Testing of SuperFRS magnets in B180 - Update on the CERN/GSI Collaboration

Stephan Russenschuck for the testing team,

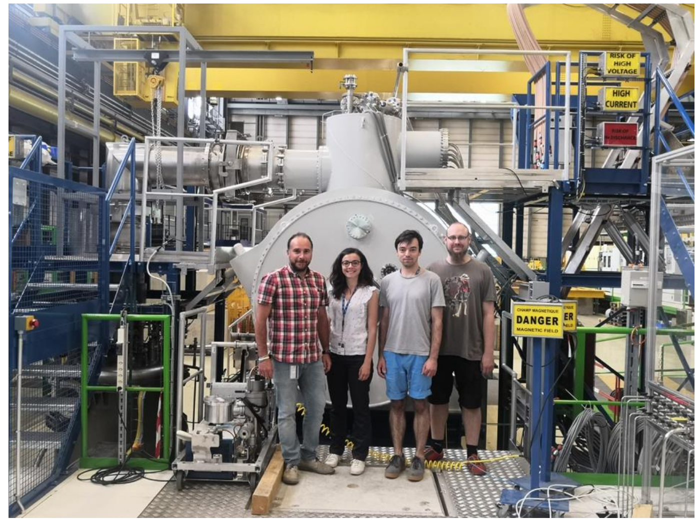
and with special thanks to Germana Riddone

and Antonella Chuichiolo for their input

19.11.2020

Overview

- Planning and organizational matters
- A few highlight from operation
- Results from magnetic measurements
- Next steps
- Resources
- Points needing attention



Testing @ CERN, History

Project leader
CERN: Luigi Serio
GSI: Pierre Schnizer

2010 — CERN-GSI Agreement K1727
General agreement on collaboration in accelerator science and technologies

2011

2012 — **Addendum No.2**
Cryogenic testing of SuperFRS Magnets at CERN

2013

2014 — Addendum No.4
Procurement of pre-cooler, QPS, Survey tools

2015 — Amendment to K1727
Extension of scope

2016 — Addendum No.5
Floor, control room

2017

CERN: Lisette Van Den Boogaard
GSI: Kei Sugita

2018 — **Addendum No.12**
Test facility operation phase

2019 — Books closed for project

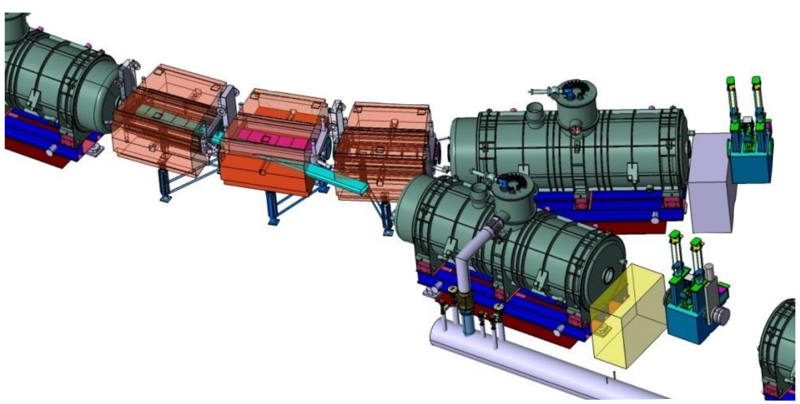
CERN: Stephan Russenschuck
GSI: Kei Sugita

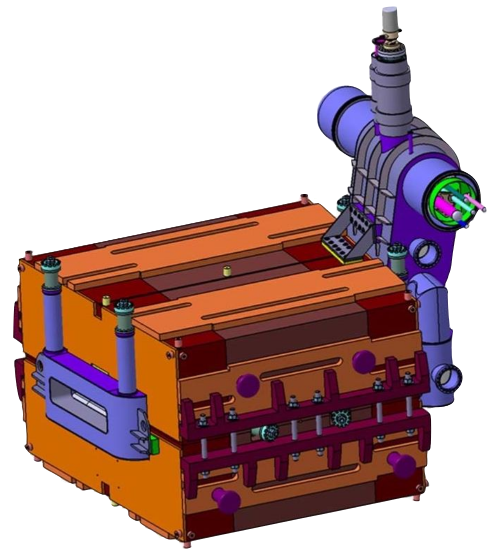
2020 — Operation in times of Sars-Cov-2

CERN: Germana Riddone

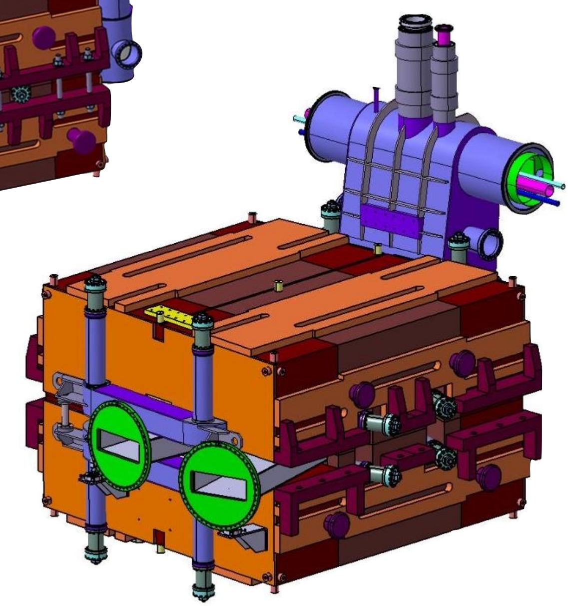
Dipole magnets

- ➔ Large aperture, 340 mm × 140 mm
- ➔ Weight: 60 tons
- ➔ L = 15.4 H, E = 450 kJ, I = 245 A
- ➔ Forced-flow cooling with 20x10 mm^2 tubes (heat-pipe thermosyphon)
- ➔ Warm iron yoke
- ➔ 24 dipole magnets (11 types of different bending angles)





Standard dipole



Branching dipole

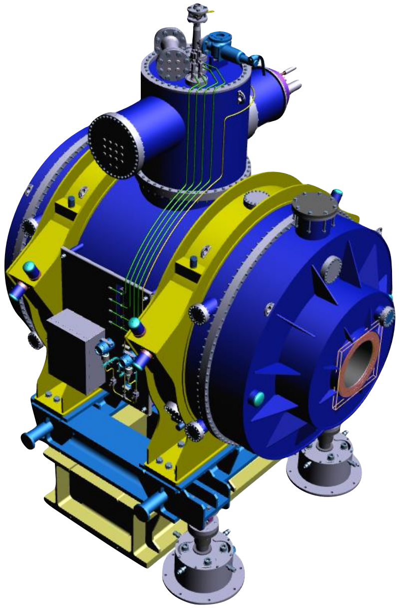
Elytt, CEA design, FAIR-China group

Multiplets

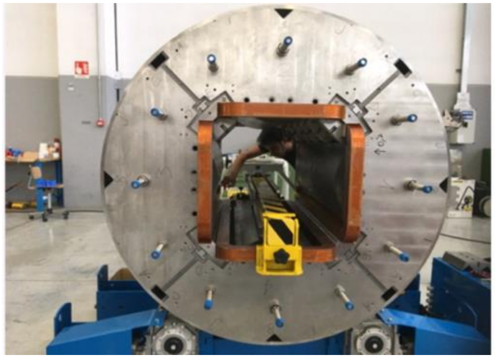
- ➔ Large aperture ø 380 mm
- ➔ Helium bath cooled (cold iron yoke, 4.5 K)
- ➔ Super-ferric, 1.2-m-long yoke
- ➔ L = 43 H, E = 950 kJ, I = 300 A
- ➔ Long and short quadrupoles + sextupoles, steerers, octupoles
- ➔ 30 (+ 2 spares) multiplets
- ➔ 25 – 60 tons
- ➔ max. 7 m

Long multiplet (max. 9 magnets)

Delivery to CERN 23.11.2020



Short multiplet (quad + sextupole)



ASG, CIEMAT design, Dubna

Multiplet configurations

- ➔ Combination of
  - long quadrupole magnet
  - short quadrupole magnets
  - sextupole magnets
  - steering dipole magnets
  - octuple magnets
- ➔ Positioning order in the cryostat
- ➔ 32 multiplets - **19 types**

The test facility must be compatible with all 30 types of magnets: 11 types of dipoles, 19 types of multiplets. In total 56 assemblies.

186 magnetic circuits

Cold mass contents													Type
Upstream		➡	➡	➡	➡	⊗	➡	➡	➡	➡	Downstream		
			ST		LQ		LQ		ST				A
			0.50	0.30	1.20	0.40	1.20	0.30	0.50				
				LQ		LQ		LQ					B
				1.20	0.40	1.20	0.40	1.20					
				LQ		LQ		LQ					B
				1.20	0.40	1.20	0.40	1.20					
				SE		SQ+OC							C
				0.50	0.25	0.80							
				SE		LQ							D
				0.50	0.25	1.20							
						LQ		SE					E
						1.20	0.25	0.50					
				SE		LQ							D
				0.50	0.25	1.20							
						LQ		SE					E
						1.20	0.25	0.50					
						SQ+OC		SE					F
						0.80	0.25	0.50					
					ST		SE						G
					0.50	0.25	0.50						
SE		SQ+OC		ST		LQ		Filler		SQ+OC			H
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ+OC		Filler		LQ		Filler		SQ+OC		SE	I
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		Filler		LQ		SE		SQ+OC		SE	J
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
		SQ+OC		SE		LQ		ST		SQ+OC		SE	K
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		ST		LQ		SE		SQ+OC			L
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ+OC		SE		LQ		Filler		SQ+OC		SE	M
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		Filler		LQ		SE		SQ+OC			N
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
SE		SQ+OC		SE		LQ		ST		SQ+OC		SE	O
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		ST		LQ		Filler		SQ+OC			H
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ+OC		Filler		LQ		ST		SQ+OC			P
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
SE		SQ+OC		Filler		LQ		SE		SQ+OC			N
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ+OC		SE		LQ		Filler		SQ+OC		SE	M
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		Filler		LQ		SE		SQ+OC			N
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
SE		SQ+OC		SE		LQ		ST		SQ+OC		SE	O
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		ST		LQ		Filler		SQ+OC			H
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ		Filler		LQ		Filler		SQ			Q
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
SE		SQ+OC		Filler		LQ		Filler		SQ+OC			R
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
SE		SQ+OC		SE		LQ		ST		SQ+OC		SE	O
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80	0.25	0.50	
SE		SQ+OC		ST		LQ		Filler		SQ+OC			H
0.50	0.25	0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
		SQ+OC		Filler		LQ		Filler		SQ+OC			Q
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			
					~~SQ+OC~~		~~SQ+OC~~						~~S~~
					0.80	0.25	0.80						
				SE		LQ							D
				0.50	0.25	1.20							
		SQ+OC		SE		LQ		ST		SQ+OC			T
		0.80	0.25	0.50	0.25	1.20	0.25	0.50	0.25	0.80			

Scope of the CERN/GSI (operations) agreement

- CERN prepares and maintains the test facility (test-facility management)
  - ✓ guarantees the safety and functionally of the facility
  - ✓ contributes 1.4 FTEs and organizes the Field Support Units (FSU)
  - ✓ supports GSI activities and trains personnel
  - ✓ provides standard tools, offices and IT network
  - ✓ covers energy cost
- GSI@CERN executes the magnet testing and magnetic measurements
  - ✓ deploys 4 FTEs to work at CERN (as COAS)
  - ✓ defines tests plan and procedures
  - ✓ gives support for operation, upgrade and maintenance of the interfaces
  - ✓ bears the operation costs (mainly cryogenics and handling)
  - ✓ bears the cost of FSU (20 person years, 4 per year)
    - ✓ In 2020 (and 2021) still better served with students

CERN Test facility

3 benches (one commissioned, second ongoing)

3 main cryogenic sub-systems

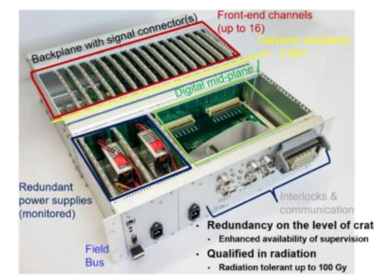
3 x ±500 A, ±120 V (LHC-type) for the main circuits + EE system with 2.8 Ohm resistance for the quadrupoles, 6 x ±600 A ±40 V for the corrector circuits, 9 load switches, interlocked (2 out of 9 commissioned).

9 Power converters, 3 with energy extraction

Load switches

Cryogenic plant

UQDS



3x3 UQDS units (new LHC baseline) for magnet protection

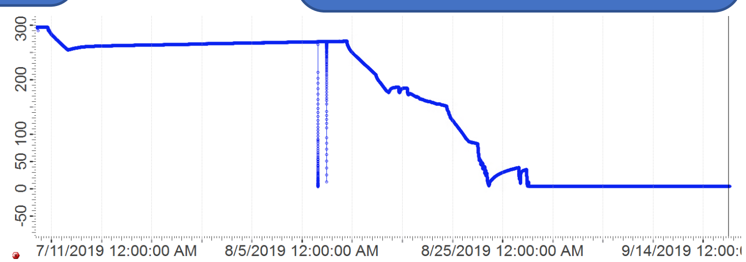
FoS Short Multiplet: July - December 2019

July 2019	August 2019	Sept. 2019	Oct. 2019	Nov. 2019	Dec. 2019

W27 W28 W29 W30 W31 W32 W33 W34 W35 W36 W37 W38 W39 W40 W41 W42 W43 W44 W45 W46 W47 W48 W49 W50 W51 W52 W1

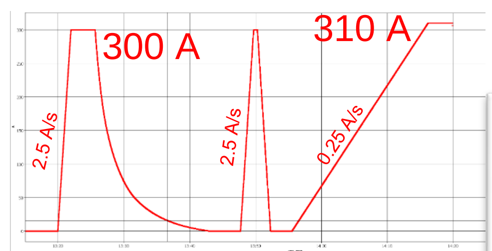
Powering

Cooldown Holiday season Cooldown



Quad Magnetic Measurements

Warmup



{50, 100, 200, 250, 300, 310}, Ult: 330 A

Stretched wire

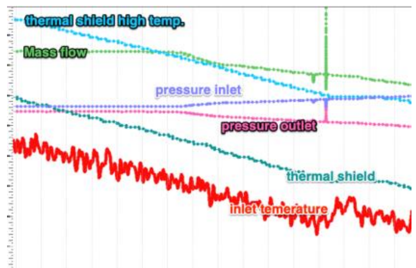
Rotating coil

New facility
New magnet
New instrumentation
New team

FoS testing and commissoning of the facility in parallel (Bench 1, so far)

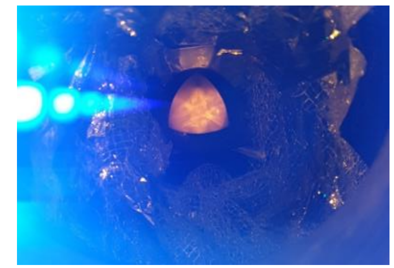
A few highlights: Cool-down

➔ 10. July – 3-week break – 9. August 2019

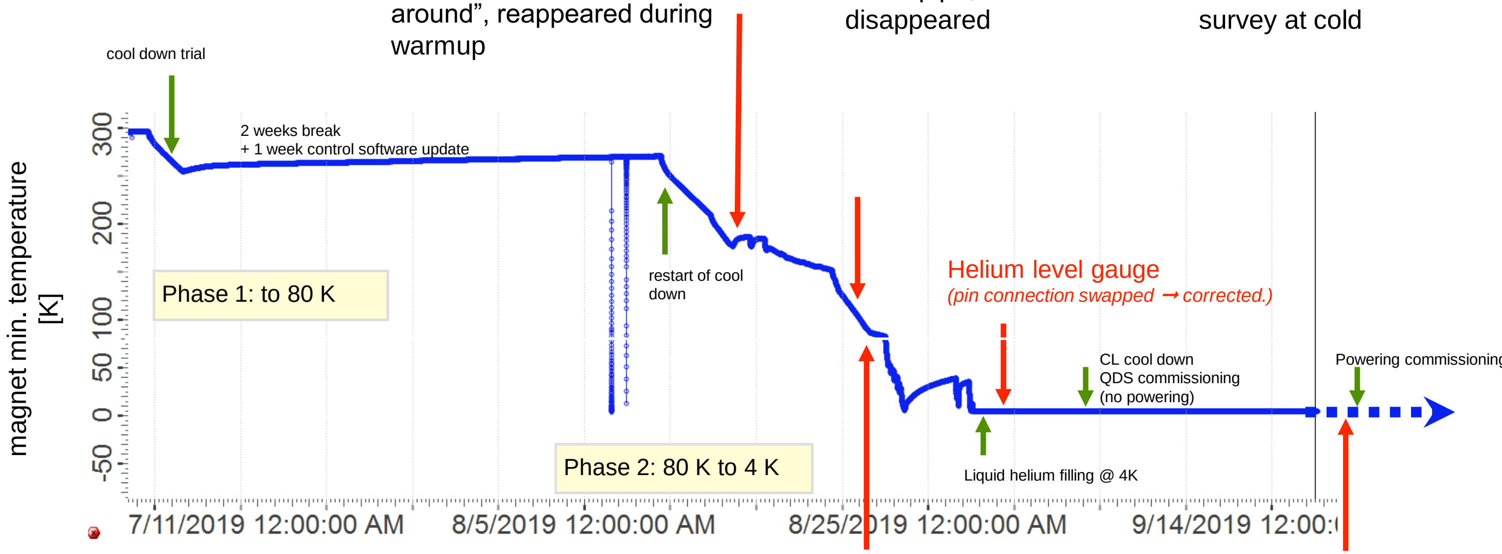


Thermal shield blocking
Disappeared after "playing around", reappeared during warmup

Condensation in beam pipe, later disappeared



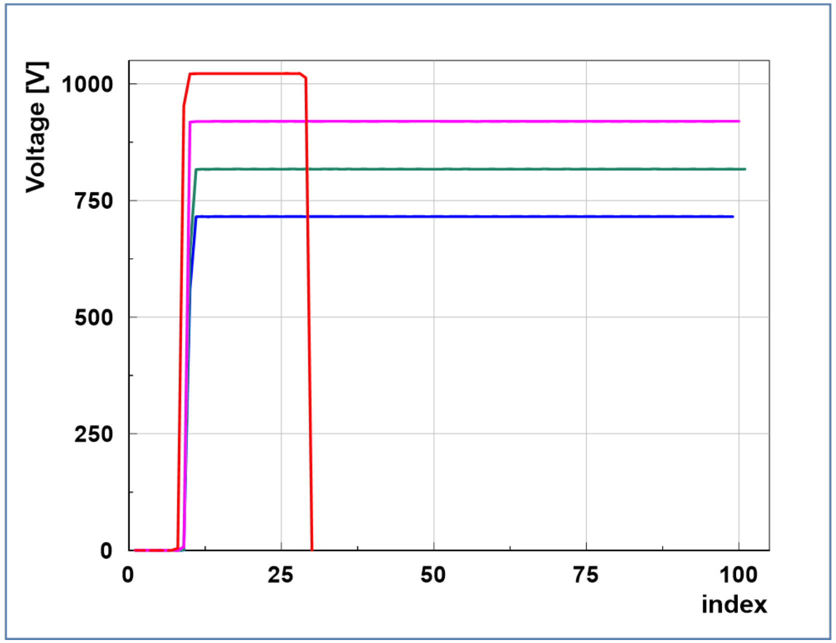
Condensation on the mirrors ➝ No cold mass survey at cold



Small helium leak to vacuum
(vacuum pump can manage it)

High voltage test failure at 1 kV
(under investigation, 3 kV passed at warm)

High Voltage Test at 4.5 K



- Quadrupole to ground (warm) @ 3 kV -> o.k.
- Sextuple to ground @ 200 V -> OK
- Quadrupole to ground @ 1000 V
- -> not o.k. at 1.1 bar LHe vessel pressure
- -> o.k. at 1.25 bar LHe vessel pressure
- No fault between sextuple and quadrupole
- **Possible fault location**: voltage taps at the cold terminal of a current lead

➔ Quadrupole current limited to 310 A, nominal 300 A, ultimate 330 A

Schedule January - June 2020

January 2020				February 2020					March 2020				April 2020				May 2020					June 2020				
W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25	W26	W27

Warmup

Cooldown

LQuad MM

Comm. RC.20

Sextupole MM

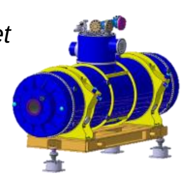
Comm RM.20& RC.20

Cross talk MM

Warmup

Transport to Bench 3

FoS Long Multiplet (9 magnets)



*Arrival LM

Installation on Bench 1

FoS Dipole

*Arrival Dipole

Installation on Bench 2

*Arrival SM

*these are based on the current schedule from the manufacturers.

Master Schedule: status 2020

Q1	Q2	Q3	Q4

TB 1

FoS SM Warmup

FoS Cooldown #2

Comm. RC.20

Covid-19 CERN Break

Cooldown #3

Sextupole MM

Comm. RM.20&RC.20

Stretched wire

Rotating coil

Cross talk

FoS SM Warmup

FoS SM transport to **TB2**

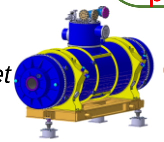
TB 2

Cooldown #4 Cryo commissioning

Possible powering

PA

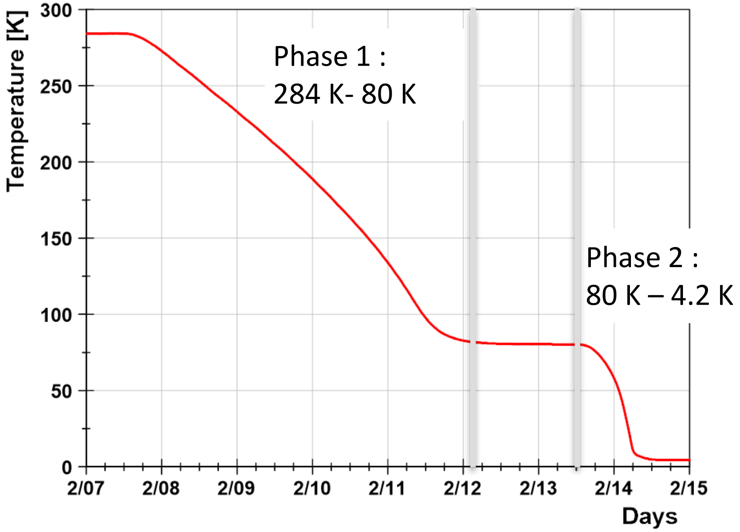
FoS Long Multiplet (9 magnets)



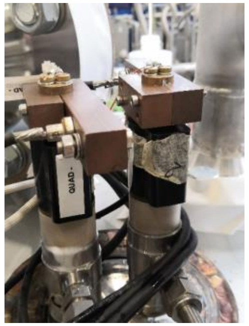
*Arrival FoS LM

Main Achievements – Test results (1)

- **Cooldown** within 40 K gradient over cold mass: duration ~7 days
- **HV test** at cold on Long Quadrupole passed at 1 kV and not at 1.5 kV
- Possible **leakage** on the Thermal Shield pipes (investigation on going on TB2)



- **Leakage** on current leads (reparation under discussion)
- **Heat loads** higher than expected: dedicated studies will be carried out on TB2 closing the holes (transport restraints and view ports) MLI plankets



Progress Meeting next Tuesday

B180 SC magnet test facility - Progress meeeting

Tuesday 24 Nov 2020, 09:00 → 11:00 Europe/Zurich

Videoconference Rooms: B180 SC magnet test facility - Progress meeeting — Join

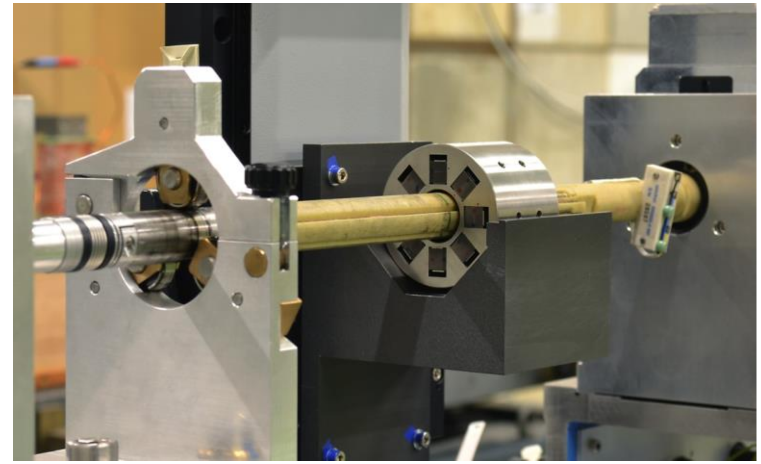
09:00 → 09:10	**Presentation of the agenda and aim of the meeting** **Speakers:** Dr Germana Riddone (CERN), Stephan Russenschuck (CERN)	10m
09:10 → 09:25	**Summary of activities in 2020** **Speaker:** Antonella Chiuchiolo (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE))	15m
09:25 → 09:35	**Cryogenic system: status, issues and next steps** **Speaker:** Thierry Dupont (CERN)	10m
09:35 → 09:50	**GSI control software maintenance and interface to TE-CRG: status, issues and next steps** **Speakers:** Matthias Michels (GSI - Helmholtzzentrum für Schwerionenforschung), Thomas Barbe (CERN)	15m
09:50 → 10:00	**Quench protection system: status, issues and next steps** **Speaker:** Daniel Calcoen (CERN)	10m
10:00 → 10:10	**Magnetic measurements: status, issues and next steps** **Speaker:** Mr Pawel Kosek (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE))	10m
10:10 → 10:25	**Power converters: status, issues and next steps** **Speakers:** Emilien Coulot (CERN), Hugues Thiesen (CERN)	15m
10:25 → 10:35	**Jumper interconnection and disconnection** **Speaker:** Gilles Favre (CERN)	10m
10:35 → 10:50	**Summary of activities in 2021** **Speaker:** Antonella Chiuchiolo (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE))	15m
10:45 → 10:55	**Conclusions**	10m

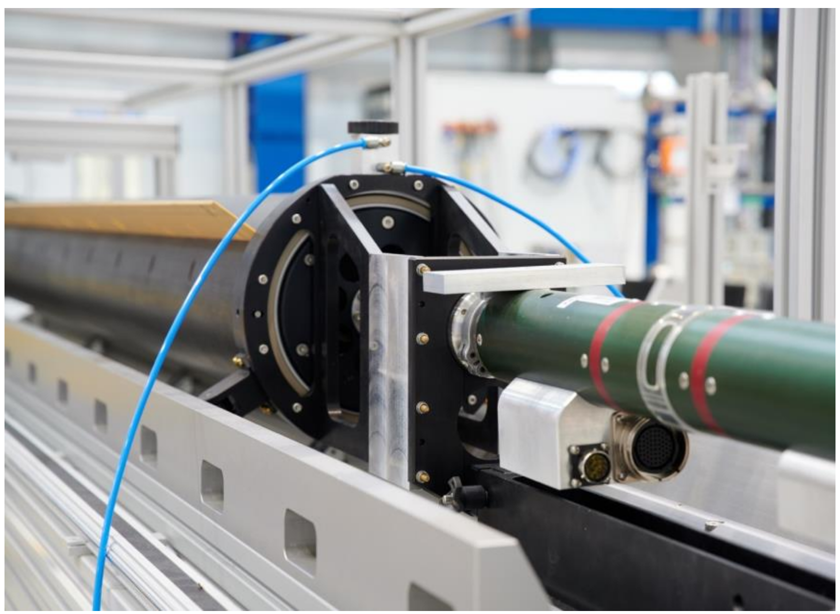
Magnetic measurements

- **FoS**
  - Time is available to measure both integrated and local field distribution and homogeneity
  - Each magnet must be measured with two systems (cross-calibration)
    - Dipoles: Stretched wire, moving fluxmeter, Hall-mapper
    - Multiplets: Stretched wire, rotating coils (+ longitudinal scanning)
- **Series**
  - Check magnet to magnet reproducibility
    - Stretched wire (coil and moving fluxmeter only if largely divergent)
    - Overall test plan required MM requires MM in less than 10 days, thus:
    - No contingency for tracing manufacturing errors.
    - No corrective actions for the magnet (shimming) is requested https://edms.cern.ch/document/1416580, but this may change.

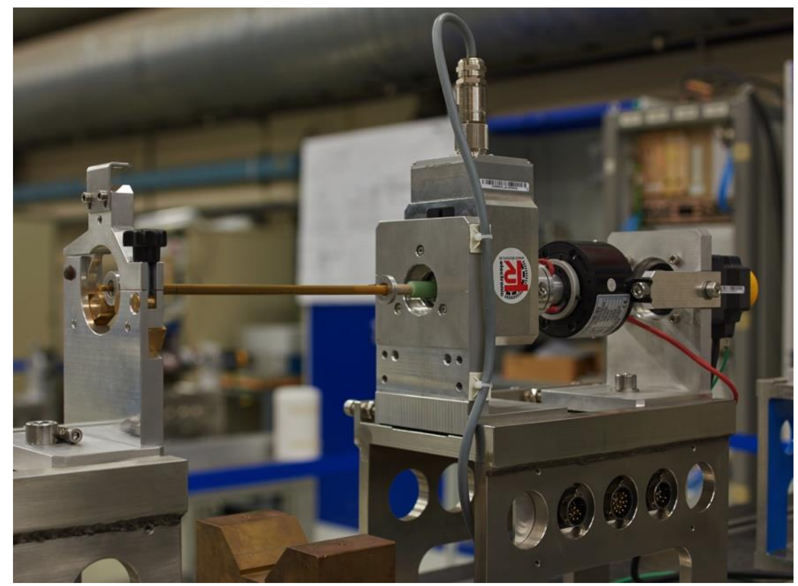
FAIR measurement requests have triggered MM R&D with nice synergies

Rotating Coil Systems



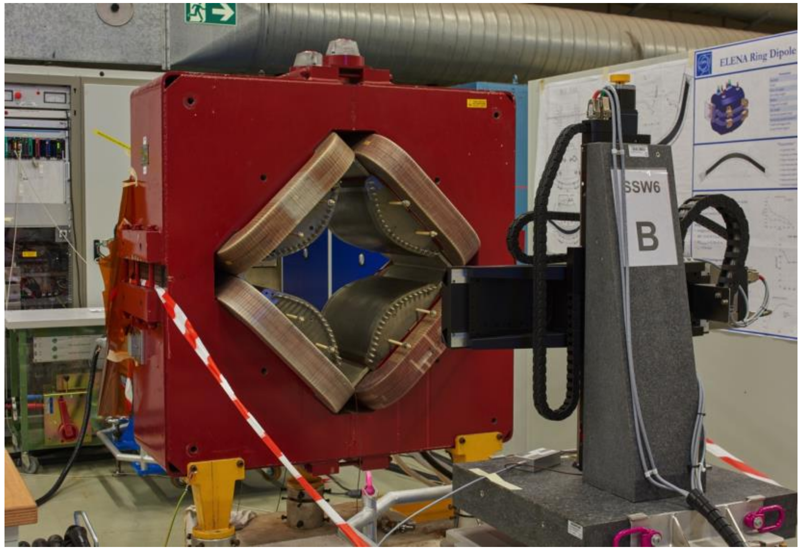


2.6 m
350 mm



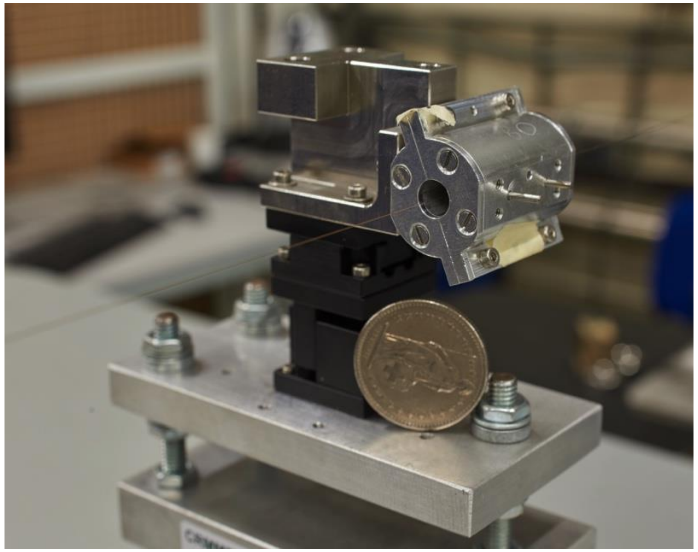
Carbon-fibre shaft, PCB induction-coil design qualified (also for HL-LHC), surface calibration can/must rely on manufacturing tolerances

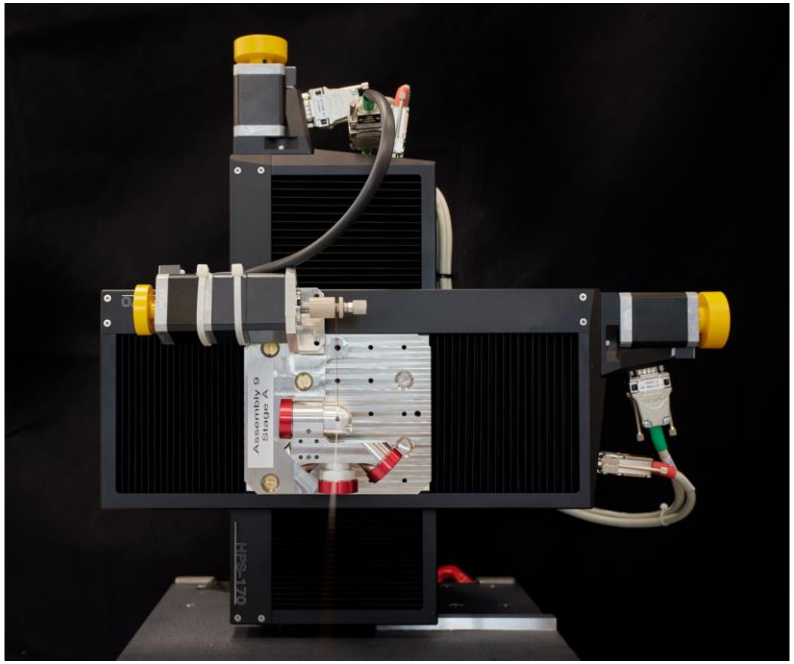
Stretched-Wire System

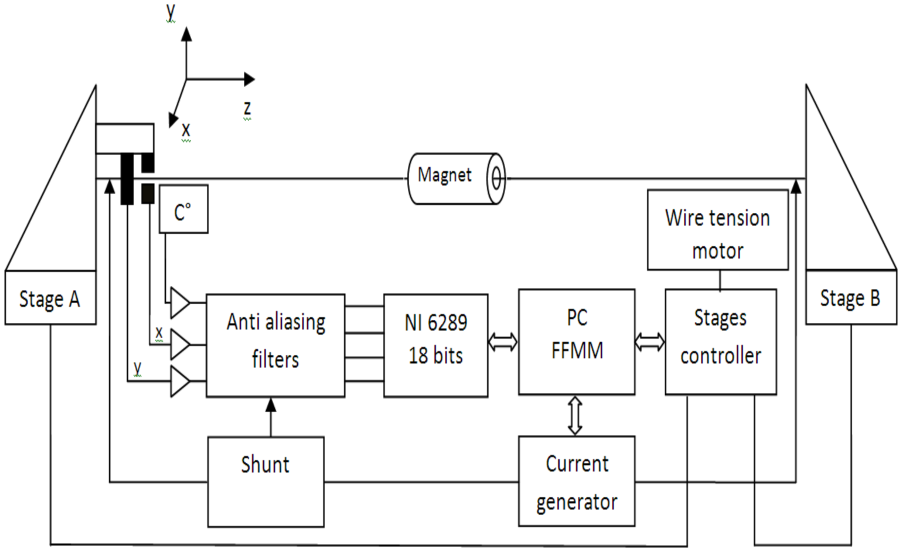


New system and techniques for large apertures

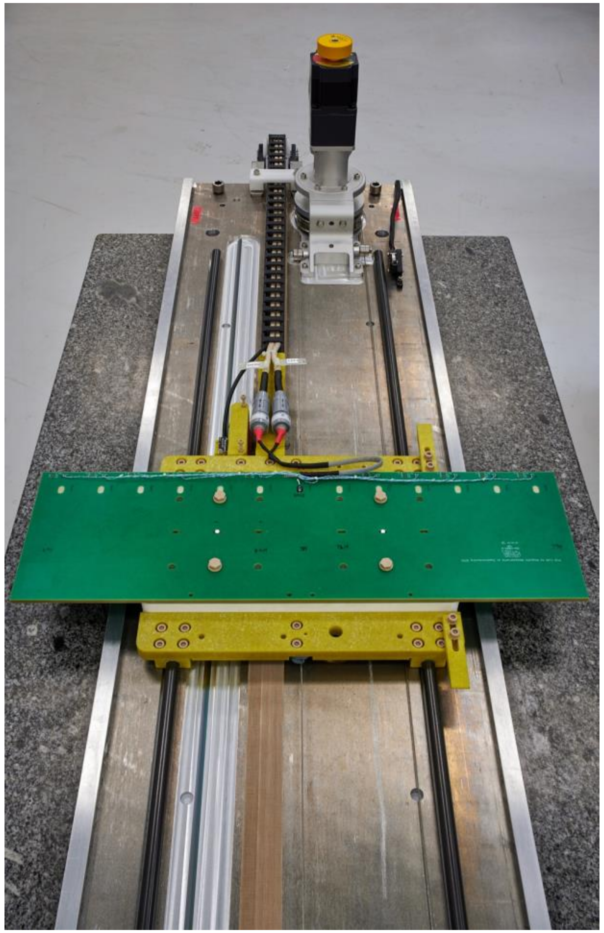
400 mm stroke

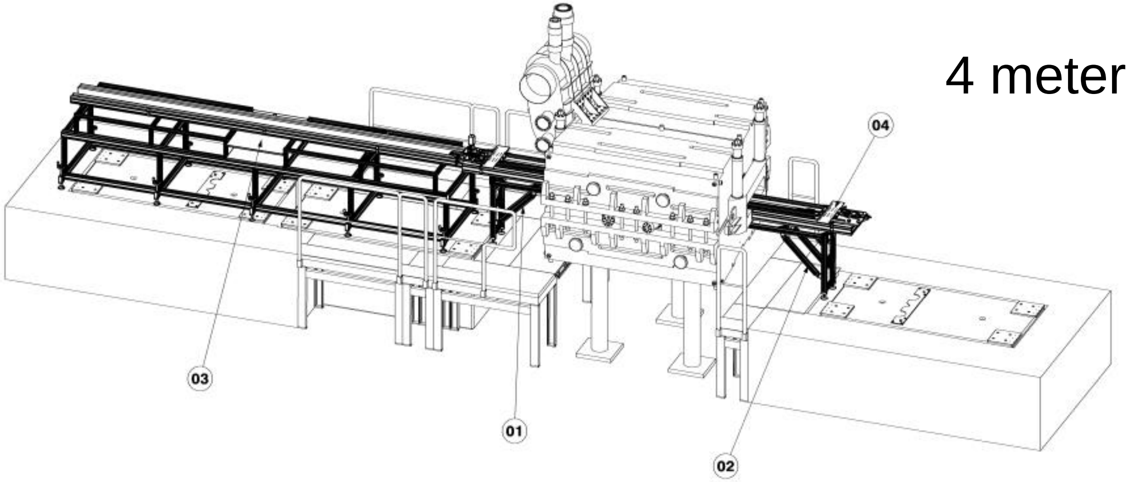




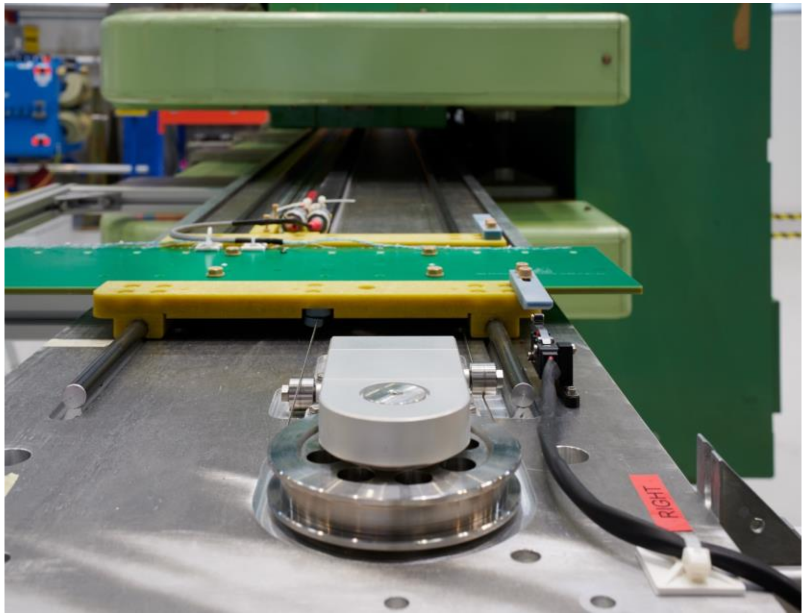


Moving Fluxmeter



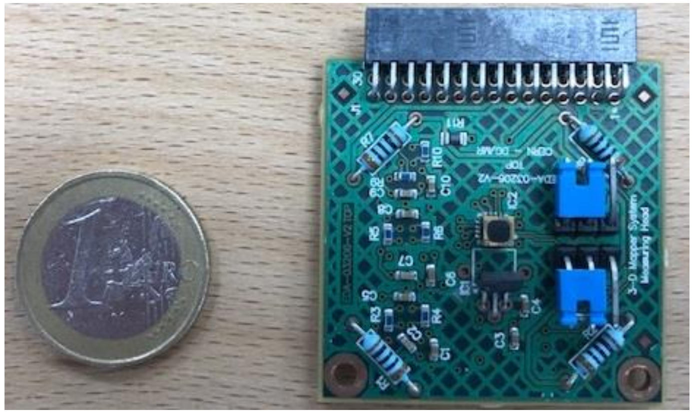


4 meter



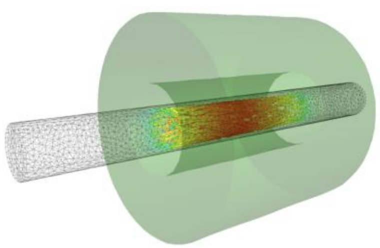
Scanning of large volumes
Mapping of Bld. 311 calibration magnets
Post-processing based on Boundary-Element techniques (field description)

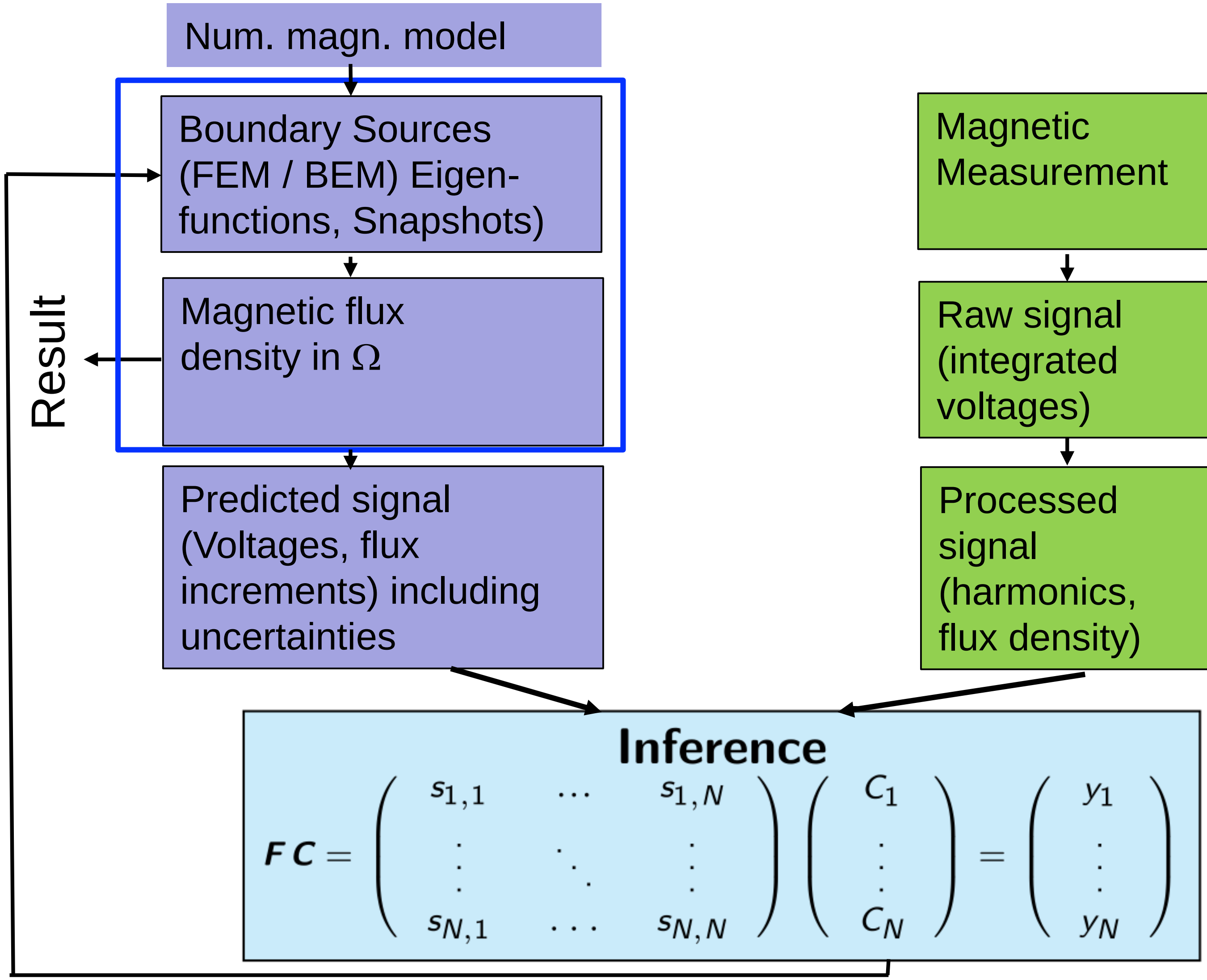
Hall Mapper



Calibration (Hall linearity, planar effect, drift)
Vibration damping
Postprocessing based on BEM (sensor fusion)

The Avatar (Generalized Field Description)





The matrix $\boldsymbol{F}$ can be:

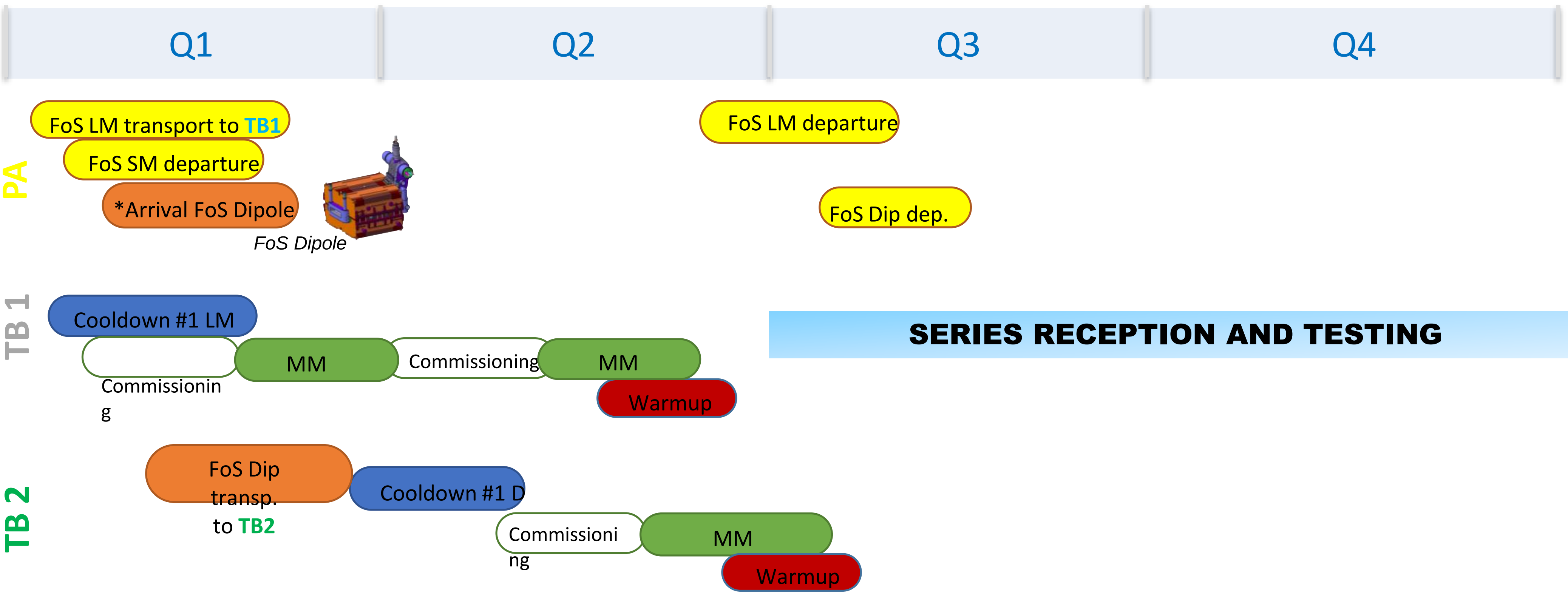
- diagonal (orthogonality)
- square (collocation)
- over-determined (least-squares)
- under-determined (Bayesian inference)

Comments

- Deployment of the GSI personnel (4 FTEs) was completed by beginning of February 2019.
- First short multiplet arrived in Feb 2019. Therefore no training of personnel on the SM18 test station (as originally foreseen).
- Transport required additional information (center of gravity).
- Non-conformities on magnet and installation (jumper/support posts), adaptations, additional tools and equipment (pumping group) needed. The path of communication to the magnet supplier is established.
- Maintenance of GSI Instrumentation Panel and Electrical Cabinet (DAQ for pressure, level and flow sensors, control and power supply for current-lead heaters). No remote access for GSI.

- But: Nothing is on the critical path. Delivery of the FoS long multiplet and FoS dipole planned for 04.2020

Master Schedule: plans 2021



Organizational structure (status 01.2020)

Magnet supplier — Technical coordinator — Technical coordinator

- Final acceptance of the magnet

Magnet Test Manager/Engineer

- Reception magnets, preparation for the tests
- Analysis and validation of magnet test program
- Databases
- Treatment of magnet NCs
- Liaise with CERN services and contractors for interventions and support
- Logistics

Magnetic Measurement Engineer

- Oversees magnetic measurement plan, liaises with GSI magnet and beams groups
- Preparation of MM instruments
- Follow up the measurements
- Analyse and document the results

Test technical engineer (applied physics)

- Coordinates the daily operation of the test facility
- Execution of the magnet test program
- First-line interventions

MM technical engineer (electromechanics)

- Performs the magnetic measurements,
- Calibrates the instruments
- DQA and processing

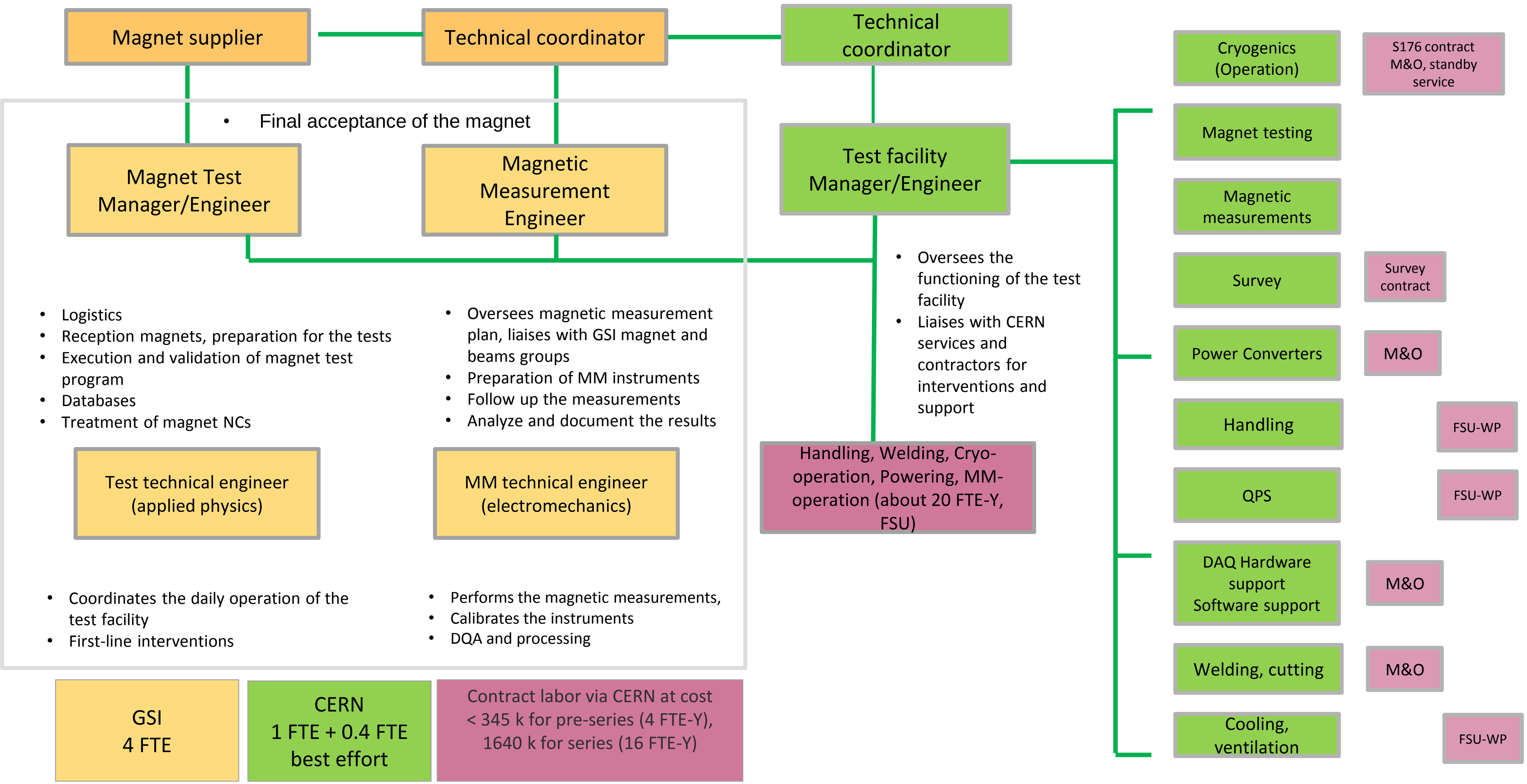
GSI
4 FTE

CERN
1 FTE + 0.4 FTE best effort

Contract labor via CERN at cost
< 345 k for pre-series (4 FTE-Y),
1640 k for series (16 FTE-Y)

Budget	
Cryogenics (Operation)	S176 contract M&O, standby service
Magnet testing	FSU-WP
Magnetic measurements	FSU-WP
Survey	Survey contrac t
Power Converters	M&O
Handling	FSU-WP
QPS	FSU-WP
DAQ Hardware support Software support	M&O
Welding, cutting	M&O
Cooling, ventilation	FSU-WP

Organizational structure (status 08.2020)



Points needing attention (1)

New test station, new systems, new magnet, new GSI@CERN team, CERN resources spread over 13 sections, non-conformities on magnet:
Successful commissioning of bench 1, powering to nominal, MM with high-precision

- ➔ So far, most cost-efficient operation, no dedicated FSU work-packages, but this will change (experience with FoS long multiplet and dipole needed to establish a final resource-loaded planning). Series measurement (Q3.2020?) will require a CERN test-facility manager to liaise with CERN experts and coordinate the FSU workpackages.
- ➔ Commissioning of powering circuits (2-9) still required (FoS long multiplet). Commissioning of the (white and green) benches still required.
- ➔ Non-negligible lead time for registration and (safety) training (COAS) has to be considered. Magnet suppliers and their contractors need work-orders to be able to intervene on the magnets. Registration of ASG and Elytt personnel as PROJ (External for projects) for packing, solving of non-conformities.

Points needing attention (2)

- In view of 21 different types of multiplets, GSI@CERN team may require a fifth person responsible for the configurations (interlock system), instrumentation, parameter settings for quench detection, polarities, HV, LV test interfaces, among others.
- Decisions and guidelines are required for storing test and measurement data (Carpenter, Wiki, MTF, Magnetic measurement request).
- The analysis team must be established, taking care of inverse-field computation and interpretation of quench detection signals. Working group on beam optics (post processing of measurement data and tracking studies) must be established.
- Safe (fenced) storage space for MM equipment, in particular for the moving fluxmeter needed (yellow-fenced area). No buffer zone for magnets.