Status of the LHC Beam Cleaning Study Group

R. Assmann, SL

BI Review 19.11.2001

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: 26.9.01

Meetings: Every two weeks (4 so far)

Web-site: **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

Work in coordination with the Machine Protection Working Group.

Report the LHC Commissioning Committee.

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

Main design considerations:

1) Machine protection / monitoring signal for losses
Intercept perturbed beam at collimators. Protect against quenches/damage.

2) Durability / hardware robustness
Make sure collimators survive beam operation. Avoid lengthy repairs.

3) Beam cleaning efficiency
Remove beam halo in nominal conditions. Protect against quenches.

Beam cleaning study group reviews collimation under those three considerations.

E.g. trade-off: Optimal phase locations of secondary coll. different for cleaning efficiency (n·180°± 20-30°) and passive protection (n·90°). *(D. Kaltchev)*

1) Machine protection role of collimators:

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 beam loss during magnet failures, …

How should the threshold be defined?

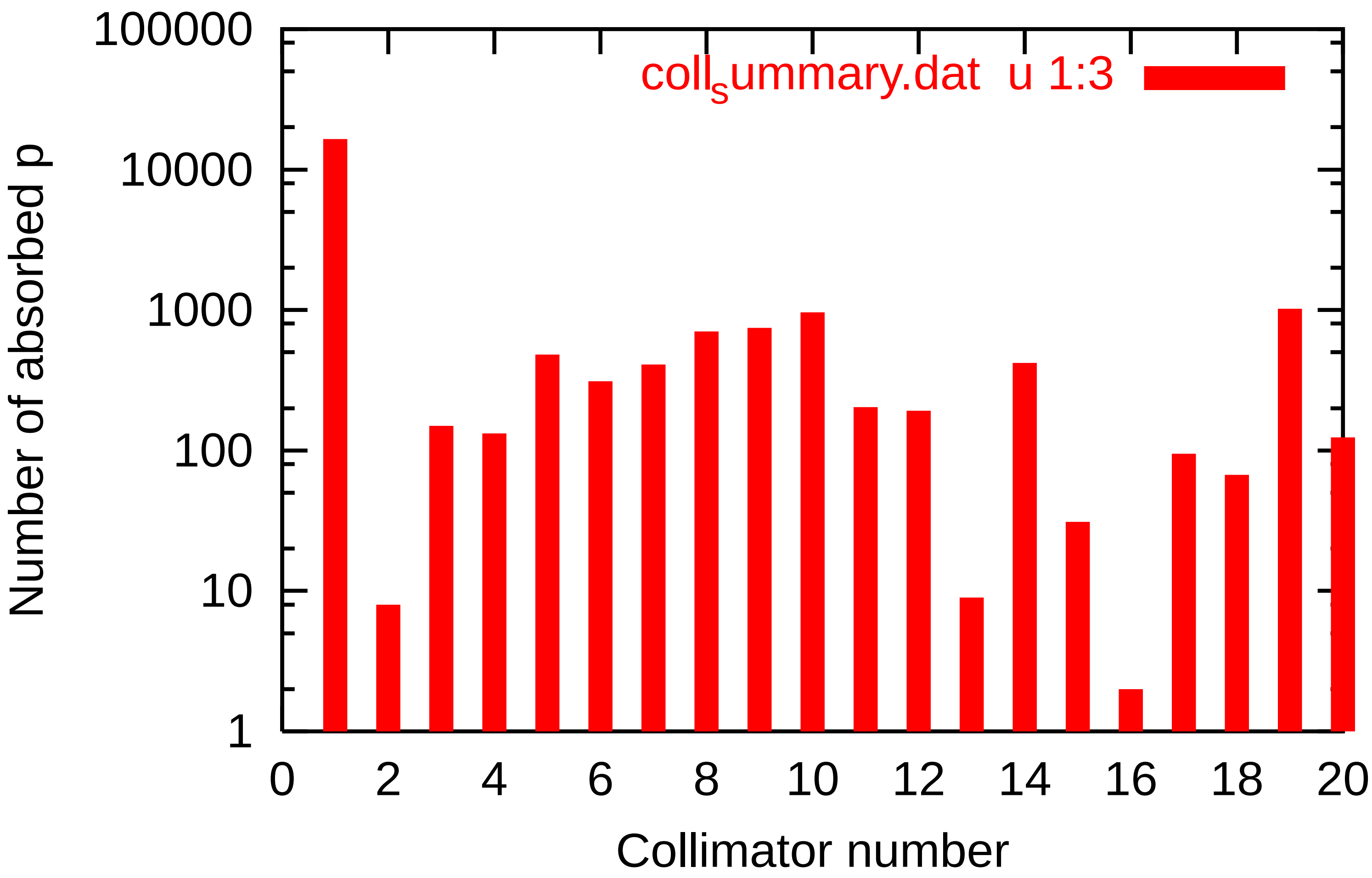
Trigger the dump based on stand-alone or overall BLM readings?

Distinguish between different beams and different collimators?

Talks from
H. Burkhardt
B. Dehning!

All this involves the study of beam with collimators… *(V. Kain, I. Baishev, B. Dehning, R. Assmann)*

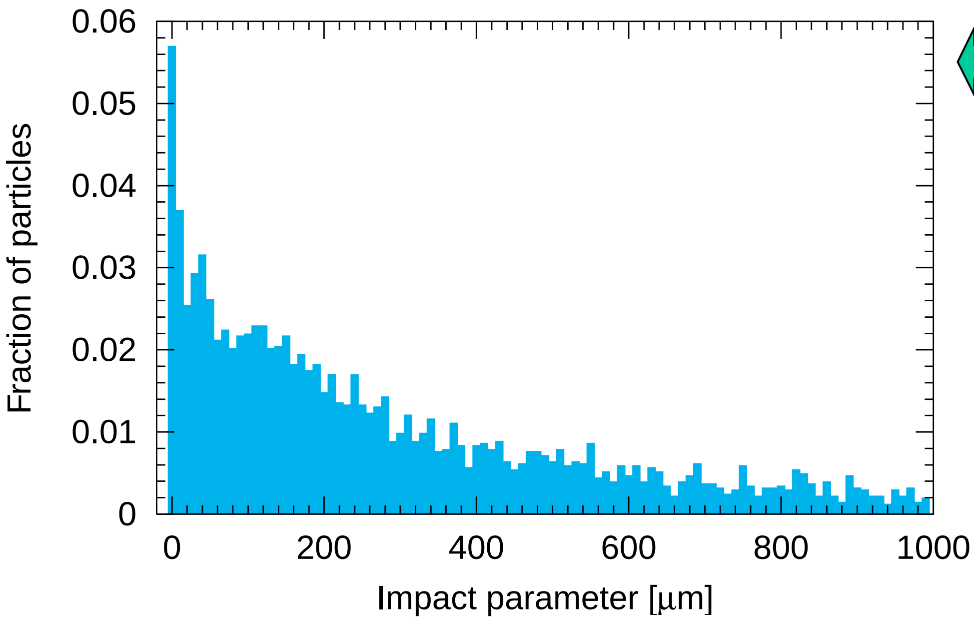
Beam losses: Nominal physics beam, vertical halo, betatron cleaning.



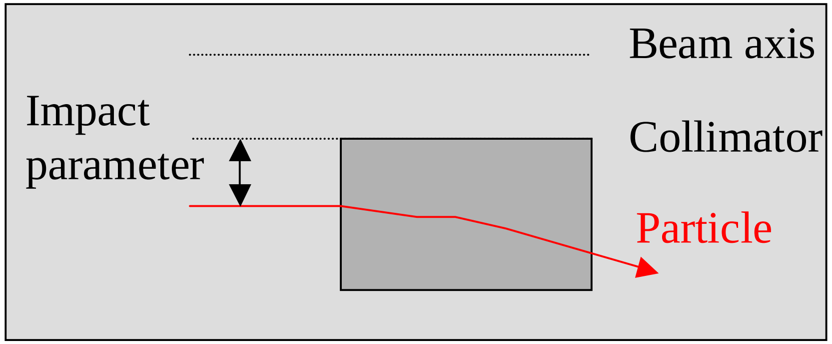
Beam loss at collimators due to impact of primary halo (vertical).

1-4: Primary collimators 5-20: Secondary collimators

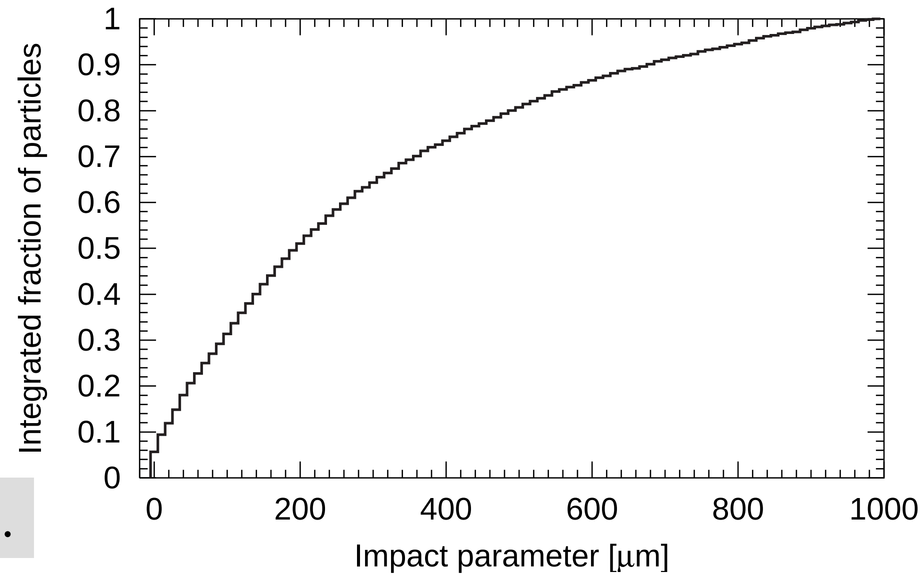
Impact parameter at sec collimators: (all results work in progress)



Histogram of impact parameter at all secondary collimators.



Integrated distribution of impact parameter.



50% of impacts at less than 200 µm!

Input to showering studies for damage/BLM…

2) Durability / hardware robustness:

Collimators must withstand the beam power that they see (repair nasty, lengthy)!

Expect (JBJ):	Heating with 4 h lifetime (physics):	**6 kW**
	Destruction limit at physics energy: (10 times higher at primary)	**$1.7\ 10^{-5}$** *of full intensity* $5\ 10^{9}$ protons
Received over some number of turns!	Destruction limit at injection:	**$1.7\ 10^{-3}$** *of full intensity* $5\ 10^{11}$ protons 5 bunches

0.2 hours lifetime ⇨ $4\ 10^{11}$ protons/s lost ⇨ $4\ 10^{8}$ protons in 10 turns

Do we understand beam losses, beam halo to the level of 10^{-5}?

What about injection oscillations (present transfer line collimation at 8 σ)?

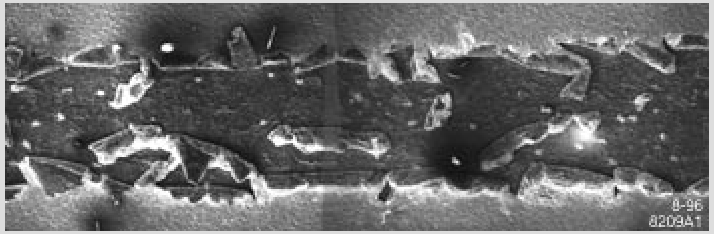
LHC operation is always critical! Can we operate this system? *(M. Lamont)*

⇨ Look at more robust system (include target, BT collimator, other experience). Estimate rate of exchange, required spares, …

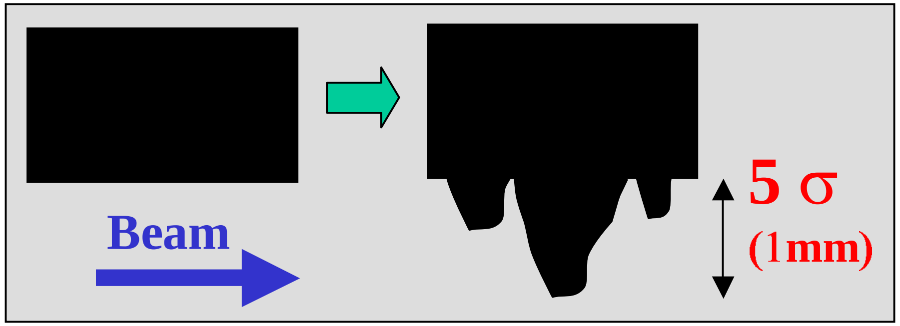
Why do we care?

Collimators were damaged in many machines (SLC, HERA, …).

Problem was found years after the damage!
(~ mm surface "mountains/valleys" at HERA)



Picture of damaged SLC collimator



Why can't we run with damaged collimators in the LHC?

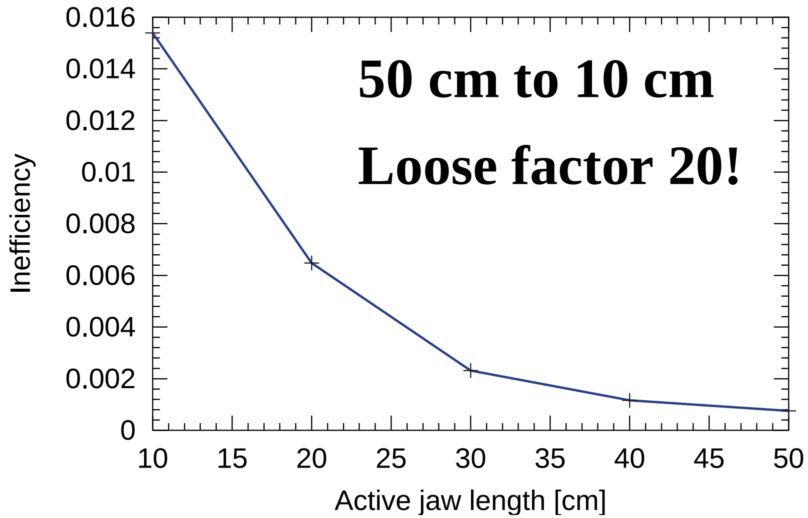
Reasoning:

Distance between primary and secondary from "mountain to mountain".

Must be above 1 σ so that secondaries do not become primaries.

Active length of secondary jaw is drastically reduced (0.5 m to ~ mm's).

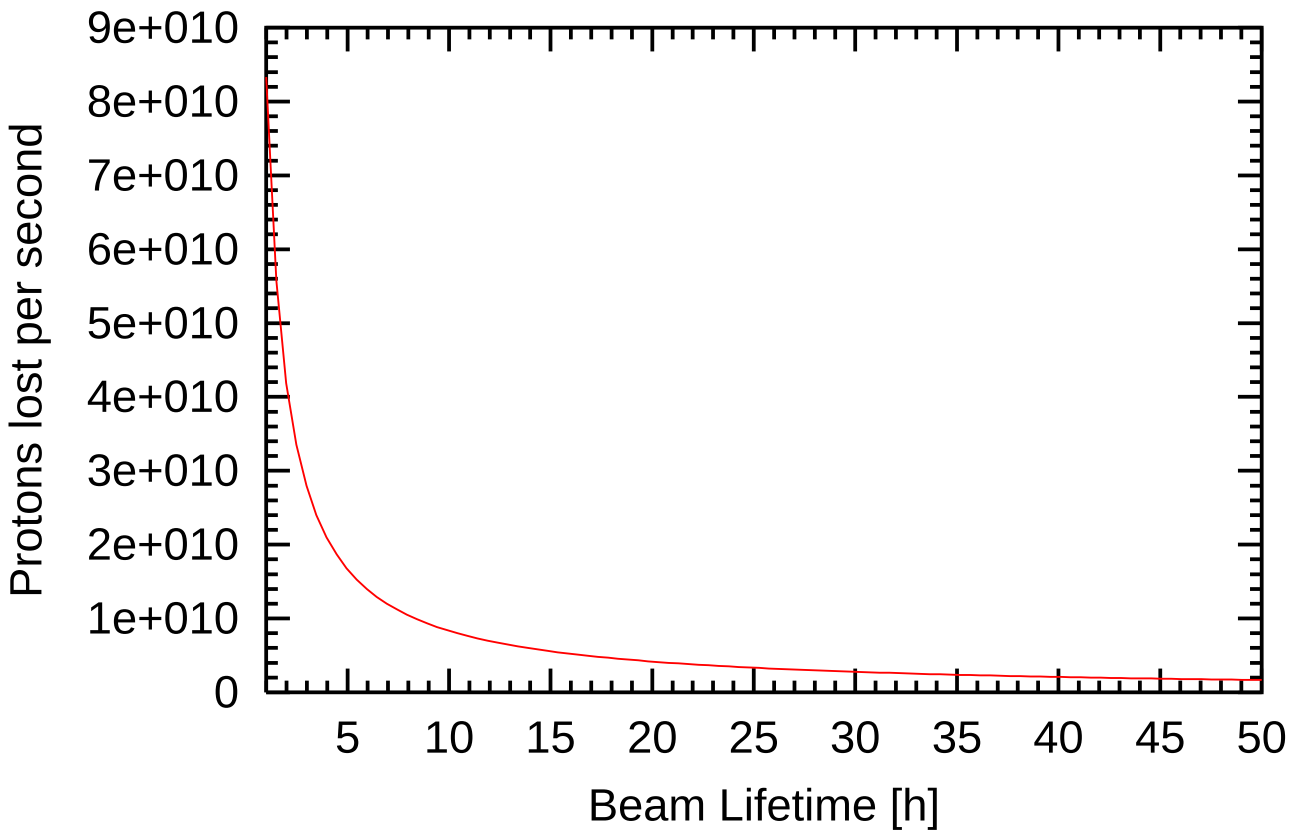
Efficiency is very bad, quenches for increased intensity. (more complicated: 3D)



3) Beam cleaning efficieny:

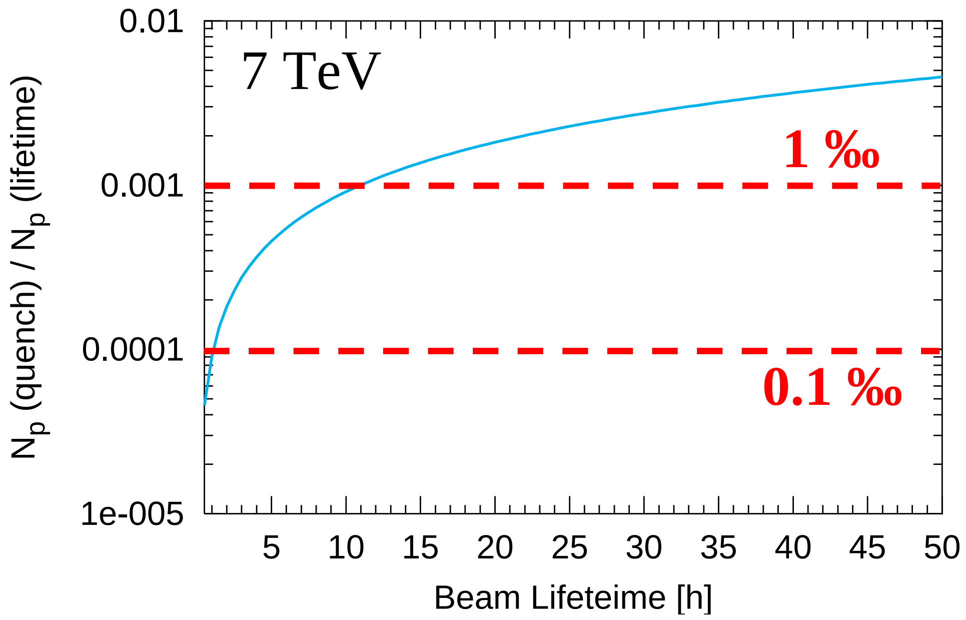
Quench limit ~ **9 orders of magnitude** below total beam intensity (fast transients).

Continuous losses: Characterize particle beam with a lifetime.



Assume that all lost particles can reach the cold aperture.

Ratio between **N protons/m 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).

Note: Required suppression somewhat relaxed compared to plot (proton 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 JBJ)

Identified concerns: **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, …

Additional consideration (related to design, not efficiency):

Impedance from the collimator jaws (requires transition pieces)

Collimators increase in length! ⇨ Rearrangement of insertions!

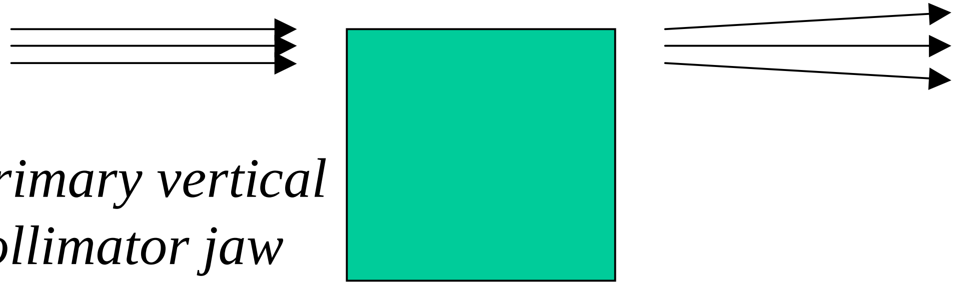
Present some preliminary results (all work in progress)

We cannot draw final conclusions (complete picture not yet available)!

Simulation set-up:

Consider betatron cleaning system
20 collimators (4 primary, 16 secondary)
Collimators at 6 and 7 sigma (nominal)
7 TeV
Design emittance: 0.5 nm
Design beta functions
No non-linearities for this study

Efficiency for vertical halo:



Primary vertical collimator jaw

Look only at particles scattered at primary vertical jaw.

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

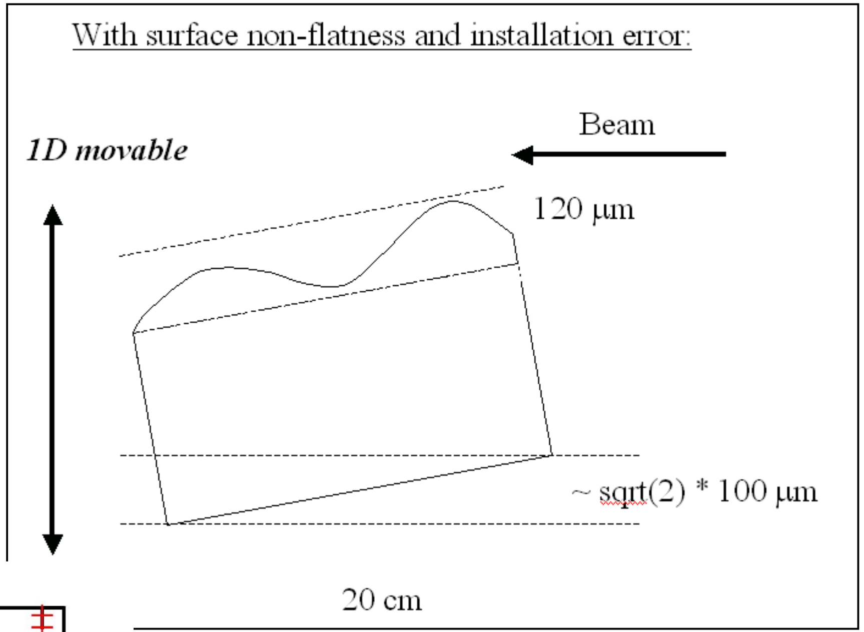
$$\text{Inefficiency}\,(N\sigma_r) = \frac{N_p\,(A_r > N\sigma_r)}{N_p\,(\text{captured})}$$

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

Tilt of secondary jaws:

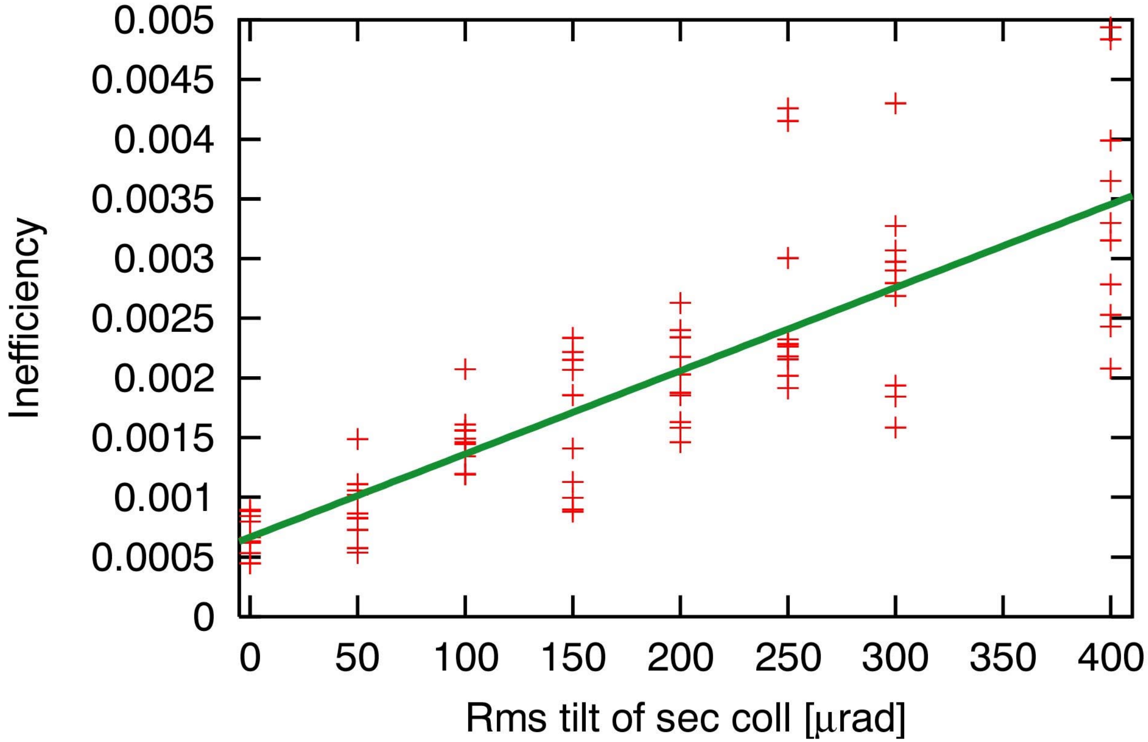
(all results work in progress)

Randomly tilt secondary jaws
(10 seeds for each angle)



Input from G. Burtin

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

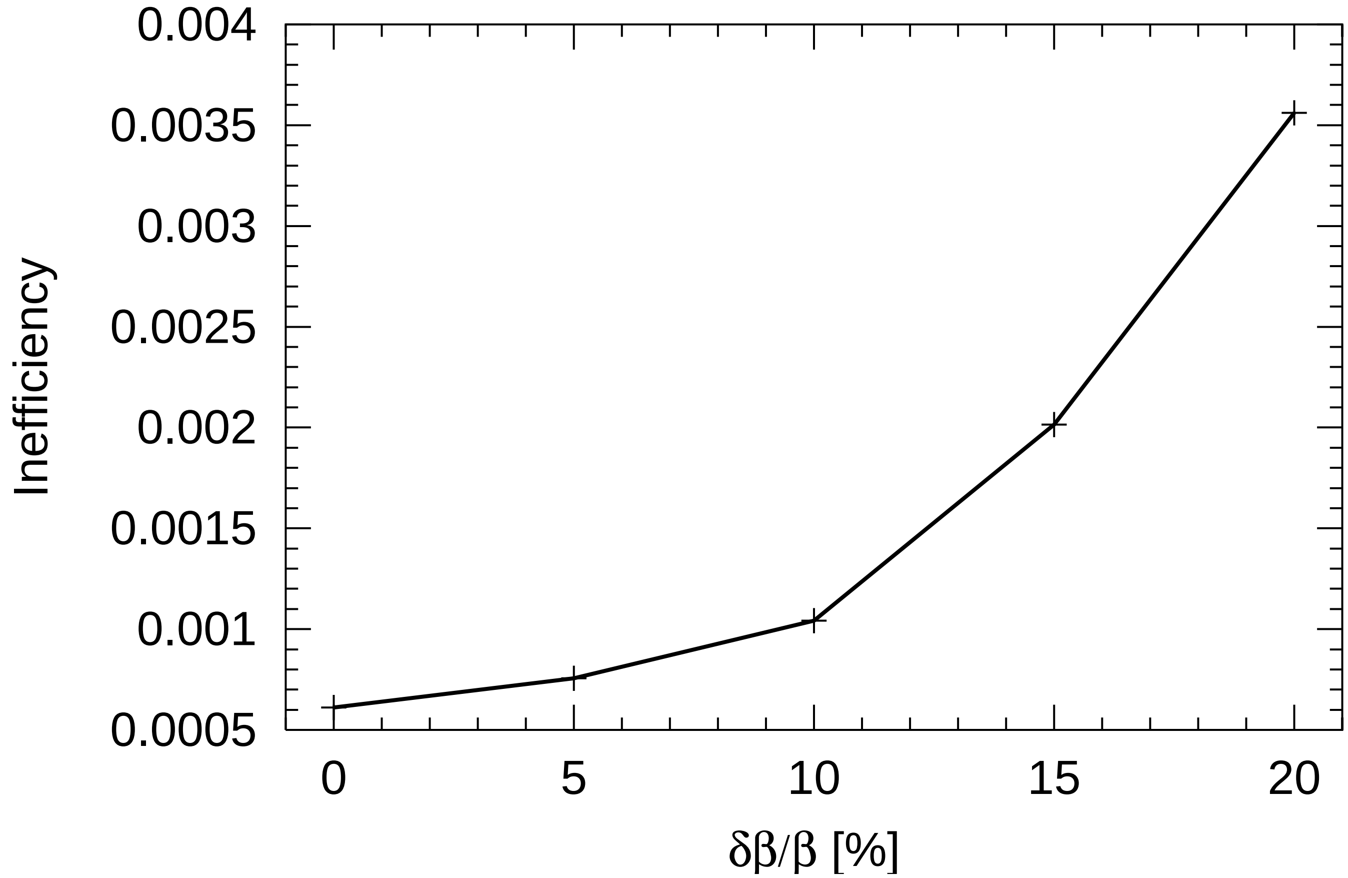


Inefficiency ~ triples for 150 µrad rms tilt. It stays below 0.25%.

No angle control foreseen!

Effect from transient beta beating: (on-momentum, worst phase)

Change of beta beat without readjustment of collimators (e.g. ramp, squeeze).



Agreement with result from D. Kaltchev.

Inefficiency ~ doubles for 10% beta beating.

Tolerances for transient beta beat and orbit:

n_1 = setting of prim coll
n_2 = setting of sec coll

$$\frac{\delta\beta}{\beta} < \left(\frac{n_2}{n_1} - 1 \right)$$

$$x_{orbit}(\mathrm{sec}) - x_{orbit}(\mathrm{prim}) < n_2 - n_1$$

Orbit stabilization: ~ 20-50 μm with ~1 Hz. Do we need faster?

(J. Wenninger)

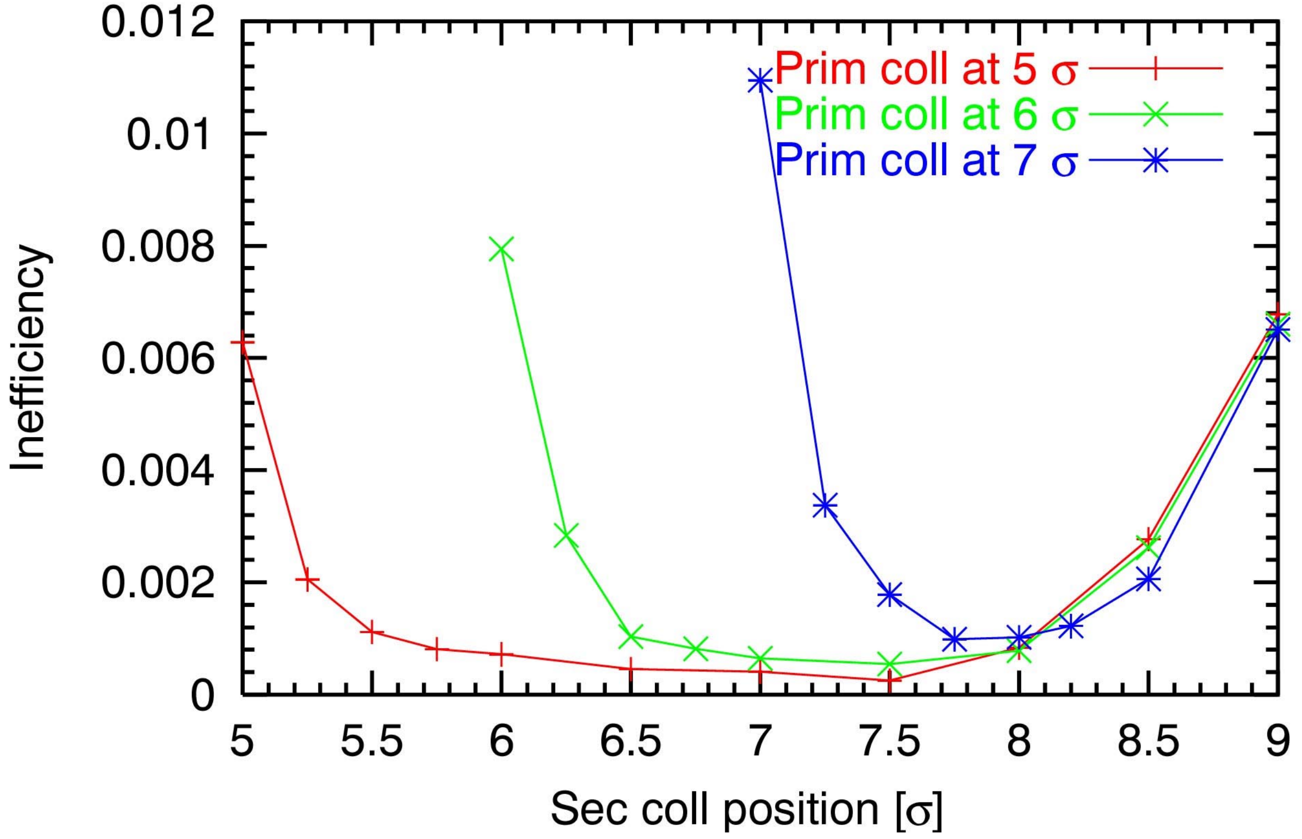
Boundary conditions:

Primary collimators should not reduce lifetime **n_1 > 5 σ**
Secondary collimators must protect cold aperture **n_2 < 10 σ**

More robust system: (go away from the 7/6 rule?)

Put n_1 to lowest possible setting (then keep optimal).
Put n_2 to highest possible setting, less critical for optimization.
Maintain a good cleaning efficiency.

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

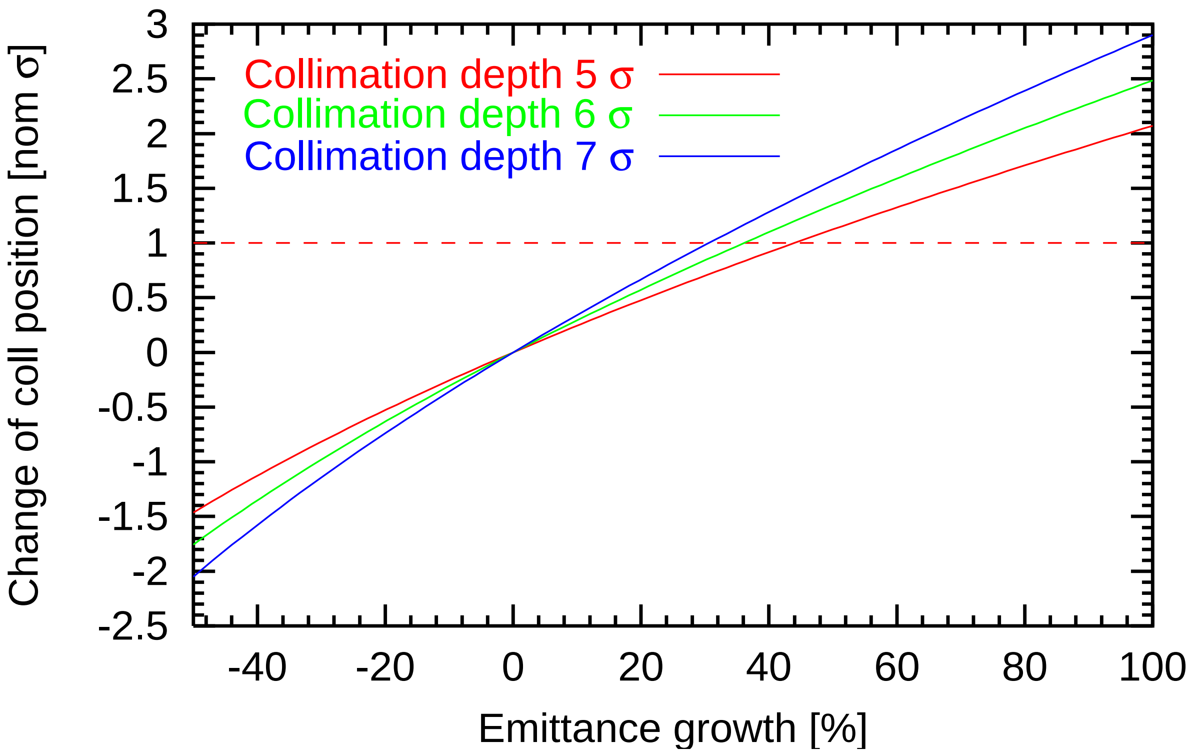


If we can collimate closer to the beam

→

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.



<u>Example:</u>

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).

Conclusion:

The **LHC Beam Cleaning Study Group has been initiated** to study the collimation system for a realistic environment. 4 meetings so far…

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

Studying three central topics for the LHC collimation system:

Machine protection: Design so that perturbed beam hits collimators first. Predict beam loss distribution (regular, irregular). Showering studies (heating, radiation, beam loss signal).

Durability: Design collimators that can handle beam power. Is a 10^{-5} damage threshold (physics) workable? Protect collimators against injection oscillations. Any significant damage will ruin cleaning efficiency.

Cleaning efficiency: Include imperfections, non-linearities, optics, orbit errors, … static and time-dependent (ramp, squeeze)

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

Inefficiency increase

100%	for 10 % beta beating
200%	for 150 μrad random tilt
1900%	for factor 5 reduction of active length for secondary collimators

Errors are **very important** (they drastically reduce the margin we have)…

There are ways to **relax tolerances** (vary collimation depth)!

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

Beam loss simulation for **failure scenarios** (including collimators).

More studies on **heating and damage** are required.

Re-consider the present design choices. Study **more robust (longer) collimators** (profit from experience for targets, …).

We must realize:

The performance of the collimation system will likely limit…

… **peak luminosity** due to maximum allowed intensity.

… **integrated luminosity** due to beam aborts and repair time.

Collimation is a performance-critical topic from day 1 of the LHC beam!

There are no easy solutions, it is a **challenging** (and interesting) task!

The **beam cleaning study group** will do its best to provide…

… a **simple as possible** system which can be operated and maintained…

… that **protects** the LHC hardware to the extent possible…

… and that has a **good durability and robustness**…

… with an **excellent cleaning efficiency**…

… and all this for the **lowest possible price** tag!

It will take work and support from many people!