CERN

Rad-hard warm magnets

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Presented by P. Fessia

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VSC: E. Page, N. Zelko
Magnetic Measurement team: M. Buzio

LHC→HL-LHC→FCC

LHC

30-50 MGy

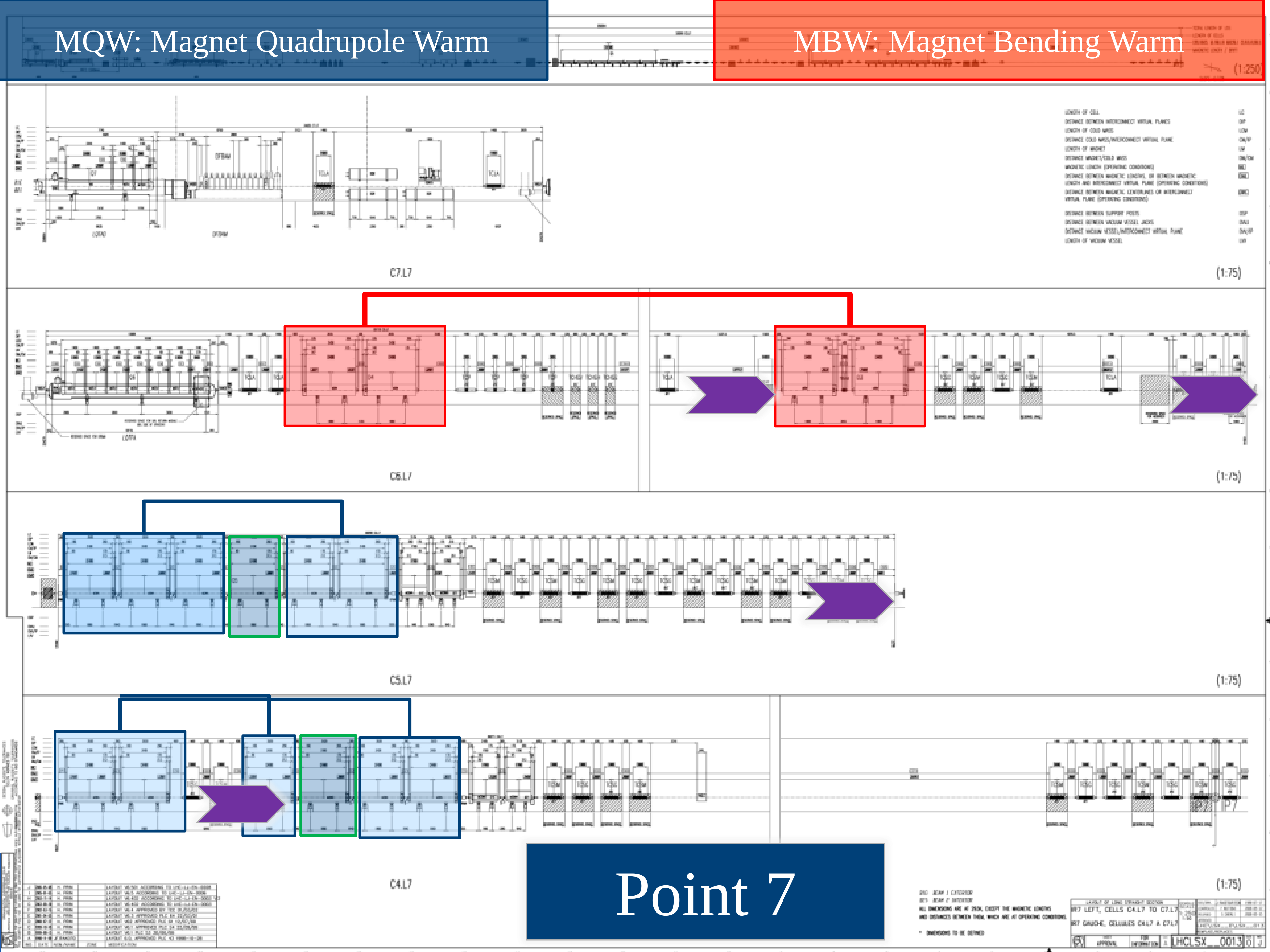
HL-LHC

250-300 MGy

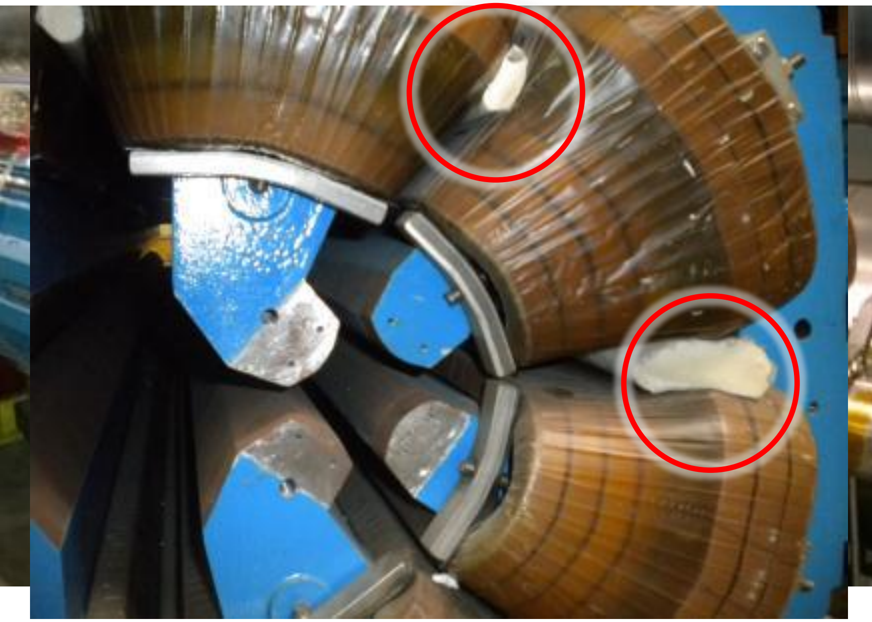
FCC

Where ?

LHC or re-acting


MQW: Magnet Quadrupole Warm
MBW: Magnet Bending Warm
C7.L7
C6.L7
C5.L7
C4.L7
(1:75)
(1:250)
Point 7

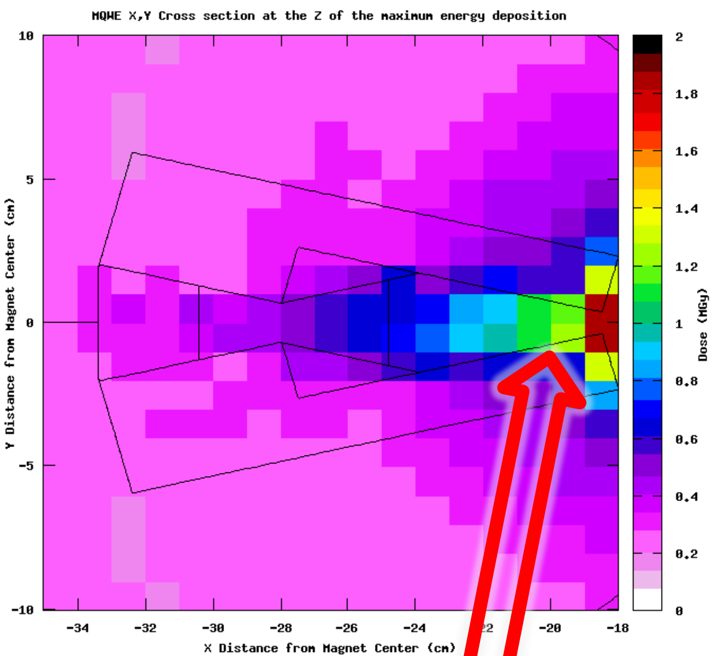
Identified Failure modes

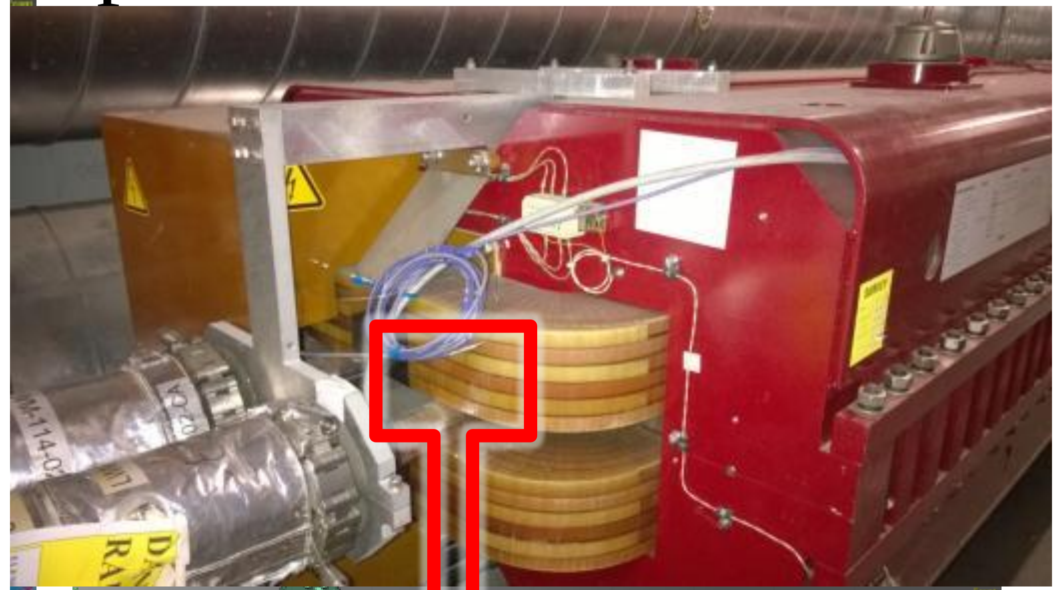


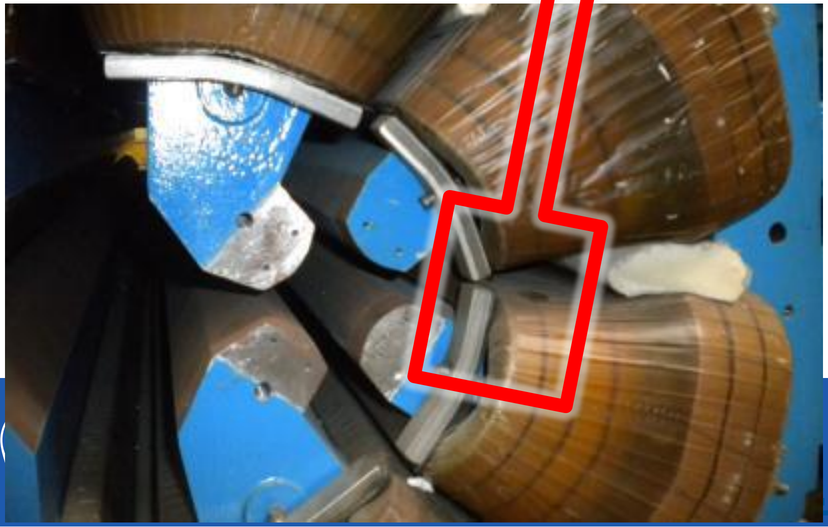
- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Degradation of the mechanical shimming performed with ambient temperature cured resins

- Degradation of the insulation system due to radiation leading to inter turn short or shorts to ground
- Remark magnet build with no coil on the mid plane and therefore out from the expected zone of highest losses

nap







1.15

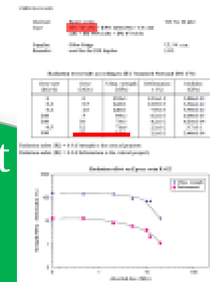
5 TeV relaxed collimator settings

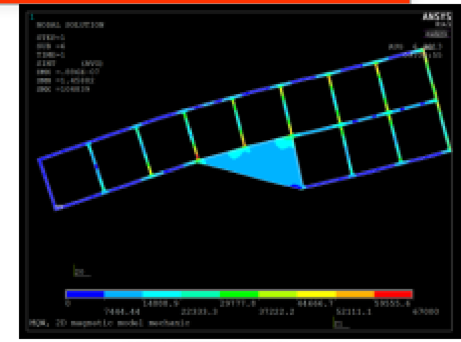
Radiation resistance dose estimation

Degradation of mechanical properties appears and it can be measured before degradation of electrical properties

Actions of the fillers on the radiation resistance

Results mechanical test of the irradiated used resin or **similar** one





Value of mechanical load in the insulation

Resins	Hardeners	Additives	Filler	Composition (p.p.)	Fig	Dose for 50% flex. (MGy)	Dose Range (MGy)
DGEBA	MDA		Papier	100-27-200	5.14	1.3	1 - 2
DGEBA	MDA		Silice	100-27-200	5.14	10	10 - 15
DGEBA	MDA		Silice	100-27-200	5.18	11.4	
DGEBA	MDA		Silice (5 micron)	100-27-20	5.16	14.8	
DGEBA	MDA		Silice (10 micron)	100-27-20	5.16	14.8	
DGEBA	MDA		Silice (40 micron)	100-27-20	5.16	14.6	
DGEBA	MDA		Silice (40 micron)	100-27-200	5.17	12.1	
DGEBA	HPA	BDMA	Silice (40 micron)	100-80-2-200	5.17	<10	<10
DGEBA	MDA		Aérosil + Sulphate de Baryum	100-27-2-150	5.14	15.8	15
DGEBA	MDA		Magnésie	100-27-120	5.14	18	18
DGEBA	MDA		Graphite	100-27-60	4.6	26.8	25 - 30
DGEBA	MDA		Graphite	100-27-60	5.18	30.5	
DGEBA	MDA		Alumine	100-27-220	4.7	23.5	20 - 50
DGEBA	MDA		Alumine	100-27-220	5.18	51.7	
DGEBA	MDA		Alumine	100-27-100	5.15	20.8	
DGEBA	MDA		Alumine	100-27-220	5.15	42.5	
DGEBA	**MDA**		**Fibre de verre**	**100-27-50**	**5.18**	**82**	**80 - 100**
DGEBA	**MDA**		**Fibre de verre**	**100-27-60**	**5.18**	**100**	
EPN	**MDA**		**Fibre de verre**	**100-29-50**	**5.18**	**>100**	**>100**
TGMD	**MDA**		**Fibre de silice**	**100-41-50**	**5.20**	**>100**	**>100**
TGMD	**DADPS**		**Fibre de silice**	**100-40-50**	**5.20**	**>100**	

Estimation of the level of resistance of the insulation system to radiation

But …

1) What is the effect of the insulation thickness on the degradation ?
2) We know that exposure to air during irradiation should make the larger the damage. How much ?
1) Worth re-evalauting the correlation between electrical and mechanical properties degradation

Point 3 and 7 coil magnet damage estimation

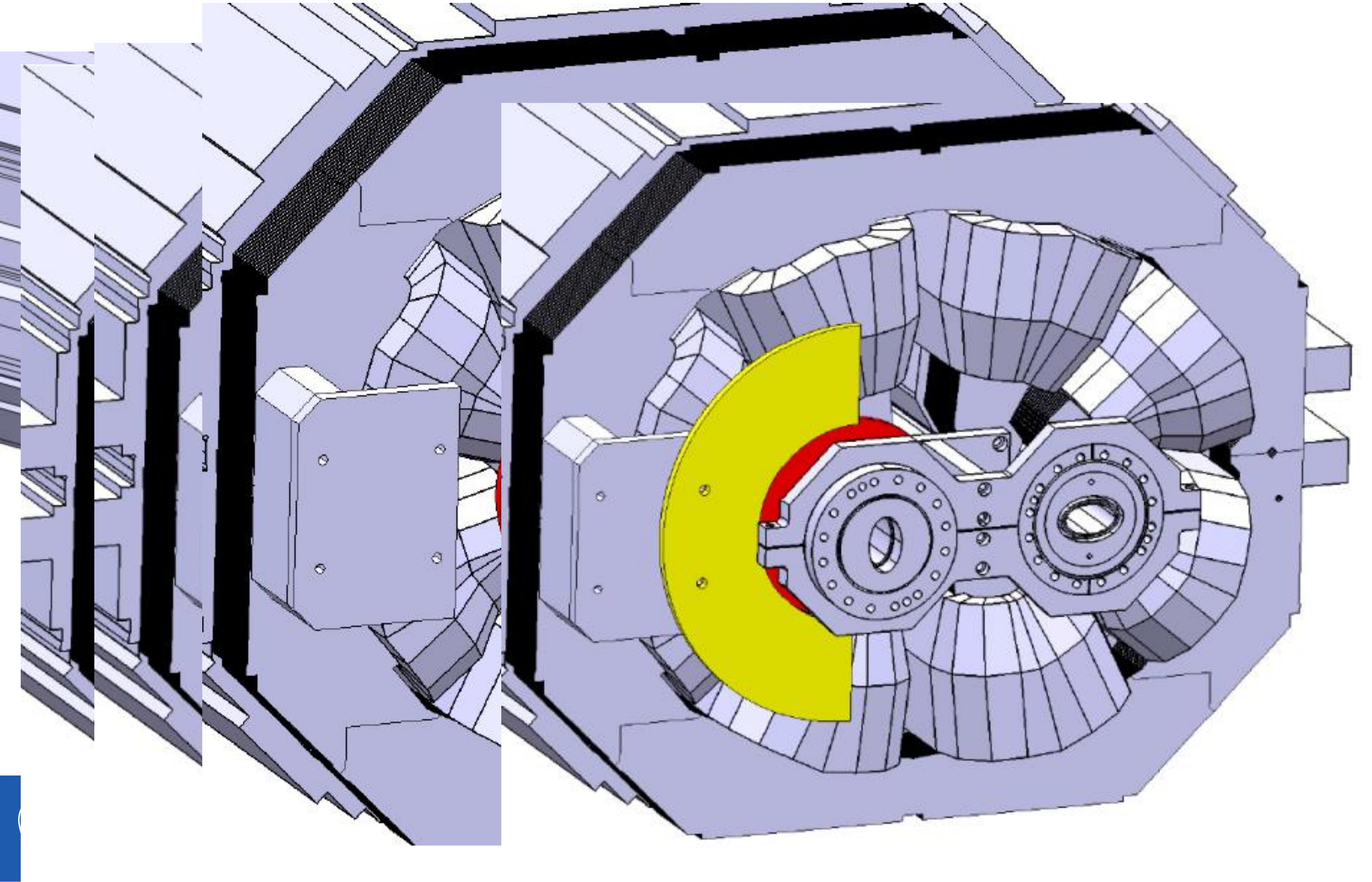
IP 3	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1	
	R	L	R	L
MQWA.A4	0	0	0	0
MQWA.B4	0	0	0	0
MQWB.4	0	0	0	1
MQWA.C4	0	0	0	1
MQWA.D4	0	1	1	2
MQWA.E4	2	3	4	8
MQWA.A5	1	2	3	5
MQWA.B5	1	3	3	6
MQWB.5	3	7	8	15
MQWA.C5	8	15	18	36
MQWA.D5	2	4	4	9
MQWA.E5	3	7	8	16
MBW.A6	2	4	5	9
MBW.B6	2	5	5	11
MBW.C6	3	7	8	15

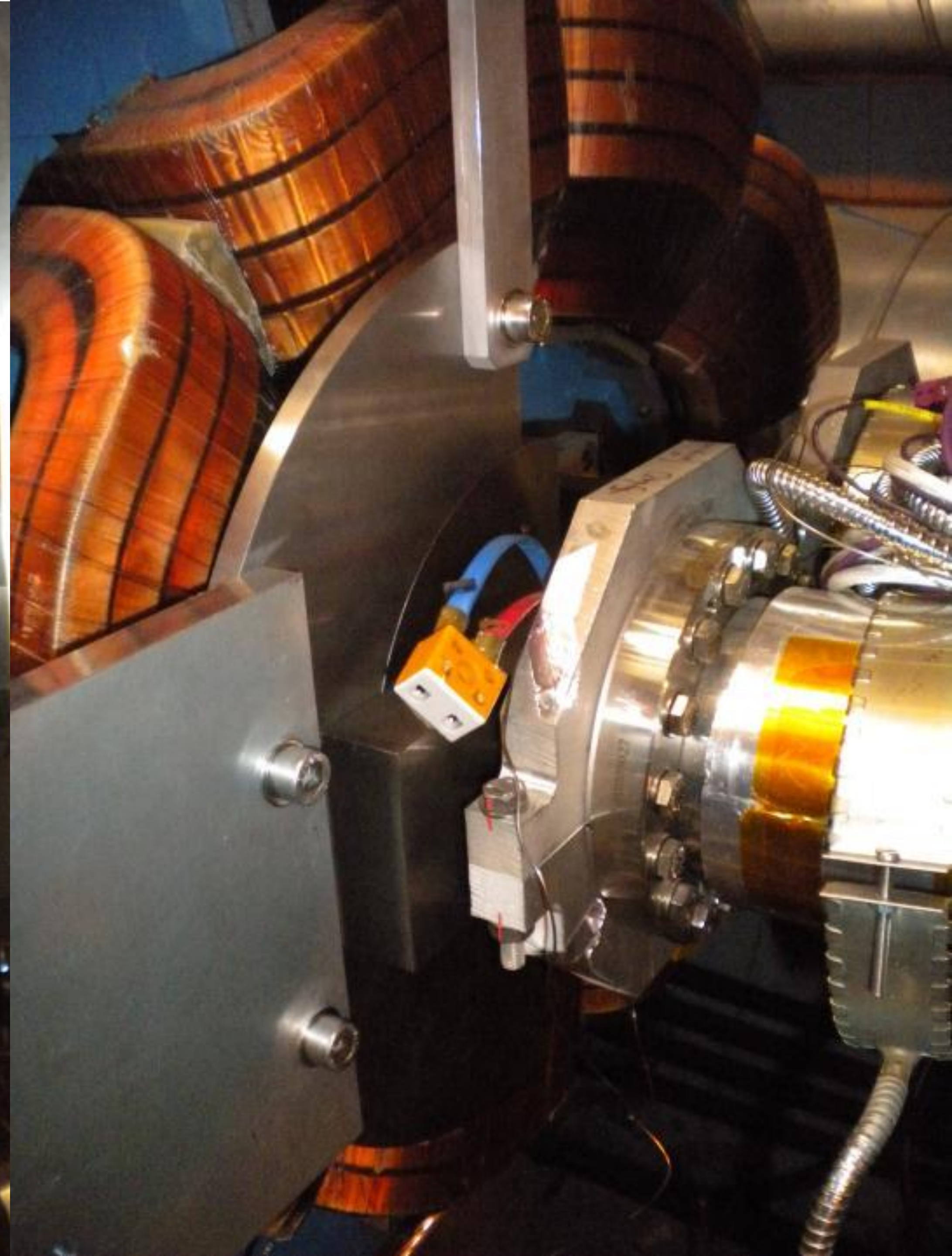
IP 7	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1	
	R	L	R	L
MQWA.A4	1	1	1	2
MQWA.B4	0	1	1	3
MQWB.4	1	2	2	5
MQWA.C4	6	6	14	14
MQWA.D4	4	4	9	9
MQWA.E4	7	14	16	32
MQWA.A5	3	3	6	6
MQWA.B5	4	4	10	10
MQWB.5	4	4	10	10
MQWA.C5	2	5	5	12
MQWA.D5	5	7	11	16
MQWA.E5	41	14	95	32
MBW.A6	22	16	52	37
MBW.B6	37	19	86	43

MQW	MBW
From 10 to 20 MGy	From 40 to 60 MGy
From 20 to 50 MGy	From 60 to 80 Mgy
Larger than 50 MGy	Larger than 80 MGy

Preparing HL-LHC or acting

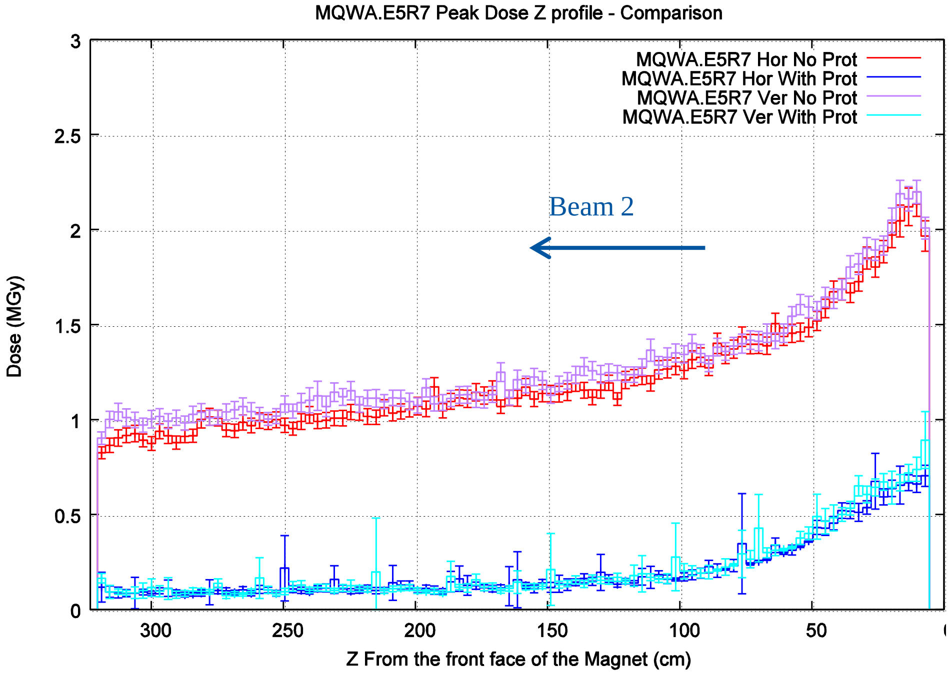
MQW shielding

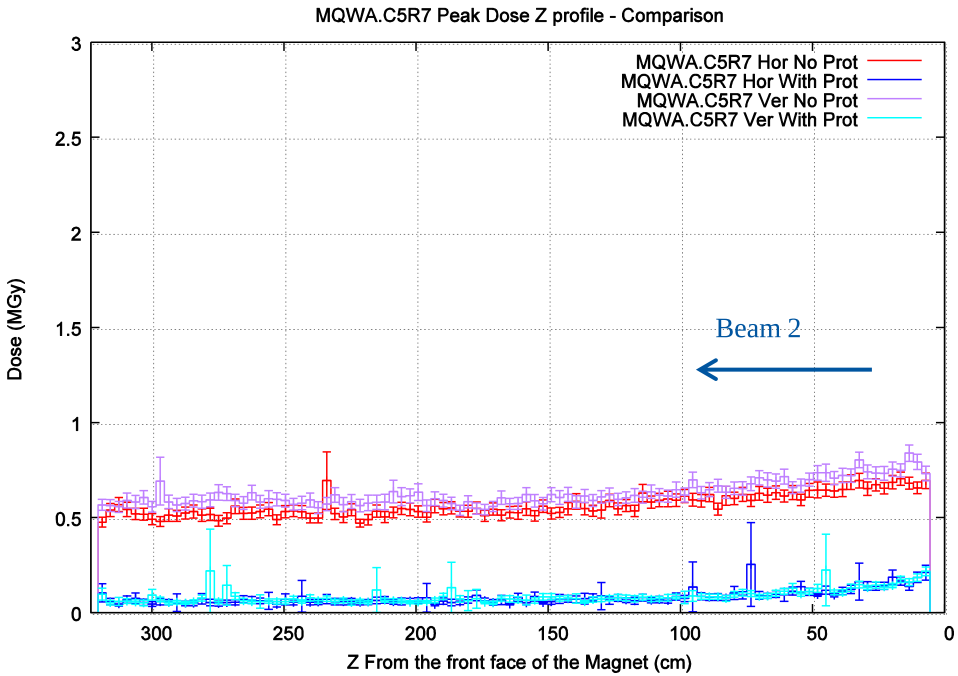


MQW shielding effect on the coil

Normalization: 1.15 10^{16} p (50 fb^{-1})





Reduction Factor 3 on most exposed magnet with the hardest spectra. It shadows 20 % the radiation on the following magnet

Reduction Factor 4 on less exposed magnet with the softer spectra.

Point 3 and 7 coil magnet damage estimation with shielding

green arrow installed LS1

yellow arrow foreseen for LS2

IP 3

	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	0	0	0	0	2	4
MQWA.B4	0	0	0	0	2	4
MQWB.4	0	0	0	1	2	4
MQWA.C4	0	0	0	1	3	6
MQWA.D4	0	1	1	2	7	14
MQWA.E4	[illegible]	3	2	5	13	24
MQWA.A5	[illegible]	2	2	3	8	15
MQWA.B5	[illegible]	3	2	4	10	19
MQWB.5	[illegible]	7	5	10	24	45
MQWA.C5	[illegible]	15	11	22	57	106
MQWA.D5	[illegible]	4	3	5	14	25
MQWA.E5	[illegible]	7	5	10	25	47
MBW.A6	2	4	3	6	15	27
MBW.B6	2	5	3	7	17	31
MBW.C6	[illegible]	7	5	9	24	44

MQW	MBW
From 10 to 20 MGy	From 40 to 60 MGy
From 20 to 50 MGy	From 60 to 80 Mgy
Larger than 50 MGy	Larger than 80 MGy

IP 7

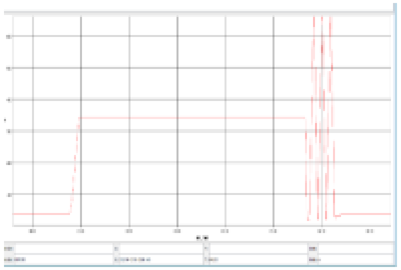
R

	Dose [MGy] for integrated luminosity 150 fb^-1		Dose [MGy] for integrated luminosity 350 fb^-1		Dose [MGy] for integrated luminosity 3000 fb^-1	
	R	L	R	L	R	L
MQWA.A4	1	1	1	2	10	15
MQWA.B4	0	1	1	3	9	22
MQWB.4	1	2	1	3	6	14
MQWA.C4	6	6	9	9	41	41
MQWA.D4	2	2	4	4	24	24
MQWA.E4	1	2	2	5	19	39
MQWA.A5	3	3	4	4	20	20
MQWA.B5	4	4	6	6	29	29
MQWB.5	4	4	6	6	29	29
MQWA.C5	2	5	3	7	11	28
MQWA.D5	3	5	6	8	34	49
MQWA.E5	14	5	32	11	278	93
MBW.A6	7	5	16	12	138	99
MBW.B6	12	6	29	14	247	123

MQW Life Test to the HL-LHC era

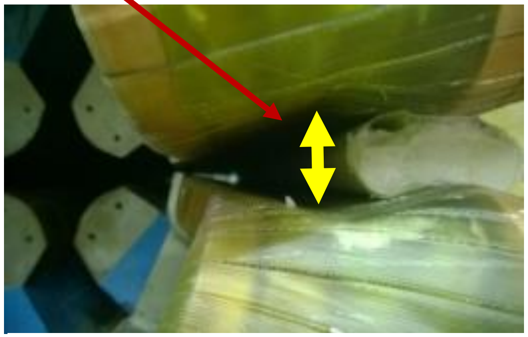
Estimation of mechanical induced damage on LHC Warm Quadrupoles

Reproduction of electromagnetic induced stresses on coils, spacers and magnet's frame to **assess life expectation of installed magnets with respect to cyclic loads during LHC operations.**



Imposed load: **4 power cycles every LHC physics run**, ~47'000 cycles expected up to HL-LHC era end.

Temperature probes and strain gauges



Coil-coil relative displacement

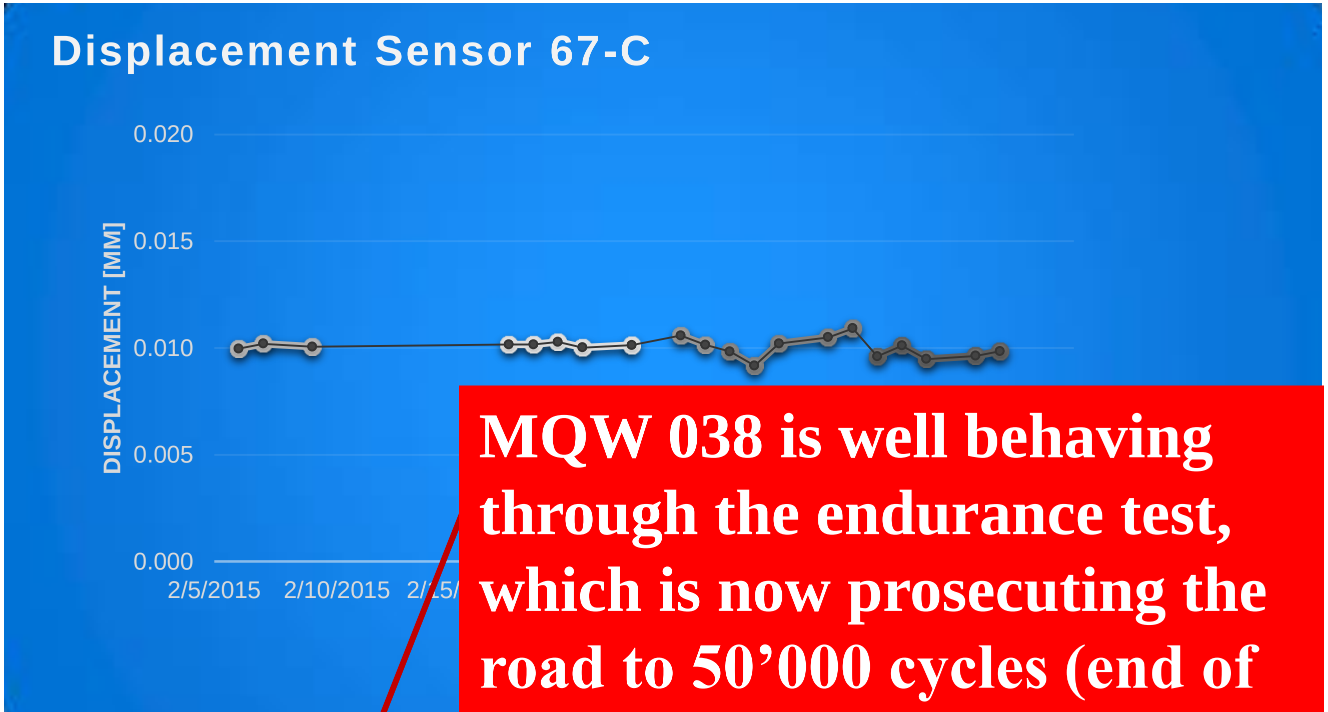
Experimental activities:

- Measure of **coil-coil displacement** to identify eventual mechanical degradation (12 positions)
- Measure of **Temperature evolution** (20 positions)
- Measure of **coils** longitudinal and transversal **deformation** (8 positions)
- **Electrical verification of the magnet** at regular intervals with **two complete certifications** (at 50% and 100% of foreseen life cycle)

Work performed in collaboration with: CERN Mechanical Laboratory, CERN Polymer Laboratory and CERN Design Office.

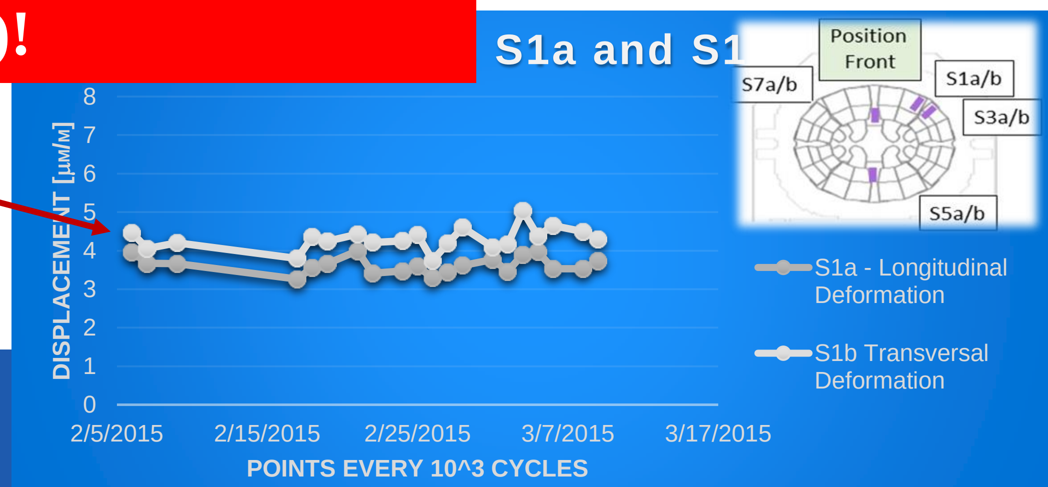
MQW Life Test: first results

Preliminary results up to 25’000 cycles (half of foreseen magnet’s life)



- Very stable signal with few oscillations mostly due to T effect.
- No influence of em fields or hysteresis effects.
- Displacements constant since beginning of test.
- Coils Strains giving regular and strong signal.

MQW 038 is well behaving through the endurance test, which is now prosecuting the road to 50’000 cycles (end of HL-LHC era)!



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MQW/MBW Coils Insulation Resins Characterization

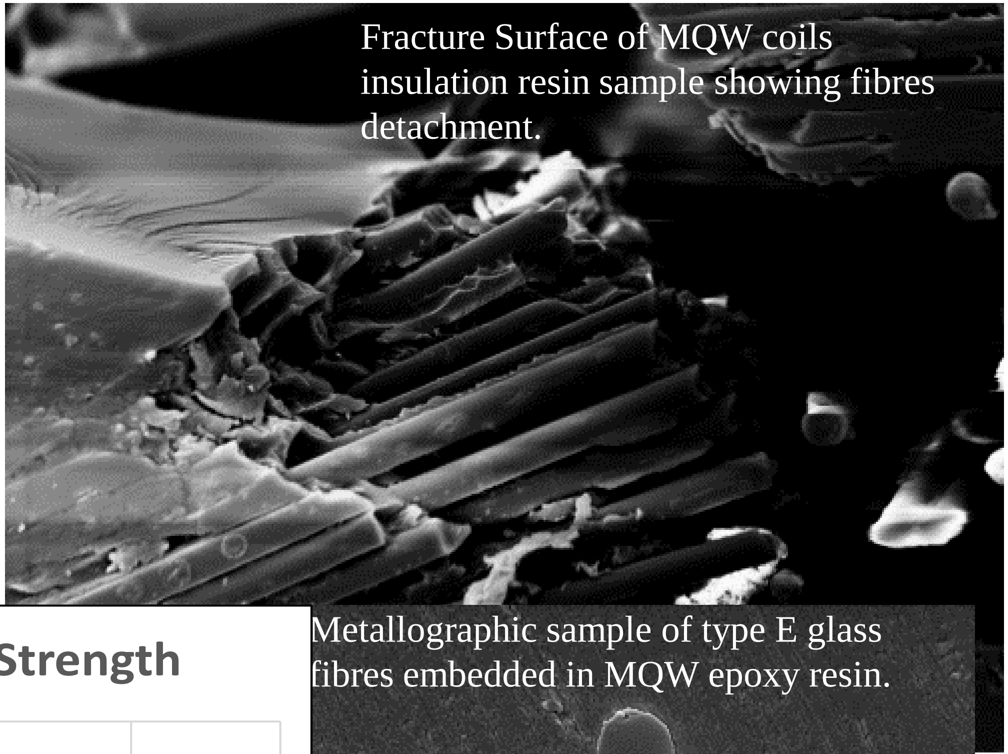
Additional activities to predict the long term behaviour of the materials used for MQW (and MBW) magnets, including:

Mechanical tests,

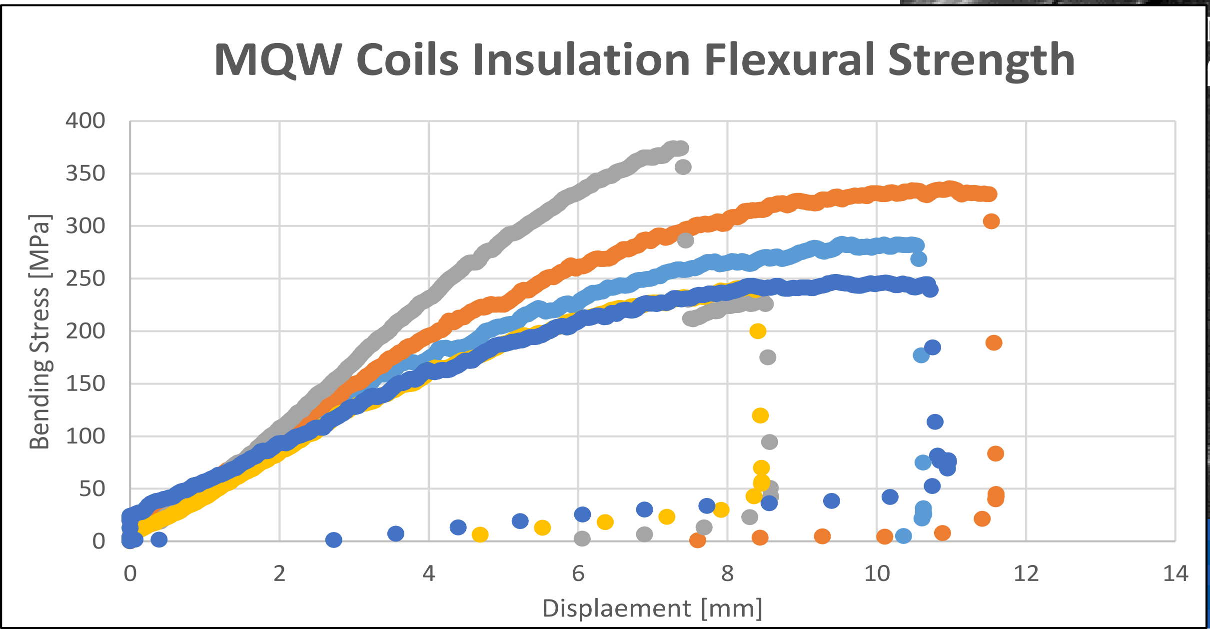
Electrical tests,

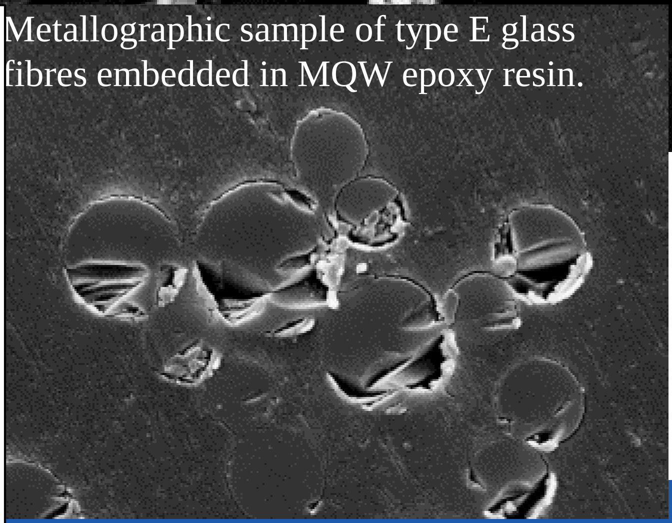
Microstructural analysis…

All evaluated as a function of received dose (irradiation campaign under preparation)!



Fracture Surface of MQW coils insulation resin sample showing fibres detachment.





Metallographic sample of type E glass fibres embedded in MQW epoxy resin.

Flexural Tests plots courtesy of O. Sacristan De Frutos (CERN Mechanical Laboratory).

FCC and HL-LHC development or pro-acting

Know better

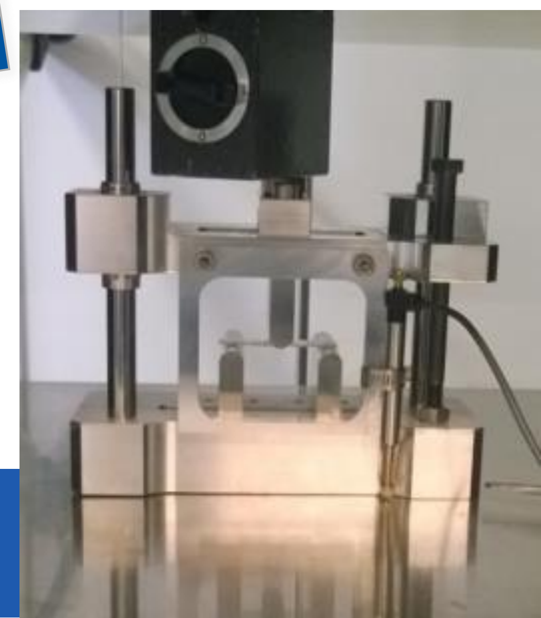
for HL-LHC and FCC

Known margin

Know before

Know better: resin testing from present to future

Presently used insulations systems and new insulation systems



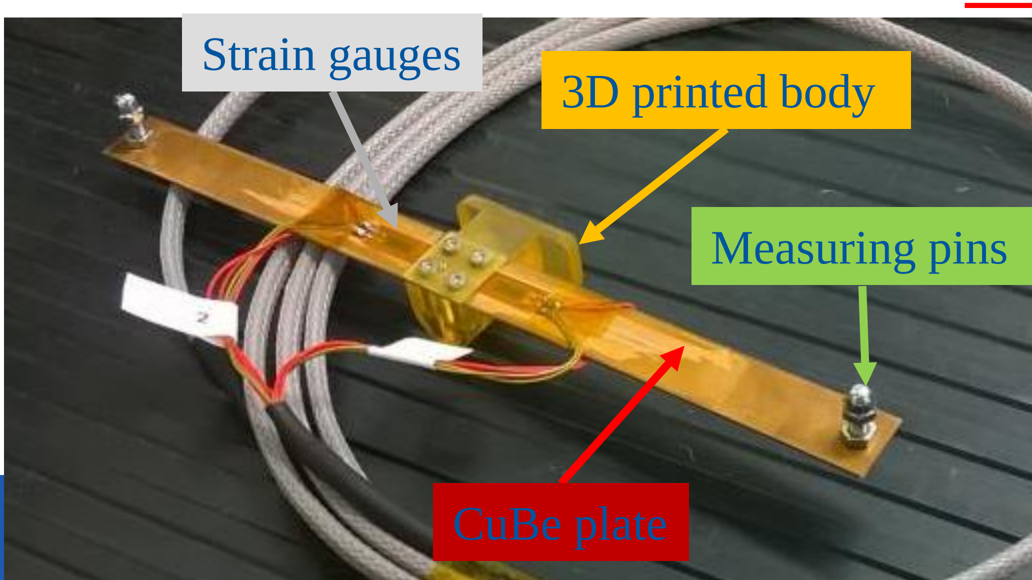
Monitoring the health of the magnet: DS R&D

High demanding requirements:

- High precision and reproducibility over a long number of cycles;
- No influence from Temperature and EM fields;
- Capable to slide in the small interstitial between MQW coils, adapting to irregular surfaces and locations…

- Displacement measured through "**Home made CuBe beam based displacement sensors**", in the following DS.
- DS are made of a CuBe plate, instrumented with strain gauges and mounted on a support structure in **3D printed polymer**.
- The DS is then calibrated and inserted inside the magnet along the interstitials between coils **up to 1.5 m depth**.
- Final accuracy achieved **~0.5 microns for excursions of ~4 mm**.

➔ **The technology can be implemented in different situations by ad hoc designs of the main body and of the CuBe plate geometry…**

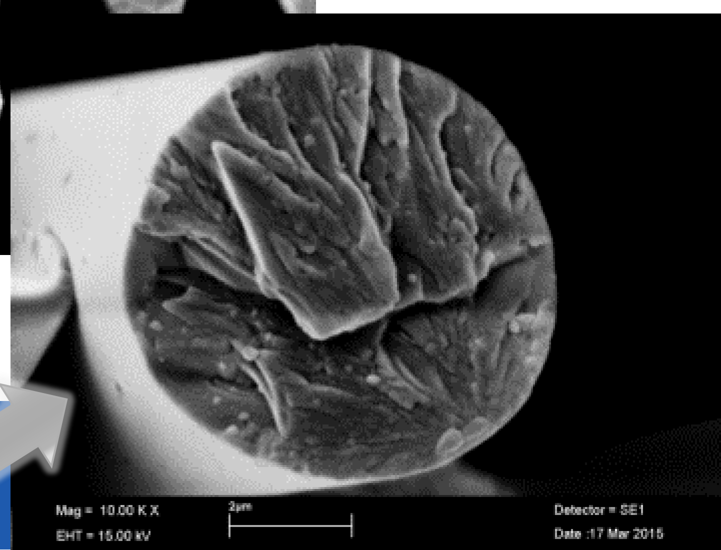


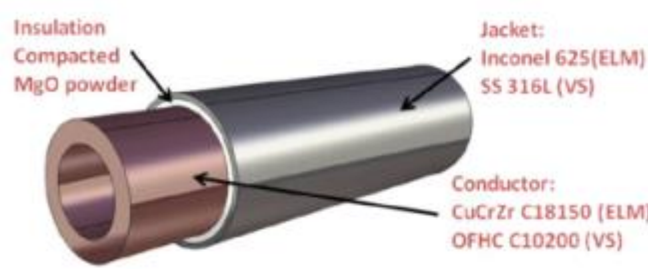
Final sensor inserted between coils 6-7

Know margin: rad hard insulation schemes

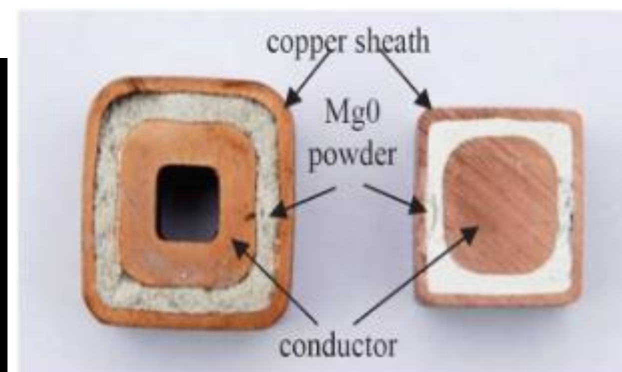
Possible schemes

- Organic insulations
  - Cyanate Esther compounds
  - High radiation hard epoxy with mica
- Non organic insulations





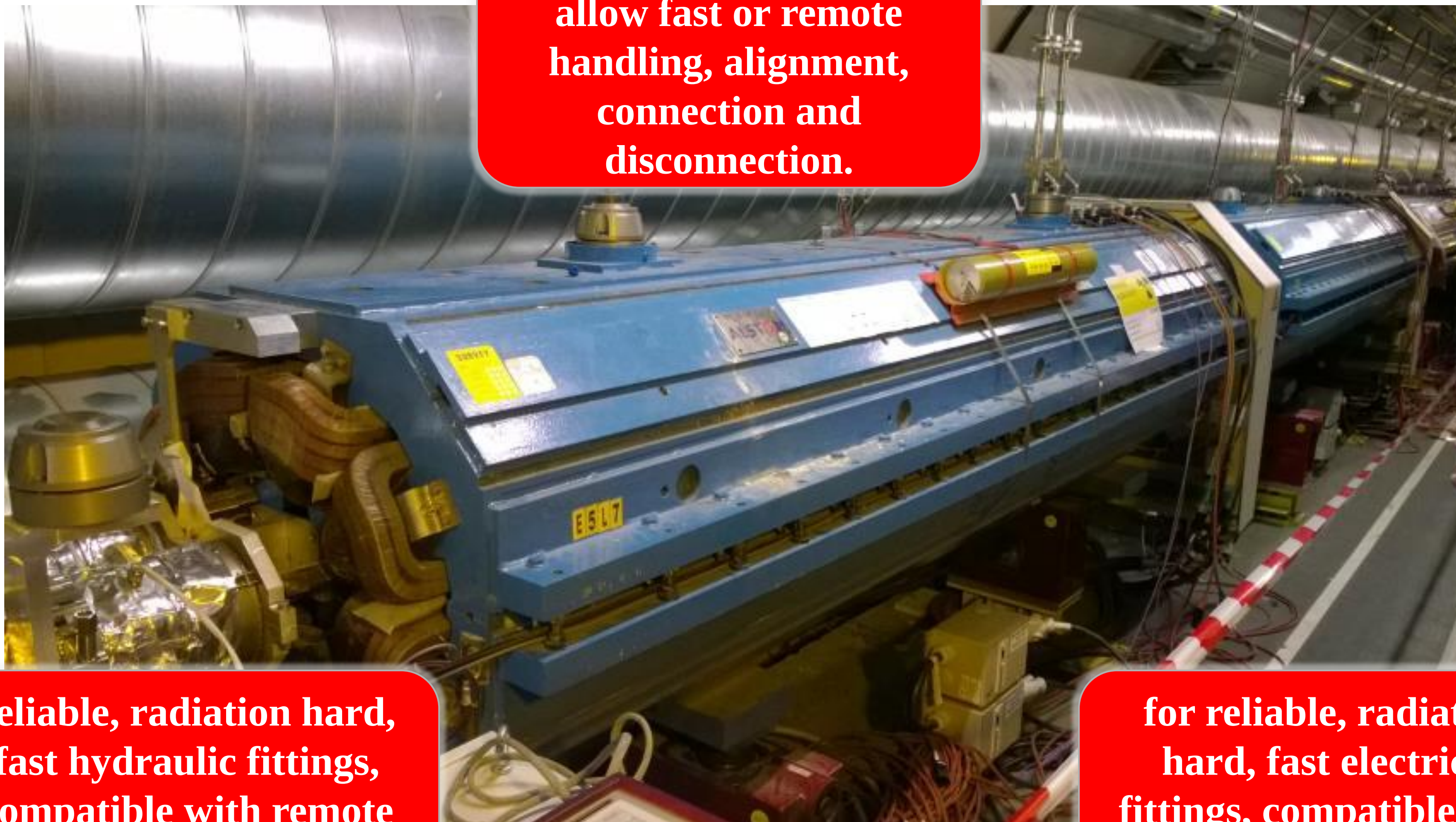
ITER cables: round shape, tailored design for different machine areas.[2]



Hitachi cables used in KEK & PSI: square shape, Cu cladding, different dimensions available. [1]

Known margin: the whole magnet

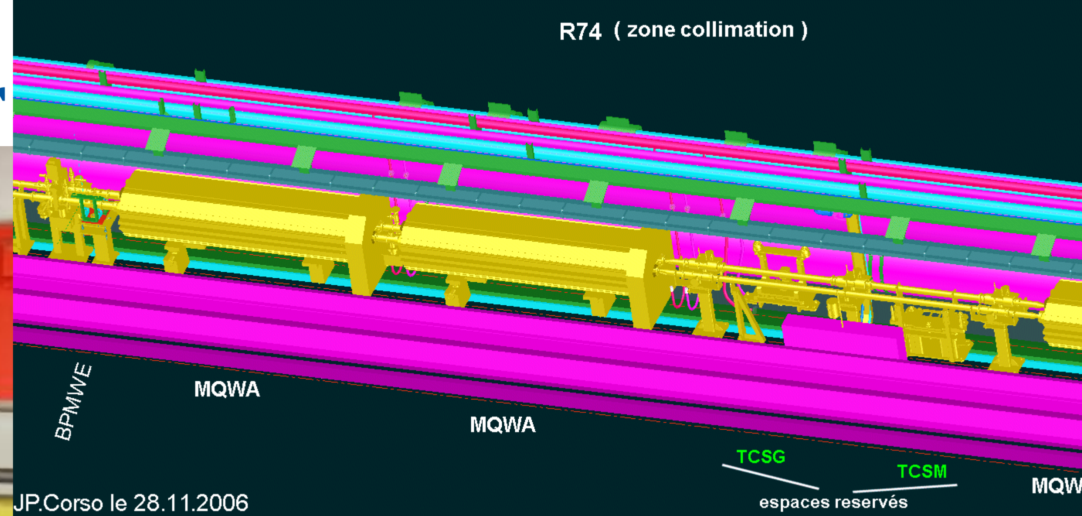
mechanical systems to allow fast or remote handling, alignment, connection and disconnection.

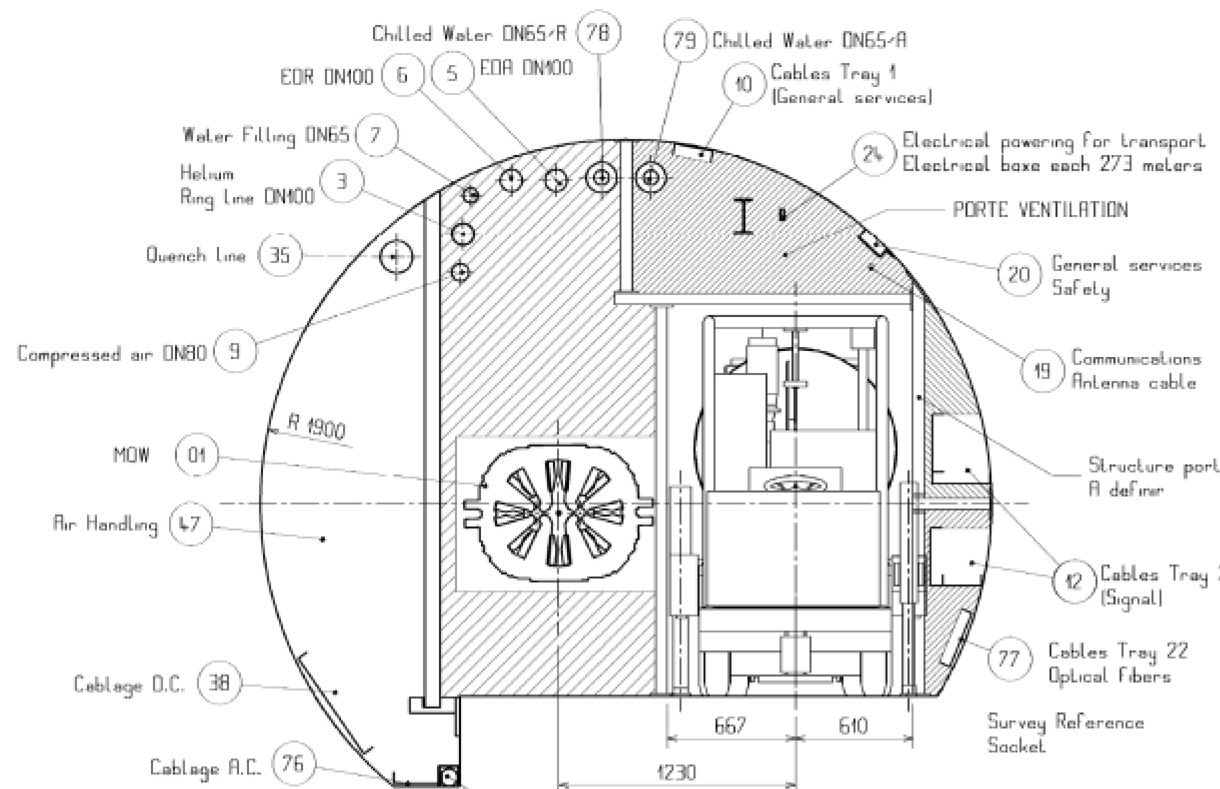


reliable, radiation hard, fast hydraulic fittings, compatible with remote handling

for reliable, radiation hard, fast electrical fittings, compatible with remote handling

Plug in magnet for





Conclusion

- The development of rad-hard magnets for FCC is a continuum of the LHC Consolidation program and of the HL-LHC development program. The Three projects are synergic and build one on the other
- A rad hard coils does not mean a rad hard magnet: electrical connection, hydraulic connections and manipulation have to be intimately integrated to provide an homogenous product. CERN needs partners in order to develop the adequate answers in the different fields