Collimation During Ramp and Squeeze

R. Assmann, CERN, AB/ABP

Acknowledgements to the colleagues in the
LHC Collimation Working Group and ABP, in particular:

*C. Bracco, T. Weiler, S. Redaelli, R. Steinhagen, G. Robert-Demolaize
for providing data and plots.*

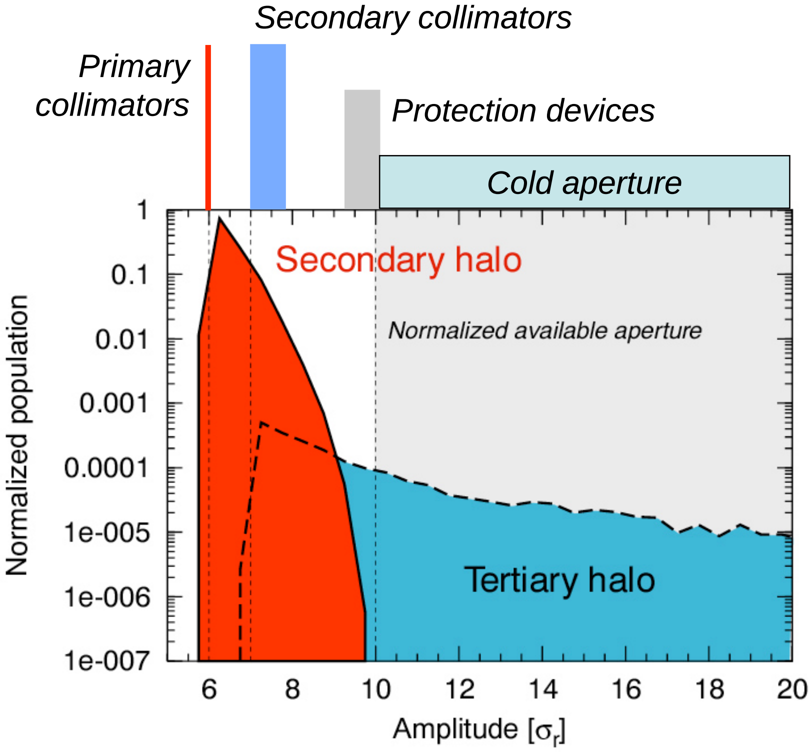
LHCCWG

November 28th, 2006

ABP Work on Collimation

- **Guillaume Robert-Demolaize** last week successfully defended his thesis at University of Grenoble:
  "Design and Performance Optimization of the LHC Collimation System" → AB seminar this Thursday before starting job in BNL.
- **Chiara Bracco** performs her PhD on commissioning of the collimation system in collaboration with EPFL:
  "Commissioning Scenarios and Tests for the LHC Collimation System"
  → Chiara will be happy to report on her results in some future meetings.
- **Valentina Previtali** will perform her PhD (starting Jan 1, 2007) on upgrade scenarios for the LHC collimation system (including crystals) in collaboration with EPFL. Valentina will participate in commissioning and analysis of phase 1 performance.
- **Thomas Weiler** (fellow) is preparing hardware commissioning paper. Will participate in HWC and is participating in collimation studies.

Secondary and Tertiary Beam Halo



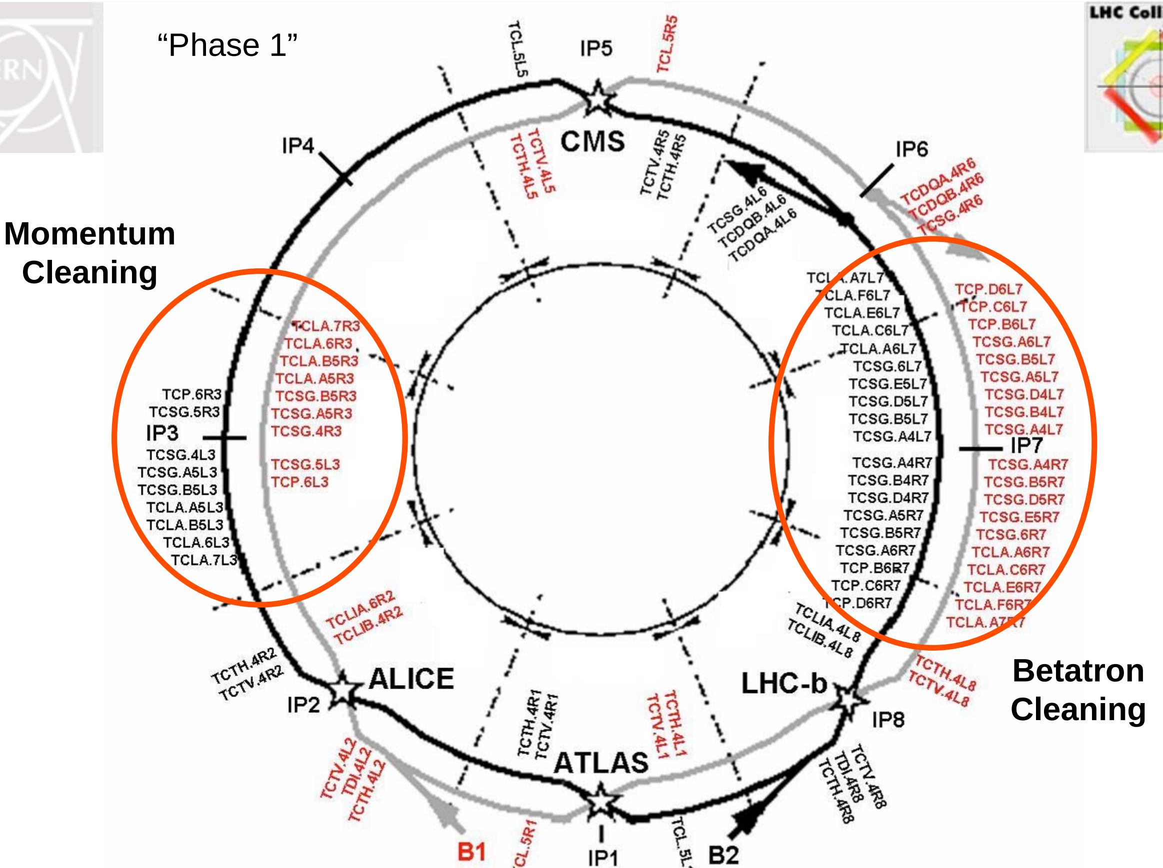
Strategy:

Primary collimators are closest.

Secondary collimators are next.

Absorbers for protection just outside secondary halo before cold aperture.

Relies on good knowledge and control of orbit around the ring!



C. Bracco

Physical Aperture and Collimator Settings

Aperture allowances: 3-4 mm for closed orbit, 4 mm for momentum offset, 1-2 mm for mechanical tolerances.

Optics	Limitation	Half aper-ture a [m]	b [m]	a_{norm} $[m^{1/2}]$	Energy	$a_{norm}/e^{1/2}$
Injection	Arc	0.012	180	**8.8×10^{-4}**	450 GeV	10
Nom. collision	Triplet	0.015	4669	**2.2×10^{-4}**	7 TeV	10

Collimator setting (prim) required for triplet protection from 7 TeV secondary halo:

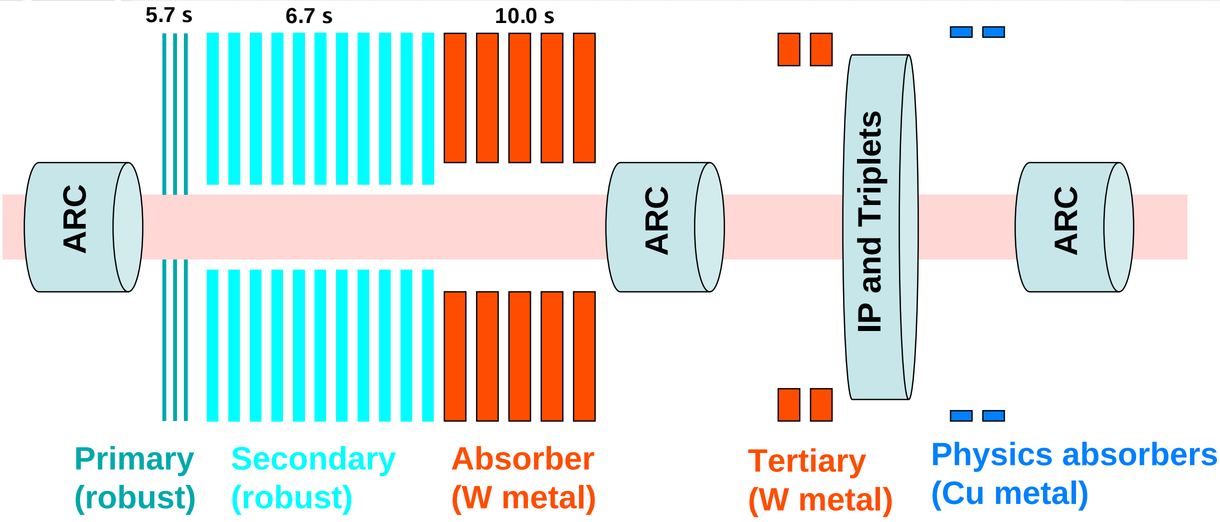
~ 0.15 ~ 0.6

$$a_{coll} \leq a_{triplet} \cdot \sqrt{\frac{\beta_{coll}}{\beta_{triplet}}} \cdot \left(\frac{A_{primary}^{max}}{A_{secondary}^{max}} \right)$$

Collimator gap must be **~10 times smaller** than available triplet aperture!

Collimator settings usually defined in sigma with nominal emittance!

Collimation at Injection



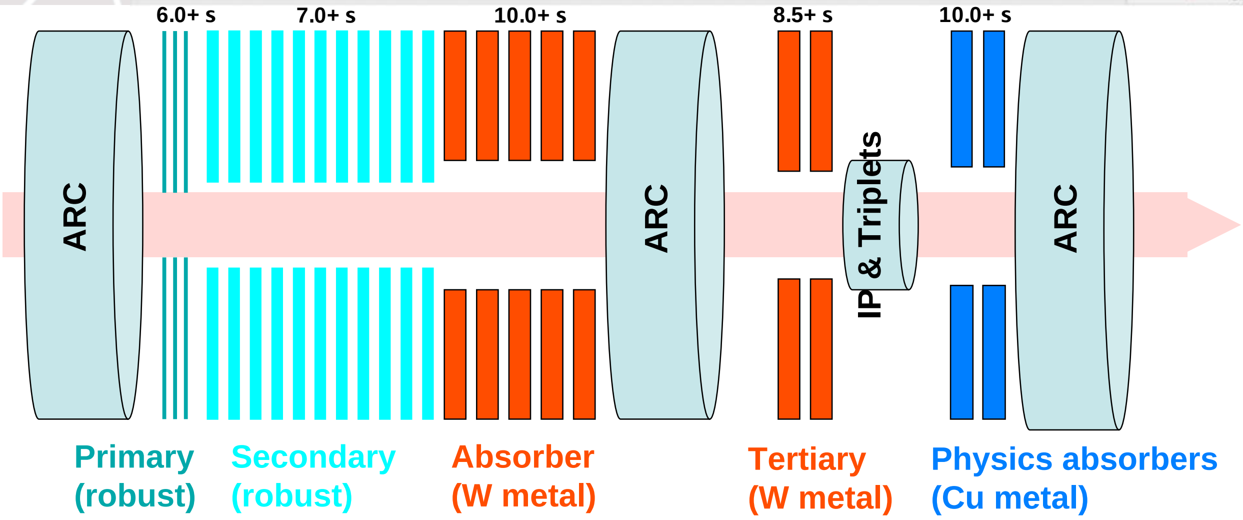
Relevant aperture limit is the arc!

Protected by 3 stages of cleaning and absorption!

First and second aperture limits by robust collimators!

Then metallic collimators with good absorption but very sensitive!

Betatron Collimation at Collision



Relevant aperture limit are the triplets at the IP's!

Protected by 4 stages of cleaning and absorption!

First and second aperture limits by robust collimators!

Then metallic collimators with good absorption but very sensitive!

Tolerances

Origin of tight tolerances:

Normalized retraction from primary to secondary collimators:

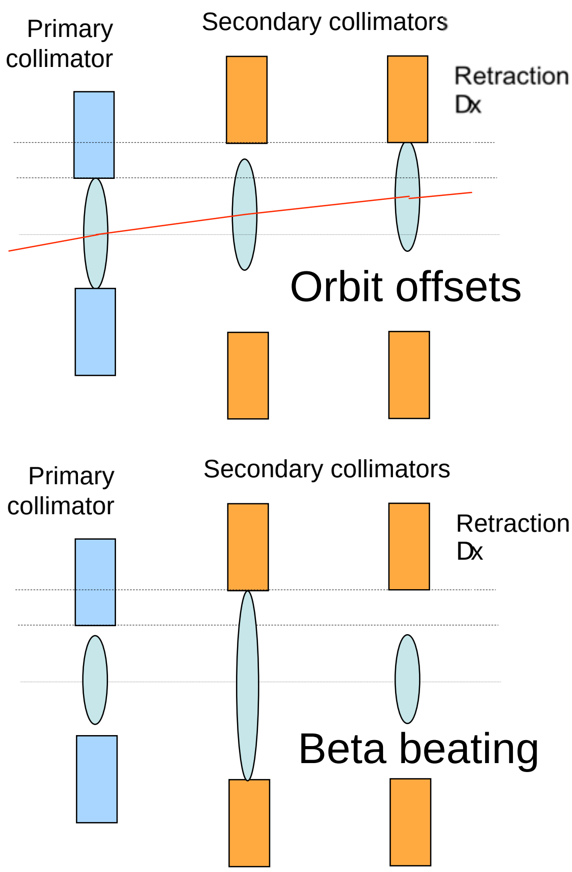
$\Delta x \sim 1\,\sigma$

(450 GeV: ~ 1.2 mm. 7 TeV: ~ 0.2 mm)

➔ **Two-stage cleaning:**

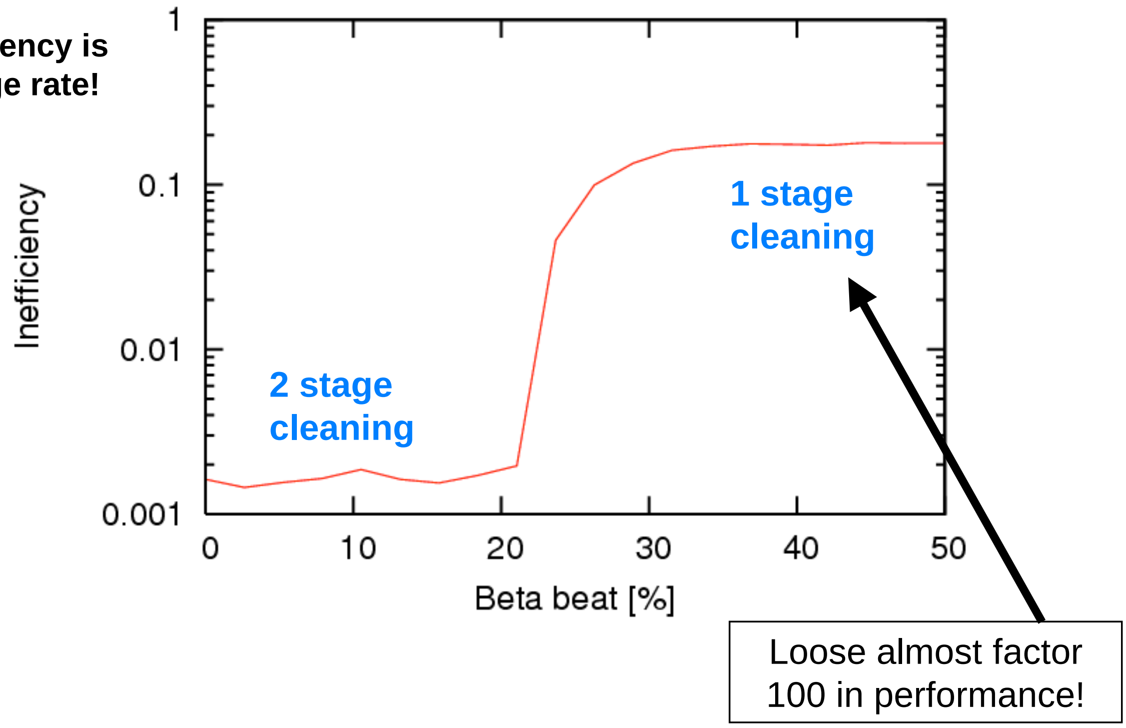
Secondary collimator must not become primary collimator! Accommodate different errors in the retraction...

- *Transient orbit changes*
- *Transient beta beat changes*
- *Static jaw deformation*
- *Transient jaw deformation*
- *Set-up errors*



Example: Transient Beta Beat at 7 TeV

Inefficiency is leakage rate!



If retraction is adjusted such to allow some maximum transient beta beat and orbit error, then **constraint of b^*:**

$$\beta^* \geq \frac{C^2}{a^2_{triplet} \cdot \beta_{coll}} \cdot \left(n_{\mathrm{prim}} + \Delta A_{\max} + 1.7 \cdot \left[n_{\mathrm{prim}} \cdot \sqrt{\frac{\Delta\beta_{\max}}{\beta_0}} + \frac{\Delta x_{\mathrm{orbit}}^{\max}}{\sigma_x} \right] \right)^2$$

- Increase triplet aperture
- Increase beta at collimators
- Small primary gap
- Sufficient number of secondaries at specific phases
- Minimize any transient beta beat
- Minimize transient orbit changes

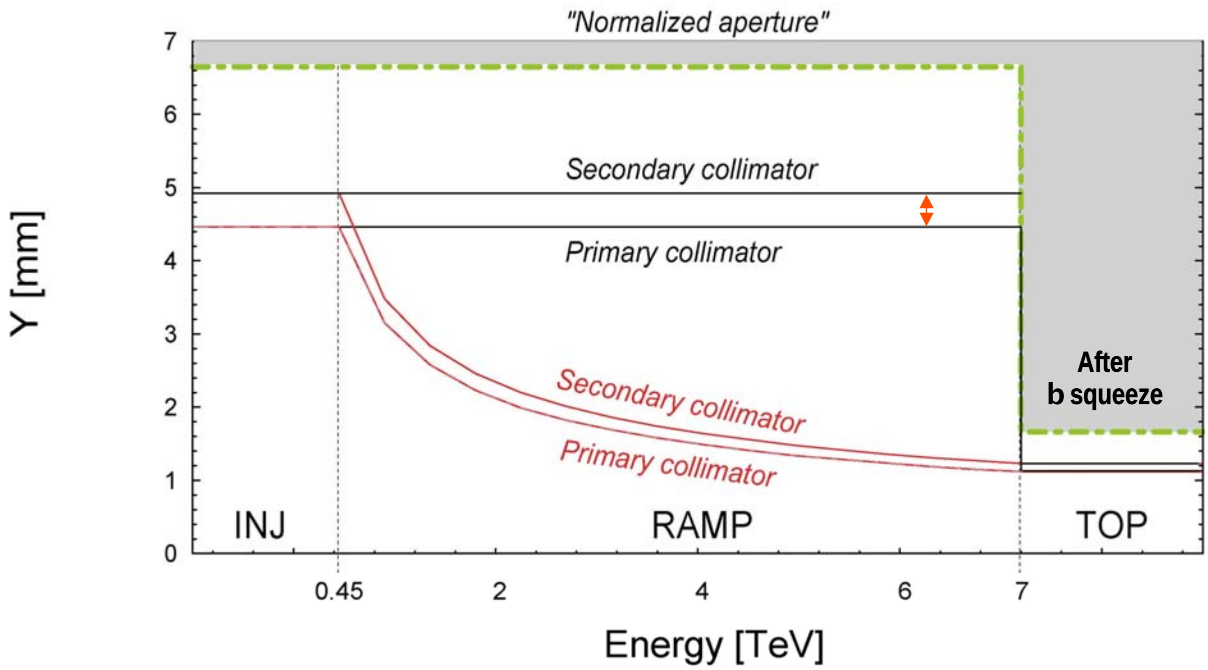
Larger b^* - A way to relax operational collimator tolerances!

(However, loose passive protection)

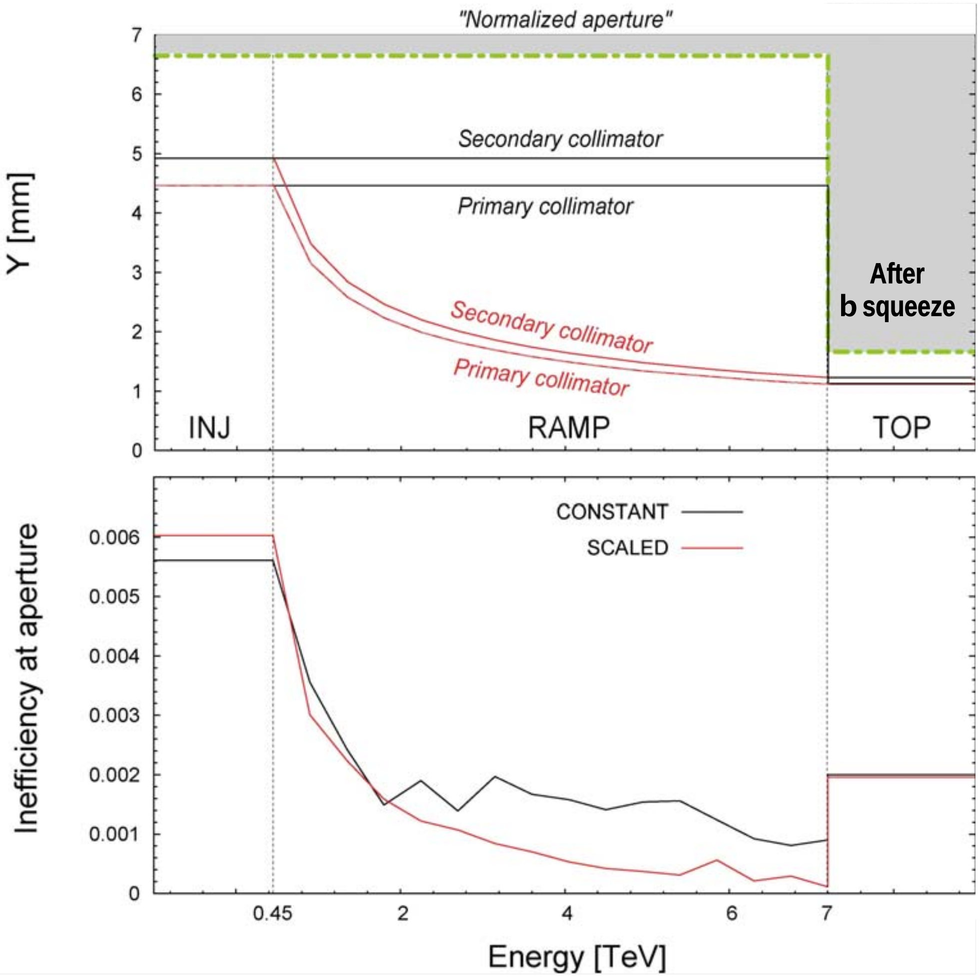
1) Collimation During Ramp

- **Injection:** Collimators closed to injection gaps. Collimator-induced impedance handled by transverse feedback.
- **Before start of ramp:** Injection protection retracted (TDI, TCLIA, TCLIB).
- **Ramp:**
  - Collimator-induced impedance effects reduced: transverse feedback can be switched off at some point.
  - In principle, collimators could stay at injection settings (no change in normalized aperture).
  - However, collimators should be somewhat closed to tighten protection.
  - Preference for squeeze or pre-squeeze during the ramp: Less energy stored in the beam and quench limits are more relaxed. See slides later.
- **End of ramp:**
  - Machine is corrected and recorded to provide reference for further steps.
  - If reference exists: Correction to reference (orbit, tune, coupling, chromaticity, ...)

Possible Vertical Collimator Settings



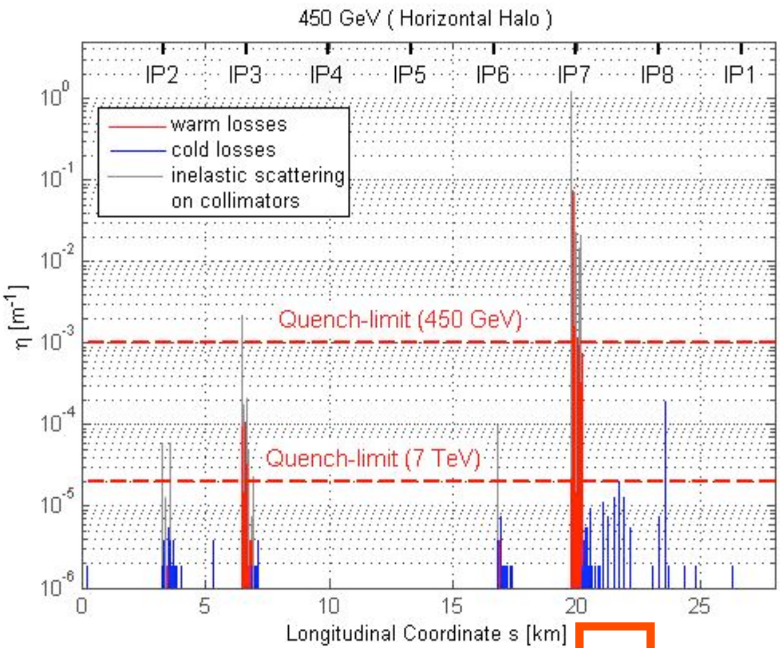
➔ *Consider very different values for retraction primary – secondary collimators…*



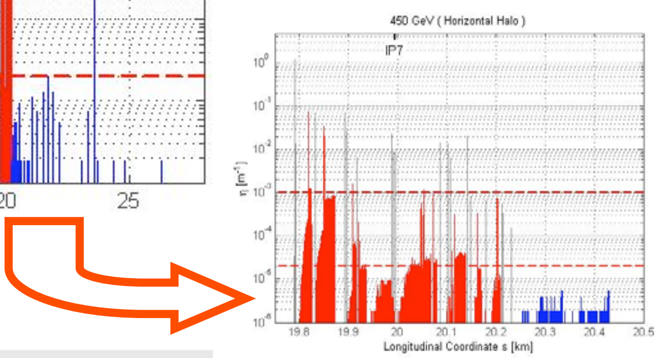
Efficiency improves if collimators are closed:

However, tolerances become tighter!

Loss Map at Start of Ramp



C. Bracco



Loss Map End of Ramp (Collimators at Injection Settings)

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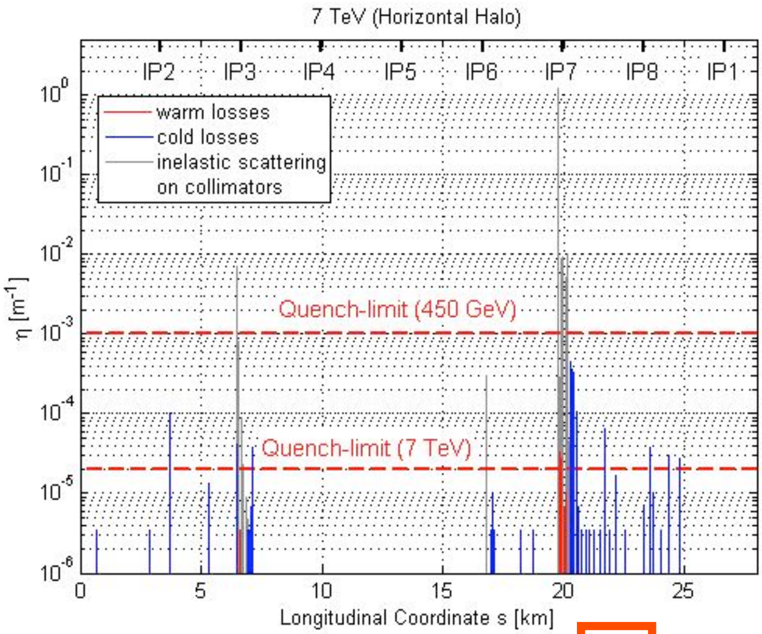
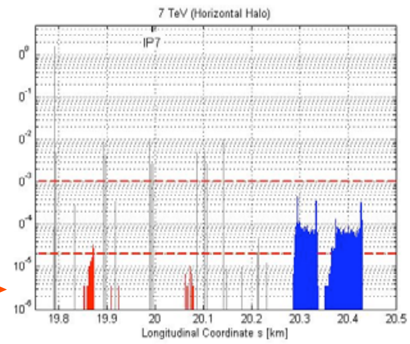
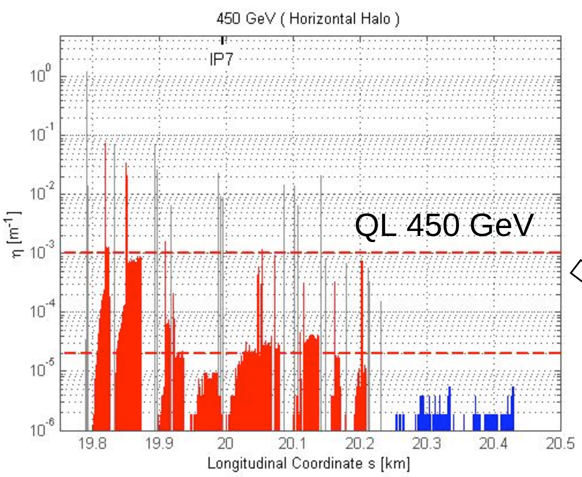
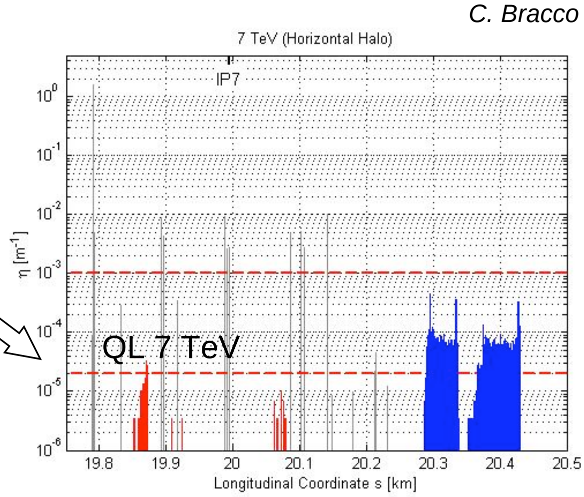




Ramp without Closing Collimators

C. Bracco

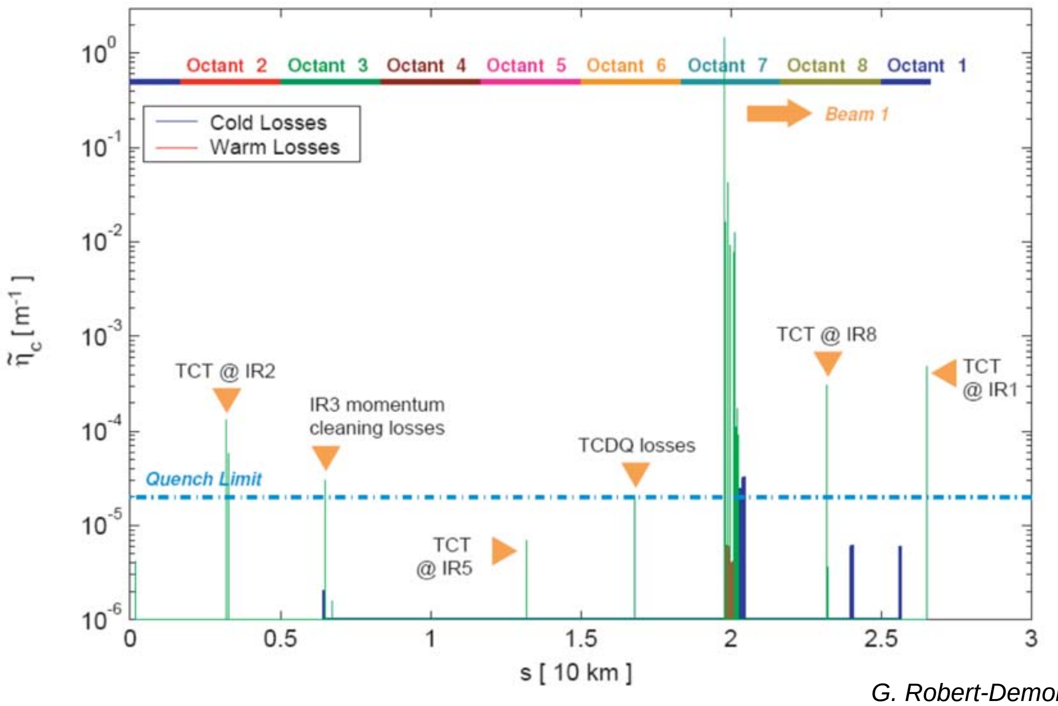




Two observations: 1) Quench limits go down.

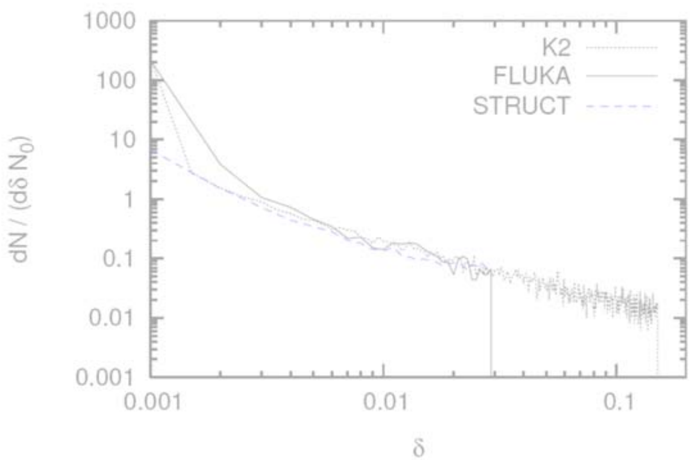
2) Local losses in DS go up because collimator not closed!

Collision: Collimators Closed (0.55m)



G. Robert-Demolaize

Single-Diffractive Scattering

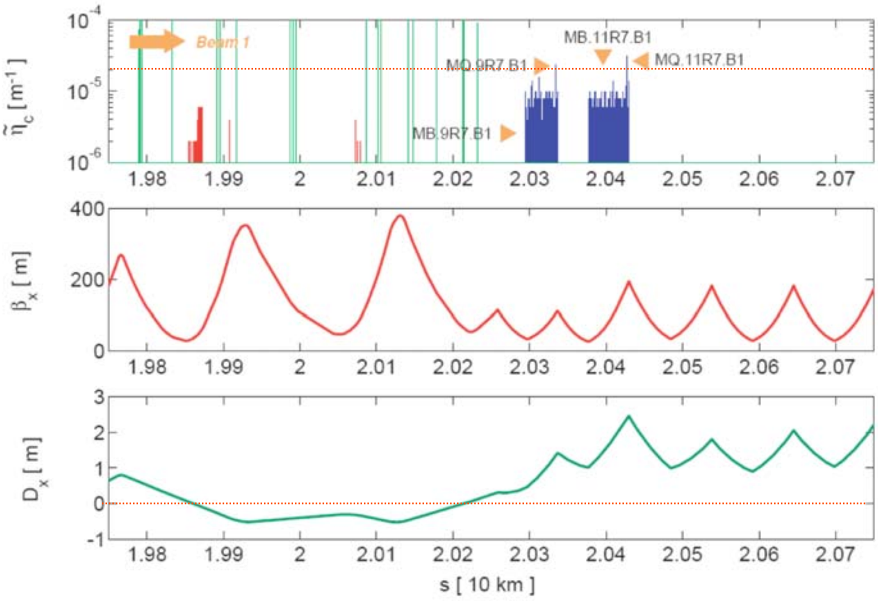


Cross-section single-diffractive scattering: Comparison FLUKA – STRUCT – COLLTRACK/K2

LHC p collimation system was optimized until fundamental limitation was met:

- Some protons experience single-diffractive scattering in primary betatron collimators: large energy offset and small betatronic kick.
- **Betatron collimators generate off-momentum halo.**
- Most of newly off-momentum protons are lost in first place with high dispersion: downstream dispersion suppressor.

Collision: Collimators Closed (0.55m)



Collimation team and FLUKA team

E [GeV/b]	7000
	Hori
TCL	ON
TCS	ON
MQ6	1.4
MQ7	0.400
MBA8R	0.200
MBB8R	0.200
MQ8	1.000
MBA9R	0.600
MBB9R	1.000
MQ9	1.800
MBA10R	0.400
MBB10R	0.030
MQ10	0.500
MBA11R	0.900
MBB11R	1.000
MQ11	5.000 mW

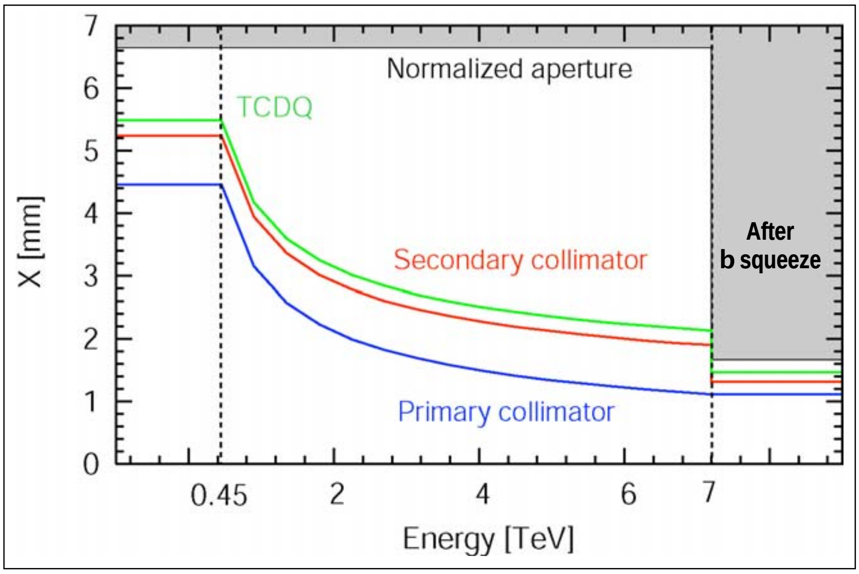
Heat load showers

Optimized Setting during Ramp

Primary closing with energy (remains at 5.7s)!

Absolute distance from secondary collimator to primary kept constant:
➔ Increased setting in s.
➔ Constant orbit and beta beat tolerances from collimation!
➔ Better cleaning efficiency!

TCDQ follows secondary collimators with constant absolute distance:
➔ Increased setting in s.



**X normalized to location of primary collimator*

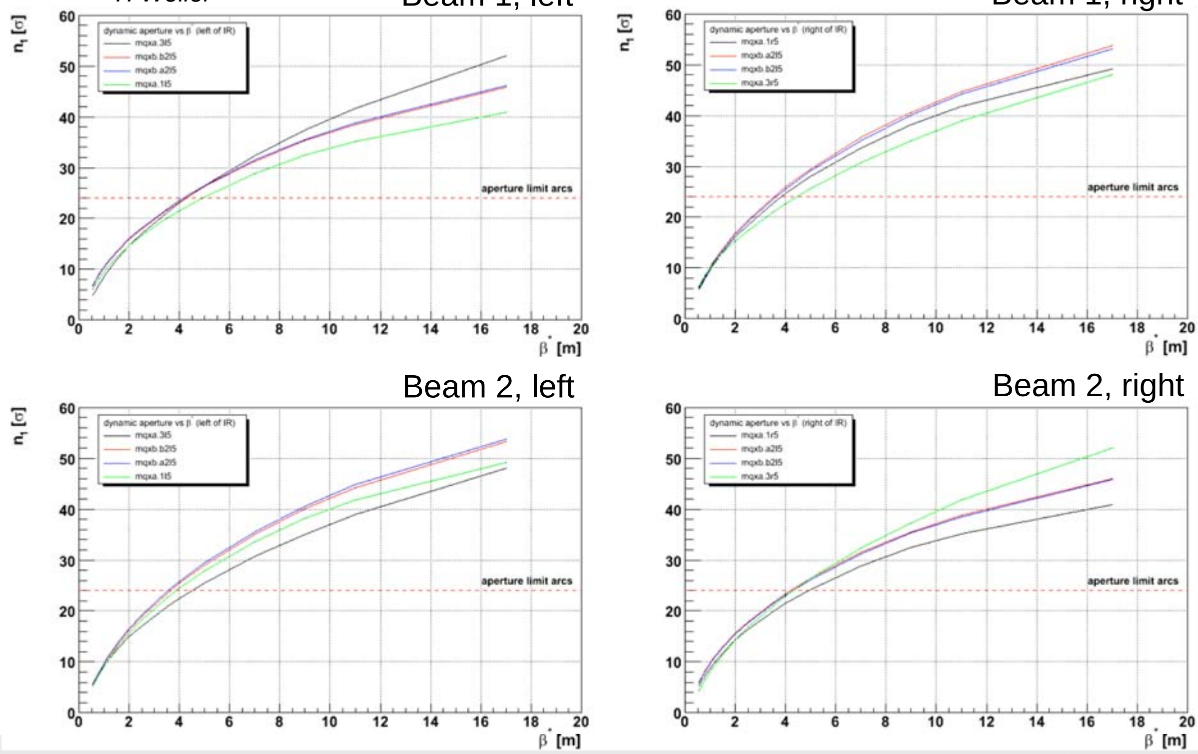
Open phase space shrinks during ramp:
➔ Improved safety against emittance blow-up
➔ Orbit errors caught earlier
➔ dI/dt is not as steep when beam loss is seen

2) Squeeze

- Squeeze reduces overall machine aperture, for b* smaller than about 6 m!
- Triplets become the aperture bottleneck in the LHC (act as primary collimators ➔ risk of quench and damage)!
- Collimators must be closed before the actual squeeze to prevent this from happening!
- Very tight machine tolerances from collimators with small gaps: proceed in steps to profit from larger tolerances as long as possible!
- Impedance will increase once collimators are being closed. Tune spread from octupoles is required to stabilize beam!
- Overall orbit and optics must be sufficiently under control to always ensure protection of the machine! Feedbacks will help to ensure this!
- Squeeze is a complex and dangerous process in the LHC…

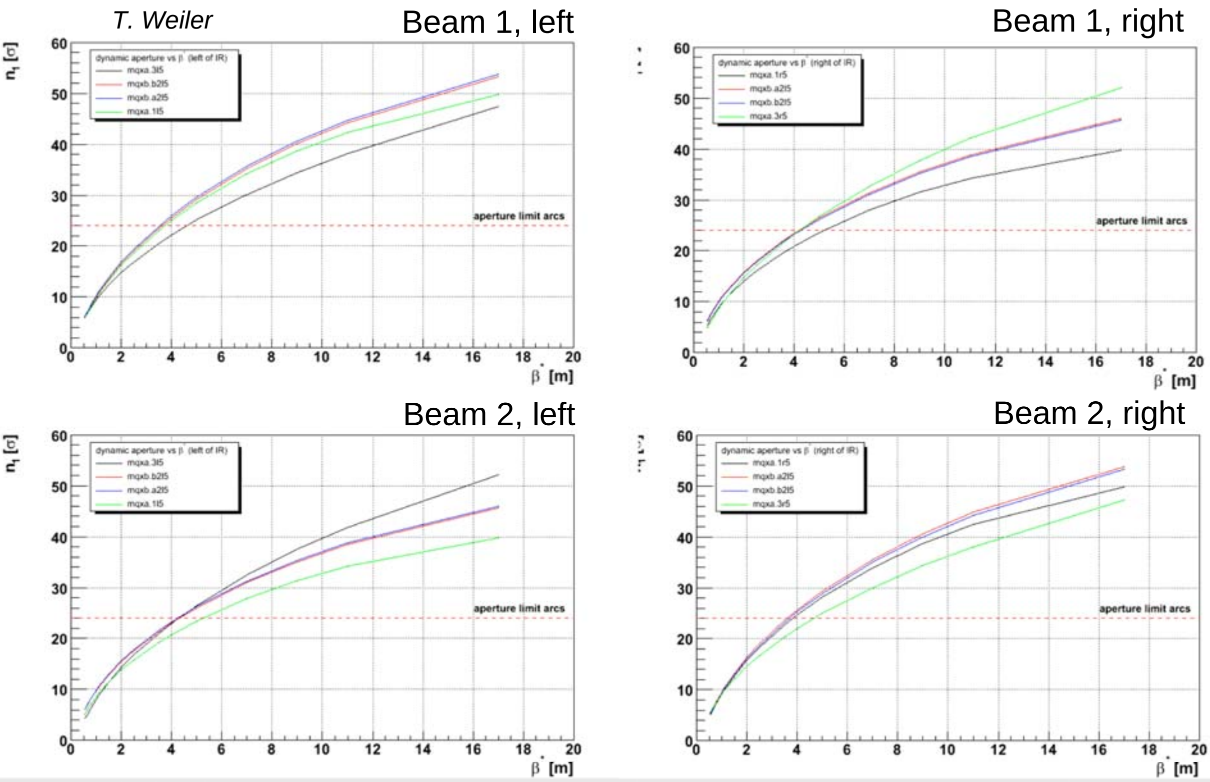
IP1 Triplet Aperture During Squeeze

T. Weiler



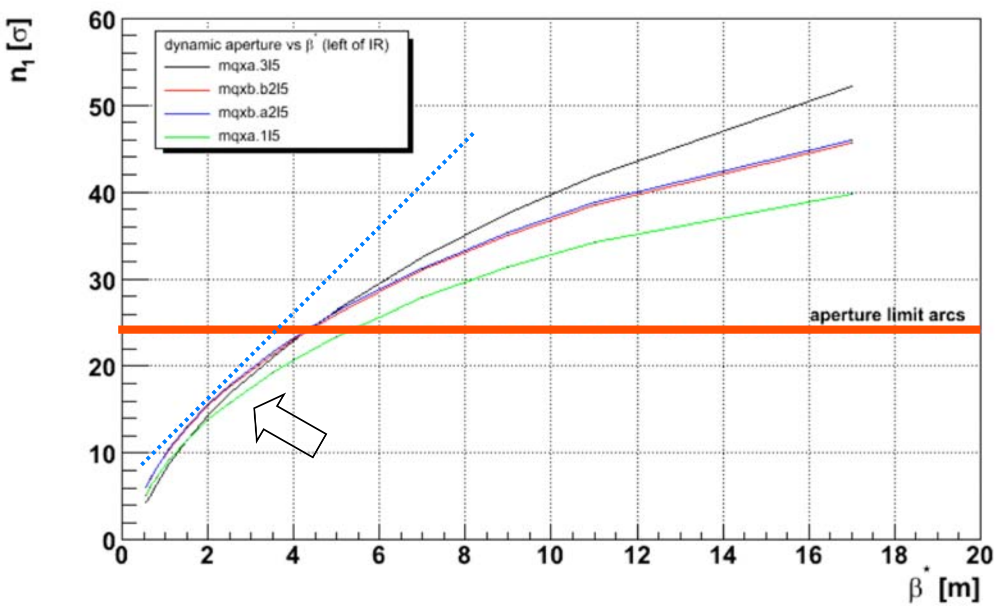
IP5 Triplet Aperture During Squeeze

T. Weiler



Limit at IP5

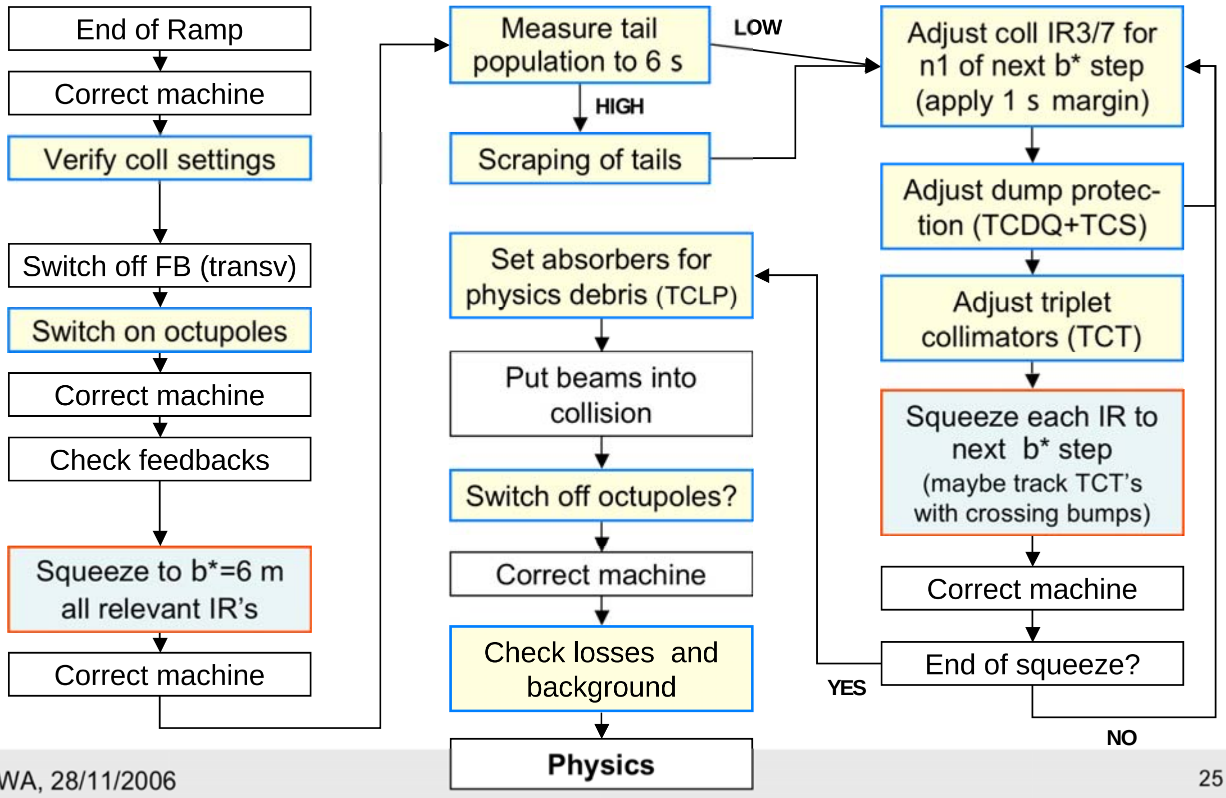
T. Weiler



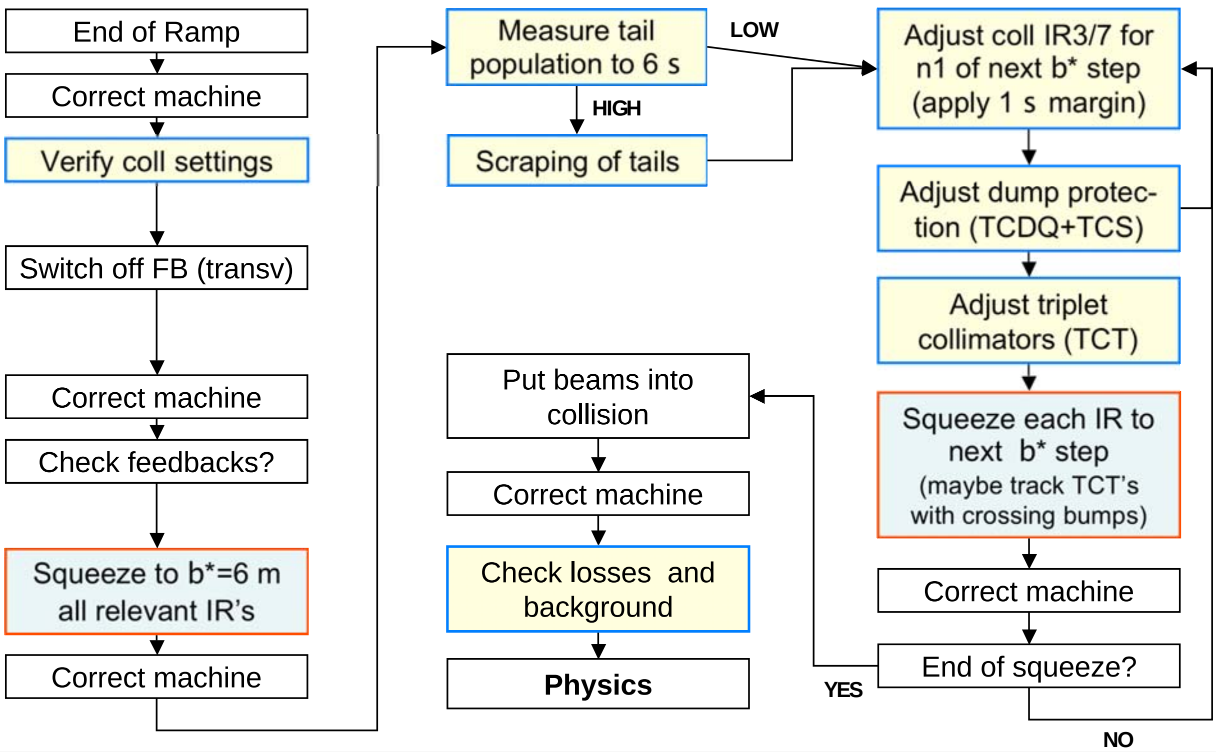
Obliged to close collimators below b* of ~6 m!

Change in n1: about 2.5 s per m in b* in relevant range!

Draft Squeeze Procedure

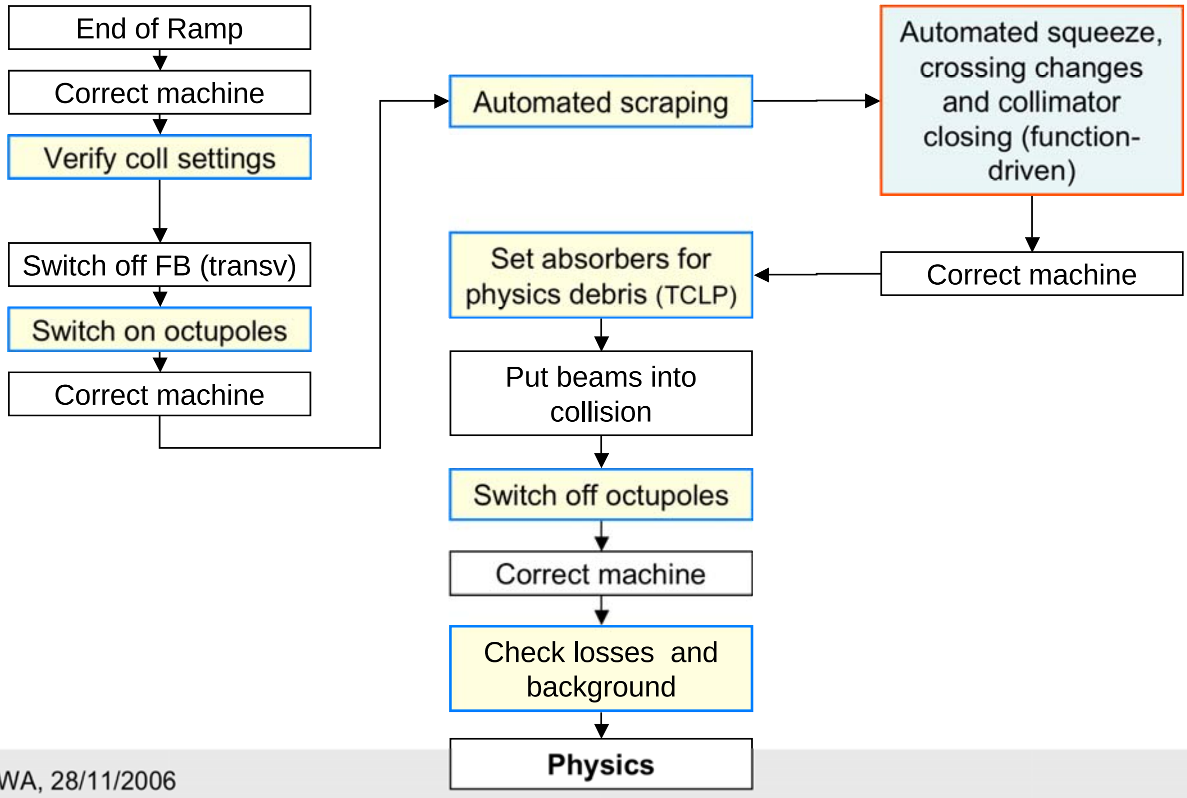


Reduced Procedure for Low Intensity



Production Procedure?

LHC Collimation Project CERN

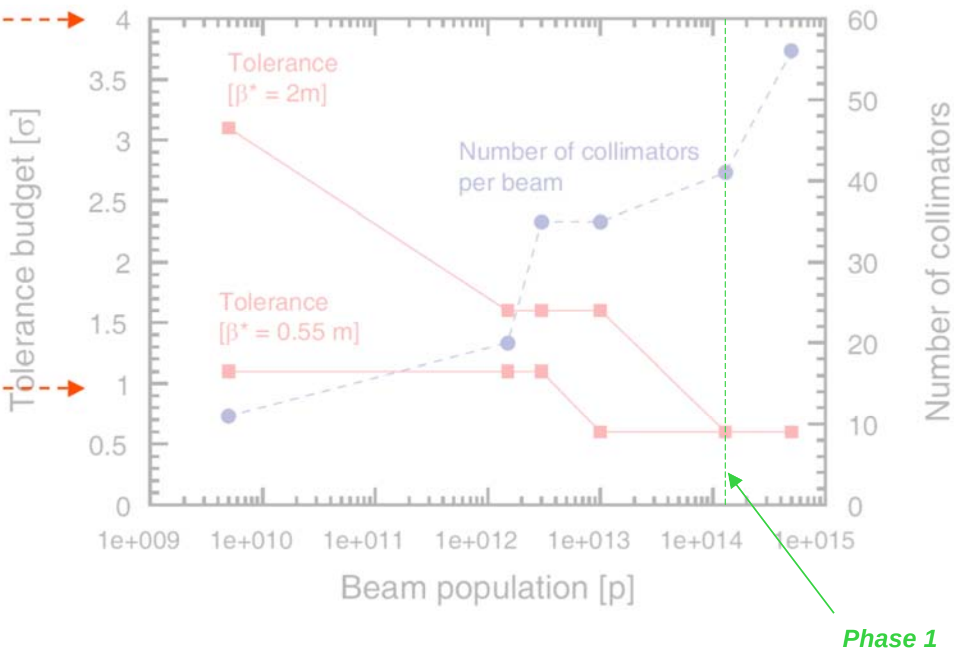


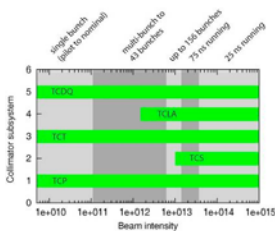
Tolerance Budget

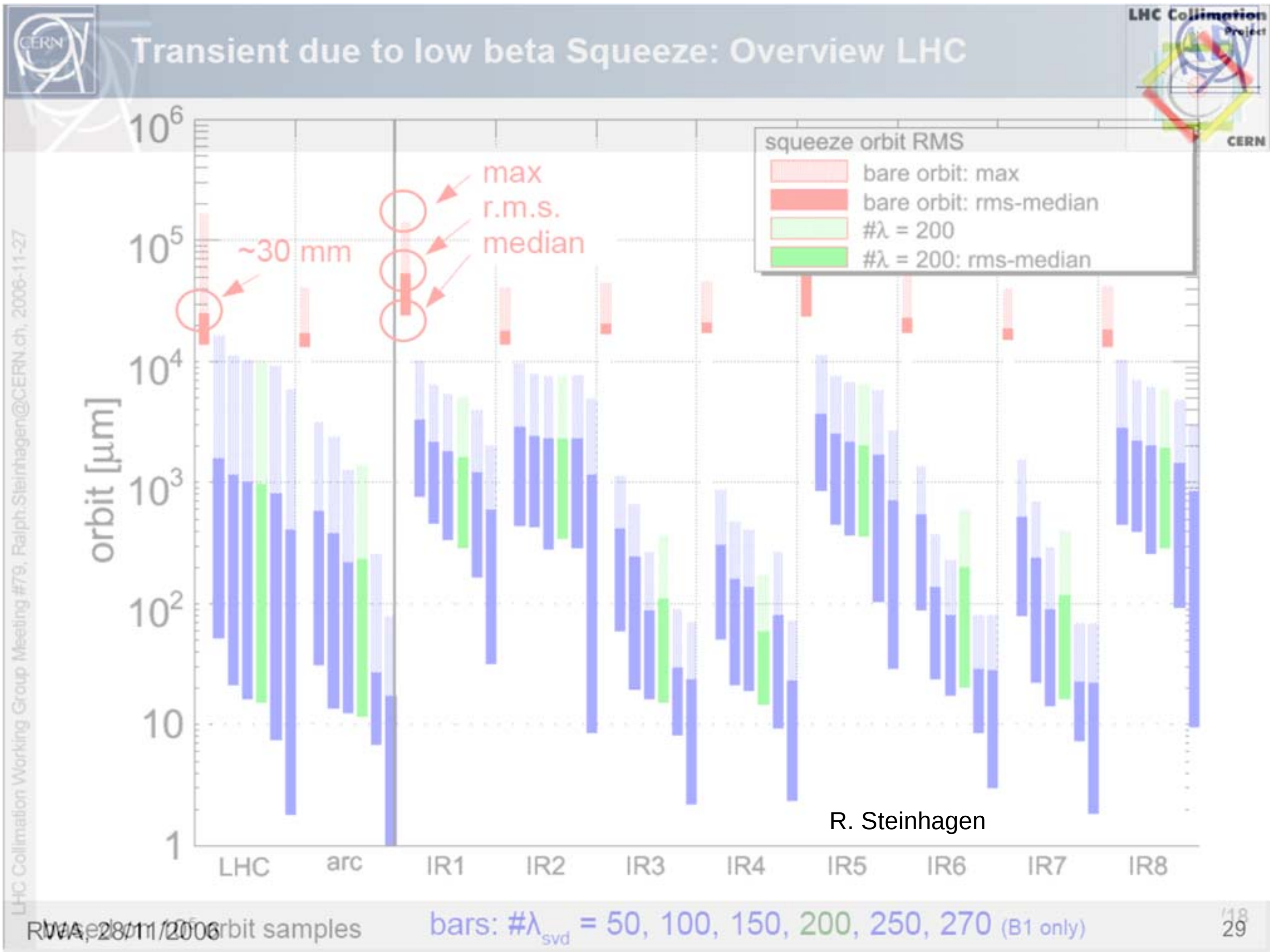
LHC Collimation Project CERN

0.8 mm at a typical collimator

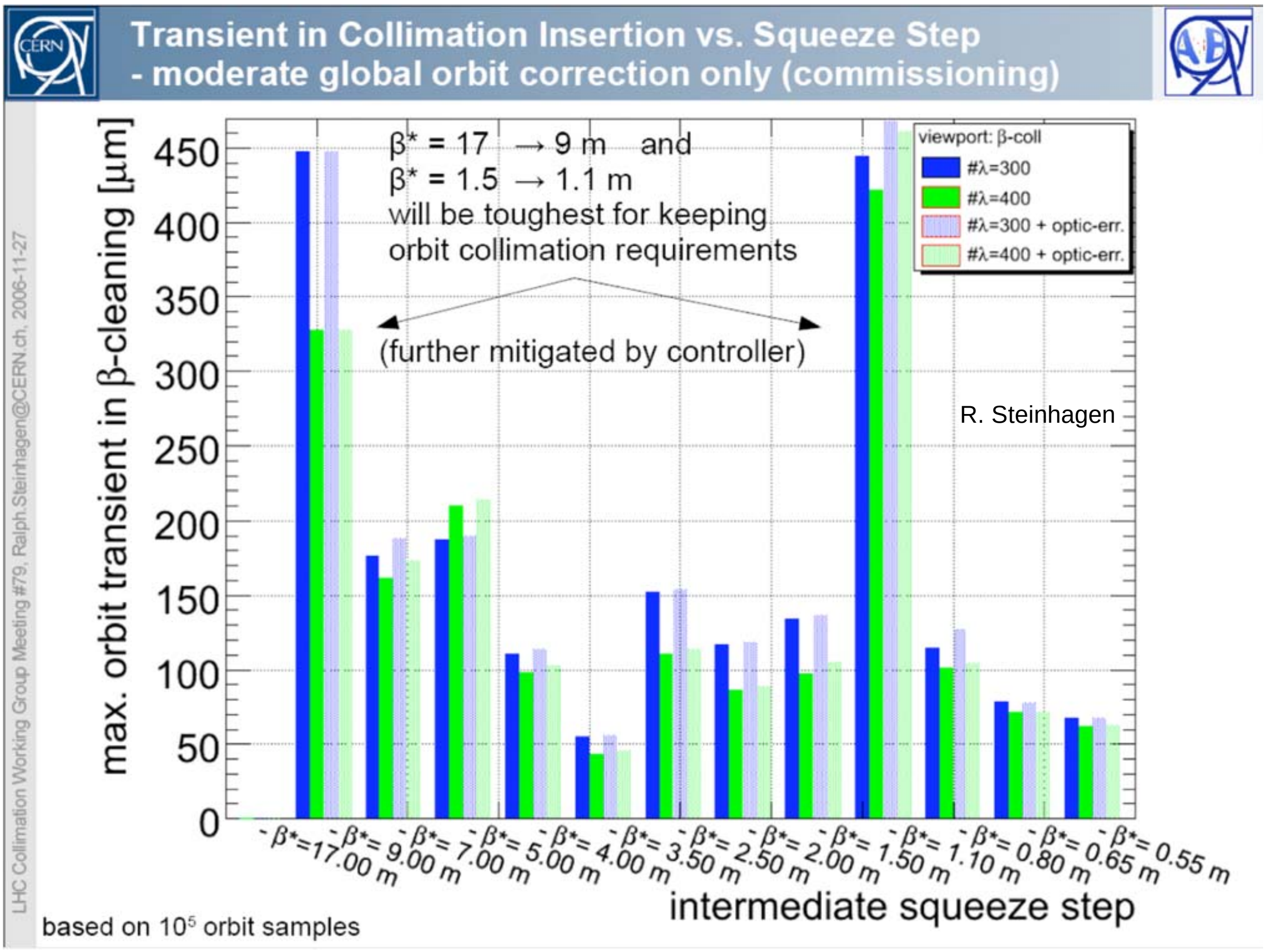
0.2 mm at a typical collimator







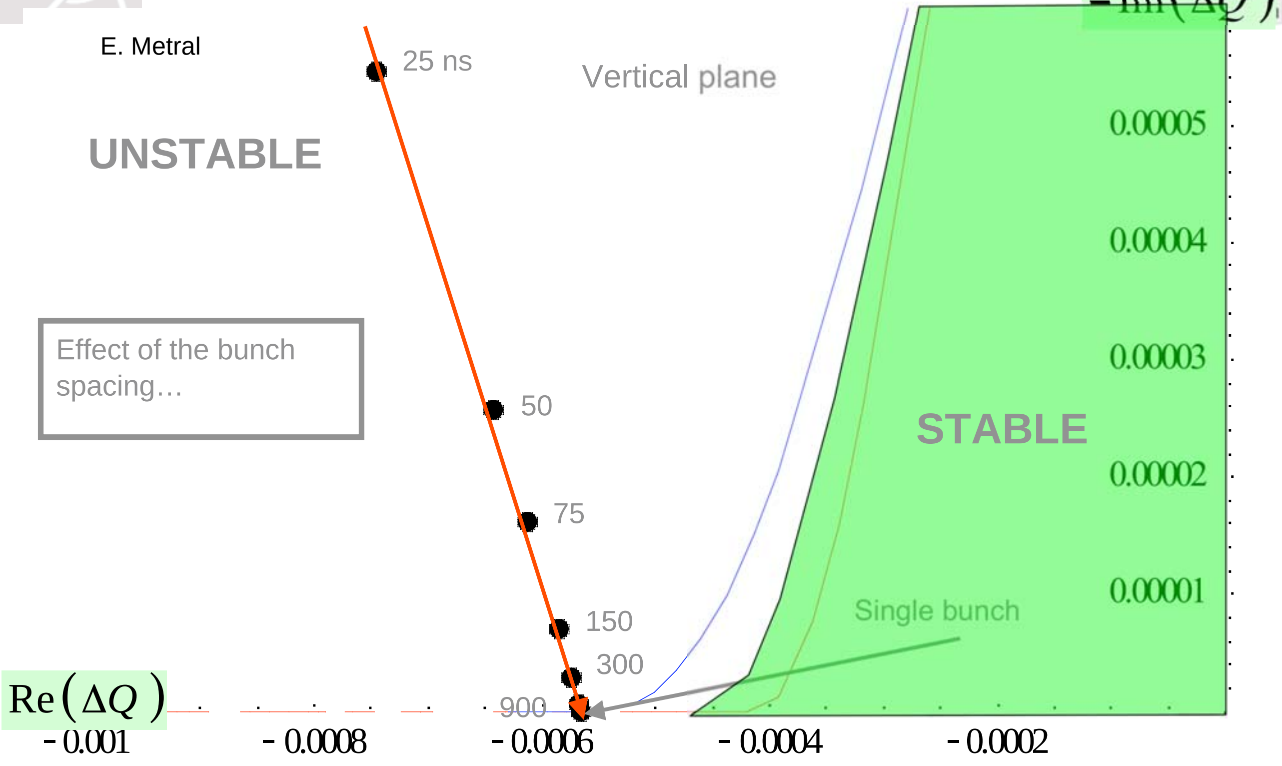
Transient due to low beta Squeeze: Overview LHC
LHC Collimation Project
CERN
squeeze orbit RMS
bare orbit: max
bare orbit: rms-median
#λ = 200
#λ = 200: rms-median
max
r.m.s.
median
~30 mm
orbit [µm]
R. Steinhagen
LHC
arc
IR1
IR2
IR3
IR4
IR5
IR6
IR7
IR8
bars: #λsvd = 50, 100, 150, 200, 250, 270 (B1 only)
RWA, 28/11/2006
29
LHC Collimation Working Group Meeting #79, Ralph.Steinhagen@CERN.ch, 2006-11-27



Transient in Collimation Insertion vs. Squeeze Step
- moderate global orbit correction only (commissioning)
β* = 17 → 9 m and
β* = 1.5 → 1.1 m
will be toughest for keeping
orbit collimation requirements
(further mitigated by controller)
viewport: β-coll
#λ=300
#λ=400
#λ=300 + optic-err.
#λ=400 + optic-err.
R. Steinhagen
max. orbit transient in β-cleaning [µm]
- β*=17.00 m
- β*= 9.00 m
- β*= 7.00 m
- β*= 5.00 m
- β*= 4.00 m
- β*= 3.50 m
- β*= 2.50 m
- β*= 2.00 m
- β*= 1.50 m
- β*= 1.10 m
- β*= 0.80 m
- β*= 0.65 m
- β*= 0.55 m
intermediate squeeze step
based on 10⁵ orbit samples
LHC Collimation Working Group Meeting #79, Ralph.Steinhagen@CERN.ch, 2006-11-27

Stability diagram (maximum octupoles) and collective tune shift for the most unstable coupled-bunch mode and head-tail mode 0 (1.15e11 p/b at 7 TeV)

E. Metral



➔ Even single bunch unstable for nominal b*!

Various Comments

- The lowest b* all around the ring determines the required collimator settings and available tolerance budget ➔ tolerances are very tight after squeeze of first IR.
- Proposed strategy for procedure in squeezing different IR's:
  - For commissioning implement squeeze one by one per IR. Once a specific IR is completed, collimators gaps are small and beam should be extracted.
  - For first simultaneous physics in several IR's, perform squeeze steps in parallel for all IR's. For example, once all collimators are closed for b*=4m, squeeze all relevant IR's (simulataneously or one after the other) down to 4m.
  - Only then do the next step: avoid squeezing with closed collimators for any IR!
- Steps in squeeze:
  - Should be also defined from steps in aperture (n1).
  - Propose steps not to be larger than 2 s (in n1), once b* is below 6 m.

Squeeze During Ramp

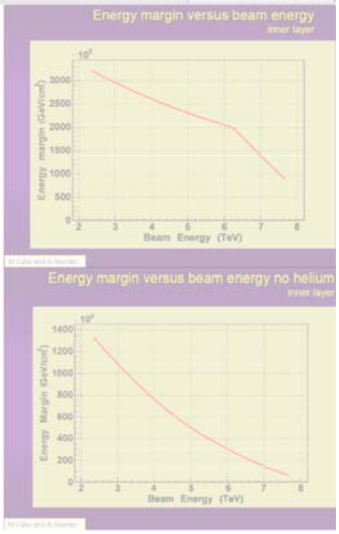
Power loss

$$P_{loss} \propto \frac{N_p^{tot}}{\tau} \cdot E_b$$

Power for quench

$$P_q \propto \frac{1}{E_b^r} \quad (r \geq 1)$$

$$\frac{P_{loss}}{P_q} \propto \frac{N_p^{tot} \cdot E_b^r}{\tau} < 1 \qquad (r$$



- Beam losses are much less dangerous in terms of quenches at lower beam energy. Win factor >2 if squeeze is done at 5 TeV.
- Clear preference for squeeze at lowest possible beam energy, for example b*=1 m (or 2 m) at 5 TeV!

Conclusion

- Optimized collimator settings during the ramp are under detailed study. First surprises seen: need to close collimators to some extent for efficiency ➔ C. Bracco.
- Need to include requirements for octupoles and scraping before start of squeeze!
- Squeeze must be commissioned in well-defined steps below b* of 6 m.
- For each step all relevant IP's should be squeezed before the next step!
- I recommend a decrease of ≤ 2 s in n1 for each step in squeeze. Aperture during squeeze has been calculated ➔ T. Weiler.
- A draft squeeze procedure with collimation has been presented. Iterate further…
- If at all possible, we should do the squeeze at lower beam energy to optimize efficiency of operation and minimize risk. Full squeeze possible for b*=2m at 5 TeV (or even 3.5 TeV?). Gain factor 2-3 in stability against quench for 5 TeV!