Solaris Commissioning

Carlo J. Bocchetta

Workshop on Testing and Commissioning (16-17 October 2018), ESS

Solaris Commissioning

- Solaris description
- History
- Context
- Some highlights from Commissioning
- Problems
- Lessons Learnt

Thanks to Adriana Wawrzyniak at Solaris for material

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Solaris Project Overview

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

SOLARIS - 3rd generation light source facility built in Krakow, Poland at the Jagiellonian University Campus.

1.5 GeV storage ring - replica of the MAX IV 1.5 GeV machine

600 MeV injector and the transfer line based on the same components but unique for Solaris.

Solaris Project Overview

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SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

SOLARIS - 3rd generation light source facility built in Krakow, Poland at the Jagiellonian University Campus.

<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)

1.5 GeV storage ring - replica of the MAX IV 1.5 GeV machine

600 MeV injector and the transfer line based on the same components but unique for Solaris.

SOLARIS - LAYOUT

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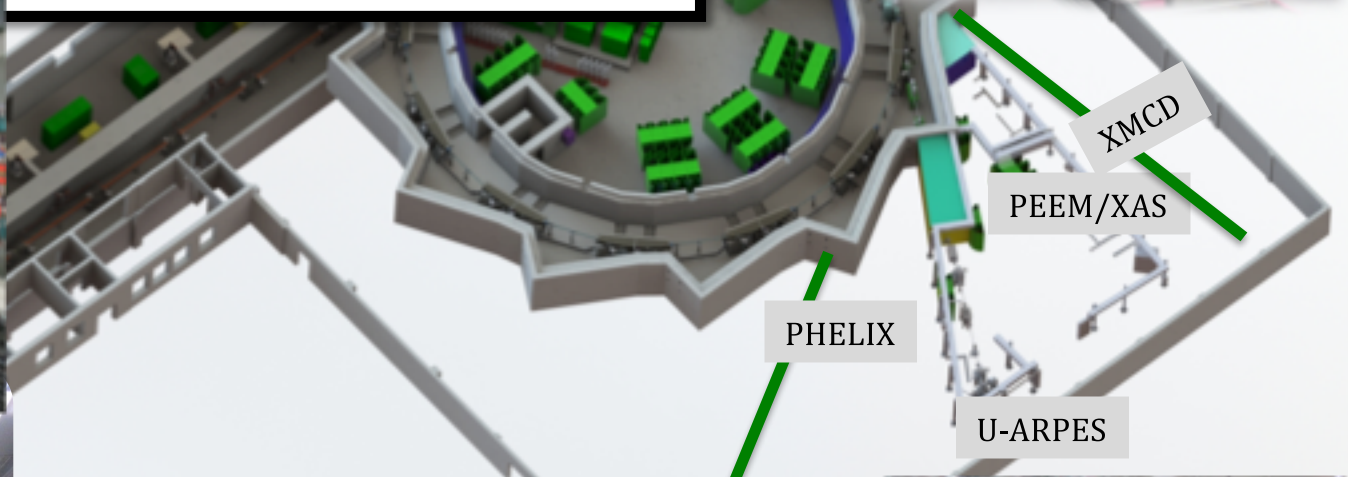
SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

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

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Solaris Project Highlights

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

- **Sharing of activities (MAX IV – Solaris) during simultaneous construction**
  - Participation in design choices.
  - Sharing and adaptation of industry calls for tender.
  - Simultaneous procurements – better prices & industrial response optimised.
  - Assistance during procurements – simultaneous technical supervision.
- **Unique replication of a complete light source**
  - Freely given design considered to be a multi-million € saving for Solaris.
  - Adaptation of original design to Poland's scientific needs (i.e., bending magnet photon ports).
  - Adaptation of design to different infra-structures – gun layout, services, …
- **Sharing of people and resources**
  - Training of Solaris personnel at MAX-lab/MAX IV.
  - Support for Solaris personnel in Lund (offices, administration,..).
  - Involvement of Solaris Personnel in on-going design of the accelerators and systems.
  - Assistance from MAX IV personnel both in Lund and Krakow.
  - Participation of Solaris personnel in Lund for MAX IV and MAX-lab activities.

Similarities to In-Kind @ ESS

Solaris Project Highlights

- **Effective and efficient use of developments – no reinvention, keeping to scope**
  - Original goals maintained over the project duration – no straying from original scope!
  - Keeping to original scope proved to be highly effective in solving the common issues that emerged and permitted concurrent project master plans to be effectively aligned.
  - Proved to be cost effective both for initial procurement and addressing changes to manufactturing processes and fixing emergent errors.
- **Optimisation of resources – financial and human**
  - Small budget was spent in a cost effective manner (common procurements, sharing of resources).
  - Entire successful project was within budget (actually given more to do more)
- **Growth of a national team of experts in accelerator technology and physics**
  - Team particularly fresh to accelerator systems – adapted exceedingly well to the dynamic challenges .
  - New team of accelerator experts now exists in Poland.

- **Effective and efficient use of industry and international laboratories**
  - Solaris out-sourced as much as it could.
  - Effective use of local industry in construction and support.
  - Participation of national research centres for installation – knowledge gained is now used for other international projects.
  - Complete out-sourcing and in-house management of accelerator installations including procurements for: all cabling, piping, PLC's, logistics, ….
  - Out-sourcing of controls integration – reduced burden of temporary employments allowing fast and cost-effective control system deployment.
  - Activation of an "Expert Service Consultancy Contract"- Allowed rapid decision making and maintaining alignment of Solaris master plan to MAX-IV master plan (e..g., procuremnts of materials for accelerator infrastructure integration, design of PSS, design of beamlline, assistance when interfacing with MAX-IV techniology,…).

No Re-inventing

  - Out-sourcing of complete design, construction and installation of a beamline from ID source to entrance of end-station – in an extremely short time ˜18 months.

Solaris Personnel

Solaris People At time of commissioning

- **41 people active with Solaris at present + JU admin**
- **Technical people (33): Accelerator Physics(1), Controls (7+1), Vacuum (1), RF Systems (4), Magnets & PS (2), Mech Engineers (4), Civil Engineering (4+1), Electrical Tech (1), Beamlines (3), Installation Coordinator (1), Radiation Protection (1), Instrumentation (2), [one PhD (diagnostics CERN)]**

Very small team – had to become multi-functional. It worked.

Linac Commissioning

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Subsystem Tests
October-Mid November2014

→

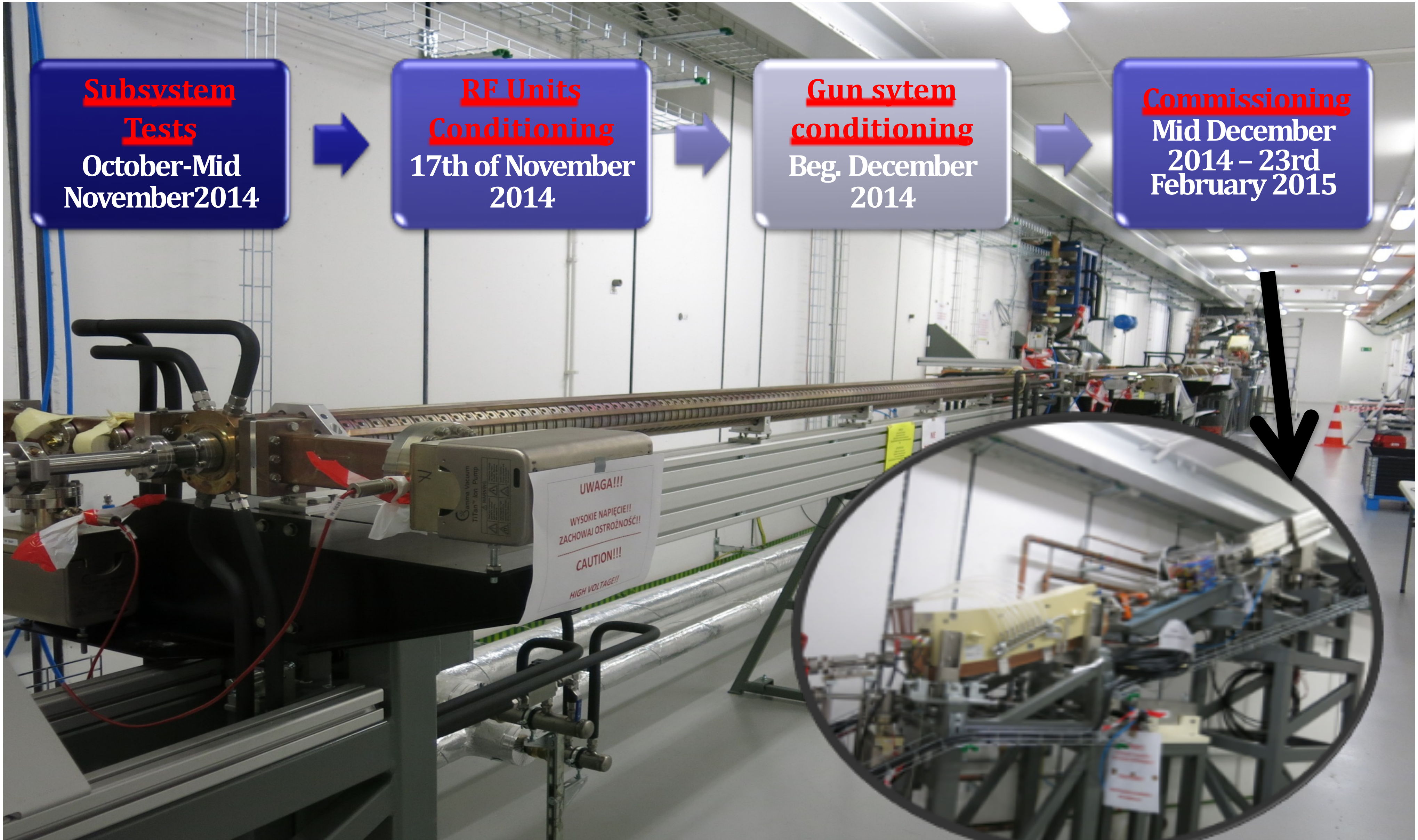
RF Units Conditioning
17th of November 2014

→

Gun sytem conditioning
Beg. December 2014

→

Commissioning
Mid December 2014 – 23rd February 2015



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First electrons @ Solaris

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19.12.2014

First electrons from SOLARIS RF GUN

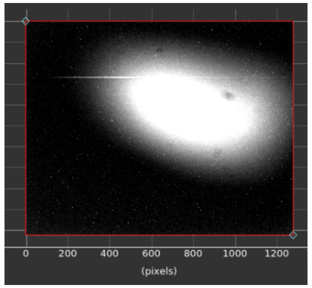
RF Power Forward to the gun= 0.86MW

Electron current = 100mA

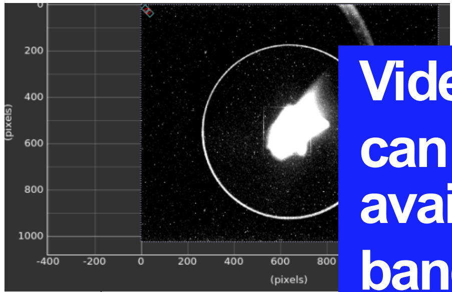
Merry Christmas and a Happy New Year

Injector

11.02.2015
Beam at the entrance to the linac

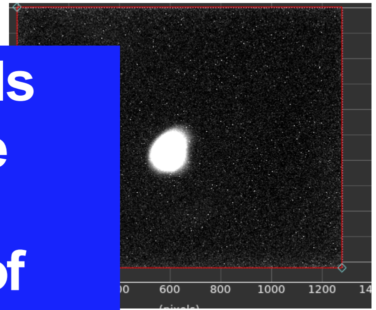


20.02.2015
Beam after 1st Unit

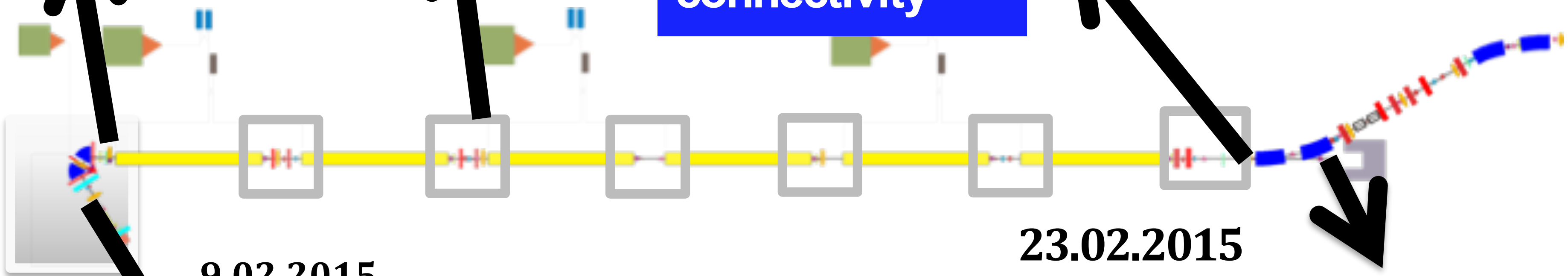


Video signals can saturate available bandwidth of ethernet connectivity

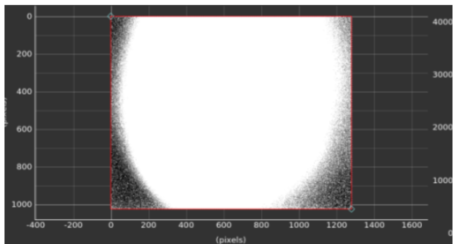
22.02.2015
Beam after 3rd unit



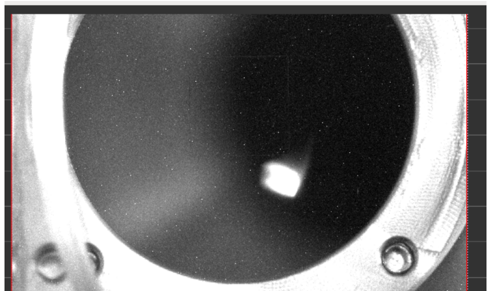
Clear information if a beam intercept is in/out of beam path. End switch information.



9.02.2015
Beam at 1st YAG after the gun

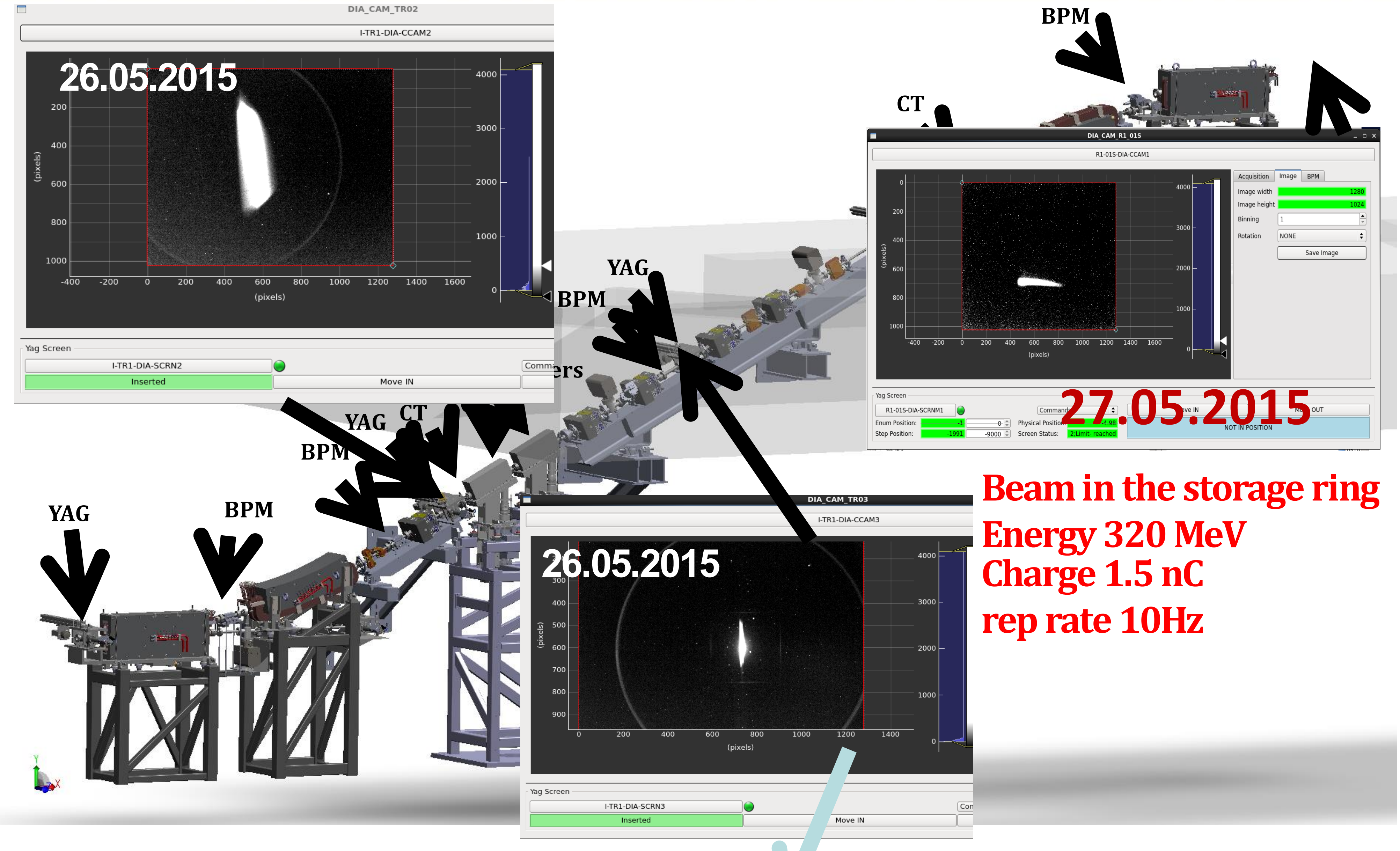


23.02.2015
Beam at the end of linac!



Estimated energy: 300 MeV

Transfer Line



Beam in the storage ring

Energy 320 MeV

Charge 1.5 nC

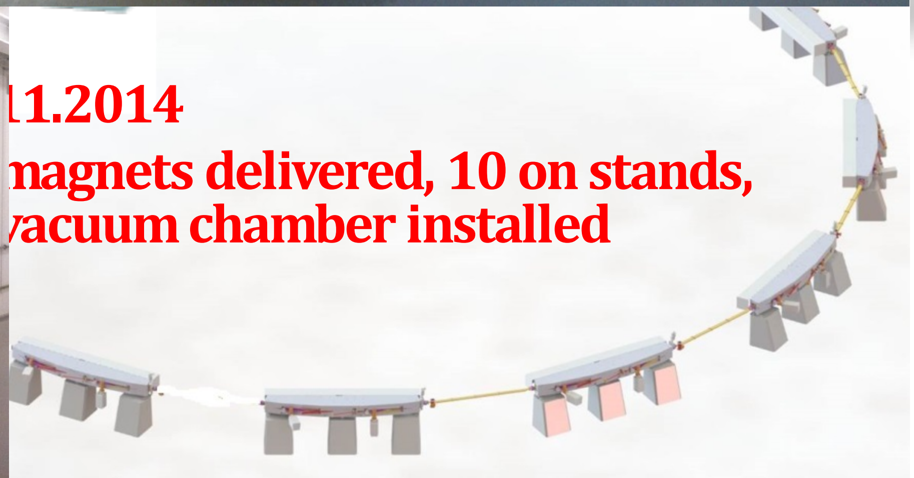
rep rate 10Hz

Linac Commissioning & SR Installation Overlap

~~24.09~~ 14.11.2014– Linac t

~~03.10~~ 17.11. 2014 – Linac s

Things don't always go to plan.
Be ready for this – risk management.



11.2014

magnets delivered, 10 on stands,

vacuum chamber installed

Commissioning plan

Storage Ring

Phase I May-July2015

Phase II September-November 2015

Phase III January-March 2016...

Post Commissioning April-July 2016

Phase I

The goal is to obtain stored beam of sufficient quality that beamline installation can use the synchrotron radiation for alignment

Transfer line commissioning
Injection
First turn
Acumultaion
Stored beam
Orbit correction & BPM calibration

Phase II

The goal is to reach the design parameters of the bare lattice, beam current excepted.

Activities

- *Linear optics correction*
- *Vacuum conditioning*
- *Ramping to 1.5GeV*
- *Increasing the current*

No IDs should be installed

Ring tunnels generally inaccessible; some open periods likely

Halls accessible

Phase III

The goal is to reach the usable beam current for the bare lattice

Optimisation of the lattice with undulator in place

Lattice optimisation with Landaus in place

Lifetime improvements

Post Commissioning

Beamlines commissioning

- 3-4 days –beamlines
- 2-1 days – machine

FOFB

Diagnostics beamline

Staged commissioning.
Clear goals.

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Commissioning organisation

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

- ✓ One shift only 8:00-18:00 with couple of people working over hours;
- ✓ Folders for each day (contains the results, plots, screenshots from commissioning)
- ✓ Logbook- daily reports
- ✓ Every morning meetings at 9:30 plan for commissioning and last day, the state of the machine (goals to be achieved, problems to solved)
- ✓ Involvement of all people in the commissioning phase ; on-call subsystem owners
- ✓ Working 5 days/week but sometimes extended up 7 days /week
- ✓ Weekly operation meetings on Mondays (status, overview, plans, problems)
- ✓ Radiation officer: Present during working hours and on call in case of alarms

Experts from outside:

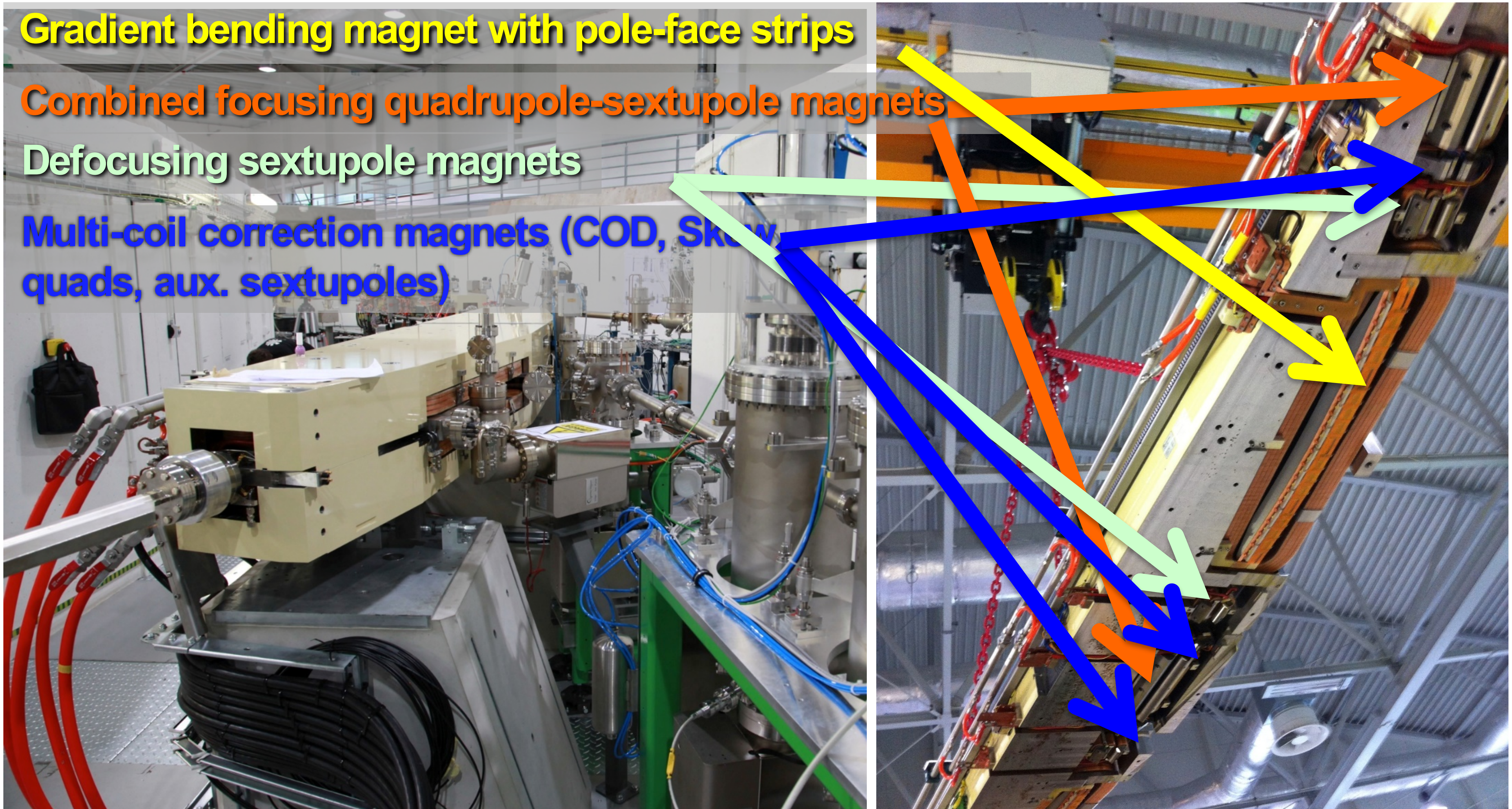
Guenther Rehm – 2 times (July 2 days; November 3 days)
Simon Leemann – July 2 days
Francis Perez – October 2 days
Dionis Kumbaro – 2 days September

Get help from experts

MAGNETS

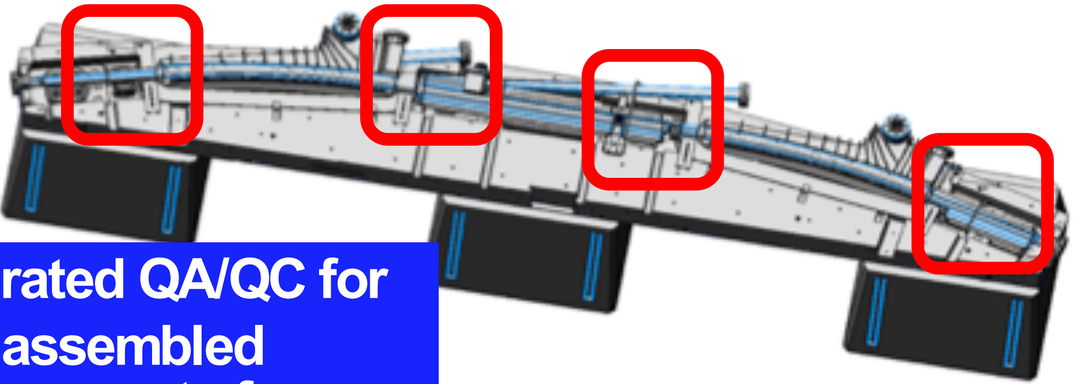
Storage Ring Magnets (mirror symmetric)

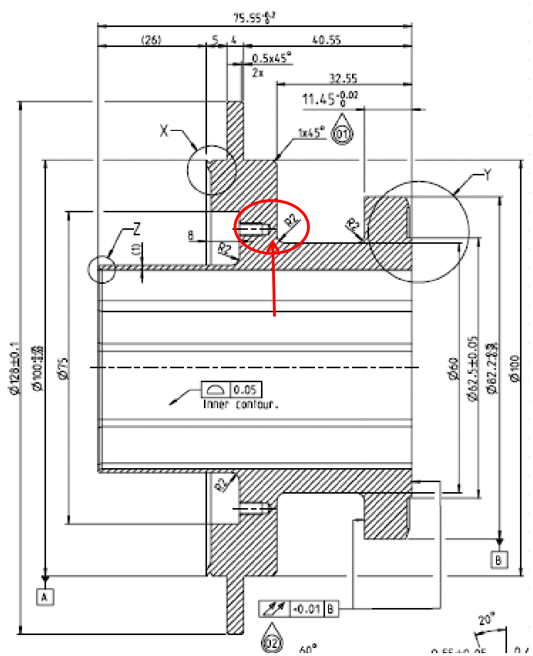
Machined from solid iron, 2 half slabs, ~4.5 m, ~7 Tons each slab



SR Vacuum System

- DBA chambers in 3 parts – no bellows.
- First two chambers assembled and baked (experience gained)
- Chambers found to be out of specification at sextupoles and BPMs (see talk of Jarek)
- Modification required by shaving off material at FMB factory
- Returning two delivered chambers to FMB
- Problems also with leaks on straight section flanges (2 out of 50).
- Final delivery for end of January 2015 – highly critical
- Storage ring will be complete by start of March





Integrated QA/QC for assembled components from different suppliers

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Open Issues

Linac energy still low ~ 470-500 MeV. Missing 100 MeV – phasing done, to optimise.

LLRF to commission (solve issues – see talk of Pawel Boroweic)

Landau cavities to be "conditioned" and installed

H20 general adjustments – and flow to main RF cavities (coupler)

Short circuits to Pole Face Strips (PFS) – See talk of Robert

PFS provide the only vertical focussing – may need for ramping, tune adjustment

Short circuit seems to be identified from PFS to vacuum chamber.

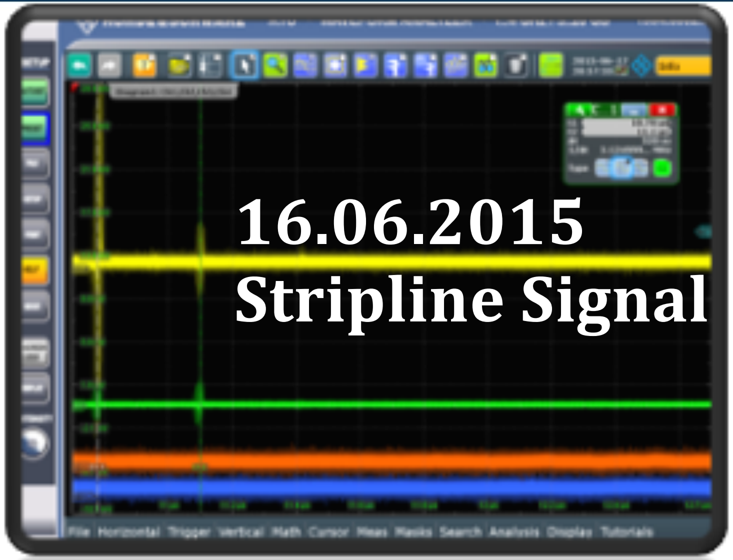
Solutions

- **Best – place additional isolation between coil and chamber**
- **Worst – dissemble entire ring (2-3 months work if vacuum is not broken)**

- **Still to determine extent of need for PFS**
- **Decision of how to proceed will be taken in coming days**

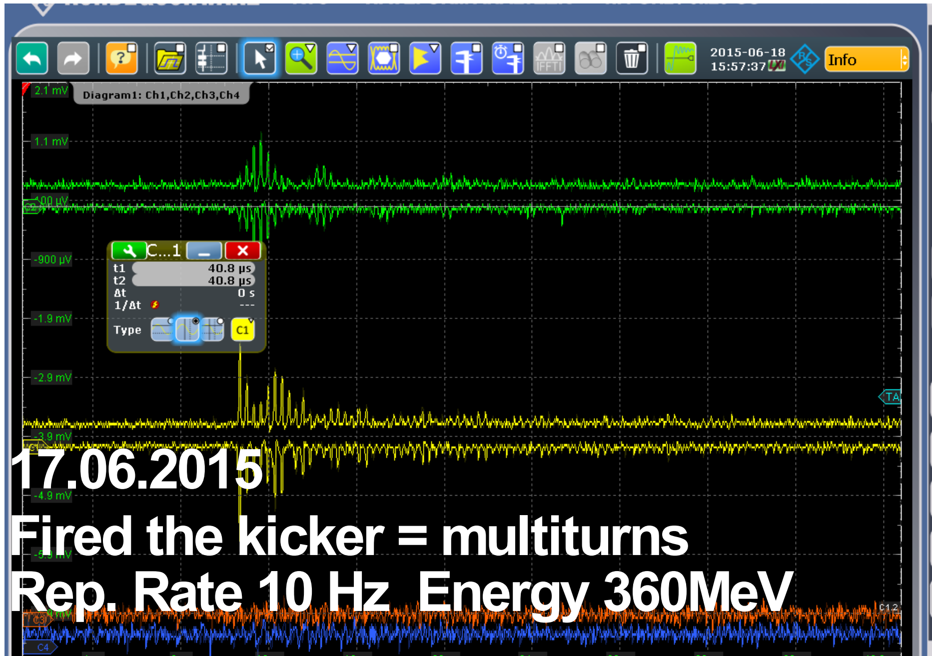
Examples of problems faced.

Storage Ring Commissioning

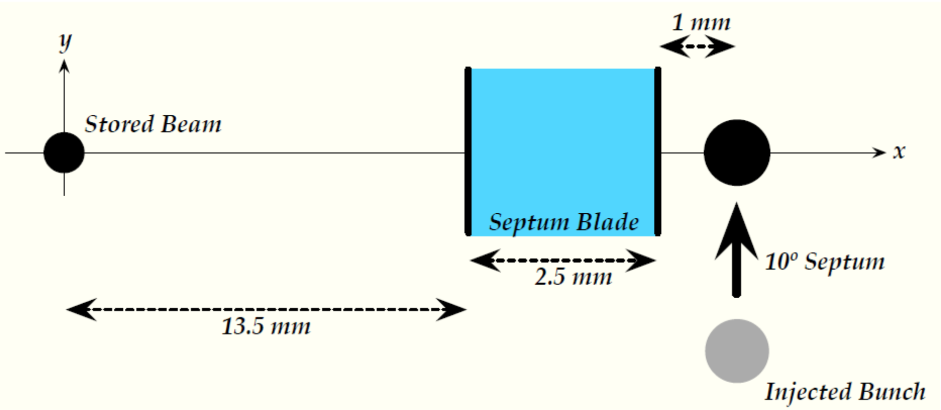


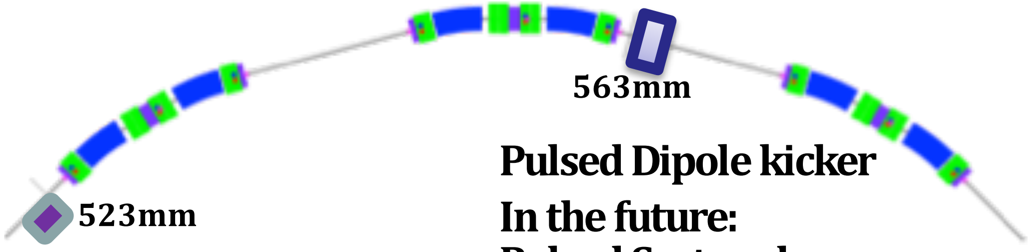
2 turns (2 yellow peaks 320 ns apart) was observed

11.06.2015 – First turn



Injection

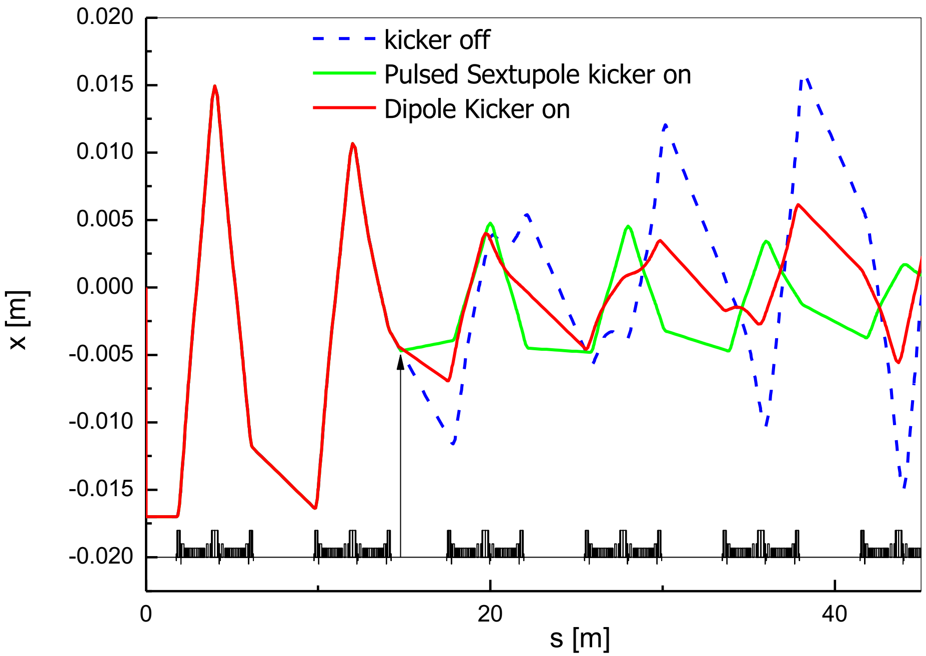


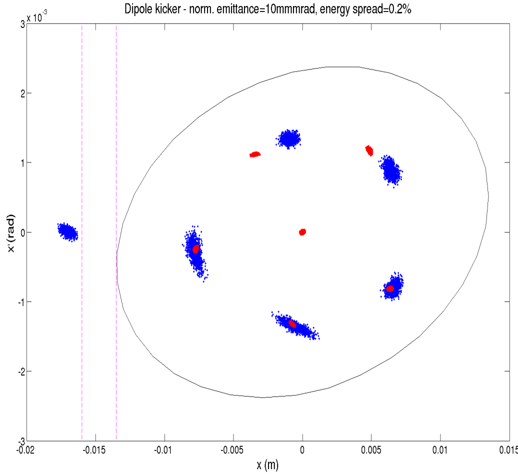


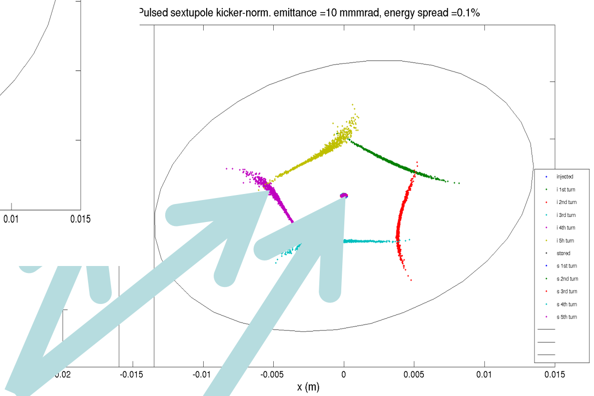
Injection

Pulsed Dipole kicker

In the future: Pulsed Sextupole kicker







Injected beam

Stored beam

S.C. Leemann, Nuclear Instruments and Methods in Physics Research A 693 (2012) 117–129

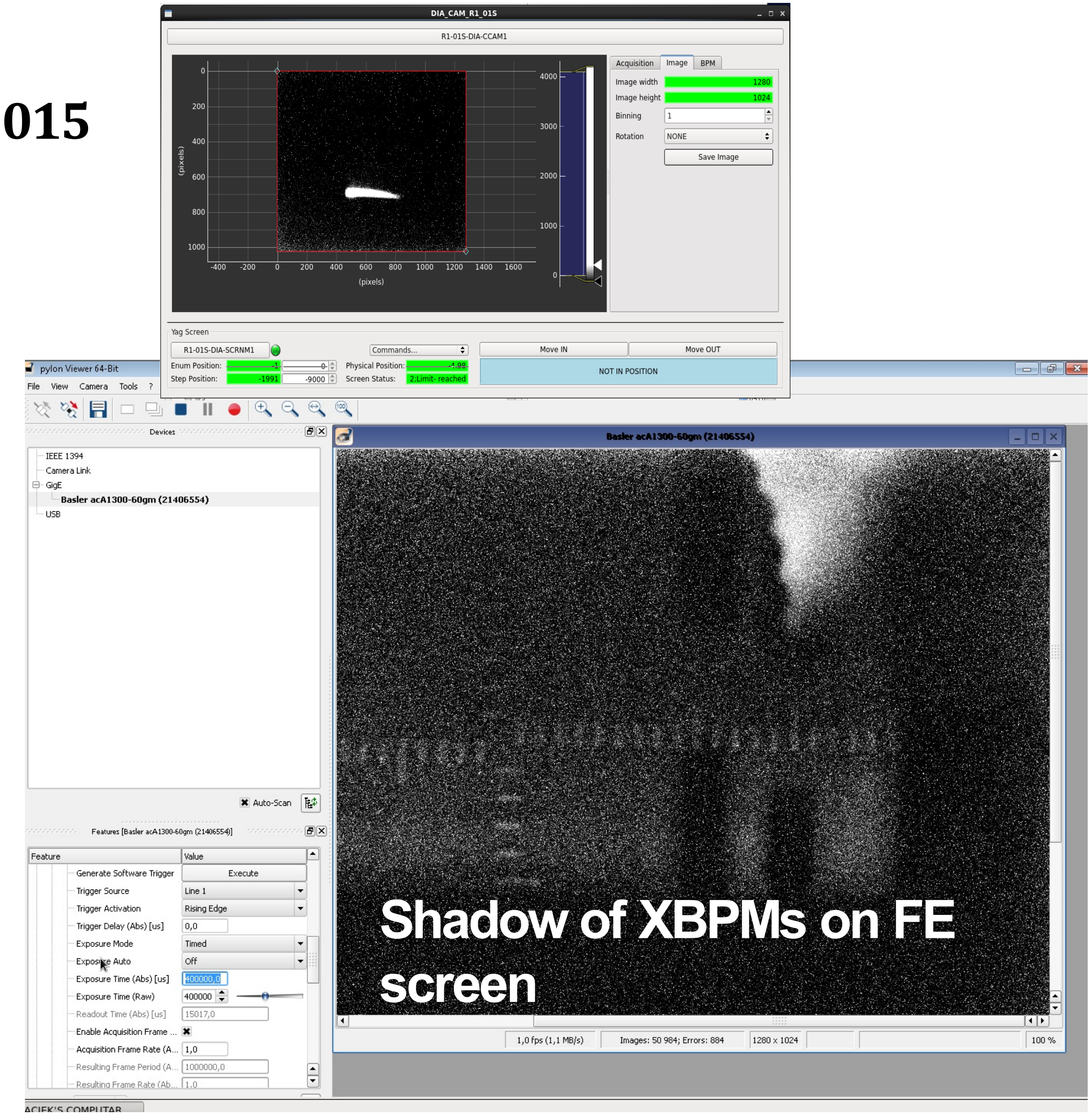
A.I. Wawrzyniak et al, IPAC'11, San Sebastian, Sept. 2011, THPC123, p. 3173

1^{st} Light

- **1^{st} Stored beam on 19^{th} June 2015**

Done with a YAG screen after septum, a radiation monitor sector 7 and a stripline after one turn

Visual diagnostics provide immediate “believable” information



Personnel Protection System (PPS)

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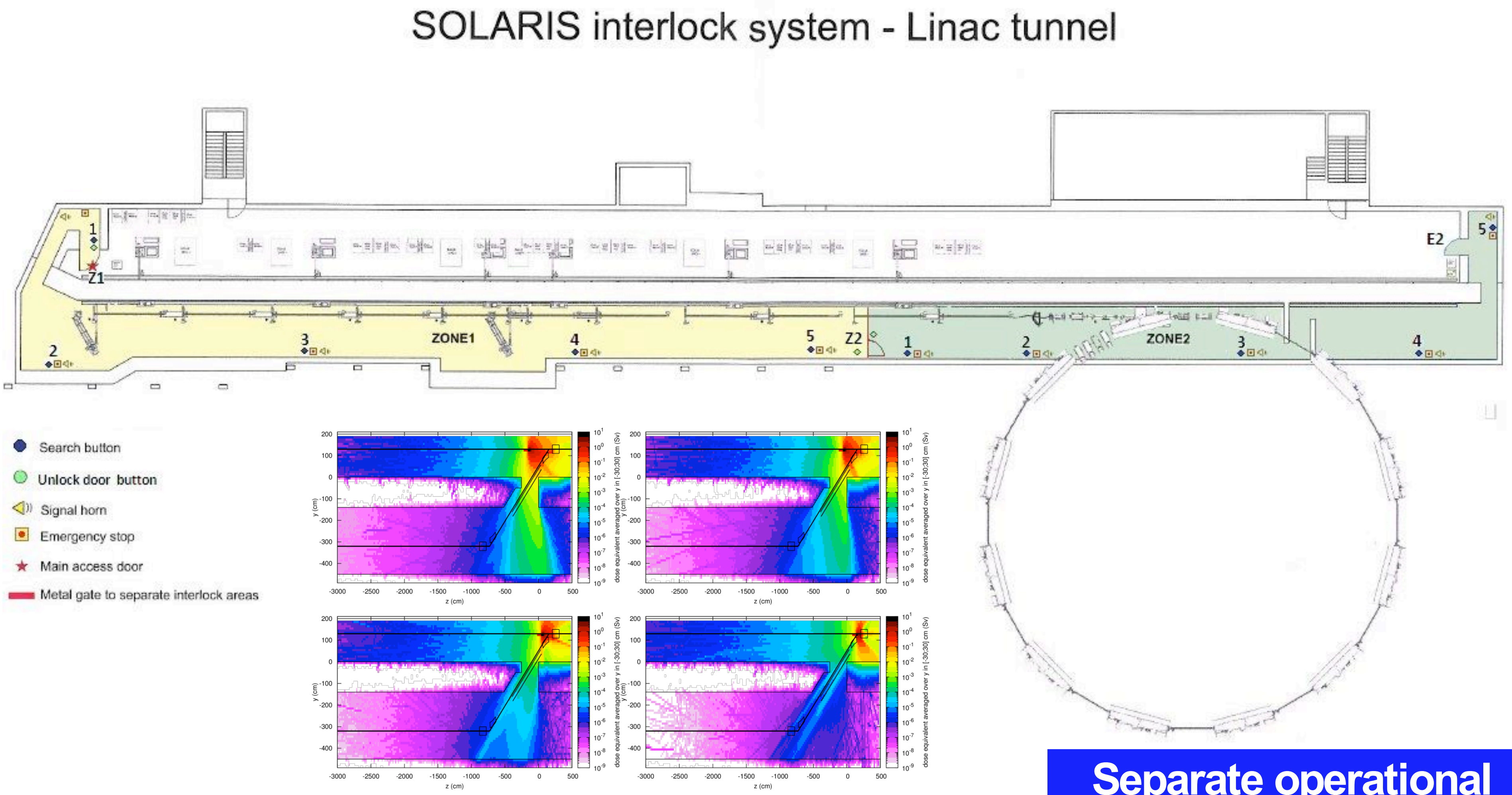

Figure 23. Zone 1 and Zone 2 inside linac tunnel.

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Separate operational locations whenever possible to allow concurrent activities

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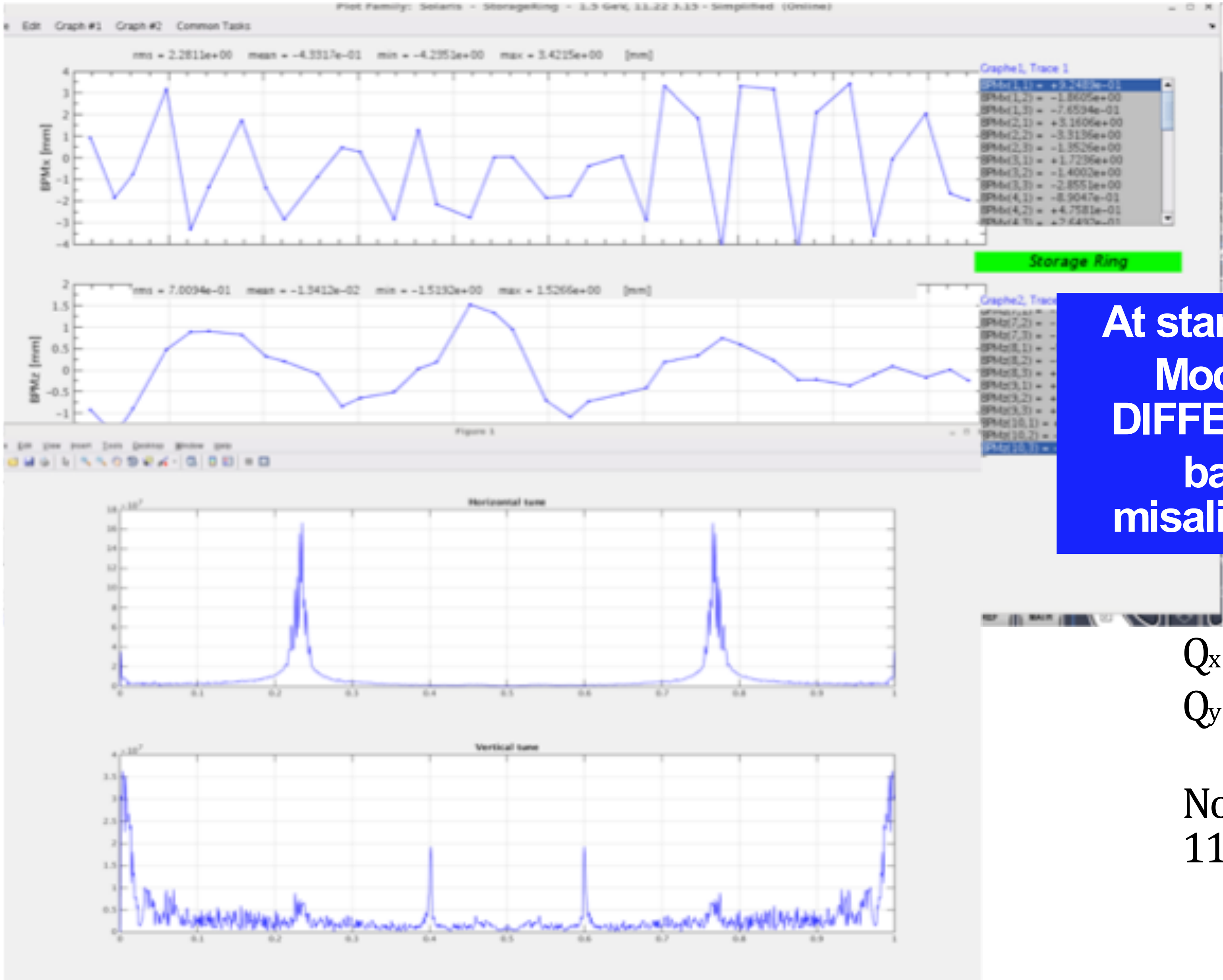
Closed orbit and Tune

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE



x_{rms}=2.281mm

y_{rms}=0.701mm

At start Machine and Model WILL BE DIFFERENT (errors, bad cabling, misalignment, etc..)

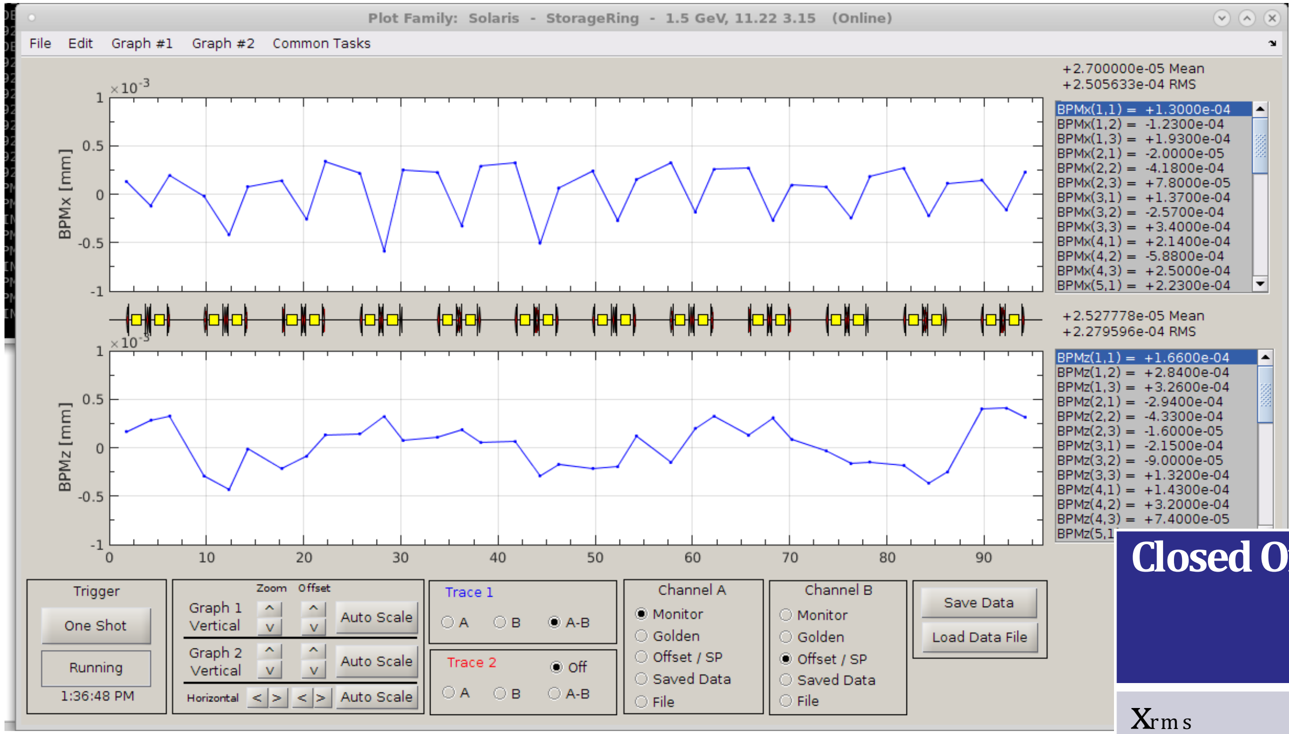
Q_x=10.78

Q_y=3.6

Nominal values:
11.22; 3.15

ORBIT CORRECTION

Closed orbit and orbit correction was improved with cooperation with Ward Wurtz from CLS (Saskatoon, Canada)



Understanding real machine is fundamental for reaching objectives

Closed Orbit	With correction &BBA before	With correction &BBA After
x_{rms}	160 µm	0.25 µm
y_{rms}	55 µm	0.22 µm

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Tune

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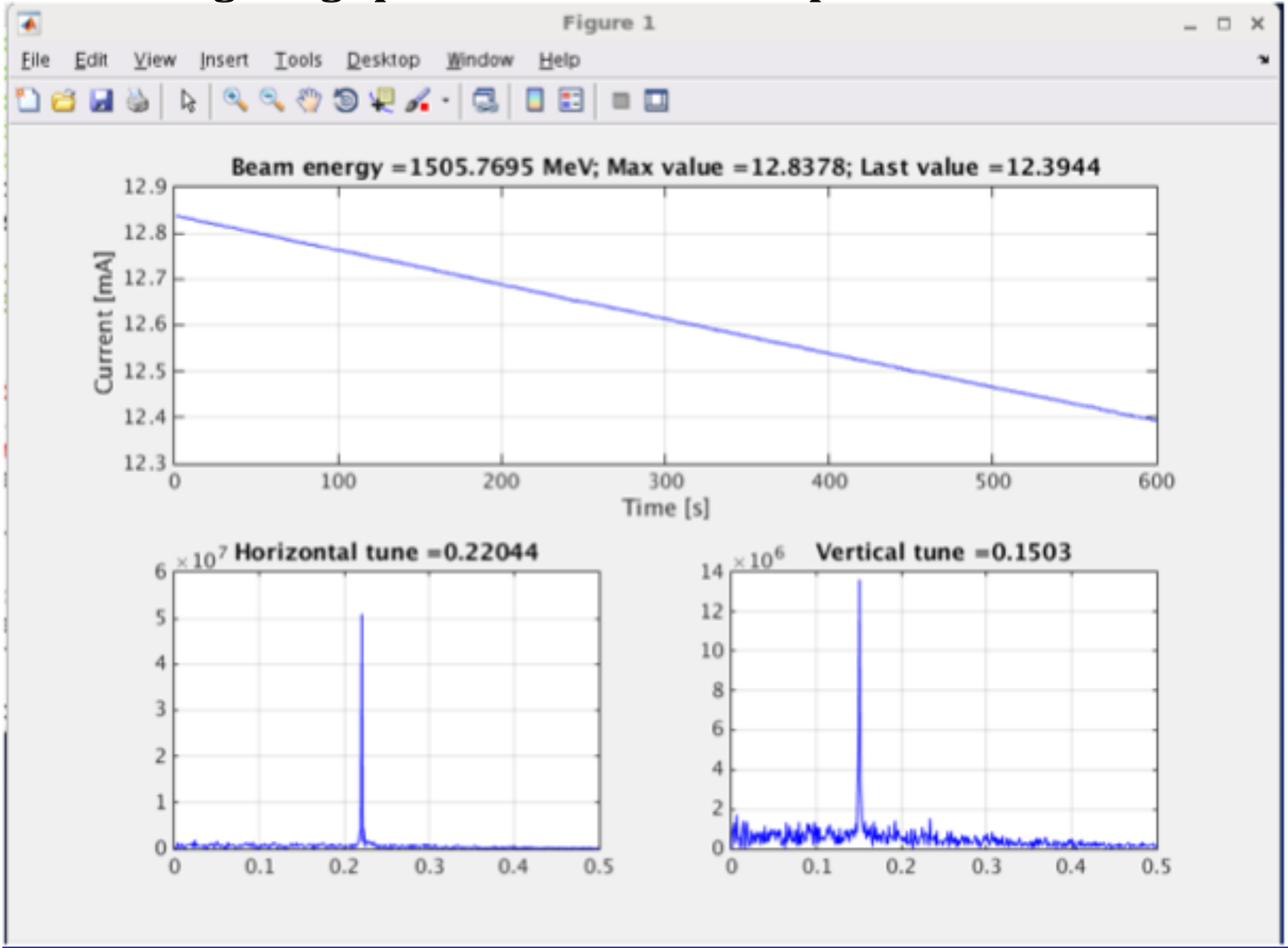
The storage ring operates at its nominal optics.



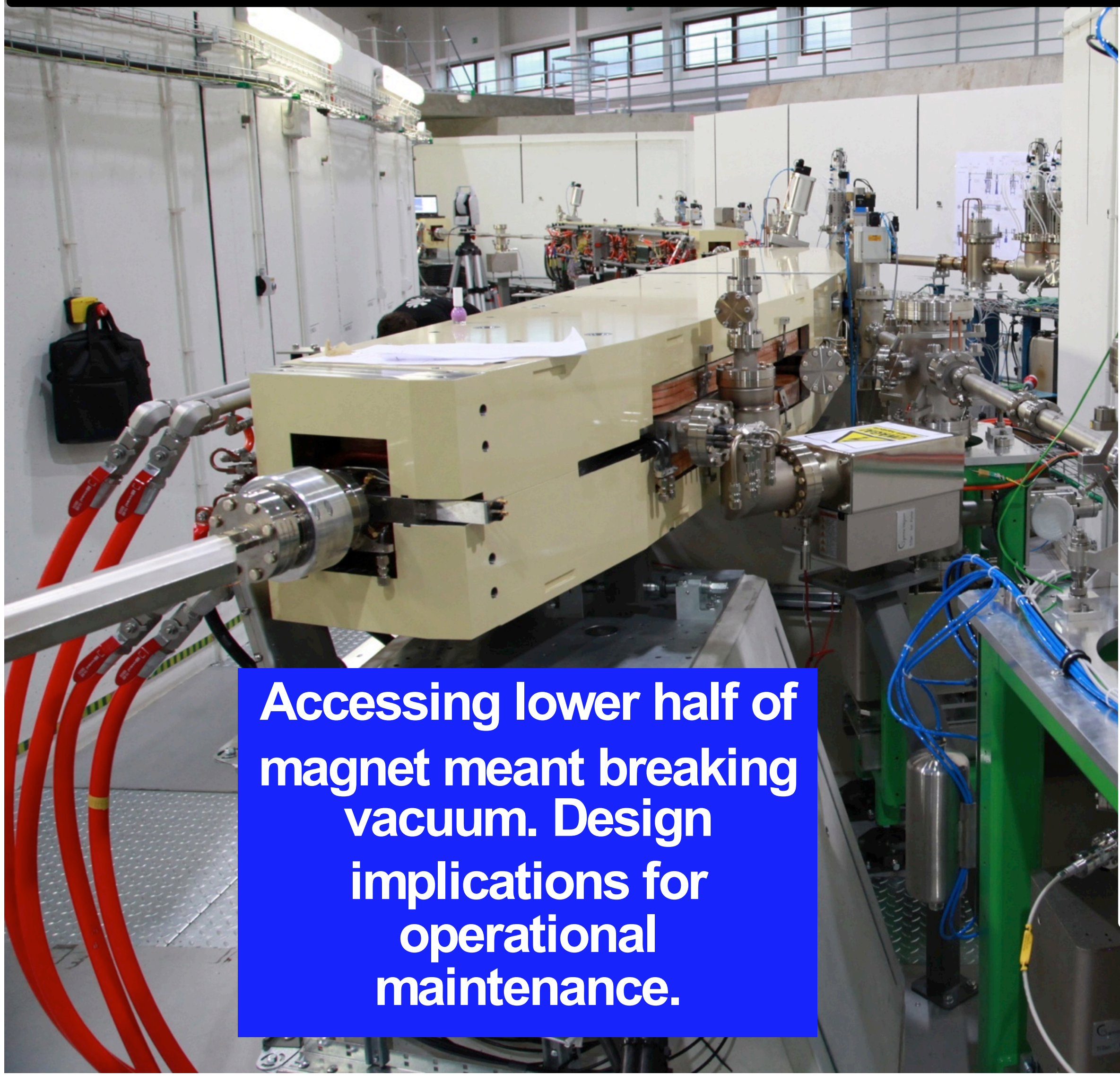
Q_x=0.22044

Q_y=0.1503

Nominal values: 11.22; 3.15

Magnets problems

Pole face strips short circuits
Skew quad in section 2 short circuit –broken coil
Power supplies problems with stability



Accessing lower half of magnet meant breaking vacuum. Design implications for operational maintenance.

Beam loss

Lack of alarms panel with clear information what caused the beam loss
Interlocks panel – lack of some signals and improvement needed
Beam losses – due to:

- Vacuum interlocks (on cavities, kicker magnet VC, beamlines)
- LLRF RF system (dephasing, detuning)
- Radiation levels (bad injection; scrapers measurements)
- Magnets /PS failure (main Danfysik PS, Semi instruments PS(SQFo)
- Water circuit interlocks (TL, SR,)
- Electricity blackout

Informative monitoring and unambiguous information very important for fast problem solving.

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BEAM STABILITY

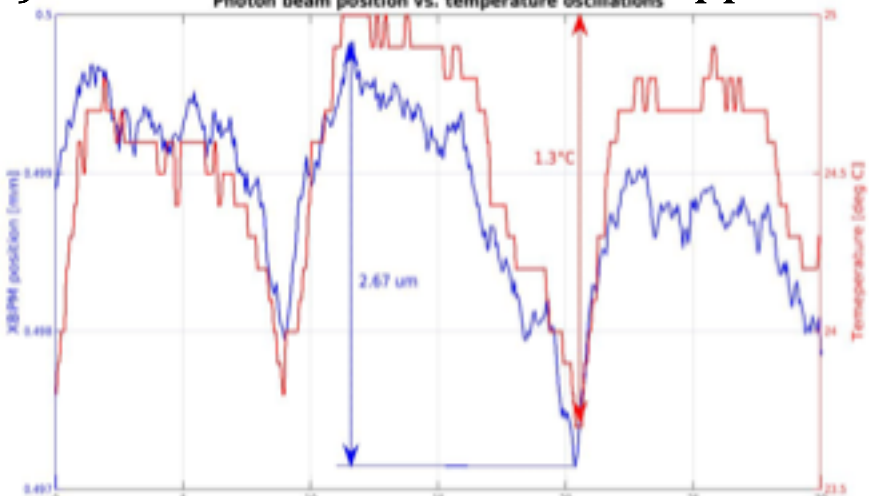
SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

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

Temperature oscillations in the range of 1.5-2.0 °C in the storage ring have impact on beam stabilty.

More in Paweł Czernecki talk

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



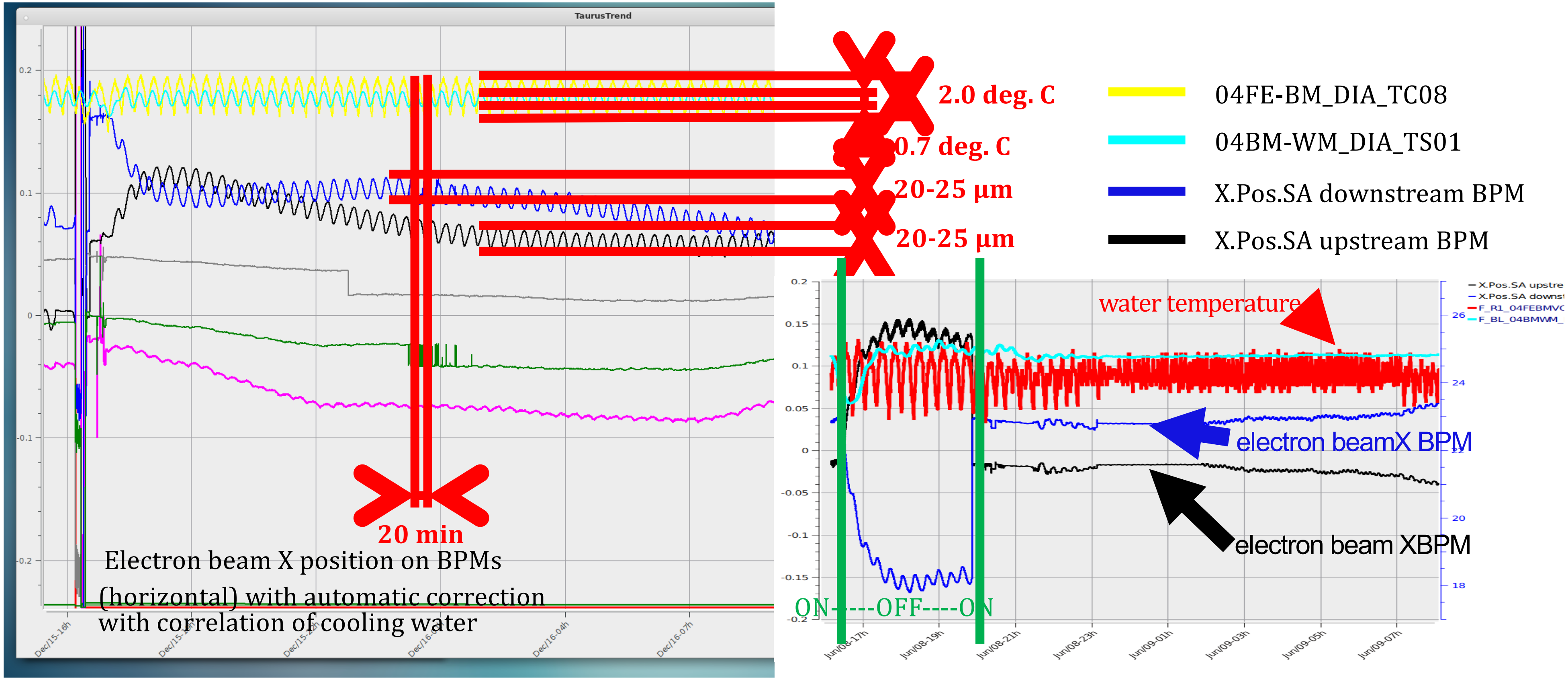
CF systems will affect the beam.

Beam drift in Storage Ring

By the end of 2016, beam diagnostics reported on the observed electron beam oscillations in the Storage Ring.

1. Amplitude of vibration
   - a) with no automatic correction: **20-25 µm**
   - b) with automatic correction: **8-15 µm**
2. Oscillation period: **20 min**
3. Place of measurement: **BPMs &XBPMs**

The direct cause of the oscillation of the electron beam and the photon beam in the Storage Ring is the oscillation of the cooling water temperature in main backbone.

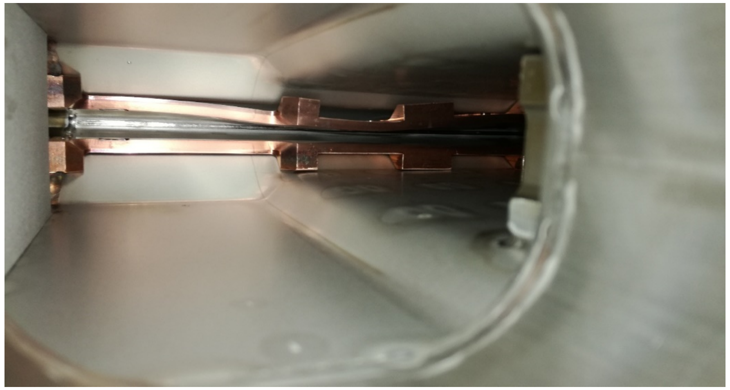


Time period: 16 h, correction ON-OFF-ON

Vacuum chambers in SR problem

- March/April collapse of the RF shieldings in VK2 in DBA 02
- Replacement of the vacuum chamber- spare installed (2 weeks shutdown)
- Broken sent to FMB for repair [details in Andrzej Marendziak's talk]
- Visual inspection of the ceramic kicker chamber insight reveal some scratches and spots indicating some sparking – added thermocouples on the kicker magnet to monitor the temperature –spare part to be purchased

Kicker magnet inspection



Machine protection to be commissioned!

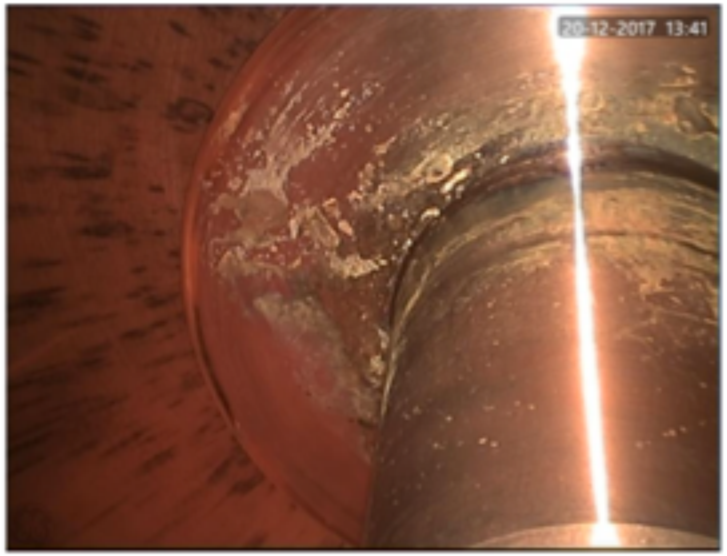
Critical spare parts should be purchased

Storage Ring RF Maintenance

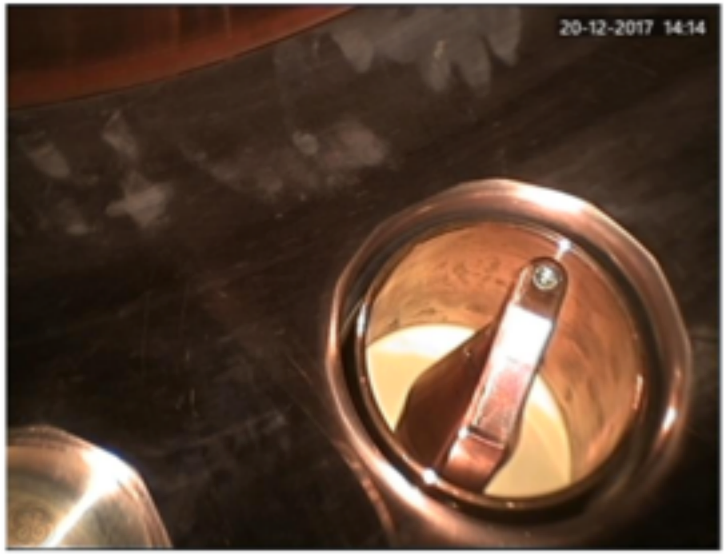
QA/QC must not be skipped

Cavities endoscopy

- Since machine installation the cavities were not inspected internally.
- During shutdown this opportunity was used to carry out an endoscopy.
- Results were slightly suprising.
- Most of cavities are clean, although some surfaces have clearly visible fingertip marks, and other impurities



100MHz CAV2, mushroom



100MHz CAV1, shell

300MHz LAN2, bottom pickup

FAILURES OF THE RF EQUIPMENT

Common faults RF, tuning systems

Modulators:

- First broken IGBT in the high voltage switch unit. Equipment after warranty.

100MHz cavities

- Leakage up to 1.0e-7 mbar*l/s at ceramic of pick-ups (already 4 pieces).

New designed pick-up's without ceramics have been delivered under warranty.

Rhode & Schwarz signal generator SMA100A (Master Oscillator for linac)

- Synchronization error on 10MHz reference, repaired under warranty -> OCXO oven problem

Overheating of 50W 20dB RF attenuators from Landau cavities pick-up

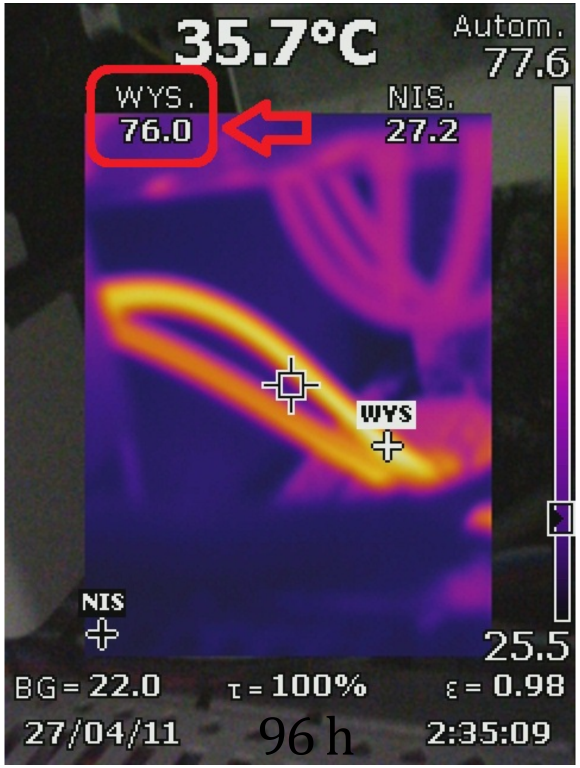
- Not detectable by LLRF because of 450MHz low pass filter in series
- Expected few watts, value from 100MHz - 3GHz spectrum measurements during commissioning at certain Landau tuning position
- Investigation on-going, >150mA beam current needed

FAILURES OF STORAGE RING PS

Breakdown of PS switch

PS overheating due to water flow limitation

Failure of 5V inner power supply for analog part of control board



Downtime:

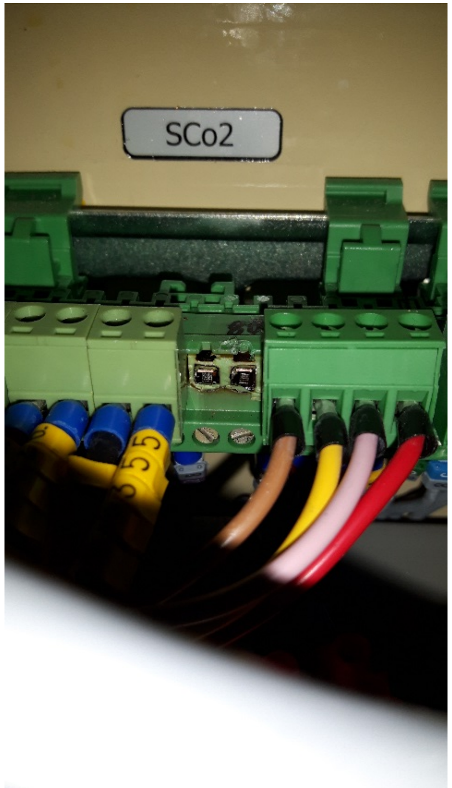
96 h

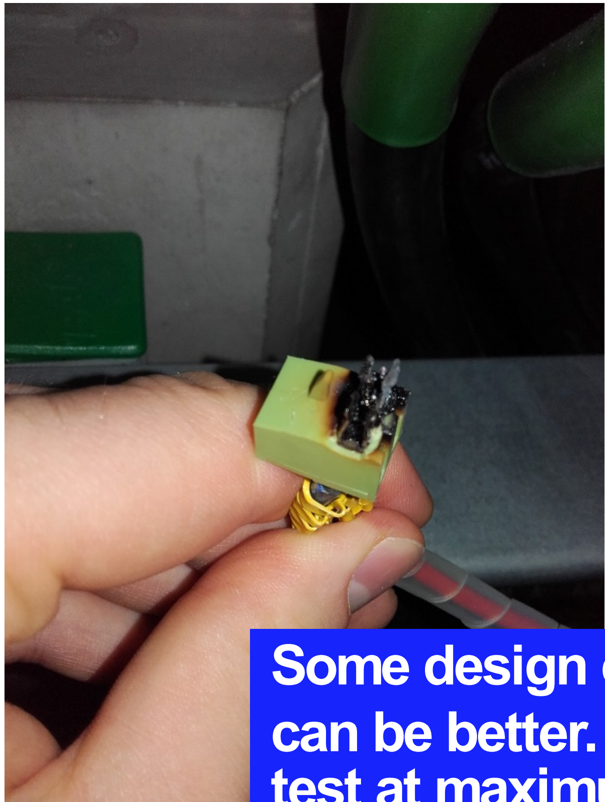
28 h

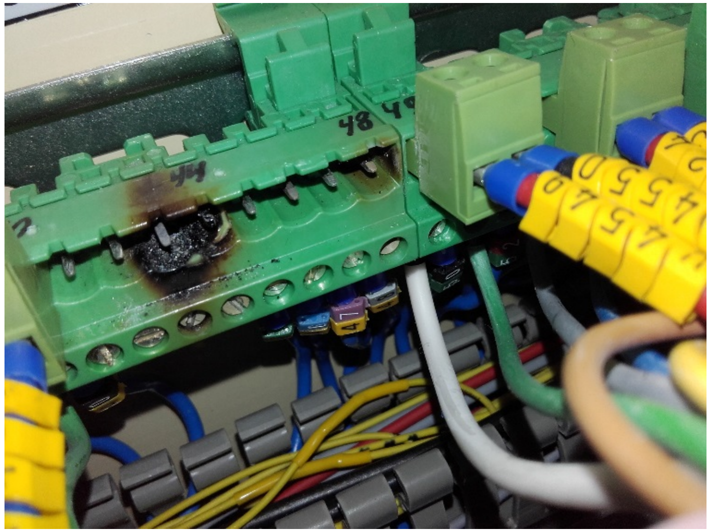
In total 220 h of downtime due to main PS problems

Corrector magnets connetors failures

Problems with connectors for corrector magnets







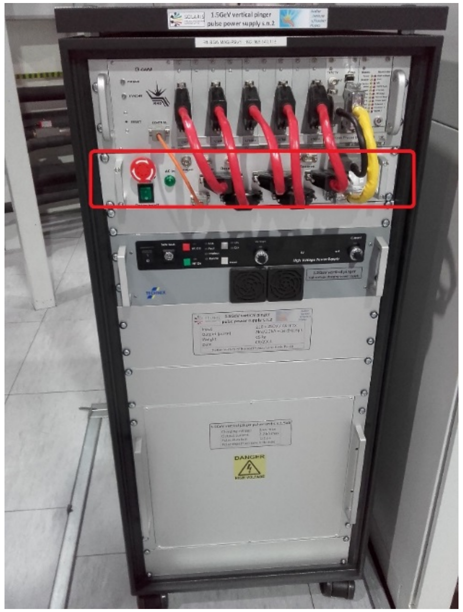
Some design choices can be better. Good to test at maximum settings.

Downtime: 6 h

Actions: - We are going to replace the connectors with solid soldered cables during winter shutdown.

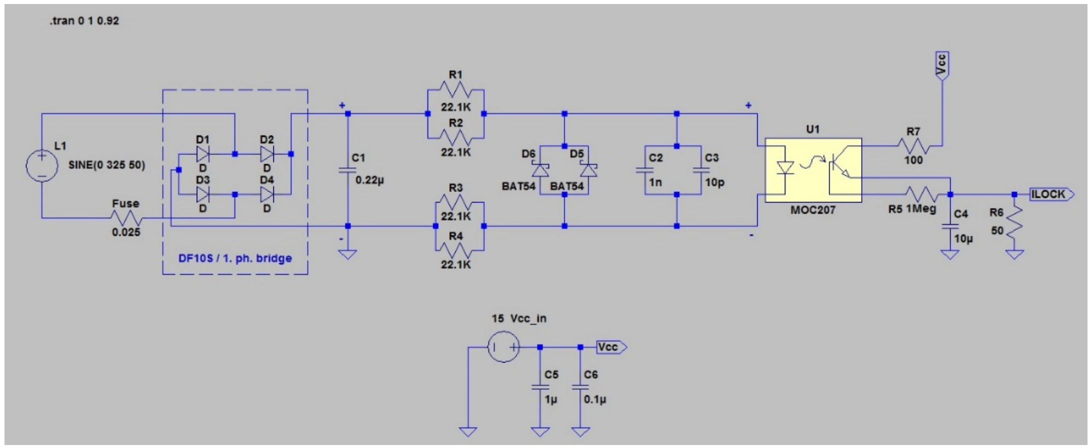
Most serious failures

Pinger failure



Actions:

- After Solaris' diagnose BINP provided us new phase detectors and replacement for other burned electronics elements;
- We are working on new improved phase detector for the Pinger;
- IGBT section (most sensitive part of the kicker and pinger) was investigated after the failure and as for now everything looks good.



Collaboration

Solaris – MAX IV interaction benefits very similar to In-Kind Contributions to ESS.

Benefits

- **Use of established expertise in design and manufacturing**
- **Support for testing and installation**
- **Support for beam commissioning (concurrent activities at both labs benefitted from shared knowledge)**

Lessons Learnt

- Special care in QA/QC for high tolerance integrated equipment from different manufacturers.
- Visual inspection (endoscope) at factory & site whenever possible.
- Special attention to terminations and testing at maximum rating.
- Interlocks to be fully tested. Spare parts essential for critical components.
- Risk assessment of concurrent installation and systems/beam commissioning

- Beam diagnostics should have sufficient time for system tests before beam.
- Visual beam diagnostics are highly effective - Quantitative vs Qualitative.

- Good component alignment and QC essential.
- RF systems need more time than anticipated for conditioning (often rushed).
- Beam response and physics modelling essential for reaching design parameters (understanding combined alignment & component errors).

- Alarm system on interlocks to provide complete information (history & correlations).
- Use expertise from other labs as much as possible
- Use personnel who built system to commission with beam.

Thank You