Report from the LHC Beam Cleaning Study Group

R. Assmann, SL/AP

LCC 7.11.2001

LHC Beam Cleaning Study Group:

Mandate: **Study beam dynamics and operational issues for the LHC collimation system. Identify open questions, assign priorities, and show the overall feasibility of the LHC cleaning system.**

The mandate is limited to one year: a "critical design review" shall be published and, depending on the outcome, the mandate can be extended for one more year.

Proposed after LCC talk by JBJ.

First meeting: 24.10.01

Meetings: Every two weeks (4 so far)

Web-page: **http://www.cern.ch/lhc-collimation**

Membership:

R. Assmann (chairman)
I. Baishev
O. Bruening
H. Burkhardt
G. Burtin
B. Dehning
S. Farthoukh
C. Fischer
E. Gschwendtner
M. Hayes
J.B. Jeanneret
R. Jung
V. Kain
D. Kaltchev
M. Lamont
H. Schmickler
R. Schmidt
J. Wenninger

Participation open to all interested colleagues!

Presentations:

26.9.01	R. Assmann	– "Simulations for LHC collimation robustness"
10.10.01	G. Burtin	– "Present Collimator Design"
	M. Lamont	– "Views on LHC Operation with Collimators"
24.10.01	D. Kaltchev	– "Move of Q7 in Cleaning Insertion"
	R. Assmann	– "Collimation Efficiency versus Active Jaw Length"
	B. Dehning	– "BLM Work and Required Simulations"
	J.B. Jeanneret	– "Collaboration with IHEP Protvino on Shower Studies"
7.10.01	J. Wenninger	– "Orbit Feedback in Cleaning Insertions"
	V. Kain	– "Preliminary Beam Loss Studies"
	J.B. Jeanneret	– "Reports on Meetings on Impedance and Collimator Alignment"

Find slides at: http://www.cern.ch/lhc-collimation

Why is collimation important?

Collimation has two tasks:

1) Machine protection

Disturbed beam is almost always first intercepted at primary collimators

Beam Loss Detectors monitor beam loss rate at collimators. → Compare signals with a threshold. ↓ Trigger the beam dump to protect the machine.

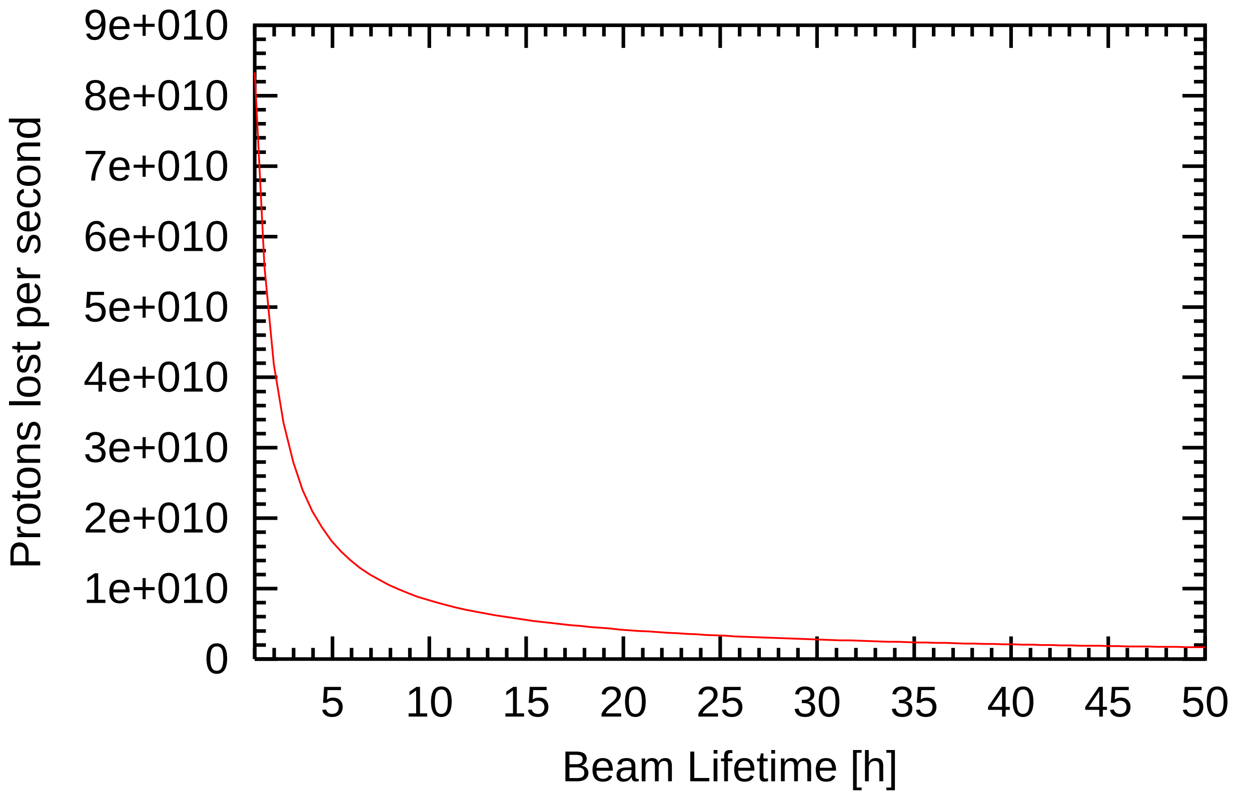
Questions: How does the beam loss signal look like?
What is the signature of “dangerous” beam perturbations?
Characterize magnet failures, … (collimator survival)
How should the threshold be defined?
Trigger the dump based on stand-alone or overall BLM readings?

All this involves the simulation of beam with collimators…

2) Beam cleaning

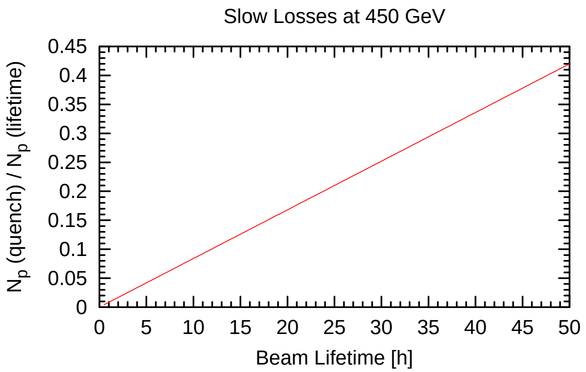
Quench limit ~ **9 orders of magnitude** below total beam intensity.

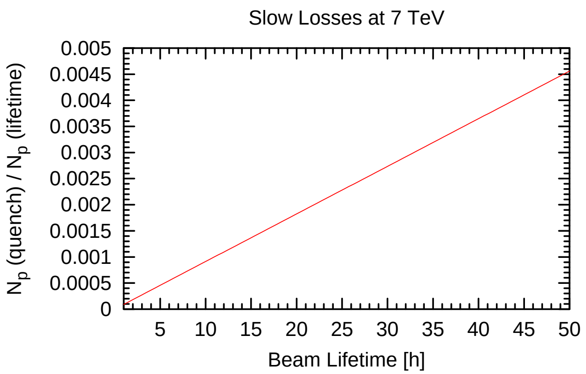
Characterize particle beam with a lifetime.

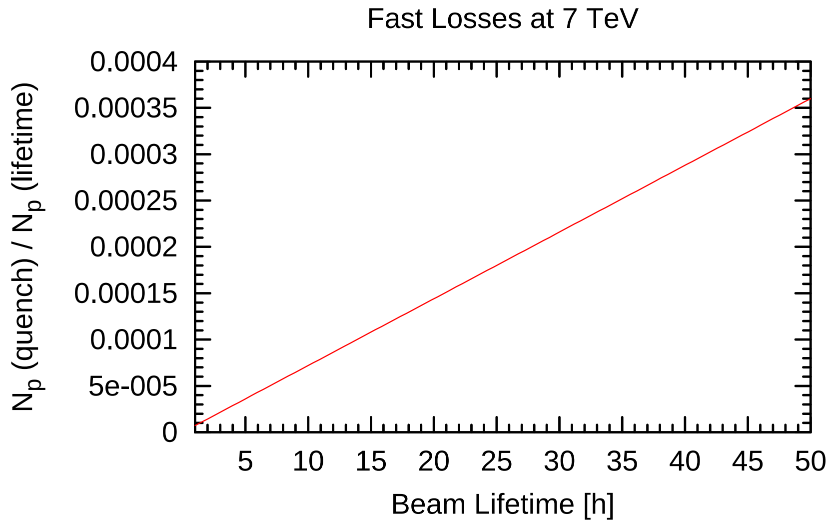


Assume that all lost particles can reach the cold aperture.

Ratio between **N protons required for a magnet quench** and
N protons lost due to beam lifetime **(max required suppression)**







Goal: Capture the lost particles in the LHC cleaning sections (suppress them).

Required suppression smaller than listed in plots (p losses diluted around the ring)

Inefficiency is defined as:

$$\text{Inefficiency}\,(N\sigma_r) = \frac{N_p\,(A_r > N\sigma_r)}{N_p\,(\text{captured})}$$

Require very efficient cleaning: **Sophisticated system!**

(see LCC talk by JBJ)

- Two-stage system (primary and secondary collimators).
- Separate betatron and momentum cleaning insertions.
- Separate systems for the two beams.
- In total 54 collimators.

The LHC Beam Cleaning Study Group:

Expected inefficiency in a realistic environment:

Beam input:	Beam loss (regular, irregular), emittance, diffusion speed, tunes, …
Coll. design input:	Surface flatness, alignment errors, positioning, heating deformations, …
Machine imperfections:	Beta beating (on/off momentum), orbit (stability?), coupling, injection oscillations, non-linear fields, …
Operational aspects:	Tunability, maintainability, stability, …

This work involves several groups and a wide range of expertise…

Additional considerations (quite important):

Collimator survival (damage threshold)
(injection oscillations?)

Expected rate of collimator repair / exchange

Impedance from the collimator jaws (requires transition pieces)

Work has started (simulation, design, operational scenarios):

Presently: Study system as it stands now with imperfections, non-linearities, etc

In the process: Re-evaluate design choices and specifications (find a workable system, not over- nor under-designed)

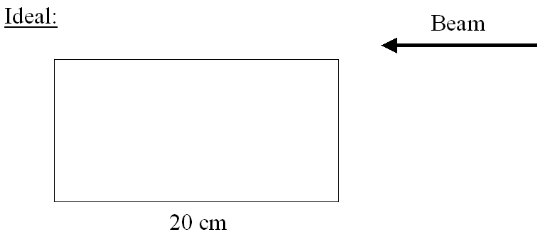
Now: **Present some preliminary results (all work in progress)**

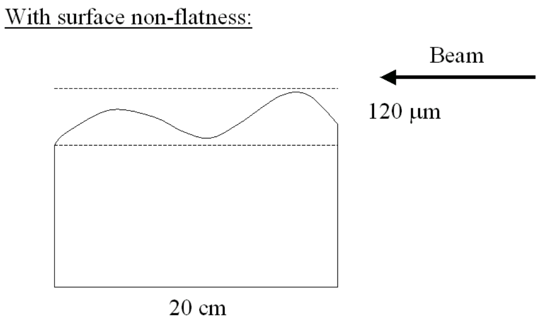
We cannot conclude from that (complete picture not yet available)!

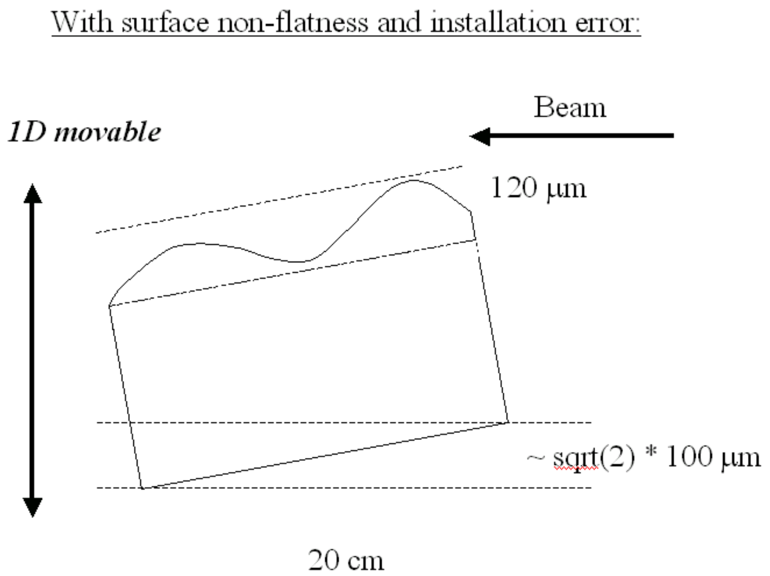
Preliminary estimates of collimator imperfections (G. Burtin):

Parameter	LEP specified	LEP achieved	Limit
Flatness[1]	50 µm	120 µm	10-15 µm
Surface roughness[2]	0.8 µm	not measured (2 µm?)	-
Position set size[3]	uncritical	2.5 – 5.0 µm	-
Repeatability	uncritical	½ step ?	-

Investigation ongoing…





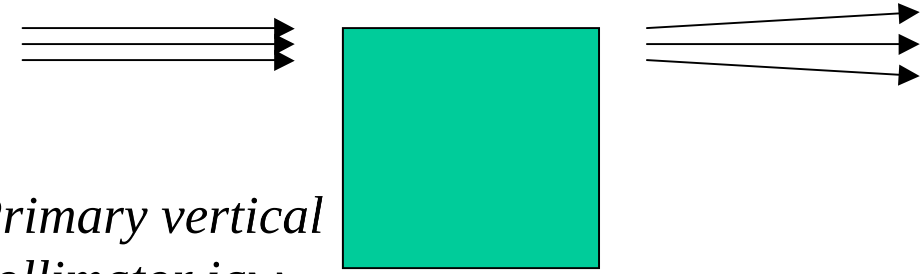


Compare to ~ µm impact parameter…

Input to simulation:

Consider betatron cleaning system
20 collimators (4 primary, 16 secondary)
7 TeV
Design emittance: 0.5 nm
Design beta functions
No non-linearities for this study

<u>Efficiency for vertical halo:</u>



Primary vertical collimator jaw

Look only at particles scattered at primary vertical jaw.

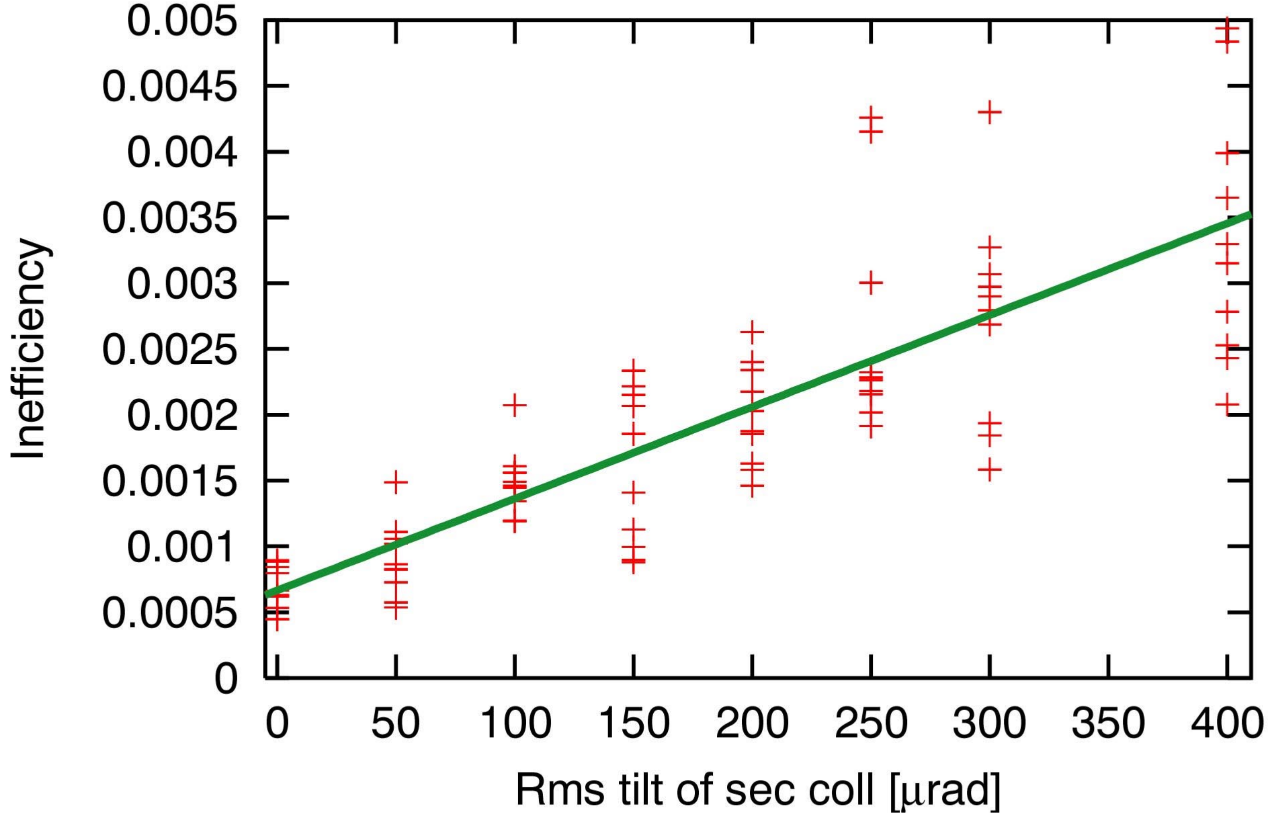
~ 20000 - 100000 particles
track on for 20 turns
~80% absorbed

$$\text{Inefficiency}\,(N\sigma_r) = \frac{N_p\,(A_r > N\sigma_r)}{N_p(\text{captured})}$$

Here, use N = 10 (particles above 10 σ are lost in the ring).

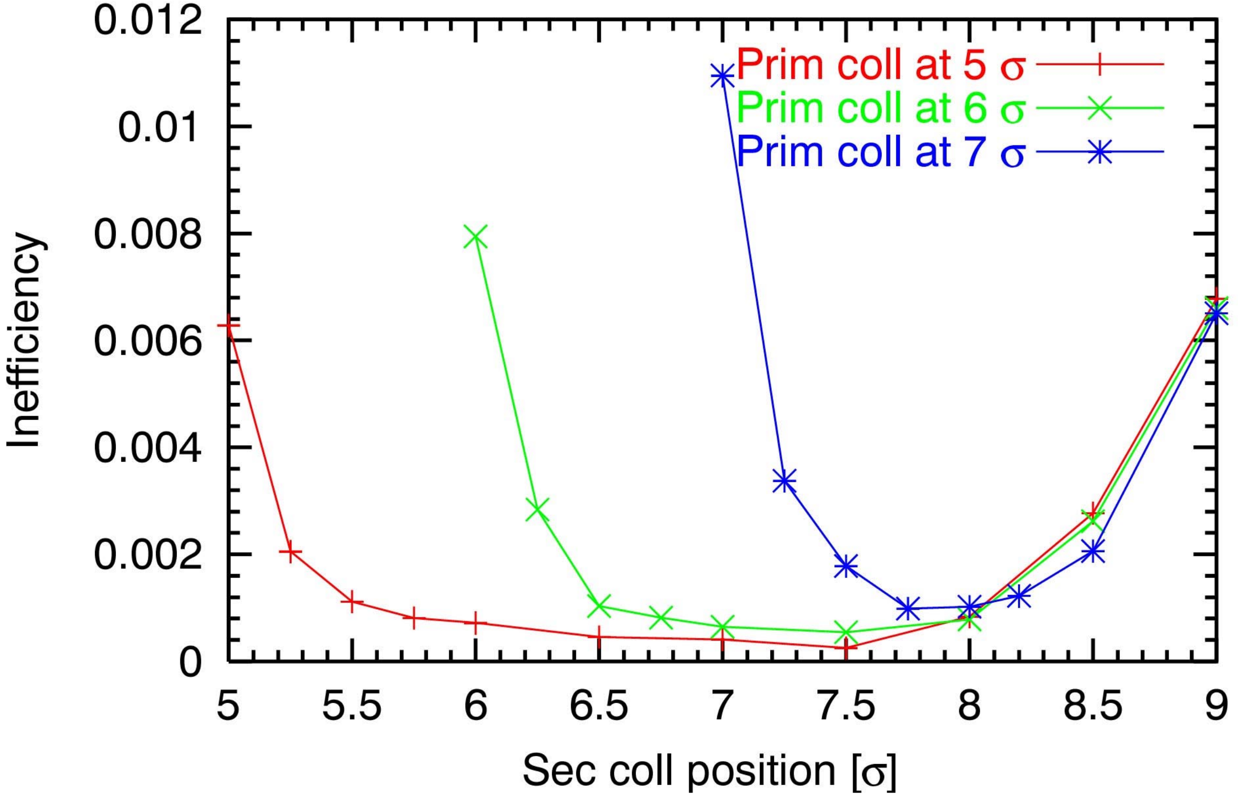
Simulation results: (all results work in progress)

Randomly tilt secondary jaws (10 seeds for each angle)



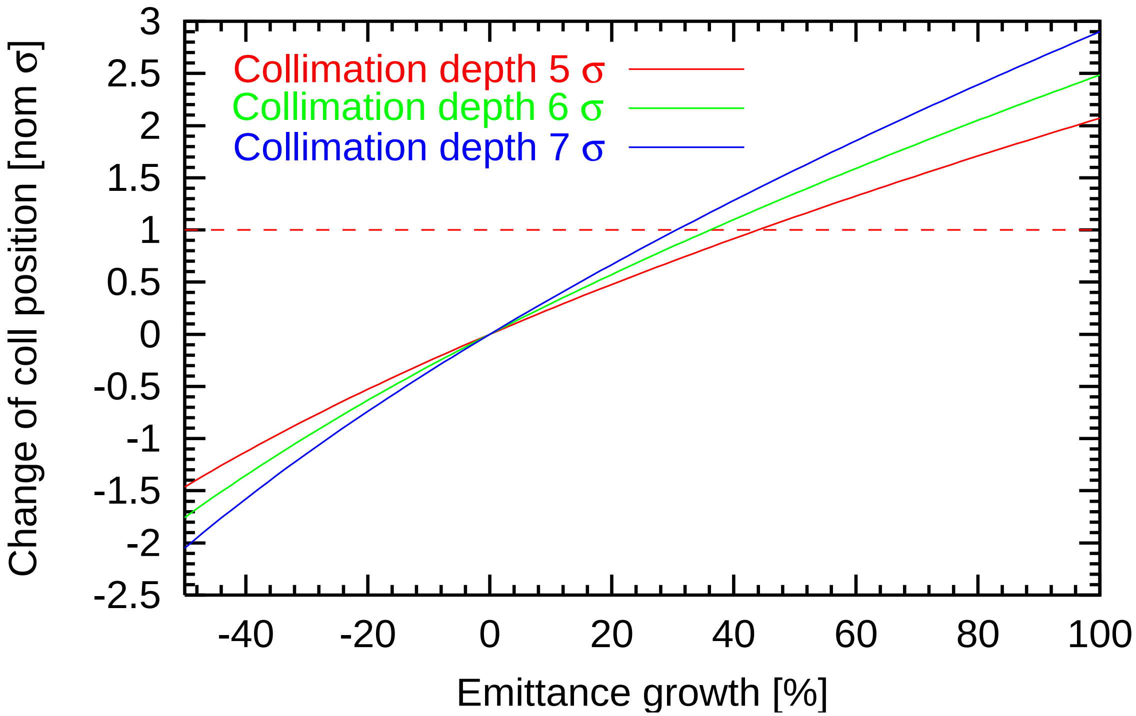
$$\eta(10\sigma) = (7.0 \pm 0.5) \cdot 10^{-6} \cdot \alpha_{coll} + (0.66 \pm 0.12) \cdot 10^{-3}$$

Study of collimation depth: Put primary collimator at one setting
Scan settings for secondary collimator



If we can collimate closer to the beam → Smaller inefficiency. More operational room for pos. of secondary (less critical). Larger tolerances for β beat, orbit change.

Dependence on emittance: Mechanical aperture stays where it is. Real collimation depth is changed.



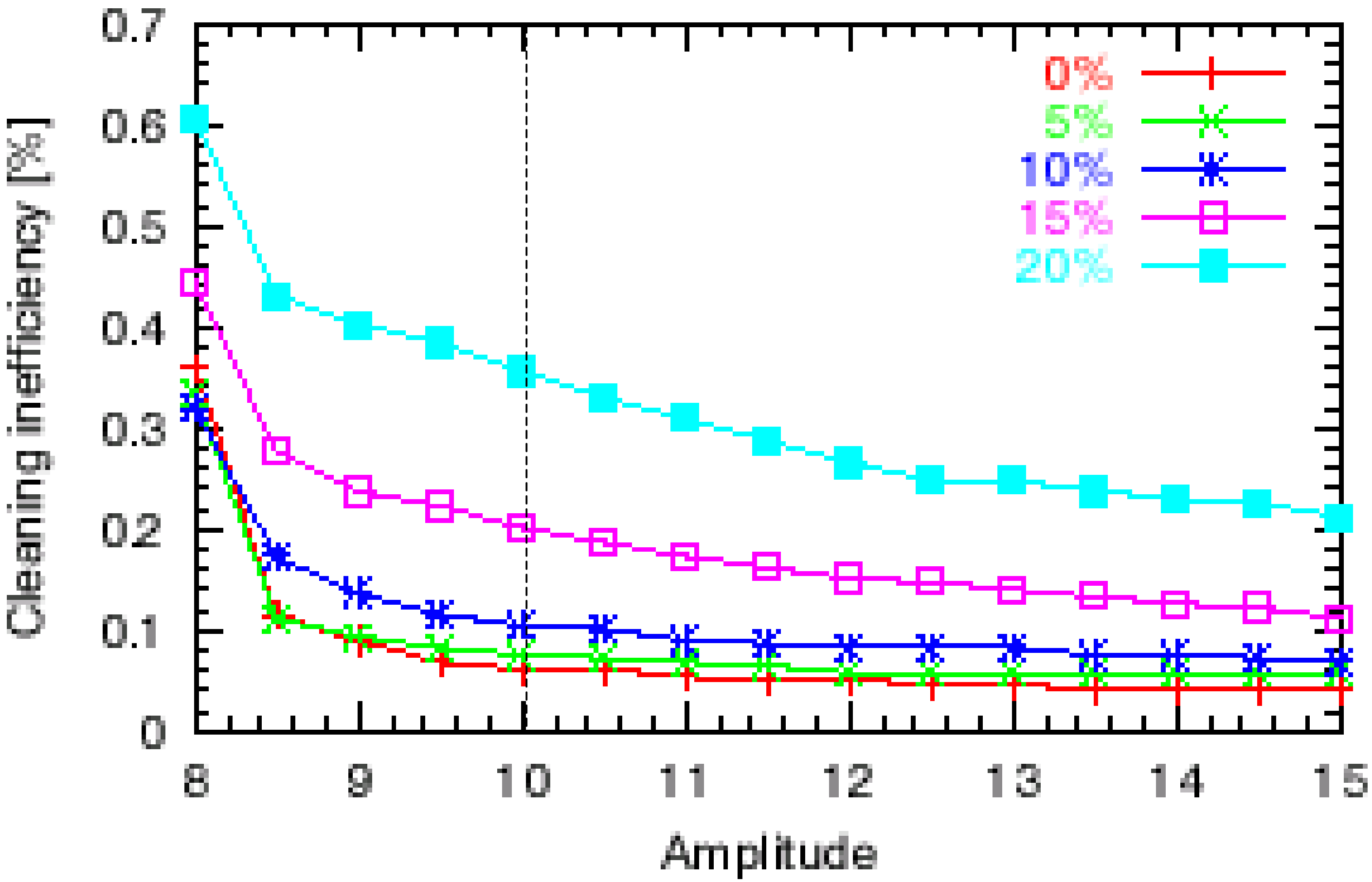
Example: Protect aperture at 10 σ (nominal).

Put collimators at 7 σ (primary) and 8 σ (secondary), nominal.

Emittance ~ 60 % larger than design value.

Collimators sit at ~ 5 σ and ~ 6 σ (real sigma).

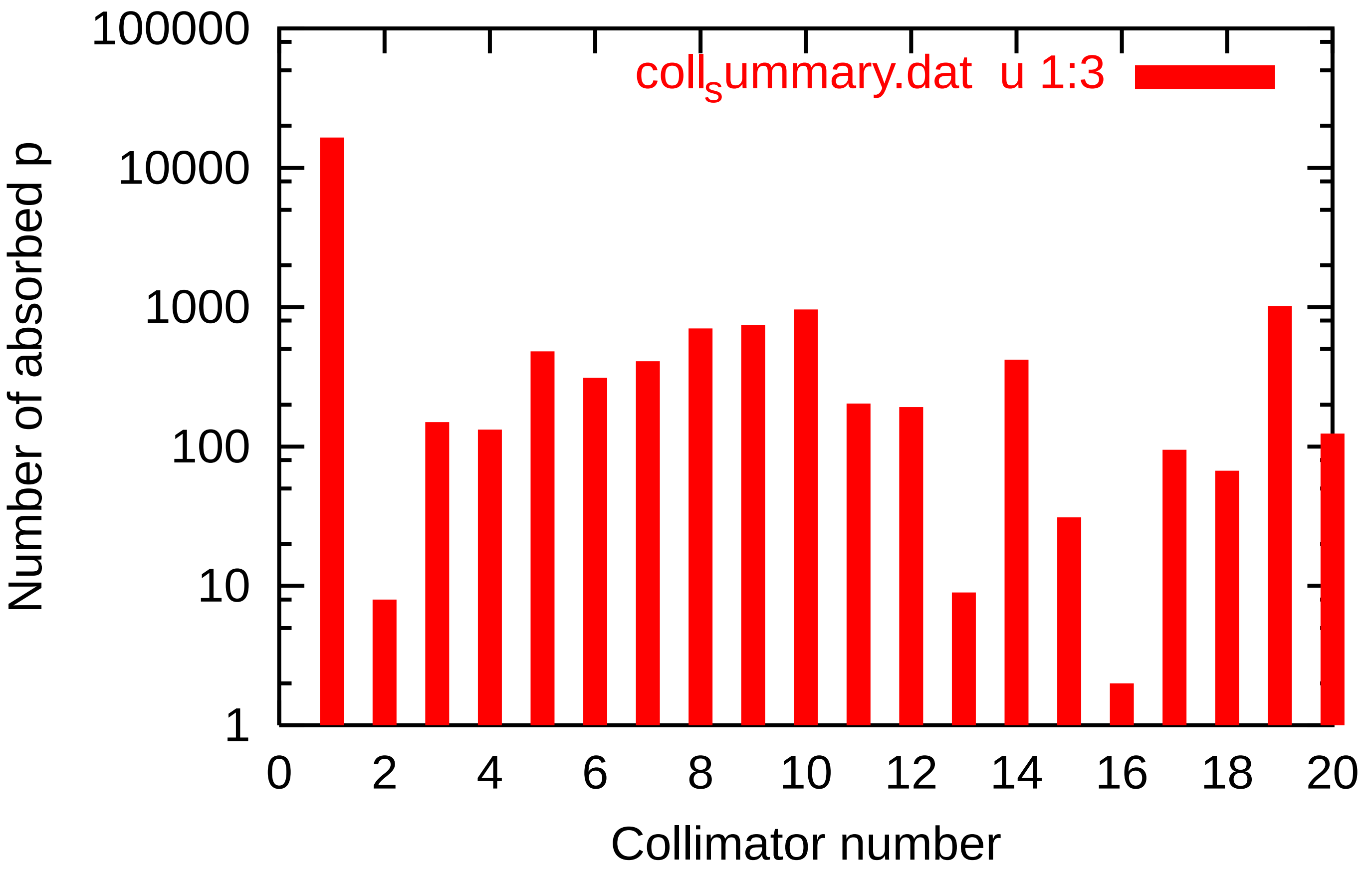
Effect from beta beating: (all results work in progress)



Only on-momentum beta beating included…

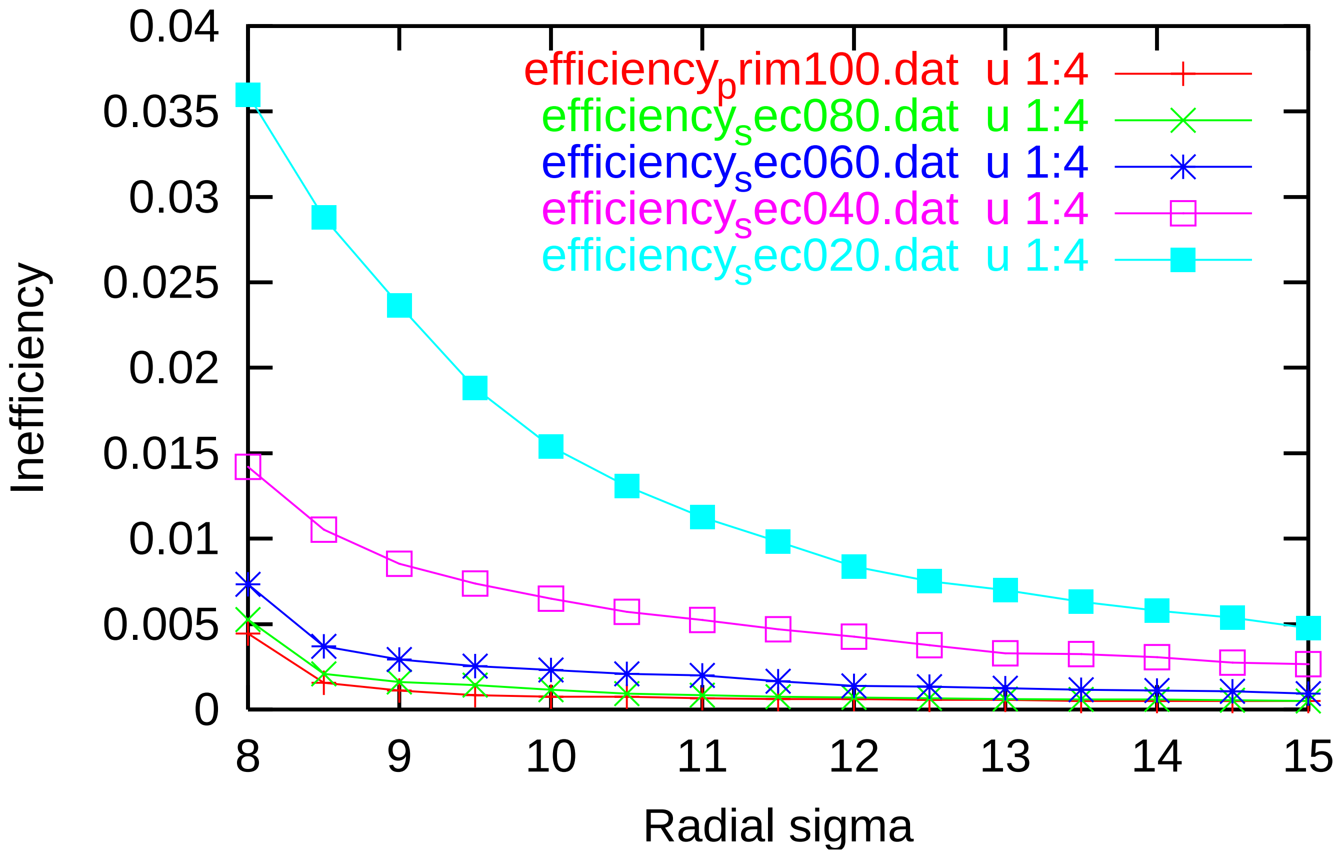
Where are the particles lost?

(all results work in progress)



This kind of plot is required for the BLM's and for study of damage due to particles lost with e.g. magnet failures.

Active length of jaws: (reduce length of secondary jaws)



As expected: Inefficiency rises sharply with reduced active length of secondary collimator.

Conclusion:

The **LHC Beam Cleaning Study Group has been started** to study the collimation system for a realistic environment.

Include **imperfections, non-linearities, optics and orbit errors**, … both static and time-dependent (e.g. ramp).

Involves **accelerator physics, operational procedures, beam instrumentation, beam protection,** …

We had four productive meetings laying the basis for our work.

Preliminary results have been obtained on collimator alignment errors, beta beating, collimation depth requirements, active length of jaws, BLM signals, …

Work on tools is ongoing (put aperture model, momentum cleaning, chromatic effects, non-linearities, …).

It is too early for any conclusion, but part of the picture emerges!