Elettra
Sincrotrone
Trieste

ELETTRA 2.0, the machine

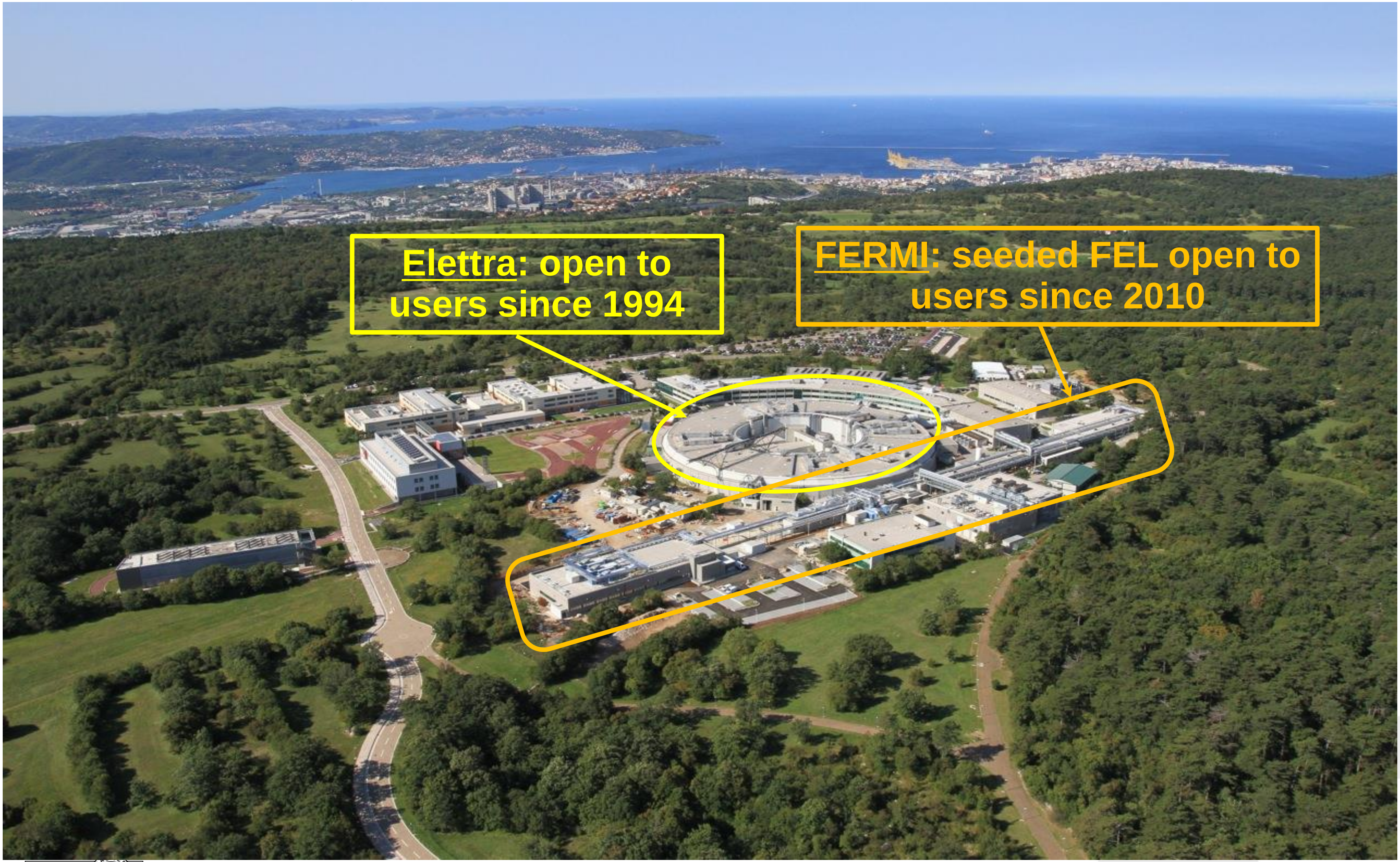
S. Di Mitri,
on behalf of E. Karantzoulis and the Elettra team

Outline:

- *Elettra*
- *Requirements*
- *Lattice analysis*
- *Best chosen lattices*
- *Current Elettra 2.0*
- *Lattice characteristics*
- *Brilliance and IDs*
- *Summary*

Emanuel.Karantzoulis@elettra.eu

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources



ISO 9001
OHSAS 18001
BUREAU VERITAS
Certification

Emanuel.Karantzoulis@elettra.eu

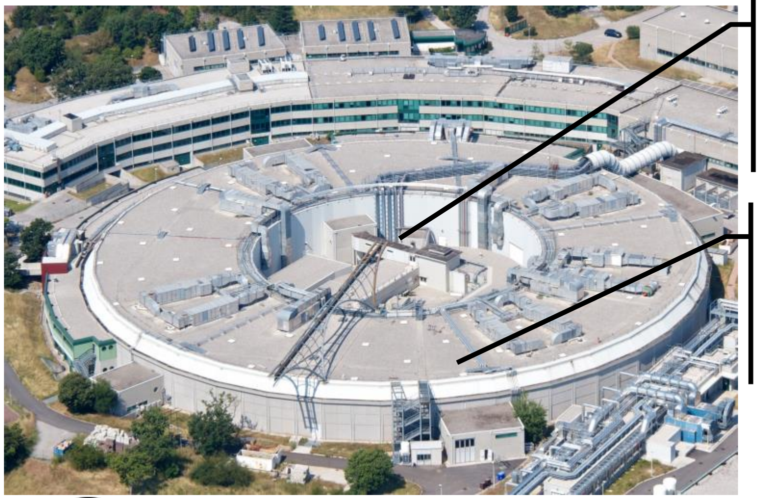
Elettra

Elettra Sincrotrone Trieste

- Third generation light source (DBA lattice, 12 fold symmetry) , commissioned in October 1993 and open to external users since 1994

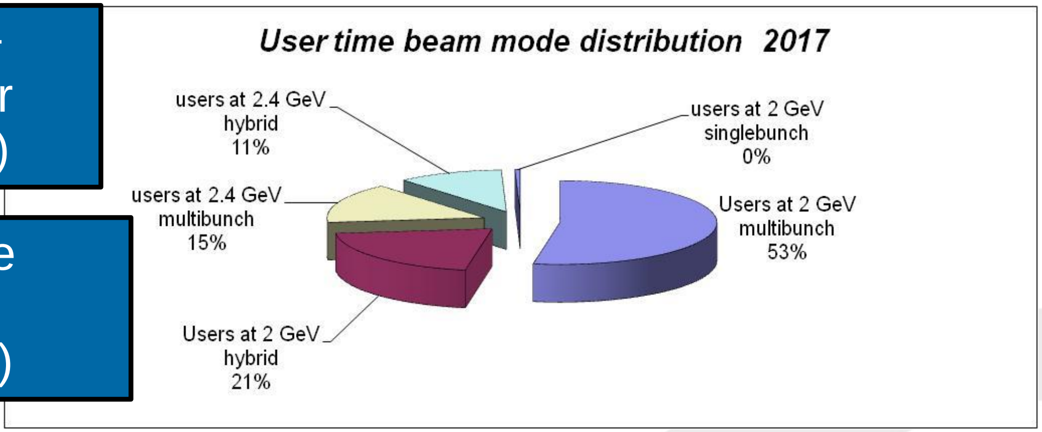
Operating modes for users all in Top-up:

- Operates for about 6400 hours per year (24h, 7/7), 5016 hours reserved for users
- 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 users / 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)



After 25 years an upgrade is needed

Emanuel.Karantzoulis@elettra.eu

Elettra 2.0 initial requirements

- The requirements were based on some interaction with the beam lines and the community of the users.
- A dedicated workshop on the future of Elettra was held in April 2014 to examine the various requirements. At that time the requirements were defined as follows:

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

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

Conserve the existing beam lines from dipoles

Use the existing injectors

Not so easy part

Emanuel.Karantzoulis@elettra.eu

PHANGS workshop

Lately (2016-2017) a new cycle of discussions started involving more our partners as well as our users.

To facilitate discussions we have organized the PHANGS workshop (December 2017)

PHotons At the Next Generation Synchrotron facilities: from production to delivery

asking for their wishes and opinions and also to think about experimental possibilities in the far future (20 years from now)


PHANGS2017 / HomePage https://www.elettra.eu/Conferences/2017/PHANGS/

PHANGS Photons at the Next Generation Synchrotron Facilities: from Production to Delivery

ICTP, Trieste, Italy / 4 – 5 December 2017

Elettra Sincrotrone Trieste

Home Venue Speakers Participants Program Registration Accommodation Contact Sponsors

The workshop is part of the XXV Elettra Users Meeting and aims at bringing together scientists to debate the perspectives and challenges for next generation storage rings, sources and photon transport optics. Special emphasis will be placed on design solutions that can serve best the scientific community by providing brightness, coherence and variable pulse-lengths. The workshop will be organized in the following sessions:

1. Next Generation Storage Rings (NGSR)
2. Insertion devices for NGSRs
3. Photon transport optics and enhanced beamline performance at NGSRs

The topics that will be discussed at the workshop are in response to the issues raised by the ongoing and planned upgrades of existing synchrotron facilities worldwide. Such upgrades are expected to add new experimental capabilities for a wide range of scientific communities from academy and industry.

TS TRIESTE CITTÀ DELLA CONOSCENZA TRIESTE CITY OF KNOWLEDGE

Scientific Committee
A. Bianco, Elettra
B. Diviacco, Elettra
E. Karantzoulis, Elettra (Chair)
L. Rebuffi, Elettra
J. Daillant, SOLEIL
E. Weckert, DESY

Local Organizing Committee
E. Karantzoulis, Elettra
S. Lizzit, Elettra
L. Gregoratti, Elettra
B. Diviacco, Elettra
L. Rebuffi, Elettra
M. Bassanese, Elettra
L. Pierandrei, Elettra
A. Accettulli, Elettra

Sponsored by

KYMA Structural Dynamics co-published by AIP Publishing | ACA PFEIFFER VACUUM

last update November 22, 2017, at 03:34 PM by Stefano Deiuri Print | Login

Emanuel.Karantzoulis@elettra.eu

Elettra Sincrotrone Trieste

Trends and Requirements

Up to now the main trend is Brilliance increase:

- Higher brilliance → lower emittance → more dipoles (MBAs)
- Smaller spot size and divergence
- High level of coherence in both planes (3^{rd} generation sources have only high vertical coherence)
- Higher flux

However many our partners and users are also interested in:

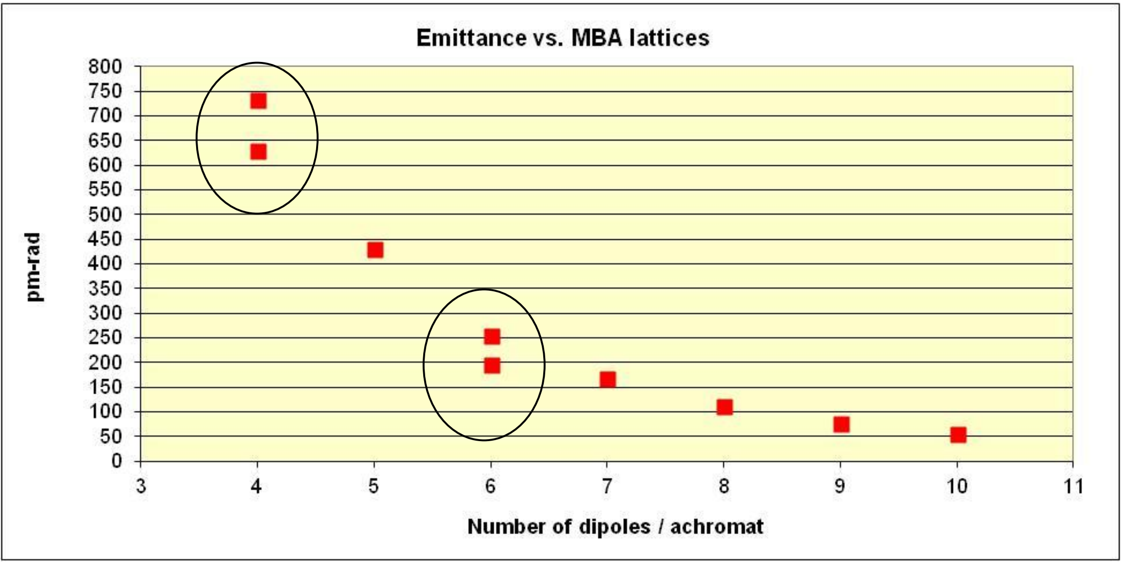
- High field dipoles (2 T and above)
- More and different types of undulators -> need more space
- Time resolved / short pulses -> need even more space
- Higher energy

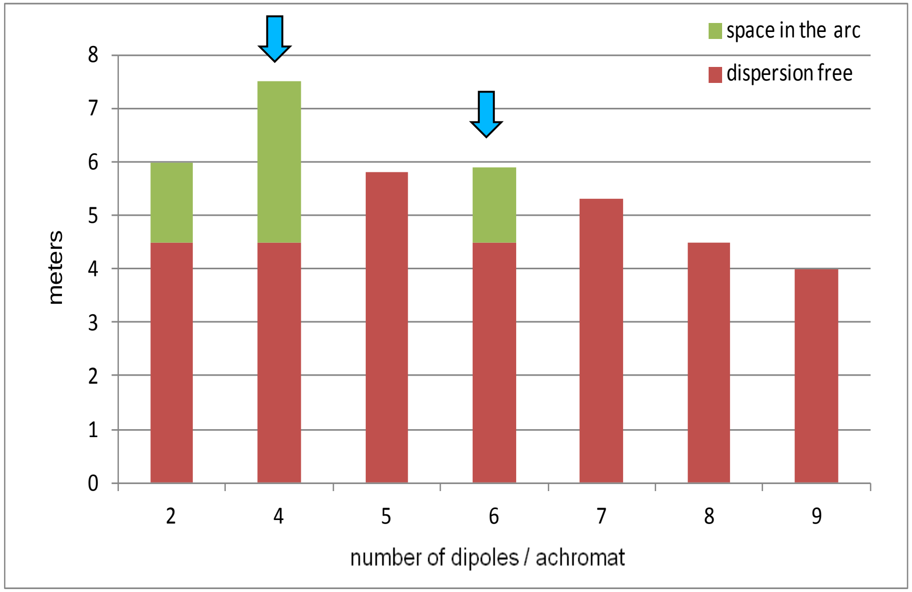
Emanuel.Karantzoulis@elettra.eu

Search for the Elettra 2.0 Lattice

Elettra Sincrotrone Trieste

All Elettra-like multi-bend lattices have been created up to 10BA





Number of dipoles / achromat	Emittance (nm-rad) @ 2 GeV	σ_x (µm) @ LS	σ_y (µm) @1% coupling @ LS	Brilliance increase factor at 1keV
2	7	240	14	
4	0.74 (0.63)	80	4.5	13 (15)
5	0.43	70	3	22
6	0.25 (0.19)	55	2.2	35 (43)
7	0.17	40	1.9	46
8	0.11	26	1.7	60
9	0.075	22	1.5	73
10	0.054	20	1.3	84

Free space available for IDs

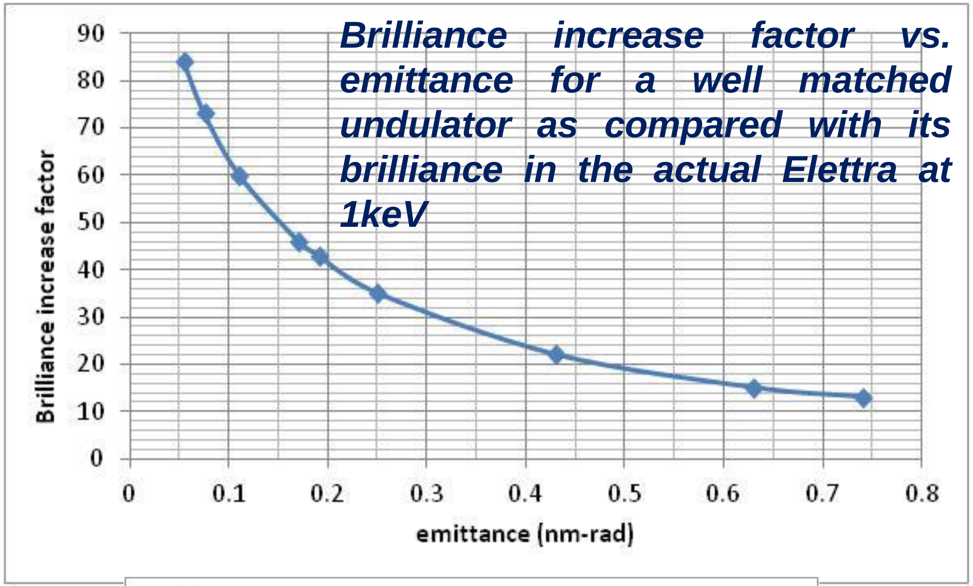
Red: free space available for IDs in the long straight section (dispersion free)
Green: free space available for IDs in the arc (dispersive)

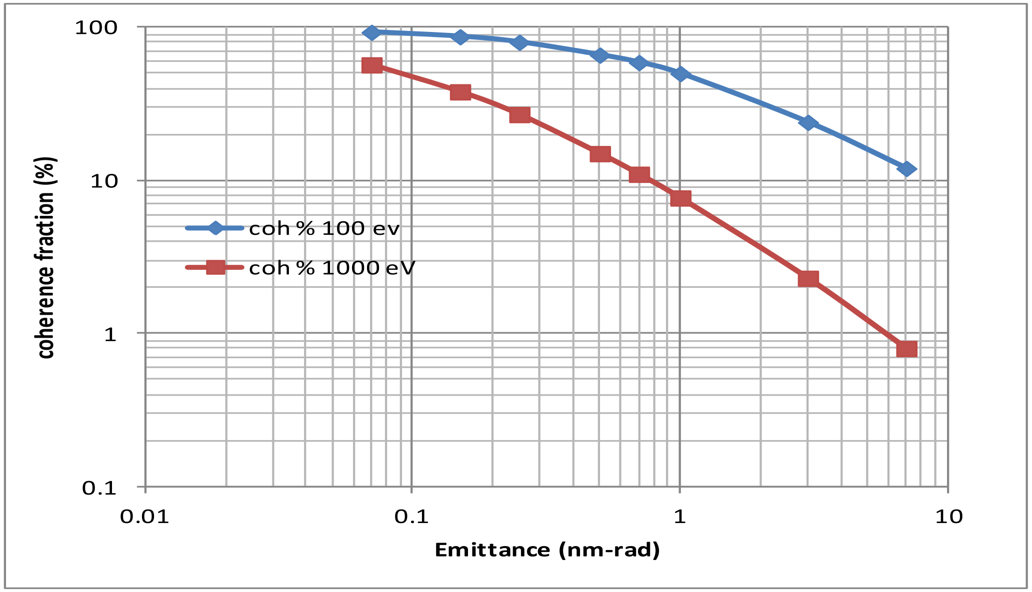
ISO 9001 OHSAS 18001 BUREAU VERITAS Certification

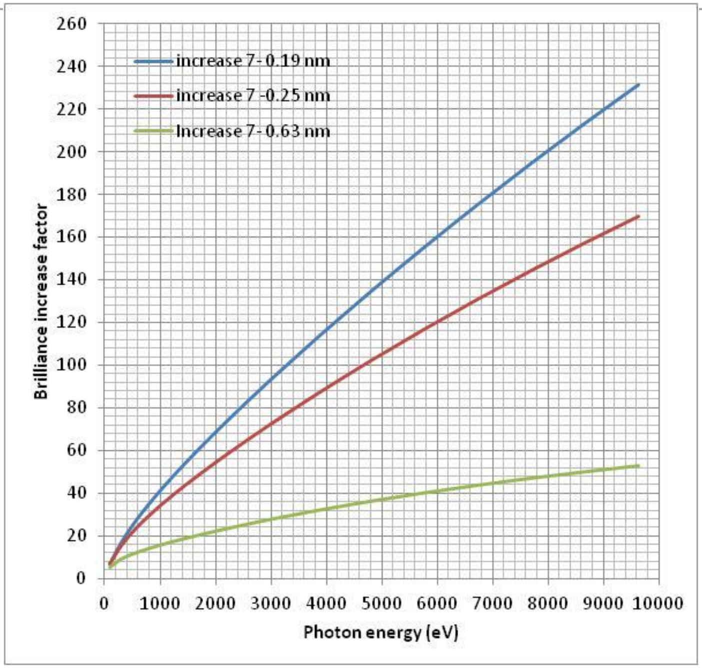
Emanuel.Karantzoulis@elettra.eu

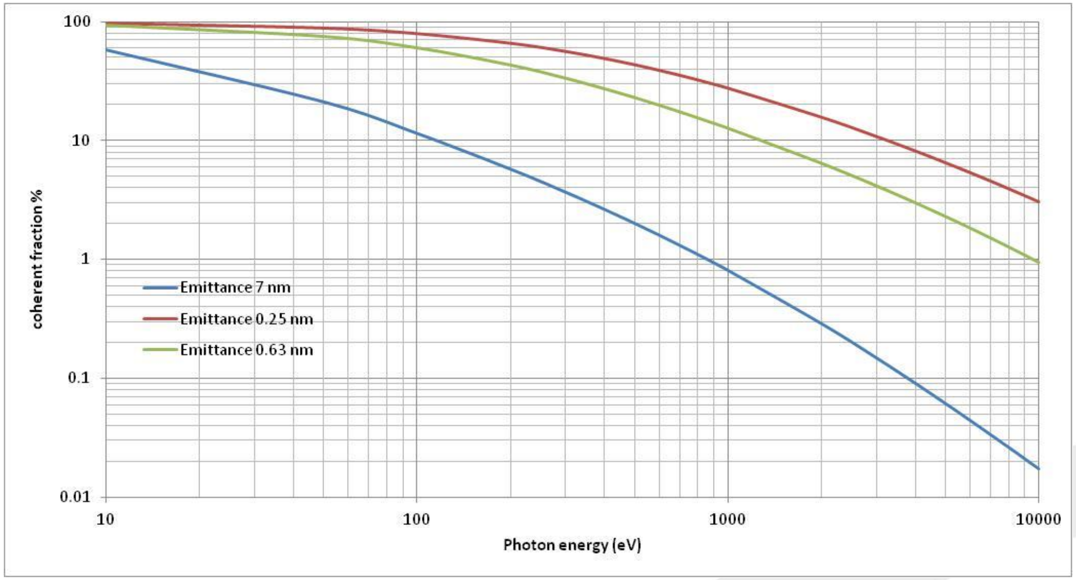
Elettra Sincrotrone Trieste

Brilliance increase factor and coherent fraction for Elettra-like SR





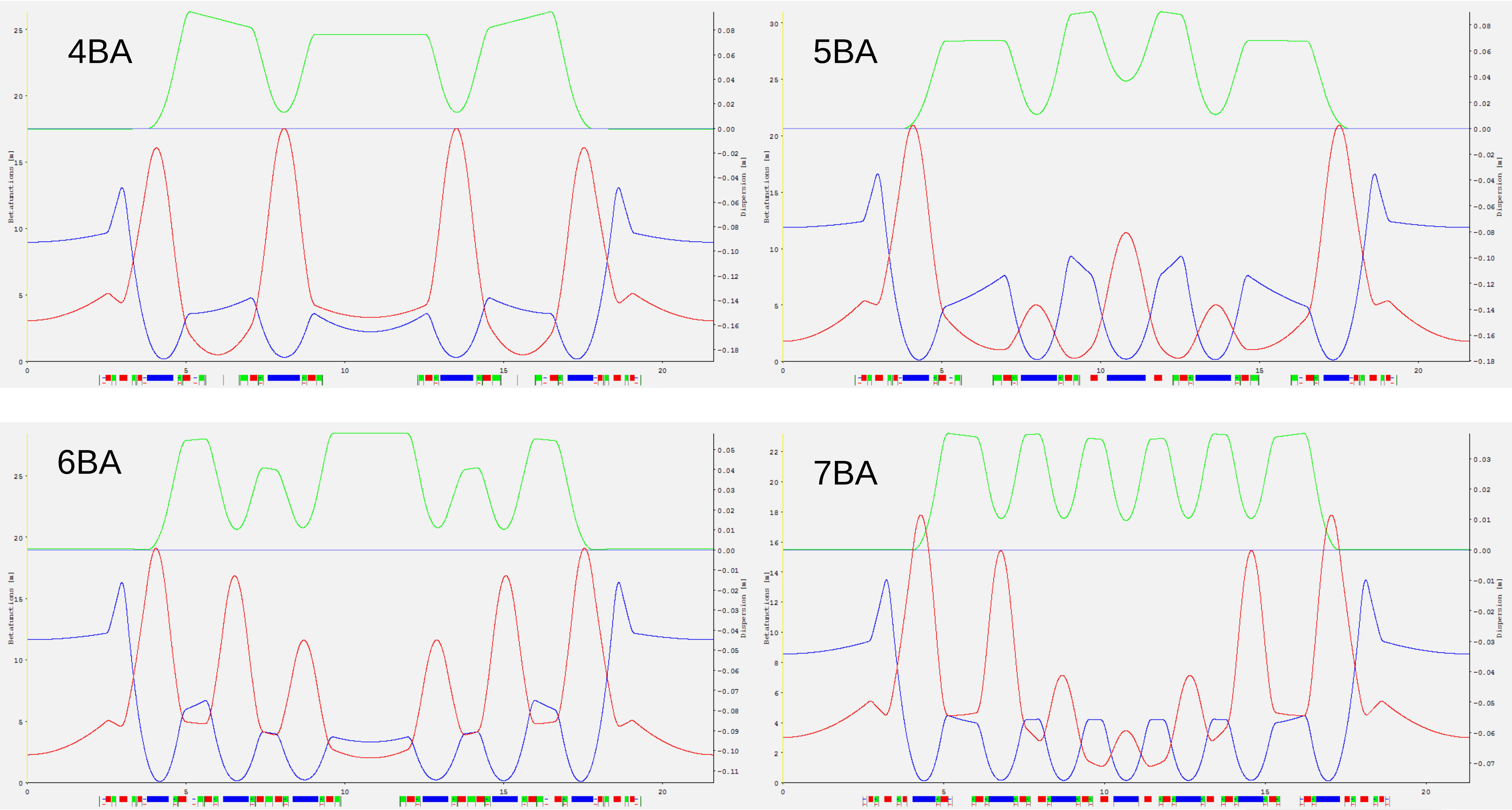




Emanuel.Karantzoulis@elettra.eu

Elettra Sincrotrone Trieste

Lattices fulfilling the free space criteria



For optics + graphics used "OPA version 3.81", PSI, 2015 by A. Streun

Emanuel.Karantzoulis@elettra.eu

Elettra
Sincrotrone
Trieste

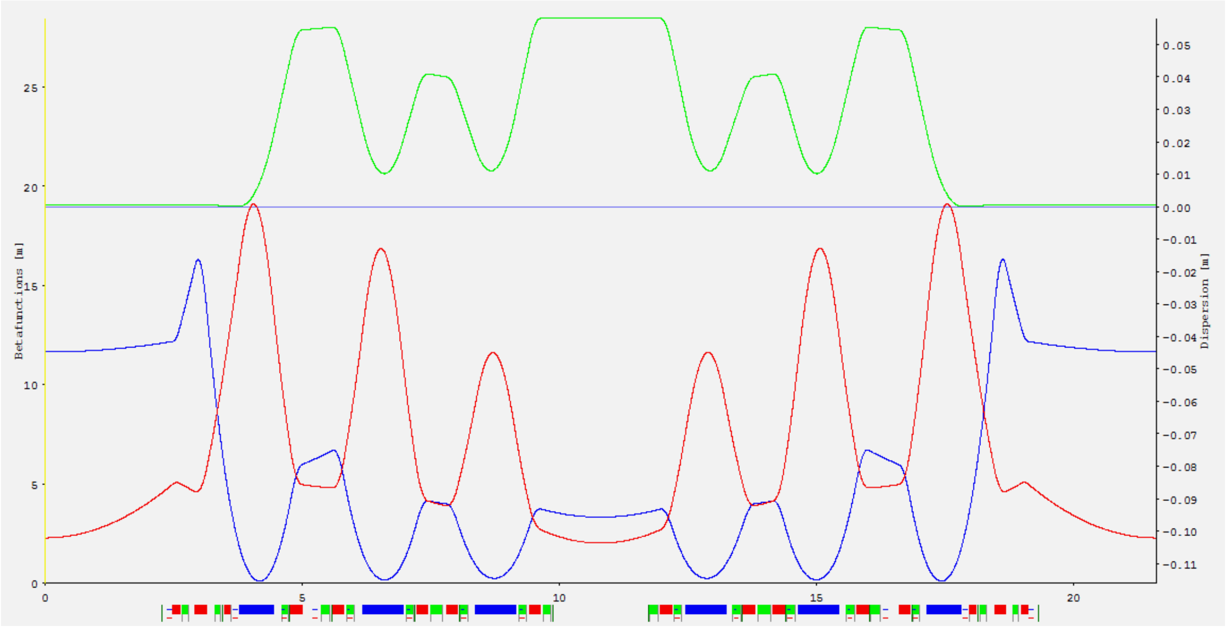
S6BA Lattice

Current version:

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

Dipoles are electromagnets at 0.8 T

No Longitudinal Gradient in the dipoles



Free space for IDs (4.5 + 1.8 m)

How to save the dipole beam lines?

Emanuel.Karantzoulis@elettra.eu

Taking care of the Dipole beam lines in S6BA

Our MBAs use dipoles with fields of about 0.8 T while at the actual Elettra the fields are 1.2 T at 2 GeV and 1.44 T at 2.4 GeV

Solutions:

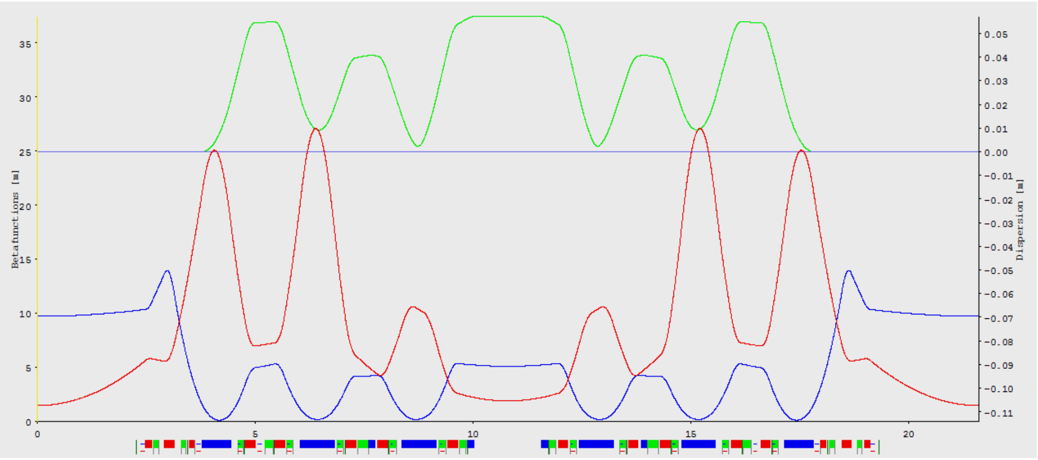
- Use LG dipoles with central field of ~2 T (for ~**3.3 deg in S6BA**) and negative angle bends (anti-bends), emittance decreases

- Use 1 m short wigglers in the arc (finite dispersion), emittance increases depending on the field. For each 2 T is 2.7% Including our superconducting wiggler of 3.5 T at the dispersion zero straight section the effect is reduced to 1.0%

- Use separate super-bends 3.5 T for the total angle of 5.7 deg - > Larger emittance increase (12% per super-bend)

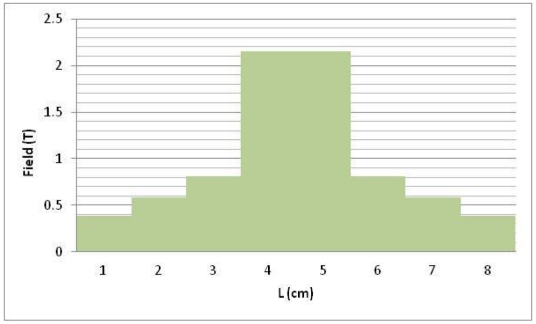
Emanuel.Karantzoulis@elettra.eu

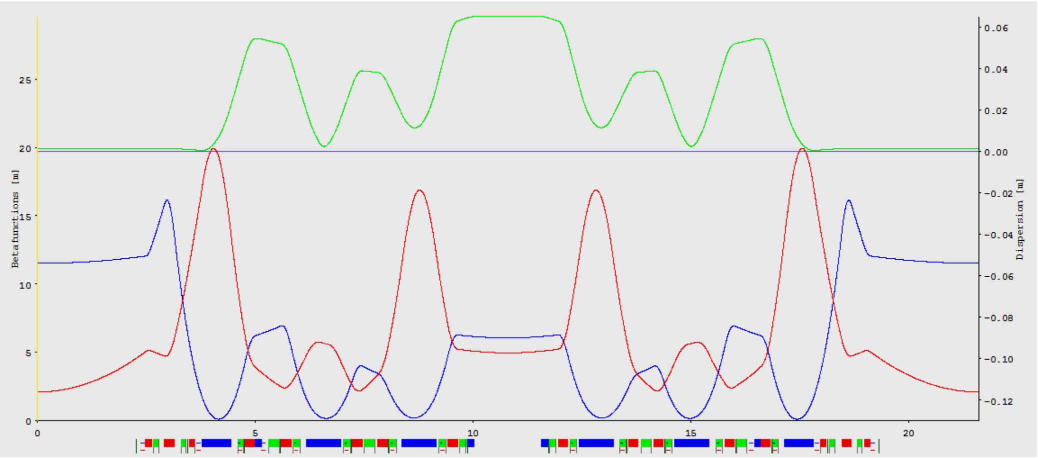
Versions of S6BA Lattices



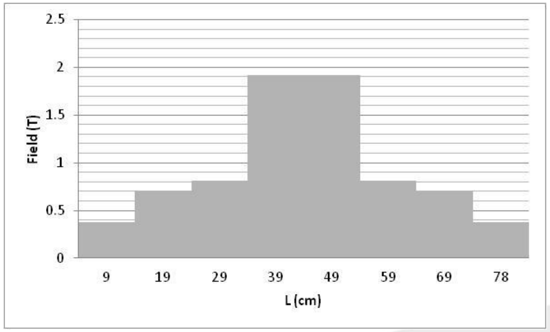
LG + anti-bend version:
Emittance 0.19 nm-rad (0.1 if round beam)

The 3 and 4 dipoles in LG with central field at ~2.2 T. **245 keV/turn**





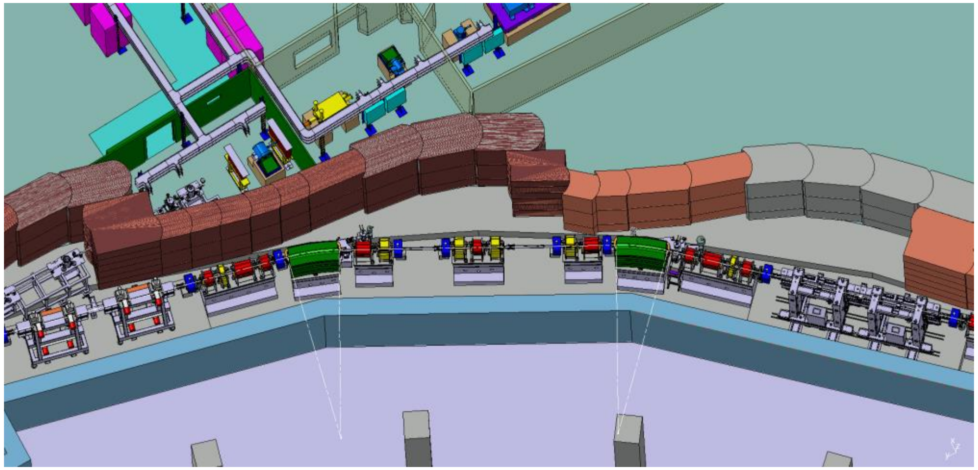
The 2 and 5 dipoles in LG with central field at ~2 T. **225 keV/turn**



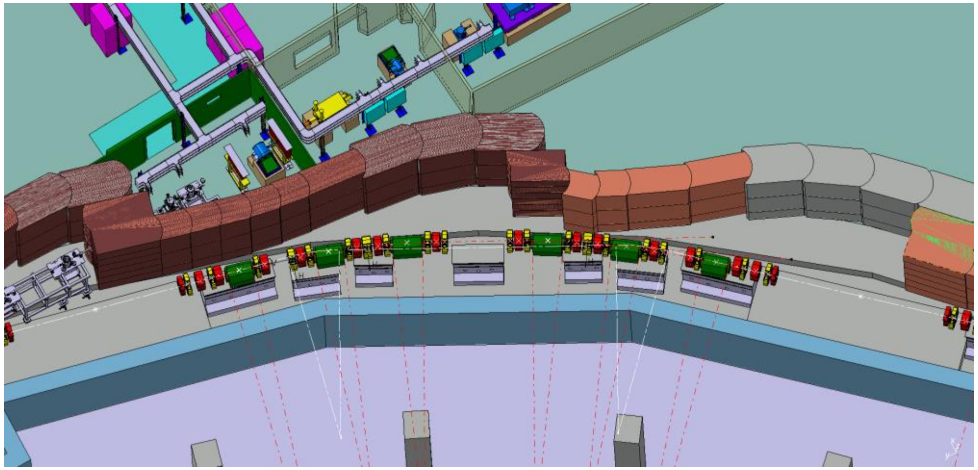
Free space for IDs (4.5 +1.55 m) – fixed at 2 GeV

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 symmetric six-bend achromat (S6BA).



Elettra



Elettra 2.0

The S6BA version is highly specialized aiming towards emittance reduction still keeping to some degree the other characteristics. The S4BA is multivalent but the emittance reduction is less.

Emanuel.Karantzoulis@elettra.eu

Other facts for S6BA

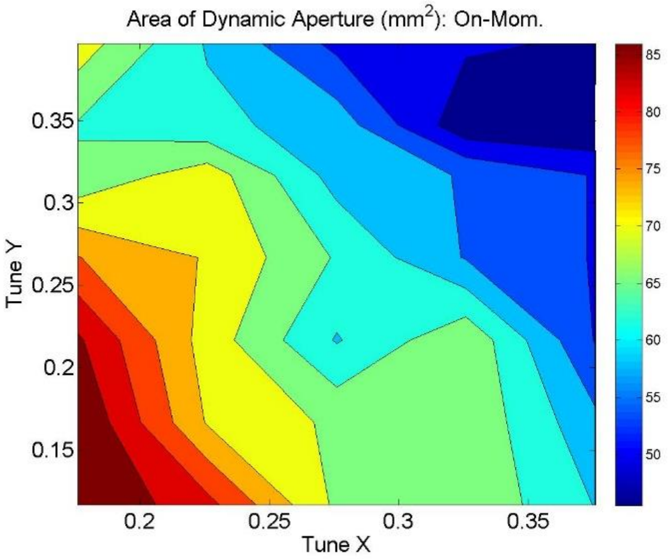
- ✓ Use of some permanent magnet dipoles is also considered
- ✓ Including errors and the existing IDs the dynamic aperture is ±7 mm horizontally and ± 2.5 mm vertically. This aperture permits off axis injection with an efficiency of more than 95%
- ✓ Lifetime is 6 hours at 2 GeV and with the third harmonic cavity (3HC, bunch lengthening) will be 18 h
- ✓ Intra-beam scattering increases the emittance by 90% at 400 mA however using the 3HC the effect is reduced down to 40%
- ✓ 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.

Emanuel.Karantzoulis@elettra.eu

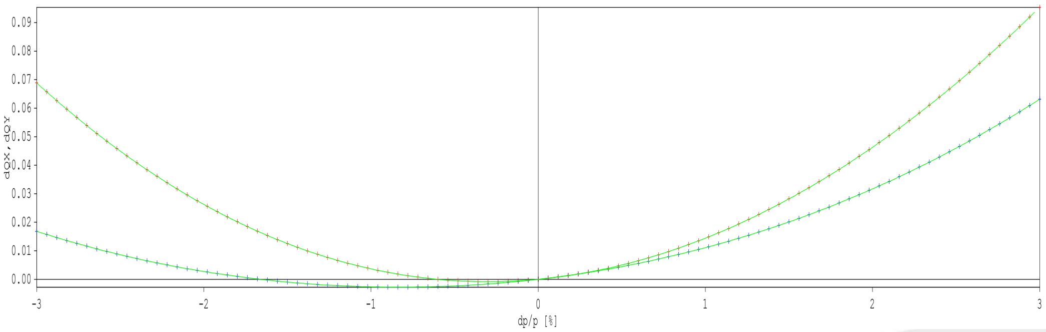
Elettra Sincrotrone Trieste

List of optics and rf functions

Circumference (m)	~ 259.2
Energy (GeV)	2
Number of cells	12
Geometric emittance (nm-rad)	0.25 (0.19)
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)



On-momentum dynamic aperture in mm^2 for the bare lattice, as a function of the working point.



horizontal and vertical tune shifts with ±3% relative momentum deviation

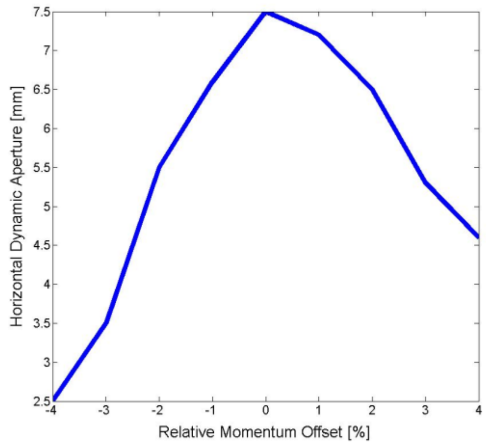
Emanuel.Karantzoulis@elettra.eu

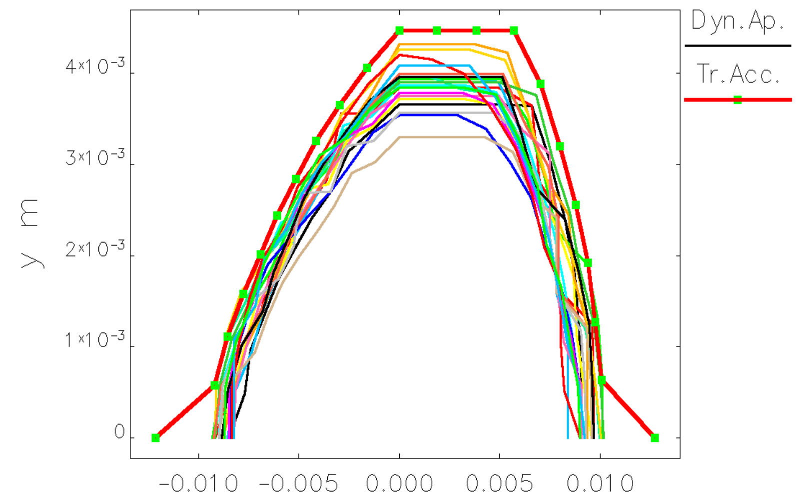
ISO 9001 OHSAS 18001 BUREAU VERITAS Certification

DA with errors

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

“elegant” runs ref. S. Di Mitri

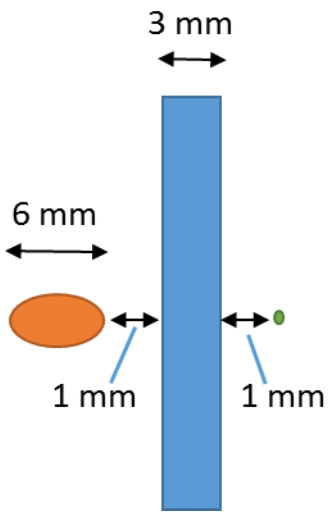


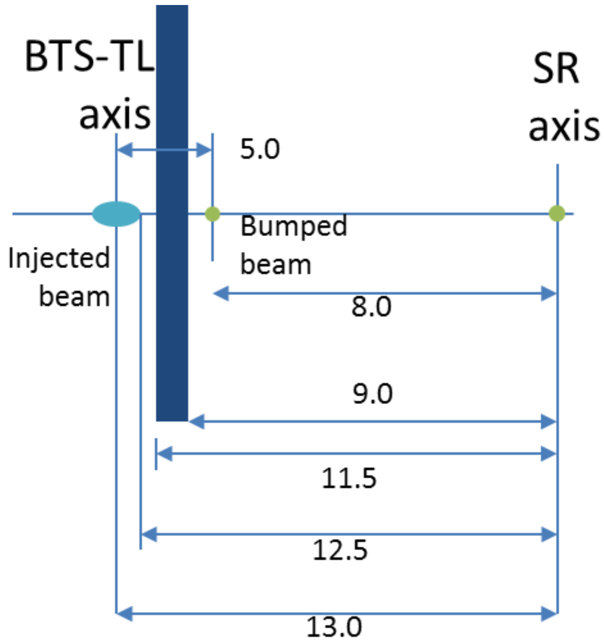


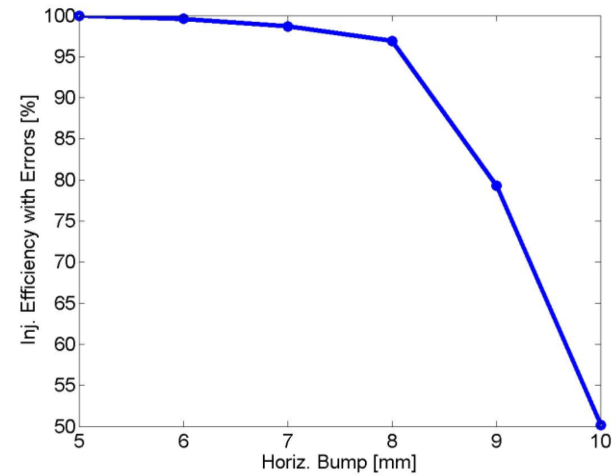
Dynamic aperture for the bare lattice (transverse acceptance), and in the presence of machine errors plus corrections, for 20 independent error seeds

Emanuel.Karantzoulis@elettra.eu

Injection studies



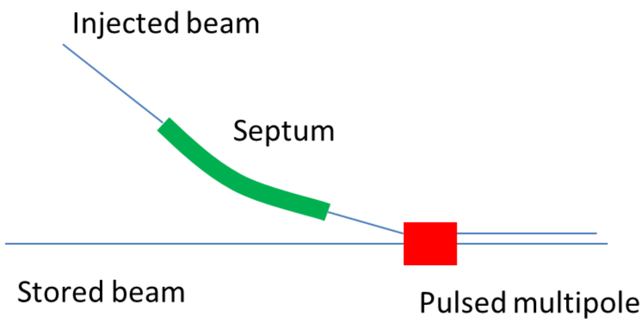


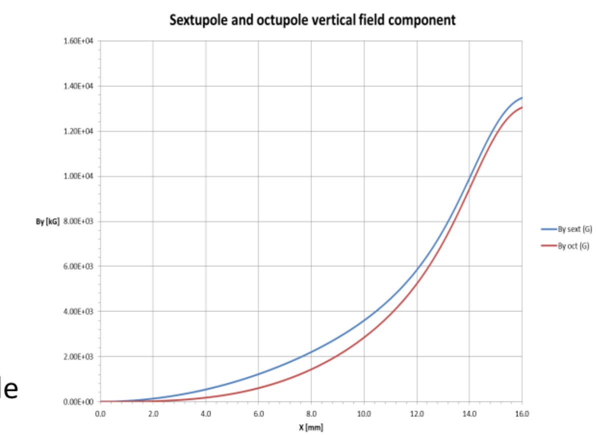


Promising using the already existing injection system + injectors. The actual 18 mm bump should be reduced to 8 mm bump and it appears possible

Ref. S. Di Mitri and R. Fabris

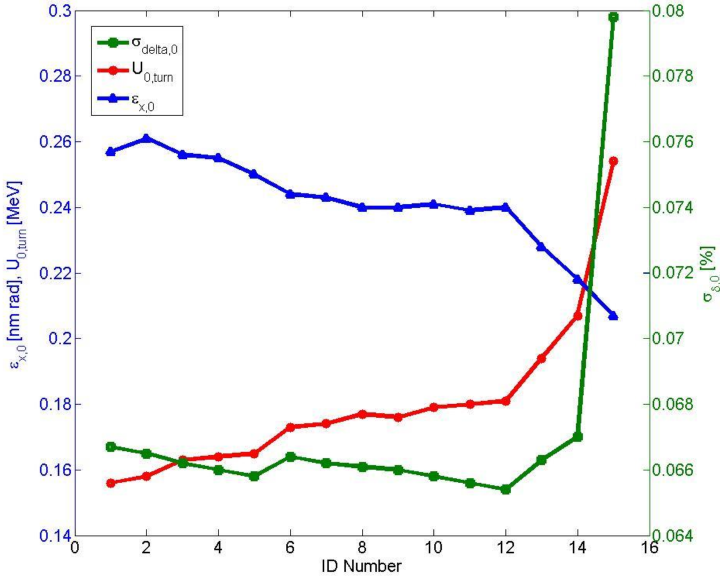
Considering also the multipole case



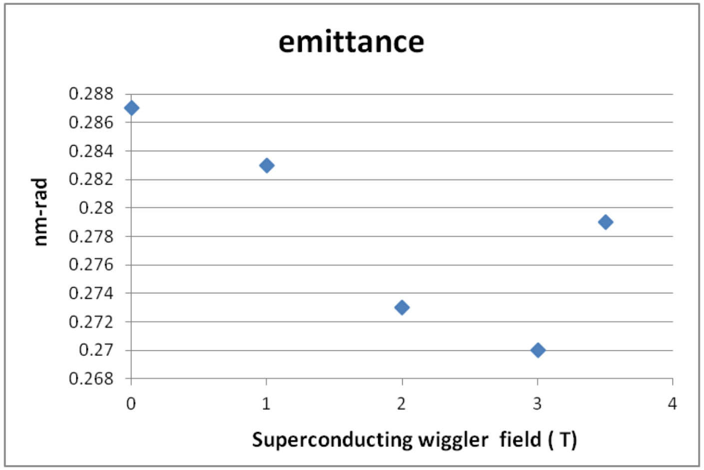


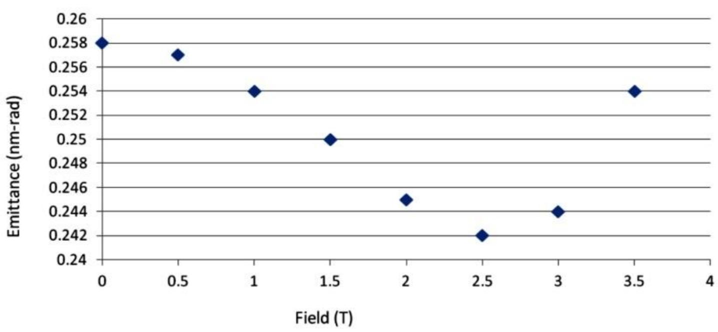
Emanuel.Karantzoulis@elettra.eu

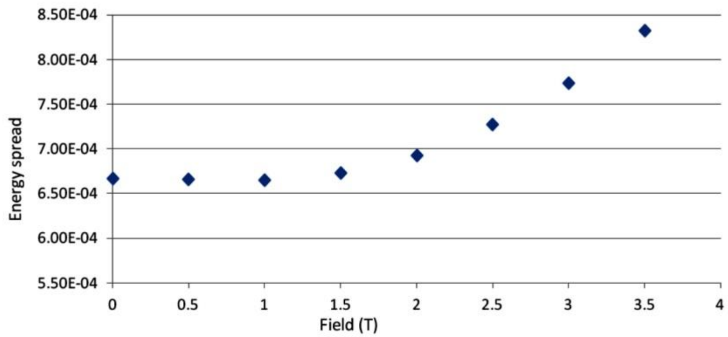
Effects of IDs

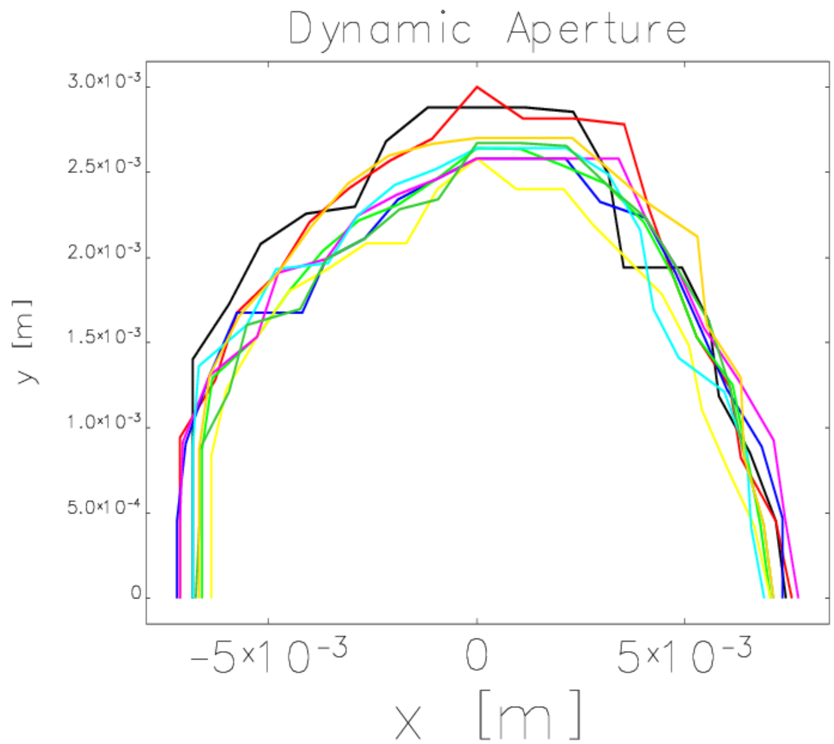


6 2T short wigglers in the dispersive region plus the SCW







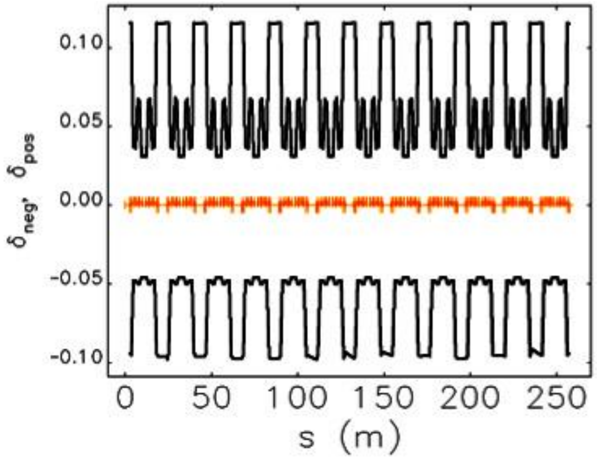


All included

Emanuel.Karantzoulis@elettra.eu

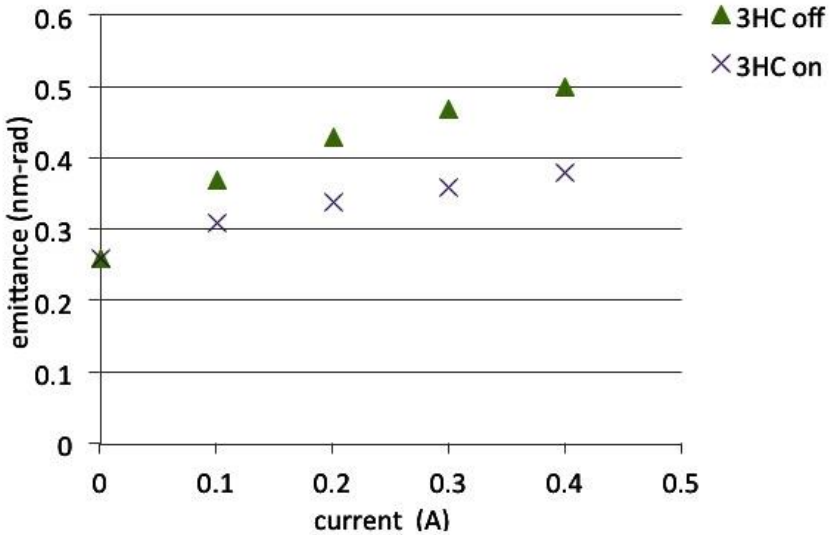
Lifetime and related issues

Elettra 2.0 is Touschek scattering dominated as the actual Elettra.



Assuming same conditions as in the actual Elettra, 1% coupling but 400 mA stored intensity and 2.4 MV effective RF voltage, the Touschek lifetime is 12 hours and including elastic (1286 h) and inelastic scattering (26 h) (assuming 3 nTorr of N_2 dynamic pressure) the total linear lifetime becomes 8 hours. Note that in this calculation the bunch length is the "zero current" bunch length (1.78 mm for 2.4 MV). Continuing to investigate the Touschek effect with a 4-D tracking using OPA, whereby particles start on axis but with momentum deviation Dp/p, the total lifetime is reduced to 6 hours for 1% coupling while becomes 12.4 hours for 10% coupling. With 3HC is expected to go 3X

Intra-beam scattering: Emittance increases by 92% at 400 mA if no bunch lengthening. With 3.5 x lengthening (third harmonic cavity) increases by 46% at 400 mA.



For the present Elettra lattice the **fast ion instability** was not an issue due to the relatively larger beam dimensions. Since Elettra 2.0 will have smaller beam dimensions investigate whether the fast ion instability will be important. Assuming 4 nTorr of CO (A=28) with the data from Elettra 2.0 one obtains a growth time of 30 ms (for the actual Elettra it is 3 sec) being easily dumped by the natural radiation damping and/or the multi-bunch feedback system.

Emanuel.Karantzoulis@elettra.eu

Magnet List

Dipoles

name	L_{mag} (m)	k	B0 (T)	B1 (T/m)	Angle (°)	ρ (mm)	N	sum
BF1	0.75	-1.91	0.5585	12.7	3.6	11937	24	72
BF2	0.84	-2.03	0.7896	13.5	5.7	8444	48	

Quadrupoles

name	L_{mag} (m)	k	B1 (T/m)	Ø (mm)	$\|B_{pole}\|$ (T)	N	sum
Q1	0.13	-2.840	18.93	26	0.246	24	192
Q2	0.22	5.774	38.49		0.500	24	
Q33a	0.13	-0.450	3.00		0.039	24	
Q33b	0.22	6.200	41.33		0.537	24	
Q333a	0.22	6.780	45.20		0.588	24	
Q333b	0.22	6.492	43.28		0.563	24	
Q4_1	0.22	5.780	38.53		0.501	24	
Q4	0.22	6.220	41.47		0.539	24	

Sextupoles

name	L_{mag} (m)	m	B2 (T/m^2)	Ø (mm)	$\|B_{pole}\|$ (T)	N	sum
SF	0.15	253.3	253.3	32	0.105	24	240
SD*	0.15	-254.7	3735.2		0.478	24	
SD2*	0.15	-253.3	6200.0		0.711	24	
SFIS	0.24	250.0	3666.7		0.469	24	
SDL*	0.15	-253.3	3715.5		0.476	48	
SFMSL	0.18	265.6	3894.9		0.499	24	
SDE*	0.12	-183.3	2688.4		0.344	24	
SD0	0.12	-33.3	489.0		0.063	24	
SEXP	0.12	45.0	660.0		0.084	24	

Correctors

name	L_{mag} (m)		N	sum
Comb (*)	nan		120	192
Alone	0.12		72	

In total 72+192+240+(120+72) = 696 magnets (50 A - 20V)

Dipole power each (422, 700 W)

Quad power each range (60, 178 W)

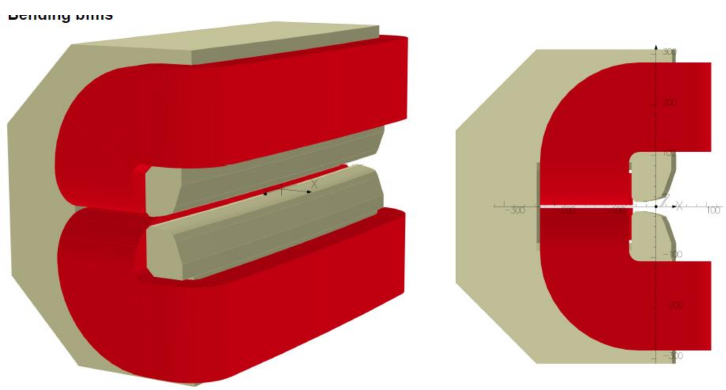
Sextupole power each range (73 - 222 W)

Magnets and PSs independent and air cooled

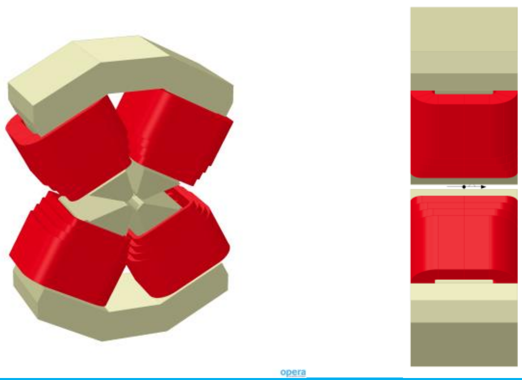
Emanuel.Karantzoulis@elettra.eu

Magnets

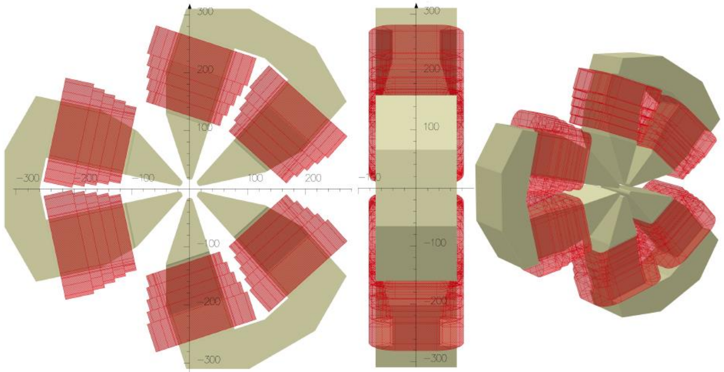
The short intra-magnet available space led us to design magnets with Lm≈Lp (max 10 mm difference). Use of new materials such as Cobalt – Iron alloys will also be considered. A quadrupole prototype is under construction at CERN



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.



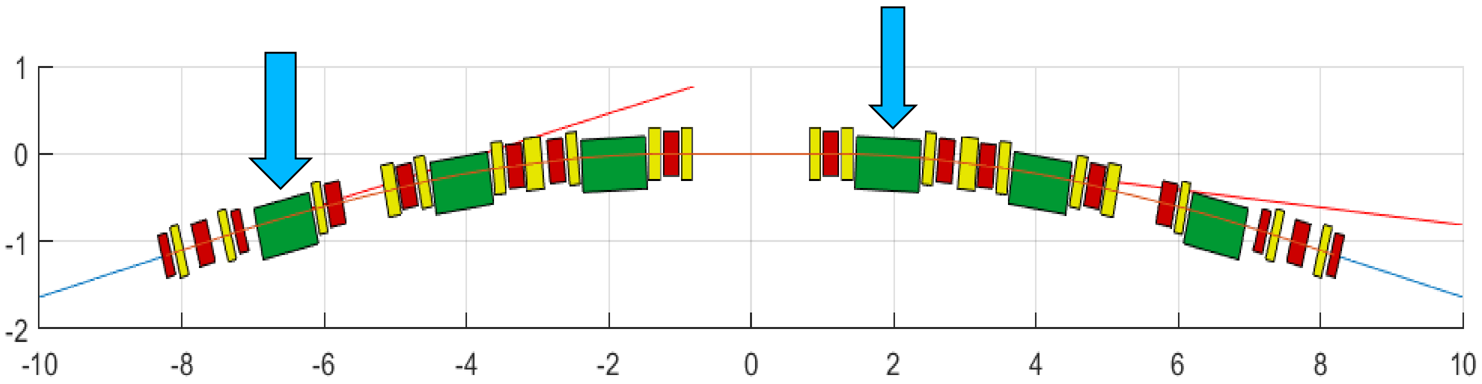
The quadrupole designs were developed with the vacuum chamber in order to resolve all the possible transversal interferences (beam lines). Asymmetric poles geometry has been opted.



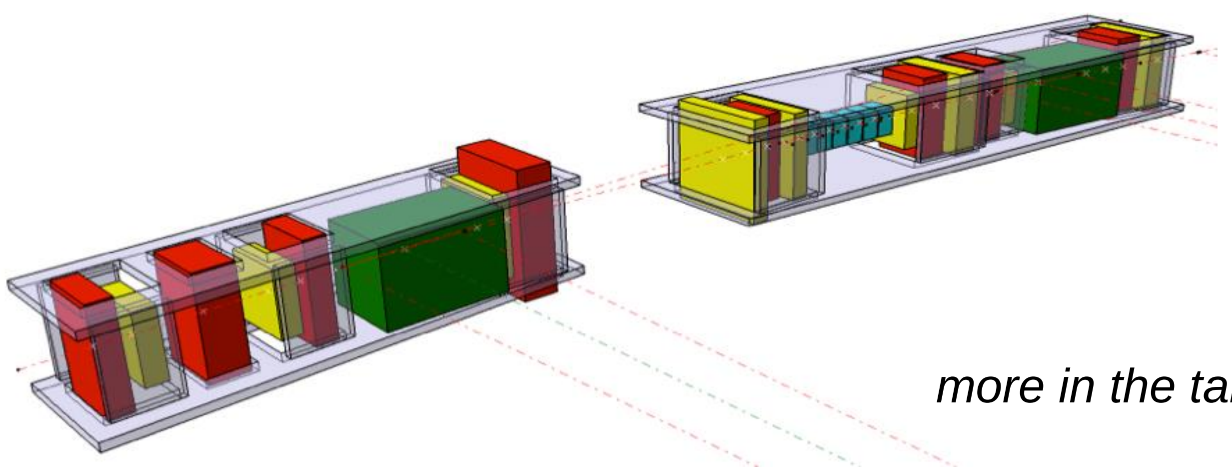
The sextupole magnets have the higher design issue. The transversal interferences between coils and vacuum chamber are resolved.

Ref. D. Castronovo (Opera)

Physical interference control



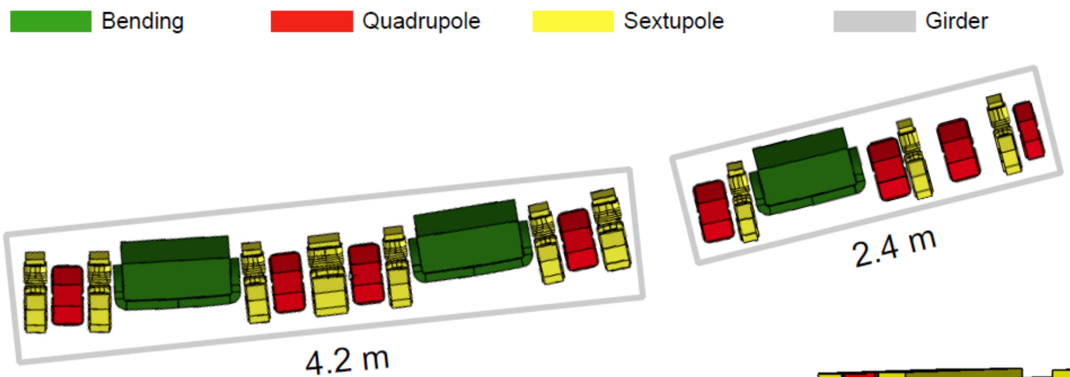
Old concrete girders will not be reused, new girders/supports will be constructed, propose 3D supports because magnets are thin.

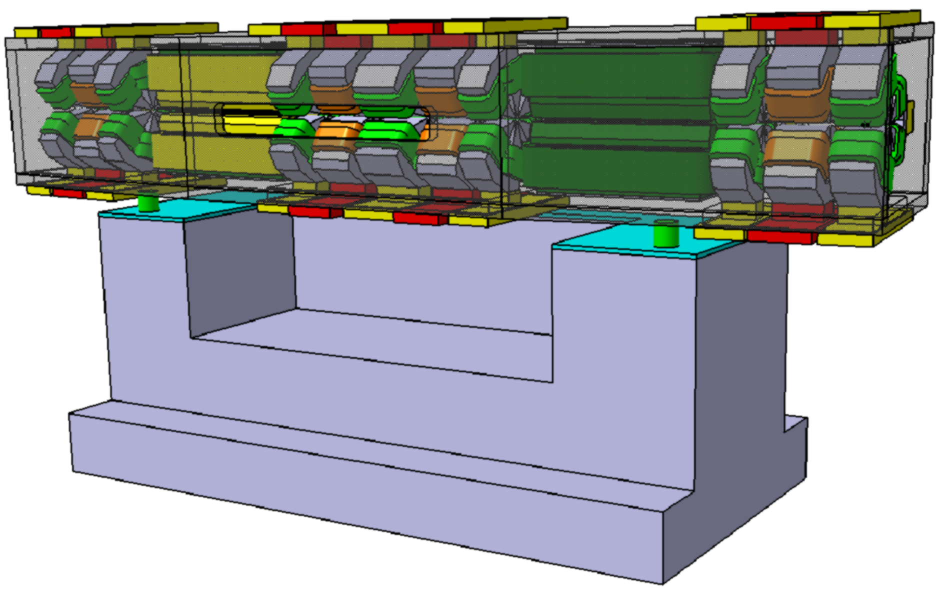


more in the talk by I. Cudin

Supports and girders

Thin magnets -> 3D supports but the magnets are not integrated like in MAX IV Lower part will support the whole of the dipole, ½ qudrupole and 2/3 of sextupole. The upper part will support ½ of quadrupole and 1/3 of sextupole. The two parts will be symmetric but not equal.





Emanuel.Karantzoulis@elettra.eu

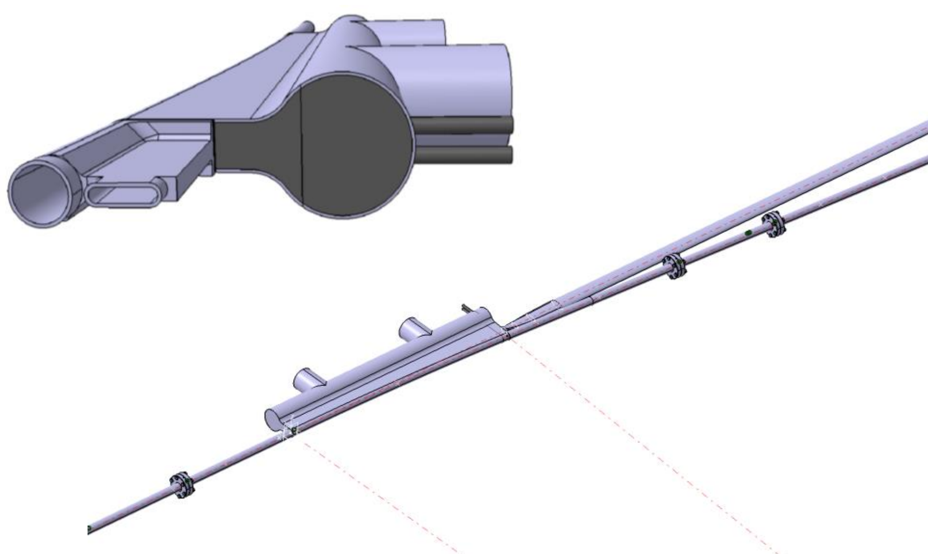
Vacuum chamber geometry Preliminary studies

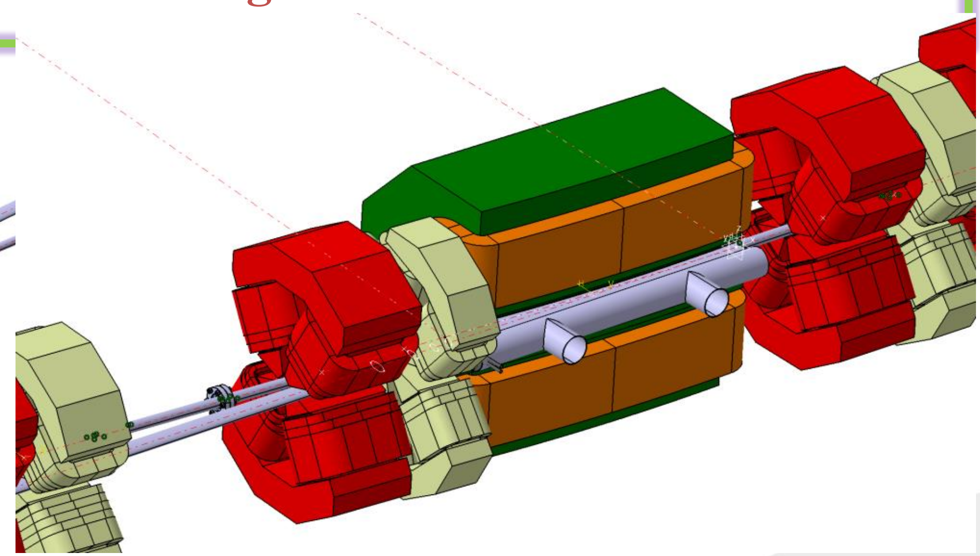
Vacuum chamber: Best compromise (considering also the magnet power) seems to be a circular cross section with 25 mm external diameter (with/without antechamber).

For the long straight sections the current vertical dimension of 9 mm is assumed.

The material maybe mixed S. Steel for light exits and straight chambers ; copper for curved pipes

Long straights with NEG and maybe also the straight short ones





(Ref. L. Sturari and I. Cudin)

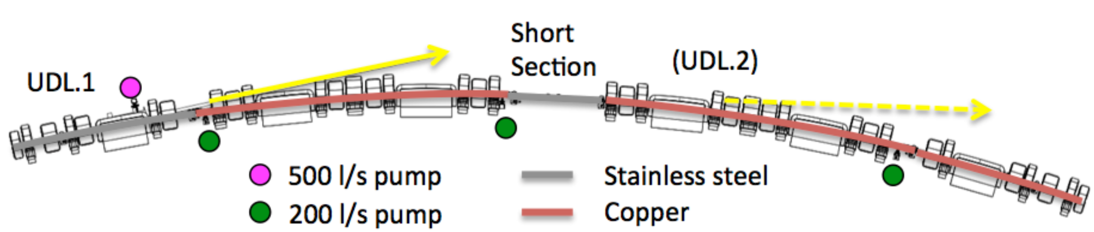
Elettra Sincrotrone Trieste

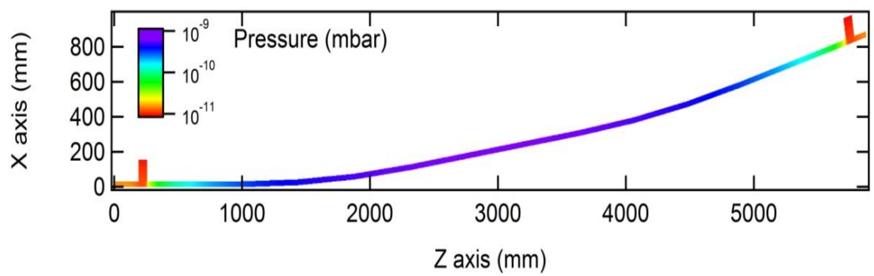
Vacuum system

The following are considered:

- *Small free distance between most of the magnets ;*
- *Heat load from synchrotron radiation (absorption, transmission, dissipation issues);*
- *The dynamic pressure inside the vacuum chamber;*
- *Compatibility with the present, insertion device vacuum chambers and front-ends.*

Target: max local pressure < 4 nTorr and average < 1.5 nTorr





The main materials under investigation for the vacuum chambers in the arc are stainless steel and copper. Copper used mainly as distributed heat sink and an internal NEG coating maybe applied to act as a distributed pumping system. Also Alluminum being very manageable is not discarded. The long straights will have alluminum low gap chambers with NEG.
Simulations using Molflow +

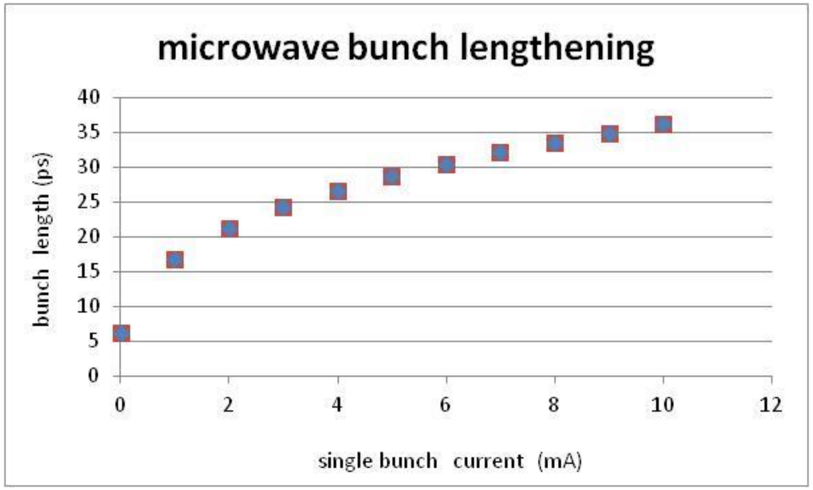
(Ref. L. Rumiz)

Impedances estimations

Low gap chambers and rf transitions dominate

Resistive wall

total length / achromat (m)	Number of pieces	Chamber height (m)	material	$Z_\perp$ kohm/m both H and V	$Z_{//}$/n ohm
5	12	0.023	S.Steel	13	0.11
12.5	12	0.023	Cu	5	0.05
5	10	0.009	Al+NEG	42	0.06



Transitions

type	D1(m)	D2(m)	L (m)	$Z_\perp$ kohm/m	$Z_{//}$/n ohm	Number of tapers	$Z_\perp$ tot kohm/m	$Z_{//}$/n tot ohm
rf	0.1	0.023	0.070	7.2	0.22	8	58	0.18
Ids	0.023	0.09	0.070	6.9	7e-4	20	138	0.01

other

type	Radius (m)	Length (m)	Width (m)	# of items	$Z_{//}$/n (ohm)	$Z_\perp$ (ohm/m)
Rf bellows	0.1	0.05	0.0015	8	6e-6	0.07
Cham. blw	0.011	0.05	0.0015	144	9e-3	9148
Pump slots	0.011	0.05	0.003	60	1.45e-2	15160
openings	0.011	0.25	0.01	30	1.353-2	14090
bpms	0.011	0.01	0.01	192	4.2e-3	2855

RF cavity	# of cavities	$Z_{//}$/n (ohm)	$Z_\perp$ (kohm/m)
	4	0.24	8

Total

	Re ($Z_{//}$/n) (ohm)	Im ($Z_{//}$/n) (ohm)	Re ($Z_\perp$) (kohm/m)	Im ($Z_\perp$) (kohm/m)
Resistive wall	0.22	0.22	60	60
Transitions		0.19		196
RF		0.24		8
Bellows+slots+openings		-0.037		-38
BPMs and other		0.004		2.8
total	0.22	0.61	60	230

For the quoted 230 kohm/m a tune frequency shift of -0.9 kHz/mA is predicted being 50% larger than that measured on the present Elettra (-0.6 kHz/mA). The new input is that the same shift will also be for the horizontal tune.

TMCI threshold is estimated to be at about 6 mA

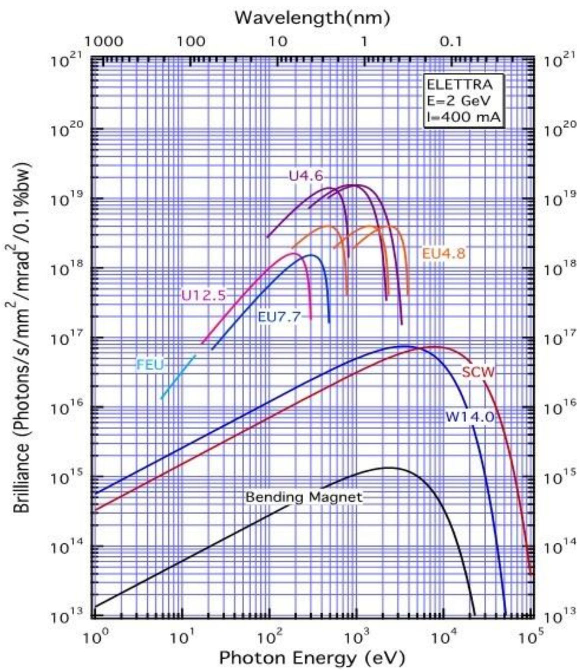
Elettra and Elettra 2.0

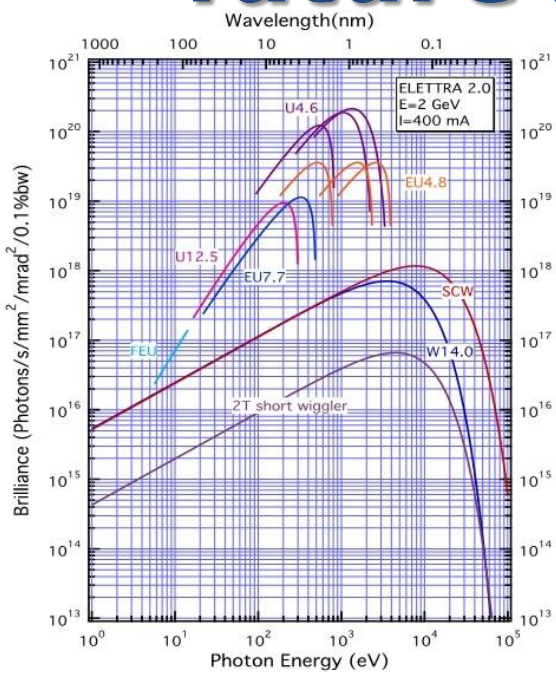
Parameter	Units	Elettra	Elettra 2.0
Circumference	m	259.2	259.2
Energy	GeV	2 - 2.4	2
Horizontal bare emittance	pmrad	7000	250 (190)
Vertical emittance	pmrad	70 (1% coupl)	2.5
Beam size @ ID (σx,σy)	μm	245 , 14 (1% coupl)	43 , 3
Beam size at short ID	μm	350 , 22 (1% coupl)	45 , 3
Beam size @ Bend	μm	150, 28 (1% coupl)	17 , 7
Bunch length (zero current)	ps	17 (100 with 3HC)	5.6 (70-100 with 3HC)
Energy spread	DE/E %	0.08	0.07
Bending angle half achromat	degree	15	3.6 and 2x5.7

ISO 9001 OHSAS 18001 BUREAU VERITAS Certification

Elettra
Sincrotrone
Trieste

Brilliance with existing and future IDs (S6BA)



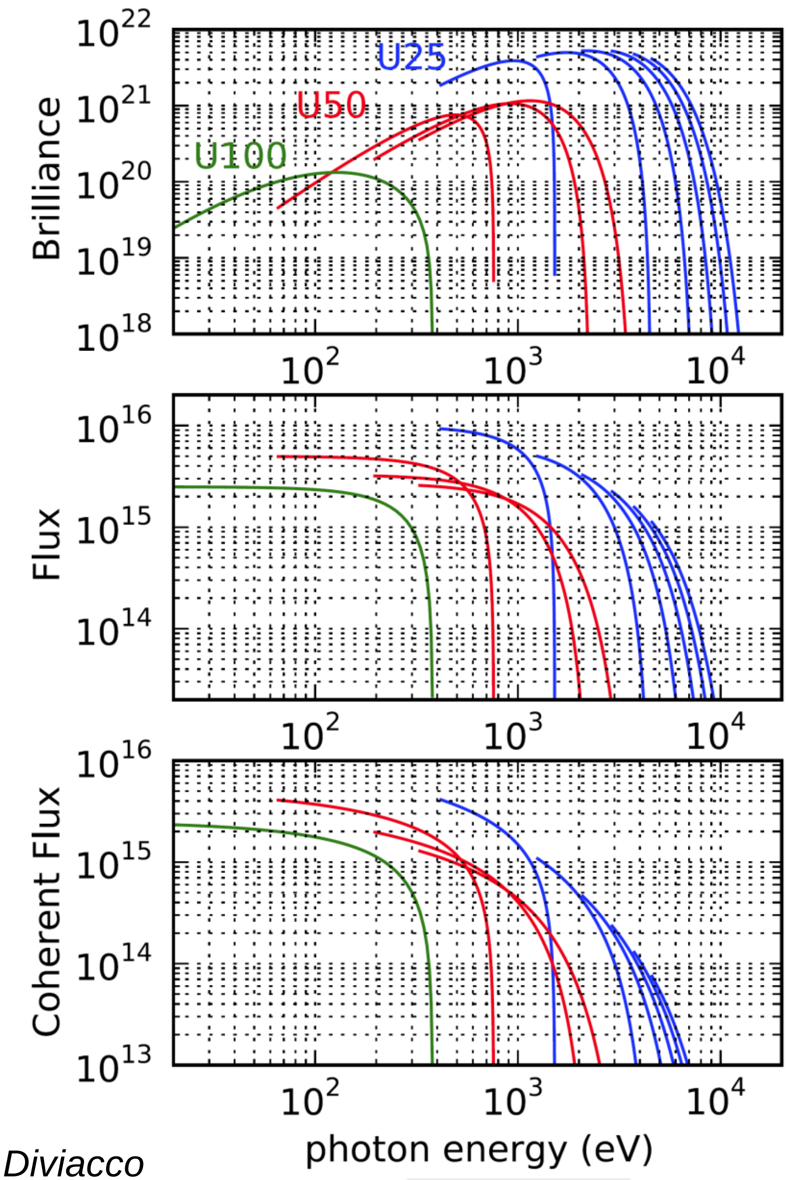


Performance in case of three well matched hypothetical insertion devices (brilliance, flux and coherent flux):

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

- A complete analysis was performed to find the best machine combining at best the various user requirements.
- Our S6BA optics is chosen as the closest to the various requests for Elettra 2.0.
- The optics is very flexible and can accommodate a number of super-bends.
- Installation of insertion devices also possible in the middle of the arc. For the moment the space available there, is 1.8 m.
- The 1.0 version of the Elettra 2.0 conceptual design report (CDR) is available since 2017.
- The Elettra 2.0 project has been approved by the government.

Acknowledgments

The following people contributed to the technical CDR (provisional) document

S. Bassanese, D. Baron, A. Bianco, F. Bille, R. Borges, P. Borsi, A. Buonnano, E. Busetto, A. Carniel, D. Castronovo, K. Casarin, M. Cautero, V. Chenda, S. Cleva, I. Cudin, S. Di Mitri, R. De Monte, B. Diviacco, A. Fabris, R. Fabris, P. Furlan, G. Gaio, F. Giacuzzo, E. Karantzoulis , G. Kourousias, S. Krecic, G. Loda, M. Lonza, A. Martinolli, E. Mazzucco, M. Miculin, D. Morelli, L. Novinec, C. Pasotti, R. Passuello, L. Pivetta, R. Pugliese, L. Rebuffi, L. Rumiz, L. Sturari, C. Scafuri, G. Stopar, P. Tosolini, G. Tromba, R. Visintini, A. Vascotto, M. Zaccaria, D. Zangrando

E. Karantzoulis (editor)

Many thanks to Prof. W. A. Barletta for reading, proofing and commenting on the CDR.

Thank you for your attention

Emanuel.Karantzoulis@elettra.eu