Status of D2 in INFN-Genova

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SUMMARY

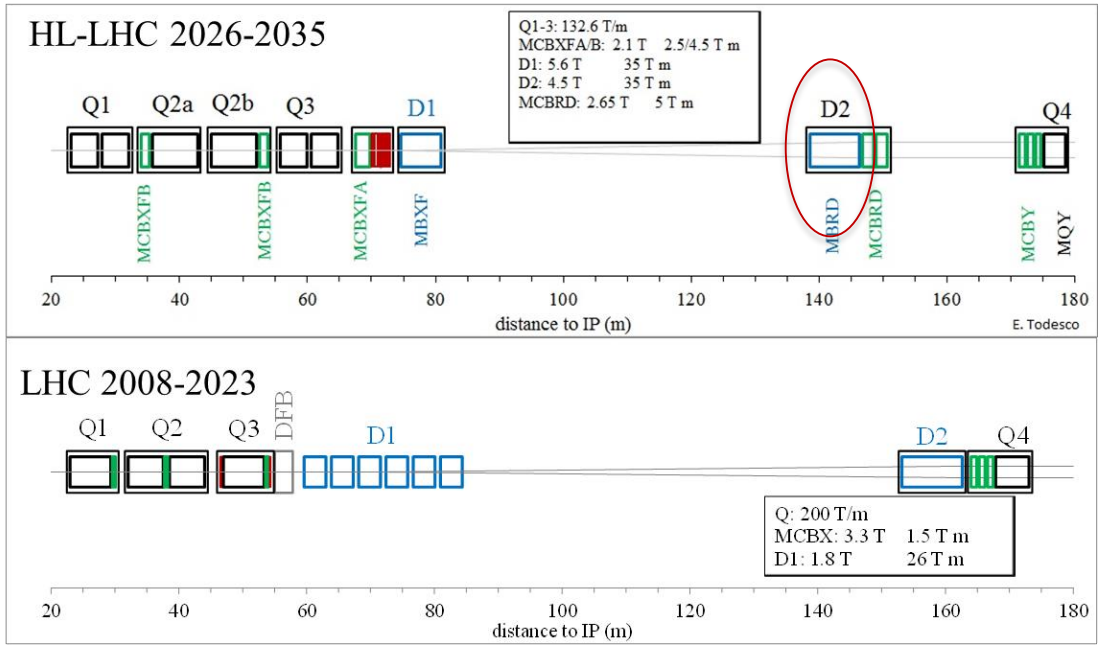
- CERN/INFN Agreements
- D2 magnet layout
- Prototype status
- Plan for the series
- Overall schedule

CERN/INFN AGREEMENTS FOR D2

- KN 3083 Framework agreement
  - Addendum n.1 KE3084
    - D2 Short Model (MBRDS1) (1.6 m) and Prototype (MBRDP1) (8 m) construction
    - Short model tested at CERN in August 2020
    - Prototype completed and will be delivered to CERN by tomorrow
  - Addendum n.11 KE4417
    - D2 Series production of 6 units (4 units for installation and 2 units as spares)
    - Contract awarded to ASG Superconductors on March 2021
    - Engineering design completed, production ready to start as soon as all new/modified components have been procured

D2 LAYOUT AND FUNCTION

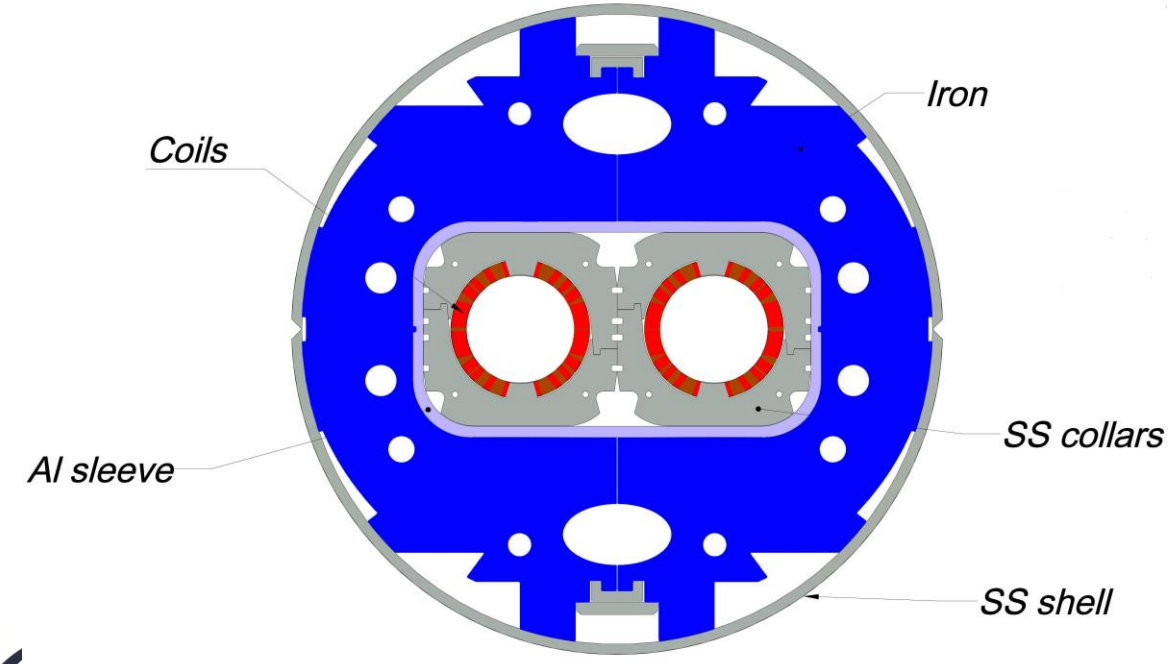
- The D2 dipole (MBRD, Main Bending Recombination Dipole) is placed in the D2 cold mass together with the orbit correctors around IP1 and IP5
- Main characteristics:
  - same field direction in both apertures (used to bring beams to collision), apertures in series
  - 35 T m integrated field at 7 TeV
  - 37.6 T m integrated field at 7.5 TeV (ultimate field)
  - 2 apertures, 105 mm in diameter, 8010 mm in physical length



No. of magnets	No. of apertures	N. coils
4 Series	8	16
2 Spares	4	8
=6 Magnets	=12 apertures	=24 coils

D2 CROSS SECTION

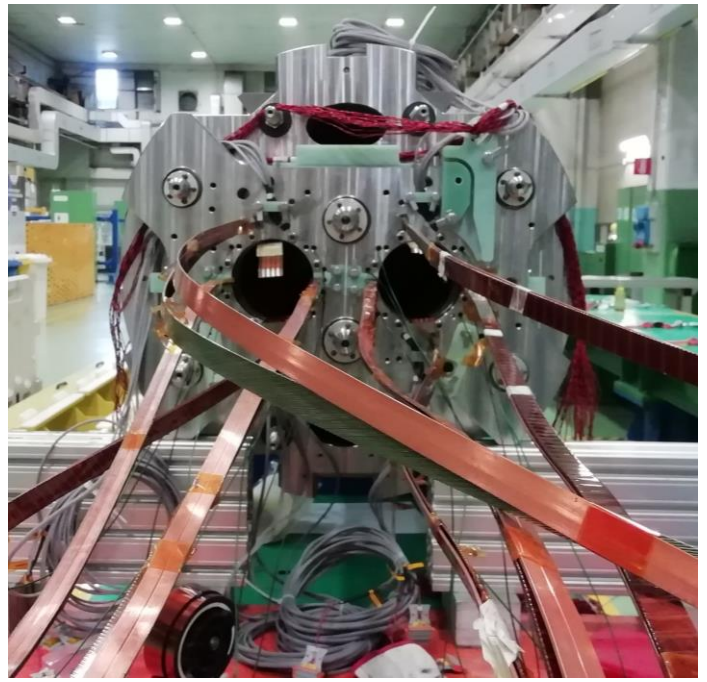
- Bore field: 4.5 T (4.8 T ultimate)
- Magnetic length: 7.8 m (8.01 m physical length)
- Challenges
  - Field quality optimization based on asymmetric coils
  - Novel structure for the two apertures based on Al shells



Main characteristics of the D2 dipole	
Bore magnetic field	4.5 T
Magnetic length	7.78 m
Peak field	5.26 T
Operating current	12.330 kA
Stored energy	2.26 MJ
Overall current density	478 A/mm^2
Aperture	105 mm
Operating temperature	1.9 K
Loadline fraction	67.5%
Multipole variation due to iron saturation	<10 units

PROTOTYPE STATUS

- The prototype has been completed and left ASG this morning

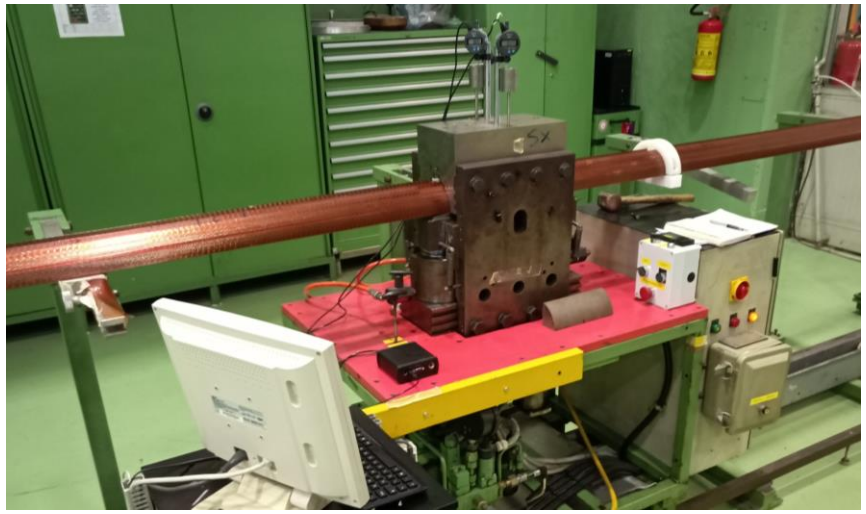


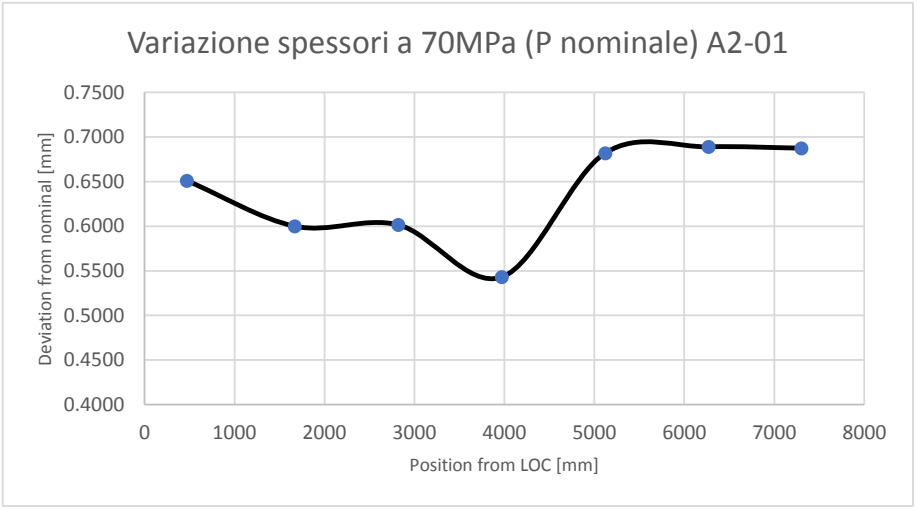
PROTOTYPE STATUS: THIRD APERTURE

- The contract for the prototype includes the construction of 3 apertures, 2 used and 1 spare
- The MBRDP1 prototype magnet was assembled with the first 2 apertures
- The assembly of the third aperture has been delayed in order to implement (and consolidate) the modifications designed for the series
- The A1-02 and A2-02 coils are ready to be assembled

PROTOTYPE ISSUES AND MITIGATION SOLUTIONS

- Most of the problems we have encountered are related to the excessive azimuthal size of the coils
- Coil dimensions are measured with a measuring press by applying several pressing cycles in 7 longitudinal points





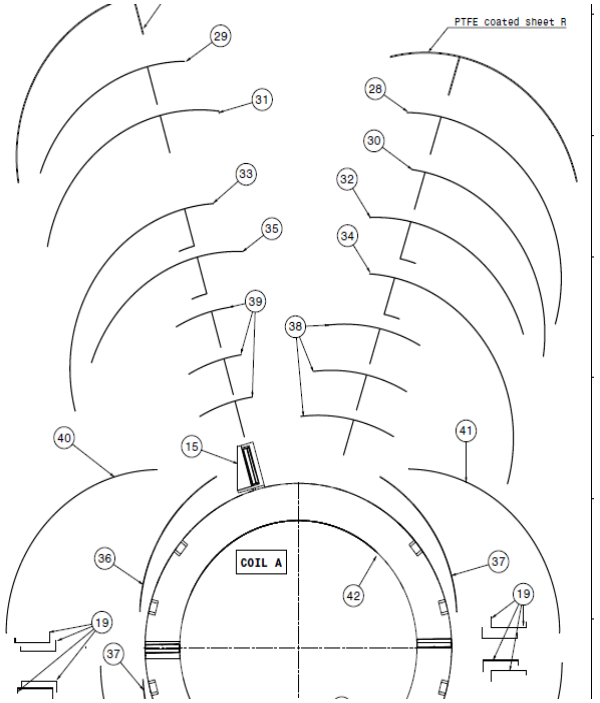
- The azimuthal dimension of the coil (one quarter of the coil) is 0.63 mm- 0.64 mm above nominal (much less than the short model anyway). The actual size of the insulated conductor can explain half of this value, the other half is probably due to manufacturing tolerances of the components and coils

PROTOTYPE ISSUES AND MITIGATION SOLUTIONS: field quality

- To keep the collaring pressure below resonable values (<110 MPa) it was decided to reduce the azimuthal dimension of each coil of 0.6 mm, by removing two polyimide layers in the midplane and three polyimide layers in the pole for a total of 584 µm
- This affect the field quality which is now different from nominal
- From warm magnetic measurements performed at ASG, we derived the expected field quality @ nominal current:

AP01	warm, I=18 A (calculated)	cold, Inom (calculated)	diff.	warm, I=18 A (measured)	cold, Inom (expected)
b2	-2.4	-5.6	-3.2	-2.9	-6.1
b3	-5.2	-4.9	0.3	7.6	7.9
b4	1.7	1.8	0.1	-0.4	-0.3
b5	6.1	6.3	0.2	11.3	11.5
b6	-0.2	-0.1	0.1	-1.5	-1.4
b7	2.1	2.5	0.4	1.7	2.1
b8	-0.9	-1.0	-0.1	-2.4	-2.5
b9	1.2	1.4	0.2	0.6	0.8
b10	-0.1	-0.1	0.0	0.0	0.0

AP02	warm, I=18 A (calculated)	cold, Inom (calculated)	diff.	warm, I=18 A (measured)	cold, Inom (expected)
b2	2.4	5.6	3.2	-3.1	0.2
b3	-5.2	-4.9	0.3	8.6	8.9
b4	-1.7	-1.8	-0.1	-0.5	-0.6
b5	6.1	6.3	0.2	11.4	11.6
b6	0.2	0.1	-0.1	1.4	1.3
b7	2.1	2.5	0.4	2.3	2.7
b8	0.9	1.0	0.1	0.3	0.4
b9	1.2	1.4	0.2	0.8	1.0
b10	0.1	0.1	0.0	-0.7	-0.7



PROTOTYPE ISSUES AND MITIGATION SOLUTIONS: wedge modification

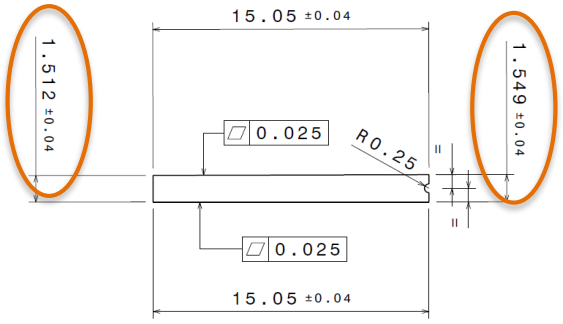
- To address both field quality and coil size issues, for the series we proposed to modify by 0.3 mm 2 wedges out of ten
- Field quality is fine tuned restoring a 127 μm thick U shaped Kapton layer on the midplane
- The proposed change satisfactorily corrects b3 and b5 and has minor influence on the other harmonics

AP01	warm prototype (calculated)	cold series, Inom (calculated)	diff.	warm prototype (measured)	cold series, Inom (expected)
b2	-2.4	-6.7	-4.3	-2.9	-7.2
b3	-5.2	-15.5	-10.2	7.6	-2.7
b4	1.7	1.4	-0.3	-0.4	-0.7
b5	6.1	-3.5	-9.6	11.3	1.7
b6	-0.2	0.5	0.8	-1.5	-0.7
b7	2.1	1.5	-0.5	1.7	1.2
b8	-0.9	-1.0	-0.1	-2.4	-2.5
b9	1.2	1.4	0.2	0.6	0.9
b10	-0.1	-0.2	-0.1	0.0	-0.1

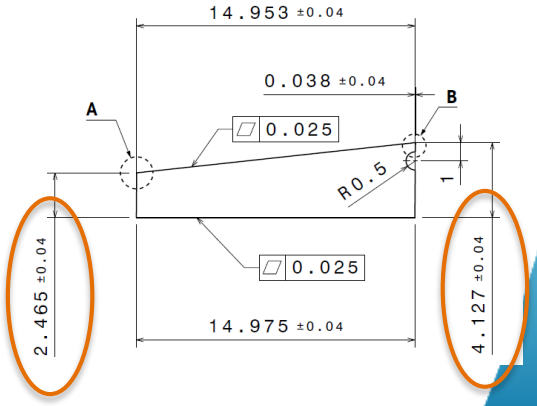
AP02	warm prototype (calculated)	cold series, Inom (calculated)	diff.	warm prototype (measured)	cold series, Inom (expected)
b2	2.4	6.7	4.3	-3.1	1.3
b3	-5.2	-15.5	-10.2	8.6	-1.7
b4	-1.7	-1.4	0.3	-0.5	-0.2
b5	6.1	-3.5	-9.6	11.4	1.8
b6	0.2	-0.5	-0.8	1.4	0.7
b7	2.1	1.5	-0.5	2.3	1.7
b8	0.9	1.0	0.1	0.3	0.3
b9	1.2	1.4	0.2	0.8	1.1
b10	0.1	0.2	0.1	-0.7	-0.5

- **Wedge modifications:** the circled dimensions are reduced by 0.3 mm

LONGITUDINAL FILLER TYPE 03

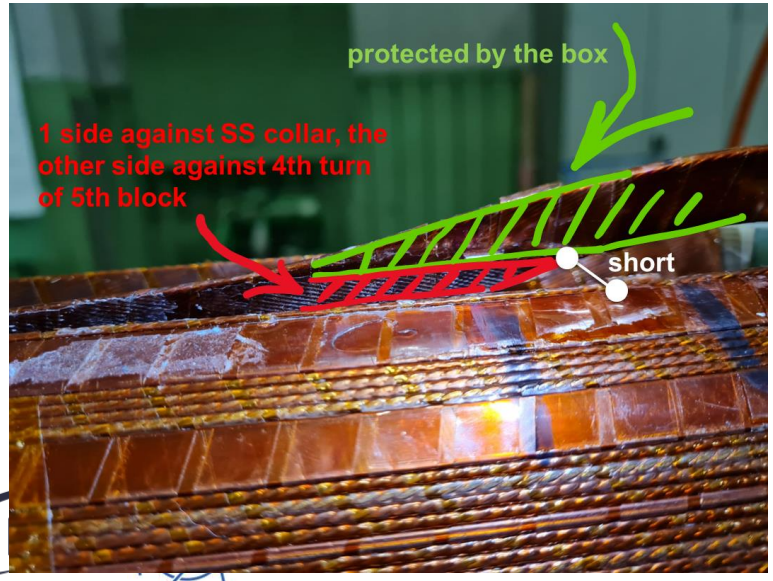


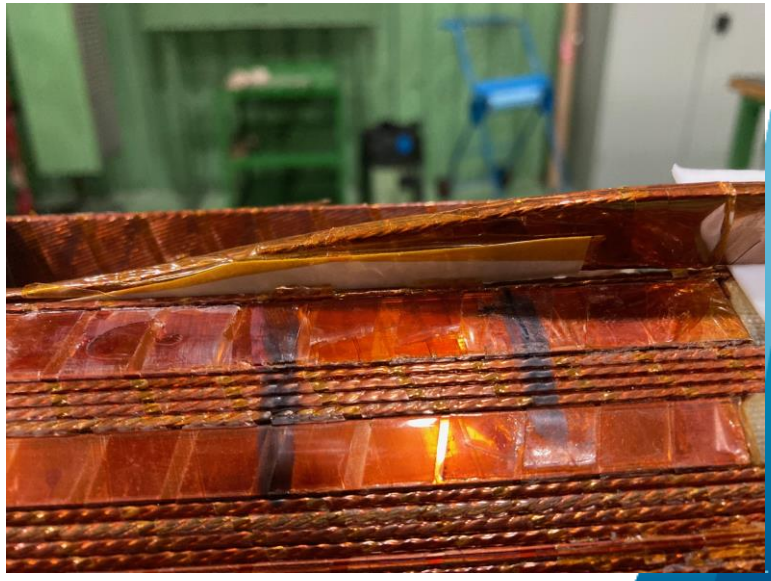
LONGITUDINAL FILLER TYPE 08



PROTOTYPE ISSUES AND MITIGATION SOLUTIONS: turn-to-turn short in coil B1-01 during collaring of AP01

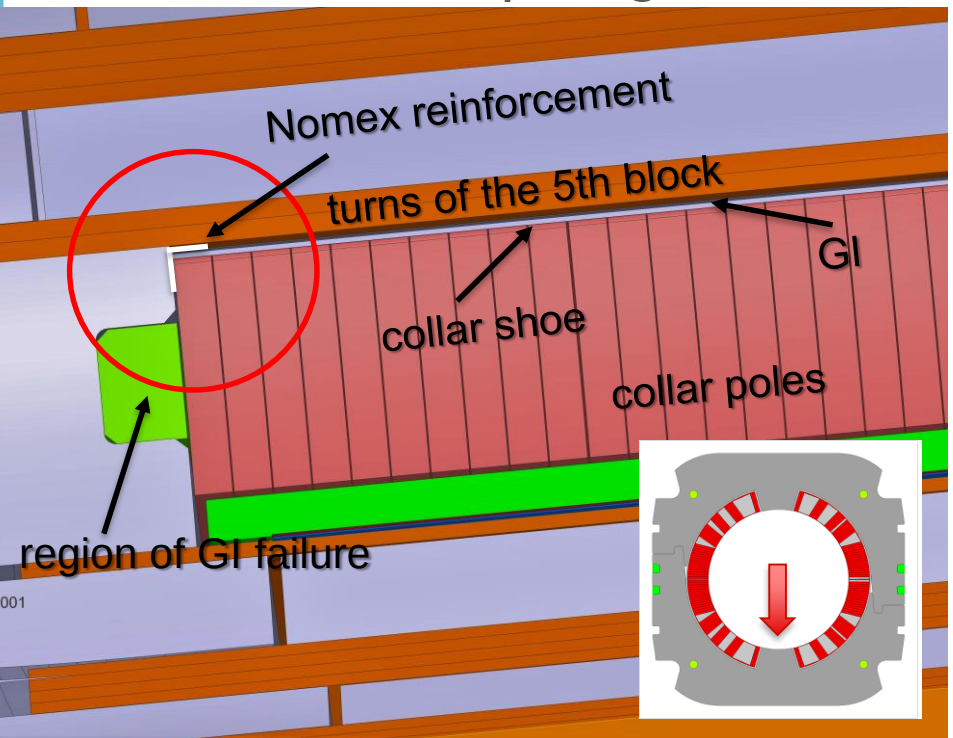
- The short was in the fifth block of coil B1-01
- Similar events occured twice in the short model, and both times the short was found to be at the level of the exit to the pole
- This issue was solved by inserting a sheet of nomex in the short location (0.18 mm thick), locally removing the last layer of Kapton (the one with the glue, 2x0.065=0.13 mm thick) ➡ this modification is permanent (both prototype and series)
- Nomex (like Kevlar) is more resistant to tears and cuts than Kapton, while being an effective insulator

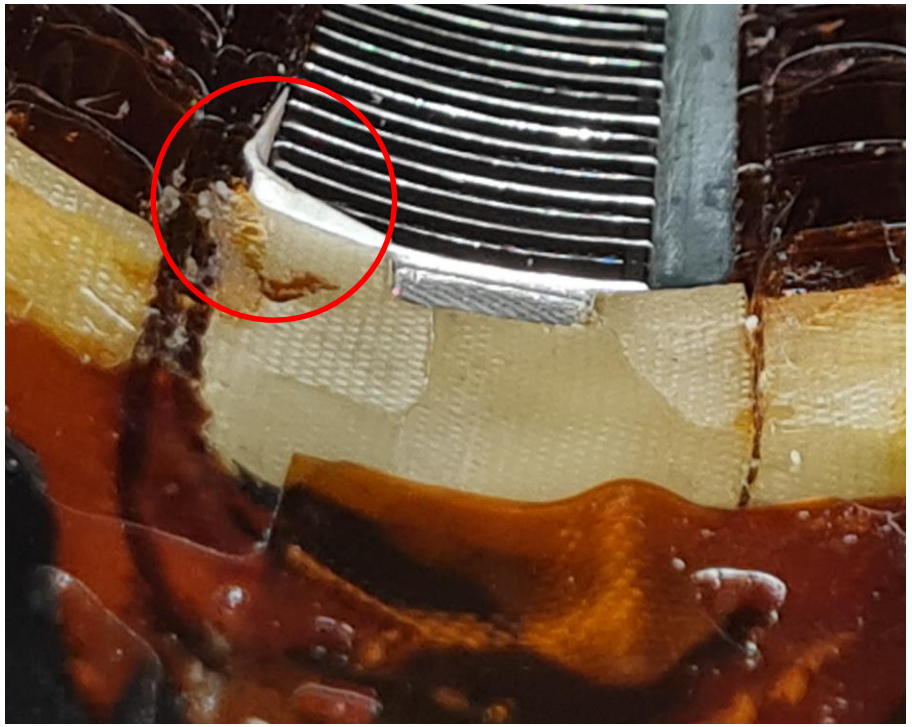


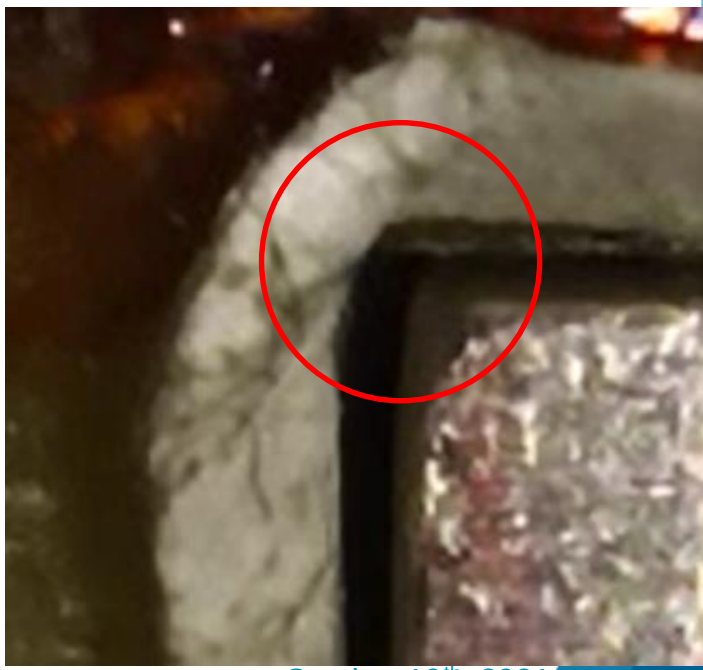


PROTOTYPE ISSUES AND MITIGATION SOLUTIONS: GI failure in coil B2-01 during Hi-Pot test

- A GI failure was detected during Hi-Pot test (3.1 kV) in coils B2-01 of AP02 aperture
- The failure was caused by the Coil Protection Sheet cutting through the Nomex reinforcement and making contact with the conductor
- The spark at 3 kV is compatible with a 1 mm air gap between conductor and sharp edge of the CPS

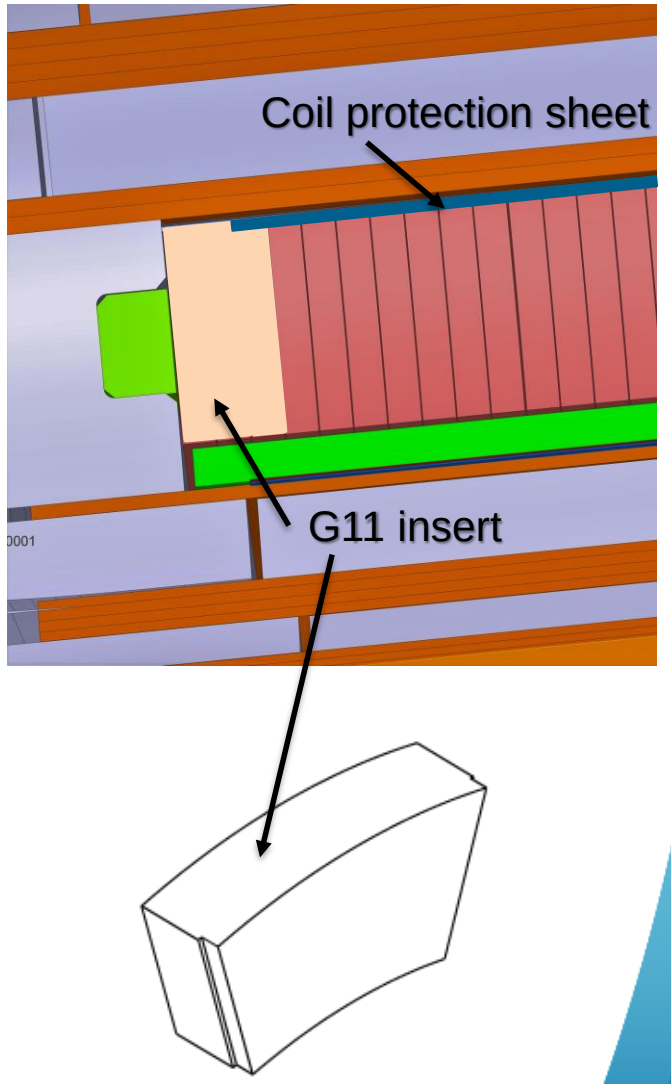






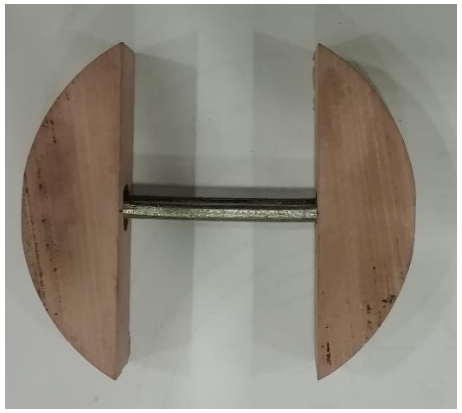
PROTOTYPE ISSUES AND MITIGATION SOLUTIONS: GI failure in coil B2-01 during Hi-Pot test

- The prototype was repaired by dropping stycast in the failure region and limiting all next Hi-Pot tests to 2.7 kV
- For the series, the failure region was re-engineered
- A G11 insert, as thick as three collars (9 mm), will be inserted in the failure region to electrically and mechanically intercept the CPS



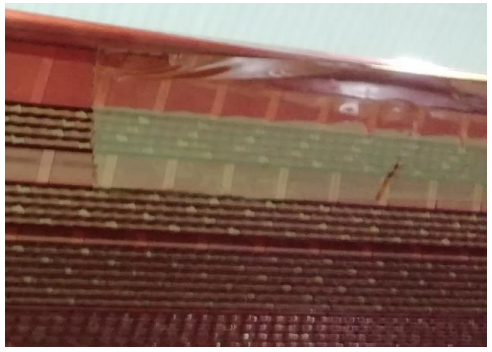
CHANGES TO BE IMPLEMENTED IN THE SERIES and tested in the third aperture

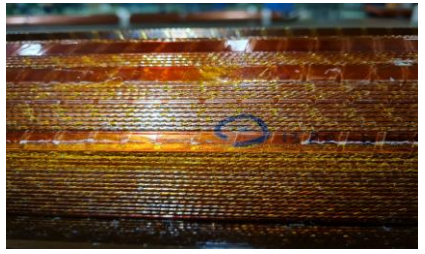
- Reinforcement of exit region with Nomex
- G11 insert in the end region
- Lead distance during collaring
  - A NC was issued because leads of AP02 are not at nominal distance and do not allow the passage of the beam tube ➡ new tooling to mantain lead distance
- Folded GI layer
  - The GI failure during Hi-Pot test could be partly due to the short air gap (1 mm) between conductor and sharp edge of the CPS ➡ a folded GI layer is added and kept in position by adhesive Kapton
- New shimming scheme
  - One layer of U shaped Kapton on the midplane is restored to verify its impact on field quality
- Insulation increase between coil and QH
  - After the short in AP01, the insulation between coil and QH was increased from 50 µm to 100 µm, by moving a 50 µm thick layer of ground insulation below the QHs



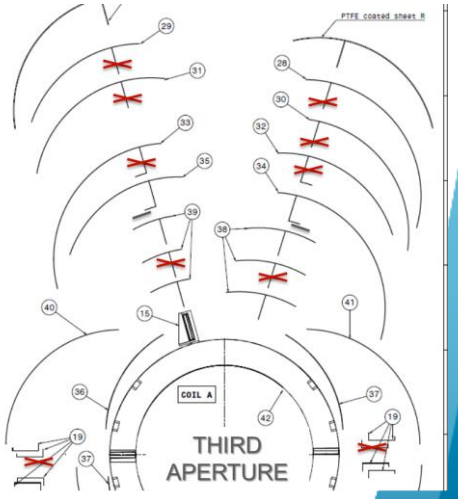
Prototype of tooling to keep lead distance

Test of GI folding on the D2 practice coil





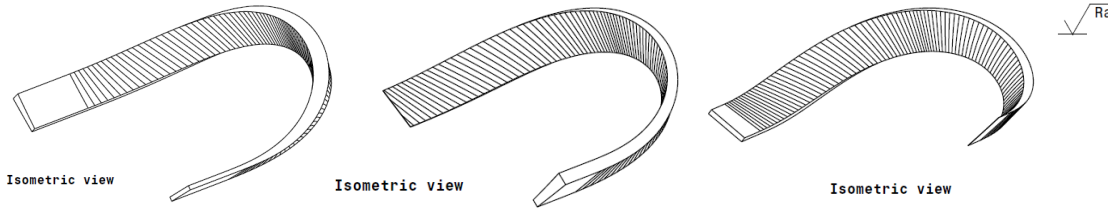
Coil to QH short in AP01



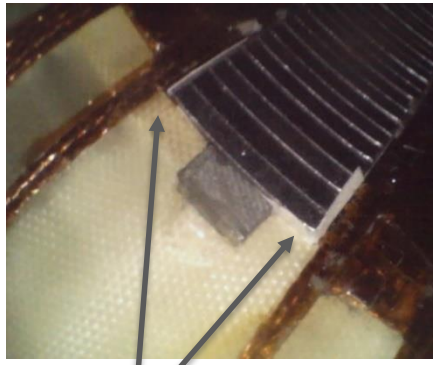
Third aperture shimming scheme

CHANGES TO BE IMPLEMENTED IN THE SERIES which cannot be tested in the third aperture

- 0.3 mm reduction of longitudinal fillers 3 and 8
- Smoothing of the 3 end spacers facing longitudinal filler 3 and 8
  - To avoid steps inside the winding
- Corner smoothing of G11 pole
  - Sharp corners of pole end spacer could have contributed to the GI failure in coil B2-01 during Hi-Pot test
- Azimuthal position of the coil protection sheet
  - In principle the CPS should slide on the insulating poly-imide layers including also the QHs. In facts, this sliding occurs only to a limited extent, causing wrinkles in the polyimide layers down to the QH the azimuthal position of the CPS is shifted at an angle between the two active parts of the QHs



End spacers to be smoothed to match the wedge cross section in the transition region



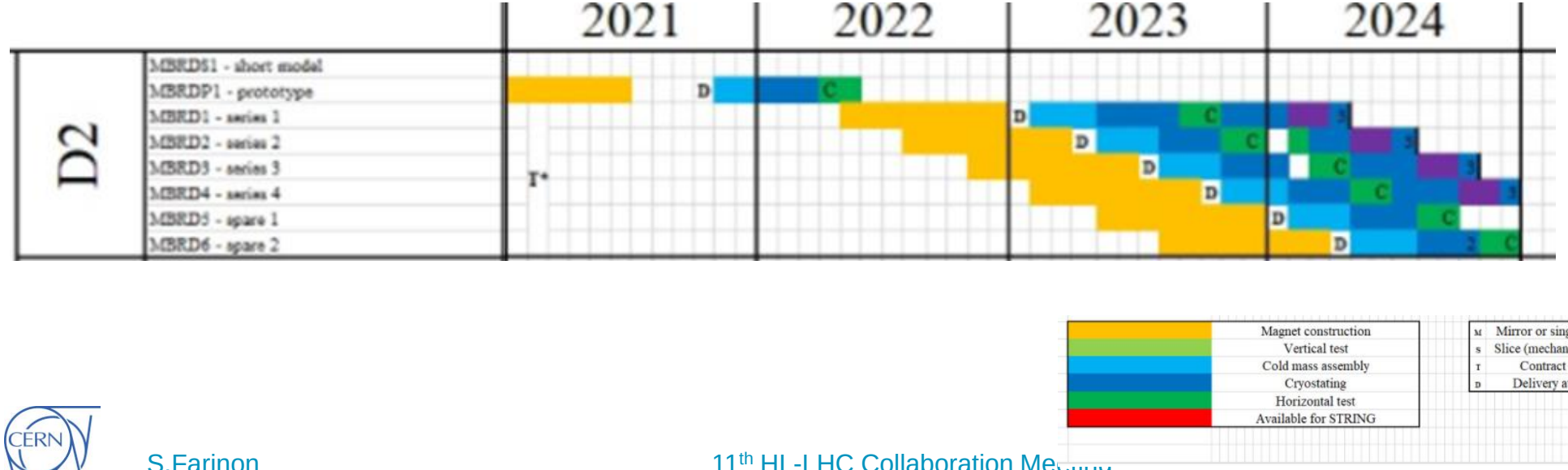
Pole end spacer corners to be smoothed in the series

Azimuthal position of the coil protection sheet

QH with wrinkes on the active part (picture of short model)

PLAN FOR THE SERIES

- The plan for the series is aligned with the updated schedule
- Bottle-neck is manufacturing of longitudinal wedges, as new dies are required for the modified wedges (3-4 months for procuring, 1-2 months for insulating)
- Procurement of unmodified components is underway
  - the fine blanking of the collars is already in progress
- The D2 series is far from the critical path



CONCLUSIONS

- The prototype has been completed and will be delivered to CERN by tomorrow
- Exploiting the experience of the prototype, several changes will be implemented in the series magnet, and some of them will be already tested in the third (spare) aperture
- The engineering design of the series is ready and the production could start as soon as all new/modified components are procured

Thank you for the attention