MBW-MQW

Some initial considerations on expected life and available options
Presented by P. Fessia

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Collimation input: Rodrick Bruce, Stefano Redaelli , Belen Maria Salvachua Ferrando
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Optics: Massimo Giovannozzi
MME design office: L. Favre, T. Sahner
Analysis of Epoxy resins: E. Fornasiere (TE-MSC-MDT)

Due the expected difference in losses between point 7 and point 3 we concentrate here on point 7 (after TS 2012 factor 10 less before factor 3)

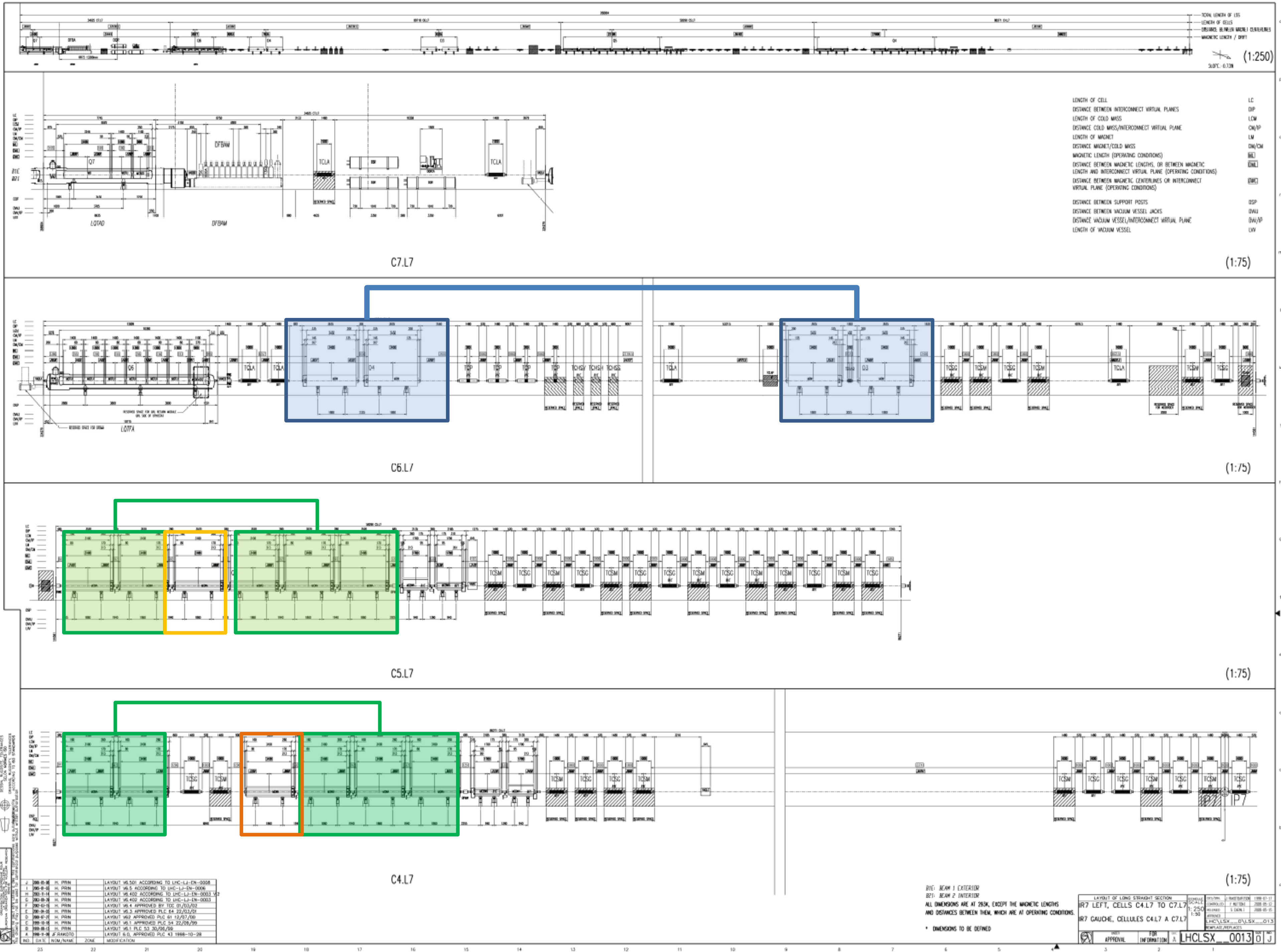
THE PROBLEM / THE MAGNETS

MQW

characteristics	RQ4.L R7	RQ5.L R7	RQT4. L7	RQT5. L7	RQT4. R7	RQT5. R7	RQ4.L R3	RQ5.L R3	RQT4. L3	RQT5.L3	RQT4. R3	RQT5.R3
I ultimate (from layout database) [A]	810	810	600	600	600	600	810	810	600	600	600	600
Voltage I ultimate [V]	381	383	29	31	27	29	451	452	38	34	42	39
I 7 TeV (Fidel report) [A]	598	610	151	17	151	17	561	593	313	441	313	441
Voltage I 7 TeV [V]	282	289	8	2	8	2	313	331	20	31	22	29
Number magnet in series in circuit	10	10	1	1	1	1	10	10	1	1	1	1
Turn/magnet	171											
Estimated ultimate inter-turn voltage [V]	0.22	0.22	0.17	0.18	0.16	0.17	0.26	0.26	0.22	0.2	0.25	0.23
Estimated inter-turn voltage at 7 TeV [V]	0.16	0.17	0.05	0.01	0.05	0.01	0.18	0.19	0.12	0.18	0.13	0.17
Estimated inter layer voltage	Same as inter turn											
Insulation thickness inter turn	2X(2X0.25) mm=1 mm glass tape											
Circuit energy ultimate [Kj]	154	164	9	9	9	9	154	164	9	9	9	9
Circuit energy 7 TeV [Kj]	84	93	0.6	0.01	0.6	0.01	74	88	2.5	5	2.5	5
Ground insulation	1X(2X0.25) mm+3X(2X0.25)=2 mm											
Resin used	EPN1138 42%+ GY 6004 42% + CY 221 16% + HY 905 100 %+ 30ml DY 073											
Dielectric resin	> 20 kV/mm											

MBW

characteristics	RD34.LR7	RD34.LR3
I ultimate [A] (layout database)	810	810
Voltage I ultimate [V]	440	700
I 7 TeV (Fidel report)	643	643
Voltage I 7 TeV	350	556
Number magnet in series in circuit	8	12
Turn/magnet	84	
Estimated ultimate inter-turn voltage [V]	0.65	0.7
Estimated inter-turn voltage 7 TeV [V]	0.52	0.55
Estimated ultimate inter layer voltage [V]	9.2	9.7
Estimated inter layer voltage 7 TeV [V]	7.2	7.8
Circuit energy ultimate [Kj]	472	793
Circuit energy 7 TeV [Kj]	297	500
Insulation inter turn [mm]	2X(2X0.15)=0.6 glass tape	
Insulation inter layer [mm]	2X(2X0.15)+2X(2X0.15)+1(glass cloth) =1.6 glass tape	
Ground insulation	2X(2X0.15)+1.5(0.15Xx)=1.8	
Resin used	EPC-1: resin ED-16 100 Hardener MA 2.28 □ K Plasticizer MGF-9 20 TEa accelerant 0.5	
Dielectric resin	? (>>15kV/mm)	



(1:250)
LENGTH OF CELL LC
DISTANCE BETWEEN INTERCONNECT VIRTUAL PLANES DIP
LENGTH OF COLD MASS LCM
DISTANCE COLD MASS/INTERCONNECT VIRTUAL PLANE CM/IP
LENGTH OF MAGNET LM
DISTANCE MAGNET/COLD MASS DM/CM
MAGNETIC LENGTH (OPERATING CONDITIONS)
DISTANCE BETWEEN MAGNETIC LENGTHS, OR BETWEEN MAGNETIC LENGTH AND INTERCONNECT VIRTUAL PLANE (OPERATING CONDITIONS)
DISTANCE BETWEEN MAGNETIC CENTERLINES OR INTERCONNECT VIRTUAL PLANE (OPERATING CONDITIONS)
DISTANCE BETWEEN SUPPORT POSTS DSP
DISTANCE BETWEEN VACUUM VESSEL JACKS DVVJ
DISTANCE VACUUM VESSEL/INTERCONNECT VIRTUAL PLANE DVV/IP
LENGTH OF VACUUM VESSEL LVV
LQTAD
DFBAM
TCLA
C7.L7
(1:75)
Q6
D4
D3
TCP
TCLA
TCSG
TCSM
LQTFA
C6.L7
(1:75)
C5.L7
(1:75)
C4.L7
(1:75)
IP7
B1E: BEAM 1 EXTERIOR
B2I: BEAM 2 INTERIOR
ALL DIMENSIONS ARE AT 293K, EXCEPT THE MAGNETIC LENGTHS
AND DISTANCES BETWEEN THEM, WHICH ARE AT OPERATING CONDITIONS.
* DIMENSIONS TO BE DEFINED
LAYOUT OF LONG STRAIGHT SECTION
IR7 LEFT, CELLS C4.L7 TO C7.L7
IR7 GAUCHE, CELLULES C4.L7 A C7.L7
ECHELLE SCALE 1:250 1:50
APPROVAL
FOR INFORMATION
A
LHCLSX__0013
0
J
LHC\LSX___0\LSX___013
REMPLACE/REPLACES

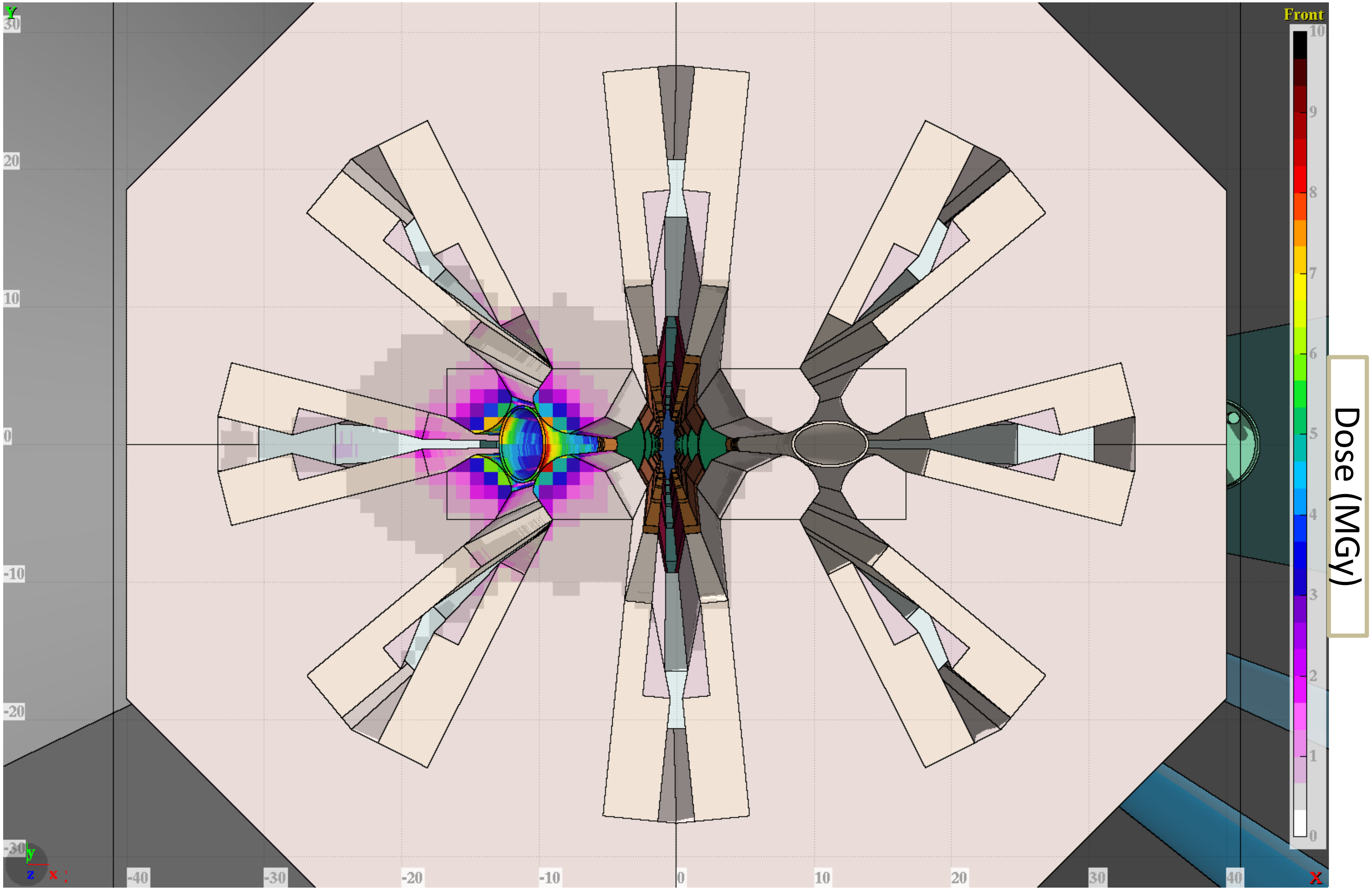
The questions

DO THEY SURVIVE TILL LS2 (100 **FB^{-1}** ***>150*** **FB^{-1}*****)***

DO THEY SURVIVE TILL LS3 (300 **FB^{-1}** ***>350*** **FB^{-1}*****)***

DO THEY SURVIVE TILL …

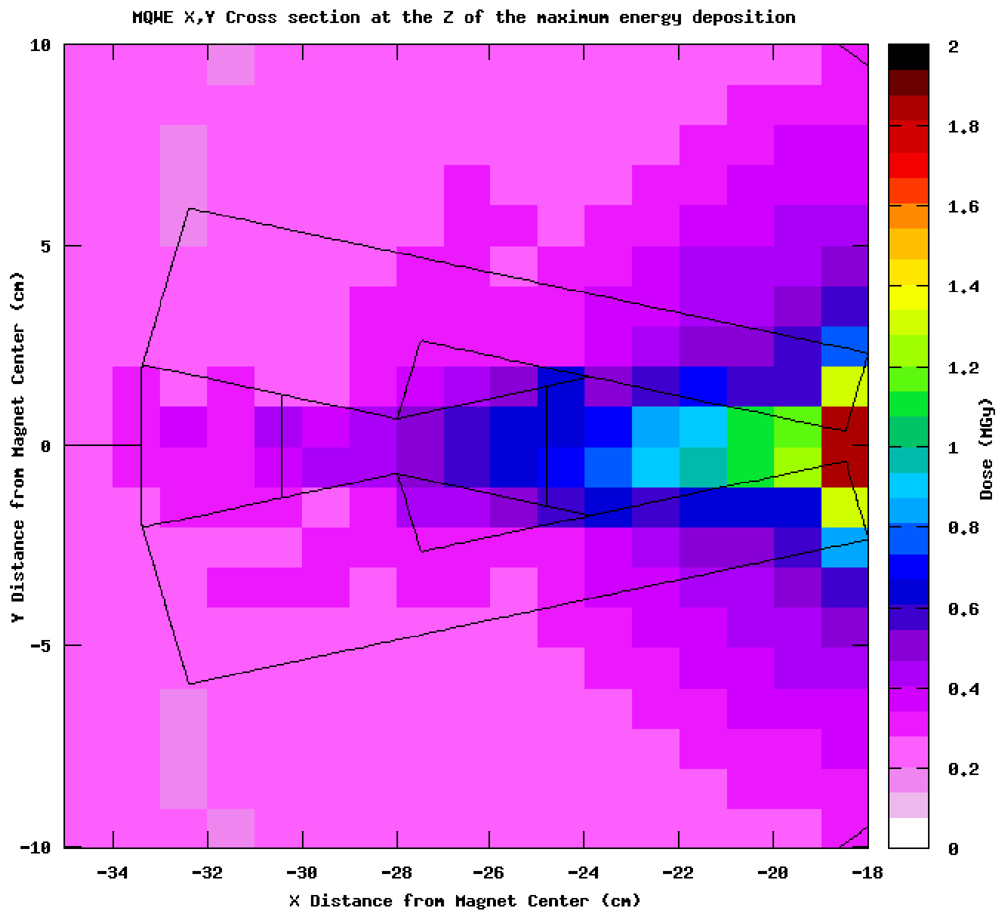
MQWA.E5R7 Dose 2d cross section at maximum



Normalization: 1.15 10^{16} p (30-50 fb^{-1}).

Computations with E 6.5 TeV relaxed collimator settings

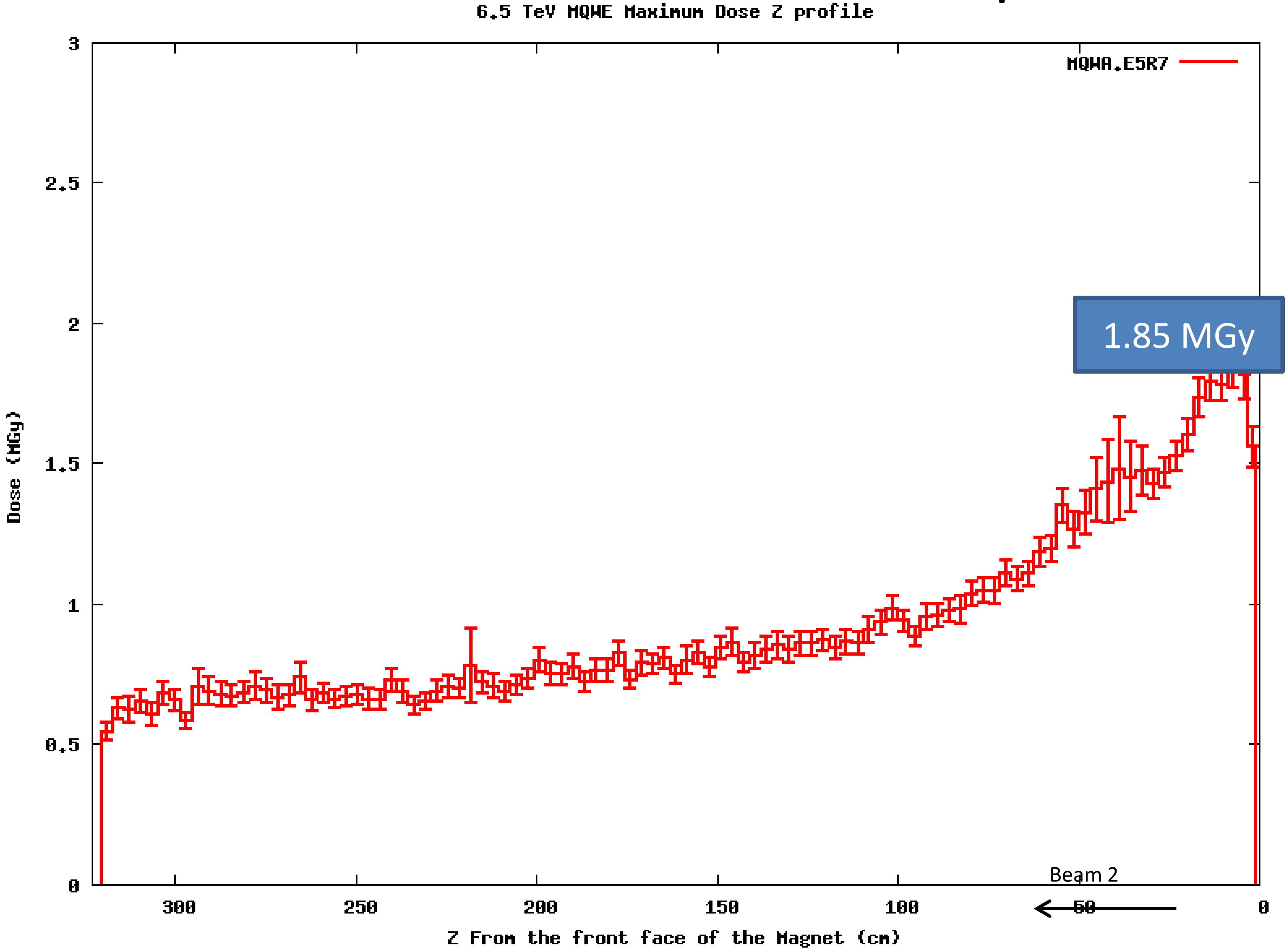
MQWA. ximum



Normalization: 1.15 10^{16} p (30-50 fb^{-1}).

Computations with E 6.5 TeV relaxed collimator settings

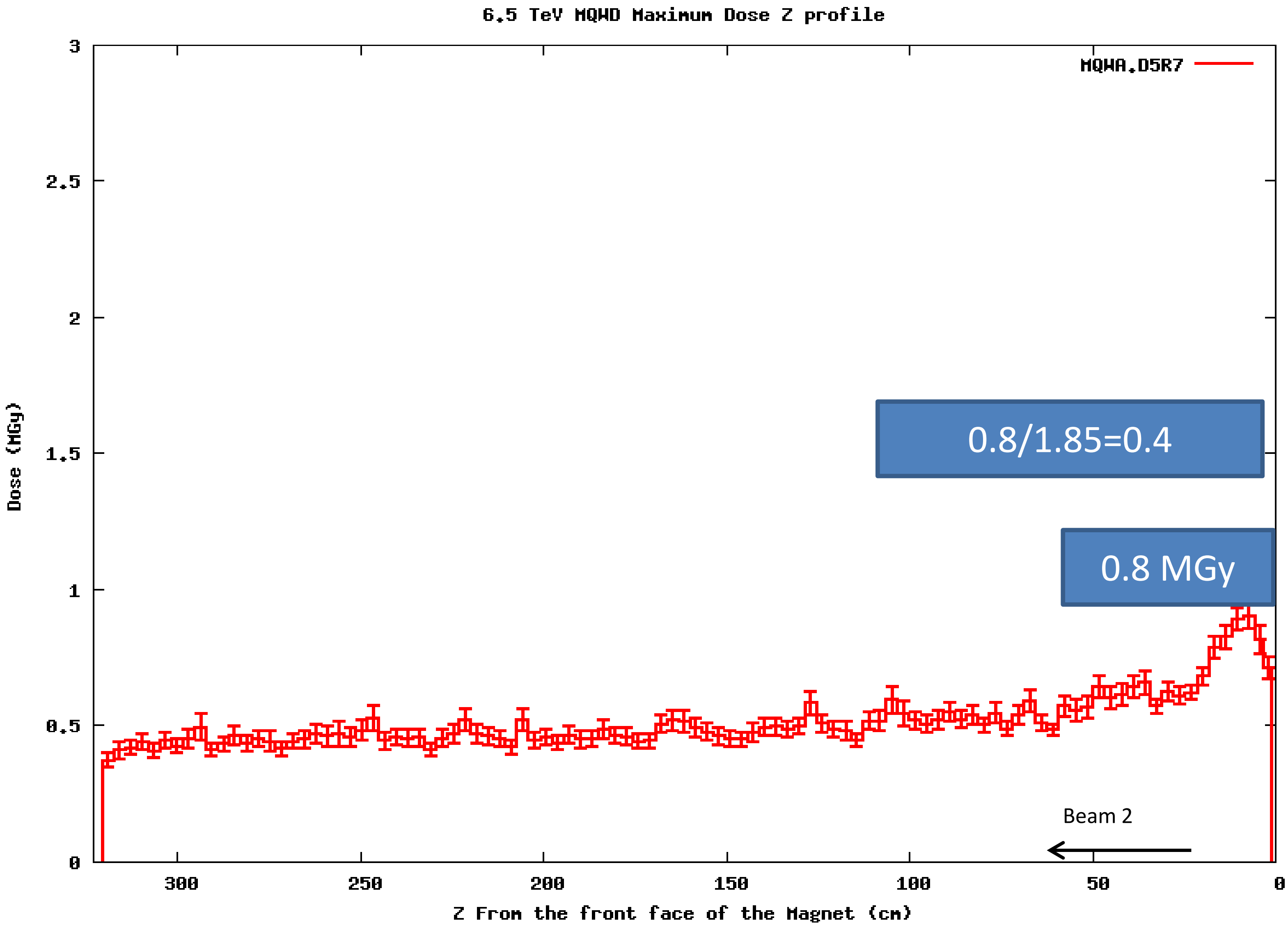
MQWA.E5R7 Dose Maximum Z profile



Normalization: 1.15 10^{16} p (30-50 fb^{-1}).

Computations with E 6.5 TeV relaxed collimator settings

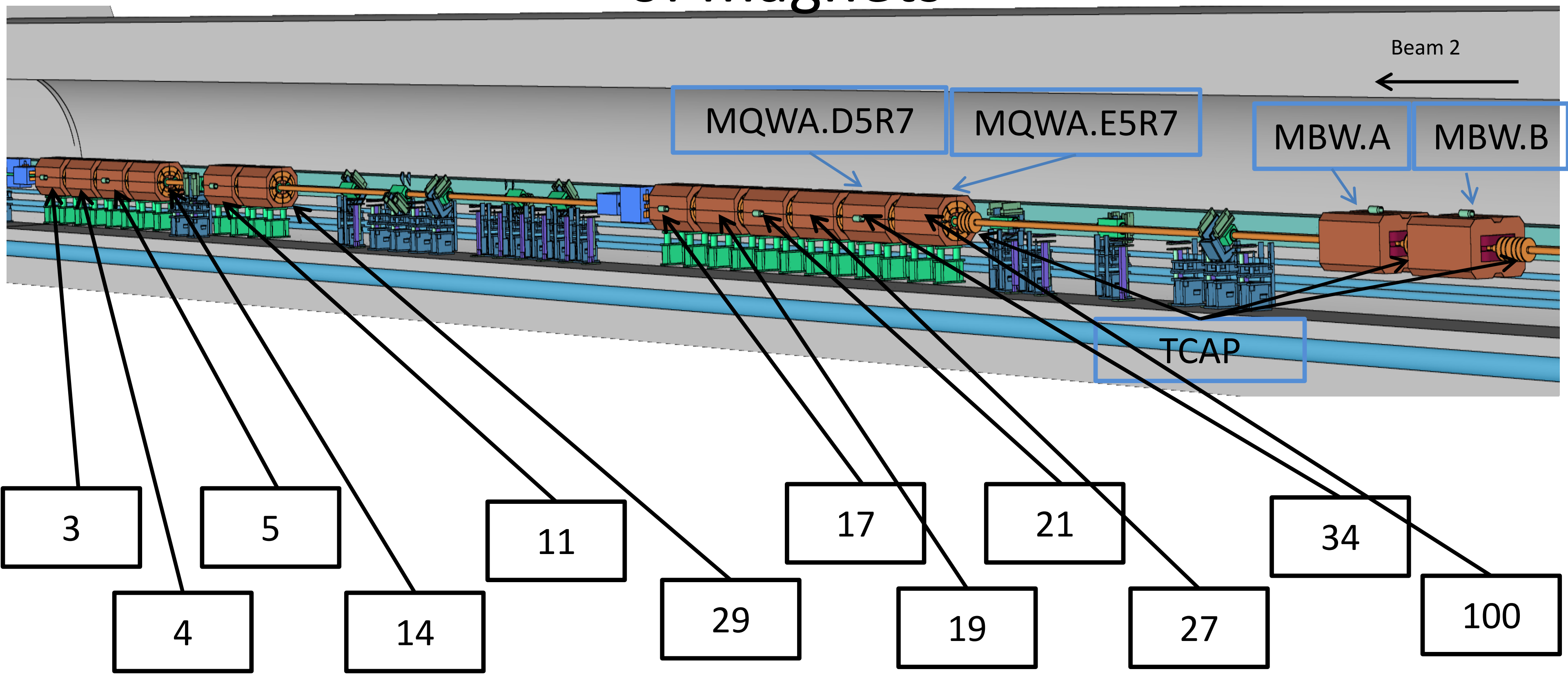
MQWA.D5R7 Dose Maximum Z profile



Normalization: 1.15 10^{16} p (30-50 fb^{-1}).

Computations with E 6.5 TeV relaxed collimator settings

Ratio of total load on left Horizontal coils of magnets



Values are in percentage (%)

Values normalized to most impacted one (MQWA.E5R7) : 12.6 GeV/p

Magnet	Fluka estimation 50 fb^{-1} old loss pattern [MGy]	Fluka ratio peak to peak [%]	Fluka ratio total load [%]	Fluka ratio peak to peak normalised second magnet [%]	Fluka ratio total load normalised second magnet [%]	Extrapolated values old loss pattern [Mgy]	Reference extrapolation 50 fb^{-1} new loss pattern [MGy]
MQWA.A4			3 %		9%	*0.08*	0.2
MQWA.B4			4 %		12%	*0.11*	0.2
MQWA.C4			5 %		15%	*0.14*	0.3
MQWB.4			14 %		41%	*0.37*	0.8
MQWA.D4			11 %		32%	*0.29*	0.6
MQWA.E4			29 %		85%	*0.77*	1.6
MQWA.A5	0.39	21 %	17 %	43%	50%		0.8
MQWA.B5	0.52	28 %	19 %	57%	56%		1.1
MQWA.C5	0.61	33 %	21 %	68%	62%		1.3
MQWB.5	0.73	40 %	27 %	82%	79%		1.6
MQWA.D5	0.9	49 %	34 %	100%	100%		1.9
MQWA.E5	1.85	100 %	100 %	206%	294%		4.0

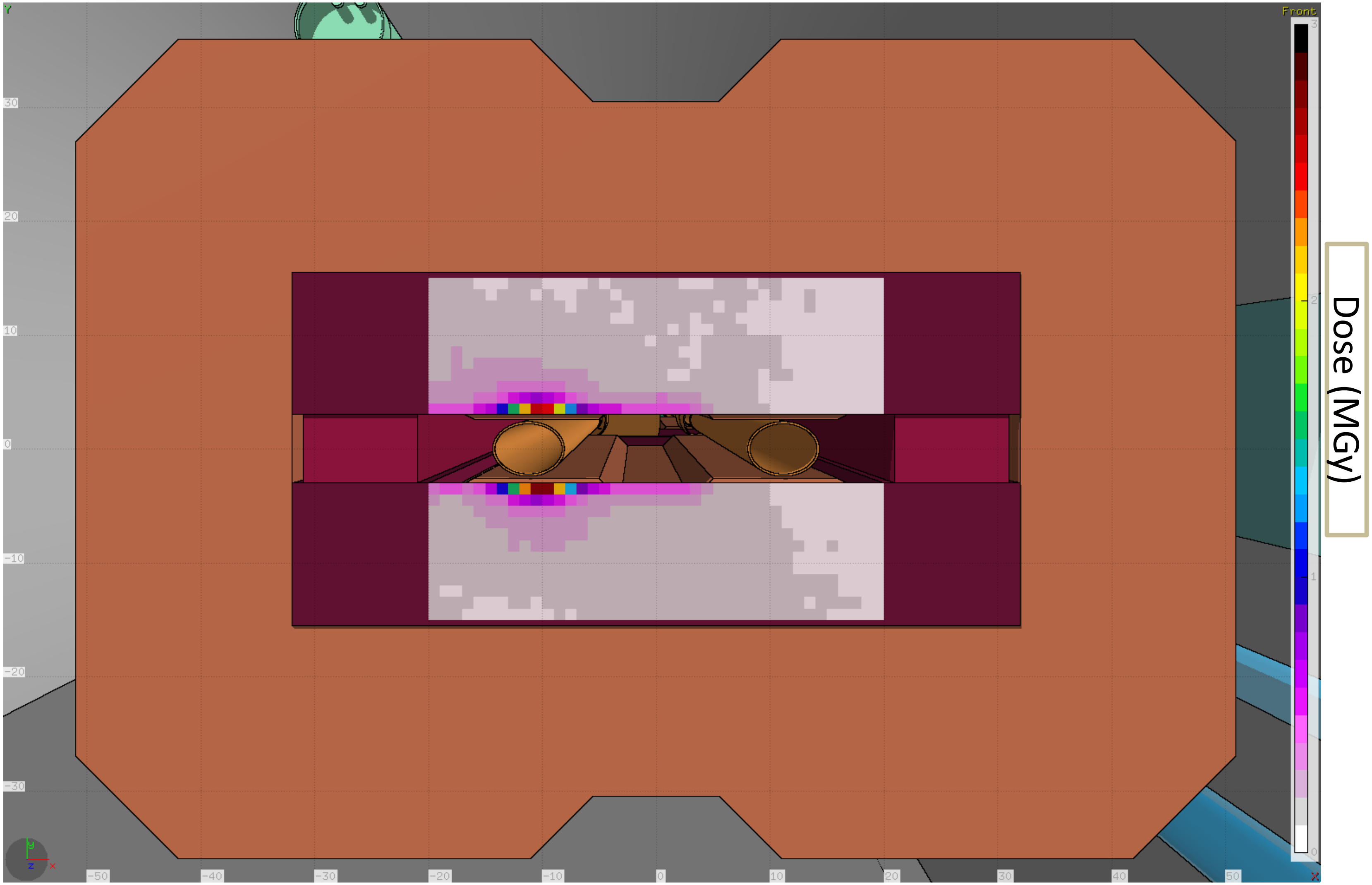
Table 2: Result from the linear fit to the cumulated losses during each fill in 2011 and 2012 as a function of the LHC delivered integrated luminosity to ATLAS.

Fit results (slope) [Gy fb]	IR7		IR3	
	B1	**B2**	**B1**	**B2**
2011	696.8	762.9	196.7	115.1
2012 before TS2	635.9	968.2	26.8	12.6
2012 after TS2	1306.7	1356.7	54.7	30.1

ESTIMATE OF WARM MAGNETS LIFETIME IN THE BETATRON AND MOMENTUM CLEANING INSERTIONS OF THE LHC

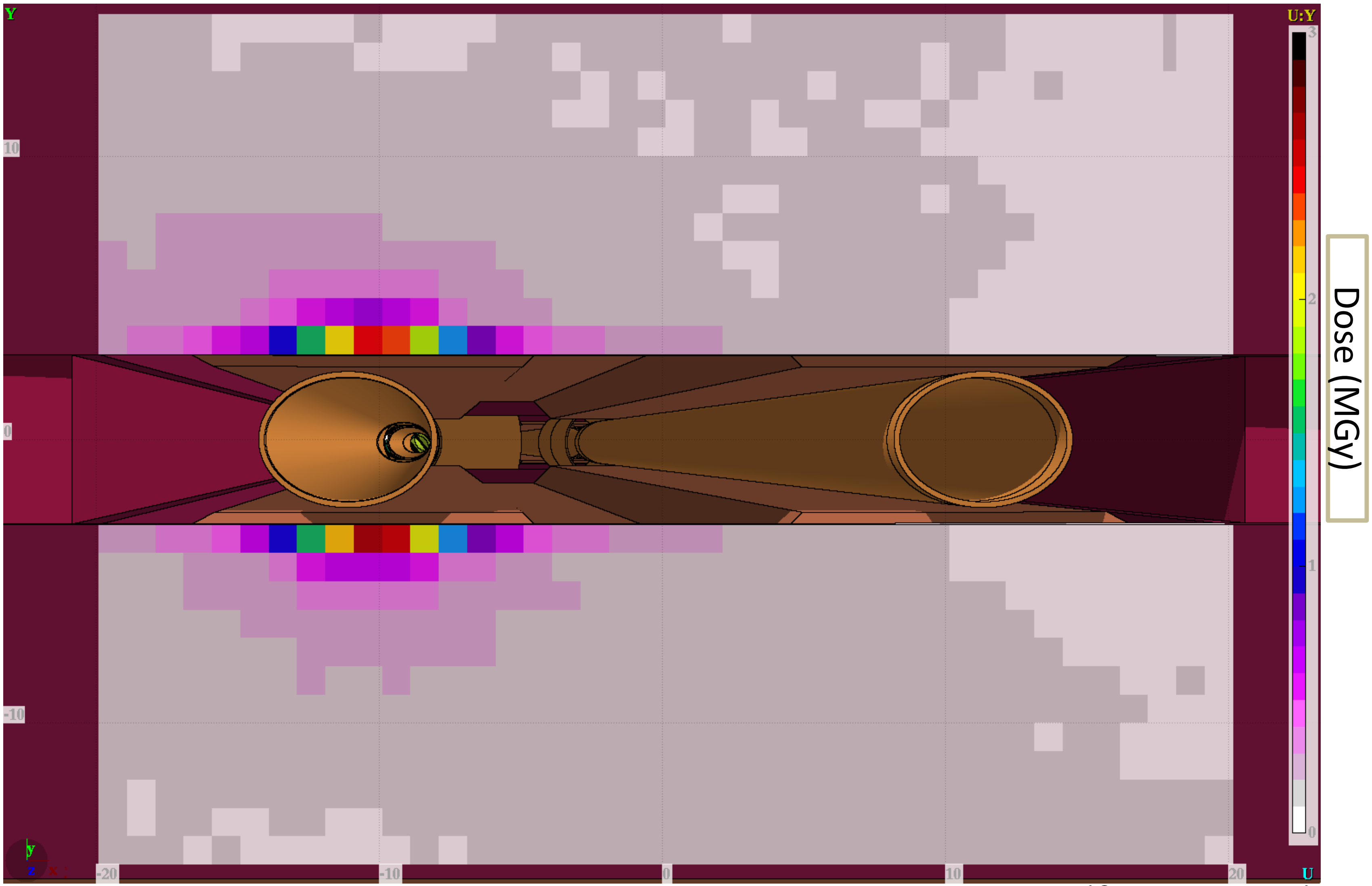
B. Salvachua*, R. Bruce, M. Brugger, F. Cerutti, S. Redaelli
CERN, Geneva, Switzerland

MBWB Dose 2d cross section at maximum



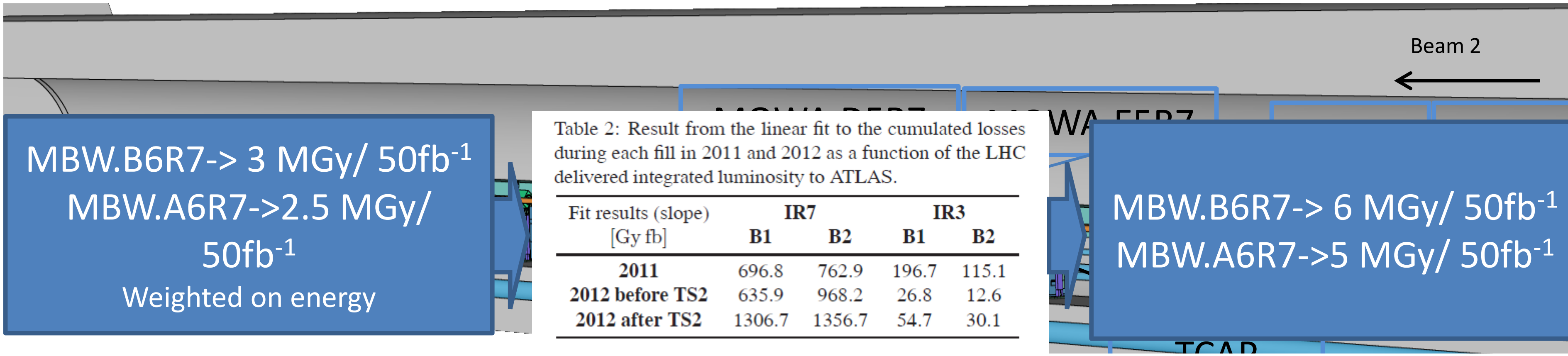
Normalization: 1.15 10^{16} p (30-50 fb^{-1})

MBWB Dose 2d cross section at maximum



Normalization: 1.15 10^{16} p (30-50 fb^{-1})

MBWA - MBWB Dose Maximum Z profile

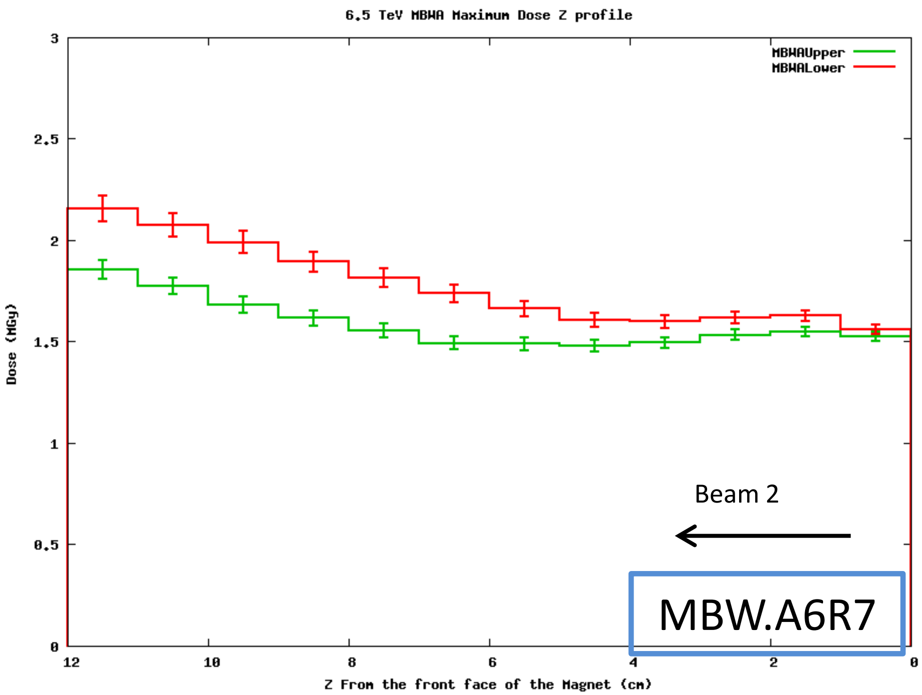


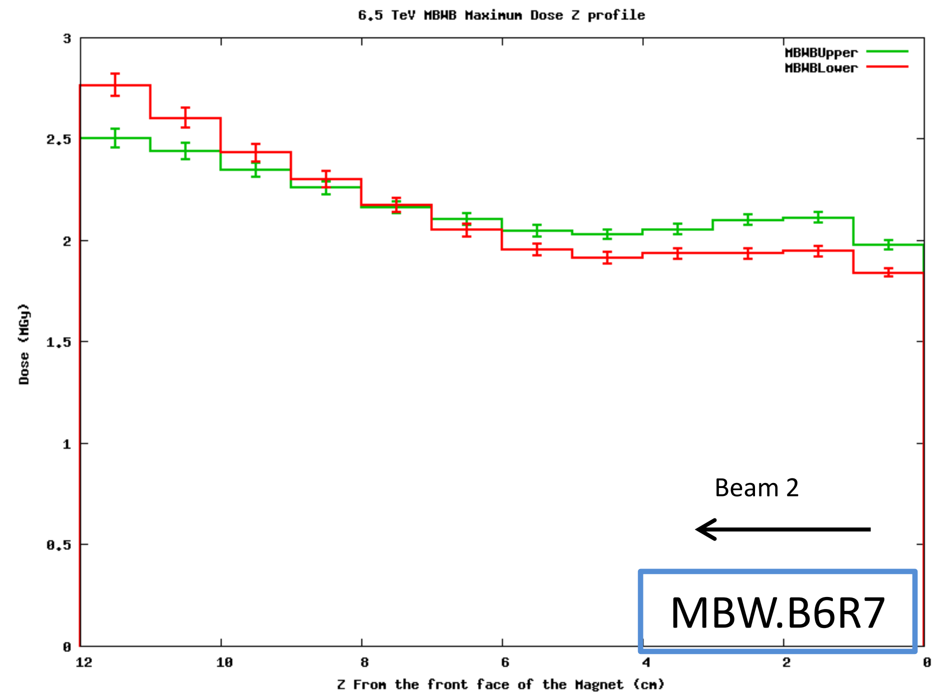
MBW.B6R7-> 3 MGy/ 50fb^{-1}
MBW.A6R7->2.5 MGy/ 50fb^{-1}
Weighted on energy

Table 2: Result from the linear fit to the cumulated losses during each fill in 2011 and 2012 as a function of the LHC delivered integrated luminosity to ATLAS.

Fit results (slope) [Gy fb]	IR7 B1	IR7 B2	IR3 B1	IR3 B2
2011	696.8	762.9	196.7	115.1
2012 before TS2	635.9	968.2	26.8	12.6
2012 after TS2	1306.7	1356.7	54.7	30.1

MBW.B6R7-> 6 MGy/ 50fb^{-1}
MBW.A6R7->5 MGy/ 50fb^{-1}





ESTIMATE OF WARM MAGNETS LIFETIME IN THE BETATRON AND MOMENTUM CLEANING INSERTIONS OF THE LHC

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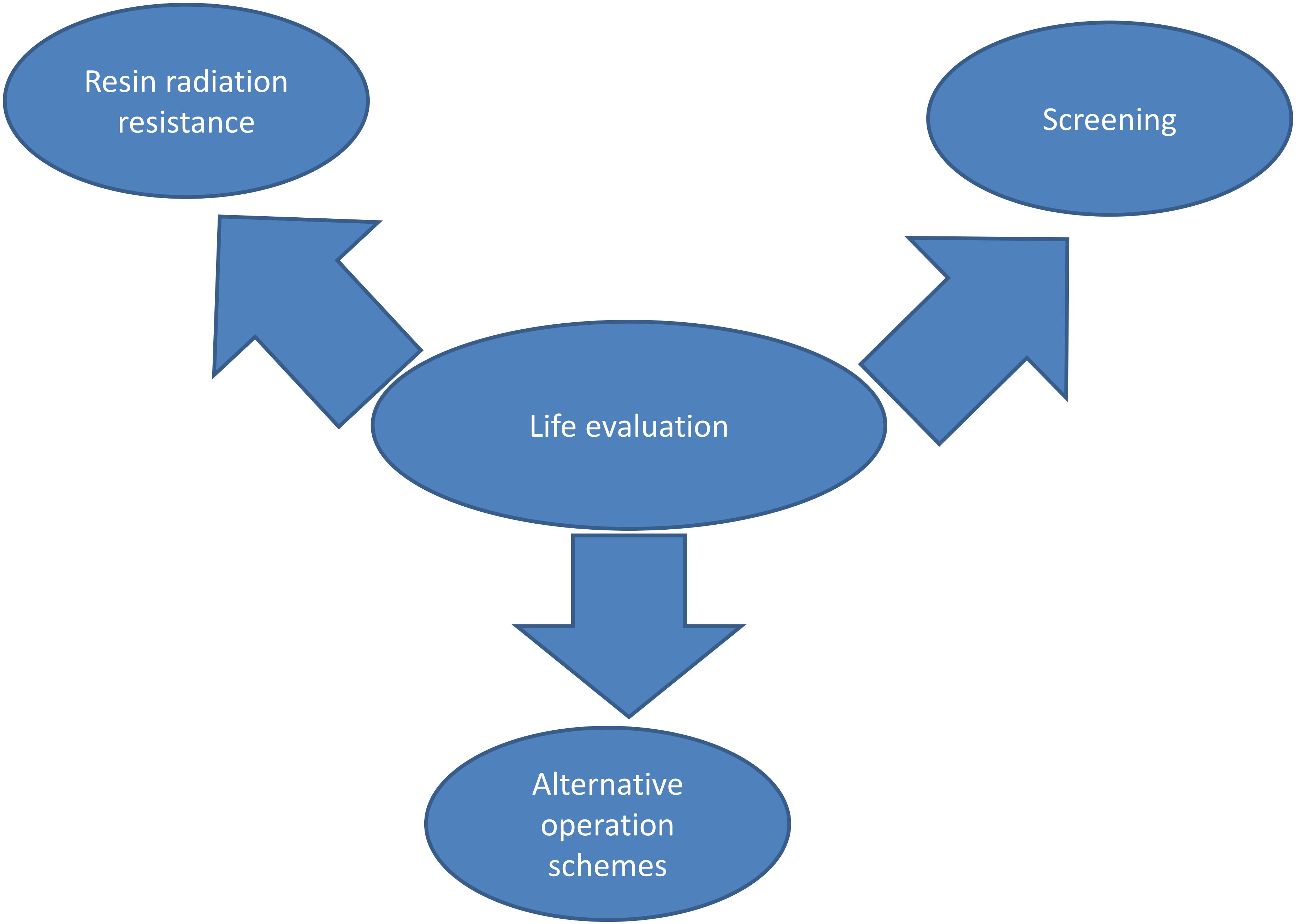
Normalization: 1.15 10^{16} p (30-50 fb^{-1})

Future scenarios

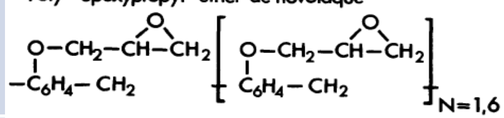
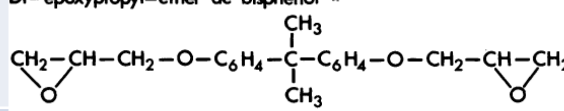
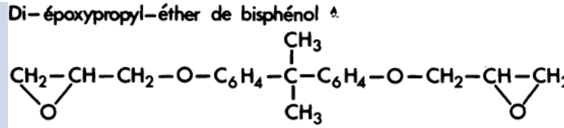
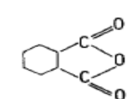
magnet	Reference extrapolation 50 fb^{-1} new loss pattern [Mgy]	Till LS2 7TeV (150 fb^{-1}) [MGy]	Till LS3 7TeV (350 fb^{-1}) [MGy]	Till HL-LHC 7TeV (3000 fb^{-1}) [MGy]
MBW.B6R7	5	16	38	323
MBW.A6R7	6	20	45	388
MQWA.A4	0.12	0.6	1.4	12
MQWA.B4	0.14	0.6	1.4	12
MQWB.4	0.18	0.9	2.1	18
MQWA.C4	0.52	2.4	5.6	48
MQWA.D4	0.4	1.8	4.2	36
MQWA.E4	1.1	4.8	11	96
MQWA.A5	0.62	2.4	5.6	48
MQWA.B5	0.7	3.3	7.7	66
MQWB.5	0.8	3.9	9.1	78
MQWA.C5	1	4.8	11	96
MQWA.D5	1.3	5.7	13	114
MQWA.E5	3.7	12	28	240


Resin radiation resistance
Screening
Life evaluation
Alternative operation schemes

RADIATION RESISTANCE

MQW resins

Resin used					
component	EPN1138	GY 6004	CY 221	HY 905	30ml DY 073
percentage	50 %	50 %	20 %	120 %	0.03

EPN 1138	Novolac Poly–époxypropyl–éther de novolaque 
GY 6004	DGEBA Di–époxypropyl–éther de bisphénol A 
CY 221	DGEBA Di–époxypropyl–éther de bisphénol A 
HY 905	HY 905 (CIBA-GEIGY) Acid anhydride hardener, liquid, modified Hexahydrophthalic anhydride (see HT 907) HPA HT 907 (CIBA-GEIGY) Acid anhydride hardener, solid, unmodified Hexahydrophthalic anhydride 
DY 073	flexibilizer

Material:	**Epoxy resin**	TIS No. **R 422**
Type	**MY 745 (50) + EPN 1138 (50) + CY 221 (20) + HY 905 (120) + DY 073 (0.3)**	
Supplier:	**Ciba-Geigy**	UL 94: n.m.
Remarks:	used for the ISR dipoles	LOI:

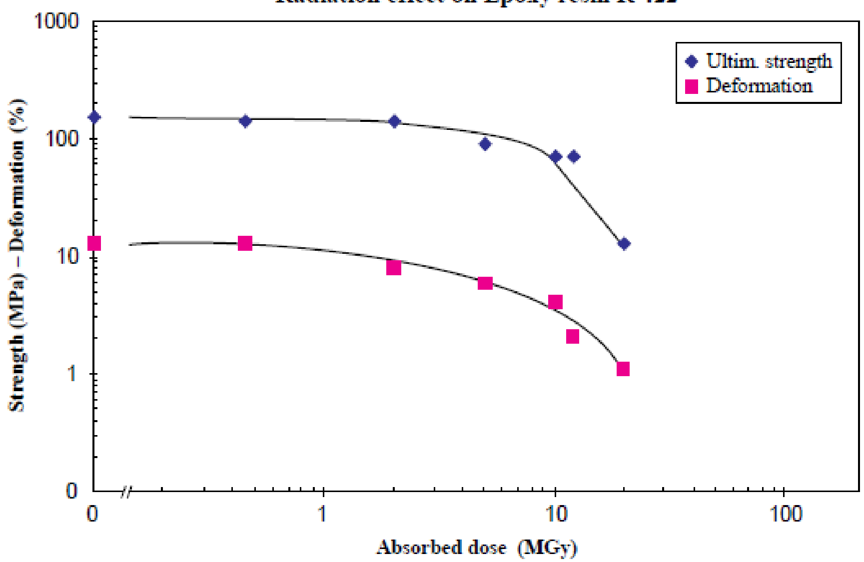
Radiation test results according to IEC Standard 544 (and ISO 178)

Dose rate (kGy/h)	Dose (MGy)	Ultim. strength (MPa)	Deformation ε (%)	Modulus (GPa)
0	0	153±3	13.1±1.9	3.80±0.03
0.2	0.5	142±1	12.9±0.3	3.50±0.02
0.2	2.0	140±1	7.9±0.3	3.50±0.02
180	5	93±2	6.1±0.3	4.00±0.03
180	10	73±3	4.2±0.2	4.10±0.04
0.5	12	71±6	2.1±0.2	3.7±0.1
180	20	13±1	1.1±0.1	3.40±0.04

Radiation index (RI) = 6.9 if strength is the critical property

Radiation index (RI) = 6.6 if deformation is the critical property

Radiation effect on Epoxy resin R 422



Material:	**Epoxy resin**	TIS No. **R 422**
Type	**MY 745 (50) + EPN 1138 (50) +** CY 221 (20) + HY 905 (120) + DY 073 (0.3)	
Supplier:	**Ciba-Geigy**	UL 94: n.m.
Remarks:	used for the ISR dipoles	LOI:

Radiation test results according to IEC Standard 544 (and ISO 178)

Dose (MGy)	Mechanical test results at RT			Mechanical test results at 77 K		
	Strength (MPa)	Deformation ε (%)	Modulus (GPa)	Strength (MPa)	Deformation ε (%)	Modulus (GPa)
0	**152.6** ± 3.0	**13.1** ± 1.9	**3.8** ± 0.03	**344** ± 19	**3.5** ± 0.5	**6.7** ± 0.9
5	**93.0** ± 2.0	**6.1** ± 0.3	**4.0** ± 0.03			
10	**73.0** ± 3.0	**4.2** ± 0.2	**4.1** ± 0.04			
14				**191** ± 13	**3.5** ± 0.3	**5.3** ± 0.2
20	**13.0** ± 1.0	**1.1** ± 0.1	**3.4** ± 0.04			
35				**124** ± 44	**2.0** ± 0.1	**6.1** ± 0.7
119				**18** ± 5.0	**0.7** ± 0.2	**2.8** ± 1.0
RI =	**6.9**	**6.6**	**> 7.3**	**> 7.3**	**7.7**	**7.7**

Radiation effect on epoxy resin R 422

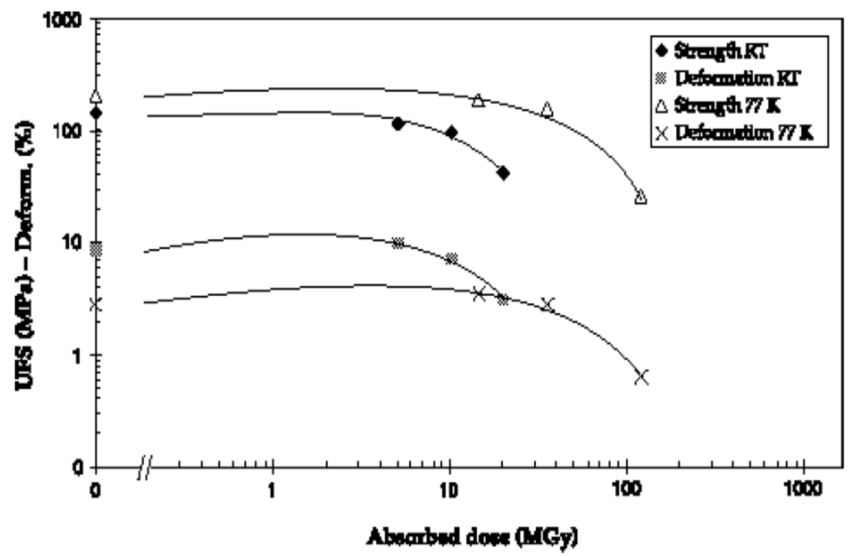


Fig. 18: Araldite MY 745 + EPN 1138 R 422

Different epoxy

Resins	Hardeners	Additives	Composition (p.p.)	Mix Temp (°C)	Viscosity (cPs)	Service life (mn)	Fig	Dose for 50% flex. (MGy)	Dose Range (MGy)
EDBAH	MA						5.4	1.4	
EDBAH	MA	BDMA	100-105-0.2	80	45	>180	5.1	1.6	1 - 3
BECP	MA						5.4	2.5	
BECP	MA	BDMA	100-110-0.2	80	40	>180	5.1	2.3	
ECC	MA		100-72	80	20	>240	5.5	1.8	
VCD	MA	BDMA	100-160-05	60	20	>180	5.4	3.7	1 - 6
DADD	MA		100-65	80	180	>240	5.4	5.5	
DGEBA + EDGDP	TETA		100-20-12	25			5.21	1.3	1 - 2
DGEBA	TETA	DBP	83-9-17	50	500	few	5.22	1.2	
DGEBA	DADPS		100-35	130	60	180	4.2	5.1	
DGEBA + EDGDP	MDA		100-20-30	80			5.21	8.2	5 - 15
DGEBA	MDA		100-27	80	100	50	5.9	13.0	
DGEBA	MPDA		100-14.5	65	200	30	5.7	23.5	**23**
DGEBA	AF		100-40	100	150	30	5.26	45.2	**45**
DGEBA	DDSA	BDMA	100-130-1	80	70	120	5.2	4.2	
DGEBA	NMA	BDMA	100-80-1	80	80	120	5.2	5.9	
DGEBA	MA		100-100	60	69	>1440	5.23	7.1	
DGEBA	MA	BDMA					5.1	12.0	5 - 15
DGEBA	MA	BDMA + Po. Gl.	100-100-0.1-10	60	65	300	5.23	12.1	
DGEBA	AP		100-70	120	26	180	5.2	13.0	
DGPP	DADPS		100-28	130			5.6	8.2	
DGPP	MA		100-135	120			5.3	13.0	
EDTC	MDA		100-20	80		40	5.9	10.0	5 - 15
TGTPE	DADPS		100-34	125	>20000		5.6	12.1	
TGTPE	MA	BDMA	100-100-0.2	125	>15000		5.3	10.6	
EPN	DADPS		100-35	100		30	5.6	23.5	**20 - 40**
EPN	MDA		100-29	100		35	5.10	37.2	
EPN	HPA	BDMA	100-76-1	80		40	5.10	13.0	
EPN	MA	BDMA	100-105-0.5	80		100	5.3+5.25	15.0	**10 - 20**
EPN	NMA	BDMA	100-85-1	100		80	5.10	20.6	
TGMD	DADPS		100-40	80		50	5.6	20.6	
TGMD	MA	BDMA	100-136-0.5	60		30	5.3	11.4	
TGMD	NMA	BDMA	100-110-1	80	500	20	5.8	18.0	**10 - 25**
TGPAP	NMA		100-137	80	<20		5.8	23.5	
DGA	MPDA		100-20	25		120-420	5.7	23.5	**20 - 30**
DGA	NMA		100-115	25	5 - 20	30-5760	5.8	28.6	

Legend

Resin
- Linear aliphatic
- Cycloaliphatic
- Aromatic

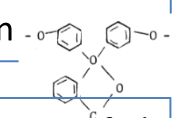
Hardener
- Aliphatic Amine
- Aromatic Amine
- Alicyclic Anhydride
- Aromatic Anhydride

Aromatic >
Cycloaliphatic >
Linear Aliphatic

Aliphatic amine harderner
→ poor radio-resistance

Aromatic amine hardener >
Anhydride hardener

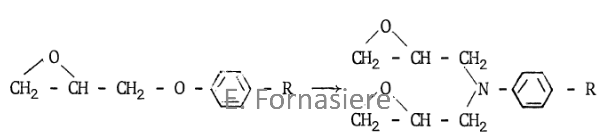
H: Too high local concentration of benzene may induce steric hindrance disturbation



Good radio-resistance even if Cl (tendence to capture n_{th})

Novolac: HIGH Radio-resistance
- Large nb of epoxy groups
  → Density + rigidity

Glycidyl-amine: HIGH R.-resistance
- ~~Quaternary carbon → weakness~~
- ~~Ether group (R – O – R') → weakness~~ **→ Repl. by amina**



DGEBA MY 745 substituted by GY 6004

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm^2)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm^2)
240 (a)	MY 745(100) + HY 906(90) + + XB 2687(1.5) 12 h 125 °C CIBA-GEIGY	0	118.8 ± 10.0	6.5 ± 0.8	$3.64 \pm 0.07 \times 10^3$
298	MY 745(100) + HY 906(90) + + XB 2687(1.5) 5 h 110 °C + 16 h 125 °C	0	100.4 ± 37.3	8.3 ± 4.0	$3.68 \pm 0.04 \times 10^3$
		5×10^6	118.8 ± 32.4	11.2 ± 4.1	$3.65 \pm 0.12 \times 10^3$
		1×10^7	100.0 ± 44.1	7.0 ± 3.5	$4.08 \pm 0.10 \times 10^3$
		2.5×10^7	48.1 ± 17.7	2.9 ± 1.1	$4.20 \pm 0.21 \times 10^3$
	CIBA-GEIGY	5×10^7	13.7 ± 2.9	1.2 ± 0.4	$3.42 \pm 0.00 \times 10^3$
299	MY 745(100) + HY 906(90) + + XB 2687(1.5) 24 h 125 °C	0	107.7 ± 20.6	7.9 ± 2.0	$3.84 \pm 0.15 \times 10^3$
		5×10^6	114.9 ± 34.3	9.3 ± 3.3	$3.76 \pm 0.12 \times 10^3$
		1×10^7	68.7 ± 21.6	4.4 ± 1.3	$4.02 \pm 0.16 \times 10^3$
		2.5×10^7	36.3 ± 8.8	2.2 ± 0.5	$4.25 \pm 0.24 \times 10^3$
	CIBA-GEIGY	5×10^7	8.8 ± 1.96	0.6 ± 0.2	$3.21 \pm 0.00 \times 10^3$

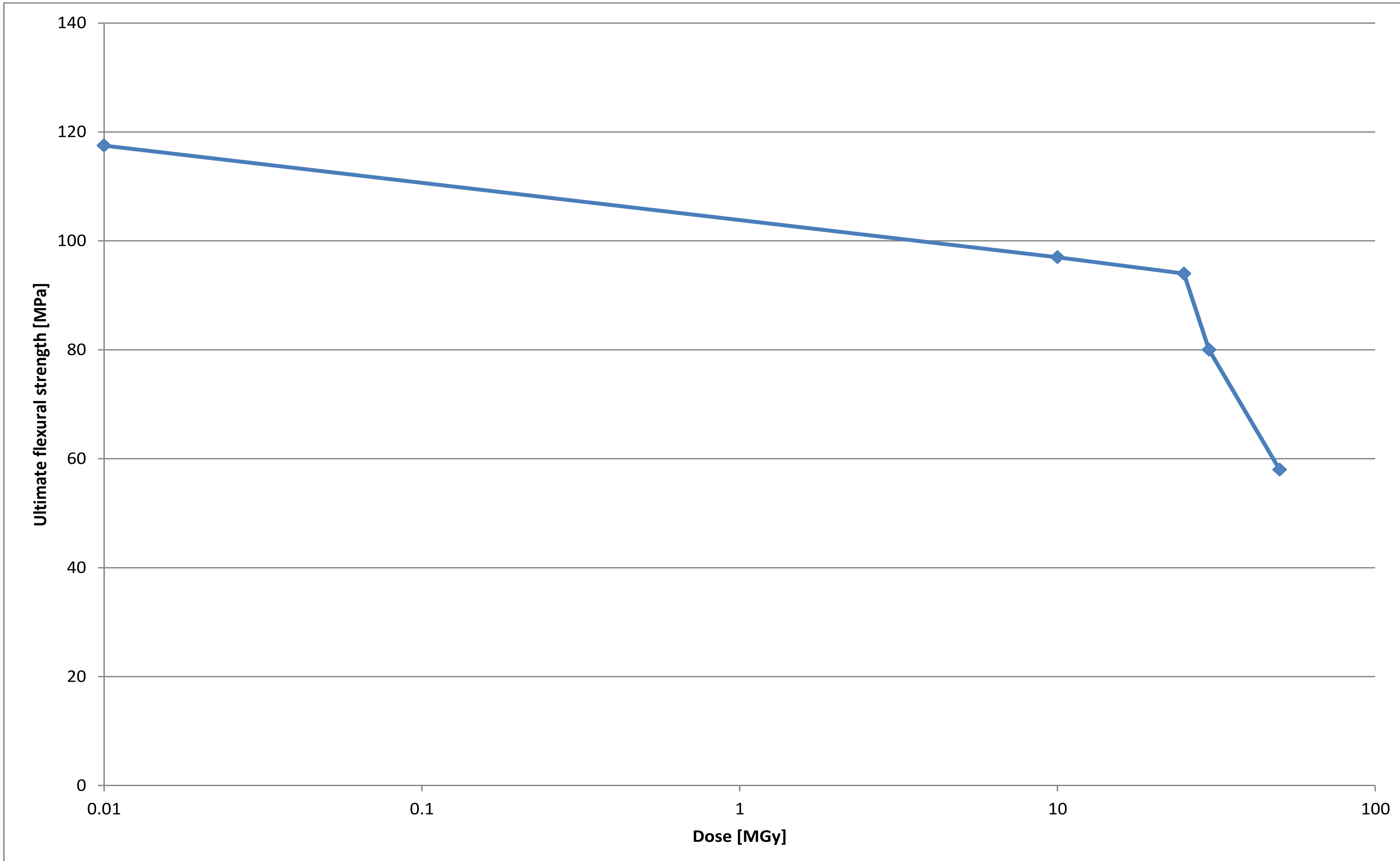
CY 222 (similar to CY 221)

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm^2)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm^2)
103 (a)	CY 222 + HY 920 (Pure resin)	0	too flexible for testing		
		5×10^6	too flexible for testing		
		1×10^7	too flexible for testing		
		3×10^7	15.7 ± 2.0	5.4 ± 3.6	$8.04 \pm 1.32 \times 10^2$
	BBC Baden	5×10^7	12.8 ± 1.0	1.4 ± 0.3	$1.66 \pm 0.13 \times 10^3$

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm^2)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm^2)
89	EPN 1138(50) + MY 745(50) + + CY 221(20) + HY 905(120) + + DY 063(0.3)	0	131.5 ± 24.5	9.3 ± 3.2	$3.55 \pm 0.15 \times 10^3$
		6×10^6	92.2 ± 6.9	4.6 ± 0.3	$3.75 \pm 0.13 \times 10^3$
	24 h 120 °C	1×10^7	68.7 ± 22.6	3.5 ± 1.2	$3.56 \pm 0.07 \times 10^3$
	Type ISR	2×10^7	62.8 ± 13.7	3.0 ± 0.7	$3.88 \pm 0.08 \times 10^3$
	ALSTHOM	6×10^7	6.9 ± 0.3	0.7 ± 0.1	$1.90 \pm 0.24 \times 10^3$
123	EPN 1138(50) + MY 745(50) + + HY 905(103) + XB 2687(0.25)	0	118.7 ± 21.6	8.4 ± 3.1	$3.30 \pm 0.05 \times 10^3$
		5×10^6	114.8 ± 21.6	9.8 ± 3.4	$3.34 \pm 0.12 \times 10^3$
	24 h 120 °C	1×10^7	78.5 ± 8.8	4.3 ± 0.4	$3.45 \pm 0.13 \times 10^3$
	ALSTHOM	2×10^7	53.0 ± 6.9	2.8 ± 0.3	$3.51 \pm 0.06 \times 10^3$
203	EPN 1138(100) + HY 906(95) + + DY 062(0.5)	0	130.5 ± 19.6	8.7 ± 2.2	$3.52 \pm 0.05 \times 10^3$
	2.5 h 80 °C + 12 h 160 °C	5×10^6	115.8 ± 19.6	7.1 ± 1.8	$3.88 \pm 0.17 \times 10^3$
	CIBA-GEIGY	1×10^7	122.6 ± 7.8	7.2 ± 0.7	$3.95 \pm 0.04 \times 10^3$
297	EPN 1138(50) + MY 745(50) + + CY 221(20) + HY 905(120) + + XB 2687(0.3)	0	124.2 ± 24.5	12.4 ± 3.7	$3.73 \pm 0.25 \times 10^3$
		5×10^6	91.9 ± 8.8	6.4 ± 0.6	$3.80 \pm 0.13 \times 10^3$
	24 h 120 °C	1×10^7	68.9 ± 11.8	4.5 ± 0.9	$4.01 \pm 0.09 \times 10^3$
		2.5×10^7	13.7 ± 0.3	1.2 ± 0.4	$3.26 \pm 0.04 \times 10^3$
	CIBA-GEIGY	5×10^7	2.1 ± 0.0	0.7 ± 0.0	$5.27 \pm 0.00 \times 10^2$

MBW BINP used resin.

We looked at molecule and there is good indication that it should radiation hard as witnessed by the tests



1st conclusion

MQW

- The pure resin mix used shall keep substantial mechanical properties at least till 15-20 MGy

MBW

- The pure resin mix used shall keep substantial mechanical properties at least till 40-50 MGy

Filler contribution

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 (20 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 Barium	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	5.14	30.5	
(DGEBA	MDA		Alumine	100-27-220	4.7	23.5)	**20 - 50**
DGEBA	MDA		Alumine	100-27-220	5.14	51.7	
DGEBA	MDA		Alumine	100-27-100	5.15	20.6	
DGEBA	MDA		Alumine	100-27-220	5.15	42.5	
DGEBA	**MDA**		**Fibre de verre**	**100-27-50**	**5.19**	**82**	**80 - 100**
DGEBA	**MDA**		**Fibre de verre**	**100-27-60**	**5.18**	**100**	
EPN	**MDA**		**Fibre de verre**	**100-29-50**	**5.19**	**>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**	

Legend

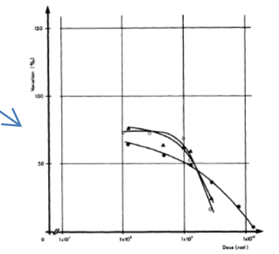
Resin
- Linear aliphatic
- Cycloaliphatic
- Aromatic

Hardener
- Aliphatic Amine
- Aromatic Amine
- Alicyclic Anhydride
- Aromatic Anhydride

2 Categories of fillers:
1. Powder fillers
2. Glass/Silice fibers

Paper [cellulose $(C_6H_{10}O_5)_n$]
→ Strong decrease of radio-resistance

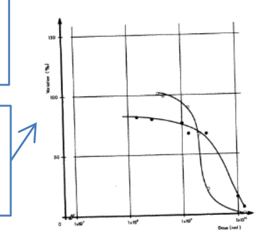
The bigger the powder, the more radio-resistant



Hardener choice not influenced by filler

High r.-resistance for Graphite and Alumina

The more fillers, the more radio-resistant



Best Radio-Resistant materials are obtain with Glass/**Silice** (influence of boron) fibers and aromatic resins (**Novolac** and **glycidyl-amine**)

E. Fornasiere

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm^2)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm^2)
97	Magnet coil resin Orlitherm® (Base: DGEBA + MNA + + other components)	0	97.1 ± 16.7	5.8 ± 1.7	$3.53 \pm 0.11 \times 10^3$
		5.6×10^6	64.7 ± 10.8	3.6 ± 0.6	$3.51 \pm 0.06 \times 10^3$
		1.1×10^7	52.9 ± 14.7	3.0 ± 0.8	$3.55 \pm 0.13 \times 10^3$
		2.2×10^7	39.2 ± 6.8	2.0 ± 0.4	$3.75 \pm 0.15 \times 10^3$
	BBC Baden	5.6×10^7	7.9 ± 1.0	1.0 ± 0.1	$2.26 \pm 0.21 \times 10^3$

175	Magnet coil resin Orlitherm® reinforced with a fibre-silanized woven glass tape type 1	0	510.1 ± 11.8	5.2 ± 0.1	$1.91 \pm 0.07 \times 10^4$
		1×10^7	364.9 ± 5.9	4.2 ± 0.4	$1.91 \pm 0.01 \times 10^4$
		5×10^7	285.5 ± 13.7	3.4 ± 0.2	$1.85 \pm 0.06 \times 10^4$
	12 h 165 °C BBC Baden	1×10^8	169.7 ± 22.6	2.7 ± 0.4	$1.56 \pm 0.14 \times 10^4$
176	Magnet coil resin Orlitherm® reinforced with glass woven tape type 2 with a special silane finish	0	450.3 ± 24.5	5.2 ± 0.3	$1.64 \pm 0.07 \times 10^4$
		1×10^7	419.9 ± 18.6	5.0 ± 0.1	$1.62 \pm 0.05 \times 10^4$
		5×10^7	387.5 ± 55.9	5.2 ± 0.5	$1.61 \pm 0.01 \times 10^4$
	12 h 165 °C BBC Baden	1×10^8	281.5 ± 28.5	4.9 ± 0.3	$1.44 \pm 0.01 \times 10^4$
99	Magnet coil resin Orlitherm® reinforced with fibre-silanized woven glass tape type 1 and mica-paper tape	0	224.6 ± 11.7	5.0 ± 0.5	$2.96 \pm 0.74 \times 10^4$
		1.1×10^7	191.3 ± 2.9	5.2 ± 0.4	$7.99 \pm 0.54 \times 10^3$
		3.1×10^7	130.4 ± 5.9	4.6 ± 0.5	$8.00 \pm 0.50 \times 10^3$
		6.3×10^7	84.4 ± 14.7	3.9 ± 0.5	$5.85 \pm 0.49 \times 10^3$
	BBC Baden	1.0×10^8	54.9 ± 1.9	3.2 ± 0.2	$4.59 \pm 1.01 \times 10^3$

No.	Material and Supplier	Dose (Gy)	Ultimate flex. strength S (N/mm^2)	Deflexion at break D (mm)	Modulus of elasticity M (N/mm^2)
89	EPN 1138(50) + MY 745(50) + + CY 221(20) + HY 905(120) + + DY 063(0.3)	0	131.5 ± 24.5	9.3 ± 3.2	$3.55 \pm 0.15 \times 10^3$
	24 h 120 °C	6×10^6	92.2 ± 6.9	4.6 ± 0.3	$3.75 \pm 0.13 \times 10^3$
	Type ISR	1×10^7	68.7 ± 22.6	3.5 ± 1.2	$3.56 \pm 0.07 \times 10^3$
		2×10^7	62.8 ± 13.7	3.0 ± 0.7	$3.88 \pm 0.08 \times 10^3$
	ALSTHOM	6×10^7	6.9 ± 0.3	0.7 ± 0.1	$1.90 \pm 0.24 \times 10^3$
123	EPN 1138(50) + MY 745(50) + + HY 905(103) + XB 2687(0.25)	0	118.7 ± 21.6	8.4 ± 3.1	$3.30 \pm 0.05 \times 10^3$
	24 h 120 °C	5×10^6	114.8 ± 21.6	9.8 ± 3.4	$3.34 \pm 0.12 \times 10^3$
		1×10^7	78.5 ± 8.8	4.3 ± 0.4	$3.45 \pm 0.13 \times 10^3$
	ALSTHOM	2×10^7	53.0 ± 6.9	2.8 ± 0.3	$3.51 \pm 0.06 \times 10^3$

fibre

94	EPIKOTE 154 + MNA + glass tape	0	441.4 ± 18.6	5.5 ± 0.6	$1.85 \pm 0.10 \times 10^4$
		5×10^6	394.4 ± 12.7	5.2 ± 0.5	$1.77 \pm 0.06 \times 10^4$
		1×10^7	270.8 ± 44.2	3.6 ± 0.9	$1.82 \pm 0.10 \times 10^4$
		2×10^7	308.0 ± 21.6	4.1 ± 0.3	$1.85 \pm 0.11 \times 10^4$
	MICAFIL	5×10^7	234.5 ± 3.9	3.0 ± 0.2	$1.95 \pm 0.16 \times 10^4$

2^{nd} conclusion

MQW

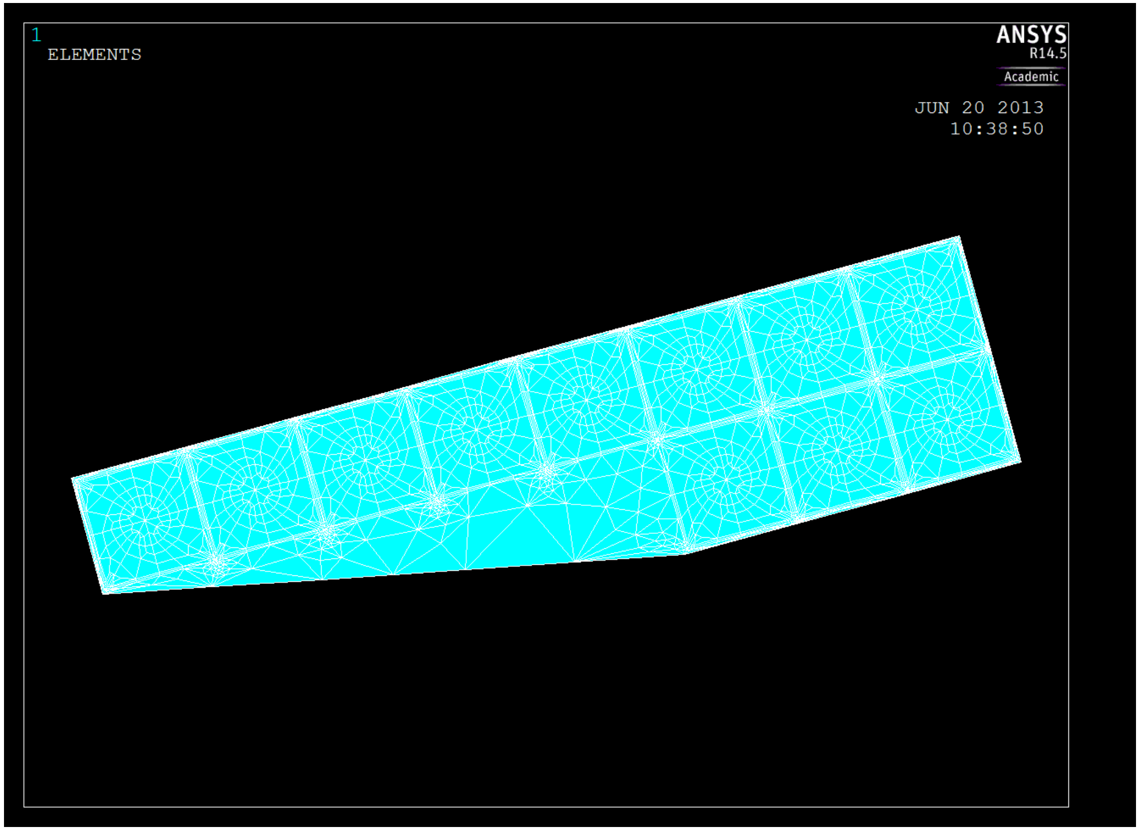
- Presence of glass fibre shall increase the substantial mechanical properties at least to 30-40 MGy

MBW

- Presence of fibre glass should probably extend life till 60- 70 MGy

Caveat

- We need to perform a rough evaluation of stresses to demonstrate that we are effectively in a low stress situation



SCREENS

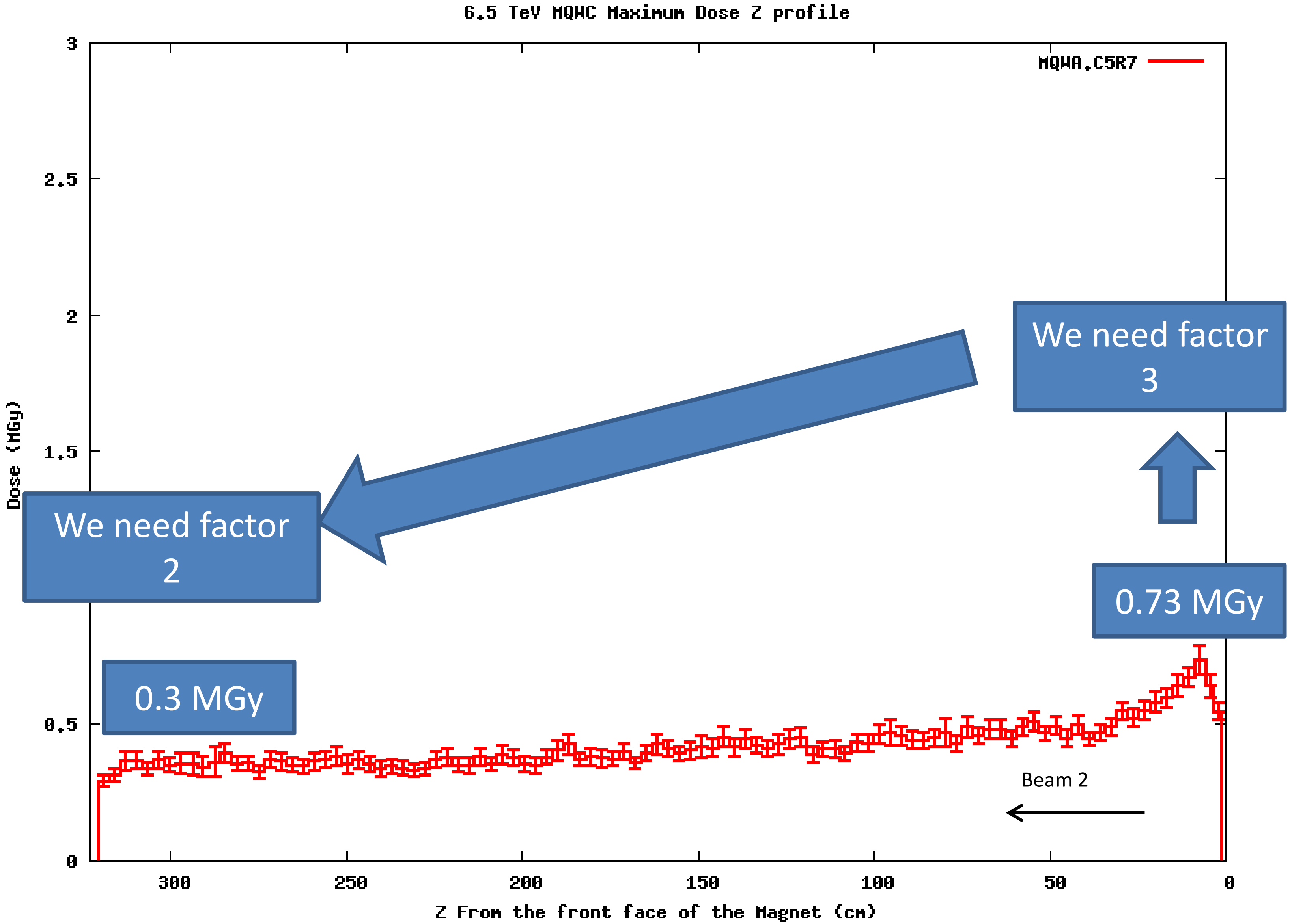
Screen options

	MQW	MBW
where	Between iron poles and the coil	Between coil ends and vacuum chamber
Possible thickness	15-30 mm	2-4 mm
Segmentation	Yes for easy extraction and possibility to tune material along the length	no
Materials	Tungsten/steel	Tungsten

Looking for screen efficiency of …

magnet	Till LS3 7TeV (350 fb^{-1}) [MGy]	Factor to gain	Till HL-LHC 7TeV (3000 fb^{-1}) [MGy]	Factor to gain
MBW.B6R7	38	Not necessary but good for ageing	323	6
MBW.A6R7	45	Not necessary but good for ageing	388	7
MQWA.A4	1.4		12	
MQWA.B4	1.4		12	
MQWB.4	2.1		18	
MQWA.C4	5.6		48	1.5
MQWA.D4	4.2		36	
MQWA.E4	11		96	3
MQWA.A5	5.6		48	1.5
MQWA.B5	7.7		66	2
MQWB.5	9.1		78	2.5
MQWA.C5	11		96	3
MQWA.D5	13		114	3.5
MQWA.E5	28	(1.5)	240	7

MQWA.C5R7 Dose Maximum Z profile

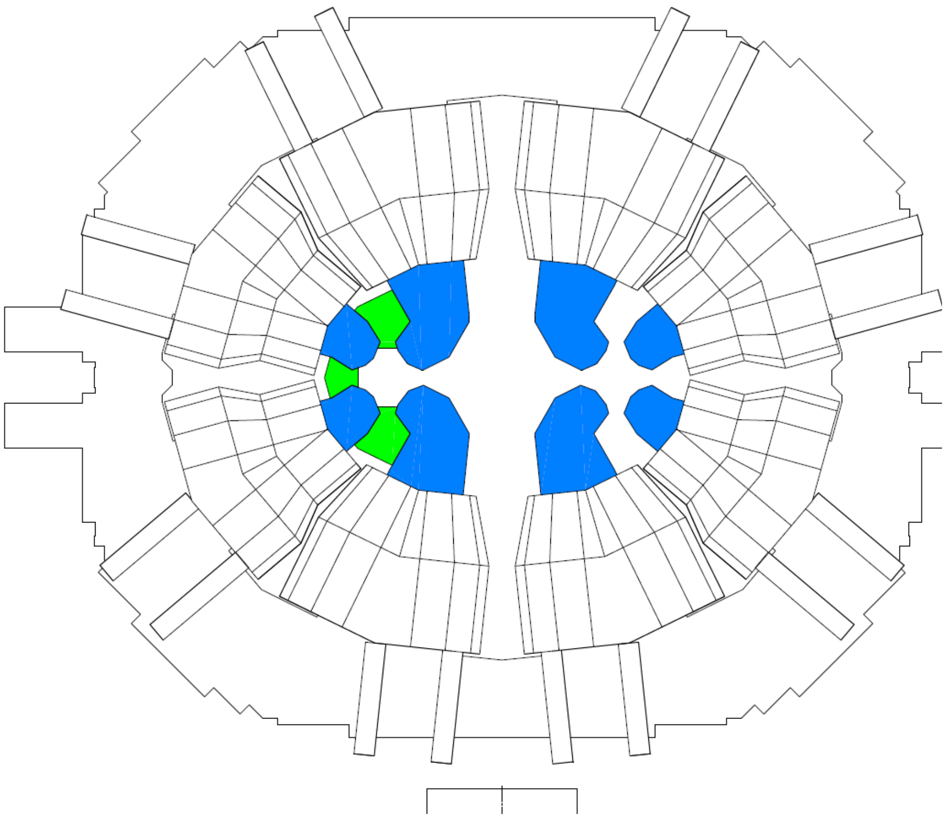


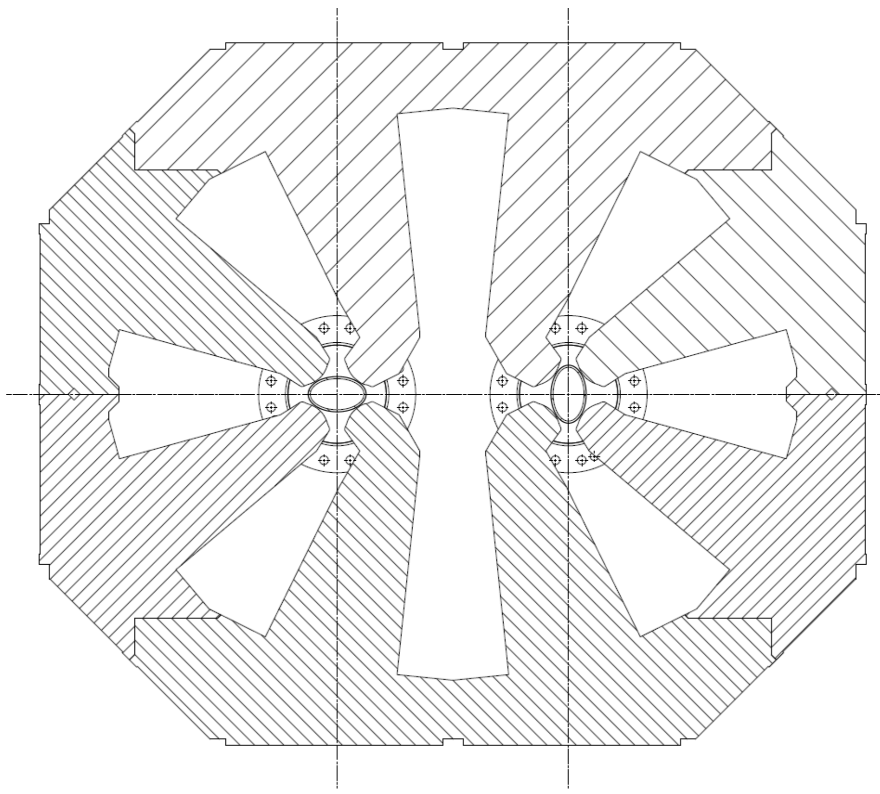
Normalization: 1.15 10^{16} p (30-50 fb^{-1})

MQW screen

fast prototyping pieces to be produced on Monday. Then test of insertion with the vacuum chamber and geometry to FLUKA team

MBW under design





THE DIFFERENT OPERATING SCENARIOS

Different scenarios see slides from M. Giovannozzi

Option A

1) Reconfigure the MQWA in pos. C5 as MQWB
2) Remove MQWA.E5
3) Connect new MQWB.C5 in the circuit RQ5.LR7
4) Substitute MQWA.E5 with an absorber at least effective as previous MQWA.E5

Other operating scenarios

Option B

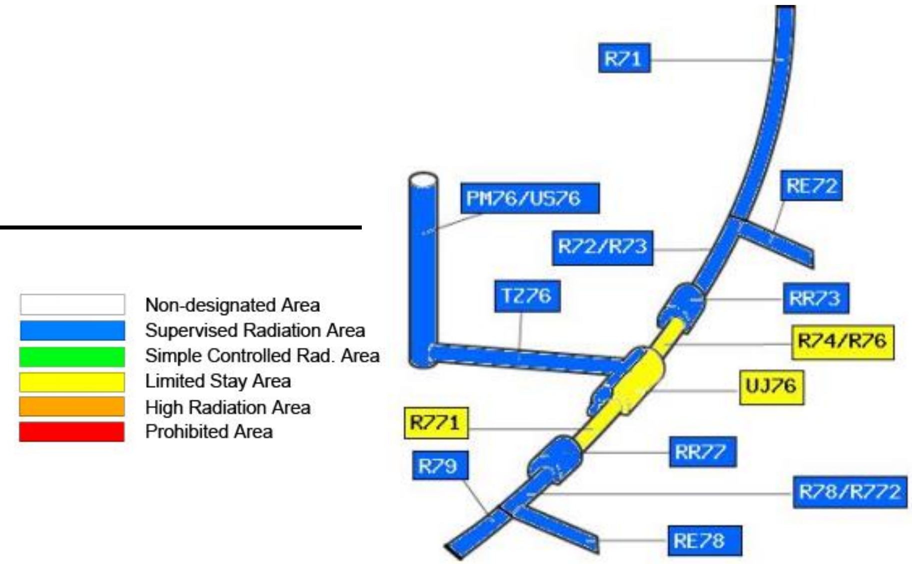
1) Connect MQWA.E5 on a new power supply circuit (600 A)
2) In case of failure of MQWA.E5 ramp up the other 4 magnets to 810 A to regain the previous strength

Not applicable because of saturation and b3 increase

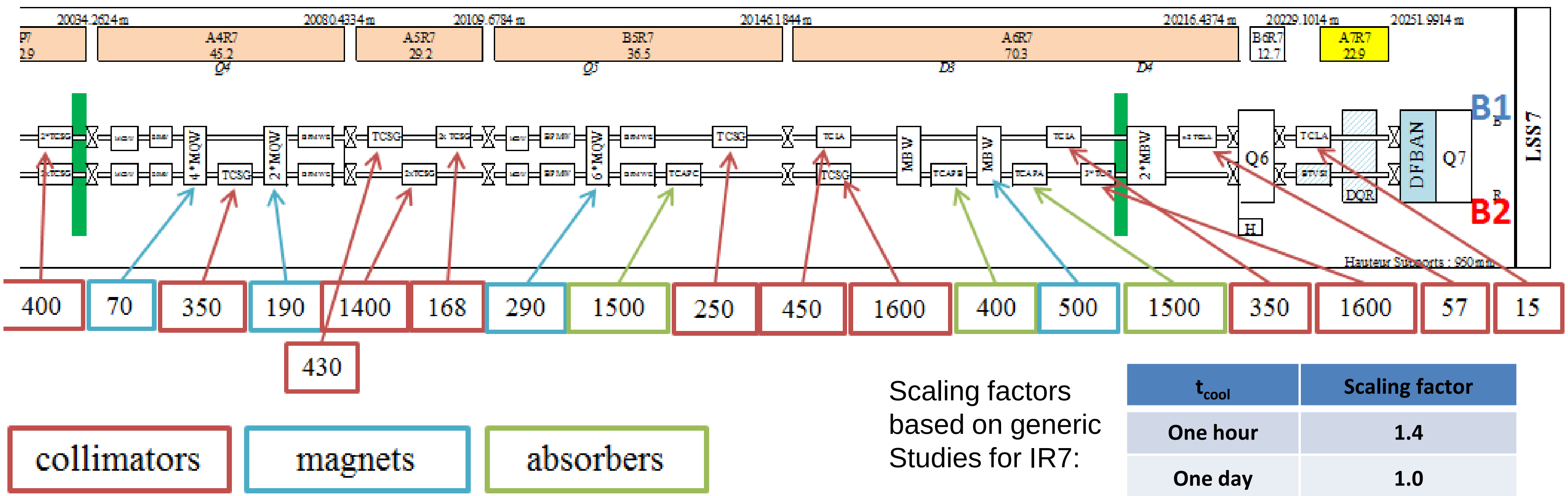
Conclusions

- LS2 shall be reached by both MQW and MBW
- LS3 should be reached by both MQW and MBW, but MQWA.E5 and MBW. X6 will have accumulated some ageing dose. Run (resins test in parallel with representative geometry to confirm)
- In HL-LHC perspective
  - MQW could meet the target combining screening and modified operation scenario
  - MBWs need a very effective screen. Due to the available space looks to be a challenge
- We should try to install screens in MQWA. E5 and MQWA.D5 and MBW already in LS1 to prevent ageing
- In LS2 we should target to implement the new operation scenario
- Probable need to design and build a new MBW for LS3 (HL-LHC operation)

LHC Point 7



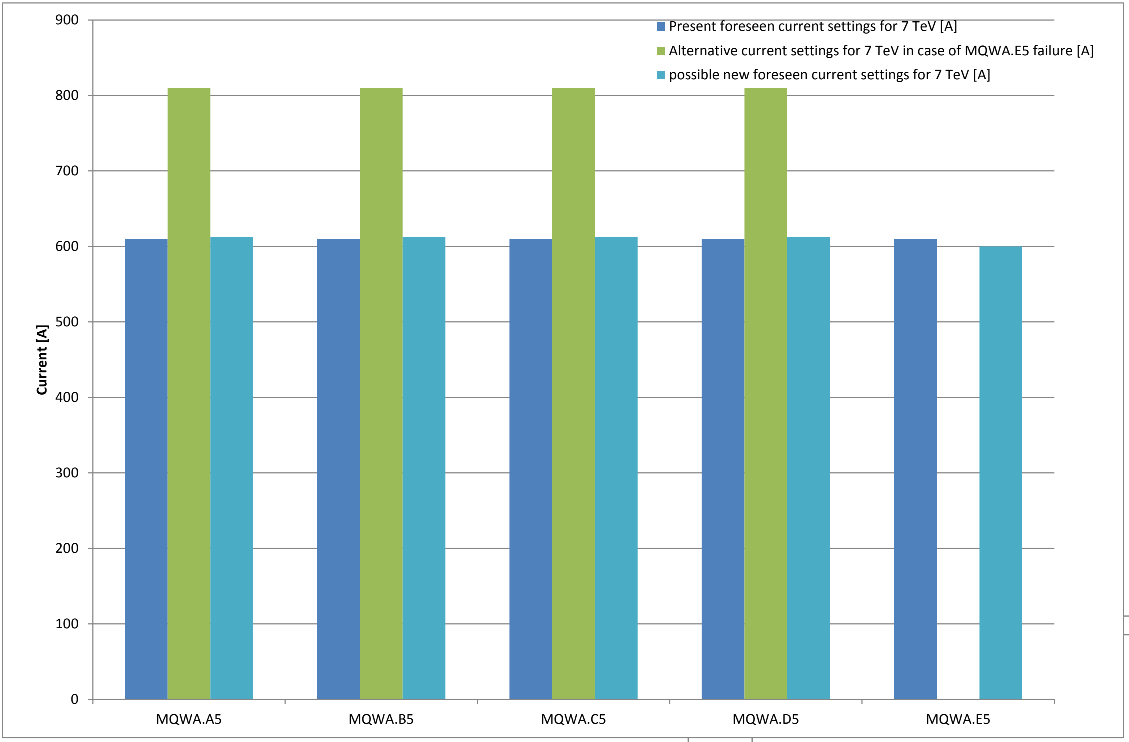
Ambient dose equivalent rates in µSv/h at 40cm measured on Dec 20, 2012
(last "good" fill on Dec 5, i.e. cooling time >1week)



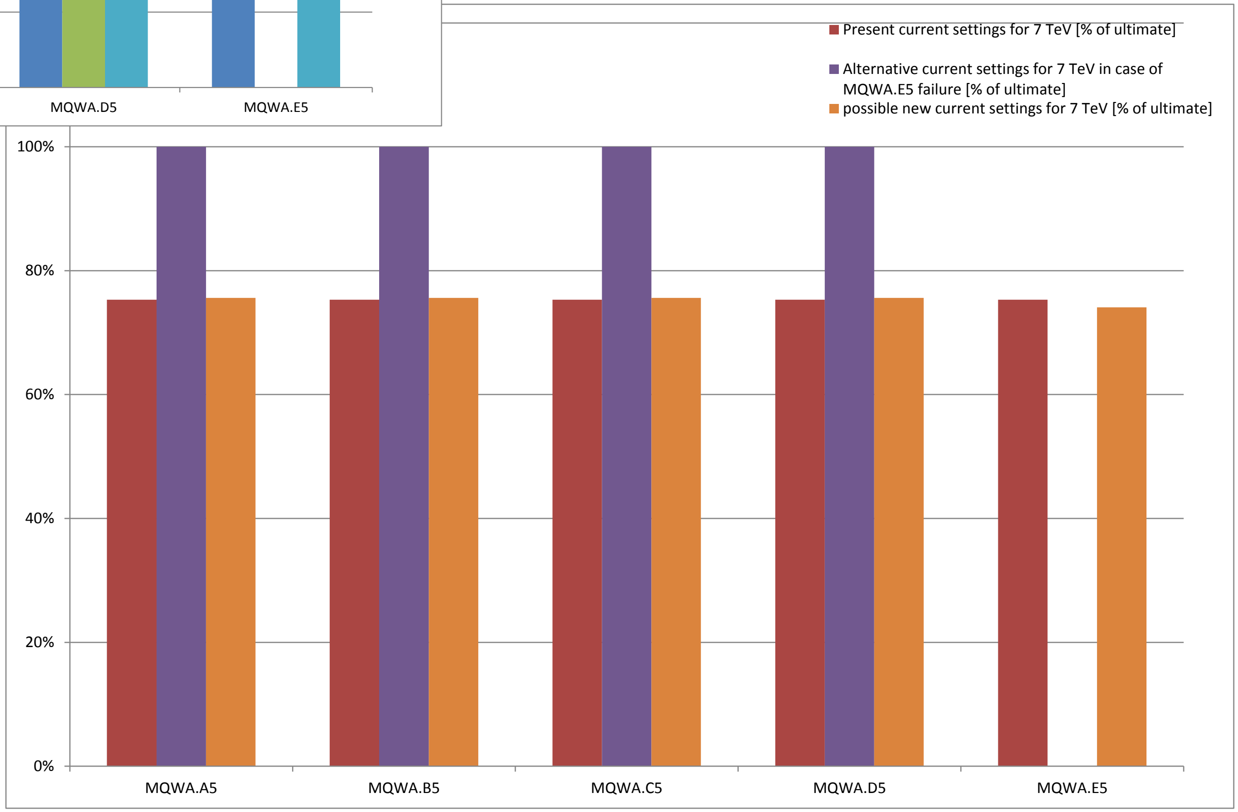
Scaling factors based on generic Studies for IR7:

t_{cool}	Scaling factor
One hour	1.4
One day	1.0
One week	0.73
One month	0.45
4 months	0.20

APPENDIX



If we put the 2 MQWA.E on 2 separate power converters 600 A …



HISTORY (SPS, ISR, …)

Table 1

Technical application, composition, curing conditions, and short survey on properties of the tested impregnation systems based on ARALDITE® and ARACAST® epoxy resins

Type	1	2 and 2a	3	4	5
Technical application CERN	Vacuum impregnation of ISR magnet coils	Vacuum impregnation of SPS magnet coils	Comparative systems		
			Standard 1	Standard 2	Hydantoin
Composition: a)					
- Epoxy resins	EPN 1138 Araldite MY 745 Araldite CY 221	Araldite MY 745	Araldite CY 205= Araldite F	Araldite CY 205 = Araldite F	Aracast CY 362
- Hardener	HY 905	HY 906	HY 905	HY 906	HY 905
- Accelerator	XB 2687	XB 2687	DY 061	DY 064	XB 2687
Parts per weight of the components	50:50:20:120:0.3	100:90:1.5	100:100:1	100:80:1	100:120:1.5
Curing conditions for test specimen	24 h/120 °C	Type 2: 5 h/110 °C + 16 h/125 °C Type 2a: 24 h/150 °C	8 h/80 °C + 8 h/130 °C	24 h/150 °C	12 h/90 °C + 18 h/140 °C
Processing properties b)	Medium viscosity, very good long pot-life, long gel-time.	Medium viscosity, long pot-life, medium gel-time.	Medium viscosity, short pot-life, short gel-time.	Medium viscosity, short pot-life, short gel-time.	Low viscosity, long pot-life, short gel-time.
Mechanical and thermo-mechanical properties b)	Good flexibility, medium heat distortion temperature respectively glass transition temperature (medium cross-linking grade).	Good flexibility, higher transition temperature than type 1 (higher cross-linking grade). Type 2a: less flexible and higher glass transition temperature.	Good flexibility, medium glass transition temperature (medium cross-linking grade).	Medium flexibility, high glass transition temperature (high cross-linking grade).	Medium heat distortion temperature respectively glass transition temperature (medium cross-linking grade).
Electrical properties b)	Medium tracking resistance.	Good properties as a function of temperature.	Very good tracking resistance.	Good dielectrical properties as a function of temperature.	Very good tracking resistance.

a) For more details see Table 2; b) For more details see Table 3.

ARALDITE® and ARACAST® are trade names of Ciba-Geigy epoxy resins.

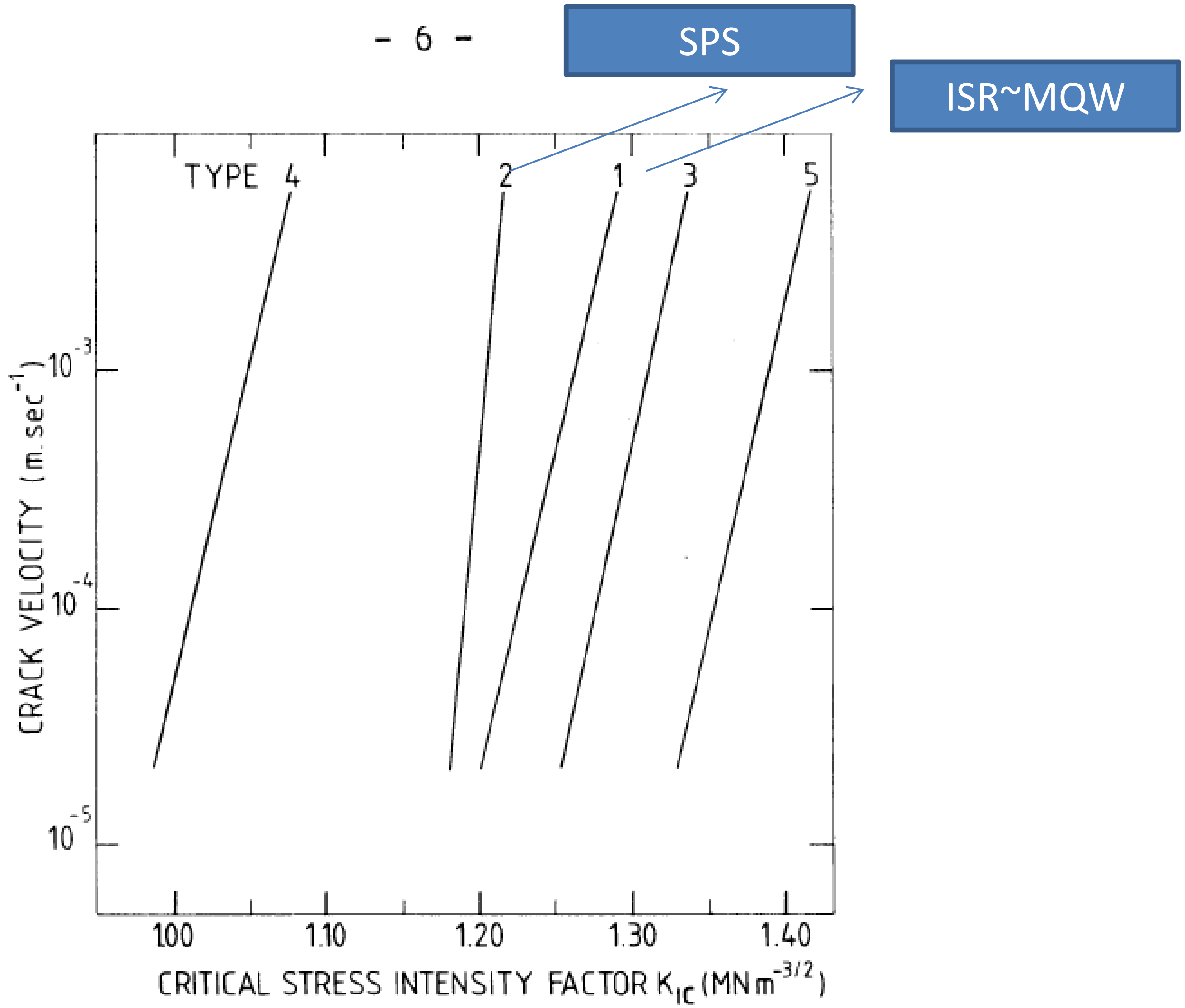
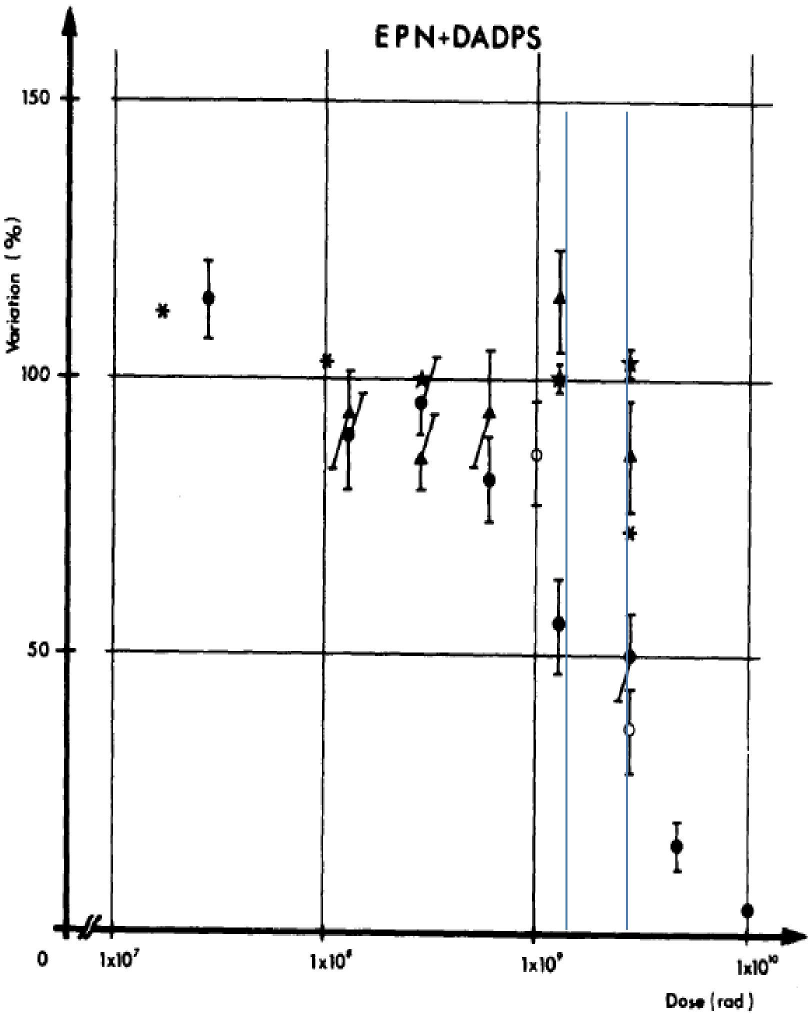
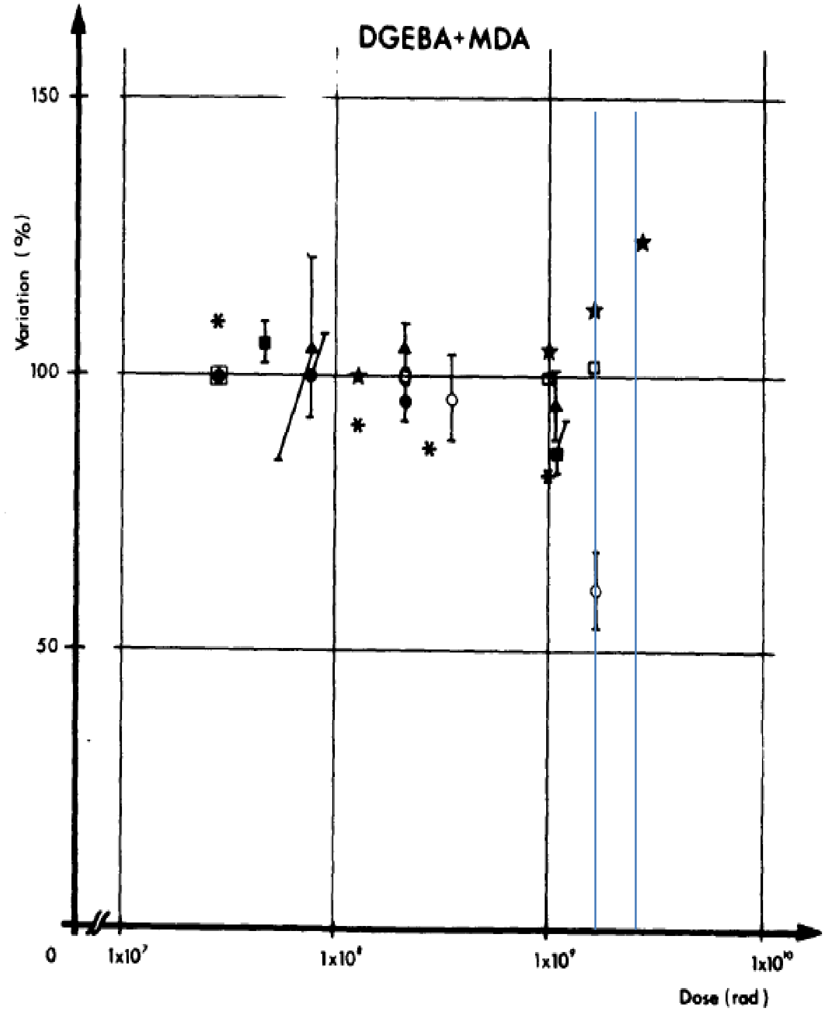


Fig. 4 Crack velocity as a function of critical stress intensity factor



Modifications des propriétés mécaniques du EPN+DADPS
en fonction des doses absorbées

●	1 - Résistance à la flexion	14,5	kg/mm²
○	2 - Résistance à la traction	9,1	kg/mm²
▲	3 - Module d'élasticité	245	kg/mm²
△	4 - Allongement à la rupture		mm
■	5 - Résistance au choc		kg-m/cm²
□	6 - Dureté		
★	7 - Absorption d'eau - 25 °C, 4 jours	0,5	%
✱	8 - Point de fléchissement à la chaleur	216	°C



Modifications des propriétés mécaniques du DGEBA+MDA
en fonction des doses absorbées

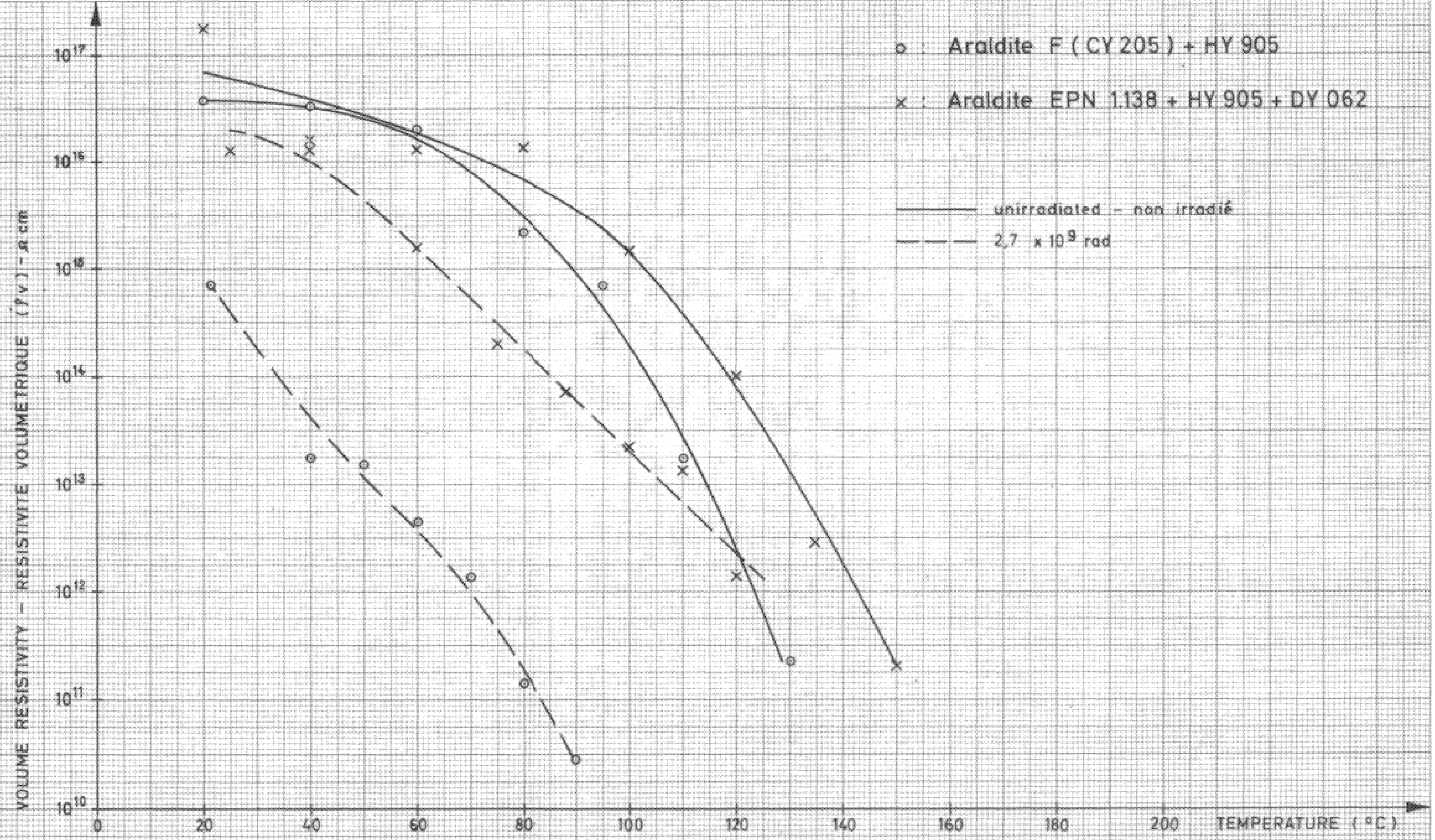
●	1 - Résistance à la flexion	17	kg/mm²
○	2 - Résistance à la traction	7,2	kg/mm²
▲	3 - Module d'élasticité	325	kg/mm²
△	4 - Allongement à la rupture		mm
■	5 - Résistance au choc	25	kg-m/cm²
□	6 - Dureté	86	Shore D
★	7 - Absorption d'eau - 25 °C, 4 jours	0,6	%
✱	8 - Point de fléchissement à la chaleur	158	°C

Table III.1e

Effect of nuclear radiation on the dielectric strength of epoxy resins

Resin composition	Dielectric strength (kV/mm) versus dose (rad)						
	0	2.3×10^8	5.6×10^8	6.8×10^8	1.2×10^9	1.2×10^9	2.7×10^9
1) Araldite F + MDA	21.2 ± 0.8				17.7 ± 0.8(83.5)		16.1 ± 0.8(76)
2) Araldite F + DADPS	21.4 "				18.5 " (86.5)		17.5 " (82)
3) Araldite F + MA	19.0 "				18.2 " (96)		17.8 " (93.5)
4) Araldite B + AP	18.1 "				17.4 " (96)		14.5 " (80)
5) Araldite F + DPA + TETA	19.6 "	19.5 ± 0.8(100)		16.5 ± 0.8(84)	0		
6) EPN + MA + BDMA	22.5 "		21.0 ± 0.8(93.5)			20.0 ± 0.8(89)	
7) EPN + MDA	19.1 "		20.0 " (105)			18.5 " (97)	
8) TGMD + MA + BDMA	20.1 "		18.7 " (93.5)			18.0 " (90)	
9) TGMD + MDA	23.4 "		23.3 " (100)			25.2 " (108)	

The values in brackets represent the percentage of the initial value.

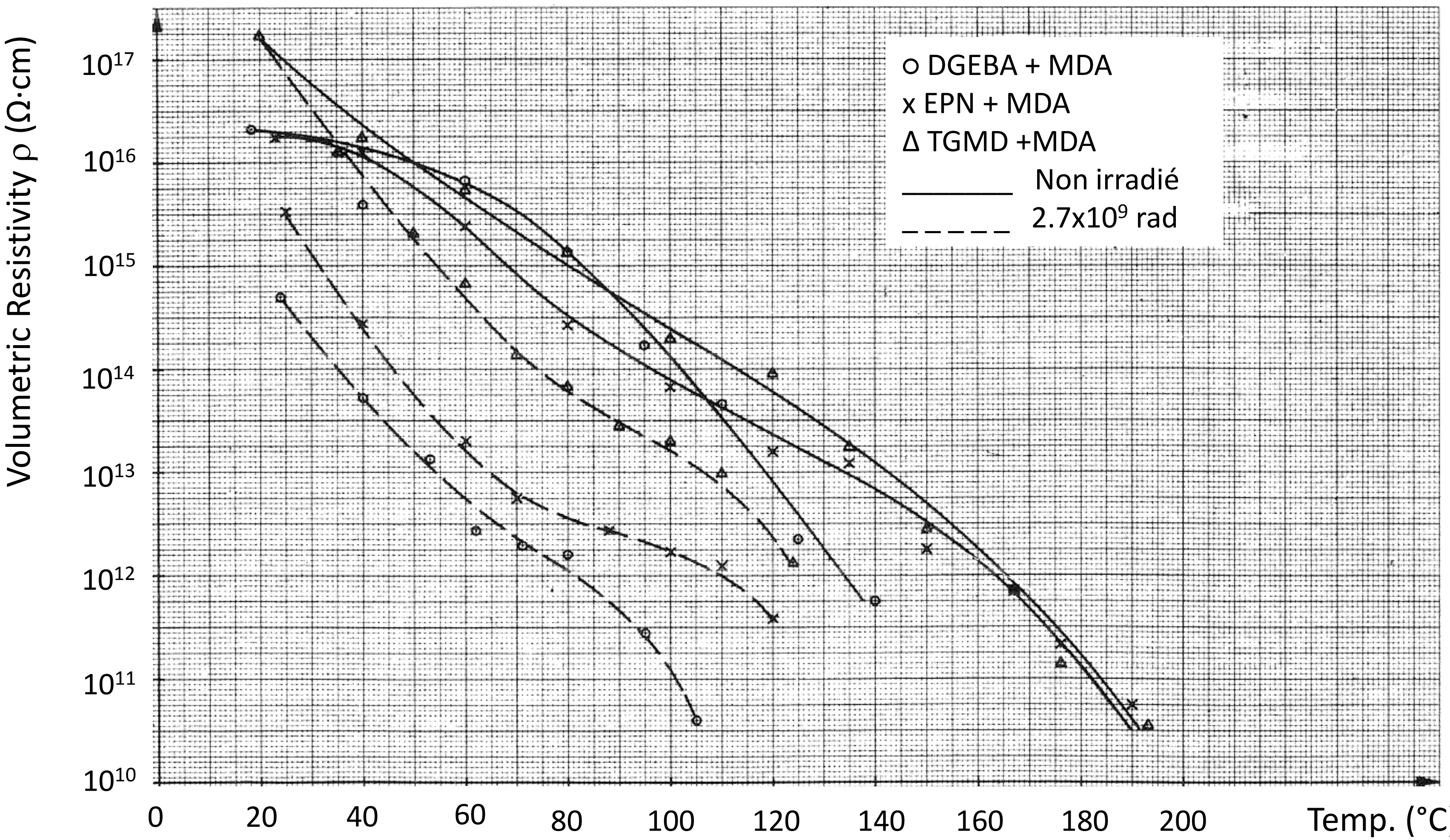


VOLUME RESISTIVITY VS TEMPERATURE FOR IRRADIATED EPOXY RESINS CURED WITH HY 905

RESISTIVITE VOLUMETRIQUE VS TEMPERATURE POUR DES RESINES EPOXYDES IRRADIEES DURCIE AVEC HY 905

Fig. 11

Electrical Properties Changes 2



ρ = ~10^{16} Ω·cm @RT

T ↑ => ρ ↓

High mechanical radio-resistance → High electrical resistance (mechanical degradation occurs first)

Example of low mechanical-resistance system:
DGEBA-DBP-TETA → ρ = ~10^{13} Ω·cm @RT for 6.8x10^{8} rad

DGEBA considerations

4.1 Pure resin combinations (Table 2 and Figs. 1 to 6)

The radiation resistance of composite insulating materials depends primarily on the binding material, in particular in cases where the other components are inorganic, e.g. glass tape, mica, etc. For this reason pure resins that are generally used as binding materials were included in this study. On the other hand, not too much importance should be attributed to these results since the radiation resistance may be considerably improved by the reinforcing materials.

Comparing the results and taking the half-value dose for flexural strength after irradiation as the parameter, the following radiation resistance was found:

- No. 338, epoxy resin + isocyanate — up to 1×10^8 Gy
- No. 348, epoxy resin: DGEBA + anhydride + other components — up to 3×10^7 Gy
- No. 336, epoxy resin: DGEBA + anhydride + other components — up to 1×10^7 Gy
- No. 337, silicone resin — up to 1×10^7 Gy
- No. 369, silicone resin — up to 1×10^7 Gy
- No. 368, epoxy resin: DGEBA + anhydride + other components — up to 3×10^6 Gy

No.	Material Type Supplier Remarks	Dose (Gy)	Flex. strength at max. load S (MPa)	Deflexion at max. load D (mm)	Modulus of elasticity M (GPa)	RI IEC 544-4 at 10^5 Gy/h
336	Solventless epoxy resin (Base: DGEBA + anhydride hardener + other components)	0.0	85.0 ± 3.0	4.6 ± 0.1	3.36 ± 0.02	7.3
		3.0×10^5	90.6 ± 7.5	4.6 ± 0.1	3.54 ± 0.09	
	Micadur resin	1.0×10^6	94.4 ± 6.0	5.2 ± 0.3	3.47 ± 0.11	
	BBC, Baden	3.0×10^6	84.2 ± 6.0	4.6 ± 0.6	3.41 ± 0.16	
	HV machine insulation application	1.0×10^7	75.0 ± 6.1	4.0 ± 0.4	3.46 ± 0.06	
		3.0×10^7	31.4 ± 0.0	2.9 ± 0.0	1.93 ± 0.0	
		1.0×10^8	6.4 ± 2.5	0.8 ± 0.3	1.00 ± 0.32	

PROPOSALS I

	Traction test	Flexural test	Leakage current in air humid	Dielectric in air humid	Leakage current in air humid after 1 month in water	Dielectric in air humid after 1 month in water
0 MGy	Y	Y	(Y)	Y	(Y)	Y
10 Mgy		Y	(Y)	Y	(Y)	Y
20 Mgy	Y	Y	(Y)	Y	(Y)	Y
40 Mgy	Y	Y	(Y)	Y	(Y)	Y
50 MGy			(Y)	Y	(Y)	Y
60 MGy	Y	Y	(Y)	Y	(Y)	Y
70 MGy	Y	Y	(Y)	Y	(Y)	Y

Wafer 1 and 2 mm thickness resin and glass fibre

PROPOSALS II

	Shear test	Leakage current in air humid	Dielectric in air humid	Leakage current in air humid after 1 month in water	Dielectric in air humid after 1 month in water
0 MGy	Y	(Y)	Y	(Y)	Y
10 Mgy		(Y)	Y	(Y)	Y
20 Mgy	Y	(Y)	Y	(Y)	Y
40 Mgy	Y	(Y)	Y	(Y)	Y
50 MGy		(Y)	Y	(Y)	Y
60 MGy	Y	(Y)	Y	(Y)	Y
70 MGy	Y	(Y)	Y	(Y)	Y

Insulated cables, 2 resins, 3 samples