JAGIELLONIAN UNIVERSITY
IN KRAKOW

SOLARIS
NATIONAL SYNCHROTRON
RADIATION CENTRE

Commissioning of high-power RF at Solaris Light Source

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On behalf of Solaris Team

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Outline

1. Introduction to Solaris project
2. Injector
3. Storage ring
4. Installation
5. Commissioning

SOLARIS location

SOLARIS @ Jagiellonian University new Campus: Czerwone Maki 98, Kraków, Poland

We started from empty field

SOLARIS history

The motivation

- Polish synchrotron radiation users community - >300
- Polish Synchrotron Radiation Users Society (PTPS)
- Polish Synchrotron Consortium – 36 members
- Long lasting initiative to built a SR source in PL
- **2009 – 40 M€ package assigned**

The goal

- The best possible synchrotron radiation source for the money
- Upgreadable

The context

- New MAX-IV facility in Lund - 2 rings:
- MAX IV ring: 3 GeV, 528m circumference
- MAX II replacement: 1.5 GeV, 96m circumference ring
- SOLARIS - **replica** of the new 1.5 GeV MAX-lab ring
- New MAX-lab magnet technology - Integrated Double Bend Achromats

Courtesy of M.Stankiewicz

SOLARIS history

National Project, executed by Jagiellonian University

Timetable

- Conceptual design 2009
- Project approved 2010
- Deadline: December 2015

Budget

- 50 M€ - EU funds

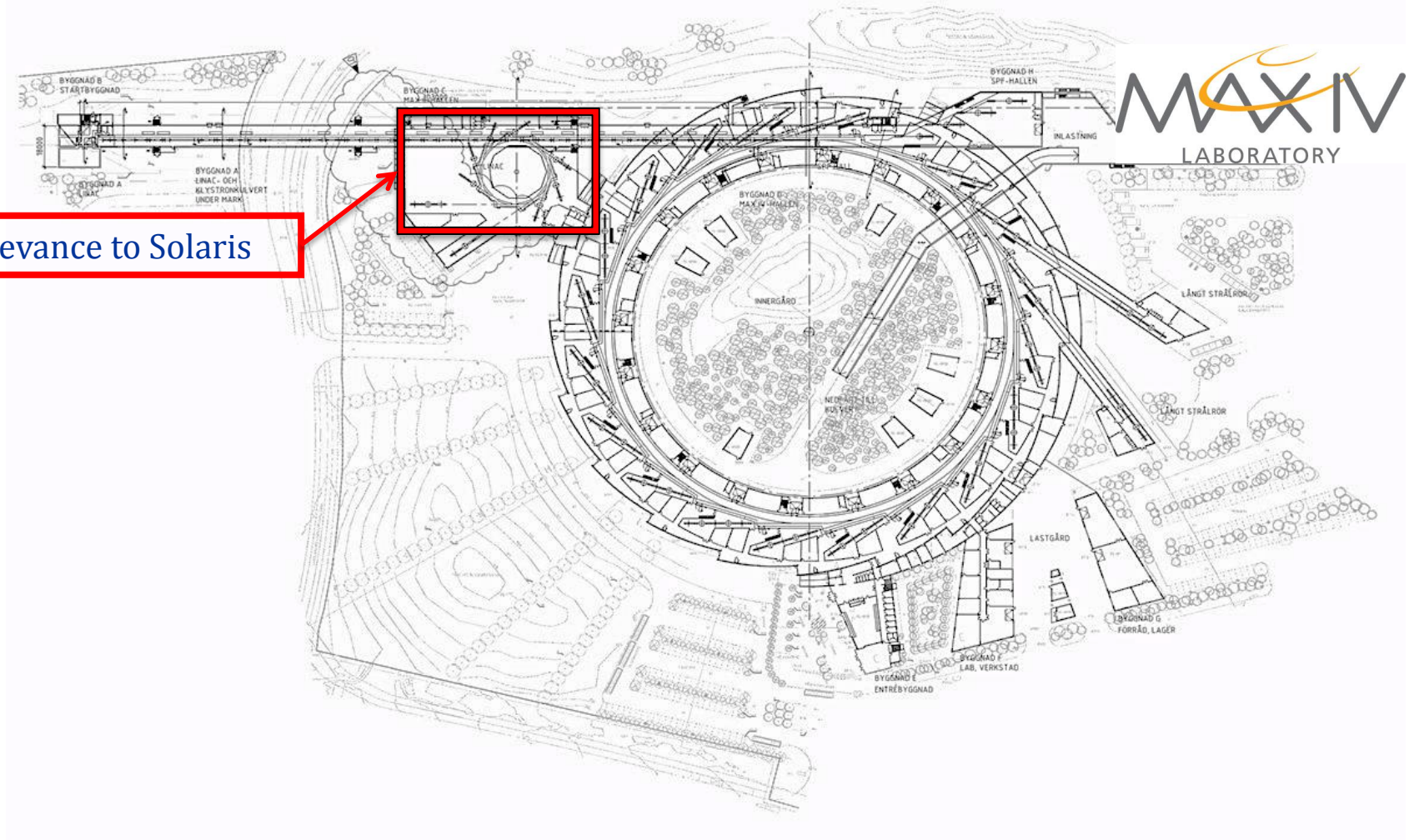
Deliverables

- Building (Land donated and administrative support by the Jagiellonian University)
- Machine (linac + synchrotron)
- 2 experimental beamlines: PEEM/ XAS and UARPES

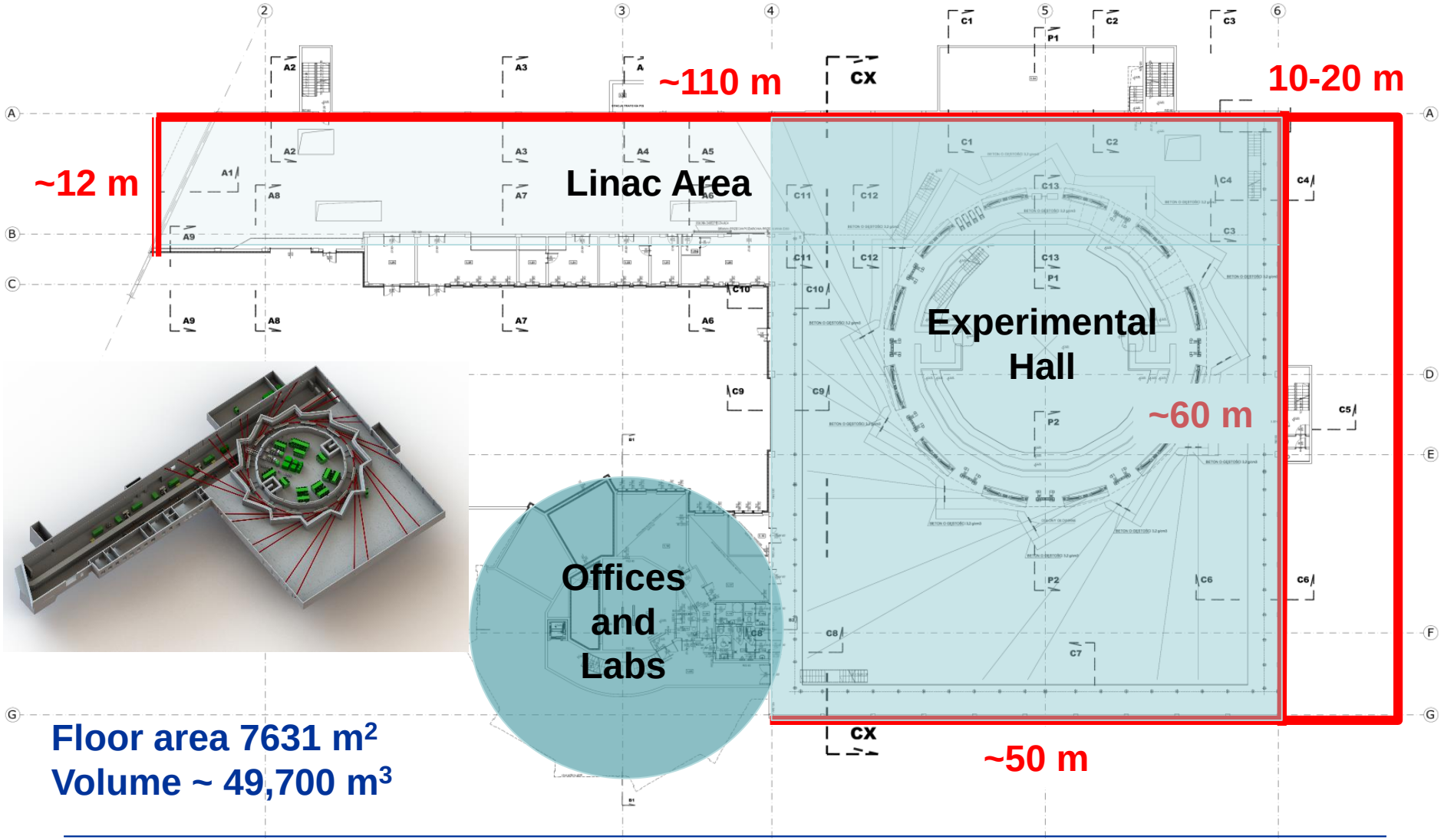
Courtesy of M.Stankiewicz

SOLARIS as a replica of Max IV

Solaris is the replica of the 1.5 GeV MAX IV Storage Ring and part of the injector but Max IV design had to adopted to SOLARIS building



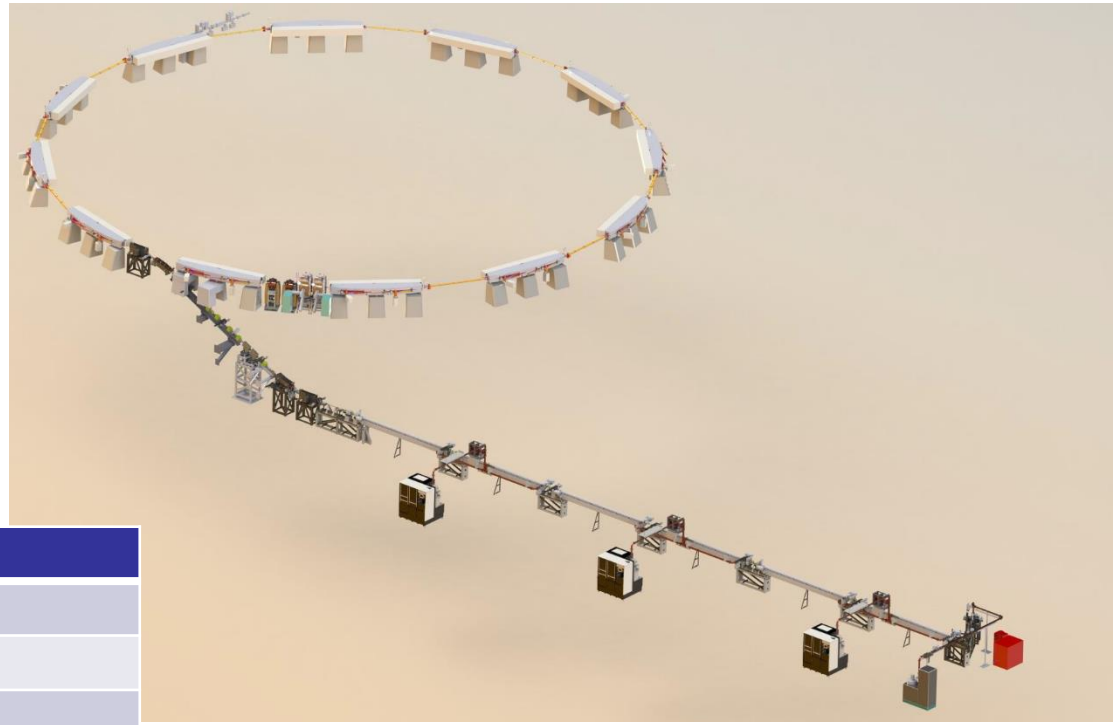
SOLARIS building



Floor area 7631 m²
Volume ~ 49,700 m³

SOLARIS as a replica of Max IV

Storage Ring Parameters	Value
Energy	1.5 GeV
Current	500 mA
Circumference	96 m
Horizontal emittance (bare lattice)	5.982 nm rad
Coupling	1%
Tunes Q_x, Q_y	11.22, 3.15
Natural chromaticities ξ_x, ξ_y	-22.96, -17.14
Momentum compaction	3.055×10^{-3}
Momentum acceptance	4%
Overall Lifetime	13 hrs



Injector Parameters	Value
Energy max	600 MeV
Bunch charge	0.1 nC
Emitance (geom, rms) x/y	3.1 / 2.0 nm rad
Energy spread (rms)	0.23%
Bunch length (rms)	3.68 ps
Injection rep. rate	2 Hz (linac up to 100Hz)

SOLARIS
Major collaborations

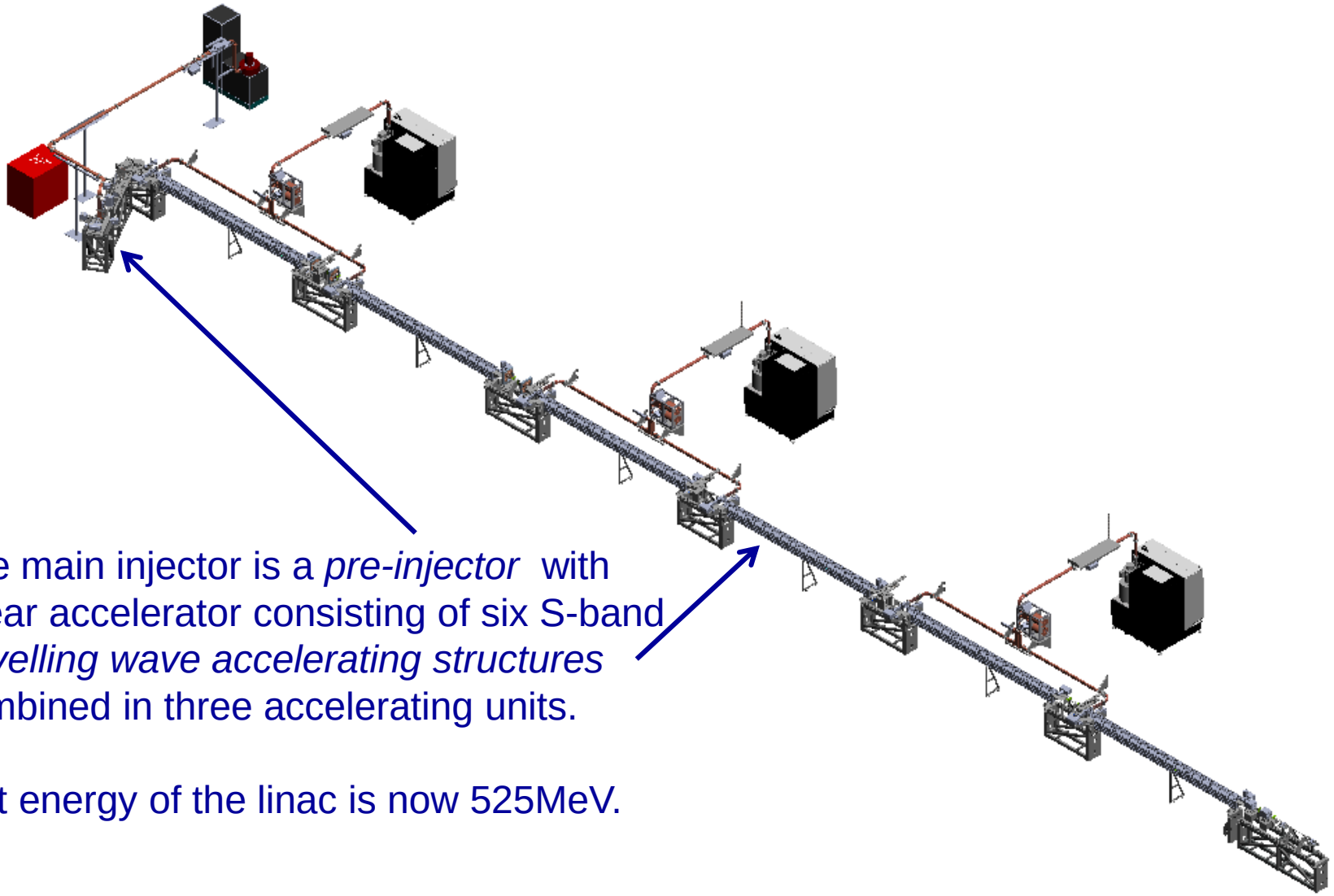
Max IV

- Agreement established between Jagiellonian and Lund Universities for mutual cooperation in the construction of Solaris based on MAX IV.
- MAX IV freely giving all know-how, reports, designs, info on tenders, training, ..., to Solaris
- Solaris team (technical) is hosted at MAX IV and participate in project activities and training. Sharing of mutual resources and also providing a support to MAX IV.
- Procurements for Solaris are as options in MAX IV tenders.

Elettra

- Commercial contract for expertize of activities in all aspects of synchrotron construction
- PSS design, design of transfer line, vacuum chamber components, beamline and front-end, EPU insertion device

Linac



The main injector is a *pre-injector* with linear accelerator consisting of six S-band *travelling wave accelerating structures* combined in three accelerating units.

Exit energy of the linac is now 525MeV.

Pre-injector

Isolator
- Manufacturer: AFT, Backnang – Waldrems, Germany
- Forward peak power: 20 MW
- Forward average power: 5 kW
- Reverse power: 100% at any phase
- Filled with SF6

RF thermionic gun
- Manufacturer: Max IV, Lund, Sweden
- Cathode: BaO
- Energy of beam: 1.5-3 MeV
- Rep. Rate: 10Hz

Stripline chopper to fit bunches time structure to the 100 MHz bucket
- Manufacturer: Max IV, Lund, Sweden

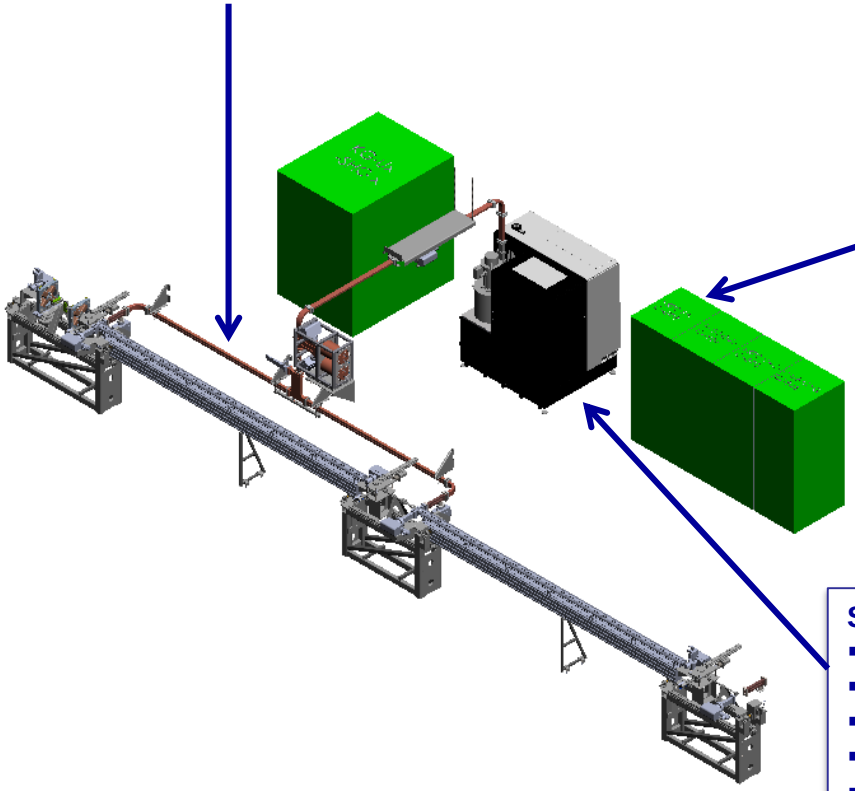
RF window

S-band K1 RF Unit for RF thermionic gun
- Manufacturer: ScandiNova Systems AB, Uppsala, Sweden
- Solid-state modulator
- RF frequency: 2998,5 MHz
- RF peak power from Klystron: 8 MW
- Pulse length: 3 µs
- Repetition rate: 0 – 10 Hz
- Klystron: Toshiba TH2175A-1

100MHz + 300MHz + 700MHz combiner for stripline chopper
- Manufacturer: Exir Broadcasting AB, Hörby, Sweden

Accelerating unit

Waveguides
- Manufacturer: IHEP, Beijing, China
- Size: WR284
- Flanges: LIL for UHV, CPR for SF6

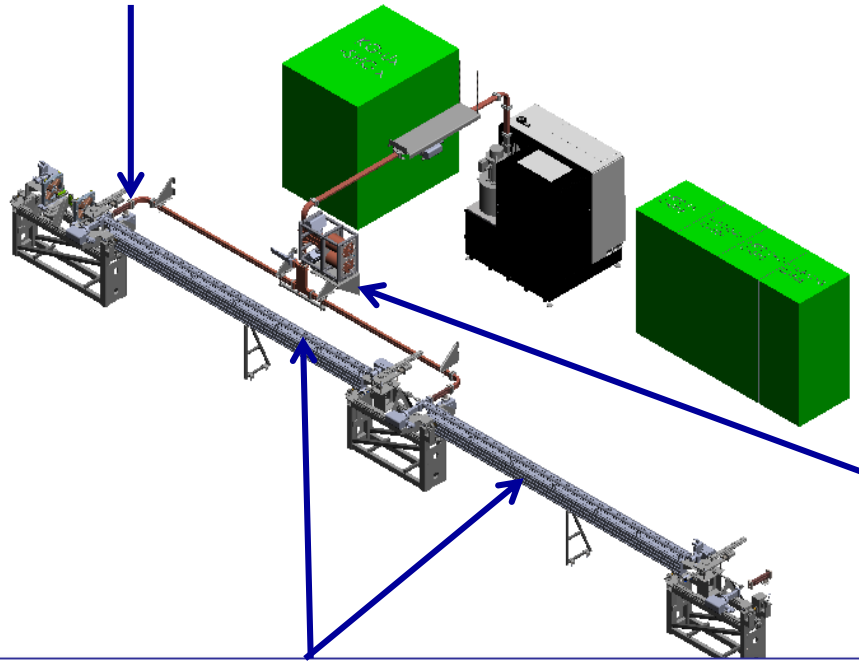


„LLRF" for each RF Unit in the Linac
- Manufacturer: Max IV, Lund, Sweden
- Pulse shaping
- Phase adjustment
- 180º phase swap for SLED
- Open loop, no feedback

S-band K2 RF Unit for accelerating sections
- Manufacturer: ScandiNova Systems AB, Uppsala, Sweden
- Solid-state modulator
- RF frequency: 2998,5 MHz
- RF peak power from Klystron: 37 MW
- Pulse length: 4,5 µs
- Repetition rate: 0 - 100Hz
- Klystron: Toshiba E37310

Accelerating unit

Waveguide directional couplers
- Manufacturer: Max IV, Lund, Sweden
- Flanges: LIL
- Coupling: 50 dB
- Some have CF40 port for ion pump connection



SLED cavity with 3dB hybrid coupler
- Manufacturer: Research Instruments GmbH, Bergisch Gladbach, Germany

Room temperature S-band travelling wave accelerating structure
- Manufacturer: Research Instruments GmbH, Bergisch Gladbach, Germany
- Resonant mode: 2π/3
- Accelerating gradient : 20MV/m
- Length: 5m

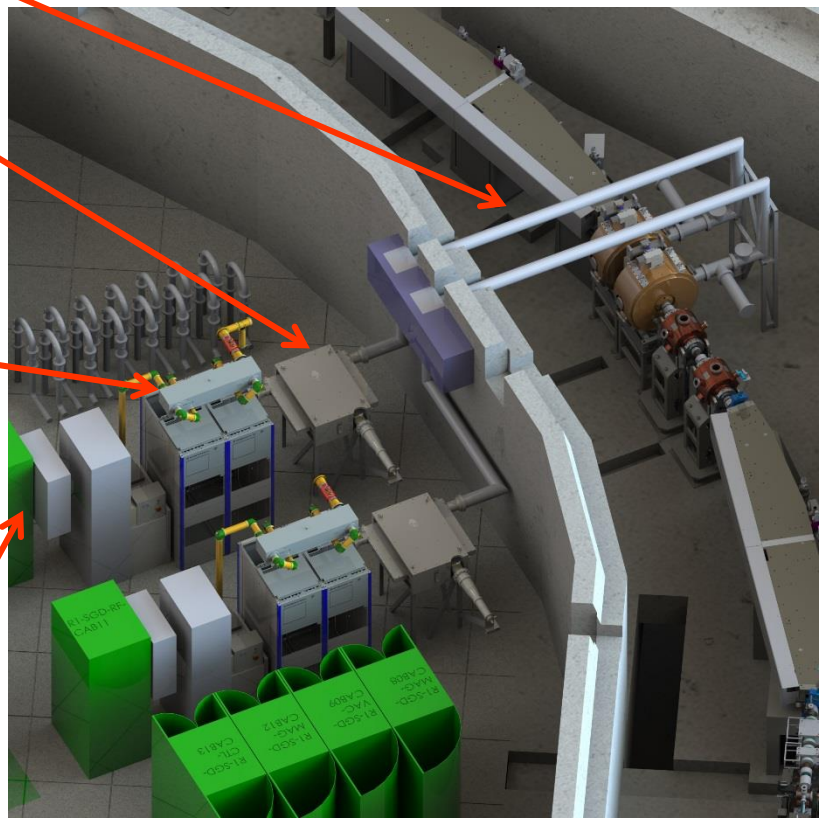
Storage Ring RF

6 1/8" EIA rigid coax line and directional couplers
- Manufacturer: Exir Broadcasting AB, Hörby, Sweden

Isolator
- Manufacturer: AFT, Backnang – Waldrems, Germany
- Forward peak power: 120 kW CW
- Reverse power: 100% at any phase

100MHz RF Transmitter THR9
- Manufacturer: Rohde & Schwarz GmbH, Germany
- Technology: Solid state
- RF frequency: 99,93 MHz
- RF peak power: 60 kW CW

Digital LLRF for Storage Ring
- Manufacturer: ALBA, Barcelona, Spain
- Commercial µTCA board
- Control of amplitude and phase cavity voltage and resonance frequency control (Tuning)
- Safety Interlock and Diagnostic
- Fast data logger
- I/Q demodulation technique

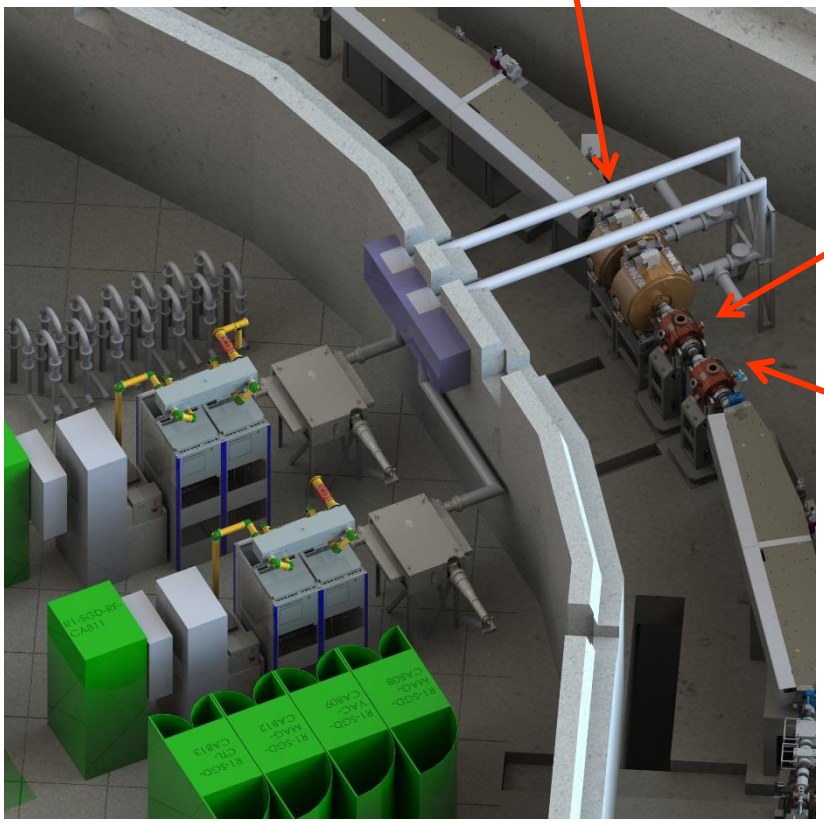


Two identical system for two cavities are controlled by LLRF

Storage Ring RF

100MHz Main Cavity
- Manufacturer: Research Instruments GmbH, Bergisch Gladbach, Germany
- Upgraded MAX-Lab cavity
- Resonant frequency: 99,93 MHz
- Tuning range: ±540 kHz
- Gap voltage: 300 kV

300MHz Landau Cavity
- Manufacturer: Research Instruments GmbH, Bergisch Gladbach, Germany
- Tuning range: ±550 kHz
- Total voltage: 487 kV



Plunger for fast detuning of Landau Cavity during injection and ramping
- Manufacturer: Measline Krakow, Poland
- Detuning range: 500 kHz

Storage of components 12.2013-05.2014

Expected beginning of installation: December 2013

Building handover: 05.05.2014
Postponed installation caused logistic problems

Accelerating structures (pressurized with N_2) - building of Solaris in container

Waveguides (pressurized with N_2)– storage place at Jagiellonian University

Main cavities (vacuum) – Max Lab, Sweden

Modulators + klystrons (vacuum) – Scandinova, Sweden

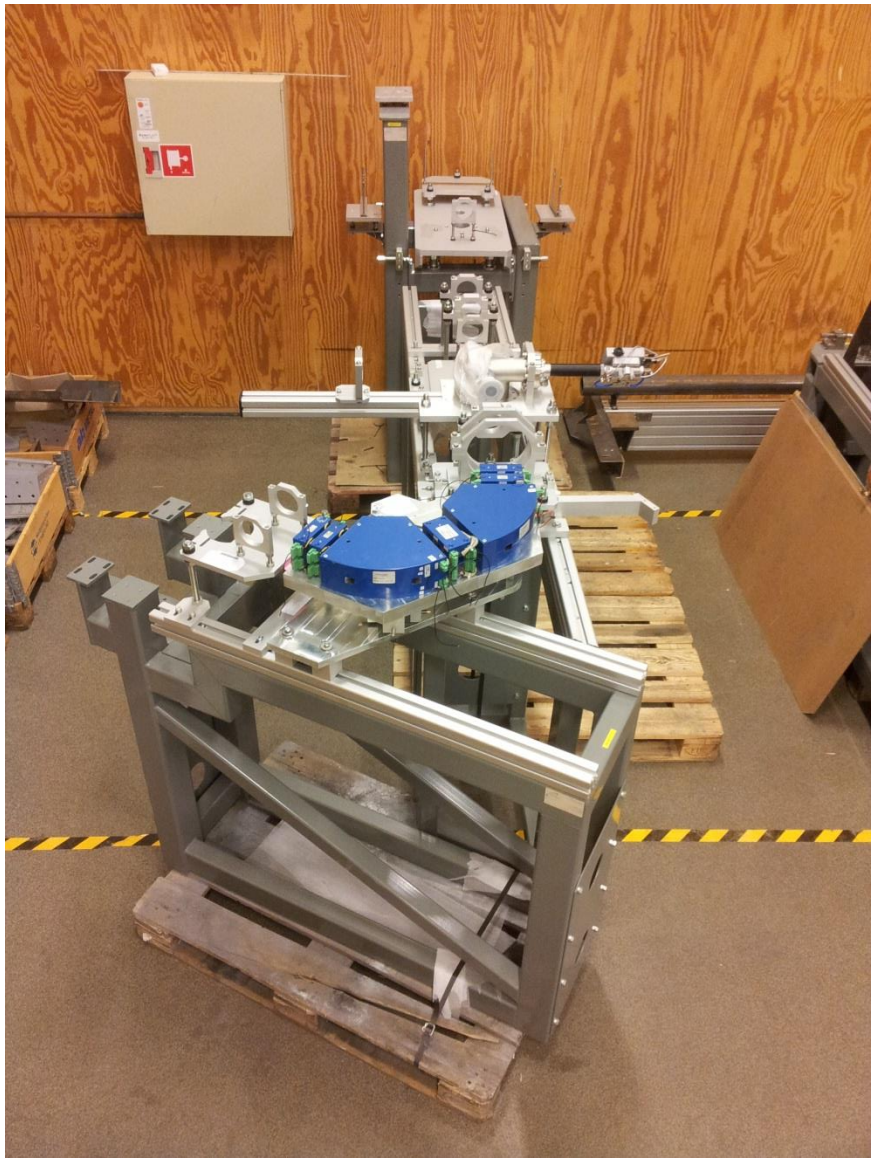
Electron Gun System
Test assembly

March 2014 at Max LAB

Good training to avoid assembly mistakes in Solaris

Delivered as a „plug-in" component

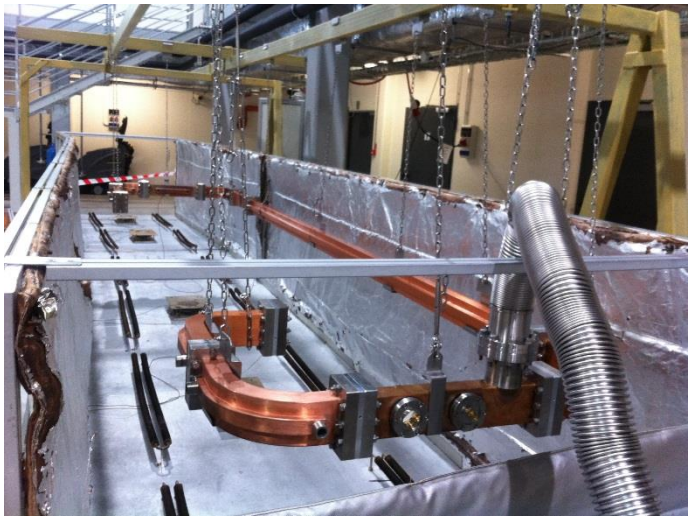
Gun was conditioned in test-stand at Max LAB



Bake-out of waveguides

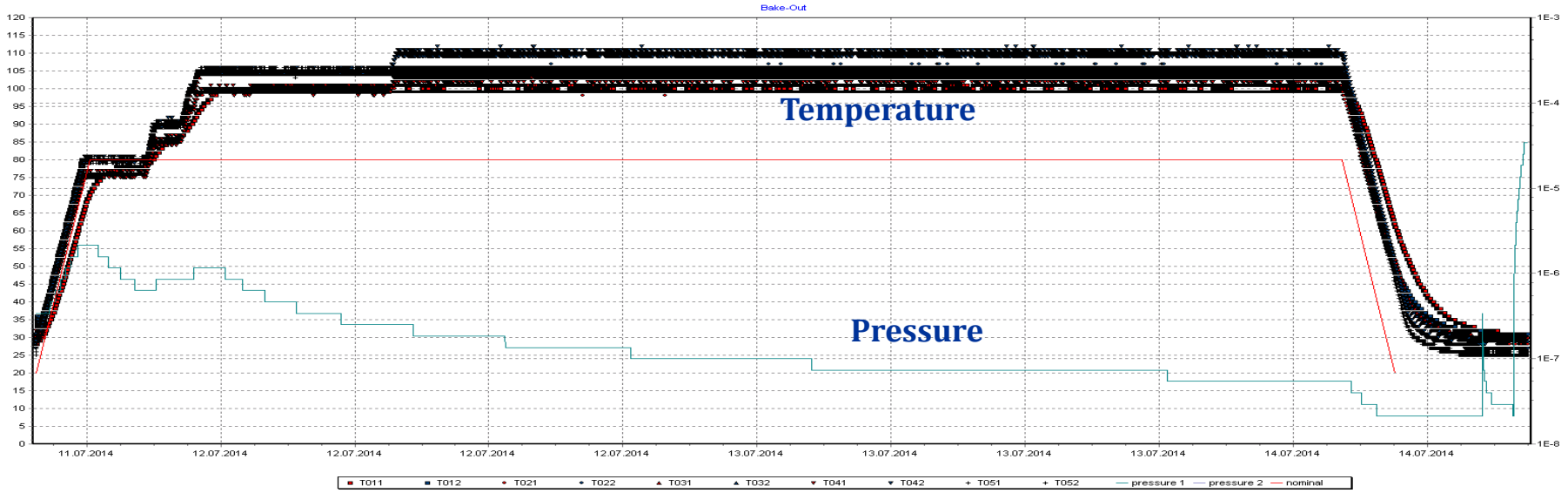
June -July 2014

3 days cycle at 110 °C



Oven borrowed from PSI

Thank you!



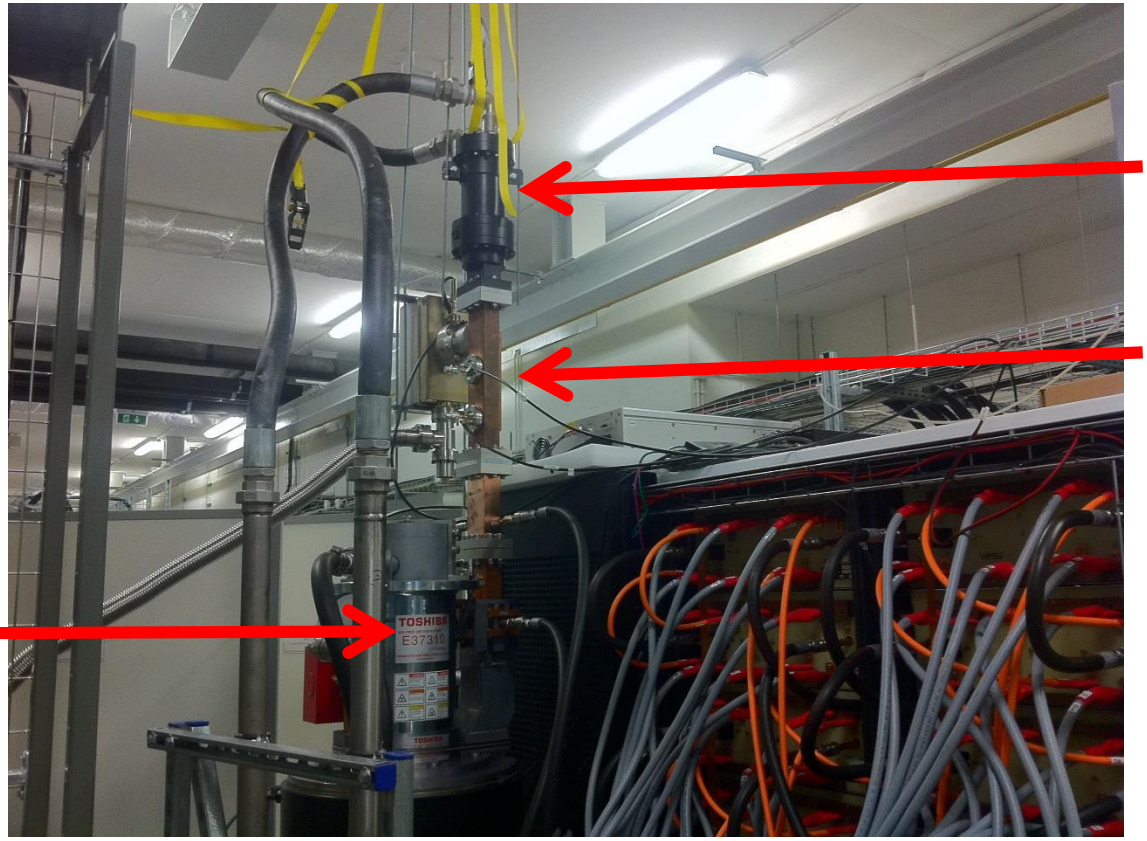
Injector Installation

02.06.2014	Start of linac installation
17.06.2014	Start of linac vacuum assembly
08.2014	Linac under vacuum
08-11.2014	Cabling and water installation
09.2014	Gun system and transfer line under vacuum
10.2014	SAT of modulators
11.2014	Connecting of klystrons to waveguides
11.2014	Start of conditioning of waveguides and accelerating structures

RF sub-system test Linac

Start-up of high power RF

One K2 modulator driven up to 33MW on dummy load



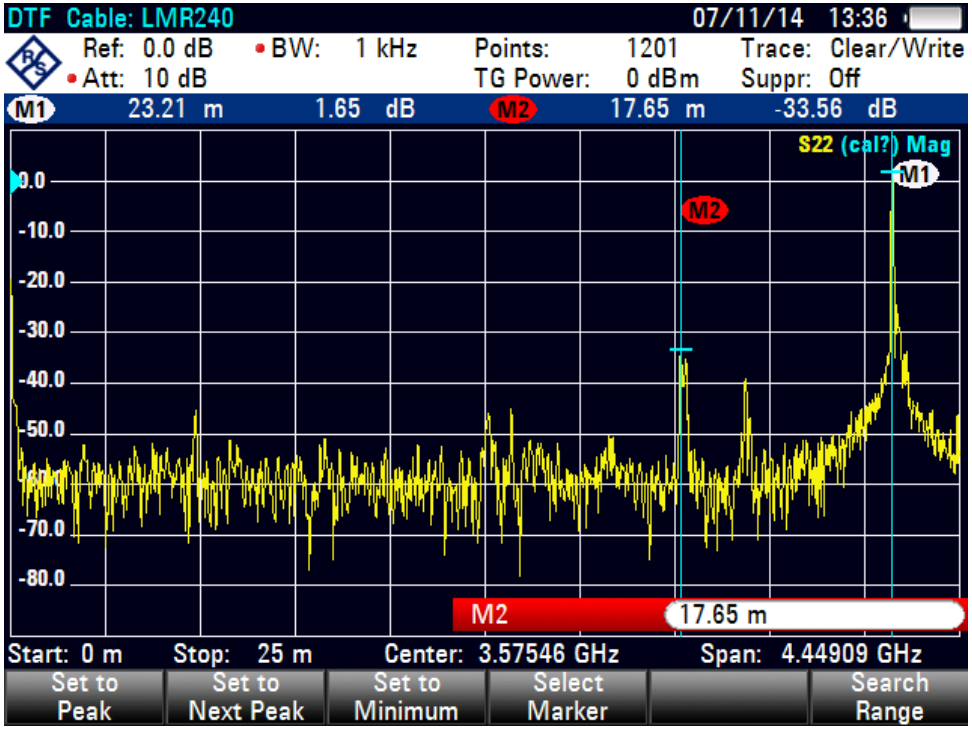
Water cooled waveguide dummy load

waveguide directional coupler

klystron

RF cables

1. Education of sub-contractor about importance of work quality
2. Each RF cable examinated before and after installation in terms of:
   - Attenuation at working frequency
   - Distance to fault
   - VSWR
3. Each RF cable has unique serial numer and „from-to" descritpion
4. Around 5% of cables have to exchanged



Injector
Some issues during installation

1. Contamination of waveguides during venting after baking.
    - Viton sealings have broken, exchange to copper one for the next batches
2. Dimension of 3m long waveguides.
    - Manufacturing process – extrusion, not straight
    - Correct order of works to fit with flanges to accelerating structure
3. Water leak in connection on accelerating structure
    - Research Instruments has fixed in-situ
4. Vacuum leak in waveguide, LIL flange brazing
    - New one has been manufactured by HERT Beijing, leaking one has been re-brazed
5. Vacuum leak in waveguide directional coupler
    - Exchange to new one
6. Wrong length of the CPR type waveguide, no possibility to connect gun's modulator
    - Our mistake in 3D model.
    - New waveguide has been manufactured by MaxLab in one week!
7. Water leak in modulator during SAT
    - Not properly crimped water hose

Injector
Conditioning strategy

Klystron conditioning in diode mode has been acomplished in 4 days (after 2,5 years of storage)

1. **Short RF pulse without SLED phase inversion at 1Hz**
   - Increasing of klystron's high voltage, then elongation of RF pulse and start from lower voltage
   - Since conditioning of waveguides after power divider were not efficient, SLED have been used
2. **Short RF pulse with SLED phase inversion at 1Hz**
   - Increasing of klystron's high voltage, then elongation of RF pulse and start from lower voltage
   - When reasonable high voltage has been achieved, increasing of repetition rate to 5Hz, 10Hz, 50Hz and 100Hz with start from lower voltage (it depends on vacuum activation)
3. **Nominal RF pulse length at 100Hz**

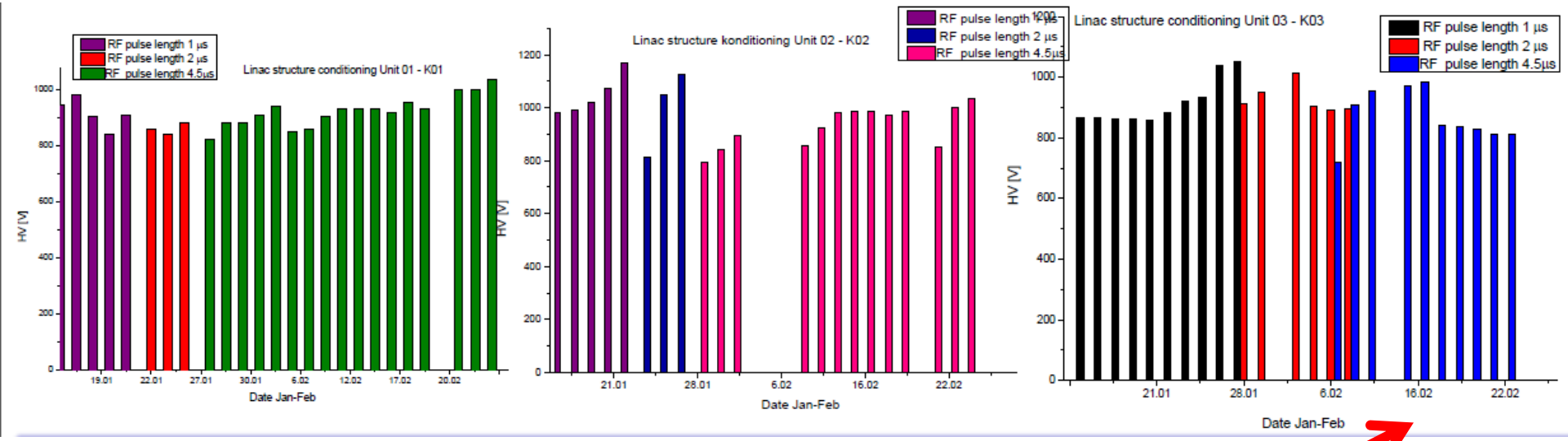
Baking out of waveguides before installation helped in conditioning process

Shifts organisation for linac conditioning (January- February & May-June):

Monday -Friday; 7 a.m. – 9 p.m.

Injector Conditioning

January – February 2015

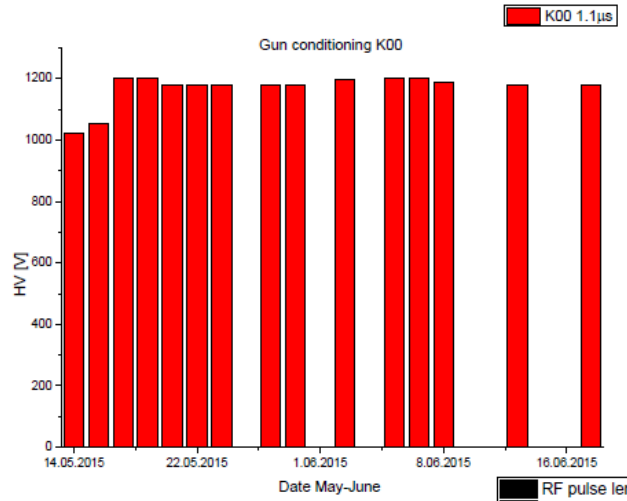


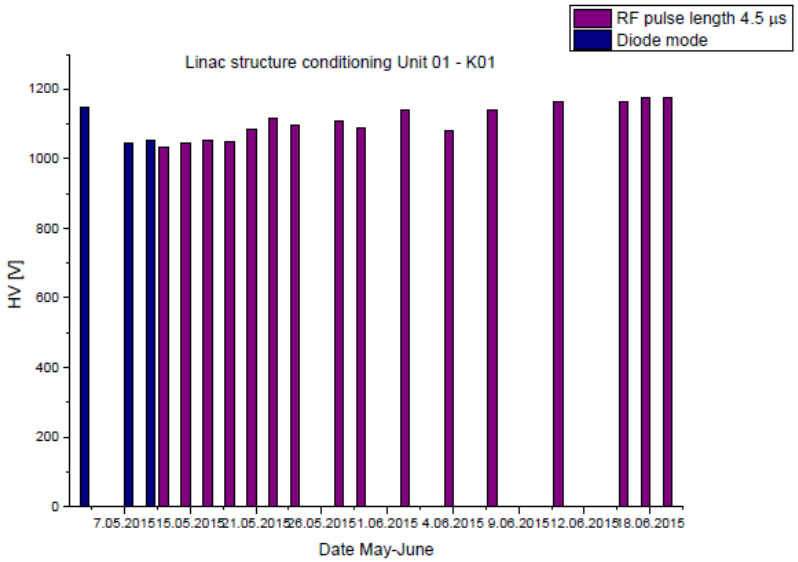
3rd accelerating unit worse at nominal pulse length

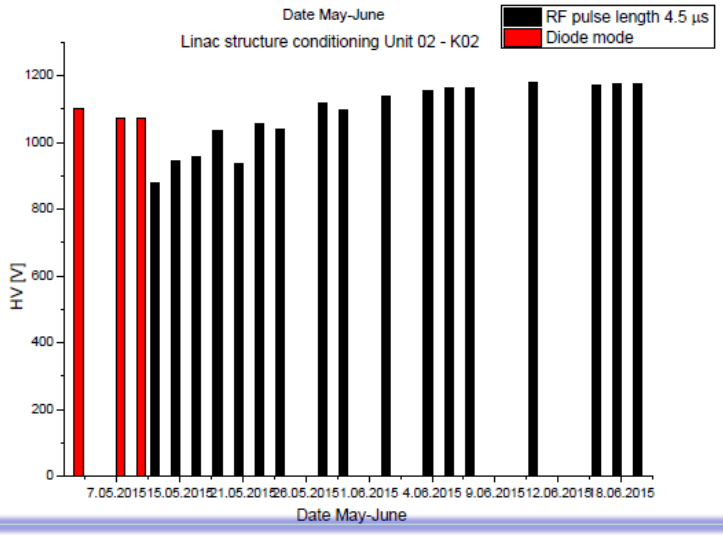
Courtesy of A.Wawrzyniak

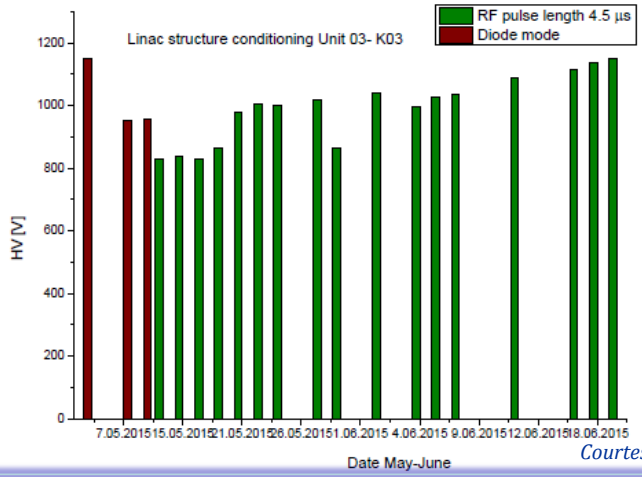
Injector Conditioning

May – June 2015, after shutdown for transfer line installation



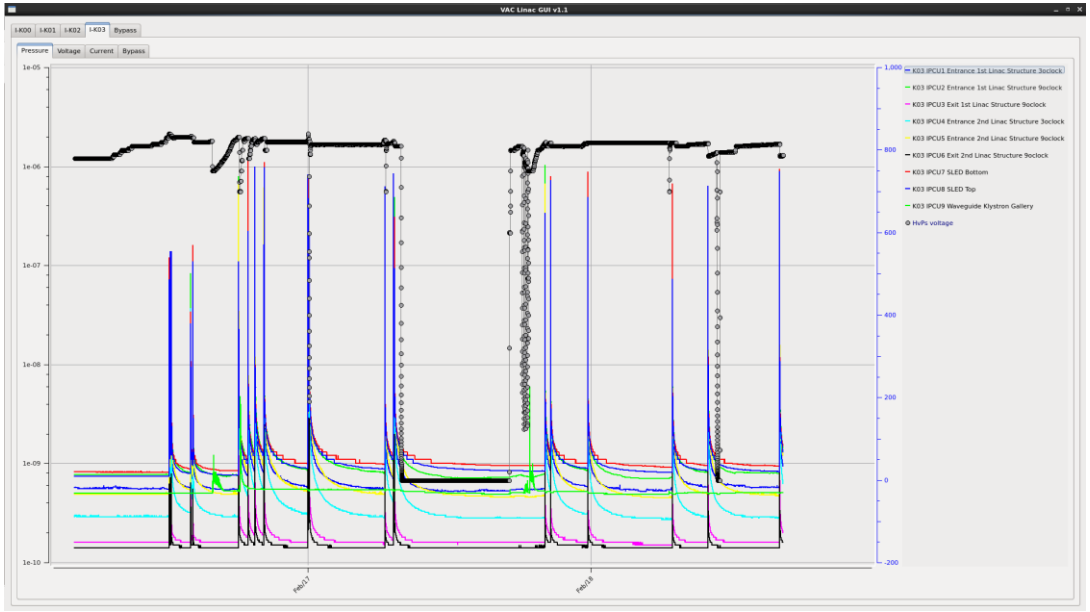






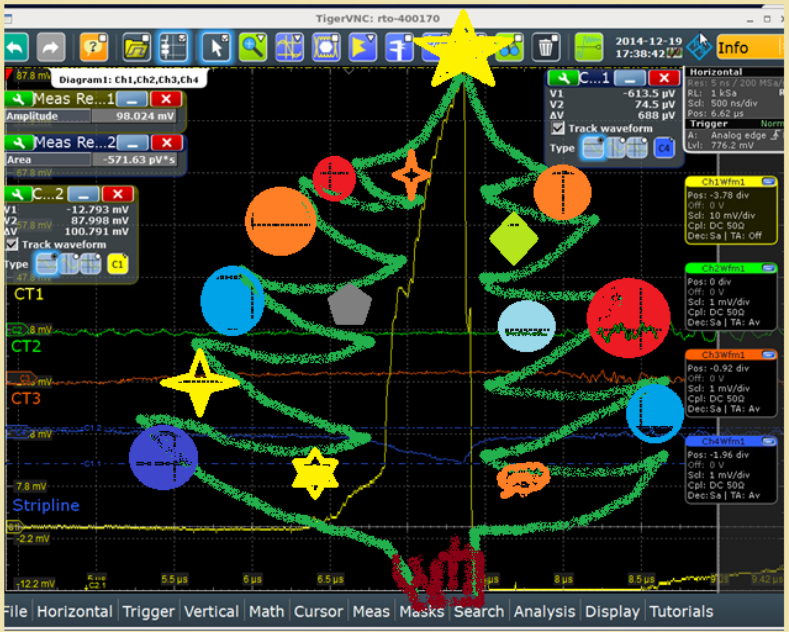
Courtesy of A.Wawrzyniak

Arcing in waveguides



- **Broken many of 20dB attenuators and RF sensor diodes**
- **Still some conditioning necessary after weekend shutdown**

First beam from RF thermionic gun



19.12.2014

First electrons from SOLARIS RF GUN

RF Power Forward to the gun= 0.86MW

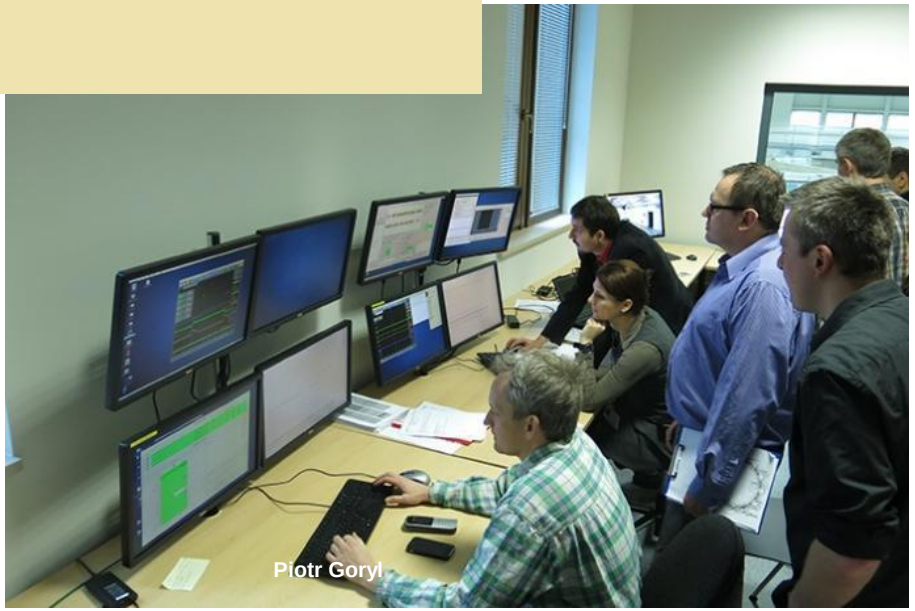
Electron current = 100mA

Merry Christmas
and a Happy New Year

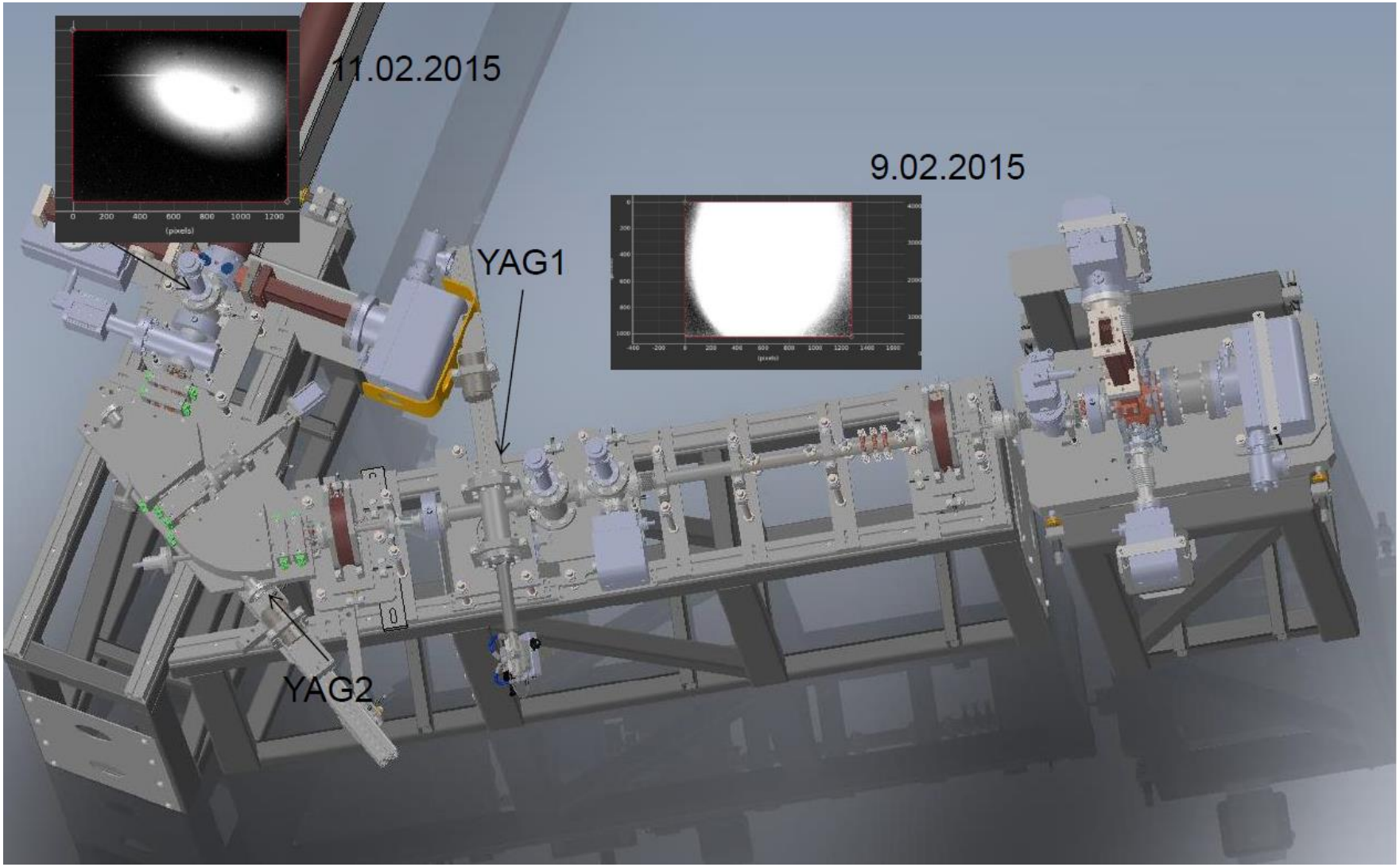
SOLARIS TEAM

Current transformer signal just after gun

Last day (Friday) before Christmas shutdown

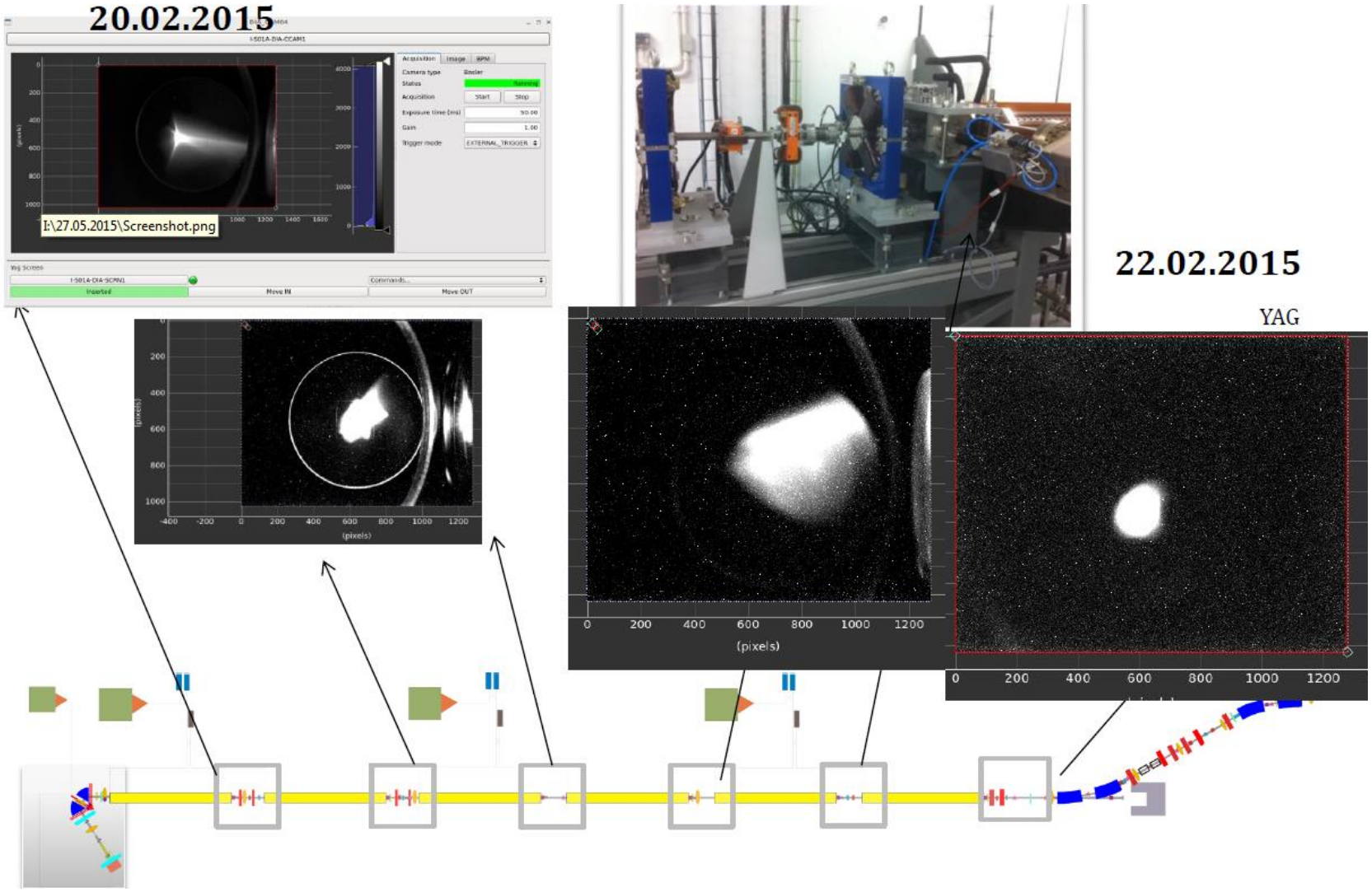


Beam commissioning in gun system



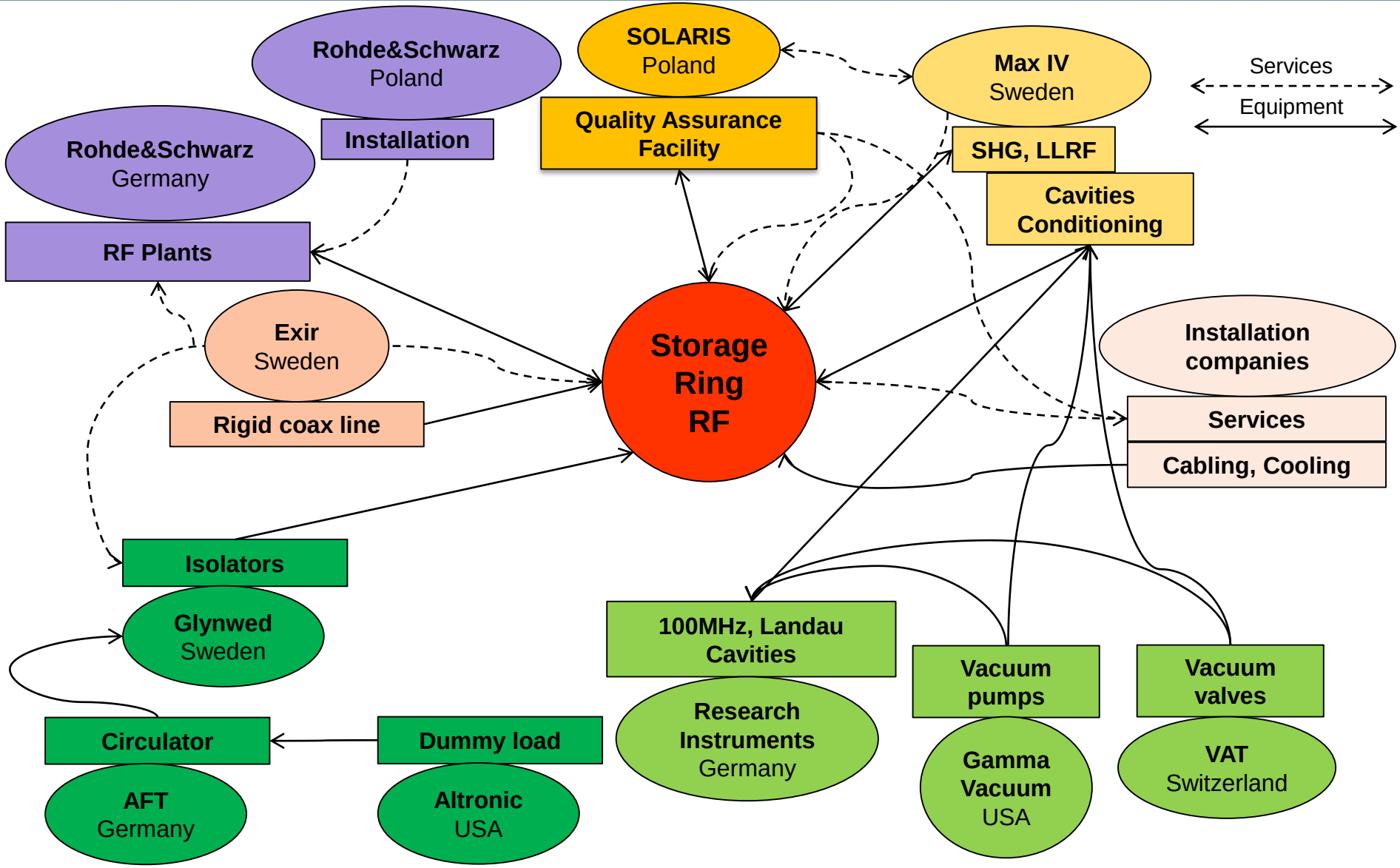
Courtesy of A.Wawrzyniak

Beam in linac



Courtesy of A.Wawrzyniak

Storage Ring RF Integration



Storage Ring RF
High power RF

1. **Modification of raised floor, electrical grid in service galery 02.2015**
2. **Signature of contract with Rhode&Schwarz, Sweden in December due to formal reason with delivery date 10.03.2015**
    - **SAT of transmitters 23 - 27.03.2015**
    - **First THR9 system and highest installed RF power in Band II in Poland**
3. **Signature of contract with Rhode&Schwarz Poland for installation of transmitters and assistance during SAT**
    - **16 - 20.03.2015**
4. **Signature of contract with Exir, Sweden for installation of rigid line and assistance during SAT of circulators**
    - **Connection of transmitters to circulators with rigid line 07.04.2015**
    - **Connection of circulators to cavities with rigid line 15-17.04.2015**
5. **SAT of circulators 08 - 10.04.2015. AFT required to fix SAT date 8 weeks in advance**

Storage Ring RF
High power RF

High power SR RF installed and tested within 5 weeks

10.03.2015 to 17.04.2015

Storage Ring RF
Rohde & Schwarz plants

1. **Delivery and installation**
   - **Among of 24 delivered packages one with water connectors was missing, it has been shipped in 2 days**
   - **Installation time not correctly estimated, finishing during SAT of 1st system**
2. **SAT of transmitters on dummy load**
   - **PLC interlocks not ready (Solaris), locally wired interlock loop**
   - **Both systems achieved 60kW RF output**

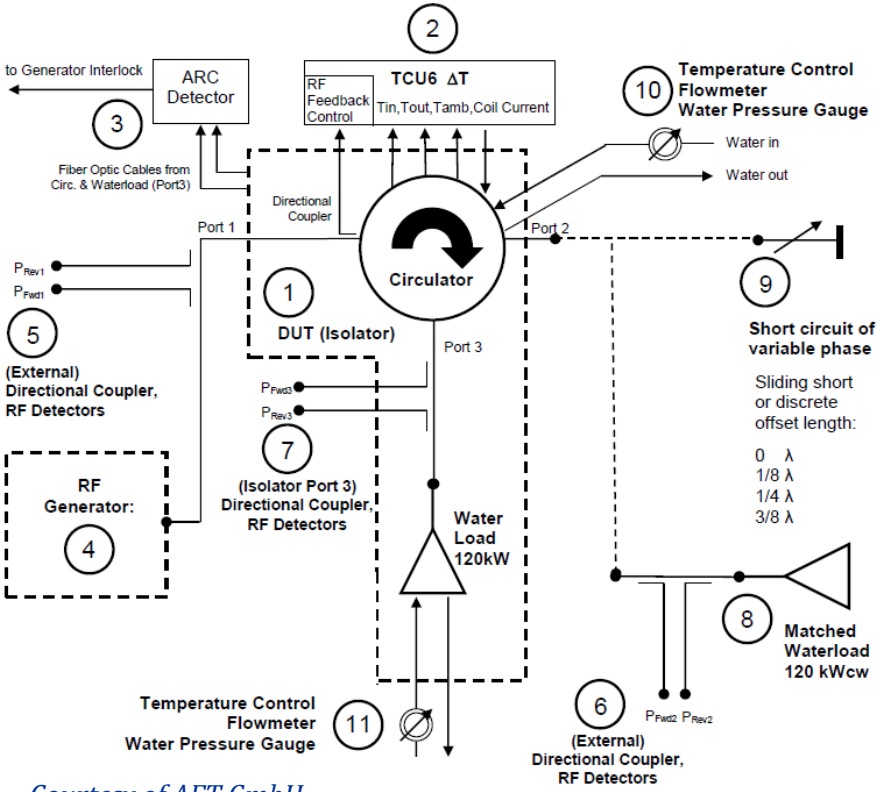
Storage Ring RF AFT circulators

Delivery and installation

- New 2-ports arc detector electronics

SAT

- Test at dummy load and 0λ, 1/8λ, 1/4λ, 3/8λ terminations



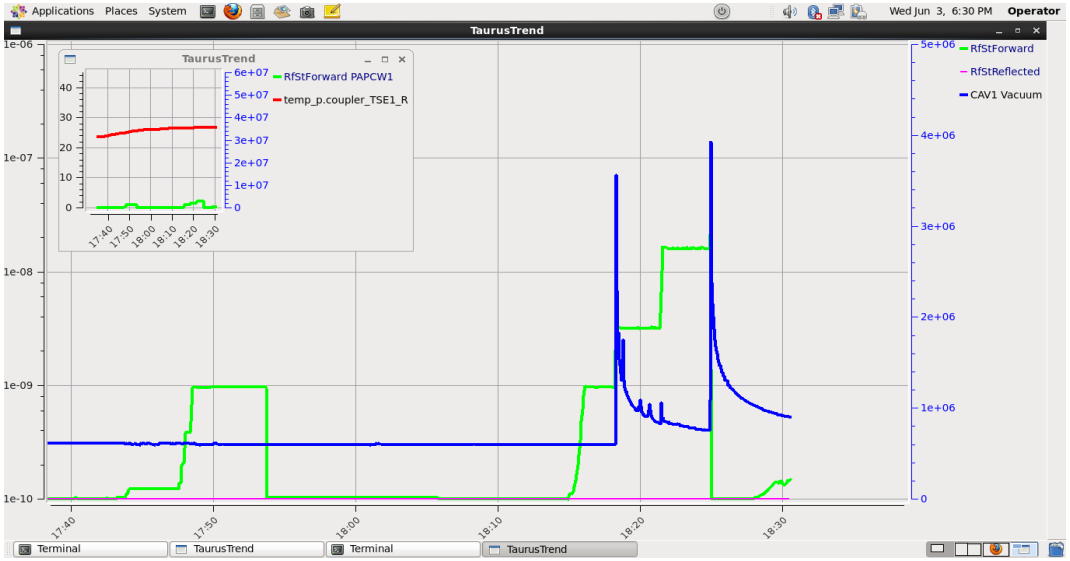
Courtesy of AFT GmbH

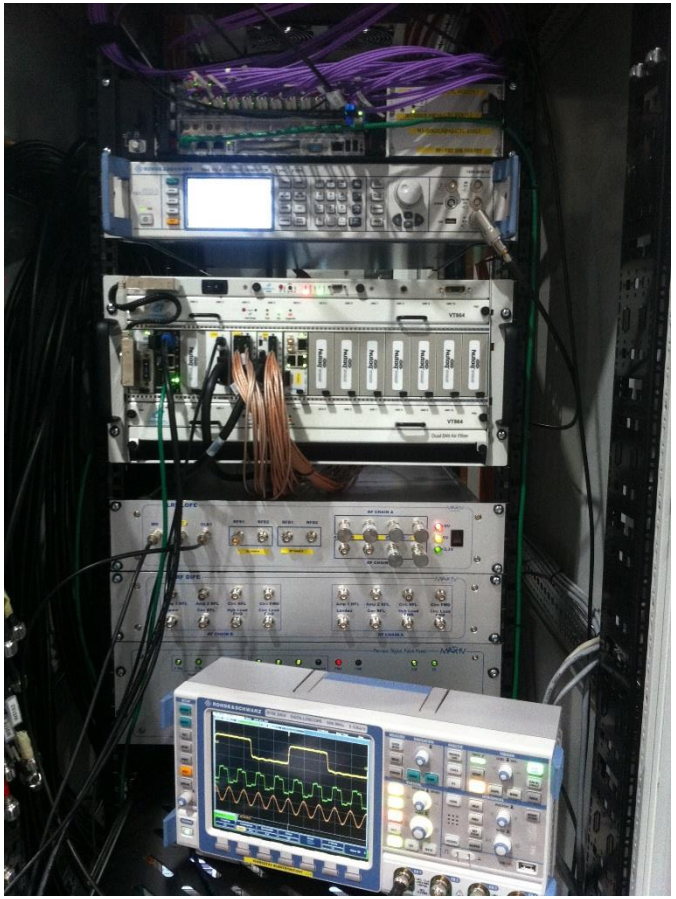
Storage Ring RF Integration issues

- Vibroisolators damage in cooling fan support, replaced for new, safe type
- Foreign object in cooling circuit, removed
- Damage of ceramic insulator (myself) in ion HV connector. Exchange of ion pump, additional venting was necessary
- False alarms from arc detectors in circulators. After long investigation found that ground connection between arc detector and PLC works like antenna. Optocouplers has been installed.
- Overlooked β tuning (from 1 to 2) during installation for beam operation, additional venting was necessary. Phase matching of pick-ups at the same time.
- Not sufficient flow in water cooling of main cavities, additional pump installed

Storage Ring RF LLRF

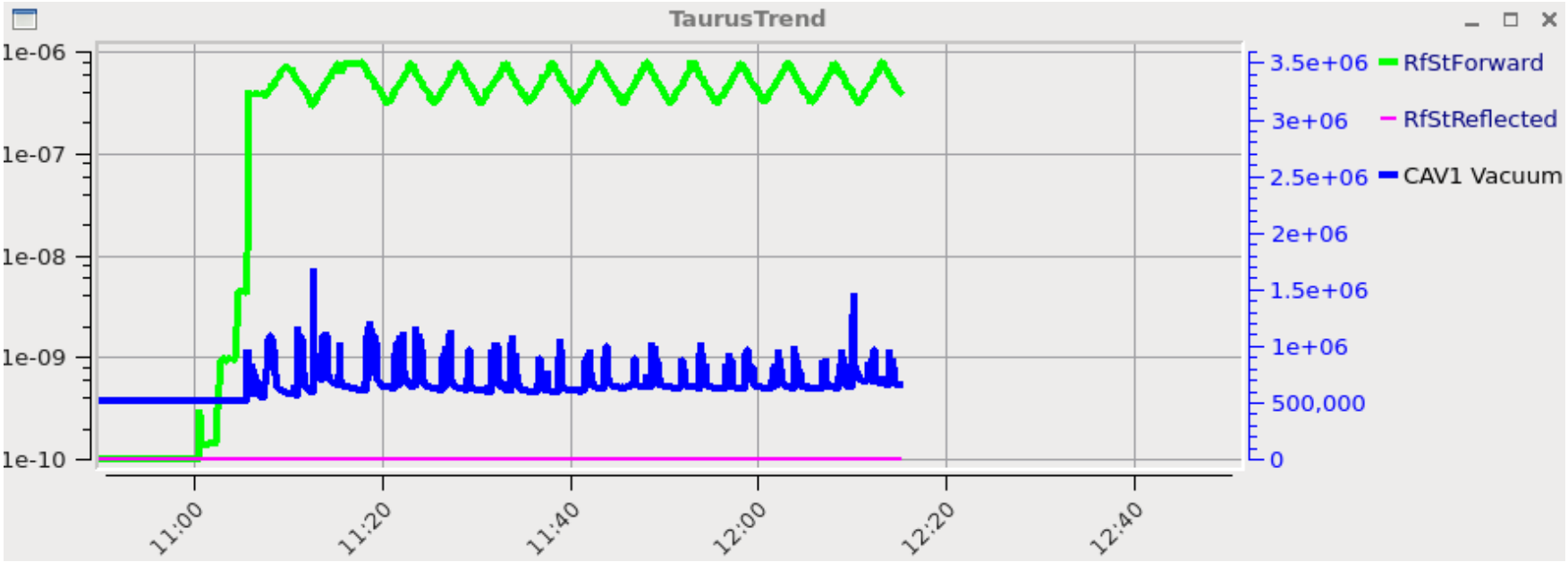
Delivered on 18.05.2015
Commissioning with presence A.Salom (Alba synchrotron).
03.06.2015 first RF in one cavity from LLRF





Automatic cavity conditioning:

- **Disabling RF transmitter at 1,3e-07mbar, manual reset is required**
- **High vacuum level at 5,0e-08mbar**
- **Low vacuum level at 1,0e-08mbar**
- **Controlling of RF power to keep vacuum between low and high**
- **Additional code for sweep of RF power especially around multipacting area**
- **Both cavities conditioned up to 30kW** (there were conditioned before installation at Max Lab as well)



Storage Ring RF Landau cavities

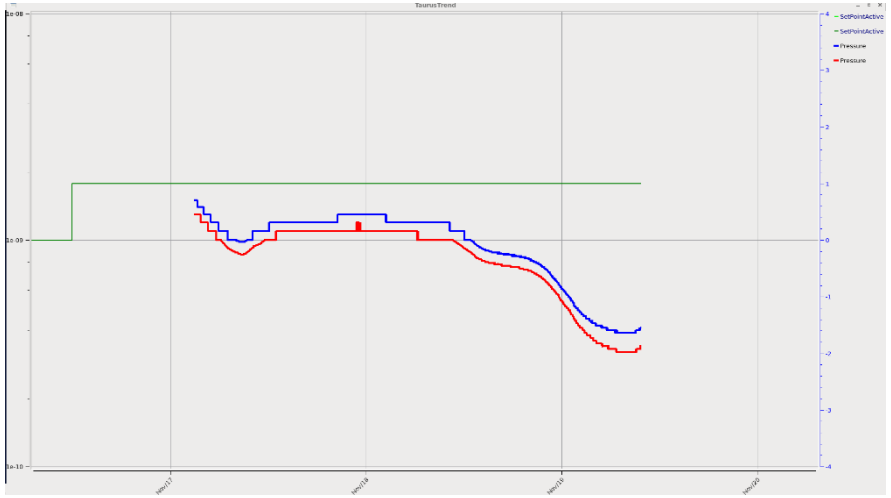
Delivered to Solaris but not installed in first stage of commissioning.

- Easier start-up of SR

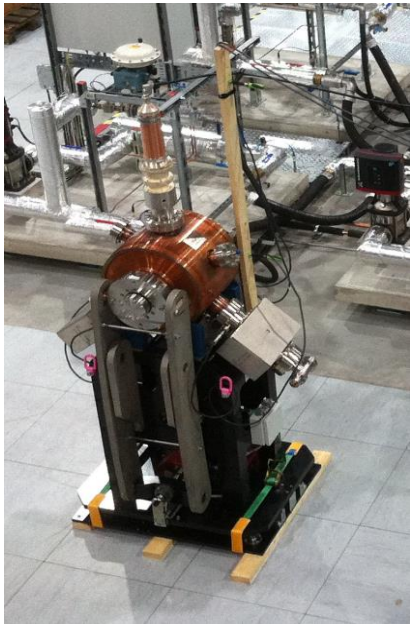
07.2015 Baked out

11.2015 Conditioning at 50W only because no test-stand available @ Solaris

- Power coupler borrowed from Max IV
- 50W RF power, monitoring of Pfor and Pref
- Without cooling, without tuning of cavity
- Manual reflected RF power optimisation (change of signal generator frequency)
- Vacuum interlock
- No radiation has been observed, No shielding required

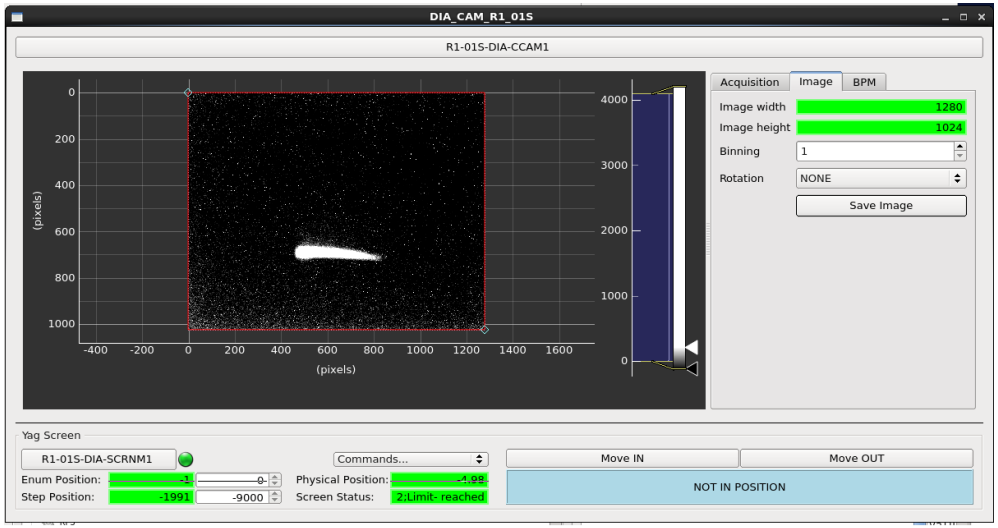


12.2015 Installation in SR

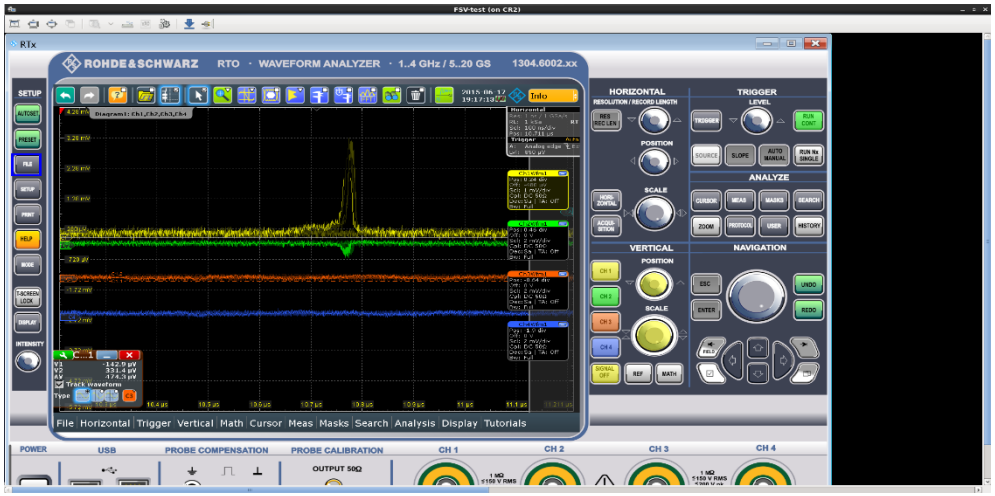


Beam in SR

04.05.2015 restart of linac after storage ring installation



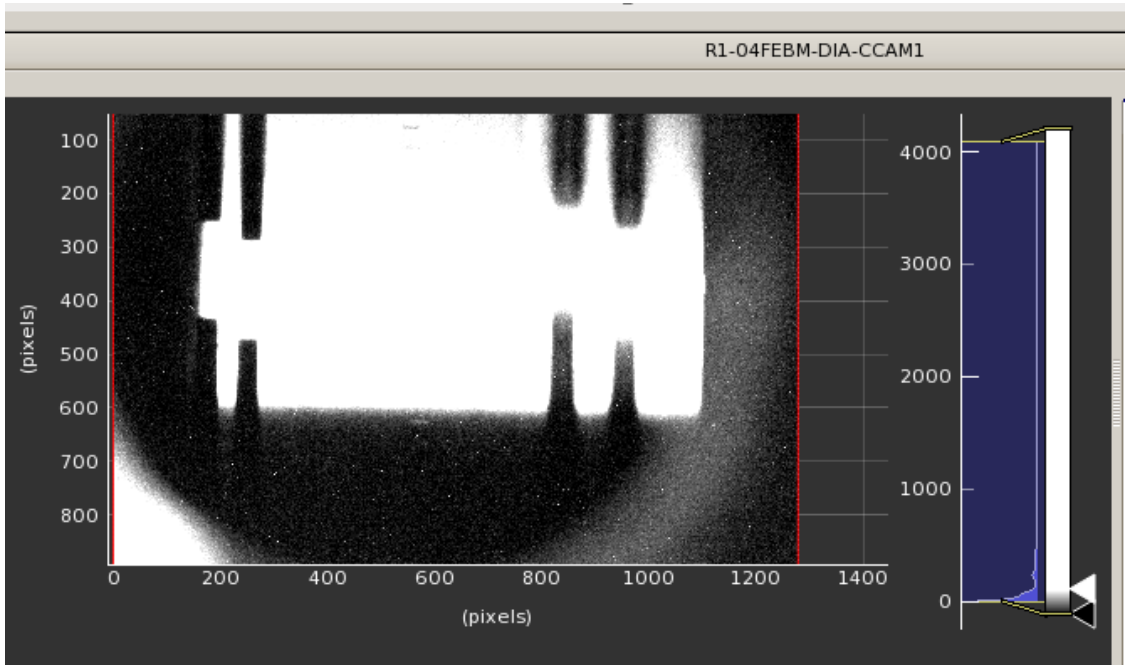
27.05.2015 first beam in storage ring,
Energy 320 MeV
Charge 1.5 nC
Rep. rate 10Hz



11.06.2015 first turn in storage ring
stripline kicker connected
to scope

Beam in SR

31.07.2015 Max. accumulated current 13,5 mA



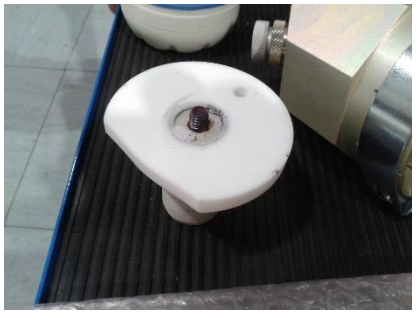
Photon beam @ BL04 front end YAG screen

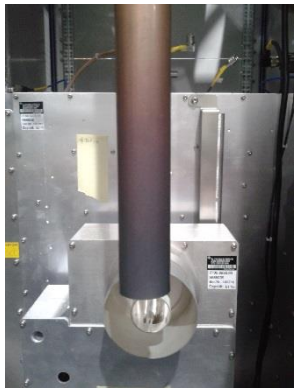
Recently we accumulated 408 mA! More than 10 Ah accumulated beam dose.

Storage Ring RF Operational expierence

Rhode & Schwarz transmitters, modularity make operation possible even with some issues:

- Overheating of 3 1/8” elbow, wrong inner spacer assembly





- Cooling pumps didn’t start, thermal interlock switched off transmitter but permanent problem with one module. After 2 visits in service it will be exchange for the new one.

100MHz cavities

- Stacked tuner mechanism, not enough grease in tapered roller bearings. Exchanged to new ones.
- Leakage up to 1.0e-7 mbar*l/s at ceramic of pick-up (already 4 pieces), even after one discharge in the cavity. They will be replaced for pick-up loop without ceramic.

Ceramic – vacuum side, 30 x

Metal inclusions

Crack

Acknowledgment

I WOULD LIKE TO EXPRESS SPECIAL THANKS TO

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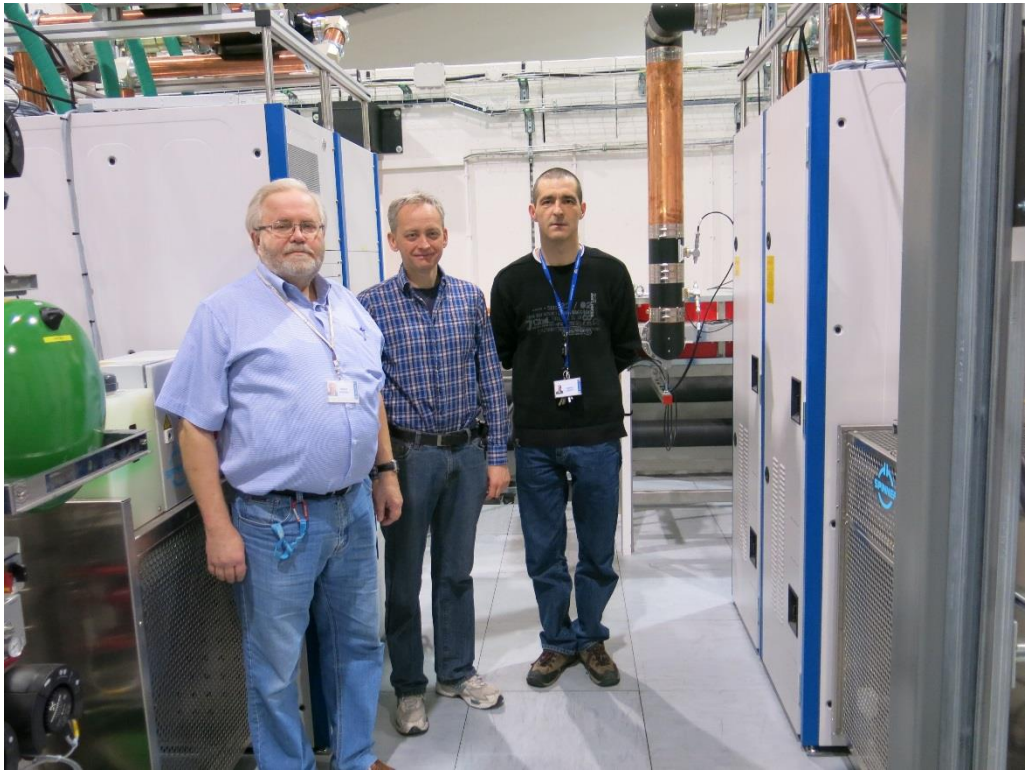
ELETTRA TEAM for the assistance and consultancy in various areas of the project

ANGELA SALOM for support with LLRF



Virtual tour of SOLARIS:

http://synchrotron.wkraj.pl/?EN#

Thank you for your attention