Review of the MQW and MBW lifetime taking into account results from the reading of the dosimeters collecting data in the 2016 RUN

Dosimeter (installation, reading, analysis): P. Schwarz, I. Brunner, I. Sancho Fernandez
Magnet team: P. Fessia, N. Mariani [ITER], I. Sanchez Fernandez, P. Schwarz
FLUKA analysis: C. Bahamonde, F. Cerutti, E. Skordis, A. Lechner
R2E scaling: R. Garcia Alia, O. Stein
Shielding functional design C. Bahamonde, A. Lechner
Estimation of the integrated proton intensity evolution: A. Apollonio, R. De Maria
Collimation inputs: R. Bruce, A. Mereghetti, D. Mirarchi, R. Bruce, Stefano Redaelli
Preliminary design for the absorber : A. Bertarelli, L. Gentini, F. Carra

Summary

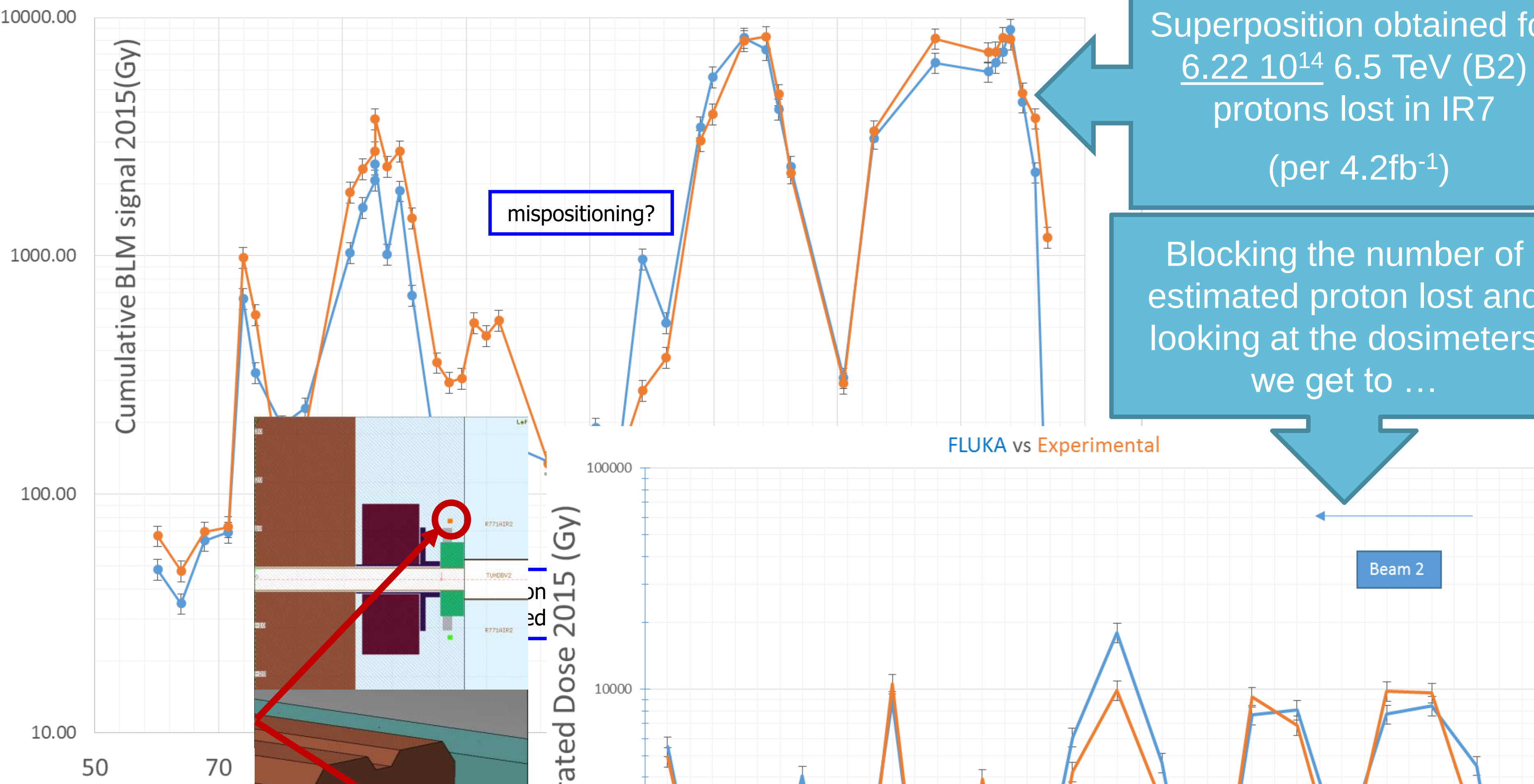
- Recall of last year results from dosimeter reading
- This year dosimeter results
- New scaling
- New estimates
- Preliminary proposal for new action plan

IMPORTANT

THE NEW SCALING FOR LOSSES SHOWED HERE DOES **NOT** APPLY TO THE IP 1 AND IP 5. ALL CONSIDERATIONS APPLY ONLY AND EXCLUSIVELY TO THE CLEANING INSERTIONS

Recall of the analysis progress last years

Year	Direct experimental data	Dose repartition between magnets	Scaling parameter	Material properties	Observations
2013	Initial set of dosimeters (not tailored to magnets) and RP surveys	FLUKA analysis for the collimation nominal losses of 1.15 10^{16} proton/(**30**-50 fb^{-1})	*Luminosity* following proposed scaling that was proposed at IPAC 2013	Extrapolation of previous experimental data of similar resins	
2016	Dosimeters from 2015 RUN	FLUKA analysis for the collimation nominal losses of 1.15 10^{16} proton/(30-**50** fb^{-1})	*Luminosity* following proposed scaling that was proposed at IPAC 2013	Experimental data of really employed insulation system	Measured doses lower then expected



Superposition obtained for 6.22 10^{14} 6.5 TeV (B2) protons lost in IR7

(per 4.2fb^{-1})

Blocking the number of estimated proton lost and looking at the dosimeters we get to …

6.22 10^{14} 6.5 TeV (B2) protons lost in IR7

(per 4.2fb^{-1}) corresponds to 7.5 10^{15} proton equivalent losses per 50 fb^{-1} (IR7 only, one beam only)

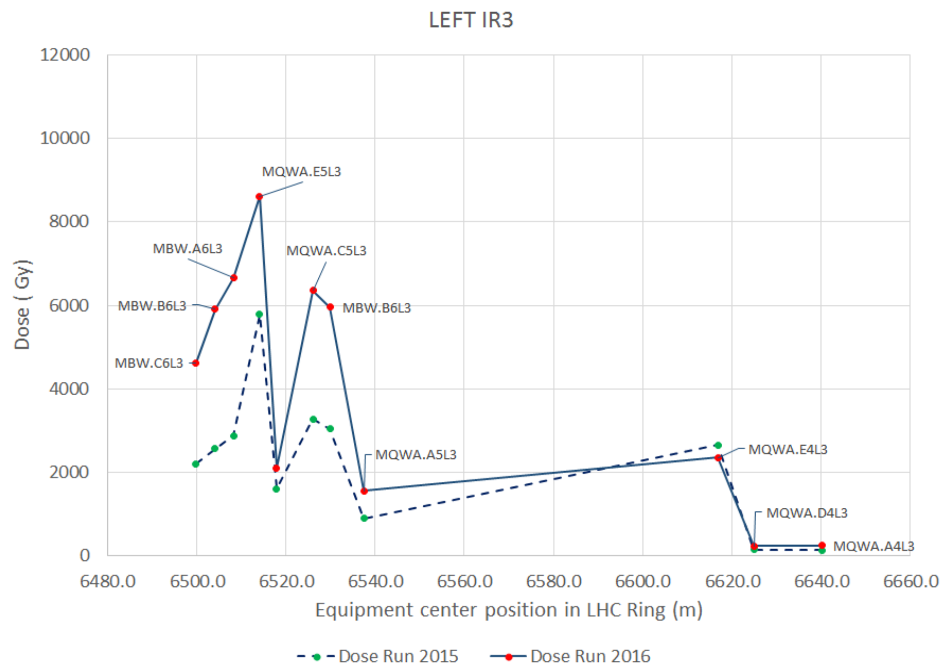
Previous assumption of 1.15 10^{16} proton (equivalent) losses per 50 fb^{-1} (IR7 only, one beam only) in line with the 2005 estimate of 1.15 10^{16} annual proton losses [M. Lamont, LHC Project Note 375]

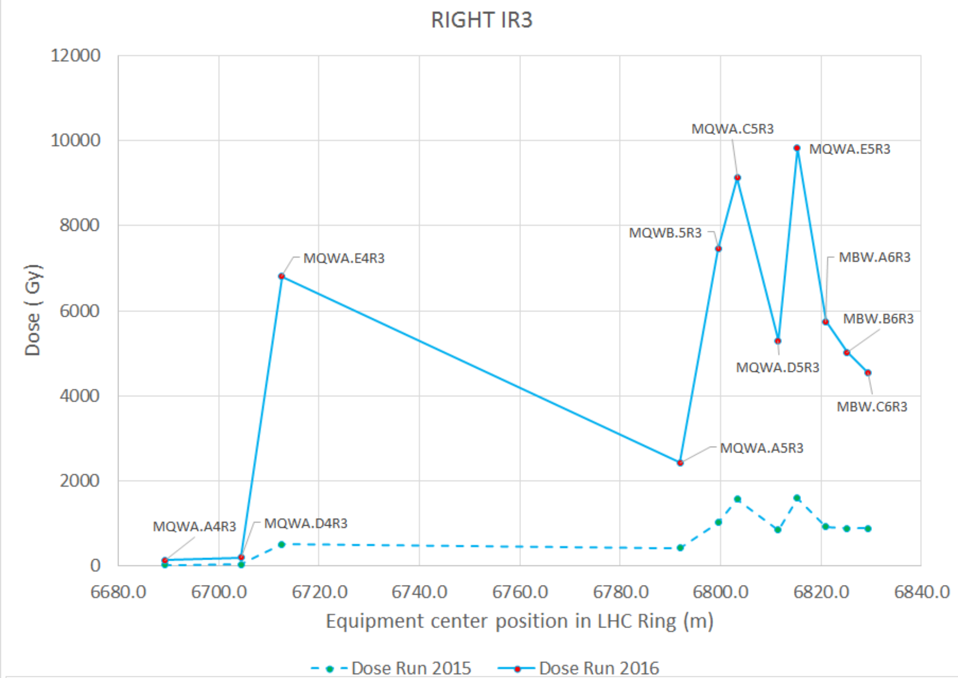
Based on the next slide, for lifetime projection purposes in 2016 we conservatively sticked to the old loss to lumi ratio for dose estimation

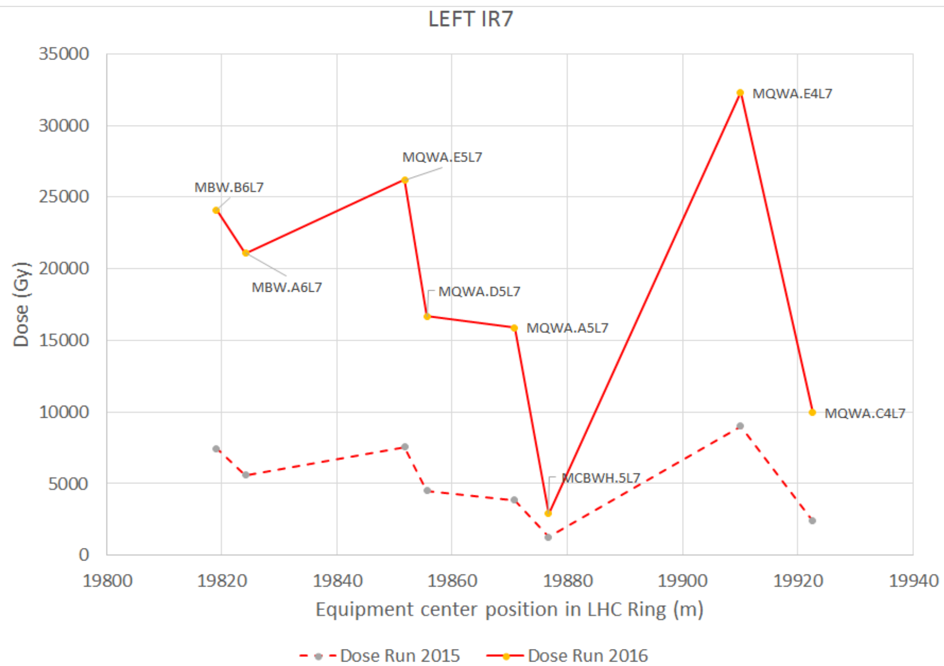
Recall of the analysis progress last years

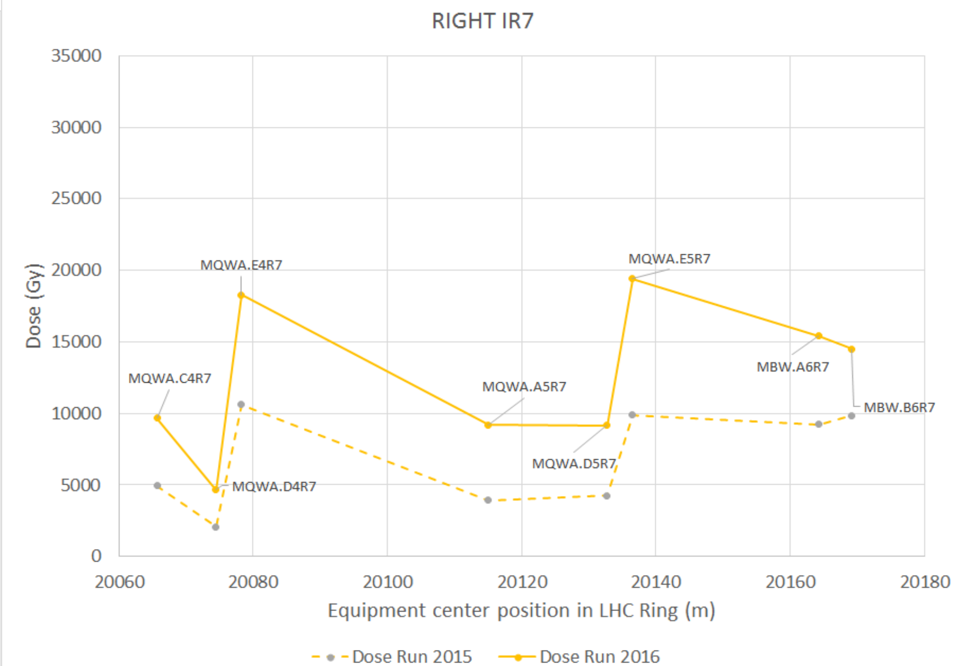
Year	Direct experimental data	Dose repartition between magnets	Scaling	Material properties	Observations
2013	none	FLUKA analysis for the collimation nominal losses of 1.15 10^{16} proton/(**30**-50 fb^{-1})	Luminosity following proposed scaling that was proposed at IPAC 2013	Extrapolation of previous experimental data of similar resins	
2016	Dosimeters from 2015 RUN	FLUKA analysis for the collimation nominal losses of 1.15 10^{16} proton/(30-**50** fb^{-1})	Luminosity following proposed scaling that was proposed at IPAC 2013	Experimental data of really employed insulation system	Measured doses lower then expected
2017				Experimental data	

Dosimeter 2015 Run vs. 2016 Run

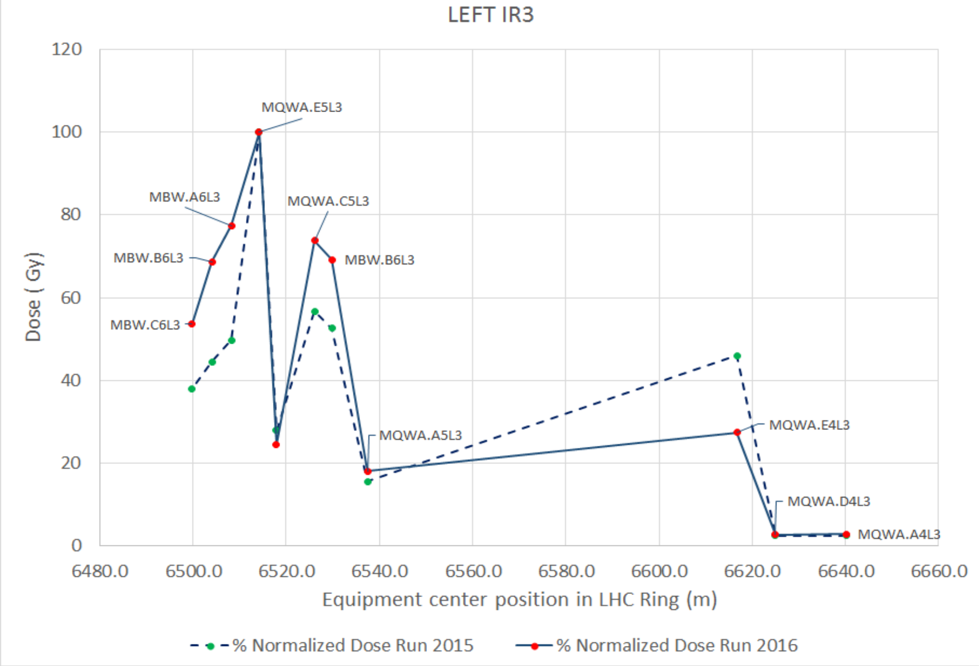


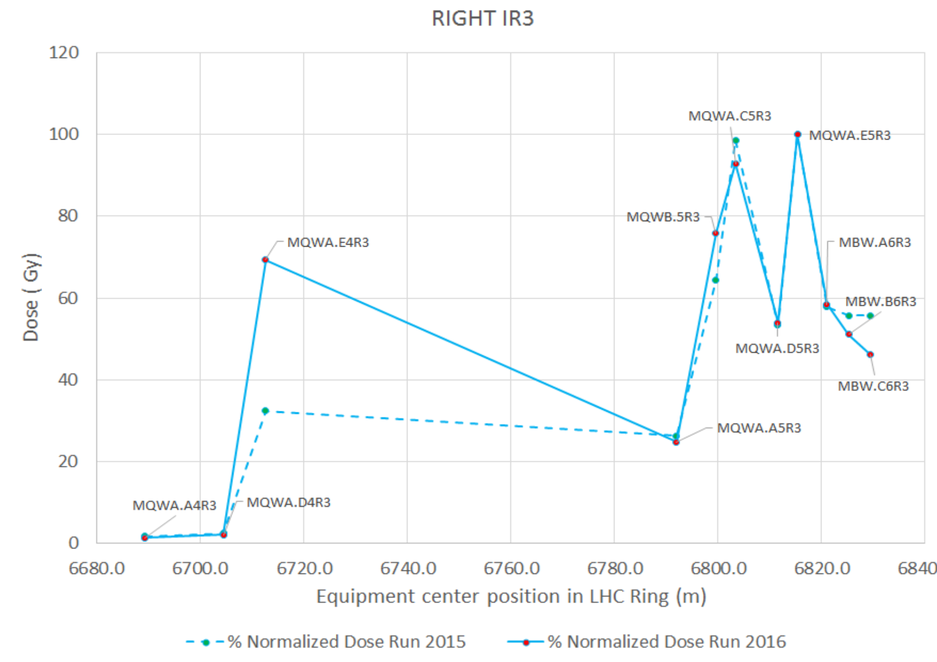


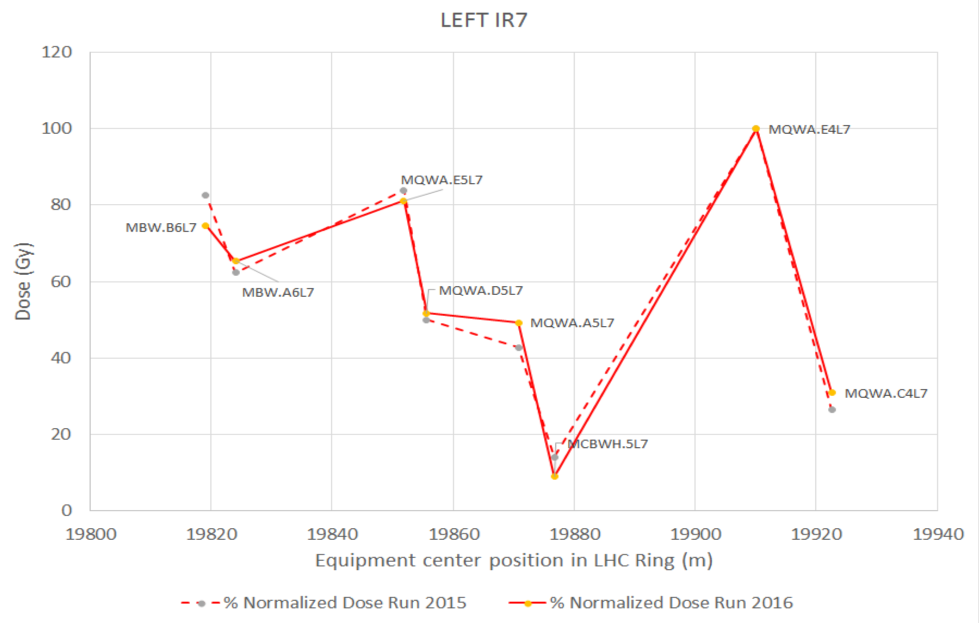


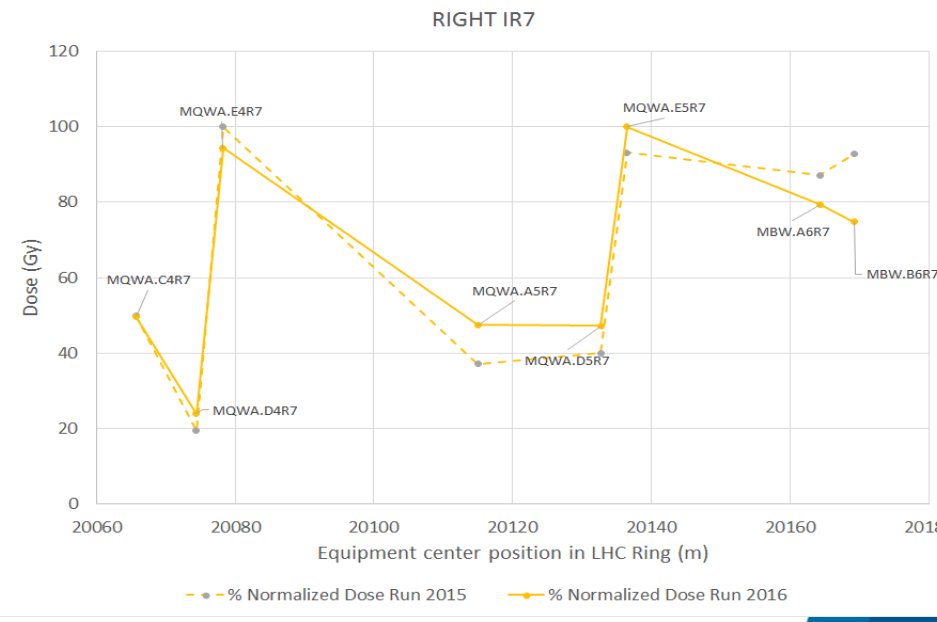


Dosimeter 2015 Run vs. 2016 Run: values normalised to the maximum of EACH measurement data sets



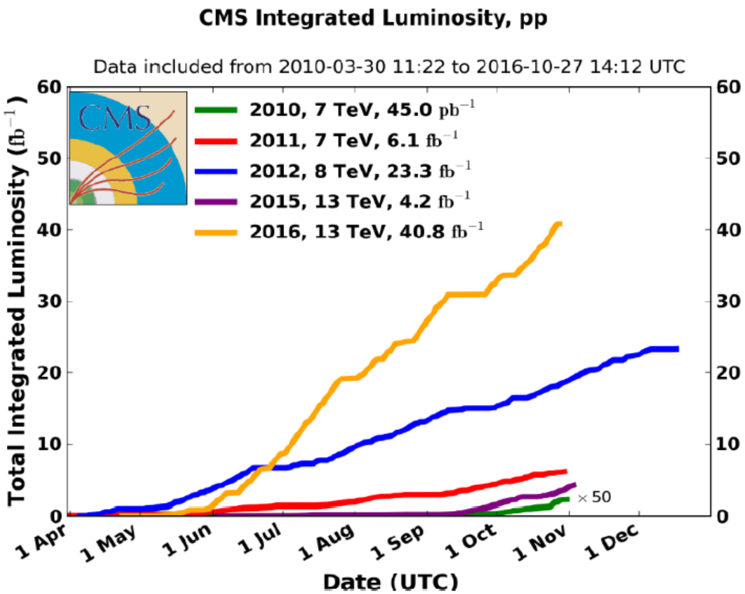






Ratio recorded cumulative dose 2015 Run vs. 2016 Run

Integrated luminosity and intensity



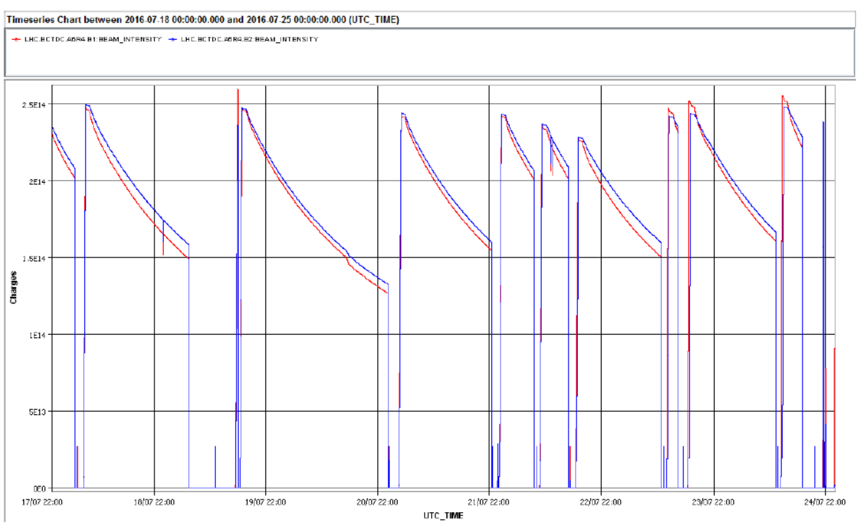
EXPECTED ratio for luminosity scaling r=9.8

```
#Integrated luminosities (in fb-1)

lum_2012 = 23.3
lum_2015 = 4.2
lum_2016 = 40.8
```

Intensity time integration

Data for B1+B2

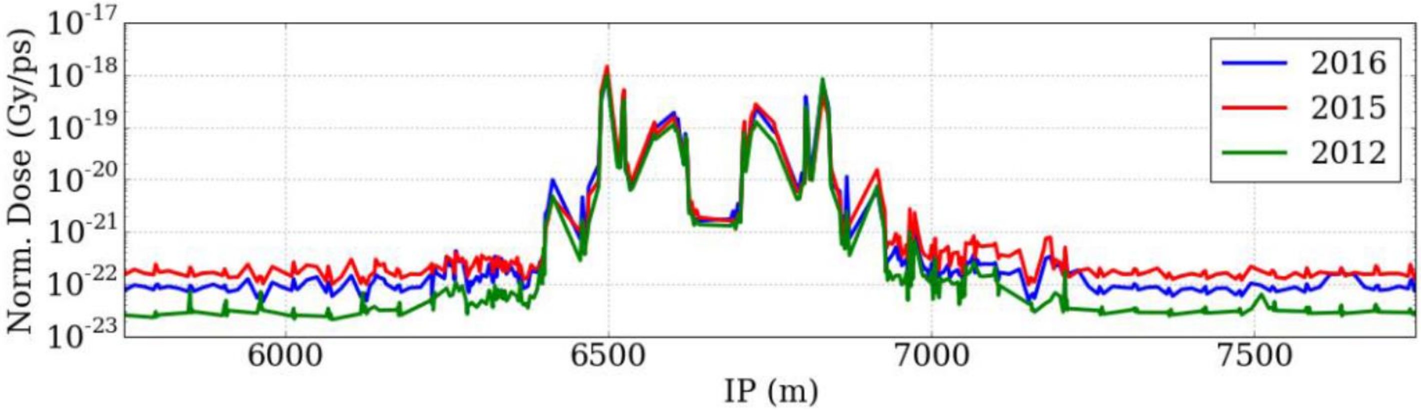


Integrated pp intensity in ps (in Stable Beam, SB):
2012: **2.95e21** (2.28e21)
2015: **7.61e20** (4.95e20)
2016: **2.63e21** (2.20e21)

Total SB duration:
2012: 1814h
2015: 751h
2016: 1785h

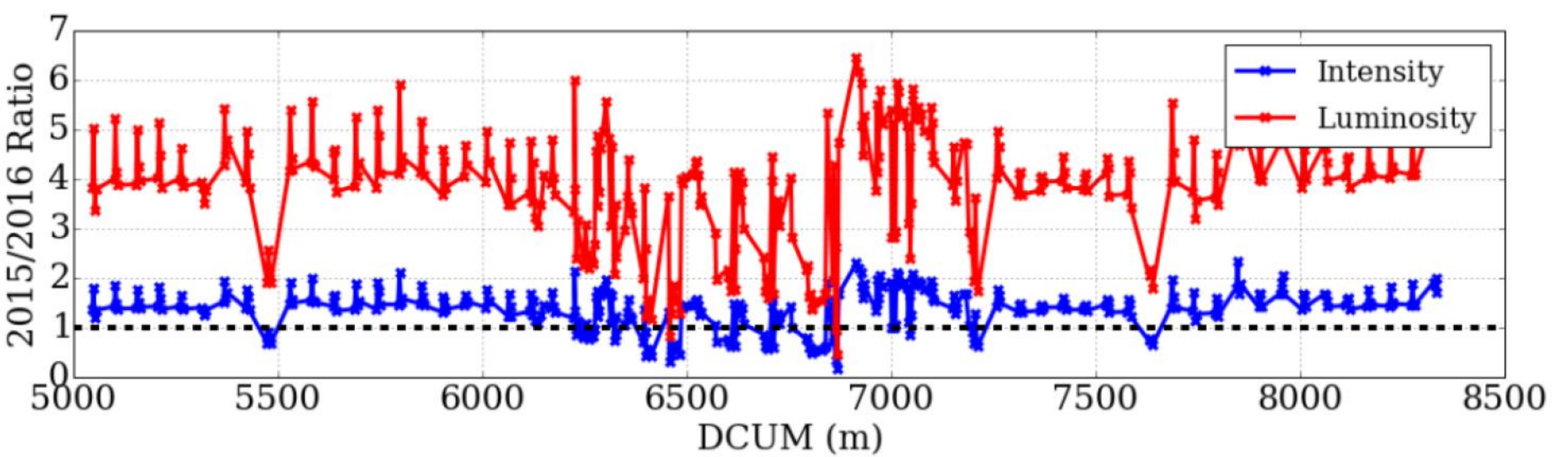
Average intensity per beam during SB in p (A):
2012: **1.75e14** (0.31)
2015: **9.15e13** (0.16)
2016: **1.71e14** (0.31)

P3 integrated BLM losses per integrated intensity

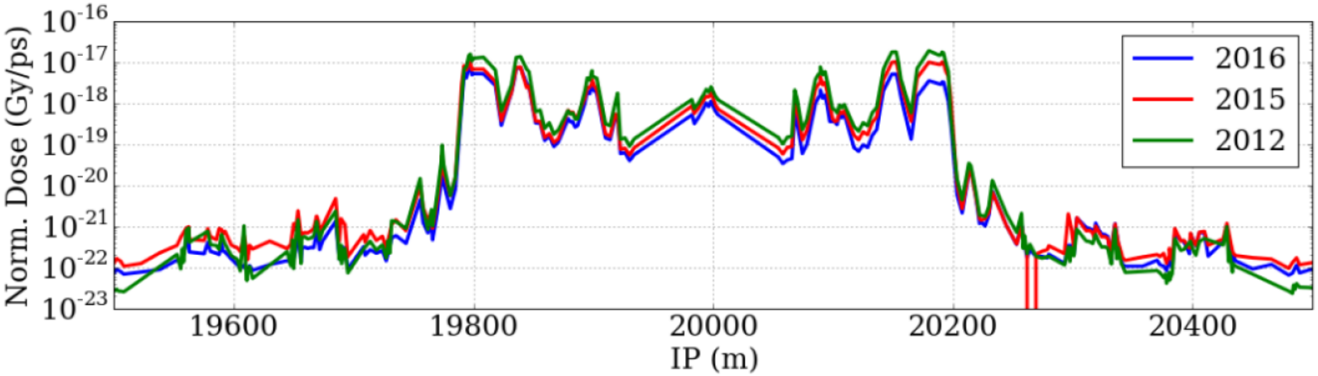


- Intensity scaling looks even better for P3 in high-loss region

P3 scaling for 2015/2016

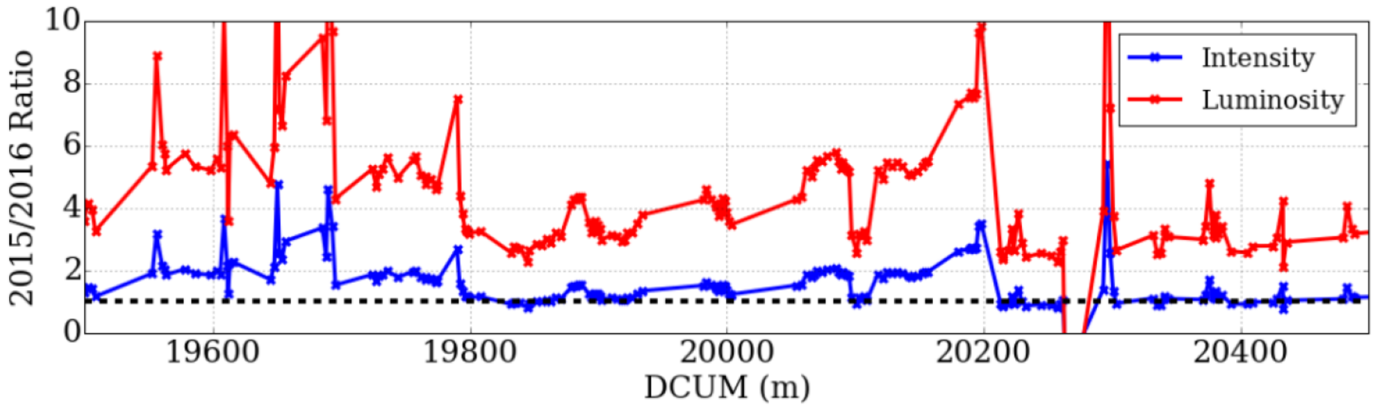


P7 integrated BLM losses per integrated intensity



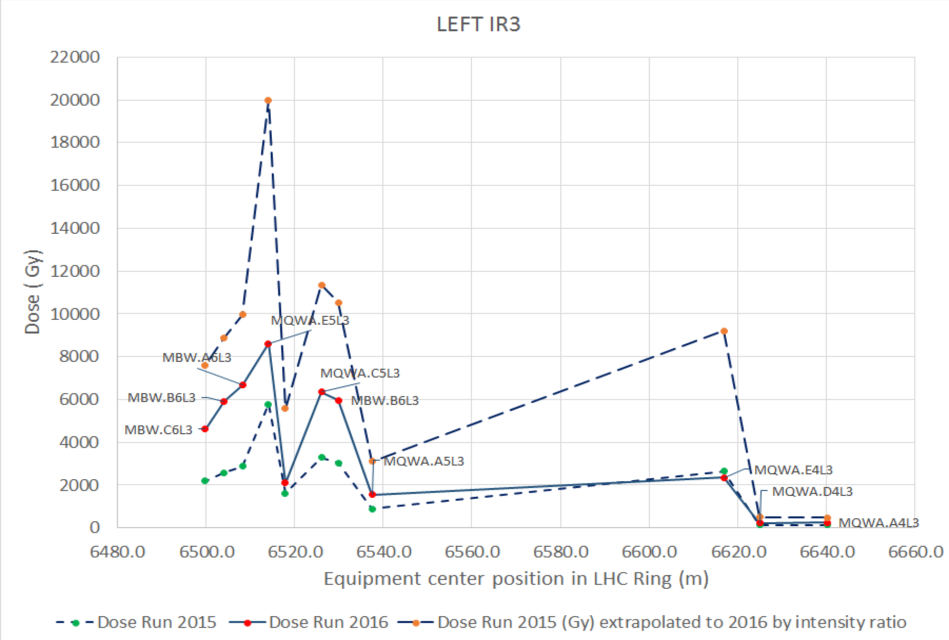
- Similar trend, but already visible that normalized 2016 values are lower

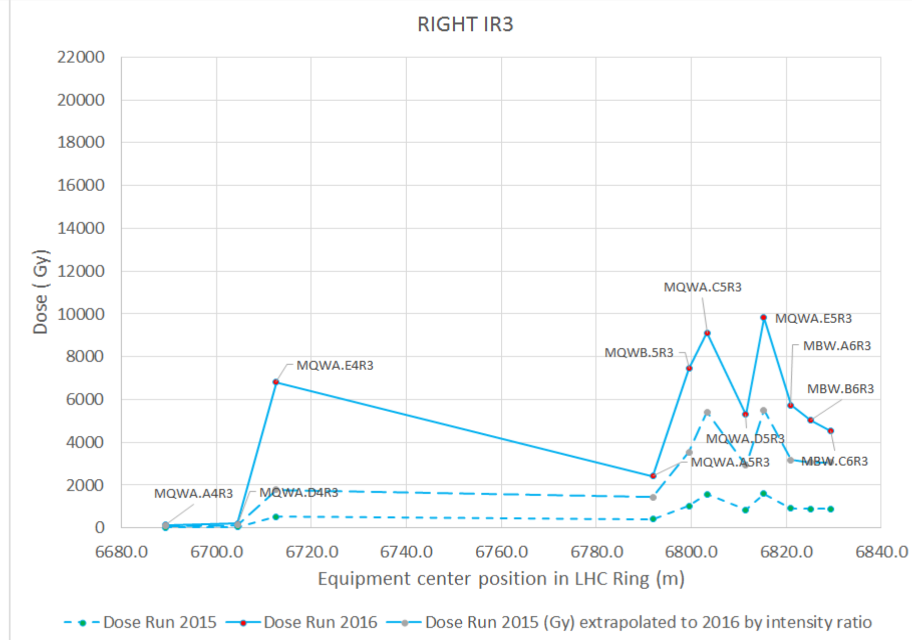
P7 scaling for 2015/2016

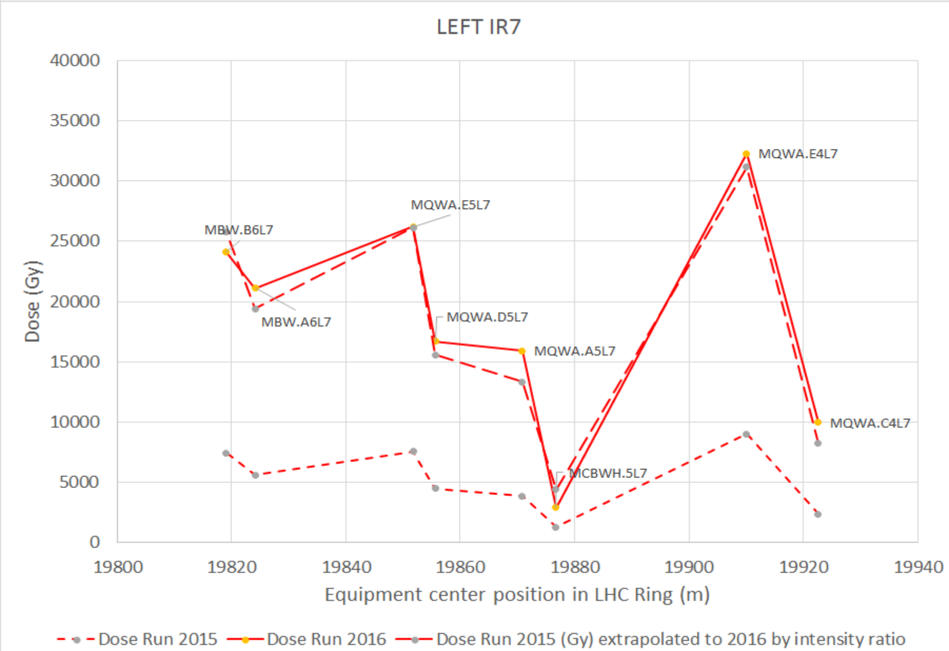


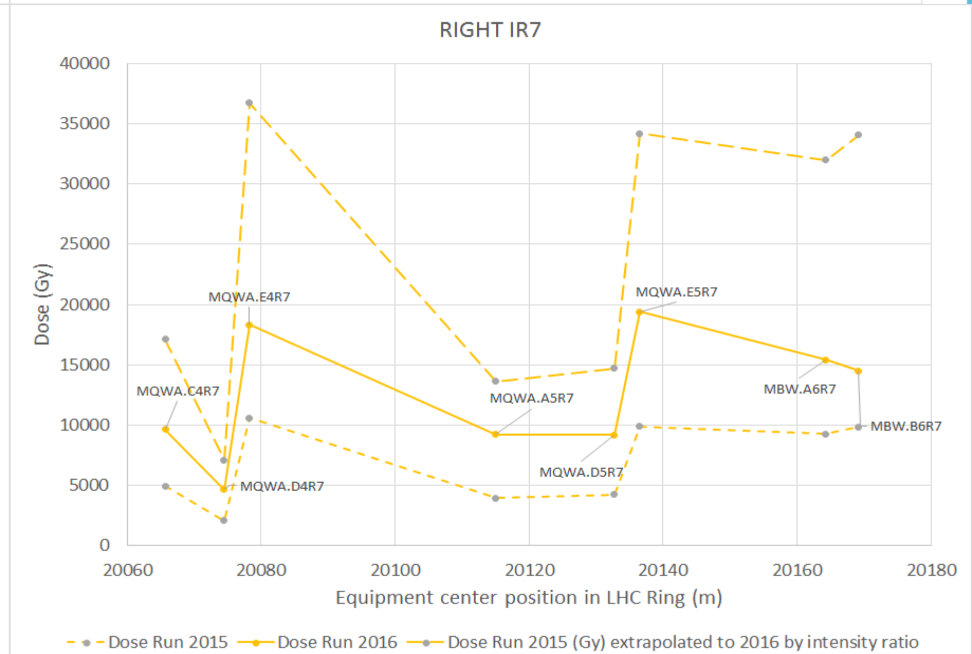
- Clearly better scaling with intensity, especially in high-loss region (19800-20200) where ratio is mostly near one
- Still, significant outliers (e.g. change in collimator settings?)

Scaling with integrated intensity

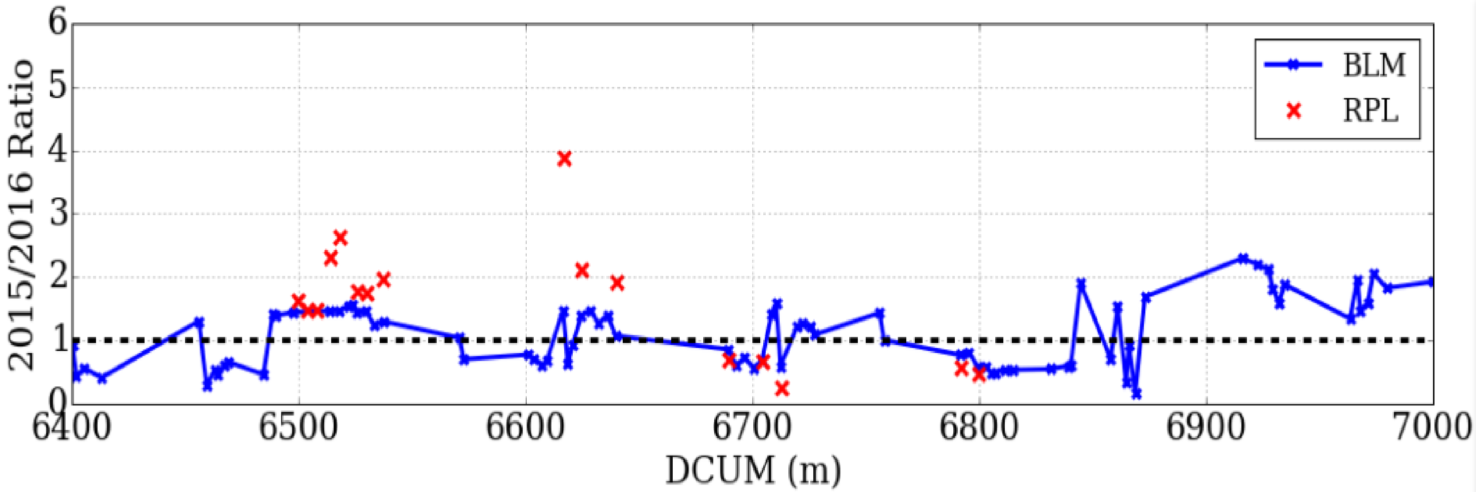




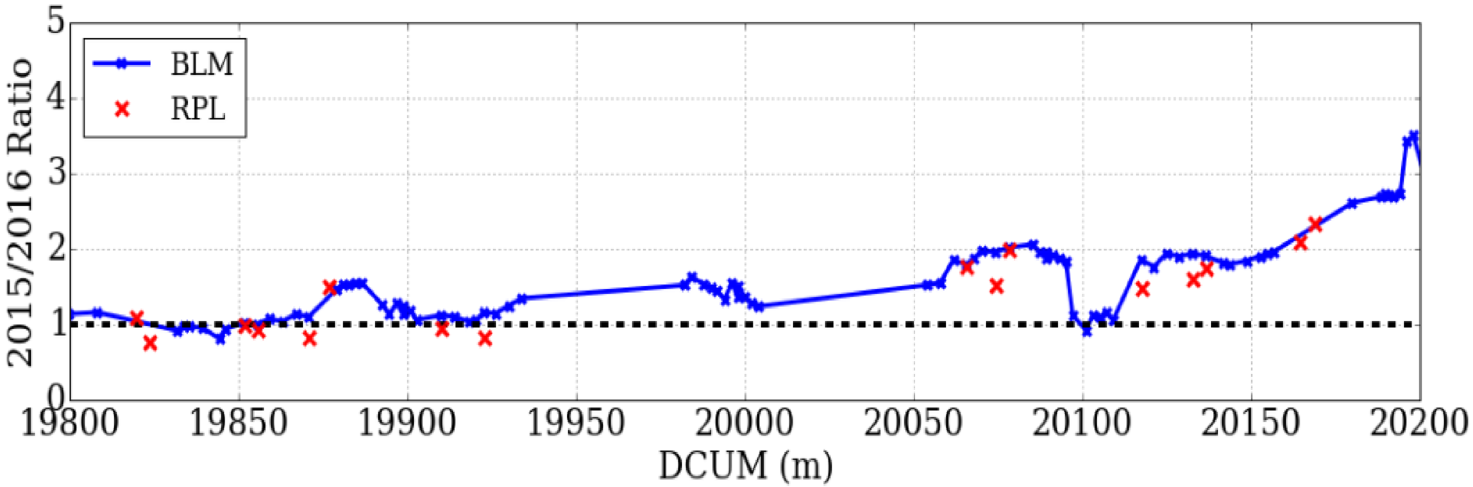




BLM scaling vs. RPL scaling



IP 3



IP 7

New procedure to estimate dose

- Divide the dose recorded by each dosimeter by the integrated intensity recorded during the time of irradiation (value in Gy/p•s)
- For each magnet take the maximum value in Gy/p•s between 2015 Run and 2016 Run and between Left and Right (maximum among 4 values)
- Scale those values with the projected integrated intensity
- Use FLUKA models to transform the dose on the dosimeter to dose on the coil hot spot *and on the spacers for the MQW magnets* *(the dosimeter are not on the coil)*
- Thanks to FLUKA interpolate missing locations

Projected intensity and luminosity evolution and effect on scaling of quantity respect one or the other (2015 equal 1)

Year	Measured ∫ P intensity (1 beam) [p•s]	Estimated ∫ P intensity (1 beam) [p•s]
2016	**$1.32\ 10^{21}$**	**$1.49\ \ 10^{21}$**
2017		**$2.05\ \ 10^{21}$**
Typical LHC after LS2		**$2.41\ \ 10^{21}$ *($4.3\ \ 10^{21}$)***
Typical HL-LHC		**$4.3\ \ \ 10^{21}$**

From change of scaling parameter we can therefore expect a reduction in the integrated dose of about 5.
In addition 2016 table of dose estimation did not take into account the observed reduction in losses integrating it in the safety margins.
We can therefore expect reduction of dose between 5 and 10 times

In the new estimation we do not introduce safety on top of estimation a part from

1) Using maximum proton intensity ($4.3\ \ 10^{21}$) also in Run III
2) The ultimate HL luminosity is reached adding 3 years of machine operation

Conclusions on Materials Tests

- Results up to 75 MGy (8 months long irradiation campaign) have been analysed showing slightly greater resistance with respect to expectations:
  - Glass fibres effect (MQW have more Fibres than MBW) enhances MQW Coils Mechanical Properties, which remain good after 50 MGy;
  - MBW Coils material was not 100% polymerised after curing, initial increase of mechanical properties after 10 MGy with sequential gradual degradation, at 50 MGy strength is still comparable to non irradiated samples;
  - At 50 MGy (MQW) and 75 MGy (MBW) start of bubbles formation with detrimental effect on electrical properties, which remain however well above reference values.
  - MQW Spacers matrix after 10 MGy is already heavily damaged.
- Update of Materials Limits with new definitions:

Material	Beginning of Damage (no bubbles, limited variation in properties)	Moderate Damage (bubbles formation and beginning of properties reduction)	Failure on Component (extensive bubbles, properties loss)
MQW Coils	10-50	50-75	>75
MBW Coils	50-75	75-90	>90
MQW Spacers	5-10	10-15	>15

Coil damage Point 7

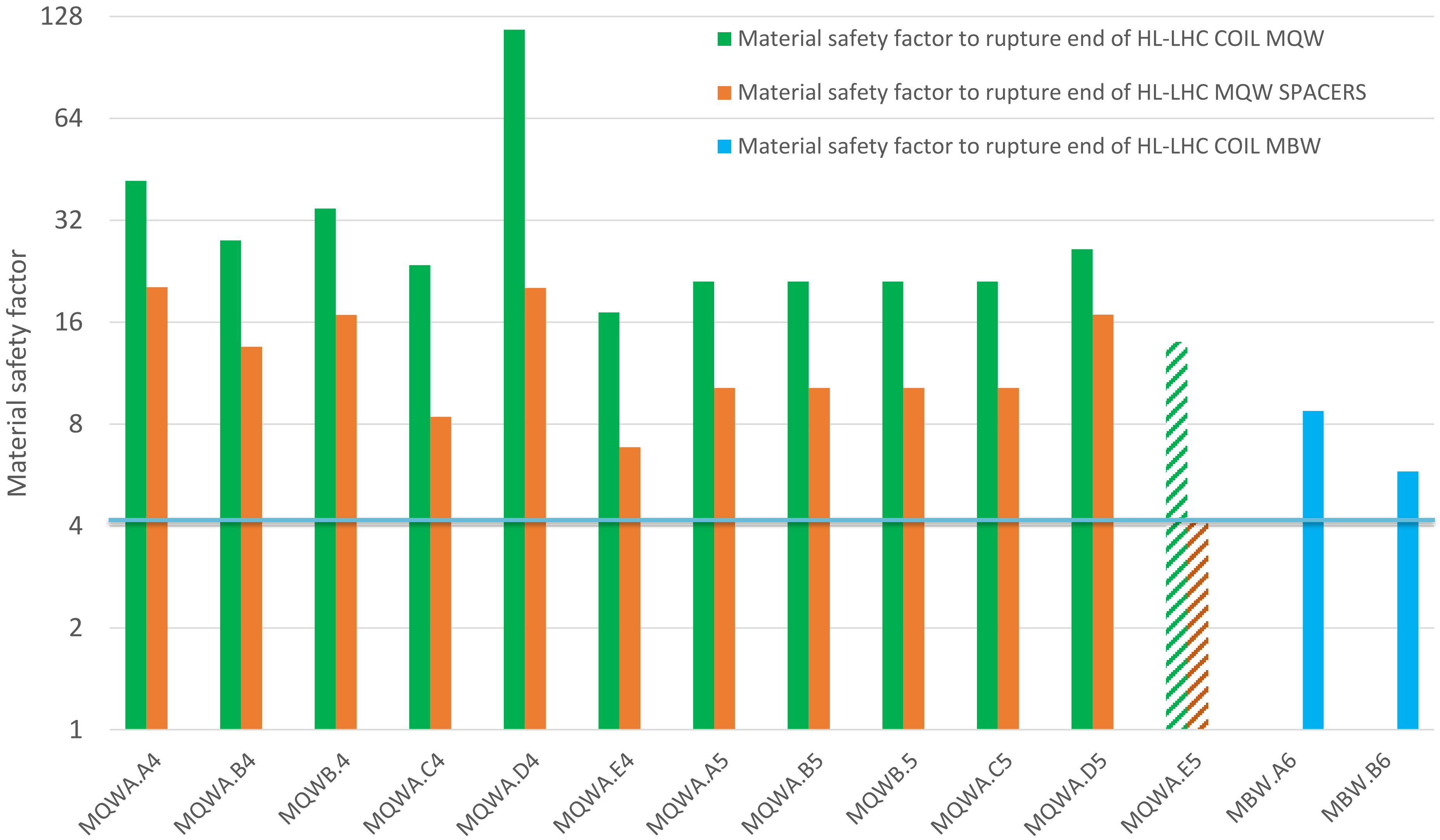
table 2016

IR7	Dose [MGy] for integrated luminosity 150 fb $^{-1}$ (LS2)		Dose [MGy] for integrated luminosity 350 fb $^{-1}$ (LS3)		Dose [MGy] for integrated luminosity 3000 fb $^{-1}$ (LS6)		Dose [MGy] for integrated luminosity 4000 fb $^{-1}$ (End of HL-LHC)	
	R	L	R	L	R	L	R	L
MQWA.A4	0	0	1	1	9	7	13	10
MQWA.B4	1	1	1	1	14	11	19	14
MQWB.4	1	1	2	1	9	7	12	9
MQWA.C4	4	3	5	4	26	20	34	26
MQWA.D4	2	1	2	2	15	11	20	15
MQWA.E4	1	1	2	2	25	19	33	25
MQWA.A5	2	1	2	2	13	10	17	13
MQWA.B5	3	2	4	3	18	14	24	18
MQWB.5	3	2	4	3	18	14	24	18
MQWA.C5	3	2	4	3	18	14	23	18
MQWA.D5	3	2	5	4	31	24	41	31
MQWA.E5	3	2	6	5	59	45	78	60
MBW.A6	4	2	7	5	71	48	95	64
MBW.B6	4	3	9	6	89	60	119	80

table 2017

IR7	Dose [MGy] for integrated luminosity 150 fb $^{-1}$ (LS2)	Dose [MGy] for integrated luminosity 350 fb $^{-1}$ (LS3)	Dose [MGy] for integrated luminosity 3000 fb $^{-1}$ (LS6)	Dose [MGy] for integrated luminosity 4000 fb $^{-1}$ (End of HL-LHC)
MQWA.A4	0.2	0.5	1.5	1.8
MQWA.B4	0.3	0.8	2.3	2.7
MQWB.4	0.6	1.0	1.9	2.2
MQWA.C4	0.9	1.4	2.8	3.2
MQWA.D4	0.2	0.3	0.6	0.6
MQWA.E4	0.5	1.3	3.8	4.4
MQWA.A5	1.0	1.6	3.2	3.6
MQWA.B5	1.0	1.6	3.2	3.6
MQWB.5	1.0	1.6	3.2	3.6
MQWA.C5	1.0	1.6	3.2	3.6
MQWA.D5	0.8	1.3	2.5	2.9
MQWA.E5	0.6	1.6	4.6	5.4
MBW.A6	1.2	3.1	8.9	10.3
MBW.B6	1.9	4.7	13.4	15.5

Point 7: material safety factor to rupture end of HL-LHC. MQW:coils and spacers, MBW: coils



Coil damage Point 3

table 2016

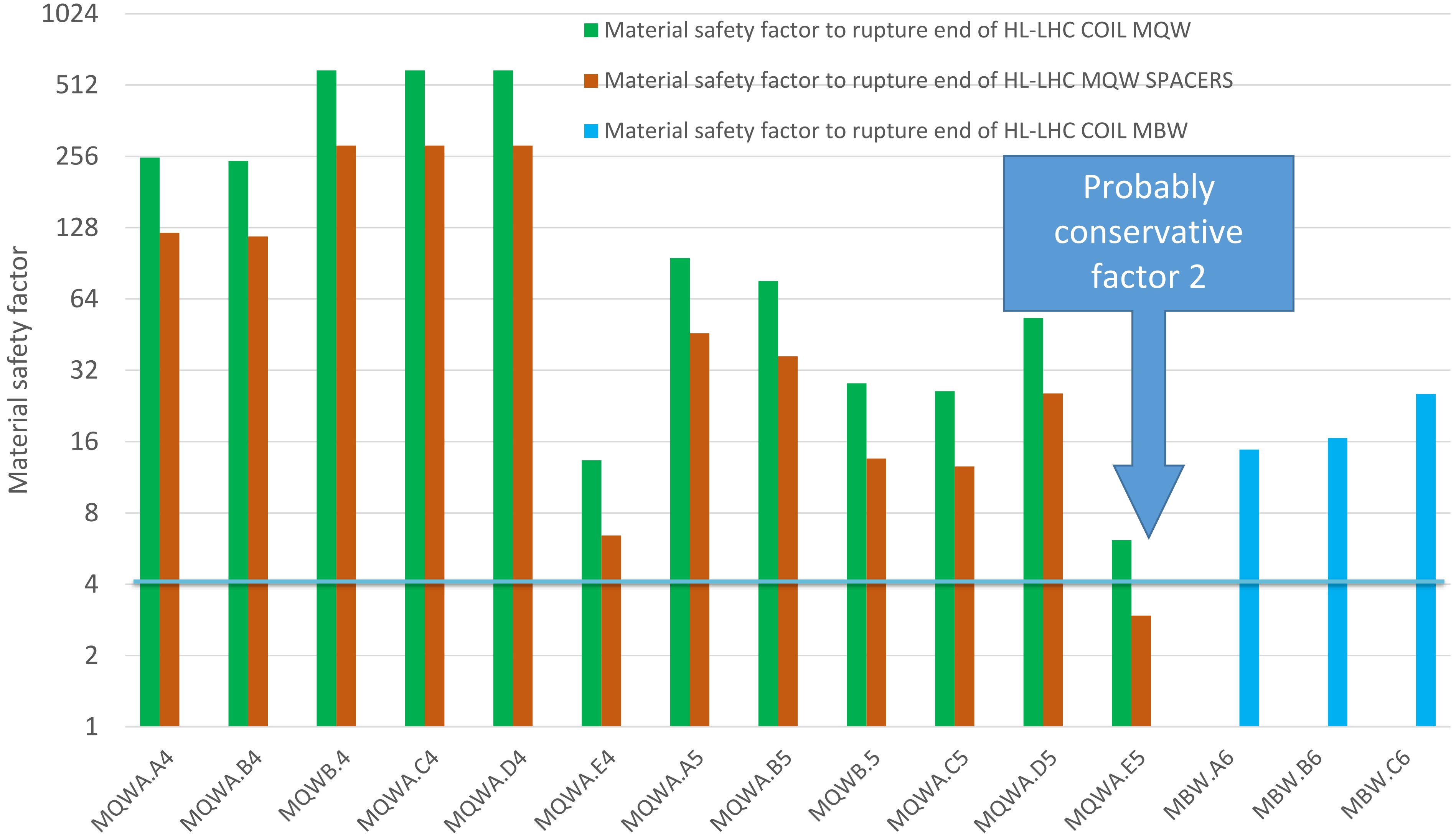
IR3	Dose [MGy] for integrated luminosity 150 fb $^{-1}$ (LS2)		Dose [MGy] for integrated luminosity 350 fb $^{-1}$ (LS3)		Dose [MGy] for integrated luminosity 3000 fb $^{-1}$ (LS6)		Dose [MGy] for integrated luminosity 4000 fb $^{-1}$ (End of HL-LHC)	
	R	L	R	L	R	L	R	L
MQWA.A4	0	0	0	0	3	3	3	3
MQWA.B4	0	0	0	0	3	3	4	4
MQWB.4	0	0	0	0	3	3	4	4
MQWA.C4	0	0	0	0	4	4	5	5
MQWA.D4	0	0	1	1	9	9	12	12
MQWA.E4	2	2	**3**	**3**	**15**	**15**	**20**	**20**
MQWA.A5	1	1	**2**	**2**	**10**	**10**	**13**	**13**
MQWA.B5	2	2	**3**	**3**	**12**	**12**	**16**	**16**
MQWB.5	4	4	**6**	**6**	**29**	**29**	**38**	**38**
MQWA.C5	10	10	**14**	**14**	**68**	**68**	**88**	**88**
MQWA.D5	2	2	**3**	**3**	**16**	**16**	**21**	**21**
MQWA.E5	5	5	**6**	**6**	**30**	**30**	**39**	**39**
MBW.A6	4	4	**6**	**6**	**28**	**28**	**37**	**37**
MBW.B6	3	3	**4**	**4**	**20**	**20**	**26**	**26**
MBW.C6	3	3	**4**	**4**	**17**	**17**	**23**	**23**

table 2017

IR3	Dose [MGy] for integrated luminosity 150 fb $^{-1}$ (LS2)	Dose [MGy] for integrated luminosity 350 fb $^{-1}$ (LS3)	Dose [MGy] for integrated luminosity 3000 fb $^{-1}$ (LS6)	Dose [MGy] for integrated luminosity 4000 fb $^{-1}$ (End of HL-LHC)
MQWA.A4	0.0	0.1	0.3	0.3
MQWA.B4	0.0	0.1	0.3	0.3
MQWB.4	0.0	0.1	0.1	0.1
MQWA.C4	0.0	0.1	0.1	0.1
MQWA.D4	0.0	0.1	0.1	0.1
MQWA.E4	0.7	1.7	4.8	5.6
MQWA.A5	0.2	0.3	0.7	0.8
MQWA.B5	0.3	0.4	0.9	1.0
MQWB.5	0.8	1.2	2.4	2.7
MQWA.C5	0.8	1.3	2.5	2.9
MQWA.D5	0.4	0.6	1.3	1.4
MQWA.E5	1.5	3.7	10.5	12.2
MBW.A6	0.7	1.9	5.2	6.1
MBW.B6	0.7	1.7	4.7	5.4
MBW.C6	0.4	1.1	3.0	3.5

Point 3: material safety factor to rupture end of HL-LHC. MQW:coils and spacers, MBW: coils

REMARK NEED OF LARGER MARGIN BECAUSE OF PRESENT REPARTITION OF LOSSES POINT 7 VS POINT 3

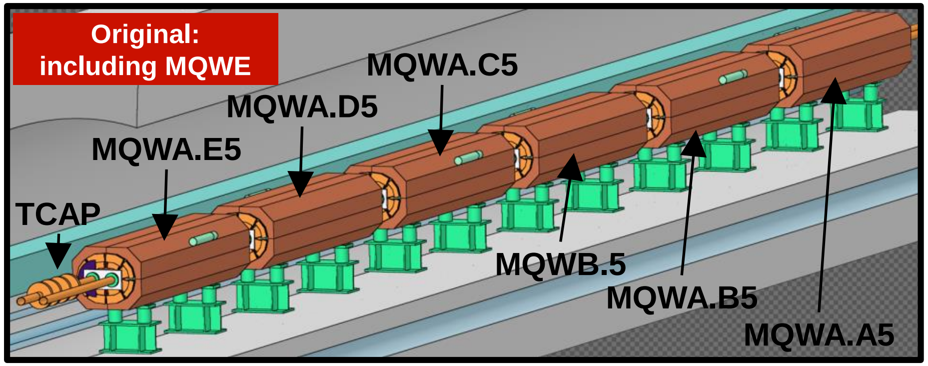


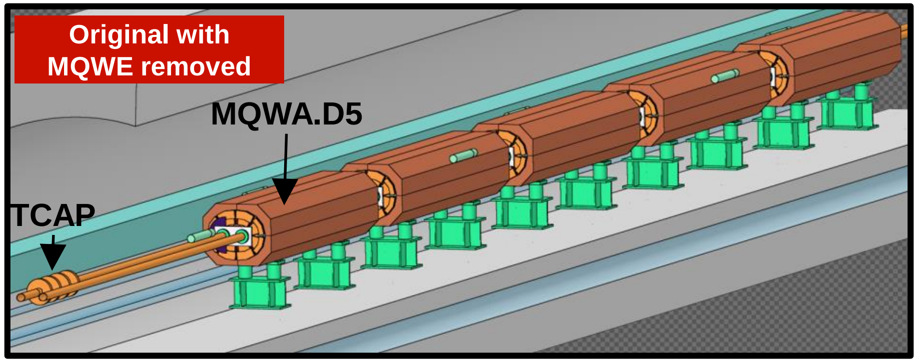
Actions

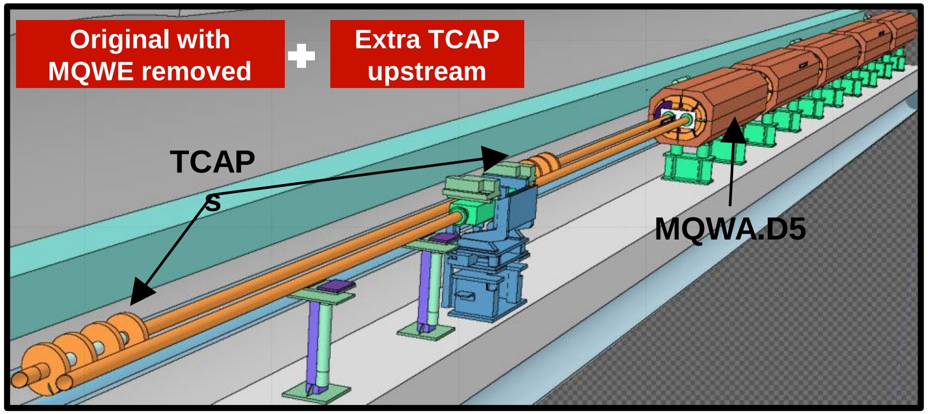
Till LS2 included: confirmed

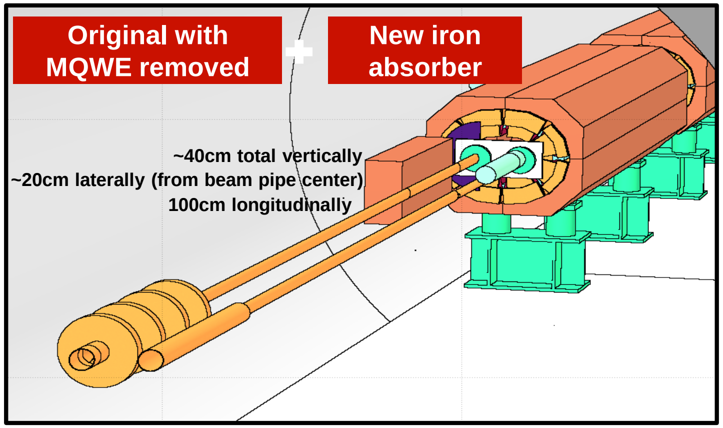
When	Present action plan	Comment and new proposed action plan
YETS 2017-2018	Reading of the dosimeter of 2017 run	Confirmed. Revaluation of scaling
LS2	Installation shielding IP3	Confirmed. Procurement placed. Delivery ongoing
	Installation shielding IP7	Confirmed. Procurement placed. Delivery ongoing
	Removal MQWA.E5 IP7	Confirmed. Recovery of 2 spares

Cases studied



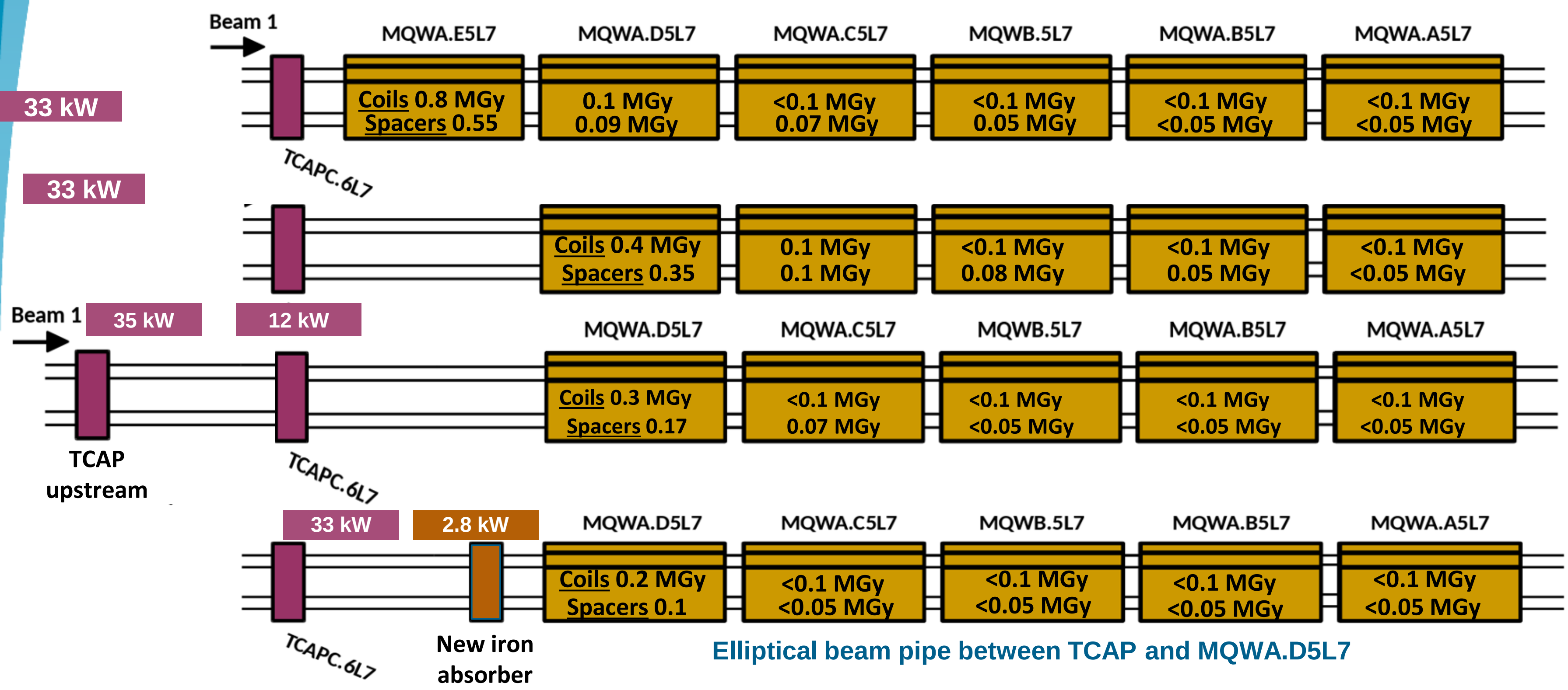






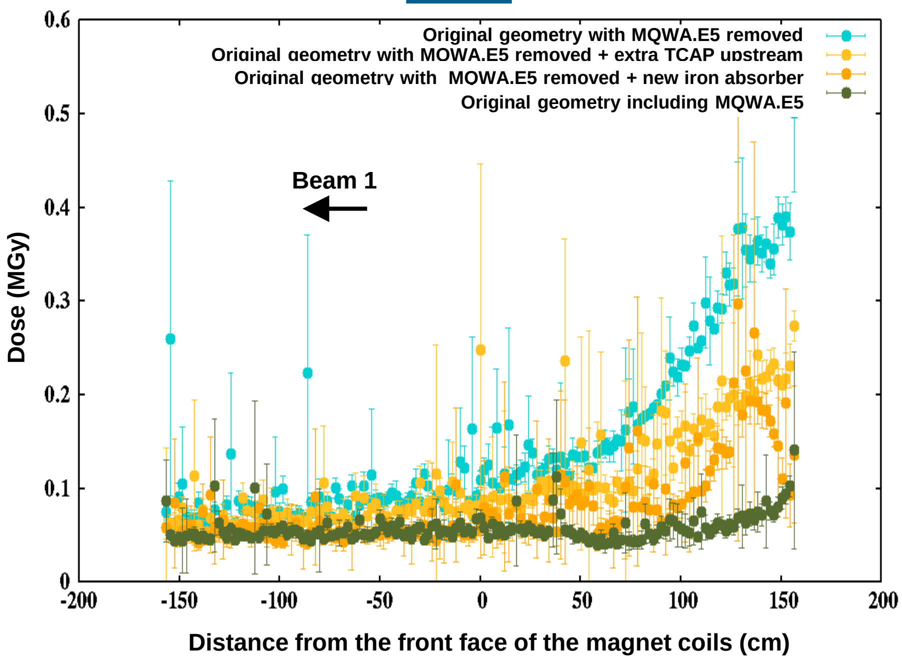
HiLumi HL-LHC PROJECT

Peak dose the magnet coils and spacers

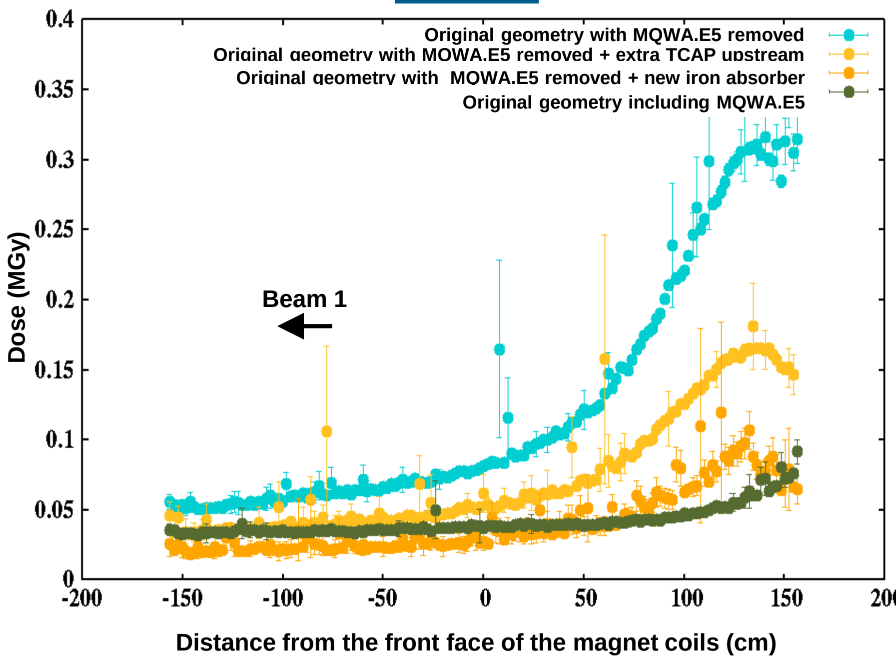


Peak dose longitudinal profile MQWA.D5

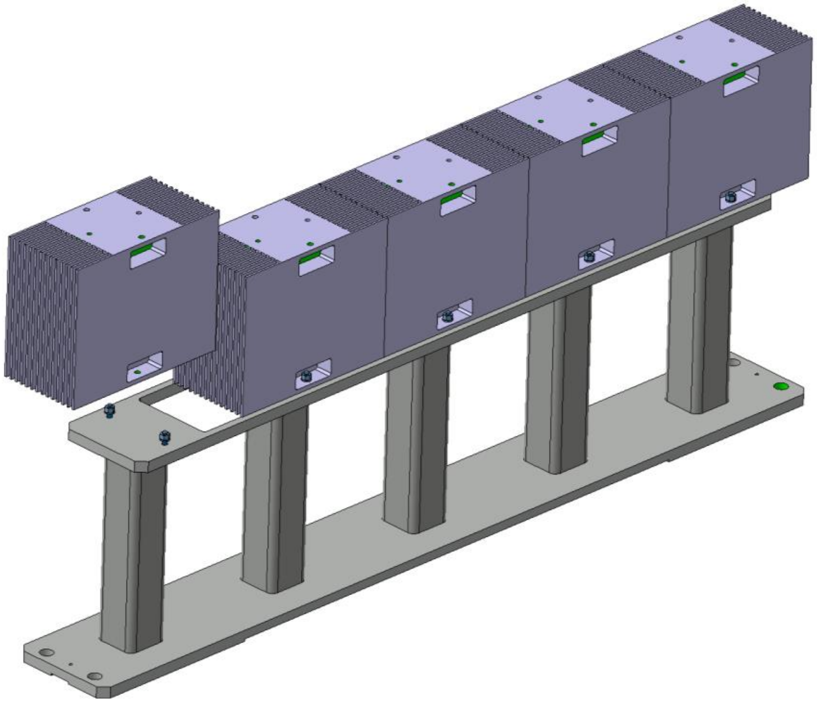
Coils

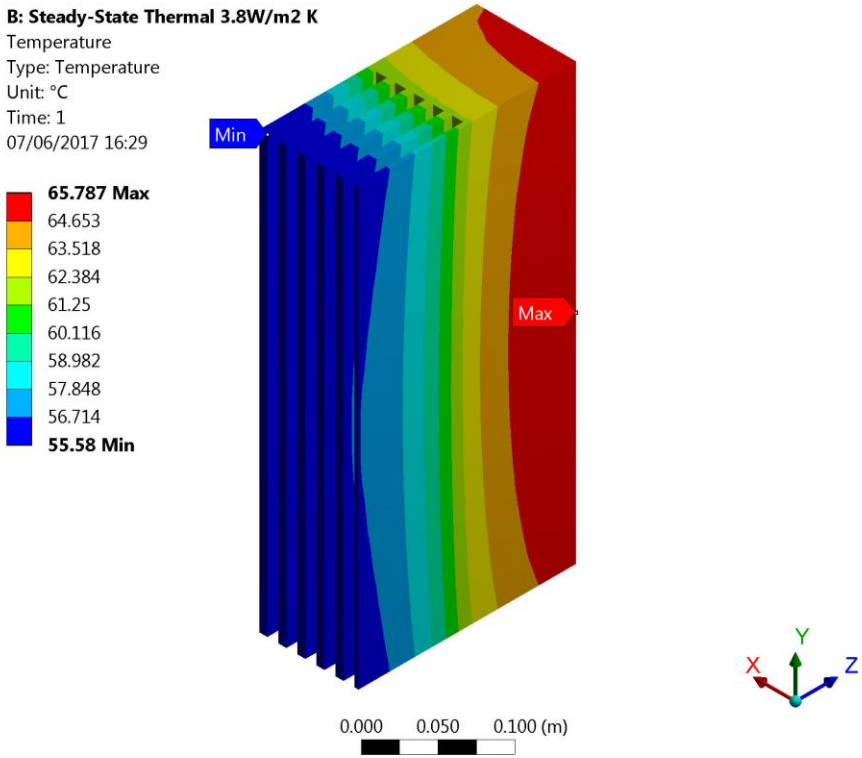


Spacers



Preliminary design being developed by EN-MME team (cost-time effective solution)





Baseline: Iron block (20x40x100 cm³) – C. Bahamonde ColUSM #83

Material: low carbon steel

No active or forced cooling

Natural convection only: requires splitting the block in several parts and adding finned surfaces

Total length increases to (more than) 2 m

Total power to be dissipated estimated to **~1.2 kW** (corresponding to 1 hr BLT at HL-LHC intensity) – *to be confirmed by additional FLUKA simulations*

0.2 hr BLT (10 s) leads to marginal average temperature increase.

Energy is uniformly distributed on bulk absorber

After LS2: revised

When	Present action plan	Comment and new proposed action plan
RUN 3	Production of 4 sets of rad-hard coils for MBW.	Taking into account that 1) We have 4 spares 2) We have 2 sets of spare coils 3) That we could move magnet at dog leg start (before the primary collimators) to second part (after primary collimator) We propose not to procure these units and invest some money in having tooling to open these magnets

Proposal about what to do

When	Present action plan	Comment and new proposed action plan
RUN 3	Production of 6+1 MQW magnets with rad hard coils.	Taking into account that 1) We have 4 spares 2) We have 10 of spare coils (mix not enough for 1 full magnet) 3) We will have 2 spare magnets more from LS2 4) We could shuffle magnets in LS3 We propose not to procure extra magnets or coils but we develop the capacity to open and close MQW units.

The budget allocated to this activity is largely reduced.
We do not pursue any more development of advanced insulation system
We re-allocate personnel according to project and WP need

Alternative solution to suppress the trims MQW (recovering 6 units) unbalancing the currents between the apertures is being developed following proposal by A. Milanese. It will require infrastructure rearrangement and cost and impact should be evaluated

Extra slides

Estimates of Integrated Intensity for HL-LHC

A. Apollonio

2016

- 153 days of p-p luminosity production
- 50 % stable beams, 30 % fault (no beam), 20 % operations
- My Chamonix presentation: 10.3 h stable beams fills, 4.8 h turnaround = total 179 fills
- Bunch intensity, number of bunches: 1.2e11, 2220
- Average beam intensity during stable beams (from Ruben): 1.71e14
- Integrated intensity over 10.3 h fill: 1.71e14*10.3*3600 = 6.3e18 ps
- Integrated intensity over the cycle (assuming 3/5 time spent at injection and 2/5 rest of the cycle): [3/5*(1.71e14+0/2+2/5*1.71e14]*4.8*3600 = 2.07e18 ps
- Integrated intensity over luminosity production period: (6.3e18 + 2.07e18)*179 = **1.49e21 ps per beam**
- Smaller intensities during intensity ramp-up balance out the re-commissioning with beam (not included in the calculation)

2017

- 136 days of p-p luminosity production
- 50 % stable beams, 20 % fault (no beam), 30 % operations → 109 days of fault-free operation with beam
- 109 days with 15 h stable beams fills, 4 h turnaround = total 138 fills
- Bunch intensity, number of bunches: 1.25e11, 2560 (Chamonix 2017)
- Bunch intensity after 15 h: 0.46e11 (assuming 15 h lumi lifetime)
- Average bunch intensity during stable beams: 0.85e11
- Integrated intensity over 15 h fill: 0.85e11*2560*15*3600 = 11.7e18 ps
- Integrated intensity over the cycle (assuming 3/5 time spent at injection and 2/5 rest of the cycle): [3/5*(1.25e11+0)*2560/2+2/5*1.25e11*2560]*4*3600 = 3.2e18 ps
- Integrated intensity over luminosity production period: (11.7e18 + 3.2e18)*138 = **2.05e21 ps per beam**
- Smaller intensities during intensity ramp-up balance out the re-commissioning with beam (not included in the calculation)

Typical LHC Production Year

- 160 days of p-p luminosity production
- Same parameters as for 2017 (previous slide), but scaling up to 160 days
- Integrated intensity over luminosity production period: 2.05e21*160/136 = **2.41e21 ps per beam**
- Smaller intensities during intensity ramp-up balance out the re-commissioning with beam (not included in the calculation)

HL-LHC

- 160 days of p-p luminosity production
- 45 % stable beams, 25 % fault (no beam), 30 % operations → 120 days of fault-free operation with beam
- 120 days with 2 fills of 7 h stable beams per day, 5 h turnaround = total 240 fills
- Bunch intensity, number of bunches: 2.2e11, 2736 (standard HL)
- Bunch intensity after 7 h: 0.8e11
- Average bunch intensity during stable beams: 1.5e11
- Integrated intensity over 7 h fill: 1.5e11*2736*7*3600 = 10.3e18 ps
- Integrated intensity over the cycle (assuming 3/5 time spent at injection and 2/5 rest of the cycle): [3*(2.2e11+0)*2736/2+2*2.2e11*2736]*3600 = 7.58e18 ps
- Integrated intensity over luminosity production period: (10.34e18 + 7.58e18)*240 = **4.3e21 ps per beam**
- Smaller intensities during intensity ramp-up balance out the re-commissioning with beam (not included in the calculation)

Maximum in dose per p•s