MQXFB08 Coils:
Coil fabrication, manufacturing data and NC

N. Lusa, S. Izquierdo Bermudez, L. Baudin, A. Vieitez Suarez, P. M. Quassolo, L. Grand-Clement, R. Berthet

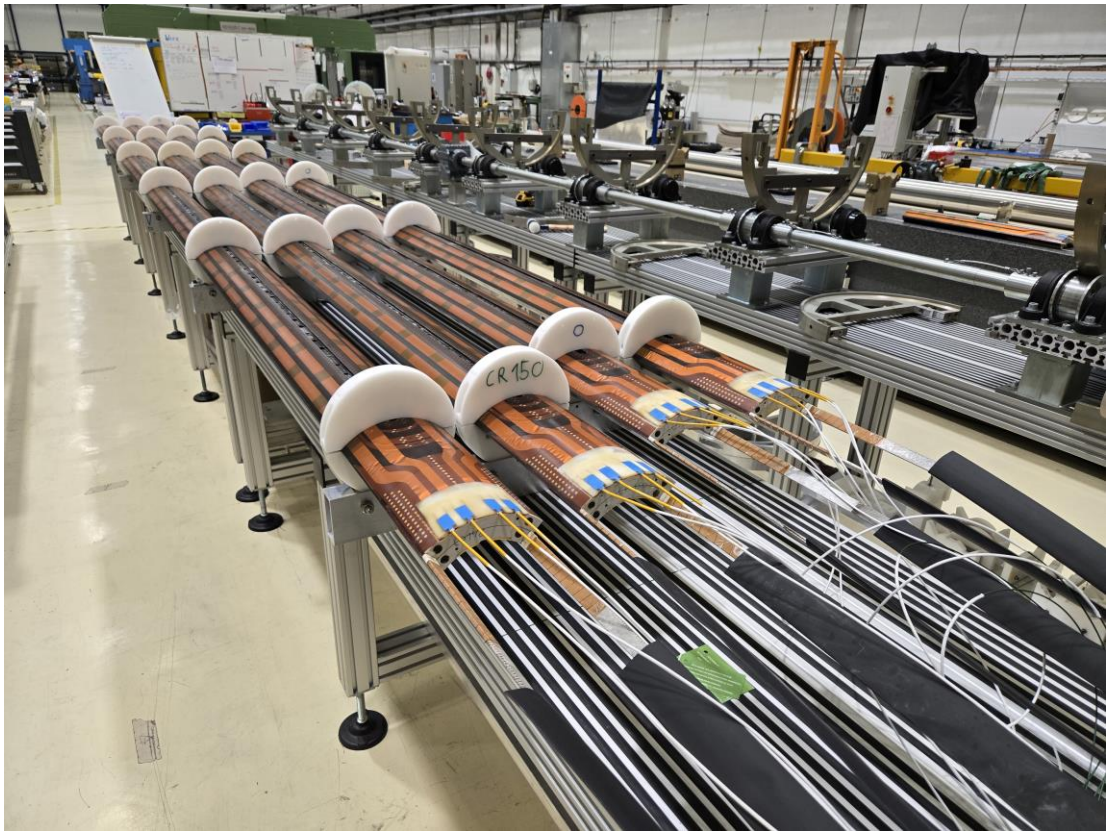
On behalf of MQXFB Coil Fabrication and QA team

https://indico.cern.ch/event/1470347/

06/11/2024

Coils for MQXFB08

- **Virgin coils available at the time of assembling MQXFB08**
  - Coil 109: Spare coil of MQXFBP1 (no b_6 correction)
  - Coil 114: Quarantined, due to the electrical insulation issue QH to coil
  - Coil 116: Quarantined, due to conductor damage during handling
  - Coil 122: Conform coil
  - Coils 148-149-150-151: Coils proposed for MQXFB08



Outline

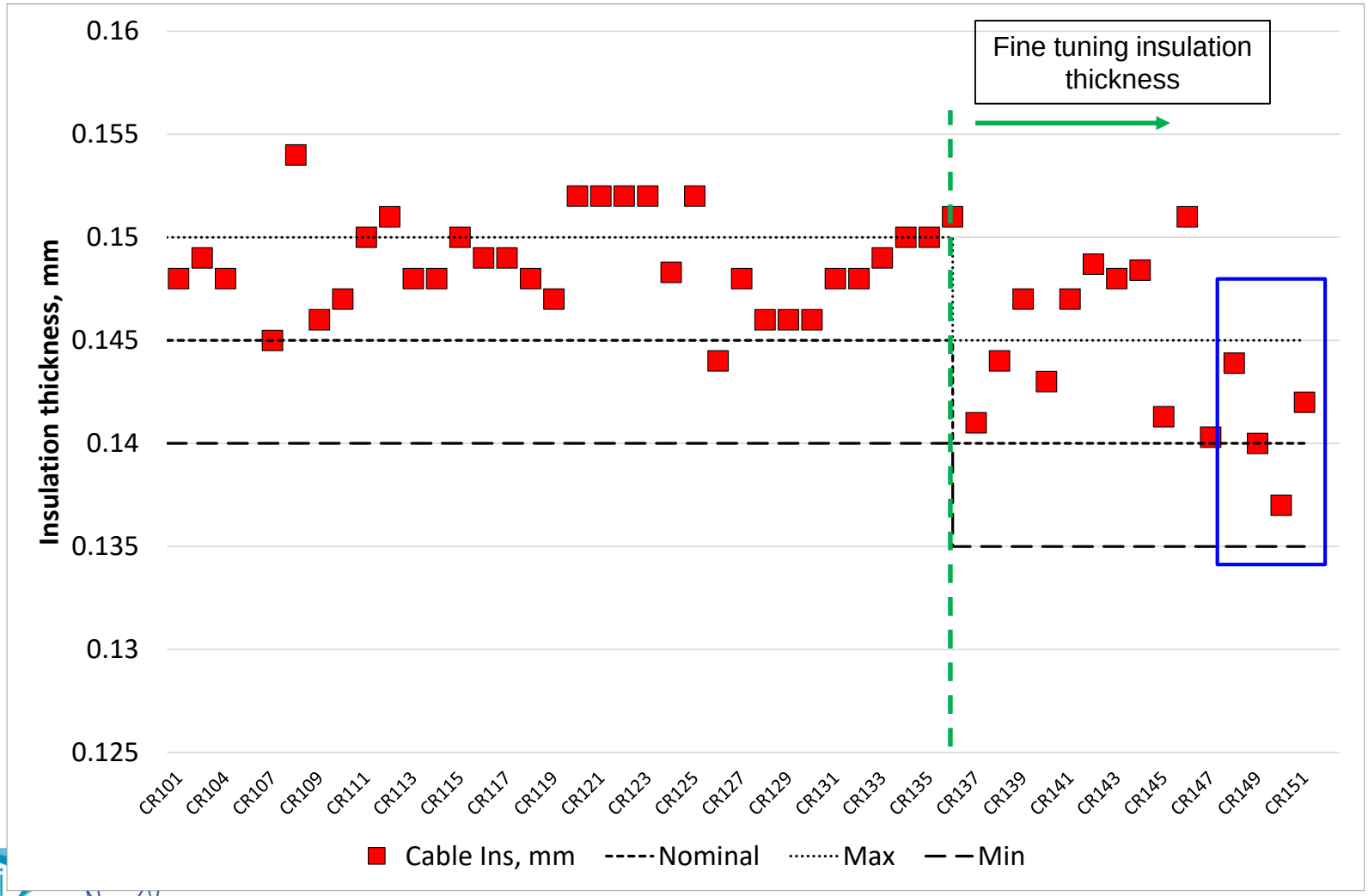
- Manufacturing data
- Non-conformities
- Conclusion/Proposal

Outline

- Manufacturing data
  - Analysis of MQXFBP2 coils and comparison improvements with respect to MQXFBP1 available here
  - Analysis of MQXFBP3 coils and comparison improvements with respect to MQXFBP2 available here
  - Analysis of MQXFB02 coils and comparison improvements with respect to MQXFBP3 available here
  - Analysis of MQXFB03 coils and comparison improvements with respect to MQXFB02 available here
  - Coil fabrication data and non-conformities of MQXFB04 coils available here
  - Coil fabrication data and non-conformities of MQXFB05 coils available here
  - Coil fabrication data and non-conformities of MQXFB06 coils available here
  - Coil fabrication data and non-conformities of MQXFB07 coils available here
- Non-conformities
- Conclusion/Proposal

Cable insulation thickness

- Target insulation thickness is 145 (+0 µm/-10 µm)



Cable insulation thickness

- Target insulation thickness was 145 ± 5 µm
  - Measured insulation systematically above target
  - Fine tuning of the insulation parameters in 2023 → well centered aroud 145 µm
- Since then, recurrent mechanical instability → popped strands detected during the cable insulation inspection (not in the last 4 cables used for CR151, CR152, CR153 and CR154)
  - Insulated cable HCMQXFBC09-4200419A (used in coil CR143)
  - Insulated cable HCMQXFBC09-4200454A (used in coil CR145)
  - **Insulated cable HCMQXFBC09-4200455A (used in coil CR148)**
  - **Insulated cable HCMQXFBC09-4200409A (used in coil CR149)**
  - **Insulated cable HCMQXFBC09-4200412A (used in coil CR150)**

Details in NCRs section

Reaction and impregnation fixture closure

REACTION

- The torque required to close the fixture is directly linked to the number of heating cycle the bolts were subjected to
  - Nominal torque required: 160 Nm
  - For B08 coils nominal torque was required (no need to further increase the torque)

IMPREGNATION

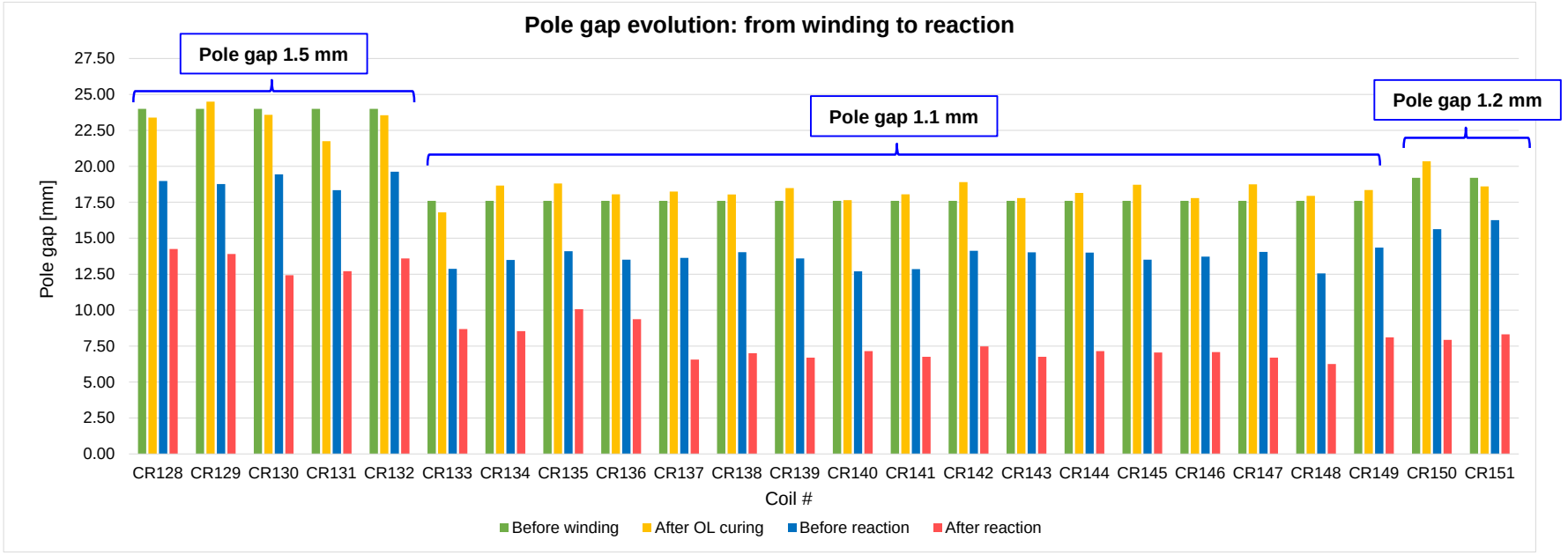
- Very reproducible from coil to coil
  - OL impregnation closure: 60 Nm
  - IL impregnation closure: 120 Nm (never needed more)
- Gap between blocks/plate is measured at determined steps of the closure
- The 4 coils proposed for B08 assembly were impregnated using the same impregnation fixture (#15)

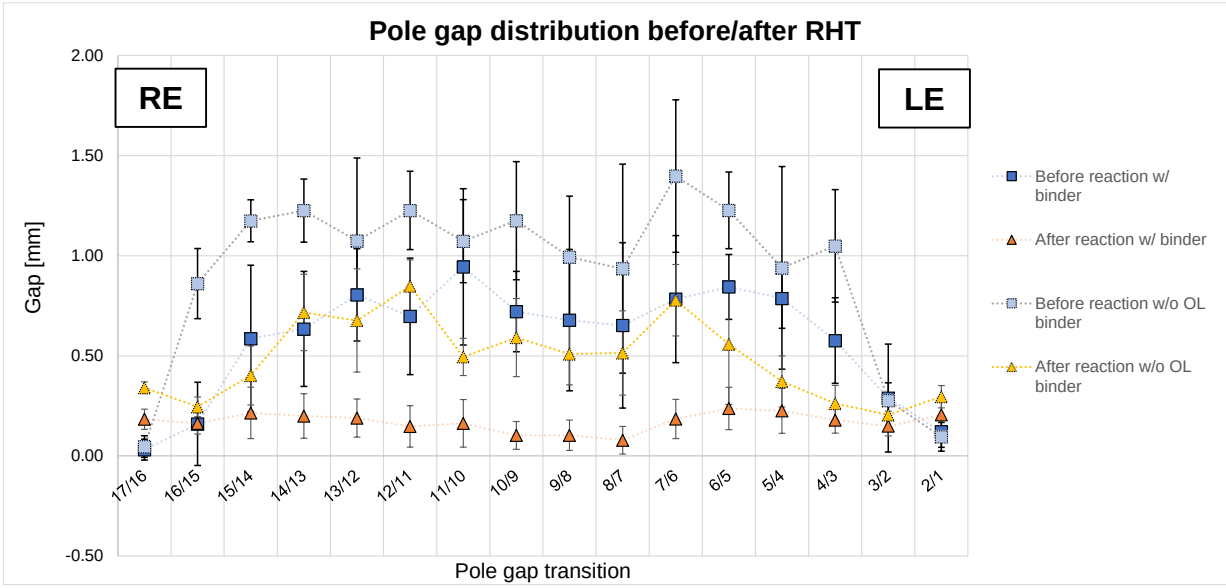
Coil elongation during reaction fixture opening

Coil elongation during reaction fixture opening						
Magnet	**Coil #**	**CS [mm]**	**NCS [mm]**	**Total [mm]**	**Total/L_m**	**Fab. Line**
B03	CR128, 129, 130, 131	2.6 - 4.2	3.1 - 4.8	5.7 - 8.7	0.8 - 1.2 ‰	CERN
B04	CR132, 133, 134, 135	2.1 - 4.3	2.9 - 3.8	5.1 - 8.0	0.7 - 1.1 ‰	
B05	CR136, 137, 139, 140	2.0 - 3.4	2.1 - 3.6	4.1 - 7.0	0.6 - 1.0 ‰	
B06	CR141, 142, 143, 144	2.9 - 3.4	2.8 - 3.7	5.8 - 6.6	0.8 - 0.9 ‰	
B07	CR138, 145, 146, 147	2.0 - 3.4	2.6 - 3.5	4.6 - 6.9	0.6 - 1.0 ‰	
B08 (proposal)	CR148	2.8	2.6	5.4	0.7 ‰	
	CR149	1.9	2.2	4.1	0.6 ‰	
	CR150	2.7	2.9	5.6	0.8 ‰	
	CR151	1.6	2.0	3.6	0.5 ‰	
	AUP 146 -147	2.9 - 3.6	0.6 - 0.4	3.6 - 4	0.8 ‰ - 0.9 ‰	FNAL
	AUP 237 -238	1.6 - 2.1	1.6 - 2.1	3.1 - 4.1	0.7 ‰ - 1 ‰	BNL

Pole gaps

- In new generation MQXFB coils pole gaps in the middle of the coil are not closed after reaction, as it is the case for AUP coils

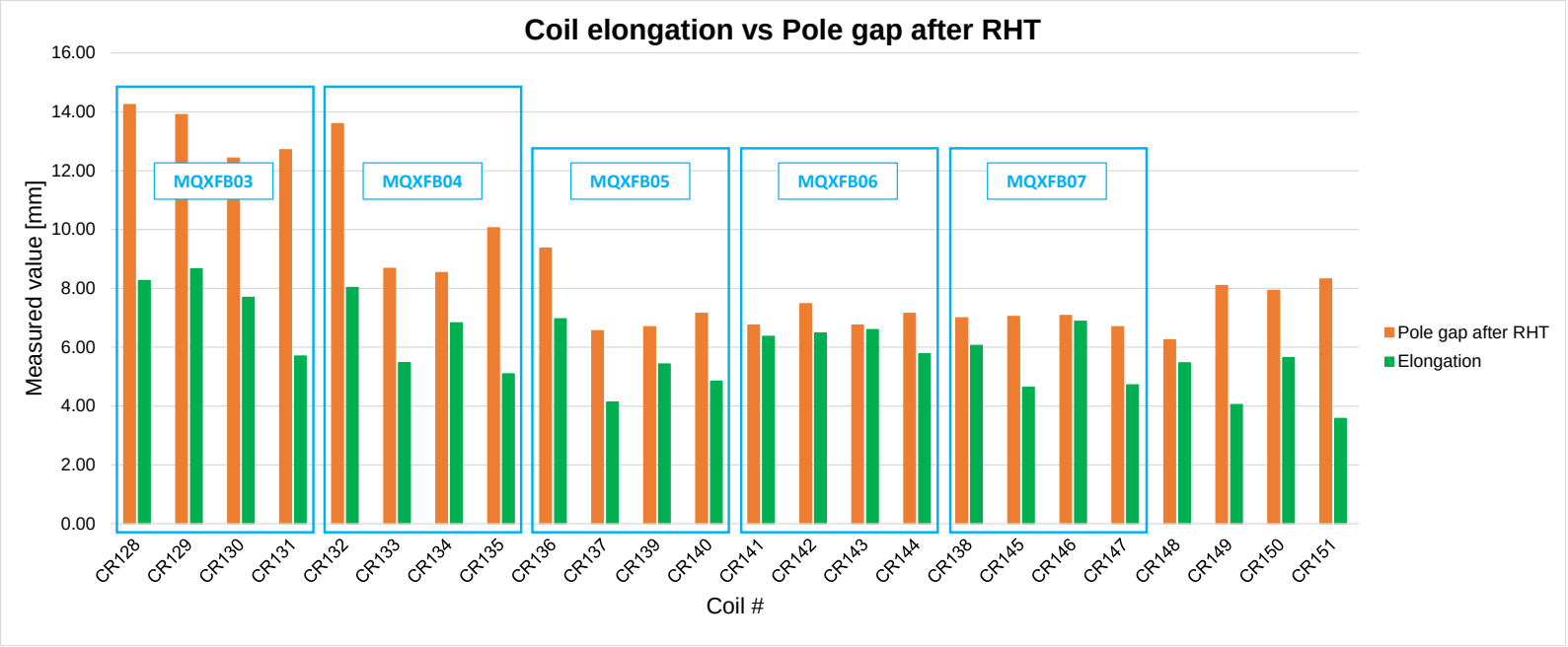




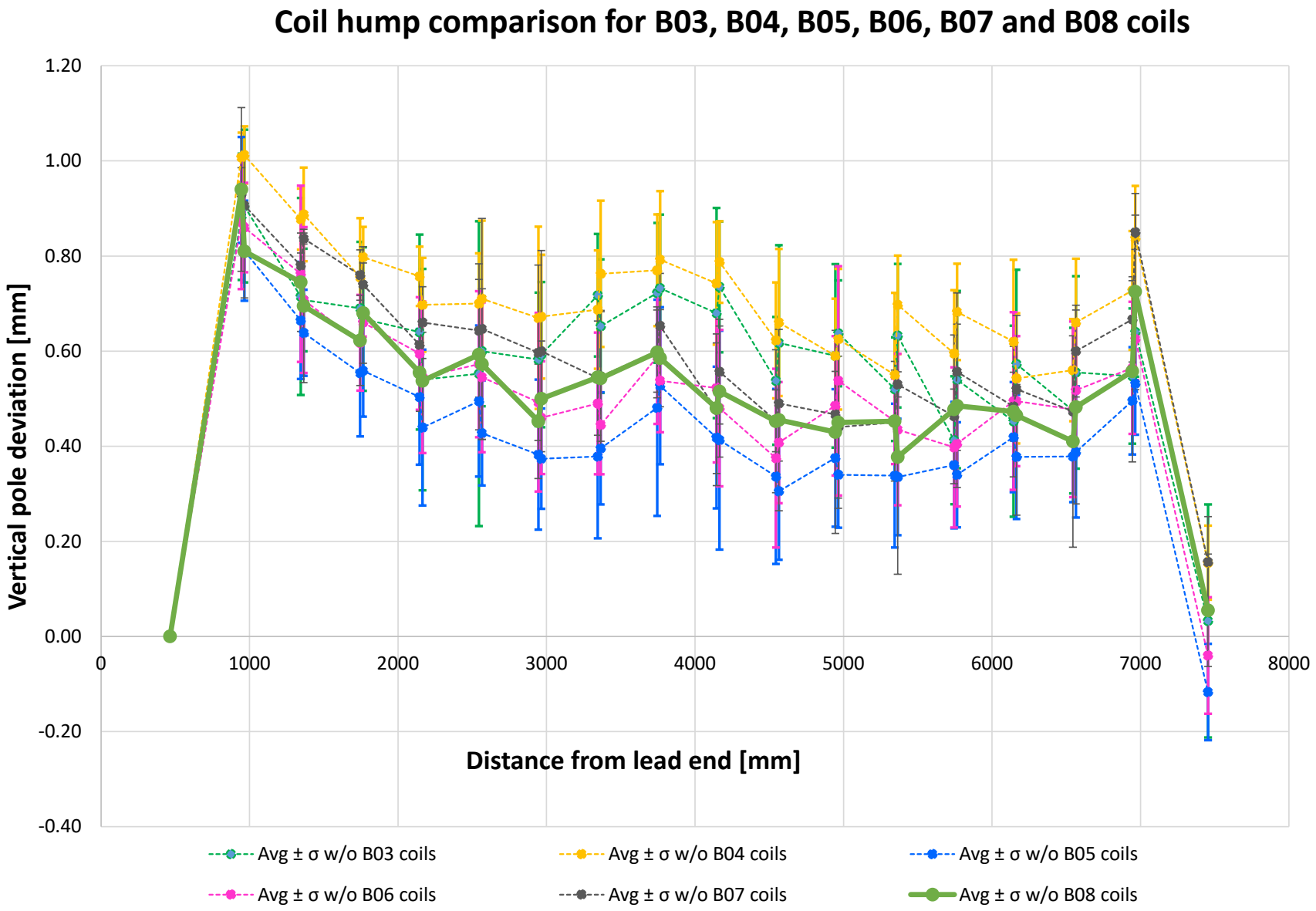
Pole gaps vs Coil elongation

- The reacted coil gradually elongates on both ends during the mold opening and pole gap increases (indico 1220226)
- From coil CR150 pole increased: 2.46 mm/m → 2.69 mm/m

Coil #	Total /L_m [‰]	Manufacturing line
CR127	1.50	CERN w/ binder
CR128 – CR151	0.83	CERN new gen. coils
AUP 146 – 147	0.89	FNAL
AUP 237 – 238	0.88	BNL

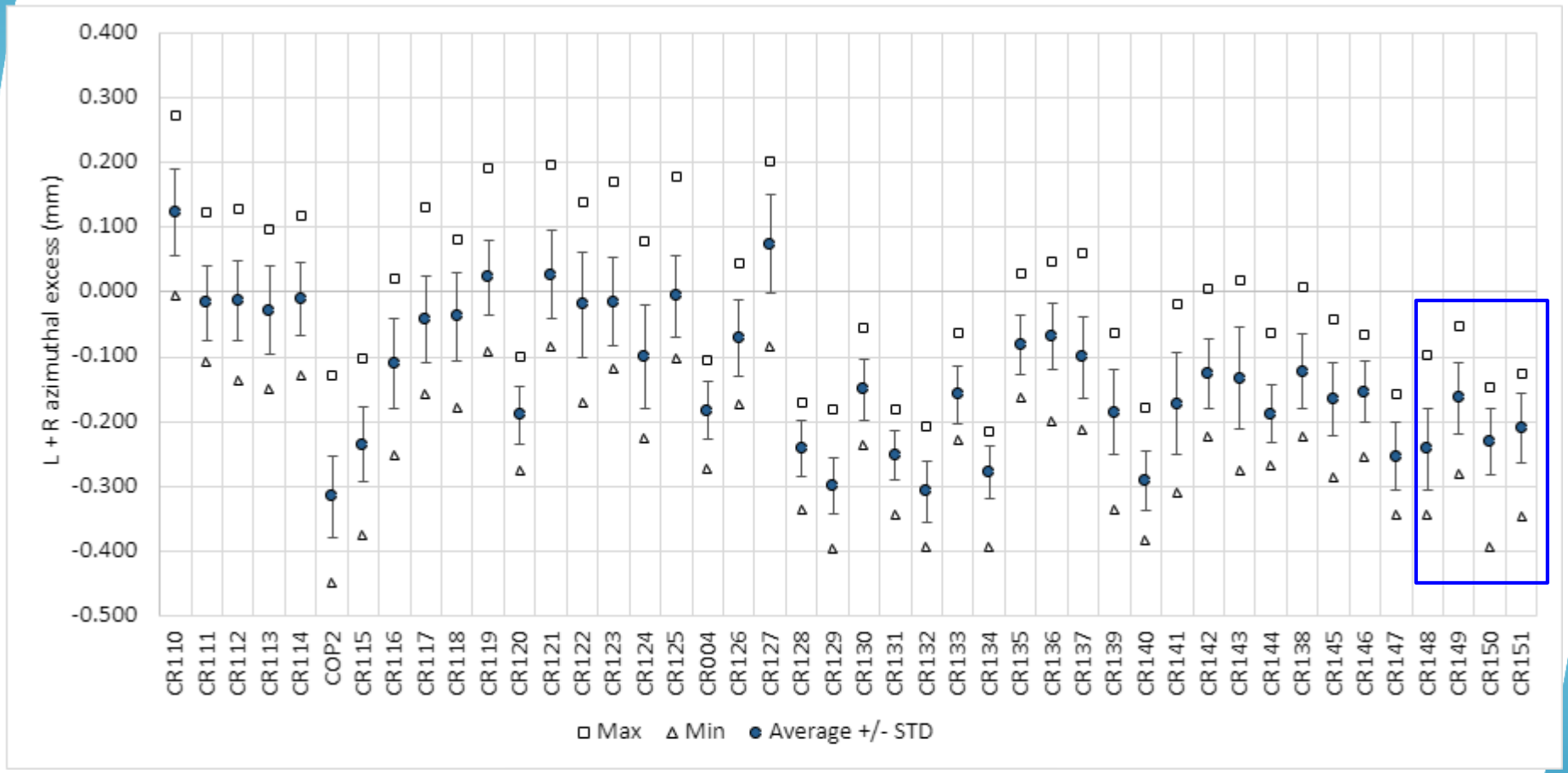


Coil hump after reaction



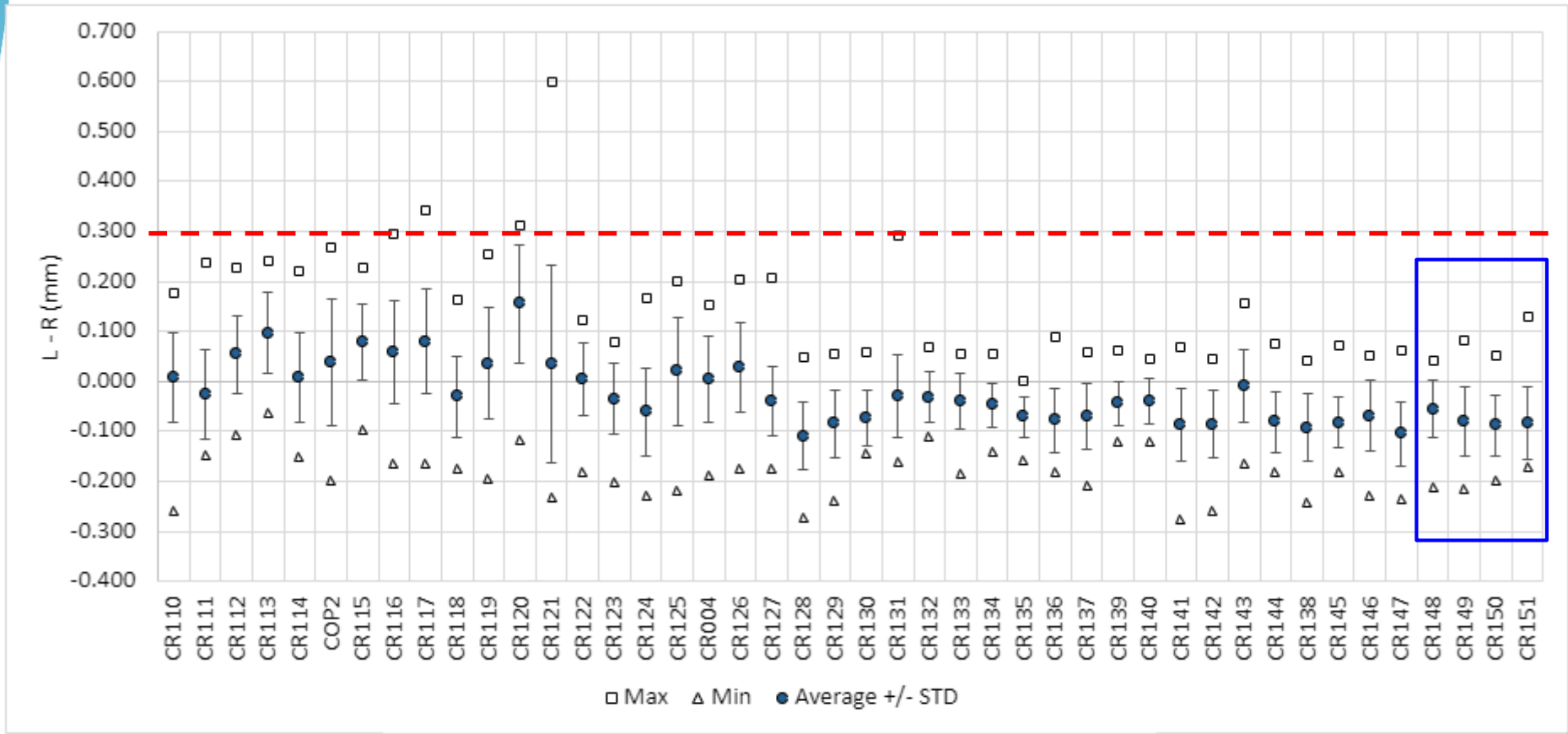
Impregnated coil geometry (Faro arm) - L+R

- The coils do not have ‘belly’



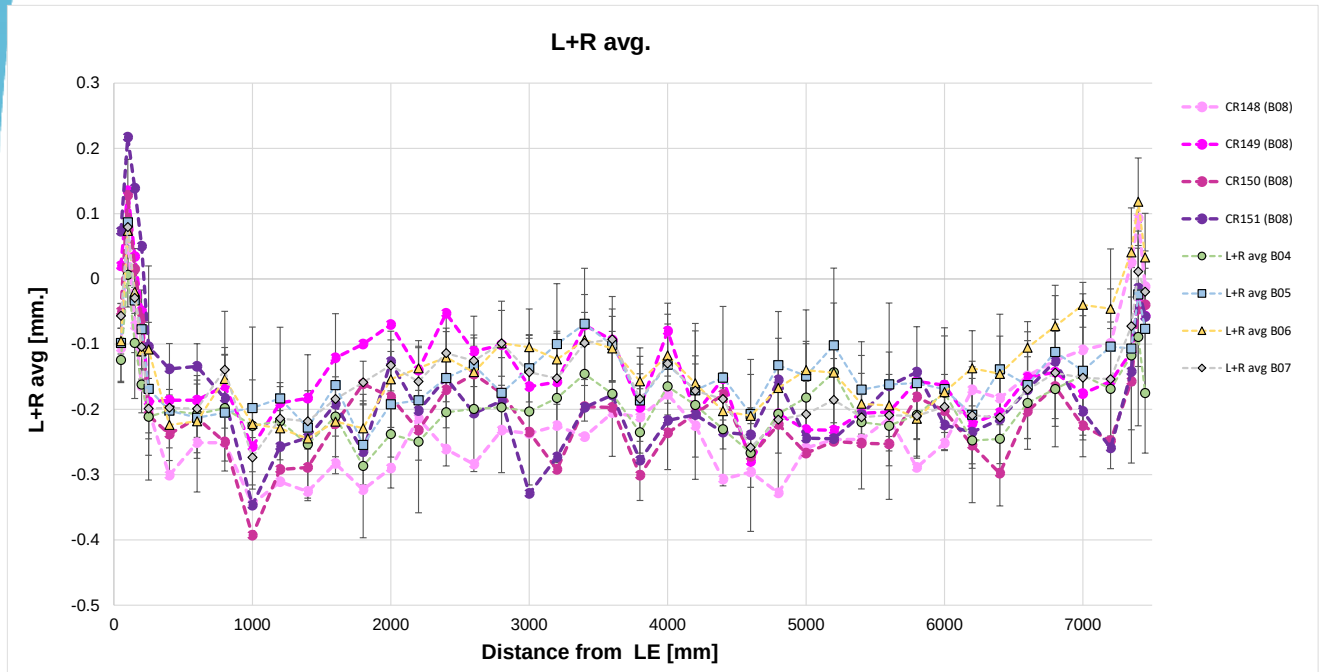
Impregnated coil geometry (Faro arm) – L-R

- In terms of asymmetry, within specification (<0.3 mm) → no need of pole key machining

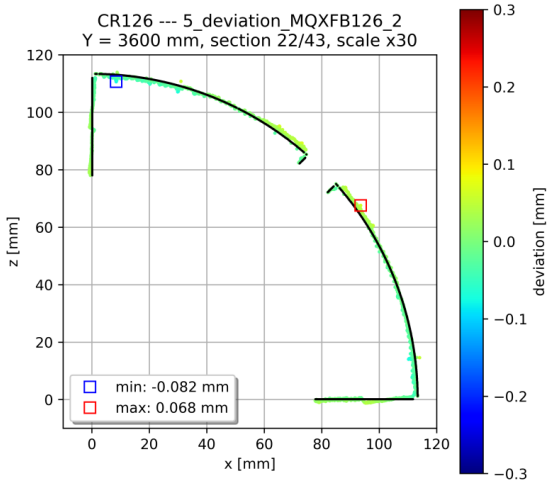


Impregnated coil geometry (Faro arm)

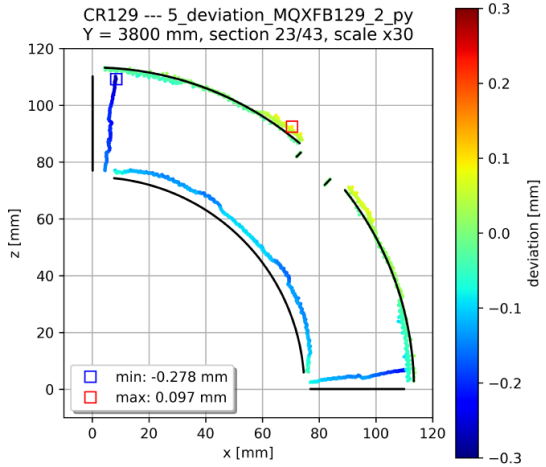
- Systematic behavior in terms of coil shape to previous coils without binder: mid-plane has a little ‘wedge’ (the coil covers 89.6 degrees instead of 90 degrees)
- Based on FEM we expect ≈ 15 MPa increase in the mid-plane stress (inner edge) under conservative assumptions, confirmed with a mock-up test, see https://indico.cern.ch/event/1260584/



Typical cross-section standard coil



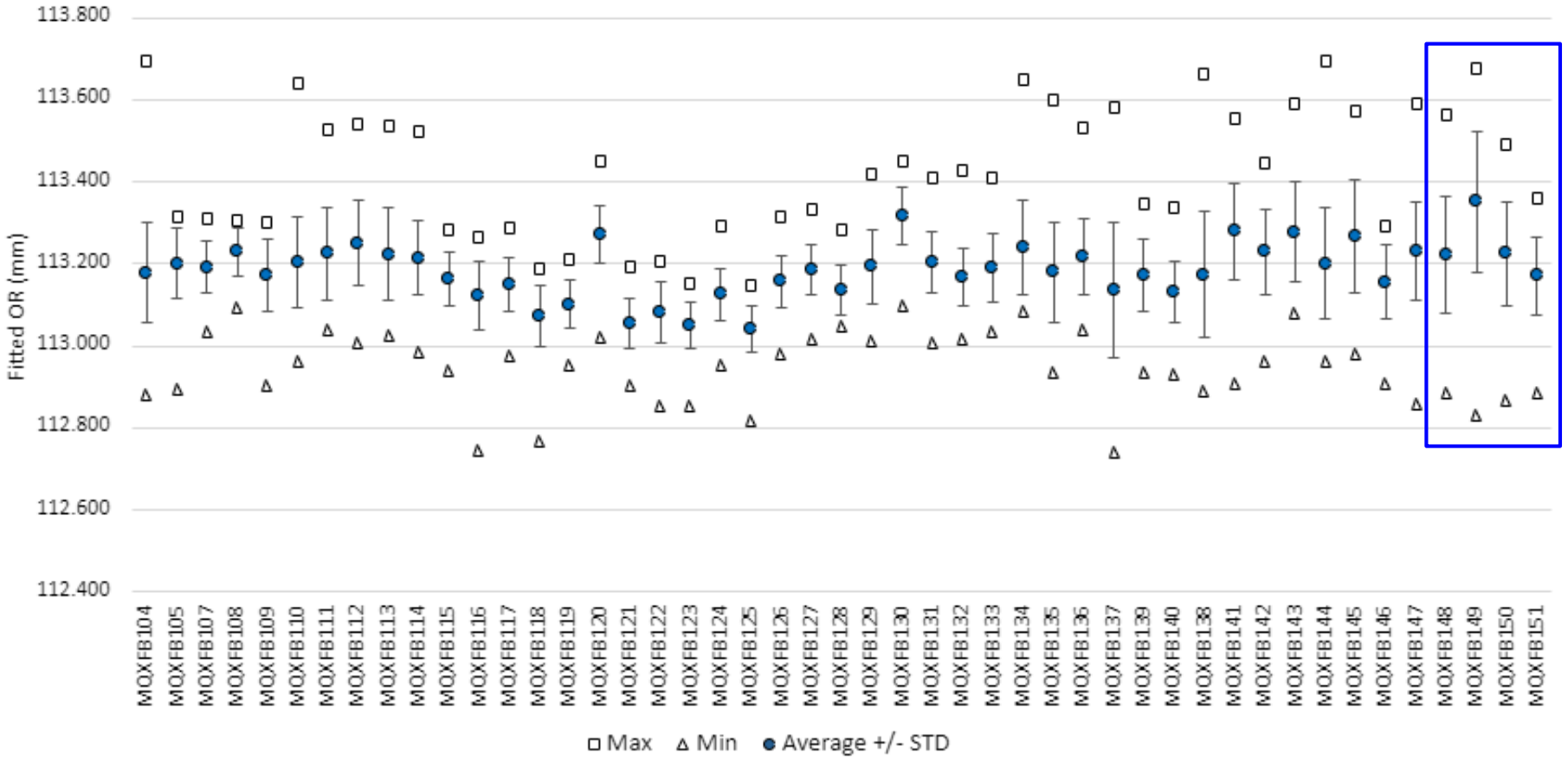
Typical cross-section coil without binder in the OL



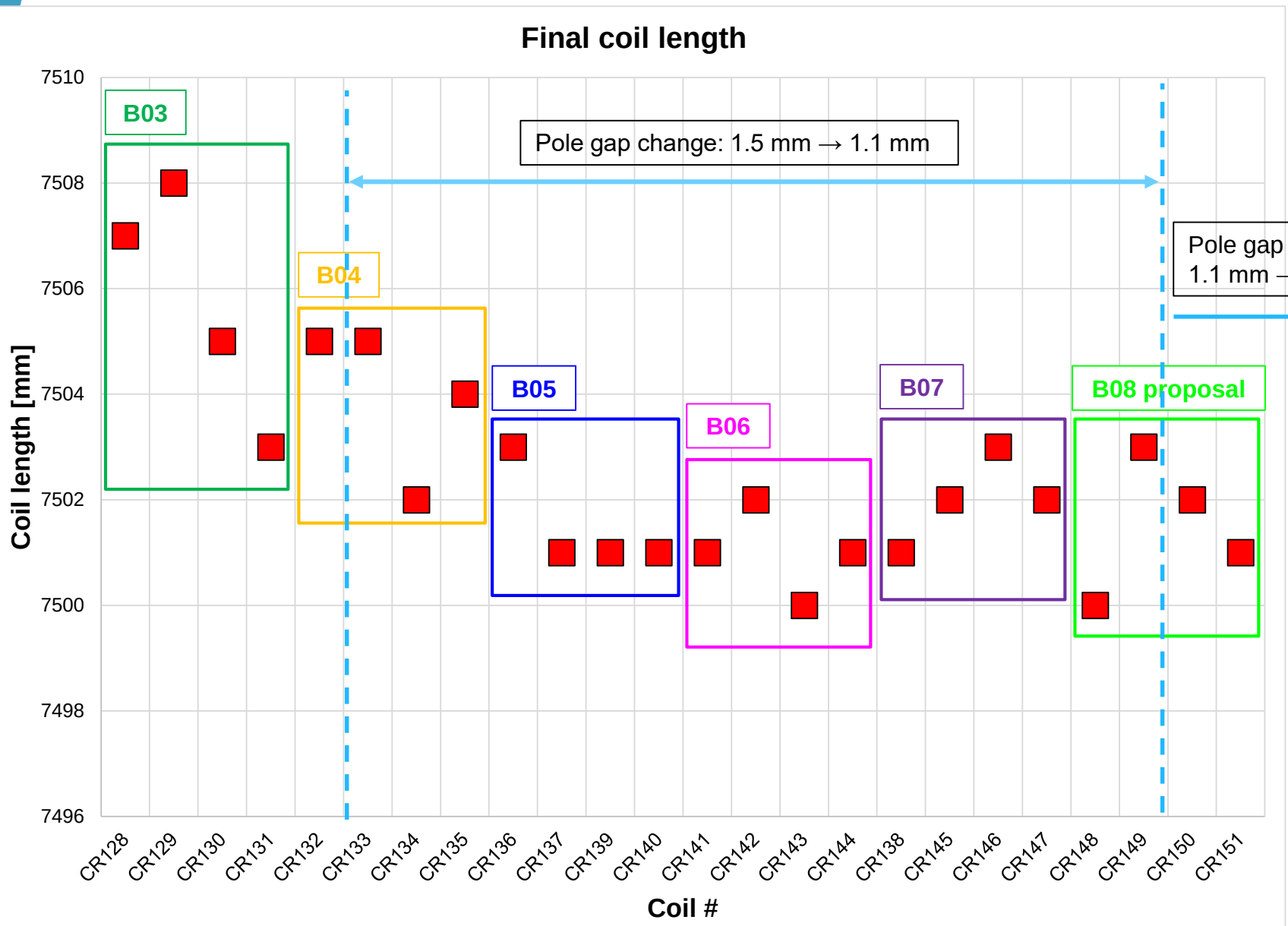
Further detail about coil metrology in Penelope’s presentation

Impregnated coil geometry (Faro arm) - OR

- The proposed coils are very similar in terms of OR



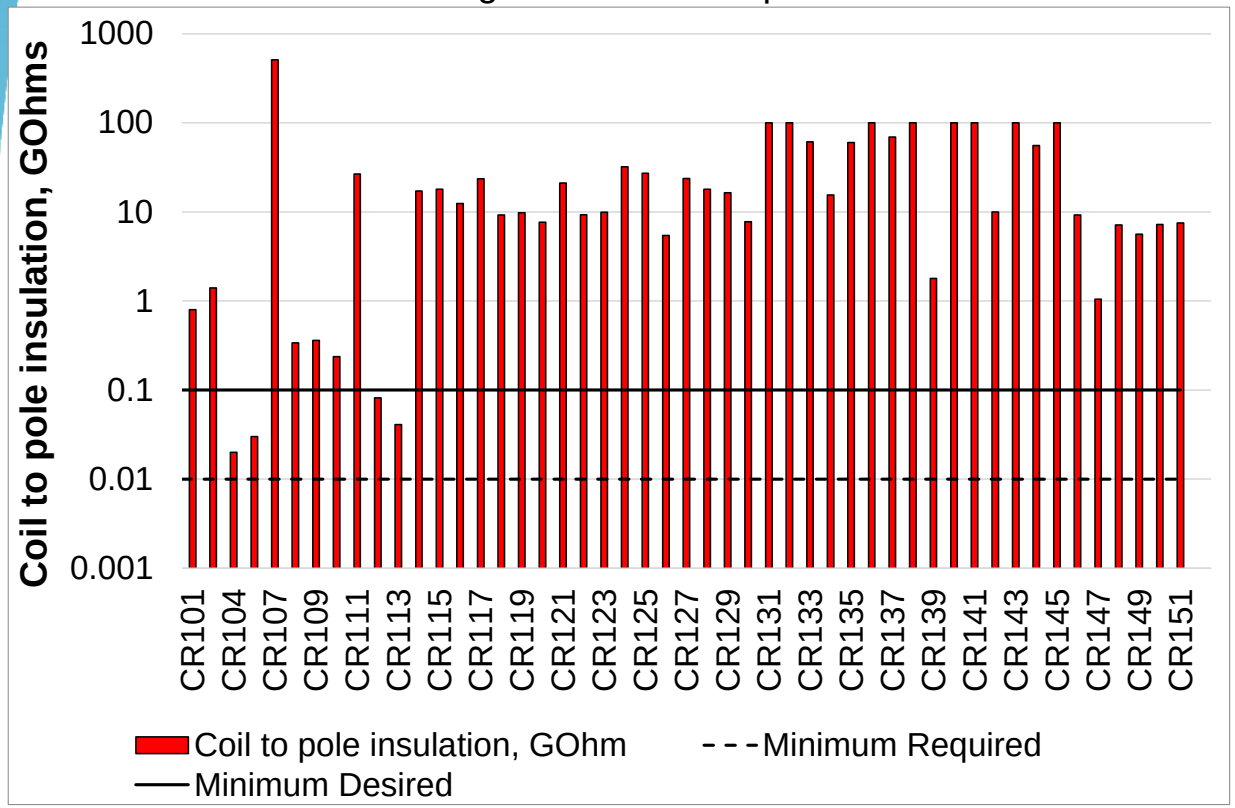
Final coil length



Dielectric strength

Coil to pole

- Since coil 114, coil to pole insulation always above the minimum desired thanks to the reduction of ceramic binder and the use of heat cleaned fiber glass around the pole

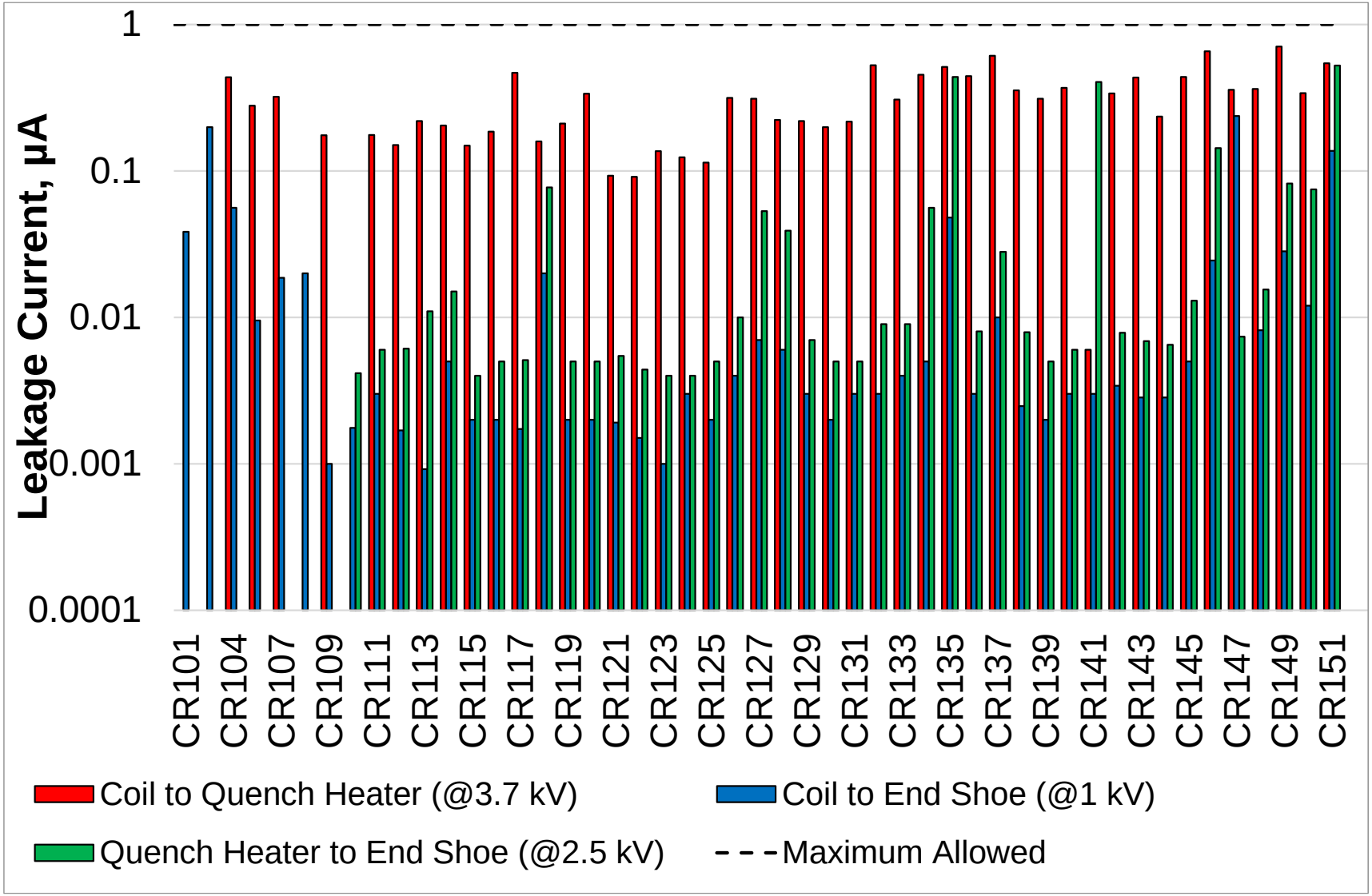


From production performance monitoring plots EDMS 2374351

QH to coil

- From coil 126, 'mini-swap' quench heaters with improved fabrication process and higher qualification test voltages (see EDMS 2646046)

Dielectric strength



Outline

- Manufacturing data
- Non-conformities
- Conclusion/Proposal

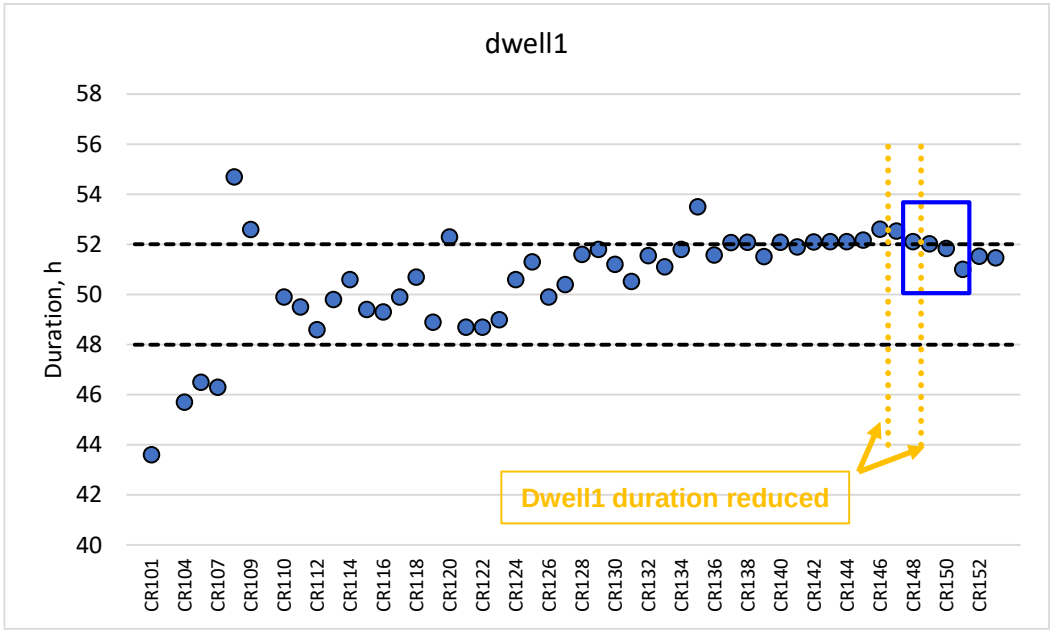
Analysis of non-conformities

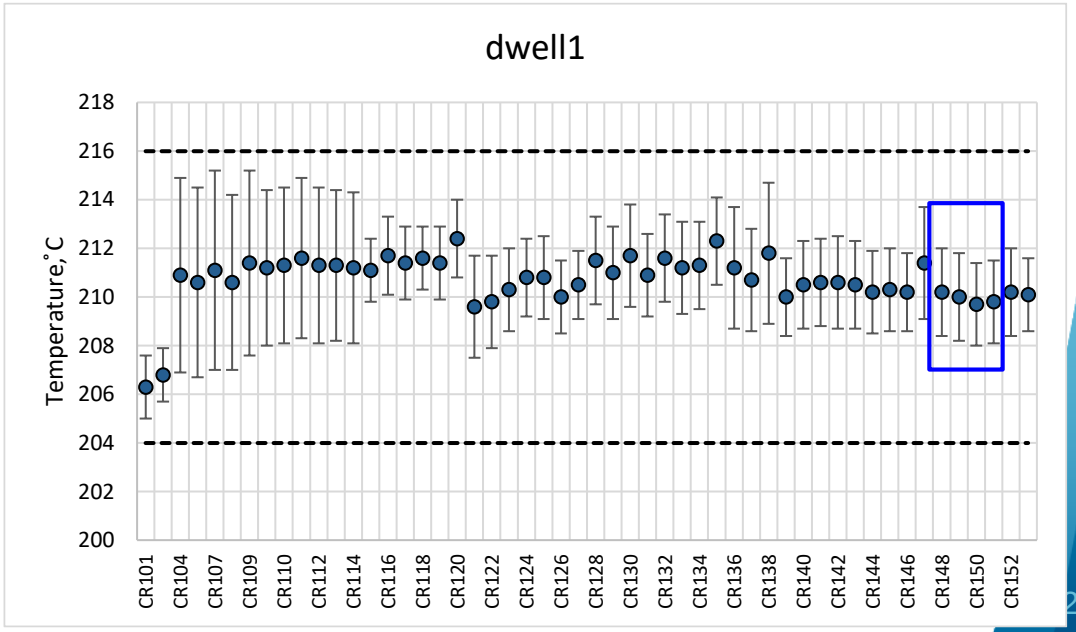
CR148	3093358	Popped strands during cable insulation inspection	Non-critical level 2
	3118068	Emergency stop during outer layer curing	Non-critical level 1
	3129199	Dwell1 and dwell2 durations out of specifications	Non-critical level 1
CR149	2811007	Popped strands observed during cable inspection	**Non-critical level 3**
	3138474	Dwell1 duration out of specification	Non-critical level 1
	3154270	Superficial defect on the OD of the impregnated coil	**Critical level 3**
CR150	3132312	Popped strand repair	Non-critical level 1
CR151	3170110	Epoxy resin leak during impregnation	Non-critical level 1

Very minor, not described in further detail in the slides
Described in detail in the next slides
Series of minor nonconformities in heat treatment, see next slides

RHT NCR – dwell1

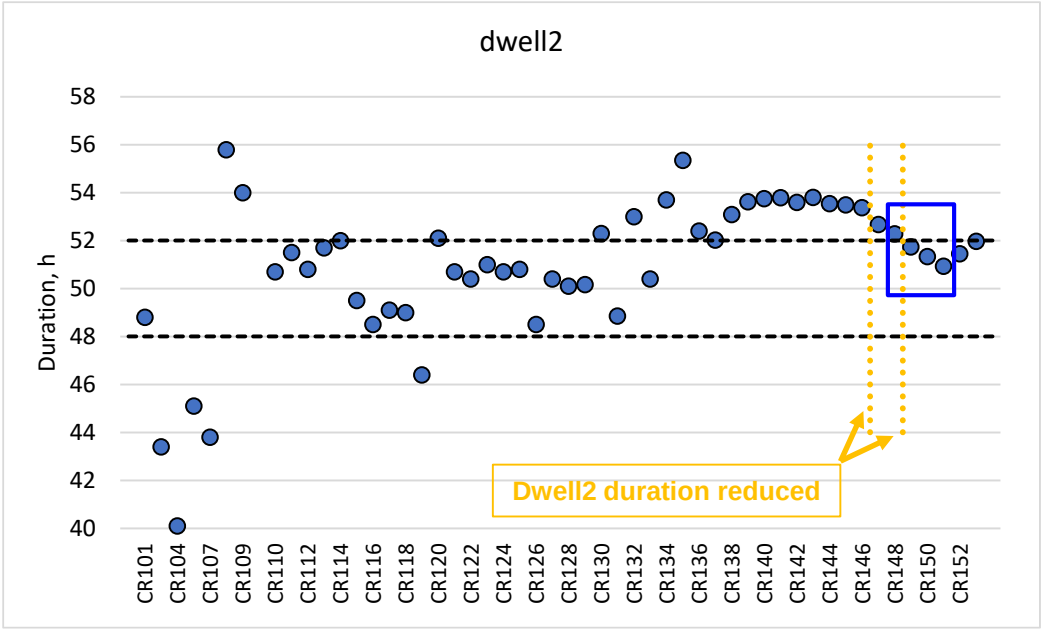
- The duration of dwell1 is slightly out of specification in 2 out of 4 coils:
  - CR148: 52.11 h
  - CR149: 52.02 h
  - CR150: 51.84 h
  - CR151: 51 h
  - Spec. 52 h maximum allowed
- Temperature homogeneity within specification

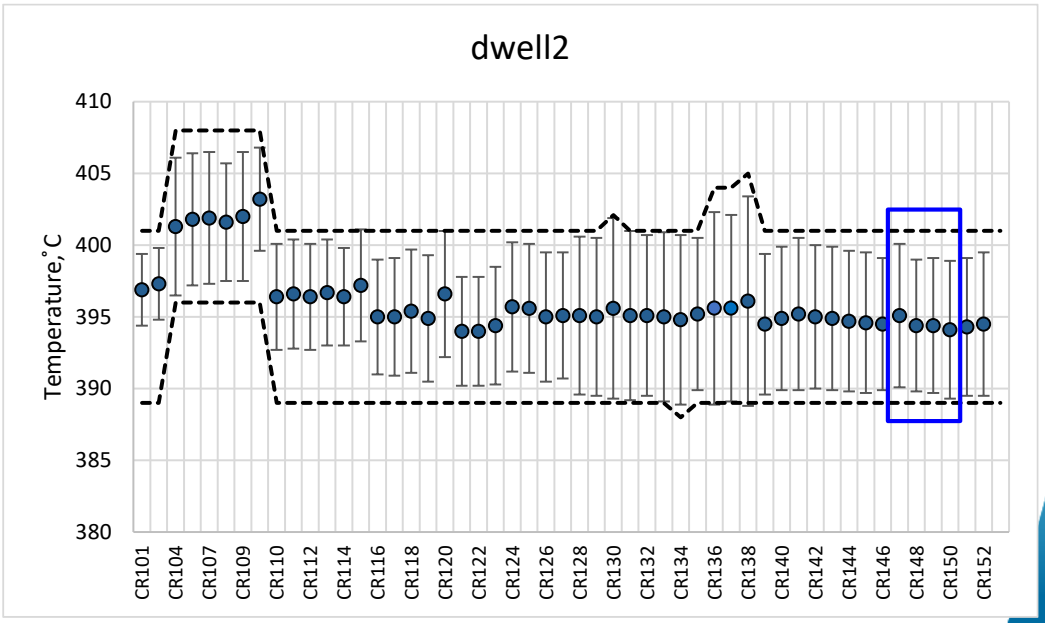




RHT NCR – dwell2

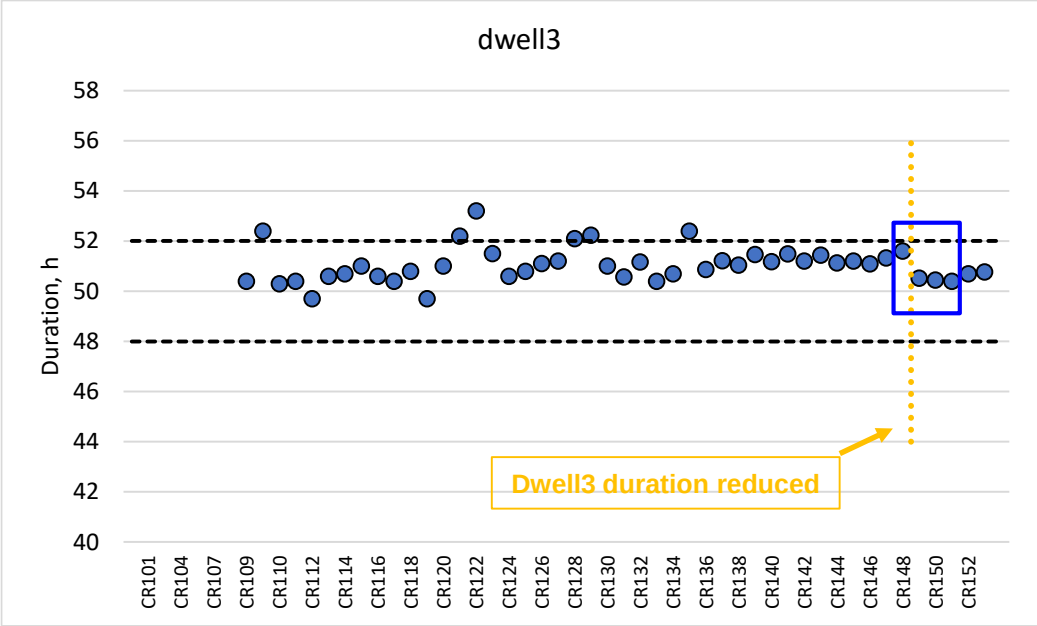
- The duration of dwell2 is out of specification for 1 coil out of 4:
  - CR148: 52.29 h
  - CR149: 51.74 h
  - CR150: 51.34 h
  - CR151: 50.94 h
  - Spec. 52 h maximum allowed
- Temperature homogeneity within specification

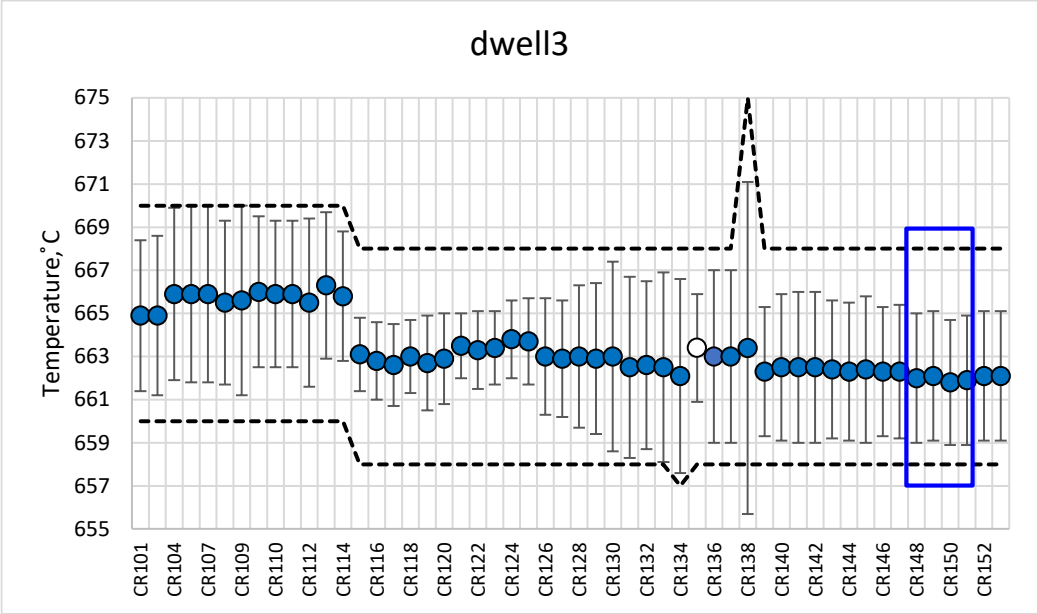




RHT NCR – dwell3

- The duration of dwell3 is within specification for the 4 coils (52 h max. allowed)
- Temperature homogeneity within specification and Dwell3 mean H/2 within specifications





CR148 (NCR 3093358) → Popped strands during cable inspection

- During the visual inspection of the cable insulation, 102 popped strands were detected between 30m and 442m from the beginning of the spool

- All the popped strands were set back using a dedicated pliers
- The popped strands are expected to be in the outer layer of the coil
- During winding no popped strand was detected by the operator

- Investigations pointed to:
  - Cable insulation process
    - This issue starts appearing in a systematic way with the fine-tuning of the insulation parameters → phenomenon still to be understood
    - Issue not observed in the last 4 ULs of cable received

CR149 (NCR 2811007) → Popped strands during cable inspection

- During the visual inspection of the cable insulation, 1 important popped strand was detected at 6.5m from the beginning of the spool, then several minor ones up to 285m (about 50 popped strands)

- All the popped strands were set back using a dedicated pliers
- The popped strands are expected to be in the outer layer of the coil
- During winding no popped strand was detected by the operator

- Investigations pointed to:
  - Cable fabrication
    - No strand in the cable is affected by the non-standard oil issue
    - No indication the problem is related to the cabling machine
  - Cable insulation process
    - This issue starts appearing in a systematic way with the fine-tuning of the insulation parameters → phenomenon still to be understood
    - Issue not observed in the last 4 ULs of cable received

CR149 (NCR 3154270) → Defect on the QH after impregnation

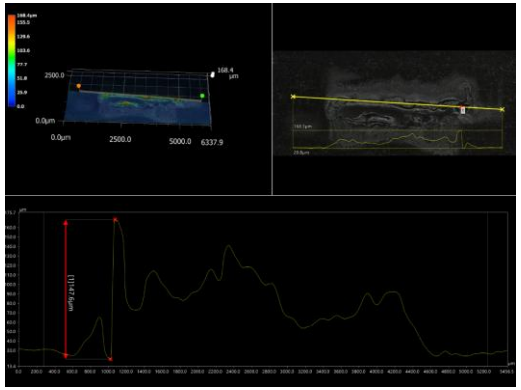
- Superficial defect on the OD impregnated coil at the level of the heater strip at 5620 mm from LE side
- Pictures taken during preparation for impregnation were checked
  - No defect was present neither on the OD of the reacted coil nor on the QH surface

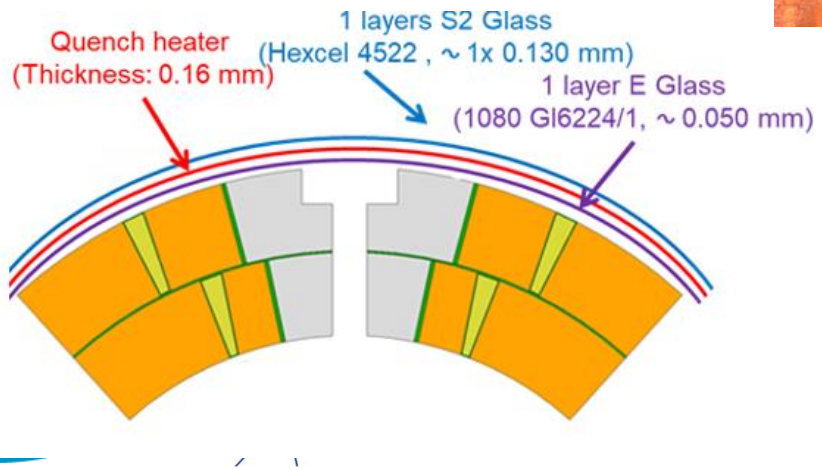
Action plan

- Thanks to EN-MME and TE-MSC-LMF-EE the following steps were performed
  1. Replica of the superficial defect to assess the depth (EDMS 3155368)
  2. Microscopy to better define the defect and its origin (EDMS 3155368)
  3. Staged dielectric test to assess the insulation QH to coil (EDMS 3156284)

Results 1/2

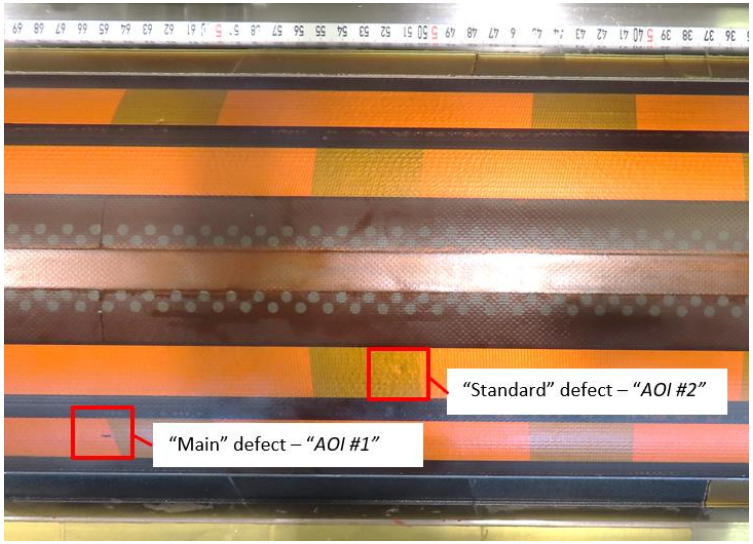
1. Based on the analysis of the replica the maximum depth of the defect is 150µm (in principle above the QH)
2. Inspection of the surface showed a shallow cavity with a burnt aspect and no metallic particle was observed
3. The electrical test passed successfully up to nominal (3.7kV for 120s)

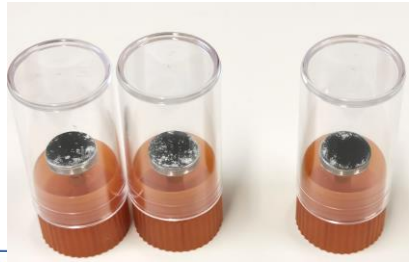




Results 2/2

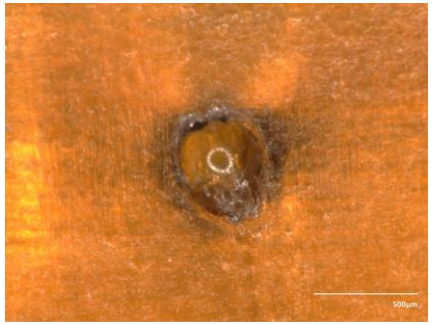
- It was decided to collect samples from the main defect (AOI#1) and from a more standard one (AOI#2) to analyse with SEM-EDS (EDMS 3175548)

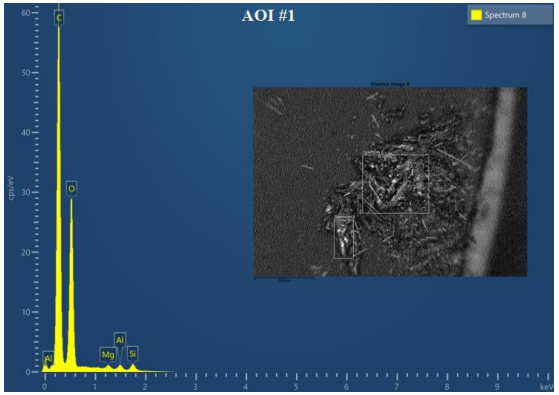


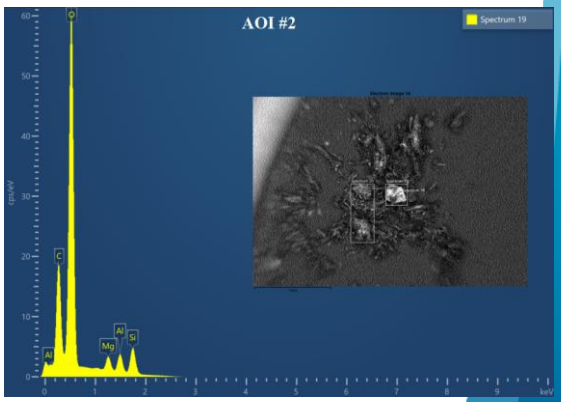


Defect AOI#1

Defect AOI#2







S2 glass composition: 64-66% SiO_2, 9-11% Al_2O_3, 9-11% MgO

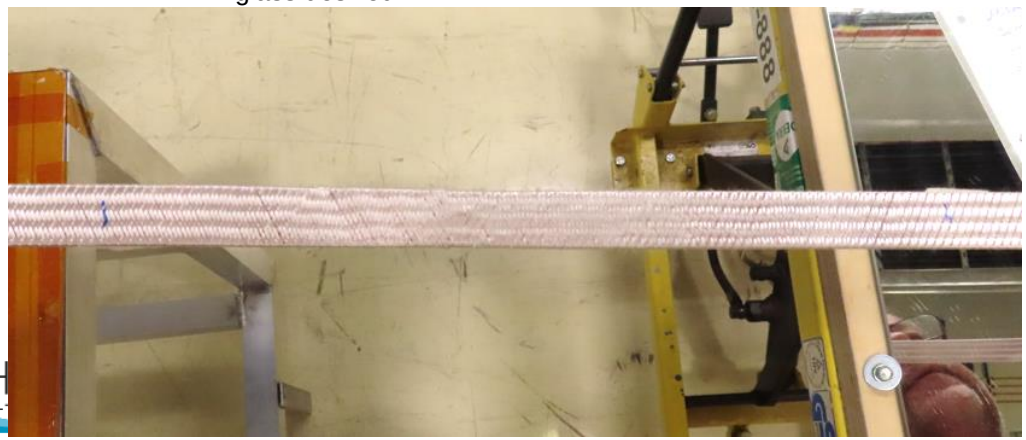
The end of the story

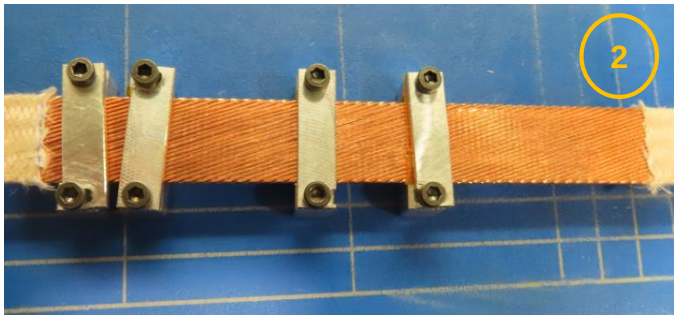
- The main defect AOI#1 disappered during the manual scratching (very superficial as from replica measurement)
- The integrity of the quench heater was not compromised (confirmed by the microscopy)
- SEM-EDS analysis did not reveal any exogeneous particle (only S2 glass chemical composition)
- Local repair of the scratched area was performed
- Coil acceptance electrical test successfully performed

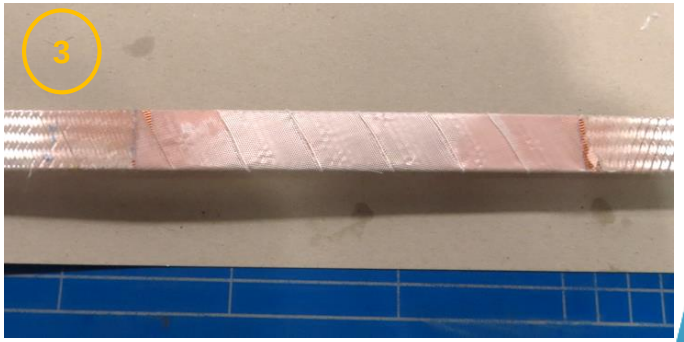
More details in technical note EDMS 3177956

CR150 (NCR 3132312) → Popped strand repair

- During the cable insulation inspection, among several minor popped strands, a more pronounced one was detected at 641m from the beginning of the spool
  - For the major one an in-situ intervention at the supplier company was performed
- Standard ‘repair’ strategy did not work (overthickness of 0.8mm)
  - Decision to locally remove the S2 glass insulation to set back in place the concerned strand and restore the insulation
    1. S2 glass removal from the concerned area
    2. Strand back in place via dedicated clamps
    3. Restoring of the cable insulation wrapping 1 layer of 0.125 mm S2 glass desized







Outline

- Manufacturing data
- Non-conformities
- Conclusion/Proposal

Conclusion/Proposal

- Use CR148 - CR149 - CR150 - CR151 for MQXFB08 assembly
- The coil instrumentation started and the magnet loading is planned for either the end of the year or beginning of 2025

Thank you!