Elettra
Sincrotrone
Trieste

MULTI-BEND LATTICE ANALYSIS TOWARDS A DIFFRACTION LIMITED RING BASED LIGHT SOURCE

Emanuel Karantzoulis

Outline:

- *Elettra*
- *Points of view*
- *Trends and requirements*
- *Lattice analysis*
- *Best chosen lattices*
- *Current Elettra 2.0*
- *Brilliance and IDs*
- *Summary*

Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources

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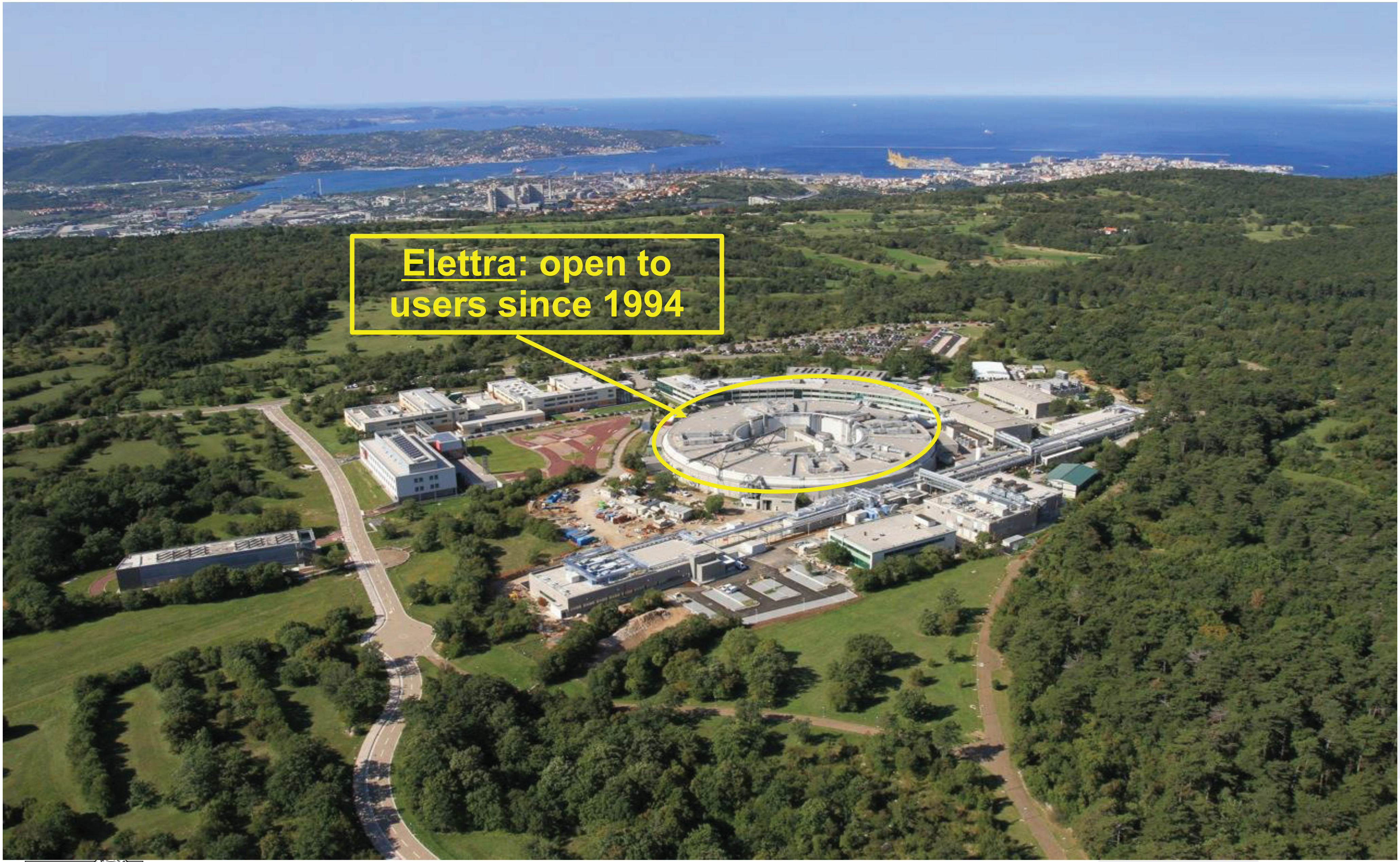
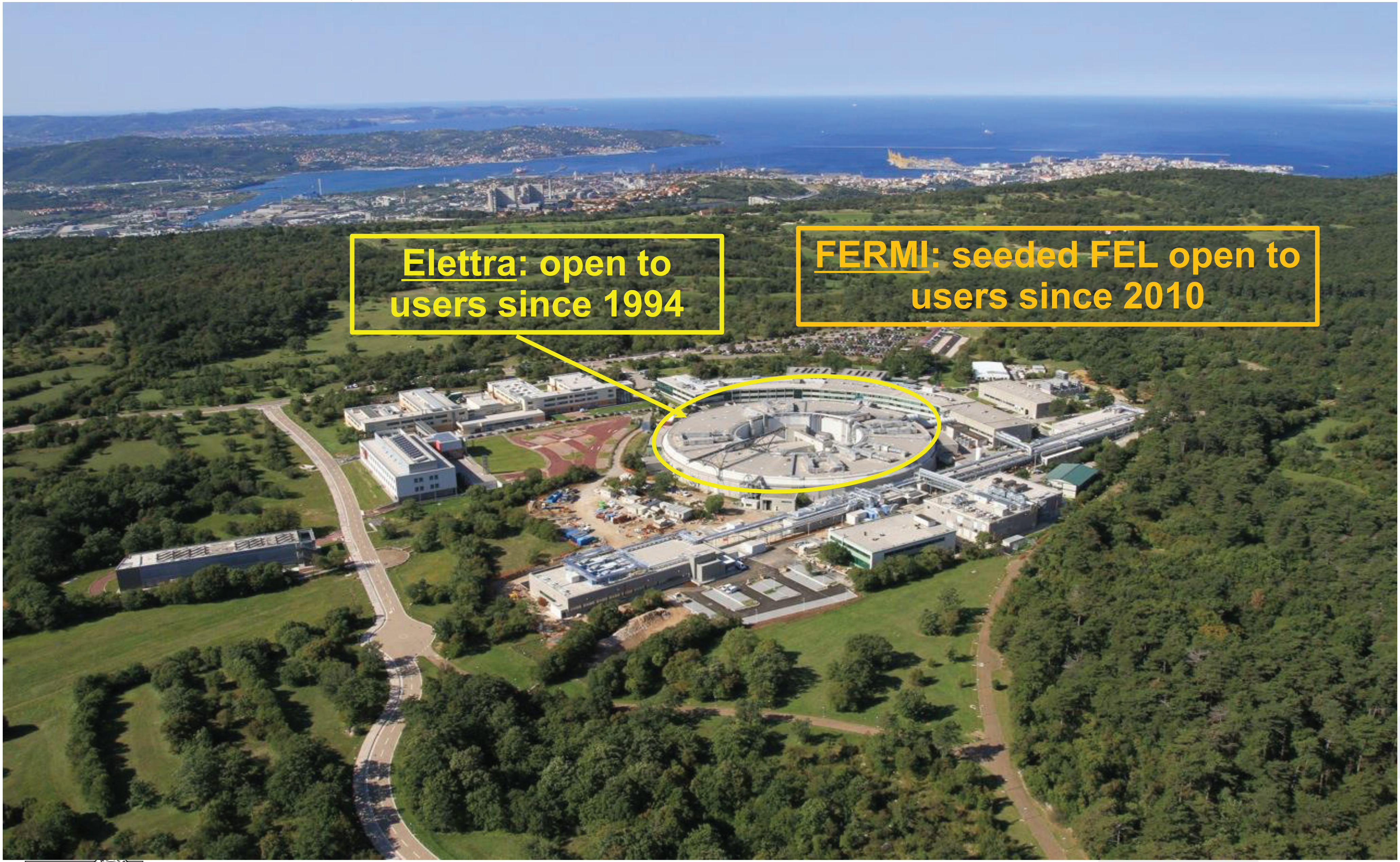


Elettra - Sincrotrone Trieste, Italy: 2 complementary Light Sources



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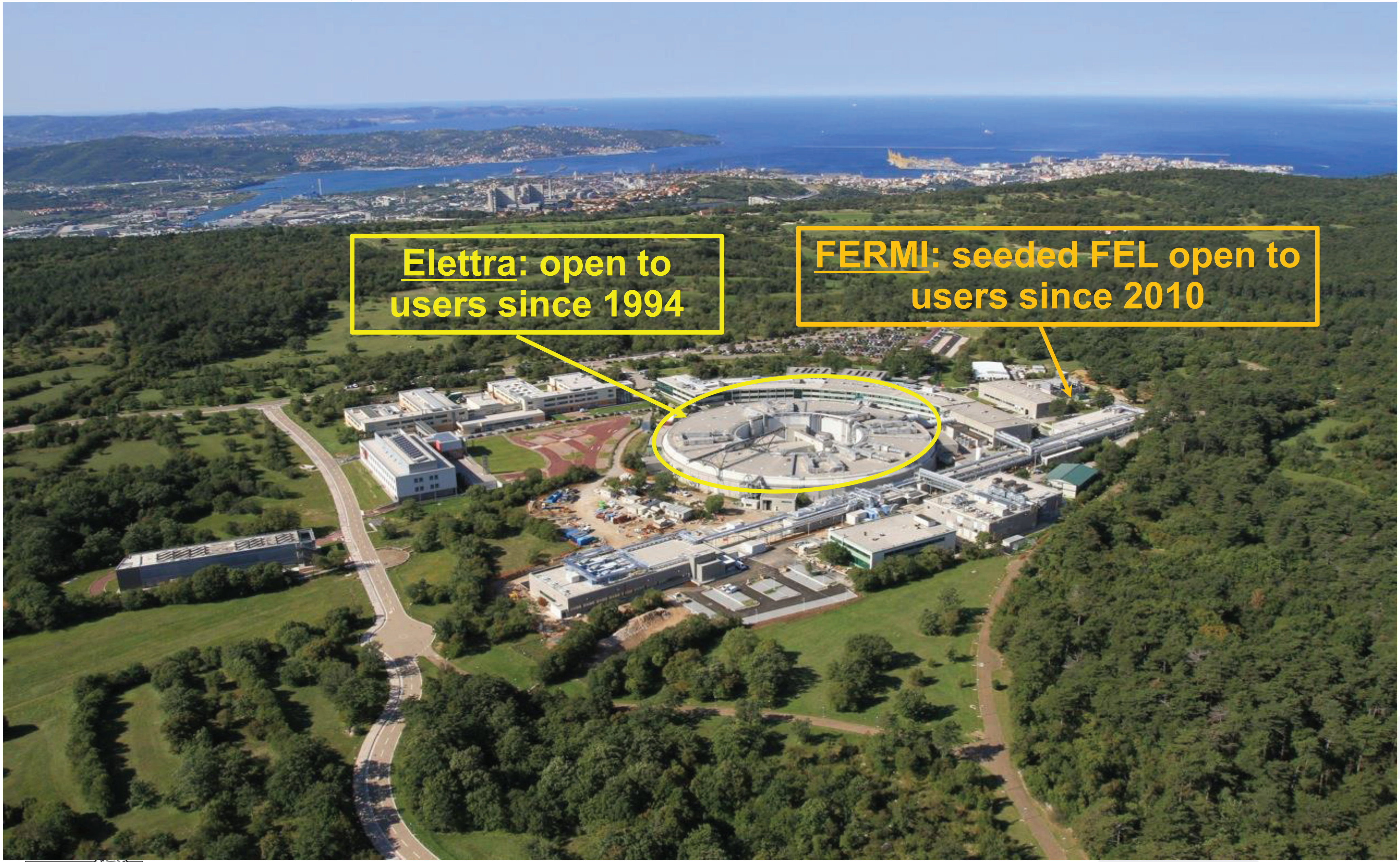

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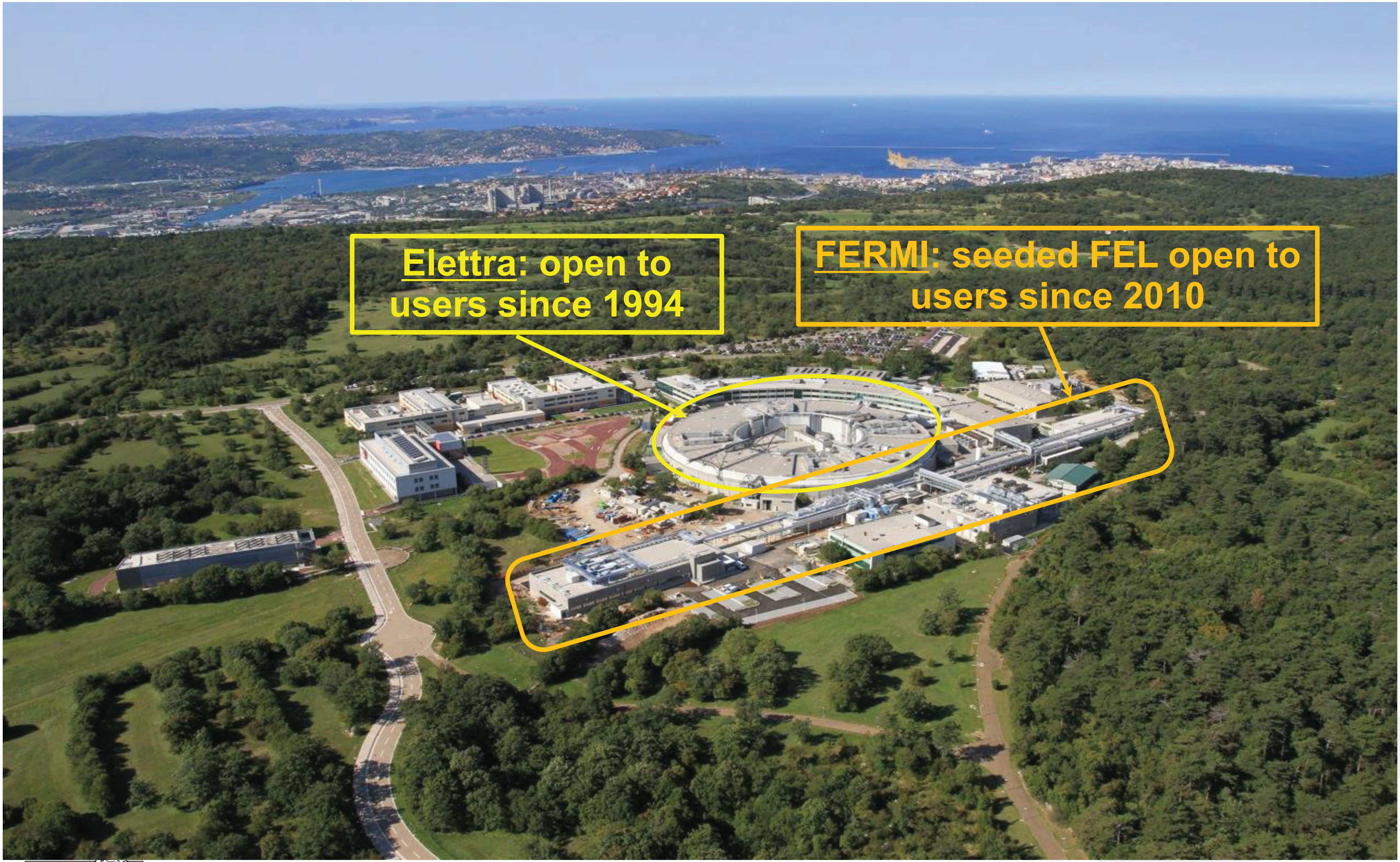


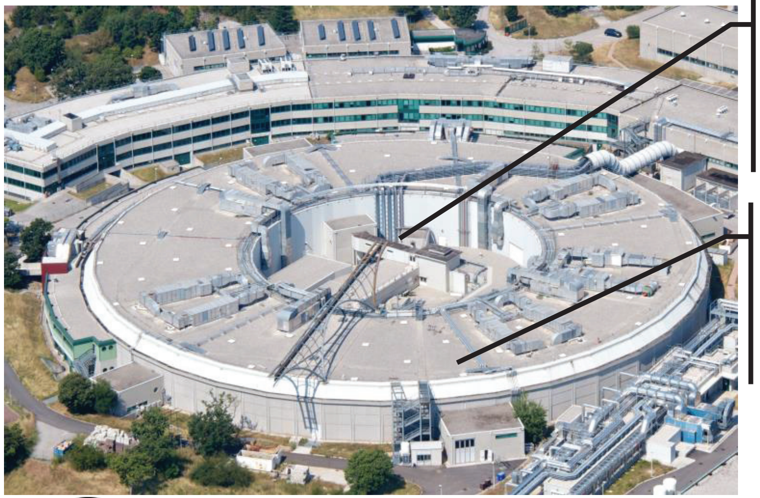
Elettra

Elettra Sincrotrone Trieste

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

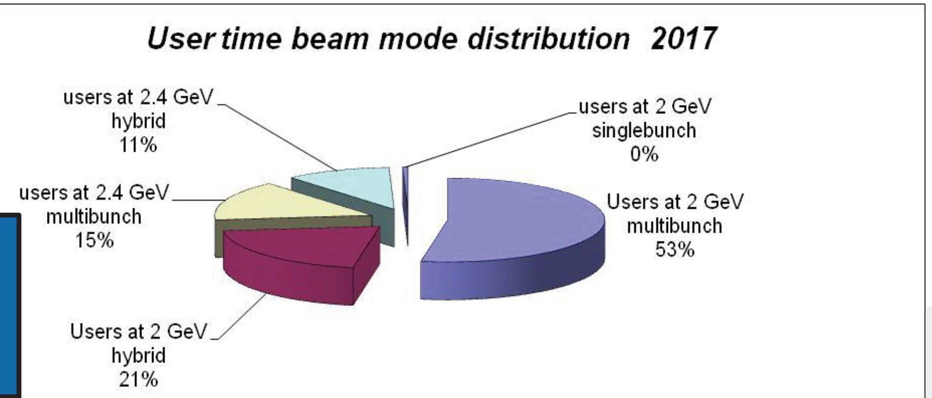
Operating modes for users all in Top-up:

- 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)



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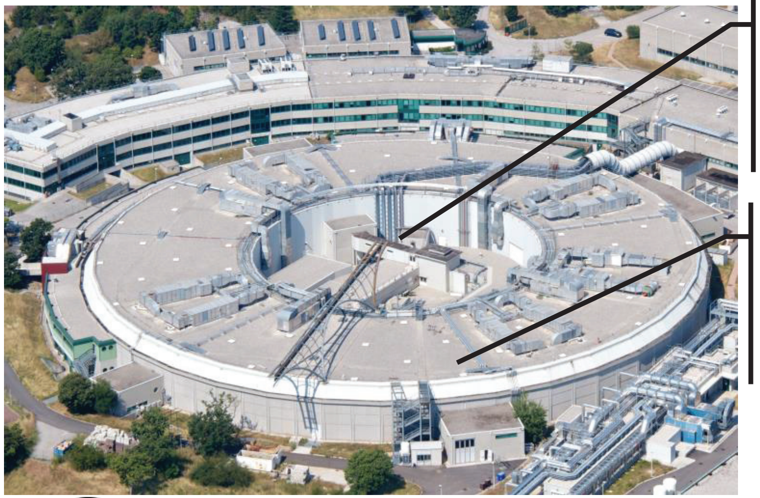

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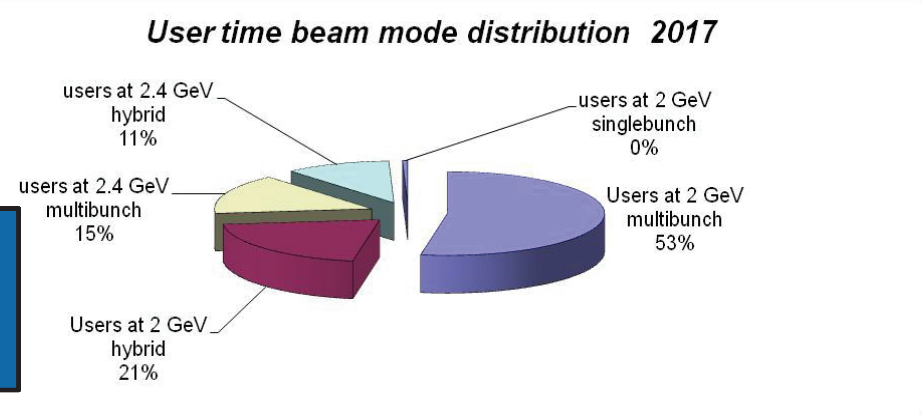

After 25 years an upgrade is needed

Elettra Points of View

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Machine people

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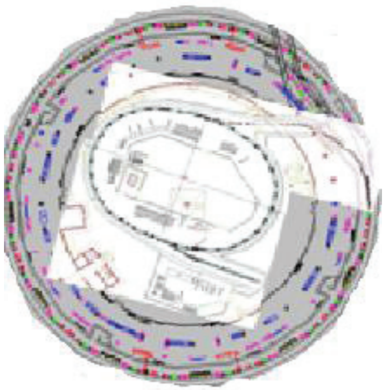
Machine people



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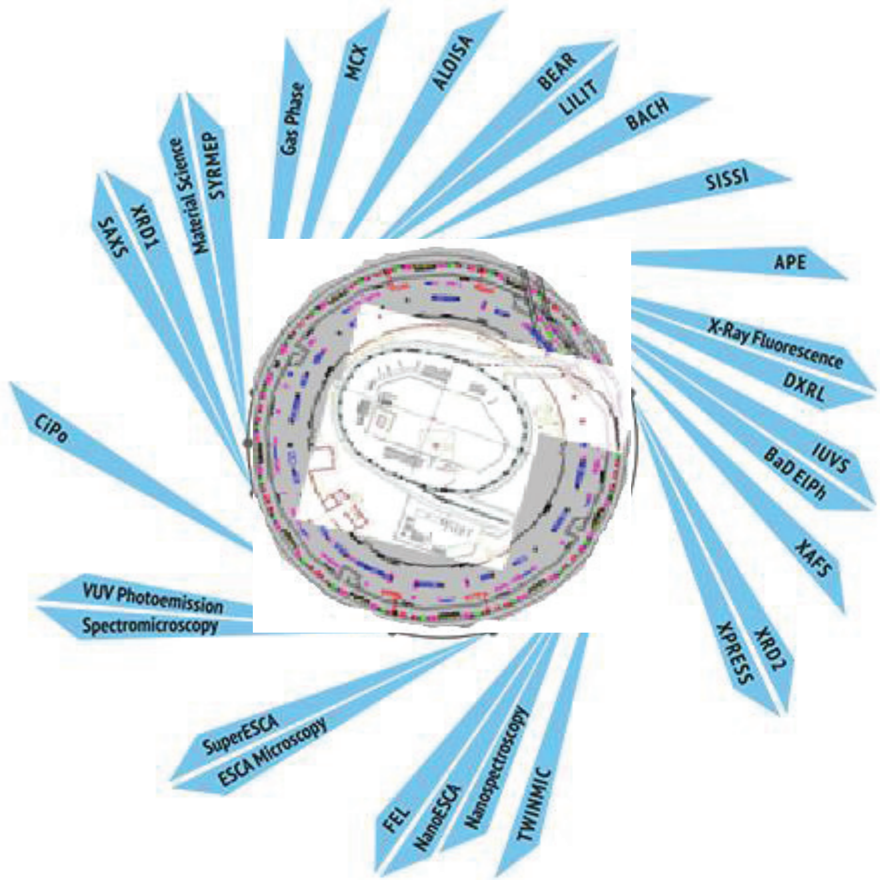

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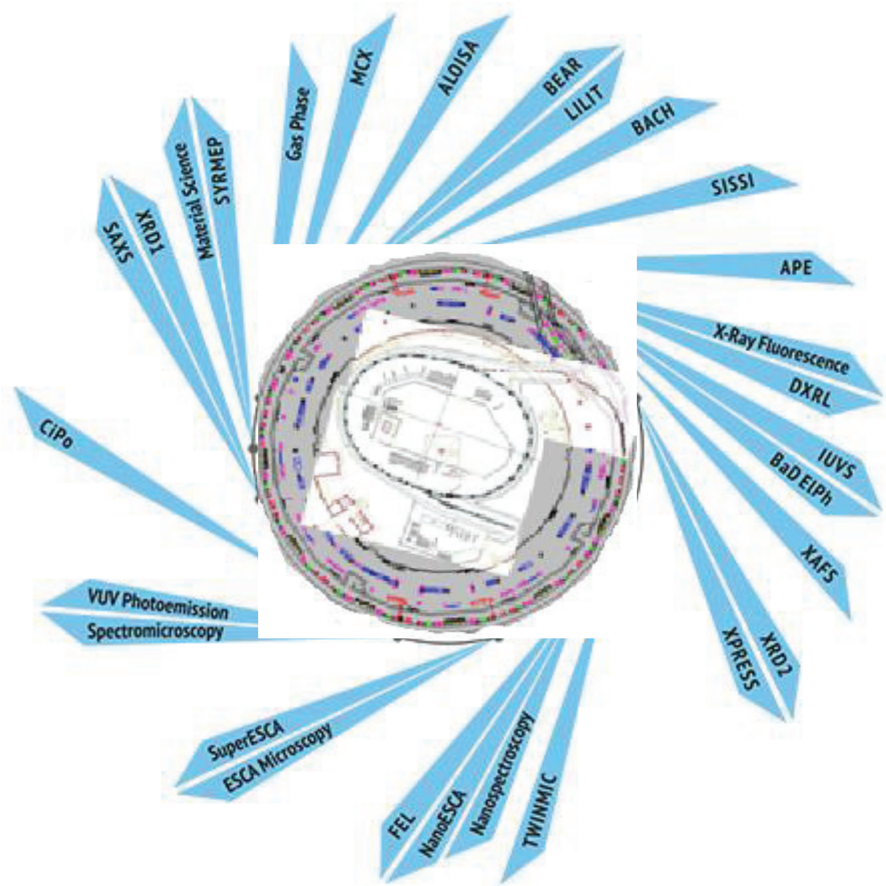
Beam Lines people



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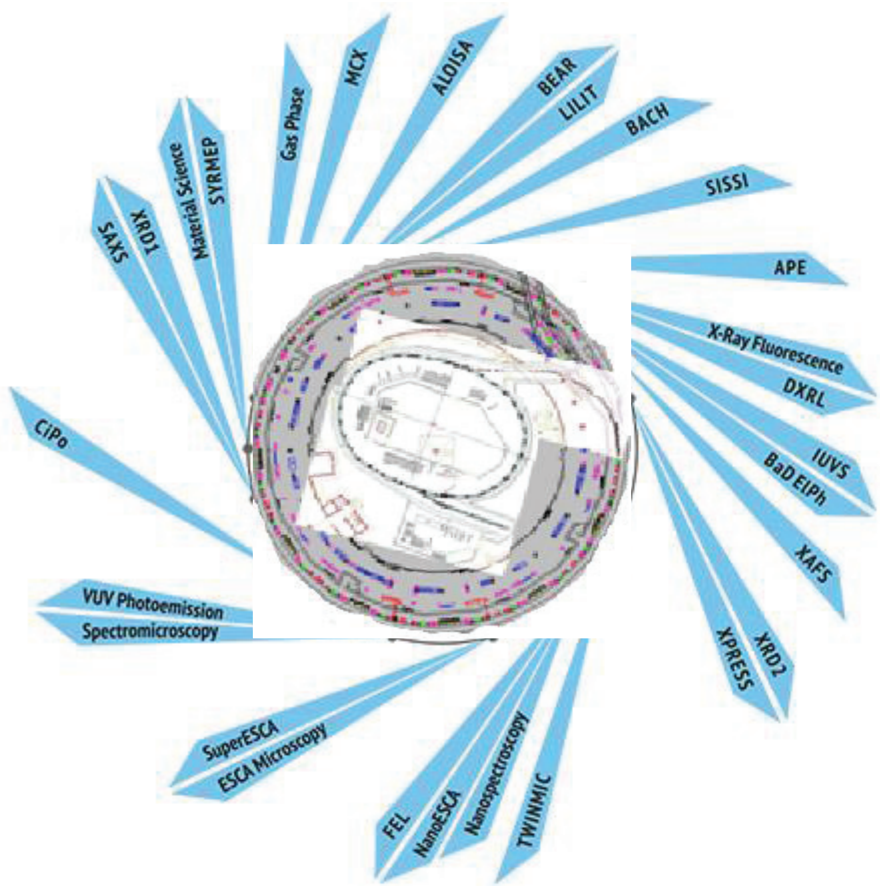

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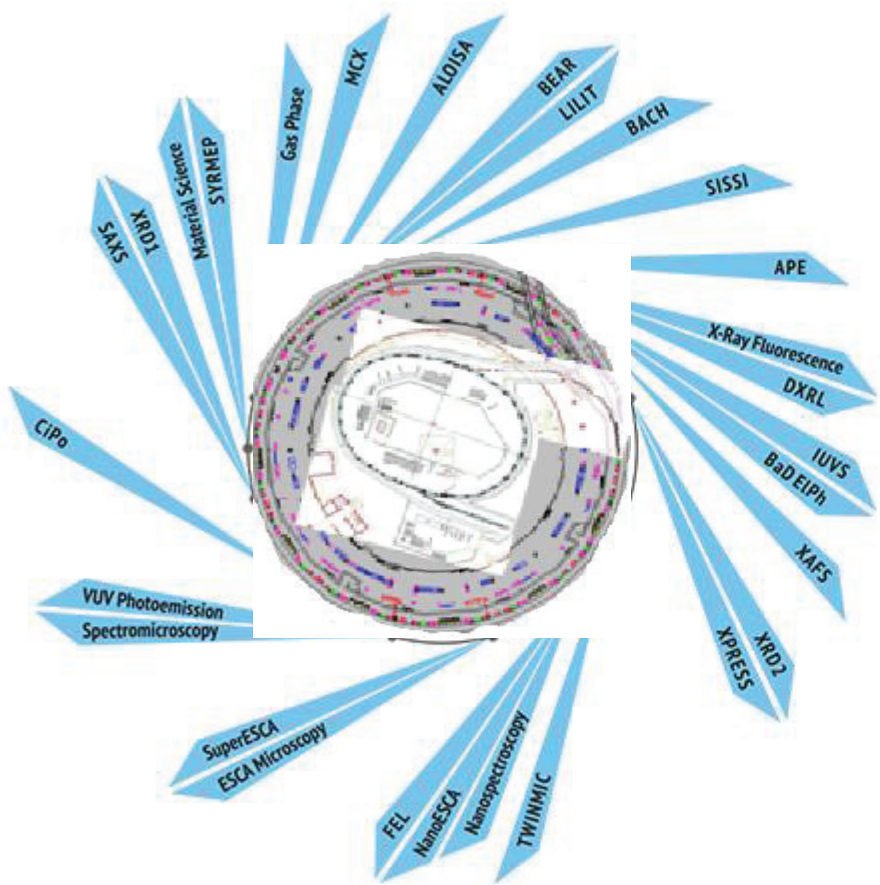

Elettra Points of View

Elettra Sincrotrone Trieste

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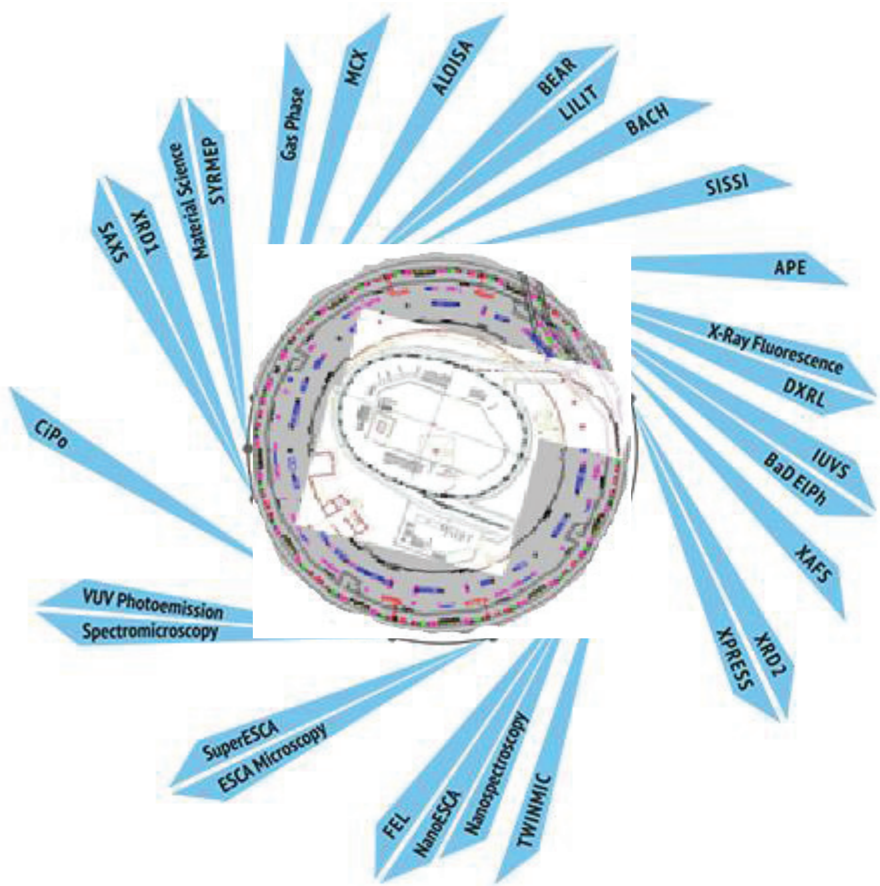

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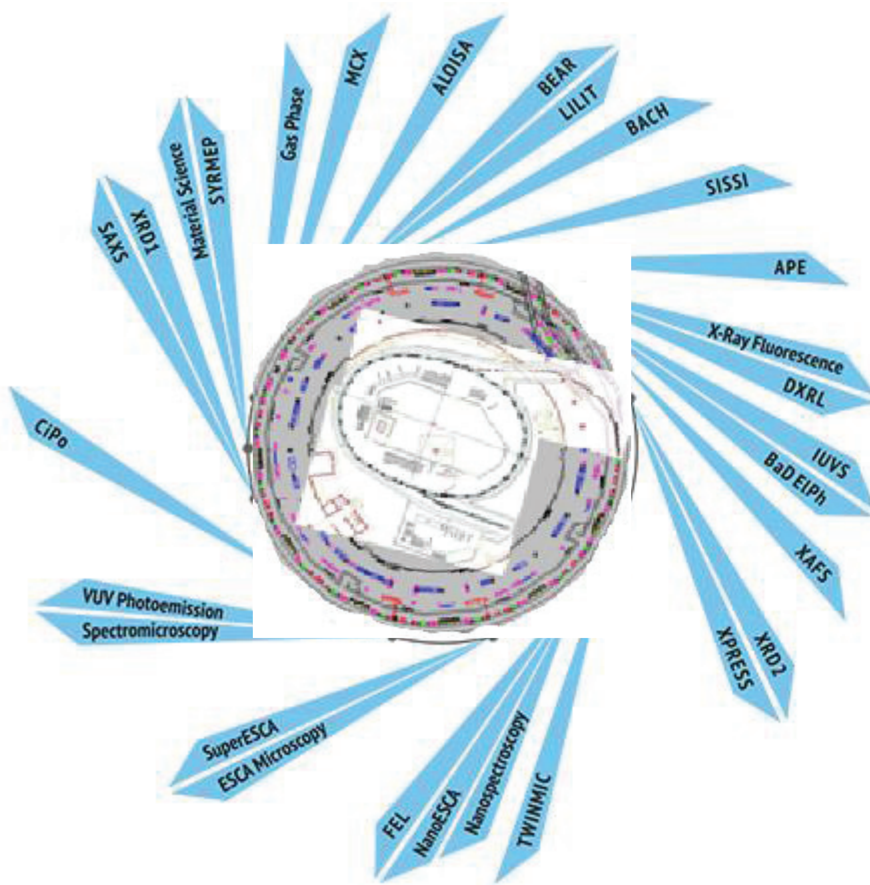

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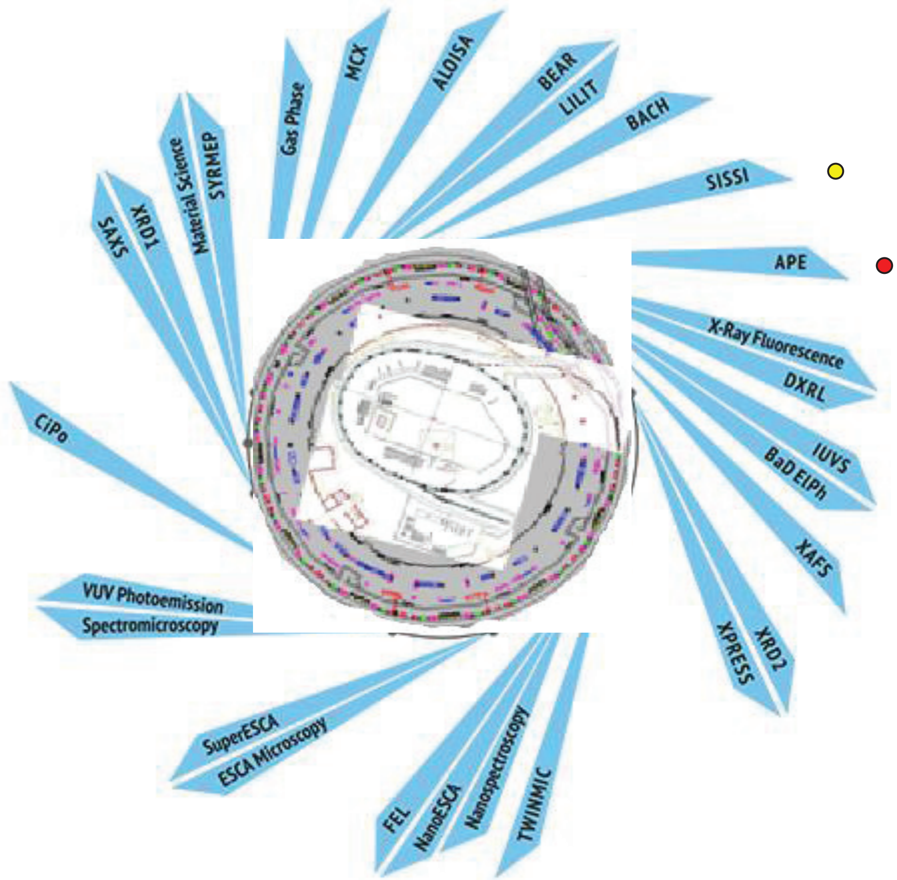

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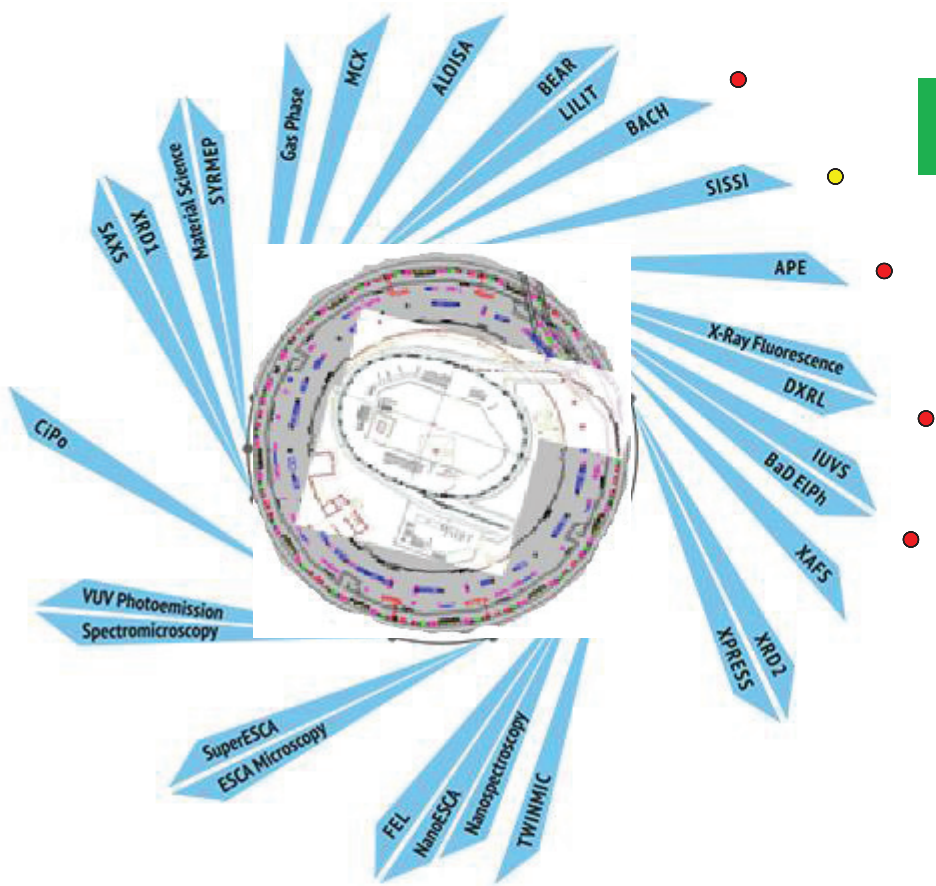

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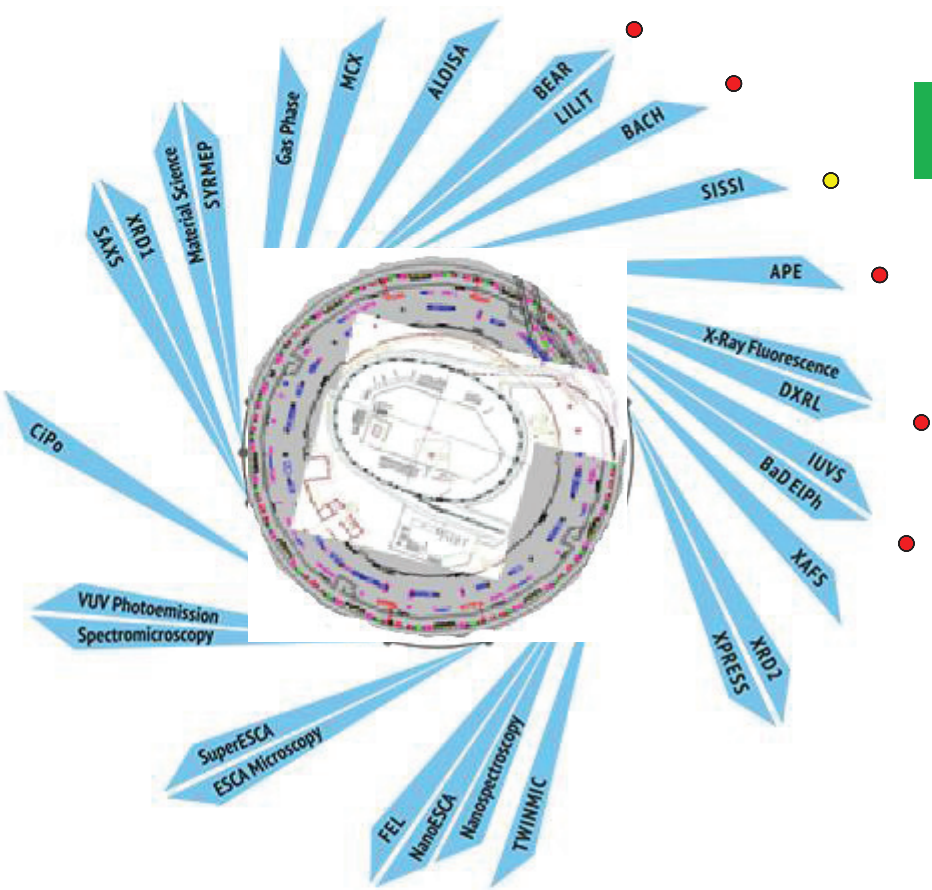

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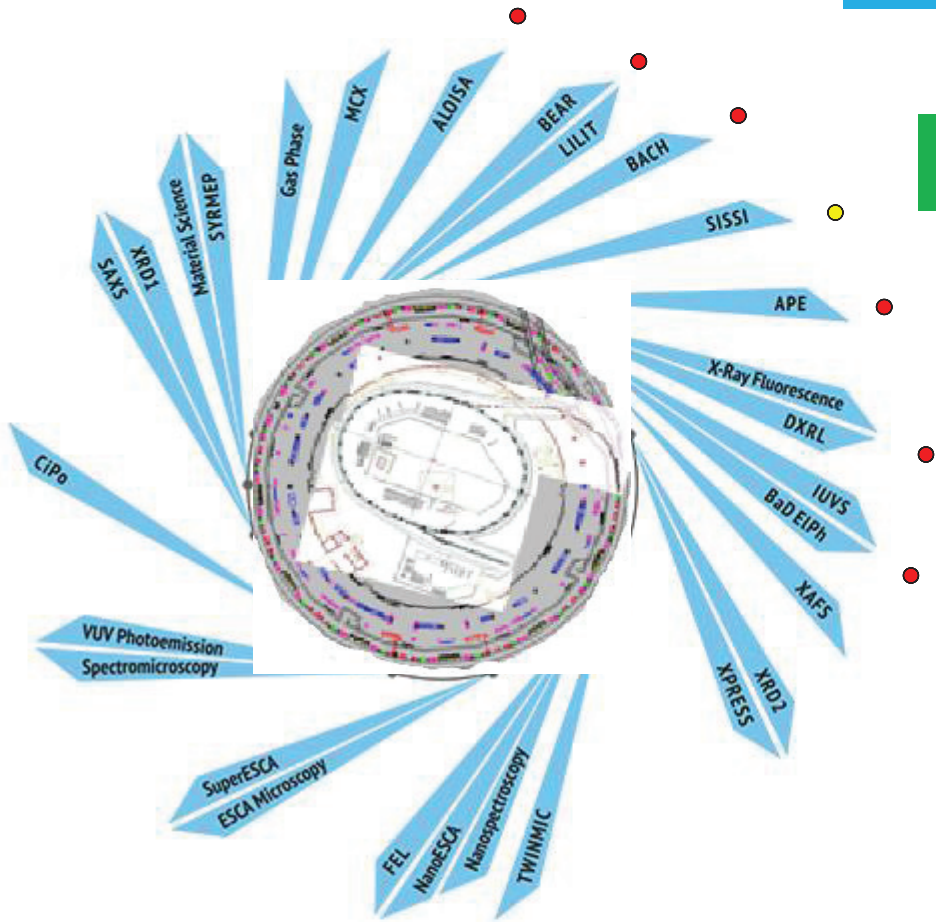

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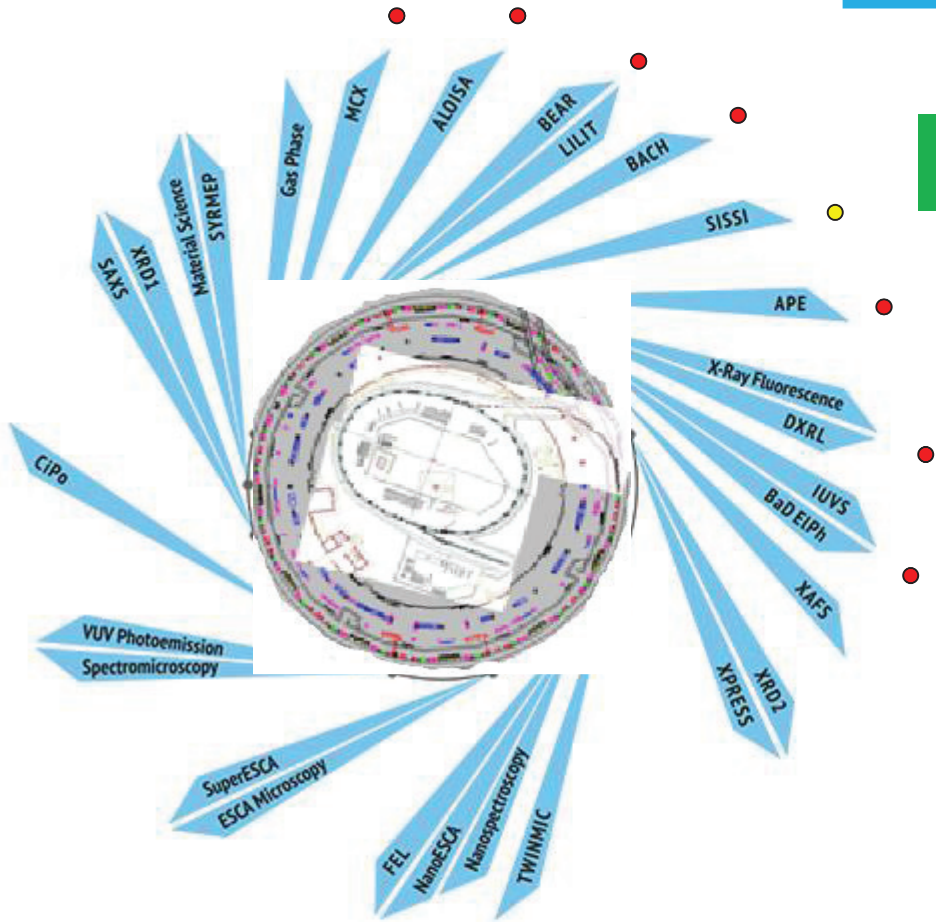

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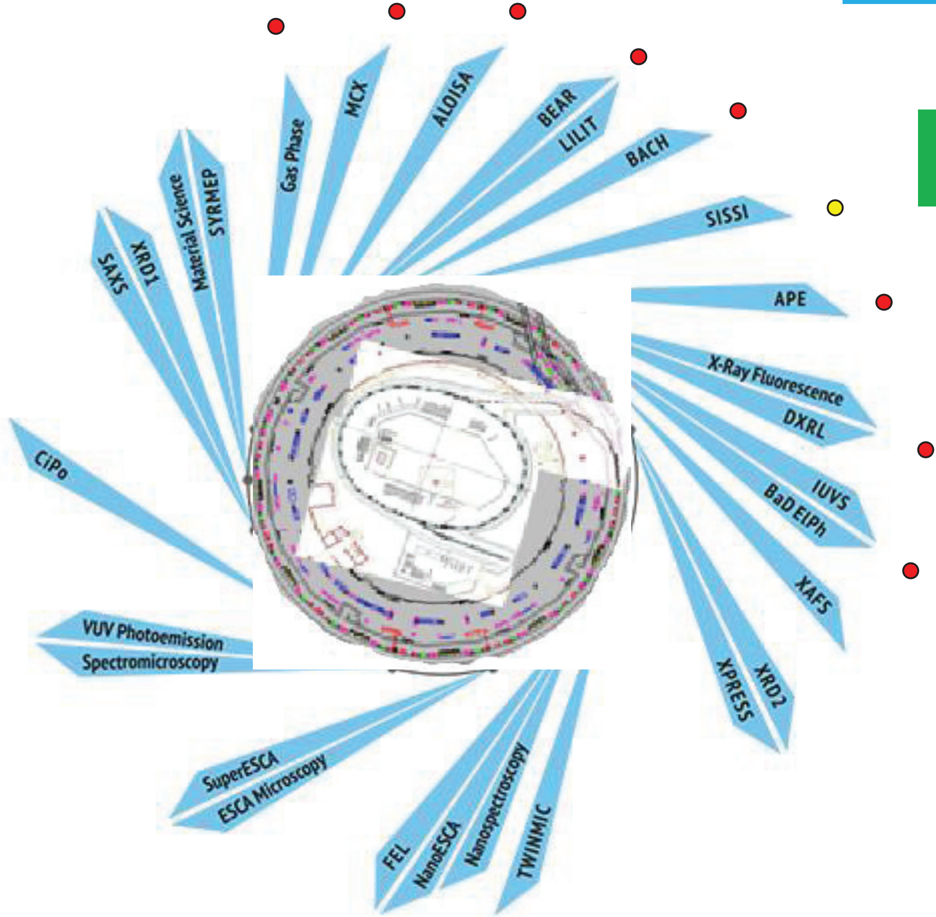

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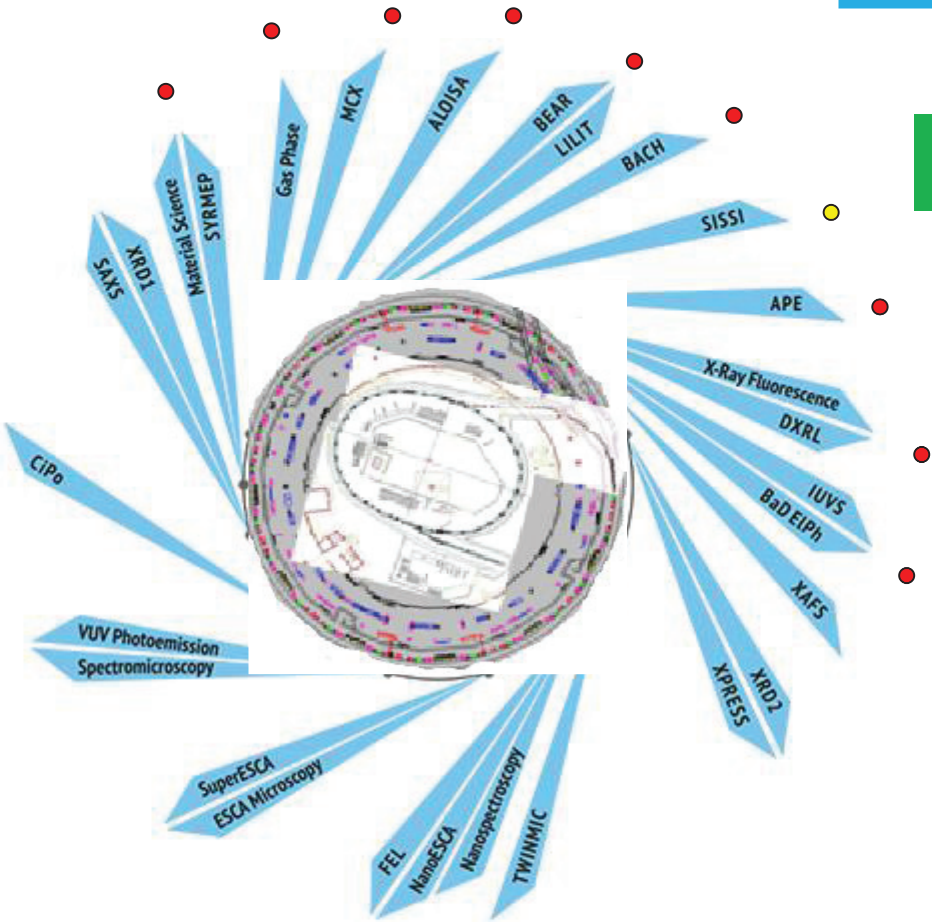

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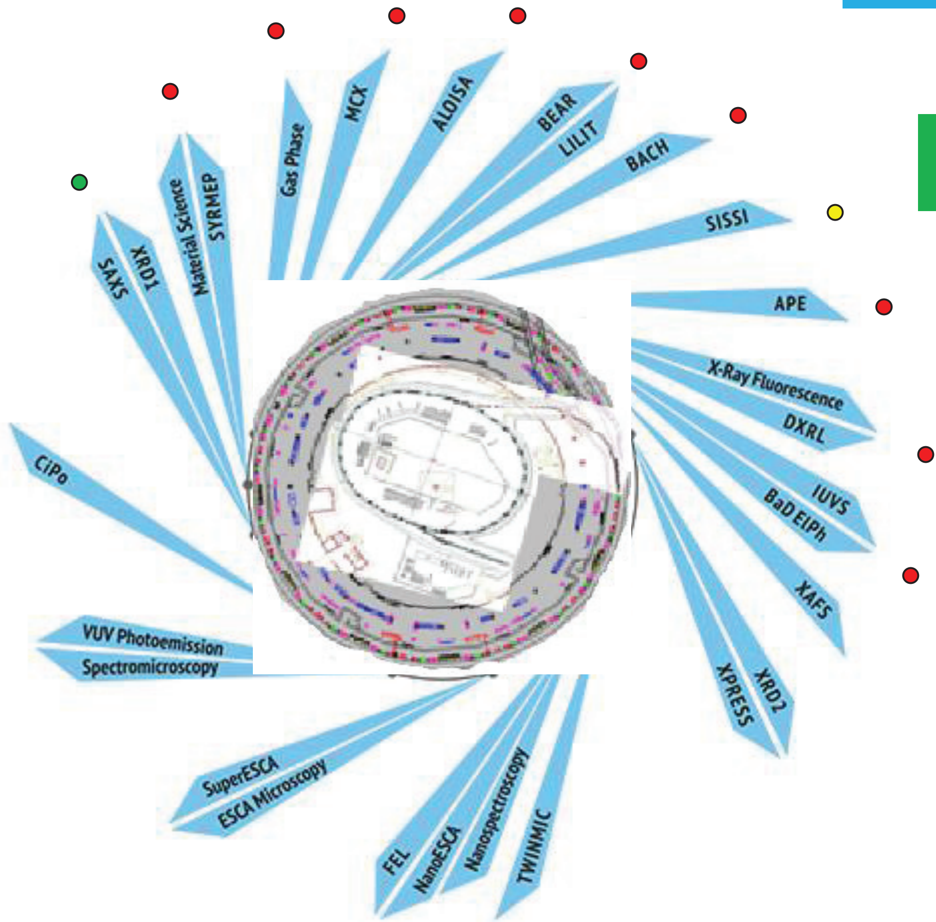

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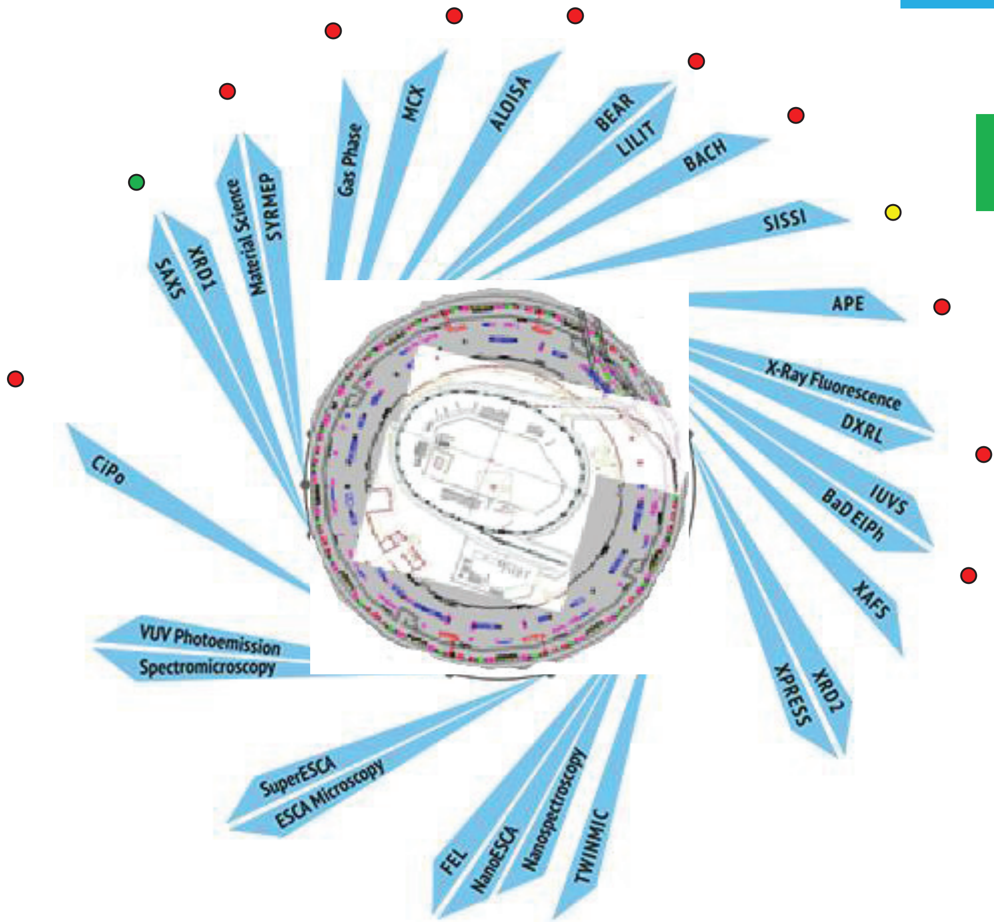

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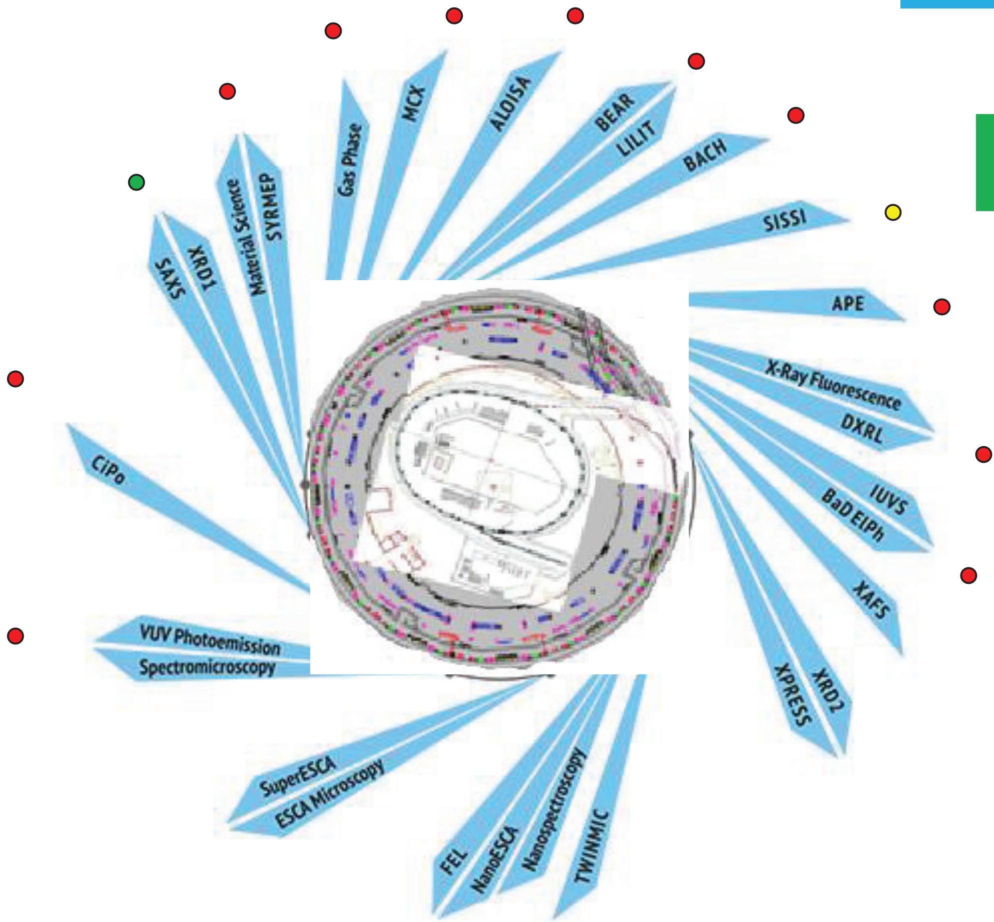

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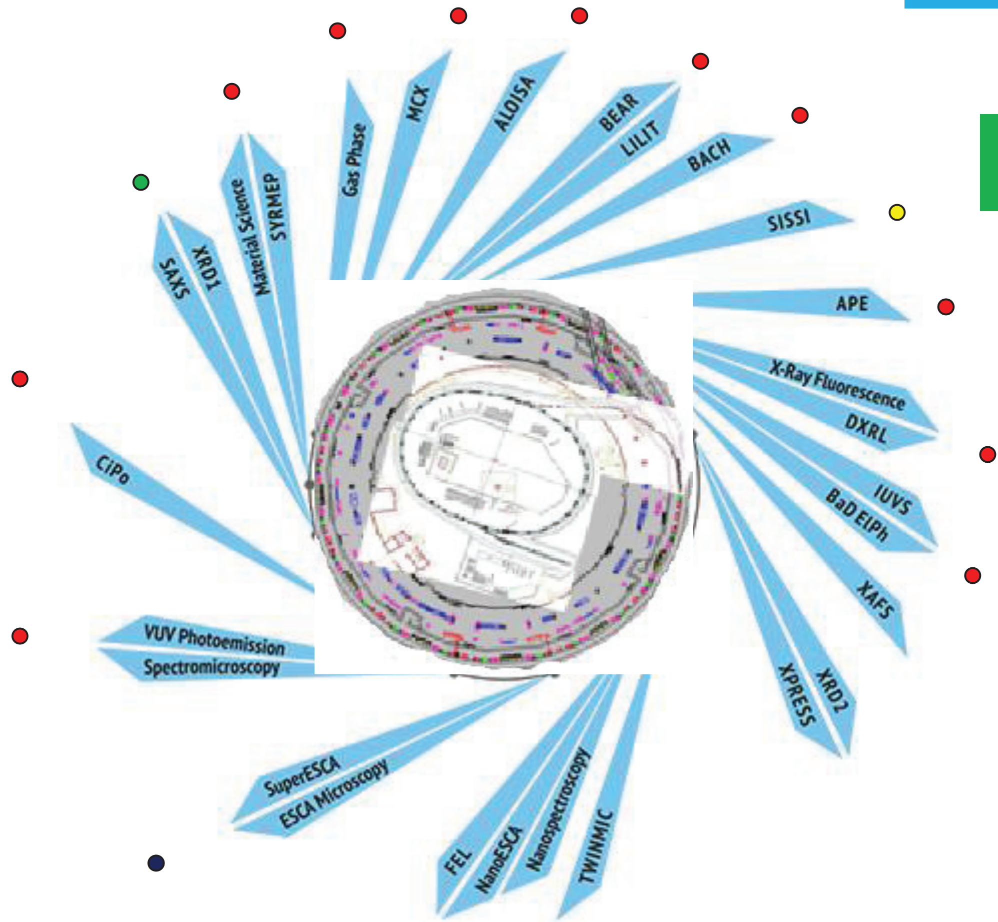

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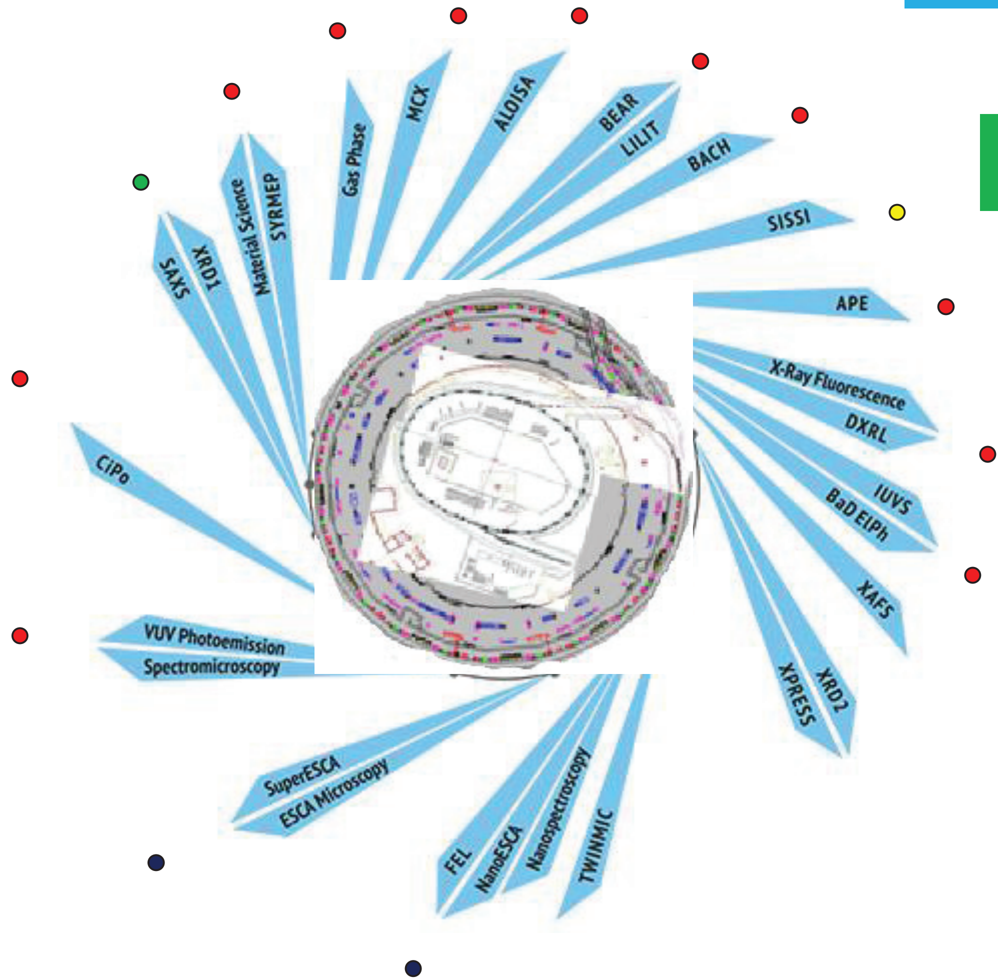

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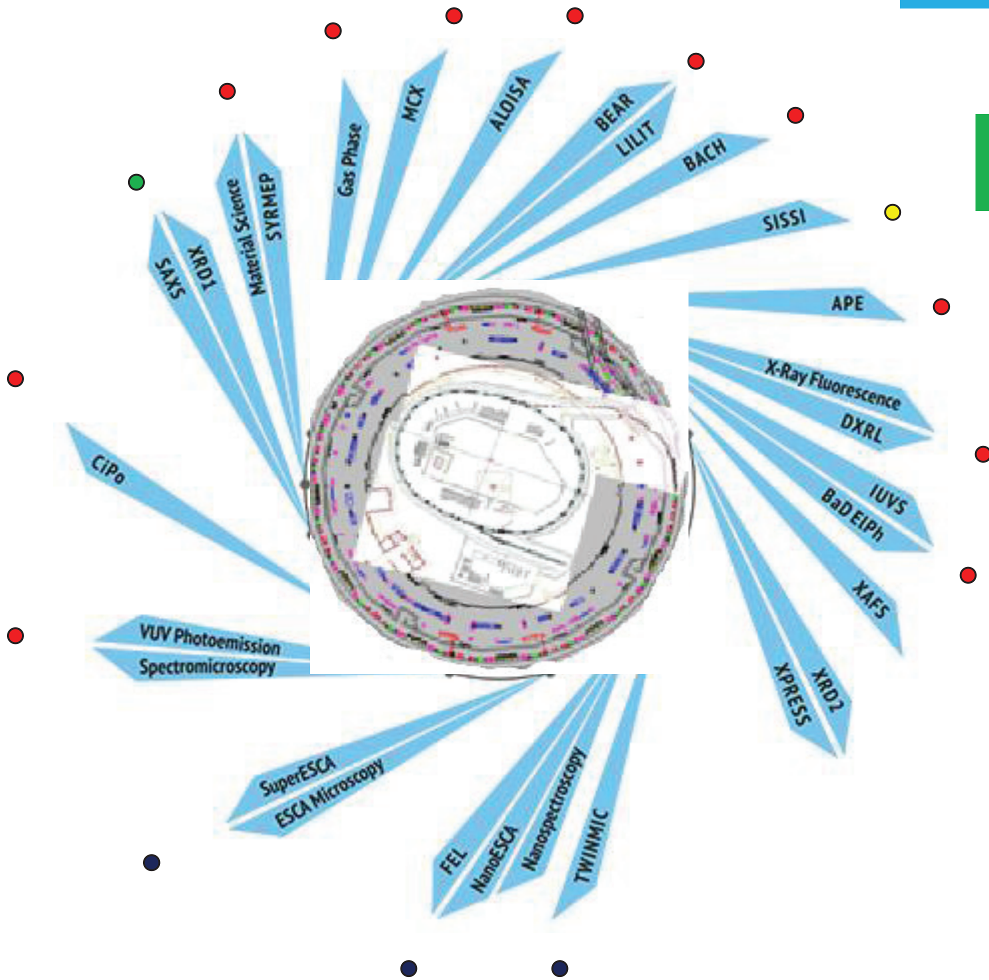

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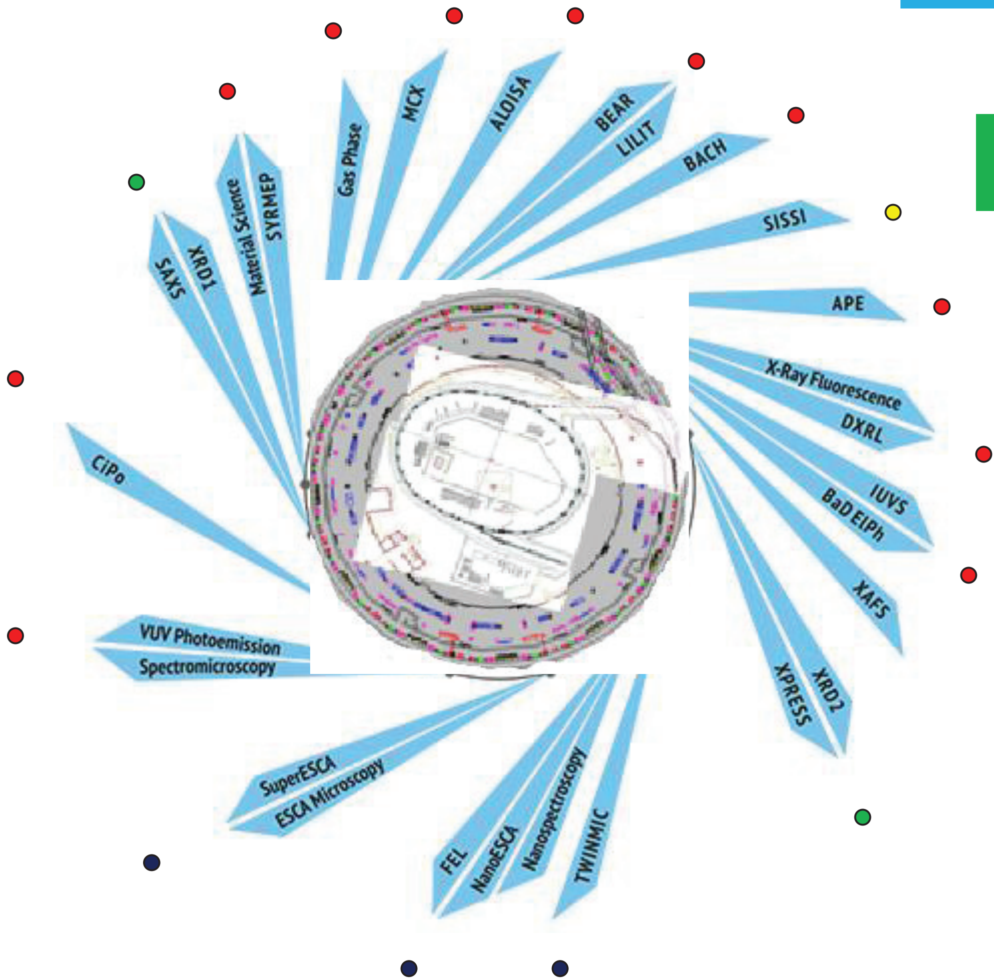

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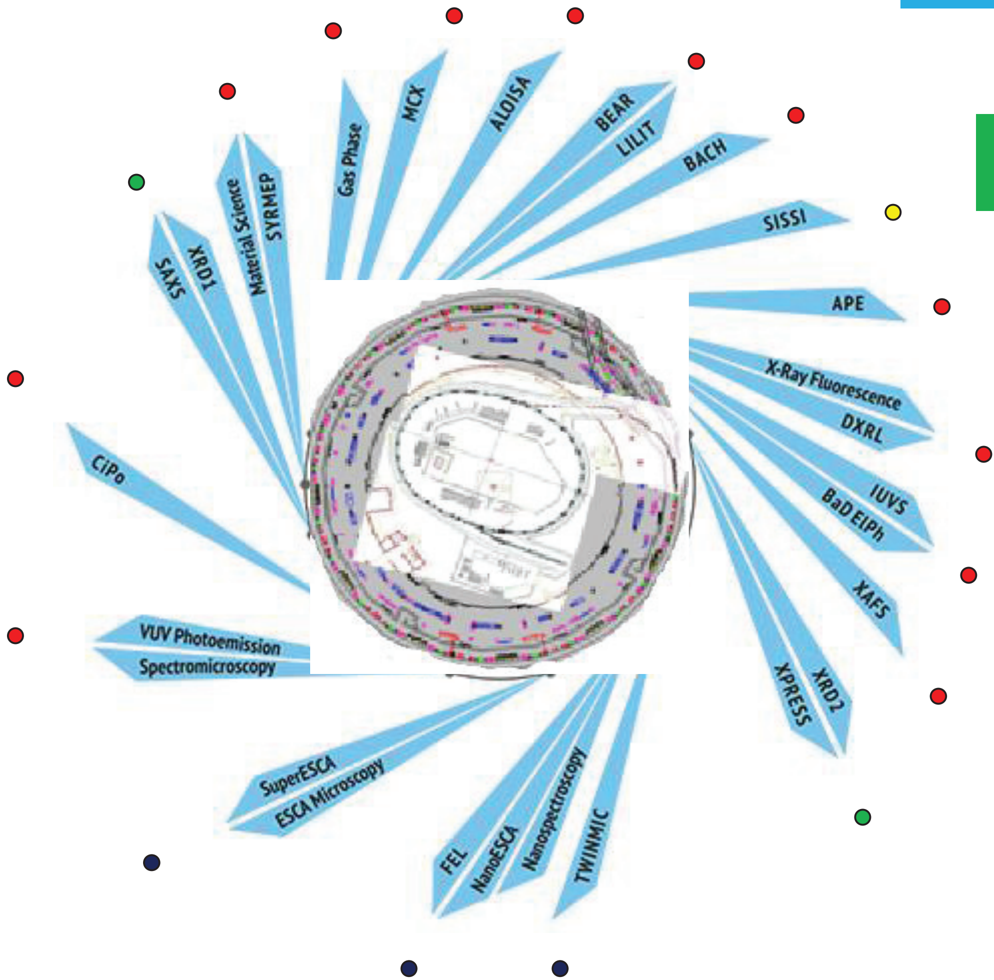

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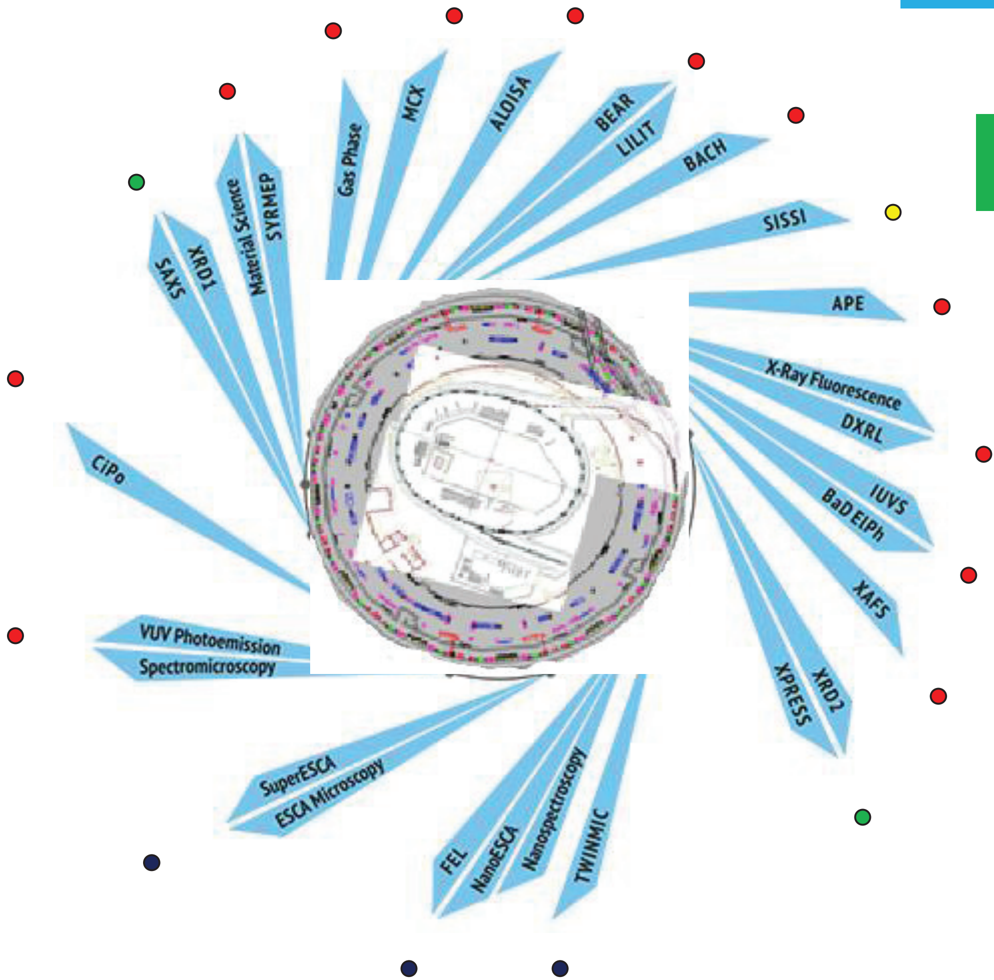

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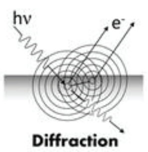

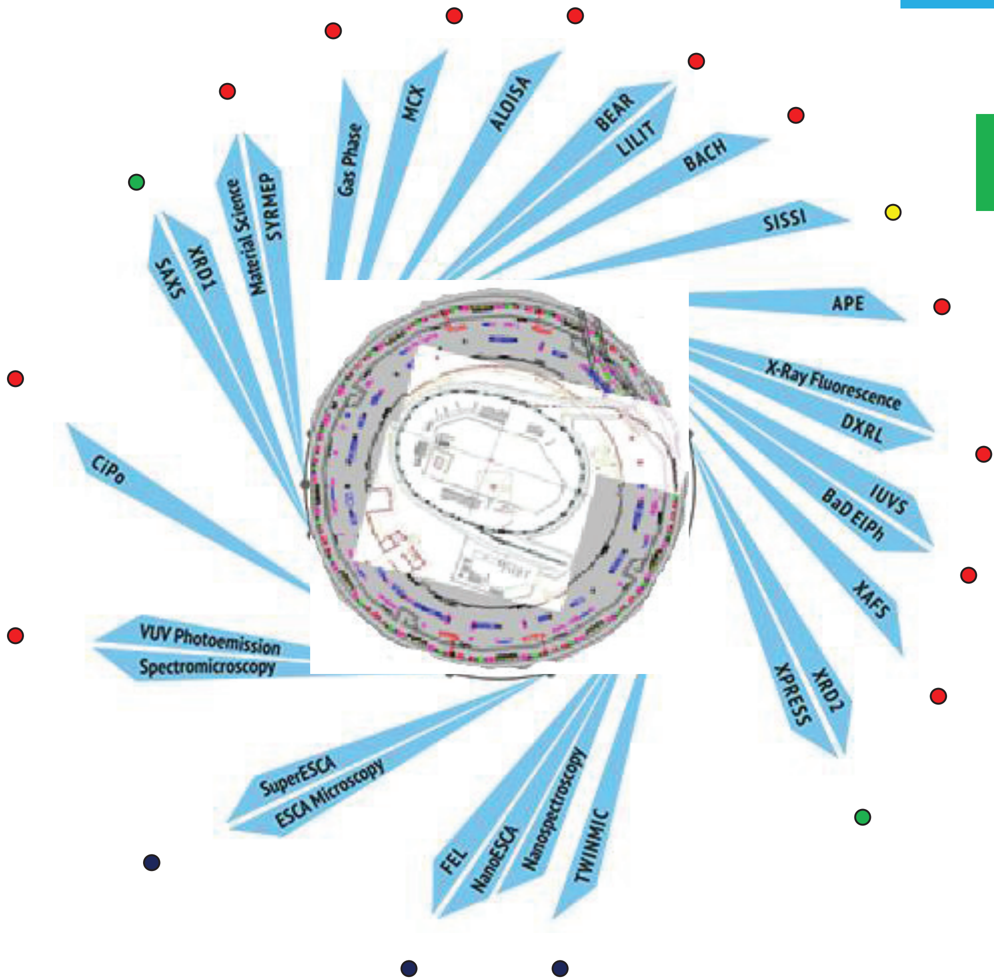

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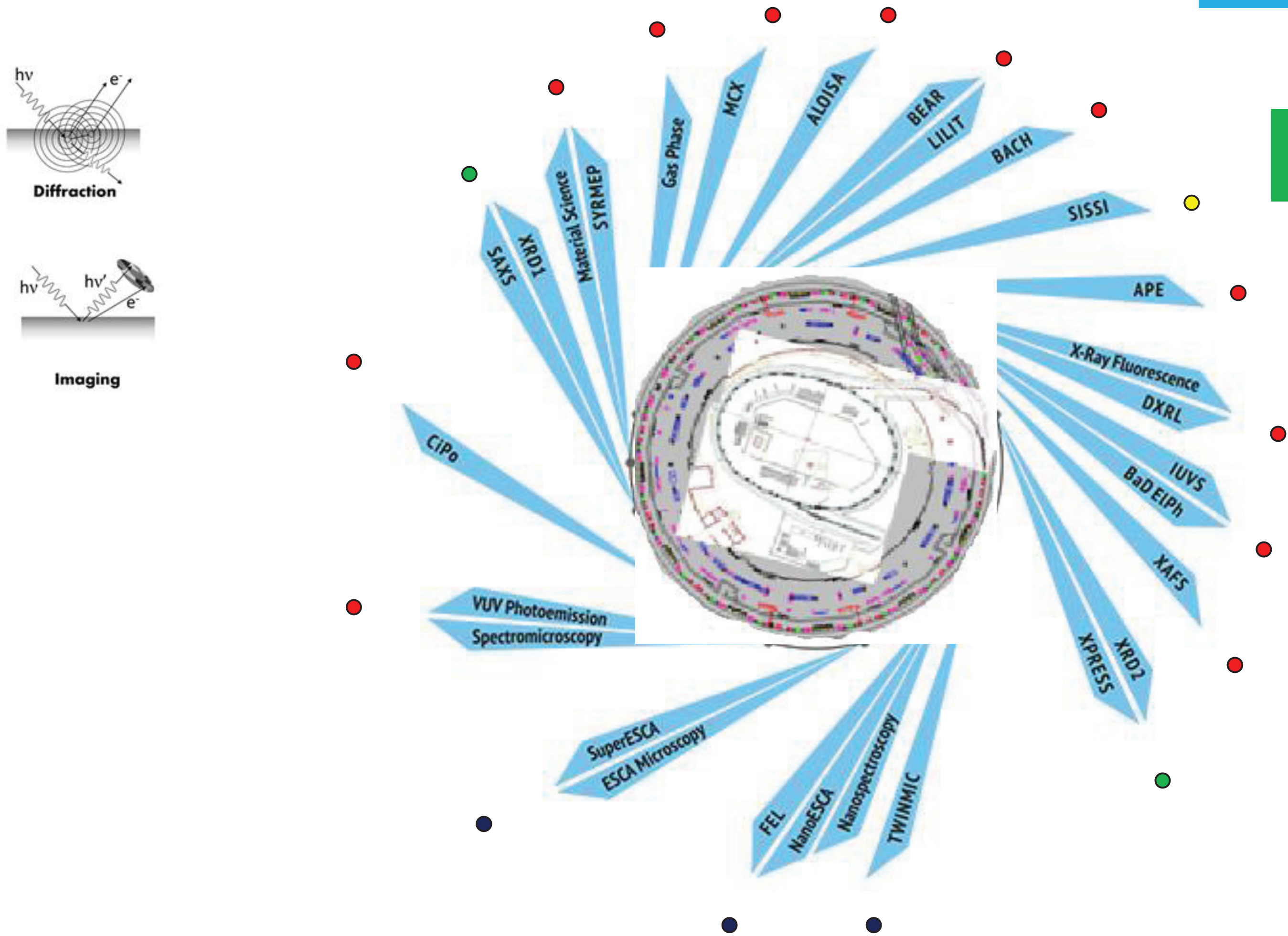

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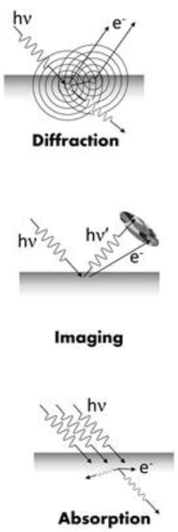

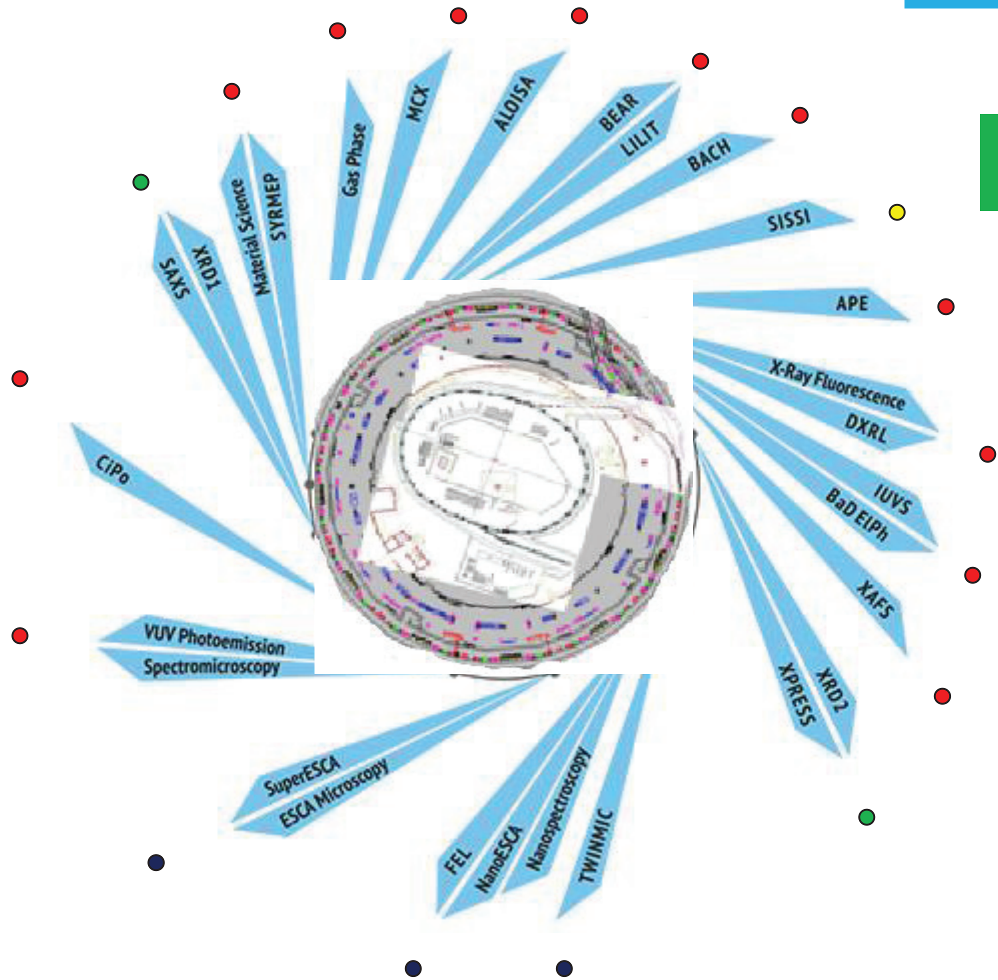

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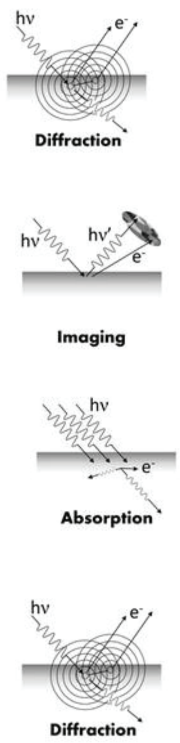

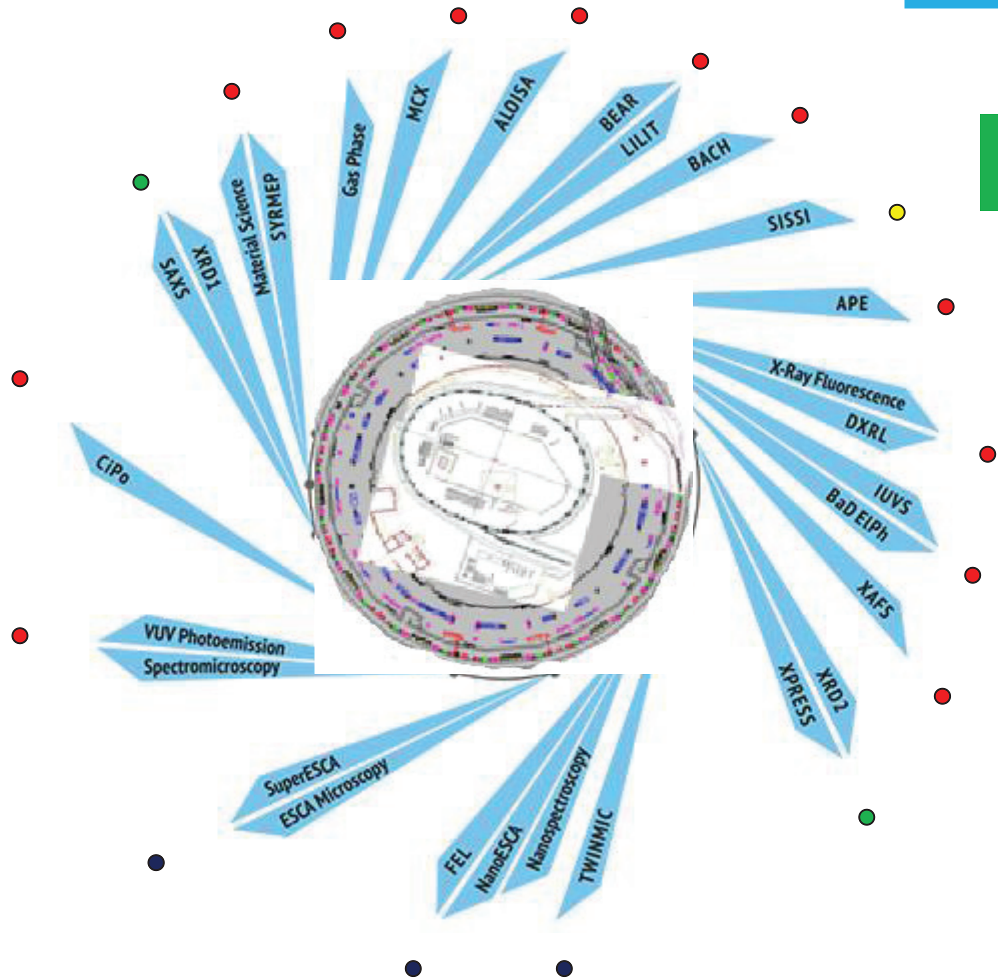

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Elettra Sincrotrone Trieste

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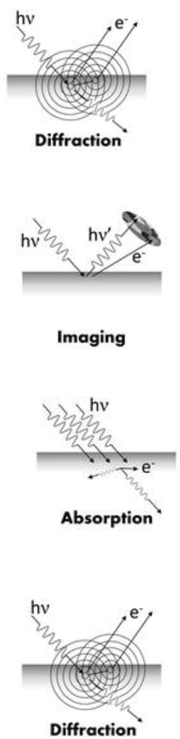

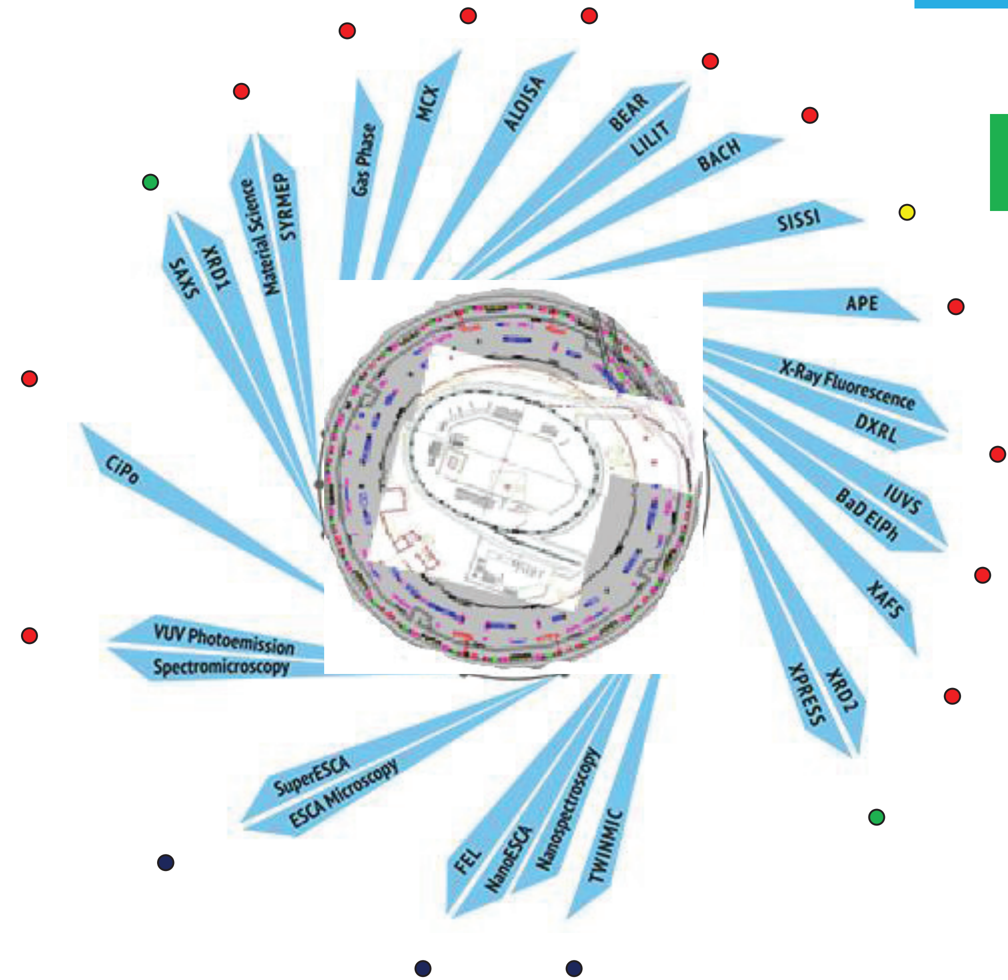

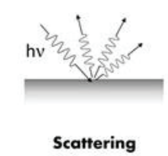

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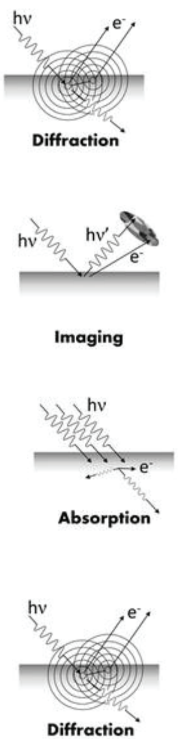

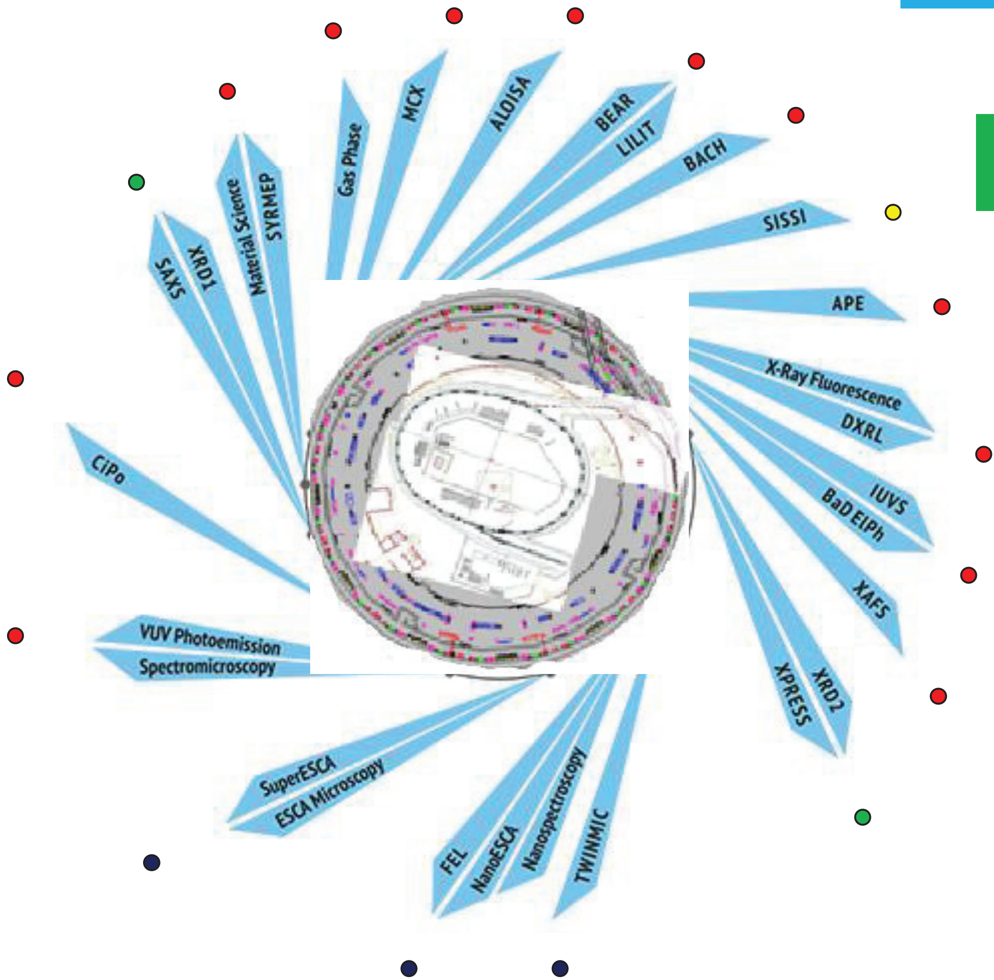

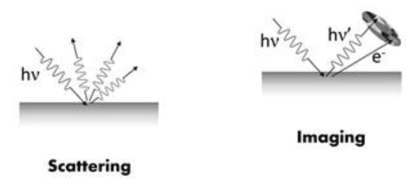

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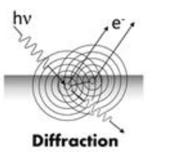

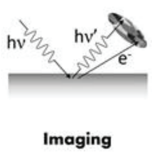

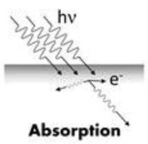

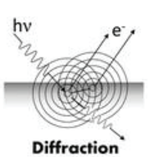

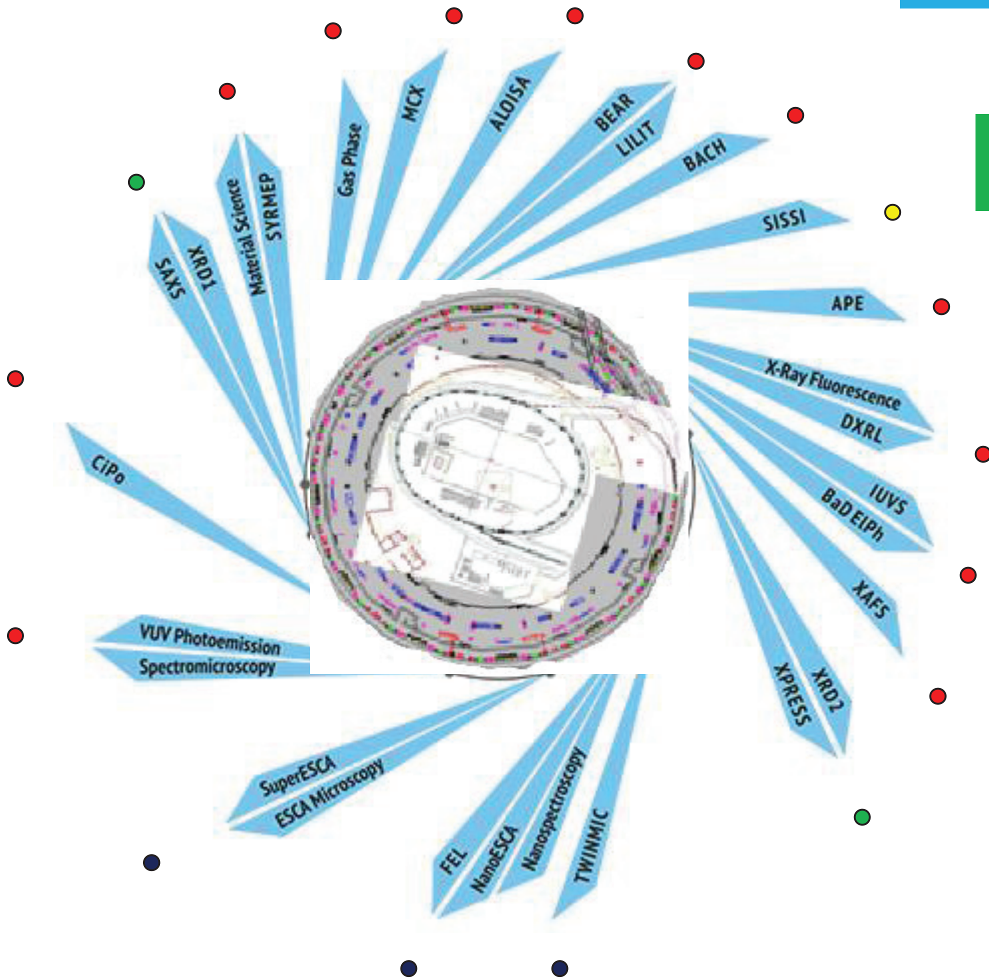

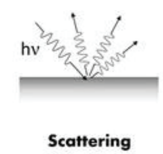

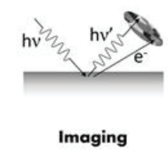

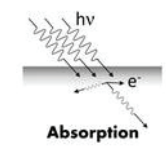

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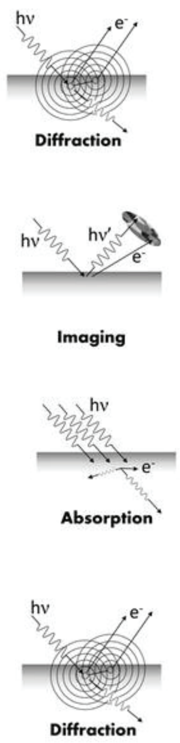

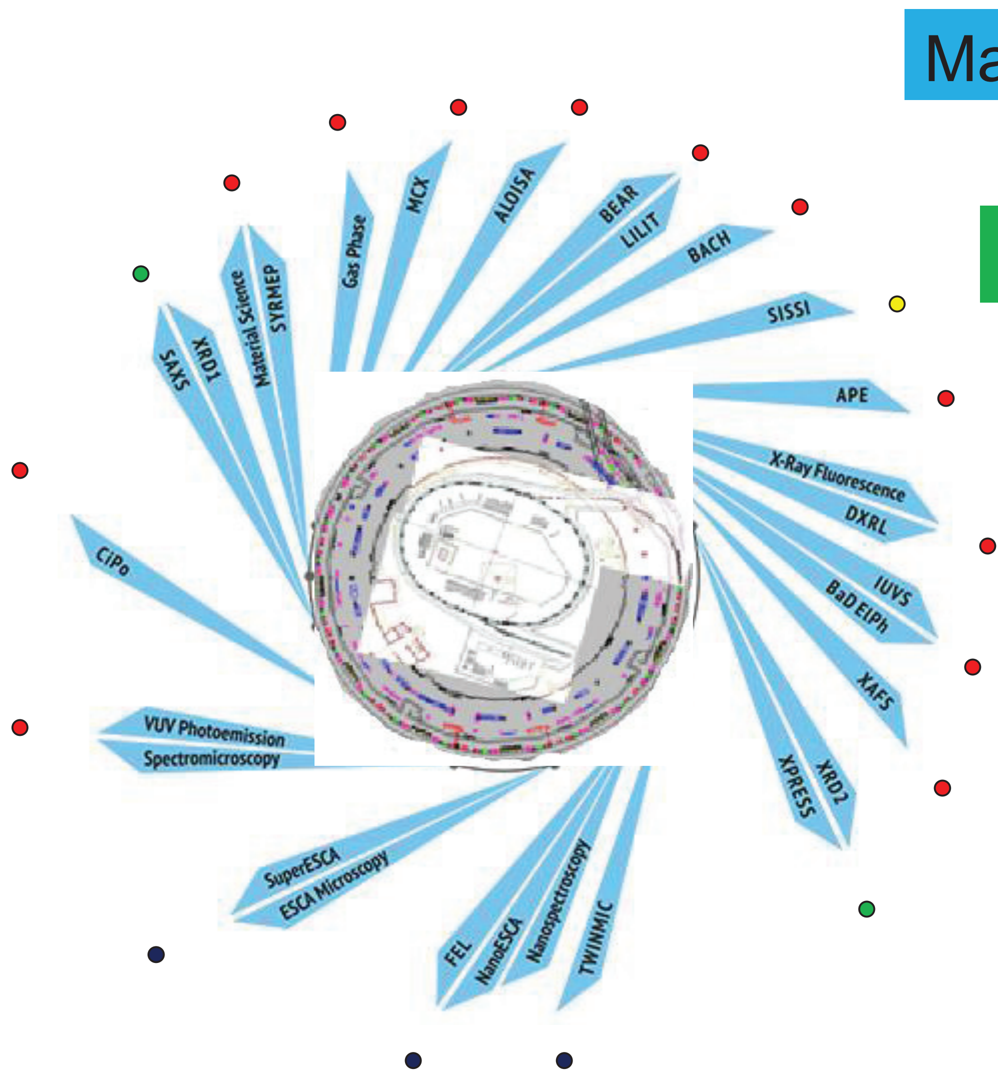

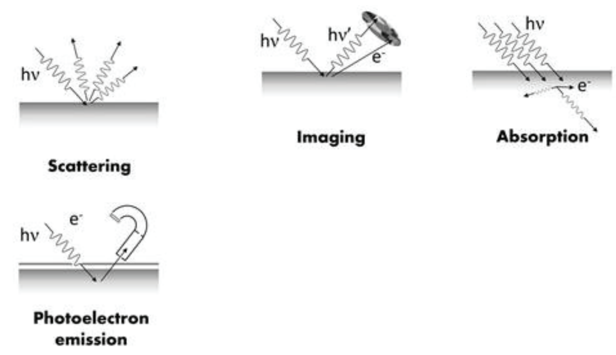

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Elettra Points of View

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Beam Lines people

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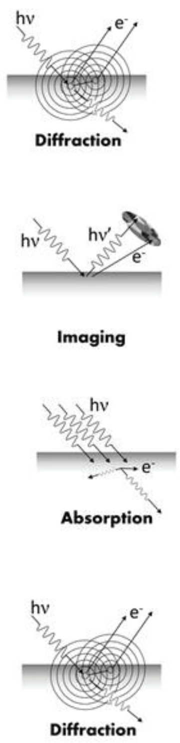

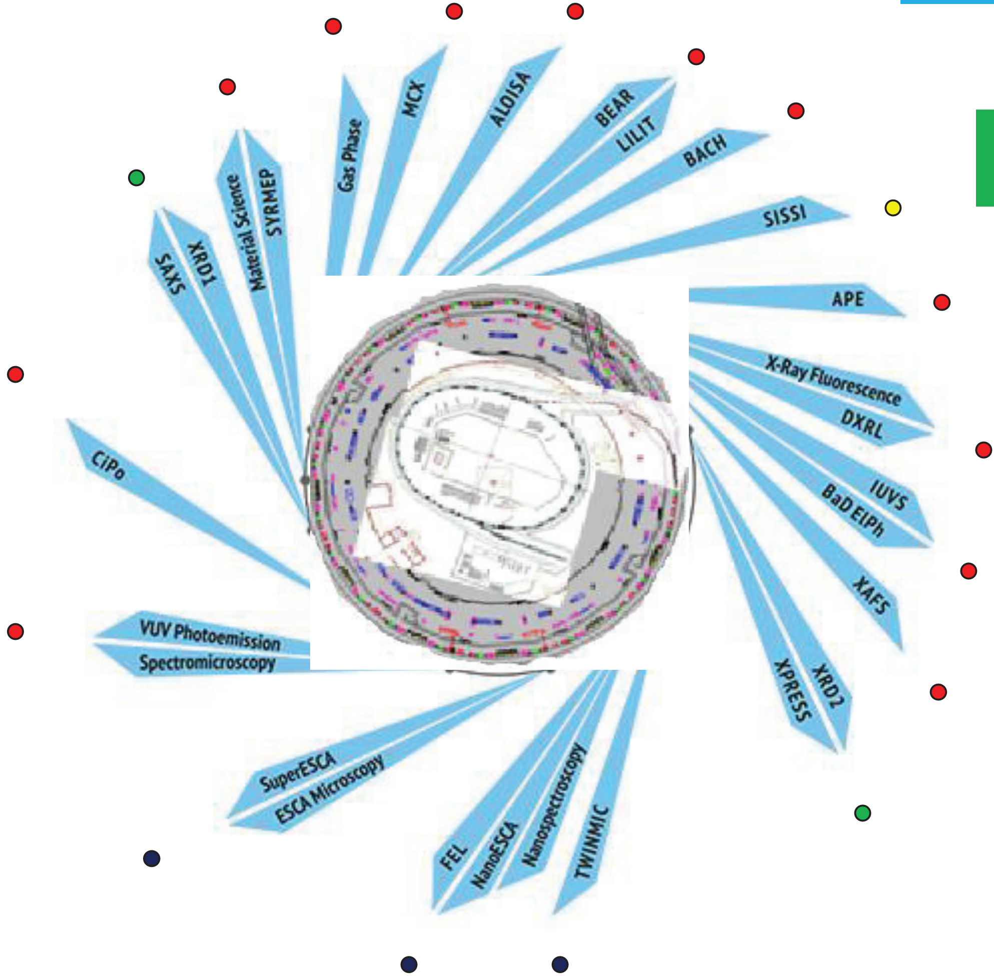

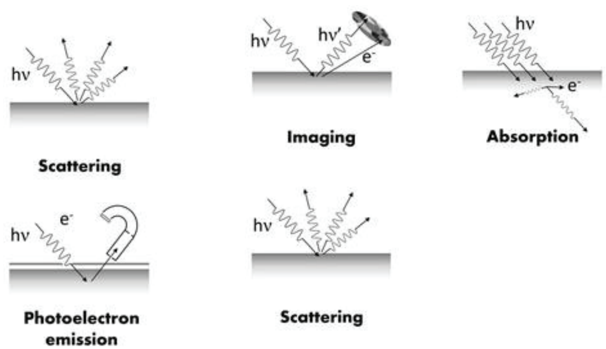

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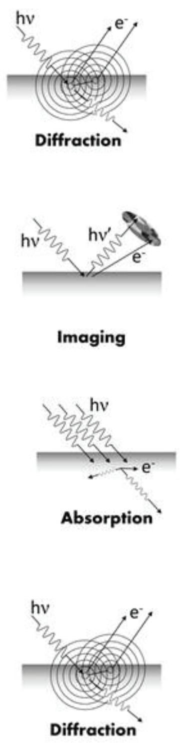

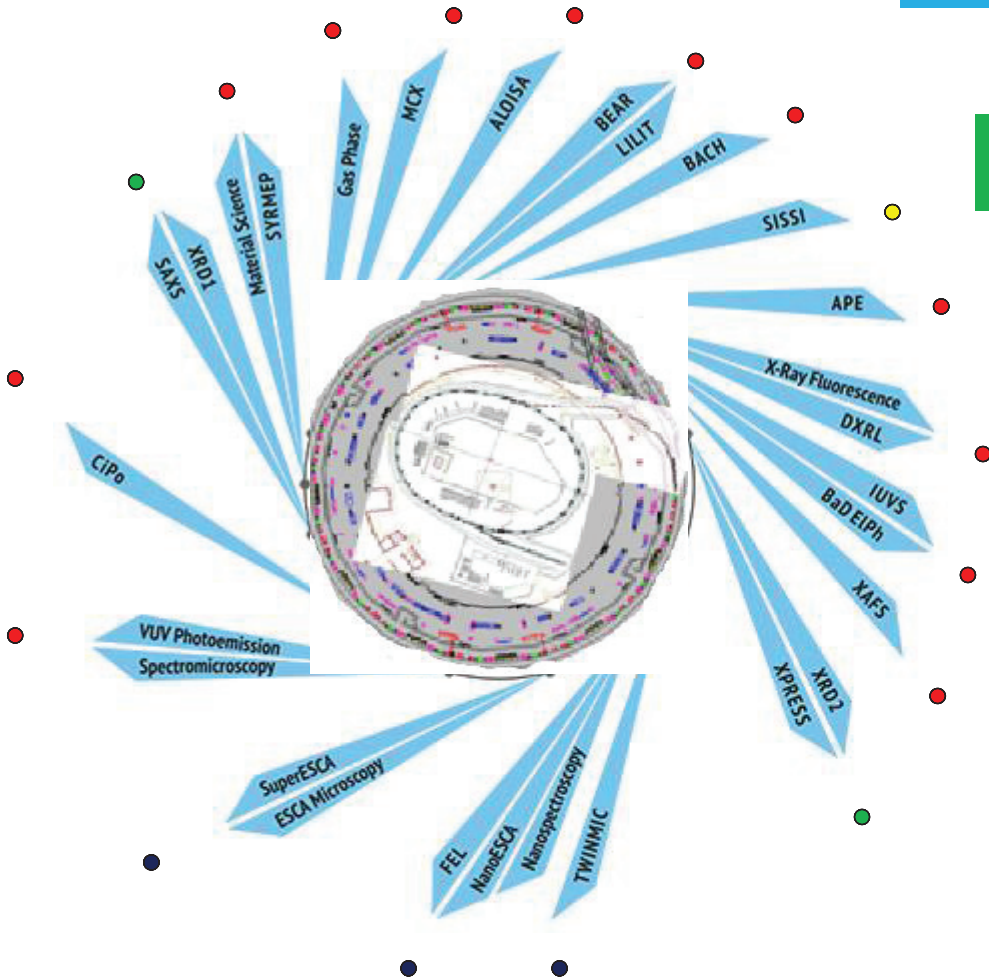

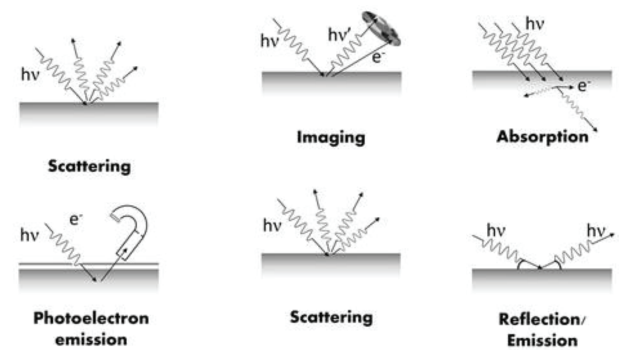

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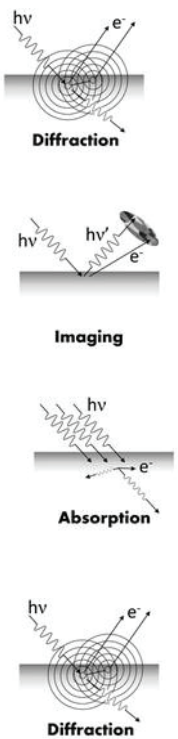

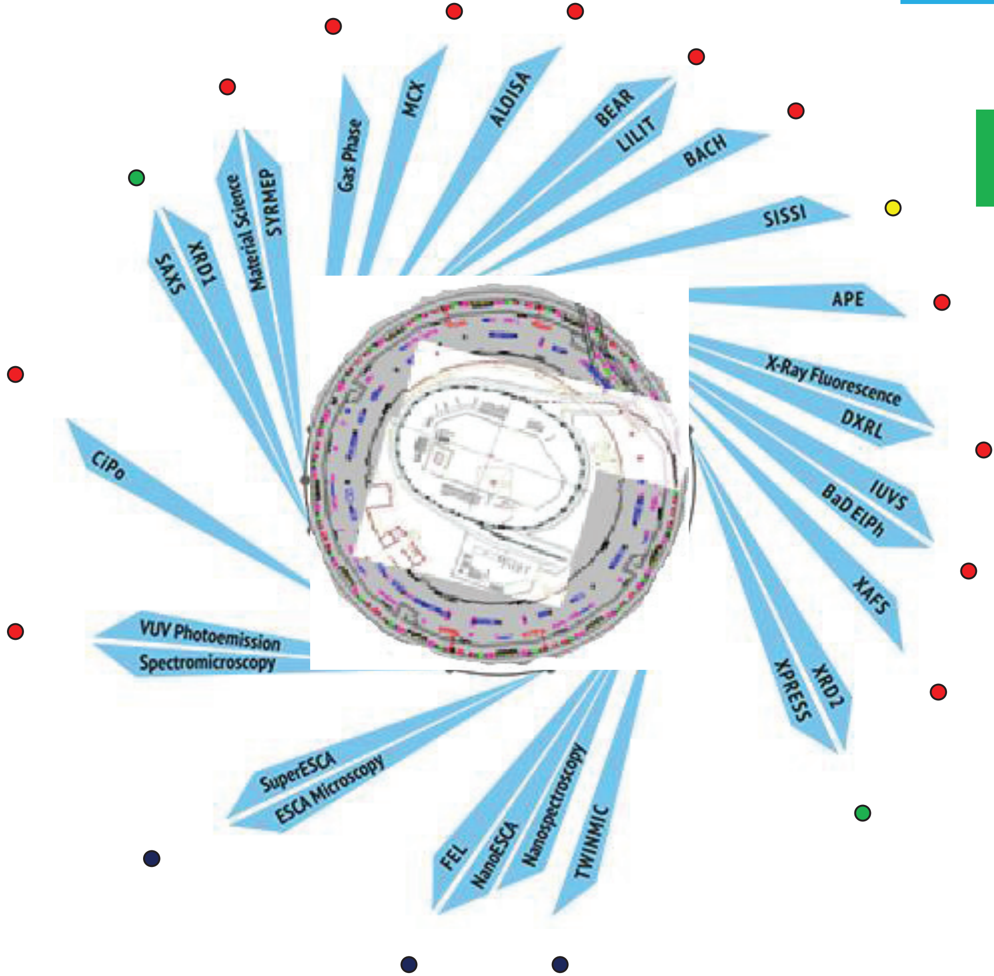

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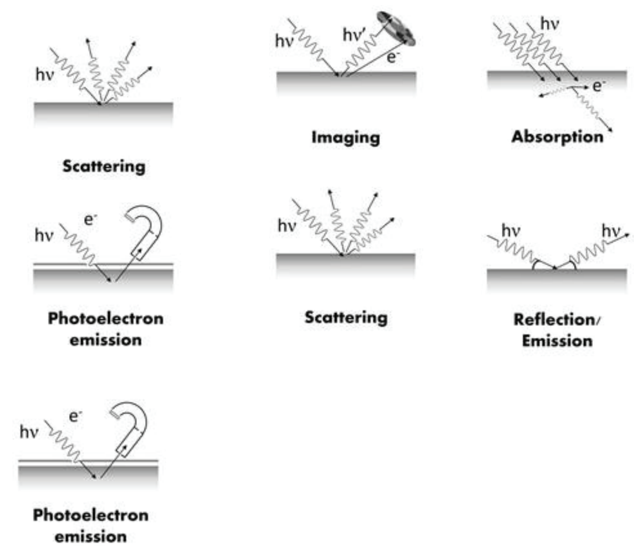

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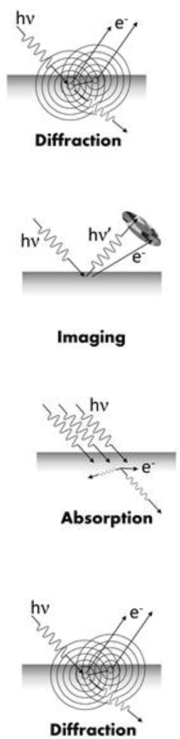

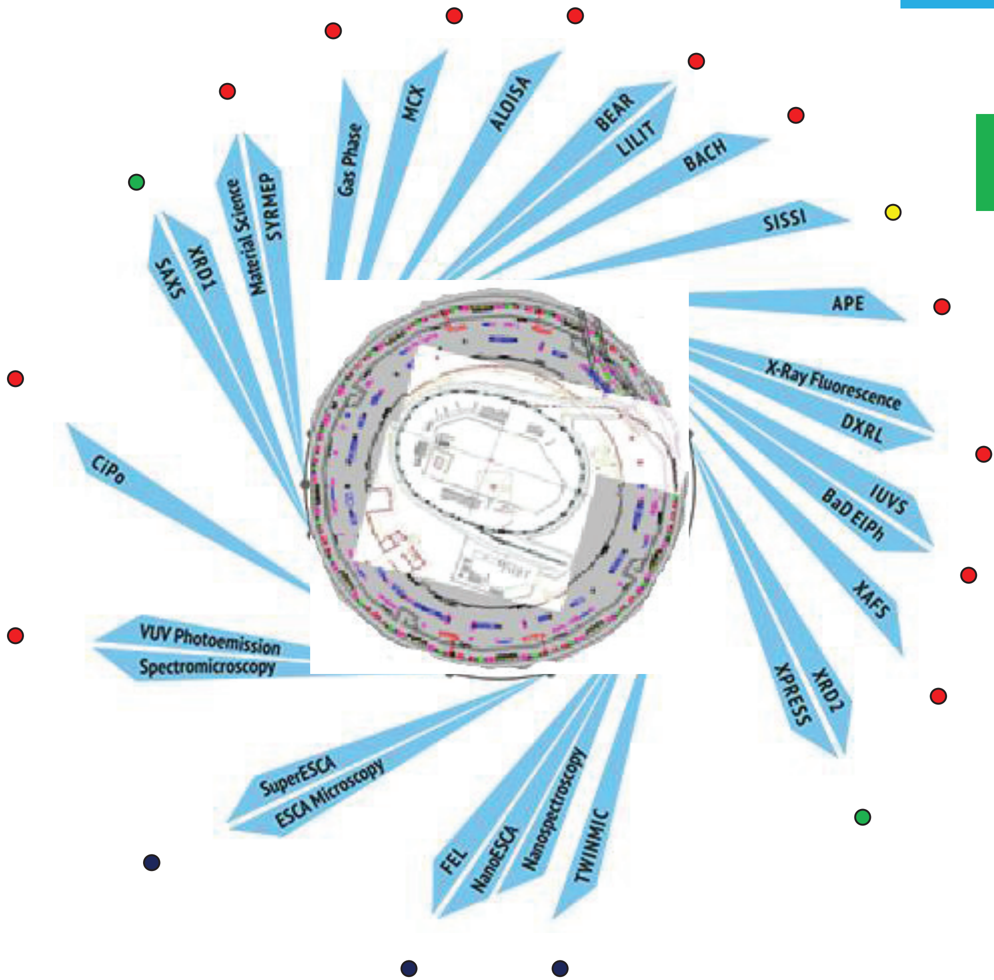

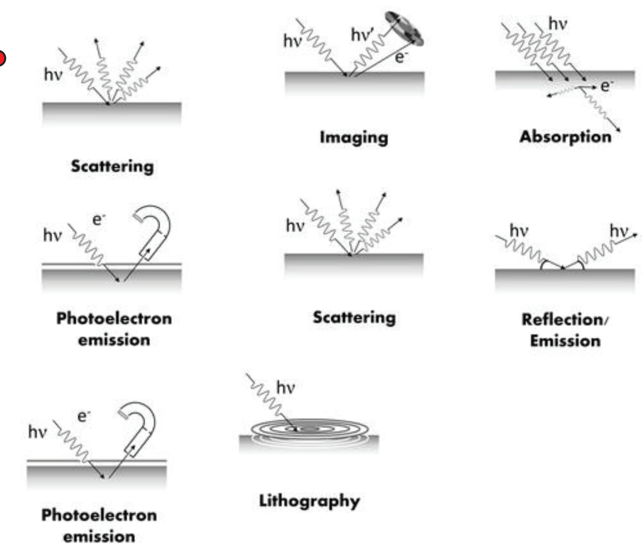

The whole picture MUST be considered for optimal results

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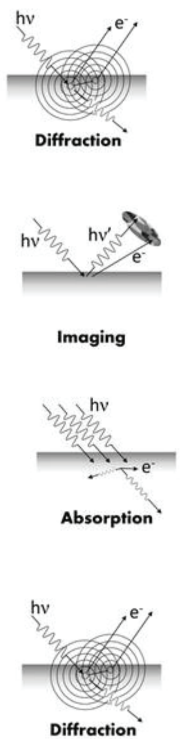
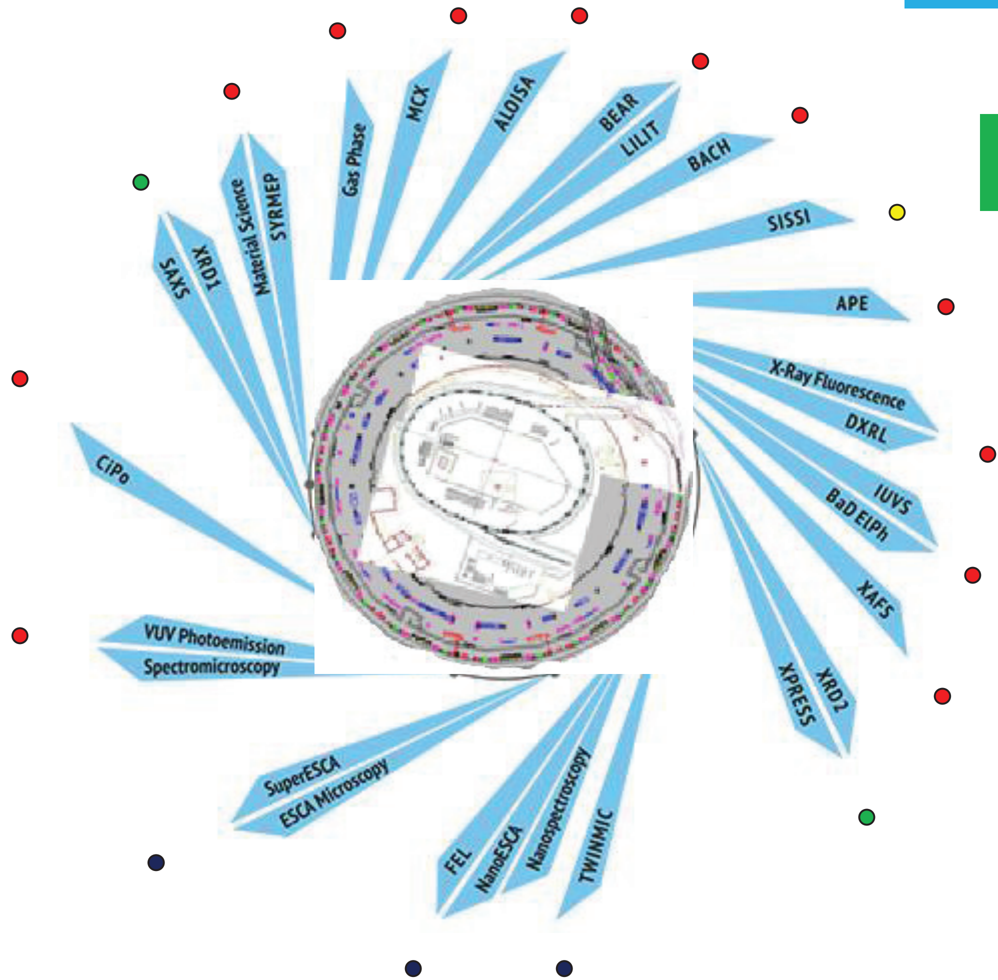
Elettra Points of View

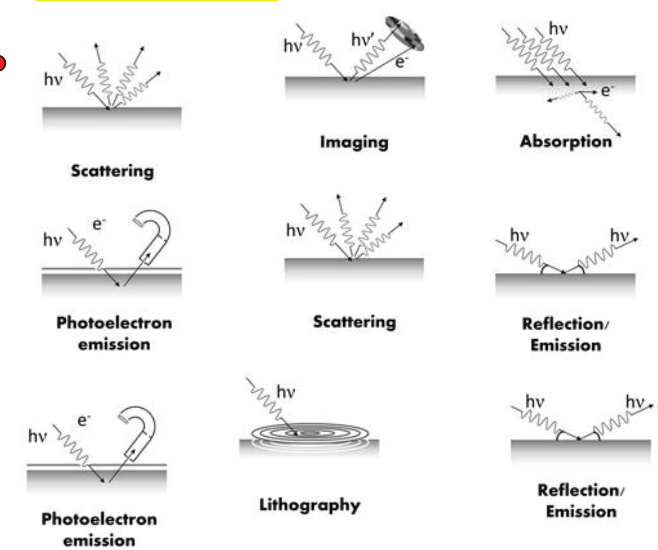
Machine people

Beam Lines people

Users





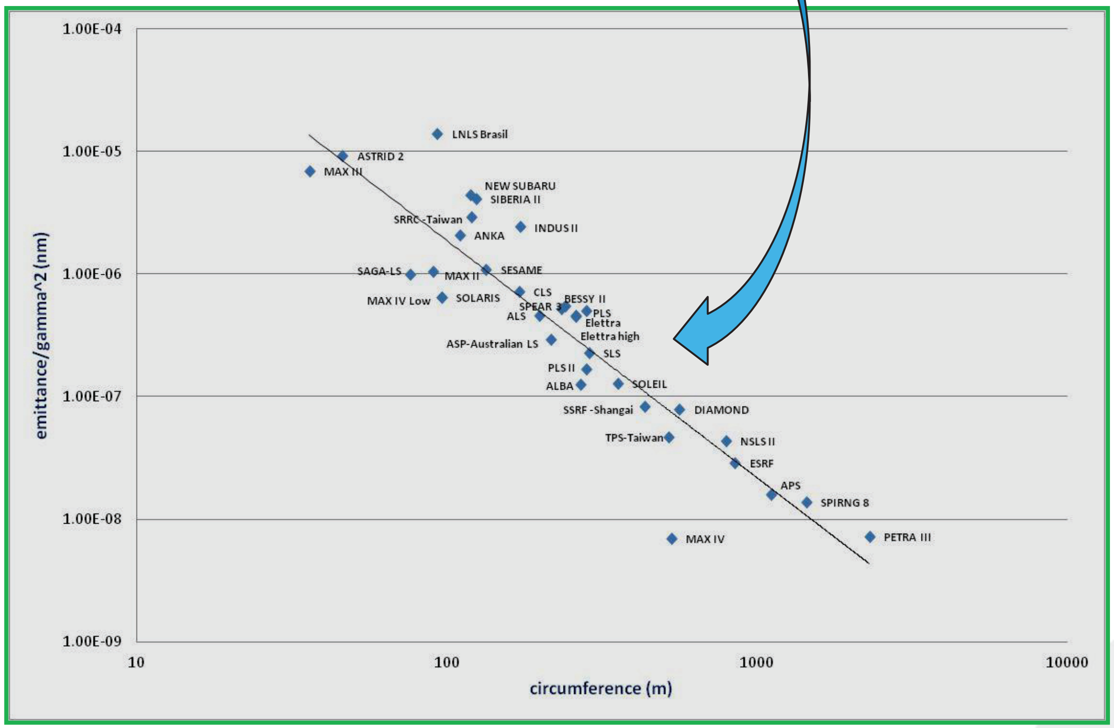


The whole picture MUST be considered for optimal results

SR generations and trends

Generation	Time period	Radiation use from	Energy range (GeV)	Emittance nm-rad
1	60s and early 70s	Parasitic	0.18-6	500
2	Mid 70s to 80s	Dipoles	0.7-2.5	100
3	90s to 2015	Wigglers and undulators	0.7-8 many in 2-3 GeV	1-20
NGSR	2015-2035	Undulators	2 – 7 for the moment	0.02-0.5

Average Brilliance
10^{13}
10^{16}
10^{19}
10^{22}



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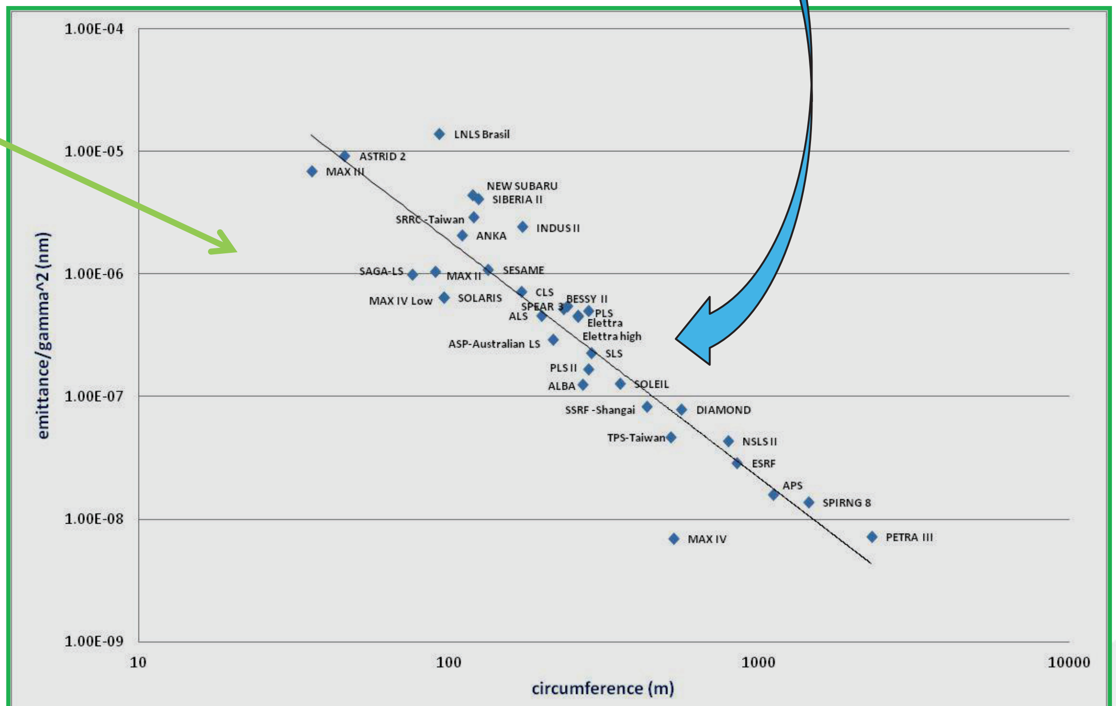

SR generations and trends

Elettra Sincrotrone Trieste

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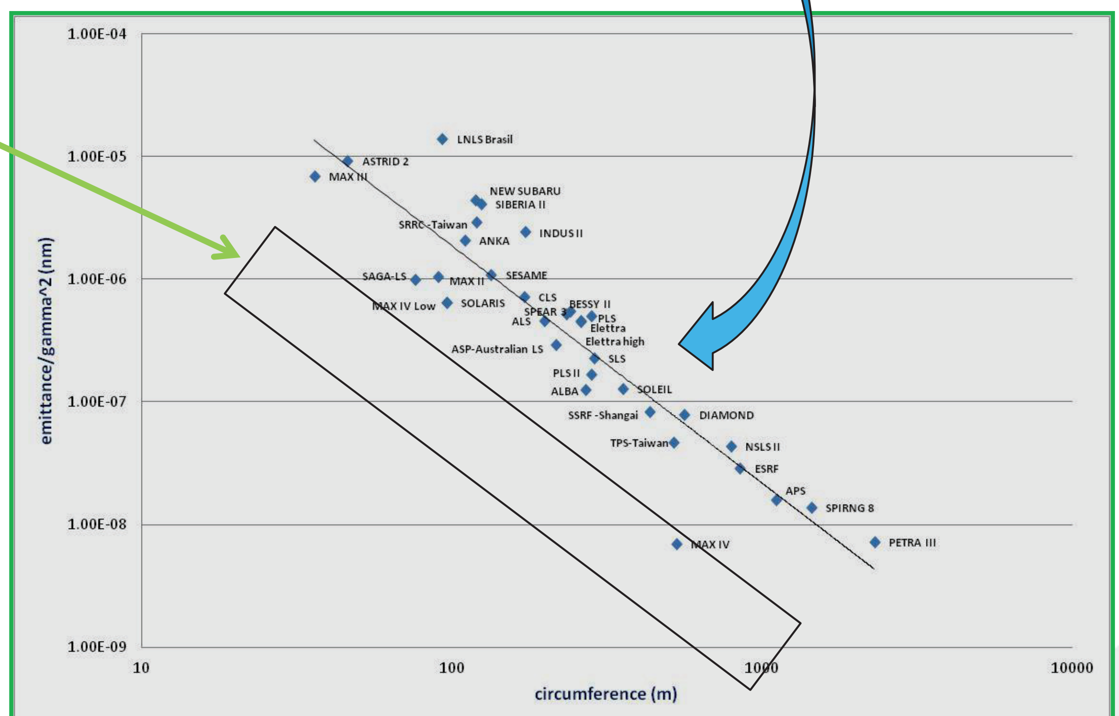

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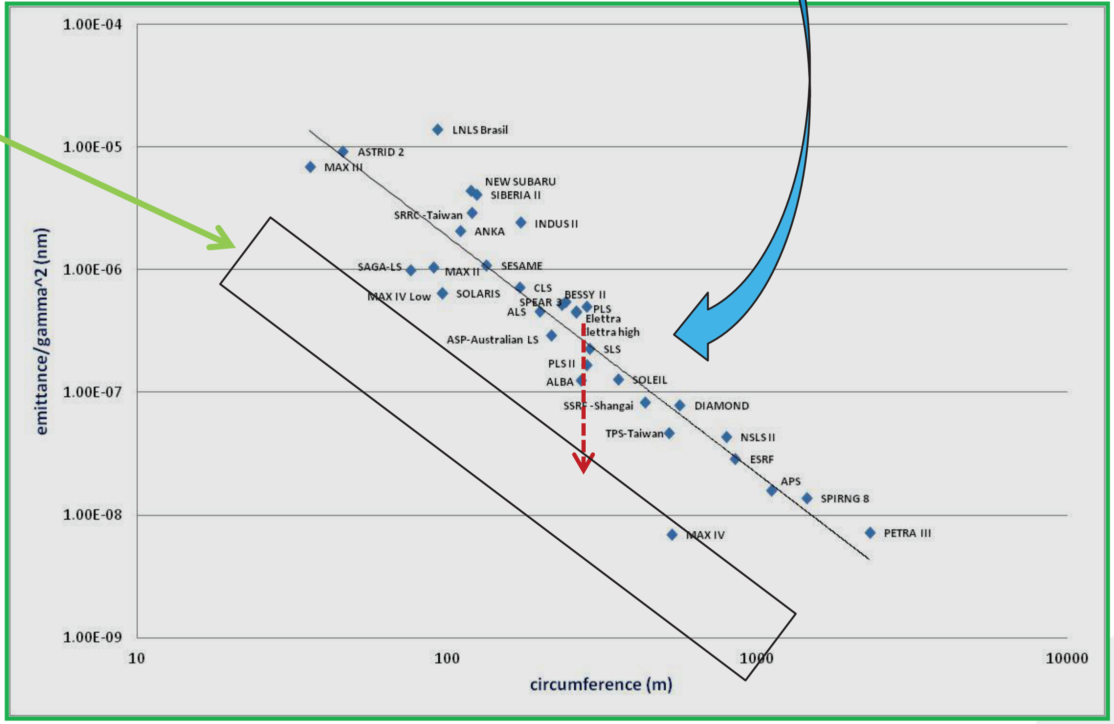

Elettra 2.0 initial requirements

- 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:

Easier part

Not so easy part

Elettra 2.0 initial requirements

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- 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

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 **A**t the **N**ext **G**eneration **S**ynchrotron 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

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.

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

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

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

Trends and Requirements

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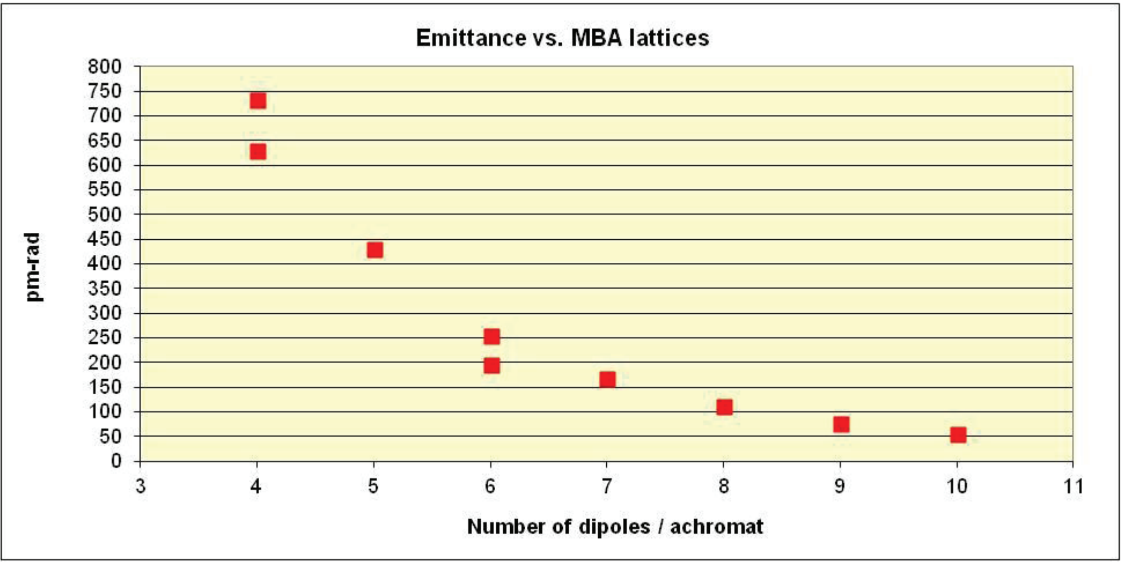
- Higher flux

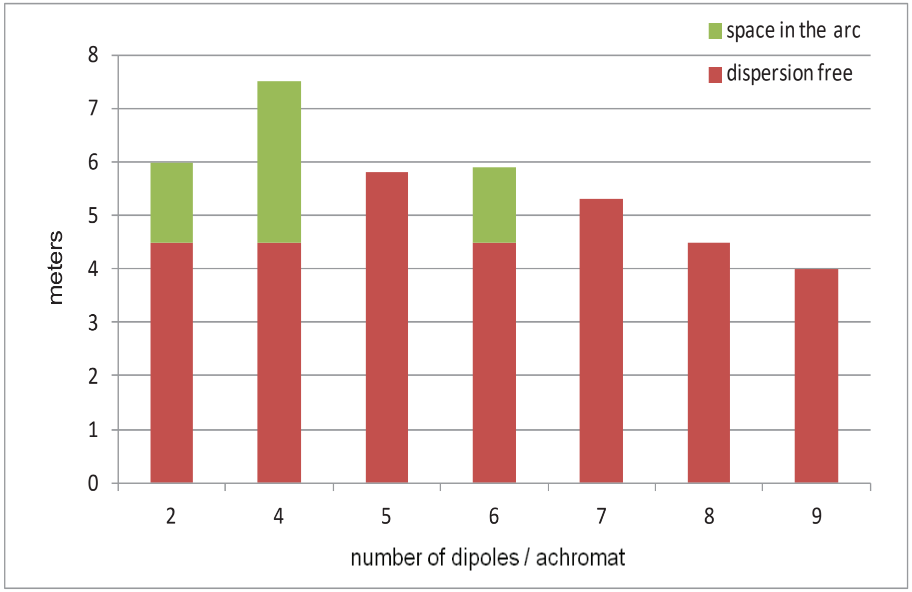
However many our partners and users are also interested in:

- 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

Search for the Elettra 2.0 Lattice

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





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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)

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Elettra Sincrotrone Trieste

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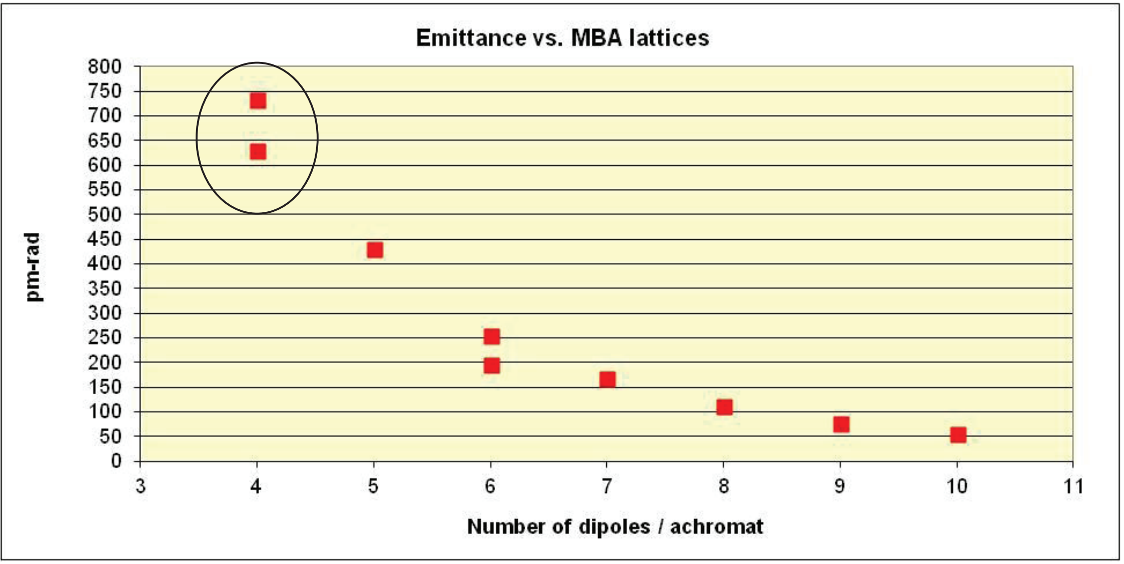

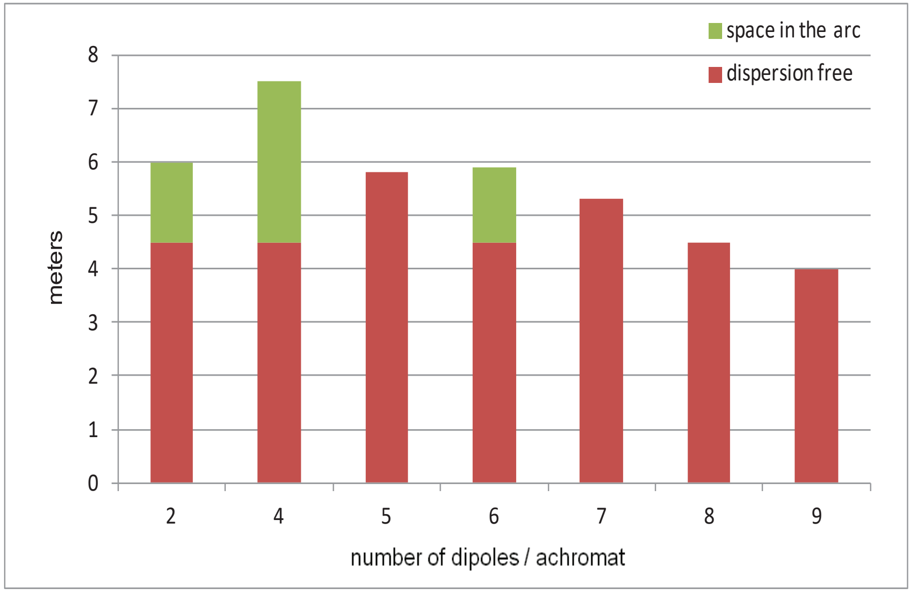

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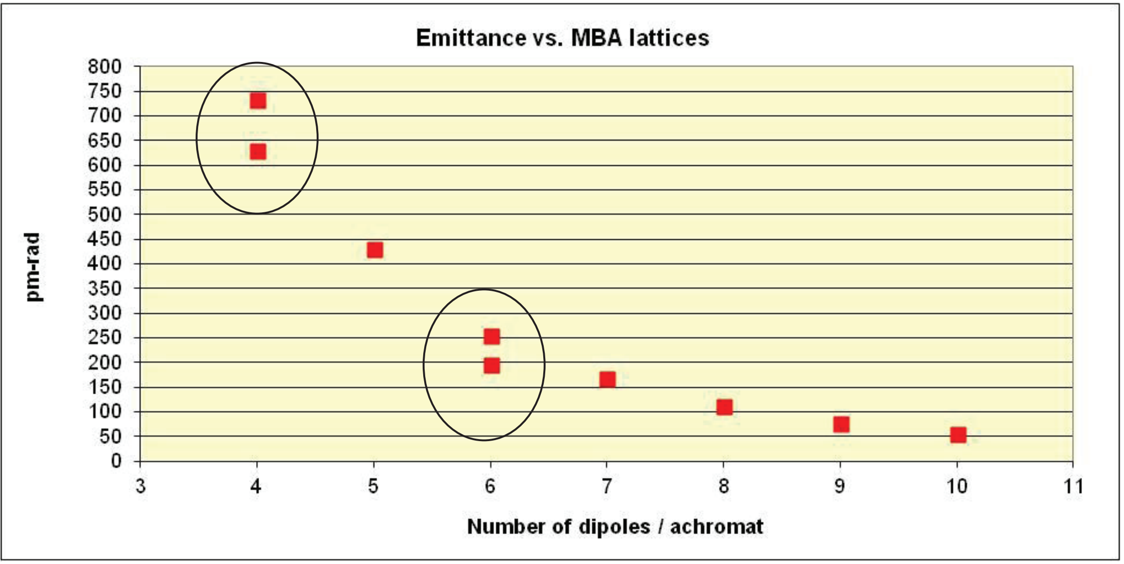

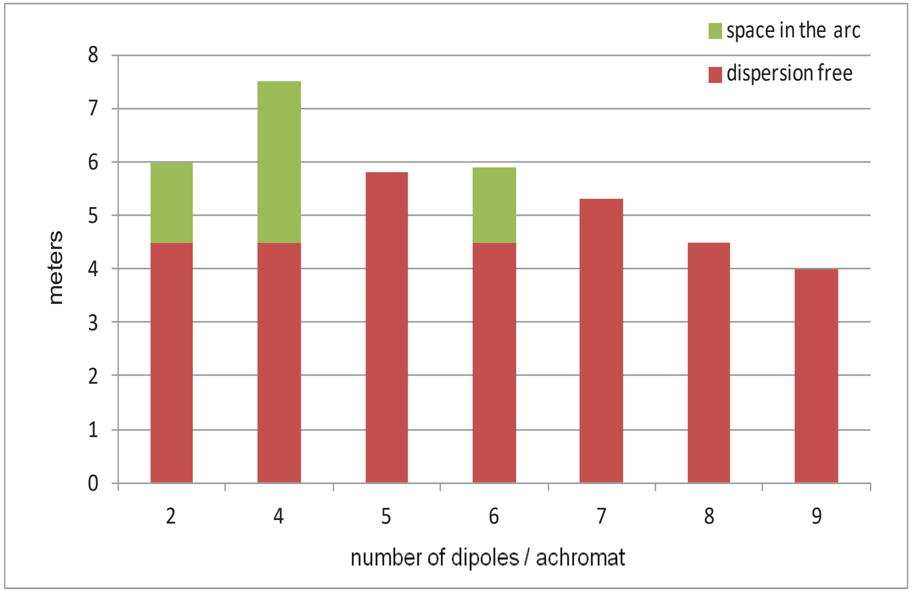

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Elettra Sincrotrone Trieste

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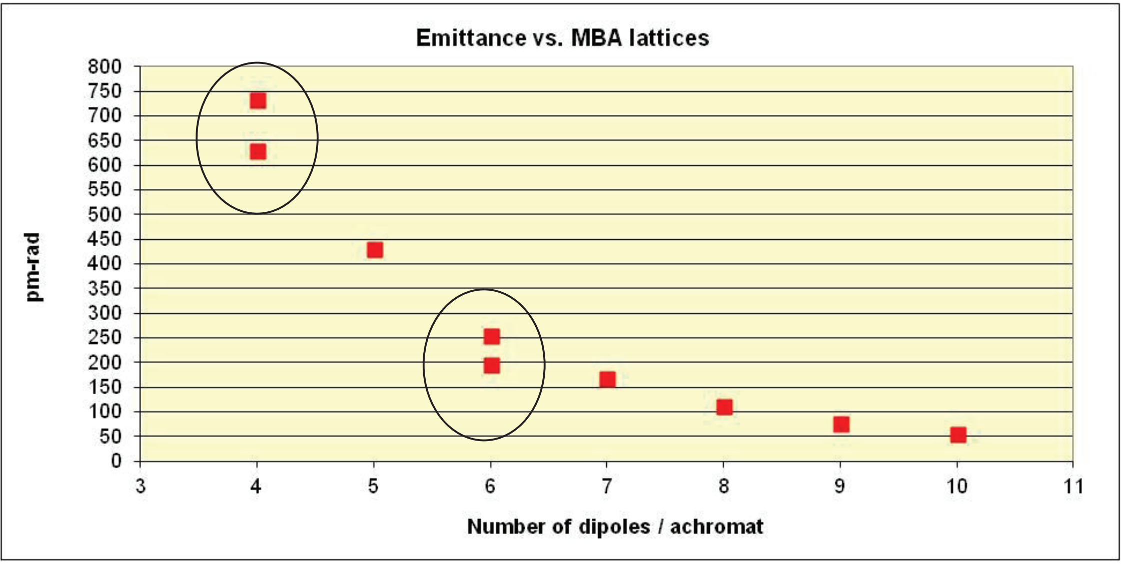

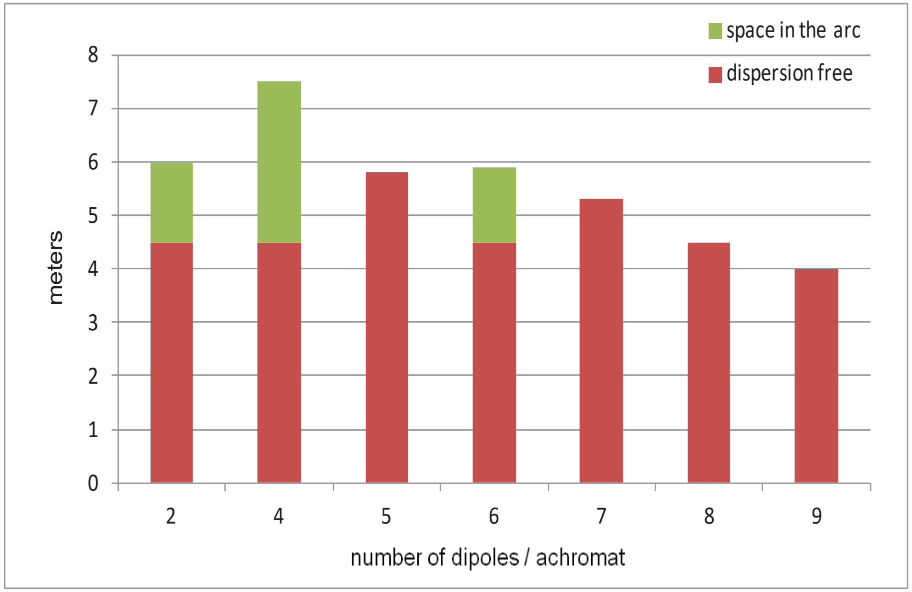

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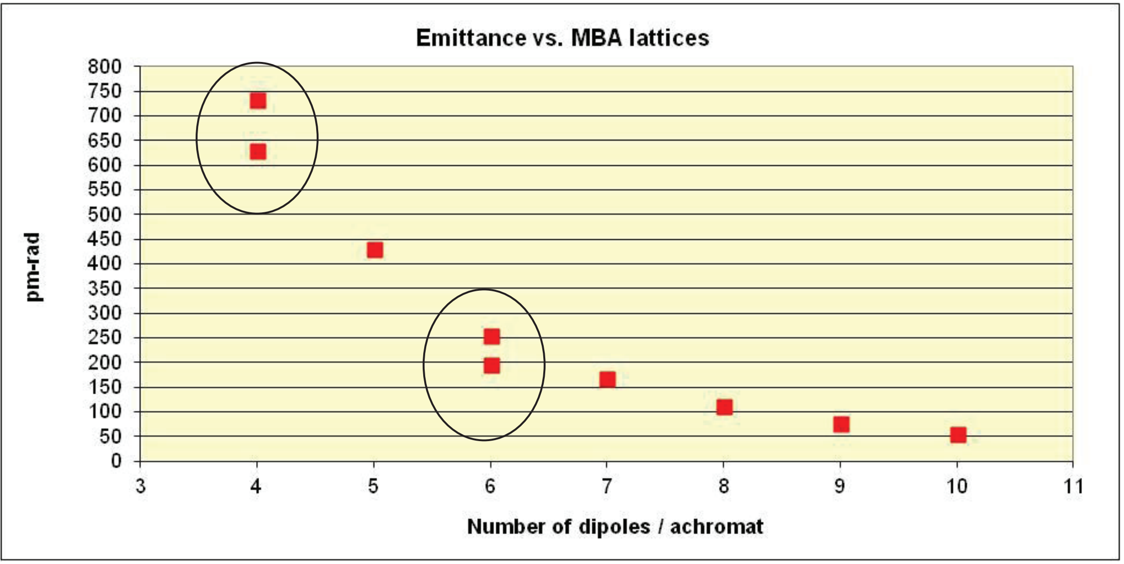

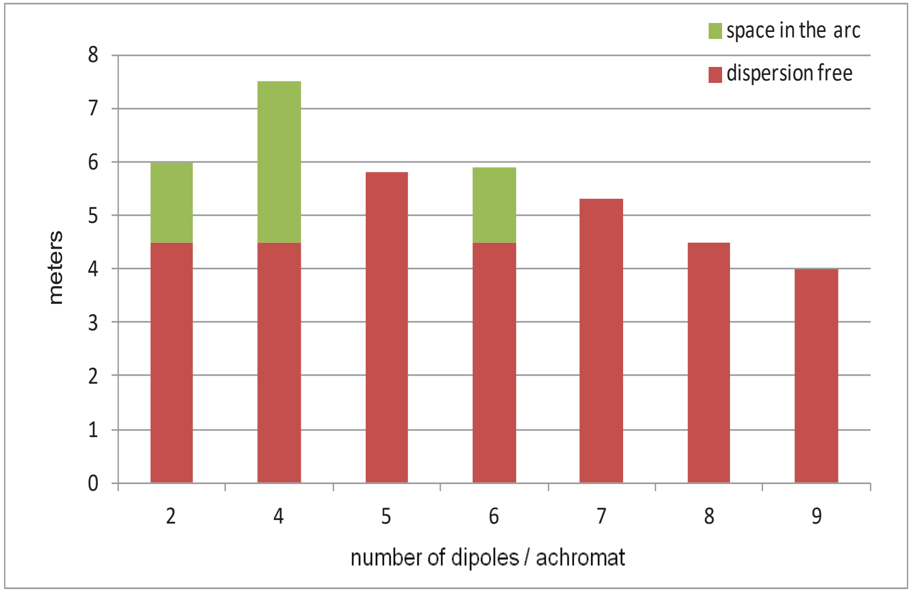

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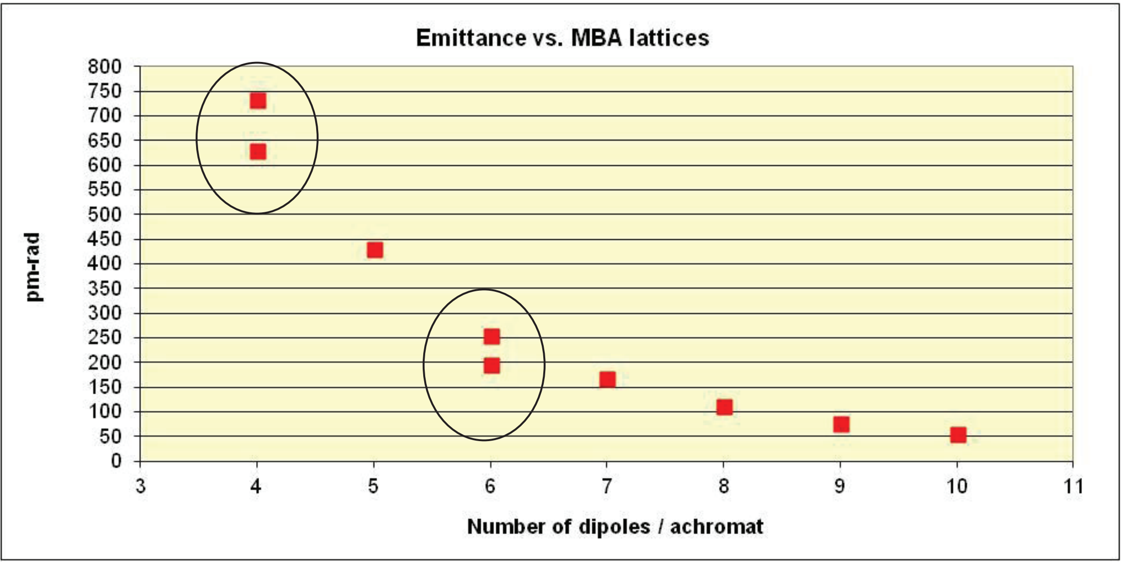

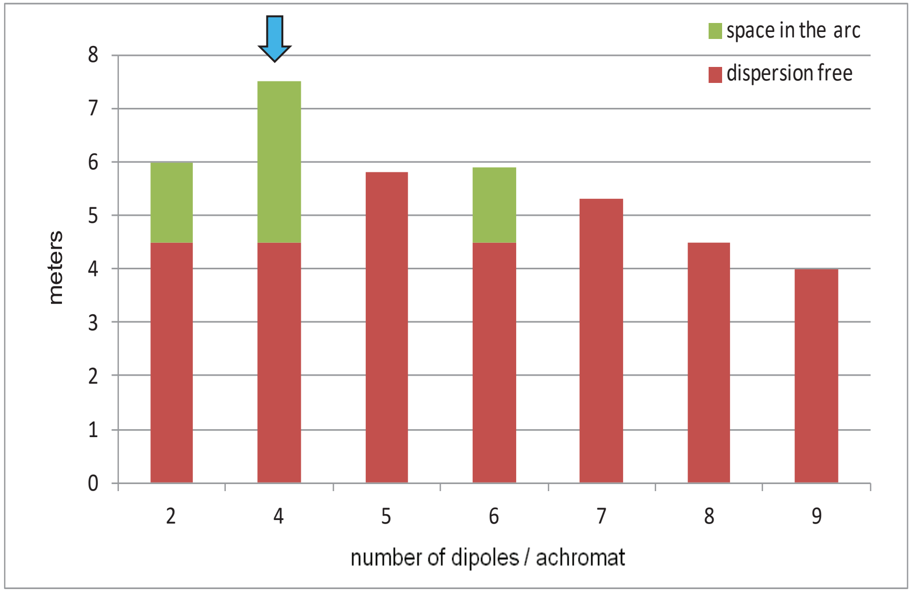

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Elettra Sincrotrone Trieste

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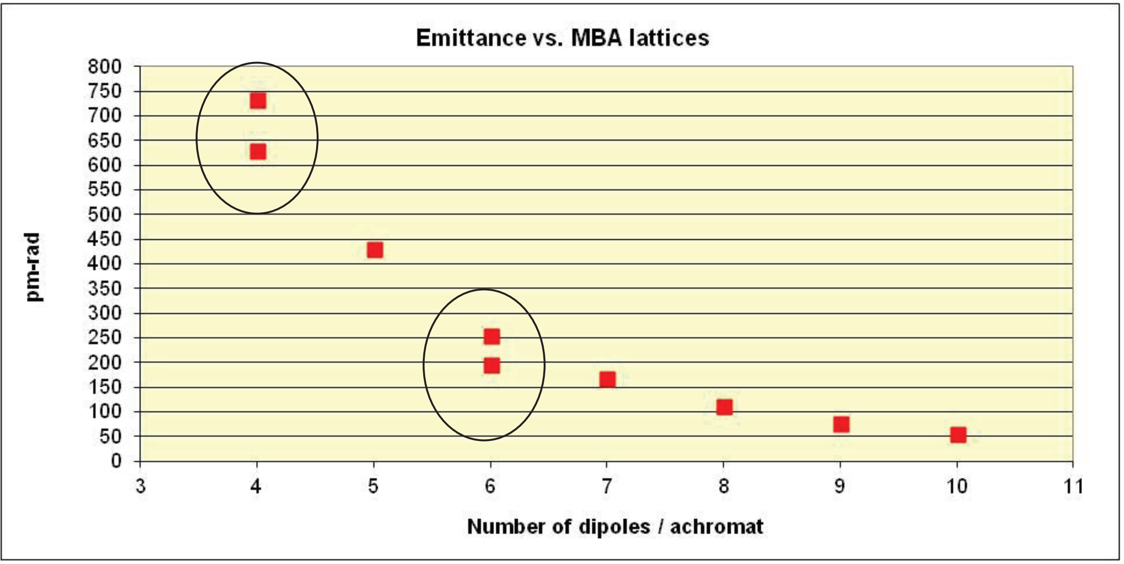

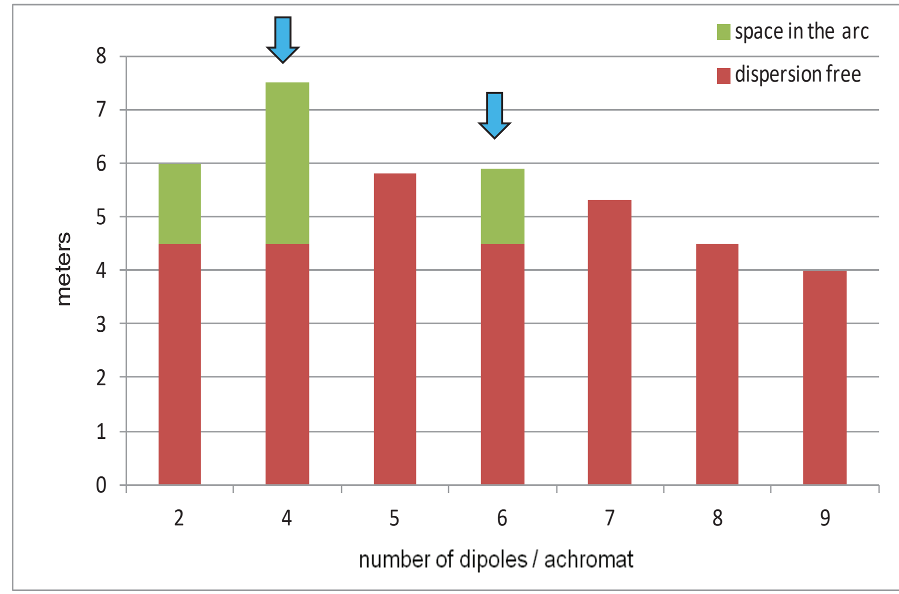

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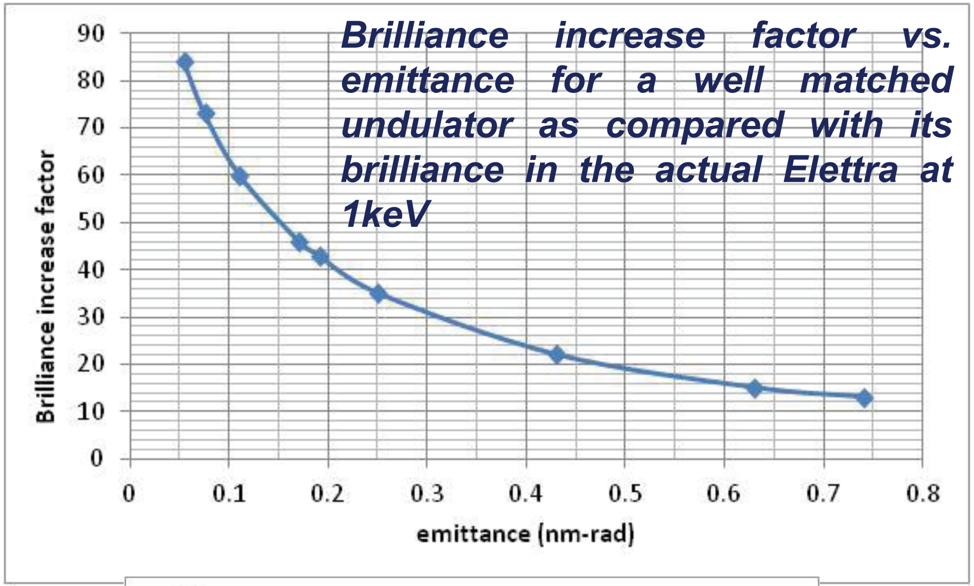
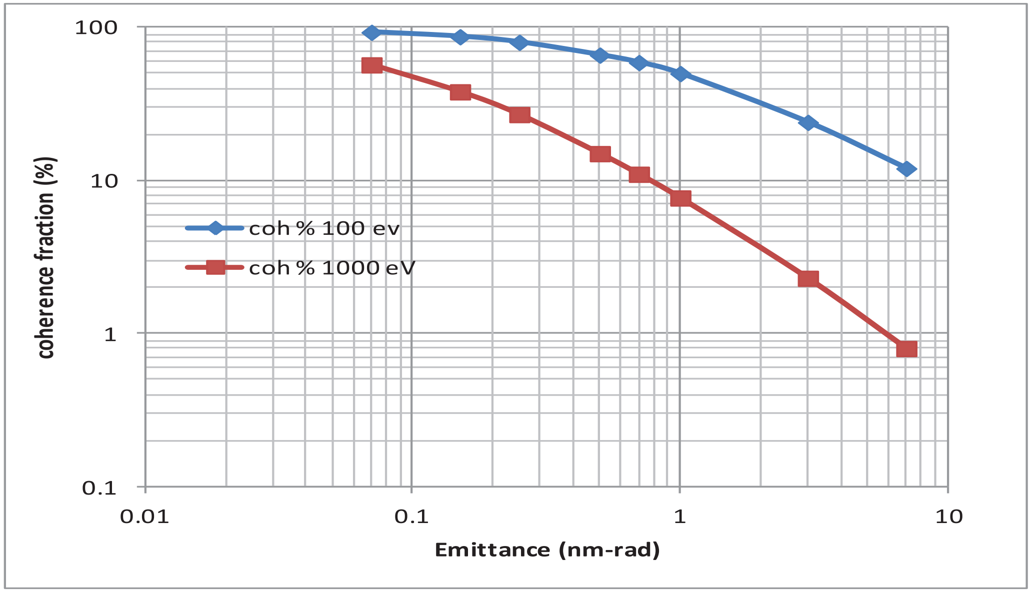
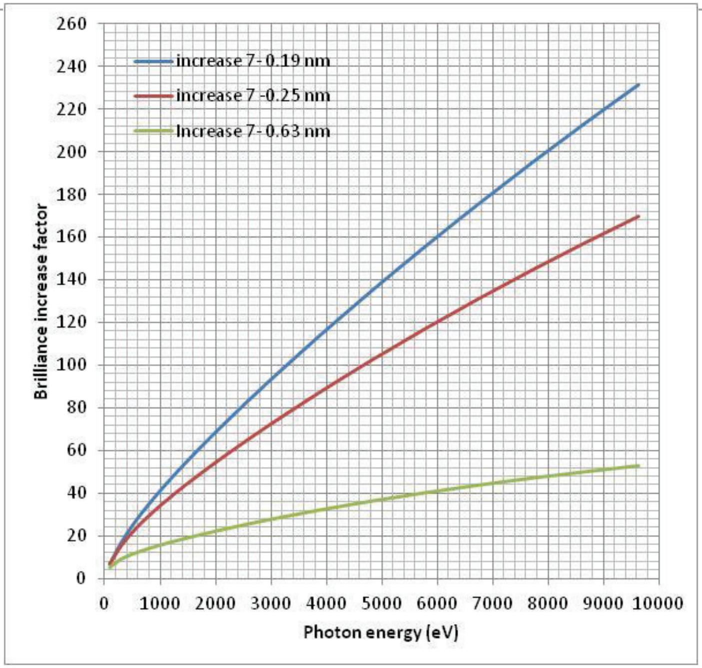
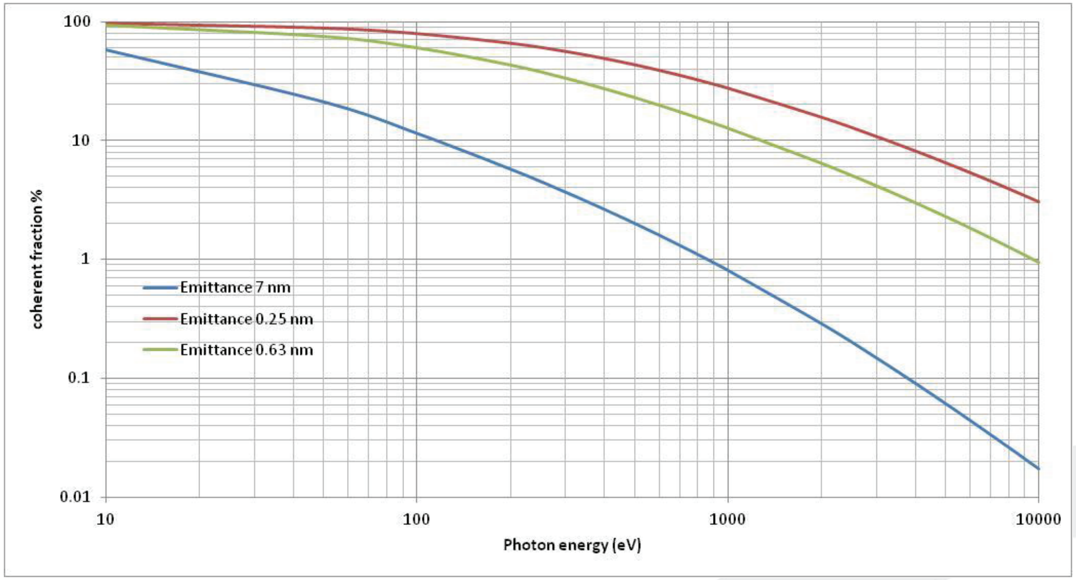
Brilliance increase factor and coherent fraction for Elettra-like SR

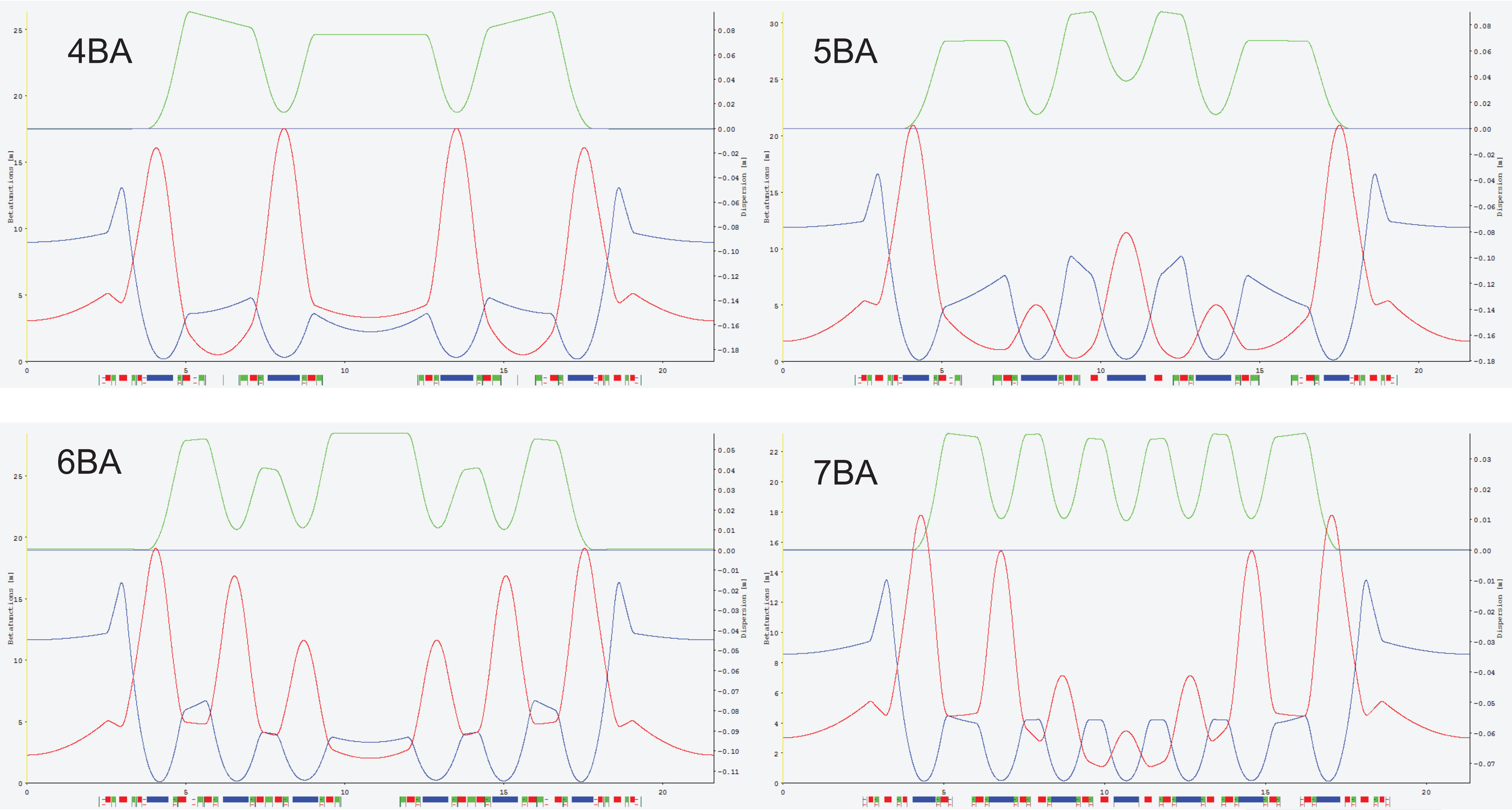








Lattices fulfilling the free space criteria



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

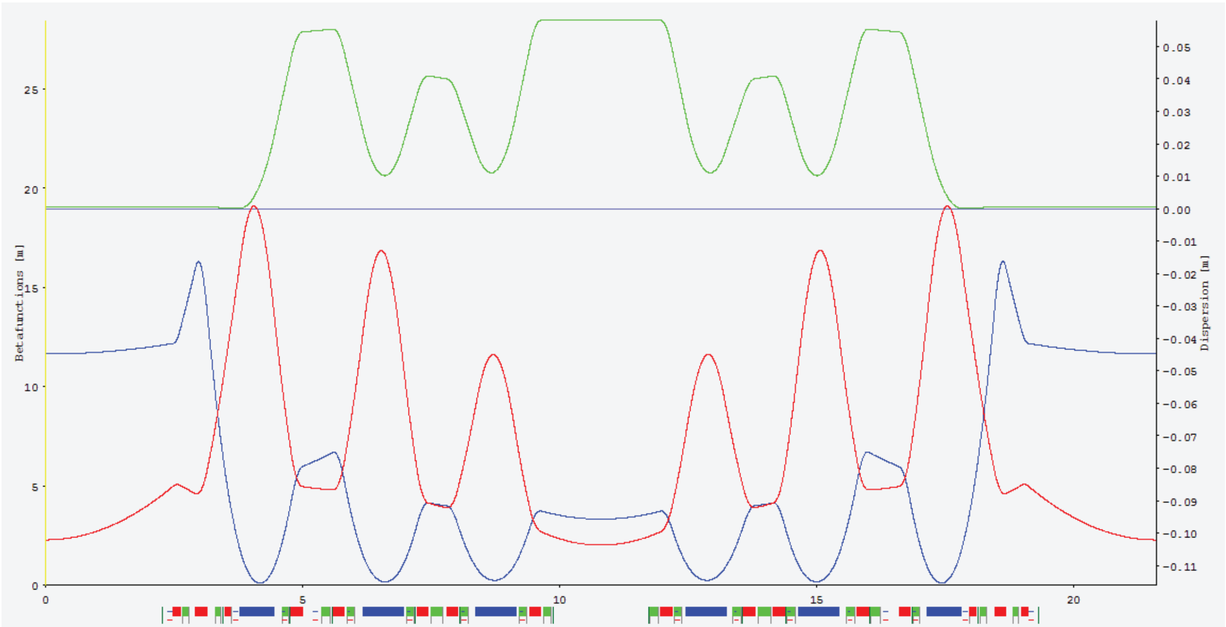
S6BA Lattice

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?

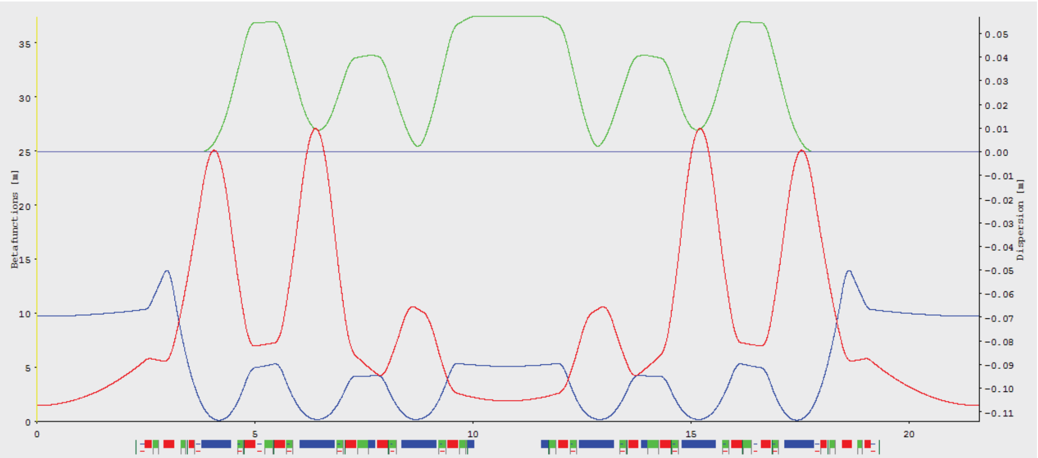
Taking care of the Dipole beam lines in S6BA

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:

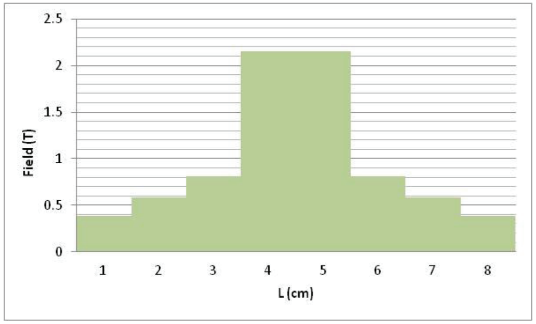
- Use LG dipoles with central field of ~2 T (for ~**3.3 deg in S6BA**) and negative angle bends (anti-bends), emittance decreases
- Use 1 m short wigglers in the arc (finite dispersion), emittance increases depending on the field. For each 2 T is 2.7% Including our superconducting wiggler of 3.5 T at 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)

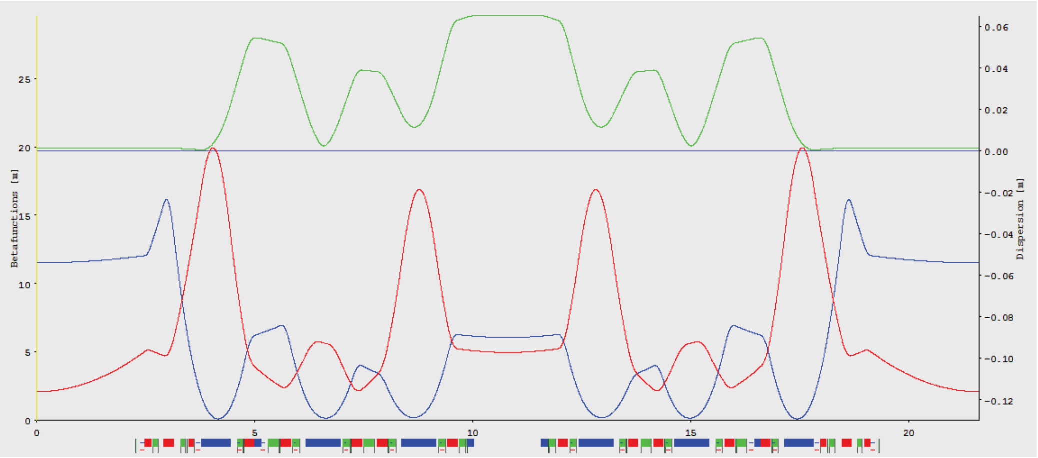
Versions of S6BA Lattices



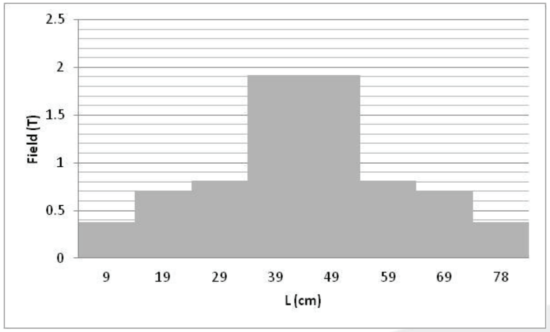
LG + anti-bend version:
Emittance 0.19 nm-rad (0.1 if round beam)

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





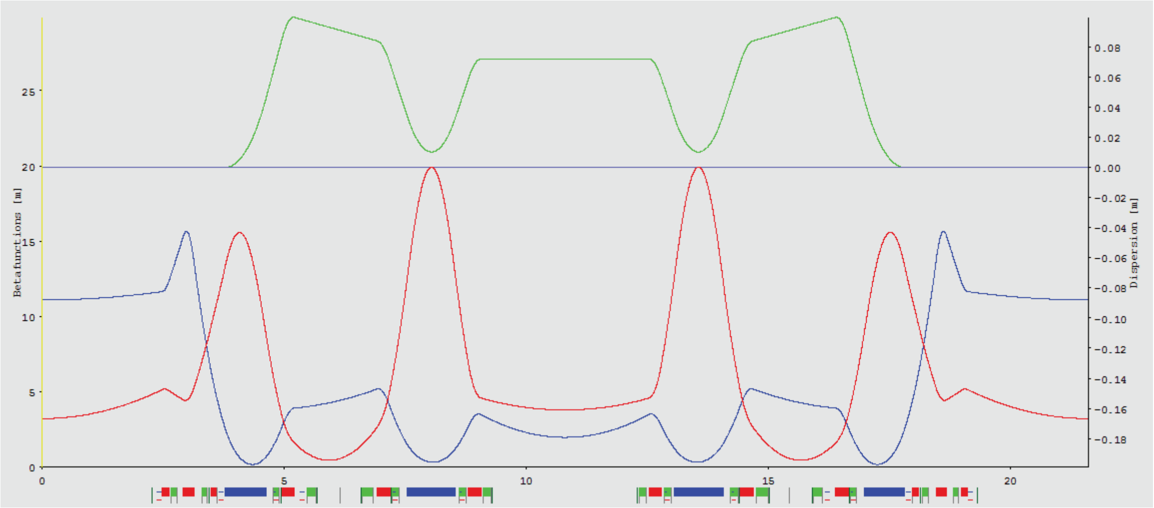
The 2 and 5 dipoles in LG with central field at ~2 T. **225 keV/turn**



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

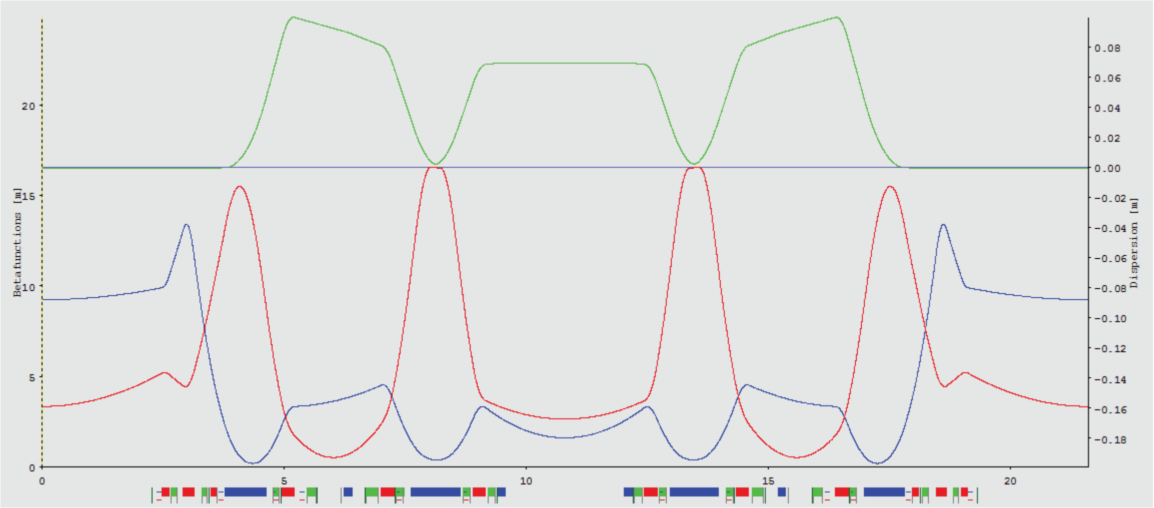
Elettra Sincrotrone Trieste

S4BA Lattices

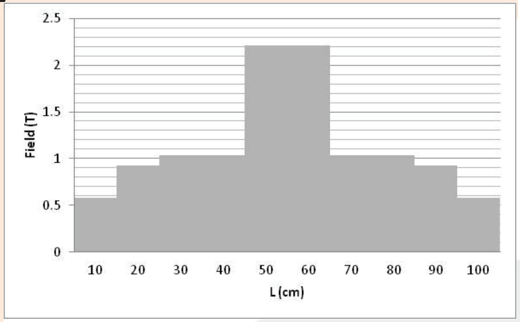


Emittance 0.73 nm-rad (0.43 if round beam) 207 keV/turn
Dipoles electromagnets at 0.8 T
No LG.

Large free space for IDs or other (4.5 + 3.4 m)



LG+anti-bend version:
Emittance 0.63 nm-rad (0.34 if round beam) 251 keV/turn
The 2 and 3 dipoles in LG with central field at 2.2 T.



Large free space for IDs or other (4.5 + 2.4 m) , lower quadrupole strengths , less magnets, larger dynamic aperture. Higher energy possible for example 2.5 GeV (but at a higher emittance).

Comparison between S6BA and S4BA

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)

Circumference (m)	~ 259.2
Energy (GeV)	2 (pos. 2.5)
Number of cells	12
Geometric emittance (nm-rad)	0.73 (0.63)
Horizontal tune	24.3
Vertical tune	15.2
Betatron function in the middle of straights (x, y) m	(9, 3)
Horizontal natural chromaticity	-46
Vertical natural chromaticity	-58
Horizontal corrected chromaticity	+1
Vertical corrected chromaticity	+1
Momentum compaction	4.43e-004
Energy loss per turn (with no IDs) (keV)	210
Energy spread	7.53e-004
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Beam revolution frequency (MHz)	1.1566
Harmonic number	432
Orbital period (ns)	864.6
Bucket length (ns)	2
Natural bunch length (mm, ps)	2.5 , 8.4
Synchrotron frequency (kHz)	6.33 (@2MV

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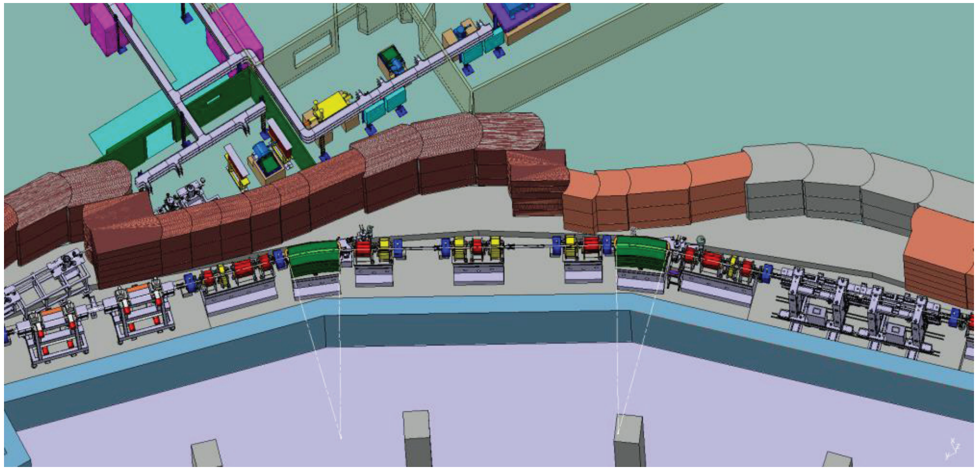
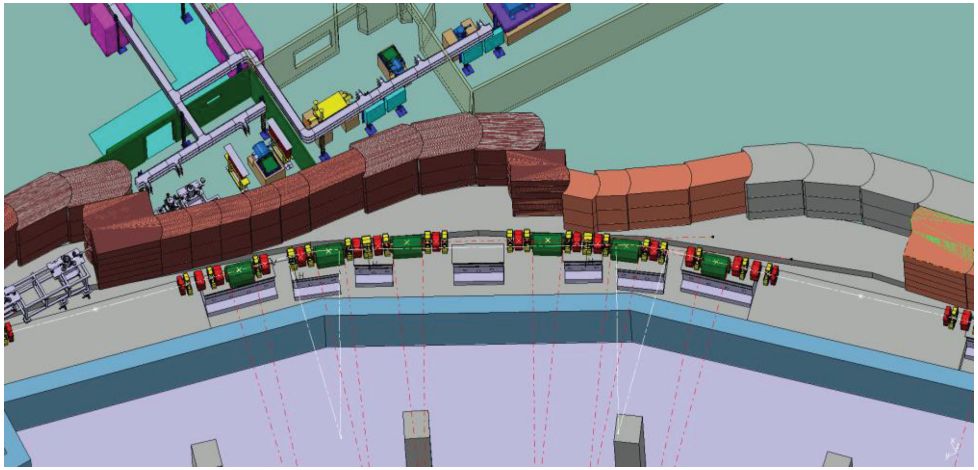
Elettra 2.0 Lattice in the tunnel

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.

Magnets

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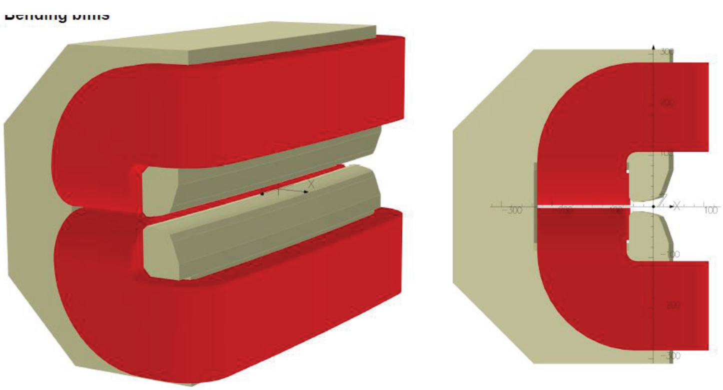
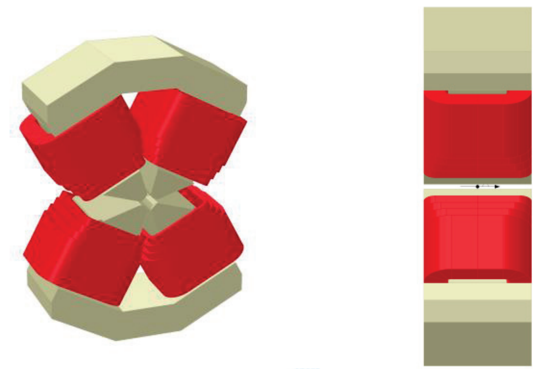
The short intra-magnet available space led us to design magnets with Lm≈Lp (max 10 mm difference). Use of new materials such as Cobalt – Iron alloys will also be considered. A quadrupole prototype is under construction at CERN

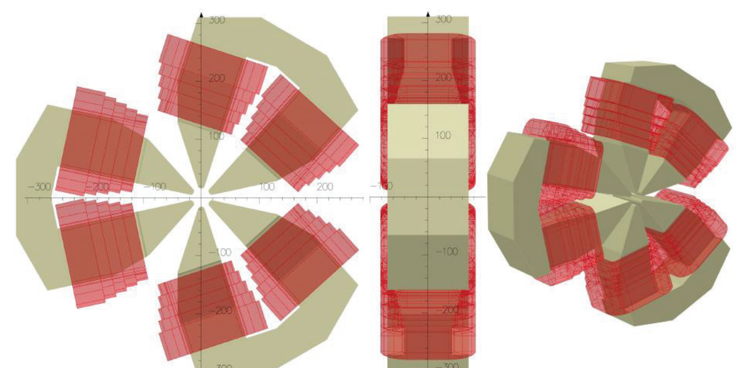




The bending integrated quadrupole component is done by only the pole profile geometry. In order to optimize space and performances, different coil and frame geometries are evaluated. Space between the pole terminations will be employed in order to obtain the requested frame stiff.

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)

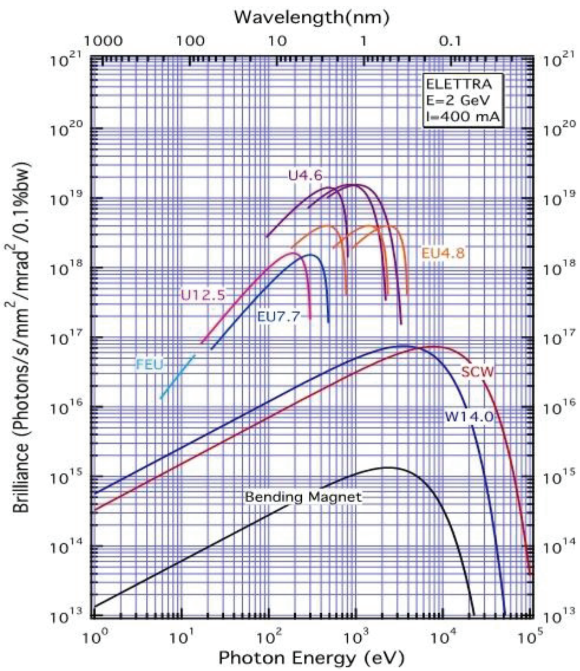
Other facts for S6BA

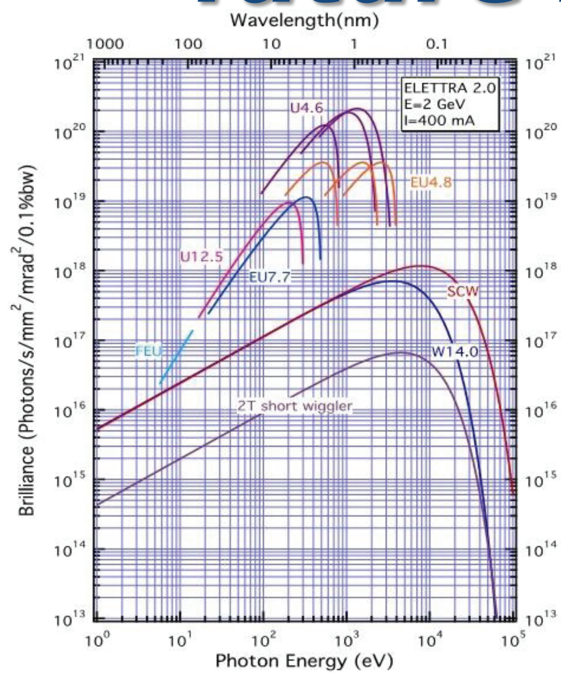
- ✓ Use of some permanent magnet dipoles is also considered
- ✓ Including errors and the existing IDs the dynamic aperture is ±7 mm horizontally and ± 2.5 mm vertically. This aperture permits off axis injection with an efficiency of more than 95%
- ✓ Lifetime is 6 hours at 2 GeV and with the third harmonic 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.

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

Brilliance with existing and future IDs (S6BA)



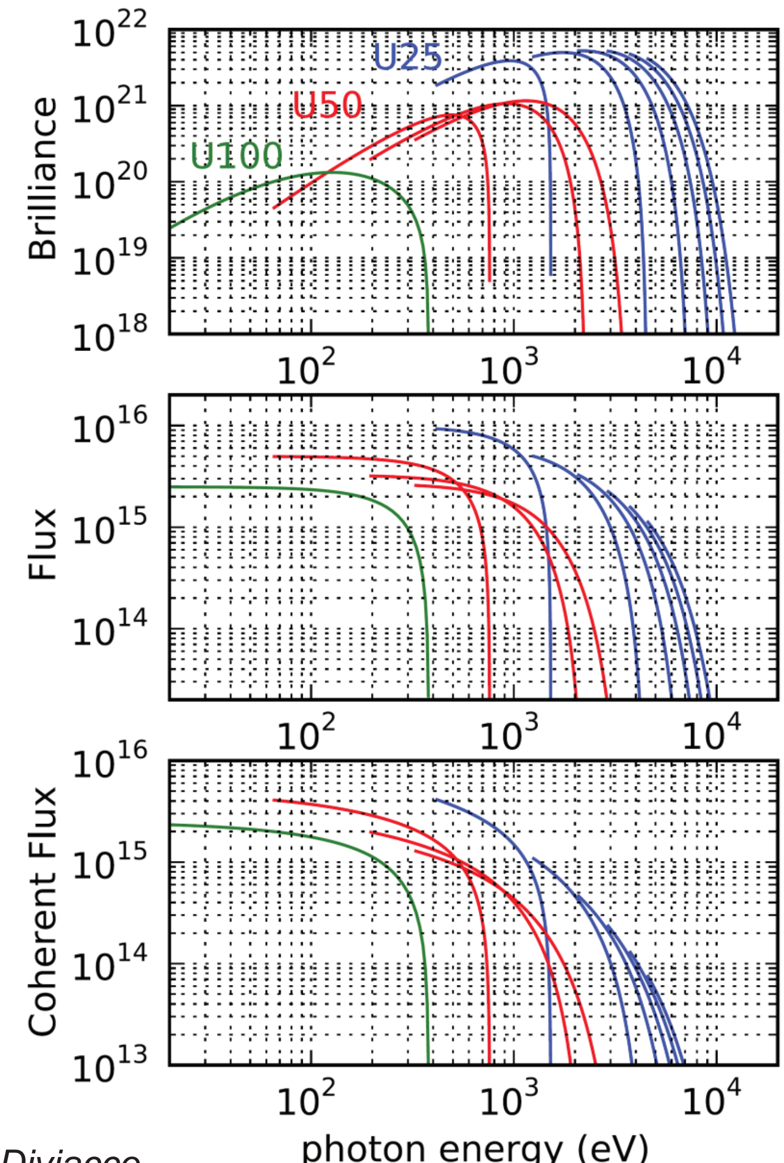


Performance in case of three well matched hypothetical insertion devices (brilliance, flux and coherent flux):

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

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.

Elettra
Sincrotrone
Trieste

THANK YOU

www.elettra.eu