

ESRF-EBS : Mise en œuvre et mise en service, performance et redémarrage de l'exploitation utilisateurs

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On behalf of the ESRF Accelerator and Source Division

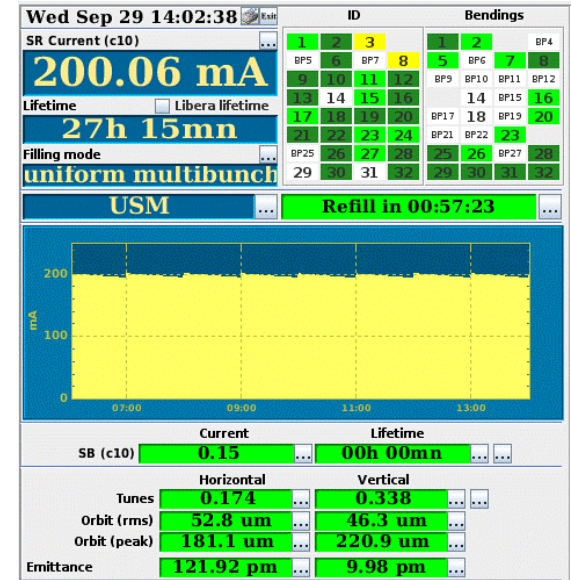
Roscoff
12 - 15 octobre 2021

Division Accélérateurs - Société Française de Physique

La Division Accélérateurs fête ses 25 ans !

Thèmes
Démarrages et mises en service
Retours d'expériences
Fonctionnement et fiabilité
Médical et petites machines
Instrumentation et technologies associées
Accélération laser plasma
Projets à venir

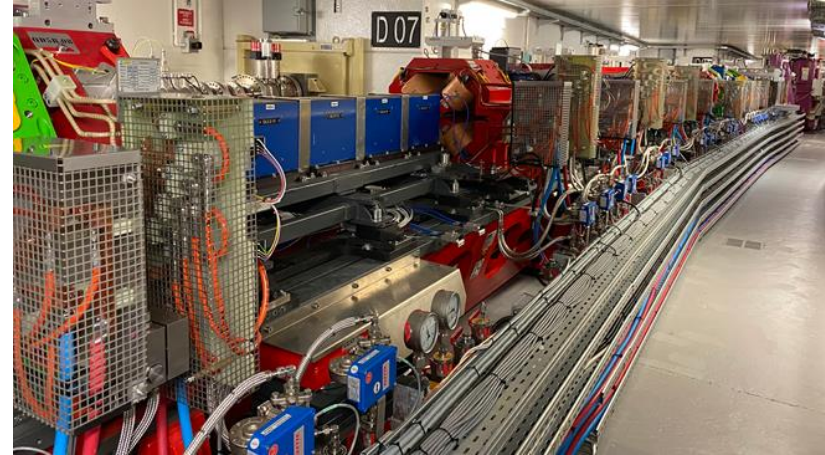
<http://accelerateurs.fr>



The European Synchrotron



- The ESRF-EBS project
- Implementation and start-up
- Commissioning and restart of user operation
- COVID-19 pandemic: impact and lessons learnt



ESRF FACTS AND FIGURES

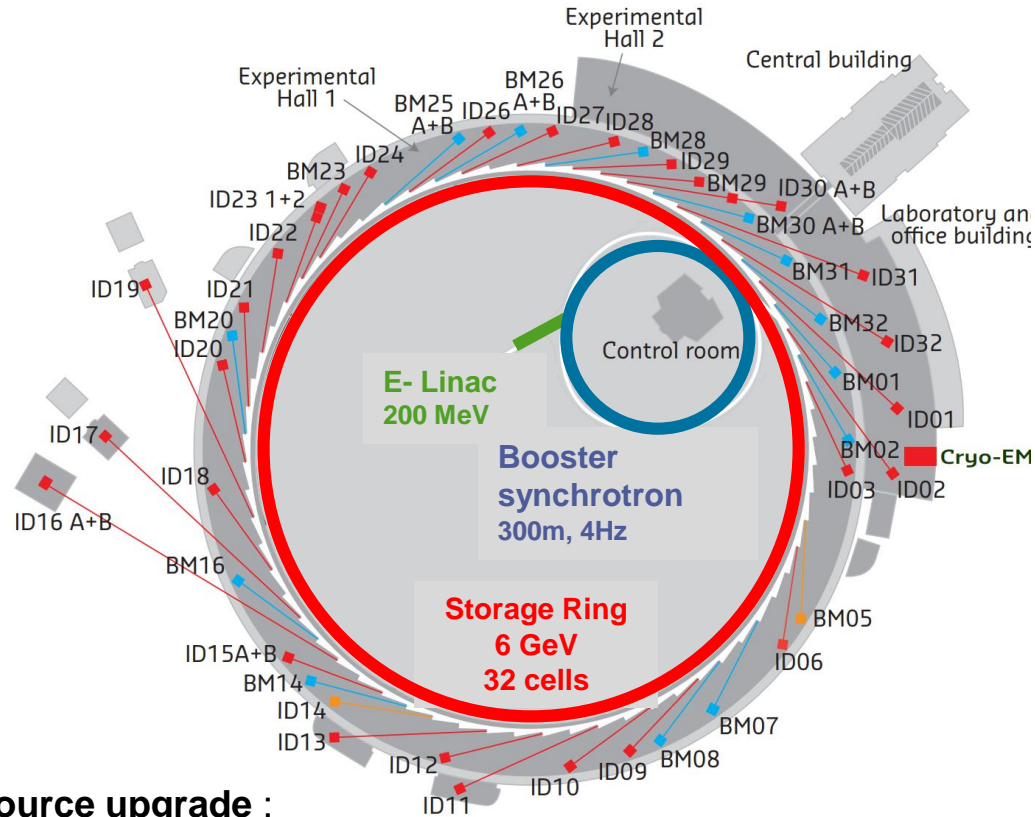
Light source in operation since 1994

Located in Grenoble, France

22 partner nations

Annual budget: 100 million euros

Staff: 650



Purple Book January 2008

Orange Book January 2015

ESRF UPGRADE PHASE I
180 M€ (2009-2015):
ESFRI ROADMAP 2006-2016
ON TIME – WITHIN BUDGET

- 19 new beamlines, many specialised in *nano*-beam science
- Upgrade and renewal of facilities and support laboratories

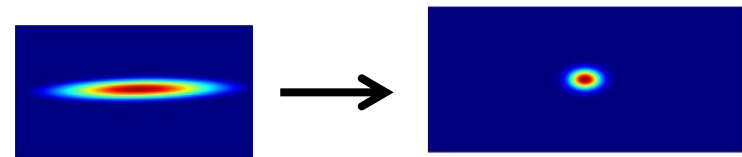
ESRF-EBS
Extremely Brilliant Source
150 M€ (2015-2022):
ESFRI LANDMARK (2016)

Revolutionary design for a new generation of synchrotron source storage rings

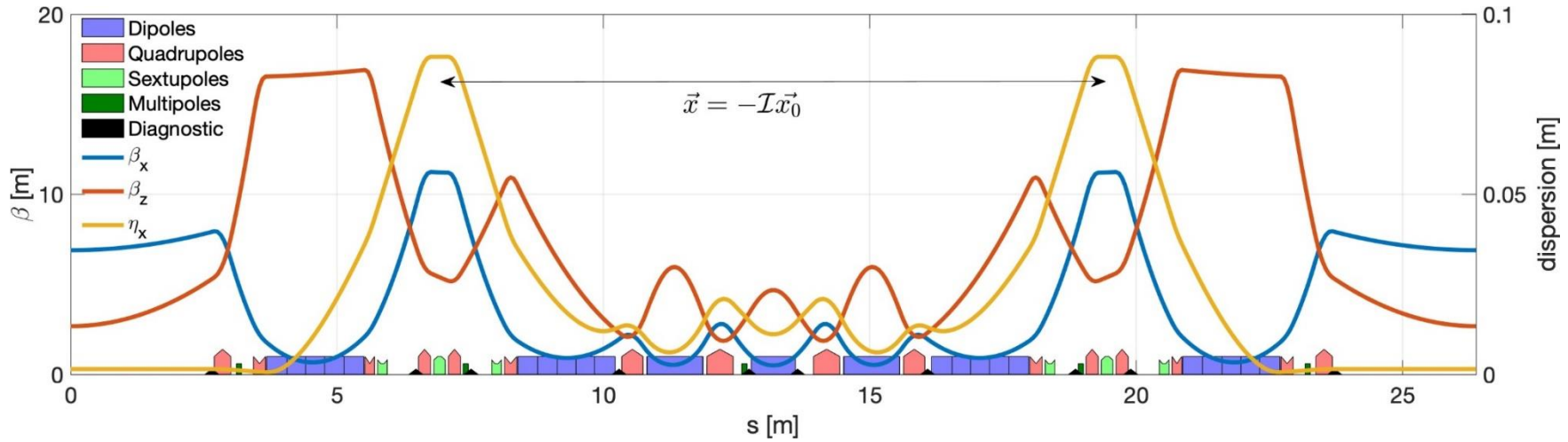
ESFRI

The **ESRF Extremely Brilliant Source upgrade** :

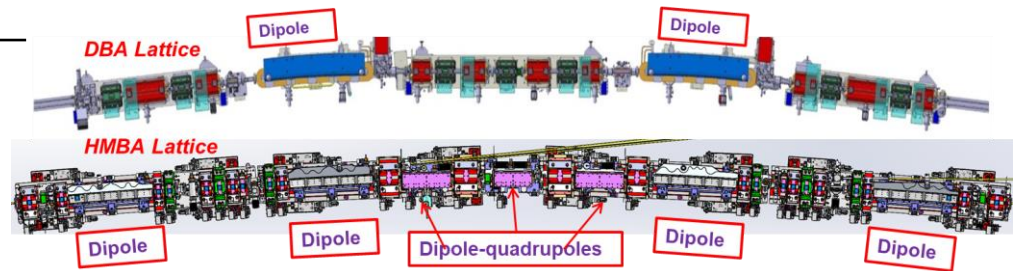
- Decrease the horizontal emittance
- Increase the source brilliance
- Increase the source coherence



THE ESRF-EBS UPGRADE

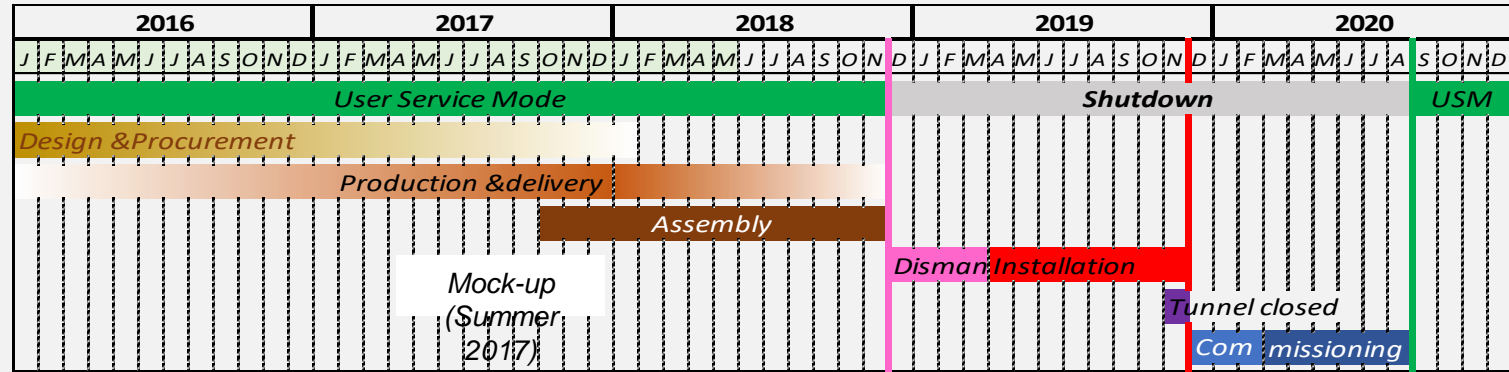


	<i>Units</i>	ESRF	ESRF-EBS
Energy	<i>GeV</i>	6	6
Circumference	<i>m</i>	844.4	844
Lattice		DBA	HMBA
Current	<i>mA</i>	200	200
Lifetime	<i>h</i>	50	25
Emittance H	<i>pm.rad</i>	4000	133
Emittance V	<i>pm.rad</i>	4	10*



31 magnets per cell instead of 17

ESRF-EBS PROJECT IMPLEMENTATION



Old ESRF-Storage Ring



- 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

ESRF-EBS



ESRF-EBS: INSTALLATION IN THE TUNNEL



Dismantling



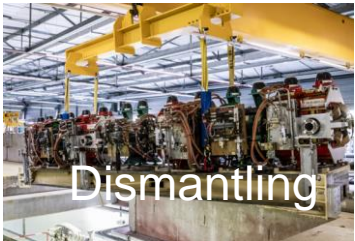
Entering girders



Interconnection & alignment



Radiofrequency



Dismantling



Moving girders



Piping

Cabling



Straight section for IDs



December 2018



Girder in place



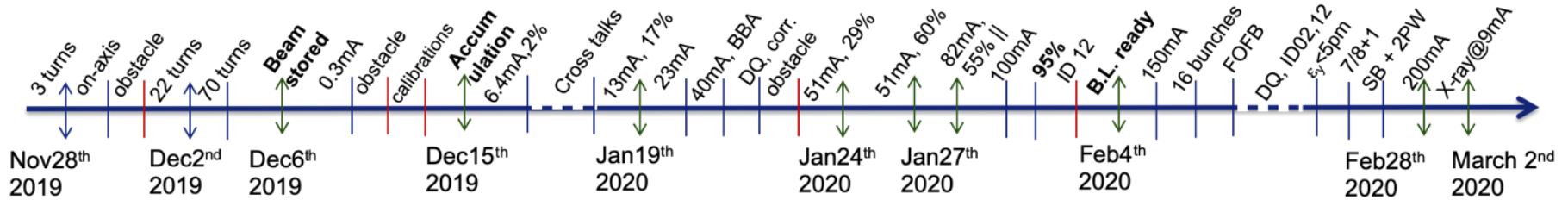
Injection zone



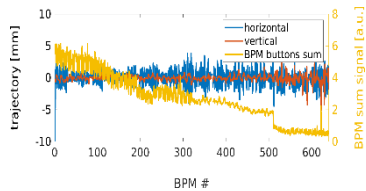
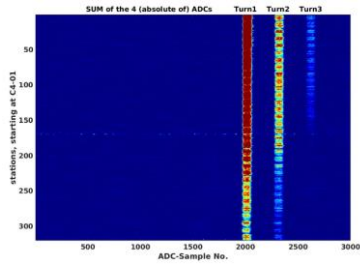
Front ends

November 2019

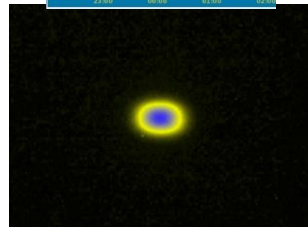
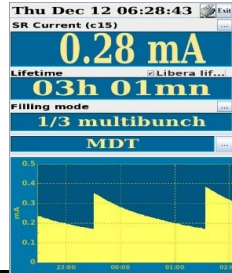
ESRF-EBS: COMMISSIONING



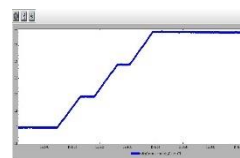
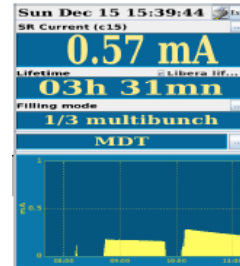
28th November
First turns



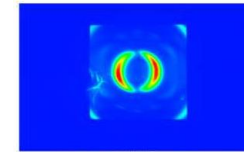
6th December
Beam stored



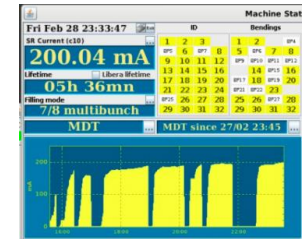
15th December
Accumulation



30th January
First Beam on
26 Beamlines

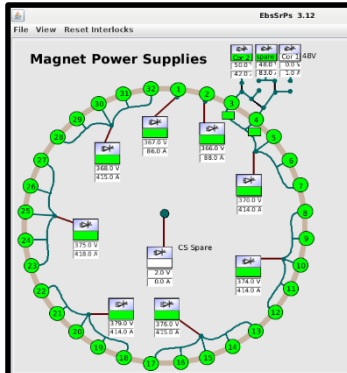
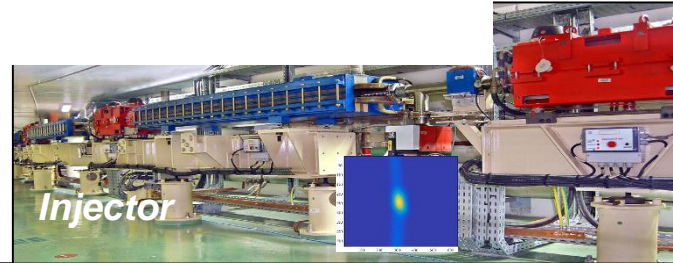


28th February
200 mA achieved

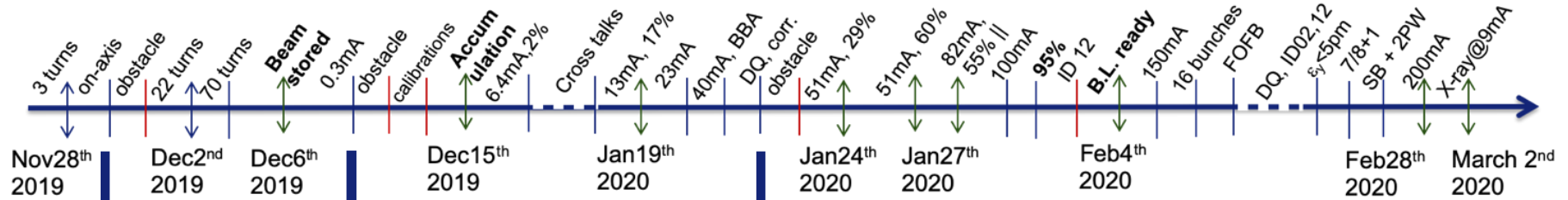


ESRF-EBS: EQUIPMENT COMMISSIONING

- **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**



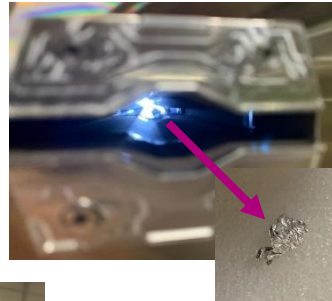
ESRF-EBS: BEAM COMMISSIONING OBSTACLES



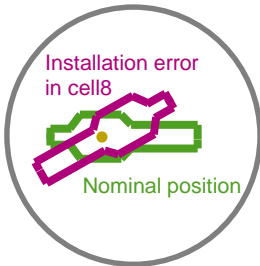
Obstacle in Cell-5 Ch7
AL piece fall during
installation of DQ2



Piece of wire
accidentally into SS-23
ID chamber



3 physical obstacles on the beam
path found during commissioning.

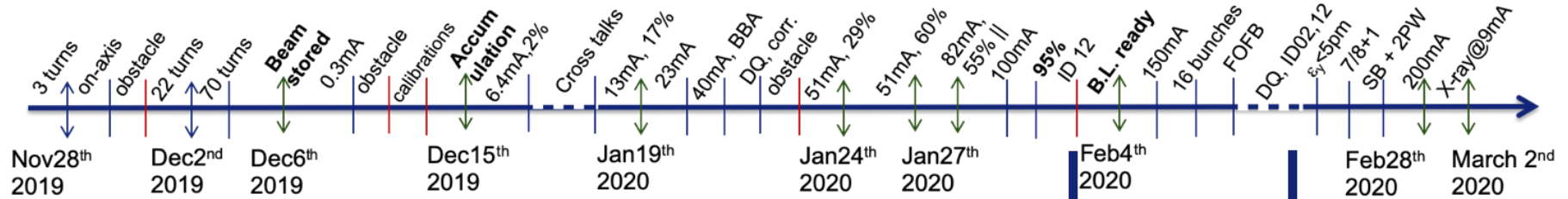


Installation mistake
Cell8-Bellow 9-11

Detected, get around, resolved by:

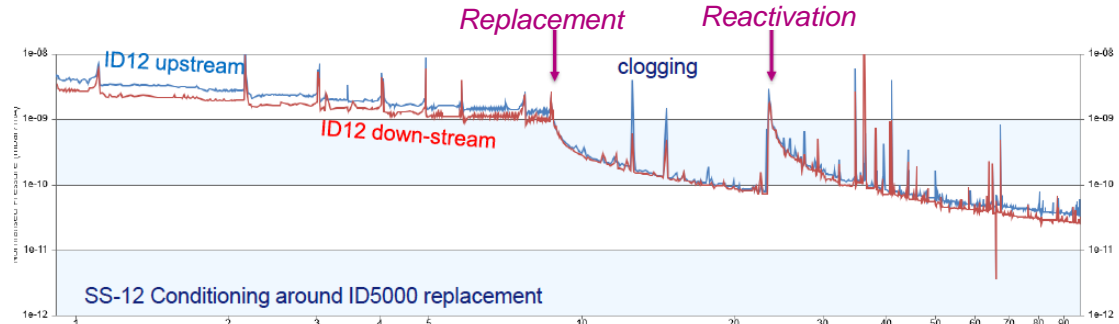
- Very useful beam loss and turn by turn BPM diagnostics
- Bumps, non-closed injection bump, off-energy operation, distorted close orbit,...
- Intervention to remove the obstacles one by one
- Largely beneficial to injection efficiency, lifetime, optics tuning

ESRF-EBS: BEAM COMMISSIONING VACUUM ISSUE



A Few ID NEG coated ID chambers with poor vacuum

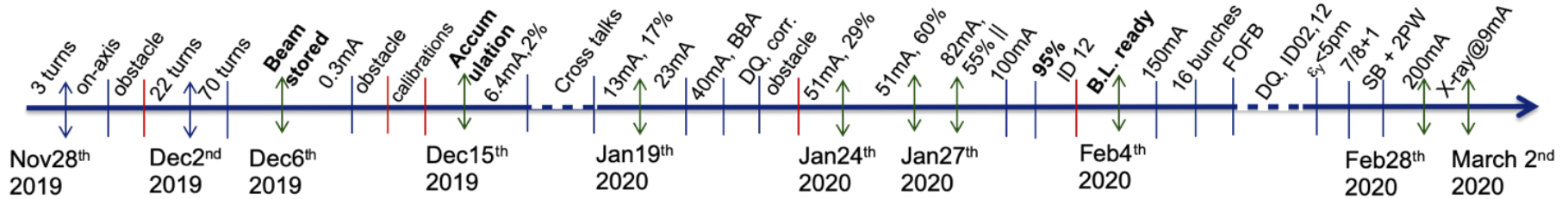
ID12 was contaminated → poor vacuum → replaced



Detected, resolved by:

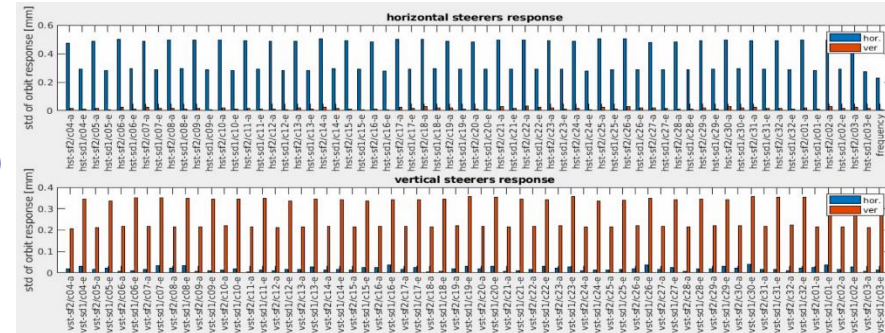
- Very useful beam loss diagnostics for detection
- Intervention to exchange the chamber
- Lifetime increase by a factor 3

ESRF-EBS: BEAM COMMISSIONING OPTICS TUNING



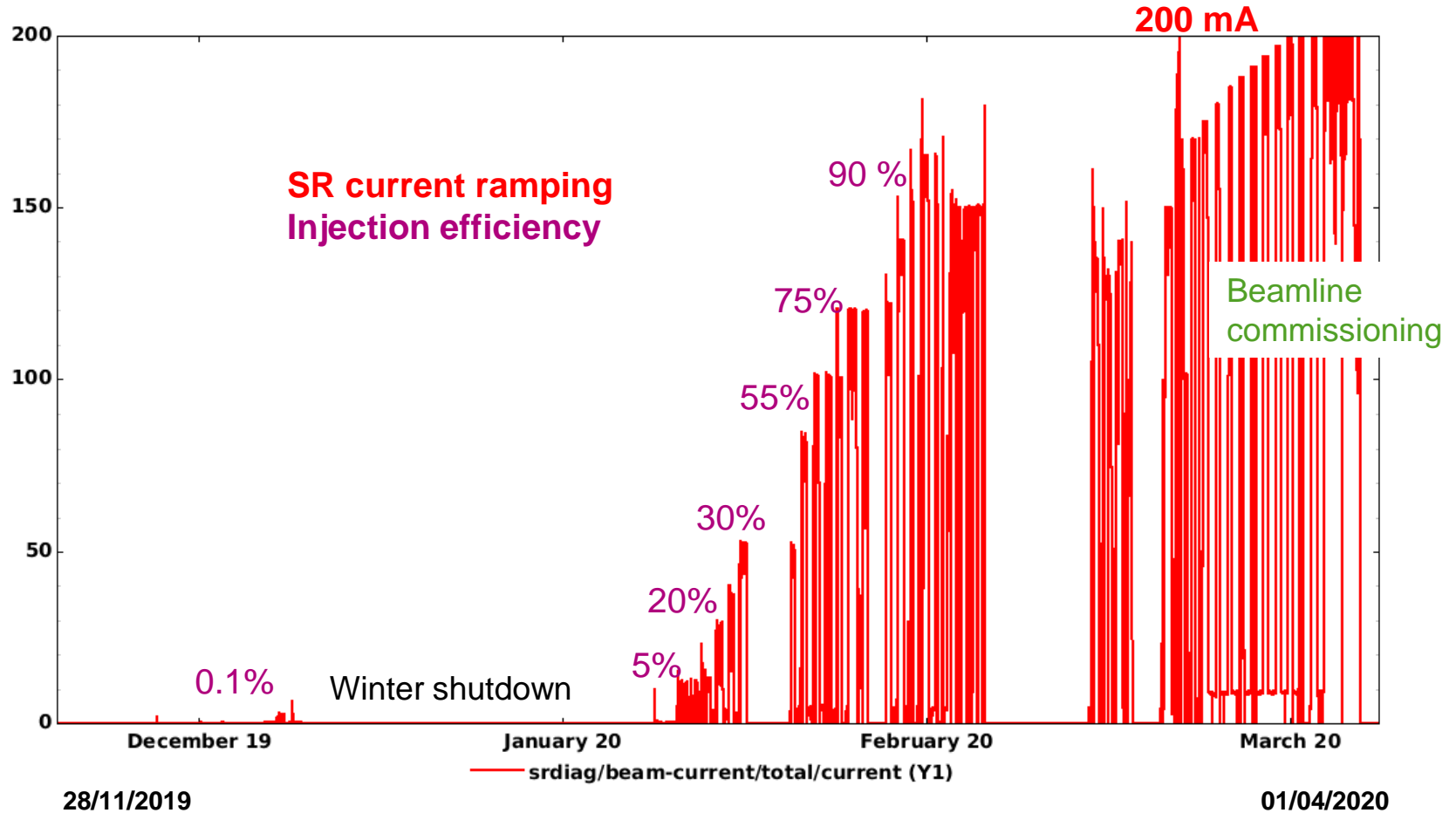
Optics tuning:

- 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 (100 μm rms both plane)
 - Eigen vector optimization (from 64 to 162)
 - Eigen mode analysis (correction of DQs missing angle)
- Lattice re-correction after BM sources (SB and 2PW) installation
- Coupling correction** ($\varepsilon_v < 1\text{pm.rad}$)
- 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: COMMISSIONING FROM 28/11 TO 01/04

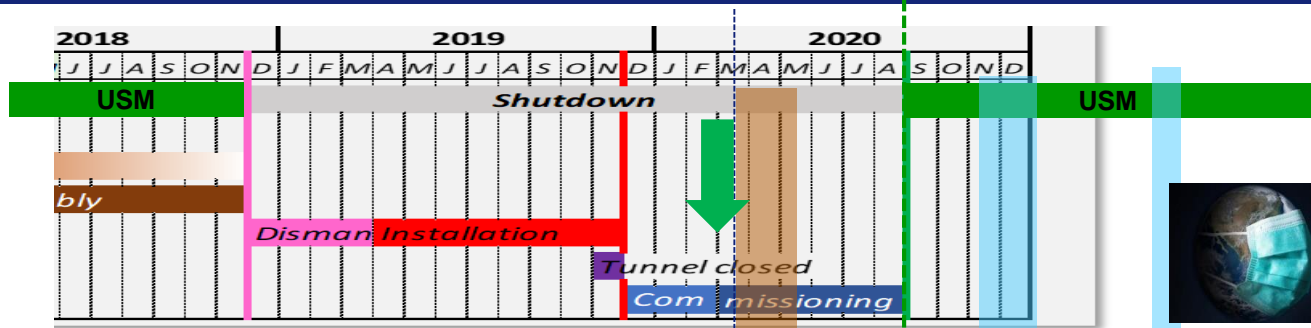
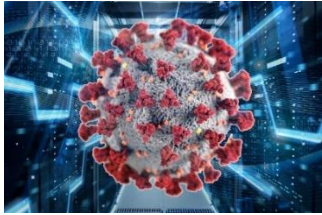


LESSONS LEARNED FROM THE INSTALLATION AND THE COMMISSIONING

- ✓ 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 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, including control system
- ✓ All systems (RF, diagnostics, power,..) operational and reliable from start of commissioning
- ✓ Efficient beam position monitor and beam loss detectors available from the start of commissioning



ESRF-EBS IMPACT OF COVID-19 PANDEMIC



→ 28 Feb. 2020 plan: Machine ready for beamlines → **Achieved**

→ 03 March 2020 plan: Start of beamline commissioning → **Achieved**

But: *17-03/20 to 11/05/20: First lockdown in France* (declared on 14/03/20)
→ **ESRF Closure** → **Stop operation**

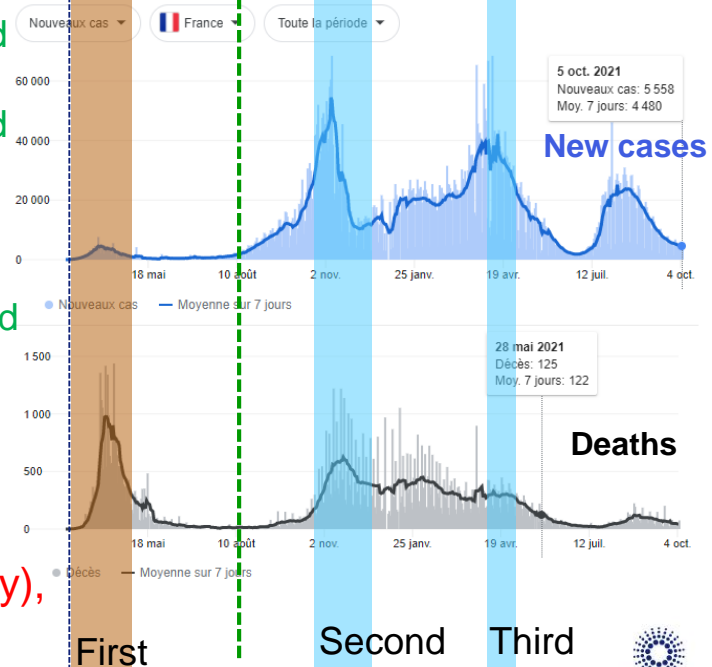
→ 25 August 2020 plan: Start of user operation → **Achieved**

But: *30/10/20 to 15/12/20: Second lockdown*

03/04/21 to 03/05/21: Third lockdown

→ **Adaptation of the operation planning for users**

**COVID-19 impacted the schedule as of 14 March 2020 (only),
affecting mostly the beamline and user programme**



ESRF AT THE TIME OF THE COVID-19 PANDEMIC

- Ensuring safe working conditions on site , strictly following French regulations
- Objective: Restarting user service mode (USM) on 25 August 2020 with a maximum number of beamlines open

➔ ESRF KEPT FULLY OPERATIONAL FROM 25-08-2020 TO DATE!



2020

Normal operation of accelerators

CLOSURE

Less than 10 people on site

1st WAVE

Less than 100 people on site

2nd WAVE

Gradual Increase of people on site

RESUME OPERATION

Complete USM preparation

USM OPERATION

Back to USM

16 March – 11 May

Closure, continuity plan,
Teleworking.

Restart of the accelerator with minimum people onsite on 22 April,... but stopped due to a water leak....

12 May – 1 June

Resume gradually storage ring & beamline commissioning,
COVID-19 research
USM preparation
Telework privileged

2 June – 10 July

13 July – 24 August

From 25 August

Back to USM
Strict COVID-19 sanitary
Telework privileged

IMPACT OF COVID-19 FOR THE OPERATION

Jan 2020	Feb 2020	Mar 2020	Apr 2020	May 2020	Jun 2020	Jul 2020	Aug 2020	Sep 2020	Oct 2020	Nov 2020	Dec 2020
Wed 01	Sat 01	Sun 01	Mon 01	Tue 01	Wed 01	Thu 01	Fri 01	Sat 01	Sun 01	Mon 01	Tue 01
Thu 02	Sun 02	Mon 02	Tue 02	Wed 02	Thu 02	Fri 02	Sat 02	Sun 02	Mon 02	Tue 02	Wed 02
Fri 03	Mon 03	Tue 03	Wed 03	Thu 03	Fri 03	Sat 03	Mon 03	Tue 03	Wed 03	Thu 03	Fri 03
Sat 04	Tue 04	Wed 04	Thu 04	Fri 04	Sat 04	Mon 04	Tue 04	Wed 04	Thu 04	Fri 04	Sat 04
Mon 05	Wed 05	Thu 05	Fri 05	Sat 05	Mon 05	Tue 05	Wed 05	Thu 05	Fri 05	Sat 05	Mon 05
Tue 06	Fri 06	Sat 06	Mon 06	Tue 06	Wed 06	Thu 06	Fri 06	Sat 06	Mon 06	Tue 06	Wed 06
Wed 07	Sun 07	Mon 07	Tue 07	Wed 07	Thu 07	Fri 07	Sat 07	Sun 07	Mon 07	Tue 07	Wed 07
Thu 08	Sat 08	Mon 08	Tue 08	Wed 08	Thu 08	Fri 08	Sat 08	Mon 08	Tue 08	Wed 08	Thu 08
Fri 09	Sun 09	Mon 09	Tue 09	Wed 09	Thu 09	Fri 09	Sat 09	Sun 09	Mon 09	Tue 09	Wed 09
Sat 10	Mon 10	Tue 10	Wed 10	Thu 10	Fri 10	Sat 10	Mon 10	Tue 10	Wed 10	Thu 10	Fri 10
Mon 11	Tue 11	Wed 11	Thu 11	Fri 11	Sat 11	Mon 11	Tue 11	Wed 11	Thu 11	Fri 11	Sat 11
Tue 12	Wed 12	Thu 12	Fri 12	Sat 12	Mon 12	Tue 12	Wed 12	Thu 12	Fri 12	Sat 12	Mon 12
Wed 13	Thu 13	Fri 13	Sat 13	Mon 13	Tue 13	Wed 13	Thu 13	Fri 13	Sat 13	Mon 13	Tue 13
Thu 14	Fri 14	Sat 14	Mon 14	Tue 14	Wed 14	Thu 14	Fri 14	Sat 14	Mon 14	Tue 14	Wed 14
Mon 15	Tue 15	Wed 15	Thu 15	Fri 15	Sat 15	Mon 15	Tue 15	Wed 15	Thu 15	Fri 15	Sat 15
Tue 16	Wed 16	Thu 16	Fri 16	Sat 16	Mon 16	Tue 16	Wed 16	Thu 16	Fri 16	Sat 16	Mon 16
Wed 17	Thu 17	Fri 17	Sat 17	Mon 17	Tue 17	Wed 17	Thu 17	Fri 17	Sat 17	Mon 17	Tue 17
Thu 18	Fri 18	Sat 18	Mon 18	Tue 18	Wed 18	Thu 18	Fri 18	Sat 18	Mon 18	Tue 18	Wed 18
Fri 19	Sat 19	Mon 19	Tue 19	Wed 19	Thu 19	Fri 19	Sat 19	Mon 19	Tue 19	Wed 19	Thu 19
Sat 20	Mon 20	Tue 20	Wed 20	Thu 20	Fri 20	Sat 20	Mon 20	Tue 20	Wed 20	Thu 20	Fri 20
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Tue 28	Wed 28	Thu 28	Fri 28	Sat 28	Mon 28	Tue 28	Wed 28	Thu 28	Fri 28	Sat 28	Mon 28
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Thu 30	Fri 30	Sat 30	Mon 30	Tue 30	Wed 30	Thu 30	Fri 30	Sat 30	Mon 30	Tue 30	Wed 30
Fri 31	Sat 31	Mon 31	Tue 31	Wed 31	Thu 31	Fri 31	Sat 31	Mon 31	Tue 31	Wed 31	Thu 31

Jan 2021	Feb 2021	mar 2021	avr 2021	mai 2021	juin 2021	juil 2021	août 2021	sept 2021	oct 2021	nov 2021	dec 2021
ven 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01	dim 01
dim 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02	mer 02
mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03	mer 03
jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04	jeu 04
ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05	ven 05
mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06	mer 06
jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07	jeu 07
ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08	ven 08
mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09	mer 09
jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10	jeu 10
ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11	ven 11
mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12	mer 12
jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13	jeu 13
ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14	ven 14
mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15	mer 15
jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16	jeu 16
ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17	ven 17
mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18	mer 18
jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19	jeu 19
ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20	ven 20
mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21	mer 21
jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22	jeu 22
ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23	ven 23
mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24	mer 24
jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25	jeu 25
ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26	ven 26
mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27	mer 27
jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28	jeu 28
ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29	ven 29
mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30	mer 30
jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31	jeu 31

2020

2021

COVID 19 first lockdown

Second lockdown

Third lockdown

Machine Commissioning

Beamline Commissioning

August 2020

USM

From the start of the second lockdown to summer 2021, number of user shifts [blue] reduced (3&4 days /week).



MDT & Interventions



Tests with beamlines

Limited access to the site:

- Opportunity to improve tools for remote control
- Dedicated chat channels, Confluence, JIRA and Jlogbook have been actively used
- Development shifts /interventions were often performed via video-conferencing
 → Very efficient for short and fast support, including activities with beamlines

Video-conferencing and remote control are new operation tools for the future



Gary Harlow
@garyharlow

I've taken over the dining table for our (now) remote beamtime at [@esrf id31](#) [@SoM_esrf](#) investigating ORR on stepped surfaces with high energy surface x-ray diffraction.

[Traduire le Tweet](#)



IMPLEMENTING REMOTE ACCESS SOLUTIONS TO KEEP SCIENCE AT THE FOREFRONT

- New protocols for user programme operation, so that a majority of experiments can be conducted or followed up remotely
- Implementation new solutions that allows users to interact remotely with beamline control software and tools
- Implementation of large-scale sample mail-in solutions for user experiments
- Remote data analysis with improved data transfer



43/44

43 out of 44
beamlines hosted
user experiments

13 175

13 175 shifts delivered
(105 400 hours)

1 872

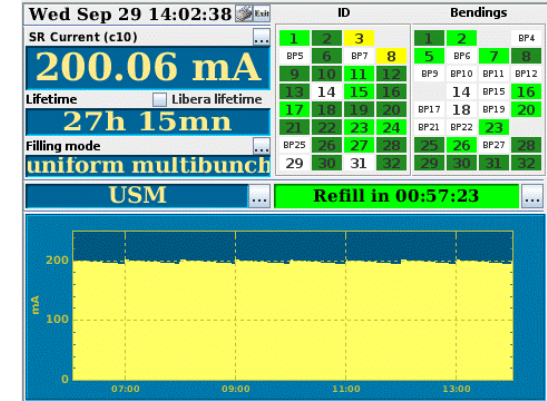
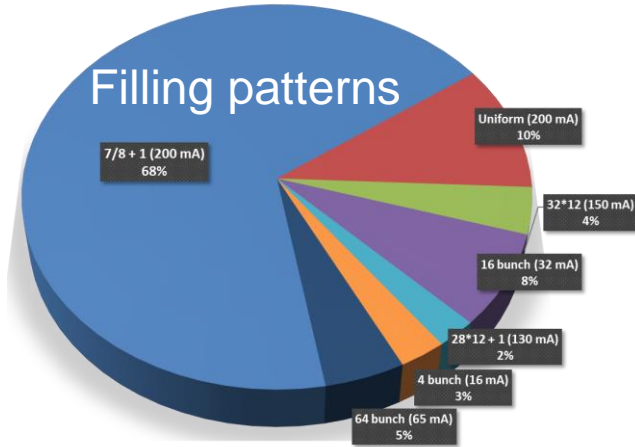
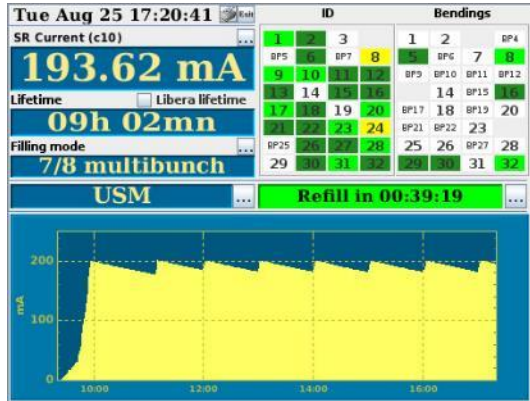
1 872 user
experiments

1 262

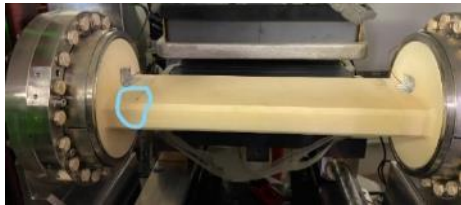
1262 fully remote (68%),
192 only one user (10%),
and 418 with users (22%)



BEAM DELIVERY FROM 25/08/2020 TO 29/09/2021



	7/8 + 1	Uniform	32*12	28*12+1	62 bunch	16 bunch	4 bunch
I_{max} (mA)	196+4 * (192+8)	200	150 * (200)	125+3* (200)	65*	35* (90)	20* (40)
Lifetime (hours)	> 22	> 25	> 22	> 23	~ 14	~ 8	~ 5
ε_v (pm) *	10	10	20	20	20	20	20

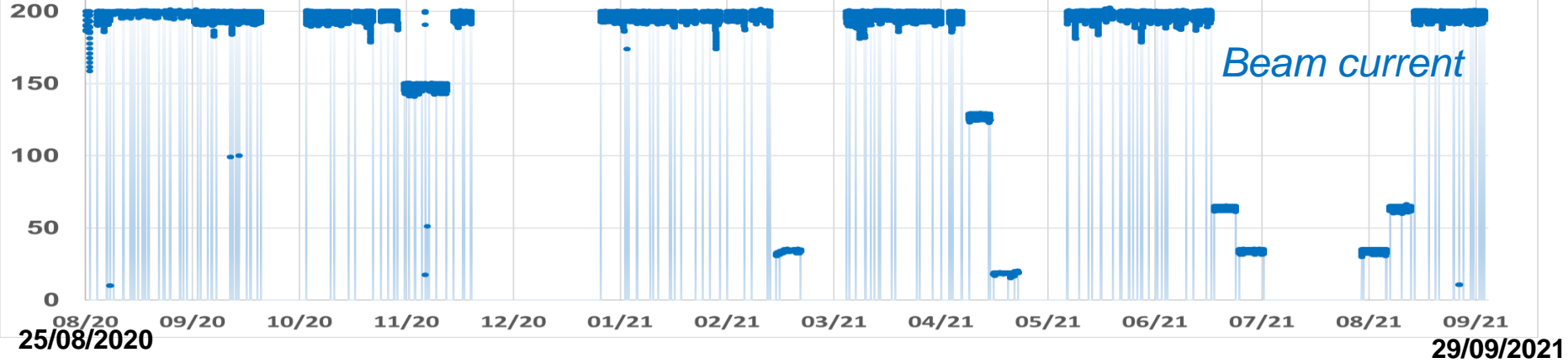


* Intensity limitation for timing modes due to mechanical weakness of the kicker ceramic chambers

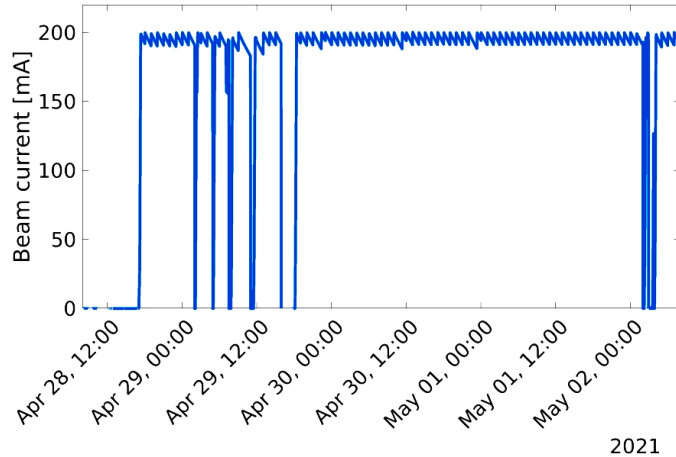
* Vertical emittance artificially increased from 1 to 10 pm rad for an operational lifetime

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

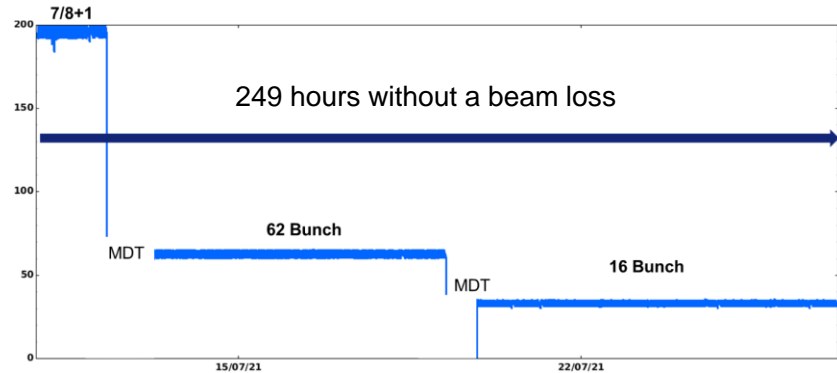
BEAM DELIVERY SINCE THE START OF USM



Some disturbed weeks !!

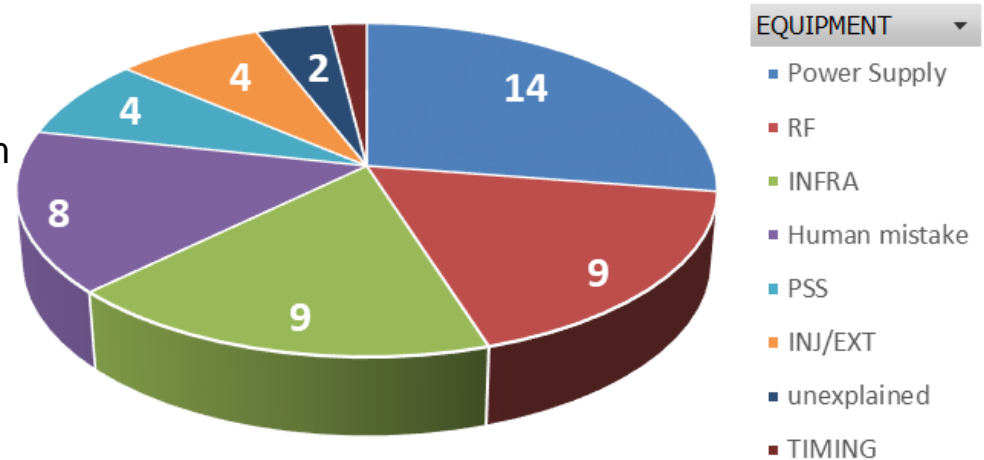


But also quiet time !



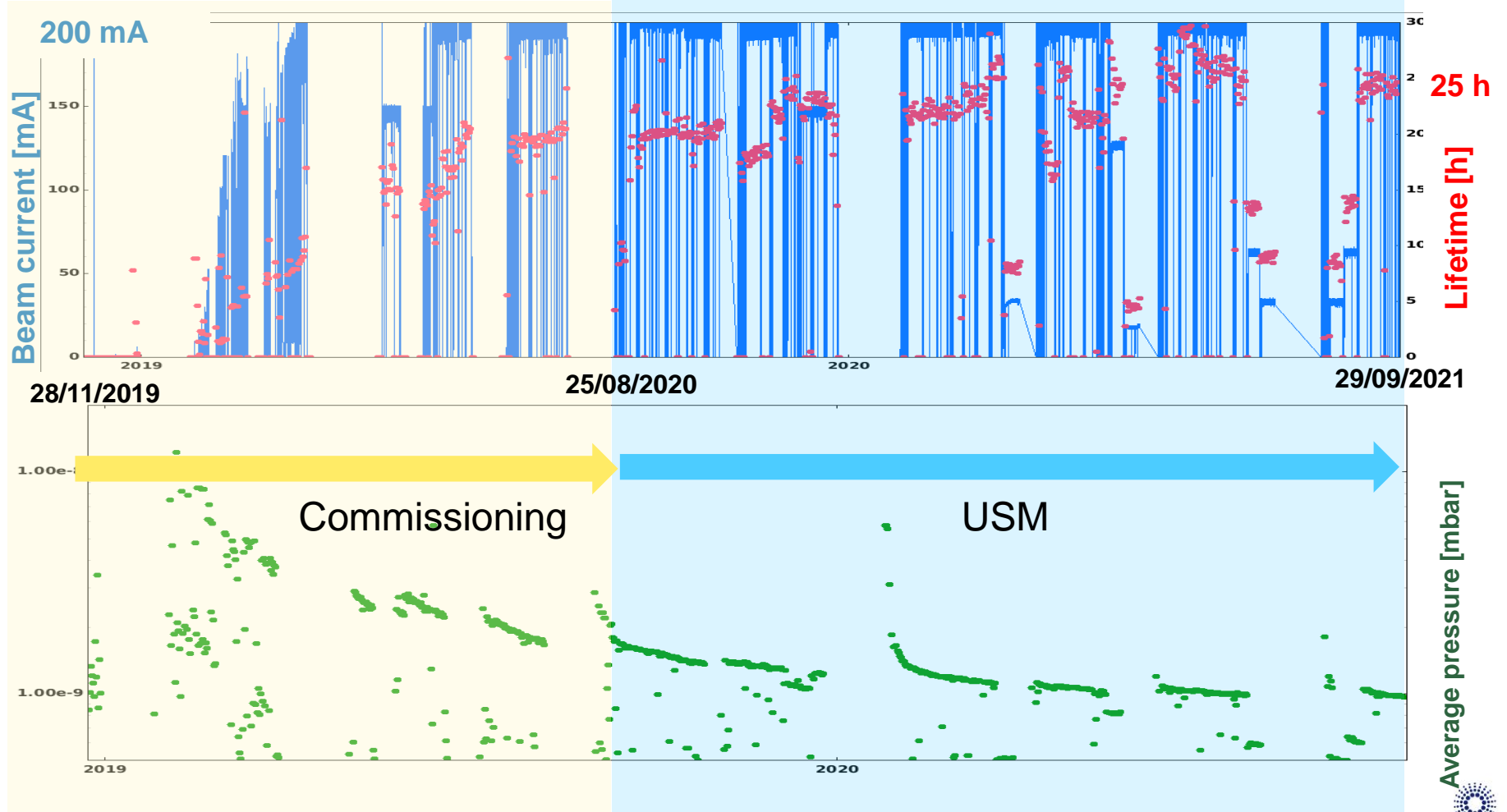
- Overall reliability comparable to that of the old source
- Magnet power supply system was the most complex hardware to develop and commission
 - ✓ *Hot swap system under commissioning*
- Human mistakes due to development (*mostly at the beginning*)
- Infrastructure (*mains, cooling, doors*)
- Operation disturbed by a few long failures from sub-systems not linked to EBS design
 - ✓ *aluminum NEG coated ID vacuum chambers*
 - ✓ *RF master source*
 - ✓ *20 KV high voltage cable defect*
- RF highly reliable

	2017	2018	2020	2021
			<i>EBS</i>	<i>EBS</i>
Availability (%)	98.3	98.5	96.1	98
Mean time between failures (hrs)	64.3	104.3	46.0	73.4
Mean duration of a failure (hrs)	1.11	1.60	1.80	1.46

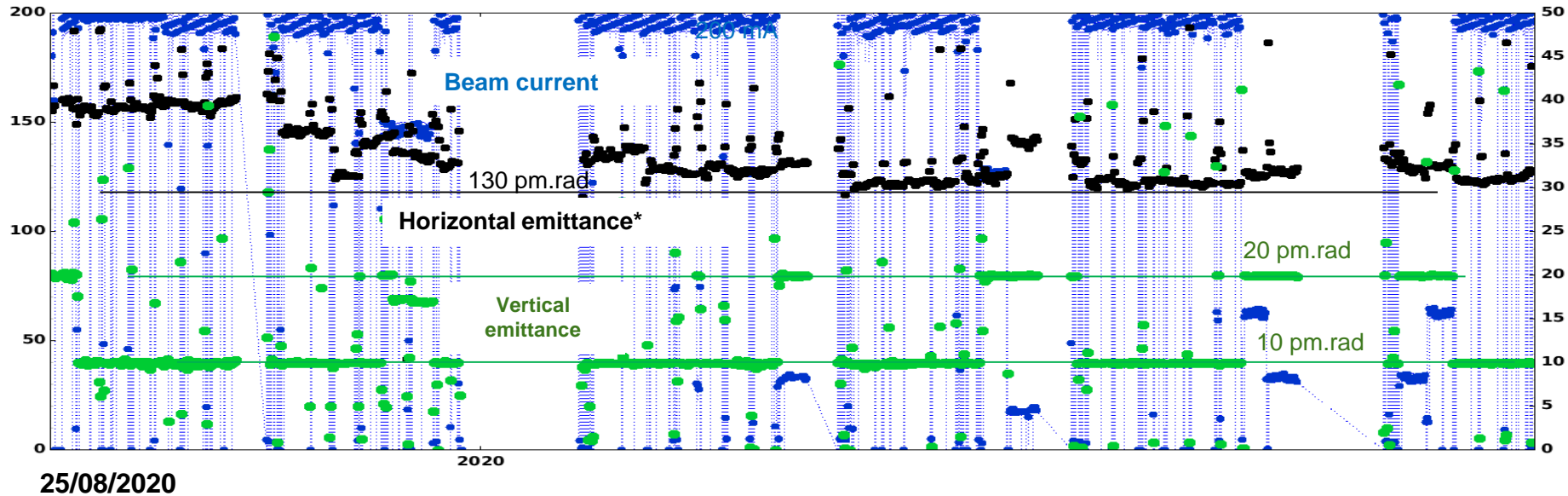


Number of failures 2021

OVERVIEW: BEAM CURRENT & LIFETIME



VERTICAL AND HORIZONTAL EMITTANCES FROM 25/08/2020 TO 29/09/2021



Horizontal emittance diagnostics modified and calibrated during run 2020-06 and run 2021-1

→ Typical today: 130 ± 20 pm.rad

Vertical emittance artificially blown up using white noise excitation up from 1 pm.rad to 10 or 20 pm.rad to get an operational lifetime

→ Typical today: 10 pm \pm 1 pm.rad

ESRF-EBS: PARAMETER ACHIEVED

	Design	Realized today
Total current	200,90,40 mA	200, 35, 20 mA
MTBF	> 30 h	> 70 h
Up-Time	98%	98 %
Injection Efficiency	> 90 %	> 80 %
Lifetime	> 20 h	> 25 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

Results:

- Despite the impact of the Covid-19 pandemic, users recovered the beam on the scheduled day and with an adapted operation planning
 - Main performances achieved (beam current, beam modes, lifetime, emittances, stability)
 - Excellent reliability of the hardware
 - Delay in the beamline commissioning and upgrade programme
 - Additional operating and support tools and methods have emerged
- Beamlines are now progressing and upgrading to take full benefit of the source
- Users are starting to come back

Objectives for the machine:

- Fine tuning of beam parameters
- Implementation of the hot-swap system for the power supplies
- Reduce injection perturbation and go back to injection from every 1 hour to every 20 mn
- Nominal beam current in time-structured modes

MANY THANKS FOR YOUR ATTENTION

