The Synchrotron Light Facility in Brazil

Liu Lin
LNLS Accelerator Physics Group

Forum on Particle Accelerator Projects in Mexico – Guanajuato November 12, 2015.

LNLS – the Brazilian Synchrotron Light Laboratory

About Brazil

Area	8.5 x 10^6 km^2	World rank 5th
Population	202 million	World rank 5th
GDP (2014)	$2.35 trillion	World rank 7th

Source: wolframalpha

- UVX – the only synchrotron in Latin America
- Over 85% built in Brazil
- Operating for users since July 1997.

LNLS – the Brazilian Synchrotron Light Laboratory

LNLS - CNPEM

- City of Campinas – State of São Paulo
- 100 km west from city of São Paulo
- Population: 1 million
- Close to Unicamp – University of Campinas, a public State university with 41 thousand students.

The institution - CNPEM

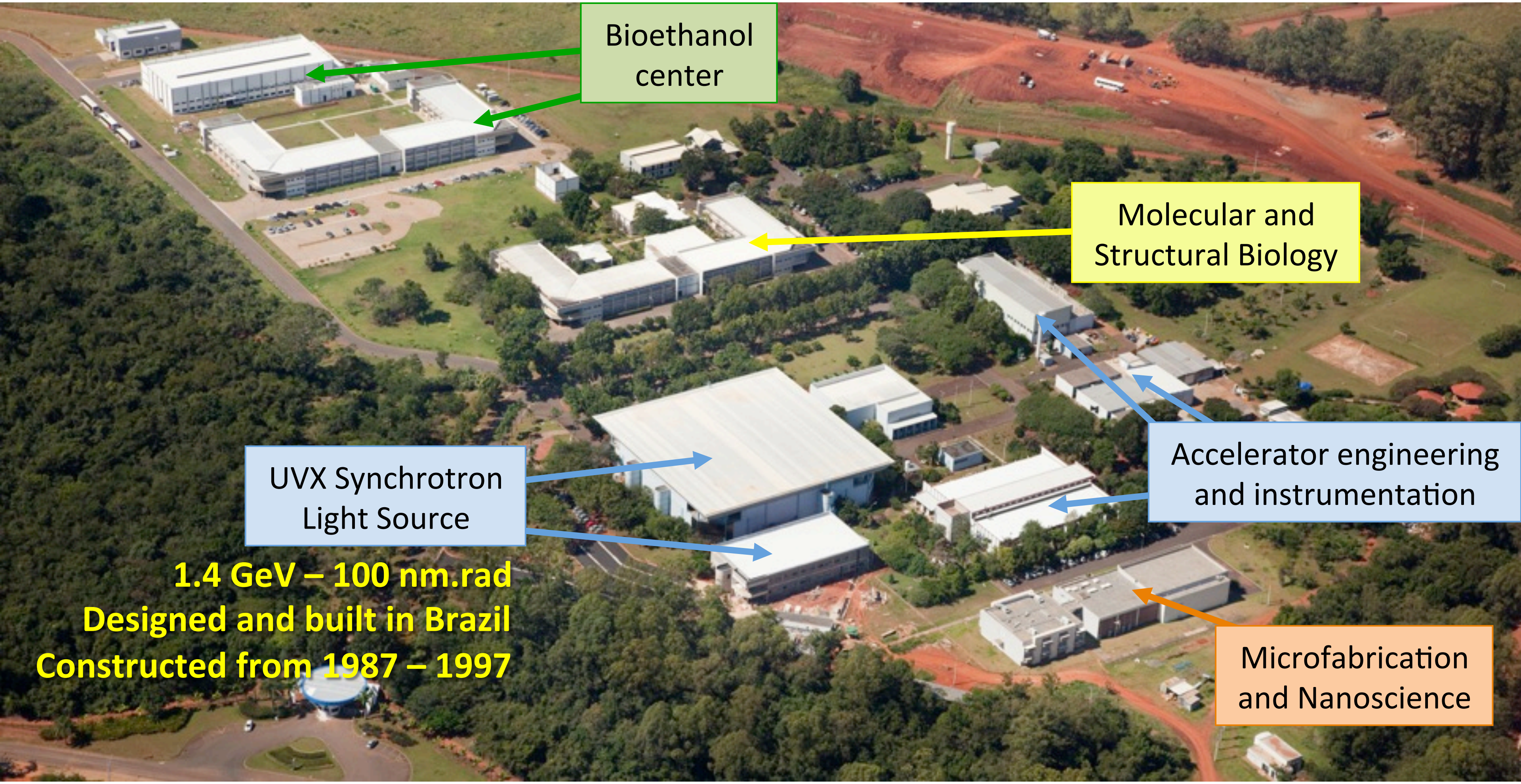
CNPEM Centro Nacional de Pesquisa em Energia e Materiais

"Organização Social"
Private, non-profit organization
that signs a Contract with MCTI

LNLS

CTBE

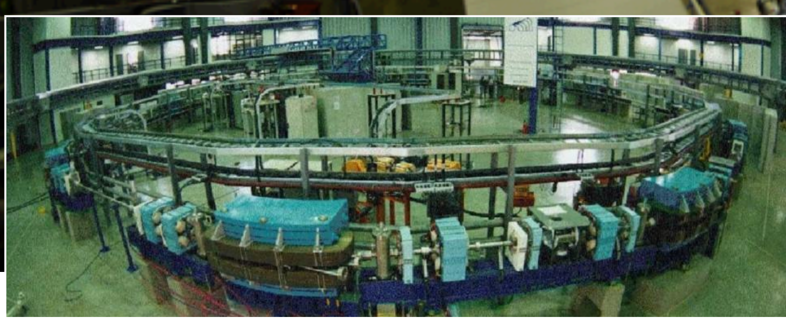
LNNano



1.4 GeV – 100 nm.rad
Designed and built in Brazil
Constructed from 1987 – 1997

The first machine - UVX

- 1.37 GeV / 250 mA
- 100 nm.rad emittance
- 20 beamlines in operation



- **Design and construction: 1987 to 1997**
- **Designed and built in Brazil**
- **The only synchrotron light source in Latin America**

LNLS: from scratch to a state-of-the-art machine in 30 years - Brief history

LNLS sirius

20ª RAU REUNIÃO ANUAL DE USUÁRIOS DO LNLS 22 e 23 de fevereiro

Aldo Felix Craievich

First discussions: ~ 1981

Projeto Radiação Síncrotron
CBPF/CNPq

CBPF/CNPq
Centro Brasileiro de
Pesquisas Físicas

Pre-history of LNLS

- September/1982 – **CNPq installs the PRS** (Projeto Radiação Síncrotron) to "perform a viability study for the creation of a Synchrotron National Lab."
- **1982/1983 – meetings organized by CBPF, funded by CNPq**

PROJETO RADIAÇÃO SINCROTRON

PRS

RIO DE JANEIRO

1983

CONSELHO NACIONAL DE DESENVOLVIMENTO CIENTÍFICO E TECNOLÓGICO - CNPq

CENTRO BRASILEIRO DE PESQUISAS FÍSICAS - CBPF

CBPF/PRS 007/83

COURS SUR LE RAYONNEMENT SYNCHROTRON

Y. PETROFF
(L.U.R.E.)

Publicação Especial do Centro Brasileiro de Pesquisas Físicas (CBPF)
Série: Projeto de Radiação de Sincrotron (PRS), coordenado por Ramiro de Porto Alegre Muniz, Aldo F. Craievich

CBPF/PRS - 001/83 - Proposta preliminar do estudo de viabilidade para a implantação de um Laboratório Nacional de Radiação de Sincrotron

CBPF/PRS - 002/83 - Notícia sobre a proposta preliminar do estudo de viabilidade para a implantação de um Laboratório Nacional de Radiação de Sincrotron

CBPF/PRS - 003/83 - Encontro das Sociedades Científicas sobre a proposta preliminar do estudo de viabilidade para a implantação de um Laboratório Nacional de Radiação de Sincrotron

CBPF/PRS - 004/83 - Resumos dos trabalhos apresentados no Encontro sobre Técnicas e Aplicações da Radiação Sincrotron

CBPF/PRS - 005/83 - Round Table on Technical Aspects of Synchrotron Radiation

CBPF/PRS - 006/83 - Conceptual Design of a 1.2 GeV Storage Ring extending in the Hard X-Ray Region

CBPF/PRS - 007/83 - Cours sur le Rayonnement Synchrotron

CBPF/PRS - 008/83 - Anais do Encontro "Técnicas e Aplicações da Radiação Sincrotron"

CENTRO BRASILEIRO DE PESQUISAS FÍSICAS - CBPF

CBPF/PRS - 010/84

THE PHYSICS OF ELECTRON STORAGE RINGS.
AN INTRODUCTION

M. SANDS
UNIVERSITY OF CALIFORNIA

CENTRO BRASILEIRO DE PESQUISAS FÍSICAS - CBPF

Diretor
Prof. Ramiro de Porto Alegre Muniz

Coordenador do Projeto Radiação Sincrotron
Prof. Roberto Lobo

Pre-history of LNLS

- September/1982 – **CNPq install the PRS** (Projeto Radiação Síncrotron) to "perform a viability study for the creation of a Synchrotron National Lab."
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- December 1984 – Campinas, São Carlos, Niterói and Rio de Janeiro present proposals to host the Lab
- **January/1985 – Small team (5 people) goes to Stanford (Projetc 1)**

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THE BRAZILIAN SYNCHROTRON RADIATION PROJECT

A.R.D.Rodrigues and R.Lobo
P.O.Box 369
13560 - São Carlos - SP - Brazil

The proposal for a brazilian national laboratory for synchrotron radiation is presented. The first design study led to a system consisting of a LINAC, an injection ring and a low emittance storage ring. The main ring is designed to be upgraded to 3GeV with an emittance of $4 \cdot 10^{-8}$ rad.m. The design study also indicated the possibility of using the injection ring as a soft x-Rays/VUV source.

Construction and Commissioning of Dedicated Synchrotron Radiation Facilities

Proceedings of Workshop
October 16-18, 1985

The case for a future national synchrotron radiation laboratory in Brazil was firstly discussed in 1981 by a group of physicists. The subject was further discussed by the community of condensed matter physicists in april 1982 and in a meeting of scientific societies in august 1982, wich recommended deeper studies. The case study with the support of the Brazilian Research Council (CNPq) started in september 1982 and its results were presentend in january 1984 in a second meeting of the scientic societies. The existence of such national laboratory was considered as a very efficient investiment in science and it was decided to continue with studies towards machine parameters definition and technical aspects involved in the constructions of the equipment. Here we present a first design, wich satisfies the performance stablished by these studies, for the National Laboratory for Synchrotron Radiation (LNRS).

Pre-history of LNLS

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- December 1984 – Campinas, São Carlos, Niterói and Rio de Janeiro present proposals to host the Lab
- January/1985 – Small team (5 people) goes to Stanford (Projetc 1)
- **January/1985 – Campinas is chosen as the place**
- November/1985 – Minister Renato Archer announces the decision to build LNRS
- December/1986 – CNPq buys a building to host the first technical groups
- **June/1987 – the first team of LNRS (26 people) start to work in this building**

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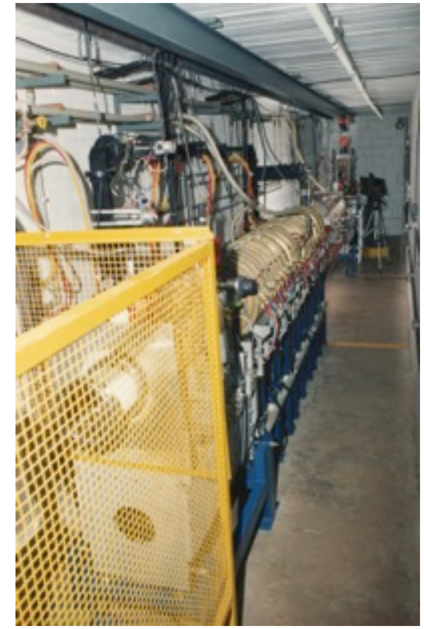
Even though the Project was moving forward, there were strong criticisms from the scientific community:

- **Too much money on a single project**
- **Lack of technical knowledge/personnel**
- **Lack of users**

First LNLS building

Development of all prototypes, installation of a 50 MeV LINAC and first beamlines

Building



Human Resources

Lack of personnel with knowledge in accelerator engineering and scientific instrumentation

The solution was to hire young people, most seeking for their first job, and train them in a “hands on” approach

26/July/1991
Some of the young people that built LNLS – 2nd meeting of the International Advisory Committee

Training also the users

- In the early 80's, there were around 10 people in Brazil who new/used synchrotron radiation
- LNLS has been doing a continuous effort, since the very beginning, to form and train users through schools, workshops, sending people abroad, etc.

20ª RAU Aldo Felix Craievich

Encontro

Técnicas e Aplicaçoes da Radiação Síncrotron
PRS/CBPF, Rio de Janeiro, agosto de 1983

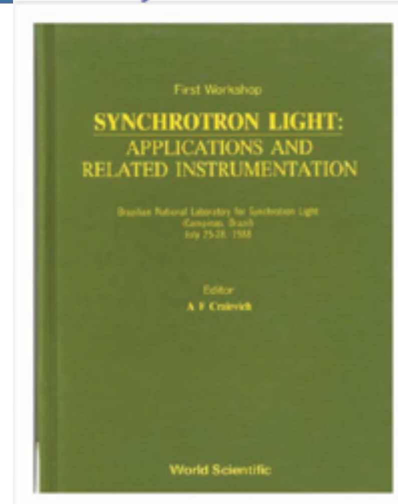
220 participantes

R. Lobo (CBPF)
A.Craievich (CBPF)
A. Moreira (CBPF)
R. P. A. Muniz (CBPF)
C. Tsallis (CBPF)
A. Ribeiro Costa (CBPF)
G. Bemsky (CBPF)
J. Benuzzi (CBPF)
J. Rogers (UNICAMP)
R. A. Douglas (UNICAMP)
S. Caticha-Ellis (UNICAMP)
C.E.T. Gonçalves da Silva (UNICAMP)
V. Baranauskas (UNICAMP)
C. Suzuki (UNICAMP)
Y. Mascarenhas (IFSC)
A.R.D. Rodrigues (IFSC)
A.J. Castro (IFSC)
J. Slaets (IFSC)
M. Aegerter (IFSC)
E.E. Castellano (IFSC)
G. Moscati (IFUSP)
R. Salinas (IFUSP)
C. Pimentel (IFUSP)
L.Q. do Amaral (IFUSP)
B. Marechal (UFRJ)
G.G. Bezerra de Souza (UFRJ)
E. Zanotto (UFSCar)
P. Viccaro (UFRGS)
T. Polga (CTA)
C. Cusatis (UFPr)
W.G. Machado (UFGo)
H. Wiedemann (Stanford University)
J. Le Duff (LAL, Orsay)
J. Doucet (Physique des Solides, Orsay)
Y. Petroff (LURE, Orsay)

20ª RAU Aldo Felix Craievich

I Workshop

Synchrotron Light.
Applications and Related Instrumentation
25-28 de julho de 1988



A. Guinier, France
R. Fourme, France
J. Peisl, Germany
G. Will, Germany
G. Rossi, France
K. Malek, France
G. Schaffer, Germany

20ª RAU Aldo Felix Craievich

I Workshop de Usuários

10-14 de dezembro de 1990


Laboratório Nacional de Luz Síncrotron / LNLS

I Workshop Anual de Usuários do LNLS

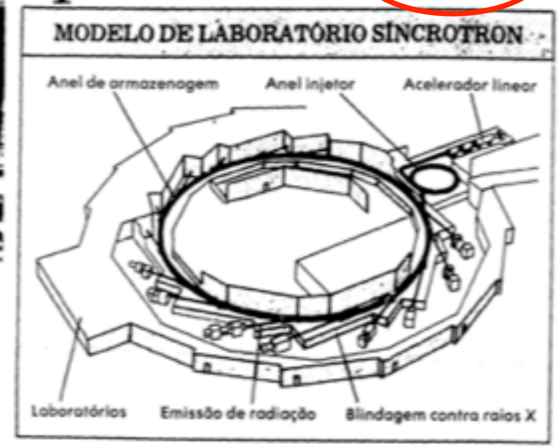
Cópia das Transparências

1987 ...beginning with optimism and high inflation!

Ciência e Tecnologia

p. A14

Laboratório de Síncrotron pode estar pronto em 1992



Partículas viajam na velocidade da luz

primeira página

FOLHA DE S.PAULO

SAYAD DEIXA O INCOR E FALA POUCO

Inflação de 16,82% em janeiro é recorde e dispara o gatilho

Financeiras já cobram taxa recorde de 1.199%

Caderneta rende 17,4% e recupera suas perdas

Folha de São Paulo, 14/Fev/1987

1993-1995

Magnets production

1992

Brazilian Journal of Physics, vol. 23, no. 1, March, 1993 53

Design and Applications of a Toroidal Grating Beamline

A. Rubens B. de Castro[1] P. T. Fonseca[1] J. G. Pacheco
J. E. Verdugo, M. S. Z. Graeff[1], G. B. Fraguas[1]
Laboratório Nacional de Luz Síncrotron/CNPq, Caixa Postal 6192, 13081-970, Campinas, SP, Brasil
[1] *also at Instituto de Física "Gleb Wataghin", Universidade Estadual de Campinas Caixa Postal 6165, 13081-970, Campinas, SP,*

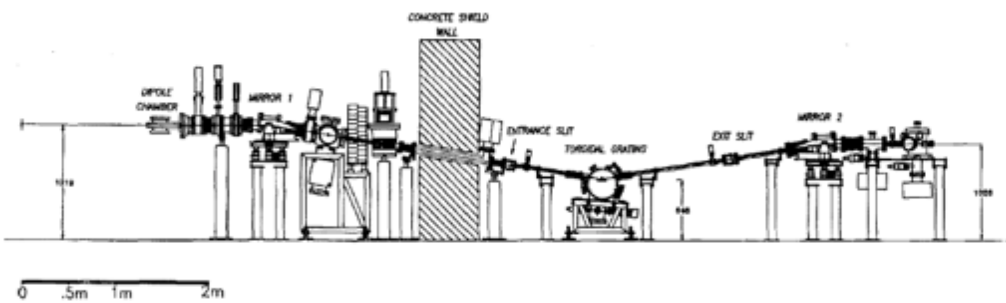
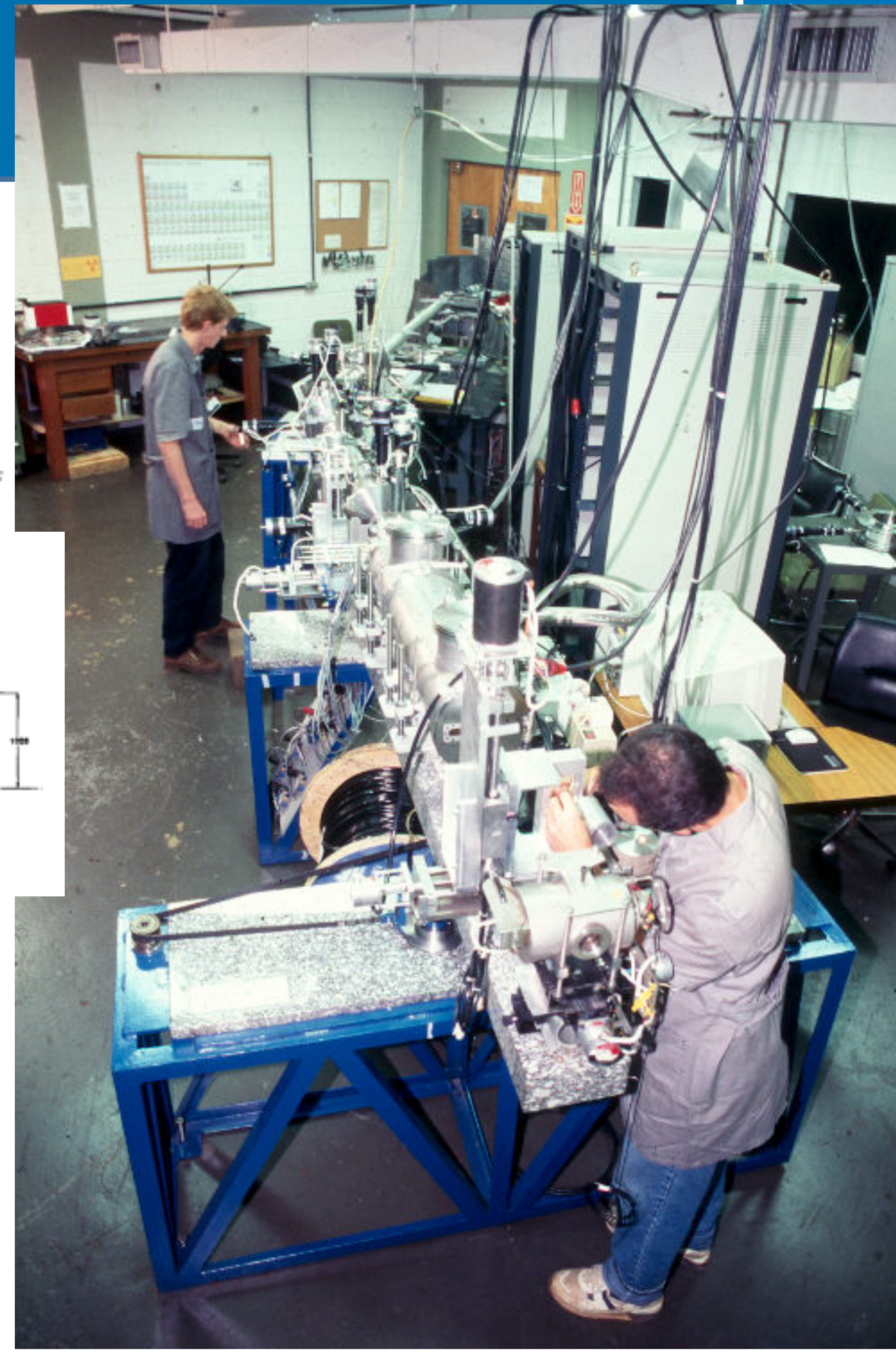
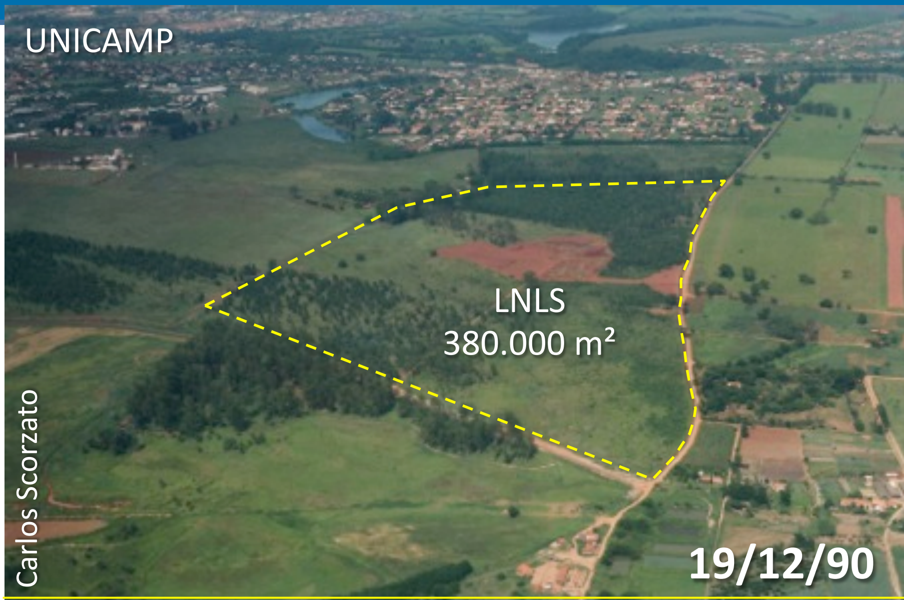


Figure 1: The LNLS TGM beamline, as installed at CAMD (Baton Rouge-USA)

First beamline designed and built by LNLS is installed for testing at the Center for Advanced Microstructures and Devices (CAMD) at Louisiana State University (USA)



1990 a 1996 – Constructions at LNLS Campus



May/1996 – assembly of ring concluded

Nelson Chinaglia

6/11/1996

Assembly of first beamlines

LUX

BOLETIM INTERNO DO LNLS
Laboratório Nacional de Luz Síncrotron

14

Luz Síncrotron chega a Estação Experimental

A luz síncrotron chegou pela primeira vez a uma estação experimental acoplada ao anel de armazenamento do LNLS.

Foi às **22:10 horas do dia 28 de outubro de 1996** (segunda-feira)

A foto, obtida por Guilherme Tráguas, mostra a luz síncrotron chegando à câmara de amostra instalada na linha de luz TGM, construída pelo Grupo de Instrumentação de Ultravioleta de Vácuo.

Precedendo este fato notável, no dia 25, sexta-feira, às 3:10 horas (madrugada), a equipe do Departamento de Projeto havia conseguido obter uma corrente armazenada de 11,9 mA (quase 12 miliampéres), a 1,15 GeV. Ou seja, 81% da corrente armazenada a 120 MeV sobreviveu quando elevada a 1,15 GeV.

28 out 1996

LUX

BOLETIM INTERNO DO LNLS
Laboratório Nacional de Luz Síncrotron

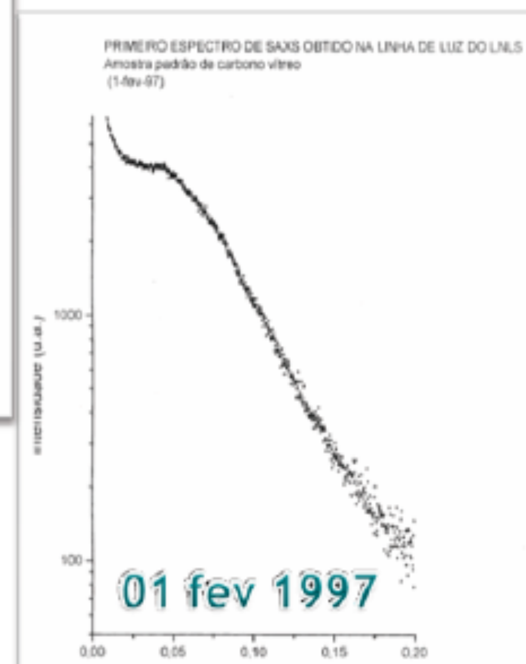
15

Primeiro espectro da estrutura fina de absorção de raios X

Às 15 horas do domingo, dia 3 de novembro, foi obtido o primeiro espectro da absorção de Raios X na linha de luz D04B-XAFS do LNLS. Pela primeira vez, foi medida a estrutura fina da absorção em torno da borda K do cobre, conforme gráfico abaixo.

Primeiro espectro de absorção da borda K do cobre obtido no LNLS no dia 3 de novembro de 1996 às 15:00 hs

03 nov 1996



01 fev 1997

April/1997 – open for users

First call for proposals

Beginning of operation as a National Lab with 5 beamlines

BOLETIM LNLS

MCT-CNPq
LABORATÓRIO NACIONAL DE LUZ SÍNCROTRON

1997
Nº 1
ABRIL

Laboratório começa a receber pesquisadores

CIENTISTAS JÁ PODEM ter acesso à fonte de luz síncrotron brasileira para realizar pesquisa científica. O Ministério da Ciência e Tecnologia e o Conselho Nacional de Desenvolvimento Científico e Tecnológico vão entregar o equipamento aos pesquisadores em maio.

O LNLS É UM CENTRO nacional de pesquisas, aberto a cientistas de qualquer nacionalidade que desenvolvem estudos de materiais, em níveis atômico e molecular, utilizando a luz síncrotron.

EM LINHAS DE LUZ E estações experimentais instaladas no LNLS, os pesquisadores encontram a infra-estrutura adequada para realizar experimentos para aplicações em áreas da Física, Química, Ciência dos Materiais, Biologia e Ciências do Meio Ambiente.

CINCO LINHAS E ESTAÇÕES EXPERIMENTAIS estão em fase de testes e estarão abertas a usuários externos a partir de julho de 1997. Outras duas linhas estarão disponíveis a partir de setembro. Em fevereiro de 1998, a oitava linha de luz ficará pronta. As aplicações desta instrumentação científica estão descritas resumidamente neste Boletim.

AS PROPOSTAS SUBMETIDAS AO LNLS serão analisadas por *referees*. Três aspectos são essenciais: relevância científica ou tecnológica do tema da pesquisa, competência dos cientistas autores da proposta e viabilidade técnica das experiências propostas com os equipamentos disponíveis no Laboratório.

Visão parcial do anel de armazenamento de elétrons do LNLS com instrumentação que leva luz síncrotron até estações experimentais

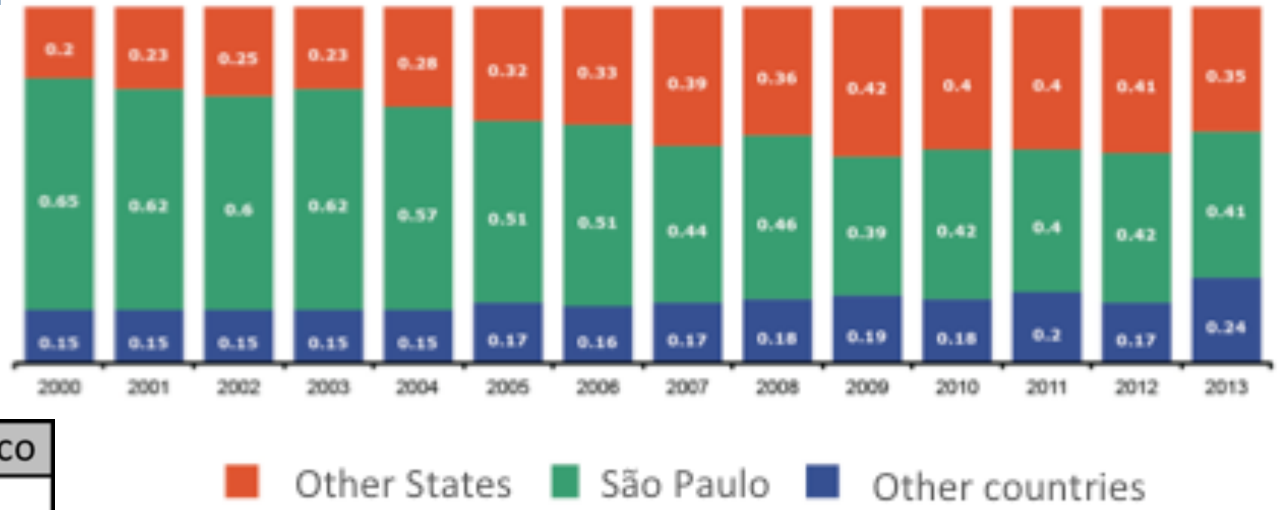
O USUÁRIO ACADÊMICO não paga pelos fótons nem pela infra-estrutura básica disponível no LNLS. Em troca, assume o compromisso de publicar os resultados da pesquisa, tornando-os acessíveis para a comunidade científico-tecnológica.

NENHUM GRUPO DE pesquisa tem direito de uso exclusivo sobre equipamentos instalados no LNLS. Esta diretriz institucional é aplicada aos equipamentos desenvolvidos e construídos por integrantes do quadro próprio do Laboratório ou por usuários externos.

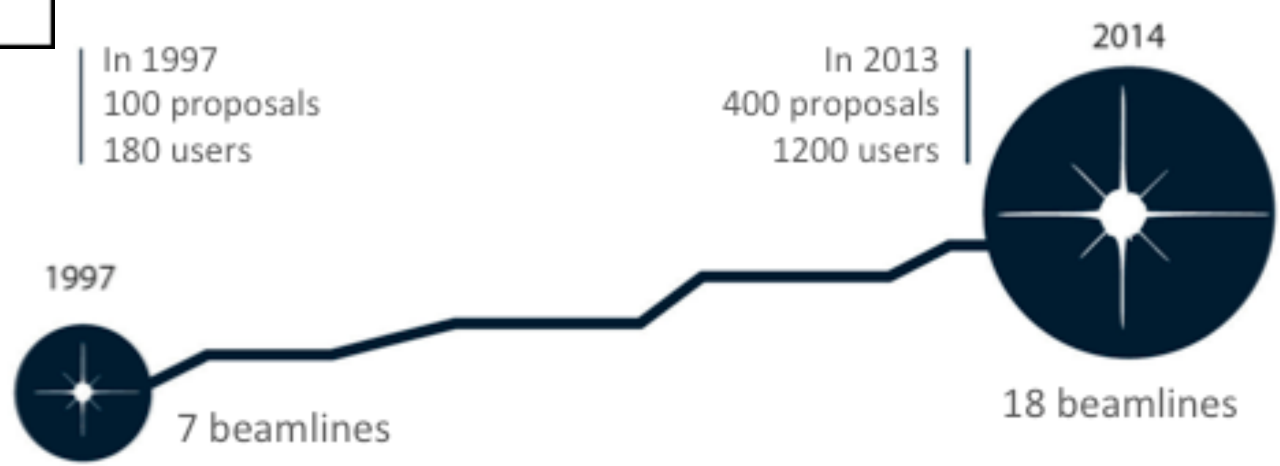
O LNLS É UM INSTRUMENTO DE fomento à pesquisa que o CNPq coloca à disposição dos cientistas.

Formulário **Proposta de Pesquisa** está disponível na home-page do LNLS (http://www.lnls.br) ou pode ser solicitado à Secretaria de Apoio ao Usuário pelo e-mail "secre@lnls.br"

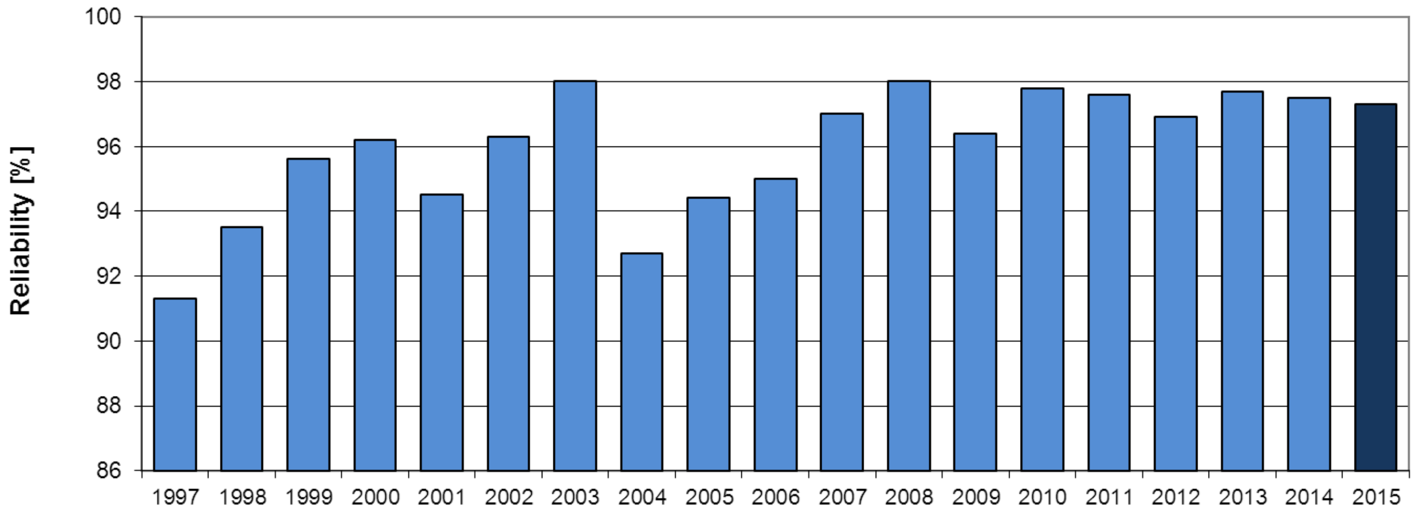
The UVX user community

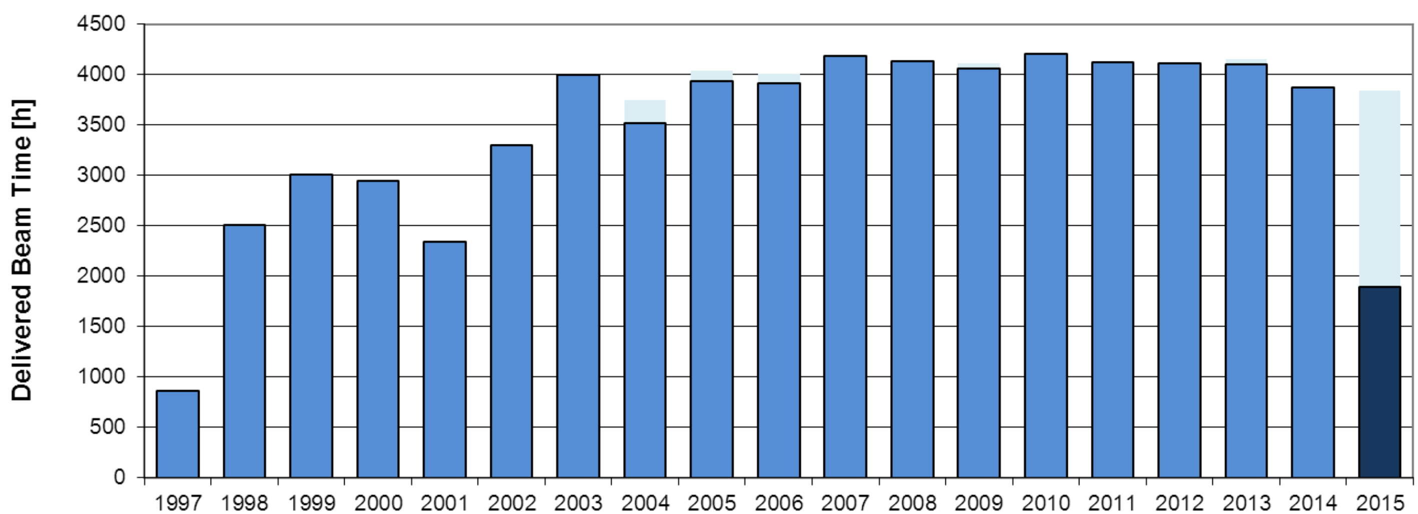


Year	Users From Mexico
2010	3
2011	5
2012	5
2013	1
2014	2



UVX Performance Parameters





2015: Jan - Jun

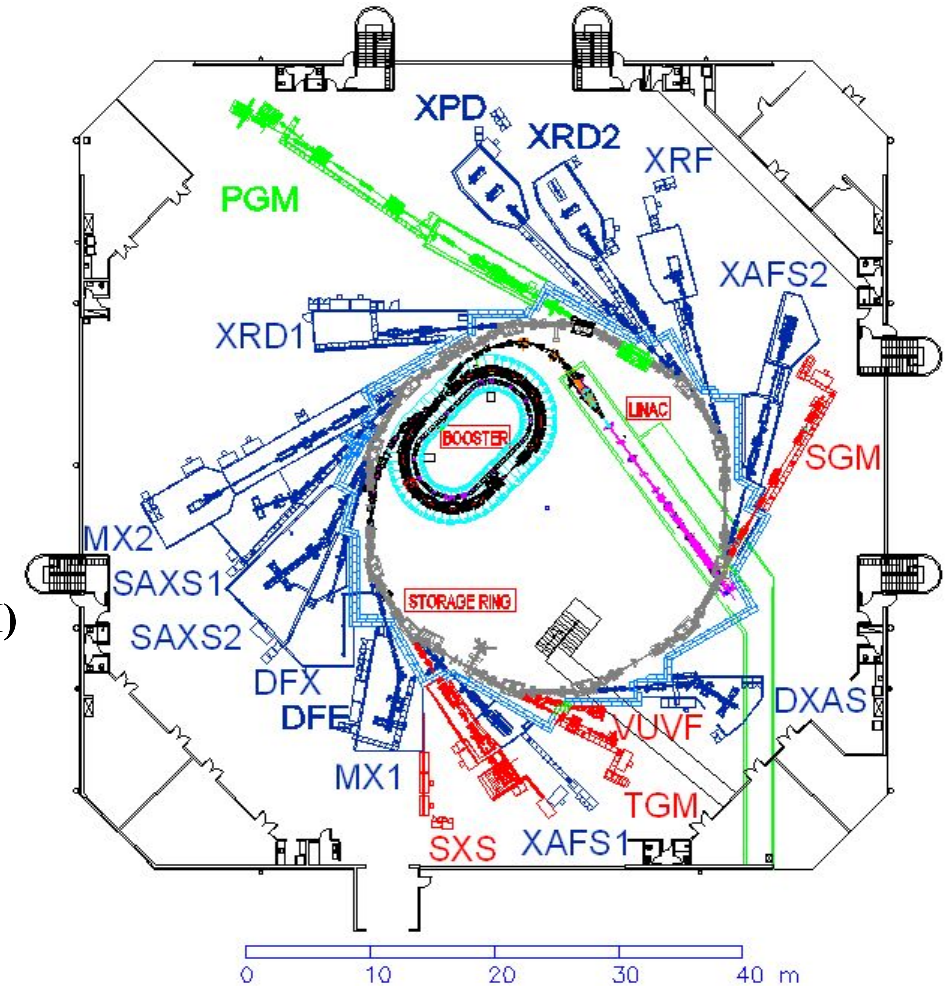
UVX beamlines

VUV and Soft X-ray (5)

- **Toroidal Grating Monochromator (BM)**
- **Spherical Grating Monochromator (BM)**
- **Planar Grating Monochromator (undulator)**
- **Soft X-Rays Spectroscopy (BM)**
- **Infrared nanospectroscopy (BM)**

Hard X-ray (13)

- **small angle X-ray scattering I (BM)**
- **small angle X-ray scattering II (BM)**
- **X-ray absorption spectroscopy (BM)**
- **dispersive X-ray absorption spectroscopy (BM)**
- **X-ray diffraction I (BM)**
- **X-ray diffraction II (BM)**
- **X-ray powder diffraction (BM)**
- **X-ray fluorescence (BM)**
- **X-ray imaging (BM)**
- **crystallography of macromolecules (BM)**
- **MAD protein crystallography (wiggler)**
- **X-ray absorption spectroscopy II (BM)**
- **Materials science (SC wiggler)**



UVX beamlines

VUV and Soft X-ray (5)

- **Toroidal Grating Monochromator (BM)**
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- **Infrared nanospectroscopy (BM)**

Hard X-ray (13)

- **small angle X-ray scatter**
- **small angle X-ray scatter**
- **X-ray absorption spectro**
- **dispersive X-ray absorpt**
- **X-ray diffraction I (BM)**
- **X-ray diffraction II (BM)**
- **X-ray powder diffraction**
- **X-ray fluorescence (BM)**
- **X-ray imaging (BM)**
- **crystallography of macromolecules (BM)**
- **MAD protein crystallography (wiggler)**
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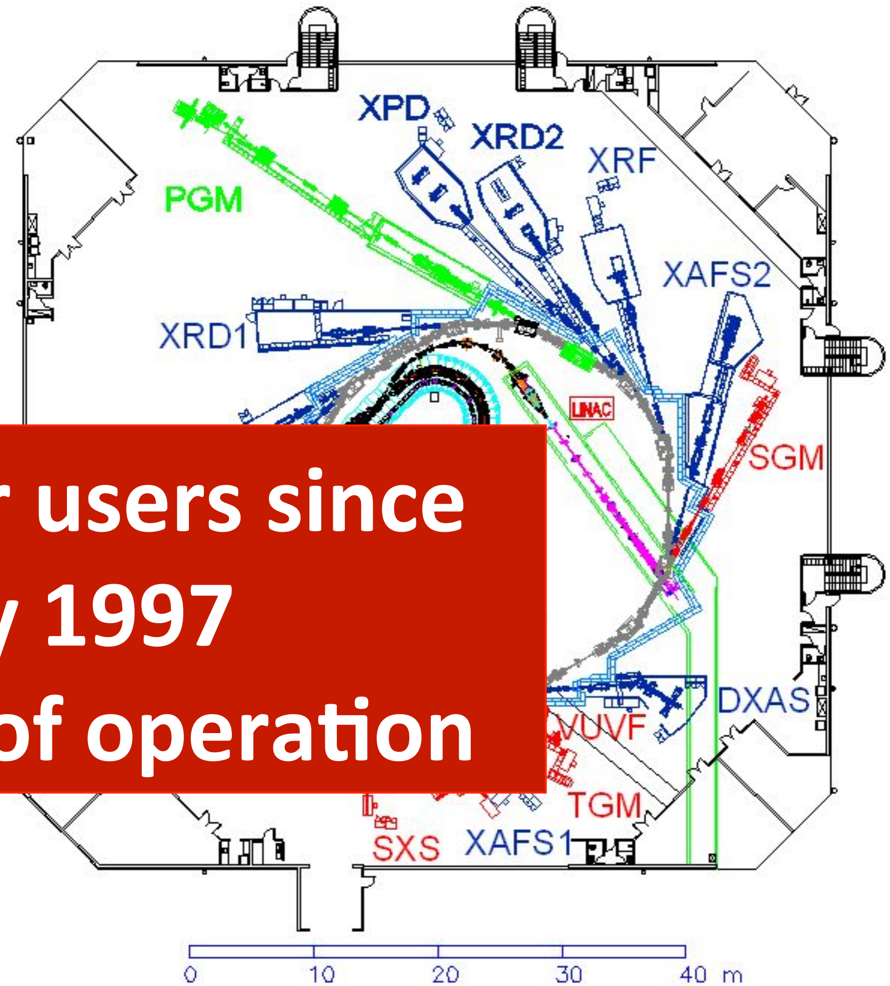


Open for users since July 1997
18 years of operation

The new Brazilian Synchrotron Light Source

2008 – Proposal to prepare a conceptual design of a new light source in presented to MCTI


Ministério da Ciência e Tecnologia

LNLS

Laboratório Nacional de Luz Síncrotron

BRASIL

UM PAÍS DE TODOS

GOVERNO FEDERAL

LNLS-2: UMA NOVA FONTE DE LUZ SÍNCROTRON DE ALTO DESEMPENHO PARA O BRASIL

Proposta para Preparação de um Projeto Conceitual Detalhado

Laboratório Nacional de Luz Síncrotron LNLS

Campinas, Fevereiro de 2008

2003 – In the 13th User Meeting, the users discussed the need to start studying the possibility of a new, more competitive, light source

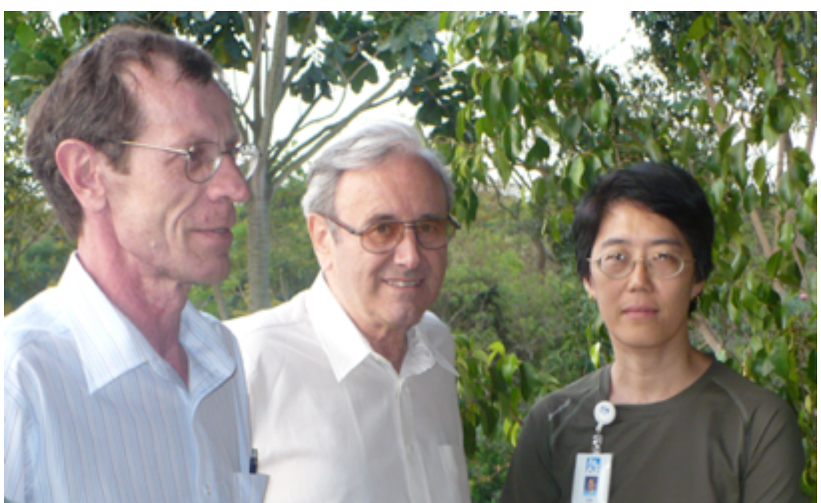
2006 – Recommendation, in the 2006-2009 Strategic Plan of ABTLuS, that a task force should be created in LNLS to study a new, low emittance light source

2009

1st Workshop LNLS-2: Scientific Cases
10 and 11 of February

2nd Workshop New Source: Scientific Case
27 and 28 of August

Many internal meetings to define the conceptual project



2010 - 2011

- Refinement of project
- Infra-structure
- First permanent magnet prototypes

Proceedings of IPAC'10, Kyoto, Japan WEPEA006

SIRIUS (BR): A NEW BRAZILIAN SYNCHROTRON LIGHT SOURCE

L. Liu*, X. R. Resende and A. R. D. Rodrigues
LNLS - Laboratório Nacional de Luz Síncrotron, CP 6192, 13084-971, Campinas, SP, Brazil.

Abstract

We report on the status of Sirius, the new 3 GeV synchrotron light source currently being designed at the Brazilian Synchrotron Light Laboratory (LNLS) in Campinas, Brazil. The new light source will consist of a low emittance storage ring based on the use of permanent magnet technology for the dipoles. An innovative approach is adopted to enhance the performance of the storage ring dipoles by combining low field (0.5 T) magnets for the main beam deflection and a short slice of high field magnet. This short slice will create a high bending field (2.0 T) only over a short longitudinal extent, generating high critical photon energy with modest energy loss from the complete dipole. There are several attractive features in this proposal, including necessity for lower RF power, less heating of the vacuum chambers and possibility to reduce the beam emittance by placing the longitudinal field gradient at a favorable place.

INTRODUCTION

In order to satisfy the future demand for synchrotron radiation in Brazil, a proposal for a new ring is being developed to replace the existing 1.37 GeV UVX light source, a facility that is being operated for users since July 1997 in Campinas, São Paulo. The proposed new source, Sirius, is a 3rd generation 3.0 GeV low emittance synchrotron light source facility to be built in the same LNLS site, as shown in Figure 1.

Many alternative lattices have been analysed in the last year, including the 2.5 GeV, 16 cell TBA lattice presented at PAC09 [1]. That design was based on the use of low field (0.45 T) permanent magnets for the storage ring dipoles. The use of permanent magnets can reduce both the investment and operation costs of the project with the elimination (or significant decrease) of power supplies and cooling systems. The low dipole field also favors emittance reduction by wigglers. There is however the considerable drawback of excluding hard x-ray bending magnet sources, which can have substantial demand from users since the beam size is naturally very small at dipole sources and some experiments do not need the high brightness of the insertion devices.

In the second half of 2009 a new idea came up that would allow the implementation of hard x-ray dipole radiation sources but would still preserve the benefits of low overall dipole radiation power. The idea is to combine the low bending field for the main beam deflection with a high magnetic field which extends over only a very short longitudinal length (a slice magnet, for 1° deflection) so that the hard x-ray radiation is produced only at the beamline exit. In addition, this high field slice could be used to create a longitudinal bending field profile designed to help reducing the emittance. The idea was implemented in the new lattice design and, together with further considerations on the need to produce high brightness radiation up to about 100 keV, led to a modification of the project to a 3.0 GeV electron storage ring with 20 TBA cells. The permanent magnet dipoles now combine a low bending field of 0.5 T for the main beam deflection with a 2.0 T slice to produce hard x-ray bending magnet photons of 12 keV critical energy.

UVX
1.37 GeV
Sirius
3.0 GeV

Figure 1: Aerial view of the LNLS site with the planned new Sirius light source.

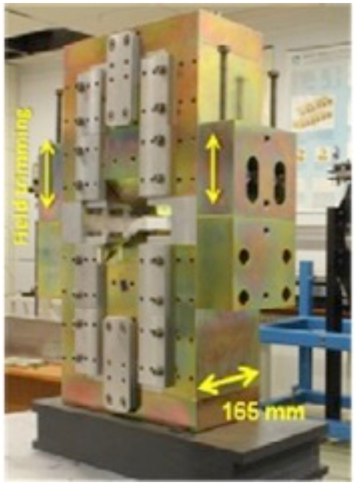
THE STORAGE RING LATTICE

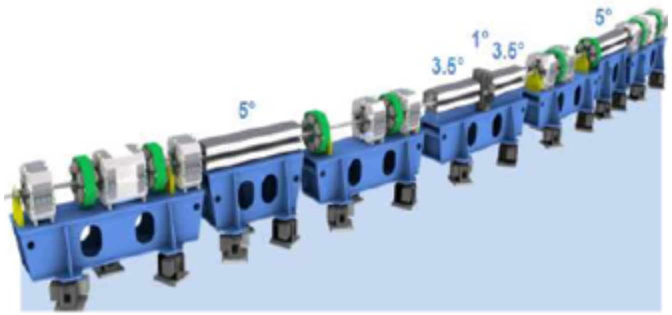
Linear optics – emittance optimization

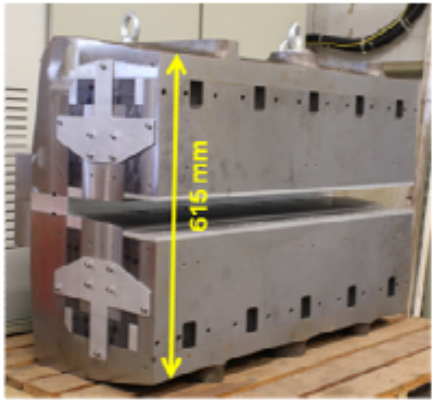
The 3.0 GeV low emittance Sirius lattice structure is of a modified TBA type, with the middle dipole split to accommodate the high field slice in its center, as shown in Figure 2. Concerning emittance reduction, the center of the middle dipole is the most favourable position to place the high field slice since this is where the so called H function is small [2]. In addition, this is also a proper position for the dipole synchrotron light port. Besides the longitudinal field variation, we also resort to other known recipes to reduce the emittance, specifically, the use of transverse field gradient in the dipoles to increase the horizontal damping partition number, the allowance of slightly positive values for the horizontal dispersion at the straight sections (thus breaking the achromat condition), and the increase in the inner bending angle in the TBA cell with respect to the outer angles [3].

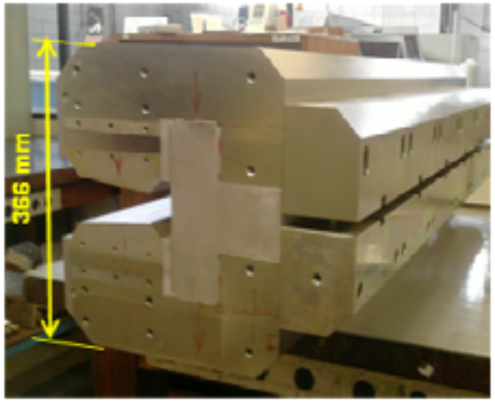
Based on the above guidelines along with the obvious (and conflicting) requirements of a low emittance lattice with large dynamic aperture and limited circumference, we propose a 20-cell modified TBA structure for Sirius. The total deflection per cell of 18° is divided into 5° for each outer dipole and 8° for the middle one. The latter, in

*liu@lnls.br









2011

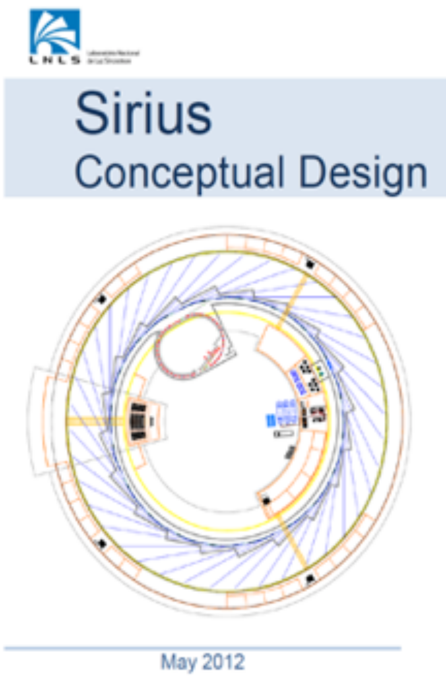
- Initiative “Construção de uma Fonte de Luz Síncrotron de 3ª geração” is incorporated in the Multiannual Plan 2012-2015 of the Federal Government

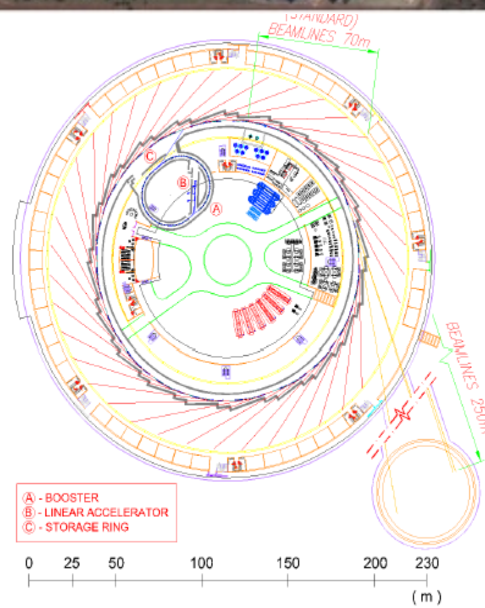
- Sirius Project is included in the National Strategic Plan for Science, Technology and Innovation ENCTI 2012-2015

- **Sirius Project is included in the 2012 Federal Budget Law**

2012

Project mature enough to be presented to an International Committee – MAC (Machine Advisory Committee) – 18 to 20 of June





2012 - Most important MAC recommendation

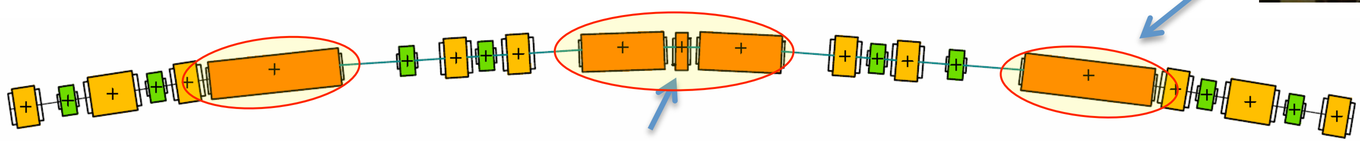
The present lattice design is excellent by today's standards, but the committee urges LNLS to **push for tomorrow's brightness standard (e.g. <1 nm emittance)**.

- **Sirius presented to the Machine Advisory Committee meeting in June 2012:**

Emittance: **1.7 nm.rad**

3-Bend Achromat, **480m** circumference

permanent magnets



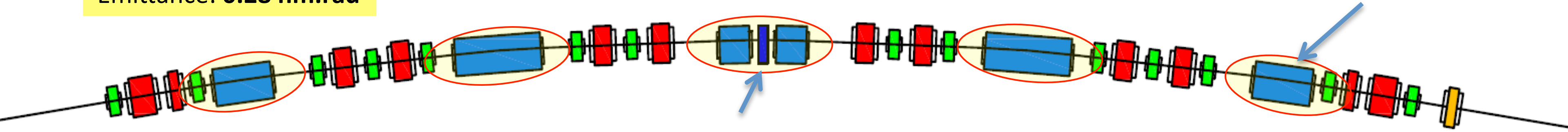
2T permanent magnet superbend

- **Sirius four months after 2012 MAC recommendation**

5-Bend Achromat, **518m** circumference

Emittance: **0.28 nm.rad**

Electromagnetic magnets



2T permanent magnet superbend

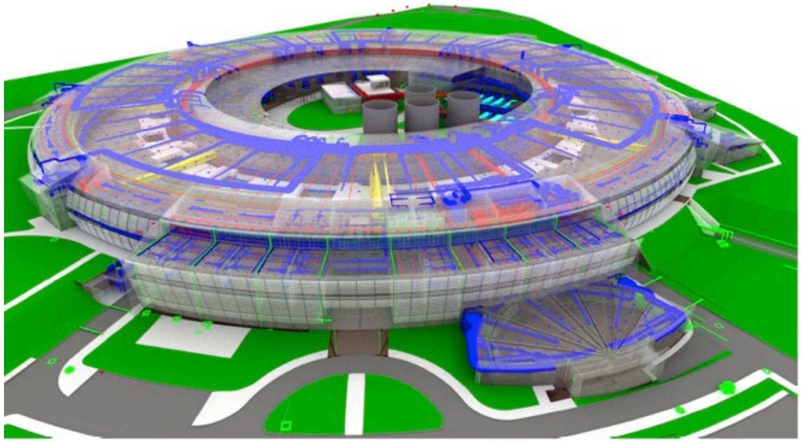
7-m SS

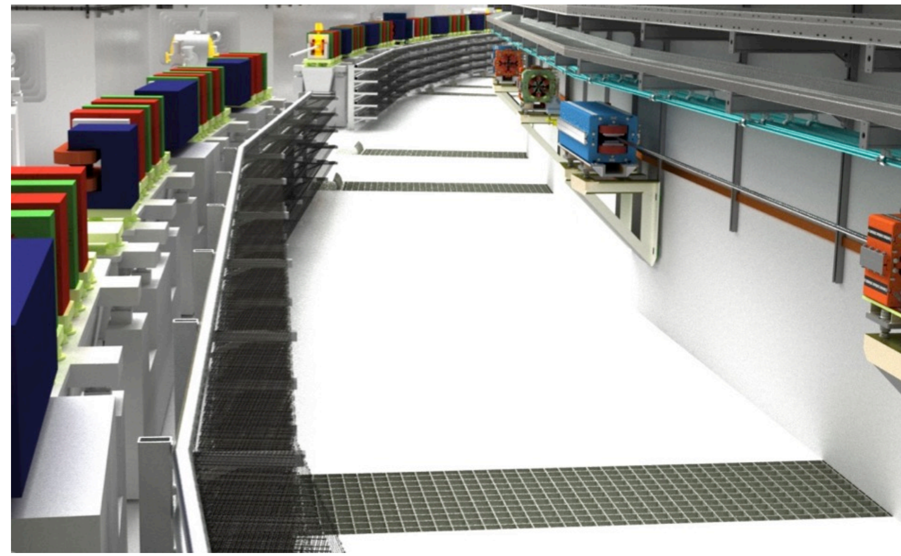
6-m SS

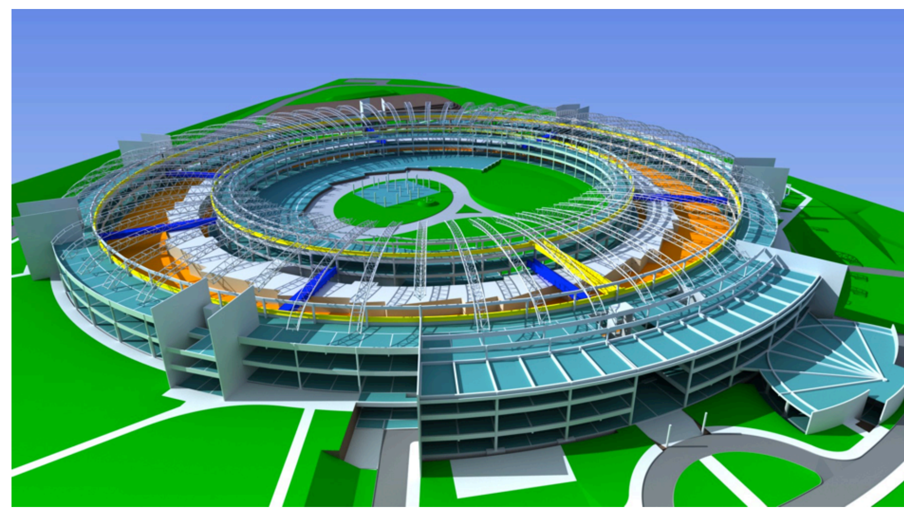
2013 - Sirius @ CNPEM campus

- Schedule
  - Nov. 2017 start of machine installations
  - mid 2018 start of SR commissioning

2012-2014 – Executive project concluded







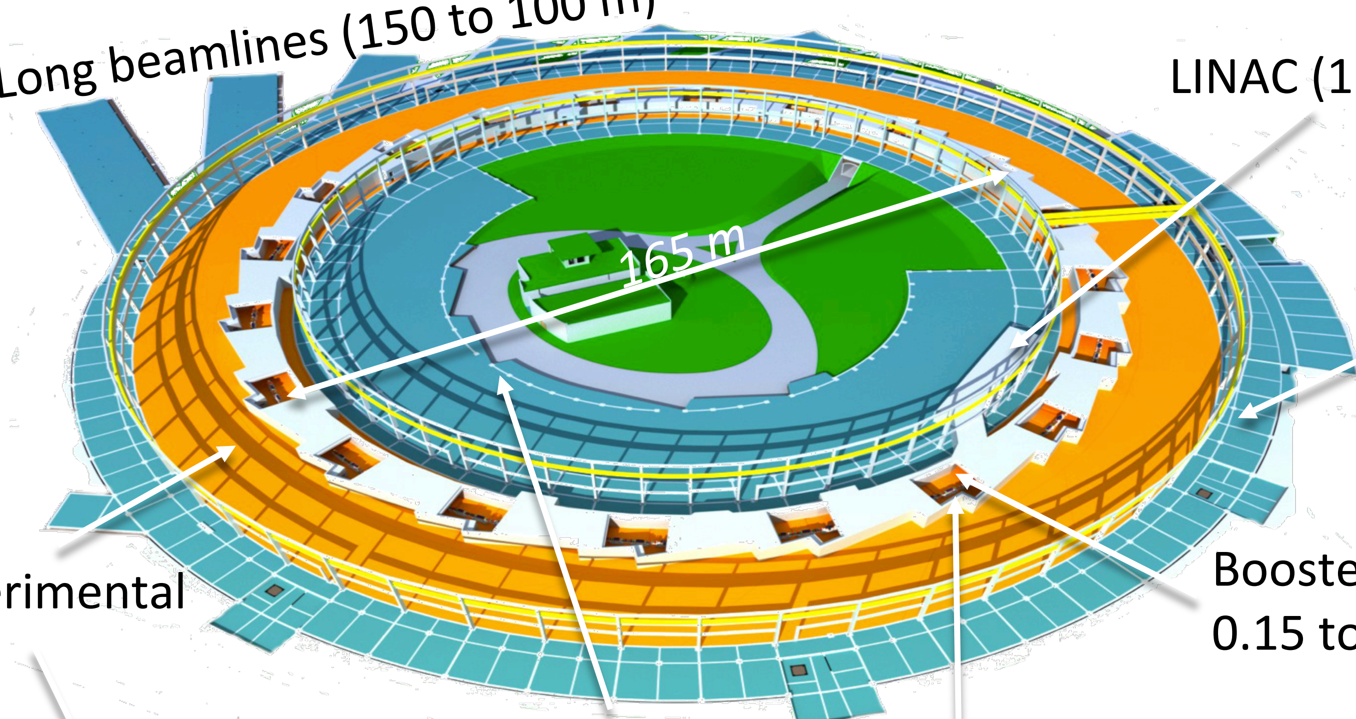
- Total area - 68.000 m^2
- Special floor to minimize effects of vibration on the accelerator and beamlines

Engineering
A Hill International Company

Building

Long beamlines (150 to 100 m)

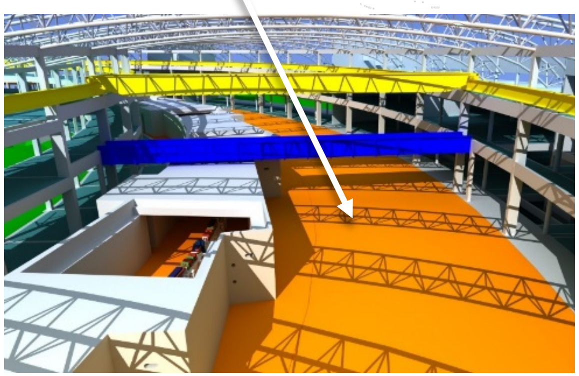
LINAC (150MeV)



Aux. labs. and offices

Experimental hall

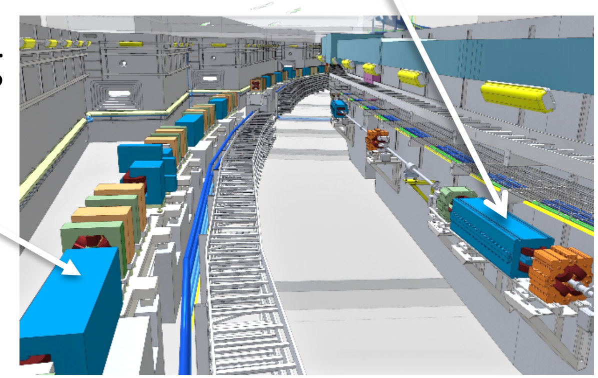
Booster (Inner wall; 0.15 to 3 GeV)



Technical area

- Electrical energy
- Cooling water plant
- Compressed air
- Air conditioning
- LHe plant
- RF amplifiers
- Power supplies
- Control room

Storage ring (3 GeV)



2014 – Landwork finished

October 2014

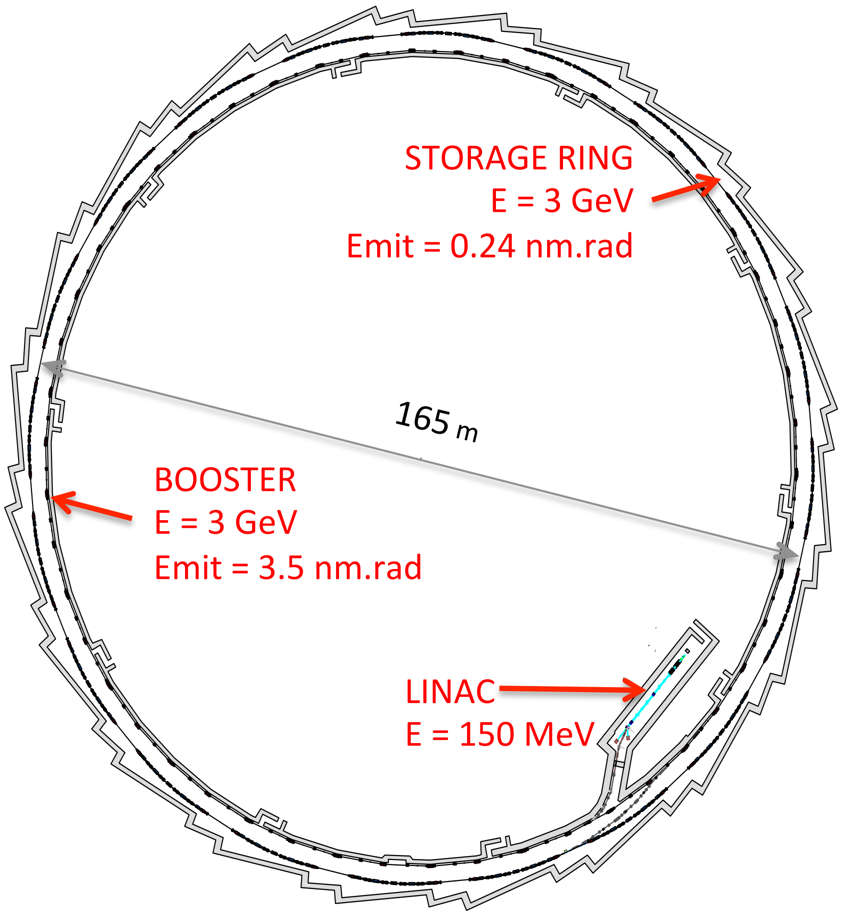
2014 – Construction started in December

LNLS
sirius

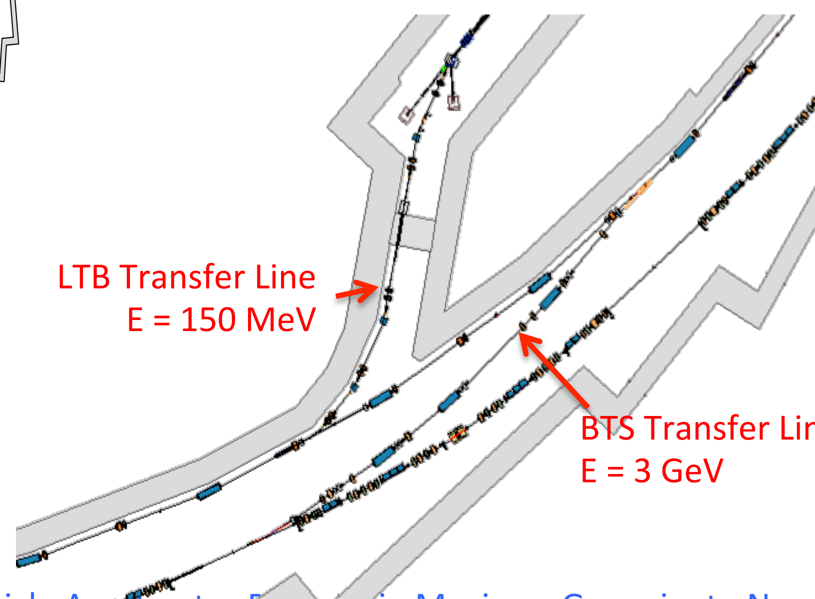
Racional
Racional Engenharia Ltda

- 40 months construction – conclusion in April 2018.
- Important milestone: September 2017 – tunnel ready to start assembling the accelerators.

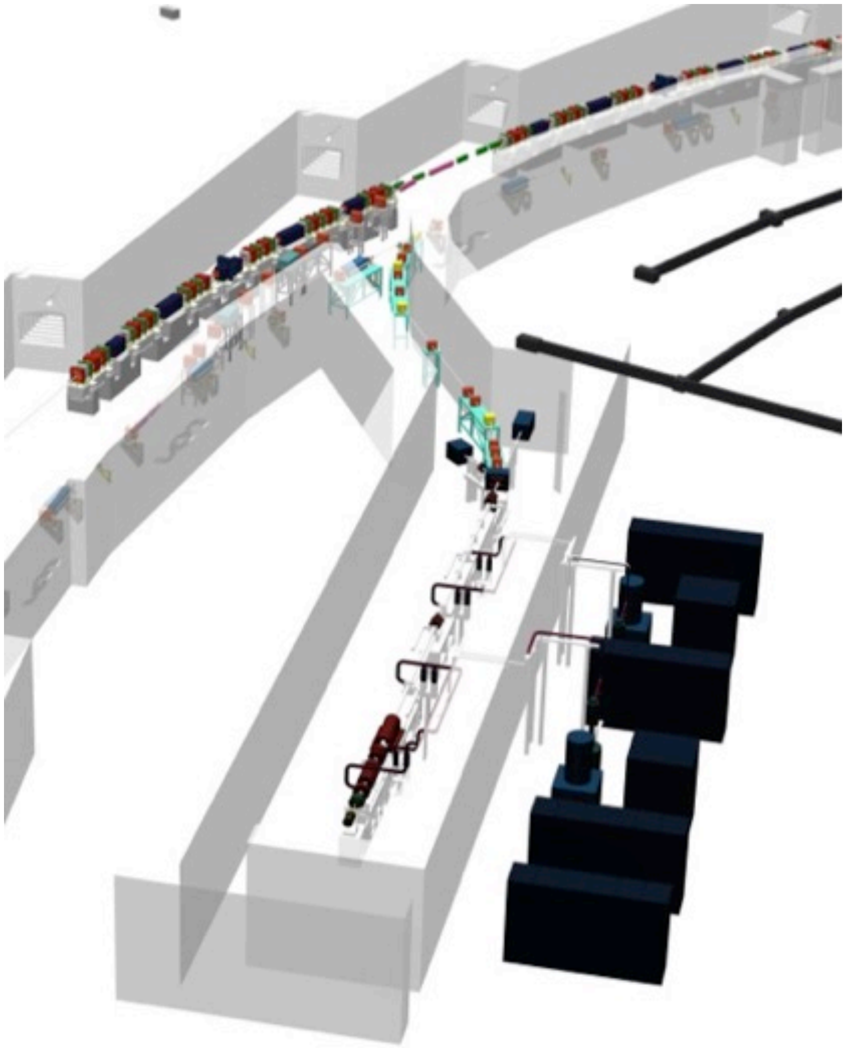
Sirius Accelerators Layout

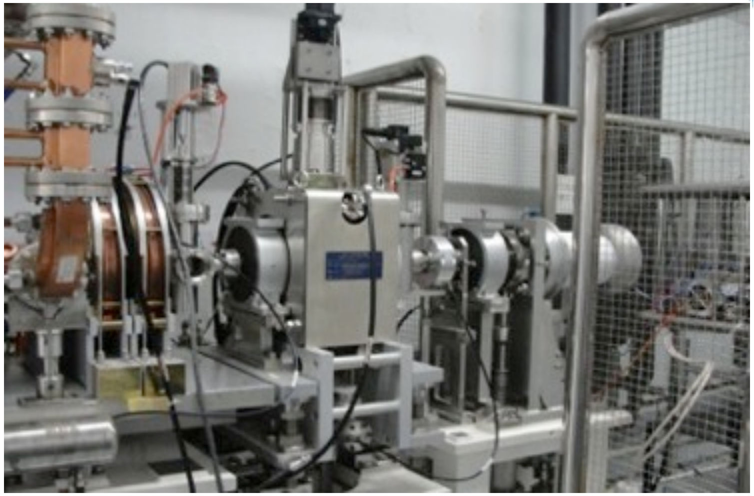


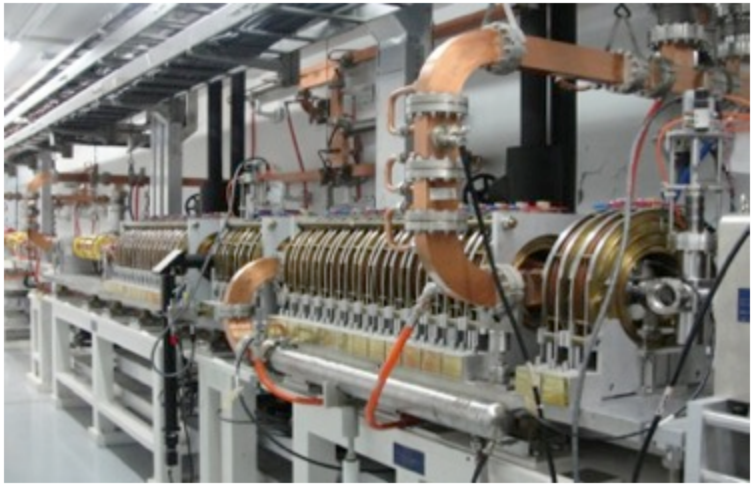
Concentric storage ring and booster share the same tunnel



2015 – Present Status: LINAC

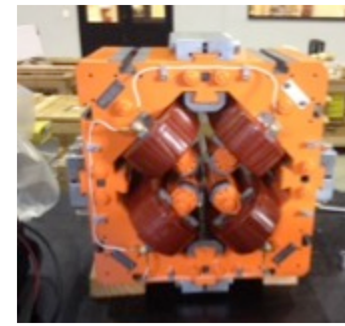






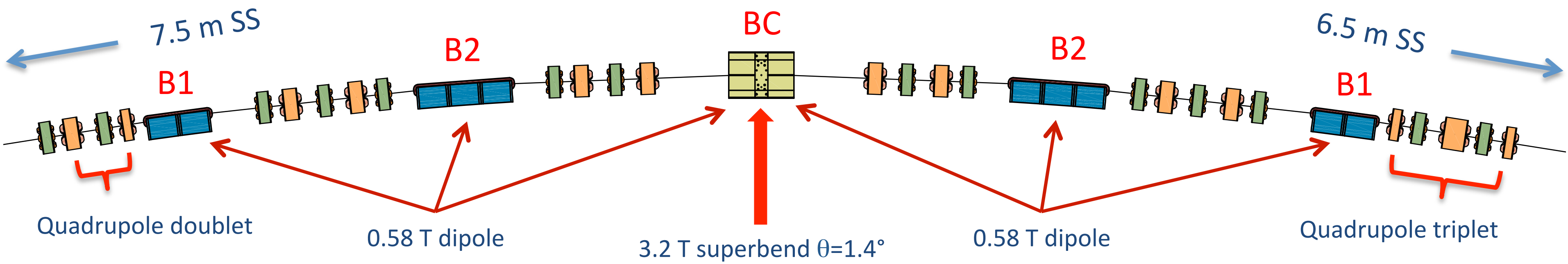
LINAC (150 MeV) – Order placed to SINAP (Shanghai Institute of Applied Physics)/China

2015 – Present Status: Booster

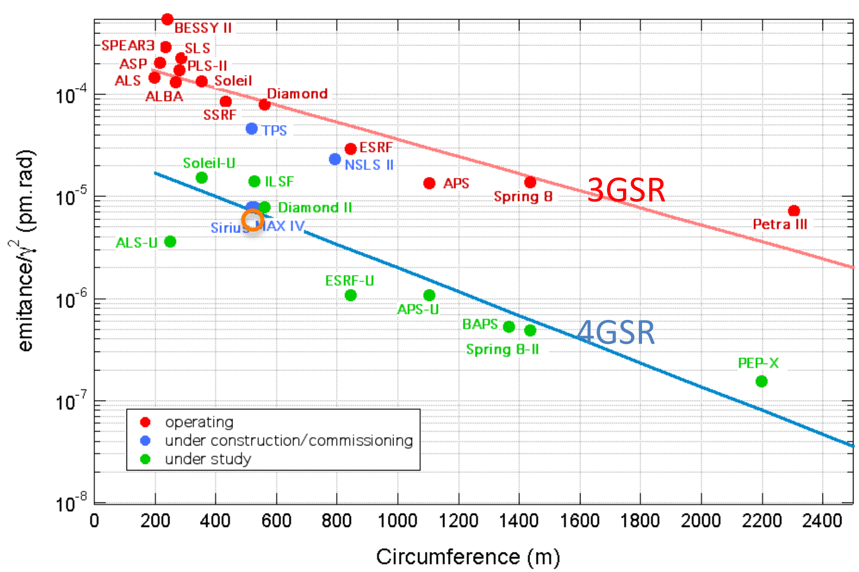


- All projects of magnets concluded and sent to WEG;
- Correctors already received;
- Prototypes of quads received;
- Order placed for the RF cavities (RI);
- Many prototypes fabricated: vacuum chamber, girders, RF amplifier, etc.

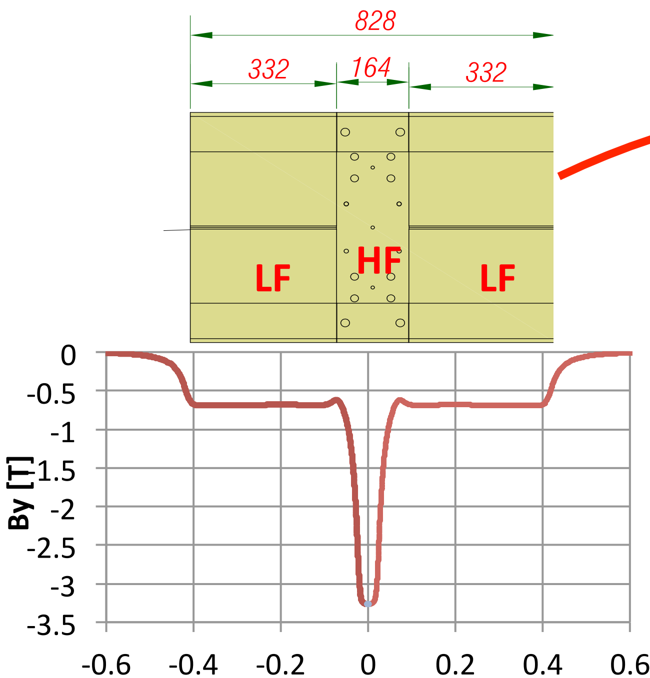
Storage Ring Parameters

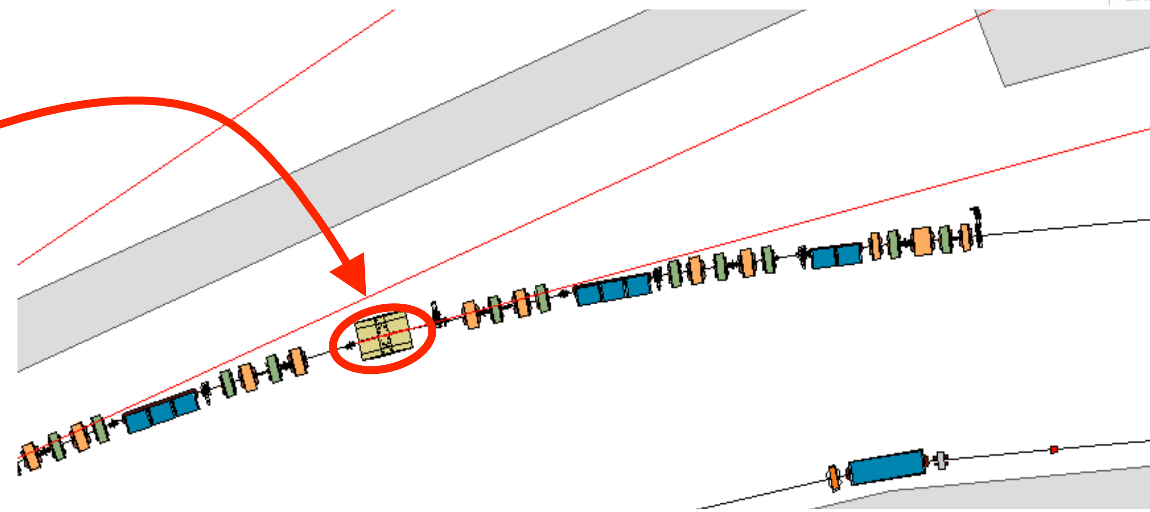


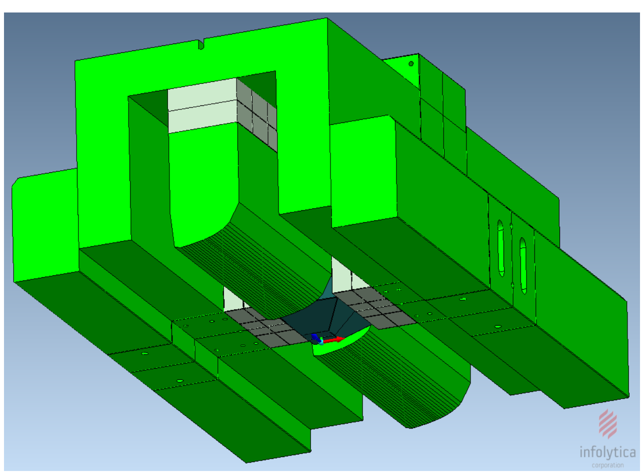
Beam energy	3.0	GeV
Circumference	518.4 m	m
Lattice	20 x 5BA	
Straight sections (SS)	10 x 7.5m; 10 x 6.5m	
# of SS for IDs	18	
Nominal current, top up	350	mA
Betatron tunes (H / V)	48.10 / 13.17	
Hor. Emittance	**240 – 150**	**pm.rad**
Vert. emittance (k=1%)	2.4	pm.rad
Number of bunches	$864 = 2^5 \times 3^3$	
Natural bunch length	9 (2.6)	ps (mm)
Energy spread	0.095 – 0.086	%
RF frequency	500 MHz	MHz



BC: Low Field + High Field Superbend

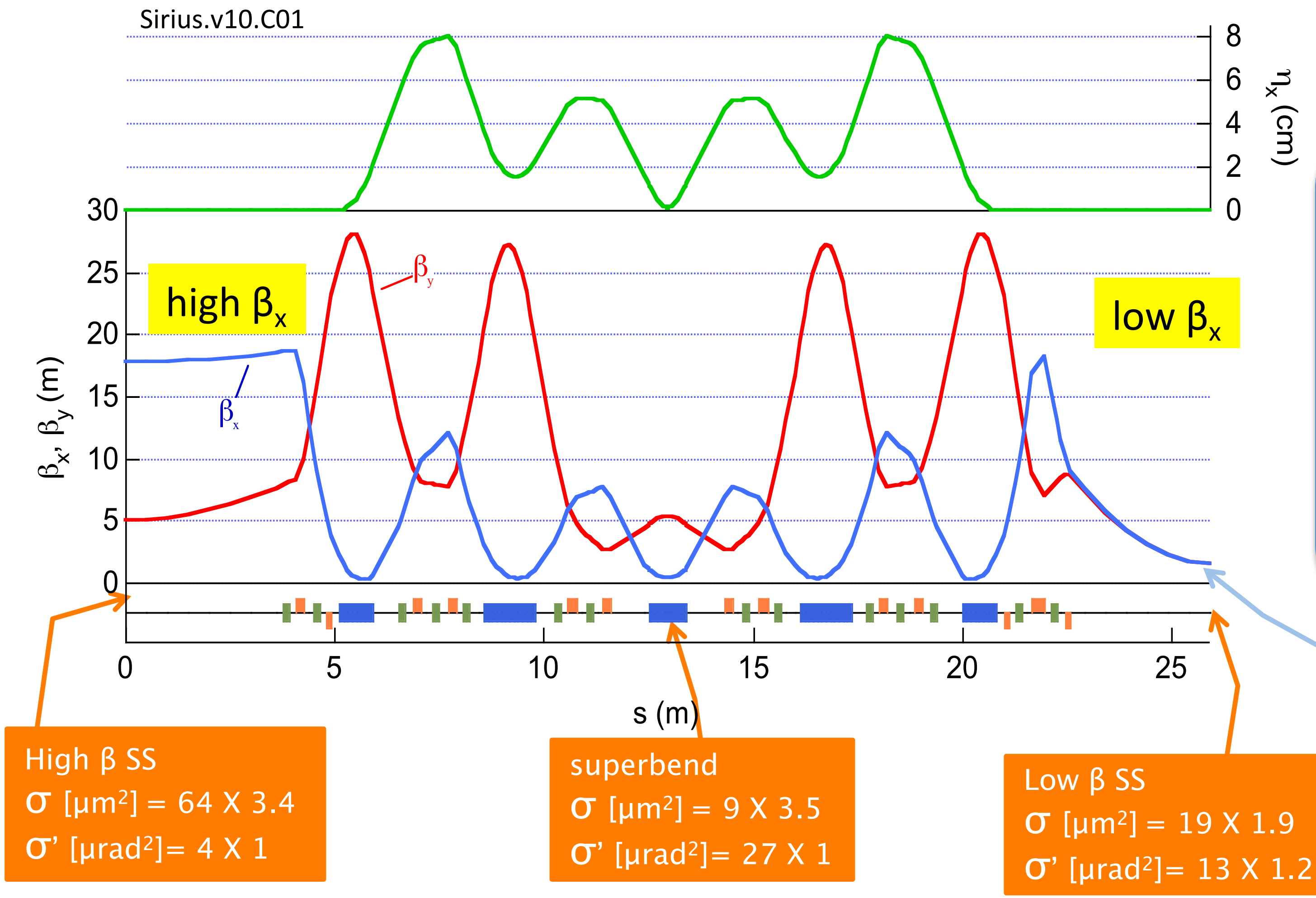


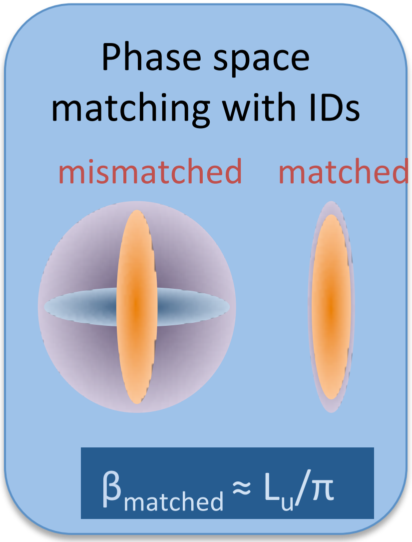




- Permanent magnet (NdFeB)
- Low field (0.6 T) with transverse gradient
- High field insert (3.2 T) superbend
  - 19 keV critical energy
  - 1.4° deflection
  - Hard X-rays produced only at beamline exit
  - Total energy loss/turn from dipoles = 532 keV

Optical functions



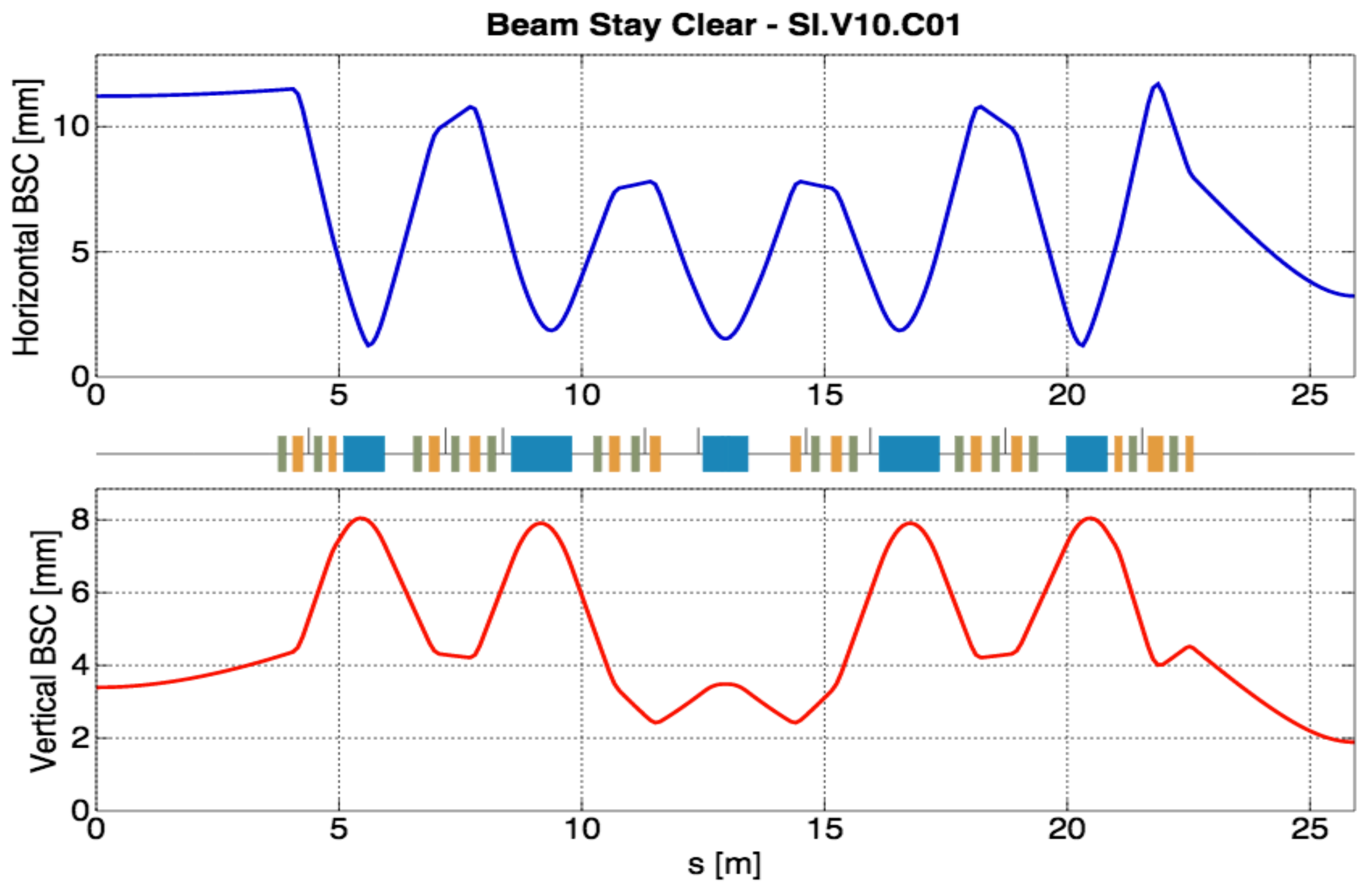


- 10-fold symmetry, alternating high and low β_x straights. Achromatic.
- Other configurations under study, e.g. 5-fold symmetric, with fewer high β_x straights.

Beam stay clear – required free aperture for the beam

Horizontal: limited by vacuum chamber at high β_x section. Corresponds to full gap of 8 mm in the horizontal plane for a 2 m long ID at the center of low β_x section.

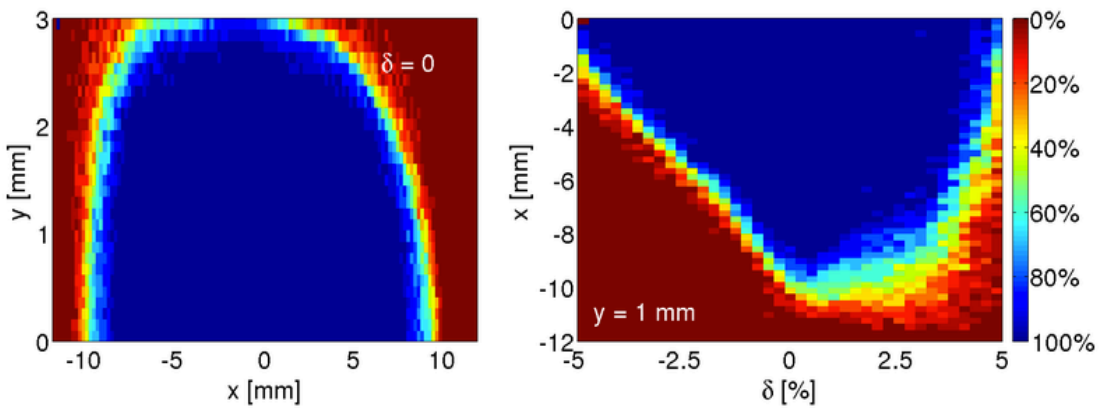
Vertical: limited by a 2 meter long ID with full gap of 4.5 mm at the center of low β_x section.



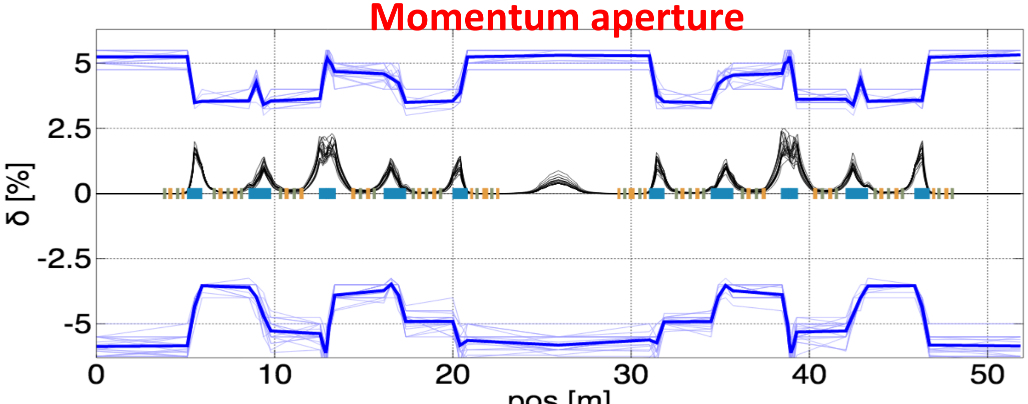
Non-linear dynamics

- Dynamic and momentum apertures optimized with 14 sextupole families. No octupoles.
- Optimization in progress including magnets measured data and different IDs. No EPUs with vertical polarization.
- 6D tracking with alignment and multipole errors, physical limitations (including IVUs at minimum gap), orbit, tune and coupling corrections.

Dynamic aperture



Momentum aperture



Random gaussian errors

- Alignment, magnets: 40 μm
- Alignment, girders: 80 μm
- Roll: 0.3 mrad
- Excitation: 0.05 %
- Multipole: $\Delta B/B_{x=12\ mm} = 1\text{x}10^{-4}$

Orbit correction

- BPMs close to strong sextupoles and quadrupoles (BBA).
- BPMs: 180 (9/cell)
- CHs: 120 (slow) / 80 (fast)
- CVs: 120 (slow) / 80 (fast)

Physical limitations

- straight sections: ∅ = 24 mm
- dipoles: ∅ = 24 mm
- IVUs: full gap = 4.5 mm, L=2m

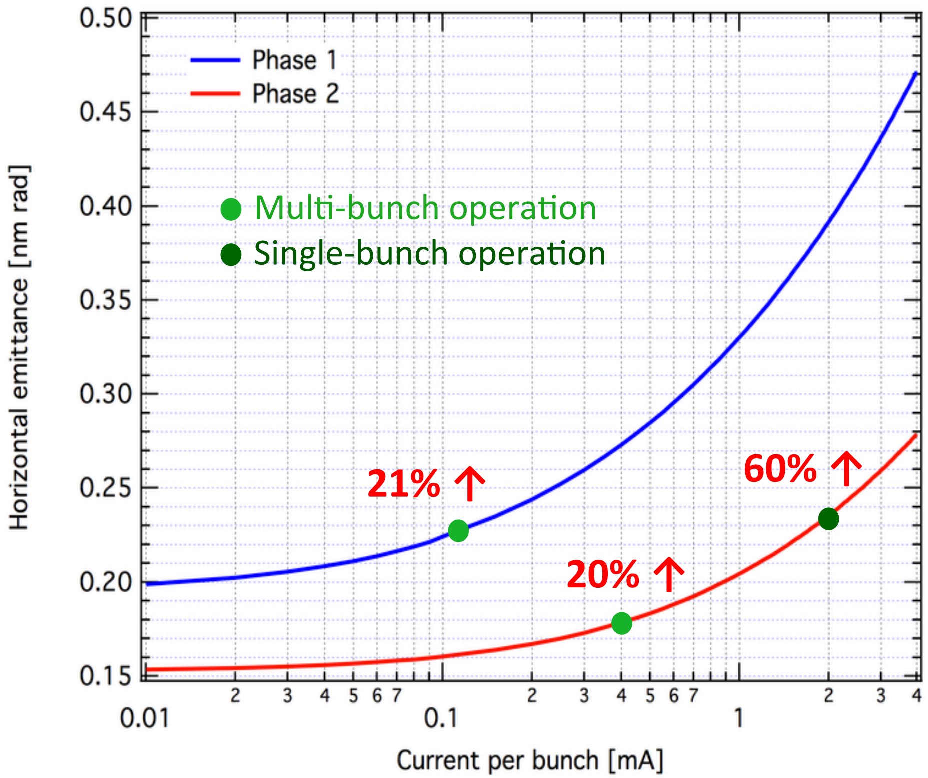
Operation Phases

	Phase 0 Commissioning	Phase 1 Initial User Mode	Phase 2 Final User Mode	
Maximum total current	100	100	350	mA
Current/bunch (uniform fill)	0.116	0.116	0.405	mA
Single bunch current	-	-	2	mA
RF Cavities	2 SC	2 SC	2 SC + 3HC	
Natural emittance*	0.24	0.19 **21% ↓**	0.15 **37% ↓**	nm.rad
IDs	-	6 IVUs, 2 EPUs	12 IVUs, 8 EPUs	
Natural energy spread*	0.095	0.091	0.086	%
Natural bunch length*	2.6	2.2	11.7	µm

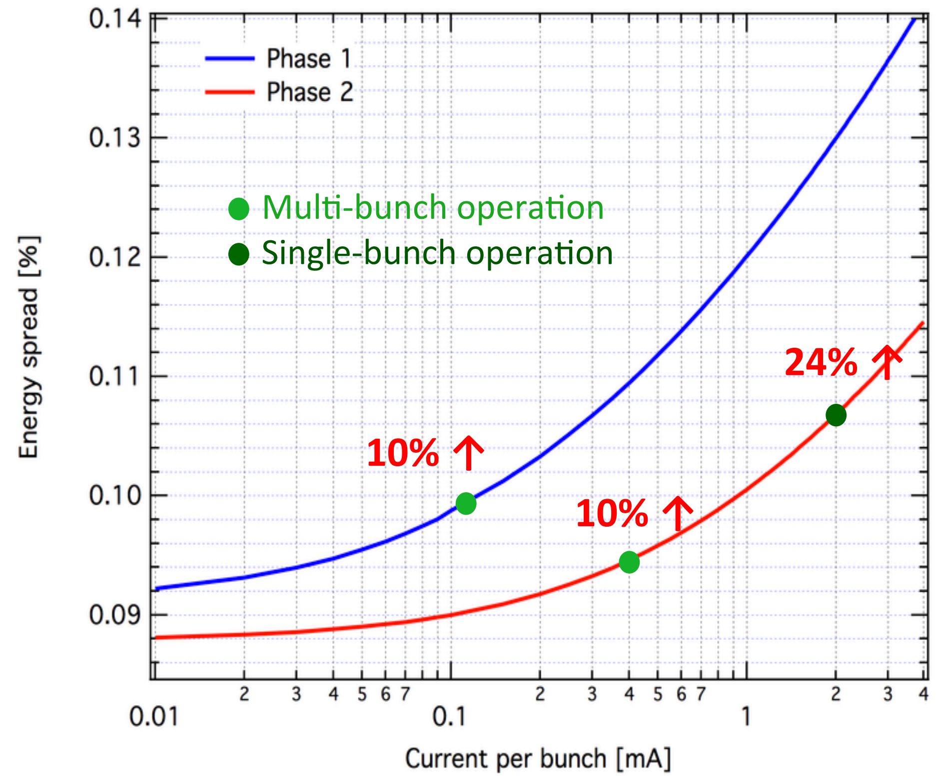
*Considering zero current

Intra Beam Scattering effects

Emmitance



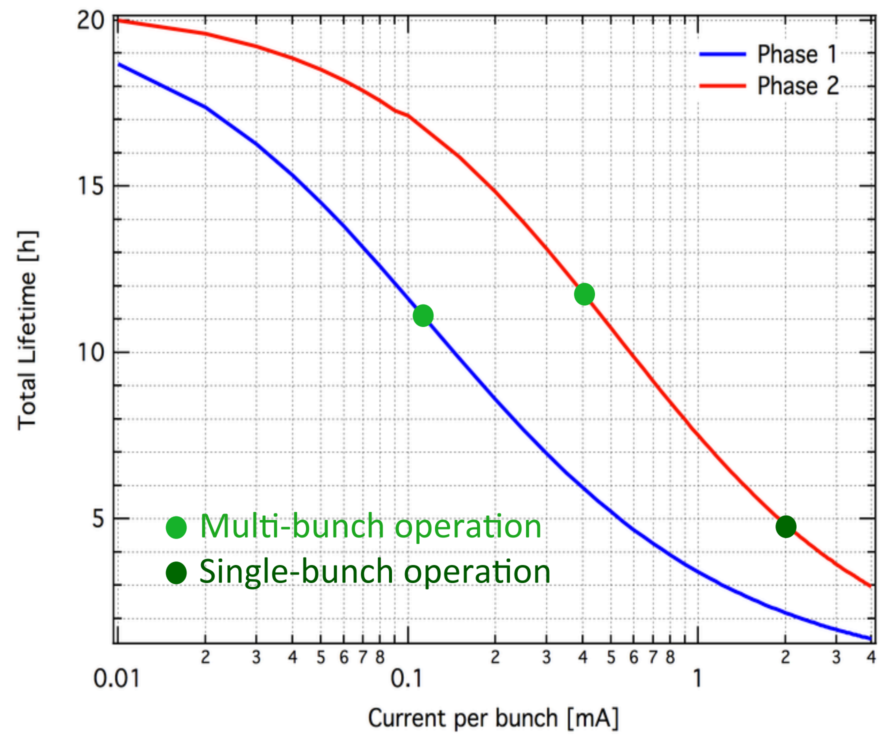
Energy spread



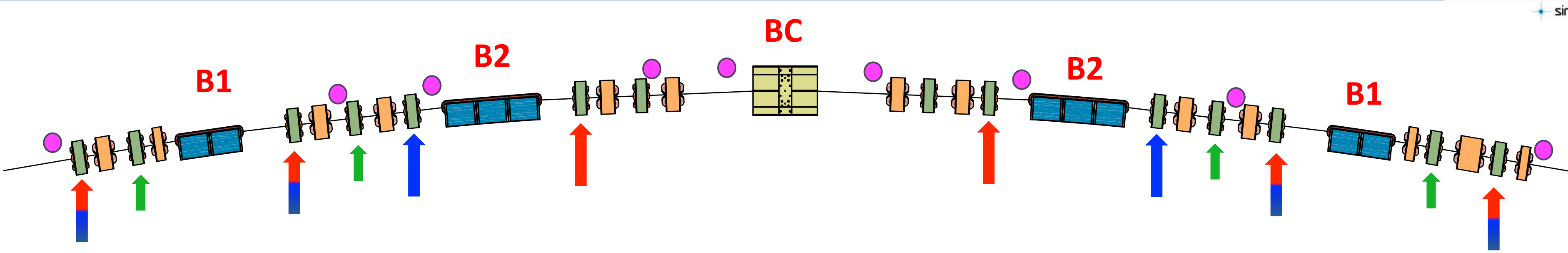
Beam lifetime

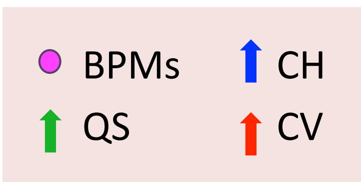
	Comm.	Ph. 1	Ph. 2	Ph. 2 500 mA	Ph. 2 SB	
Current	100	100	350	500	2	mA
Touschek	25.5	23.6	27.5	19.7	6.3	h
Elastic	69.1	35.2	35.2	35.2	35.2	h
Inelastic	49	49	49	49	49	h
TOTAL	**13.5**	**11.0**	**11.7**	**10.0**	**4.8**	**h**

Total lifetime vs current per bunch



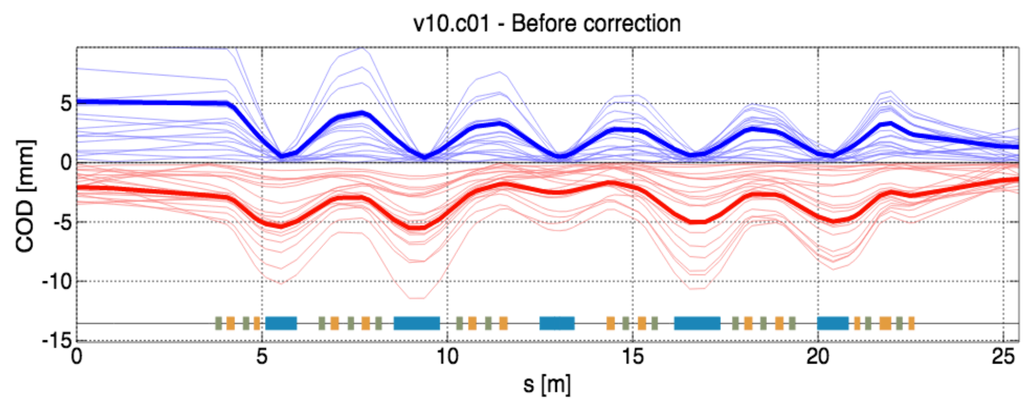
Slow orbit feedback and coupling correction

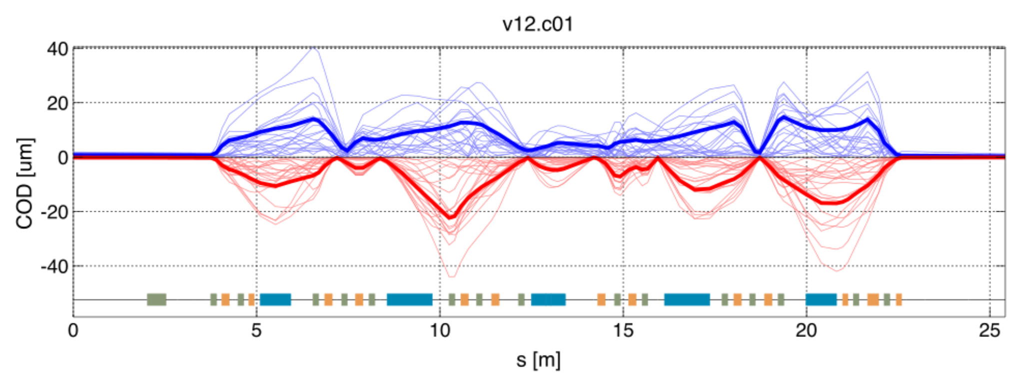




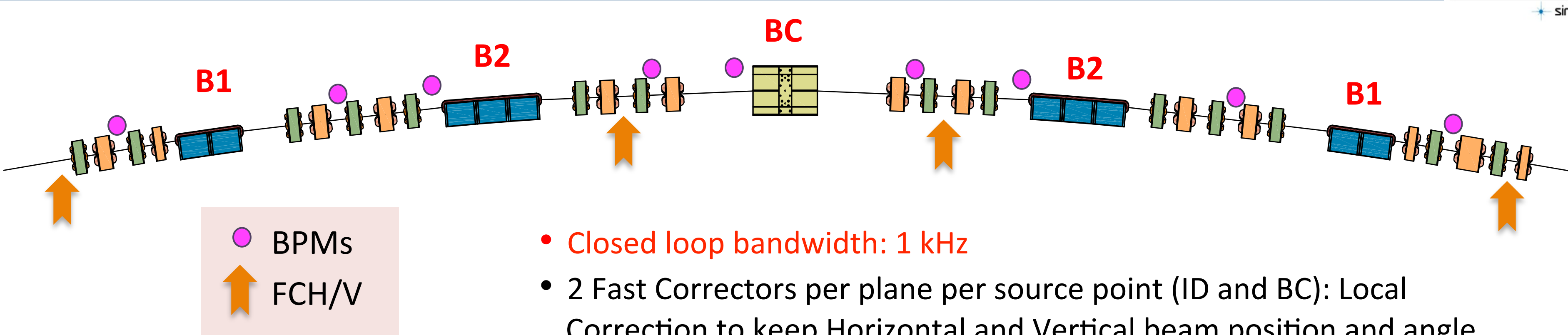
Random errors: Gaussian truncated at ± 1 σ

	Dip	Quad	Sext	Girders	BPMs	
x, y	40	40	40	80	20	µm
Roll	0.3	0.3	0.3	0.3	-	mrad
Excit.	0.05	0.05	0.05	-	-	%



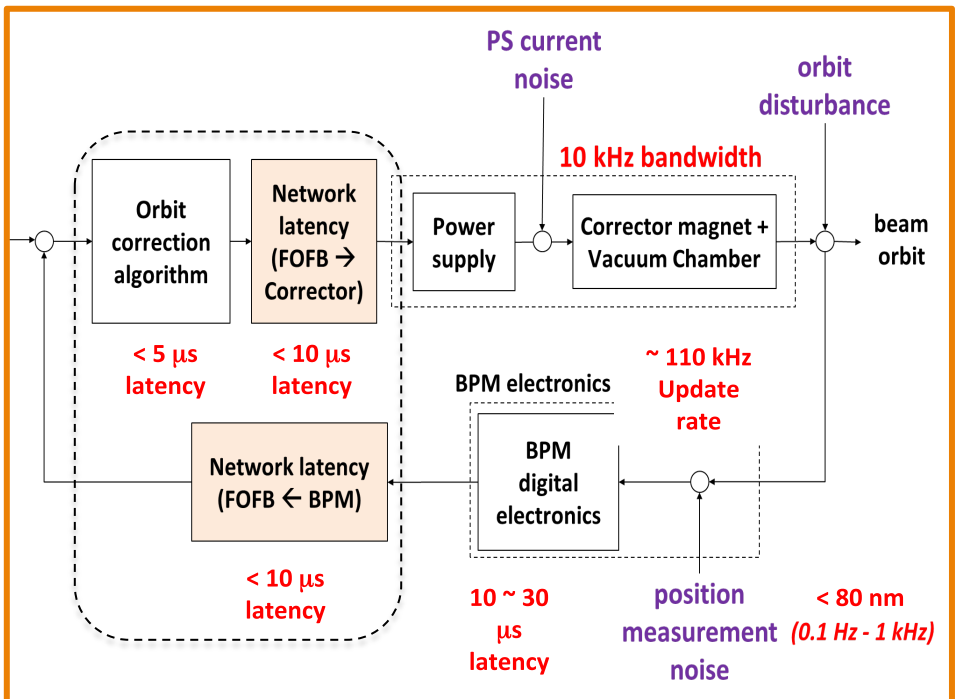


Fast Orbit Feedback (FOFB)

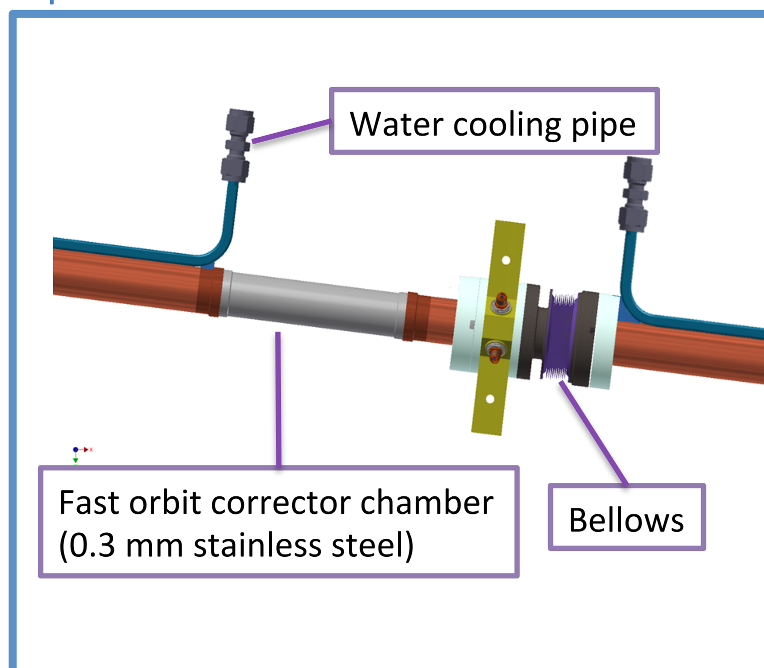


- Closed loop bandwidth: 1 kHz
- 2 Fast Correctors per plane per source point (ID and BC): Local Correction to keep Horizontal and Vertical beam position and angle.

FOFB Model

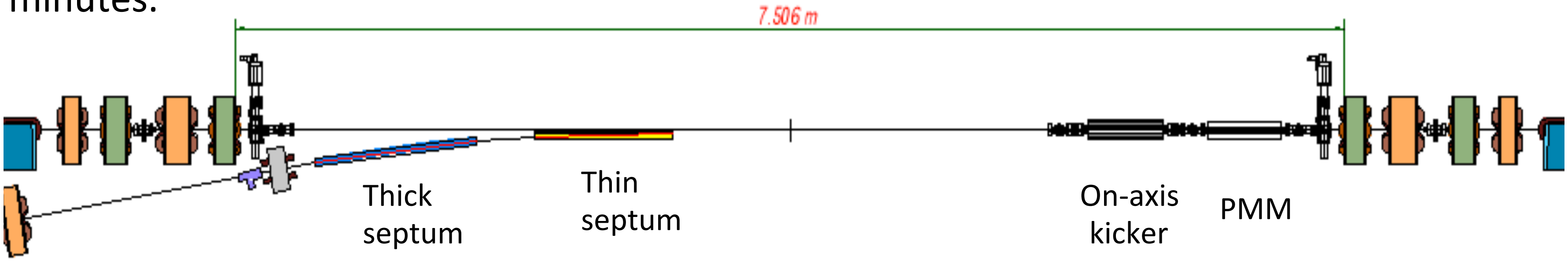


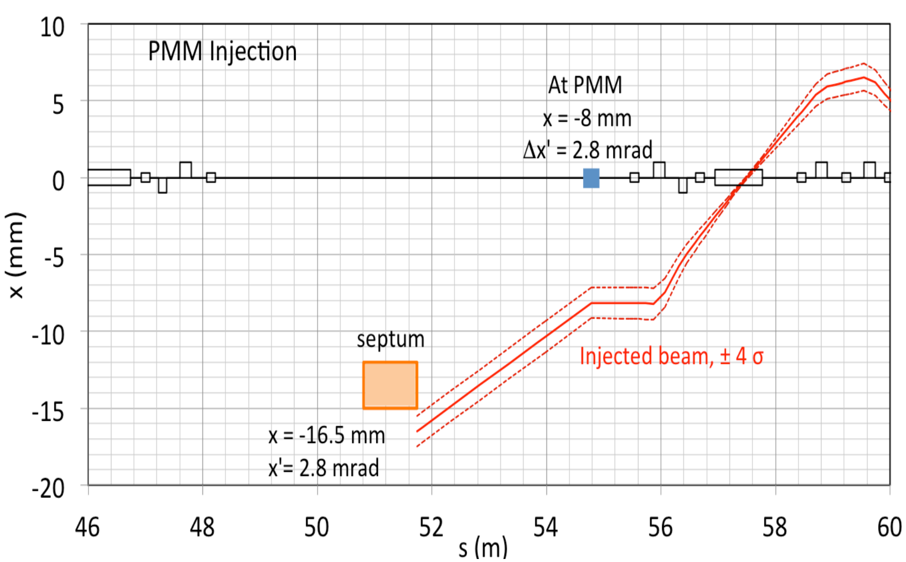
Special vacuum chamber

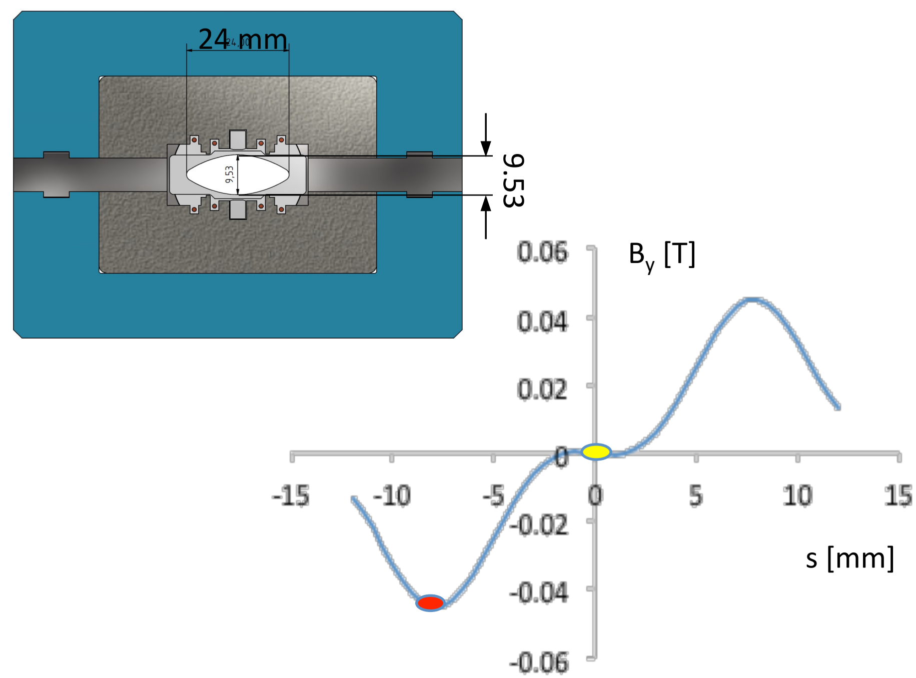


Injection with Pulsed Multipole Magnet (PMM)

Injection process will be more transparent to users. Top-up requires injections every few minutes.

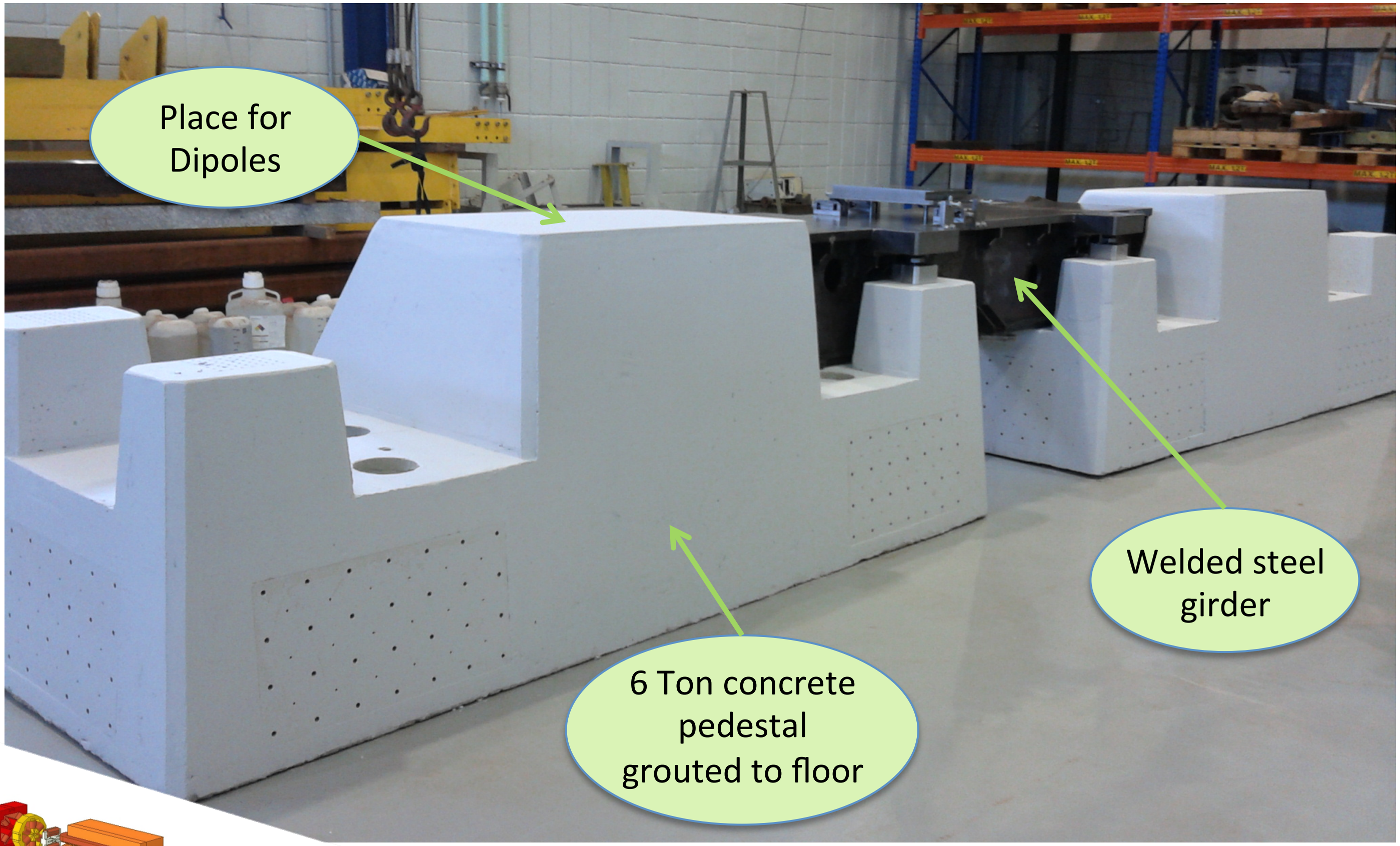


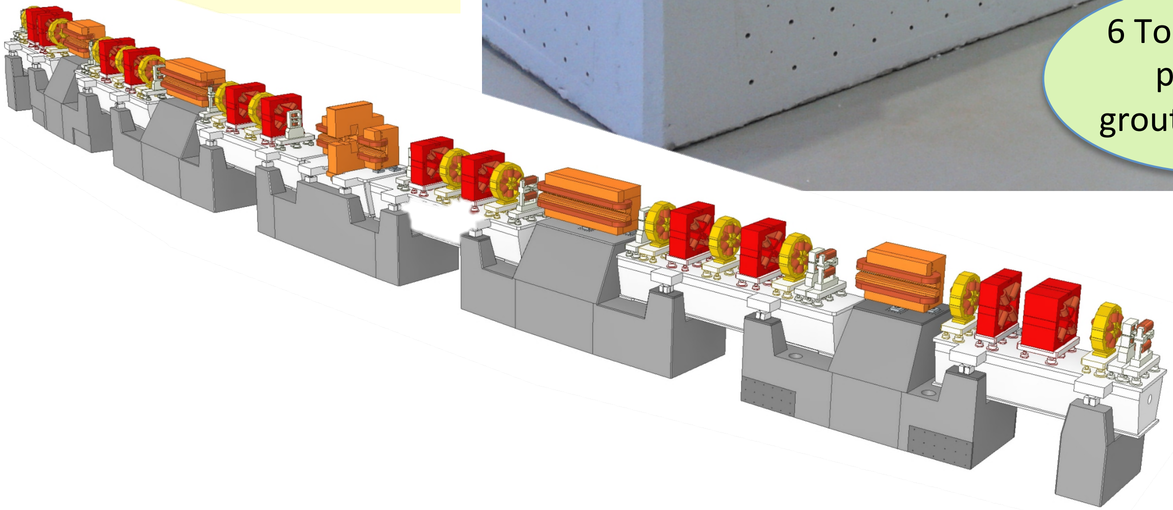




Magnet girders/pedestals system

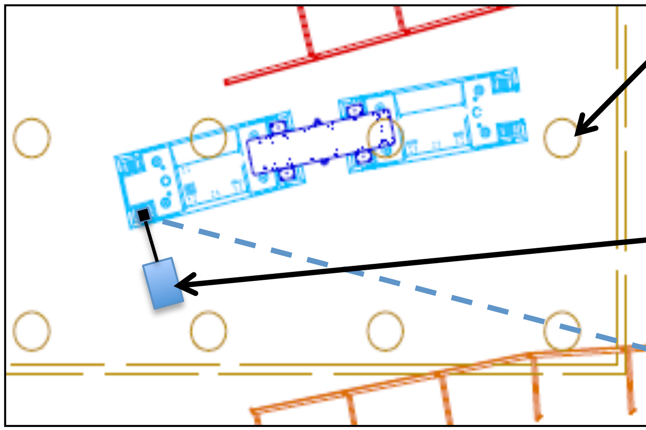
Taking advantage of mass attenuation and vibration damping of concrete pedestals





Pedestal stiffness measurement

Pedestal position on top of DIAMOND slab

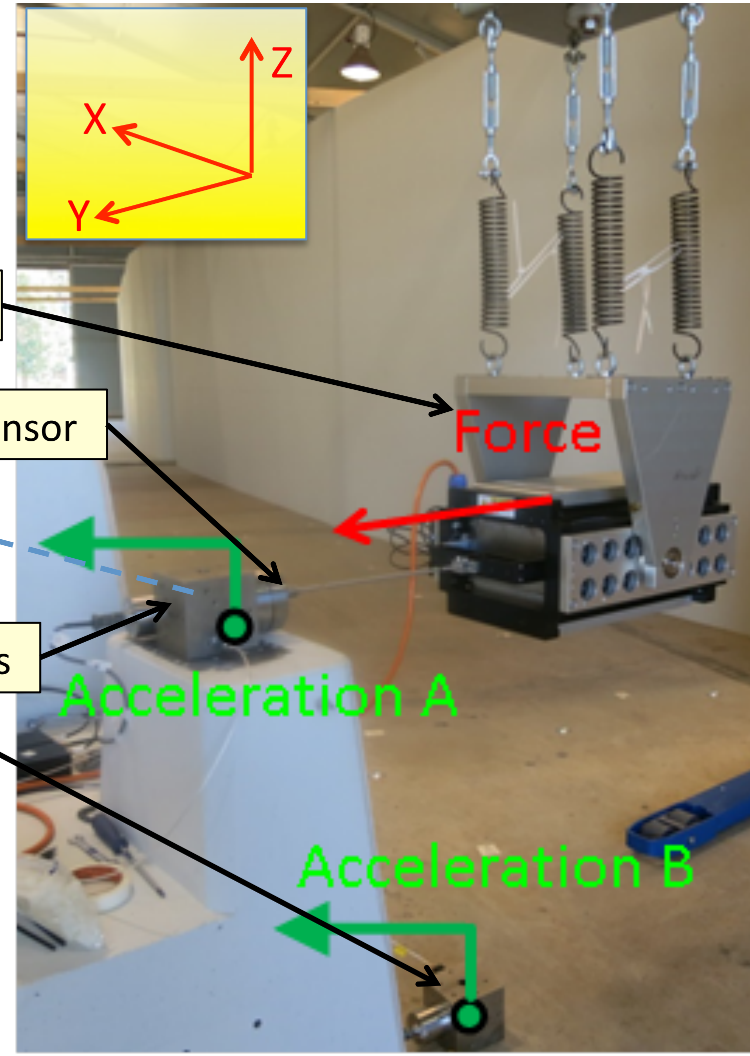


Piles

900N shaker

Force sensor

Accelerometers



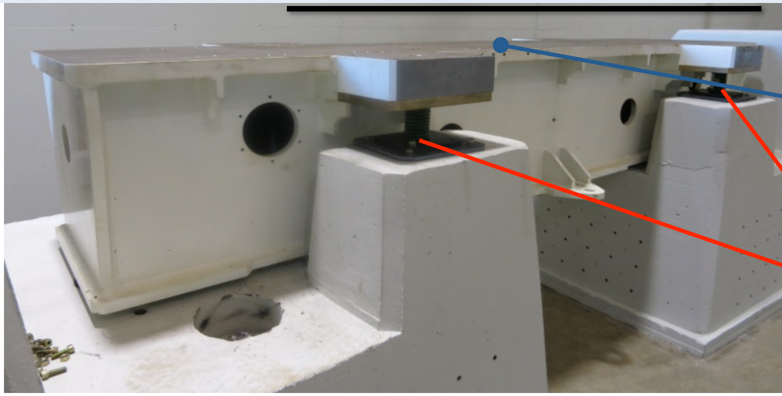
Measured stiffness (10-150Hz)

Direction	Stiffness [N/µm]
X-direction	770
Y-direction	410
Z-direction, excluding floor	4900
Z-direction, including floor	2000

Low stiffness in X and Y directions

Slab stiffness is lower than girder's

Girder free mode measurements

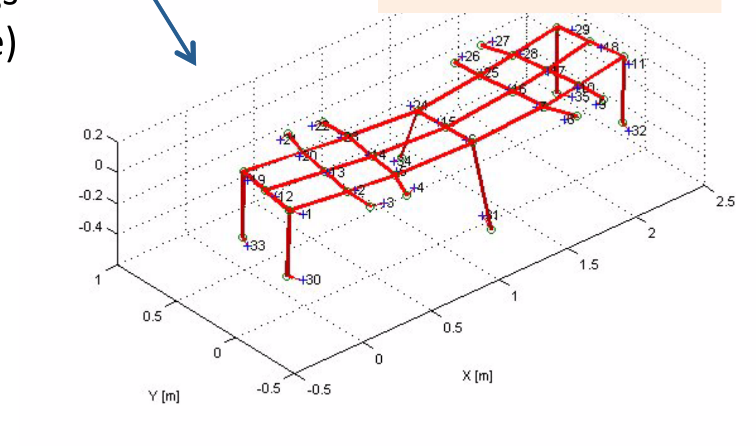


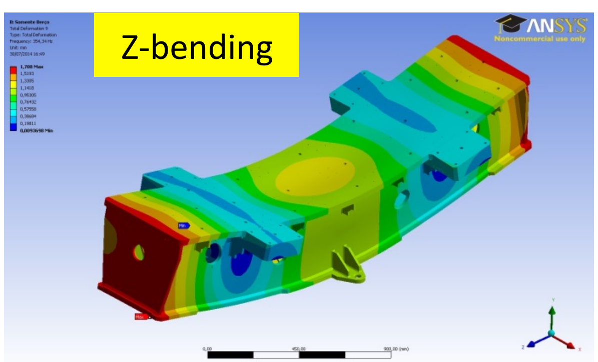
Isolation springs (2Hz resonance)

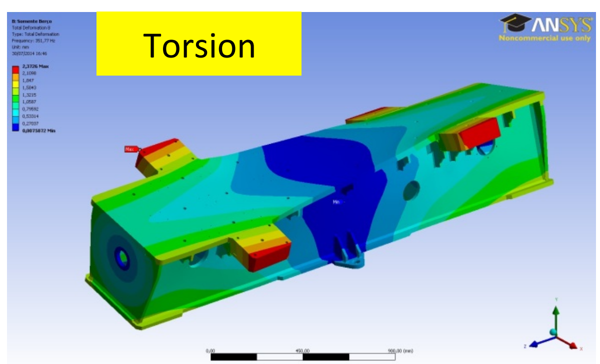
Accelerometers installed in 35 positions

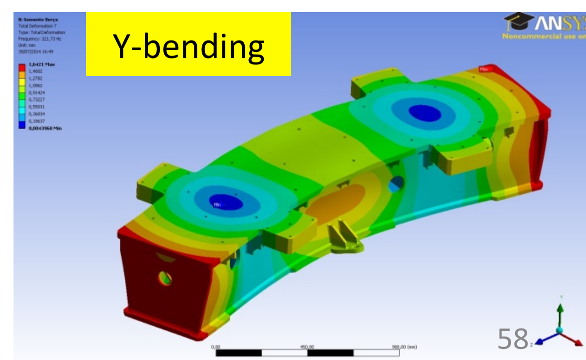
Girder based on PETRA III design

Lowest modes	Frequency [Hz]	Predicted by FEM [Hz]
Y-bending	319	322
Torsion	333	352
Z-bending	354	354
Plate membrane mode	501	
Second order Z-bending	552	



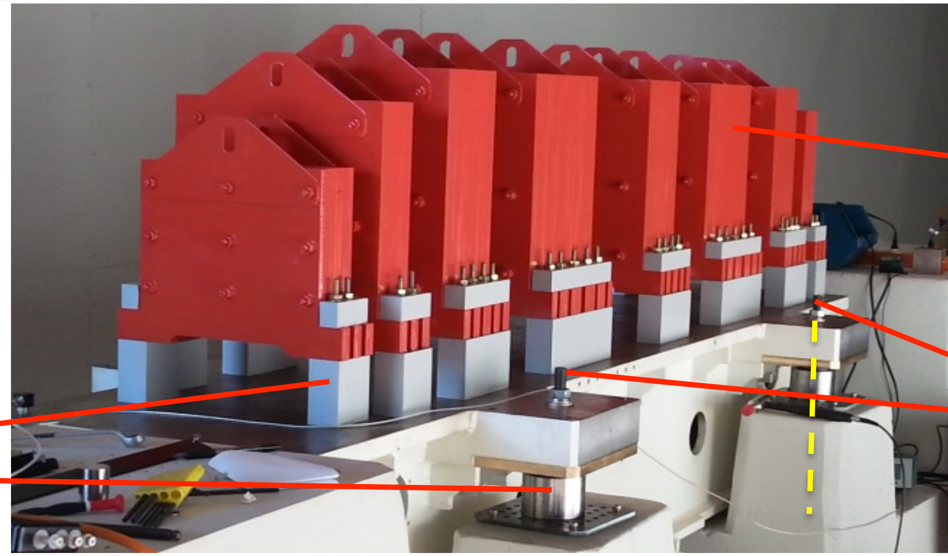






Magnet/girders/pedestals vibration measurements

Girder based on PETRA III design



Dummy magnets

Locking screws (on the concrete)

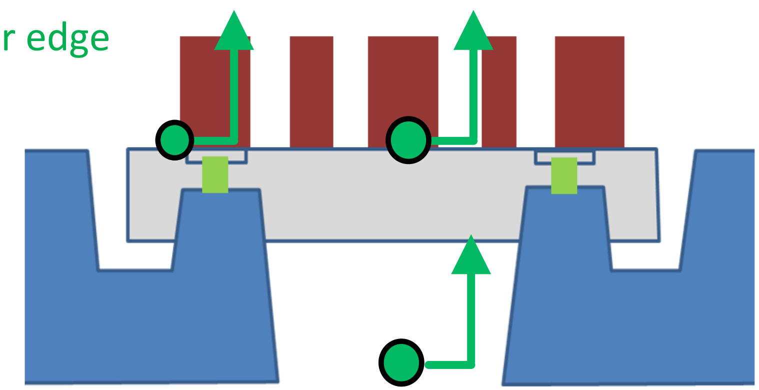
Stiff steel spacers

900N Shaker

Shaker Force

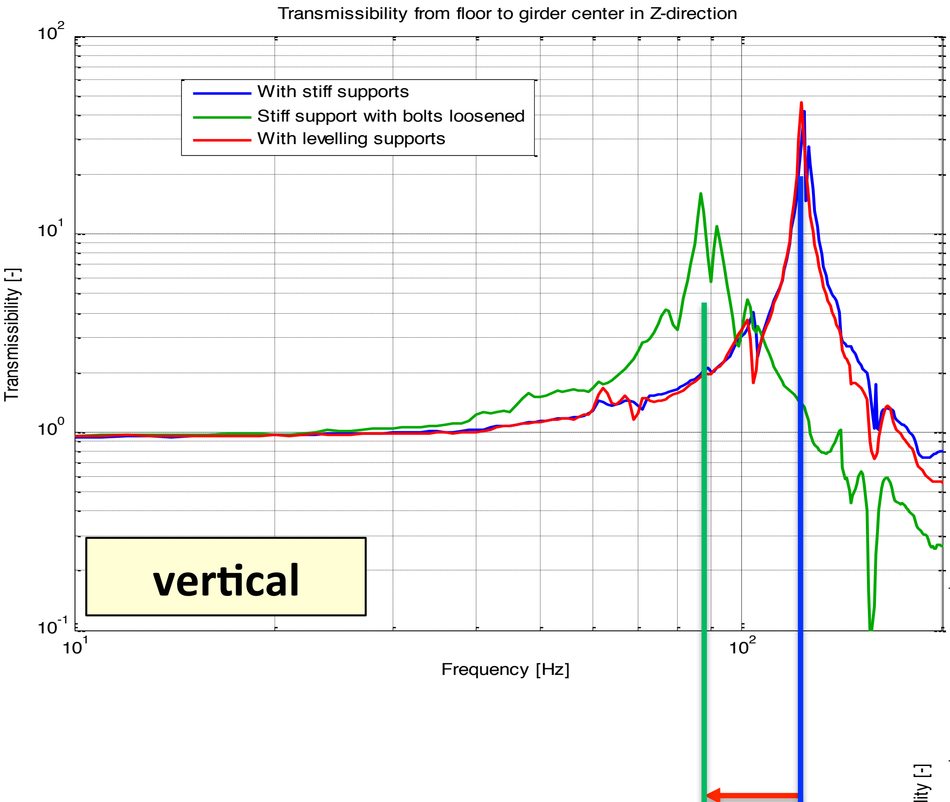
Acceleration: Girder edge

Acceleration: Girder center



Acceleration: Floor

Slab to girder transmissibility measurements

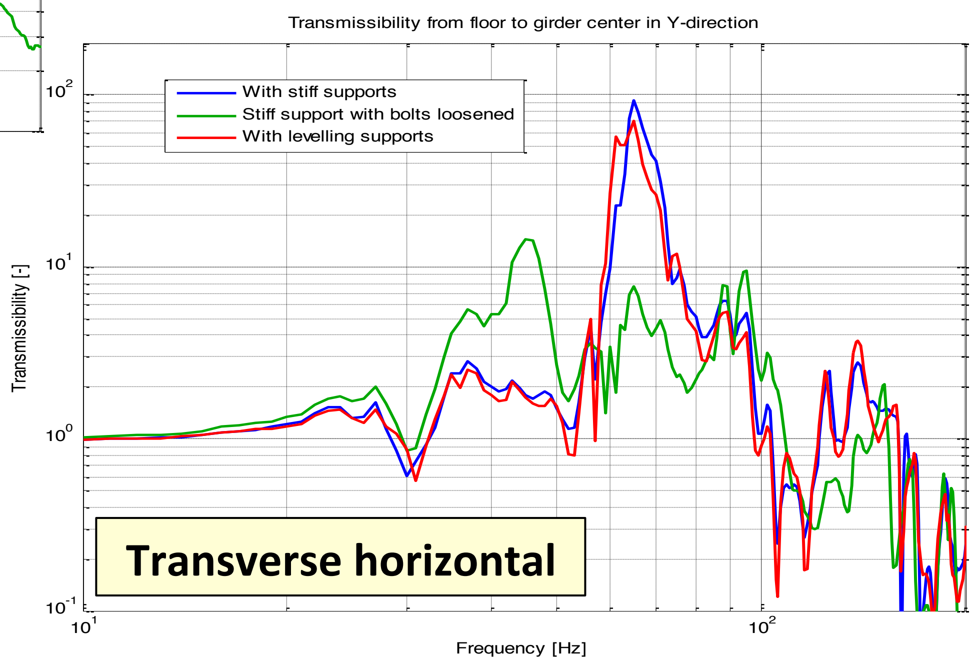


Stiff supports (bolts tightened)

Stiff supports (bolts loosened)

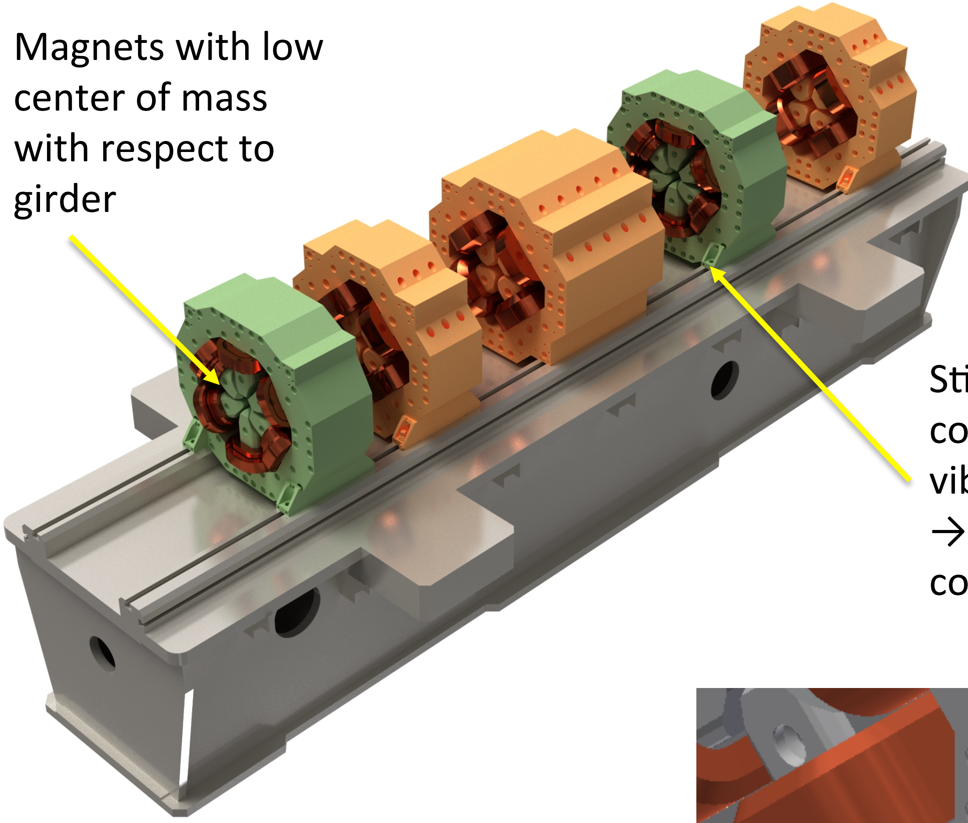
With Nivel

Bad News for kinematic supports



Integrated magnet/girder design

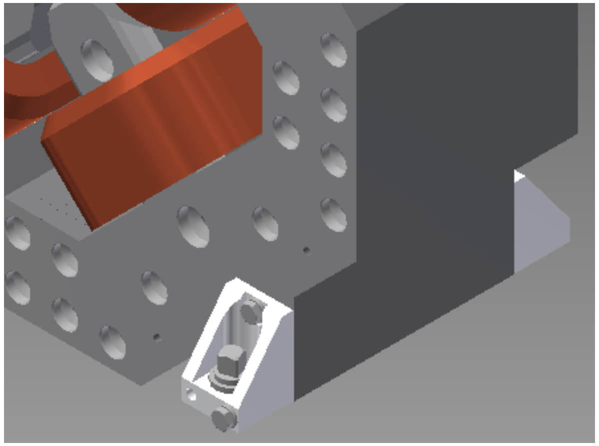
Magnets with low center of mass with respect to girder

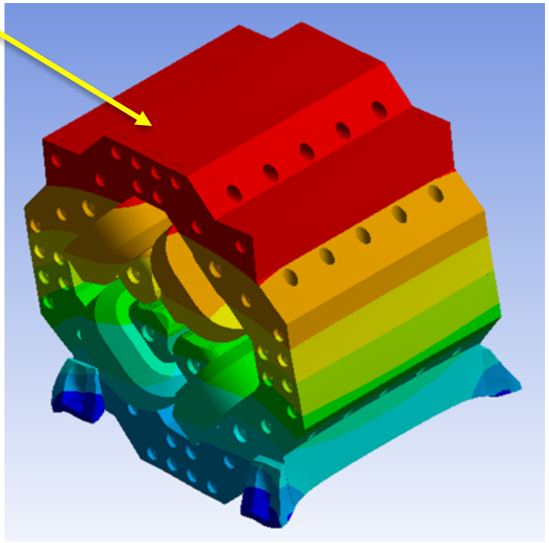


Work flow

1. Preliminary magnetic design
2. Full mechanical design taking into account vibration and alignment
3. Magnetic design refinement

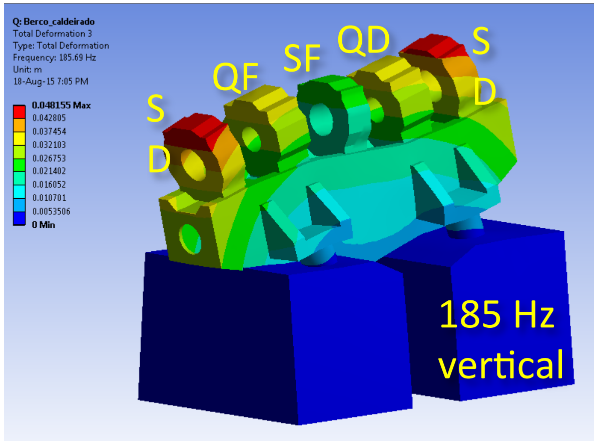
Stiff magnet/ girder connection to increase vibrational resonances → alignment by construction

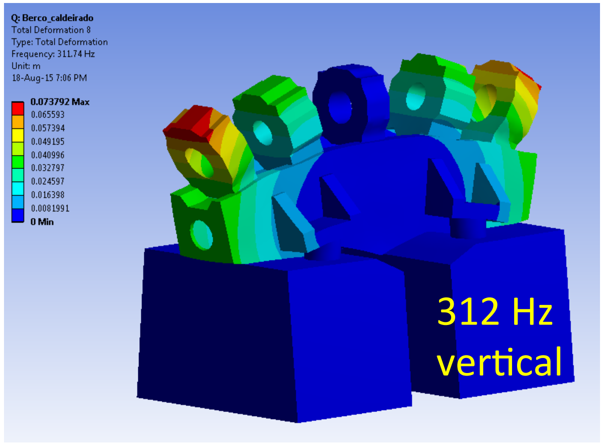


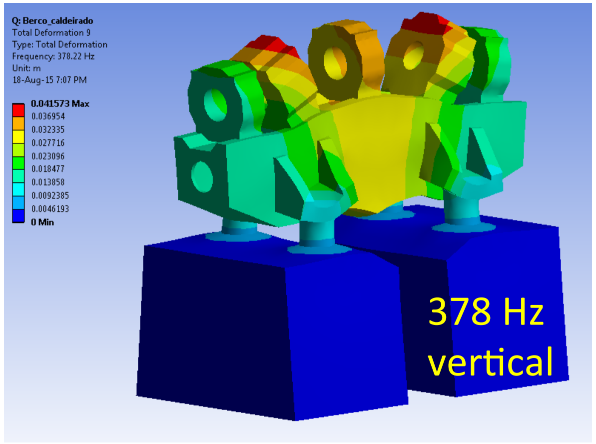


Latest girder design

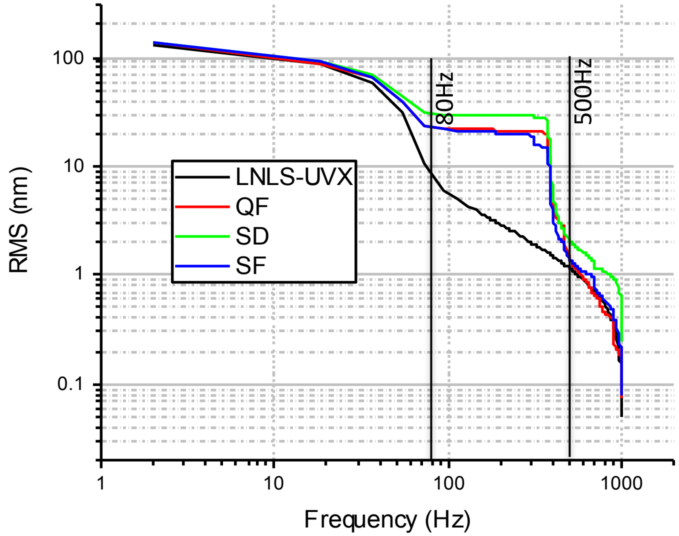
Complete system modal analysis:

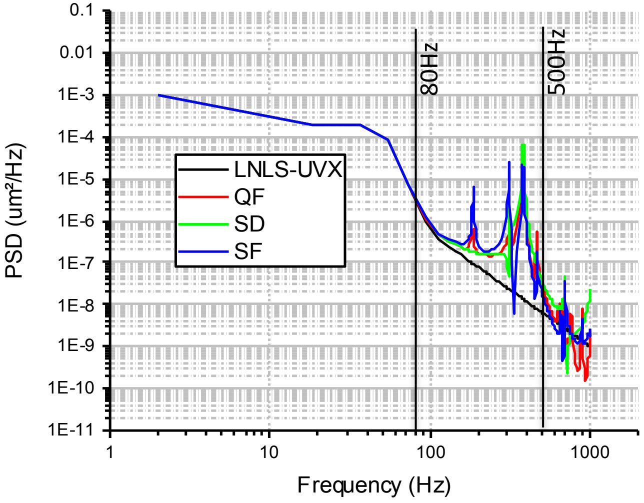






Complete system simulations with the UVX slab power spectrum as input:





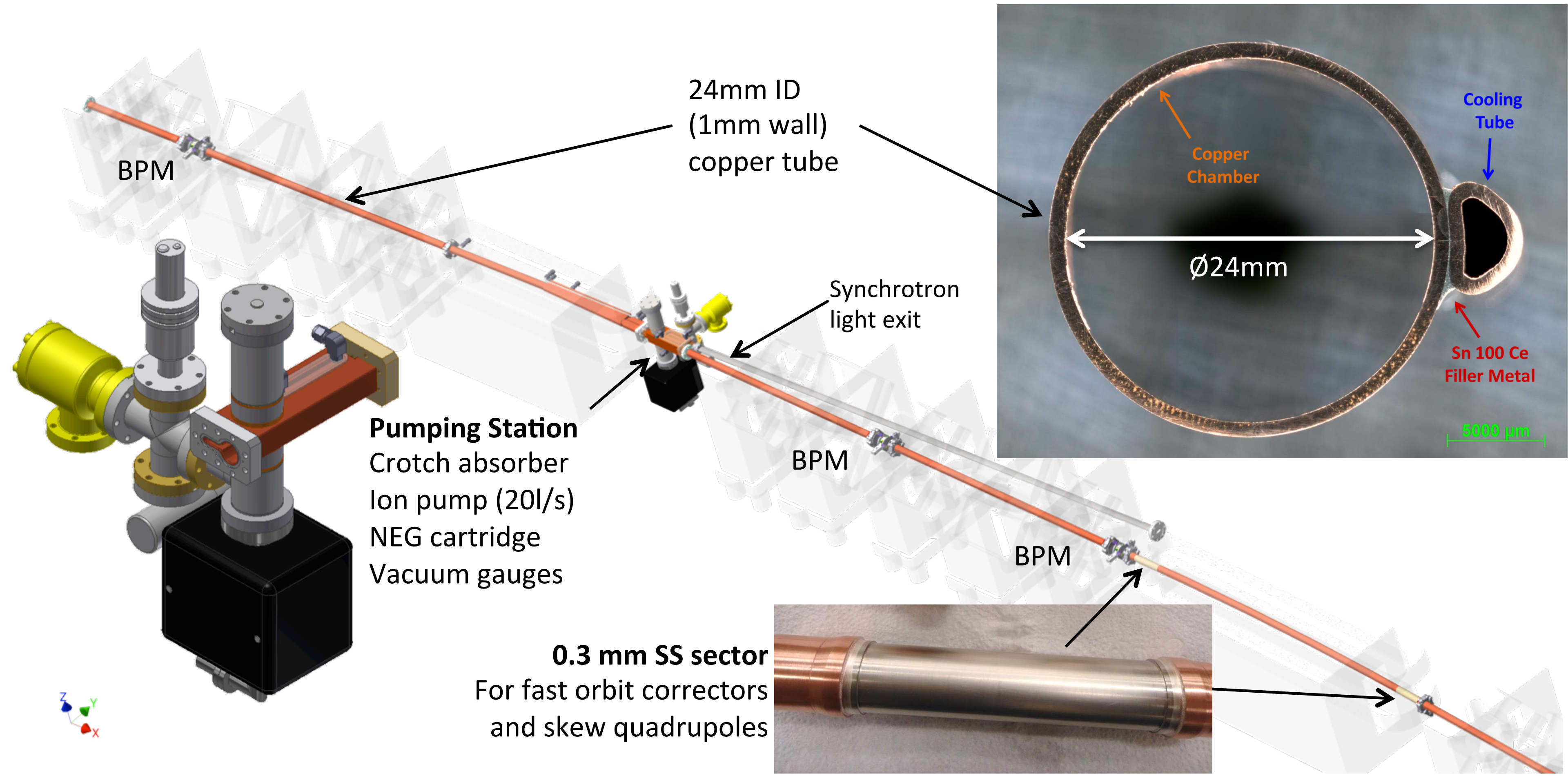
Full NEG coated storage ring copper vacuum chamber

Pros (full NEG coated strategy)**:**

- Simple chamber's design
- More compact -> space saving
- Low photon desorption -> fast vacuum conditioning

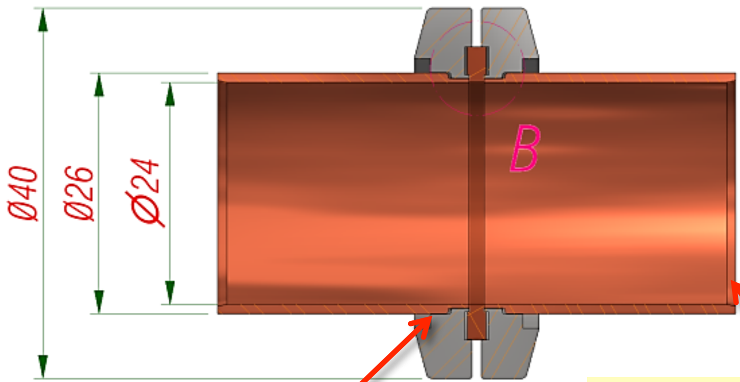
Cons (full NEG coated strategy)**:**

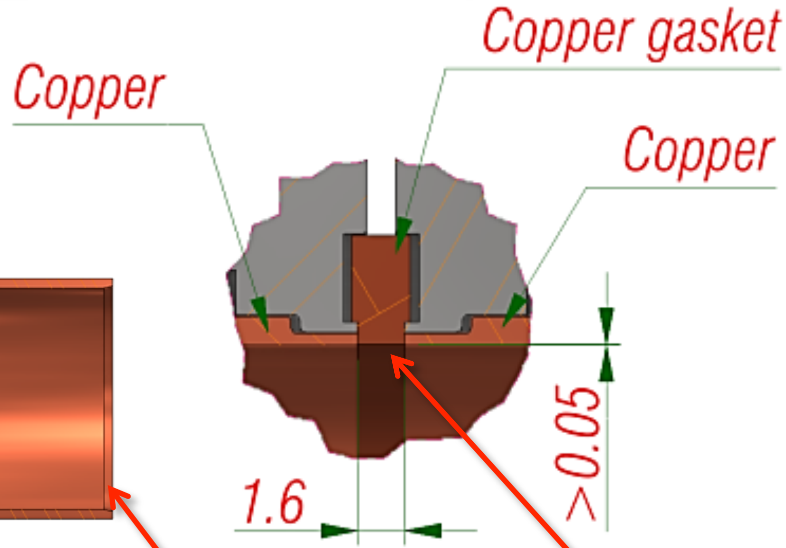
- Limited number of activations
- High temperature (200°C) bake-out for NEG activation
- Many bellows to accommodate chamber's expansion during bake-ou



Low RF-impedance vacuum flange development

Chain-clamp design





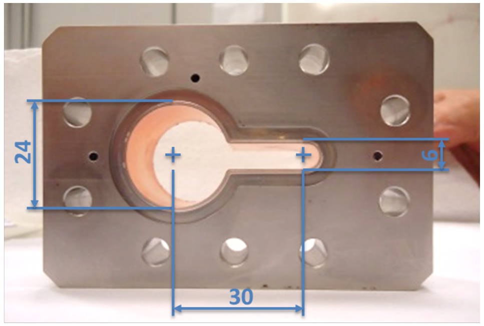
Brazed joint

to be TIG welded to copper vacuum chamber

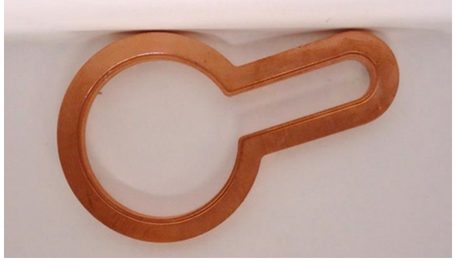
"zero gap" copper seal

UHV leak tight with 3.5 N.m (<5E-10mbar·ls)

Keyhole design

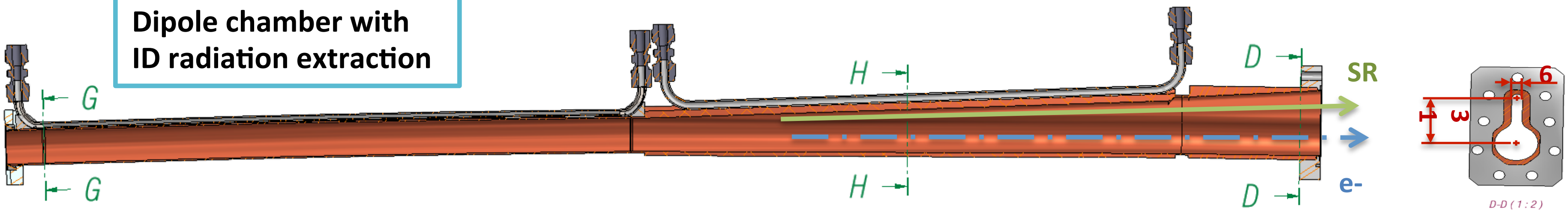


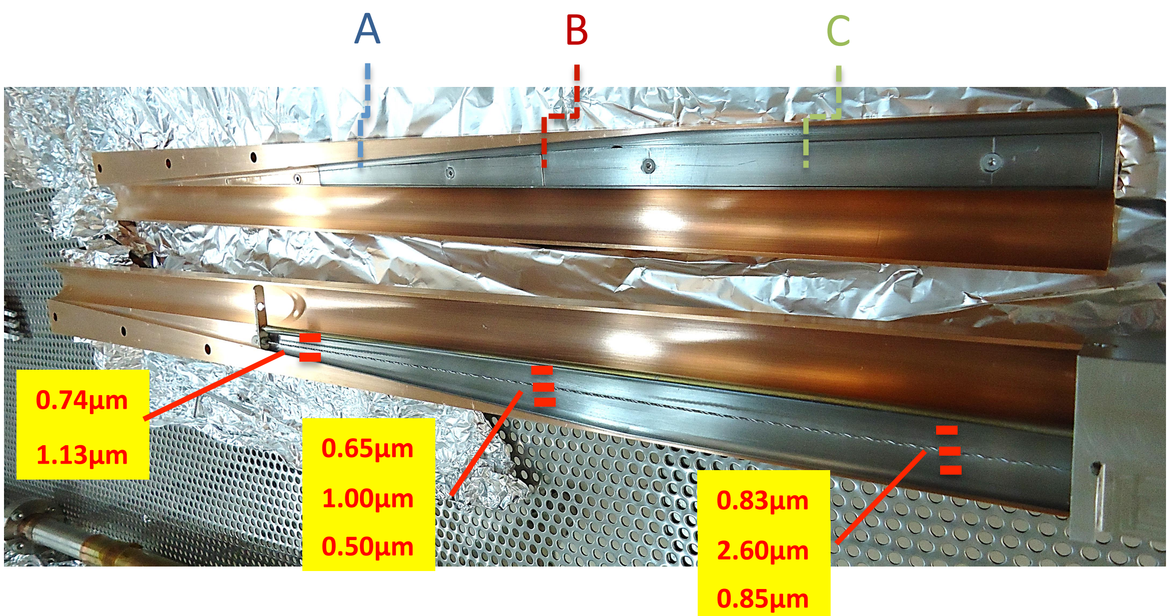
100's of flanges in the ring!



Vacuum - NEG coating R&D for narrow gaps

Dipole chamber with ID radiation extraction



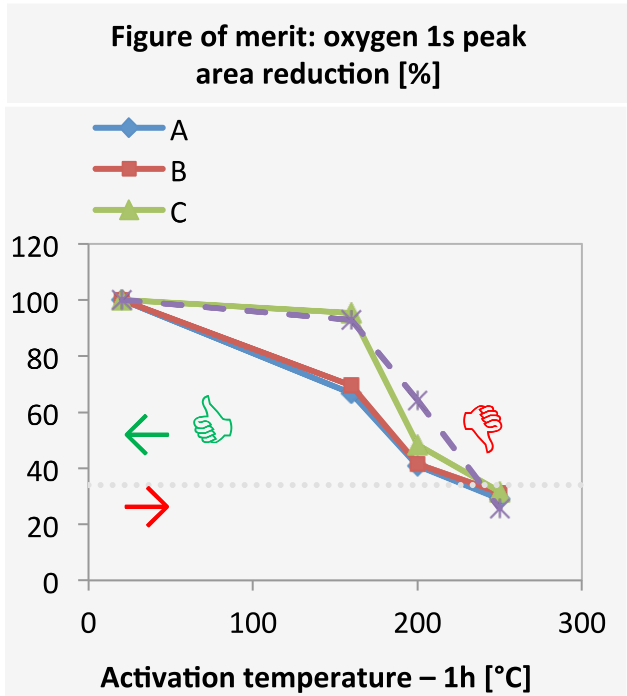


Coating procedure (2 steps):

1. Coating of the circular profile
2. Coating of the narrow gap – " keyhole" sector

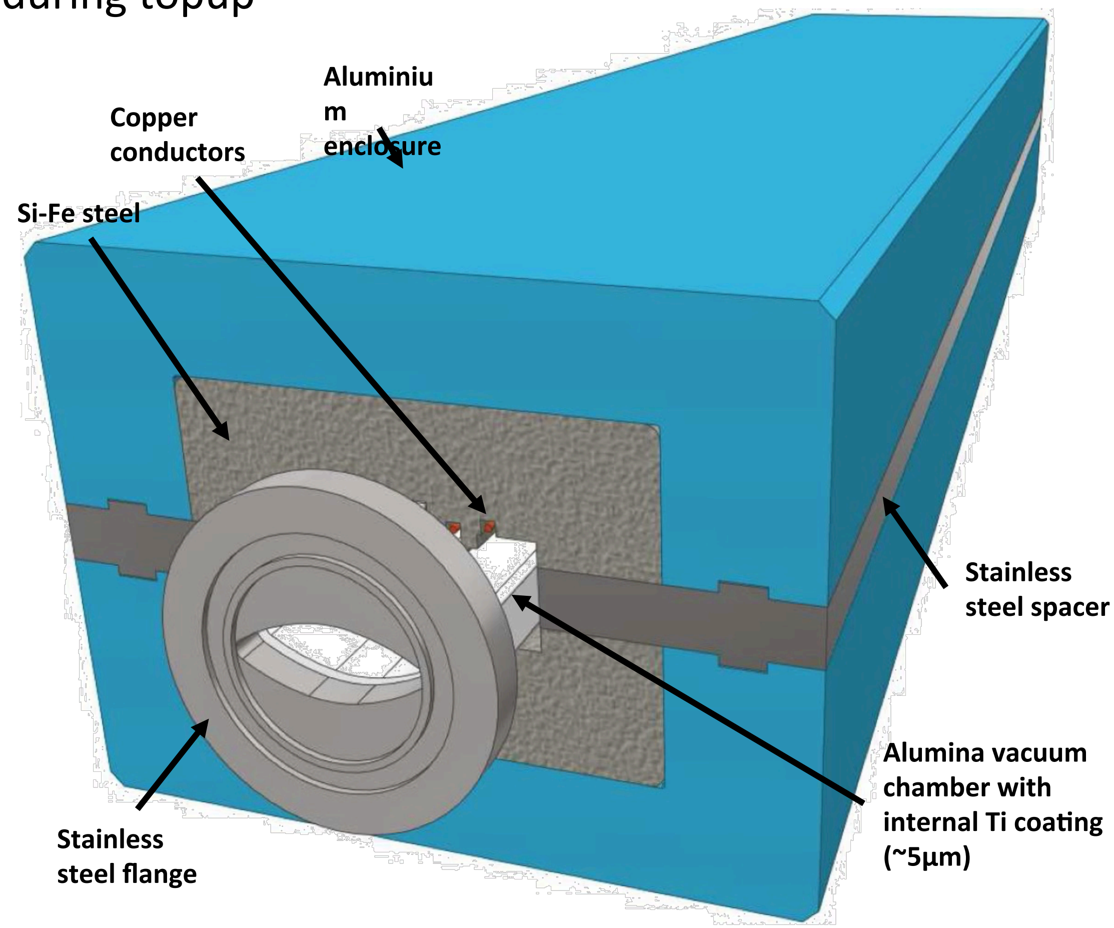
Coating thickness set to 2µm

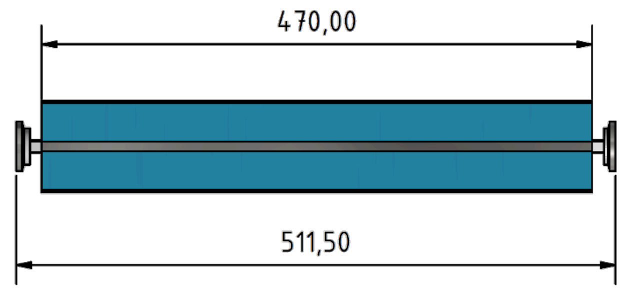
NEG film activation
(XPS analysis)

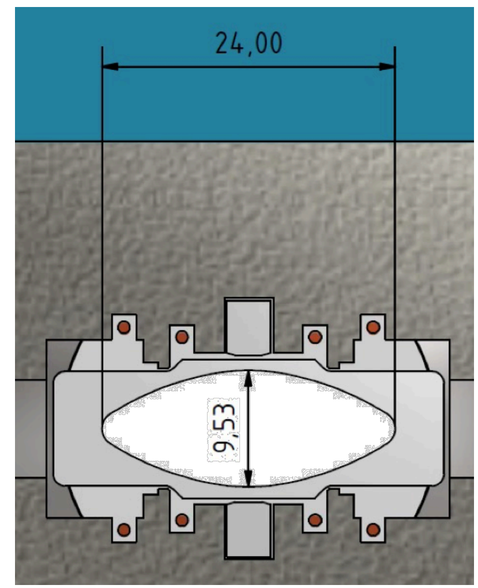


Multipole kicker

A pulsed multipole magnet will be used to improve stored beam shaking during topup

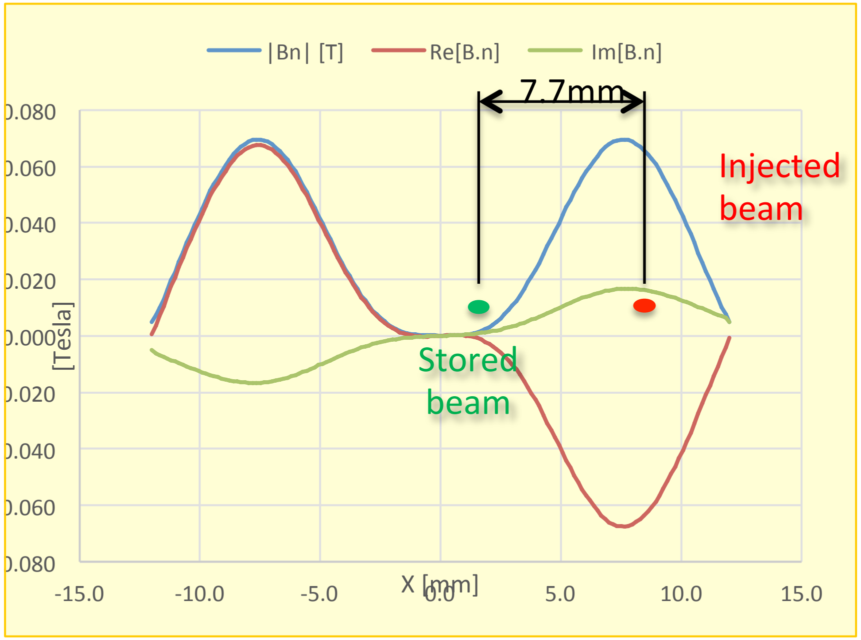




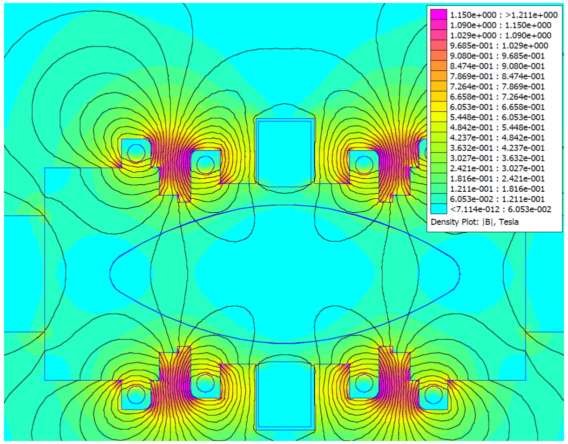


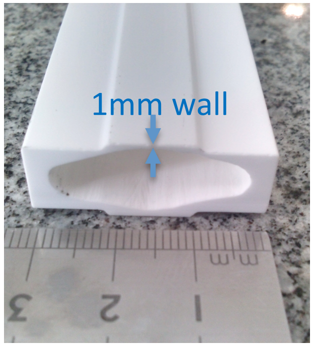
Multipole kicker

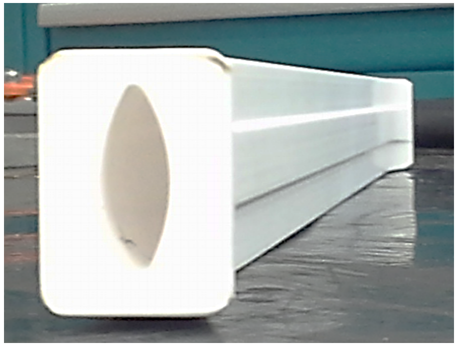
Half-sine of	1.64μs
Current	1000A
Voltage	5612V
Inductance	8.1μH
Resistance	0.06Ω
Peak field	0.070Tesla
@ x =	7.7mm
Field @ x = ±1 mm	0.000 3Tesla

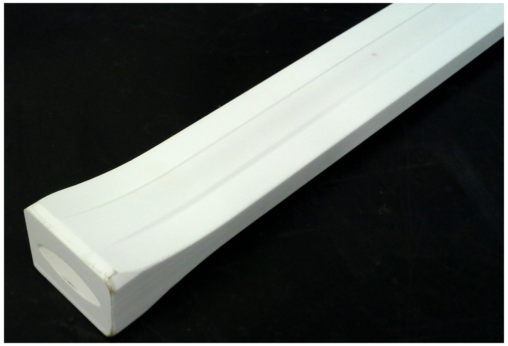


PMM field map at 1000A, 152kHz and a 10μm Ti coating.





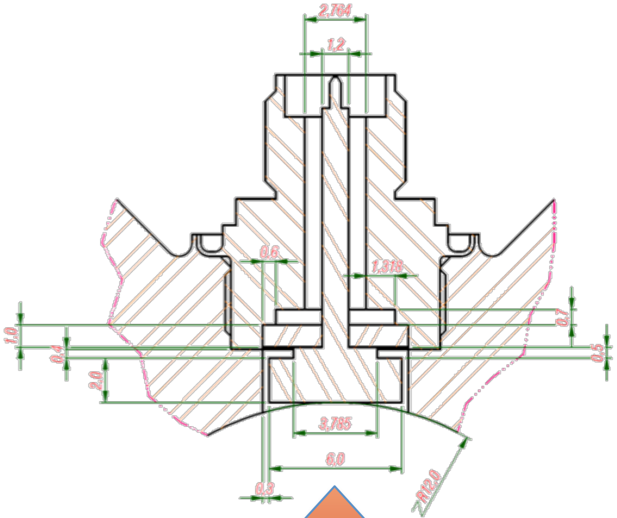




Beam position monitors - button geometry choice

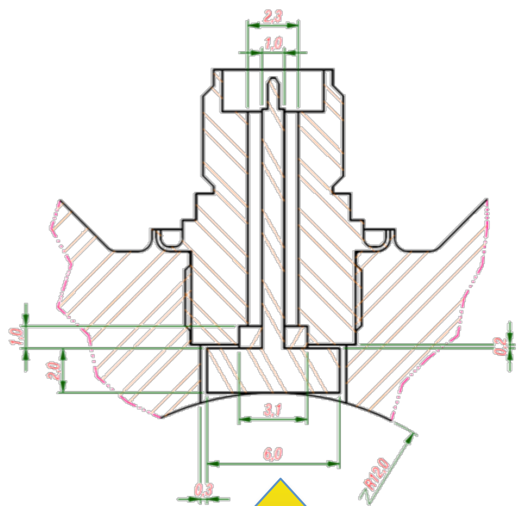
Step-Shaped BPM Button

Based on the geometry style implemented at ALBA.



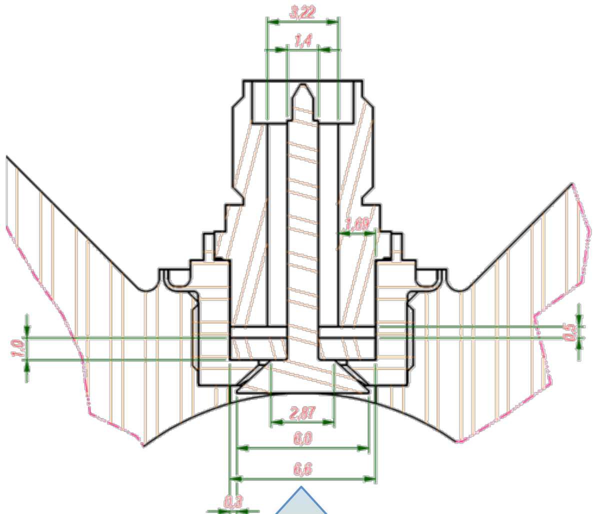
Flat BPM Button

Reduced ceramics dimensions to decrease wakelosses.



Bell-Shaped BPM Button

Conical profile shifts the HOMs to higher frequencies and hide the ceramics from the beam.



Input power

37% reduction

50% reduction

From electromagnetic (wakefield) simulations, wakelosses are calculated

Beam position monitors - button design

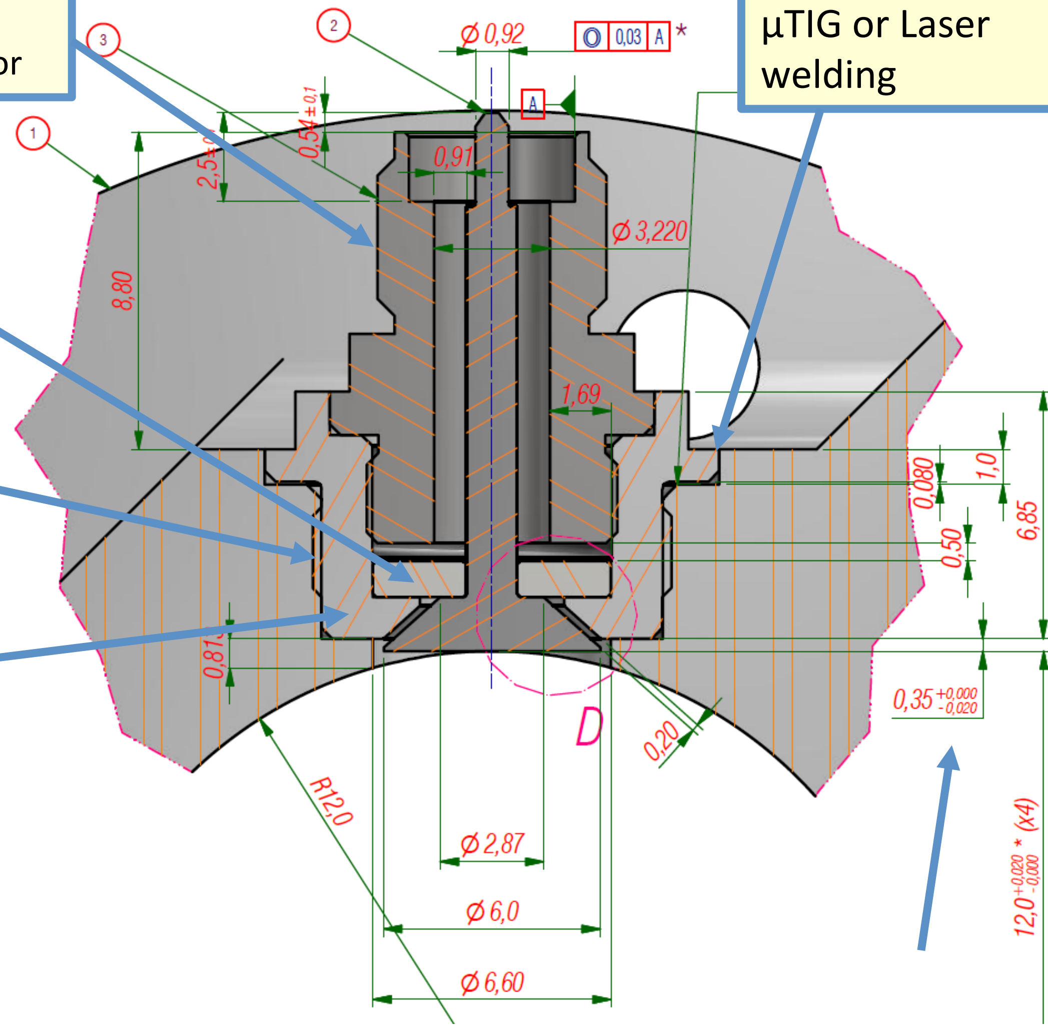
RP-SMA connector

µTIG or Laser welding

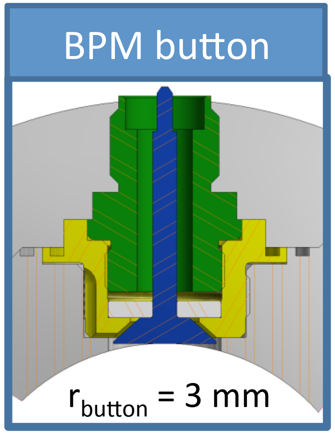
Brazed Al2O3 insulator, 1 mm thickness.

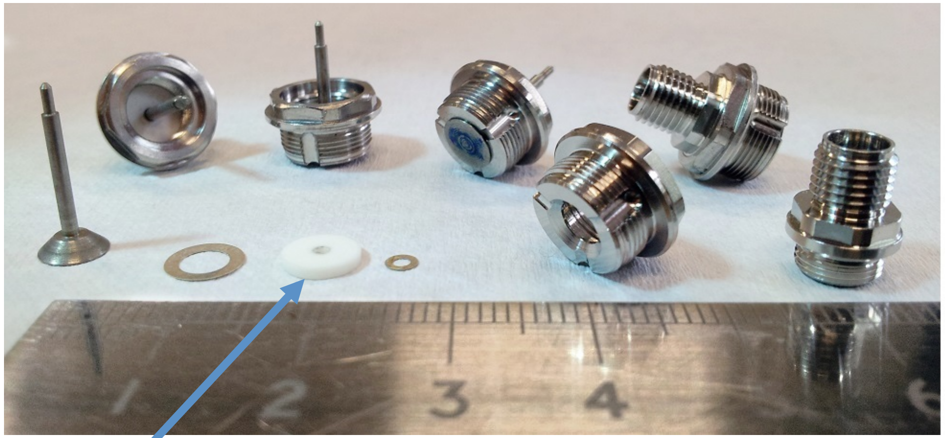
Threads: thermal contact, RF shielding and fixation

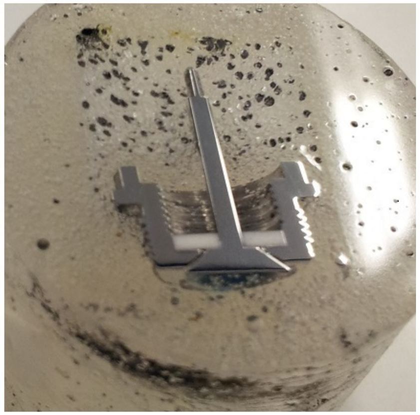
Ti alloy non-magnetic



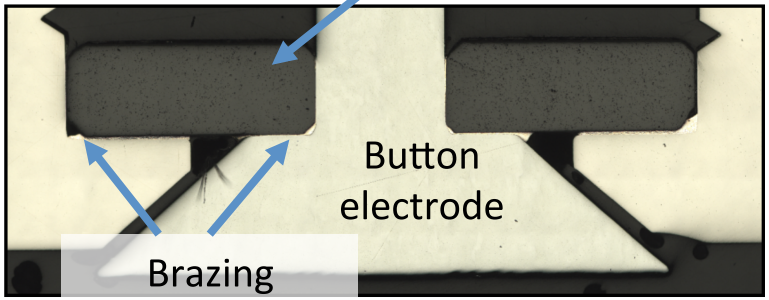
Beam position monitors - prototypes

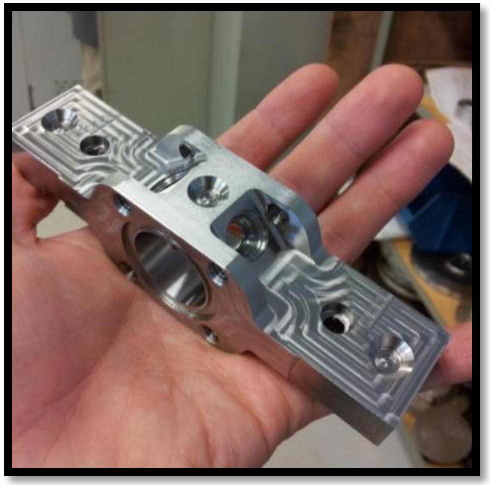


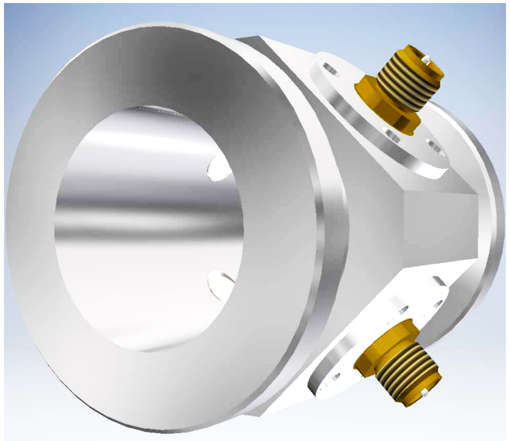




Alumina



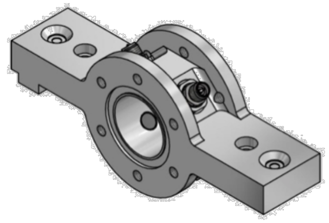


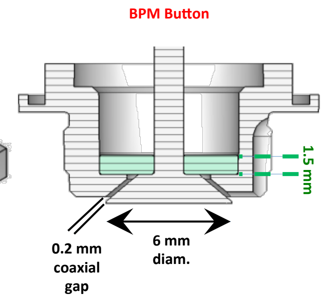


BPM Electronics and firmware

Open Hardware development

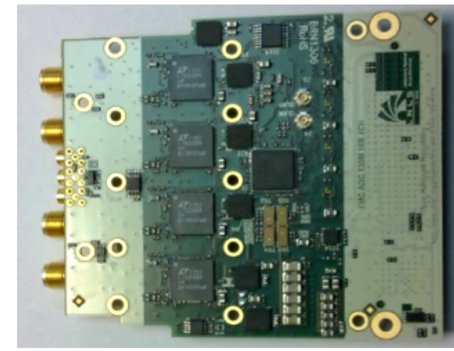
Requirements for Sirius RF BPM electronics



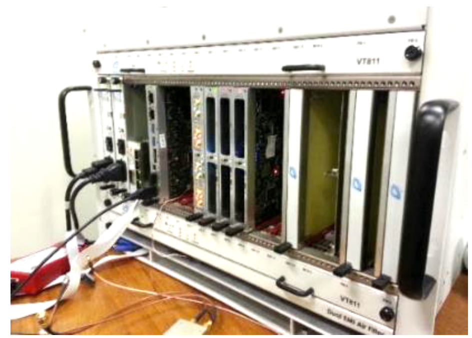


Parameter	Target Spec	Obtained
Resolution *(0.1 Hz – 1 kHz) @ 500 mA*	80 nm	~50 nm
Long term stability (RMS)	140 nm	< 140 nm

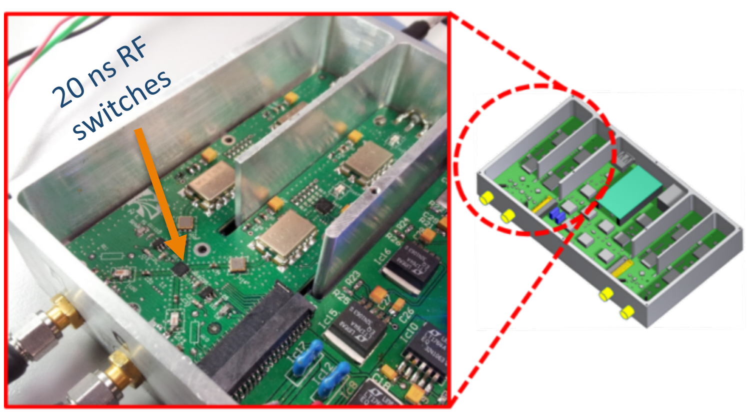
FMC standard 130 MSP/s 16-bit ADC board



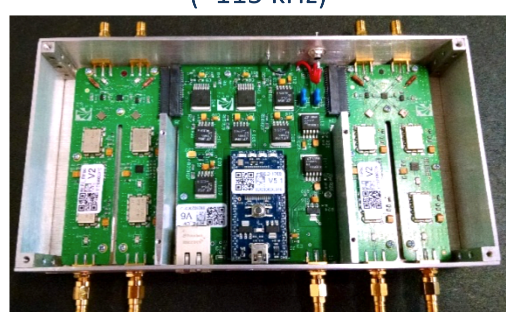
Commercial MicroTCA crate



RF Front-End (diagonal channels)

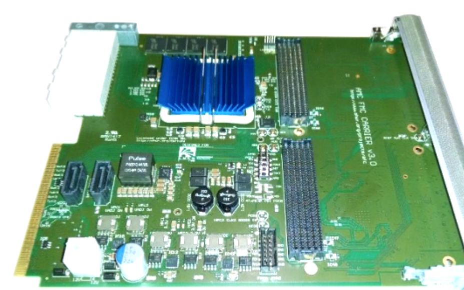


Switching @ FOFB rate (~115 kHz)



AMC FMC carrier

Designed by Warsaw University of Technology (WUT) for LNLS

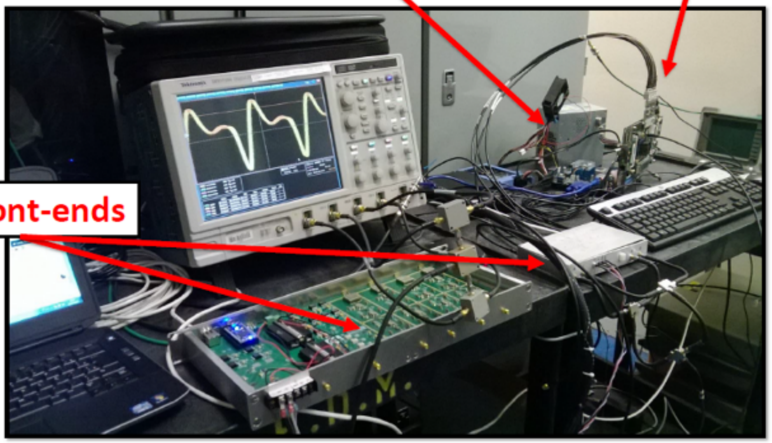


BPM Electronics

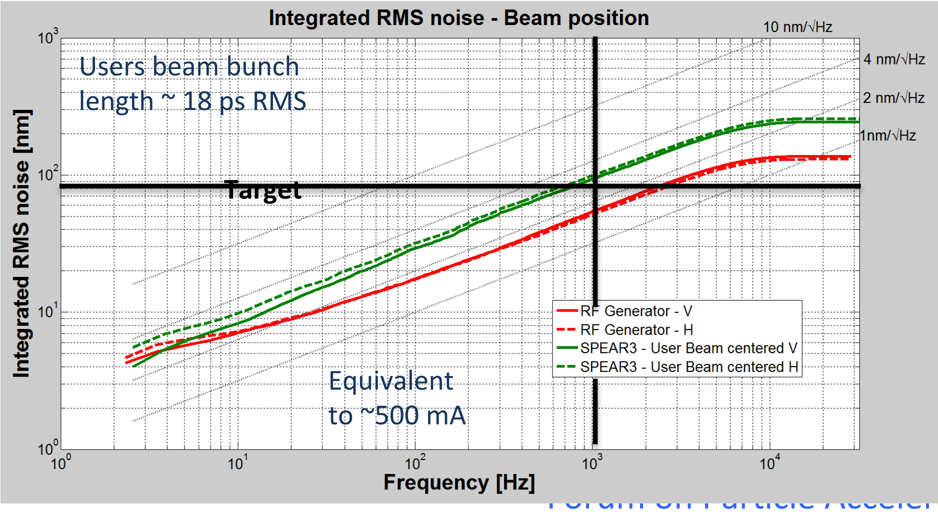
Control PC and FPGA processing board

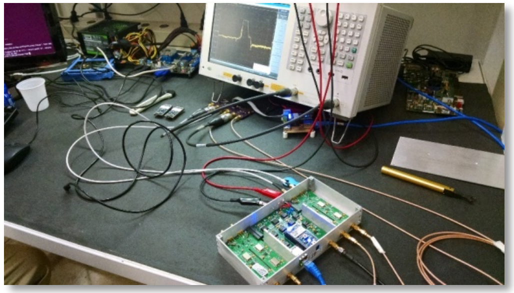
16-bit 130 MSPS AD converter

RF front-ends



Tests performed at SPEAR3 (SLAC/SSRL)





Complete rack test @ LNLS

Solid State RF Amplifier (SSA) @ LNLS

Collaboration with LURE/SOLEIL since 1999

(special tanks to Ti Ruan)

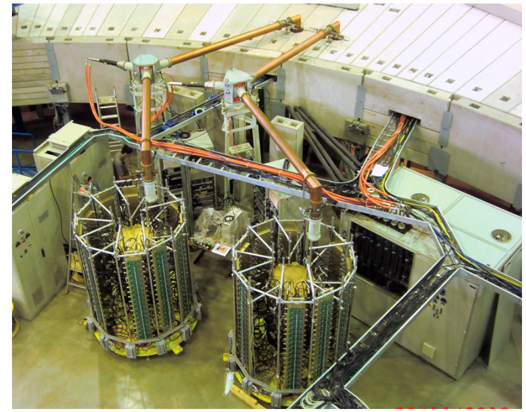
1999 - Prototype module with 230W

2001 - Booster operating with 900W

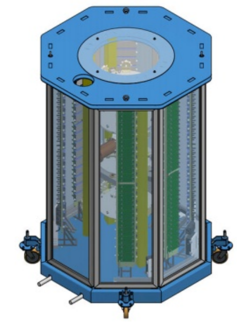
2007 – Booster upgraded to 2.2kW

2010 – Storage Ring operating with 2 x 50 kW SSA

2001 – Booster
900 W @ 476 MHz
ELETTRA Cavity

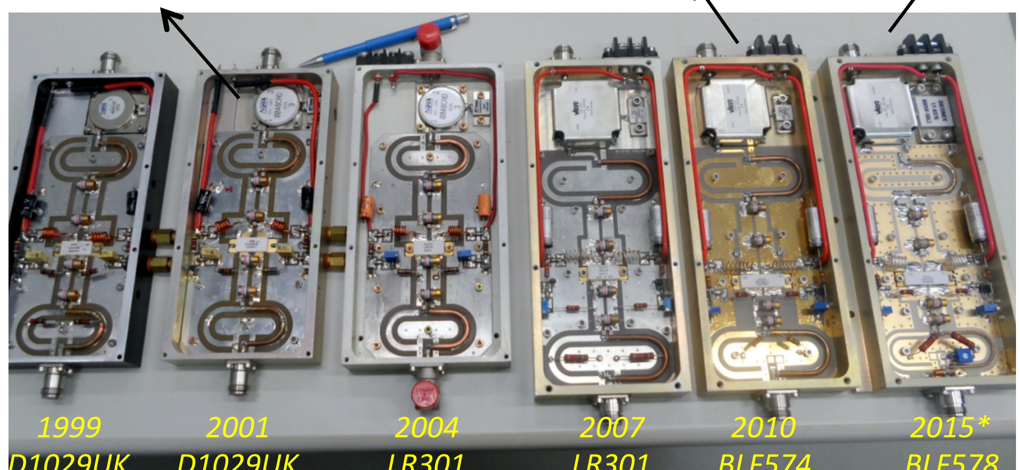


2010 – Storage Ring
2 x 50 kW @ 476 MHz
ELETTRA Cavities



Sirius

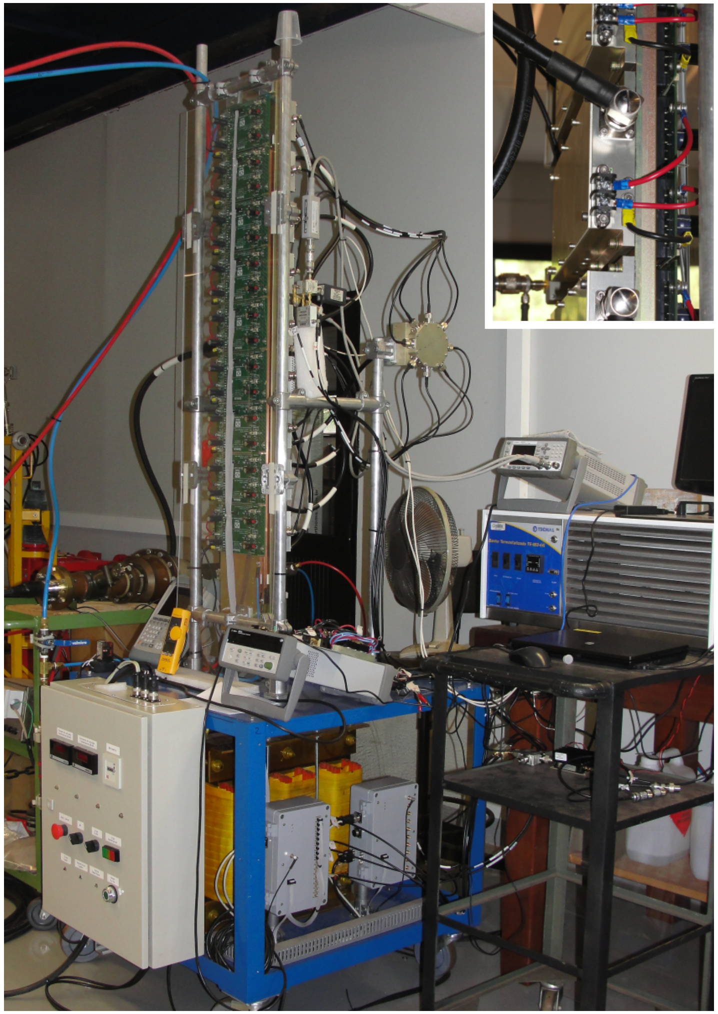
2015 - Booster
50 kW @ 500 MHz



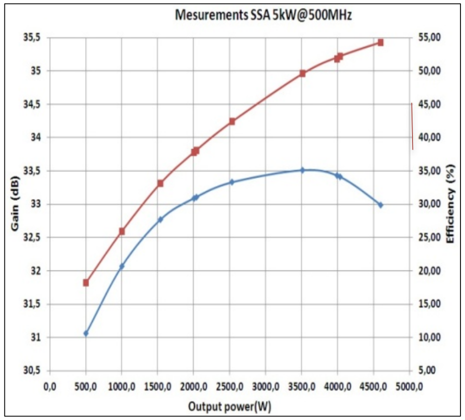
230W 230W 300W 300W 350W 600W

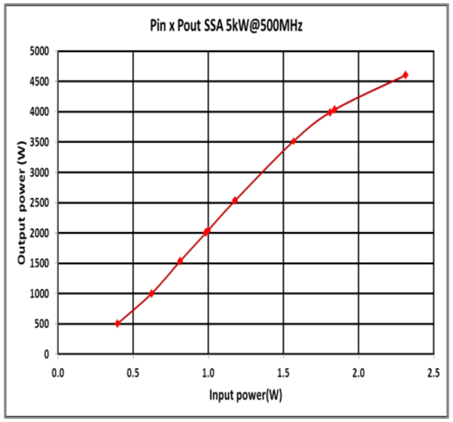
- High reliability
- No beam loss due to module failures
- 4 years in routine operation – 7 modules failed (out of 324), 6 fixed in house
- Whole SSA – 4 beam losses in 4 years due to failures in water flow meters and power supplies

RF systems



- Booster Solid State Amplifier
  - 4.5 kW prototype assembled and tested (33dB gain)
  - Long term reliability tests performed
  - 50 kW SSA designed
- Storage Ring Amplifiers
  - Studying a new design
- RF cavities
  - Booster cavity ordered (PETRA 5 cell)
  - SR SC cavities purchasing process started
    - Effective HOM damping
    - Lower broadband impedance
    - Smaller number of RF plants: 2 cavities in one straight section

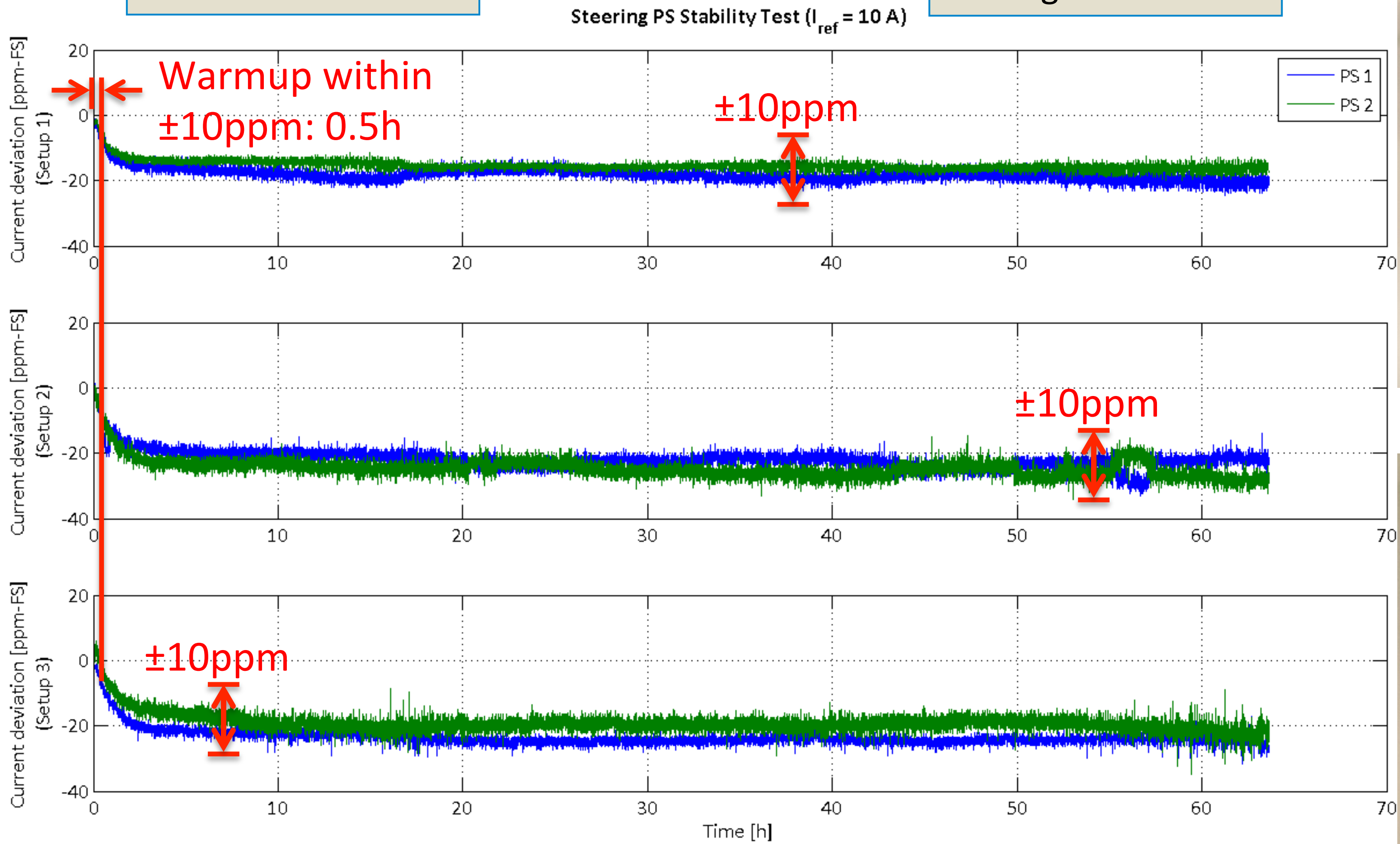


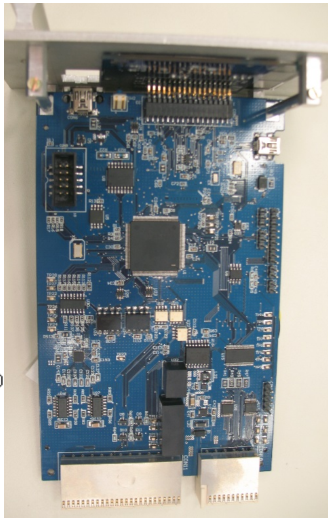


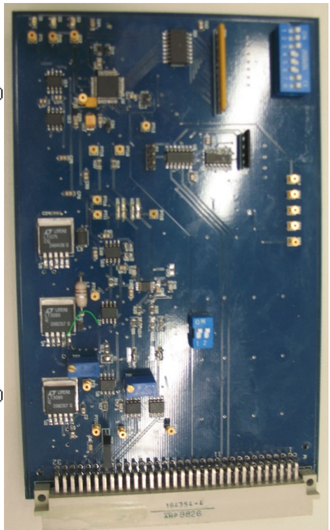
Development of digital PWM current supplies

18bit-resolution ADC

150ps resolution Digital PWM







Thank you