Coil detailed design and fabrication

Winding and reaction

F. Rondeaux

Outline

- Coils detailed geometry
  - Overview
  - Geometry details
  - Layer jump
  - Posts design
  - Electrical insulation

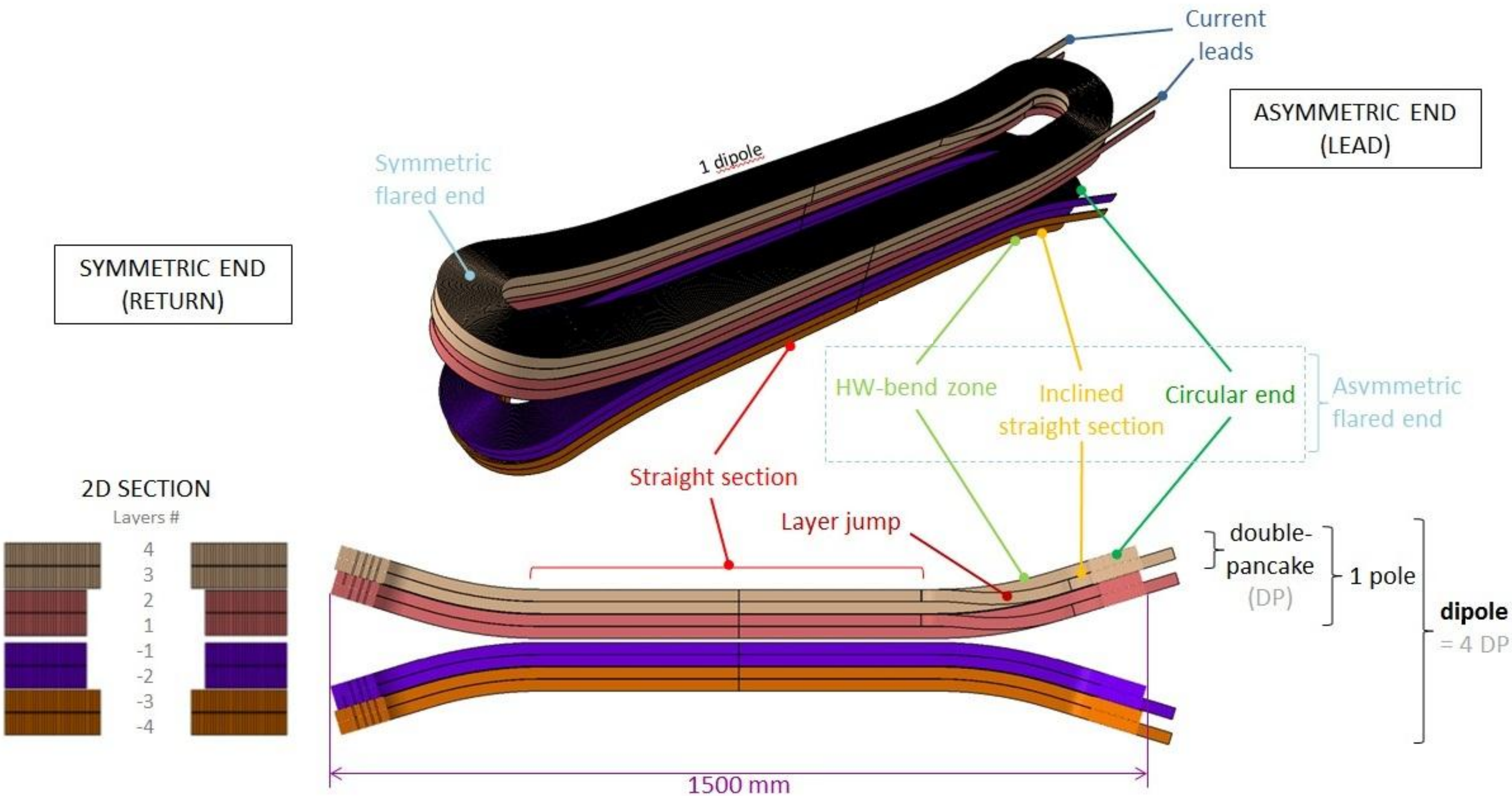
- Winding tooling and process

- Reaction tooling

  Reaction process, impregnation tooling and process will be discussed by Juan Carlos in the next presentation

- Tests program

Coils detailed geometry - overview

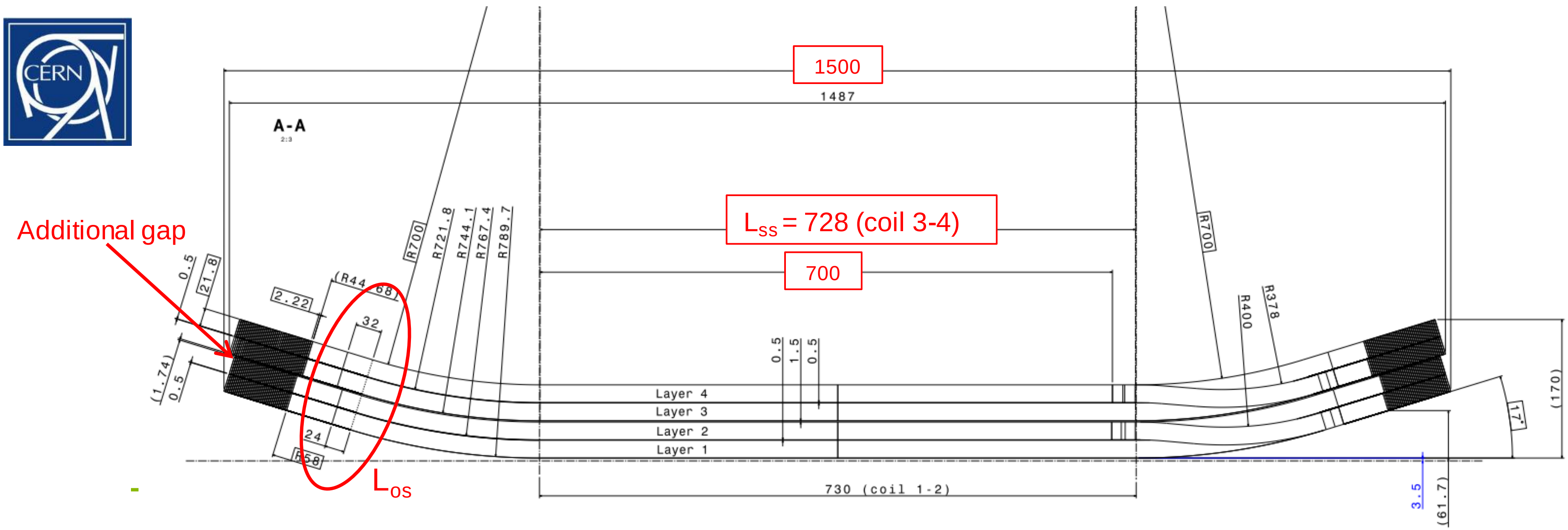


1 color = 1 cable unit lenght (223 m / 253 m)

Coils geometry details

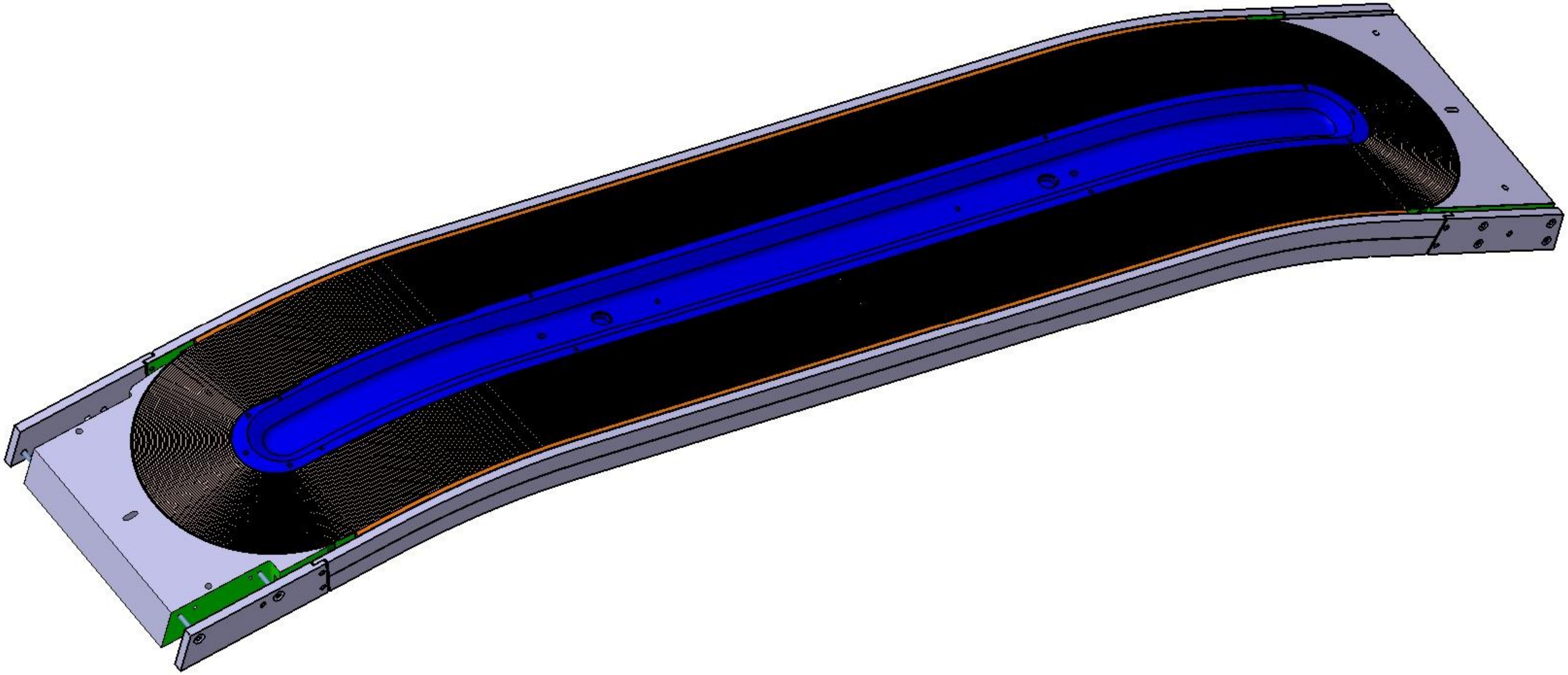
- Adjustments in double pancake 1-2 and 3-4 following the last review:
  - ➢ Forced contact between the coils along the straight section: reduce L_{ss} by 2mm for coil 3-4. The ramp angles remain identical everywhere (17°).
  - ➢ Avoid stress concentration around sharp edges in the ends: enlarge L_{os} to 32mm for coil 3-4.

    => additional gaps of 0.24 mm are created along the ends (to be filled during the assembly process)
  - ➢ Inter-coils insulation thickness has been increased from 0.5 to 1.5 mm for the instrumentation traces, leading to increase the HW radiuses for coil 1-2
- R_{HW} = 700 mm, aperture > 61 mm, h_{tot} < 200 mm



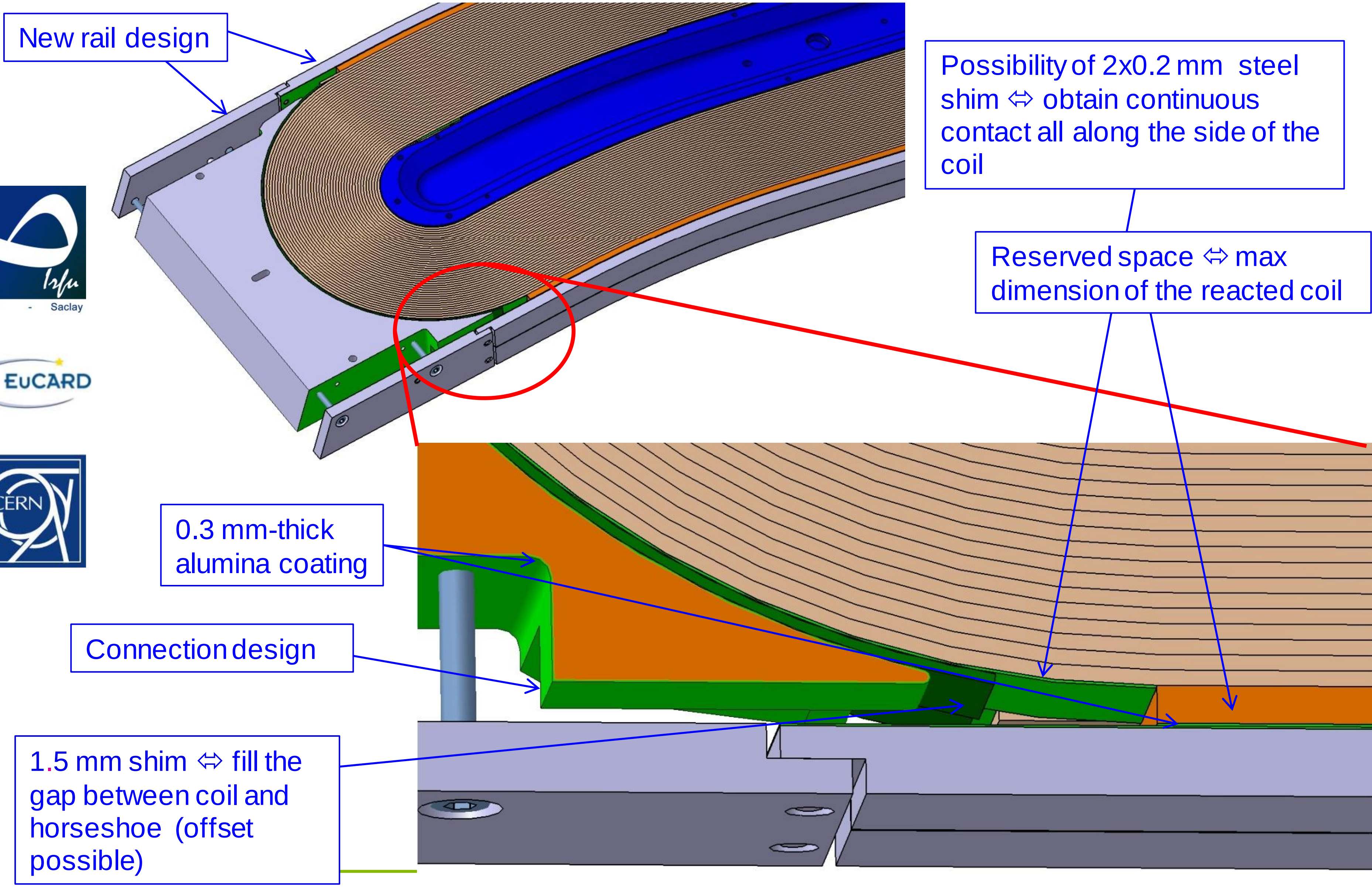
Detailed 3D model of coil 3-4

View of the double pancake with its components



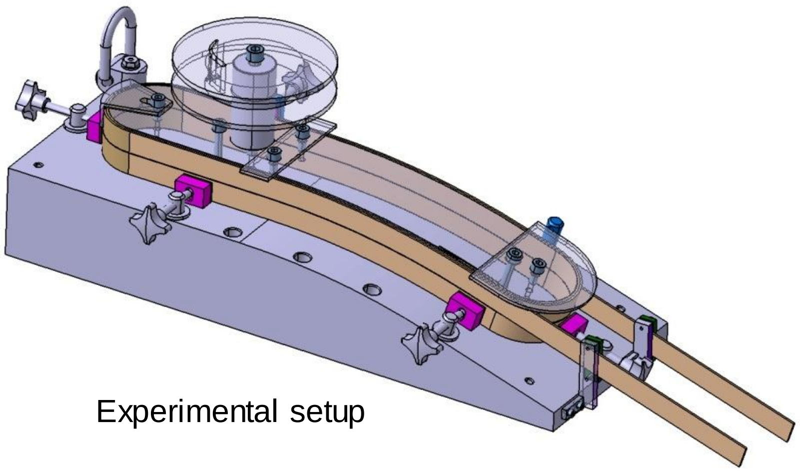
Draftsman:
Jean-François Millot

Detailed 3D model of coil 3-4

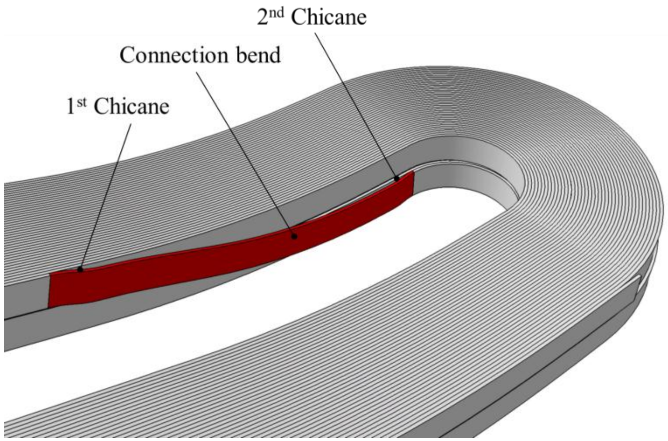


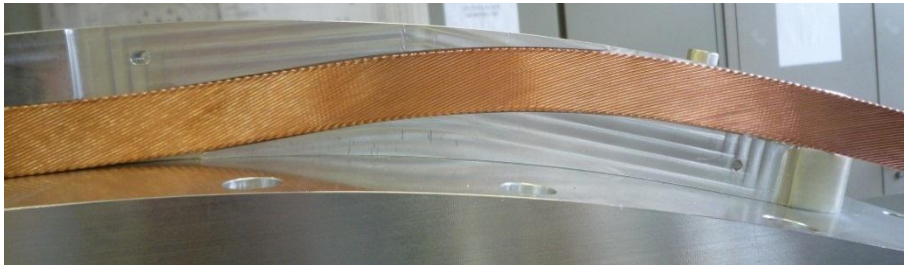
Layer jump

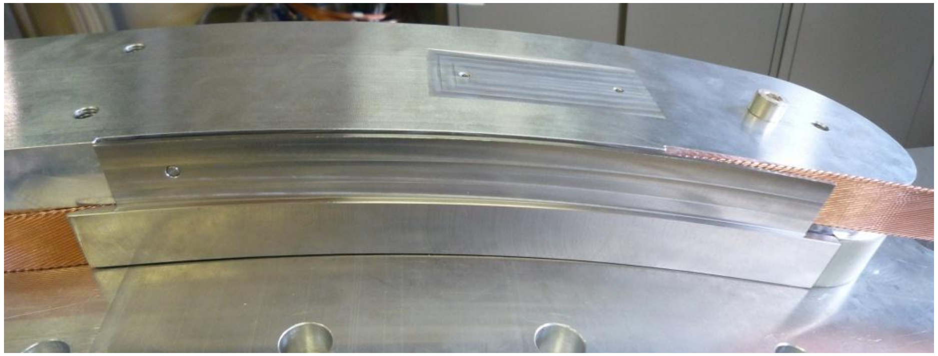
- In the HW zone, « double chicane » solution selected
- Shim easier to position and fix, ensure better protection of the jump zone
- Tests have been done:



Experimental setup

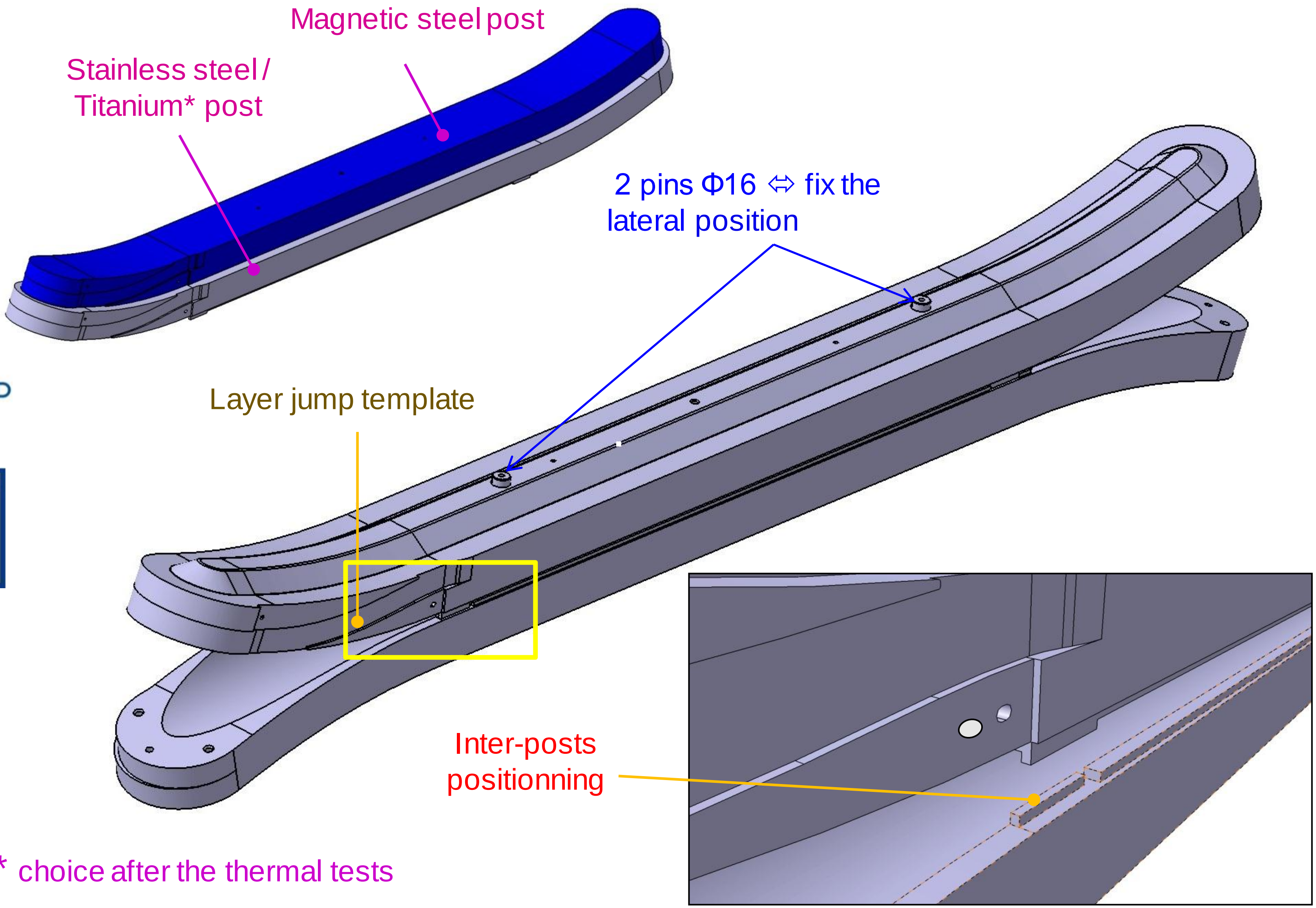






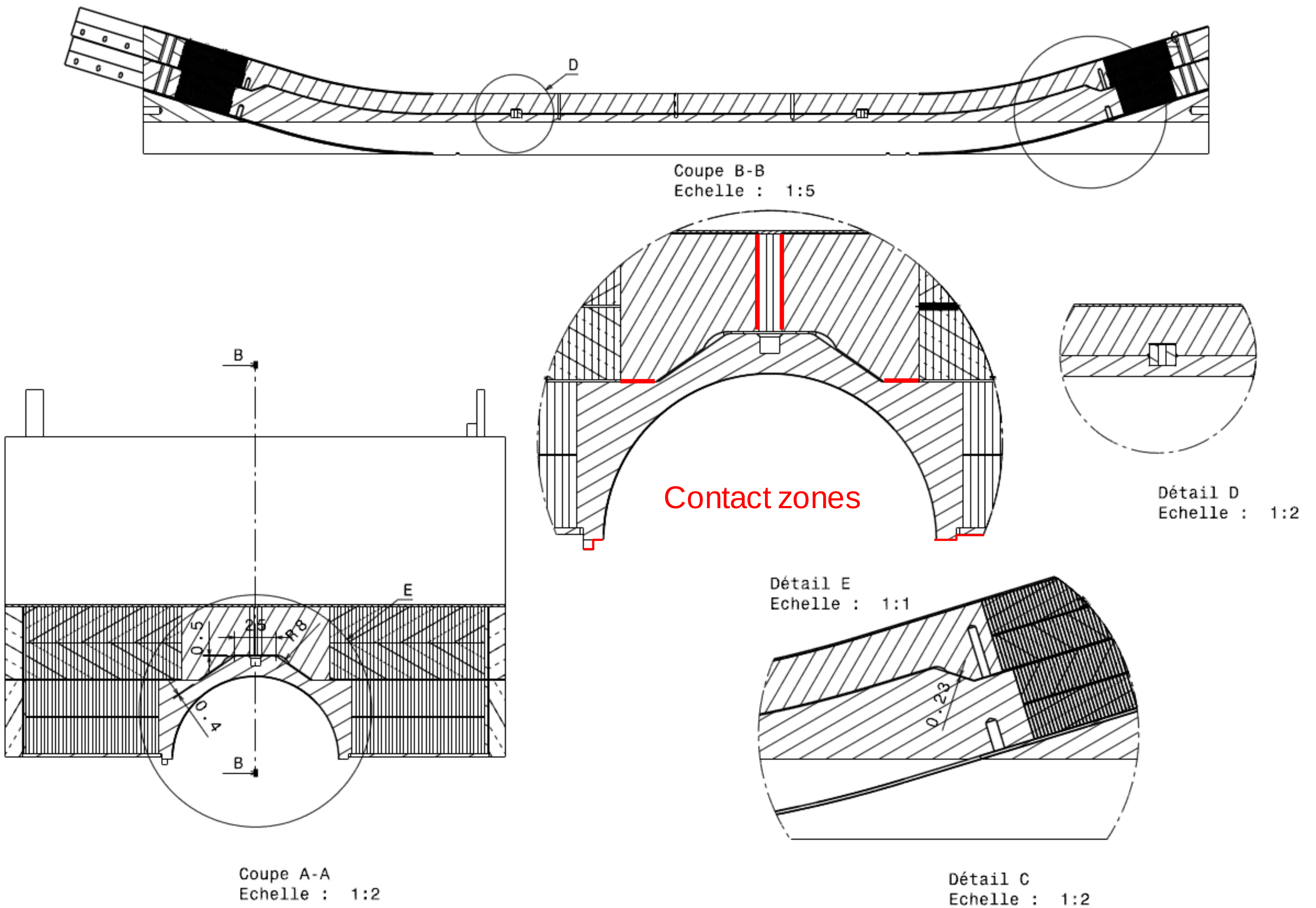
Ref : report on layer jump test SAFIRS-00373-E (2011)

Posts design



* choice after the thermal tests

Posts design

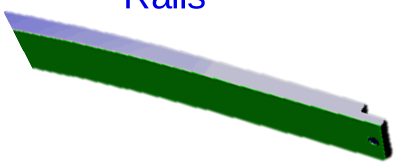


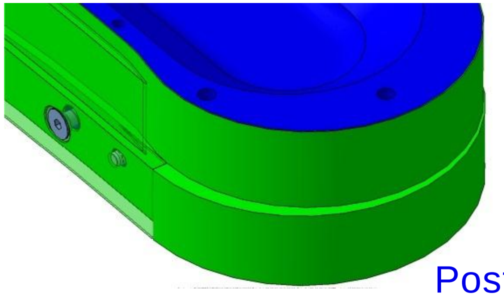
Electrical insulation

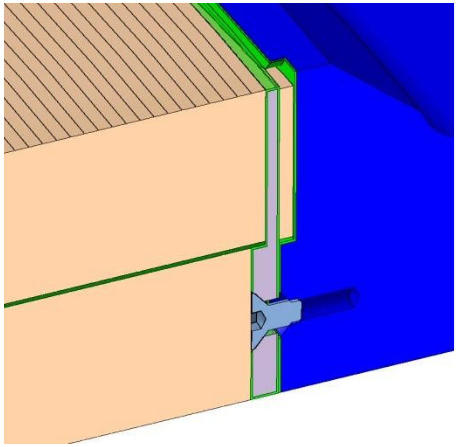
- Glass fiber impregnated with epoxy resin
  - Around cable: braid 0.2 mm
  - between layers: sheet of 0.5 mm
  - between double pancakes: enlarge to 1.5 mm to allow the installation of the instrumentation (voltage taps connections + quench heaters)

- Alumina coating - some parts are partially or totally covered:

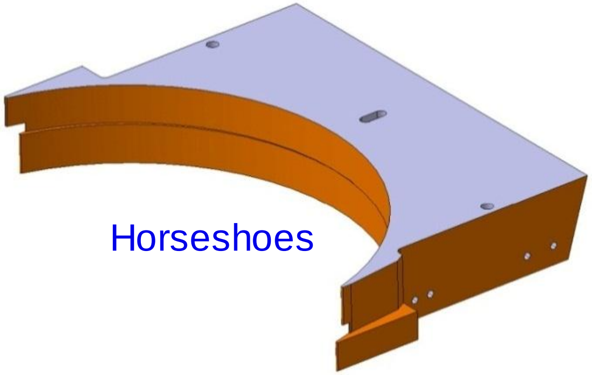
Rails



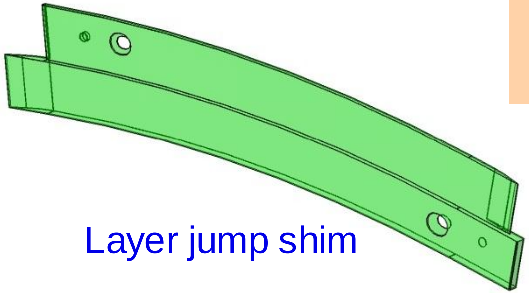




Posts

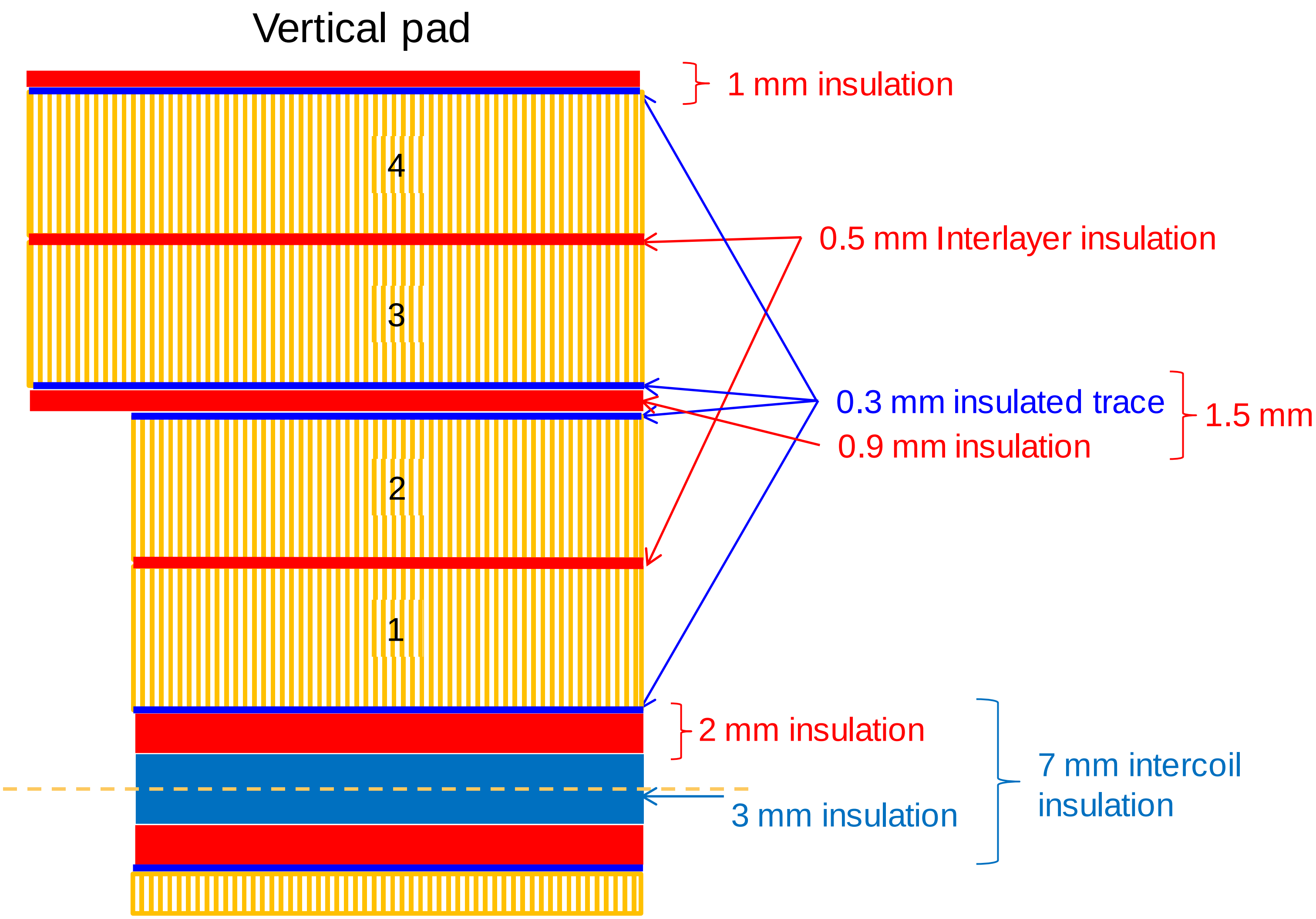


Horseshoes

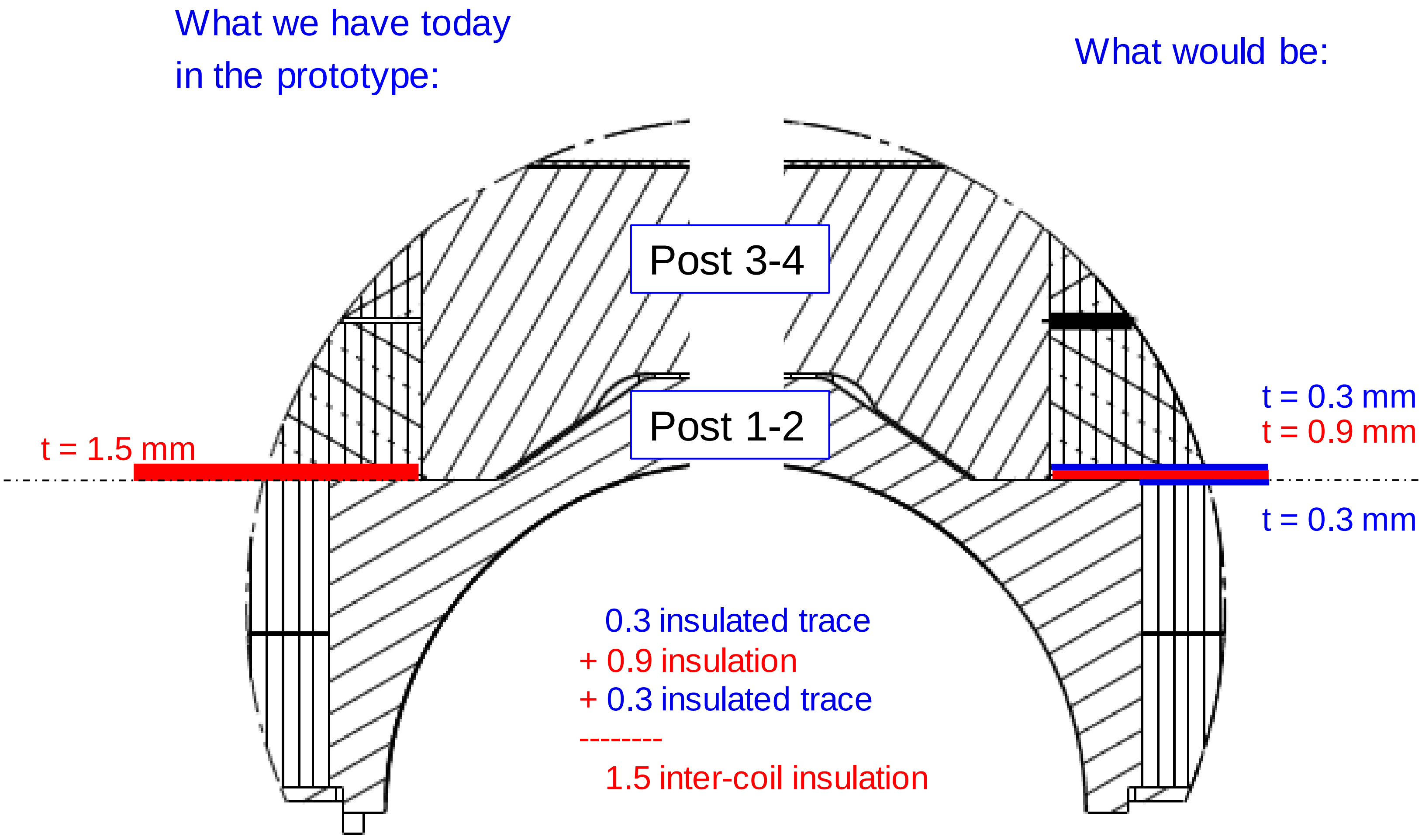


Layer jump shim

Electrical insulation



Insulation between double pancakes = 1.5 mm



Fabrication process – main steps

- Conductor insulation
- Conductor preparation
- Winding
- Preparation for the heat treatment:
  - Assembly of the reaction mold around the wound coil
  - Transport to CERN

At Saclay

- Heat treatment
- Preparation for impregnation :
  - Nb_3Sn/NbTi splice soldering
  - Instrumentation, ground insulation and quench heaters integration
- Impregnation
- Coil assembly
- Magnet assembly

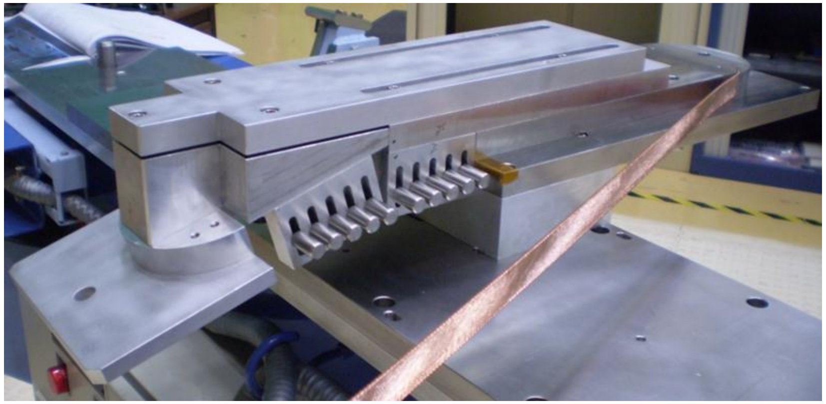
At CERN

(cf. Juan Carlos' presentation)

Winding tests

Upside down winding

- Simpler tooling
- Is the winding easier ? → Yes
- Is the conductor stable and in good position? → Yes



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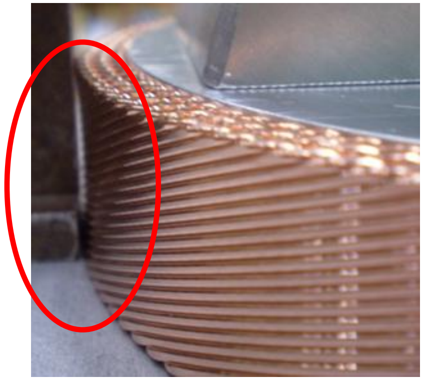
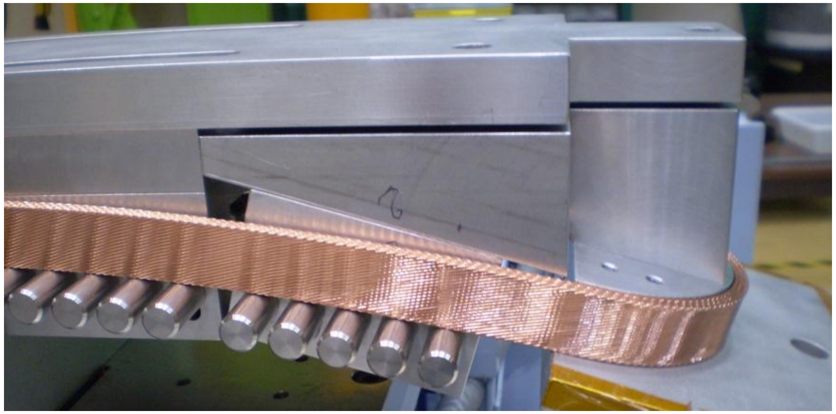


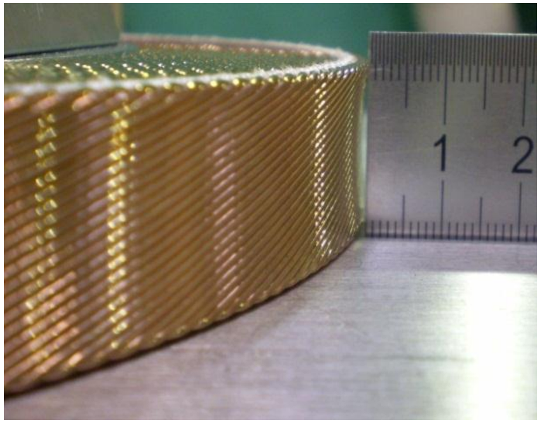
Dishing

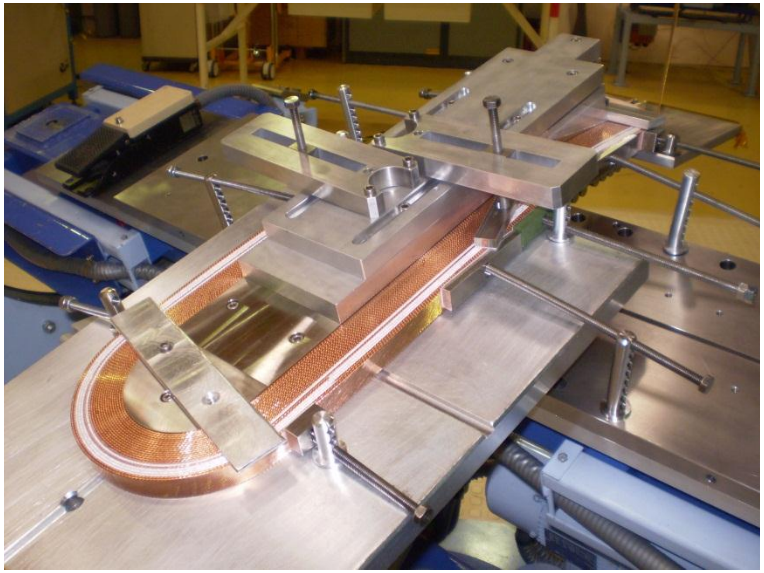


Ref: reports on winding tests
SAFIRS-00152-B (2010) - SAFIRS-00372-C (2011)

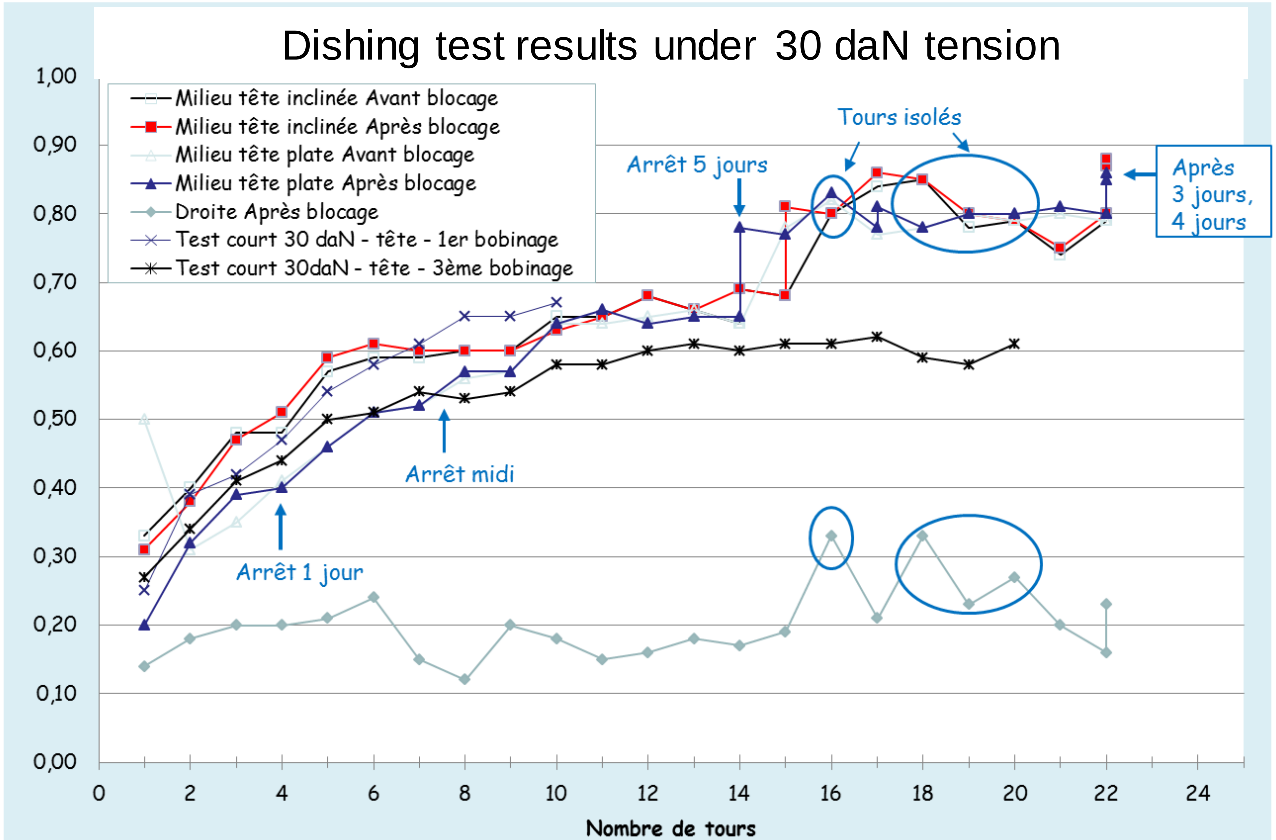
Dishing

- Before winding: 0.18 to 0.34 mm under tension of 10 daN
- Test over 22 turns (4 with insulation) at 30 daN
- Dishing increases turn after turn from ~0.2 mm to ~0.9 mm
- Around 0.2 mm in the straight section
- Slightly larger with flared ends (+ ~0.1 mm)
- Time-dependent





Dishing



- Questions: Behavior of Nb_3Sn similar regardless of the strand type?
  Impact on the field quality? On the mechanics?

- How to deal with it?
  Should we force the conductor flat? Adapt the molds?

Fabrication process – main steps

- Conductor insulation
- Conductor preparation
- Winding
- Preparation for the heat treatment:
  - Assembly of the reaction mold around the wound coil
  - Transport to CERN
- Heat treatment
- Preparation for impregnation :
  - Nb_3Sn/NbTi splice soldering
  - Instrumentation, ground insulation and quench heaters integration
- Impregnation
- Coil assembly
- Magnet assembly

At Saclay

At CERN

(cf. Juan Carlos' presentation)

Winding

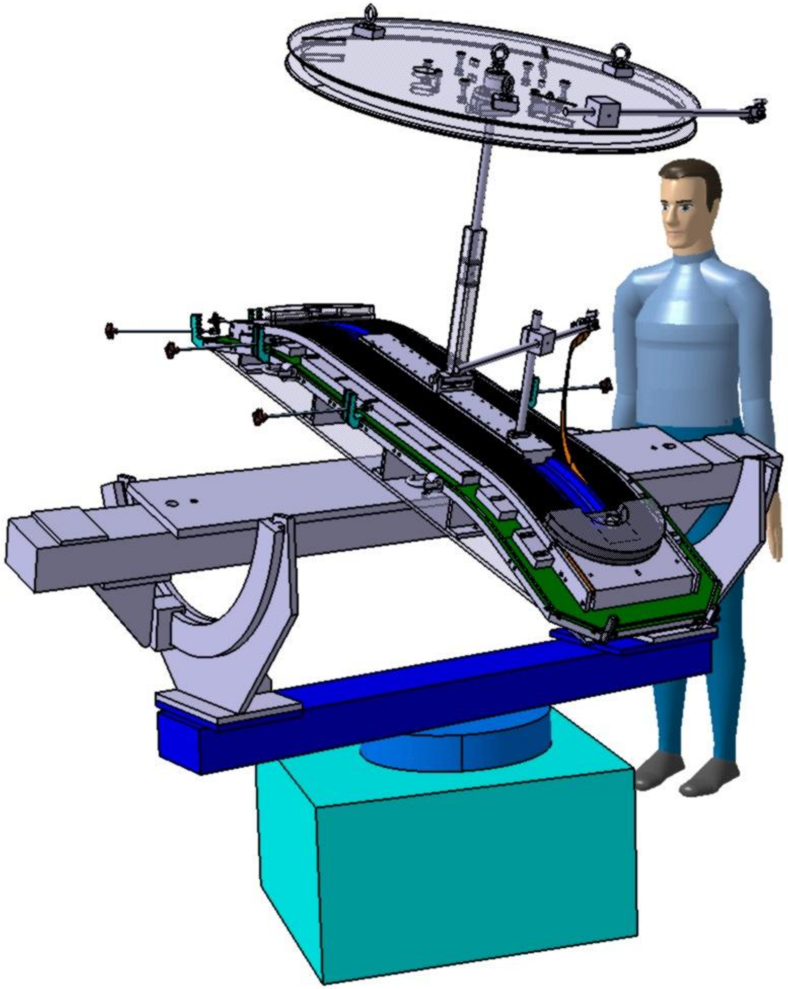
Heavy pieces are equipped to be handle with crane

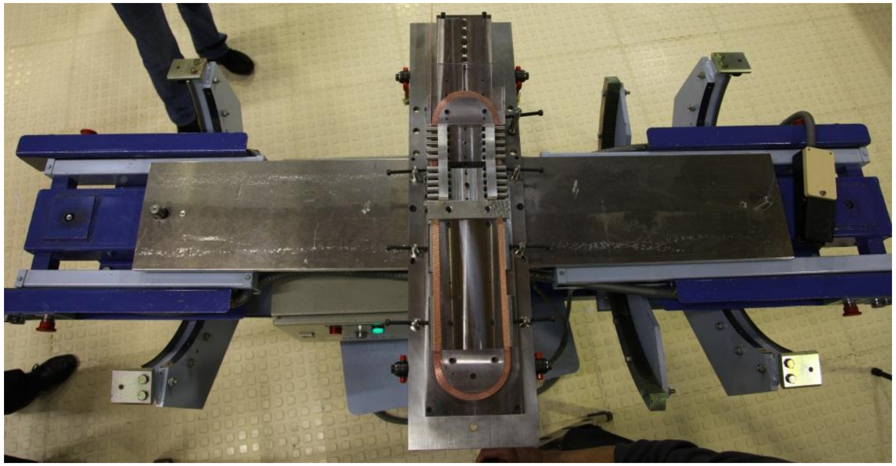
Winding table: 190 kg – 1.72 m * 0.45 m

Stock spool with cable : ~ 60kg

Iron post: 34 kg

Horseshoes: 8 kg





Winding machine existing at Saclay

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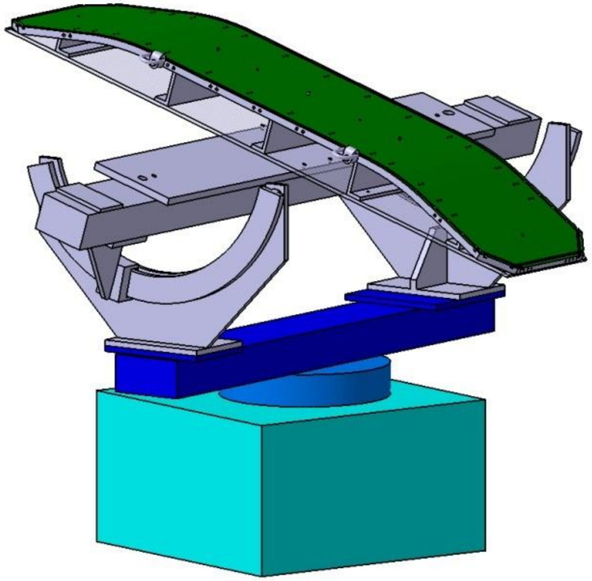
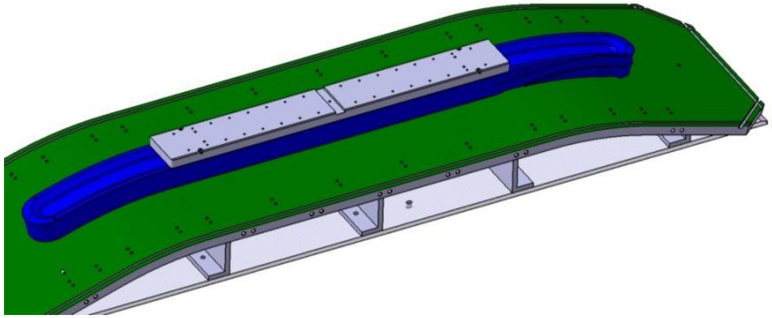
Winding process - installation

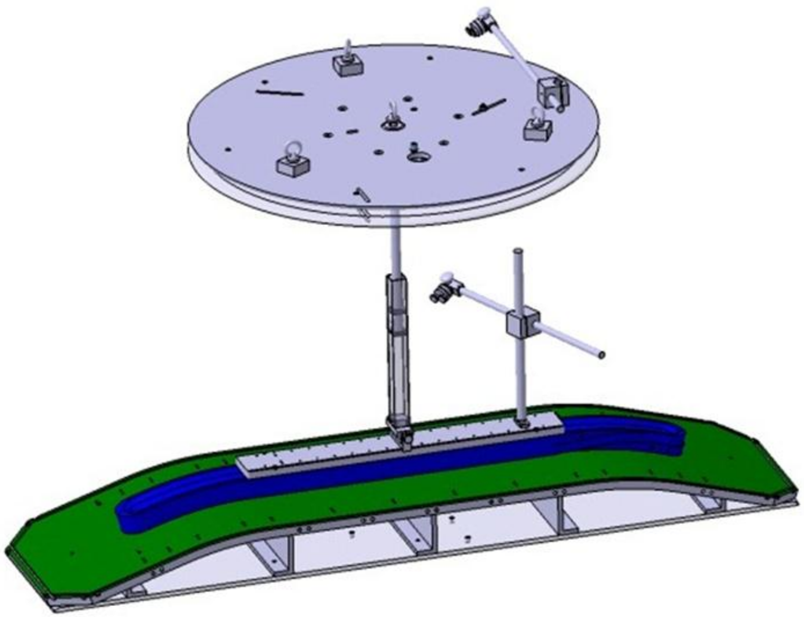




Post fixed on the winding table

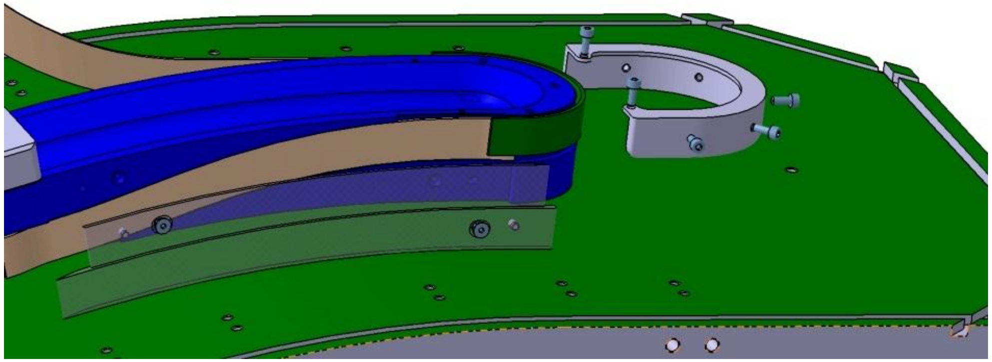
The winding table is fixed on the winding machine - the table can be tilted to follow the geometry of the coil.

Protection sheet on table: 0.2 mm of mica



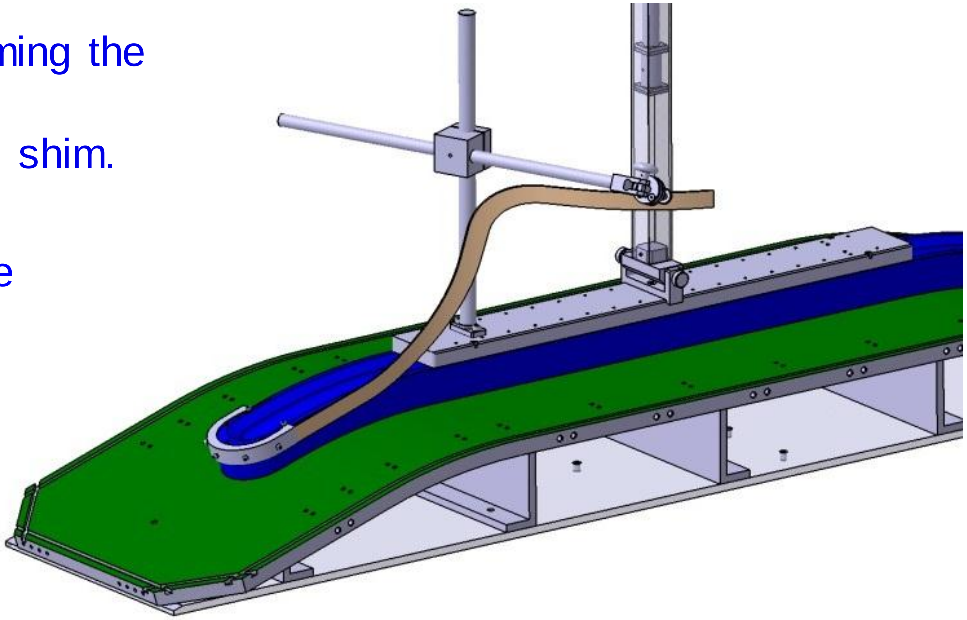
The cable is installed
- layer 4 on the support spool on the tensioner
- layer 3 on the stock spool

Winding layer 4



The coil winding will start by forming the layer jump.
It is protected with the layer jump shim.

The first layer is wound clockwise



Winding layer 4

During winding, conductor turn will be maintain by lateral compression system using pressure wedges and rods.

Voltage tapes are introduced according to the instrumentation design.

At the end of the layer 4 winding, the bottom layer is maintained through rails and pressure wedges.

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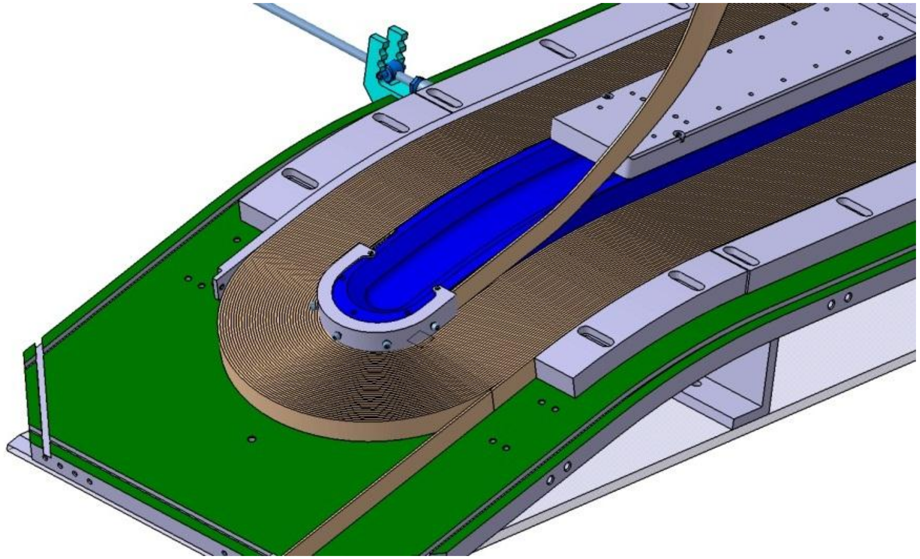
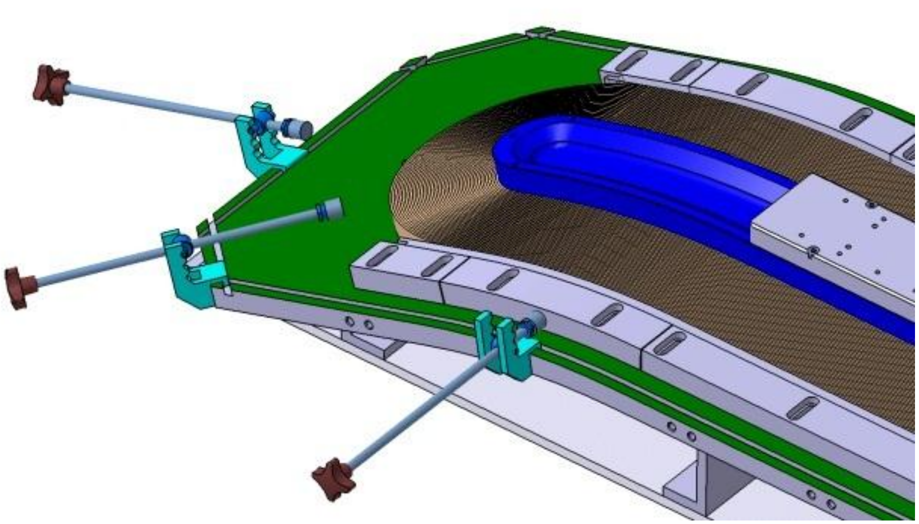
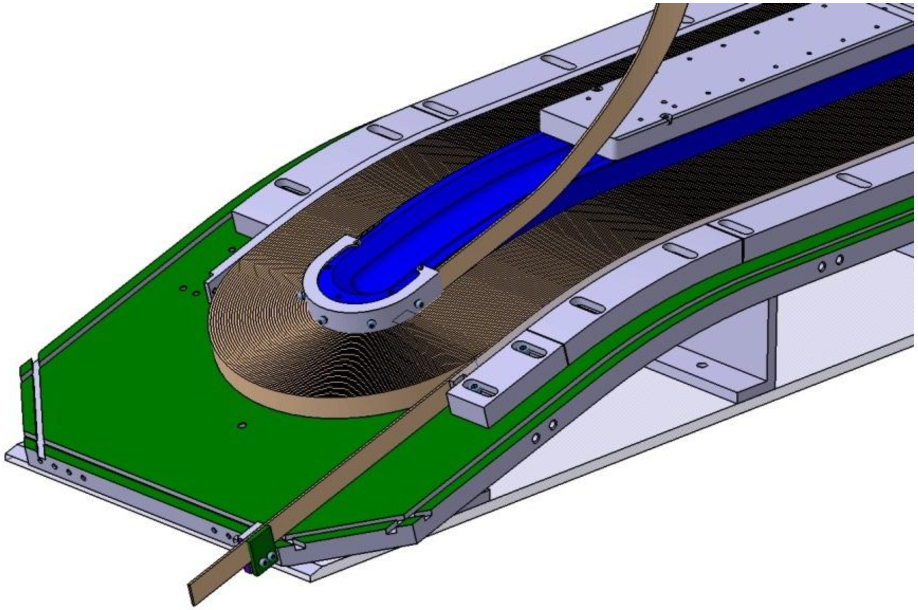
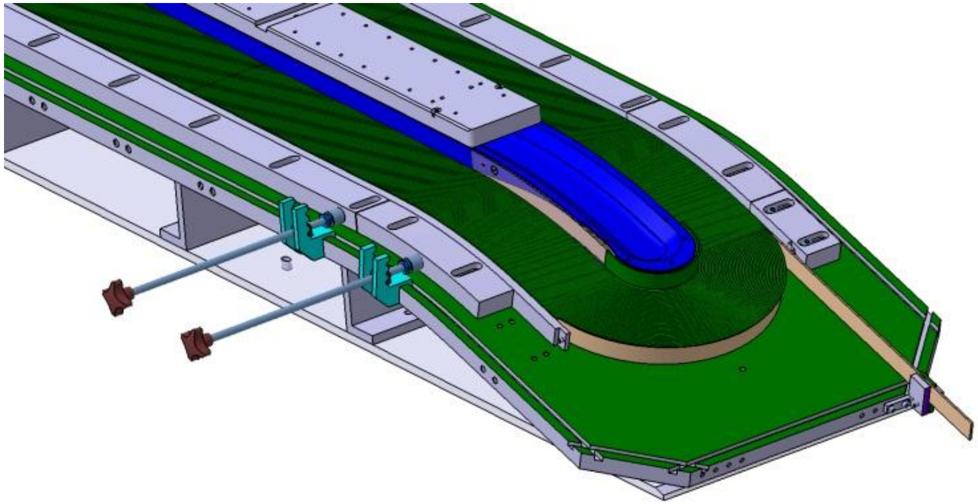




Winding layer 4

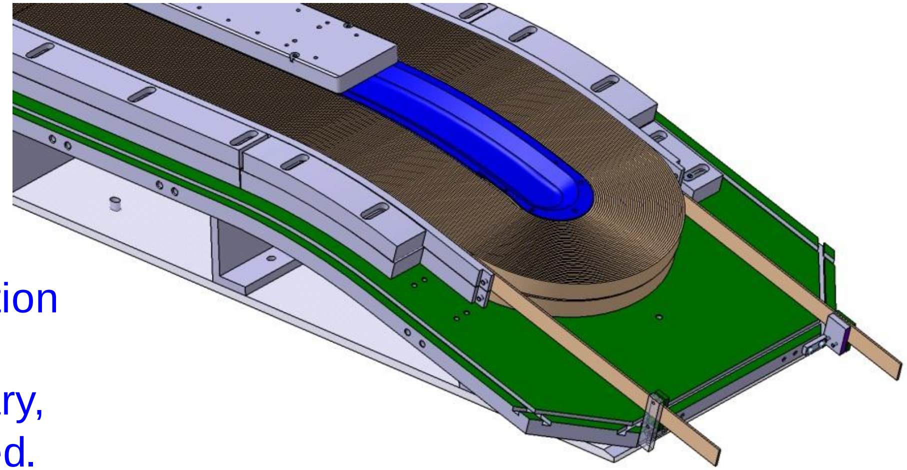
The cable is fixed and cut.





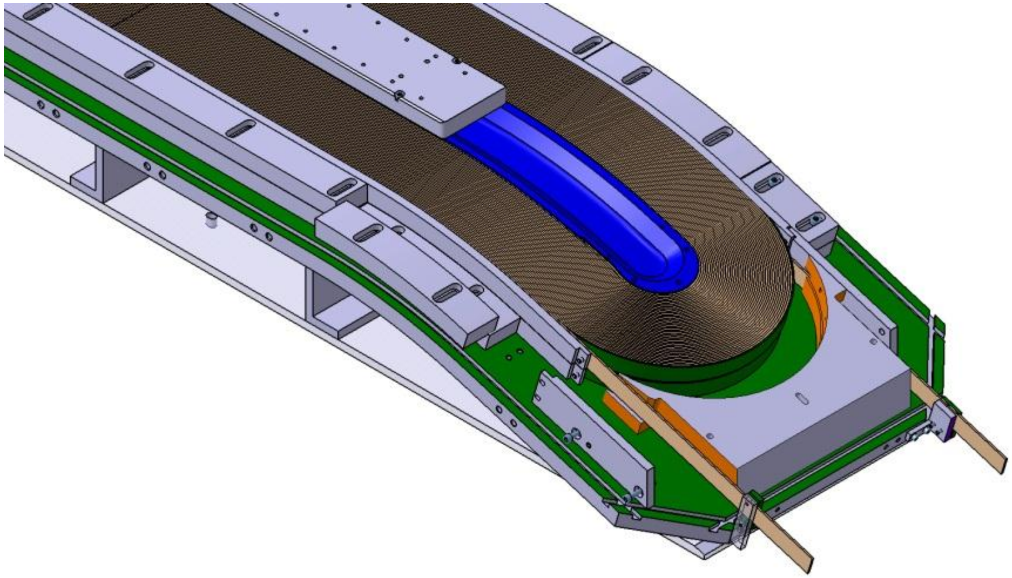
The interlayer insulation is installed and fixed.

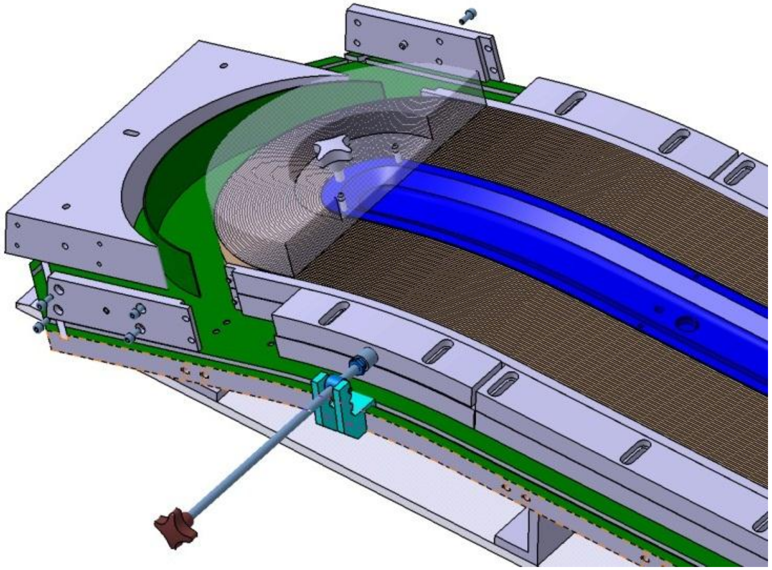
Winding layer 3



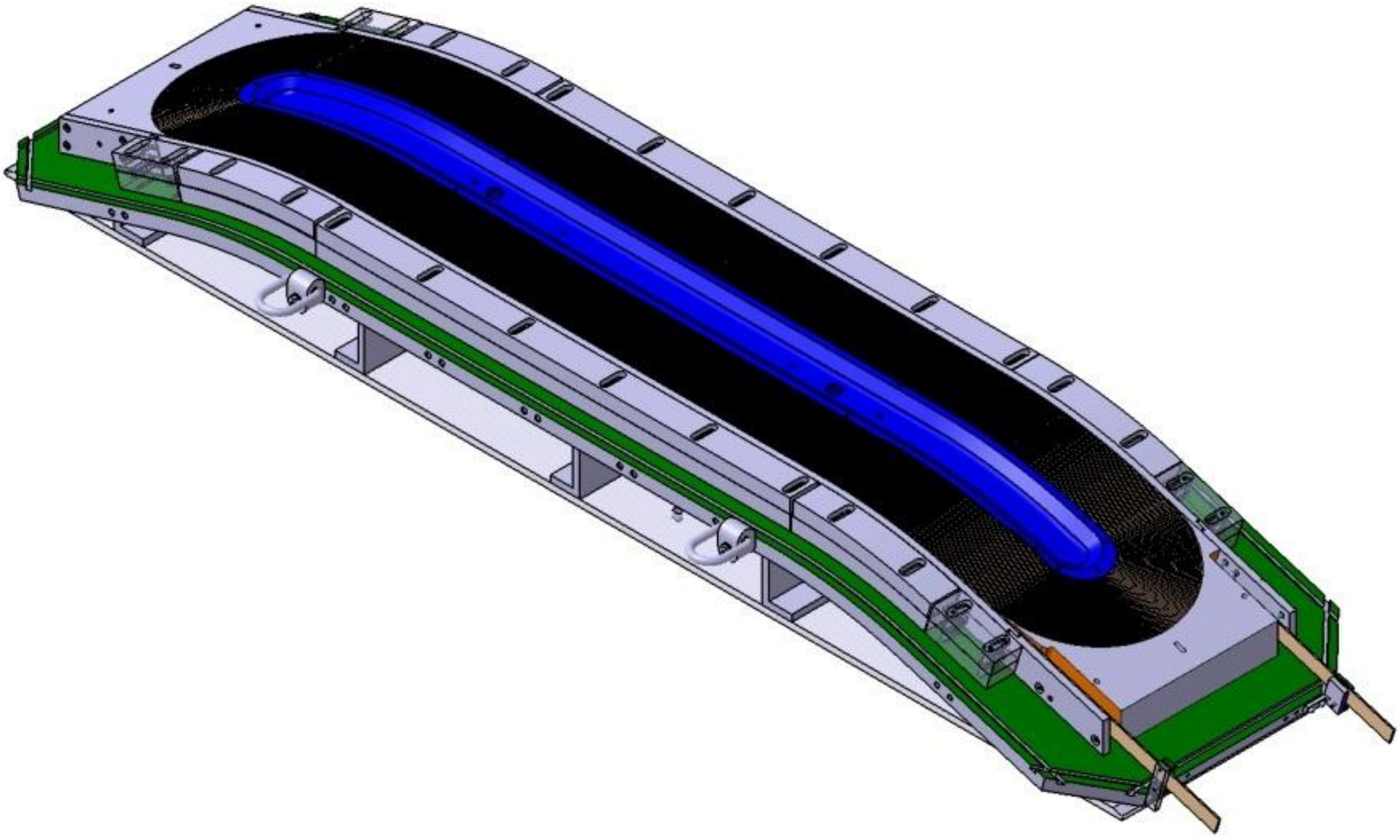
The layer 3 is wound over the insulation

Horseshoes are adjusted, if necessary, pushed in place and the rails are fixed.

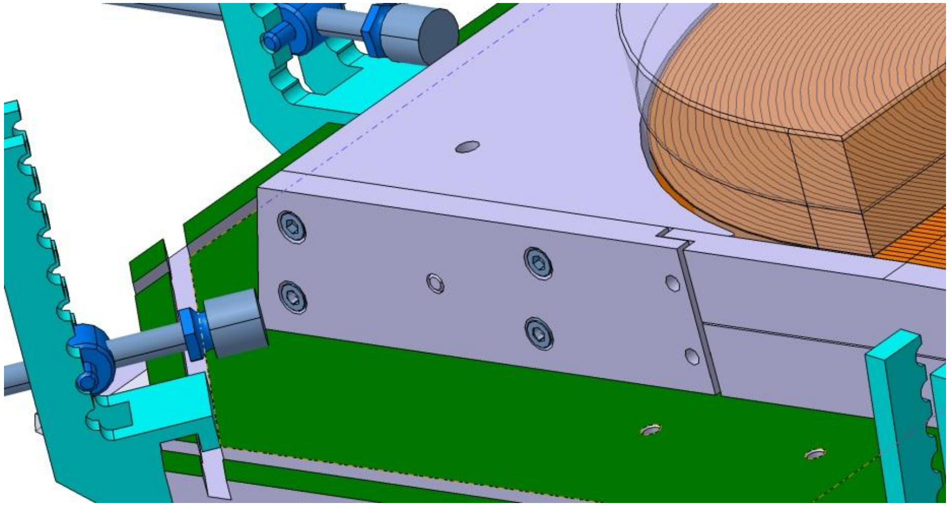




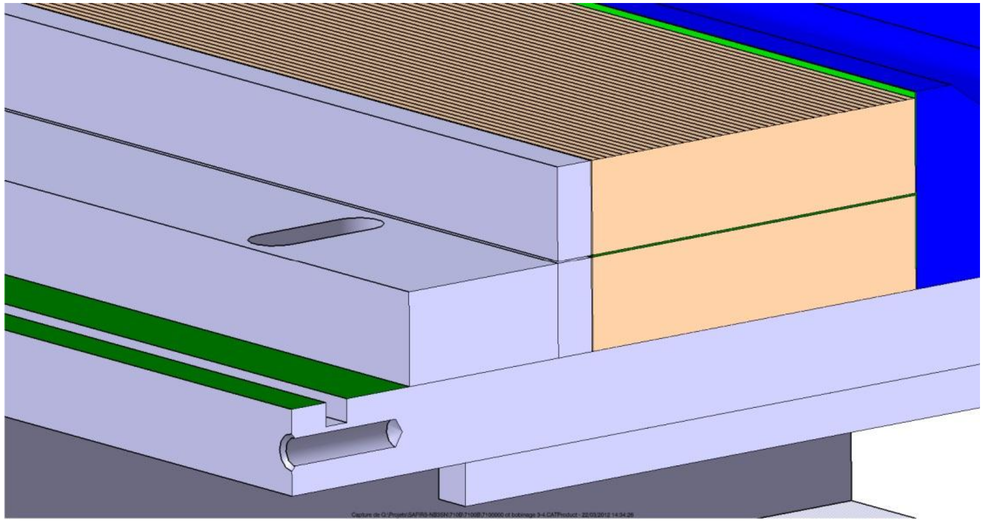
Winding completed



Rails geometry



Fixation of the rails on the horseshoes



Section of the coil

Fabrication process – main steps

- Conductor insulation
- Conductor preparation
- Winding
- Preparation for the heat treatment:
  - Assembly of the reaction mold around the wound coil
  - Transport to CERN

At Saclay

- Heat treatment
- Preparation for impregnation :
  - Nb_3Sn/NbTi splice soldering
  - Instrumentation, ground insulation and quench heaters integration
- Impregnation
- Coil assembly
- Magnet assembly

At CERN

(cf. Juan Carlos' presentation)

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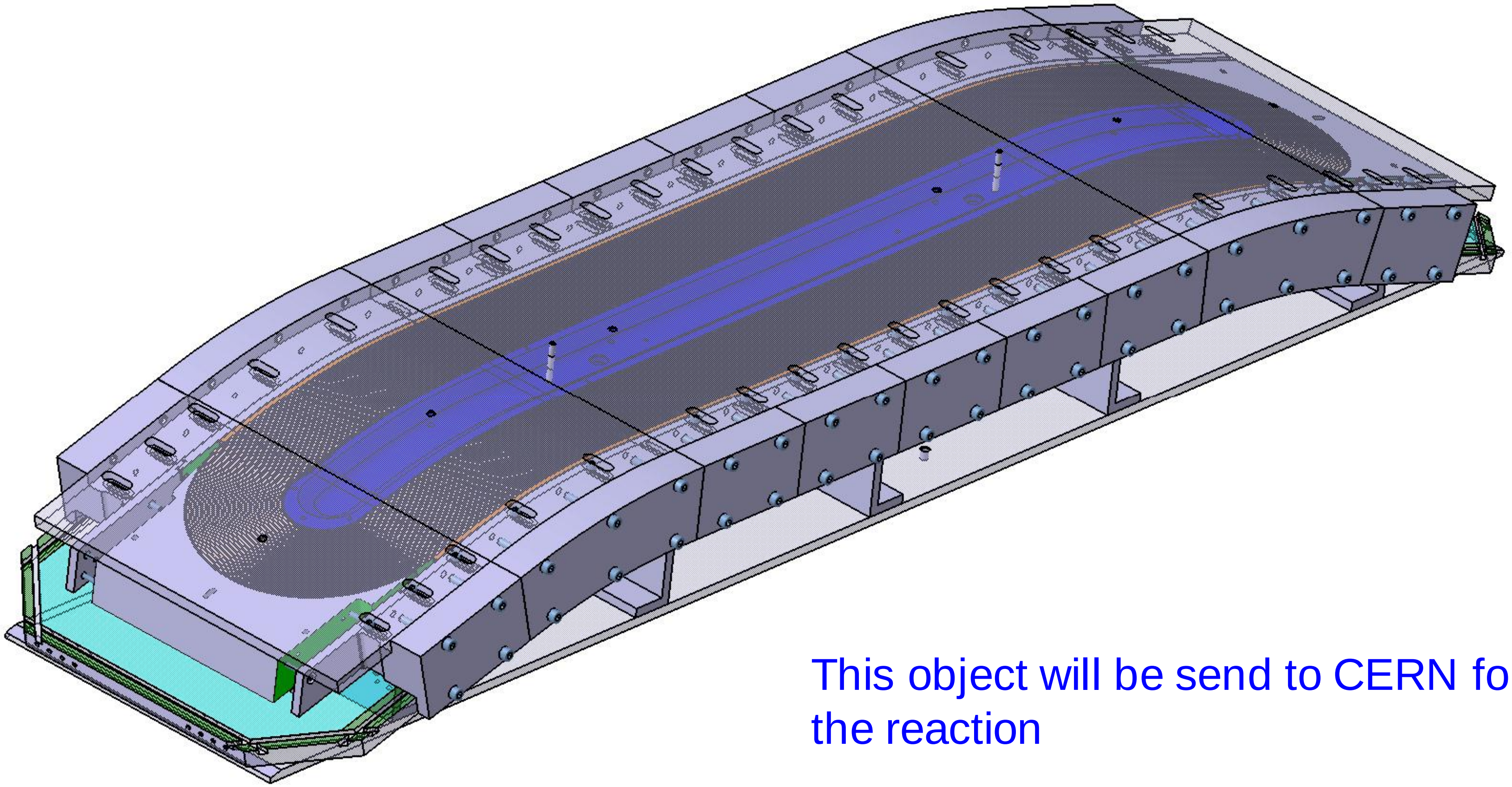
CERN

Reaction tooling

The winding table is part of the reaction tooling.

Top plates and pressure wedges are added to complete the tooling.

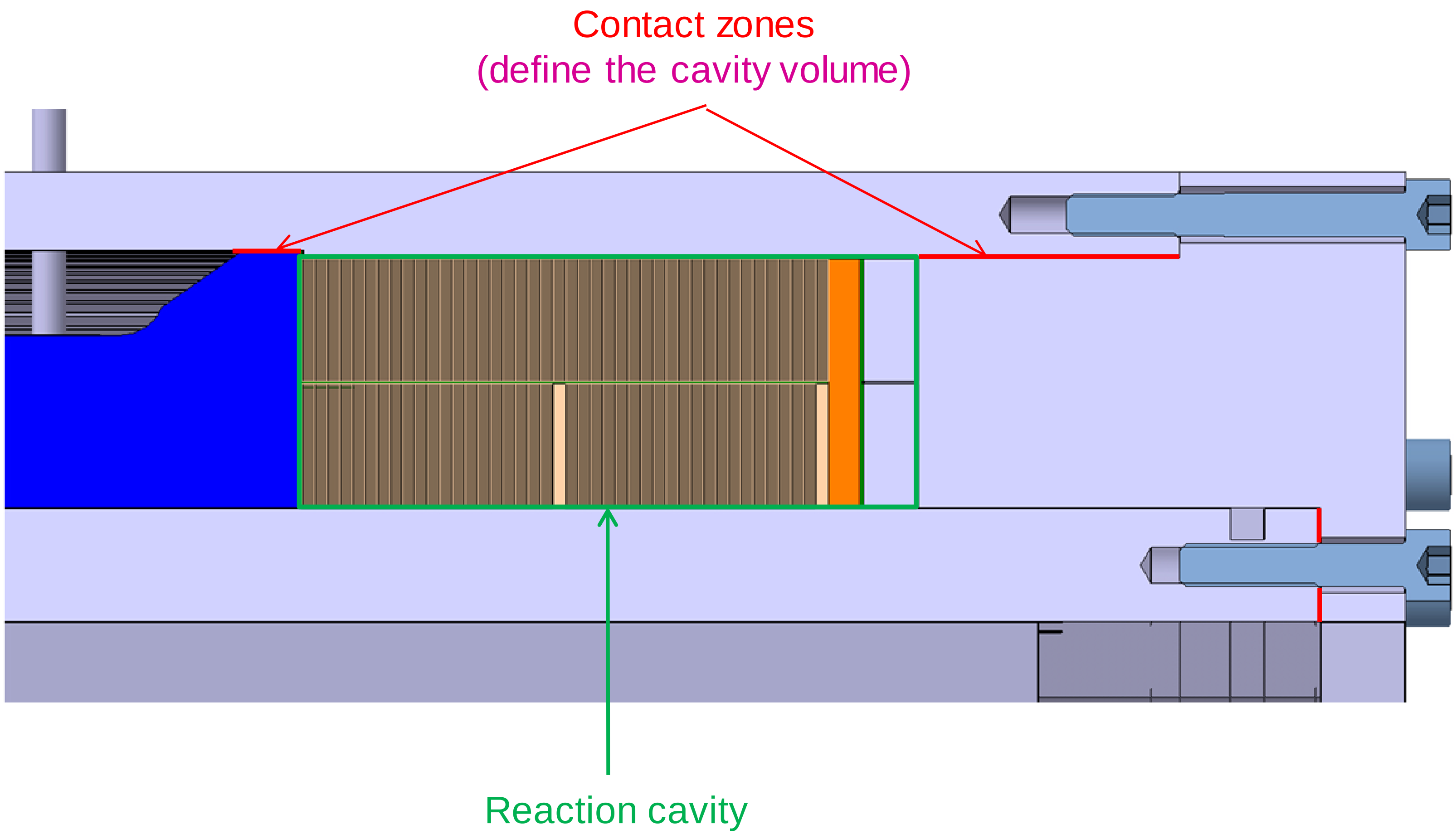
Segmentation of the pressure wedges to allow replacement of the compression wedges.



This object will be send to CERN for the reaction

Capture de P:\SAFIRS-NB3SN\720B\7200B\7200000_REACTION_TOOLING 3-4 ASSEMBLY - V3.CATProduct - 21/03/2012 12:58:41

Reaction tooling



4% (respectively 2%) have been added to the dimensions with respect on bare cable thickness (respect. bare cable width).

Tests

- *Winding configuration: cf. slide 14*
- *Layer jump: cf. slide 7*
- *Dishing: cf. slides 15,16*

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- Mechanical test on stacks under preparation (waiting final insulated conductor)
  - Compression at 300 K, at 4K
  - Thermal restraint

- Conductor behavior during heat treatment: cf. following slide
  - Tests to be performed on the 2 types of conductor (PIT, IT)

- Construction of 2 full-scale prototypes with non annealed Cu cable

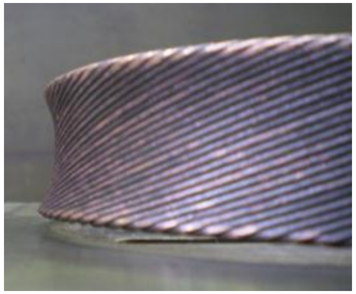
  1- Type 3-4 (42 turns + the smaller HW bends radius)

  2- Type 1-2

Cable behavior during heat treatment

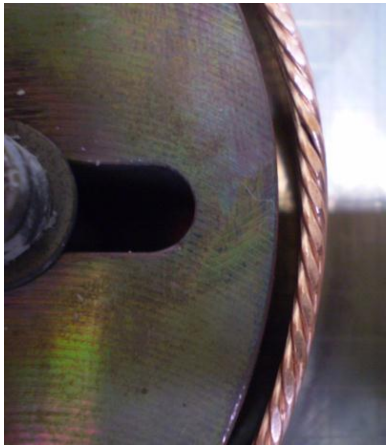
Preliminary tests

1) PIT cable without "end mandrel"

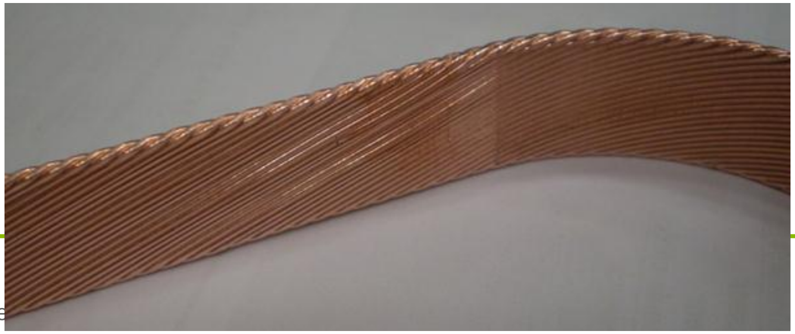


- The dishing is significantly increased after heat treatment
- No significant change in overall dimensions

2) PIT cable with "end mandrel"



- The cable is unstable in straight parts
- The end mandrel has moved (~0.6 mm) and 1.4 mm gap between cable and mandrel has been measured
- Dishing in the end part has disappeared



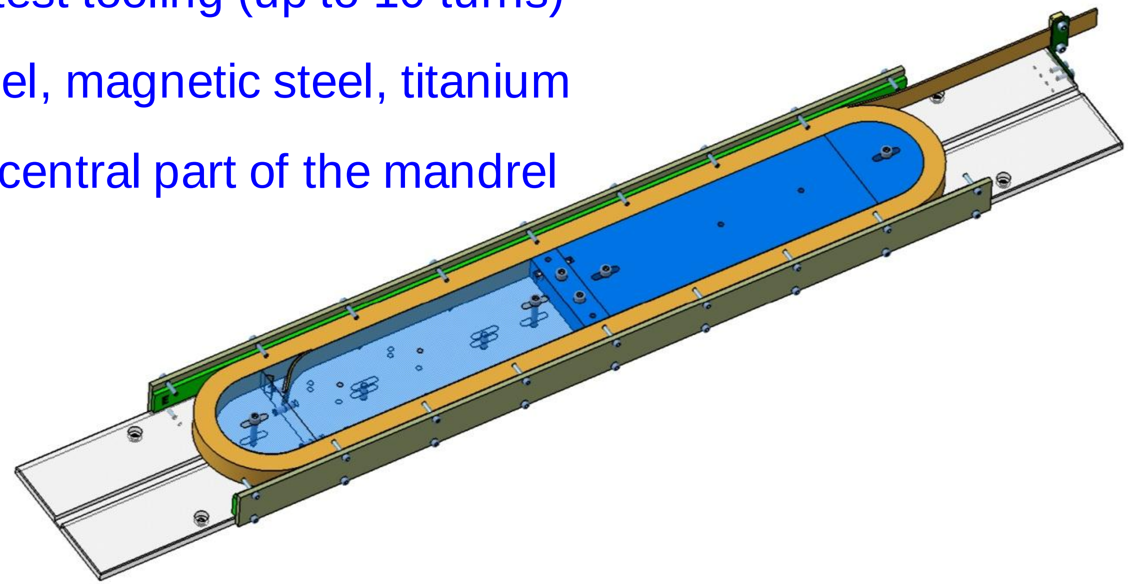
Ref: SAFIRS-00375-I (2011)

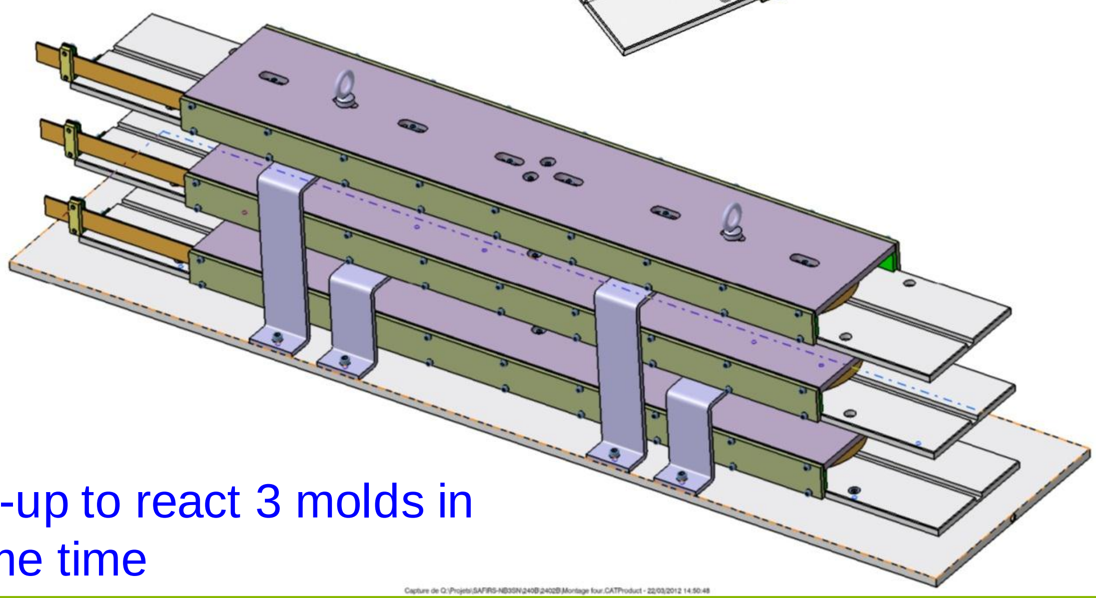
Conductor behavior during heat treatment

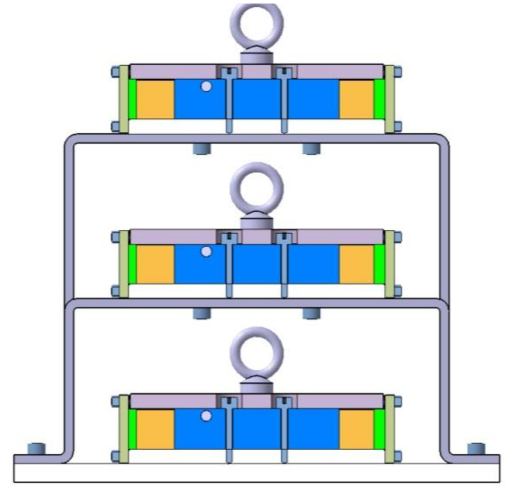
New multi-turn dilatation test tooling (up to 10 turns)

3 materials : stainless steel, magnetic steel, titanium

Possibility to remove the central part of the mandrel







Set-up to react 3 molds in same time

Tests program

- *Winding configuration: cf. slide 14*
- *Layer jump: cf. slide 7*
- *Dishing: cf. slides 15,16*

CEA - Saclay

- Mechanical test on stacks under preparation (waiting final insulated conductor)
    - Compression at 300 K, at 4K
    - Thermal contraction
- Conductor behavior during heat treatment: cf. slides 30, 31
    - Tests to be performed on the 2 types of conductor (PIT, IT)
- Construction of 2 full-scale prototypes with non annealed Cu cable

  1- Type 3-4 (42 turns + the smallest HW bends radius) ➔ winding in July

  2- Type 1-2

Conclusion

- The 3D model is available for the coil 3-4
  - ➢ available soon for the coil 1-2

- The winding tooling fabrication is on-going

- The winding of the first full scale prototype is foreseen for July

- The reaction mold is designed, waiting for approval