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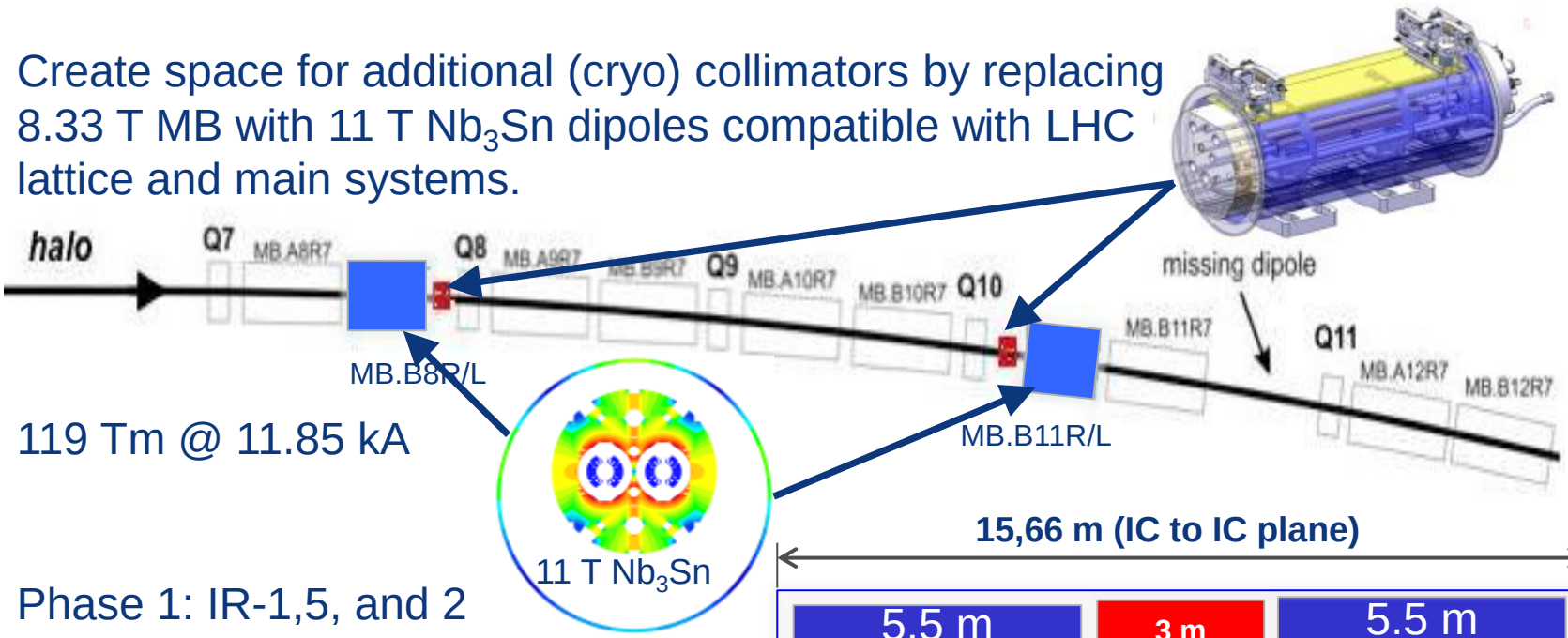
Nb3Sn Coil Production for 11 T Dipole Model Magnets

Outline

- 11 T Project Introduction
- Some Nb_3Sn features
- Cable insulation
- Coil Fabrication
  - Winding
  - Curing
  - Reaction
  - Splicing
  - Impregnation
  - Instrumentation
  - Handling
- Quality control
- Long tooling procurement plan

11 T Dipole Project

- Create space for additional (cryo) collimators by replacing 8.33 T MB with 11 T Nb_3Sn dipoles compatible with LHC lattice and main systems.

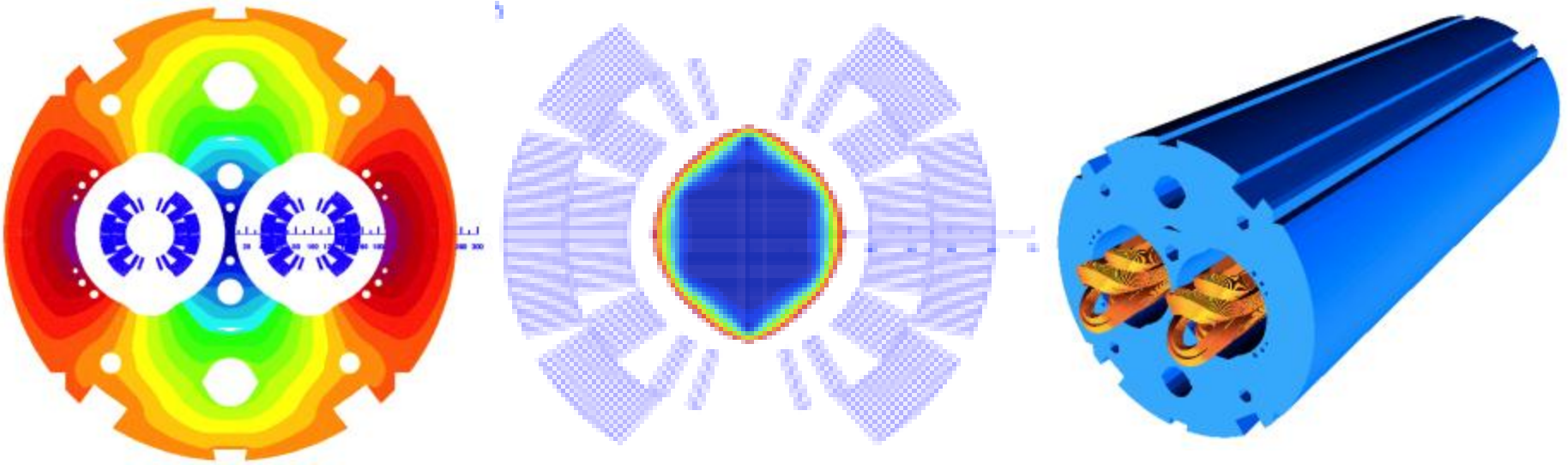


- 119 Tm @ 11.85 kA
- Phase 1: IR-1,5, and 2
  - 3 x 4 MB => 24 x 5.5 m CM + spares
- Phase 2: Point-3,7
  - 2 x 4 MB => 16 x 5.5 m CM + spares
- Joint development program between CERN and FNAL underway since Oct-2010.

11 T Dipole Model Program

Date	Description	Length	Remarks	Goals
May-12	1-in-1 Demonstrator Magnet	2 m	Construction at FNAL	Cable technology Coil Technology Quench performance Magnetization effects
Q3-2013	2-in-1 Demonstrator Magnet 1	2 m	FNAL collared coils CM-Assembly at CERN	2-in-1 structure Field quality: - iron saturation - cross-talk - Magnetization effects Quench performance Reproducibility
Q4-2013	2-in-1 Demonstrator Magnet 2	2 m	CERN collared coils CM-Assembly at CERN	
2015	2-in-1 Prototype Cold Mass	5.5 m	Aperture 1 by FNAL Aperture 2 by CERN CM assembly at CERN	Scale-up Long tooling Fabrication of long coils CM assembly Magnetic performance

11 T Dipole Magnetic Design



B_0(11.85 kA) = 11.25 T (20 % margin on the load-line @1.9K)

- 60 mm bore and straight cold mass
- Systematic field errors below the 10^{-4} level and conductor positioning at 50..100 µm level
- 6-block design, 56 turns (IL 22, OL 34)
- 14.85-mm-wide 40-strand Rutherford cable, no internal splice
- Coil ends optimized for low field harmonics and minimum strain in the cable

Nb_3Sn Superconductor

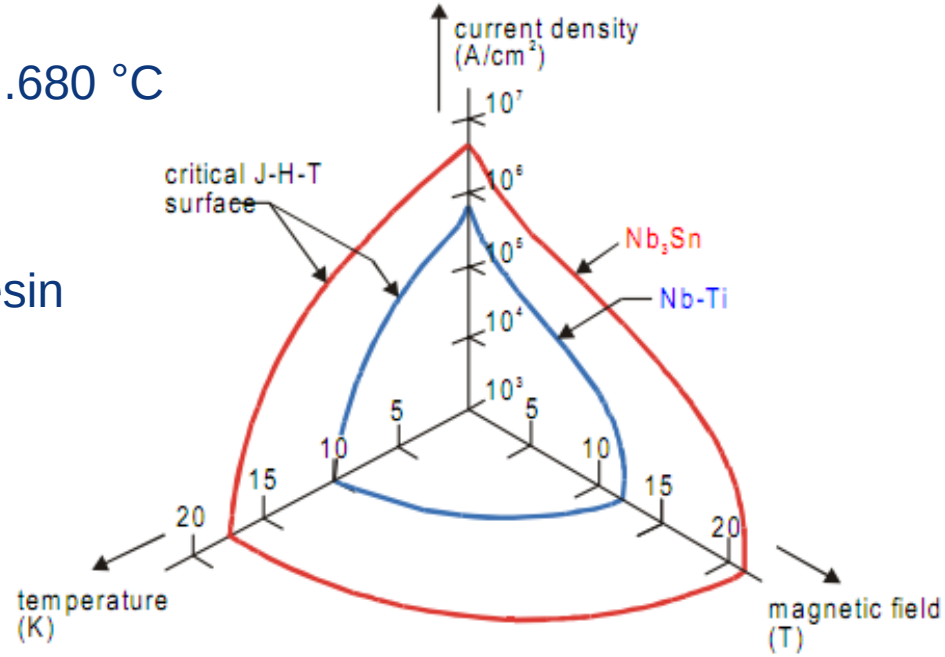
- Nb_3Sn critical parameters (J_c, B_{c2} and T_c) very attractive for accelerator magnets
- Requires (long) heat treatment @ 650..680 °C

  => Only inorganic insulation materials
- Brittle, strain sensitive after reaction
- Requires vacuum impregnation with resin

  => less efficient heat extraction by He
- Magneto-thermal instabilities

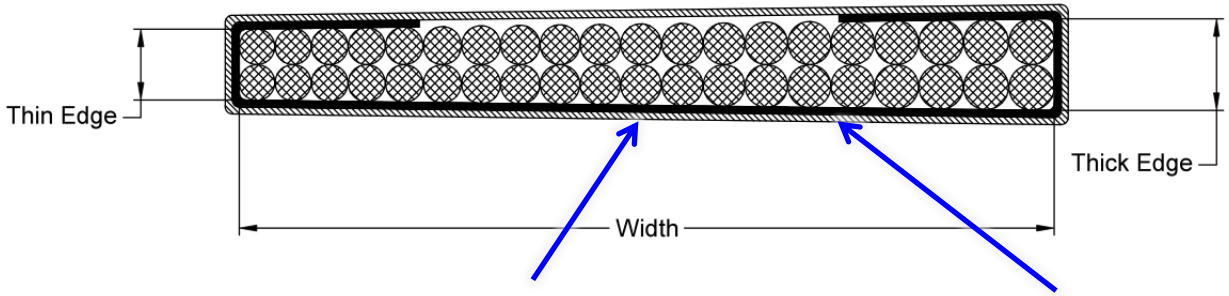
  => small filaments, small strands, high RRR
- Filaments ~50 µm (NbTi 6 µm)

  ⇒ Persistent current effects

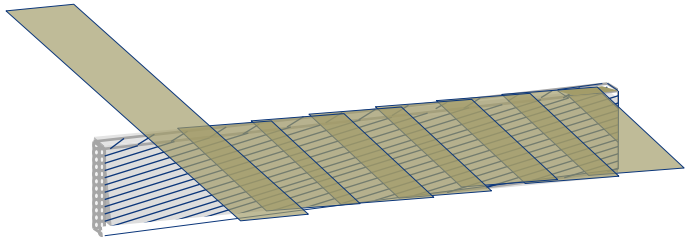


- Sensitive cabling compaction to avoid J_c degradation (cable stability)
- "Wind and react"-process most commonly used for accelerator magnets
- Cost ~5 x NbTi

Cable Insulation

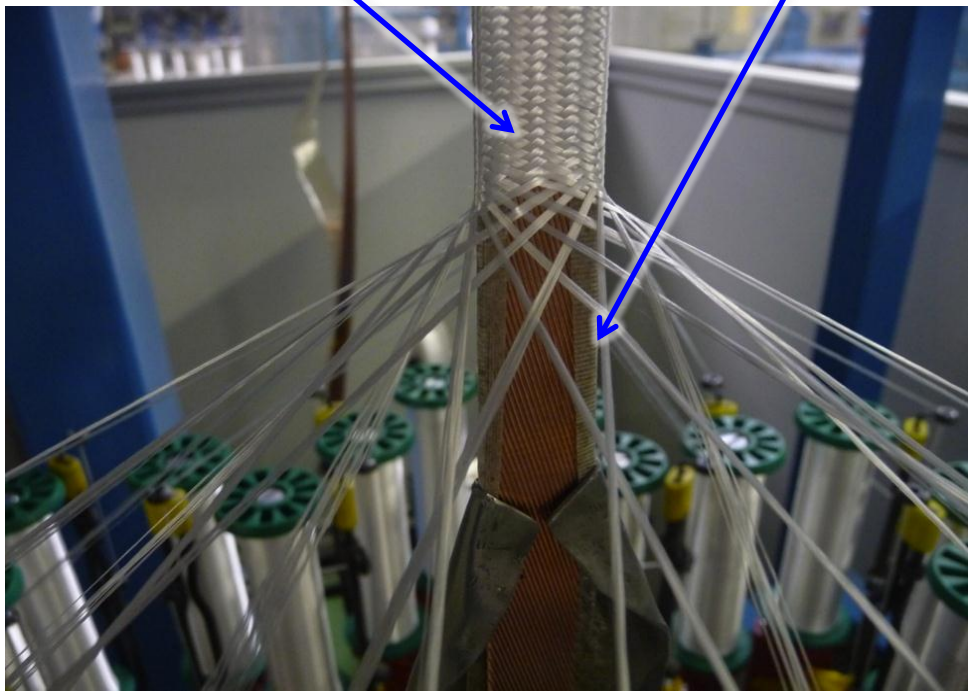


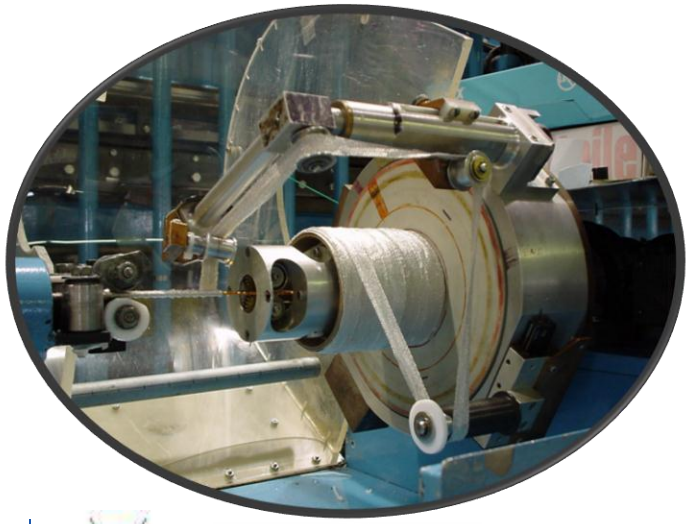
E-glass wrapping



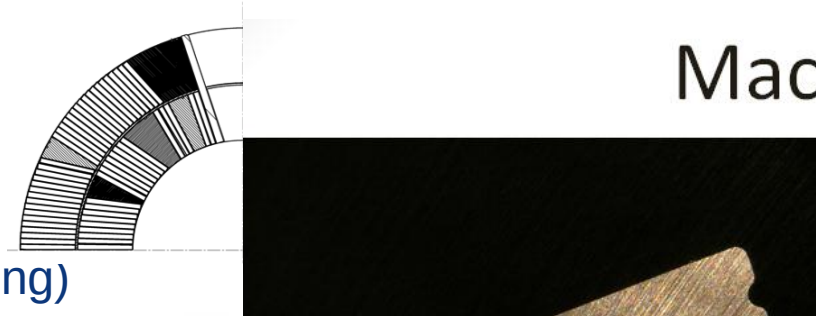
S-2 Glass sleeving

Mica tape

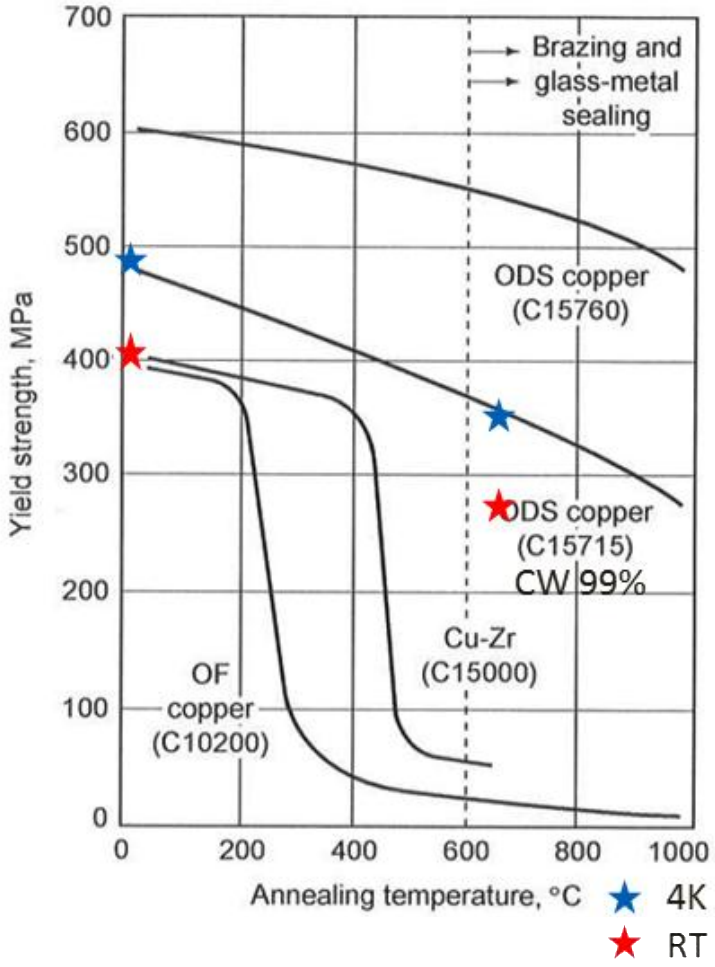




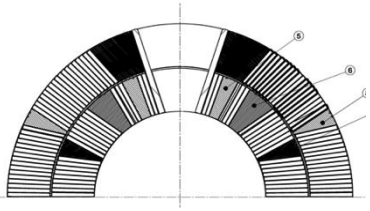
Coil Components



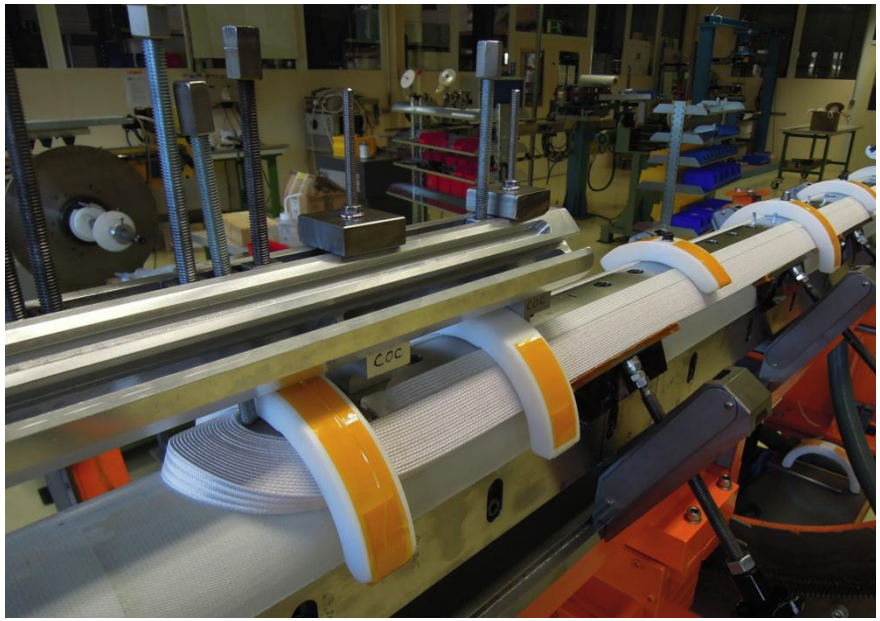
- 316L End spacers (Selective Laser Sintering)
- ODS (Oxide Dispersion Strengthened) Cu-alloy wedges

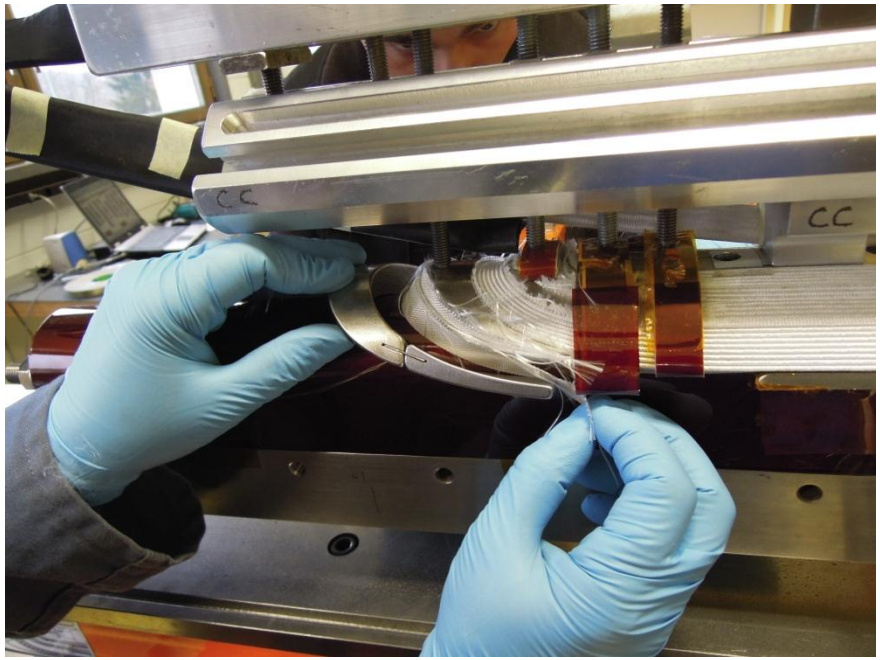


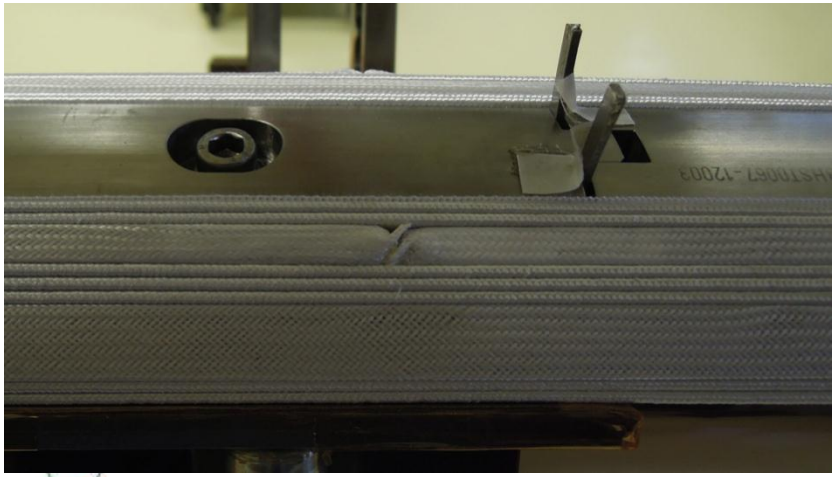
Winding



- Relatively low winding tension of 15..30 kg (cable stability)
- End regions require great care to avoid insulation defects
- Outer layer wound on cured inner layer and pre-formed inter-layer insulation

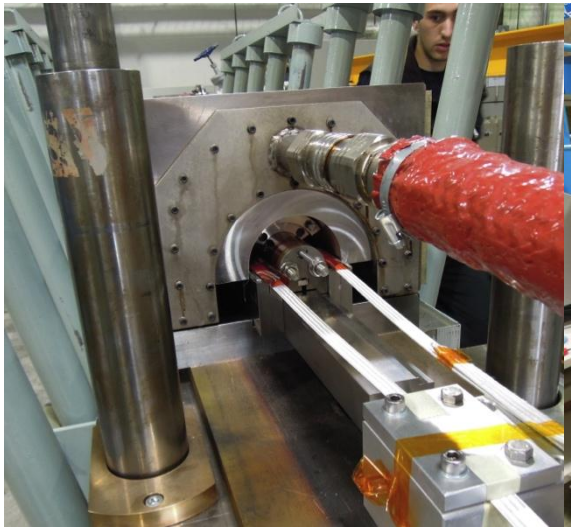


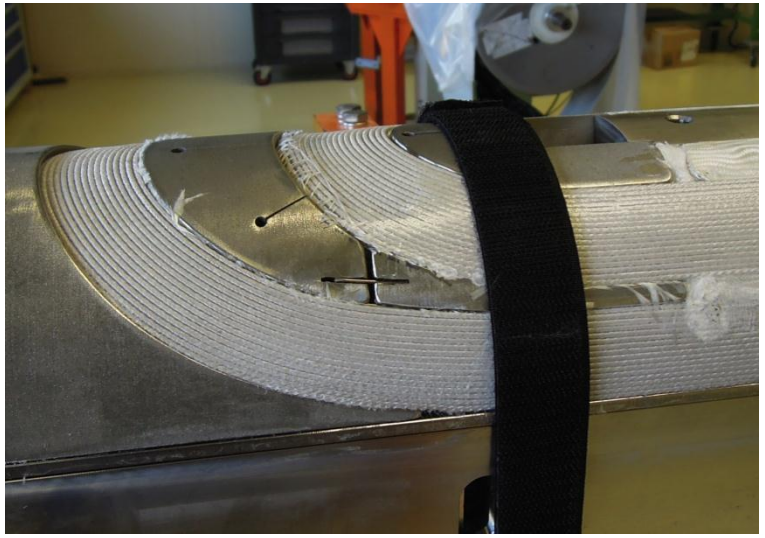




Ceramic Binder

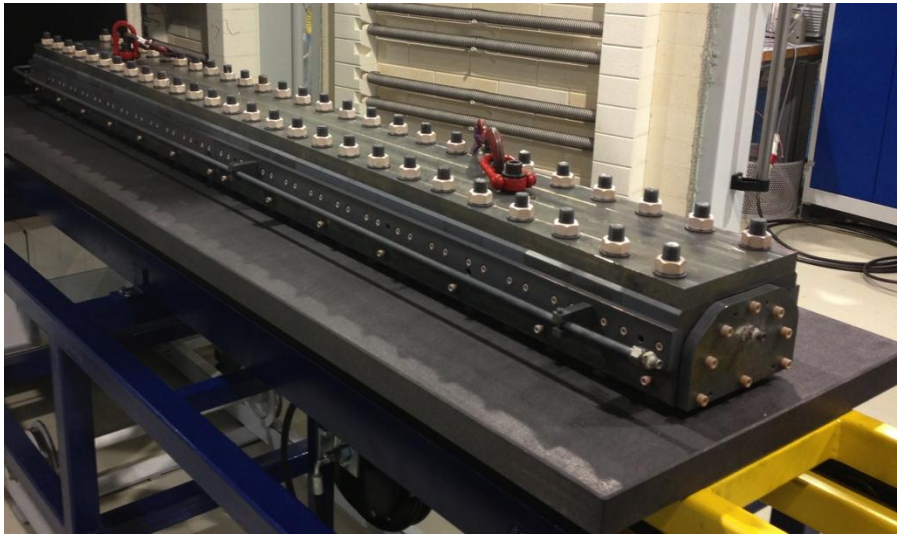
- After winding of each layer ceramic binder CTD-1202 is applied on the cable insulation
- Coils are cured at at 80°C for 1 h and 150°C for 2h in a closed cavity mold.
- Azimuthal coil pressure is approx. 20 MPa





Reaction

- Coil size precisely defined by closed cavity mold
- Tooling design allows for coil expansion of 3%/1% in azimuthal/radial direction
- Reaction with positive argon pressure in the tooling
- Modular tooling for easy scale-up



Reaction..

~10 days

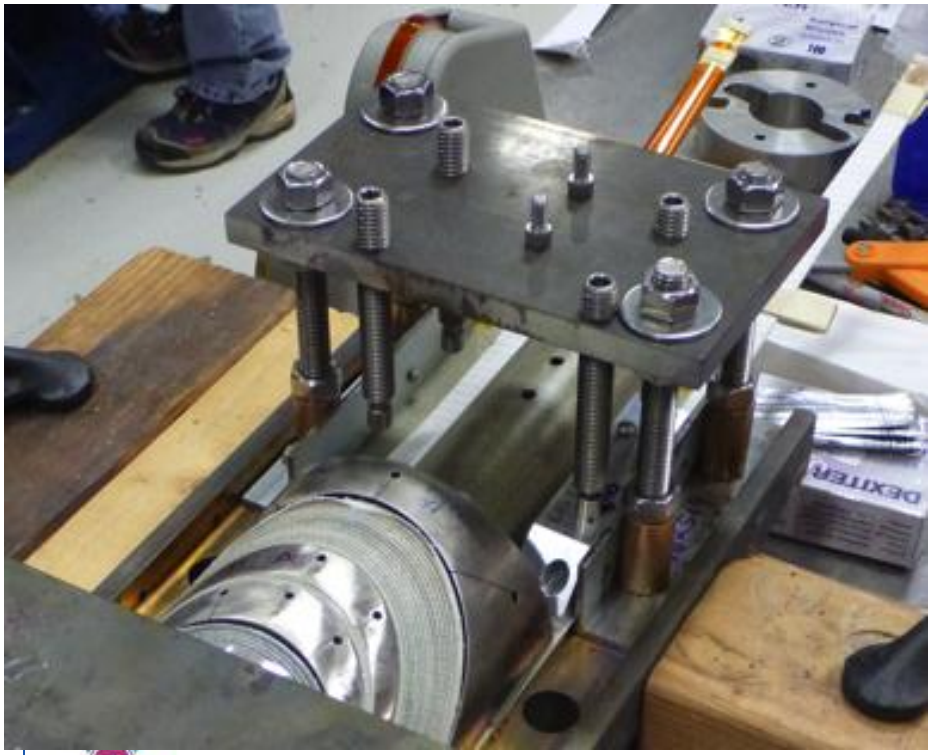
Step #	Type	Start	Rate/time
1	Ramp	20C	25C/hour
2	Soak	210C	72 hours
3	Ramp	210C	25C/hour
4	Soak	400C	48 hours
5	Ramp	400C	50C/hr
6	Soak	640C	48 hours
7	Ramp	640C	-100C/hr

Characteristics	
Available space in the retort (Lxlxh)	2.5m x 0.6m x 0.5m
Max. operating temperature	1000 °C
Temperature uniformity	± 3 °C (25 °C - 750 °C)
Max. temperature ramp up	70 °C/h (20 °C - 900 °C)
Maximum load	600 kg/m
Inert gas atmosphere	YES
Temperature sensor qty / absolute accuracy	20 / ±1 °C Typ K (to 1150°C)
Power	165 kW
Heating zones	5 (controlled and separated in vertical direction)
Manual and Automatic control	YES
Ventilation fan	Yes
Cooling flaps	Yes
Transfer table	Yes

Splicing

- After reaction the Nb_3Sn leads are carefully cleaned avoiding any mechanical strain to the brittle cables

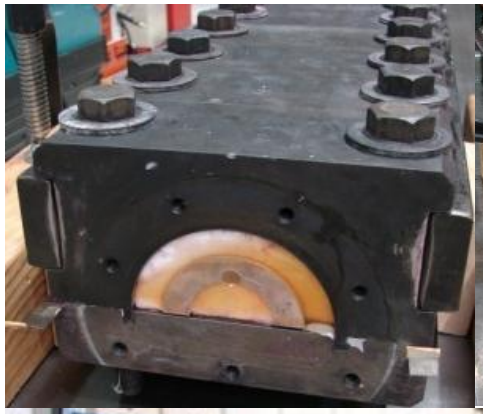
- The splices between Nb-Ti and Nb_3Sn cables are soldered within the reaction tooling.

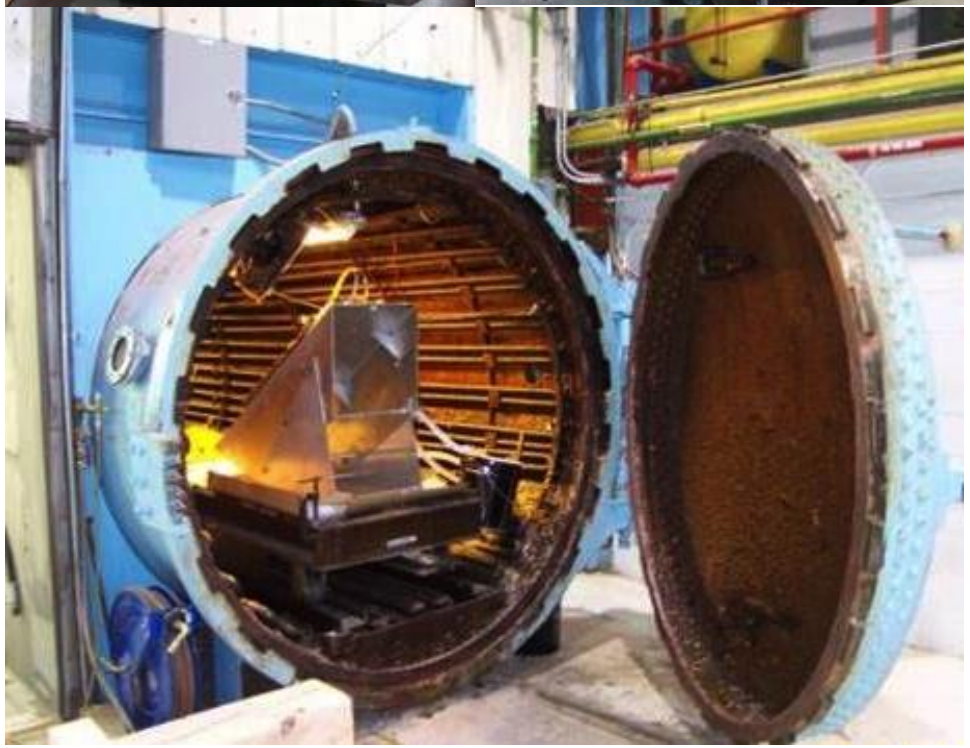


Impregnation

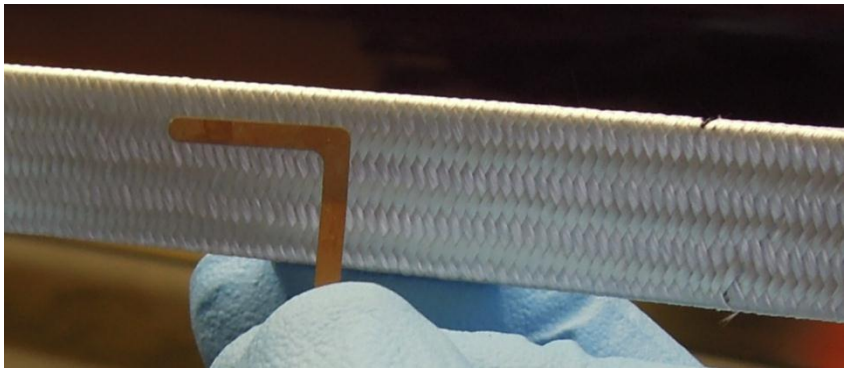
- Reacted coil is transferred from reaction tool into the impregation mold
- All voids are filled with glassfiber and/or ceramic putty, and possible insulation defects are repaired
- 0.2 mm S2-cloth is applied on the outer surface
- Impregnation with CTD101K in the a vacuum oven at 30-50 mm Hg with epoxy temperature of 60° C
- Curing at 125° C for 21 h

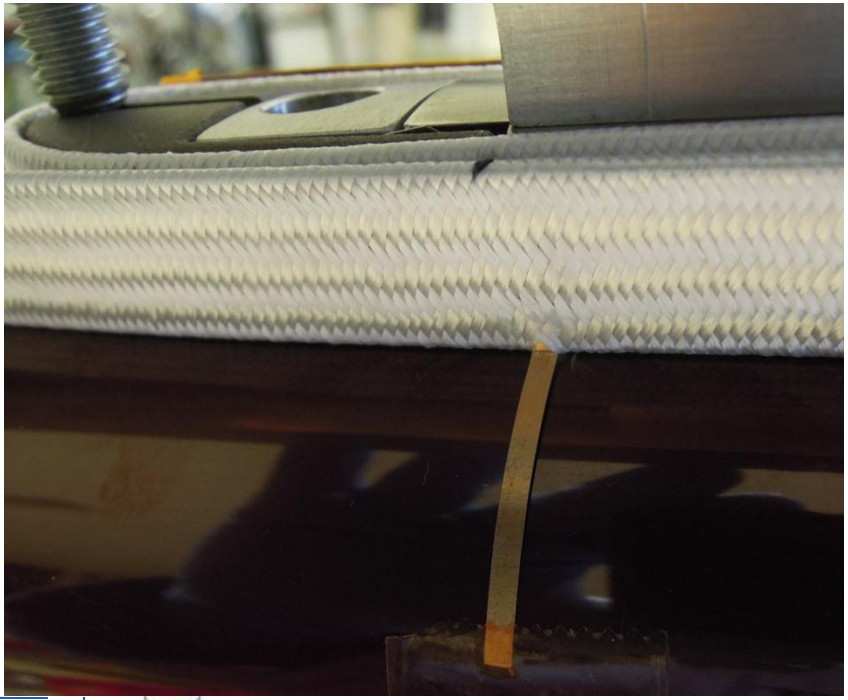
Impregnation..

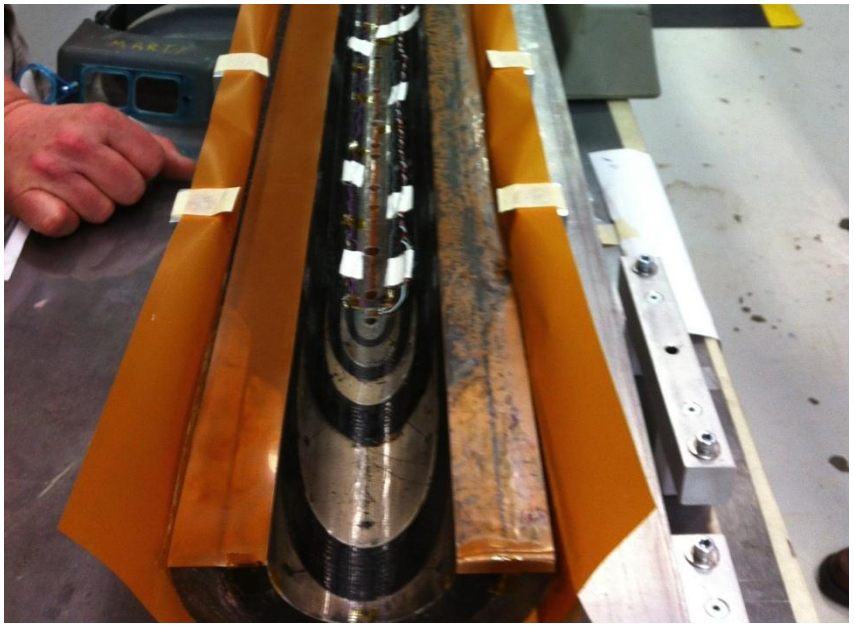


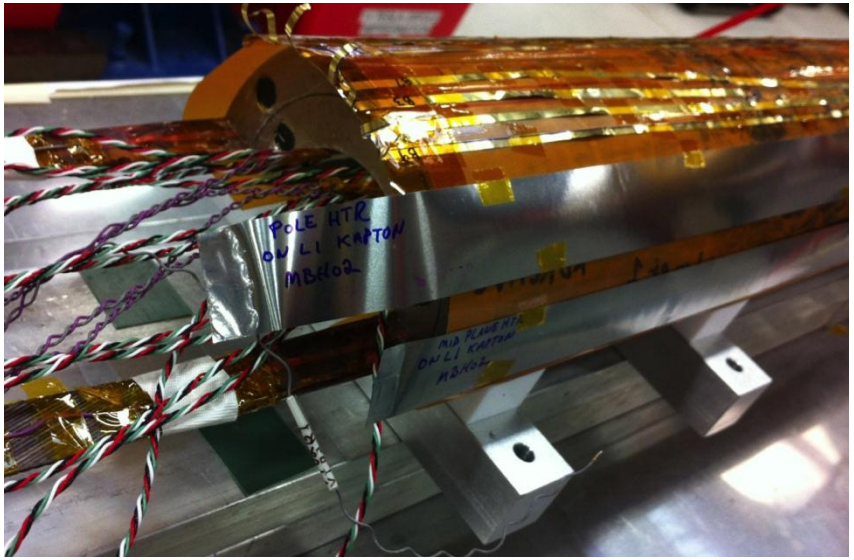


Instrumentation

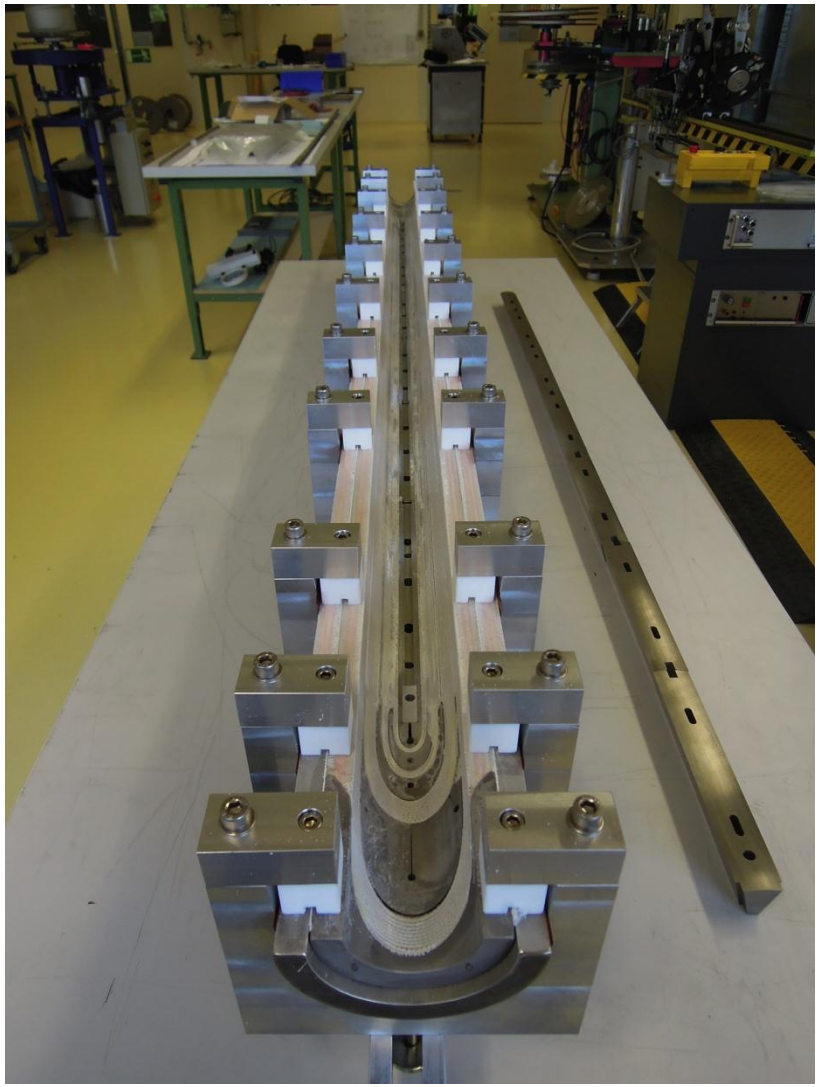




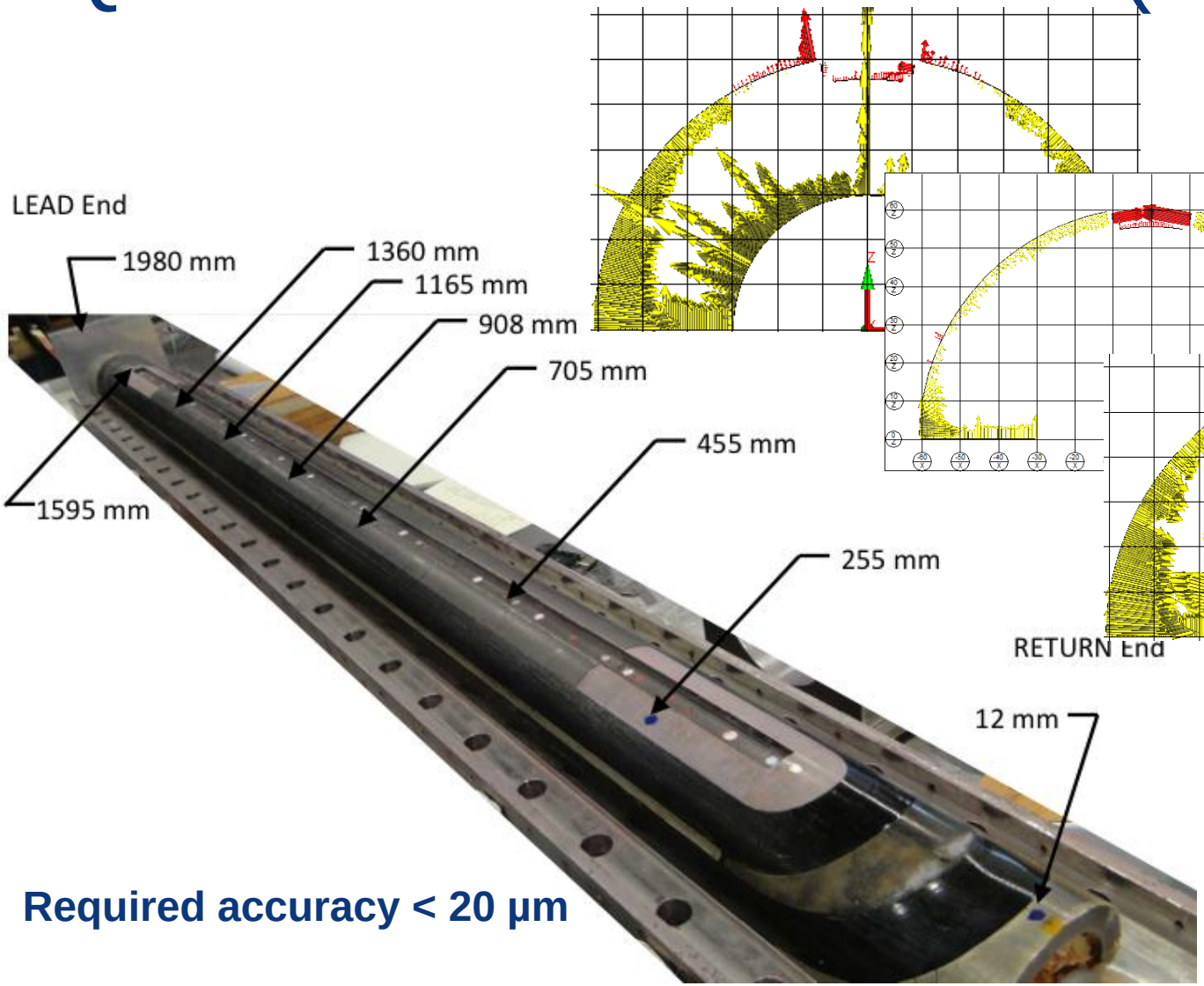




Handling

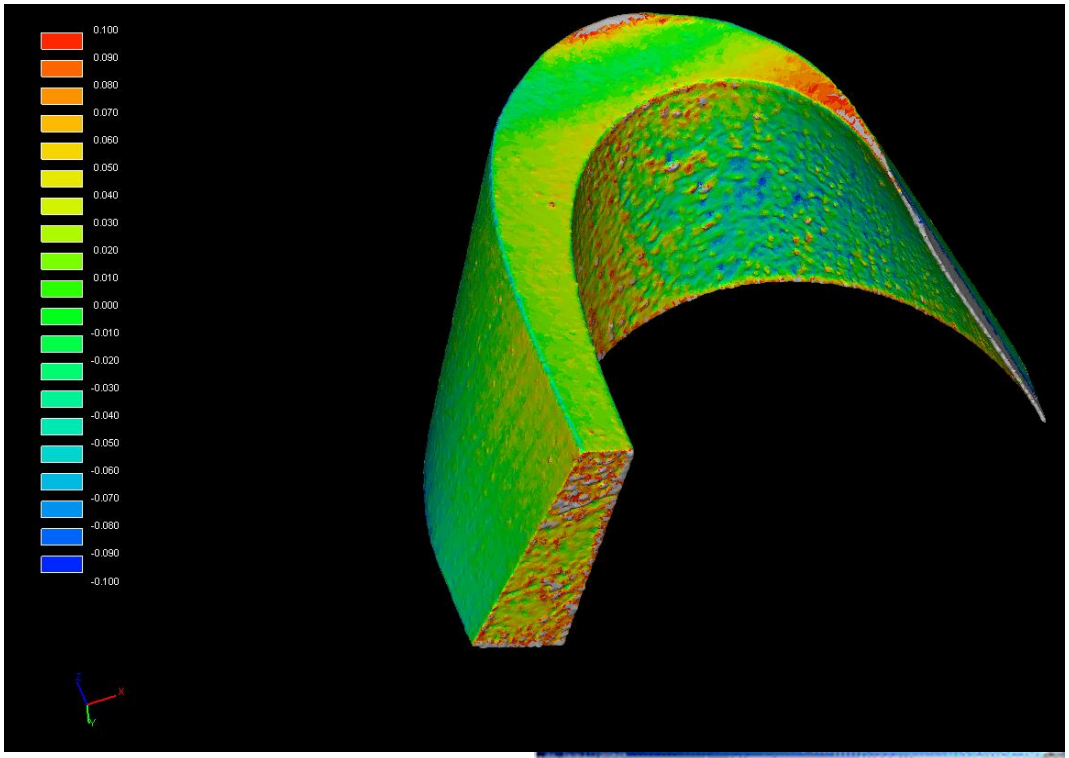


QC: Dimensional Control (CMM)



Required accuracy < 20 µm

QC: Photogrammetry



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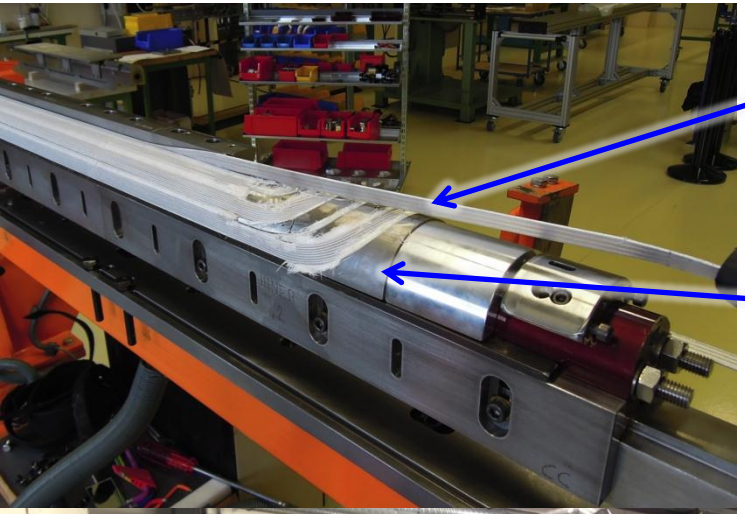
Some Cost Indications



220 m of insulated 40-strand Nb_3Sn cable: 40 kCHF

A set of 23 end spacers: 10 (SLS) .. 20 kCHF (CNC)

Impreg. Tool (2.5 m): 50 kCHF

Impreg. System (2.5 m): 200 kCHF

Reaction furnace (2.5 m): 250 kCHF

Reaction tool (2.5 m): 50 kCHF

Scaling-up..

Large Magnet Facility in B180

Curing press – 15 m

Winding machine – 10 m

Long Tooling Procurement Plan

- Winding machine available
  - Needs to be adapted: length, winding mandrel, integration of the additional spool, process control system upgrade
  - Design work to start in early December
  - First winding trials (with dummy cable) scheduled as from mid-2013
- Curing press available
  - Curing moulds to be developed, design work to start in mid-2013
- Reaction furnace (6.5 m)
  - Market Survey completed
  - Invitation to tender, IT-3861/TE, completed
  - Contract signature expected in January 2013
  - Delivery to CERN expected in the end of 2013
- Impregnation chamber
  - Market Survey, MS-3898/TE, completed
  - IT to be launched in January 2013
  - Contract signature expected in late April 2013
  - Delivery to CERN expected in first quarter of 2014

Acknowledgements

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J-M. Mucher, L. Oberli, J-C. Perez, L. Rossi, T. Sahner, F. Savary, S. Sgobba, D. Smekens...


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