Considerations about Q6 thresholds

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Introduction

- The SC Q6 magnets in IR3 and IR7 (MQTLH, 4.5K) are exposed to showers from TCLAs
- Operational experience showed that the Q6 BLM thresholds pose a performance bottleneck for certain loss conditions:
  - *Losses in IR3 and IR7 at the beginning of the ramp (2022 and 2024)*
  - *Fragment leakage in IR7 during Pb operation (2023)*
- The Q6 BLM master threshold model is ignorant of collimation losses → assumes direct proton losses on the Q6 aperture
- As a consequence, several ad-hoc corrections had to be applied on top of the model to avoid premature dumps (→ several corrections in the 2023 Pb run)
- However, it is important to understand the actual quench margin we have for the Q6 for Pb collimation losses
- In this presentation, I analyse the observations of the 2023 Pb run and present a proposal for increasing the Q6 thresholds

Recap: dumps in 2023 Pb run

	Event Timestamp	Beam Mode	Beam Energy [MeV]	Fill Number	Stable Beam	BLM
1	Event Timestamp	Beam Mode	Beam Energy [MeV]	Fill Number	Stable Beam	BLM
2	27-SEP-2023 17.38.16.	RAMP	5642280	9195	0	Q6R7
3	27-SEP-2023 19.42.16.	RAMP	6328320	9196	0	TCTPH.4L1
4	28-SEP-2023 03.15.52.	RAMP	6312840	9199	0	TCTPH.4L1
5	01-OCT-2023 20.36.49.	ADJUST	6799200	9214	0	multiple
6	03-OCT-2023 02.16.09.	RAMP	6331920	9219	0	Q6R7
7	06-OCT-2023 19.32.01.	STABLE BEAMS	6799320	9234	0.285	TCLD.A11R2
8	11-OCT-2023 01.41.23.	RAMP	450480	9241	0	Q8R3
9	13-OCT-2023 05.10.15.	STABLE BEAMS	6799320	9251	2.37	TCLD.A11R2
10	16-OCT-2023 11.50.25.	RAMP	6145080	9265	0	11L7
11	16-OCT-2023 14.16.37.	RAMP	5969640	9266	0	11L7
12	16-OCT-2023 18.14.46.	STABLE BEAMS	6799320	9267	0.694	TCLD.A11R2
13	18-OCT-2023 02.16.20.	RAMP	6240000	9272	0	Q6R7
14	20-OCT-2023 02.32.11.	ADJUST	6799320	9280	0	TCLD.A11R2
15	21-OCT-2023 05.31.01.	STABLE BEAMS	6799320	9284	1.12	Q6R7
16	24-OCT-2023 00.15.41.	RAMP	6714360	9295	0	TCTPV.4L2
17	24-OCT-2023 04.02.06.	STABLE BEAMS	6799320	9296	1.05	Q6R7
18	24-OCT-2023 14.17.56.	ADJUST	6799320	9299	0	Q6R7
19	24-OCT-2023 17.10.32.	FLAT TOP	6799320	9300	0	TCTPV.4L2
20	25-OCT-2023 17.05.17.	ADJUST	6799200	9304	0	Q6R7

2023 Pb run:

- **18 BLM dumps** in physics fills (9 in ramp, 9 at top energy)
- Mostly at **Q6R7** (7x), **TCLDs** (4x) and **TCTs** (4x)

Q6 dumps:

- 5x **RS06** (last 5 dumps)
- 1x **RS08**
- 1x **RS10/11**

Q6 dump events in 2024 Pb run

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				9234	0.285	TCLD.A11R2
				9241	0	Q8R3
				9251	2.37	TCLD.A11R2
				9265	0	11L7
				9266	0	11L7
				9267	0.694	TCLD.A11R2
				9272	0	Q6R7
				9280	0	TCLD.A11R2
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				9299	0	Q6R7
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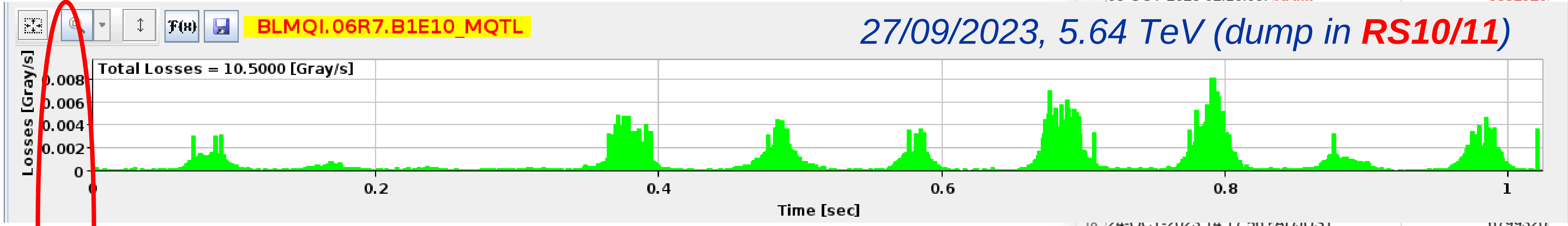
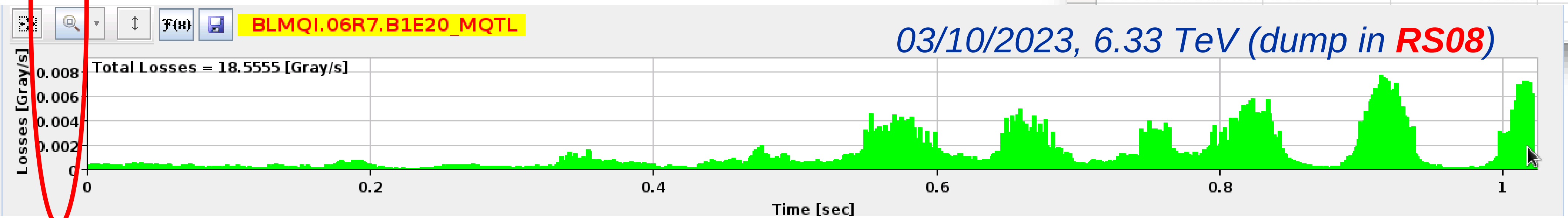
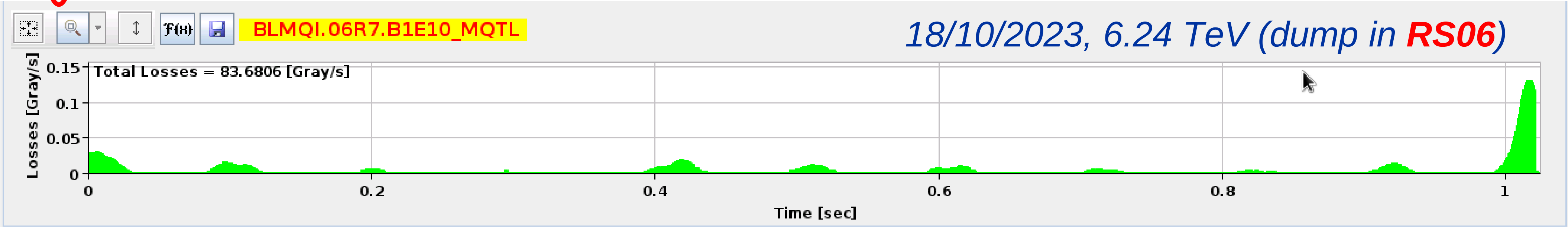
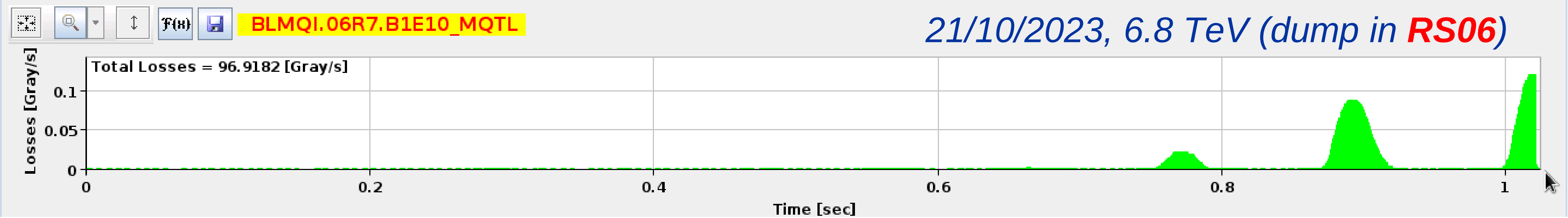
				9304	0	Q6R7

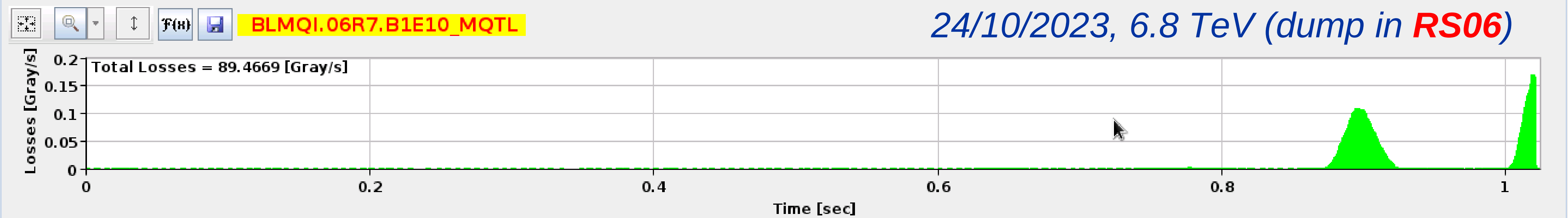


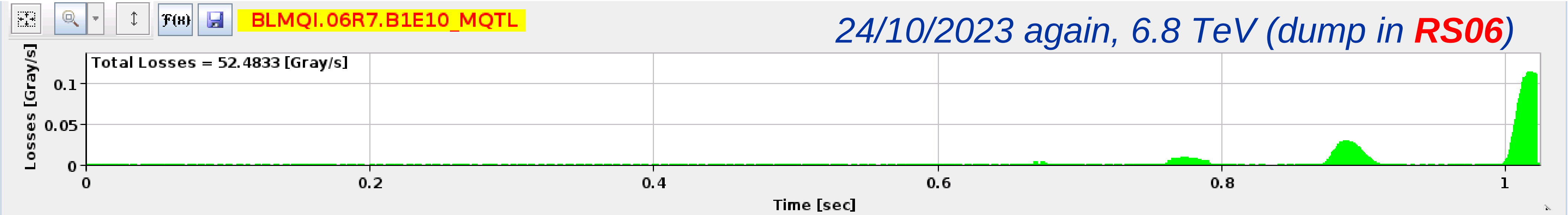


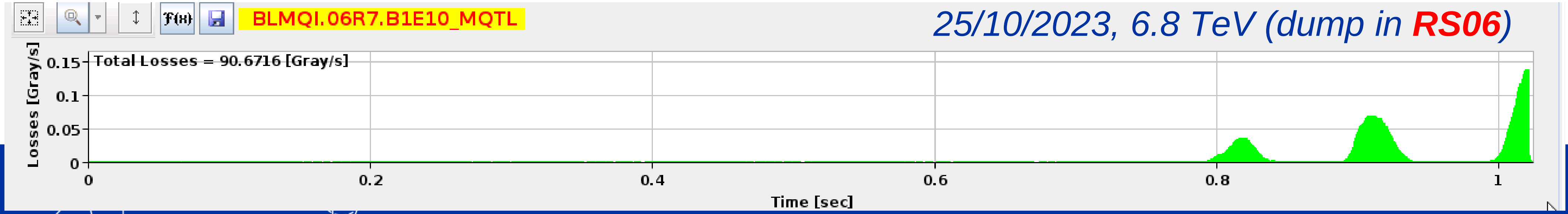


Q6 dump events in 2024 Pb run









Sig-thr ratio for Q6 dump events in 2023 (RS06)

18/10/2023	Signal RS06	Threshold RS06	Ratio
BLMQI.06R7.B1E10_MQTL	0.109145	0.108478	1.00615
BLMTI.06R7.B1E10_TCLA.C6R7.B1	0.172254	0.466303	0.369403
BLMTI.06R7.B1E10_TCLA.D6R7.B1	0.699897	1.94289	0.360234
BLMTI.05R7.B1E10_TCSG.E5R7.B1	0.106931	0.380572	0.280975
BLMQI.06R7.B1E20_MQTL	0.0237612	0.108478	0.219042

24/10/2023	Signal RS06	Threshold RS06	Ratio
BLMQI.06R7.B1E10_MQTL	0.10354	0.100999	1.02516
BLMTI.05R7.B1E10_TCSG.E5R7.B1	0.19745	0.37926	0.52062
BLM2I.11R7.B1E24_MBB_MBB	0.0403276	0.096694	0.417066
BLMTI.06R7.B1E10_TCLA.C6R7.B1	0.17595	0.466921	0.37683
BLMTI.06R7.B1E10_TCLA.D6R7.B1	0.710402	1.94547	0.365158
BLM2I.11R7.B1E23_MBB_MBB	0.0334288	0.096694	0.345719
BLM2I.11R7.B1E23_MBA_MBA	0.0204838	0.096694	0.211842

25/10/2023	Signal RS06	Threshold RS06	Ratio
BLMQI.06R7.B1E10_MQTL	0.101743	0.100999	1.00737
BLMTI.05R7.B1E10_TCSG.E5R7.B1	0.210411	0.37926	0.554793
BLM2I.11R7.B1E24_MBB_MBB	0.038002	0.096694	0.393017
BLMTI.06R7.B1E10_TCLA.C6R7.B1	0.175218	0.466921	0.375262
BLMTI.06R7.B1E10_TCLA.D6R7.B1	0.69501	1.94547	0.357246
BLM2I.11R7.B1E23_MBB_MBB	0.034451	0.096694	0.356292
BLM2I.11R7.B1E23_MBA_MBA	0.020152	0.096694	0.208413

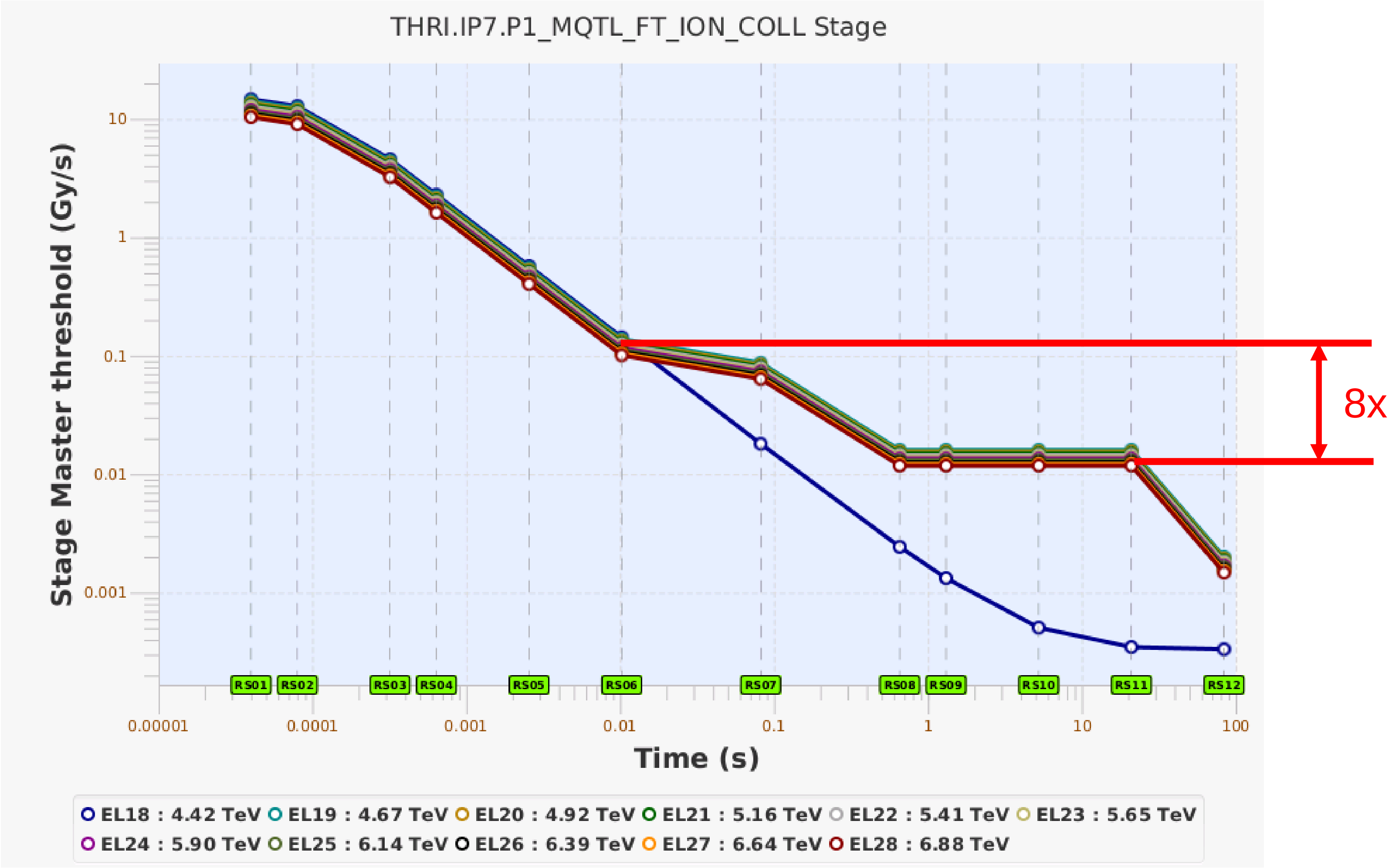
21/10/2023	Signal RS06	Threshold RS06	Ratio
BLMQI.06R7.B1E10_MQTL	0.101734	0.100999	1.00728
BLMTI.05R7.B1E10_TCSG.E5R7.B1	0.196181	0.37926	0.517273
BLM2I.11R7.B1E24_MBB_MBB	0.0384597	0.096694	0.397748
BLMTI.06R7.B1E10_TCLA.C6R7.B1	0.180442	0.466921	0.38645
BLMTI.06R7.B1E10_TCLA.D6R7.B1	0.699435	1.94547	0.35952
BLM2I.11R7.B1E23_MBB_MBB	0.0320483	0.096694	0.331442
BLM2I.11R7.B1E23_MBA_MBA	0.0195399	0.096694	0.20208

24/10/2023	Signal RS06	Threshold RS06	Ratio
BLMQI.06R7.B1E10_MQTL	0.101628	0.100999	1.00623
BLMTI.05R7.B1E10_TCSG.E5R7.B1	0.173381	0.37926	0.457155
BLMTI.06R7.B1E10_TCLA.C6R7.B1	0.191589	0.466921	0.410324
BLM2I.11R7.B1E23_MBB_MBB	0.0346923	0.096694	0.358785
BLMTI.06R7.B1E10_TCLA.D6R7.B1	0.695351	1.94547	0.357421
BLM2I.11R7.B1E24_MBB_MBB	0.0335472	0.096694	0.346944

Tables include all BLMs, which exceeded 20% of thresholds in RS06

- TCSG.E5R7 was about a factor 2 behind
- Some DS magnets were a factor of 2.5 behind
- TCLAs just upstream of Q6 were about a factor of 3 behind

Why did we dump first on the Q6 in RS06?

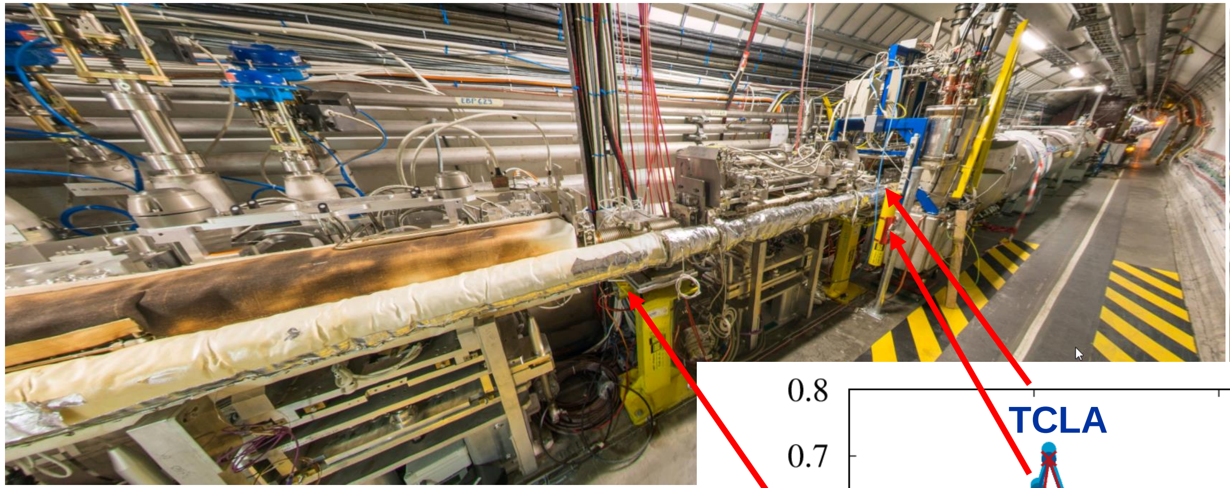


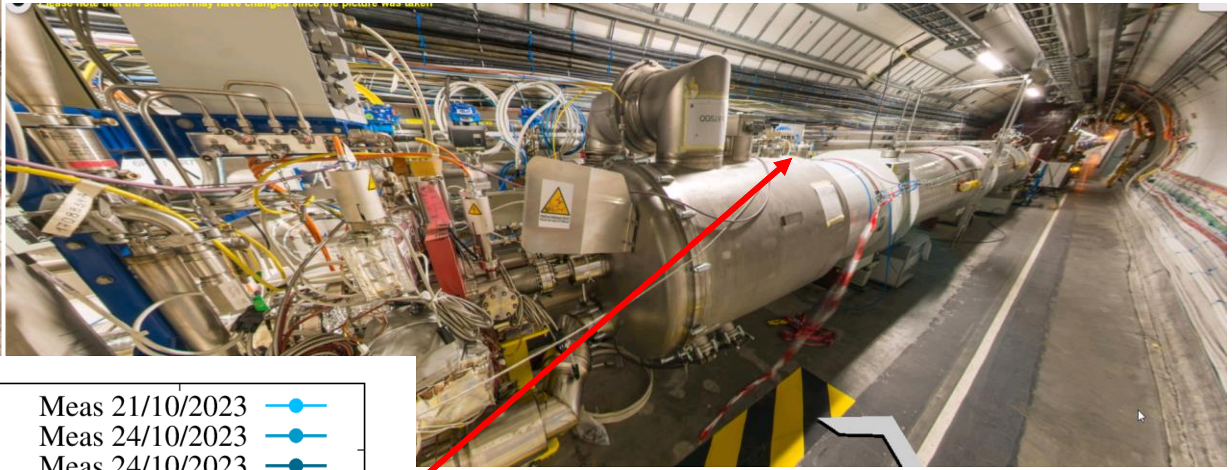
For RS08-11, the Q6 thresholds were aligned to the “50-60kW” level like the collimators.

But:
For collimators, RS06 is 24x higher than RS08-11

For the Q6, RS06 is “only” 8x higher than RS08-11
→ Q6 was the bottleneck for 10ms losses

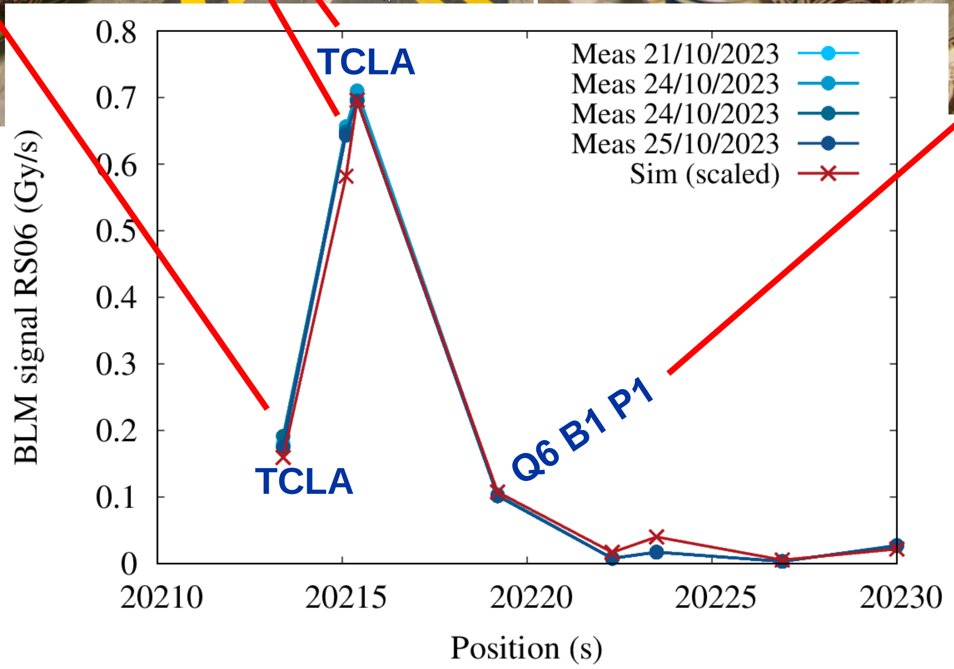
Energy deposition in Q6 coils during 2023 dumps

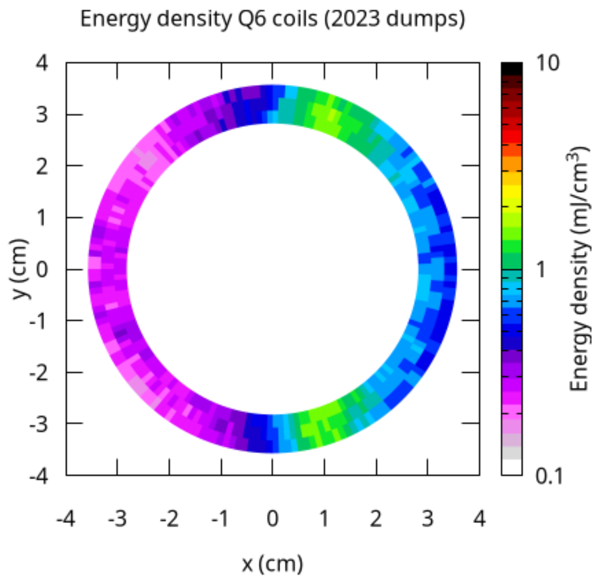




2023 dumps:

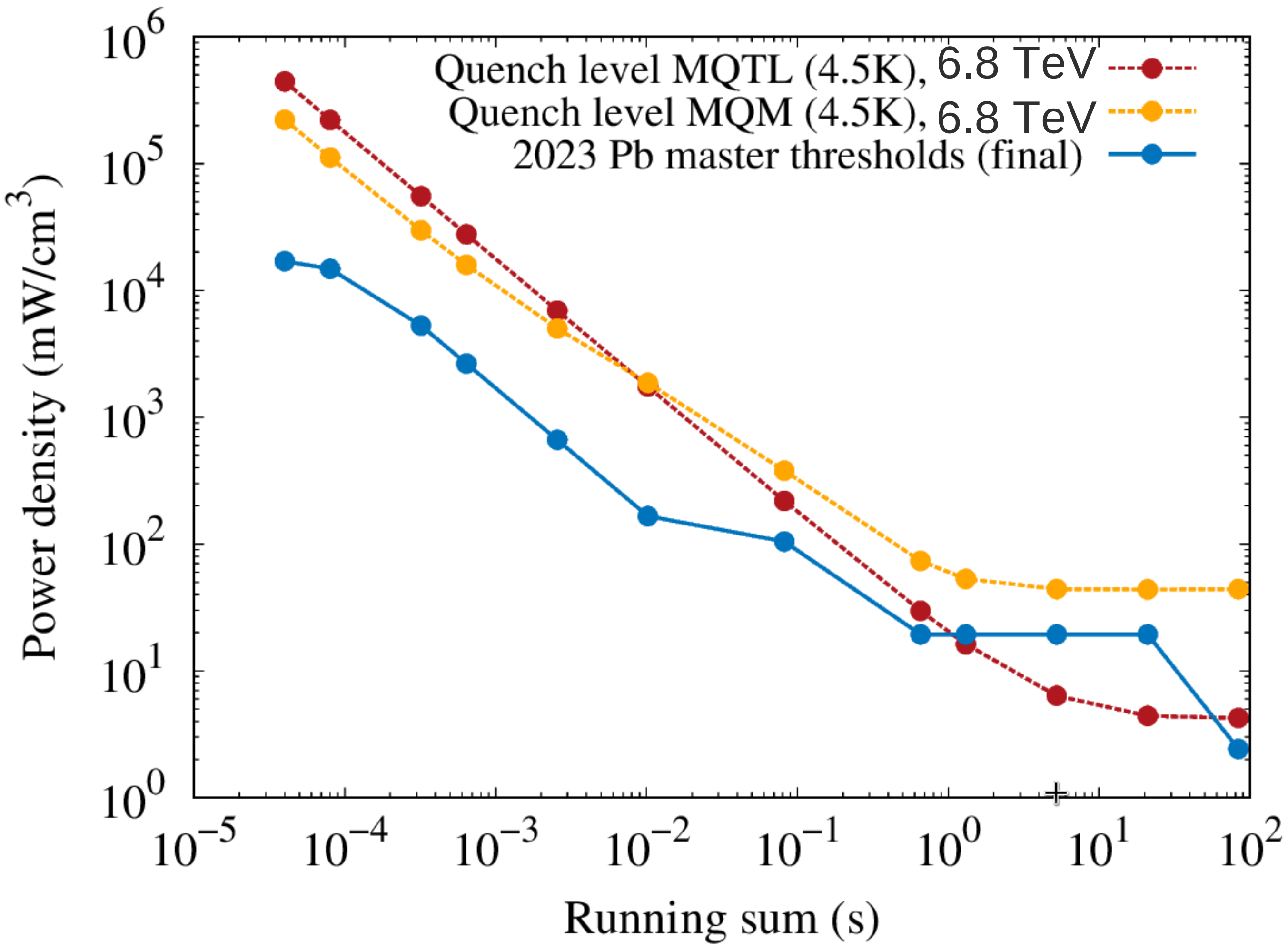
- Estimated peak energy density in Q6 coils was **1-2 mJ/cm³** (in 10 ms)
- Quench level for 10 ms is around 20 mJ/cm3 (or likely even higher)
- Factor of 10+ margin…





Simulation reproduces BLM signal pattern quite well!

Energy deposition in Q6 coils during 2023 dumps



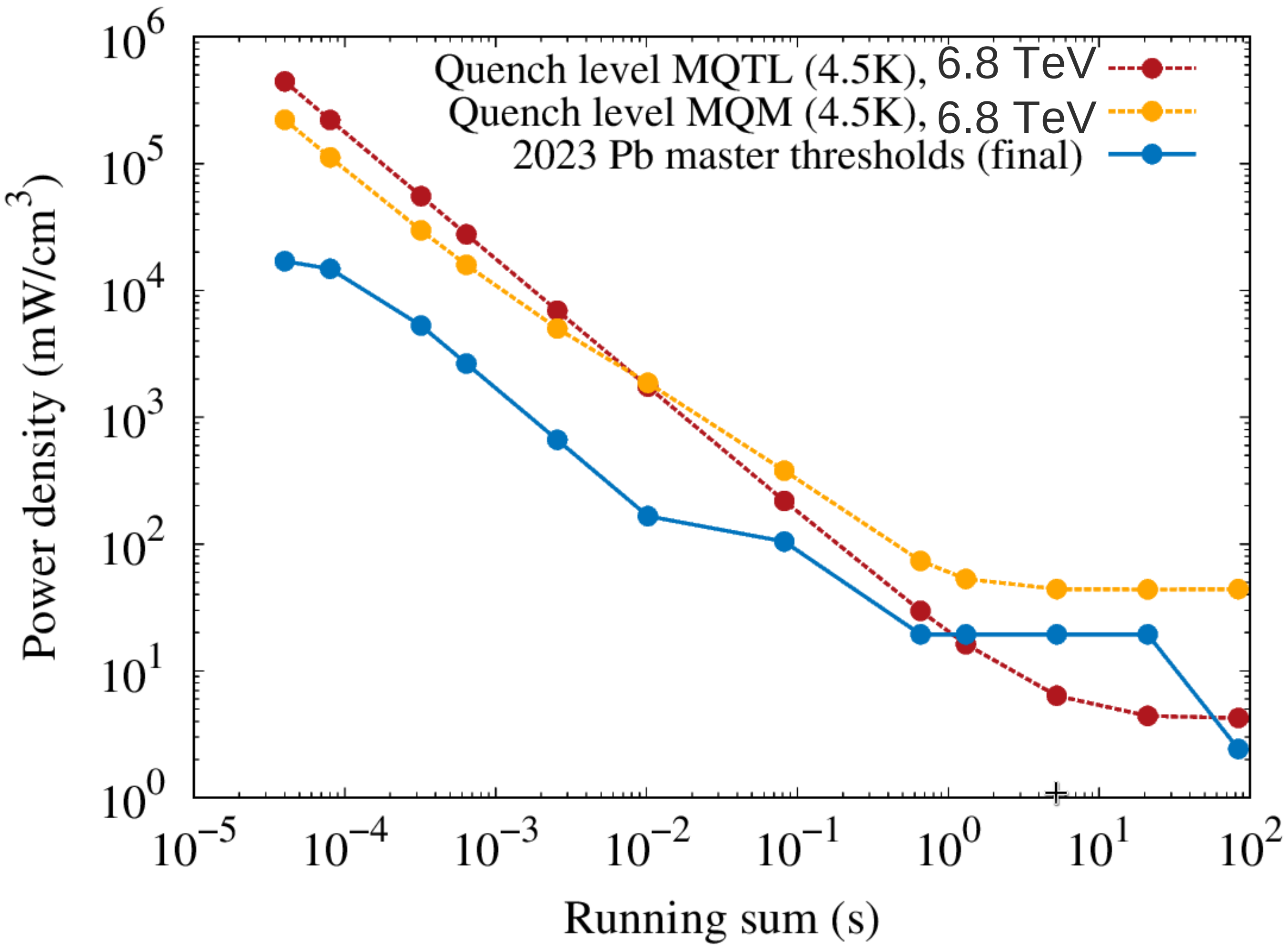
The figure compares:

- **Blue curve:** the **power density in Q6 coils** we allow for with the present Q6 master thresholds (family THRI.IP7.P1_MQTL_FT_ION_COLL)
- **Red curve:** the **assumed quench level of the MQTL (4.5K)** – likely too conservative for long RS
- **Yellow curve:** the **assumed quench level of the MQM (4.5K)**

Note: for convenience the quench level is expressed in terms of power density for all loss durations

Possible increase of Q6 thresholds

Note: we were already at MF=1 at the end of 2023 → any increase must come from master threshold



Approach:

- Let's rather consider MQM quench levels as the reference (MQTL likely too low)

Could envisage a possible increase of master thresholds in the IR7 P1 and P2 Q6 ion coll families (THRI.IP7.P1_MQTL_FT_ION_COLL and THRI.IP7.P1_MQTL_FT_ION_COLL):

- Increase RS01-06 master thresholds by up to a factor of 5
- Increase RS07-11 by a factor of 2
- Align RS12 to RS07-11
- At least, for all energy levels 18-28

Or increase even by higher factors and compensate with smaller MF?

Conclusion

- **Q6 BLM thresholds:**
  - Have margin to increase Q6 for Pb collimation leakage → risk of quenching remains small
  - Should converge this week about the exact factors
- **What else?**
  - Depending on the loss maps, should also evaluate a possible increase of R06 at DS magnets

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Recap of present Q6 BLM master threshold model

- Like for most superconducting magnets, the BLM master threshold model for the Q6 in IR3/7 was **updated in LS1**
- Remember: for each magnet type, a certain loss scenario was assumed - the thresholds where then based on following ingredients:
  - QP3 predictions of quench levels (including corrections from Run 1 quench tests)
  - FLUKA calculations of BLM response factors and the energy deposition in the coils
- For the Q6, the assumed scenario is a **dynamic orbit bump with direct proton losses on the Q6 aperture**

BLM signal at quench

$$D^{QL}_{BLM}(E,t) = \frac{D^{p}_{BLM}(E,t) \times QL(E,t)}{\varepsilon^{p}(E,t)} \qquad [Gy] = \frac{[Gy/p] \times [mJ/cm^3]}{[mJ/cm^3/p]}$$

D^{QL}_{BLM} = BLM signal at quench level
D^{p}_{BLM} = BLM signal per proton lost
QL = Quench level
ε^{p} = Peak energy density in coils per proton lost

$$MasterThreshold(E,t) = \mathrm{N} \times D^{QL}_{BLM}(E,t) \times AdHoc(t)$$

$$AppliedThreshold(E,t) = MonitorFactor \times MasterThreshold(E,t)$$

The practice was to set the master thresholds to three times the quench level for the given loss scenario.

This means, with MF=0.333 the applied thresholds are aligned with the quench level.

‚Dynamic orbit bump'-scenario

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Testing beam-induced quench levels of LHC superconducting magnets

B. Auchmann, T. Baer, M. Bednarek, G. Bellodi, C. Bracco, R. Bruce, F. Cerutti,
V. Chetvertkova, B. Dehning, P. P. Granieri, W. Hofle, E. B. Holzer, A. Lechner,
E. Nebot Del Busto, A. Priebe, S. Redaelli, B. Salvachua, M. Sapinski,
R. Schmidt, N. Shetty, E. Skordis, M. Solfaroli, J. Steckert, D. Valuch,
A. Verweij, J. Wenninger, D. Wollmann, and M. Zerlauth

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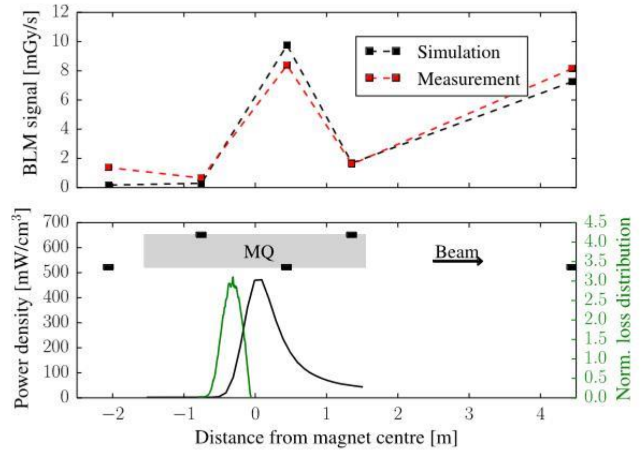


FIG. 20. Up: Detail of the comparison between the BLM signal and the simulated signal from FLUKA for the dynamic orbit-bump quench test. Down: FLUKA simulated peak energy density (black) deposited in the coil
tion of protons lost on the
indicates the magnet, black b

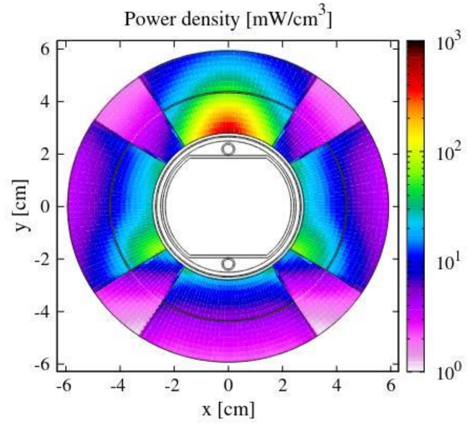
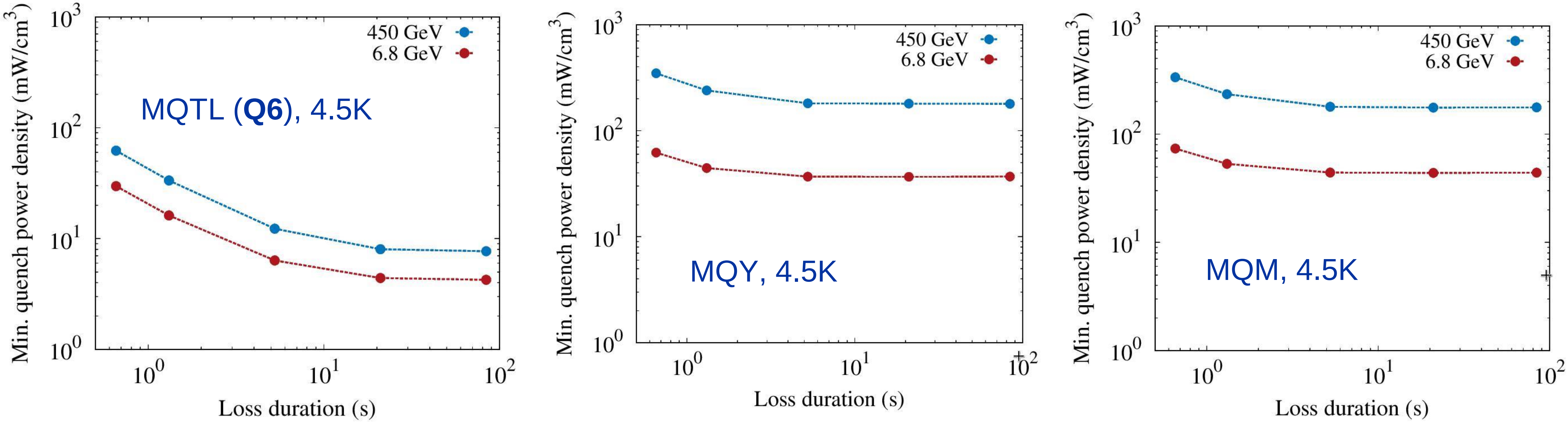


FIG. 21. Simulated transverse power density distribution from FLUKA during the dynamic orbit-bump quench test in MQ.14R2 coils at the position where the maximum energy deposition occurs. Results correspond to 2.54×10^9 protons impacting on the magnet beam screen. Spatial coordinates are with respect to the center of the vacuum chamber.

- The **DOB-scenario** was one of the scenarios probed in the Run 1 quench tests (for an MQ)
- The scenario was then adopted for the BLM thresholds for multiple magnet types (<u>considering of course magnet-dependent quench levels</u>)
- Assumes a concentrated loss distribution (<1m) in one plane → gives rise to localized heating in the coils

MQTL (Q6) vs MQY, MQM quench levels

Quench levels for MQTL (Q6), MQY and MQM magnets as implemented in the BLM thresholds (all for 4.5 K):



- According to the QP3 calculations, the MQTL seems to have rather low quench levels compared to other magnets for long loss durations (>1s), e.g. for 1.3s@450GeV: MQTL=34mW/cm^3, MQY/MQM=240mW/cm^3
- This is one of the main reasons why the Q6 thresholds are quite low for RS08-12