Update on HL-LHC studies on triplet aperture

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Outline

Motivation

- The HL-LHC based on the ATS scheme requires a new IR layout.
- The present IR protection of the incoming beam is based on one TCT.
- Final triplet must be protected.
- Aperture limitations might also appear upstream of the TCT.
- Both cleaning and machine protection aspects should be considered.
  - Here we cover the cleaning aspects.
- First step: assess cleaning losses at IR aperture bottlenecks without TCT
- Using SixTrack with collimation to simulate local losses at different apertures
- Open questions:
  - Another TCT further upstream?
  - How effective is the cleaning for the present TCT?
  - Minimal tolerable aperture before installing additional protection?

Introduction and setup of SixTrack simulations

HL-LHC lattice

- Lattice version: hllhcv1.11t
- Cofiguration: Squeezed β^* ($\beta^*_{x,y}$(IR1, IR5) = 15 cm).
- Perfect machine.

Collimator setup

- CollDB: CollDB.hllhcv1.11t.b1
- CollPositions: CollPositions.hllhcv1.11t.b1.b1.dat
- Tertiary collimators fully open (999σ).

Collimator configuration

- TCP IR7: 6σ
- TCSG IR7: 7σ
- TCLA IR7: 10σ
- TCP IR3: 12σ
- TCSG IR3: 15σ
- TCLA IR3: 17.6σ

Simulation parameters

- Beam 1 and 2.
- 6σ horizontal beam halo of type 2 (no energy spread).
- 6.4×10^6 protons.
- 2000 jobs of 50×64 protons.
- 200 turns

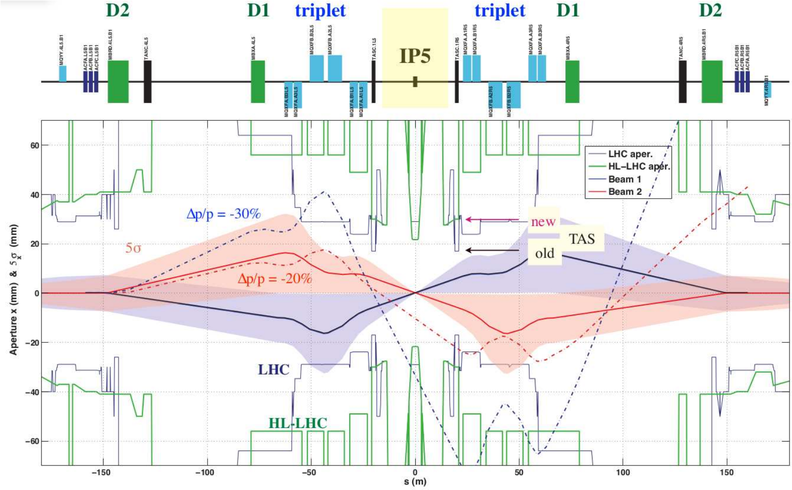
Aperture scan

The triplet aperture has been scanned (reduced in steps with a cleaning simulation at each step) for different configurations.

- HL-LHC: IR1 upstream Q2, Q4 and Q5, horizontal and vertical halo, beam 1.
- HL-LHC: IR5 upstream Q2. horizontal halo, beam 1.
- HL-LHC: IR1 downstream Q2: horizontal halo, beam 1.
- HL-LHC: IR1 upstream Q2 beam 2.

The aperture has been reduced in steps of 2-4 mm.

IR5 and the Final Triplet: Beam envelope



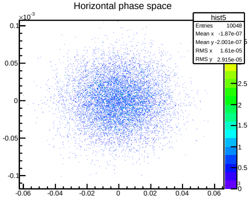
∗Helmut Burkhardt: High-Luminosity LHC, LNF 2013.

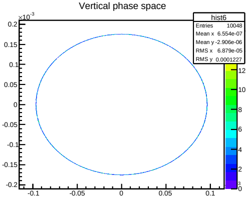
Optics in IR1 and IR5

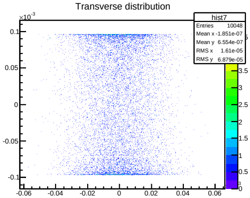
	Name	s [m]	β_x [m]	β_y [m]	σ_x [mm]	σ_y [mm]	x [mm]	y [mm]	Aperture [mm]
IR1L									
Q1	MQXA.1L1	26635.9	7000	4674	1.9	1.5	0.0	-7.8	49
Q2	MQXB.A2L1	26626.8	17653	4315	3.0	1.5	0.0	-8.8	59
Q3	MQSX.3L1	26612.3	20672	7013	3.2	1.9	0.0	-14.0	59
Q4	MQY.4L1.B1	26491.0	3224	1821	1.3	1.0	0.0	0.0	37
Q5	MQML.5L1.B1	26464.7	1555	664	0.9	0.6	0.0	0.0	40
IR1R									
Q1	MQXA.1R1	29.3	4674	7000	1.5	1.9	0.0	9.1	49
Q2	MQXB.A2R1	37.5	4315	17653	1.5	3.0	0.0	15.0	59
Q3	MQSX.3R1	46.7	7013	20672	1.9	3.2	0.0	16.2	59
Q4	MQY.4R1.B1	171.2	1821	3224	1.0	1.3	0.0	0.0	37
Q5	MQML.5R1.B1	198.8	664	1555	0.6	0.9	0.0	0.0	40
IR5L									
Q1	MQXA.1L5	13306.3	7000	4674	1.9	1.5	-9.1	0.0	49
Q2	MQXB.A2L5	13297.2	17653	4315	3.0	1.5	-15.0	0.0	59
Q3	MQXA.3L5	13282.3	20672	7013	3.2	1.9	-16.2	0.0	59
Q4	MQY.4L5.B1	13161.4	3224	1821	1.3	1.0	0.0	0.0	37
Q5	MQML.5L5.B1	13135.1	1555	664	0.9	0.6	0.0	0.0	40
IR5R									
Q1	MQXA.1R5	13358.6	4674	7000	1.5	1.9	7.8	0.0	49
Q2	MQXB.A2R5	13366.8	4315	17653	1.5	3.0	8.8	0.0	59
Q3	MQXA.3R5	13382.6	7013	20672	1.9	3.2	14.0	0.0	59
Q4	MQY.4R5.B1	13500.5	1821	3224	1.0	1.3	0.0	0.0	37
Q5	MQML.5R5.B1	13528.1	664	1555	0.6	0.9	0.0	0.0	40

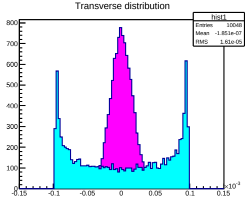
Beam halo used as SixTrack starting conditions

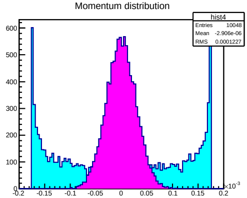
- Example of vertical halo (the same for the horizontal halo).
- 6σ horizontal beam halo of type 2 (no energy spread).
- 6.4×10^6 protons (just a fraction represented in the plots).





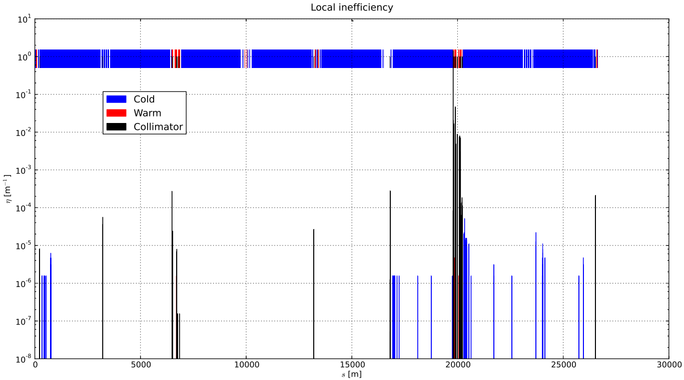






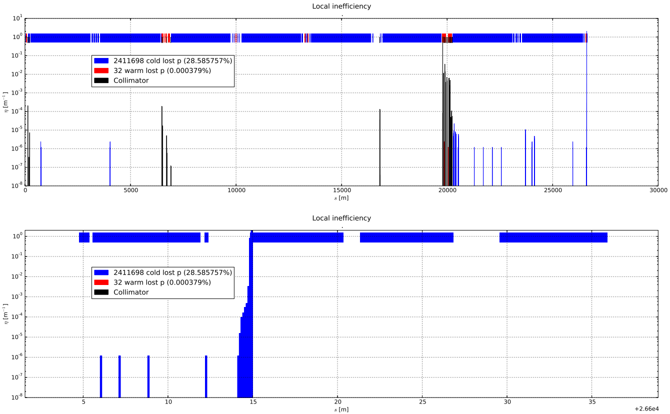
Nominal loss map

- Tertiary collimators are in the nominal position.

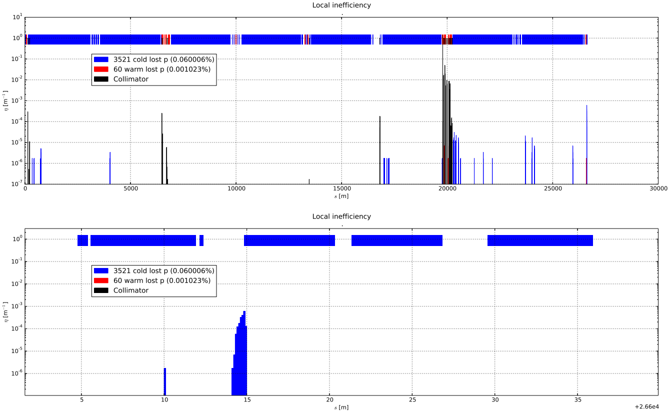


- Keeping the nominal loss map in mind is a reference for future loss maps with reduced apertures.

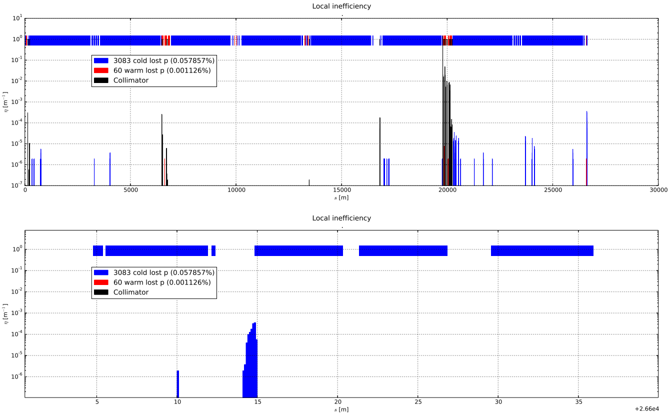
Some examples: IR1 B1 Q2 Upstream, AP = 20 mm (4σ)



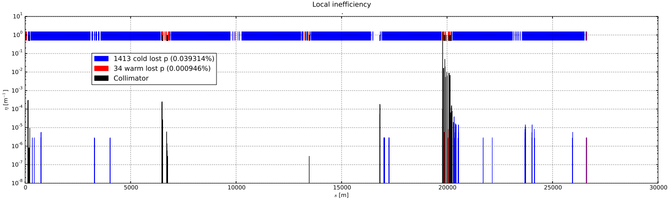
Some examples: IR1 B1 Q2 Upstream, AP = 32 mm (8σ)

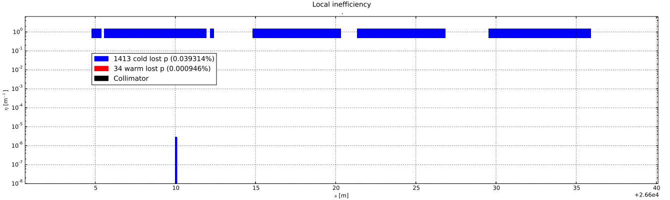


Some examples: IR1 B1 Q2 Upstream, AP = 36 mm (9.3σ)



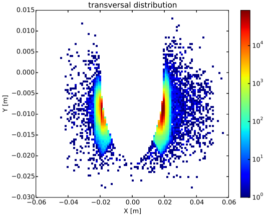
Some examples: IR1 B1 Q2 Upstream, AP = 59 mm (17σ)



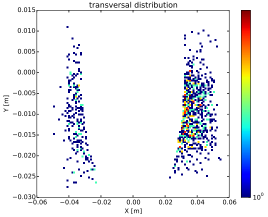


IR1 B1 Q2 Upstream: Spatial distribution of impacts

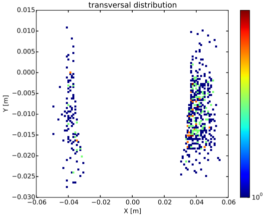
20 mm (4σ)



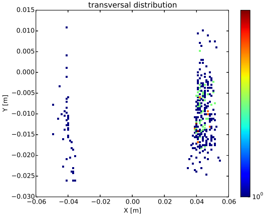
32 mm (8σ)



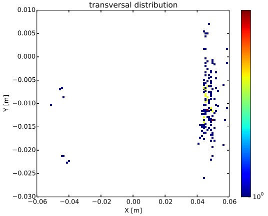
36 mm (9.3σ)



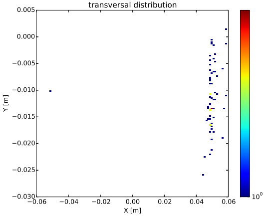
40 mm (10.7σ)



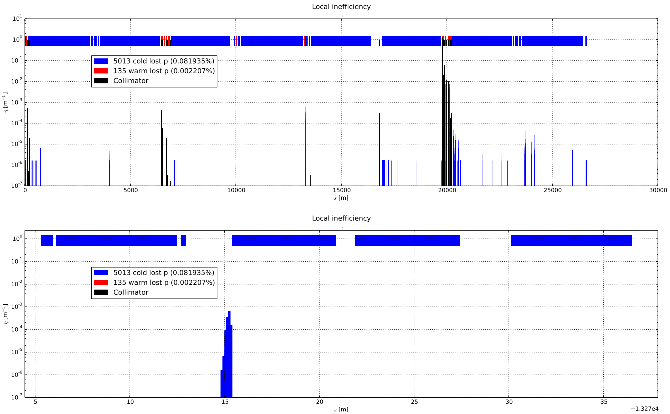
44 mm (12σ)



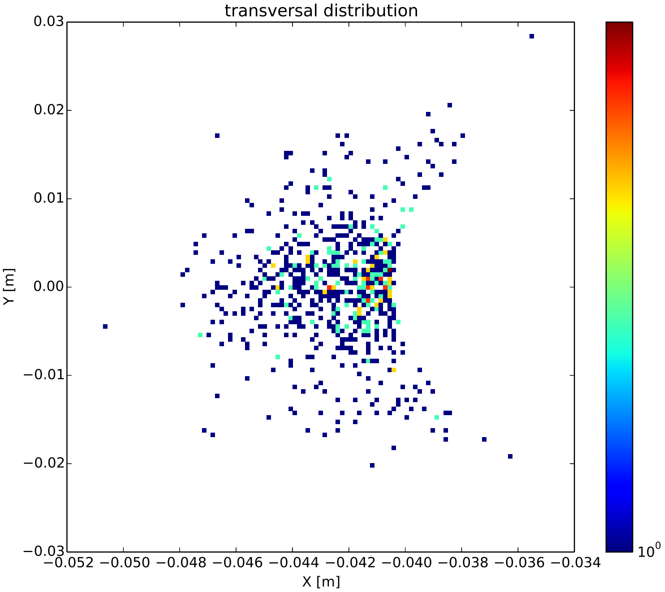
48 mm (13.3σ)



One more example: IR5 B1 Q2 Upstream, AP = 40 mm (7.7σ)



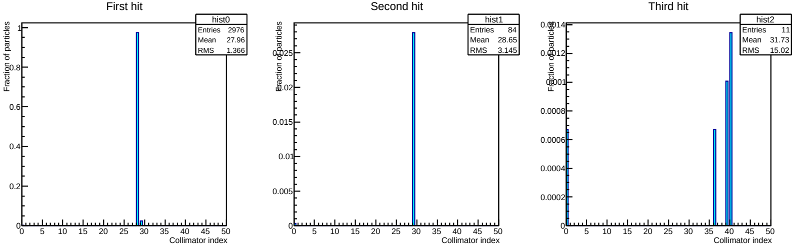
Some examples: IR5 B1 Q2 Upstream, AP = 40 mm (7.7σ)



History of the particles hitting the triplet

- We can extract the history of the particles that finally hit the magnets in the Interaction Region.
- That can explain the origin of these particles and might give information about how to mitigate them.

Example: IR5 B1 Q2R Horizontal Halo.

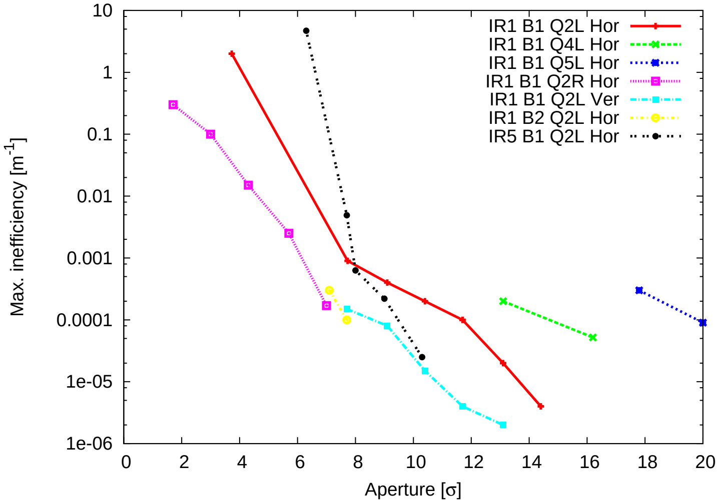


In that case, most of the particles hit just once a primary collimator and just a few hit a second primary collimator. A very few percentage hits also a secondary collimator before hitting the triplet.
We need to further investigate this.

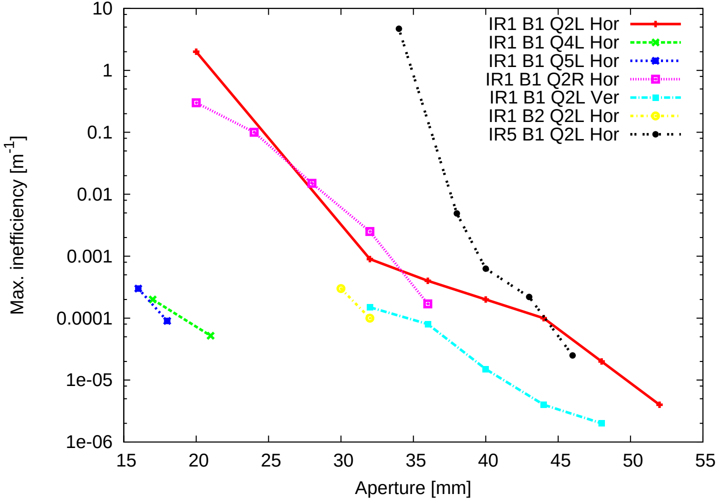
Maximum losses as a function of the aperture in σ units

- Aperture is calculated using the σ where the losses are produced.

$$Ap[\sigma] = \frac{Ap[\text{mm}] - x/y}{\sigma_{x,y}}$$



Maximum losses as a function of the aperture in mm



Conclusions and future prospects

The results shown are ongoing study to determine the aperture that can be tolerated without local protection.

- The scanning of the aperture of Q2 has been done for several cases including IR1 and IR5, upstream and downstream of the IP.
- Results show a qualitative approach of the impact of the triplet aperture on the collimation system.
- We have identified the positions where the aperture reduction causes a major impact (i.e. IR1 downstream and IR5 upstream.)

Next steps

- Clarify allowed local inefficiency.
- Assess machine protection aspects: aperture protection in case of asynchronous dumps.
- Detailed analysis of the history of the particles that hit the triplet aperture.
- Consider the impact of different error sources.
- Close TCT's to verify the relation between the TCT setting and the aperture they protect. Are TCT's in cell 5 sufficient?