

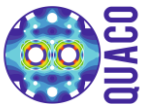


# Introduction to the technical content The Q4 magnet (MQYY) for HL-LHC

Helene Felice (CEA-Saclay) for the QuaCo team

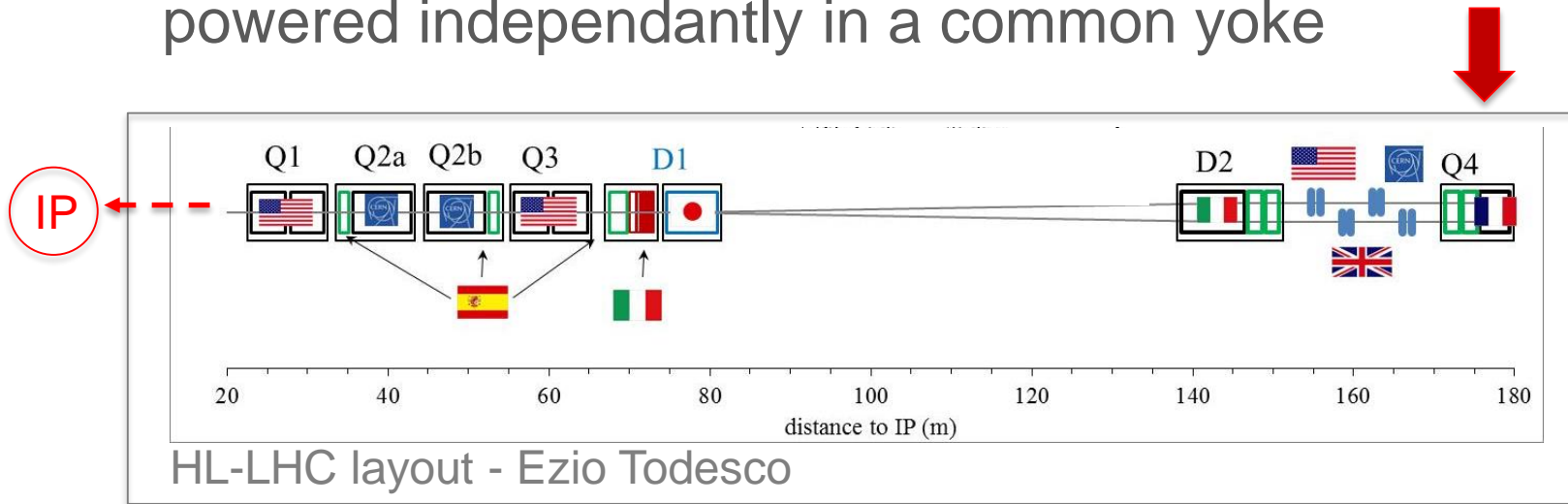
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OMC – CERN – March 30<sup>th</sup> 2016



# Context of the Q4 magnet (MQYY)

- One of the insertion magnets of the high luminosity upgrade located before the interaction points
- Matching section magnet tailoring the beam size in the insertion region to the acceptance of the machine's lattice
- Double aperture magnet: 2 individual apertures powered independantly in a common yoke



# Timeline of the Q4 magnet development and production

## **SINGLE APERTURE SHORT MODEL**

developed at CEA to be completed in 2017

## **PROTOTYPES (First-of-a-kind)**

Double aperture full length prototype magnet

Scope of QuaCo

03/2016 – 2020

## **SERIES**

4 double aperture magnets

Not part of QUACO

2020-2023

# Scope of Quaco

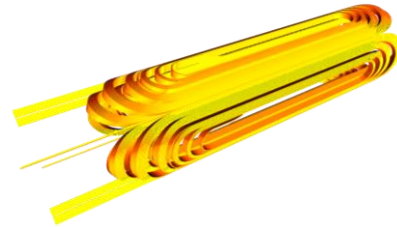
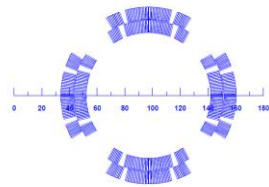
- Development of the Q4 prototypes in 3 phases:
  - Conceptual Design
  - Engineering Design & Prototyping
    - Detailed design
  - First-of-a-kind
    - Fabricate a Q4 magnet

## Q4 Functional Requirements: a sample

- Double 90 mm aperture NbTi quadrupole
- Apertures powered independently allowing for unbalanced regime
- Operating temperature of 1.9 K
- 194 mm distance between apertures at 1.9 K
- Magnetic length of 3.67 m at 1.9 K
- Room temperature outer diameter: 614 mm
  
- 440 T integrated gradient
- Field quality: relative field harmonics below 100 ppm.

# Example of Technical Background provided by the QUACO Consortium

- Example of 2D and 3D Magnetic Design
  - CAD files of the end design,
  - Text files / ROXIE file with magnetic design info



- Support on Quench Protection
  - Protection analysis
  - Quench heaters design (CAD models and spec)
  - Quench heaters to be implemented in the magnet

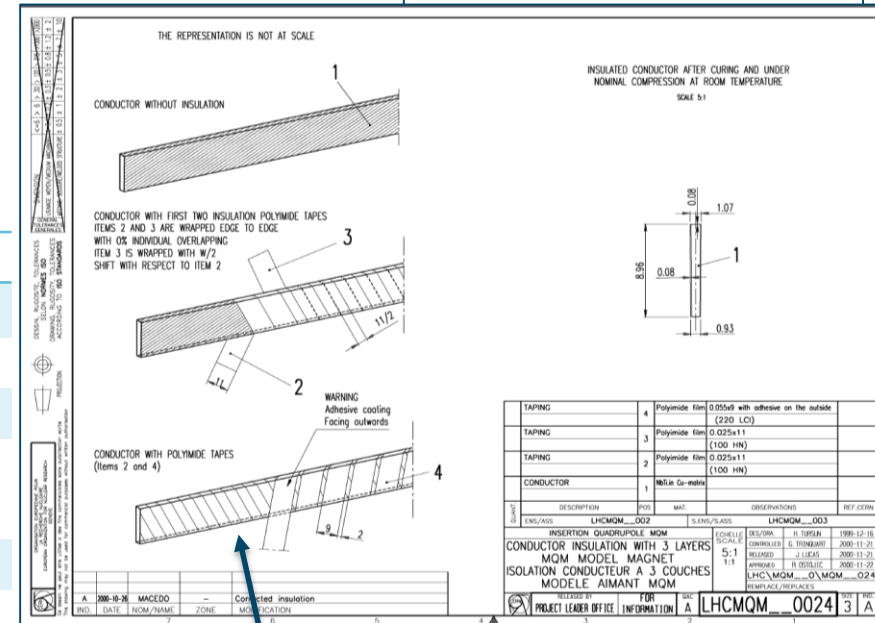
# Conductor

- The insulated NbTi conductor will be provided by the QUACO Consortium
- Conductor parameters:

Parameters	unit	
Strand diameter	mm	0.475
Cu/No Cu		1.75
RRR (cable)		>80
Superconductor current density at 5 T, 4.2 K	A/mm <sup>2</sup>	2800
Number of strands per cable		36
Cable bare width	mm	8.8
Cable bare inner thickness	mm	0.770
Cable bare outer thickness	mm	0.910
Insulation thickness per side radial	mm	0.080
Insulation thickness per side azimuthal	mm	0.080



## Technical Specification of the superconducting cables for the LHC MQM and MQY quadrupoles



3 layers of Polyimide tapes  
Adhesive coating on the outside of the last tape requiring curing step.

# Technical Output by companies

- Magnetic validation or modification
- Mechanical Design of the support structure
  - FEM analysis
  - CAD design
- Magnet fabrication procedures and tooling
  - Coil fabrication procedures and tooling
  - Magnet assembly procedures and tooling
- Assembled magnet
- Magnet validation: warm magnetic measurements, QA/QC

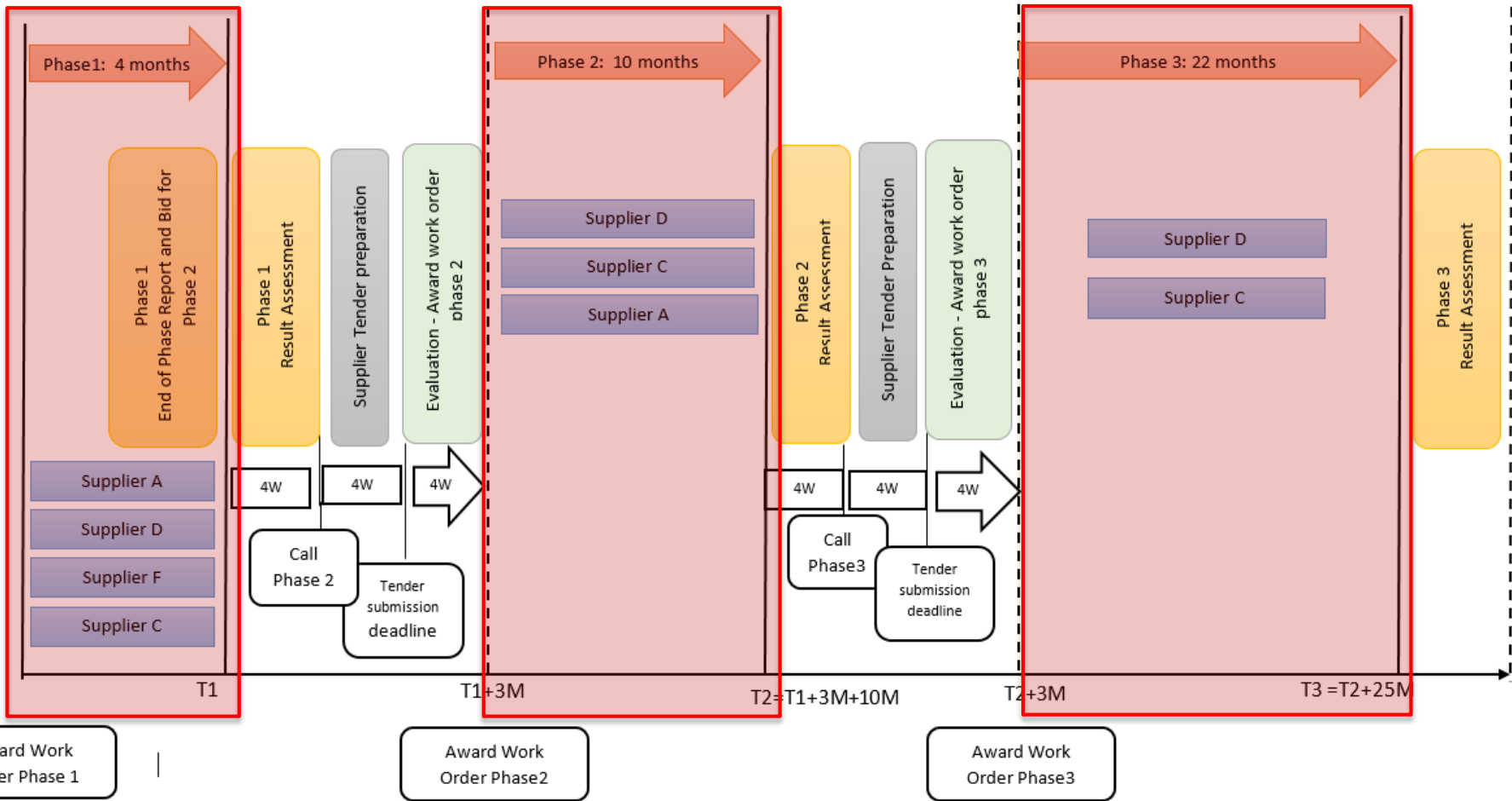


# Phase-by-Phase

Phase 1  
Conceptual Design

Phase 2  
Engineering Design  
and prototyping

Phase 3  
First-of-a-kind and  
acceptance



## A note on Mock-ups

- In phase 2, in order to demonstrate some critical step in the fabrication process, small scale prototypes of specific, critical components could be manufactured.
- The foreseen mock-ups should be detailed in the development and manufacturing plan.

# Notes on Tooling

- 2 types of tooling
  - Infrastructure tooling: winding machine, curing press...
  - Magnet tooling: winding mandrel, curing mold...
- Tooling procurement
  - Both types of tooling are part of the tender.
  - The timing of the tooling procurement is still in discussion and shall be defined in the manufacturing and development plan based on Consortia guidelines by each awarded company => budget allocation between phases is for now indicative

# Special components and materials

- Provided by CERN
  - NbTi insulated Cable
  - Quench heaters
  - Low carbon steel for magnetic yoke (Hot rolled: 5.8 mm thickness, 650 x 3000 to 4000 mm)
  - Warm magnetic measurements probe
  
- Provided by CERN upon request
  - Austenitic steel material
  - Rad hard Material for end parts

# Scope of Phase 1

- Perform preliminary magnetic design with field calculation
- Perform preliminary mechanical design
  - Evaluation of the mechanical forces in presence;
  - Conceptual design of the support structure;
- Communicate relevant parameters to the QUACO Consortium for quench protection study;
- Provide a preliminary CAD model of the magnet;
- Propose concept of tooling and processes for all phases:
  - Concept of coil fabrication tooling;
  - Concept of magnet assembly tooling;
  - Concept of manufacturing and assembly process;
- Describe work carried out at the company premises and subcontracted;
- Establish project documents

# Deliverables of Phase 1

- Project documents
  - Detailed schedule for 3 phases
  - QA/QC plan for phase 1 to 3 including Inspection and Test Plan (ITP)
- Development plan including detailed plan for the mock-ups to be developed in phase 2 and manufacturing process of the magnet.
- Preliminary CAD model of the magnet.
- Mid-phase report.
- Conceptual design report covering all the results obtained in Phase 1

# Scope of Phase 2

- Provide the detailed magnetic and mechanical calculation ;
- Iterate with consortium representative to implement the results of the quench protection analysis;
- Provide the detailed magnet CAD model and the detailed magnet tooling CAD model;
- Establish the plan for instrumentation ;
- Establish manufacturing and assembly procedures;
- Establish the manufacturing drawings of
  - The coil components, coil fabrication tooling, mechanical support structure components, magnet assembly tooling.
- Demonstrate manufacturing processes by fabrication of mock-ups if necessary including dedicated tooling;
- Procure the magnet components/tools according to manufacturing plan (excluding the components provided by the consortium);
- **Demonstrate the capability to start magnet fabrication 3 months after the beginning of phase 3** from a magnet components point of view as well as from a tooling standpoint.

## Deliverables of Phase 2

- Manufacturing plan of the quadrupole magnet showing that the schedule can be met in phase 3.
- Manufacturing and assembly procedures.
- Manufacturing drawings of:
  - Coils and coil components;
  - Support structure components;
  - Magnet fabrication tooling.
- Mock-ups in agreement with development plan.
- Quarterly status reports.
- Engineering design report covering all the results obtained in Phase 1&2.



## Scope of Phase 3

This phase consists in the manufacturing of the Q4 model designed in phases 1 and 2

- Procure the magnet components/tools according to manufacturing plan (excluding the components provided by the consortium);
- Perform coil winding and curing;
- Manufacture the iron yoke components;
- Manufacture the mechanical structure components;
- Manufacture the connection box of each aperture;
- Implement Instrumentation;
- Perform QC Measurements during the whole manufacturing process;
- Prepare for shipping, ship and deliver to the consortium.

## Deliverables of Phase 3

- Q4 quadrupole delivered to the QUACO Consortium.
- Quality control and test reports in compliance with functional specification.
- Quarterly status reports.
- Final Manufacturing report including all the results obtained in phase 1 to 3.

# Interfaces with the cold mass and cryostating

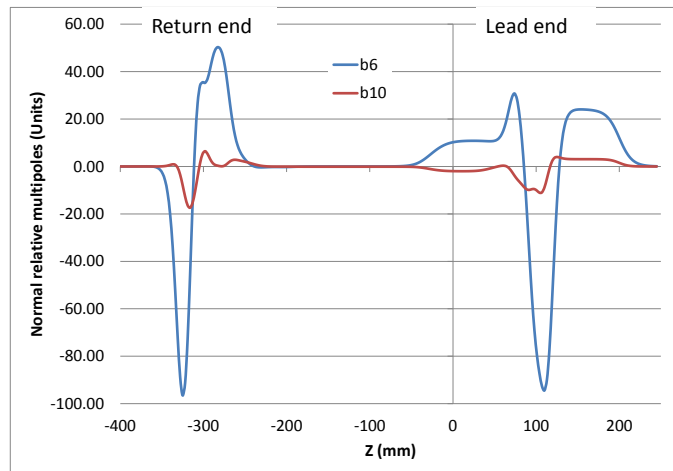
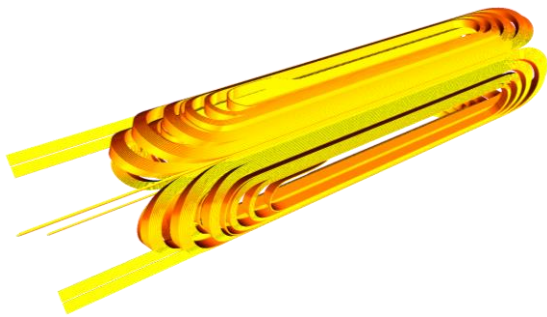
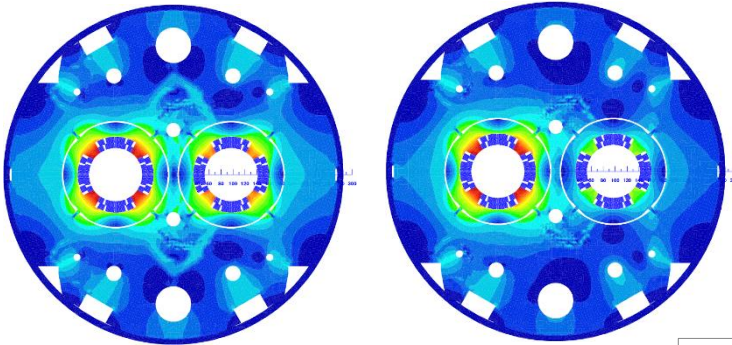
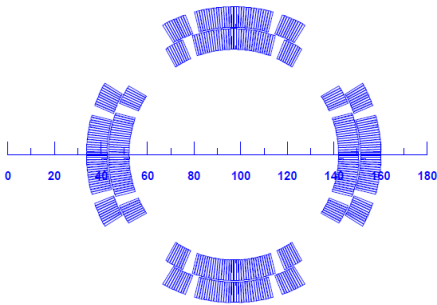
- Components to be accounted for the integration of the magnet in the cold mass and the cryostat and with which compatibility must be ensured
  - Bus bar and powering circuit.
  - Correctors magnet which will be assembled in the same cold mass (yoke diameter, cooling holes).
  - Magnet handling features.
  - Supports of the magnet in the cryostat.
  - Alignment features.
  - Yoke features for LHe containment assembly.
  - ...
- The final interfaces details will be provided by the QUACO Consortium at mid-term of phase 1.

# First-of-a-kind acceptance

- QA/QC plan and results
  - Electrical integrity
  - Mechanical measurements
- Magnetic measurements at room temperature.
- The cold test of the assembled magnet is not part of the scope of QuaCo.

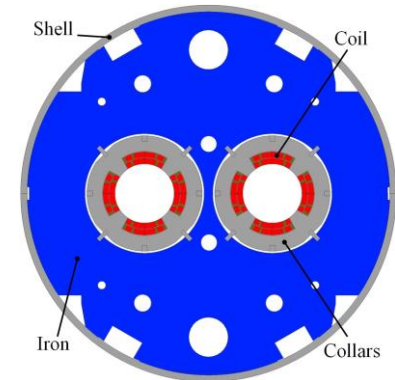
# Example of the short model

- Single aperture magnet
- Cross-section optimized for double aperture
- End design optimized to minimize integrated harmonics

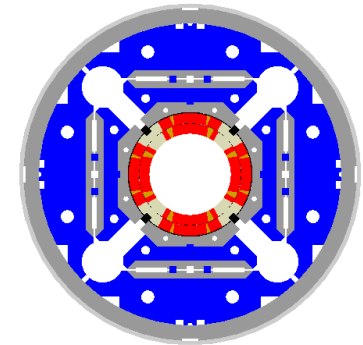


# Mechanical Support structure

- Design options are open
  - Collars technology



- Shell-based support structure (bladder and keys)



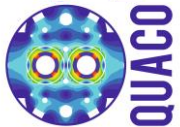
- Technical solution chosen by the awarded companies will be evaluated during each phase result assessment

# Post-QuaCo: Perspectives

- QuaCo is dedicated to the Q4/MQYY prototypes or « first-of-a-kind »
- Following QuaCo a small series of 4 to 6 Q4 magnets will need to be built (2020-2023)
- Spare LHC magnets:
  - 5 MQ magnets, 2020-2023
    - Double aperture, 3.1 m magnetic length at 1.9 K, 56 mm aperture
  - 5 MQY magnets, 2023-2025
    - Double aperture, 3.4 m magnetic length at 4.5 K, 70 mm aperture



*Questions?*





DIMENSION  
 <=6 > 6 > 30 > 120 > 300 > 1000 > 2000  
 USAGE: MOTOY/MEDIUM MACHINING  
 GENERAL TOLERANCES  
 GENERAL FINISH

DESSIN, RUGOSITE, TOLERANCES  
 SELON NORMES ISO  
 DRAWING, RUGOSITY, TOLERANCES  
 ACCORDING TO ISO STANDARDS

PROJECTION

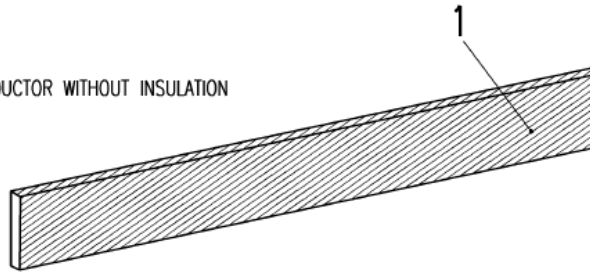
ORGANISATION EUROPEENNE POUR  
 LA RECHERCHE NUCLEAIRE  
 EUROPEAN ORGANIZATION FOR  
 NUCLEAR RESEARCH

CEA

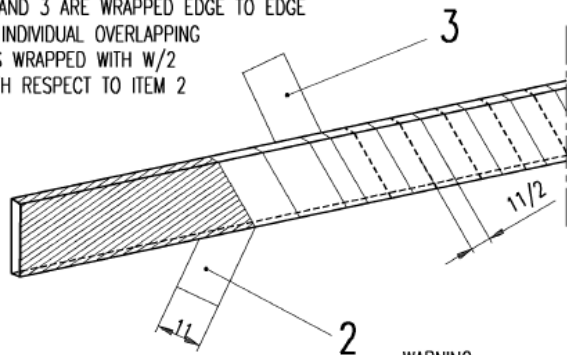
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 This drawing may not be used for commercial purposes without written authorisation

THE REPRESENTATION IS NOT AT SCALE

CONDUCTOR WITHOUT INSULATION

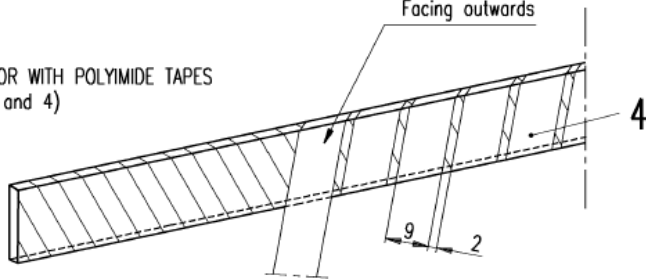


CONDUCTOR WITH FIRST TWO INSULATION POLYIMIDE TAPES  
 ITEMS 2 AND 3 ARE WRAPPED EDGE TO EDGE  
 WITH 0% INDIVIDUAL OVERLAPPING  
 ITEM 3 IS WRAPPED WITH W/2  
 SHIFT WITH RESPECT TO ITEM 2



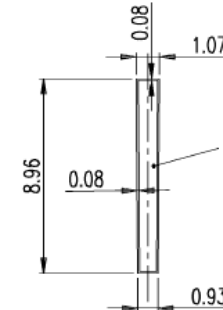
WARNING  
 Adhesive coating  
 Facing outwards

CONDUCTOR WITH POLYIMIDE TAPES  
 (Items 2 and 4)



INSULATED CONDUCTOR AFTER CURING AND UNDER  
 NOMINAL COMPRESSION AT ROOM TEMPERATURE

SCALE 5:1



QUANT.	DESCRIPTION	POS	MAT.	OBSERVATIONS	REF.CERN
	TAPING	4	Polyimide film	0.055x9 with adhesive on the outside (220 LCI)	
	TAPING	3	Polyimide film	0.025x11 (100 HN)	
	TAPING	2	Polyimide film	0.025x11 (100 HN)	
	CONDUCTOR	1	NbTi in Cu-matrix		
ENS/ASS	LHCMQM__002		S.ENS/S.ASS	LHCMQM__003	
INSERTION QUADRUPOLE MQM					
CONDUCTOR INSULATION WITH 3 LAYERS					
MQM MODEL MAGNET					
ISOLATION CONDUCTEUR A 3 COUCHES					
MODELE AIMANT MQM					
ECHELLE SCALE			DES/DRA. H. TURSLIN 1999-12-16		
5:1			CONTROLLED G. TRINQUART 2000-11-21		
1:1			RELEASED J. LUCAS 2000-11-21		
			APPROVED R. OSTOJIC 2000-11-22		
			LHC\MQM__O\MQM__O24		
			REPLACE/REPLACES		
RELEASED BY	FOR	QAC	LHCMQM__0024		
PROJECT LEADER OFFICE	INFORMATION	A	SIZE	IND.	
			3	A	

IND.	DATE	NOM/NAME	ZONE	MODIFICATION
A	2000-10-26	MACEDO	-	Corrected insulation