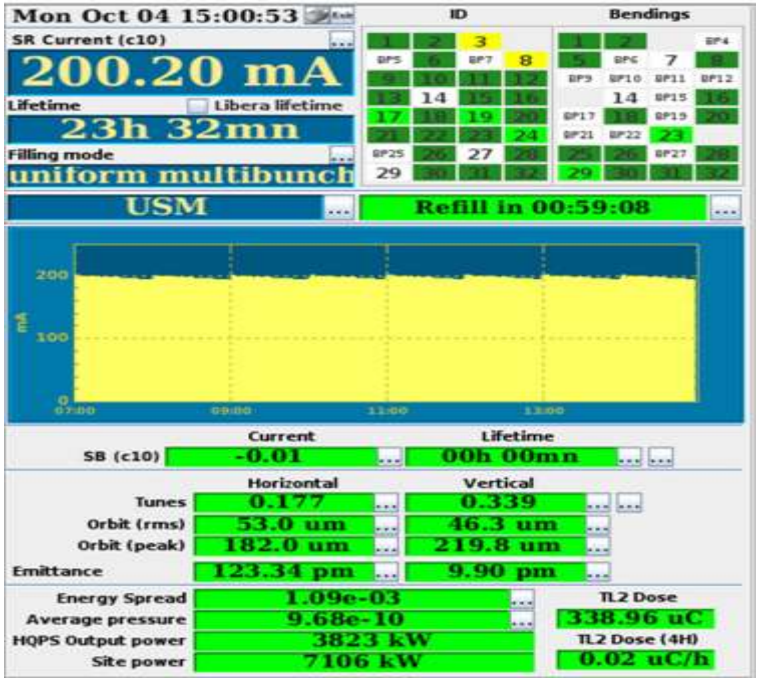
Thursday 09 February

10h15 10:45	Welcome coffee
10h50-11h20:	ESRF introduction (Yannick Lacaze)
11h20-12h00:	The ESRF facility…from yesterday to EBS (JLR)
12h00-12h30:	ESRF operation as of today (JLR)
12h30-13h30:	Lunch at the canteen
13h45-14h30:	Visit of the control room (JLR, Andrea Franchi)
14h30-14h50:	Visit of a beamline (ID32, Kurt Kummer 2029)
14h50-15h15:	Visit of the ID Laboratory (Gael LeBec)
15h15-15h45:	Visit of the RF (Vincent Serriere)
15h45-16h00:	Wrap up
16h00:	Departure

2 groups (13h45–15h45)



ESRF | The European Synchrotron

1) Introduction

2) The ESRF from yesterday to EBS

3) The ESRF-EBS Upgrade

4) ESRF operation today

Thursday 9 February 2023
JUAS 2023 Revol Jean-Luc

THE ESRF IN GRENOBLE – GIANT INNOVATION CAMPUS

GIANT

INNOVATION CAMPUS

WELCOME TO THE EPN SCIENCE CAMPUS

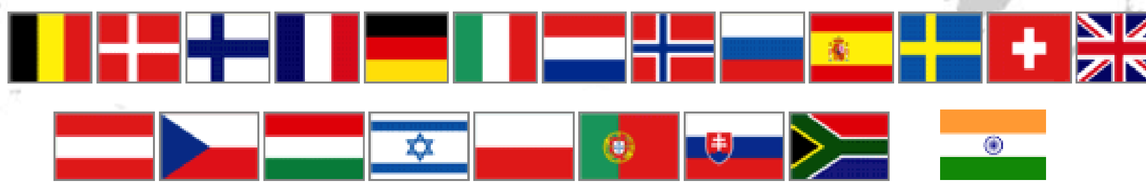
A MODEL OF INTERNATIONAL COOPERATION: 22 PARTNER NATIONS

13 Member states:

France	27.5 %
Germany	24 %
Italy	13.2 %
United Kingdom	10.5 %
Russia	6 %
Benesync (Belgium, The Netherlands)	5.8 %
Nordsync (Denmark, Finland, Norway, Sweden)	5 %
Spain	4 %
Switzerland	4 %

9 Associate countries:

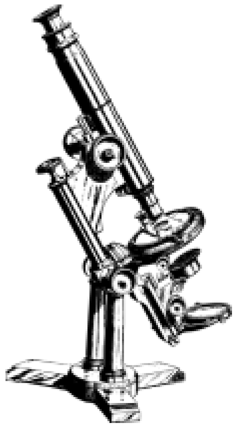
Israel	1.5 %
Austria	1.3 %
Centralsync (Czech Republic, Hungary, Slovakia)	1.05 %
Poland	1 %
Portugal	1 %
India	0.66 %
South Africa	0.3 %

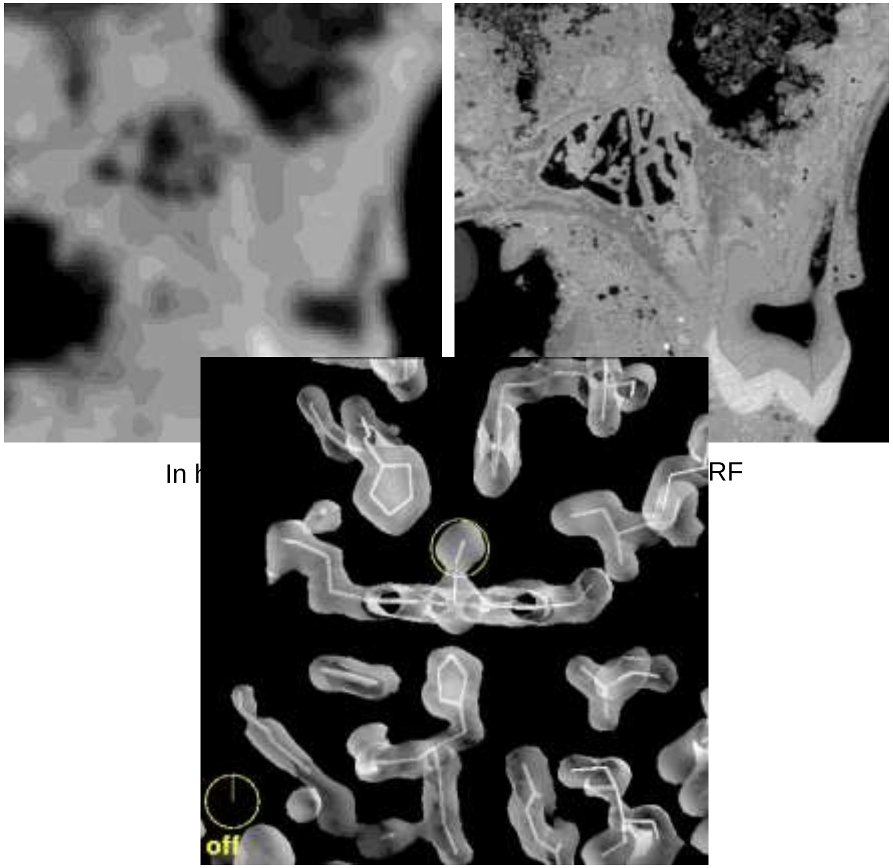


22 partner nations
Annual budget: **100 million euros**
Staff: **650 people, 40 different nationalities**
Legal status: **Private civil company subject to French law**

Super microscope producing X-rays

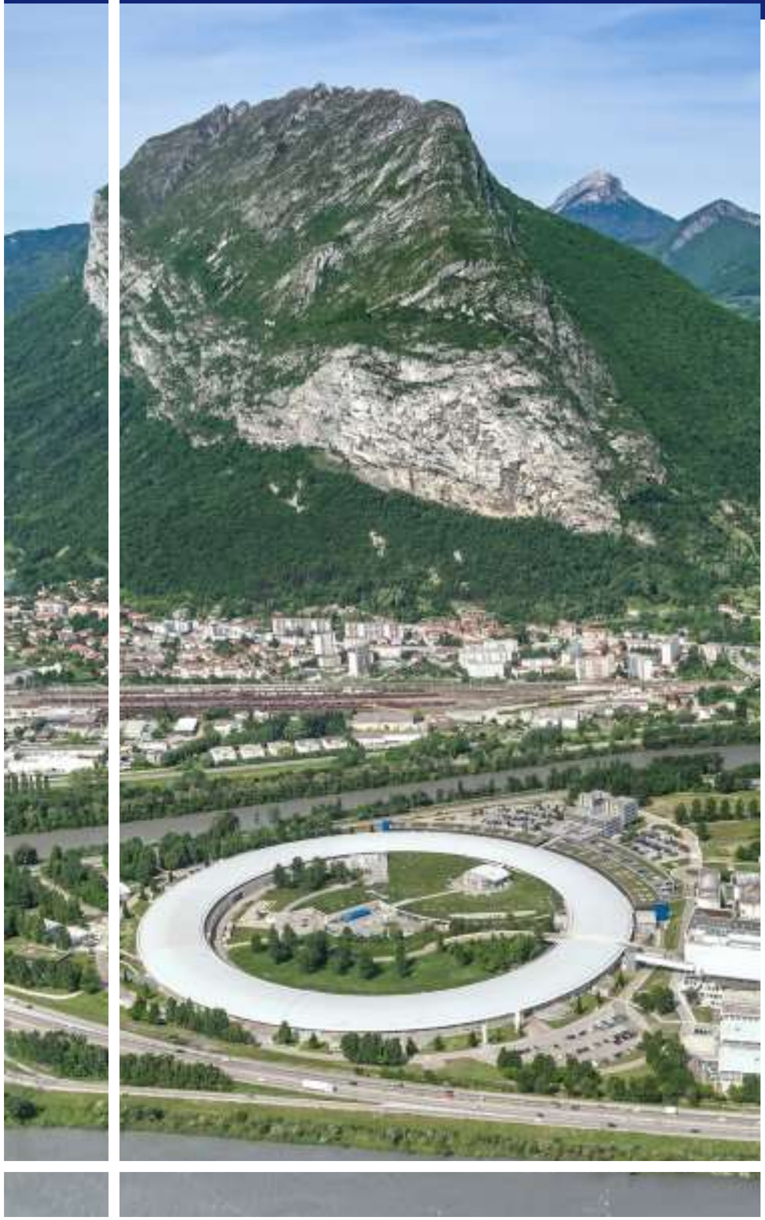
10 trillion times brighter than in hospitals





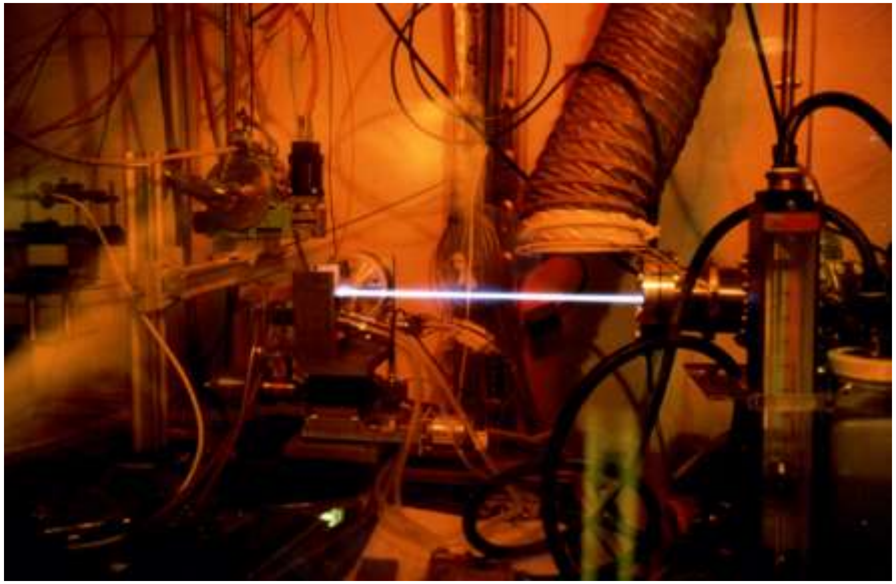
In h… RF

Schotte et al., 2003, Science 300



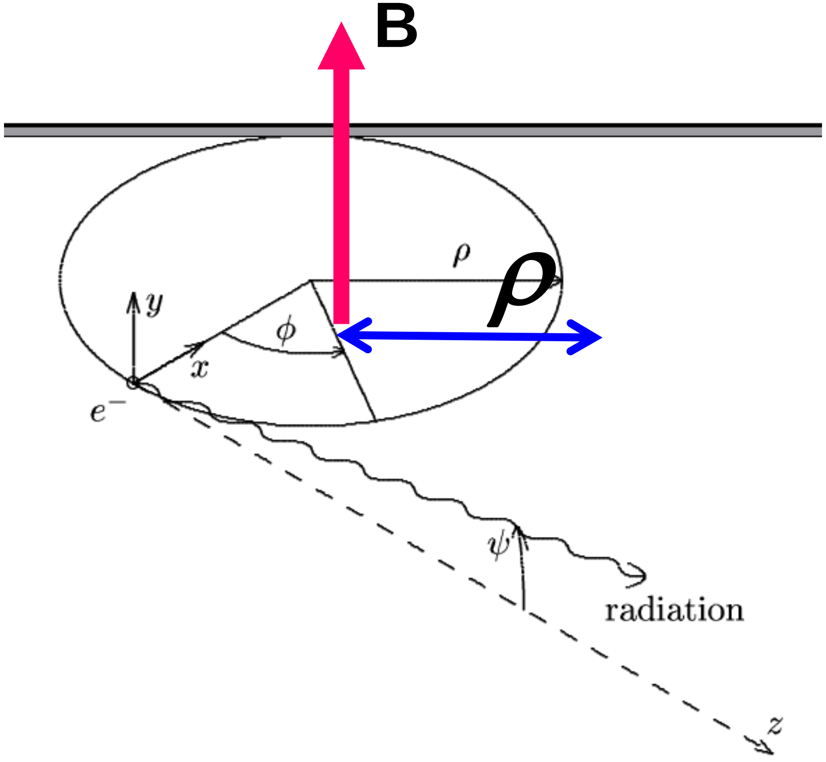
ESRF
The European Synchrotron

Principle and science



PRINCIPLE

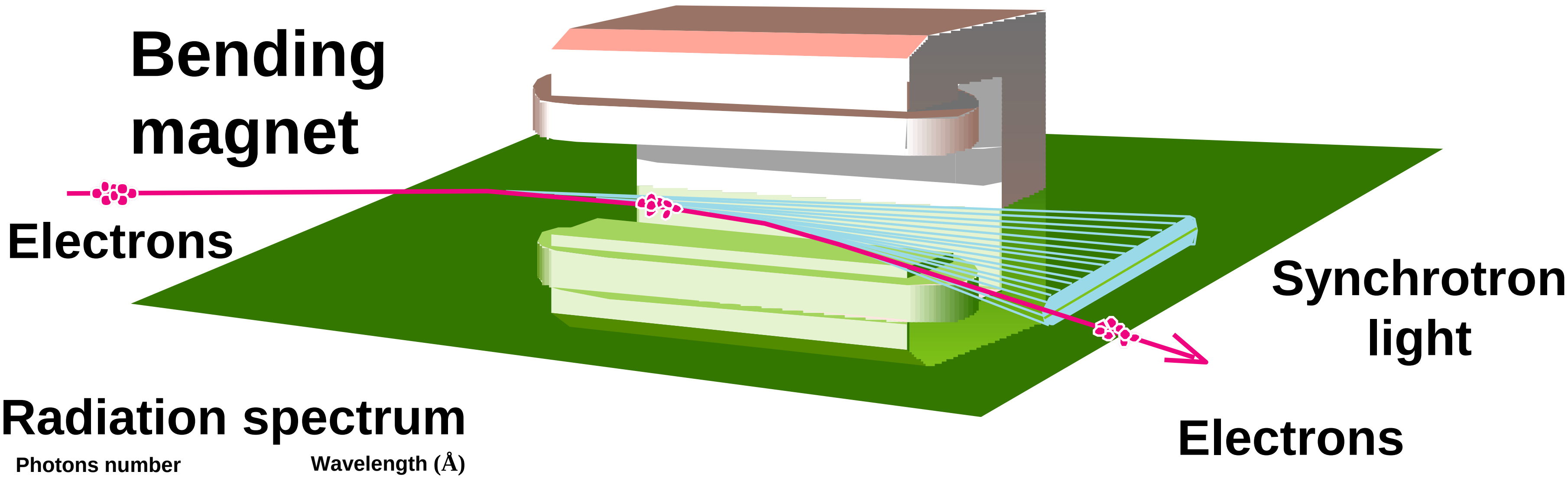
- When a charged particle is deviated in a magnetic field,
  it loose energy by emitting electromagnetic radiation (photons),call synchrotron radiation, tangent to the trajectory.



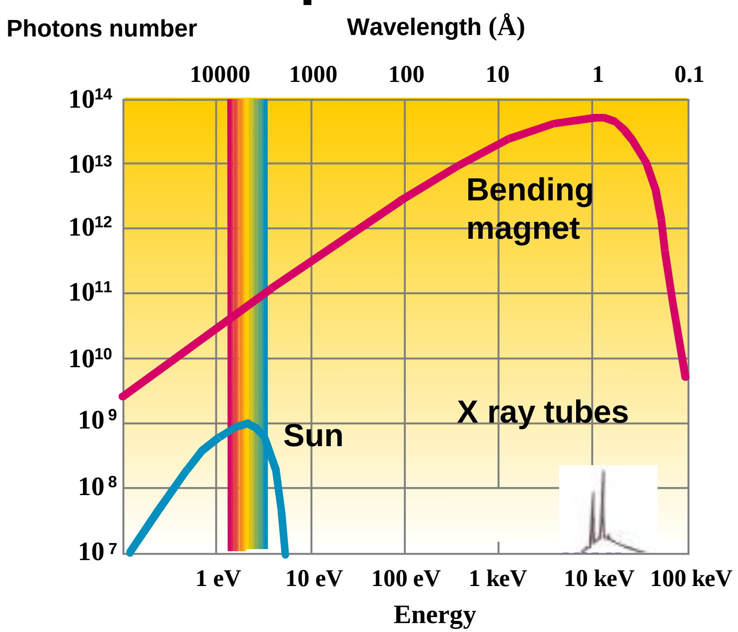
$$P \propto \left(\frac{E}{mc^2}\right)^4 \frac{I}{\rho}$$

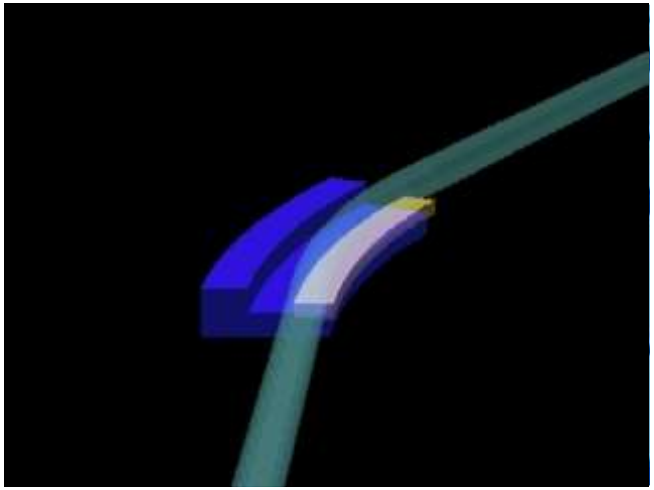
Large difference between electrons and protons !

Scale with the square of the energy!



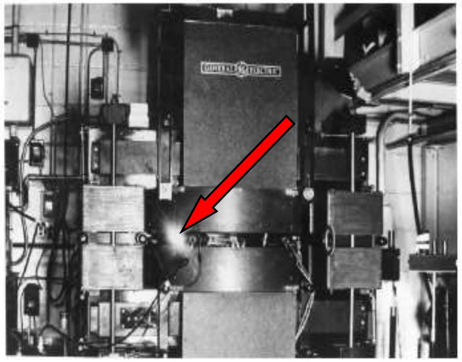
Radiation spectrum





FROM PARASITIC USE TO DEDICATED USER FACILITY

1947: First observation of synchrotron radiation

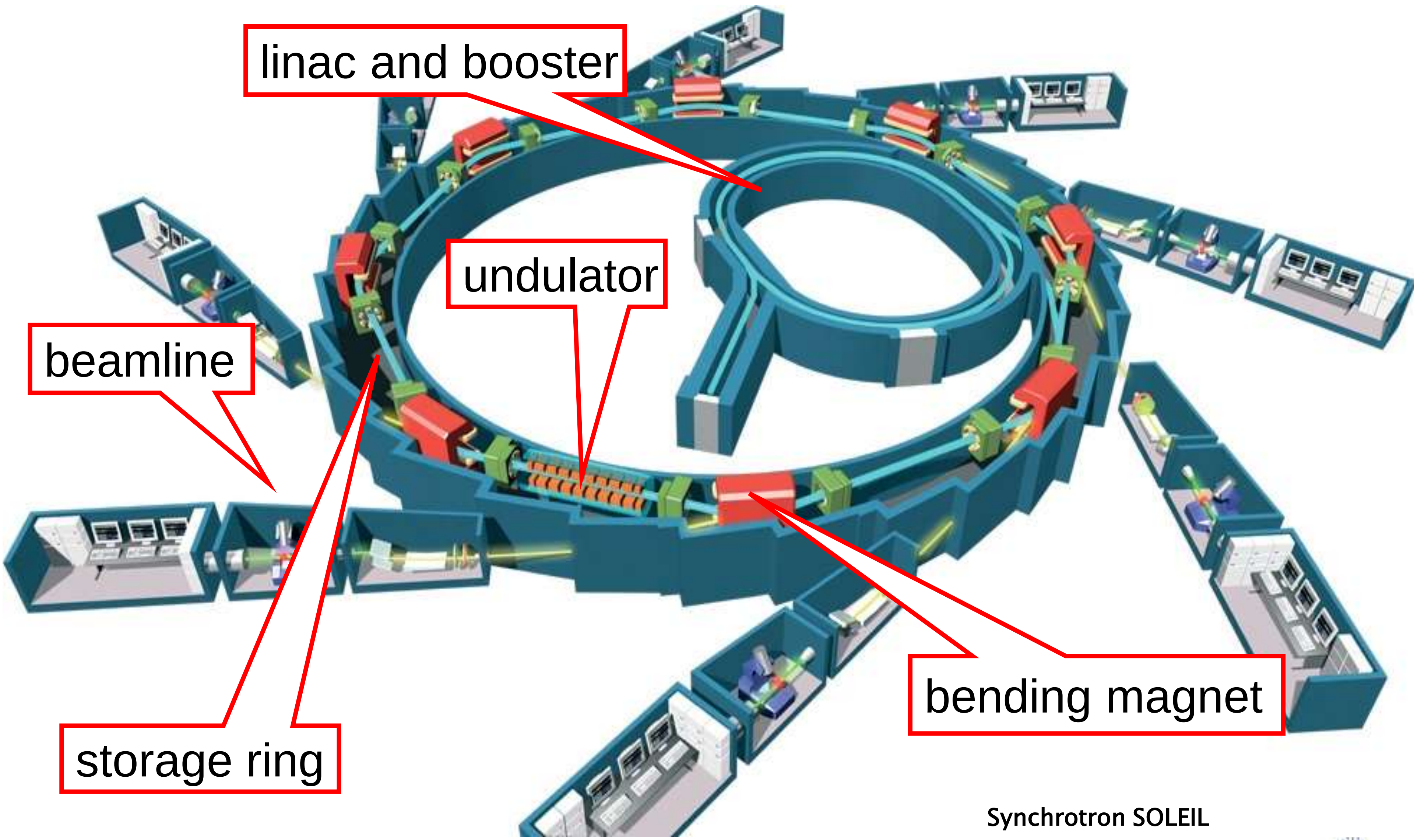


« Nina », first beamline at Daresburry in1966 (synchrotron 6 GeV électron). 1st generation

1981: SRS (UK) 1st dedicated X ray light source
2nd generation

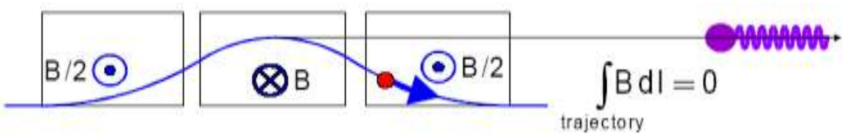
1994: Inauguration of the l'ESRF, The first X ray light source of the 3rd generation

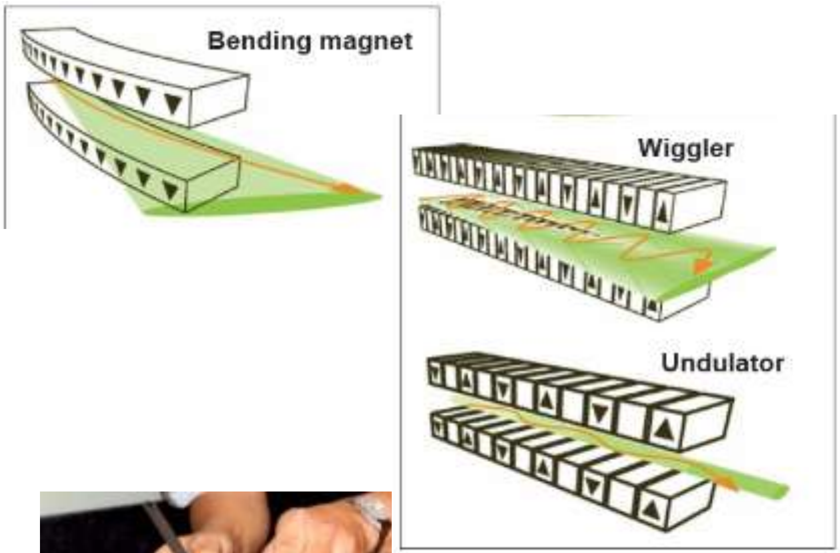
A TYPICAL USER FACILITY

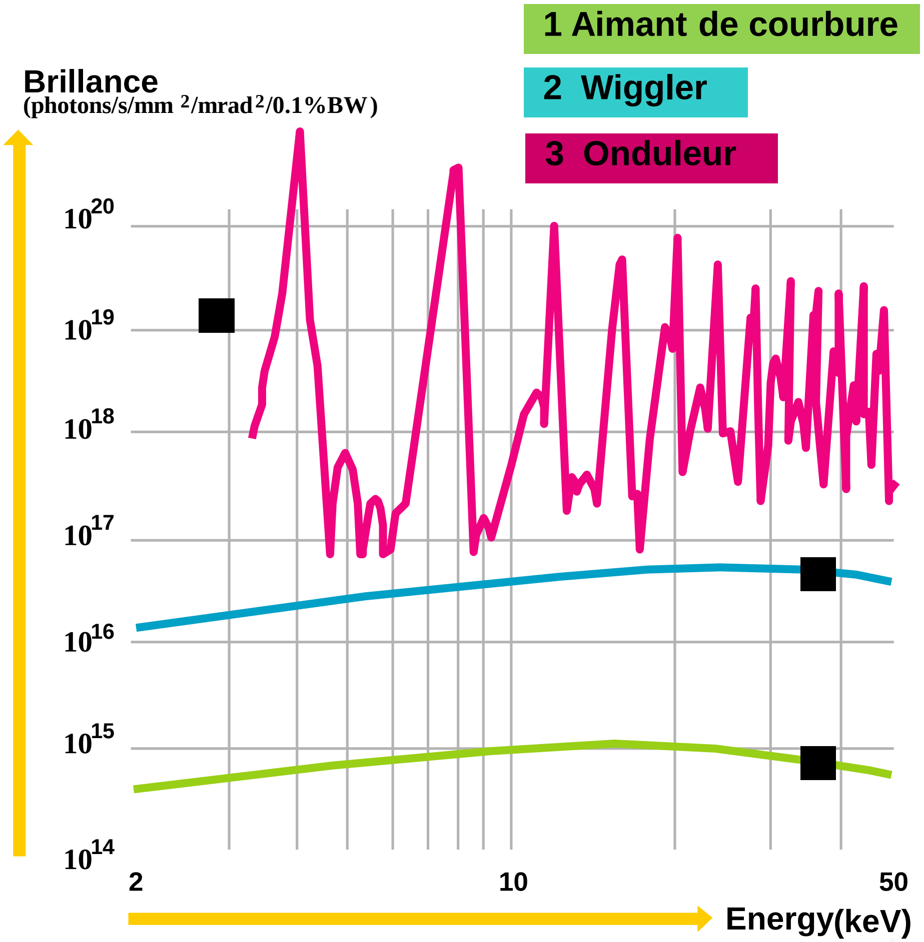


Synchrotron SOLEIL

Insert permanent magnets to provide an alternative magnetic field to bend the trajectory.







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BRILLIANCE OF LIGHT SOURCES

Progress of X ray light sources are summarized in the evolution of the brilliance

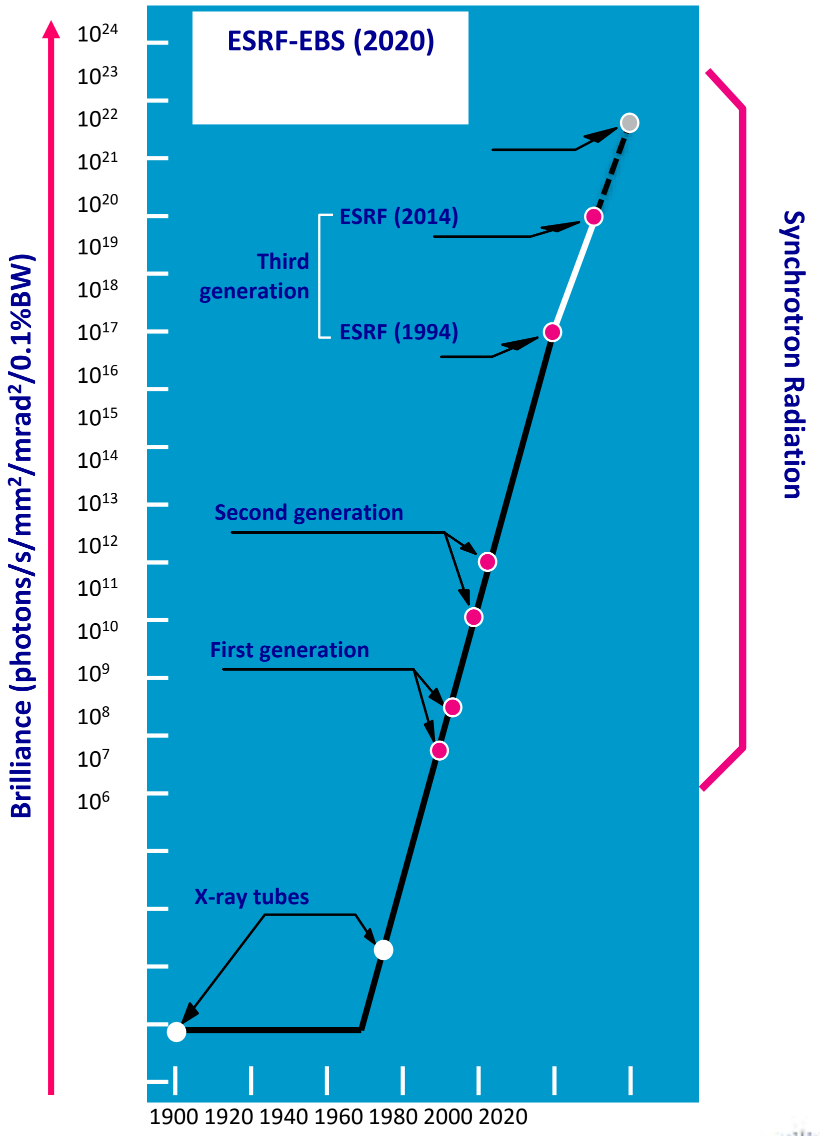
Brilliance =
photons /s / mm² /mrad² /0.1% bandepassante

Number of photons per second

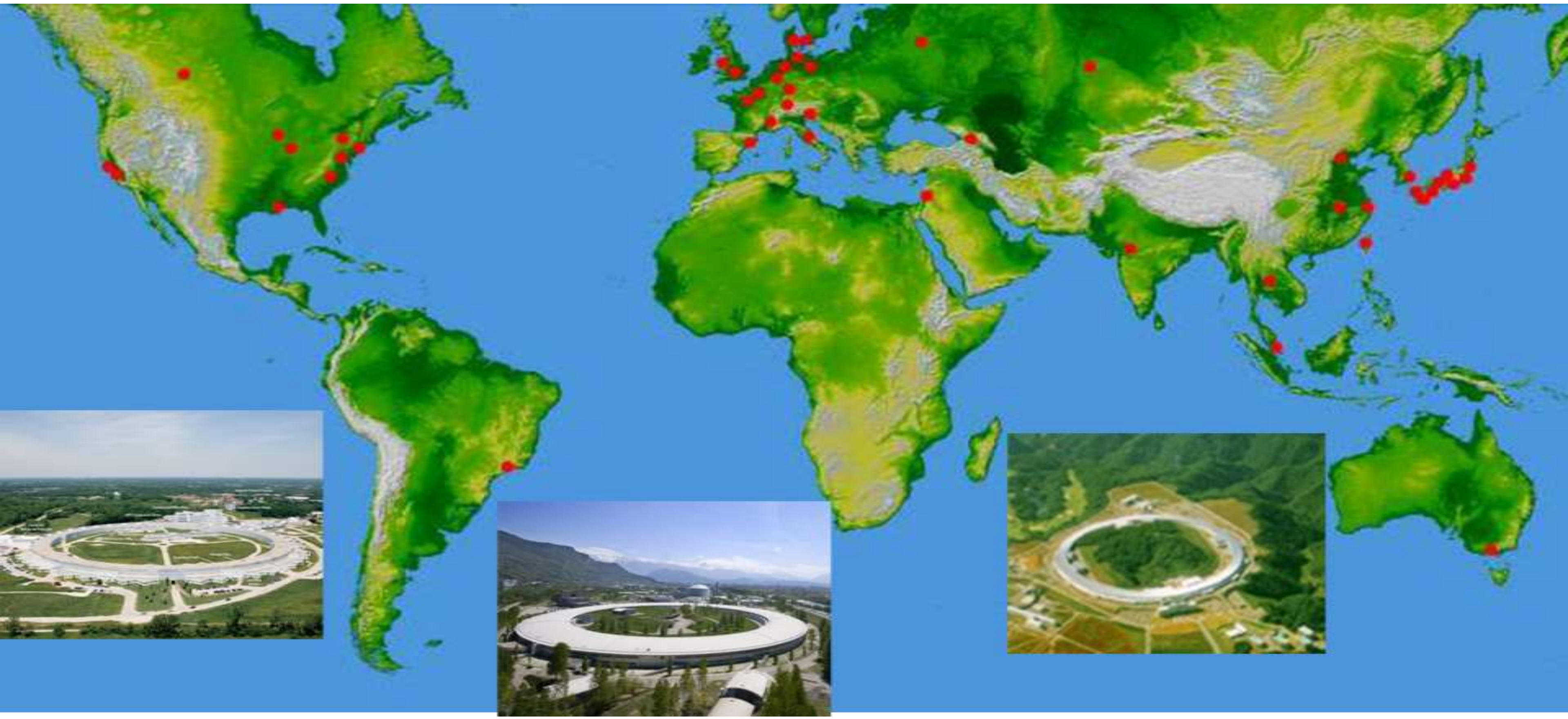
Size horizontale*vertical

Divergence horizontal *vertical

In a bandwith of 0.1 % around the considered energy.



MORE THAN 50 SYNCHROTRON LIGHT SOURCES AROUND THE WORLD



DIFFERENT TYPE OF SOURCES

Many Medium energy rings :2.7-3.5 GeV

SOLEIL, DIAMOND, CLS, ALBA, SSRF, TPS ,Australian Synchrotron, NSLS II, MAXIV …






High energy rings (≥ 6.GeV)

SPRING 8

ESRF Upgrade

APS Upgrade

Petra III

X FELs

- LCLS (Stanford)
- SACLA (SPRING8)
- Flash, European XFEL (Hamburg)
- Fermi@ elettra
- …..

LCLS

SACLA

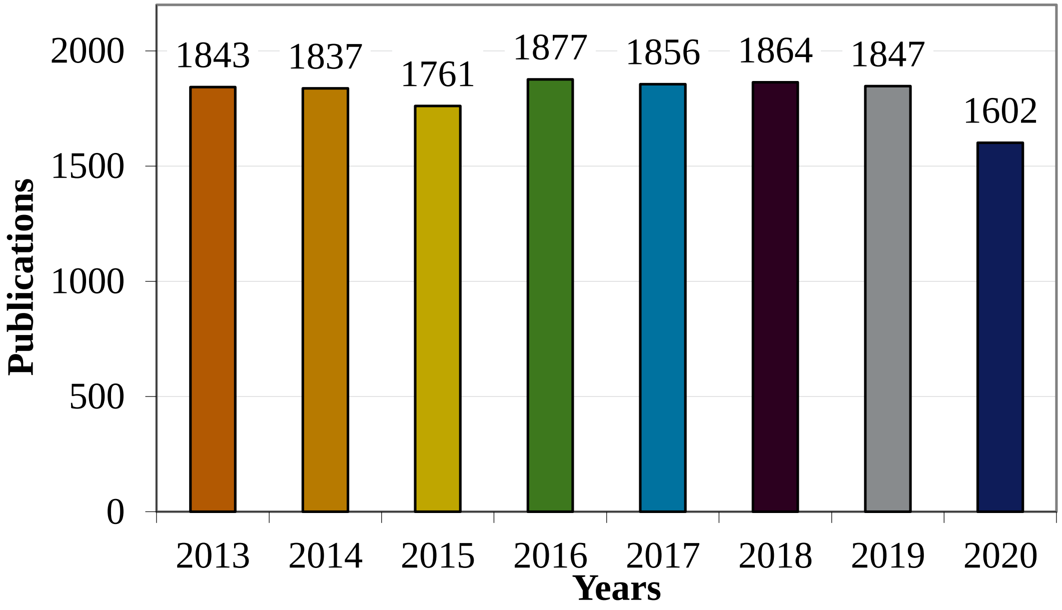
European XFEL

Fermi

Laser plasma acceleration: 5th generation light source

How does it work?

- Committees to select the best proposals
- 9000 scientific visits each year
- Public research and industrial research



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How does it work?

- Committees to select the best proposals
- 9000 scientific visits each year
- Public research and industrial research

How much does it cost?

	Partner countries	Other countries
Public research	Free + All travel expenses are covered	Free
Proprietary research	450€/hour	540€/hour

SCIENCE AT THE ESRF

Fields

Health, Biology

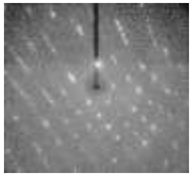
Earth Sciences, Paleontology

Cultural heritage

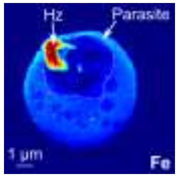
Chemistry, Energy, Materials

Nanosciences, Information technologies

Techniques



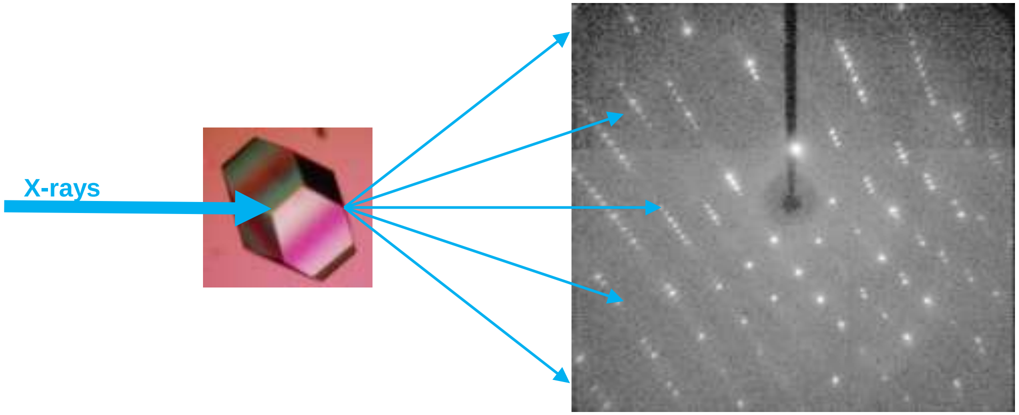
Diffusion Diffraction

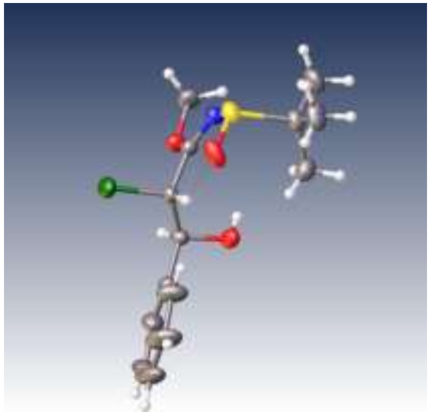


Spectroscopy

Imaging

DIFFUSION – Protein crystallography



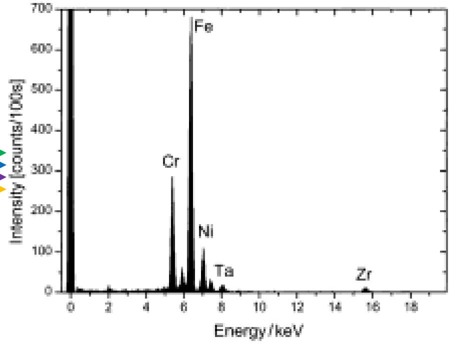


Protein crystal

Diffraction pattern

Atomic model

SPECTROSCOPY – X-Ray Fluorescence spectrometry (XRF)



Sample

Emission spectrum

Chemical map

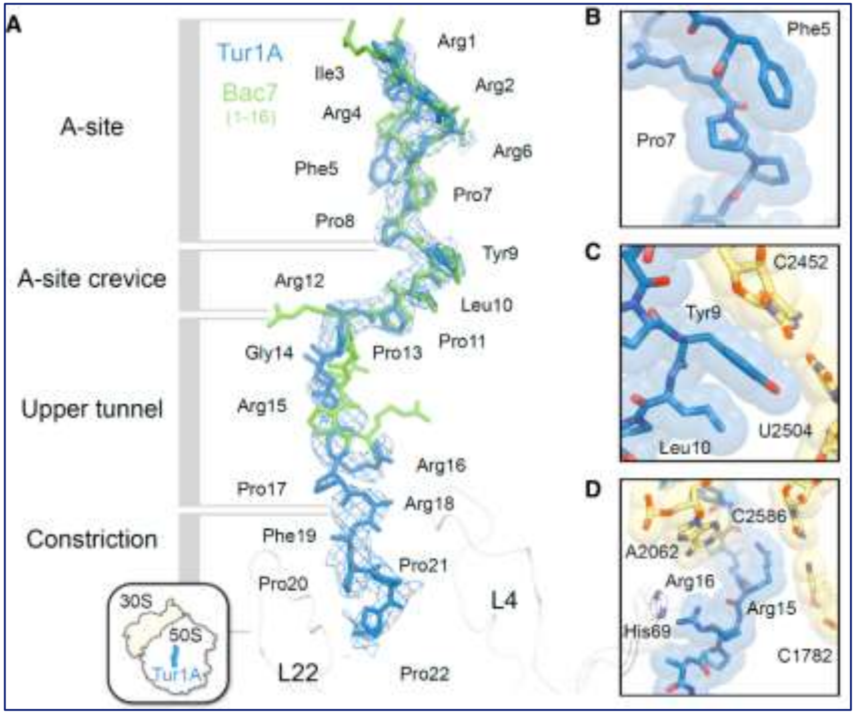
IMAGING – Phase contrast microtomography

Sample Microtomography 3D model

HEALTH - BIOLOGY

Dolphins antibacterial peptides: a way to new antibiotics?

ID23-2 – 2018



Mardirossian et al., Cell Chemical Biology, 8th March 2018.

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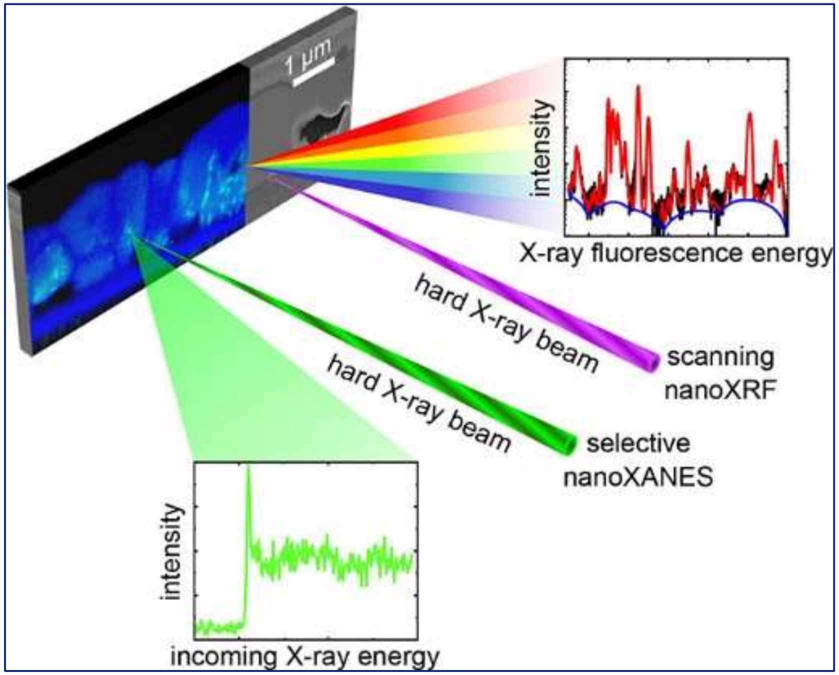
ENERGY

Using CZTSe Kesterite to improve solar cells efficiency

ID16B - 2020



Ritzer et al, ACS Applied Energy Materials, 2020, 3, 1.

PALEONTOLOGY

***Massospondylus carinatus'* eggs**

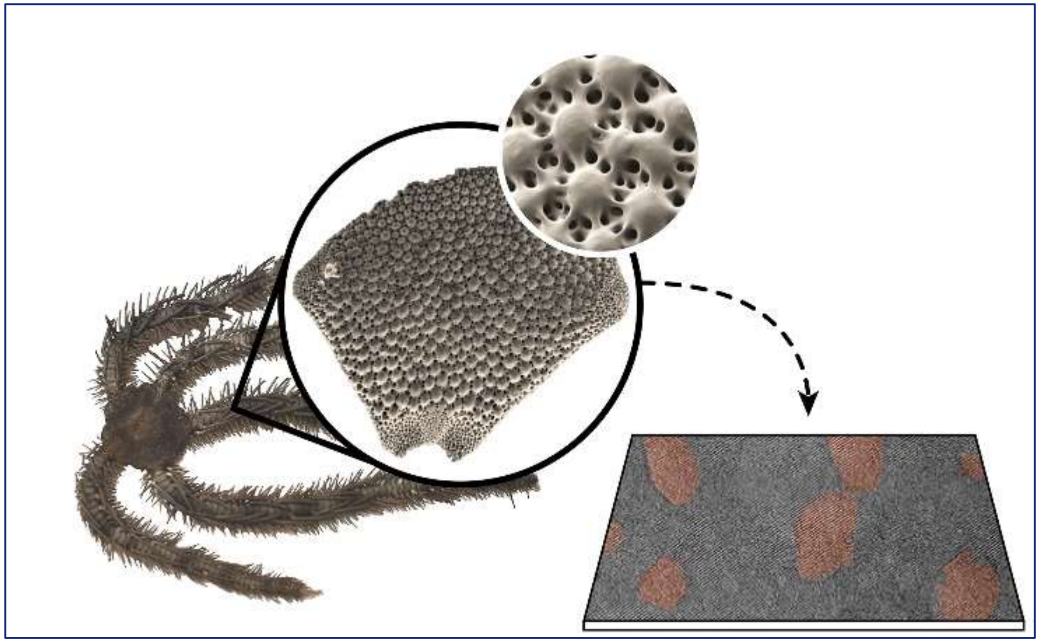
ID19 - 2020

Chapelle et al, Scientific Reports, 2020, 10, 4224.

NANOCIENCES

Ophiocoma wendtii helps ceramic materials engineering

ID13, ID16B, ID22 - 2017



Polishchuk et al, Science, 2017, 358.

CULTURAL HERITAGE

Virtual exploration of a 17th Century metal box

BM05 – 2015

THE ACCELERATOR COMPLEX

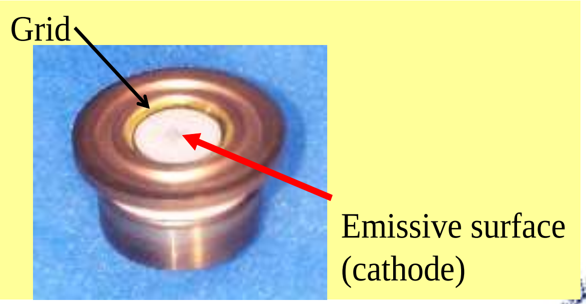
How it works in real?

THE LINEAR ACCELERATOR

The Linac consists in one **TRIODE** (cathod – anod – grid) powered with 100 KV. Electrons produced have then an energy of 100 keV.

The electrons are then accelerated in 2 sections (each section = 6 meters), accelerating the beam by 100 MeV, i.e., a total of 200 MeV.

Operation mode	Long pulses	Short pulses
Peak current	25 mA	250 mA
Pulse length	1µs	2ns
Energy spread	+/- 1%	+/- 0.5%



THE TRANSFER LINE FROM THE LINAC TO THE BOOSTER: TL1

- Length: 16 metres
- Main components: 2 bending magnets, 7 quadrupoles, 2 pairs of steerers
- Diagnostics: insertable screens + synchrotron radiation

 screens

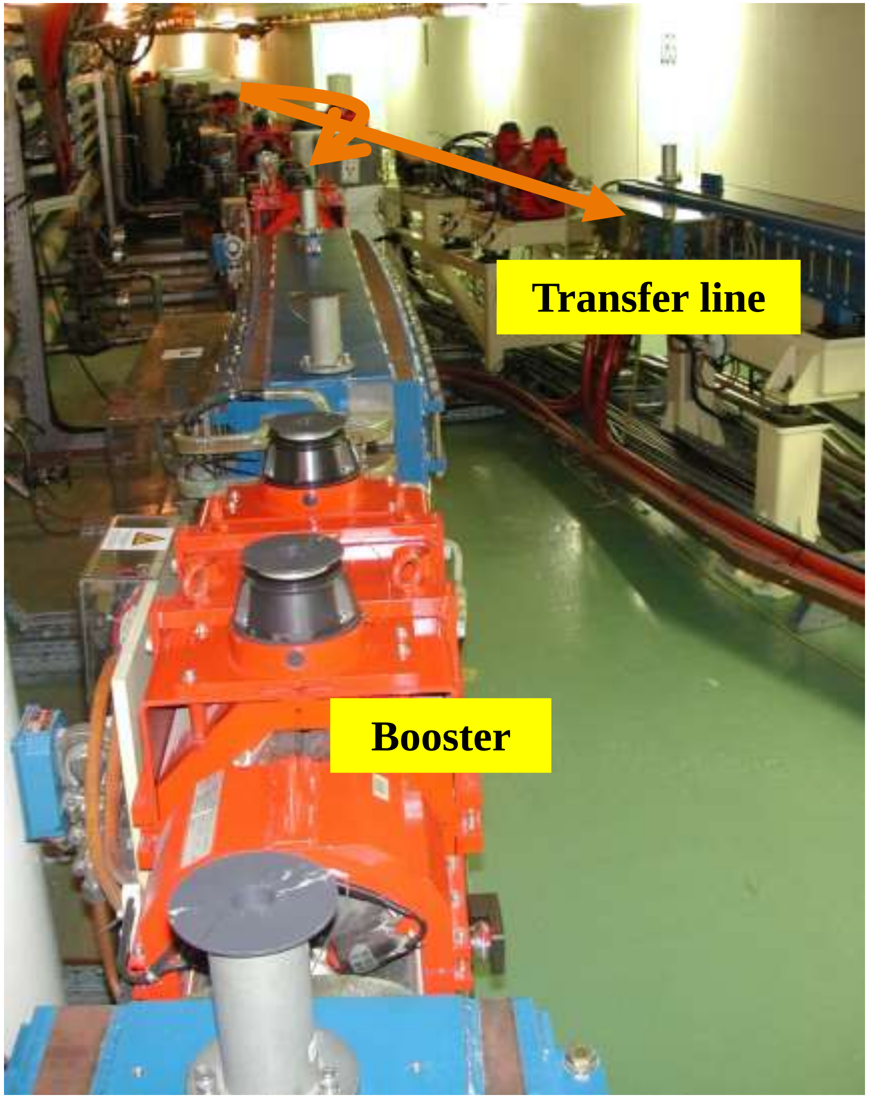
THE SYNCHROTRON (OR BOOSTER)

Goal: Accelerate the electrons from 200 MeV to 6 GeV

Cycle: period of 250 msec

Length: 300 metres

THE TRANSFER LINE FROM THE BOOSTER TO THE STORAGE RING: TL2



Goal:

Transfer the 6 GeV electrons from the Synchrotron to the storage ring:

- 5 bending magnets (powered in serie with Booster dipoles)
- 14 quadrupoles
- 9 insertable screens
- Beam Position Monitors
- Synchrotron radiation screens (1 screen / dipole)
- Length: 65 metres

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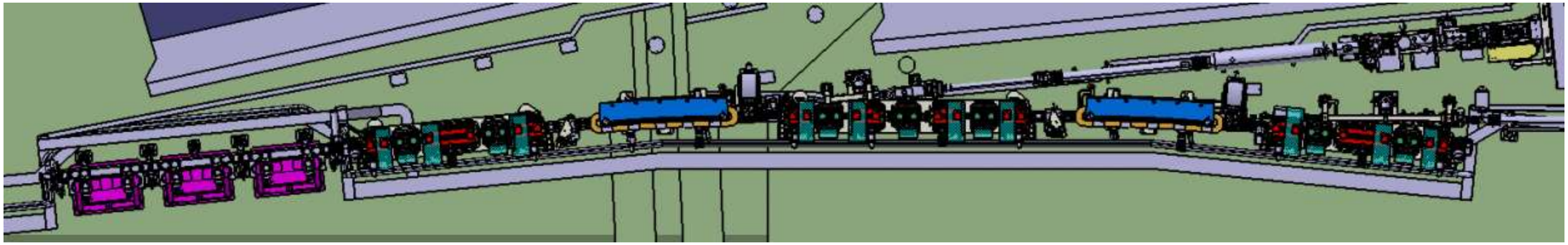
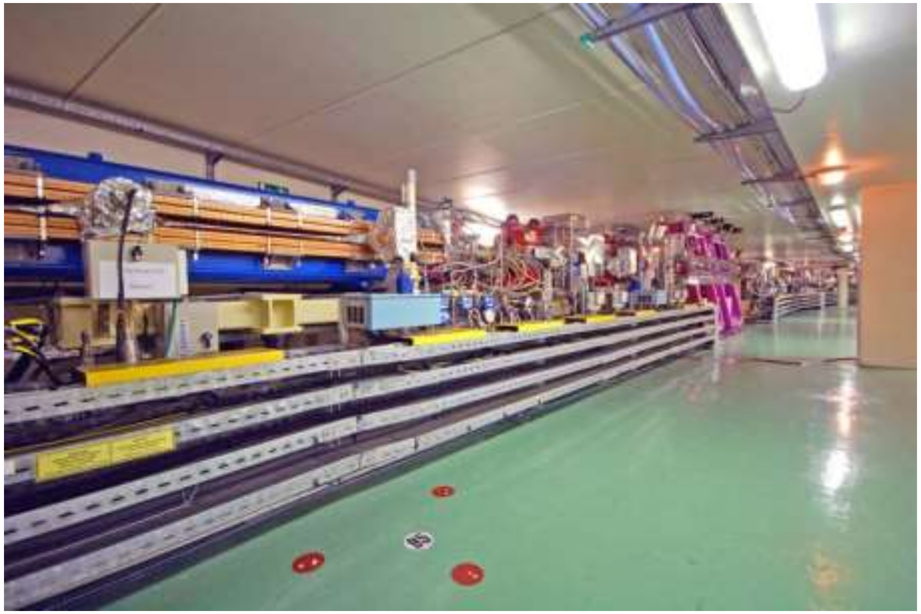
THE STORAGE RING …. YESTERDAY

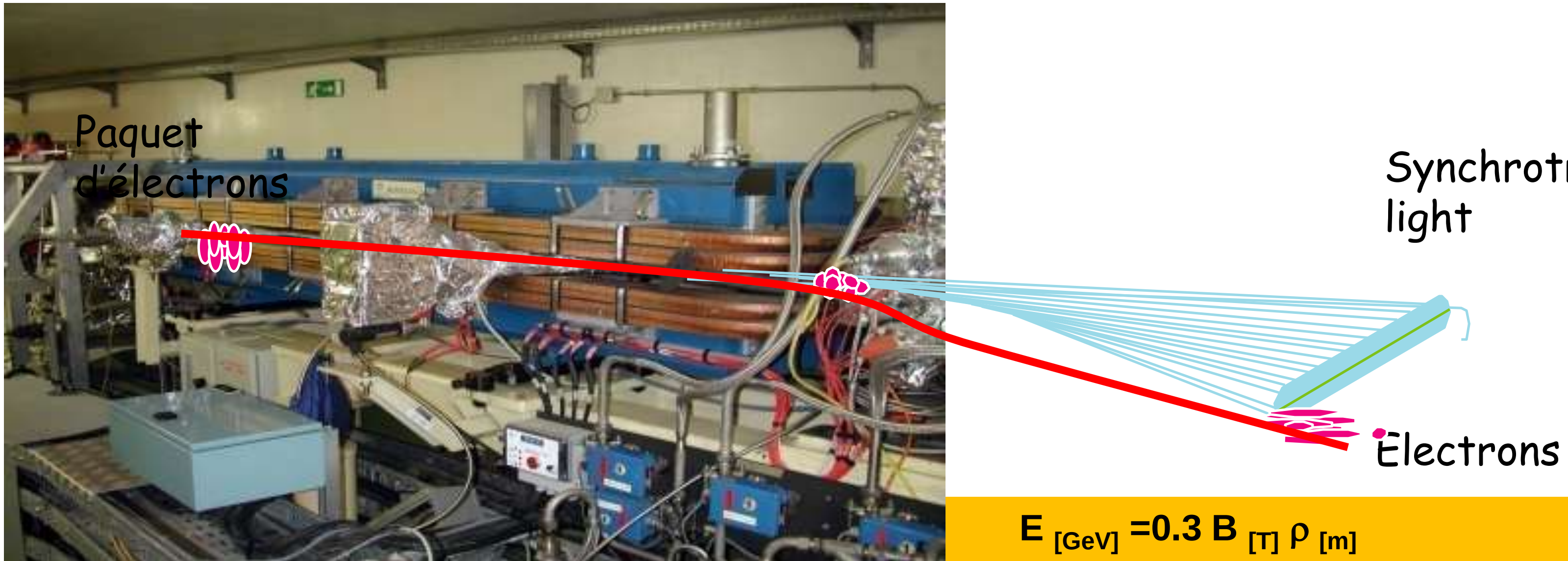


- Circumference: 844 metres
- 16 super-periods of 2 mirror cells➔ 32 cells
- Energy: 6 GeV
- Nominal intensity: 200 mA
- Emittance: 4nm rad
- Usual coupling : 0.1 %



THE STORAGE RING BENDING MAGNETS

64 bending magnets (dipoles)



$E_{[GeV]} = 0.3\, B_{[T]}\, \rho_{[m]}$

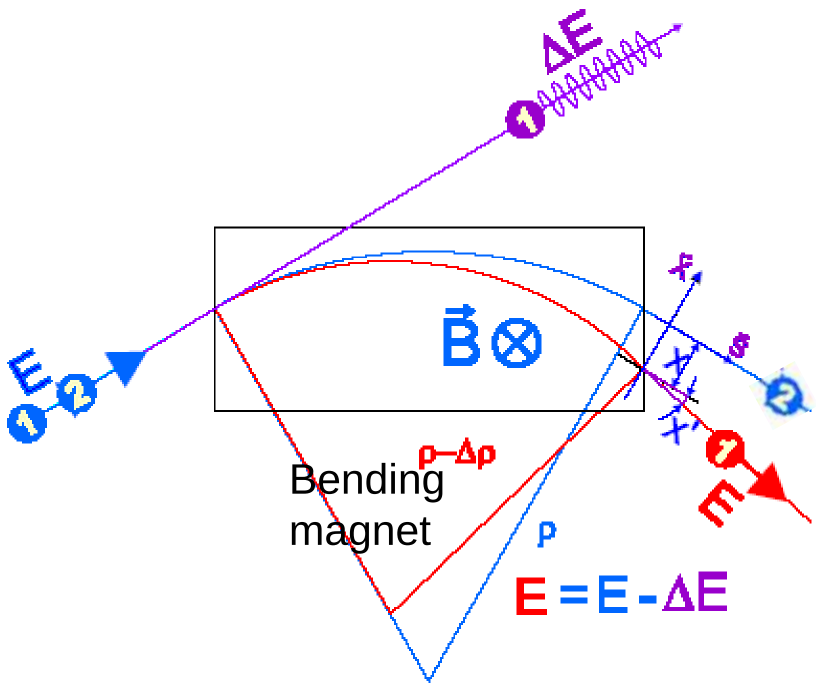
B=0.8 T $\rho = 25\ m$

Energy lost per turn of ring by one electron

$$\Delta E_{[keV]} = 88.5 \frac{E^4_{[GeV]}}{\rho_{[m]}} = 4.6 \text{ MeV}$$

The power radiated around the length of the ring bending magnets by a current of 200 mA = 920 kW

Numbers : 64 (2 per cells)
Bending angle : 5.625 °
Magnetic field : 0.8612 Tesla
Number of family : 1
Nominal intensity : 714.993 A



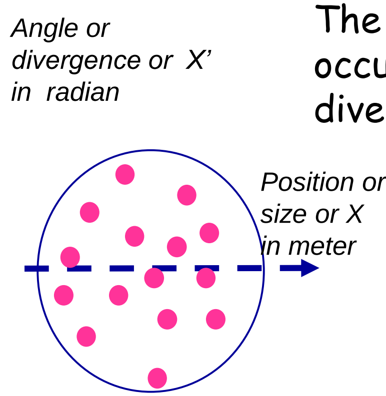
Electron 2 emits Δe at the exit of the bending magnet.

- ➔ *same energy when crossing the magnet*
- ➔ *stay on the reference trajectory*

Electron 1 emits ΔE at the entrance of the bending magnet.

- ➔ *lower energy when crossing the magnet*
- ➔ *larger curvature*

A horizontal beam size and divergence (or emittance) and an energy spread is created.



The beam emittance is the **surface** occupied by the beam in size and divergence.

$$\varepsilon_{x[m*rad]} = \frac{1}{\pi}\oiint dx\,dx'$$

THE STORAGE RING QUADRUPOLE MAGNETS

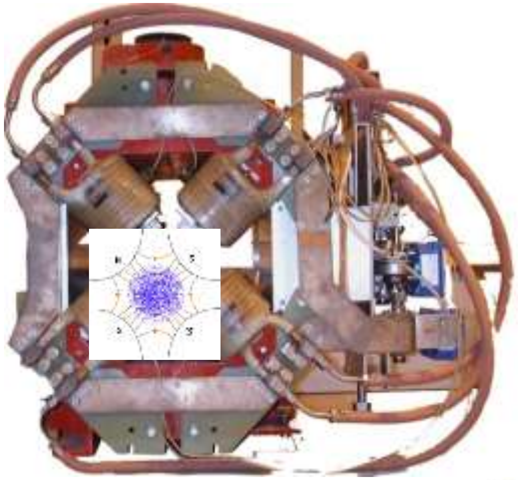
256 quadrupoles shared in 6 families

Name	Number
QF2	32
QD3	32
QD4	64
QF5	64
QD6	32
QF7	32

The goal of the **quadrupoles** is to focus the electron beam so as to maintain its size as small as possible

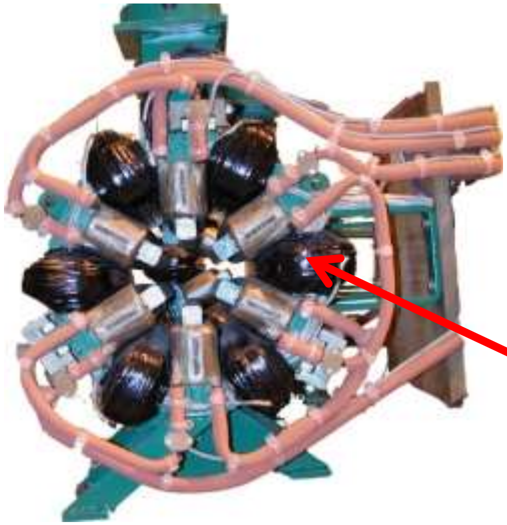
The quadrupole settings are also important for:

- the tune values,
- the beam size,
- the injection efficiency,
- the betatronic resonances,   etc



THE STORAGE RING SEXTUPOLE MAGNETS

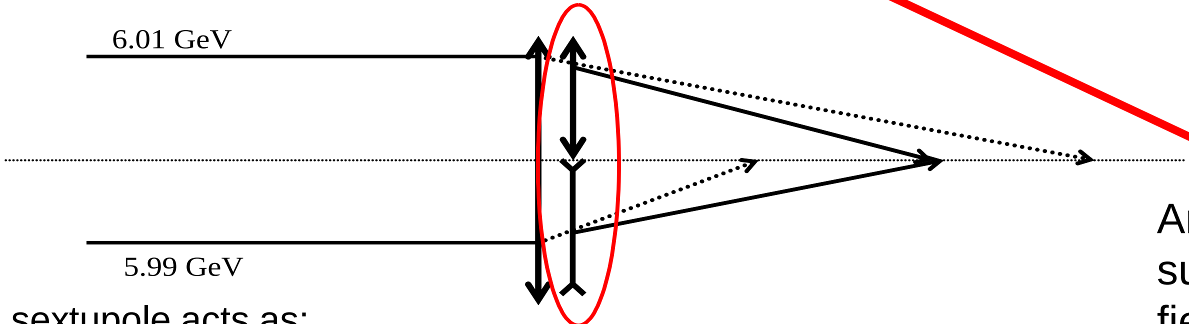
224 sextupoles shared in 7 families



Name	Number
S4	32
S6	32
S13	32
S20	32
S19	32
S22	32
S24	32

Their settings are important for:

- the chromaticities,
- the betatronic resonances
- the dynamic aperture,
- and therefore the beam lifetime



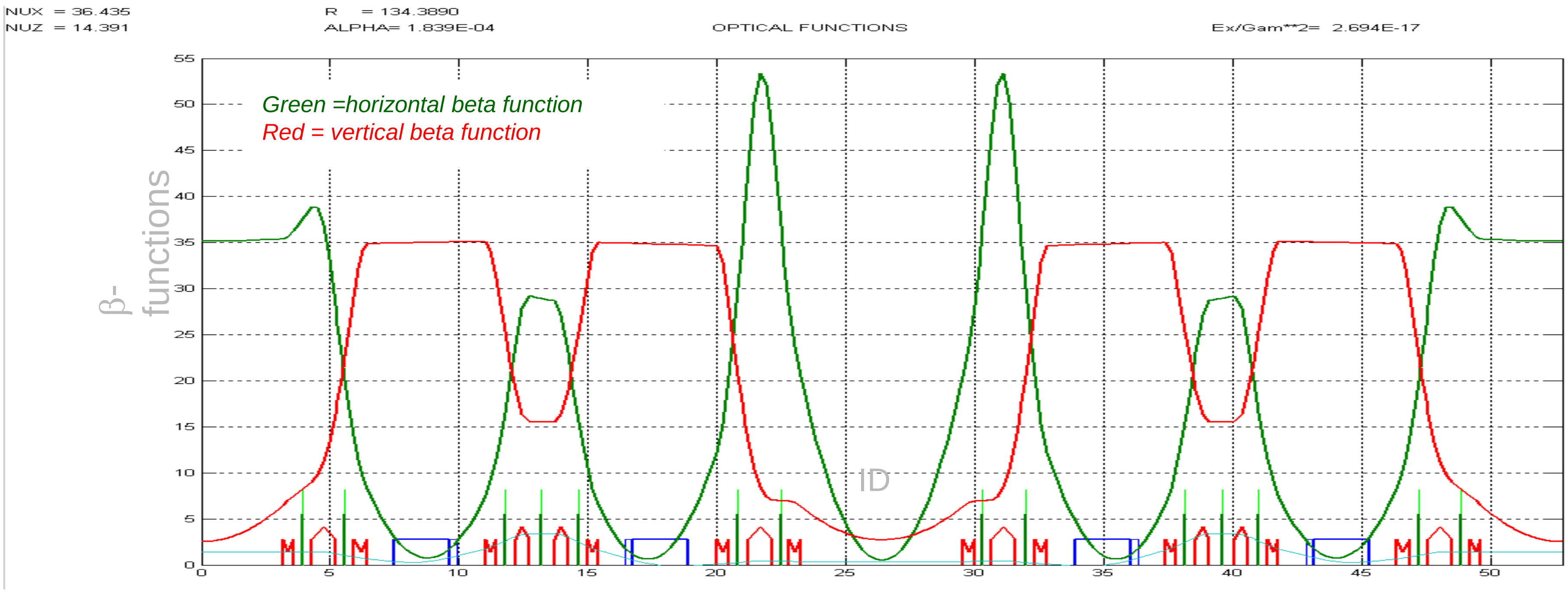
And steerers (3 power supplies to get a H or V field)

A sextupole acts as:

- A focusing quadrupole for the electrons which have a higher energy

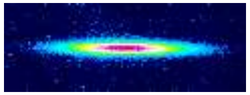
- A defocusing quadrupole for the electrons which have a lower energy

THE ESRF STORAGE RING LATTICE



5 m 5 m 5 m

Even cells



Odd cells

ESRF Horizontal emittance = 4 nm.rad

ESRF vertical emittance = 5pm

Vertical emittance is determined by the coupling to the horizontal motion due to magnet or alignment imperfections.

$$\sigma_x = \sqrt{\varepsilon_x \beta_x} \qquad \sigma'_x = \sqrt{\varepsilon_x / \beta_x}$$

$$\sigma_y = \sqrt{\varepsilon_y \beta y} \qquad \sigma'_y = \sqrt{\varepsilon_y / \beta_y}$$

Taille *Divergence*

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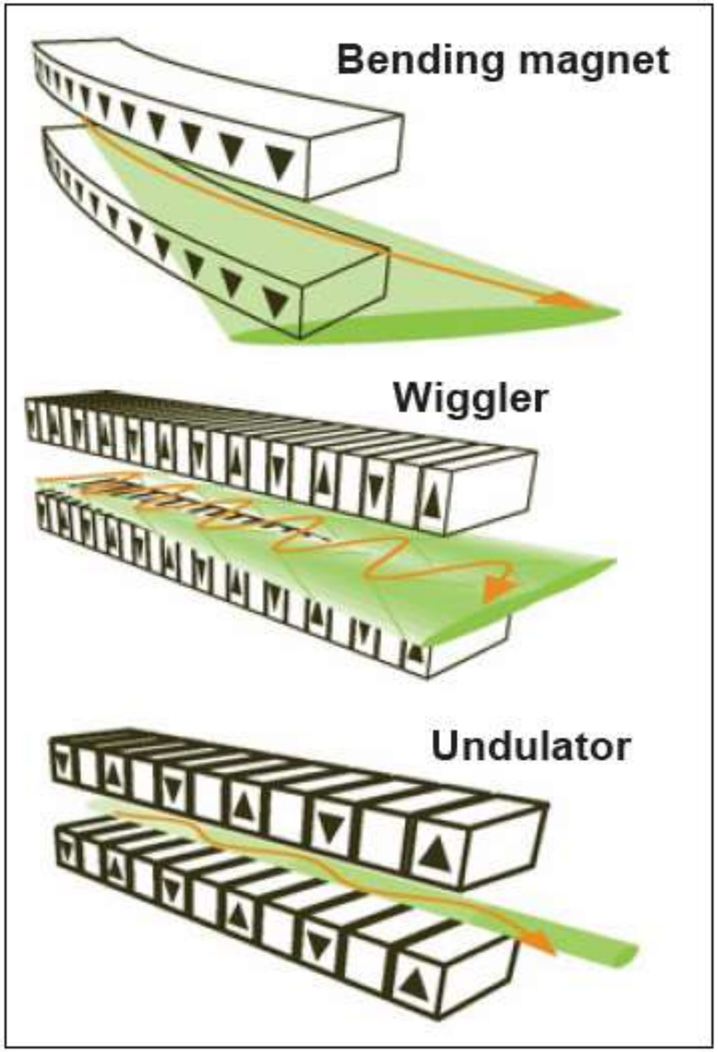
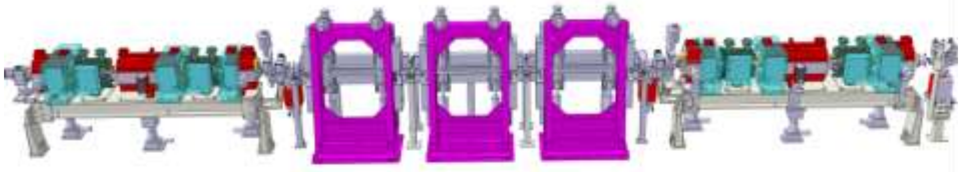
INSERTION DEVICES … IN THE STRAIGHT SECTIONS…



Goal: produce X-rays with specific properties which are different from those emitted by the dipoles, for example, tuneable energy spectrum, polarisation, higher brilliance...



INSERTION DEVICES

In-air *length =1.64 m*

In-vacuum
Length=2.4 m

(2.4 m flenge to flange , 2m magnetic asembly)

Power generated by one undulator (1.6 m) = 3kW

Available power = 250 kW

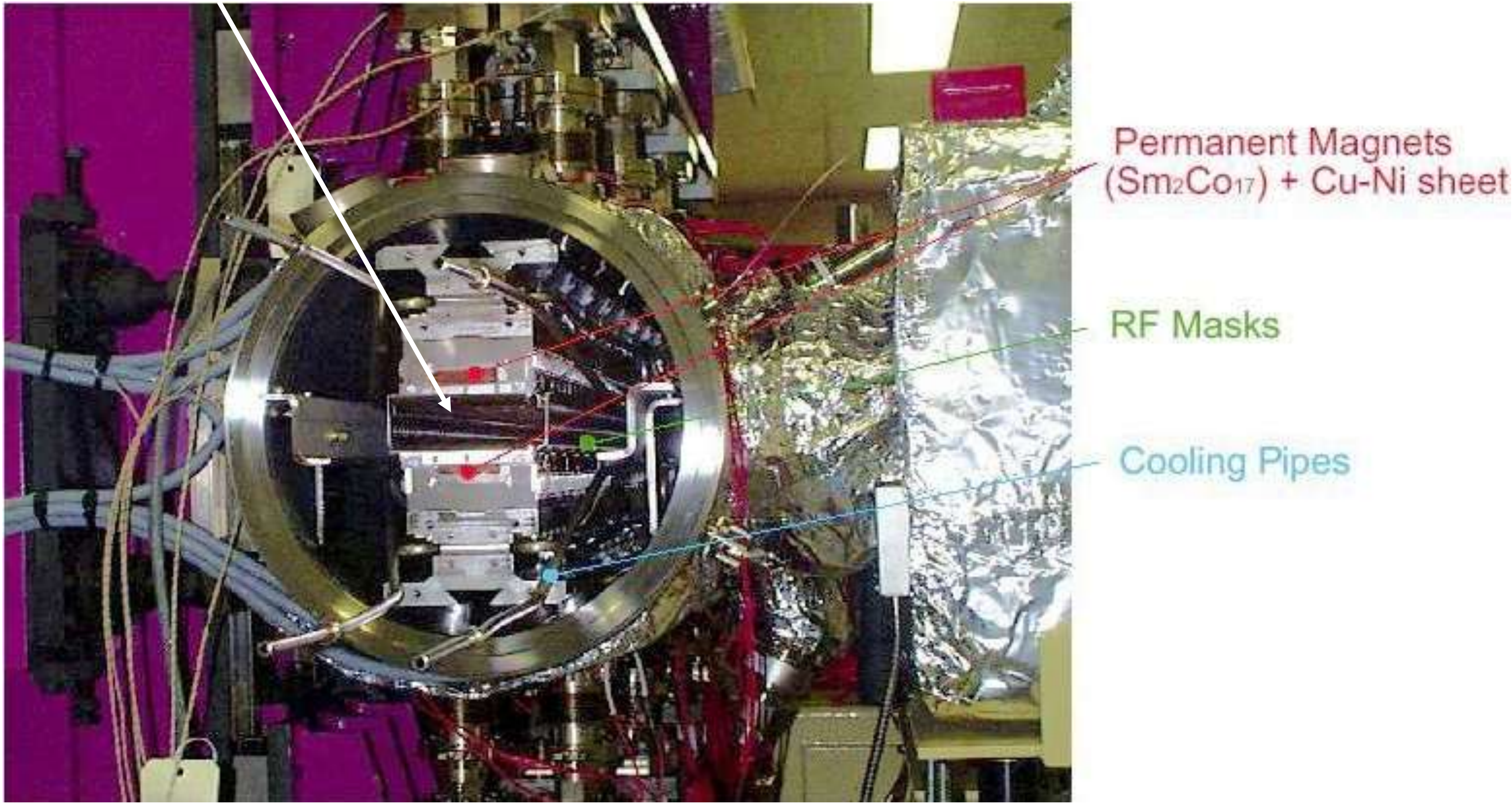
But less than 100 kW is used!!

$2 kW/mm^2$ at 200 mA

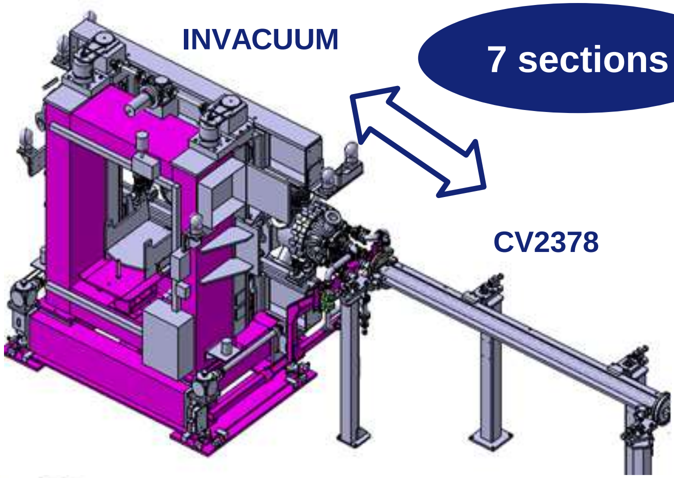
8000 kW of Electrical power is needed to produce it!!
Efficiency: 2% !

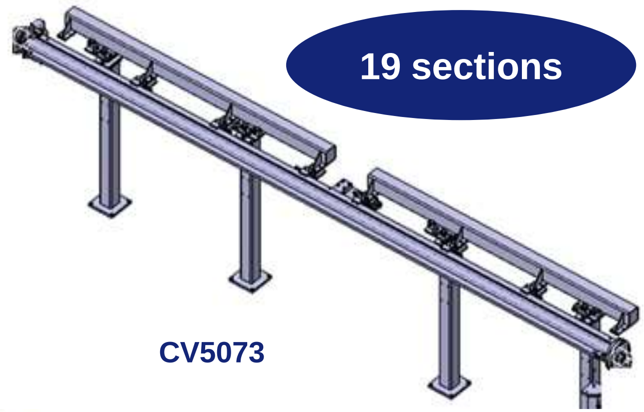
IN-VACUUM UNDULATORS

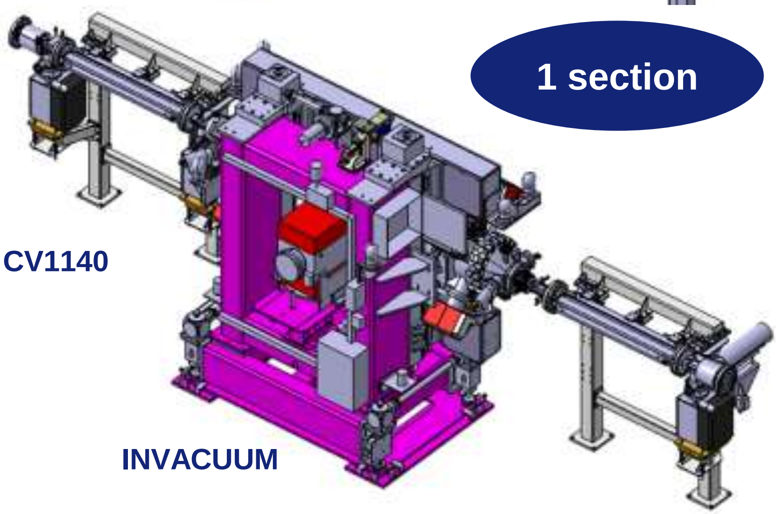
The jaws of the in-vacuum undulators can be closed down to 5 mm

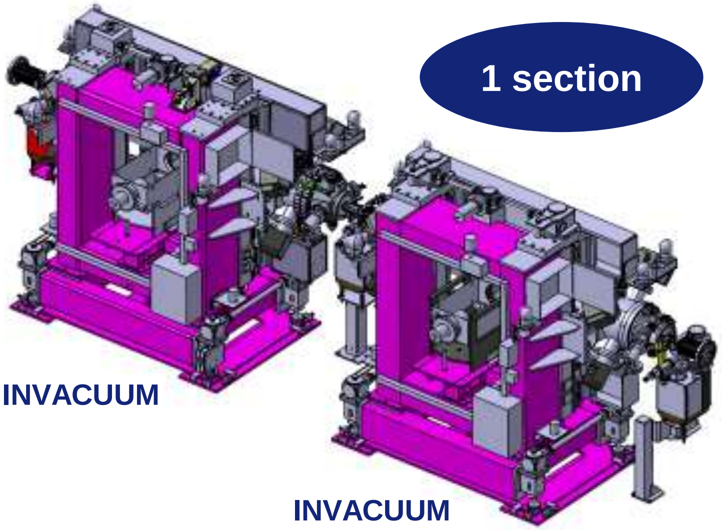


STRAIGHT SECTIONS INSTALLATION : 4 TYPES

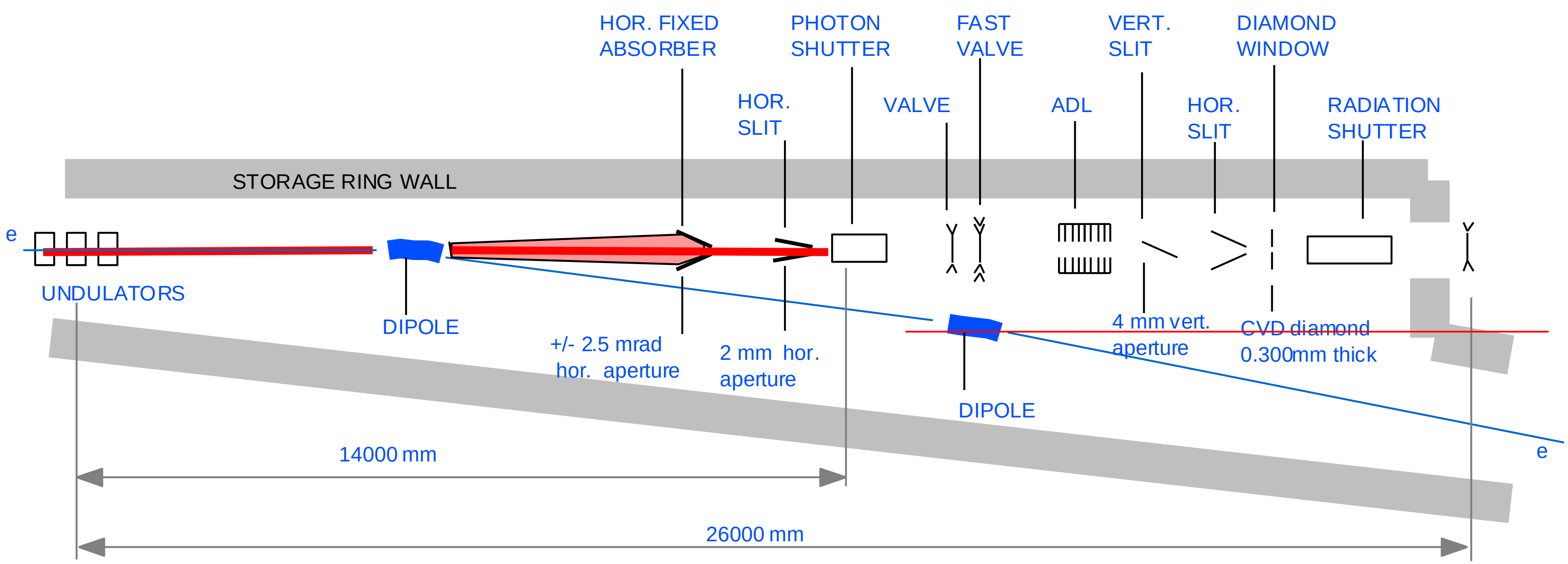


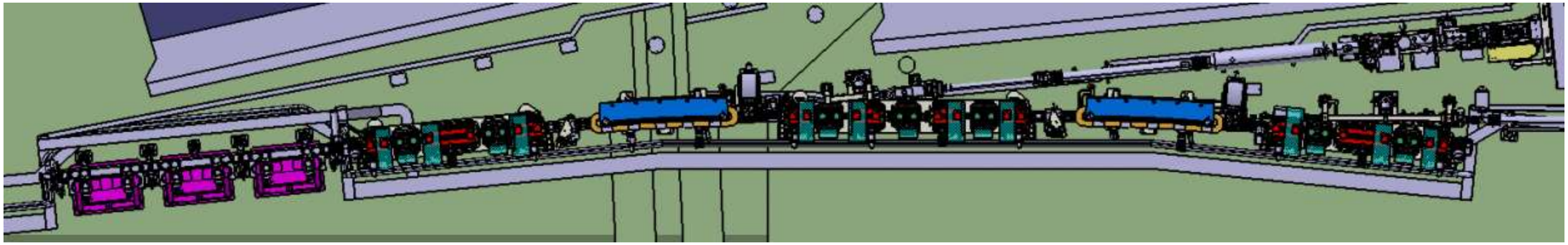






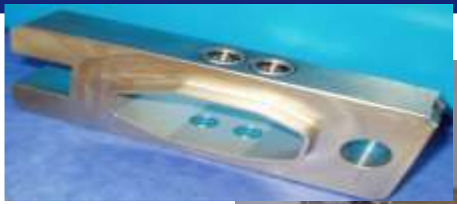
THE STORAGE RING FRONT ENDS





Goal: Drive the X-rays produced either by the dipoles, or by the insertion devices, from the storage ring to the beam line.

THE VACUUM SYSTEM

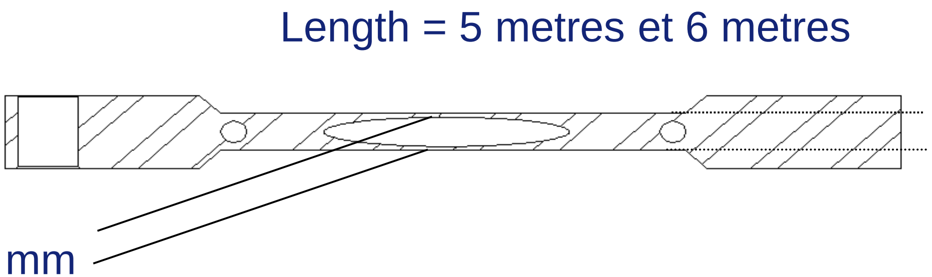


Goal: control and maintain an excellent vacuum level in the storage ring:

10^{-10} mbar without beam (static pressure)
10^{-9} mbar with beam (dynamic pressure)

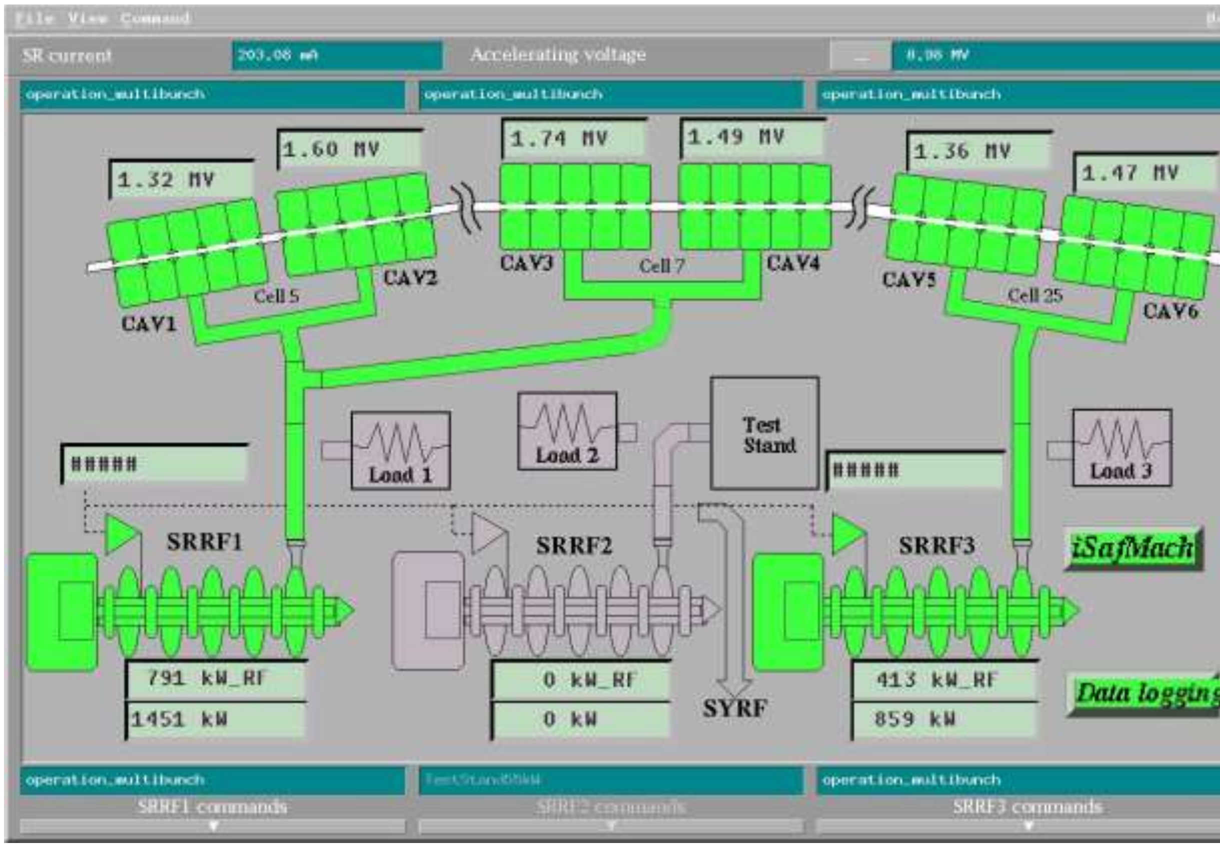
- This vacuum level is ensured by the ionic pumps, NEG coating
- The pressure control is done with Penning gauges.

ID chambers



- Extruded aluminium
- The internal side of these vacuum vessels is covered with a thin coat of NEG material (Non Evaporable Getter) made of an alloy of Titanium, Zirconium, Vanadium. The particularity of this alloy is to trap chemically certain molecules (mainly CO and CO_2) acting as vacuum pumps.

THE STORAGE RADIOFREQUENCY SYSTEM



Goal: compensate the energy loss turn / turn by the electrons, following the synchrotron radiation emission, i.e., 4.8 MeV (with all insertion devices)

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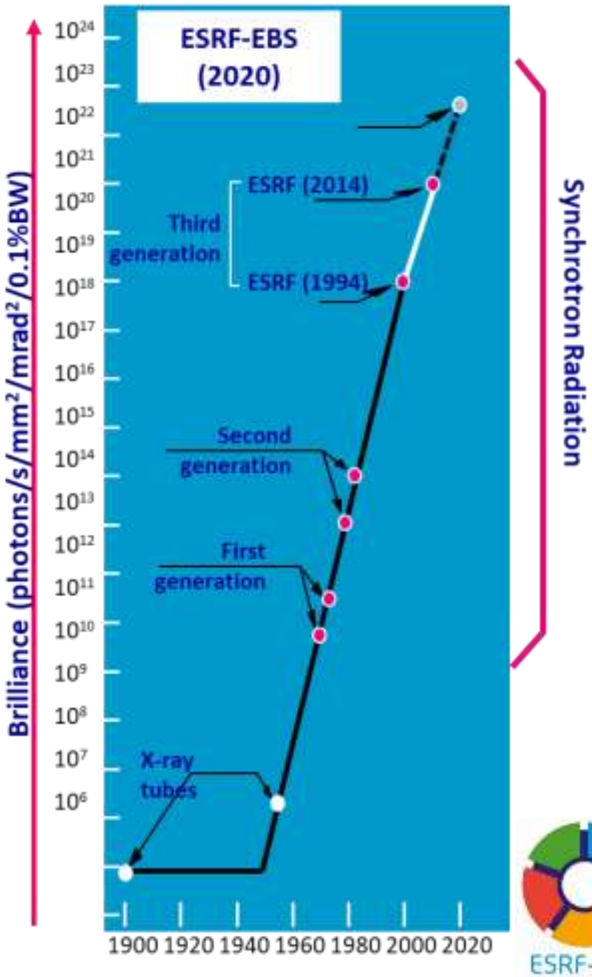
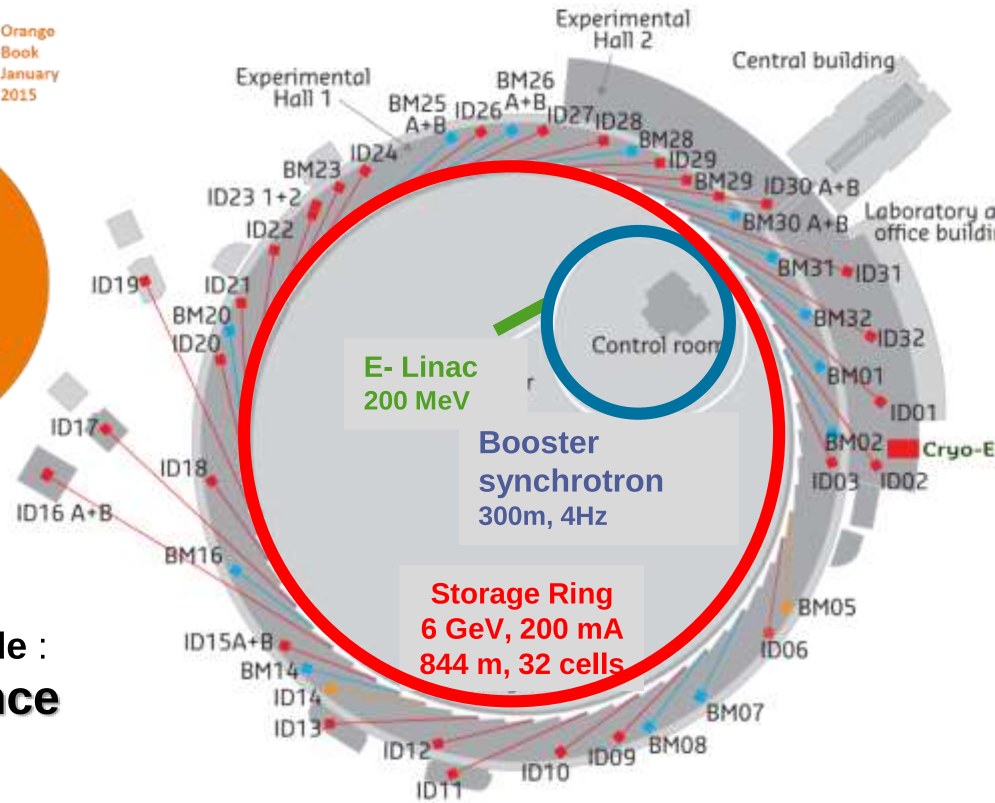
The ESRF-EBS Upgrade



ESRF | The European Synchrotron

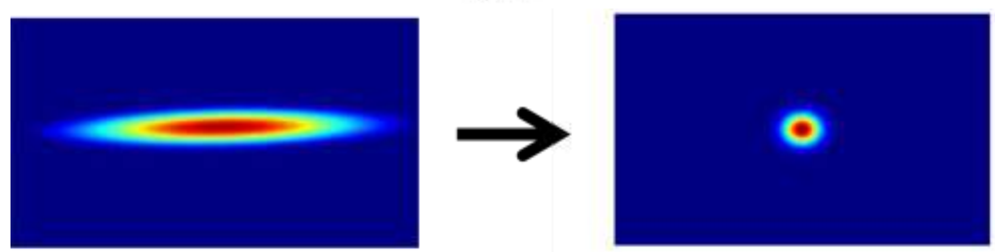
ESRF-EBS

OVERVIEW OF THE PROJECT



The **ESRF Extremely Brilliant Source upgrade** :

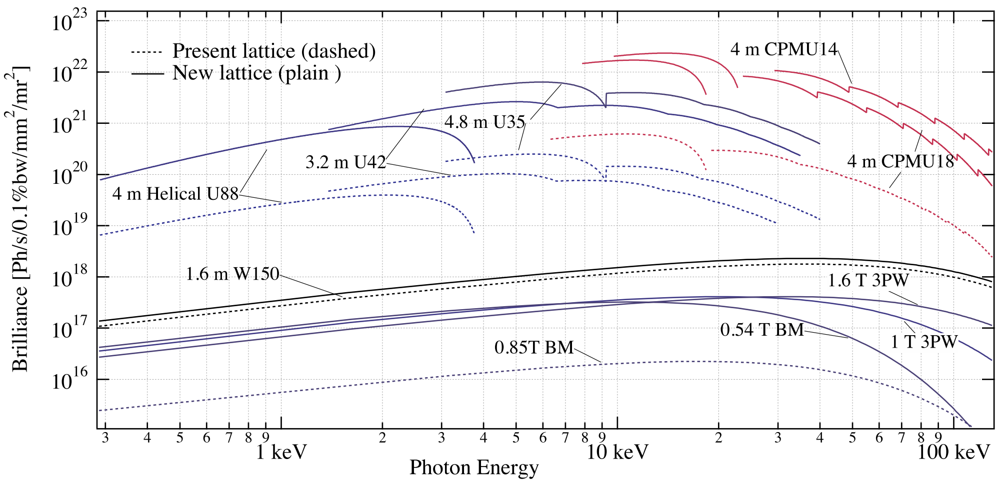
- **Decrease the horizontal emittance from 4nm to 0.14nm**
- Increase the source brilliance
- Increase the source coherence



Budget for the source: 104 M€

BRILLIANCE AND COHERENCE INCREASE

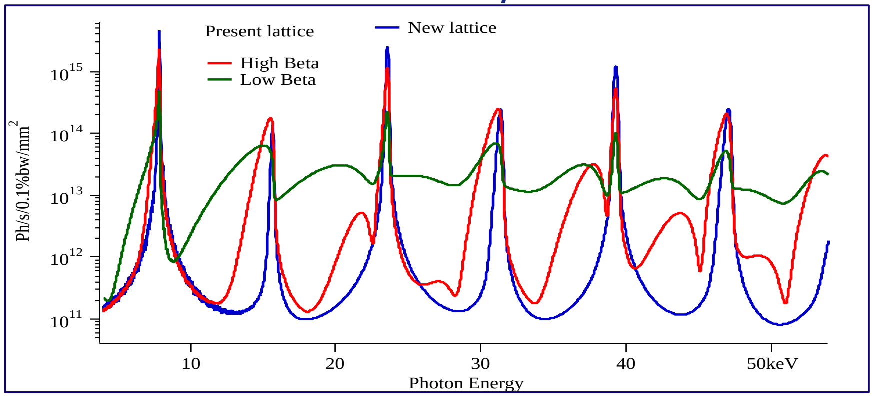
Brilliance



Hor. Emittance [nm]	4	0.135
Vert. Emittance [pm]	4	5
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

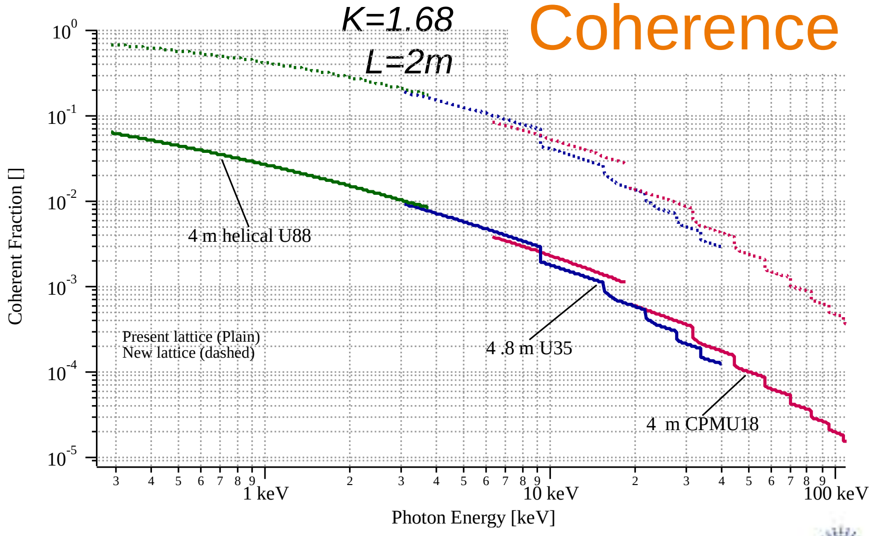
Source performances will improve by a factor 50 to100

18mm Undulator spectrum



Undulator: CPMU18, K=1.68 L=2m

Coherence



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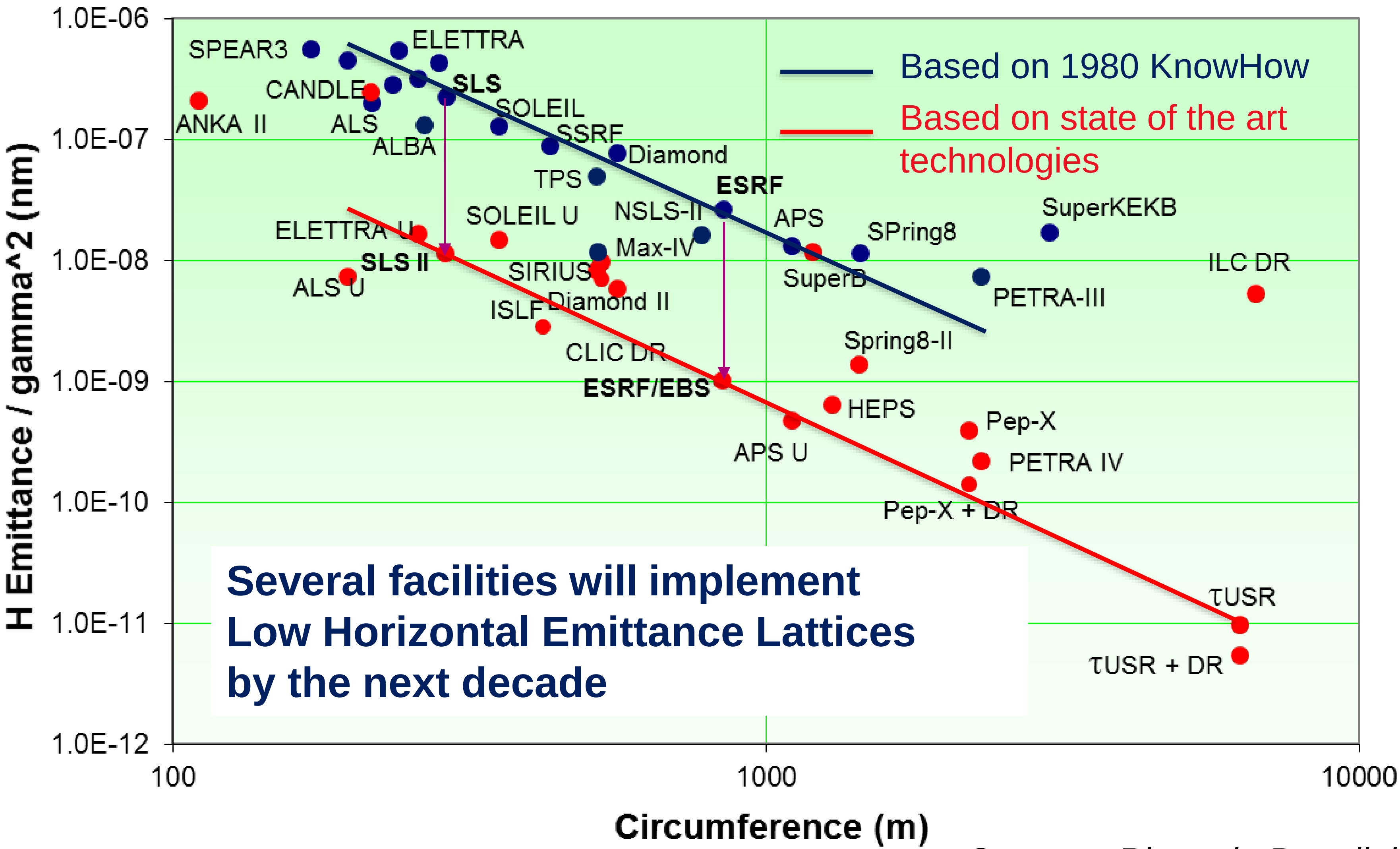
LOW EMITTANCE RINGS TREND



Several facilities will implement Low Horizontal Emittance Lattices by the next decade

Courtesy Riccardo Bartolini

DECREASING THE HORIZONTAL EMITTANCE

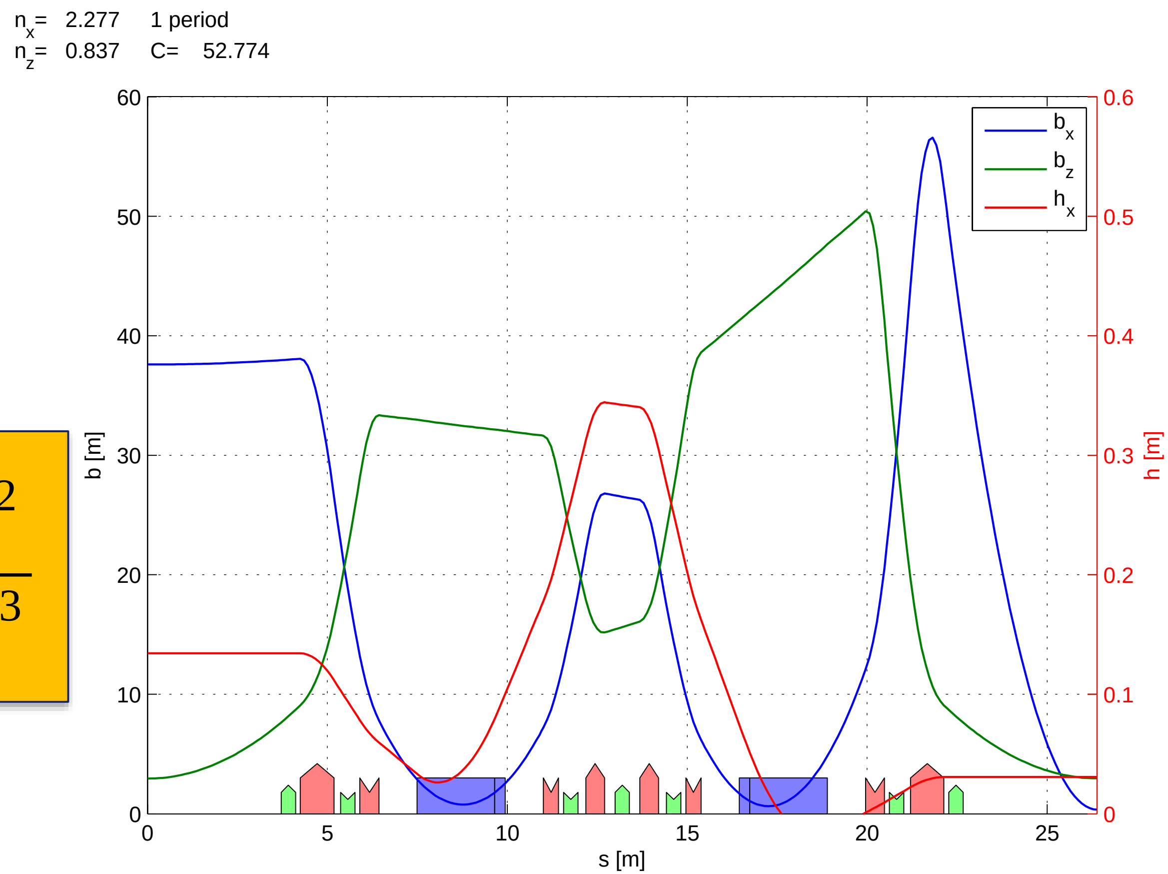
Low emittance:
Careful tuning of β_x and η_x in the dipoles (where the radiation occurs)
β_x: envelope function
η_x: dispersion

How clever we are

Energy

$$\varepsilon_x = F(Lattice)\frac{E^2}{N^3}$$

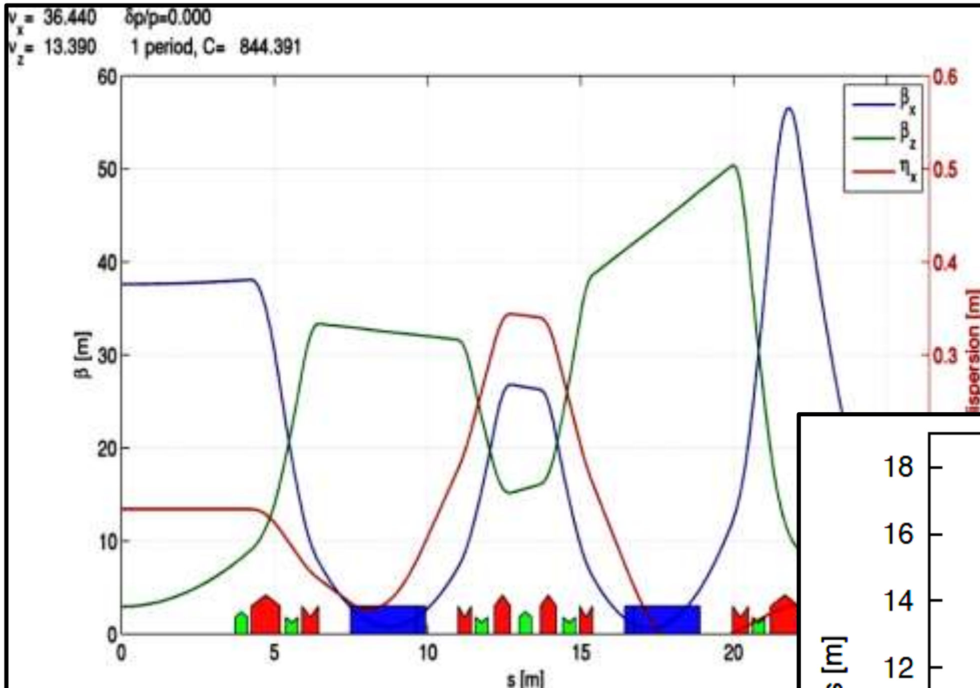
Number of identical dipoles



Emittance reduction ➔ large number of bending magnets

- Increase the number of cells
  - ➔ Large circumference
- Put more dipoles per cell
  - ➔ Compact machine

THE EVOLUTION TO MULTI-BEND LATTICE

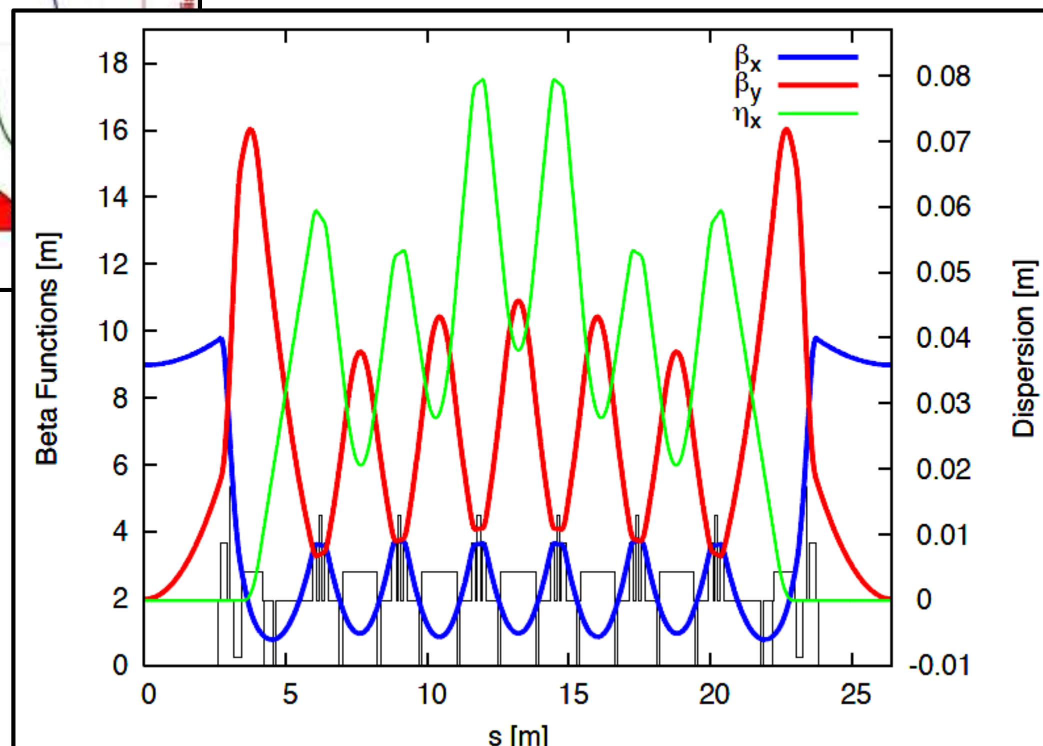


Double-Bend Achromat (DBA)

- Many 3rd gen. SR sources
- Local dispersion bump (originally closed) for chromaticity correction

Multi-Bend Achromat (MBA)

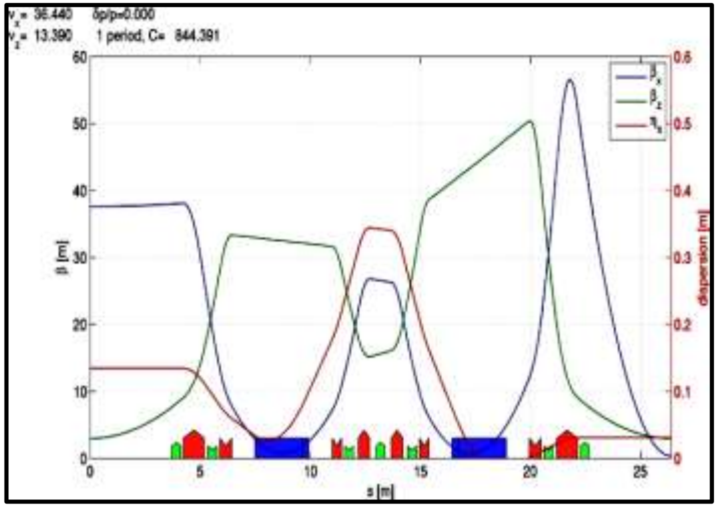
- MAX IV and other USRs
- No dispersion bump, its value is a trade-off between emittance and sextupoles (DA)



THE HYBRID MULTI-BEND (HMB) LATTICE

ESRF existing DBA cell

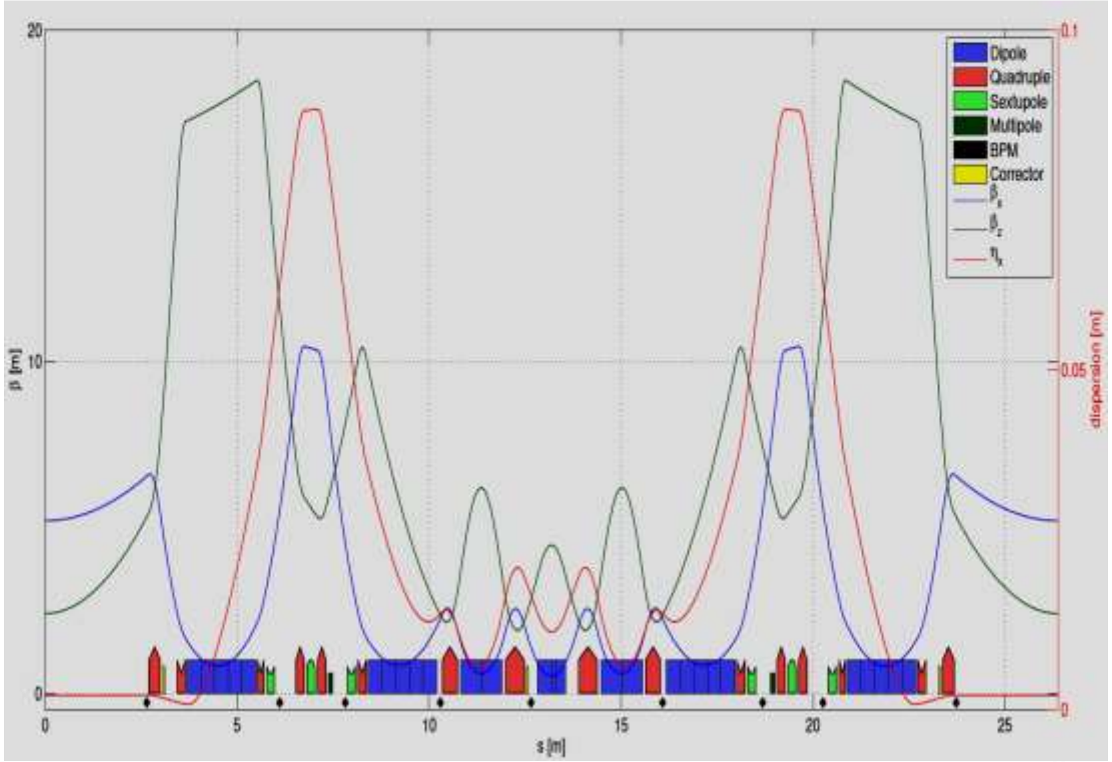
- Ex = 4 nm•rad
- tunes (36.44,13.39)
- nat. chromaticity (-130, -58)



ESRF HMB cell

- Ex = 140 pm•rad
- tunes (76.21, 27.34)
- nat. chromaticity (-99, -82)

- **Multi-bend for lower emittance**
- **Dispersion bump for efficient chromaticity correction => "weak" sextupoles (<0.6kT/m)**
- **Fewer sextupoles than in DBA**
- **Longer and weaker dipoles => less SR**
- **No need of "large" dispersion on the inner dipoles => small *Hx* and Ex**



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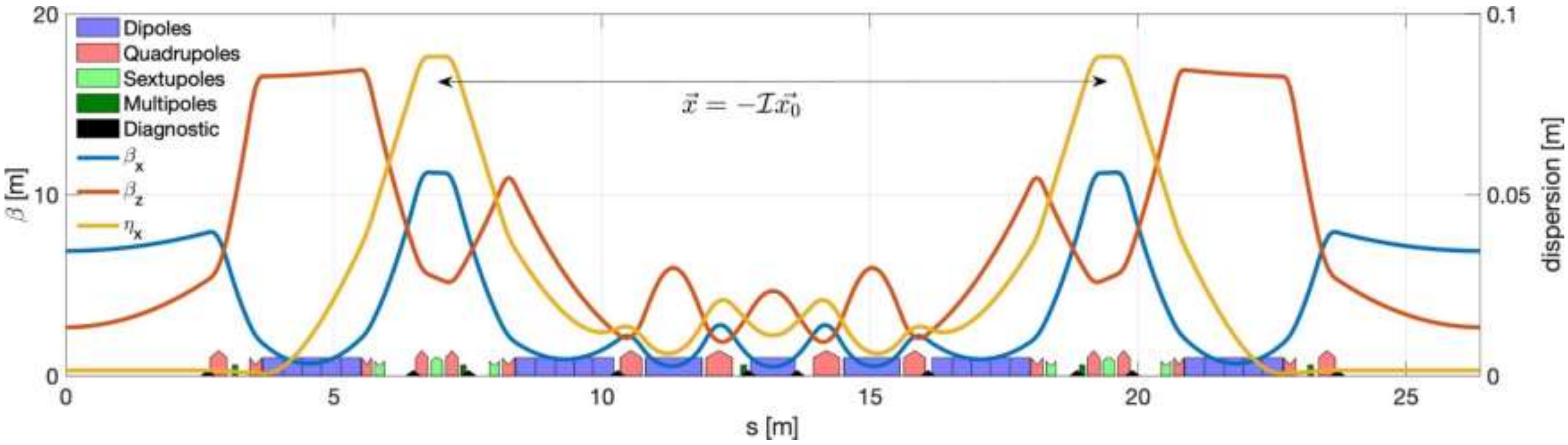
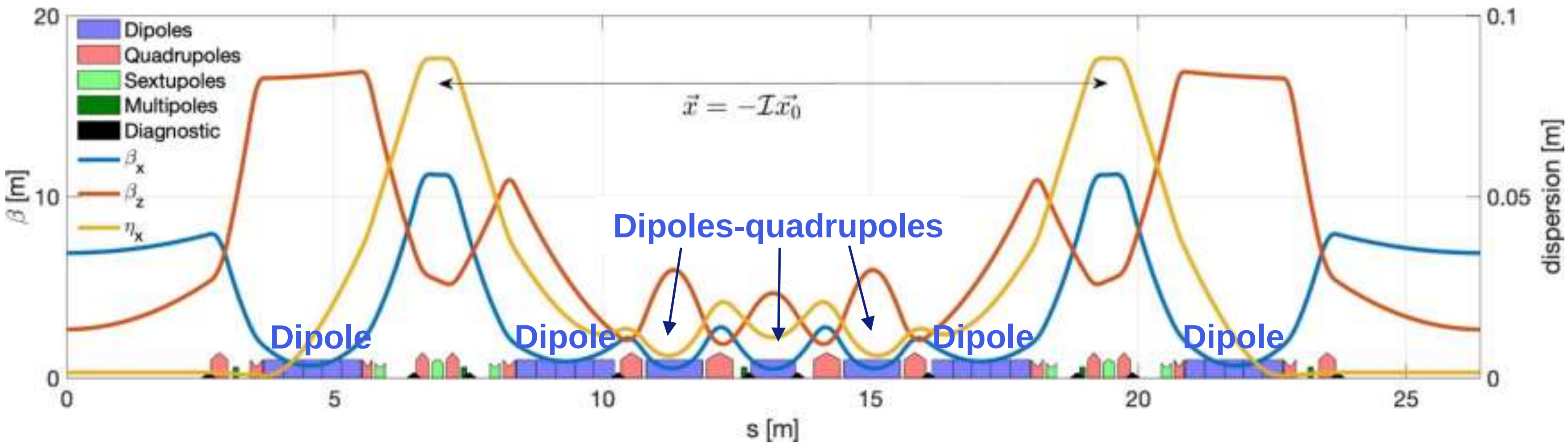
THE ESRF-EBS UPGRADE OBJECTIVES AND CONSTRAINTS



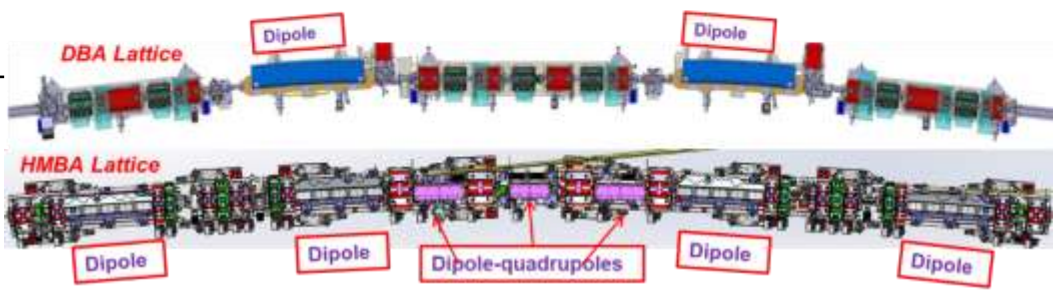
Main constraints were:

- Horizontal equilibrium emittance < 150 pm.rad
- Keep the electron energy (6 GeV)
- Fit existing tunnel and infrastructure
- Maintain IDs and bending magnets beamlines
- Use existing injector chain
- Preserve the time structure operation and a multibunch current of 200 mA
- Minimize power consumption
- Maintain standard User-Mode Operations until the day of shut-down for installation
- Limit the downtime for installation and commissioning to less than 18 months

THE ESRF-EBS UPGRADE LATTICE



	Units	ESRF	ESRF-EBS
Energy	*GeV*	6	6
Circumference	*m*	844.4	844
Lattice		DBA	HMBA
Current	*mA*	200	200
Lifetime	*h*	50	25
Emittance H	*pm.rad*	4000	133
Emittance V	*pm.rad*	4	10*



31 magnets per cell instead of 17

*Free space between magnets (for one cell): **3.4m** instead of **8m***

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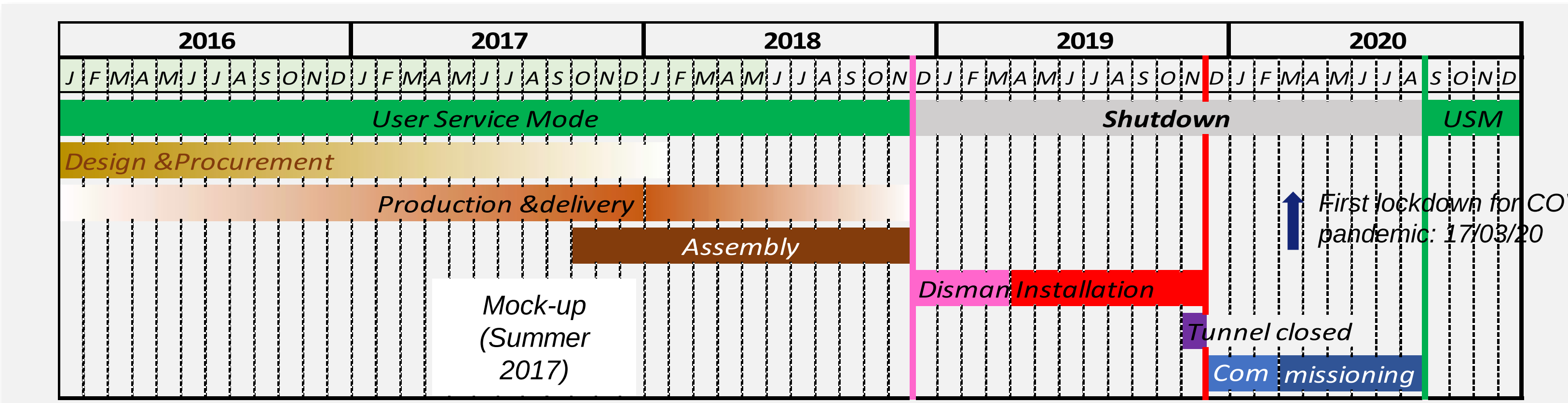
ESRF-EBS PROJECT IMPLEMENTATION

Project approval: January 2015



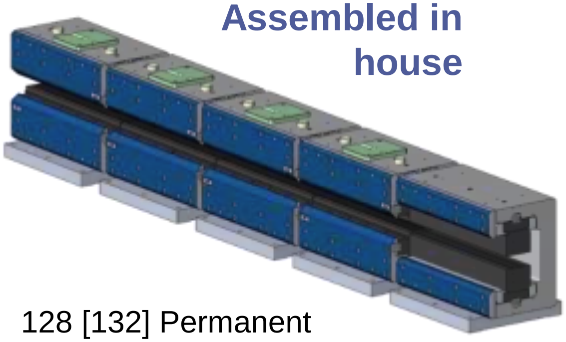
Old ESRF-Storage Ring

ESRF-EBS

October 2017	Start of girder assembly
10 December 2018	End USM, start shutdown
	Dismantling
	Installation
8 November 2019	Tunnel closed
	Tests & Injector restart
28 November 2019	Accelerator commissioning
2 March 2020	Beamline commissioning
25 August 2020	Start User Mode Operation

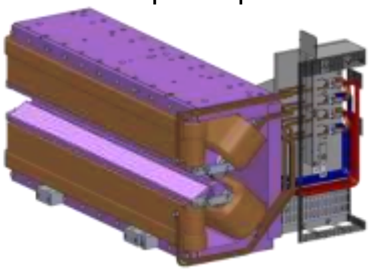
EBS COMPONENTS: MAGNETS

Assembled in house

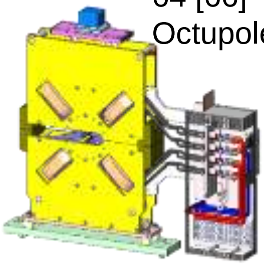


128 [132] Permanent Magnet Dipoles

96 [100] Dipole-quadrupoles

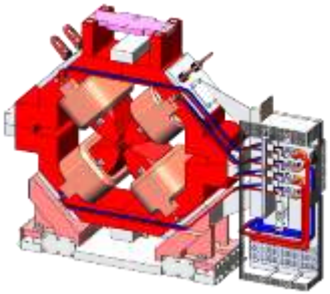


64 [66] Octupoles



More than 1000 Magnets

512 Quadrupoles (128 [132] HG, 384 [392] MG)



192 [196] Sextupoles

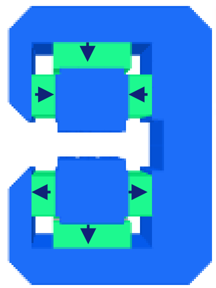
96 [98] Correctors

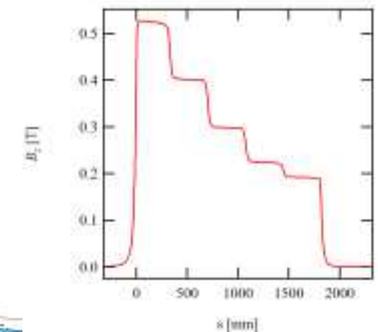
32 Cubicles for DC-DC converters to power each magnet individually

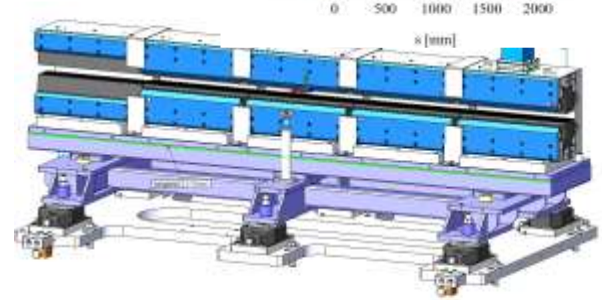
COMECA

EBS COMPONENTS: DIPOLES

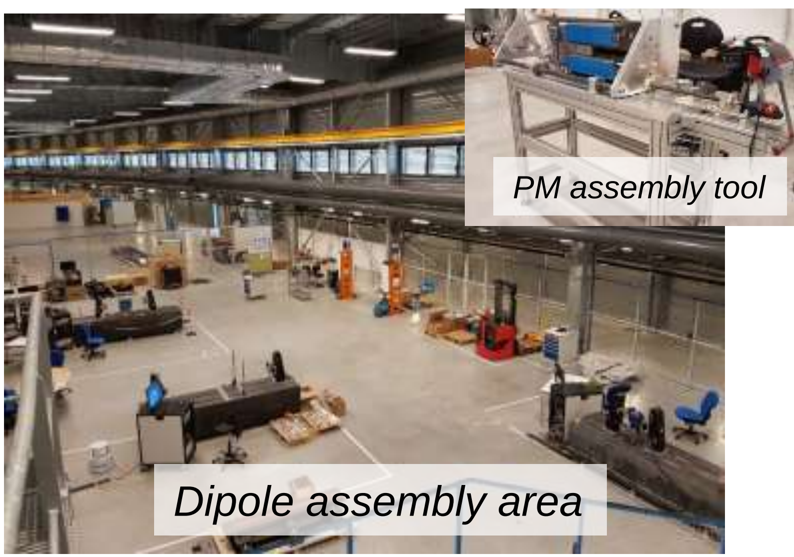
- Each dipole based on 5 PM modules
- Strength 0.67-0.17 T &
- Iron length 1788 mm
- 25.5 – 30.5 mm GAP
- Iron: Pure Iron
- Permanent magnet Sm_2Co_{17}







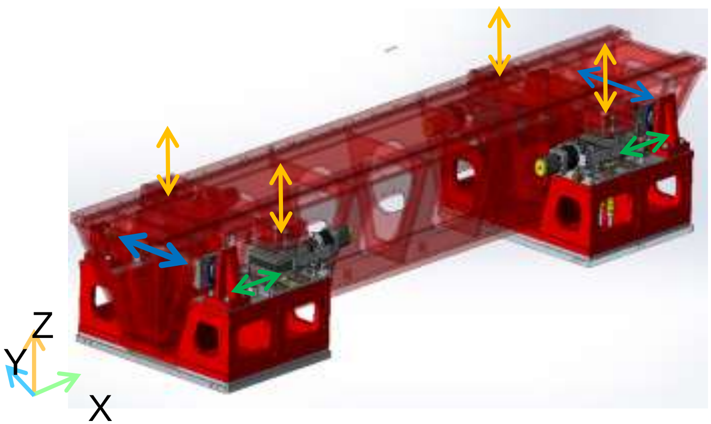
Around 6000kg of PM, 660 Iron modules



PM assembly tool

Dipole assembly area

EBS COMPONENTS: GIRDERS



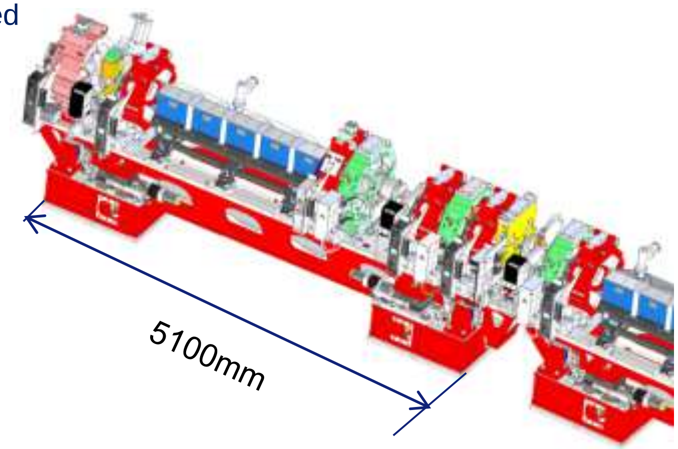
Four identical girders per cell

- **Motorized Z adjustment** resolution 5µm
- **Manual Y adjustment** resolution 5µm
- 1st natural frequency :
  - 50Hz (design criteria)
  - 49 Hz measured

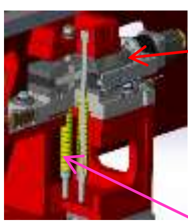
128 + 1 Girders

- 4x32 (Arcs)
- 1 (Injection Cell)

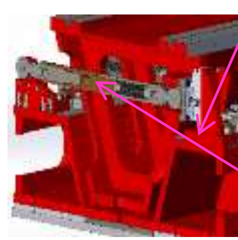
Nortemeca
AVS



• Vertical movement



• Horizontal movement



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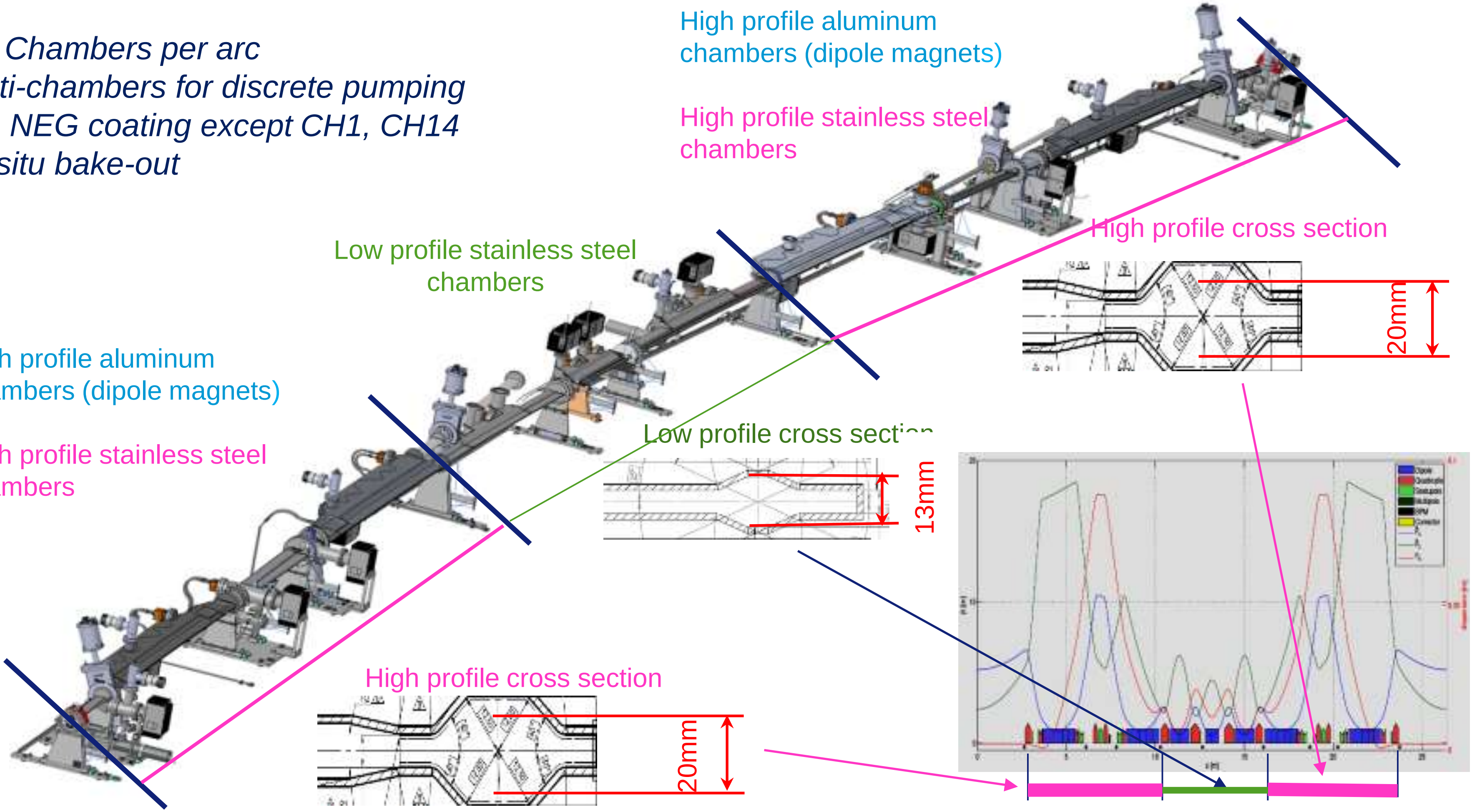
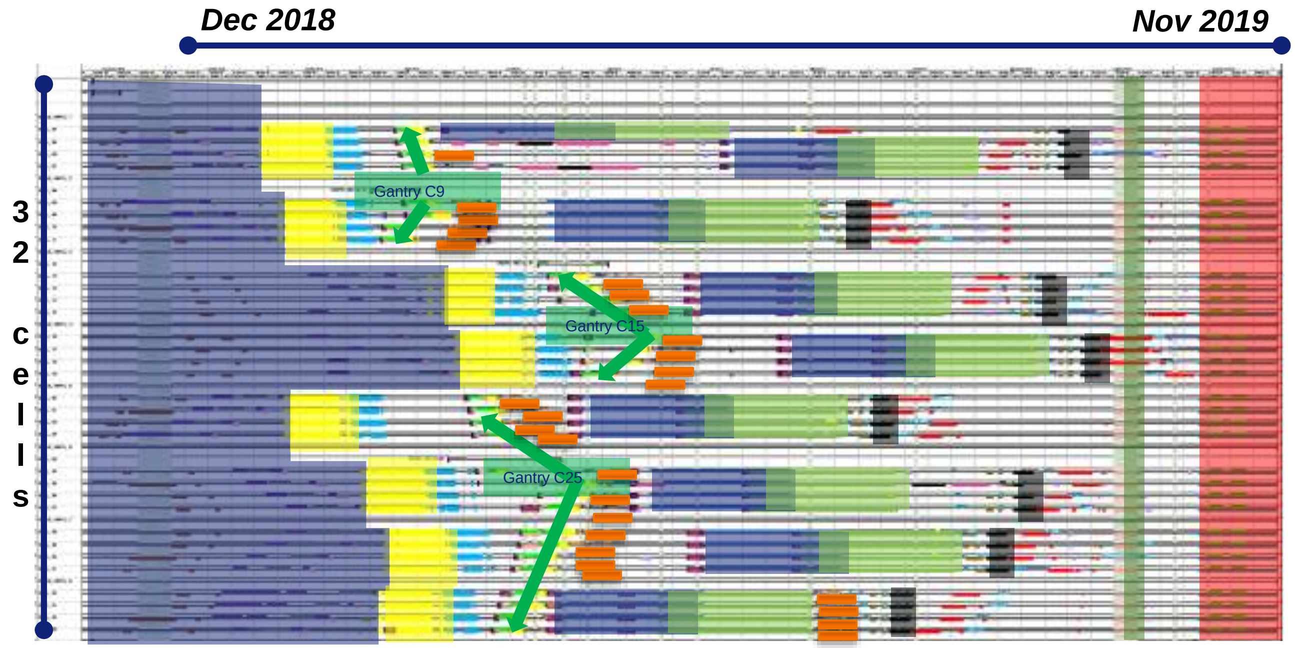
EBS COMPONENTS: VACUUM CHAMBERS

14 Chambers per arc
Anti-chambers for discrete pumping
No NEG coating except CH1, CH14
In situ bake-out



DISMANTLING + INSTALLATION: DEC 2018 – NOV 2019

Dismantling
Civil works
Girder entry
Vacuum connection
Piping
Cabling
FE
Straights Sections
Bakeout
IDs
Equipment test
PSS test
Alignment &
Global tests



+ all the activities in the technical areas

- Dismantling done in 2 shifts
- Installation done in normal days + late evenings for roof opening/closure

EBS installation

ESRF-EBS

Extremely Brilliant Source

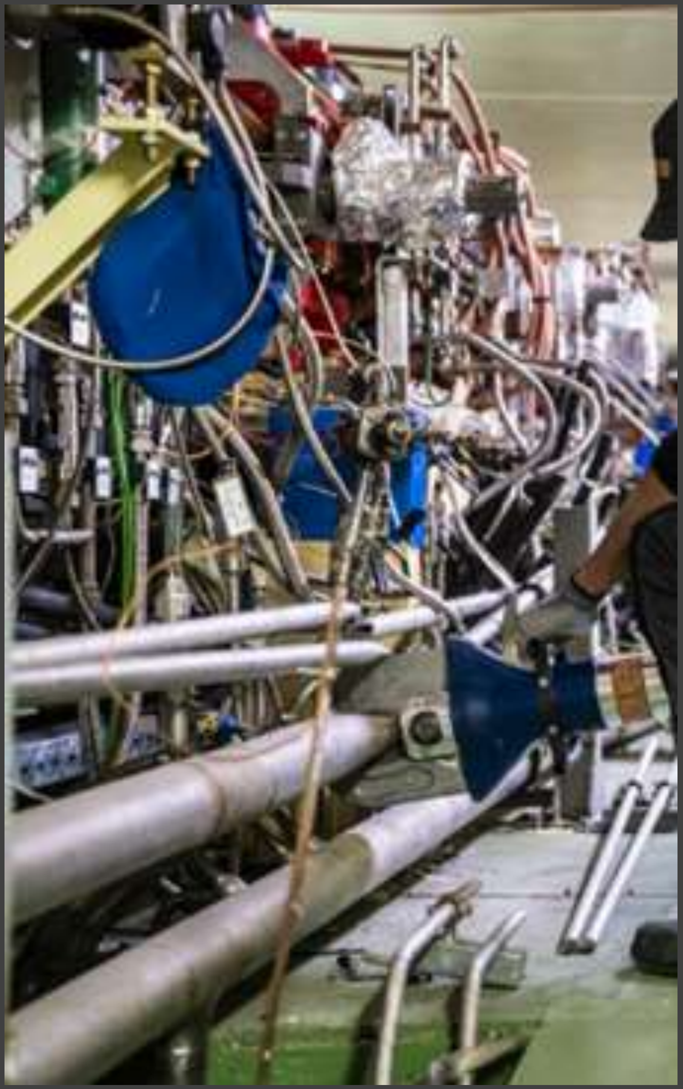
10 December 2018

10 December 2018

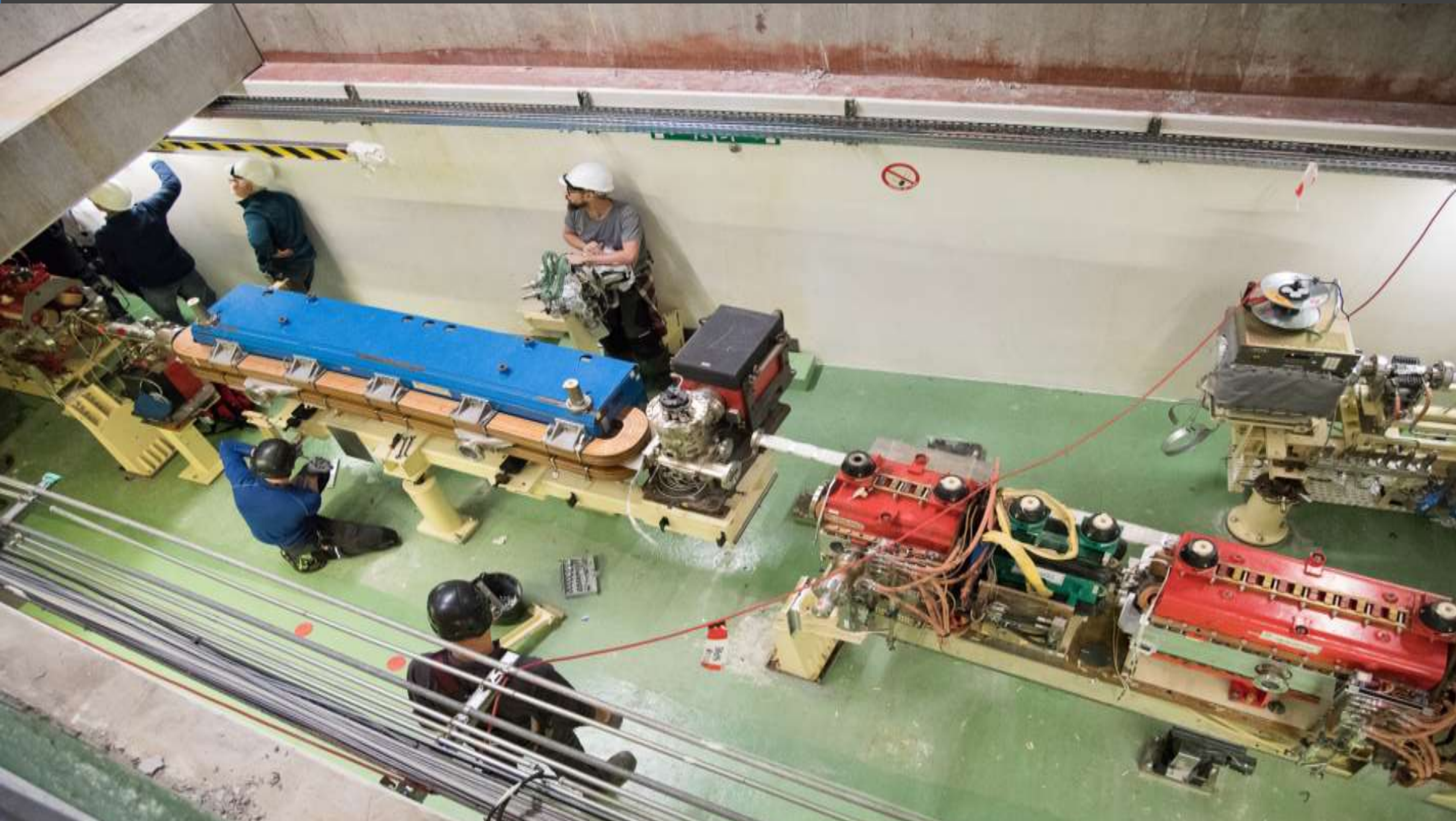
ESRF-Storage Ring

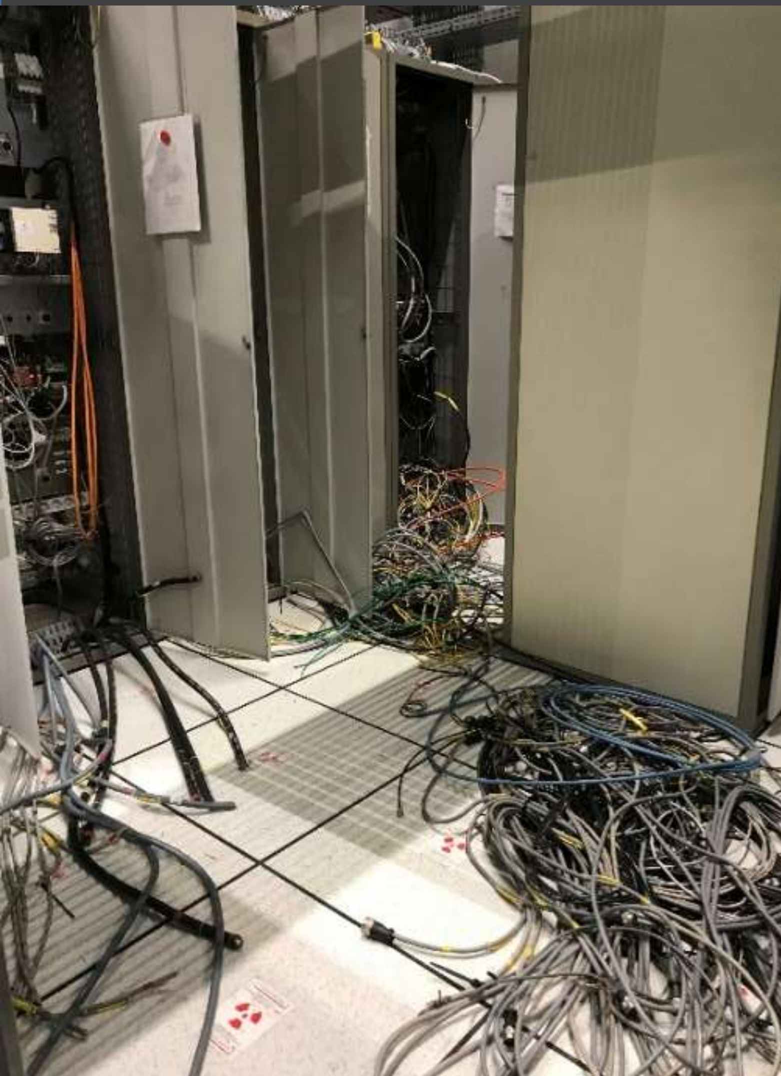
10 December 2018

Dismantling in the tunnel

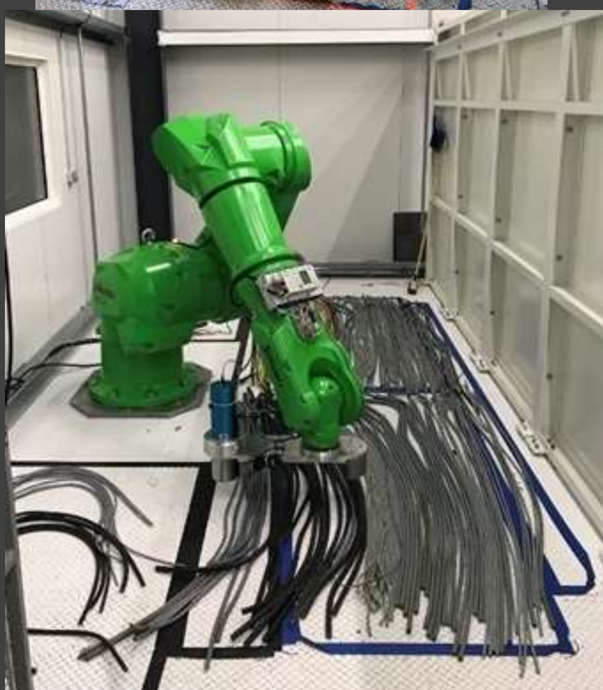

STILL



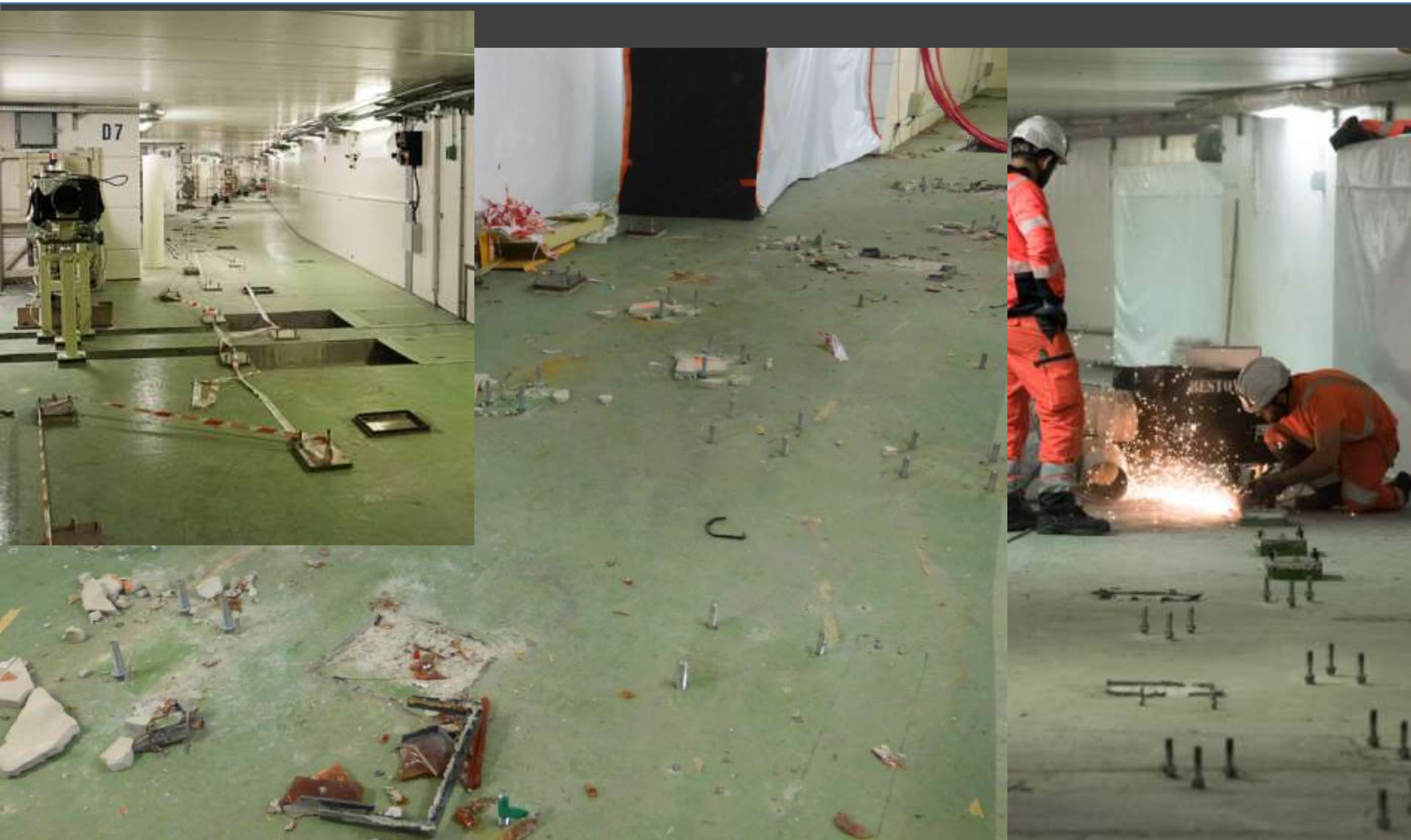



CO

Non activation measurements

Civil work

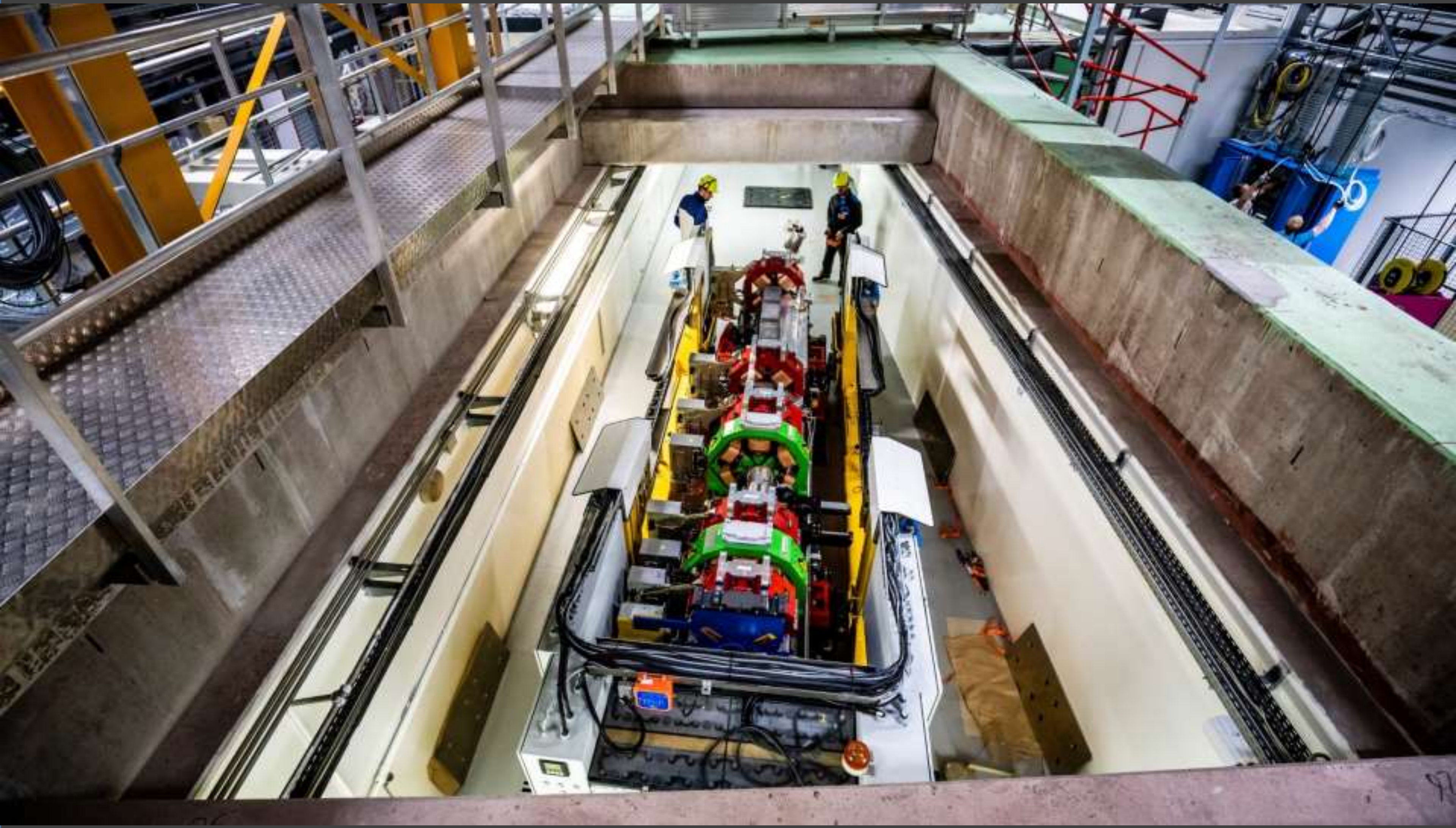

D7


ID5

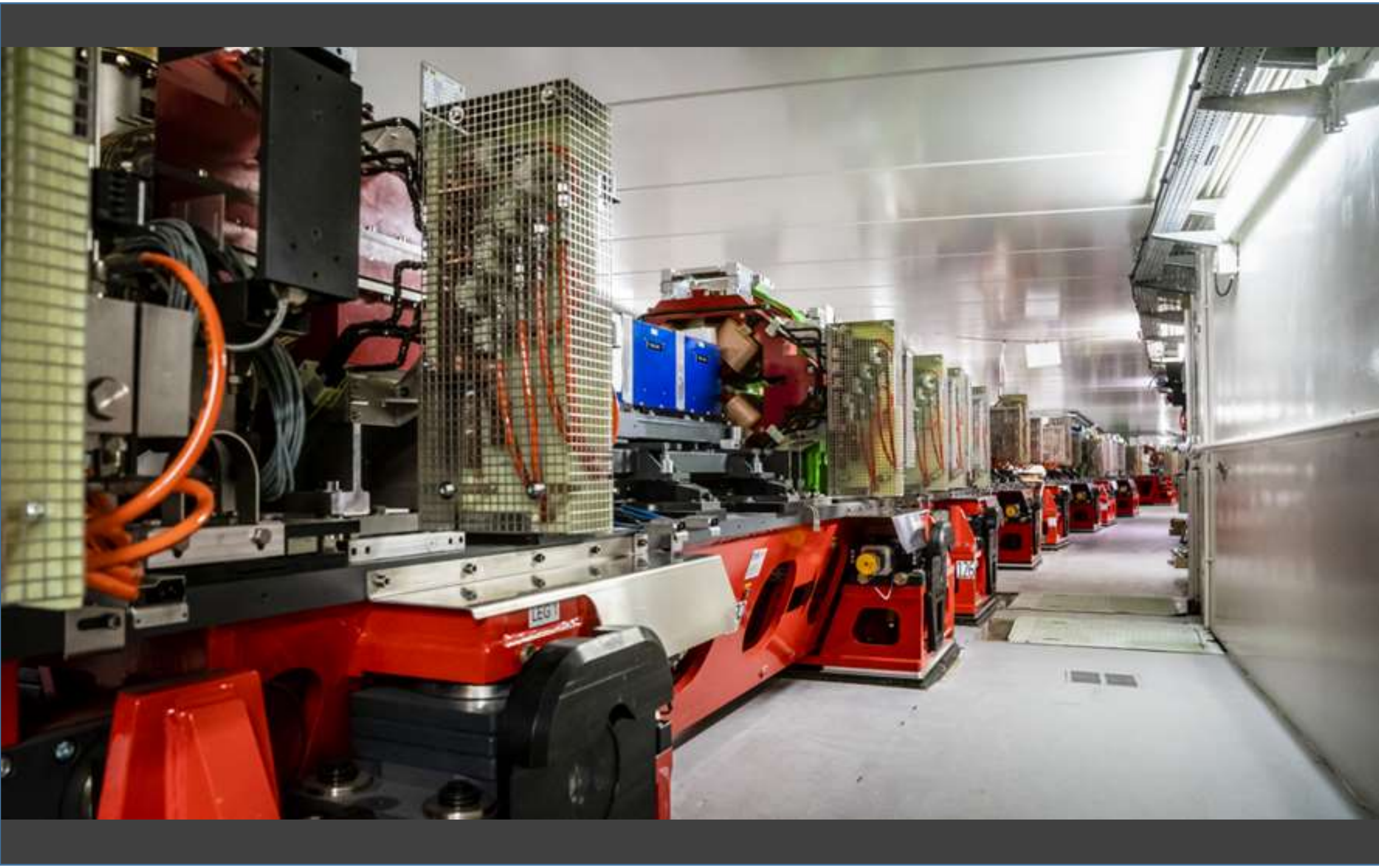
Installation of the girders


MEDIACO

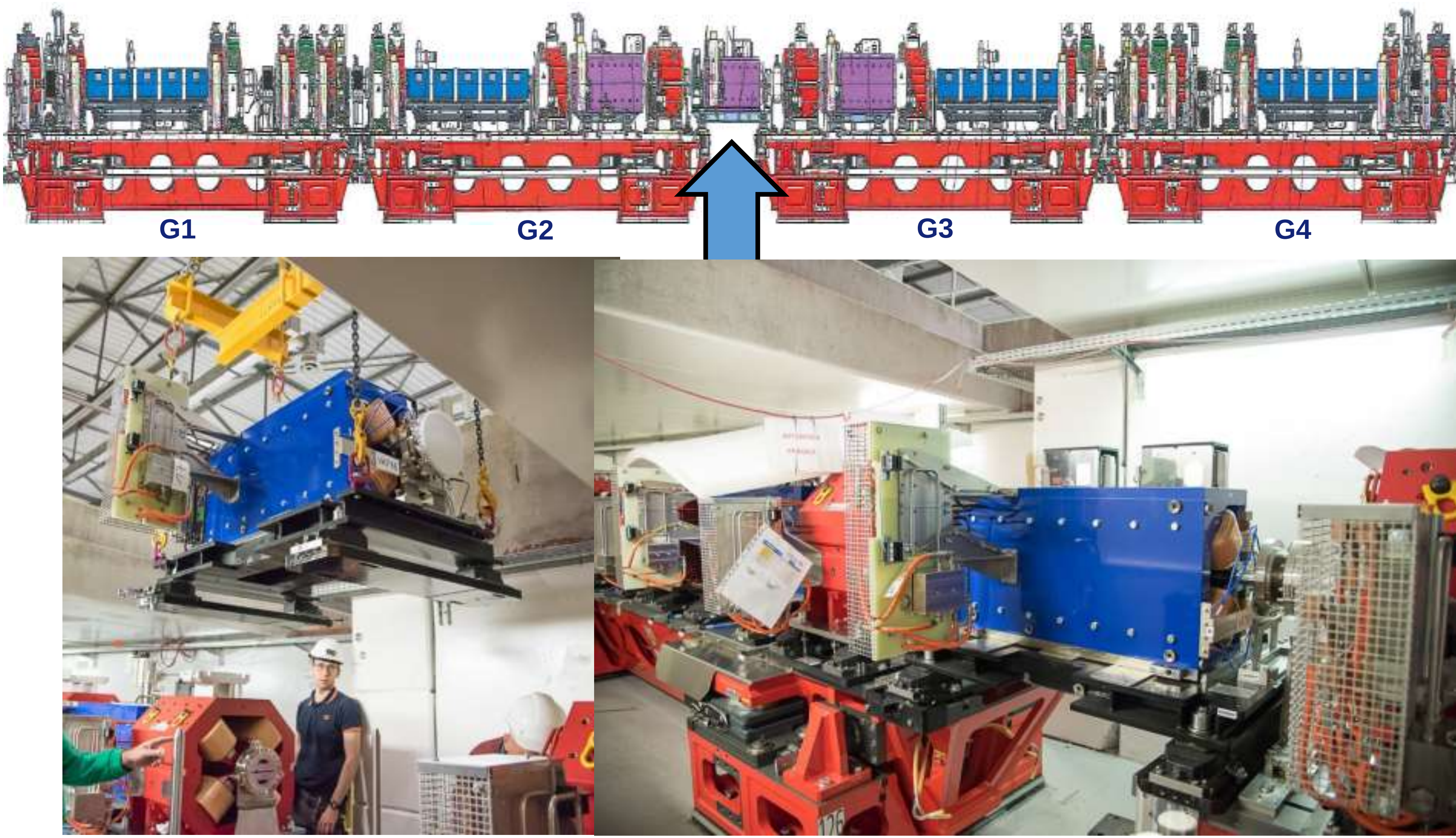

4
3

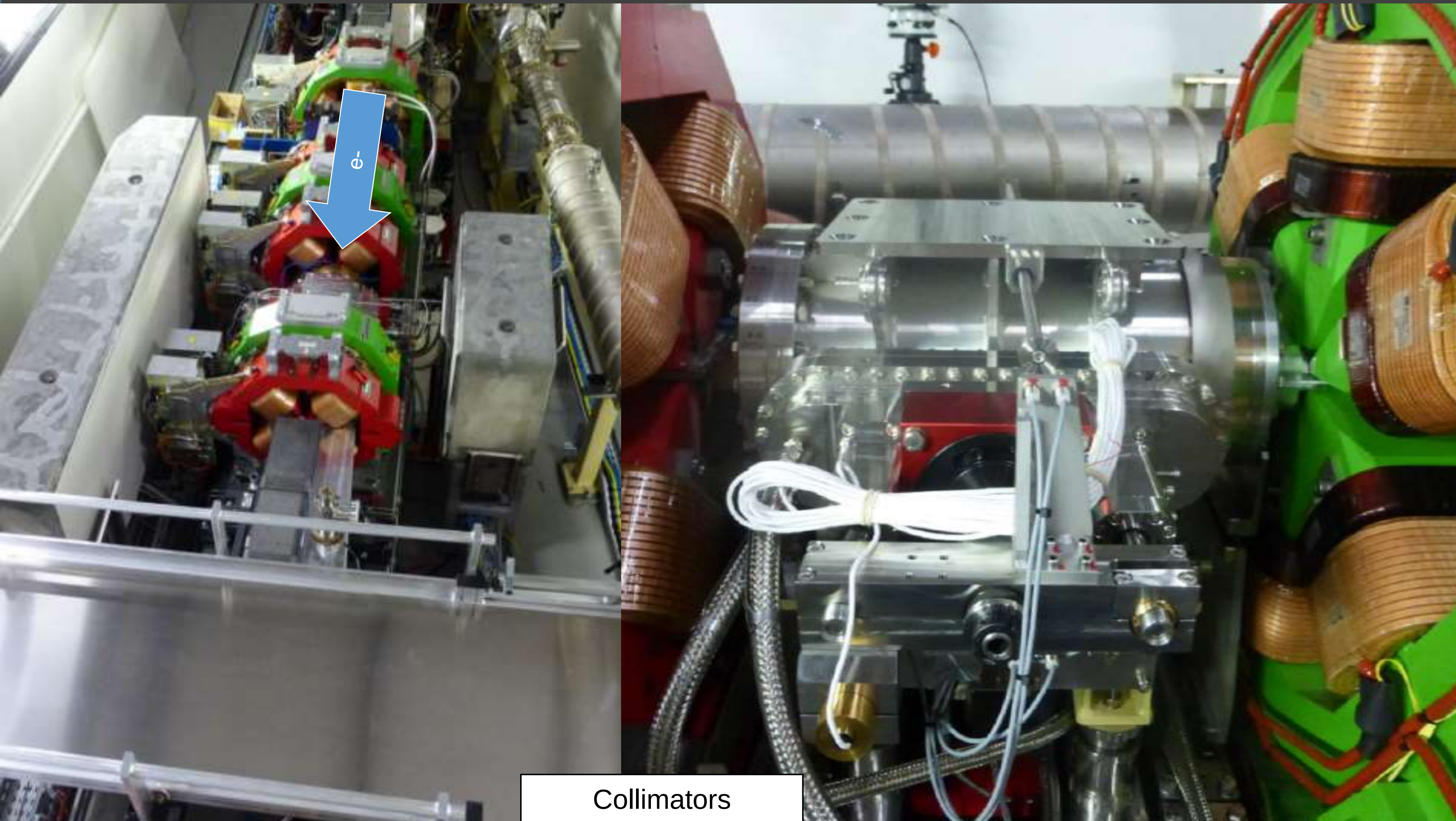



SPIE



Interconnection of the girders and special chambers


G1
G2
G3
G4

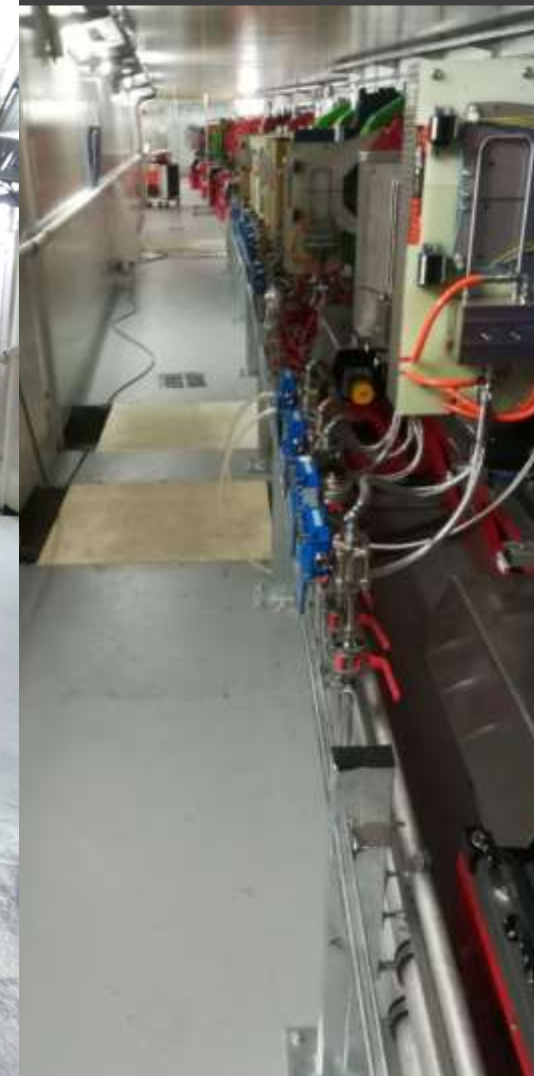


Collimators

Piping & Cabling



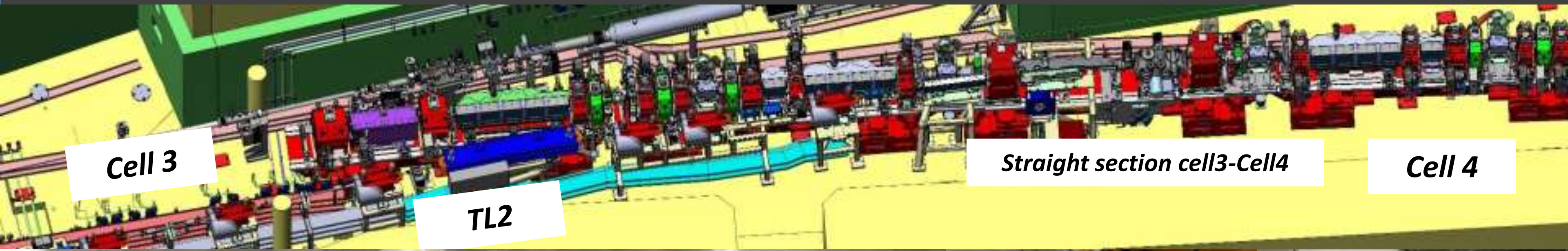




Straight sections Reconstruction



D13

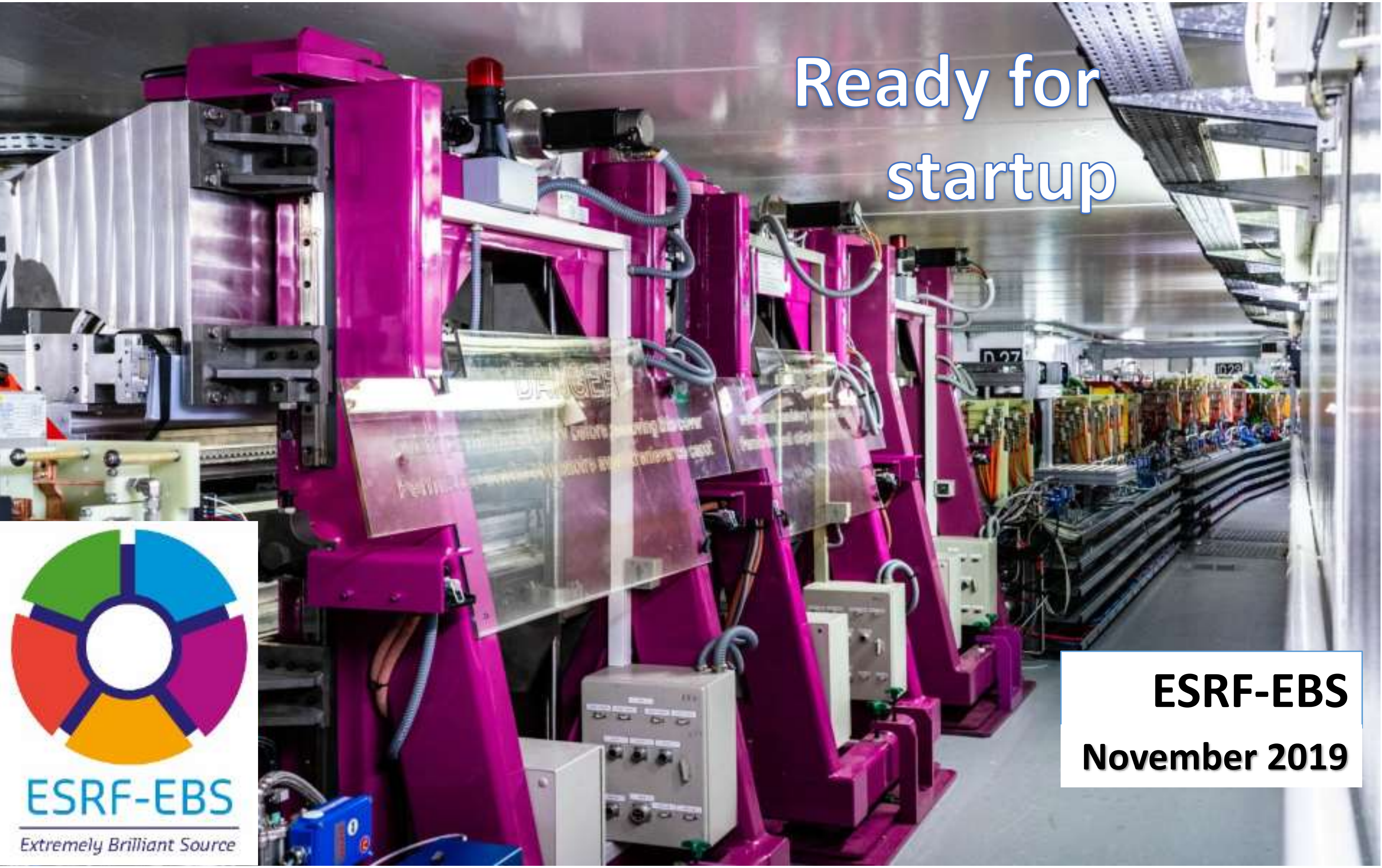

Cell 3
TL2
Straight section cell3-Cell4
Cell 4


D 02


D 08


D 07

Ready for startup



ESRF-EBS
Extremely Brilliant Source

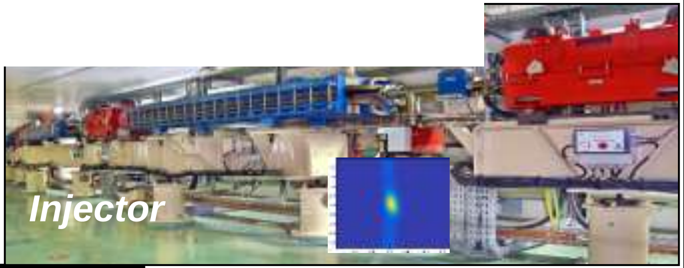
ESRF-EBS

November 2019

Tests

ESRF-EBS: EQUIPMENT TEST AND STARTUP

- ***Control software*, optics tools, commissioning scripts validated** *prior and during shutdown on the Storage Ring simulator*
- ***Low and high level control* for all equipment** *(including vacuum):*
  ➔ Started as soon as the cabling is done
- **Power test of the magnets** *from August to November with tunnel not accessible*
- ***During last weeks of the shutdown with tunnel close** (14/10 to 28/11)*:
  - ➔ Final alignment & survey
  - ➔ Validation of the personal safety system
  - ➔ Global power test of the magnets
  - ➔ Interlocks
  - ➔ Injection/extraction elements
  - ➔ Radio-frequency power commissioning
  - ➔ **Injector commissioning**



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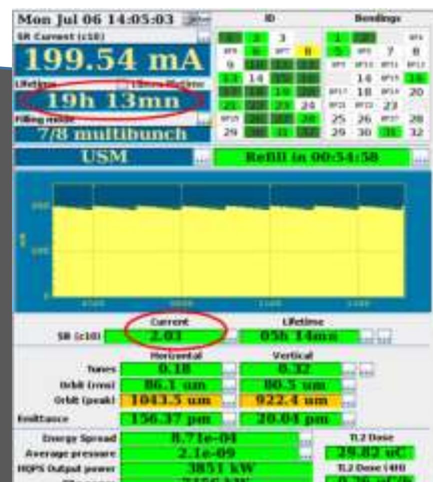
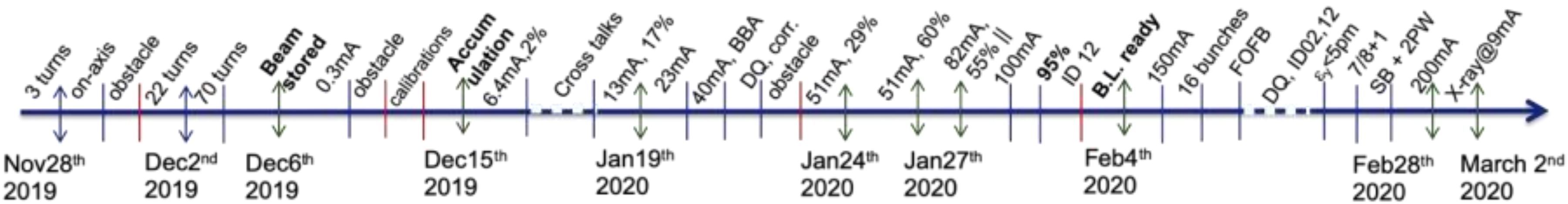
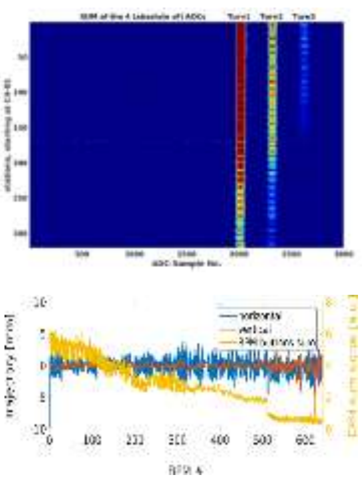
Commissioning



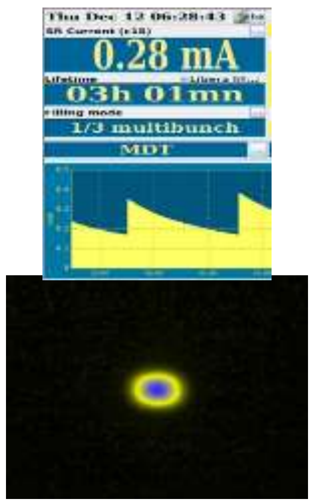
ESRF-EBS: BEAM COMMISSIONING



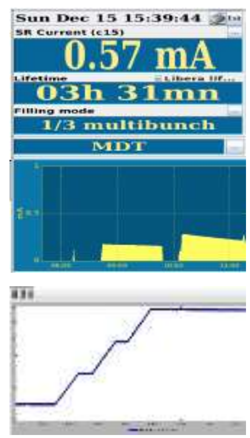
November 28th
First turns



December 6th
Beam stored



December 15th
Accumulation

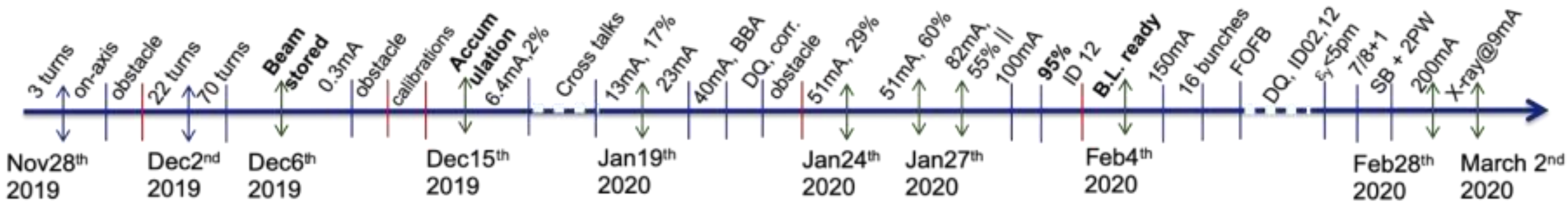


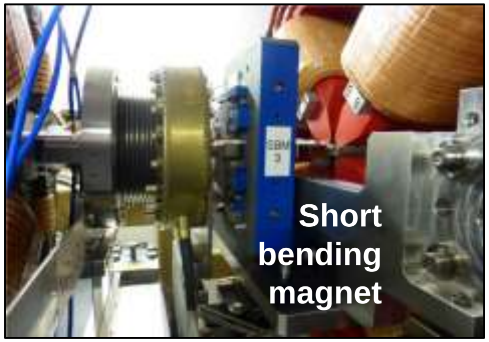
January 30th
First Beam on
26 Beamlines

February 28th
200 mA achieved

3 physical obstacles on the beam path and poor vacuum in a few ID NEG coated chambers slowed down the overall commissioning.

ESRF-EBS: BEAM COMMISSIONING



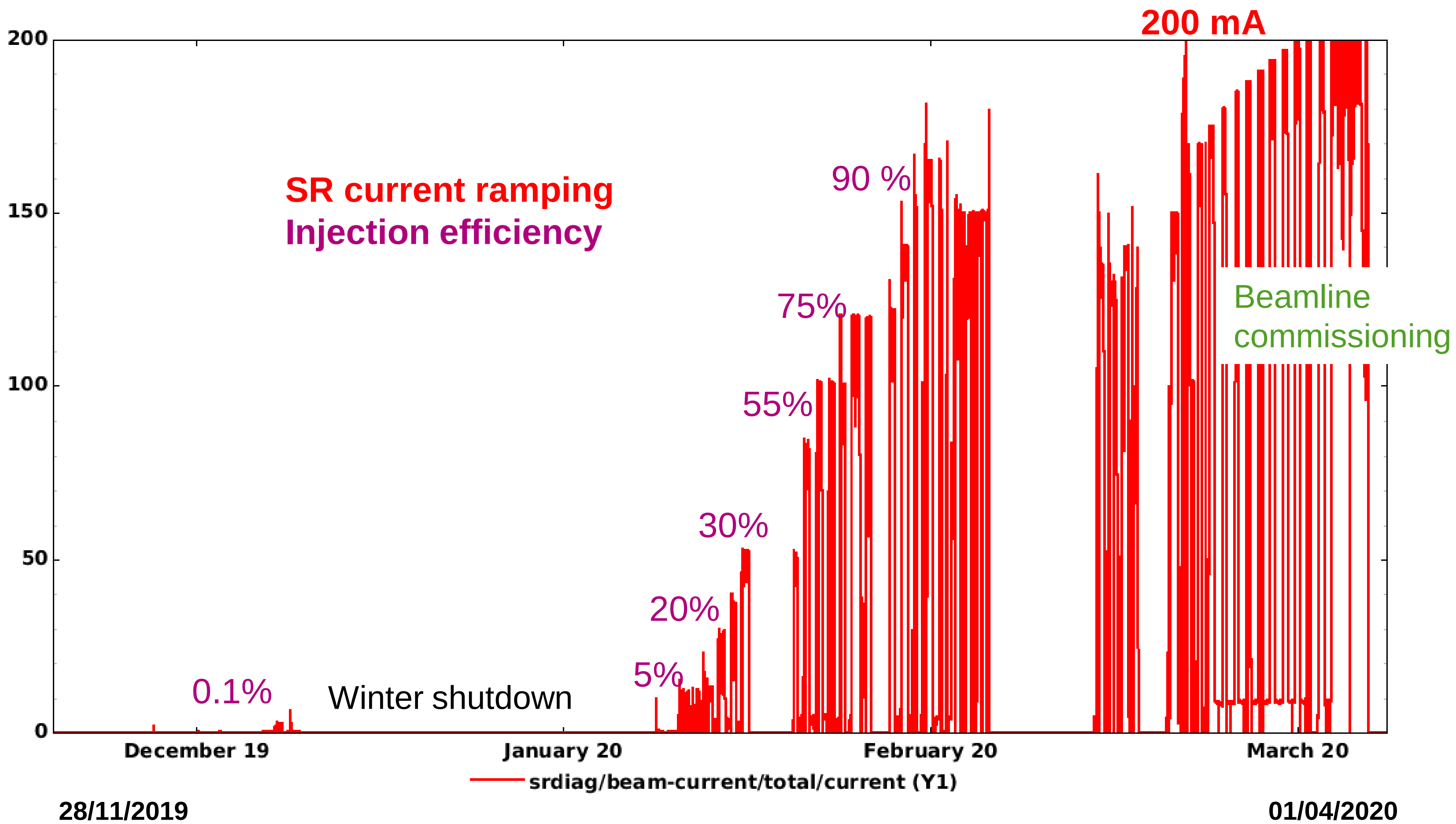


25 February MDT	BM 05	2PW
25 February MDT	BM 16	SB
March 8 MDT	BM 29	2PW
March 8 MDT	BM 30	SB
June Shutdown	BM 01	2PW
June Shutdown	BM 02	SB
June Shutdown	BM 08	SB
June Shutdown	BM 20	SB
June Shutdown	BM 31	2PW
June Shutdown	BM 32	SB
August Shutdown	BM 23	2PW
August Shutdown	BM 25	2PW
August Shutdown	BM 26	SB
August Shutdown	BM 28	SB
October Shutdown	BM 07	2PW
October Shutdown	BM 14	2PW
October Shutdown	BM 18	3PW

BM sources:

- No BM sources at the start of commissioning
- Most of the sources installed during shutdown
  (First installations done on a running machine)
- **Optic readjusted** after each installation
- Installation delayed due to lock-down
  Delay in the beamline commissioning
  Necessity to run one shift at low current for initial RP validation

ESRF-EBS: COMMISSIONING FROM 28/11 TO 01/04



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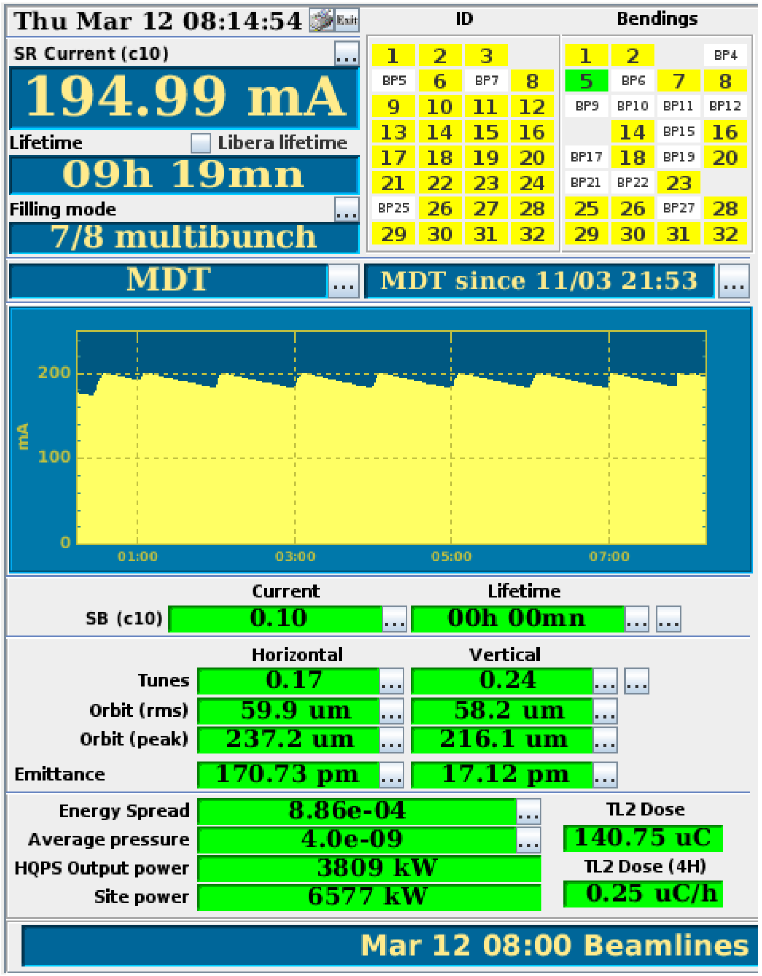
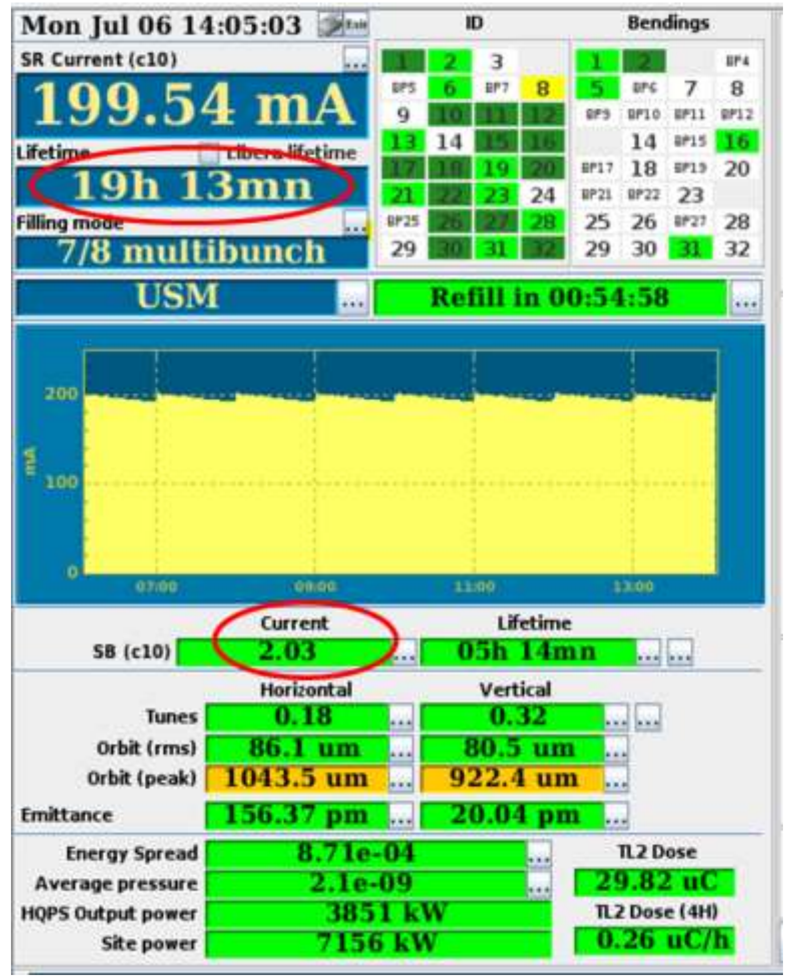
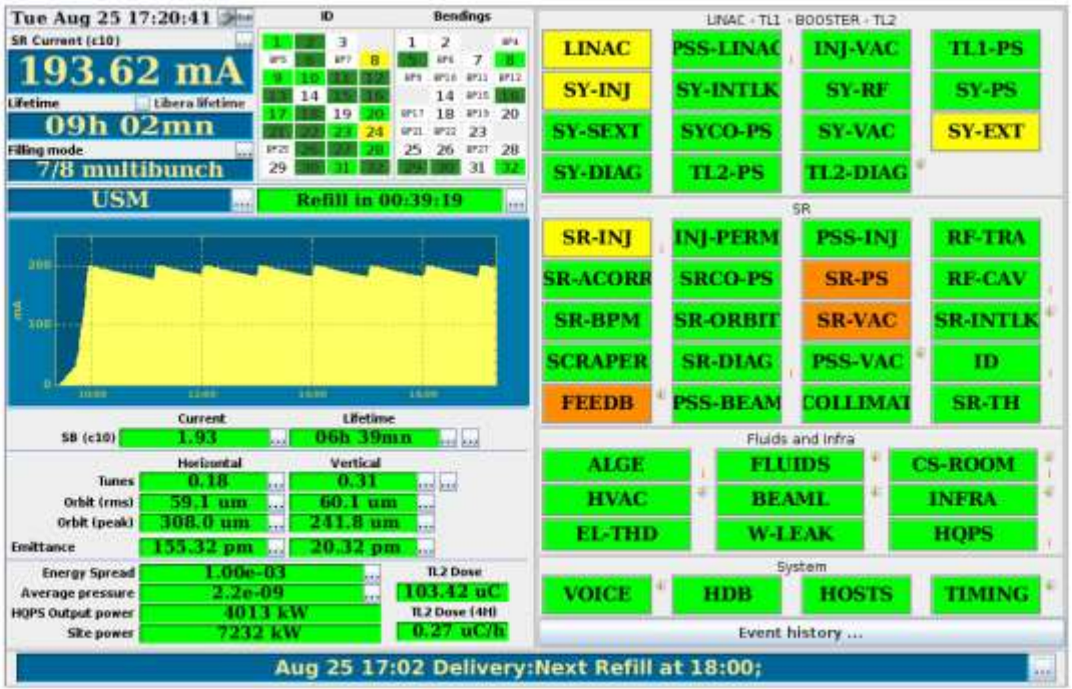
STATUS ON 12 MARCH AND 6 JULY





And … **the 25th August 2020, first official USM shift starts !**



- 28 beamlines take beam
- 200 mA
- $\varepsilon_v = 20$ pm rad

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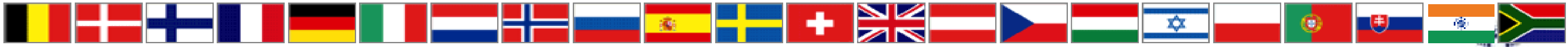
THE ESRF TODAY

ESRF

Operation



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OPERATION SCHEDULE 2022 (01/01 → 31/12)

Run 1 | Run 2 | Run 3 | Run 4 | Run 5

janv 2022		févr 2022		mars 2022		avr 2022		mai 2022		juin 2022	
sam 01	s s s	mar 01	. . .	mar 01	. . .	ven 01	. . .	dim 01	. . .	mer 01	. . .
dim 02	s s s	mer 02	. . .	mer 02	. . .	sam 02	. . .	lun 02	M M M	jeu 02	. . .
lun 03	s s s	jeu 03	. . .	jeu 03	. . .	dim 03	. . .	mar 03	. . .	ven 03	. . .
mar 04	s s s	ven 04	. . .	ven 04	. . .	lun 04	M M M	mer 04	. . .	sam 04	. . .
mer 05	s s s	sam 05	. . .	sam 05	. . .	mar 05	. . .	jeu 05	. . .	dim 05	. . .
jeu 06	s s s	dim 06	. . .	dim 06	. . .	mer 06	. . .	ven 06	. . .	lun 06	. . .
ven 07	s s s	lun 07	. . .	lun 07	M M M	jeu 07	. . .	sam 07	. . .	mar 07	M M M
sam 08	s s s	mar 08	M M M	mar 08	. . .	ven 08	. . .	dim 08	. . .	mer 08	. . .
dim 09	s s s	mer 09	M M M	mer 09	. . .	sam 09	. . .	lun 09	. . .	jeu 09	. . .
lun 10	s s s	jeu 10	. . .	jeu 10	. . .	dim 10	. . .	mar 10	. . .	ven 10	. . .
mar 11	s s s	ven 11	. . .	ven 11	. . .	lun 11	M M M	mer 11	s s s	sam 11	. . .
mer 12	s s s	sam 12	. . .	sam 12	. . .	mar 12	. . .	jeu 12	s s s	dim 12	. . .
jeu 13	s M M	dim 13	. . .	dim 13	. . .	mer 13	. . .	ven 13	s s s	lun 13	M M M
ven 14	M M M	lun 14	M M M	lun 14	. . .	jeu 14	. . .	sam 14	s s s	mar 14	. . .
sam 15	M M M	mar 15	. . .	mar 15	s s s	ven 15	. . .	dim 15	s s s	mer 15	. . .
dim 16	M M M	mer 16	. . .	mer 16	s s s	sam 16	. . .	lun 16	s s s	jeu 16	. . .
lun 17	M M M	jeu 17	. . .	jeu 17	s s s	dim 17	. . .	mar 17	s s s	ven 17	. . .
mar 18	. . .	ven 18	. . .	ven 18	s s s	lun 18	. . .	mer 18	s s s	sam 18	. . .
mer 19	. . .	sam 19	. . .	sam 19	s s s	mar 19	M M M	jeu 19	s M M	dim 19	. . .
jeu 20	. . .	dim 20	. . .	dim 20	s s s	mer 20	. . .	ven 20	M M M	lun 20	M M M
ven 21	. . .	lun 21	M M M	lun 21	s s s	jeu 21	. . .	sam 21	M M M	mar 21	. . .
sam 22	. . .	mar 22	. . .	mar 22	s s s	ven 22	. . .	dim 22	M M M	mer 22	. . .
dim 23	. . .	mer 23	. . .	mer 23	s s s	sam 23	. . .	lun 23	M M M	jeu 23	. . .
lun 24	M M M	jeu 24	. . .	jeu 24	s M M	dim 24	. . .	mar 24	. . .	ven 24	. . .
mar 25	. . .	ven 25	. . .	ven 25	M M M	lun 25	M M M	mer 25	. . .	sam 25	. . .
mer 26	. . .	sam 26	. . .	sam 26	M M M	mar 26	. . .	jeu 26	. . .	dim 26	. . .
jeu 27	. . .	dim 27	. . .	dim 27	M M M	mer 27	. . .	ven 27	. . .	lun 27	M M M
ven 28	. . .	lun 28	M M M	lun 28	M M M	jeu 28	. . .	sam 28	. . .	mar 28	. . .
sam 29	. . .			mar 29	. . .	ven 29	. . .	dim 29	. . .	mer 29	. . .
dim 30	. . .			mer 30	. . .	sam 30	. . .	lun 30	M M M	jeu 30	. . .
lun 31	M M M			jeu 31	. . .			mar 31	. . .		

juil 2022		août 2022		sept 2022		oct 2022		nov 2022		déc 2022	
ven 01	. . .	lun 01	s s s	jeu 01	. . .	sam 01	. . .	mar 01	M M M	jeu 01	. . .
sam 02	. . .	mar 02	s s s	ven 02	. . .	dim 02	. . .	mer 02	. . .	ven 02	. . .
dim 03	. . .	mer 03	s s s	sam 03	. . .	lun 03	M M M	jeu 03	. . .	sam 03	. . .
lun 04	M M M	jeu 04	s s s	dim 04	. . .	mar 04	. . .	ven 04	. . .	dim 04	. . .
mar 05	. . .	ven 05	s s s	lun 05	M M M	mer 05	. . .	sam 05	. . .	lun 05	M M M
mer 06	. . .	sam 06	s s s	mar 06	. . .	jeu 06	. . .	dim 06	. . .	mar 06	. . .
jeu 07	. . .	dim 07	s s s	mer 07	. . .	ven 07	. . .	lun 07	M M M	mer 07	. . .
ven 08	. . .	lun 08	s s s	jeu 08	. . .	sam 08	. . .	mar 08	. . .	jeu 08	. . .
sam 09	. . .	mar 09	s s s	ven 09	. . .	dim 09	. . .	mer 09	. . .	ven 09	. . .
dim 10	. . .	mer 10	s s s	sam 10	. . .	lun 10	. . .	jeu 10	. . .	sam 10	. . .
lun 11	M M M	jeu 11	s s s	dim 11	. . .	mar 11	. . .	ven 11	. . .	dim 11	. . .
mar 12	. . .	ven 12	s s s	lun 12	M M M	mer 12	s s s	sam 12	. . .	lun 12	. . .
mer 13	. . .	sam 13	s s s	mar 13	. . .	jeu 13	s s s	dim 13	. . .	mar 13	s s s
jeu 14	. . .	dim 14	s s s	mer 14	. . .	ven 14	s s s	lun 14	M M M	mer 14	s s s
ven 15	. . .	lun 15	s s s	jeu 15	. . .	sam 15	s s s	mar 15	. . .	jeu 15	s s s
sam 16	. . .	mar 16	s s s	ven 16	. . .	dim 16	s s s	mer 16	. . .	ven 16	s s s
dim 17	. . .	mer 17	s s s	sam 17	. . .	lun 17	s s s	jeu 17	. . .	sam 17	s s s
lun 18	. . .	jeu 18	s M M	dim 18	. . .	mar 18	s s s	ven 18	. . .	dim 18	s s s
mar 19	M M M	ven 19	M M M	lun 19	M M M	mer 19	s s s	sam 19	. . .	lun 19	s s s
mer 20	. . .	sam 20	M M M	mar 20	. . .	jeu 20	s M M	dim 20	. . .	mar 20	s s s
jeu 21	. . .	dim 21	M M M	mer 21	. . .	ven 21	M M M	lun 21	M M M	mer 21	s s s
ven 22	. . .	lun 22	M M M	jeu 22	. . .	sam 22	M M M	mar 22	. . .	jeu 22	s s s
sam 23	. . .	mar 23	. . .	ven 23	. . .	dim 23	M M M	mer 23	. . .	ven 23	s s s
dim 24	. . .	mer 24	. . .	sam 24	. . .	lun 24	M M M	jeu 24	. . .	sam 24	s s s
lun 25	. . .	jeu 25	. . .	dim 25	. . .	mar 25	. . .	ven 25	. . .	dim 25	s s s
mar 26	. . .	ven 26	. . .	lun 26	M M M	mer 26	. . .	sam 26	. . .	lun 26	s s s
mer 27	s s s	sam 27	. . .	mar 27	. . .	jeu 27	. . .	dim 27	. . .	mar 27	s s s
jeu 28	s s s	dim 28	. . .	mer 28	. . .	ven 28	. . .	lun 28	M M M	mer 28	s s s
ven 29	s s s	lun 29	M M M	jeu 29	. . .	sam 29	. . .	mar 29	. . .	jeu 29	s s s
sam 30	s s s	mar 30	. . .	ven 30	. . .	dim 30	. . .	mer 30	. . .	ven 30	s s s
dim 31	s s s	mer 31	. . .			lun 31	. . .			sam 31	s s s

A standard year = 5600 USM hours

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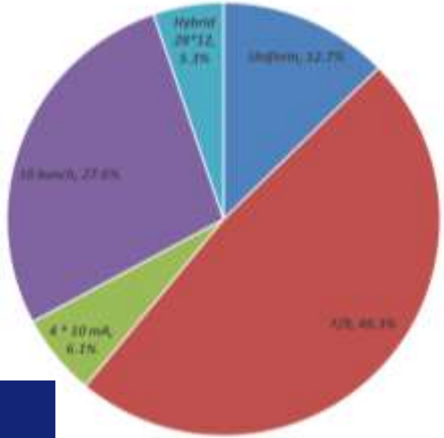
2022: BEAM DELIVERY

2022



	7/8 + 1	Uniform	28*12+1 (Hybrid)	16 bunch	4 bunch
I_{max} (mA)	192+8	200	192 + 8	75	40
Lifetime (h)	> 20	~ 25	> 16	~ 5.5	~ 5
ε_v (pm)	10	10	20	20	**40**
Nominal Reached on	13/09/22	21/11/20	14/11/22	23/08/22	05/12/22

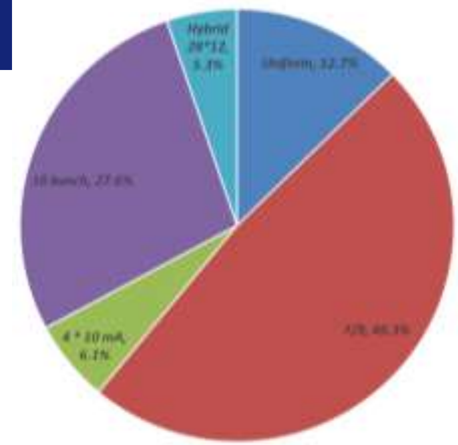
** Intensity limitation for timing modes due to mechanical weakness of the kicker ceramic chambers*

** Vertical emittance artificially increased from 1 pm rad for an operational lifetime*

** All timing modes delivered with a purity of 10^{-9} with cleaning process in the booster*

2022 : DELIVERY MODES : WHAT THEY LOOK LIKE ?

2022

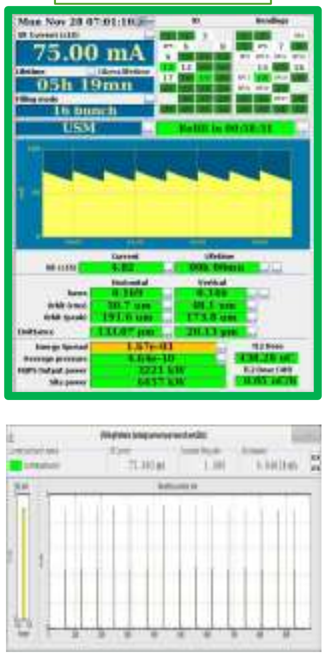


7/8 + 1

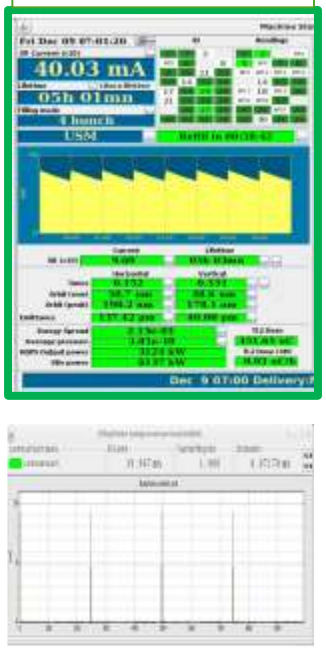
Uniform

28 * 12 + 1

16 bunch



4 * 10 mA bunch



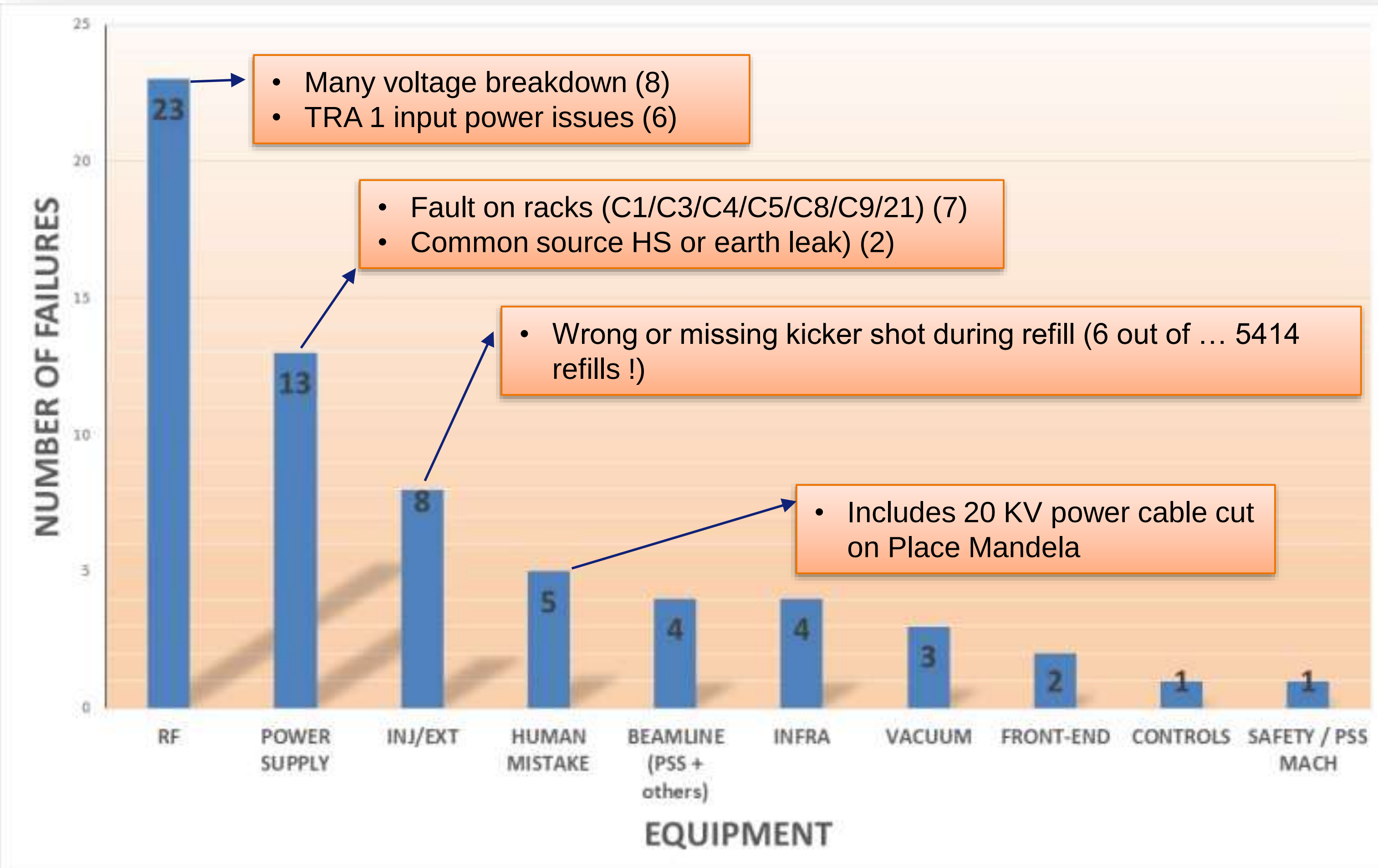
2021 : HIGHLIGHTS OF BEAM DELIVERY

Machine Statistics for 2018 at the ESRF and for 2020 – 2022 (EBS)

- **4978 hours of beam delivered in 2021 out of 4648 scheduled**
- **Overall availability in 2021: 96.35 %**
- **5438 hours of beam delivered in 2022 out of 5490 scheduled**
- **Overall availability in 2022: 99.06 %**

MACHINE – USM	2018	2020	2021	2022
Availability (%)	98.47	96.08	96.35	**99.06**
Mean Time Between Failures (hrs)	104.30	46.00	66.4	**88.5**
Mean duration of a failure (hrs)	1.60	1.80	2.42	**0.83**

2022 : SUMMARY OF FAILURES AFFECTING MTBF



Total : 64 failures (seen from machine side)

8 failures only can be directly attributed to EBS developments still in progress.

36 triggered **outside working hours**

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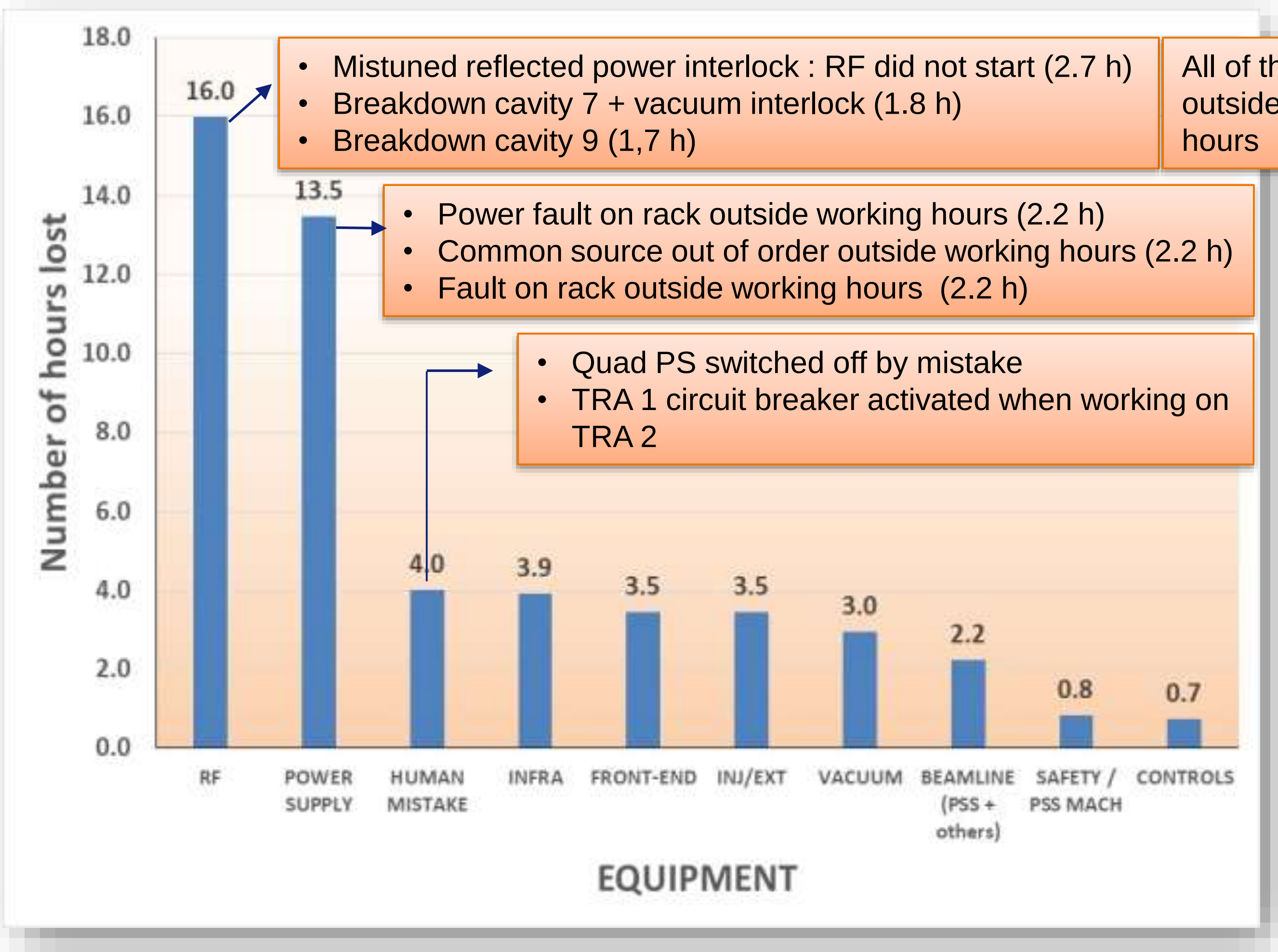
2021 : SUMMARY OF FAILURES AFFECTING AVAILABILITY



- **Total : 51 hours**
- More than 34 hours of intervention outside working hours

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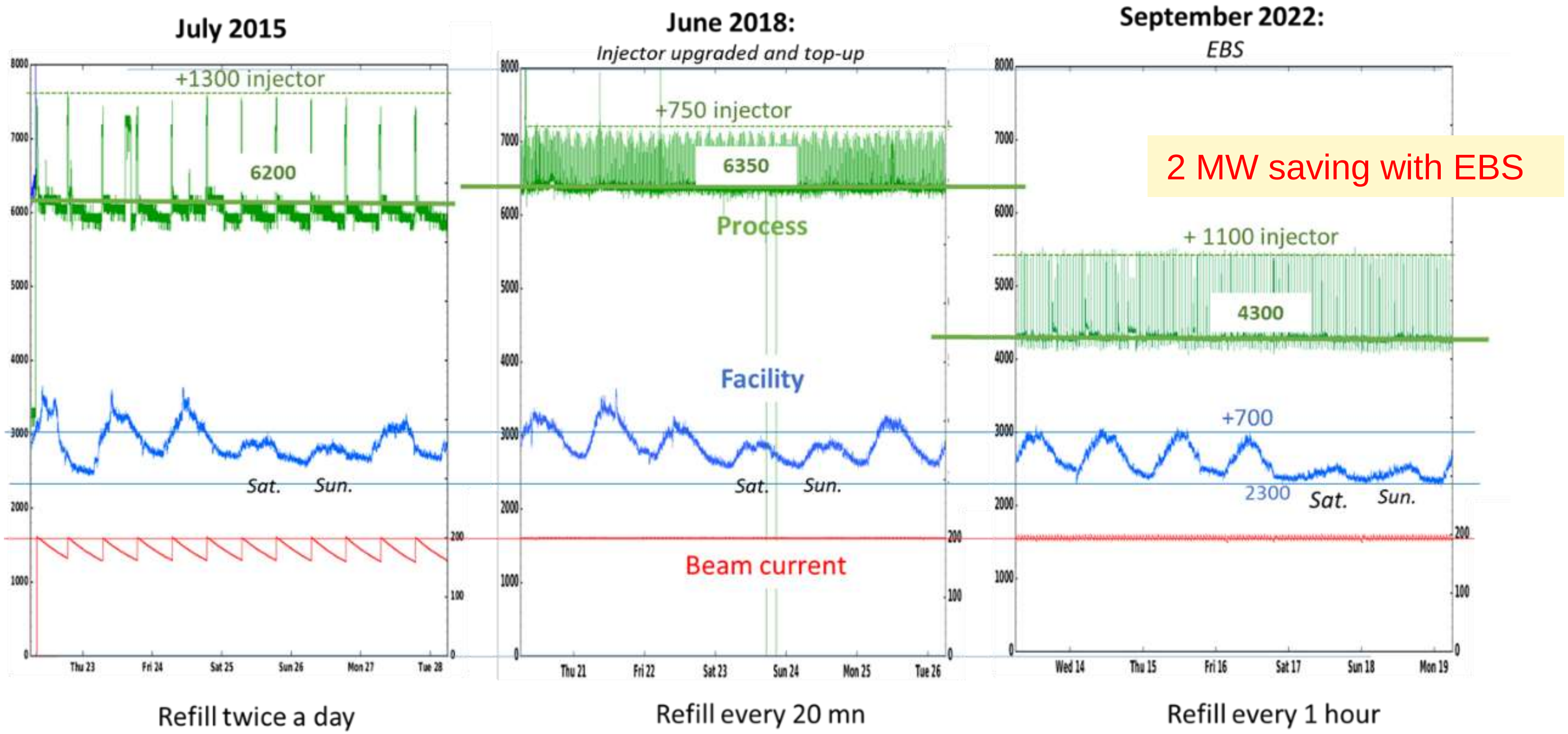
ESRF ENERGY CONSUMPTION OVERVIEW

Electricity consumption before EBS = 65 350 MWh

after EBS = 53 000 MWh (-20%)



STORAGE RING RF - ECO MODE SINCE END OCTOBER 2022

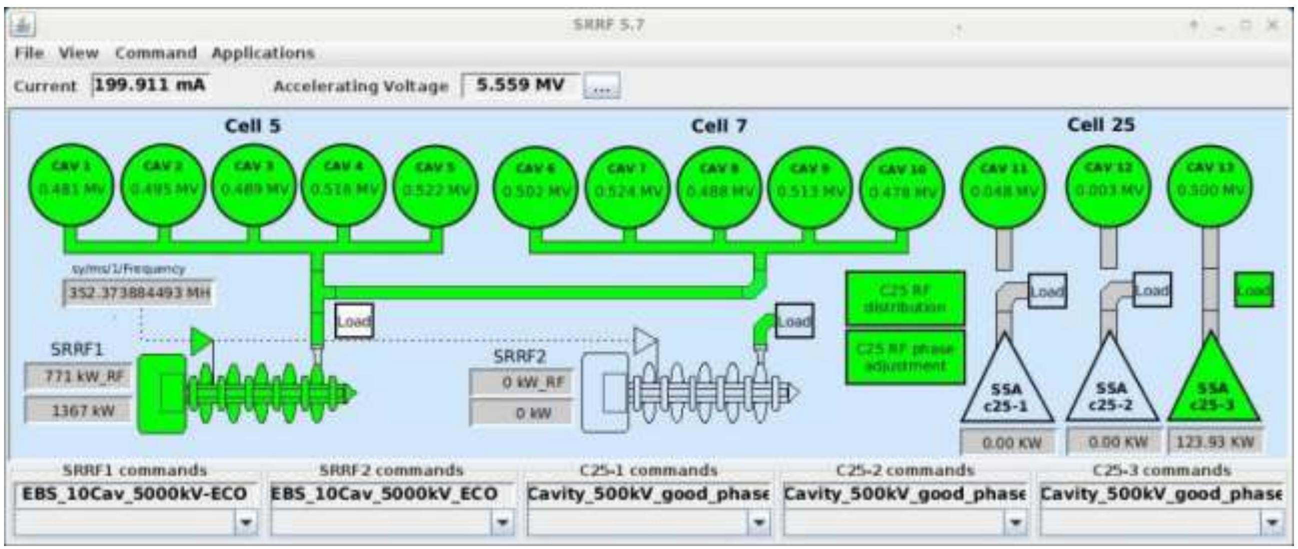
ECO mode: Reduction of total accelerating voltage from **6.0** to **5.5 MV**

- **And Increase AC to RF conversion efficiency:**

  10 years old 150 kW SSA in cell 25 operated way below nominal power , at 90 …100 kW, where the efficiency is low.

  ⇒ Increase the share of Klystron power by increasing Cav 1 to 10 voltage from 4.5 to 5.0 MV

  ⇒ Operate with only 1 SSA e.g. Cav 13 at 0.5 MV



RESULT:

- **200 kW AC power savings** at 200 mA
- **Same beam lifetime** for typical ID losses around 0.4 … 0.5 MeV/turn
- 500 kW total savings possible if operation at 100 mA

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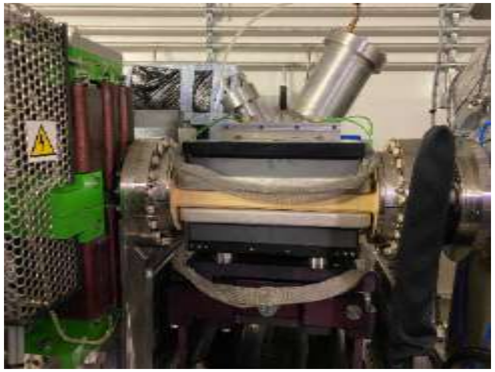
LIMITATION IN CURRENT



Intensity limited for all timing modes (i.e. high intensity / bunch)

- Abnormal temperature of the ceramic chambers observed

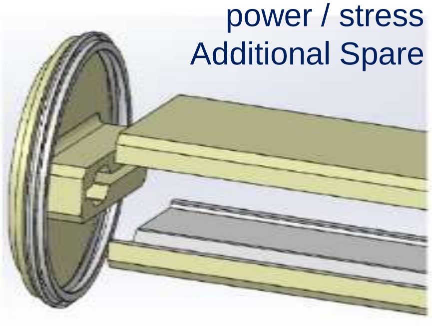
Existing ceramic kicker and shaker chambers fragile: present design does not withstand thermal stress
➔ Cause: assembly from several parts with glazing joints (bubbles)

Delay in the procurement of new chambers
➔ impose to implement a mitigation strategy

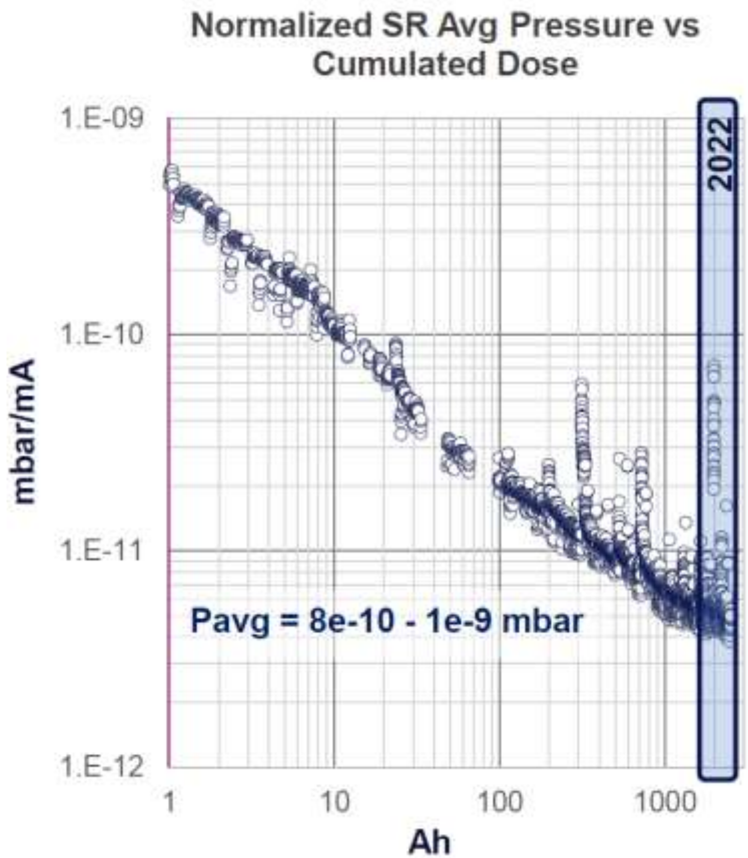
increase of the coating (reduced impedance) thanks to the implementation of slow ramping kicker power supply

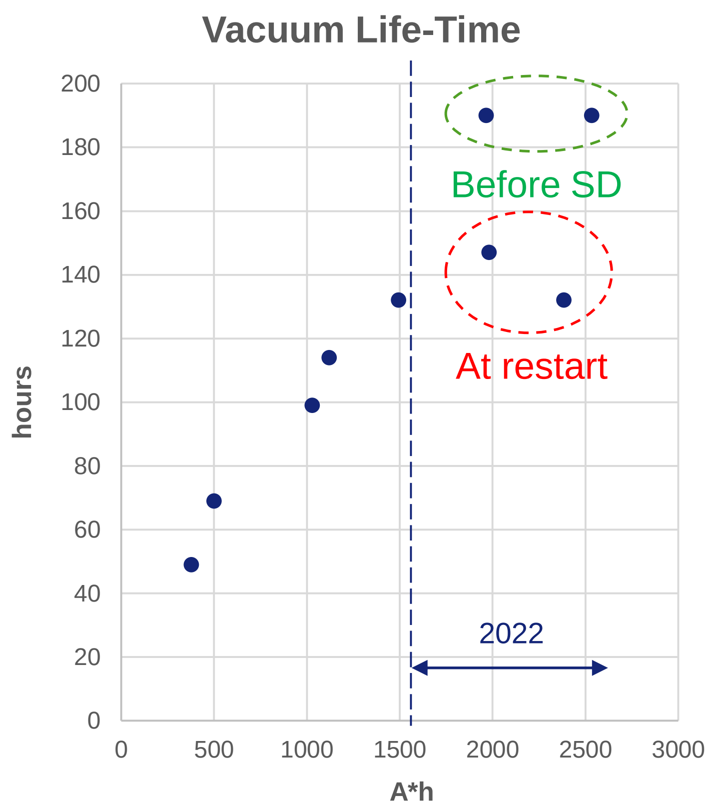
- Additional spare, with original design should allow test at full current in 16-bunch in May-23
- New design deliveries should allow installation in 2024

Existing Kickers:
Original Design
Additional Coating -> reduce power / stress
Additional Spare



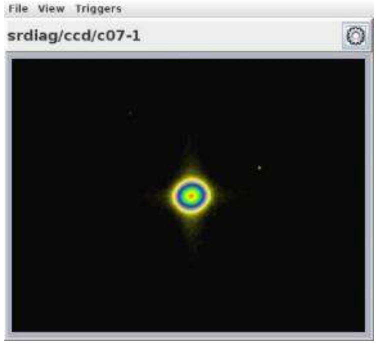
New Kicker Design :
One Single Piece
Eliminate ceramic junction
All 4 same geometry



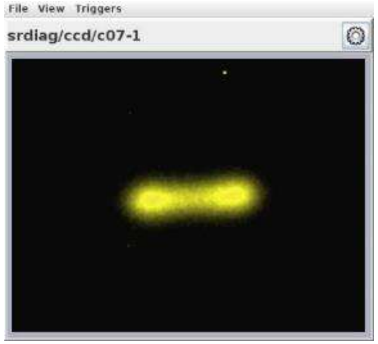


- Still conditioning
- Reaching lowest measurable limit at some locations

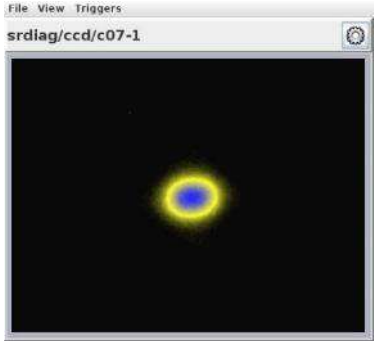
INJECTION PERTURBATION BY KICKERS AND SEPTA



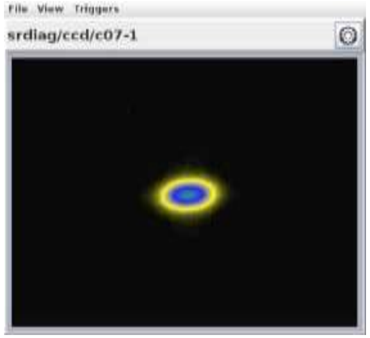
Kickers OFF



Kickers ON



Horizontal compensation ON



Horizontal and Vertical compensation ON

- Off-axis injection scheme very similar to the one of the previous machine proved to be very efficient for the commission and the restart but*:*
- Perturbations of the closed orbit during top-up injections and a greater sensitivity of the beamlines due to the reduced beam size of the stored beam prevent some beamlines from acquiring data
  and consequently limits today the full exploitation of EBS
  - ✓ Top-up frequency reduced from one every 20 minutes to one every 1hour to limit disturbances
  - ✓ Kicker power supplier upgrade and feedforward compensation are effective but not sufficient
  - ✓ New injection schemes are under evaluation

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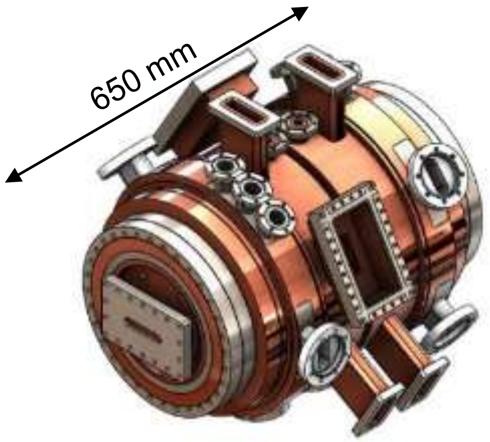
STATUS - 4TH HARMONIC RF SYSTEM FOR BUNCH LENGTHENING

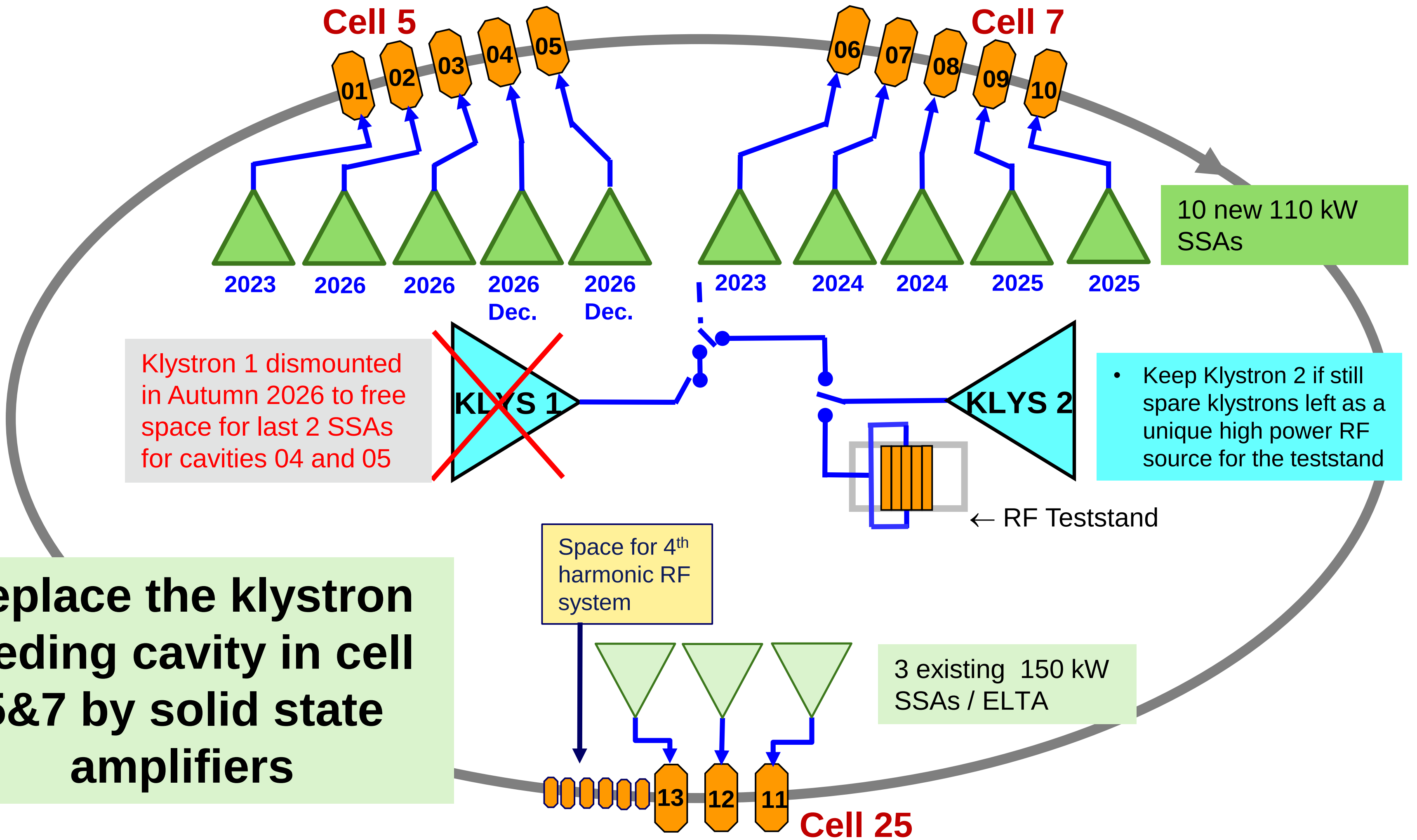
For all modes: Hor. Emit. ε_z = 135 pm	Multibunch 7/8 filling	16-bunches	4-bunches
Total current	200 mA	92 mA	40 mA
Current per bunch	0.23 mA	5.75 mA	10 mA
Bunch length (calc.)	13 ps	31 ps	37 ps
Vert. Emit. ε_z set at	10 pm	20 pm	20 pm
Touschek Lifetime	33 h	≈ 4,5 h	≈ 4 h



Priority for high I / bunch (16 bunch and 4 x 10 mA)

- Reduced Touschek scattering, IBS and microwave instability by bunch lengthening (factor 3):
  - Increased lifetime → less frequent injections, reduced loss rate and radiation load
  - Room for smaller In-Vacuum ID gaps
  - alleviate possible impact from future lattice developments like mini-beta straights
  - Reduced emittance and energy blow up
- Reduced heat-load and stress of critical chambers, like ceramic chambers or In-Vacuum IDs

GRADUAL IMPLEMENTATION OF 10 SSA (EACH 110 KW RF, MAX 250 KW AC)



Replace the klystron feeding cavity in cell 5&7 by solid state amplifiers

DAMAGES IN THE STORAGE RING DUE TO RADIATION

Some equipment are already suffering from radiation damages around the straight sections equipped with Aluminum NEG coated vacuum chambers.

- Aging of HLS captors of girder1
- Increasing number of faulty ion pump cables
- Change in color, degradation, brittleness of insulating of cables

Several actions implemented or in progress until summer 2023 shutdown:

- Visual inspection of the cables to follow-up their status
- Identification of the damaged devices
- Risk assessment study

- Installation of lead shielding on HLS captors
- Replacement of damaged cables
- Installation of additional lead shielings
- Installation of lead shielding on the FE photon shutters

CONCLUSION

- **EBS project run in parallel with ESRF operation**
  - No impact on user operation
  - Continuation of the development of the existing machine, preparation of the new SR
- **Project execution completed on schedule :**
  - Engineering Design, Procurement, Delivery of main components, Mock-up cell, Assembly
  - Dismantling/installation
  - Commissioning of the new source
  - Beamline commissioning
  - Back to operation with users on 25 August
- **Present status and overview**
  - The new source is available for new science.
  - Beamlines are now taking full benefit from the source, and continue to develop and upgrade
  - Main performances achieved (beam current, beam modes, lifetime, emittances, stability)
  - Excellent reliability of the equipment
  - Still a lot to fine tune the operation of the new storage ring
  - New projects already been launched for future improvement

MANY THANKS FOR YOUR ATTENTION