Magnetic measurements on MQXFS4a at cryogenic temperature

Lucio Fiscarelli

WP3 meeting, 11/07/2018

Outline

MQXFS4a

- At cryogenic temperature (1.9 K)
  - Magnetic measurement systems
  - Measurement results
    - Transfer function
    - Multipoles
    - Magnetic shimming
    - Field repeatability

Current cycles

Reference current levels

Current [kA]	Symbol	Gradient [T/m]	Remarks
0.02	I_{warm}	0.18	At ambient temperature
0.2	I_{res}	1.80	Reset level after pre-cycle. It was 0.1 kA on MQXFS5
0.96	I_{inj}	8.50	Injection level
6.0	I_{lim}	48.80	Current limit (pre-training)
16.48	I_{nom}	132.60	Nominal level
17.76	I_{ult}	143.20	Ultimate level

Pre-cycle (applied to all measurements):

- From 100 to I_{nom} at 14 A/s,
- Hold for 300 s at I_{nom},
- Ramp down to I_{res} at 14 A/s
- Hold for 0 s at I_{res}
- Ramp to I_{inj} at 14 A/s

Studies performed:

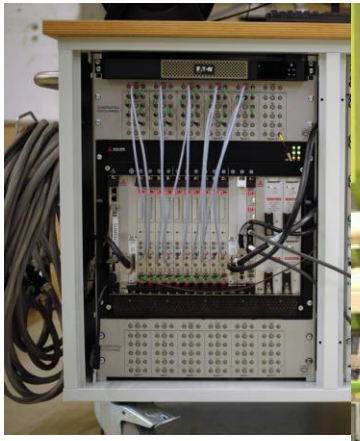
- Stair-step cycle (21 current steps)
- Machine simulation cycles to I_{nom}
- Machine simulation cycles to I_{nom} with gradient coil

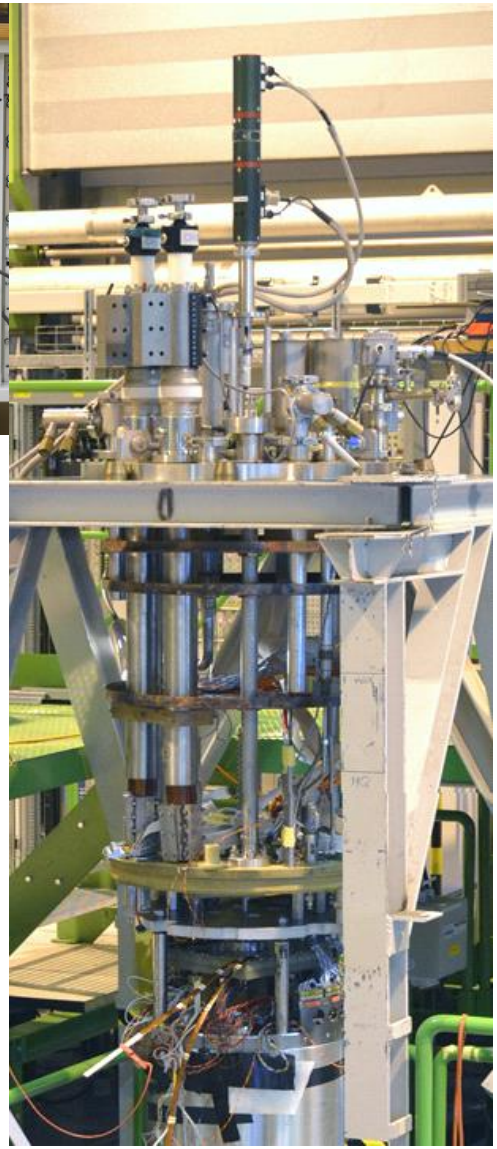
HiLumi HL-LHC PROJECT

Measurement system at cryogenic temperature

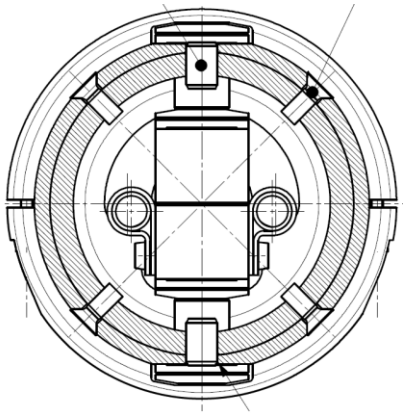
FAME at cryogenic temperature in SM18

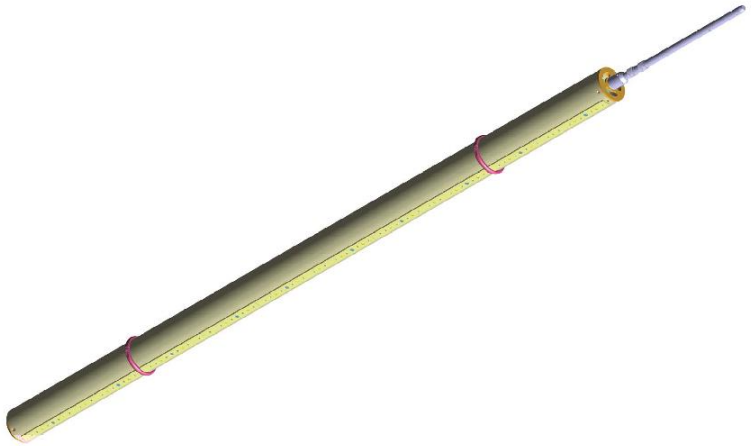
- FFMM software
- Fast Digital Integrators (10x)
- Motor + encoder + slip-ring unit (MRU)
- Vertical rotating shaft
  - L = 420 mm x 5 segments





Coil	unit	A	B	C	D	E
Inner length	mm	420	420	420	420	420
Magnetic surface	m^2	0.36	0.36	0.36	0.36	0.36
Measurement radius	mm	43.62	19.6	0.03	19.6	43.62





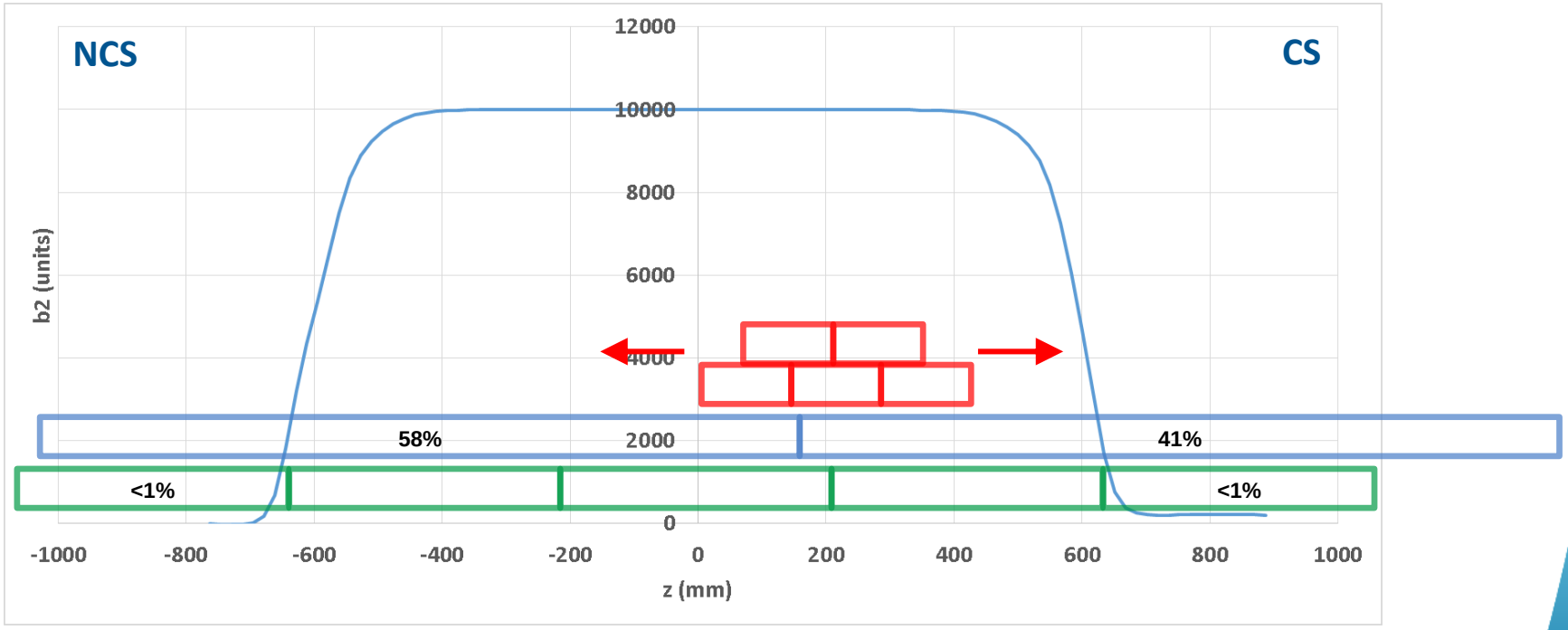
Position of the probes

Horizontal rotating shafts for measurements at room temperature

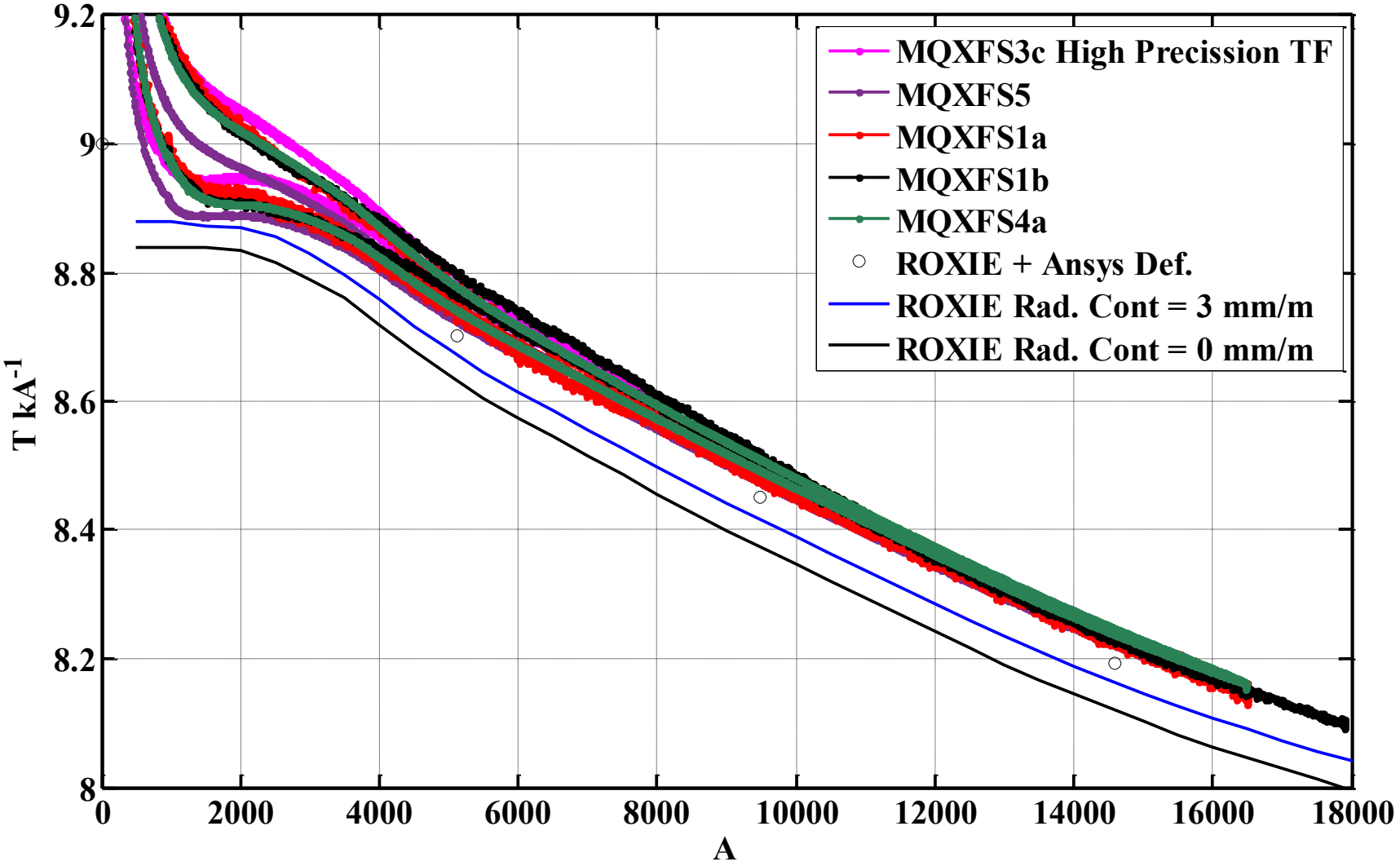
- L = 130 mm
- L = 1200 mm

Vertical rotating shafts for measurements at cryogenic temperature

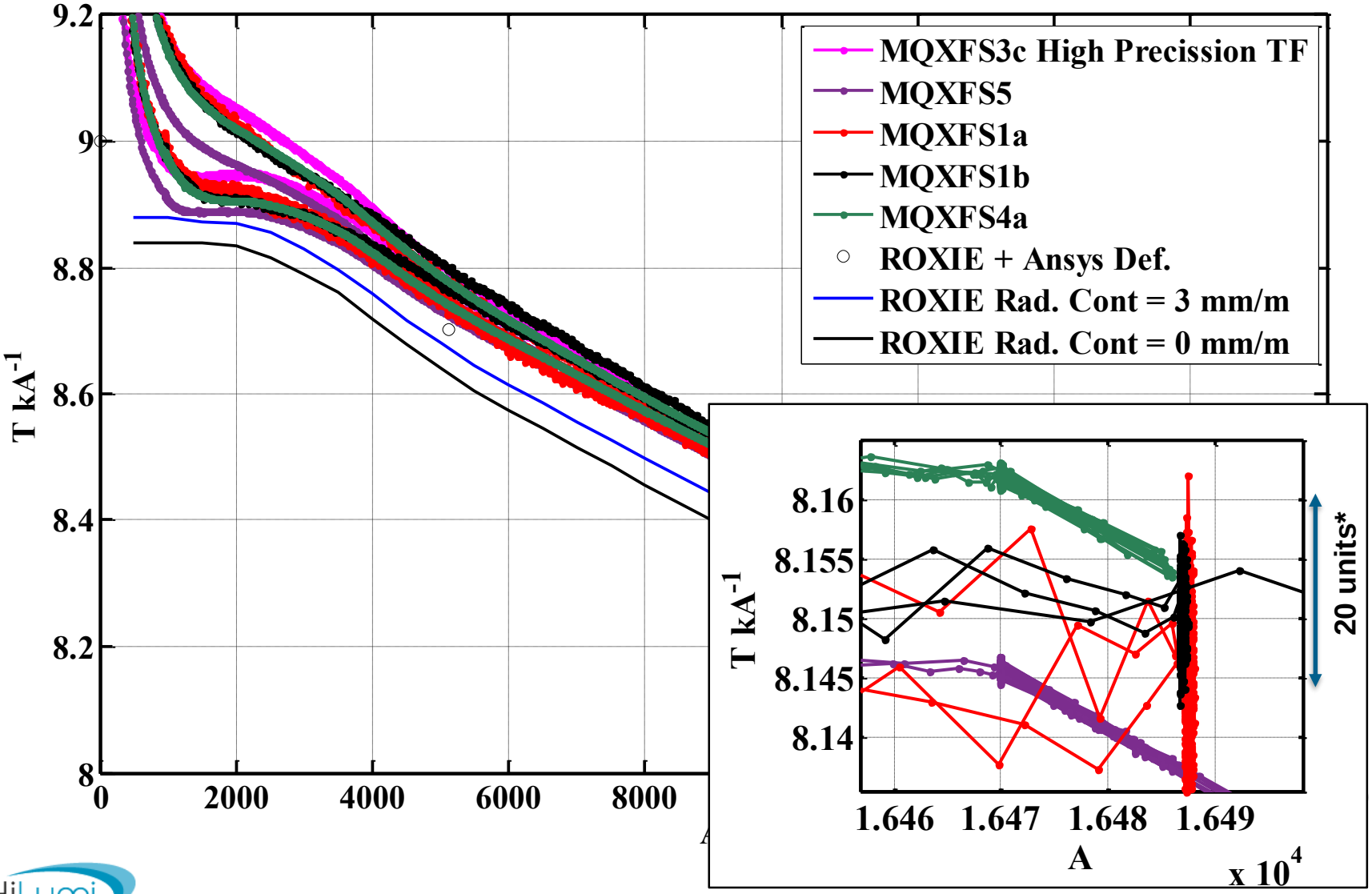
- 5 x L = 420 mm



Transfer function

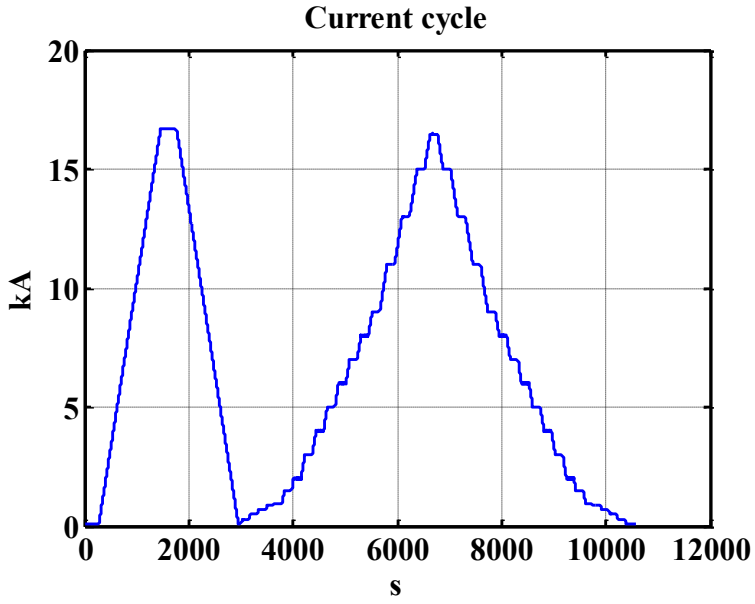


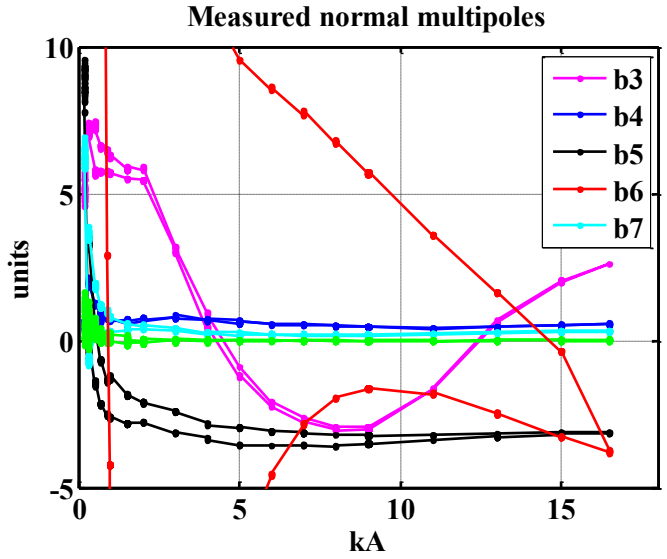
Transfer function

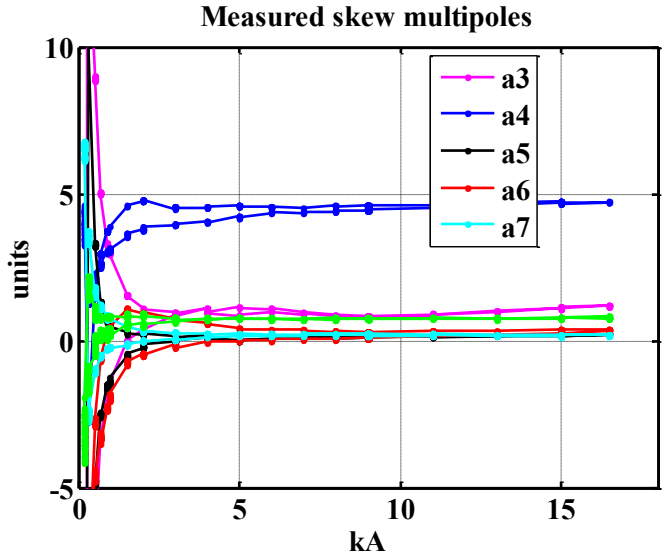


* In the same range of the measurement uncertainty (calibration)

Multipoles





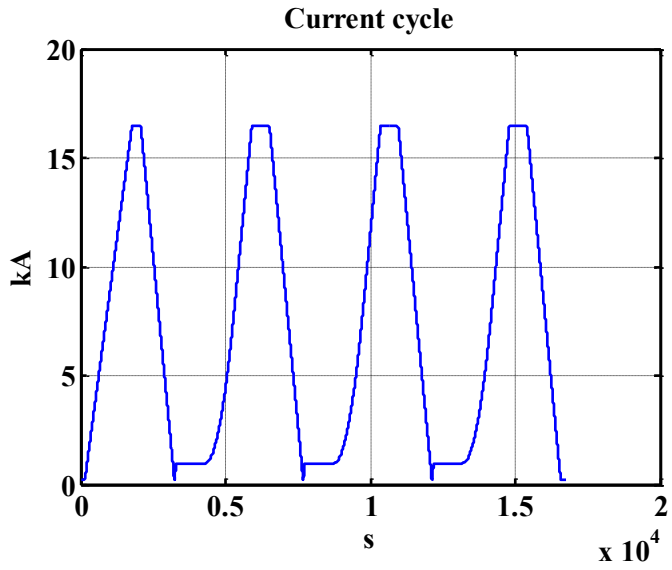


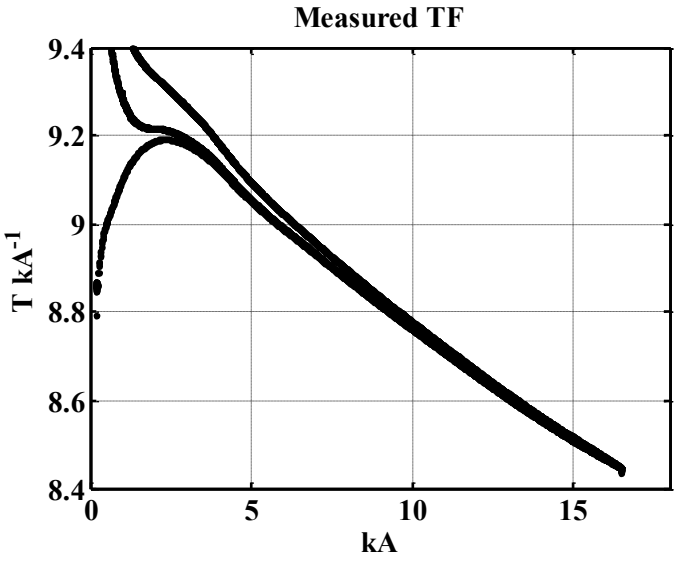
	I_{inj}	I_{nom}	I_{inj}	I_{nom}
n	**bn**		**an**	
3	5.71*	2.61*	2.94	1.18
4	0.73	0.55	3.89	4.75
5	-2.62	-3.16	0.51	0.21
6	-4.23	-3.78	0.47	0.37
7	0.31	0.32	-0.24	0.18
8	-0.03	0.01	0.83	0.78
9	-0.08	-0.27	-0.10	0.12
10	2.73	0.09	-0.18	-0.01

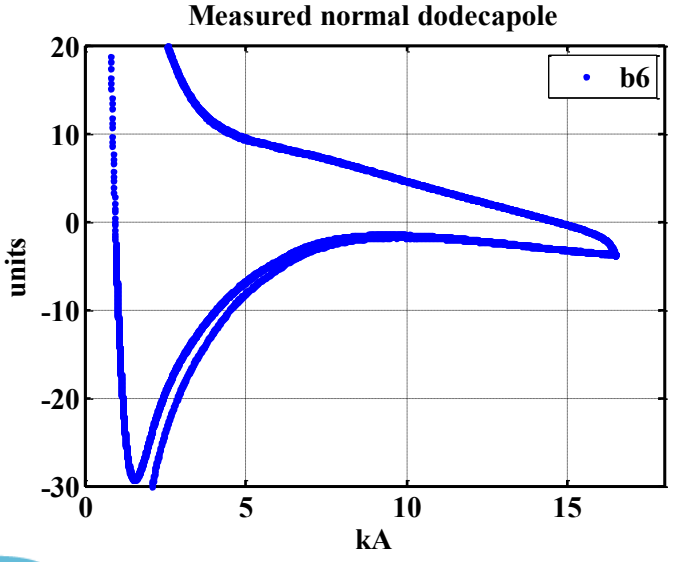
* Magnetic shims

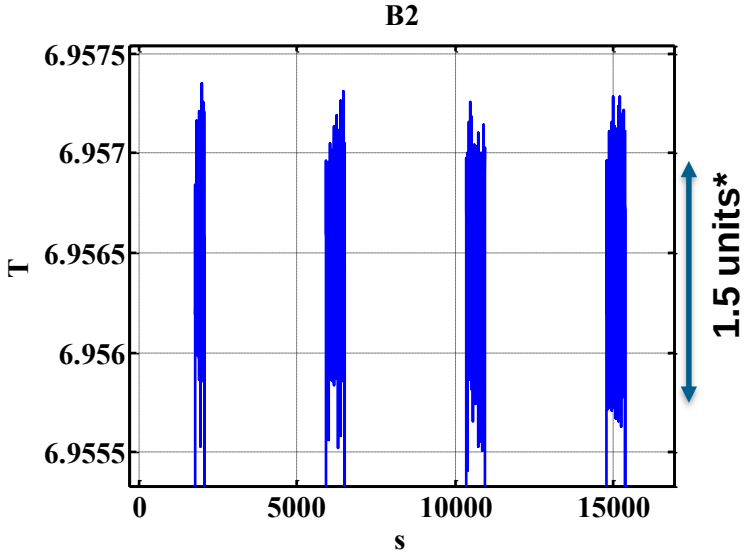
The reference frame is different wrt MM at ambient temperature

Field repeatability









* In the same range of the measurement precision (noise)

Conclusions

MQXFS4a

- Preliminary results of MM tests at 1.9 K
  - Performed cycles: “stair step” and “machine cycles”
  - Transfer function in agreement with previous models
  - Multipoles same as at ambient temperature
  - Magnetic shimming with expected effect
  - Main field repeatability (cycle to cycle) ~ 1 unit

Status of magnetic measurement systems in view of next magnets

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Outline

- MCBRDP1 “CCT proto”
  - September 2018
- MBRDS1 “D2 short model”
  - October 2018
- MCBXFBP1 “nested orbit corrector”
- HO “12-pole” and “skew quad” protos
  - December 2018
- MQXFBP1 “QXFB proto”
  - June 2019

MCBRDP1 and MBRDS1: new shafts

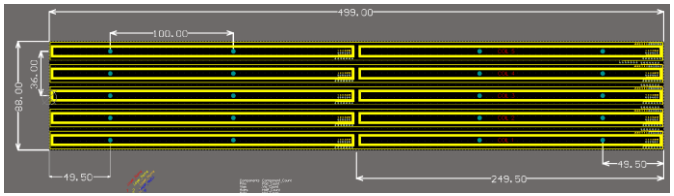
Ø 105 mm, L= 2.5 m, 5 (10) segments
3 shafts required

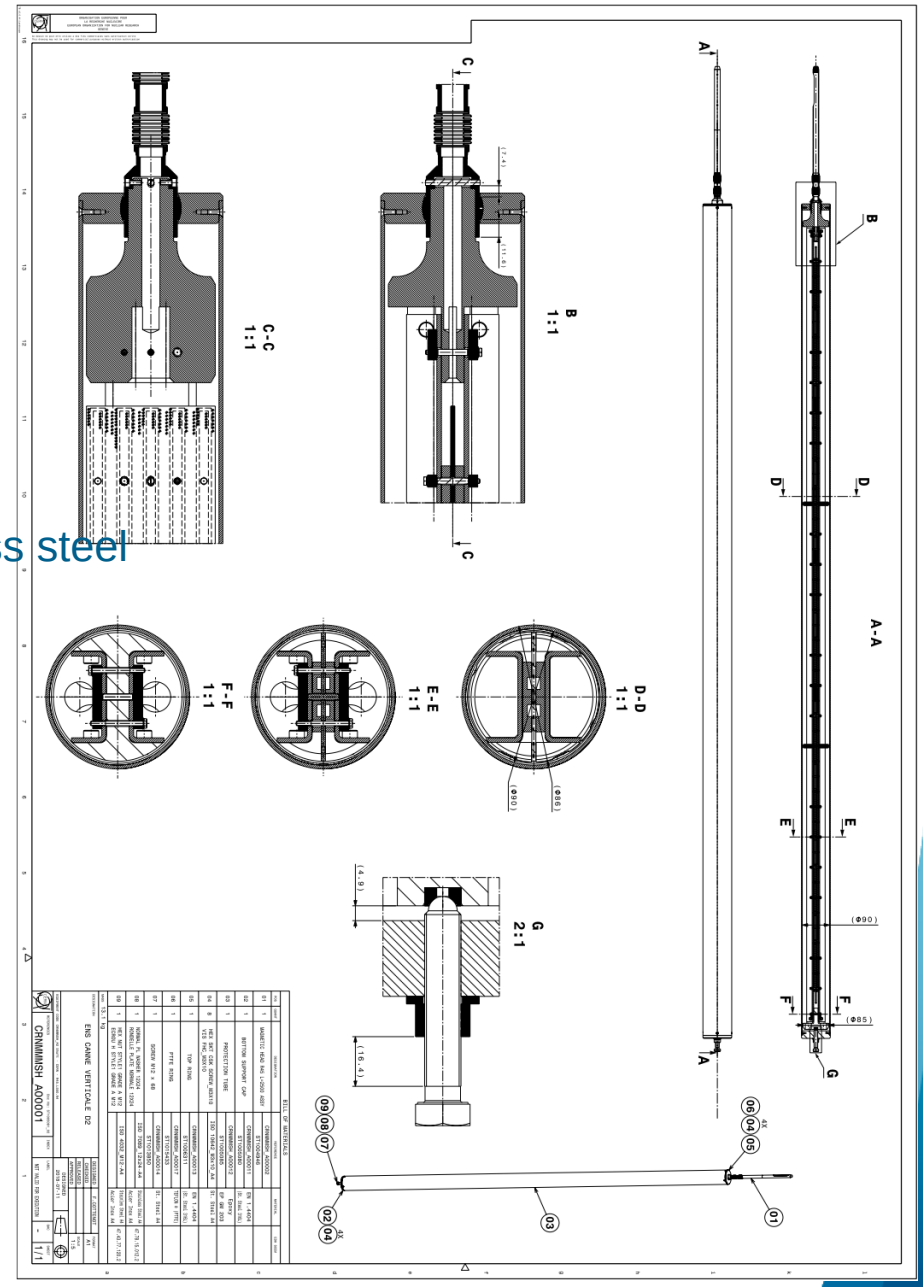
- **Structure elements (Design Office)**
  - 8 pieces
    - U-shaped profiles, G11
    - Shims, G11
    - End caps, G11
    - Protection tube, G11
    - Tube caps, stainless steel
    - Mechanical/electric extension, stainless steel

Final drawings released
Procurement ongoing

- **PCBs (PCB service)**
  - 5 PCB's each shaft
  - length 500 mm
  - Coil length 500 mm or 2x 250 mm

PCB service is going to produce (1 month)



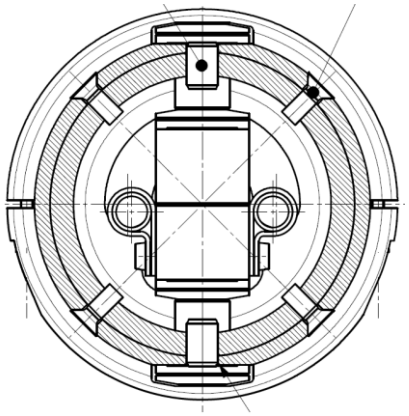


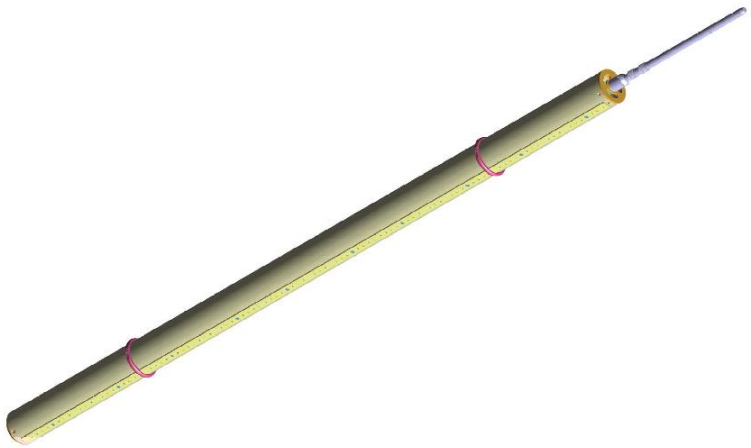
MCBXFBP1: reuse of existing shaft

Shaft already used for MQXF short models

- Vertical rotating shaft
  - L = 420 mm x 5 segments

Coil		A	B	C	D	E
Inner length	mm	420	420	420	420	420
Magnetic surface	m^2	0.36	0.36	0.36	0.36	0.36
Measurement radius	mm	43.62	19.6	0.03	19.6	43.62





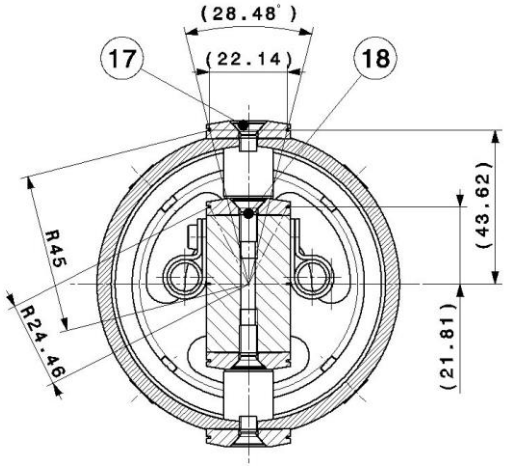
HO “12-pole” and “skew quad” protos: reuse of existing shafts

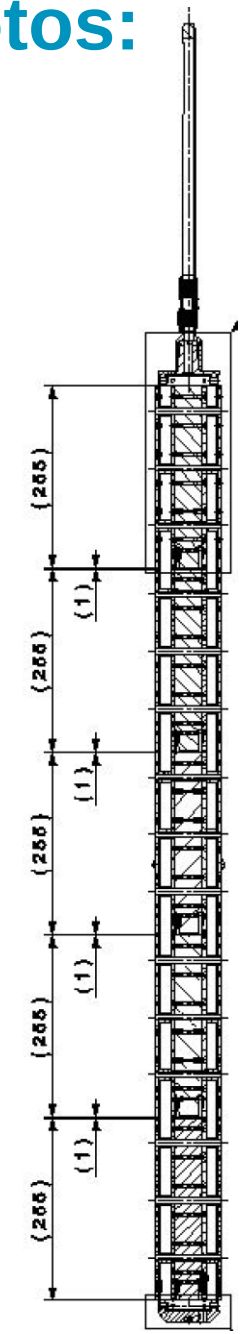
Shaft already used for other HO prototypes

- Vertical rotating shaft
  - L = 255 mm x 5 segments

Option to send the shaft to LASA and perform MM there

Coil		A	B	C	D	E
Inner length	mm	255	255	255	255	255
Magnetic surface	m^2	0.36	0.36	0.36	0.36	0.36
Measurement radius	mm	44	22	0	22	44





MQXFBP1 “QXFB proto”

At ambient temperature

- Rotating-coil scanner prototype
- A support tube with inner diameter 100 mm is required

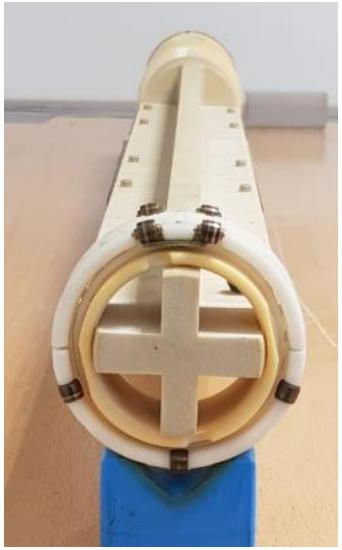
At cryogenic temperature

- Long shaft-chains
- An anti-cryostat is required

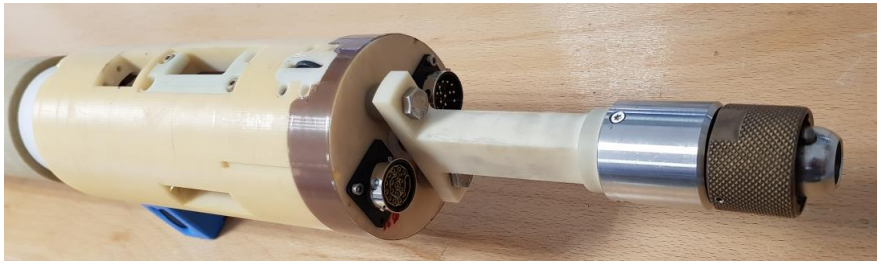
MQXFBP1: scanner prototype

“Travelling mole”

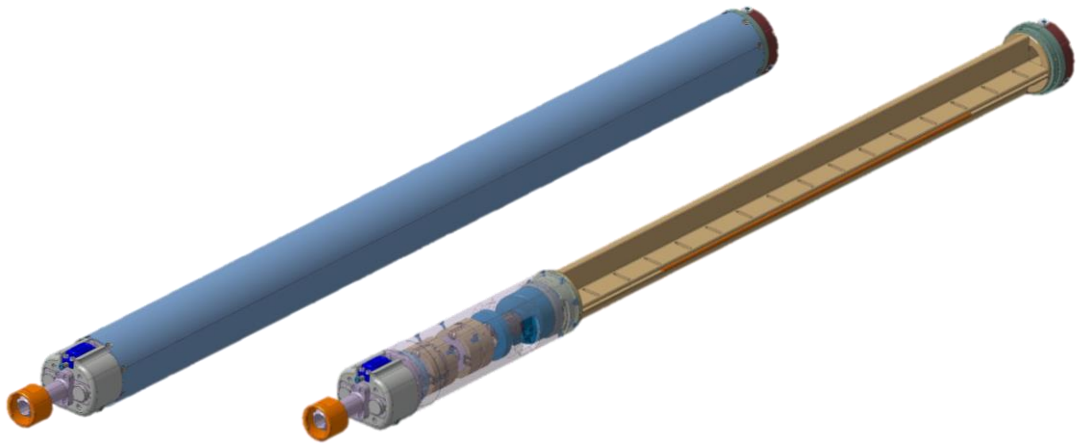
- Same approach as for the old “QIMM”
- On-board encoder and tilt sensor
- Motor unit fixed outside
- Mechanical extensions for translating and rotating the probe
- The probe is supported by a tube Ø 100 mm
- PCB coil with length 500 mm (100 mm)
- Measurement radius ~ 45 mm
- CCR targets for referring magnetic axis to external points
- Option for AC mode (to be tested)



The system is available and under test in our lab



MQXFBP1: scanner final version



- The design finished at the Design Office (production drawings)
- Open point on the inner diameter of the support tube

- The system for industry will require a positioning system
  - Motor unit on board and wire-actuated encoder

- This device will not measure the position of the cold bore tube (AC mole)

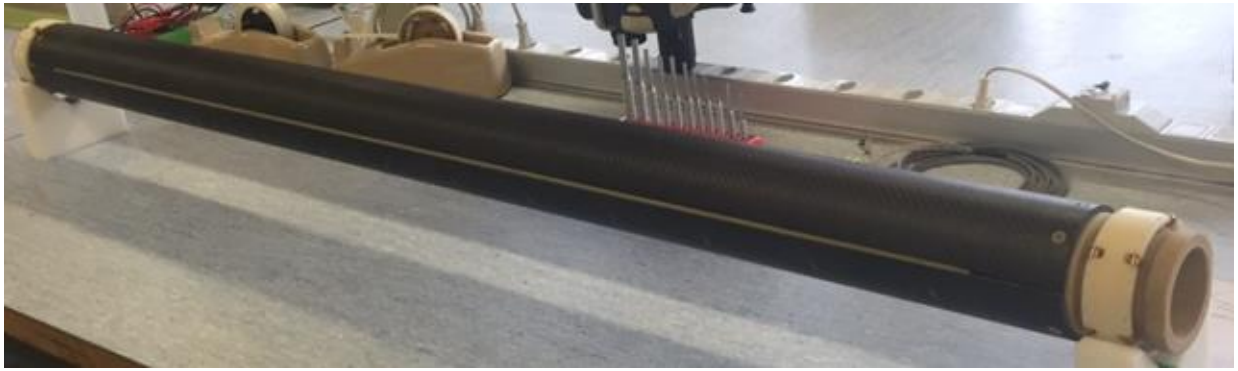
MQXFBP1: long shaft chains

- Design for the MQXFB prototype has to be lunched asap
  - Production lead time is >6 months
- Definition of some parameters
  - Diameter
  - Measurement coil length
- Drawings of cryo-assembly and anti-cryostat required
- Handling tools are required

MQXFBP1: long shaft chains

Carbon fiber shell + PCB radial coils

We have already produced 3 units (assembled and calibrated)



New feature:
retroreflectors on reference holes of the PCB

Accurate knowledge of the coil position
(integral field, magnetic length, longitudinal center)

Conclusions

- MCBRDP1 and MBRDS1
  - New shafts are in production
  - Procurement of G11 structure
- MCBXFBP1 and HO correctors
  - Reuse of existing systems
- MQXFBP1 “QXFB proto”
  - At ambient temperature
    - We have a prototype system
  - At cryogenic temperature
    - Design and procurement of the systems (1 year)