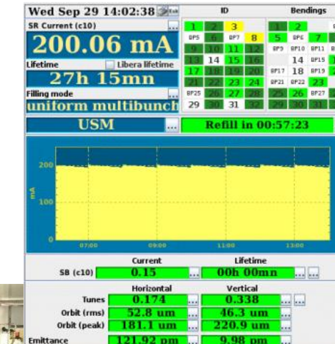
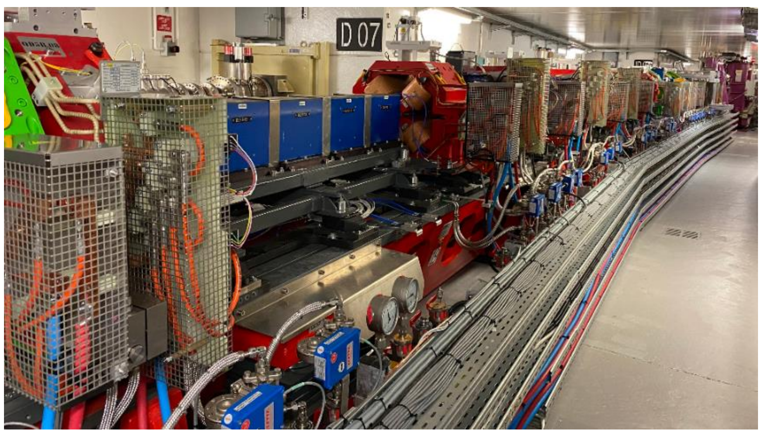
ALBA SYNCHROTRON LIGHT SOURCE, Barcelona Spain, 27 September 2023

ESRF-EBS Implementation, Commissioning and Restart of user operation

Jean-Luc Revol

On behalf of the EBS Accelerator Project Team





ESRF | The European Synchrotron

My position at ESRF:

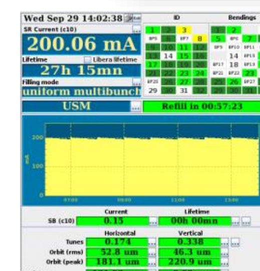
- Operation Manager *(From January 2002)*
- Engineer in the Radio-Frequency Group *(October 1989 to January 2002)*

My involvement in EBS:

- ✓ Coordinator of the accelerator parts of the Purple Book (Phase 1), White Paper and Orange Book (Phase2)
- ✓ Coordinator of the TDS phase, including budget and planning
- ✓ Coordinator in the Accelerator Project Office during implementation
- ✓ EBS procurement coordinator
  - *Preparation and follow-up of the budget*
  - *Follow-up of the contracts execution and deliveries*
- ✓ Coordination of Equipment set-up and commissioning
- ✓ Coordination of the return to operation





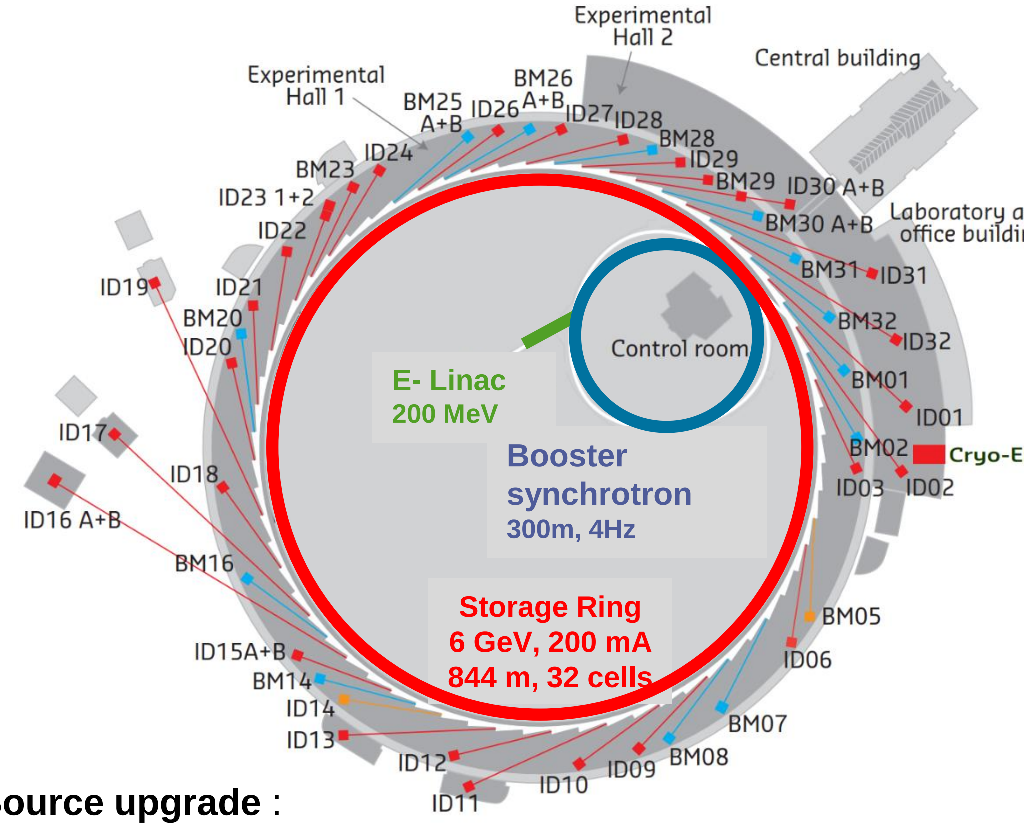


OUTLINE

- **ESRF-EBS Project overview** *[20 mn]*
  - Objectives (Lattice, technical constraints,..)
  - EBS time line
  - Accelerator main components
  - Design & procurement
  - Assembly Phase & Mockup Cell
  - Upgrades and preparatory work prior shutdown
  - Logistics
- **Shutdown activities** *[PPT Film 5 mn]*
  - Dismantling
  - Installation in the tunnel
  - Installation in the technical zones
- **Restart** *[20 mn]*
  - Beam commissioning
  - Performance
  - User operation
- **Lessons learned** *[10 mn]*
- **Conclusion**

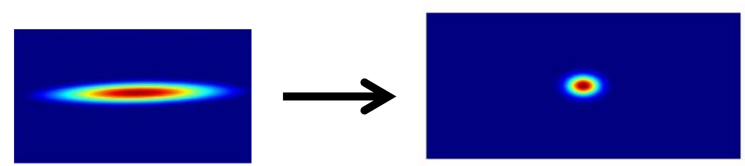
ESRF FACT AND FIGURES

Light source in operation since 1994
Located in Grenoble France
22 partner nations
Annual budget: 100 million euros
Staff: 650 people
***Legal status:* Private civil company subject to French law**



The **ESRF Extremely Brilliant Source upgrade** :

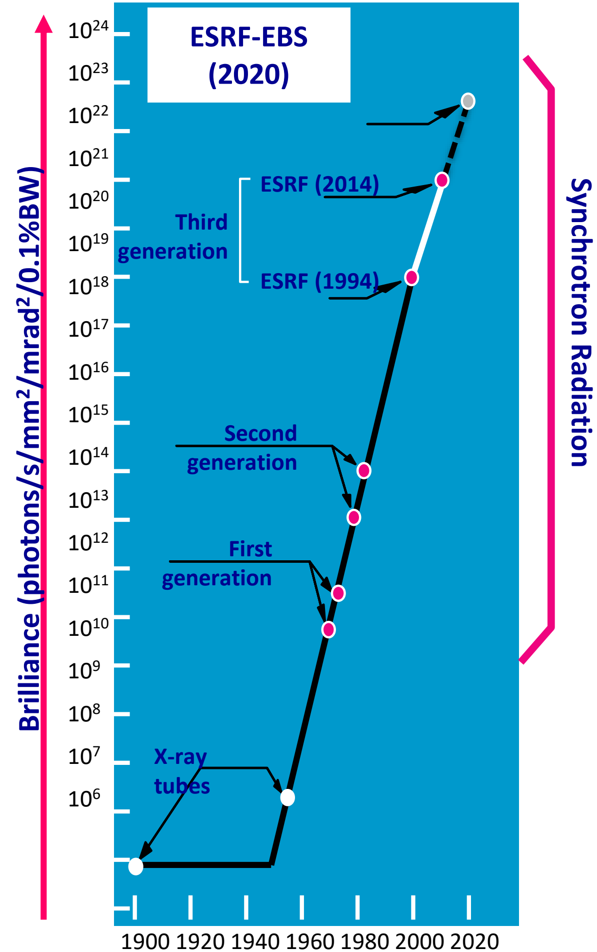
- Decrease the horizontal emittance
- Increase the source brilliance
- Increase the source coherence



ESRF Extremely Brilliant Source
ESRF-EBS – 150 M€ (2015-2022)

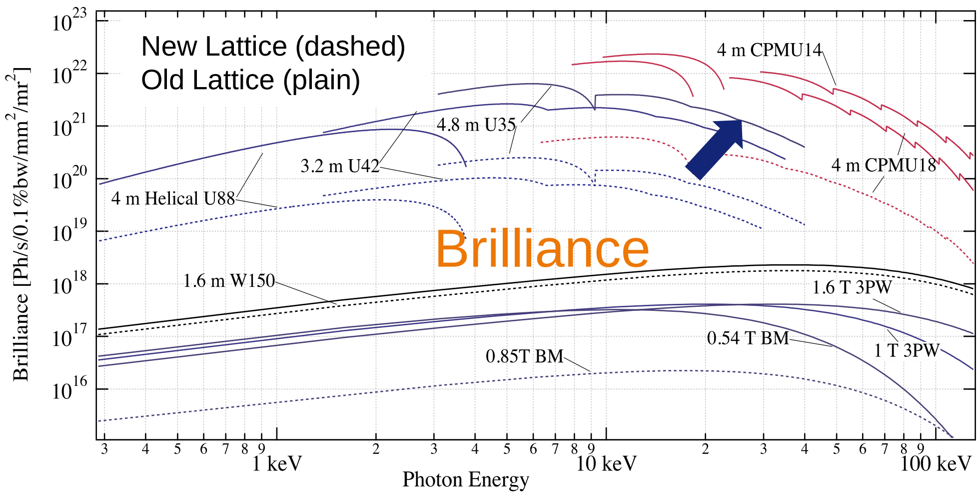
ESRF-EBS
Extremely Brilliant Source

- ~100 times more brilliant and coherent X-rays
- Programme to exploit the qualities of this new and unique extremely brilliant X-ray source:
  - Creation of new beamlines
  - Innovative detector programme
  - « Data as a Service » strategy



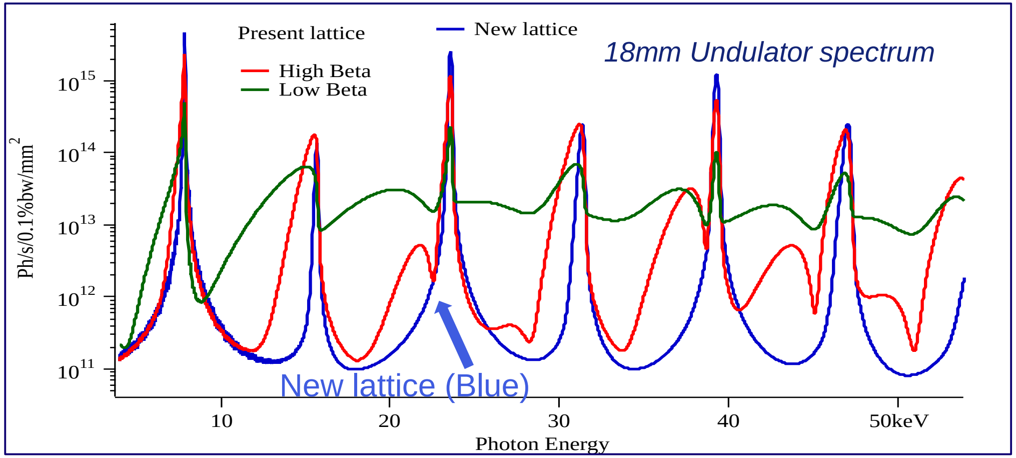
Budget for the source only: 104 M€

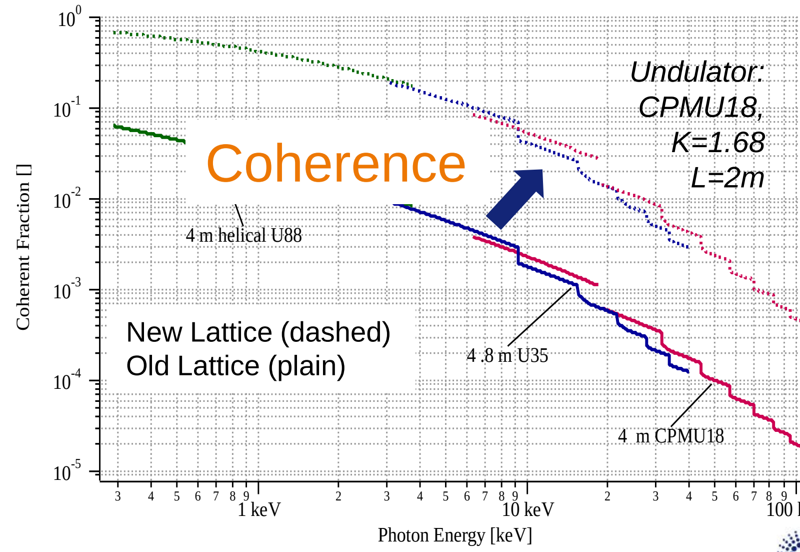
ESRF-EBS: BRILLIANCE AND COHERENCE INCREASE



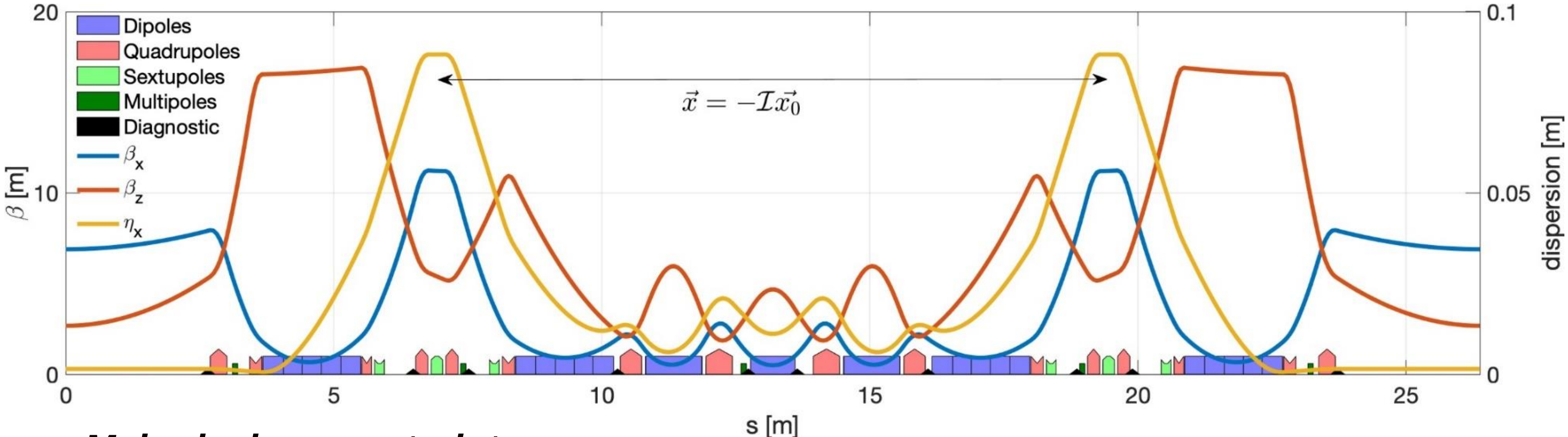
Hor. Emittance [nm]	4	0.135
Vert. Emittance [pm]	4	5
Energy spread [%]	0.1	0.09
β_x[m]/β_z [m]	37/3	6.9/2.6

Source performances improved by a factor 50 to100





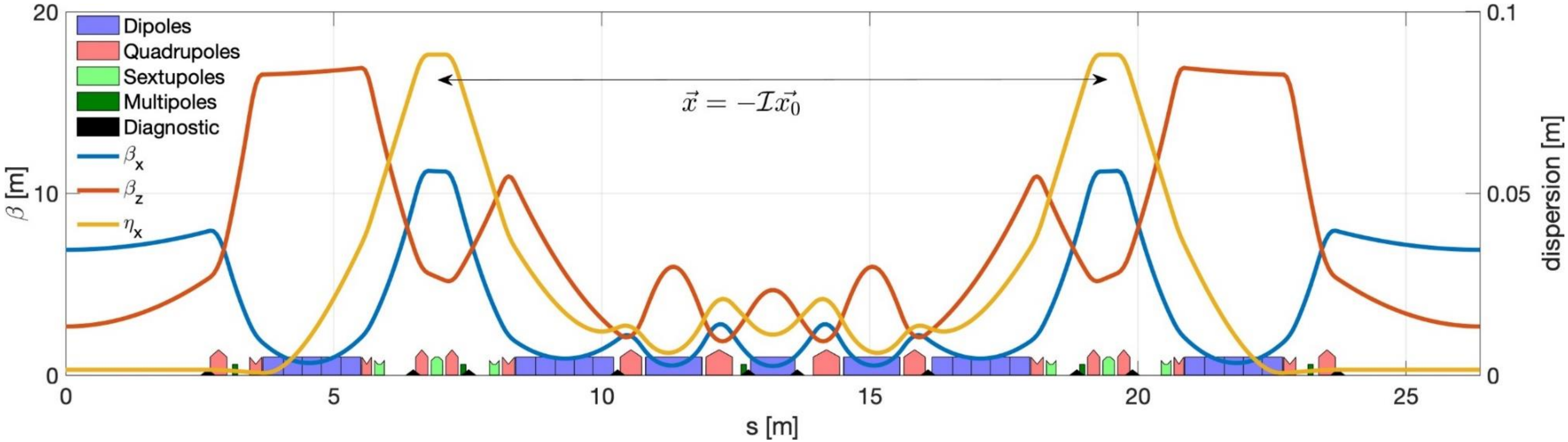
THE ESRF-EBS UPGRADE OBJECTIVES AND CONSTRAINTS



Main design 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



Hybrid Multi Bend Achromat lattice features:

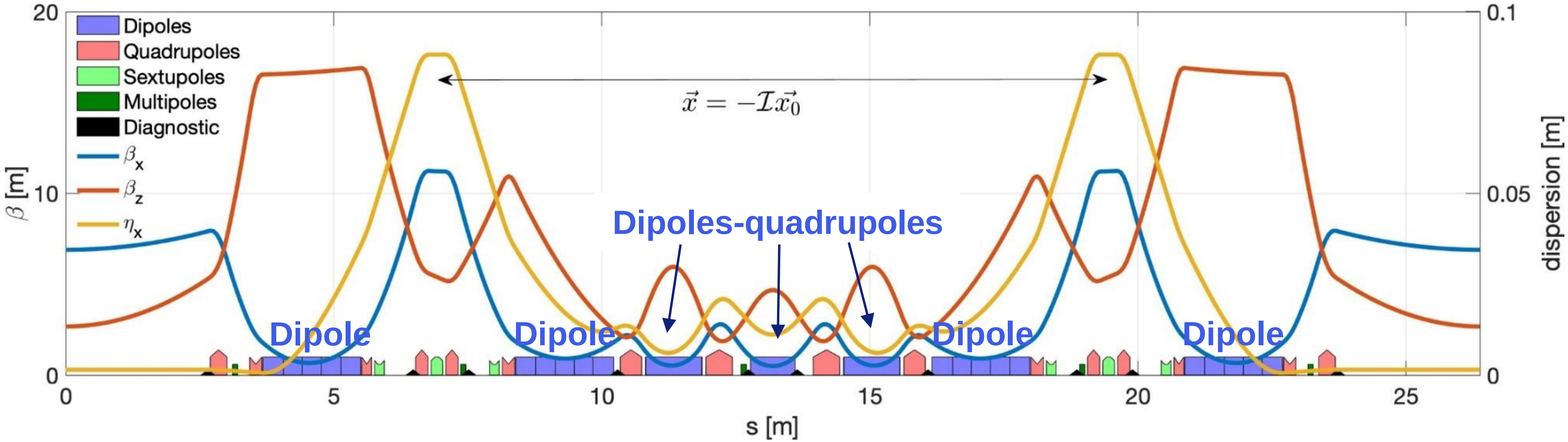
- Multi-bend for lower emittance: Longer and weaker dipoles => less SR

  longitudinal gradient permanent dipoles and combined function magnets with low dispersion
- Dispersion bump for efficient chromaticity correction with –I transform:

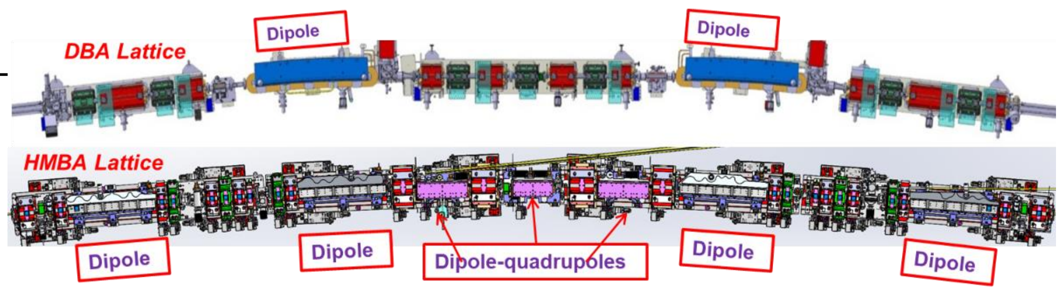
  Weaker, fewer sextupoles with partial compensation of aberrations for improved lifetime and acceptance
- Small beta functions in the central part of the arc
- ESRF-EBS design:

  ε_x = 135 pm.rad., Lifetime 20h, injection efficiency >90%

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*



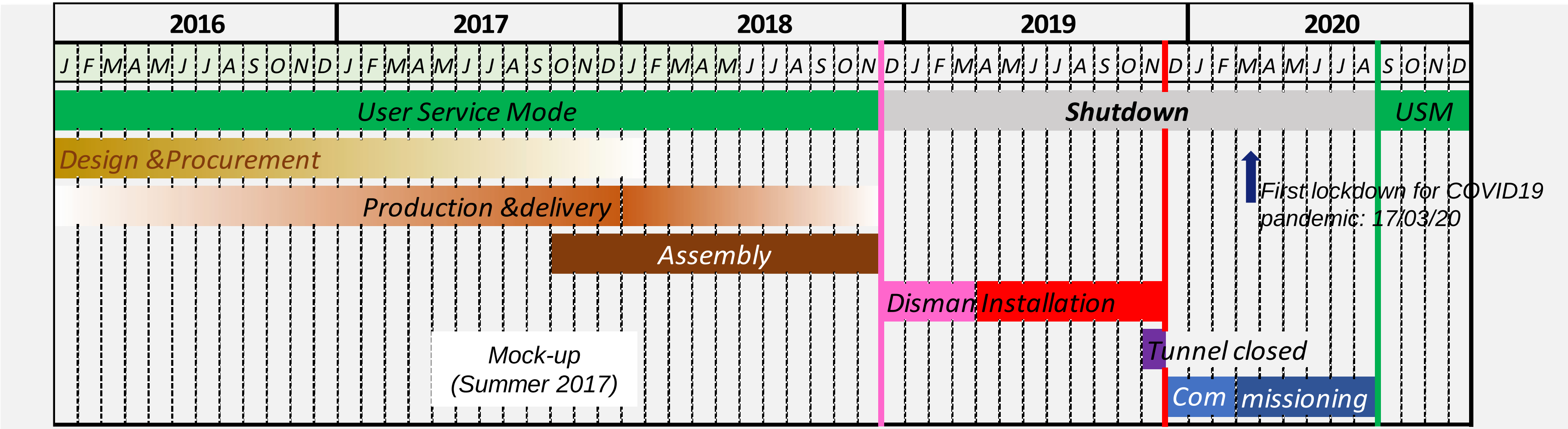
31 magnets per cell instead of 17

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

EBS STORAGE RING MASTER SCHEDULE

Project start: January 2015

First idea 2012, white paper Nov 2012 , TDS (orange book) & council approval Nov 2015



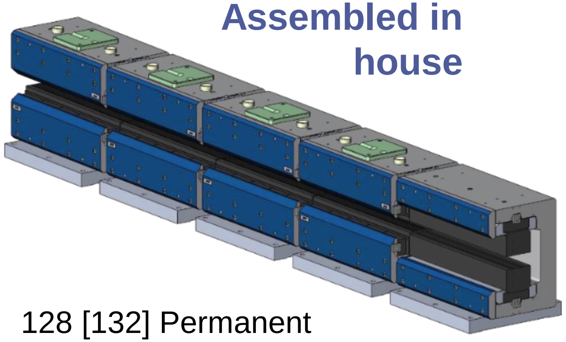
Old ESRF-Storage Ring

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**

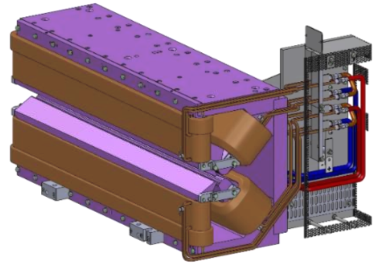
EBS COMPONENTS: MAGNETS

Assembled in house



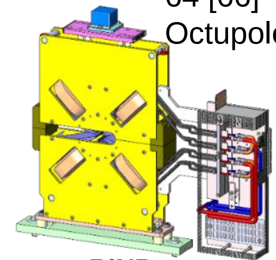
128 [132] Permanent Magnet Dipoles

96 [100] Dipole-quadrupoles



TESLA

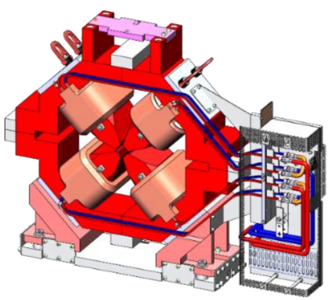
64 [66] Octupoles



BINP

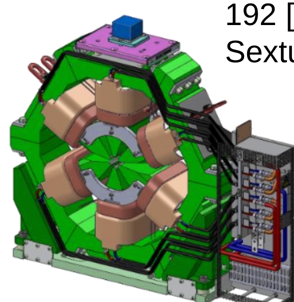
More than 1000 Magnets

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



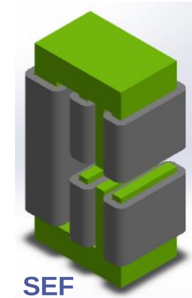
TESLA ***(MG)***
DANFYSIK ***(HG)***

192 [196] Sextupoles



DANFYSIK

96 [98] Correctors

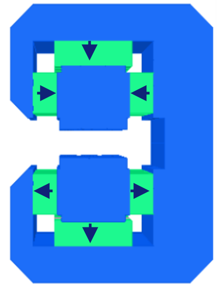


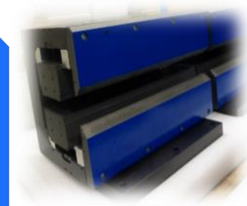
SEF

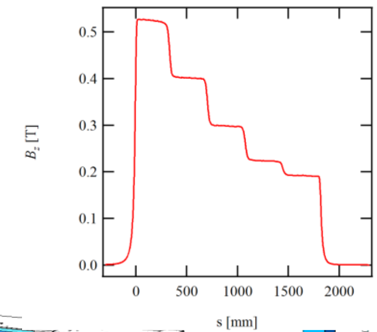
32 Cubicles for DC-DC converters to power each magnet individually
COMECA

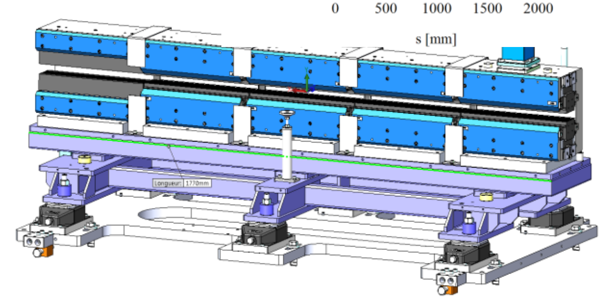
EBS COMPONENTS: DIPOLES

- 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}

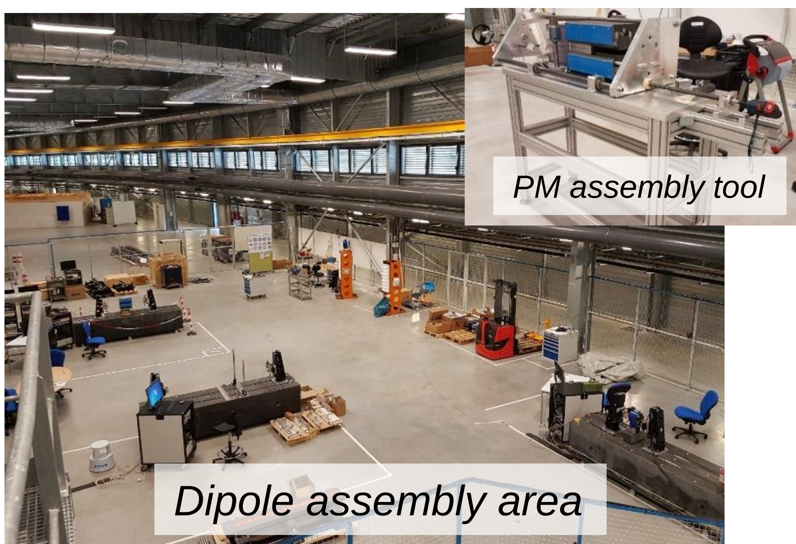








Around 6000kg of PM, 660 Iron modules



Dipole assembly area

PM assembly tool

EBS COMPONENTS: VACUUM CHAMBERS

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

FMB, Pink
CECOM, Cinel

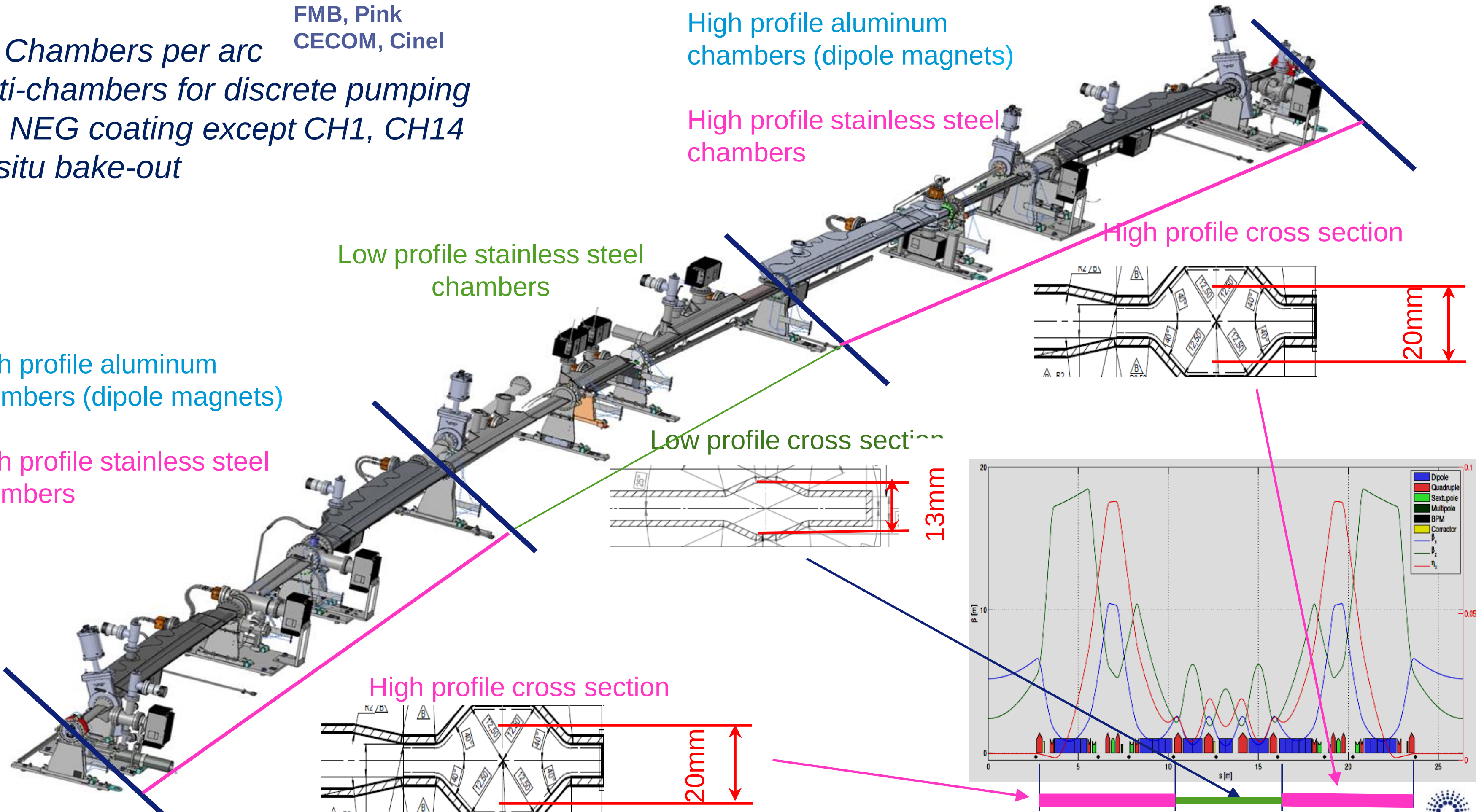
High profile aluminum chambers (dipole magnets)

High profile stainless steel chambers

Low profile stainless steel chambers

High profile aluminum chambers (dipole magnets)

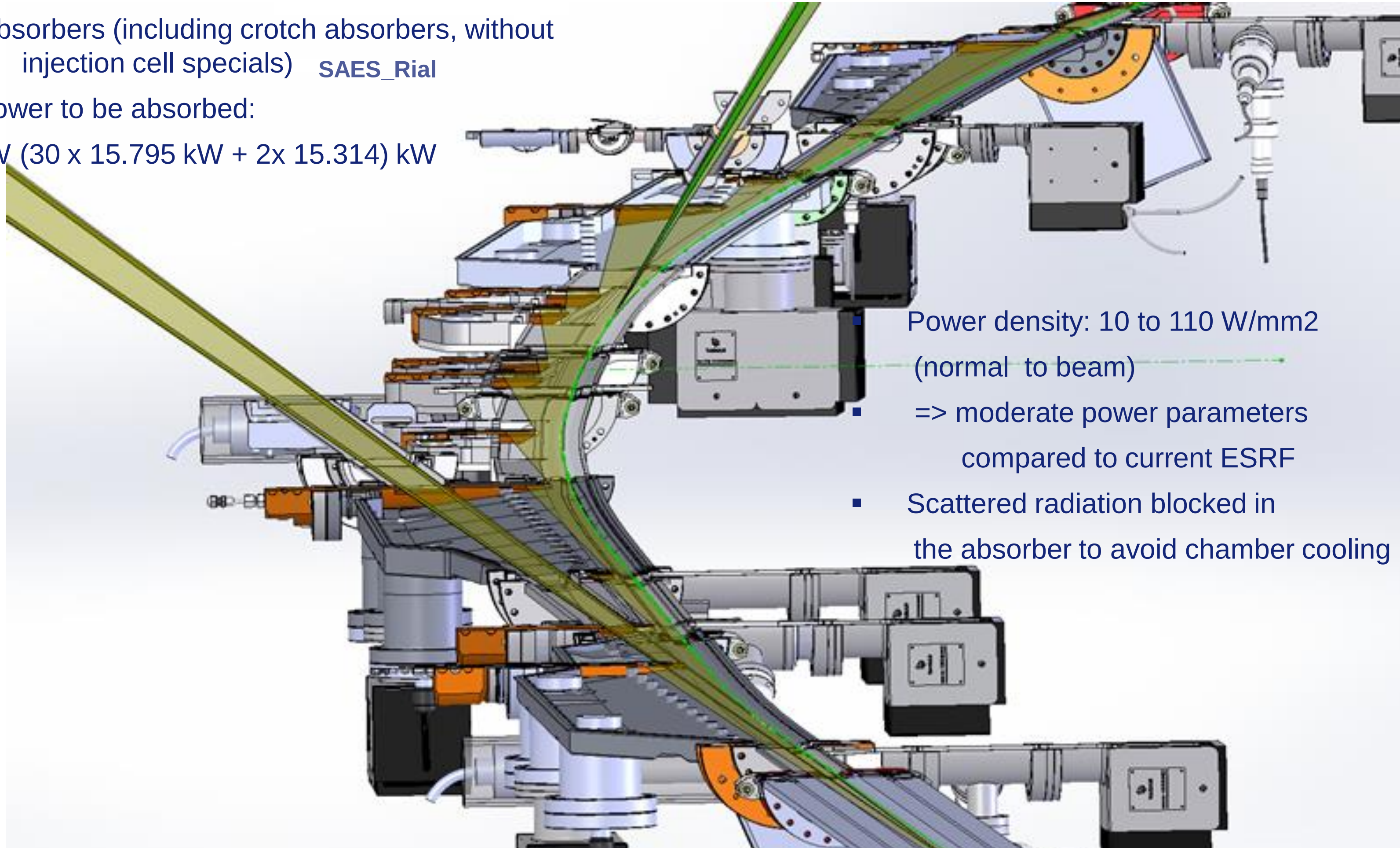
High profile stainless steel chambers



EBS COMPONENTS: PHOTON ABSORBERS

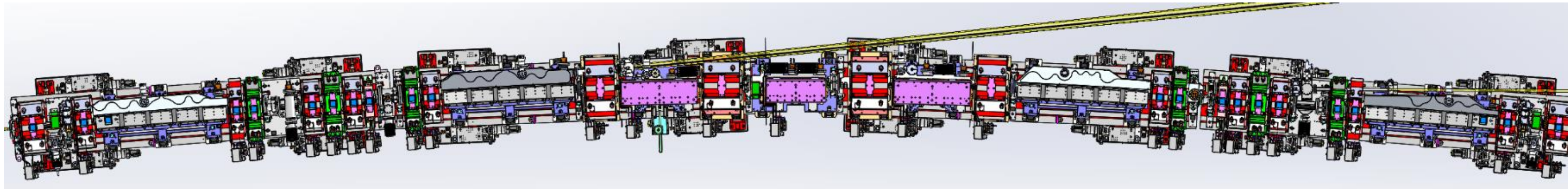
- ~391 absorbers (including crotch absorbers, without injection cell specials)
- Total power to be absorbed:

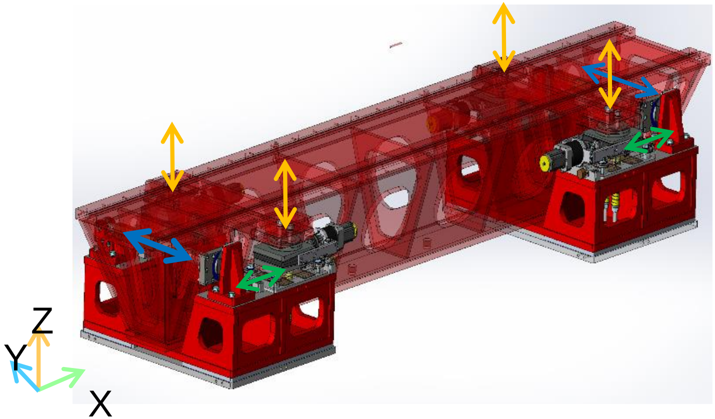
504.5 kW (30 x 15.795 kW + 2x 15.314) kW



- Power density: 10 to 110 W/mm2 (normal to beam)
- => moderate power parameters compared to current ESRF
- Scattered radiation blocked in the absorber to avoid chamber cooling

EBS COMPONENTS: GIRDERS





Four identical girders per cell

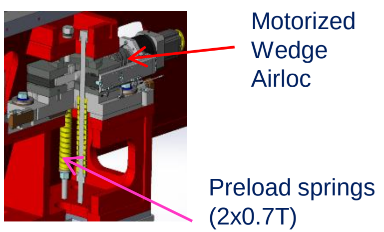
- **Motorized** **Z adjustment** resolution 5µm
- **Manual Y adjustment** resolution 5µm
- 1st natural frequency :
  - 50Hz (design criteria)
  - 49 Hz measured

128 + 1 Girders

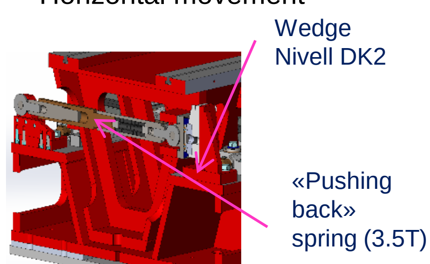
- 4x32 (Arcs)
- 1 (Injection Cell)

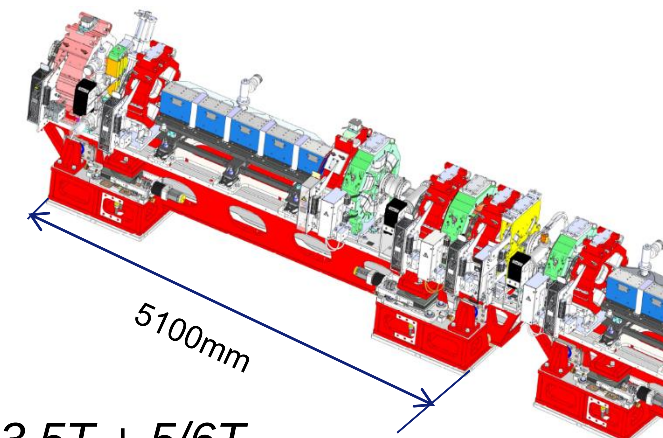
Nortemeca
AVS

- Vertical movement



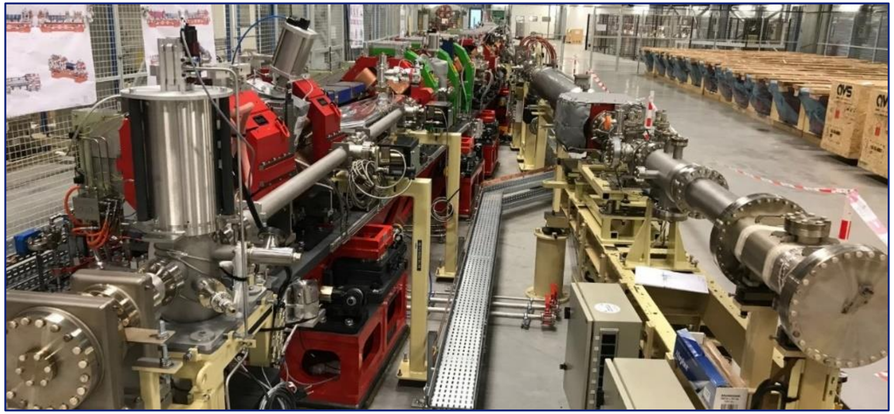
- Horizontal movement

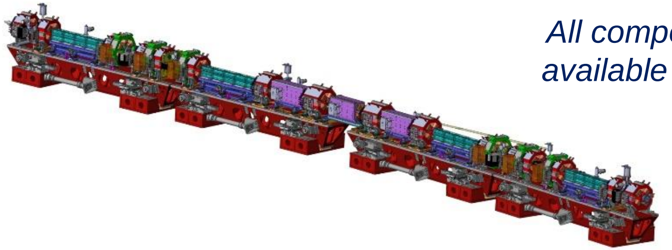




3,5T + 5/6T

MOCKUP CELL





All components should be available to build a full cell in advance

Validate design and procurement:

- Debug technical and assembly issues
- Validation of the engineering prior series production
- Identify omitted and delayed components

Validate girder Assembly:

- Validate assembly process and tools
- Write assembly procedures *(specific alignment tools…)*
- Check assembly time
- Validate bake out process

Validate installation:

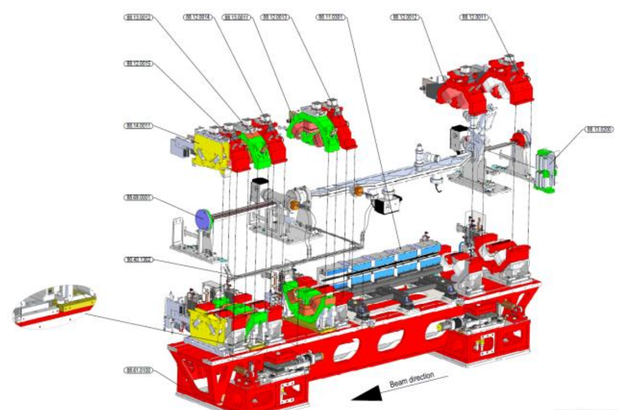
- Check installation process and tools
- Validate full cell installation including all equipment
- Validate tunnel layout

First arc under vacuum September 2017.

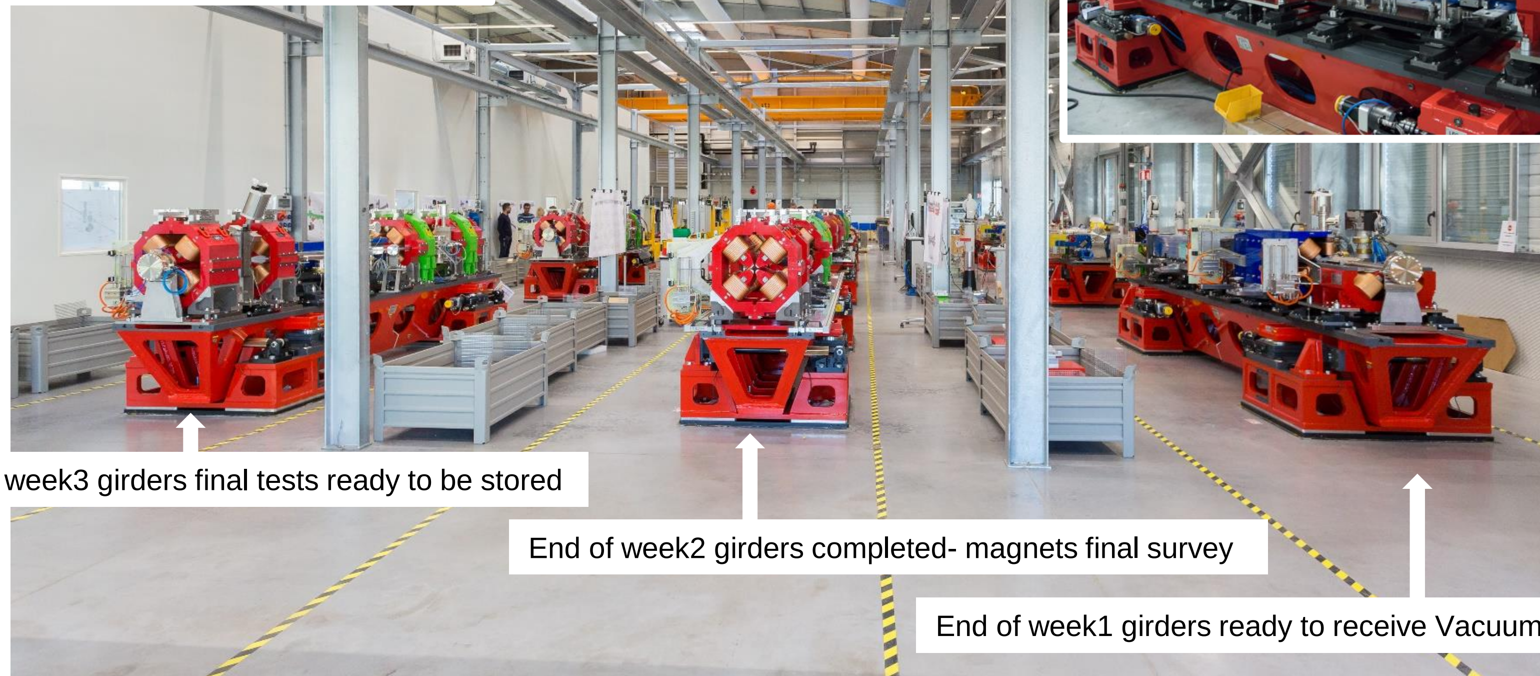
➔ *But was dismounted too early (May 2018) for space reason*

GIRDER ASSEMBLY

- Assembly building delivered in October 2017
- 3 assembly lines + 1 vacuum preparation line
- 3 to 4 girders assembled per week
- 128+1   girders assembled



ASSEMBLY PROCESS – ASSEMBLY LINES



End of week3 girders final tests ready to be stored

End of week2 girders completed- magnets final survey

End of week1 girders ready to receive Vacuum chambers

LOGISTICS & STORAGE: A KEY ISSUE


12 Cavity assembled and stored


Assembled girders handling

Storage and logistics are key issues for an upgrade

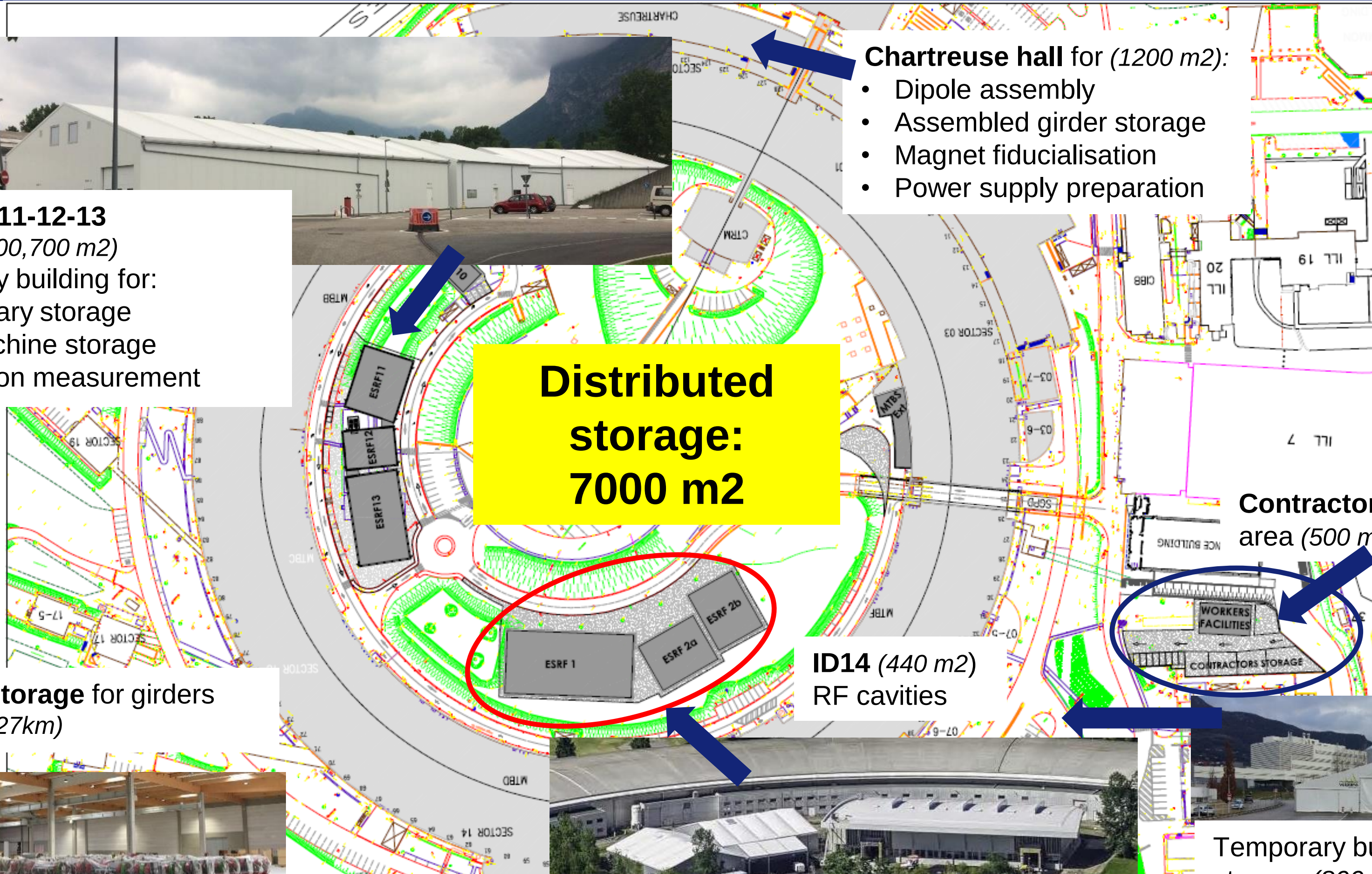

Components storage


Assembled girders storage


Assembled girders storage

During dismantling, we need to store the new and the old machine outside the SR tunnel !!

LOGISTICS: BUILDINGS FOR THE ASSEMBLY AND INSTALLATION PHASES



ESRF 10-11-12-13
(200,500,300,700 m2)
Temporary building for:
- temporary storage
- old machine storage
- activation measurement

Chartreuse hall for *(1200 m2)*:
- Dipole assembly
- Assembled girder storage
- Magnet fiducialisation
- Power supply preparation

Distributed storage: 7000 m2

Contractors buildings and area *(500 m2,100 people)*

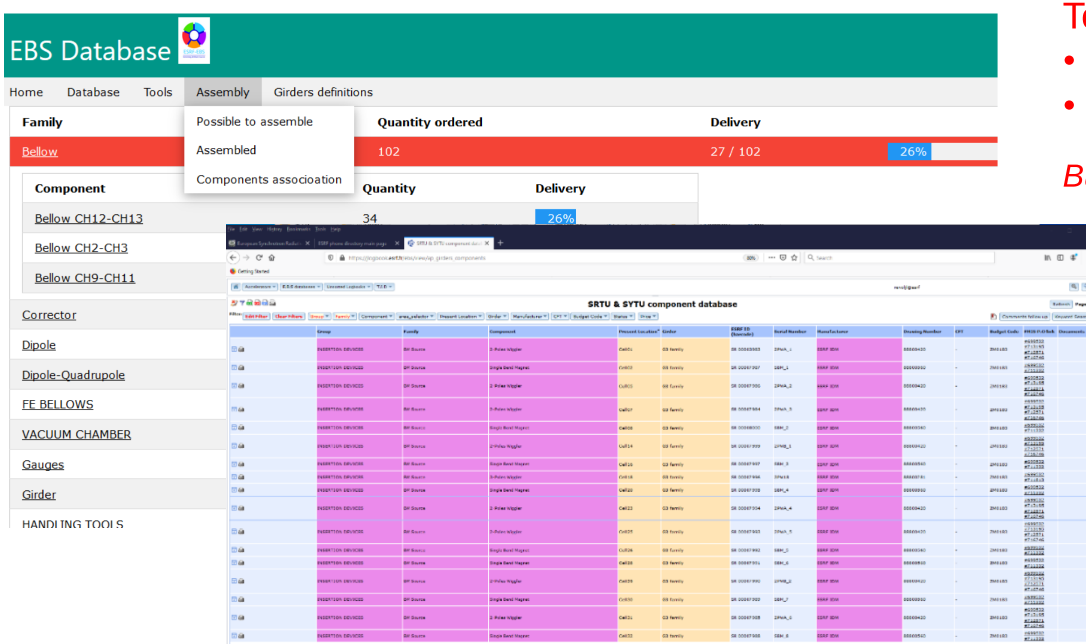
ID14 *(440 m2)*
RF cavities

Outside storage for girders
(1000 m2, 27km)

ESRF1 *(1100 m2)* Girder assembly hall
ESRF2 *(2*500 m2)* Storage buildings

Temporary building storage *(800 m2)*

LOGISTICS: COMPONENTS DATABASE



Today

- 17000 Components for the tunnel
- 2650 Components for the technical zone

But still work in progress to integrate all components

- SAT progress
- Assembly schedule
- Assembly components preparation
- Assembly follow-up
- Installation preparation
- Installation follow-up
- Commissioning follow-up

Database daily updated

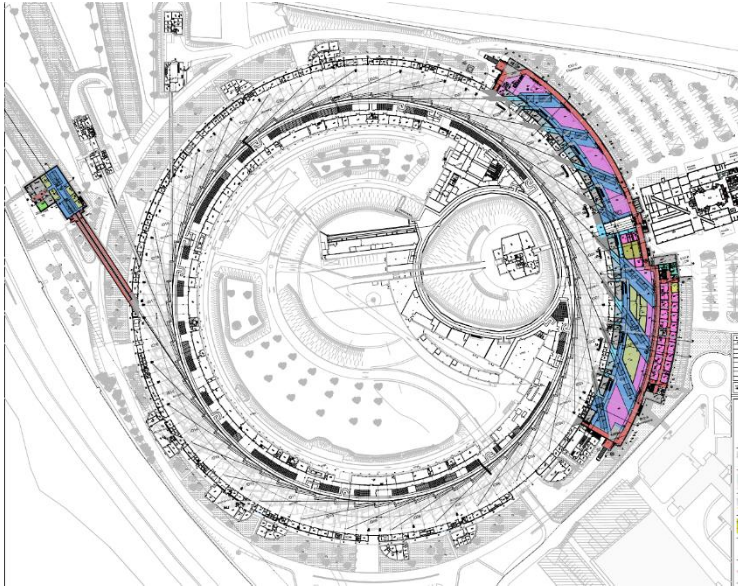
- Type
- Quantity
- Delivery date
- Status
- Serial number
- Location
- …

→ …FAT,SAT, ready for assembly

Now fully used for the operation

FAT: Factory Acceptance Test
SAT: Site Acceptance Test

BENEFIT FROM PHASE 1: INFRASTRUCTURE UPGRADE

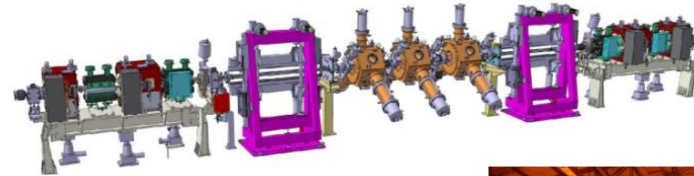


Experimental hall extension expertise:

- *New buildings*
- *Expertise of 5 months long shutdown*
- *Expertise on restart accelerators and beamlines*

- Upgrade of the electrical mains distribution
- Upgrade of the water cooling system and chillers
- Installation 1μm filters at the entrance of the 32 cells
- New High Quality Power Supply to improve mains quality
- Renovation of the EXPH Roof Membrane

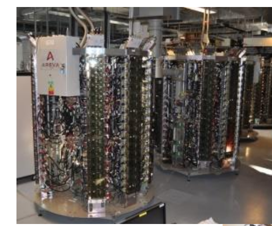
BENEFIT FROM PHASE 1: DEVELOPMENT OF ACCELERATOR COMPONENTS

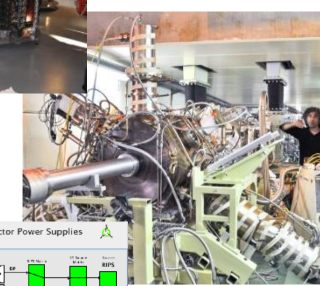


- **Upgrade of BPM electronics**
- **6 m long straight sections**
- **7 m straight sections**
- **SSA RF Transmitters**
- **HOM damped RF Cavities**
- **Cryogenic in-vacuum undulators**
- **…..**

→

- BPM system ready for EBS
- Expertise in vacuum chambers and magnet development
- Expertise in installation
- Expertise in power supply
- RF design ready and validated for EBS



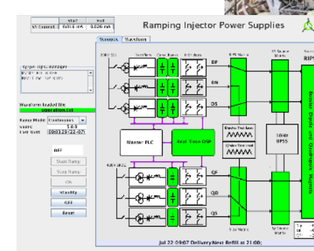


- **Upgrade of the injector for topup operation** *(BPM electronics, quadrupole movers, two additional RF cavities, linac upgrades, new booster magnets power supplies, bunch cleaning system)*

→

Injector ready for EBS

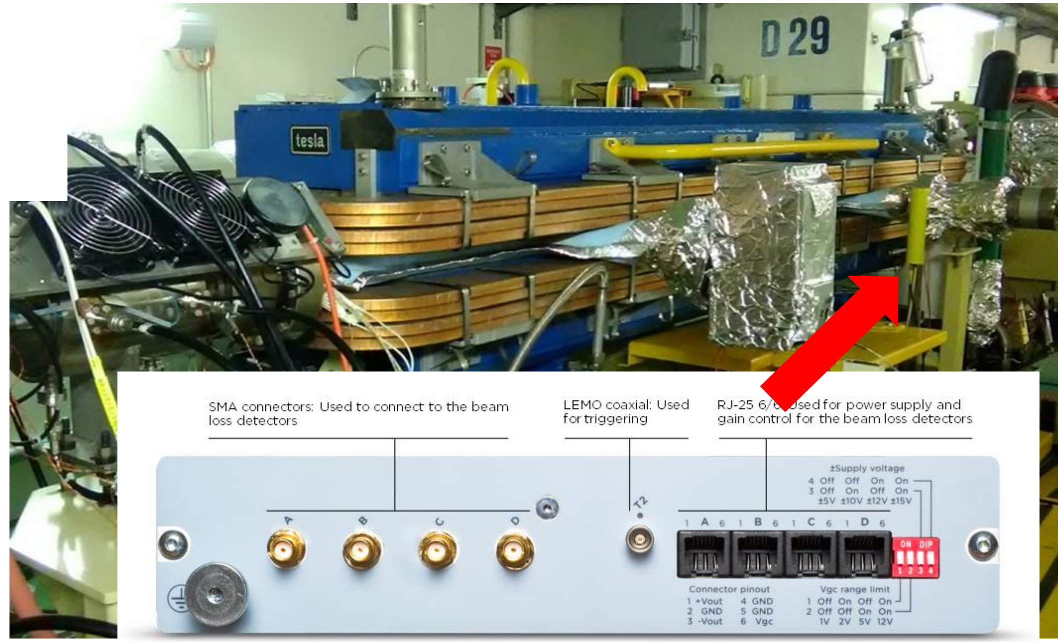
[Girders moved during shutdown by 17.5 mm, radial, for the new RF frequency (+172 kHz)]



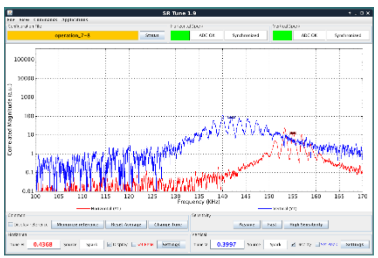
PRIOR SHUTDOWN: VALIDATION OF NEW DIAGNOSTICS

New Beam loss monitors installed and commissioned on the old machine:

- 4 BLDs per cells
- Get references to be compared to the new machine

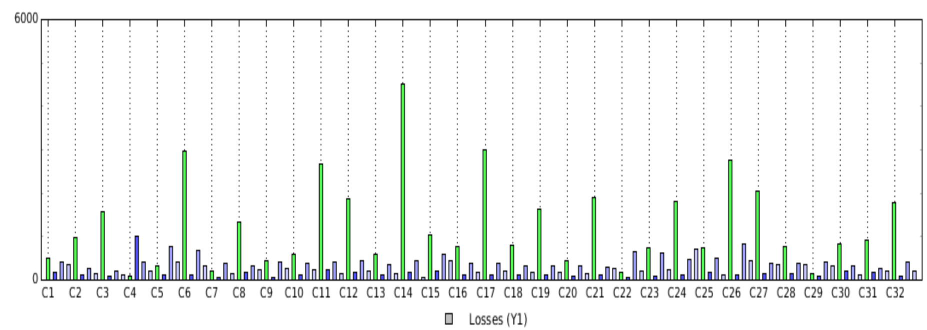


New tune monitor installed and commissioned on the old machine



Complementary Spark BPM electronics validated on the old machine

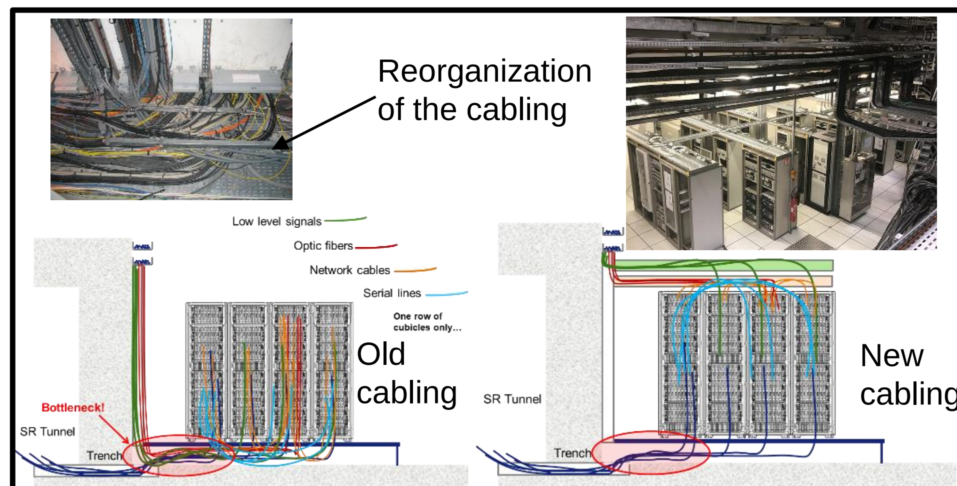
complementary to the existing Brillance electronics (6 brilliance, 4 sparks per cell)



Implementation of the new timing system

PRIOR SHUTDOWN: ANTICIPATED TASKS

- **A new distribution of LN2 for cryogenics in-vacuum undulators.**
- **Installation of VDC distribution for power supply**
  260 cables installed - 24 870 m –
  during Machine shutdowns only
- **Reorganization of the cabling in the cubicle**
  Separation of tunnel cables from others to ease the dismantling
- **Cleaning of the technical zone**
  Clearing out the working areas
  Mark and sign post
  Prepare sorting areas & boxes



DISMANTLING + INSTALLATION: DEC 2018 – NOV 2019

Dismantling

Civil works

Girder entry
Vacuum connection

Piping
Cabling

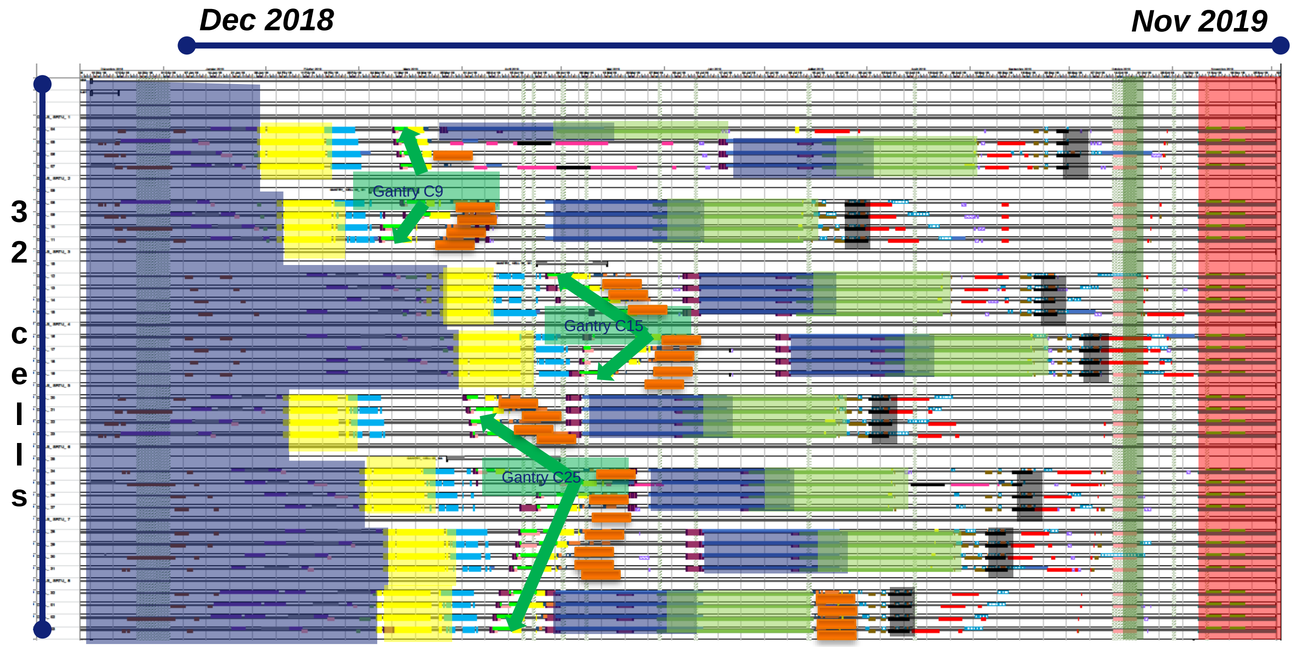
FE

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

LOGISTICS: HANDLING

Crane operations:

Dismantling: 3 Cranes in 2 shift for dismantling + forklift operators

Installation: 2 Cranes in shift + 1 normal day + forklift operators

→Pick load of 40 handling staff

→≈5000 opening/closing during the project (equivalent of 30 years of ESRF operation)

→ No specific shutdown of the overhead cranes thanks to specific maintenance plans.

Tools:

Many special tools designed for the EBS project, but also new procedures: it will partially help us for the operation of the new machine.

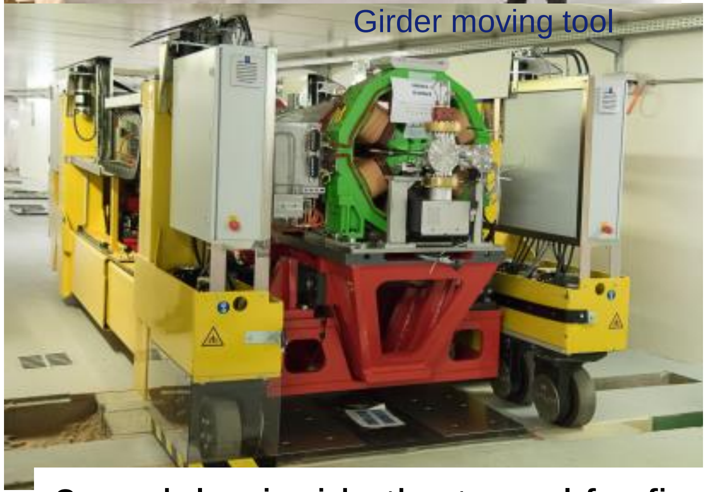
LOGISTICS: SPECIFIC TOOLS TO MOVE THE GIRDERS

Capacity of the existing cranes was not sufficient for the installation of the new girder

2 Gantries for
3 entrance points

Rollers in experimental hall

Girder moving tool

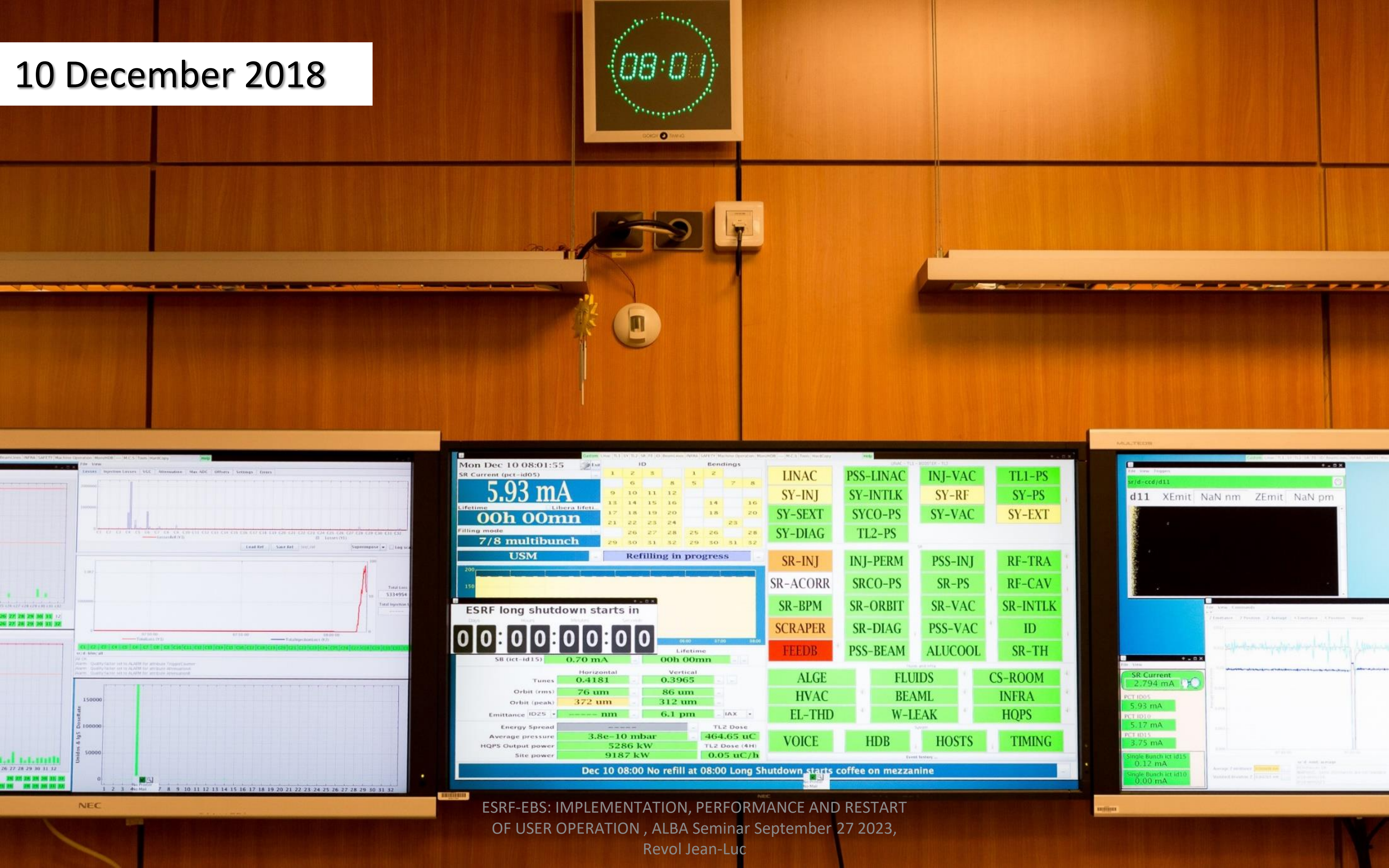


2 modules inside the tunnel for final installation at ± 1 cm *(2 spare modules)*

EBS installation

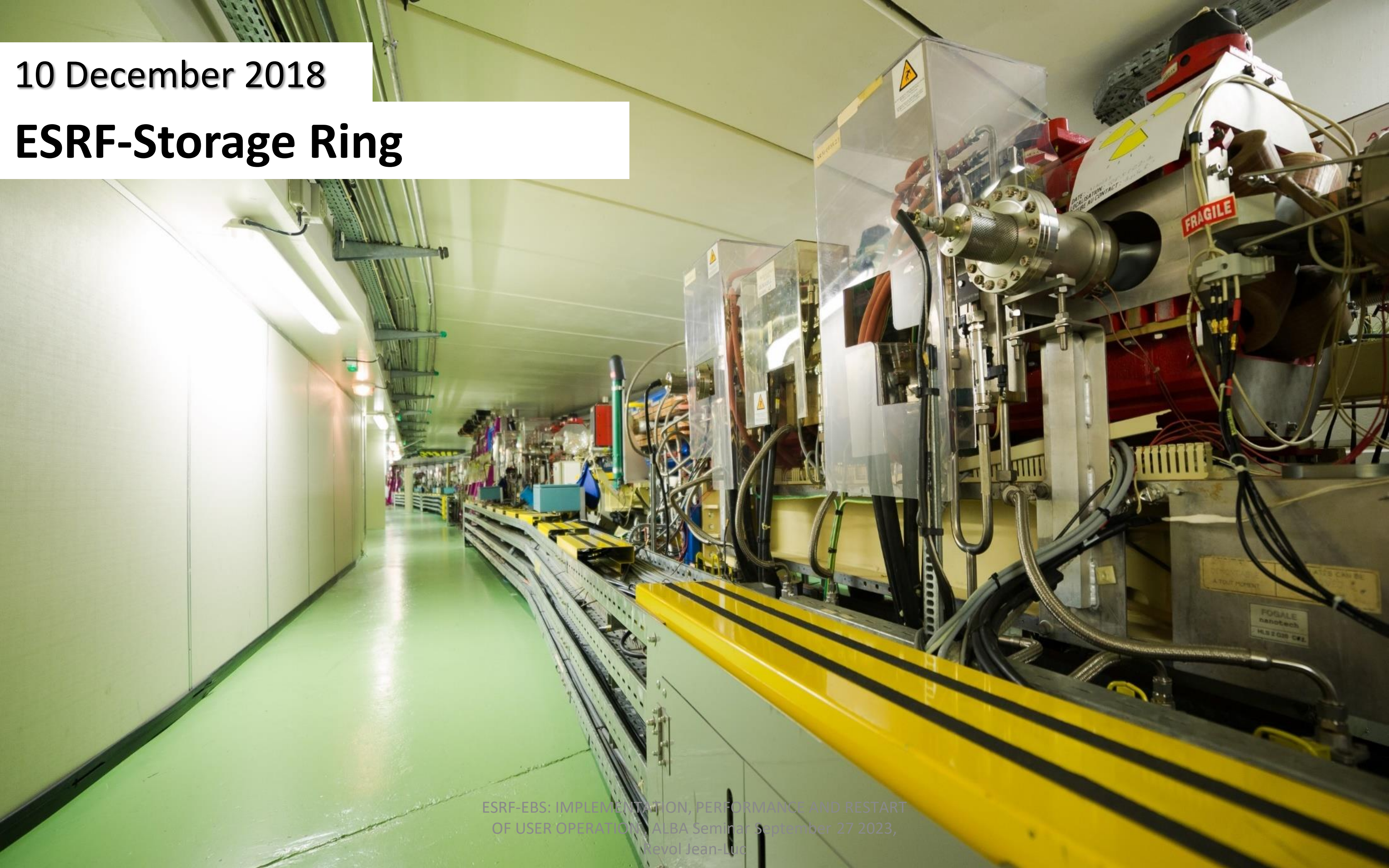
ESRF-EBS
Extremely Brilliant Source

10 December 2018



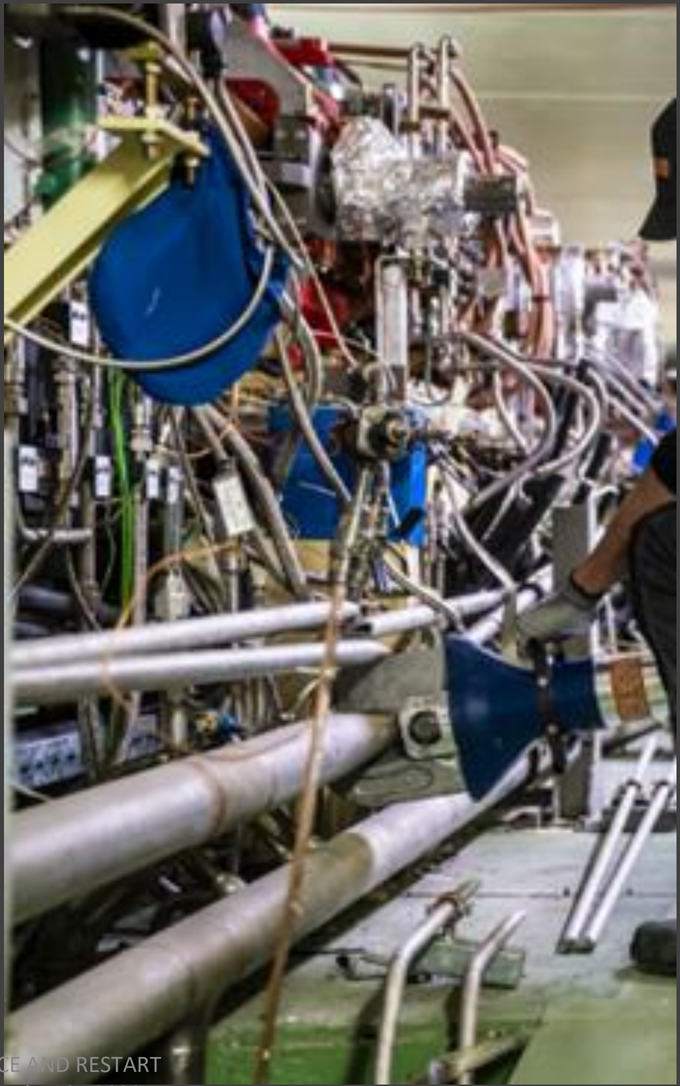
10 December 2018

ESRF-Storage Ring

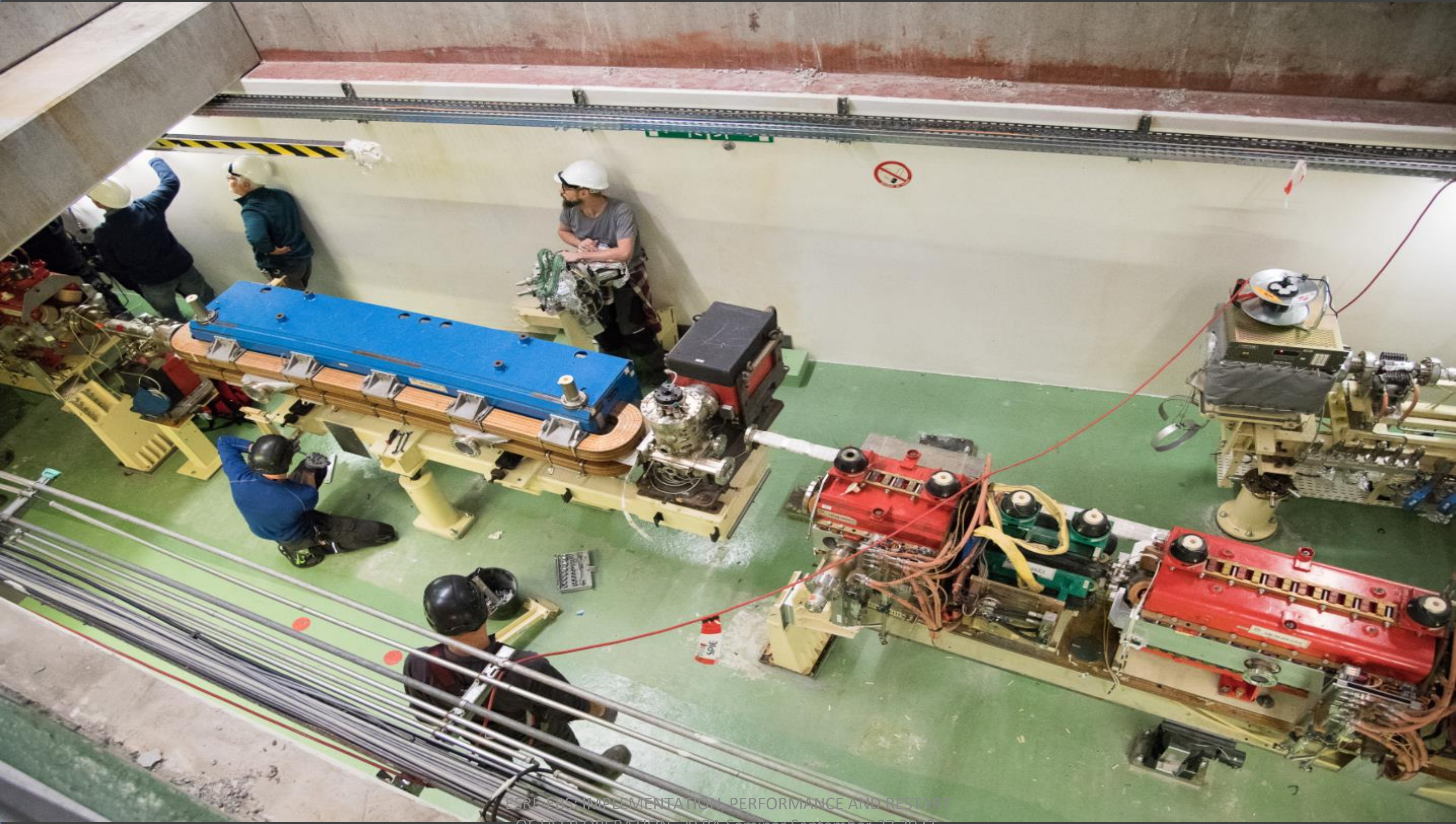


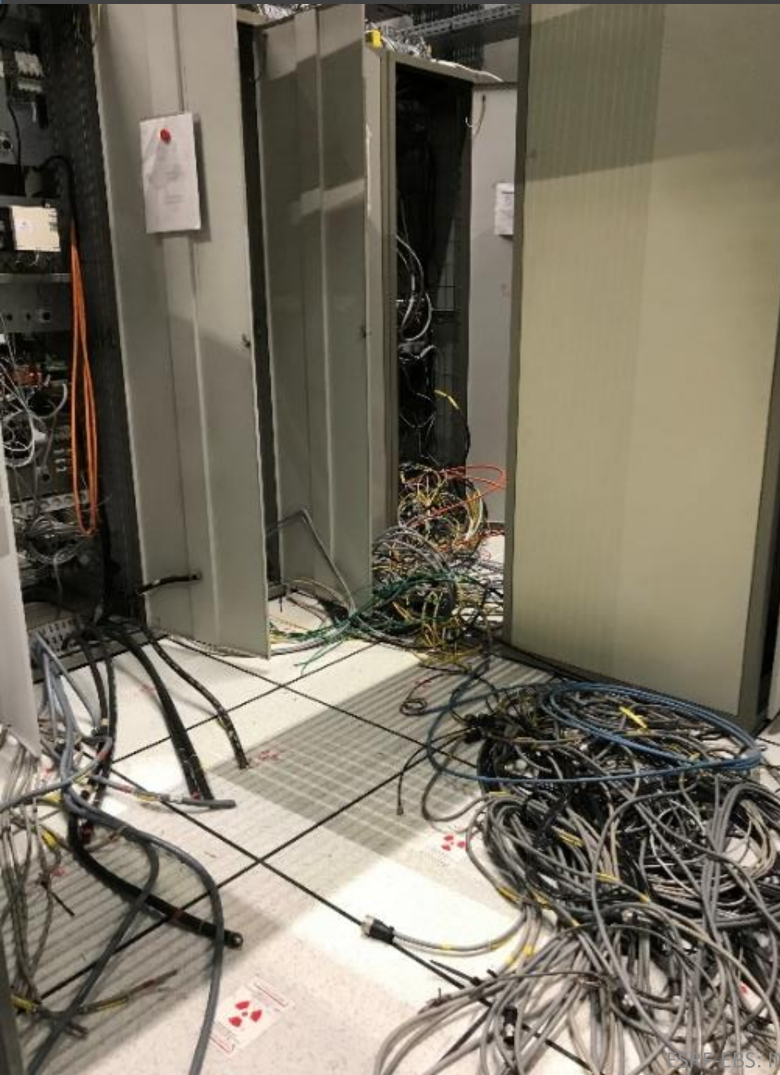
10 December 2018

Dismantling in the tunnel




STILL
STILL
RX60-30

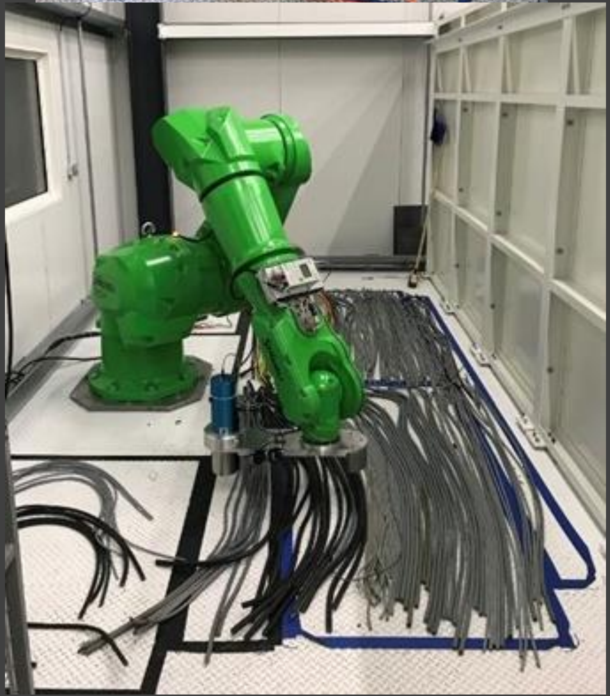





DI
PS
BiLT


CO

Non activation measurements




Traction Levage
CMU 1t

Civil work


D7


D31


ID5

Installation of the girders

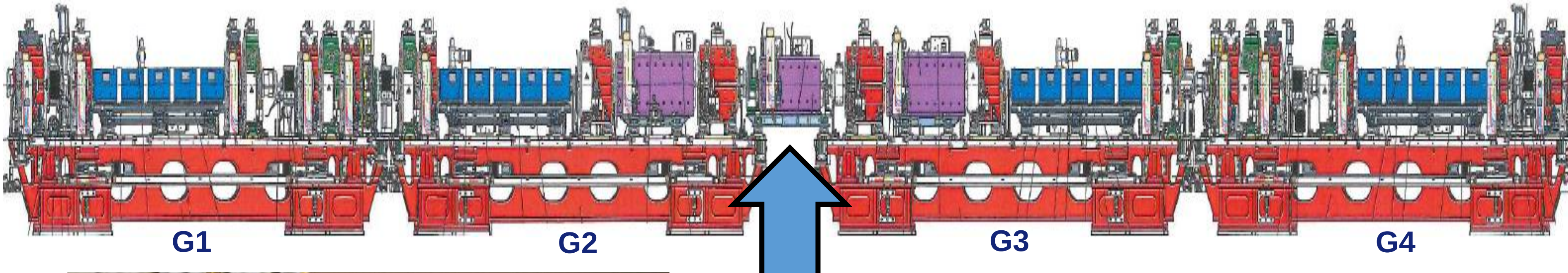

KRONE


MEDIACO
CEPTIONNEL


VT3
4
VT3
3
131

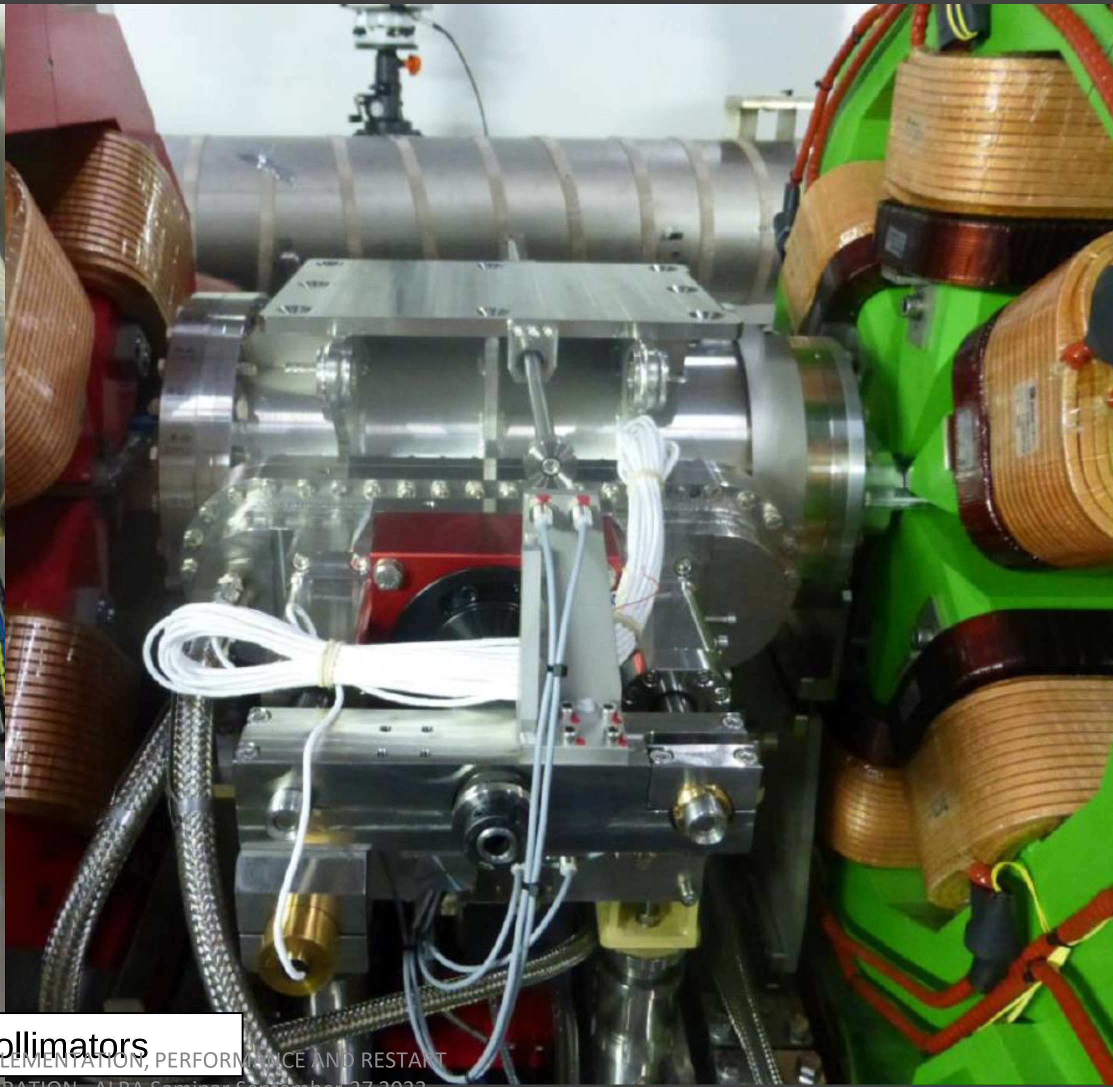

TENSION
SPIE
SOUS

Interconnection of the girders and special chambers


G1
G2
G3
G4

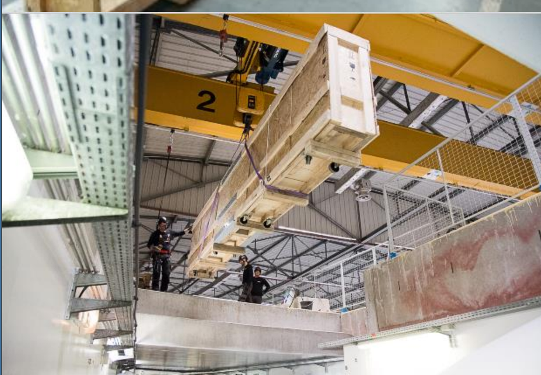

VA716


ATTENTION
FRAGILE

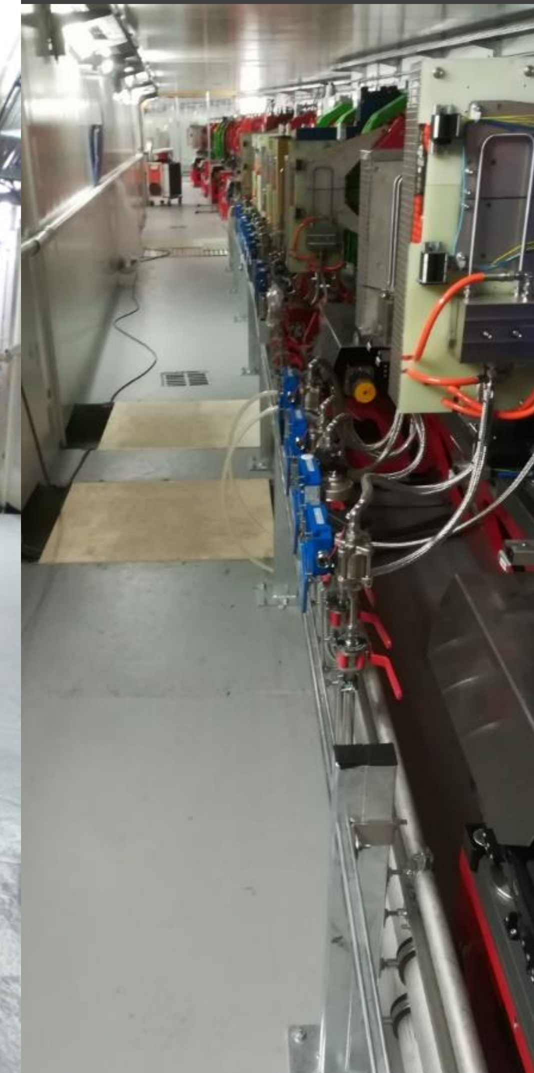


Collimators

Piping & Cabling



2

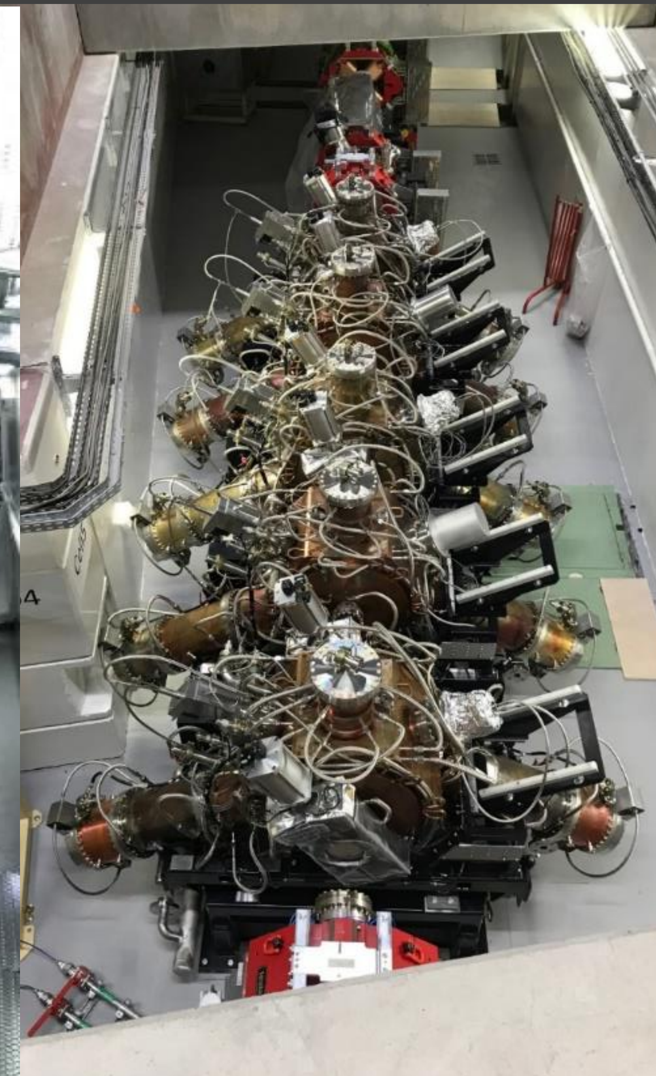




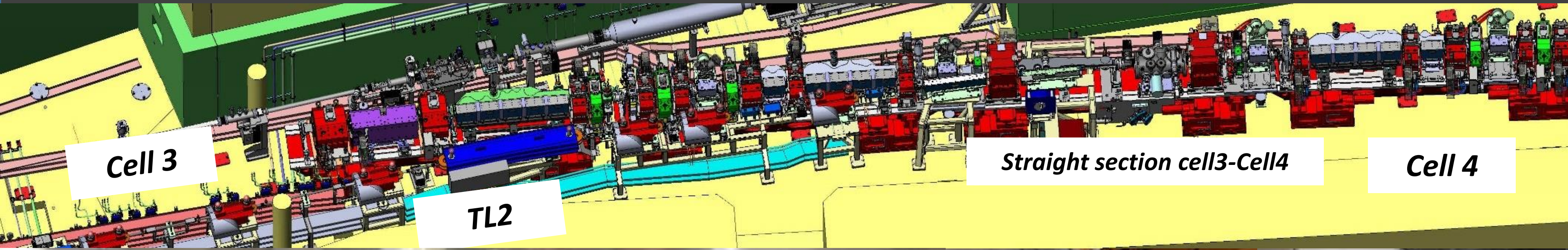



651310

Straight sections Reconstruction

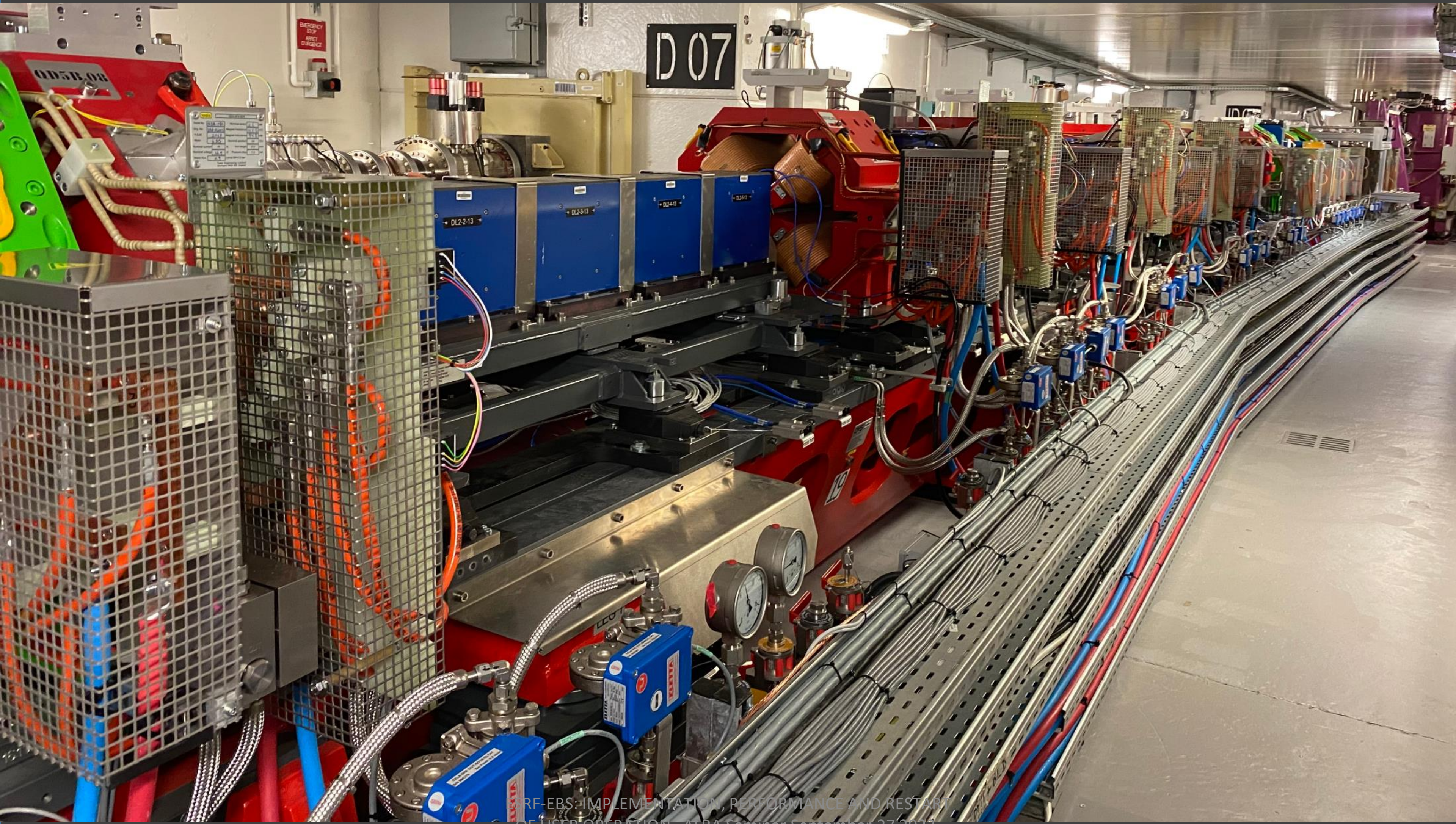



D 13

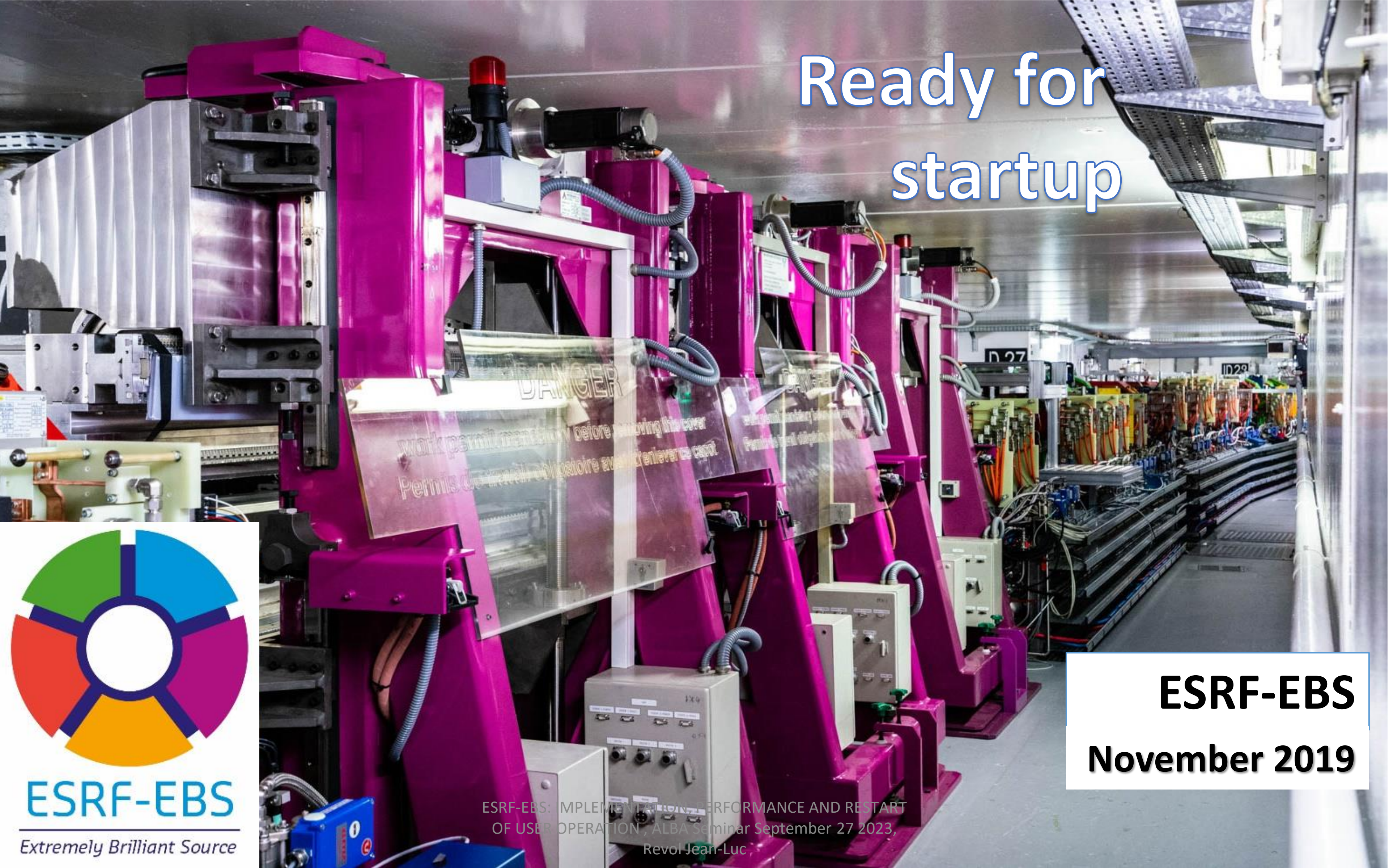

Cell 3
TL2
Straight section cell3-Cell4
Cell 4


D02


D 08
D09


D 07

Ready for startup

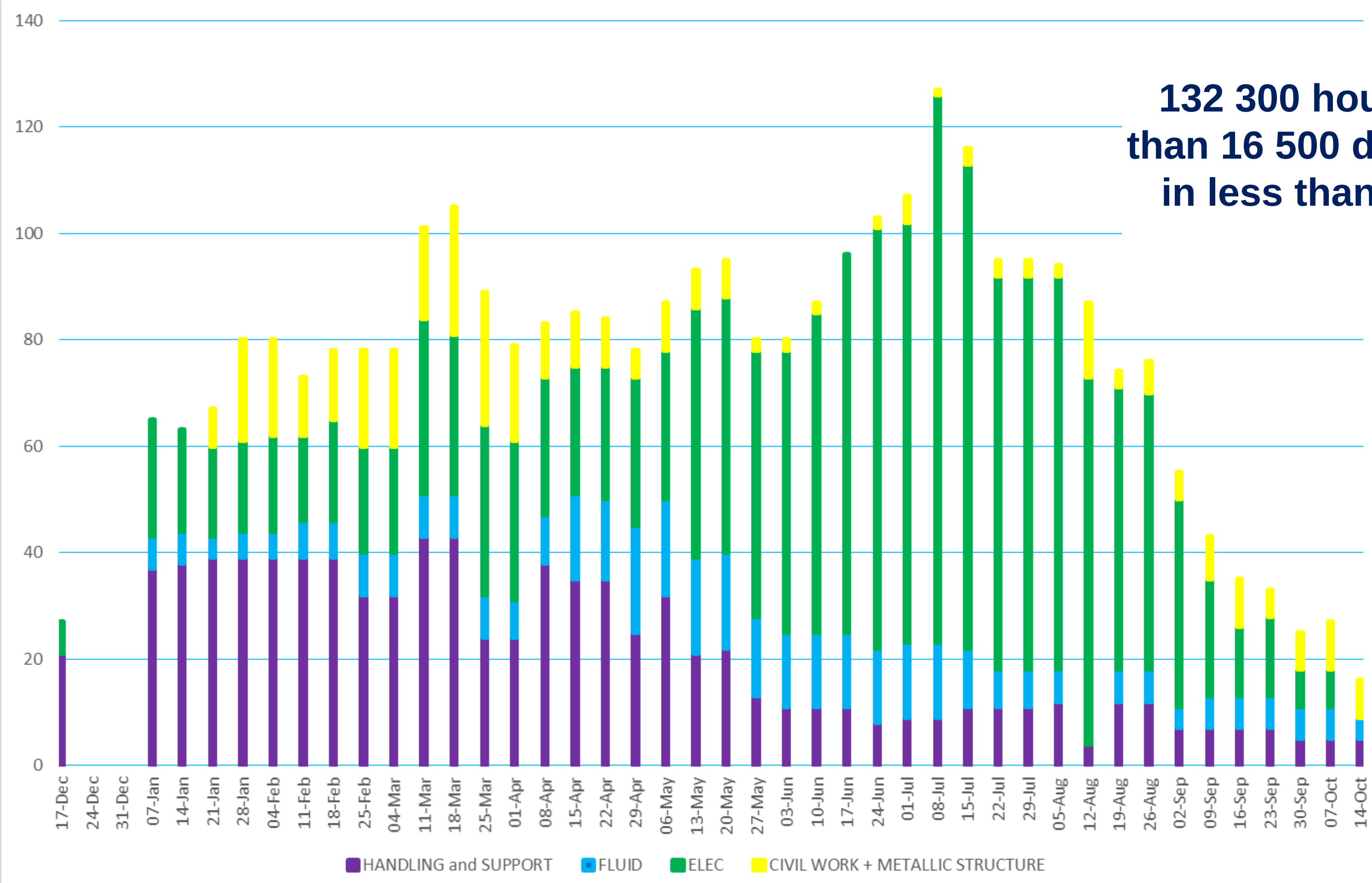


ESRF-EBS

November 2019

ESRF-EBS
Extremely Brilliant Source

CONTRACTORS STAFF ON SITE



132 300 hours i.e more than 16 500 days of works in less than 11 Months

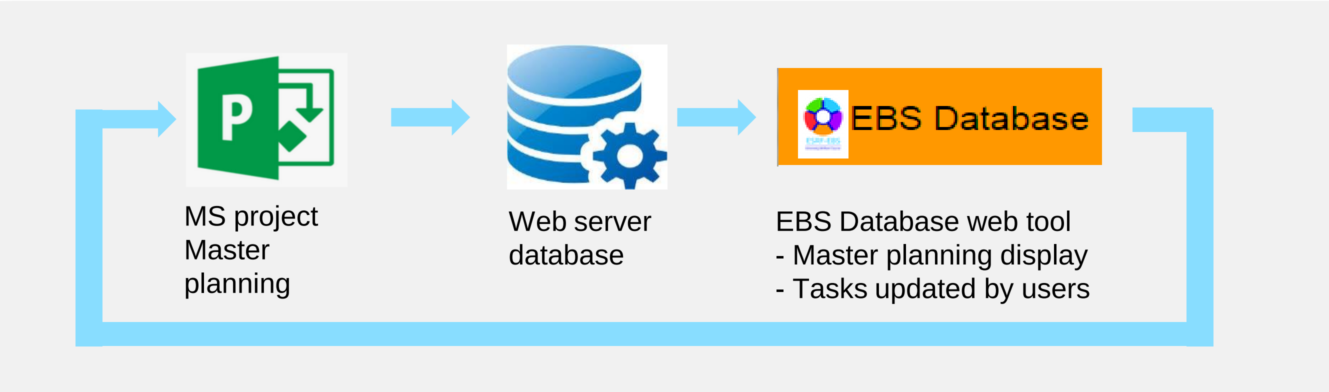
SHUTDOWN FOLLOW-UP

During the whole shutdown, took place :

- Daily meetings with the ESRF staff directly involved
- Weekly meetings with the sub-contractors working on site
- Weekly project report meeting to ESRF staff *(usual operation meeting kept)*
- Every 2 weeks project report to the director board *(usual directors meeting)*

Daily meeting was the occasion to :

- Update the status of the tasks ongoing
- List the tasks for the coming days and week
- React in case of unforeseen event or difficulties
- Update and adapt the Master Planning in accordance to the last information received



SHUTDOWN PROGRESS

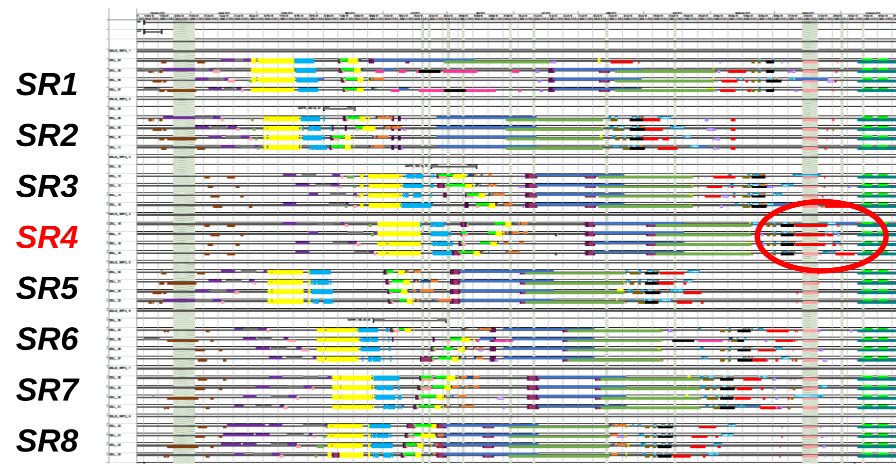
So far we had **<u>no need to largely modify the planning</u>.**

In general we have had all the tasks completed slightly ahead of schedule, but the start of sub sequential ones were usually locked by many constraints (availability of resources, tooling, safety etc) and in general cannot be changed.

Only the final tasks in the last zones *(in particular SRTU4 that is the last one to be completed)* were in the critical path, so they could directly affect the tunnel-lockout date.

Given the fact that:

- ✓ The most critical phases from a technical and logistic point of view have been dismantling and girder roll-in
- ✓ The remaining tasks were in general proceeding slightly faster w.r.t. plan (in particular vacuum, front-end, TZ, piping and cabling installation)
- ✓ Piping and cabling tasks strongly depending on external resource cannot be moved
- ✓ <u>Coactivity, safety issues and rare resources</u> management are the drivers of the planning



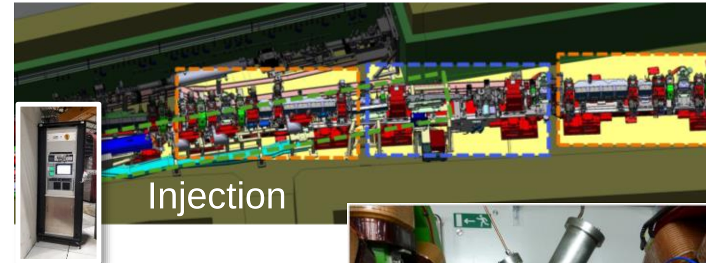
CRITICAL ITEMS FOR THE INSTALLATION

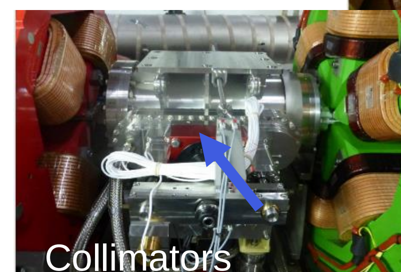
- ✓ **Injection cell**
  The injection cell, which is different and more complicate was treated as an independent project (with dedicated planning), was just on time in the design and procurement (including equipment outside tunnel).

- ✓ **Ceramic chambers**
  The design and procurement of those complicate chambers was late and are still a week point for the machine.

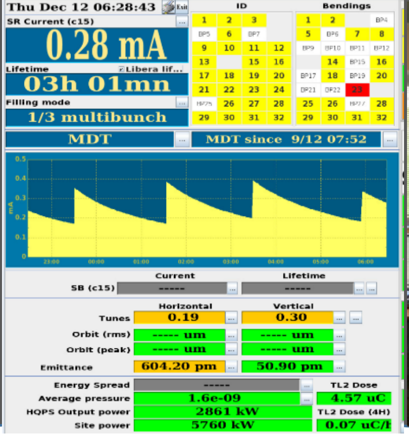
- ✓ **Collimators**
  The procurement of those complicate equipment was just on time) due to a complicate design and manufacturing.

- ✓ **DC-DC converters**
  The procurement and qualification of those components were longer than foreseen.

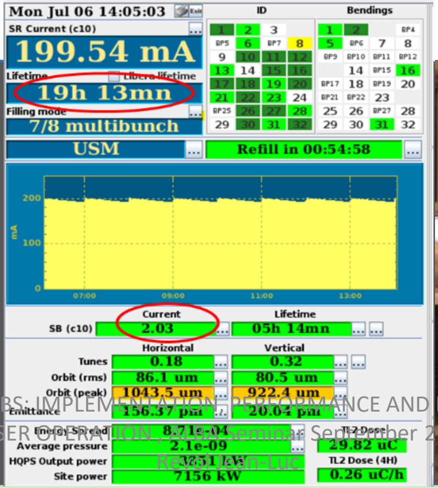




Commissioning



Commissioning



AVAILABILITY OF SERVICES DURING SHUTDOWN

Electricity

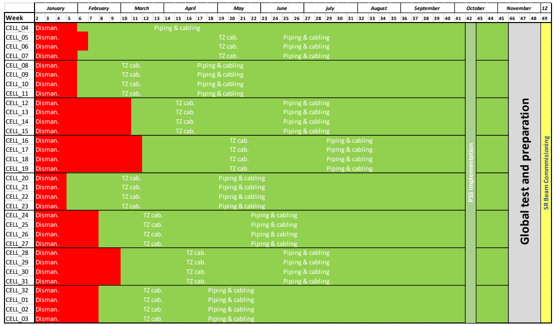
- Wall plug always available
- 400 V mains not available during dismantling and cabling & piping tasks, available during test periods prior SR cabling
- Full power from tunnel closure

Fluids

- Deionized water (SRE) available after piping task
- Reduced flow (SRE) available in Labs, technical rooms, and booster prior the end of SR piping
- Compressed air & Nitrogen networks available after completion of piping tasks
- Industrial water cooling always available

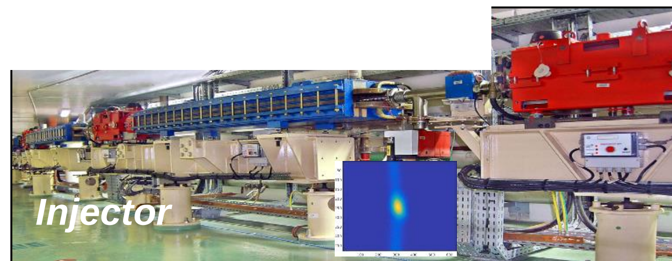
Control system

- Computing network + Wi-Fi available after dismantling period
- WI-FI requalified in the tunnel when most of equipments are installed
- Control System available after dismantling period (outside specific CS development and debugging periods)



ESRF-EBS: EQUIPMENT TEST AND STARTUP

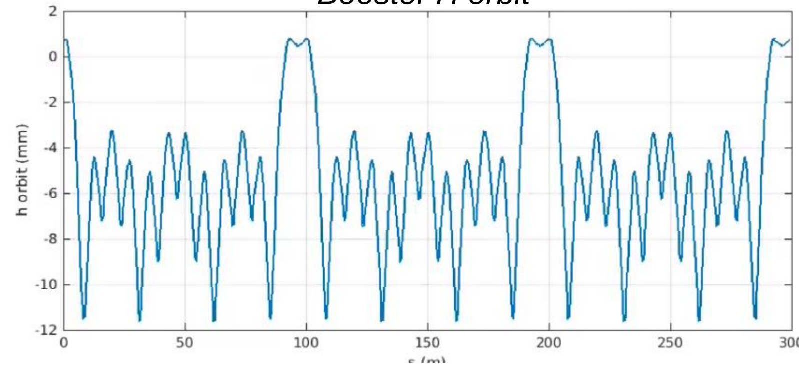
- ***Control software*, *optics tools, commissioning scripts validated*** *prior and during shutdown on the Storage Ring simulator*
- ***Low and high level control for all equipment*** *(including vacuum):*
  ➔ Started as soon as the cabling is done
- **Power test of the magnets** *from August to November 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**



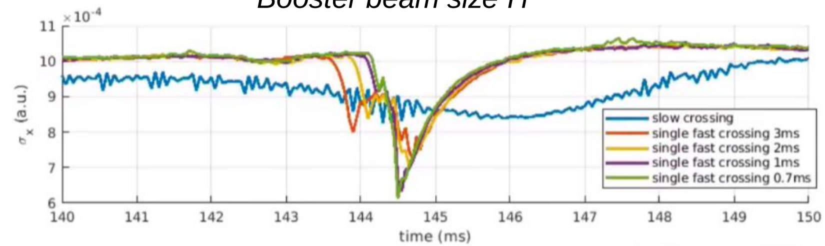
INJECTOR COMMISSIONING

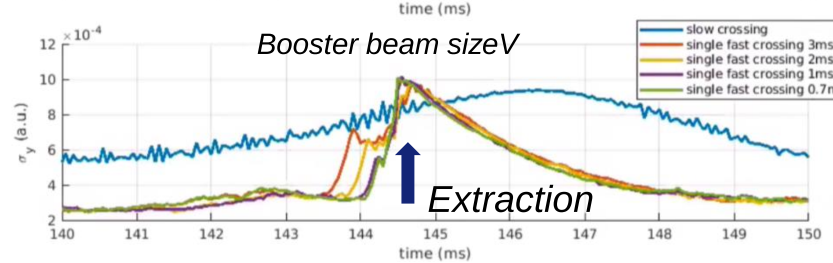
- A lot of upgrade during Upgrade phase 1
- Substantial work during shutdowns
  Reduction of booster circumference
  [Girders moved during shutdown by 17.5 mm, radial, for the new RF frequency (+172 kHz)]
  Upgrade of septa
  Adaptation of transfer line 2
- Operation off-energy
  Only part of booster reduction was applied to the reduction
  [40kHz mismatch,-1.4% off-energy
  ε_x: 120 nm ➔ 85 nm
- Operation with emittance exchange
  Fast tune vertical tunechange with power supply
  H beam size reduced by 40%
  V beam size increased by 3
  Injection efficiency improved by 5-10%
- Commissioning performed in a few days

Booster H orbit

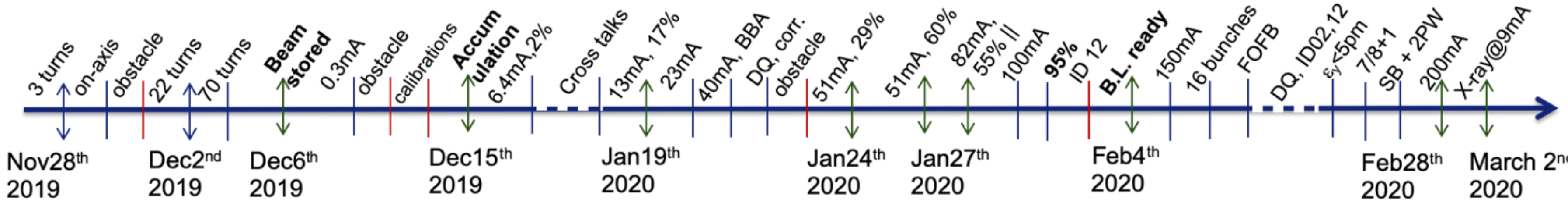


Booster beam size H

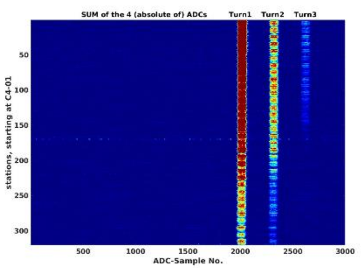


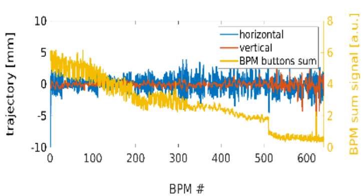


ESRF-EBS: BEAM COMMISSIONING

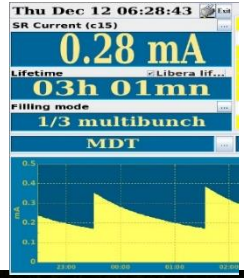


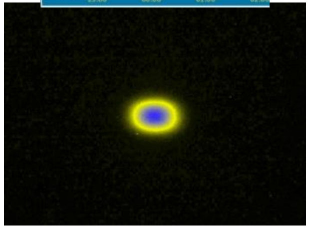
November 28th
First turns



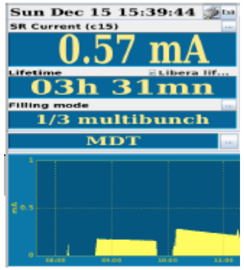


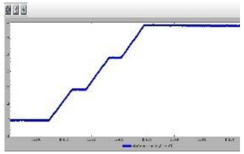
December 6th
Beam stored



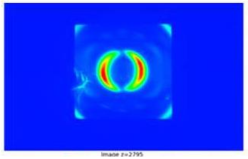


December 15th
Accumulation

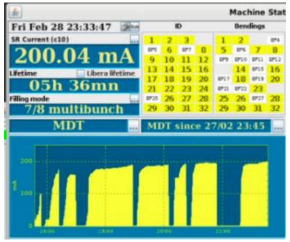




January 30th
First Beam on
26 Beamlines

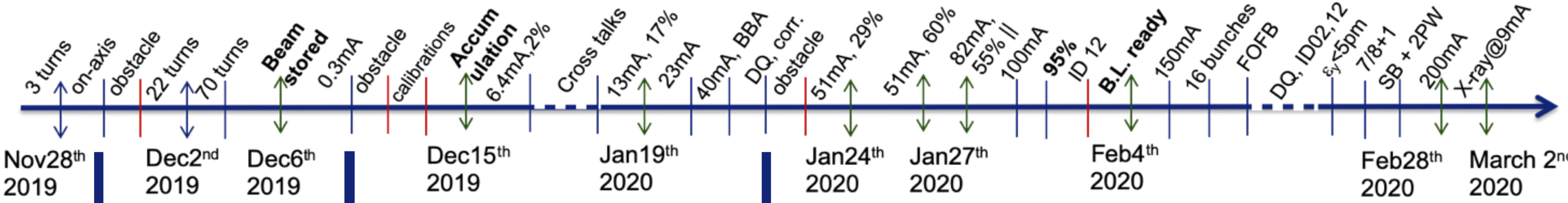


February 28th
200 mA achieved

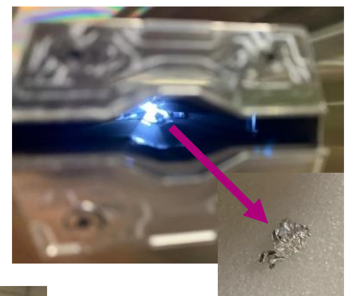


3 physical obstacles on the beam path and poor vacuum in a few ID NEG coated chambers slowed down the overall commissioning.

ESRF-EBS: BEAM COMMISSIONING

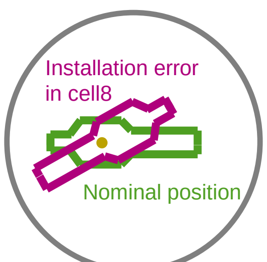


Obstacle in Cell-5 Ch7 AL piece fall during installation of DQ2



Piece of wire accidently into SS-23 ID chamber

3 physical obstacles on the beam path found during commissioning.

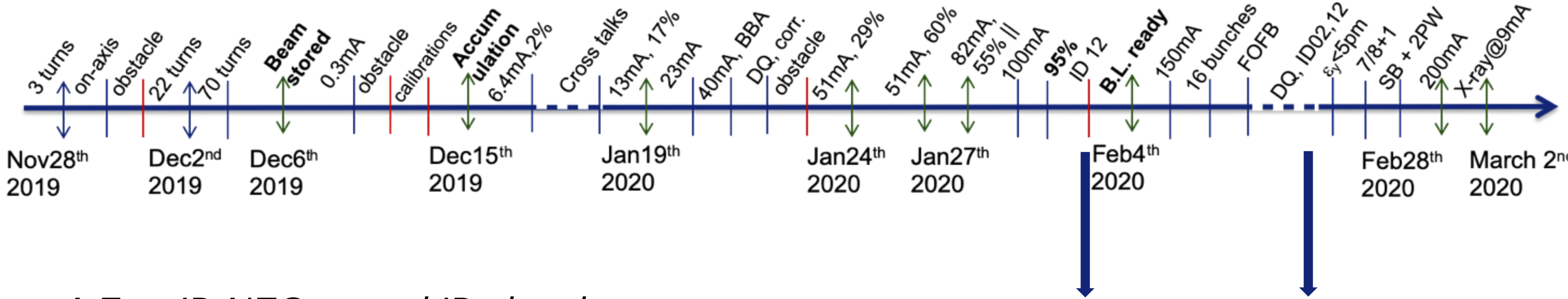


Installation mistake Cell8-Bellow 9-11

Detected, get around, resolved by:

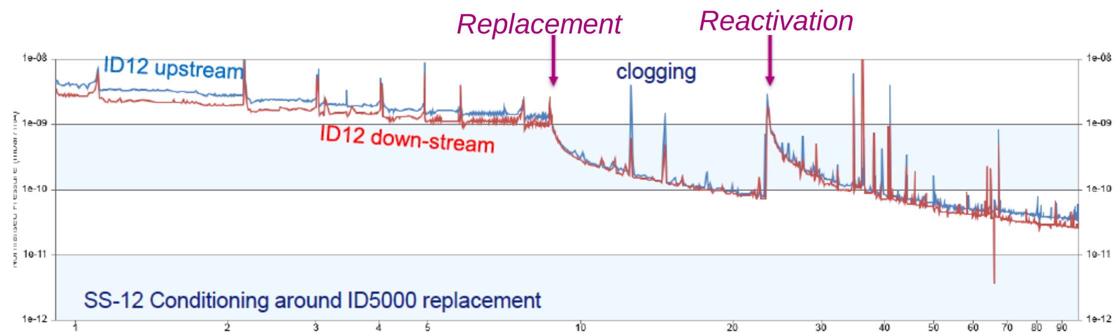
- Very useful beam loss and turn by turn BPM diagnostics
- Bumps, non-closed injection bump, off-energy operation, distorted close orbit,,…
- Intervention to remove the obstacles one by one
- Largely beneficial to injection efficiency, lifetime, optics tuning

ESRF-EBS: BEAM COMMISSIONING



A Few ID NEG coated ID chambers with poor vacuum

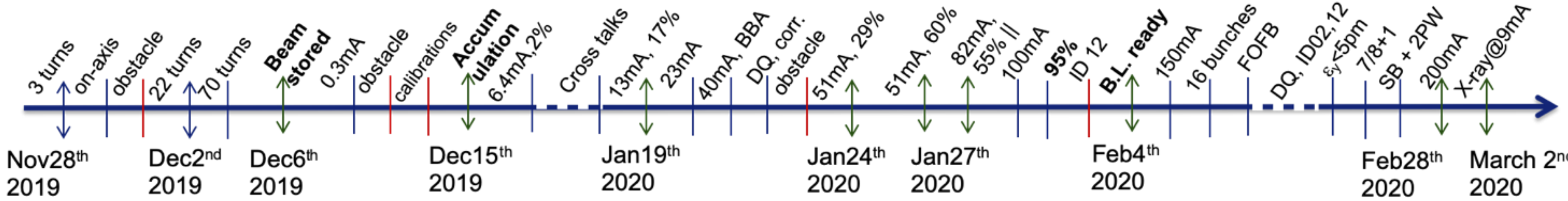
ID12 was contaminated ➔ poor vacuum ➔replaced



Detected, resolved by:

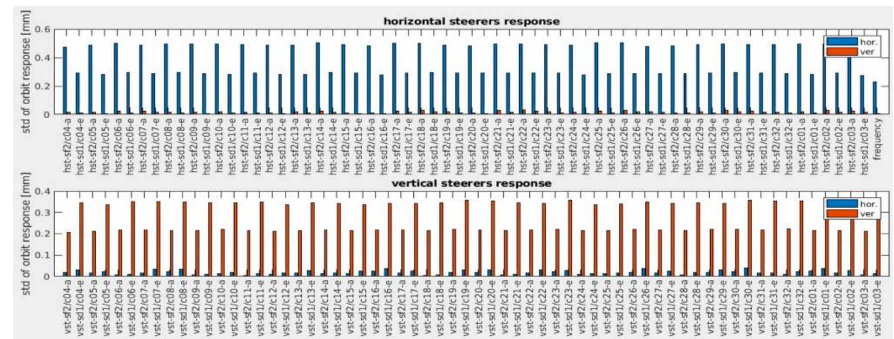
- Very useful beam loss diagnostics for detection
- Intervention to exchange the chamber
- Lifetime increase by a factor 3

ESRF-EBS: BEAM COMMISSIONING



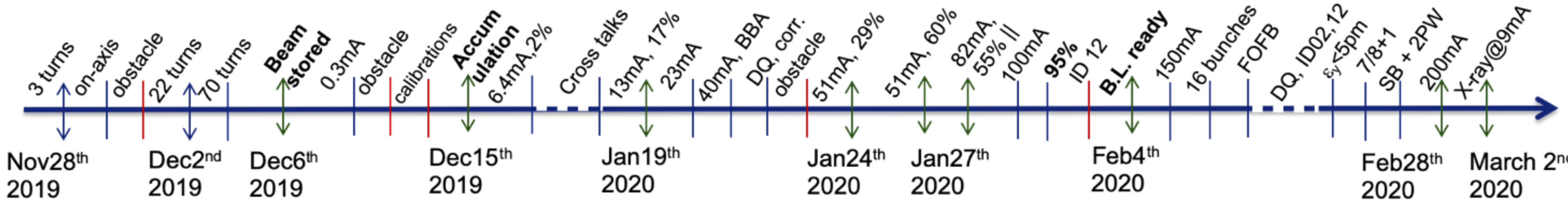
Optics tuning:

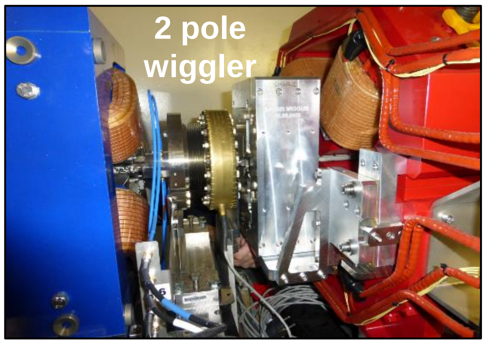
- Optics correction (magnet modeling)
  Add magnetic cross talk between adjacent magnets
  Correct wrong calibration factor
  Excellent alignment of components(<50 μm in both plane)
- Orbit steering
  Beam base alignment (100μm rms both plane)
  Eigen vector optimization (from 64 to 162)
  Eigen mode analysis (correction of DQs missing angle)
- Lattice re-correction after SB and 2PW installation
- Coupling correction (ε_v< 1pm.rad)
- Dynamic aperture and injection efficiency studies
  (Still lower than model)
- Automatic lifetime/losses optimizer
  (sextupoles, octupoles,skew scanning)

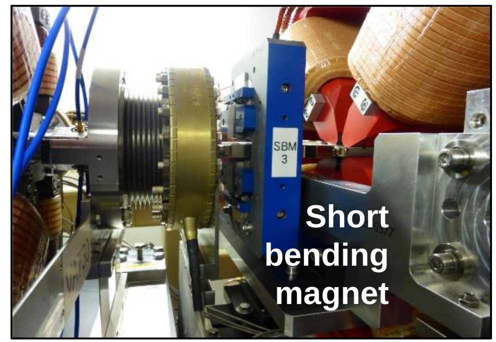


$\Delta\beta/\beta >$	**1.5% H ,**
	1.5% V,
$\Delta\eta \sim$	**0.7 mm H,**
	0.7 mm V
IE	**80%**

ESRF-EBS: BEAM COMMISSIONING





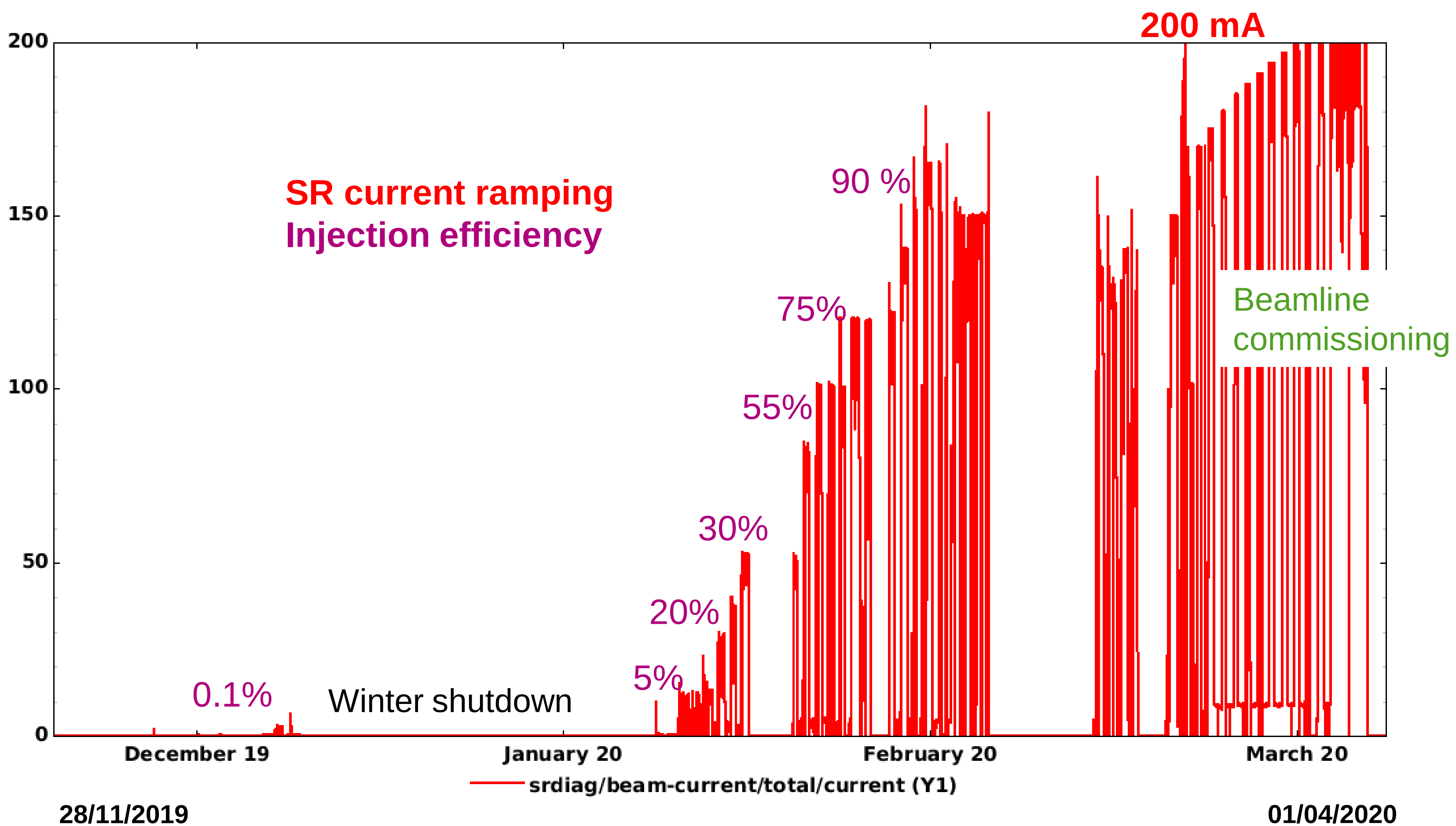


25 February MDT	BM 05	2PW
25 February MDT	BM 16	SB
March 8 MDT	BM 29	2PW
March 8 MDT	BM 30	SB
June Shutdown	BM 01	2PW
June Shutdown	BM 02	SB
June Shutdown	BM 08	SB
June Shutdown	BM 20	SB
June Shutdown	BM 31	2PW
June Shutdown	BM 32	SB
August Shutdown	BM 23	2PW
August Shutdown	BM 25	2PW
August Shutdown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

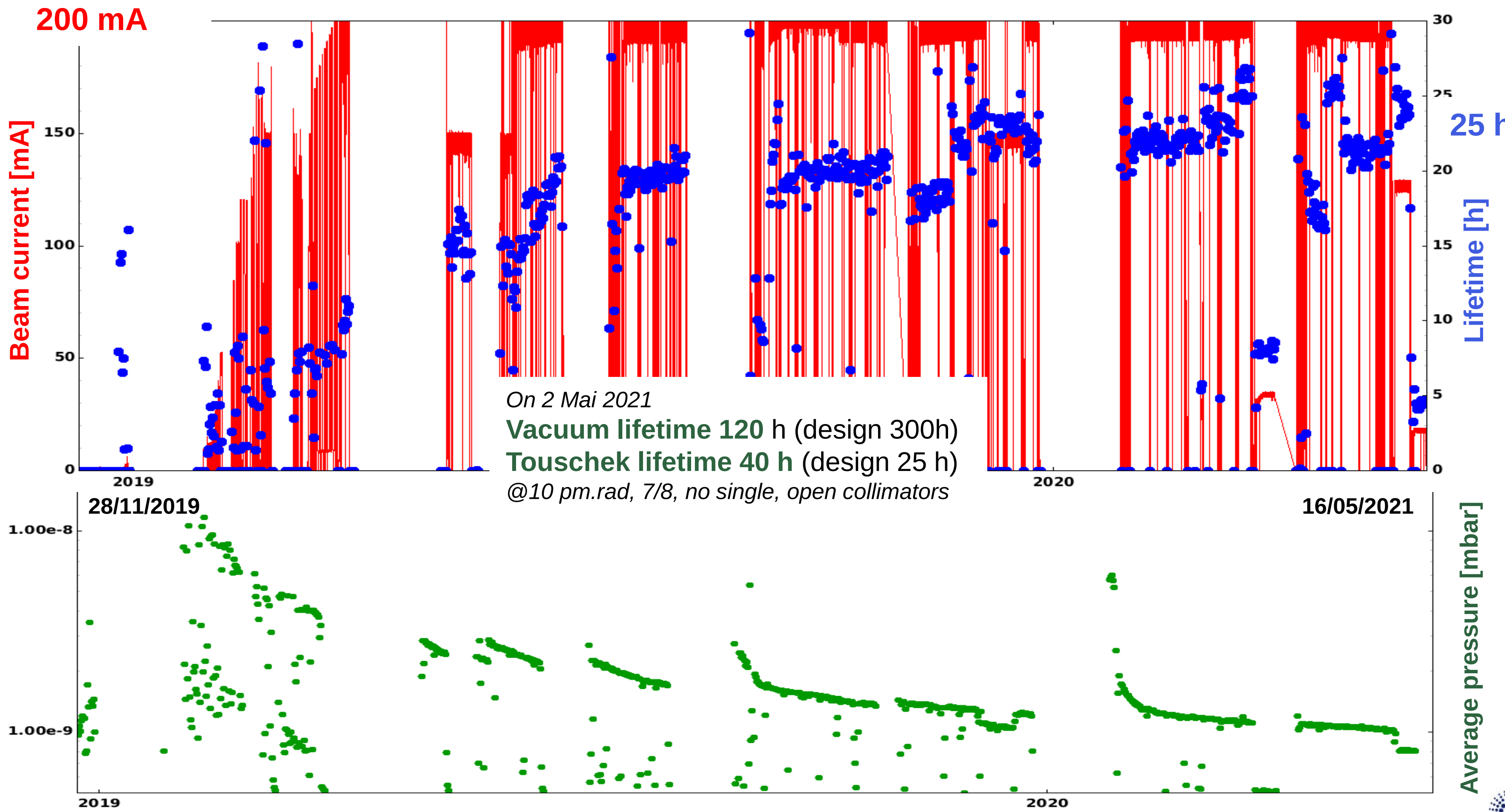
BM sources:

- 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



ESRF-EBS PERFORMANCE: LIFETIME



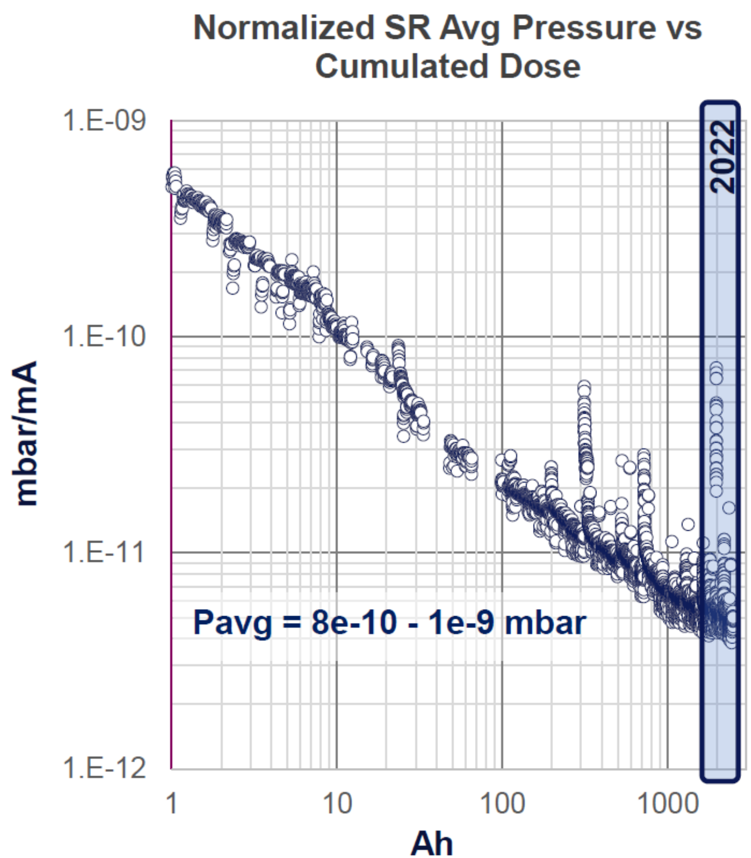
On 2 Mai 2021

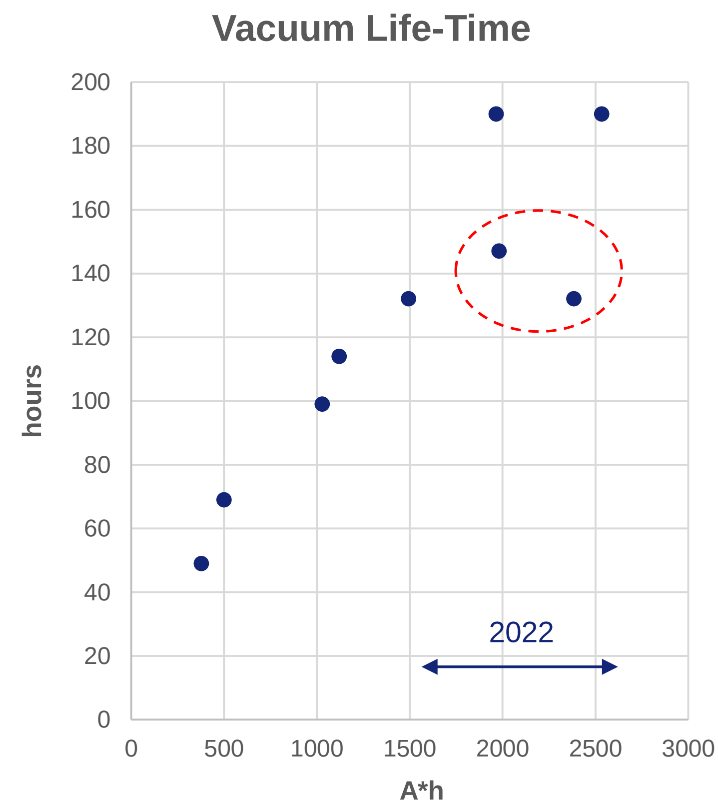
Vacuum lifetime 120 h (design 300h)

Touschek lifetime 40 h (design 25 h)

@10 pm.rad, 7/8, no single, open collimators

ESRF-EBS PERFORMANCE: LIFETIME

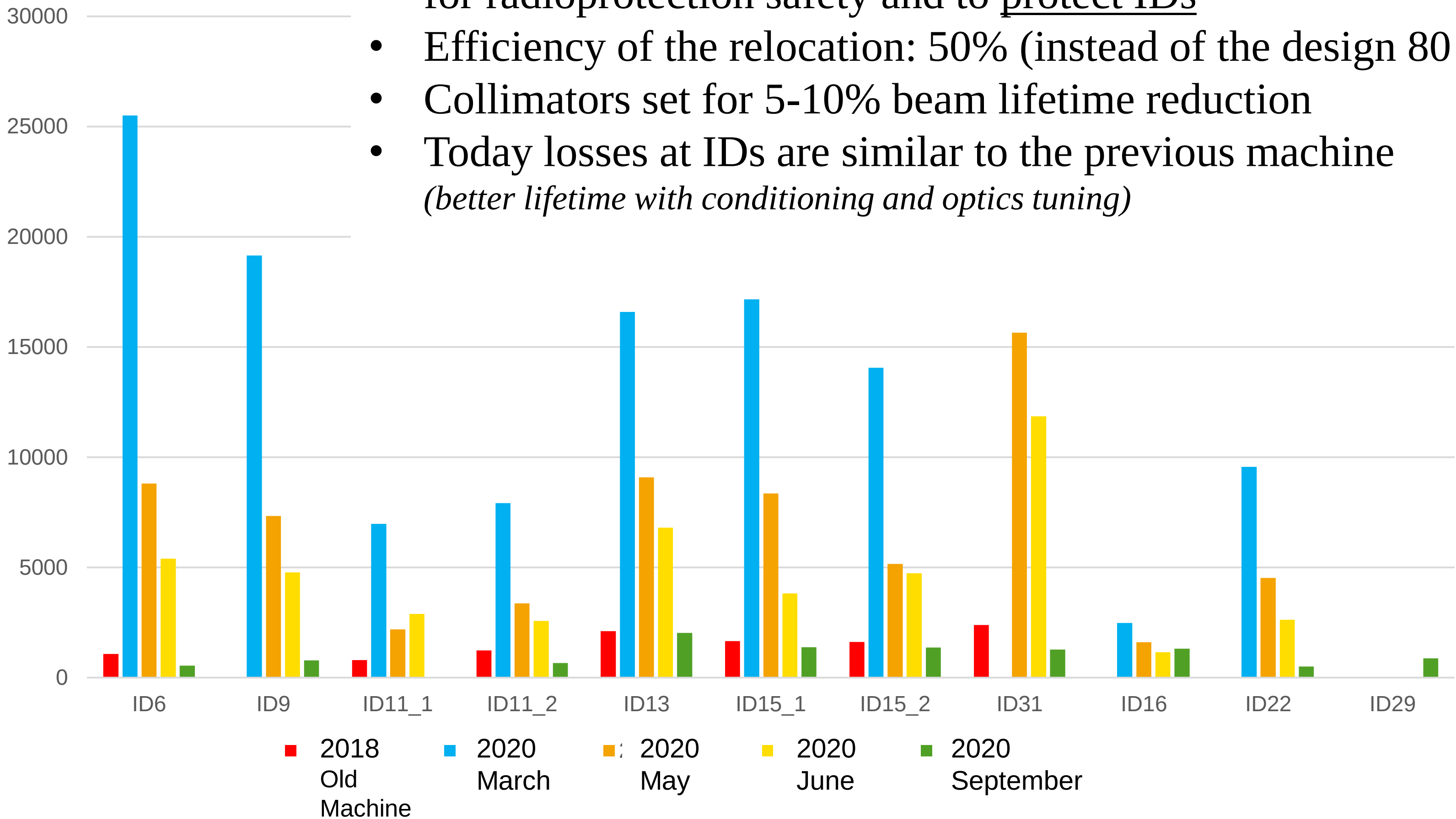




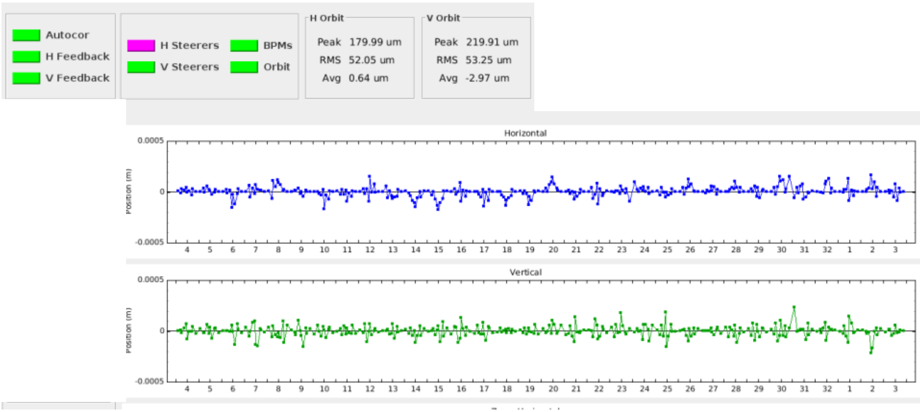
- Still conditioning
- Reaching lowest measurable limit at some locations

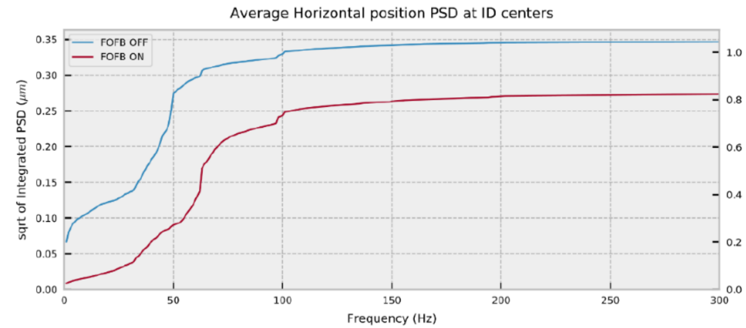
ESRF-EBS PERFORMANCE: ELECTRON BEAM LOSSES ON THE INVAC IDS

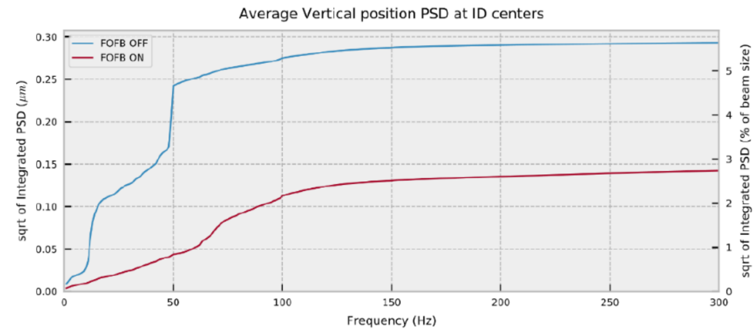
- Electron beam losses localized at two shielded collimators for radioprotection safety and to protect IDs
- Efficiency of the relocation: 50% (instead of the design 80 %)
- Collimators set for 5-10% beam lifetime reduction
- Today losses at IDs are similar to the previous machine
  (better lifetime with conditioning and optics tuning)



ESRF-EBS PERFORMANCE: BEAM STABILITY





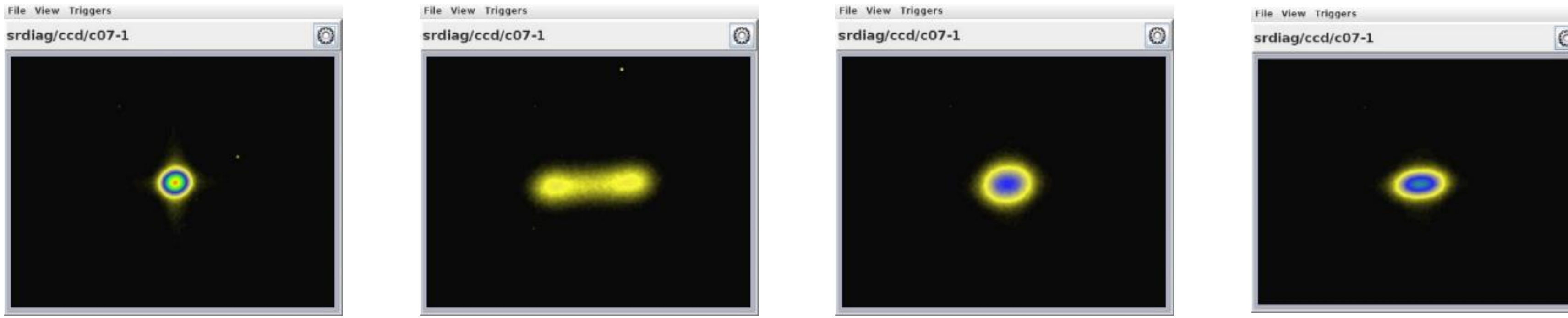


- Close orbit corrected down to 50 μm in both planes
- Residual AC motion at ID centers
  with **fast orbit feedback**:
  0.8% of horizontal beam size
  2.8% of vertical beam size

✓ *Despite the reduction in the horizontal emittance, the beam stability fulfils today the beamline requirements*

✓ *Task force established to monitor and further improve the beam stability against different sources of perturbation*

ESRF-EBS PERFORMANCE: INJECTION PERTURBATION BY KICKERS AND SEPTA



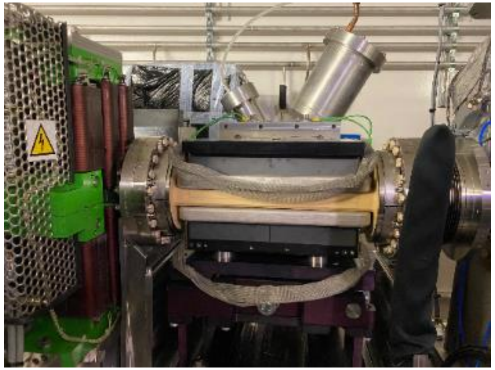
Kickers OFF | Kickers ON | Horizontal compensation ON | Horizontal and Vertical compensation ON

- 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
  - ✓ Septum compensation is efficient
  - ✓ Kicker power supplier upgrade (slow ramping) and feedforward compensation are effective but not sufficient
  - ✓ New injection schemes are under evaluation

ESRF-EBS PERFORMANCE: LIMITATION IN CURRENT

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

- Abnormal temperature of the ceramic chambers observed,
- K3 chamber broke when ramping in16 bunch



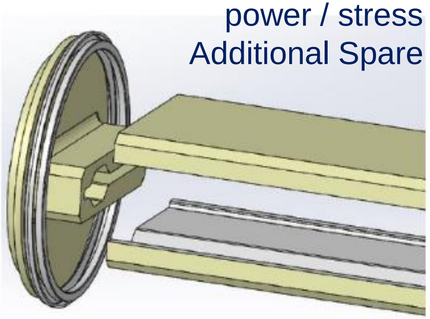
Existing ceramic kicker and shaker chambers fragile:
present design does not withstand thermal stress
➔ Cause: assembly from several parts with glazing joints (bubbles)

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

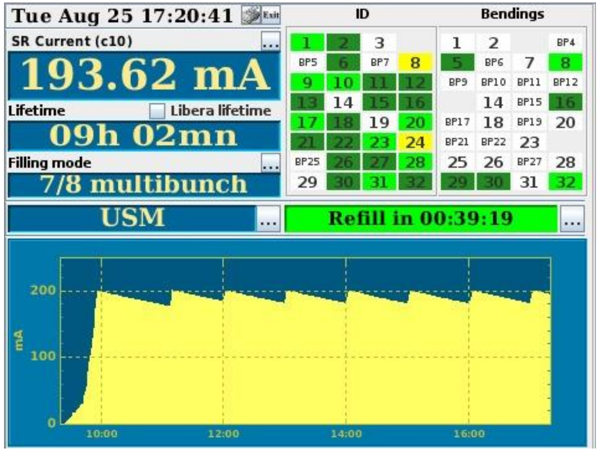
- Additional spare, with original design is difficult to procure
- New design deliveries should allow installation in 2024

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

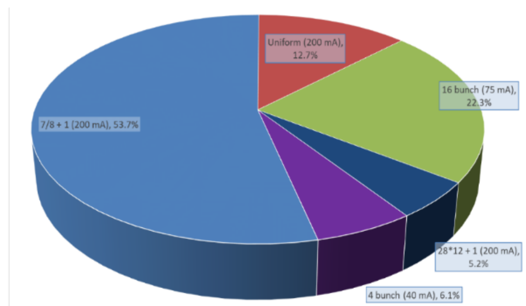


New Kicker Design :
One Single Piece
Eliminate ceramic junction
All 4 same geometry

ESRF-EBS: USER MODE OPERATION



Filling modes (2023)



	7/8 + 1	Uniform	28*12+1 (Hybrid)	16 bunch	4 bunch
I_{max} (mA)	192+8	200	192 + 8	**75** ~~(90)~~	40
Lifetime (h)	> 20	~ 25	> 16	~ 5.5	~ 5
ε_v (pm)	10	10	20	20	**40**
Reached	13/09/22	21/11/20	14/11/22	23/08/22	05/12/22

USM resumed on 25th August 2020
at 8:00
as initially planned

- *Intensity limitation due to mechanical weakness of the kickers ceramic chambers*
- *Vertical emittance artificially increased from 1 to 10 or 20 pm rad for an operational lifetime*
- *All timing modes delivered with a purity of 10-9 with cleaning process in the booster*

ESRF-EBS: RELIABILITY

	2017	*2018*	**2020** EBS	**2021** EBS	**2022** EBS	**2023(07)** EBS
Availability (%)	***98.3***	***98.5***	**96.1**	**96.4**	**99.1**	**99.3**
Mean time between failures (hrs)	***64.3***	***104.3***	**46.0**	**66.4**	**88.5**	**121.7**
Mean duration of a failure (hrs)	*1.11*	*1.60*	1.80	2.42	0.83	0.8

- **Overall reliability comparable to that of the old source**
- Magnet power supply system was the most complex hardware to develop and commission
- Operation disturbed by a few long failures from sub-systems not directly linked to EBS design
  - ✓ *aluminum NEG coated ID vacuum chambers, RF master source, 20 KV high voltage cable defect, cavity couplers, cryo-invacuum undulators*
  - ✓ Two problems of copper deposits in the SR cooling:
    - *Copper clogging in the magnet flow meters ➔ now reduced by regular checks of the flowmeters and by improving the absolute filtration in all cells.*
    - *Copper deposits in the absorber needle valves ➔temporarily solved by increasing the flow rate and modification of the circuit*

ESRF-EBS: RELIABILITY

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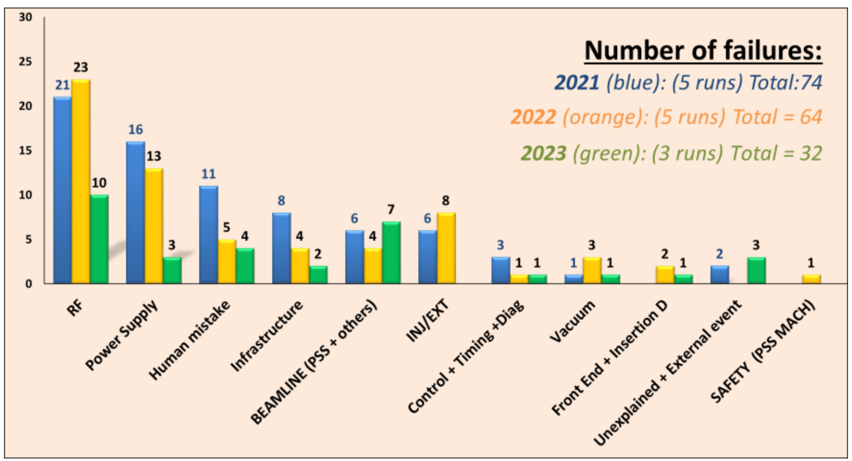
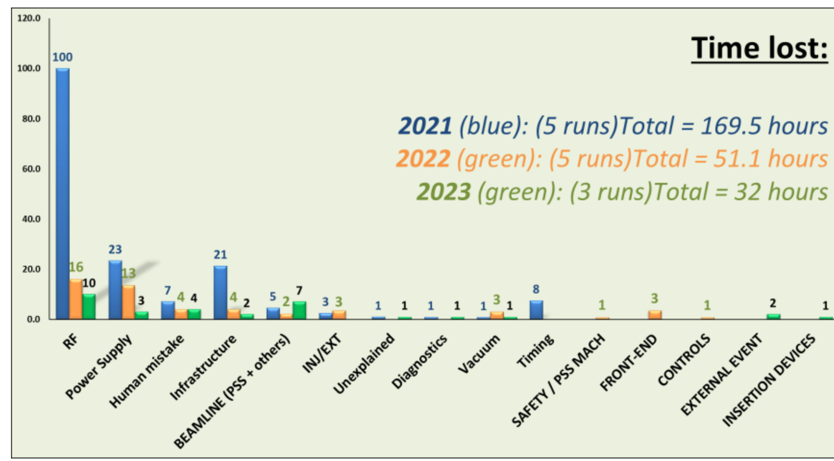




- ***Only 1.6% of refill skipped (2022)***

RADIATION DAMAGES IN THE NEW STORAGE RING

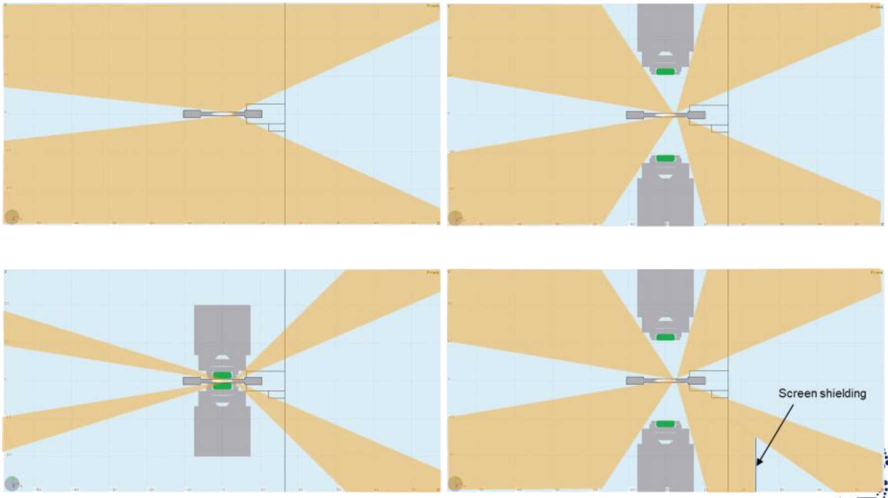
Some equipment are already suffering from radiation damages around the straight sections equipped with Aluminum NEG coated vacuum chambers.

- *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:

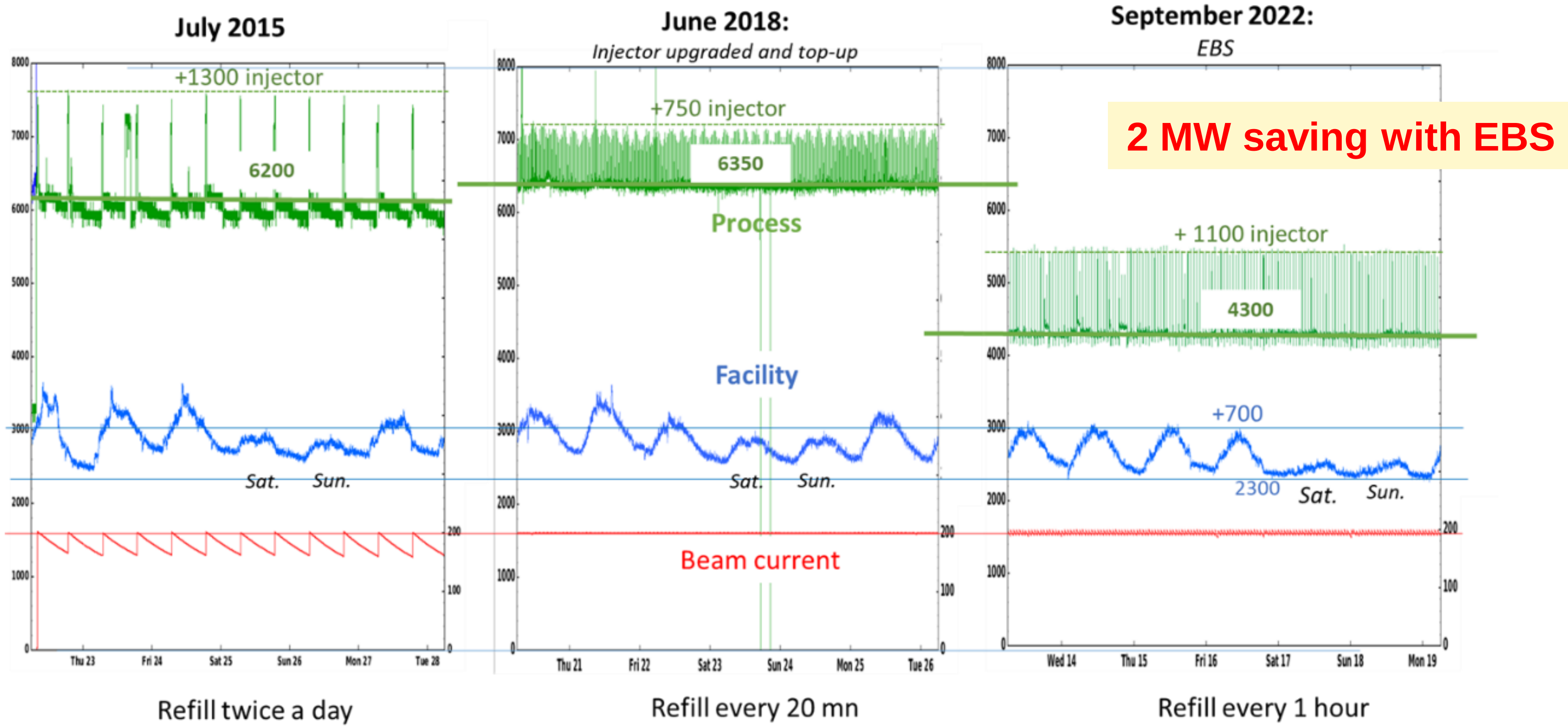
- *Visual inspection of the cables to follow-up their status*
- *Identification of the damaged devices*
- *Installation of lead shielding on HLS captors and FE photon shutters*

- Replacement of damaged cables
- Installation of additional lead shielings



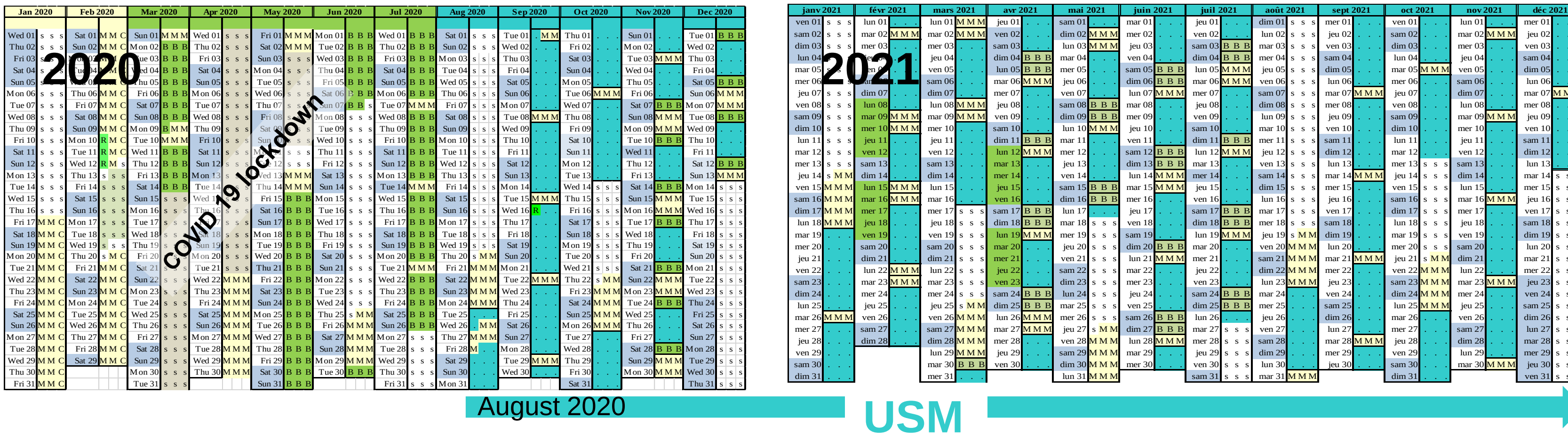
ESRF ENERGY CONSUMPTION OVERVIEW

Electricity consumption	before EBS =	65 350 MWh
	after EBS =	53 000 MWh (-20%)



ESRF-EBS: IMPACT OF COVID-19 PANDEMIC

- Commissioning of the SR completed when the first lockdown was declared in France.
- The two-month restrictions impacted heavily the beamline commissioning.
- During the second and third lockdowns, number of user shifts reduced.



Limited access to the site:

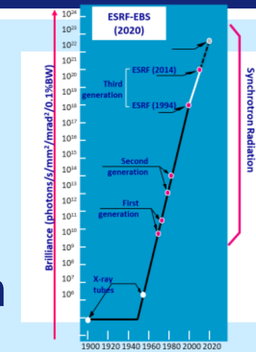
- *Opportunity to implement tools for remote control*
- *Development shift/interventions often performed via video-conferencing*
- *Very efficient for short and fast support*

LESSONS LEARNED: SPECIFICITY OF AN UPGRADE

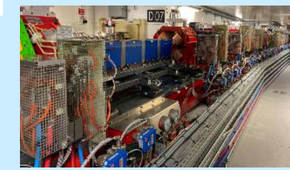
Life of an institute like ESRF and ALBA:

Starts with a green field project

Continuous development program



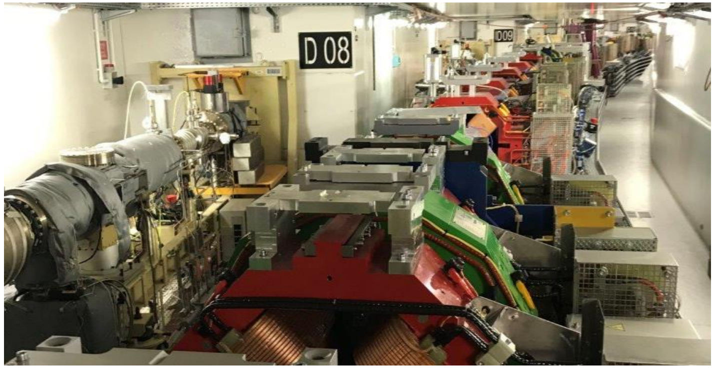
Large Upgrade



	Green field	*Development*	*Upgrade*
Pressure from users	+	+++	+++++
Planning and issue date	+	+++	+++++
Buildings & infrastructure	+++++	+	+
Space management	+	+++	+++++
Qualified staff and expertise	+	+++	+++++
Budget	+++	+++	+++

LESSONS LEARNED: TECHNICAL ASPECTS

- ✓ Large benefit from phase 1 upgrade for the infrastructure and accelerator components
- ✓ Capitalize on the expertise for installation and start-up gained on the existing facility prior upgrade *(staff, procedures, control…)*
- ✓ Pre-assembly and anticipated tasks as much as possible executed prior the shutdown
- ✓ Design, procurement and installation procedures validated on the mockup
- ✓ Activities concentrated on the storage ring during installation, limited activity for beamlines & infrastructure
- ✓ Validation of control and tools on a simulator
- ✓ Equipment test started as soon as possible before startup. including control system
- ✓ All systems (RF, diagnostics, power,..) should be operational and reliable from start of commissioning
- ✓ Efficient beam position monitor and beam loss detectors available from the start of commissioning



LESSONS LEARNED: PLANNING AND DECISION MAKING

We did (and re-did) a few time the planning !!..........
But the master planning never changed

- Planning should remain simple with the main tasks and managed by one person present during all the project *[EBS: MS project 6323 lines for the 32 cells]*,
  - *detailed planning of each tasks should be managed by the technical groups,*
  - *management of the critical resources is the driver*
  - *simple web access to the data base for all staff,*
  - *status of macro tasks updated by the technical groups.*
- The project organisation will evolve and adapt according to the project phases but the core people involved from the beginning should be kept.
- Fast and efficient escalating decision making is mandatory to keep the planning objective and the efficiency

LESSONS LEARNED: PROJECT AND OPERATION

- Operation is the priority…. And …Project is the priority….
  Impossible to separate it …same people involved
  `

  Issues popping up from the operation often require immediate actions which disturb the upgrade progress

- No need to separate and dedicate people only to the new project,
  staff should remain involved in the operation in order to guarantee the quality of the delivery and the ongoing development of the present machine.
  ````

  But the operation should also be delegated to the younger staff and less expertise staff in order to train then and give more time of the experts to work on the project.

- Everybody will finally move from the operation of the present machine to the construction and operation of the new machine
  ````

LESSONS LEARNED: HUMAN ASPECTS

- ✓ Stress and queries is obviously coming from the fact that we stop and destroy a nice and performant running machine with the objective to built a new and challenging one !

- ✓ Upgrade is also associated to a change of generation
  - Recruitment wave of new staff
  - Retirement wave (usually waiting the end of the project)
  - Creation of a new expertise
  - A chance to update (or get !) the documentation
  - A chance to modernize the working methods (data base…)

- ✓ Upgrade is a fantastic occasion to reinvigorate the institute

LESSONS LEARNED: SPECIFICITY OF THE TDR

For EBS the TDR phase was (extremely) **short**, [but we had the upgrade phase 1]:

- ➔ First idea 2012, white paper Nov 2012
- ➔ TDS (orange book) & council approval Nov 2015
- ➔ Project kick-off Jan 2015
- ➔ First Magnet CFT July 2015.

With more time, TDR should not only give a technical design report produce by a reduced number of persons but should allow:

- Fix and distribute a reference lattice
- Select technical and engineering solutions *(start drawings which is time consuming,..)*
- Built prototype of critical devices *(not done for EBS)*
- Select the logistics solutions *(storage, transport, preassembly, start the administrative process..)*
- Organize the procurement *(prequalification, preparation of specs,.)*
- Elaborate a first planning
- Elaborate the project implementation organisation and team
- Start to recruit new staff *(new temporary positions, anticipation of retirements,..)*

As much as possible should be ready before the realisation is launched
Modifications and adaptation are difficult later due to the interaction between the hardware components and the interactions between the tasks.
The exciting and challenging part begins really with the start of procurement …with the obligation to built a new running performant … with no possibility to step back !!

ESRF-EBS: CONCLUSION AND PERSPECTIVES

Main results:

- Dismantling and installation on schedule
- Fast equipment and beam commissioning of the new source
- Despite the impact of Covid-19 pandemic, users received back the beam on the scheduled day.
- Main performances achieved (beam current, beam modes, lifetime, emittances, stability)
- Excellent reliability of the equipment

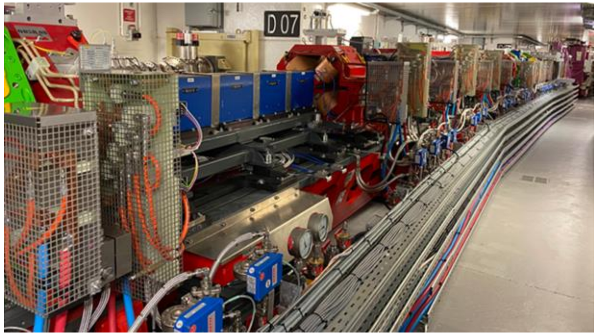
➢ Beamlines are now taking full benefit from the source, and continue to develop and upgrade

Today objectives for the source:

- Fine tuning and follow-up of beam parameters, including beam stability
- Implementation of the hot-swap system for the power supplies
- Minimize injection perturbation and revise injection frequency if needed
- Nominal beam current in time-structured modes

The operation oriented projects:

- New ceramic chambers
- Solid-State Amplifiers (SSA)
- 4Th Harmonic cavities
- Injector upgrade
- Mini-beta optics



ESRF-EBS: PARAMETER ACHIEVED

	Design	Realized today
Total current	200,90,40 mA	**200, 75, 40 mA**
MTBF	> 30 h	**> 100 h**
Up-Time	98%	**> 99 %**
Injection Efficiency	> 90 %	**> 70 %**
Lifetime	> 20 h	**> 20 h**
ε_H	< 140 pm rad	**< 130±20 pm rad**
ε_V	10 pm rad	**10 pm rad**
Stability	< 0.05 σ	**< 0.01 σ**

BEAMLINE UPGRADE (STILL IN PROGRESS)

Four new beamlines fully optimized for EBS

- EBSL3-BM18: *High throughput large field phase-contrast tomography beamline*
- EBSL8-ID29: *Serial crystallography beamline*
- EBSL1-ID18: *Beamline for coherence applications*
- EBSL2-ID03 *Beamline for hard X-ray diffraction microscope*

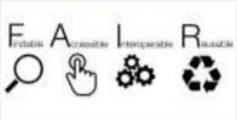
Refurbishment Programme

ID18 (ID14), ID21, ID24, BM23
ID26, ID27, BM29, ID32

10 new high-end 2D detectors

New insertion devices

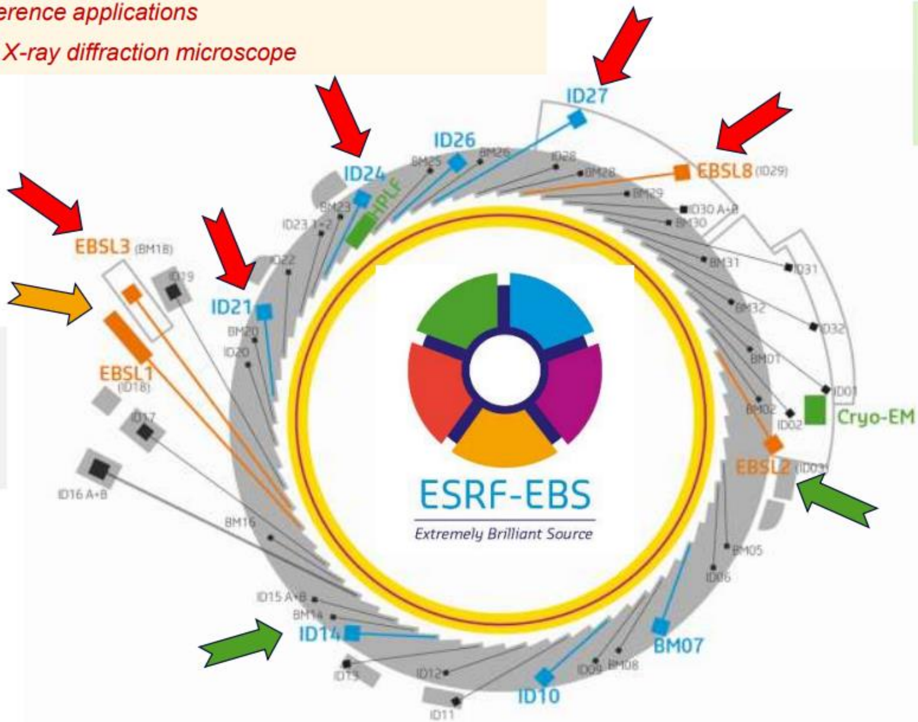
ESRF Data Policy
on all beamlines



New BL control system

Bliss

New access modes
BAG, mail-in, etc…



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