Update on radiation dose to resistive magnets in IR3/7 and plans for new studies

A. Lechner on behalf of SY/STI, in close collaboration with TE/VSC, BE/ABP, HL-LHC WP5 collimation, R2E

17/04/2024

Introduction

- The warm magnets in IR7 and IR3 (MBWs and MQWs) are exposed to the radiation showers induced by betatron and momentum collimation losses
- In particular, the **cumulative ionizing dose** in coil insulation (MQWs and MBWs) and coil spacers (MQWs) can lead to a degradation of material properties
- In Run 1+2, concerted effort between TE/MSC, BE/ABP (collimation team) and SY/STI (FLUKA and R2E teams) to estimate the expected dose values for HL-LHC and to develop shielding solutions
  - In IR7, all shielding has been installed in LS1 and LS2
  - In IR3, some of the planned front shielding for MQWs could not be installed
- In this presentation, I will summarize the latest IR7 dose estimates for HL-LHC and the plans for IR3 dose studies

Material limits (P. Fessia et al.)

Material	Dose corresponding to the beginning of damage (no bubbles, limited variation in properties) [MGy]	Dose corresponding moderate damage (bubbles formation and beginning of properties reduction) [MGy]	Dose corresponding to the failure on component (extensive bubbles, properties loss) [MGy]
MQW Coils	10-50	50-75	>75
MBW Coils	50-75	75-90	>90
MQW Spacers	5-10	10-15	>15

From LHC-MW-EC-0002

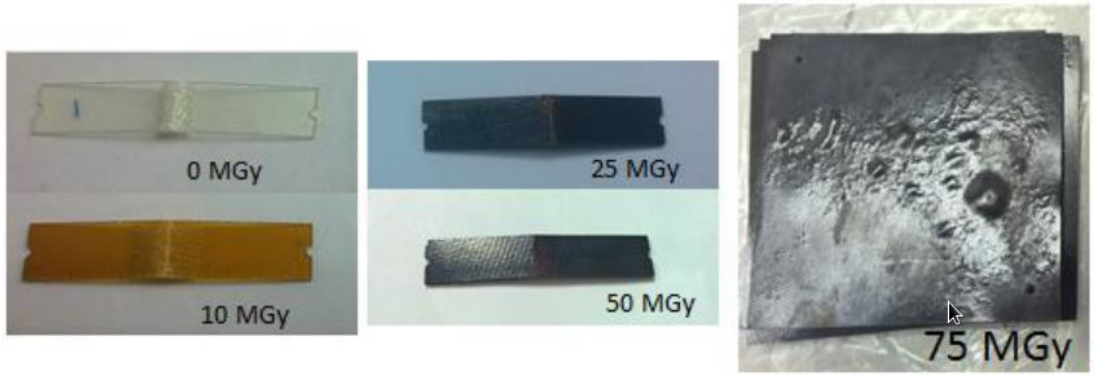


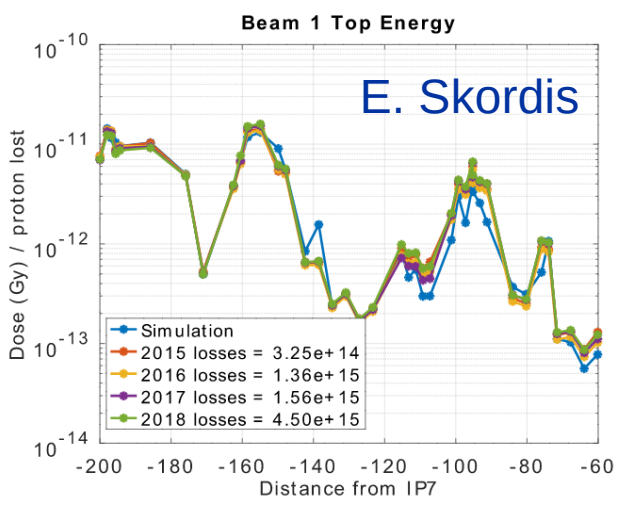
Figure 5 — MQW coil samples degradation after different radiation doses.

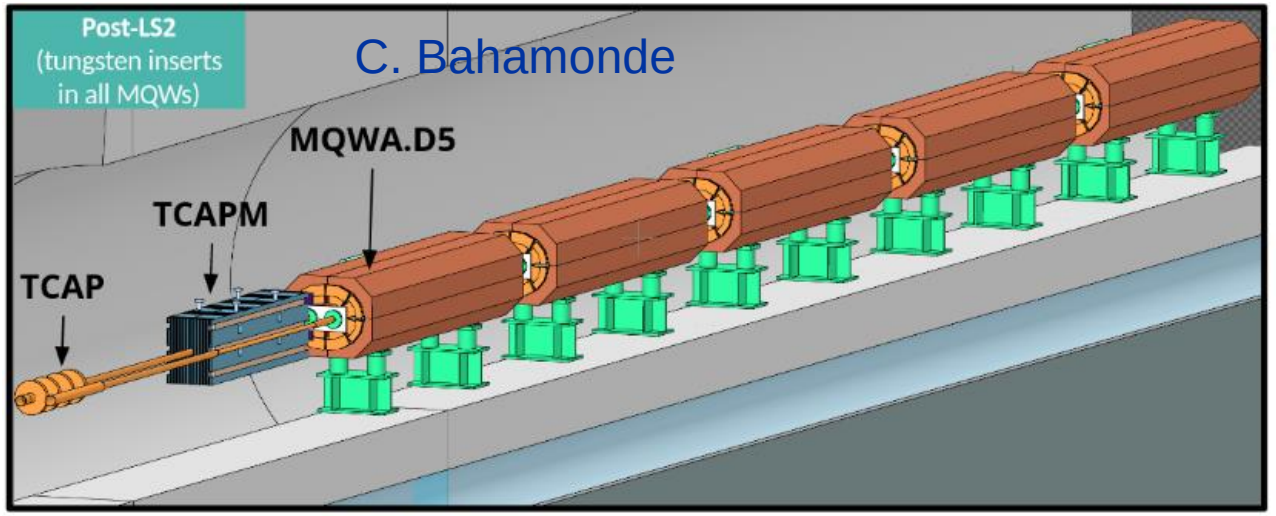
Dose to resistive magnets in IR7

How to estimate IR7 dose values for HL-LHC?

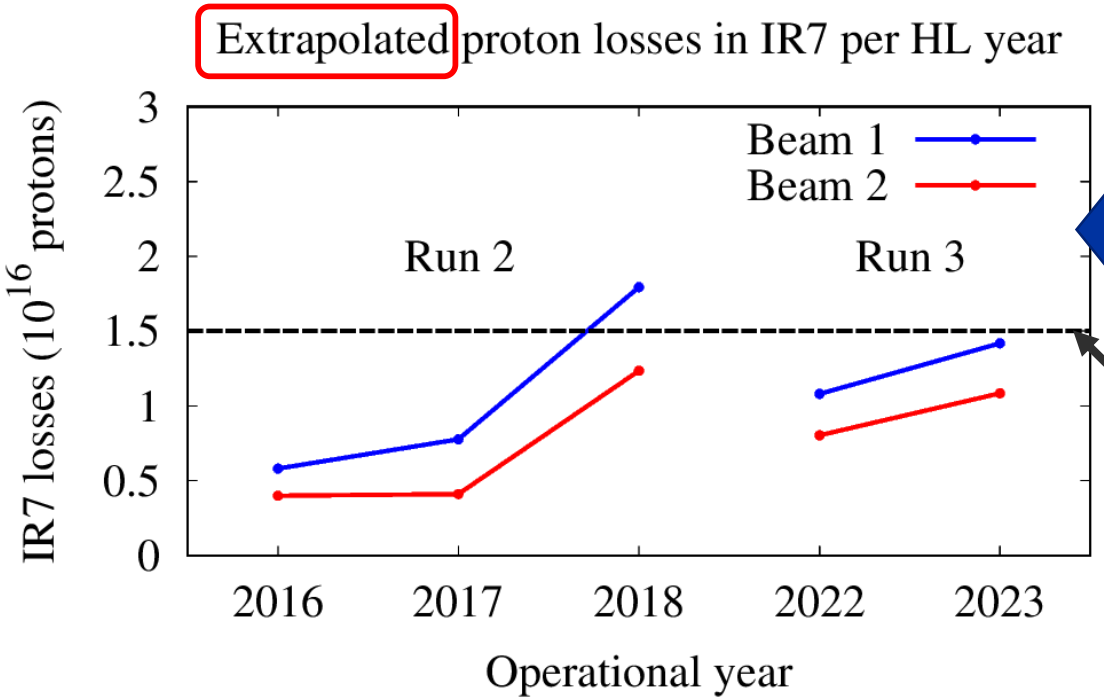
- Since Run 2, annual exercise to estimate cumulative proton losses in IR7 (BLM data, FLUKA simulations, BCT data) → **extrapolate losses to HL era**

- Detailed FLUKA shower simulations, benchmarked against RPL measurements (**note: dosimeters are on the outside of magnets and do not give the peak dose values inside coils and spacers → peak values can be many times higher than dosimeter measurements**)





Extrapolated proton losses in IR7 for HL-LHC era



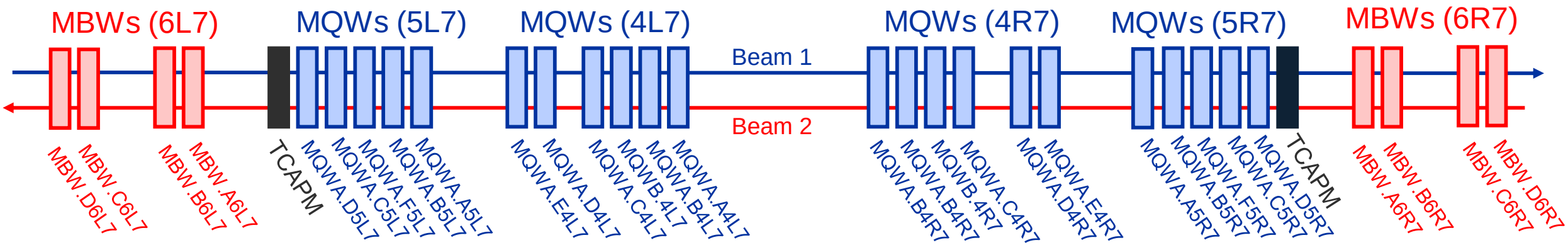
Annual losses from different years in Run 2 & 3 scaled to HL beam parameters and operating conditions (assumption: losses are proportional to the time-integrated proton current in the machine)

Present assumption: **1.5x10^{16} protons lost in IR7 per HL year**

E. Skordis, G. Lerner, A. Canesse, V. Rodin et al.

For more details see recent presentation in MCWG: A. Canesse, Cumulative number of lost protons in 2022-2023 at the LHC IR7, link.

IR7: warm magnet layout and radiation shielding



Radiation shielding installation in IR7 (P. Fessia et al., S. Redaelli et al.):

LHC-MW-EC-0001 (2013)
Radiation Shielding Installation for the MBW and MQW Magnets in IR 3 and 7 of the LHC. First phase during LS1

First batch of shielding in IR7 MQWs and MBWs in **LS1**

LHC-MW-EC-0002 (2018)
Radiation Shielding Installation and Possible Optics Change for the MBW and MQW Magnets in IR 3 and 7 of the LHC. Second phase LS2, LS3 and HL-LHC

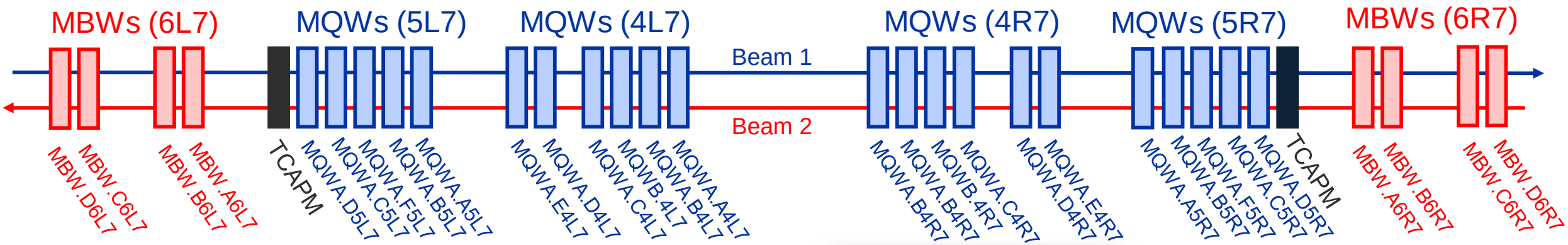
Second batch of shielding in IR7 MQWs in **LS2**

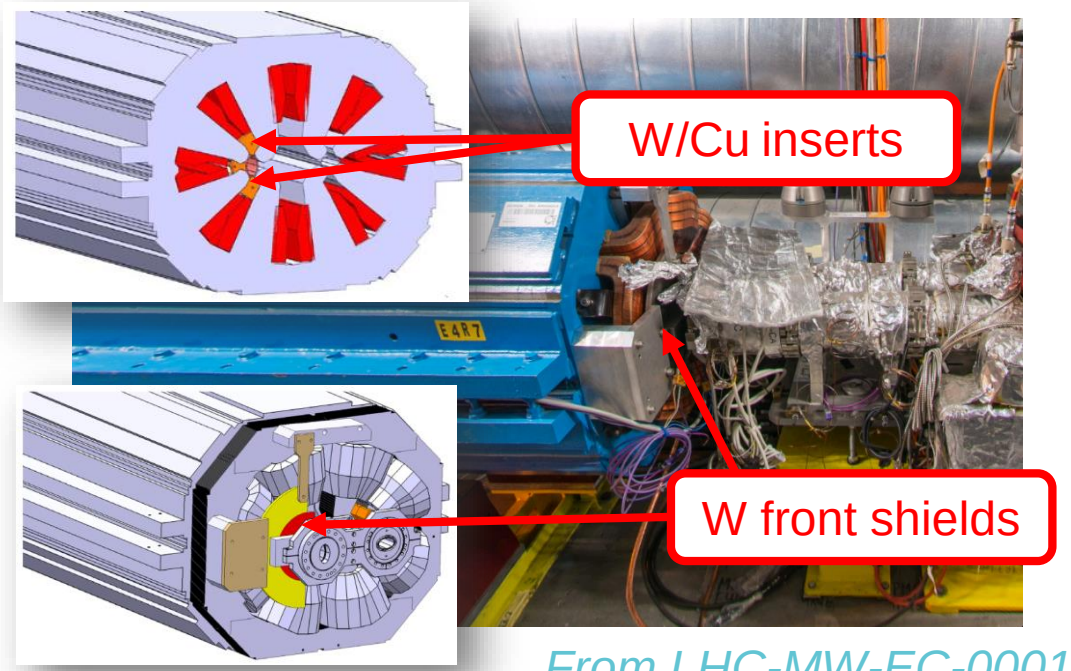
LHC-TCAP-EC-0001 (2019)
Installation of New Passive Absorbers (TCAPM) for Warm Magnet Protection in IR7

Replacement of MQWA.E5L7/E5R7 with TCAPM in **LS2**

No further shielding installation in IR7 foreseen

IR7: warm magnet layout and radiation shielding





From LHC-MW-EC-0001/2

IR7: latest HL dose predictions for warm magnets

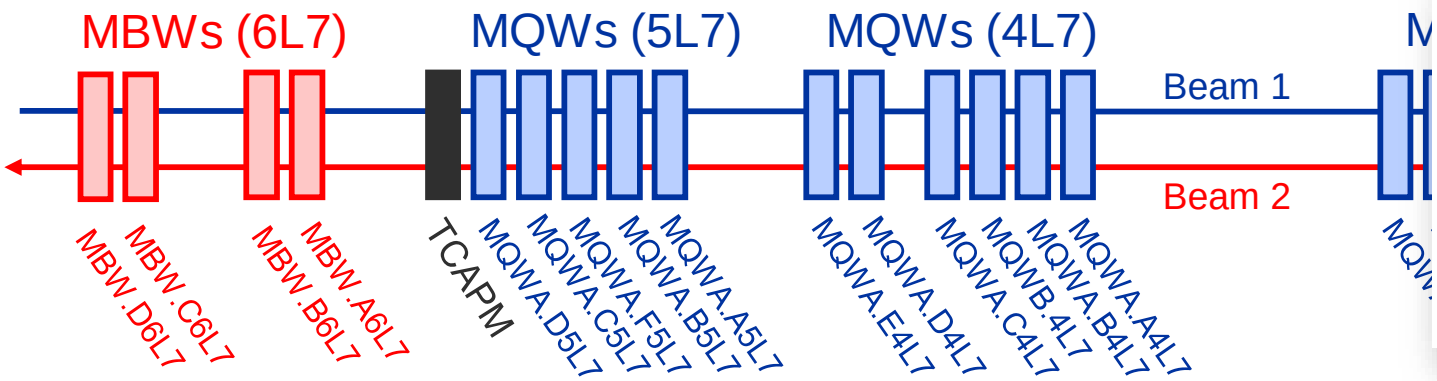


Table 4 — New material radiation limits.

Material	Dose corresponding to the beginning of damage (no bubbles, limited variation in properties) [MGy]	Dose corresponding moderate damage (bubbles formation and beginning of properties reduction) [MGy]	Dose corresponding to the failure on component (extensive bubbles, properties loss) [MGy]
MQW Coils	10-50	50-75	>75
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MQW Spacers	5-10	10-15	>15

Simulated dose values in most exposed magnets, scaled to **1.8×10^{17} protons lost in HL era** ($=1.5 \times 10^{16}$ protons lost per year, for 12 years)

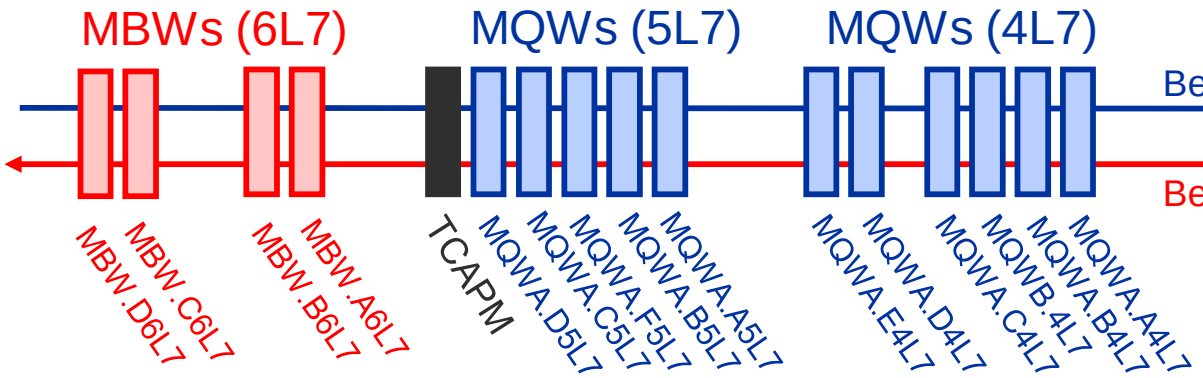
Loss scaling was established in Run 2 (2015-2018), and confirmed by 2022+2023 BLM and BCT data.

Note that the dose values in the ECRs are outdated since the loss scaling was refined

	Coils	Spacers
MBW.B6L7/R7	16 MGy	N/A
MBW.A6L7/R7	13 MGy	N/A
MQWA.D5L7/R7	1.3 MGy	1.1 MGy
MQWA.C5L7/R7	0.9 MGy	0.5 MGy
MQWA.E4L7/R7	2 MGy	1.8 MGy
MQWA.D4L7/R7	<0.7 MGy	<0.7 MGy
MQWA.C4L7/R7	<1 MGy	<1 MGy

Scaled from the FLUKA results presented by Bahamonde (ColUSM #104) and E. Skordis (CWG #237), contribution from ramp and injection energy not included

IR7: Run 2 dose estimates vs HL dose predictions



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Run 2 (4 yrs)	Coils	Spacers
MBW.B6L7/R7*	0.9 MGy	N/A
MBW.A6L7/R7*	0.7 MGy	N/A
MQWA.D5L7/R7**	0.2 MGy	0.2 MGy
MQWA.C5L7/R7**	no sim	no sim
MQWA.E4L7/R7*	0.1 MGy	0.1 MGy
MQWA.D4L7/R7**	0.1 MGy	0.1 MGy
MQWA.C4L7/R7**	0.2 MGy	0.2 MGy

HL-LHC (12 yrs)	Coils	Spacers
MBW.B6L7/R7	16 MGy	N/A
MBW.A6L7/R7	13 MGy	N/A
MQWA.D5L7/R7	1.3 MGy	1.1 MGy
MQWA.C5L7/R7	0.9 MGy	0.5 MGy
MQWA.E4L7/R7	2 MGy	1.8 MGy
MQWA.D4L7/R7	<0.7 MGy	<0.7 MGy
MQWA.C4L7/R7	<1 MGy	<1 MGy

*Shielding installed in LS1
**Shielding installed in LS2

Scaled from the FLUKA results presented by Bahamonde (ColUSM #104) and E. Skordis (CWG #237), contribution from ramp and injection energy not included

Dose in Run 2 was generally less than 20% of the dose expected in HL-LHC

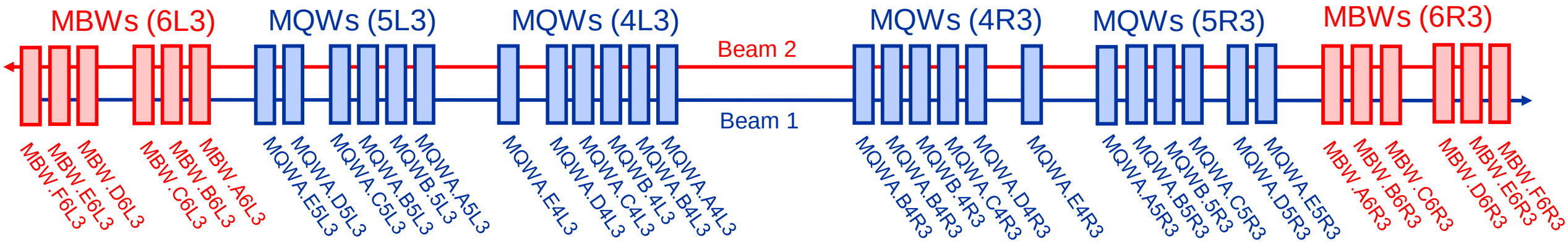
IR7: summary and conclusions

- All the HL-LHC radiation shielding planned for IR7 has been installed
- Established a robust scaling of the IR7 proton losses expected in HL-LHC, which was confirmed by recent Run 3 data
- The FLUKA simulations have been benchmarked against RPL measurements in Run 2
  - *Generally, a good agreement within a factor of two was found*
  - *The benchmarks still have to be repeated with Run 3 data (but expect no surprises)*
- **The predicted dose values for HL-LHC are at least 2-3 times lower than the dose range where onset of damage is expected**
- Note: the presented HL dose values do **NOT** include
  - the proton-induced dose in HL-LHC during injection/ramp
  - the ion-induced dose in HL-LHC
  - the dose accumulated in Run 1-3

Expect that the sum of these contributions can maybe add 50% on top of the HL predictions (very rough estimate), but this can vary from position to position

Dose to resistive magnets in IR3

IR3: warm magnet layout and radiation shielding



Radiation shielding installation in IR3 (P. Fessia et al.):

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Radiation Shielding Installation for the MBW and MQW Magnets in IR 3 and 7 of the LHC. First phase during LS1

First batch of shielding in IR3 MQWs and MBWs in **LS1**

LHC-MW-EC-0002 (2018)
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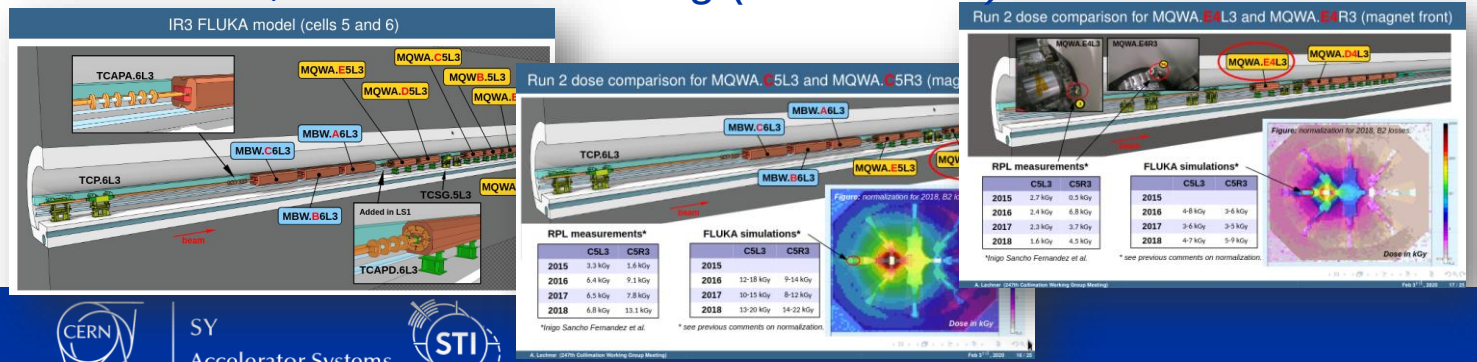
Second batch of shielding in IR3 MQWs in **LS2**

Front face shielding could not be installed on six magnets (MQWA.E4, D5, E5), see presentation of P. Schwarz, CWG #247, 03/02/2020, link

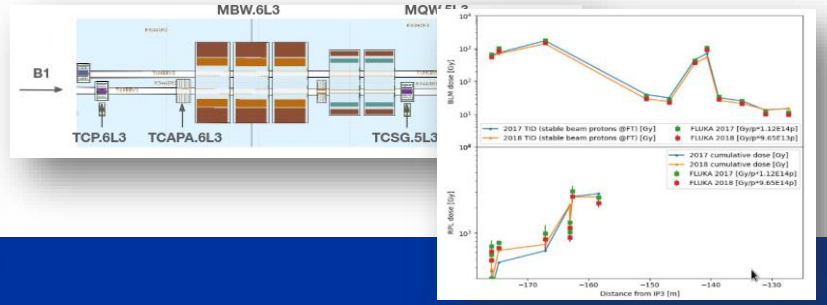
IR3: dose estimates for HL-LHC – study plans

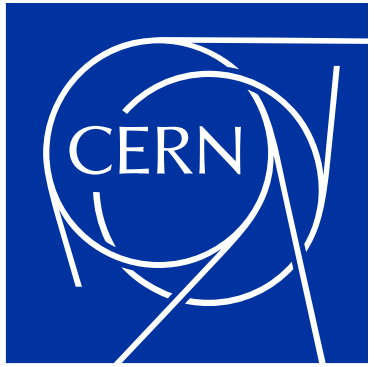
- At the moment, we don't have yet up-to-date HL dose predictions for IR3 resistive magnets, but we plan to address this topic by new simulations in the coming months
  - Note: the past HL dose predictions for IR3 in LHC-MW-EC-0002 are outdated
  - Cannot quantify at the moment if some of the dose values are higher than in IR7
- The contribution of Pb runs cannot be neglected in IR3, so we need separate studies for protons and ions
- One of the challenges is to establish a scaling of beam losses for HL-LHC → more difficult for IR3 than for IR7; likely, we need different approaches for protons and ions
- First simulation benchmarks* against Run 2 RPL and BLM measurements showed satisfactory agreement, but need to extend these studies to Pb operation and Run 3 data

A. Lechner, 247th CWG meeting (03/02/2020):



A. Waets, 142nd ColUSM Meeting (02/07/2021):





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Predicting IR7 proton losses for HL-LHC era

- The cumulative ionizing dose in the MBW/MQW coil insulation and the MQW spacers depends on **the total number of protons lost in IR7** until the end of HL-LHC
- The approach of estimating the number of lost protons changed with time:
  - Initially (until 2016), it was assumed that losses scale with **integral luminosity**
  - Later (in 2017) it was found that the **integral stored intensity** was a better measure
- In addition, the scaling with integral stored intensity was refined during Run 2 when more beam loss measurement data became available

→ *As a consequence, the dose predictions for HL changed with time*

LHC-MW-EC-0001 (2013)
Radiation Shielding Installation for the MBW and MQW Magnets in IR 3 and 7 of the LHC. First phase during LS1

IR7 dose scaling with **integral luminosity**
About 1x10^{18} protons lost in HL

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IR7 dose scaling with **integral intensity**
About 1x10$^{??}$ protons lost in HL

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Installation of New Passive Absorbers (TCAPM) for Warm Magnet Protection in IR7

IR7 dose scaling with **integral intensity**
About 1x10^{17} protons lost in HL