JAGIELLONIAN UNIVERSITY IN KRAKOW

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

Introduction to SOLARIS NSRC

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On behalf of Accelerators Department

National Synchrotron Radiation Center SOLARIS

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Seminar „ACTTIS-project”
14th December 2021

OVERVIEW

SOLARIS National Synchrotron Research Centre

First light source infrastructure in Poland.
Build with unique collaboration between MAXIV Laboratory and Jagiellonian University.
Green field project financed from EU Funds.
Located at Jagiellonian University Campus in Krakow.
Design&installation: 2010-2015
In operation since May 2015.
First Users: October 2018
Staff in 2021: 96 Employees
Accelerator Department: 15 Employees
Beamline's Scientists: 23

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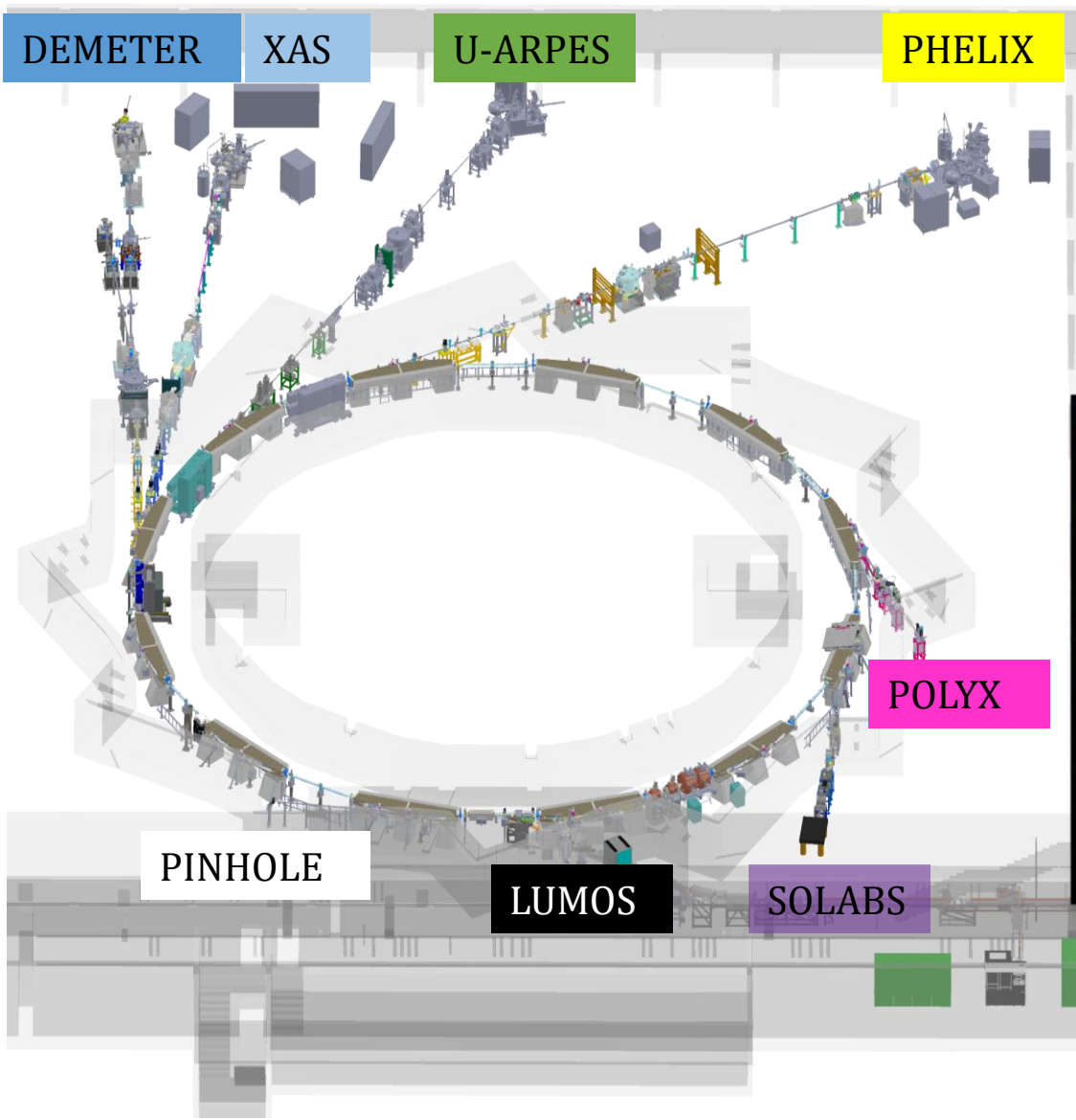
ACCELERATORS



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

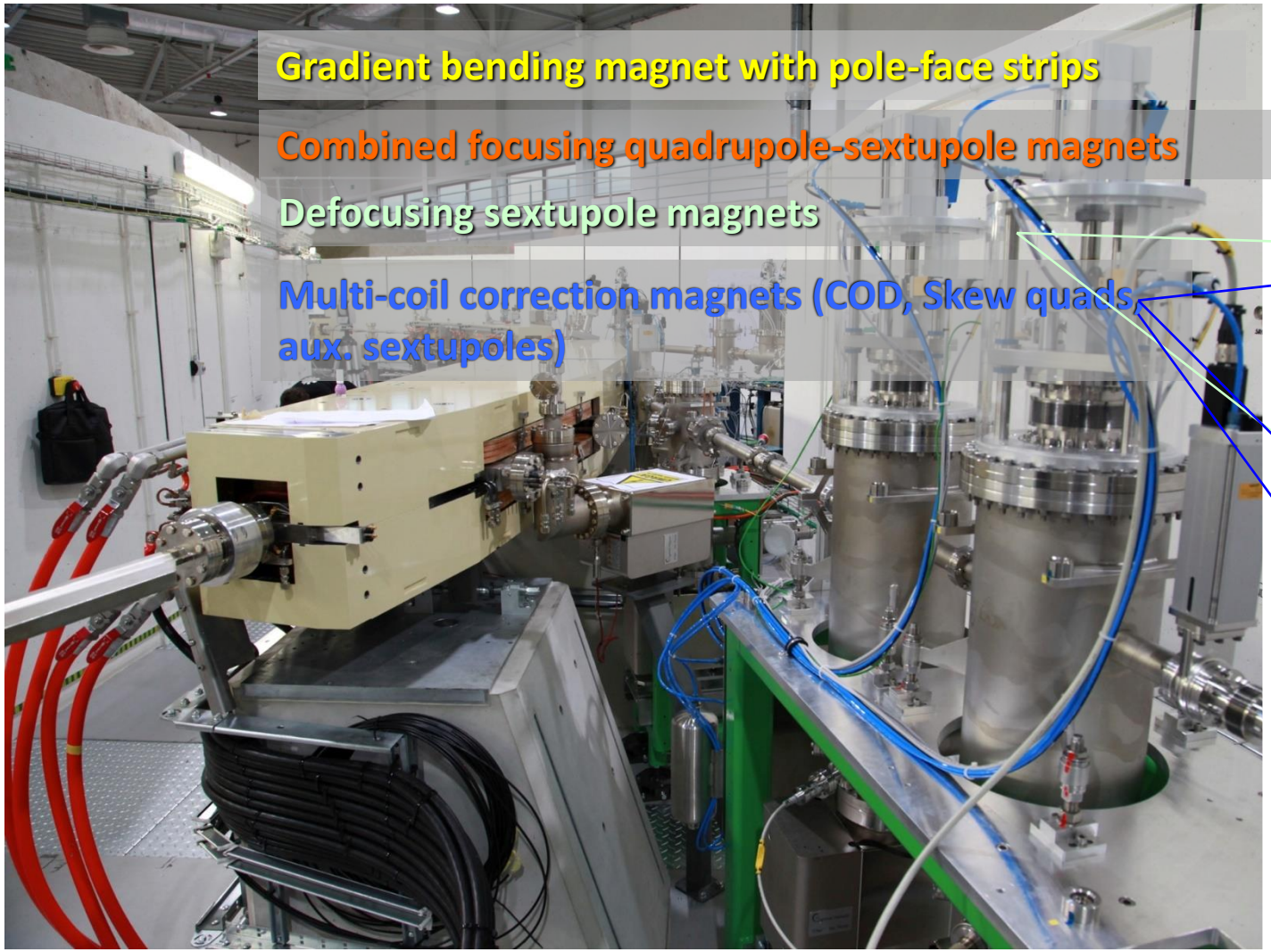
600 MeV Linac

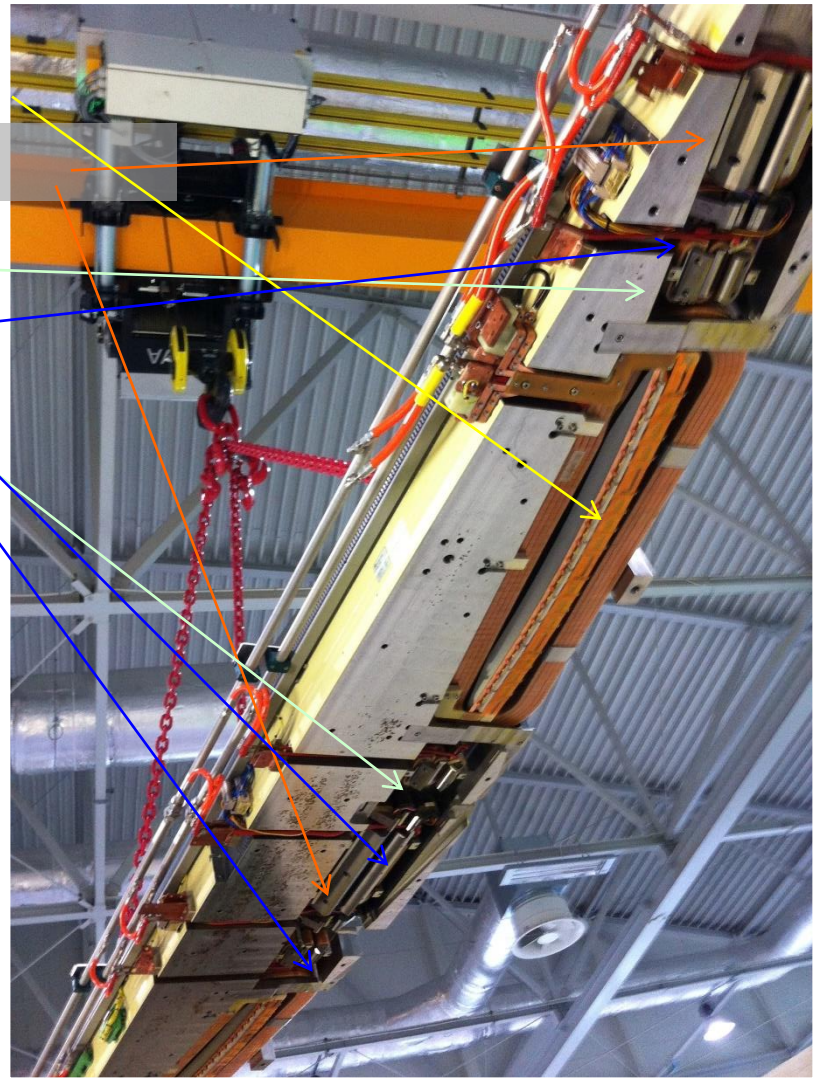
RF Thermionic Gun
6 S-band 2998.5 MHz accelerating structures
Accelerating gradient 20 MeV/m
3 RF Units & SLED cavities
Dog-leg vertical transfer line
In operation since Dec. 2014

DBA MAGNETS

Storage Ring Magnets (mirror symmetric)

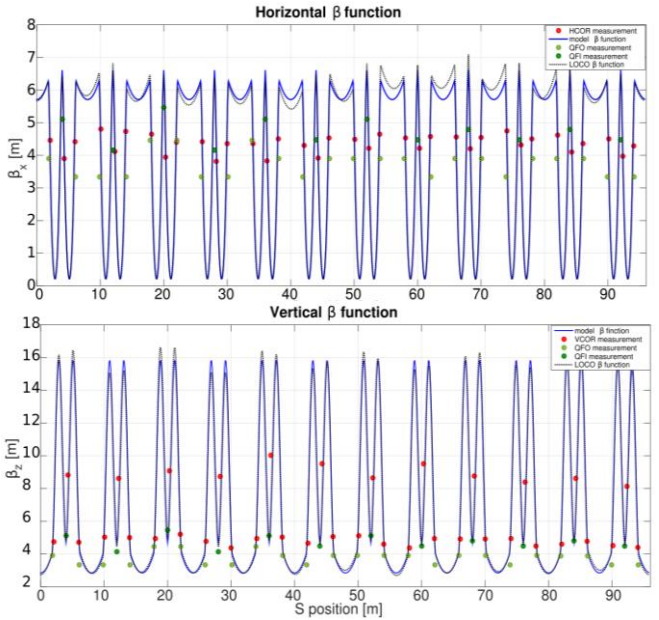
Machined from solid iron, 2 half slabs, ~4.5 m, ~7 Tons each slab



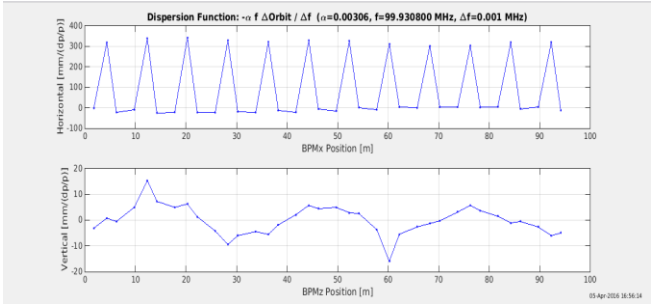


MACHINE PARAMETERS

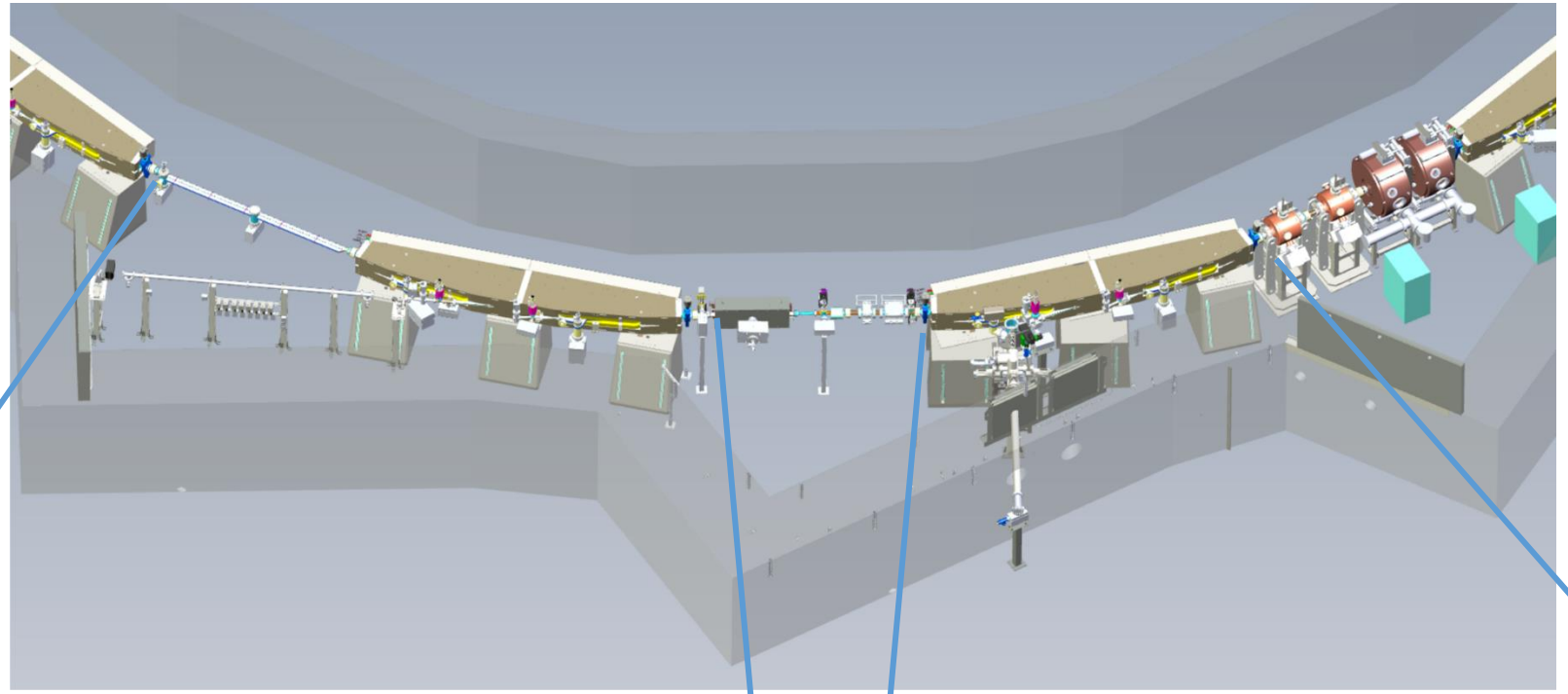
Parameter	Designed	Measured
Energy	1.5 GeV	1.45 ±0.05 GeV
Max. Current	500 mA	500 mA/400 mA (op)
Harmonic number	32	32
Natural emittance (bare lattice)	5.982 nmrad	7.5 ±1.5 nmrad
Coupling	1 %	0.83 %
Tune ν_x, ν_y	11.22, 3.15	11.22, 3.15
Corrected chromaticity ξ_x, ξ_y	+2,+2 ; +1, +1	+1.4, +1.6;+0.9,+0.9
Energy loss/turn	114.1 keV	103.7 ±12.3 keV
Momentum acceptance	4%	3.7± (0.3)%
Synchronous phase	168°	167.4° ± 2.7°
Synchrotron tune	0.00239	0.00228
Physical acceptance horizontal/vertical	18 /4 mmrad	15.68/3.77 mmrad
Lifetime	13h	15 h



Method	Hor. beating	Vert. beating
QUAD	26.84%	33.52%
ORM	13.14%	23.49%
LOCO	16.45%	11.73%



SOLARIS diagnostic beamlines



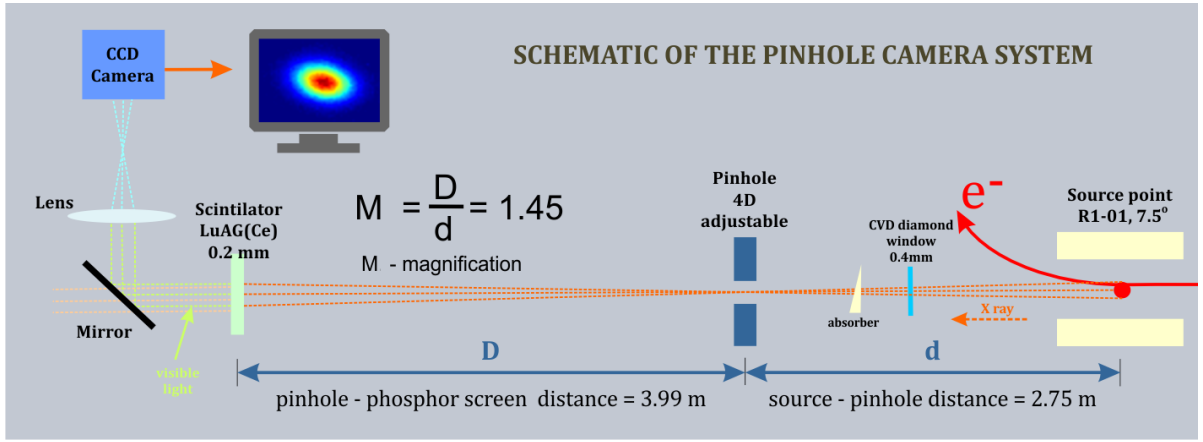
PINHOLE DIAGNOSTIC BEAMLINE

The PINHOLE, depicts the electron beam by analyzing the emitted **X-rays**.
The beamline was installed during summer shutdown **2018**.
Now is available to monitor transversal beam size during operation.

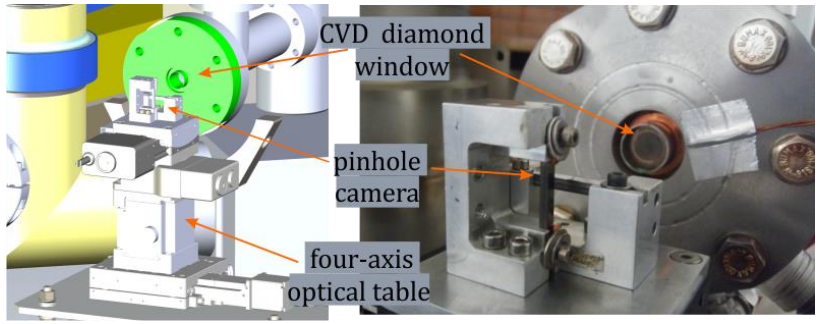
LUMOS DIAGNOSTIC BEAMLINE

The LUMOS will be operated in **the visible and IR region**.
The beamline was installed during summer shutdown **2019**.
It is foreseen to take the first beam profile measurements from LUMOS at the end of 2019.

PINHOLE diagnostic beamline

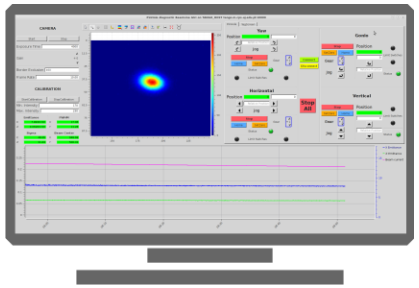


The PINHOLE, depicts the electron beam by analyzing the emitted **X-rays**.
The beamline was installed during summer shutdown **2018**.
Now is available to monitor transversal beam size during operation.
The design of the beamline was modified to provide sufficient X-ray photon flux for proper imaging (CVD diamond window).

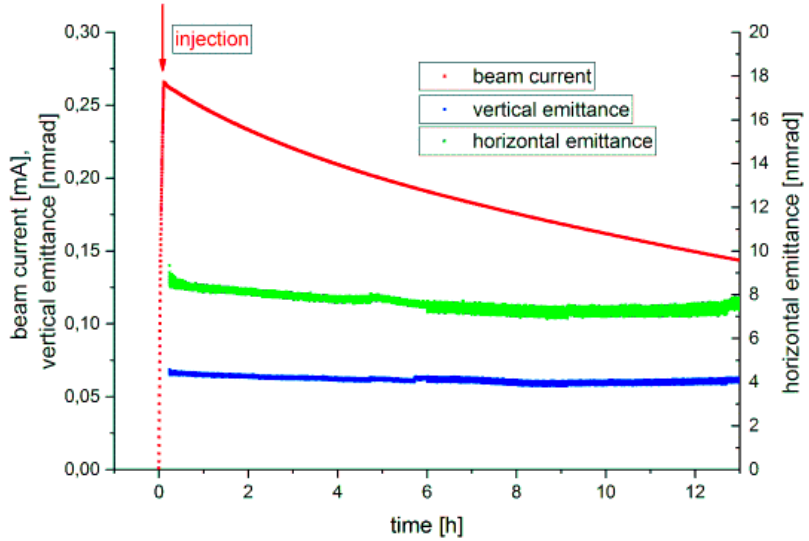


X-ray beam is converted to the visible light at the image plane by 0.2 mm thin scintillator crystal LuAG(Ce) with a peak emission of 535 nm.
Instead of an aluminium exit window a CVD (chemical vapour deposited) diamond with thickness of 400 um was chosen. It improves the simulated photon flux by a factor of 200.

CONTROL PROGRAM

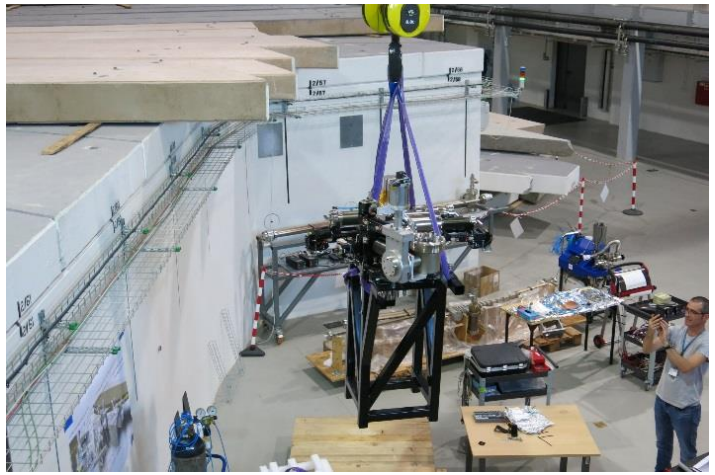


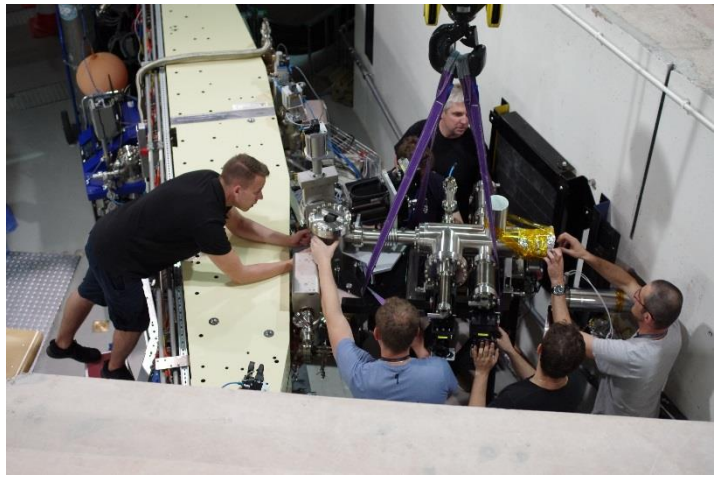
The PINHOLE software consists of three layers:
- Taurus based GUI
- TANGO Controls devices
- PLC program

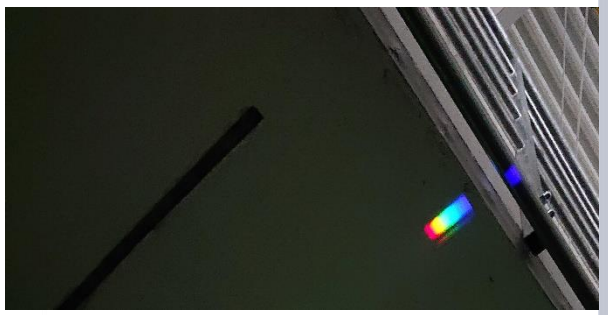


Horizontal (green dots) and vertical (blue dots) emittance measured continuously over 13 hours.

LUMOS diagnostic beamline

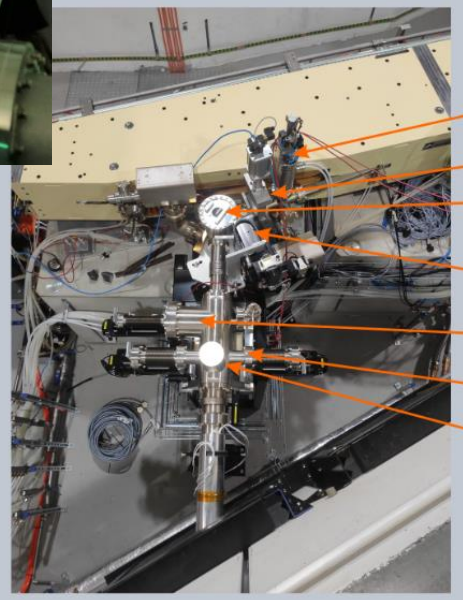




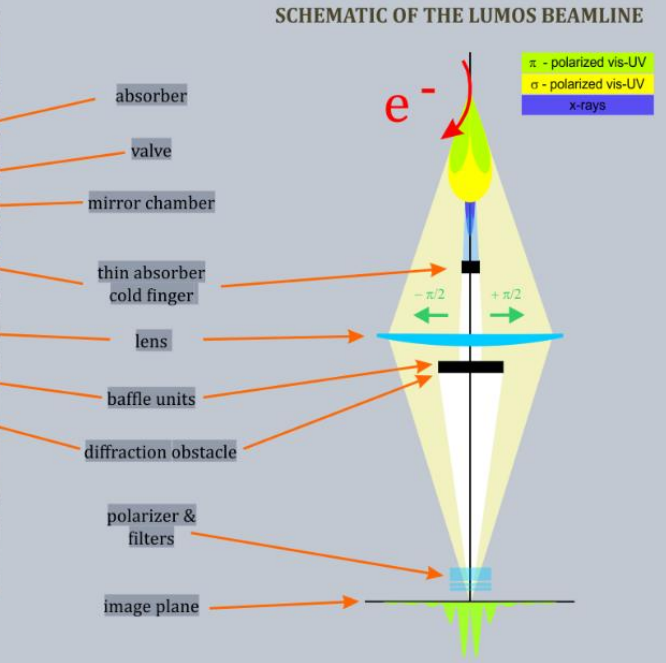


Streak camera model SC-10 with S25 photocathode by Optronis

The LUMOS is operated in the visible and IR region.
The beamline was installed during summer shutdown 2019.
This beamline is used for transverse beam profile and longitudinal bunch length measurements as well as to study the longitudinal beam dynamics.



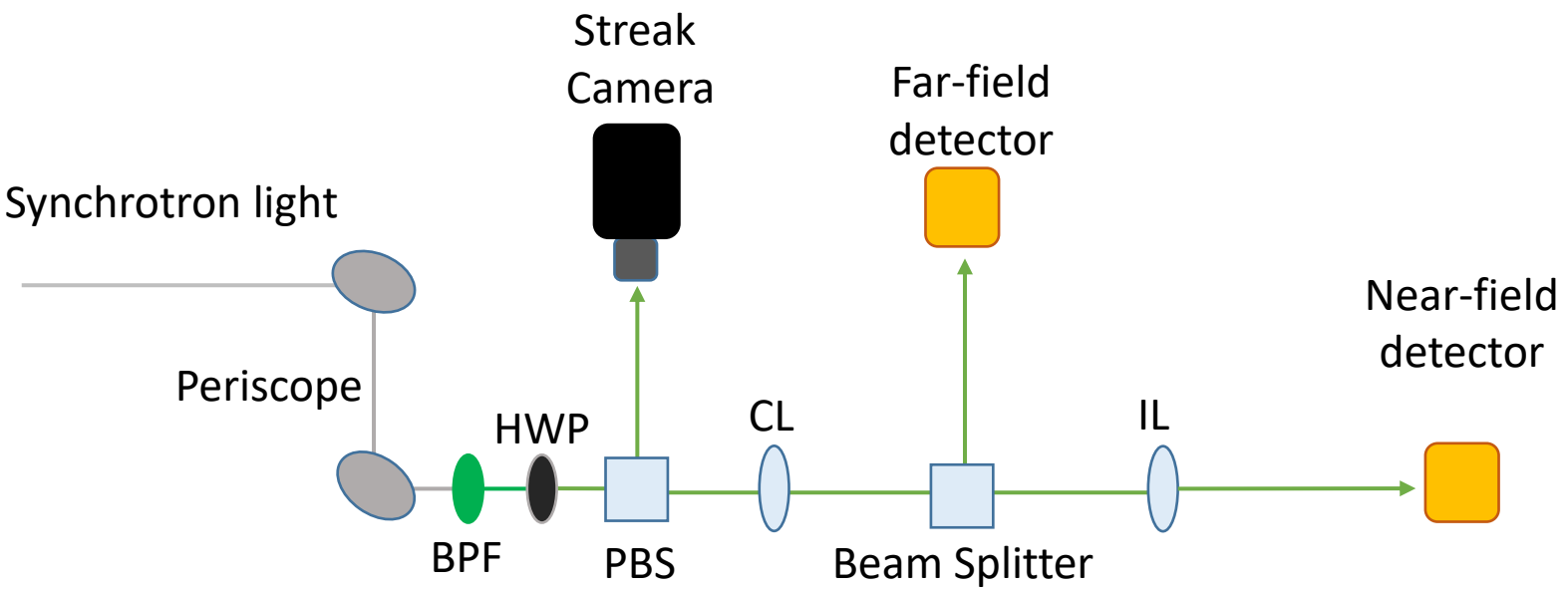
diagnostic beamline LUMOS – top view



LUMOS has a similar configuration to the existing diagnostic beamline at MAX IV 1.5 GeV storage ring.
New beamline will enable a wide range of new optical diagnostic measurements.

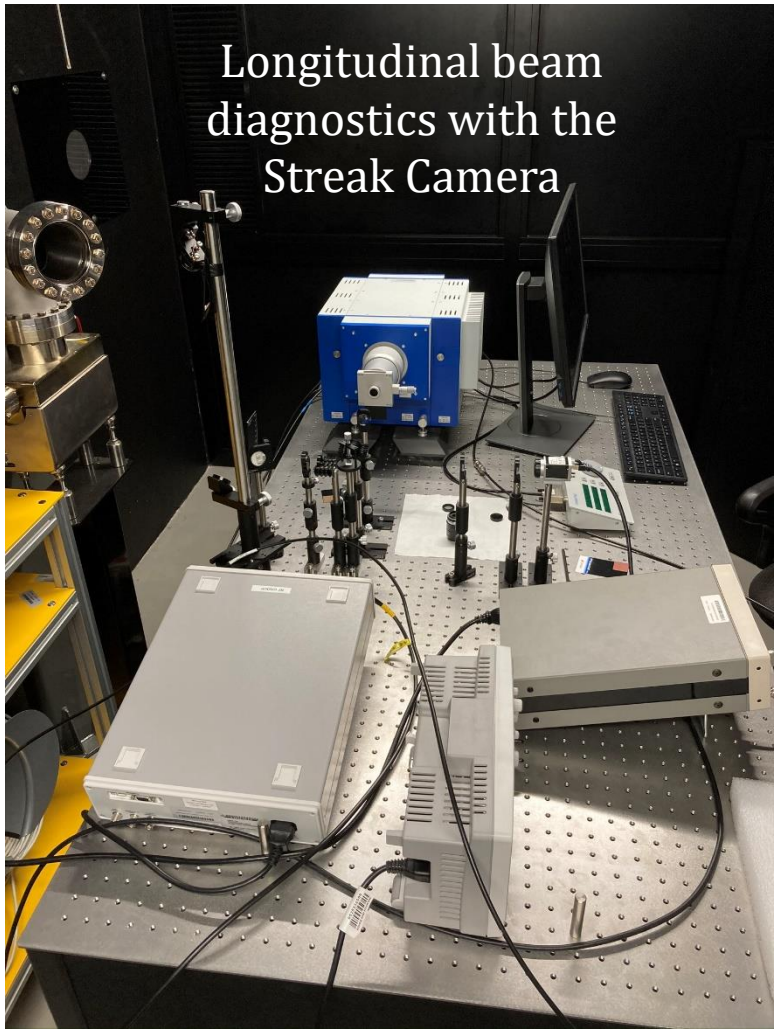
LUMOS DIAGNOSTIC BEAMLINE

Scheme of the experimental setup



BPF: Band Pass Filter (to select a narrow band)
PBS: Polarizing Beam Splitter
HWP: Half-Wave Plate (to rotate the polarization)
CL: Collimation Lens (to parallelize the light beam)
IL: Imaging Lens (to form an image of the beam in the focal plane)
Detector: CCD Camera/Power Meter
Streak camera (Optronis SC-10, res. 1.5ps FWHM)

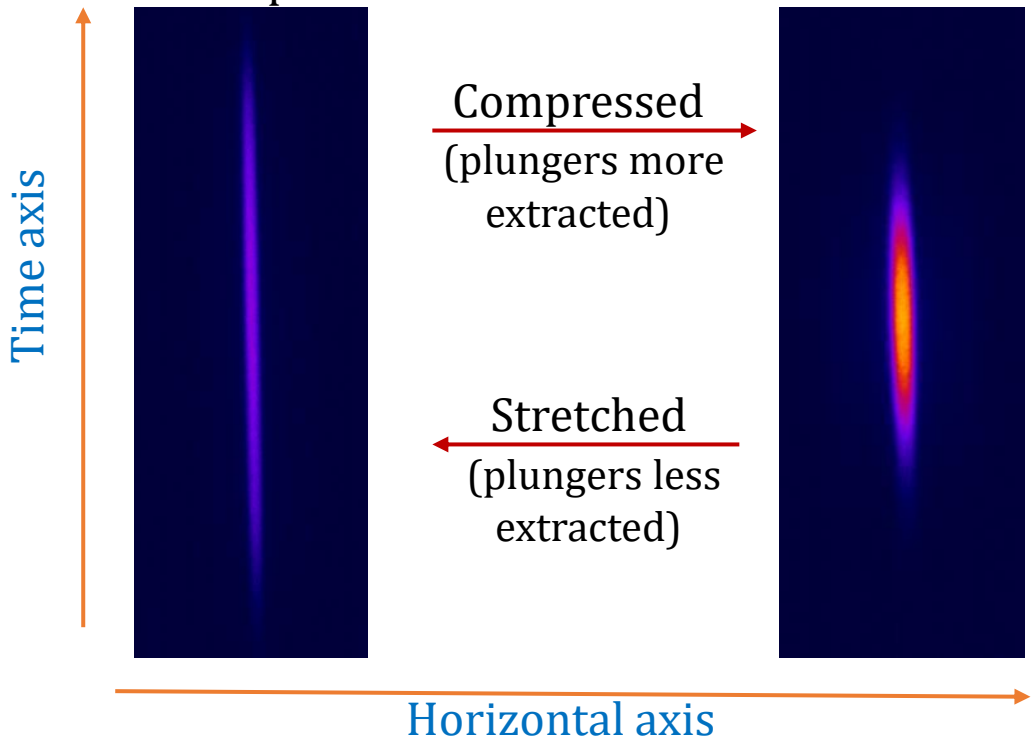
View of the LUMOS diagnostic beamline



MEASUREMENTS

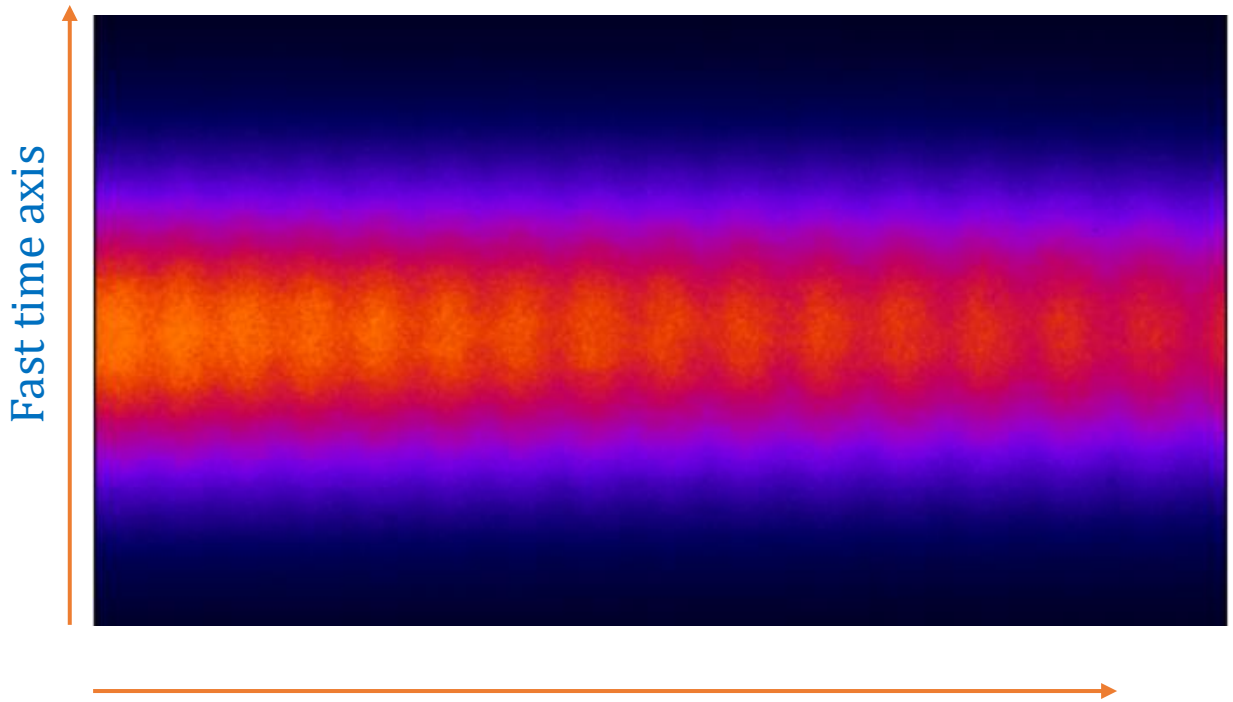
Streak-camera measurements @SOLARIS Storage Ring

1.5 GeV, 30 mA, all bunches overlapped,
i.e. one sweep unit



Measured bunch lengths 415-130 ps rms

1.5 GeV, 30 mA, portion of the filling pattern,
i.e. two sweep units



Measured bunch length 130 ps rms

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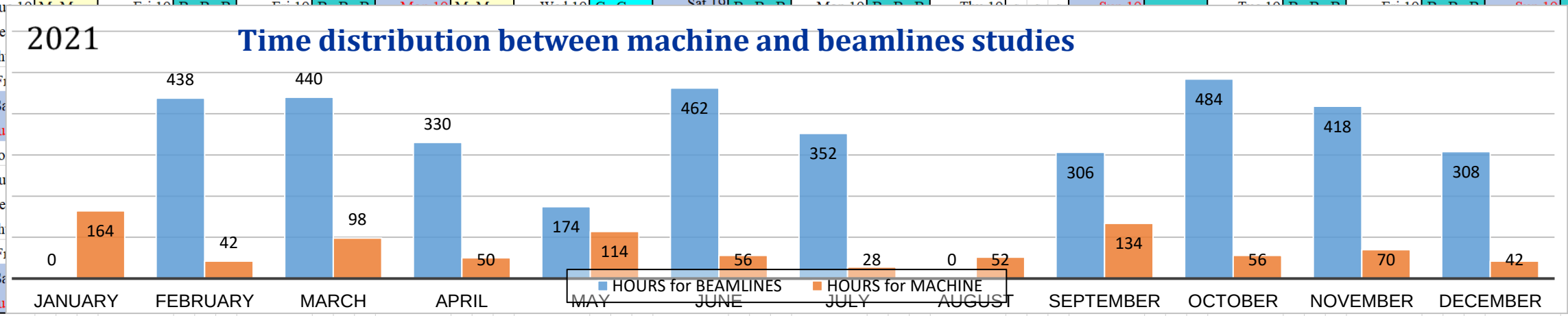
OPERATION IN 2021

Jan 2021		Feb 2021		Mar 2021		Apr 2021		May 2021		Jun 2021		Jul 2021		Aug 2021		Sep 2020		Oct 2021		Nov 2021		Dec 2021	
Fri 01	s s s	Mon 01	C C .	Mon 01	M M .	Thu 01	M M .	Sat 01	s s s	Tue 01	B B B	Thu 01	B B B	Sun 01	s s s	Wed 01	M M .	Fri 01	B B B	Mon 01	. . .	Wed 01	B B B
Sat 02	s s s	Tue 02	C C .	Tue 02	B B B	Fri 02	M . .	Sun 02	s s s	Wed 02	B B B	Fri 02	B B B	Mon 02	s s s	Thu 02	M M .	Sat 02	B B B	Tue 02	M M .	Thu 02	B B B
Sun 03	s s s	Wed 03	C C .	Wed 03	B B B	Sat 03	. . .	Mon 03	s s s	Thu 03	. . .	Sat 03	B B B	Tue 03	s s s	Fri 03	M M .	Sun 03	. . .	Wed 03	B B B	Fri 03	B B B
Mon 04	s s s	Thu 04	B B B	Thu 04	B B B	Sun 04	. . .	Tue 04	s s s	Fri 04	B B B	Sun 04	. . .	Wed 04	s s s	Sat 04	. . .	Mon 04	M M .	Thu 04	B B B	Sat 04	B B B
Tue 05	s s s	Fri 05	B B B	Fri 05	B B B	Mon 05	. . .	Wed 05	s s s	Sat 05	B B B	Mon 05	M M .	Thu 05	s s s	Sun 05	. . .	Tue 05	B B B	Fri 05	B B B	Sun 05	. . .
Wed 06	s s s	Sat 06	B B B	Sat 06	B B B	Tue 06	B B B	Thu 06	s s s	Sun 06	. . .	Tue 06	B B B	Fri 06	s s s	Mon 06	M M .	Wed 06	B B B	Sat 06	B B B	Mon 06	M M .
Thu 07	s s s	Sun 07	. . .	Sun 07	. . .	Wed 07	B B B	Fri 07	s s s	Mon 07	M M .	Wed 07	B B B	Sat 07	s s s	Tue 07	M M .	Thu 07	B B B	Sun 07	. . .	Tue 07	B B B
Fri 08	s s s	Mon 08	M M .	Mon 08	M M .	Thu 08	B B B	Sat 08	s s s	Tue 08	B B B	Thu 08	B B B	Sun 08	s s s	Wed 08	C C .	Fri 08	B B B	Mon 08	M M .	Wed 08	B B B
Sat 09	s s s	Tue 09	B B B	Tue 09	B B B	Fri 09	B B B	Sun 09	s s s	Wed 09	B B B	Fri 09	B B B	Mon 09	s s s	Thu 09	C C .	Sat 09	B B B	Tue 09	B B B	Thu 09	B B B
Sun 10	s s s	Wed 10	B B B	Wed 10	B B B	Sat 10	B B B	Mon 10	O . .	Thu 10	B B B	Sat 10	B B B	Tue 10	s s s	Fri 10	C C .	Sun 10	. . .	Wed 10	B B B	Fri 10	B B B
Mon 11	s s s	Thu 11	B B B	Thu 11	B B B	Sun 11	. . .	Tue 11	O . .	Fri 11	B B B	Sun 11	. . .	Wed 11	s s s	Sat 11	. . .	Mon 11	M M .	Thu 11	. . .	Sat 11	B B B
Tue 12	s s s	Fri 12	B B B	Fri 12	B B B	Mon 12	M M .	Wed 12	M M .	Sat 12	B B B	Mon 12	M M .	Thu 12	s s s	Sun 12	. . .	Tue 12	B B B	Fri 12	B B B	Sun 12	. . .
Wed 13	O . .	Sat 13	B B B	Sat 13	B B B	Tue 13	B B B	Thu 13	M M .	Sun 13	. . .	Tue 13	B B B	Fri 13	s s s	Mon 13	M M .	Wed 13	B B B	Sat 13	B B B	Mon 13	M M .
Thu 14	O . .	Sun 14	. . .	Sun 14	. . .	Wed 14	B B B	Fri 14	M M .	Mon 14	M M .	Wed 14	B B B	Sat 14	s s s	Tue 14	B B B	Thu 14	B B B	Sun 14	. . .	Tue 14	B B B
Fri 15	O . .	Mon 15	M M .	Mon 15	M M .	Thu 15	B B B	Sat 15	. . .	Tue 15	B B B	Thu 15	B B B	Sun 15	s s s	Wed 15	B B B	Fri 15	B B B	Mon 15	M M .	Wed 15	B B B
Sat 16	. . .	Tue 16	B B B	Tue 16	B B B	Fri 16	B B B	Sun 16	. . .	Wed 16	B B B	Fri 16	B B B	Mon 16	s s s	Thu 16	B B B	Sat 16	B B B	Tue 16	B B B	Thu 16	B B B
Sun 17	. . .	Wed 17	B B B	Wed 17	B B B	Sat 17	B B B	Mon 17	M M .	Thu 17	B):A B	Sat 17	B B B	Tue 17	s s s	Fri 17	B B B	Sun 17	. . .	Wed 17	B B B	Fri 17	B B B
Mon 18	M M .	Thu 18	B B B	Thu 18	B B B	Sun 18	. . .	Tue 18	M M .	Fri 18	B B B	Sun 18	. . .	Wed 18	s s s	Sat 18	B B B	Mon 18	M M .	Thu 18	B B B	Sat 18	B B B



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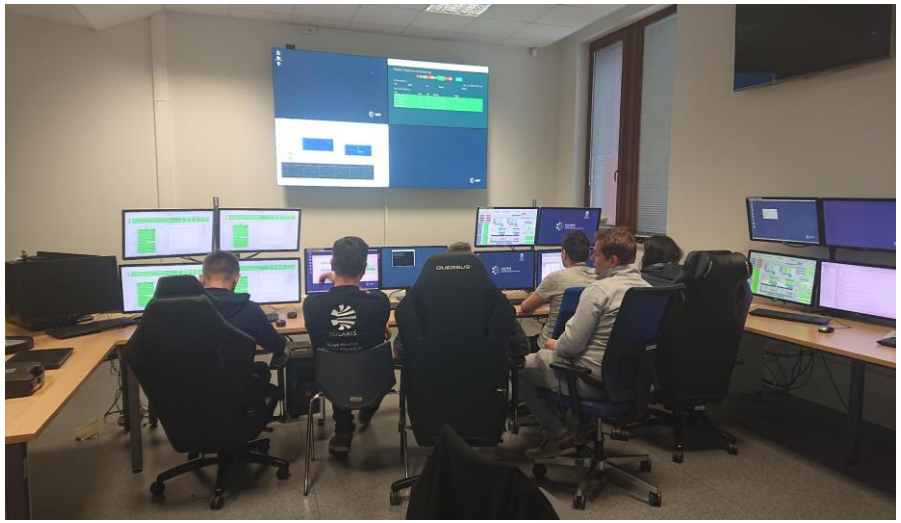
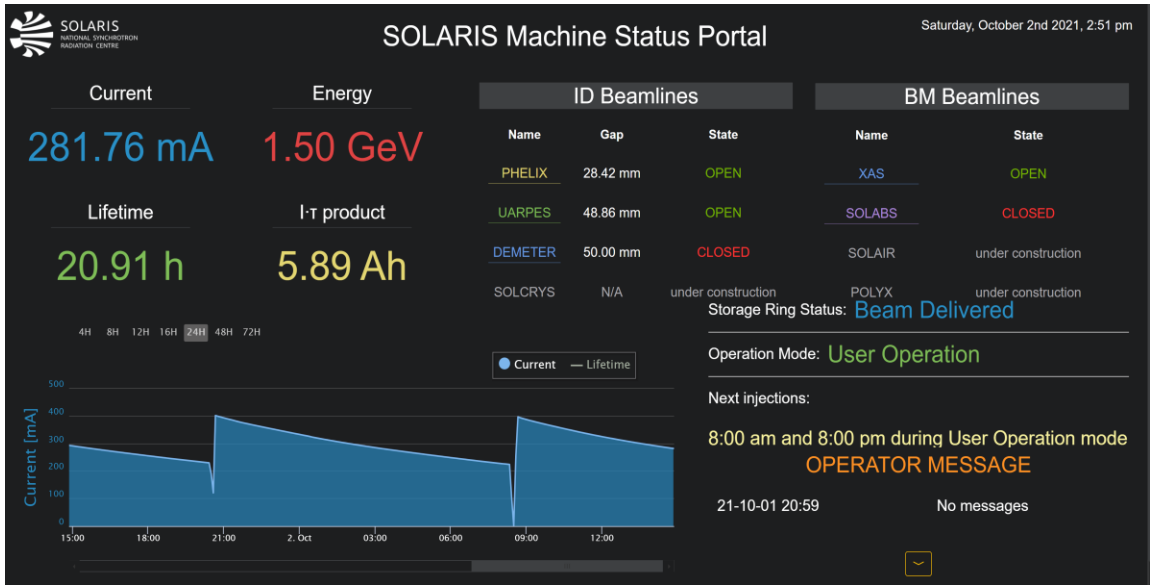
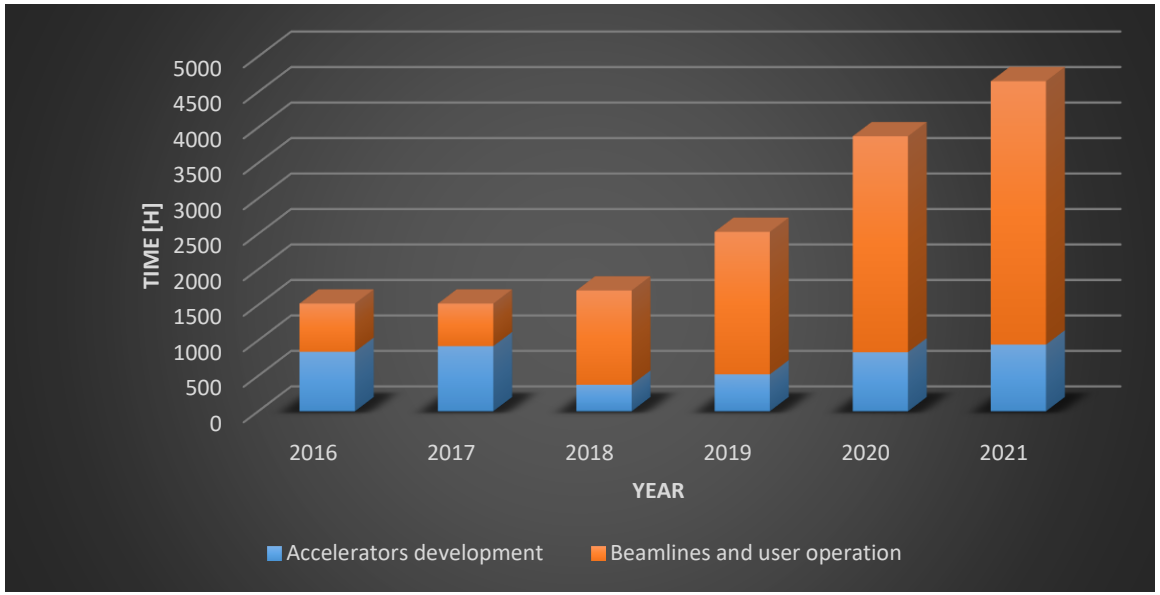
SOLARIS OPERATION

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

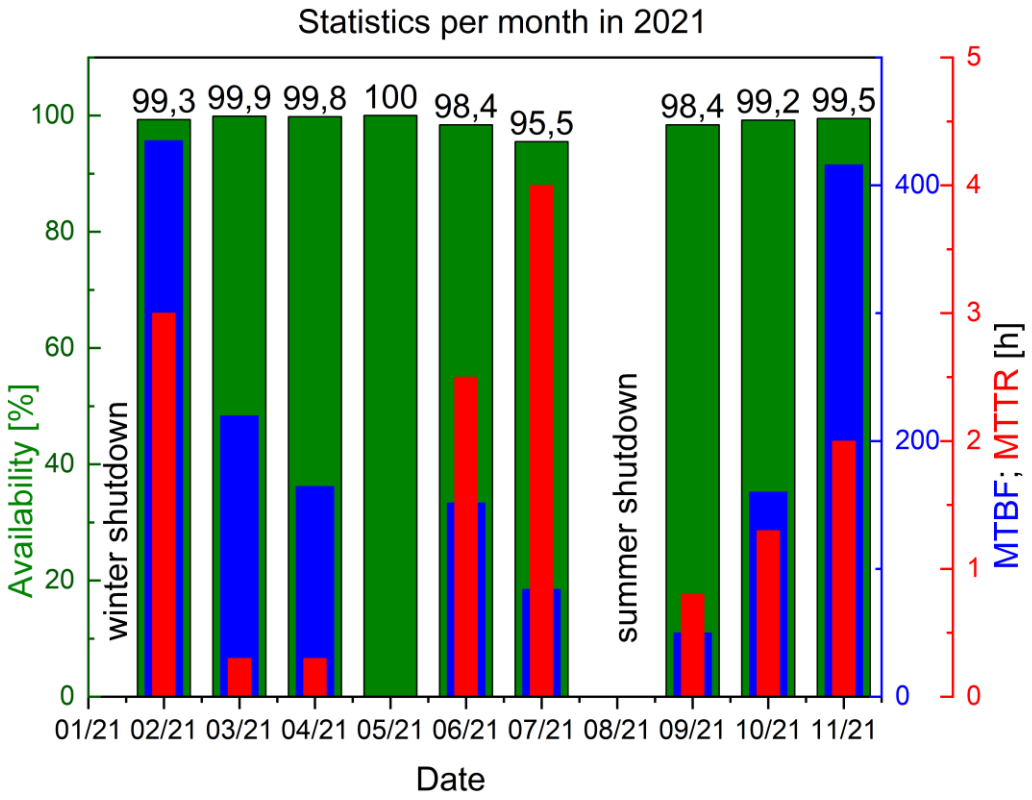




AVAILABLILITY



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

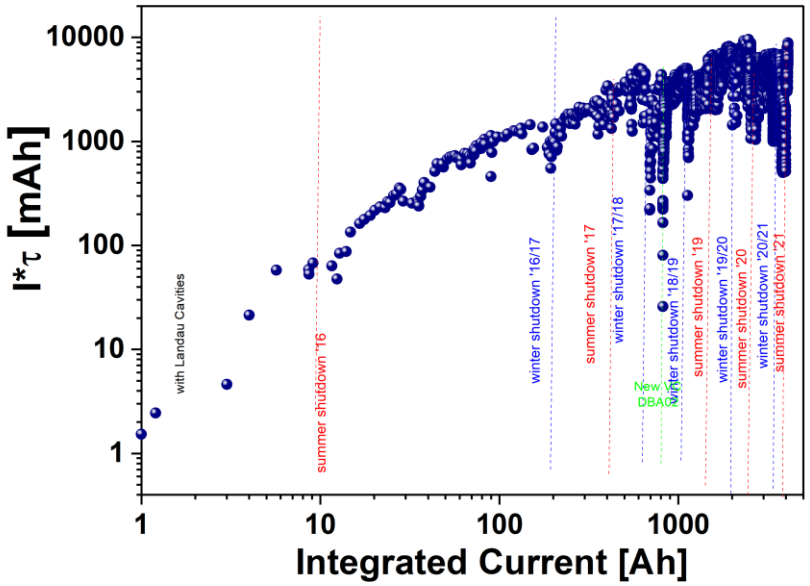


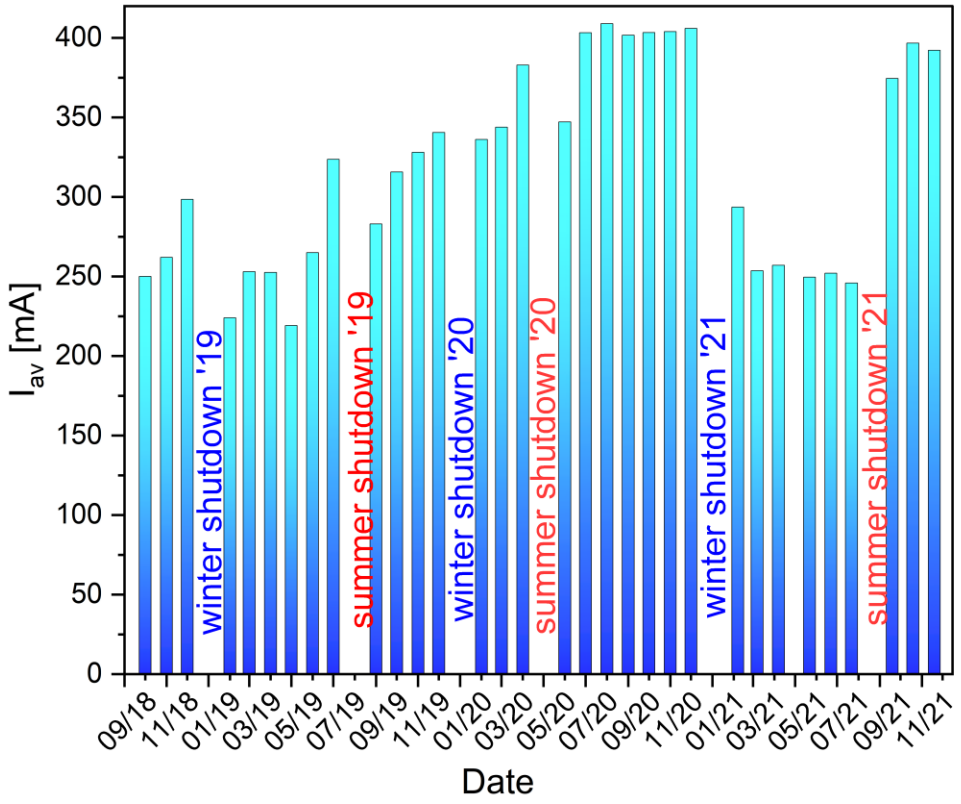
Year	Total Beamtime	Availability	MTBF	MTTR	Average current
2018	1704 h	90.4 %	16.3 h	1.5 h	270 mA
2019	2530 h	91.9 %	22.8 h	1.7 h	284 mA
2020	3868 h	93.0 %	76.0 h	3.6 h	385 mA
2021	**4654 h**	**99.0 %**	**168.7 h**	**2.2 h**	**302 mA**

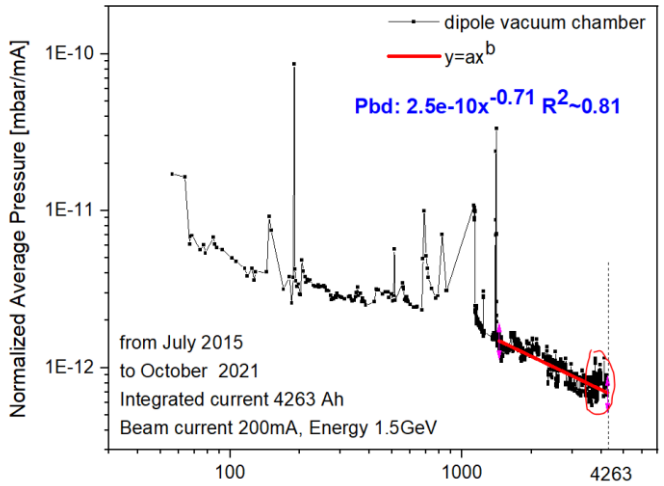
Reliability of UPS: **99.91%**

Reliability of electrical system: **99.61%**

AVERAGE CURRENT DELIVERED







Normalized average pressure measured by 24 sputter ion pumps from all band section (dipole vacuum chambers) for 200mA of beam current and 1.5GeV energy of electrons

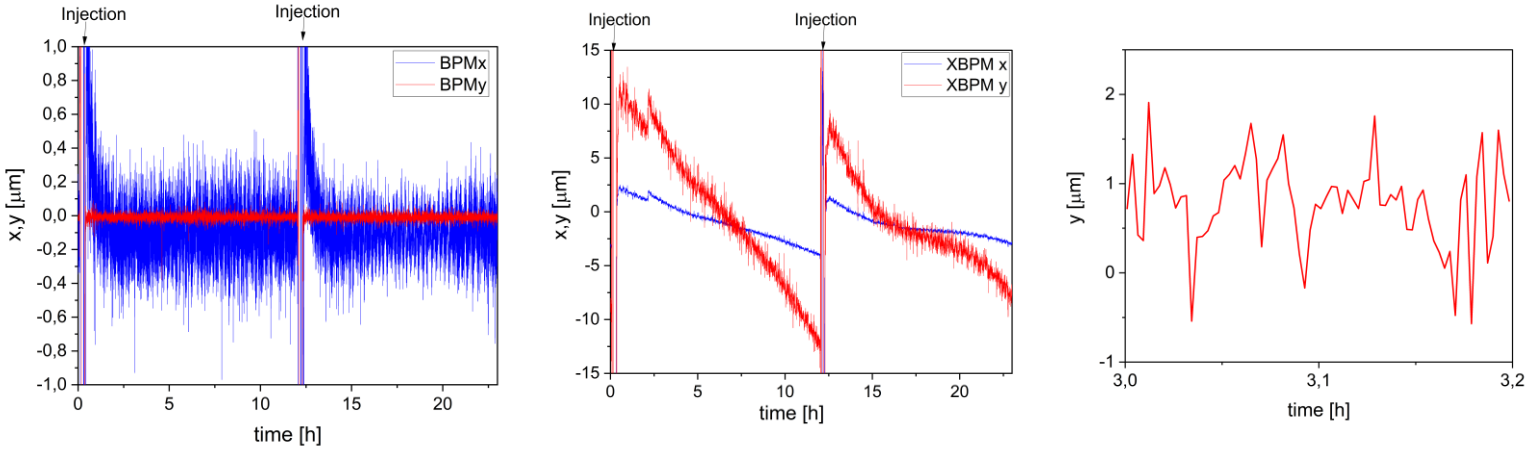
CLOSED ORBIT AND STABILITY

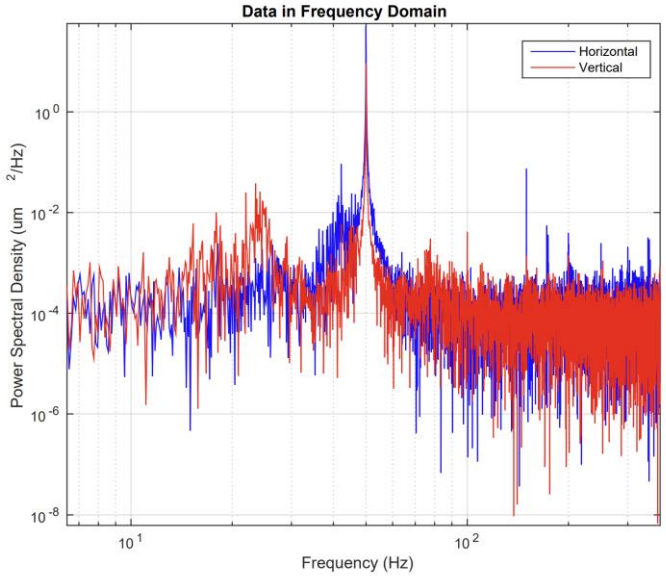
Closed orbit correction (slow orbit feedback):

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.

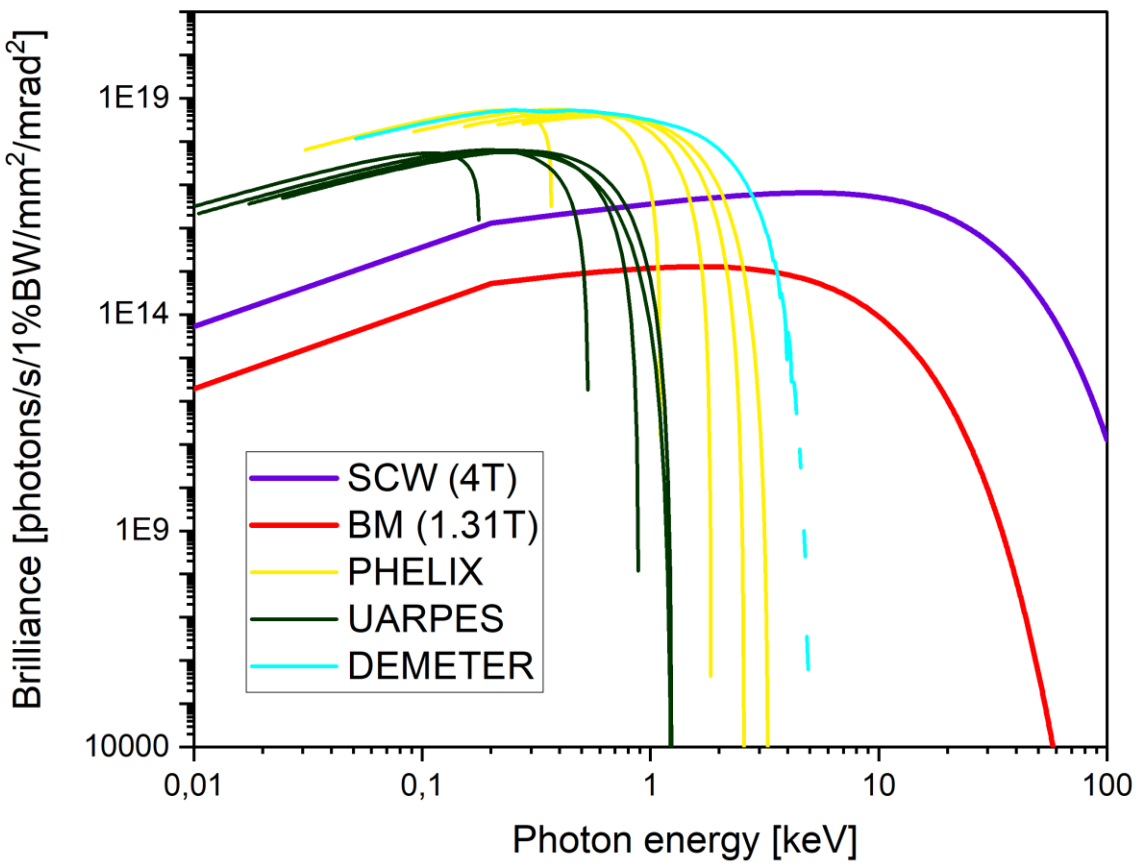




The Solaris beamlines require the 2 µm over 8 h long-term stability of the photon beam measured at the front end XBPM location. However, at the moment the drift of 0.5 µm for the electron beam and 10 µm for the photon beam is observed during 8 h of beam decay with slow orbit SOFB running. The medium-term oscillations of the photon beam measured on XBMPs are in the range of 0.5-1 µm rms. The reasons of those beam instabilities may rise from the vibration coming from the water circuit pumps. The second reason is the thermal stability, the temperature changes can affect the BPM readings due to thermal expansion of the vacuum vessels, girders and optical components. The PSD in the frequency domain showing modes in the range from 1-300Hz.

Insertion devices at SOLARIS

Beam Line	04 - DEMETER	05 - UARPES	06 - PHELIX
ID type	EPU	EPU APPLE II type, quasiperiodic	EPU APPLE II type
Type of magnets	Permanent NdFeB NEOMAX 39SH	Permanent NdFeB	Permanent NdFeB
Magnetic period length	46.6 mm	120 mm	58 mm
Number of periods	44	21	44
Minimum gap	14 mm	20 mm	14 mm
Maximum gap	> 200 mm	140 mm	220 mm
Length of magnet assemblies	2116.9 mm	2669,9 mm	2676.6 mm
Total length of undulator	2136.9 mm	2699 mm	2700 mm
Peak B field at min. gap	0.71 T	0.774 T	0.879 T
Available energy Range	100 – 2000 eV	total: 8–100 eV NIM: 8 eV–30 eV PGM: 16 eV–100 eV	50–1500 eV for linear horizontal, linear vertical, and circular polarization 70–1500 eV for linear polarization inclined at 45°
Polarization	Circular left- and right-handed, linear horizontal and vertical	Circular, elliptical, linear horizontal and vertical, linear skewed.	Circular, elliptical, variable linear
Manufacturer	ADC	Kyma	Kyma



Research Infrastructure

Development of SOLARIS research infrastructure

2018 – beginning of cooperation with users of two beamlines (three end stations): **PEEM**/**XAS** and **UARPES**

2019 – extending the SOLARIS offer by cryo-electrone microscope **Titan Krios G3i** (Cryo-EM) research infrastructure

2021 – the third beamline available for users: **PHELIX**

2021 – opening the fourth beamline **DEMETER** with two end-stations **PEEM** i **STXM**

2021 – opening the second cryo-electron microscope – **Glacios** - and beginning of cooperation with industry

2021 – Commissioning of **SOLABS** beamline

- **XAS** - (X-ray absorption spectroscopy) – a universal station for X-ray absorption spectroscopy;
- **UARPES** - (ultra-angle-resolved photoemission spectroscopy) - allows for measurements of fundamental quantities, i.e., the energy and the momentum;
- **PHELIX** – enables a wide range of spectroscopic and absorption studies characterized by different surface sensitivity;
- **PEEM** – (PhotoEmission Electron Microscope) - allows for the creation and modification of research systems and imaging of their surfaces in a wide range of temperatures and with high resolution;
- **STXM** - provides chemical analysis at the nanoscale through the combination of X-ray absorption spectrometry and microscopy;
- **Cryo-EM** i **Glacios** - the latest generation of a cryo-electron microscopes.

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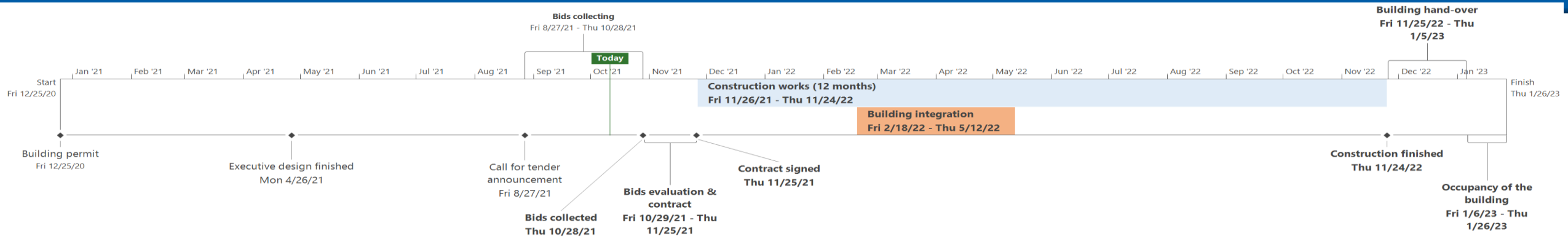
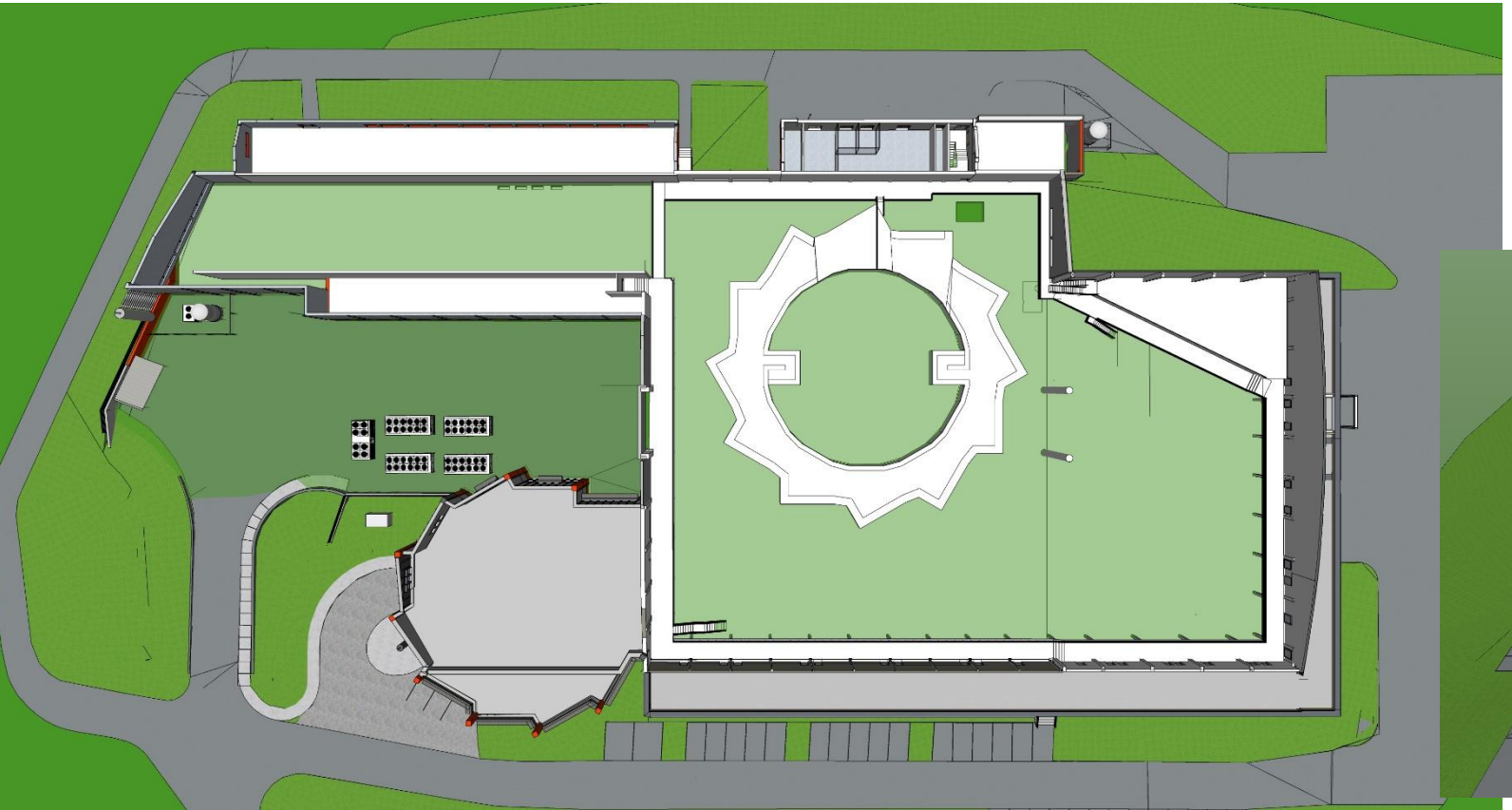
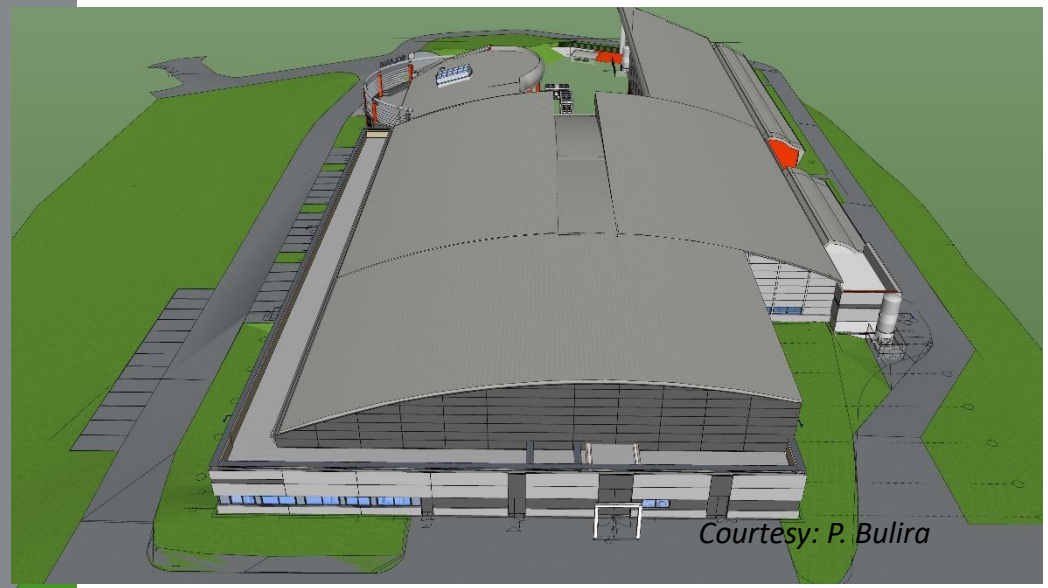
BUILDING EXTENSION







Courtesy: P. Bulira

PLANS FOR NEXT BEAMLINES

Four new beamlines under design and construction

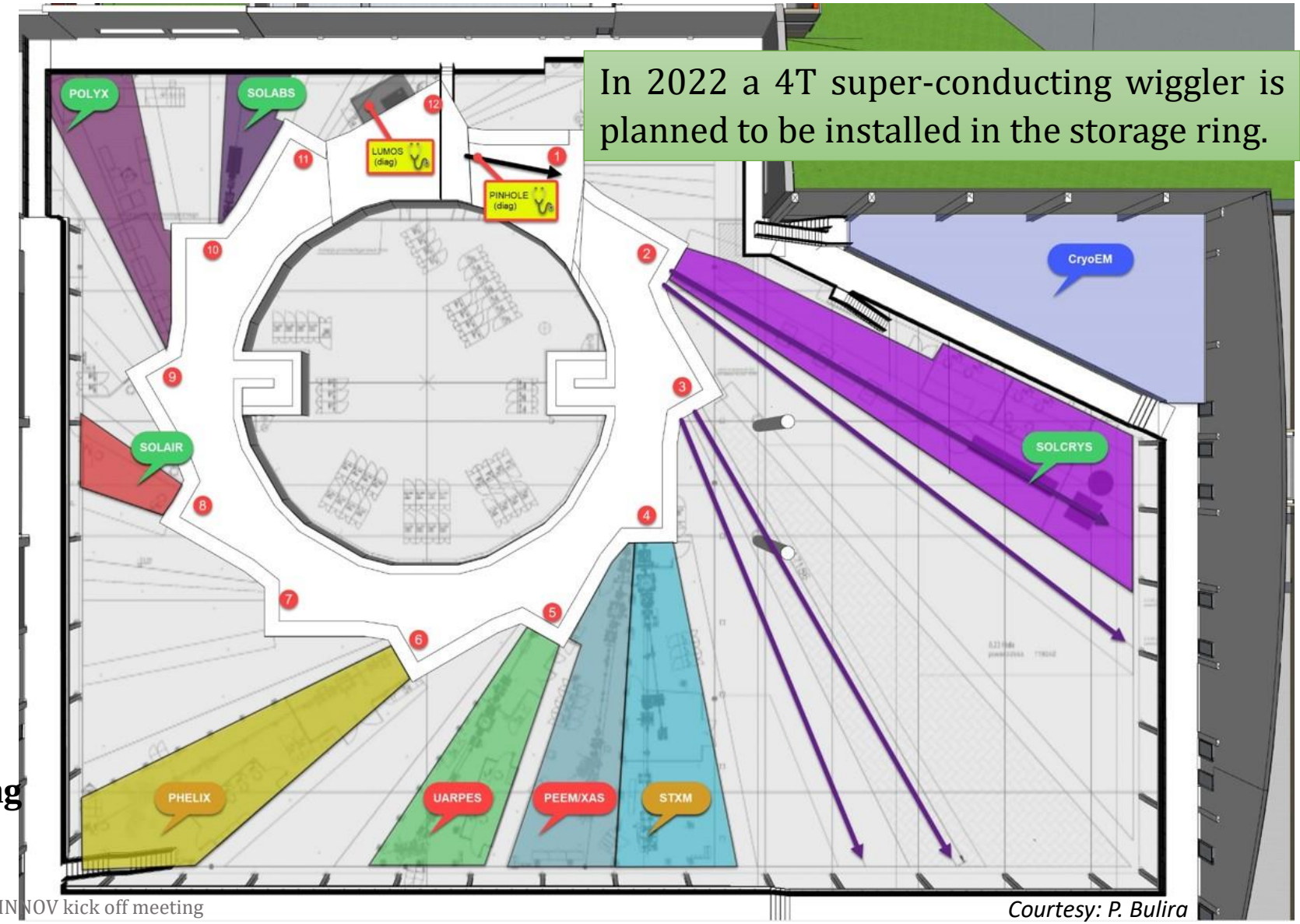
POLYX beamline front end installed in summer 2021

SOLABS beamline first light extracted after monochromator in September ’21
Redesign and installation of the dipole chamber for **SOLAIR beamline** (delivery end of 2021)
Building extension planed for end of 2022

SOLCRYS beamline installation 2023
2 Beamlines under commissioning and will be available for users from **October 2021**

- **Operational**
- **Under commissioning**
- **Under construction**

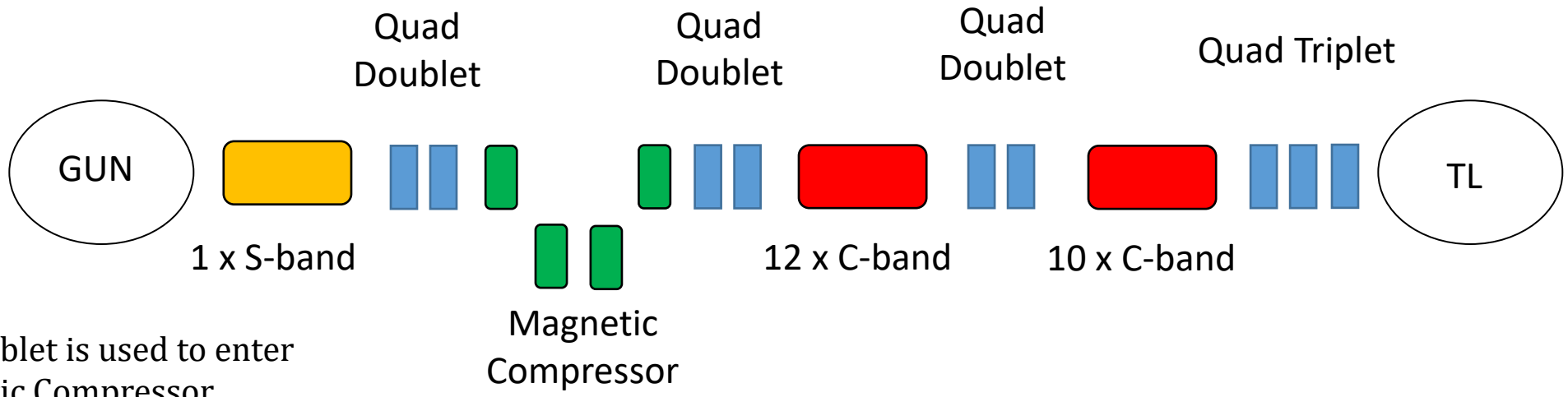
In 2022 a 4T super-conducting wiggler is planned to be installed in the storage ring.



Courtesy: P. Bulira

CONCEPT OF LINAC UPGRADE

Magnetic layout of the C-band LINAC with bunch compressor

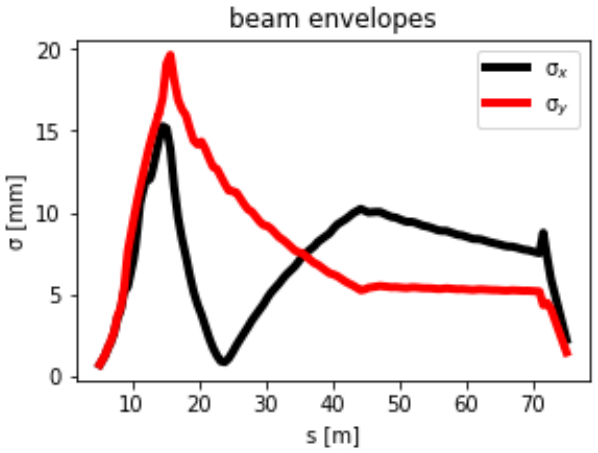


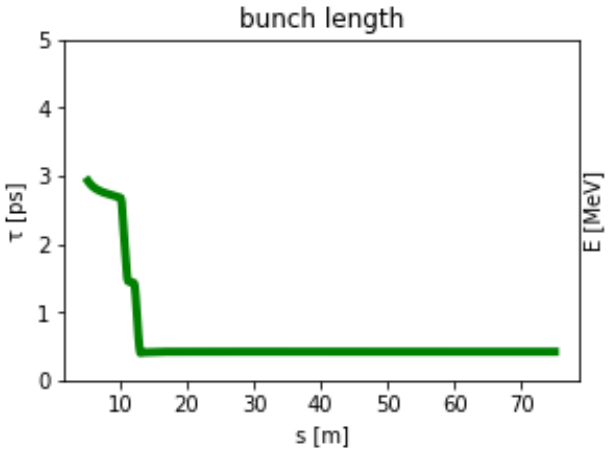
A matching doublet is used to enter into the Magnetic Compressor

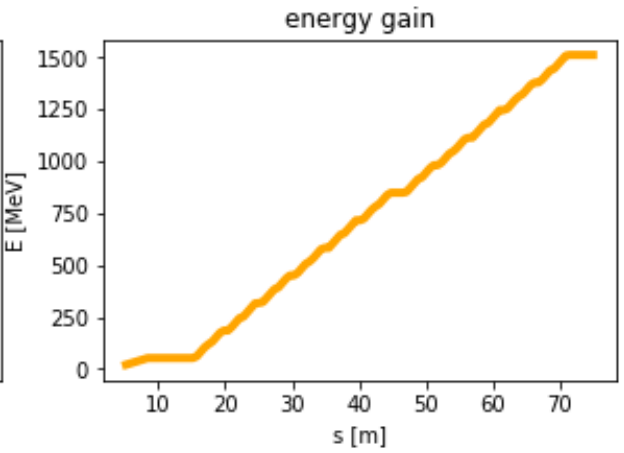
A second doublet is used to enter into the C-band LINAC

A third doublet is used for general or fine tunability of the optics

A matching triplet is used to focus the beam into the Transfer Line







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CONCLUSIONS & FUTURE PERSPECTIVES

- A very good performance of SOLARIS storage ring has been reached.
- The stability of the electron and photon beam need to be improved. The FOFB to be implemented soon.
- The facility is opened up for the users with two beamlines and high beam availability.
- Two new beamlines (PHELIX and DEMETER) are under the commissioning phase and will be available for the users within the next months.
- Four new beamlines are under construction and will be available for users in 2-3 years .
- The 4T superconducting wiggler is planned to be installed in 2023 as a source for hard X-ray beamline.
- Conceptual design on full energy linac is ongoing.
- SOLARIS is a visible partner on the European Arena
  Part of CERIC-ERIC consortium
  Part of LEAPS consortium
- SOLARIS is collaborating with many facilities around the word
- SOLARIS is opened to commercial research

Acknowledgments:
Authors would like to thank all SOLARIS team members for the excellent work during SOLARIS installation, commissioning and operation.


thank you
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謝謝
شكراً جزيلاً
ngiyabonga
рахмат
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спасибо
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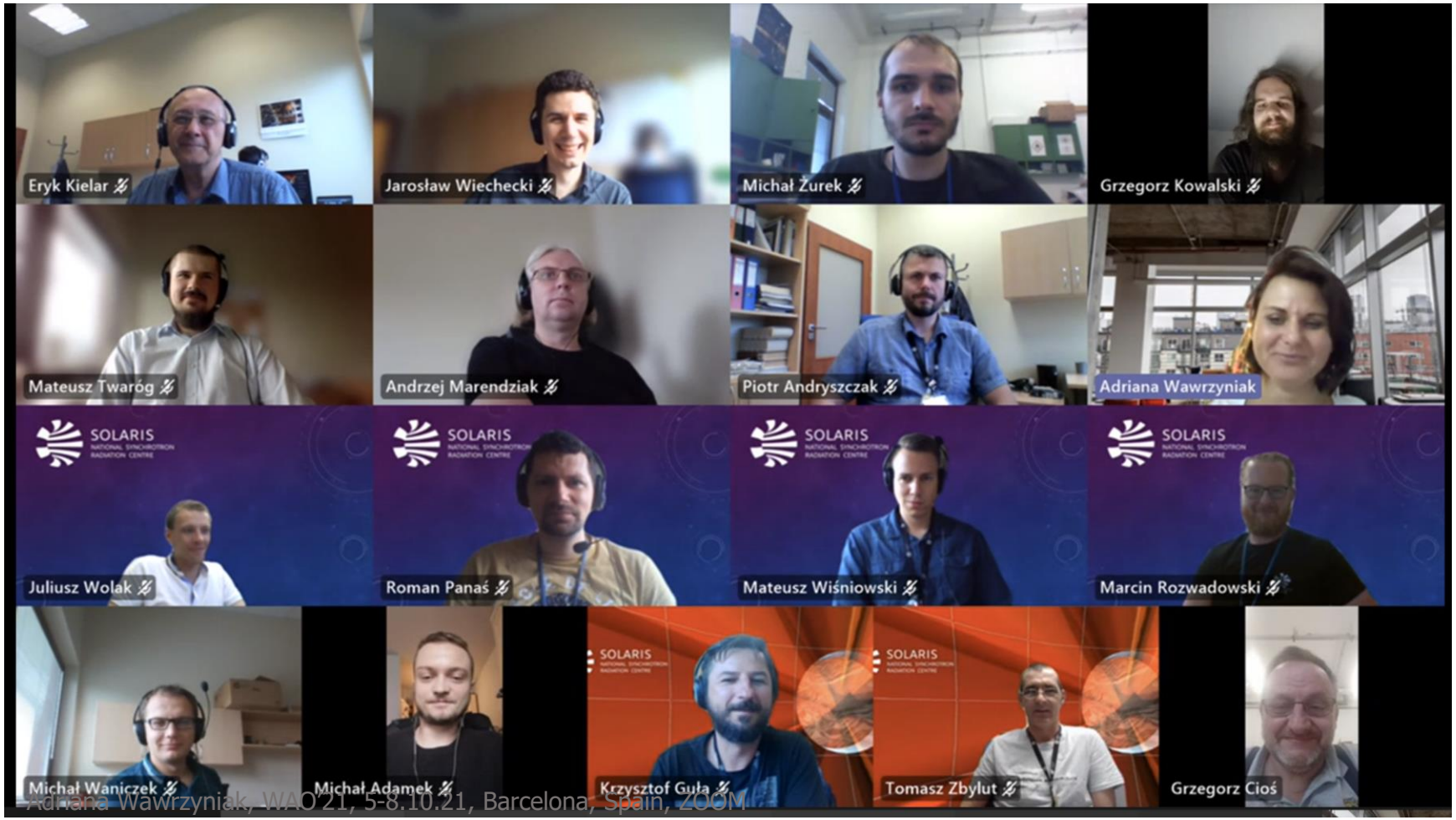
tapadh leat
obrigado
bedankt
dziękuję
go raibh maith agat
sukriya
kop khun krap
arigatô
dakujem
grazie
terima kasih
merci
mochchakkeram
hvala
mauruuru
sagolun
takk
merci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