Status of Robustness Studies for the LHC Collimation

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Why is collimation important?

One important issue for LHC: Handling of large beam power to avoid quenches…

Number of protons per beam: \( \sim 3 \times 10^{14} \)

Quench threshold (fast transients): \( \sim 6 \times 10^5 \) p/m in 10 turns

Control fast transient beam losses to \( 2 \times 10^{-9} \)!

Quench threshold (steady state): \( \sim 6 \times 10^6 \) p/m/s

Beam loss for 35h beam lifetime: \( \sim 3 \times 10^9 \) p/s

Factor \( \sim 500-1000 \) too high! Beam cleaning!
LHC beam cleaning:

Two-stage collimation system:

**Primary collimators** (0, ±45, 90 degree) to scatter particles. 0.2 m long. Aluminium. Two planar parallel jaws at $\pm 6 \sigma$.

**Secondary collimators** (many angles) to capture scattered particles. 0.5 m long. Copper. Two planar parallel jaws at $\pm 7 \sigma$.

Cleaning efficiency optimized in design.

Simulation tools:

New simulation tools developed.

COLLIMATE (C_MATERIAL, C_LENGTH, C_ROTATION, C_APERTURE, C_OFFSET, C_TILT, X, XP, Y, YP, P, S, NP, ENOM, ...)

Include: Collimator rotation angle, material, length, aperture, alignment offset, jaw tilt.

Track: Particle offsets, angles, energies, ...

Either as drift (no interaction) or scatter/absorb particles randomly.

Implemented in new program COLLTRACK (linear transfer matrix) and into full non-linear SIXTRACK code.
Tracking through the LHC:

Courant-Snyder invariant
\[ \gamma_x x^2 + 2\alpha_x xx' + \beta_x x'^2 = \epsilon_x \]

Particles at
\[ N_{\sigma y} = \left| y \right| / \sigma_y \] (same for y)

Collimators cut phase space at
\[ N_{\sigma x}^2 + N_{\sigma y}^2 \geq C_{\sigma}^2 \]

Simulate:
\[ (C_\sigma - \Delta N)^2 \epsilon_x \]
\[ (C_\sigma + \Delta N)^2 \epsilon_x \]
Reduction of phase space with collimation:

Turn 0

Turn 1

Turn 2

Turn 3

Turn 4

Turn 50
Incoming

![Graph showing the incoming direction with Y [mrad] on the y-axis and Y [mm] on the x-axis.]
Turn 1

![Diagram showing Y [mrad] vs. Y [mm]]
Realistic impact parameter:

Particles drift ~ 1 µm outwards per turn!
Particle survival:

Inefficiency =

How many particles escape above N $\sigma$?  E.g.  N=8.
Cleaning inefficiency:

Radial excursion: $N_{\sigma x}^2 + N_{\sigma y}^2 \geq C_\sigma^2$

Elliptical beam pipe...
Beta beating (transient):

Beta beating modulates collimator depth along collimation system...
Conclusion:

New tools implemented to study **LHC beam cleaning efficiency in the presence of imperfections**.

Functionality of **tracking with collimators** demonstrated.

Error studies have been started:

- **Optics** imperfections (*transient beta beating*)
- **Orbit** errors
- **Collimator imperfections** (offset, rotation, tilt)
- **Magnet** failures
- **Collimator damage** during loss scenarios

Consequences for collimator design, functionality, operational scenarios to be addressed in future work…