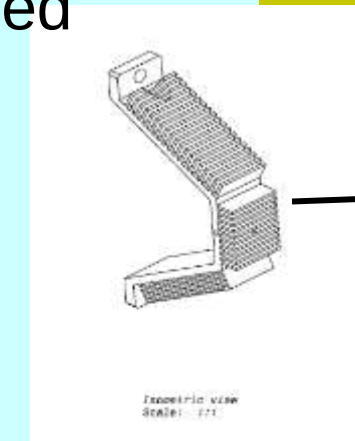
Courtesy D. Castronovo

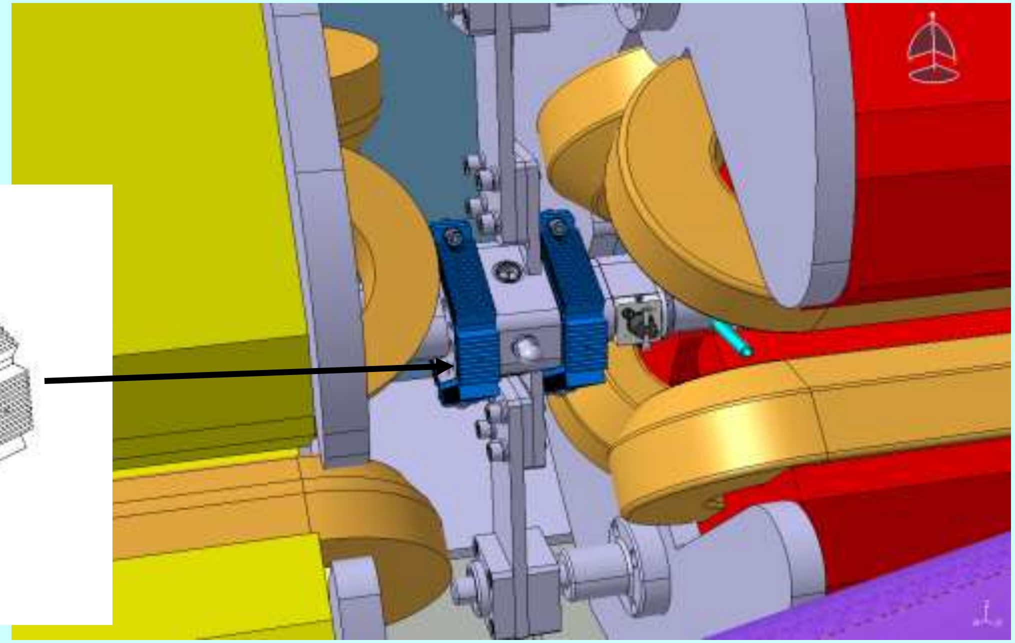




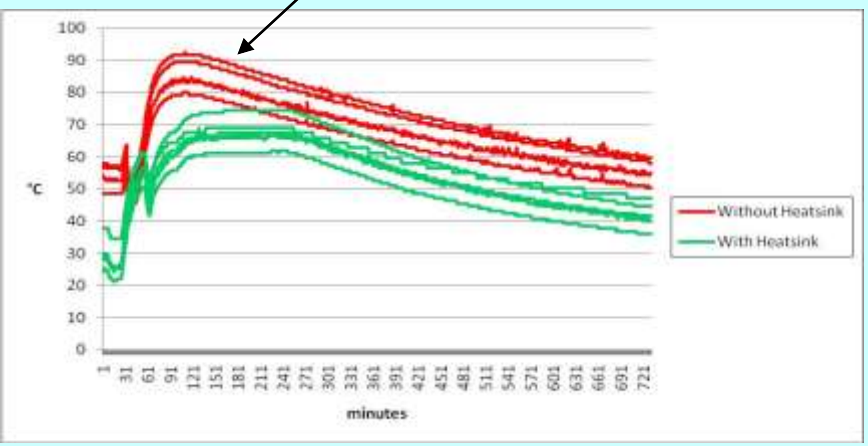
BPM cooling

24 hottest bpms (after dipoles) will be air-cooled with a fan system





dangerous for vacuum leak



With a fan the temp drops between 40 and 50 deg

So in near future we are going to try up to 200 mA at 2.4 GeV

G. Loda and R. Geometrante

Superconducting wiggler

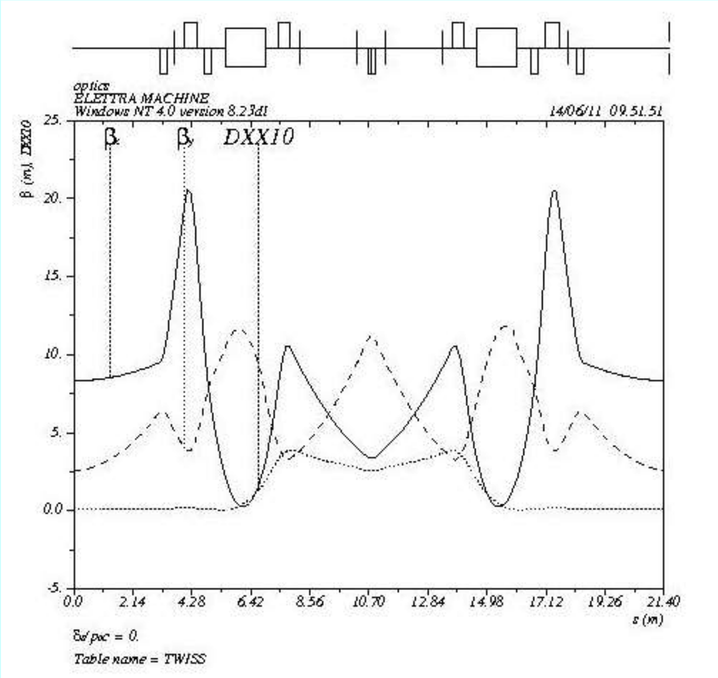
The multipole superconducting wiggler is a high flux and brightness source in the 10-25 keV range for the second Diffraction beamline (XRD-II). However since 2004 not used and next year has to serve 3 beam lines

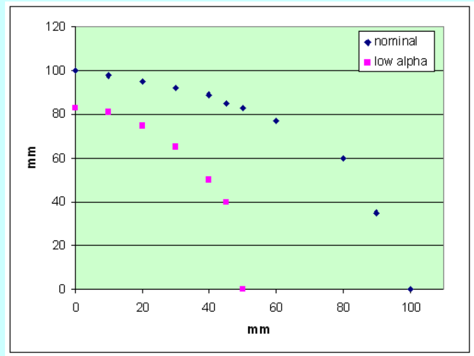
Period length	64 mm
Peak field	3.5 T
Total no. of poles	49
Internal aperture	81 mm (H) x 10.7 mm (V)
Total power	18.3 kW (2 GeV, 400 mA)

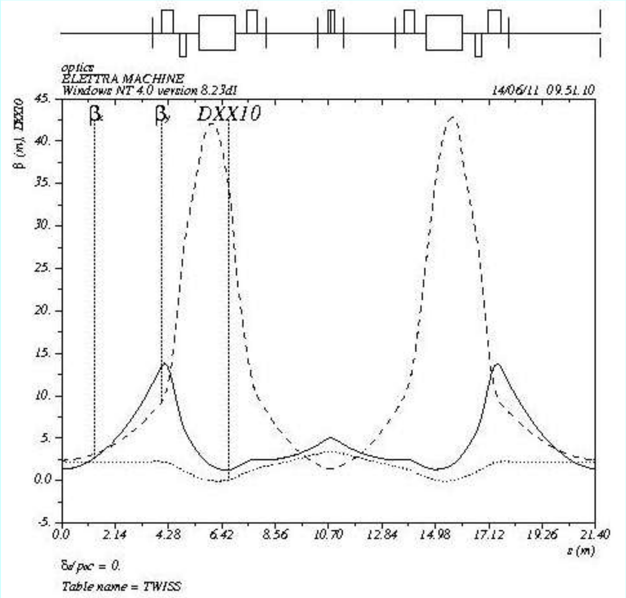
Its consumption as measured in 2004 of 0.6-0.7 l/h would be an additional difficulty with top up operations; however during tests in May 2011 it has been observed: 2 l/h without field and 7 l/h with magnetic field that anyway could not go above 0.9 T

Contract with BINP for major upgrades that guarantee 1-2 refills per year at 3.5 T and 330 mA at 2 GeV

low alpha optics in Elettra







Thu Aug 25 10:34:11 2011	
Current:	52.26 [mA]
Life Time:	24.64 [h]
Inj. Rate	0.000 [mA/s]
Energy:	2.000 [GeV]
Int. Current:	15744.52 [Ah]

Managed to inject and accumulate →

QD strength	Momentum compaction	Emittance (nmrad)
1.8	-1.00E-04	
1.75	-5.00E-05	
1.715	-7.00E-07	
1.7145	3.00E-07	14
1.7125	3.00E-06	7.6
1.695	3.00E-05	7.2
1.6	2.00E-04	5.7
1.31	1.60E-03	14

Conclusions

- Top-up at both 2 and 2.4 GeV is the regular mode of operations
- Availability is improving as expected; we have to fight ageing
- Efforts to increase reproducibility and stabilization are increasingly successful
- The upgrade program continues (but lack of manpower)

Problems: The team is very much involved with FERMI@Elettra construction and commissioning, practically no other accel. physicist dedicated to Elettra available.

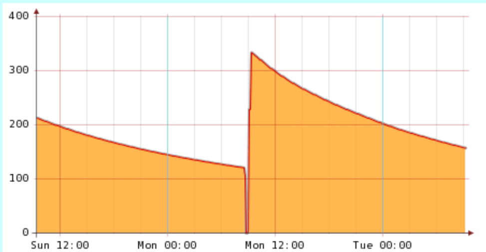
Elettra complex, optics and numbers

Beam height in experimental area [m]	1.3			
Number of achromats	12			
Length of Insertion Device (ID) straight sections [m]	6(4.8 utilizabile per ID's)			
Number of straight sections of use for ID's	11			
Number of bending magnet source points	12			
Beam revolution frequency [MHz]	1.157			
Number of circulating electron bunches	1 - 432			
Time between bunches [ns]	864 - 2			
Tunes: horizontal/vertical	14.3/8.2			
Natural emittance [nm-rad]		7	9.7	
Energy lost per turn without ID's [keV]		255.7	533	
Maximum energy lost per turn with ID's [keV] (all)		315	618.5	
Critical energy [keV]		3.2	5.5	
Bending magnet field [T]		1.2	1.45	
Geometrical emittance coupling %	≤ 1%			
Spurious dispersion (at the centre of IDs): horizontal (rms max/min) [	6/2.			
Spurious dispersion (at the centre of IDs): vertical (rms max/min) [cm	2/0.5			
Operation mode	mainly multibunch - also hybrid and single			
Injection energy range [GeV]	0.750 - 2.4			
max current [mA]		350	150	
Machine dominated by the Touschek effect				
Energy spread (rms) %		0.08	0.12	
Lifetime [hours]		8.5	26	
Bunch length (1 s) [mm] &		5.4	7	
Beam dimensions (1 s) &				
ID source point - horizontal/vertical [µm]		241/15	283/16	
Bending magnet source point - horizontal/vertical [µm]		139/28	197/30	
Beam divergence (1 s) &				
ID source point - horizontal/vertical [µrad]		29/6.	35/8.	
Bending magnet source point - horizontal/vertical [µrad]		263/9	370/13	
&: The values shown (taking into account the energy spread) are averages, obtained from a consideration of different angle and position values of the spurious dispersion and can very by ±10%				

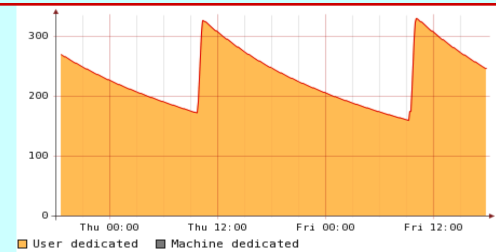
Magnet lattice	**FODO with missing magnets**
Maximum energy	**2.5 GeV**
Injection energy	**100 MeV**
RF frequency	**499.654 MHz**
Circumference	**118.8 m**
Revolution period	**396 ns**
Harmonic number	**198**
Equilibrium emittance (2.5 GeV)	
Normal Emittance Optic	**226 nm.rad**
Low Emittance Optic	**166 nm.rad**
r.m.s. energy spread (2.5 GeV)	**$7.18\ 10^{-4}$**
Energy loss per turn (2.5 GeV)	**388 keV**
Damping times (h,v,l) (2.5 GeV)	**5.1, 5.1, 2.6 ms**
Betatron tunes Q_x , Q_y	**5.39, 3.42** **6.8 , 2.85**
Natural chromaticities ξ_x, ξ_y	**-6.6, -4.7** **-11.1, -5.2**
Momentum compaction factor	**0.0443** **0.0308**
Maximum β_x, β_y, D_x	**10.8, 13.8, 1.621 m** **15.0, 17.2, 1.683 m**
Peak effective RF voltage *(available 1.1MV)*	**0.84 MV (τ_q~1 s)** **0.73 MV (τ_q~1 s)**

The three phases of Elettra's life

1994 - 2007 Ramping



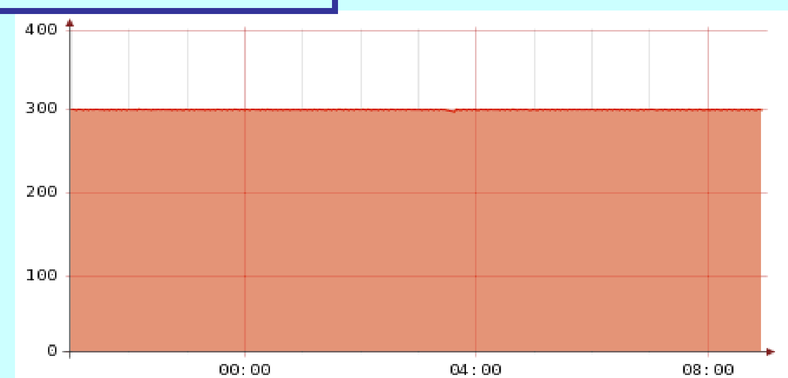
Since 2008 Full energy injection



Decay mode, 2 GeV (340mA) and 2.4 GeV (140) – SRFEL at 1 GeV.

Since May 2010 Top-up

Top-up at 2 GeV (310 mA)
&
2.4 GeV (150 mA)



The only source operating at 2 different energies