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Tight collimator settings with $\beta^* = 1.0$ m

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Summary

In this MD we have driven all collimators from relaxed settings, used routinely during the 2011 operation, to tight settings (primary collimator at 4 nominal σ) during the ramp and squeezed to $\beta^* = 1.0$ m. The tertiary collimators (TCTs) in IR1 and IR5 were then aligned both with non-colliding and colliding beams. After the alignment, loss maps were performed in order to qualify the cleaning for physics operation.

1 Introduction and motivation

Several parameters influence the luminosity in the LHC. One important parameter is the optical β-function at the collision points, β^*. In order to optimize luminosity β^* should be made as small as possible. On the other hand, as β^* is decreased, the beam size blows up in the inner triplet magnets. For reasons of machine protection and cleaning, the triplets must at all times be protected by the tertiary collimators (TCTs), which in turn is the last step of the cleaning hierarchy of the LHC collimation system [1, 2, 3]. A lower limit on β^* is therefore imposed by machine protection considerations [4, 5].

Following the method in Refs. [4, 5], it has been shown [6] that if the collimation system is moved closer to the beam, using the tight collimator settings tested in Ref. [7], enough aperture margins can be gained to squeeze to $\beta^* = 1.0$ m. In this note, we summarize the alignment of the TCTs in IR1 and IR5 in this configuration, before and after the collapse of the separation bumps, and describe the achieved cleaning performance in terms of loss maps.

2 Machine conditions

Two nominal bunches were injected, with normalized emittances between 1.6 μm and 2.5 μm. The machine was ramped to 3.5 TeV and the collimators moved in to tight settings during the ramp. The settings in units of beam σ are shown in Table 1 for the different collimator

Table 1: Collimator half opening, in units of σ, at top energy and squeezed optics for tight settings and relaxed settings.

Collimators	Relaxed setting (σ)	Tight setting (σ)
TCP IR7	5.7	4.0
TCS IR7	8.5	6.0
TCL IR7	17.7	8.0
TCP IR3	12.0	12.0
TCS IR3	15.6	15.6
TCL IR3	17.6	17.6
TCT	11.8	9.3
TCS IR6	9.3	6.8
TCDQ IR6	9.8	7.3

families, both for tight settings, used in this MD, and the relaxed ones used previously during operation in 2011. The centers from previous setups were used and only the gap opening changed. A squeeze to $\beta^* = 1.0$ m was then performed and the half crossing angle reduced to 100 μrad in accordance with Ref. [6]. This corresponds to approximately a 8 σ beam-beam separation in the drift space for a normalized emittance $\epsilon_n = 2.5$ μm.

3 Alignment of TCTs

The first alignment of the TCTs was performed with the parallel separation bump still active (0.7 mm at the IPs). First the primary collimators were aligned to define the beam edge, which was found at an half gap of about 3.8 σ. Using the new software for semi-automatic parallel alignment [8], the TCTs were then moved in parallel towards the beam, and stopped automatically and individually when the beam was touched. Each TCT was then centered in semi-automatic mode, where each jaw moved and stopped automatically when losses were encountered. The found centers for all TCTs are shown in Table 2.

At this point, the parallel separation was collapsed and collisions found in IP1 and IP5. Afterwards the TCTs were realigned due to the change of orbit. The found centers are shown in Table 2. In beam 2, the setup conditions were rather hard. When the collimators were moved into the beam, no sharp loss signals were observed, but rather a steady slow increase of the noise level on the BLMs. Sometimes spikes were observed on the BLMs although the beam was not touched, which was made evident by the fact that no losses were observed on the consecutive step. In order to achieve a sharp spike, the collimator step size had to be increased from 10 μm to 15 μm in some cases. Because of these beam conditions, the setup time in beam 2 was slightly longer than in beam 1. The achieved setup time was on average about 10 minutes per collimator.

It should be noted that a large offset of about 860 μm was found on TCTH.4R5.B2 between the centers before and after the separation bumps were collapsed. This center was not expected to change, since theoretically the orbit is only affected in the separation plane (vertical in IR5). The center of 40 μm, which was found after the separation bumps were

Table 2: The found centers at the TCTs in mm, with separation on and off, for beam 1 and beam 2.

Collimator	center, separation on (mm)	center, separation off (mm)
TCTH.4L1.B1	0.263	0.488
TCTVA.4L1.B1	1.888	1.878
TCTH.4L5.B1	−3.348	−3.598
TCTVA.4L5.B1	0.210	0.980
TCTH.4R1.B2	−0.648	−0.468
TCTVA.4R1.B2	1.433	1.223
TCTH.4R5.B2	0.898	0.040
TCTVA.4R5.B2	0.235	−0.485

collapsed, was re-confirmed within 20 μm by retracting the jaws and aligning them again three times. A possible explanation could come from the fake spikes observed during the setup with beam 2. No major drifts were observed on the BPMs. It should be noted, however, that a drift of the center of the same collimator of 600 μm was found during a later setup with 120 μrad crossing angle.

4 Loss map qualification

Once the alignment was finished, betatron loss maps were performed for both beams and planes by crossing the third order resonance. The resulting BLM signals around the ring are shown in Figs. 1 and 2 with a zoom in IR7 in Figs. 3 and 4. The losses are normalized to the highest loss (primary collimator in IR7) and the background has been subtracted. As can be seen in Fig. 4, the loss signal on some of the secondary collimators have approximately the same height as the the signal on the primary collimators. We consider these loss maps satisfactory for operation, although signs are present that the loss pattern inside IR7 is slightly degraded for beam 2 compared to after a fresh collimation setup. This is an indication of machine drifts over time after the collimation setup in March was performed. Therefore the loss pattern could be improved by a new alignment.

The highest losses in the cold region downstream of IR7 are listed in Table 3. The obtained values are consistent, but slightly worse, than what was obtained in the previous MD on tight collimator settings [7]. As in the last MD, the observed losses in the Q7 and Q5 downstream of IR7 were significantly higher (about 10^{-4}) than in the routinely performed loss maps with relaxed collimator settings. These BLMs are situated close to collimators and the signals are therefore likely to be induced by upstream showers. Therefore, these losses have been excluded in Table 3. Furthermore, the loss peak in the Q11 is also much higher than with relaxed settings. In beam 1 horizontal plane, the highest loss was found in the Q8 in this MD but in the Q11 in the previous MD. It should be noted, however, that the highest loss peak is lower than what is found during operation with relaxed settings in accordance with the results in Ref. [7].

The agreement with the previous MD [7] confirms the assumptions used to estimate the

Table 3: Obtained local cleaning inefficiencies downstream of IR7 for both beams and planes. The losses in Q5 and Q7 have been excluded as they are likely caused by showers from nearby collimators.

	element	inefficiency
beam 1 hor	Q8R7	4.46×10^{-5}
beam 1 ver	Q11R7	4.94×10^{-5}
B2 hor	Q8L7	1.24×10^{-4}
B2 ver	Q8L7	6.05×10^{-5}

intensity reach in the LHC [9, 10, 11].

The local cleaning inefficiencies in IR1 and IR5 are shown in Figs. 5 to 8. The leakage from the TCTs to the triplets was also found to be sufficiently low—observed losses are about or a little less than one order of magnitude lower. This is sufficient for machine protection. We therefore consider the tight collimator settings, with the TCTs at 9.3 σ, qualified for physics operation.

5 Conclusion

We have described the setup and qualification of tight collimator settings for physics runs with $\beta^* = 1.0$ m. The TCTs in IR1 and IR5 were aligned after squeezing to $\beta^* = 1.0$ m, both with the beams separated and colliding. The setup was complicated by noisy signals in beam 2, but was nevertheless finished. An unexpected drift of the center of TCTH.4R5.B2 occurred when the separation bump was collapsed and the center with colliding beams was verified through several re-alignments. This is still to be understood and a re-check of the center before the collapse of the separation bump could be useful. The other collimators, outside IR1 and IR5, were driven to tight settings around the centers found in the previous most recent alignment.

The settings were qualified through loss maps (crossing the third order resonance to provoke beam losses). A slight degradation of the loss pattern was visible in IR7 for beam 2, which is a consequence of the machine drifts over time and the smaller margins between the different collimator families. In spite of this, the loss maps still indicate a satisfactory cleaning performance and constitute a sufficient qualification for operation with physics beams.

Even though the tight collimator settings are not presently used in the 2011 run, they are a promising concept for 2012, as they could allow $\beta^* < 1.0$ m in view of recent aperture measurements [12]. Furthermore, the intensity reach calculated for LHC [9, 10, 11] is based on the improved cleaning performance provided by the tight settings. Our results in this MD confirms these assumptions on the achievable cleaning inefficiency.

6 Acknowledgements

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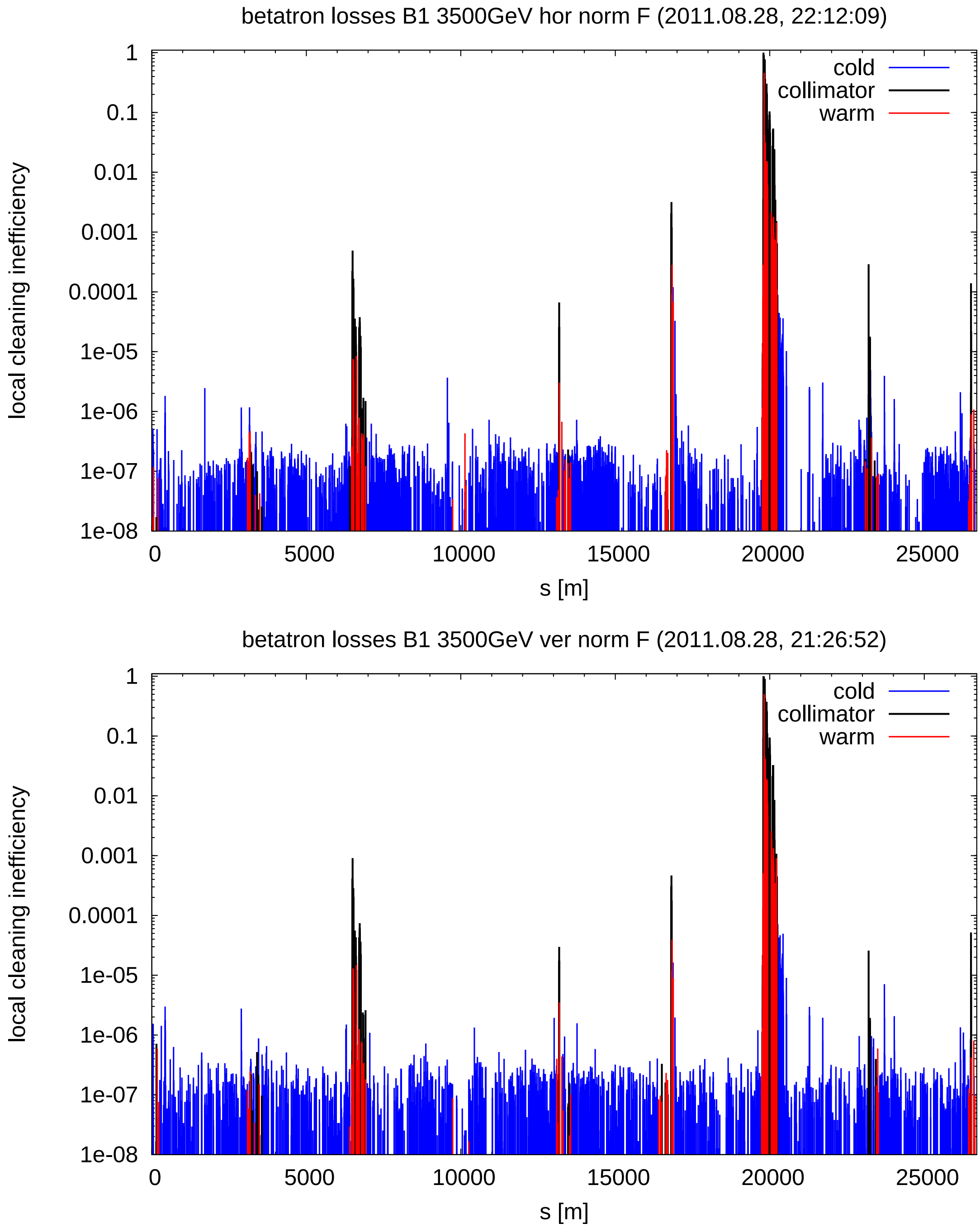


Figure 1: Losses around the ring, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.

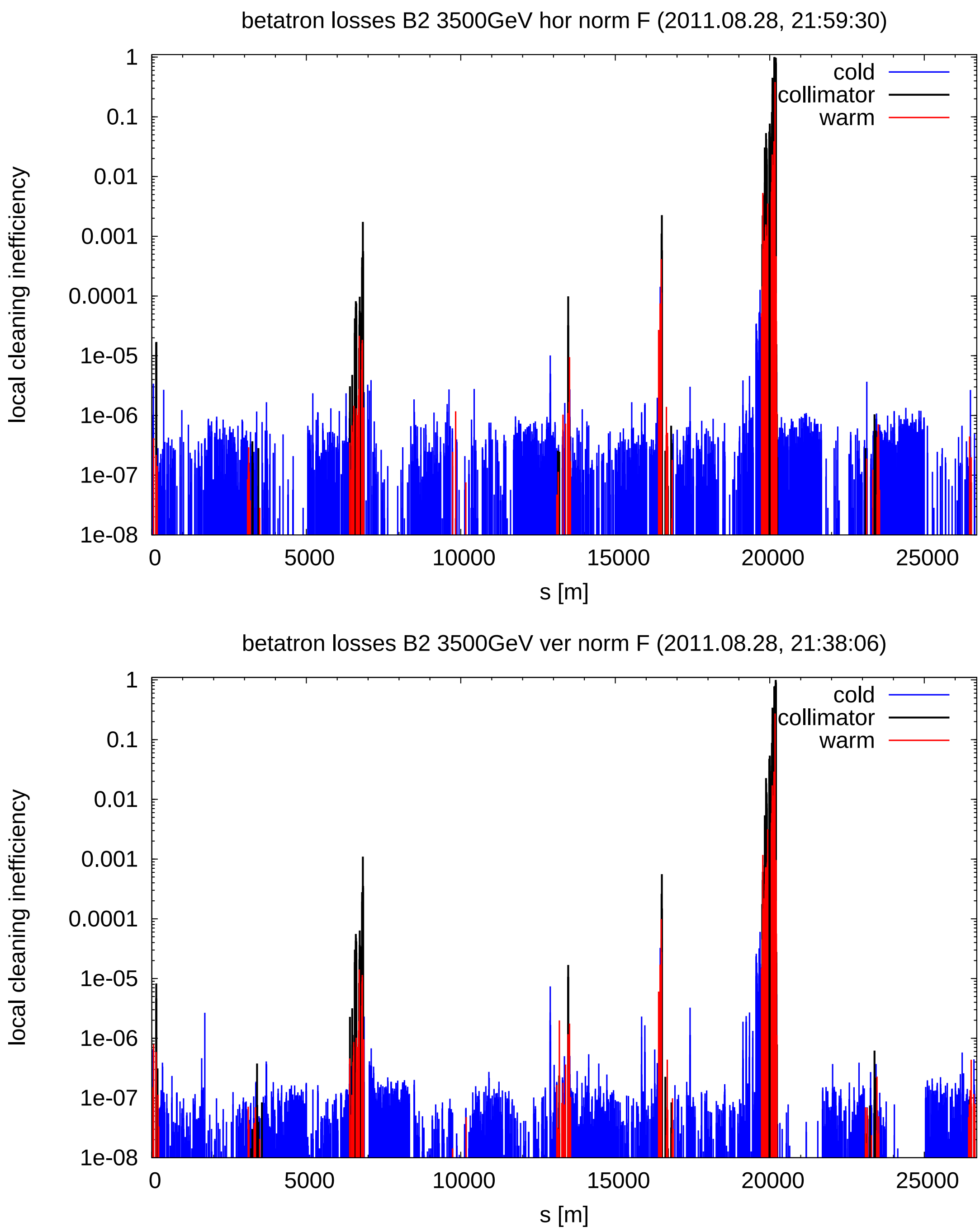


Figure 2: Losses around the ring, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.

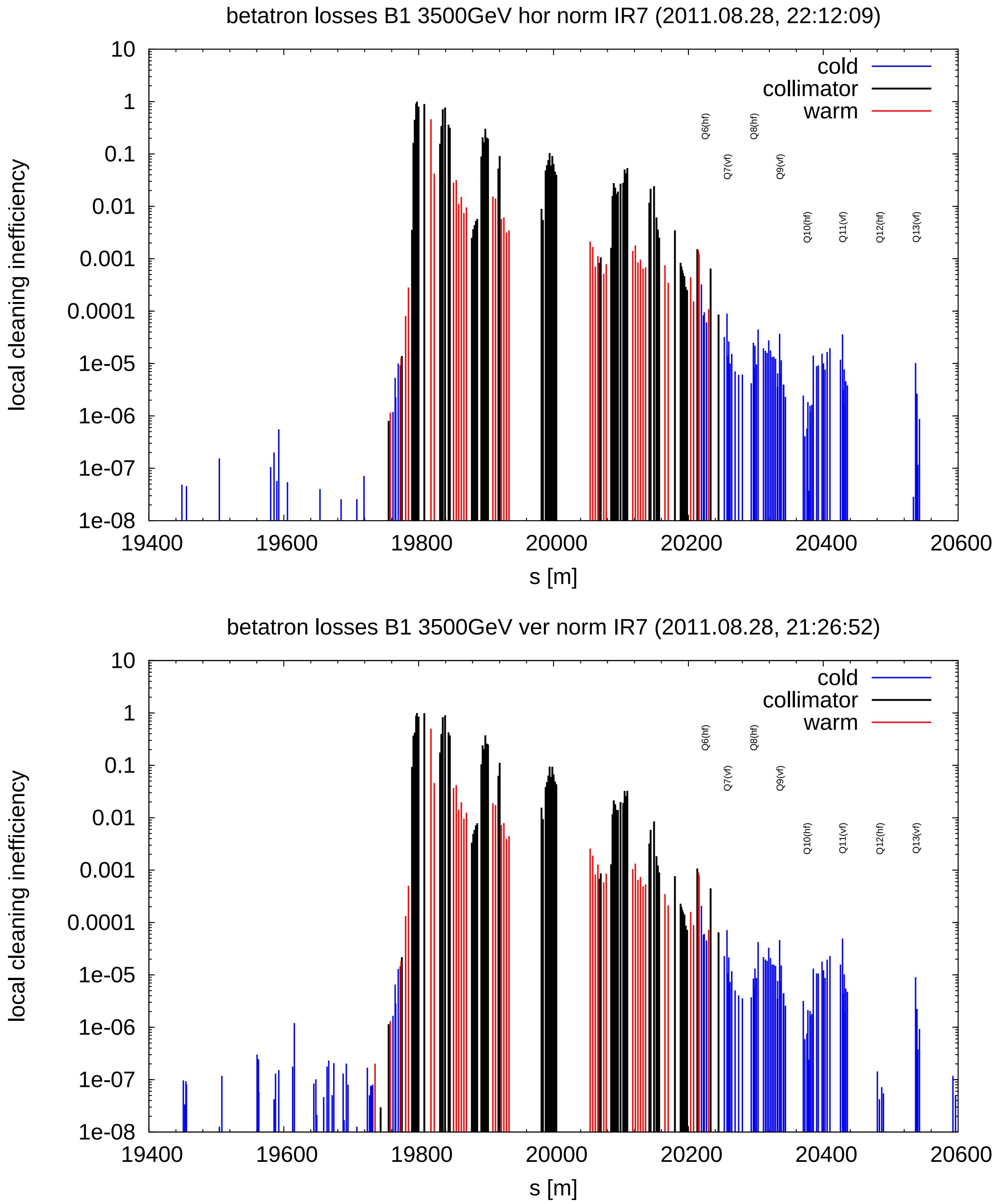
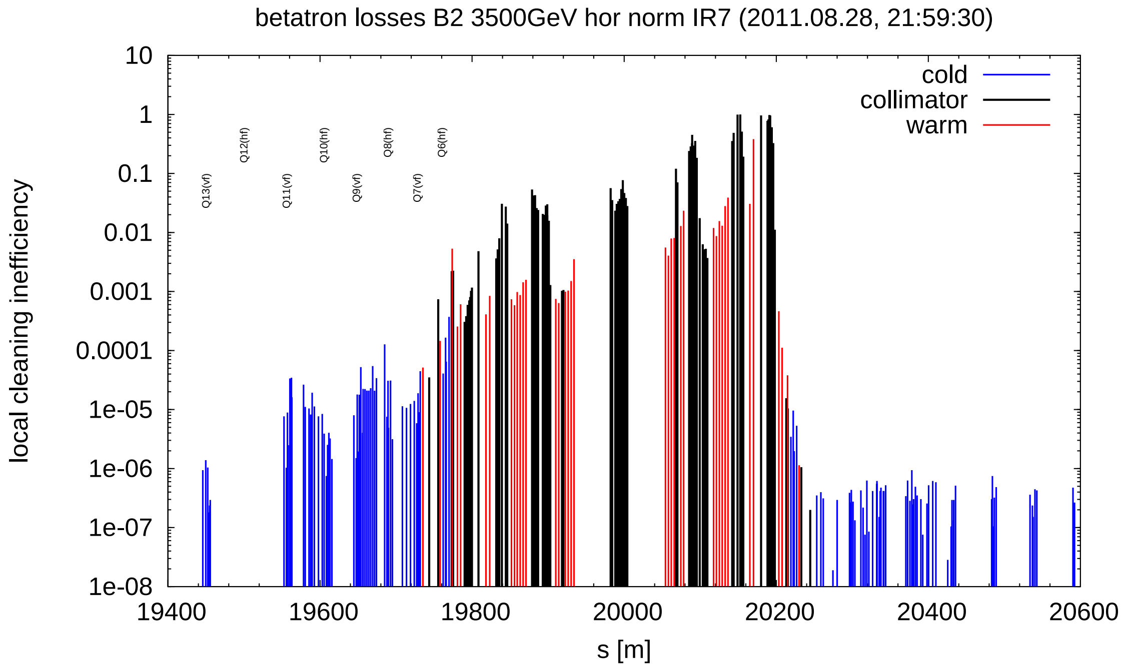


Figure 3: Losses in IR7, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.



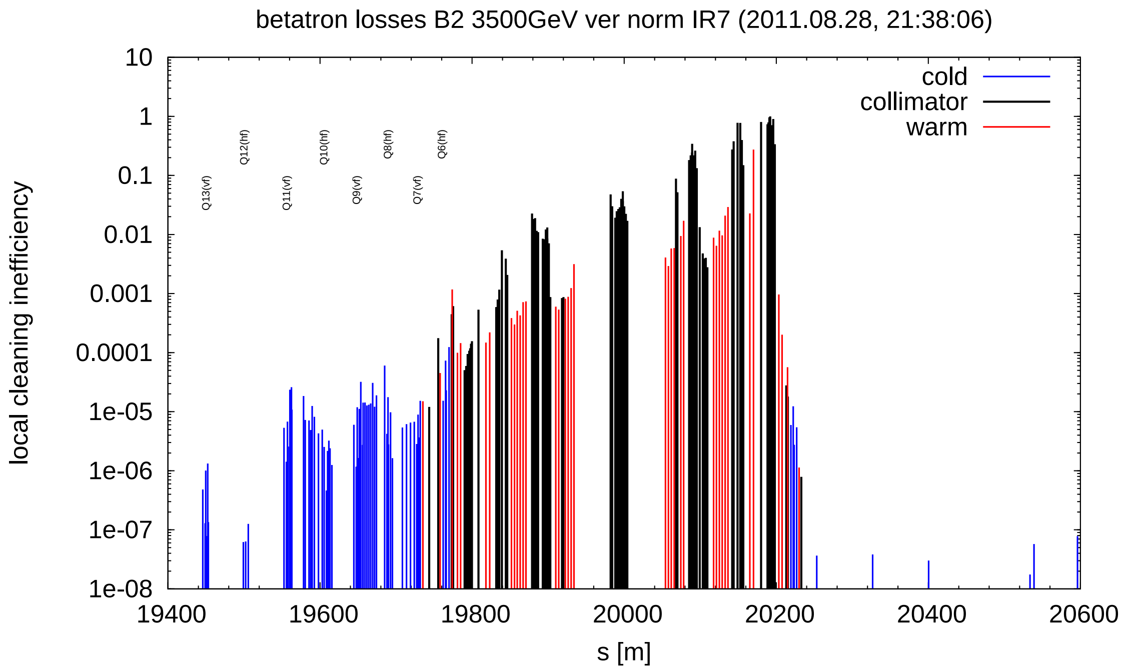
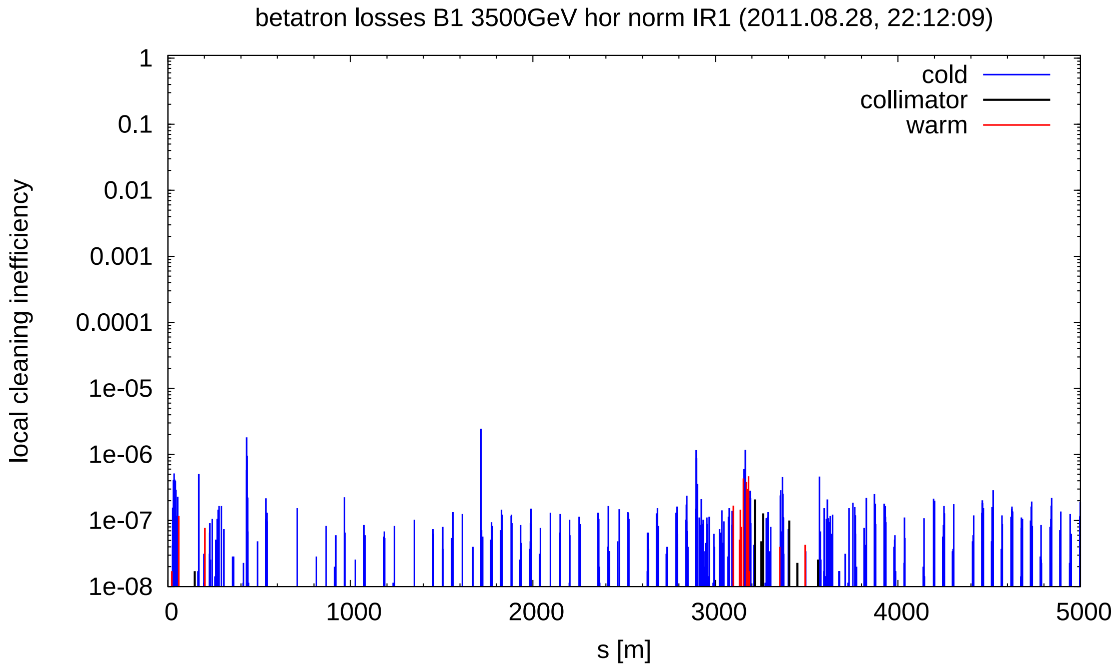


Figure 4: Losses in IR7, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.



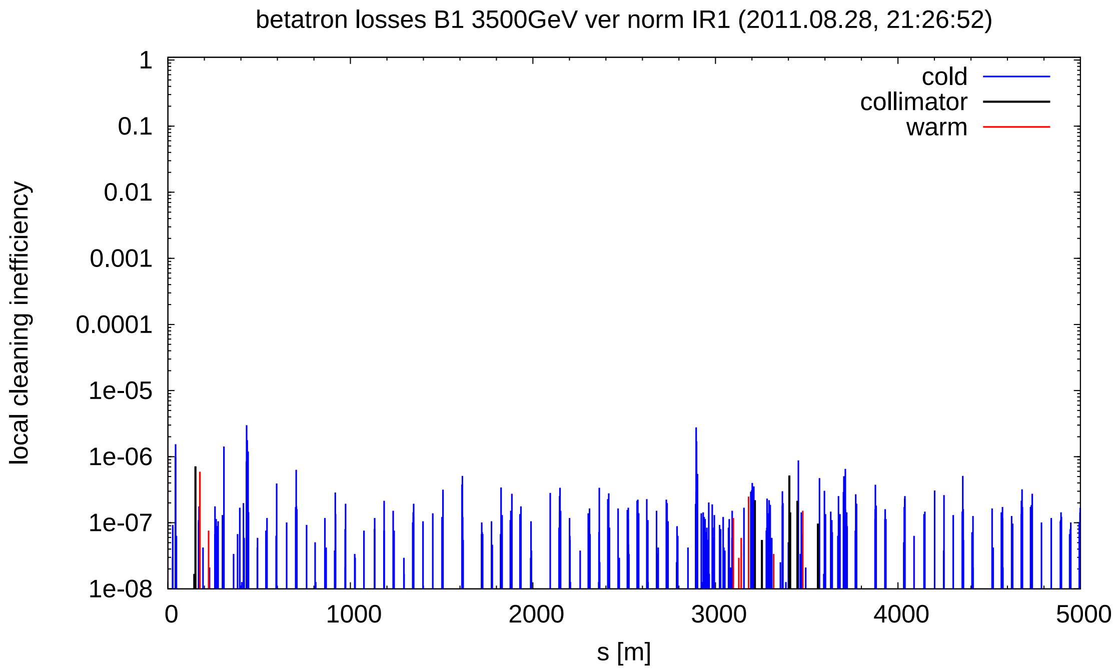
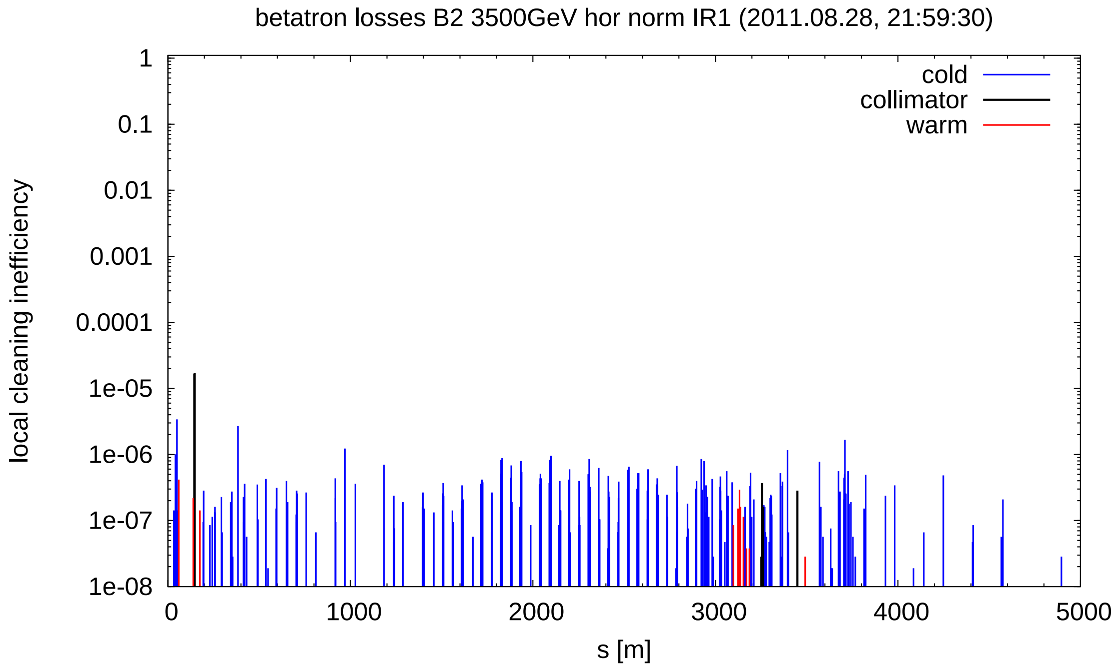


Figure 5: Losses IR1, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.



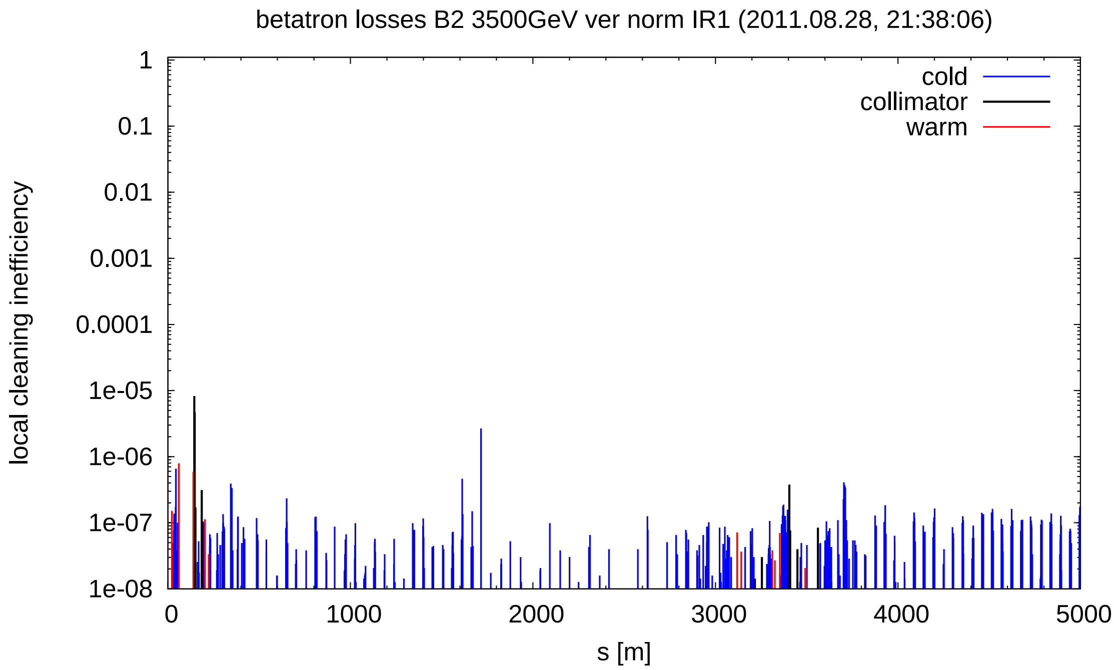


Figure 6: Losses IR1, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.

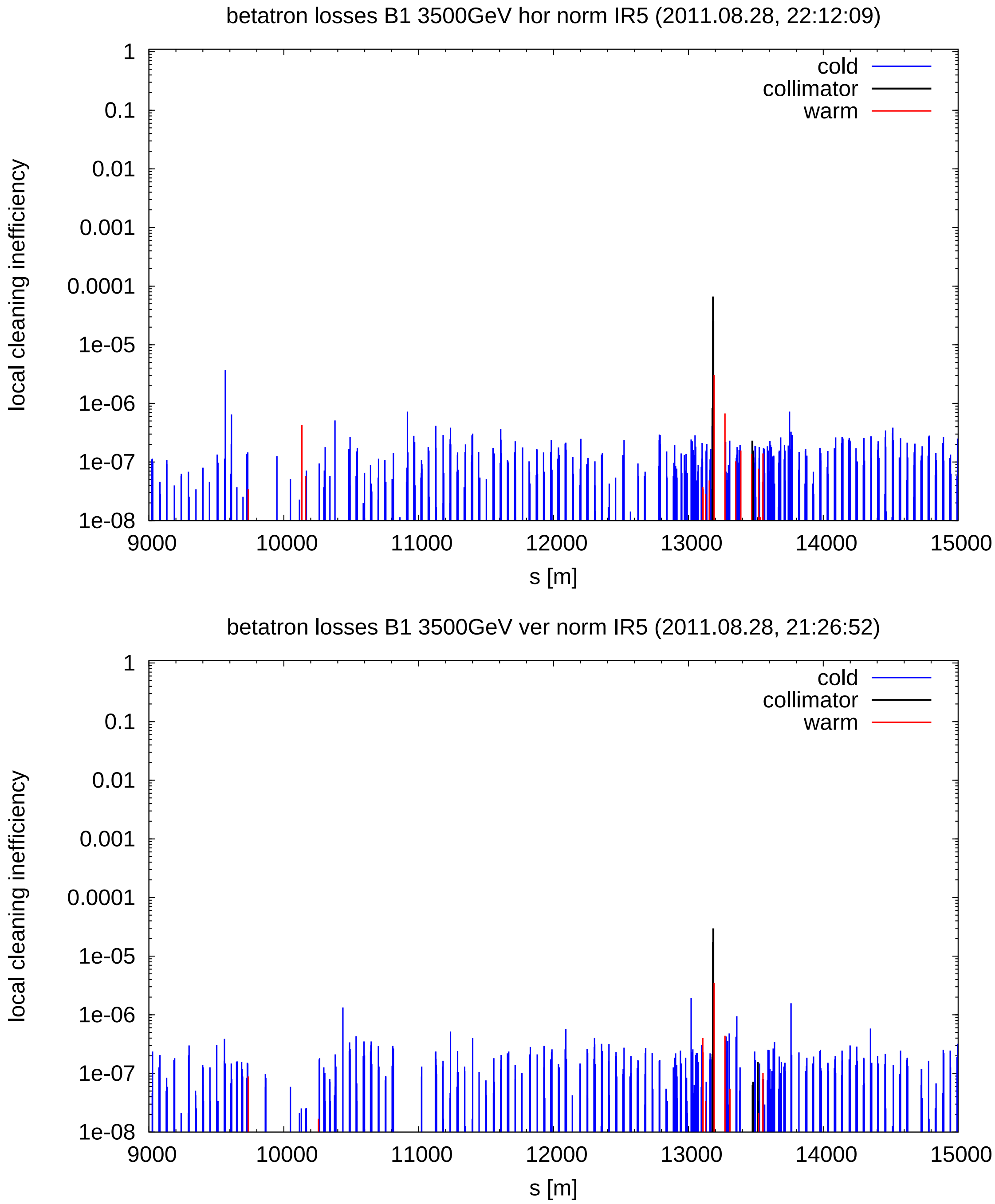


Figure 7: Losses in IR5, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.

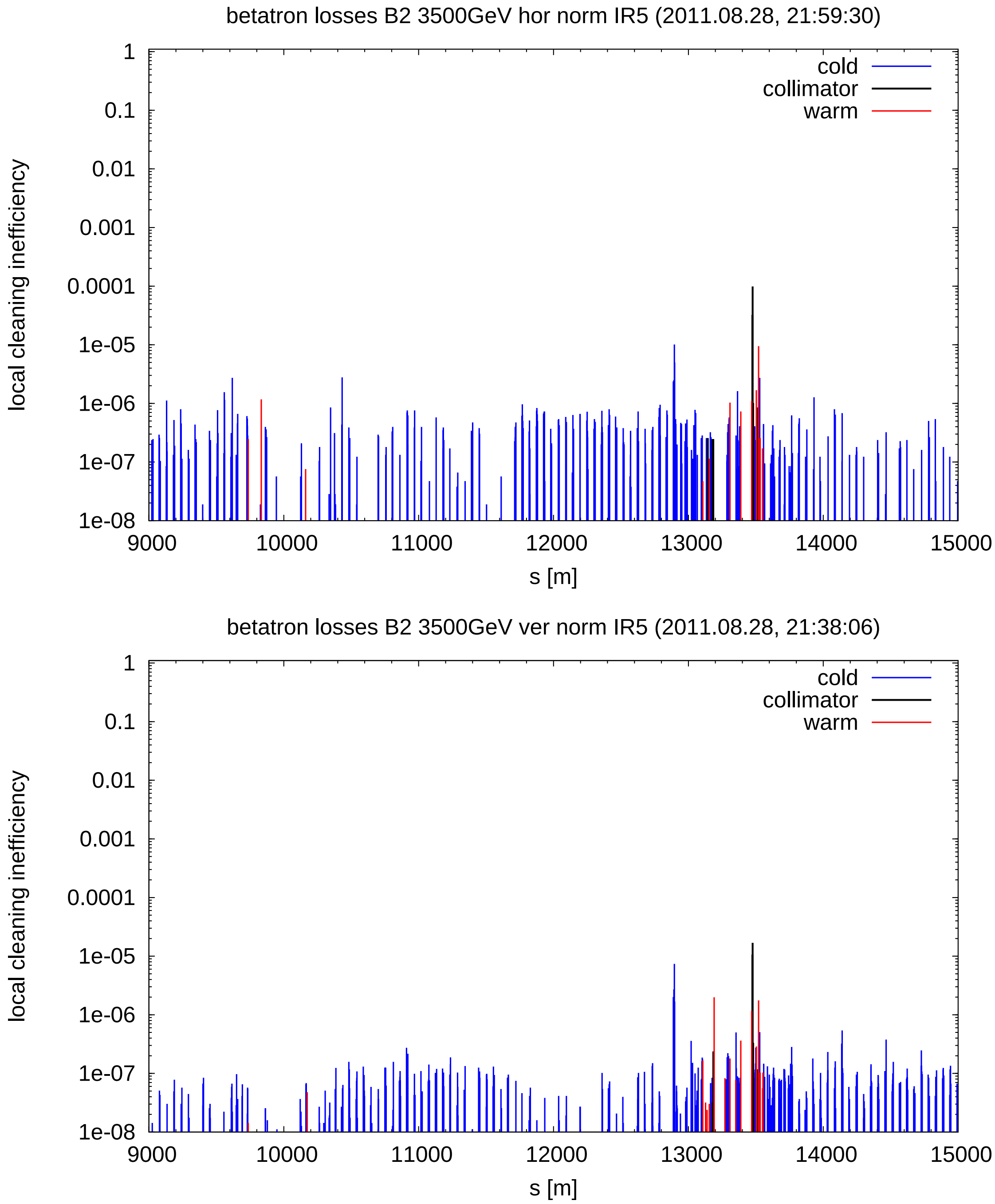


Figure 8: Losses in IR5, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.