Hi-Lumi LHC Twin Aperture Orbit Correctors 0.5 m Model Magnet Development & Cold Test

Presented by G. De Rijk

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MT 25 Amsterdam August 2017 Mon-Mo-Or1

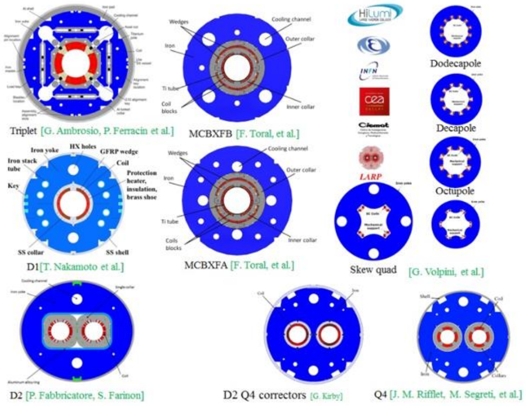
Talk Over View

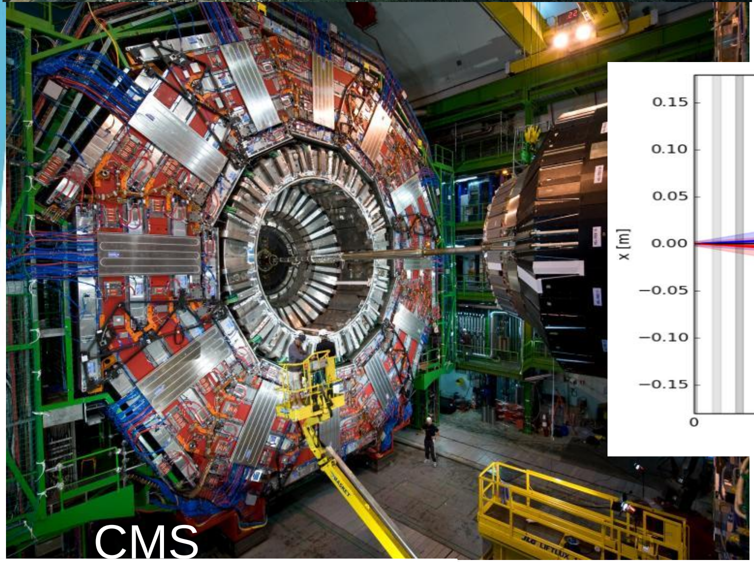
- What is “High Luminosity LHC”
- Orbit Corrector Function & Environment
- CCT aperture development :
- Winding tests
- Coil development
- Cold test
- Planning
- Conclusions

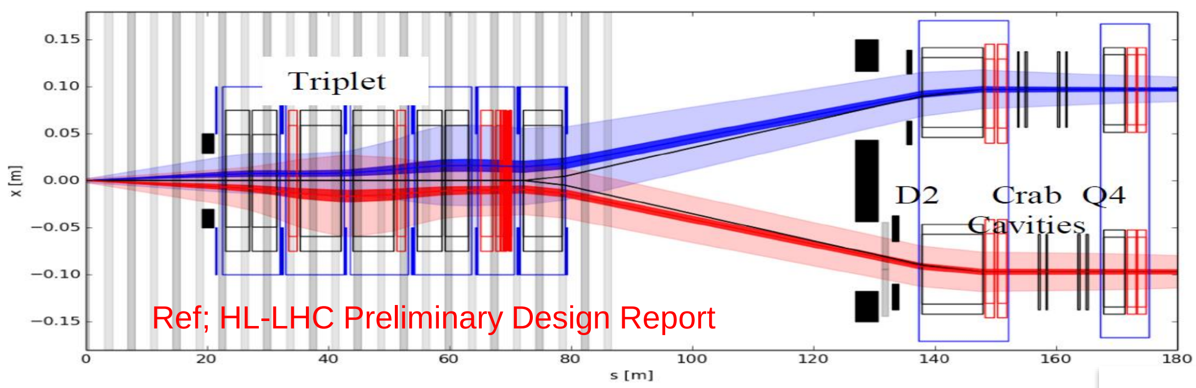
What is “High Luminosity LHC”

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

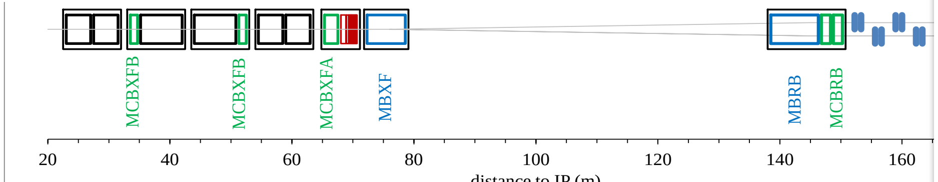
Upgrade Magnet Set







Ref; HL-LHC Preliminary Design Report



Specification and choice of CCT

Specification

- 2 aperture H,V dipole corrector
- $\int B = 5 Tm$, B= 2.8 T, L_{mag}=1.8m
- Imax = 600A

Ribbon cosΘ vs CCT

Ribbon CosΘ

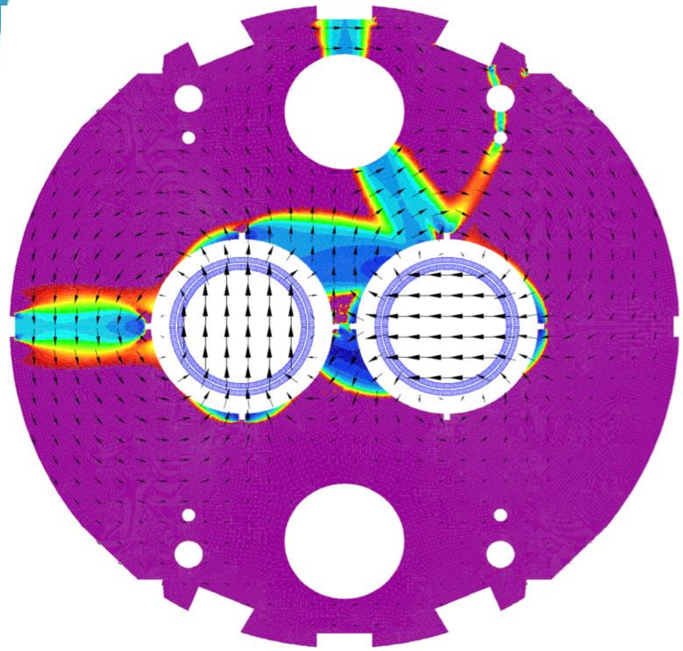
- Field quality limited due to collars using up yoke space between the apertures
- Ribbon glue is rad hard limited
- Ribbon conductor suffers from electrical shorts during production and ongoing degradation during operation, probably due to radiation damage.

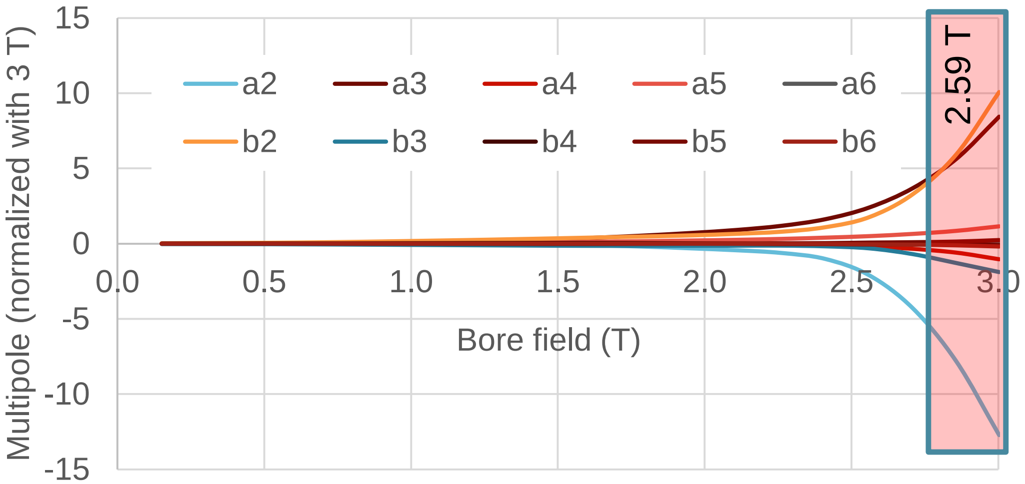
CCT:

- Radiation hard “full metal jacket” design
- Low cost
- Fast to produce.
- Very good field quality
- Little tooling

HiLumi HL-LHC PROJECT CERN

Magnetic Field Optimization





More complicated than one plot,

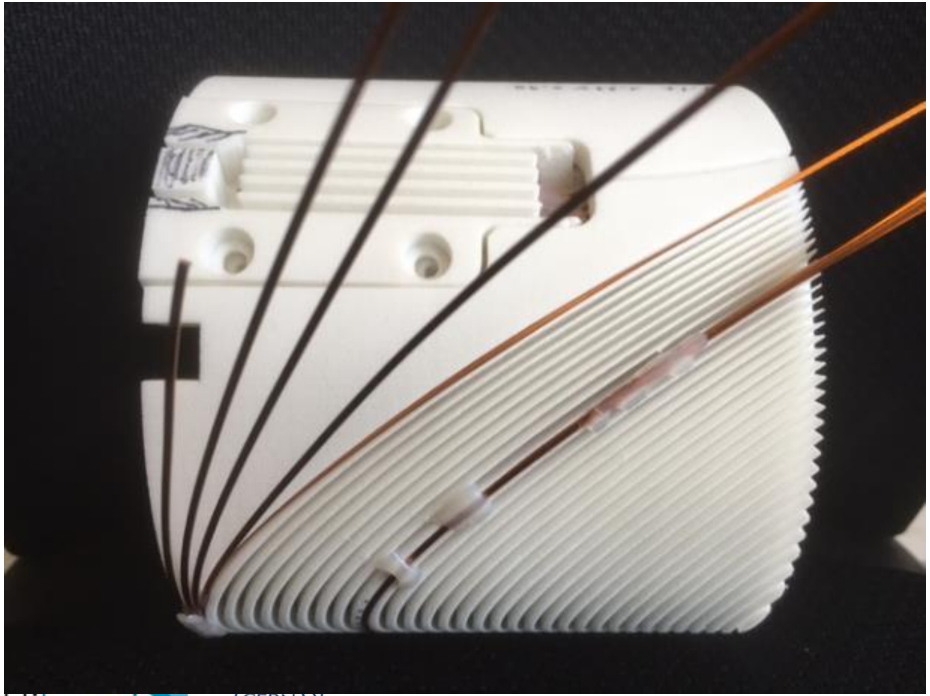
Example of one configuration Presenting harmonic solution due to high field in the adjacent aperture

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.

1st winding test with the rectangular wire

!!!! Rectangular wire failed !!!

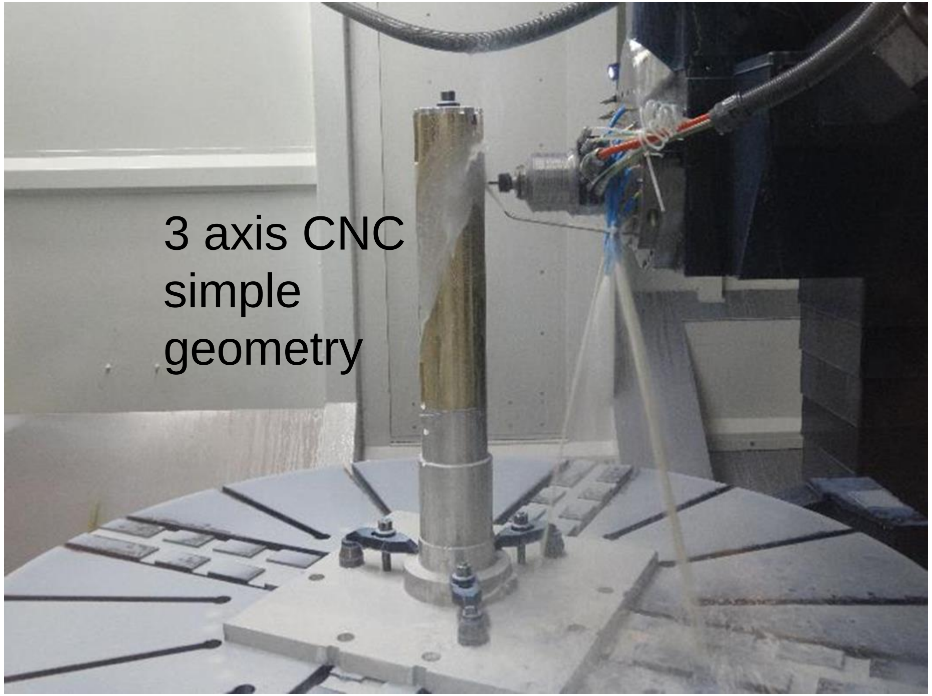
Impossible to wind in channel



The enamel rectangular wire rotated as we tried to wind and finally was impossible to wind into the slot!

Cutting tests 0.1mm to 0.4mm wall thickness select 0.35mm min value.

1mm dia x 7 mm high speed tool.

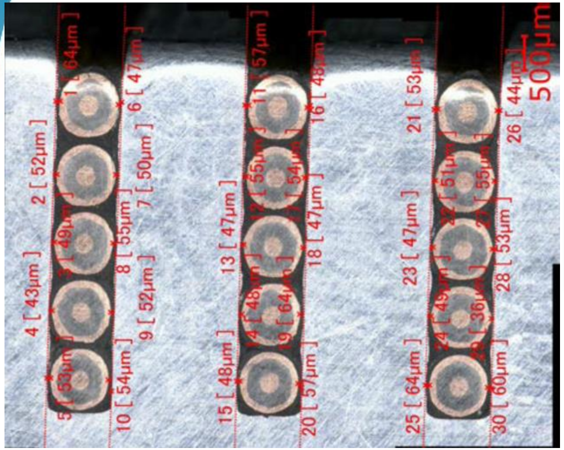


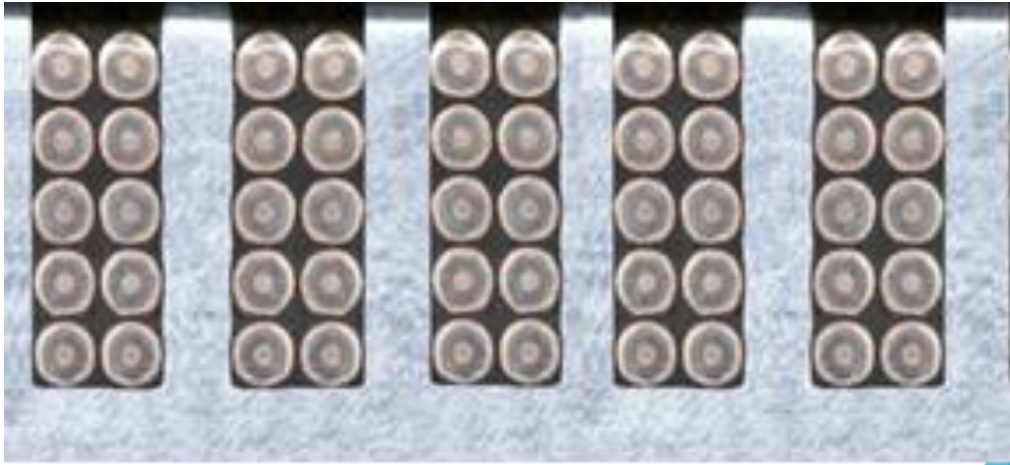
3 axis CNC simple geometry

Machining the short 0.5m model CCT formers
Multi pass cuts.

- With 1 mm slot the tool breaks often
- Many passes needed

Machined former development





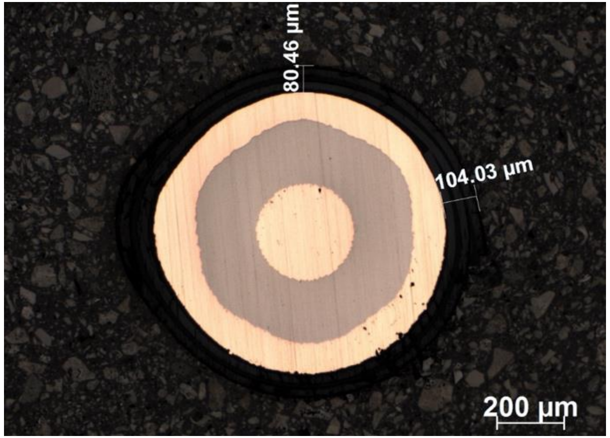
The 1mm wide x 5mm deep channel could not be machined over the 128 m long 0.5m former!

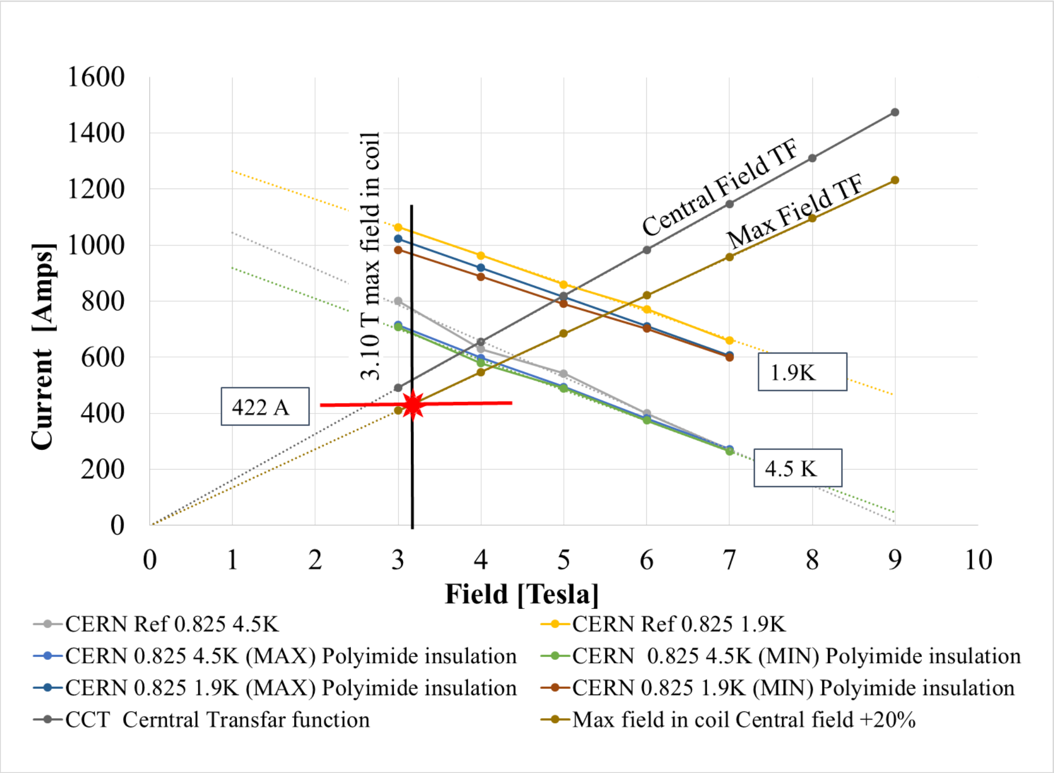
Moving to a 2 mm wide slot, the cutting tool is much stronger!

The machining time / cost to machine the channel is reduced!

The double slot width reduces machining time (cost) but doubles the number of joints

Wire Performance with polyimide insulation





Insulation curing temperature 420 C for 30 sec degraded the wire Ic by 10%.

Magnet margin is still high at 55 % SS

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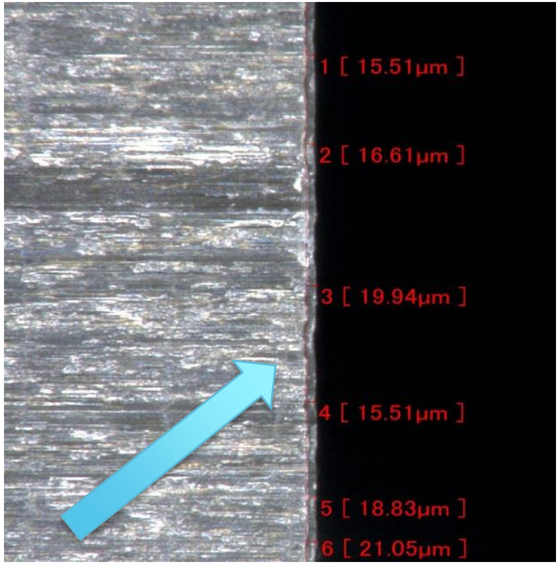
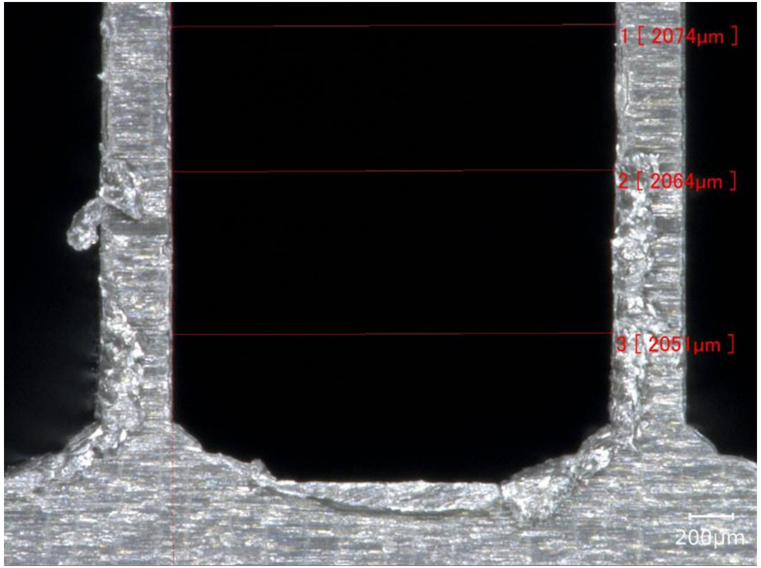
CERN

It was difficult to find a supplier for the polyimide insulation

CNC machined slot width 2.10 mm wide.
Anodization 0.040 mm layer thickness
Anodization surface build up 0.020mm
final slot width 2.06 mm

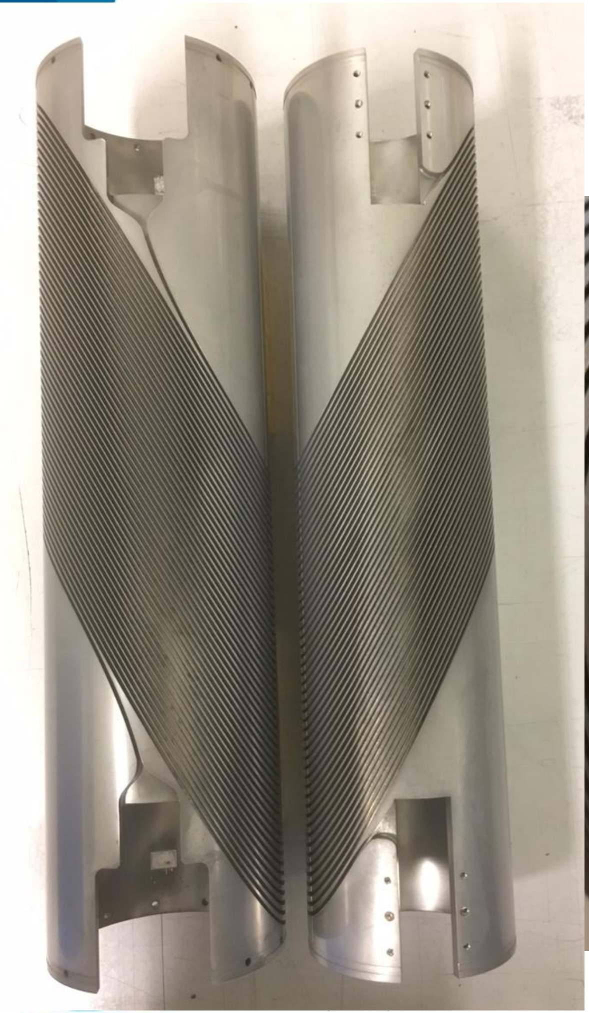


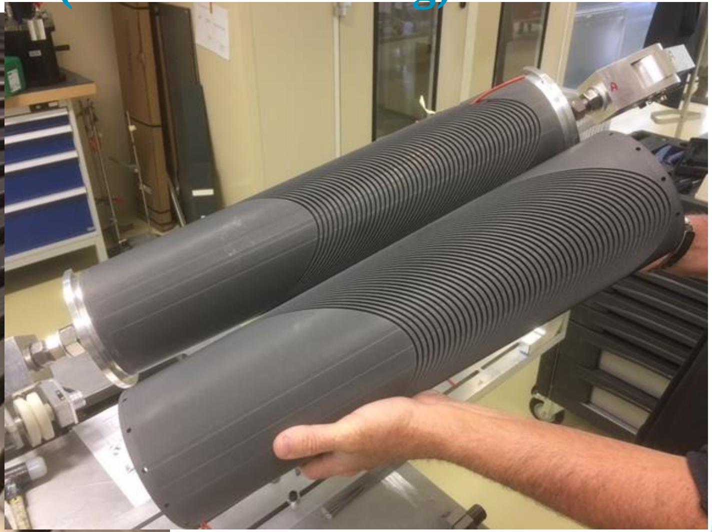
Anodized coating 0.02mm

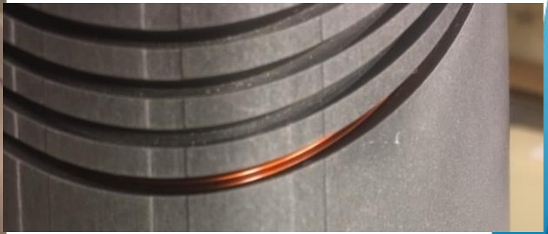


The anodized coating give a hard surface protection that bonds well to the resin & provides some electrical insulation

Al formers 6082-T6 for the final magnets Polishing test to de-burr? and then Hard Anodization (Micro-Machining)

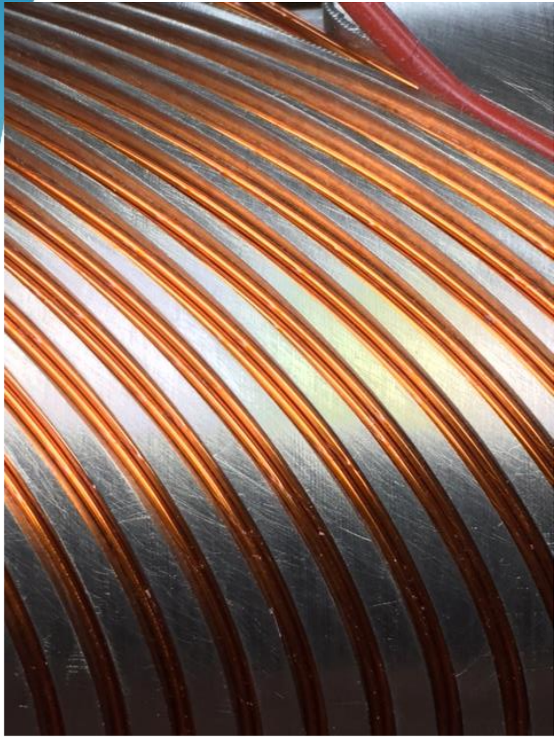


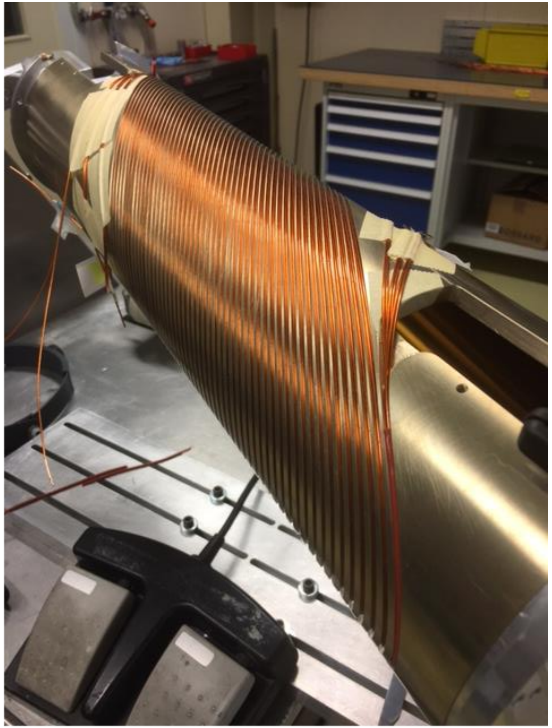


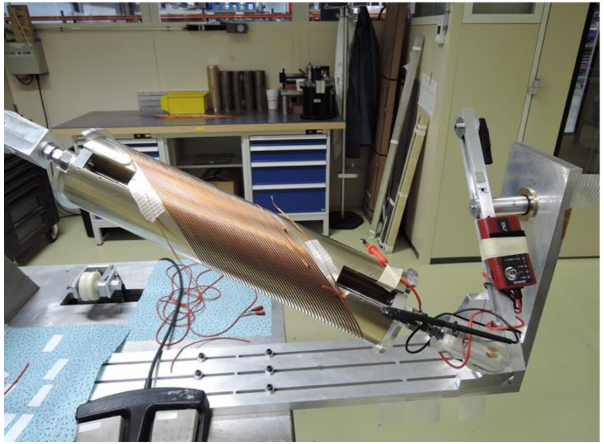


Example of polishing to remove burrs

Coil Winding first model



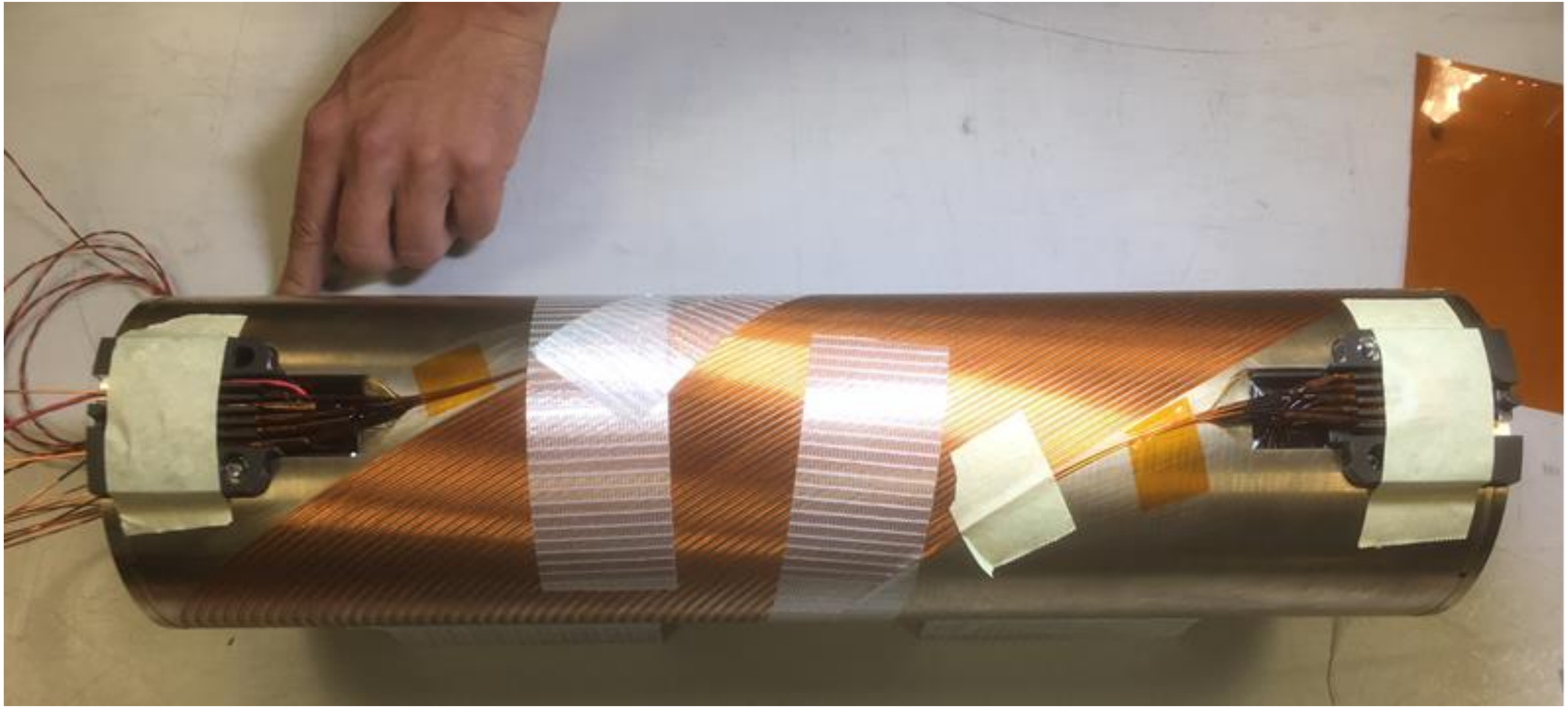




First single aperture model still with Al-bronze formers

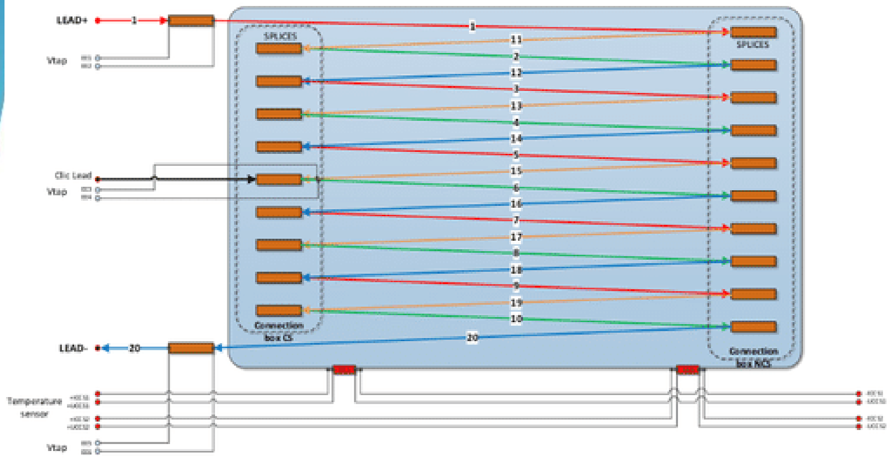
Two wires are wound at the same time, with low tension.
This is repeated until we have the full 2 wide by 5 high coil.

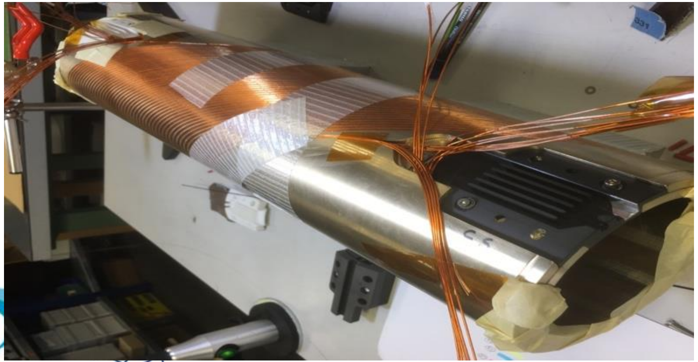
Joints at both end in the magnet former

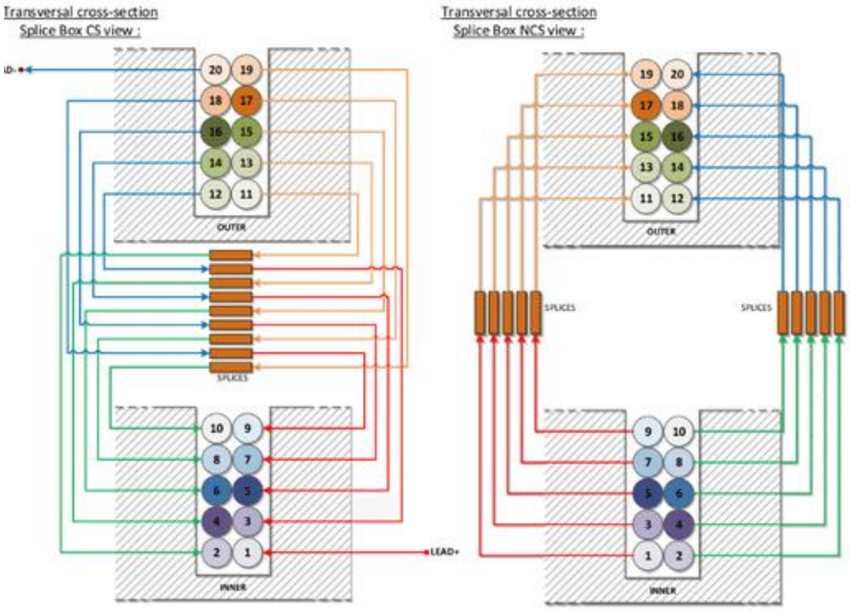


The joints have to be on the former to cope with thermal contraction effects

Wiring Diagram

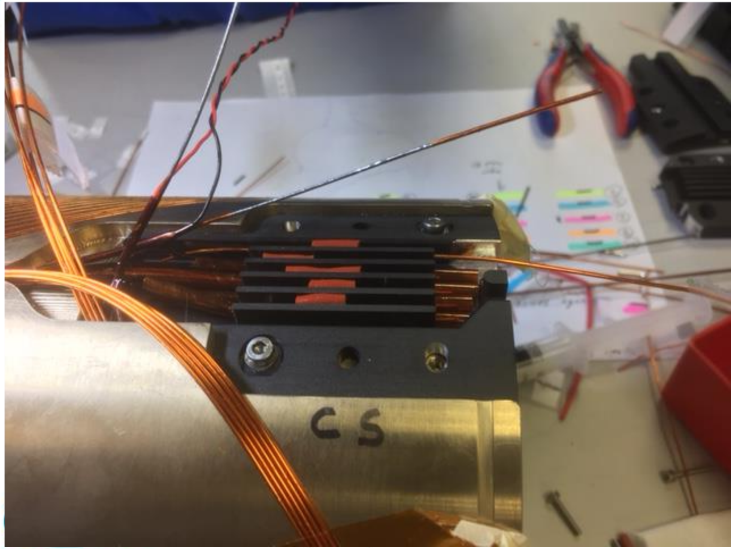


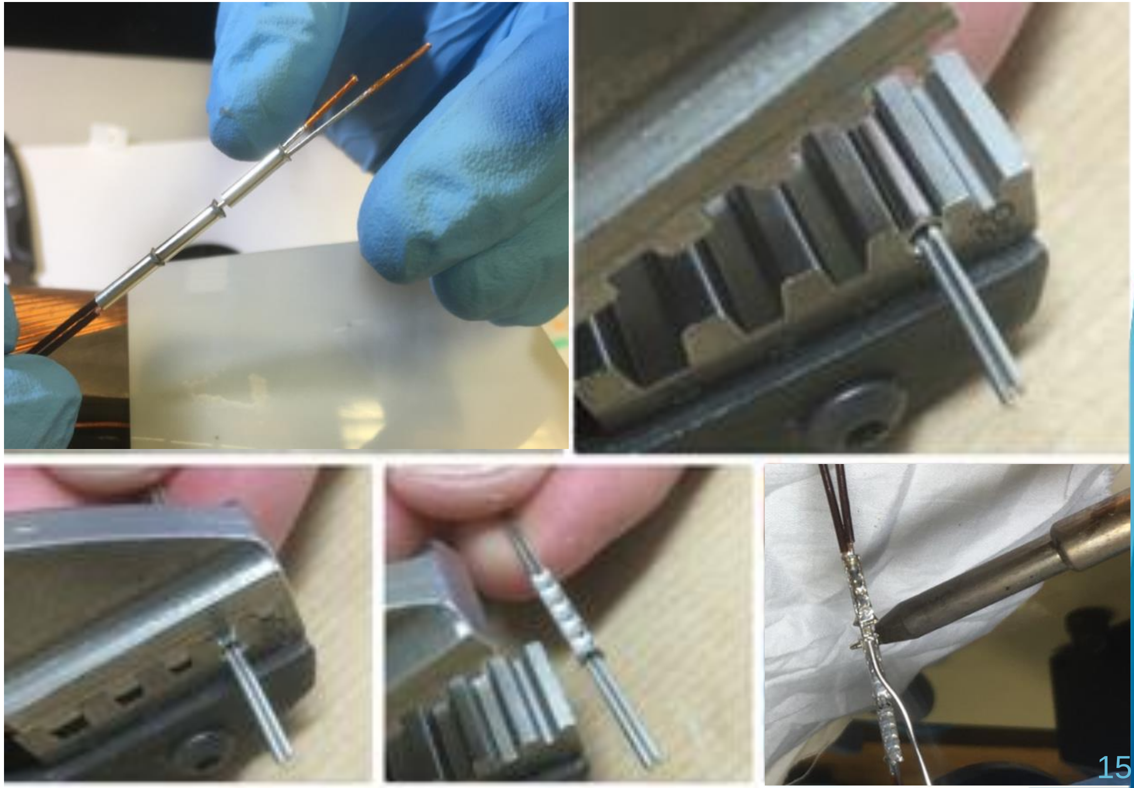




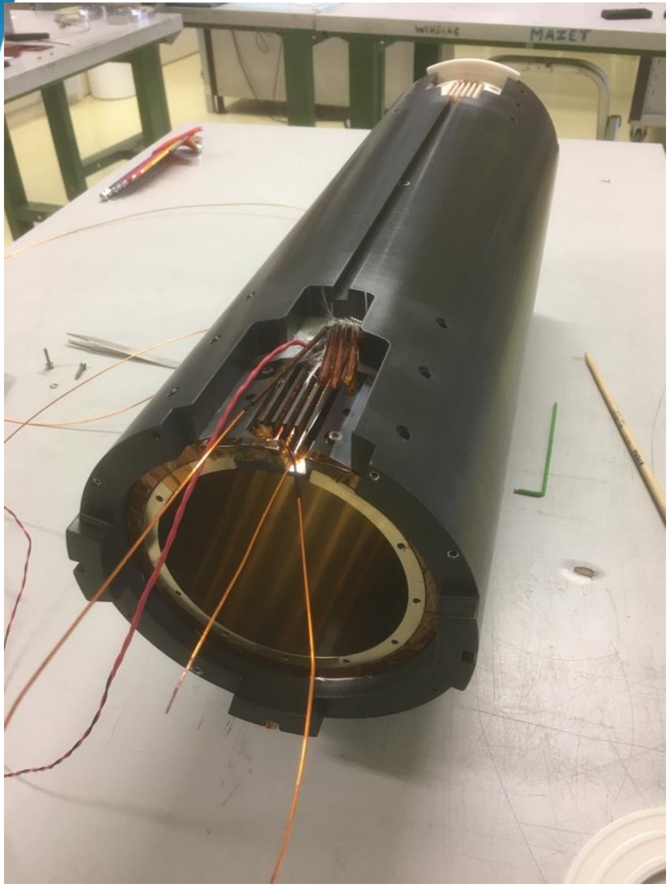
Jointing

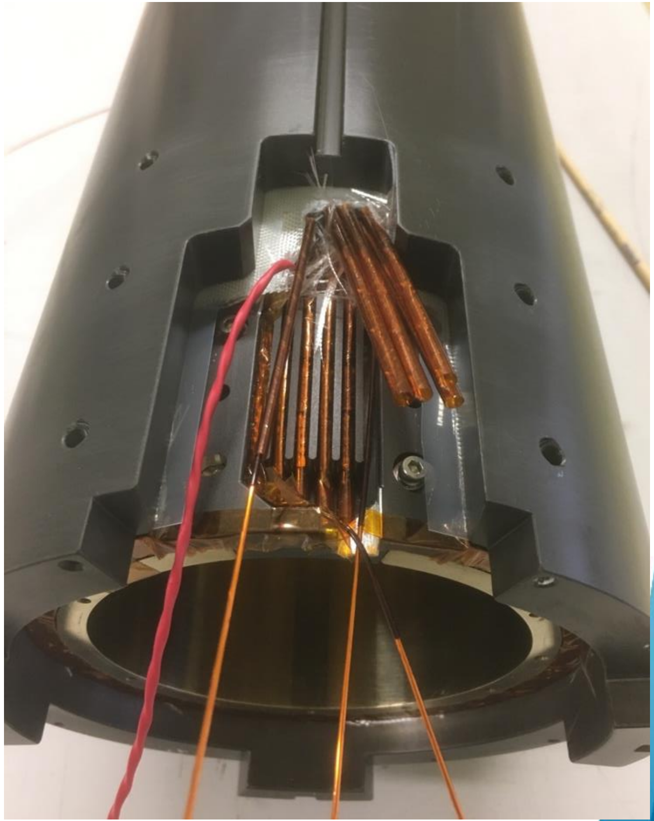
Jointing system:
1) Tined wires,
2) Copper tubes
3) Crimp for mechanical support
4) Solder
5) Insulation





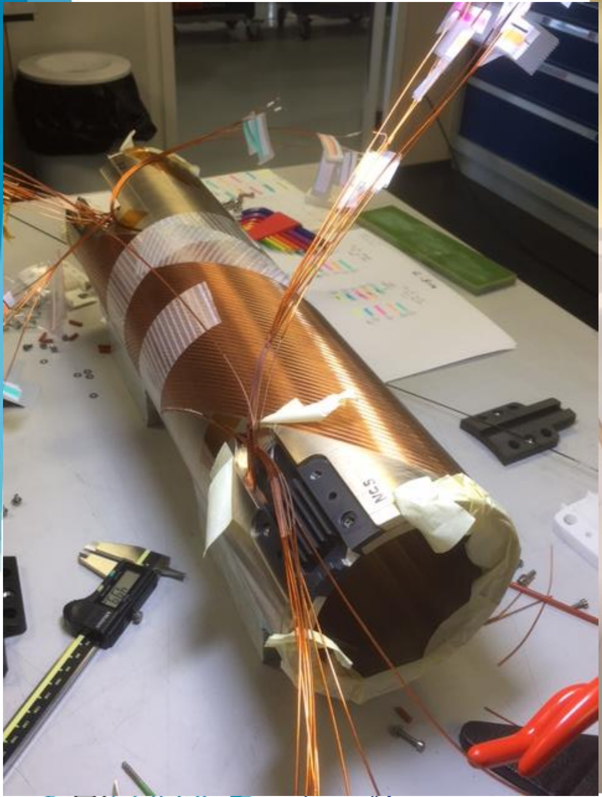
Joint box

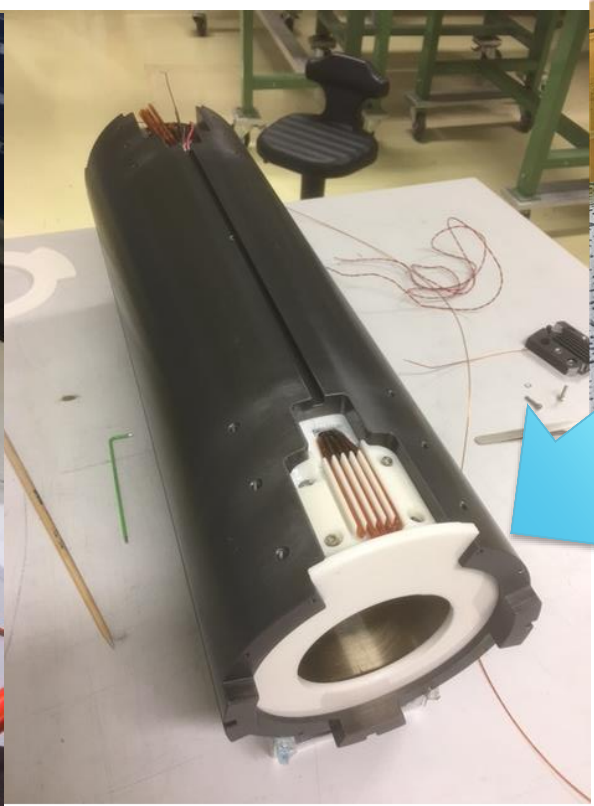


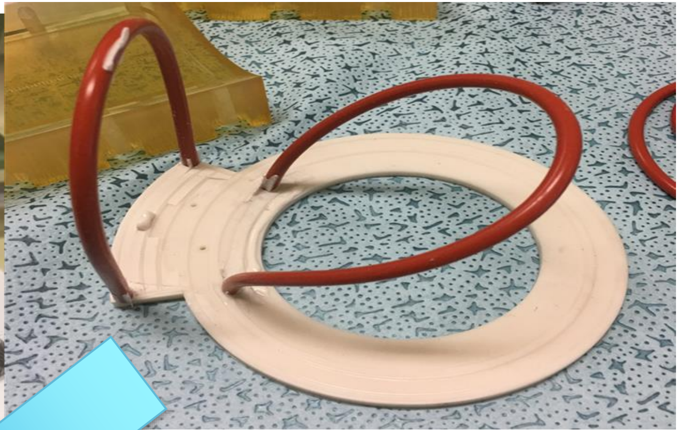


In total a single aperture has only 9 pieces !

Coils impregnated inside the magnet outer support tube



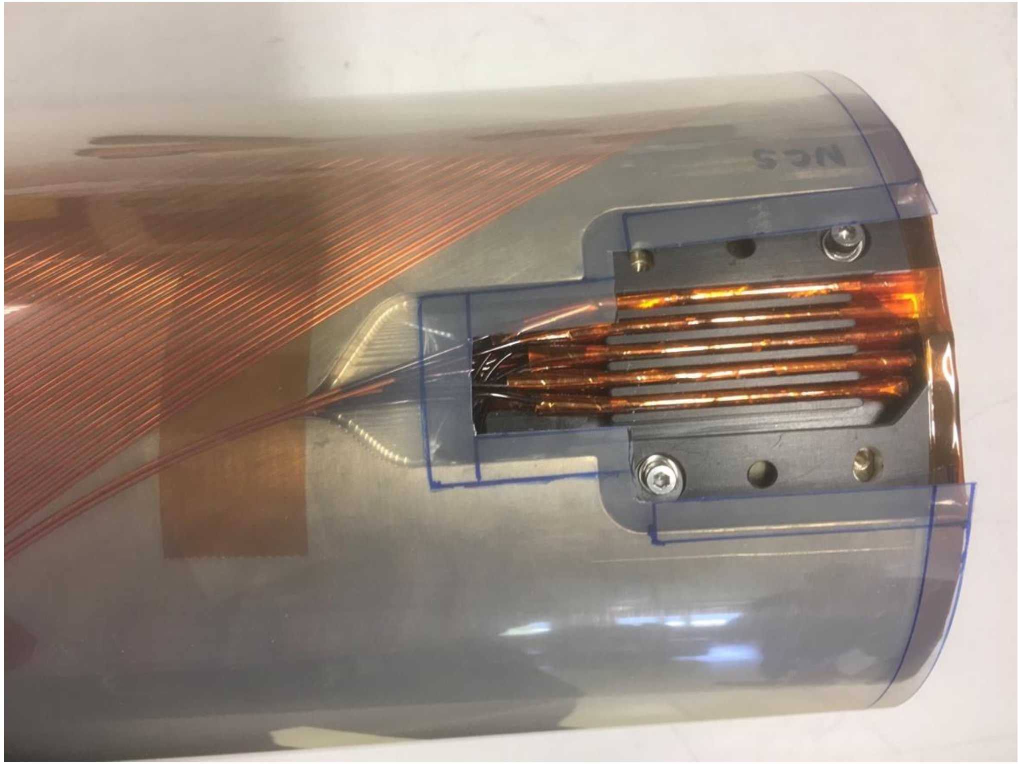


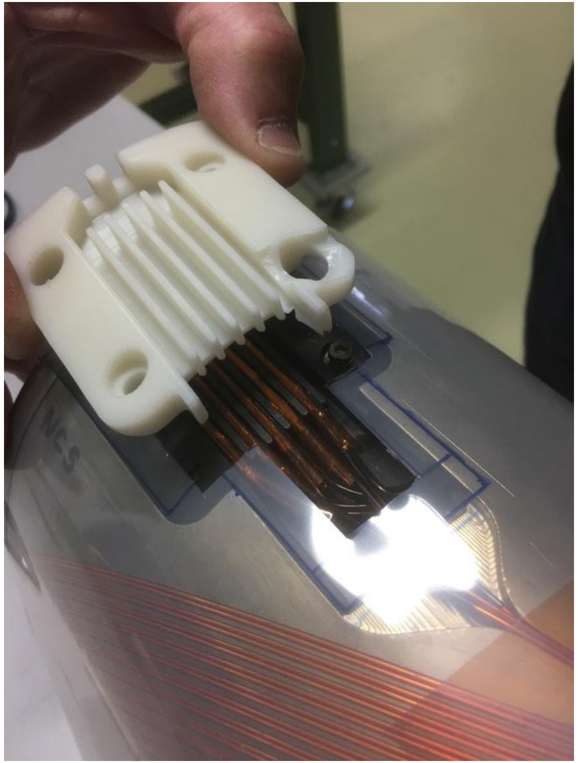


Vacuum / pressure Impregnation seal

Seal mechanical support

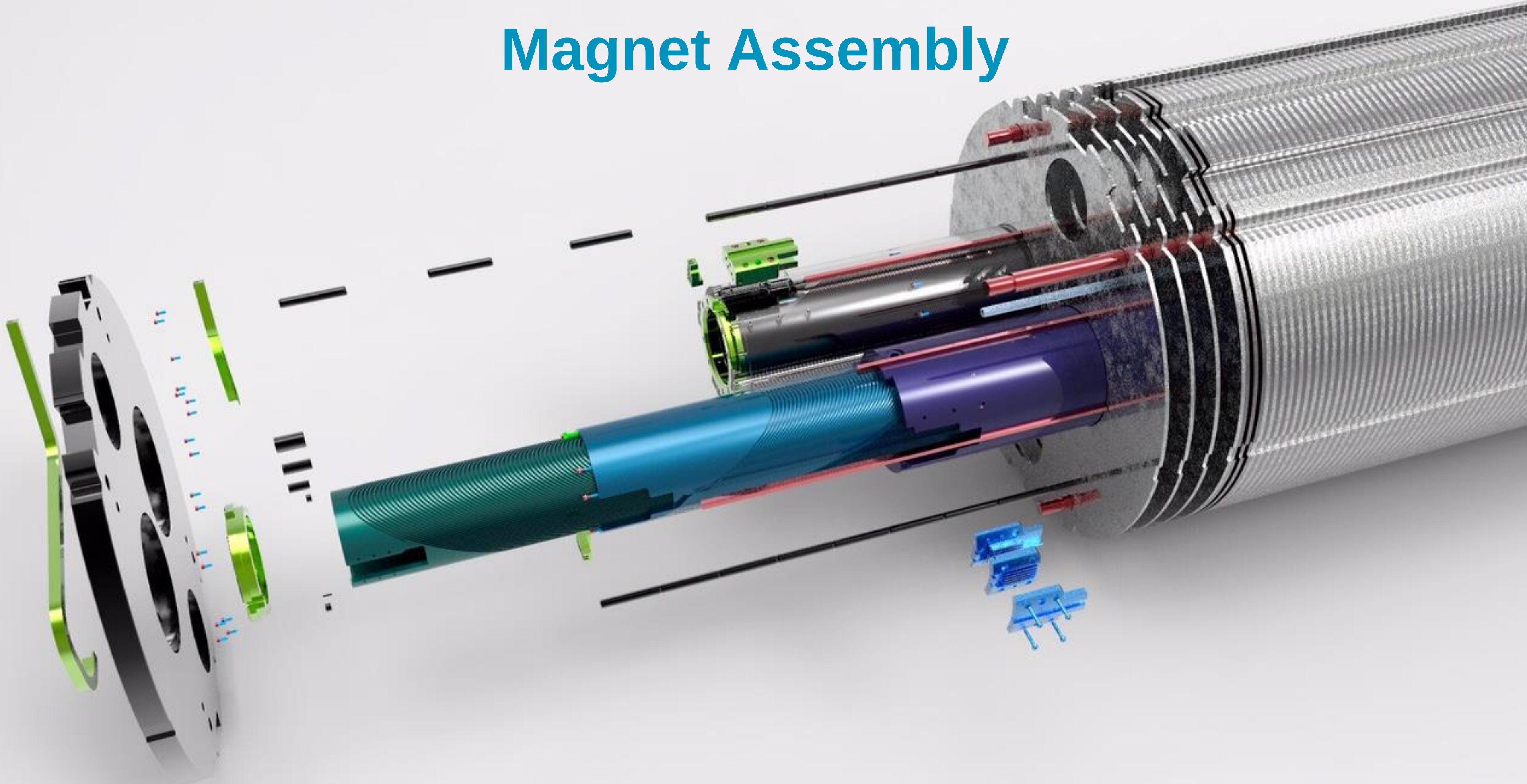
Insulation between the two layers





Two layers of insulation Polyimide or Mylar with min 4 mm brake down distance from ground or the other former

Magnet Assembly



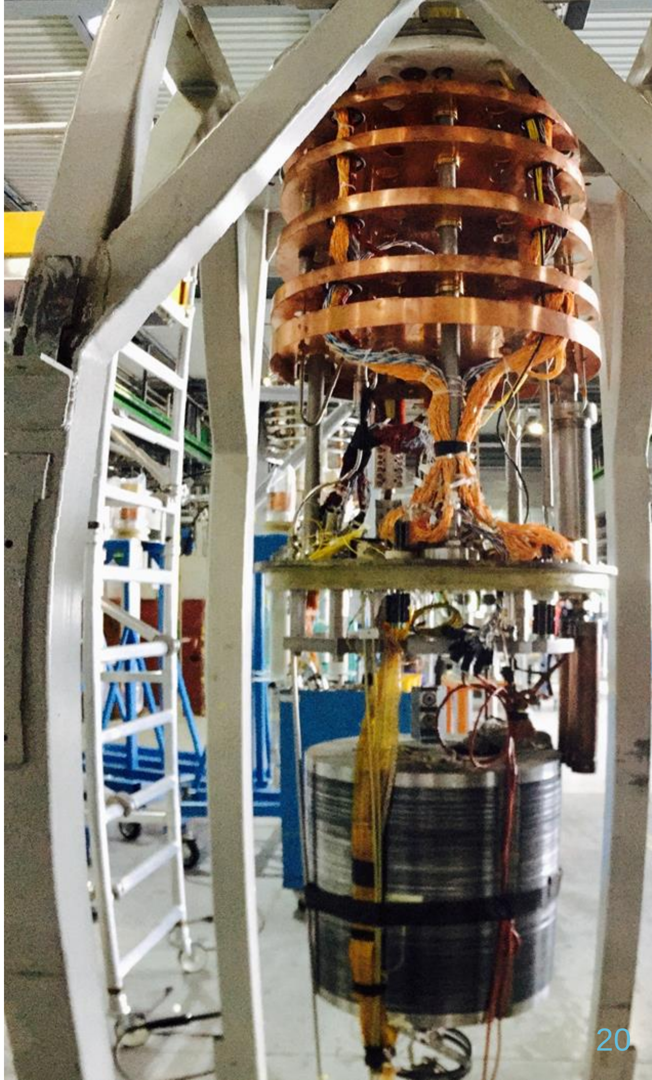
First model Magnet Test

First test of 0.5 m model, single aperture Al-Bronze former

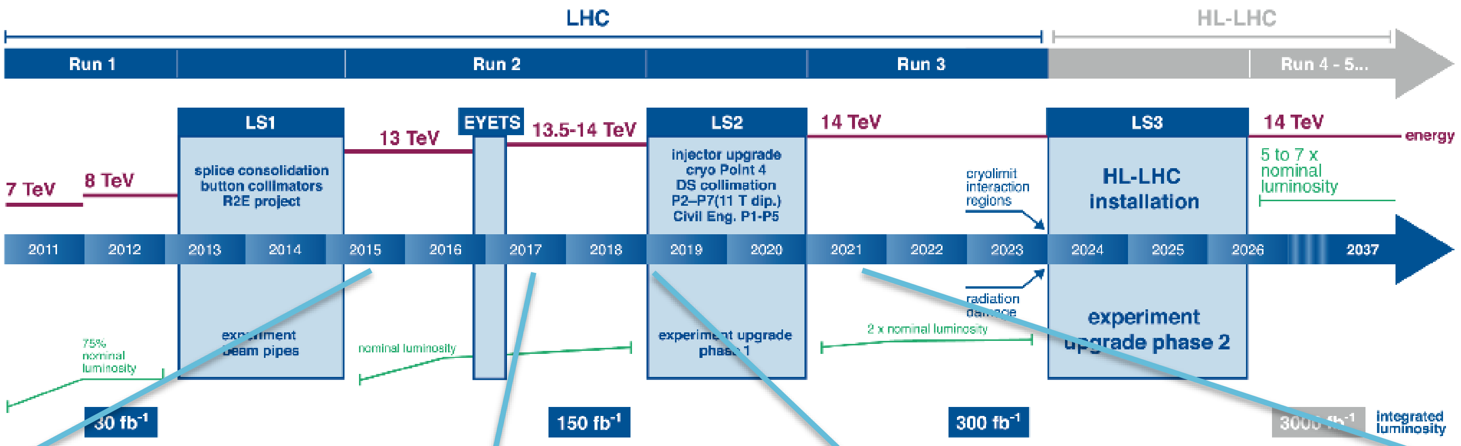
- Tested to 1.9K
- RRR of wire measured at 253, high!
- No quench up to 422 A nominal
- One quench at 438 A (short model hot spot 63K, voltage to Ground 320V, for 2.2m magnet this would then be 193 K and 330 V)
- Then No quench up to 460 A ultimate design value
- Thermal cycle no quench.
- Nominal ramp rate 4.2 A/s.
- Max tested ramp rate with no quench 40 A/s

Joint resistances: Average 5.7 nOhm's
120 +/- 20 nΩ over one aperture.

Energy distribution during quench : with 0.7 Ω dump:
Coil 13%, Dump 59%, aluminium support tube and formers 28%

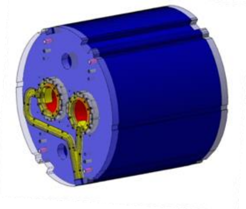


LHC / HL-LHC Plan



LHC/ HL-LHC Plan (last update 22.02.2016)

0.5m model tested
Summer 2017



Full size prototype
Assembly during 2018

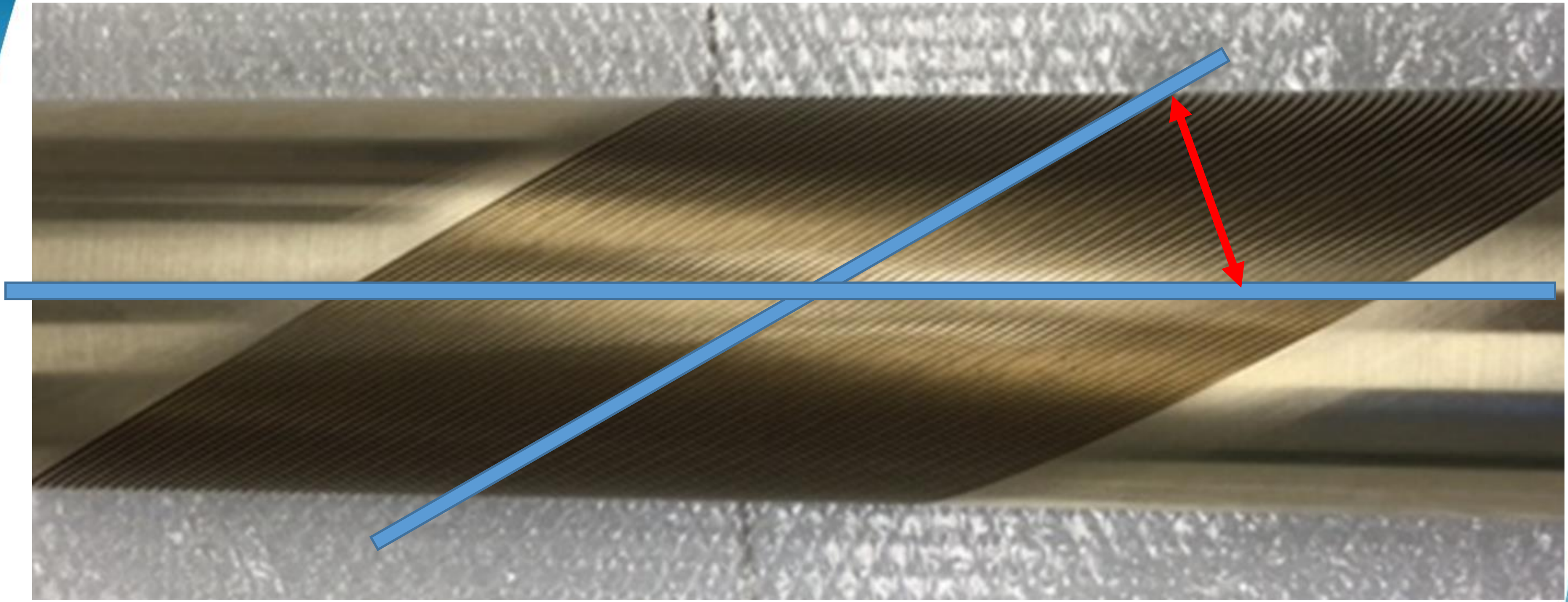
18 - 20 off twin aperture
magnets production in industry
delivery ~ 2020

Closing Comments and Conclusions

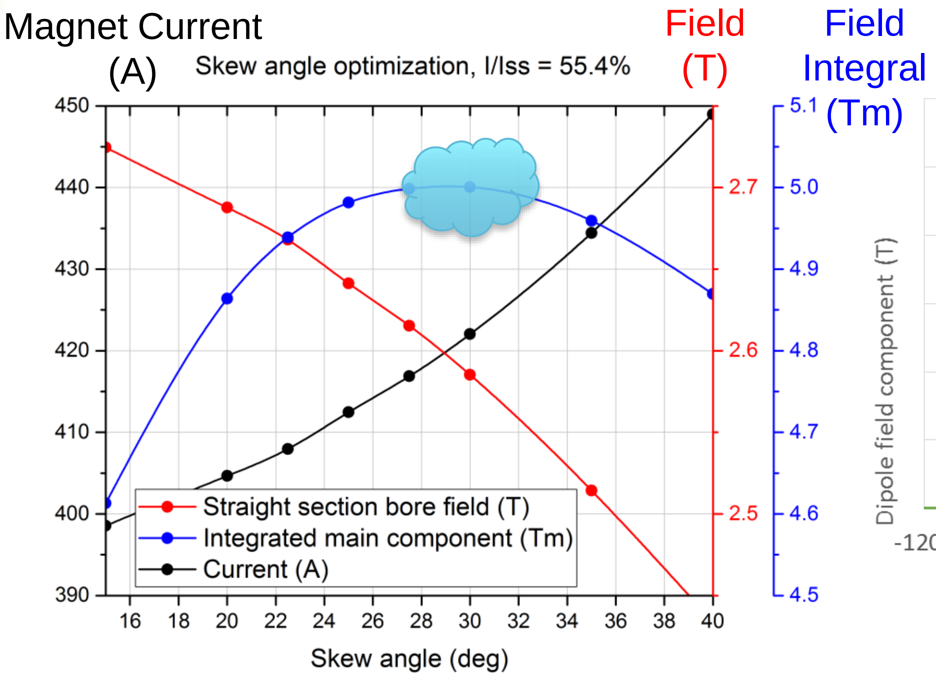
- CERN is developing a CCT 3 Tesla orbit corrector for use Hi-Lumi LHC
- This old idea from the 1960's has many positive points:
    - Simple design / Potentially low-cost, No significant tooling.
    - Field errors appear to be insensitive to small mechanical errors.
    - Radiation hard design, "Full metal jacket around impregnated conductor".
- Short 0.5 metre Proof of concept model test successfully completed .
- 2.2 m prototype test planned for winter 2017 / 2018 Full Field quality will be measured in this test .
- Series production ~ 18 to 20 – twin aperture magnets Should start in 2019

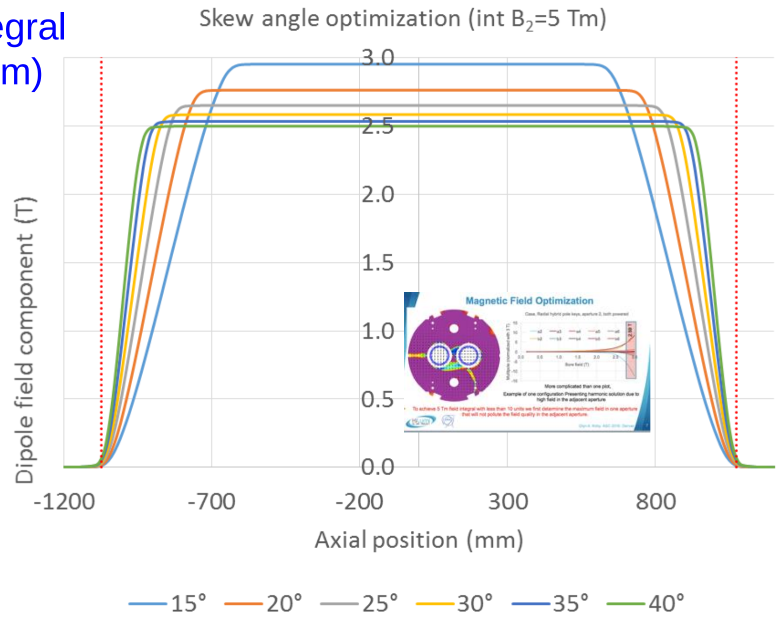
Thank you for your attention

Extras



Definition of CCT skew angle





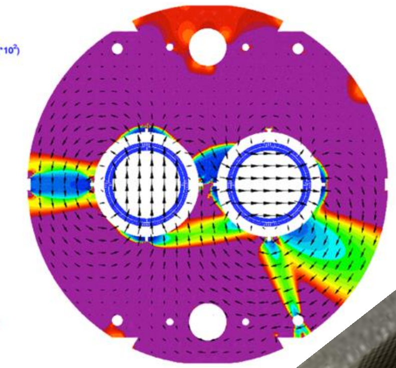
CCT skew angle optimisation

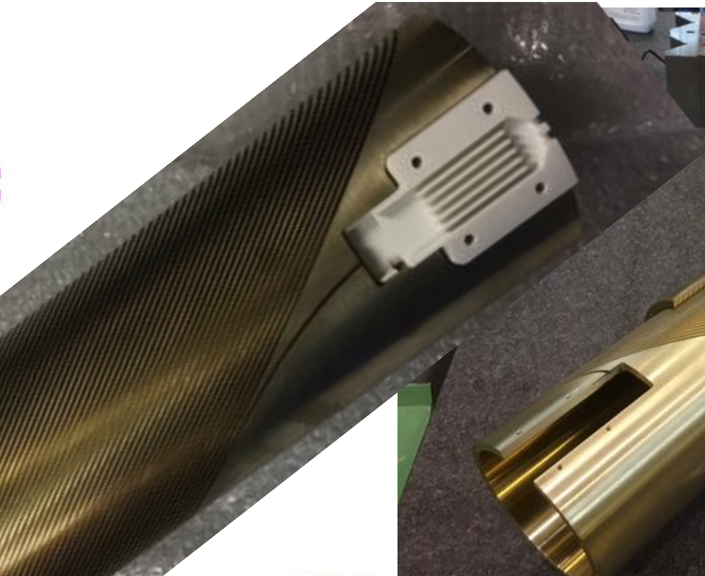
Due to the cross talk the max aperture field is set to ~2.7 T

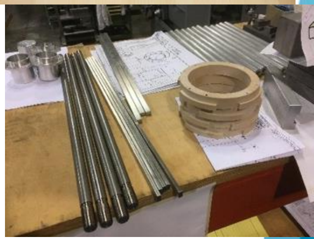
For a fixe d 5 Tm integral & magnet length ~2m the optimum skew angle is 30 deg.

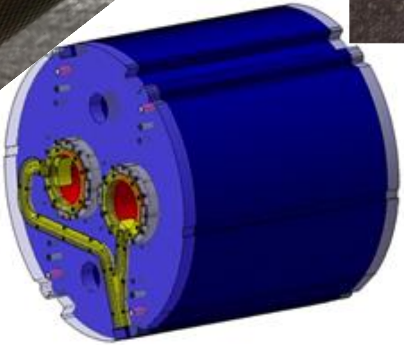
Lower skew angles give more field less conductor but have longer ends!

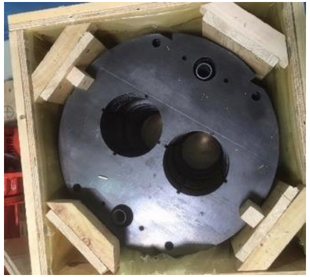
Components for the 0.5m model



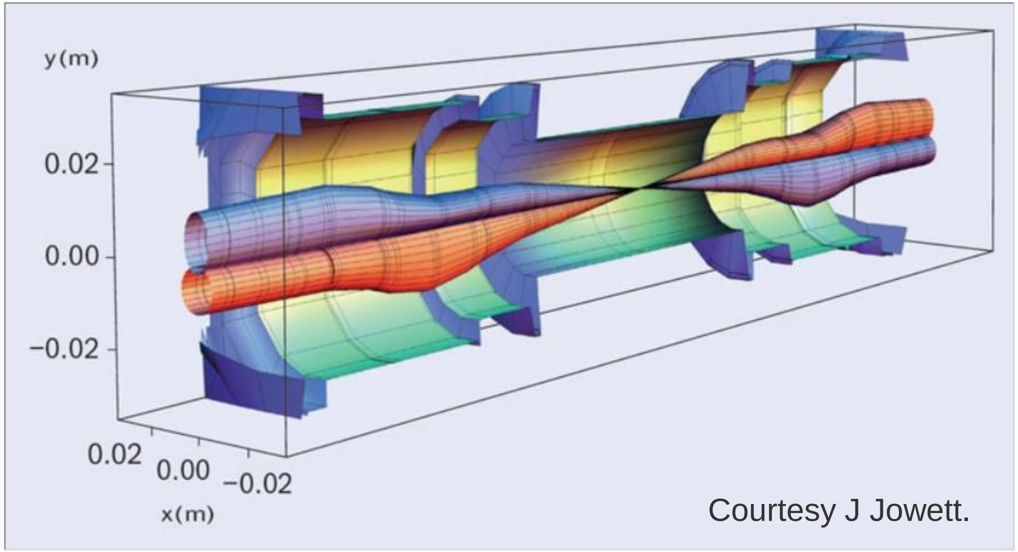




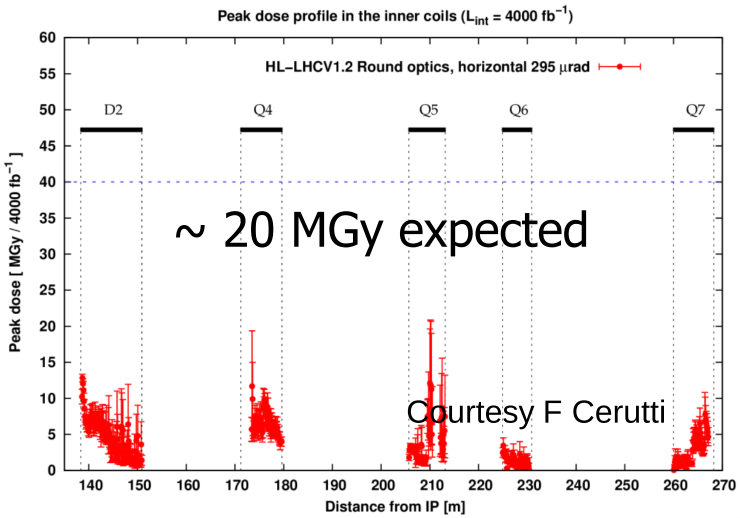




Orbit Corrector Function & Environment

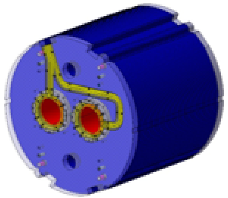


Courtesy J Jowett.



Courtesy F Cerutti

The two counter rotating HL-LHC beams are brought to full energy, then the sets of orbit correctors quickly (within 100 sec) maneuver the two beams into collision.



Manufacturing follow-up F 0.5	
ITEM Number	ST0772446
Definition	Q4 CORRECTOR ASSEMBLY
Nomenclature	LHCMCBYY0035
Date	03.05.2016
Q4 CORRECTOR ASSEMBLY v3	CDD folder
Extracted by	L. Gentini

Design resposible	Drawing status	Manufacturing / order res...
L. Gentini	(blank)	(blank)
(blank)		

									Design.			Manufacturing	
Nomencl re	ST number	Definition		Make or E	Material	SCEM	Supp	Su er	Design responsibl	Drawi statu	Design No	Manufacturing order responsib	M
LHCMCBYY(	ST0732836	D2Q4 CORRECTOR EXTERNAL PIP	2	CERN Design	Alu EN AW-5083 (H116)				L. Gentini				
LHCMCBYY(	ST0739488	FIX INSULATING END PLATE	2	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0747071	WIRE EXIT BOX	2	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0737413	500 mm KEY	4	CERN Design	EN 1.4307 (St. Steel 304L)				L. Gentini				
LHCMCBYY(	ST0763312	Q4 CORRECTOR YOKE V2	84	CERN Design	ARMCO® (Fe 99,99%)				L. Gentini				
LHCMCBYY(	ST0765324	Q4 FIX EXTREMITY FLANGE V2	1	CERN Design	EN 1.4306 (St. Steel 304L)				L. Gentini				
LHCMCBYY(	ST0772764	Q4 FREE EXTREMITY FLANGE V2	1	CERN Design	EN 1.4306 (St. Steel 304L)				L. Gentini				
LHCMCBYY(	ST0772447	MAGNET COIL ASSEMBLY v3	2	CERN Design					L. Gentini				
LHCMCBYY(	ST0772448	INNER COIL v3	2	CERN Design	Copper				L. Gentini				
LHCMCBYY(	ST0772487	OUTER COIL v3	2	CERN Design	Copper				L. Gentini				
LHCMCBYY(	ST0776711	INSULATING FREE END PLATE	2	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0776540	CONNECTION BOX 2	4	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0776578	YOKE ROD V2	4	CERN Design	EN 1.4307 (St. Steel 304L)				L. Gentini				
LHCMCBYY(	ST0772446	V3 Q4 CORRECTOR ASSEMBLY							L. Gentini				
LHCMCBYY(	ST0769171	INSULATING WIRE LINE 1 V2	1	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0769172	INSULATING WIRE LINE 2 V2	1	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0769174	INSULATING WIRE COVER 1 V2	1	CERN Design	Epoxy GF EP GC 308 (G-11)				L. Gentini				
LHCMCBYY(	ST0779927	HYBRID YOKING KEY - OUTER PAR	4	CERN Design	ARMCO® (Fe 99,99%)				L. Gentini				
LHCMCBYY(	ST0779653	HYBRID YOKING KEY - INNER PART	4	CERN Design	EN 1.4306 (St. Steel 304L)				L. Gentini				
LHCMCBYY(	ST0779921	HYBRID YOKING KEY ASSEMBLY	4	CERN Design					L. Gentini				
	ISO 4032_M16-A4	HEX NUT STYLE1 GRADE A M16	4	Normalized	Stainles Steel A4 Acier Inox A4	47.43.77.160.4							
	ISO 4762 M3x8-A4	HEX SKT HD CAP SCREW_M3X8	17	Normalized	St. Steel A4								
	ISO 4762 M4x12-A4	HEX SKT HD CAP SCREW_M4X12	16	Normalized	St. Steel A4	47.62.71.155.7							
	ISO 7089_16x30-A4	NORMAL PL WASHER_16X30	4	Normalized	Stainless Steel A4 Acier Inox A4	47.78.15.016.8							
	ISO 8752_12x80-A2	Slot heavy duty spring pin_12x80	28	Normalized	Stainless Steel A2 Acier Inox A2								
	ST0343798	SPRING LOCK WASHER M04 (GROV	16	Commercial Item	St. Steel A4	47.78.15.202.8	Bossard	BN673					
	ISO 4762 M3x25-A4	HEX SKT HD CAP SCREW_M3X25	24	Normalized	St. Steel A4	47.62.71.110.0							
	ST0263158	SPRING LOCK WASHER M03 (GROV	24	Commercial Item	St. Steel A4	47.78.15.200.0	Bossard	BN 673					
	ST0529388	HEX SKT LOW HD SCREW M4x8	8	Commercial Item	St. Steel A2		BOSSARD	BN 2844					
	ISO 4762_M2x8-12.9-A0	HEX SKT HD CAP SCREW_M2X8	52	Normalized	Steel 12.9								

Low number of drawings / components ~ 20 leading to low cost of manufacture!

HiLumi HL-LHC PROJECT

CERN

2017 | 2018

August | September | October | November | December | January | Febuary | March

w32 w33 w34 w35 w36 w37 w38 w39 w40 w41 w42 w43 w44 w45 w46 w47 w48 w49 w50 w51 w52 w1 w2 w3 w4 w5 w6 w7 w8 w9 w10 w11 w12 w13 w14

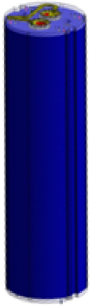
MT | EUCAS

2nd CCT apertuer v2 design 0.5m long

- New former design
- CNC m/c 0.5m formers
- Polish formers ?
- Hard anodize
- joint box manufactuer
- Winding 0.5 m inner former
- Winding 0.5 m outer former
- Coil assembly , jointing,
- impregnation
- yoke assembly
- Cold test ! — Test 500mm

2.2m full lengh model

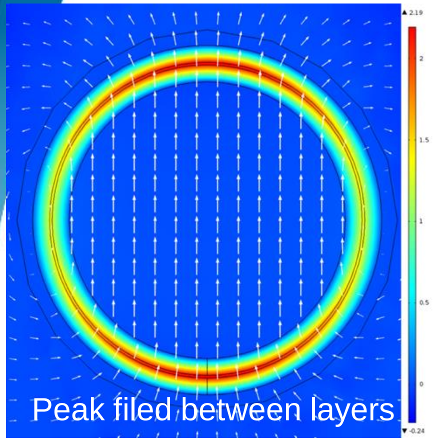
- component manufactuer — just Joint boxes needed
- former manufactuer — Formers and outer suport tube m/c
- polishing + Anodization
- CERN 0.825 wire insulation (430 c for 30 sec?
- CERN 0.825 wire insulation (200 c)
- modify 927 coil winding m/c
- coil winding aperture 1
- coil assembly / jointing
- impregnation
- coil winding aperture 2
- coil assembly / jointing
- impregnation
- Magnet assembly into yoke
- Wiring and prep for text
- cold test — Test 2.2m twin

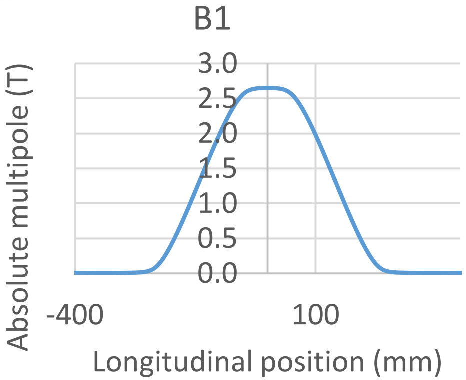


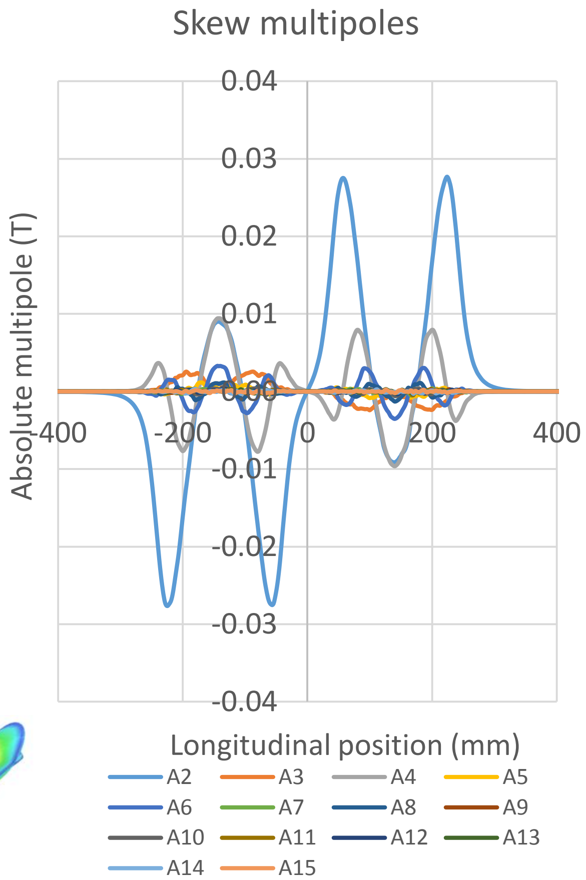
Faster 0.5 m model 9 wires, design

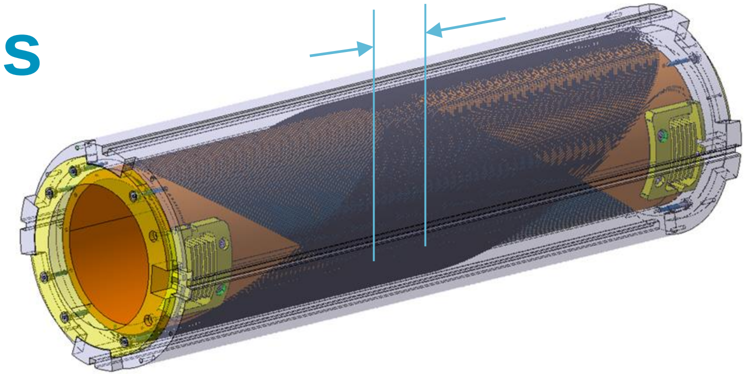
- CNC m/c 0.5m formers
- joint box manufactuer
- Winding 0.5 m inner former
- Winding 0.5 m outer former
- Coil assembly , jointing,
- impregnation
- yoke assembly
- wiring prep for Cold test !
- cold test twin app 0.5m 422 A & 464A — cold test

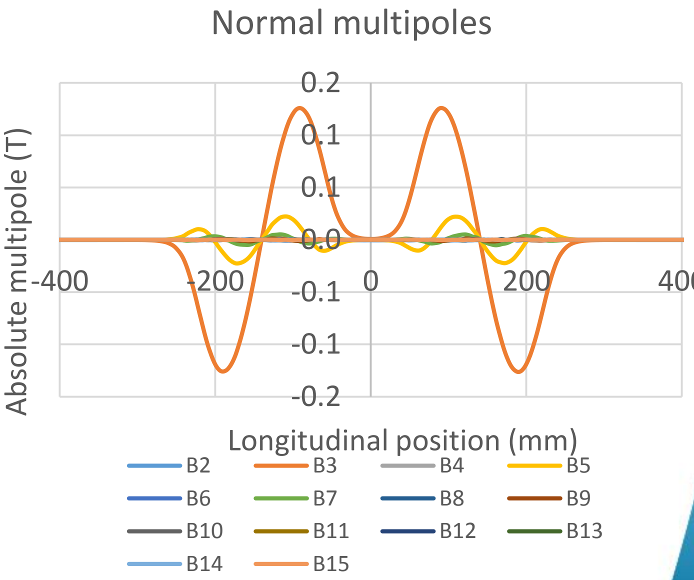
CCT Field profiles

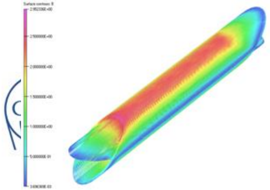


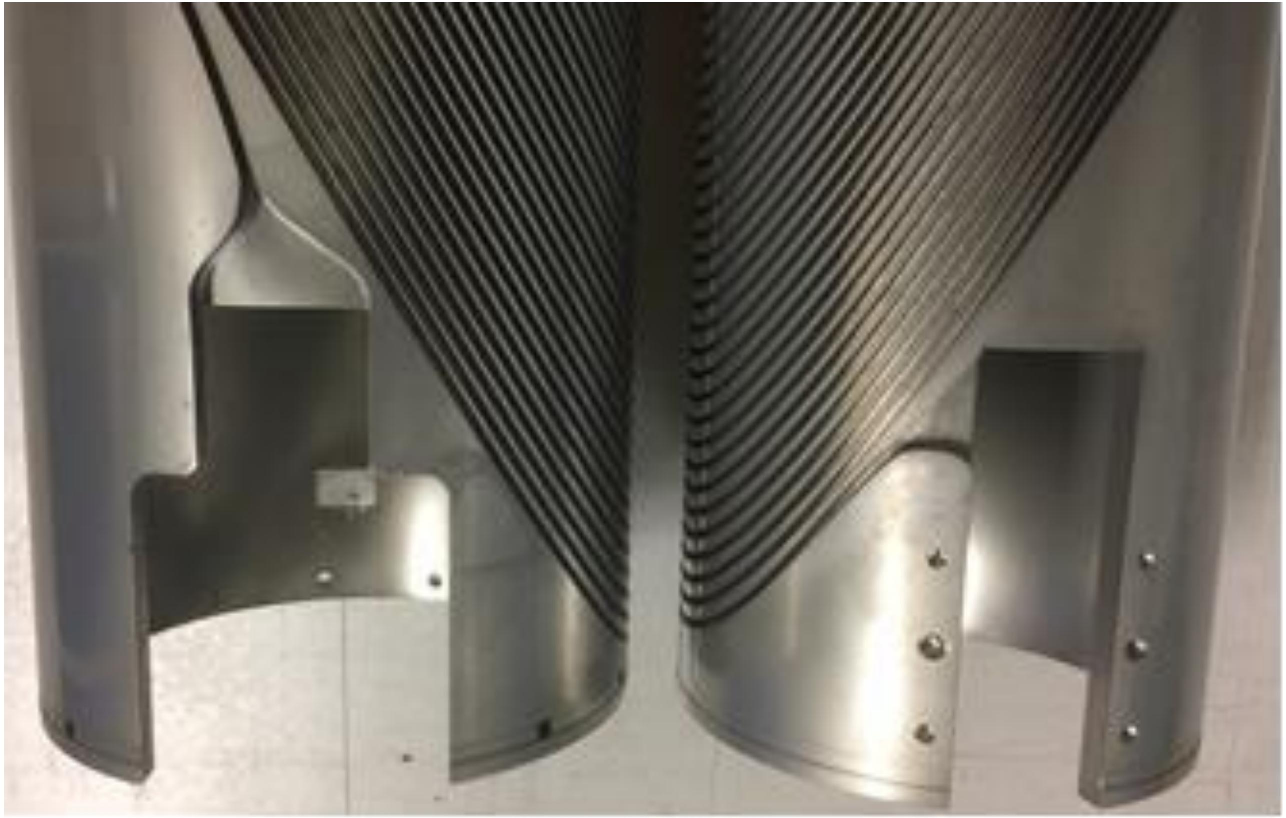




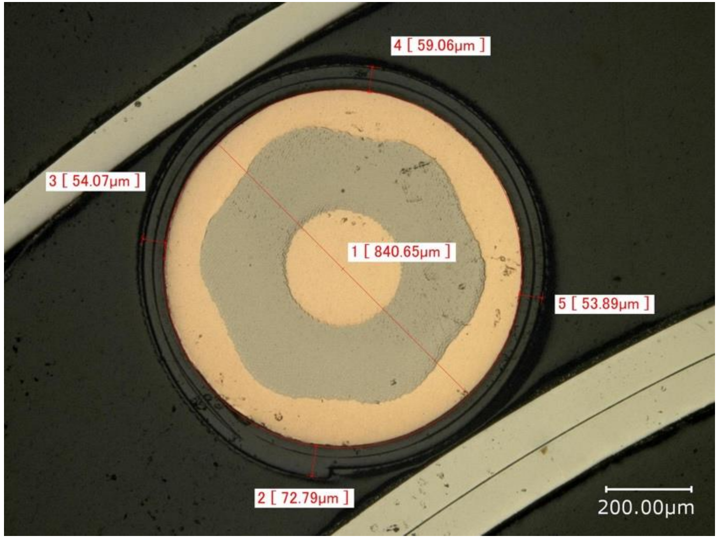


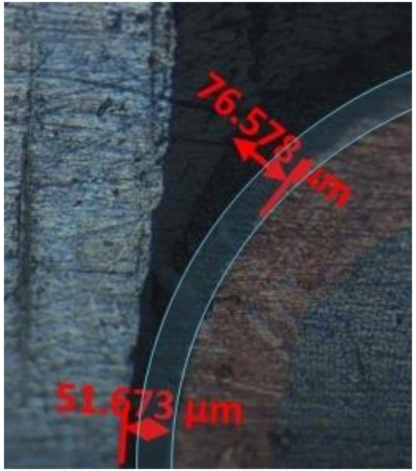






Base line insulation





Glass sleeve compressed thickness ~ 0.052 mm

Polyimide 48 % overlapped wrapped 4mm wide tape,

Insulation tested at > 9 kV (very good)

Polyimide tape provides electrical insulation

Glass sleeve impregnated with radiation hard resin provides mechanical support.