Collimation IR layout for the incoming beam

Hector Garcia Morales
Roderik Bruce, Regina Kwee-Hinzmann, Elena Quaranta, Stefano Redaelli

Royal Holloway University of London

November 20, 2014

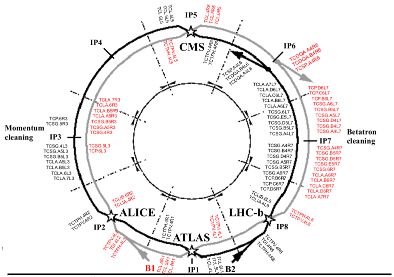
Outline

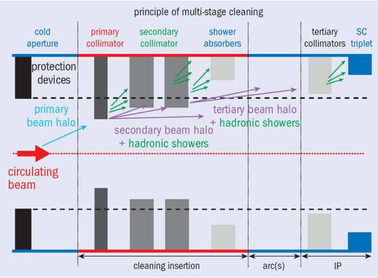
The (HL-)LHC collimation system [1]

- The LHC is designed to collide protons with an unprecedented energy of 7 TeV and a total stored energy of 362 MJ per beam.
- If protons deviate from the nominal trajectory they might hit the the vacuum chamber and can cause quenches and possible material damage.
- The beam losses need to be carefully controlled.

Multi-stage Collimation System

- Protection of elements against losses during normal and abnormal operation
  - Also reduction of experimental backgrounds.
- A three stage system is installed in IR3 and IR7.



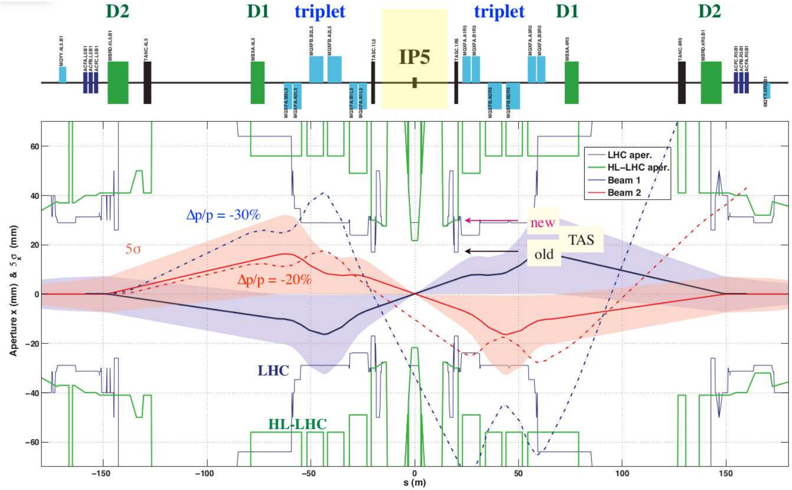


[1] More details in R.Bruce talk on Tuesday

Motivation for HL-LHC collimation

- The HL-LHC stored beam energy will be almost two times the energy stored in the LHC.
- The HL-LHC based on the ATS scheme requires a new IR layout and new aperture bottlenecks might appear.
- The present IR protection of the incoming beam is based on two TCTs.
- Both cleaning and machine protection aspects should be considered.
- Open questions:
  - Another TCT pair further upstream?
  - How effective is the cleaning for the present TCT?
  - Minimal tolerable aperture before installing additional protection?

IR5 and the Final Triplet: Beam envelope



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

Final triplet aperture scan

SixTrack simulations setup

Cleaning simulations performed to estimate the IR losses without TCTs, for perfect and imperfect apertures

HL-LHC lattice

- Lattice version: hllhcv1.0
- Configuration: Squeezed β^* ($\beta^*_{x,y}$(IR1, IR5) = 15 cm).
- Perfect machine.

Collimator setup

- CollDB.hllhcv1.11t.b1 and 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

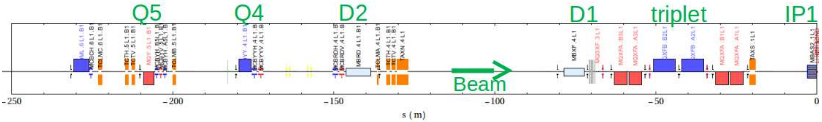
Aperture scan

Idea

Reducing aperture is a way to consider the impact of different error sources like orbit or β-function errors.

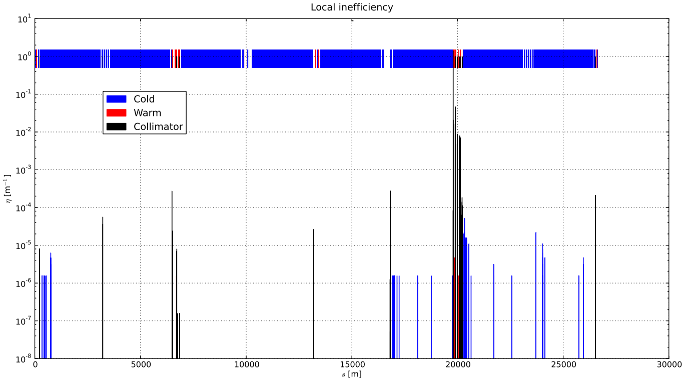
The aperture has been scanned (reduced in steps of 2-4 mm with a cleaning simulation at each step) for different magnets have been considered.

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



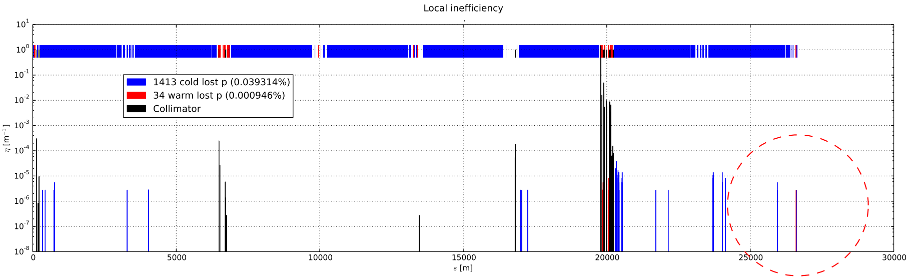
Nominal loss map

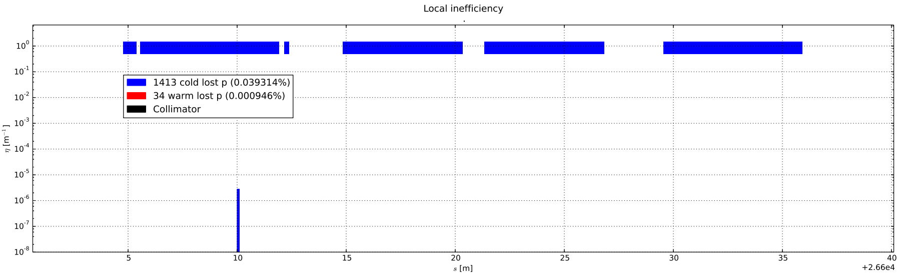
- Tertiary collimators are in the nominal position.



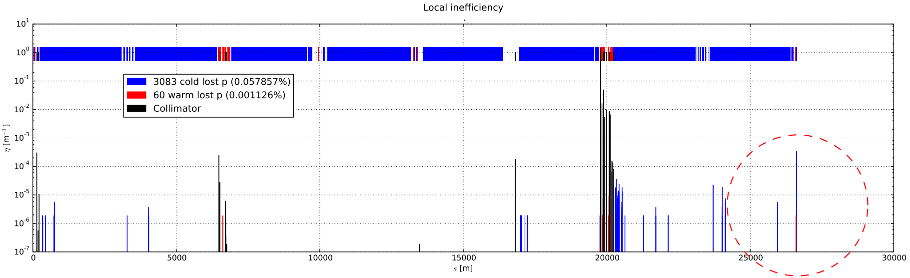
- Keeping the nominal loss map in mind is a reference for future loss maps with reduced apertures.

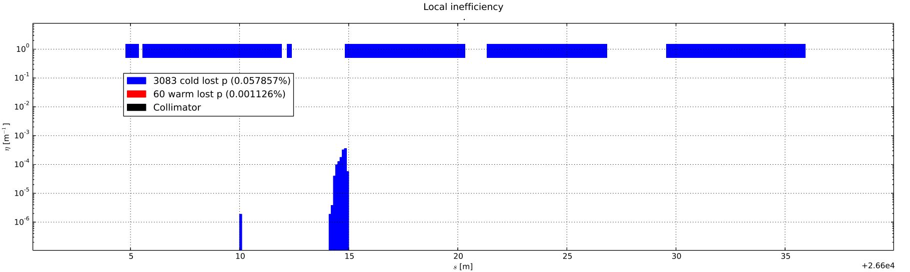
Some examples: IR1 B1 Q2 Upstream, AP = 59 mm (17σ)



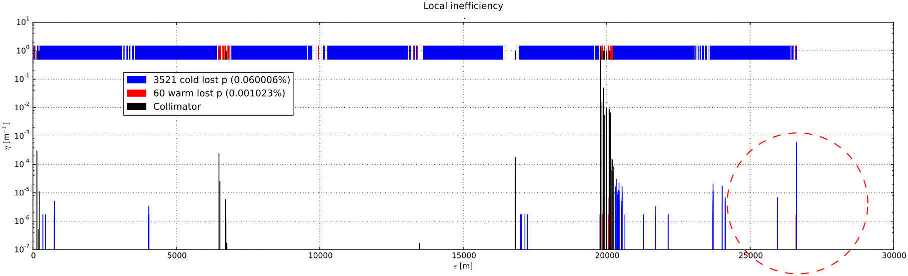


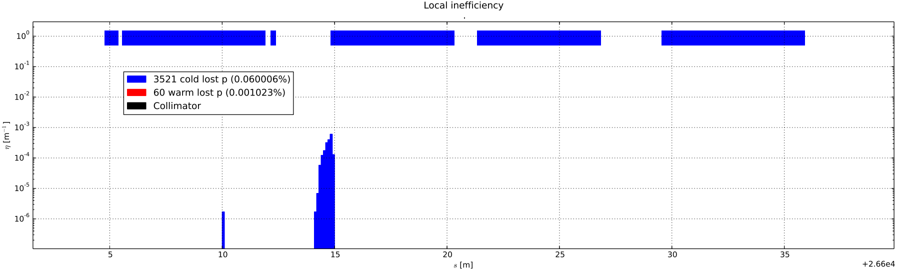
Some examples: IR1 B1 Q2 Upstream, AP = 36 mm (9.3σ)





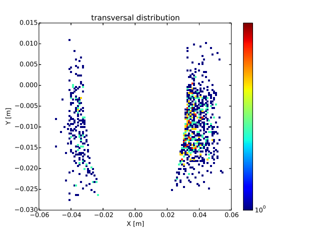
Some examples: IR1 B1 Q2 Upstream, AP = 32 mm (8σ)



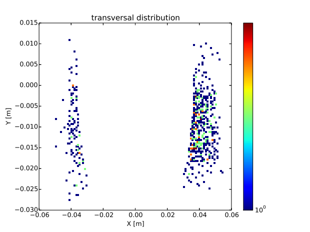


IR1 B1 Q2 Upstream: Spatial distribution of impacts

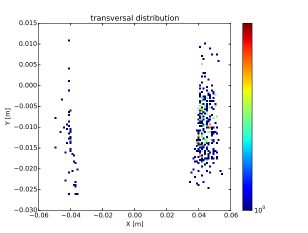
32 mm (8σ)



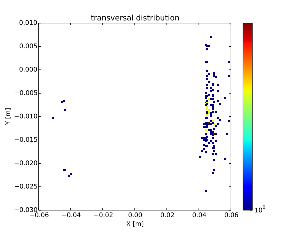
36 mm (9.3σ)



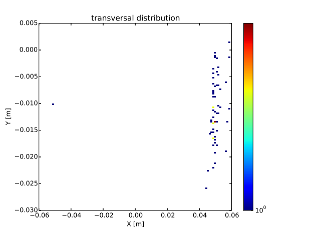
40 mm (10.7σ)



44 mm (12σ)



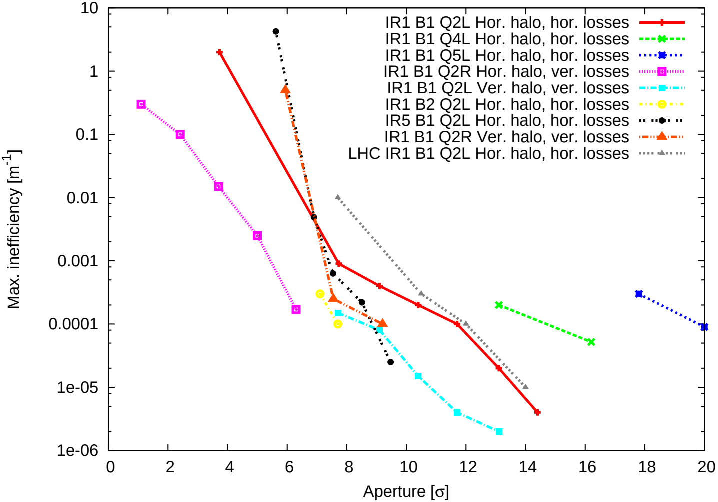
48 mm (13.3σ)



Maximum losses as a function of the aperture in σ units

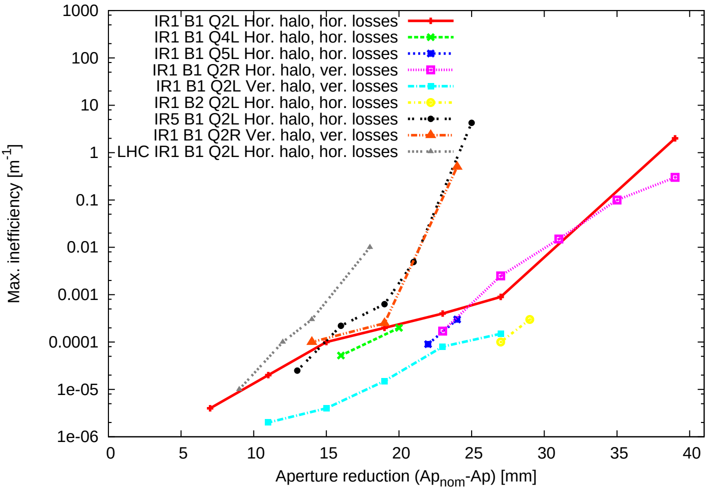
- Aperture is calculated using the σ of the location where the losses are produced.

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



Maximum losses as a function of the aperture reduction in mm

The same plot but as a function of the aperture reduction with respect to its nominal value.



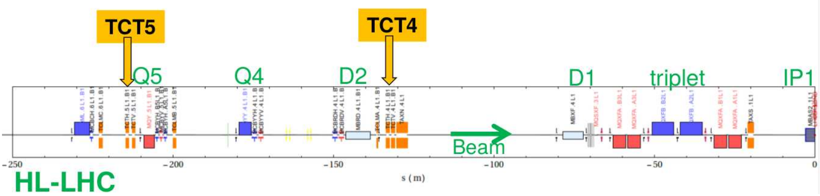
TCT protection

TCT protection

Goal

Determine whether the current protection is enough or an upgraded protection including TCTs in cell 5 is required.

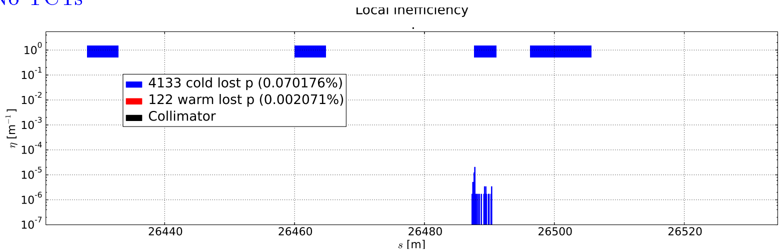
- In previous simulations, Tertiary collimators (TCTs) were fully open and they did not offer any protection to the Final Triplet.
- First we include TCTs in cell 4 (current protection) at 8.3σ.
- Then we also include TCTs in cell 5 (upgraded protection) at 8.3σ.



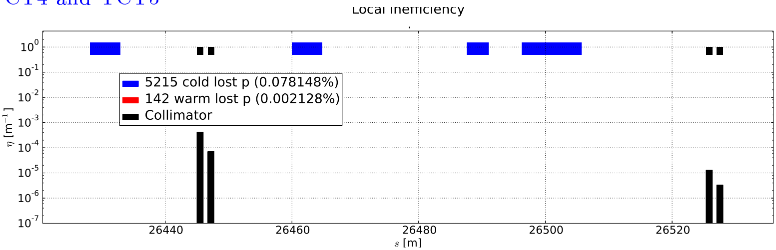
TCT protection: TCT in cell 4 and in cell 5

Quadrupole	Q1	Q2	Q3	Q4	Q5
Aperture [mm]	28.0	43.0	44.0	20.0	20.0
Aperture [σ]	8.9	8.7	8.7	15	22

No TCTs



TCT4 and TCT5

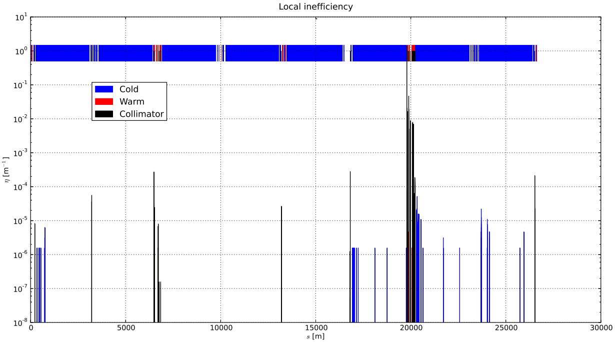


TCT scan

TCT scan

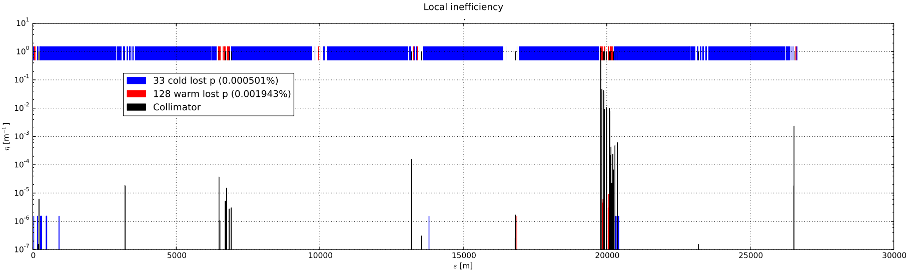
- In all the previous cases, TCTs have been set to 8.3σ.
- Now we scan the TCTs aperture considering the nominal optics and apertures.
- Motivation: to define a lower limit on the TCT setting in terms of cleaning.
- A smaller TCT setting gain aperture and thus reach in β^*.
- We consider losses in the vertical plane where asynchronous beam dump has no effect.

Nominal loss map with TCTs at 8.3σ:

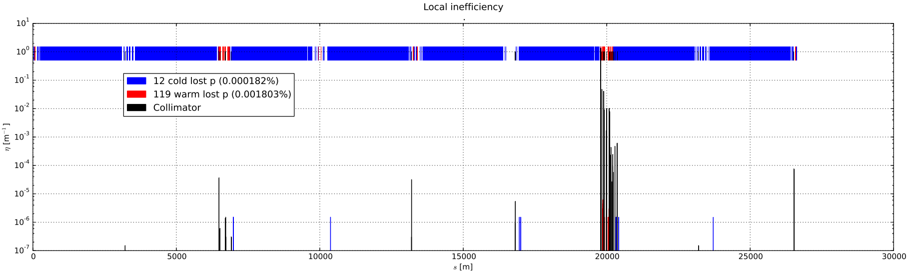


TCT scan Vertical Halo B1

TCT at 7σ

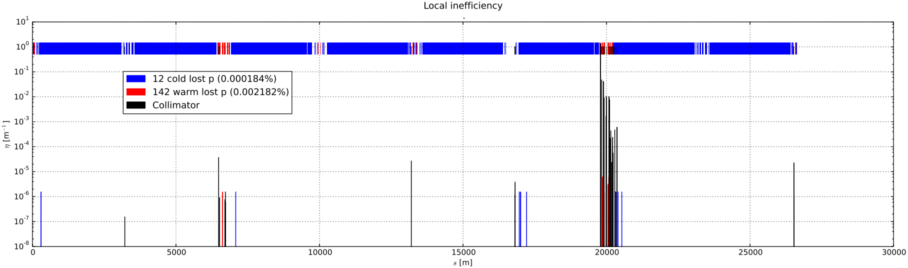


TCT at 9σ

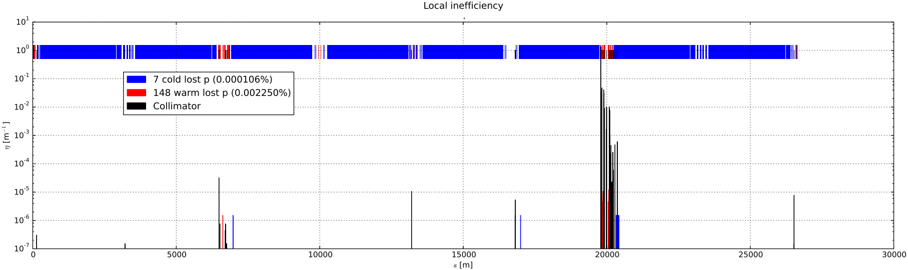


TCT scan Vertical Halo B1

TCT at 10σ



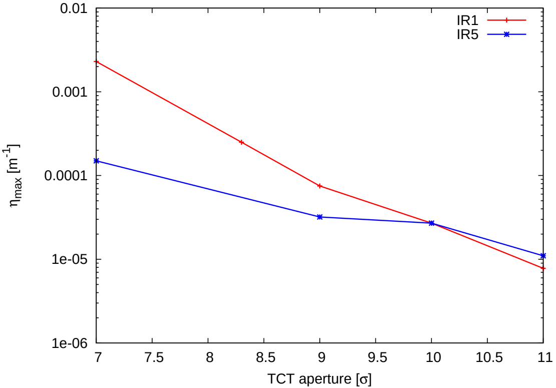
TCT at 11σ



TCT scan Vertical Halo B1: Impacts on collimator

Goal

- Understand the hierarchy limit for cleaning.
- Important for β^* reach if we have a more robust collimator.

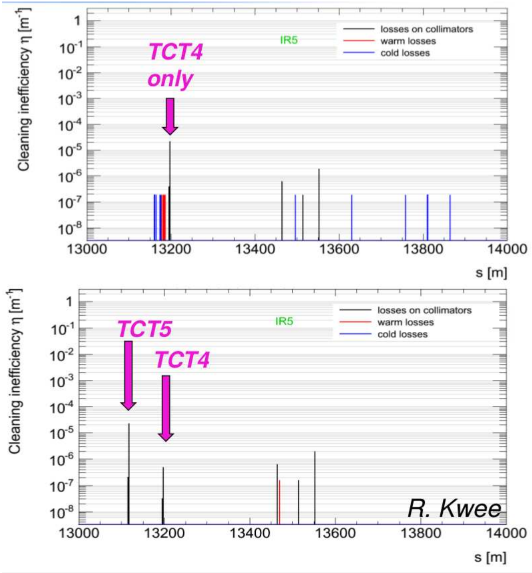


- Maximum allowed losses on TCT to be defined based on tolerable background for experiments.
- In Run 1, the TCT inefficiency was simulated at about 10^{-4}. At least this level should be acceptable.
- Simulation to be repeated using collimator settings with 2 sigma retraction.

IR Losses during Asynchronous dumps and backround reduction

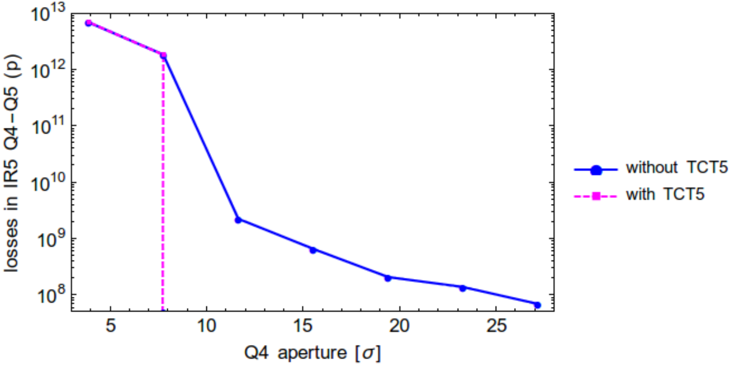
TCT5 for background reduction

- And additional advantage of the installation of TCT5 is that also can reduce the experimental background.
- Simulations performed by R. Kwee show that TCT5 can take over losses from TCT4.
- The final effect on the detector are being studied using shower calculations.



IR Losses during Asynchronous dumps

- Asynchronous beam dump: fast one-turn failure where one or several bunches could be kicked directly onto the aperture and cause damage
- Study the losses in the IR during asynchronous dumps
- Simulation in SixTrack with and without TCTs performed by E. Quaranta.



- Even at nominal aperture, impacts seen in Q4/Q5 and triplet that might be enough to quench at 7 TeV.
- TCT5 efficiently blocks all aperture losses if inside the aperture.

Conclusions

Conclusions

Aperture scan

- The scanning of the aperture of the final triplet and Q4/Q5 has been done for several cases including IR1 and IR5, upstream and downstream of the IP.
- We have identified the positions where the aperture reduction causes a major impact (i.e. IR1 downstream and IR5 upstream.)
- Apertures down to 12σ are allowed in the triplet and Q4/Q5.
- Simulated losses for Ap $> 12\sigma$ will possibly need TCTs for cleaning.

TCT protection

- When reduced apertures are considered, current TCT protection in cell 4 seems not to be sufficient.
- Introducing TCT in cell 5 the losses in Q4/Q5 are avoided when apertures are reduced (or errors are considered) ...
- ...TCT5 also protects from asynchronous beam dumps...
- ...and it could reduce the experimental background as well.

TCT scan

- Cleaning constraints give some room to adjust TCT setting. Lower limit to be defined based on acceptable background