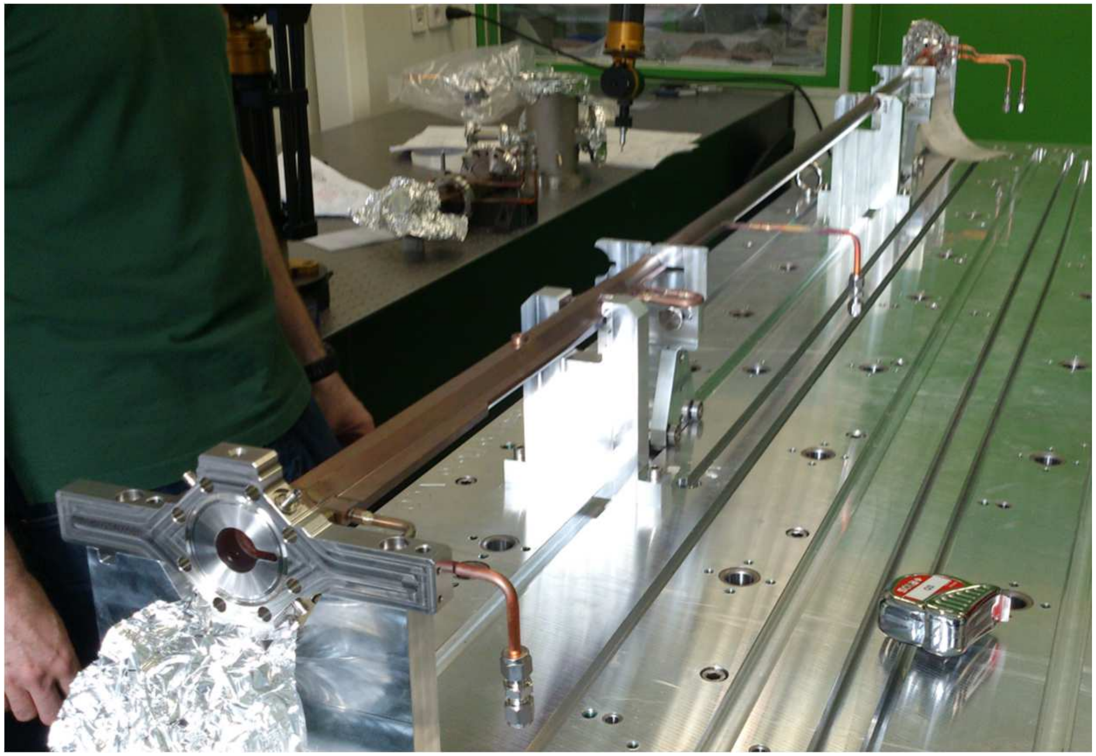
Vacuum System of the MAX IV 3 GeV ring

Dieter Einfeld on behalf of Eshraq AL-Dmour

DLSR workshop-SLAC

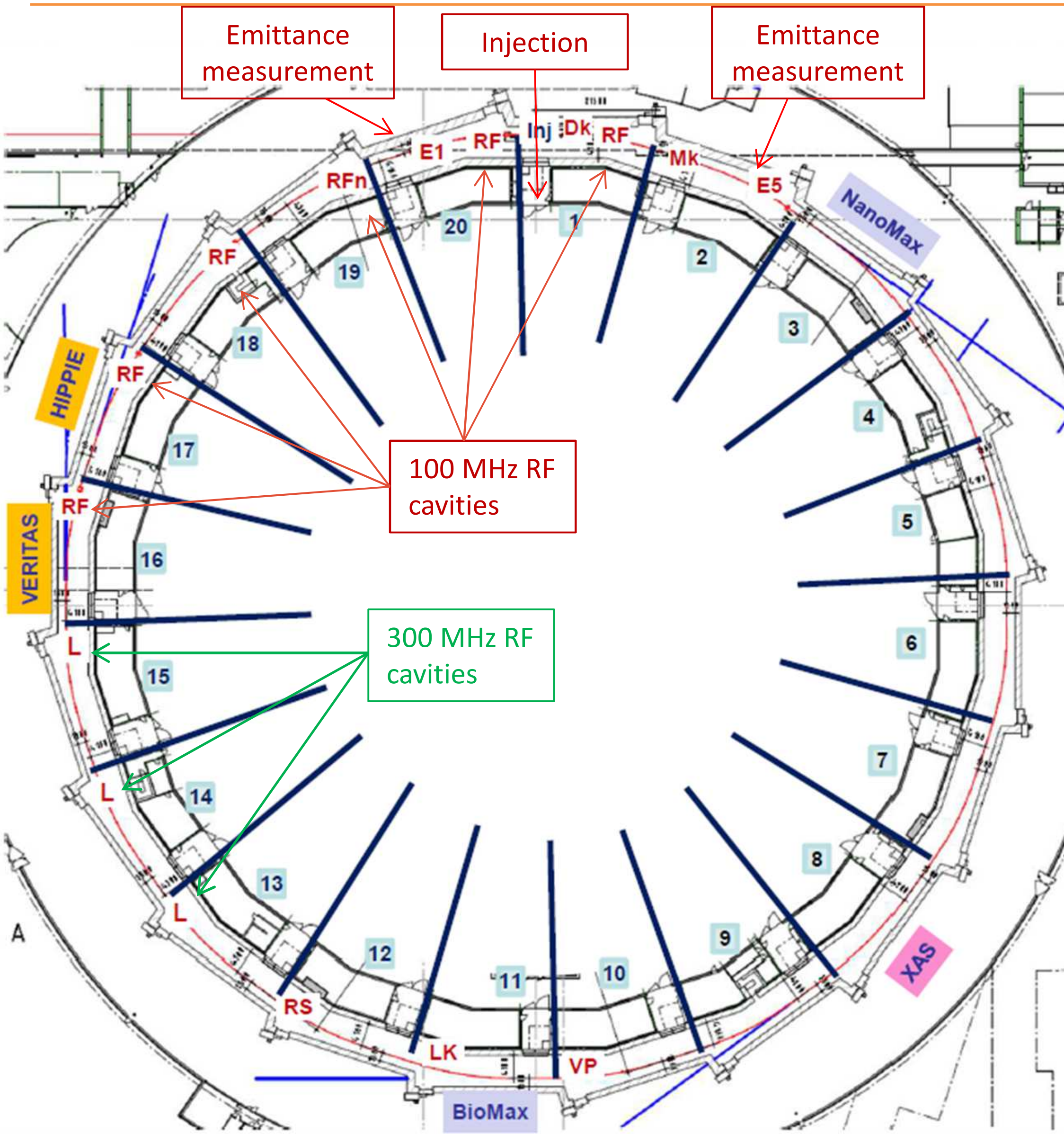


10th Dec. 2013

Contents

- MAX IV 3 GeV ring vacuum system layout,
- Vacuum system requirements,
- Vacuum chambers,
  - Design of the chambers,
  - Finite Elements Analyses,
- NEG coating issues and R&D at CERN,
- Present status,
- Installation.

The vacuum system layout



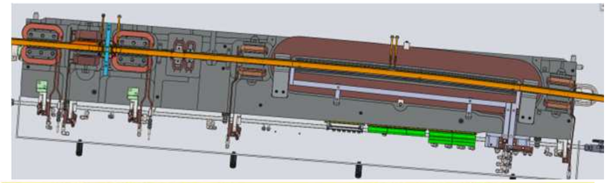
20 sectors:

- **Non standard items (L=long straight, S=short straight, U=unit cell, M=matching cell):**
  - **Inj: Injection (L)**
  - **Dk: Dipole kicker (S1)**
  - **Mk: Multipole kicker (L)**
  - **E1: Emittance (S1)**
  - **E5: Emittance (U5)**
  - **RF: 100 MHz cavities (S2)**
  - **RFn: cavity with DCCT (S2)**
  - **RS: Cavity spare position (S2)**
  - **L: Landau cavities 300 MHz (S2)**
  - **LK: Longitudinal kicker (S2)**
  - **VP: Vertical pinger (S2)**
  - **19 long straight (L) are available for IDs of which for day one:**
  - **IVU 2 m long**
    - **3.03L: NanoMax**
    - **3.11L: BioMax**
  - **EPU 4 m long gap 11 mm**
    - **3.16L: VERITAS**
    - **3.17L: HIPPIE**
  - **Wiggler 2 m long in vac.**
    - **3.08L: XAS**

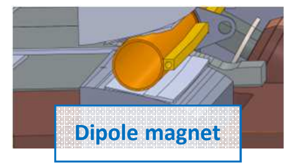
(L=long straight, S=short straight, U=unit cell, M=matching cell)

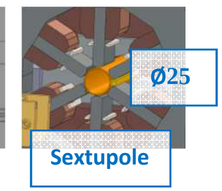
Vacuum system constrains and requirements

- **Compact lattice and magnets are made of solid block**
  - Small longitudinal distance between magnets.
  - Little space around the magnets.

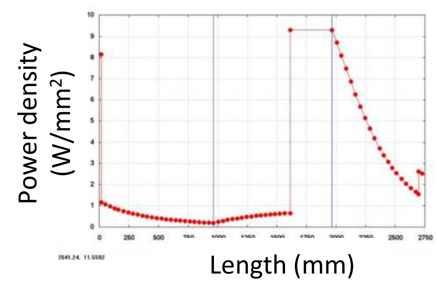


- **Small aperture of the magnets**
  - Magnets' aperture Ø25 mm.

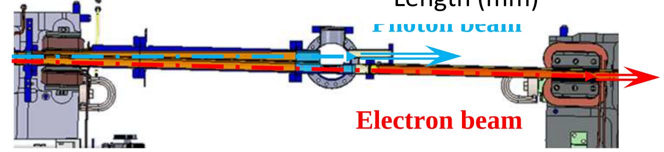




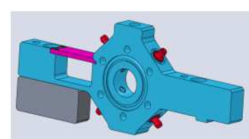
- **Low target pressure with beam**
  - Average pressure 1e-9 mbar.
- **Removal of the SR power (BM & ID)**
  - Power density along bent vacuum chamber walls and absorbers.

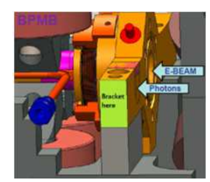


- **Extraction of synchrotron radiation**
  - Limited by small bending angle.



- **Stable positioning of BPM**
  - Disentangling the BPMs from the chambers.



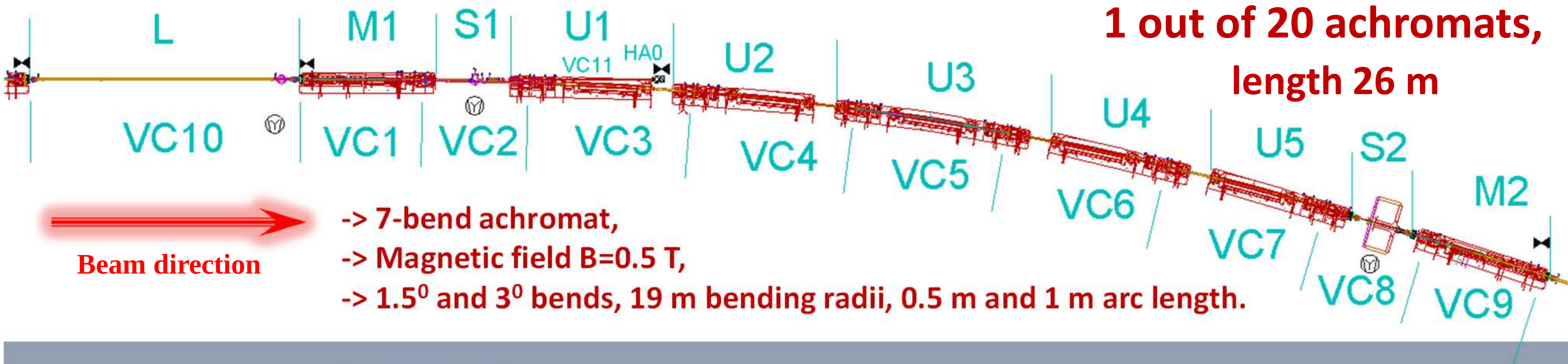


The vacuum system layout

- The vacuum chamber inside diameter is **22 mm** (27 mm in the dummy straight sections), **1mm thickness**.
- **Copper vacuum chambers OFS** (resistance to activation cycles)**.**
- Areas with **St. steel** for fast corrector coils.
- **Distributed cooling.**
- Distributed pumping all along the chamber length, using **NEG coating**.
- **One Lumped absorber** per achromat is needed to extract the photon beam to the front ends.
- **Welded bellows** to allow the VC to expand without affecting the BPM position.

The vacuum system layout

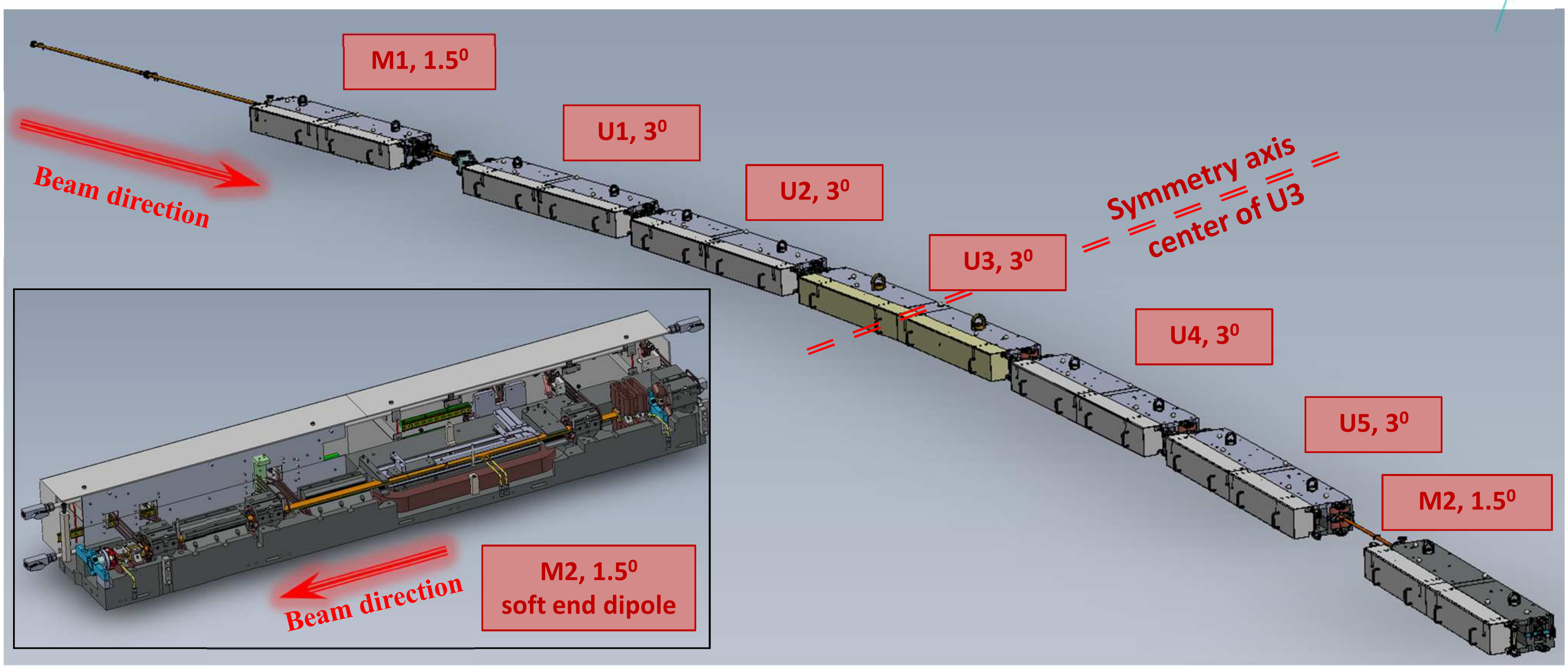
1 out of 20 achromats, length 26 m



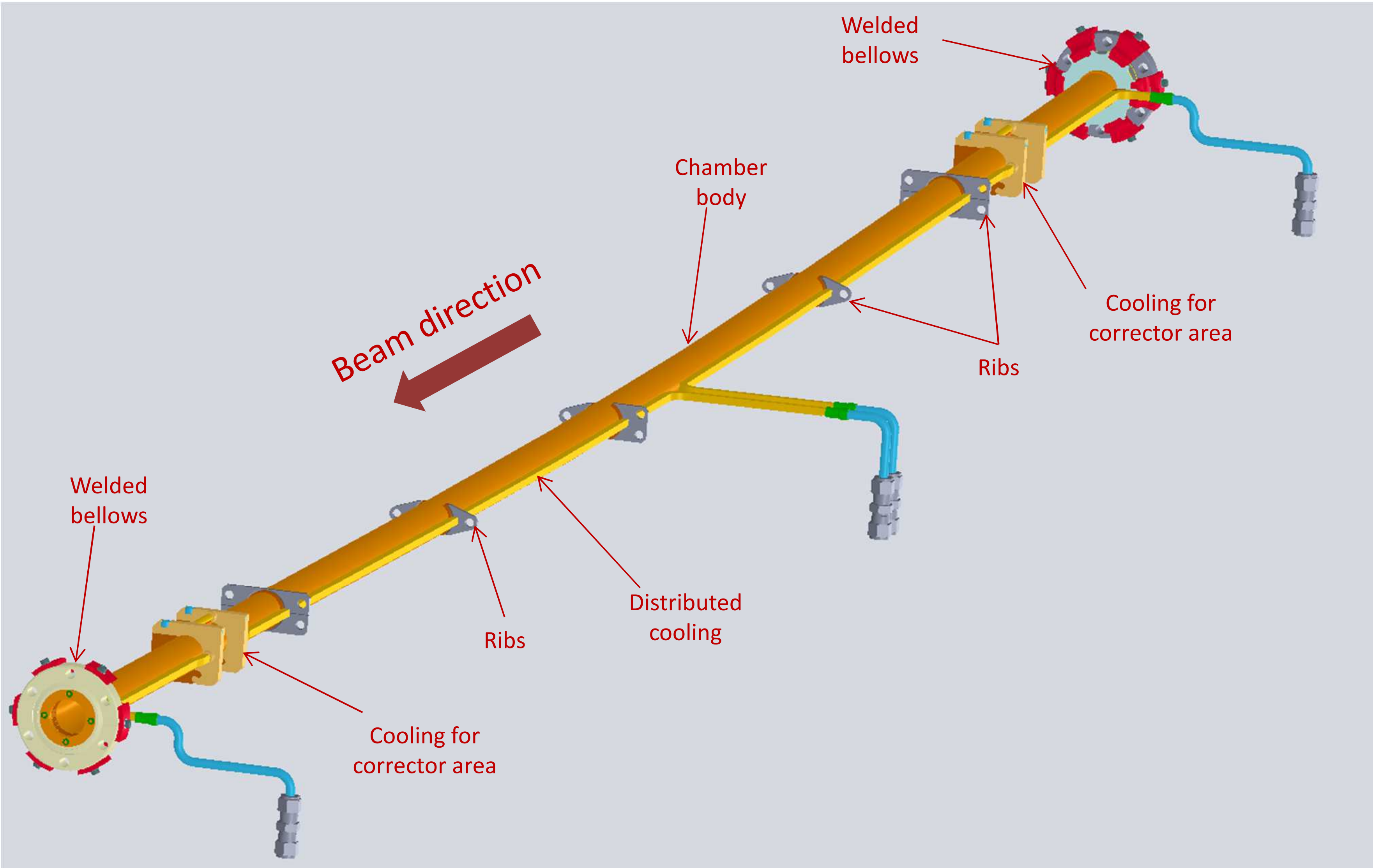
-> 7-bend achromat,

-> Magnetic field B=0.5 T,

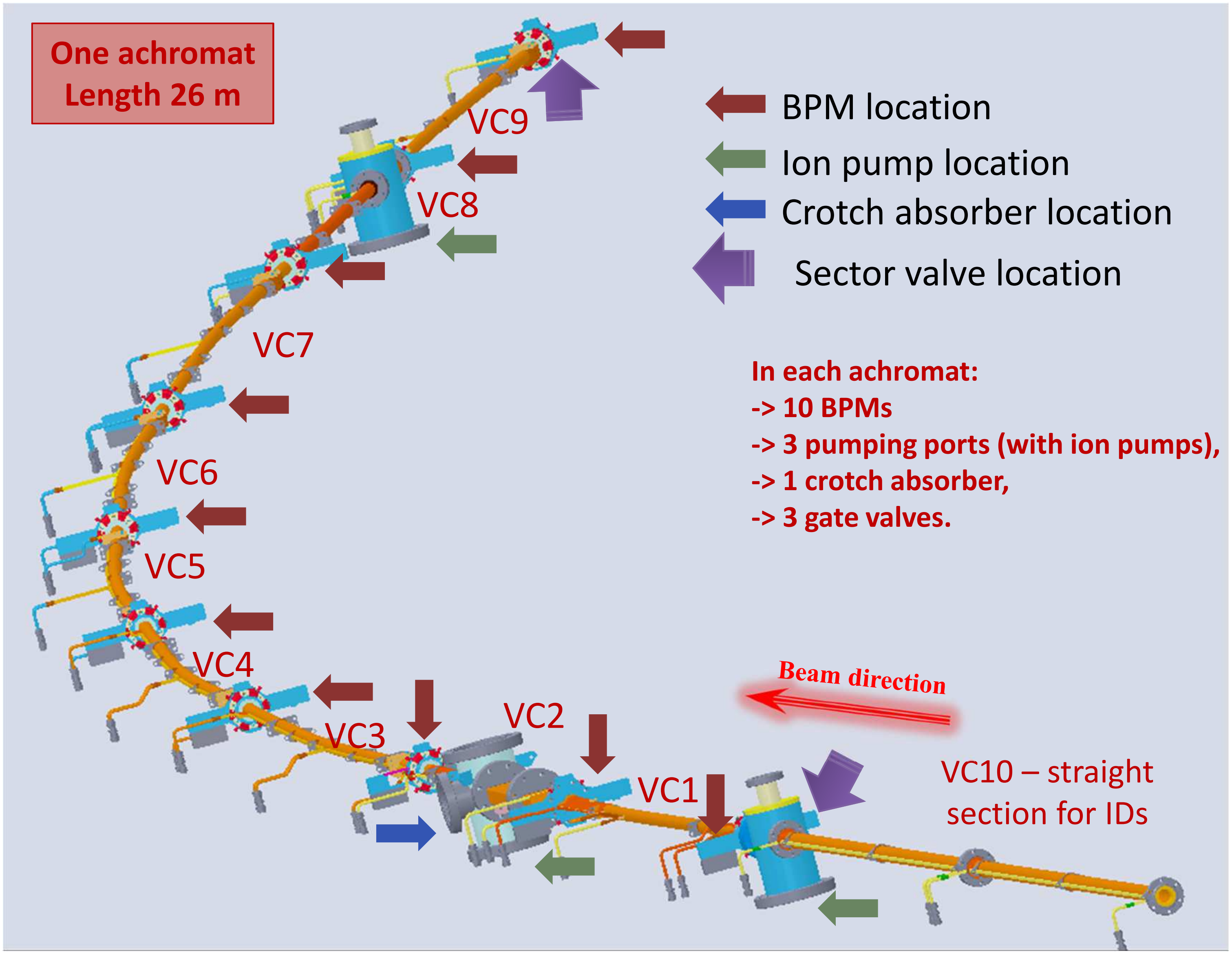
-> 1.5^0 and 3^0 bends, 19 m bending radii, 0.5 m and 1 m arc length.



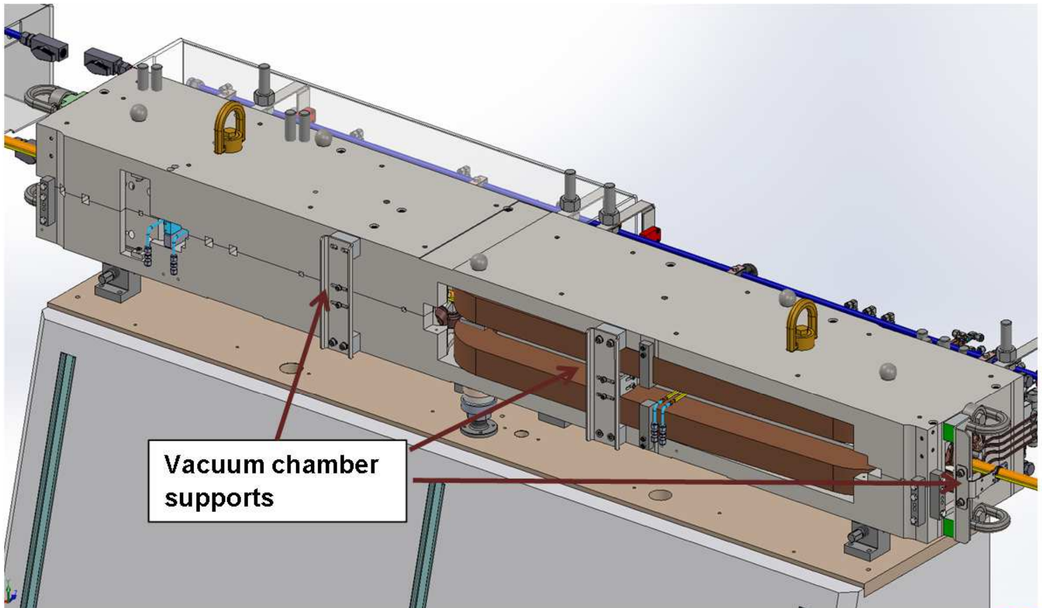
General Vacuum chamber geometry

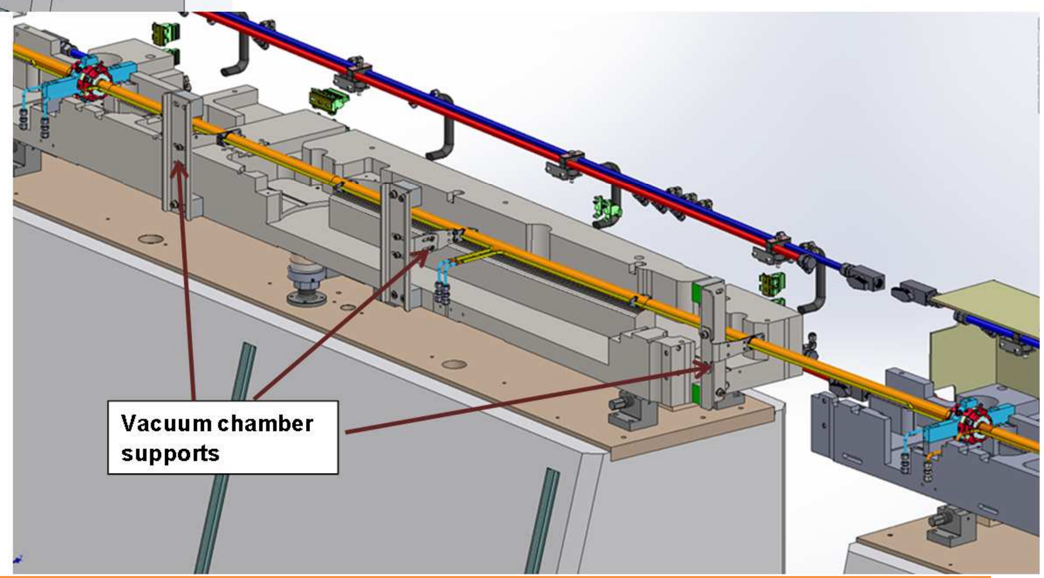


The vacuum system layout



Fixation of the vacuum chamber

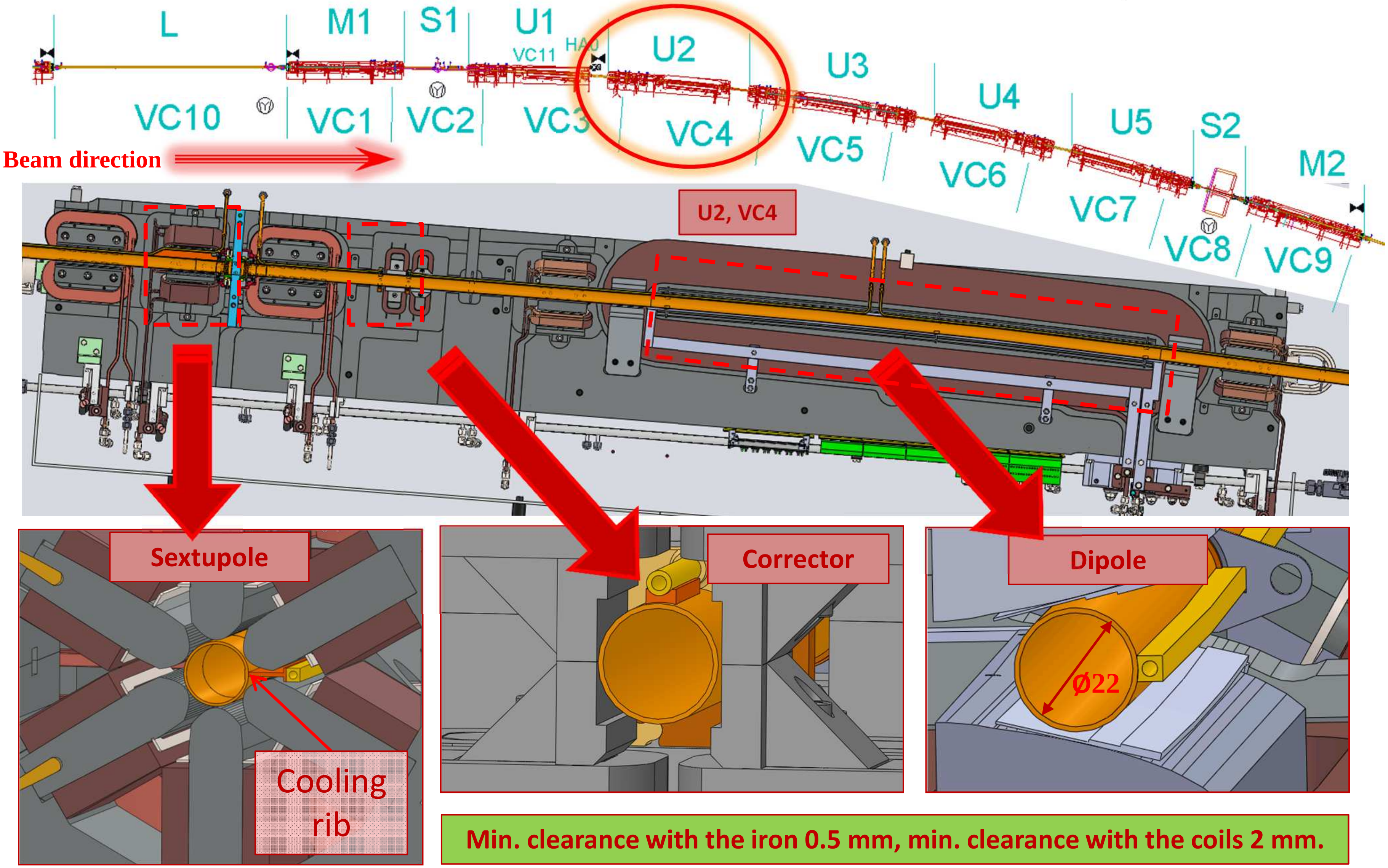




Items summary of the vacuum system

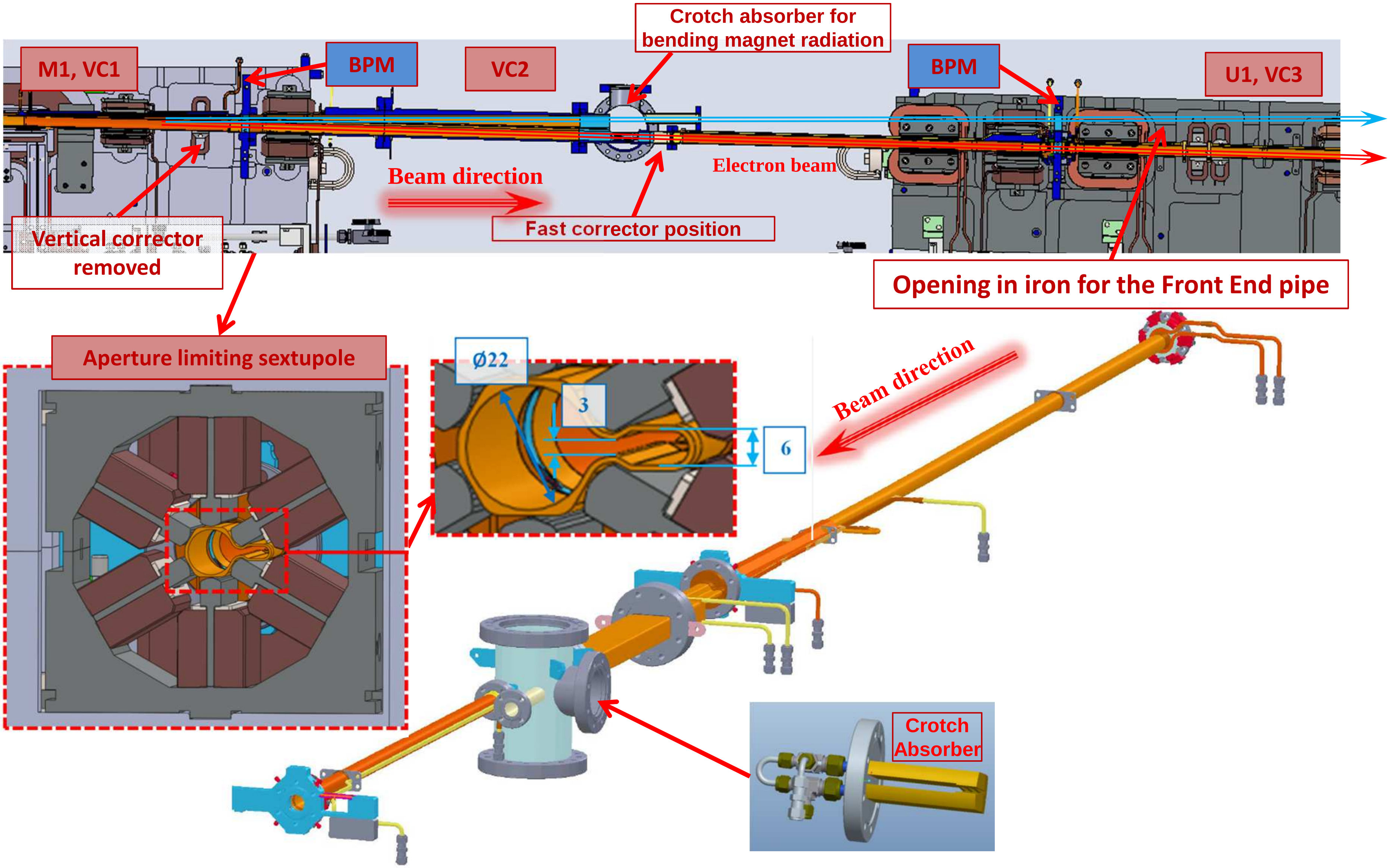
item-	QTY in standard achromat	total in the machine (incl. non standard achromats
No. of VC within the achromat	17	308
No. of VC in FE pipe	5	100
No. of BPM within the achromat	10	226
no. of crotch absorbers	1	19
no. of stand-alone bellows	2	133
No. of gate valves (RF gate valves).	2	60
No. of ion pumps	4	84
No. gauges	1	20
No. of RGA	1	20
No. of right angle valves for rough pumping	3	60

Vacuum chamber layout and the magnets

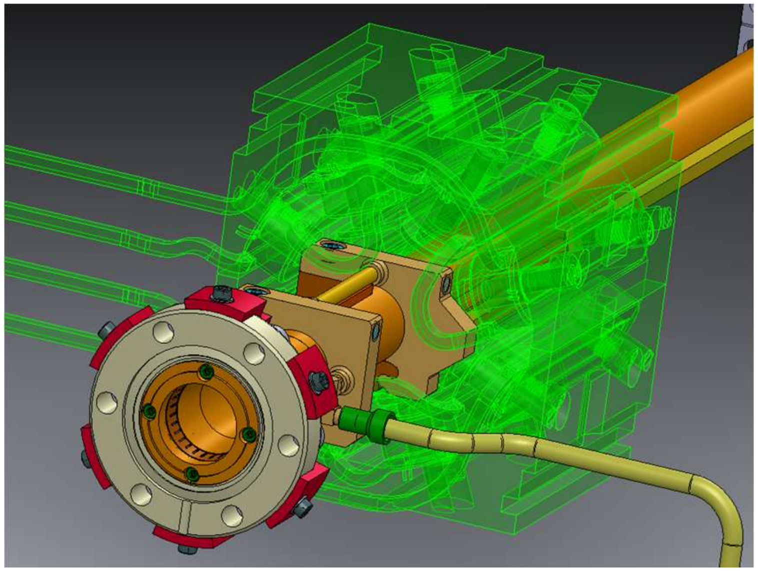


Min. clearance with the iron 0.5 mm, min. clearance with the coils 2 mm.

Vacuum chamber for beam extraction (VC2)



Vacuum chamber layout and the magnets



Dummy parts of the vacuum chamber will be supplied to **the magnets' suppliers**.

The supplier of the vacuum chambers will have
Gauges with the outer shape of the magnet.

Calculations being performed to assure safe design for:

- ✓ Distributed absorbers (BM radiation).
- ✓ Bellows RF fingers.
- ✓ BPM stability.
- ✓ Crotch absorbers (bending magnet radiation).
- ✓ Insertion devices absorbers.
- ✓ Deformation of VC.

Heat Load Calculations:

The emitted power within the bending magnets per mrad is:

(P/mrad) = 4.223*(E/GeV)^2*(B/T)*(I/A) W

The opening angle of the radiation cone is:

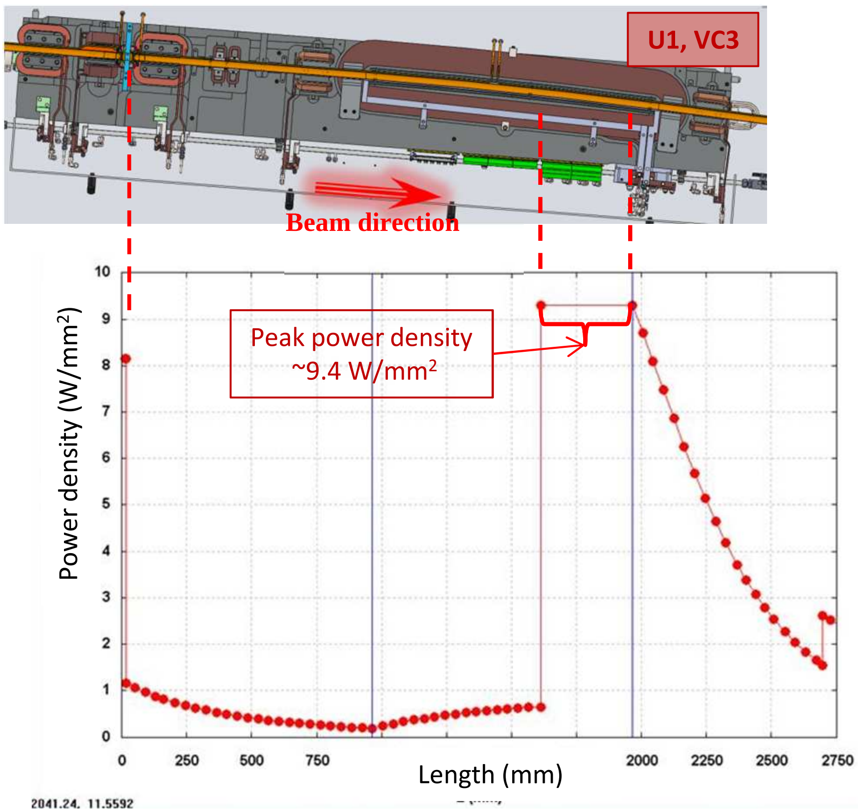
σ(y) ~ 0.33 mrad / (E/GeV)

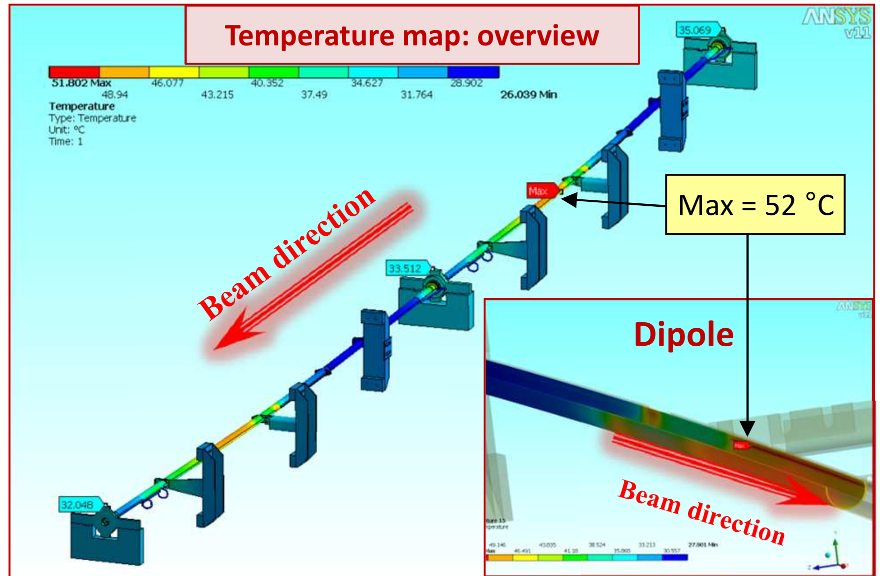
With both equations the power density on the vacuum chambers goes with E^3*B

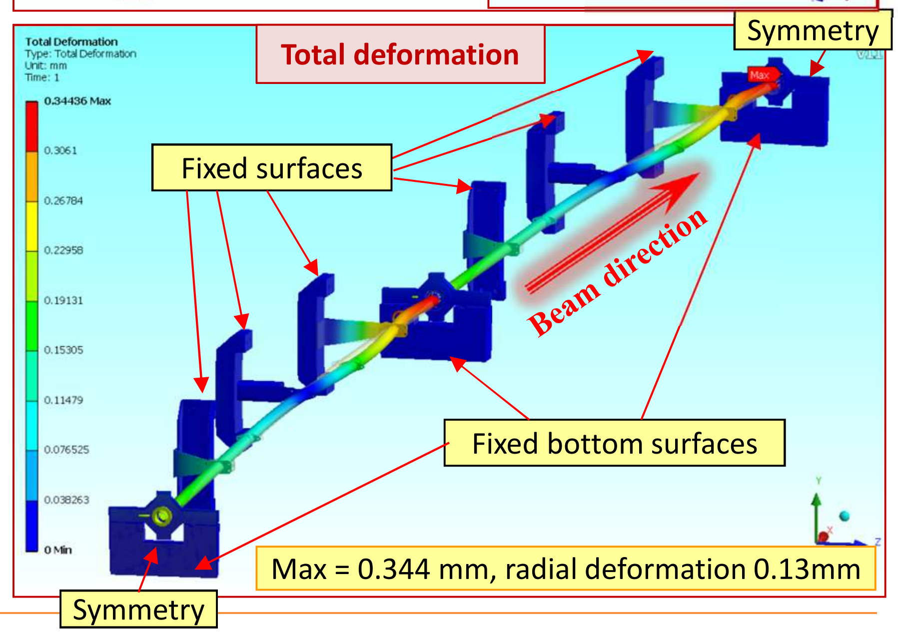
Finite Element Analyses (FEA)

Case study: BPM stability
two consecutive vacuum chambers (VC6-VC7) analyzed for temperature distribution, deformation and stress.

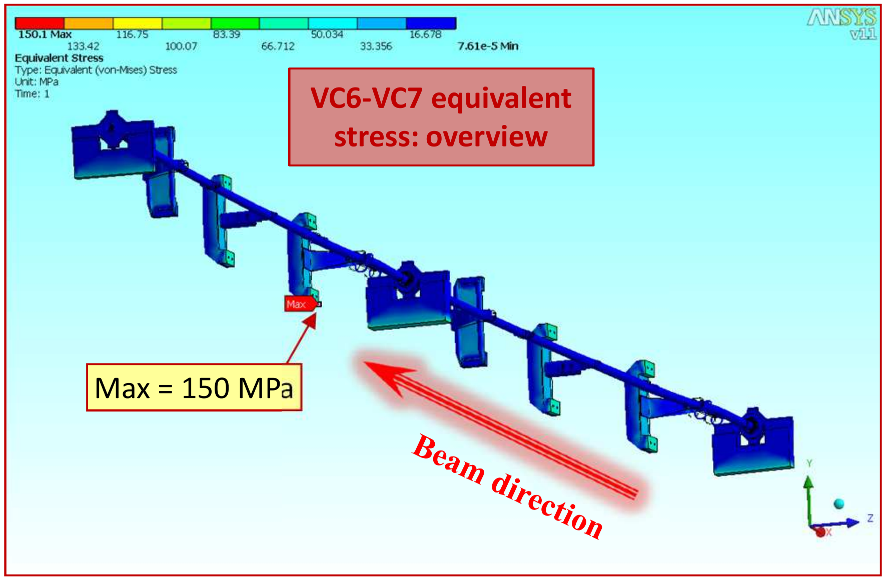
Input: power density from 3^0, 0.5 T bending magnet:

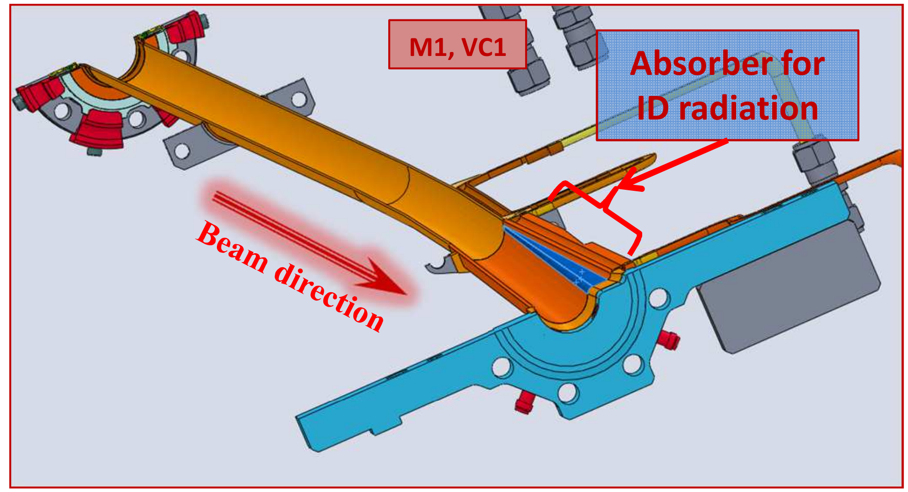


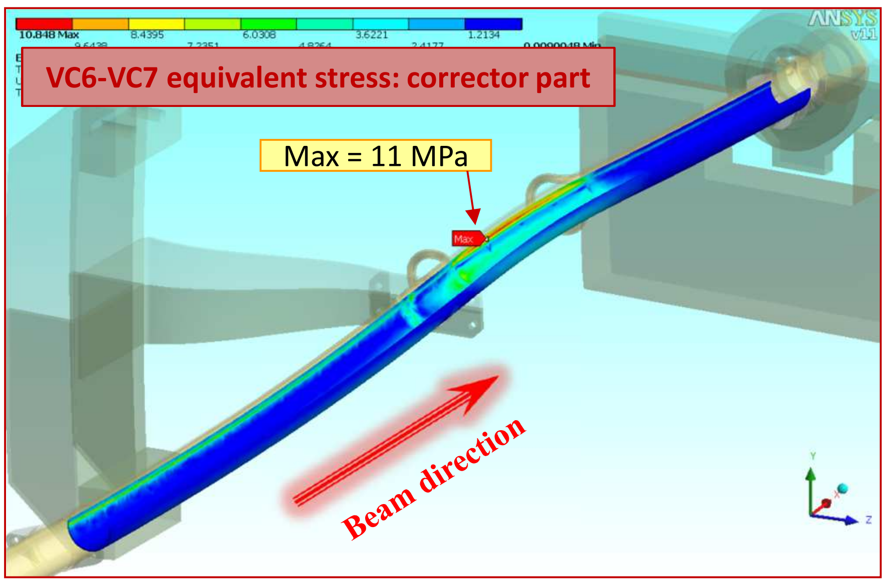


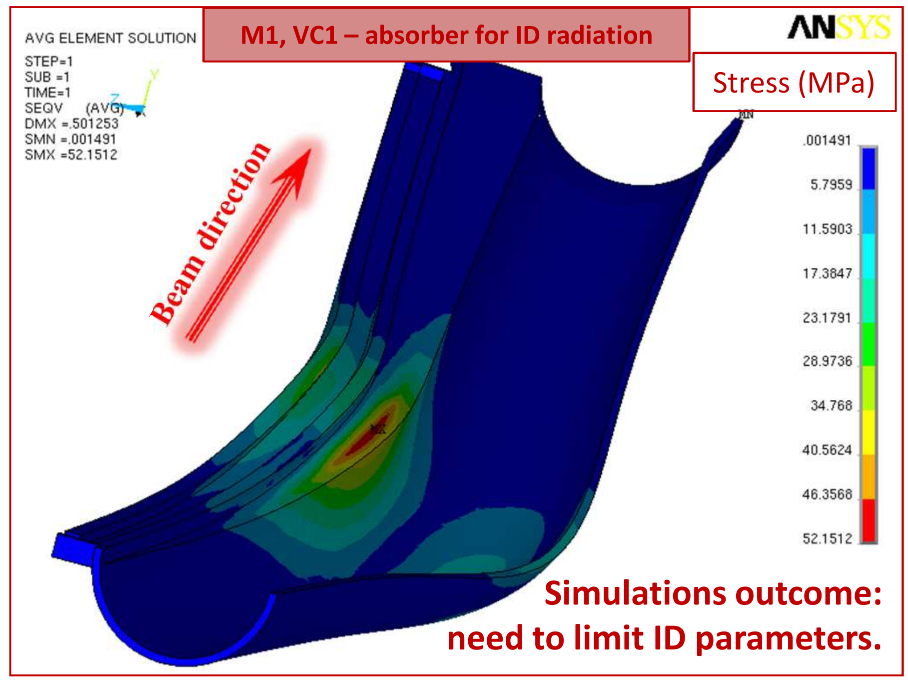


Finite Element Analyses (FEA)









Schedule for standard VC production.

- Work in the conceptual design: 2009.
- End of the conceptual design (DDR): Aug. 2010.
- Collaboration agreement for the design of the vacuum system with ALBA: Sep. 2010
- Design review meeting: 16-17 May 2011.
- Call for tender for the vacuum chambers production: Dec. 2011.
- Signature of the contract: April. 2012.
- Final design review meeting: Sep. 2012.
- Factory acceptance test of prototypes: June 2013.
- Final delivery date: April 2014.

NEG coating requirements

The choice of NEG coating has crucial impact on the vacuum system design, vacuum chamber manufacturing and installation. Therefore, it should be considered at the very beginning of the machine design.

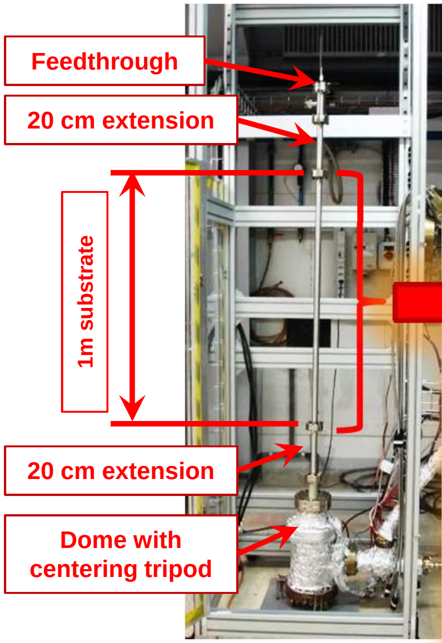
Important factors for vacuum chamber manufacturing that are foreseen to be fully NEG coated:

- Choice of **material** and its **surface treatment** must ensure NEG film adhesion. It is recommended not to mix different material types in a single chamber, to keep chambers free from integrated bellows and other complicated assemblies.
- **Manufacturing** processes and chamber **geometry** have to be compatible with the NEG-coating to ensure the film adhesion.
- **Geometry** of the chamber have to be compatible with used thin film deposition technology.
- **Handling, cleanliness** and **storage** of chambers during manufacturing, before and after the coating is crucial.
- **Installation**: in-situ activation needs.

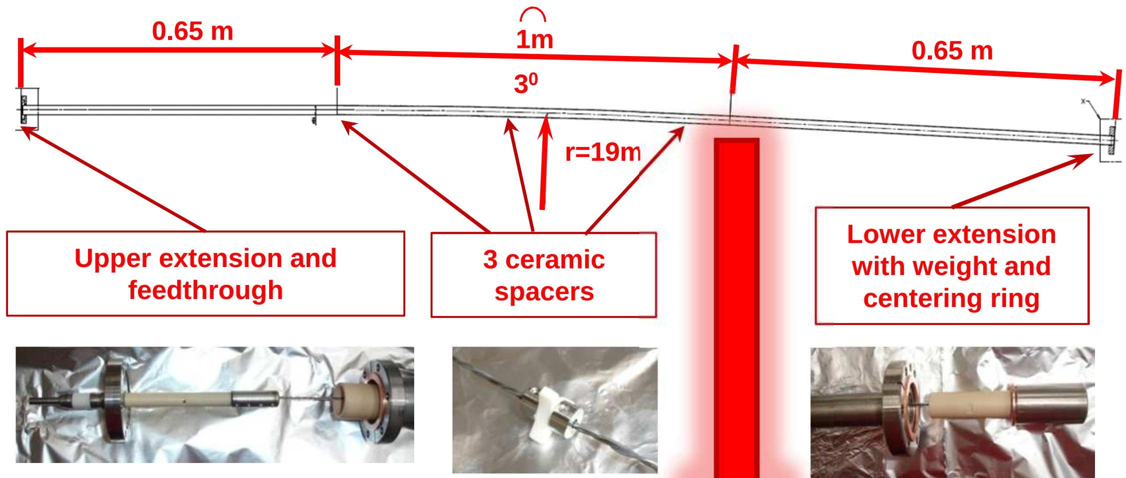
NEG coating R&D at CERN

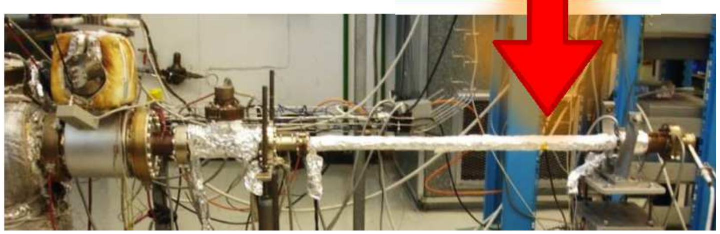
Aim: to verify the feasibility of the NEG coating of small (22 mm inside diameter), bent tubes.

Coating of 1 m long, straight tube



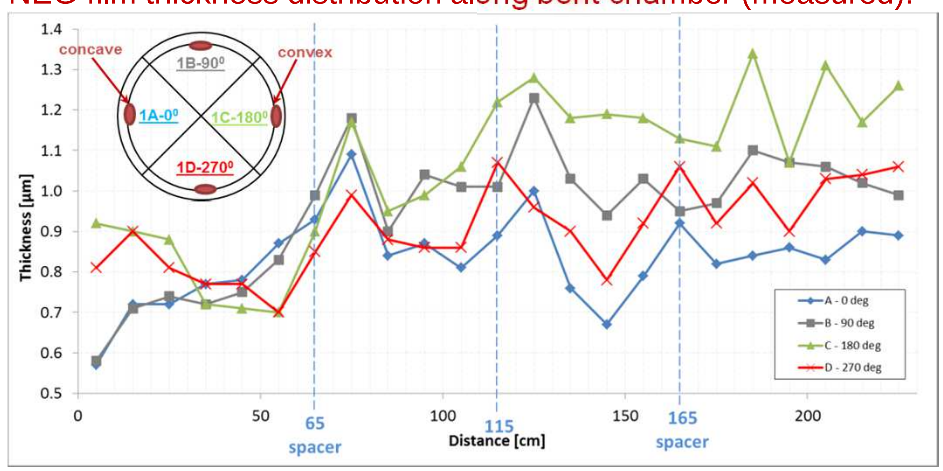
Coating of bent chambers





Sticking factor evaluation for hydrogen.

NEG film thickness distribution along bent chamber (measured):



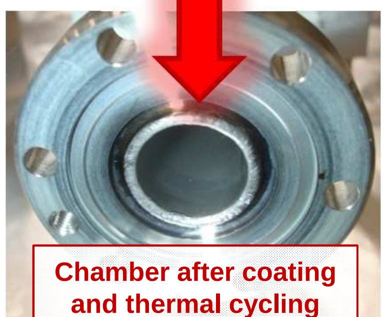
NEG coating R&D at CERN

Aim: to verify the NEG coating adhesion on copper substrates.

Verification of NEG-coating adhesion on OFS extruded copper tubes surface treated at CERN).

Thermal cycling of NEG coated, extruded OFS copper chambers

Chamber before coating

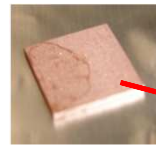


Chamber after coating and thermal cycling

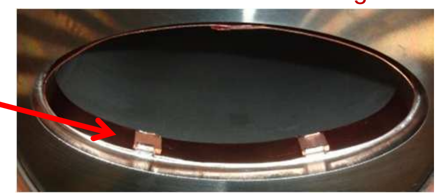
Verification of NEG coating adhesion on Wire-eroded copper substrate:

Small samples for XPS analyses:

As received:

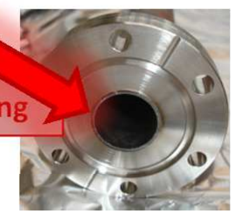


Installed for NEG-coating:

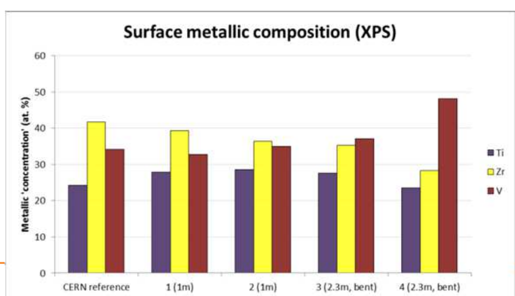


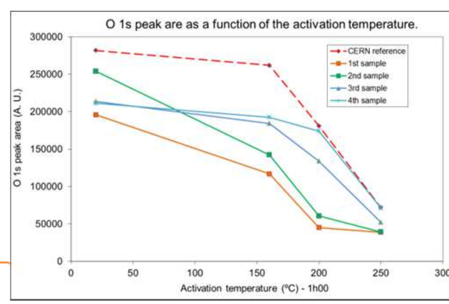
Vacuum chamber:

NEG-coating

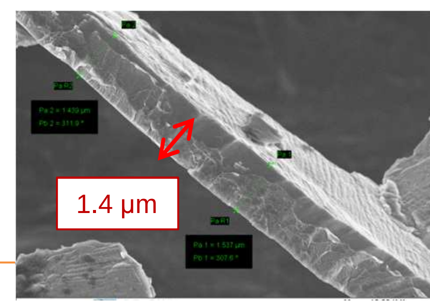


Aim: to verify NEG film activation behavior by XPS





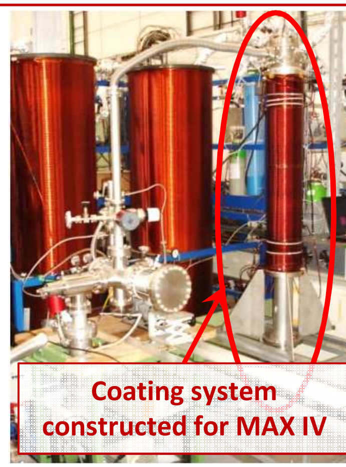
NEG film thickness measurements by SEM:



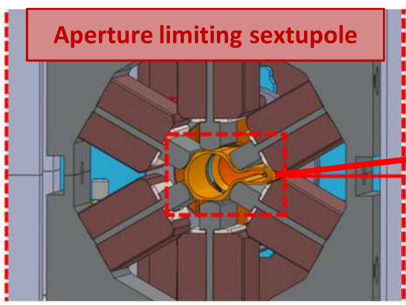
NEG coating R&D at CERN

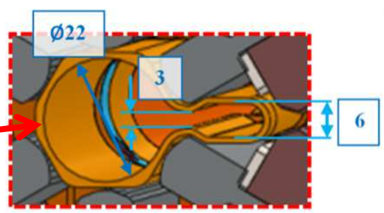
Aim: to develop coating procedure for chambers with small antechamber (minimum vertical aperture 5 mm),

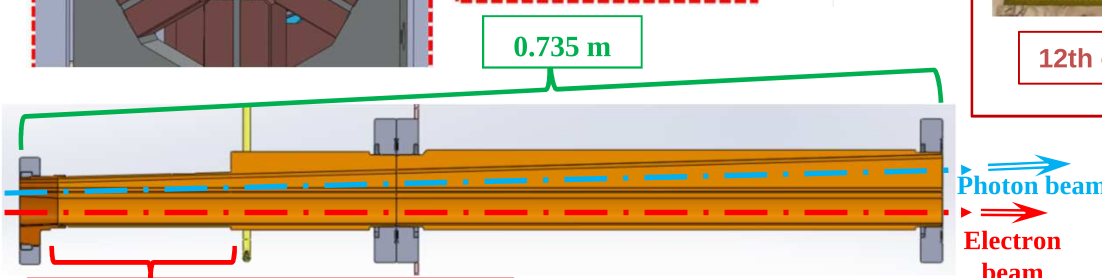
Coating facility at CERN used for LHC and MAX IV chambers



Coating system constructed for MAX IV

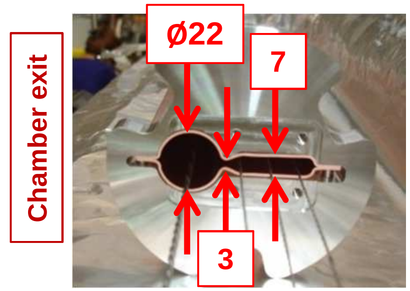


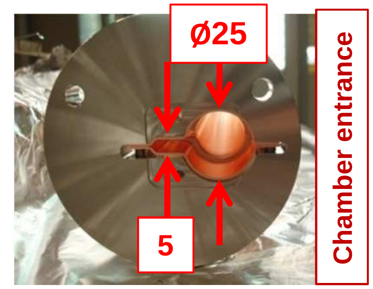




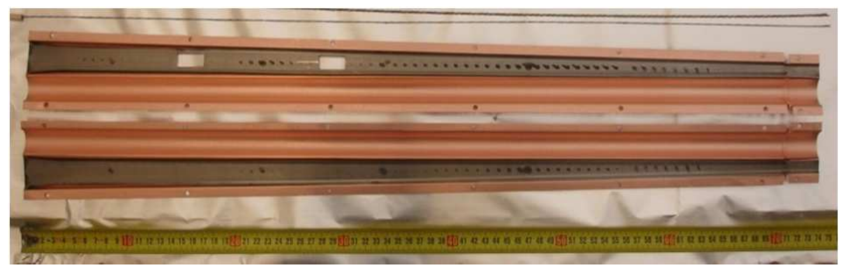
Space for sextupole limiting the aperture

Prototype made in two halves to facilitate inspection of the coating.





Example: coating trial results for magnetic field of 360 - 270



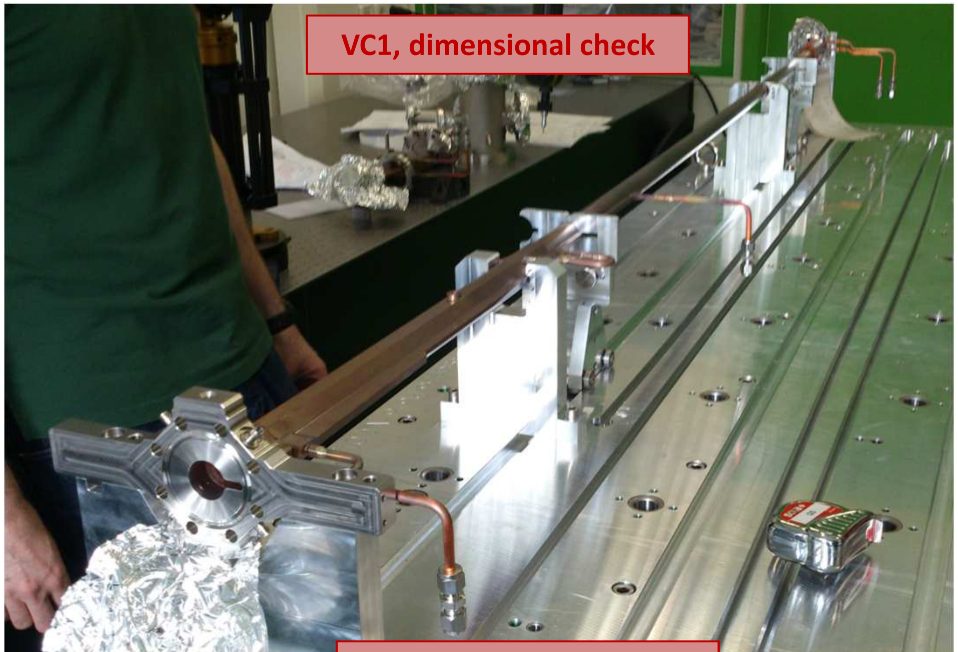
12th coating - 1 cathode (3.6e-1 mbar, 650V, 0.04A, 26W)

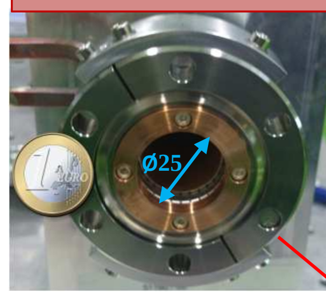
Summary

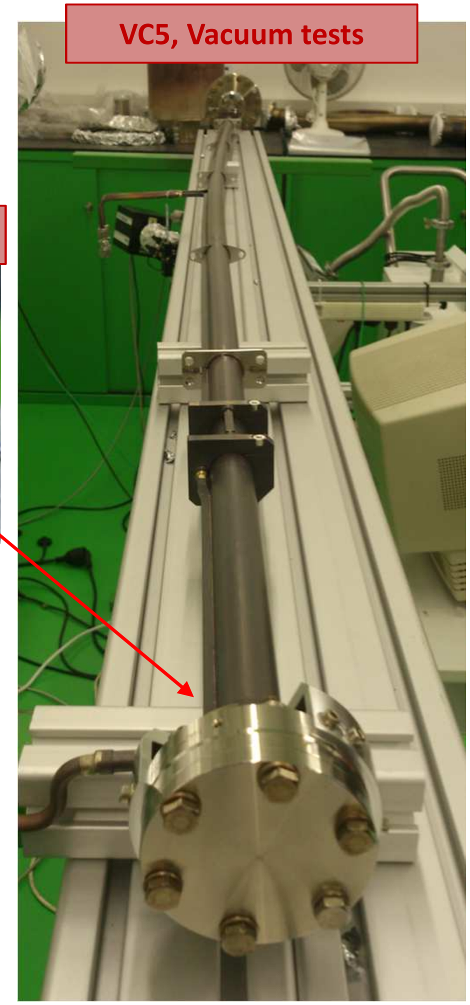
- **NEG coating has to be considered at the beginning of the design of NEG-coated ring and it implies some limitations to the vacuum chambers design.**
  Geometry of all the chambers to be coated have to be compatible with the NEG-coating deposition process. Enough space through the magnets should be provided in order to design chambers of reasonable size and to be able to place necessary components for the vacuum system (cooling channels, bellows, let the SR out to front ends etc).
- **Vacuum chamber should be free of intrinsic bellows and other complicated assemblies making the surface treatment or future stripping of complete chamber possible.**
  - **Case of MAX IV (bellows welded to the vacuum chambers):**
    Surface treatment -> Chamber manufacturing -> NEG-coating
  - **Recommendation (stand alone bellows):**
    Chamber manufacturing -> Surface treatment –> NEG-coating
- **Materials selection and manufacturing processes**:
  All used materials, joining and manufacturing processes, surface treatments and thermal history of the components has to be identified and verified if it is compatible with the NEG-coating.
  - **Case of MAX IV (wire-eroded copper, used brazing alloy): T**ests had to be made for this kind of surfaces and brazing to confirm that the NEG film deposited on such components activates as expected and that the adhesion is good.
- **Handling** during manufacturing of already surface treated chambers is crucial. Any contamination or particles inside the chamber that is prepared to be NEG coated can be a source of bad film activation or peeling off.
- **Bakeout and NEG activation:** it is very convenient to be able to bake the vacuum system and perform the NEG activation in-situ inside the magnets.
- Ensure that the chambers can cope with the **power** coming from synchrotron radiation from **bending magnets** and **all** planned **insertion devices**.
- Visual inspection of NEG coated chambers: difficult, time consuming and puts risk to damage the coating.

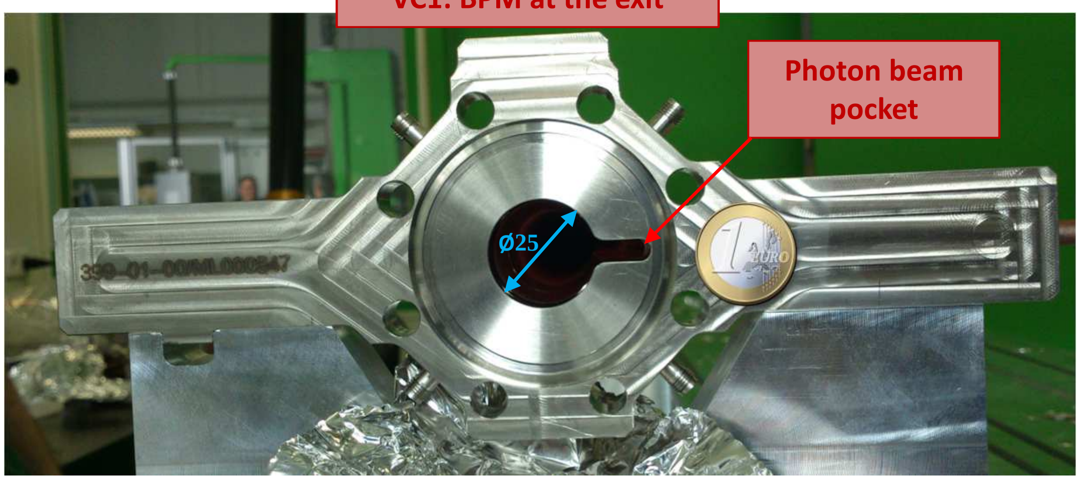
Where are we now?

Factory Acceptance Test: June 2013









Where are we now?

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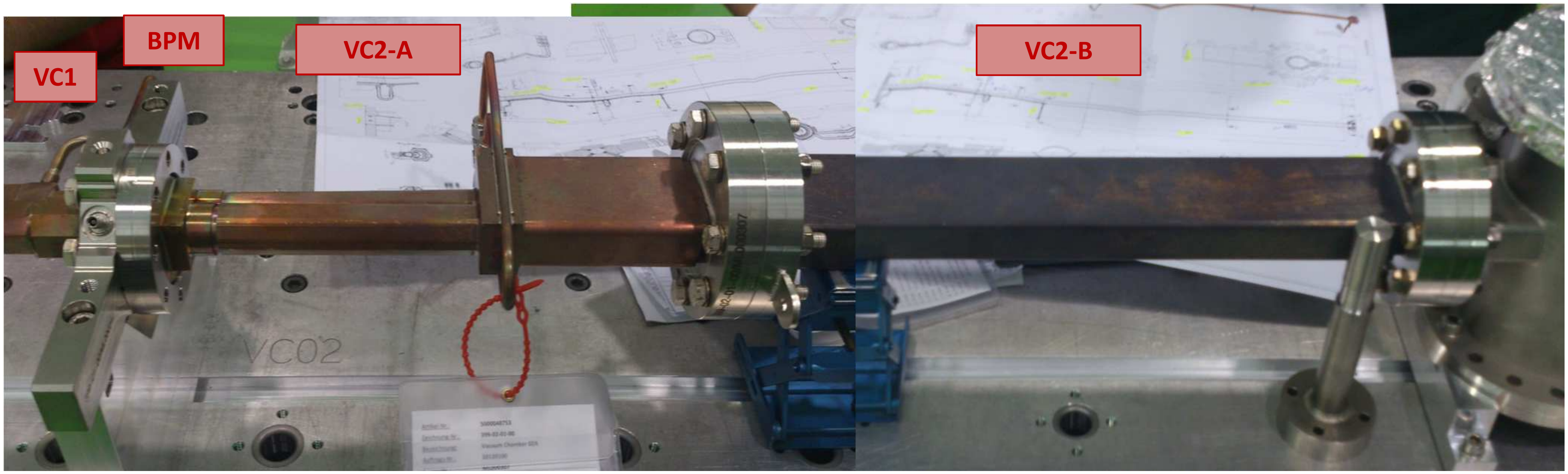
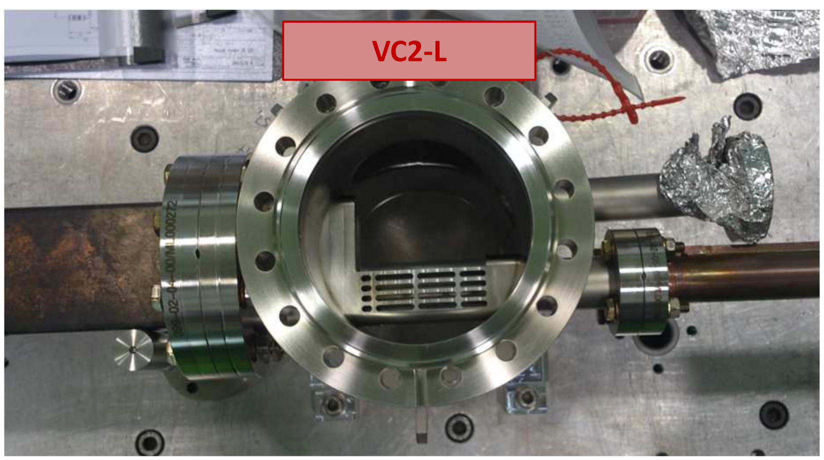
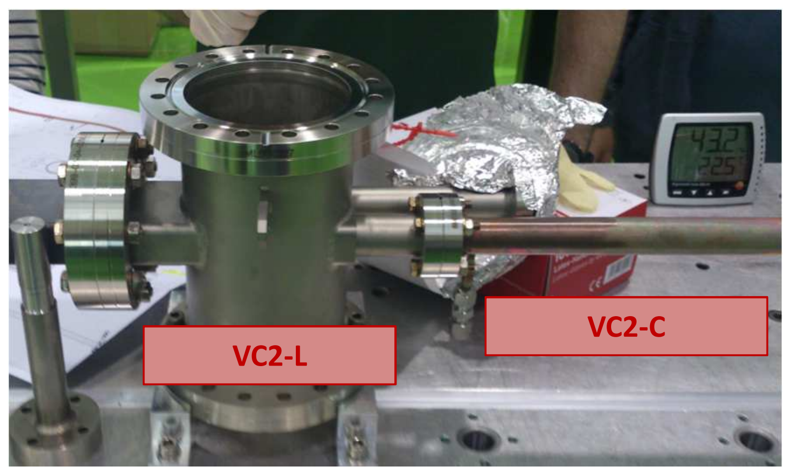
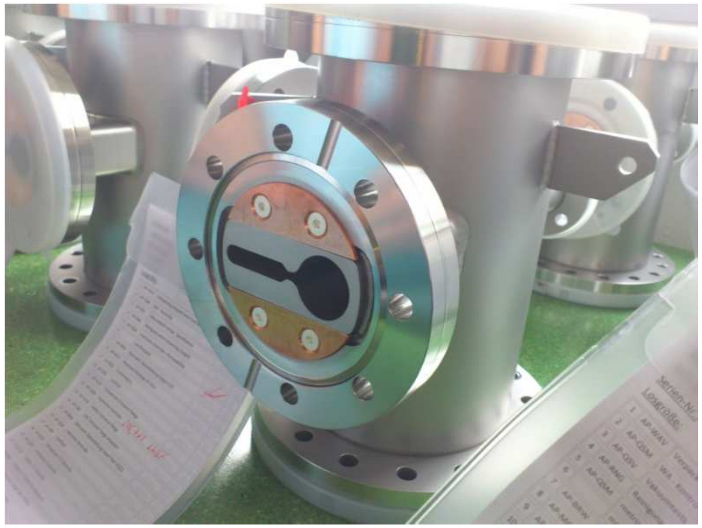






Where are we now?

Aug. 2013

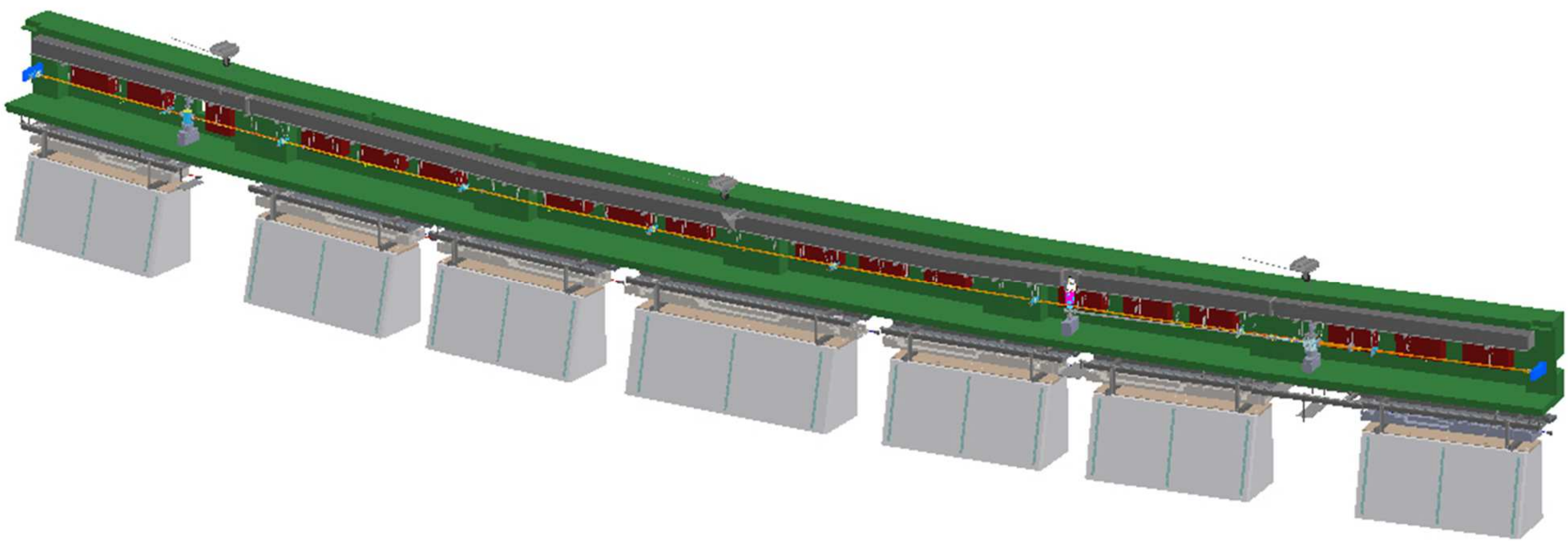


Nov. 2013

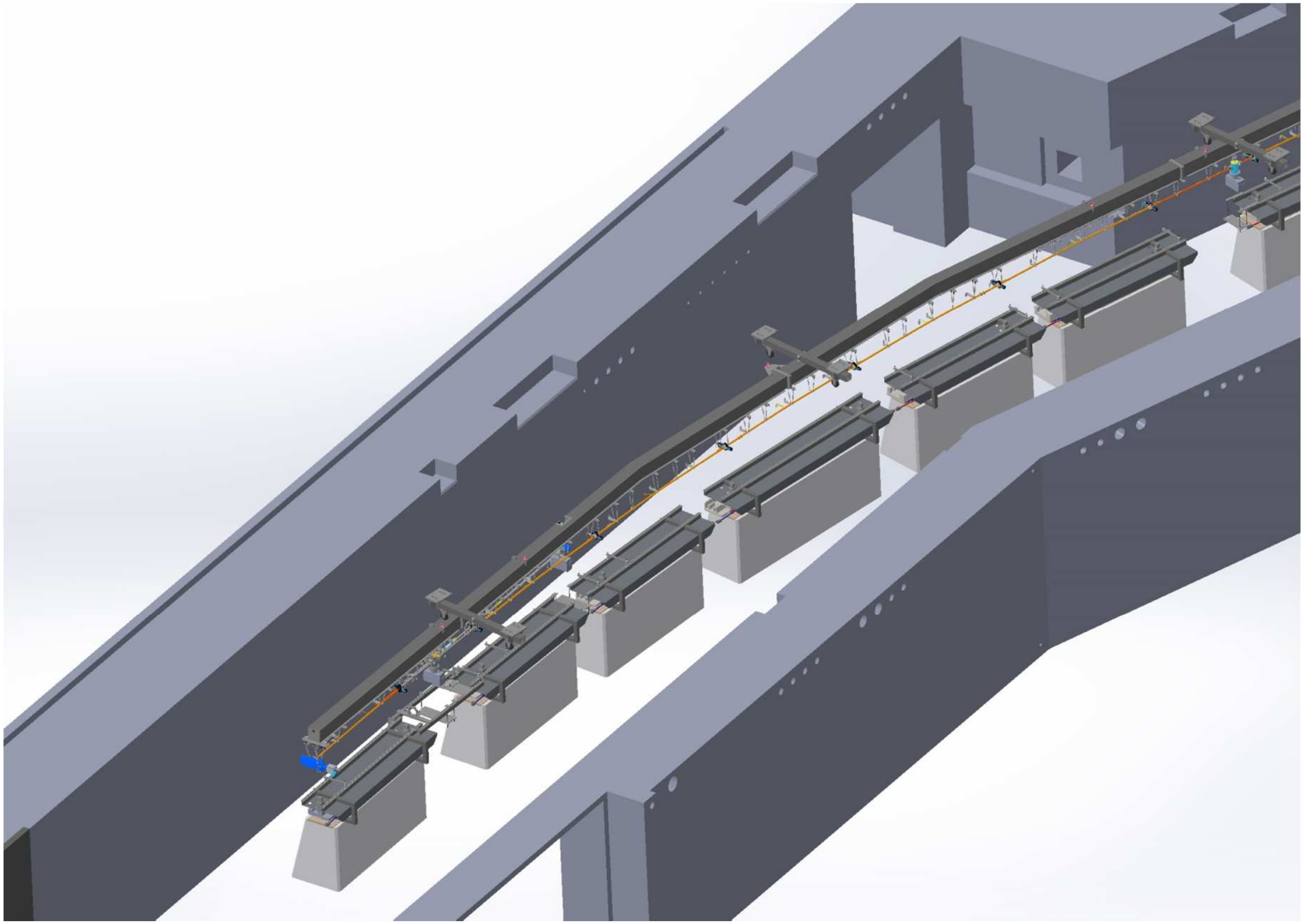
Installation

- **One achromat assembled, baked, activated and placed under vacuum inside the magnet block.**
- **Procedure:**
  - **Magnets in place and upper half is removed.**
  - **Place assembly tables between the girder plates and above the lower half of the magnet block.**
  - **Assembly tables use references on the magnet block.**
  - **Assemble one full achromat, pump down and leak check.**
  - **Connect chambers to strong-back and release from the tables.**
  - **Slide oven around the chambers, cover and do bakeout.**
  - **After bakeout, remove oven and place chambers to tables, and check no deformation occurred.**
  - **Release chambers from tables, remove tables, and place chamber on the magnet block.**
  - **Close magnets.**

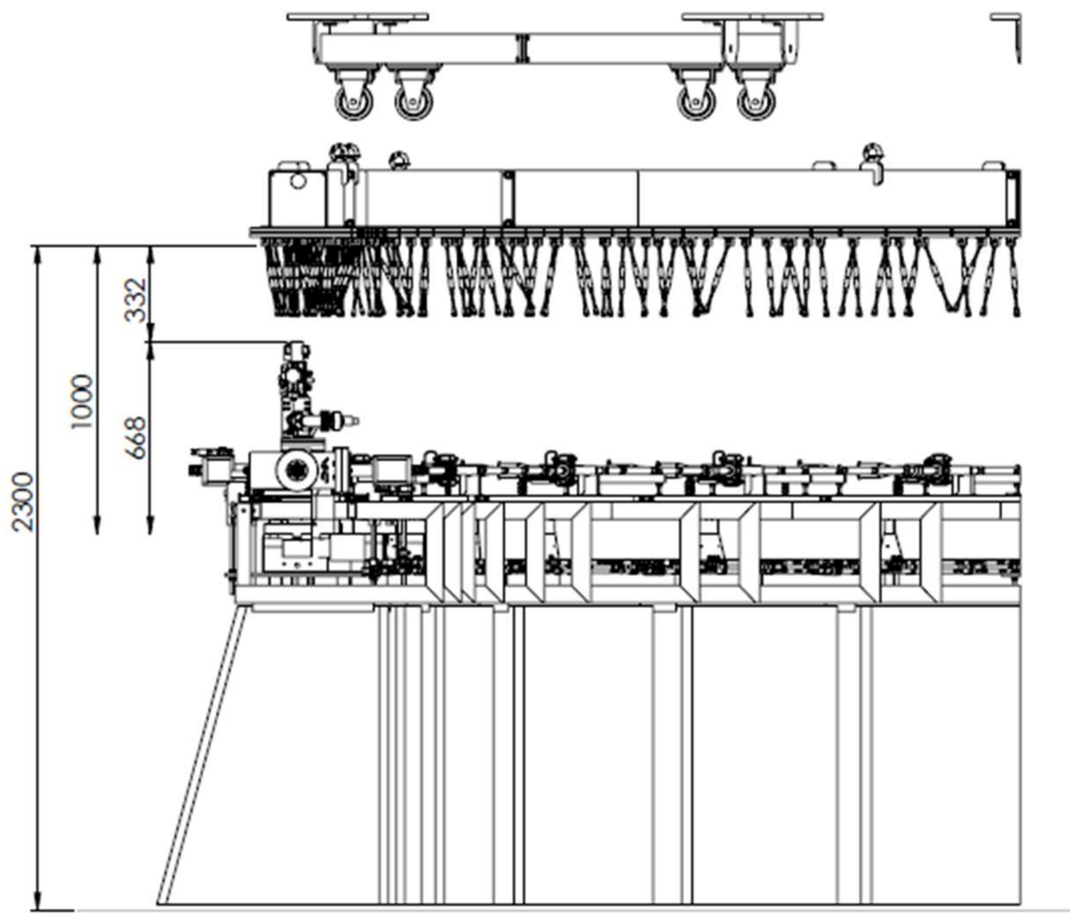
Installation



Installation



Installation



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Thank you for your attention

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