LHC Collimation and Beam Loss Control

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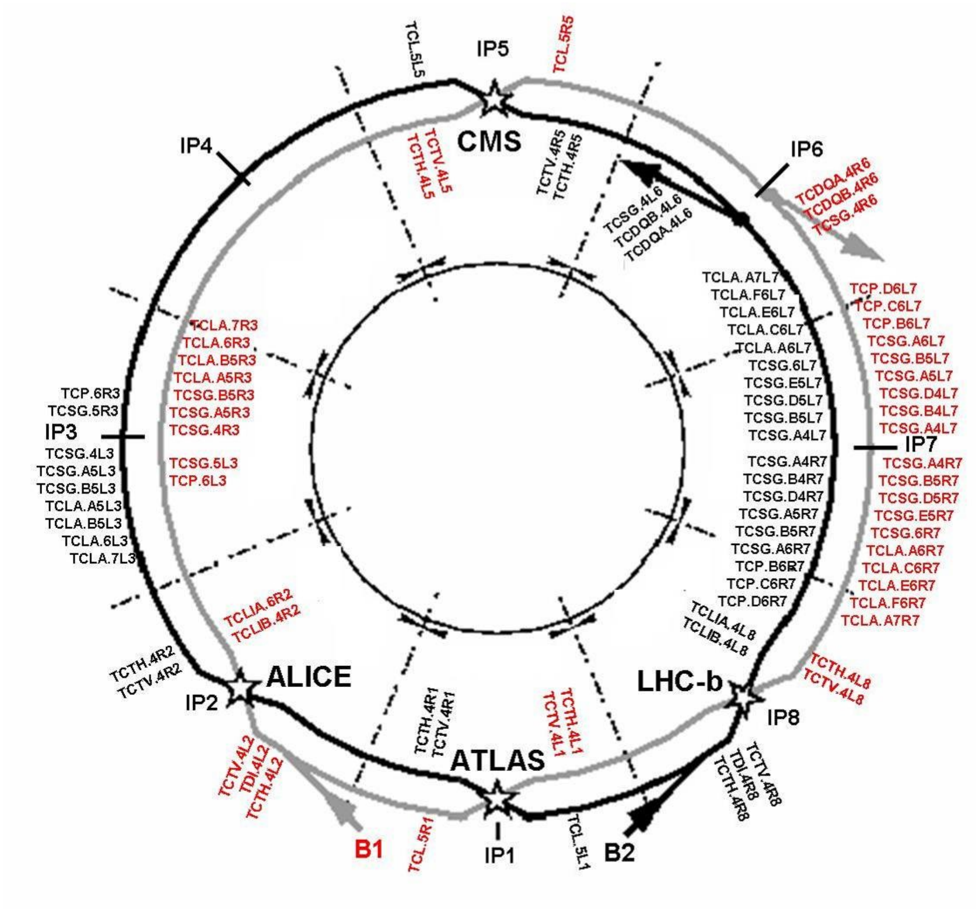
Overview

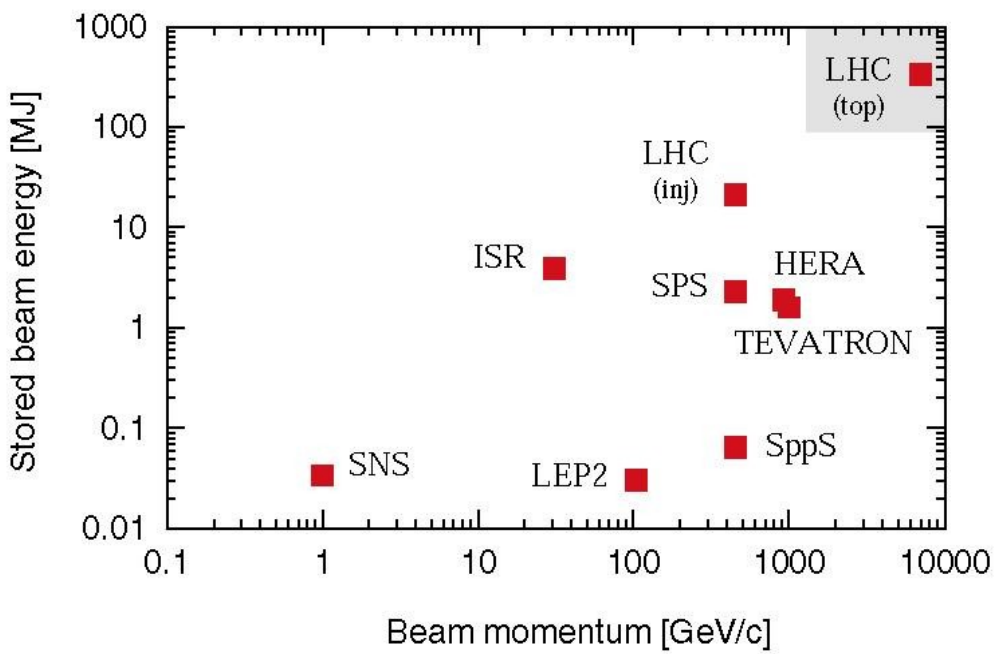
- Introduction to LHC
- Multi-stage cleaning
- System Layout
- Collimator Design
- Simulation Tools
- System Performance
- System Upgrade
- Summary

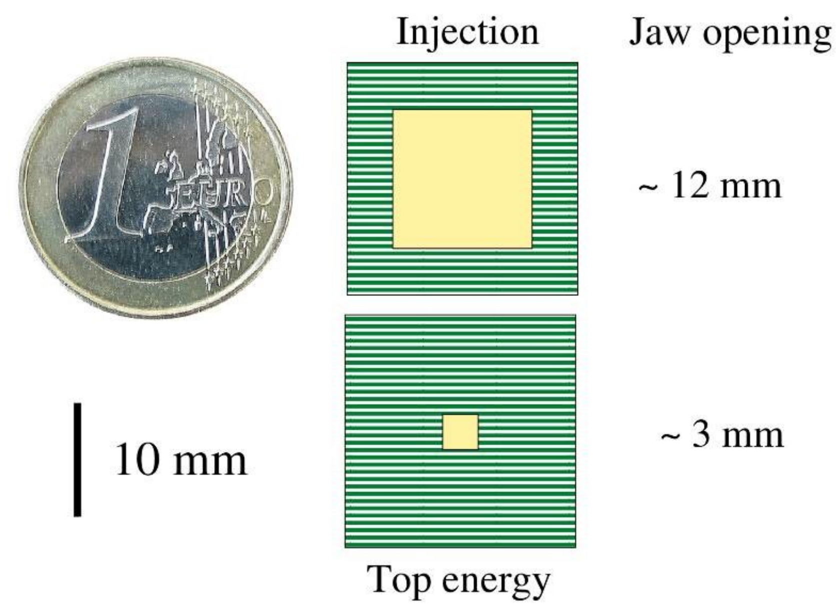
The LHC



- 7 TeV protons for collisions
- super conduction magnets to bend and focus the beam
- four experimental insertion
- two dedicated cleaning insertion in regions with normal conducting magnets
- dump protection devices (in case of kicker failure)
- injection protection devices

The LHC Challenge





- High stored energy (360 MJ per beam) and stored energy densities.
- Small collimation gaps at injection 1σ ~ 1 mm and at top energy 1σ ~ 0.2mm.

Loss Rates (slow)

The following table summarises the specified maximum loss rates for safe operation of the LHC machine and its collimation system.

Mode	T [s]	τ [h]	R_{loss} [p/s]	P_{loss} [kW]
Injection	cont.	1.0	0.8×10^{11}	6
	10	0.1	8.6×10^{11}	63
Ramp	1	0.0006	1.5×10^{13}	1098
Collision	cont.	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

• keep in mind that for nominal LHC operation at 7 TeV the beam lifetime is 20h.

Loss Rates (fast)

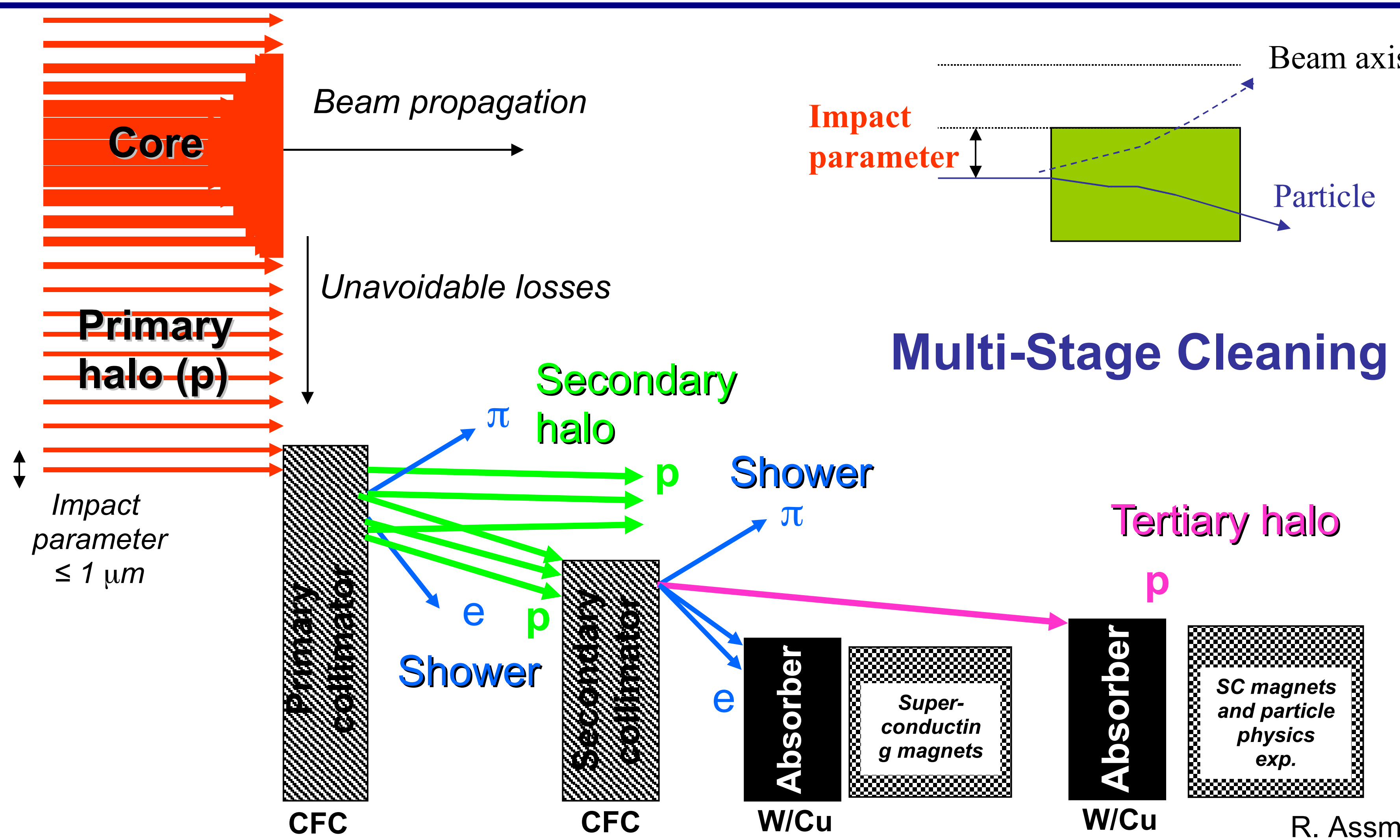
Beside the continuous losses driven by beam dynamics processes, there could be also operational instabilities and machine failures. LHC collimators are designed to sustain following failure scenarios.

- Injection failures, one full injection batch impacting on a collimator (tested with real collimator in SPS extraction line).

- Shock impacts of 6.4 MJ/mm^2 within 200 ns at (7 TeV) .

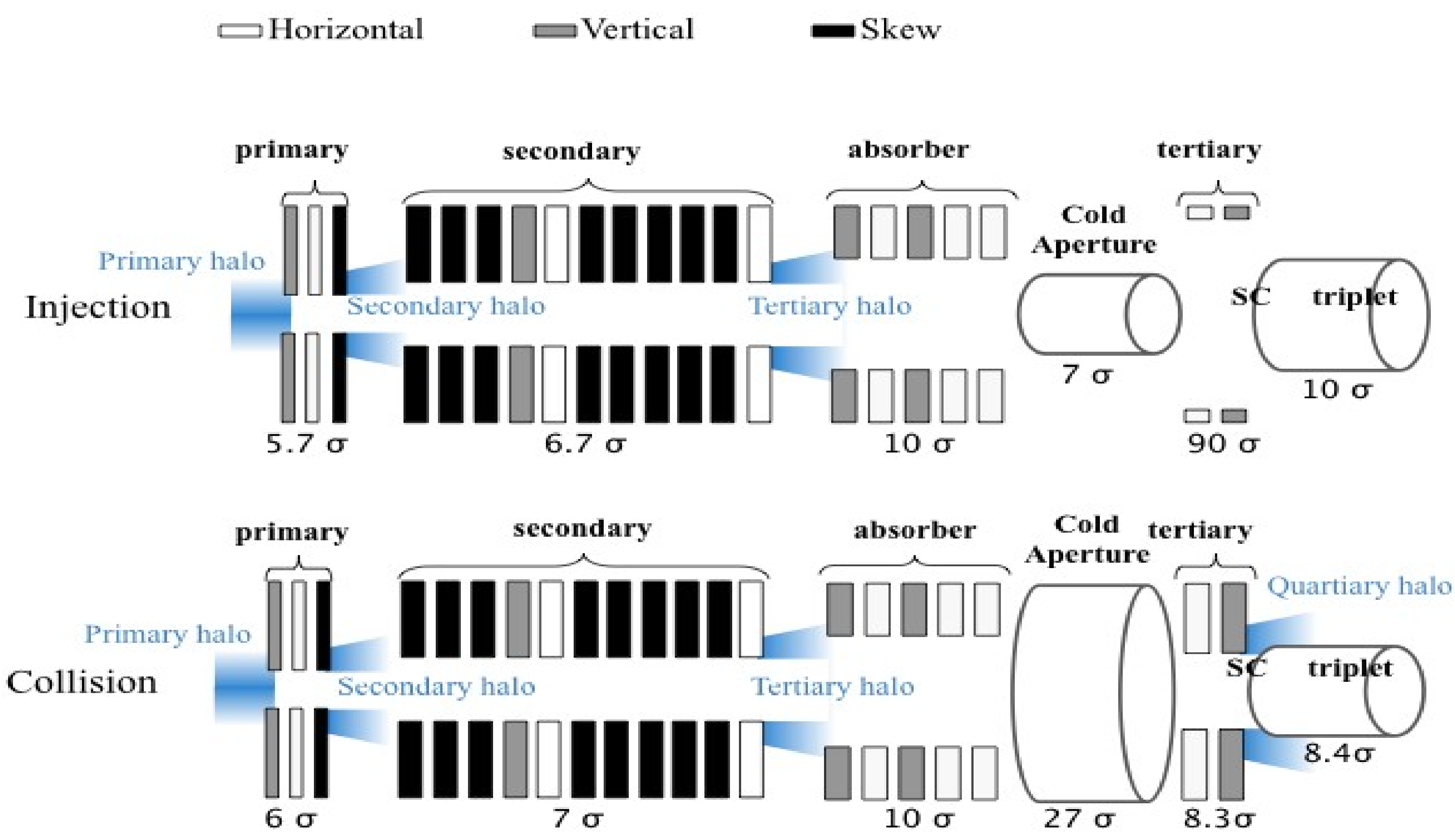
- TCT type collimators (for triplet protection) one bunch, in case of asynchronous dump (dump kicker pre-fire) and misalignment of TCT or dump protection devices, otherwise these collimator are always in the shadow of primary/secondary collimators or dump protection.

Multistage Cleaning



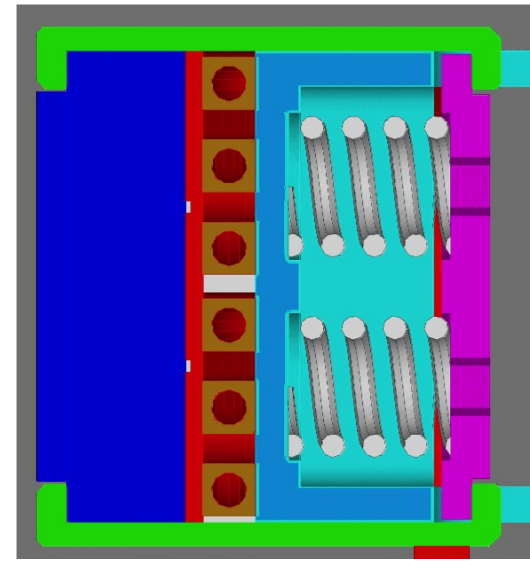
R. Assmann

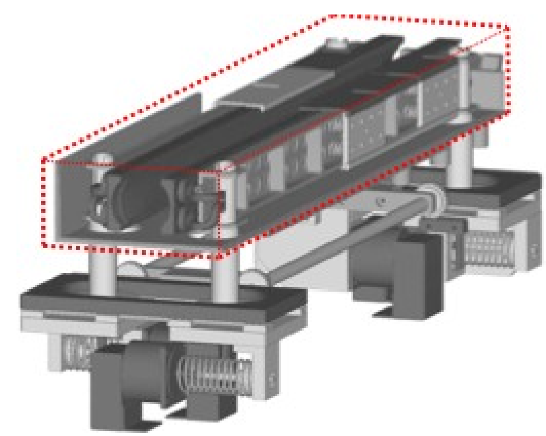
Collimator Settings



C. Bracco

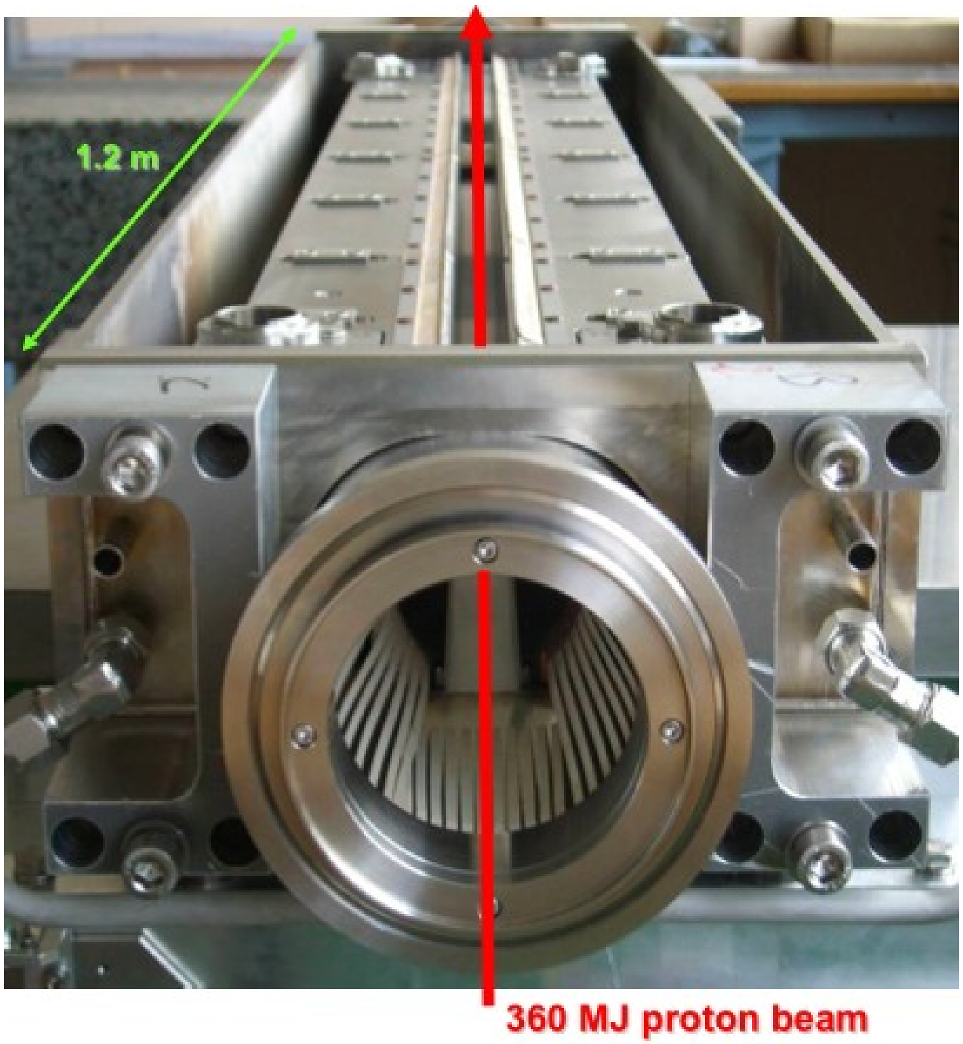
Collimator Jaw

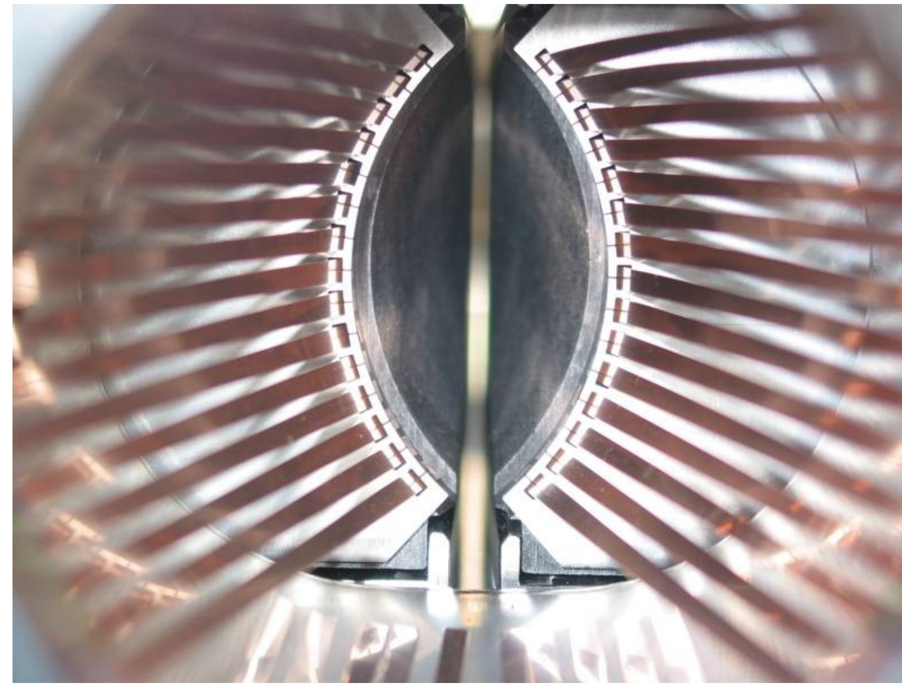




Collimator jaw before installation in the vacuum tank, material fibre reinforced carbon clamped on copper support including active cooling

Collimator Vacuum Tank

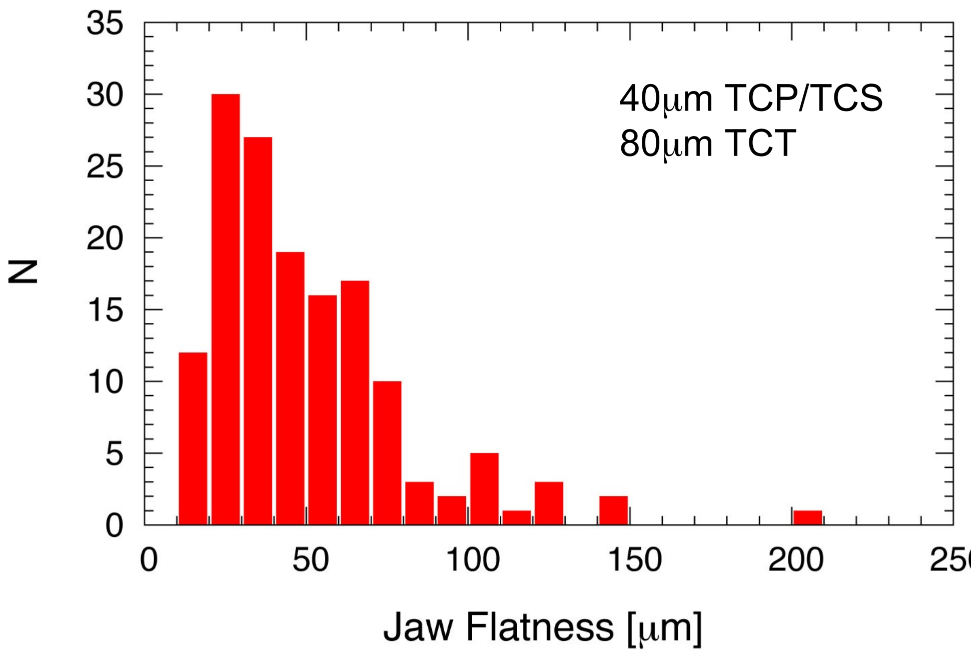


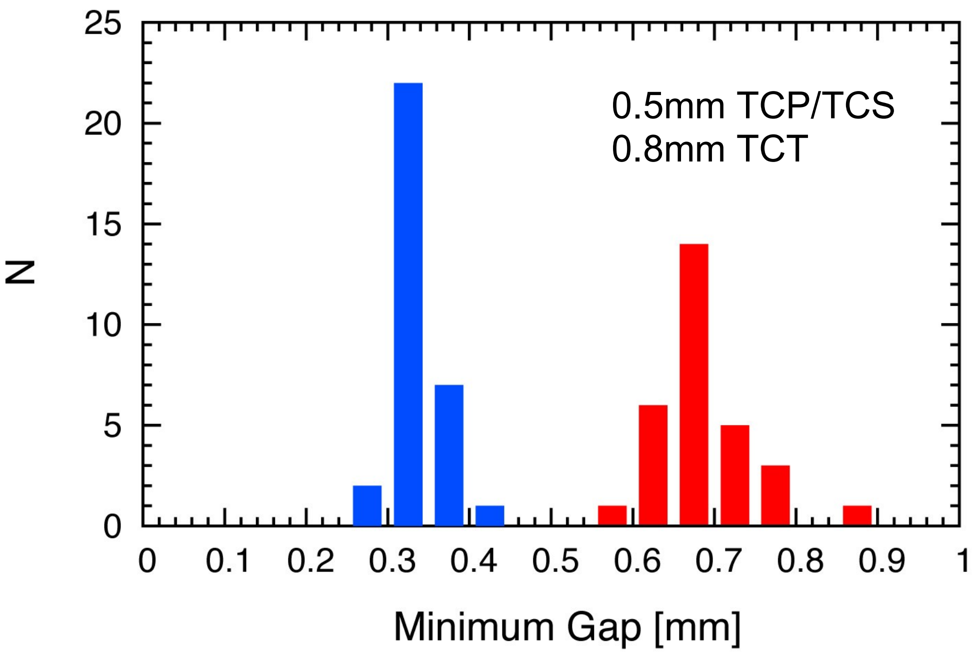


Closed collimator jaws

Open collimator vacuum tank with two jaws installed

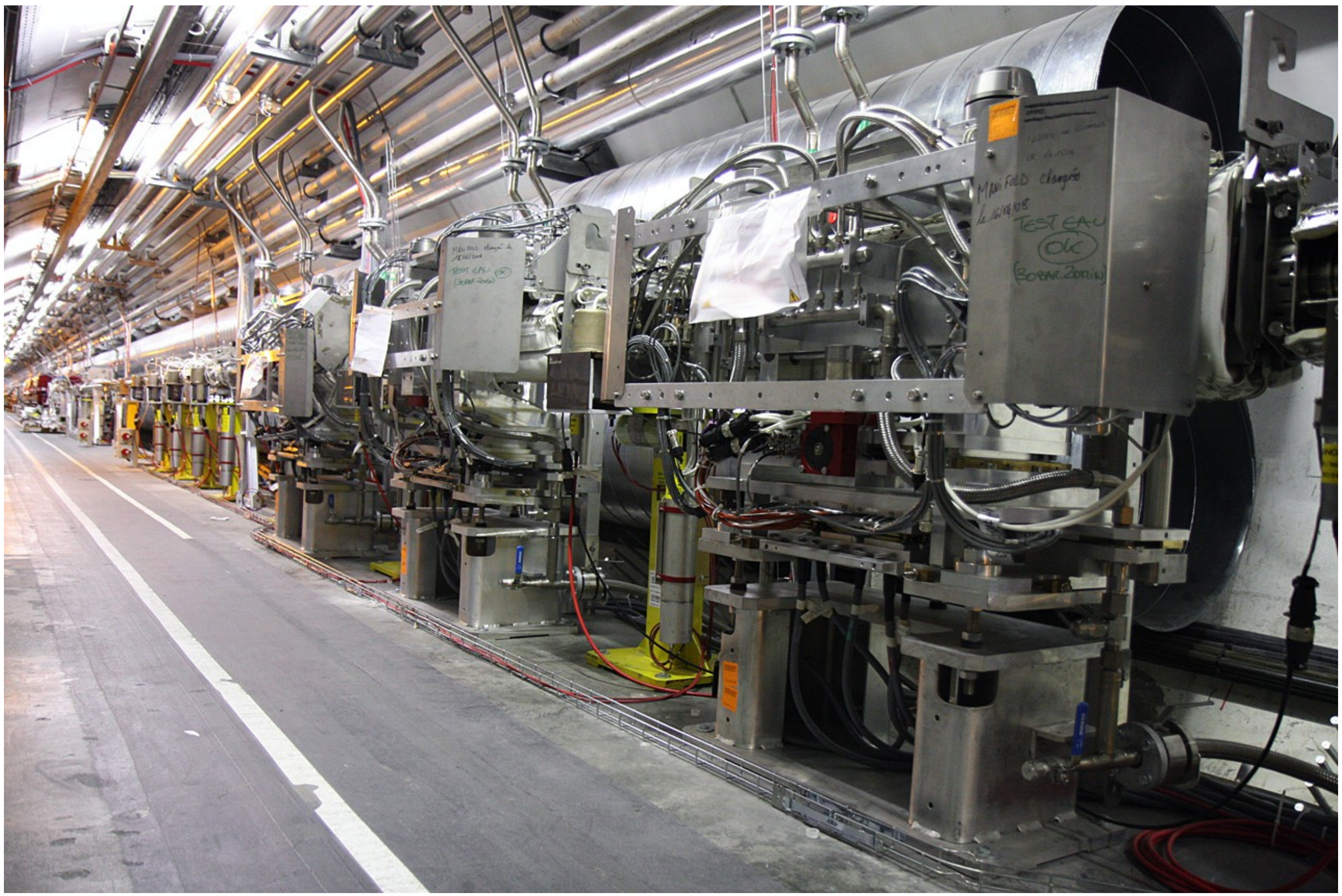
Production





Mechanical parameters (e.g. jaw flatness, minimum gap) continuously monitored during production. In case one of the parameter was out of tolerance collimator was placed in a suited location.

Installed Collimators

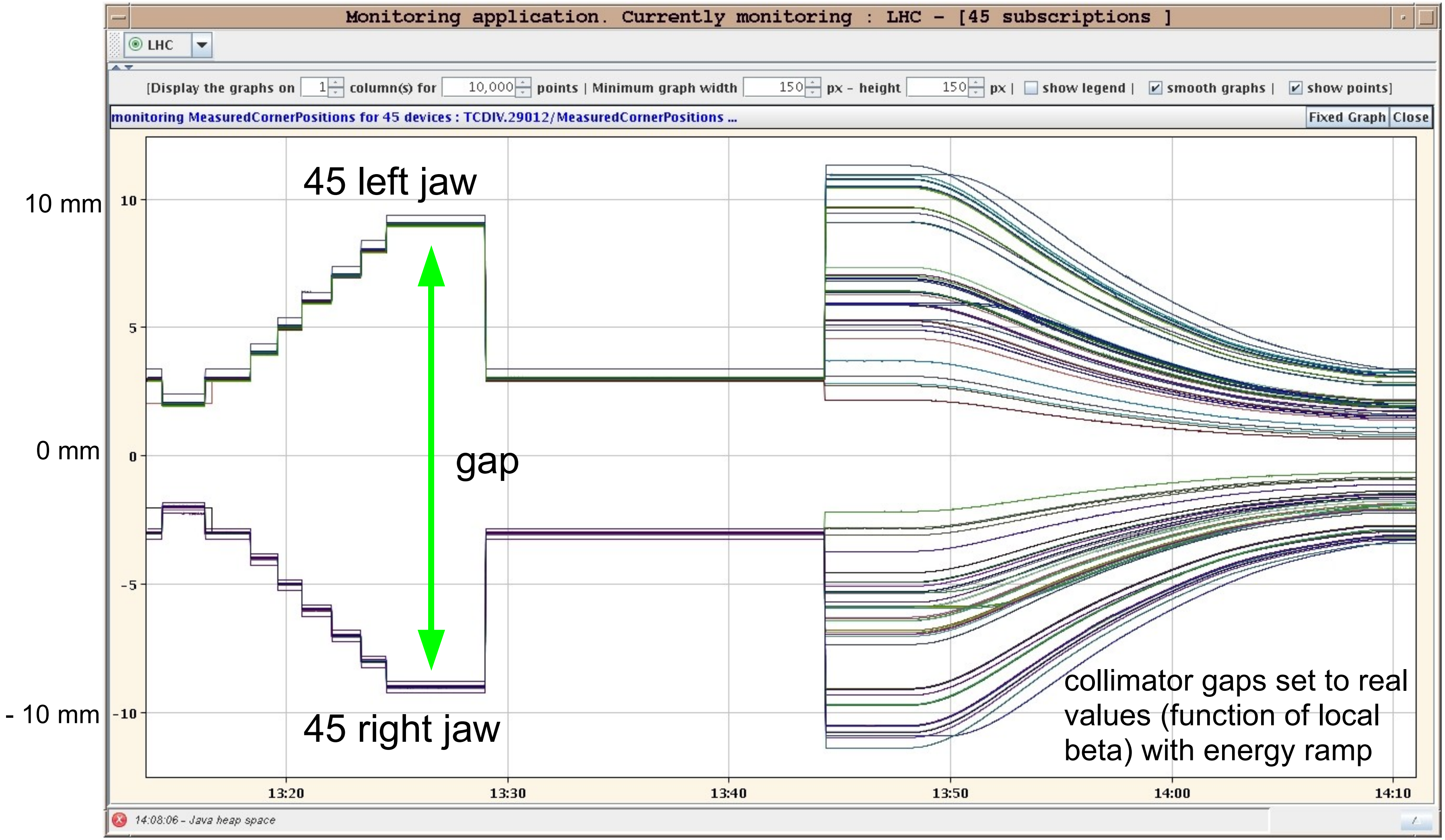


76 movable collimators installed in the LHC ring and the transfer lines (two jaws each.

Hardware commissioning complete.

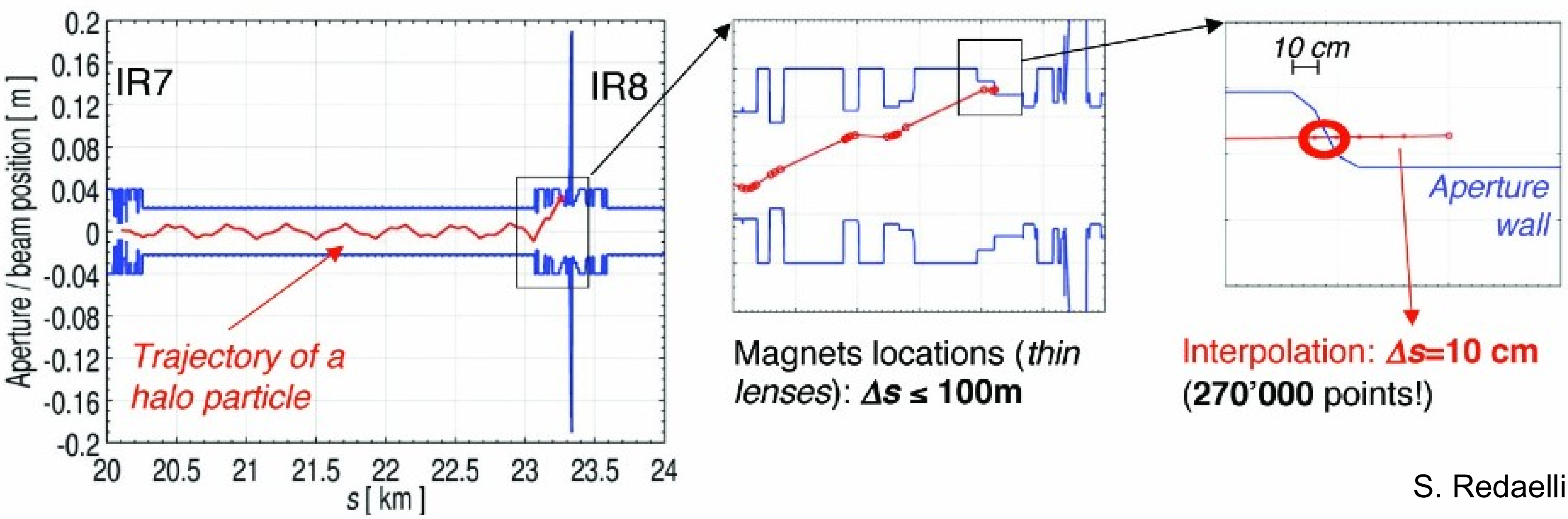
Additional 10 TCS type collimators and 6 special design beam collimators will be installed during first shut-down.

Collimator Steering



Simulation Tools

- MadX for optics generation (crossing, closed orbit, ...)
- Extended version of SixTrack for particle tracking (~5 million particles over 200 turns), including mechanical alignment errors.
- Applying LHC aperture model to the tracked particles to get the losses to the aperture with a 10 cm resolution.



S. Redaelli

Cleaning Efficiency

quench threshold
7.8×10^6 p/m/s at 7 TeV
7.0×10^8 p/m/s at 450 GeV

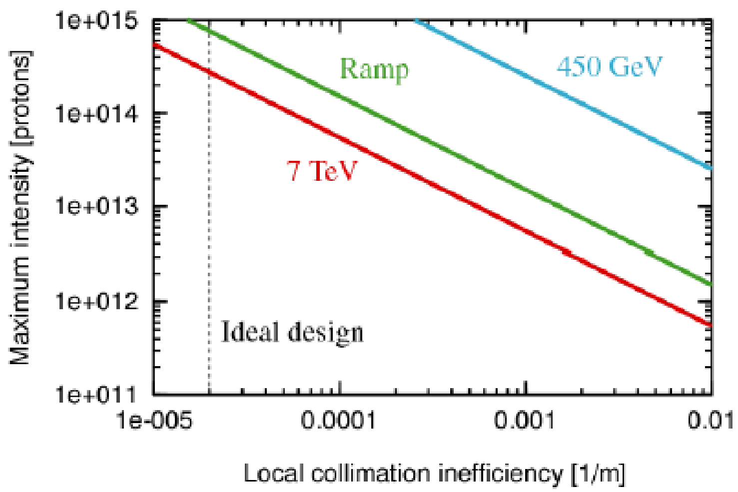
beam lifetime
e.g. 0.22h

allowed intensity

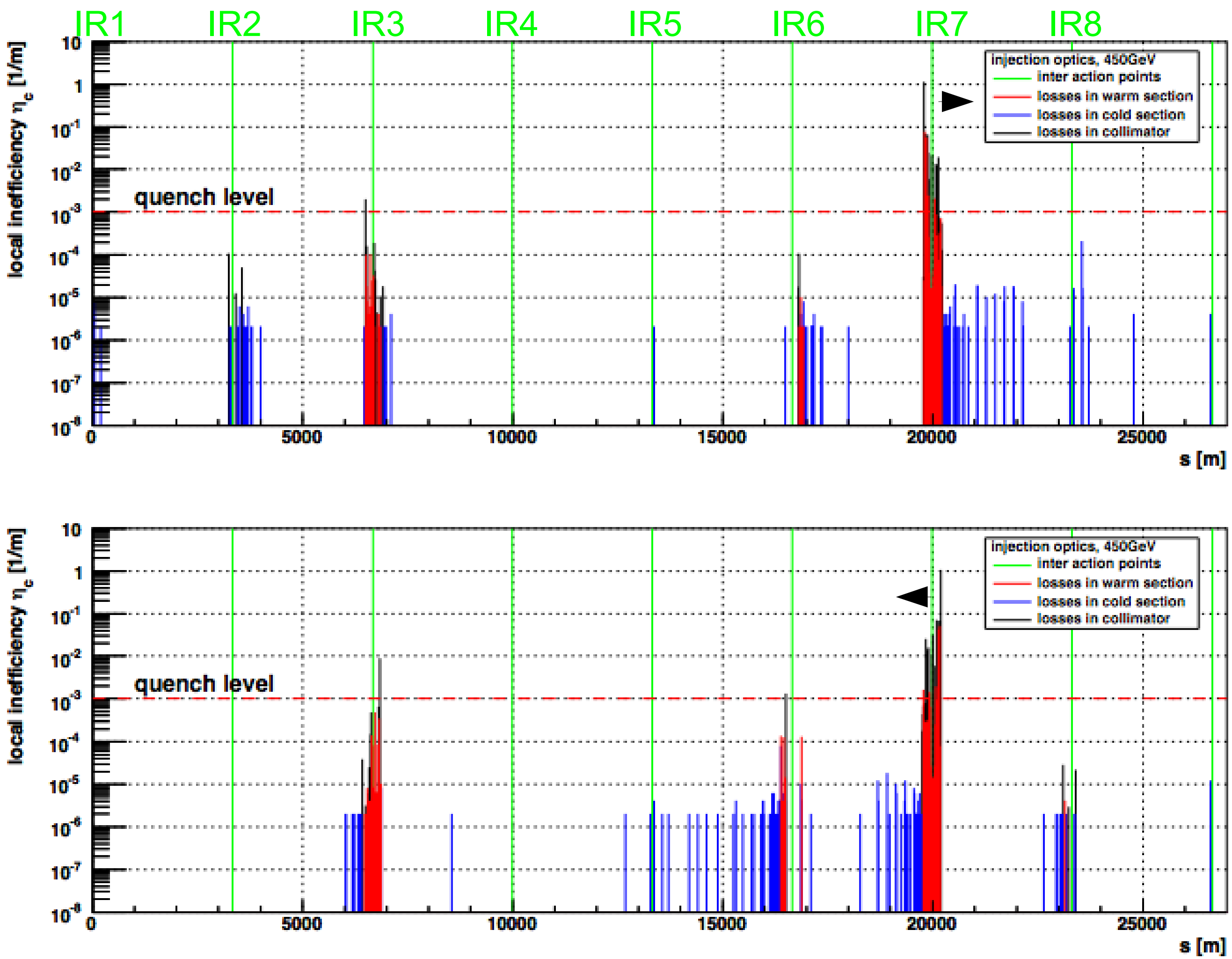
dilution length
50 m (simplified)

$$N_p^{max} \approx \frac{\tau \cdot R_q \cdot L_{dil}}{\eta_c}$$

cleaning inefficiency
(for $L_{dil} = 1$ m)
$\eta_c = 2 \times 10^{-5}$ m^{-1} at 7 TeV
$\eta_c = 1 \times 10^{-3}$ m^{-1} at 450 GeV

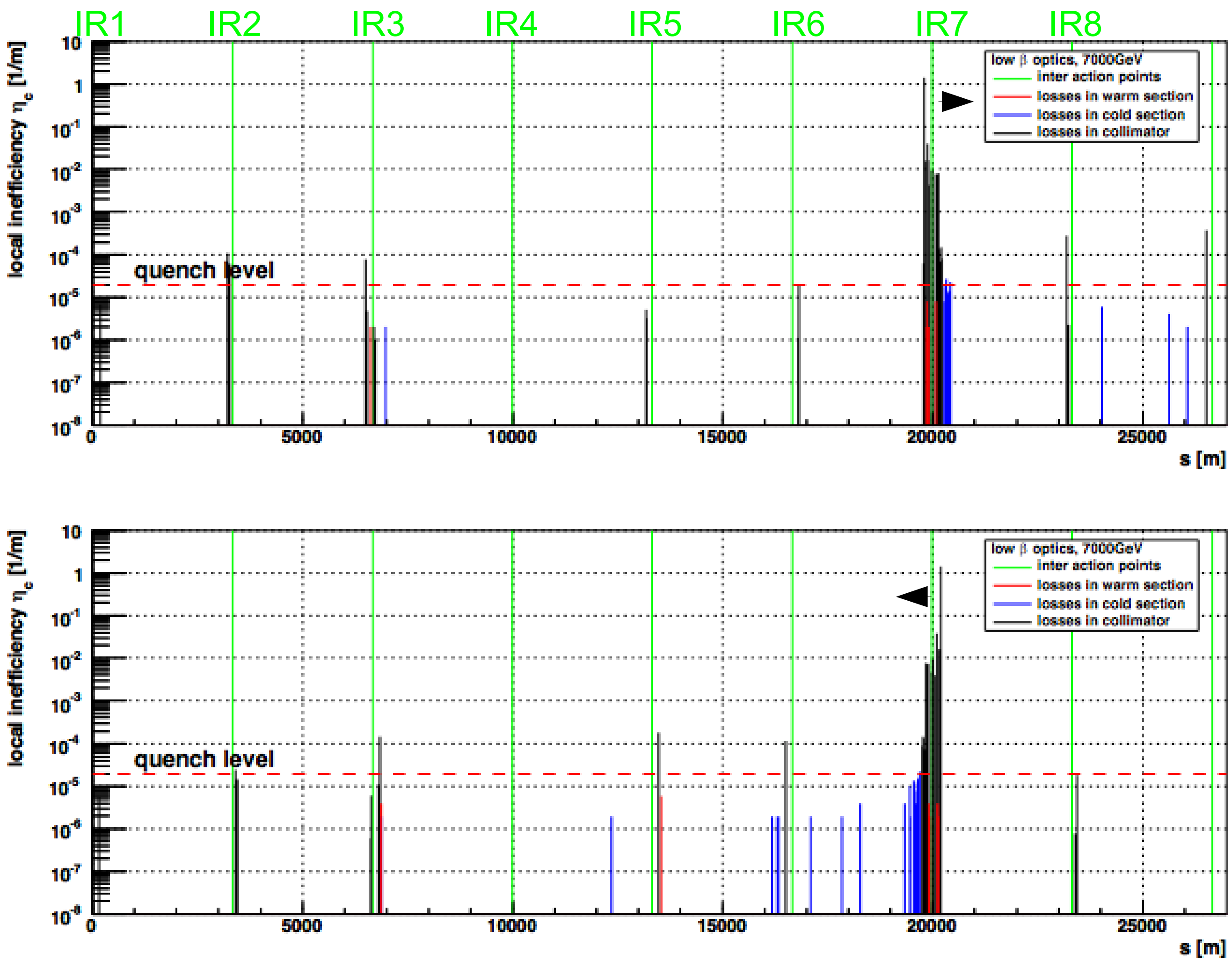


Phase 1 Performance
injection



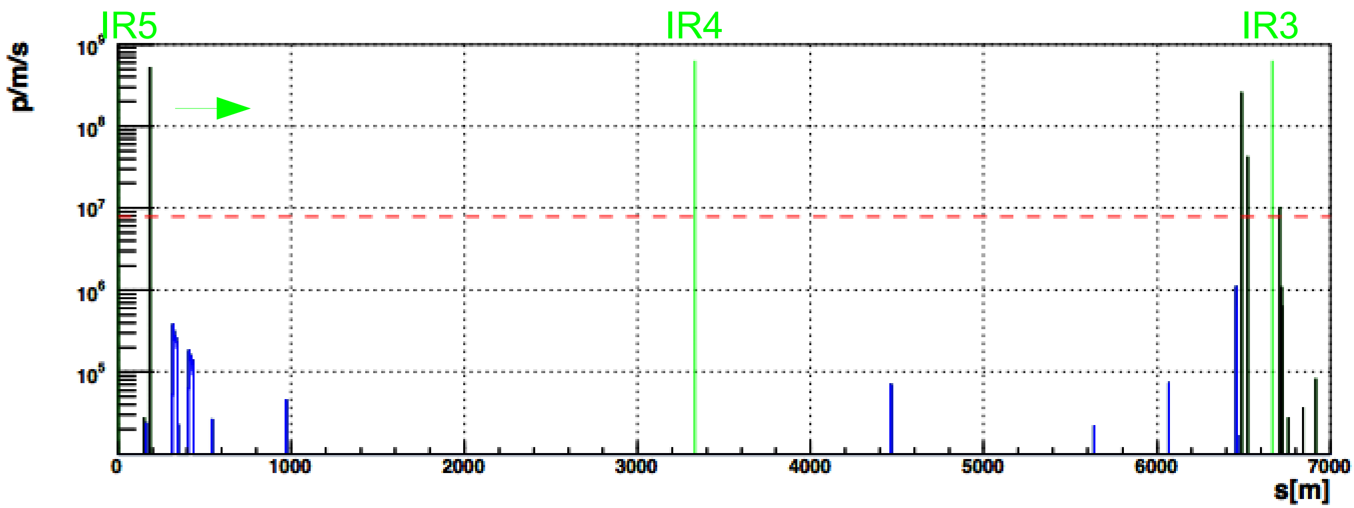
- 450 GeV injection optics horizontal betatron halo for beam1 (top) and beam2 (bottom)
- ideal machine
- quench level for 0.1h beam lifetime and nominal intensity $3x10^{14}$ p

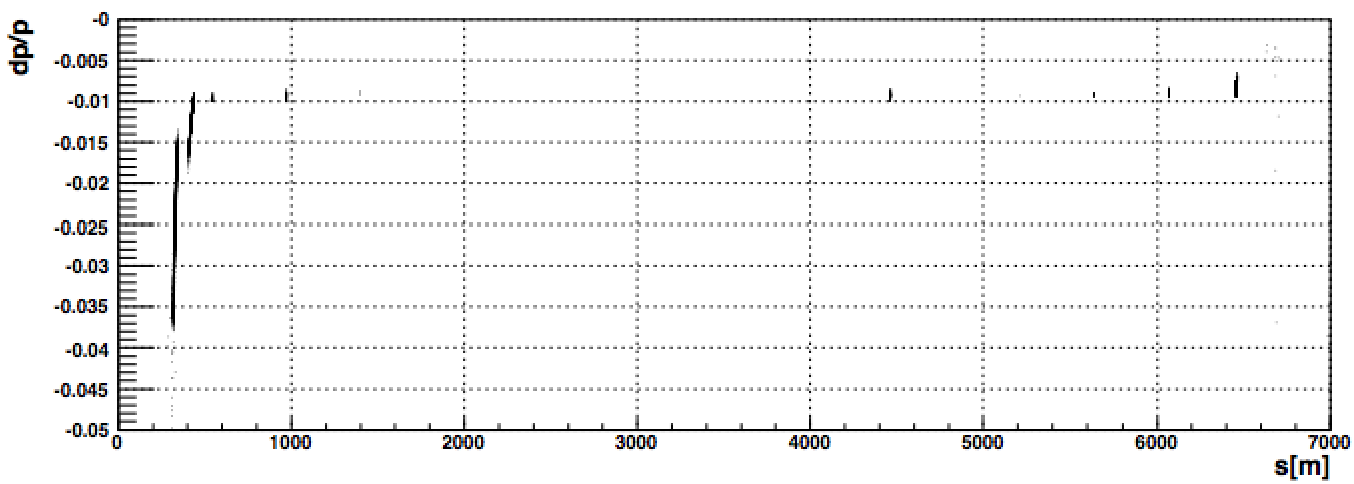
Phase 1 Performance
7TeV



- 7 TeV injection optics horizontal betatron halo for beam1 (top) and beam2 (bottom)
- ideal machine
- quench level for 0.2h beam lifetime and nominal intensity $3x10^{14}$ p
- Intensity reach up to 40% of nominal.

Losses from p-p Interactions



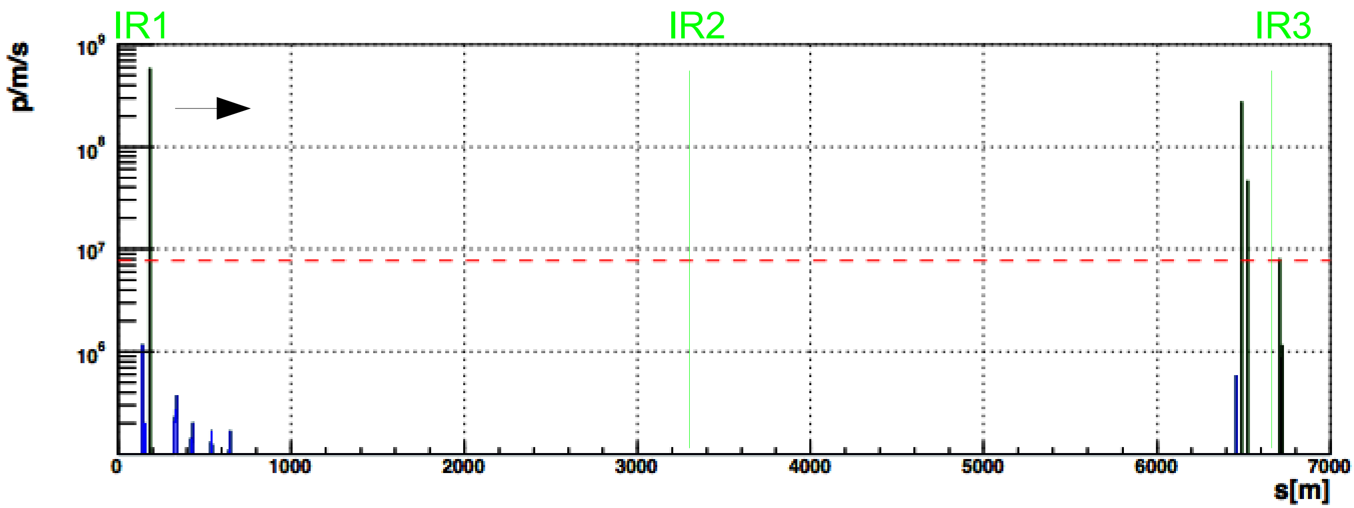


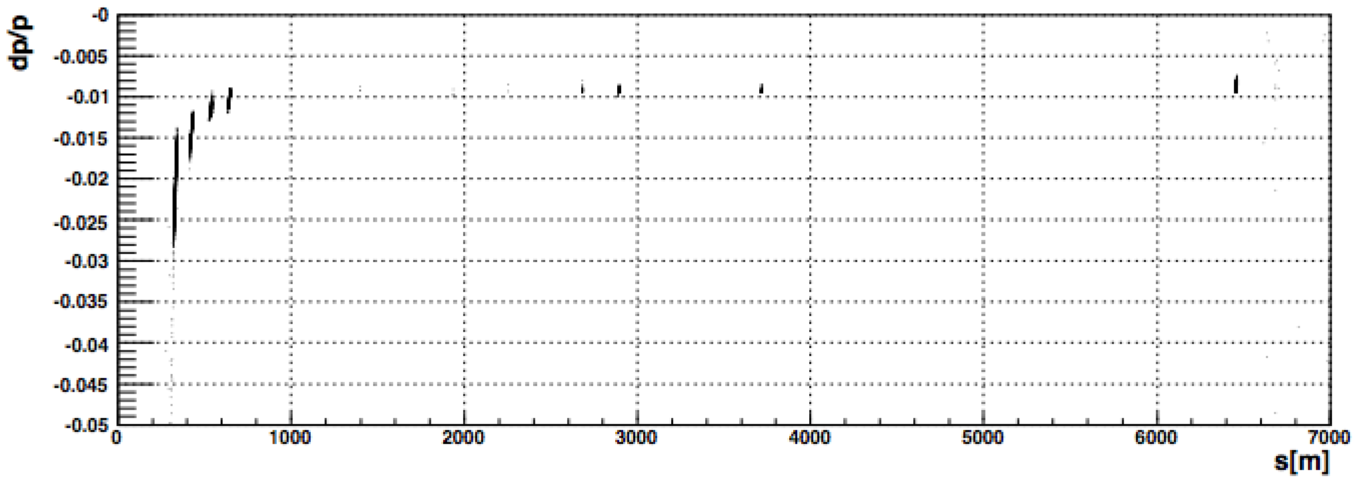
Proton losses from p-p interactions in IR5 (CMS) downstream to IR3 (momentum cleaning). Losses are scaled to peak luminosity for single diffractive and double pomeron exchange events.

Loss locations according to momentum offset of the protons.

Proton input from event generator.

Losses from p-p Interactions



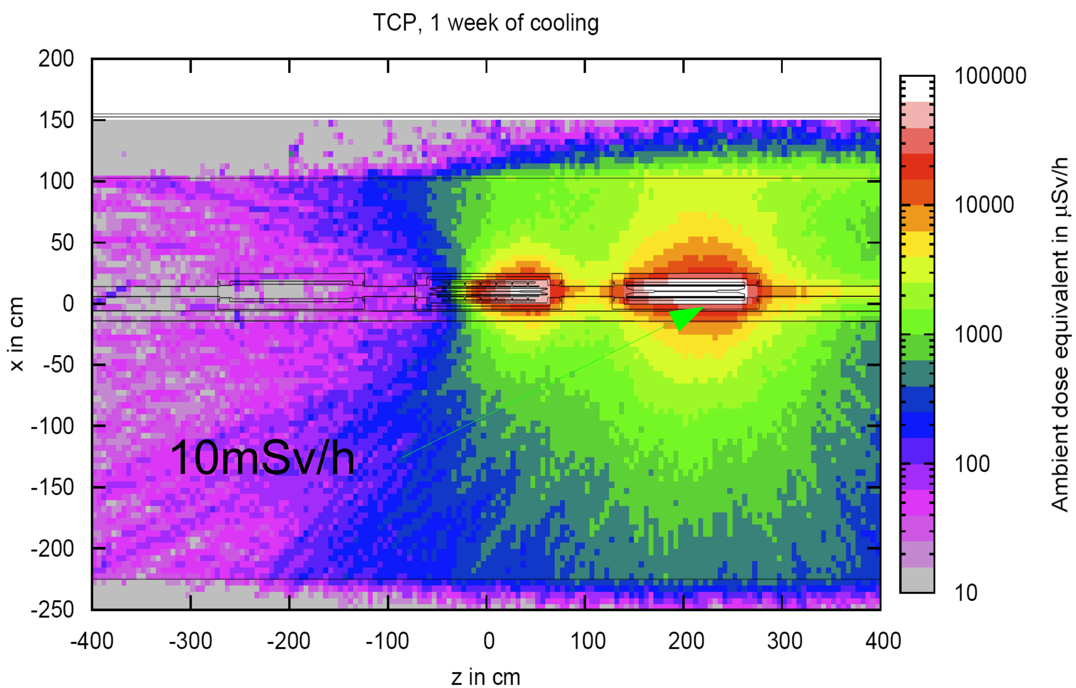


Proton losses from p-p interactions in IR1 (Atlas) downstream to IR3 (momentum cleaning). Losses are scaled to peak luminosity for single diffractive and double pomeron exchange events.

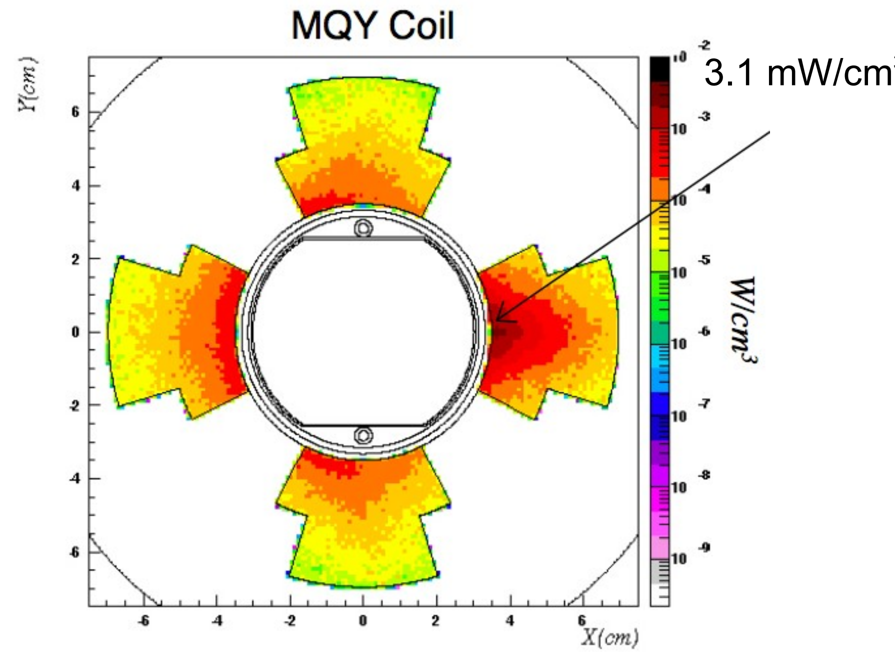
Loss locations according to momentum offset of the protons.

Proton input from event generator.

Energy Deposition Studies



S. Roessler

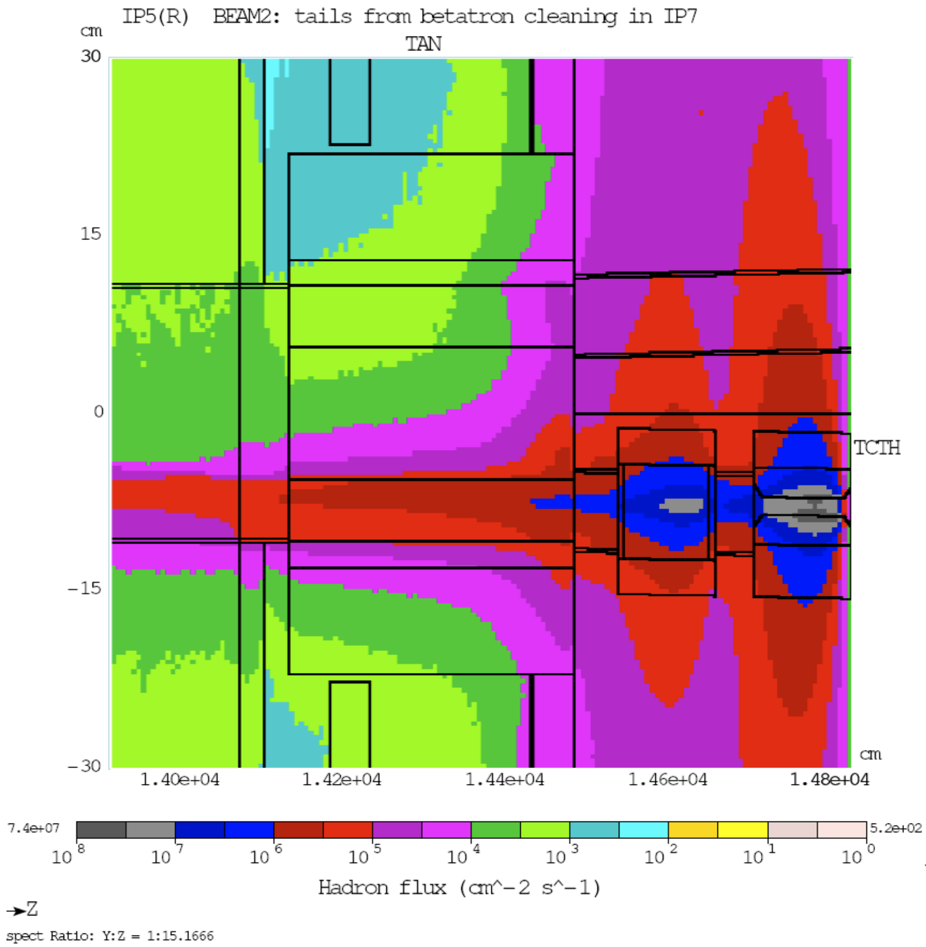


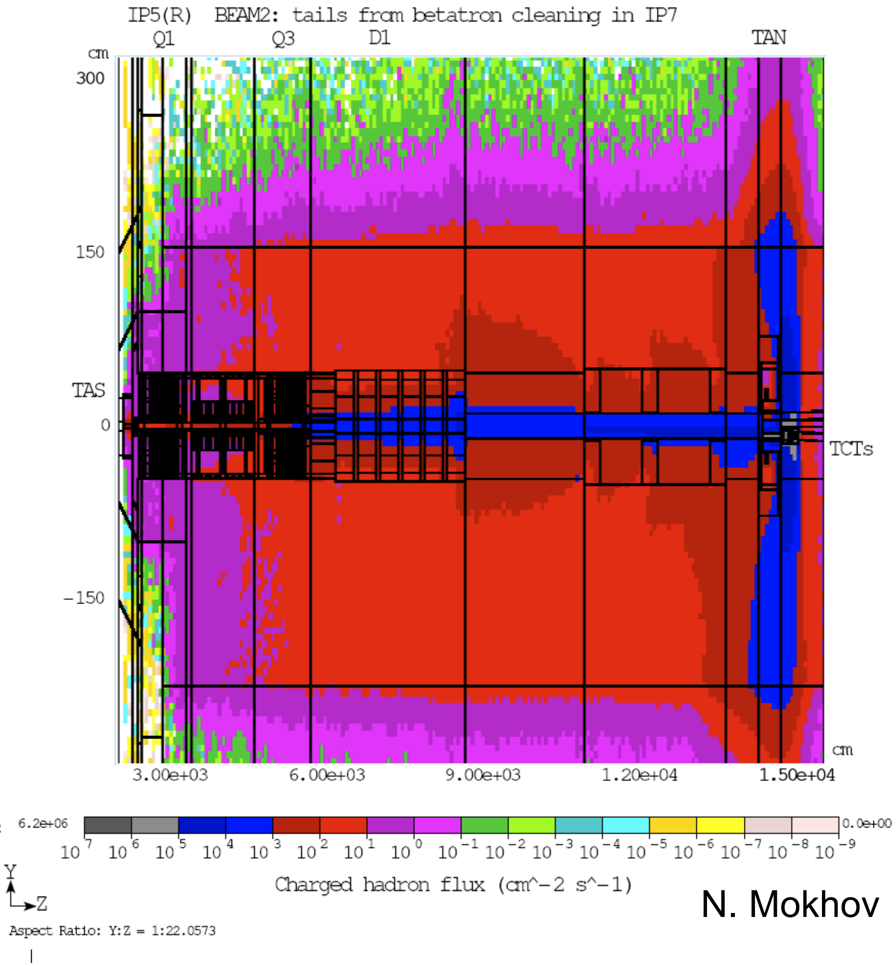
L. Sarchiapone

Activation level of primary collimators after one week of cool down. 180 days operation nominal annual losses 1.15×10^{16} p/beam, and horizontal halo.

Energy deposition on super conducting MQY coil generated by collimator for dump protection (quench limit 5mW/cm^3), 0.2h beam lifetime assumed.

Background Studies



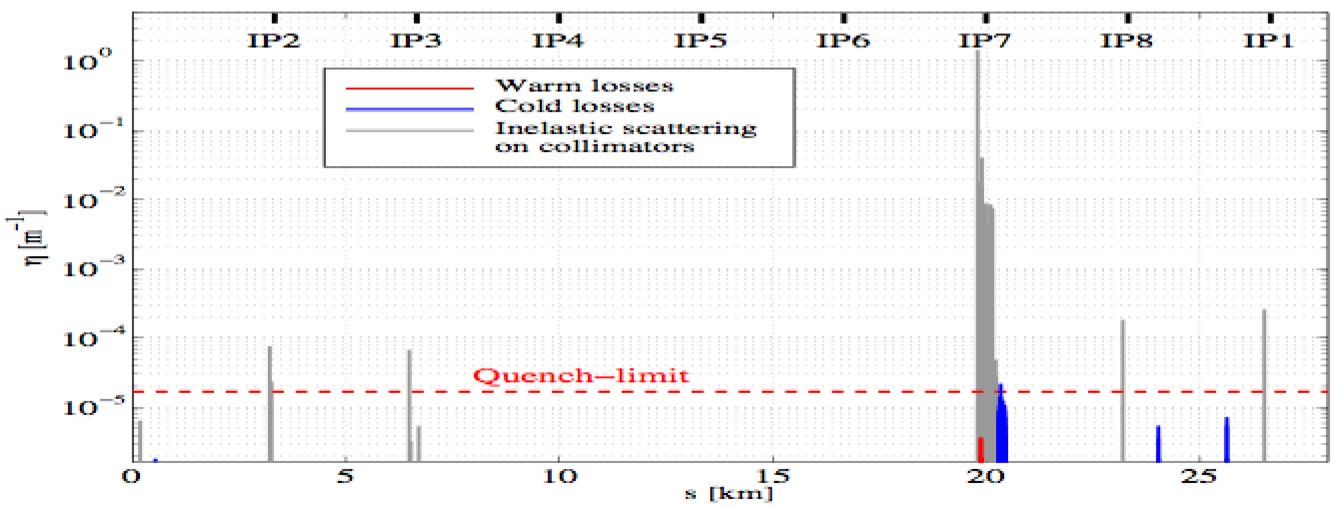


N. Mokhov

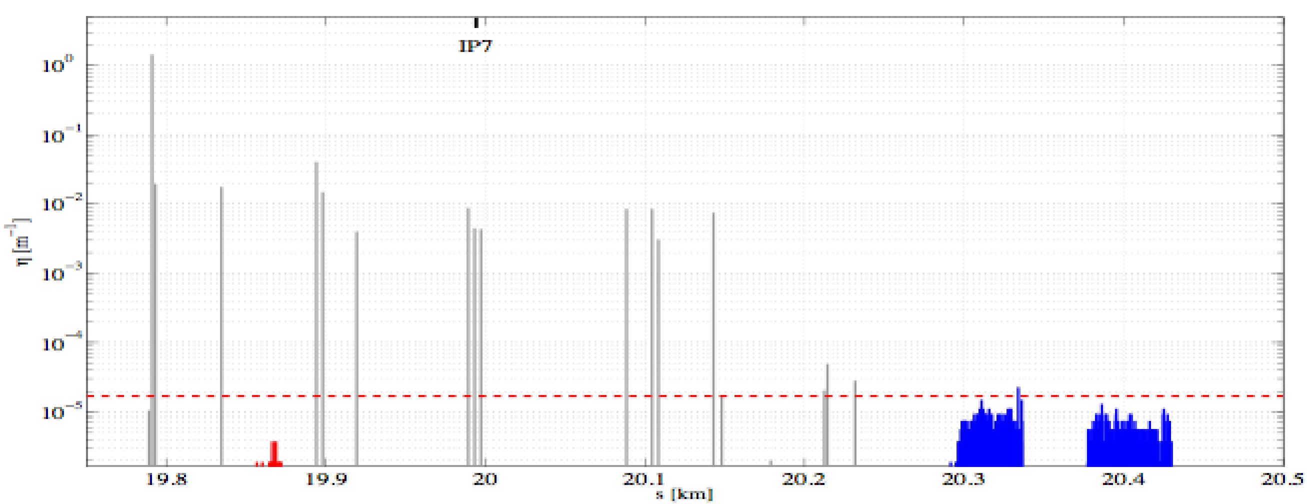
Hadron flux in TCT TAN region in IR5 (from betatron halo)

Charged hadrons from 20m to 150m from IR5

Upgrad Studies



Performance of the system using metallic secondary collimators (1m long) in the reserved locations. Standard settings, ideal machine.



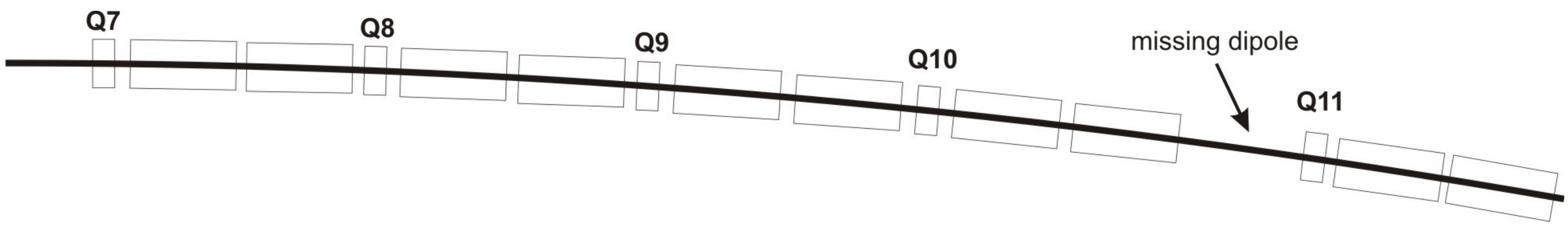
Zoom to the cleaning insertion, the intensity is limited by the losses in the dispersion suppressor region at the end of the cleaning insertion.

C. Bracco

Proposal for Phase II Efficiency Improvement

Problem from the cleaning efficiency side of view of the Phase I and Phase II system are the losses in the dispersion suppressor after the cleaning insertions.

Idea for a possible Phase II system is to add additional collimators in the dispersion suppressor at the location of the seen loss peaks.



=> make use of the space available from the missing dipole.

Proposal for Phase II Efficiency Improvement

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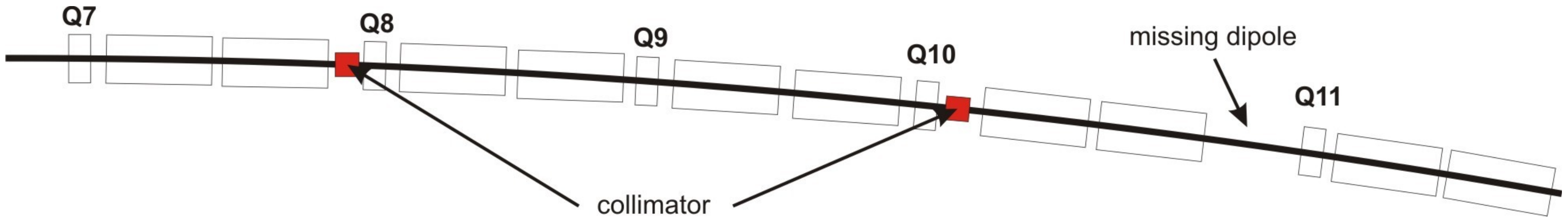
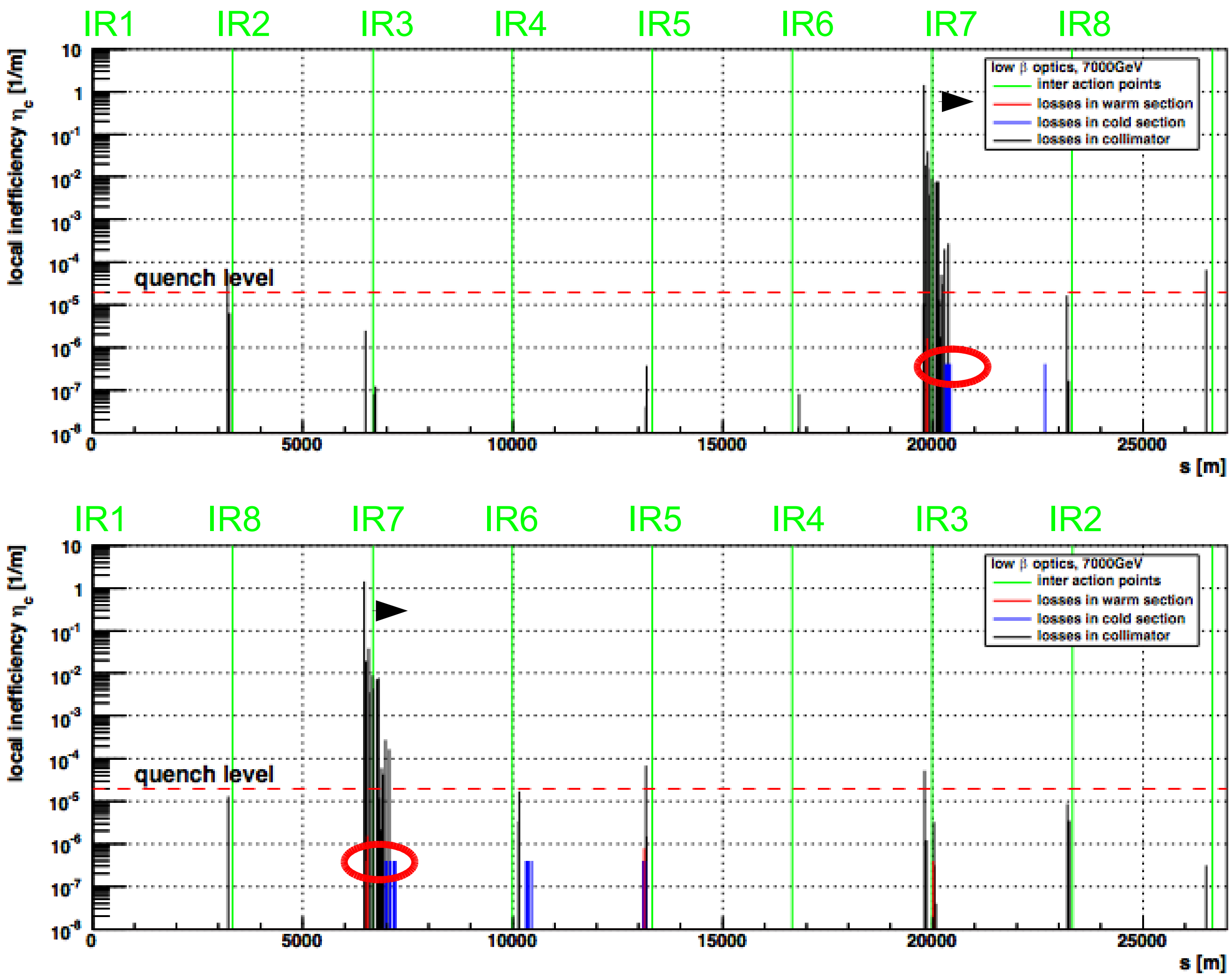


symmetric shift of the two dipole magnets at the beginning and the end of the dispersion suppressor by 3 m.

System Performance



Lossmaps around the LHC for beam1 (upper plot) and beam2 (lower plot) using metallic secondaries at standard settings (7σ), carbon secondaries at injection opening and "cryogenic" collimators (1m copper) placed at 300m and 387m from IR7, opening 15 σ.

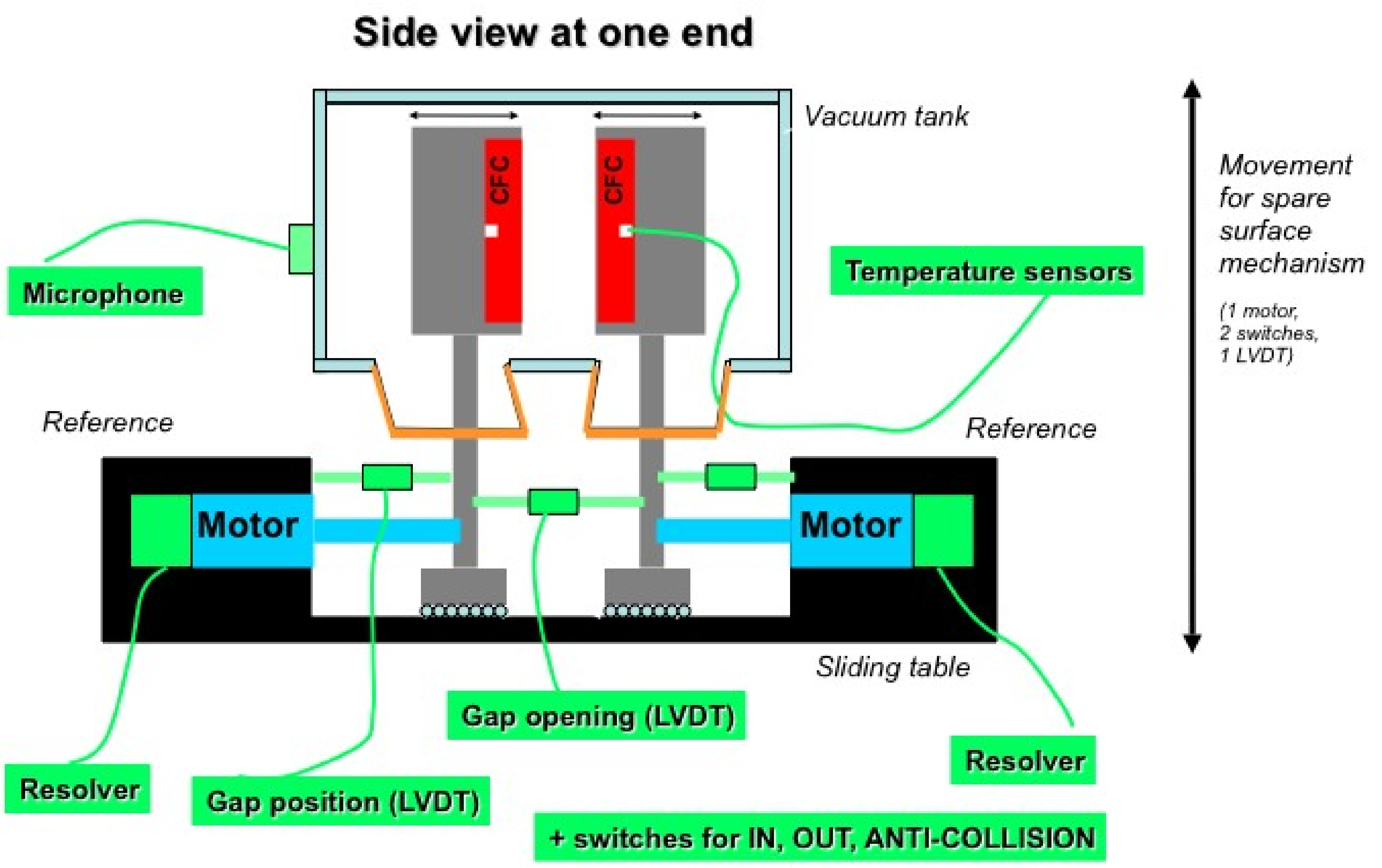
Improvement of cleaning efficiency approximately a factor 30.

Summary

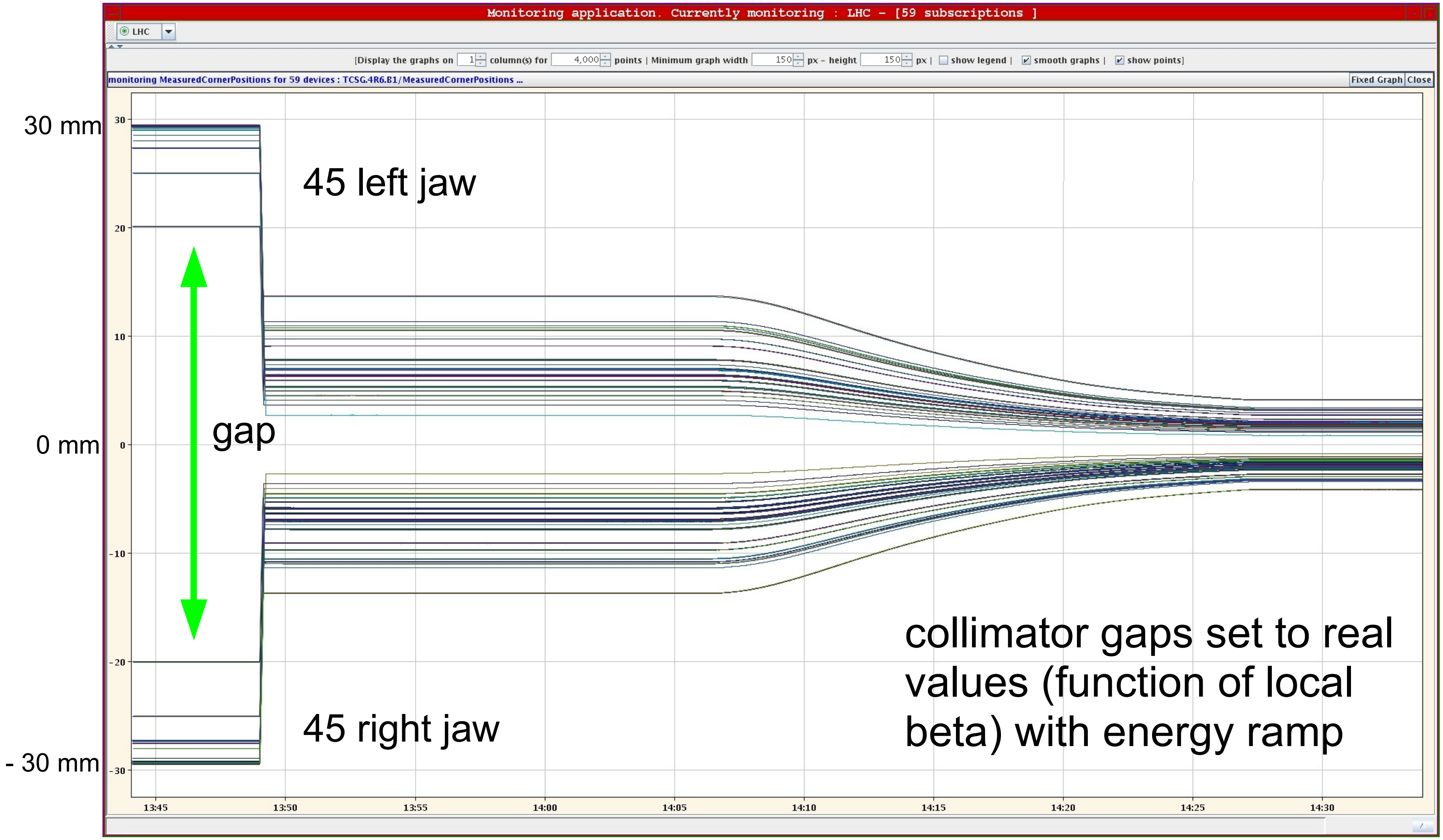
- 76 collimators installed in the LHC ring and its transfer lines and ready for startup.
- Hardware commissioning finished.
- Steering of collimators is extensively tested from control room, e.g. energy ramp (including magnets whenever possible).
- Simulation tools available to access system performance
- Performance reach of full Phase I system up to 40% of nominal intensity.
- Beam lossmaps as input for energy deposition studies, activation studies and background studies for the experiments.
- Upgrade studies for Phase II are ongoing, improvement of up to factor 30 possible.

Spare Slides

Sensor Positions

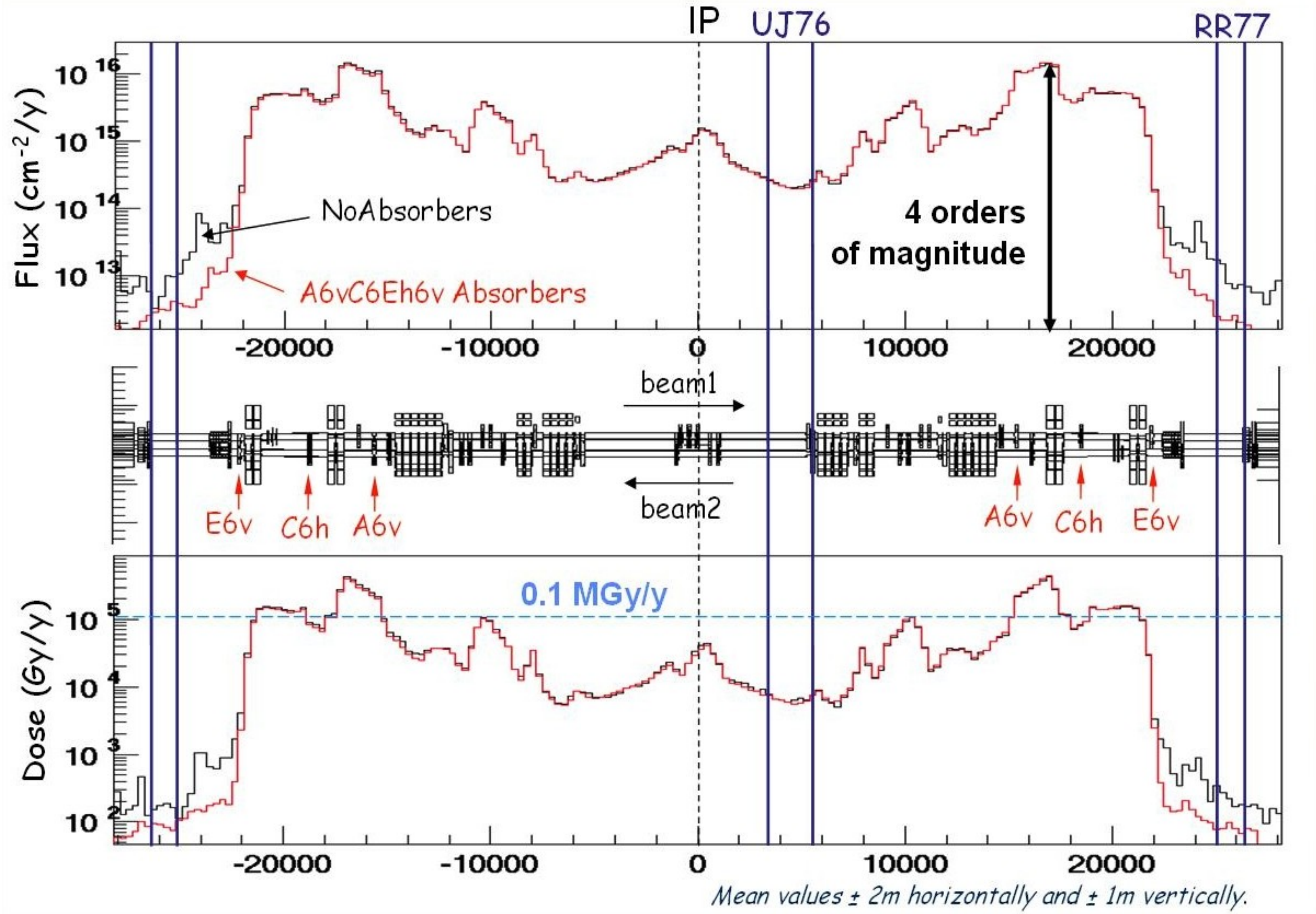


Status



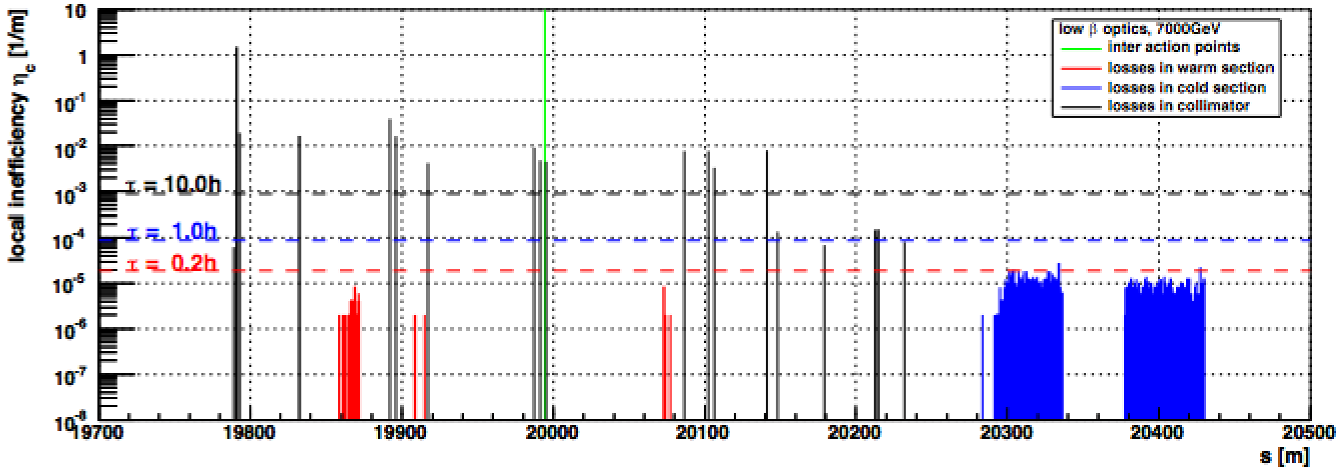
Monitoring application. Currently monitoring : LHC - [59 subscriptions]
monitoring MeasuredCornerPositions for 59 devices : TCSG.4R6.B1/MeasuredCornerPositions ...
30 mm
0 mm
- 30 mm
45 left jaw
gap
45 right jaw
collimator gaps set to real values (function of local beta) with energy ramp
13:45
13:50
13:55
14:00
14:05
14:10
14:15
14:20
14:25
14:30

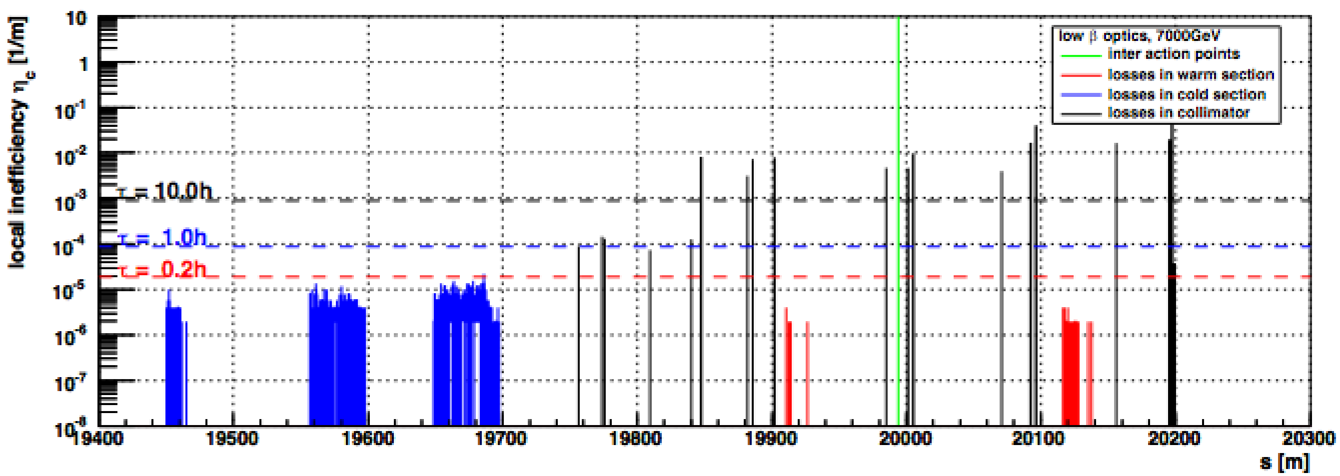
Energy Deposition (Fluka)



K. Tsoulou, et al.

Phase 1 Performance
7TeV (zoom to IR7)

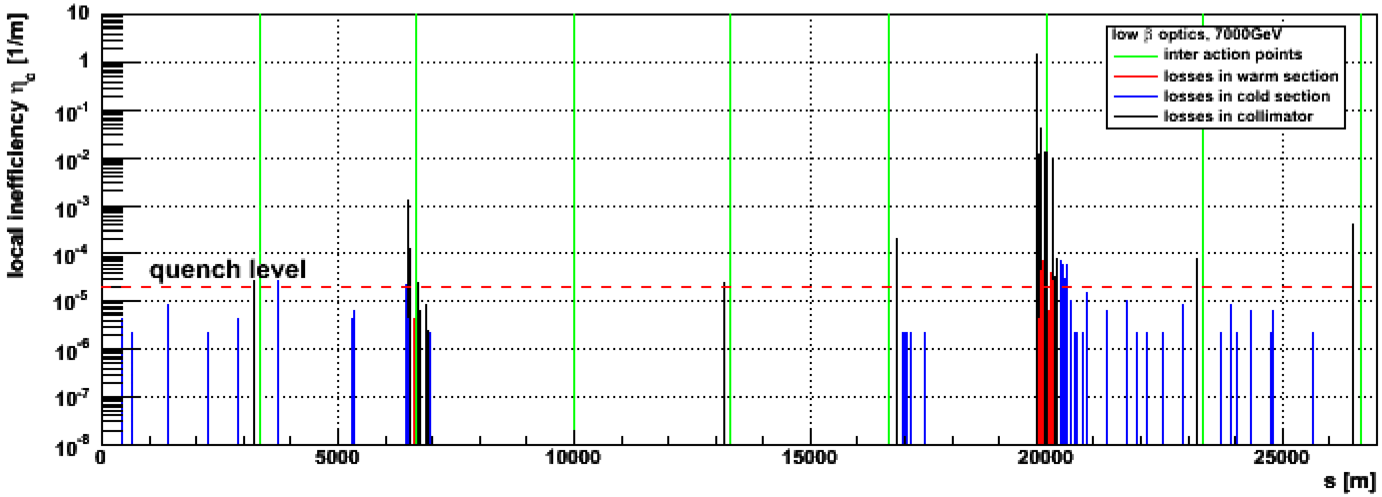


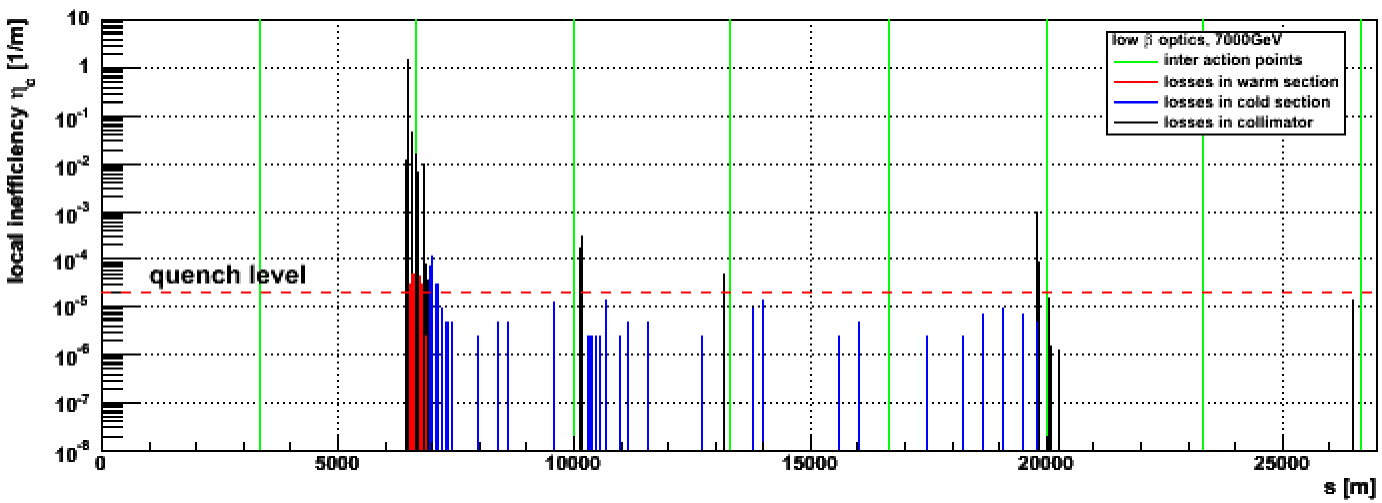


- 7 TeV injection optics horizontal betatron halo for beam1 (top) and beam2 (bottom)
- ideal machine
- quench level for 0.2h beam lifetime and nominal intensity $3x10^{14}$ p
- Intensity reach up to 40% of nominal.

Performance for Start-up

5TeV relaxed collimator settings





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