Hi-Lumi CCT Orbit Corrector Update

April 5th 2017

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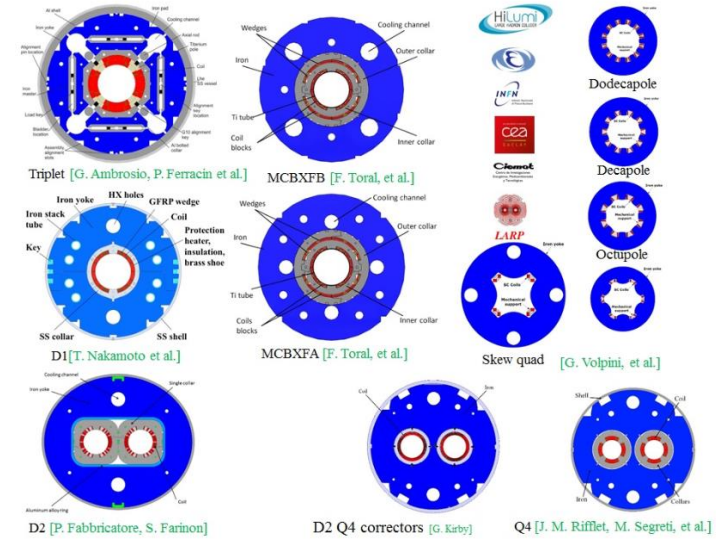
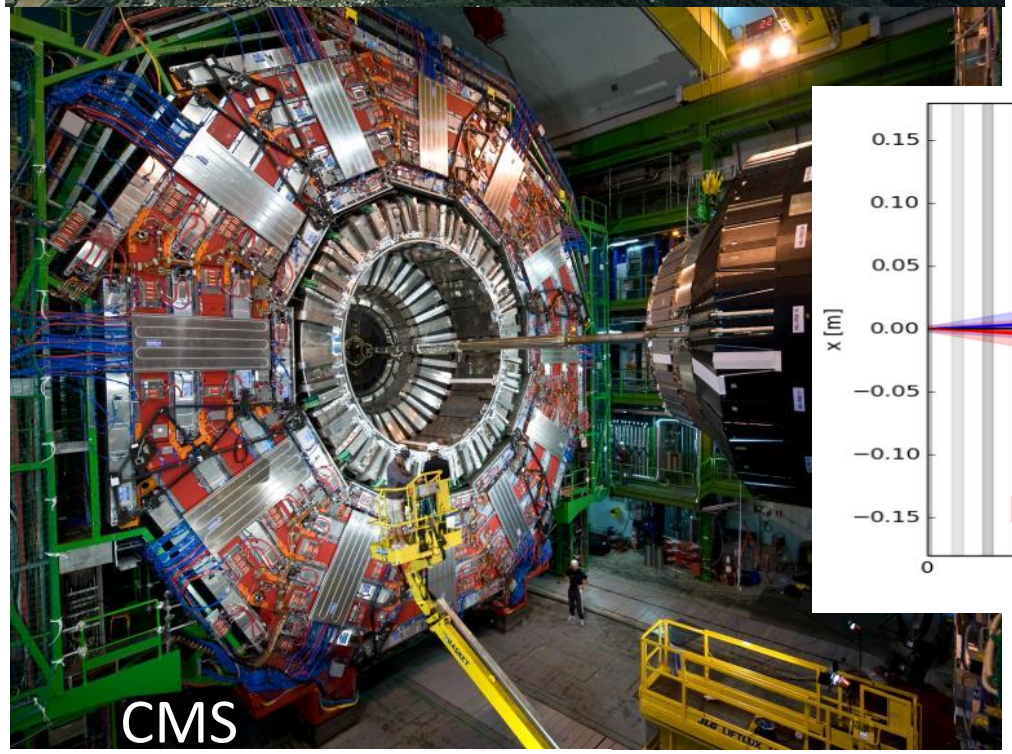
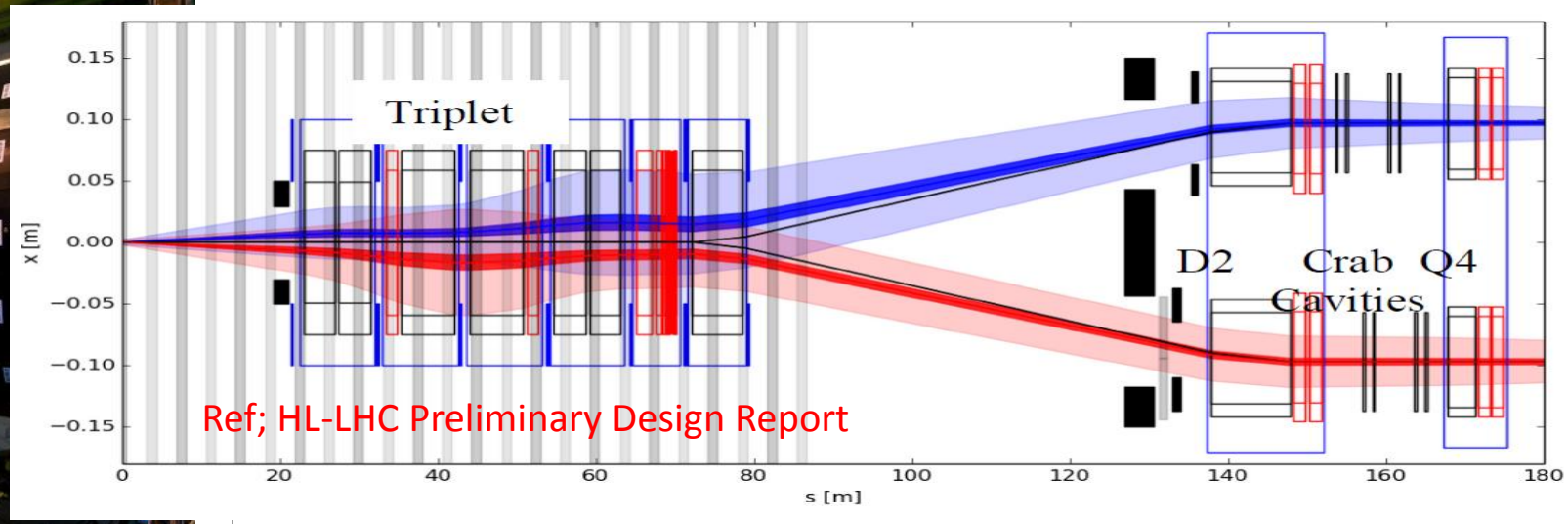
What is “High Luminosity LHC”

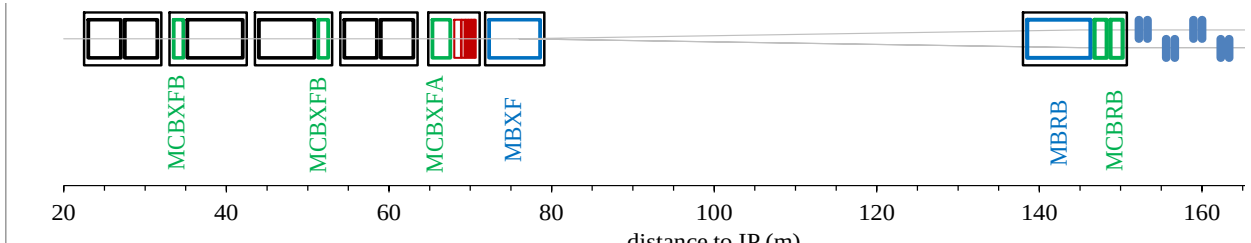
Goal of Hi-Lumi LHC
increase Luminosity by
factor ~10
In CMS and ALTAS
Installation Due 2024 -
2026



Upgrade Magnet Set



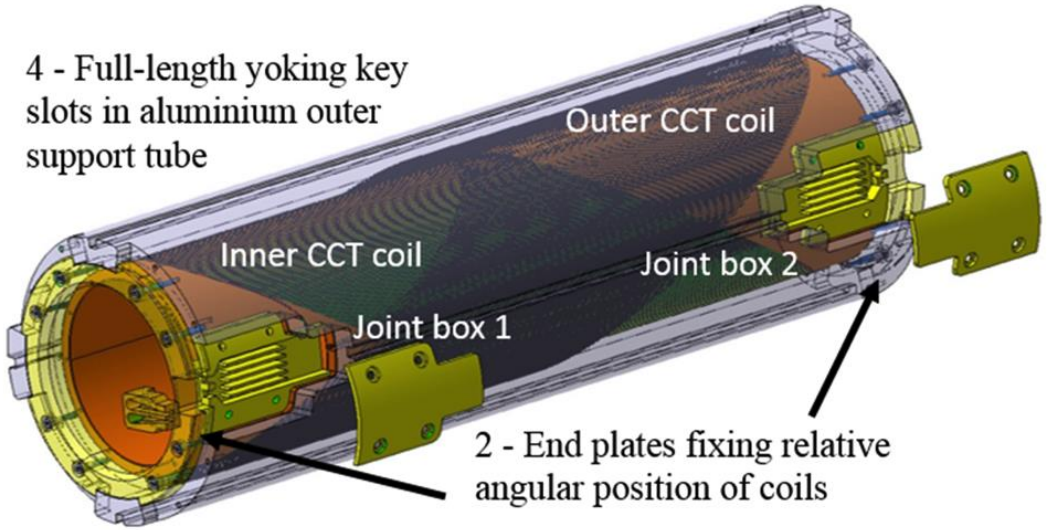


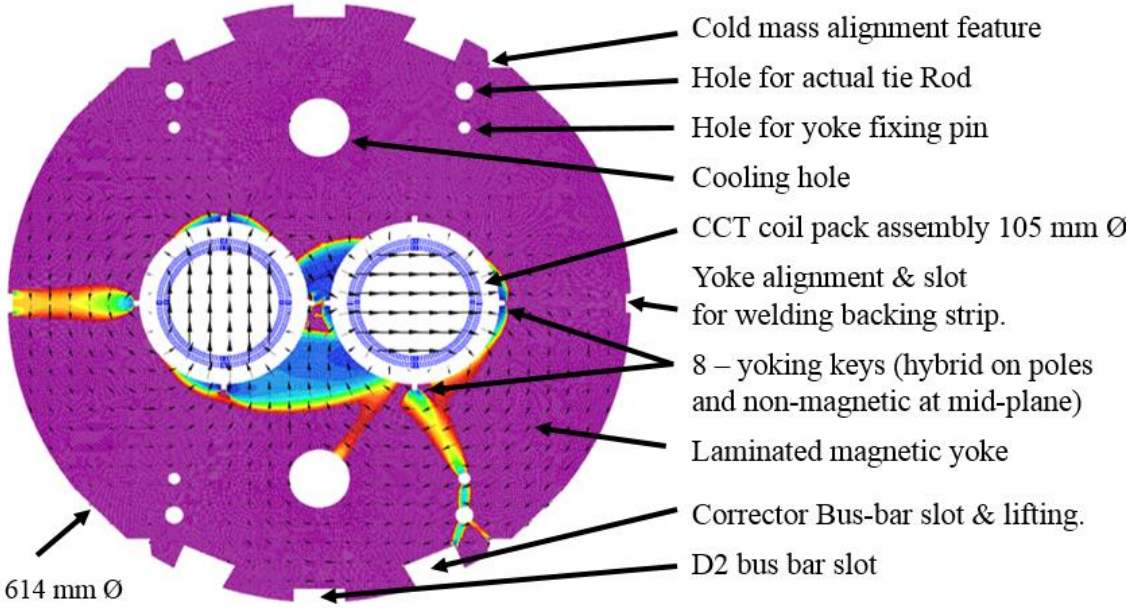


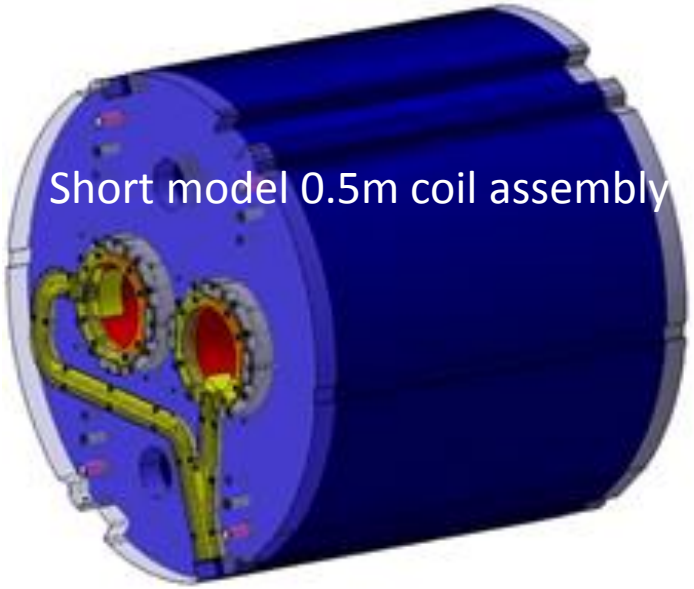
Magnet Spec.

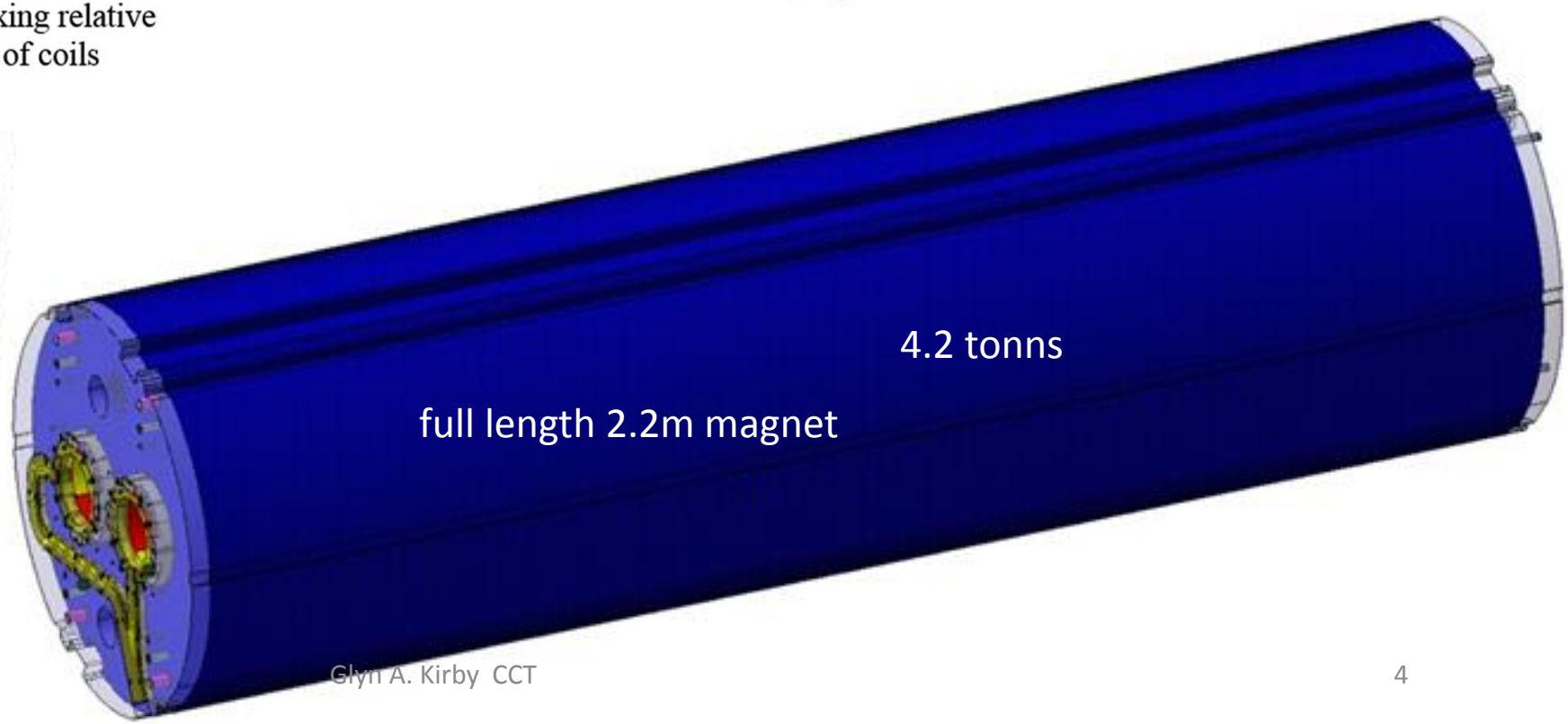
- Integrated field 5 Tm. Magnetic length ~ 1.92 m @ ~2.65T
- Magnet ~ 2.19 m long mechanical
- Multipoles ~< 10 units at all operational fields and configurations. Apertures independent.
- Aperture: 105 mm. (When cold)
- Beam distance: 188 mm.
- Faster Ramps rates ~100 s is the target value !
- Current < 600 A. Power supply (today 435A)
- Dose of 10 to 15 MGy so we need a radiation hard insulation.
- Yoke : Std LHC design: rotated yoke , yoke keys ,and spring pins. (614 mm dia)

Design


4 - Full-length yoking key slots in aluminium outer support tube
Outer CCT coil
Inner CCT coil
Joint box 2
Joint box 1
2 - End plates fixing relative angular position of coils

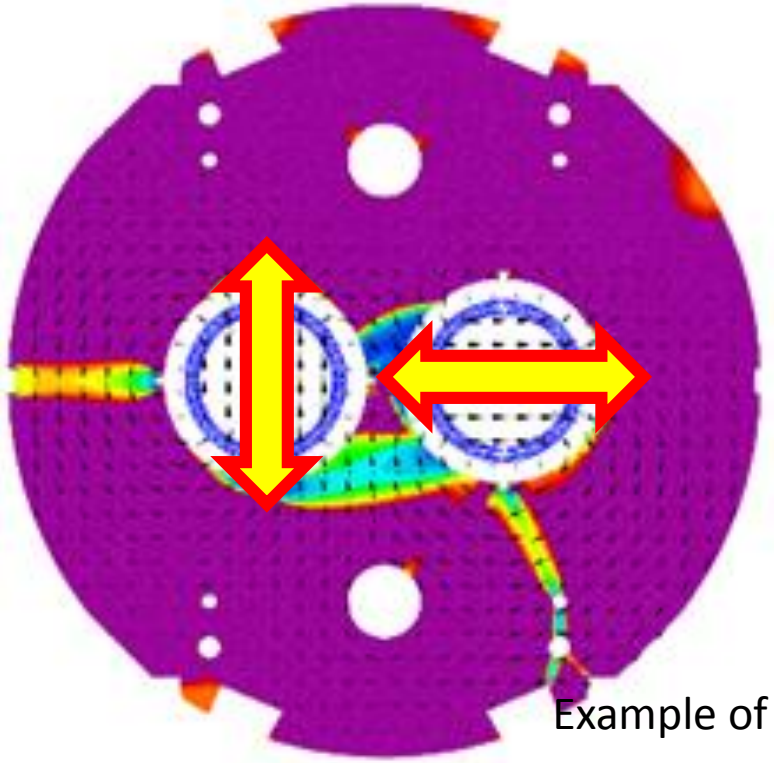

Cold mass alignment feature
Hole for actual tie Rod
Hole for yoke fixing pin
Cooling hole
CCT coil pack assembly 105 mm Ø
Yoke alignment & slot for welding backing strip.
8 – yoking keys (hybrid on poles and non-magnetic at mid-plane)
Laminated magnetic yoke
Corrector Bus-bar slot & lifting.
D2 bus bar slot
614 mm Ø

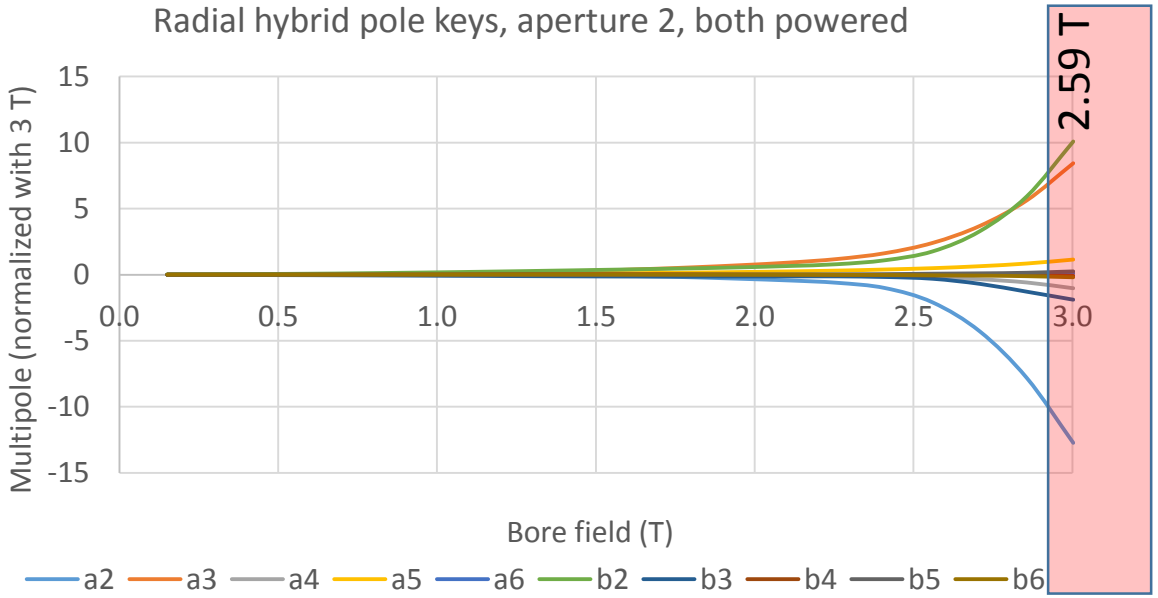

Short model 0.5m coil assembly


4.2 tonns
full length 2.2m magnet

Magnetic Field Optimization, Independently powered apertures

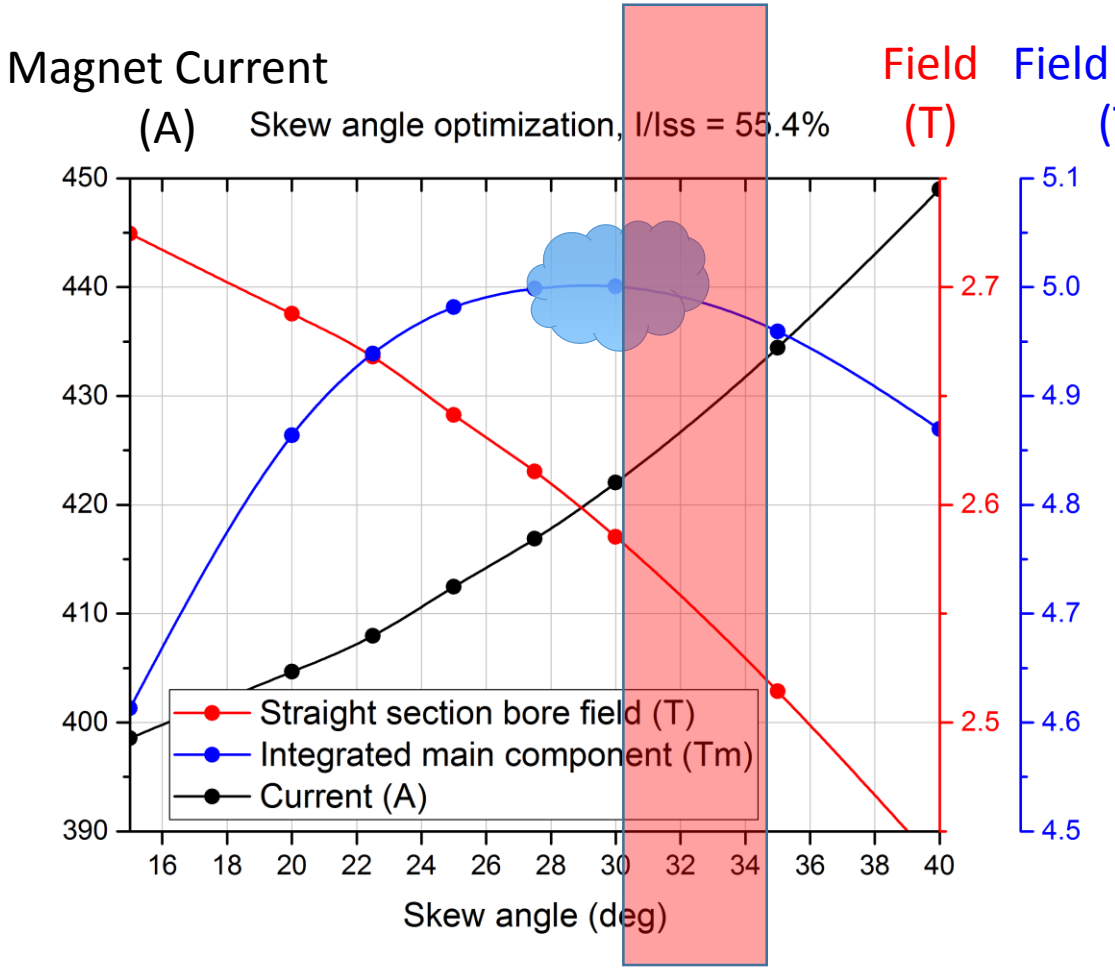
- To achieve 5 Tm field integral with less than 10 units we first determine the maximum field in one aperture that will not pollute the field quality in the adjacent aperture.

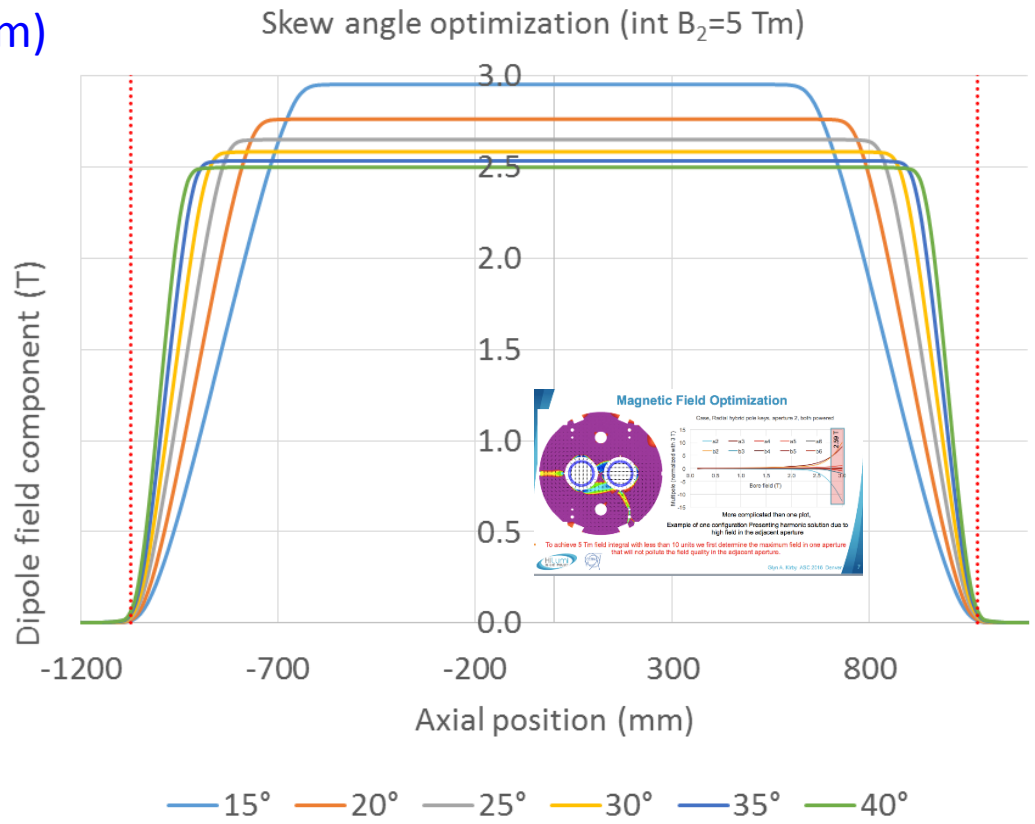




More complicated than one plot, Details to follow!

Example of one configuration Presenting harmonic solution due to high field in the adjacent aperture





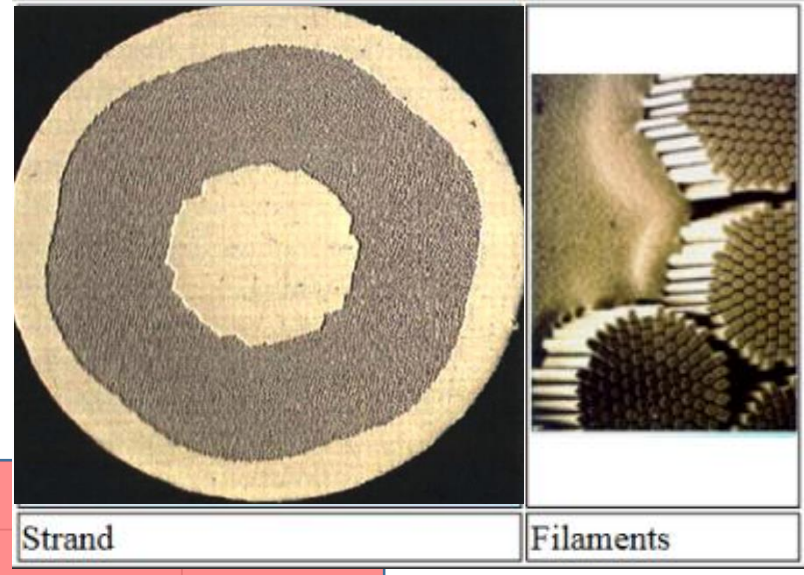
CCT skew angle optimisation

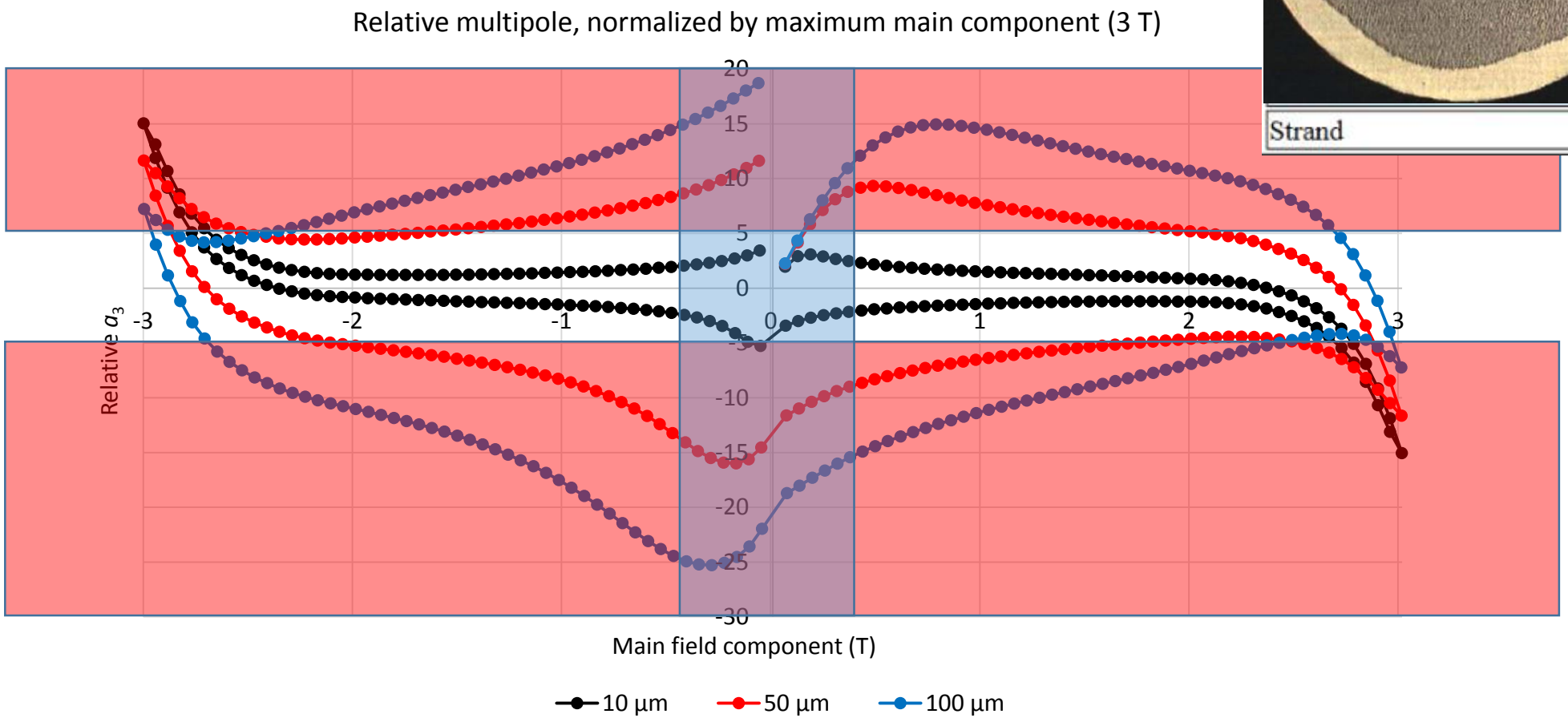
Due to the cross talk the max aperture field is set to ~2.7 T

For a fixed 5 Tm integral & magnet length ~2m the optimum skew angle is 30 deg.

Lower skew angles give more field less conductor but have longer ends!

Magnetization & IFCC

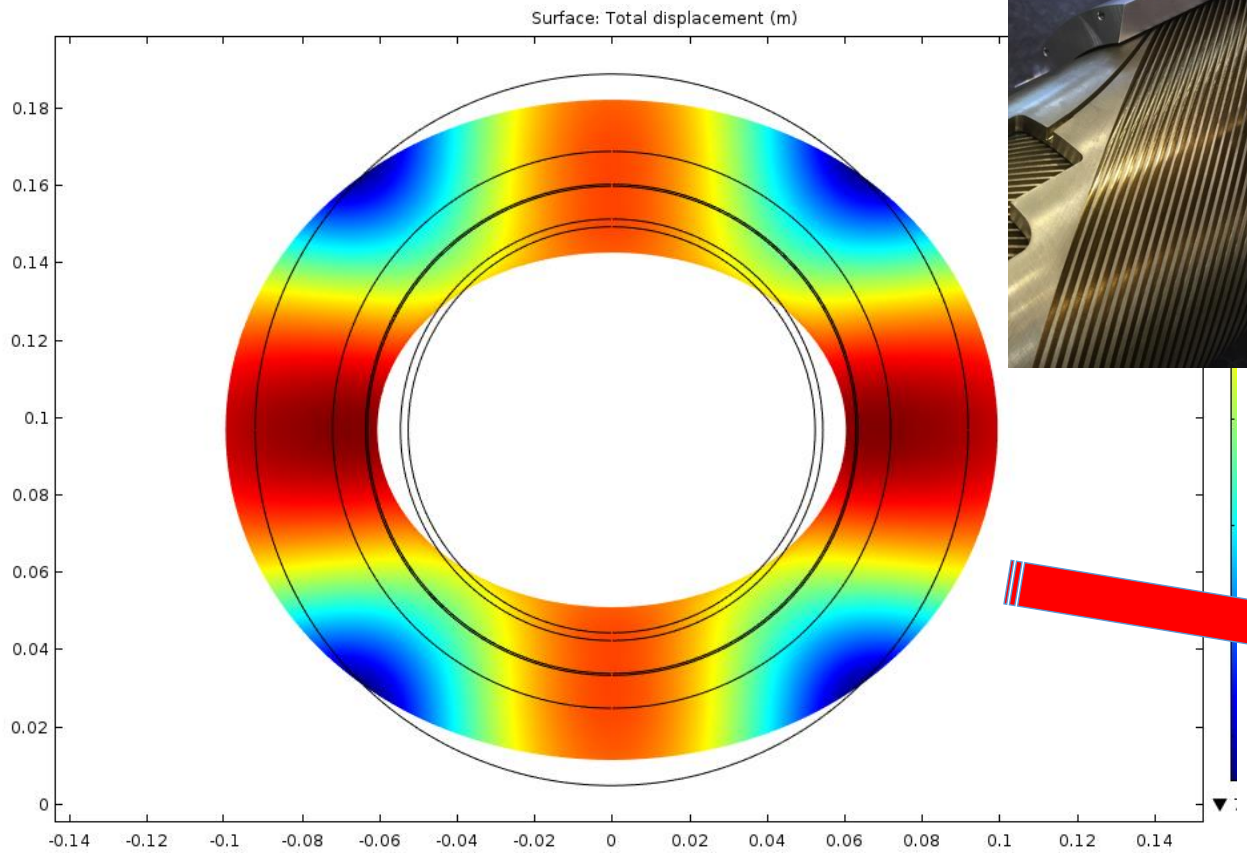




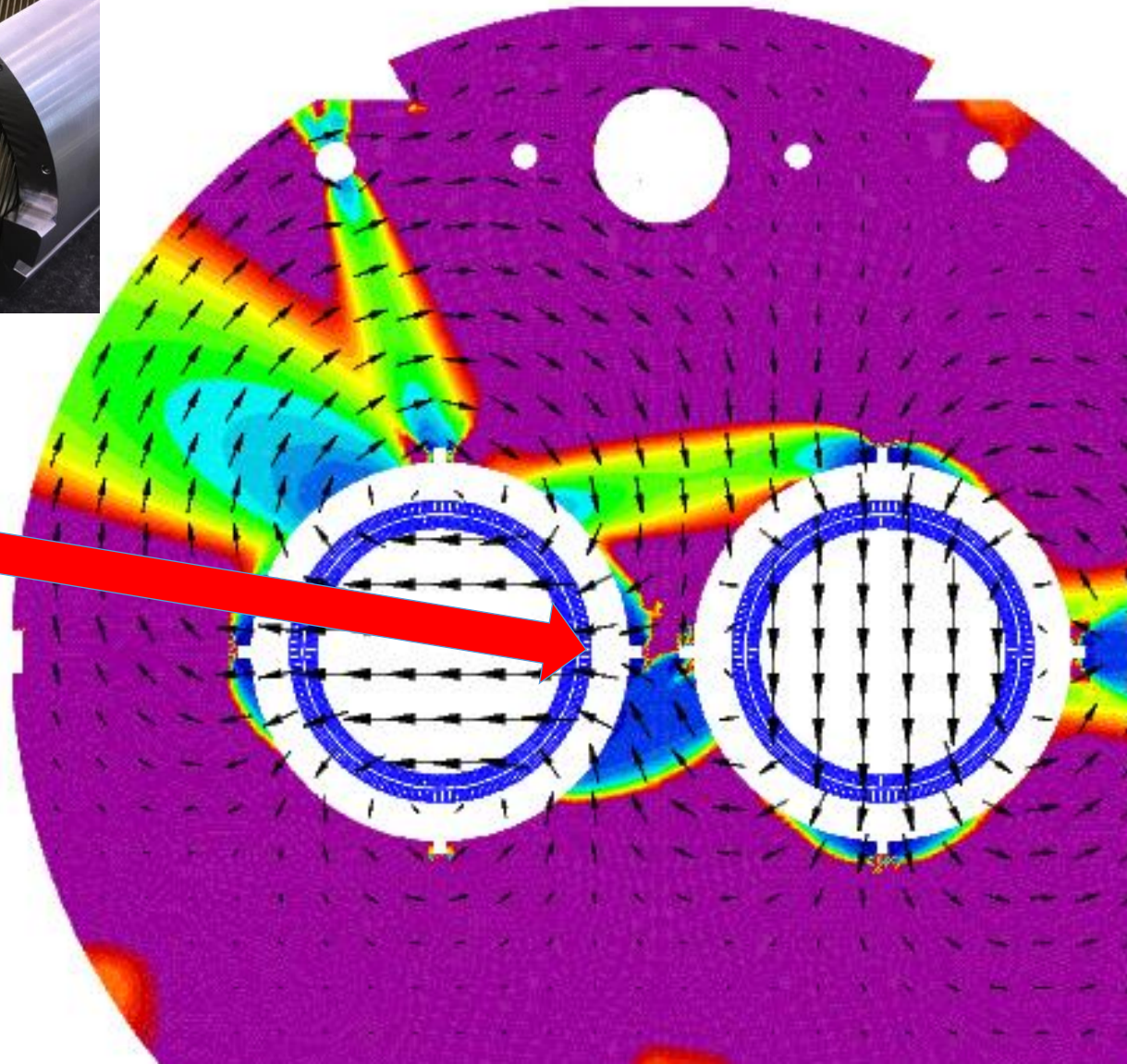
? We need to measure field in a magnet test
As we are not happy with calculations yet!

Small filaments 6um?

Outer support collar thickness f(deflection)



0.5m model yoke design

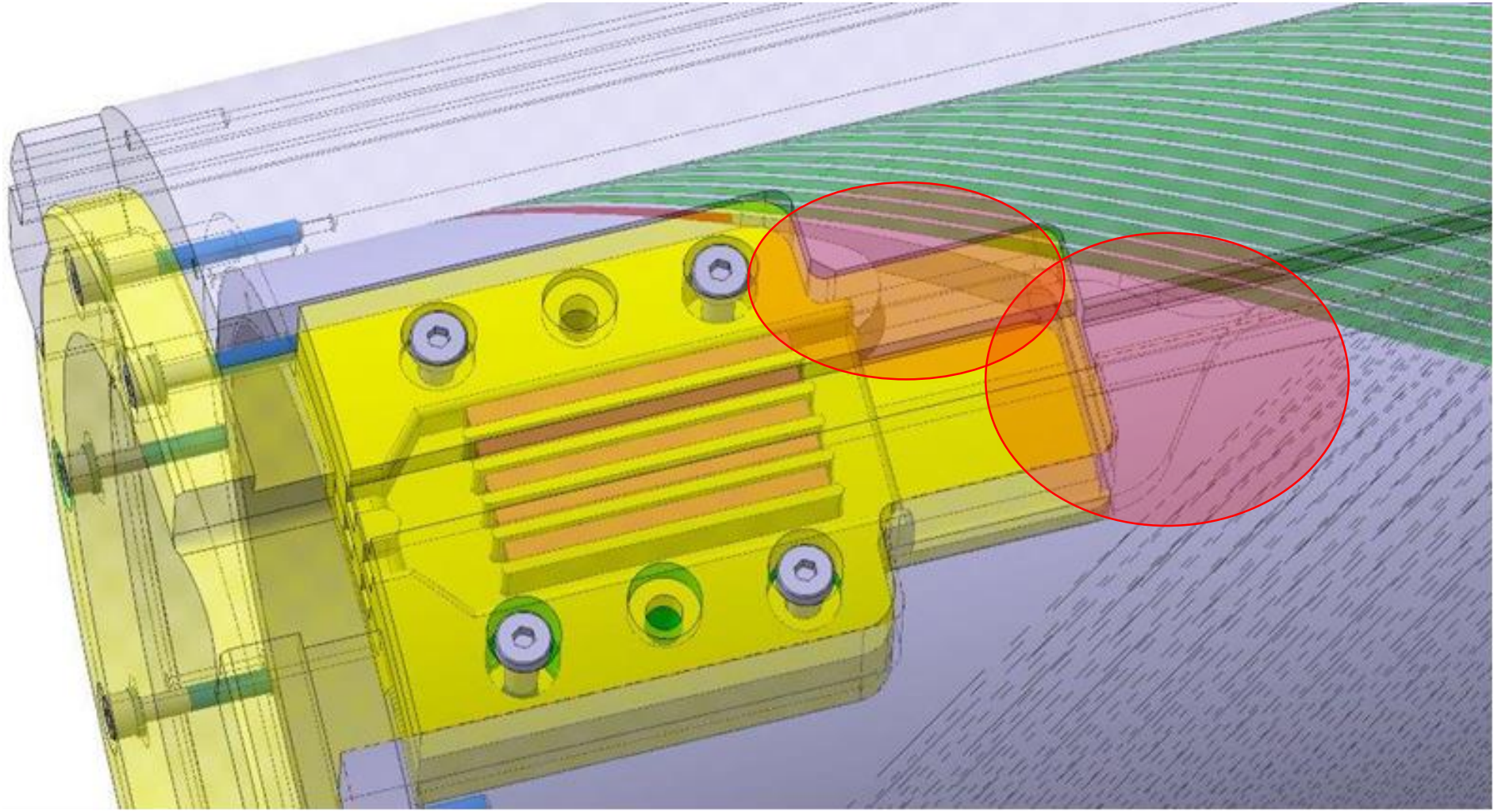


20 mm Al (70 GPa) & 3 T bore field deflection < 40 um
15 mm Al (70 GPa) & 3T bore field deflection < 50 um
With Inner support tube 2mm stst.

E_{coil} = 44 GPa E_{collar} = 70 GPa

Outer Coil Former Support < 50 um deflection

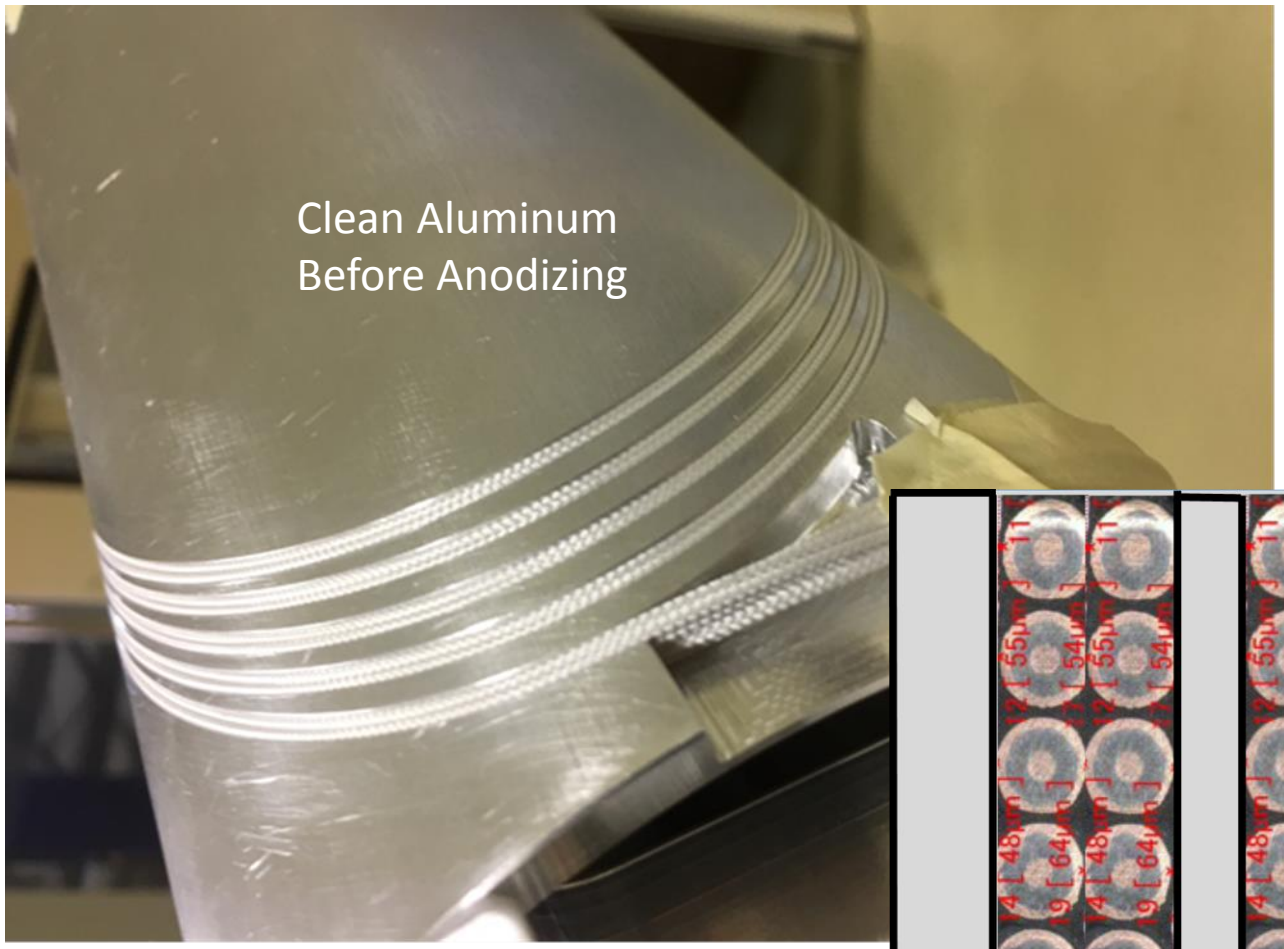
Adjustments to the inner and outer formers

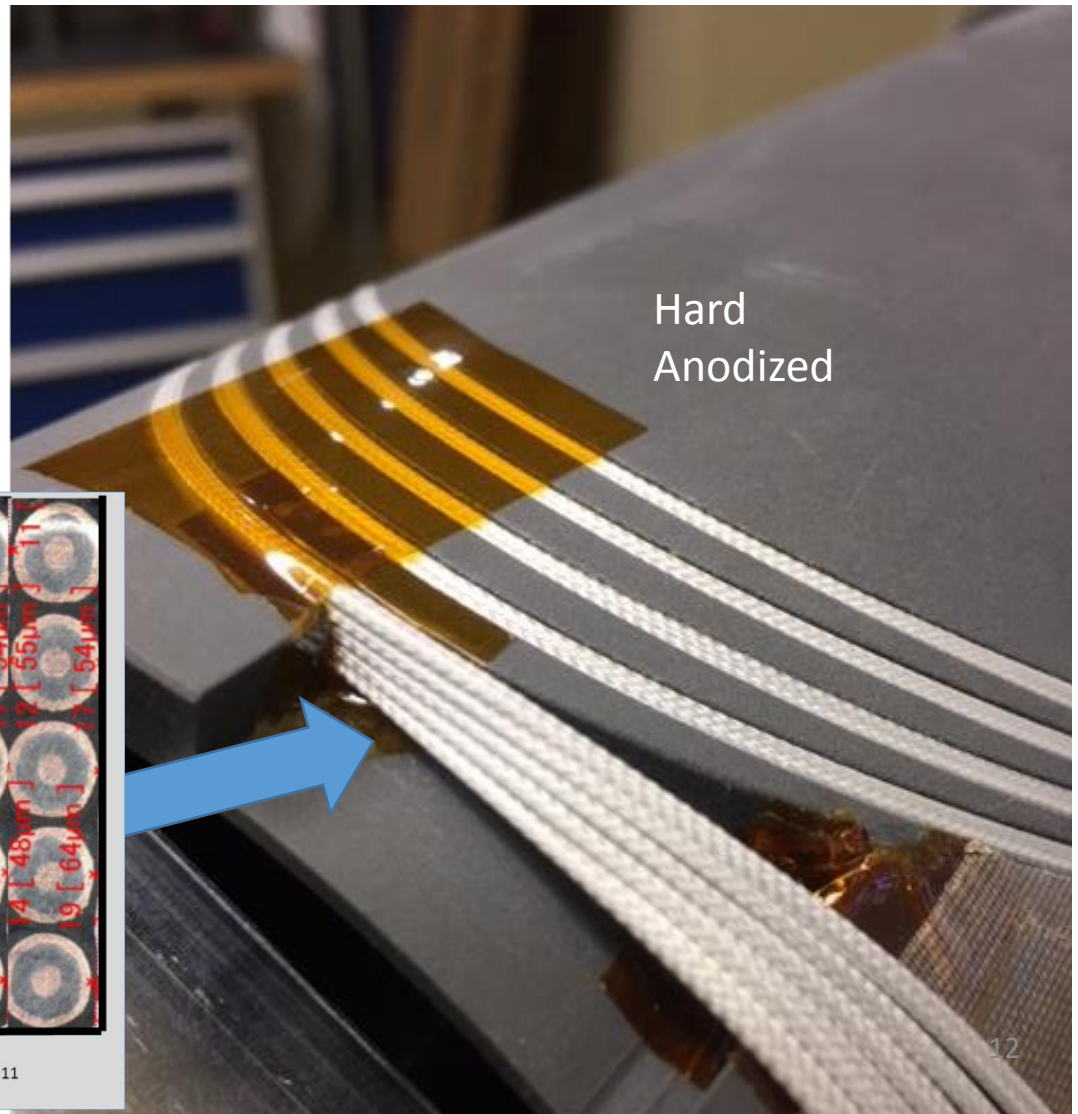


Aluminium formers 6082-T6 polishing test to de-burr? and then Hard Anodization (Micro-Machining)

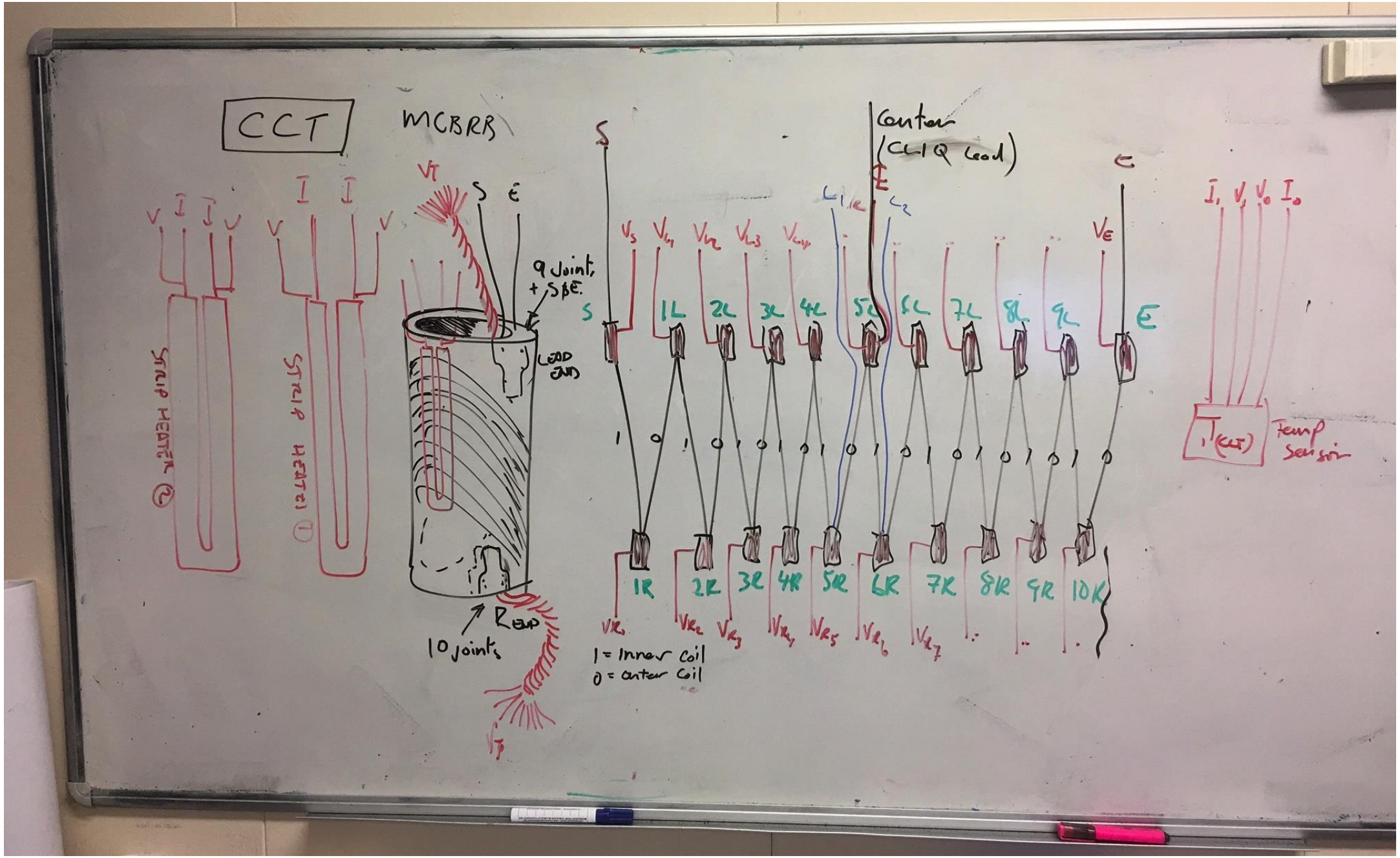
Example of polishing to remove burrs

2 x 5 wire coil, Hard Anodized former
this is part of the ground insulation design

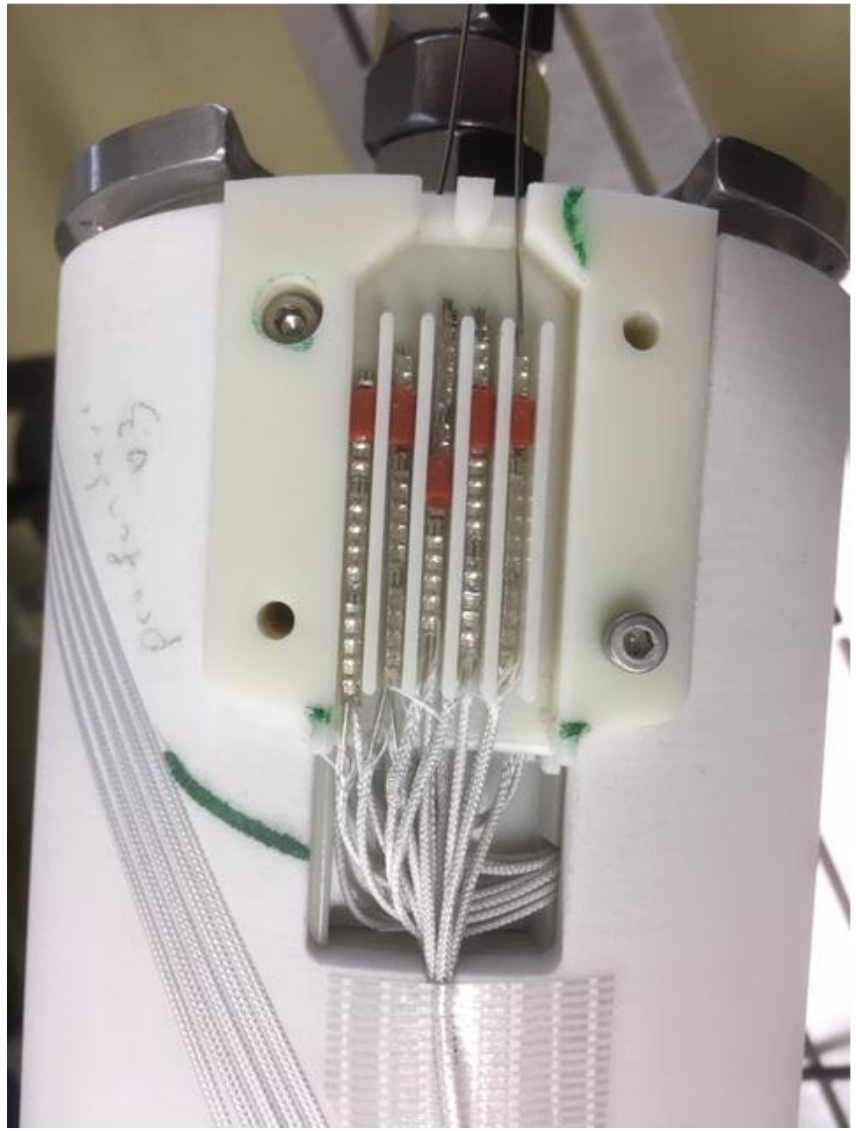




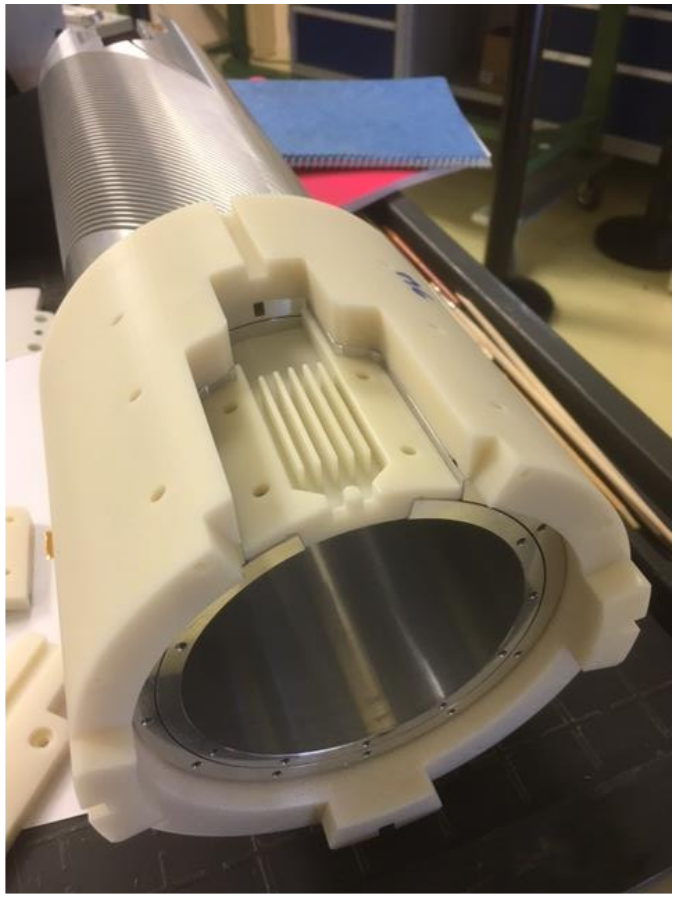
Wiring diagram.

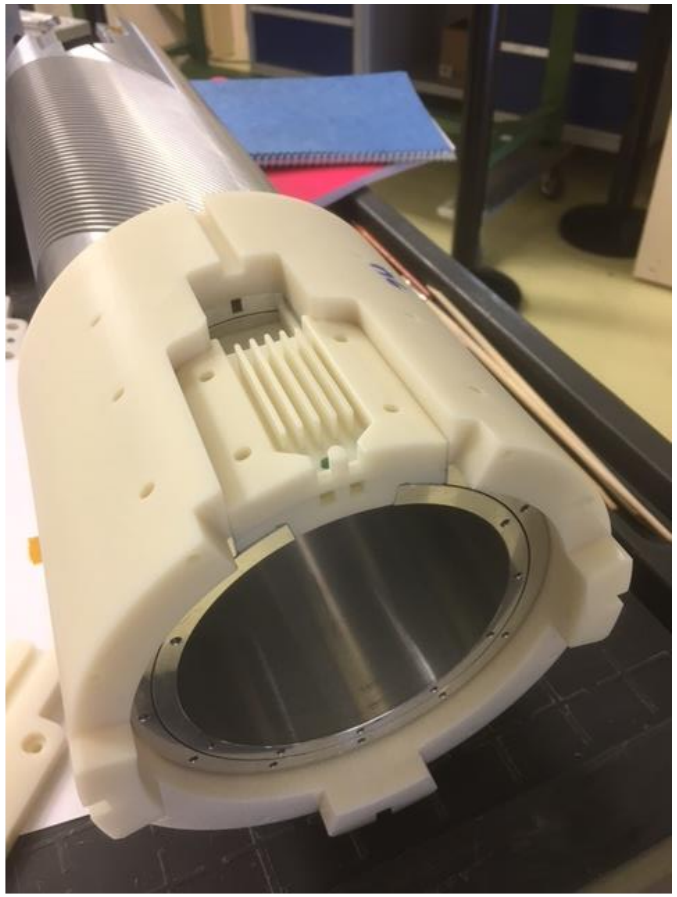


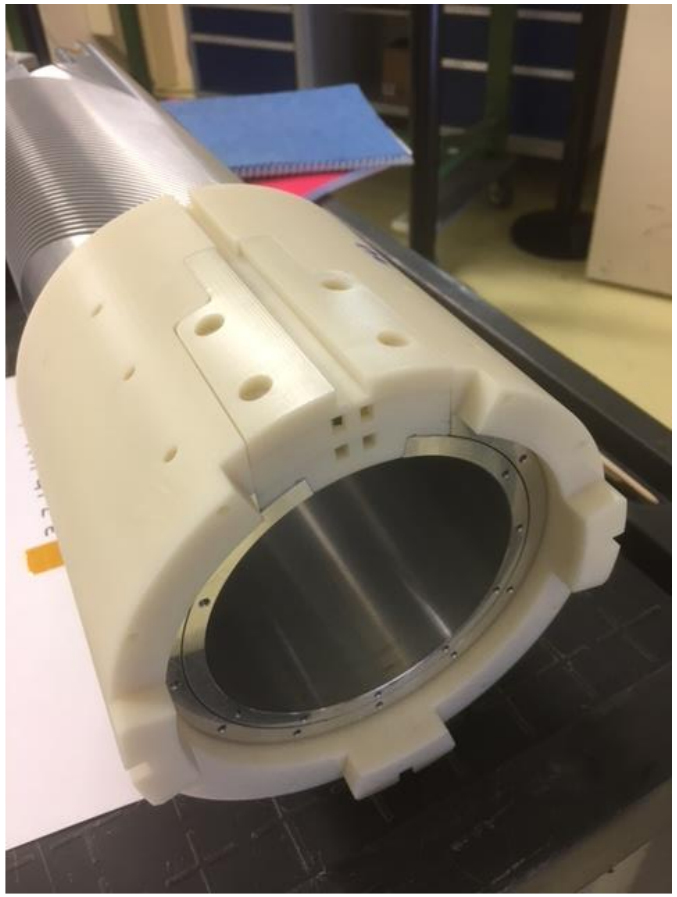
10 joints ,in 2 layer joint boxes at both ends



Two layer Joint box + cover + support tube





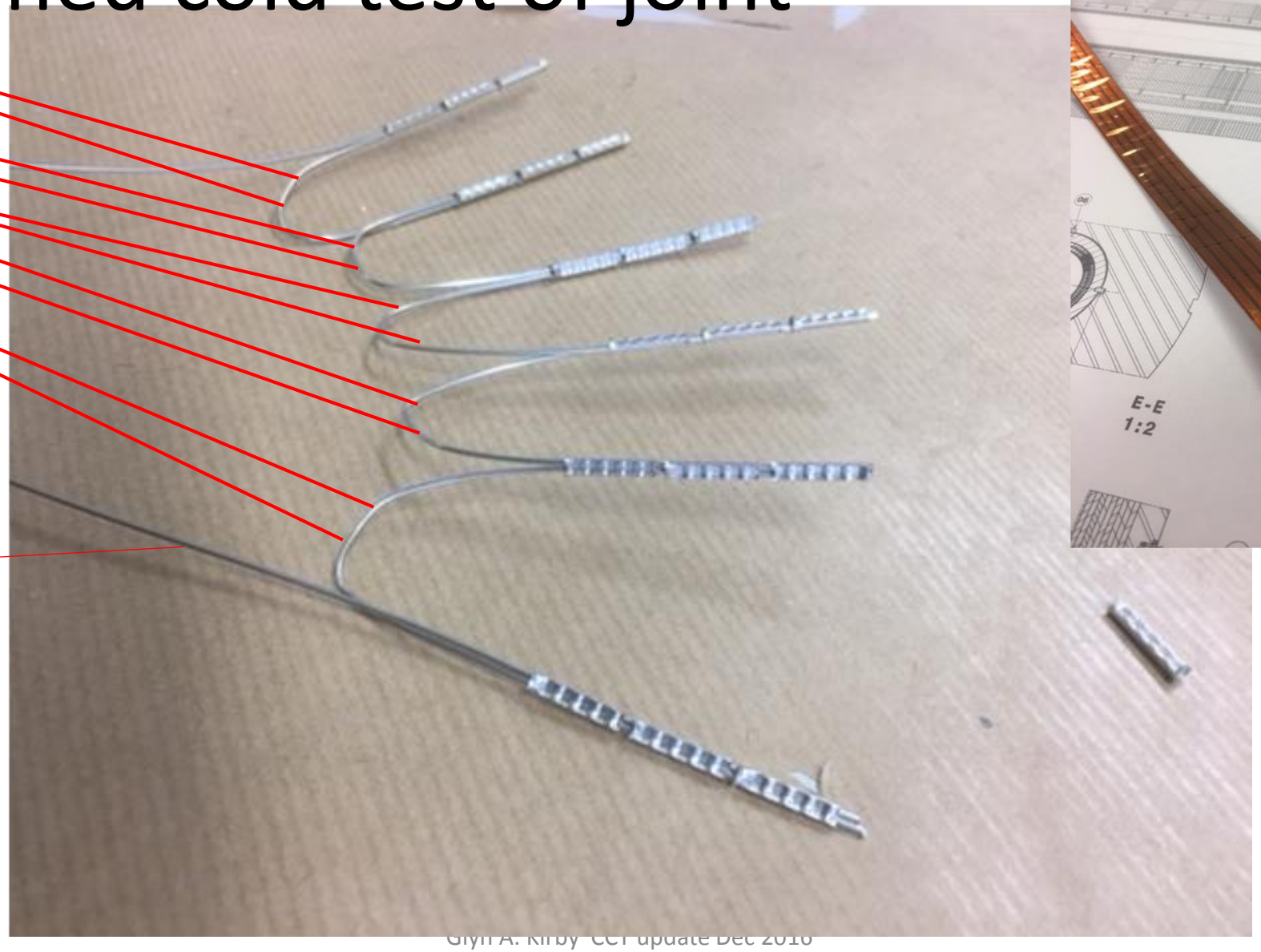


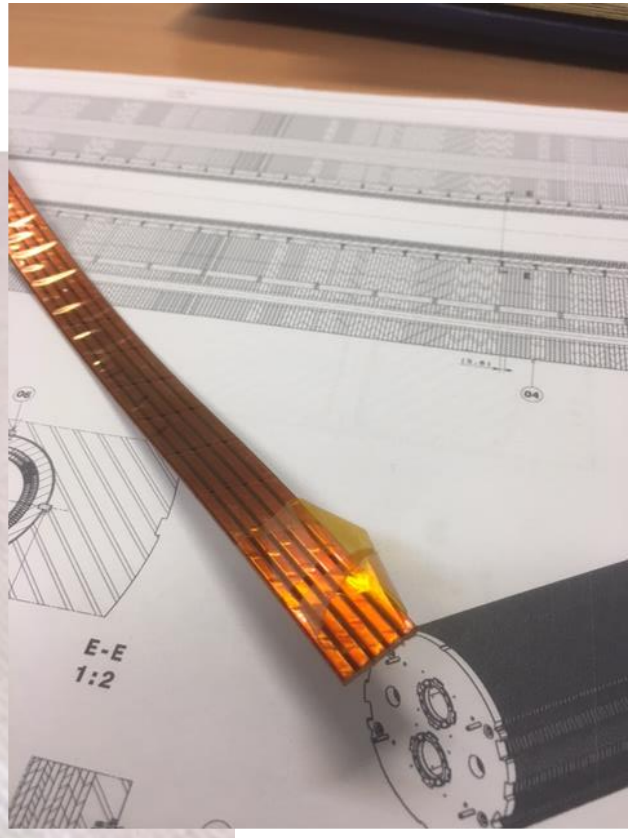
LHC corrector Joint design re-used
(Crimped then soldered)





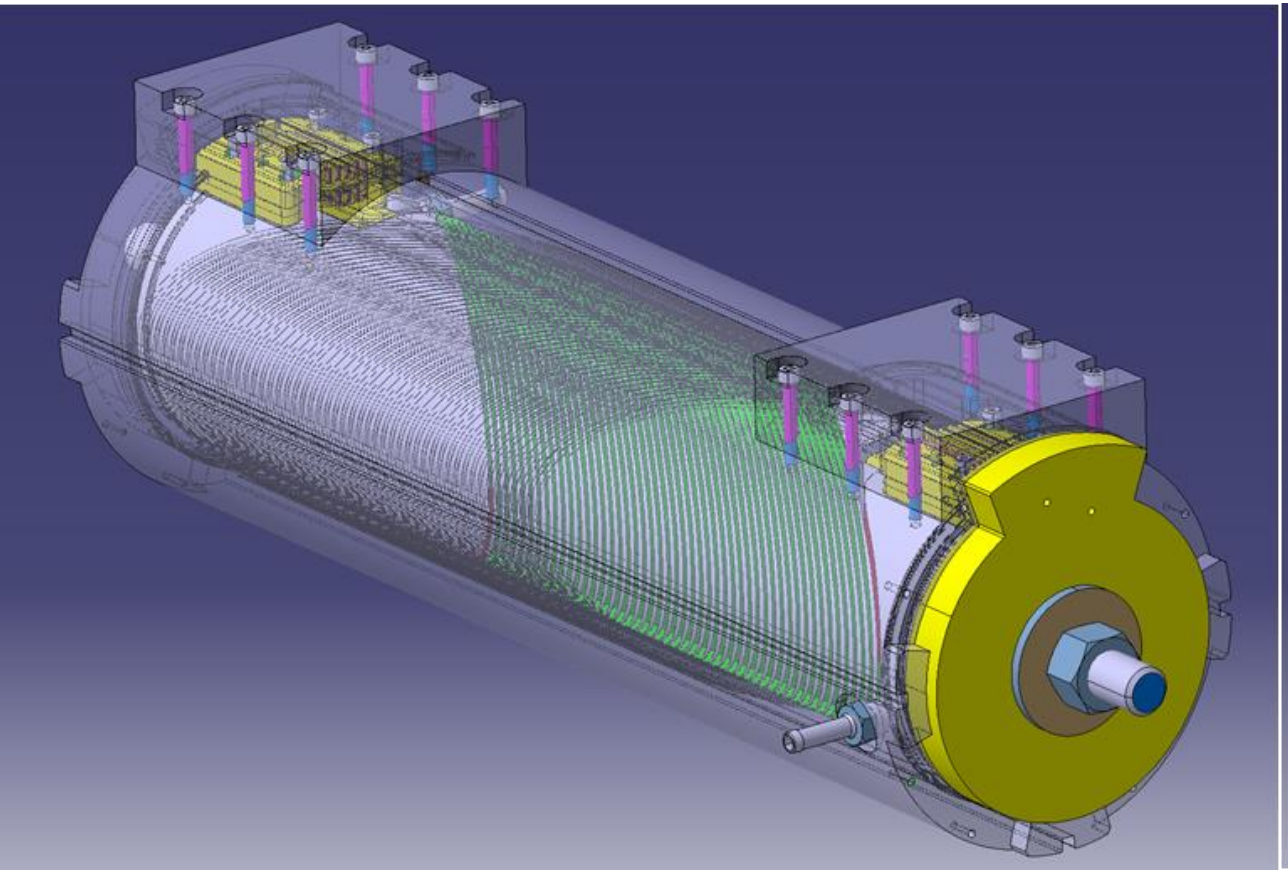

/e are planned cold test of joint ystem

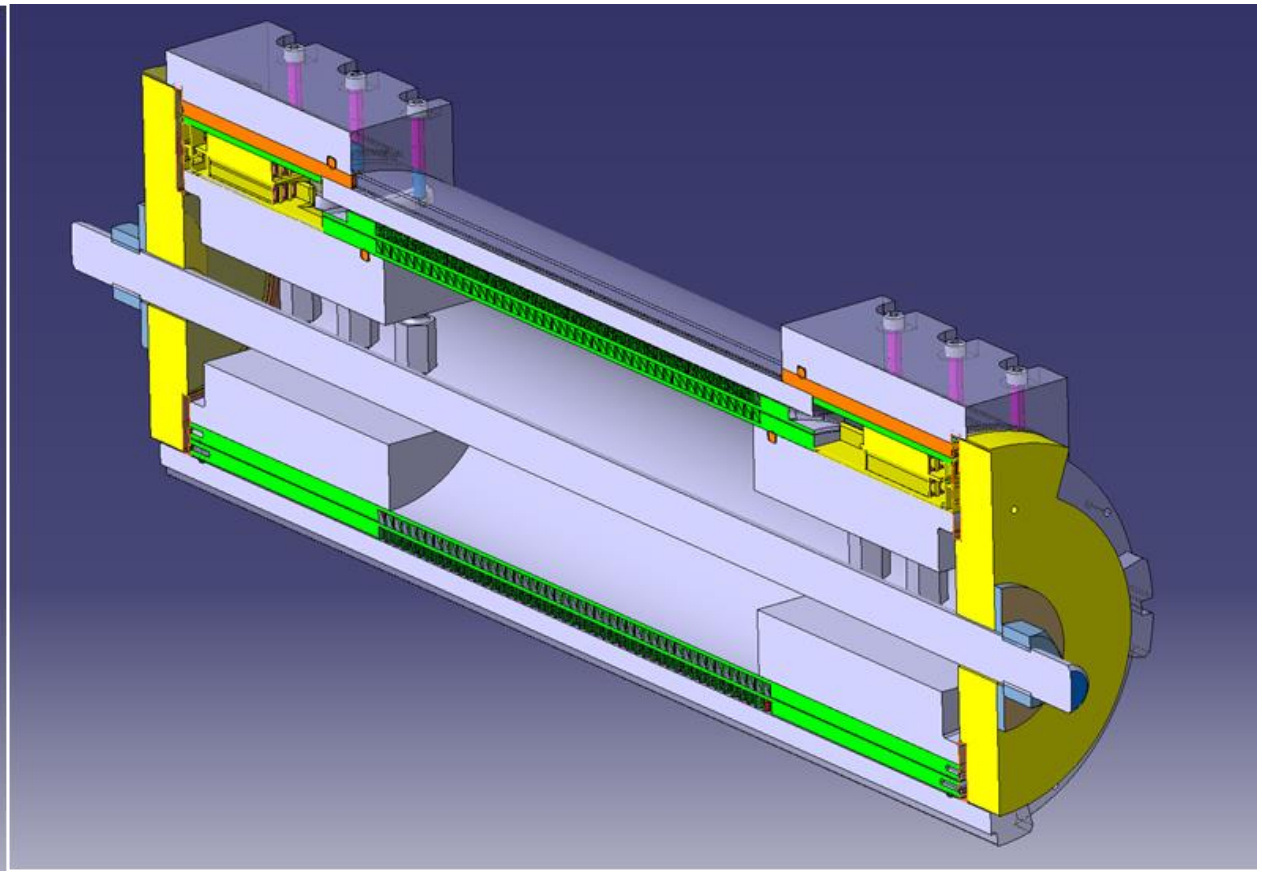




Cold mass 600A bus bar connection test

Pressurized impregnation 3 to 6 Bar

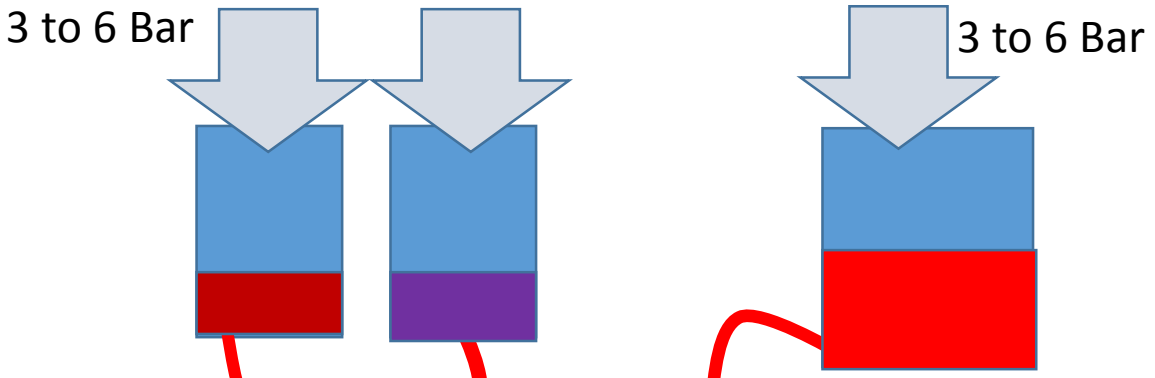


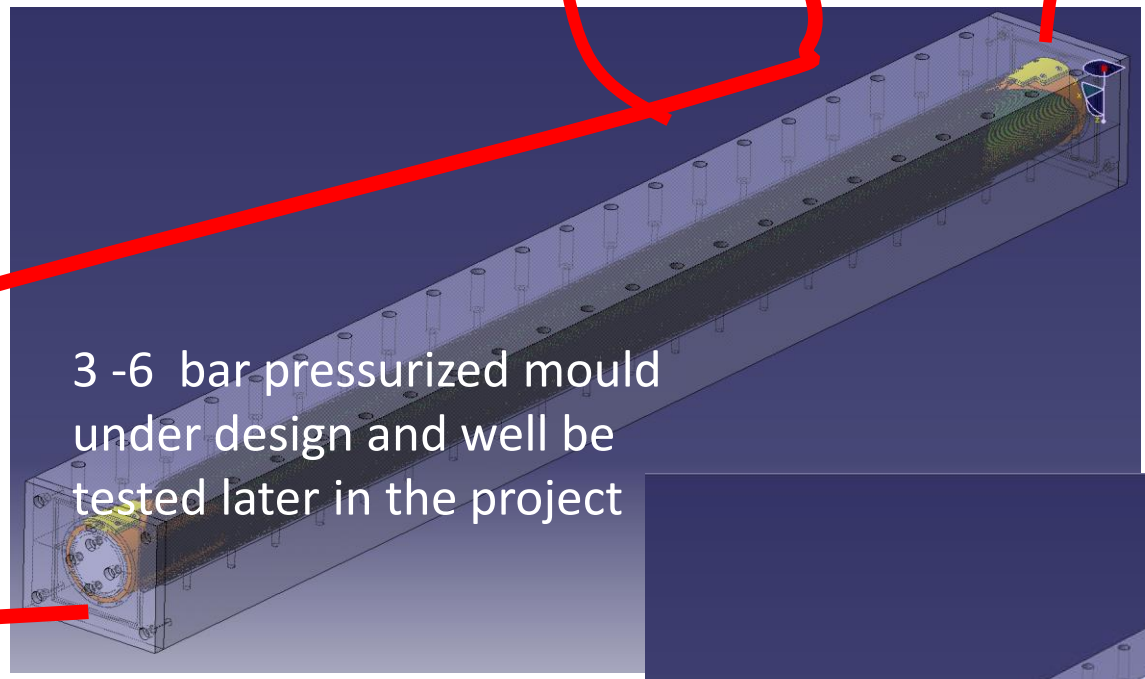


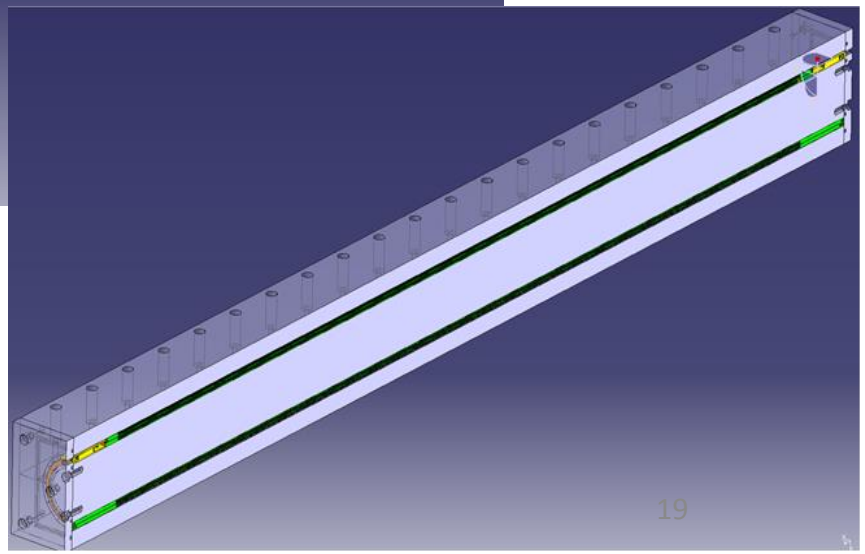
Impregnation

- CTD101K or later (CTD422 Rad HARD)
- 3 to 6 Bar

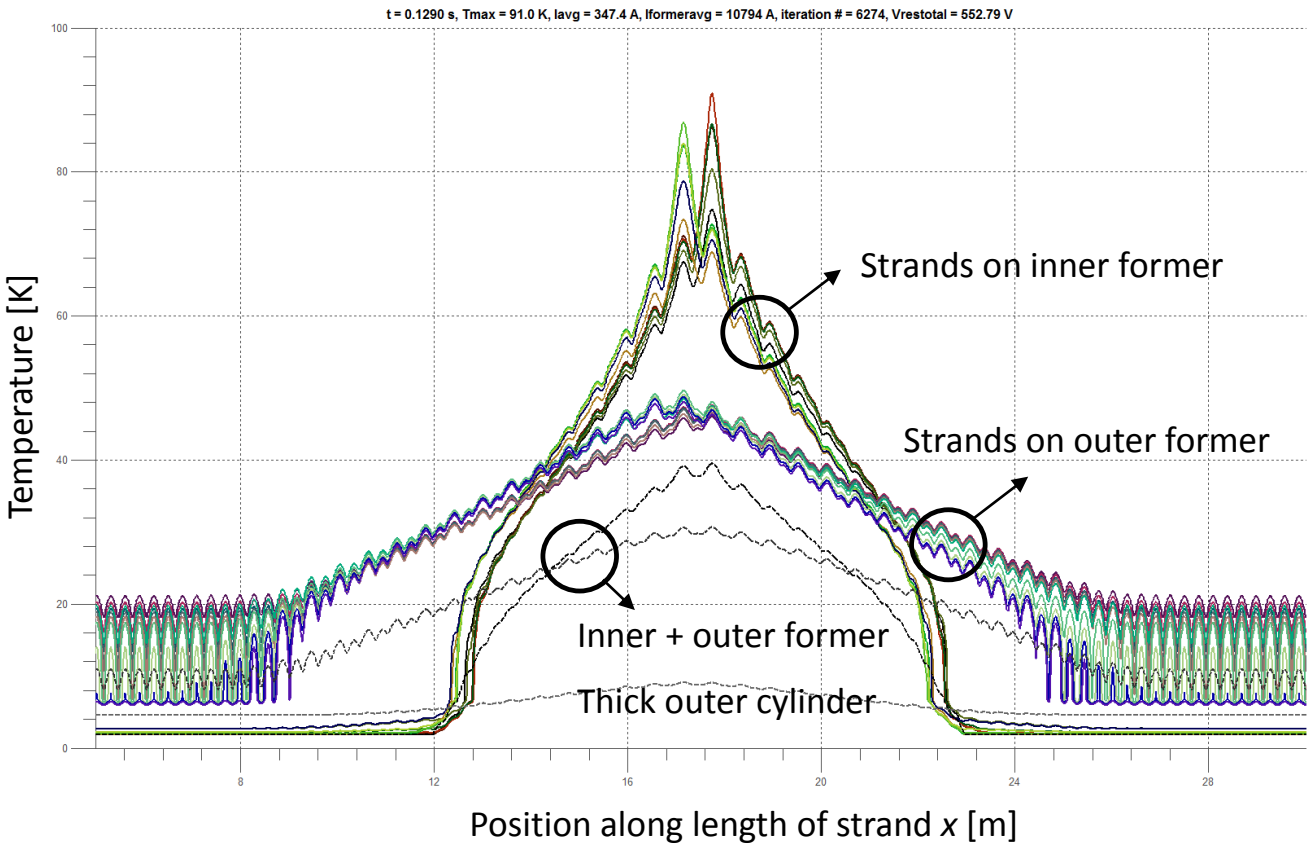
- Process:
- Vacuum out assembly
- De-gas resign
- Pre-heat assembly
- Fill slowly from lower end
- See resin exit
- Allow resin to fill vacuum bubbles
- Add 3 to 6 bar at both ends inert gas
- Increase temp to cure resin

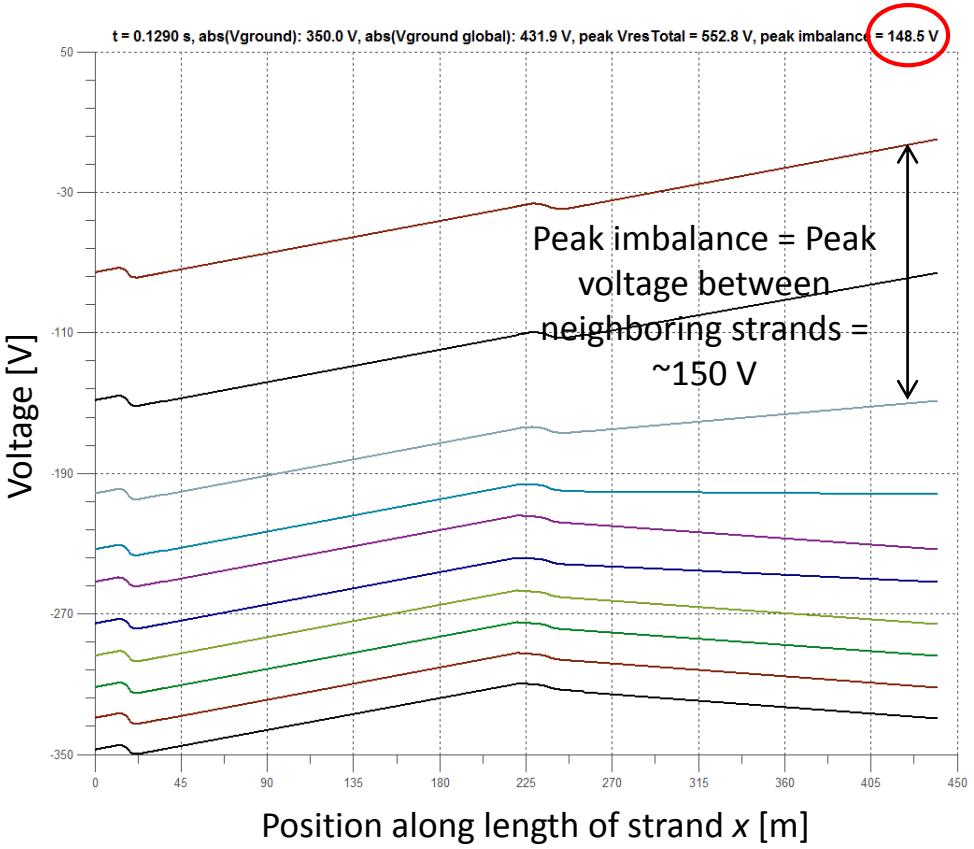


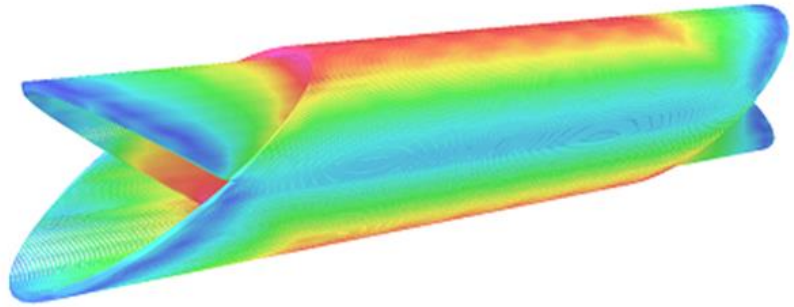




Quench Analysis



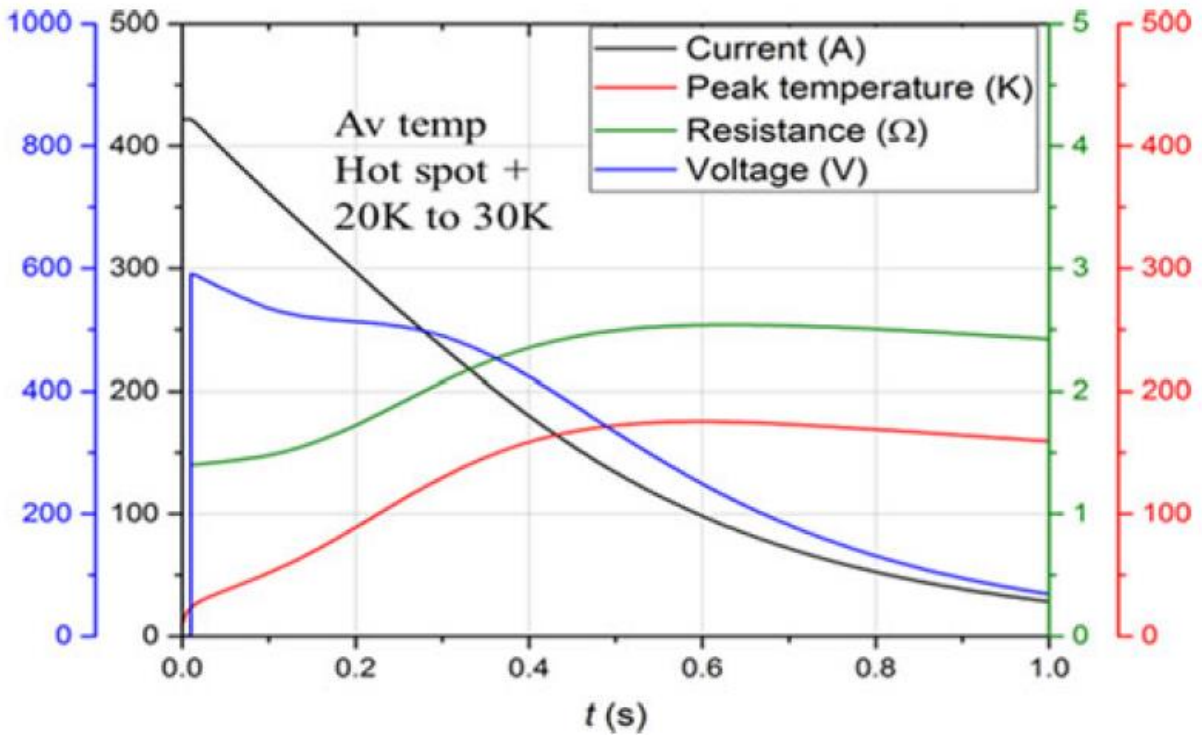




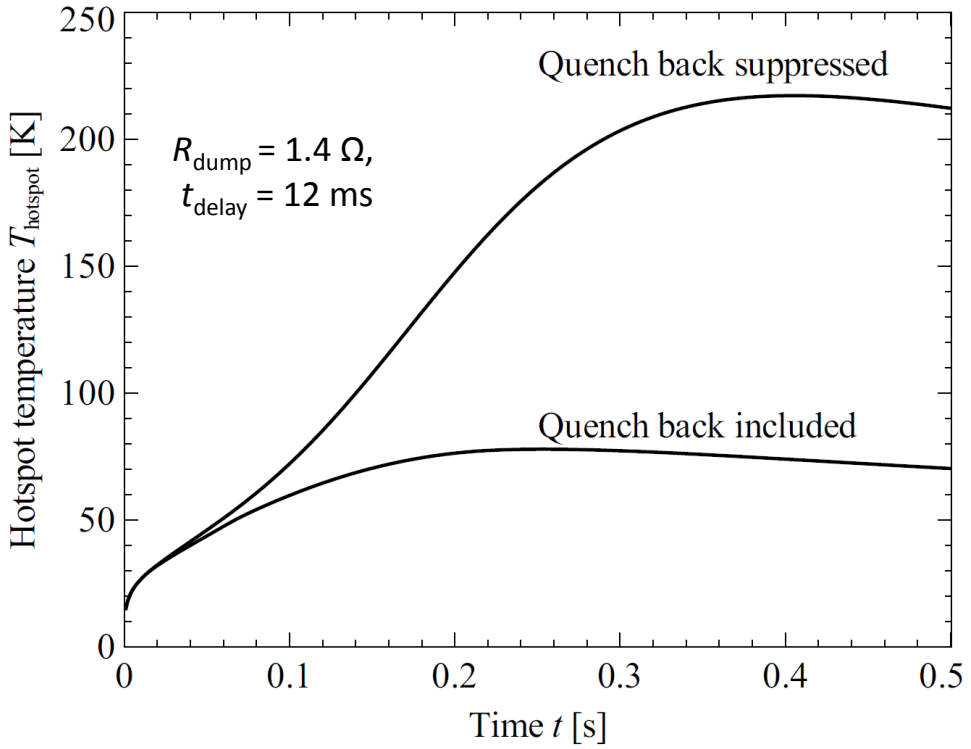
Inhomogeneous quench-back: Inner-most strand in slot quenches before outer-most strand, strands on outer former quench before those on inner former

Comparison with Juho's results

J. Rysti's results



Results of the new model



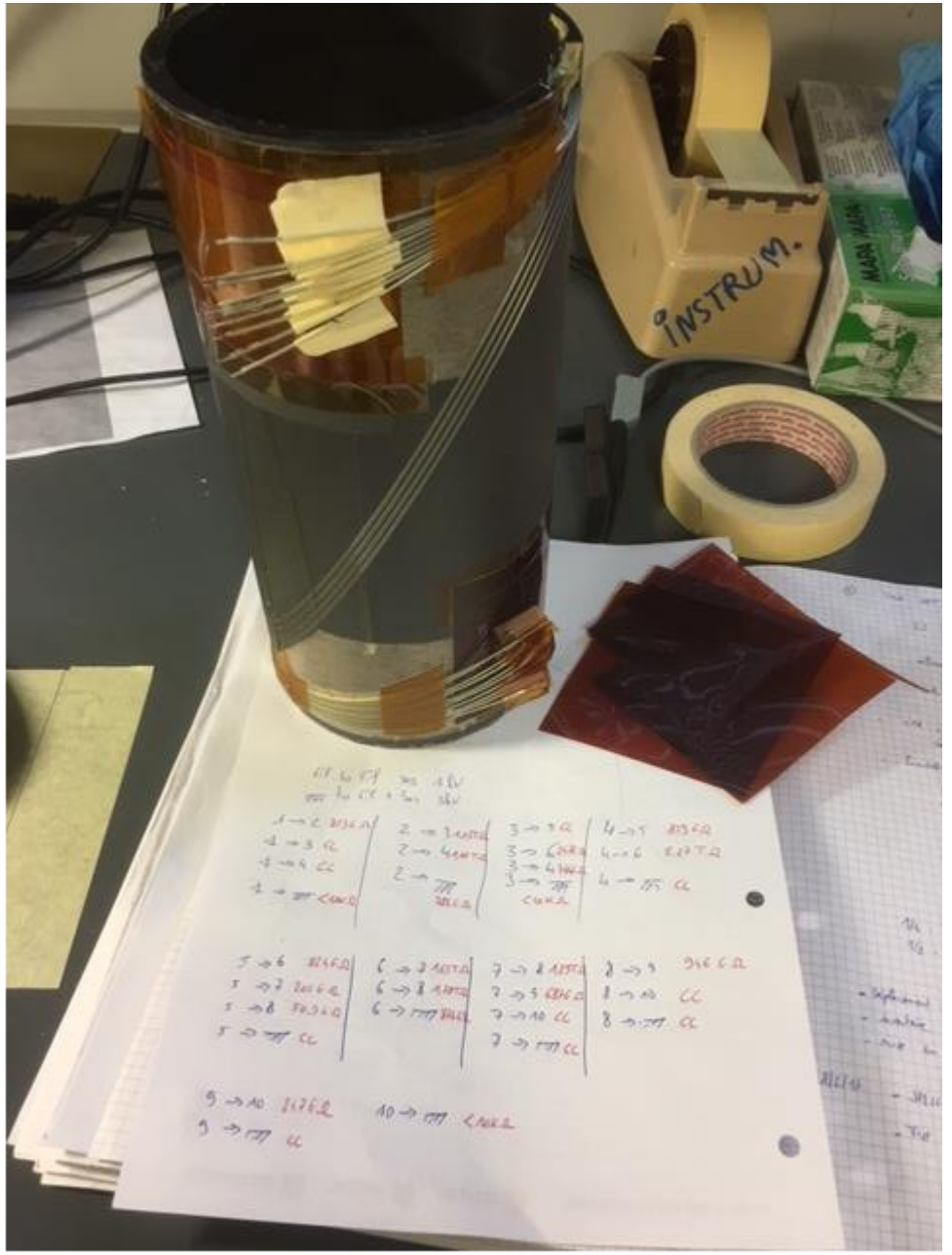
Comparison of results

- With quench back suppressed, new model is slightly more pessimistic (190-200 K) vs. 220 K
- Different underlying assumptions (bronze former vs. aluminum former, 5 strands per slot vs 10 strands per slot, cable vs. individual strands, etc.) may explain this 20-30 K difference
- **Quench back makes a big difference: 220 K without QB, 80 K with QB!**

Voltage Testing CERN std.

- Turn to turn Design value 150 V
- Voltage to ground, Design value 435 V

- Test CERN spec.
- At cold = Nominal x 2 + 500V = 1370 V
- At room temp = Cold value x 2 = 2740 v

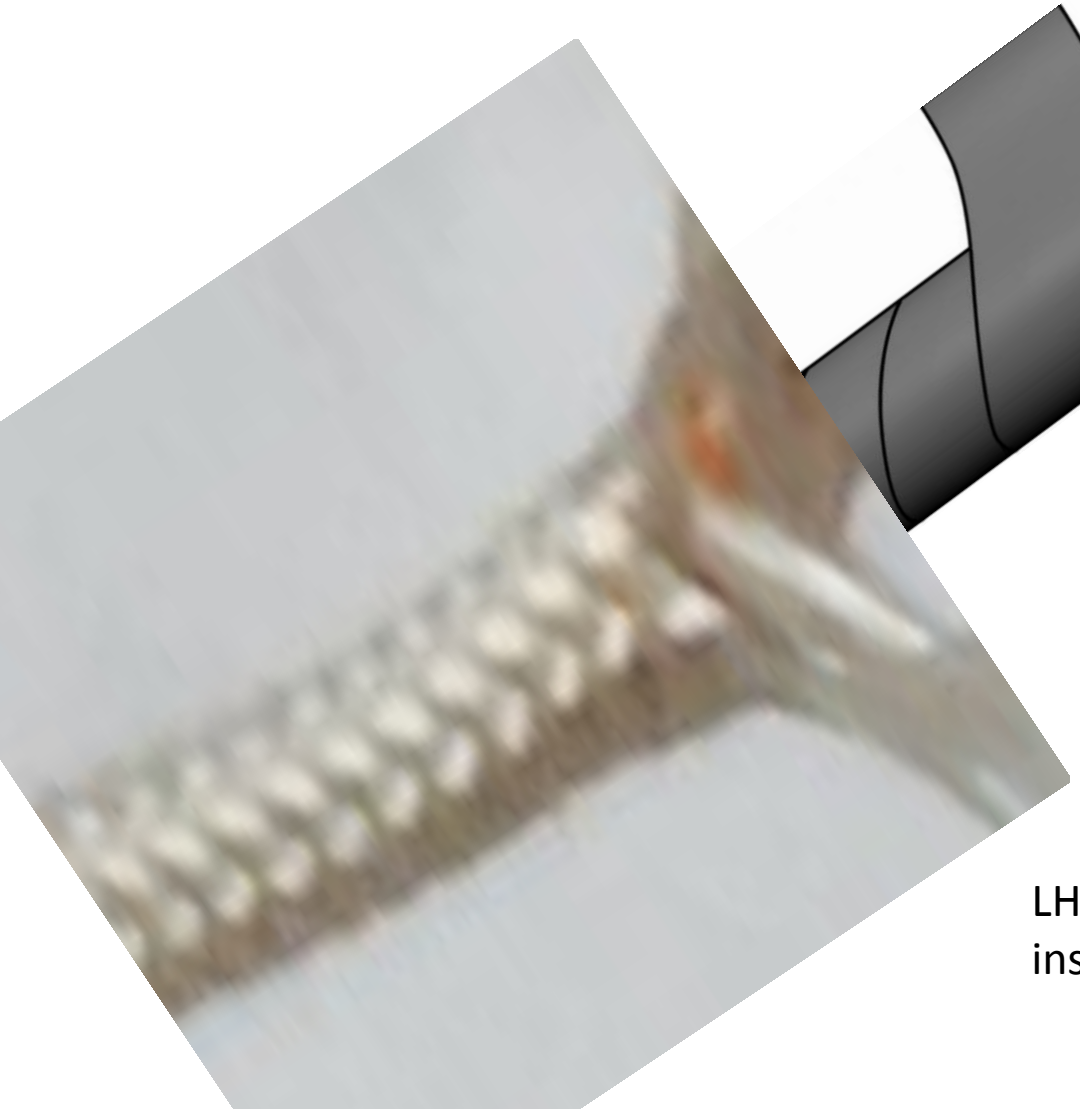


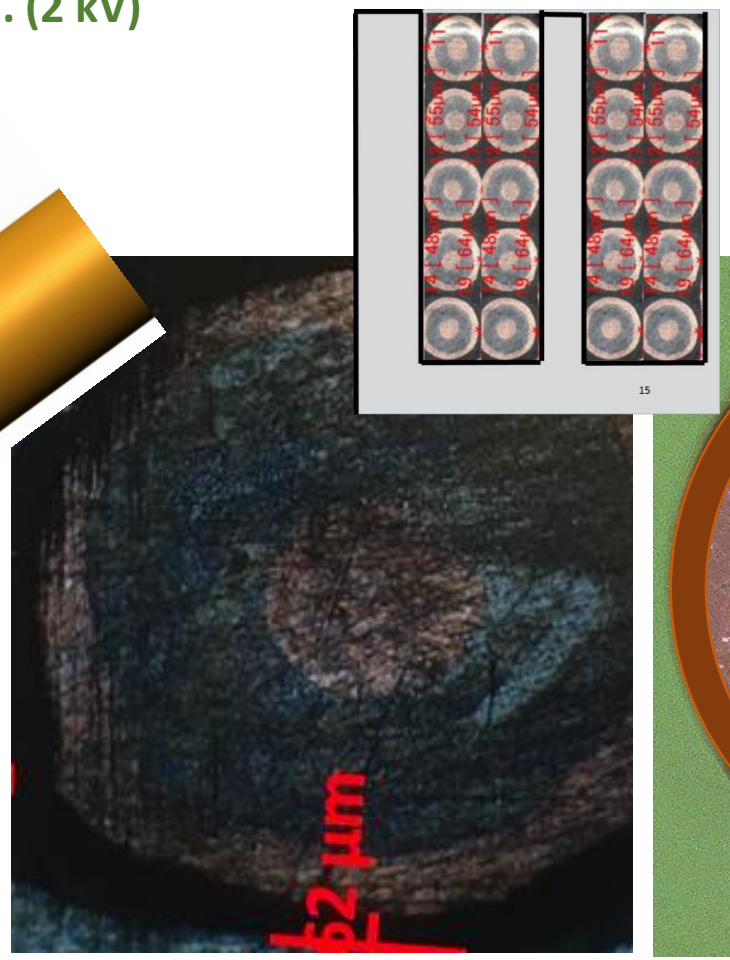
Insulation systems

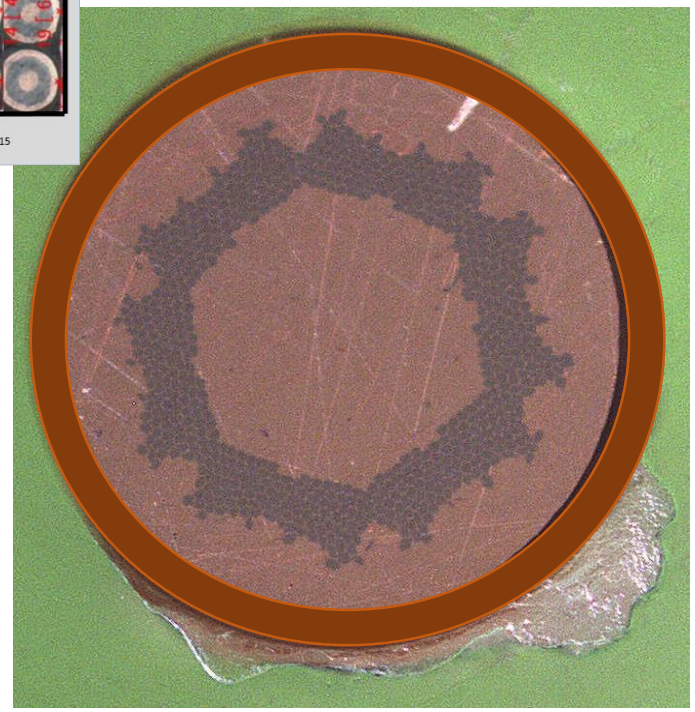
LHC dipole Nb-Ti wire 0.825 dia 1.95:1 Cu:Sc with Kapton tape 0.038mm thick 50% overlapping (1 kV)

Support S2 Class 0.05mm thick sleeve, Resin Impregnated. (2 kV)

Former Hard anodized. (1 kV)



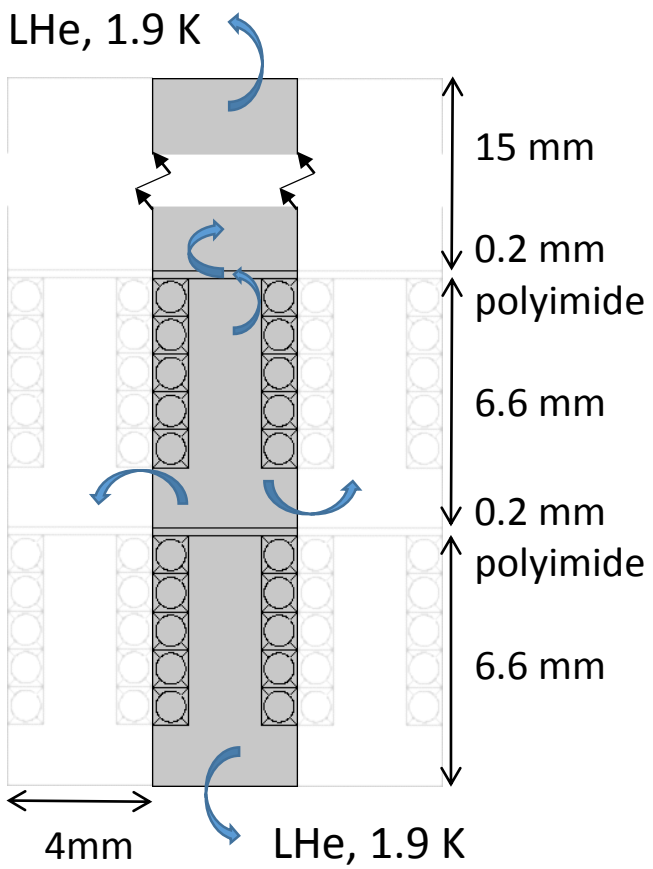


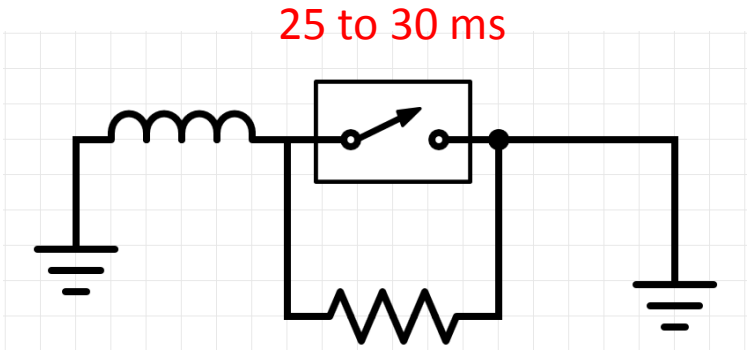


LHC wire , 49% overlapped 0.038 mm x 6 mm Polyimide tape then bonded insulation = 7 kV insulation + glass sleeve impregnated for support.

CCT coil, d//dt

Transverse heat transfer model
(see: https://indico.cern.ch/event/616774/ for details)



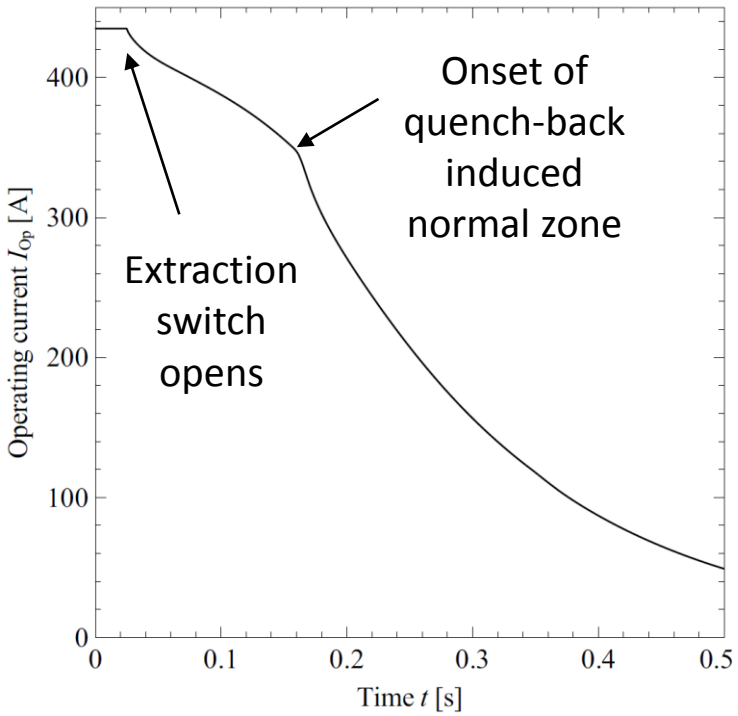


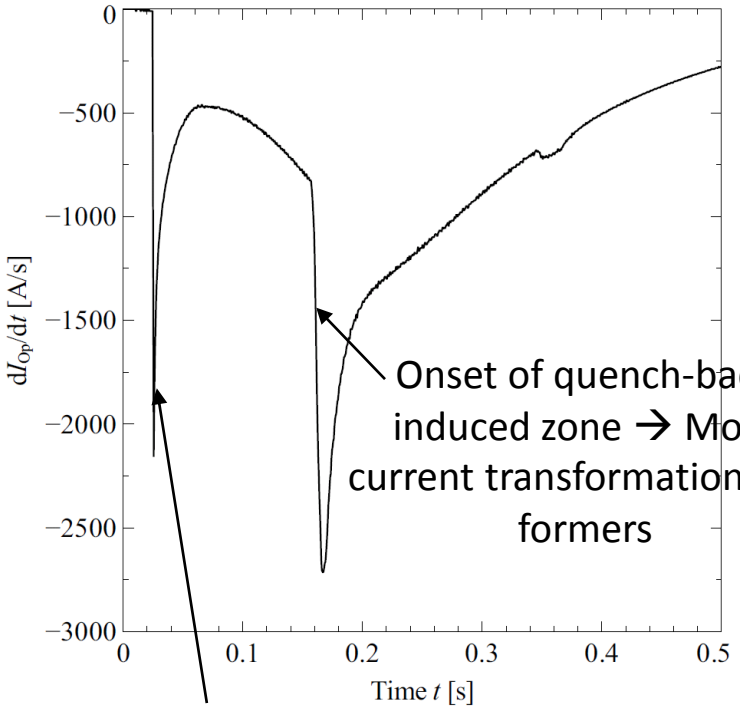
0.7 , 1.0 , 1.7 Ohm dump options

CCT coil, quench model

- CCT coil (2.2m) switched in series with a dump resistor after 25 ms
- Internally, current is transformed into aluminum formers (Quench back)

CCT coil, dI/dt, R_{dump} = 0.7 Ω, t_{delay} = 25ms

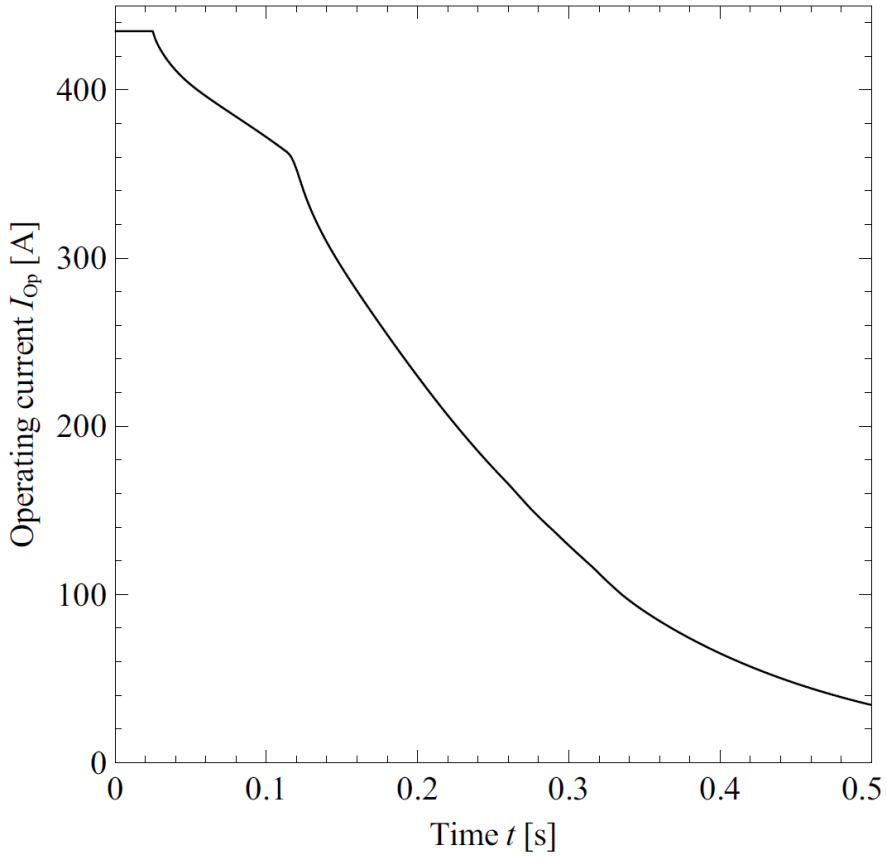


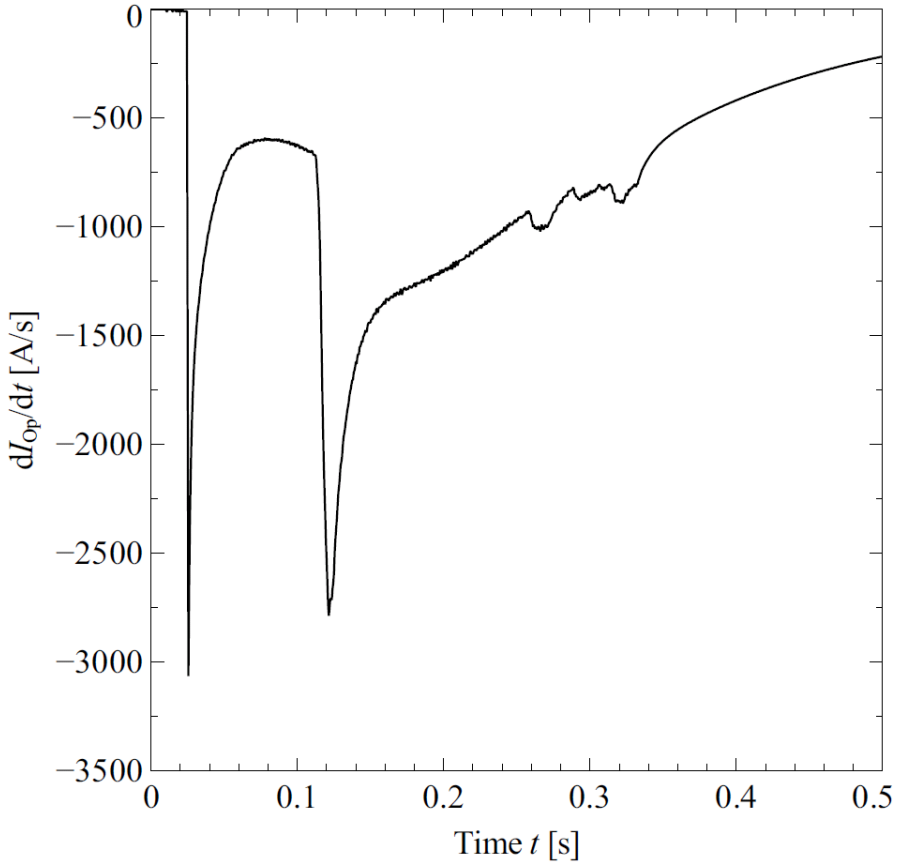


After switch opening, current is transformed into formers until saturation

- Assumed coupling to aluminum formers is somewhat pessimistic, i.e. likely the degree of quench back is higher
- dI_{op}/dt shown here is thus indicative of magnitude, and cannot be taken as an upper limit
- Peak hotspot temperature = 198 K

CCT coil, dI/dt, R_{dump} = 1.0 Ω, t_{delay} = 25ms





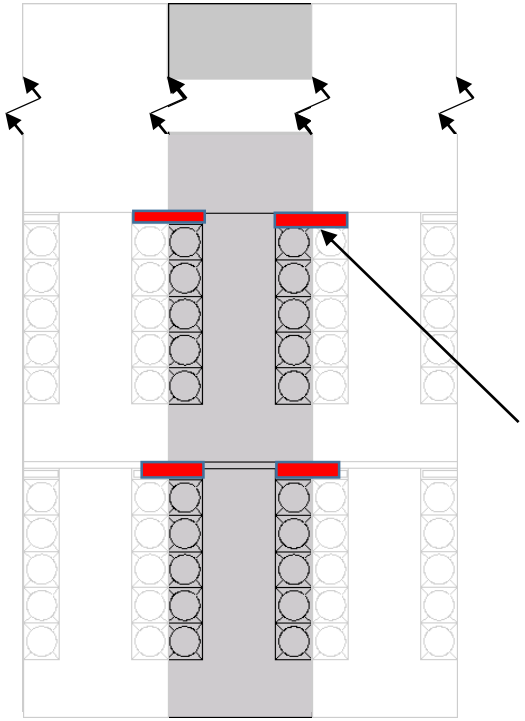
- Same as previous slide, but higher R_{dump} → More transformation into aluminum formers → Somewhat higher dI_{op}/dt
- Peak hotspot temperature = 140 K

Cost reduction idea,

- Can we make the magnet protectable with a passive system and save the cost of the switch and dump resistor?

CCT coil, non-linear quench back

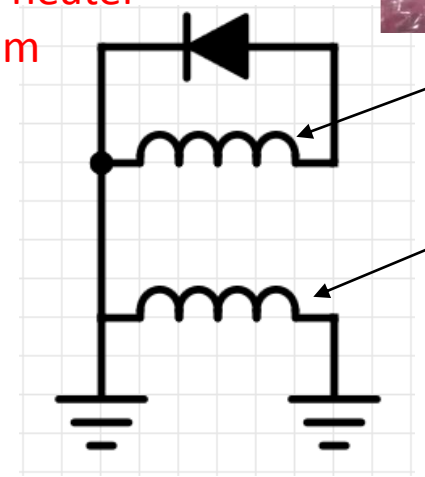
Transverse heat transfer model
(see: https://indico.cern.ch/event/616774/)



Copper strip (200 µm thick, RRR=100), insulated with 50 µm polyimide foil, on top of superconducting strands

? Radiation kGrays

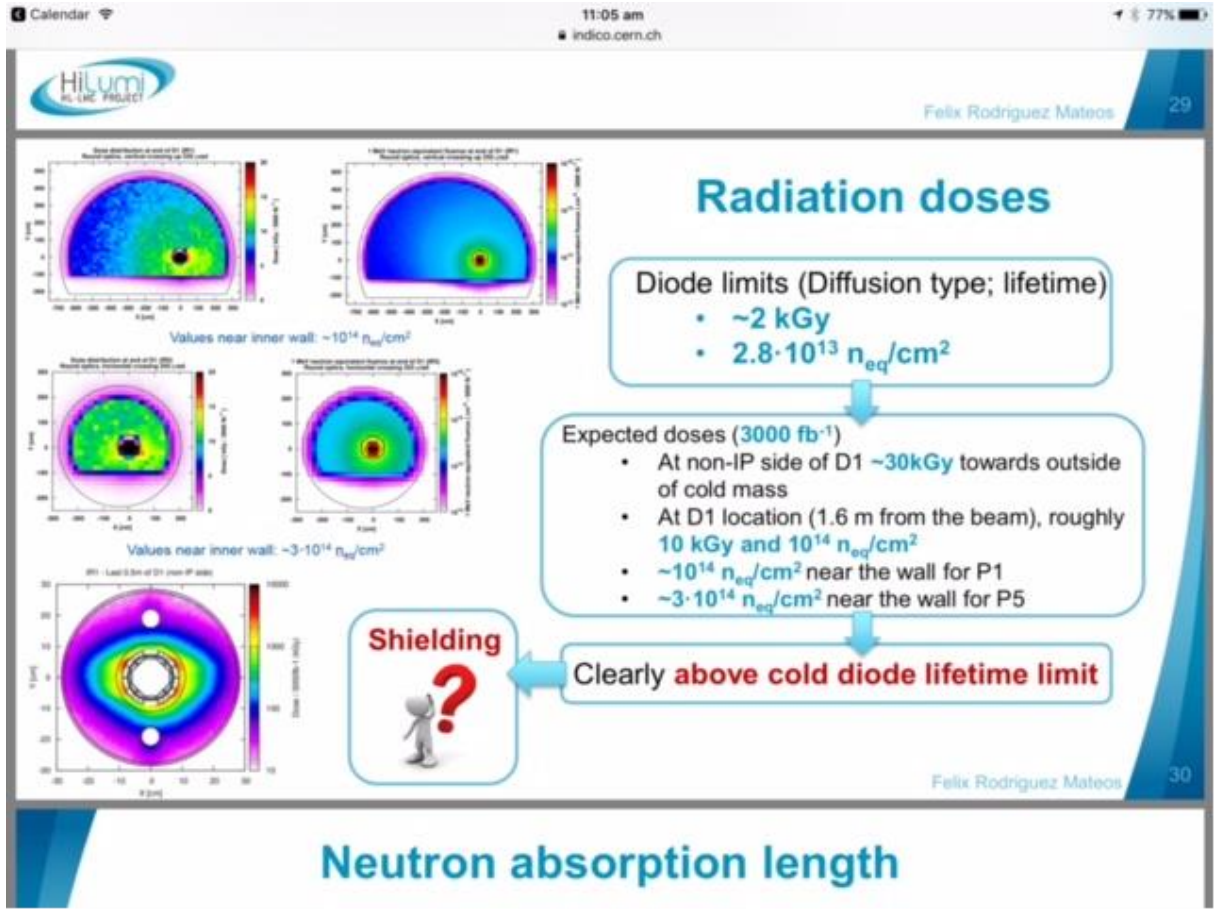
Copper strip heater
0.2mm x 2mm



Non-linear quench-back, concept

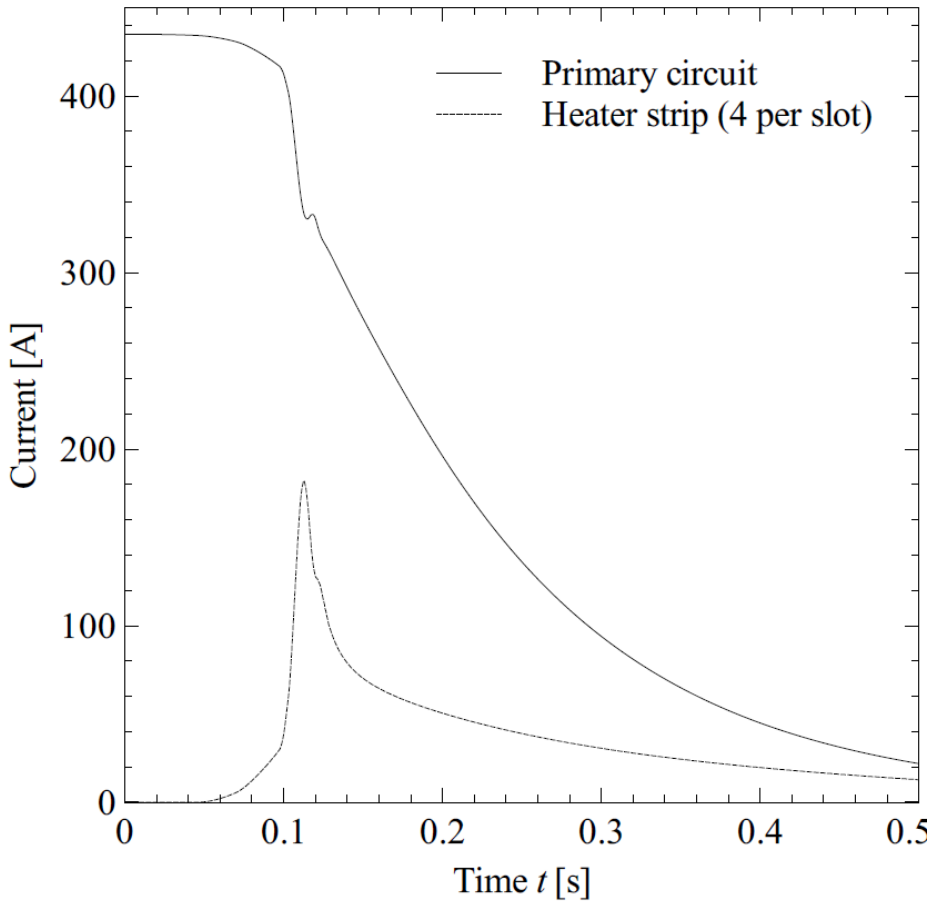
- Superconducting strands are in close thermal contact with a normal conducting copper strip
- Non-linear quench-back: Transformation only occurs above critical dI_{op}/dt (with: $V_{res,primary} * 1/10 > V_{diode}$)
- In addition: Regular quench-back due to aluminum formers

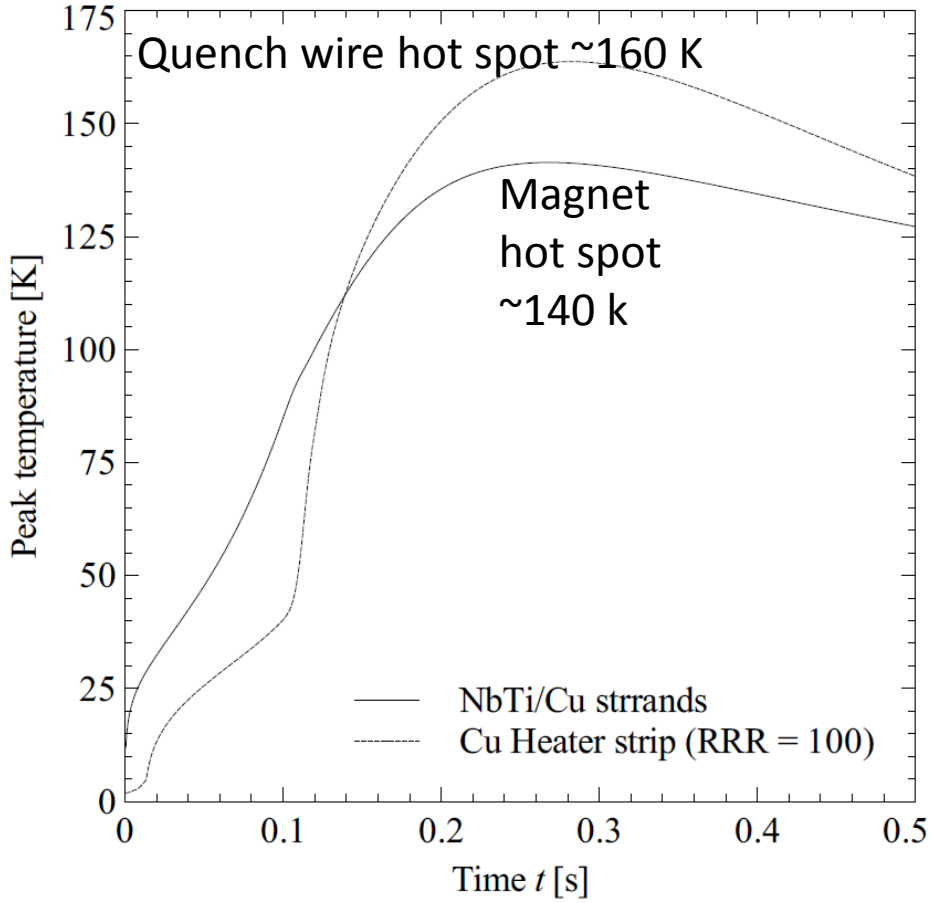
Where to put the diode?



We need a similar radiation map for the D2 orbit corrector

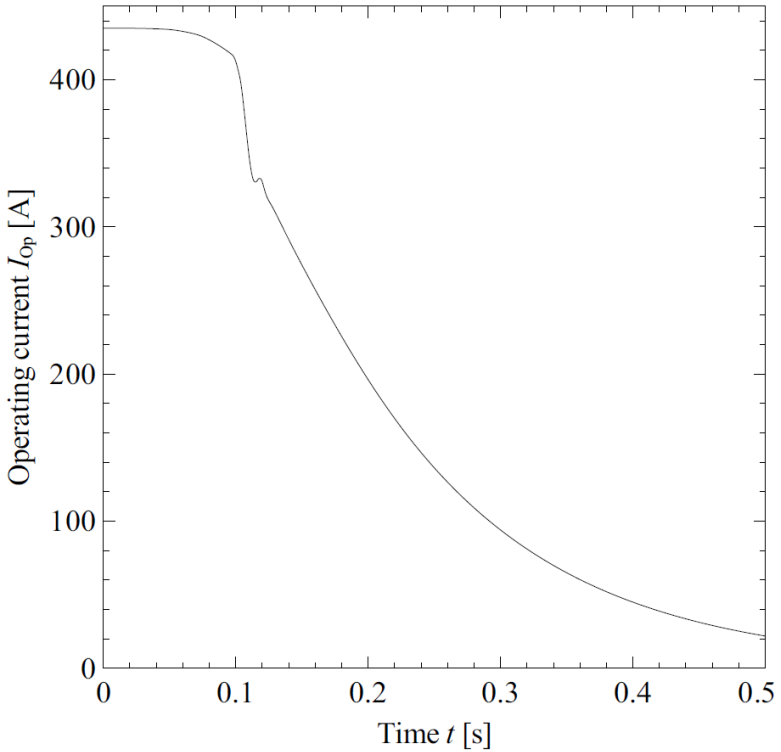
We will test to opening voltage at cold, assume 6 v cold up from 0.6v at room temperature.

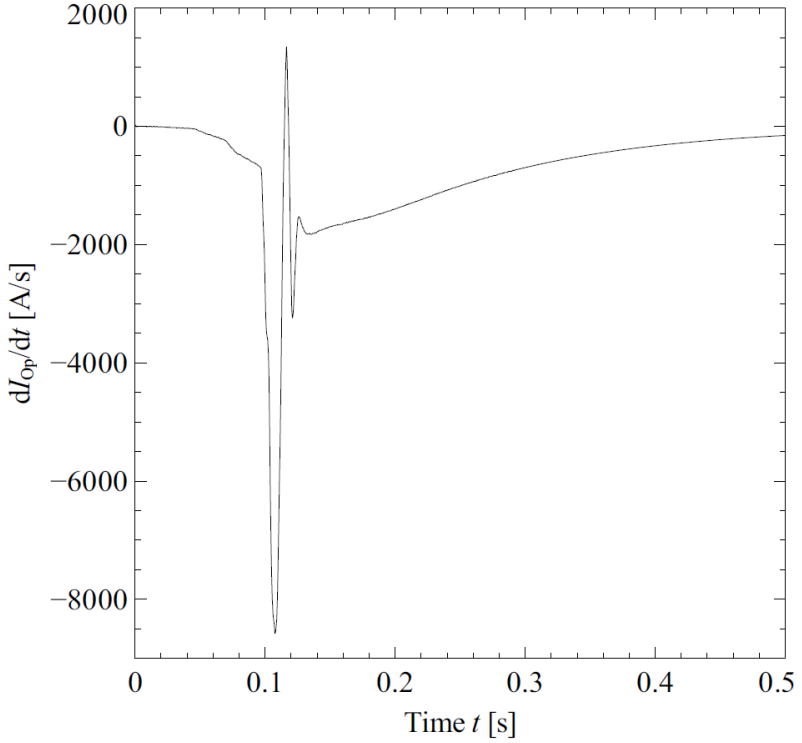




here is temperature and current as a function of time for the 2.2 m CCT with diode and heater circuit. Here I assume that there are four copper strips (200 um thick, 50 um kapton insulation) sitting next to each other in the slot, which are all connected in series with a diode with a threshold of 6 V

Non-linear quenchback, d*I*/d*t*

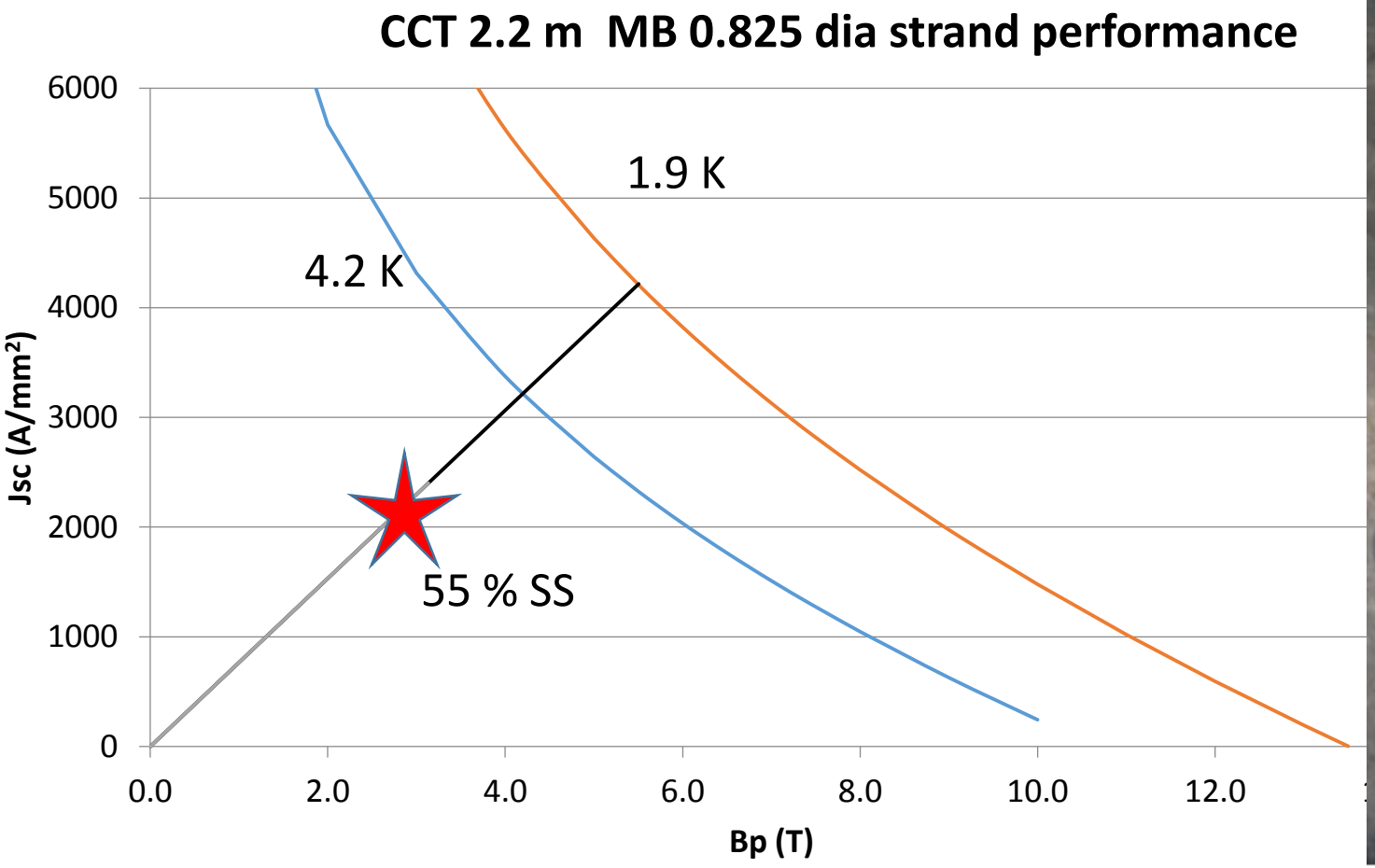


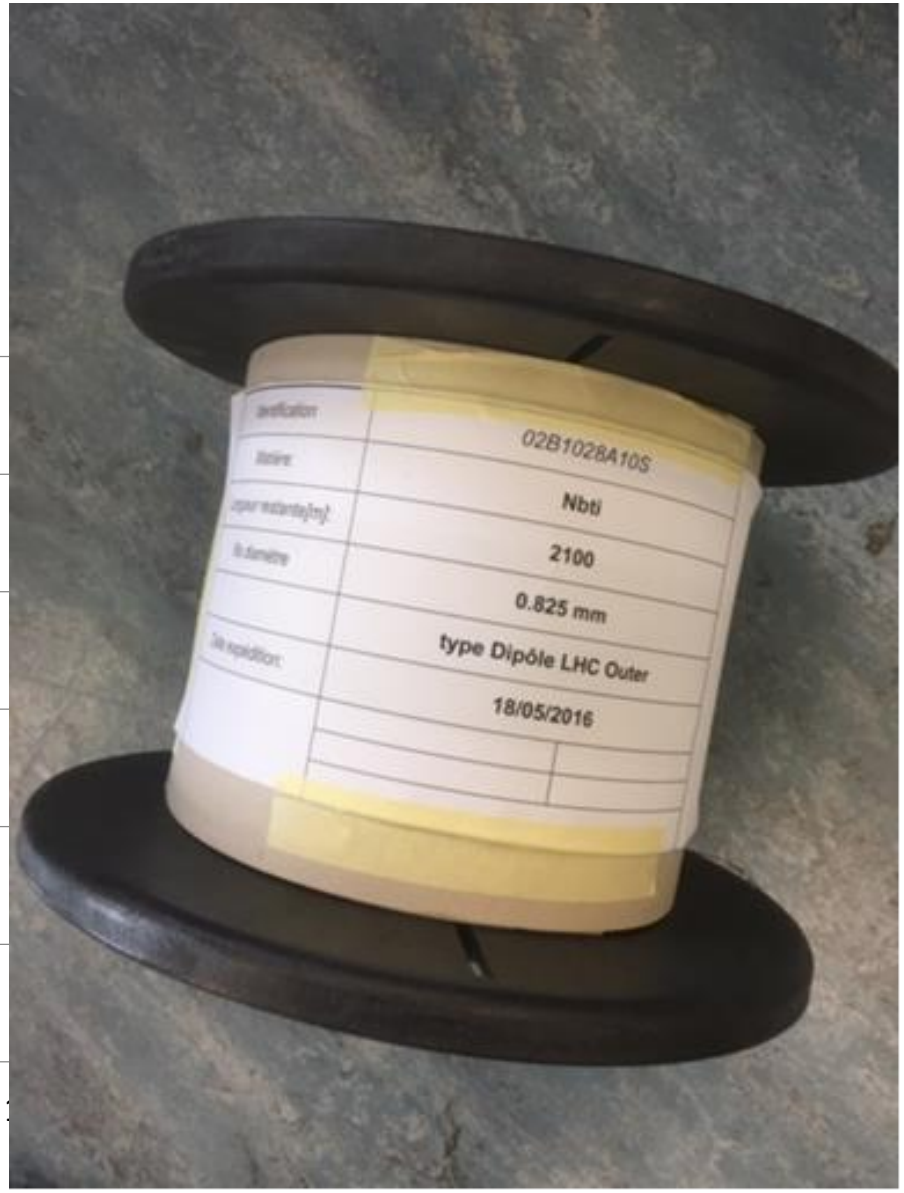


Non-linear quenchback

- With: 1 copper strip per slot and $V_{diode,threshold}$ = 1.5 V (Or: four copper strands per slot, $V_{diode,threshold}$ = 6 V): No transformation into secondary until power convertor voltage is equal to 10 x 1.5 = -15 V, or total resistive voltage over primary is equal to 15 V (assuming PC is shorted)
- No extraction, no active quench-protection, fully self-protected
- Peak hotspot temperature: 141 K, peak copper strip temperature: 160 K
- But: Very fast homogeneous quench + transformation into copper strip + aluminum formers → Highest dI_{op}/dt of these three options

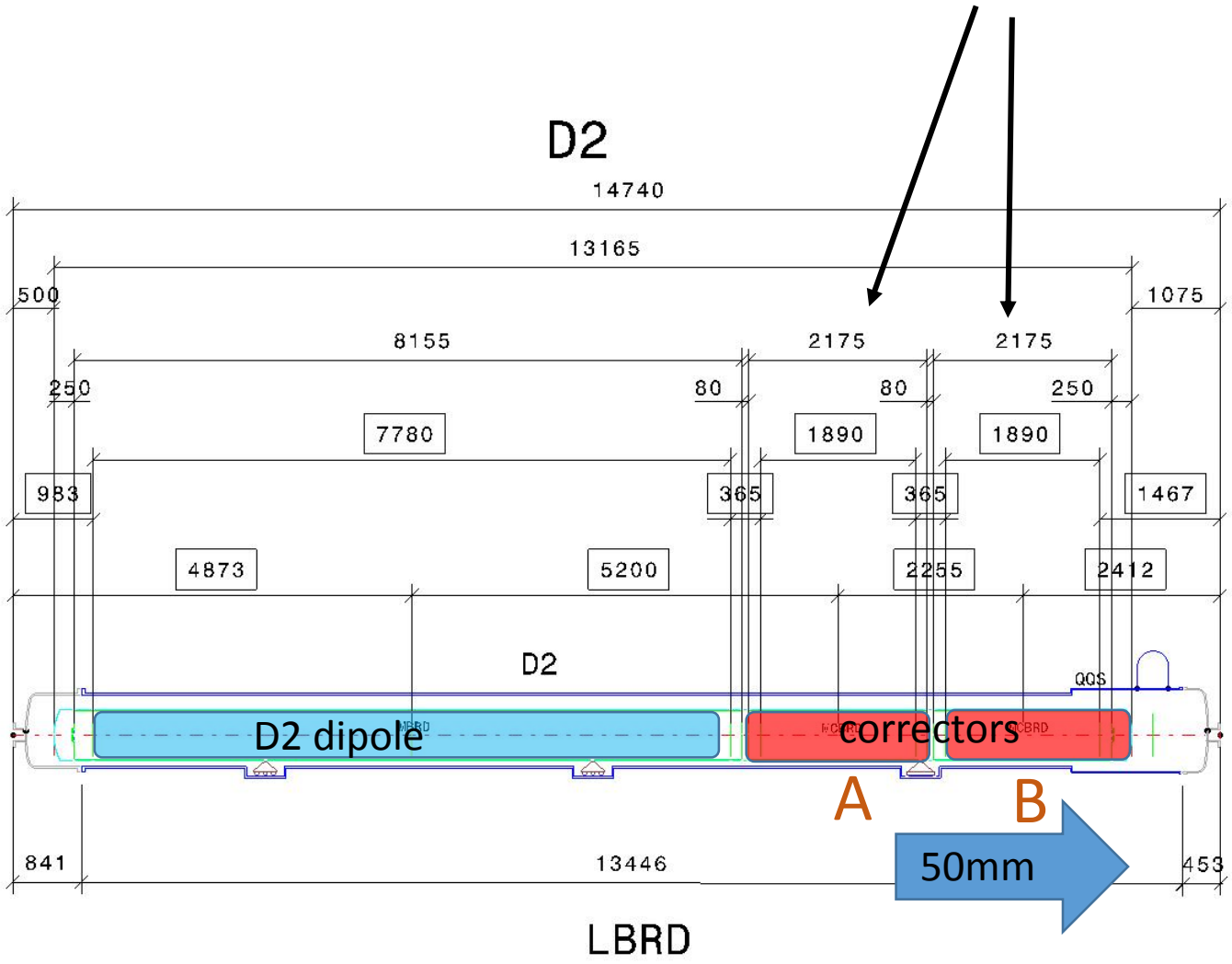
Low SS to give margin for the heat load





Integration

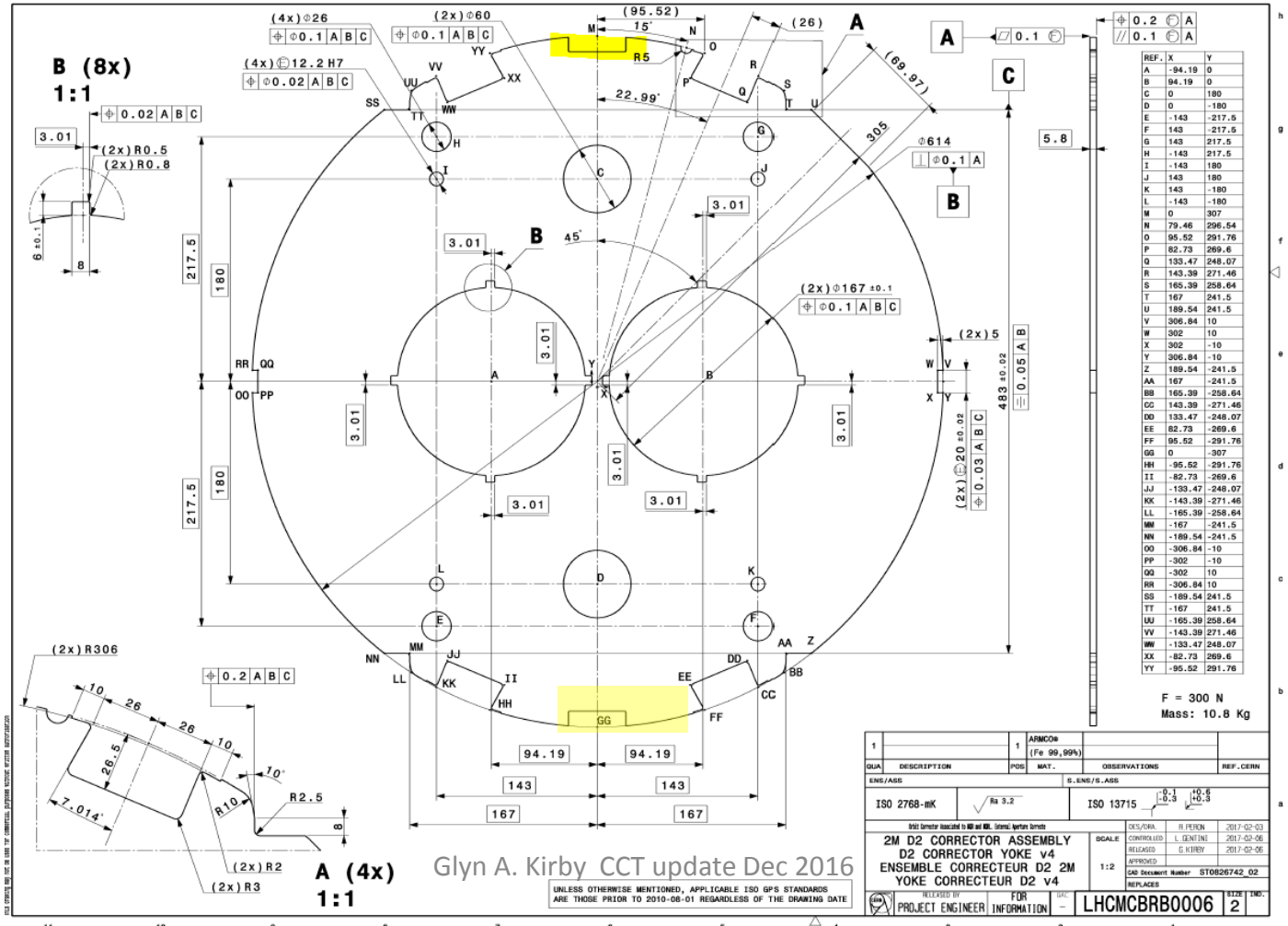
Base line corrector length
2194.4 mm



Corrector “A” and “B” are being moved 50mm to the right minimum to give space for an assembly operating on the D2

D2 bus bar slot was modified to make it 4mm deeper both top and bottom as the lamination is flipped top to bottom alternatively .

(this is the old drawing we still need to change it)



Corrector powering bus

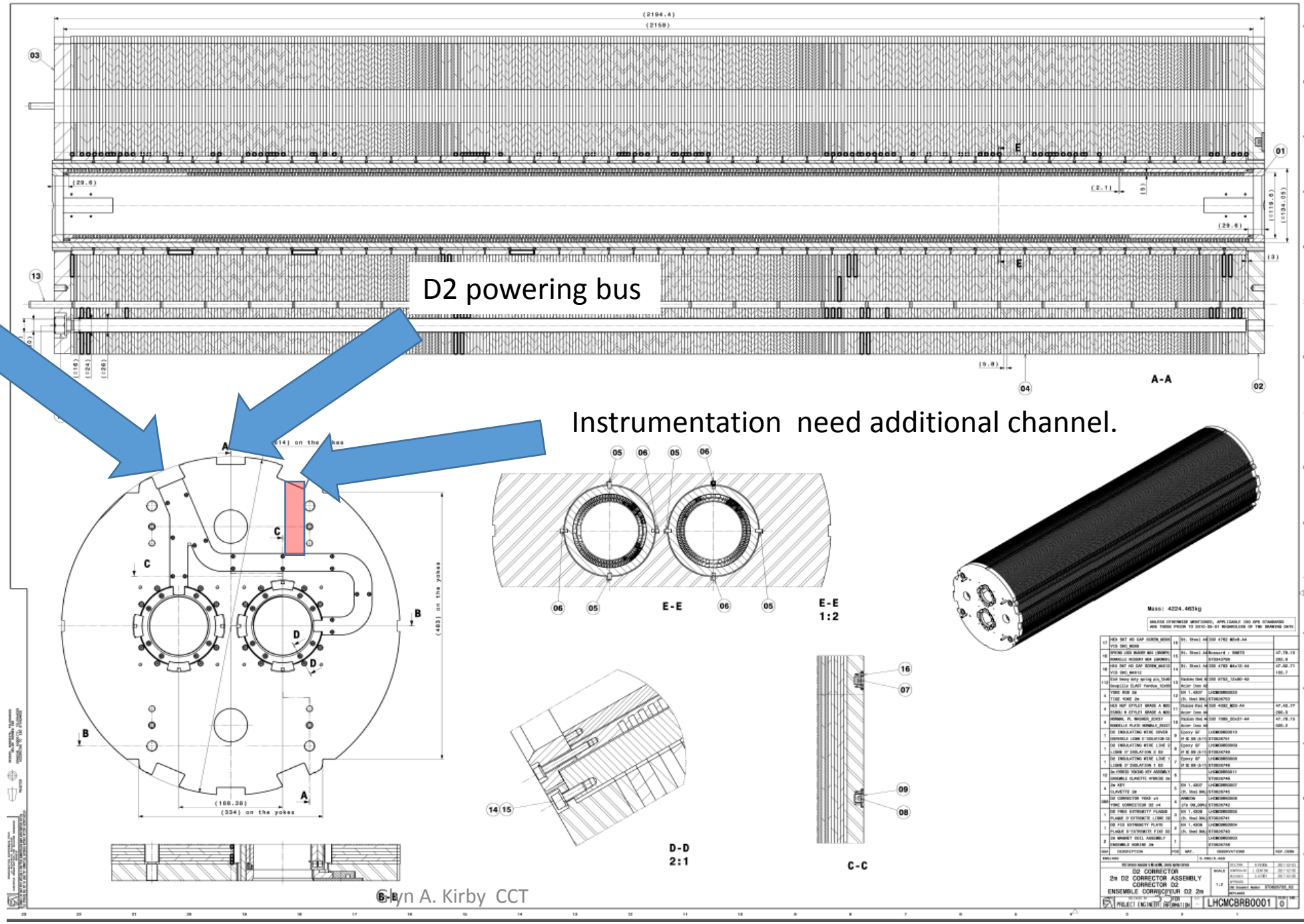
Joint between Magnet wire and bus bar

D2 powering bus

Instrumentation need additional channel.

We still need some adjustment of the end plate channels

1) lift into position
2) Connect wiring
3) Weld closed
4) Rotate 180 deg.



2.2 m Components

Should be ordered mid to late April

Good morning Glyn,

Here below are the deadlines concerning the quotation:

- within 7th April for the following parts:
  - LHCMCBRB0008(v.0);
  - LHCMCBRB0009(v.0);
  - LHCMCBRB0010(v.0);
  - LHCMCBRB0015(v.0);
  - LHCMCBRB0016(v.0).
  - LHCMCBRB0018(vAA);
  - LHCMCBRB0019(vAB);
  - LHCMCBRB0020(vAB).
- within 11th April for the following parts:
  - LHCMCBRB0004(v.0);
  - LHCMCBRB0005(v.0);
  - LHCMCBRB0007(v.0);
  - LHCMCBRB0011(v.0);
  - LHCMCBRB0017(v.0);
  - LHCMCBRB0023(v.0).
- within 18th April for the parts LHCMCBRB0006(v.0).
- for the following parts to be defined after a meeting:
  - LHCMCBRB0012;
  - LHCMCBRB0013;
  - LHCMCBRB0014.

For the parts in Additive Manufacturing the order has already been launched. Waiting for the delivery in the week 15.

In order to respect the planning, during the time between the *Price Enquiries* and the *orders* it's better to complete all modification of the drawings especially for the "ARMCO discs" and the linked components (LHCMCBRB0004, LHCMCBRB0005….etc.).

Please let me know also about the ARMCO sheets.

Thank you in advance.

		2017																														
			March					April				May					June				July						August				Septe	
		w9	w10	w11	w12	w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24	w25	w26	w27	w28	w29	w30	w31	w32	w33	w34	w35	w36	w37		
500mm 2x5mm slot model																																
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polish formers ?																																
Hard anodize																																
Oxford/Bruker insulated wire delivery																																
Oxford wire CGP glass insulation																																
CERN LHC wire insulation with Polyimide																																
CERN wire CGP glass insulation																																
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Coil assembly & jointing																																
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Cold test !																				Test 500mm												
2.2m full lengh model																																
tendering for formers, yokes, all parts																																
component manufactuer																																
former manufactuer																				Former manufactuer												
CERN 0.825 wire insulation	? Still looking! Now sent to be insulated																															
manufactuer winding/impregnation tooling																				winding and impregnation												
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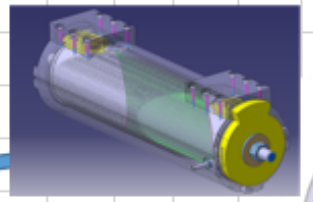
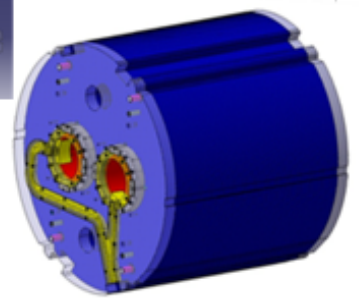
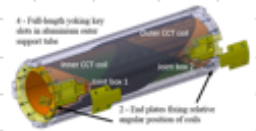
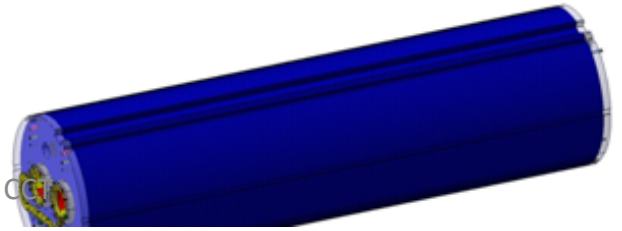
SM18 closed





Summing up!

- We now have the formers , but they need polishing and anodizing
- We will have both the Aluminium and the Bronze sets interesting comparison, thermal contraction and energy extraction at quench , quench performance.
- Insulated wires:
  - Oxford wire still in the post
  - CERN wire sent to be insulated with Polyimide 0.038 mm thk tape
- Sealing joint box for impregnation was difficult.
- Orders for 2.2 m magnet about to be placed
- Working on resin impregnation system and resins I would like a tough resin, not the brittle ctd101k
- 0.5, model a little delayed , but not the 2.2m prototype.


The End