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Cleaning performance and beam losses with 0.6 m long primary collimators at IR7

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Contents:

Motivation

- Length of primary collimators (TCPs) of the momentum cleaning (IR3) were increased from 0.2 m to **0.6 m**, as proposed by I. Bayshev (39th LCWG meeting, 04/06/2005):

  → More particles are absorbed in the TCP and hence less energy is deposited in the downstream element - safer for quenches and improved lifetime of components

- After finalizing the betatron cleaning layout (58th LCWG meeting, 09/05/2005), by including active absorbers (TCLA's), we wanted to investigate the option of longer TCP also for IR7

We need to assess:

1) Cleaning performance of the system with long TCPs

2) Deposited energy in cold magnets and lifetime of various components

→ *Inputs for FLUKA team*

Simulation tools

Halo generation and tracking
done with SixTrack + K2

⇒ *Halo production in the two stage collimation system and multi-turn tracking of secondary and tertiary halos (δE/E, field errors, correction schemes, …)*

⇩

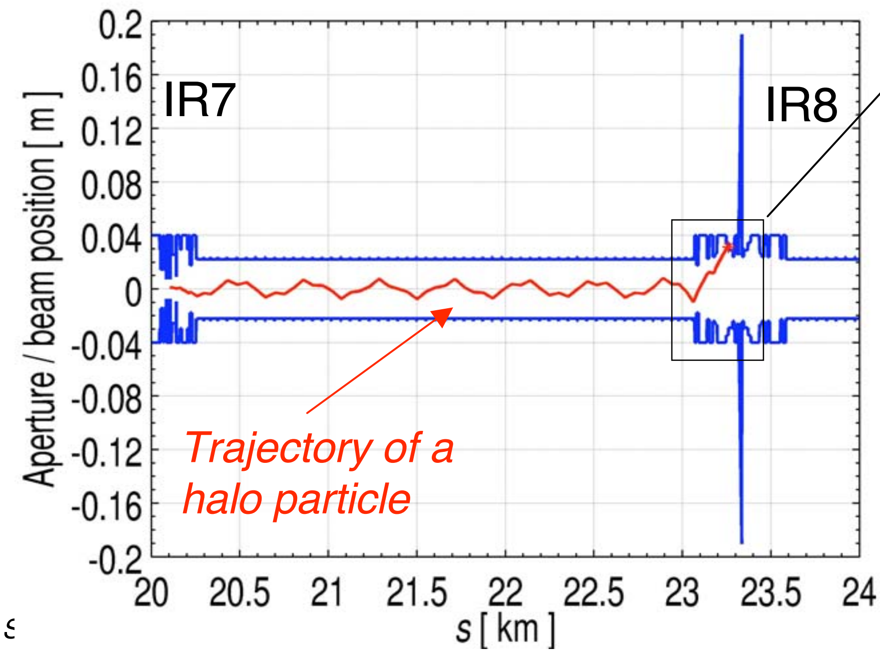
Trajectories of secondary and tertiary halo part's

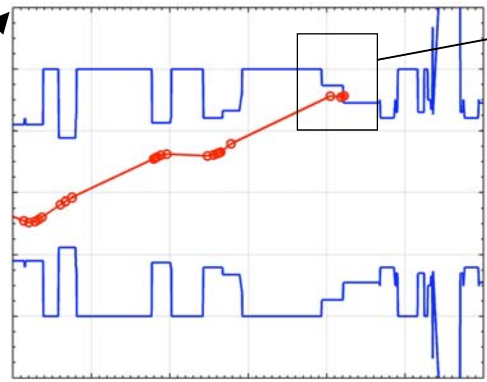
⇩

Aperture model for the full LHC ring,
10 cm longitudinal spatial resolution.

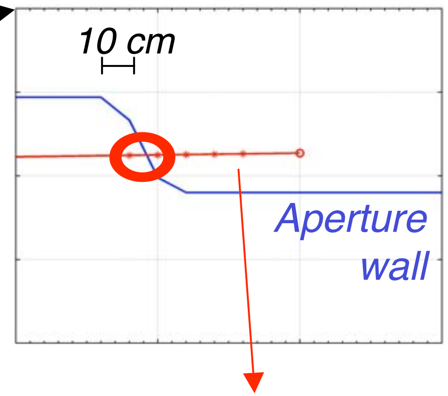
⇒ *Reconstruction of beam trajectory provides longitudinal and transverse distributions of losses*

Off-line treatment of effects such as closed orbit, misalignments, kicks from D1… D4 magnets





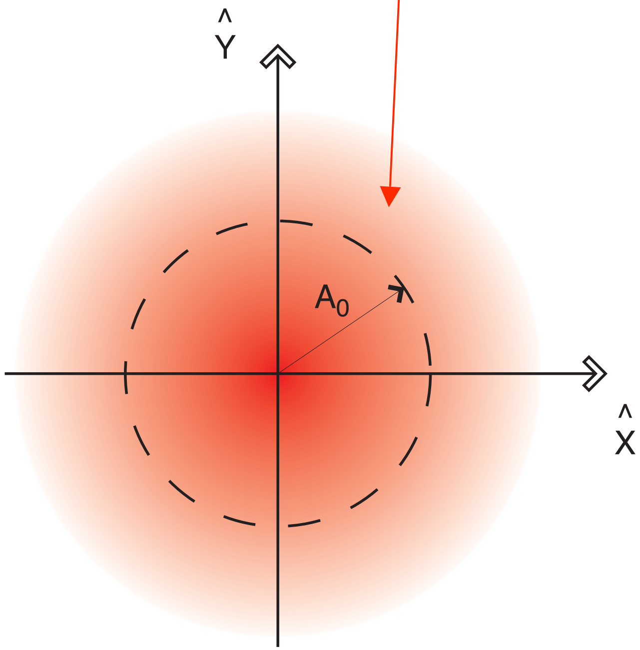
Magnets locations (*thin lenses*): $\Delta s \leq$ **100m**



Interpolation: Δs**=10 cm**
(**270'000** points!)

Calculation of the cleaning inefficiency (leakage rate)

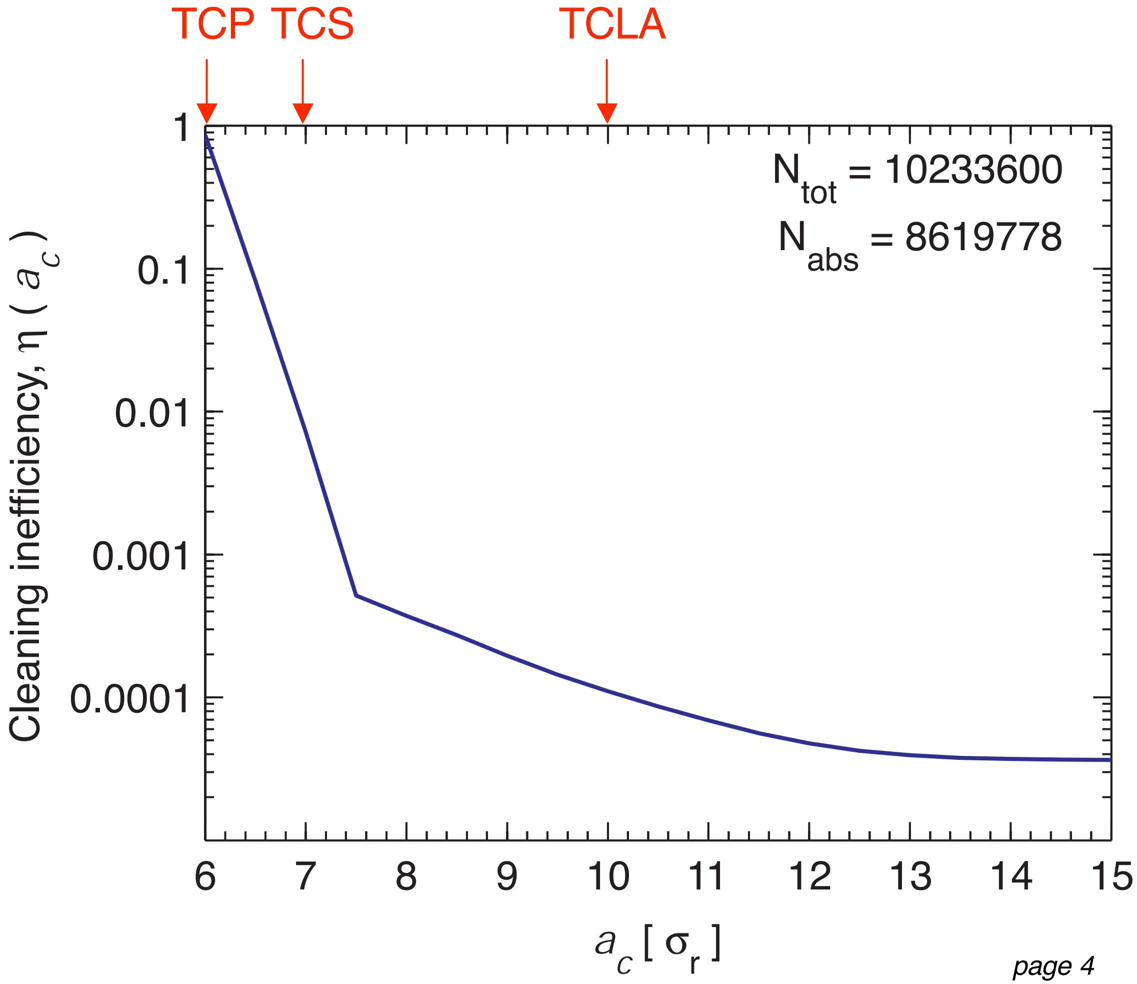
$$\boxed{\eta_c(A_0) = \frac{N_p(A > A_0)}{N_{\rm abs}}}$$



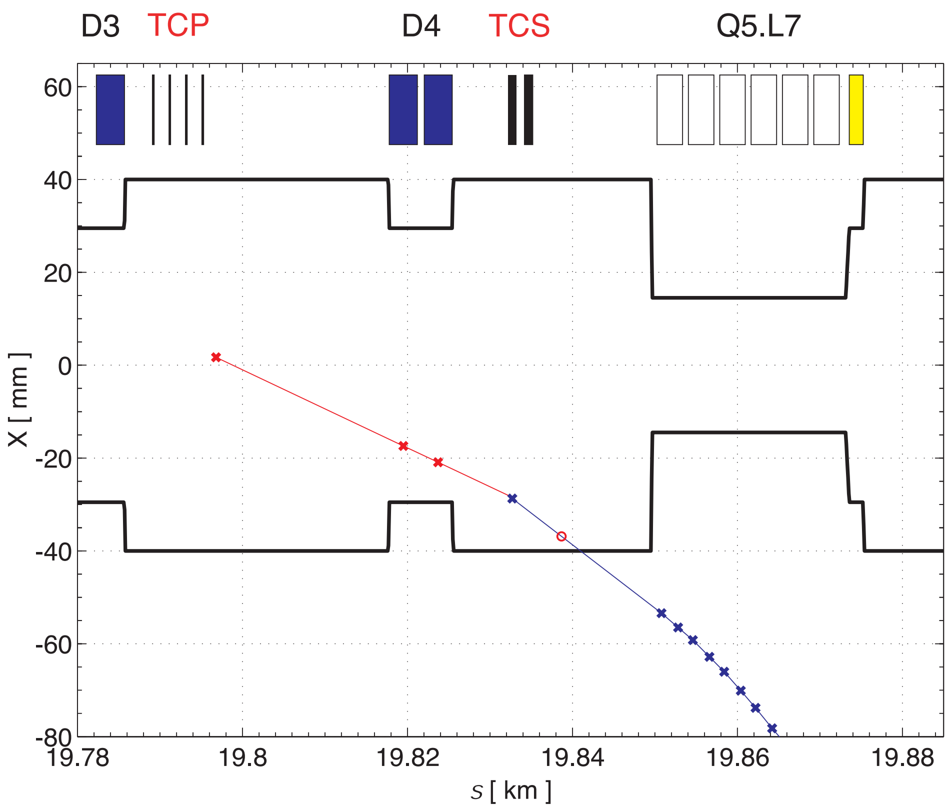
Approximated calculation of the halo population…

Exact location of losses around the ring are required!

Example - Horizontal halo at 7 TeV,
10^6 particles tracked for 200 turns
$A_{TCP} = 6\sigma$, $A_{TCS} = 7\sigma$; $A_{TCLA} = 10\sigma$



Calculation of beam loss patterns



Follow the trajectory of each halo particle, see where it is lost and calculated the *Loss rate of protons per unit length*:

$$\boxed{\frac{dN}{dt\,ds} = \frac{1}{ds}\frac{dN(ds)}{\tau_b}\frac{N_{\mathrm{Nom.}}}{N_{\mathrm{Abs.}}}}$$

Assumptions on:

Beam intensity $\rightarrow$ $N_{\mathrm{Nom.}} = 3\times10^{14}\ \mathrm{p}$

Beam lifetime $\rightarrow$ $\begin{cases} \tau_b^{\mathrm{inj}} = 0.1\ \mathrm{h} \\ \tau_b^{\mathrm{top}} = 0.2\ \mathrm{h} \end{cases}$

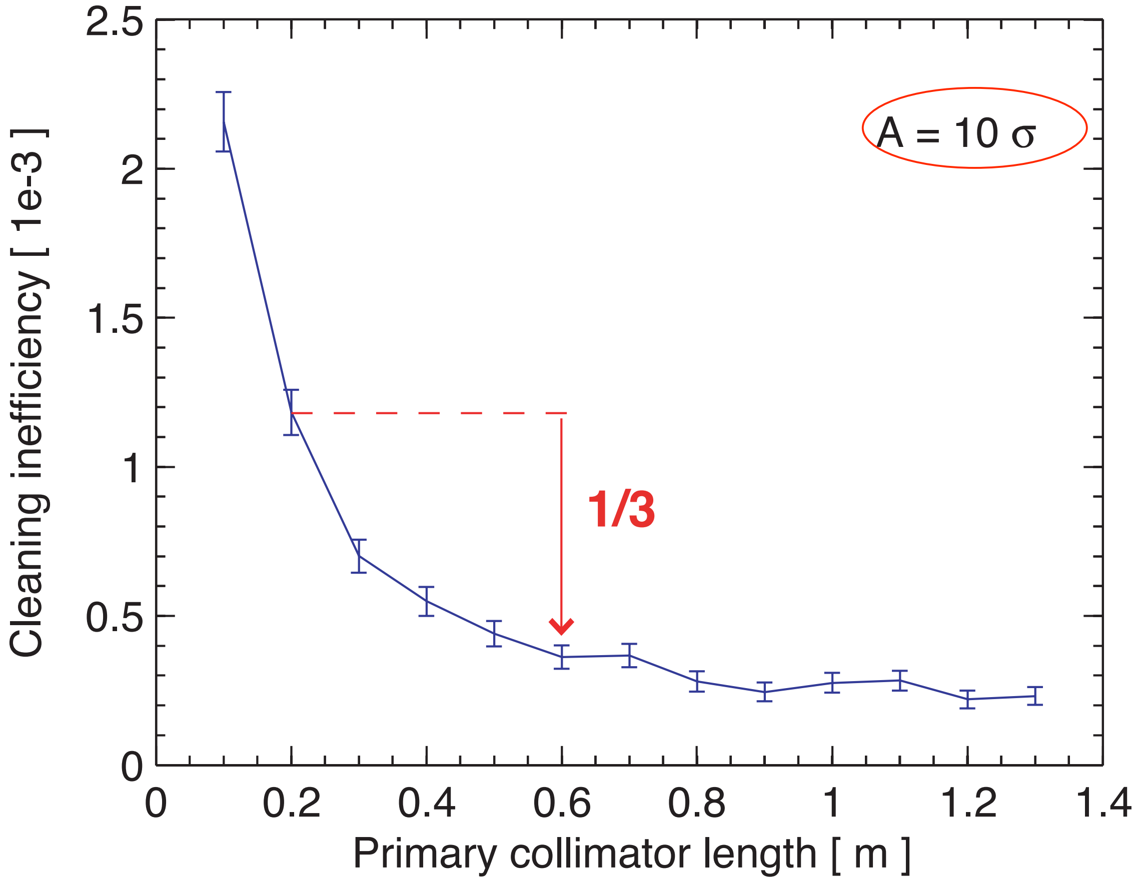
The local loss rate of protons must be compared with the *quench limit of superconducting magnets*:
(standard values are assumed until results of more precise estimates will be available)

$$\begin{cases} R_{\mathrm{Q}}^{\mathrm{inj}} = 7\times10^{8}\ \mathrm{p/m/s} \\ R_{\mathrm{Q}}^{\mathrm{top}} = 7.6\times10^{6}\ \mathrm{p/m/s} \end{cases}$$

Simulation setup (see G. Robert-Demolaize, 56th LCWG of 02/05/2005)

- Simulation included all the collimators of the layout (V6.5) - Phase I collimation system
  - → TCP, TCS and TCLA of IR3 and IR7
  - → TCT around detector regions (7 TeV only)
  - → Protection devices (TCLI, TCDQ, TDI)
  - → TCLP to protect from debris from experiments
- Nominal gaps are considered
- Perfect machine (no optics errors) and perfect cleaning

Simulation results - Cleaning inefficiency at 450 GeV



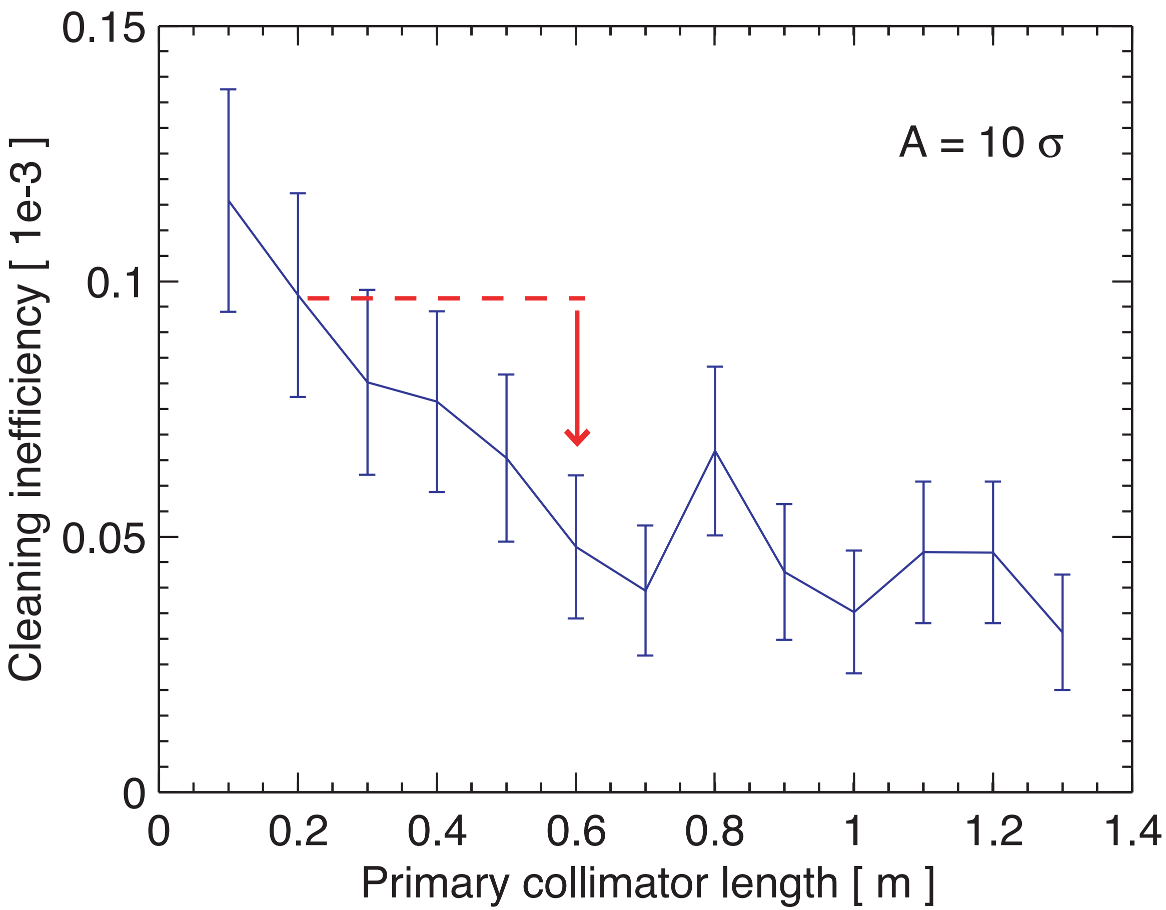
$$\eta_c(A_0) = \frac{N_p(A > A_0)}{N_{\mathrm{abs}}}$$

Horizontal halo, perfect cleaning, N=256000 tracked particles per case.

Longer TCP's improve the cleaning inefficiency - gain a **factor 3** at A = 10 σ!

No significant improvement for L_{TCP} above 0.6 m.

Simulation results - Cleaning inefficiency at 7 TeV



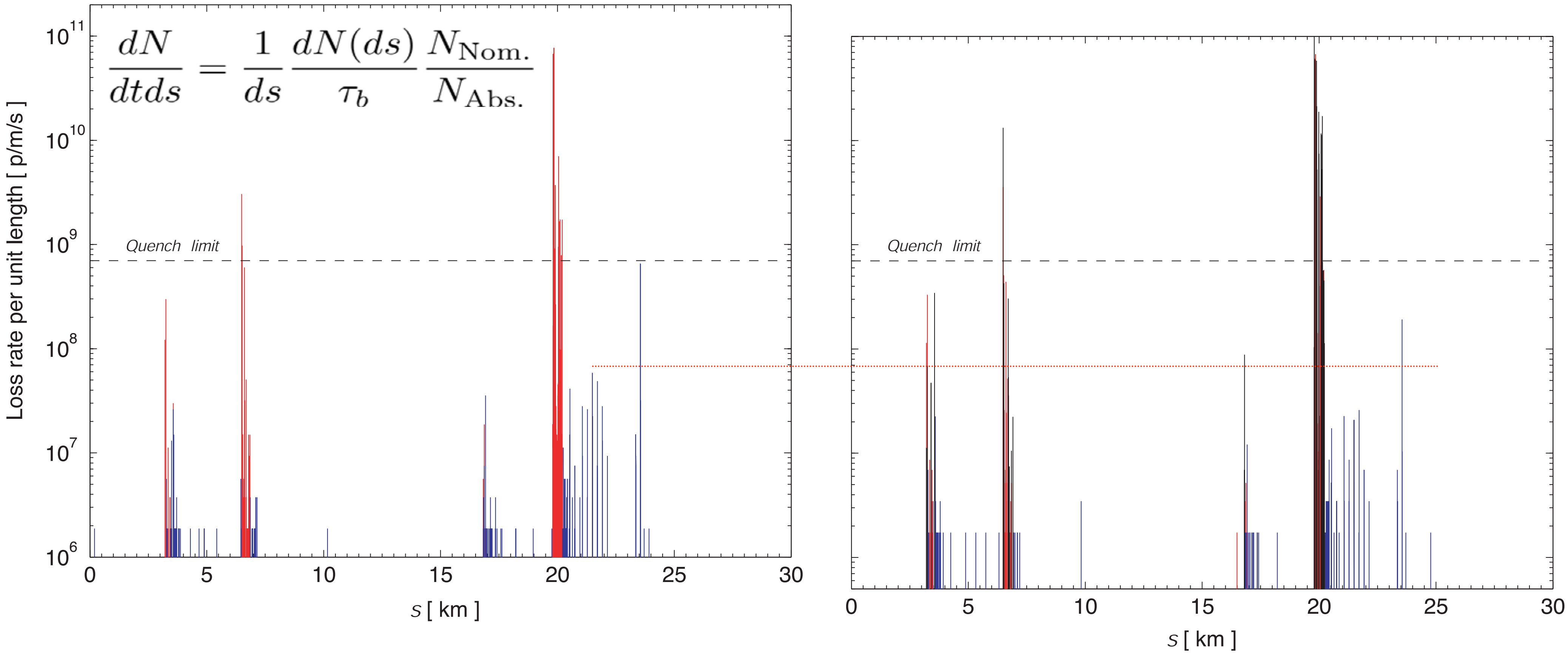
Horizontal halo, perfect cleaning, 256000 tracked particles per case.

Trend confirmed but less improvement: **10-30%**

Agreement with previous simulations by R. Assmann, with IR7 only (2002)

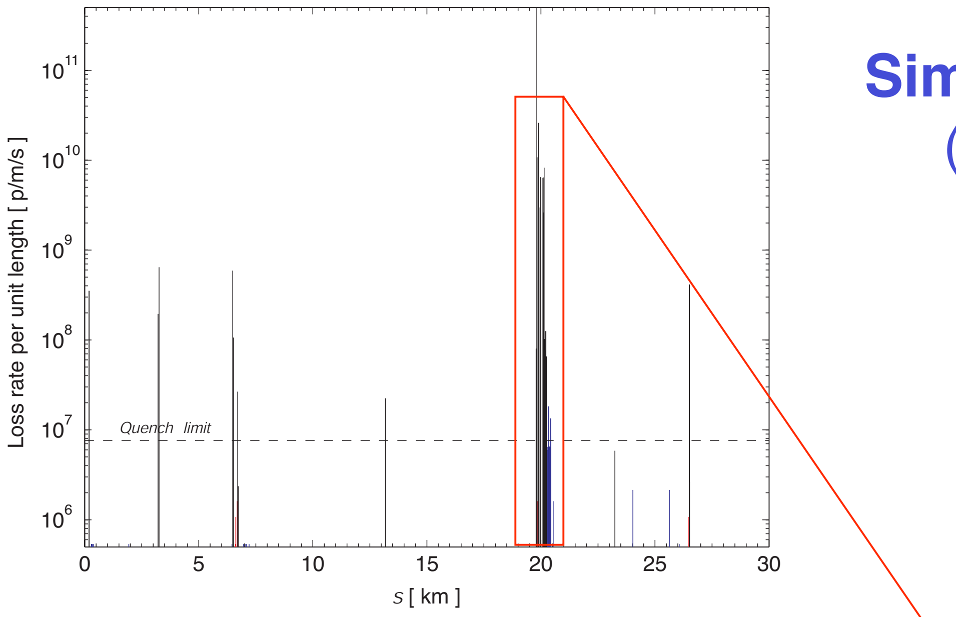
Simulation results - Loss maps at 450 GeV

(τ_b = 0.1 h; I_{nom} = 3x10^{14} p; perfect optics)



Preliminary results for a perfect cleaning and optics.

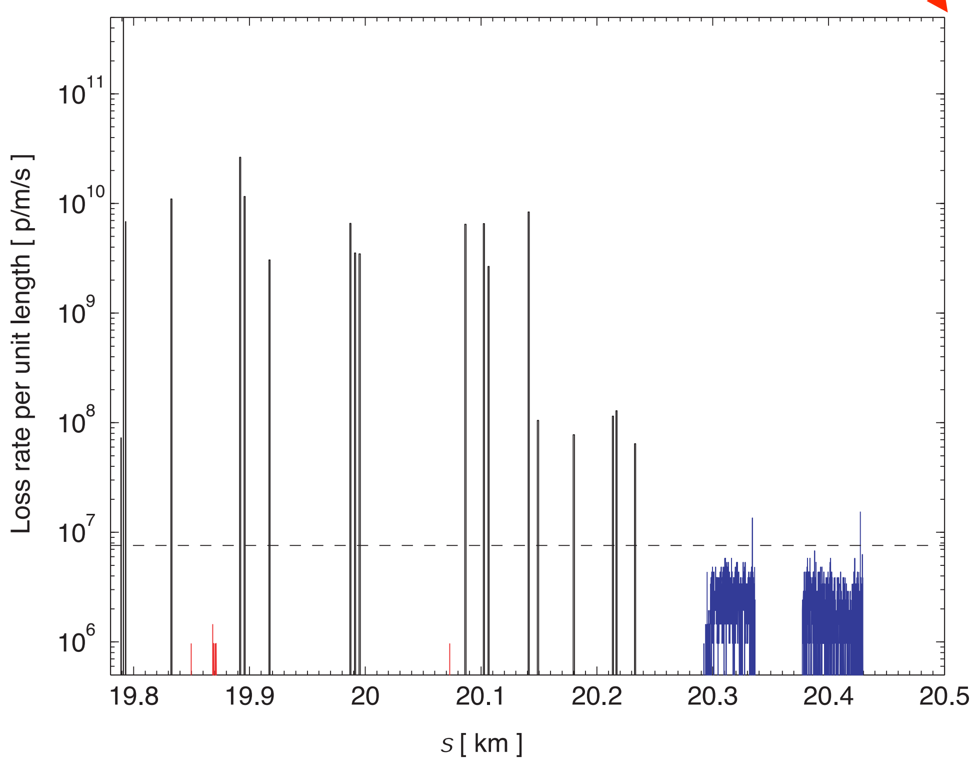
Reduced loss peaks with 0.6 m long TCP.

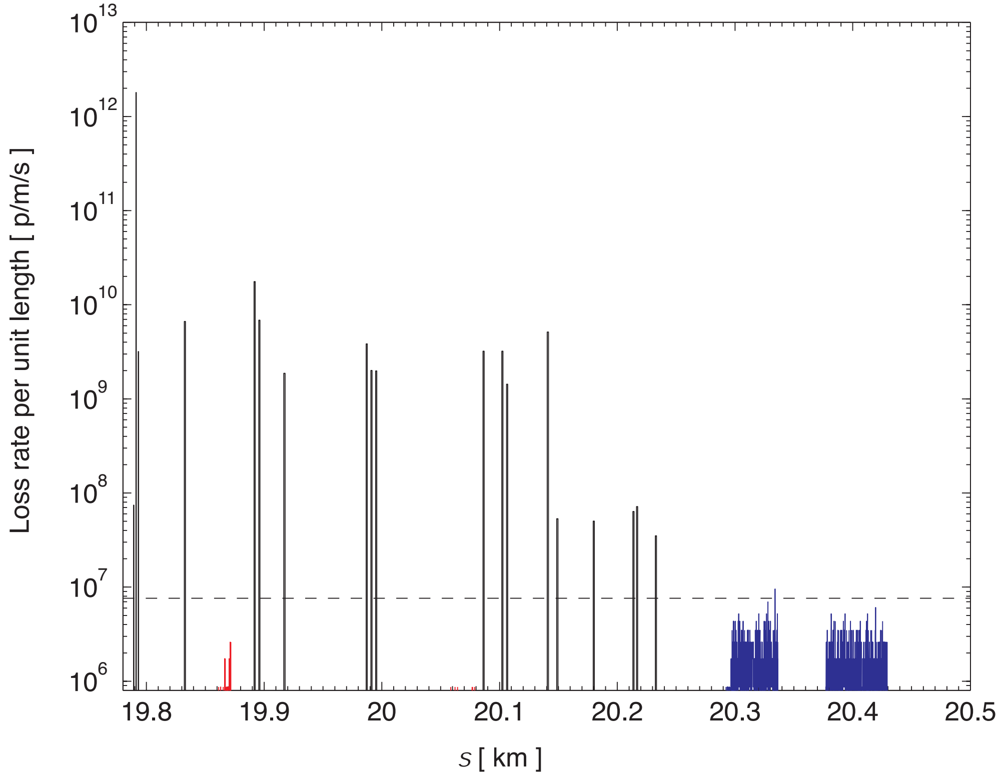


Simulation results - Loss maps at 7 TeV

(τ_b = 0.2 h; I_{nom} = 3x10^{14} p; perfect optics)

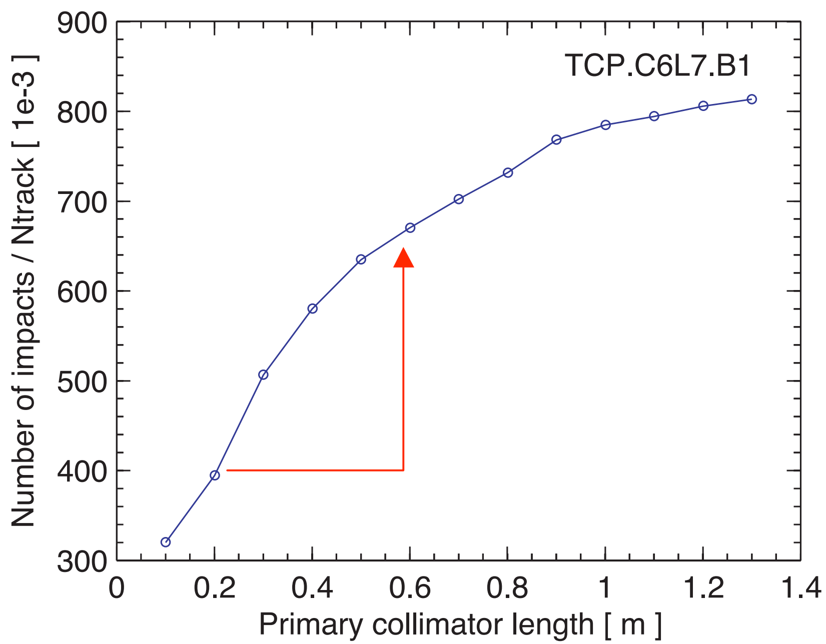
Loss peaks are *slightly* smaller with long primary collimators!

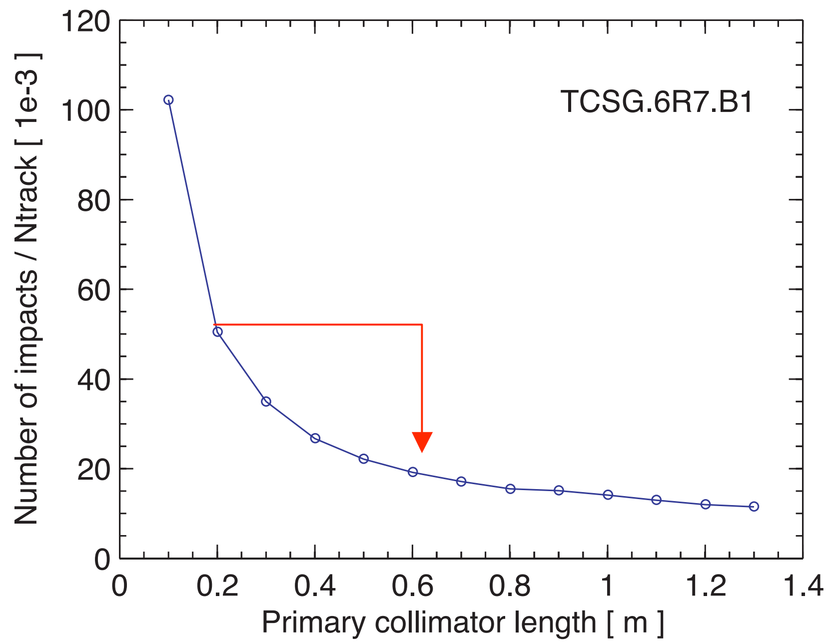




Simulation results - Number of inelastic collisions

(Horizontal halo at injection, Np=256000)





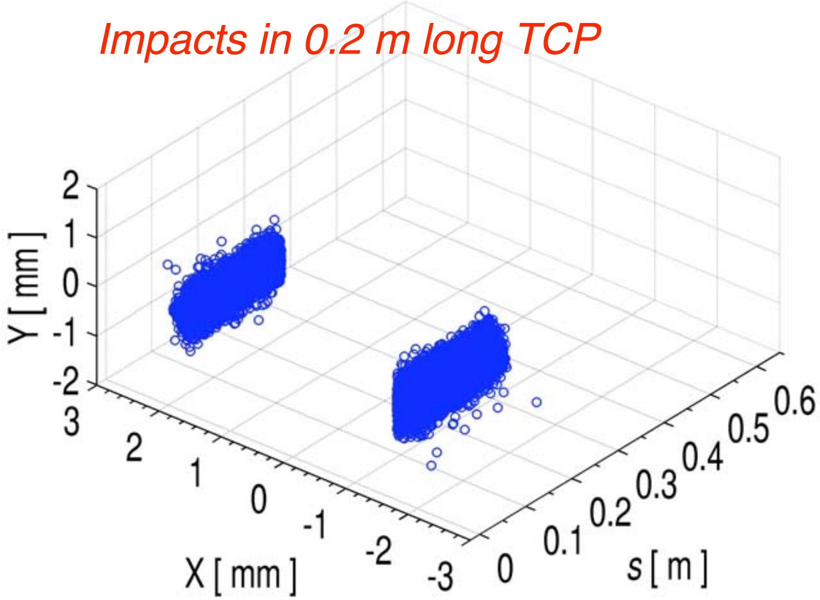
As expected, more particles are absorbed in the TCP's if their length is increased ⇒ Less load on the downstream collimators and components

⇒ There should be NO ISSUE if the TCP can withstand the additional load
- Energy deposition studies will tell!

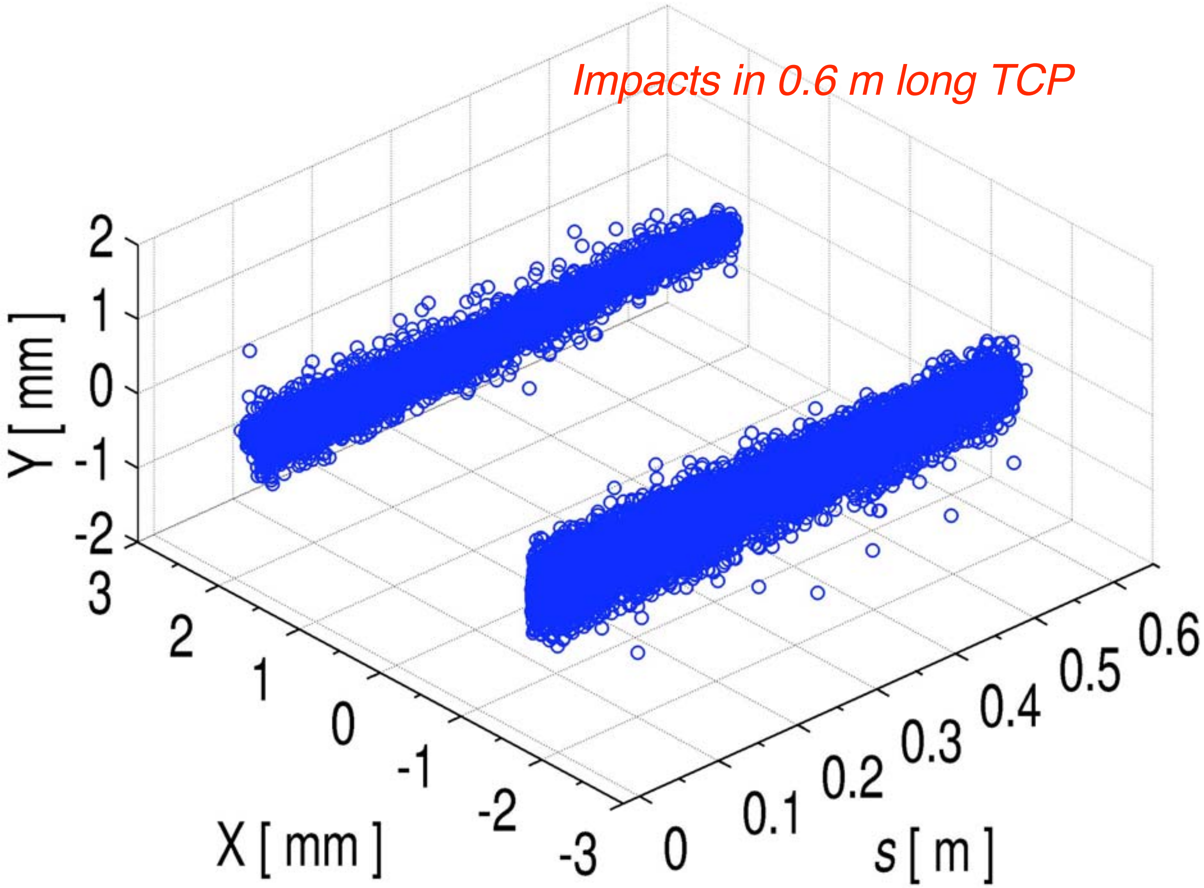
Simulation results - FLUKA inputs for energy deposition studies

Location of inelastic impacts of protons with each collimators used as input for energy deposition studies!

Impacts in 0.2 m long TCP



Impacts in 0.6 m long TCP



Impact file will be provided to the FLUKA team!

Conclusions

- Performance of the betatron cleaning system investigated for different lengths of the primary collimators
- As expected, longer primary collimators improve the cleaning performance of the betatron cleaning (IR7)

  Improved cleaning inefficiency, in particular at injection

  Local losses around the ring are (slightly) reduced

  No significant gain for $L_{TCP} > 0.6$ m
- Proposed length of **0.6 m** for the primary collimators is supported!
- Final assessment requires energy depositions studies (quenches/lifetime of various elements)

  Inputs are now available for the FLUKA team
- Further studies: investigate the effect of TCP angle?

Calculation of the proton loss rate per unit length

$$\boxed{\frac{dN}{dtds} = \frac{1}{ds}\frac{dN(ds)}{\tau_b}\frac{N_{\mathrm{Nom.}}}{N_{\mathrm{Abs.}}}}$$

From aperture model — ***dN(ds)*** : number of particles lost around the full ring

From tracking — N_{abs} : number of particles lost in the cleaning insertion
($dN(ds)/N_{abs}$ is the cleaning inefficiency!)

For *slow losses*, all the particles that drift out of the beam core interact first with the primary collimators: $\Rightarrow$

$$\frac{dN}{dt} \propto \frac{N_{\mathrm{Nom.}}}{\tau_b}\frac{1}{N_{\mathrm{Abs.}}}$$

Assumptions on:

1. Total beam intensity $\longrightarrow$ $N_{\mathrm{Nom.}} = 3\times 10^{14}\ \mathrm{p}$
2. Beam lifetime $\longrightarrow$ $\begin{cases} \tau_b^{\mathrm{inj}} = 0.1\ \mathrm{h} \\ \tau_b^{\mathrm{top}} = 0.2\ \mathrm{h} \end{cases}$

Quench limit of superconducting magnets:

$$\boxed{\begin{array}{l} R_{\mathrm{Q}}^{\mathrm{inj}} = 7\times 10^{8}\ \mathrm{p/m/s} \\ R_{\mathrm{Q}}^{\mathrm{top}} = 7.6\times 10^{6}\ \mathrm{p/m/s} \end{array}}$$