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:	~ $3\ 10^{14}$
Quench threshold (fast transients):	~ $6\ 10^{5}$ p/m in 10 turns

Control fast transient beam losses to $2\ 10^{-9}$!

Quench threshold (steady state):	~ $6\ 10^{6}$ p/m/s
Beam loss for 35h beam lifetime:	~ $3\ 10^{9}$ p/s

Factor ~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 **±6** σ.

Secondary collimators (many angles) to capture scattered particles.

0.5 m long. Copper. Two planar parallel jaws at **±7** σ.

Cleaning efficiency optimized in design.

Include imperfections: **Collimator misalignments. Optics errors, Orbit errors. Non-linear fields. Component failure.**

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

$$\gamma_x x^2 + 2\alpha_x x x' + \beta_x x'^2 = \epsilon_x$$

Particles at

$$N_{\sigma y} = |y|/\sigma_y$$

(same for y)

Collimators cut phase space at

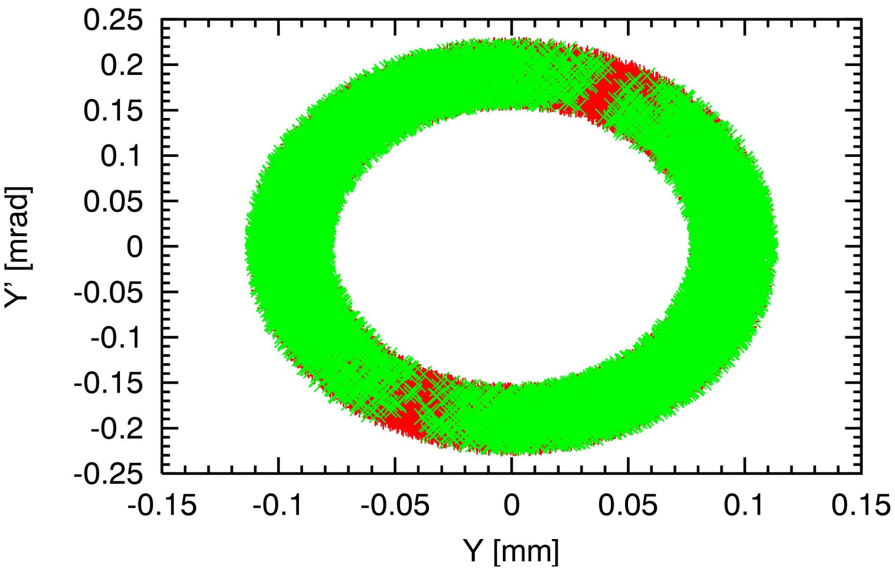
$$N_{\sigma x}^2 + N_{\sigma y}^2 \geq C_\sigma^2$$

Simulate:

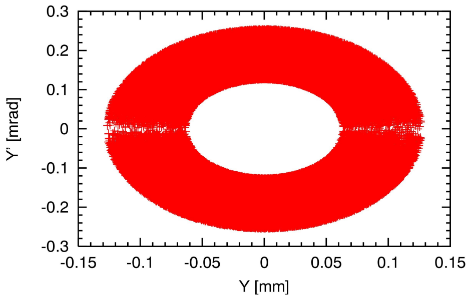
$$(C_\sigma - \Delta N)^2 \epsilon_x$$

to

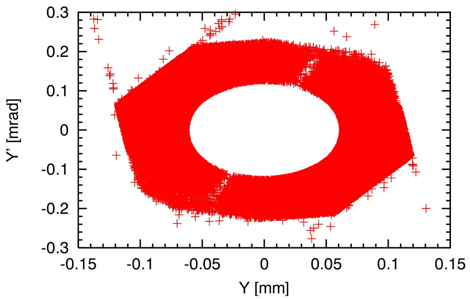
$$(C_\sigma + \Delta N)^2 \epsilon_x$$



Reduction of phase space with collimation:



Turn 0



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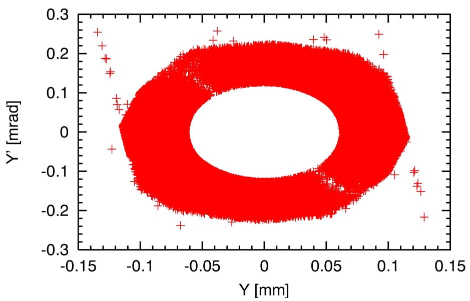

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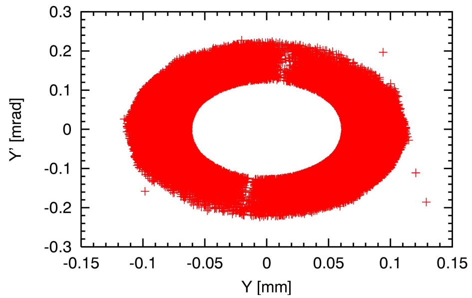

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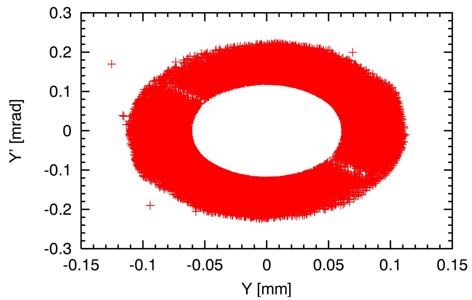

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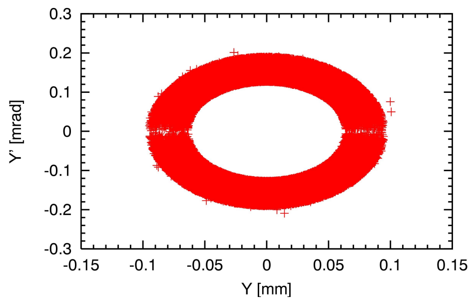
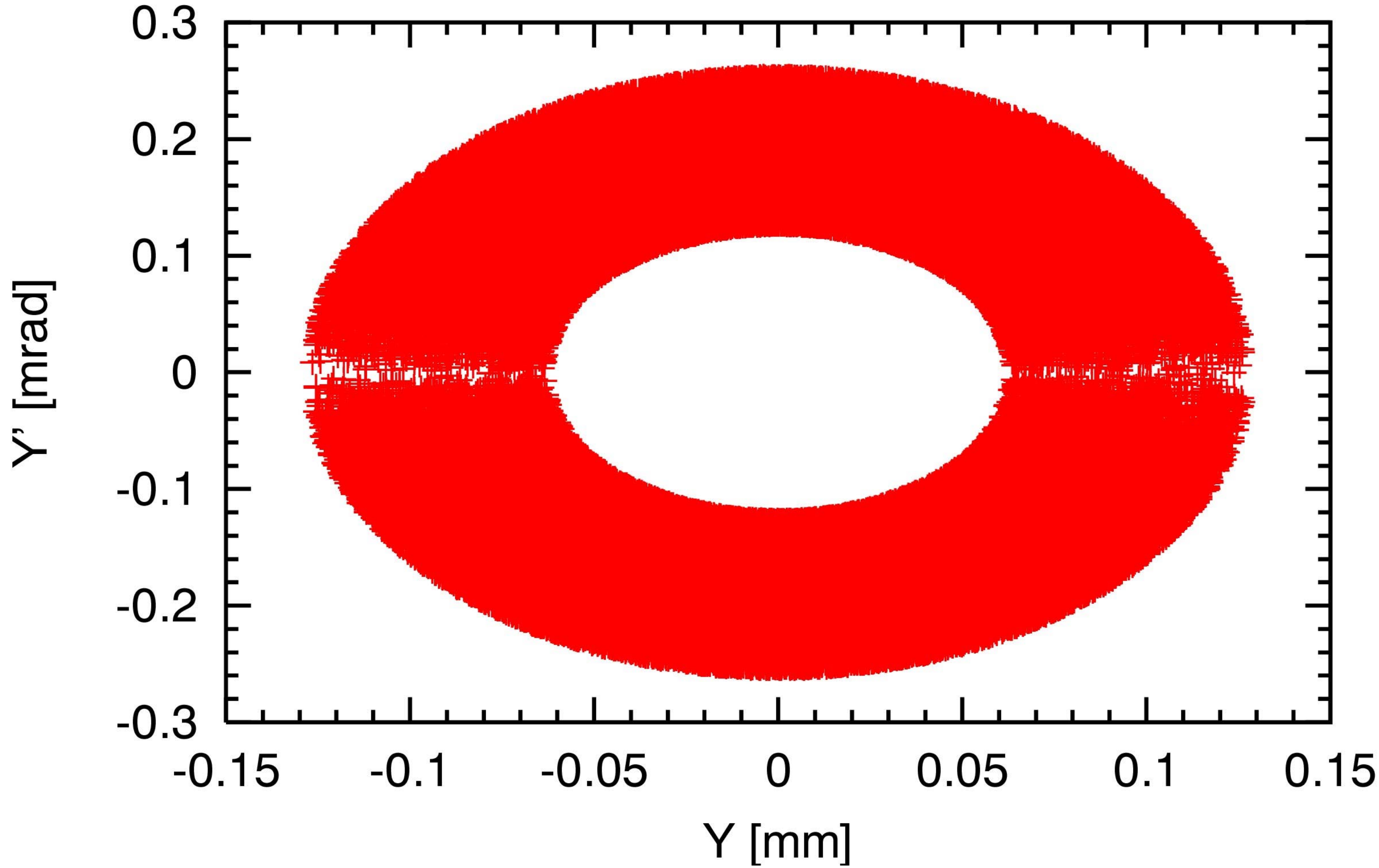
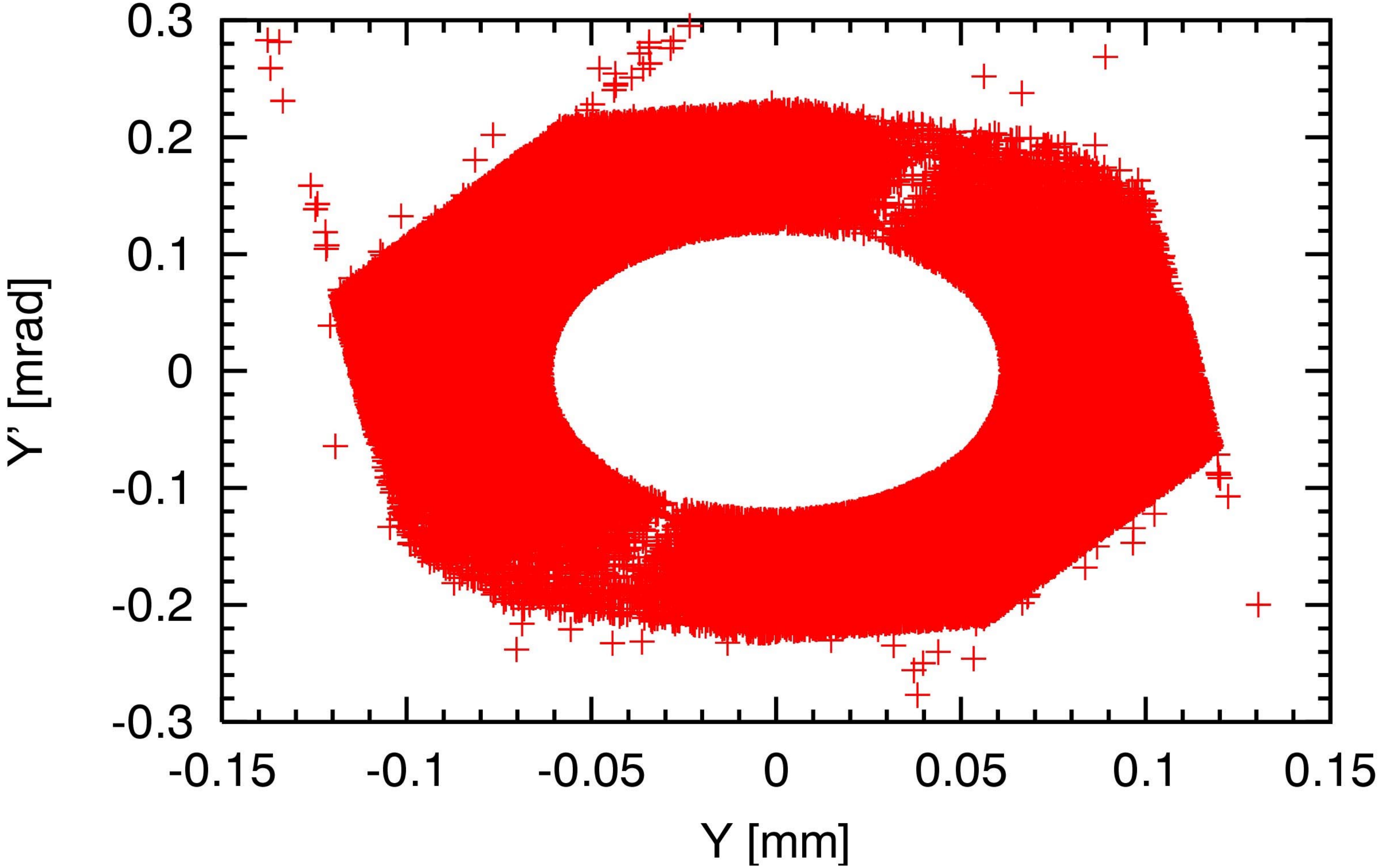


Turn 50

Incoming



Turn 1



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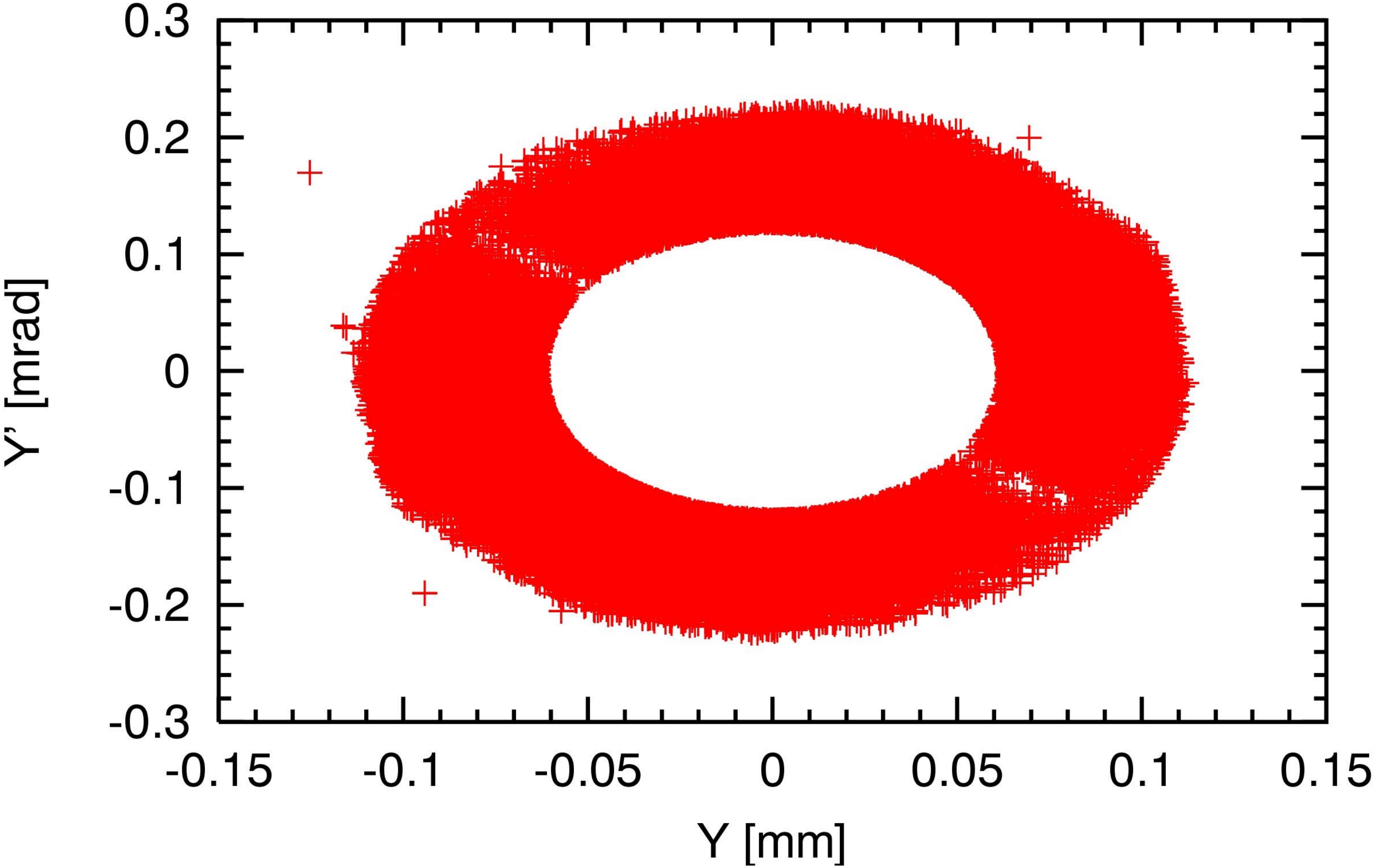
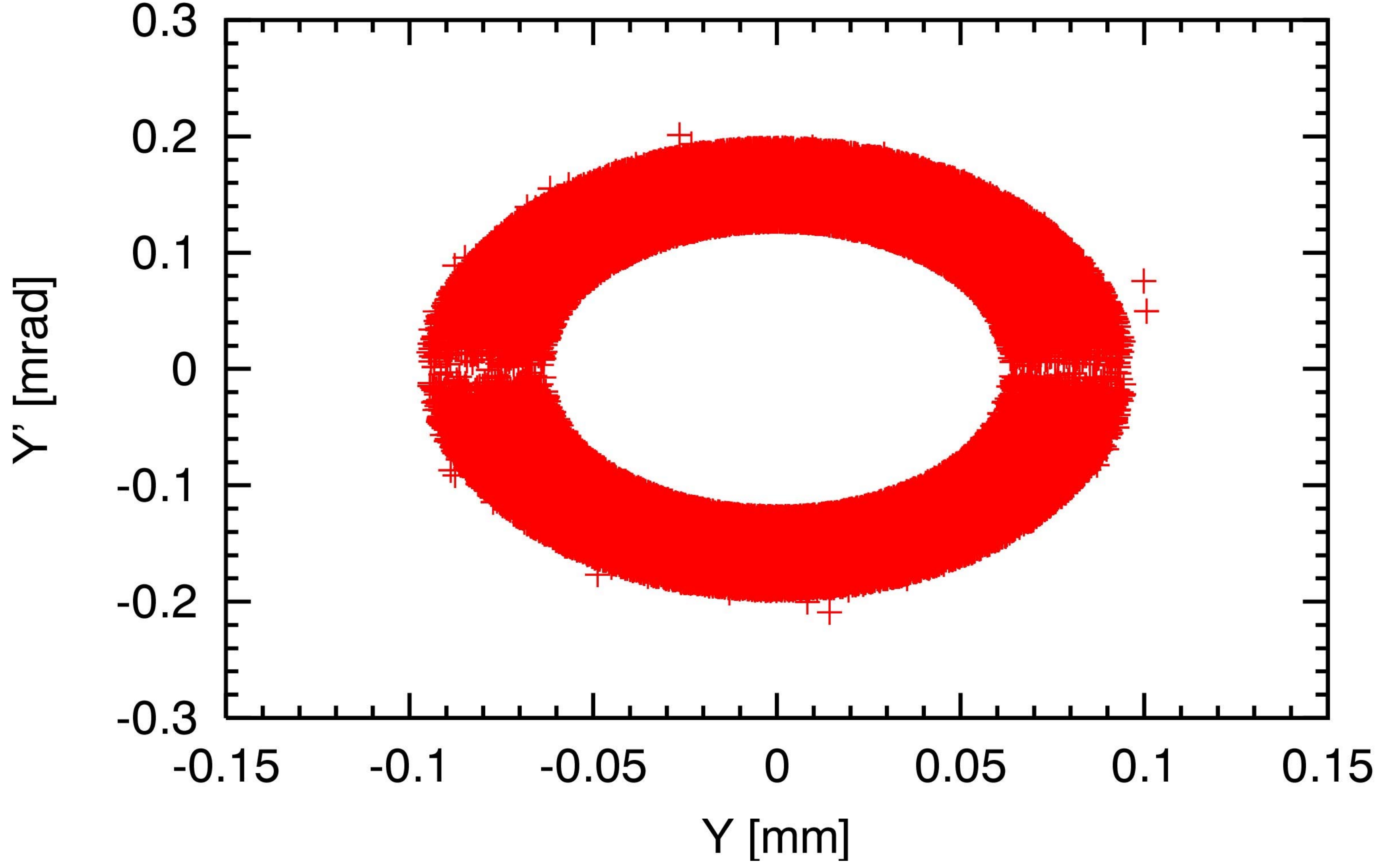
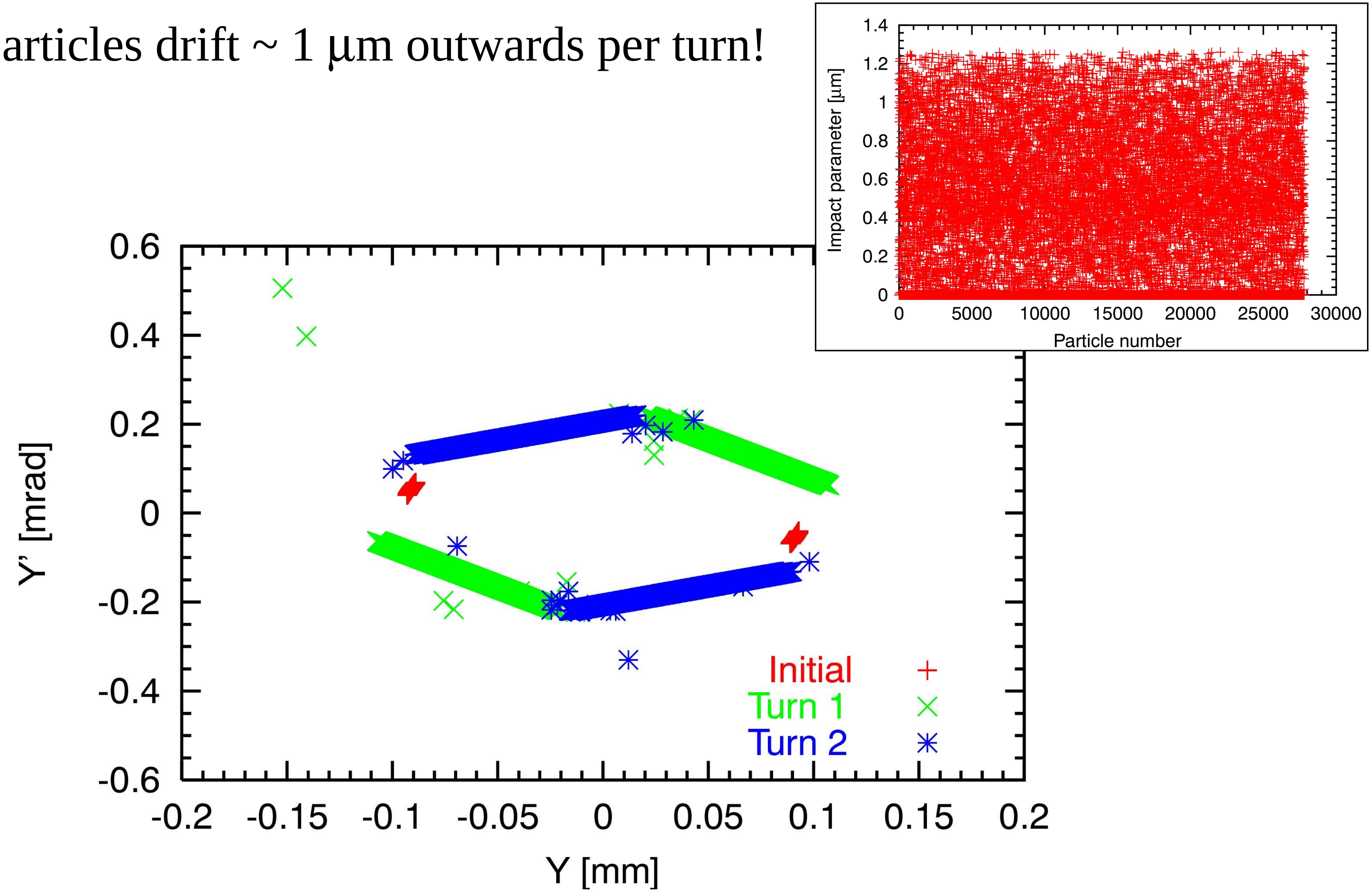


Turn 50



Realistic impact parameter:

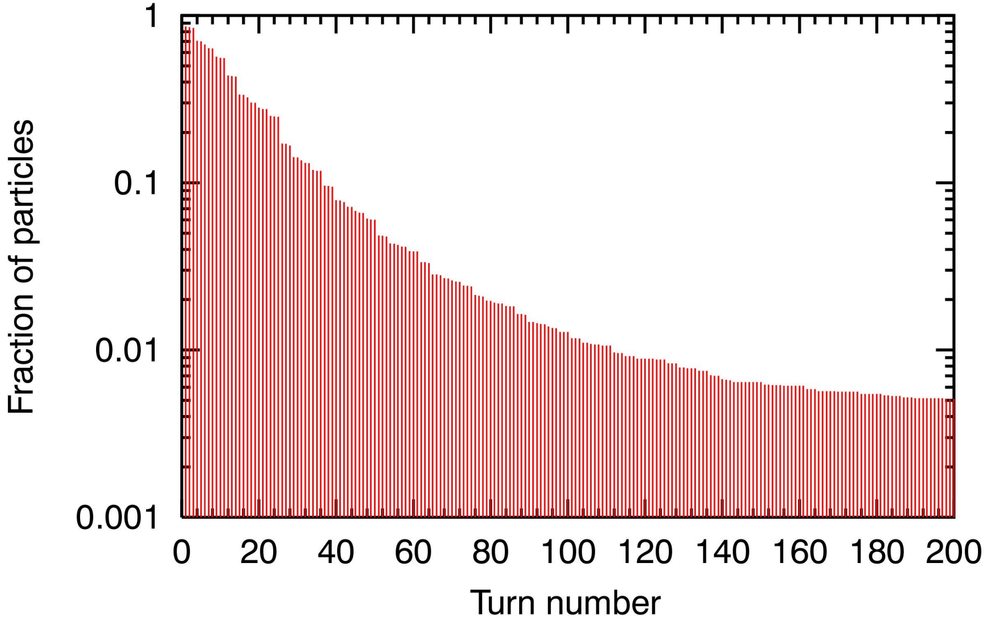
Particles drift ~ 1 μm outwards per turn!

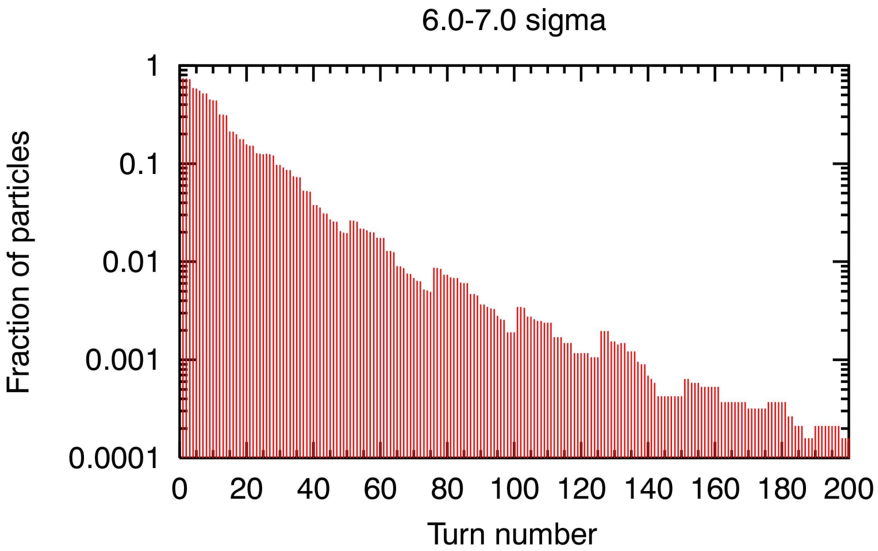


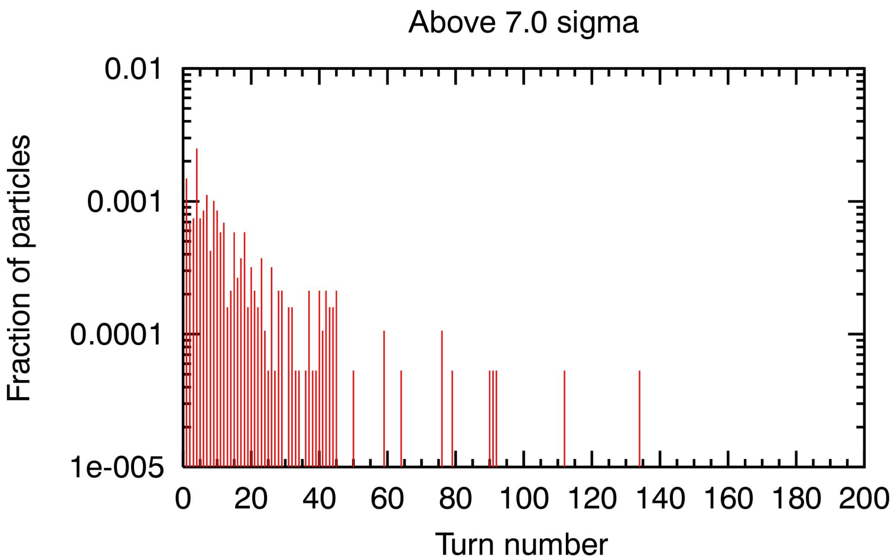
Particle survival:

Inefficiency =

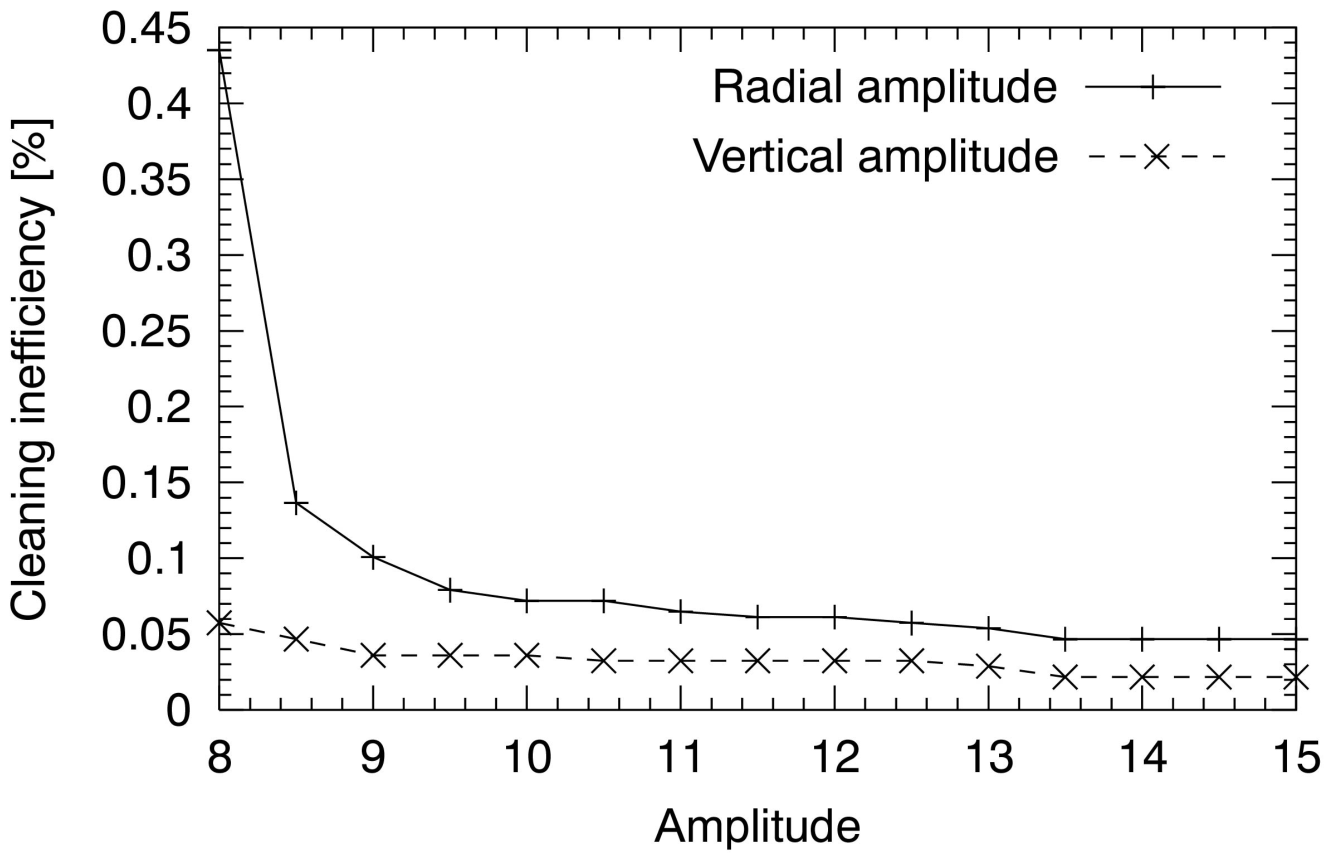
How many particles escape above N σ?   E.g. N=8.







Cleaning inefficiency:

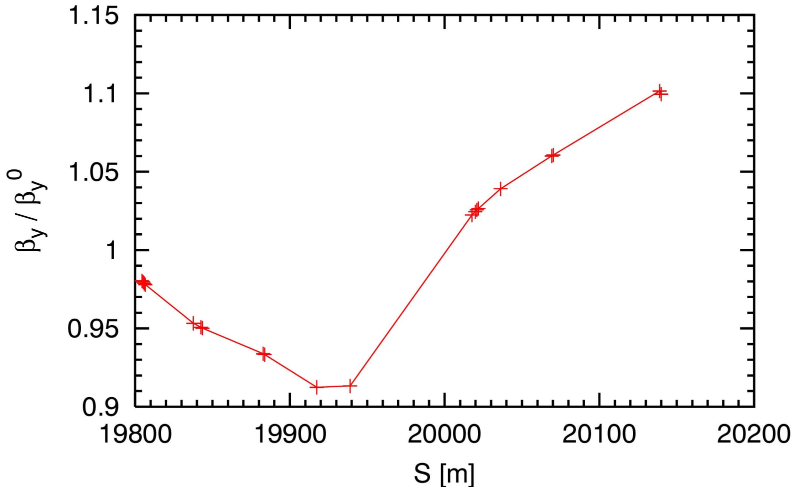


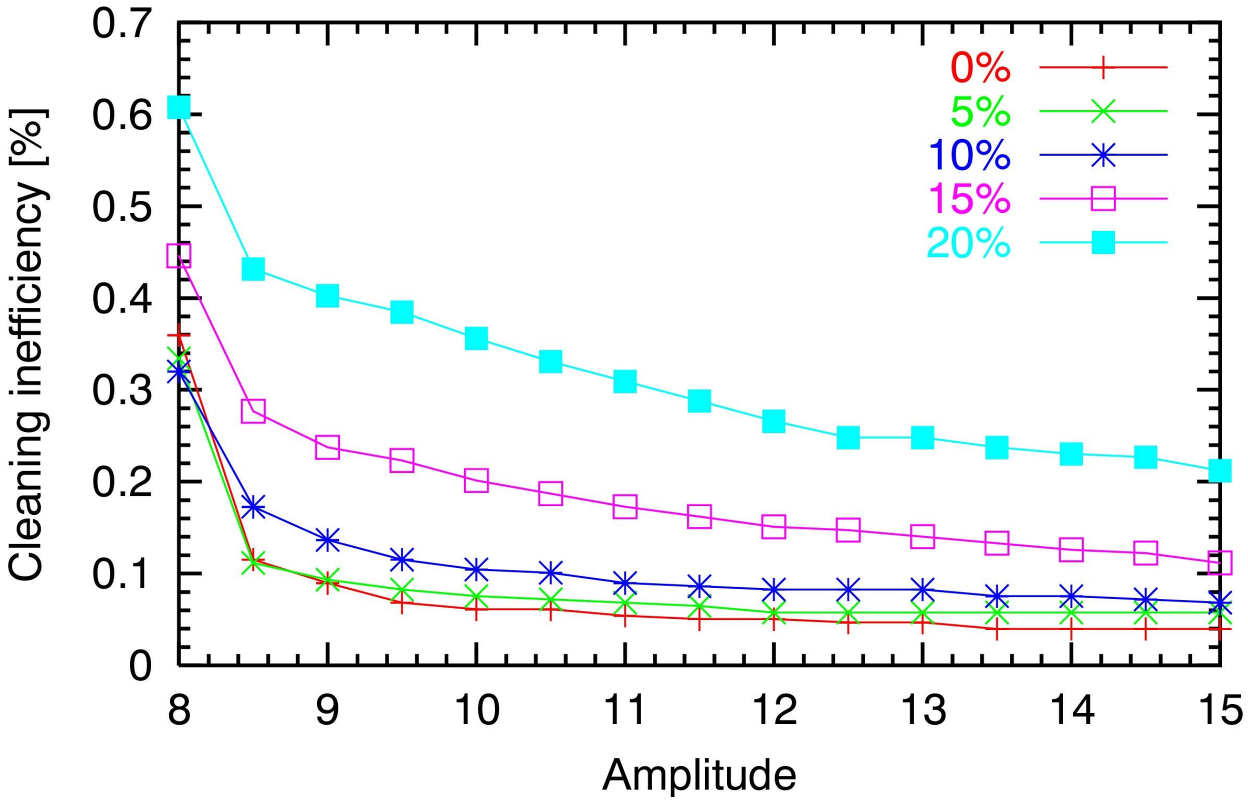
Radial excursion: $$N_{\sigma x}^2 + N_{\sigma y}^2 \geq C_\sigma^2$$

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…