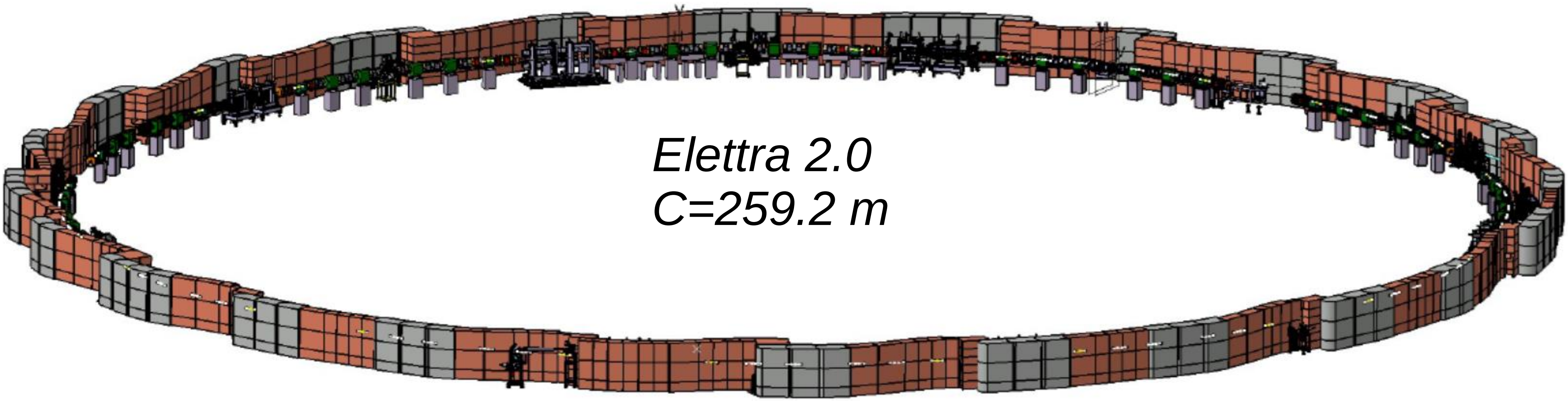
Elettra 2.0

Current Elettra
Circumference 259.2 m
12 fold symmetry
Energy 2 (& 2.4 GeV for 25% UT)
Emittance 7 (10) nm-rad
Beam dim @IDs 250/14 um
28 beam lines - 10 from dipoles

Emanuel Karantzoulis

on behalf of the Elettra team



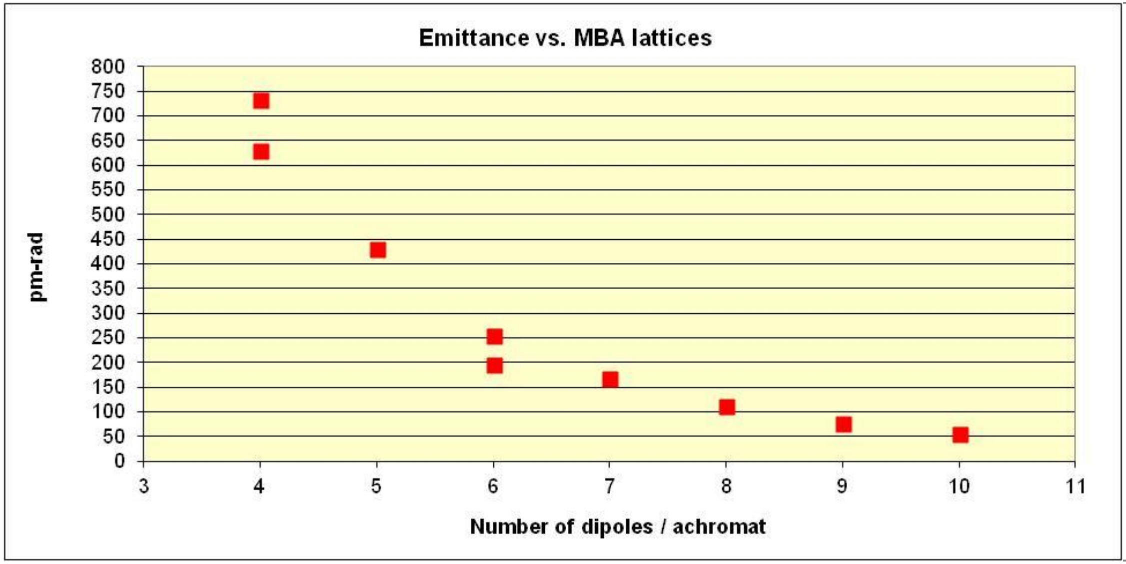
Elettra 2.0
C=259.2 m

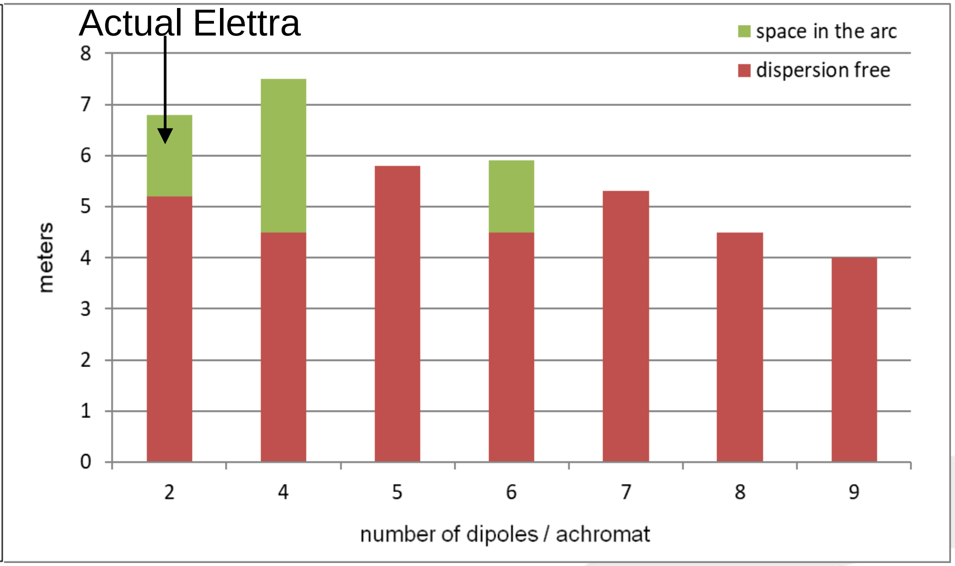
Preface

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

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

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



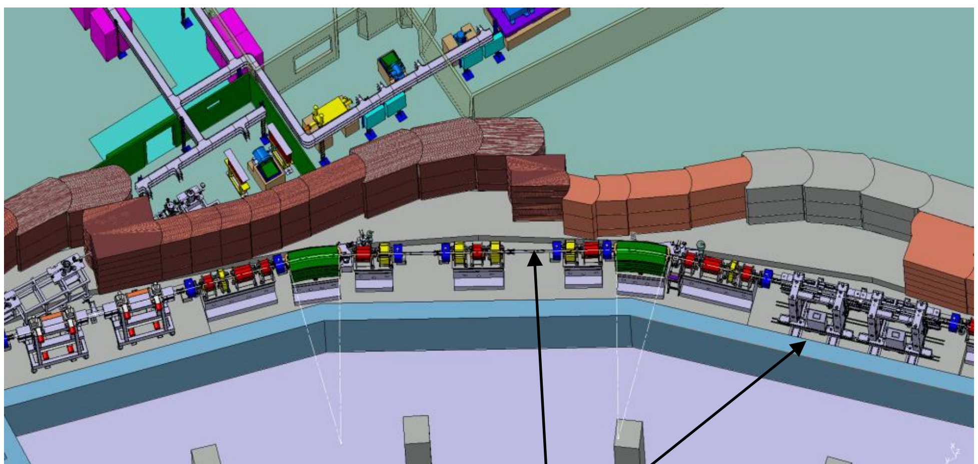


The obvious choice is a 6 BA lattice

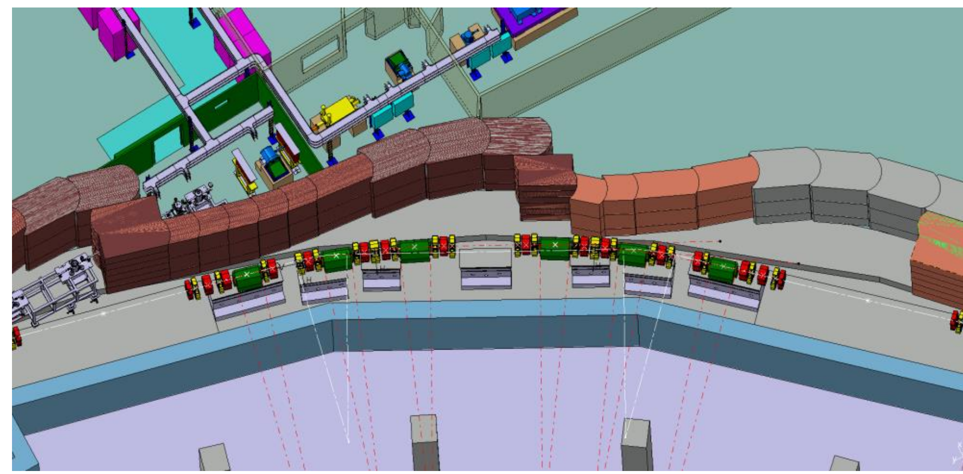
Elettra
Sincrotrone
Trieste

Almost but not quite done

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



Elettra



Elettra 2.0

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

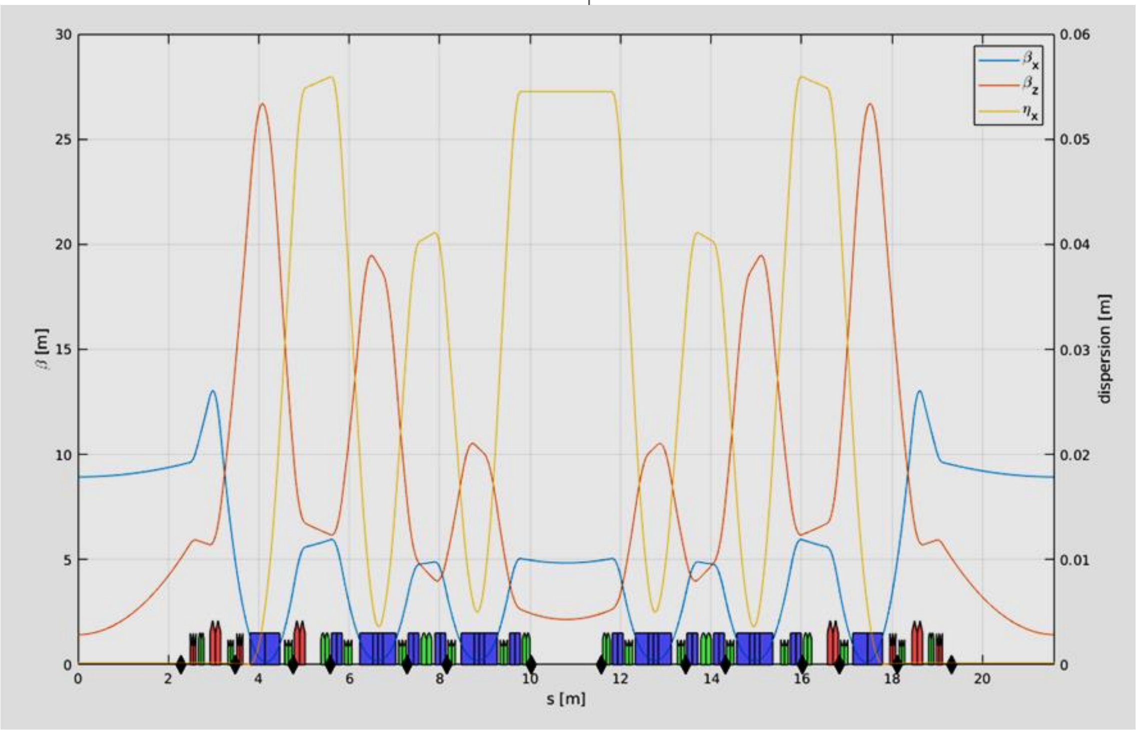
But further requirements forced us seek better but more difficult solutions

Elettra 2.0 revised and final requirements

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

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

The S6BA-E Lattice

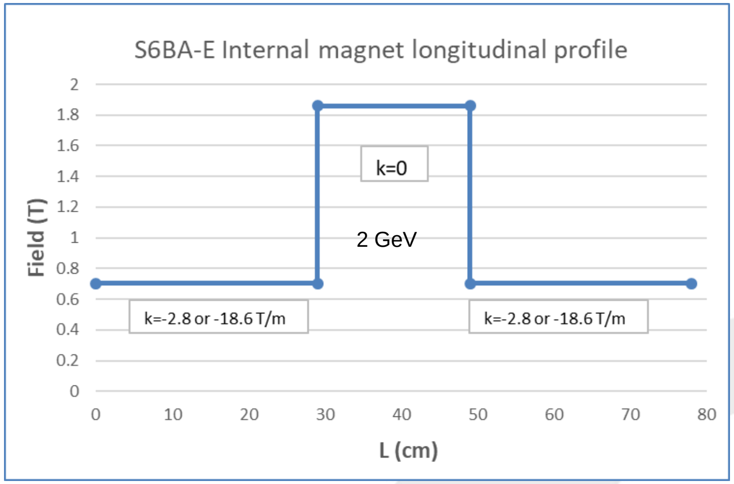


This upgraded version uses 8 reverse-bends/achromat and 4 longitudinal + transverse gradient dipoles/achromat.
Conserves the free space required for IDs while the gradients on the quadrupoles are reasonable

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

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

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



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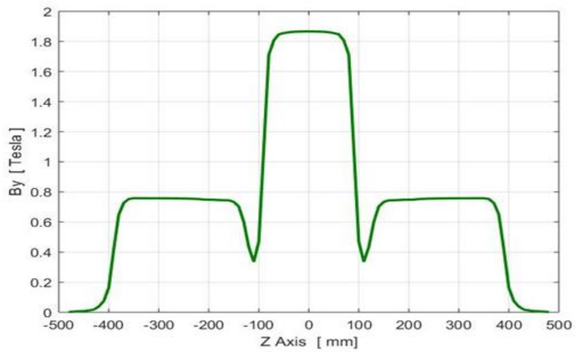
Field choice for the Longitudinal Gradient Dipoles

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



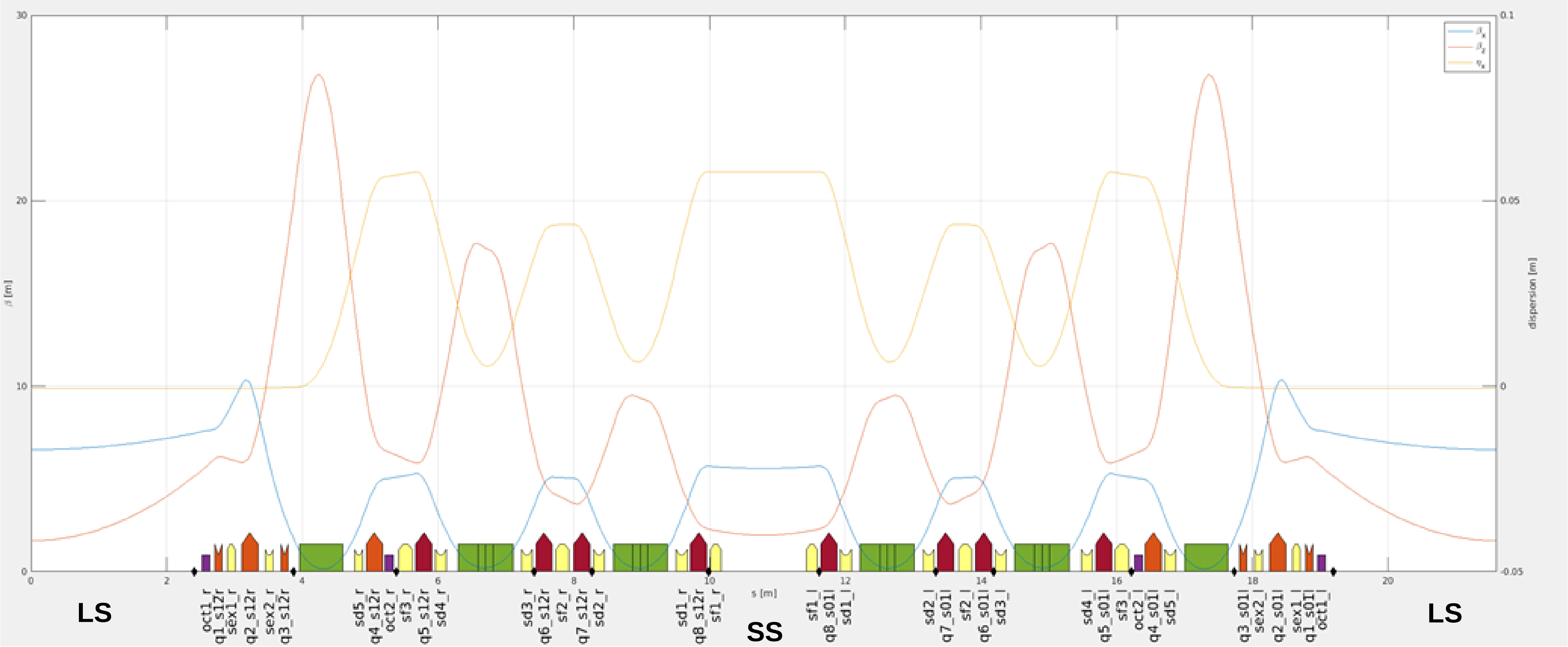
2.4 GeV	L1 T G=21T/m	L2 T G=0	L3 T G=21 T/m	Emittance pmrad
VH-LG	0.77 T	2.16	0.77	140
H-LG	0.92 T	1.78	0.92	150
M-LG	1.036 T	1.46	1.036	177

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

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

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

Final S6BA-E optics



The lattice is 12-fold symmetric (24 arcs) and is invariant under relative length changes of the LS and SS.
Choosing **LS=4.84 m and SS=1.17 m (from magnet to magnet)** the LSs coincide to those of the actual Elettra i.e. no radial shift of the beam lines using IDs on the LSs

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

Brief Description

Each arc of Elettra 2.0 consists of 3 unit cells i.e. 3 dipoles 1 with only vertical field gradient and 2 with combined transverse and longitudinal gradient, 8 quadrupoles four of which are shifted to give the required anti-bend angle (all the same -0.4 deg/each with shift of -5.16 mm) and 10 combined sextupoles (6 with correctors for orbit control and 2 with skew quadrupole coils) and 2 combined multipoles (octupoles and correctors) for controlling the tune shift with amplitude. The magnets will be powered independently, although they may be grouped in families.
There are 8 correctors/arc (total 192) and 6 bpm/arc (total 144)

Coupling will be in the range of up to 10%, for simulations we fix it to 2 or 3%
No round beam is needed or required by the users

Energy 2.4 GeV	LS at 3% cpl	LS at 10% cpl	SS at 3% cpl	SS at 10% cpl
σx (um) /σ’x (urad)	36 /5.7	35/5.5	63/6	63/5.8
σy (um) /σ’y (urad)	3.2/1.9	5.7/3.4	3.5/1.8	6/3
Energy 2.0 GeV				
σx (um) /σ’x (urad)	30/4.8	29/4.6	53/5	52/4.8
σy (um) /σ’y (urad)	2.7/1.6	4.7/2.8	2.9/1.5	5.1/2.6

Beam lines

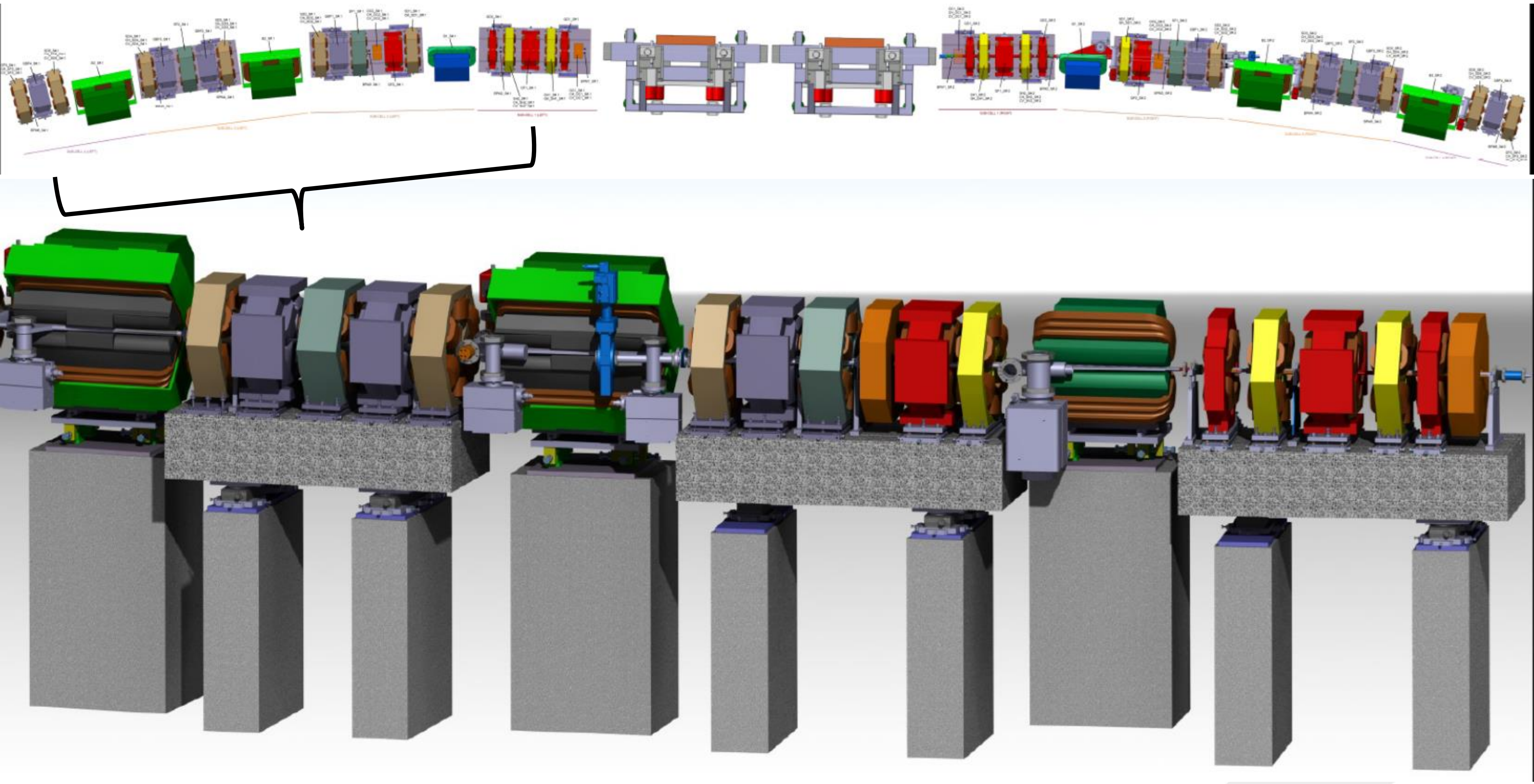
Elettra Sincrotrone Trieste

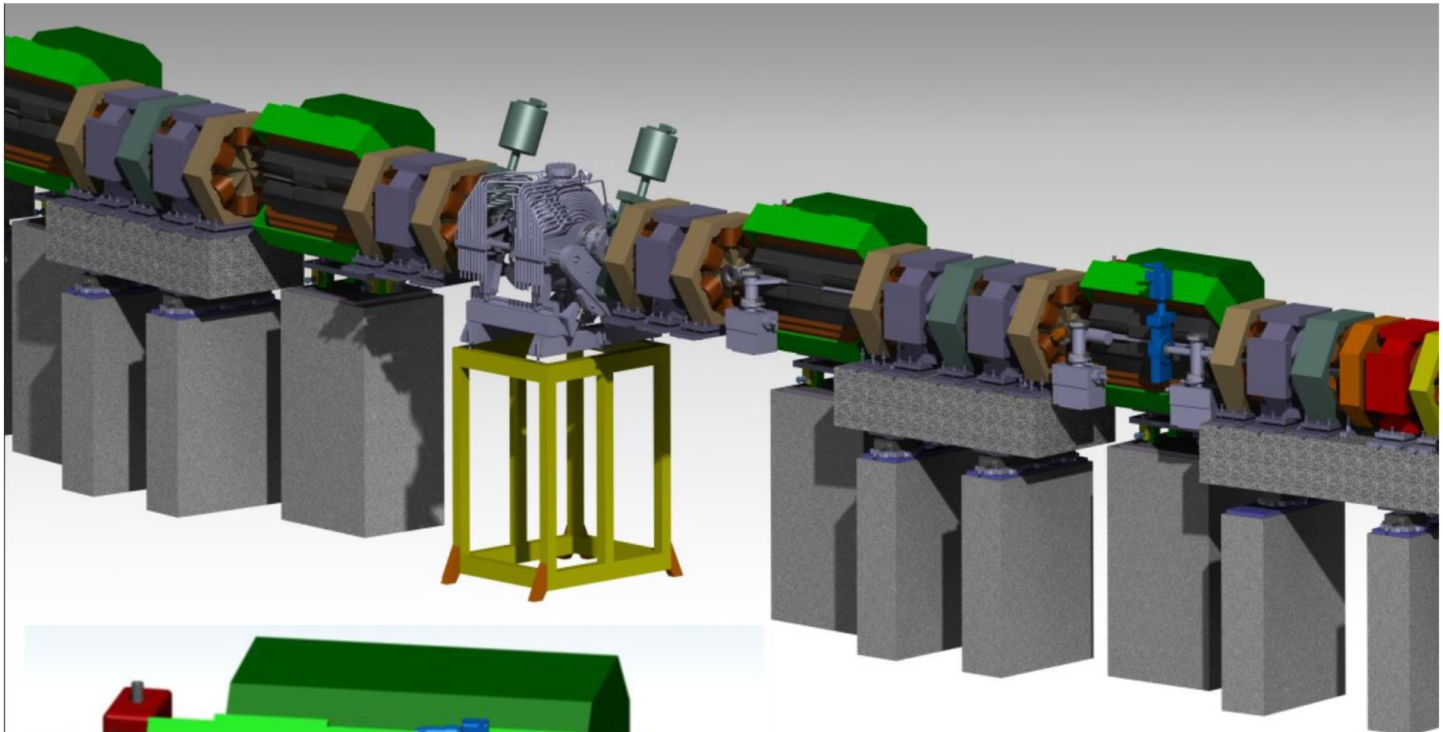
Insertion devices

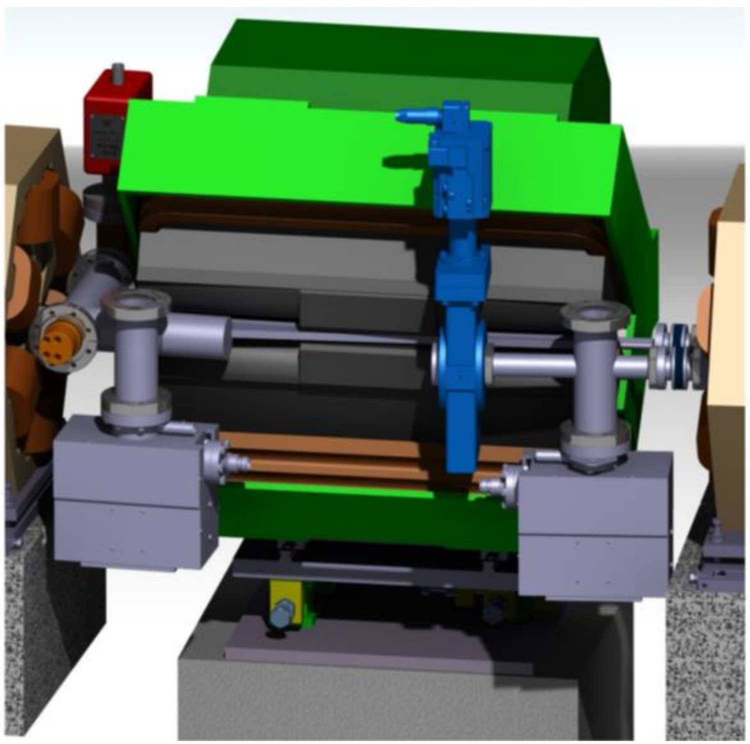
BL long sect.	Machine long sect.	BL short sect.	Short sect. free for BL	Machine short sect.	BL on BM	BM free for BL	BL: beamlines	hν-range	source	length (m)	period (cm) ; field (T)
				1.1		1.1 (BM)**					
1.2							Nanospectr/NanoESCA	20*-1500 eV	Ellipt. Und.	2x2	10 ; 1
(in case of Crab Cavities)		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

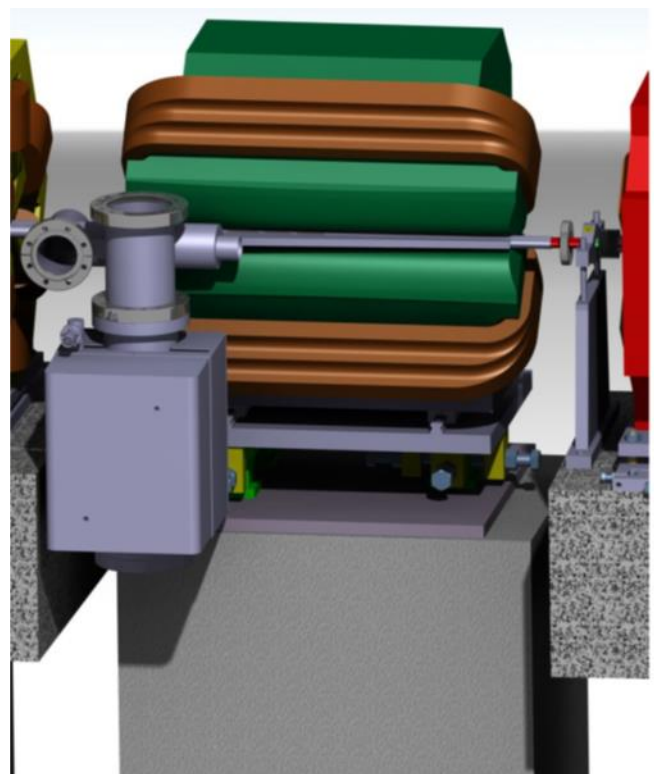
31 beam lines (Elettra actual has 28 beam lines) of which: 2 from super-bends (6T), 2 mini-wigglers, 3 IVU (new micro-spot beam lines) and 1 CDI. The micro-spot and CDI the present machine cannot support.

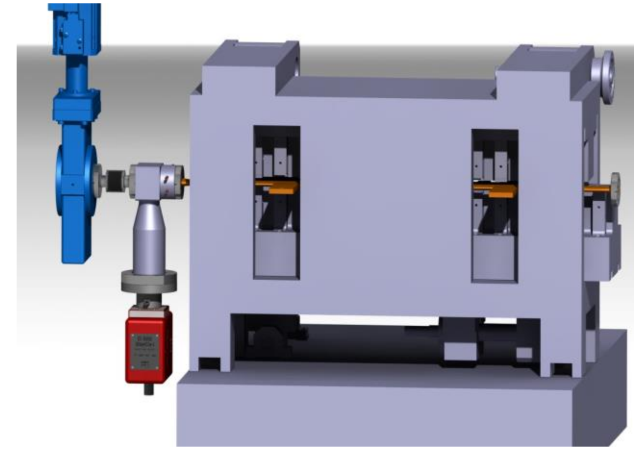
Elettra
Sincrotrone
Trieste

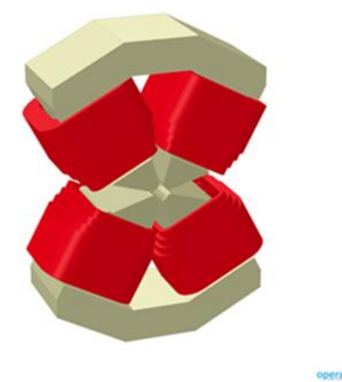


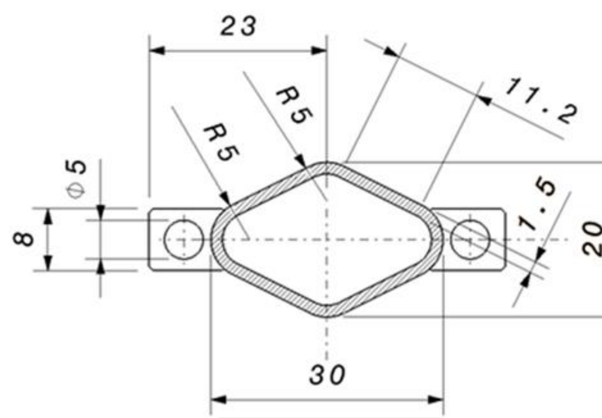










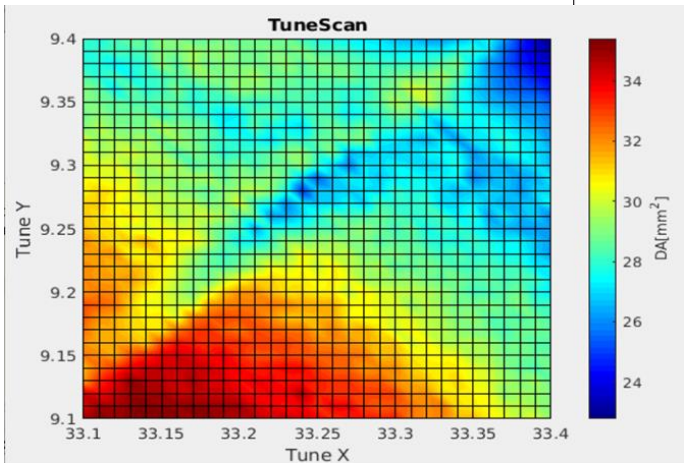

23
R5
R5
11.2
Φ5
8
1.5
20
30

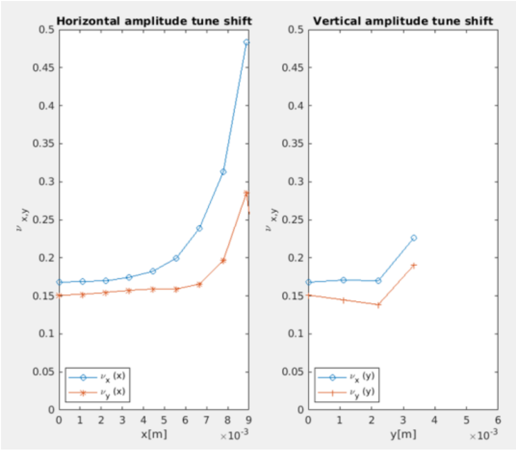
Machine parameters

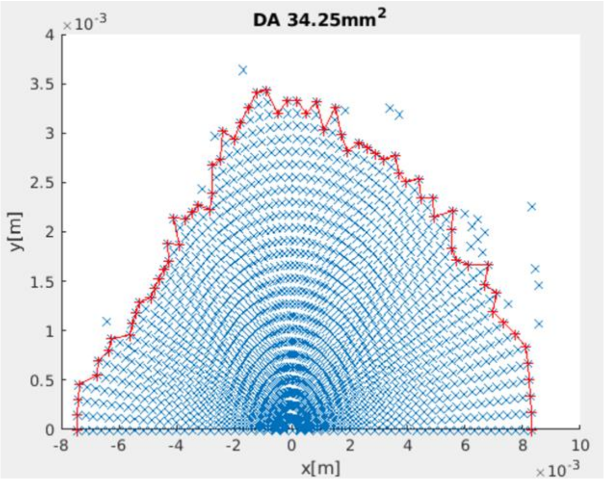
Elettra

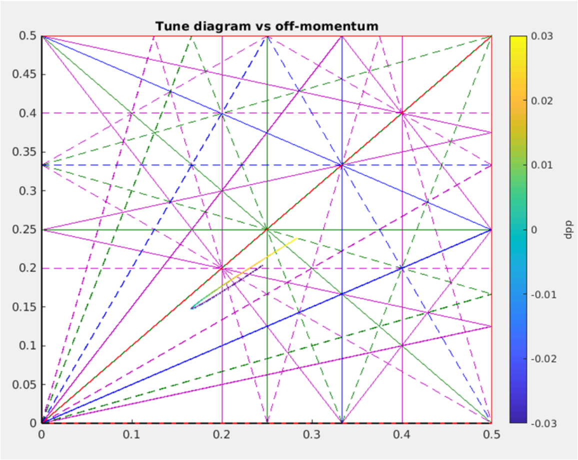
Circumference (m)	259.2	259.2
Energy (GeV)	2	2.4
Number of cells	12	12
Geometric emittance (pm-rad) 2% coupling	147	212
Horizontal tune	33.29	33.29
Vertical tune	9.18	9.18
Beta functions in the middle of straights (x, y) m	(5.7 , 1.6)	(5.7 , 1.6)
Horizontal natural chromaticity	-71	-71
Vertical natural chromaticity	-68	-68
Horizontal corrected chromaticity	+1	+1
Vertical corrected chromaticity	+1	+1
Momentum compaction	1.2e-004	1.2e-004
Energy loss per turn no IDs (keV)	220	457 (w SBs 486)
Energy spread	7.8e-004	9.3e-004
Jx	1.598	1.66
Jy	1.00	1.00
JE	1.402	1.34
Horizontal damping time (ms)	9.45	5.46
Vertical damping time (ms)	15.67	9.08
Longitudinal damping time (ms)	9.45	6.78
Dipole field (T)	<0.88 + 1.16T central	<1.03+1.46T central
Quadrupole gradient in dipole (T/m)	<19	<22
Quadrupole gradient (T/m)	<50	<60
Sextupole gradient (T/m^2)	<3500	<4000
RF frequency (MHz)	499.654	499.654
Beam revolution frequency (MHz)	1.1566	1.1566
Harmonic number	432	432
Orbital period (ns)	864.6	864.6
Bucket length (ns)	2	2
Natural bunch length (mm, ps)	1.3 , 4.3	1.7 , 5.7
Synchrotron frequency (kHz)	3.17 (@2MV)	2.86 (@2MV)

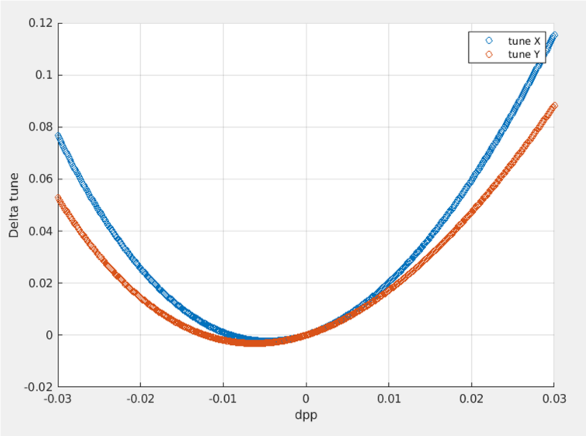
Linear optics

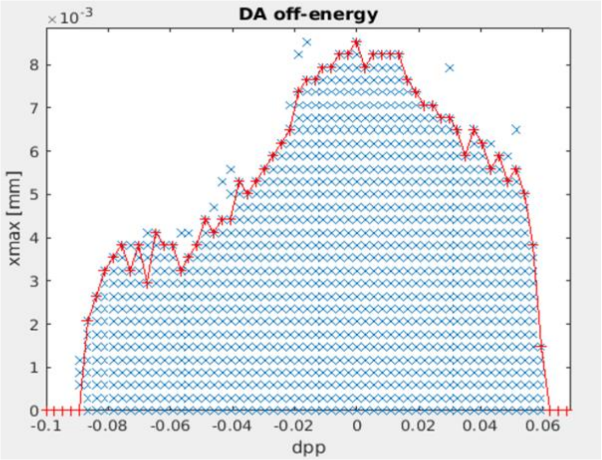












Including errors

Values at 1 σ
Errors are assumed to be standard deviation of Gaussian distributions with 2-sigma cutoff.

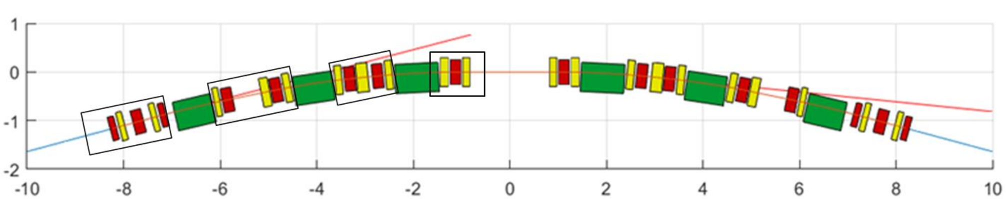
Element Type	Parameter	Value	Unit
Dipoles	Dx	20	um
	Dy	20	um
	Dz	300	um
	Roll angle	100	urad
	DBl/Bl	0.01	%
Quadrupoles on the girder	Dx	20	um
	Dy	20	um
	Dz	300	um
	Roll angle	50	urad
	DBl/Bl	0.03	%
Sextupole /multipoles on the girder	Dx	20	um
	Dy	20	um
	Dz	300	um
	Roll angle	50	urad
	DBl/Bl	0.03	%
Correctors	Dz	20	um
	Roll angle	100	urad
BPMs	Dx	20	um
	Dy	20	um
	Dz	300	um
	Roll angle	100	urad
Girders	Dx	50	um
	Dy	50	um
	Dz	300	um
	Roll angle	100	urad

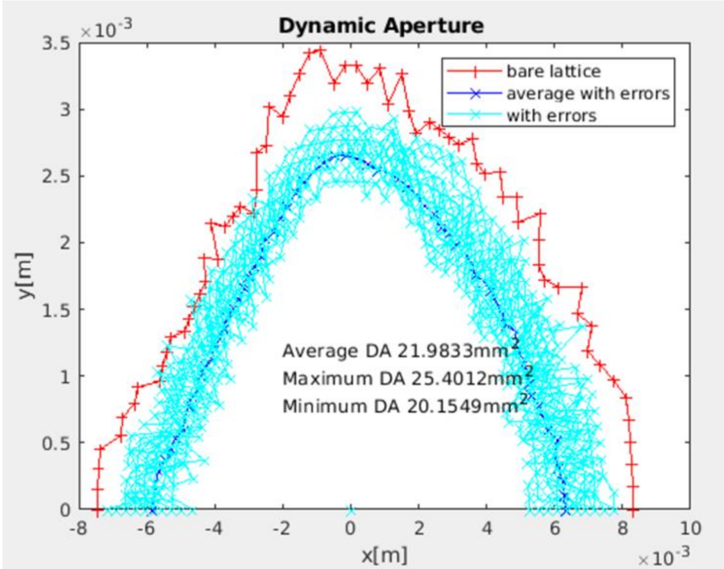
Dipole field errors	Normal		Skew	
Errors for 10 mm radious	*systematic*	random	systematic	random
dipole		3.E-04		3.E-04
quadrupole	*3.E-03*	*3.E-03*	3.E-03	3.E-03
sextupole	*6.E-04*	*6.E-04*	2.E-04	2.E-04
octupole and higher	*3.E-04*	*3.E-04*	1.E-05	1.E-05

Quadrupole field errors	Normal		Skew	
	systematic	random	systematic	random
quadrupole		3.E-03		3.E-03
sextupole	*3.E-04*	*3.E-04*	3.E-04	3.E-04
octupole and higher	*6.E-04*	*6.E-04*	2.E-04	2.E-04

Sextupole field errors	Normal		Skew	
	systematic	random	systematic	random
quadrupole		1.E-03		3.E-03
sextupole	*3.E-04*	*3.E-04*	3.E-04	3.E-04
octupole and higher	*6.E-04*	*6.E-04*	2.E-04	2.E-04

Octupole field errors	Normal		Skew	
	systematic	random	systematic	random
sextupole		2.E-03		
octupole	*2.E-04*	*3.E-04*	3.E-04	3.E-04
higher multipoles	*2.E-04*	*3.E-04*	1.E-04	3.E-04





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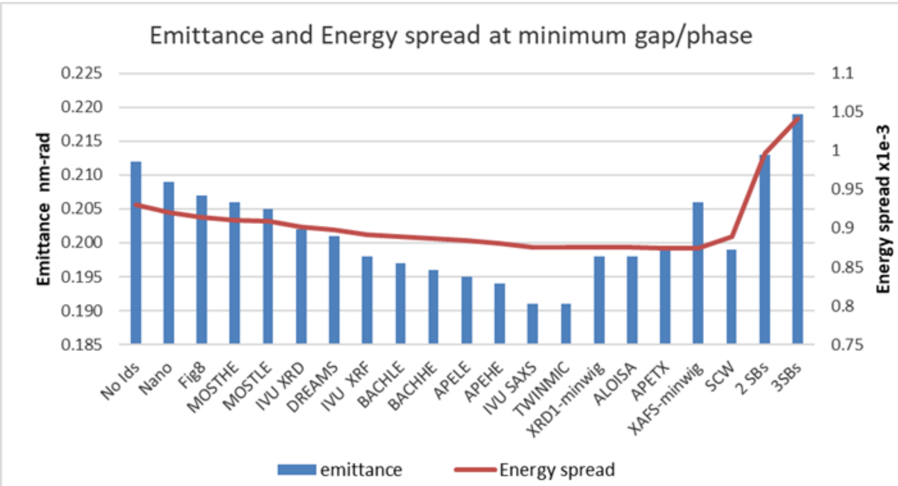
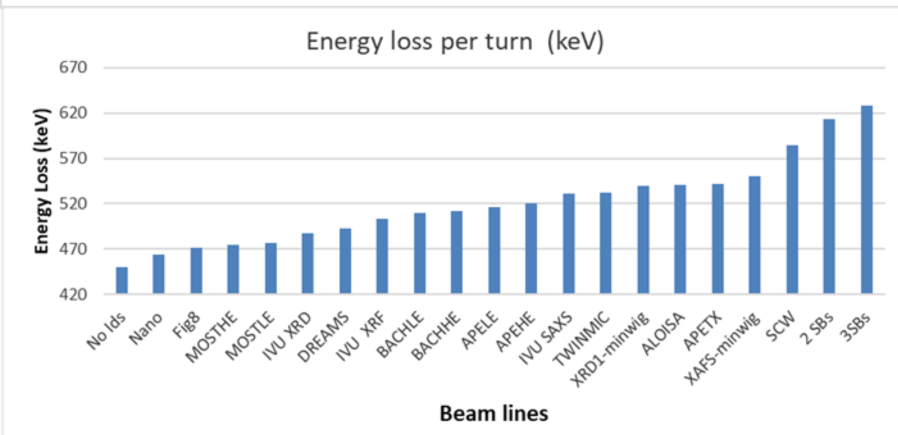
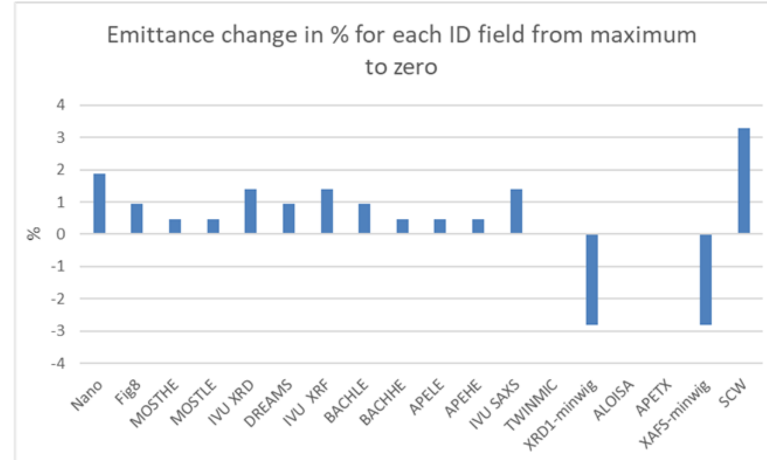
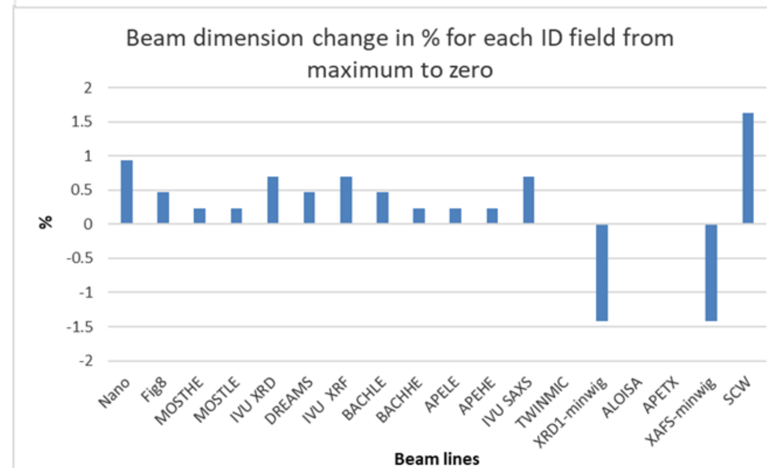
IDs and SBs effect





RF 500 MHz 4 single cell Elettra type cavities with SS amplifiers of 130 KW each

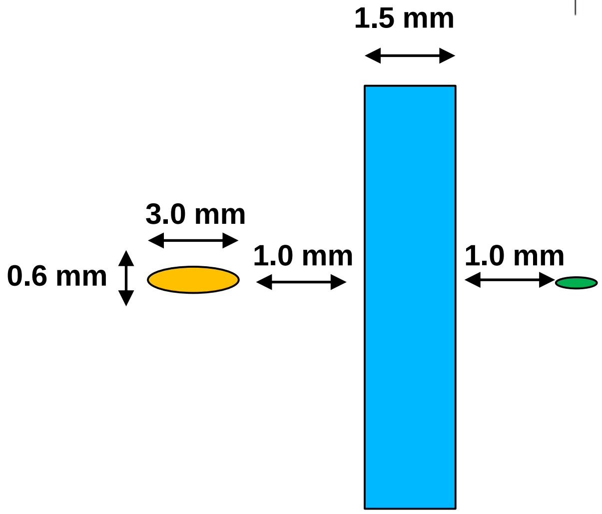




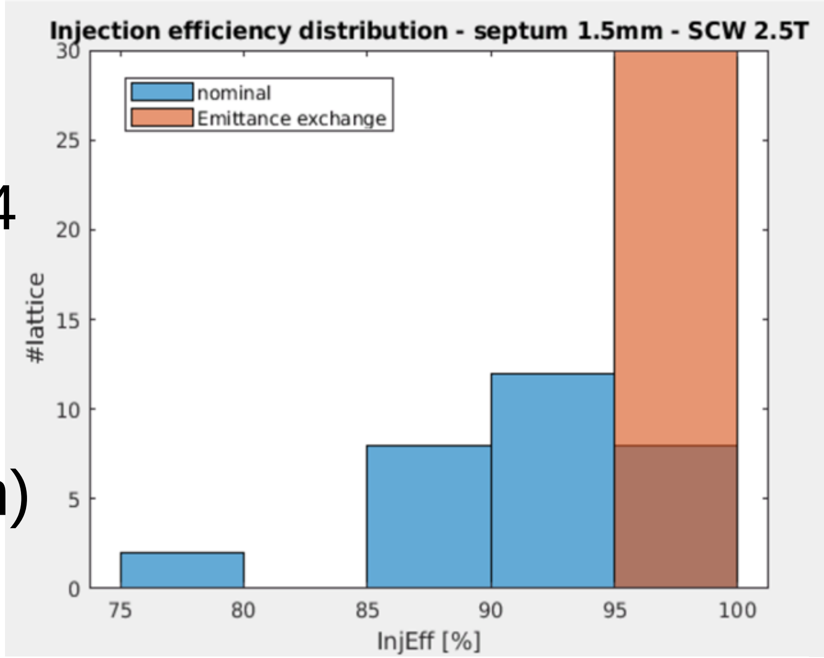
Emittance, energy spread and energy loss per turn versus the cumulative number of insertion devices at minimum gap / max phase. At the end the effect of 2 and 3 super-bends is added for completeness.

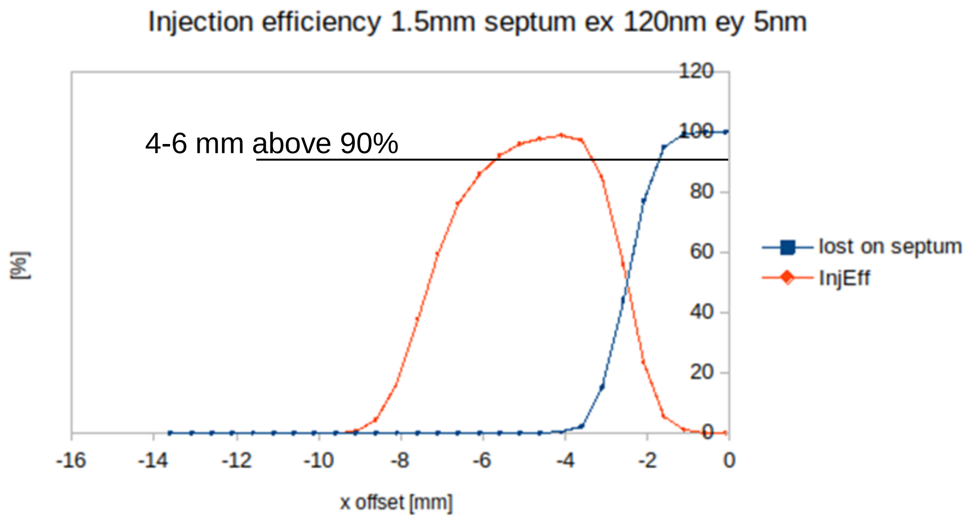
Emittance and beam dimension changes from maximum to zero field of each ID

Injection

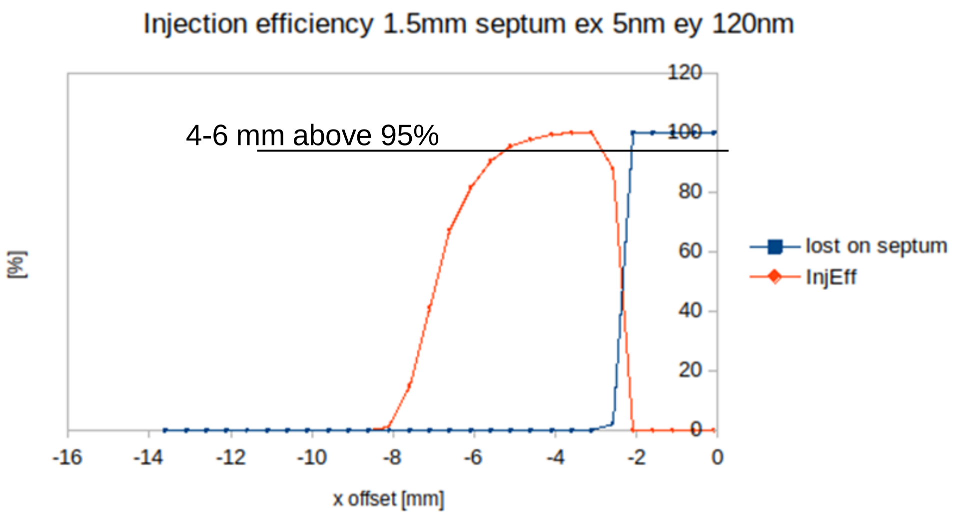


Injection studied either as in Elettra (4 kickers 2 septa) or most probable with two kickers and 3 septa (1 anti-septum)



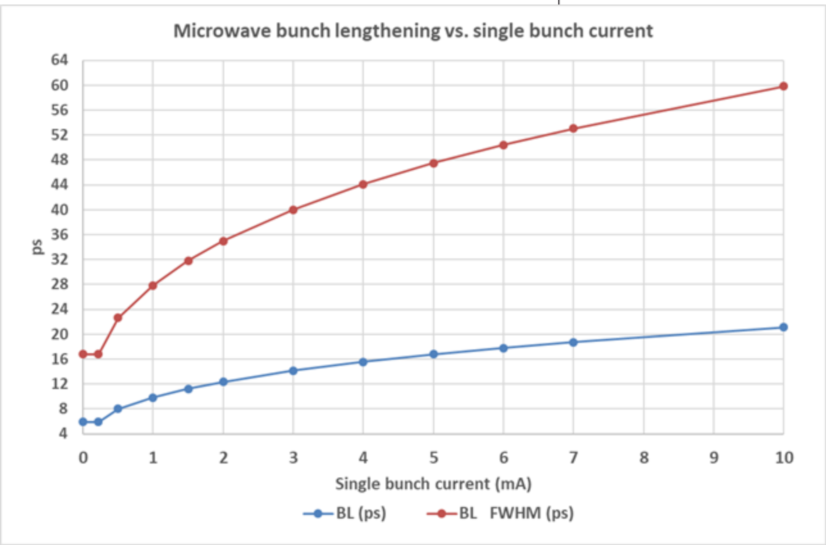


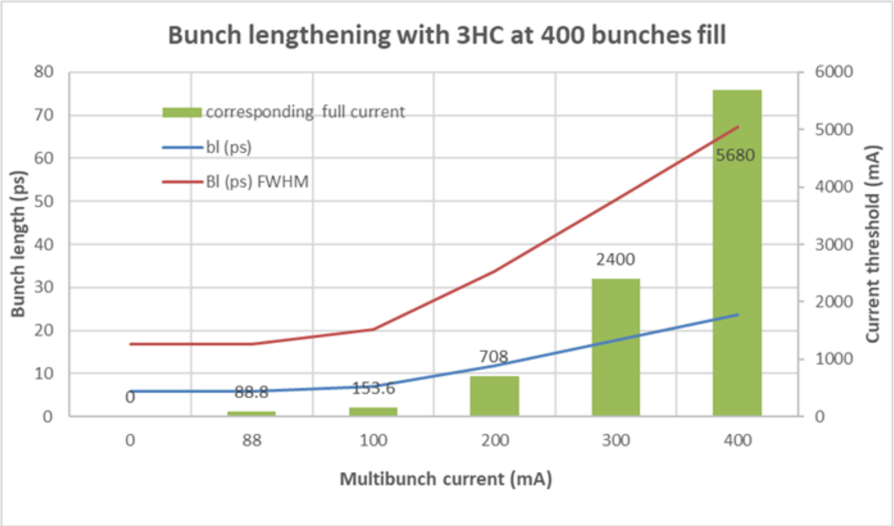
Injection efficiency versus the horizontal beam offset from the stored beam

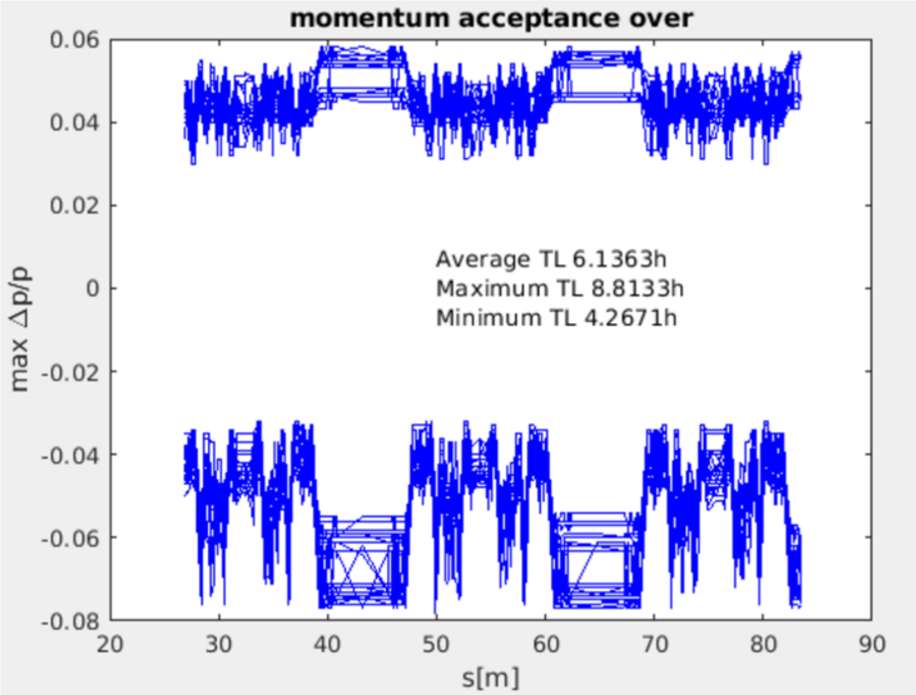


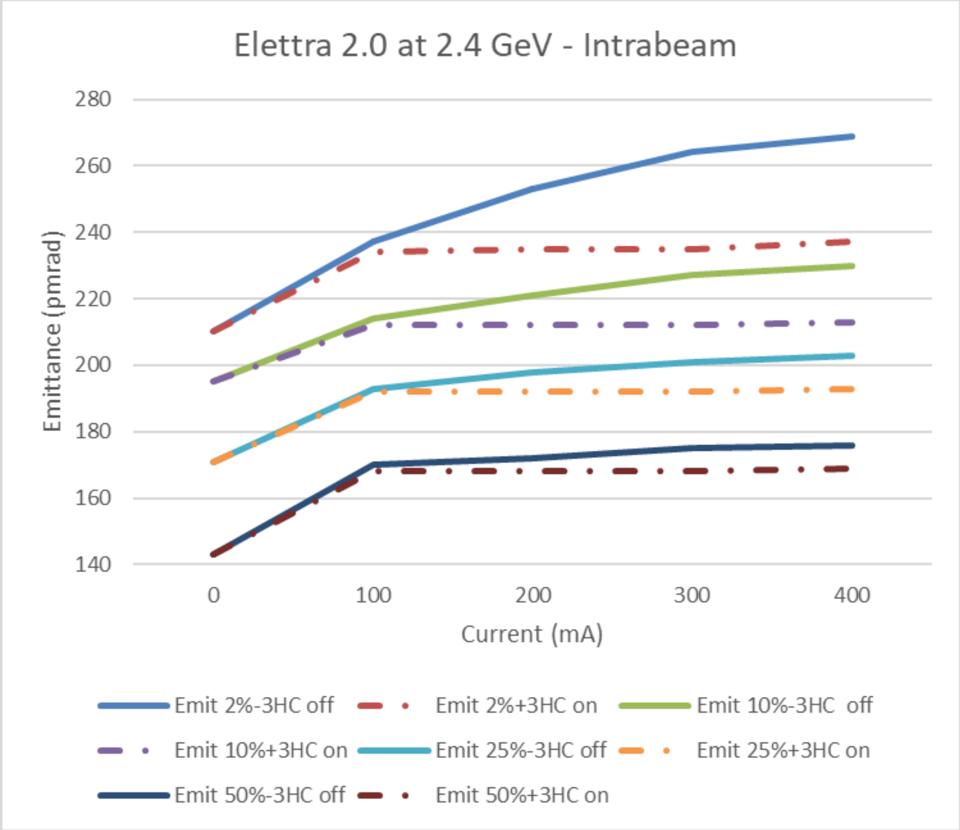
Injection efficiency versus the horizontal beam offset in case of emittance swap in the booster.

Bunch length, Touschek and intra-beam



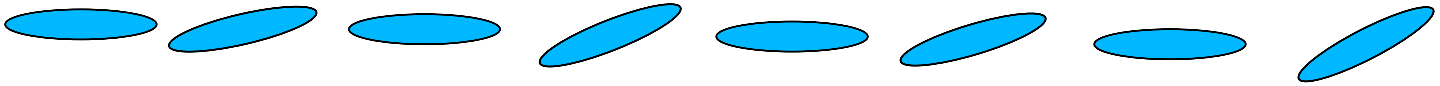






Very short photon pulses via deflecting (crab) cavities

ANL-SLAC - Elettra collaboration



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

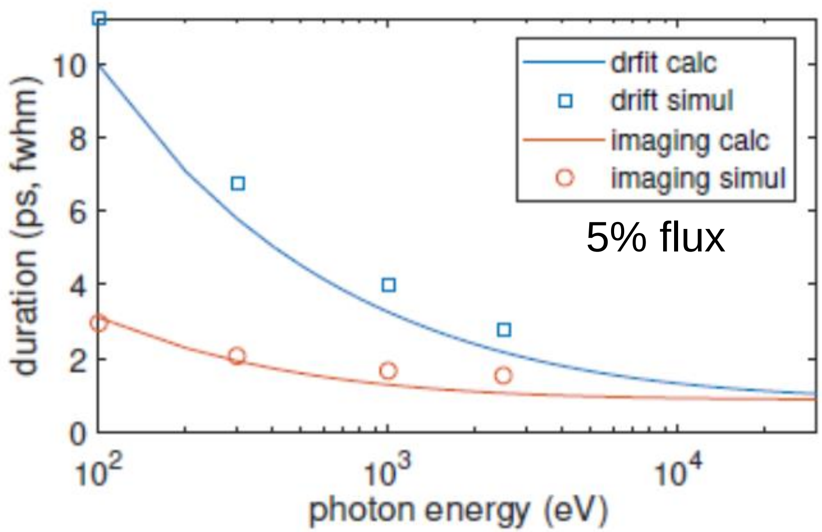
The tilted bunches will give:

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

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

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

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



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

Effects of the Crab cavities

- ✓ Deflecting voltage ~ 0.8 MV (i.e. tilt of 0.33 mrad)
- ✓ The effect on the emittance seems small ~10 pm increase
- ✓ The injection efficiency into the tilted bunches is about 90%
- ✓ The total losses with 4 bunches at 2 mA each is calculated to be about 3% above the regular losses.
- ✓ The impact on the lifetime for the regular bunches is about 15% reduction.

Elettra Sincrotrone Trieste

The Project

has been approved, financed and running (does not include the crab part)

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

Summary

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

Thank you for your attention