



Status of MQYY

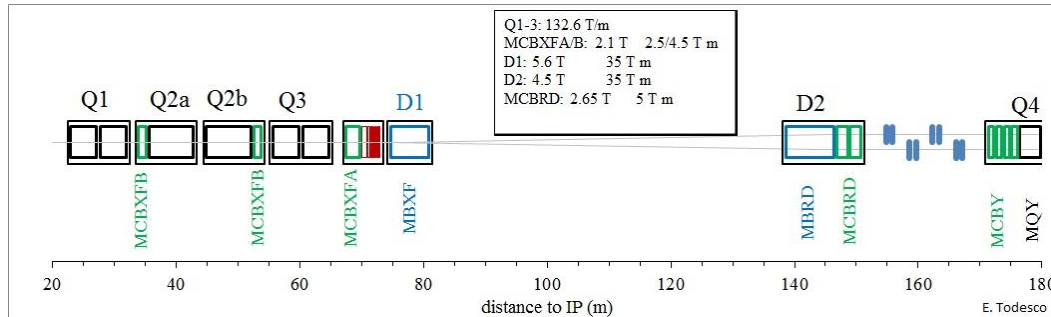
Helene Felice for the MQYY team

CEA: D. Simon, M. Segreti, J.M. Rifflet, A. Madur, S. Somsom, R. Machado-Correia, A. Bonelli, J.M. Gheller, D. Bouziat, A. Acker, P. Graffin, H. Neyrial

CERN: : A. Foussat, J. C. Perez, N. Bourcey, L. Fiscarelli, O. Dunkel, G. Kirby, J. Fleiter, E. Todesco, M. Guinchard, P. Gros-Claude, P. Viret

QUACO team: M. Lossasso, I. Bejar-Alonso, F. Toral, T. Martinez, P. Krawczyk, R. Nietubic

History of MQYY development

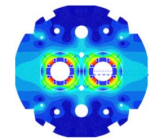


Q4 is the LHC MQY, double aperture quadrupole with 70 mm aperture

Layout of the magnets close to the interaction point

Initial HL-LHC baseline: use of **MQYY**, a new double aperture quadrupole with 90 mm aperture

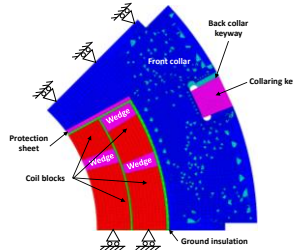
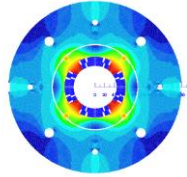
- **2011**: CEA- CERN initiative (J.M. Rifflet et M. Segreti) within the High Lumi design study (FR contribution)
- **March 2014**: CERN/CEA collaboration agreement => activities on MQYY (WP2)
- **September 2015**: Formal decision to change the cable
- **June 2016**:
 - **Decision to keep MQY to reduce cost (MQYY out of the baseline)**
 - Decision to continue with the development of MQYY short model and prototype
 - Updated CEA-CERN collaboration content: **Single aperture model MQYYM** developed by CEA and CERN
 - Parallel development: **two prototypes** developed in the QUACO initiative



Short Model and Prototypes

2 different paths

MQYYM Expected to be completed and tested by end of 2018



11/2016

11/2017

08/2018

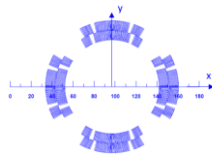
05/2020



**Concept. Design
PHASE 1
4 months
11/2016 to 03/2017**

**Engineering Design
PHASE 2
13 months
07/2017 to 08/2018**

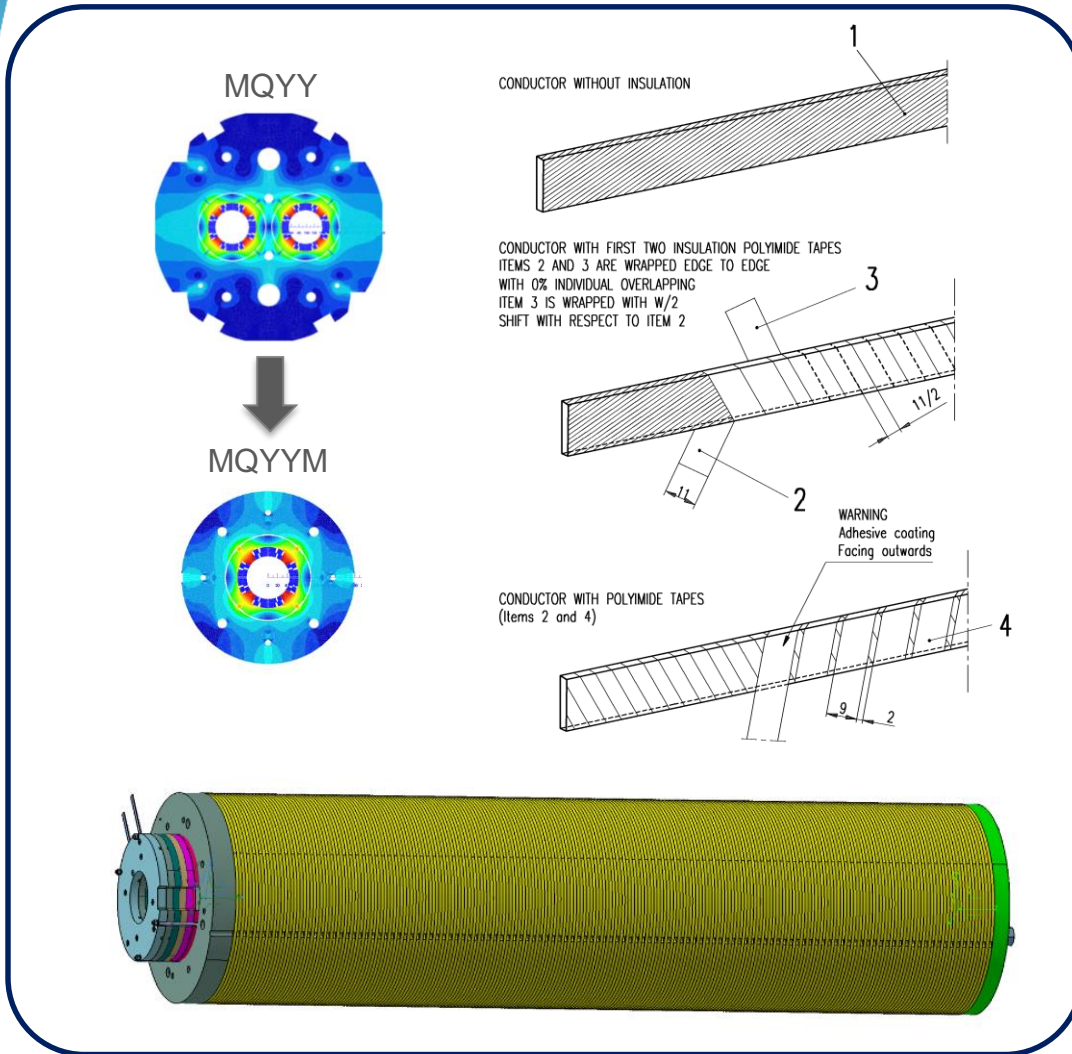
**Manufacturing
PHASE 3
18 months
11/2018 to 05/2020**



- Baseline magnetic design **provided but not imposed**
- ROXIE provided without the BEM FEM module
- Mechanical support structure design **up to companies**



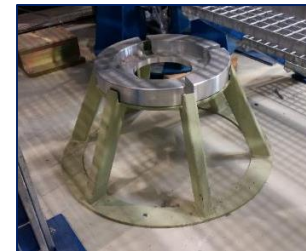
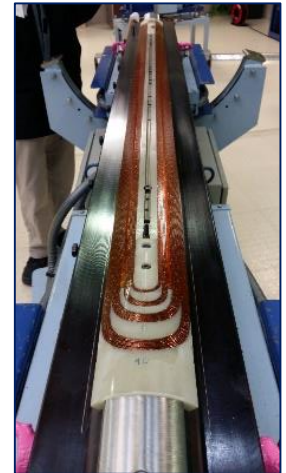
Overview of MQYYM



Physical length	1350 mm
Magnetic length at 1.9 K	1204 mm
Outer diameter	360 mm
Bare cable width	8.8 mm
Bare cable thickness	0.77/0.91 mm
Insulation thickness at nominal	0.080 mm
Short sample current	5980 A
Operating Gradient	120 T/m
Operating current	4550 A
Bpeak at operation	6.42 T
Loadline margin	23 %
Prestress level	60 MPa

MQYYM Manufacturing plan

- **Conductor from CERN**
 - Insulated conductors for 10 coils at CEA
- **Coils fabricated at CEA/Saclay**
 - Winding and polymerization
 - Coil instrumentation
- **Assembly will be performed at CERN (927) by CEA team supported by 927 team**
 - Collaring using 927 collaring press
 - Connection box assembly
 - Yoking
 - Warm Magnetic measurements
- **All components designed by CEA**
- **All interface tooling or specific tooling designed by CEA.** Design is supported/reviewed by N.Bourcey and J.C. Perez
 - Winding tooling
 - Assembly tooling (based on CERN existing tooling)
 - Coil measuring tooling (based on CERN existing tooling)
 - GPI forming tooling
 - ...
- **Procurement**
 - < 5 kCHF: order placed directly by CEA
 - > 5 kCHF: procurement through CERN but followed by CEA
 - Writing of a CERN spec by CEA team
 - Nordine Azizi / Arnaud Foussat (CERN)
 - Hubert Neyrial / H el ene Felice (CEA)



Most of the orders

H. Felice for the MQYY team

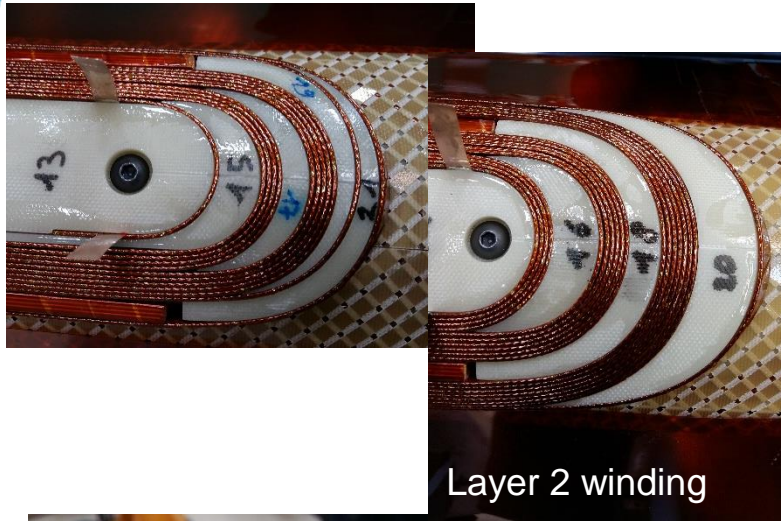
Coil Fabrication status

	Fabrication dates
Coil 0	22/03-27/04/2017
Coil 1	17-31/07/2017
Coil 2	4-14/09/2017
Coil 3	15-29/09/2017
Coil 4	23-31/10/2017
Coil 5	27/11-9/12/2017
Coil 6	8-19/01/2018
Coil 7	5-16/02/2018



- Initial plan in agreement: 10 coils
- Cable at CEA for 10 coils
- End parts manufactured for 8 coils (coils 0 to 7)
- 5 coils made: coil 0 + coils 1 to 4
- Discussion to be planned on final number of coils to manufacture
 - Minimum proposal: Coils 5 and 6 => MQYYM proposal: coils 2/3/5/6

Fabrication: coil 0

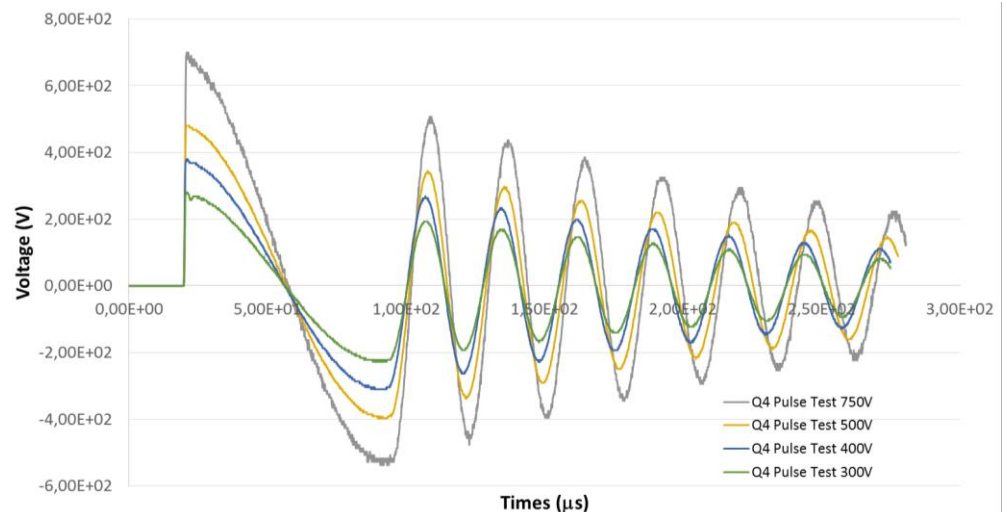


Layer 2 winding



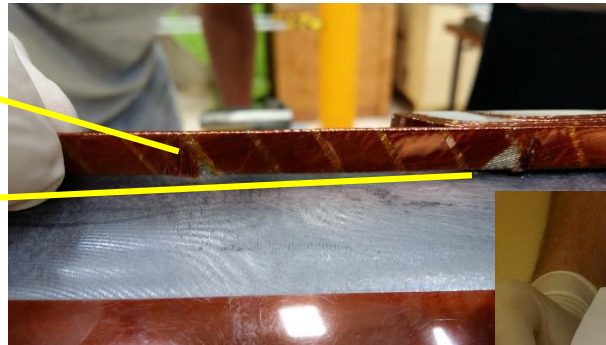
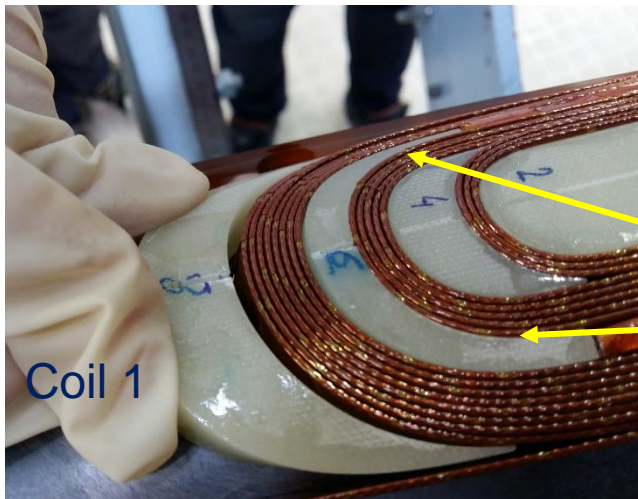
Soldered vtaps

- Good matching of the coil parts with the winding
- **CuBe Broken flags** after polymerization
=> Require smoothing of the sharp edges to avoid damaging the flags
- Impulse test showing change of frequency as V increases
=> Turn to turn weakness?
=> likely due to the weld of the vtaps using Tin Indium solder (fusion T < polymerization T!)



Coil 1

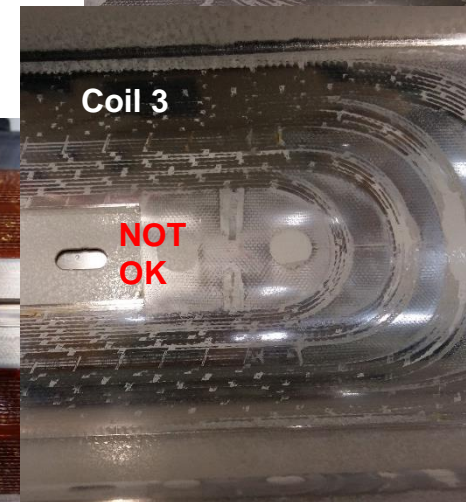
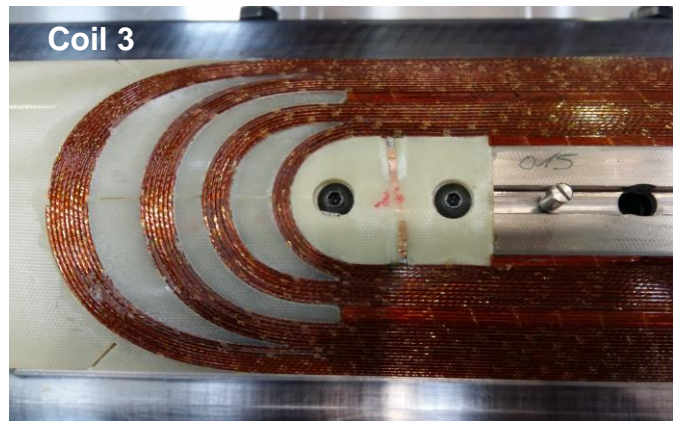
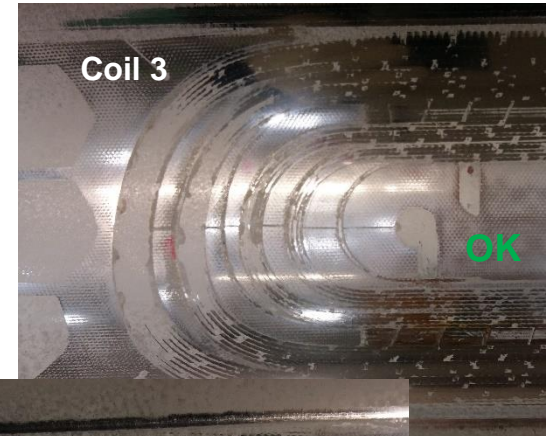
- Vtaps:
 - narrower CuSn_6 flags and SnAg solder
 - Grooves added in the end part
- **Slit** in some of the spacers, filled with G10 pieces before polymerization
- Finalization of procedures for insulation of angular wedges



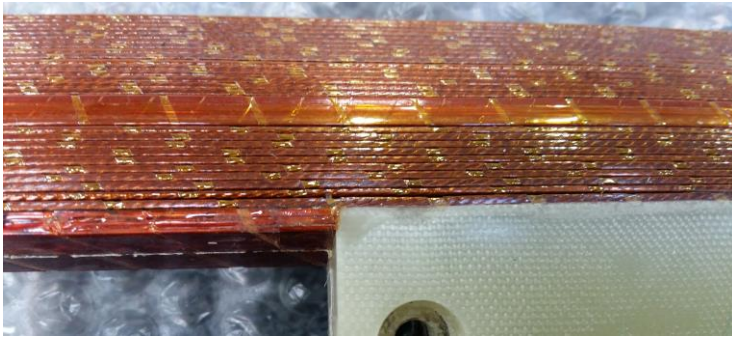
Coil 2 to 3



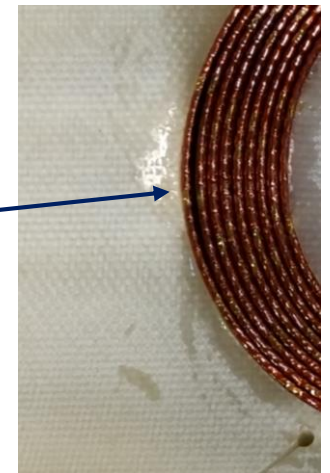
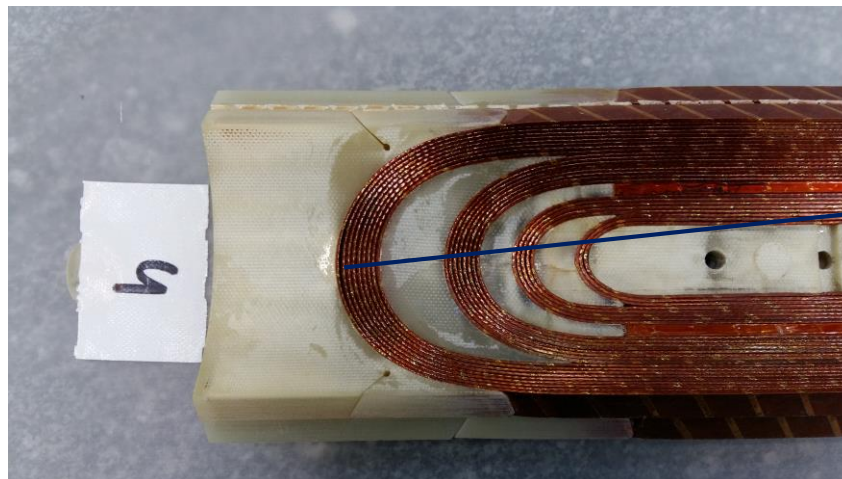
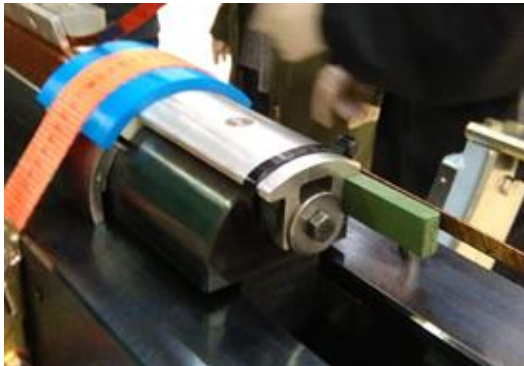
- No major issue during coil fabrication of coil 2 and 3
- Concern on vtap flags: grooves are not deep enough => some compression of the taps



Coil 4

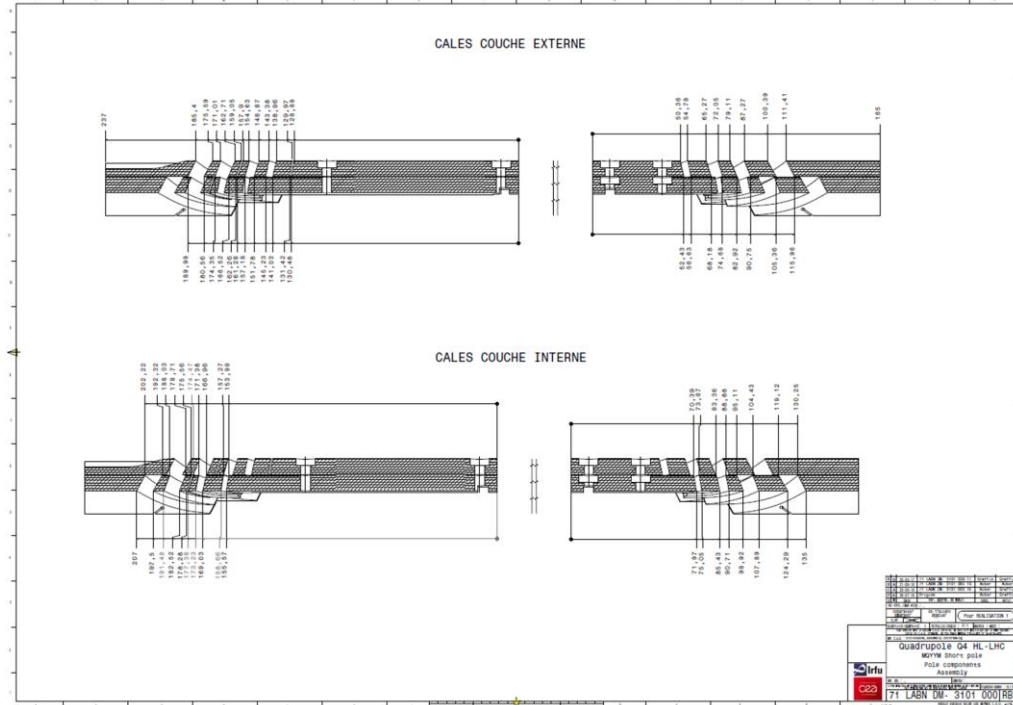


- Vtaps/endpart groove problem solved
- But :
- Unglued turn on the outer layer => adhesive missing? Unexpected cleaning?
- gap in the last but one turn in the RE IL: investigation ongoing. Last turn winding tension relaxation after lead cutting is suspected



Comparison of coil dimensions

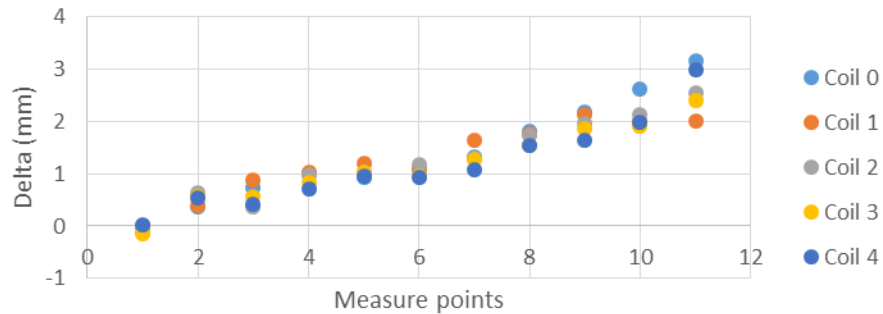
- Coils are 5 mm longer in average than nominal (1350 mm):
 - Coil 0: 4.9 mm longer
 - Coil 1: 4.2 mm longer
 - Coil 2: 5.3 mm longer
 - Coil 3: 5.4 mm longer
 - Coil 4: 5.3 mm longer
- Length build-up in end regions
- Measurements taken with a large caliper. Uncertainty of about 0.5 mm



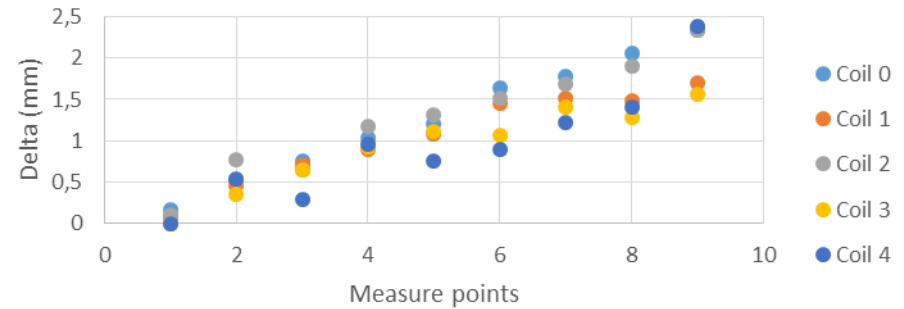
Comparison of coil dimensions

Delta = Actual size – Nominal size

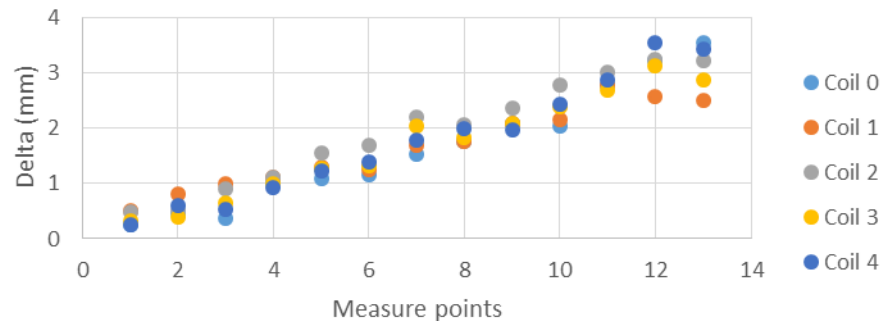
Delta LE Inner Layer



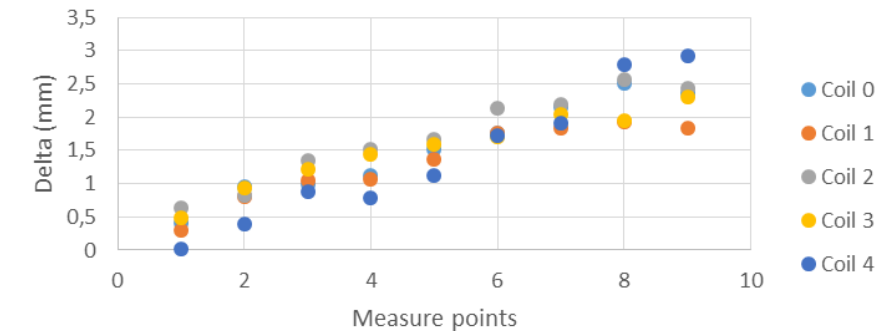
Delta RE Inner Layer



Delta LE Outer Layer



Delta RE Outer Layer

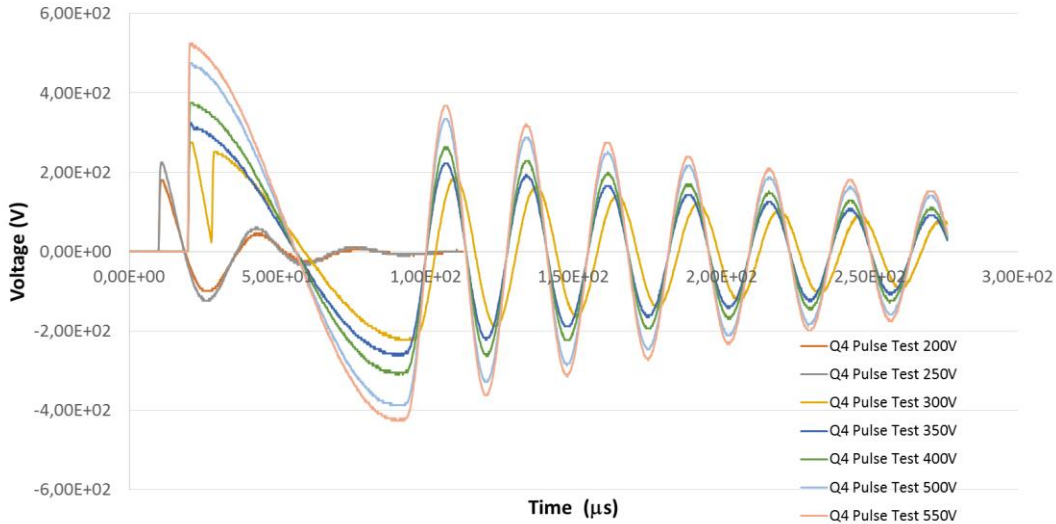


Change of torque on endparts after winding from coil 1 to 2 to reduce winding tension relaxation in the straight section

Spread of delta is unclear for now

Electrical tests on coil 1 and 2

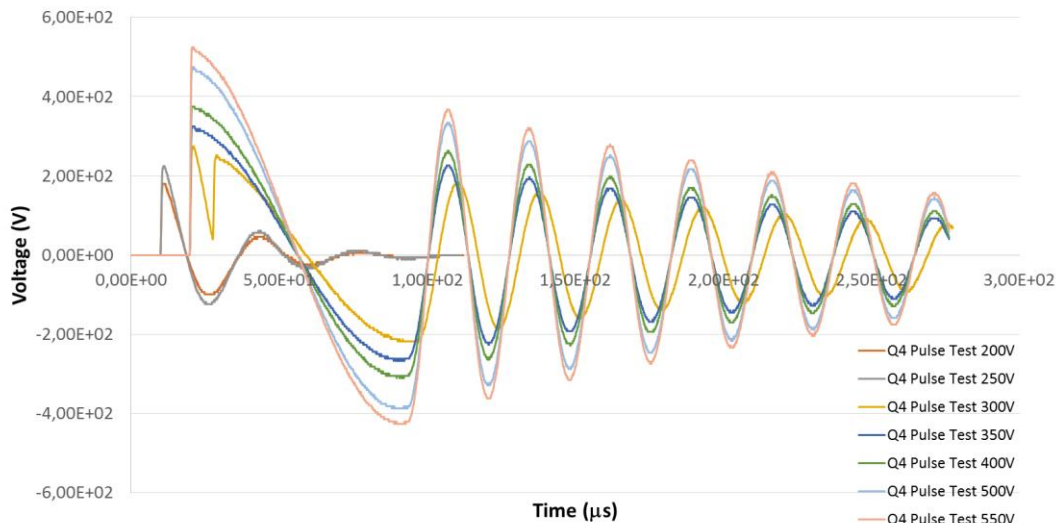
Coil 1



Coil 1

R (DC measurement)	568
L (mH) at 100 Hz	1.99
Average f_{pulse} (kHz)	35.2 +/- 2.9
Average f_{pulse} (kHz) from 300 V	36.2 +/- 1

Coil 2

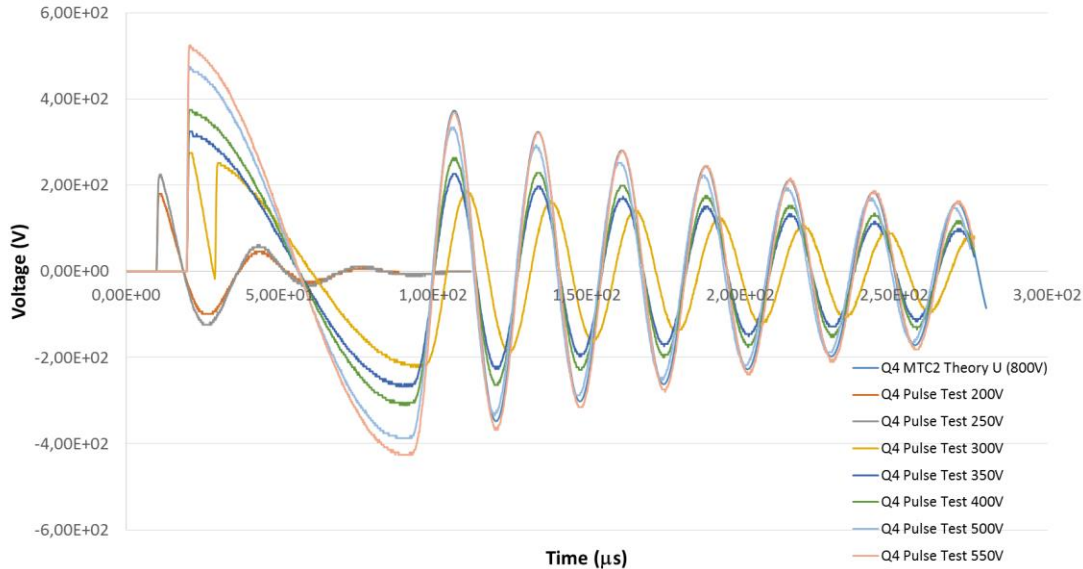


Coil 2

R (mΩ)	567
L (mH) at 100 Hz	1.97
Average f_{pulse} (kHz)	35.3 +/- 3.7
Average f_{pulse} (kHz) from 300 V	36.6 +/- 1.3

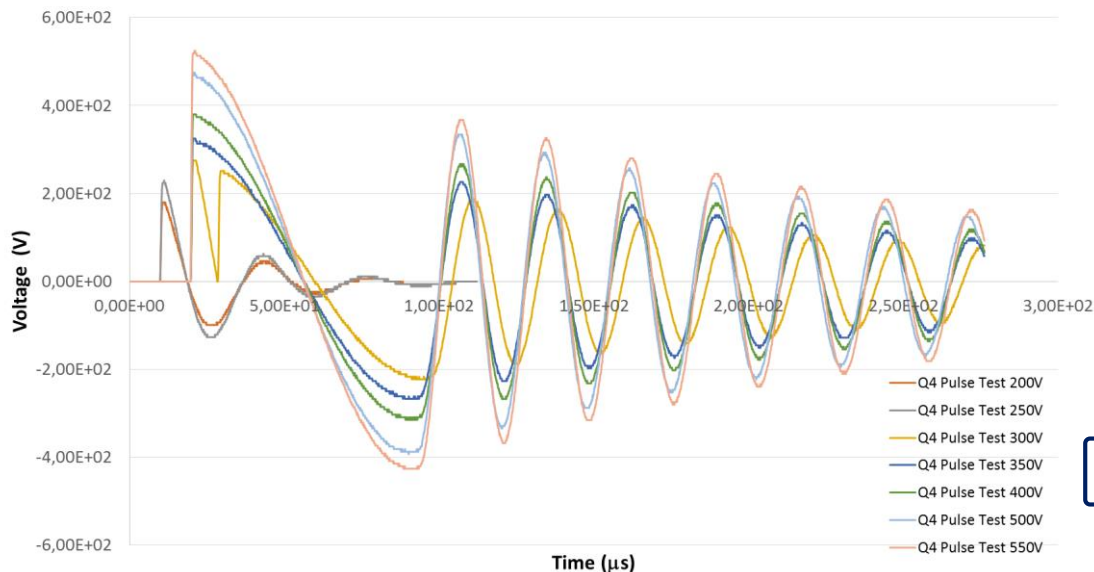
Impulse test Coil 3 and 4

Coil 3



Time (μ s)

Coil 4



Time (μ s)

Coil 3

R (m Ω)	568
L (mH)	1.98
Average f_{pulse} (kHz)	35.3 +/- 2.9
Average f_{pulse} (kHz) from 300 V	36.3 +/- 1.1

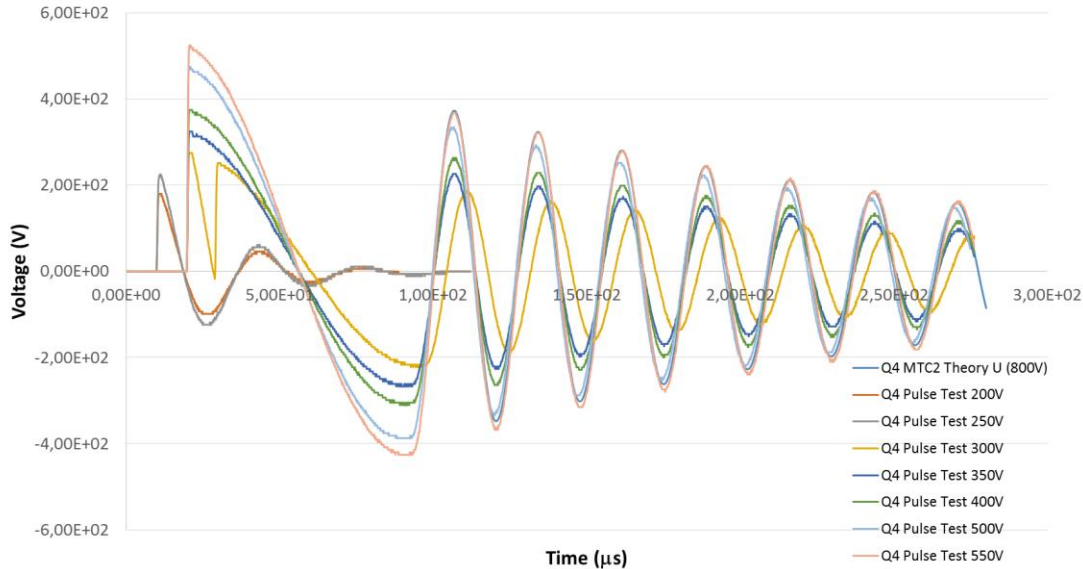
Coil 4

R (m Ω)	567
L (mH)	1.99
Average f_{pulse} (kHz)	35.6 +/- 2.5
Average f_{pulse} (kHz) from 300 V	36.5 +/- 0.8

Electrical validation of the coils 1 to 4

Impulse test Coil 3 and 4

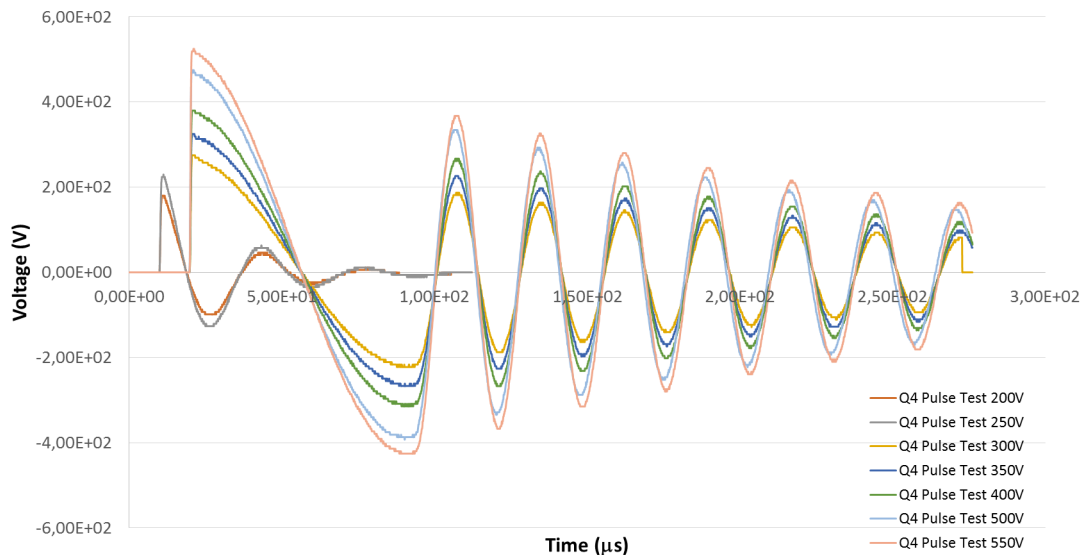
Coil 3



Coil 3

R (mΩ)	568
L (mH)	1.98
Average f_{pulse} (kHz)	35.3 +/- 2.9
Average f_{pulse} (kHz) from 300 V	36.3 +/- 1.1

Coil 4

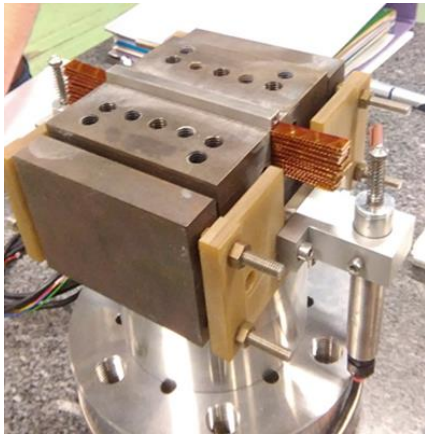


Coil 4

R (mΩ)	567
L (mH)	1.99
Average f_{pulse} (kHz)	35.6 +/- 2.5
Average f_{pulse} (kHz) from 300 V	36.5 +/- 0.8

Electrical validation of the coils 1 to 4

Supporting activity: Ten Stacks Measurements at CEA



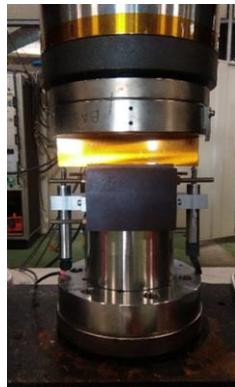
Objective 1: Rigidity measurement

Stack size	Avg Rigidity (GPa)
NS - 0.1 mm	7.3
NS	7
NS + 0.1 mm	6.9

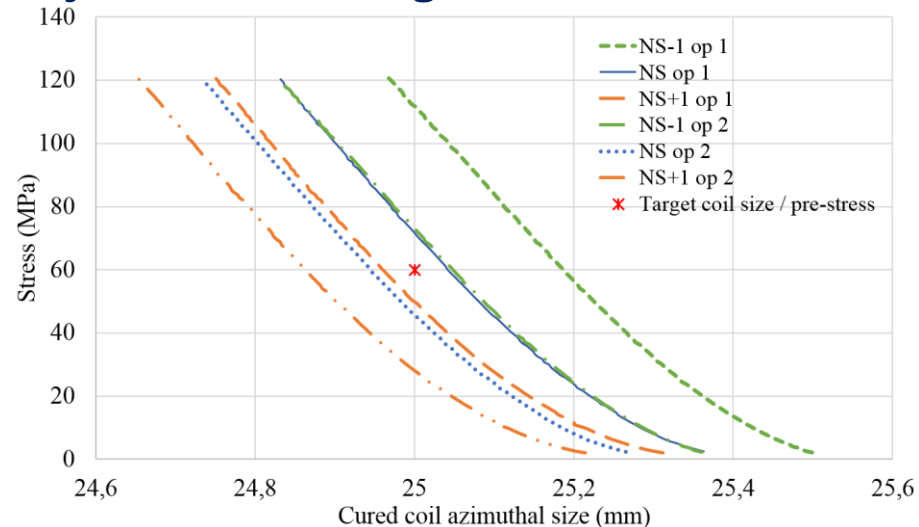
Cross-check ongoing at CERN
+ at cold
+ creep (change of dimension under constant compression)
+ stress relaxation (change of compression under constant dimension)

Stack of 18 conductors cured at:

- Nominal size
- NS - 0.1 mm
- NS + 0.1 mm

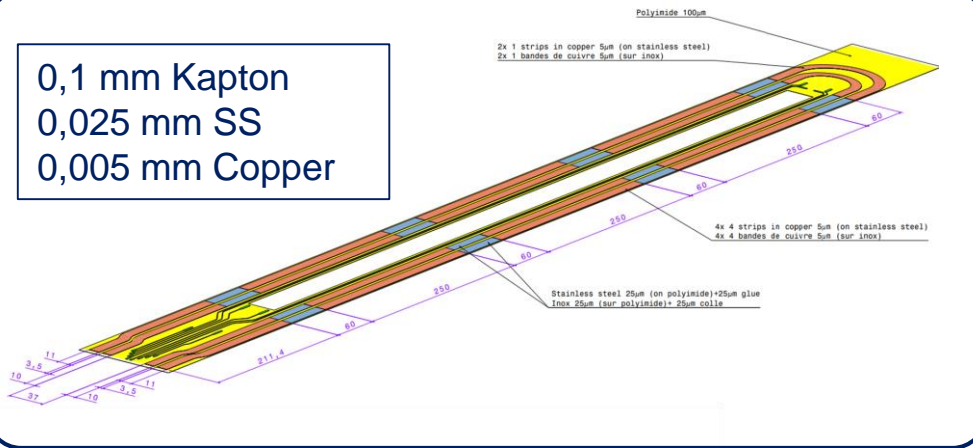


Objective 2: Curing shim choice



Traces

0,1 mm Kapton
0,025 mm SS
0,005 mm Copper



- Agreement to order 1 prototype trace to CERN
- Decision to produce 5 traces at CERN for efficiency reason
- Delivery of traces at CEA on 06/09/2017
- Measurements of the trace thickness at CEA: **145 µm** of Kapton (instead of 100)
 - Marginal Impact on hot spot temperature
 - Main Impact on magnet build-up
- Matching of vtaps pad and flags ok on coil 1
- Matching test of vtaps planned on coils 2 to 4

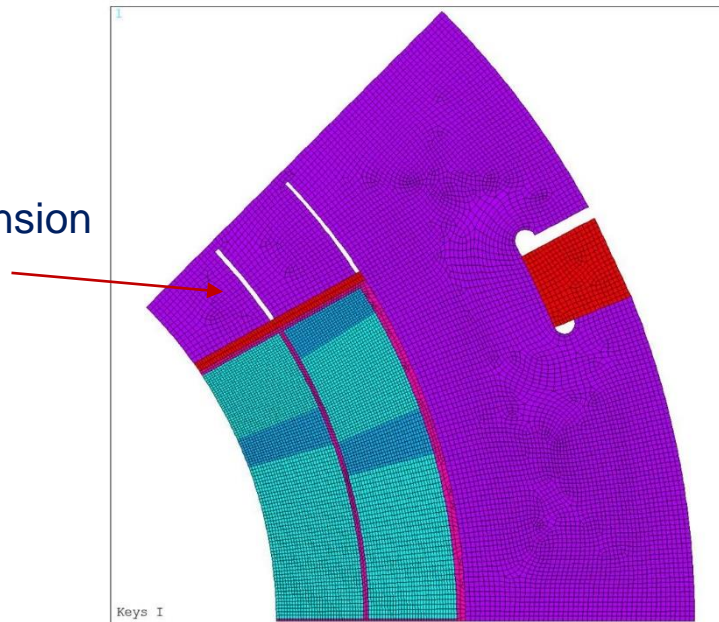
=> fabrication of new traces under discussion



Collar Instrumentation

- Instrumentation with strain gauges of 4 collars (top/bottom/left/right noses) at 3 given longitudinal positions (close to LE, at the center and close to RE)
 - Possible to reduce to 2 locations to reduce the wiring
- Instrumentation of collar flanges
- Instrumentation by M. Guinchard's team

- ANSYS analysis ongoing => slit dimension for unidirectionnal stress field

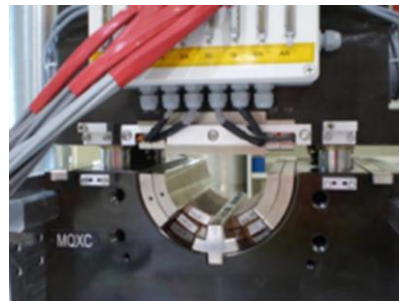


Mechanical measurement of the coils

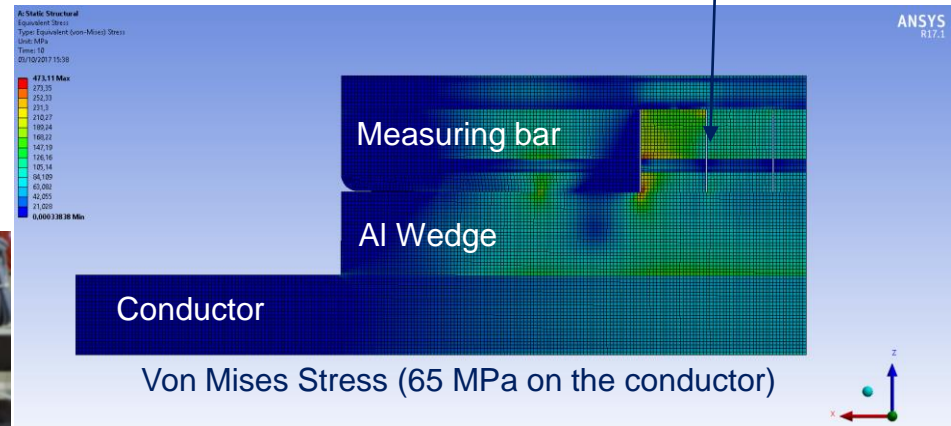
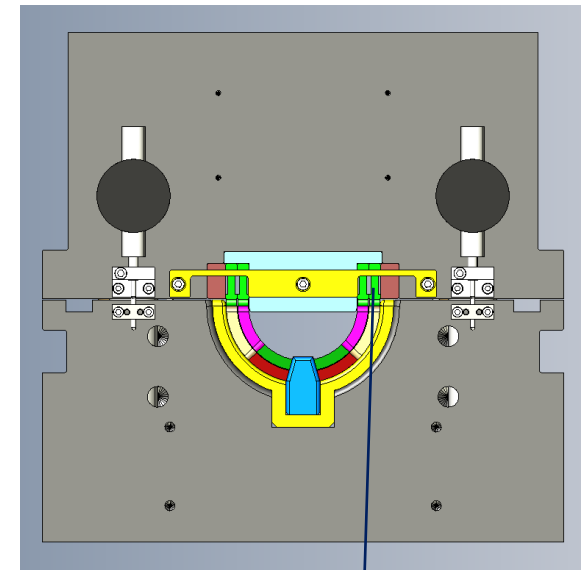
- CAD Adaptation of mechanical measurements tooling completed (feedback from JC Perez)
 - FEA analyses done to validate the measuring bars dimensions
 - CFT has been launched
 - Offers expected November 21st 2017: small number of parts, difficulty
- => Concern on offers
- **Item procurement on the critical path**

Instrumentation

- Instrumentation, software and calibration of the bars by M. Guinchard's team
- Calibration on the press:
 - CERN +CEA



Courtesy of JC Perez



Status on components and tooling

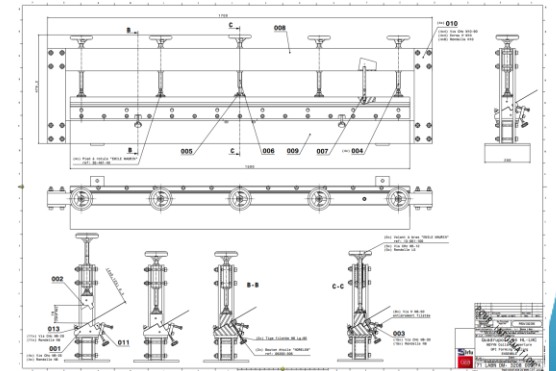
Orders and call for tenders

- **Collars:** delivered at CERN in 09/2017 .
- **Yoke laminations :** delivered at CERN in 10/2017
- **Connection box + G11 components:** specification in preparation, drawings ready, cross-checks with instrumentation
- **Flange and mechanical parts:** specification in preparation, drawings ready (to be adjusted for the routing of the instrumentation)
- **Protection shoe and pole turn protection shims:** Order placed mid October 2017
- **Assembly tooling:** order placed on 26/09/2017



CAD

- **GPI forming tooling:** designed by CEA. Drawings in preparation
⇒ Design developed in discussion with N. Bourcey and J.C. Perez
- **Transportation tooling and splicing tooling:** ongoing design



MQYYM: preparation of the test facility

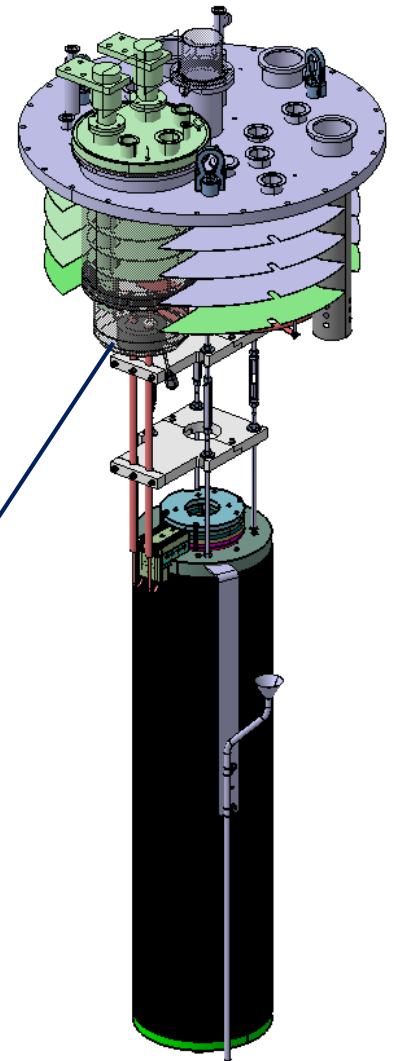
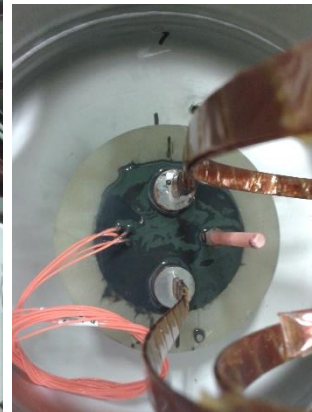
Cryogenic facility

- Effort carried out by J.M Gheller
- CEA 8 m vertical cryostat equipped with a 3 m long « sock » (tank)
- Adaptation of an existing top plate
- Saturated LHe bath at 1.9 K 23 mbar

the top plate and 4.2 K lead assembly ongoing

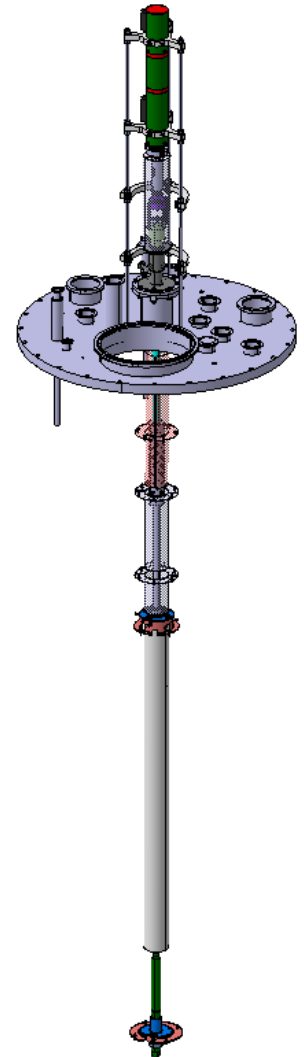
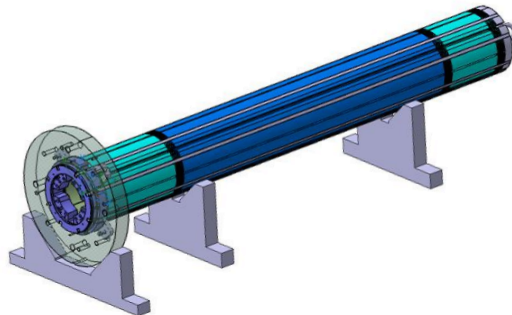
Data acquisition and magnet protection

- Effort carried out by Denis Bouziat
- Support from another group at CEA (DIS)
- Agreement made on work sequence and resources to be ready for the test



Plan for Magnetic Measurements

- **Cold** Probe, rotating unit and DAQ system will be provided by CERN
- Agreement on a probe: 47 mm in diameter, 5 modules of 222 mm in length
- Main difference identified between CERN and CEA facilities:
 - CERN: **pressurized** bath
 - CEA: **saturated** bath (23 mbar)=> Design of a sealed system using the cold probe provided by CERN
- Agreement on the fact that the operation of the system will be done by CEA (supported/trained by CERN)
- **Magnetic measurement technical review at CEA on June 14th 2017** to validate the design
- Drawings under review before CFT and finalization of the specification
- Training of Damien Simon planned in Fall 2017 on magnetic measurement acquisition system



MQYYM schedule

	Fabrication dates
Coil 0	22/03-27/04/2017
Coil 1	17-31/07/2017
Coil 2	4-14/09/2017
Coil 3	15-29/09/2017
Coil 4	23-31/10/2017
Coil 5	27/11-9/12/2017
Coil 6	8-19/01/2018
Coil 7	5-16/02/2018

Nom de la tâche	Durée	Début	Fin	Prédécesse	r
▶ Coil fabrication	70 jours?	Lun 04/09/17	Ven 08/12/17		
Connection box assembly training	1 sm	Mar 13/02/18	Lun 19/02/18	59;85	
▲ Tooling and components procurement	225 jours?	Mer 10/05/17	Mer 04/04/18		
▶ Assembly tooling	119 jours	Mer 12/07/17	Mar 09/01/18		
▶ Collars	114 jours?	Mer 10/05/17	Lun 16/10/17		
▶ Yokes	61 jours?	Lun 07/08/17	Mar 31/10/17		
▲ connexion box (2)	80 jours	Lun 09/10/17	Lun 12/02/18		
Design finalization	5 jours	Lun 09/10/17	Ven 13/10/17		
CFT	2 sm	Lun 16/10/17	Ven 27/10/17	82	
Order + fab	3 mois	Lun 30/10/17	Lun 05/02/18	83	
Delievery at CEA	1 sm	Mar 06/02/18	Lun 12/02/18	84	
▶ Coil parts (6 sets)	1 jour	Mer 26/07/17	Mer 26/07/17		
▶ other components	80 jours	Lun 16/10/17	Lun 19/02/18		
V supports for magnetic measurements	80 jours	Mer 01/11/17	Mer 07/03/18		
V supports for magnet tilting	80 jours	Mer 01/11/17	Mer 07/03/18		
▶ GPI tooling	90 jours	Mer 15/11/17	Mer 04/04/18		
▶ Coil shipping tooling	62 jours	Lun 06/11/17	Mer 14/02/18		
Magnet shipping tooling/crate					Critical path
▶ measuring coil tooling	196 jours	Ven 09/06/17	Lun 26/03/18		
▶ Trace fabrication	118 jours	Mer 26/07/17	Lun 22/01/18		
▲ Assembly preparation and assembly	171 jours?	Lun 06/11/17	Mer 18/07/18		
Assembly of the assembly tooling (at CE	1 jour?	Mer 21/03/18	Jeu 22/03/18	113DF-3 jour	
Coil measurements + set up	2,5 mois	Mar 27/03/18	Lun 04/06/18	101	
soldering/wiring of the trace	3 jours	Mar 05/06/18	Jeu 07/06/18	113	
GPI preparation	3 jours	Mer 17/01/18	Ven 19/01/18	101	
▶ Collaring	156 jours	Lun 06/11/17	Mar 26/06/18	69;115;114	
electrical integrity tests	1 jour	Mer 27/06/18	Mer 27/06/18	116	
Connection box assembly	5 jours	Mer 27/06/18	Mar 03/07/18	116	
Magnetic measurements	5 jours	Mer 04/07/18	Mar 10/07/18	121	
Yoking	1 sm	Mer 11/07/18	Mer 18/07/18	122	
Warm magnetic measurement with yoke	2 sm	Jeu 19/07/18	Mer 01/08/18	123	

▲ other components	80 jours	Lun 16/10/17	Lun 19/02/18
keys	80 jours	Lun 16/10/17	Lun 19/02/18
flanges	80 jours	Lun 16/10/17	Lun 19/02/18
protection shims	80 jours	Lun 16/10/17	Lun 19/02/18
collaring shoe	80 jours	Lun 16/10/17	Lun 19/02/18

▲ measuring coil tooling	196 jours	Ven 09/06/17	Lun 26/03/18
Design (CFT + design work)	90 jours	Ven 09/06/17	Jeu 12/10/17
CFT	5 sm	Ven 13/10/17	Jeu 16/11/17
Fabrication	3 mois	Ven 17/11/17	Ven 23/02/18
Delivery at CERN	1 jour	Lun 26/02/18	Lun 26/02/18
part validation/instrumentation	1 mois	Mar 27/02/18	Lun 26/03/18

▲ Collaring	156 jours	Lun 06/11/17	Mar 26/06/18
collars instrumentation	3 sm	Lun 06/11/17	Ven 24/11/17
assembly on vertical stand	8 jours	Ven 08/06/18	Mar 19/06/18
Collaring on press	5 jours	Mer 20/06/18	Mar 26/06/18

MQYYM : Summary and NEXT steps

SUMMARY

- **MQYYM Magnet design completed**
- **Coil 1 to 4 completed**
 - Electrical measurements validate the coils 1 to 4
 - Visual inspection not satisfactory for coil 4: investigation ongoing
- **The best is done to keep a reasonable schedule:**
 - Tight connection between CERN and CEA teams
- **Coil rigidity measurement tooling on the critical path**
- **Assembly preparation and test preparation on track**
- **Mechanical instrumentation defined**
- **Cross-check on rigidity measurements ongoing**

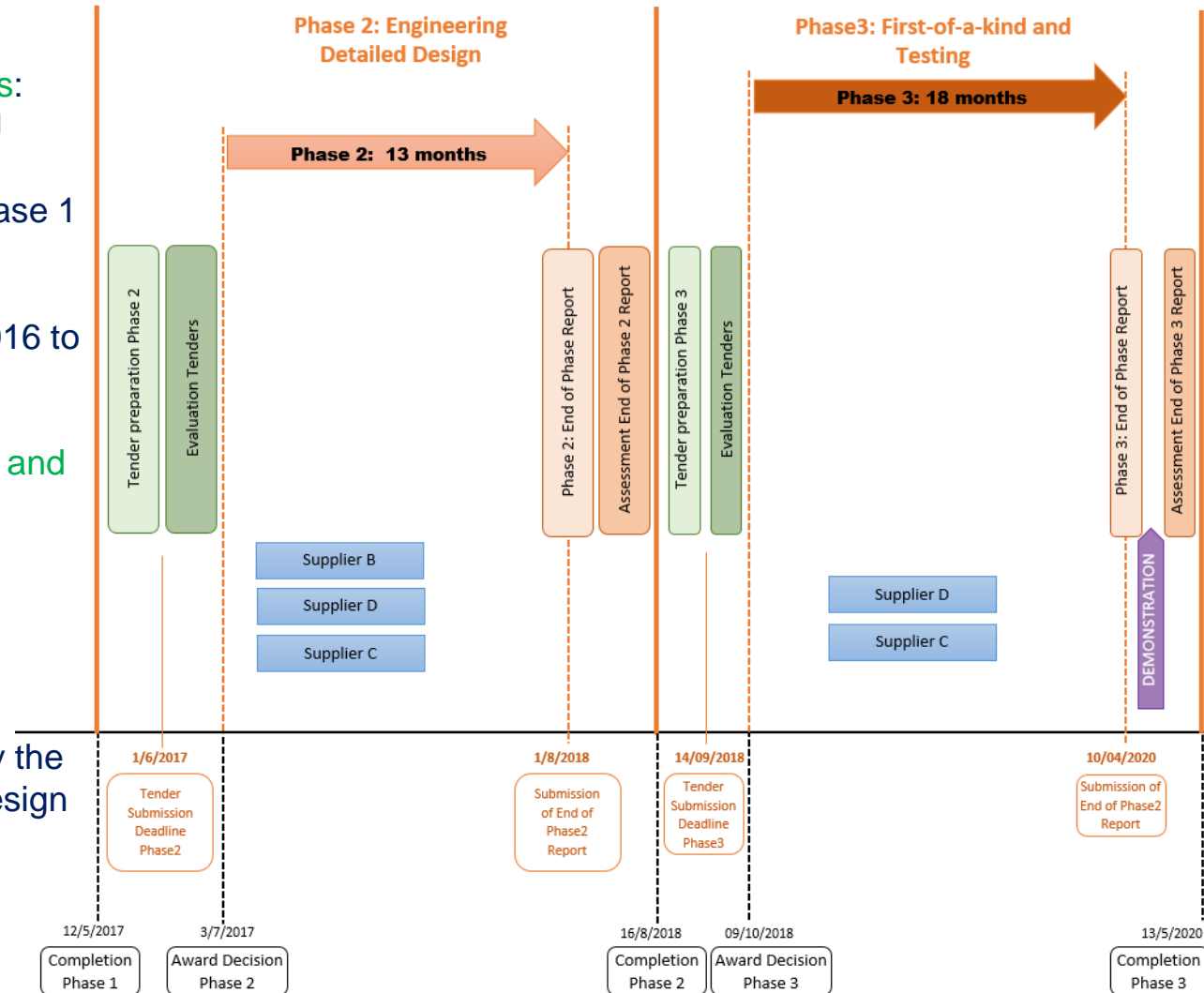
NEXT STEPS

- **Complete the procurement of the tooling and coil components**
- **Finalize some tooling design (transport, splicing...)**
- **Decision on number of coils to be manufactured**
- **Proceed with MQYYM fabrication**
- **Test remains foreseen in Fall 2018**

QUACO 101

QUACO : a EU Pre-Commercial Procurement in 3 phases aiming at the fabrication of 2 MQYY prototypes
 PCP « spirit » : innovation

- A consortium of 4 laboratories: CERN, CEA, CIEMAT and NCBJ
- 4 companies selected for Phase 1
- Phase 1: conceptual design
 - completed from Nov 2016 to March 2017
- Phase 2: Engineering design and mock-ups – ongoing
- Phase 3: Fabrication of 2 prototypes by 2 companies
- Magnetic design provided by the consortium based on CEA design
- Mechanical structure to be designed by the companies



Status of QUACO

- 3 companies remain in the game in Phase 2:
 - Antec-Tecnalia-SupraSys, Spain
 - Elytt, Spain
 - Sigmaphi, France
- 3 different designs are being explored – Details cannot be provided for confidentiality reasons
- Follow-up carried out by the consortium team

	Name	Inst.
QUACO Project Management	Marcello Losasso	CERN
EU PMT management and contracts	Christophe Veys	CERN
QUACO management and QA	Isabel Bejar Alonso	CERN
Technical Team		
CEA MQYY lead engineer	Helene Felice	CEA
CEA MQYY engineer	Damien Simon	CEA
CERN MQYY lead engineer	Arnaud Foussat	CERN
Technical expert	Fernando Toral	CIEMAT
Technical expert	Pawel Krawczyk	NCBJ
Support on manufacturing, QA deliverables	Isabel Bejar Alonso	CERN
	Pawel Krawczyk	NCBJ
Technical Secretariat	Outi Heloma	CERN

- Phase 2 objectives:
 - Demonstrate the validity of the mechanical concept by mock-ups
 - Finalize the magnet design
 - Finalize the tooling design
 - Be ready for components and tooling procurement in Phase 3 (no procurement in phase 2)
- Some material provided by CERN as part of the consortium:
 - Cockrill Iron Steel plates
 - YUS 130 Stainless steel plate
 - Insulated NbTi cable
 - Protection Heaters

- **Administrative constraint: between each phase => new tendering process**
- **The technical team has some concerns due to the very aggressive schedule imposed by the PCP**

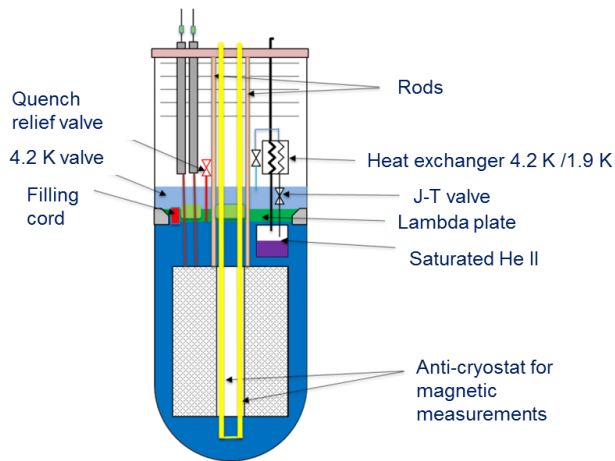
H. Felice for the MQYY team

Beyond QUACO preparation of the MQYYP test

- Similar timeline between MQ and MQYYP test

Agreement to find synergy between MQ and MQYYP tests => STAARQ project at CEA

- To minimize equipment cost and development cost
- To minimize down time between magnet tests



H. Allain (CEA)

CEA Team: J.M. Gheller, H. Allain, H. Felice, C. Lorin, D. Simon, J.C. Barriere, J. Belorgey, F. Molinié, J. Relland

Target date for operation: End of 2019

Cryogenic facility

- Design and fabrication of an **inner cryostat** to be inserted in the 8 m vertical cryostat
- Pressurized LHe bath at 1.9 K
- Introduction of Lambda plates in the main Lambda plate to accommodate the anticryostats and bus bars
- Connection to a liquifier

Data acquisition and magnet protection

- Upgrade under discussion

Max Dump resistor: 100 mohm

Power supply: 20 kA

HTS current leads under investigation

Next steps and Milestones for MQYY

■ Short Model MQYYM

CERN/CEA
collaboration
agreement

- Fabrication of last coils at CEA: **early 2018**
- Aperture collaring and yoking at CERN: **late spring 2018**
- Test at CEA: **Fall 2018**

■ Prototype MQYY

QUACO

CERN/CEA
collaboration
agreement

- End of Phase 2: **August 2018**
- Selection of two companies to proceed to the prototype fabrication phase (phase III): **October 2018**
- Prototype delivery at CEA **mid 2020**
- **Test at CEA**

Coil 4

