INNOVATIONS AND OPERATION OF THE SOLARIS SYNCHROTRON

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On behalf of Accelerator Departament

Kraków, 21.10.2024

SOLARIS National Synchrotron Research Centre

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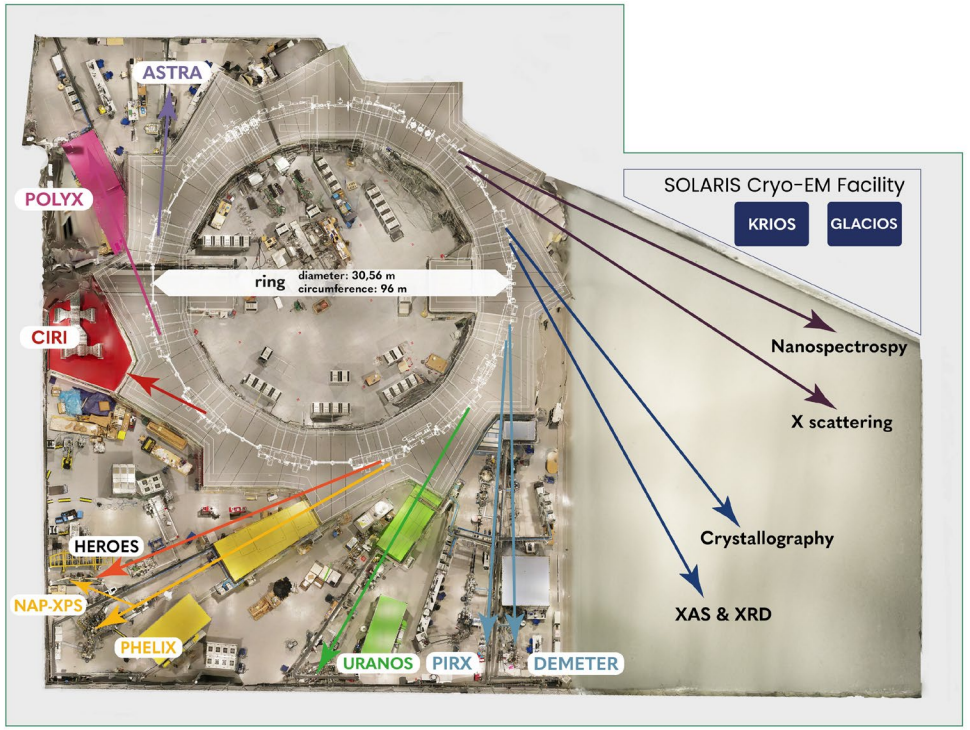
OUTLINE

1. Introduction to SOLARIS
2. Main storage ring parameters
3. Operation performance
4. Current development & future plans
5. Summary

INTRODUCTION TO SOLARIS

Solaris is a 3rd generation lights source in user operation mode built in Krakow at JU Campus.



SOLARIS timeline

2010- 2015
- Design, installation and commissioning of acceleartors

2015-2018
- Commissioning of first beamlines

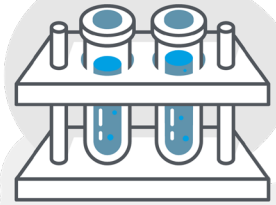
since 10.2018
- User opeartion

2021-2023
- Upgrade of the cooling system
- Extension of the building & experimental hall area

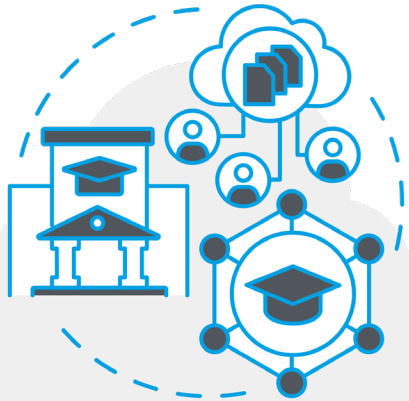
Since 2024
- Research on 7 operational beamlines, 2 cryomicroscopes,
- 4 Beamlines under construction

SOLARIS KEY PERFORMANCE INDICATORS

stientists from
24 COUNTRY
used the infrastructure



11 RESEARCH STATIONS
more under construction



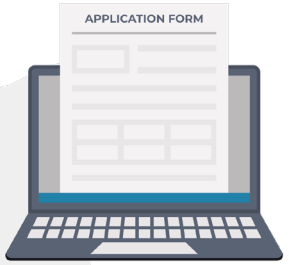
169 INSTITUTIONS
applying for beamtime

13 796 HOURS
available research time

188% OVERBOKING
for beamtime

average
7,8 IMPACT FACTOR
of publications

1 530 SCIENTISTS
registered in SUN system



386 APPLICATION
for beamtime

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SOLARIS COLLABORATION

SOLARIS Centre with its modern infrastructure, is a strategic partner in implementing EU-funded projects, supporting innovation and technological development in the region.

CERIC-ERIC
General Assembly

LEAPS leadership
during the EU presidency

LIGHT FOR UKRAINE
international cooperation

ESFRI
permanent expert

PALSA observer
Pan American Light Sources for Agriculture

NEW PROJECTS:

RIANA project

international scientific community project

ESUO EUROPEAN SYNCHROTRON AND FEL USER ORGANISATION

COMPLETED PROJECTS:

SYLINDA

LEAPS INNOVATION

BEATS

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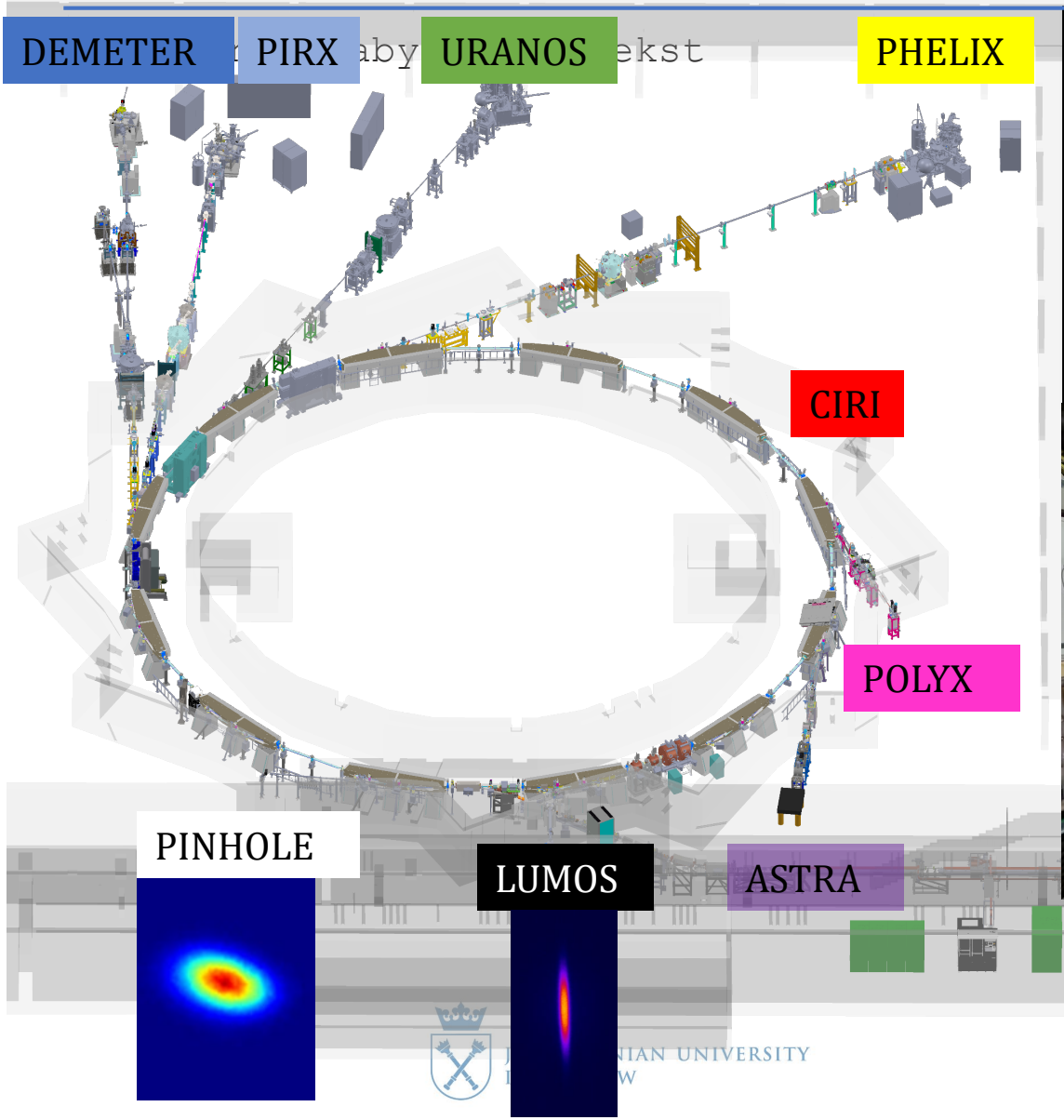
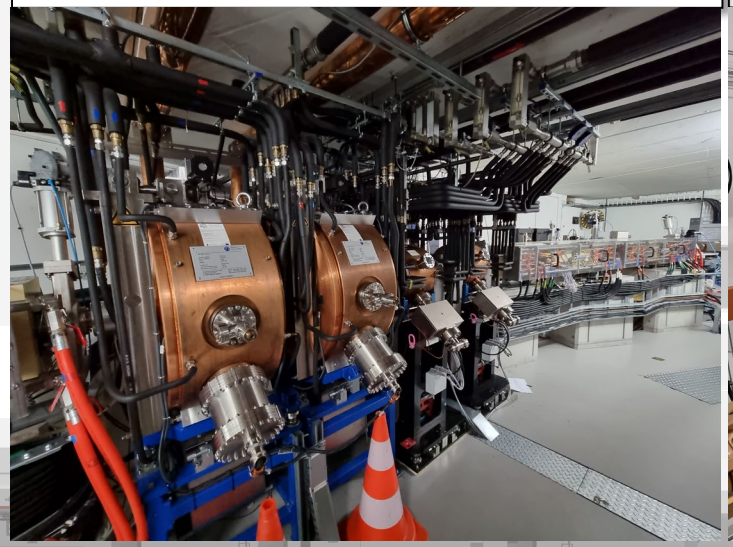
ACCELERATORS OVERVIEW



1.5GeV Storage ring

- 12 DBA Cells – 96 m circumference
- Space for ID's (10 sections) ~ 3.5 m
- 10 straight sections for IDs
- 100 MHz RF system
- 300 MHz Landau Cavities
- Injection dipole kicker
- Ramping
- In operation since May 2015



600 MeV Linac

- RF Thermionic Gun
- 6 S-band 2998.5 MHz accelerating
- structures
- Accelerating gradient 20 MeV/m
- 3 RF Units & SLED cavities
- Dog-leg vertical transfer line
- In operation since Dec. 2014

See poster presentation on RF system on Tuesday

STORAGE RING PARAMETERS

Electron energy	1.5 GeV
Design current	500 mA
Number of circulating bunches	32
Natural bunch length σ_z /w. Landau Cavities (LC)	14.2 mm /60 mm
Natural emittance (bare lattice)	5.982 nmrad
Coupling	1 %
Energy spread (bare lattice)	0.000745
Tunes ν_x, ν_y	11.22, 3.15
Natural chromaticities ξ_x, ξ_y	-22.96, -17.14
Corrected chromaticities ξ_x, ξ_y	+1, +1
Momentum compaction	3.055 x 10^{-3}
Energy loss/turn	114.1 keV
Momentum acceptance	4%

Storage Ring Magnets (mirror symmetric)

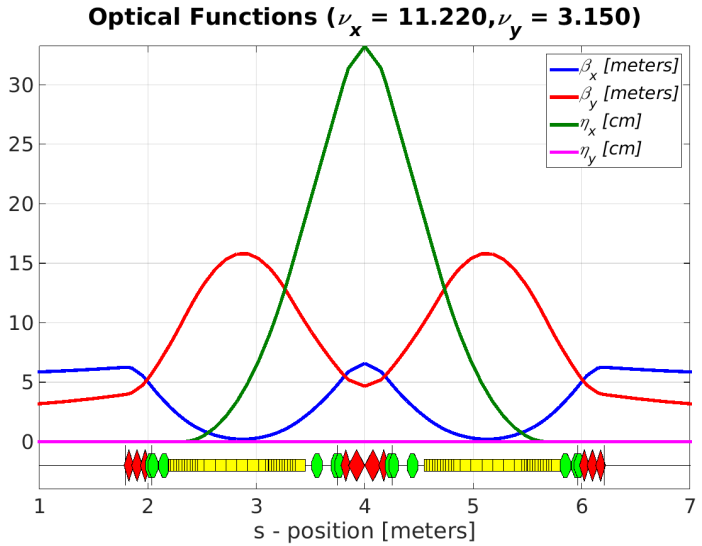
Machined from solid iron, 2 half slabs, ~4.5 m, ~7 Tons each slab

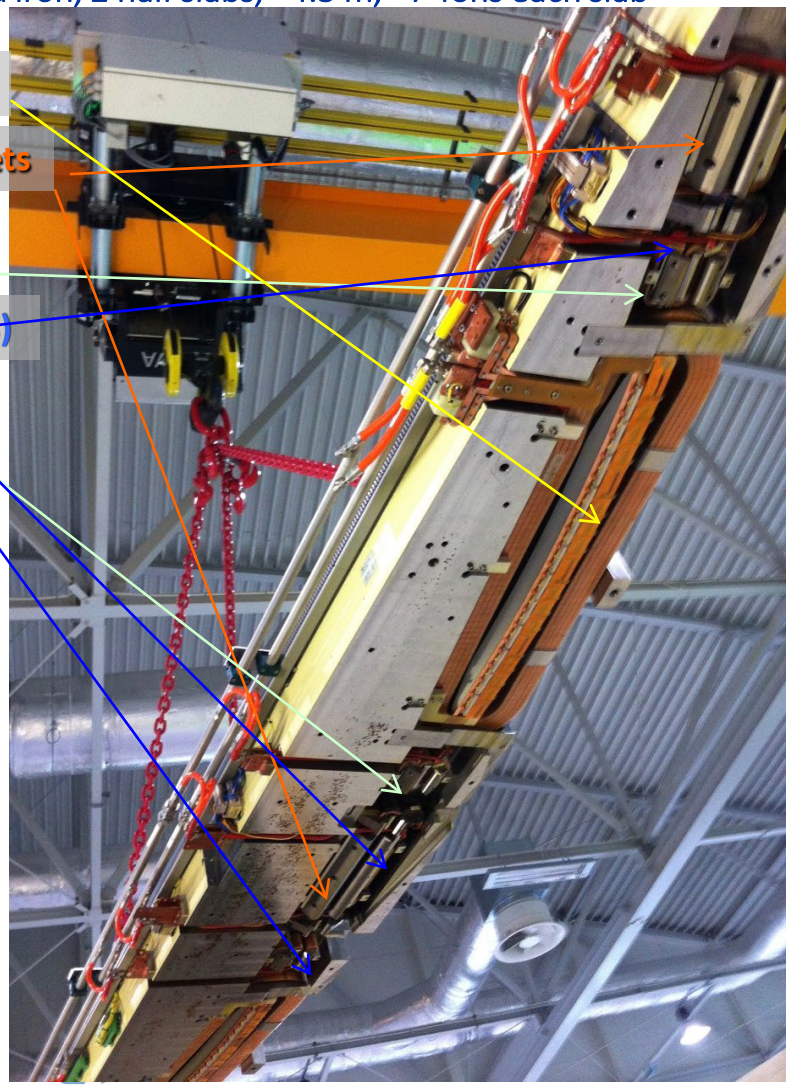
Gradient bending magnet with pole-face strips

Combined focusing quadrupole-sextupole magnets

Defocusing sextupole magnets

-coil correction magnets (COD, Skew quads, aux. sextupoles)



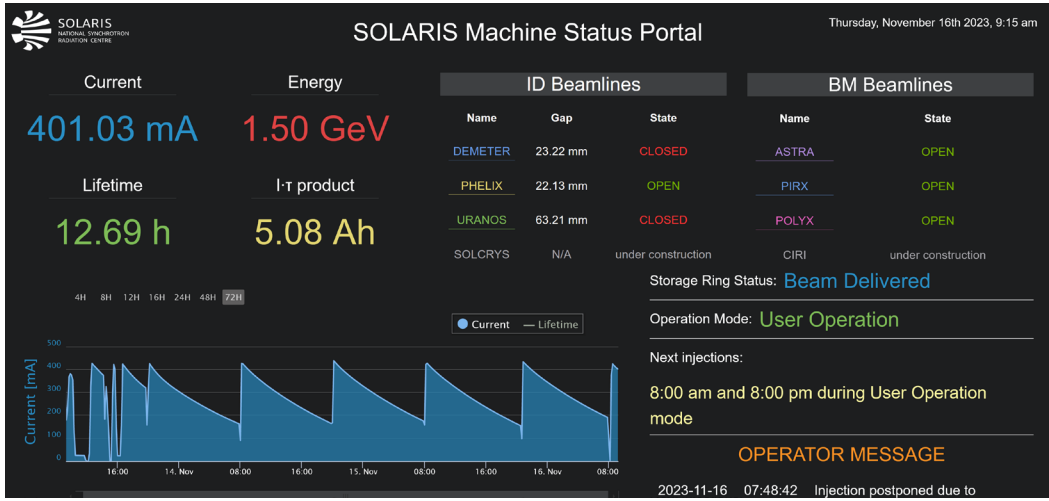


OPERATION STATISTICS

SOLARIS OPERATION

STANDARD OPERATION

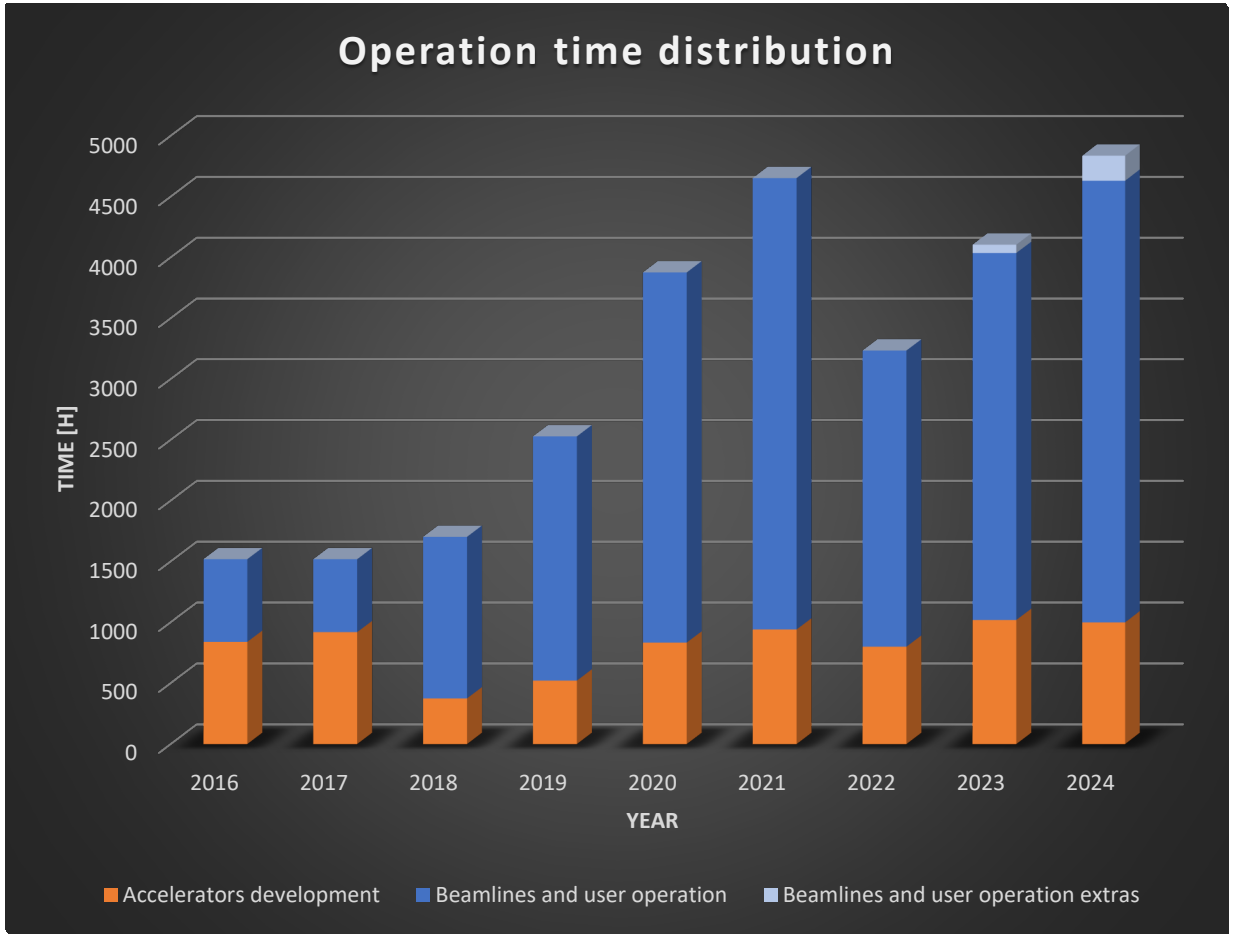
- 2 Shifts from Monday to Saturday (8:00-16:00; 14:00-22:00)
  - Monday – machine days, maintenance
  - User operation 5 days/week (Tue-Sat)
  - On call support to 2:00 am from Tuesday-Saturday
  - 2operators/shift
- Sunday – no injection, beam in the storage ring
- Injection twice/day: 8:00 am and 8 pm
- One operation mode (uniform filling pattern)
- Operation in the decay mode



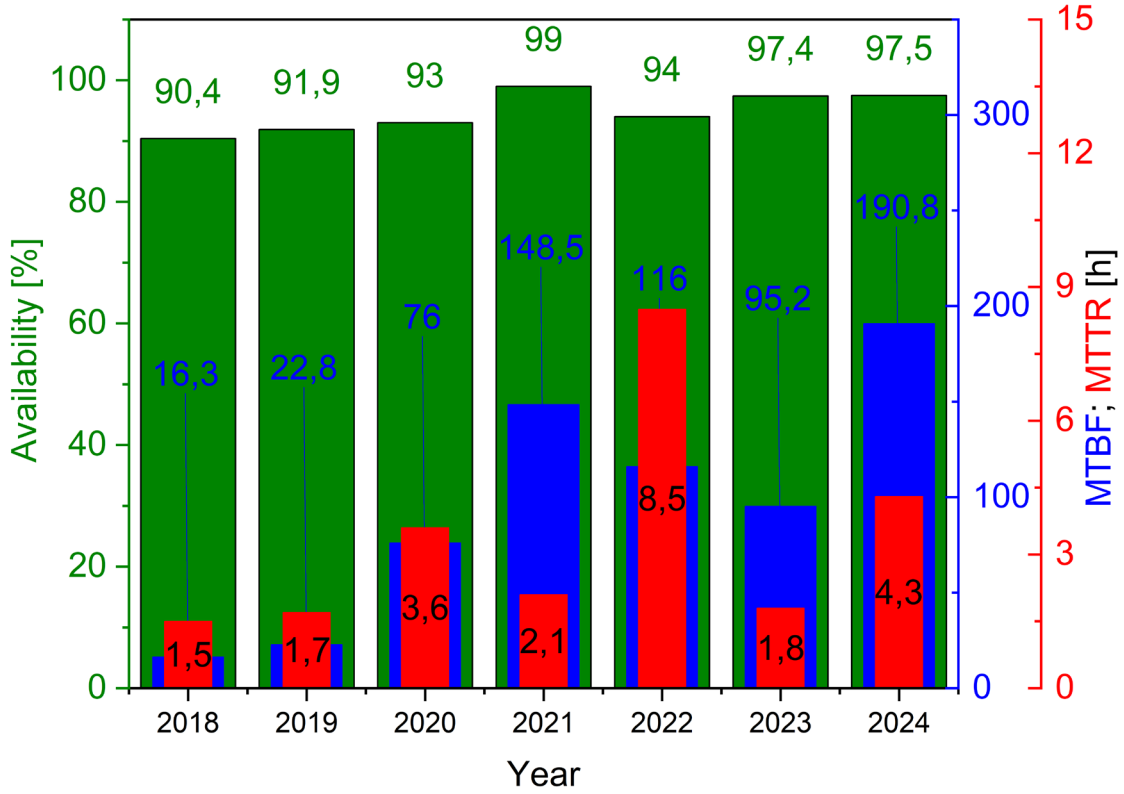
EXTRA OPERATION:

- Injection upon request on Sundays
- Pilot Sundays - 10 Sundays (April'24-January'25) with 2 injection and on call support

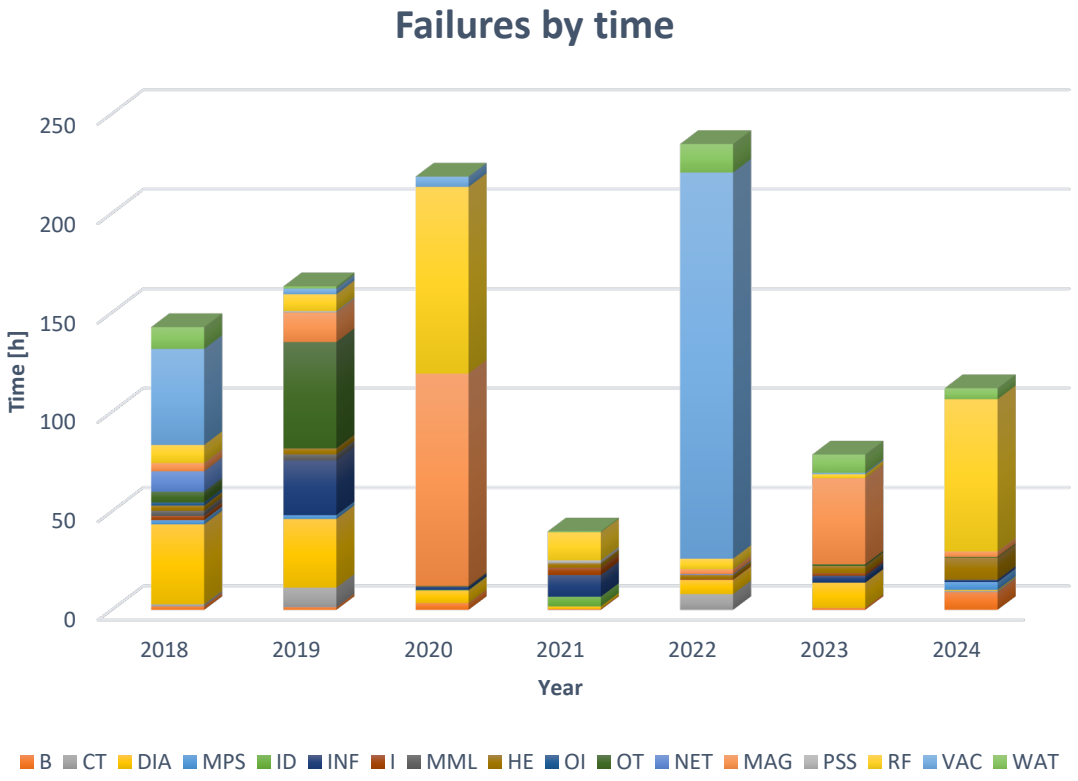
OPERATION OVER LAST YEARS

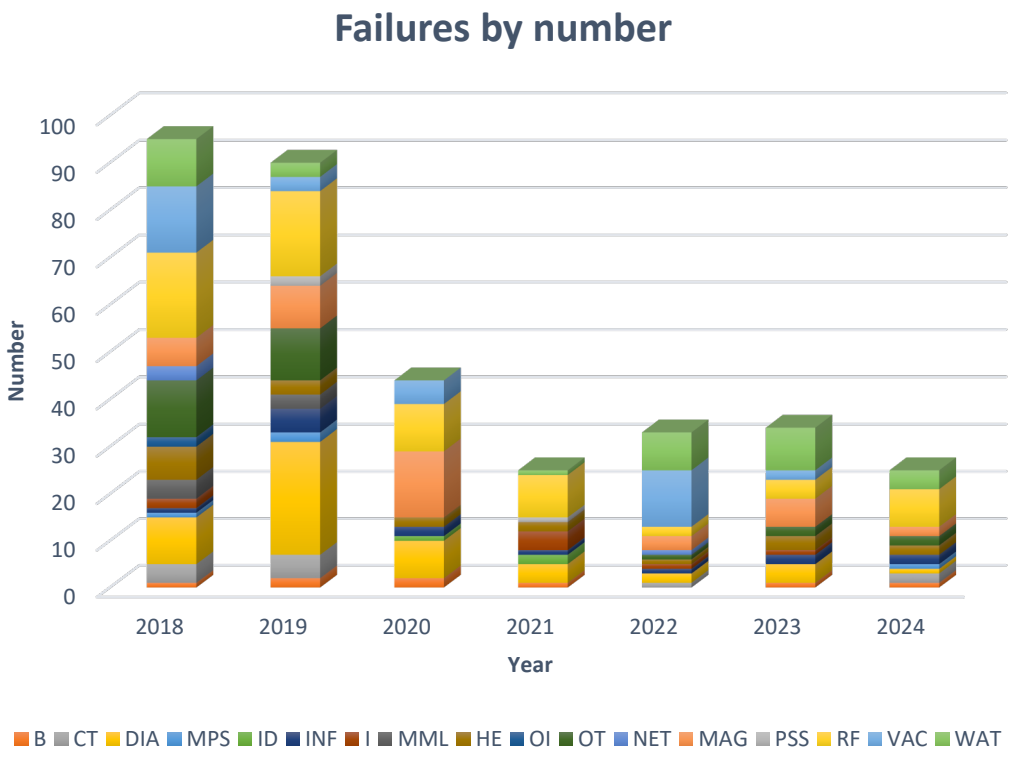


$$\text{Availability} = \frac{\textit{Delivered time}}{\textit{Scheduled time}}$$

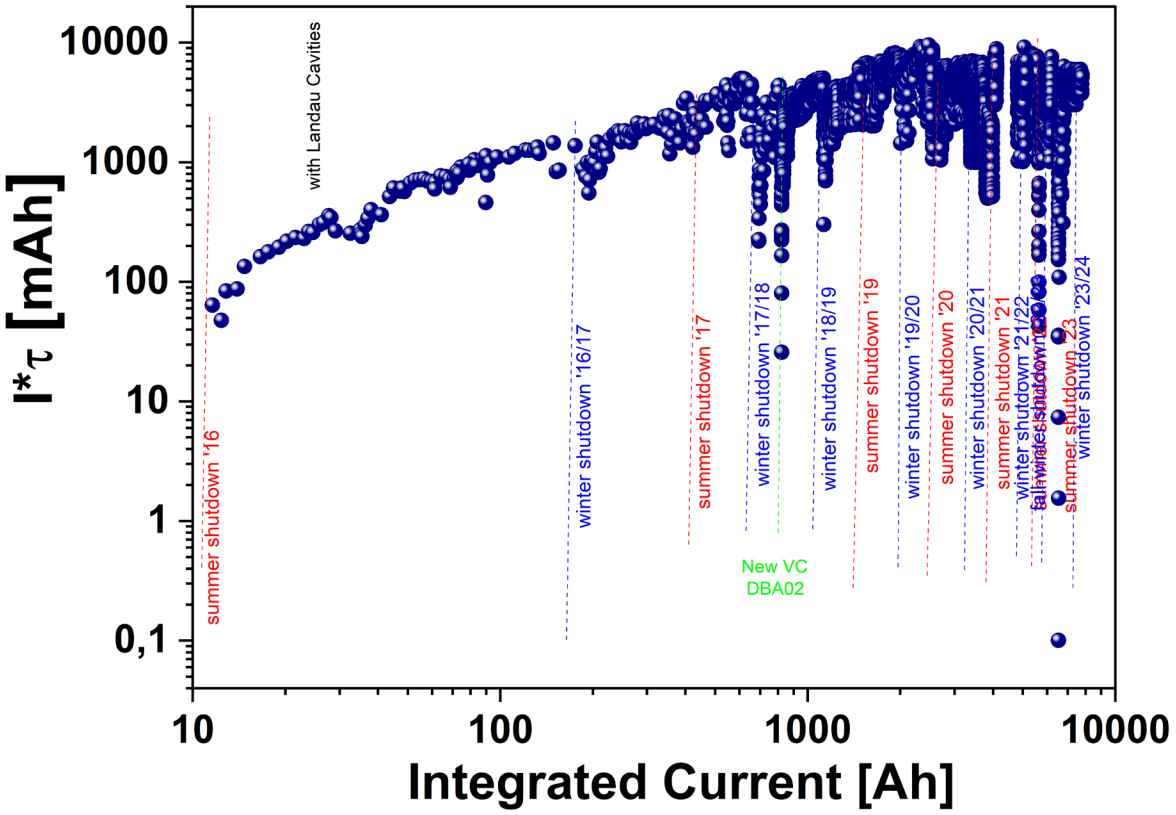


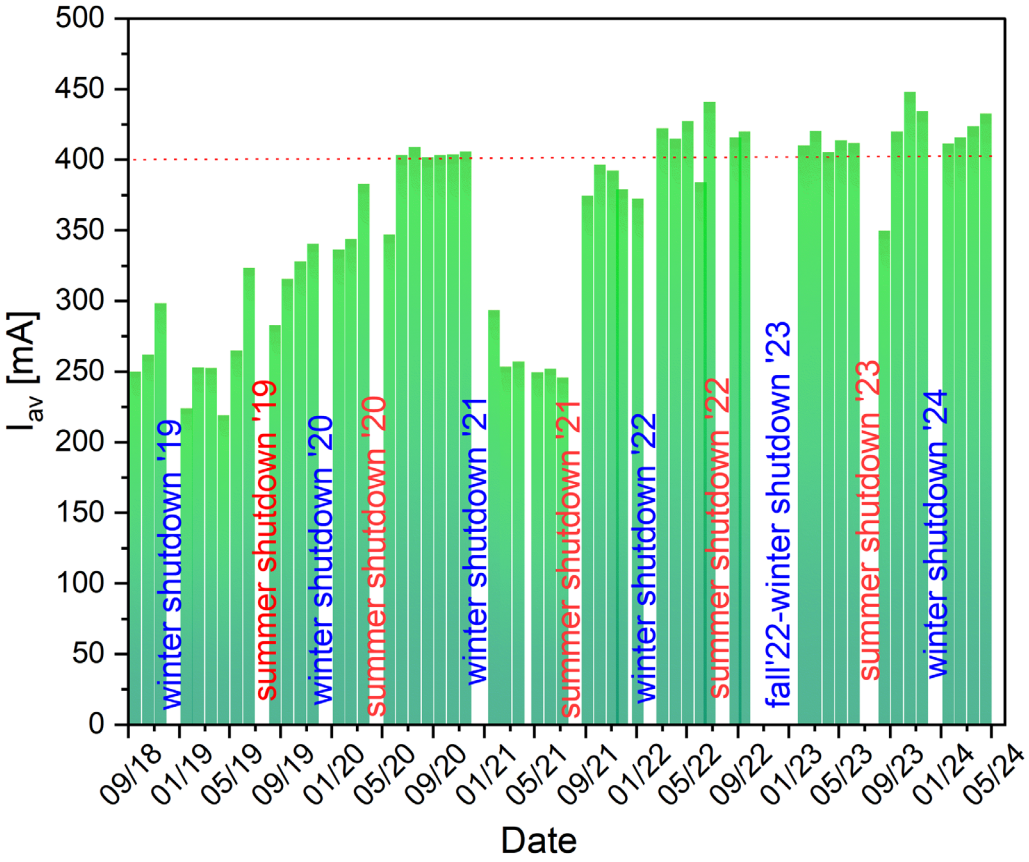
FAILURE STATISTICS





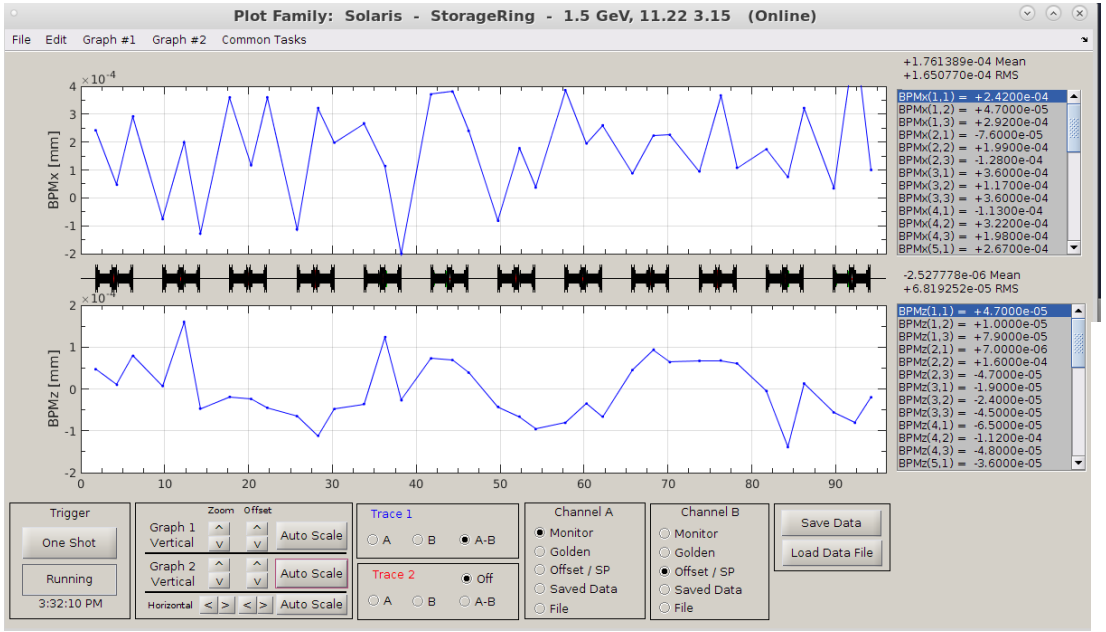
CURRENT AND LIFETIME



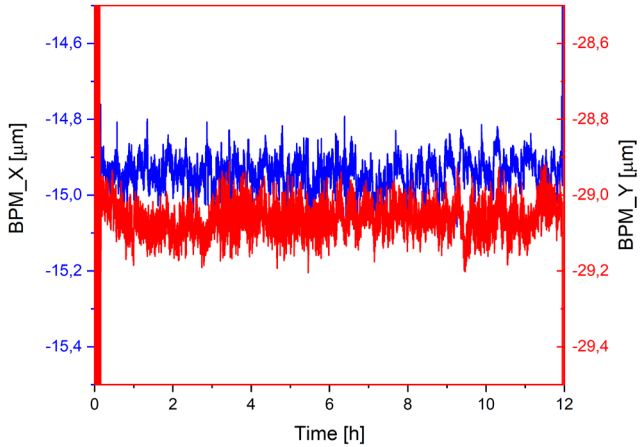


CLOSED ORBIT STABILITY &REPEATABILITY

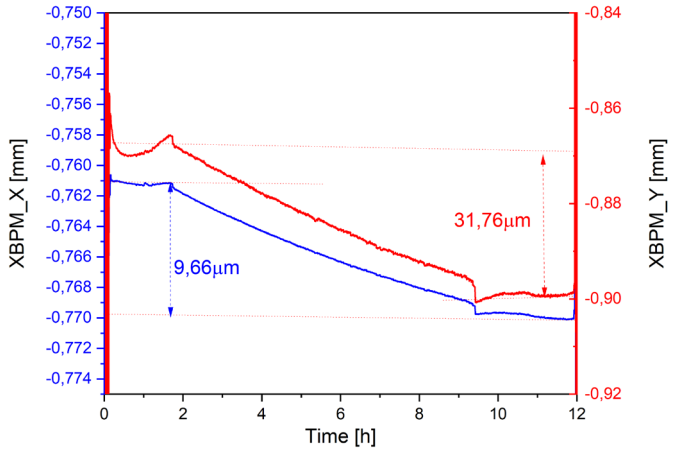
Closed orbit correction (slow orbit feedback):
36 beam position monitors (BPMs);
72 corrector magnets (36 for each plane).
After beam based calibration the closed orbit is corrected to the sub-micrometer values rms.



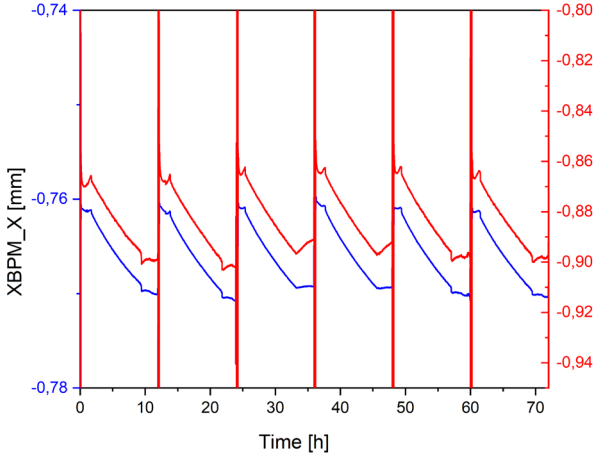
Electron beam stability in the submicrometer level



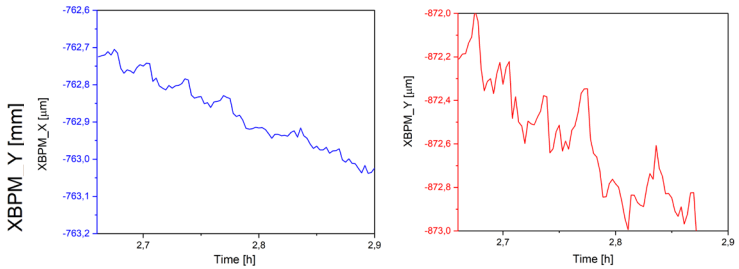
Long-term stablity of the photon beam



Repeatablity of the injection



Short-term stablity of the photon beam



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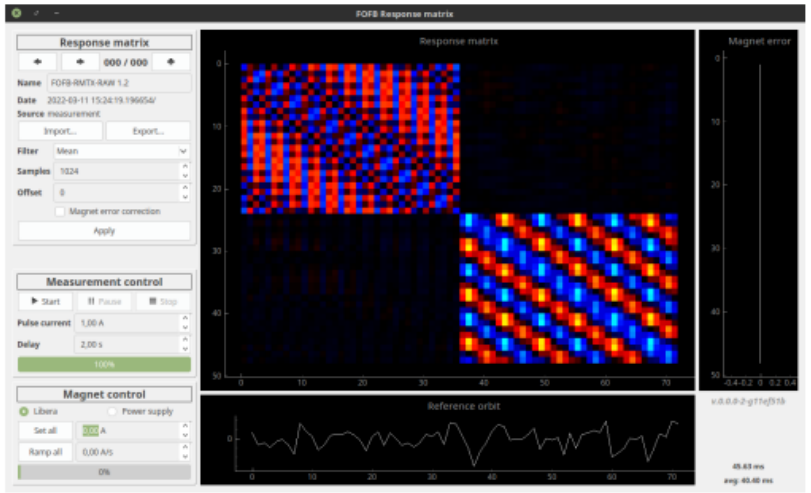
SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

SOLARIS DEVELOPMENT

FAST ORBIT CORRECTION

Fast orbit feedback system development

- ✓ All hardware installations have been finished (24 correctors installed, connected to PS, and Liberas GDX modules).
- ✓ Hardware connections were verified and tested.
- ✓ First proof-of-concept measurements and test runs were performed.
- ✓ The core of the work focuses now on experimentally determining parameter values, control software development and solving problems as they arise.
- ✓ The machine studies time is shared with other new developments, but we expect to have first FOFB-enabled operations next year.



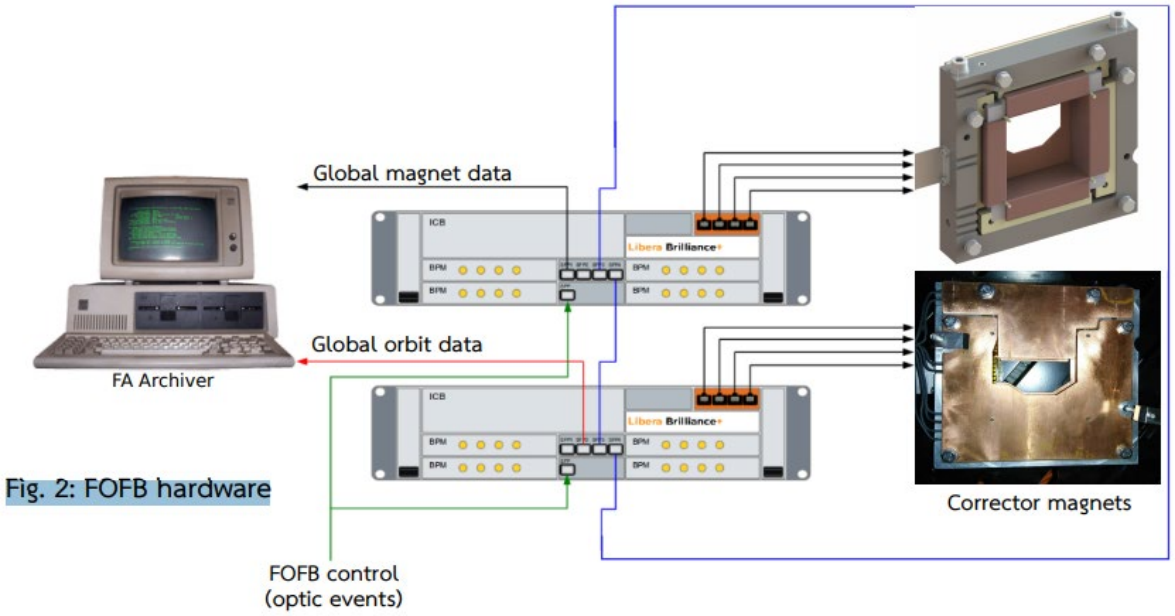
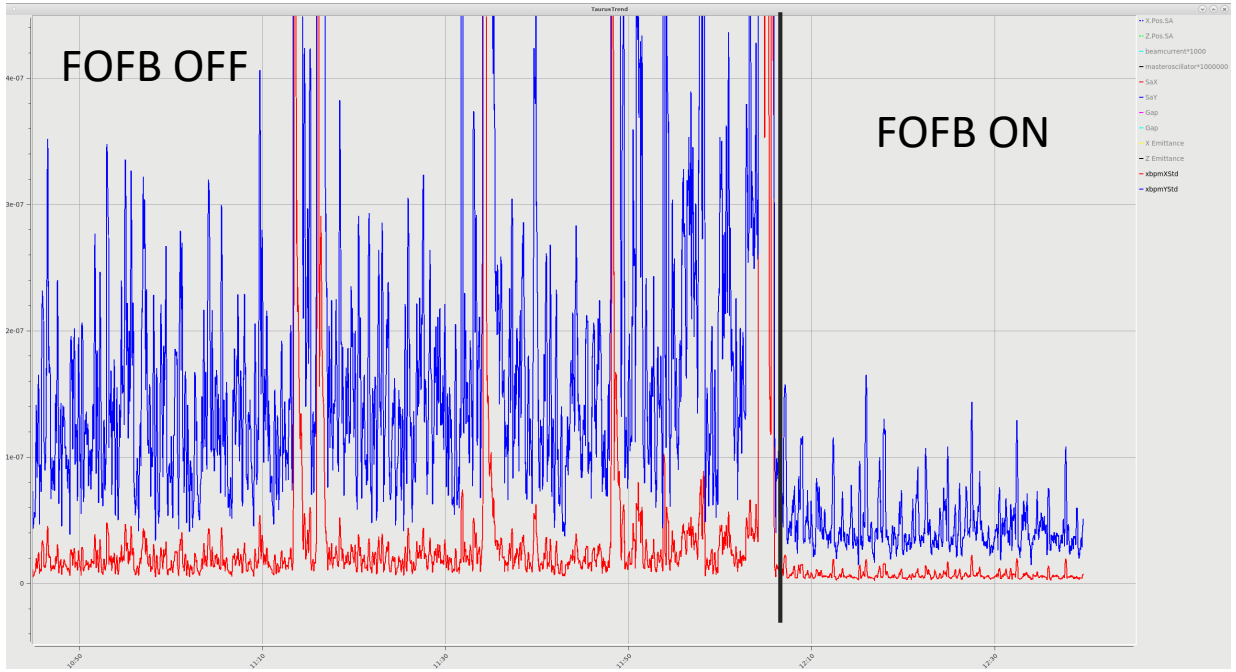
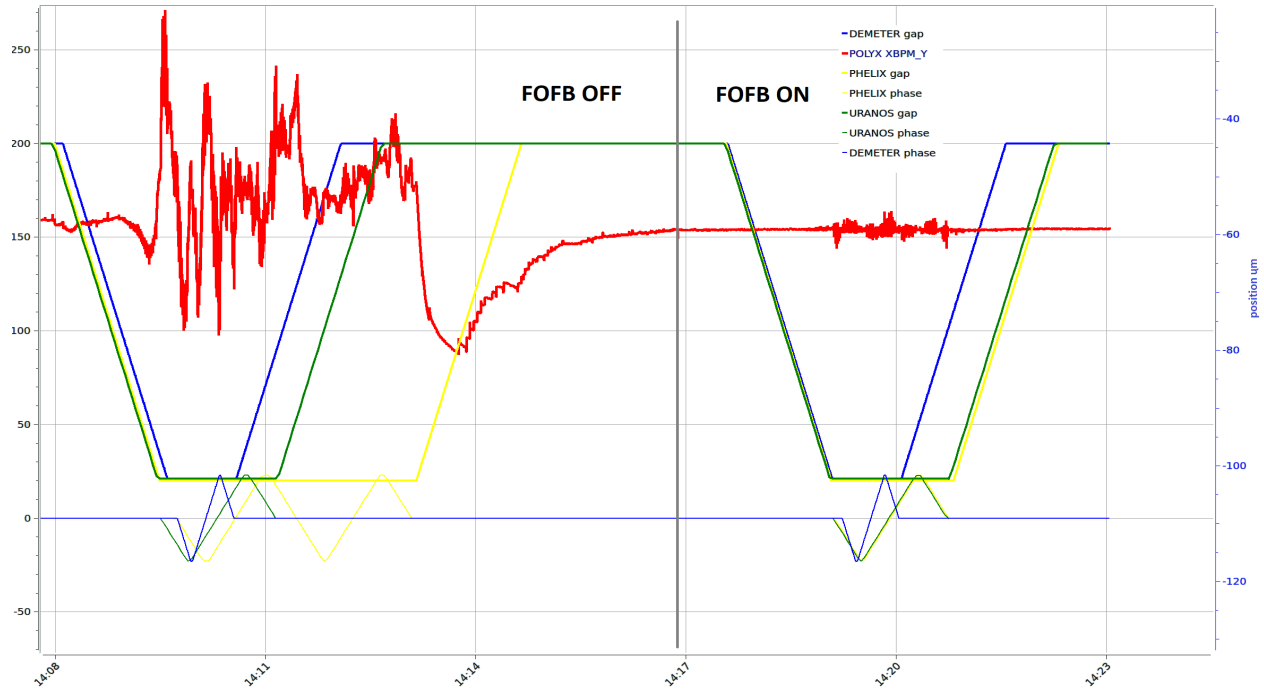


Fig. 2: FOFB hardware

FOFB PERFORMANCE



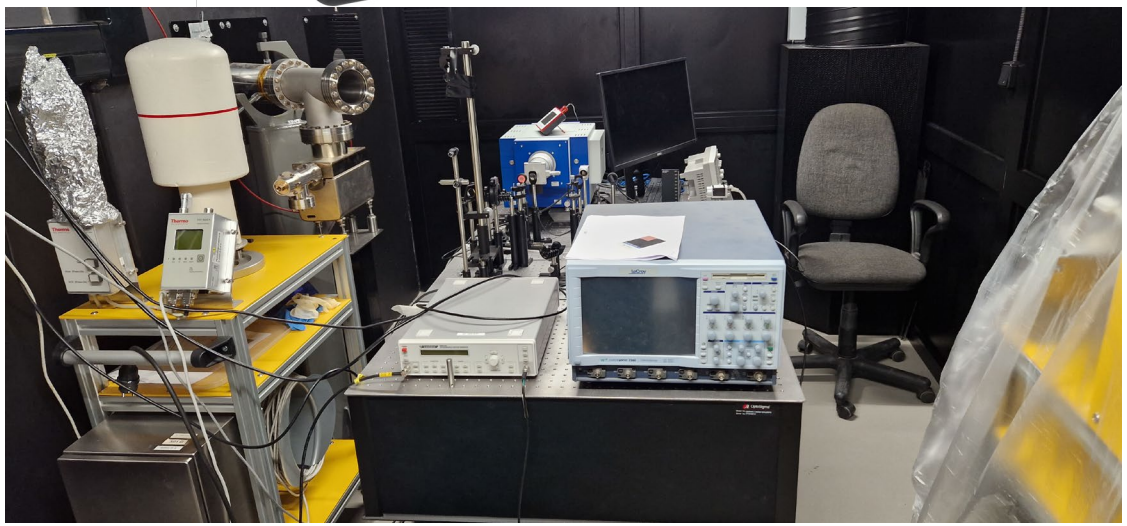
Reduction of XBPM Standard deviation.



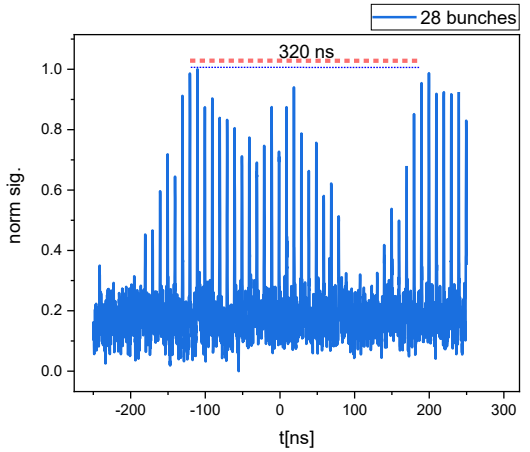
ID's impact compensation – more than 1 order of magnitude correction improvement.

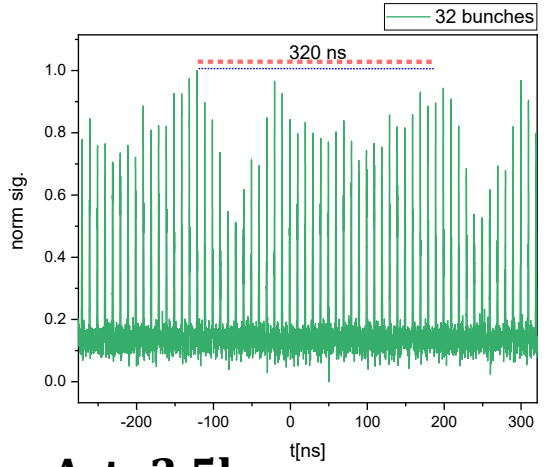
SINGLE BUNCH OPERATION DEVELOPMENT

The Filling pattern measured with fast photodiode at LUMOS beamline.

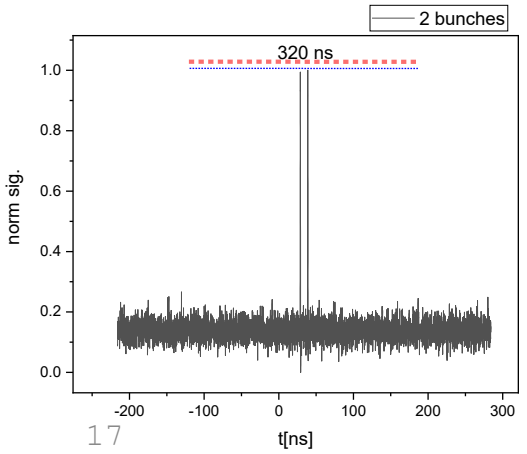


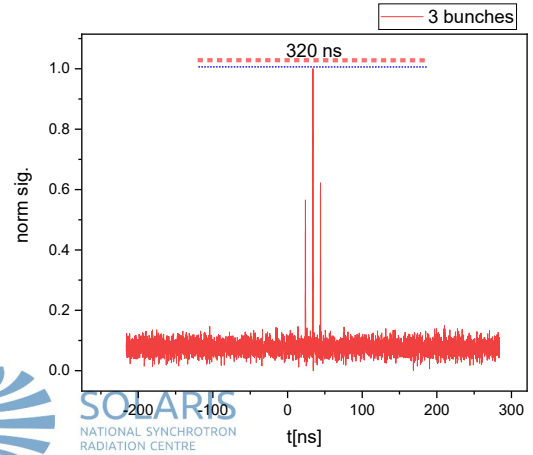
I=400 mA, t=15h





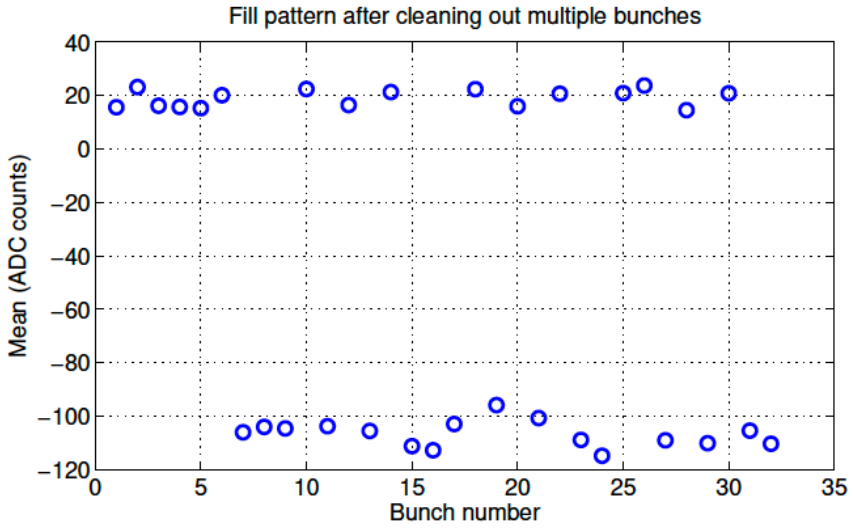
I=8-12 mA, t=2.5h





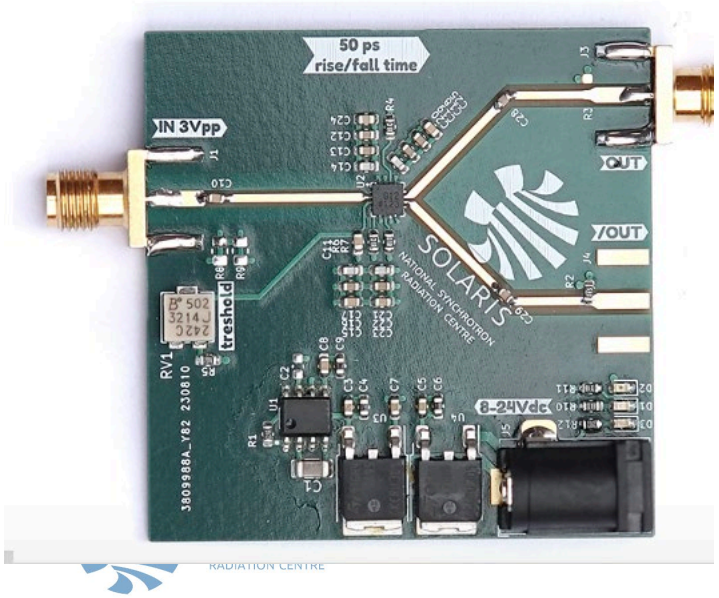
BUNCH BY BUNCH FEEDBACK SYSTEM

Demonstrated bunch-by-bunch feedback in all three planes;
The beam is currently transversely stable at 400 mA;
Mode 21 in the vertical plane oscillates at 0.5 μm steady-state amplitude, observation to be confirmed;
Strong longitudinal instabilities are seen above 3.6 mA at 1.51 GeV;
Bunch cleaning was demonstrated at the injection energy, 35 W is sufficient.
Can be also used as a diagnostic tool (tune measurement, beam excitations –machine studies)



Preparations for BBFB: 50 ps rise/fall time edges comparator design

- Typical waveform generator output is too slow for testing power amplifier for Bunch by bunch feedback; for example, 10 ns is not acceptable
- In Solaris we designed, assembled and tested ultra fast comparator to reach rise and fall edge times of around 50 ps
- Together with typical, slow generator, we got rise/fall time ca. 135 ps, but measured value is a limitation of our oscilloscope analogue bandwidth



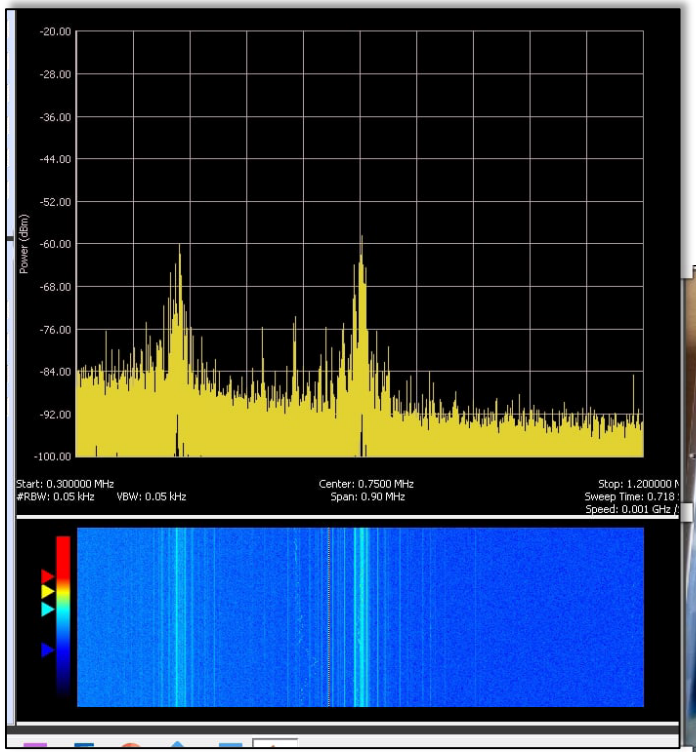
INSTALLATION AND START-UP OF BBQ MEASUREMENT SYSTEM

BBQ (Base-Band Q) system will allow us to measure TUNE without exciting the beam based on a direct diode detection method initially designed for the LHC. This allows a reliable tune measurement with micrometre or even sub-micrometre beam oscillations. It is dedicated systems optimised for beam oscillation detection. In these systems the static beam position is rejected at a very early stage with only the oscillation signal retained for further processing.
Front-end and control panel have been installed inside the ring.
Measured signal 10-16 dB above noise, during operation.
The maximum voltage on the detectors is ~80V at a current of 450mA.

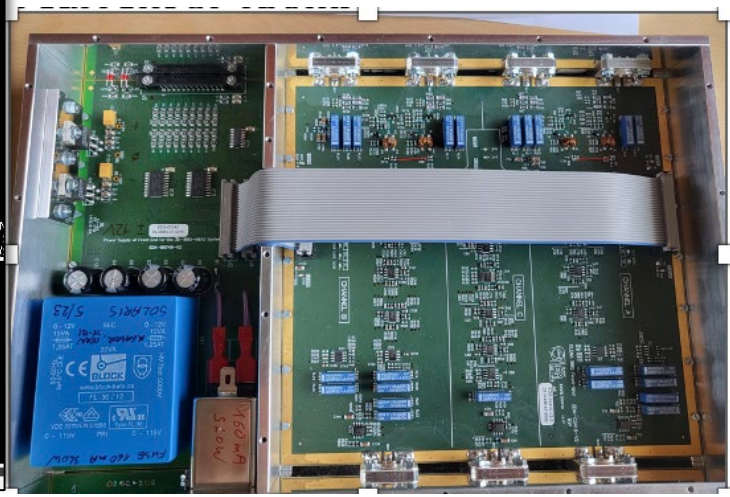
Further development:

- dedicated acquisition system
- TUNE feedback system

Device in the Storage Ring



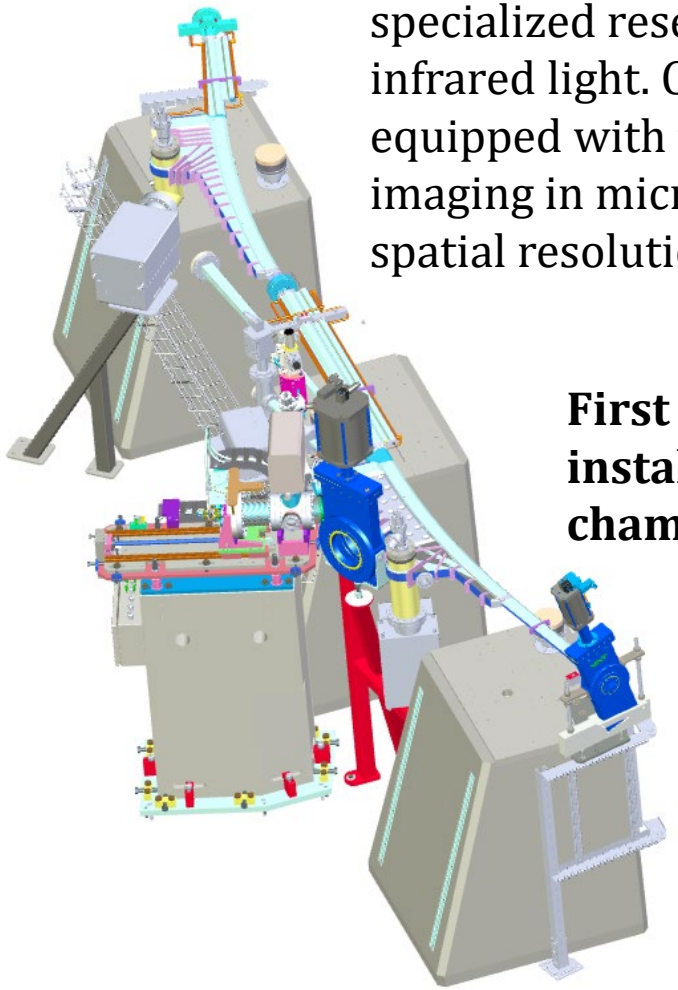
Spectrum of the beam



BBQ Frontend

NEW BEAMLINES DEVELOPMENT

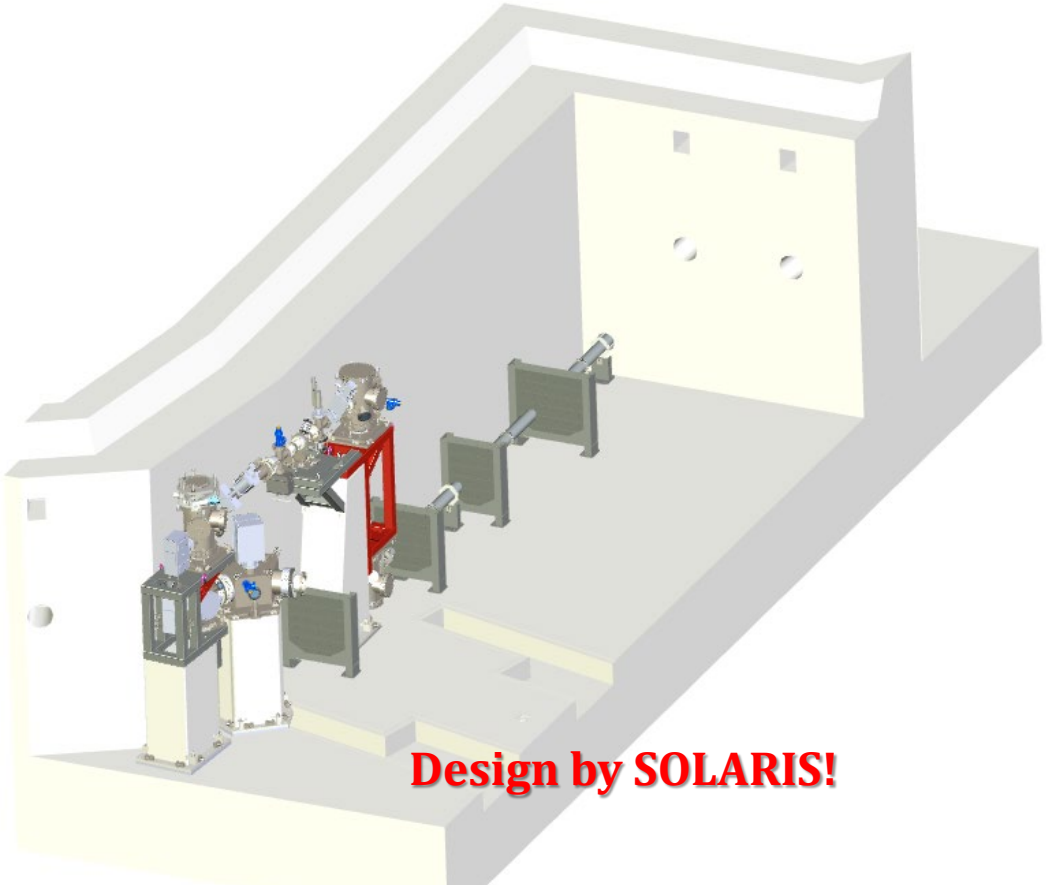
Modification of the storage ring - Beamline CIRI



CIRI **Chemical InfraRed Imaging**, is a specialized research installation using infrared light. CIRI will ultimately be equipped with three end stations for imaging in micro- and nanometric spatial resolution.

First stage – design and install new dipole vacuum chamber VK1m

Second stage – design and install new beamline inside storage ring (in progress)



Design by SOLARIS!

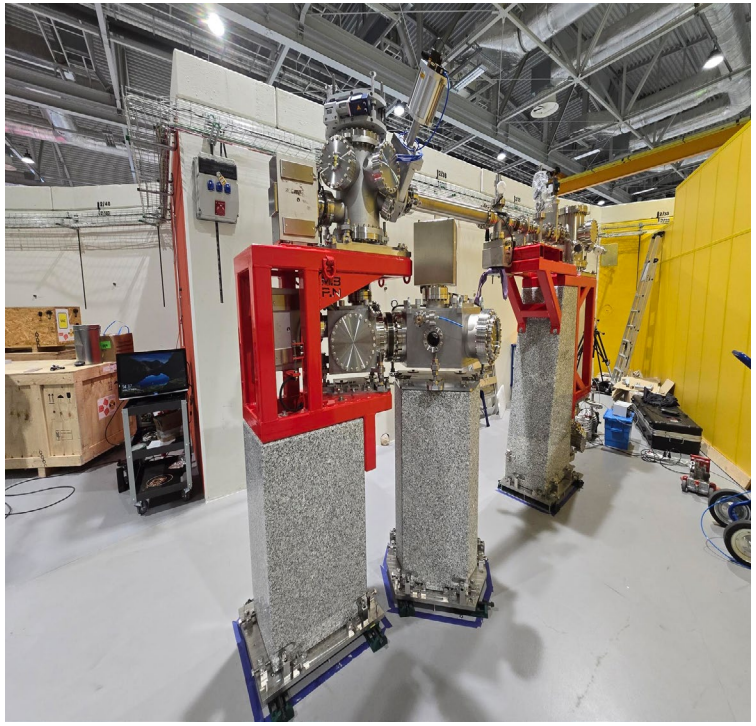
Third stage – low vacuum system and endstations at experimental hall

NEW BEAMLINES DEVELOPMENT -CIRI

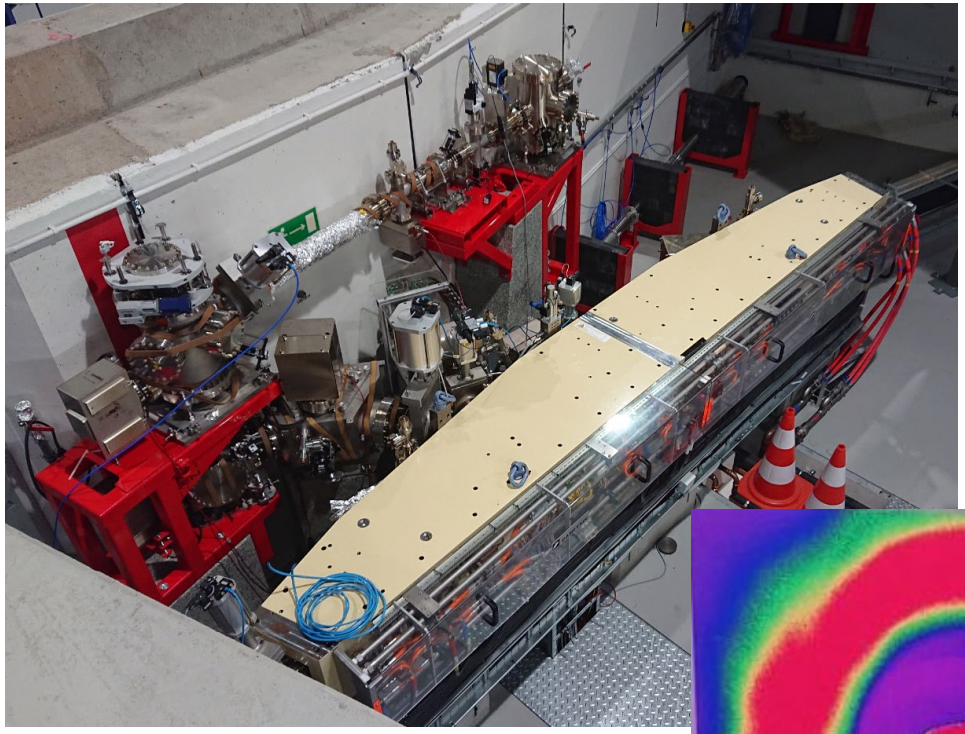
Modification of the storage ring - Beamline CIRI (first stage) – summer 2023

NEW BEAMLINES DEVELOPMENT -CIRI

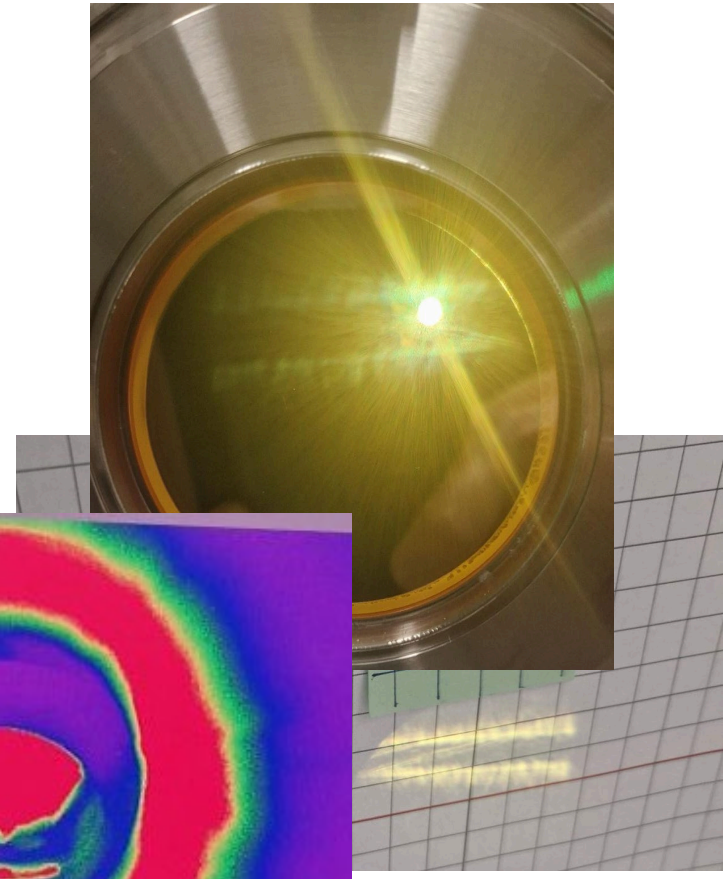
Preassembly at the experimental hall
Spring 2024

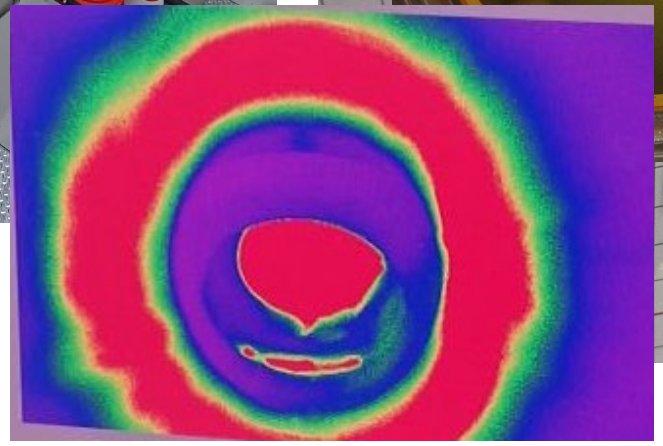


Installation in the storage ring
Summer 2024



First Light @ end of CIRI
26th August 2024





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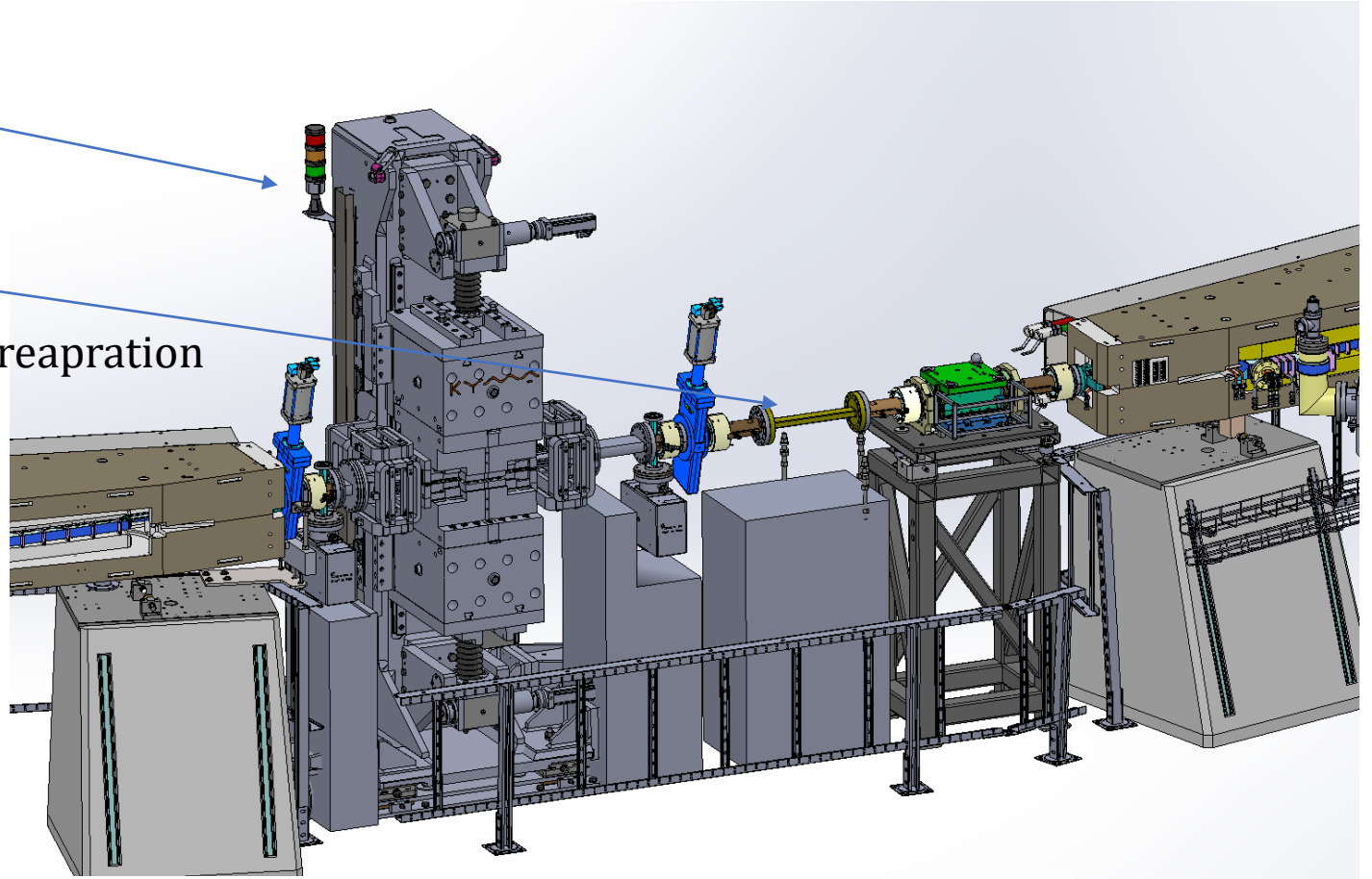
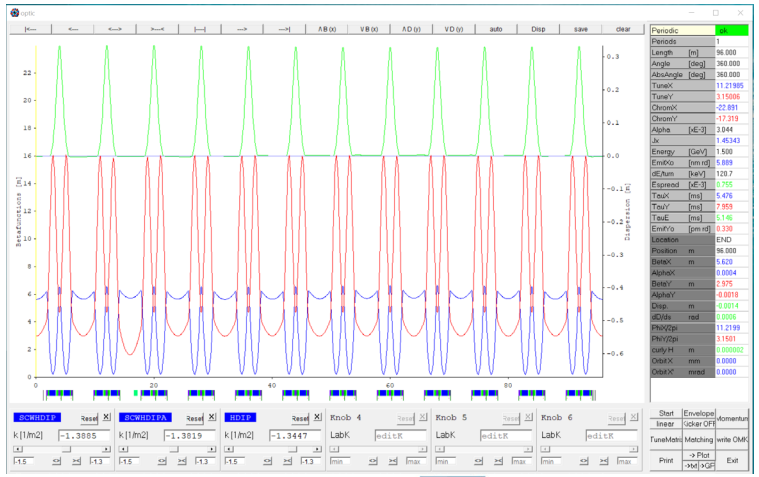
NEW BEAMLINES DEVELOPMENT -SOLCRYS

- Order for the source 3PW placed in June 2023
- Expected delivery November 2024
- The conceptual design of the straight section done
- Place holder for new injection kicekr foreseen
- Placing the order for vacuum components under preapration
- FE tender under preparation





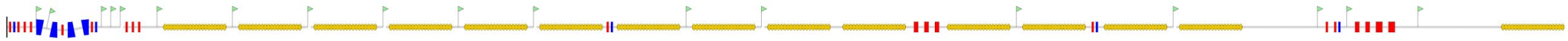
Local correction of flanking dipoles gradient of 3% & 2.5 % increase

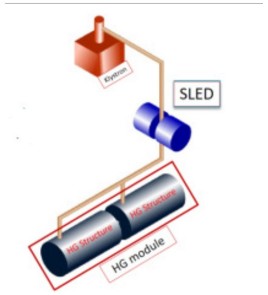
Global correction of dipoles gradient 0.25% decrease

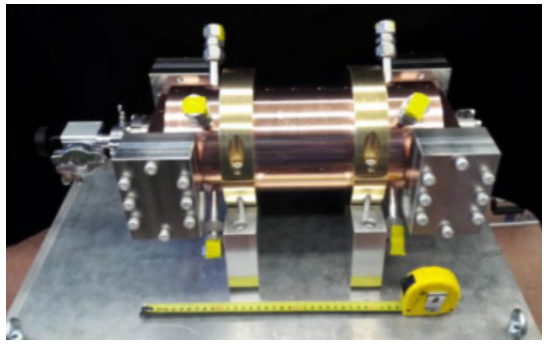
LINAC UPGRADE – NEW CONCEPT

See poster presentation on Linac upgrade on Tuesday

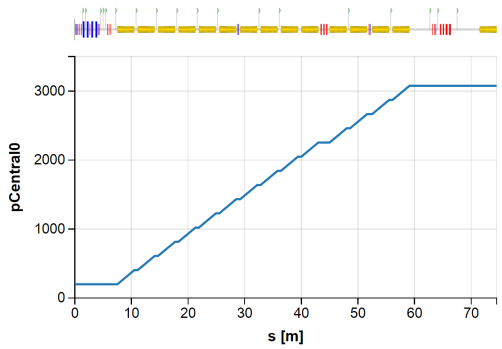
Layout of the S-band linac with 14 High Gradient (HG) structures (35MV/m) combined in 7 RF Units

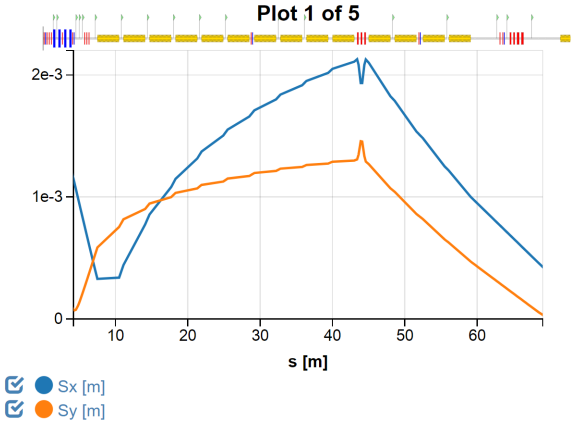


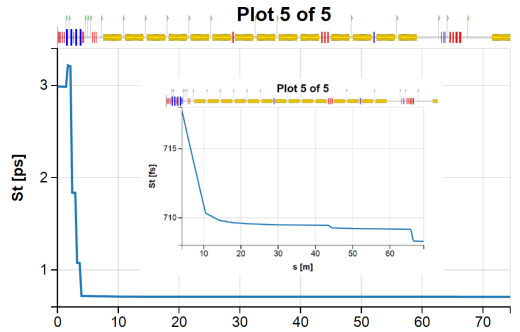


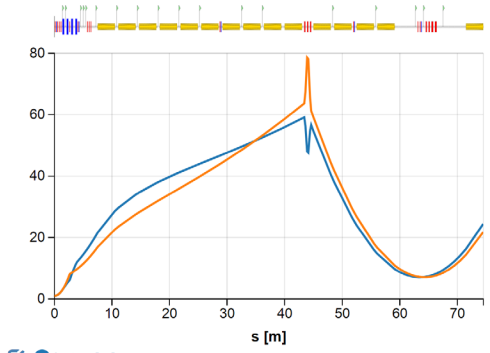


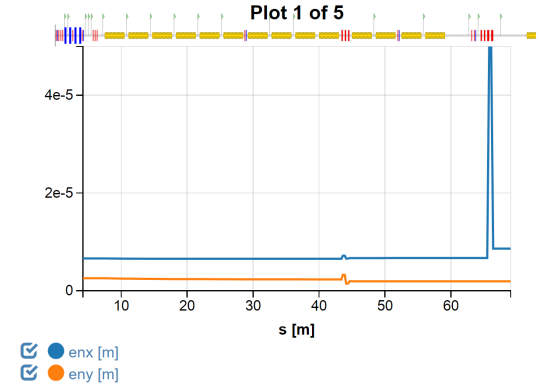
For short prototype an accelerating gradient of 40 MV/m with input RF power of 125 MW was demontsrated*

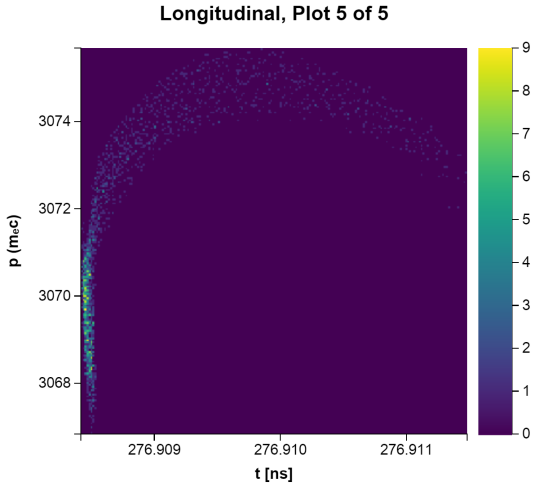












*N. Shafqat, C. Serpico, T.G. Lucas „Design and high-power test of a short prototype of high gradient S-band accelerating structure for the FERMI free electron laser linac upgrade", J.NIMA, Volume 979, 1 November 2020, 164473 https://doi.org/10.1016/j.nima.2020.16447

BUNCH LENGTH MEASUREMENT BY COHERENT DIFFRACTION RADIATION (CDR)

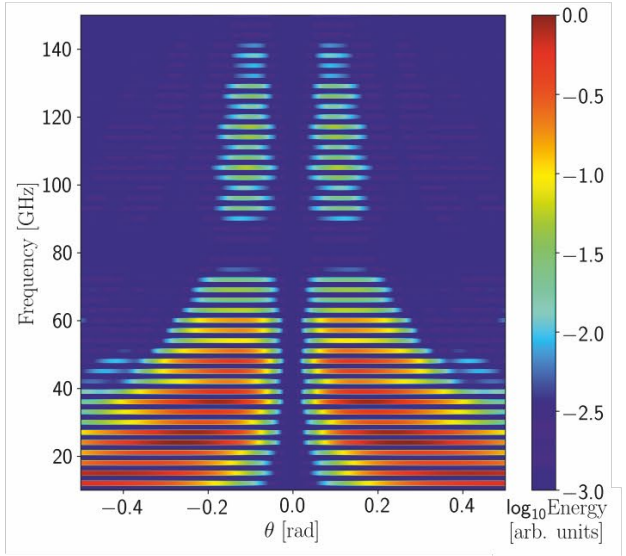


Figure 1: CDR spectral-angular distribution for the SOLARIS injector bunch repetition pattern and beam energy of 550 MeV.

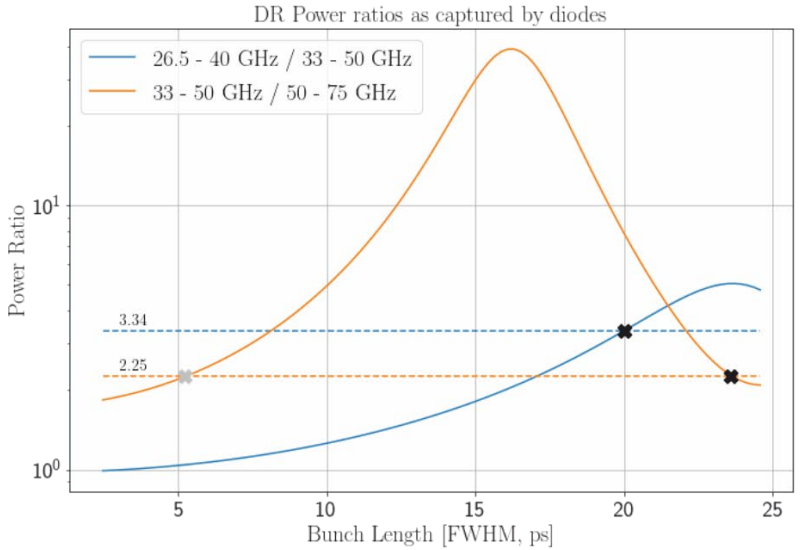


Figure 2: Bunch length to power ratio, corrected for diode aperture.

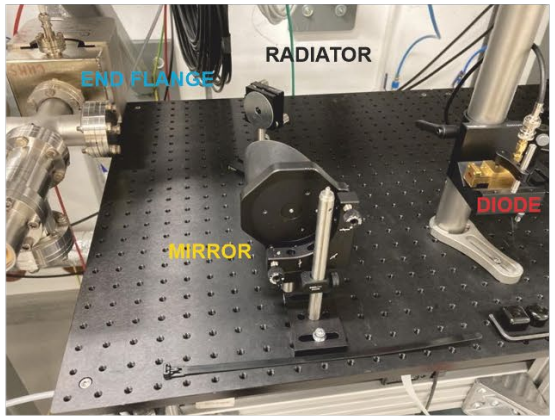


Figure 3: Experimental setup.

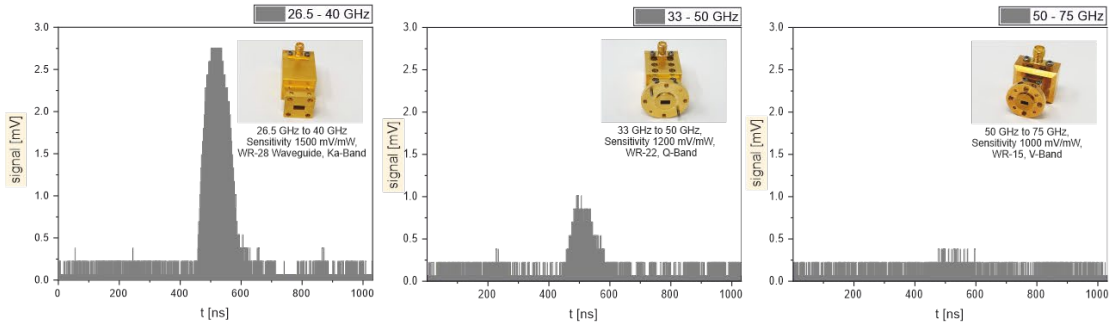


Figure 4: Signals measured by diodes with different bands.

SUMMARY

1. Solaris is a **3rd generation lights source** in **user operation** mode and in **constant development** of the infrastructure.
2. T**he beam availability** in 2024 is **97.5%** with MTBF of **190.5 h** and MTTR of **4.3 h**
3. **Fast Orbit Feedback (FOFB)** system **is now deployed** and **operational** since April with extremely good ID movement compensation.
4. **Tune measurement and tune feedback project is under development.**
5. **Bunch by Bunch Feedback system** purchesed and to be installed by end of this year.
6. **4 additional Beamlines: CIRI –** installed-first light at the end in August, **SOLCRYS , SMAUG and NAP-XPS–** design and purchase, **are underway**
7. **Design** work on **linac upgrade** and **top up injection scheme** in ongoing.
8. **Other modes** (single bunch, camshaft, dedicated filling patterns) of operation are **under development**.

Thank you for your attention!