JAGIELLONIAN UNIVERSITY IN KRAKOW

SOLARIS NATIONAL SYNCHROTRON RADIATION CENTRE

Solaris - The Polish Light Source
A new generation of high brightness storage rings

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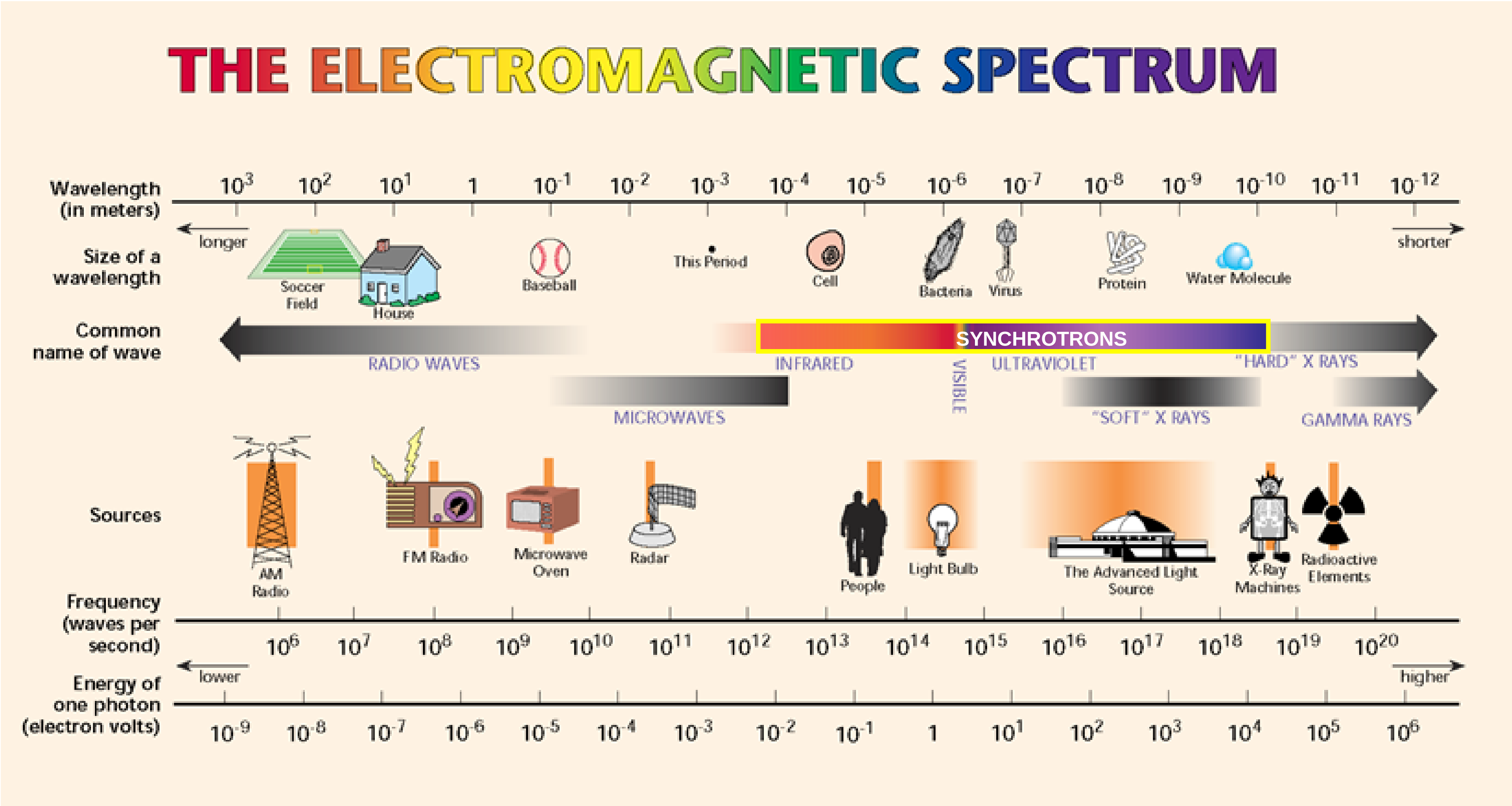
Outline

- Introduction
- MAXIV design
- Solaris project overview
- Beam commissioning
- Near and far future
- Summary

Introduction

Synchrotron – unique source of electromagnetic (EM) radiation

Change of electron trajectory => EM emission => magnets-the heart of synchrotron



Brightness

$$\text{Brightness} = \frac{\text{Flux}}{4\pi^2 \Sigma_x \Sigma_{x'} \Sigma_y \Sigma_{y'}} \propto \frac{I_{beam}}{\varepsilon_x \varepsilon_y}$$

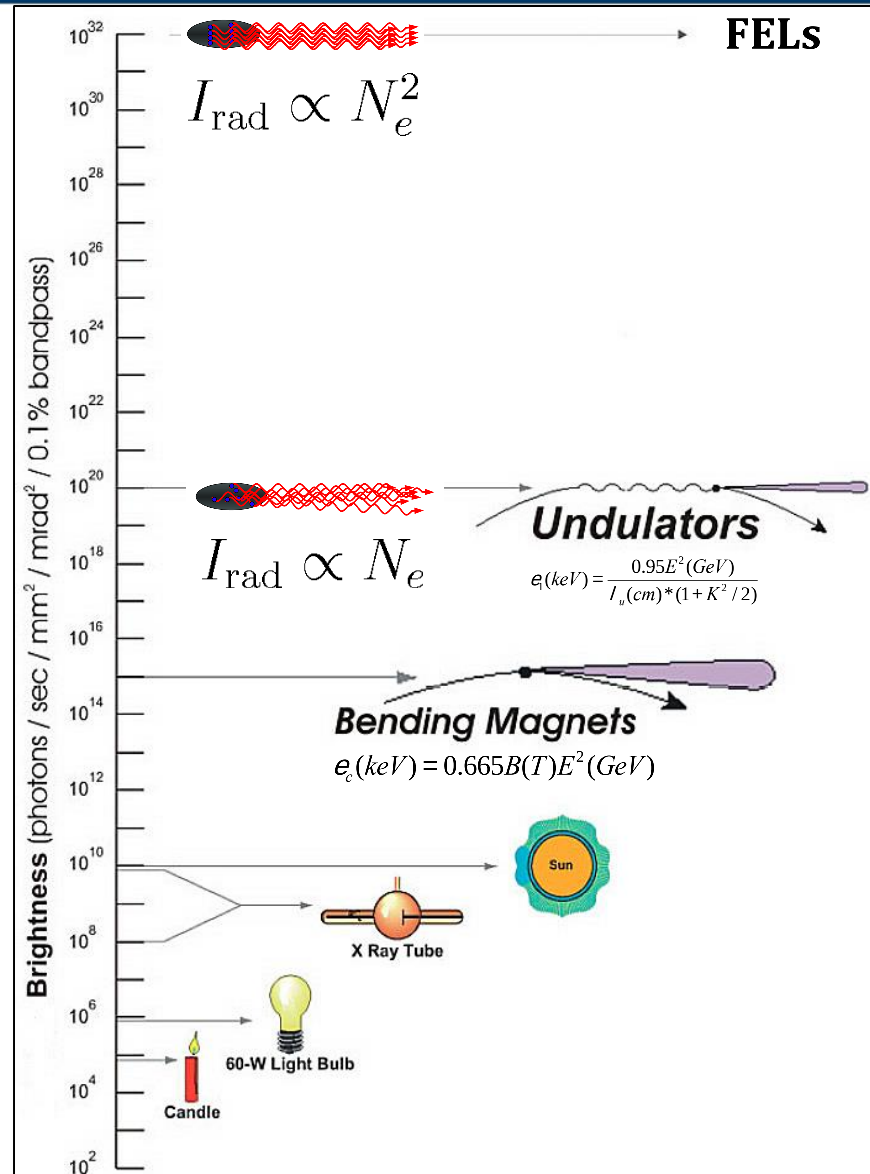
$$\Sigma_{x,y} = \sqrt{\sigma_{x,y}^2 + \sigma_r^2} \qquad \Sigma'_{x,y} = \sqrt{\sigma'^2_{x,y} + \sigma'^2_r}$$

Brightness increases with smaller emittance and higher current.

Users want diffraction limited light:

$$\varepsilon_{x,y} << \varepsilon_r = \frac{\lambda}{4\pi}$$

$$\lambda = 1\,\overset{\circ}{\mathrm{A}} \Rightarrow \varepsilon_r = 8\ \mathrm{pm} \cdot \mathrm{rad}$$



Emittance reduction

- Emittance scales with an energy and a circumference

$$e_0 = F(\mathrm{cell})\frac{E^2}{N_d^3}\,\mu\,\frac{E^2}{C^3} \qquad e_x = \frac{1}{1+k}e_0 \qquad e_y = \frac{k}{1+k}e_0$$

F(cell) – constatnt depending on the lattice design, E – beam energy, N_d -Number of magnets , C- circumference, κ -coupling

- Emittance reduction with the damping partition:

$$e_0 = C_q \frac{g^2 I_5}{J_x I_2}$$

J_x Damping partition number,
I_5, I_2 synchrotron radiation integrals
C_q –physical const.

- Emittance reduction with the damping wigglers:

$$e_w \text{ » } \frac{1}{1+\frac{U_w}{U_0}}e_0$$

U_0 , U_w –radiation losses/turn for bare lattice and with damping wiggler, respectivelly

Design challenges

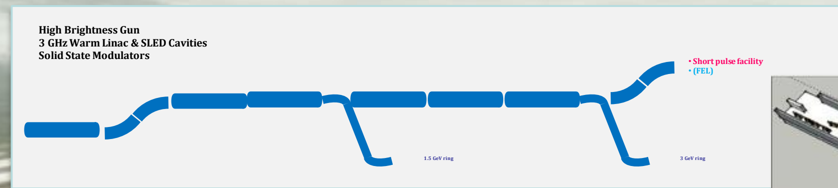
Small emittance comes from strong focusing and ultra stable beams

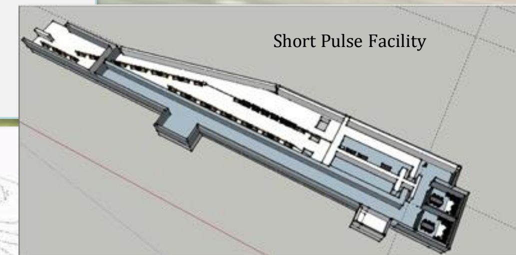
- **Strong focusing -> high negative chromaticity**
- **Strong sextupoles -> amplitude dependent tune shifts**
- **High current -> intra-beam scattering**
- **Large no of dipoles, small radius -> small momentum compaction**
- **Small dynamic aperture and momentum acceptance**
- **Injection problems**
- **Lifetime issues (dense beam)**
- **Instabilities (Head-tail instabilities, transverse coupled-bunch modes, resistive walls, longitudinal)->beam blow up, transverse oscillations ->beam loss**

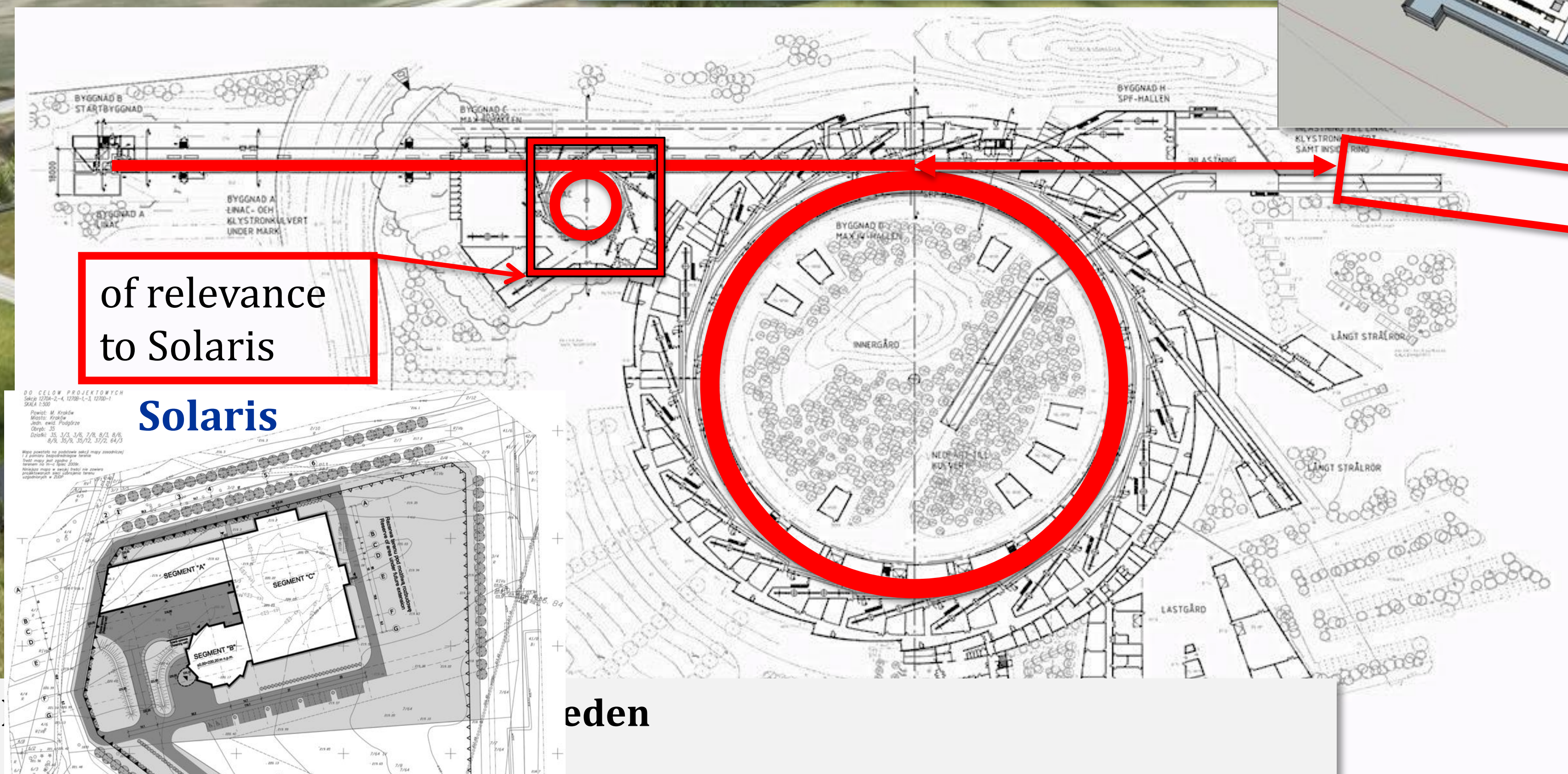
Stronger sextupoles:

- **Small bores/gap of magnets**
- **Small vacuum chambers**
- **Compact magnets design with combined function**
- **Very good alignment**

MAX IV





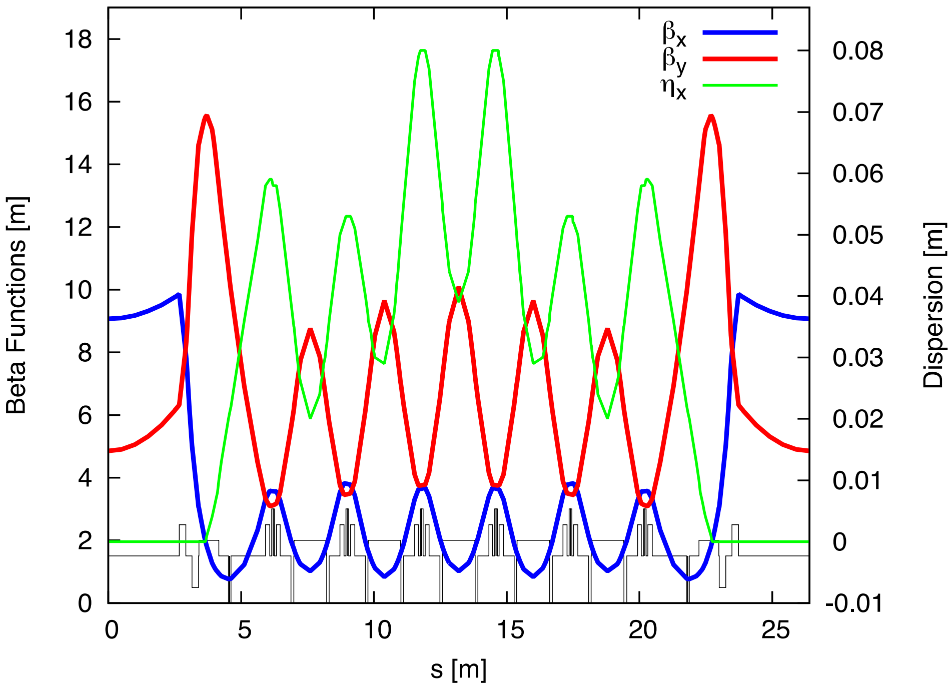


eden

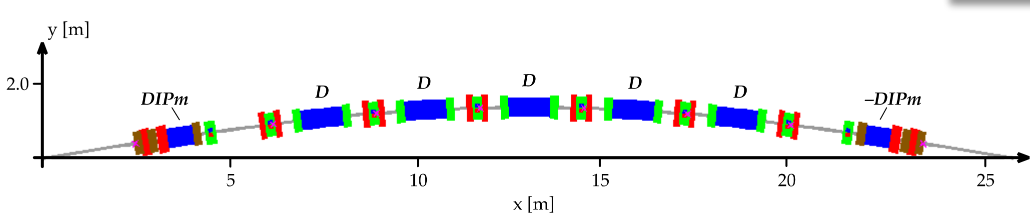
3.0 GeV ring	20 straights (ε=0.328 nmrad) 528 m circumference
1.5 GeV ring	12 straights (ε=6.0 nmrad) 96 m circumference
3.0 GeV linac	Injector + Short Pulse Facility + potential FEL

Courtesy: M. Eriksson, S. Thorin

MAXIV 3 GeV Storage Ring



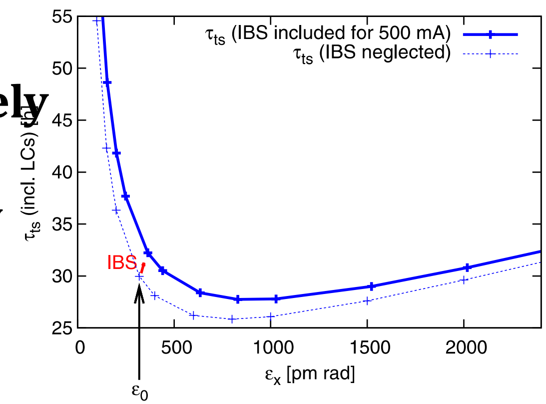
Energy [GeV]	3.0
Main radio frequency [MHz]	99.931
Harmonic number	176
Circulating current [mA]	500
Circumference [m]	528
Number of achromats	20
Length of achromat [m]	26.4
Length of long straight sections [m]	4.8
Length of short straight sections [m]	1.302
Betatron tunes (h/ v)	42.20/16.28
Natural chromaticities (h/ v)	-48.98/-50.20
Corrected chromaticities (h/ v)	+1/+1
Momentum compaction factor	3.06e-4
H. emittance (bare lattice) [nm rad]	**0.328**
Radiation losses / turn (bare lattice) [keV]	363.8
Natural energy spread (bare lattice)	0.769e-3



S.C. Leemann, MAXIV DDR, https://www.maxlab.lu.se/node/1136

Design Optimization

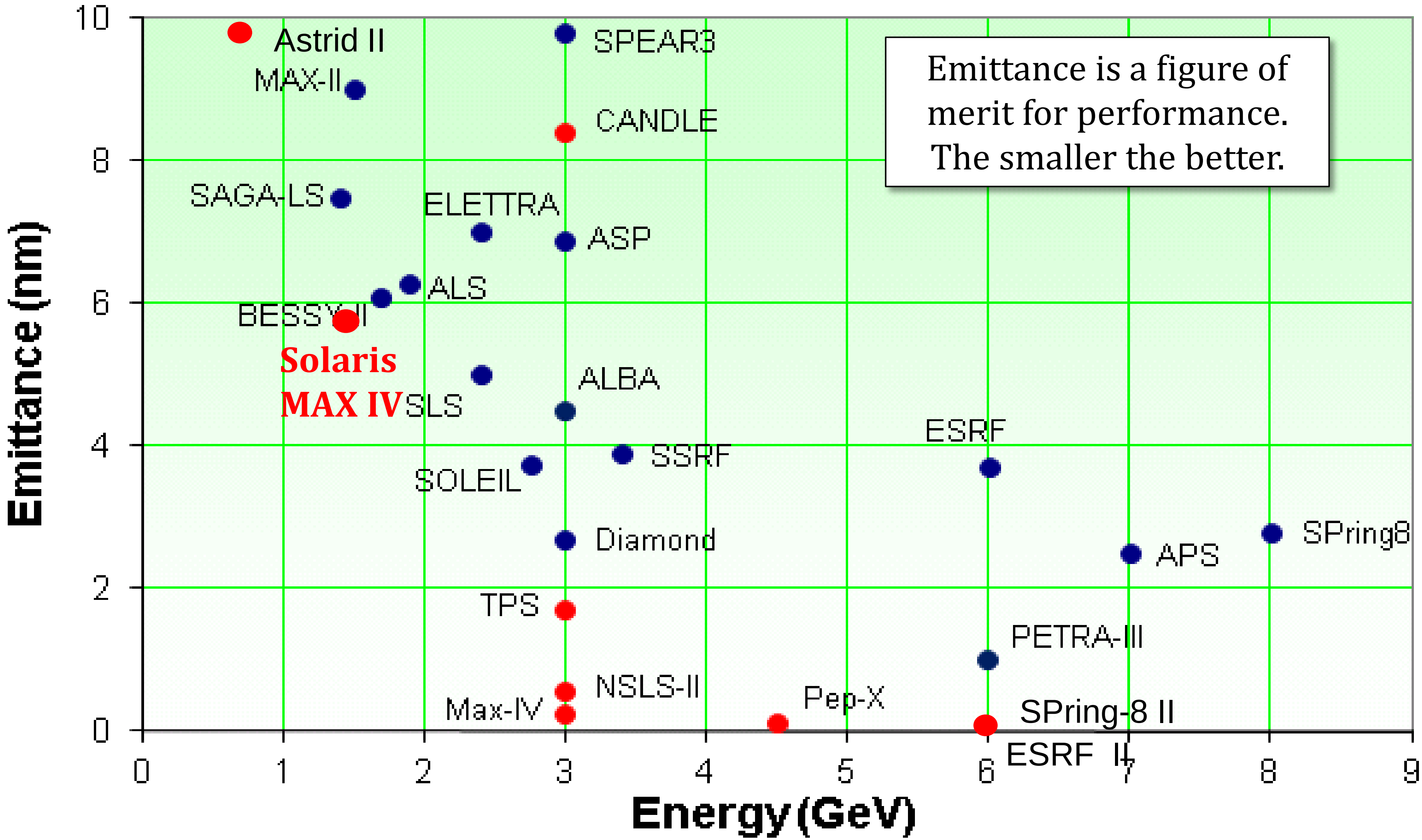
- **Compact magnet design - integrated magnet blocks**
  - **High machining tolerances- 20um**
  - **Stability – stiff object with many magnets with high natural vibration frequencies reducing the sensitivity of the magnets to the environmental vibration noise**
  - **Small gaps**
  - **Dipoles with defocusing gradient**
  - **Octupoles**
- **Narrow vacuum chambers (d=22mm)–copper-NEG coated**
  - **Reduction of ion pumps**
  - **Distributed absorbers**
- **100 MHz RF system –large RF buckets height with relatively low RF power**
- **Landau Cavities -> lengthening bunches -> lower density**
  - **Longer lifetime, lower IBS effect**
- **Injection with single multipole kicker**



S.C. Leemann, Phys. Rev. ST Accel. Beams 17, 050705 (2014)

P.F. Tavares et al., J.Synchrotron Rad, 21, 862, 2014

Emittance



Emittance is a figure of merit for performance. The smaller the better.

Solaris Project Overview

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.

- Tight collaboration with the MAX IV Laboratory in Lund, Sweden.

  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 MAXIV.

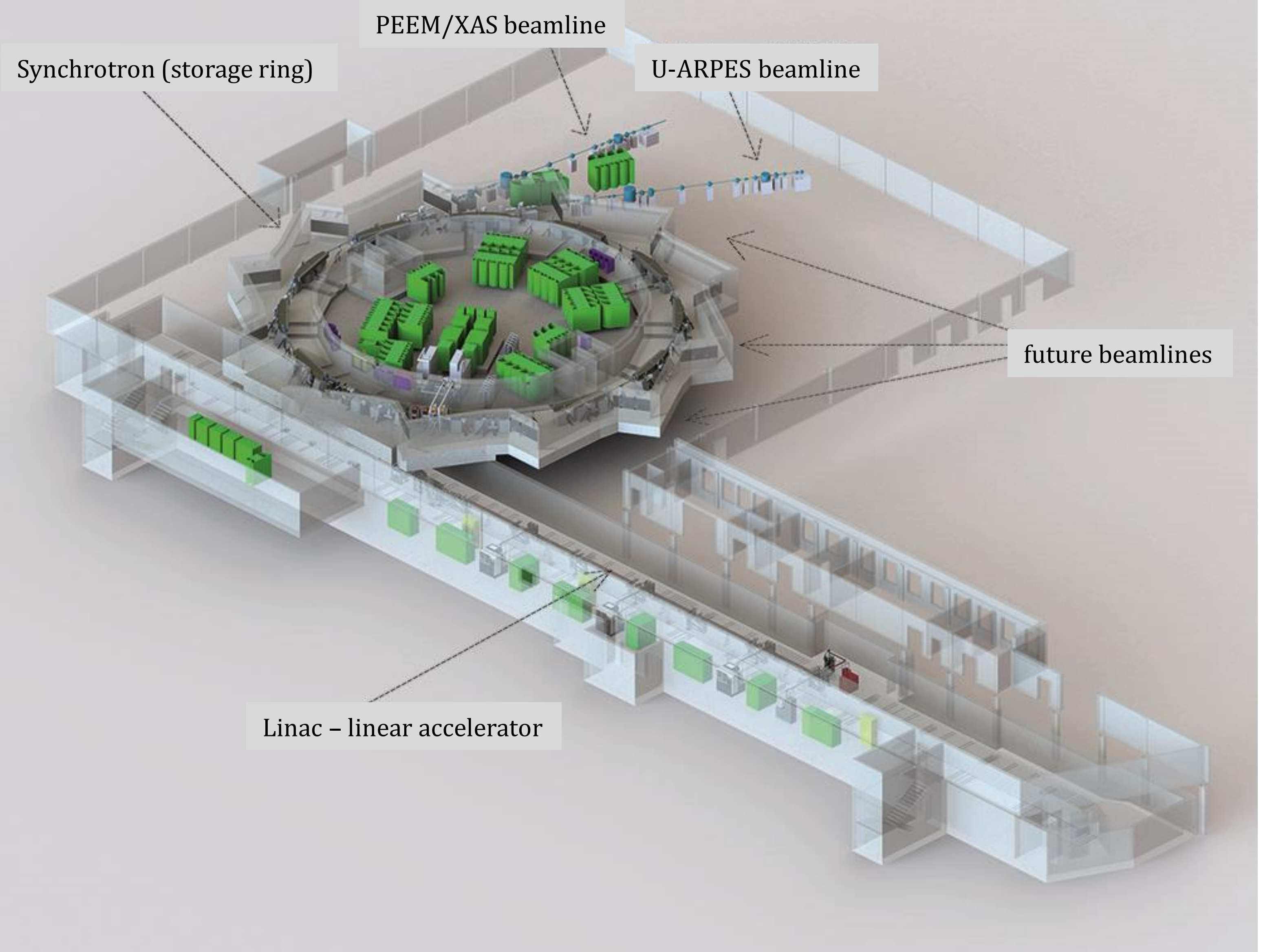
  Procurements for Solaris are as options in MAX IV tenders.

- Budget 50 M€ financed by the European Regional development Fund. The money covers:
  - People/Services (16%)
  - Buildings and laboratories (~23%)
  - Accelerators (32% Storage Ring, 16% Linac)
  - 2 beamlines (13%)
- Land donated and administrative support by the Jagiellonian University

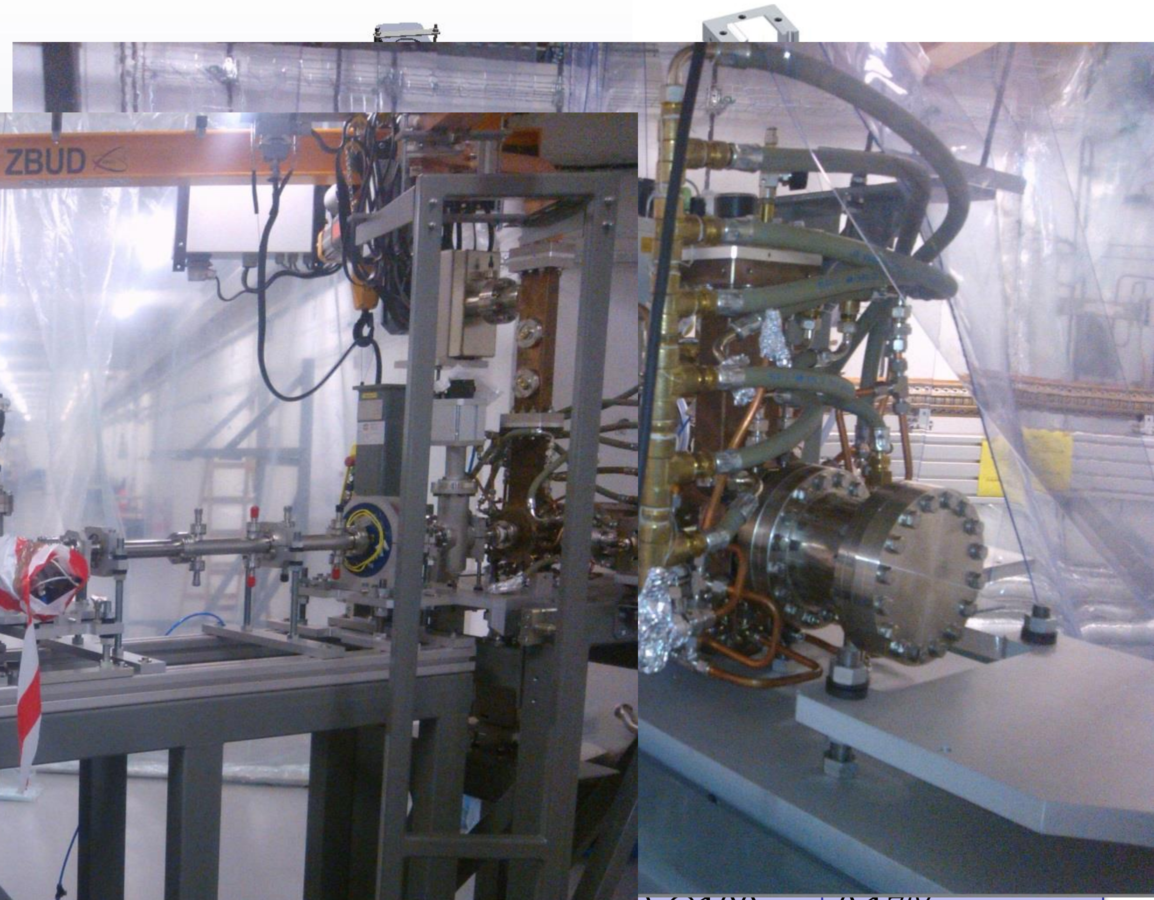
Solaris Team Activities

- **Followed machine design by MAX-IV team and provided support**
- **Handled differences – injection, ramping, ID's and general configuration.**
- **Handled all procurements – Main tenders & local supplies**
- **Trained for installation and operations**
- **Tracked civil engineering**
- **Prepared laboratories and technical areas**
- **Prepared for component delivery (participated in FAT's, oversaw SAT's)**
- **Installed and Assembled the accelerators**
- **Commissioned accelerators and auxiliary systems.**

SOLARIS - layout



Gun system

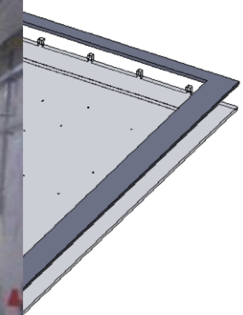


) @100	0.17%
0MeV	14 ps

Linac

- 6 a
- Pov
- 3 R

Bunch
Emitar
Energy
Energy
Bunch
Inject



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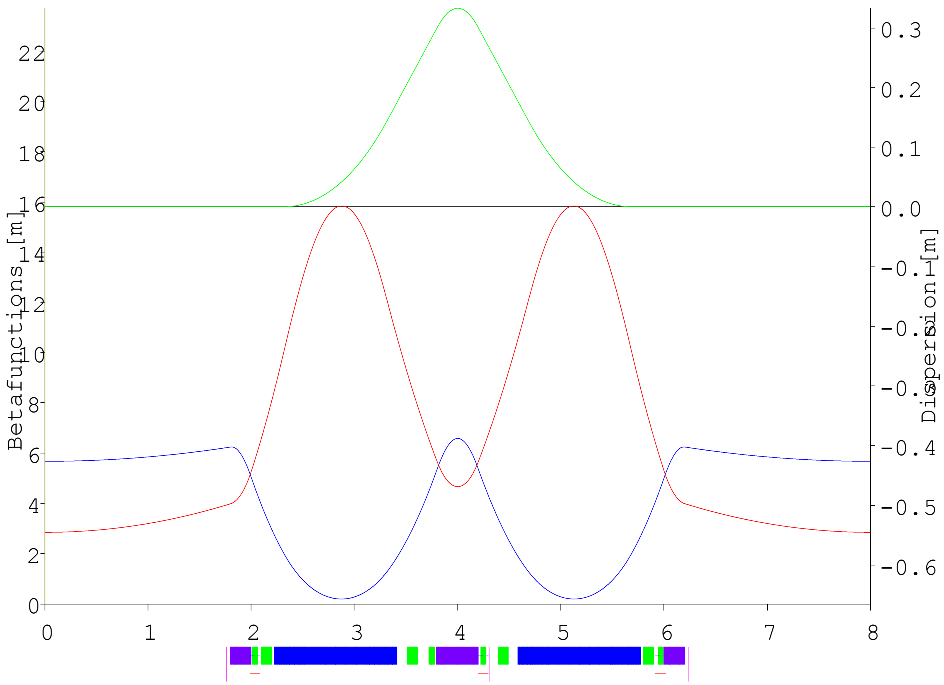
section

Storage Ring

Storage Ring Lattice



Optics design by S.C. Leemann - MAXIV

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

12 DBA Cells – 96 m circ.
Space for ID's ~ 3.5 m
10 straight sections for IDs
Combined- function magnets
- **Gradient dipoles**
- **Quads with integrated sextupole**

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 x 10^{-3}
Momentum acceptance	4%
Overall Lifetime	13 hrs

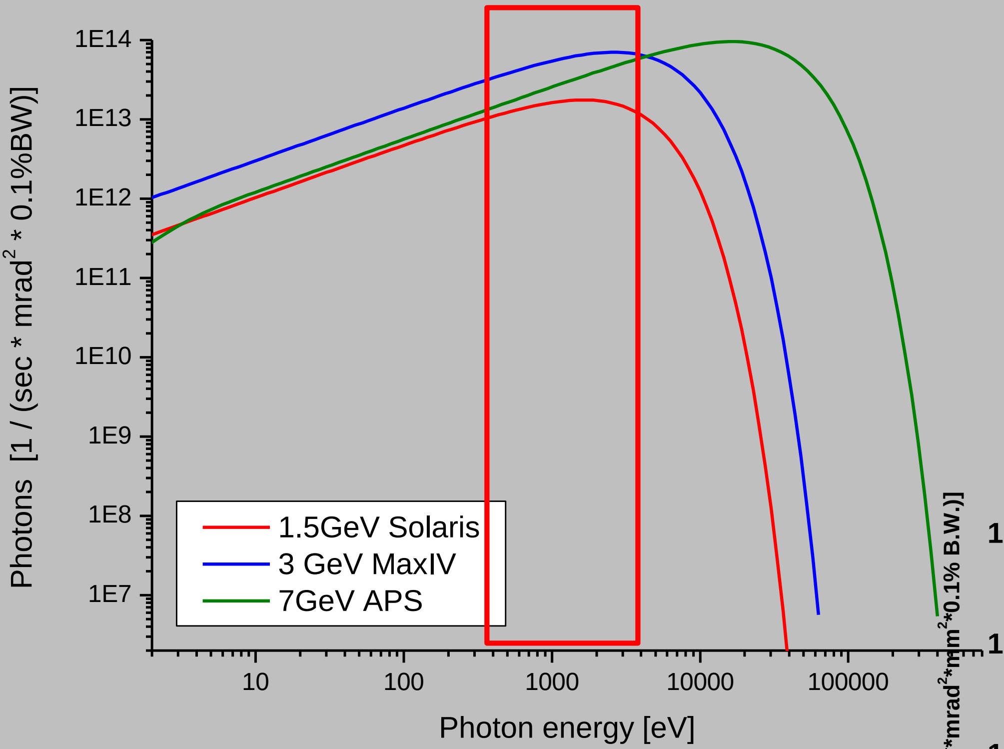
Comparison

SOLARIS – comparison

Table 2. Main parameters of low energy storage ring light sources in operation.

Light source	Location	Energy (GeV)	Circumference (m)	Emittance (nm-rad)	Current (mA)	Straight sections	Operation year
ALS	Berkeley	1.9	196.8	6.8	400	$12 \times 6.7\,m$	1993
ELETTRA	Trieste	2.0/2.4	259	7/9.7	300	$12 \times 6.1\,m$	1994
TLS	Hsinchu	1.5	120	25	240	$6 \times 6\,m$, $4 \times 30\,m$	1994
PLS	Pohang	2.5	280.56	18.9	200	$12 \times 6.8\,m$	1995
LNLS	Campinas SP	1.37	93.2	70	250	$6 \times 3\,m$	1997
MAX-II	Lund	1.5	90	9.0	200	$10 \times 3.2\,m$	1997
BESSY-II	Berlin	1.7	240	6	200	$8 \times 5.7\,m$, $8 \times 4.9\,m$	1999
New SUBARU	Hyogo	1.5	118.7	38	500	$4 \times 2.6\,m$, $2 \times 14\,m$	2000
SAGA-LS	Saga	1.4	75.6	7.5	300	$8 \times 2.93\,m$	2005
SOLARIS	**Kraków**	**1.5**	**96**	**5.6**	**500**	**12 x 3.5 m**	**2015**

Photon flux



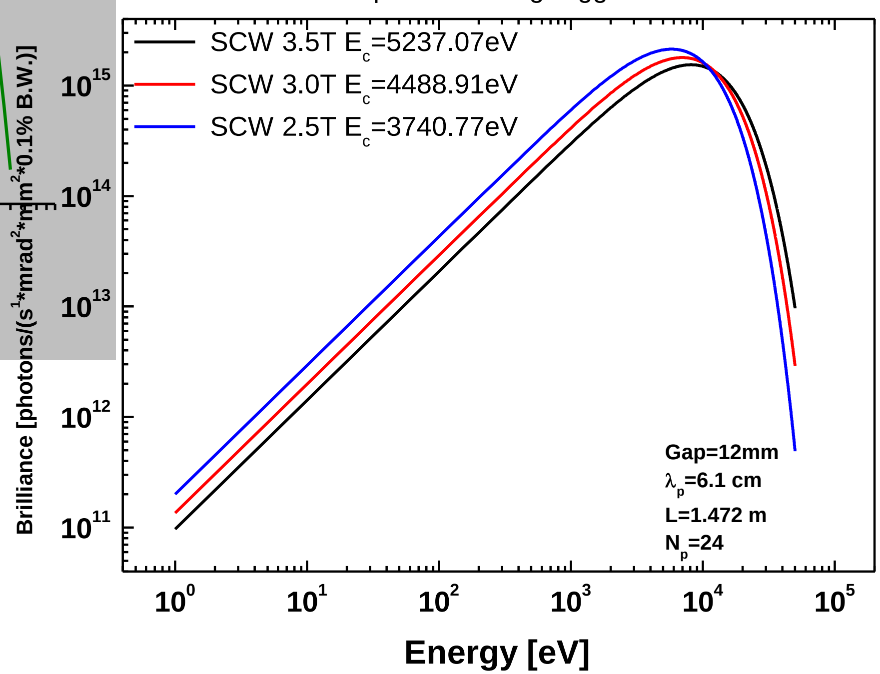
Bending magnet source size (σ):

Horizontally x vertically= **44µm x 30µm**

Straight section source size (σ):

Horizontally x vertically= **180µm x 13µm**

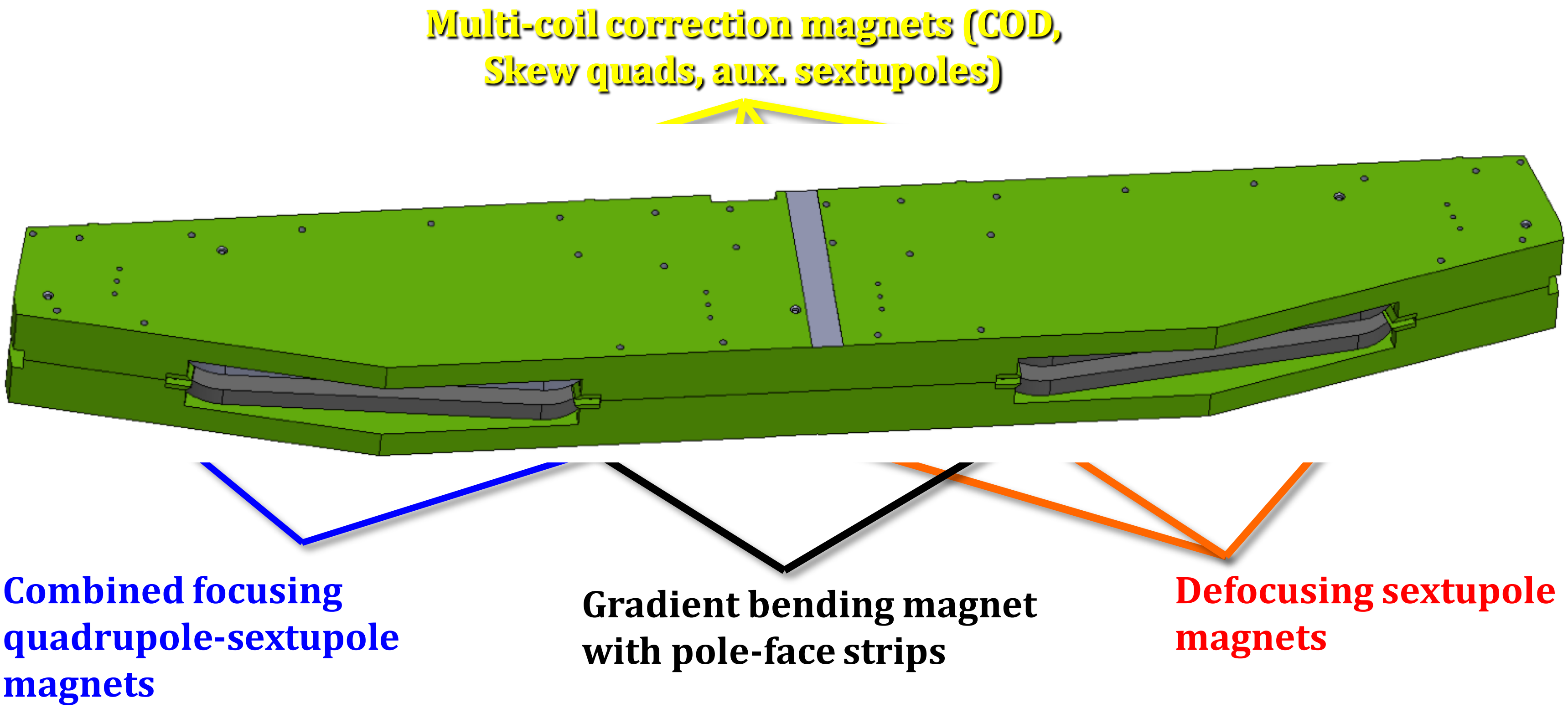
Superconducting wigglers



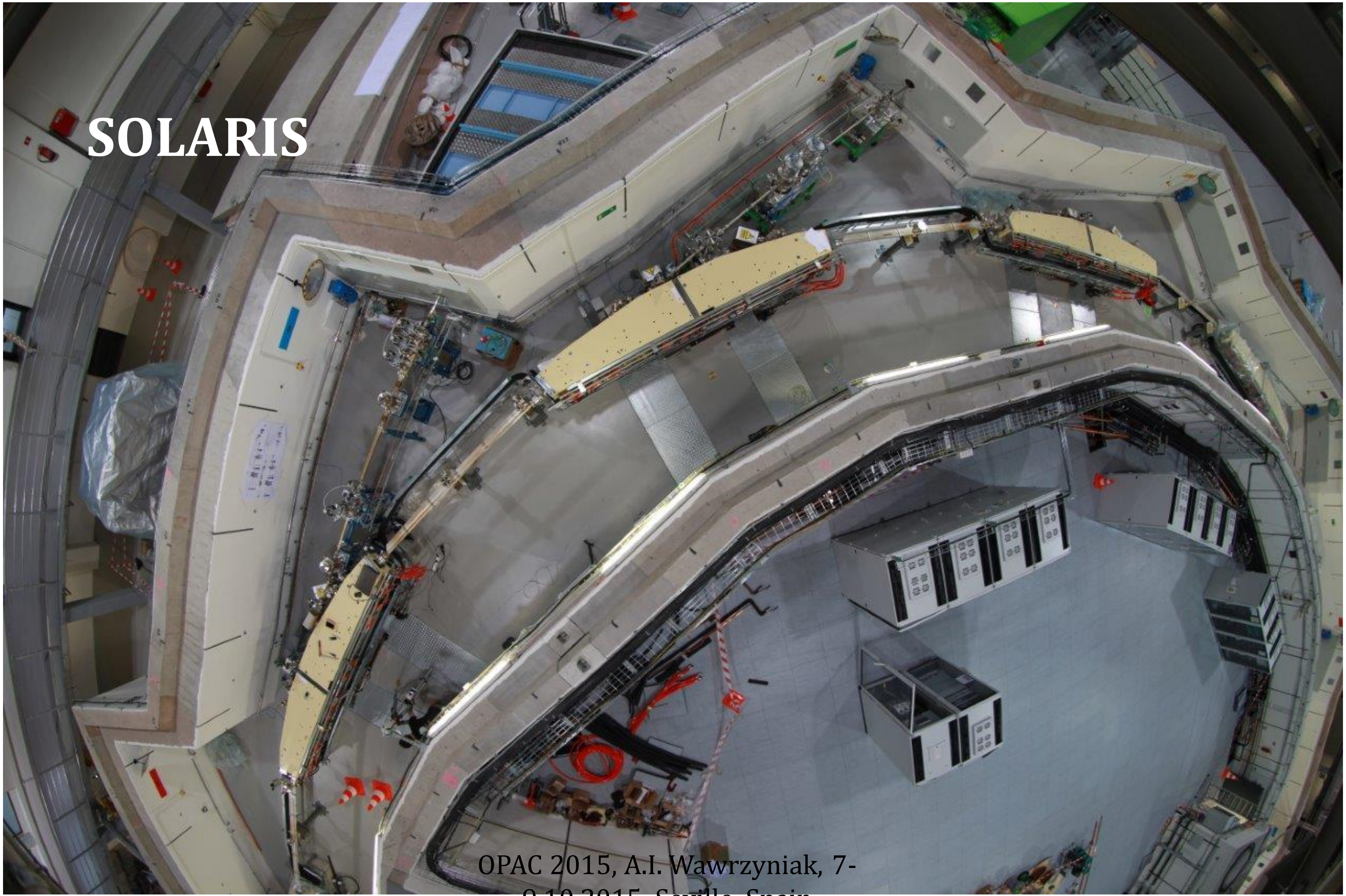
Magnets

Storage Ring Magnets (mirror symmetric)

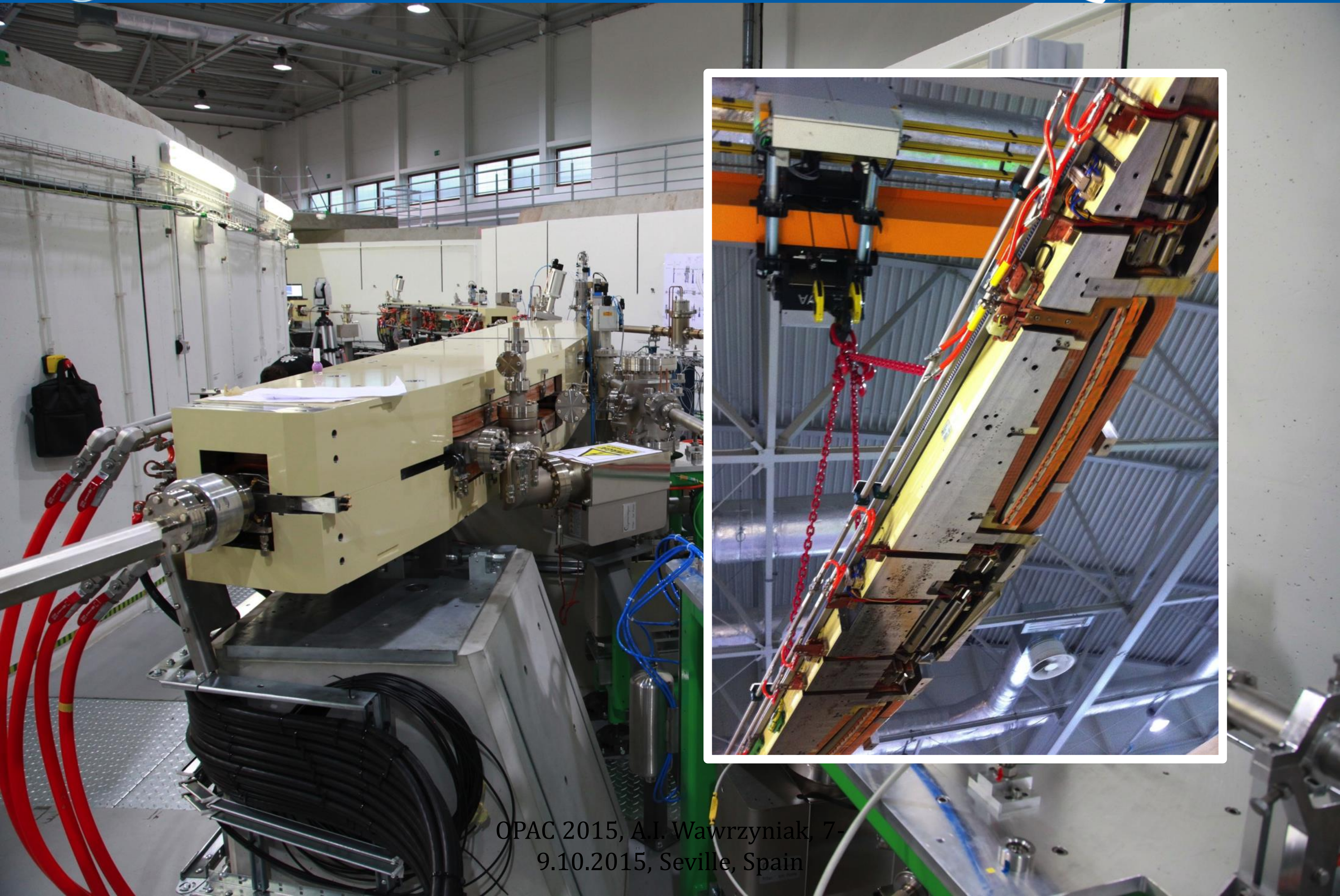
Machined from solid iron, 2 half slabs, ~4.5 m, ~7 Tons each slab



Magnets

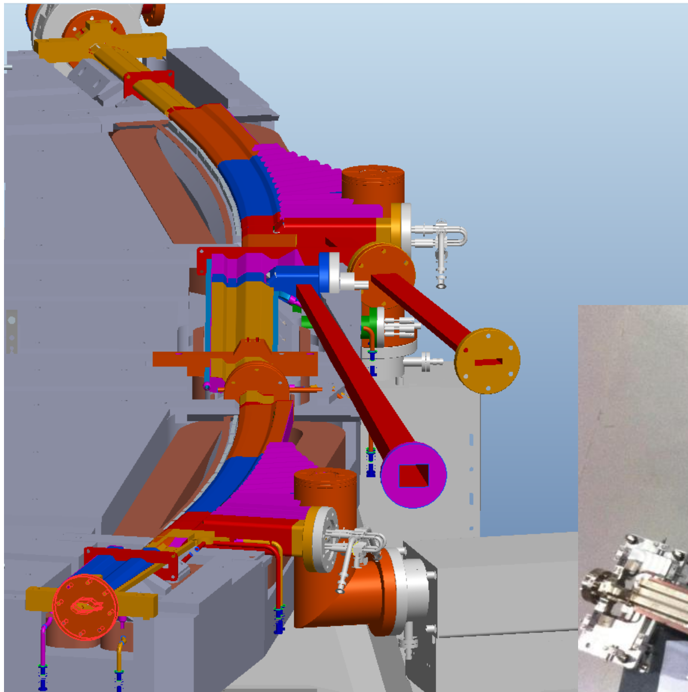


Uniqueness



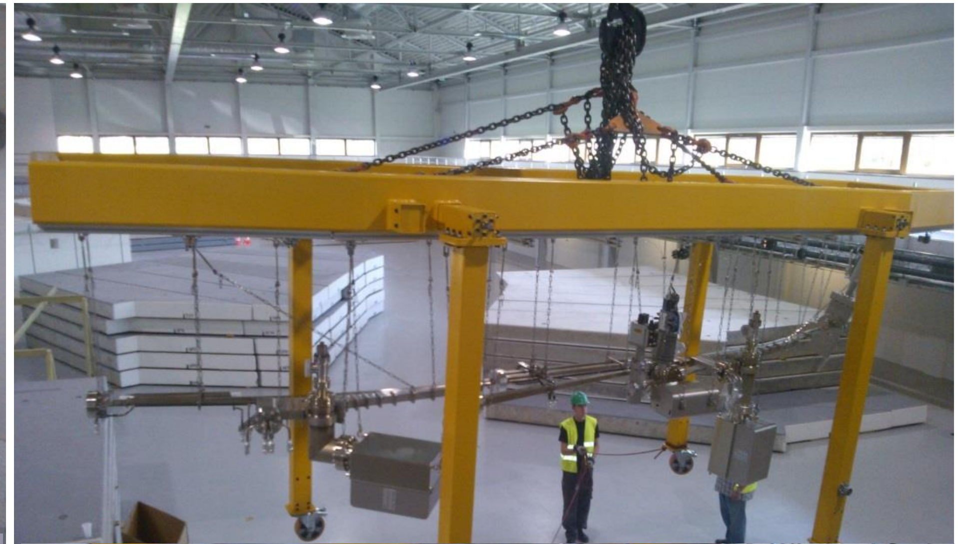
Vacuum Chambers

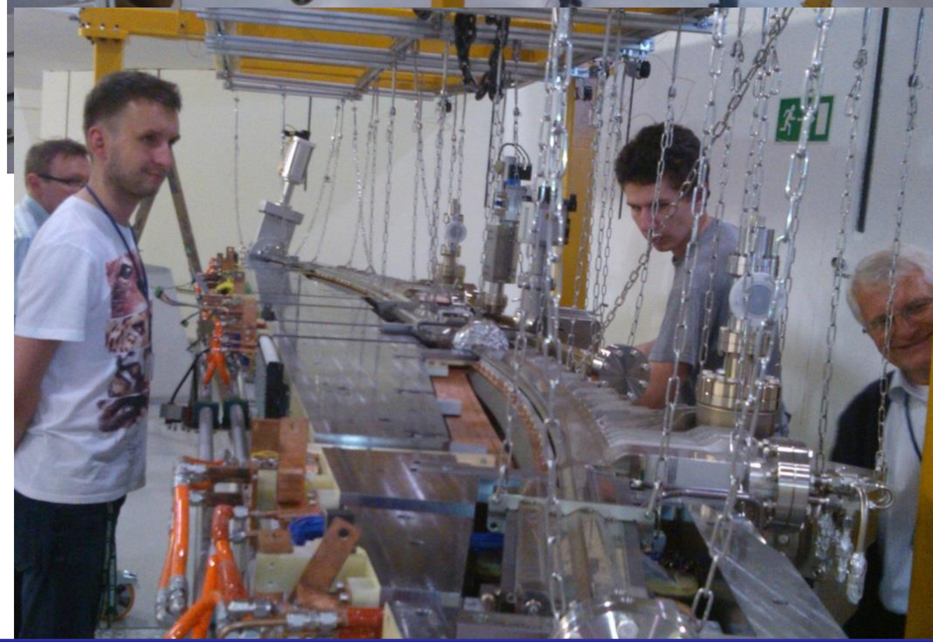
Views of ports and ID straights



NEG Strips

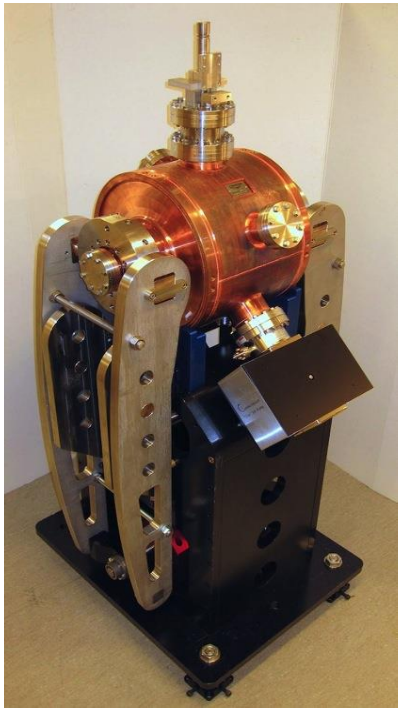
Vacuum Chambers Installation





RF System

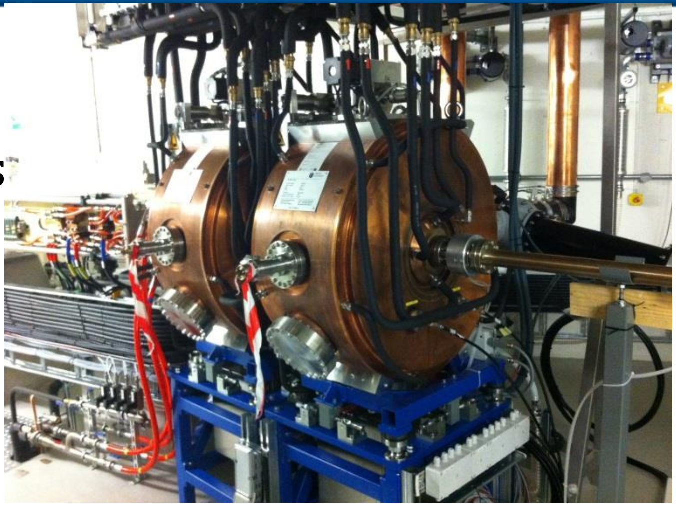
- 2x 100 MHz Main cavities
- Power source –Rhode Schwartz – solid state units 2x60 kW
- 2xLandau Cavities to be installed during winter shut down



300 MHz Landau cavity

Operation Phase	Final LC
Total LC voltage	487 kV
LC Rsh (=V2/P)	5 MΩ
Total LC Cu losses	16 kW

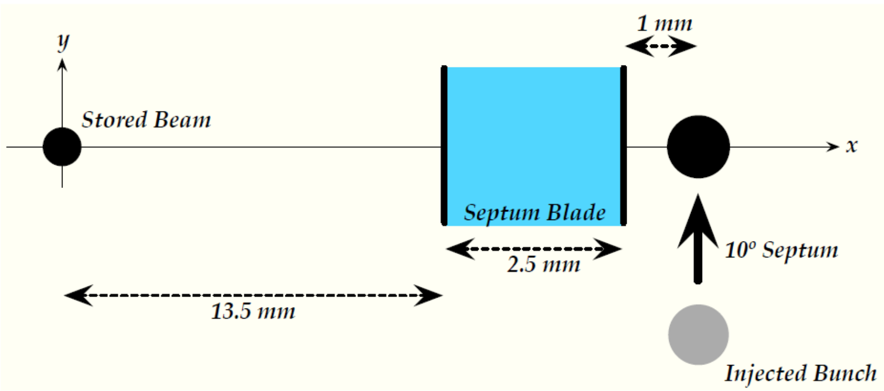
σ_s=14.2mm →60mm

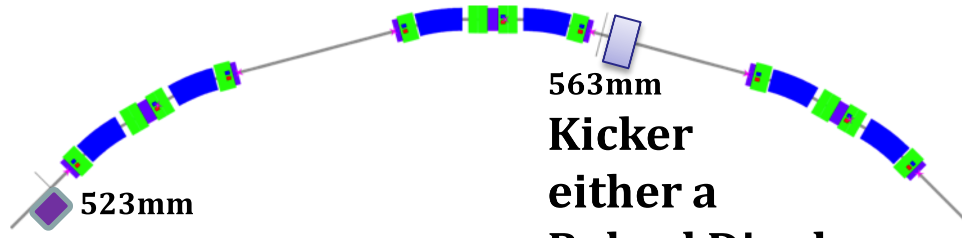


100 MHz main cavities

Operation Phase	Final MC
Energy loss	130 keV
Current	500 mA
Total SR power	65 kW
Total RF voltage	560 kV
Cavity voltage	280 kV
Cavity Rsh (=V^2/P)	3.2 MΩ
Total Cu losses	49 kW
Coupling	2.3
Min. RF station power	57 kW

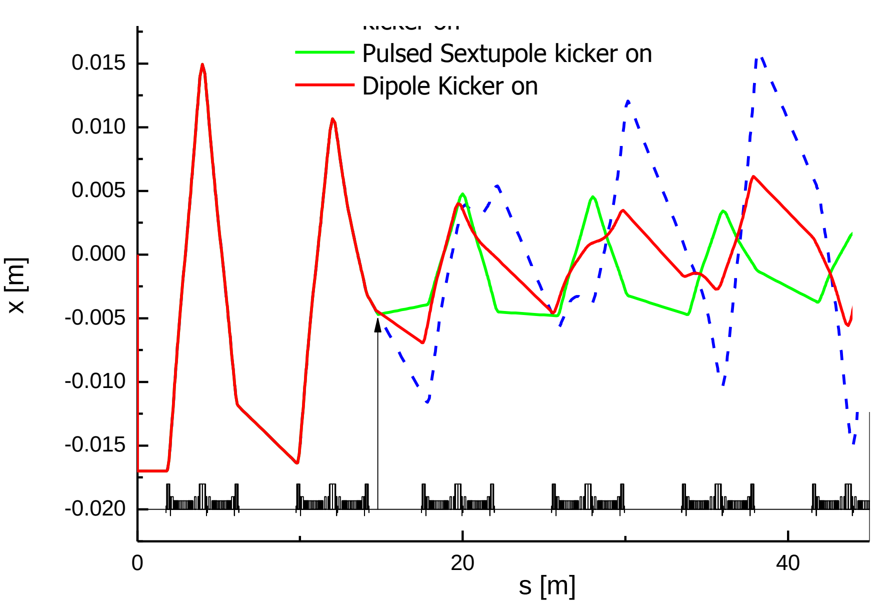
Injection

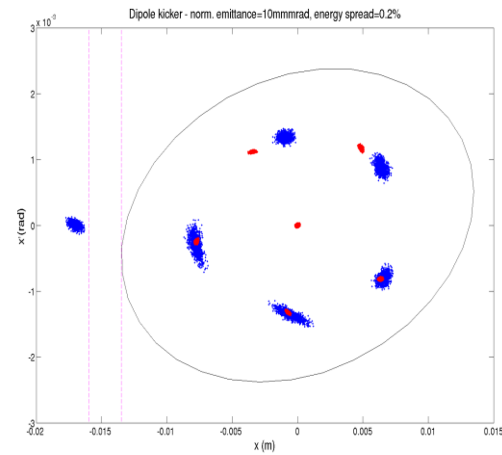


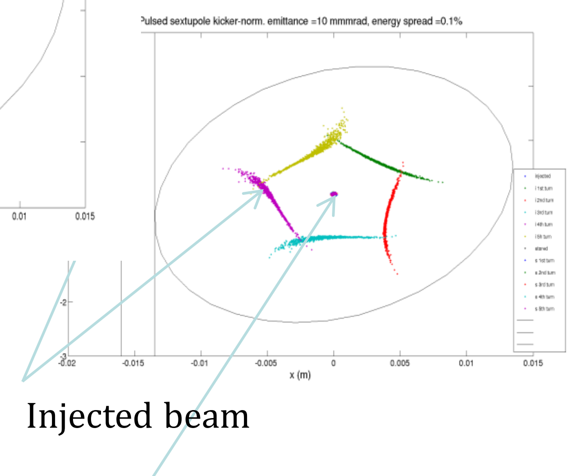


Injection

Kicker either a Pulsed Dipole or a Pulsed Sextupole







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

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Time Schedule

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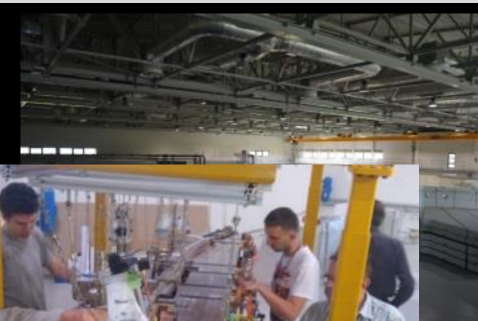
April 2010 – project start

January 2012 – start of the building construction



May 2014 – building handover

June 2014 machine installation

November 2014 linac conditioning start

April 2015 Storage ring installation do

May 2015 Solaris commissioning start

19 June 2015 first light

<u>December 2015 end of the project</u>

Commissioning

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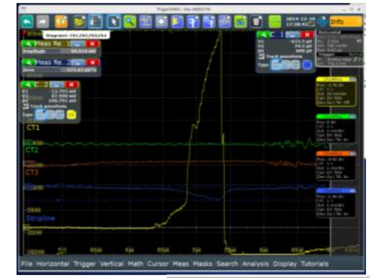
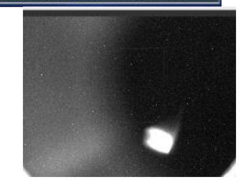
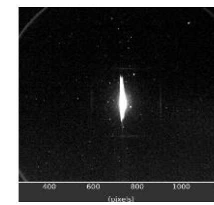
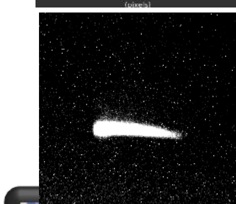
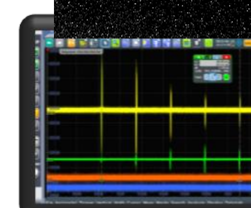
- ✓ 17.11.2014 –Linac conditioning startup
- ✓ 19.12.2014 – First electrons from RF gun
- ✓ 9.02.2015 – Linac commissioning start
- ✓ 23.02.2015 – Electron beam at the end of the linac E=300MeV
- ✓ 24.02-4.05.2015 - Storage ring and transfer line installation
- ✓ 26.05.2015 – Electron beam in the transfer line
- ✓ 27.05.2015 – First electrons in the storage ring E=320 MeV, Q=1.5 nC
- ✓ 16.06.2015 – First and few turns
- ✓ 17.06.2015 – multiturns with kicker and accumulation E= 360MeV; rep.rate 0.5Hz; stored current 7uA ;

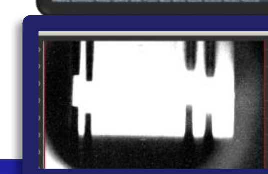






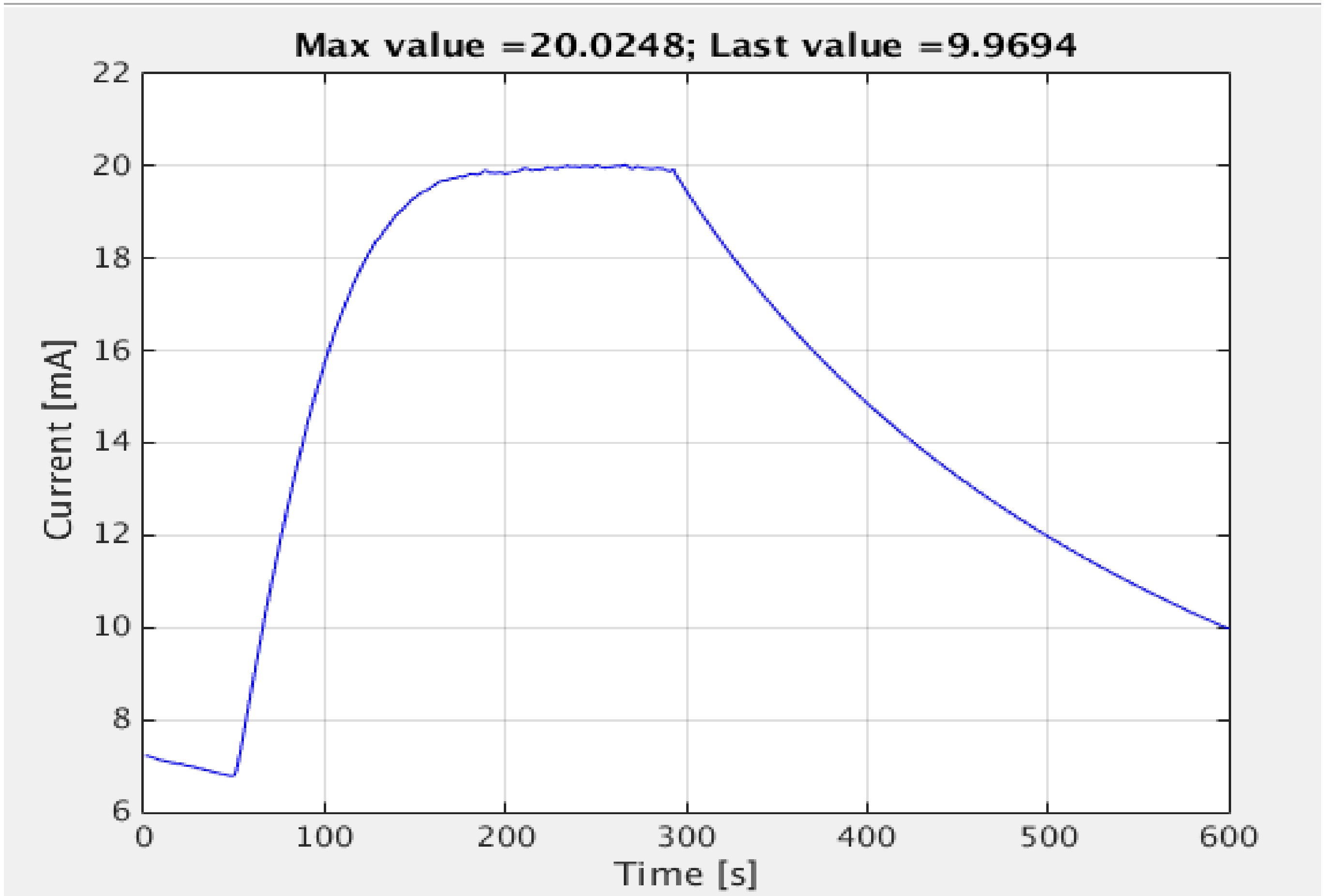






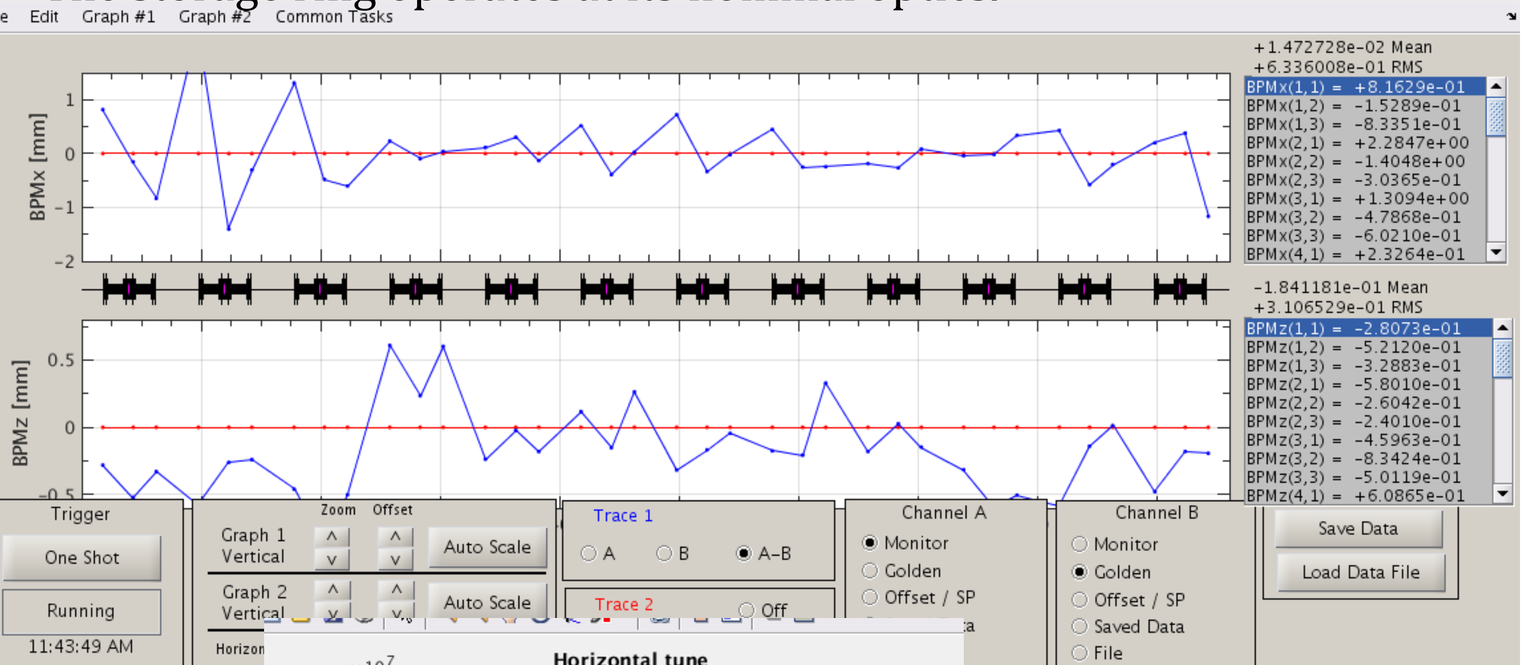
Stored current

20mA at 511MeV

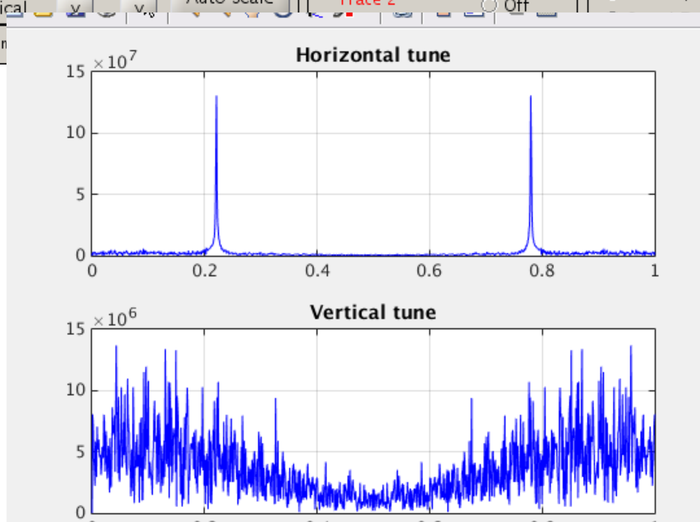


Closed orbit and Tune

The storage ring operates at its nominal optics.



x_{rms}=0.63mm
y_{rms}=0.31mm

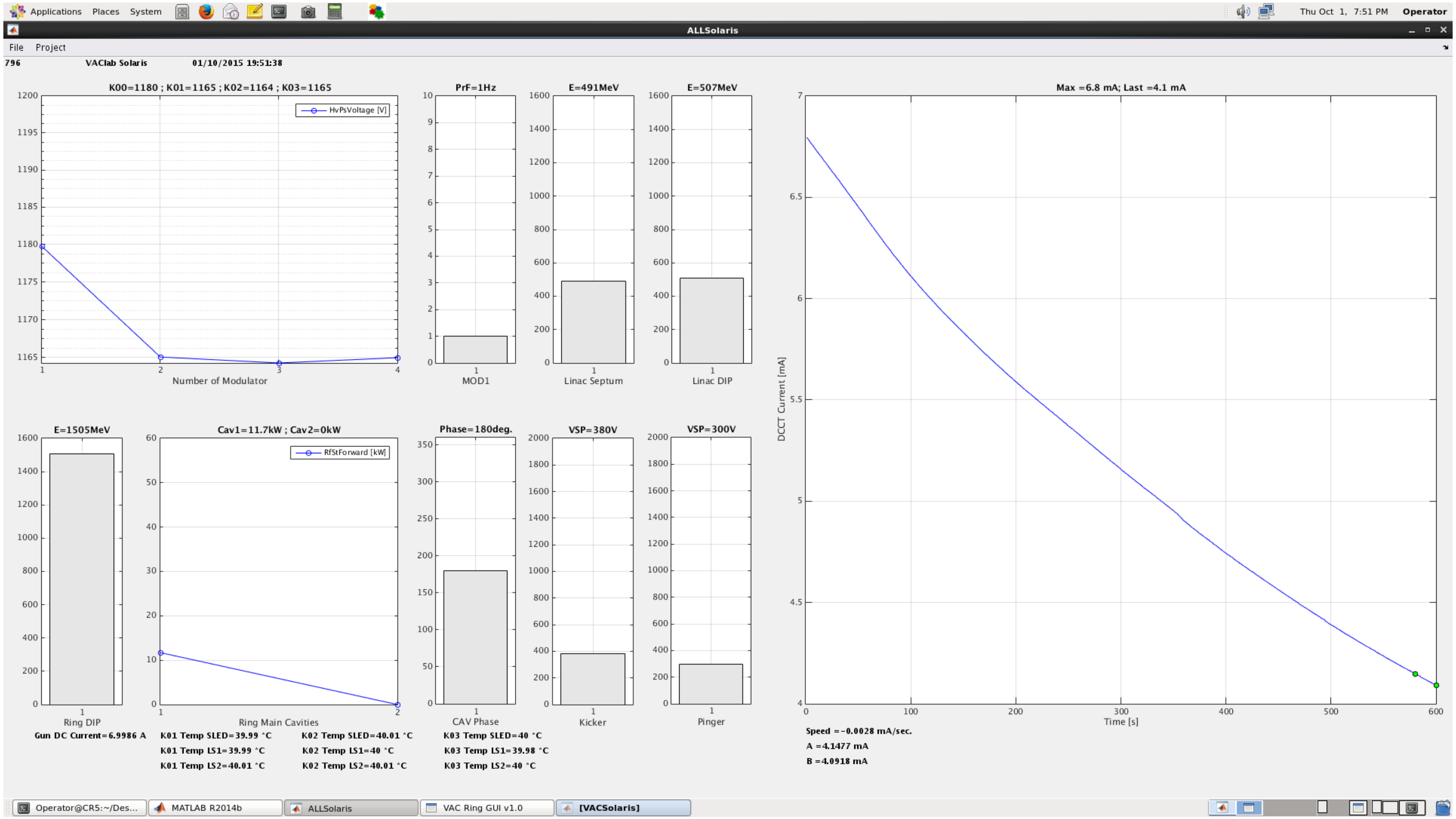


Q_x=11.220
Q_y=3.14

Nominal values:
11.22; 3.15

Ramping

Beam ramped to 1.5GeV

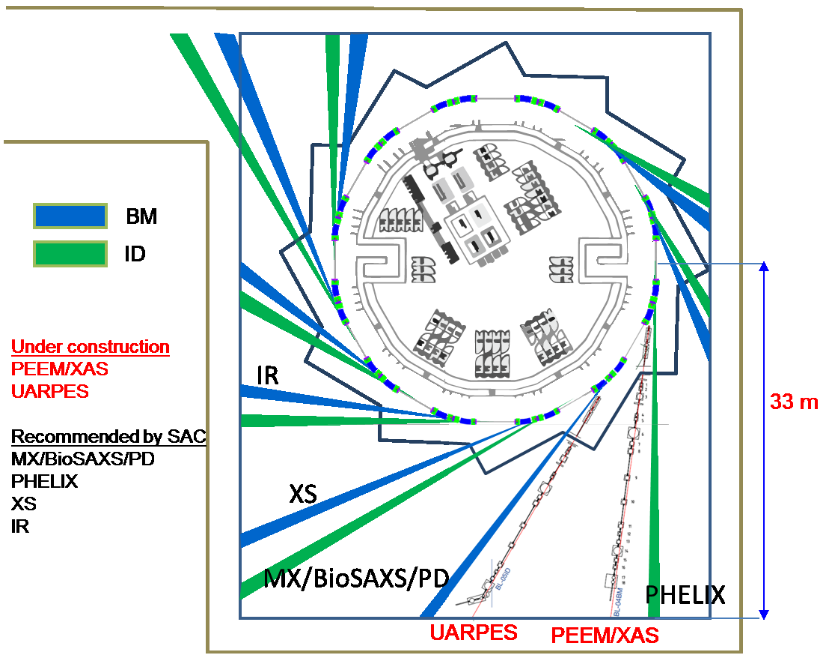


Current Activities

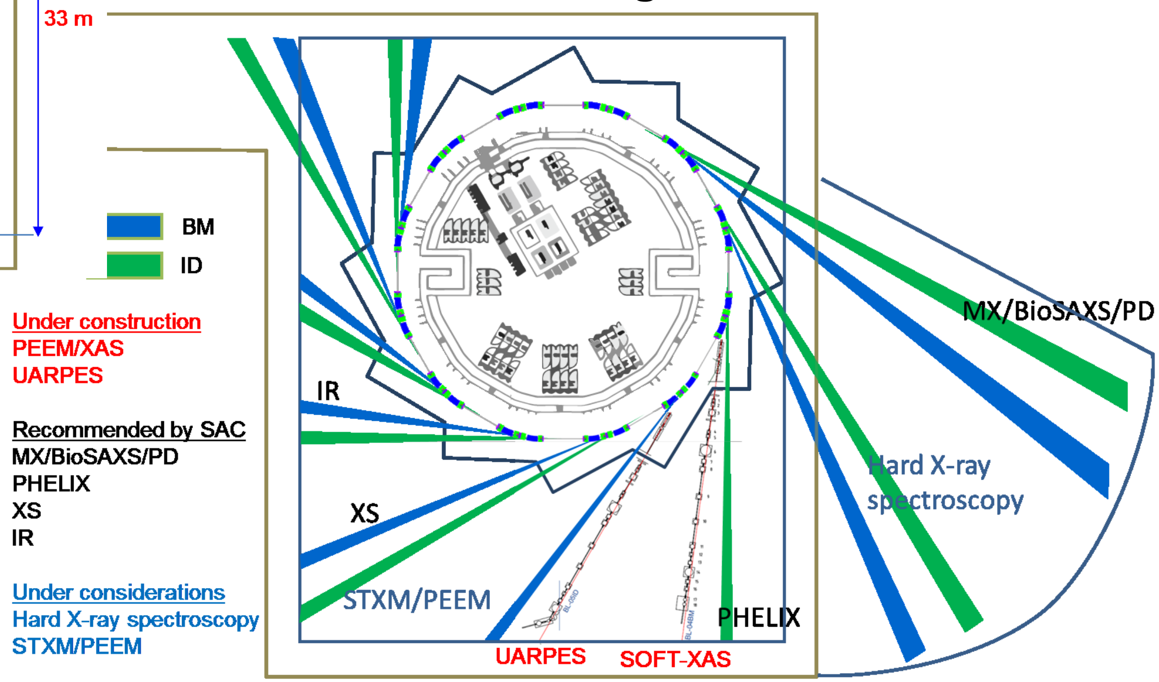
- The RF systems of linac and storage ring have not reached their full performance and are still being conditioned.
- Injection to the storage ring is done at 511 MeV with a repetition rate of 2 Hz maximum and single dipole kicker scheme.
- Optimization of the injection rate (1mA/s)
- Accumulation and ramping of more current.
- Full characterisation of the optics and closed orbit correction.
- Installation of Landau cavities.
- Beamlines commissioning
- Undulator commissioning

Beamlines

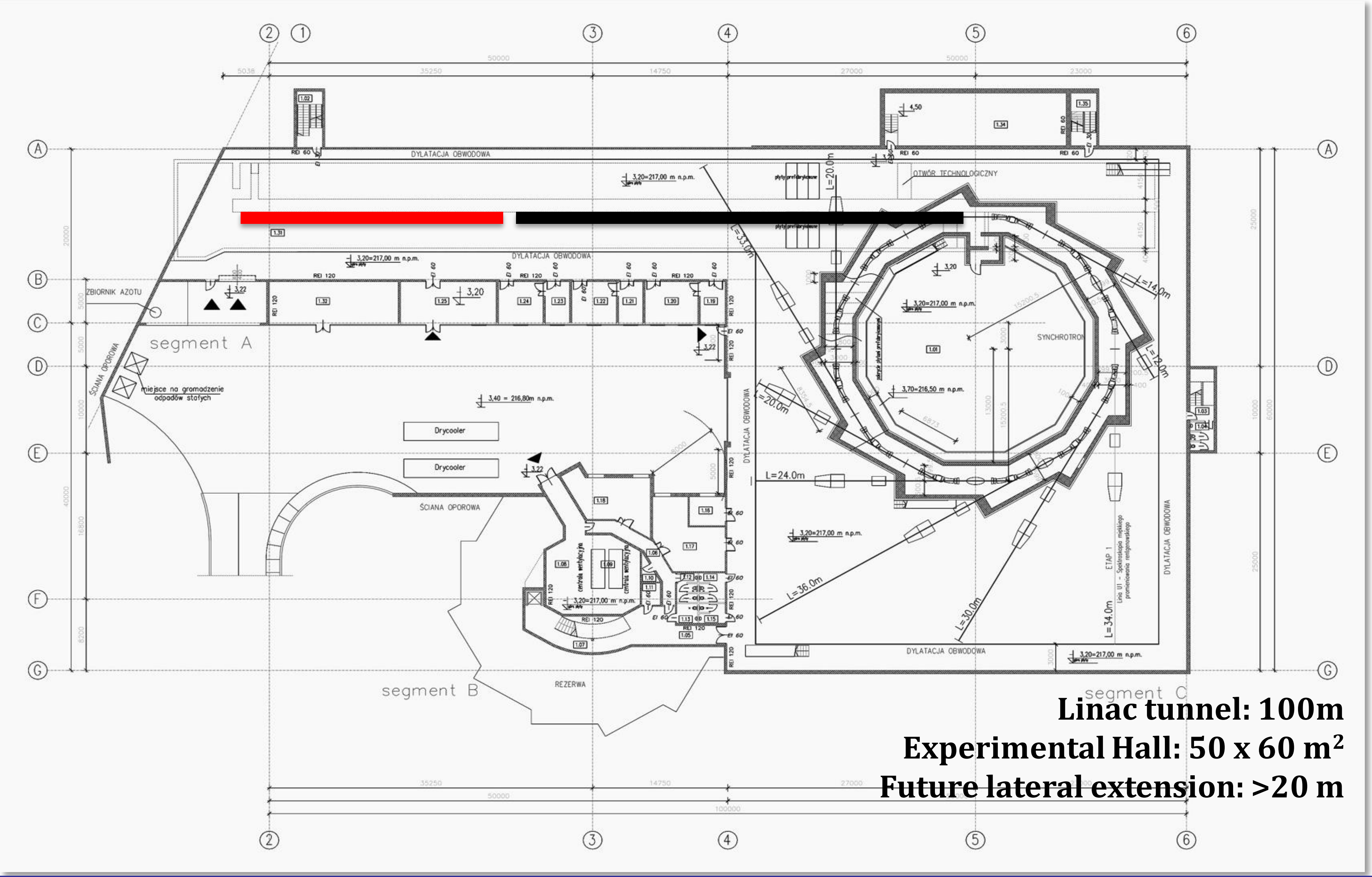
- **Up to 16 additional beamlines**



With building extension



Full Energy Injection



Linac tunnel: 100m

Experimental Hall: 50 x 60 m^2

Future lateral extension: >20 m

Near & Far Future

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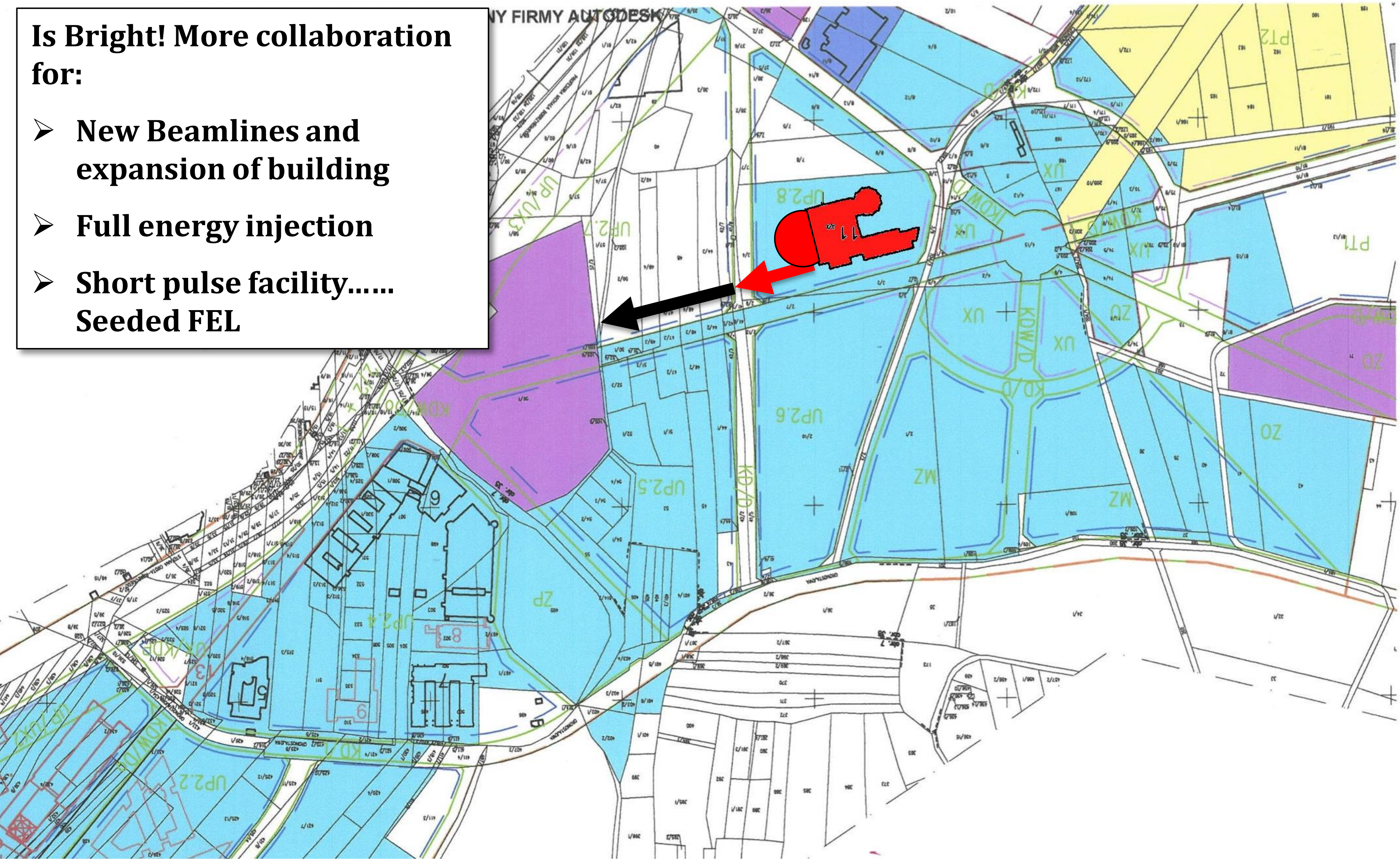
Is Bright! More collaboration for:

- **New Beamlines and expansion of building**
- **Full energy injection**
- **Short pulse facility…… Seeded FEL**



SUMMARY

Solaris is Special

- **It is Poland's Synchrotron Radiation Facility.**
- **"Green Field" Project.**
- **Uses state-of-the-art accelerators.**
- **Innovative technology guaranteeing years of return on investment and potential.**
- **Cost effective project: Maximum use of National & European funds.**
- **Innovative project: the replication of a pioneering concurrent project at MAX IV.**
- **Team building for the nation.**
- **Innovative collaboration: sharing of resources and inherent training of personnel.**
- **Inclusion of EU national accelerator network in project execution.**
- **Exciting future prospects for Solaris and its team: construction of stat-of-the-art beamlines, expansion of infrastructure, extension of linac to full energy, short-pulse facility and seeded FEL.**

Acknowledgments

MAX IV TEAM

Elettra, Sincrotrone Trieste
Machine Advisory Committee
Scientific Advisory Committee
Polish Synchrotron Users' Society
Special thanks to Dieter Einfeld
SOLARIS Team

Thank you for the attention!

1.10.2015 20mA stored and beam ramped to 1.5GeV!