ESRF | The European Synchrotron

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Alignment Strategy for the New ESRF Storage Ring

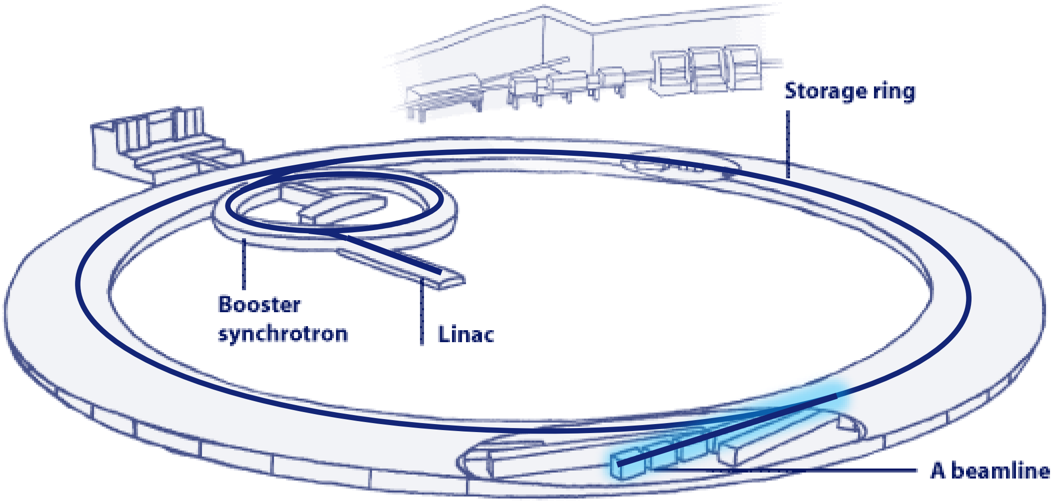
PACMAN, CERN 20-22 March 2017

The ESRF produces the most intense synchrotron generated light in the world

ESRF - France

- **100 M€** annual budget coming from **13 member** and **8 associate member states**
- **6 500 scientific visitors** every year
- **2 000 proposals** per year: **900 accepted**, 1 550 experimental sessions
- **30%** of the research involves **industrial developments**

THE ESRF



The linear accelerator (linac) accelerates the electrons from rest mass to 100 MeV

The booster accelerates the electrons from 100MeV to 6GeV

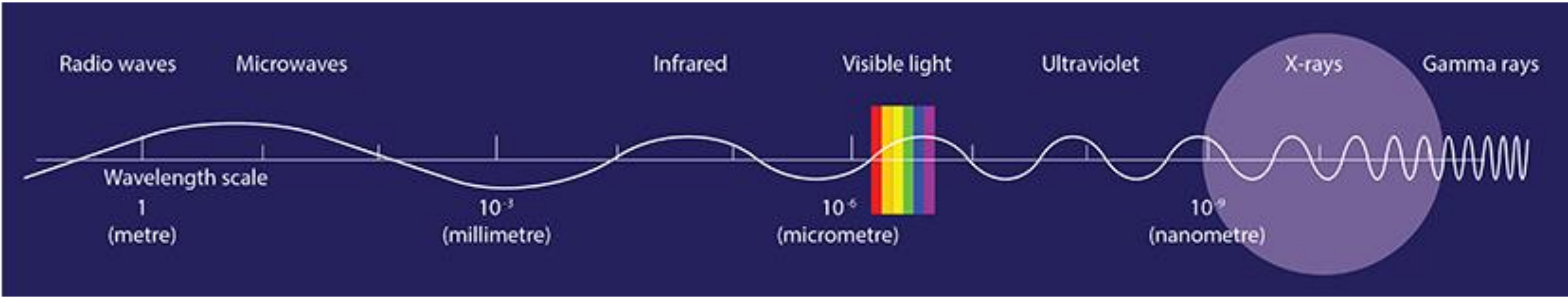
The storage ring keeps the electrons circulating at 6GeV for many hours

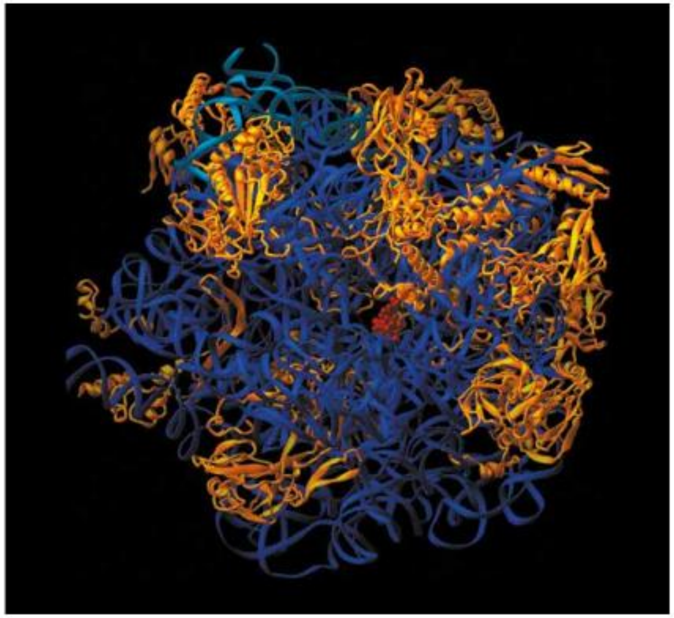
The 6GeV electrons produce synchrotron radiation in a tangential direction to the beam travel

A ESRF is composed of two main elements:

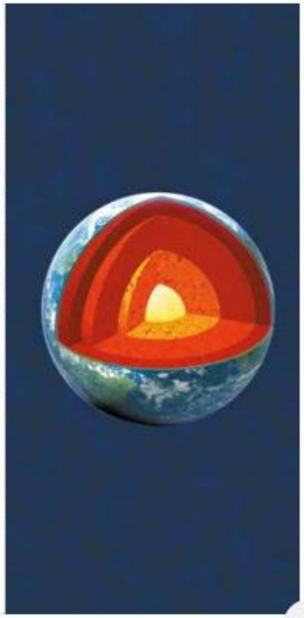
- A particle accelerator that generates synchrotron radiation – the source,
- Beamline(s) that use the synchrotron radiation generated by the accelerator to study matter.

SCIENCE IN ALL ITS FORMS ...

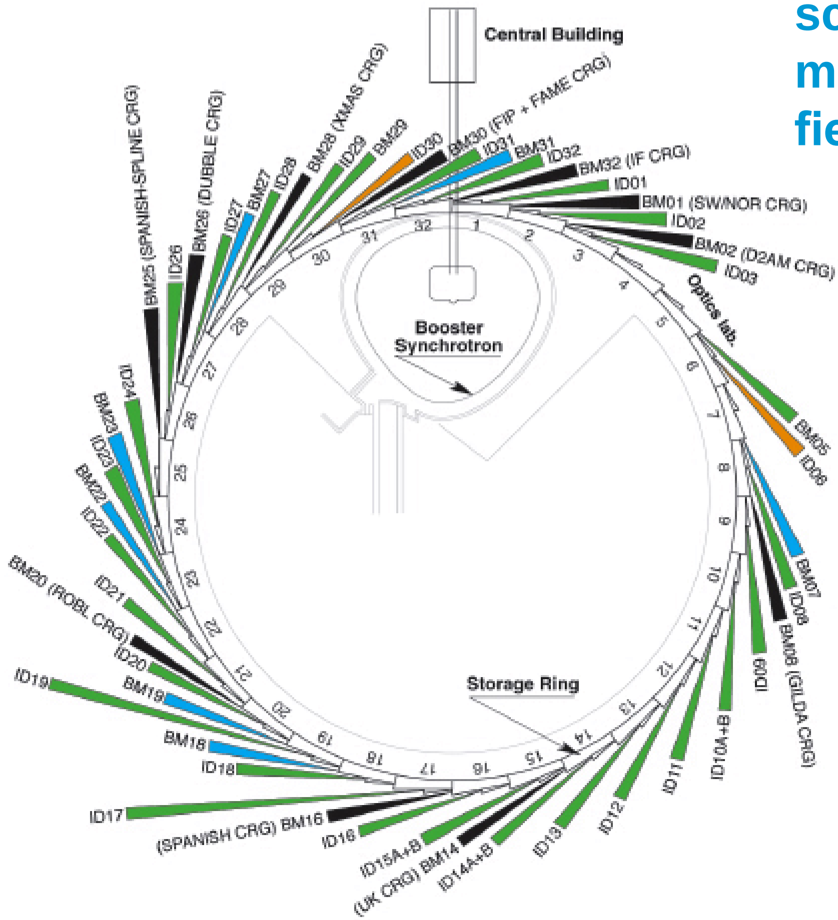






There are 43 beamlines at the ESRF that offer scientists unique opportunities to explore materials and living matter in a multitude of fields…



ESRF UPGRADE PROGRAMME

2009
2015

Upgrade PHASE I – 160 M€

In time and within budget

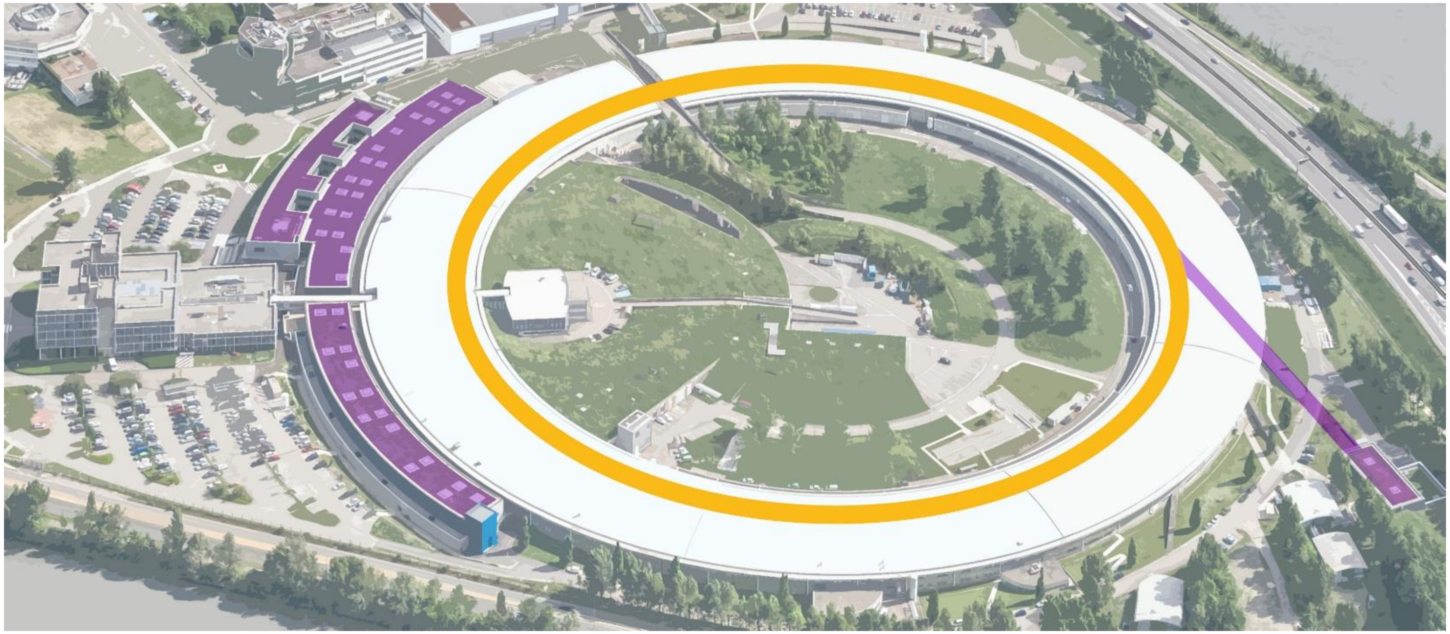
- Construction of 19 new-generation experimental stations to explore the nanoworld
- Creation of a new ultra-stable experimental hall
- Improvement and refurbishment of most of the cutting-edge scientific equipment and accelerator infrastructure

2015
2022

ESRF-EBS – 150 M€

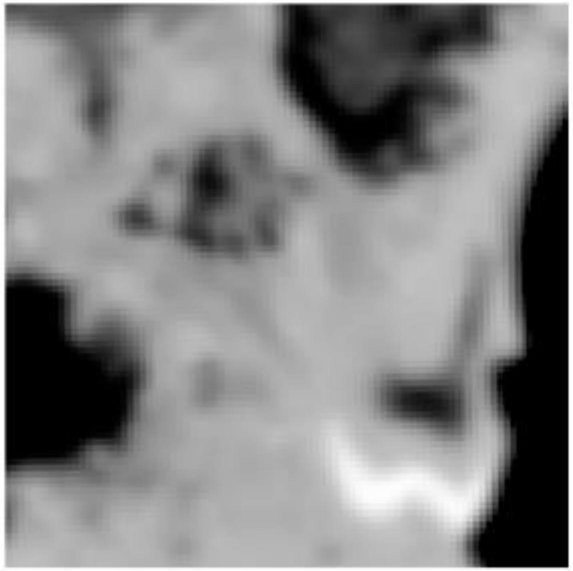
Launched in June 2015

- Construction of a new storage ring –the EBS, inside the existing structure, with performance increased by a factor of 100
- Construction of new state-of-the-art beamlines
- Ambitious instrumentation programme (optics, high-performance detectors)
- Intensified big data strategy

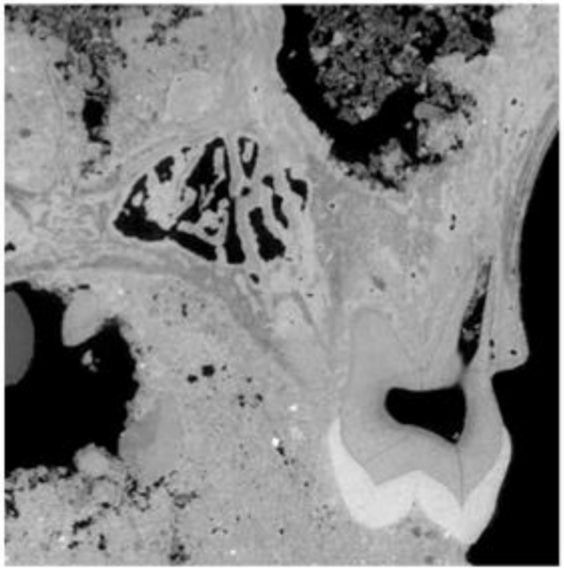


The European Synchrotron | ESRF

EXTREMELY BRILLIANT SOURCE (EBS) WHY?

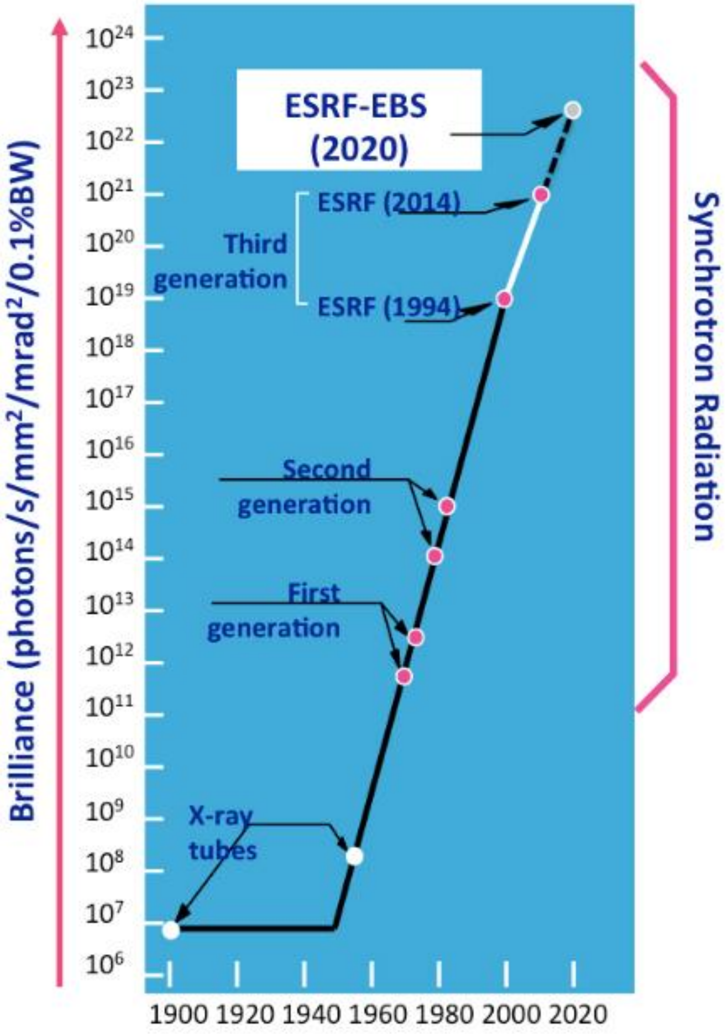


Scan at the hospital



At the ESRF

The main difference between synchrotron light and the X-rays used in hospitals is the brilliance. The higher the brilliance, the more precise the information that can be obtained from the X-ray.



The EBS is designed to increase the source brilliance…

EXTREMELY BRILLIANT SOURCE (EBS)

EBS aims to:

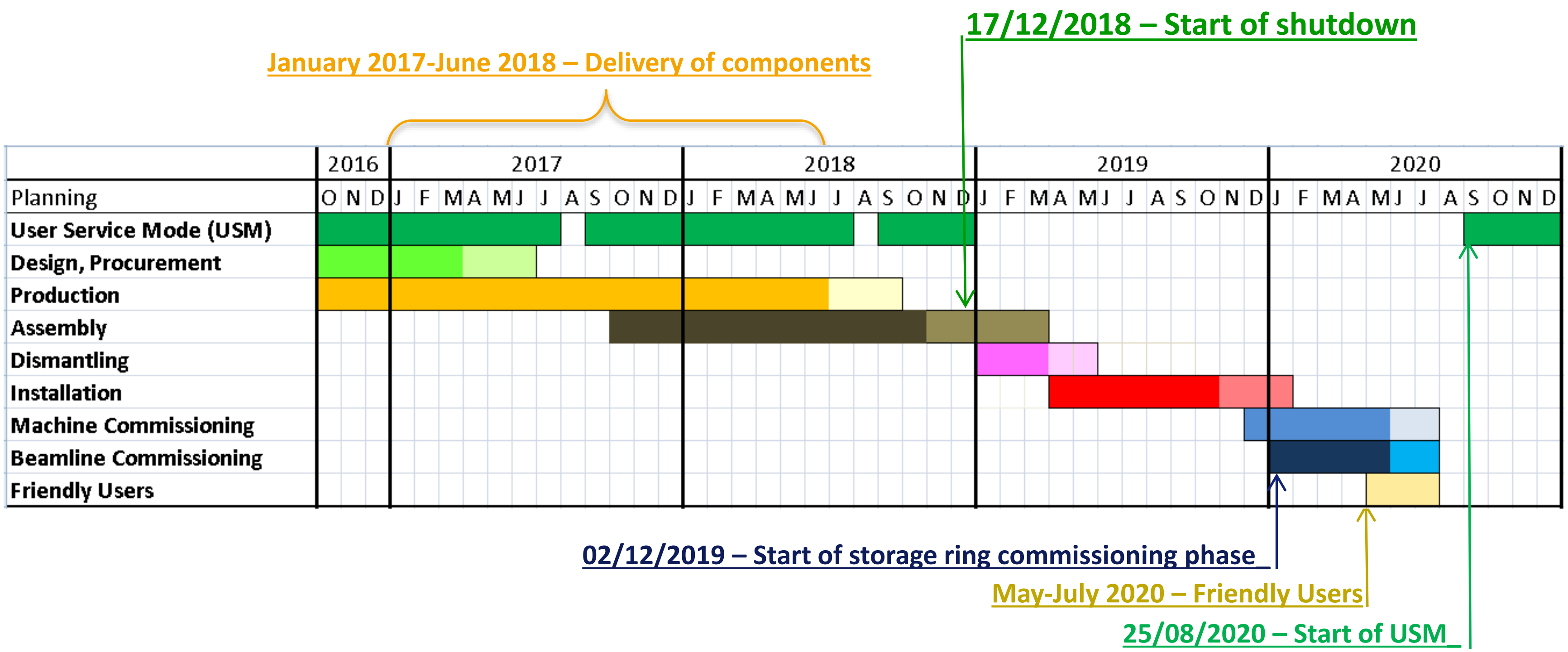
- Increase the **source brilliance**
- Increase coherent fraction of the beam
- Substantially **decrease the store ring equilibrium horizontal emittance**

Constraints:

- Must fit in the same tunnel: as much as possible same circumference
- IDs at same locations: keep beamlines where they are
- Re-use injector complex

	Now	EBS
Energy (GeV)	6.04	6
Multibunch current (mA)	200	200
Circumference (m)	844.39	843.98
Horizontal emittance (pm.rad)	**4000** →	**140**
Vertical emittance (pm.rad)	4	5

EBS TIMELINE (2017-2020)

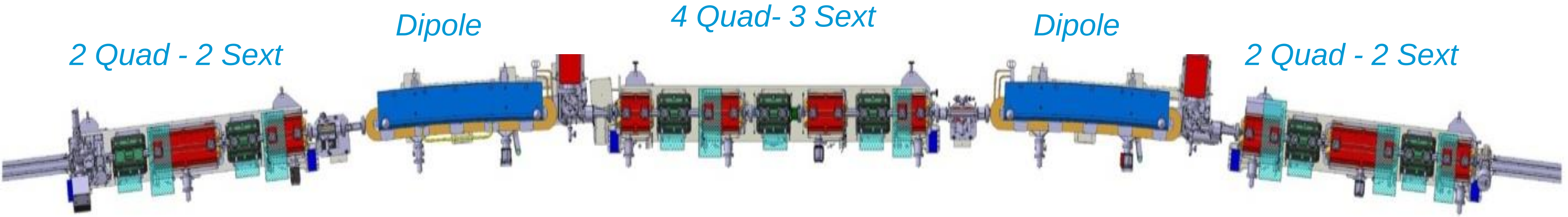


2018 – a normal year for Machine Operation

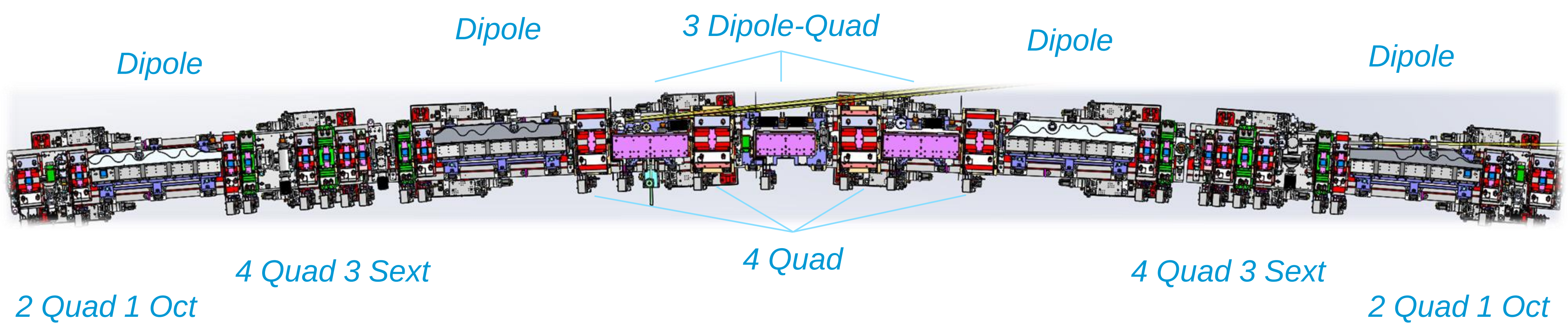
17 December 2018	Beginning of the long shutdown
03 January 2019	Dismantling starts
02 December 2019	Commissioning starts
09 January 2020	Beam available for beamline and machine commissioning
25 August 2020	Back to normal user operation (USM)

TO DECREASE HORIZONTAL EMITTANCE → NEW LATTICE

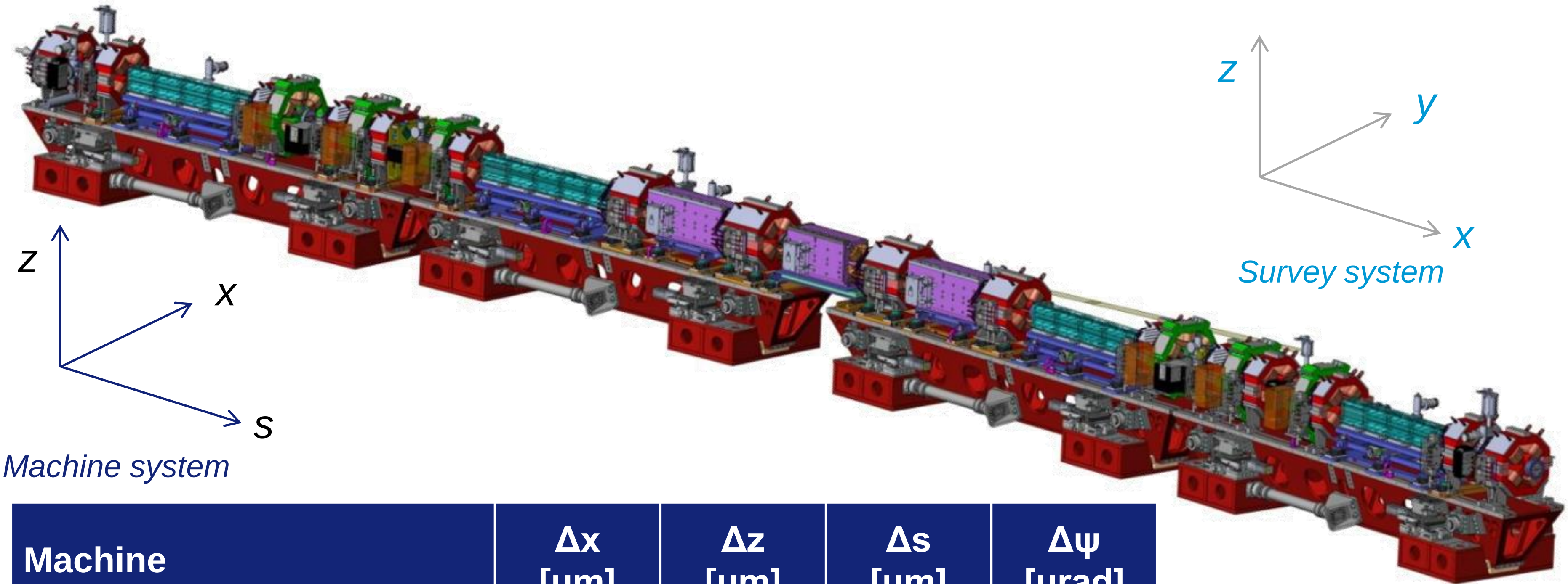
Existing ESRF lattice - Double Bend Achromat with 17 magnets



EBS lattice - Hybrid 7 Bend Achromat with 31 Magnets

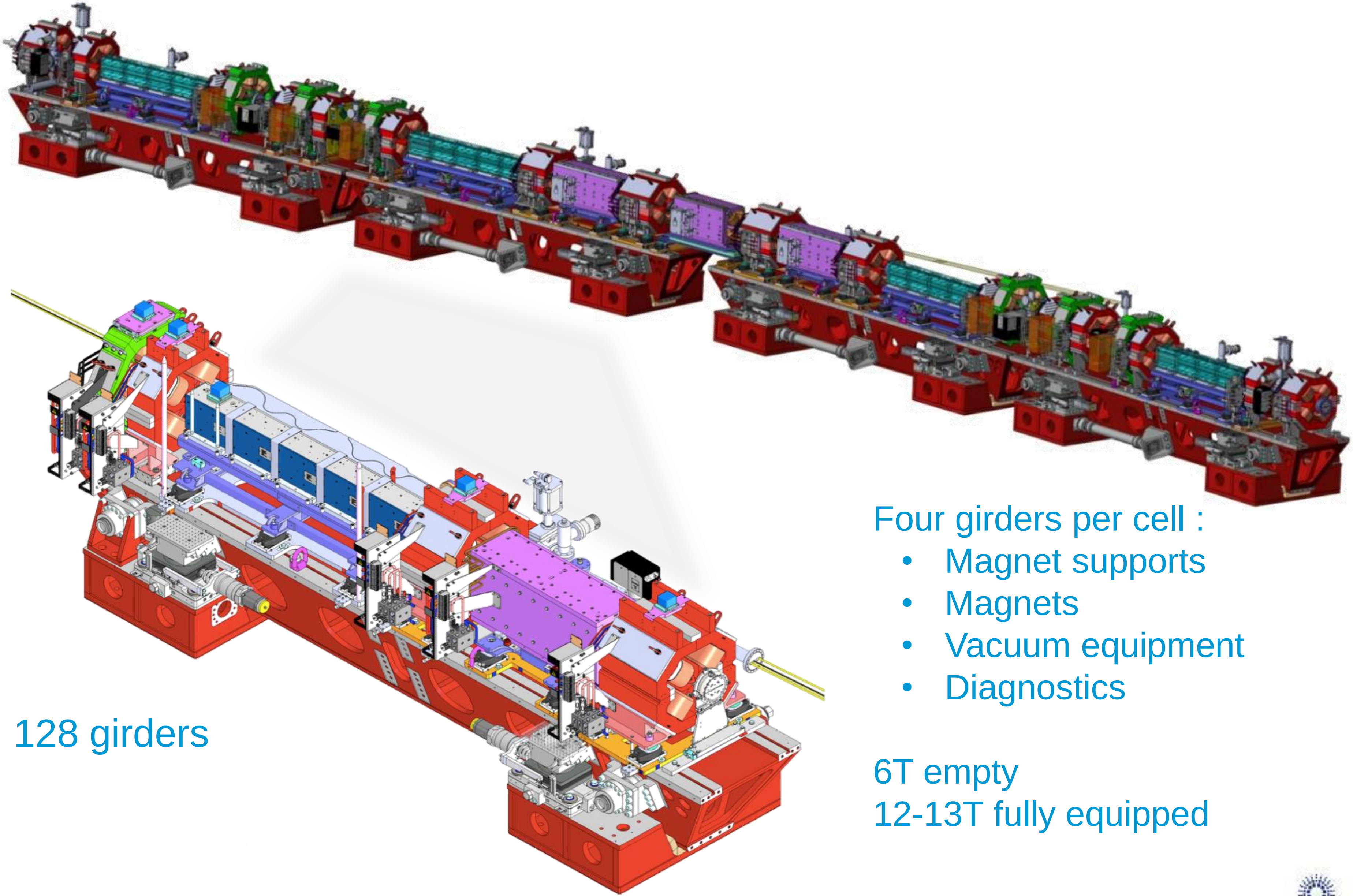


ALIGNMENT TOLERANCES



Machine	Δx [μm]	Δz [μm]	Δs [μm]	Δψ [μrad]
Long. Varying field dipoles	>100	>100	1000	500
High gradient quadrupoles, Combined function dipoles	60	60	500	200
Medium gradient quads	100	85	500	500
Sextupoles	70	50	500	1000
Octupoles	100	100	500	1000

EVERYTHING IS ASSEMBLED ON GIRDERS



128 girders

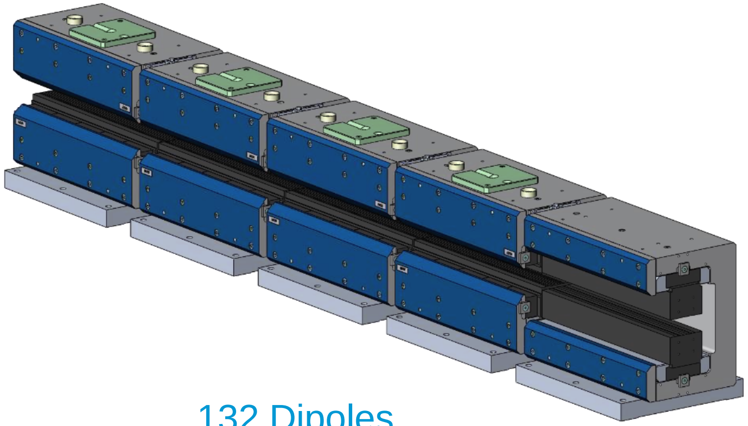
Four girders per cell :

- Magnet supports
- Magnets
- Vacuum equipment
- Diagnostics

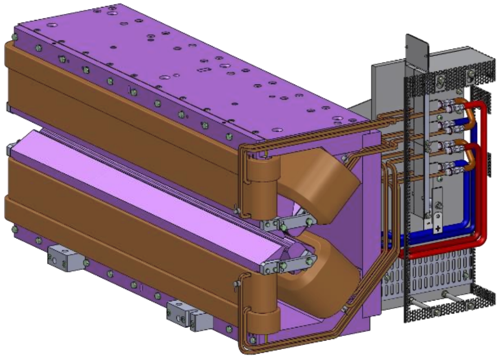
6T empty

12-13T fully equipped

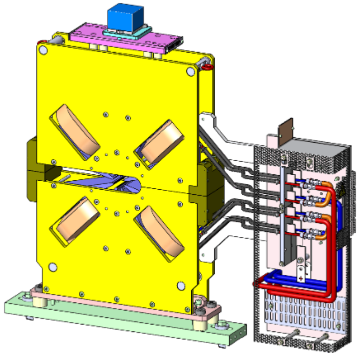
MAGNETS



132 Dipoles

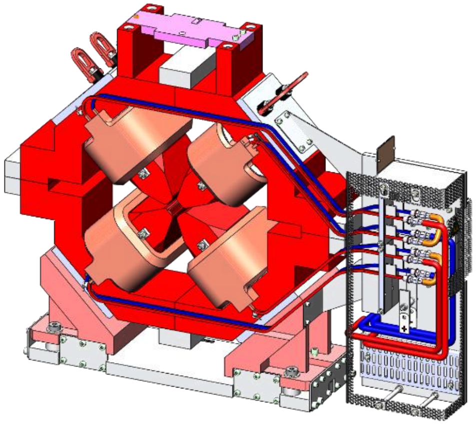


100 Dipole-quadrupoles

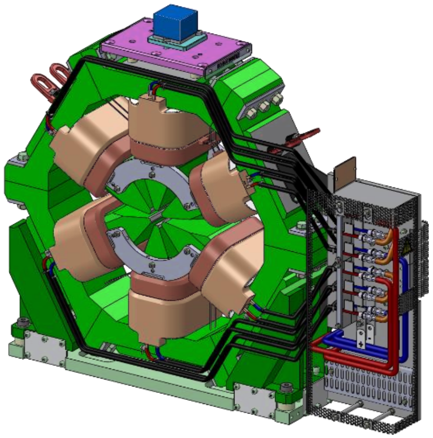


66 Octupoles

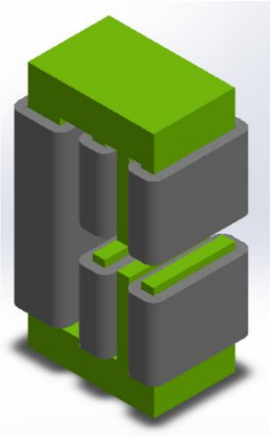
More than 1000 Magnets to be manufactured



524 Quadrupoles
(132 HG, 392 MG)

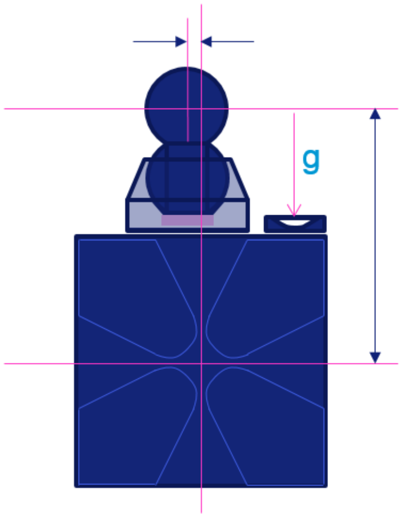


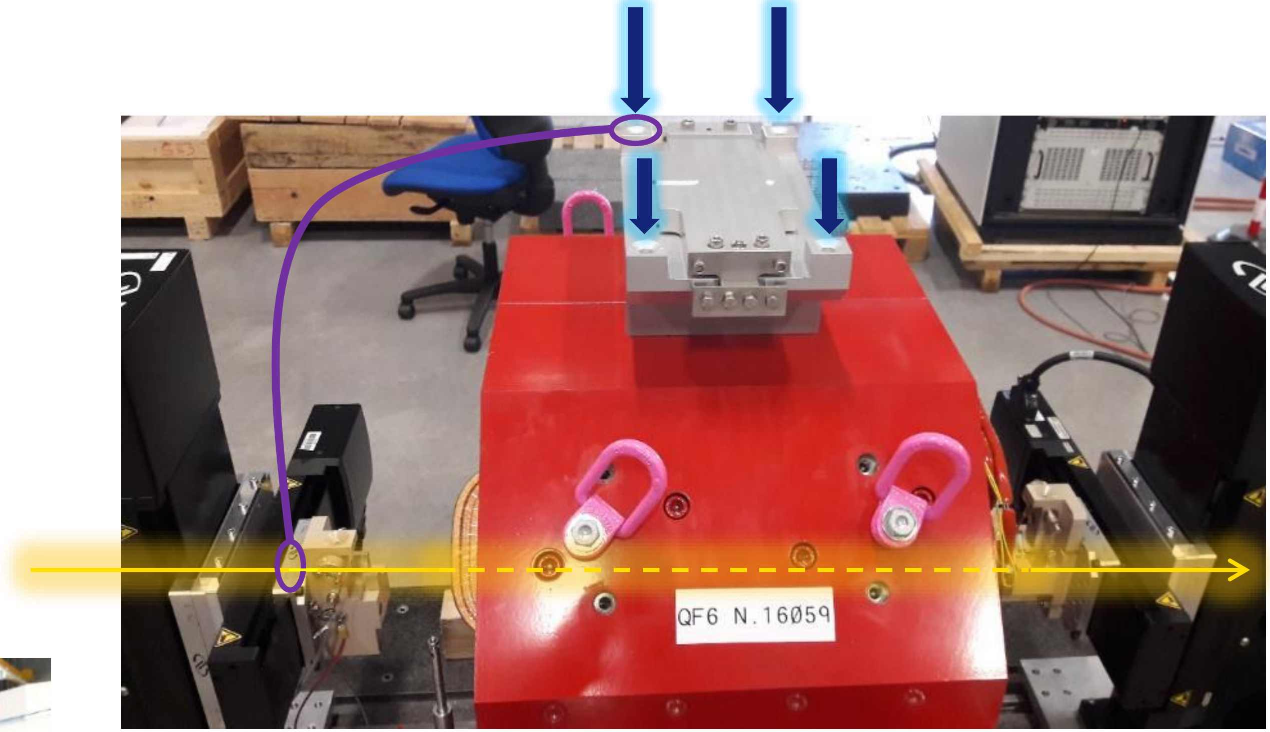
196 Sextupoles

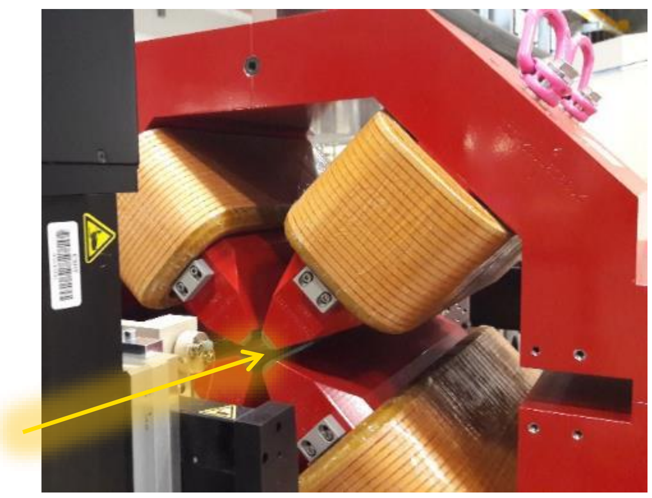


98 Correctors

MAGNET FIDUCIALISATION



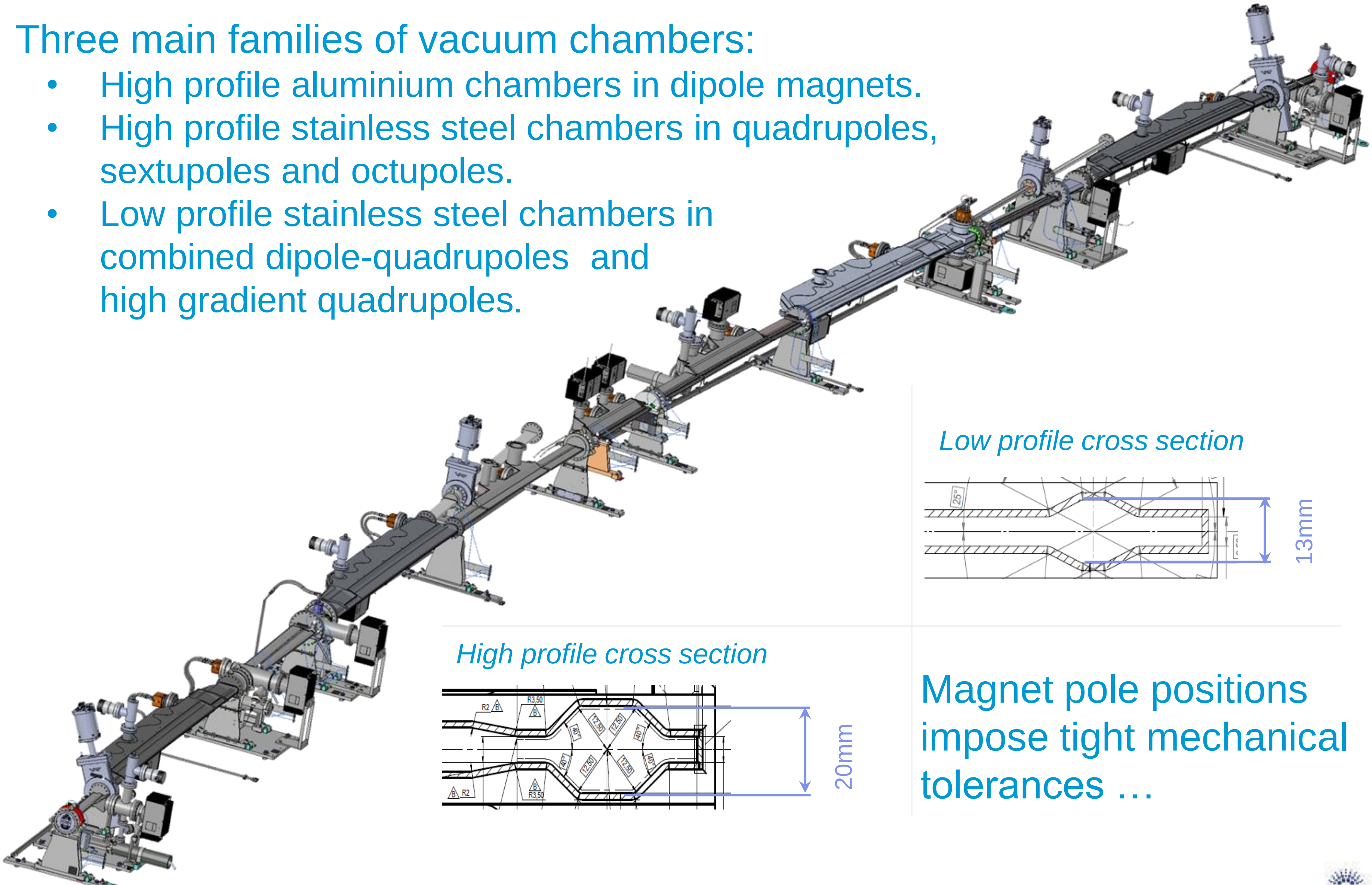




VACUUM CHAMBERS

Three main families of vacuum chambers:

- High profile aluminium chambers in dipole magnets.
- High profile stainless steel chambers in quadrupoles, sextupoles and octupoles.
- Low profile stainless steel chambers in combined dipole-quadrupoles and high gradient quadrupoles.

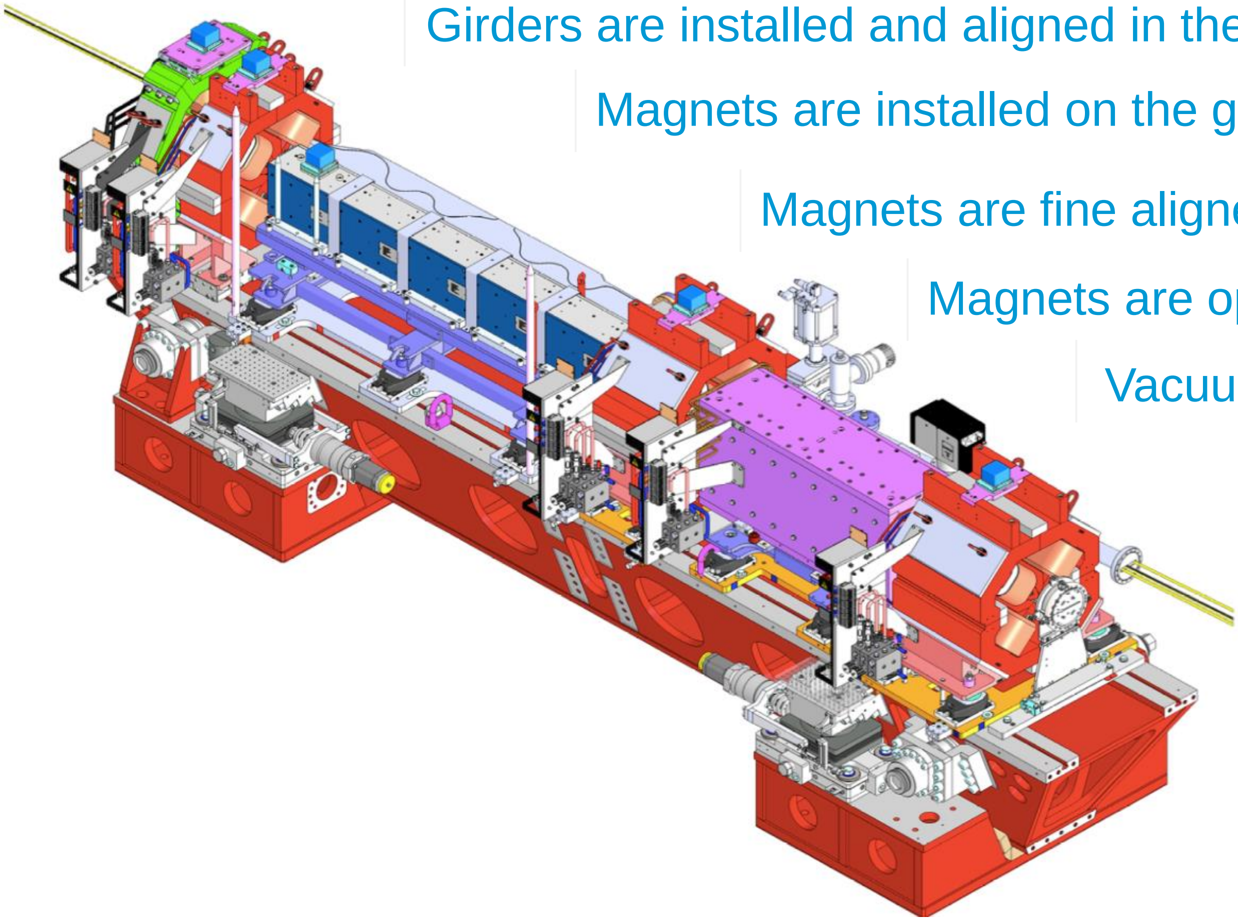


Low profile cross section

High profile cross section

Magnet pole positions impose tight mechanical tolerances …

ASSEMBLY



Girders are installed and aligned in the horizontal plane

Magnets are installed on the girder 0.5 mm

Magnets are fine aligned 0.05 mm

Magnets are opened

Vacuum string is installed

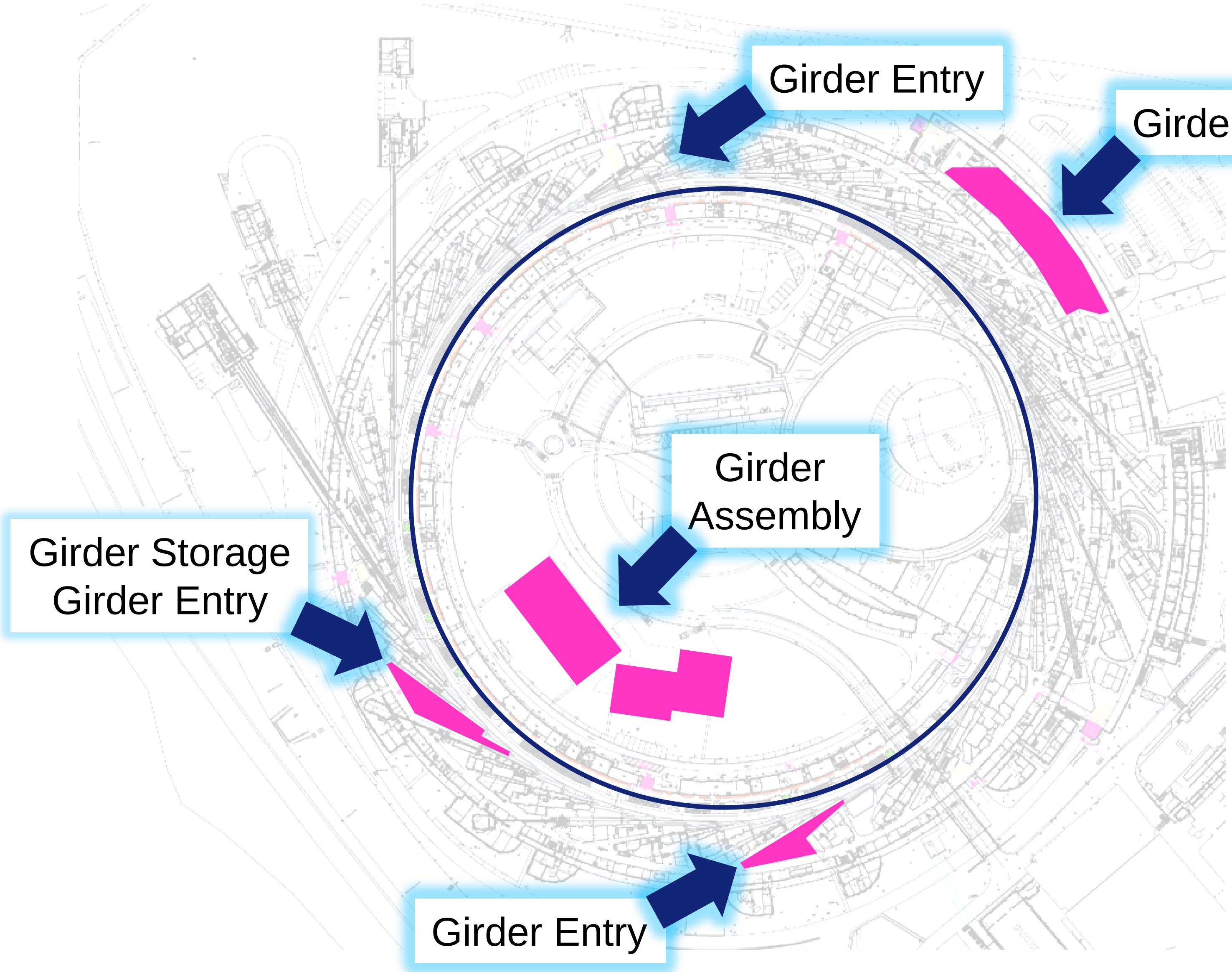
BPMs aligned 0.05 mm

Magnets are closed

Fine magnet alignment check and survey

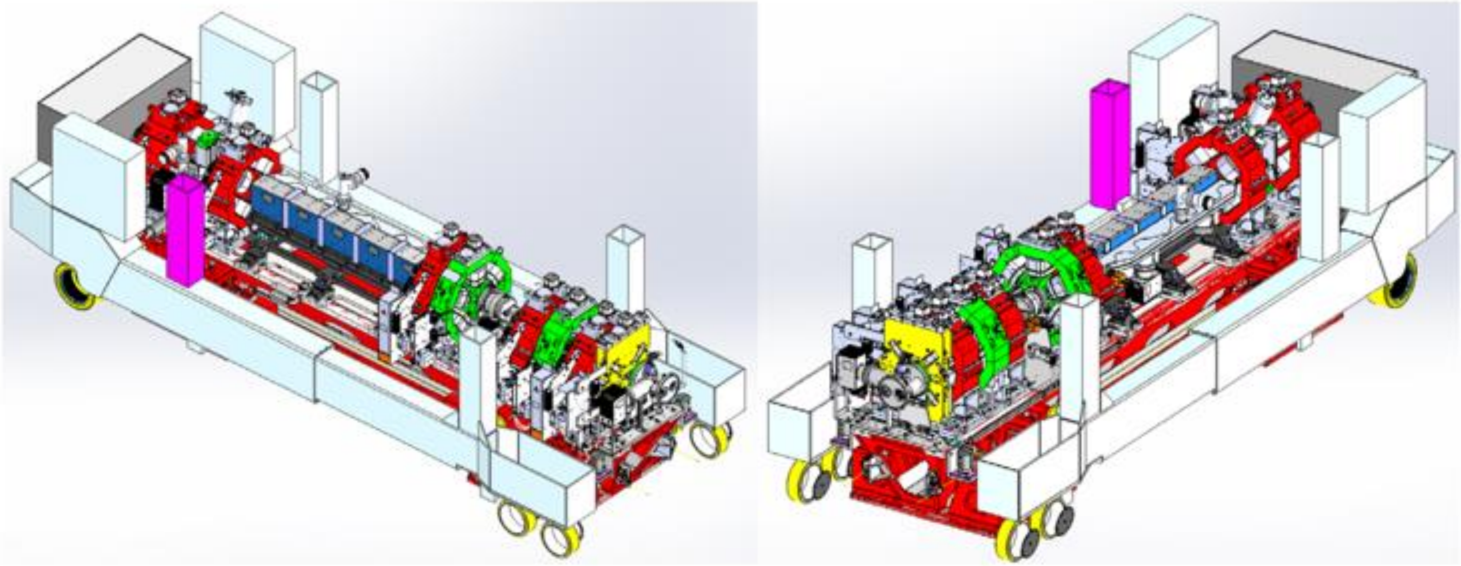
Assembly will be made in a dedicated building

LOGISTICS

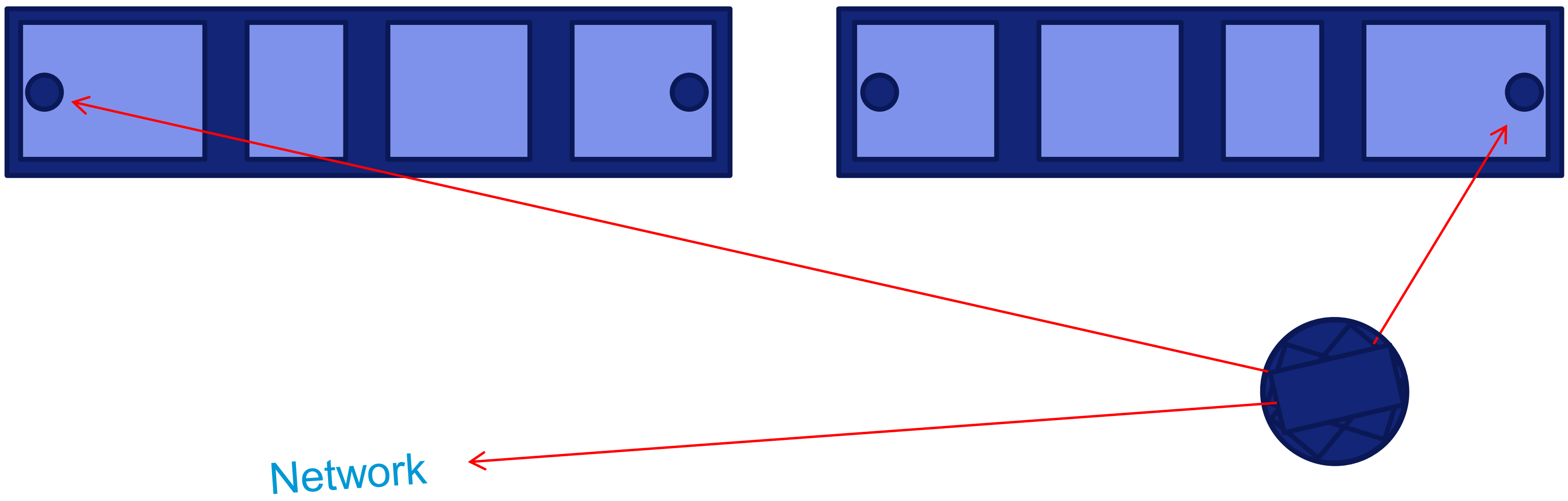


Girder Entry
Girder Storage
Girder Assembly
Girder Storage
Girder Entry
Girder Entry

TRANSPORT AND INSTALLATION

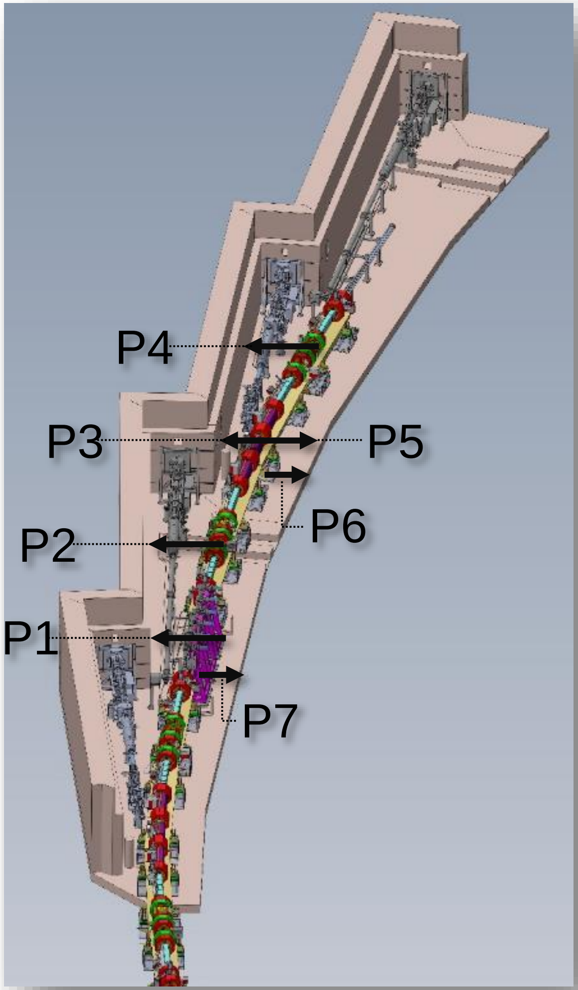


INSTALLATION – PRE-ALIGNMENT IN THE TUNNEL



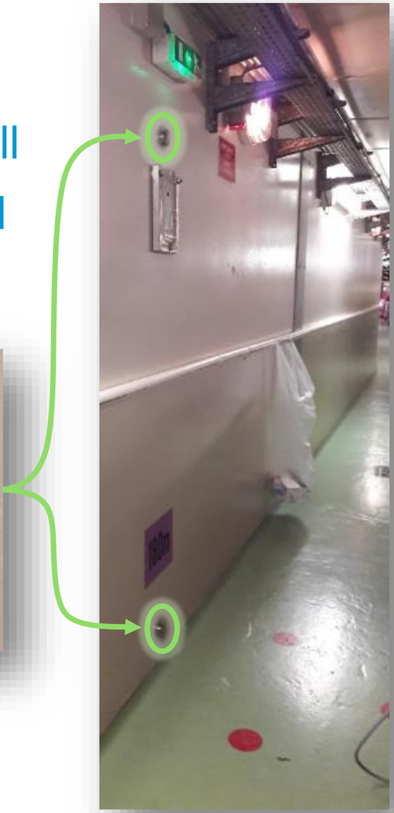
For the pre-alignment in the tunnel we will use the network to position the entry and exit points of the magnet girders

EBS INSTALLATION NETWORK



A new network was installed for the new machine
It comprises eight points
per cell:

- Four points on the exterior wall
- Four points on the interior wall

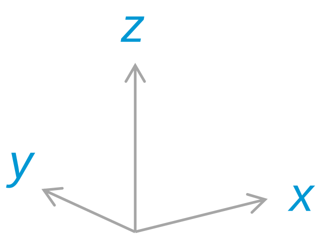


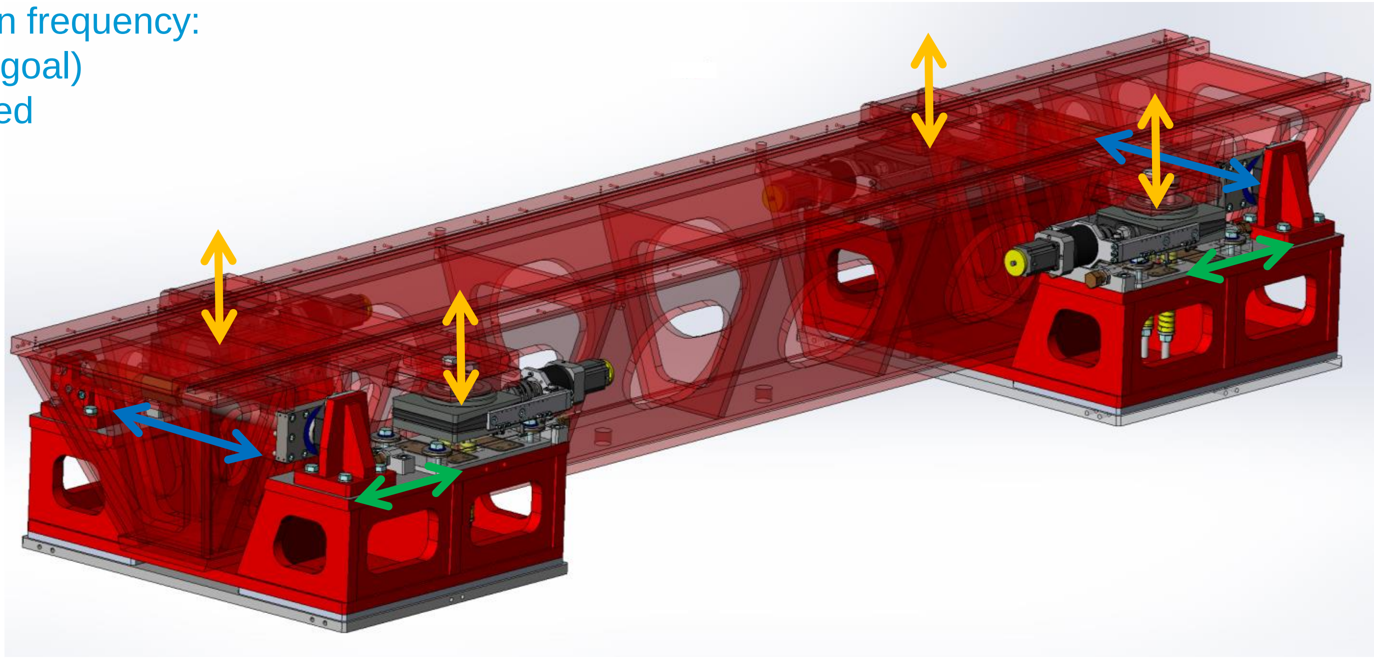
GIRDER MOVERS

Girder supported by 4 adjustable motorised wedge jacks

Y adjustment by 2 manual jacks

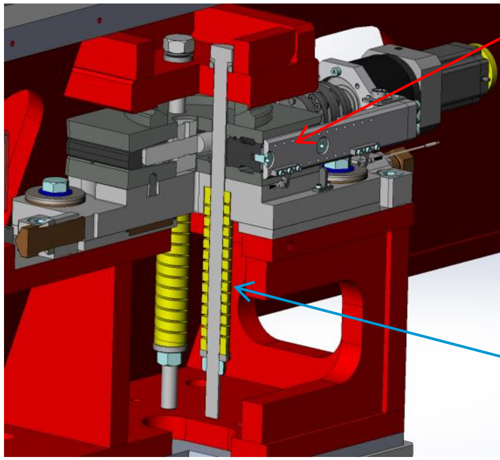
- **Motorized Z adjustment** resolution 5µm
- **Manual Y adjustment** resolution 5µm
- 1st natural Eigen frequency:
  - 50 Hz (design goal)
  - 49 Hz measured





There is 1 degree of hyperstaticity in the vertical direction managed by the girder “flexibility” for small displacements.

Vertical movement



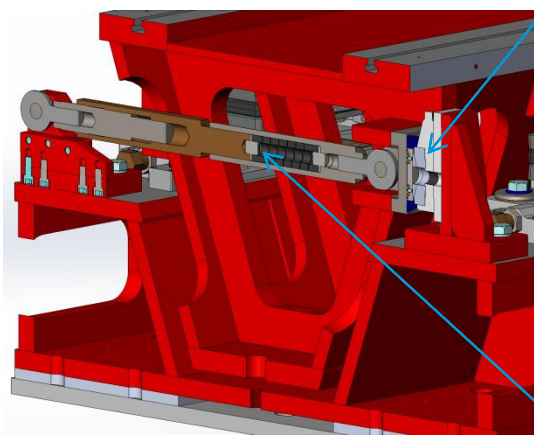
Airloc wedge 414-KSKC (modified for motorization)

Preloaded springs (2x0.7t)

Z movement:

- Accuracy: 10.8µm
- Repeatability: 3.3µm
- Increment: 0.3µm

Horizontal movement



Wedge Nivell DK2

"push back" spring (3.5t)

Horizontal movers have 3 functions:

- horizontal adjustment (+/- 3.5mm continuous, +/- 15mm global)
- guiding the vertical movement (ensuring no lateral diplacement during the vertical adjustement)
- improving the stiffness of the girder

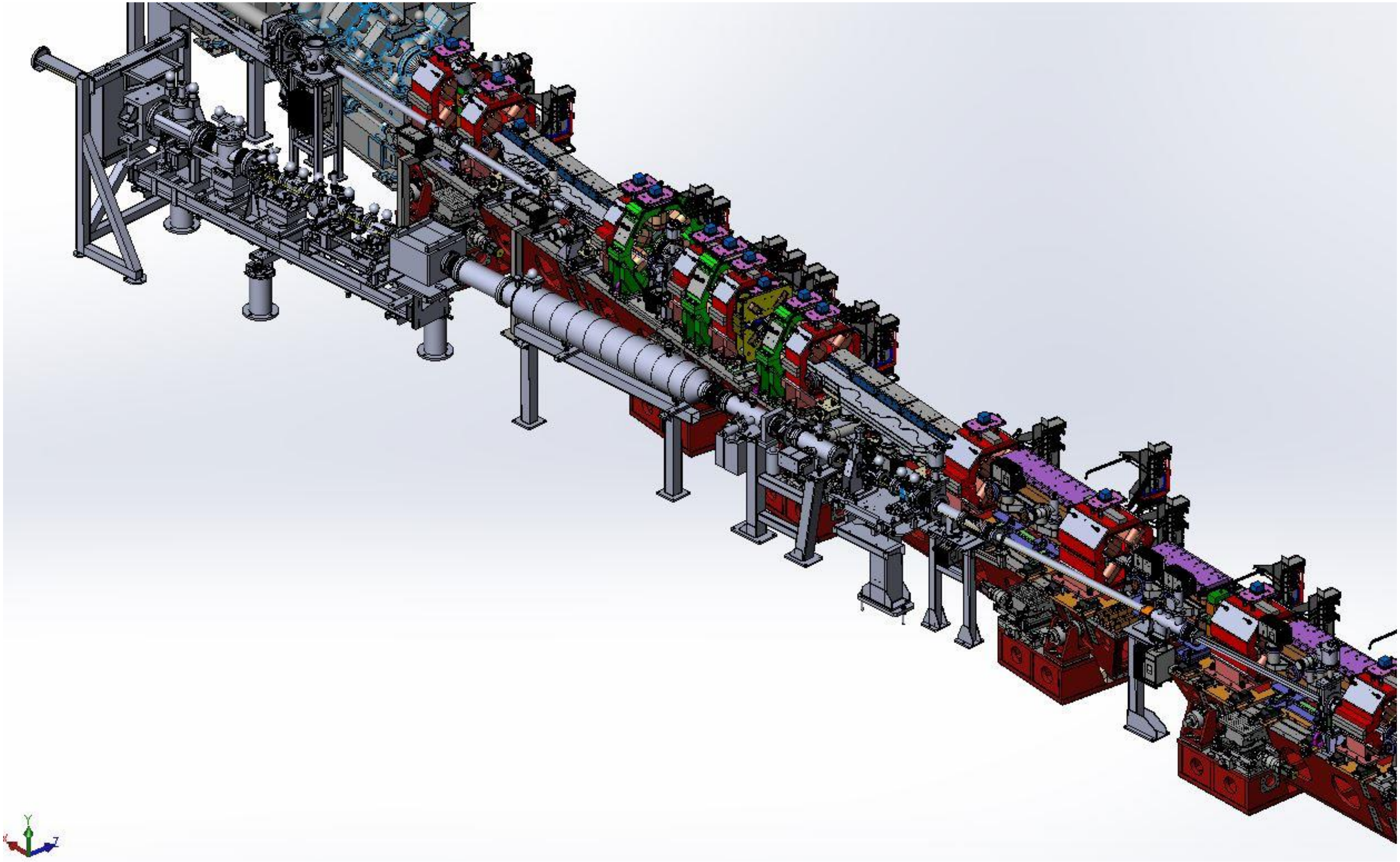
HOW DO WE ALIGN THINGS – FINAL ALIGNMENT AND SMOOTHING

When everything is installed the final alignment will be made

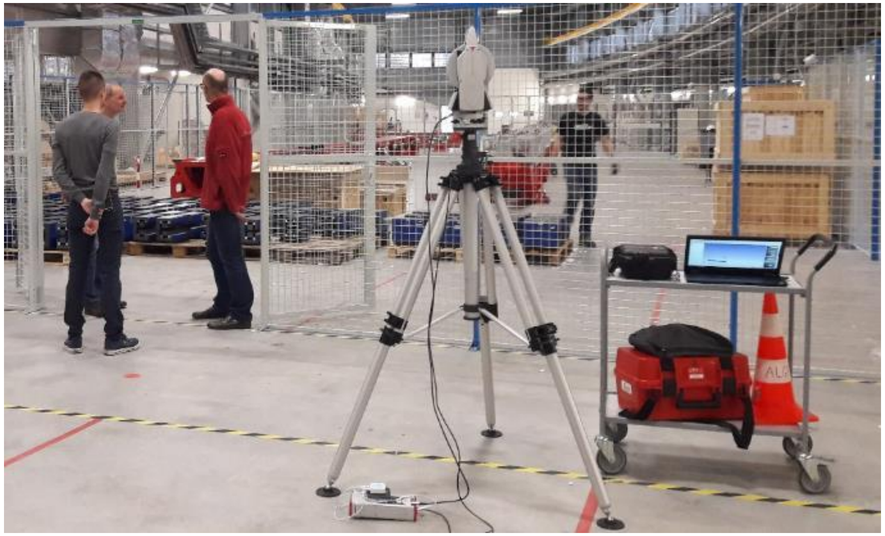
There are two key issues/goals:

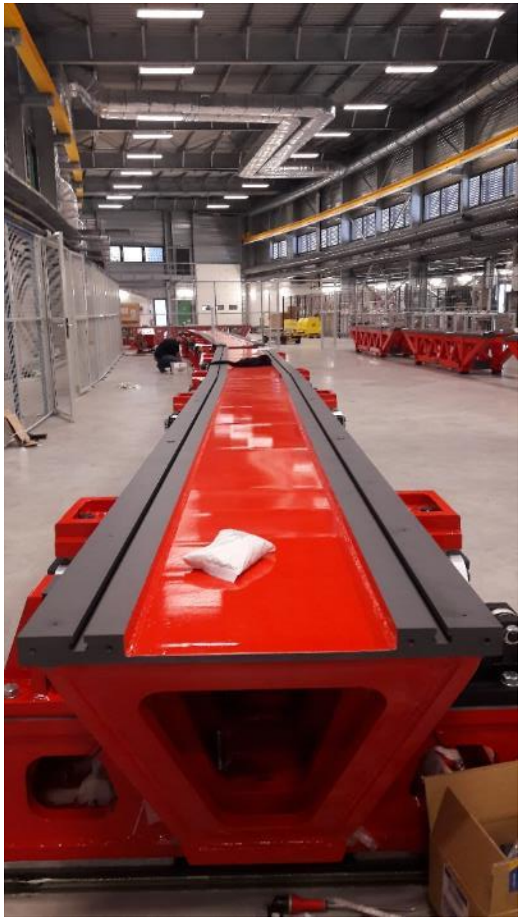
a) Adjacent girders must be within their nominal alignment tolerances – smoothing the machine
b) The machine and the beamlines must line up

FRONT ENDS



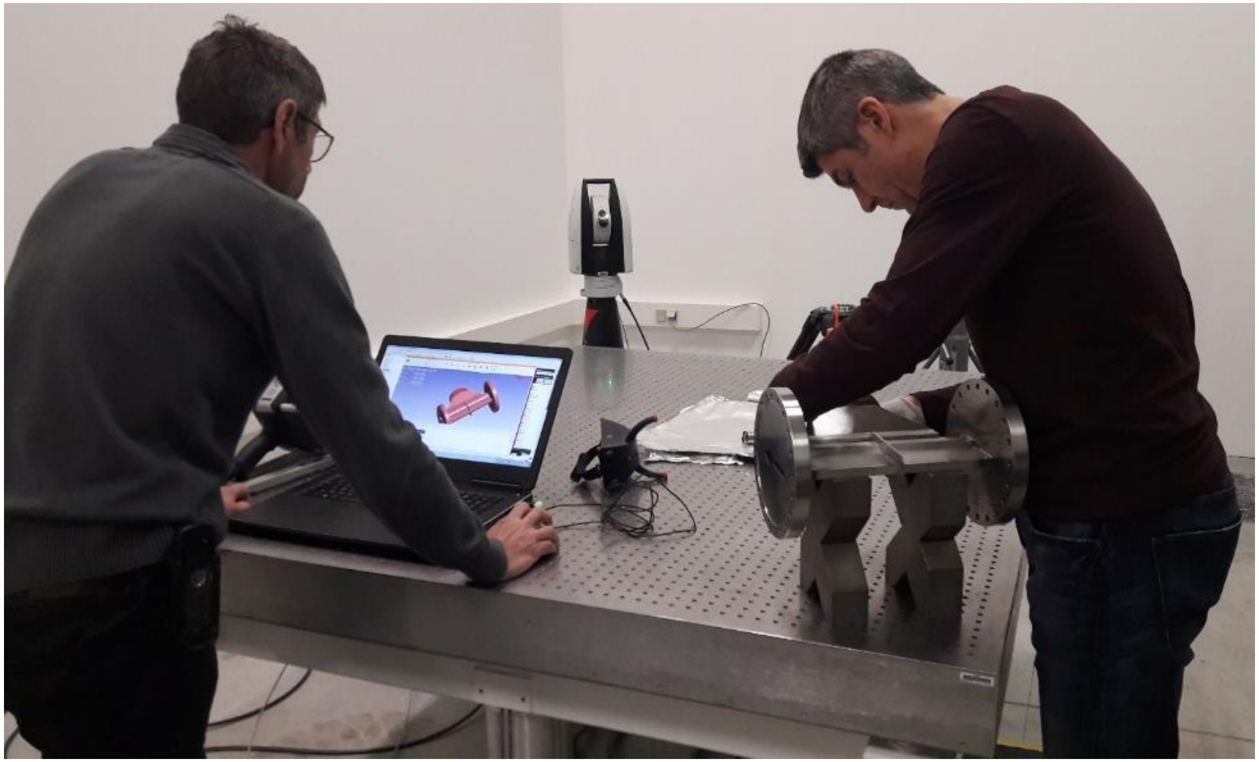
MOCK UP

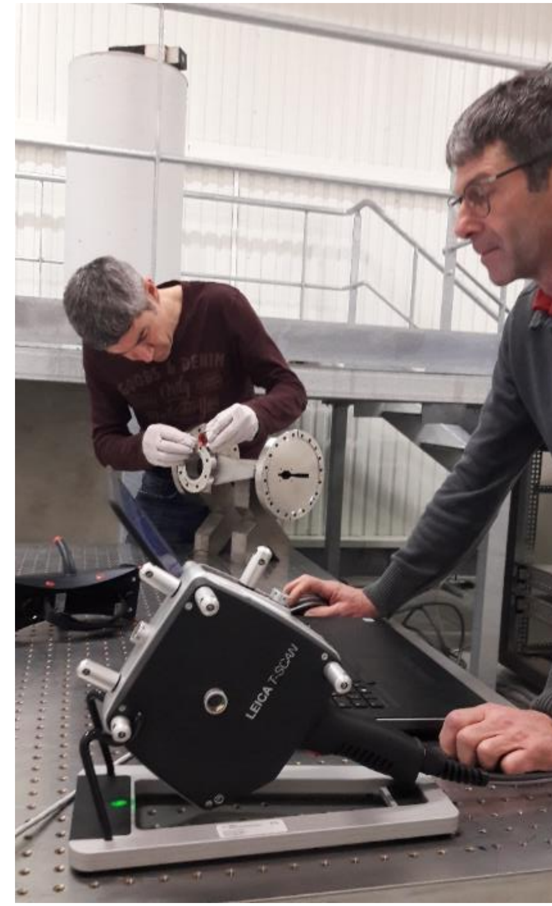




All of these things
will be done on the Mock-Up being installed in the Chartreuse Hall

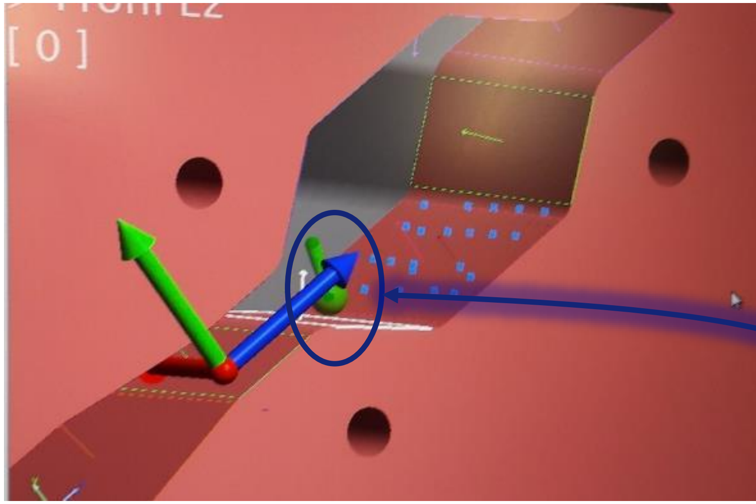
AS BUILT COMPONENT SITE ACCEPTANCE TESTING

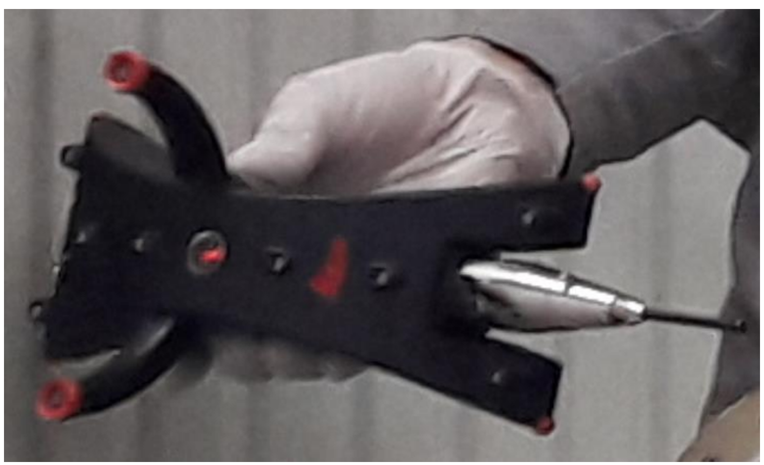


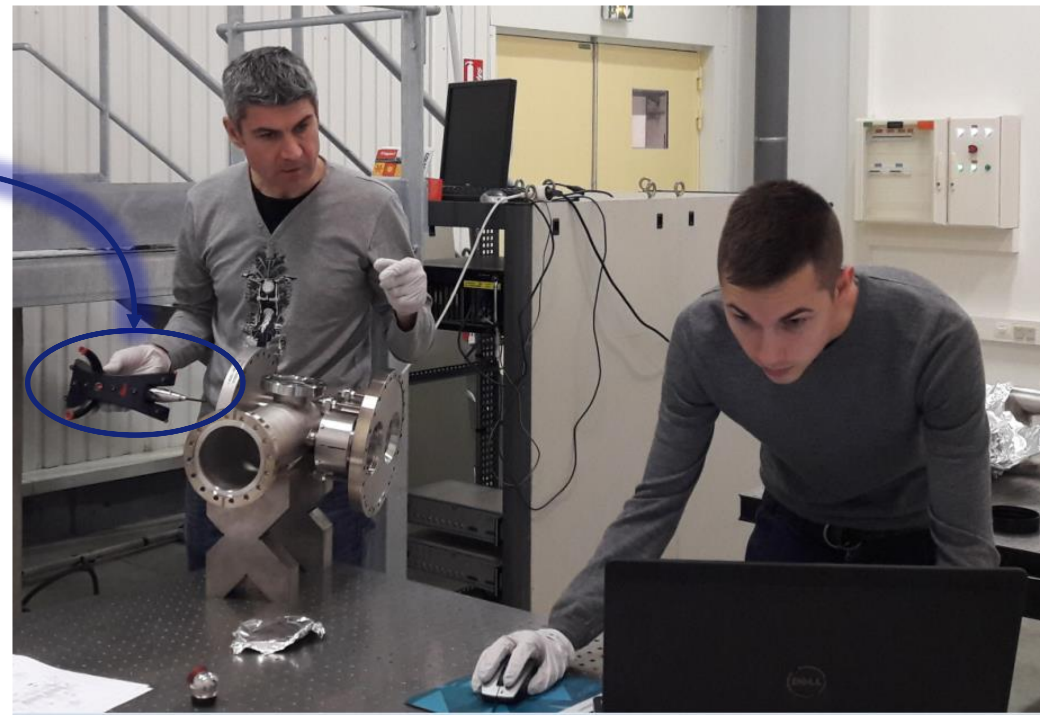


Now we now regularly use the AT960 Laser Tracker with the T-probe and T-scan to make dimensional controls on complex objects like vacuum chambers.

AS BUILT COMPONENT SITE ACCEPTANCE TESTING







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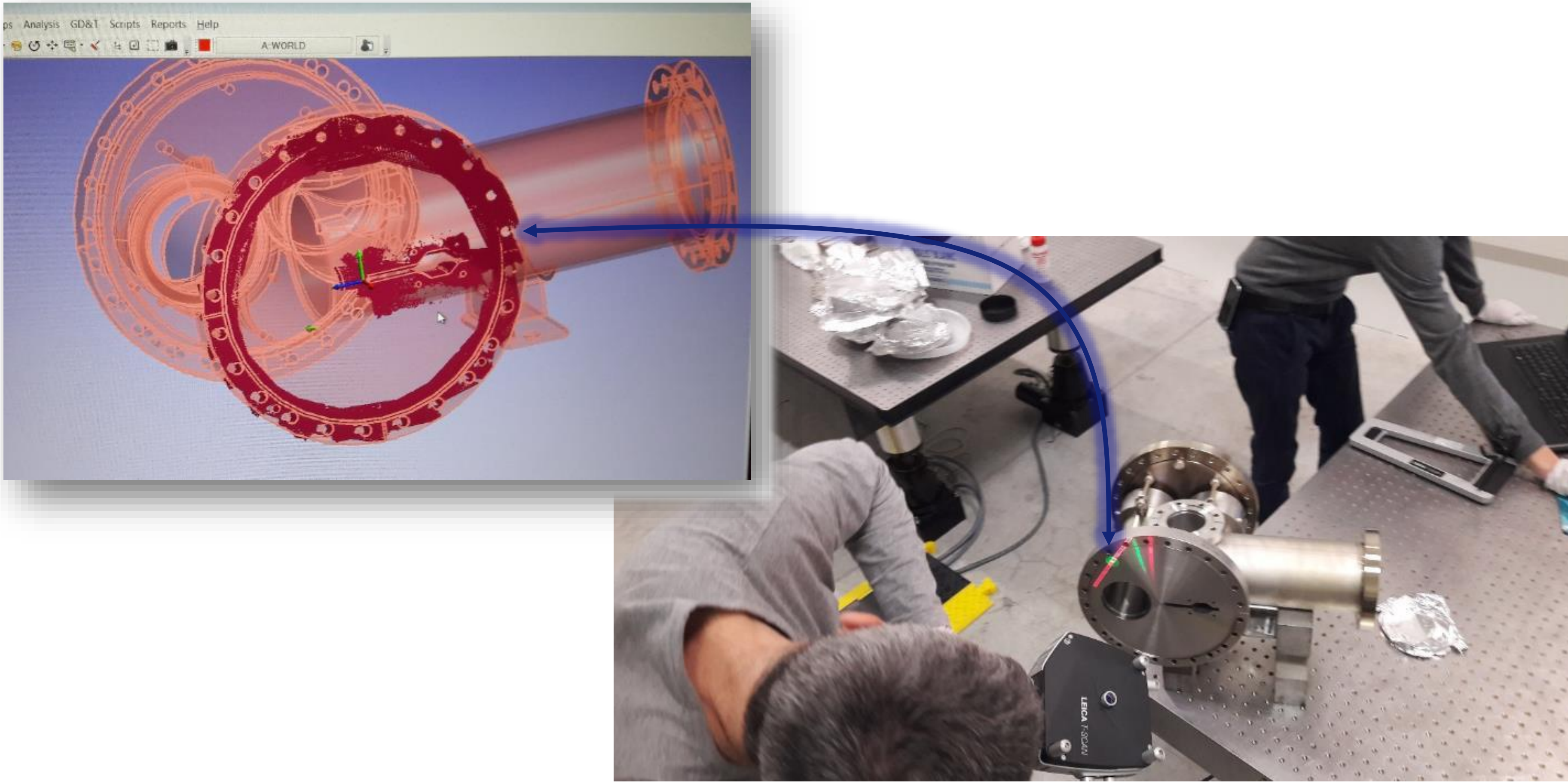
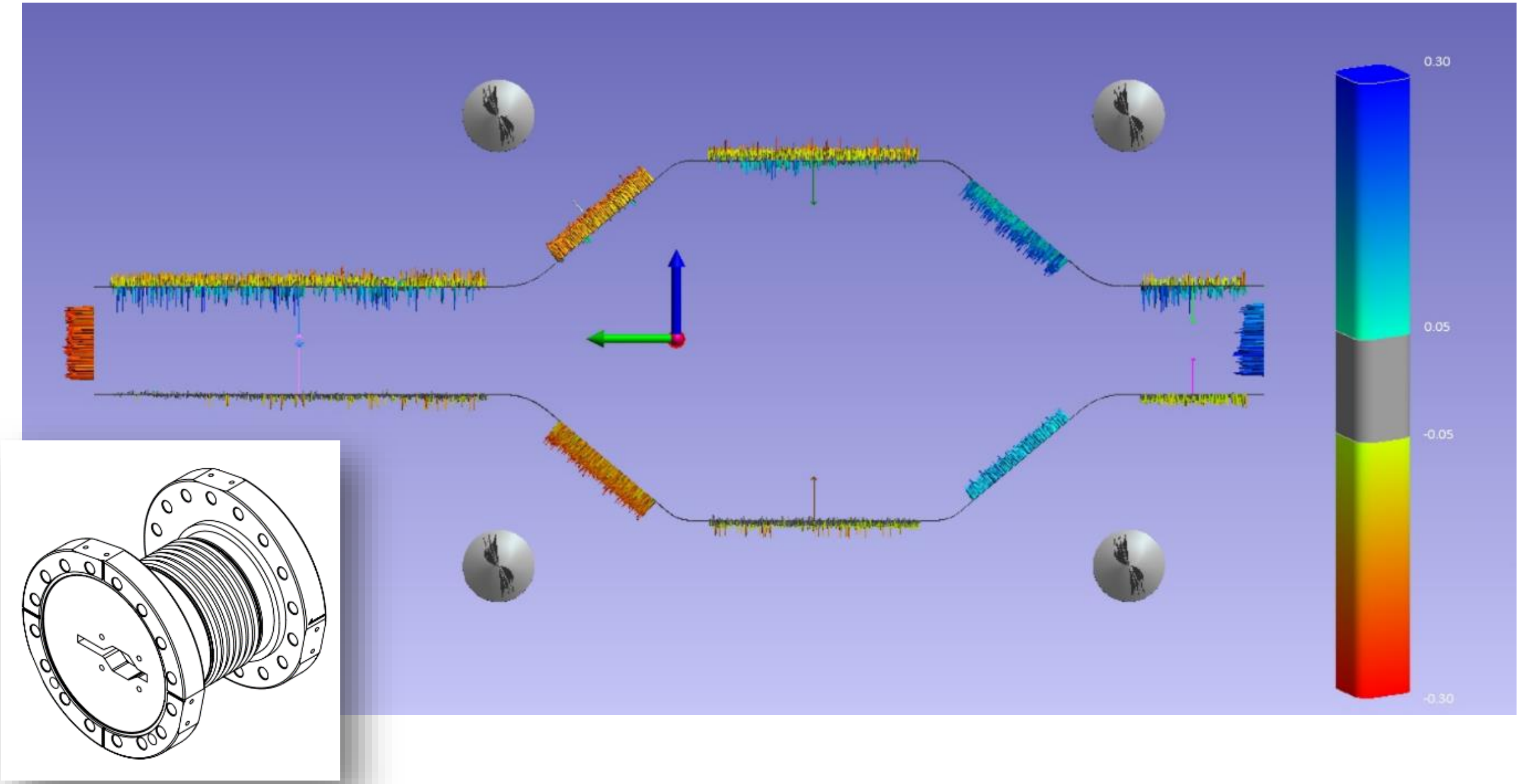
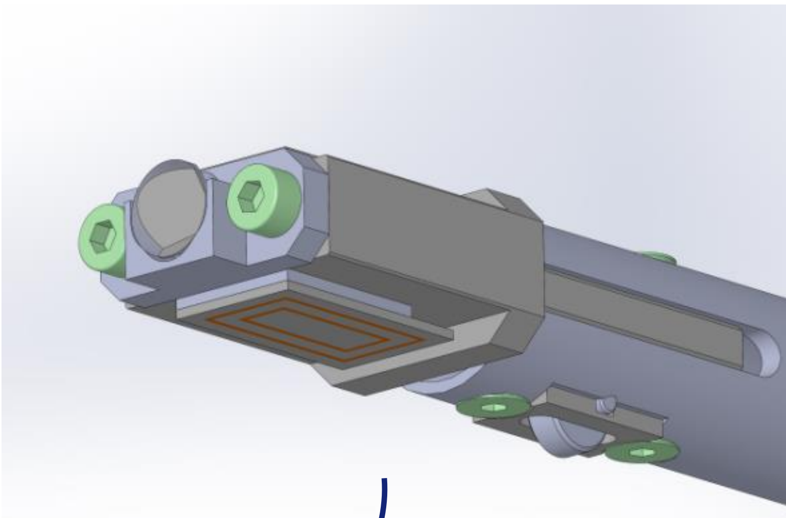
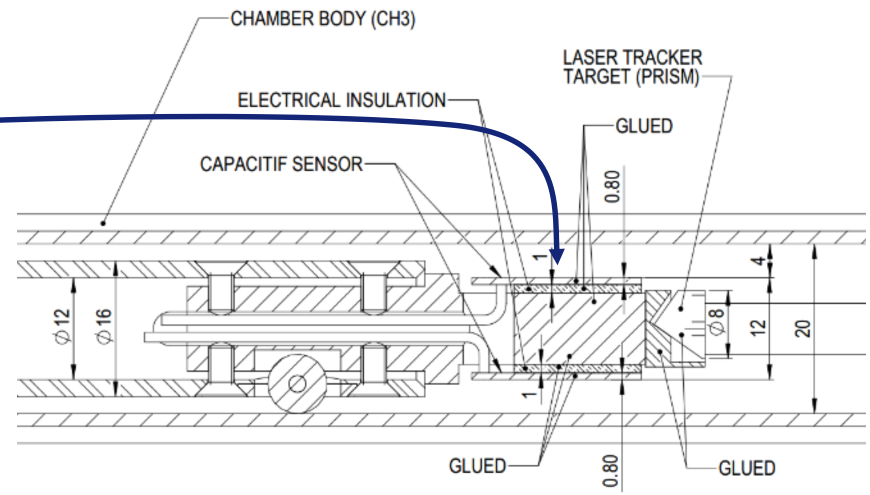


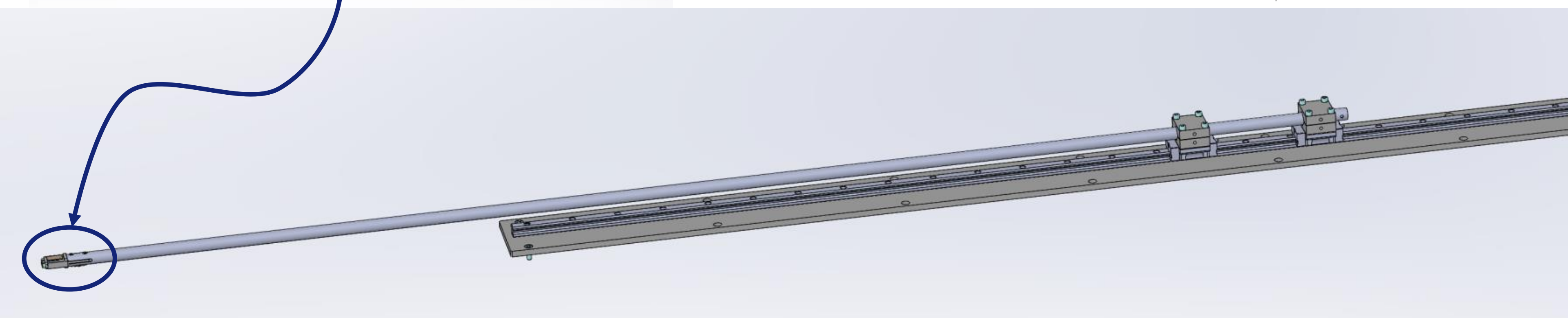
T-SCAN DENSE DIMENSIONAL CONTROL OF CHAMBER ENTRY PROFILE



AN INSTRUMENT TO MEASURE THE VACUUM CHAMBER INTERIOR PROFILE







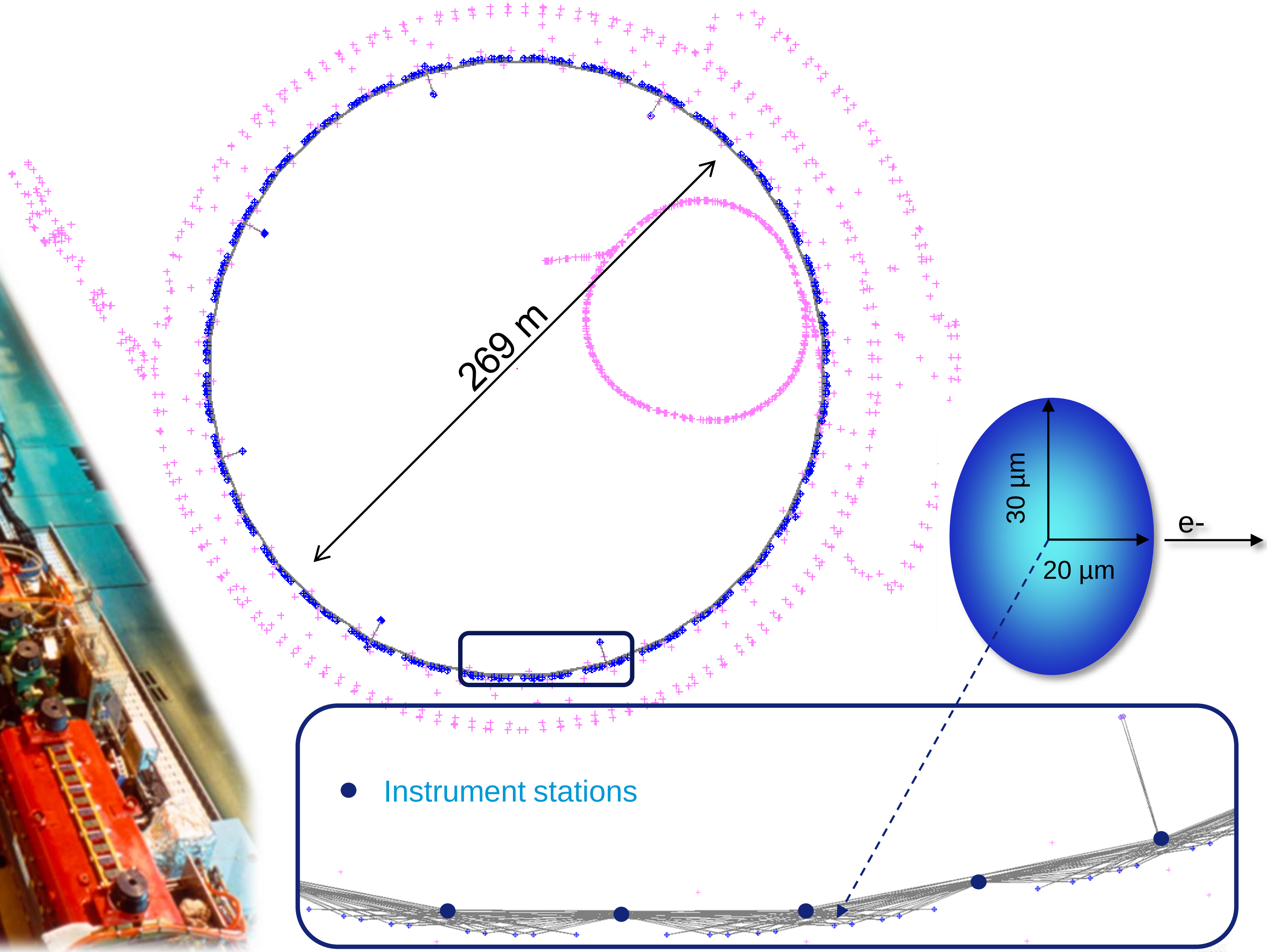
THE ESRF SURVEY NETWORKS

XY and Z

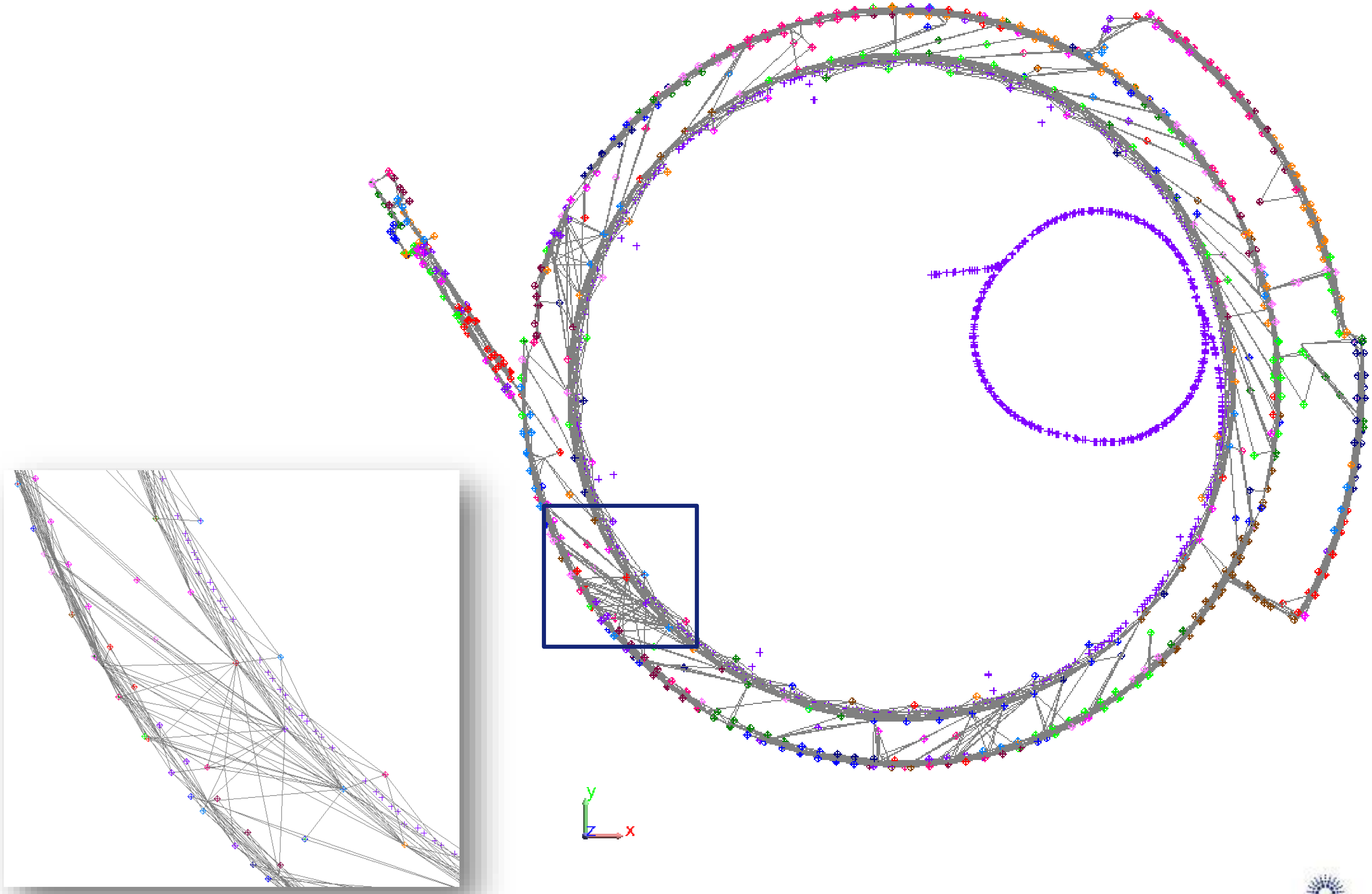
AT401/402
Laser Tracker

Angles ± 5 µm + 6 µm/m
Distance ±10 µm
ASME B89.4.19-2006 MPE

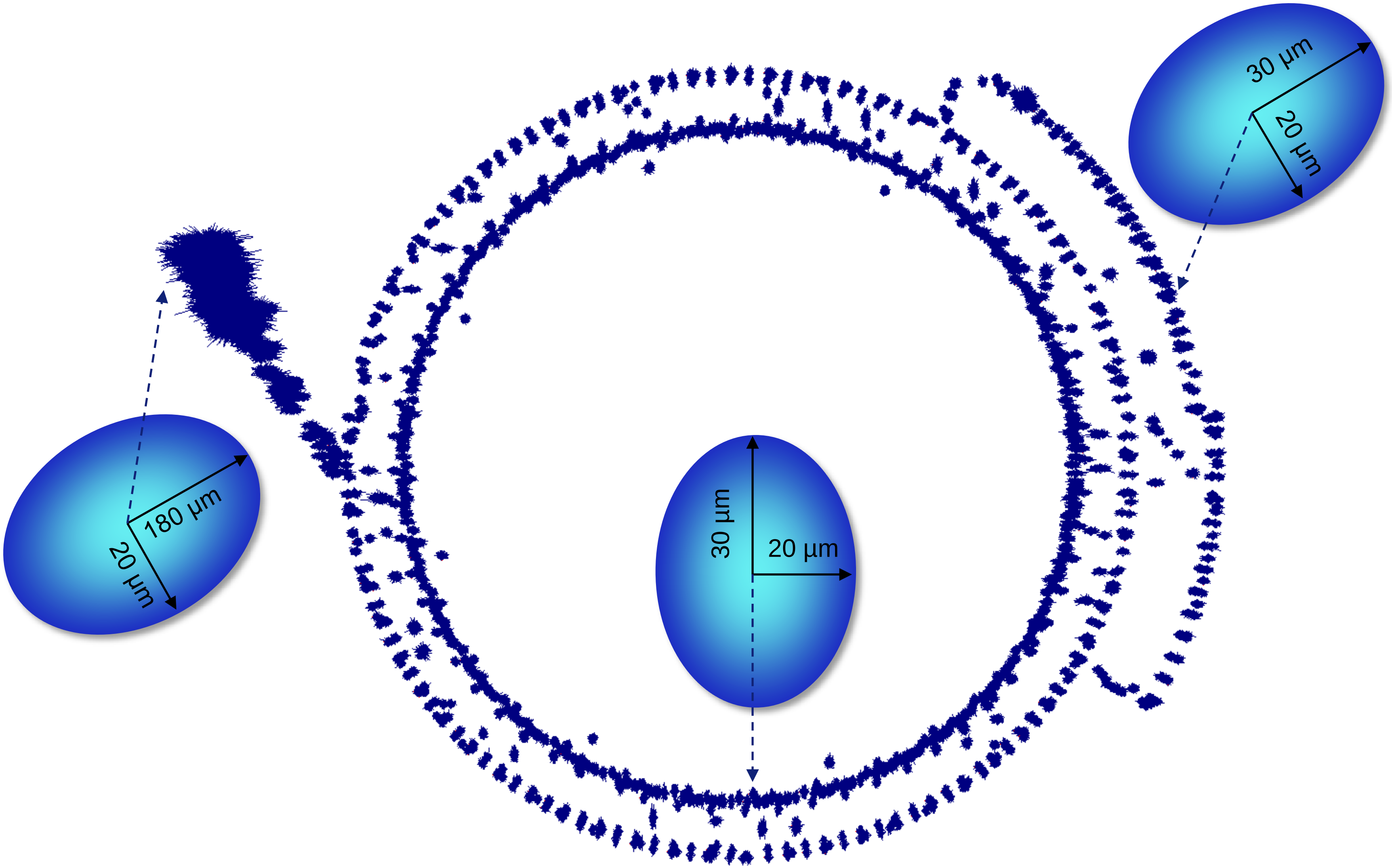
THE STORAGE RING NETWORK



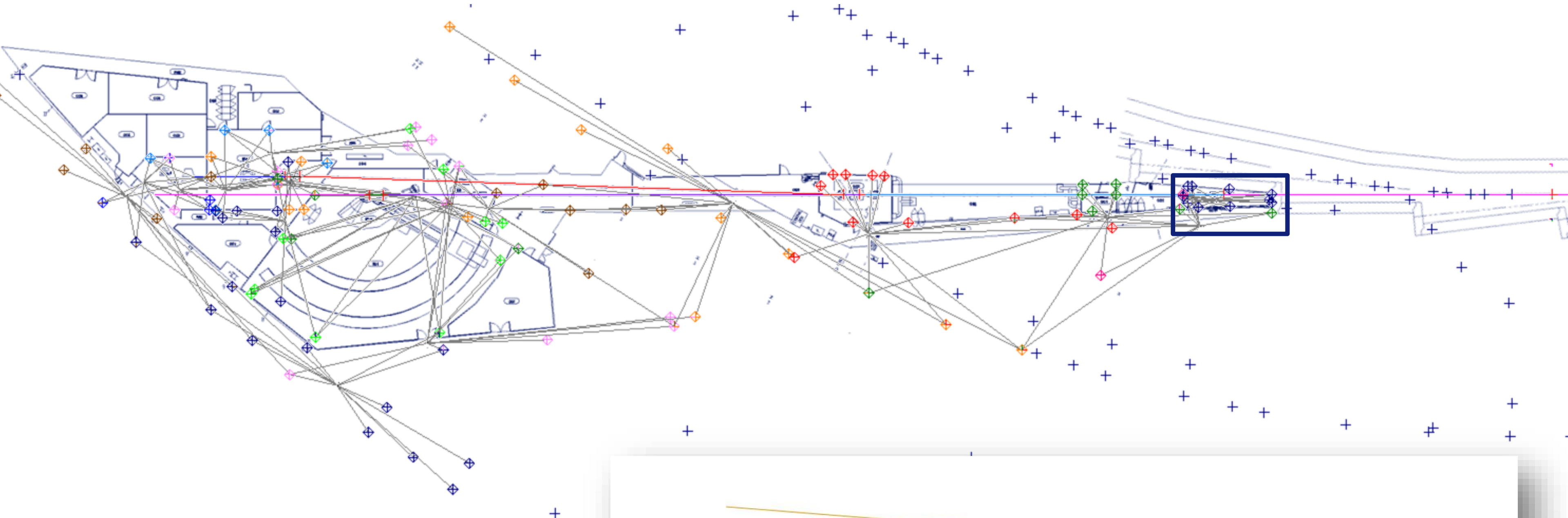
EX2 NETWORK

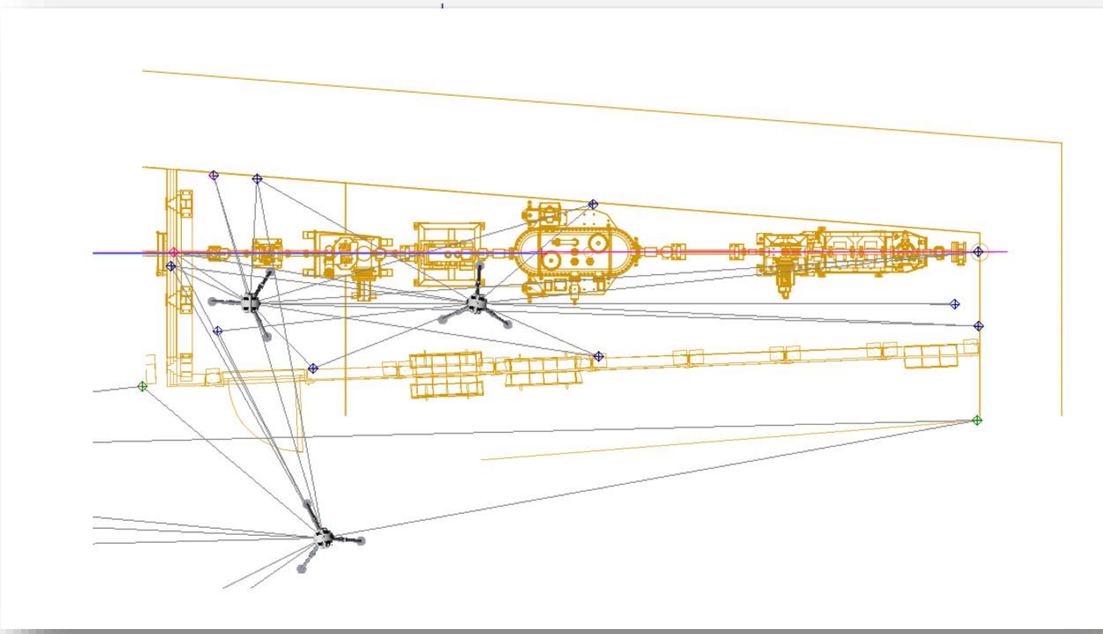


EX2 NETWORK UNCERTAINTY

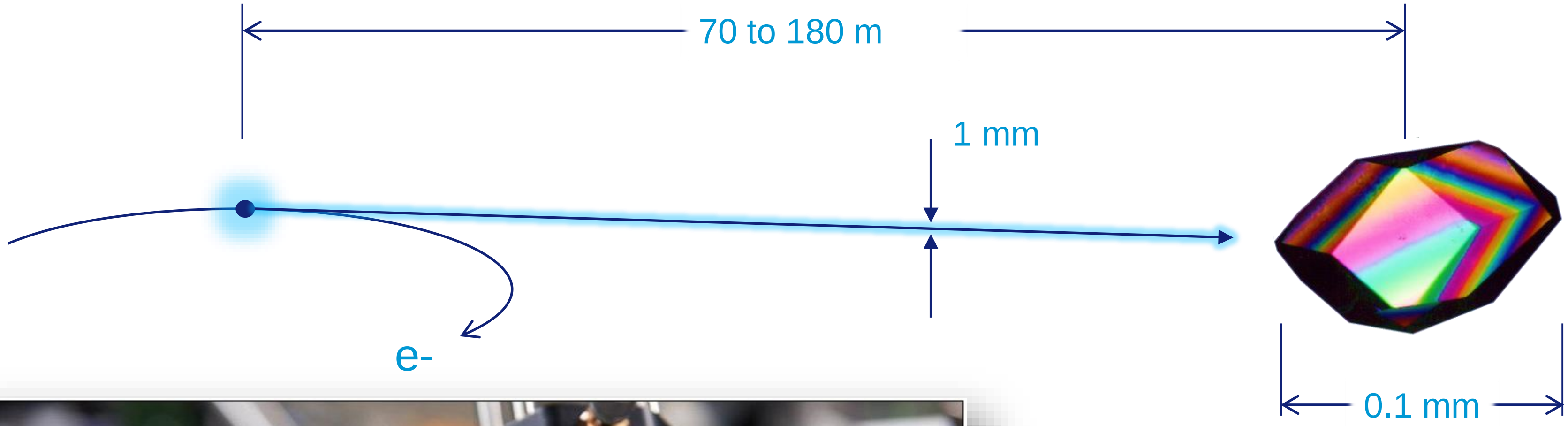


ID32 NETWORK





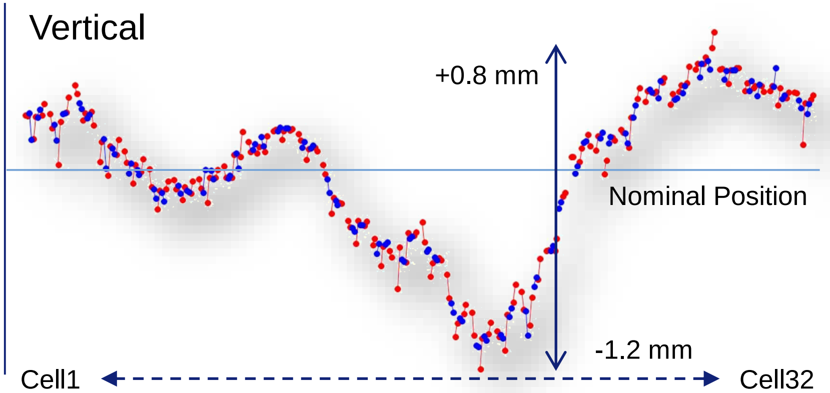
THE SCALE OF THINGS AND THE IMPORTANCE OF ALIGNMENT

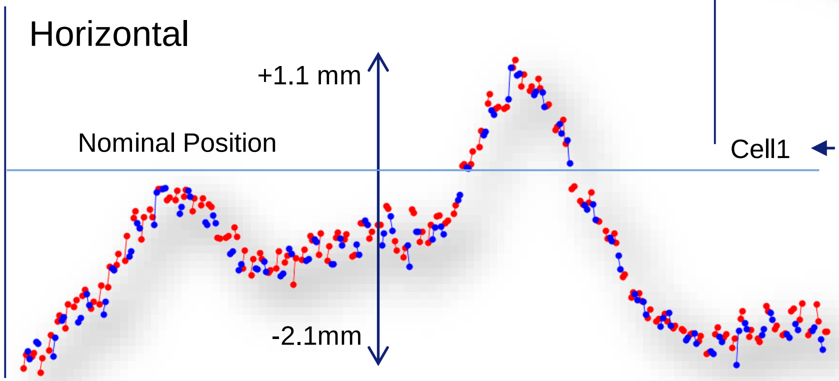


A crystal is placed on the end of the pin with a stream of cool air coming in from the right. The X-ray beam arrives from the silver pipe and the camera images the crystal

http://www.dailymail.co.uk/sciencetech/article-2828699/Inner-beauty-world-revealed-Photographer-captures-amazing-crystal-structures-objects-reveals-created.html

The new machine has a nominal design position. But the existing machine is not in its nominal position …

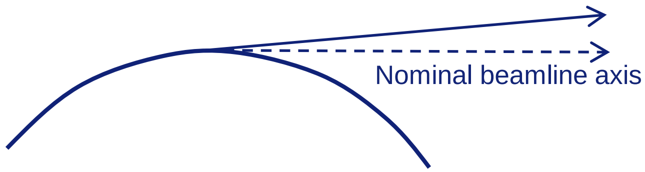




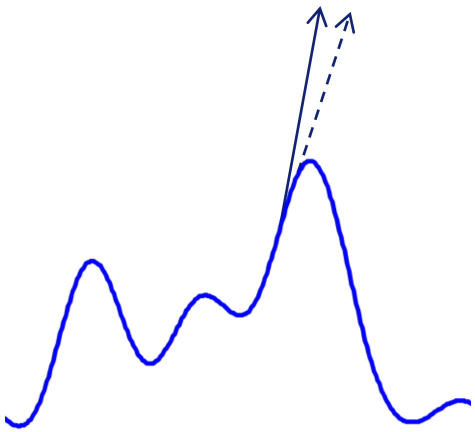
The simplest option is to align the machine in the position of the old machine …

EBS AND THE BEAMLINES – THE PROBLEM

The main problem is that there is uncertainty as to where the actual beamline axes are with respect to their expected positions?



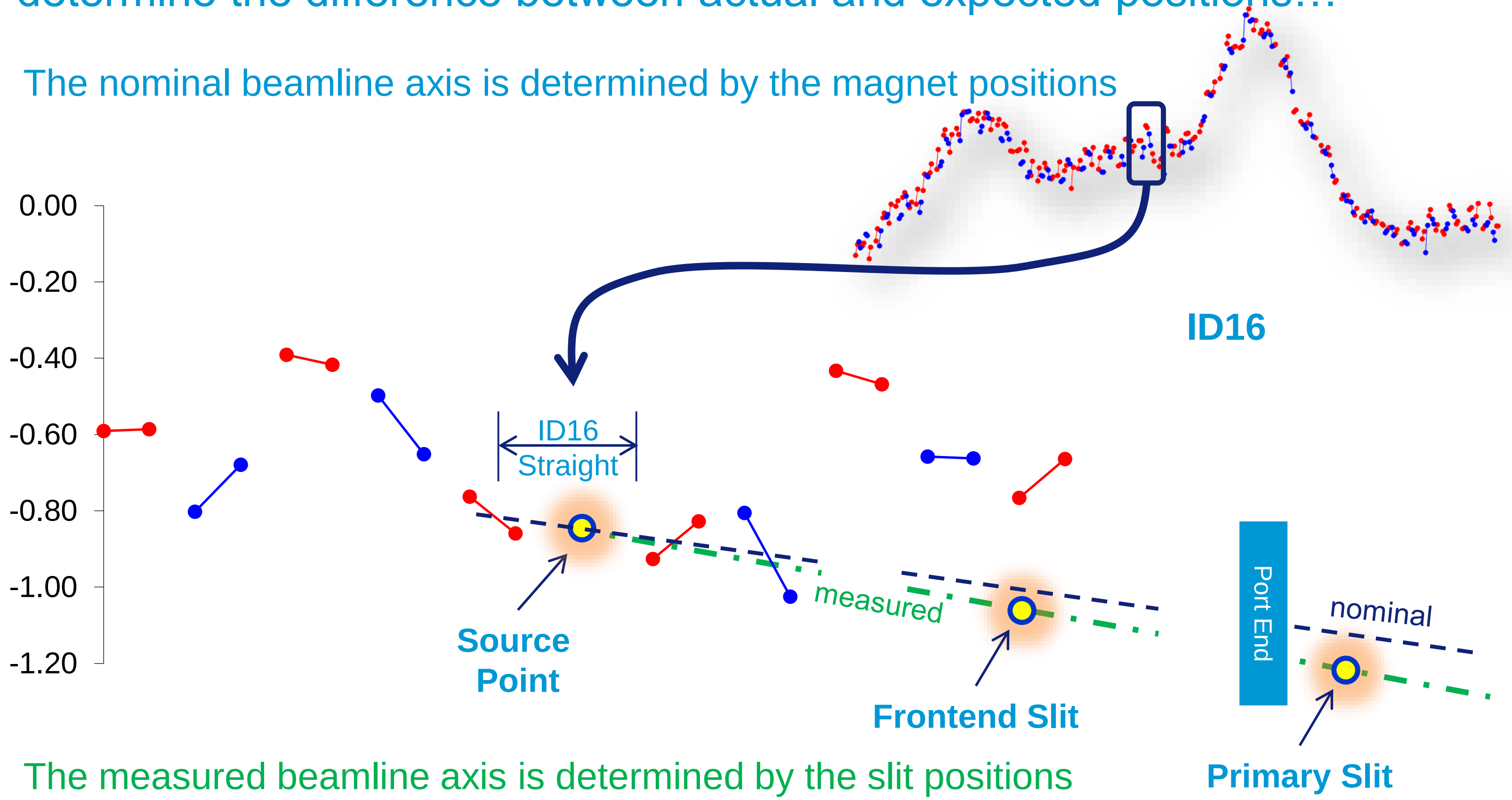
Machine and alignment errors



Long term movements

Measurements were made on selected frontend and beamline primary slits to determine the difference between actual and expected positions…

The nominal beamline axis is determined by the magnet positions



The measured beamline axis is determined by the slit positions

EBS AND THE BEAMLINES – THE PROBLEM

The standard deviation in the difference between the measured and expected primary slit positions was 0.63 mm.

This corresponds to a beamline angle uncertainty of 27 µrad at 1σ and implies alignment uncertainty of:

⟶ ±3.2 mm at 2σ at 60 m in the EXPH,

⟶ ±6.4 mm at 2σ at 120 m in the EX2, and

⟶ ±9.7 mm at 2σ at 180 m on ID16.

This means even if we align the new machine where the existing machine is, the photon beam will not necessarily be where it is today.

EBS AND THE BEAMLINES – MEASURES

We have decided the best way forward will be to …

- Ensure all FE slits are remote servo-controlled.
- Measure the all of the beamline FE and primary slits to *calibrate* the beam trajectory.
- Install a beam viewer on every beamline. The beam viewers will be fiducialised and in principle the position of the beam can be measured.
- It is planned to be able to steer the beam onto the beam viewer with a precision better that 1 mm.

Thank you for your attention …