BLM threshold strategy for the 2023 Pb run

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With input from MPP, collimation team, BE/OP, MP3, TE/MSC etc.

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Introduction

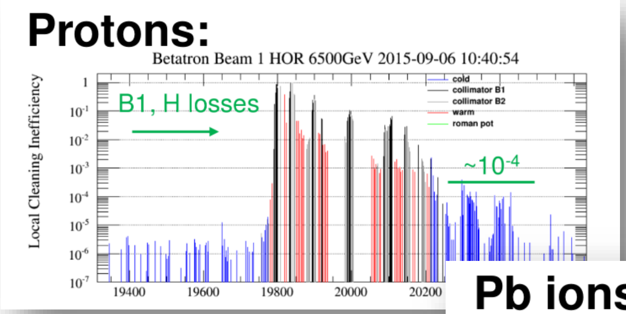
- **2023 Pb run – important differences wrt past, which affect threshold settings:**
  - Somewhat higher beam energy (6.8 vs 6.37 ZTeV) and hence reduced quench margin
  - 6x higher luminosity in IP2 (6.4×10^{27} $cm^{-2}s^{-1}$ vs 1×10^{27} $cm^{-2}s^{-1}$) and slightly higher luminosity in IP1/5
  - New systems (crystal-assisted collimation, TCLD collimator in DS next to IR2)
- **This presentation outlines the general BLM strategy for**
  - **IR7** betatron losses
  - BFPP losses in **IR1/2/5/8**
  - Losses induced by wire scanner in **IR4**

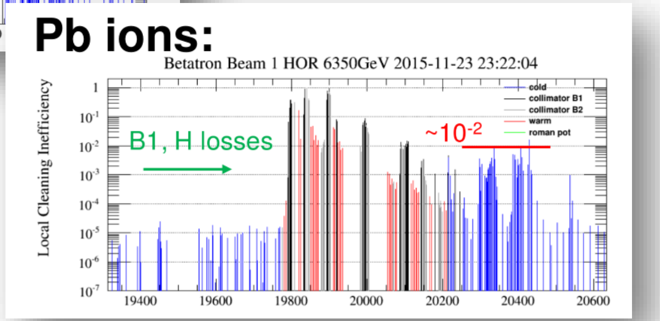
For more details, see the last BLMTWG meeting: https://indico.cern.ch/event/1318581/

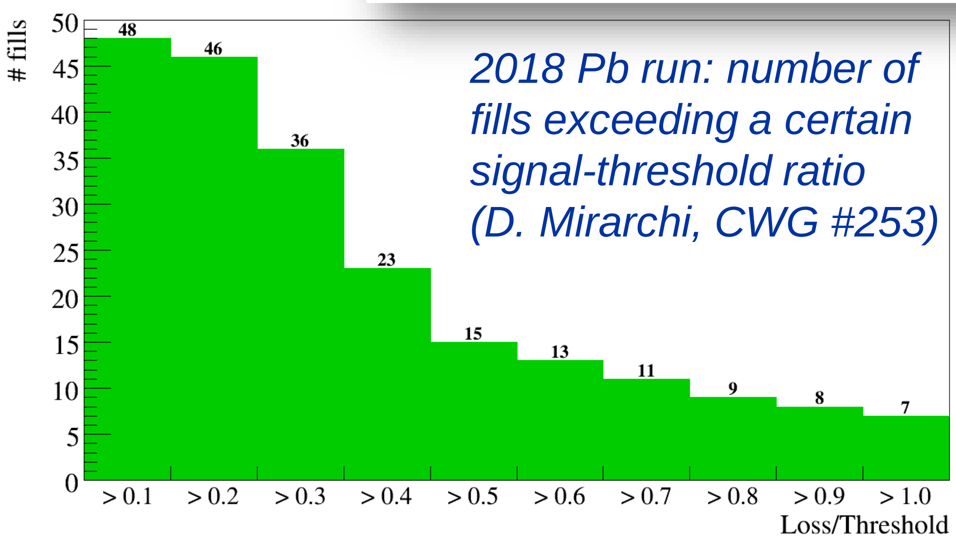
ECR is being prepared

Losses in IR7: recap of the 2018 Pb run (6.37 ZTeV)

- **Collimation leakage from IR7 to cold magnets:**
  - O(100) times worse than for protons
  - Pb collimation **quench test 2015@6.37 ZTeV** → DS dipole quench (cell 9) at peak power loss of **15 kW**
- **BLM thresholds in 2018 Pb run:**
  - Thresholds at IR7 collimators were set to **12.5 kW** → dump slightly below quench level
  - Thresholds at IR7-DS magnets were aligned to the quench level (signals measured in the quench test)
- **Experience from 2018 Pb run:**
  - No beam-induced quench in operation
  - But 7 out of 48 physics fills dumped in IR7 (“10Hz” events → these are not classical slow losses)
  - In almost half of the fills, reached 40% of dump level





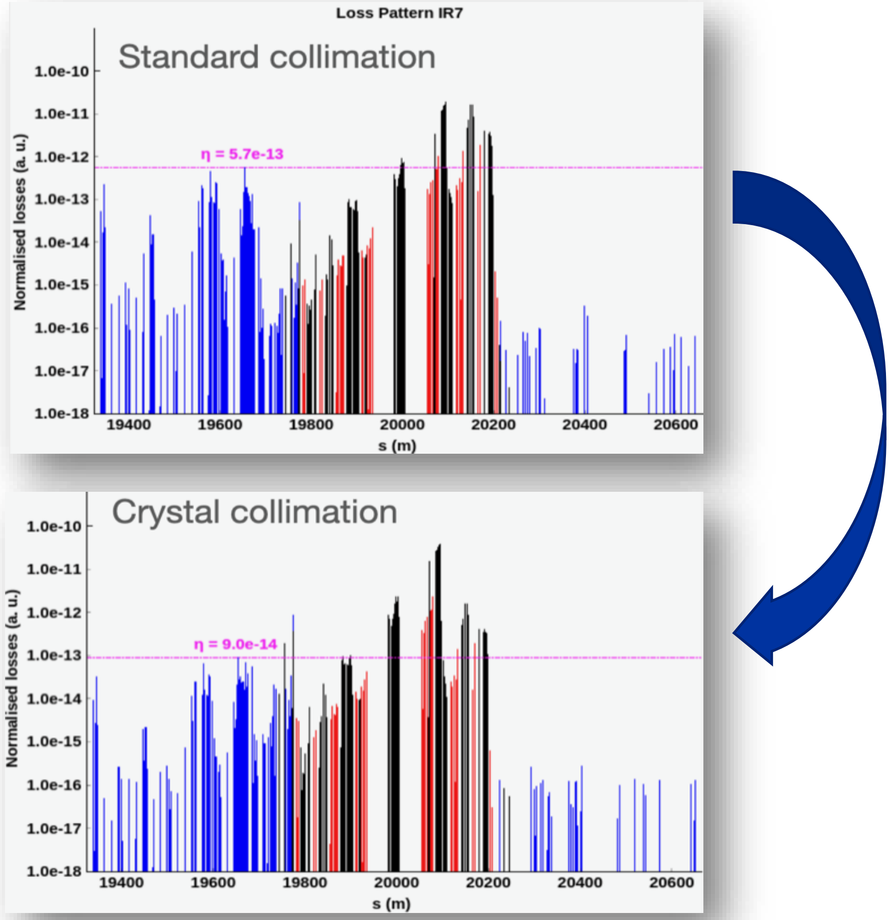


2018 Pb run: number of fills exceeding a certain signal-threshold ratio (D. Mirarchi, CWG #253)

Losses in IR7: considerations for 2023 Pb run

- **Crystal-assisted collimation is the baseline for the 2023 heavy ion run at 6.8 ZTeV**
  - Reduces relative leakage to DS magnets in cell 9 and 11 compared to 2018
  - Can afford a higher power loss in IR7 despite the higher beam energy (i.e. lower quench level)
  - However, the maximum allowed power loss in IR7 without quenching is still affected by some uncertainty → roughly estimated to be **between 30 and 50 kW**

If the BLM thresholds are set too conservatively, premature beam dumps can severely affect the ion run performance (considering in particular the 70% higher beam intensity than in 2018)



R. Bruce, Outcome of the 2022 Pb ion test, LMC #453

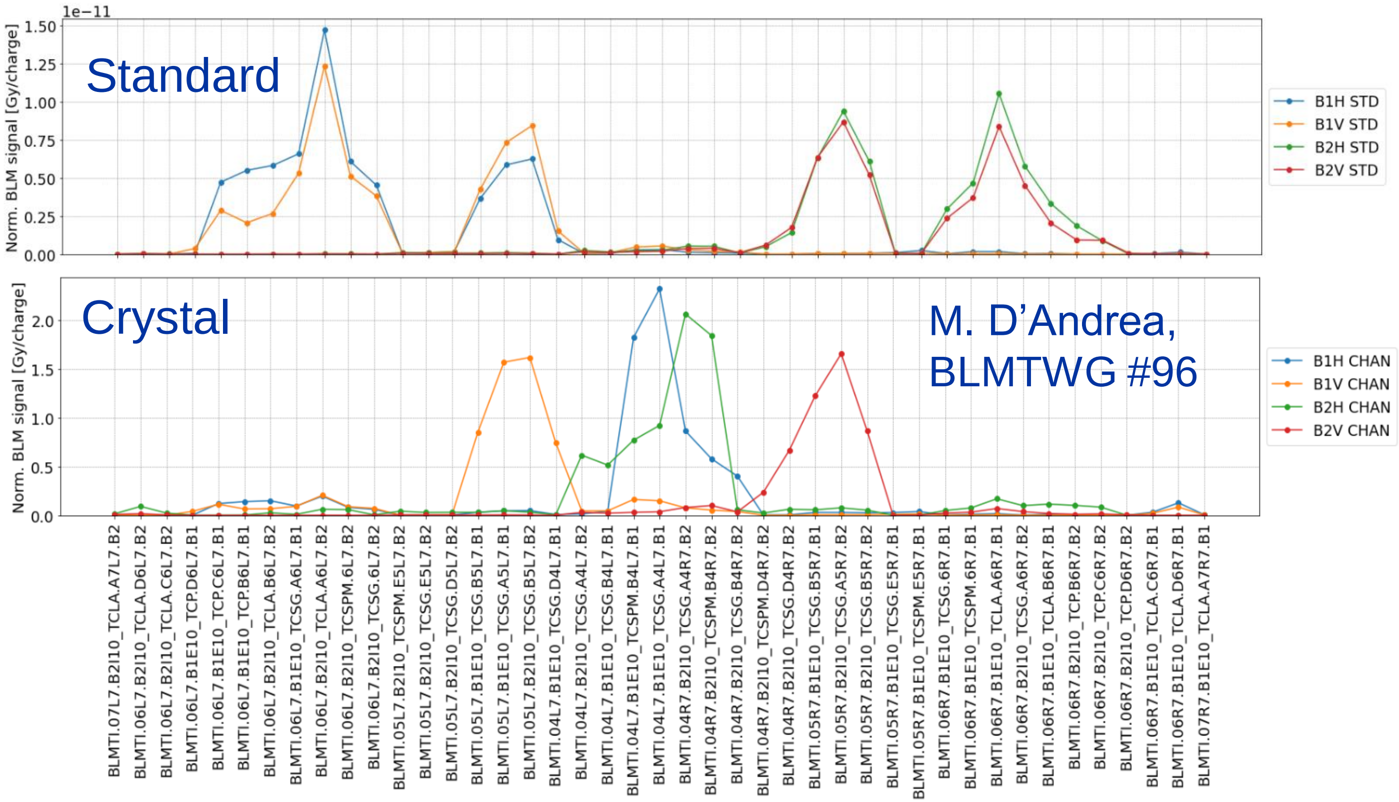
Losses in IR7: thresholds strategy for 2023 Pb run

- **We therefore propose an performance-oriented BLM threshold approach for 2023:**
  - The master thresholds for betatron losses shall allow for a power loss of **50 kW** (cold magnets in IR7 DS) to **60 kW** (IR7 collimators) for a duration of 10 sec
  - The actual power loss in IR7 can be controlled by adjusting Monitor Factor → the operational quench margin of IR7 DS magnets can be probed
  - If a quench occurs, the thresholds will be lowered again, avoiding further quenches
  - No magnets with possibly non-conform diodes are concerned
- **Power deposition in IR7 collimators@60 kW:**
  - The most impacted collimators are the secondaries intercepting the channelled beam, as well as nearby collimators
  - The total power deposition in collimator jaws is estimated to be comparable or less than for HL-LHC proton operation
  - The maximum power density in the coatings for TCSPM is estimated to be O(200 W/cm3) for an impact parameter of 1 mm → considered acceptable

Losses in IR7: BLM thresholds@collimators

Table to be updated to 60 kW

- Collimator BLM thresholds are **based on 2022 loss maps** (ion test), but might require adjustments during commissioning
- Note: the BLM patterns in IR7 are quite different for std and crystal collimation



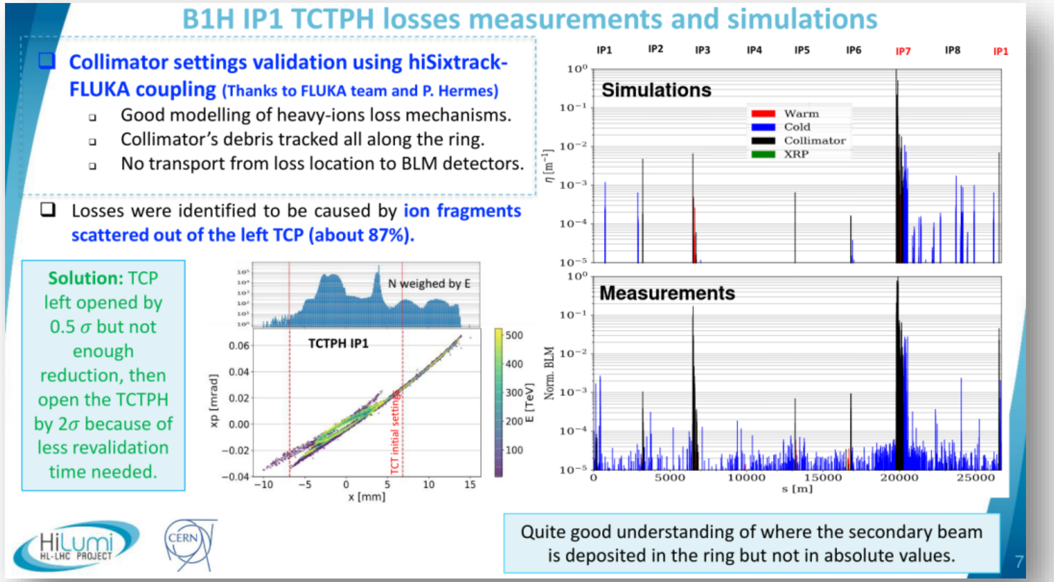
B. Salvachua, S. Morales, Vigo BLMTWG #96

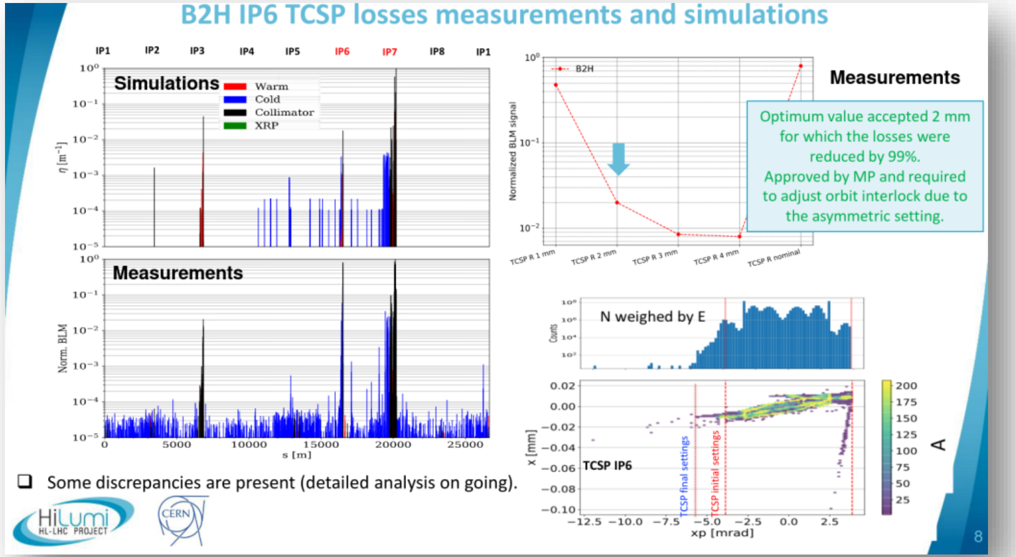
Family	BLM	Factor 6.8 TeV	Factor 450 GeV	kW master channelling	kW master amorphous
Crystal in Channeling 4.75 sigma					
THRI_COLL_7_TCLA_LO_ION ** need but is at noise levels...	BLMTI.06L7.B2I10_TCLA.D6L7.B2	1.511	0.17	62 (86)	13
	BLMTI.06R7.B1E10_TCLA.D6R7.B1			50 (50)	13
THRI_COLL_7_TCSPM_LO_ION_H_CH	**BLMTI.04L7.B1E10_TCSPM.B4L7.B1**	1.27	1.27	57 (21)	+100
	BLMTI.04R7.B2I10_TCSPM.B4R7.B2			50 (45)	+100
THRI_COLL_7_TCSPM_LO_ION_V_CH	**BLMTI.04L7.B1E10_TCSG.D4L7.B1**	0.44	2.3	50 (100)	+100
	BLMTI.04R7.B2I10_TCSG.D4R7.B2			52 (51)	+100
THRI_COLL_7_TCSG_LO_ION_H_CH	BLMTI.04L7.B1E10_TCSG.B4L7.B1	1.45	1.45	200 (26)	+100
	BLMTI.04L7.B1E10_TCSG.A4L7.B1			50 (58)	+100
	BLMTI.04R7.B1E10_TCSG.A4R7.B1			58 (184)	+100
	BLMTI.04R7.B2I10_TCSG.A4R7.B2			50 (109)	+100
THRI_COLL_7_TCSG_ME_ION_V_CH	**BLMTI.05L7.B1E10_TCSG.A5L7.B1**	0.44	0.01	57 (53)	+100
	BLMTI.05R7.B2I10_TCSG.A5R7.B2			50 (139)	+100
Crystal in Amorphous 4.75 sigma					
THRI_COLL_7_TCSG_ME_ION_V_AM	BLMTI.06L7.B2I10_TCSG.6L7.B2	0.0156	0.05	45 (65)	15
	BLMTI.06R7.B1E10_TCSG.6R7.B1			56 (25)	22
THRI_COLL_7_TCSPM_LO_ION_H_AM	BLMTI.05L7.B2I10_TCSPM.E5L7.B2	0.027	0.09	47 (54)	20
	BLMTI.05R7.B1E10_TCSPM.E5R7.B1			58 (337)	27

- Created **dedicated BLM families** for dumping on losses in the **two different planes**
- Selected at least 2 monitors per beam and plane to have some redundancy
- Caveat: cross-talk can lead to dumps below the target power values if high losses occur simultaneously on both beams in H plane

Losses in IR7: leakage to other regions

- A priori, we only plan to apply the power limits to the collimator and magnet master thresholds **in IR7 and the adjacent DS**, but not necessarily to other regions (except IR3)
- In 2018, IR7 leakage to TCTs (IR1) and TCSP (IR6) was mitigated by retracting individual TCP and TCSP jaws, hence no threshold changes for collimation leakage were needed → similar approach in 2023





Losses in IR7: Monitor Factor (MF) settings

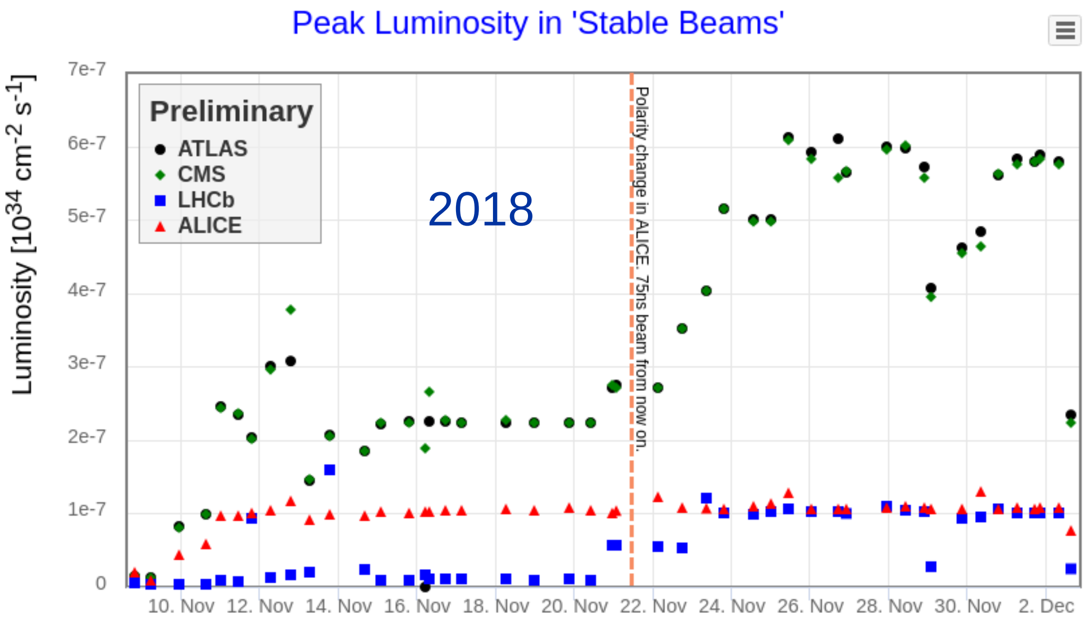
- **Propose a staged approach for the Monitor Factor (applied thresholds):**
  - Initially use **MF=0.4** for IR7 collimators and IR7 DS magnets
  - In case of premature dumps w/o quench, allow for a MF increase in **steps of 0.2 → increase to be decided jointly by BLMTWG, MPP, collimation team and OP.**
  - If a quench occurs, the settings will be reverted to the previous one

Allowed power loss by BLM thresholds at IR7 collimators:

	Duration	Proton run 2023		Proposal for Pb run 2023 (with crystals)				
		Master	Applied (MF=0.6)	Master	Pb ions (MF = 0.4)	Pb ions (MF=0.6)	Pb ions (MF=0.8)	Pb ions (MF=1.0)
RS08	0.655 s	500 kW	300 kW	60 kW	**24 kW**	36 kW	48 kW	60 kW
RS09	1.31 s	500 kW	300 kW	60 kW	**24 kW**	36 kW	48 kW	60 kW
RS10	5.24 s	500 kW	300 kW	60 kW	**24 kW**	36 kW	48 kW	60 kW
RS11	20.97 s	239 kW	143 kW	29 kW	**12 kW**	17 kW	23 kW	29 kW
RS12	83.89 s	100 kW	60 kW	12 kW	**5 kW**	7 kW	10 kW	12 kW
					Initial		**Possible steps**	

Collision losses in experimental IRs and DS

- **Experimental insertions (IR1/2/5/8)**
  - Power deposition dominated by **hadronic** and **EMD** collision products
  - Far below quench level, no BLM threshold changes in IR due to collision products expected
- **Dispersion suppressors (next to IR1/2/5/8)**
  - Distinct loss peaks from **bound-free pair production (BFPP)**
  - Special measures put in place to avoid BFPP-induced quenches (orbit bumps in IR1/5/8, TCLD collimators + orbit bumps in IR2)
  - **BLM threshold strategy: local threshold adjustments to avoid premature dumps (and BLM warnings) on BFPP ions below the target luminosities**

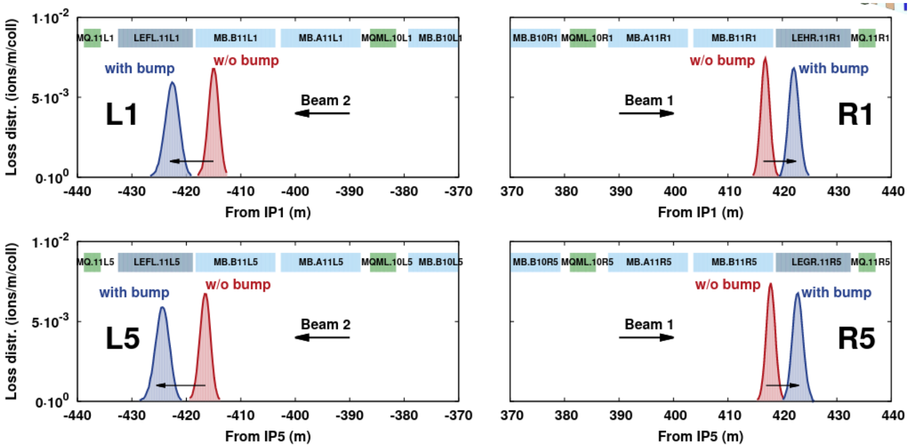


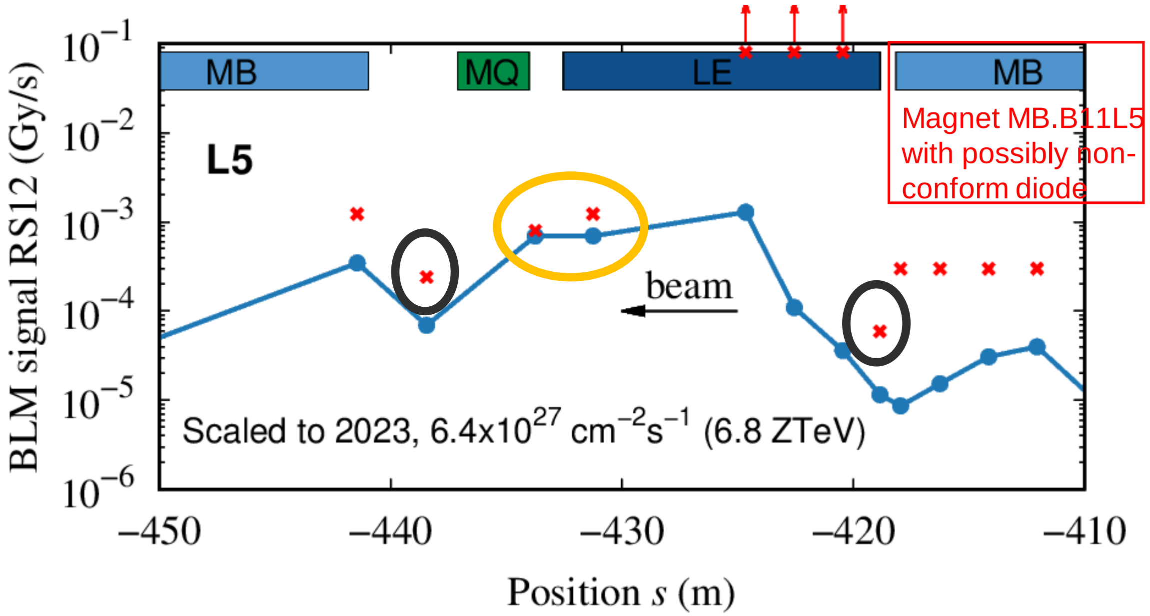
	2018	2023 (planned)
Beam energy	6.37 *Z*TeV	6.8 *Z*TeV
L_{inst} (IP1)	6.2×10^{27} $cm^{-2}s^{-1}$	6.4×10^{27} $cm^{-2}s^{-1}$
L_{inst} (IP2)	1×10^{27} $cm^{-2}s^{-1}$	6.4×10^{27} $cm^{-2}s^{-1}$
L_{inst} (IP5)	6.2×10^{27} $cm^{-2}s^{-1}$	6.4×10^{27} $cm^{-2}s^{-1}$
L_{inst} (IP8)	1×10^{27} $cm^{-2}s^{-1}$	1×10^{27} $cm^{-2}s^{-1}$

Secondary ion losses due to BFPP (IR1/5)

- Use local orbit bumps to shift losses to connection cryostat in cell 11 (upstream of Q11) to mitigate the risk of quenches
- Successfully used in 2018 run up to 6.2 $\times 10^{27}$ $cm^{-2}s^{-1}$ and will be the baseline for 2023
- 2023 Pb run: need to increase BLM thresholds at Q11 (**yellow circle**) due to higher energy, but no risk of quench if losses stay in cryostat

Simulation of loss distribution:





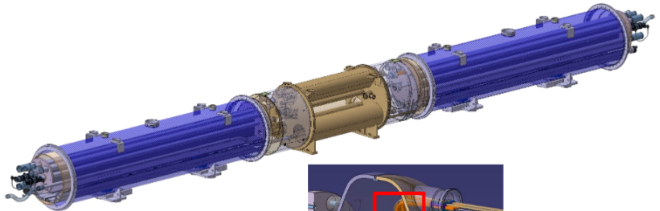
	2018	2023
E	6.37 *Z*TeV	6.8 *Z*TeV
L_{inst}	6.2×10^{27} $cm^{-2}s^{-1}$	*6.4×10^{27} $cm^{-2}s^{-1}$*
P_{BFPP}	143 W	160 W

Special case 11L5: MB.B11L5 has possibly a non-conform diode: quenches in this MB and the neighboring dipoles shall be avoided (LHC-BLM-ECR-0071) → will keep lower thresholds at two BLMs (**black circles**) to make sure that BFPP losses remain in cryostat

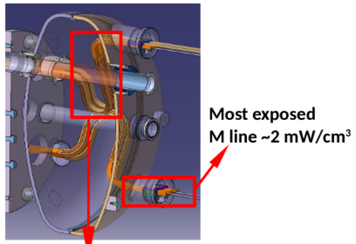
Secondary ion losses due to BFPP (IR2)

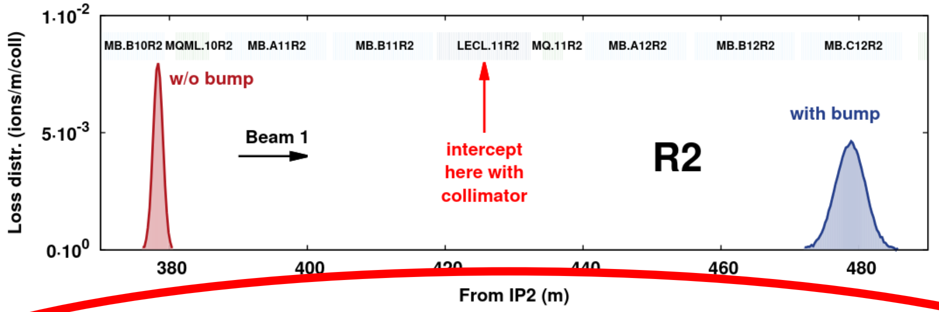
- In IR2, the TCLD collimators will be used the first time Pb physics operation in 2023
- No risk of quench, but need BLM thresholds at TCLD and adjacent MQ.11 (to be aligned with BFPP signals)

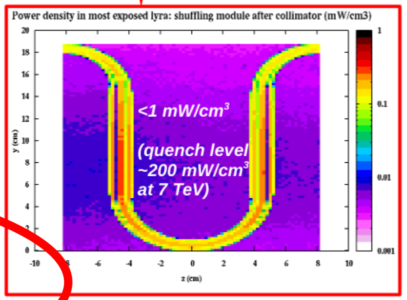
	2018	2023
E	6.37 ZTeV	6.8 ZTeV
L_{inst} (IP2)	1×10^{27} cm^{-2}s^{-1}	6.4×10^{27} cm^{-2}s^{-1}
P_{BFPP}	23 W	160 W



⇒ ***need a orbit bump + a collimator to intercept BFPP ions in connection cryostat***





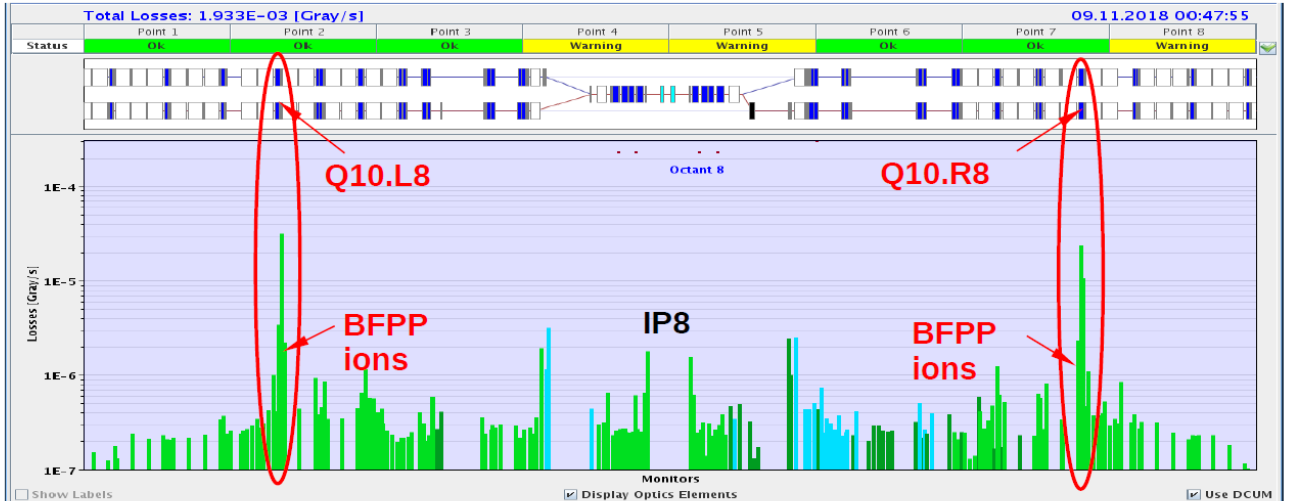


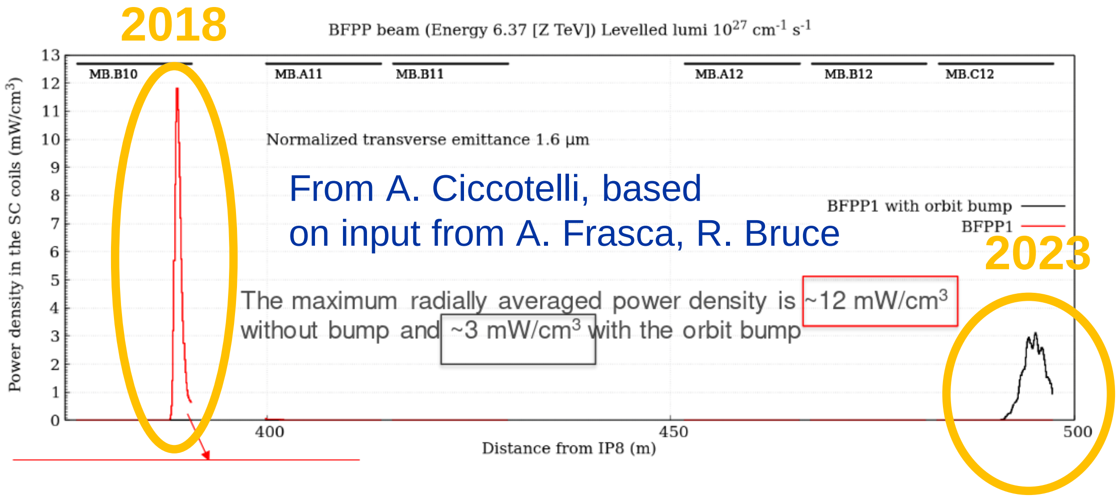
Power deposition simulations show that for a 30σ collimator gap (→ 2 mm impact):

- ⇒ ***No risk to quench bus bars of connection cryostat***
- ⇒ ***No risk to quench downstream magnets (factor of 10 below quench level)***

Secondary ion losses due to BFPP (IR8)

	2018	2023
E	6.37 ZTeV	6.8 ZTeV
L_{inst}	1×10^{27} $cm^{-2}s^{-1}$	1×10^{27} $cm^{-2}s^{-1}$
P_{BFPP}	23 W	25 W



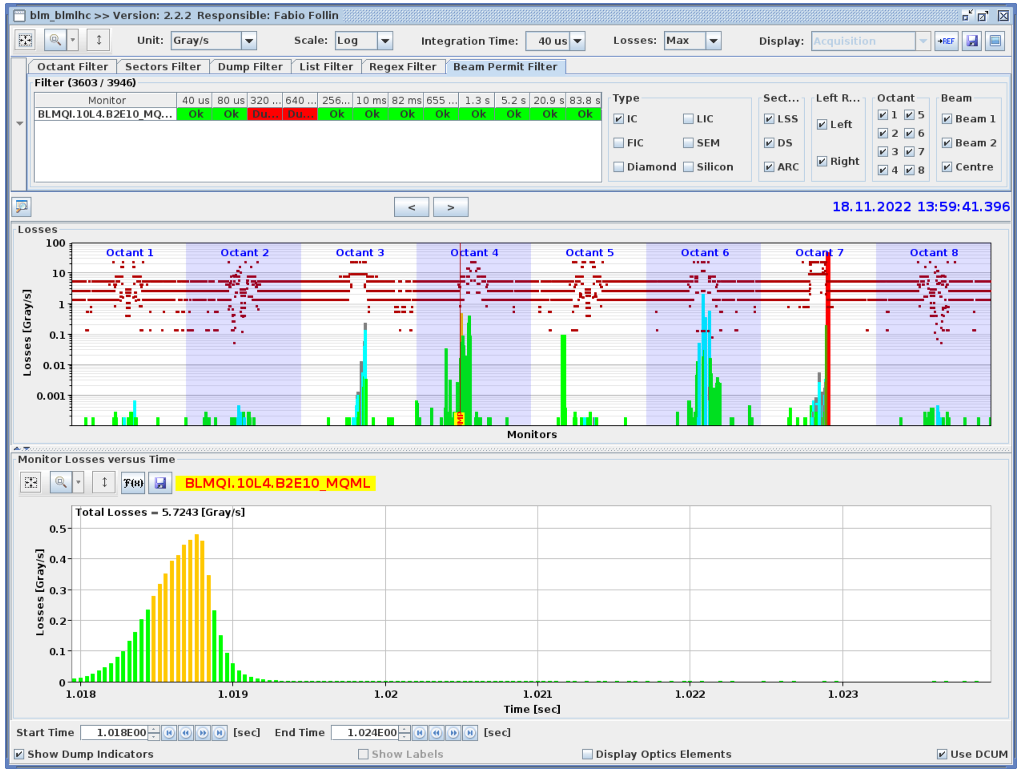


- In 2018 (6.37 ZTeV), BFPP losses were in **MB.B10**
- Power density was not too far from the estimated MB quench level of 15-20 mW/cm³ (2015 BFPP quench test)
- 2023: quench level might be a few 10% lower@6.8 ZTeV, hence risk to quench MB.B10 (even for same lumi)
- Baseline for 2023: shift losses with orbit bump to **MB.C12** → mitigates risk of quench (possibly need to increase Q12 thresholds)

Loss distribution more spread out in cell 12

Losses induced by wire scanner in IR4

- **Ion test in 2022:**
  - A dump occurred at the Q10 magnet next to IR4 while performing a wire scan
  - The Q10 magnets have reduced BLM thresholds, due to the risk of detecting symmetric quenches only with some delay (LHC-BLM-ECR-0051)
  - Performing a rough scaling, the dump limit on the Q10 BLMs is estimated to be around 0.7E11-1E11 charges at 6.8 TeV
- **BLM threshold settings:**
  - The Q10 thresholds cannot be increased without detailed power deposition studies for wire-induced losses to assess the risk of quench
  - It was agreed, that we don't change the Q10 thresholds for the Pb run



Summary (1/2)

- **Betatron losses in IR7:**
  - The proposal is to align the collimator and magnet master thresholds in IR7 (+DS) to **50-60 kW** for crystal channeling, power deposition values are considered acceptable for collimators
  - Will allow us to dynamically probe the quench level in the IR7 DS (via Monitor Factor) – aim for best machine performance → strategy for Monitor Factor increase in place
  - If a quench in the IR7 DS occurs, Monitor Factors will be reverted to previous settings, in order to avoid further quenches
  - In case the channeling condition is lost (amorphous), the power limit is about 5 times lower
  - In the unexpected case the system needs to be reverted to the standard setup (without crystals), then the master thresholds need to be changed

Summary (2/2)

- **BFPP losses in IR1/2/5/8:**
  - Measures to mitigate the risk of quenches are in place
  - BLM thresholds will be aligned to the BFPP-induced BLM signals
  - In addition, we will maintain reduced settings near BFPP loss location in L5 (dipole with possibly non-conform diode)
- **Losses induced by wire scanner in IR4:**
  - The Q10 has reduced BLM thresholds due to the risk of symmetric quenches → cannot be just increased with further power deposition studies (i.e., no ‘on-the-fly’ increase)
  - For the moment, the agreement was to maintain the present Q10 thresholds – no explicit request for dedicated studies (which would take some time)

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Quench limit of MBs – what do we know?

Summary of quench tests Run 2+3:

Year	Type	Particle type (energy)	Quench	Time profile of loss rate	Reconstructed max. energy density in MB coils	Reconstructed energy density in MB coils (10 s average)
2015	BFPP (IR5)	Pb (6.37 ZTeV)	Yes	Const for 20 s	15-20 mW/cm^3	15-20 mW/cm^3
2015	Collim (IR7)	Pb (6.37 ZTeV)	Yes	Rising for 12 s	20-30 mW/cm^3	13-19 mW/cm^3
2015	Collim (IR7)	p (6.5 TeV)	No	Rising for 5 s	*20-25 mW/cm^3 (x)*	
2022	Collim (IR7)	p (6.8 TeV)	No	Rising for 50 s	14-17 mW/cm^3	12-14 mW/cm^3

(x) Peak occurred at dipole front – different quench behaviour.

- Time profile matters → loss profile in past collimation quench tests was not constant
- Expect the steady-state quench level at **6.8 TeV** to be not higher than **15 mW/cm^3**