The 11T Dipole Magnet for HL-LHC

Holland @ CERN

F. Savary

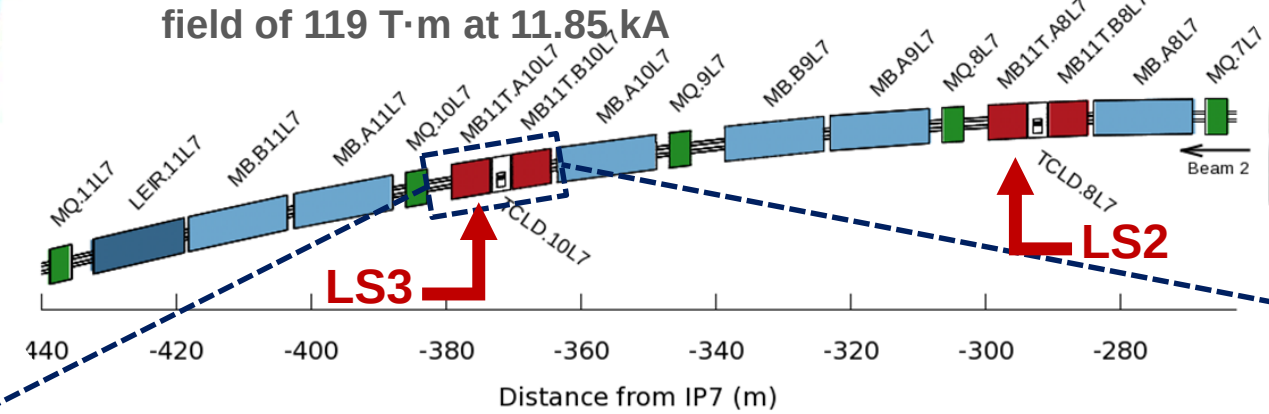
CERN Council Chamber – 2 June 2016

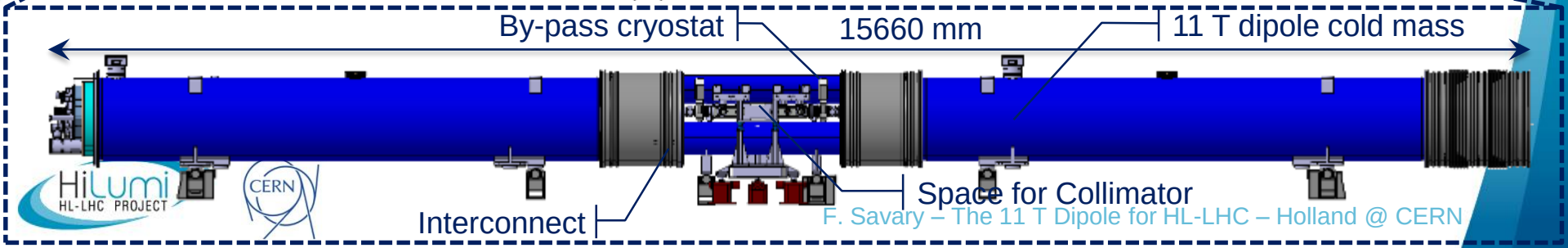
OUTLOOK

- Introduction
- Main parameters of the 11T Dipole
- The 11T Dipole Plan in the Timeline of HL-LHC
- From technology demonstration to “final” design
- Quench performance of MBHDP101
- Challenges
- Summary

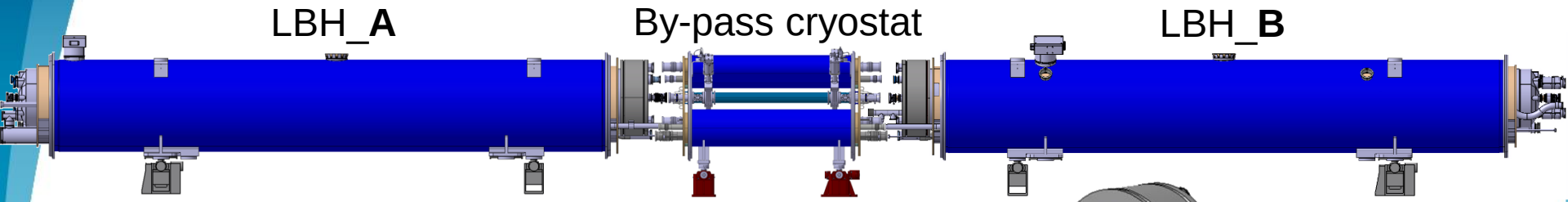
Introduction

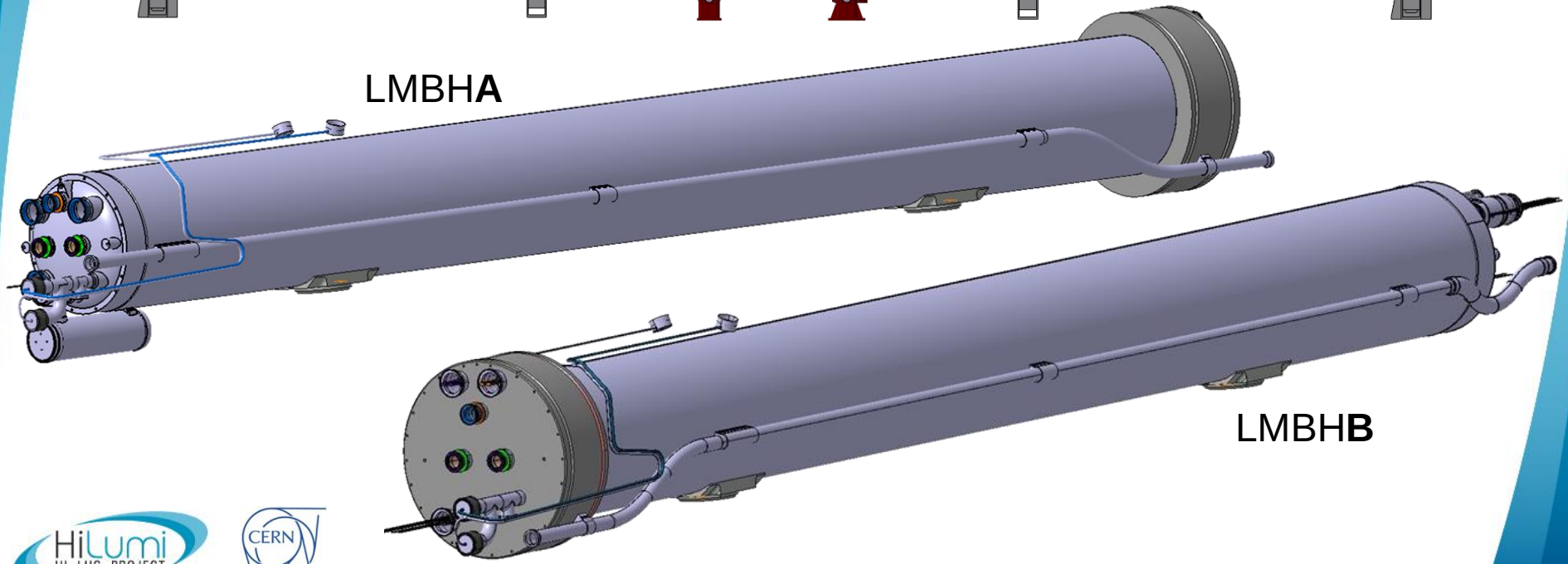
- **Create space in the dispersion suppressor regions of LHC**, i.e. **a RT beam vacuum sector**, **to install additional collimators** needed to cope with beam intensities larger than nominal
- Collimators are needed in **IP7** to absorb off-momentum particles/beam losses (proton operation)
- Replace a standard Main Dipole by a **pair of 11T Dipoles producing the same integrated field of 119 T·m at 11.85 kA**





Definition of the cryo-assembly





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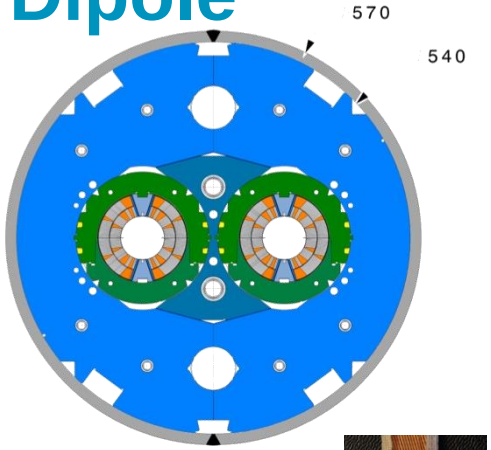
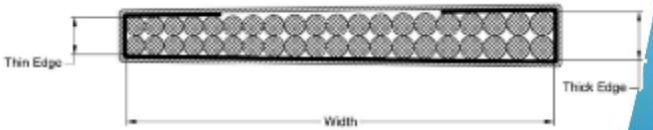
Main parameters of the 11T Dipole

Characteristic	Value	Unit
Aperture	**60**	**mm**
Distance between apertures at RT / 1.9 K	194.52 / 194.00	mm
Magnetic length	**5.307**	**m**
Coil length	5.415	m
Magnet length, between end plates	5.799	m
Cold mass assembly length	**6.252**	**m**
Operating temperature	**1.9**	**K**
Nominal operation current	11.85	kA
Bore field @ nominal current	**11.23**	**T**
Peak field @ nominal current	11.59	T
Stored energy/m at I_{nom}	0.9663	MJ/m
Cable bare width before reaction	mm	14.7
Cable bare mid-thickness before reaction	mm	1.25
Keystone angle	Degree	0.79
Strand diameter	0.700 ± 0.003	mm
Number of strands per cable	40	-
Cable insulation thickness, before/after reaction	0.150/0.110	mm





- Mica tape, COGEBI FIROX®, 80 µm
- S2-glass braided on cable
- Epoxy resin CTD-101K

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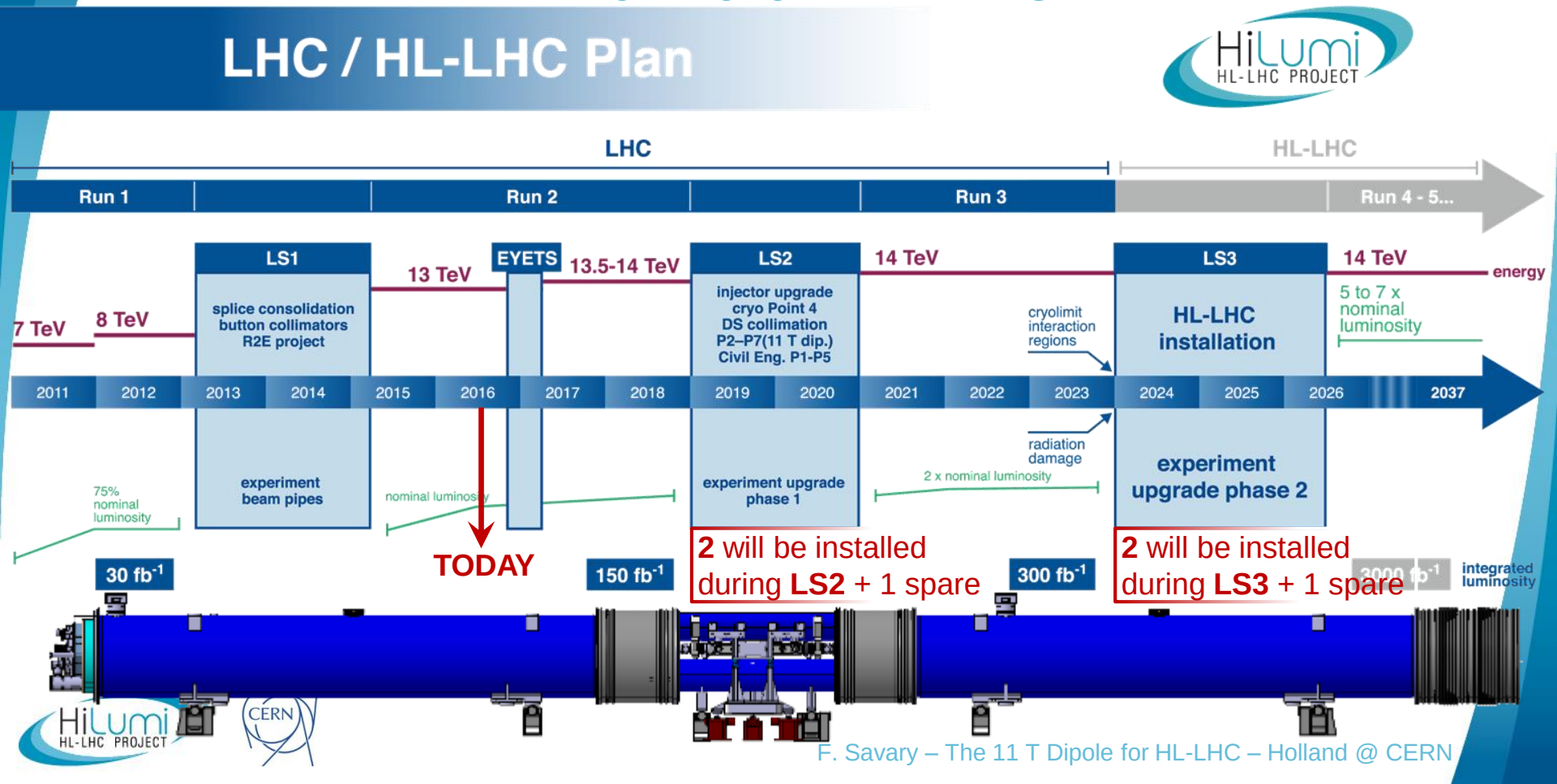
Timeline of HL-LHC



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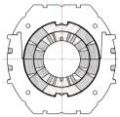
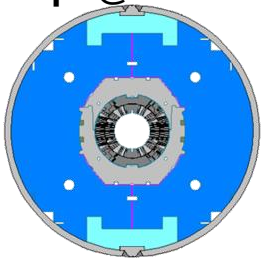
From technology demonstration to “final” design

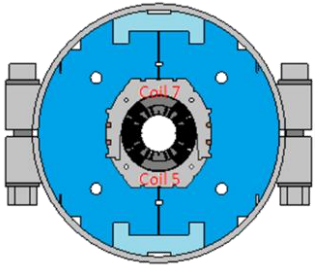
Integrated pole concept @ FNAL

Fermilab

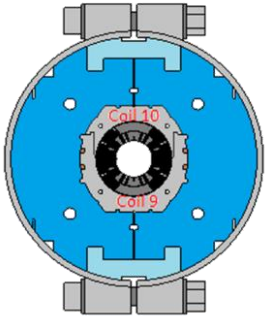




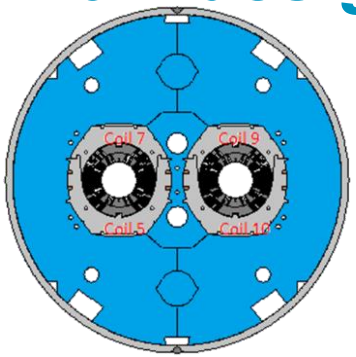
MBHSP01



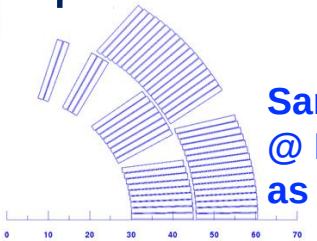
MBHSP02



MBHSP03

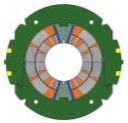


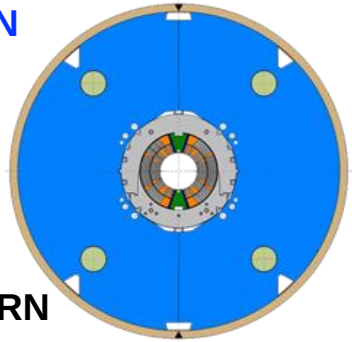
MBHDP01



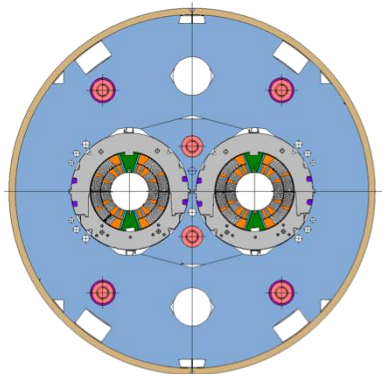
Same coil design @ FNAL and CERN as starting point

6 blocks – 56 turns

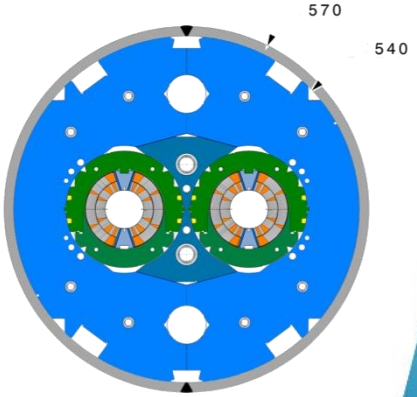




MBHSP10X [RRP]
MBHSP20X [PIT]



MBHDP101



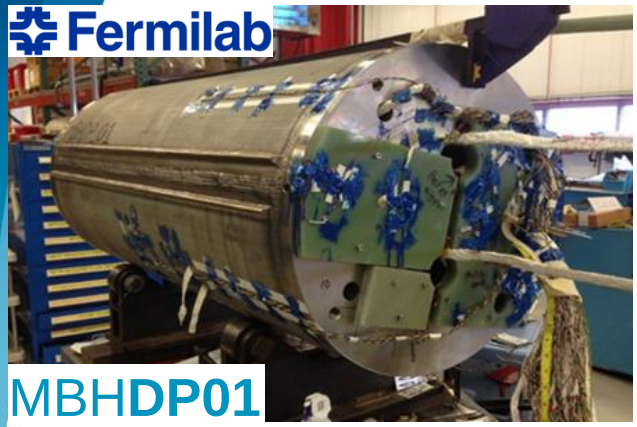
MBHDP102 [RRP] - 201 [PIT]
LBH_P001 [RRP] - 2 [PIT]

Removable pole concept @ CERN

HiLumi HL-LHC PROJECT

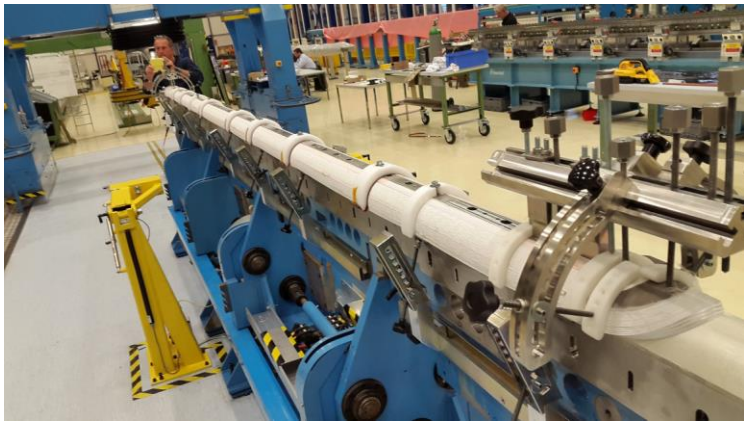
CERN

CERN



MBH**DP01**

MBH**DP101**



First 5.5 m long coils made @ CERN

The 11T Dipole Plan in the Timeline of HL-LHC

2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024

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LS2
*** 2 cryo-assemblies for IP7 B8L7 & B8R7**
*** 1 spare cryo-assembly**

LS3
*** 2 cryo-assemblies for IP7 B10L7 & B10R7**
*** 1 spare cryo-assembly**

For LS2, Models, X-Section **1**, RRP

For LS2, Prototype P1, X-Section **1**, RRP

Series Production for LS2, X-Section **1**, RRP

Beginning of winding

Cold tests of LBH_P1 + Cryo-by-pass + LBH__001

Spare available in end 2021

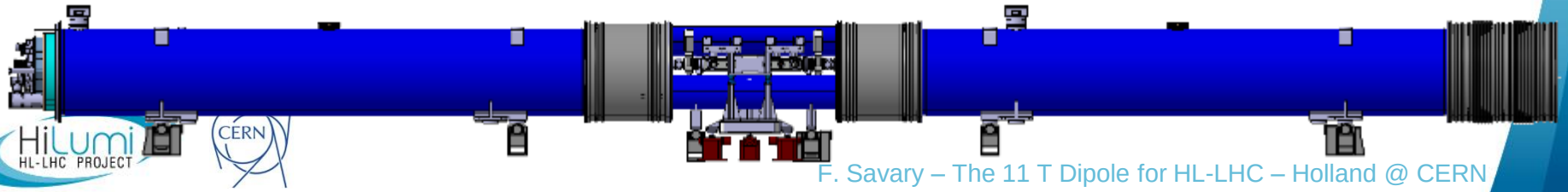
For LS3, Models, X-Section **2**, PIT & RRP

For LS3, Prototype LBH_P2, X-Section **2**, PIT

Beginning of winding

Series Production for LS2-Spare and LS3, X-Section **2**, PIT & RRP

Beginning of winding



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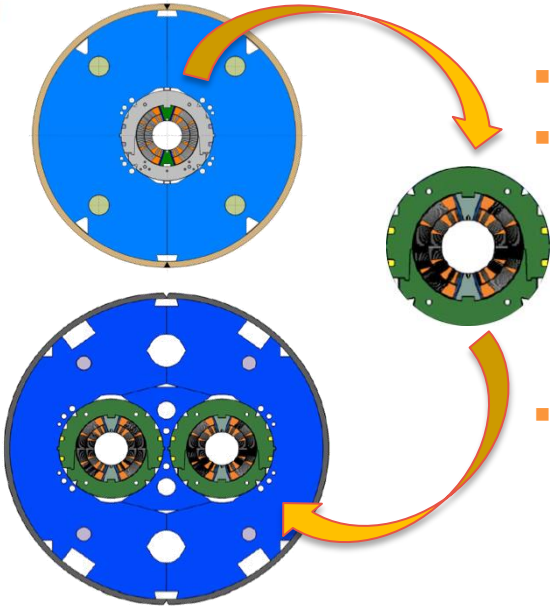
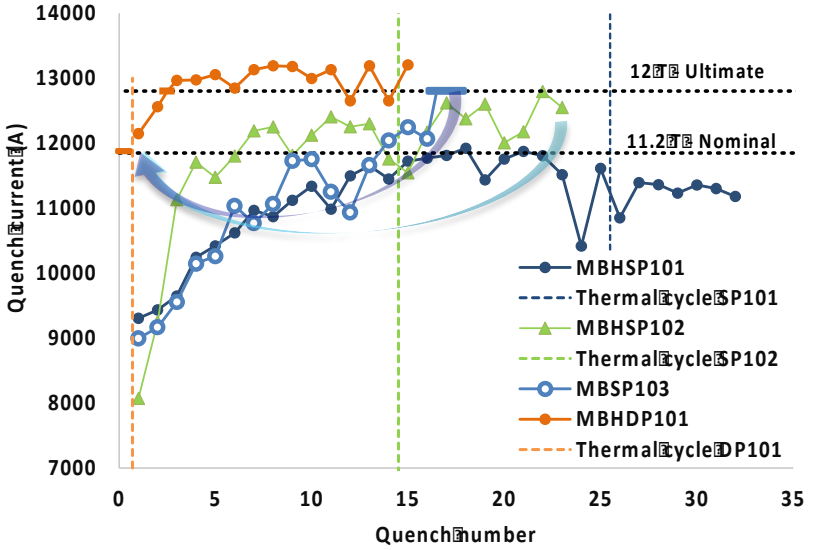
Quench performance of MBHDP101



- MBH**SP**102
- MBH**SP**103
- MBH**DP**101



- Holding current tests were performed, up to 10 hours at nominal current and 2.5 hours at ultimate current
- Not a single quench was recorded during flattop or ramp down for all models!

	Maximum current reached (kA)	% I_{ss}
SP101	11.9	82
SP102	12.8	88
SP103	12.8	90
DP101	13.2	94

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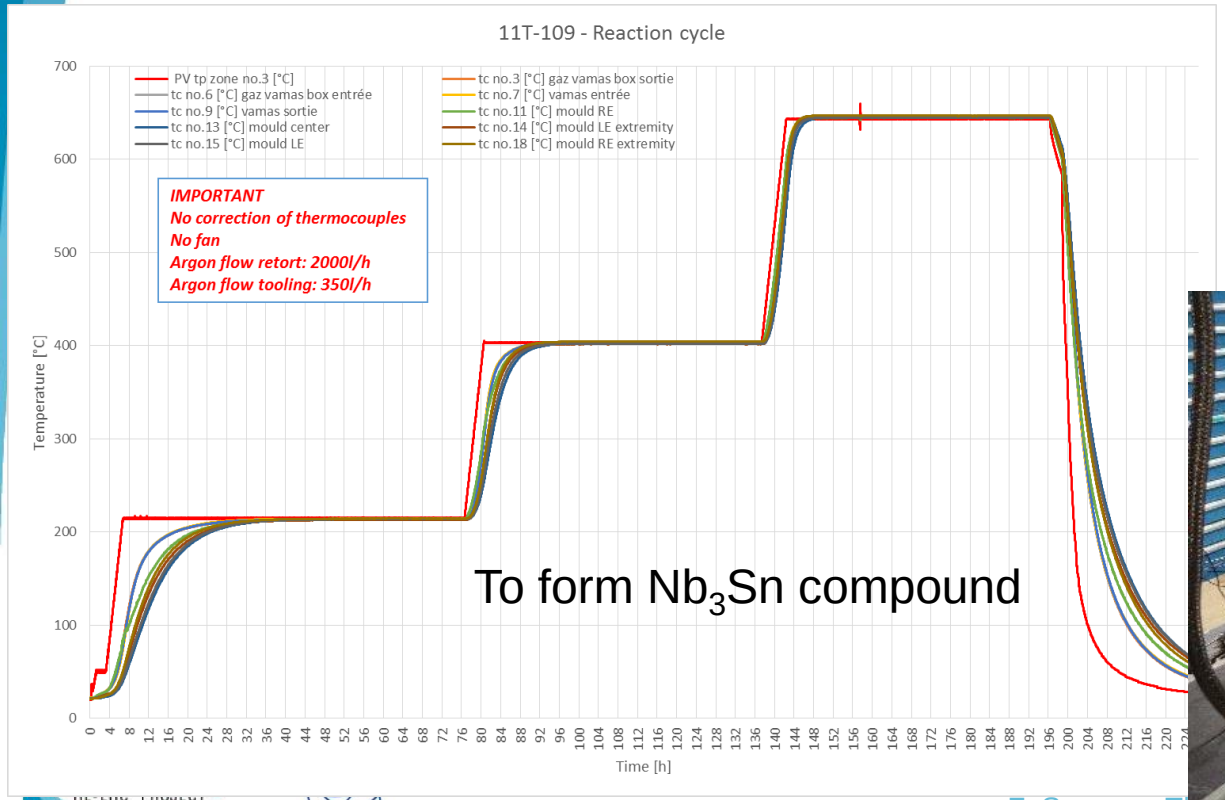
How can Holland contribute to the 11T?

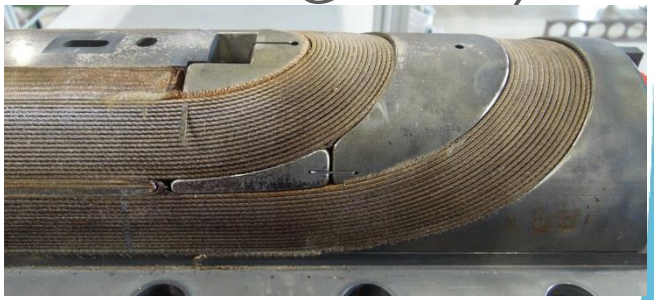
Legend: We are covered | We need more suppliers | We desperately need suppliers

Item #	Description	Raw material	2018	Later	What is challenging
1	Coil keys	AISI 316 L – DIN 1.4435			Machining (accuracy & elasticity)
2	End spacers	SLS – AISI 316 L – DIN 1.4435			Metrology, electrical insulation?
3	Saddles	Impregnated glass fiber as per IEC/EN 61212-3-1 EP-GC22			5-axes machining, GC22, accuracy
4	Removable pole	TA6V annealed (Ti6Al4V; 3.7165)			Accuracy & material
5	Wedges – precision profiles	Aluminum oxide dispersion strengthened copper (ODS)			Accuracy, material ODS
6	Quench heaters	Polyimide – St.Steel – Copper			Flexible Printed Circuits
7	Collars	YUS-130S (High Mn Steel)			Fine blanking, accuracy
8	Collaring keys	AISI 316 L – DIN 1.4435			Accuracy
9	Yoke laminations & inserts	Low carbon steel			Fine blanking, accuracy
10	Heat exchanger tube	Oxygen Free Cu – UNS C10200			Cu quality
11	Bus bars – hollow bars	Oxygen Free Cu – UNS C10200			Length, Cu quality
12	Lyras	Oxygen Free Cu – UNS C10200			Cu quality
13	Shells	AISI 316 LN – DIN 1.4429			Raw material, thickness, accuracy
14	End covers	AISI 316 LN – DIN 1.4429			Raw material, accuracy

NEW challenges w.r.t. to Nb-Ti magnets, 1

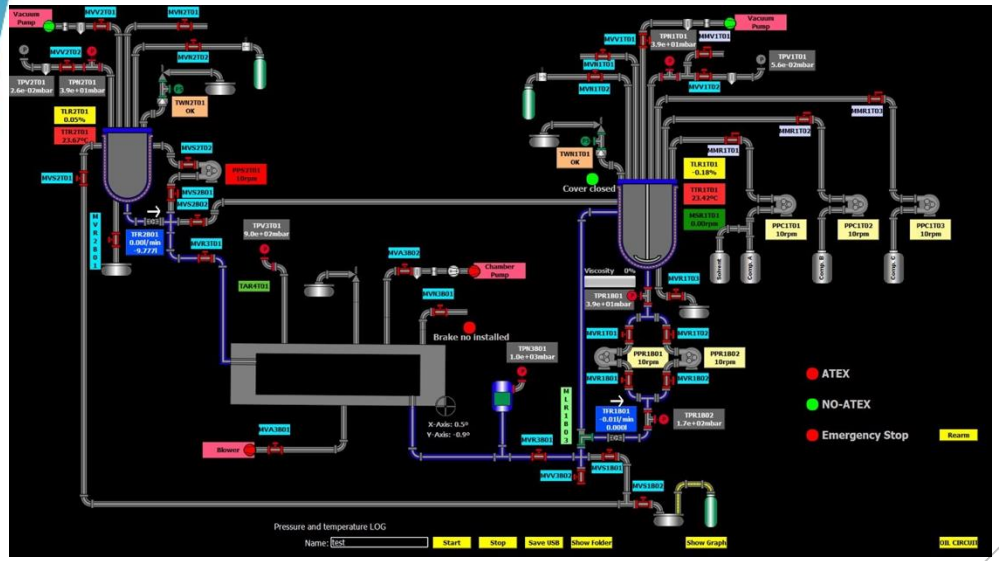
- Reaction treatment (48 h @ 210°C – 48 h @ 400°C – 50 h @ 640°C)

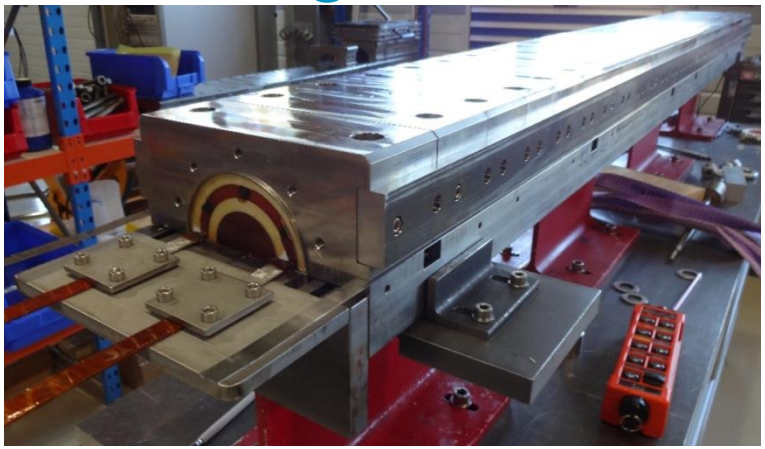


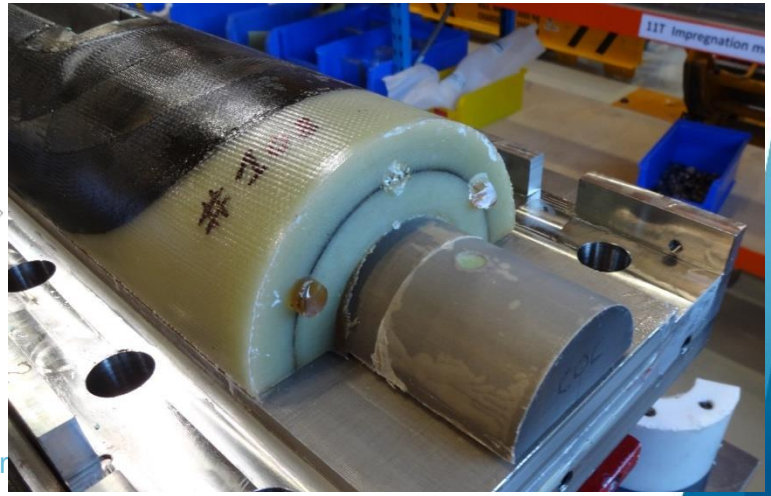


NEW challenges w.r.t. to Nb-Ti magnets, 2

- Impregnation

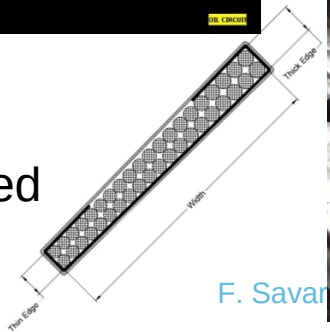




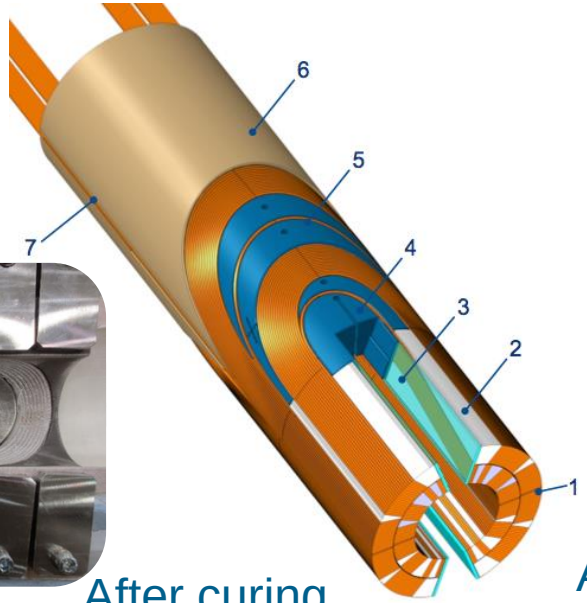


Insulation system:

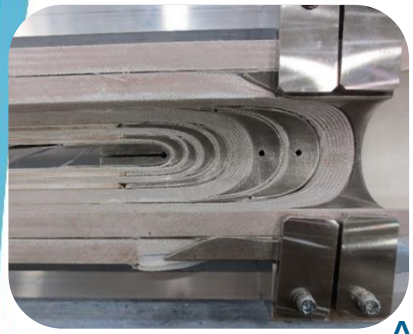
- Mica C-shaped tape
- Braided fiber glass impregnated with epoxy resin



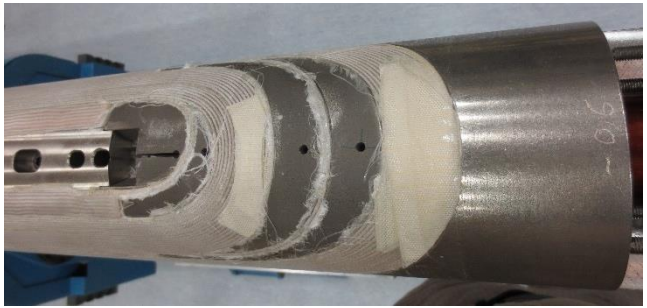
Coil keys – end spacers – saddles



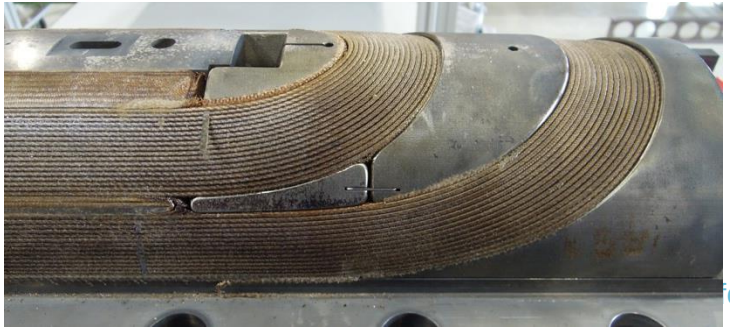
- Can be produced from STP files
- Item 4: Coil key, AISI 316 L
- Item 5: Selective Laser Sintering (SLS) end spacer, AISI 316 L, with flex. legs
- Item 6: Saddle, EP-GC22, base material woven glass cloth, matrix epoxy resin



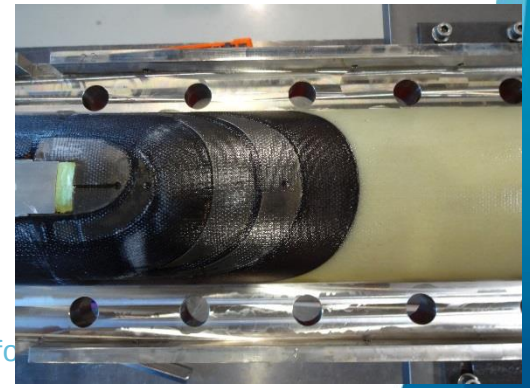
After curing



After reaction

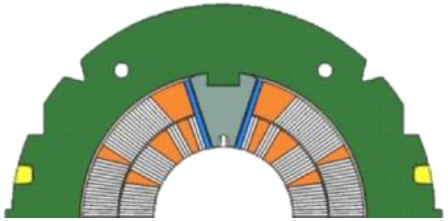


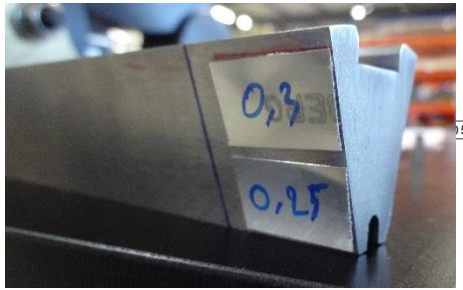
After impregnation

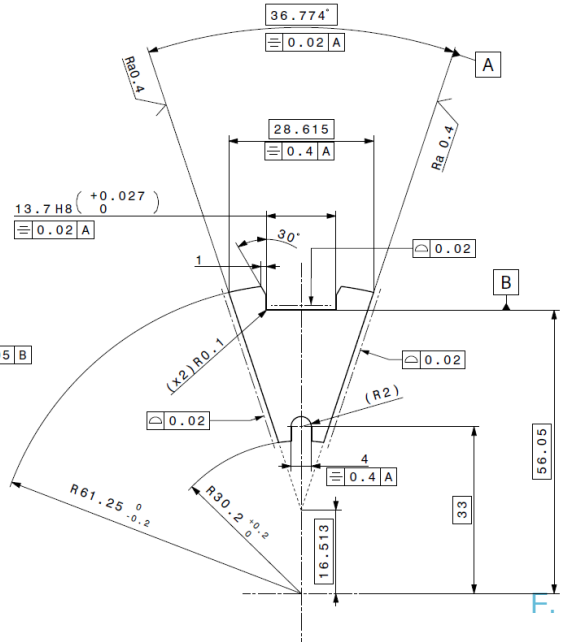


Loading pole – ODS wedge

- Loading pole, to be made of titanium, 240 mm long

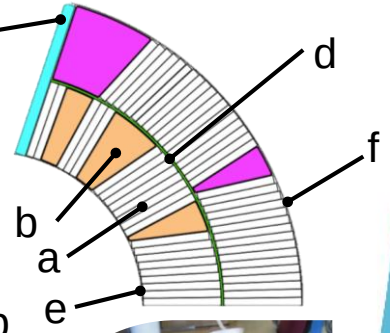


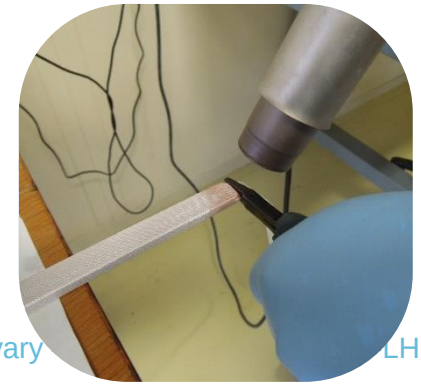




- Wedges, to be made of aluminum **Oxide Dispersion Strengthened** copper, cold drawn in length of 2.6 m

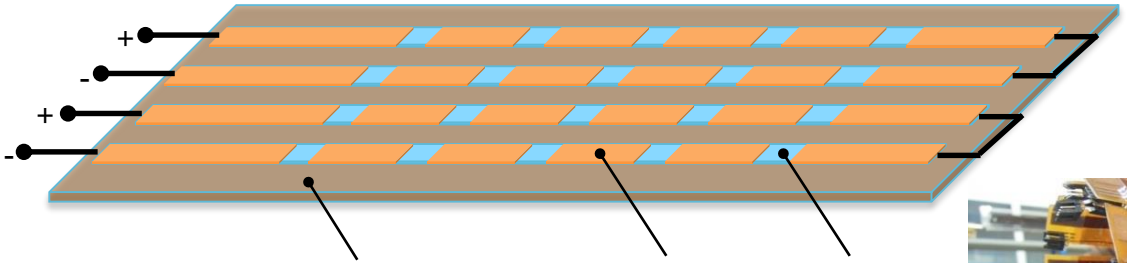
a. Insulated cable
b. Filler Wedge
c. Loading plate
d. Inter-layer
e. Inner ground wrap
f. Outer ground wrap

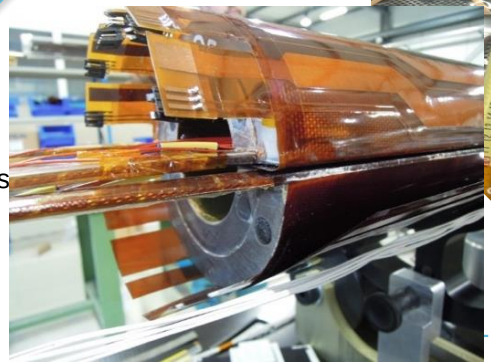




Quench heaters

- A strip of stainless steel of 20 μm running along the coil outer surface
- A thin copper layer of 5 μm (electrolytic deposition) to reduce the resistance of the strip in between 2 heating areas
- The substrate is a 50 μm polyimide film



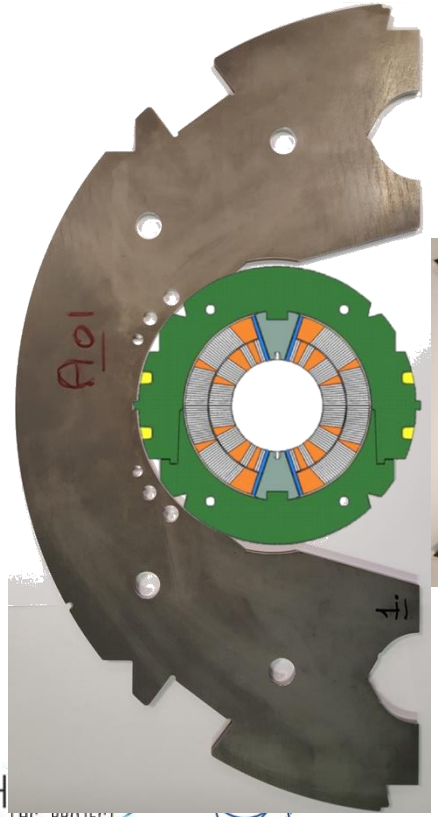


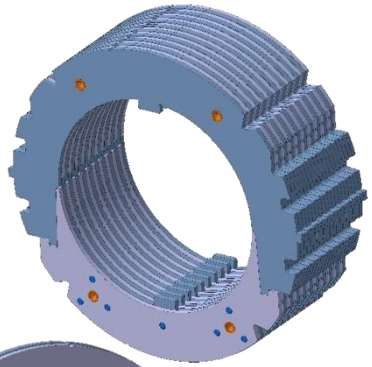
- **Overall length: 5600 mm**
- Width: 160 to 300 mm

Collars – collaring keys – yoke laminations

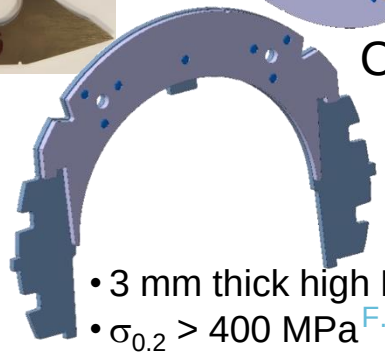
Yoke laminations: 5.8 mm thick low carbon steel

- Butraco
- Jeijen metaaltechniek B.V.
- Kusters & Bosch



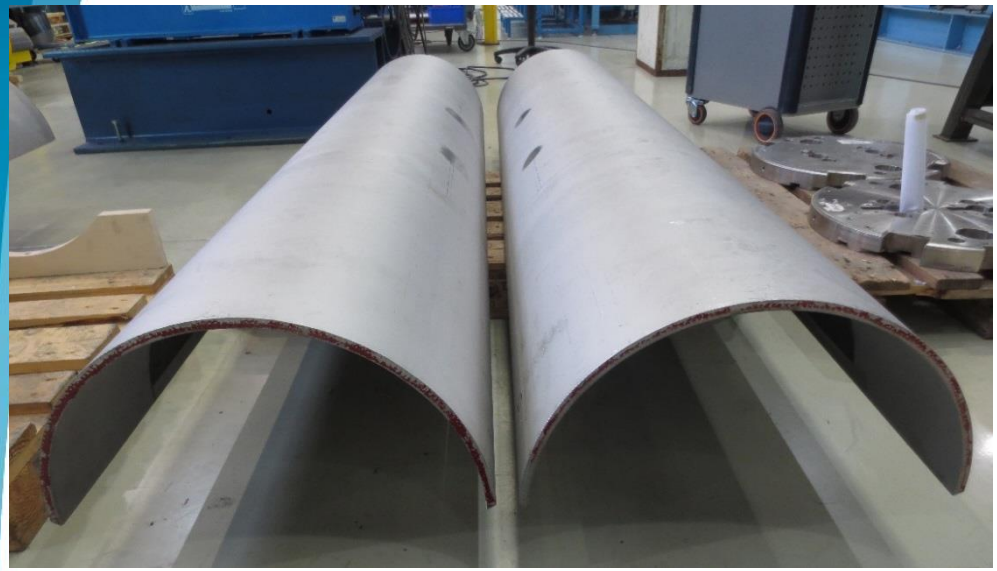


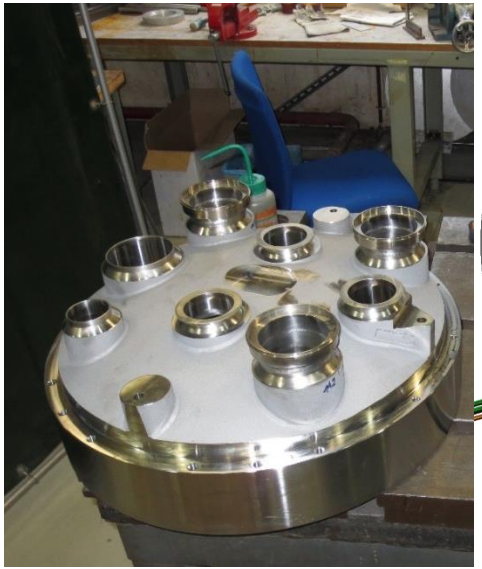
Collars

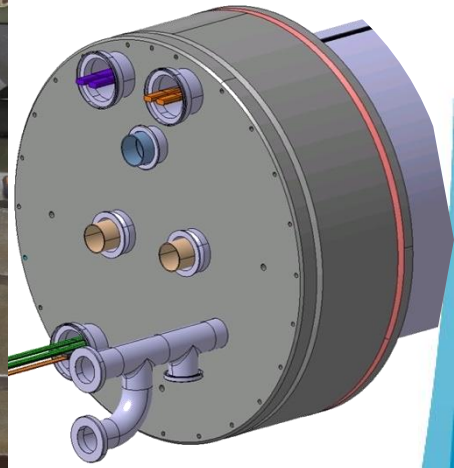


- 3 mm thick high Mn steel
- $\sigma_{0.2}$ > 400 MPa

Shells – End covers, main parts of the He vessel





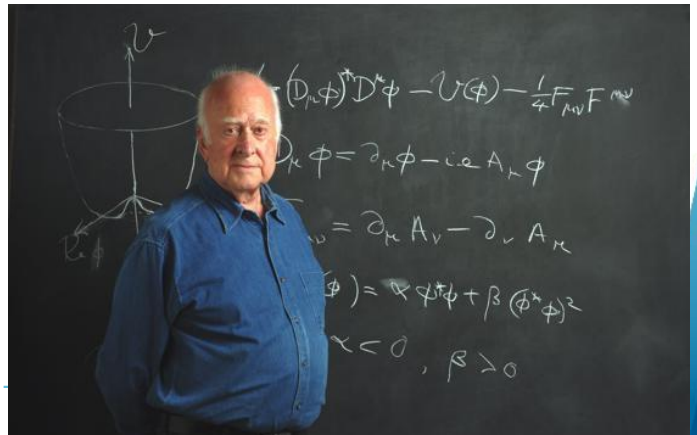


- Material: AISI 316 LN, hot rolled plates formed in folding press, thickness: 15 mm
- Tight fit with yoke laminations, i.e. need to be precise
- Weldability and Leak tightness

- Material: AISI 316 LN
- Powder metallurgy for the dished cover, or welded construction for the flat cover
- Weldability and Leak tightness

Summary

- The HiLumi HL-LHC Project is in the **construction phase**
- Most components are not standard, specifications are demanding
  - Materials (remember … will work between -271°C and +640°C for the coil components)
  - (Very) tight tolerances
- Limited quantities, but high quality requirements
- Technology developments are needed, e.g. magnets, quench heaters
- Finding the Higgs boson, and more, requires exploring the unexplored, going beyond its own limits
- Challenging, however rewarding



Thank you for your attention

For any question, email Frederic.Savary@cern.ch