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SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

Performance of Solaris Storage Ring

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Outline

- Solaris Layout
- Commissioning goals
- Commissioning results
- Current and Lifetime
- Beam stability
- Summary

Solaris

3rd generation light source facility built at the Jagiellonian University Campus in Krakow, Poland. The machine was constructed in 2015 thanks to the unique cooperation with MAXIV Laboratory in Lund, Sweden.

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<u>TIME SCHEDULE</u>

April 2010 – project start (Team: 7 persons)

January 2012 – start of the building construction (Team: 15 persons)

May 2014 – building handover & machine installation (Team: 30 persons)

May 2015 –End of installation and start of commissioning (Team: 40 persons)

December 2015 – End of the project

March 2016 – CERIC ERIC collaboration & operational funds for 5 years

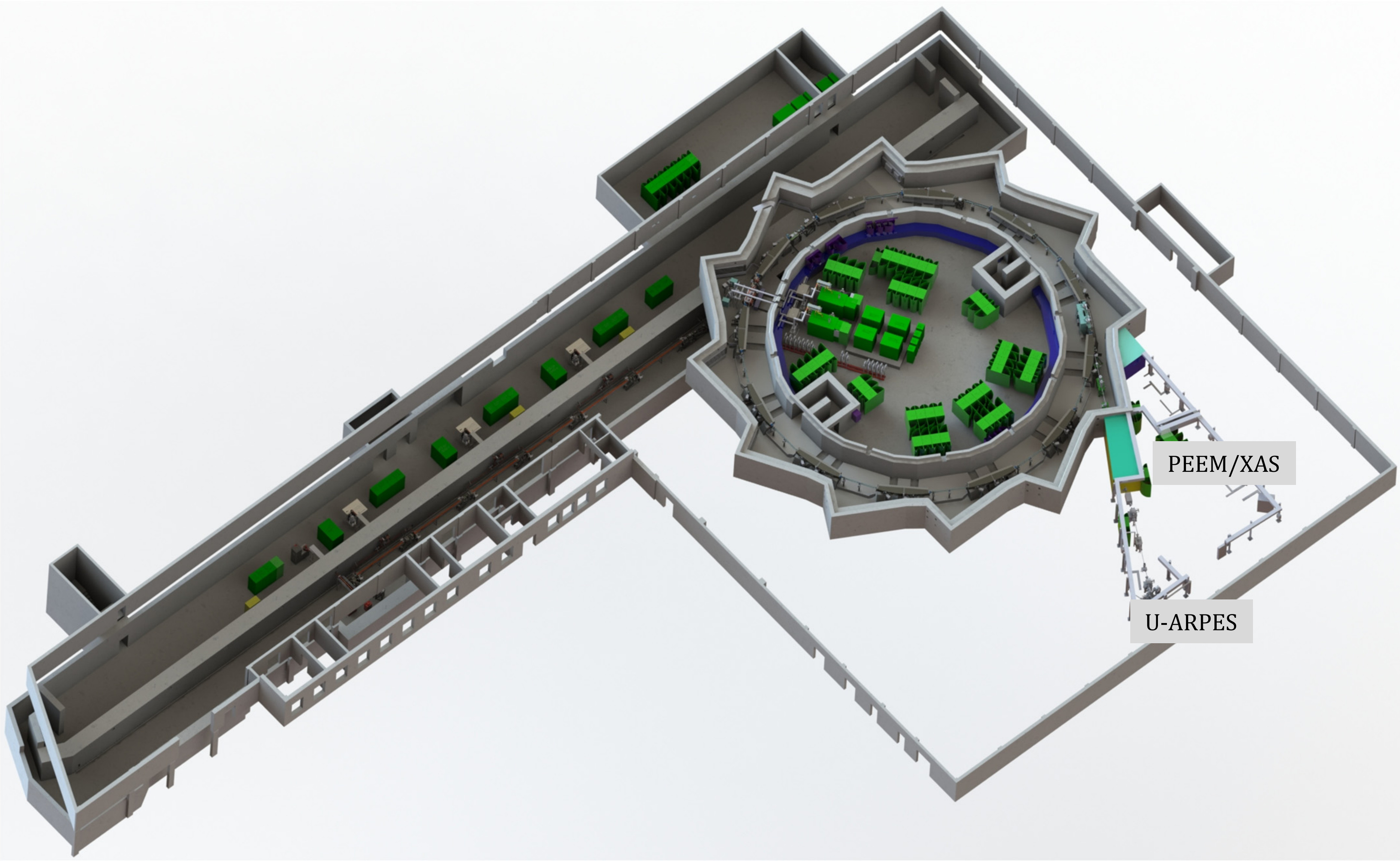
May 2016 – PHELIX beamline project approval and funded

April 2016 – start of the UARPES beamline commissioning

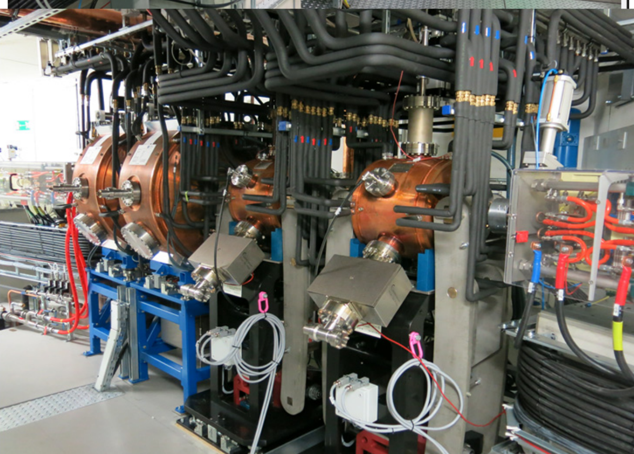
April 2017 – Start of the PEEM/XAS beamline commissioning (Team:50 persons)

Apart of the light source facility the team expertise in all areas of accelerator physics and accelerator and beamline technology has been built .

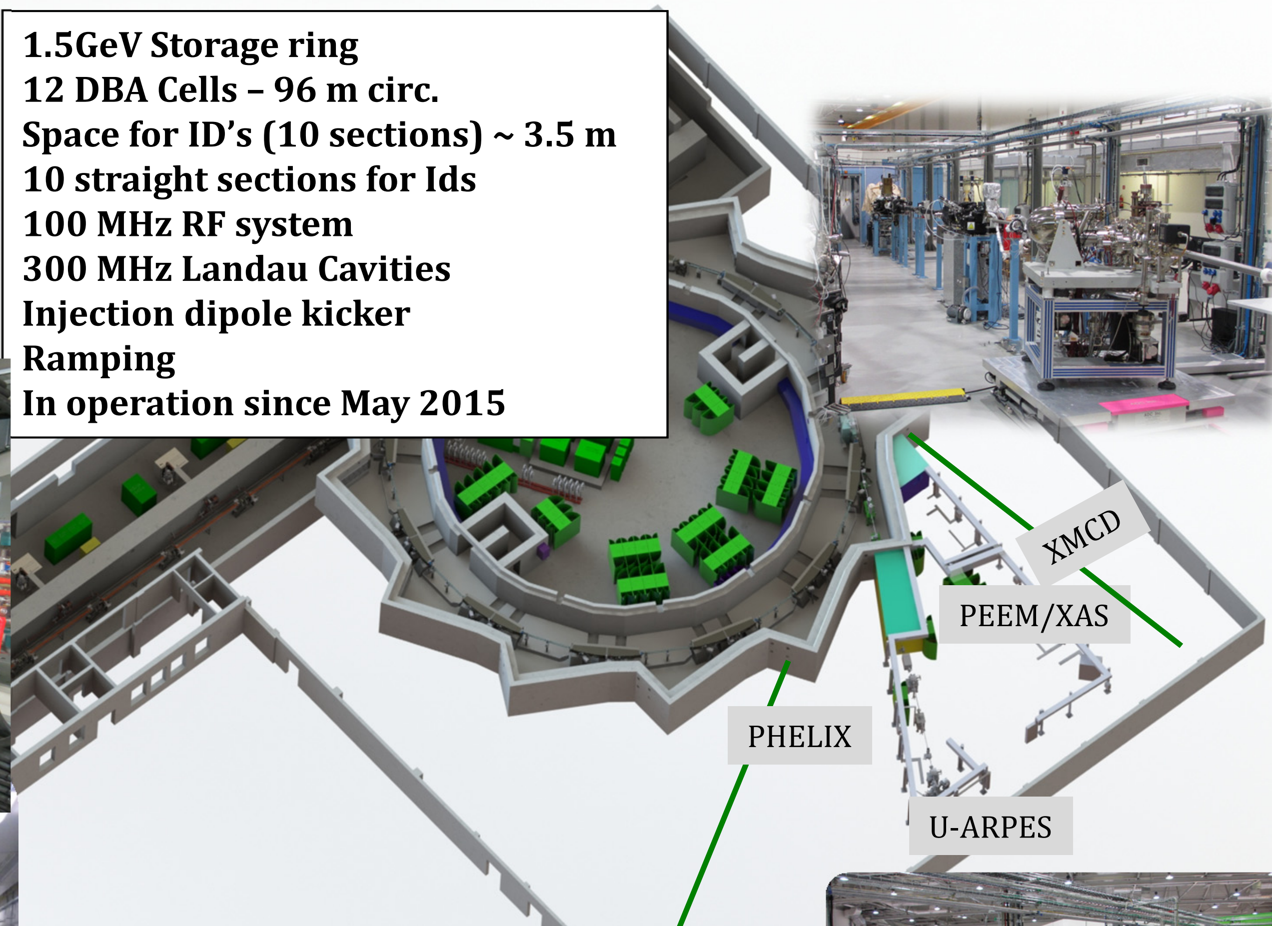
SOLARIS - layout

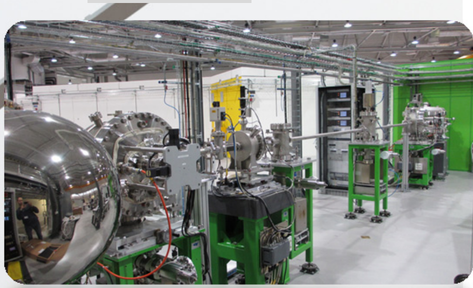


SOLARIS - layout



1.5GeV Storage ring
12 DBA Cells – 96 m circ.
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

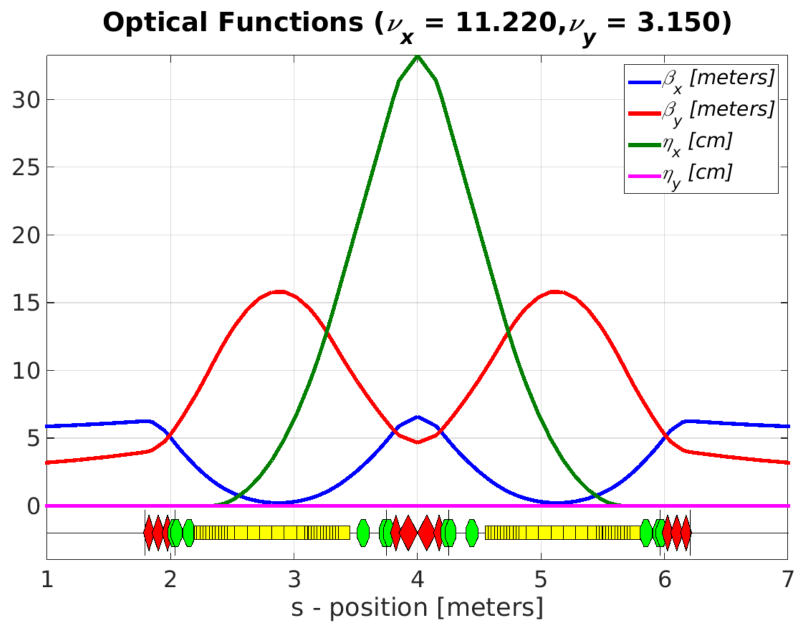




600 MeV Linac with RF Thermionic Gun
6 accelerating structures combined in 3 units
Accelerating gradient 20 MeV/m
S-band – 2998.5 MHz
3 RF Units & SLED cavities
In operation since Dec. 2014

Storage Ring

Storage Ring Lattice



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%

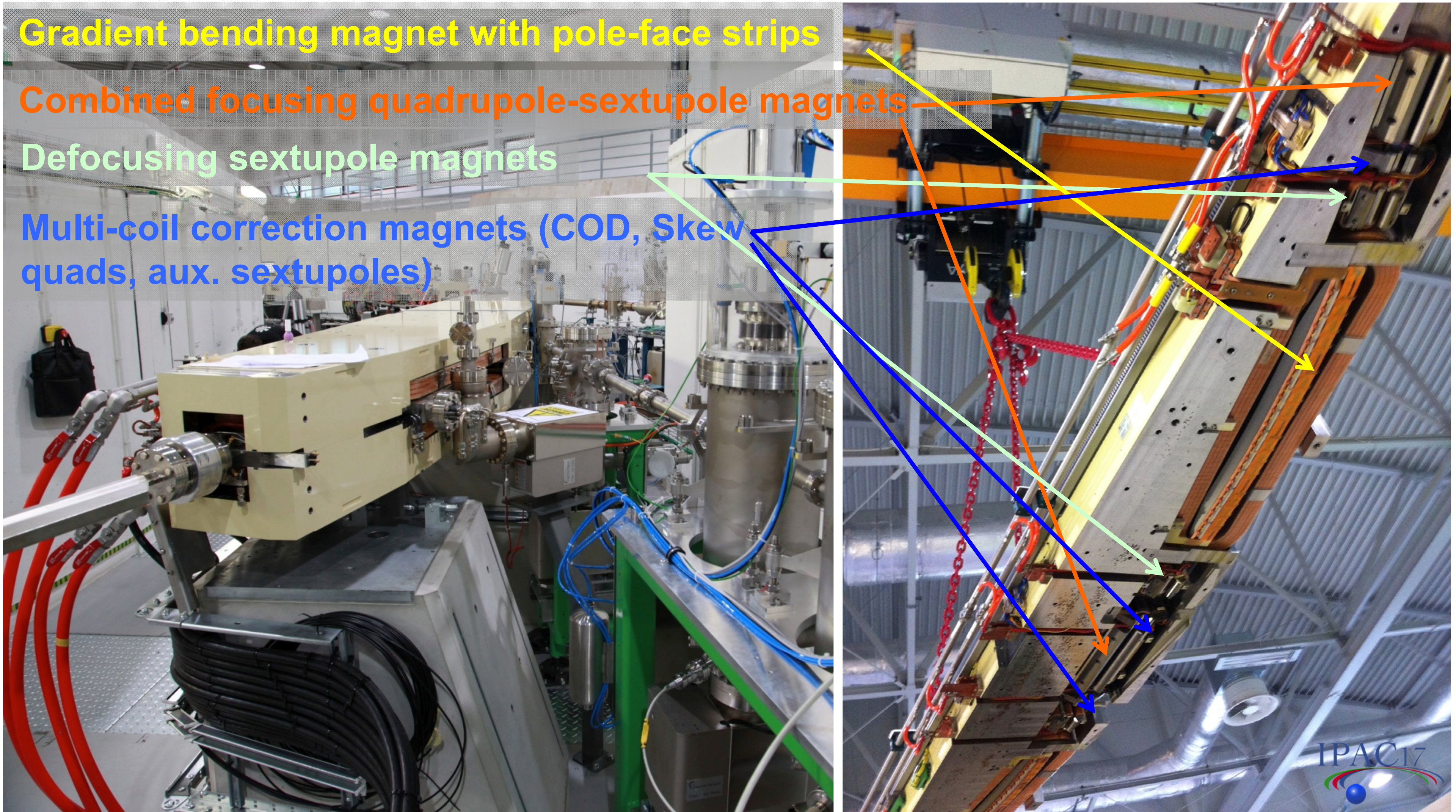
Optics design by S.C. Leemann - MAXIV

MAXIV Facility, DDR, § 3, http://www.maxlab.lu.se/maxlab/max4/DDR_public

Magnets

Storage Ring Magnets (mirror symmetric)

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



Storage Ring Commissioning

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Phase I May-July 2015

The goal: to obtain stored beam.

Transfer line commissioning

Injection

First turn

Accumulation

Stored beam

Orbit correction

!

Phase II September- November 2015

The goal: to reach the design parameters of the bare lattice.

Linear optics correction

Vacuum conditioning

Ramping to 1.5GeV

Orbit correction & BPM calibration

Increasing the current

No IDs in operation

Phase III March-December 2016

The goal: to reach the usable beam current for experiments.

Lattice optimisation with undulator in place

Beam based alignment

Injection efficiency optimisation

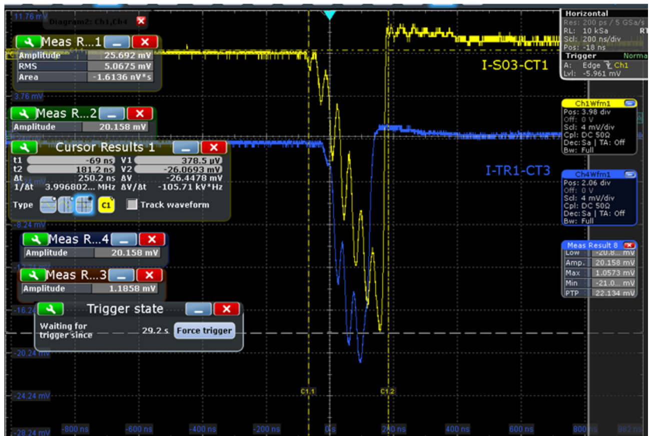
Lifetime improvements

Landau cavities tuning

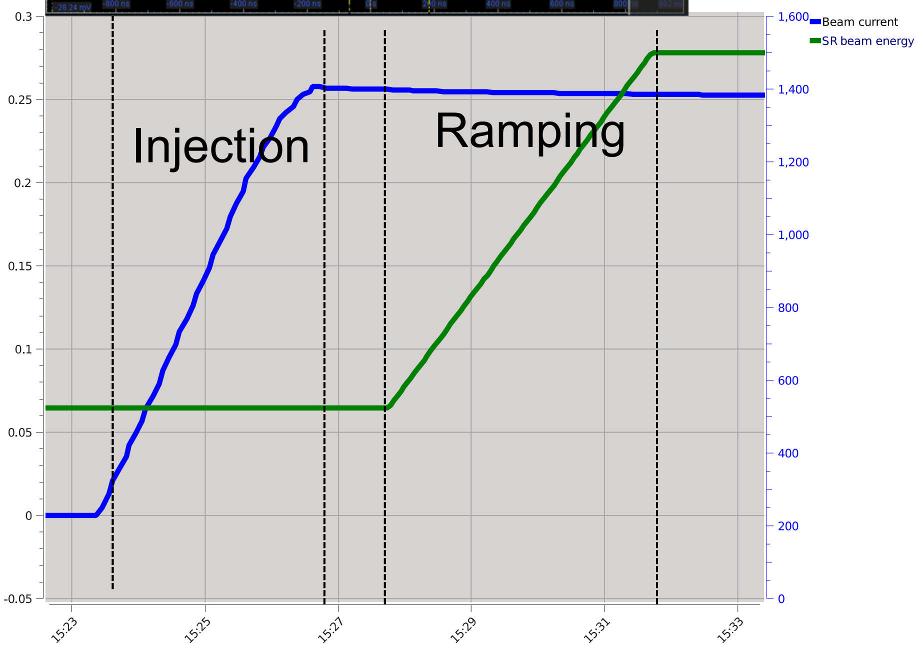
Beamlines commissioning

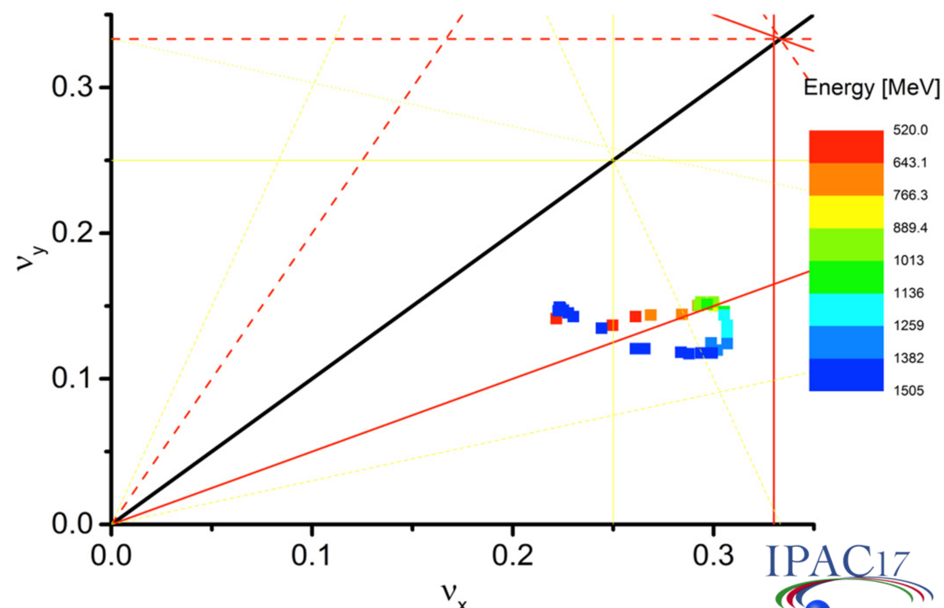
INJECTION & RAMPING

Injection at the energy of 525 MeV with the repetition rate of 1 Hz. The injection of 200 mA can be done in 140 s and ramping - in 238s. Injection efficiency – 30%.



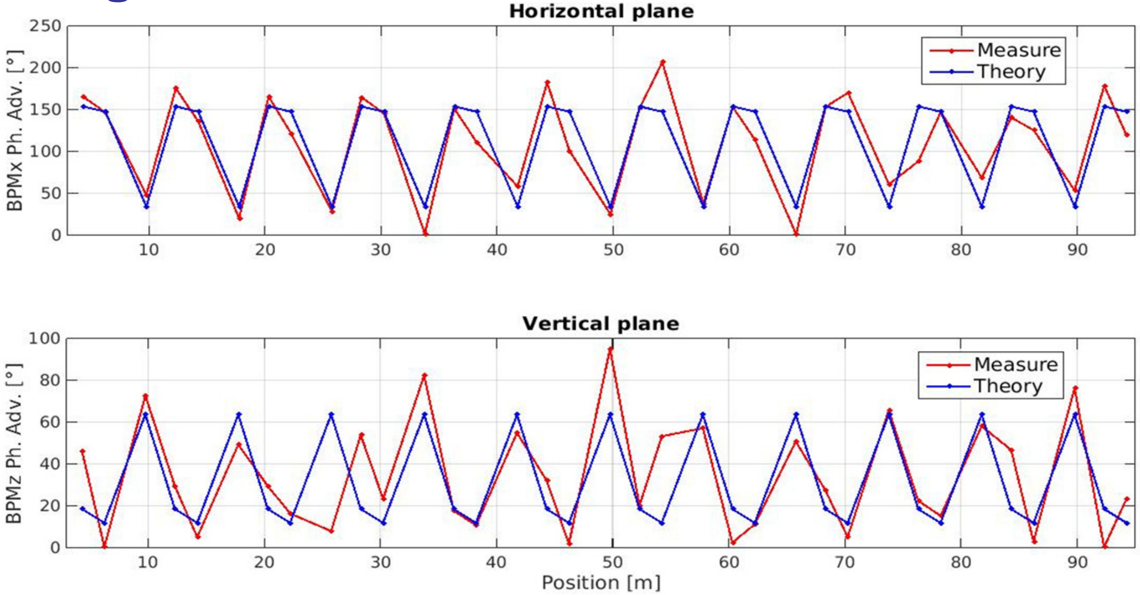
Bunch train length ~180 ns in the transfer line.



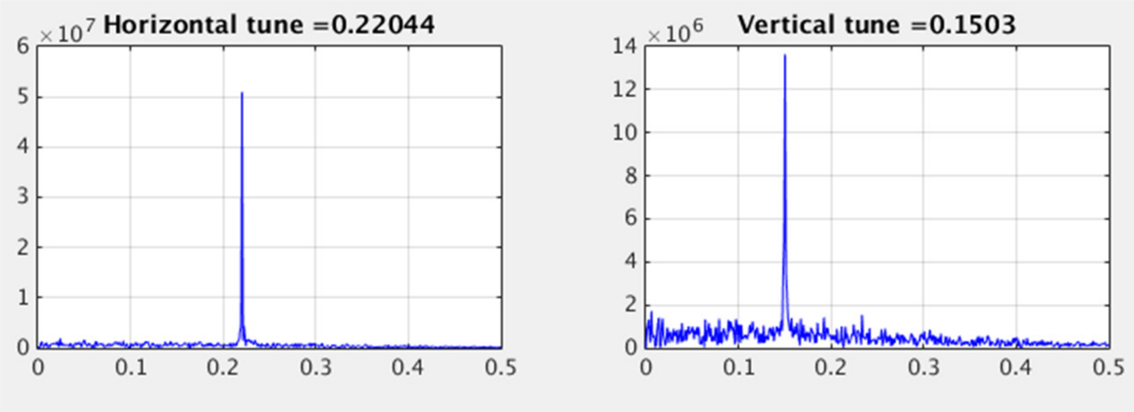


PHASE ADVANCE & TUNE

Phase advance and tune measurements done by exciting the beam with the kicker and register the TbT data on BPMs.



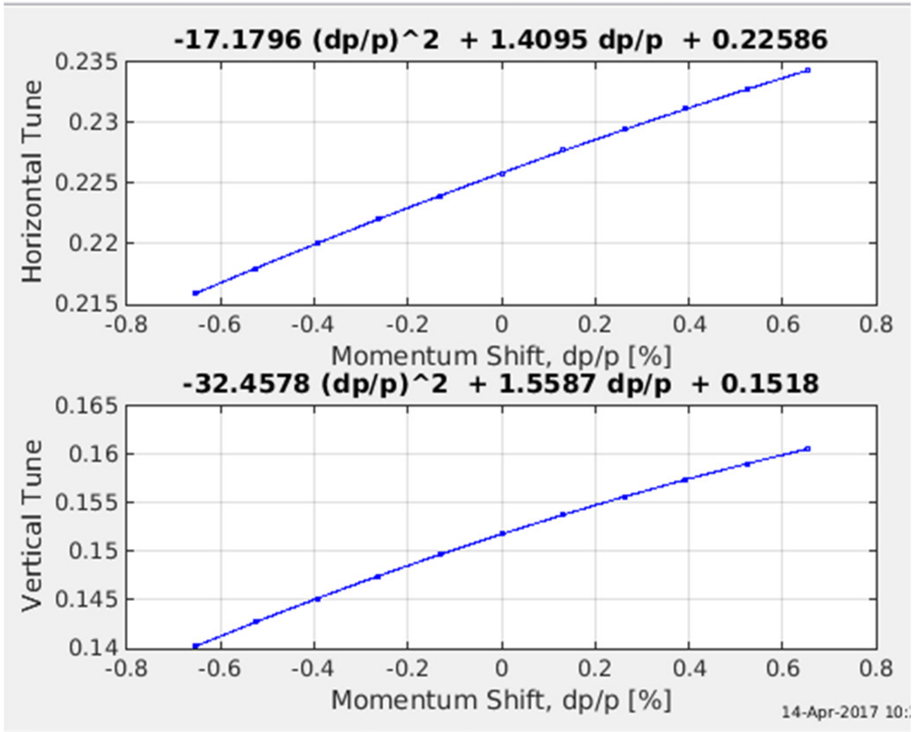
The average phase advance is 114 deg in the horizontal and 30 deg in the vertical plane

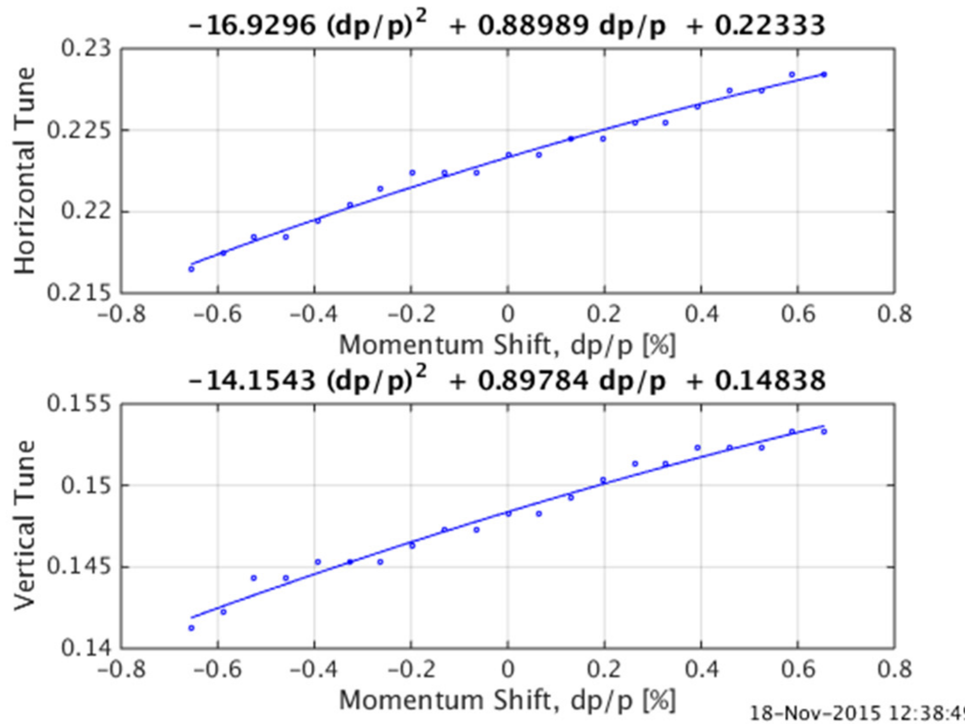


Tune corrected to the design values 11.22, 3.15

CHROMATICITIES

Chromaticity measurements for two optics





Chromaticity	Nominal 331/333	Measured
ξ_x	+2/+1	+1.41/+0.89
ξ_y	+2/+1	+1.56/+0.90

CLOSED ORBIT

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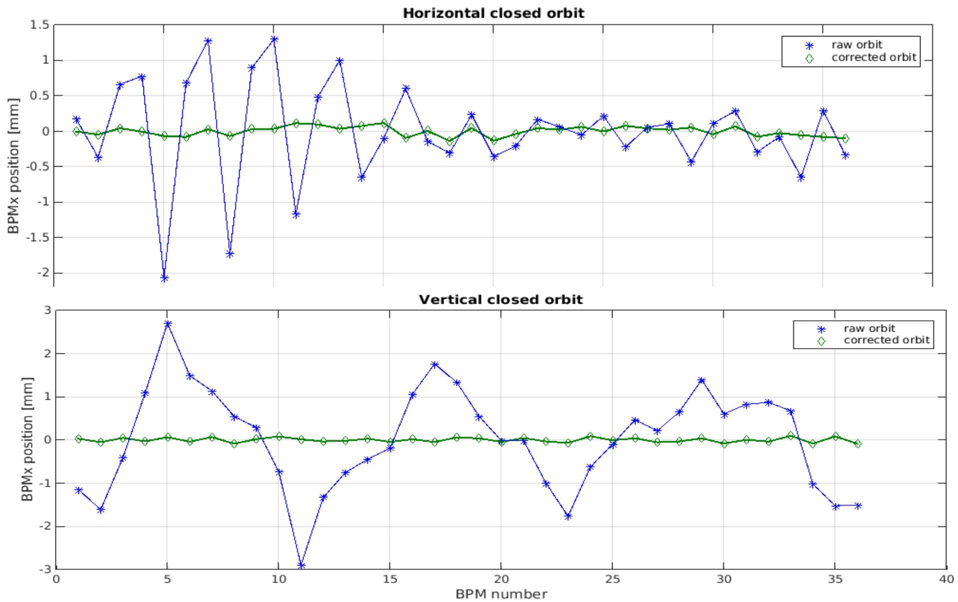
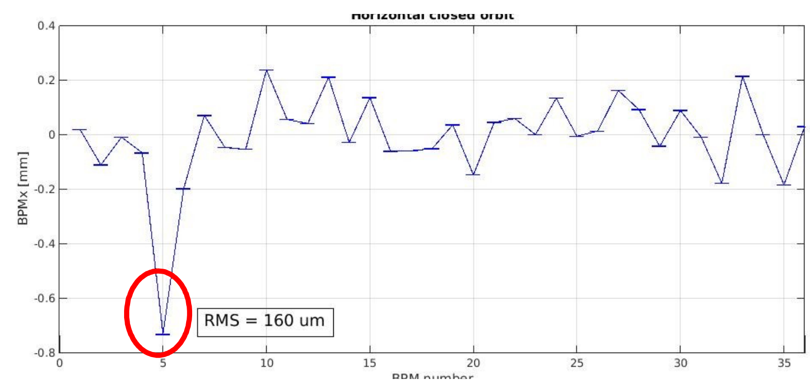
For orbit correction **36 button beam position monitors** (BPMs) with Libera Brilliance+ electronics, **36 horizontal and 36 vertical correctors** are used. **The maximum kick angle** of correctors is **0.25 mrad (10 A)**. To correct the orbit the measured response matrix and **SVD** algorithm implemented in **MML** is used.





After BBA BPM offsets <0.6 mm
Some of correctors are close to the saturation

Closed Orbit	Without Correction	With correction	After BBA
x_{rms}	701 µm	200 µm	160 (66.51) µm
y_{rms}	1090 µm	170 µm	55.42 µm

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BETA FUNCTIONS

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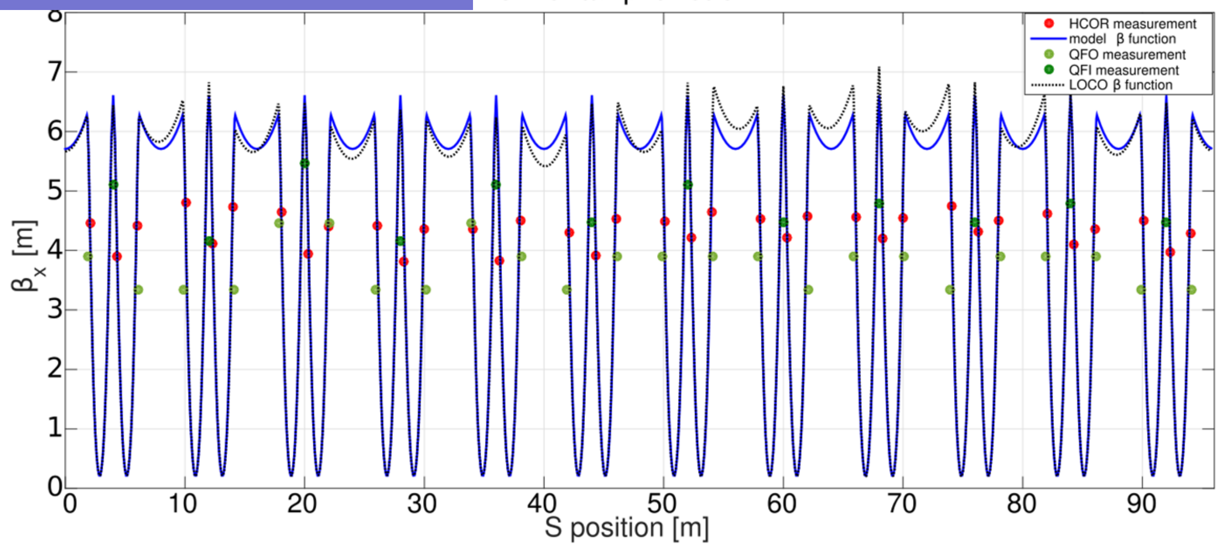
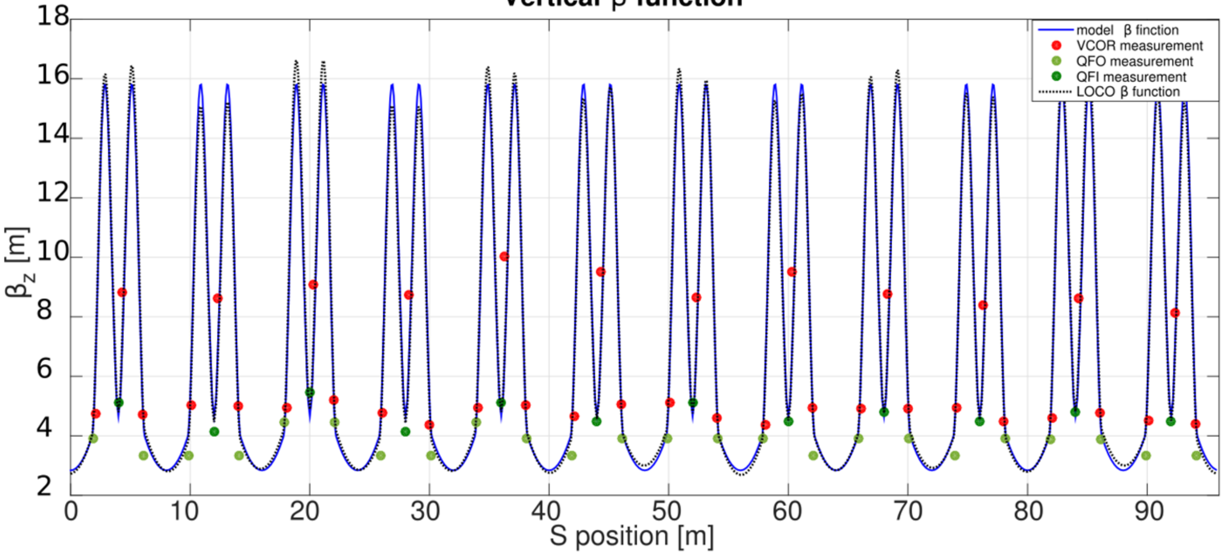
A. Kisiel, MOPIK090

Horizontal β function



Vertical β function



Quadrupole scan

$$\beta_{x,y} = \pm 4\pi \frac{\Delta Q_{x,y}}{\Delta k}.$$

ORM method

$$\beta_{x,y} = 2 \cdot \tan\left(\pi Q_{x,y}\right) \cdot \frac{\Delta x_{CM}}{\Delta \theta}$$

LOCO

$$\chi^2 = \sum_{i,j} \frac{\left(R_{i,j}^{meas} - R_{i,j}^{model}(\Delta k)\right)^2}{\sigma_i^2}$$

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

The LOCO studies has revealed that the quad strength errors are up to 0.8 % for DBA2. The shunting of the magnets is planned.

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DISPERSION

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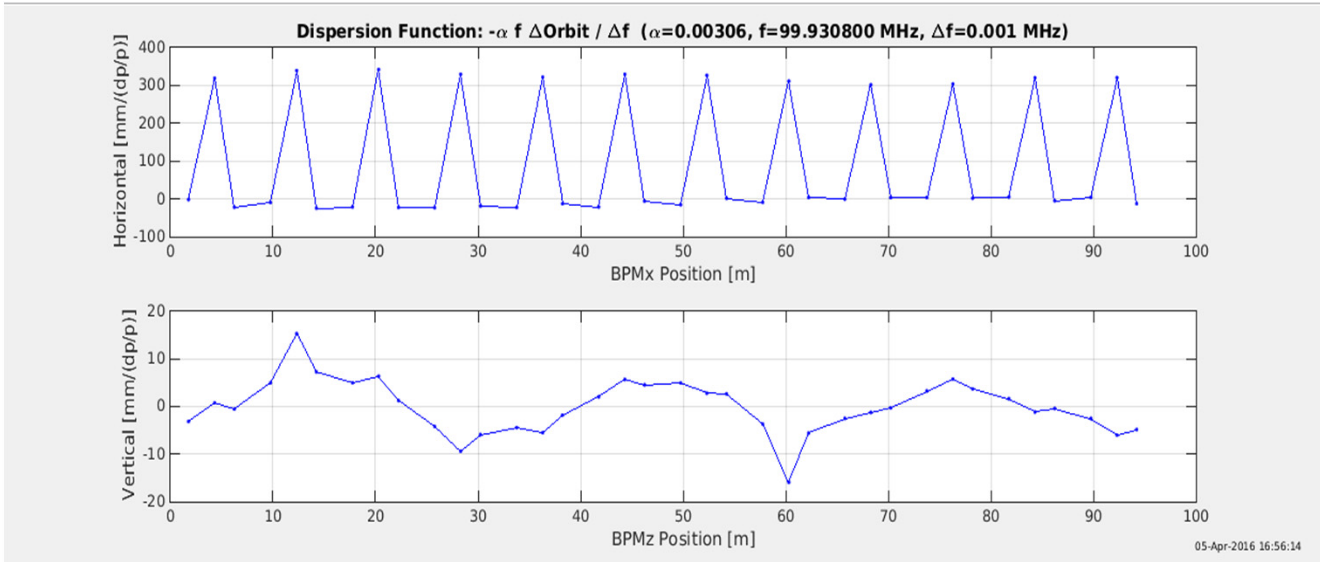
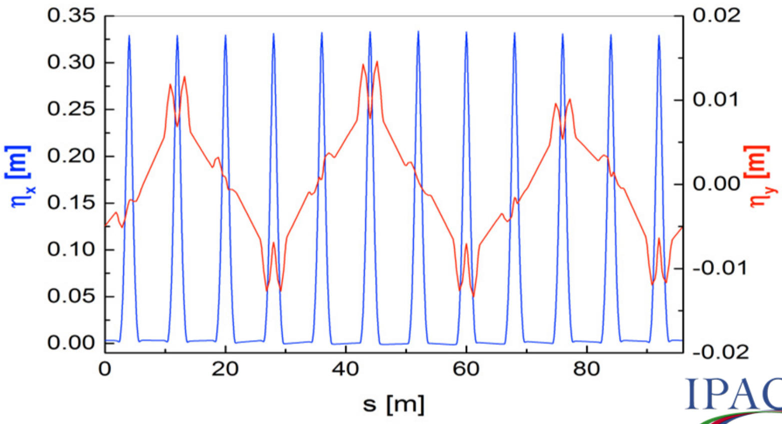
The dispersion measurement has been done by changing the RF frequency and recording the closed orbit.



The horizontal dispersion is close to the nominal. The vertical dispersion originates from the (roll angle) misalignment of quadrupole and sextupole magnets.



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SYNCHROTRON TUNE

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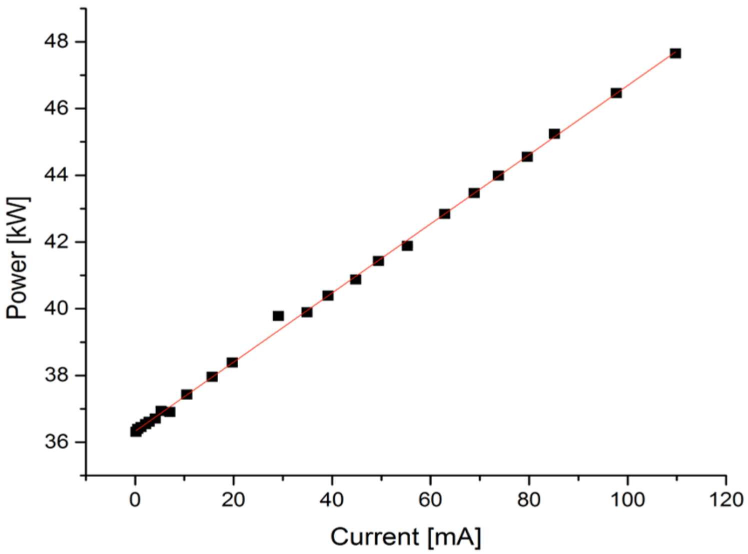
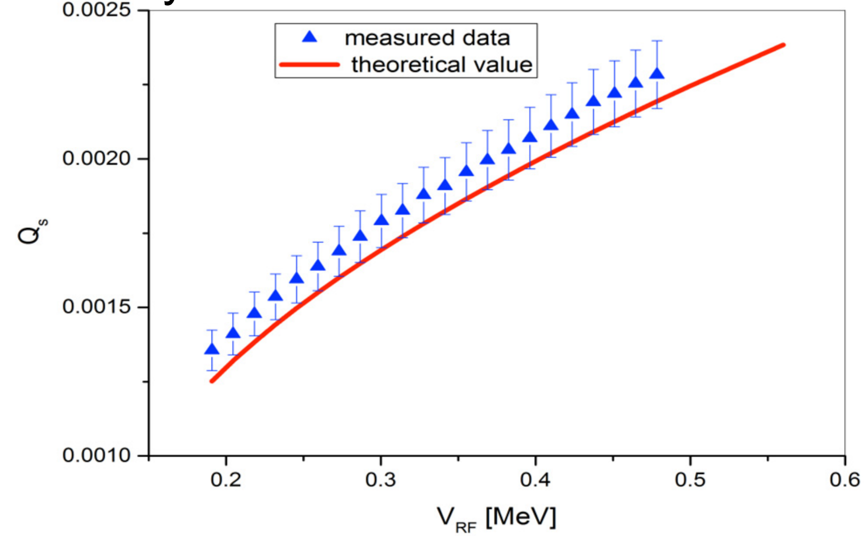


Synchrotron tune vs. total RF voltage.

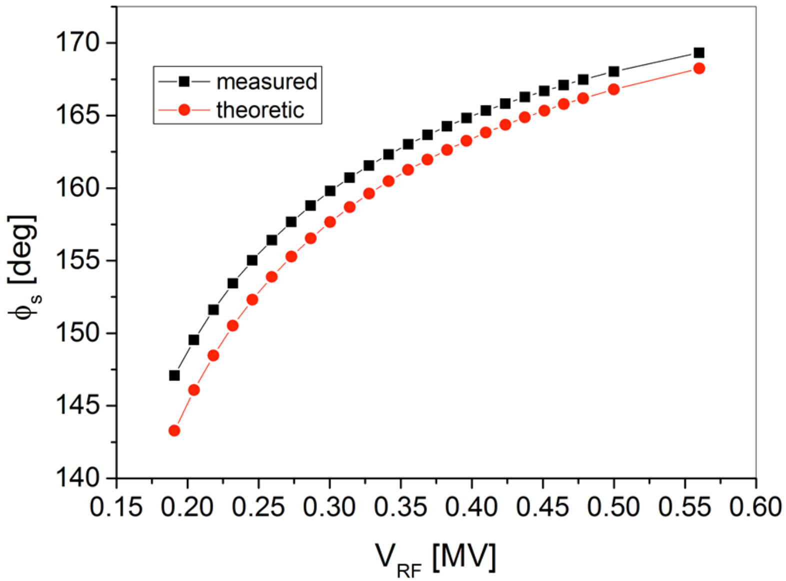


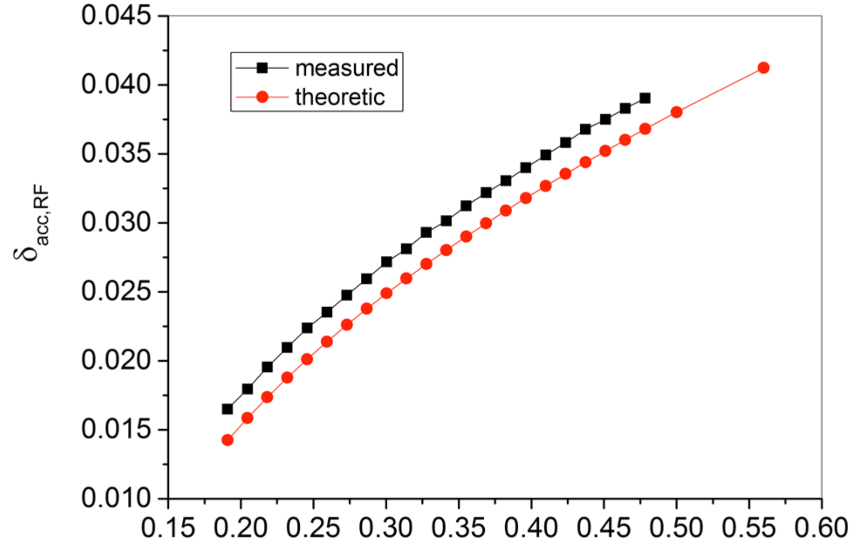
$$P_{forw} - P_{refl} = P_{cav} + \frac{IU_0}{e}$$

$$Q_s^2 = \frac{\alpha_c h}{2\pi E}\sqrt{e^2 V_{RF}^2 - U_0^2}$$

	Designed	Measured
U_o [keV/turn]	114.1	103.7 (12.3)
E [GeV]	1.5	1.45 ()
P_{cav} [kW]	49	39 (1)
Φ_s [deg]	168	167.4

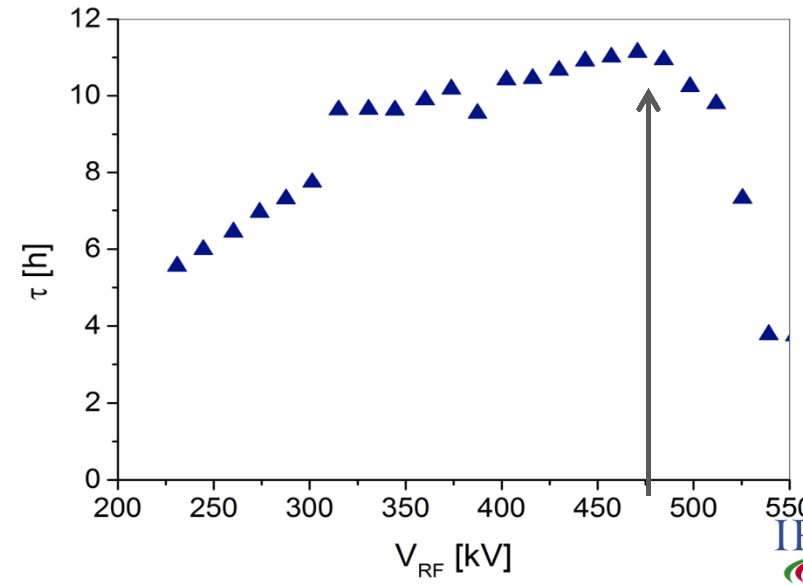
RF ACCEPTANCE





$$\delta_{acc,RF} \approx \frac{2Q_s}{h\alpha_c}\sqrt{1 + (\phi_s - \frac{\pi}{2})\tan(\phi_s)}$$

RF acceptance 3.7% ± 0.3%
V_{RF}=480kV



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VACUUM CONDITION

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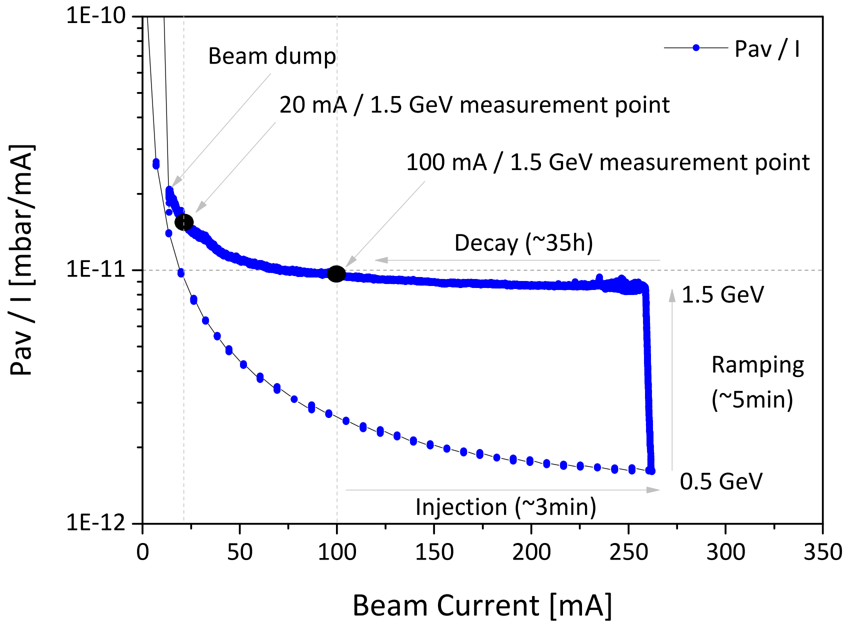
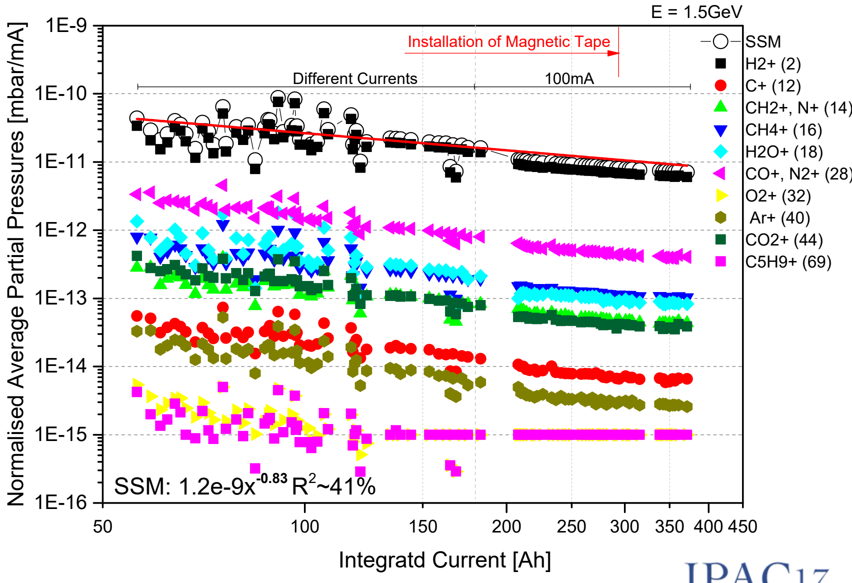
Normalized average pressure vs. beam current



The average pressure in the storage ring with 250 mA of a stored current at 1.5 GeV is $2.2 \cdot 10^{-9}$ mbar.

A. Marendziak, WEPAB068



Analysis of normalized average partial pressures over integrated current for section R1-01.

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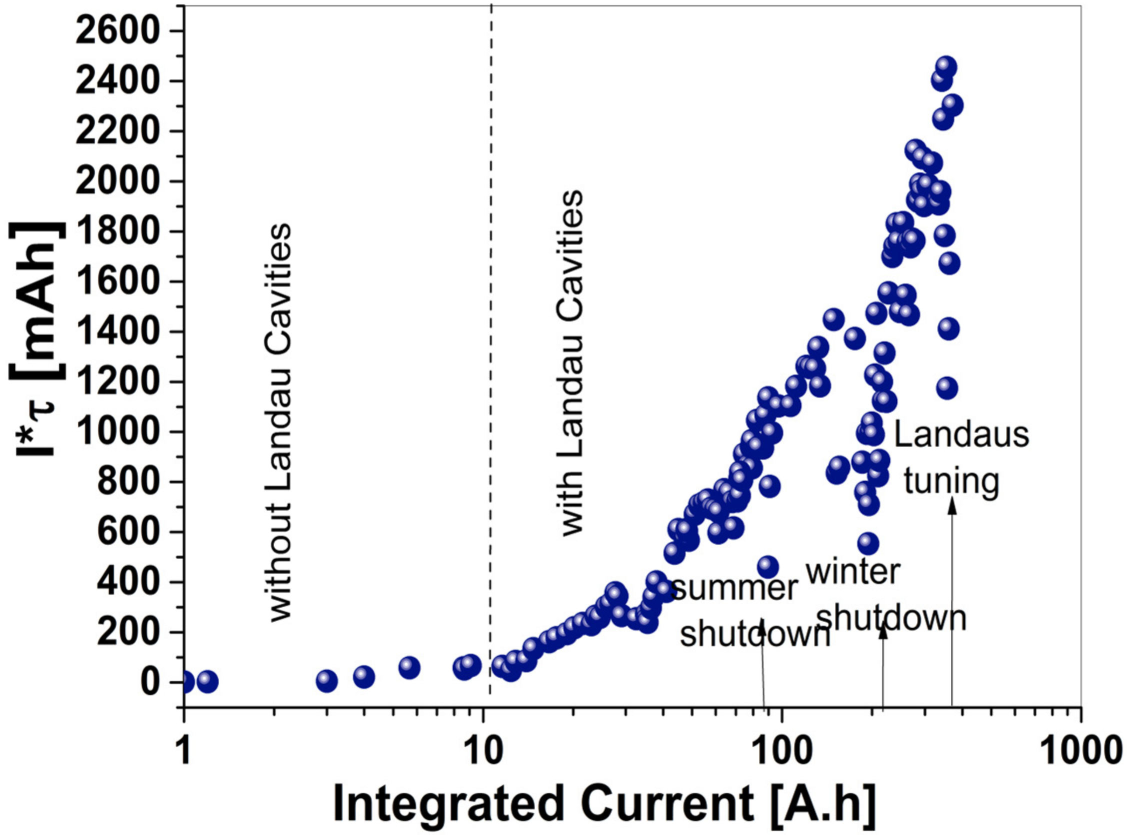
CURRENT

The bam lifetime is still increasing with the accumulated beam dose.



Maximum injected current over 600 mA.
Maximum current at full energy over 400 mA.

CURRENT

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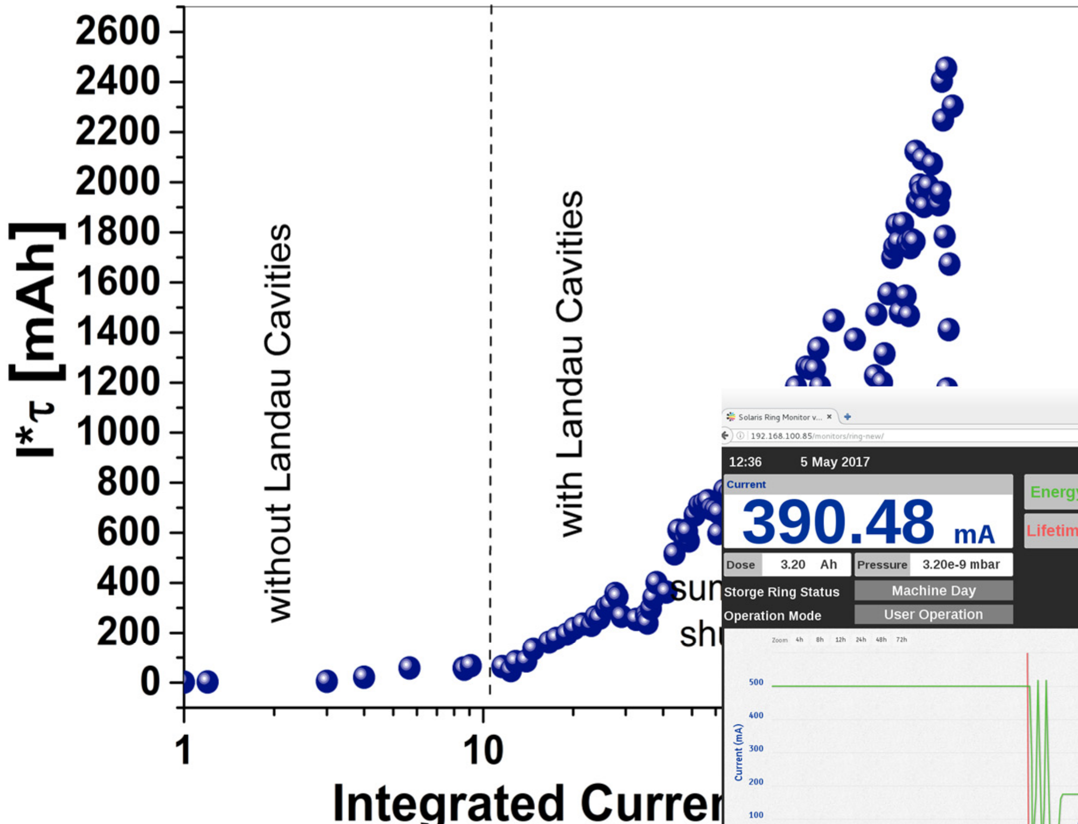

Maximum injected current over 600 mA.
Maximum current at full energy over 400 mA.

LIFETIME

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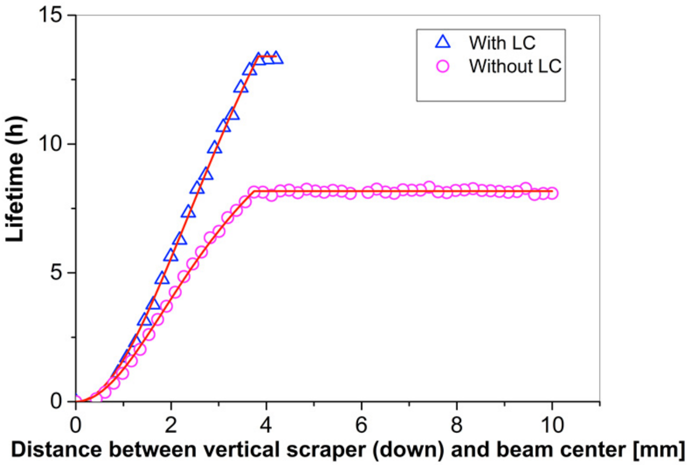
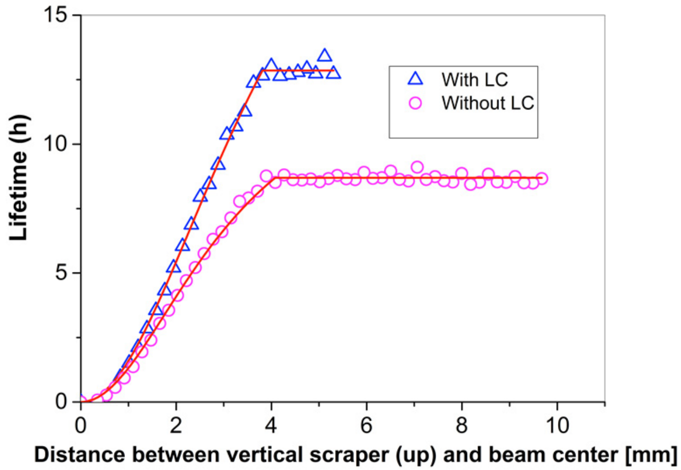
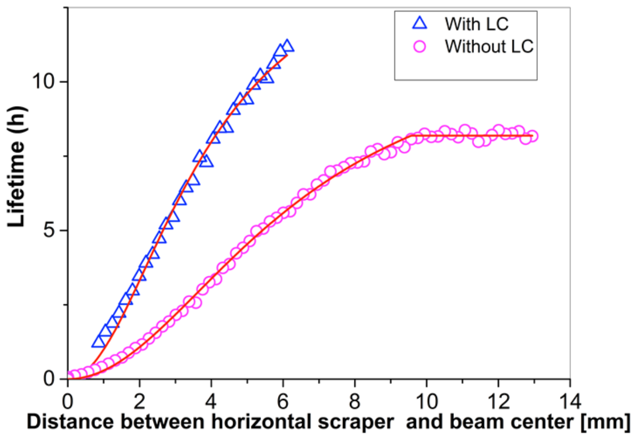
Lifetime measurements @ 1.5 GeV, I=200 mA







	without LC	with LC
Elastic scattering $\tau_{elastic}$	22.24	23.66 h
Inelastic scattering $\tau_{inelastic}$	37.45 h	43.57 h
Touschek lifetime $\tau_{Touschek}$	21. 13 h	68.81 h
Total lifetime τ_{tot}	8.41 h	12.54 h

Physical acceptance:
$A_x(\delta)$= 15.68 mm·mrad
$A_y(\delta)$= 3.77 mm·mrad

M. Jaglarz, WEPAB067

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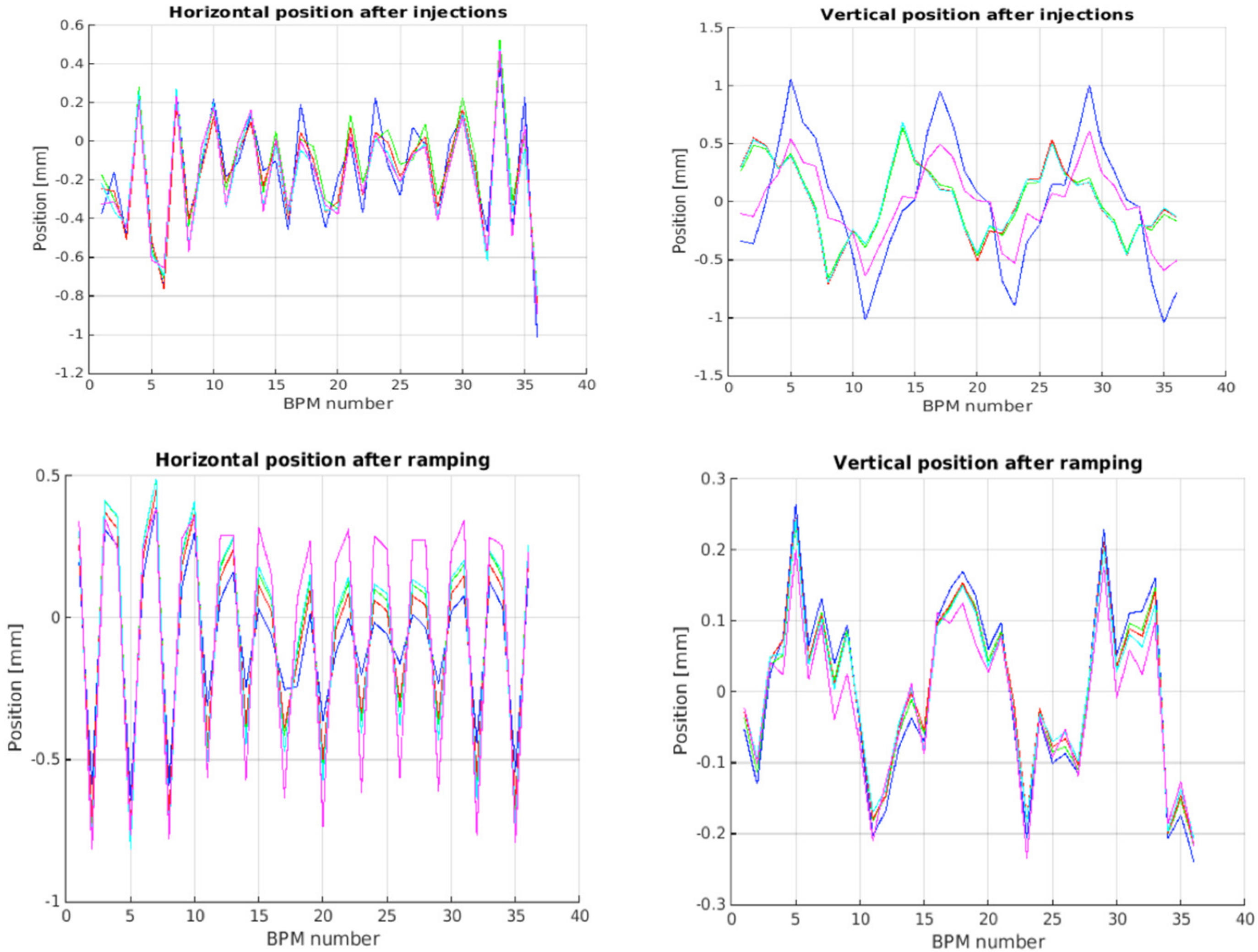
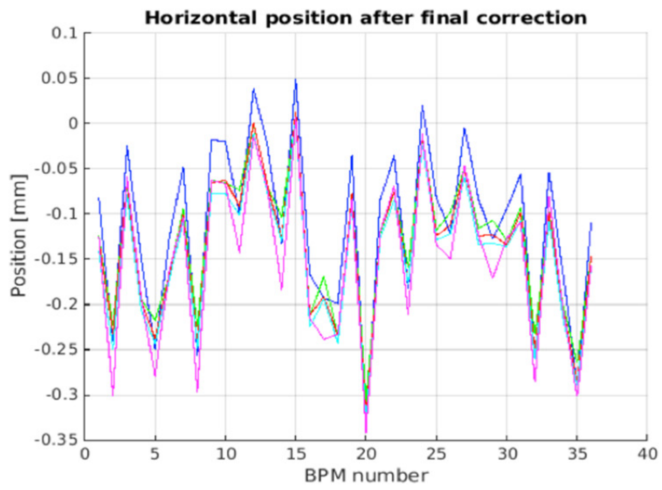
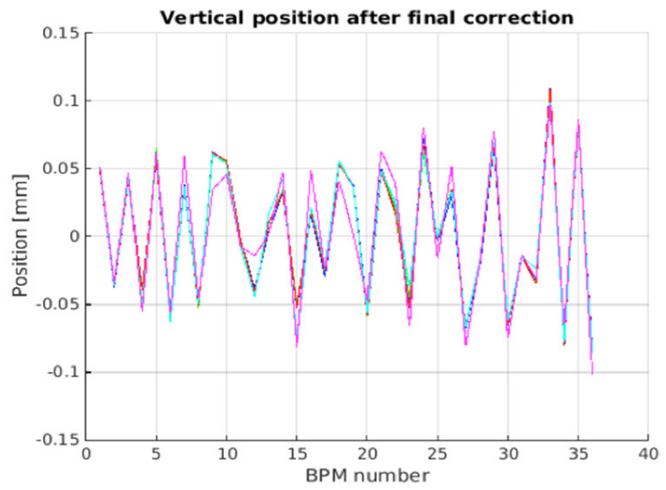
REPRODUCIBILTY

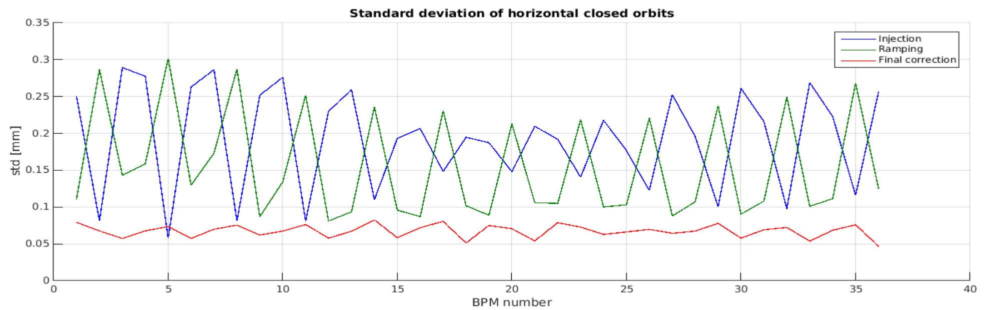
Closed orbit changes from injection to injection

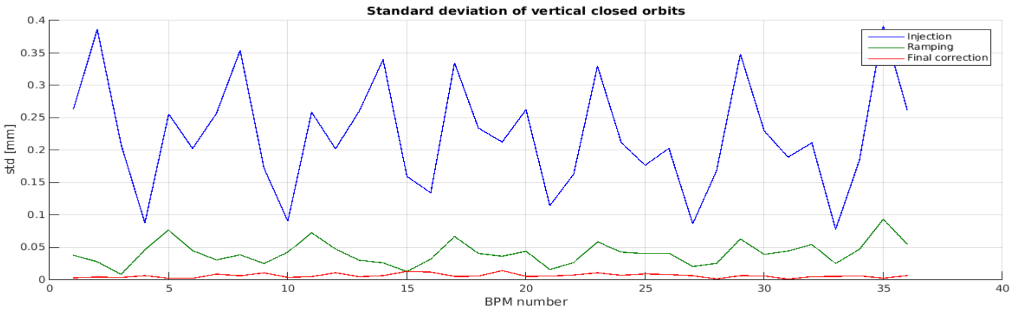


REPRODUCIBILTY









In the horizontal plane the standard deviations calculated from injection and ramping dataset are comparable reaching 200 μm and the deviation of final-corrected orbit is significantly lower (~30 μm).

In the vertical plane,for the injection orbits the deviation is up to 300 μm, after-ramping dataset - up to 100 μm and below 10 μm in corrected orbits at final energy.

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BEAM STABILITY

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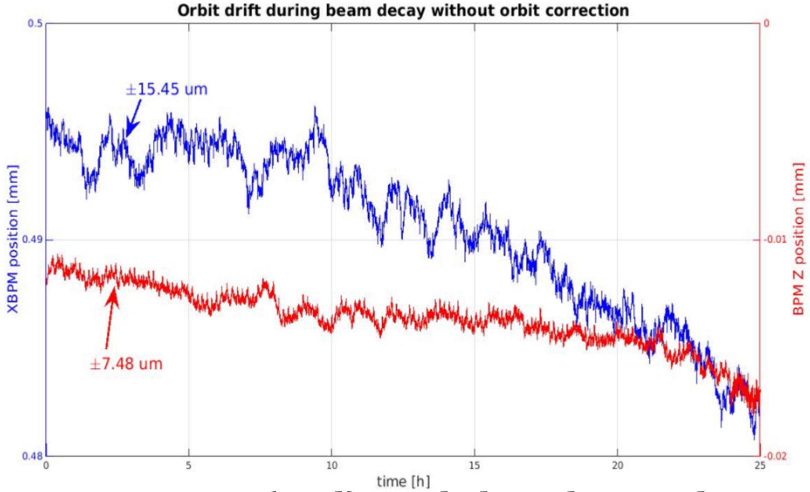
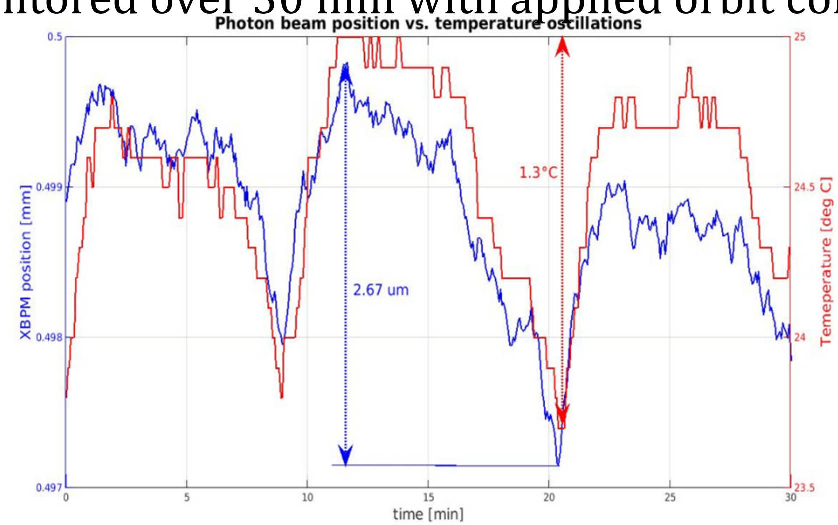
The vertical position drift of electron (red) and photon (blue) beam monitored over 25h without orbit correction.



Temperature oscillations in the range of 1.5°C in the storage ring have impact on beam stabilty.

The temperature (red) and the photon beam oscillations monitored over 30 min with applied orbit correction.



P. Czernecki, WEPVA082

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SUMMARY

- A good performance of the Solaris light source has been achieved.
- **Injection** to the storage ring occurs at **525 MeV** and the **beam is ramped** to the operating energy of **1.5 GeV without losses**.
- The **injection efficiency** has been improved reaching now **30%** and is still under optimisation. The chopper is tested and planned for installation during summer.
- **The optics** was corrected **close to the design** one. However some adjustments are still needed.
- The beta functions were measured with 3 different methods, revealing a **beta beating** in both planes in the order of **several %**. The optics correction with the local shunting is under way, these should also improve the closed orbit and relax the correctors strength.
- Studies of **synchrotron tune** have shown that Solaris storage ring is operating at c.a. **3.3% lower energy** than expected.
- The **maximum current** ramped to the final energy of **1.5 GeV** is above **400 mA** with the total **lifetime of 8 h**.
- **Tuning of the Landau** cavities **improved** the **Touschek lifetime** by factor of 3 and cured some instabilities.
- The **closed orbit** can be **restored** from injection to injection with **tens of microns** range with the orbit correction applied.
- **Temperature oscillations** in the range of 1.5°C in the storage ring have **impac**t on **beam stability**. Major changes in the cooling water system are planned in the near future to improve the thermal stability at Solaris.

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NEAR FUTURE

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- Commissioning of the UARPES Beamline by 2018
- Commissioning of the PEEM/XAS Beamline by 2018
- Installation & commissioning of the PHELIX beamline by 2020
- Installation & commissioning of the XMCD beamline (former MAXII I1011)
- USER OPERATION from the beginning of 2018
- Installation of diagnostic beamline for emittance measurements

Acknowledgments

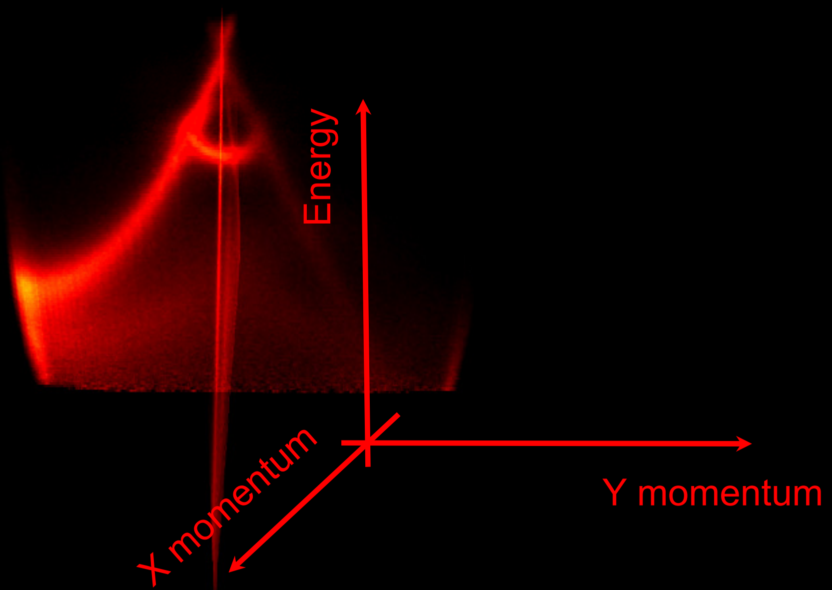
MAX IV TEAM

Elettra, Sincrotrone Trieste
Machine Advisory Committee
A. Wrulich, PSI, Switzerland
R.Walker, J. Kay, Diamond, UK
A. Nadji, SOLEIL, France
Dieter Einfeld, ESRF, France
G. Rehm, Diamond, UK
F. Perez, ALBA, Spain
SOLARIS Team

UARPES first results

First angle-resolved experiment at the UARPES beamline…. Graphene on SiC(0001) – Dirac cone

Mean ring current: 40 mA
Photon energy 50 eV
3D mode – time 4h 30 min (full dataset)
Electron energy resolution ~20 meV
Room temperature



Piotr Ciochon, Mariusz Garb, Karolina Szamota-Leandersson, Jacek Kolodziej

Thank you for the attention!