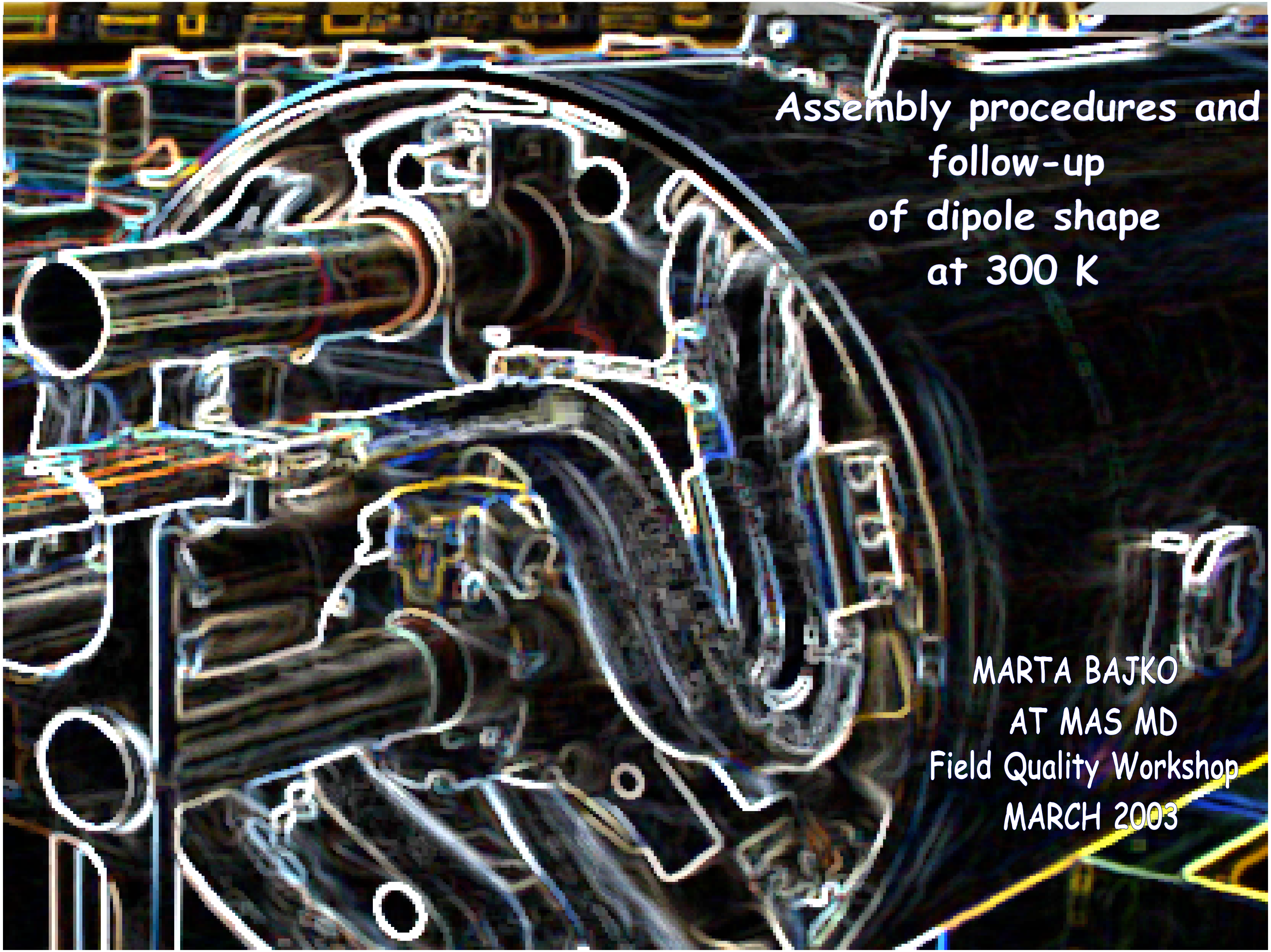

Assembly procedures and follow-up of dipole shape at 300 K

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AT MAS MD

Field Quality Workshop
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Content

- Geometrical axes and tolerances of the dipole cold masses
- Assembly steps assisted by geometry measurements
- Components and tools influencing the geometry
- Corrector magnets positioning
  - Procedure
  - Tolerances
- Critical points today
  - Assembly tolerances
  - Stability
- Conclusions

Geometrical axes of the dipoles 1

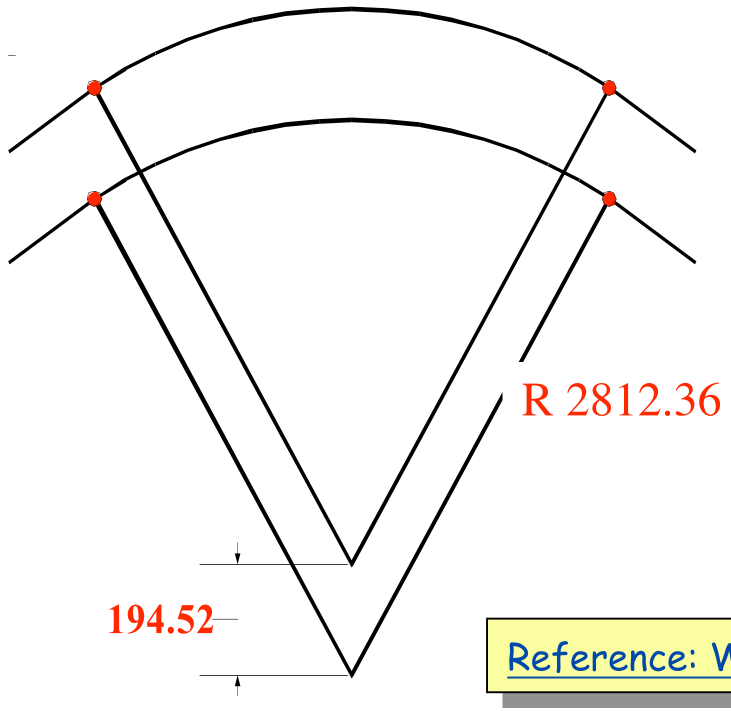
Geometrical tolerances and alignment issues

The active part of the cold mass is bent in the **horizontal plane**, inside an apical angle of 5.09 mrad with a bending radius of 2812.36m

Beyond this arc, the theoretical geometric axis is prolonged along the local tangent to the arc. The shape of the two beam channels is identical.

The centre of curvature of each aperture are 194.52 mm apart in assembly conditions.

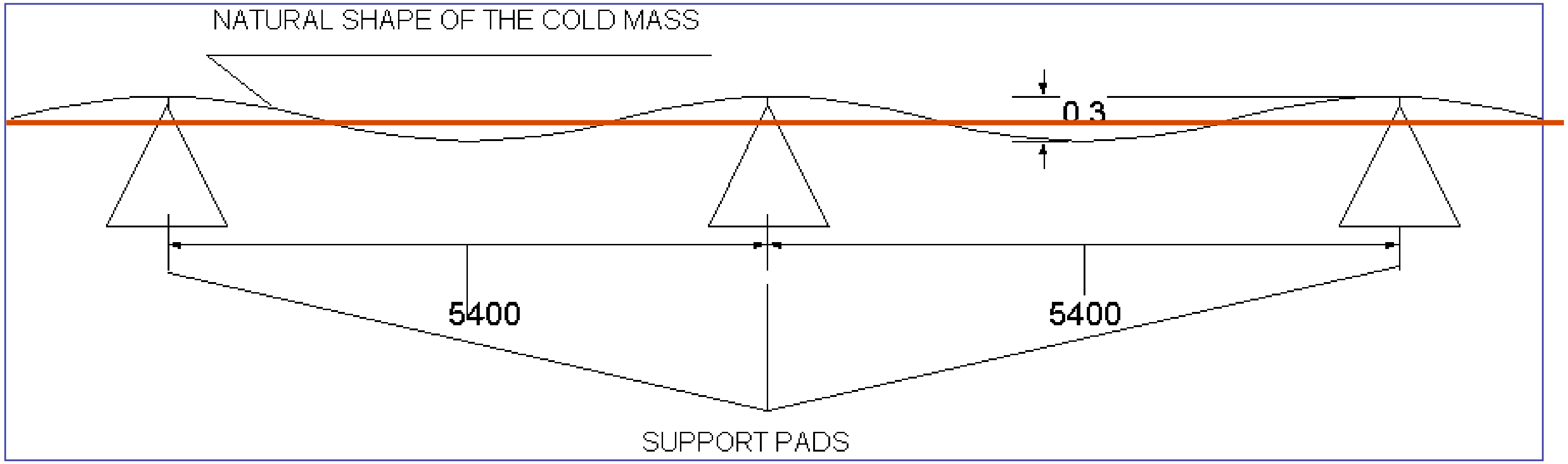
The length of the bent part is 14343mm.



Reference: WGA

Geometrical axes of the dipoles 2

Geometrical tolerances and alignment issues



In the vertical plane, the theoretical shape of the beam channels is a straight line.

Reference: WGA

Requirements for the geometry

Geometrical tolerances and alignment issues

Optical

Obtain the largest mechanical aperture to reduce particle losses

+

Position of the corrector magnets (sextupole,decapole/octupole) which are placed at the ends to correct the persistent current effect

Mechanical

Tolerance: 2 mm radially

Two adjacent magnets are interconnected in the tunnel with flexible bellows

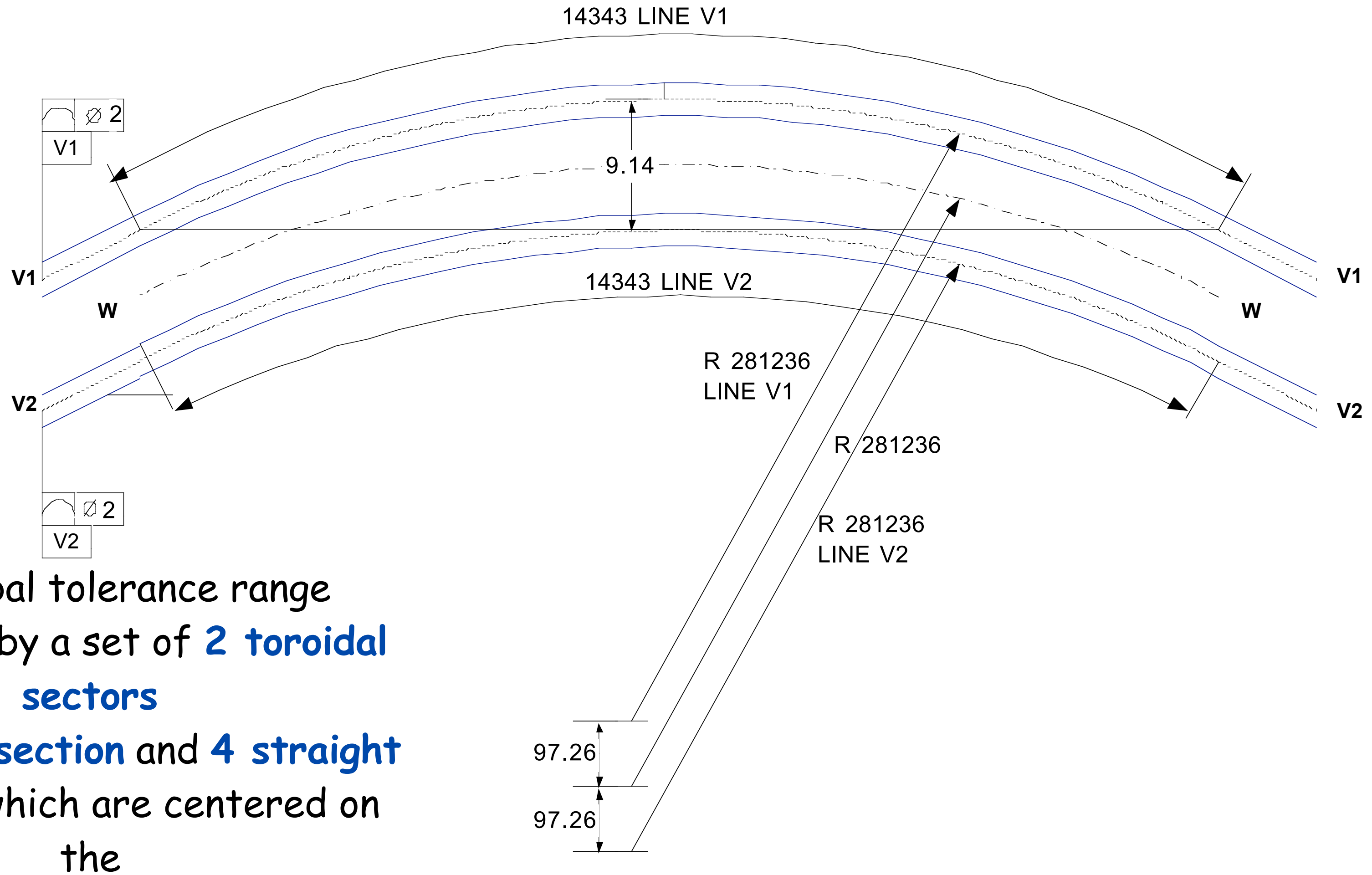
Admissible errors:

Mean :in both x and z ±0.3mm

Random : in both x and z 0.5mm at 1□

The global tolerance range

Geometrical tolerances and alignment issues

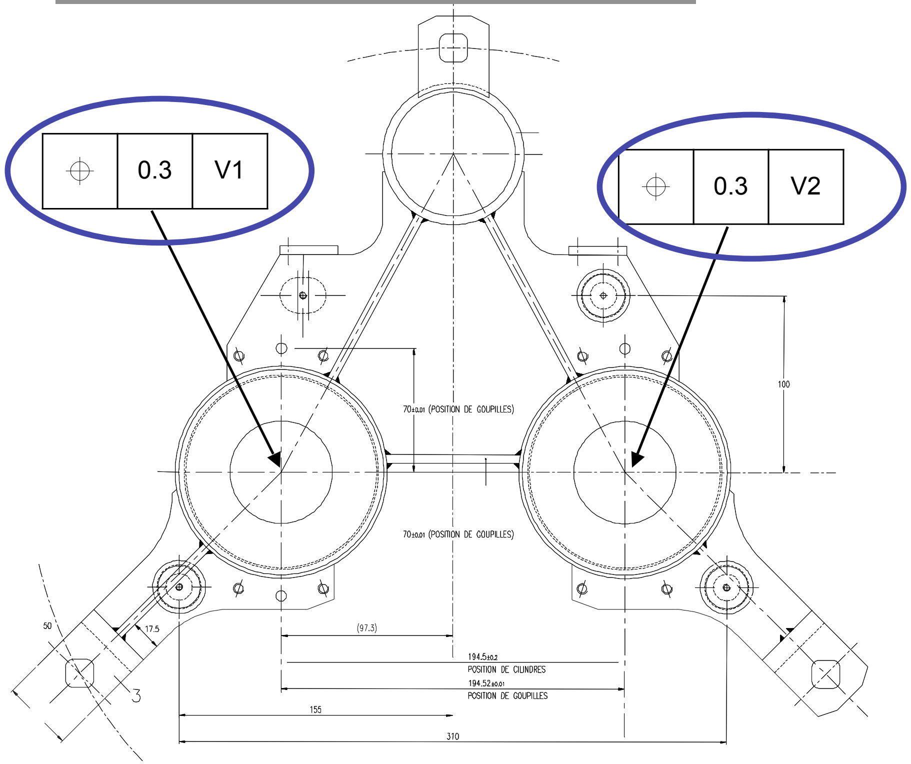


The global tolerance range is defined by a set of **2 toroidal sectors of circular section** and **4 straight cylinders** which are centered on the theoretical geometric axes.

Corrector magnets.Tolerances

Geometrical tolerances and alignment issues

The deviation of the mechnaical axes from the geometrical one : 0.1 mm at 1□ (SUPPORT)



Magnetic center of the CORRECTOR magnets:
Mean : 0.1 mm
Random: 0.1 mm @ 1 □

Measurement-assisted assembly steps

Test plane review. Geometrical Test

Datum Plane Measurement under the press (Half)
(to determine the magnet's curvature under the press, might be omitted when series production)

Datum Plane Measurement (geometric and magnetic (?) axes)
(to determine the theoretical reference system and to check if the curvature is correct)

Corrective actions if necessary for the bending

- **Positioning the cutting machine**
  Connection Side+Lyre Side
- **Positioning the corrector magnets**
  Sextupoles + Deca/Octopoles (only for A type magnets)
- **Positioning the end covers**
  Connection Side+ Lyre Side
- **Positioning of the cold feet pads**

Components positioning

Datum Plane Measurement
(to determine the theoretical system)

- **Check of the position of the cold feet pads**
- **Pre-Positioning the cbt. extremities (V1, V2)**
  Connection Side+Lyre Side
- **Check the cbt. extremities after welding of the end flanges**
  Connection Side + Lyre Side
- **Positioning the cbt. extremities (V1, V2)**
  Connection Side+ Lyre Side

Components positioning

Final checks: Datum Plane Measurement

Measurements after the pressure test

Components and tools vs the geometry

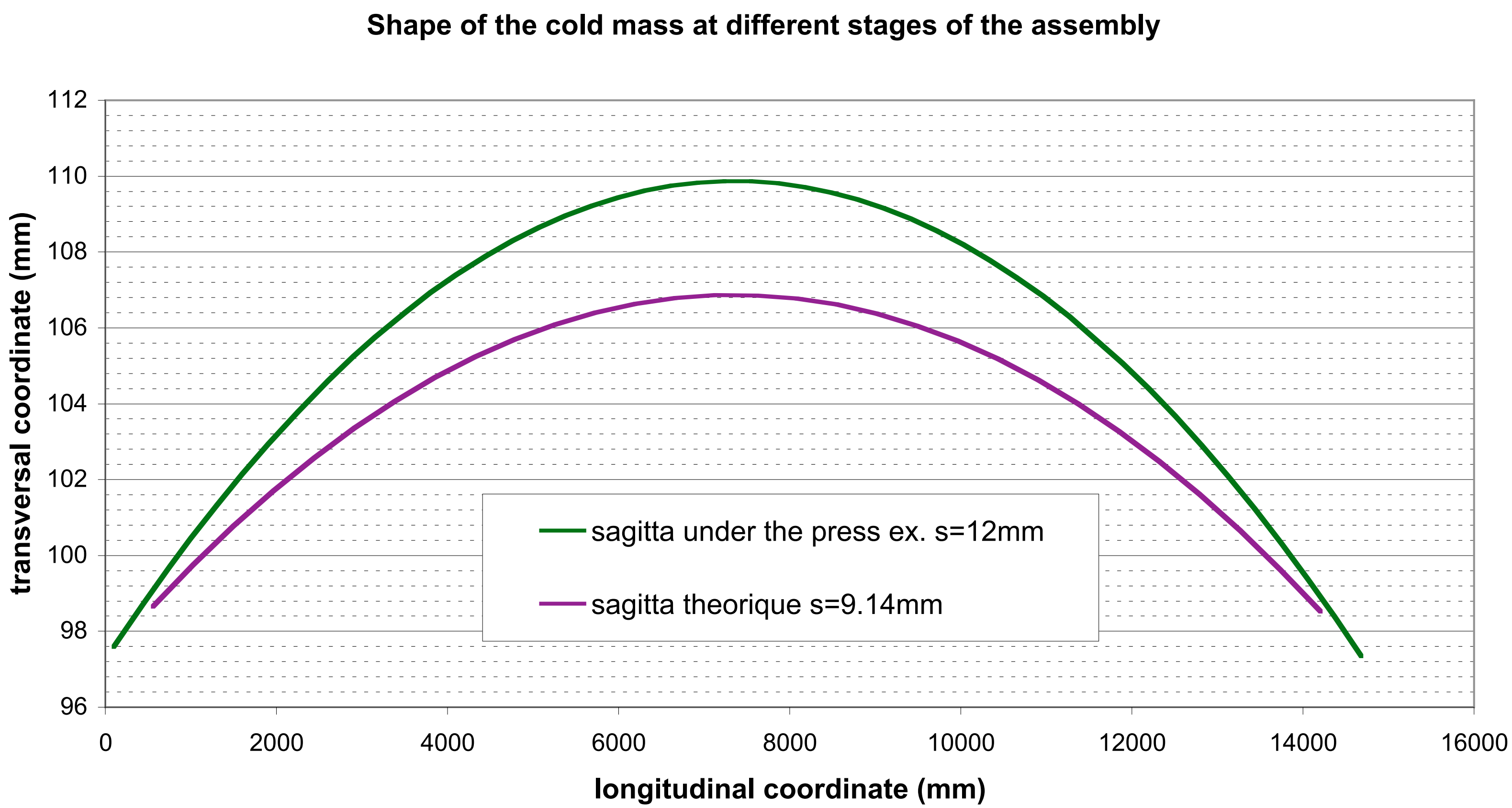
Test plane review. Geometrical Test

- Collared coils (straight and laminated)
- Half yoke (laminated)
- Half cylinders (straight or bent sagitta (s) : s_c = (0, 30mm))
- Welding press (pre bent to a $s_{wp>}$ s_{cm})

The dipole cold mass curvature in the transversal plane is obtained by placing the magnet on a curved press table and, under press load, welding the two half-cylinders to form a skin around the active part. When the load is released after welding, the magnet loses a non-negligible fraction of the curvature due to elastic spring back (aprox. 23%). To compensate the spring back, the press table is shaped to a slightly higher curvature (smaller radius) than that of the CM nominal shape, but several attempts were needed to determine the correct press table shape.

The spring back of the dipole cold masses

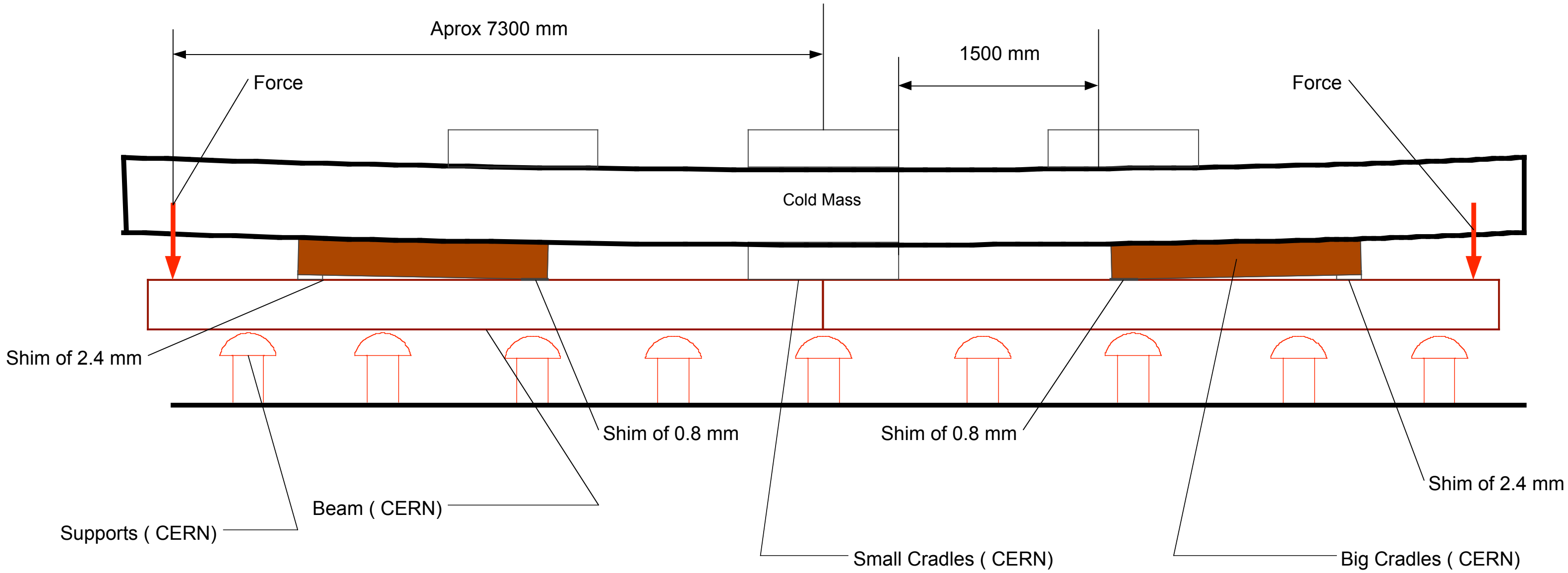
Geometrical tolerances and alignment issues



From the trials, some cold masses ended up being insufficiently or too strongly curved.

Re-shaping of the dipole cold masses

Geometrical tolerances and alignment issues



These cold masses were re-shaped under the press table or in a special re-shaping bench BUT they show an instability of their correction which was observed after the cold test of the magnets.

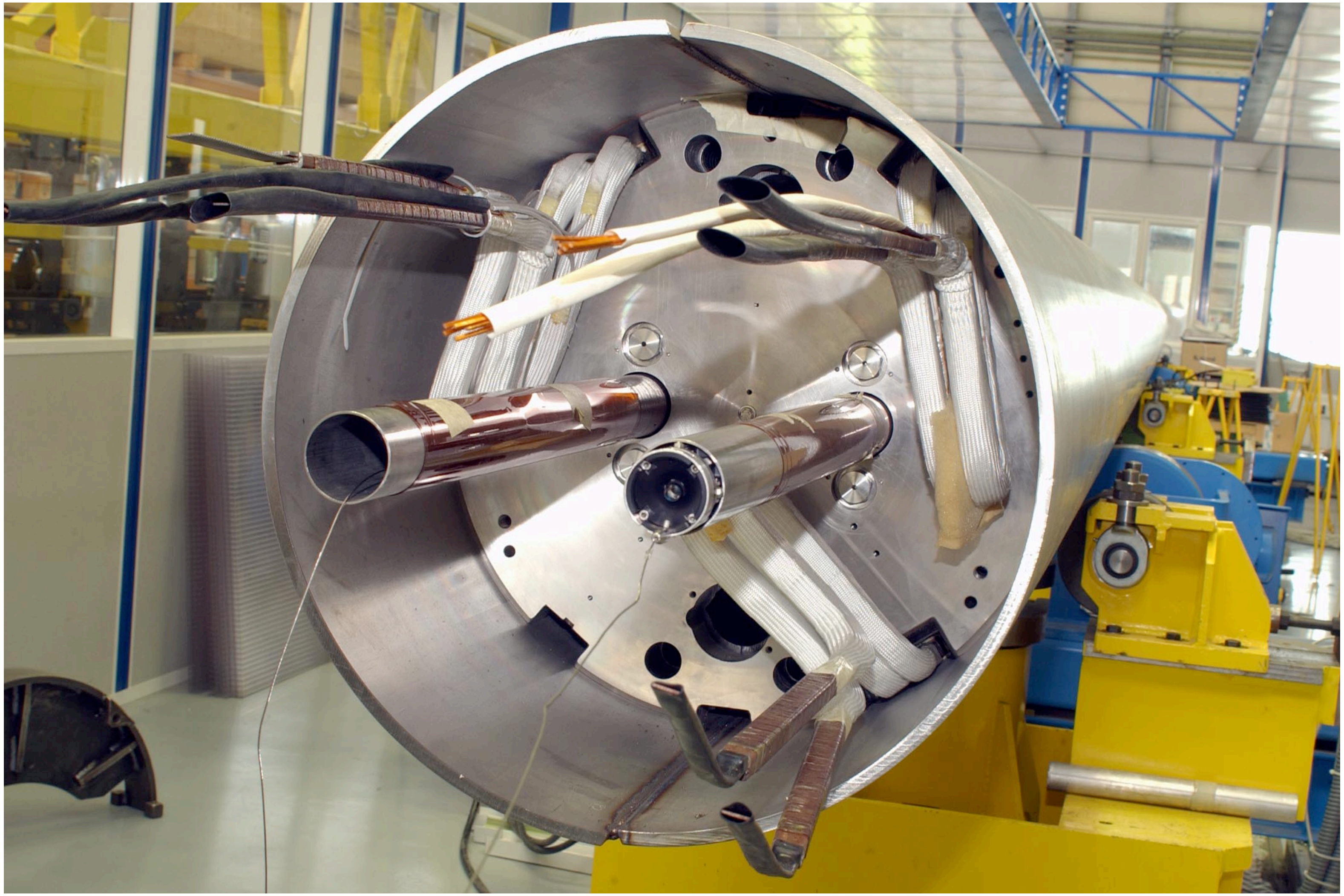
Components and tools vs the geometry

Test plane review. Geometrical Test

- Collared coils (straight and laminated)
- Half yoke (laminated)
- Half cylinders (straight or bent sagitta (s) : s_c = (0, 30mm))
- Welding press (pre bent to a $s_{wp>}$ s_{cm})
- Corrective action of the curvature (because $s_{cm} \neq s_{wp}$ - spring back of the cold mass)
- Supporting condition of the dipole cold mass

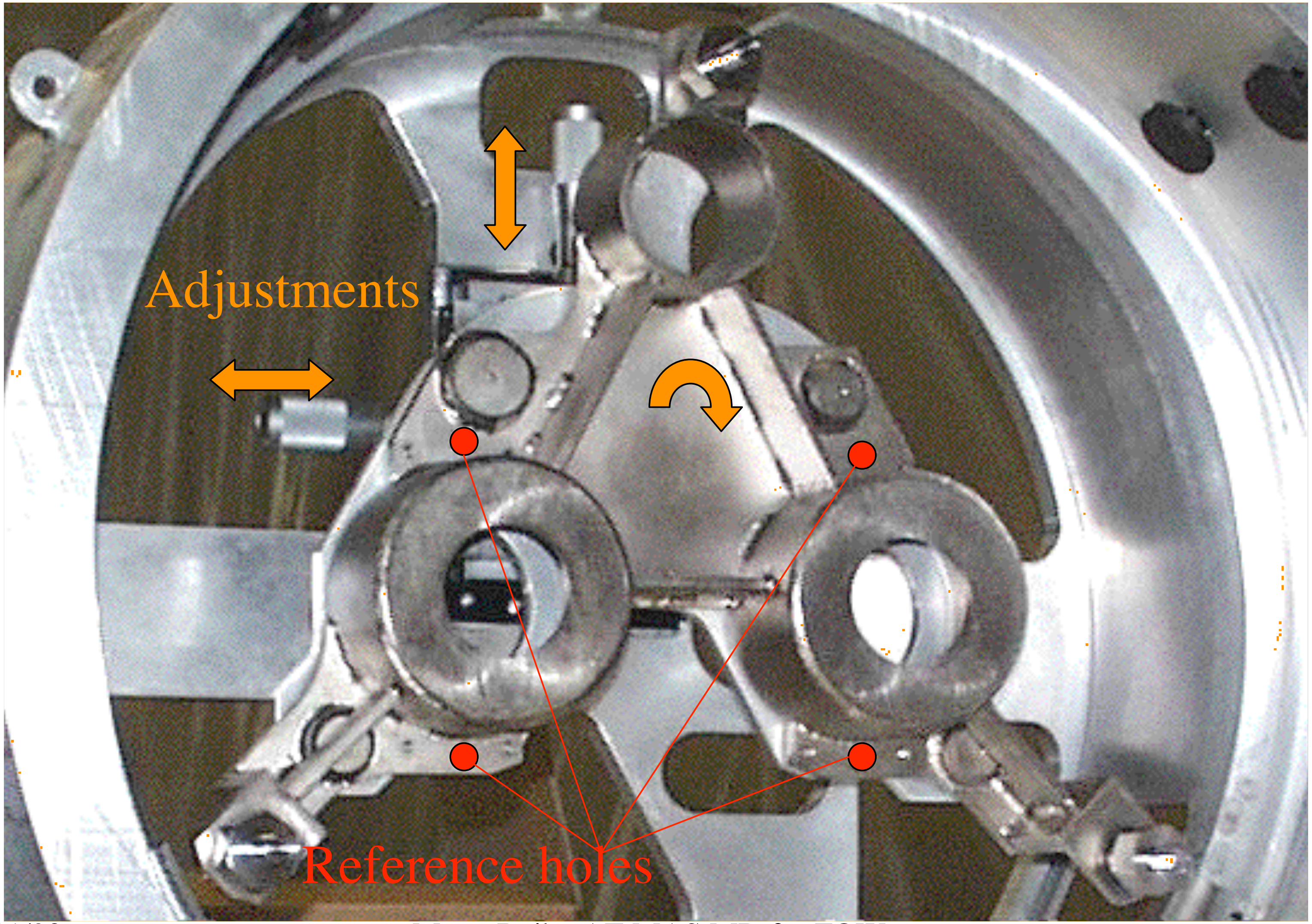
Positioning of the corrector magnets

Geometrical tolerances and alignment issues



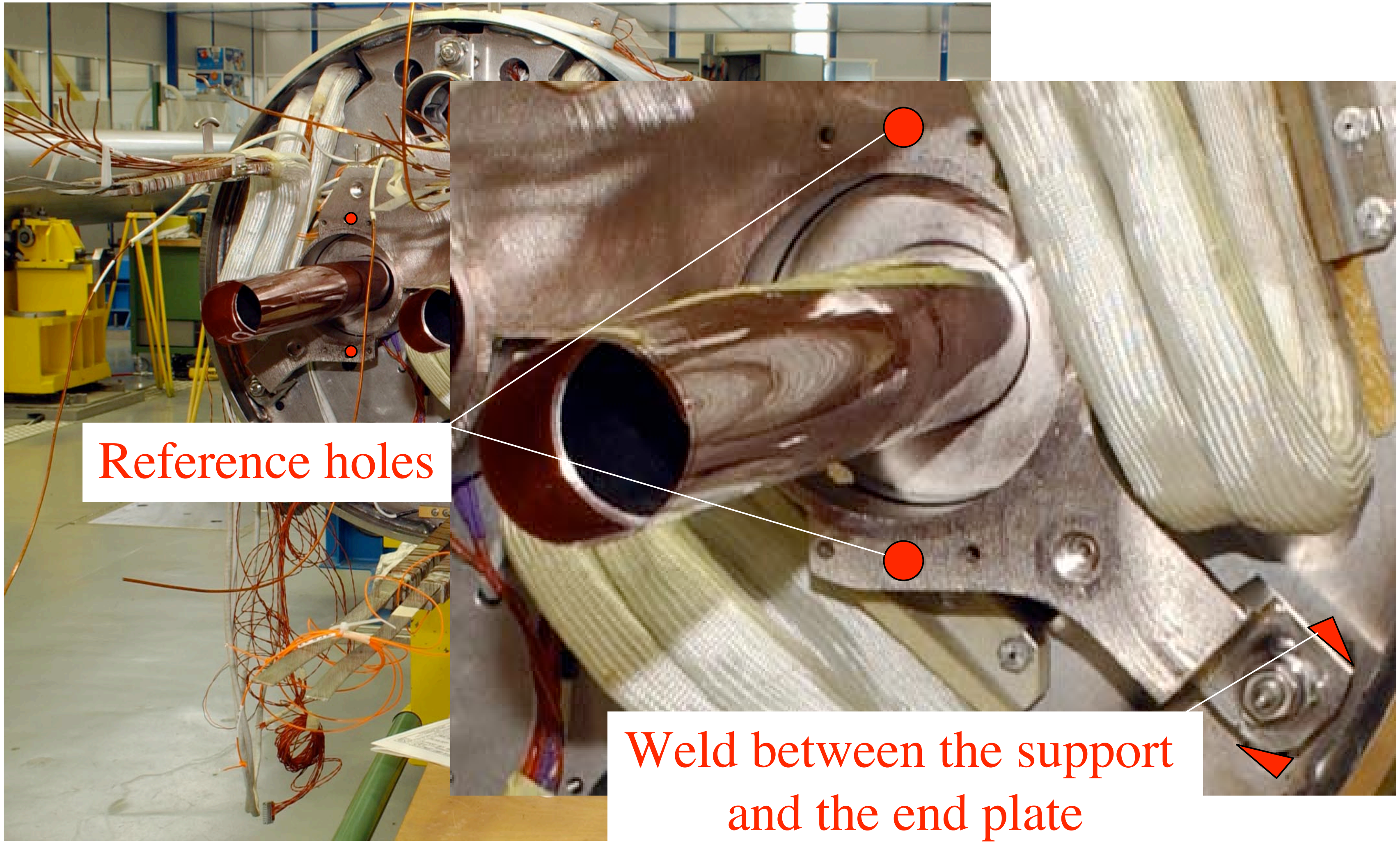
Positioning of the corrector magnets

Geometrical tolerances and alignment issues



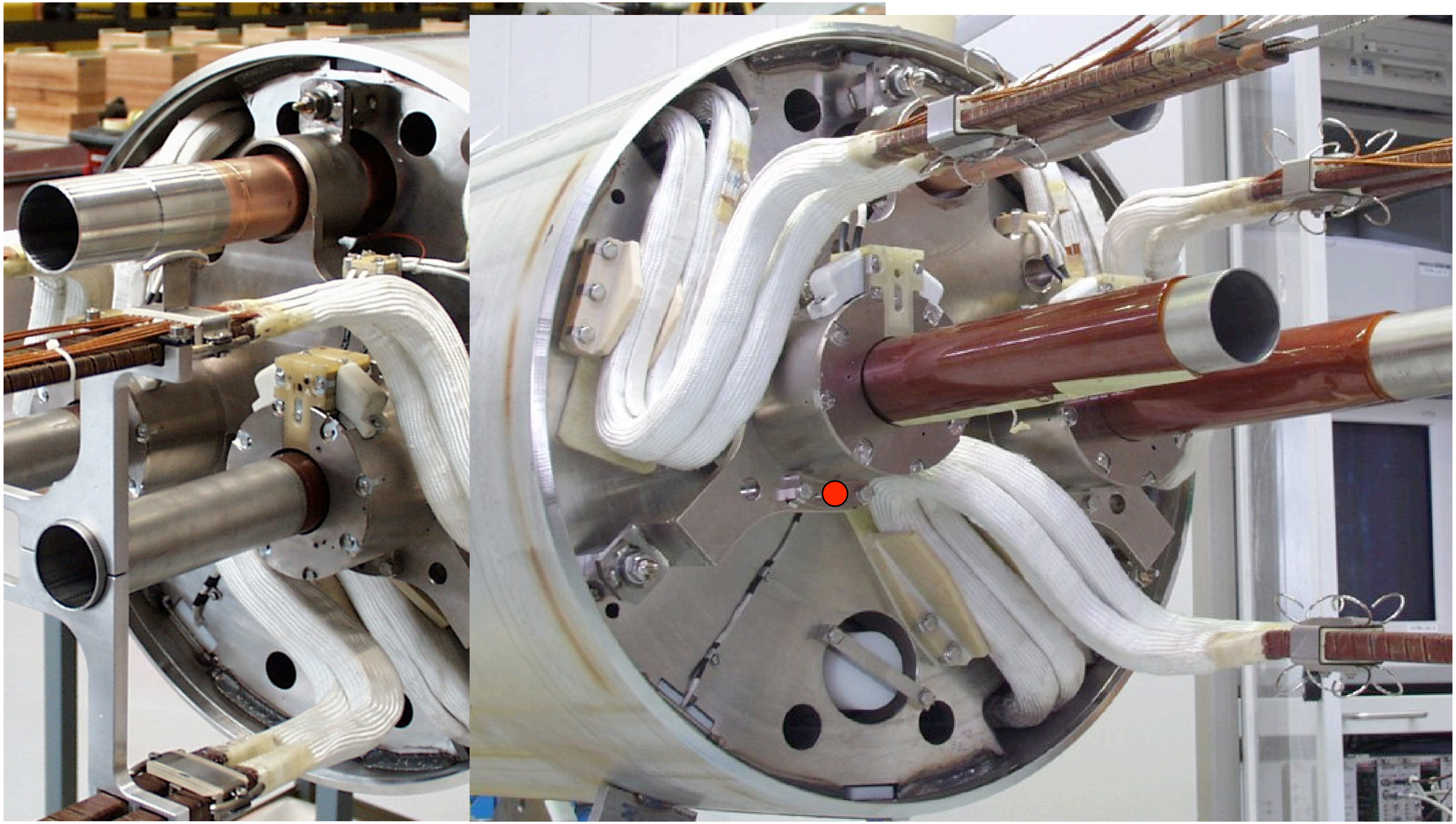
Positioning of the corrector magnets

Geometrical tolerances and alignment issues



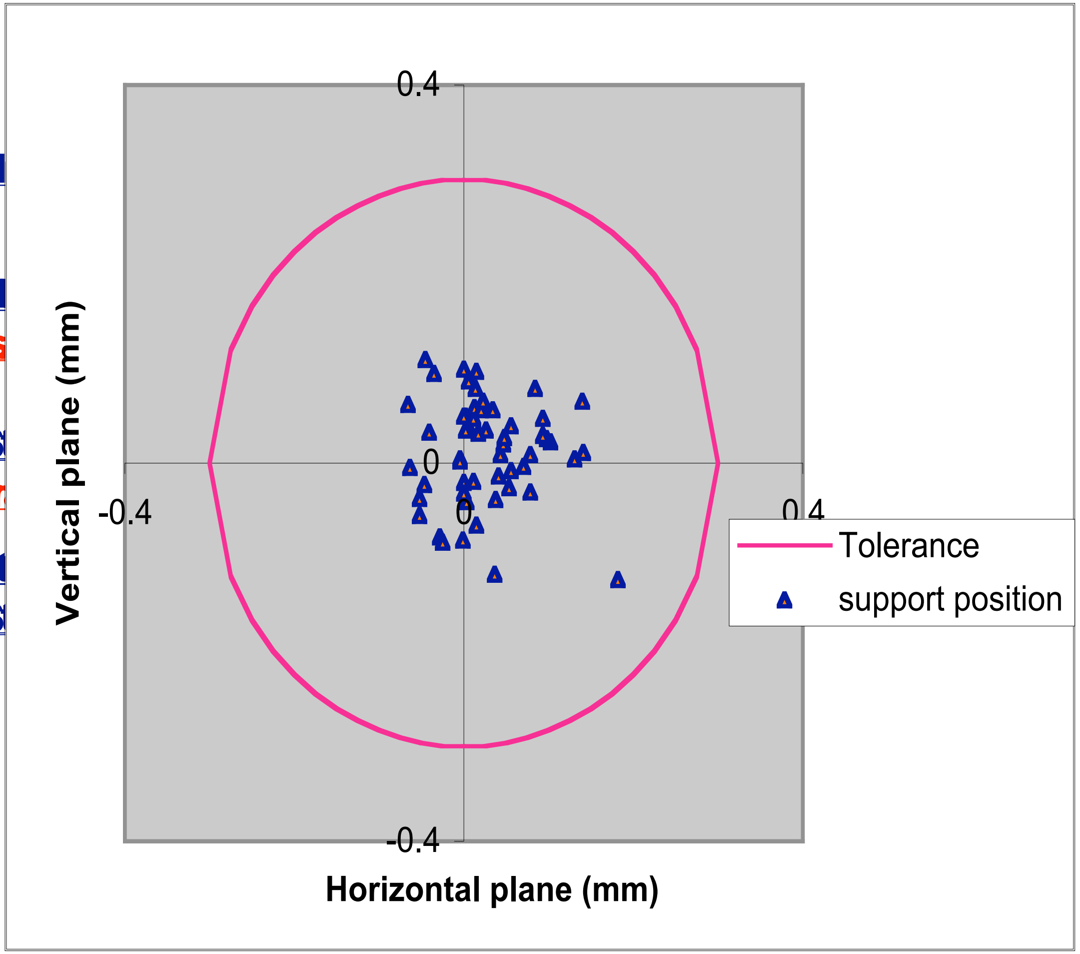
Positioning of the corrector magnets

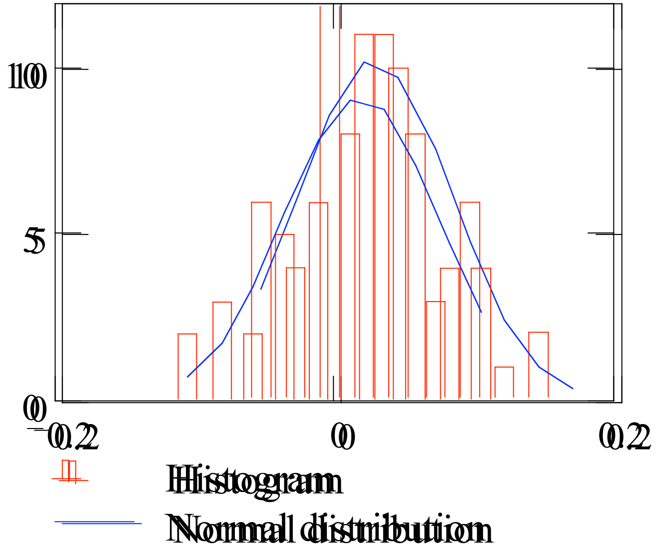
Geometrical tolerances and alignment issues



Position of the corrector magnets support

Geometrical tolerances and alignment issues





Requirements for the geometry

Geometrical tolerances and alignment issues

Optical

Obtain the largest mechanical aperture to reduce particle losses

+

Position of the corrector magnets (sextupole,decapole/octupole) which are placed at the ends to correct the persistent current effect

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Tolerance: 2 mm radially

Two adjacent magnets are interconnected in the tunnel with flexible bellows

Admissible errors:

Mean :in both x and z ±0.3mm

Random : in both x and z 0.5mm at 1□

Mechanical aperture at different stages

Geometrical tolerances and alignment issues

Assumption:

✓Magnetic versus geometric axis: 0.1 mm

Assembly:

✓Mechanic versus geometric axis: 0.33 mm

✓Measurement accuracy: 0.07 mm

Cryostating

✓Thermo mechanical deformation of the cold feet: 0.1 mm

✓Cryostat ovalisation and straightness errors: 0.1 mm

✓Geometric axes reference on the cryostat: 0.1 mm

✓Mispositionning of the dipole central foot : 0.1 mm

Dynamic effect

✓Instability of the geometry: 0.2 mm

Positioning in the tunnel

✓Transport to the tunnel: 0.15 mm

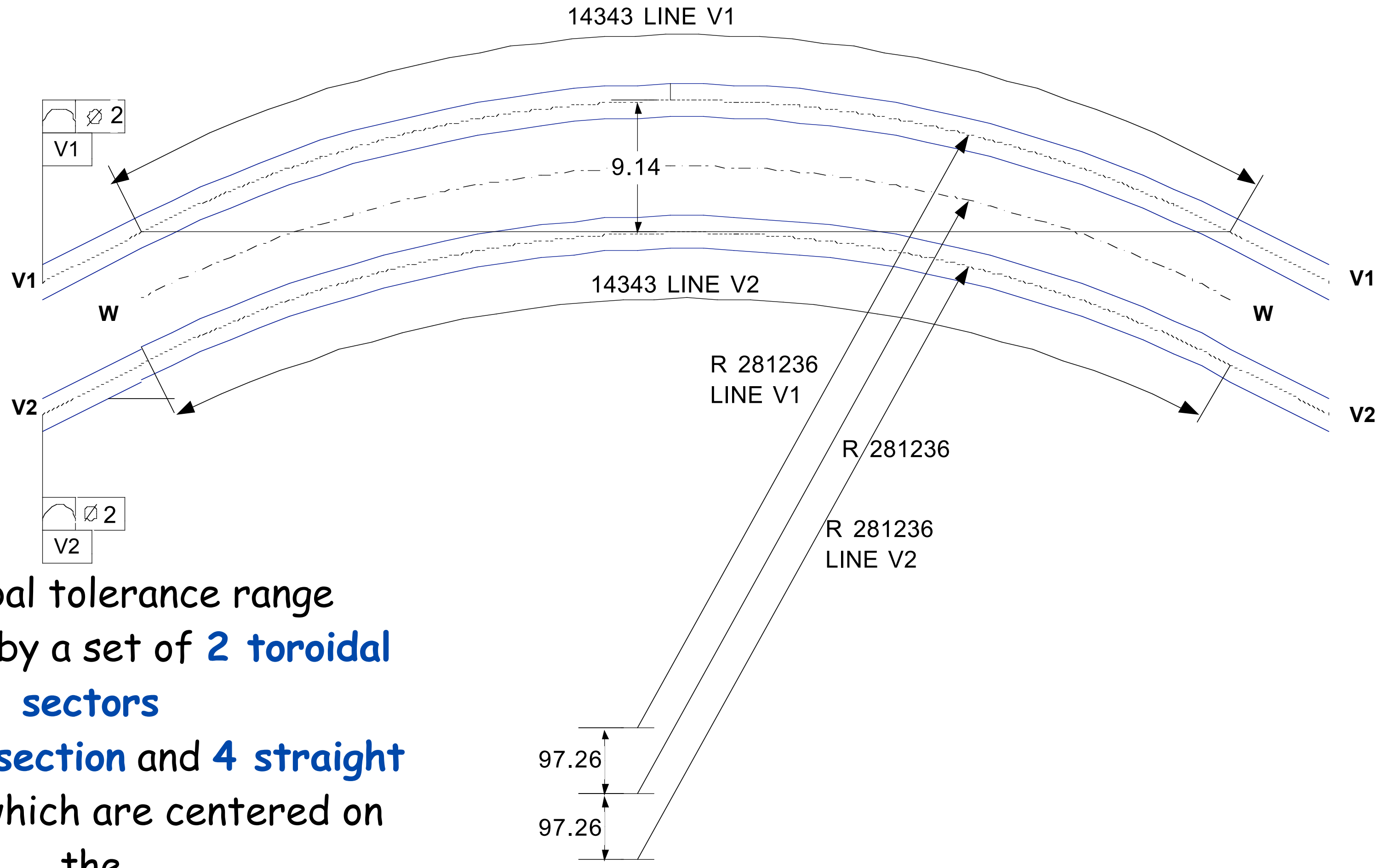
✓Tunnel movement after one year: 0.28 mm

Beam screen

✓Position of the beam screen axis : 0.3 mm

The global tolerance range

Geometrical tolerances and alignment issues



The global tolerance range is defined by a set of **2 toroidal sectors of circular section** and **4 straight cylinders** which are centered on the theoretical geometric axes.

Mechanical aperture at different stages

Geometrical tolerances and alignment issues

Assumption:
✓Magnetic versus geometric axis: 0.1 mm

Assembly: (and correction if needed)
✓Mechanic versus geometric axis: 0.33 mm
✓Measurement accuracy: 0.07 mm

Cryostating
✓Thermo mechanical deformation of the cold feet: 0.1 mm
✓Cryostat ovalisation and straightness errors: 0.1 mm
✓Geometric axes reference on the cryostat: 0.1 mm
✓Mispositionning of the dipole central foot : 0.1 mm

Dynamic effect
✓Instability of the geometry: 0.2 mm

Positioning in the tunnel
✓Transport to the tunnel: 0.15 mm
✓Tunnel movement after one year: 0.28 mm

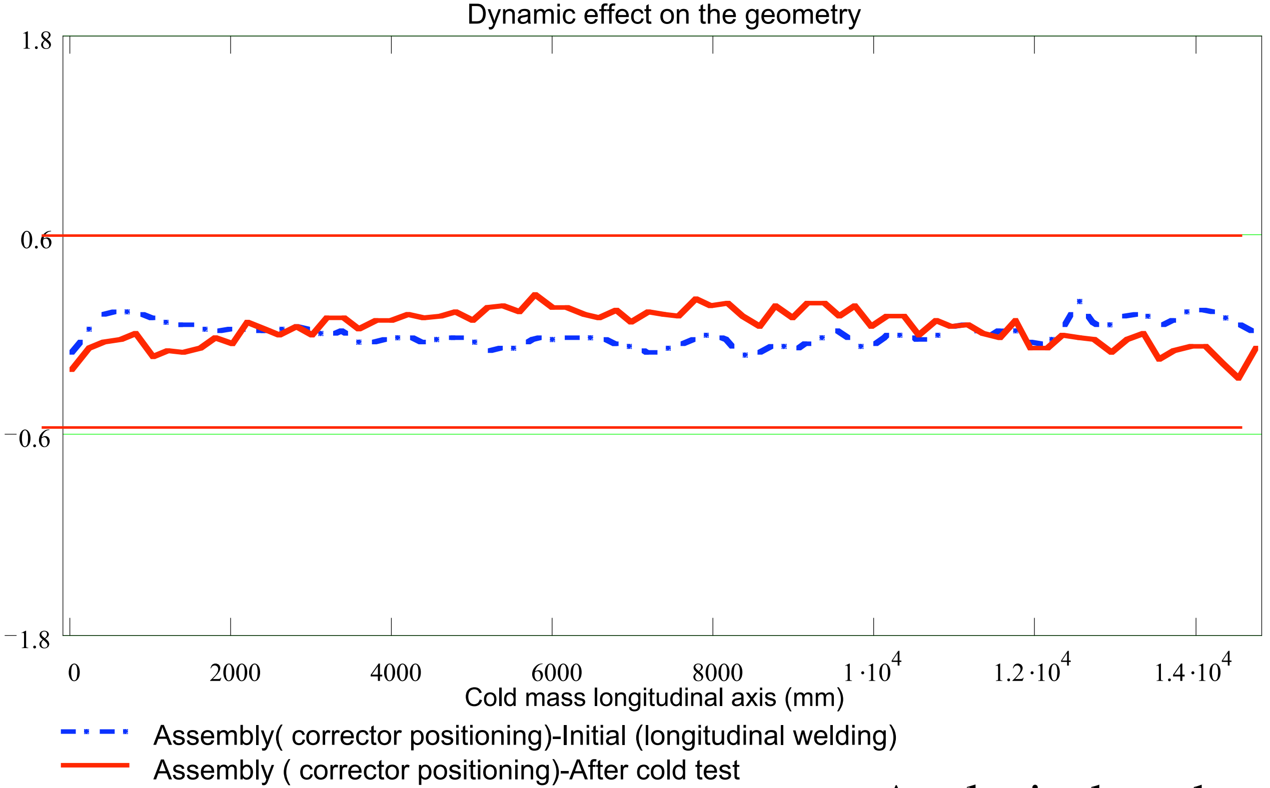
Beam screen
✓Position of the beam screen axis : 0.3 mm

Acceptable change of the geometry

Geometrical tolerances and alignment issues

Dynamic effect

✓Instability of the geometry: 0.2 mm



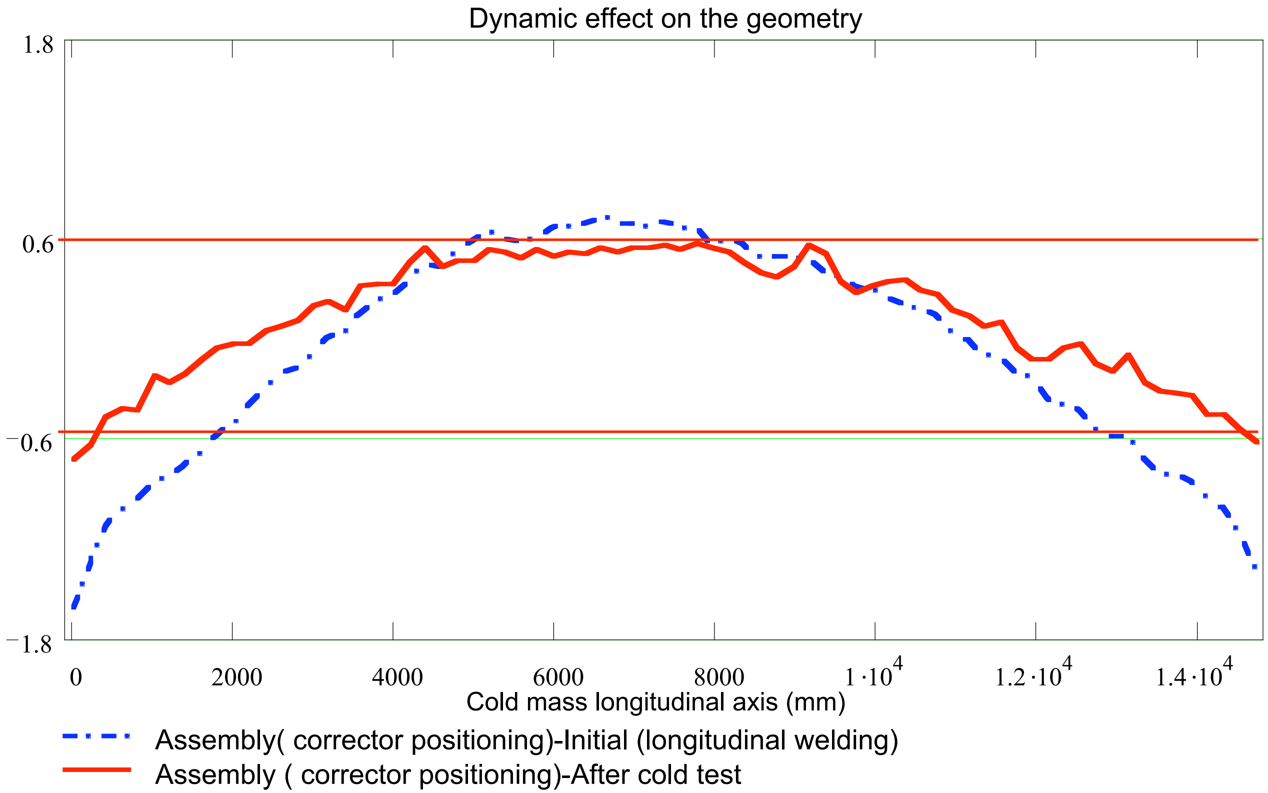
Analysis done by. R.Chamizo

Unacceptable change of the shape

Geometrical tolerances and alignment issues

Dynamic effect

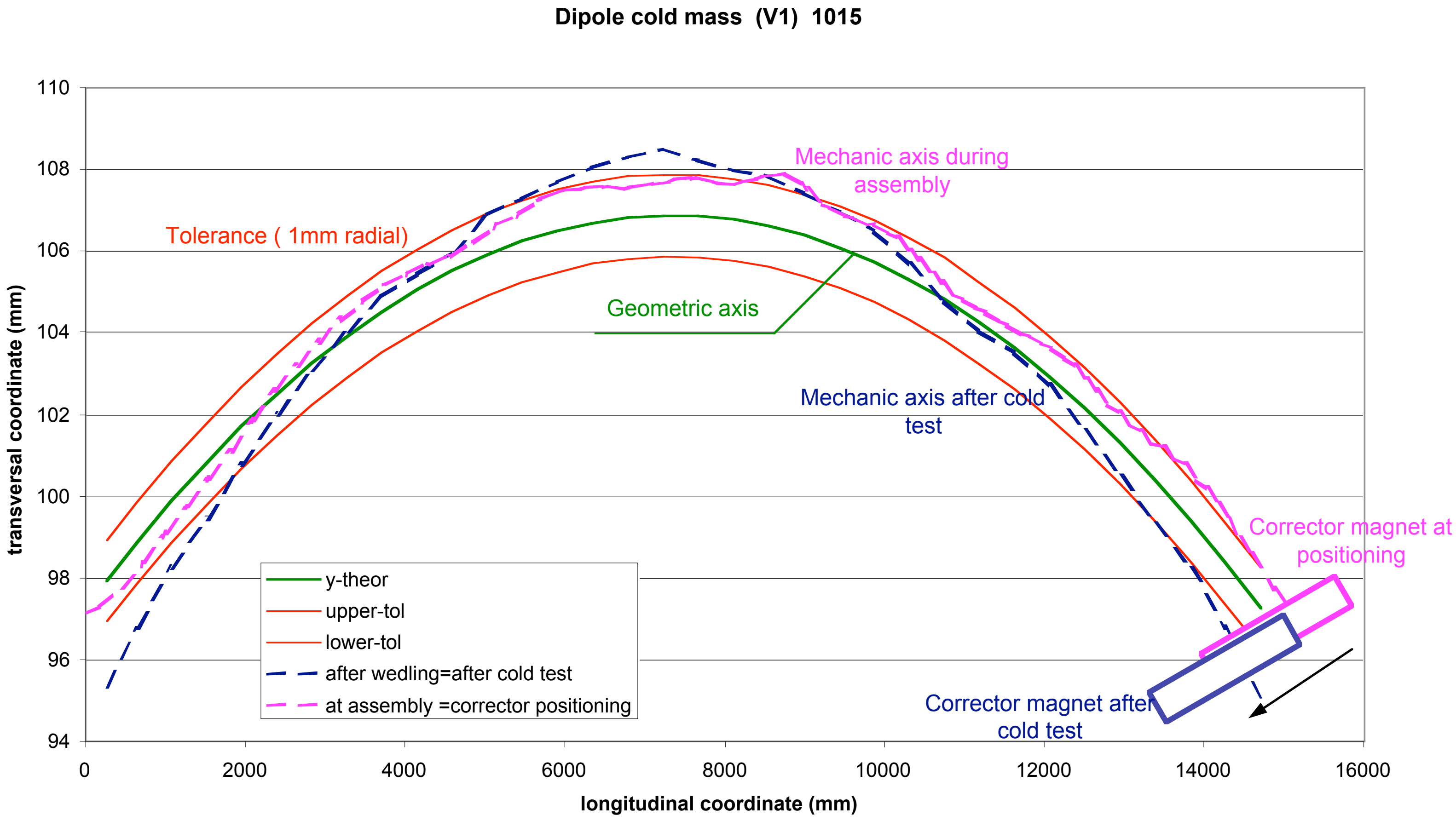
✓Instability of the geometry: 0.2 mm



Analysis done by. R.Chamizo

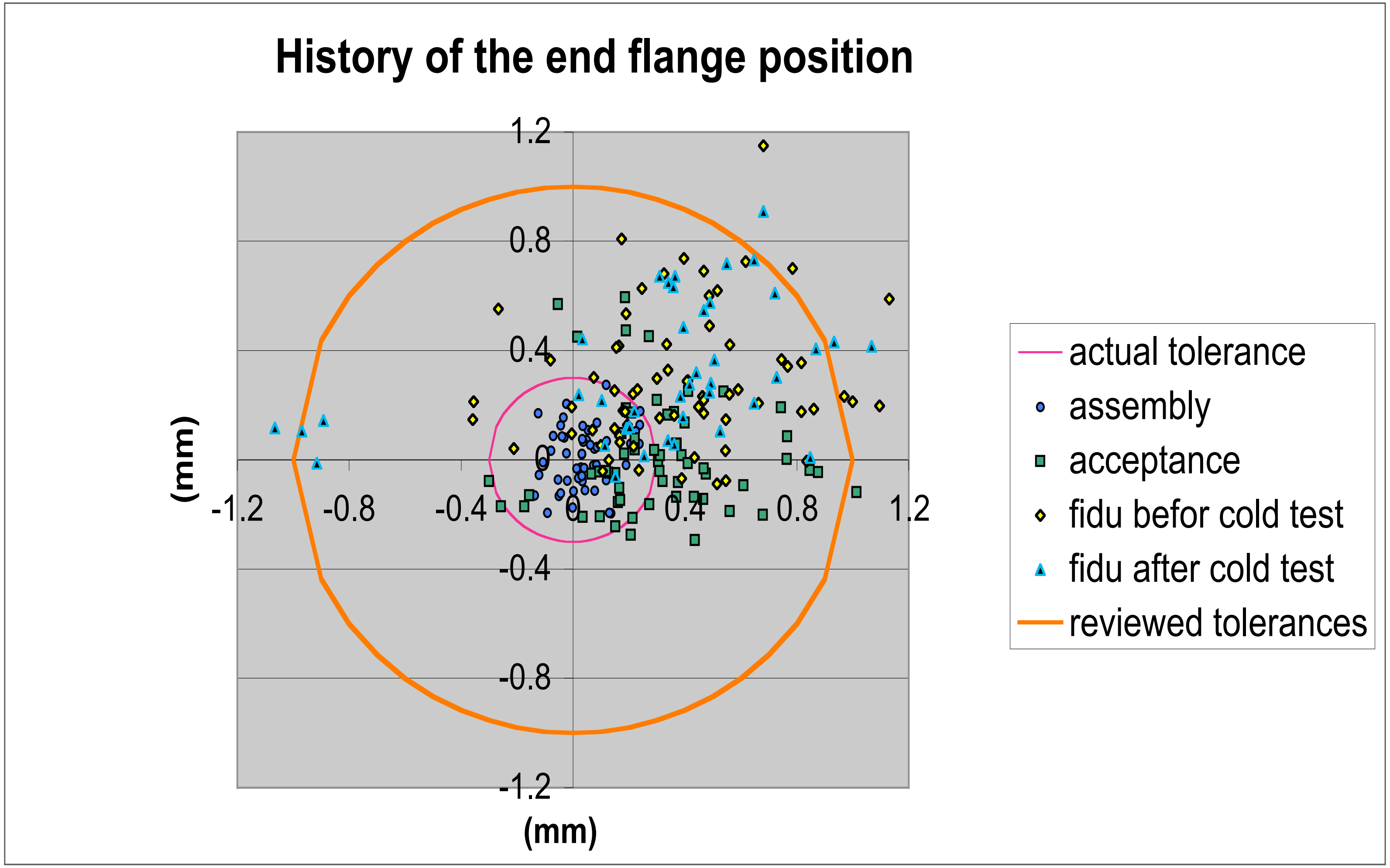
Consequences of the shape variation 1

Geometrical tolerances and alignment issues



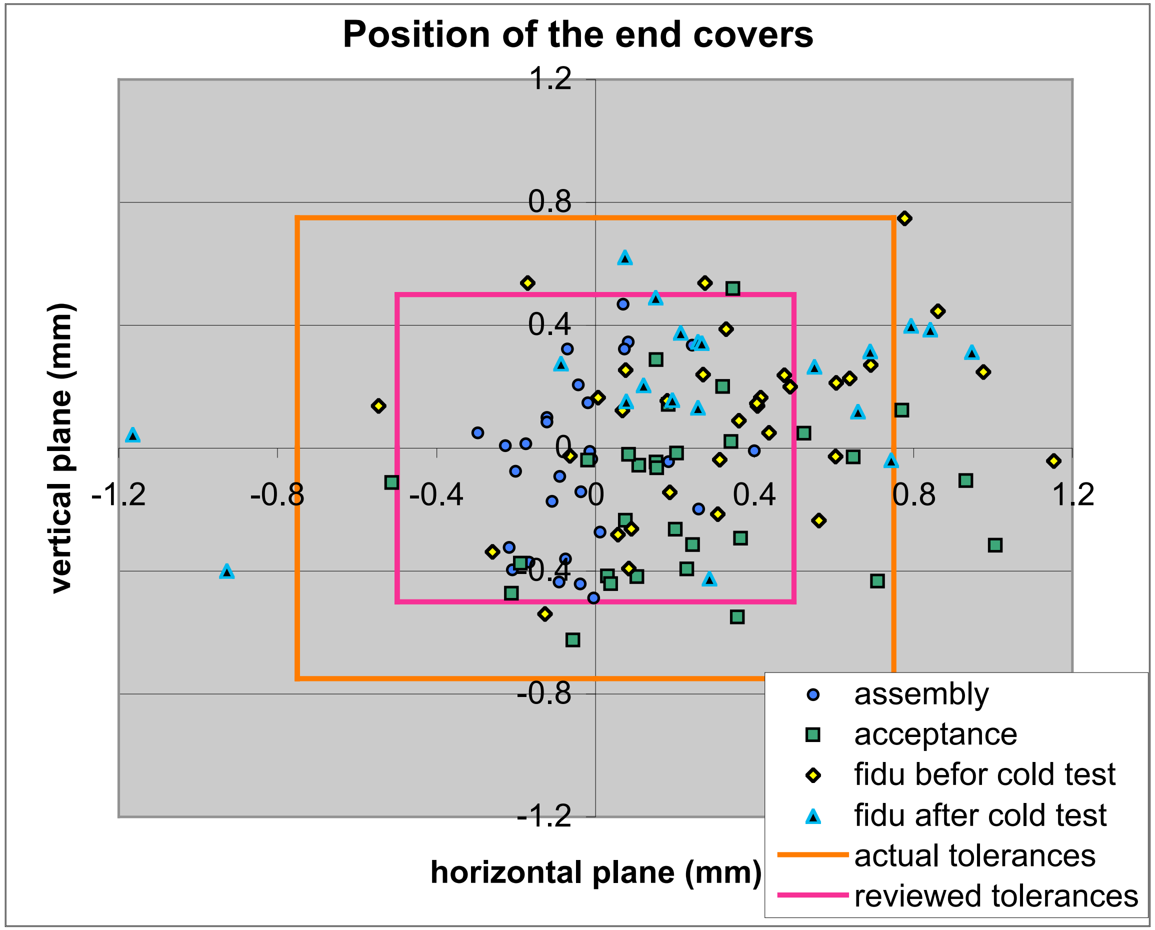
Consequences of the shape variation 2

Geometrical tolerances and alignment issues



Consequences of the shape variation 3

Geometrical tolerances and alignment issues



What we can say today regarding instability?

Geometrical tolerances and alignment issues

1. There are 6 magnets over 11 studied which has suffered changes in its shape after the assembly
2. All those magnets were re-shaped after the longitudinal welding of the half cylinders
3. All those magnets tends to take again their initial shape (after longitudinal welding); we can quantify the potential instability of each of those magnets
4. There are 10 other potentially instable magnets still in the industry both with too large or too small sagitta
5. The corrector magnets of these dipoles are most probably misaligned of aprox. 1-1.5mm transversally

Conclusions

Geometrical tolerances and alignment issues

- The parameters of the bending tools and influencing components should be adjusted to control the variation of the spring back of the magnets better than +/-1mm.

- The corrections of the cold mass geometry as it is done in the industry today is not enough stable in time (and during thermal cycling) and as a consequence the corrector magnets and the ends of the dipole cold masses in some cases after the thermal cycling is out of tolerance in spite of the successful assembly in the industry.

- A new (stable) correction procedure should be define for the existing badly shaped cold masses.

What we can propose at short term?

Geometrical tolerances and alignment issues

✓A badly shaped magnets causes problems for the assembly, BUT up to 1 mm radial error of the shrinking cylinder and 1.5 mm of the mechanical axis the assembly can be done without making a re-shaping operation which is not stabile

✓The reviewed tolerances of the different components helps for the assembly of the “ badly shaped cold masses “ without making a corrective action

✓Study solutions for a corrective action (stable in time) and the acceptability of the already reshaped magnets

Acknowledgments

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