Laboratório Nacional de Luz Síncrotron

Beam Dynamics Meets Vacuum, Collimations and Surfaces
Karlsruhe, 8-10 March - 2017

CNPEM

The Vacuum System of the Upcoming SIRIUS Light Source in Brazil

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On behalf of the Vacuum Group

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Overview

- SIRIUS layout and parameters
- Vacuum requirements
- Vacuum system layout
- Pressure profile
- Main chambers and components
  - Fabrication processes
  - Chromatic chambers
  - Flanges
  - RF shielded bellows
  - BPMs
  - Dipole chambers and pumping stations
- NEG coating facility and R&D results
- Bake-out for NEG activation
- Storage ring half-arc mock-up of the vacuum system
- Current status and schedule
- Final Remarks

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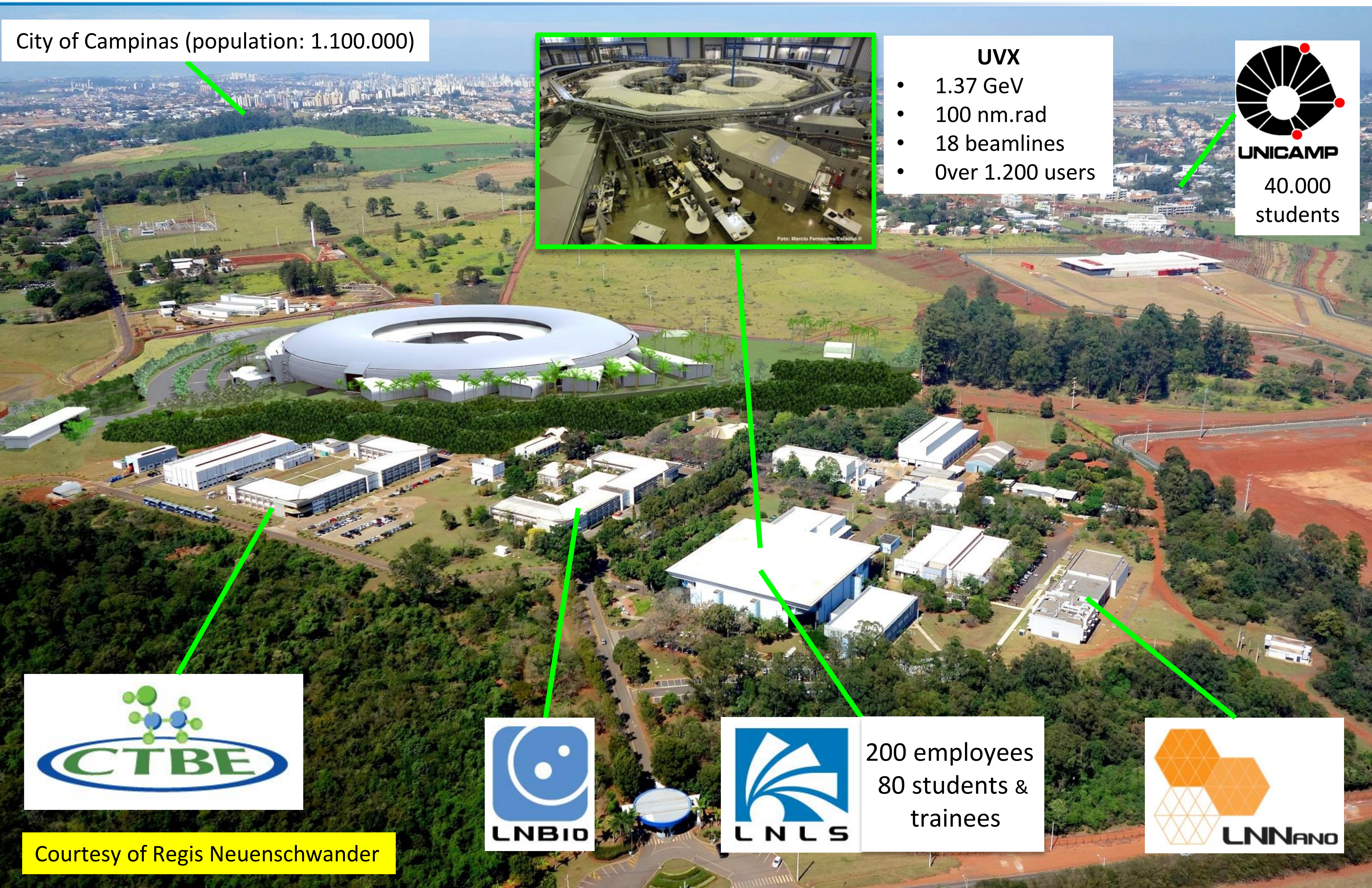

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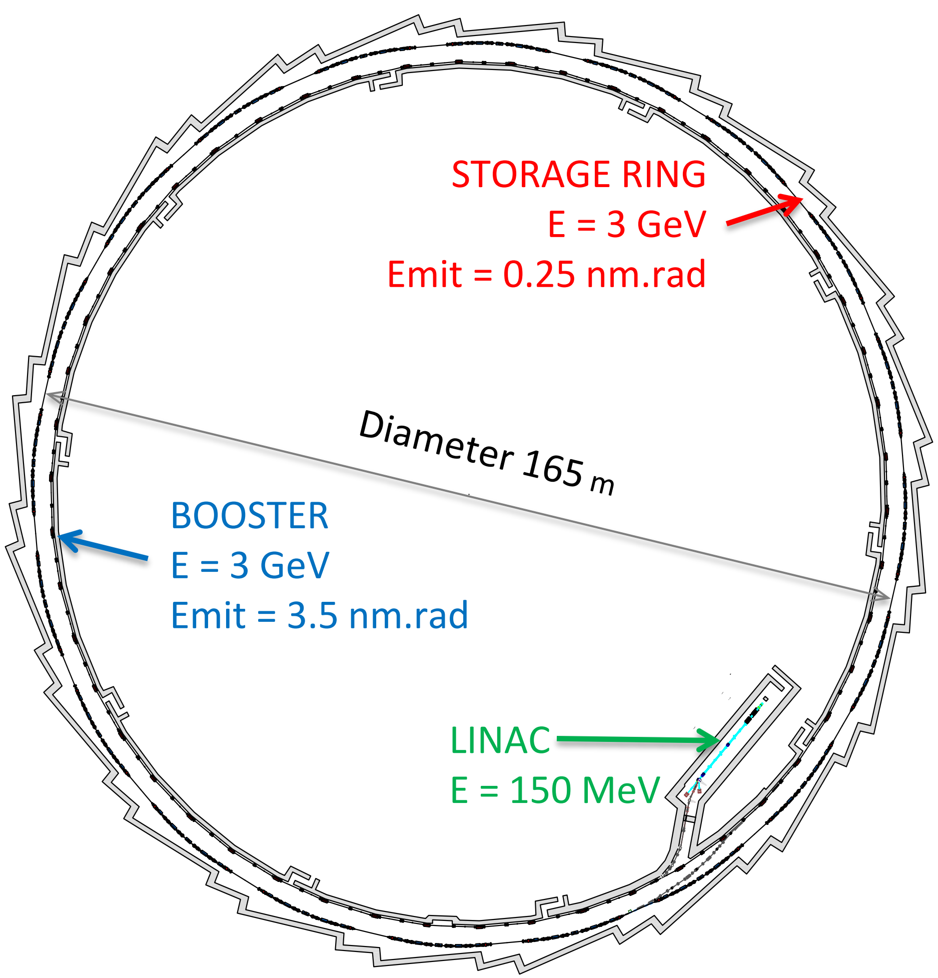
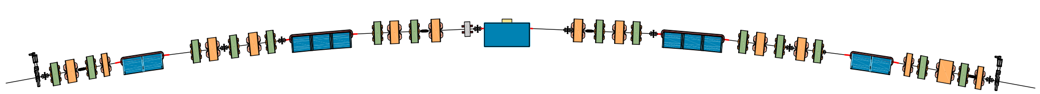
SIRIUS Layout and Parameters

Circumference 518.4 m





5 Bend Achromat

Storage Ring	
Beam energy	3.0 GeV
Circumference	518.4 m
Lattice	20 x 5BA
Hor. emittance (bare lattice)	250 pm.rad
Hor. emittance (with IDs)	→ 150 pm.rad
Betatron tunes (H/V)	48.10 / 13.17
Natural chromaticities (H/V)	-124.4 / -79.9
rms energy spread	0.95×10^{-3}
Energy loss/turn (dipoles)	532 keV
Damping times (H/V/L) [ms]	15.5 / 19.5 / 11.2
Nominal current, top up	350 mA

Booster	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Lattice	50 Bend
Cycling frequency	2 Hz

Courtesy Liu Lin

Vacuum System Requirements

- Average vacuum **< 1 x 10^{-9} mbar** (CO eq.);
- Impedance/HOM issues:
  - **Keep down** the beam impedance and HOM power
  - No steps inside the chambers
  - Transitions must be carefully studied by EM simulation
- No radiation hitting uncooled surfaces;
- NEG coatings on chambers (License Agreement with CERN, 2012) and In-situ activation;
- Tight mechanical tolerances on manufacturing due to small clearance between Magnets and Chamber;
- The Stainless Steel Booster and Transfer Lines chambers are being manufactured by a Brazilian company.

Vacuum system layout

Compact lattice and small aperture magnets

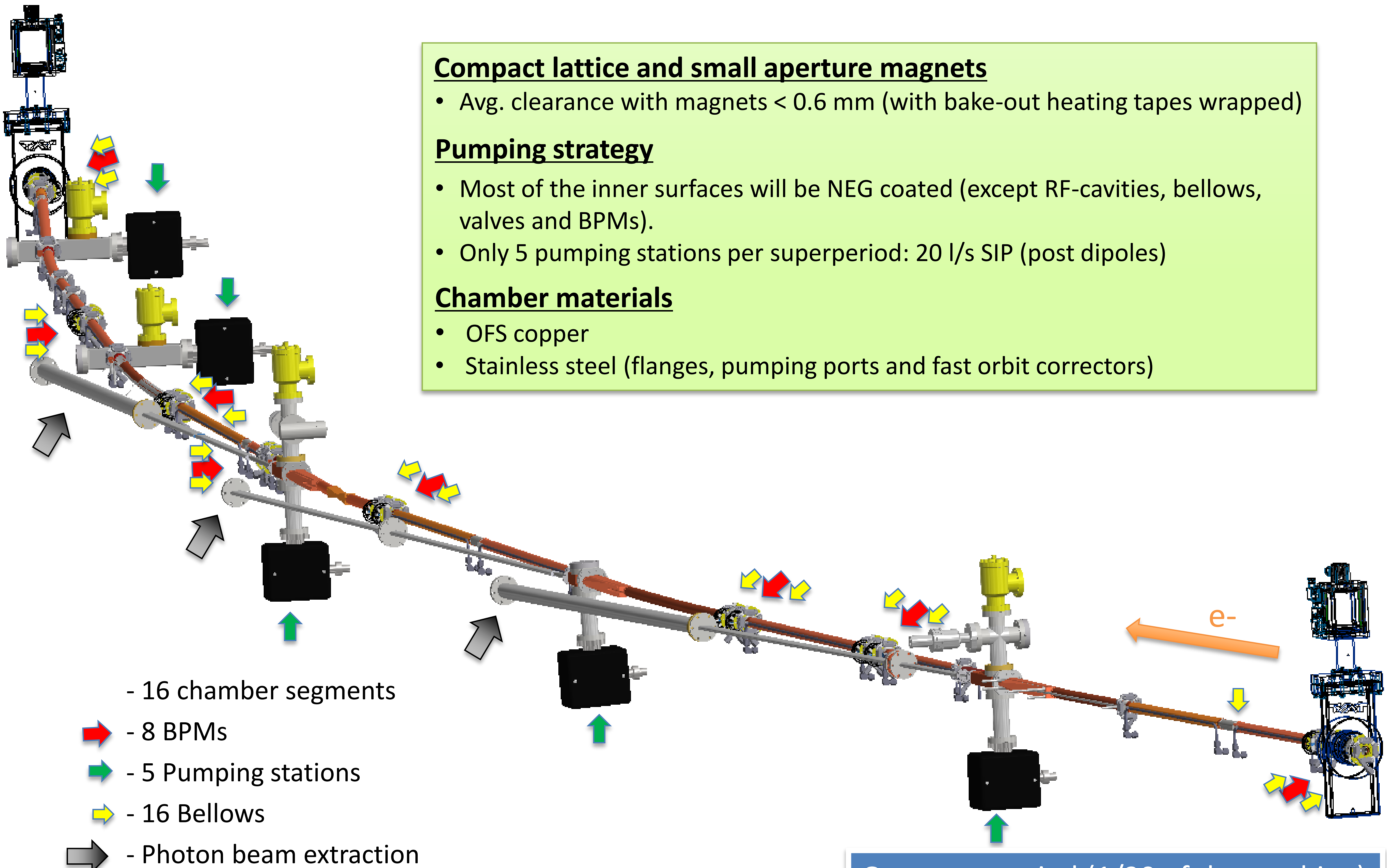
- Avg. clearance with magnets < 0.6 mm (with bake-out heating tapes wrapped)

Pumping strategy

- Most of the inner surfaces will be NEG coated (except RF-cavities, bellows, valves and BPMs).
- Only 5 pumping stations per superperiod: 20 l/s SIP (post dipoles)

Chamber materials

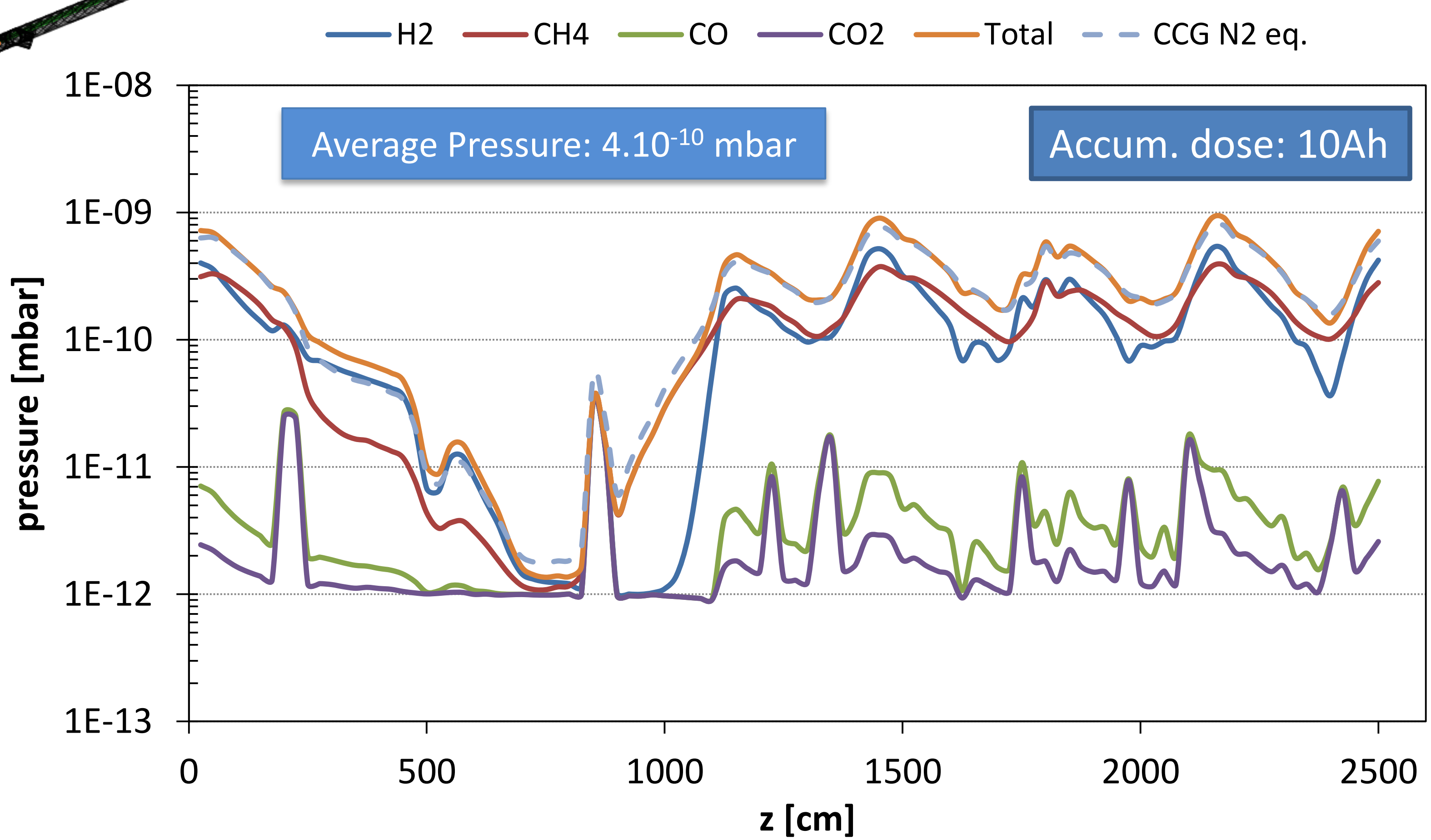
- OFS copper
- Stainless steel (flanges, pumping ports and fast orbit correctors)



One superperiod (1/20 of the machine)

Pressure profile

Synrad (R. Kersevan, CERN)



Molflow+ (R. Kersevan, CERN)

Used Sticking:

- H_2= 8.10^{-3}
- CH_4=$3.6.10^{-3}$ ~ 10 l/s/m (only on SR absorbed facets) – *M. Ady, WEPME037, IPAC2014*
- CO= 5.10^{-1}
- CO_2=5.10^{-1}

Main chambers and components: fabrication processes

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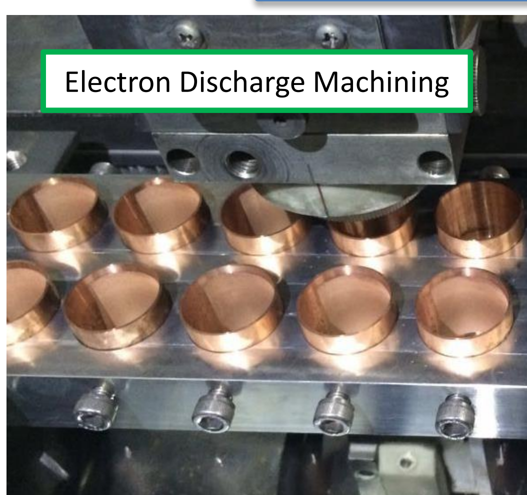
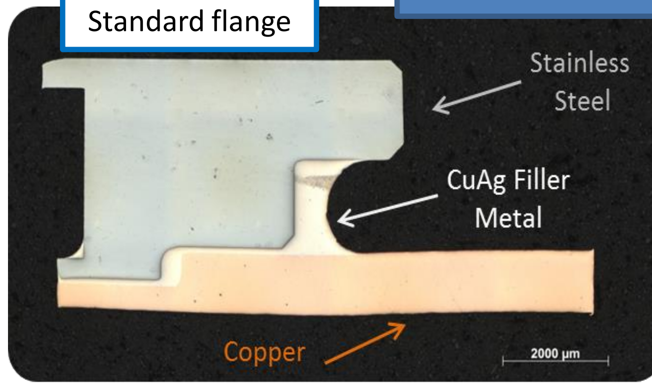
Main fabrication sequence:

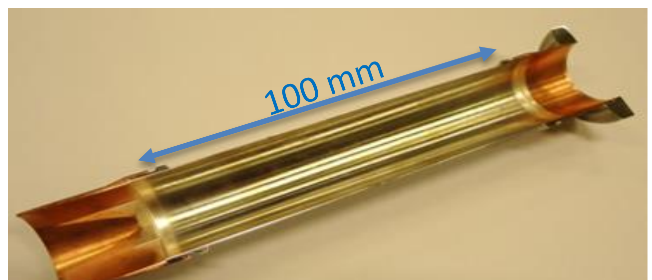
1. Machining and wire cutting
2. Flanges’ vacuum brazing
3. TIG welding parts together
4. Cooling channels’ vacuum brazing
5. Chamber’s bending
6. Final cleaning
7. NEG coating
8. Store them filled with N_2

Cooling tube forming starting from Ø6.35 x 1 mm

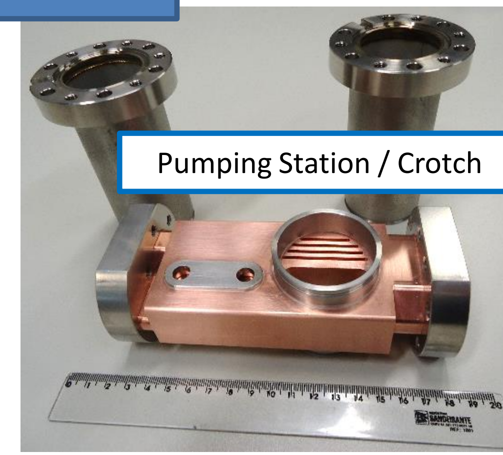


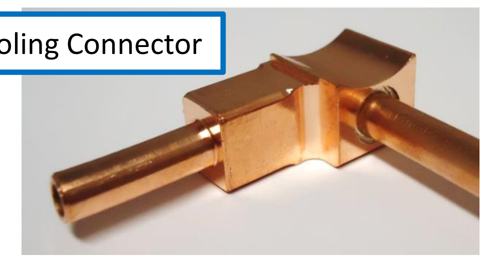
Brazed components



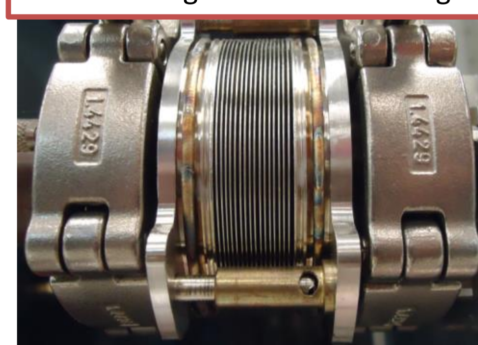


0.3 mm St. Steel for Fast Orbit Correctors





TIG Welded components



Main chambers and components: fabrication processes: cleaning procedure

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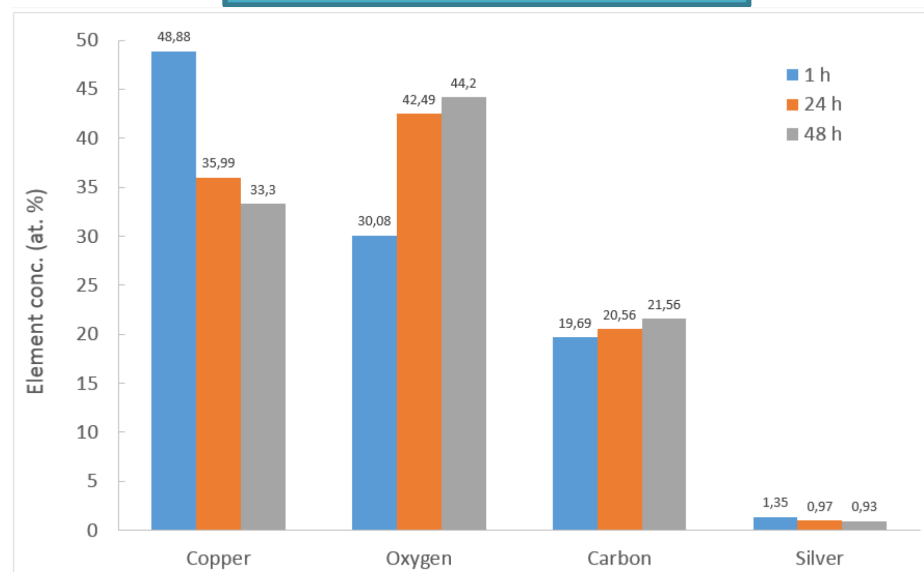
Procedure:
1. Tubes and components gross degreasing
2. Tubes etching – LNLS procedure
3. Copper components post-EDM processing
4. Fabrication process: machining, brazing, welding, etc…
5. Chambers degreasing
6. Light deoxidizing:
   - 5% ammonium citrate

Developed cleaning procedure:
1. 10% ammonium persulfate + 0,1% amonium acetate (etching ~ 15 µm)
2. 5% H_2O_2 (helps to remove silver insoluble residuals)
3. 5% ammonium citrate (deoxide + passivation)

-- Surface roughness < 0.4 µm (Ra) --

Cleaning facility – recirculation system

XPS analysis – LNLS cleaned surface



Cleaning quality criteria (based on CERN):
- Atomic % C < 44%
- Halogens (ex. F, Cl) < 1%
- Other contaminants should be analyzed

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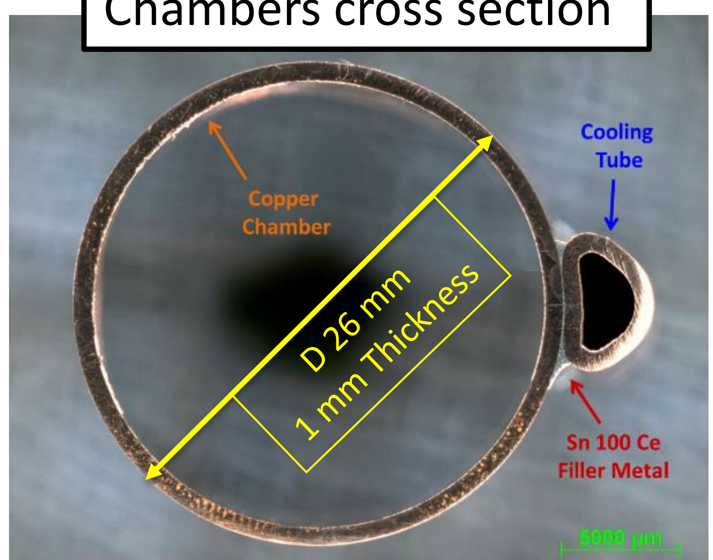
Main chambers and components: chromatic chambers

Material	Thermal expansion coefficient [1/C°]	Electrical conductivity [%IACS]	Thermal conductivity [W/m.K]	Young Modulus [GPa]	Yield Strength [MPa]
Copper OFS (UNS C107)	17.7	100	388	115	250

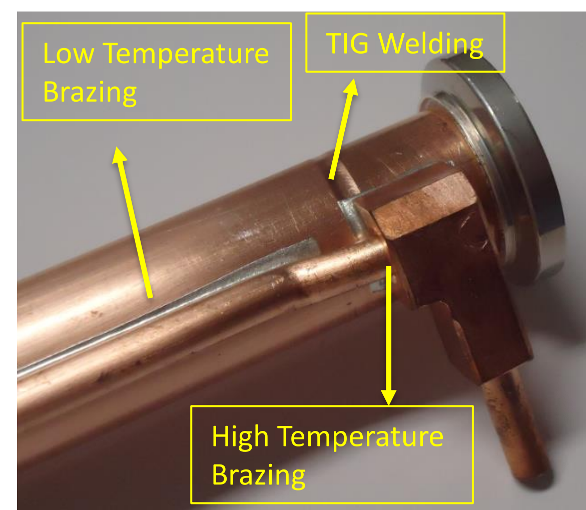
Different lengths (L) in the superperiod:

- 500 mm
- 630 mm
- 1004 mm
- 1166 mm
- 1950 mm
- 2502 mm

Chambers cross section



Magnet's aperture is 28 mm



Max. power density: 12 W/mm² (500 mA) @ thin wall tubes

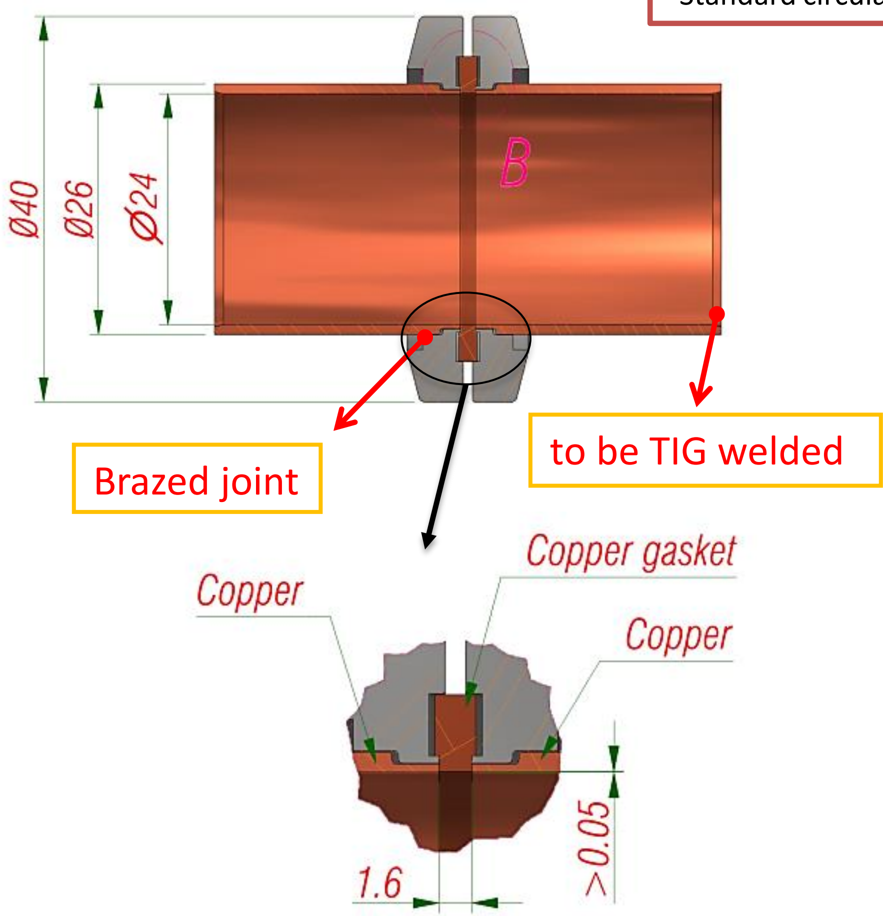
Main chambers and components: flanges

Modified KEK MO-type flange (circular and non-circular):

- No gap
- No step
- Smooth inner surface
- Beam only see copper

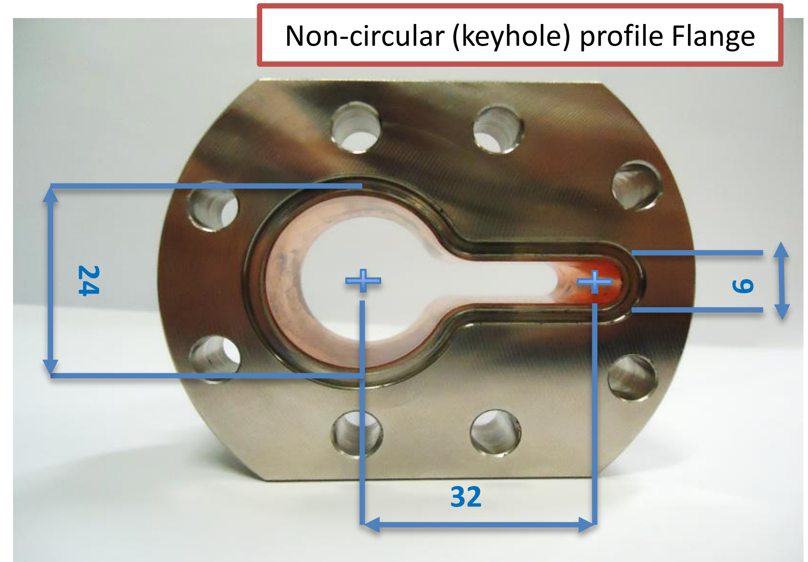
Tightening Results

Torque of 2 N.m sealing to < 1.10^{-10} mbar.L/s



Standard circular profile Flange

Non-circular (keyhole) profile Flange



Main chambers and components: RF shielded bellows

Specifications:

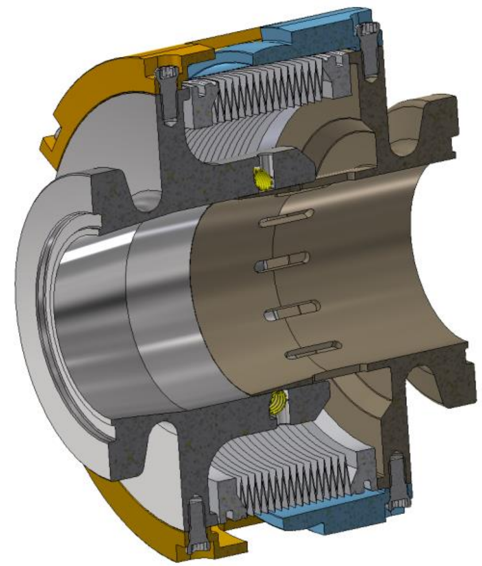
- Built-in flanges on both sides
- Max. compression: 9 mm
- Max. expansion: 2 mm
- Lateral displacements will be absorbed by copper chambers.

Model #1 (Based on Dafne's Design)

- Good Electrical Contact
- Very Compact Design
- Difficult to Manufacture and Assembly
- Power Loss = 6 W

(500mA; Natural bunch Length; Uniform Filling)

Model #2 (Contact Spring Design)



Prototyping:

Groove's Machining;

Springs:

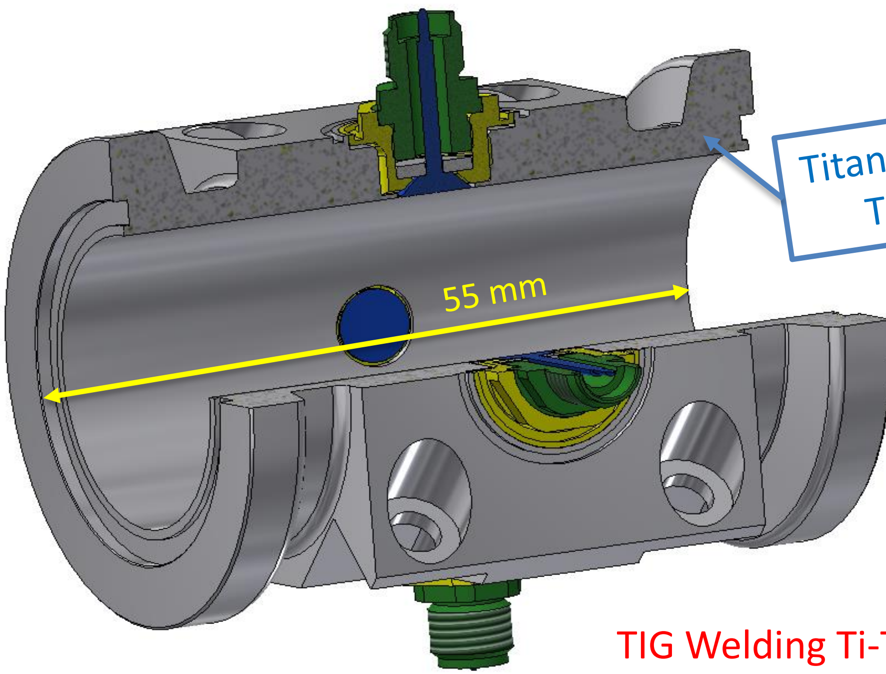
BalSeal

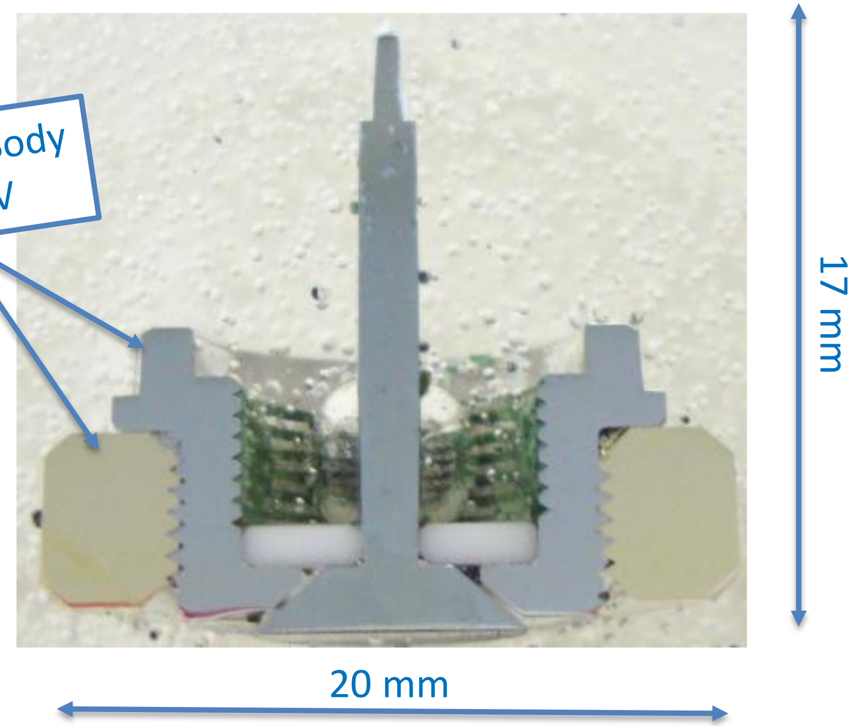
Iconn Eng.

- Good Electrical Contact
- Simpler Design and easier to Assembly
- Difficult to machine Spring's groove
- Power Loss = 10 W

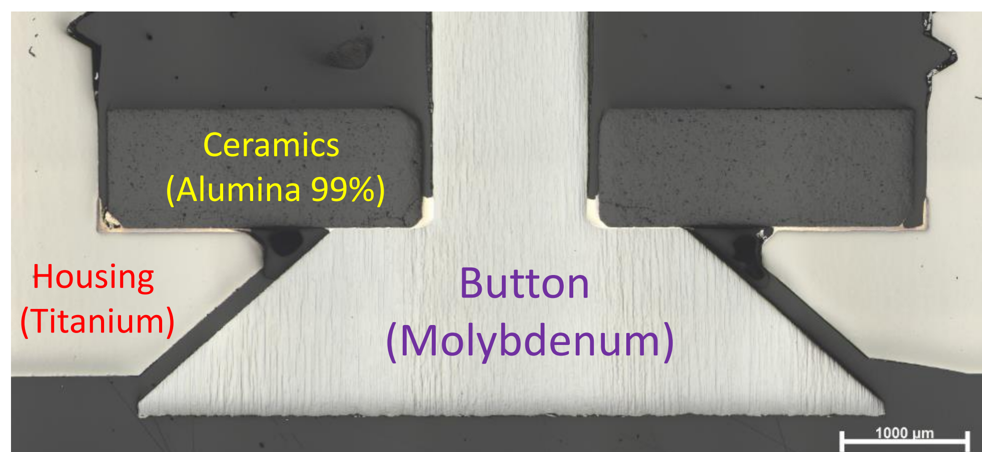
(500mA; Natural bunch Length; Uniform Filling)

Main chambers and components: BPMs

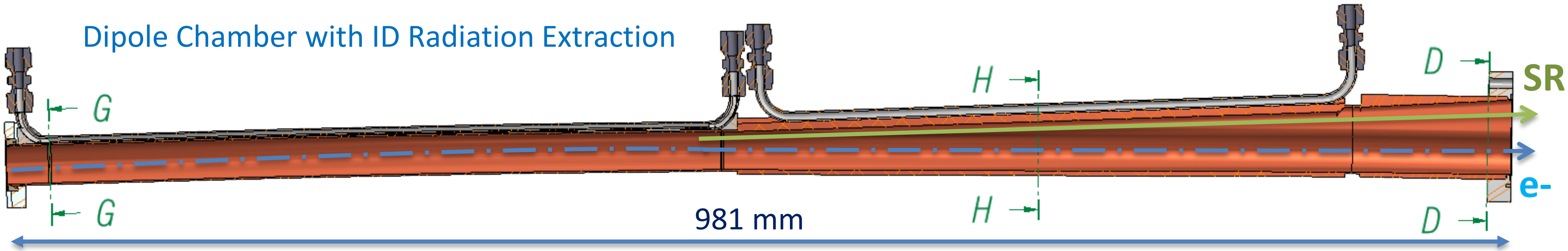




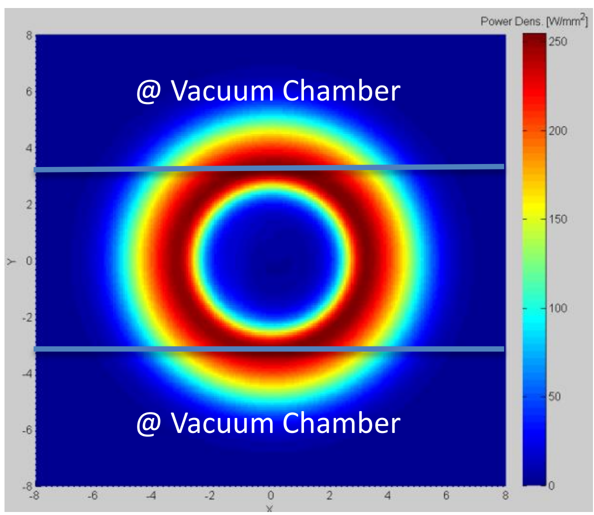
TIG Welding Ti-Ti

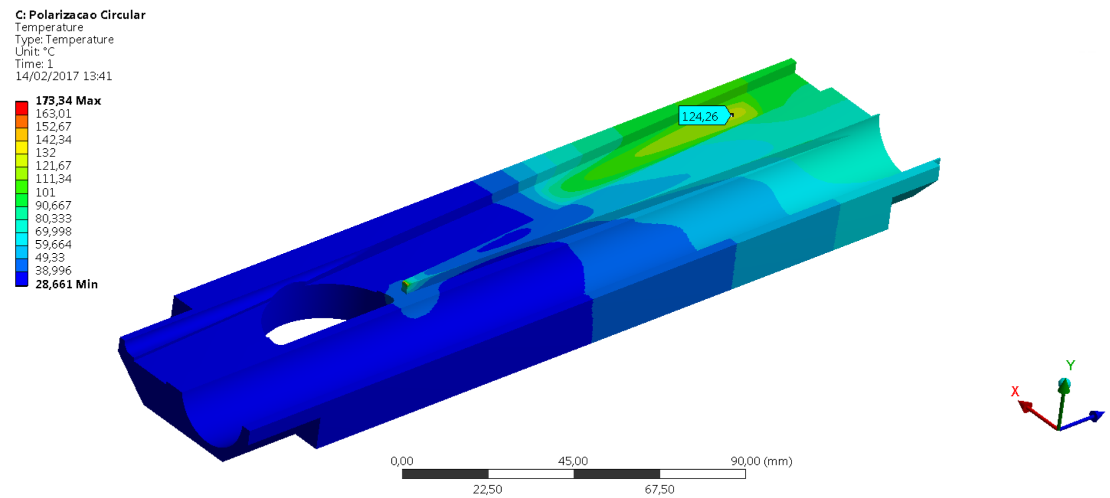


Main chambers and components: dipole chambers and pumping stations



6 mm
Vertical Gap

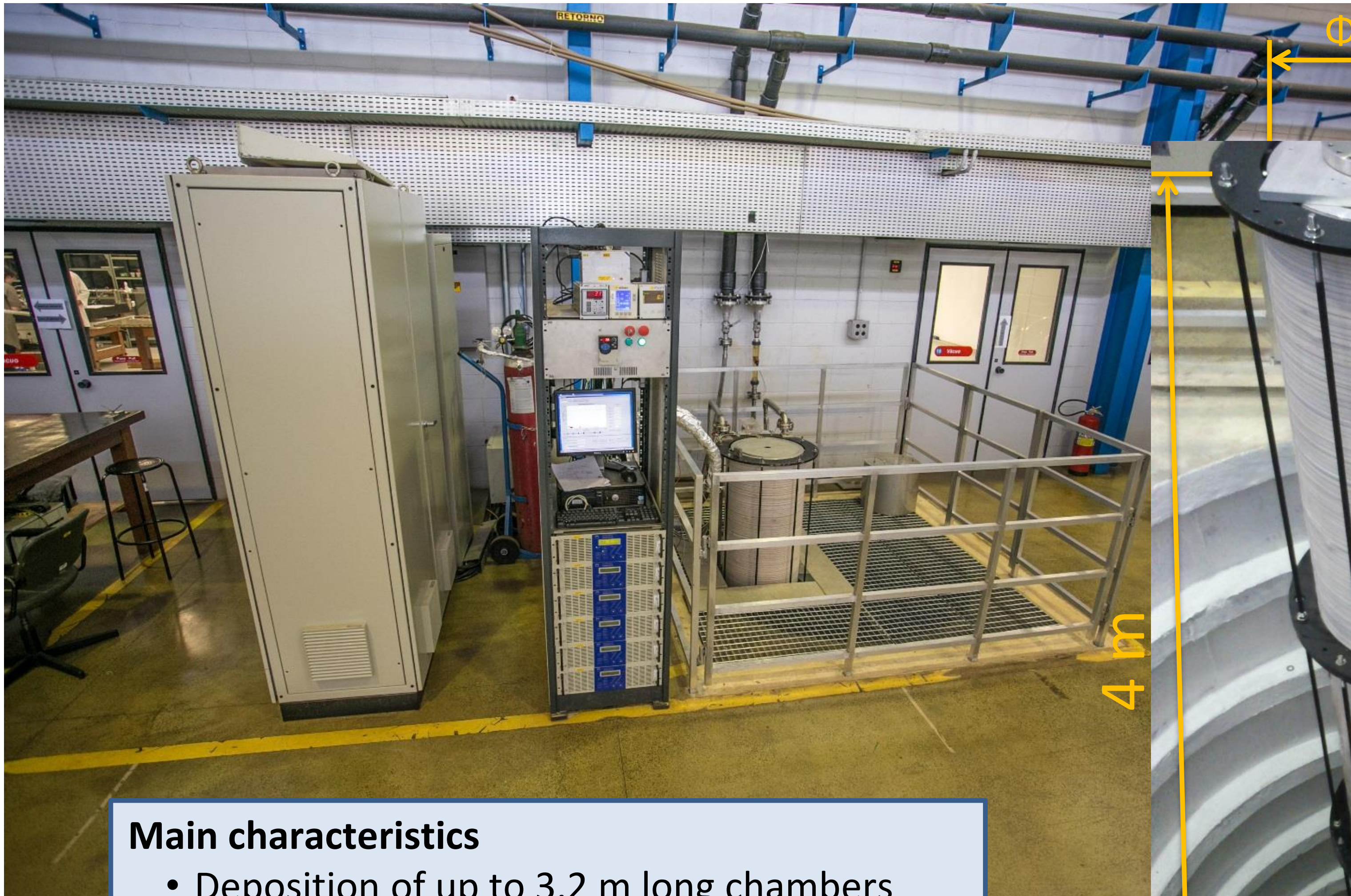




EPU 52
K = 4,14 for Circular Polarization
6 kW load @ Vacuum Chambers

Central Bending SR
3,2 T Magnetic Field
2 kW load @ Vacuum Chambers

NEG coating facility



Main characteristics
- Deposition of up to 3.2 m long chambers
- Magnetic field up to 600 Gauss
- Up to 6 straight chambers simultaneously
- Bake-out system integrated to the solenoids
- Automatic control of the deposition
- Individual control of each chamber

NEG coating R&D – Results

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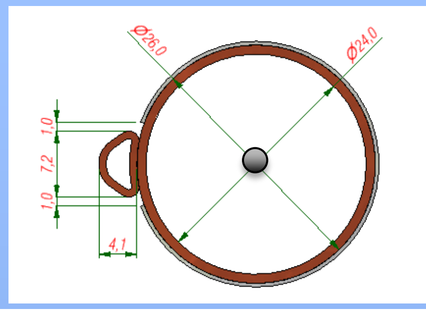
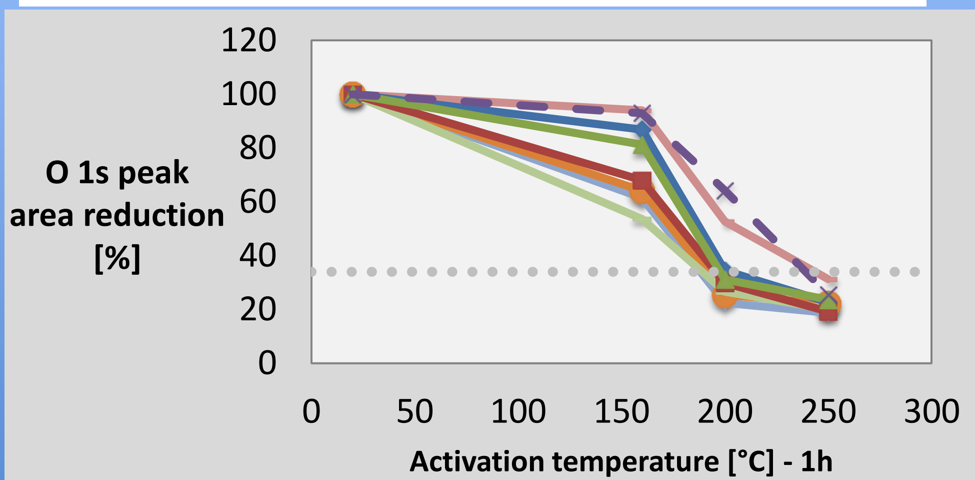
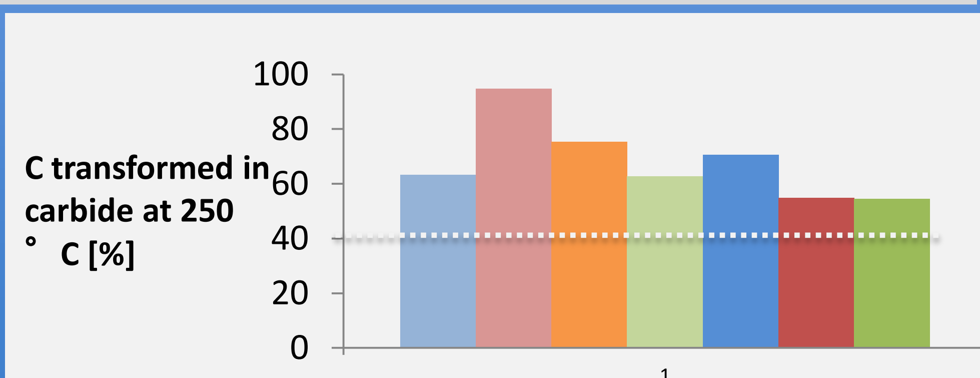
XPS analysis –circular profile



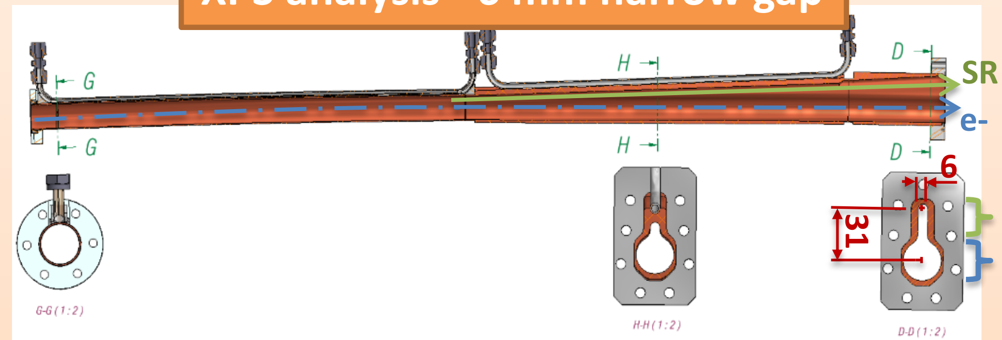
Coating procedure (1 steps):

1. Coating of the circular profile (1 cathode: 1 mm) - >



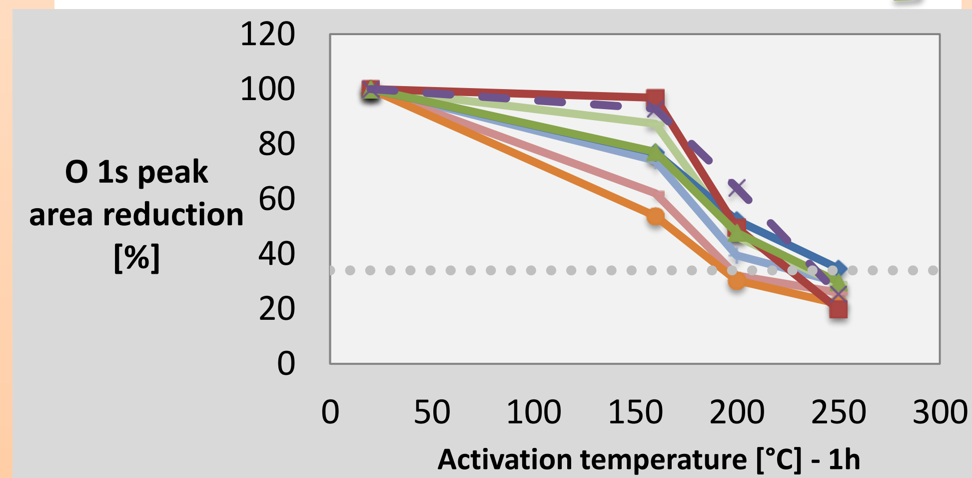


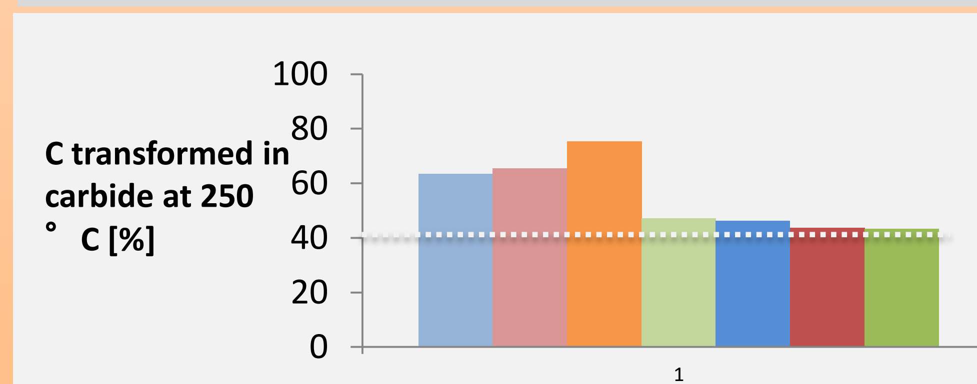
XPS analysis - 6 mm narrow gap



Coating procedure (2 steps):

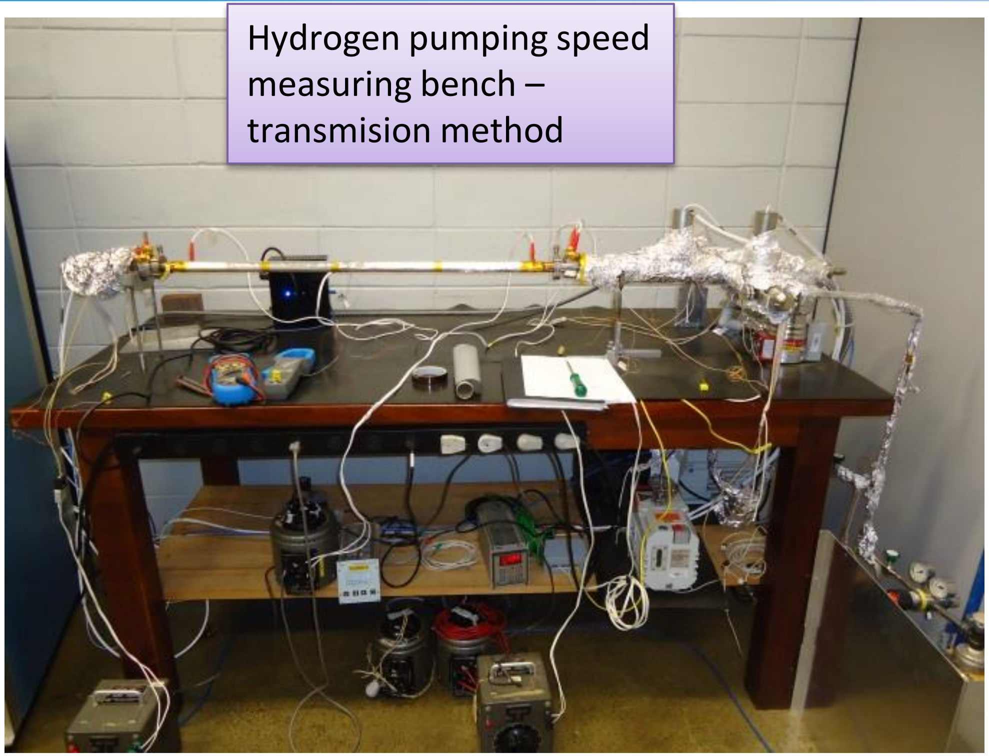
1. Coating of the circular profile (1 cathode: 1 mm) - >
2. Coating of the 6 mm narrow gap (1 cathode: 0.5 mm) ->



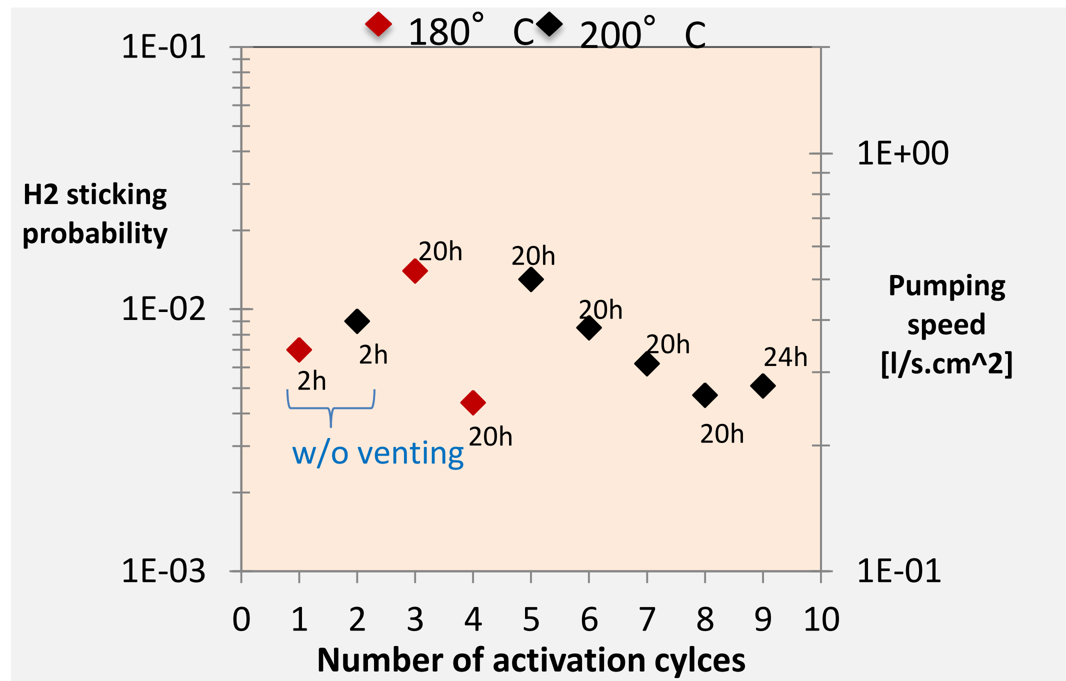


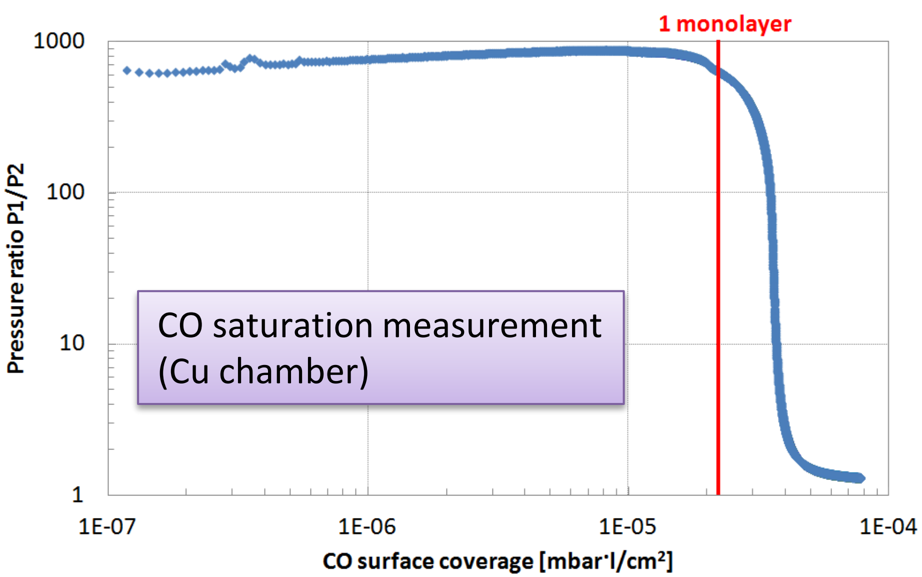
NEG coating R&D – Results

Hydrogen pumping speed measuring bench – transmision method



Aging effect -> copper tube of 24 mm ID and 1 m long





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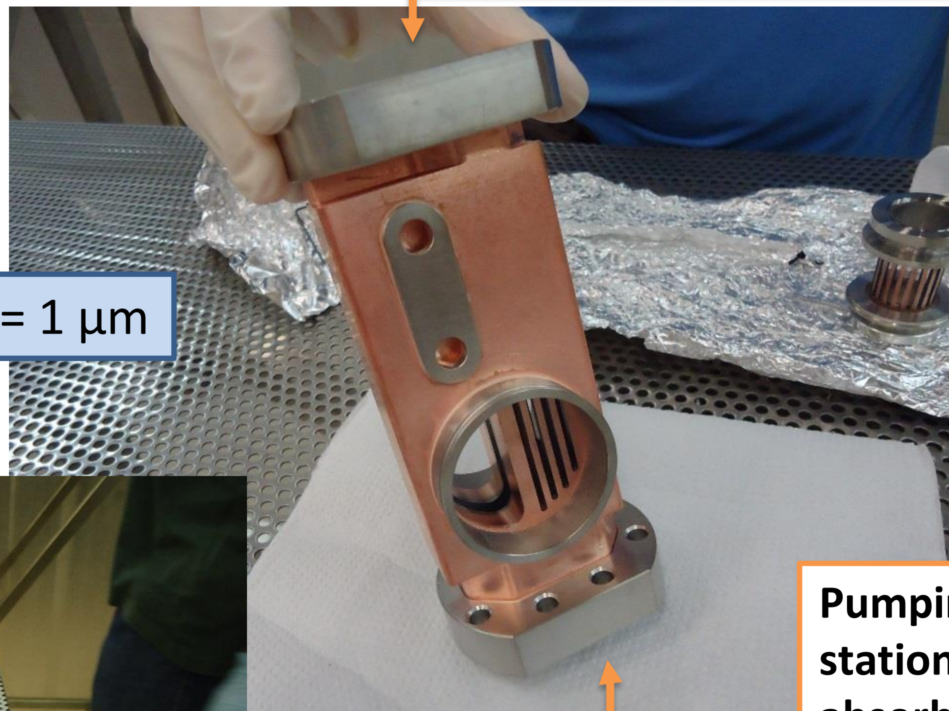
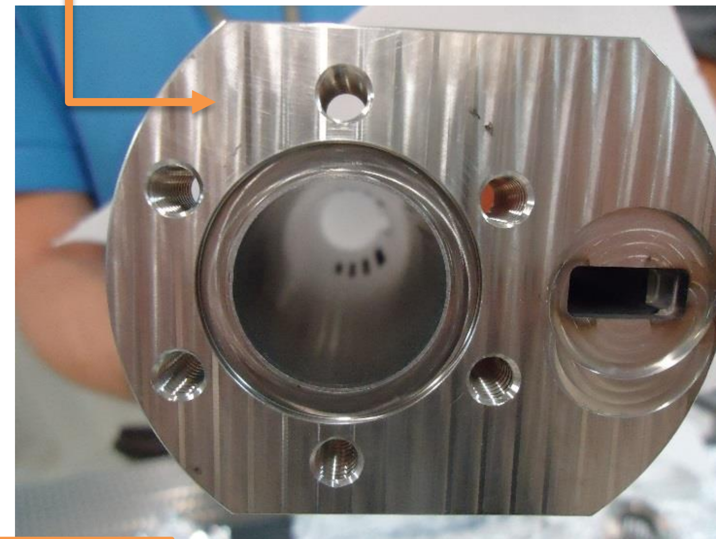
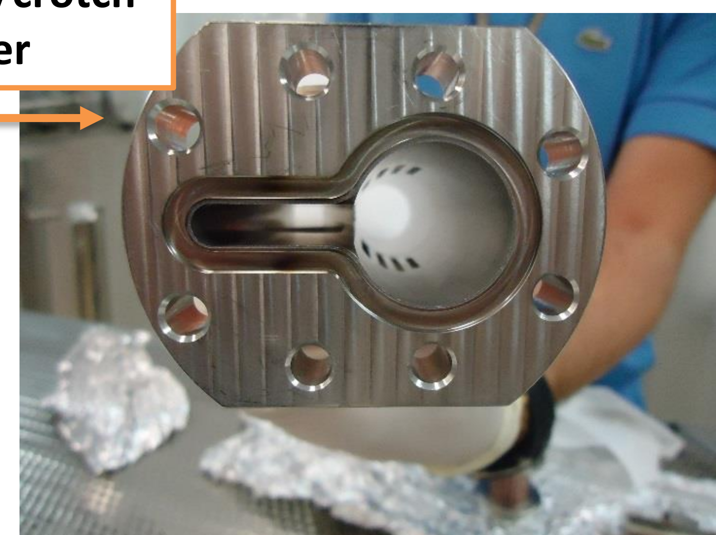
NEG coating R&D – Results: narrow gap coating of real prototypes

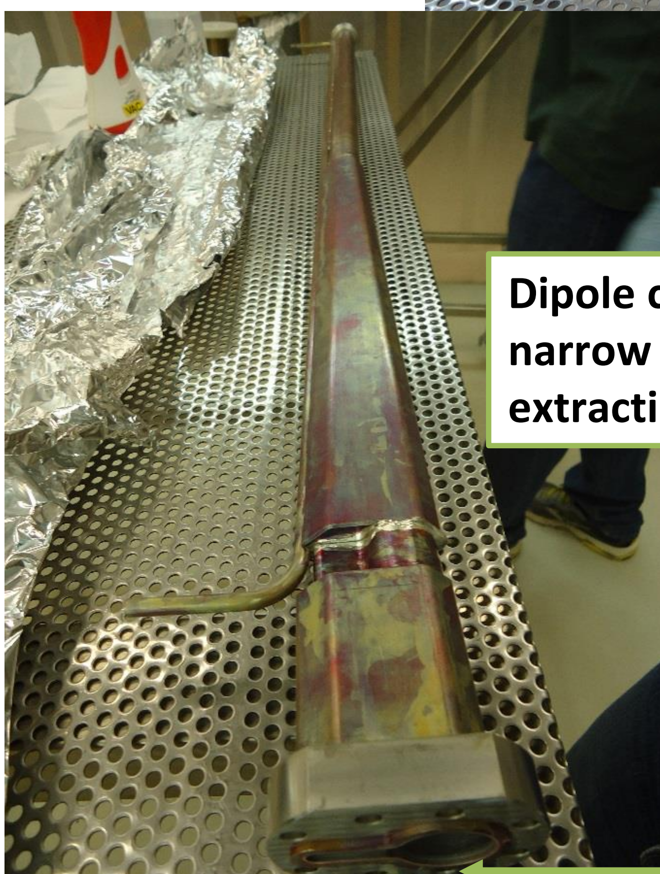
Coating thickness = 1 µm



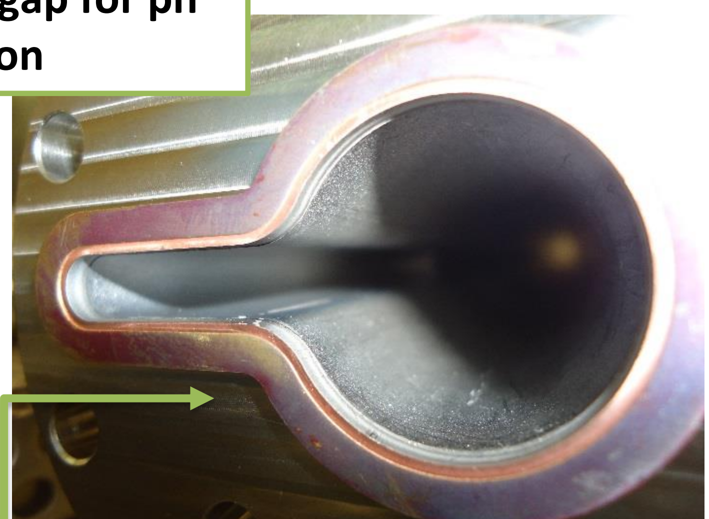


Pumping station/crotch absorber





Dipole chamber w/ narrow gap for ph extraction



Bake-out for NEG activation

The vacuum system for Sirius is being designed to be baked in-situ for NEG coating activation!

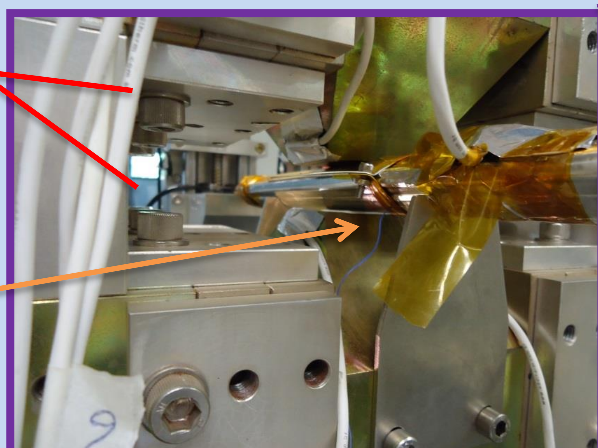
Main specifications for the required heaters:

- Thickness <= 0.4 mm
- Voltage < 50V
- Max. tested temperature 220 ^oC

Heater developed along with a Brazilian company

T_{poles}= 35.2 ^oC

0.5 mm gap



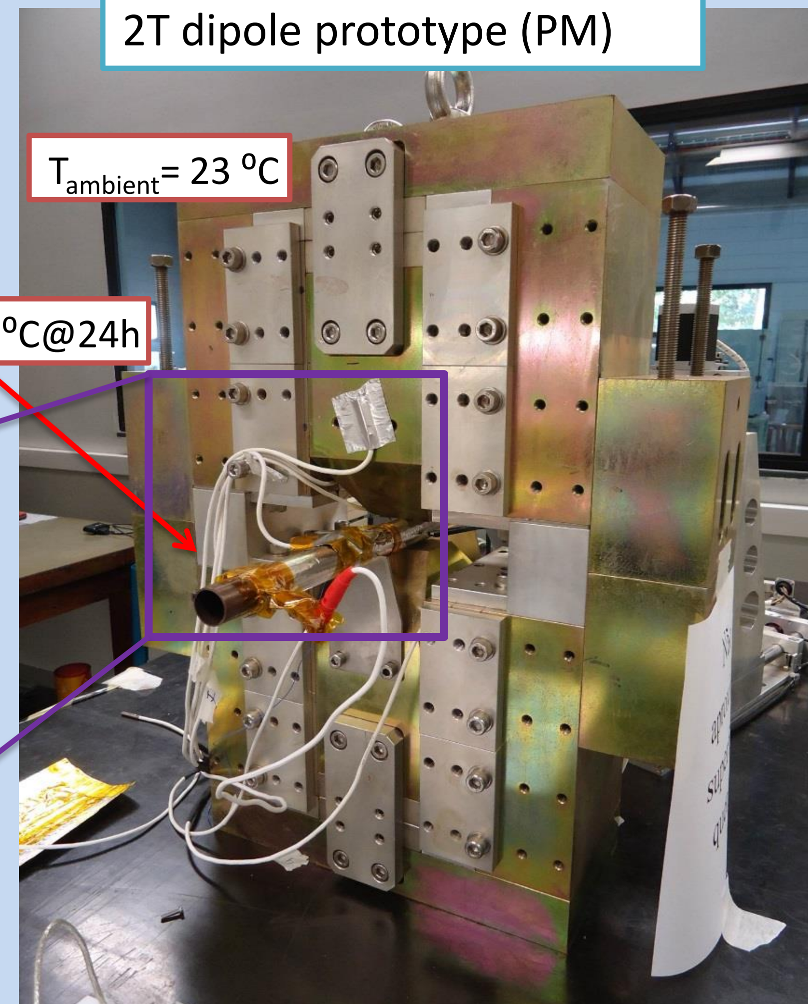
max. ΔT_{poles}= 12.2 ^oC ; max. ΔT_{PM}= 8.8 ^oC

Test of impact of an in-situ bake-out for NEG activation on permanent magnets

2T dipole prototype (PM)

$T_{ambient}$= 23 ^oC

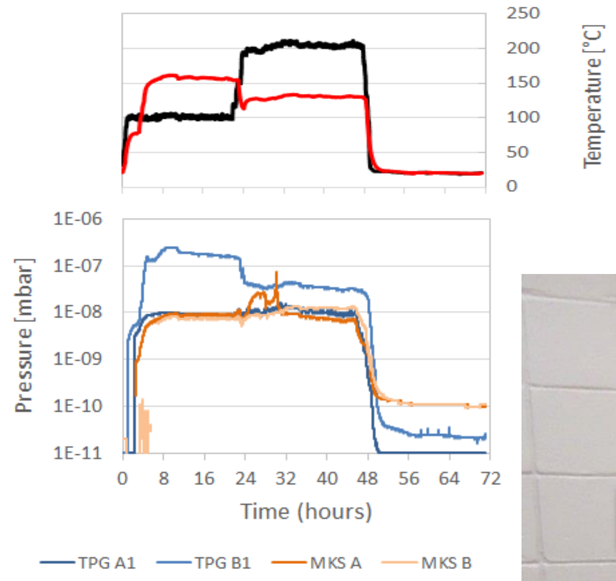
T_{tube}= 200 ^oC@24h

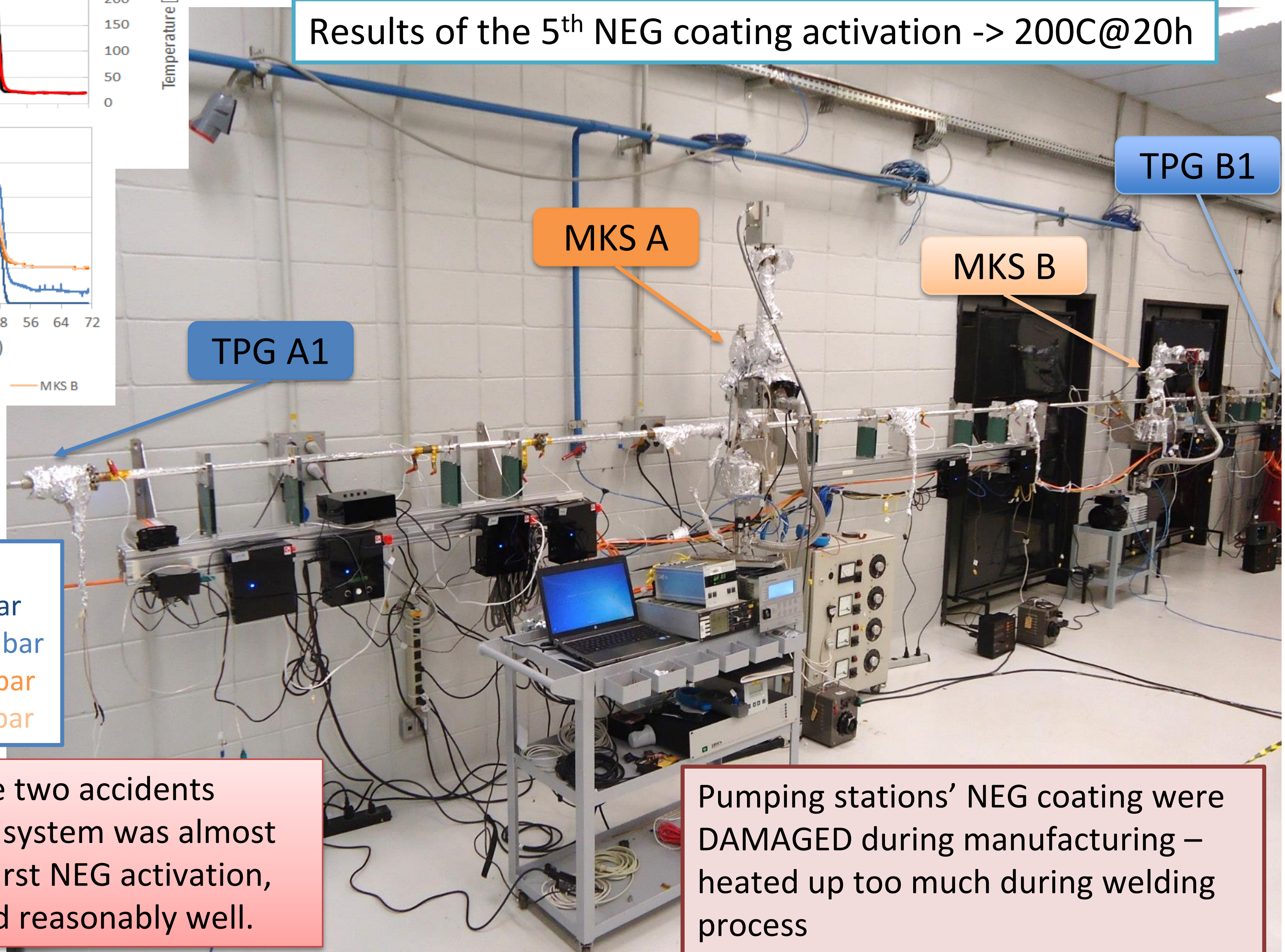


Still need to check the radiation resistance of the heating tapes!

Storage ring half-arc mock-up of the vacuum system

Results of the 5th NEG coating activation -> 200C@20h





Final pressures:

- TPG A1 < 1E-11 mbar
- TPG B1 = 2.2E-11 mbar
- MKS A = 1.1E-10 mbar
- MKS B = 1.1E-10 mbar

Although there were two accidents (power fails and the system was almost vented) during the first NEG activation, the coating activated reasonably well.

Pumping stations' NEG coating were DAMAGED during manufacturing – heated up too much during welding process

Current Status and Schedule

Present Status:

a) Standard circular flanges are brazed;

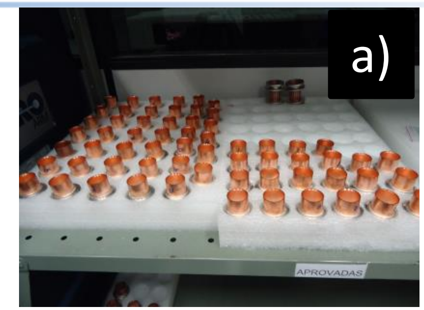
b) Cooling tubes w/ special copper connectors are brazed;

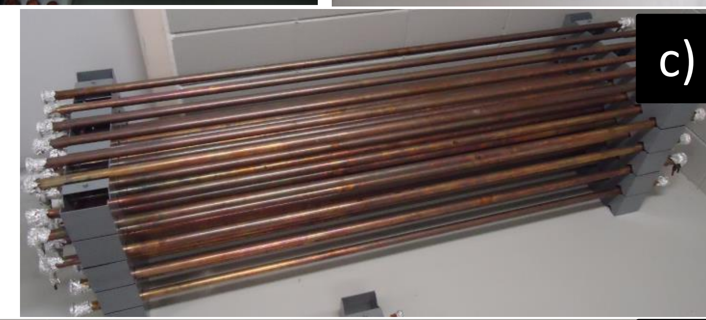
c) Vacuum chambers for straight sections (between RF shielded valves) are NEG coated;

d) 80% of copper tubes are machined, pre-cleaned and ready for welding;

e) Chromatic chambers are being NEG coated (we can coat 18 meters of chambers per run);

f) 2nd revised design of pumping station/crotch absorber is being prototyped;





Activity	Scheduled Date
Booster Stainless Steel Chambers	October 2017
NEG Deposition of Chromatic Chambers	June 2017
NEG Deposition of dipole and special Chambers	January 2018
Beginning of Vacuum Superperiod's Assembly	February 2018
Beginning of Commissioning	August 2018
First Beam for Users	July 2019

Final Remarks

- The budget for the vacuum system of Sirius is around 10 M €
- The use of NEG coated chambers must be considered right on the beginning of the design phase since it has a huge impact on infrastructure, fabrication strategy, cleaning procedures, baking strategy, etc;
- As the chamber's cross section is reduced, dimensional tolerances become tighter to minimize their contribution to beam instability. For that reason, chamber's design and fabrication are highly dependent of the inputs from impedance calculations;
- The participation of brazilian companies in Sirius Project is encouraged by the Science Ministry in order to leverage technological developments on industry.
- However, for the vacuum system of the storage ring, almost everything has been and will be built in-house to benefit from the available know-how and special infrastrutures;
- Based on tests developed so far, we are confident that the vacuum system will safely operate and achieve the machine design requirements.

Thank you!

Aknowledgements:
Vacuum Group
Materials Group
Workshop Group
Engineering Division

Any Doubts?