Status of the LHC Collimation System

Towards a More Robust System

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for the LHC Collimation Project Team

LEMIC
8. April 2003

Work done in

Beam Cleaning Study Group / Collimation WG
(since 9/2001. Mandate: AP and OP issues of collimation)

LHC Collimation Project
(since 10/2002. Mandate: finalize design, build prototype, produce full system, supervise installation, commissioning)

Close collaboration with LHC Machine Protection Working Group.

Meetings:

Collimator Project Meetings and LHC Collimation Working Group

http://www.cern.ch/lhc-collimation
http://www.cern.ch/lhc-collimation-project

The Collimation Team:

- Project Management
- Engineering/Technical Support
- Material Simulations for Collimator Jaws
- Material Tests
- Theoretical Studies/System Design/System Simulations
  (diffusion, halo, cleaning, optics, impedance, e-cloud, activation)
- Operational Scenarios/Instrumentation/MD's
- Additional Link Persons

Many team members contribute only a small fraction of their time – expertise and support anyway crucial!

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Links to related activities: B. Goddard, G. Peon, R. Ostojic, W. Kalbreier, J. Uythoven, W. Weterings

+ colleagues in Collimation WG and Machine Protection WG

Contents

Challenge 1: High Beam Power in the LHC

Physics Potential = Energy and Luminosity

High LHC luminosity translates into high transverse energy density:

$$L = \rho_e \frac{f_{rev} N_p}{4 E_b} \sqrt{d_x d_y}$$

d = demagnification (β_{coll}/β^*)
N_p = protons per bunch
f_{rev} = revolution freq.
E_b = beam energy

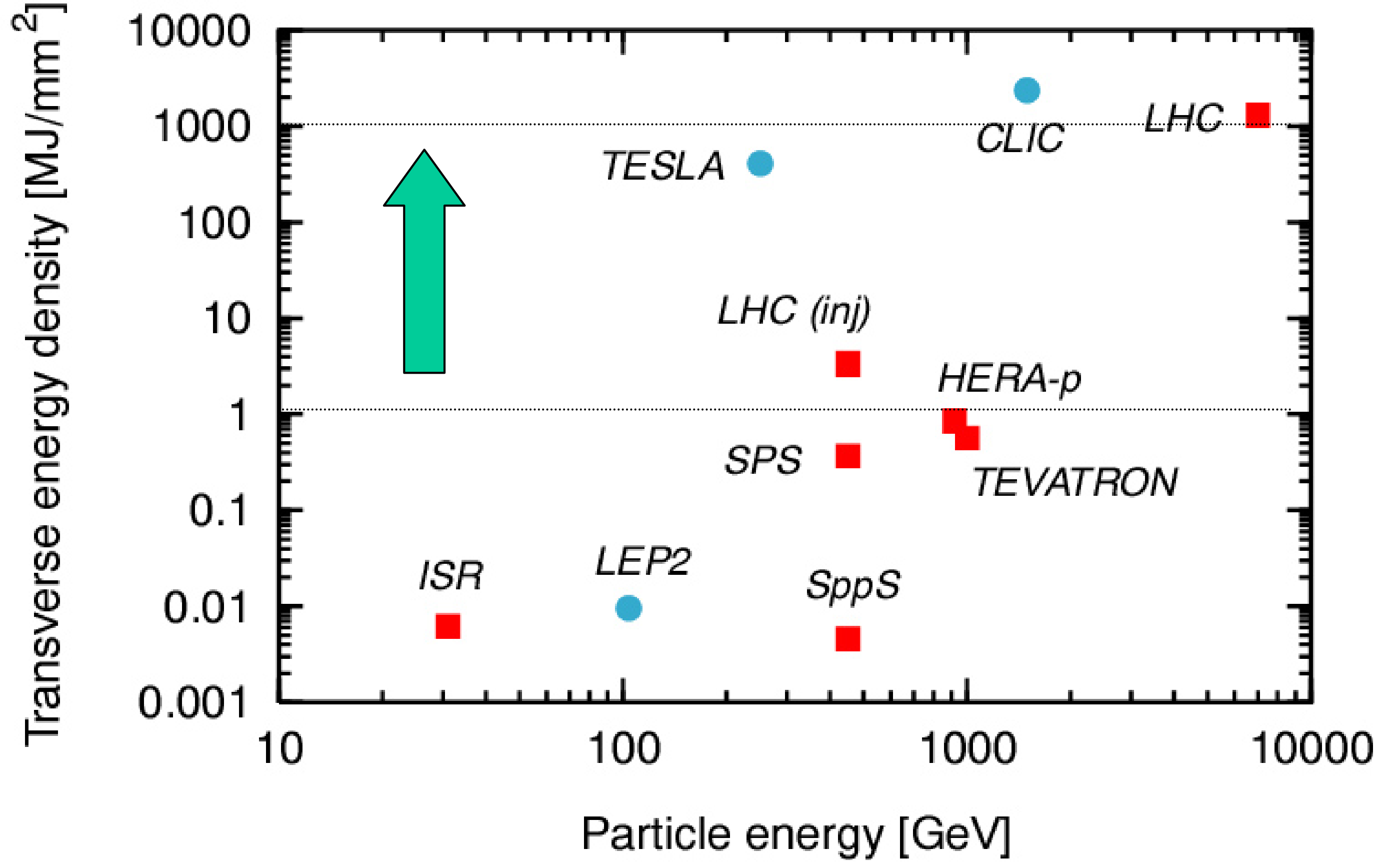
Fixed or limited

Increase luminosity via transverse energy density.

Parameter for material damage: ρ_e

LHC advancement: Factor 7 in beam energy
Factor 1000 in ρ_e

Compare…



LHC nominal
Parameters:

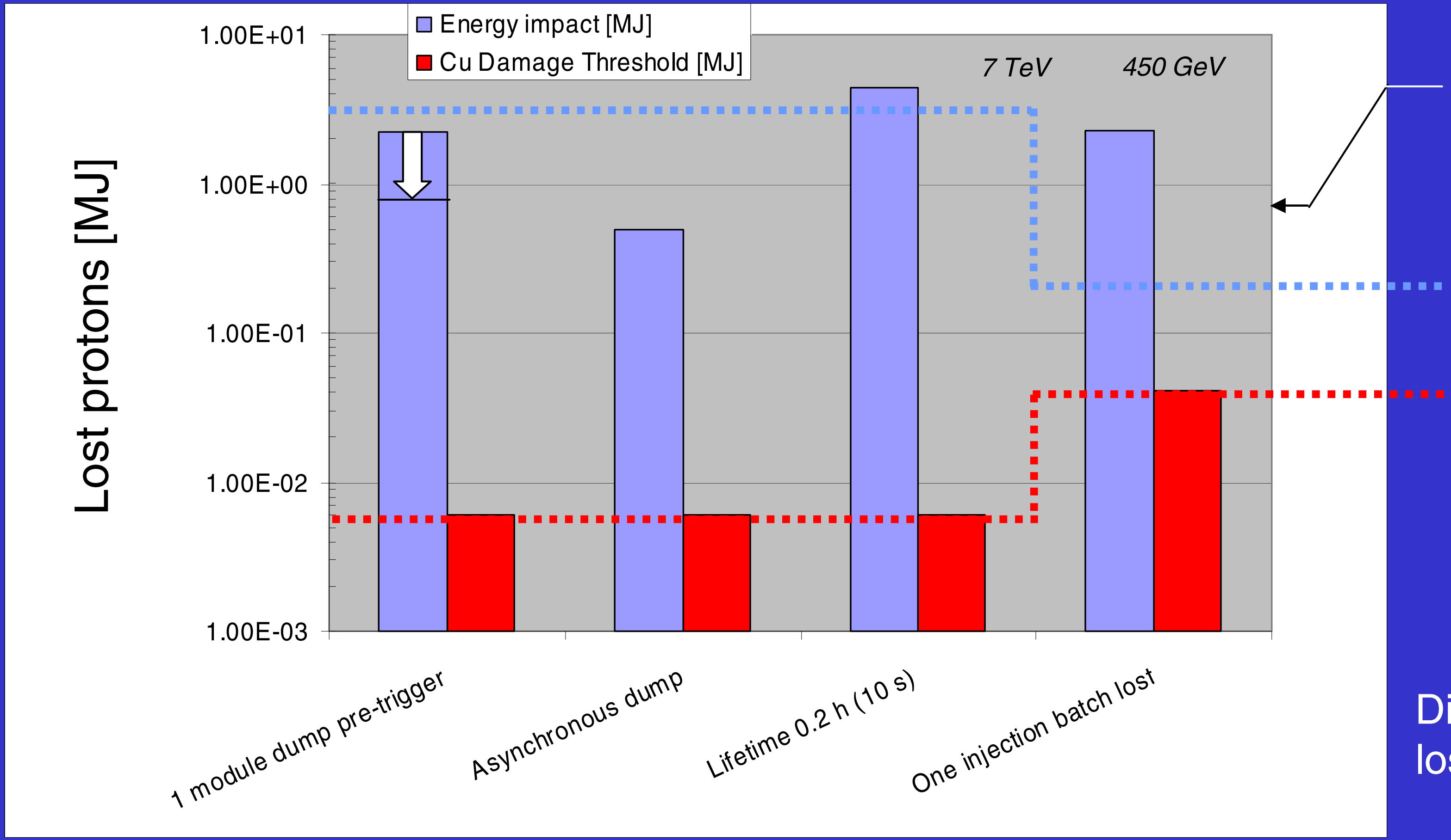
Number of bunches: Bunch population: Bunch spacing:	**2808** **1.1e11** 25 ns
Top energy: Proton energy: Transv. beam size: Bunch length: Stored beam energy:	 **7 TeV** **0.2 mm** 8.4 cm **350 MJ**
Injection: Proton energy: Transv. Beam size: Bunch length:	 450 GeV 1 mm 18.6 cm

At less than 1% of nominal intensity LHC enters new territory.

Collimators must survive expected beam loss…

Collimators will be highly activated!

Beam loss at the 10^{-5} level can damage components:



Melt 1 kg Cu

1 % of nominal beam

Damage threshold for Cu

Different beam loss cases

Observations:

- we expect losses on the **0.1% - 1% level**.
- Sufficient to **melt several kg Cu**.
- Al/Cu system (V6.4) would withstand at the 0.001% level.

  Factor 100- 400 improvement needed. Low-Z jaws!?

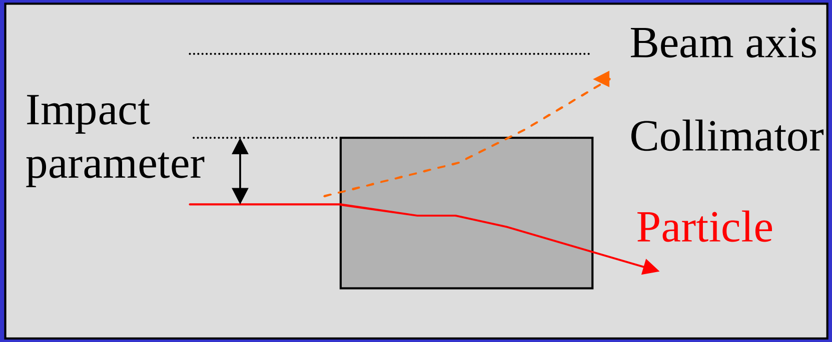
Challenge 2: Efficient Absorption of the Beam Halo

Beam halo can induce magnet quenches. Absorb the halo in the cleaning insertions with ~ 99.9% efficiency.

Use “conventional” jaws (blocks of appropriate solid materials).

Two stage cleaning systems:

1) Primary collimators:	Intercept primary halo **Impact parameter: ~ 1 μm** Scatter protons of primary halo Convert primary halo to secondary off-momentum halo
2) Secondary collimators:	Intercept secondary halo **Impact parameter: ~ 200 μm** Absorb most protons Leak a small tertiary halo



Running at the quench limit

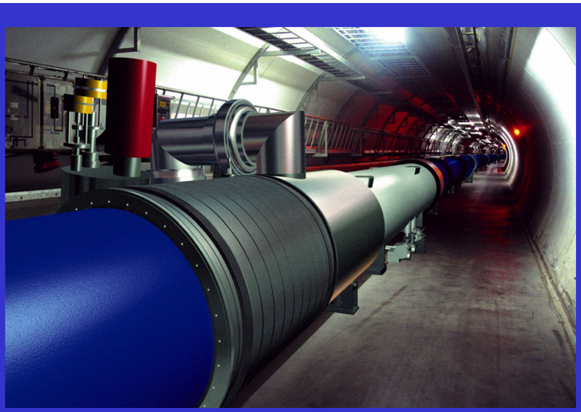


Illustration of LHC dipole in tunnel

Allowed intensity

Quench threshold
(7.6×10^6 p/m/s @ 7 TeV)

$$N_p^{\max} \approx \tau \cdot R_q \cdot L_{dil} / \eta_c$$

Beam lifetime
(e.g. 0.2 h minimum)

Dilution length
(50 m)

Cleaning inefficiency

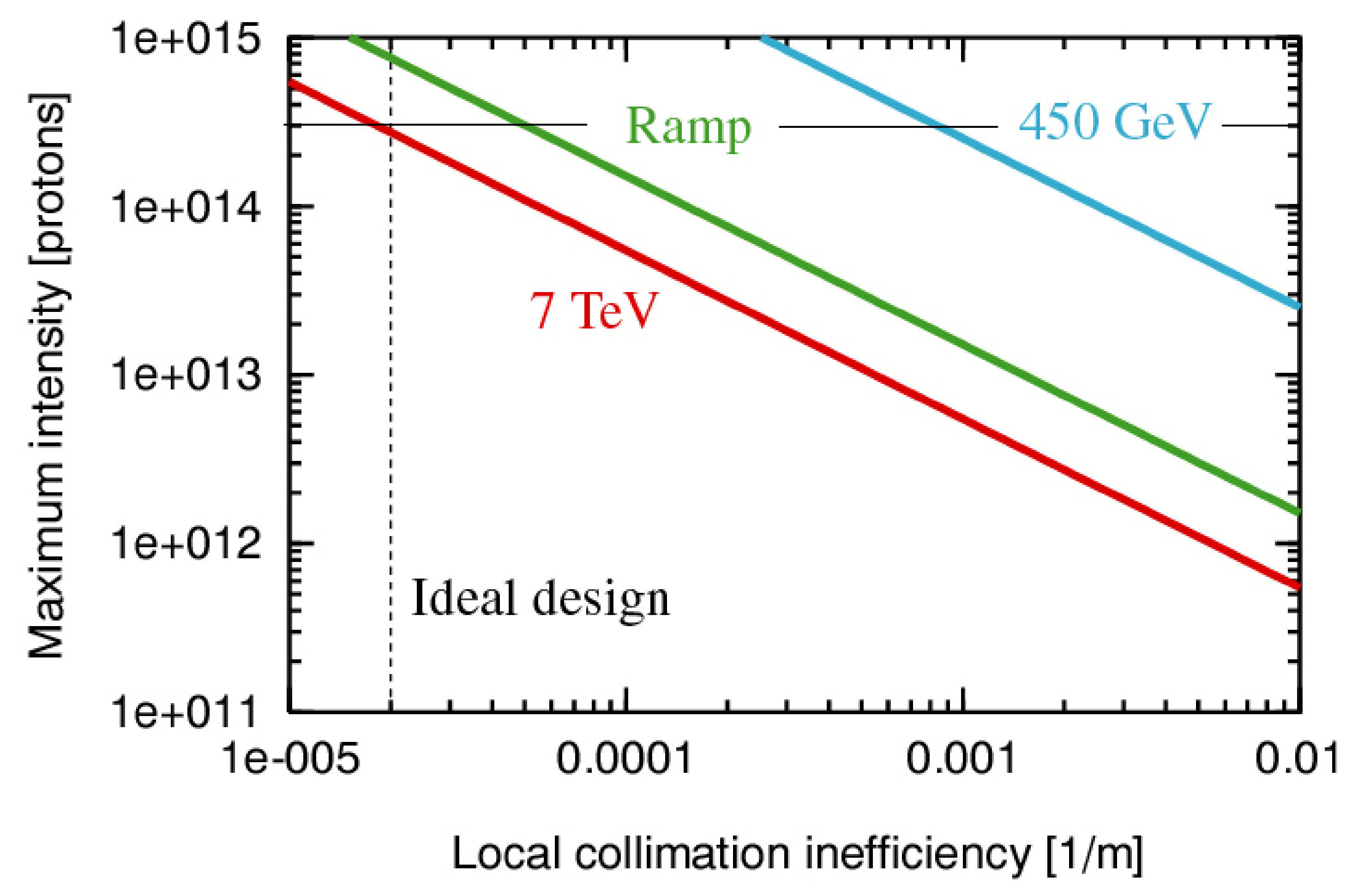
=

$$\frac{\text{Number of escaping p } (>10\sigma)}{\text{Number of impacting p } (6\sigma)}$$

Collimation performance can limit the intensity and therefore LHC luminosity.

Efficiency should be better than 99.9%.

Allowed Intensity Versus Cleaning Efficiency



For a 0.2 h minimum beam lifetime during the cycle.

Trade-off for given quench limit between:

Inefficiency – Allowed intensity – Minimum allowable lifetime

Challenge 3: Protection of aperture against halo/beam

Expected physical aperture limits (freely available, a is half aperture)

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

Energy	Location	a [m]	β [m]	**a_{norm} [$m^{1/2}$]**	$a_{norm}/\varepsilon^{1/2}$
450 GeV	Arc	0.012	180	**8.8×10^{-4}**	10
7 TeV	Triplet	0.015	4669	**2.2×10^{-4}**	10

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

~ 0.15

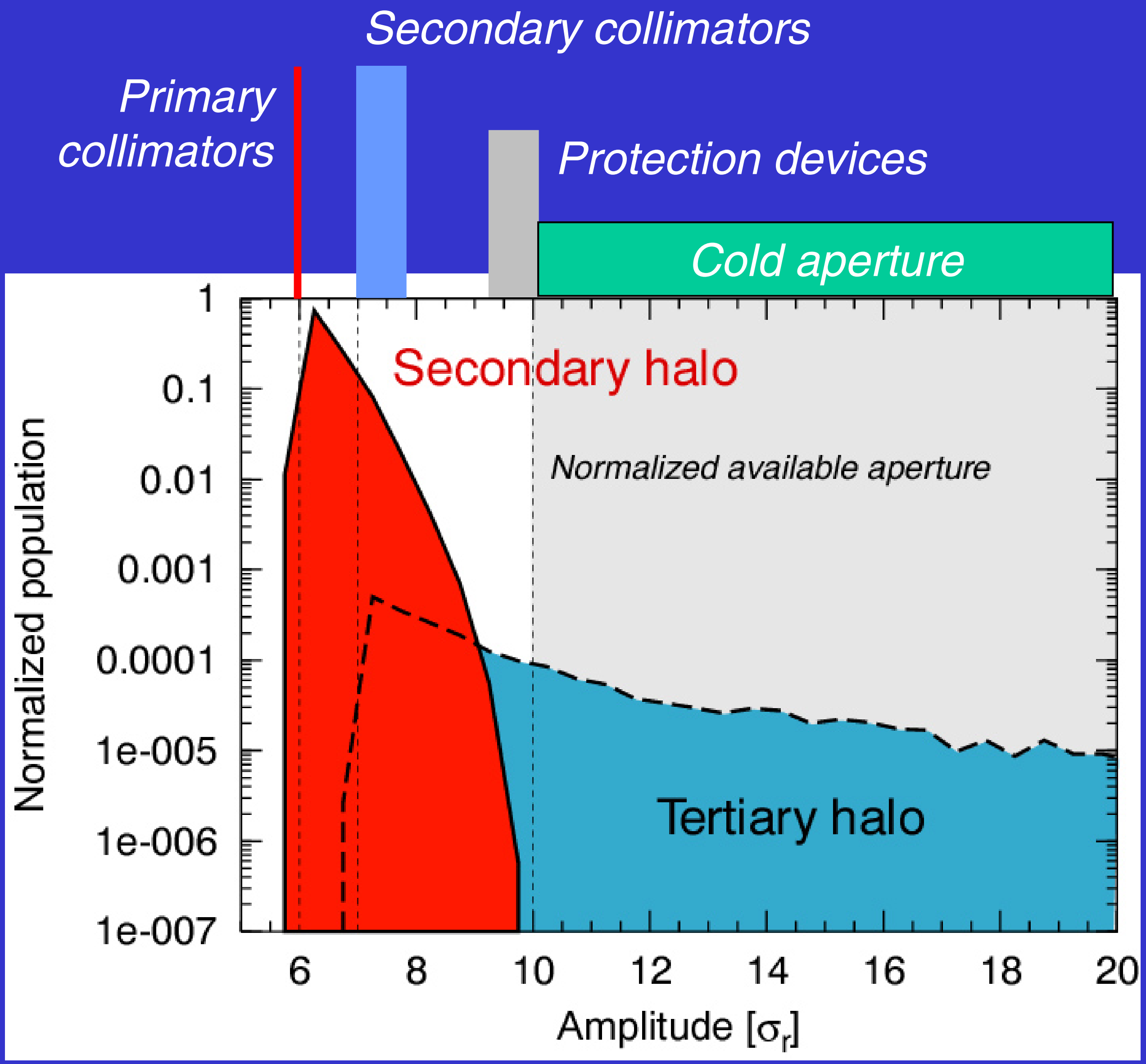
~ 0.6

$$a_{coll} \le a_{triplet} \cdot \sqrt{\frac{\beta_{coll}}{\beta_{triplet}}} \cdot \left(\frac{A^{max}_{primary}}{A^{max}_{secondary}} \right)$$

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

Collimator settings usually defined in sigma with nominal emittance!

Secondary and Tertiary Beam Halo (zero dispersion)



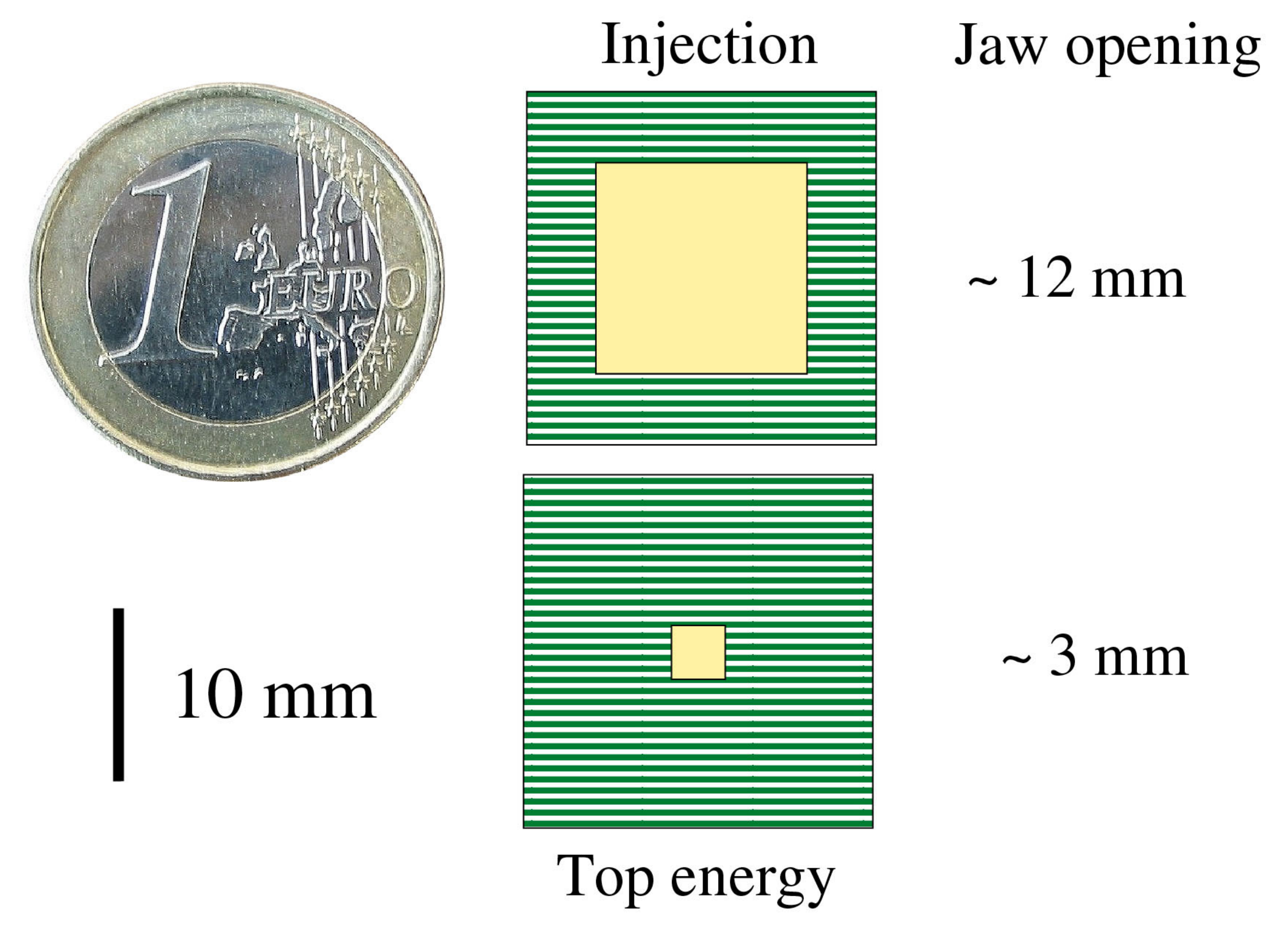
Strategy:

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!



Collimator settings:

5 - 6 σ (primary)
6 - 9 σ (secondary)

σ ~ 1 mm (injection)
σ ~ 0.2 mm (top)

Number of protons reaching 10σ:

10^{-4} of p at 6 σ

Collimator gap: Possible limitation of β^*

If collimator gaps at 7 TeV must be increased e.g. due to

- *inability to control relative orbit (0.5 σ, prim/sec)*
- *inability to control relative beta beat (8%, prim/sec)*

} *secondary collimator should not become primary*

- *impedance constraints*
- *mechanical constraints*

Then increase of β^* (lower luminosity):

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

Care required to avoid any limitation of this kind!

Contents

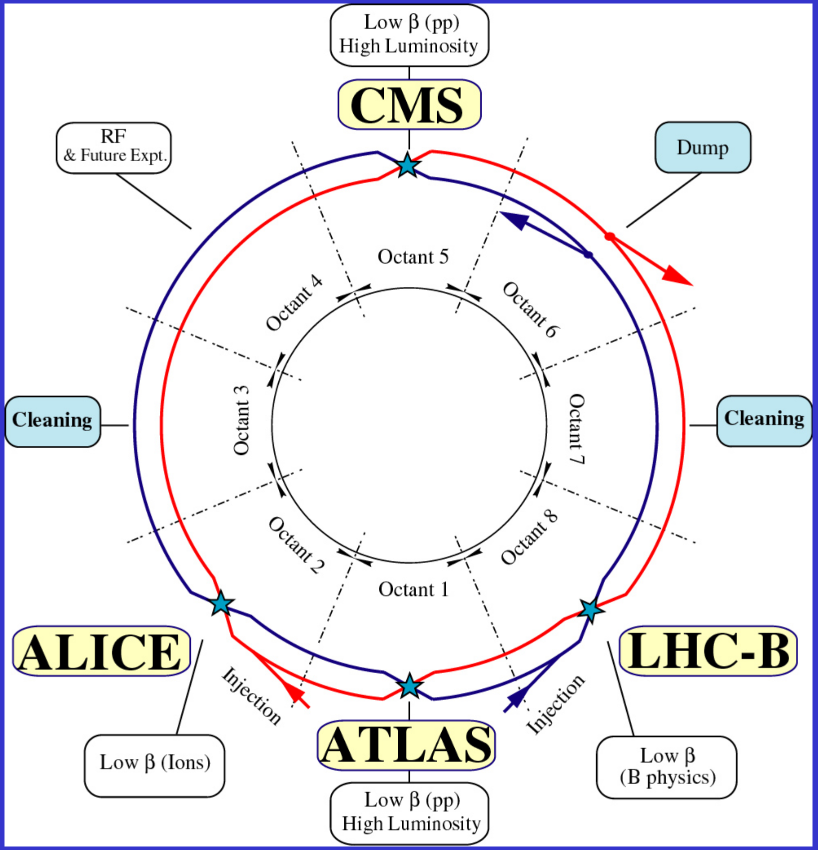
The V6.4 Collimation System

Two warm LHC insertions dedicated to cleaning:

IR3	Momentum cleaning 1 primary 6 secondary
IR7	Betatron cleaning 4 primary 16 secondary

Two-stage collimation system.

Significant system: ~ 200 degrees of freedom!



54 movable collimators for high efficiency cleaning, two jaws each *+ other absorbers/collimators for high amplitude protection (at 10 σ)*

- Basic system design (two stage system, two cleaning insertions) works.
- Required cleaning efficiency is provided.
- LEP based material choices (Al/Cu) are not adequate (100-400 times more robust required)

Contents

Basic strategy

Collimators could be damaged from:

Pre-fire of one dump kicker module
Asynchronous beam dump (miss dump gap)
Impact from one full batch at injection
Impact during low beam lifetime (0.2 h to1 h)
Protons and ions

Two possibilities:

1) A solution can be found that has sufficient robustness such that frequent damage is avoided (low Z jaws).

2) The jaws will be damaged regularly and we must foresee easy diagnostics and remote repair/exchange possibilities of the highly radioactive jaws (revolver of jaws).

Solution 1 is preferable and all effort concentrates on it for the moment!

Advance the most simple solution that promises to be adequate. Keep more complicated/less convenient concepts in mind as backup solutions. Carbon!
(Beryllium, Diamond, multi-layer structures, crystal collimation, renewable high-Z collimators, repairable high-Z collimators, tertiary collimators at the triplets, primary collimators covering the phase space, anti-kicker at dump …)

Abnormal dump actions as input for FLUKA

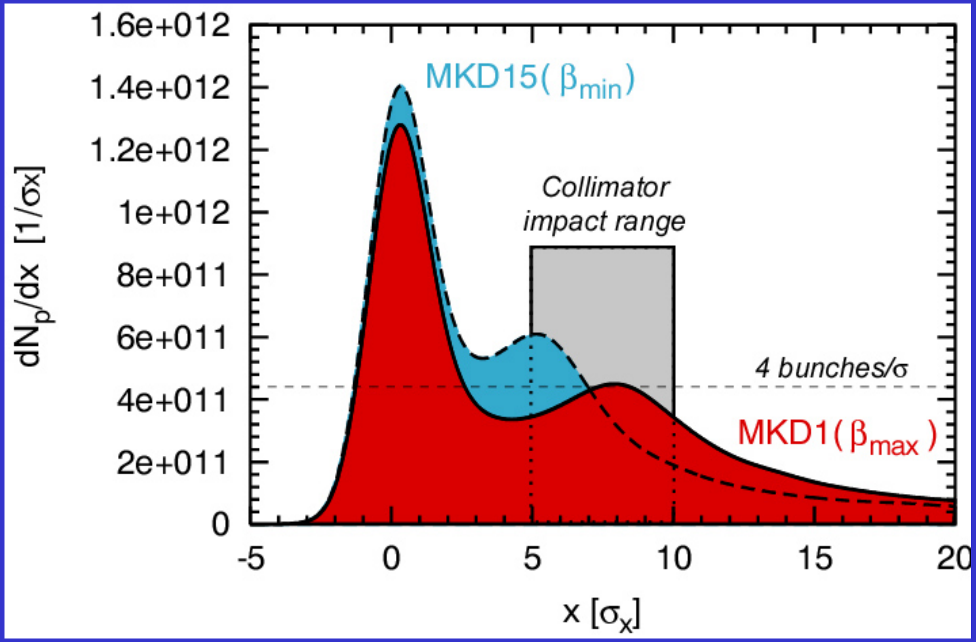
Beam dump: Designed to extract beam within 2 turns. Pulse rise time of 3 μs (dump gap).

Failure modes:

- **Total failure** of dump or dump trigger (> 100 years).
- Dump action **non-synchronous** with dump gap.
- Dump action from **1 of 15 modules**, others retriggering after 1.3 μs.

Difficult to predict

Assume at least once per year!



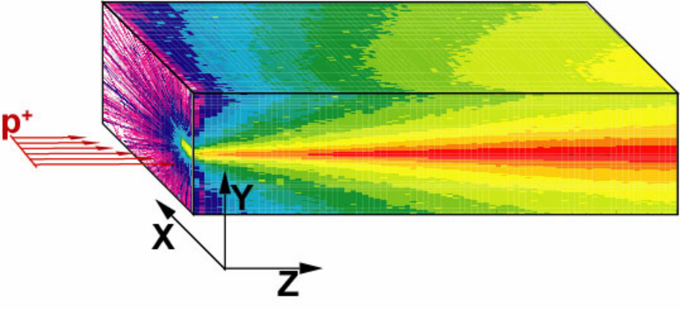
1 module pre-fire with re-triggering of 14 others after **1.3μs**:

20 bunches over 5 σ

Peak: **6 bunches in 1 σ**

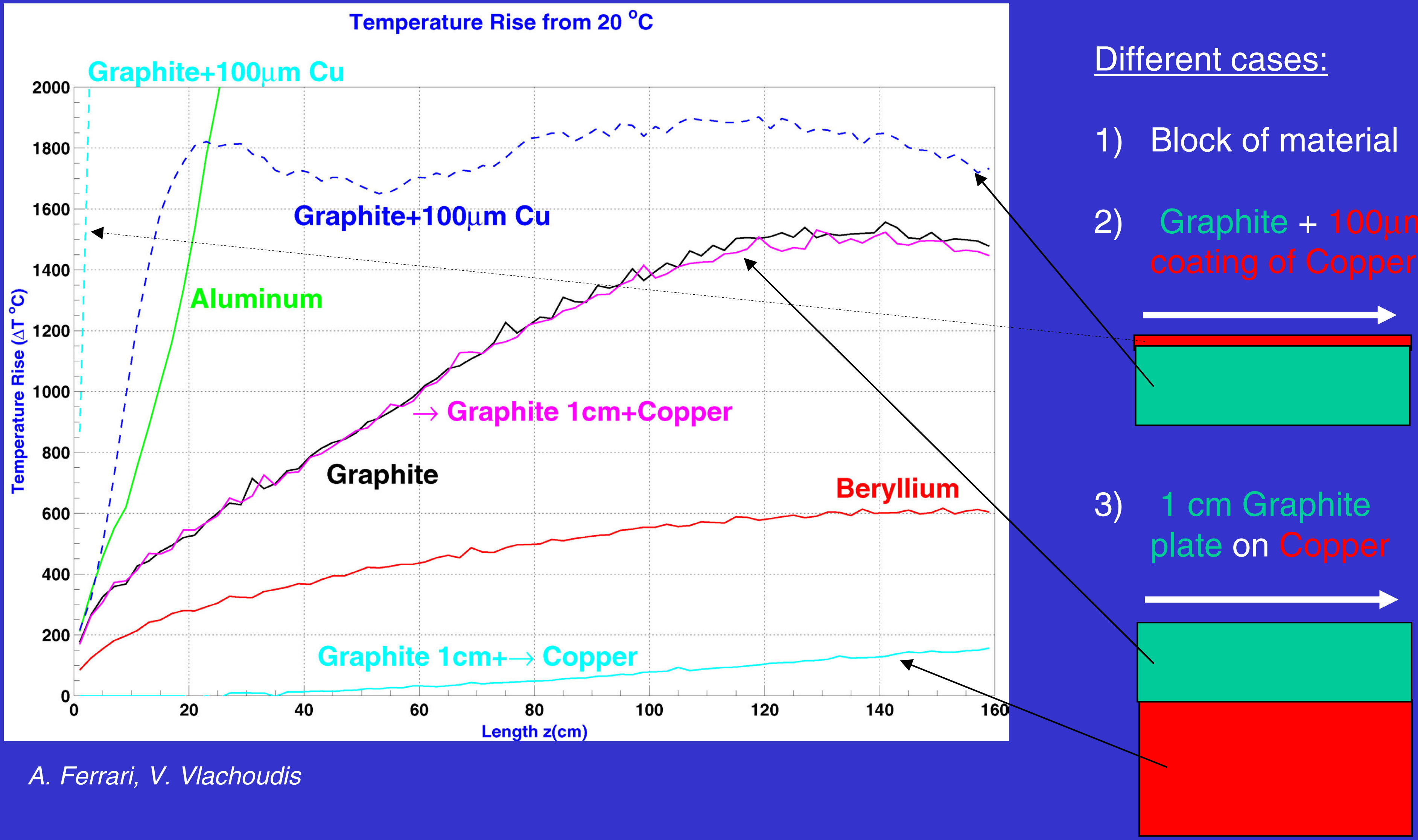
Note: Retrigger delay was recently reduced to 0.7 μs. This reduces beam impact by a factor of ~ 2.5!

R. Assmann, B. Goddard,
E. Weisse, G. Vossenberg



A. Ferrari,V. Vlachoudis

Temperature rise in different materials for one module pre-trigger at 7 TeV



Different cases:

1) Block of material

2) Graphite + 100µm coating of Copper

3) 1 cm Graphite plate on Copper

A. Ferrari, V. Vlachoudis

P. Sievers

Length of low-Z jaw: ~ 1 m (discussed later)

Summary table

Material	**Density g/cm^3**	**Max Energy GeV/cm^3**	**Max Temp ºK approx.**	**Escaping %**	**EM %**
Aluminum	2.7	1.2×10^{14}	~6500	88.8	9
Beryllium	1.848	0.2×10^{14}	900	97	1
Copper	8.96	16×10^{14}	> 10000	34.4	52.4
Graphite	1.77	0.3×10^{14}	1900	96.4	1.8
Graphite + Cu 100µm	1.77+8.9	3.6×10^{14} on Cu	2200 on C	94.1	3.9
1cm Graphite + Copper	1.77+8.9	0.22×10^{14}	1900 C, 450 Cu	94.5	3.8
Titanium	4.54	4×10^{14}	> 4000	79.5	16.7

A. Ferrari, V. Vlachoudis

Observations:

Almost all energy escapes the low Z jaw!
Lower jaw activation but more distributed!
What happens downstream?

Higher Z materials do not work (Ti)
100 µm Cu coating is not possible
Graphite is most promising!
Length of low-Z jaw: ~ 1 m (discussed later)

Further cases under preparation: Slow losses and ions

Slow loss:

Uniform “emittance” blow-up

Beam lifetime: **0.2 h**

Loss rate: 4.1e11 p/s

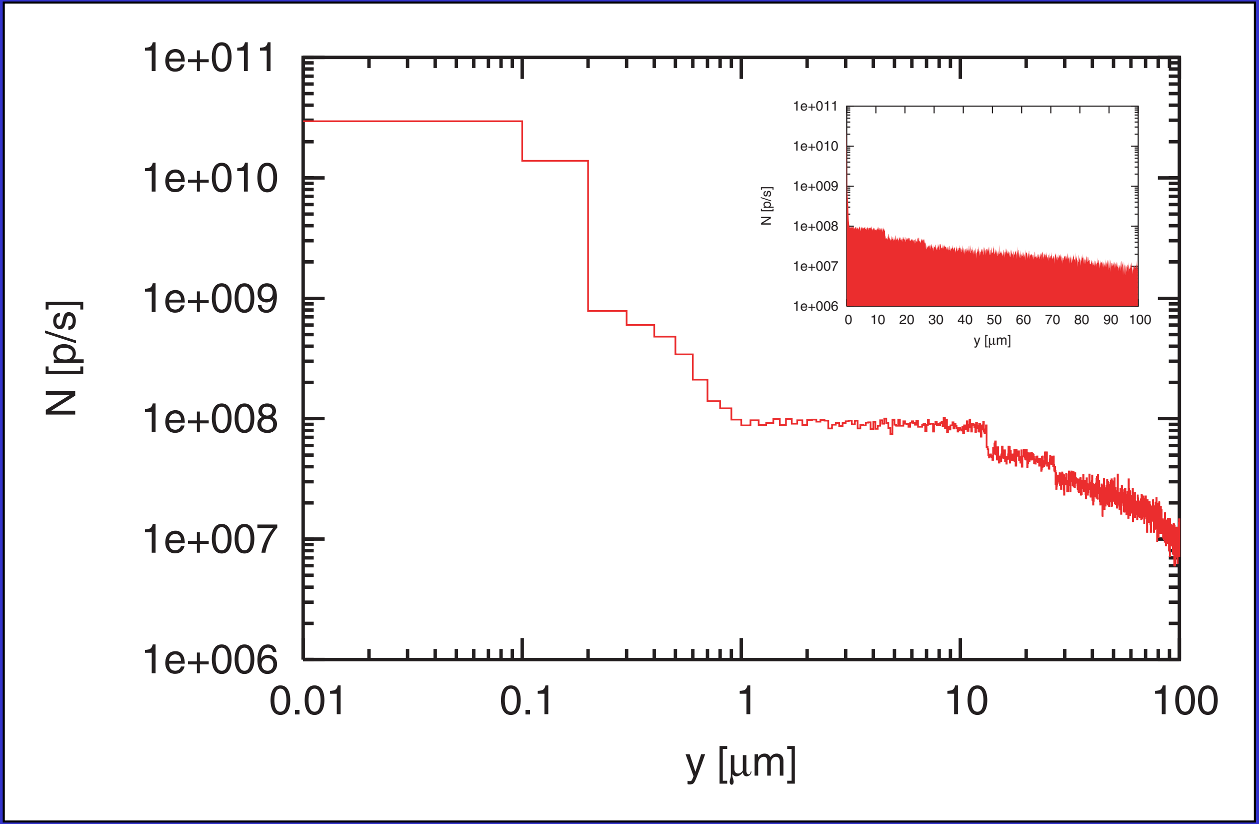
Loss in 10 s: 4.1e12 p (**1.4 %**)

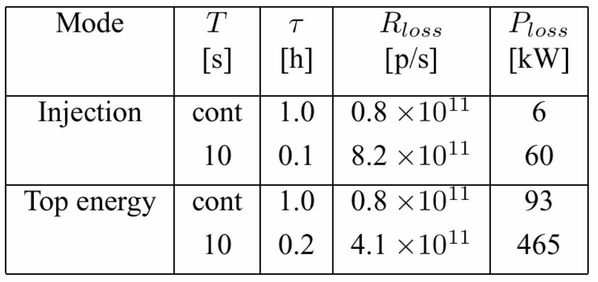
(~ 40 bunches)

Assume drift: 0.3 sig/s

5.3 **nm/turn**

(sigma = 200 micron)





Mode	T [s]	τ [h]	R_{loss} [p/s]	P_{loss} [kW]
Injection	cont	1.0	0.8×10^{11}	6
	10	0.1	8.2×10^{11}	60
Top energy	cont	1.0	0.8×10^{11}	93
	10	0.2	4.1×10^{11}	465

Transverse impact parameter

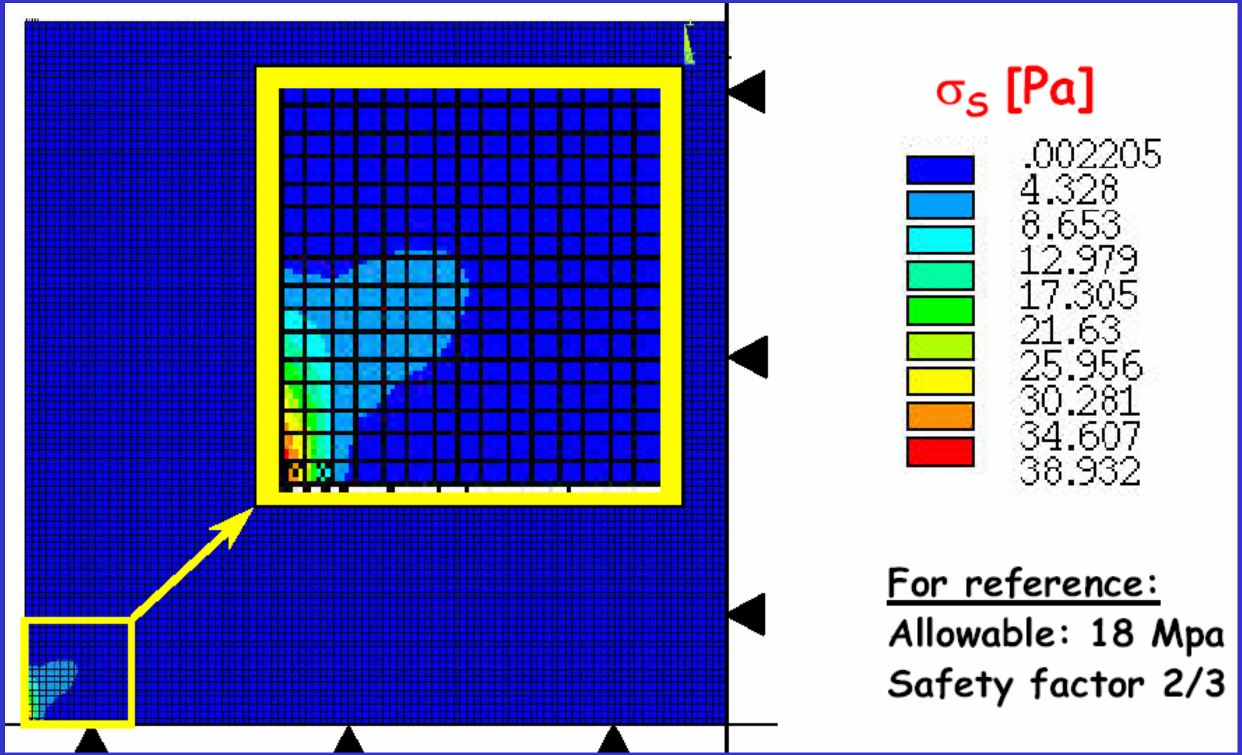
Almost all particles impact with

$y \lesssim 0.2$ µm

Surface phenomenon!

R. Assmann

Stress analysis for 7 TeV 1 module pre-trigger



O. Aberle, L. Bruno

Calculated stress in simple Graphite about a factor of 4 beyond the allowable value! Scaling to new dump re-trigger delay: **just ~ 50% missing**

This is **sufficient for the first years** of LHC with 30-50% of nominal intensity.

Other forms of Carbon are expected to be more robust (**Carbon-Carbon**). To be studied.

Beryllium is less robust than C due to **large stress** (~ 10 times beyond allowable value). Scaling to new dump re-trigger delay: **factor ~ 4 missing** !

Can we use a C-based system for the LHC?

Results show that Graphite looks promising (required robustness at reach with just 30-60% missing with new dump retriggering delay -> Carbon-Carbon?)…

However, third look at impedance in Feb 03 revealed a problem:

$$\frac{Z_\perp^{\mathrm{coll}}}{Z_\perp^{\mathrm{arc}}} \sim \frac{(L^{\mathrm{coll}}/L^{\mathrm{arc}}) \times \sqrt{\rho^{\mathrm{coll}}/\rho^{\mathrm{arc}}}}{(a^{\mathrm{coll}}/a^{\mathrm{arc}})^3} \sim$$

$$\sim \frac{(20\,\mathrm{m}/20\,\mathrm{km}) \times \sqrt{\mathrm{RRR} \sim 30}}{(1.8\,\mathrm{mm}/18\,\mathrm{mm})^3} \sim$$

$$\sim \frac{10^{-3} \times 5}{10^{-3}} \sim 5!$$

F. Ruggiero

1 INJECTION

D. Angal, L. Vos, *Coupled Bunch Instabilities in the LHC*, EPAC 2002 :

Budget transverse impedance resistive, *H*,*V*)

45 **57 MΩ/m**

Includes contribution single graphite collimator (estimated aperture and β) :

0.3 **1.1 MΩ/m**

Impedance of all graphite collimators with correct aperture and β (2003):

13.3 **16.8 MΩ/m**

New total

58 **73 MΩ/m**

Can be handled by transverse feedback

2 HIGH ENERGY

D. Angal, L. Vos, *Coupled Bunch Instabilities in the LHC*, EPAC 2002 :

Budget transverse impedance resistive, *H*,*V*)

84 **118 MΩ/m**

Includes contribution single graphite collimator (estimated aperture and β) :

2.2 **7.9 MΩ/m**

Impedance of all graphite collimators with correct aperture and β (2003):

841 **1017 MΩ/m**

New total

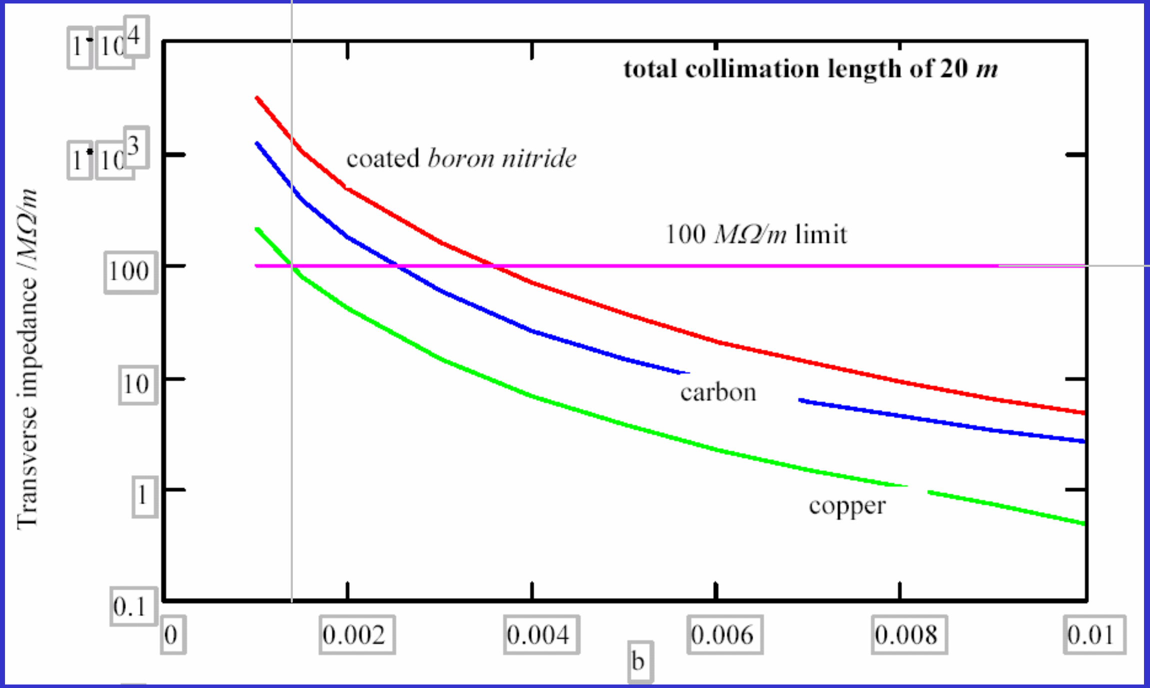
923 **1127 MΩ/m**

L. Vos

Mainly problem at 7 TeV: Al/Cu system doubles impedance budget!
C system increases impedance tenfold!

Impedance for different materials as a function of collimator half gap:

Typical collimator half gap



F. Ruggiero, L. Vos

LHC impedance without collimators

Half gap b [m]

How to counteract?

Factor 10 higher gain of transverse feedback (factor 3-4.5 margin) before collision.
Check thresholds for beam instabilities, stabilizing effect of long-range beam-beam.
Metallic plate or low-Z metal (Be?).
Copper doped graphite to reduce impedance?
Open collimators (hardly possible w/o additional collimators at triplets or increase of β^*).
Increase beta function at collimators (not possible and gain only with sqrt).
Increase triplet aperture (not possible, triplets have been built).

Too early to conclude! Studies are ongoing to address this problem!

Summary: Problems we are facing after initial analysis

1) Material robustness

7 TeV irregular dump:	C marginally OK (factor ~ 1.5 missing) Be not OK (factor ~ 4 missing) Higher Z out of question	Taking into account shortened retrigger time

Other expected beam impact scenarios impose slightly lower robustness but still very critical (injection problems, low beam lifetime, …). Cu is out of question in present approach.

2) Impedance

FR, LV Feb 2003: Impedance from C betratron collimators is 10 times the rest of the ring (7 TeV squeezed): 1 GΩ/m

Feedback can very likely not handle this impedance without significant emittance blow-up. Studies are underway. Limit from foreseen octupoles: 0.22 GΩ/m which leaves 0.12 GΩ/m for the collimators.

3) Tight operational and mechanical tolerances

Tightest tolerances on transient beta beat and orbit occur at the collimators.

Orbit tolerance on the 50 μm level. Beta beat tolerance on the 5% level.

4) Collimator reliability and maintenance in high radiation area

Very tight schedule:

May 2003:	**Choice of jaw materials and basic scheme**
April 2004:	**Proto-type collimators**
2004-2005:	**Production**
2006:	**Installation**

- Very little room for delays.
- Need to make decisions on a system that is compatible with the LHC performance and the LHC schedule!
- Judge constraints soon and decide on the best trade-off (no ideal solution!?).
- The whole machine (not just collimation) must work: Welcome discussions in the LTC, LEMIC, TB, … to help in trade-off.
- Especially take into account constraints from the experiments. We strongly realize that collimation performance will directly impact data taking (background from beam halo, spurious quenches, choice of β^*, …)

Looking for solutions

General goal: An efficient collimation system that does not limit the LHC performance (intensity, β^*, impedance, …) nor the operational flexibility (tune, phase advance, …) nor the luminosity uptime (cleaning efficiency, failure/damage rate, …).

Can we adapt the system to the three challenges (robustness, impedance, tolerances) without violating our goal?

Answer: This might be possible with a **three-stage cleaning system**.

Disclaimer: **Very preliminary thoughts, much too pre-mature for the LHC-MAC, for information of LTC/LEMIC, not ready for any decision! Work out over next weeks if no show-stopper!**
Prepared to work on this, including showering studies at IR's (A. Ferrari, …)!

Price to pay: Additional collimators (tertiary) at the triplets (e.g. before D1).

Note: Tertiary collimators/triplet absorbers first discussed by RA/RS at MPWG.

Main purpose then (before impedance problem):

1) Protect triplets.
2) Relax operational tolerances in cleaning insertion.

Now: Only way to bring collimator impedance to 100 MΩ/m level?

Other options (Be/C two stage system) still goes to 300 MΩ/m level!

Idea of a three stage system:

Relies on **adding tertiary collimator/triplet absorbers at triplets (before D1)**:

Good for machine protection (RS)
Good for cleaning efficiency (RA) → Use for relaxing tolerances and impedance…

Idea carried further to a three stage system:

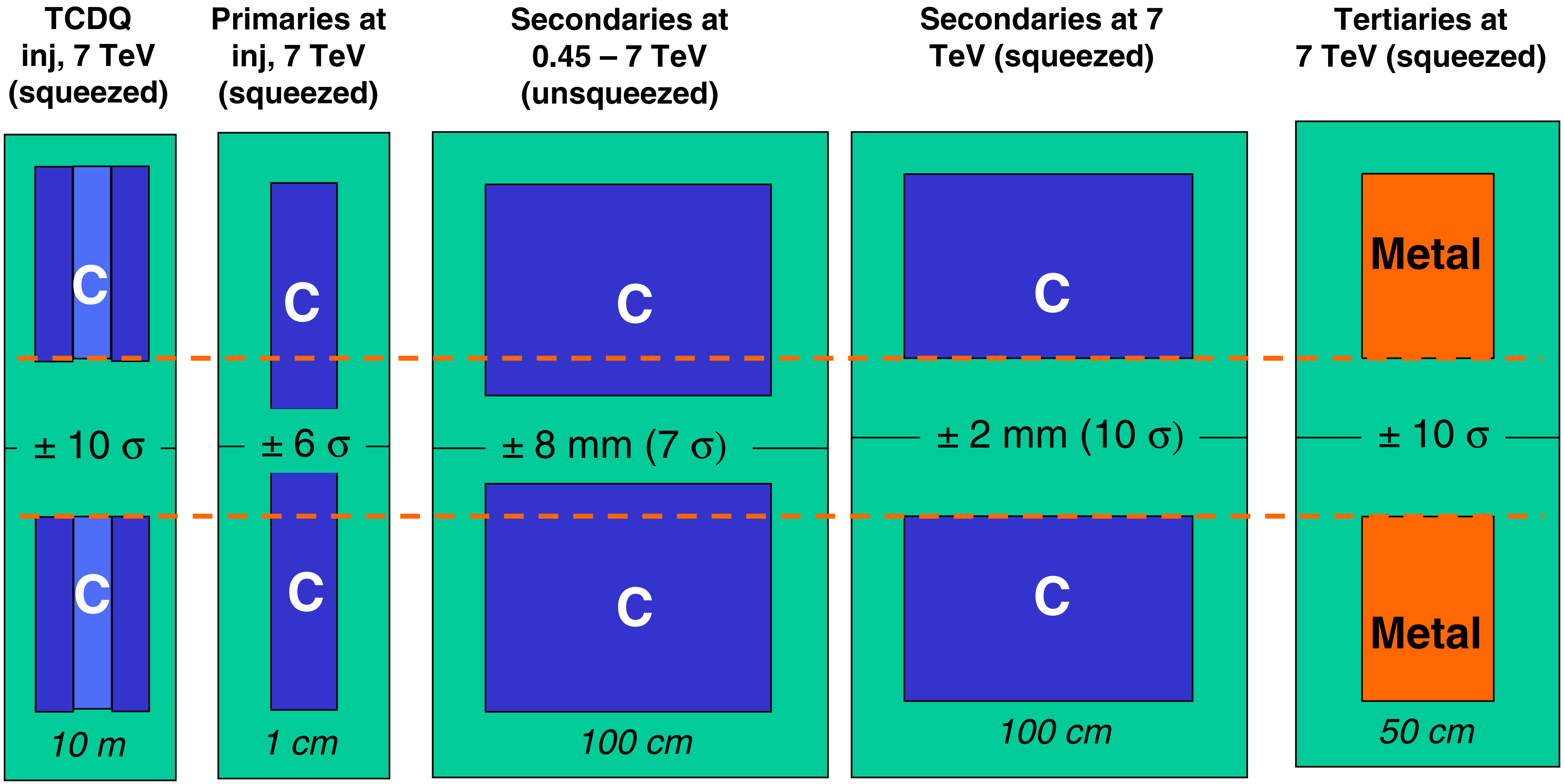
At 450 GeV: Use short primary and long secondary collimators in IR3/7.
No change of philosophy: 6/7 σ (protect downstream arc + DS)
No change of required robustness (use C for all collimators if we take into account impact of one injected batch)

At 7 TeV: Use **short primary** (1 cm C) at 6 σ. Will be very robust!
(squeezed) Use **long secondaries** (1 m C) at 10 σ. In shadow of TCDQ (10 σ).
Use **long tertiaries** (1m C) at 10 σ to clean 10 -13 σ secondary halo.
Possibility to use Be?

Note: Ignoring cases at 450 GeV, we could go to short secondaries and tertiaries, made out of metal (no impedance problem). **Hybrid system:** 0.5 m C (inj) and 0.5 m Cu (top)?

Ideally: Put 4 primaries at 0, 45, 90, 135 degrees (not possible any more).

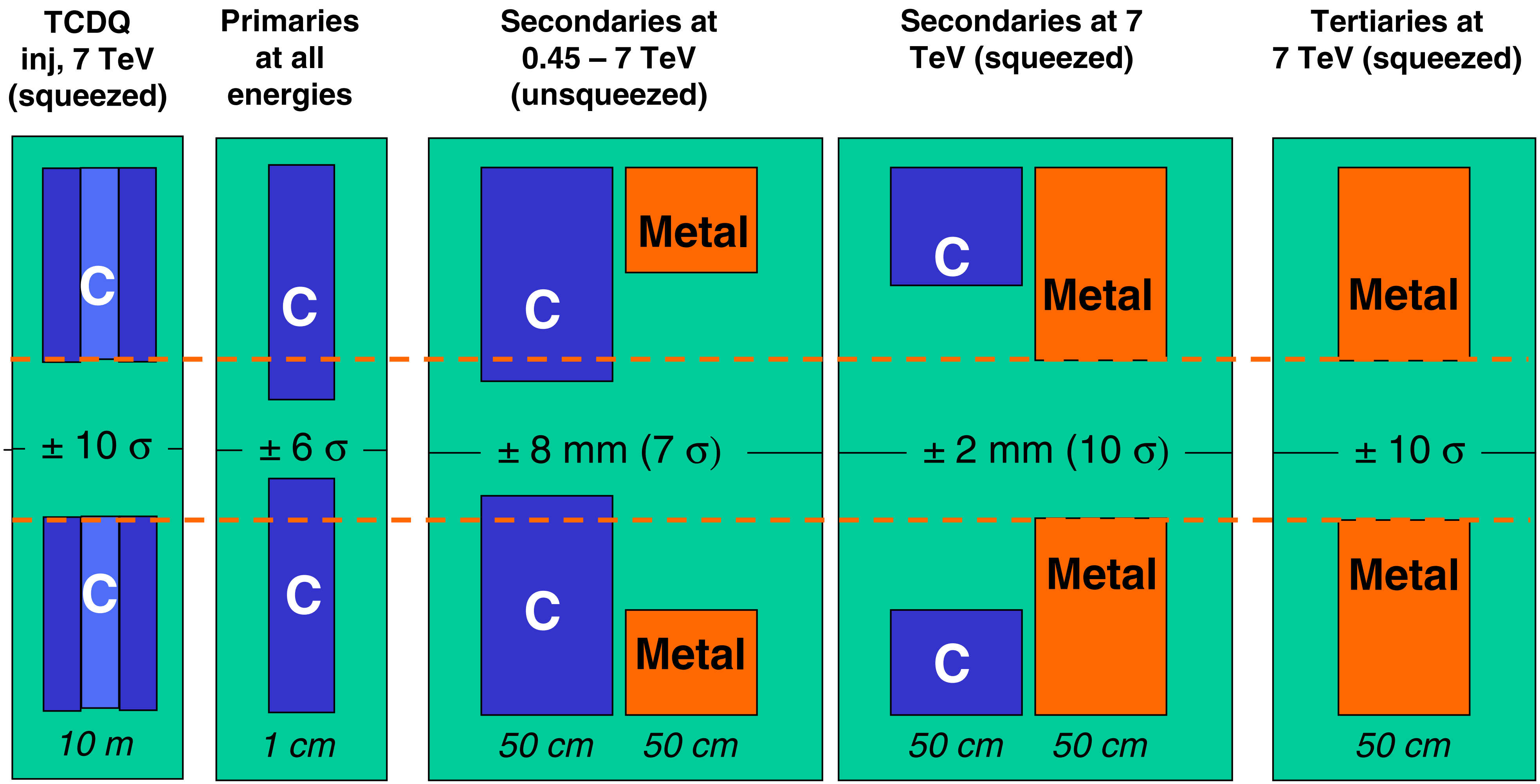
A robust, low impedance, high efficiency 3-stage system:



Primaries almost indestructible, robust low-Z secondaries, local cleaning at triplets, relaxed tolerances orbit and beta beat, good efficiency.

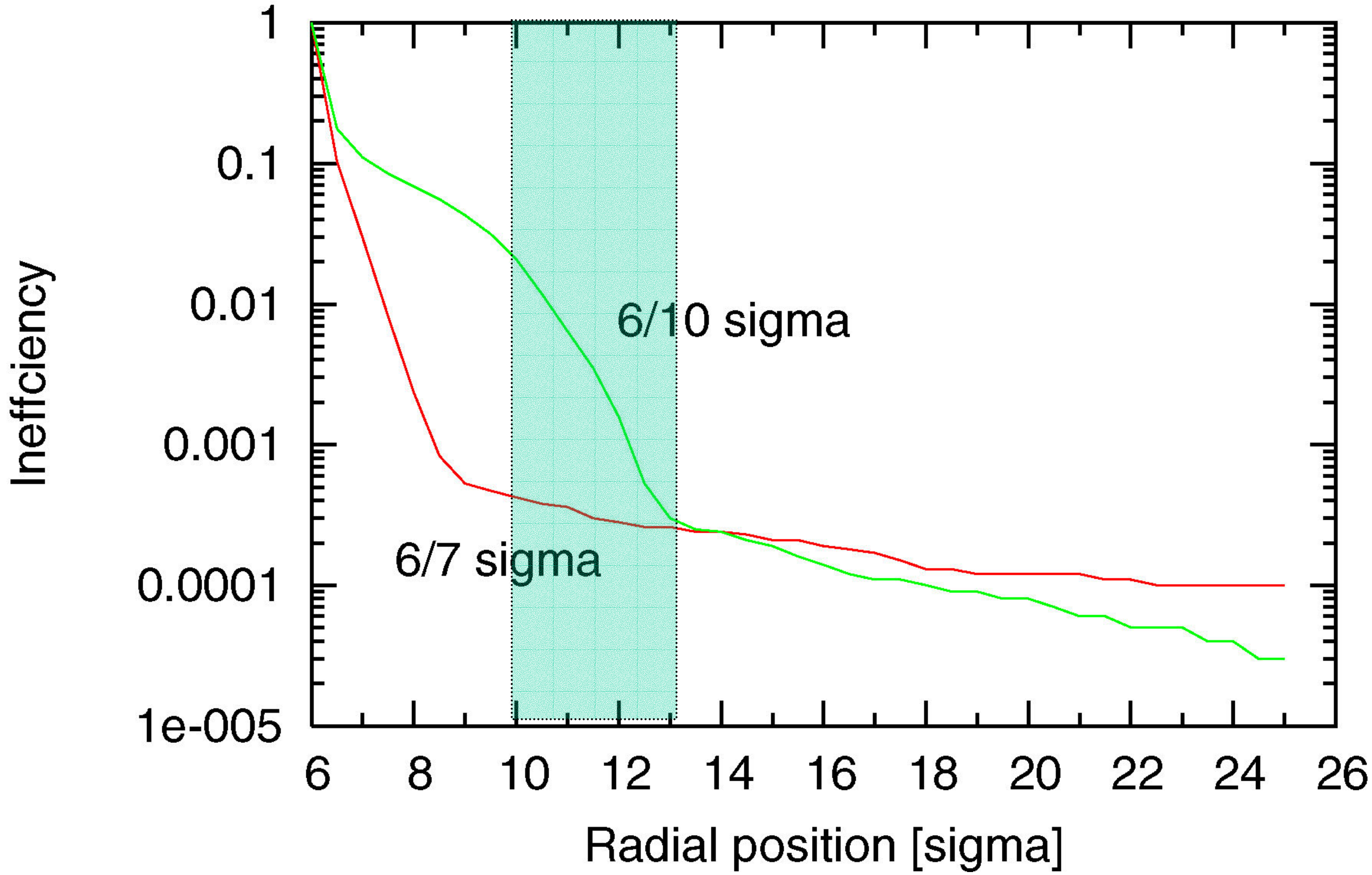
3 stage system fully based on C:	Factor 3-4 improvement in impedance!
3 stage system based on C and Be:	Factor 10 improvement in impedance! OK?
Two-stage system with C/Be (*JBJ*):	Factor 3-4 improvement in impedance!

A robust, low impedance, high efficiency, 3-stage hybrid system:



Primaries almost indestructible, robust C secondaries for injection (reduced cleaning efficiency), low impedance secondaries at 7 TeV (in shadow of TCDQ), local cleaning at triplets, relaxed tolerances orbit and beta beat, good efficiency. Same length as C system. Resistive impedance budget (20-30%) might be respected. Large flexibility (start with C at 7 TeV). No toxic materials.

Efficiency with secondaries at 10 σ (in shadow of TCDQ):



7 TeV:

40 h beam lifetime
(stable physics)

2.5 kW lost at coll.

1% on tertiary coll:
25 W

10 x less on triplet.

Produce 900 W at IP.

120 W/triplet from IP.

Open secondaries to 10 σ: Secondary halo extends to 13 σ!

Install tertiary collimators before the D1/triplets!

(protect triplet aperture bottle-neck)

Seems promising! **Can Cu withstand normal operation with low lifetimes?**

Tolerances with secondaries at 10 σ:

Significant operational gain with larger retraction!

Room until secondaries become primary collimators (quench):

1 σ retraction:

transient orbit change	1 σ	200 μm
transient beta beat	30 %	

4 σ retraction:

transient orbit change	4 σ	800 μm
transient beta beat	170 %	

Tolerance is a fraction of these values, e.g. ¼ (rough estimate).

Orbit:	**50 μm**	**→**	**200 μm**
Beta beat:	**8 %**	**→**	**40 %**

Much easier in operation! Much easier set-up! Much easier mechanical tolerances!

Details to be worked out!

Towards a three stage cleaning system?

- A three stage system addresses our three biggest worries (impedance, robustness, tolerances). It involves **installation of tertiary collimators** before the triplets (50 cm Cu?).
- **Primaries** at 6 σ are short (~ cm), almost indestructible, and uncritical for set-up.
- **Secondaries** can be put to 10 σ at 7 TeV, into the shadow of the TCDQ.TCDQ impact rate in operation must be estimated.
- A **full C based system** would reduce impedance by a factor 3-4, while offering maximum robustness.
- A **system with Be surfaces** would reduce impedance further, however is less robust and introduces toxic material.
- A **hybrid system C/Metal** would offer full robustness at injection and very low impedance at top energy (taking advantage of protection by the TCDQ). Nice possibilities for optimization (robustness vs impedance vs efficiency vs vacuum vs experimental background).
- A three stage system with retracted secondary collimators would be much easier for set-up, operation, and mechanical tolerances. **Win factor 4-5 in tolerances!**
- **Full flexibility of the LHC is maintained** (tunes, β^*, …).
- Triplet absorbers are also required for **machine protection** (RS, MPWG).
- Experiments are **better protected** against failures, however, **experimental background** from beam might increase (to be studied), even though collimators are before D1 (showers are swept out).
- In operation we always can go back to the 2-stage system (no risk).

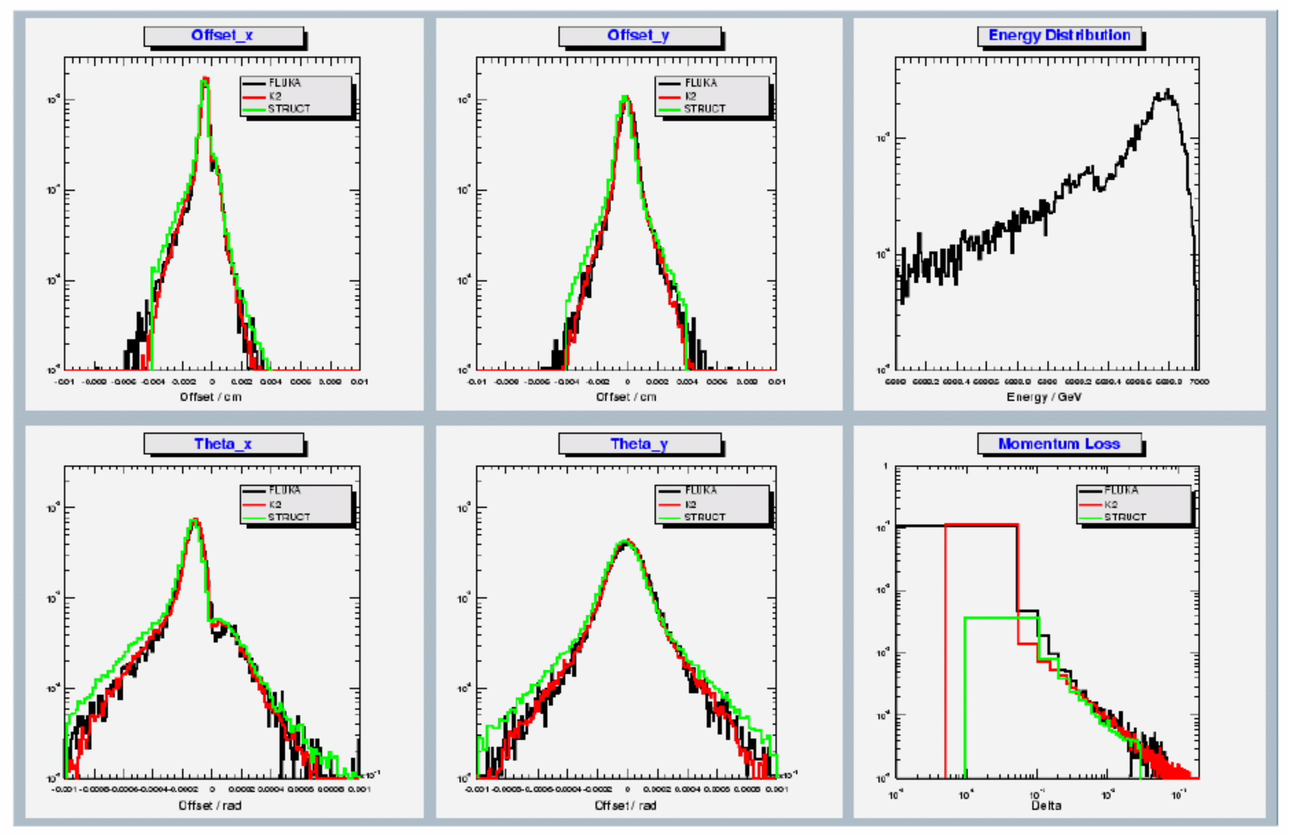
Conclusion:

- We are facing very difficult challenges.
- The **schedule for decisions** is very tight (major decision required end of April 03).
- Accurate **input and understanding of constraints** is very important for making a good decision.
- Thinking is ongoing to propose a **system which relaxes problems** as much as possible while **fully maintaining LHC performance and flexibility**.
- A **three stage system addresses** three major worries (impedance/ robustness/ tolerances) and might relax requirements. Pre-mature to judge on feasibility.
- In particular the effect on the **IR regions** will be carefully studied with showering studies.
- A three-stage system can always be operated as a two-stage system with additional triplet protection and halo absorption! **Triplets are presently the tertiary collimators!**
- Other worries under consideration: Radiation and remote handling, experimental verification of assumptions, small impact parameters, vacuum, …

Additional slides

Other supporting activities:

Work on numerical tools. Establish systematic errors.



R. Assmann, I. Baishev,
M. Brugger, J.B. Jeanneret,
D. Kaltchev

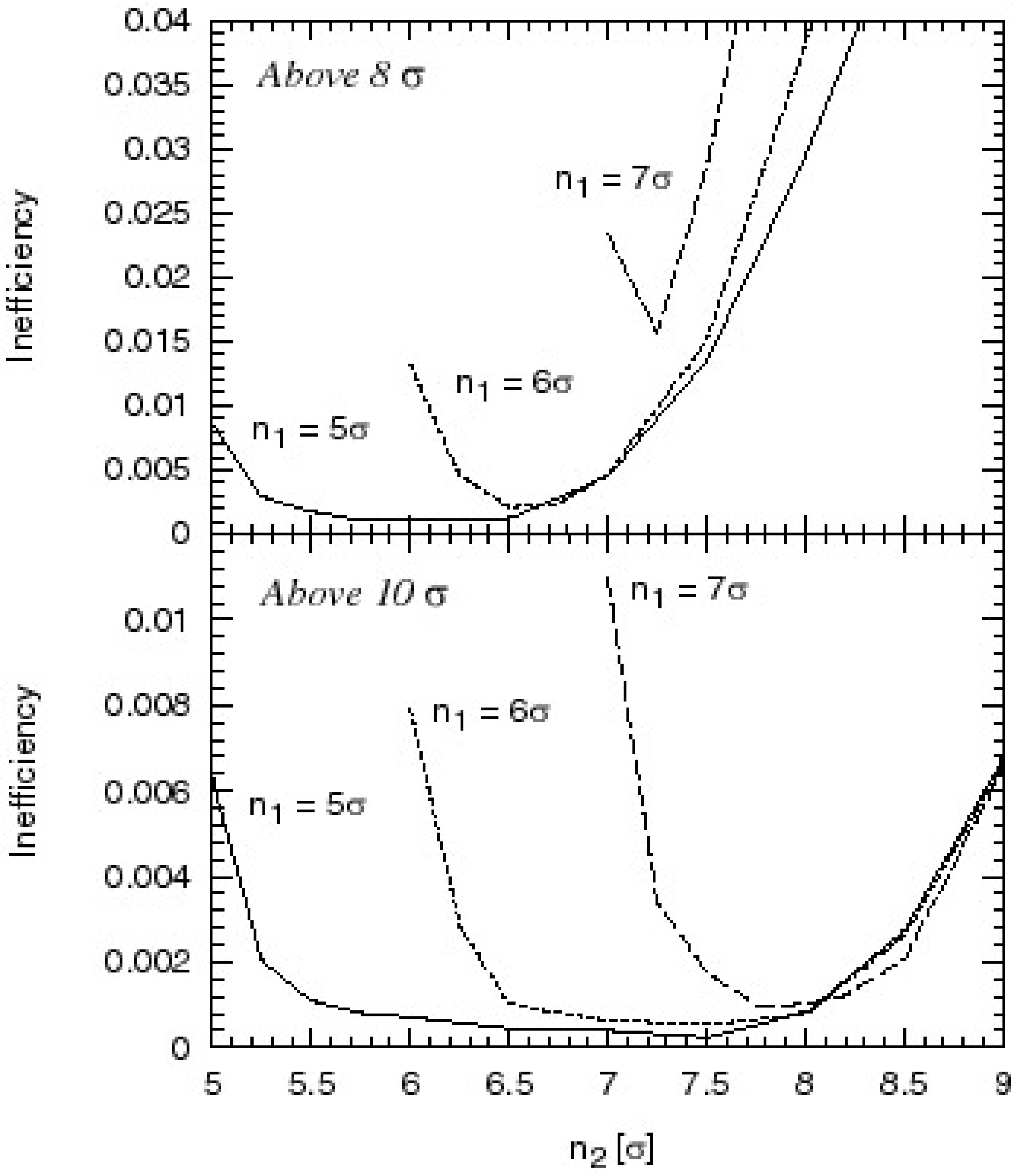
Collimator scattering and tracking with collimators in SIXTRACK:

Fully chromatic, all errors possible, non-linearities, beam-beam, …

Inefficiency for different collimator settings:

n1 = setting of primary collimator

n2 = setting of secondary collimator



Aperture limited at 8 σ

Aperture limited at 10 σ

R. Assmann

System evaluation: Tolerances

Value of imperfections for 50% increase (each) in inefficiency:

Transient changes

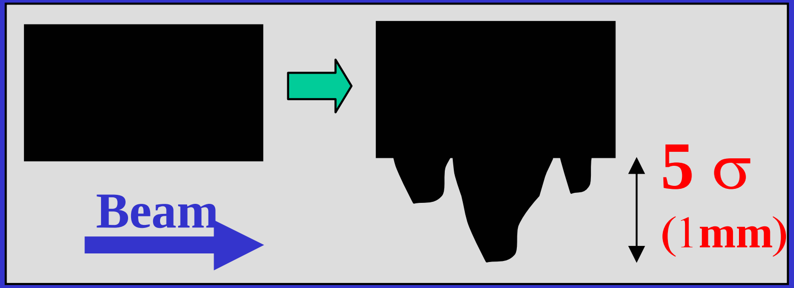
Error	Tolerance
Orbit	0.6 σ
Beta beat	8%
Longitudinal angle	50 μrad
$\Delta L/L$ (prim)	75%
Surface flatness (prim)	10 μm
$\Delta L/L$ (sec)	20%
Surface flatness (sec)	25 μm
Setting accuracy (prim)	-1.0/+0.5 σ
Setting accuracy (sec)	$\geq \pm 0.5\ \sigma$

Preliminary estimates:

Combined effect can make tolerances more severe!

Collimators need not only be robust, but also precise!

HERA experience:

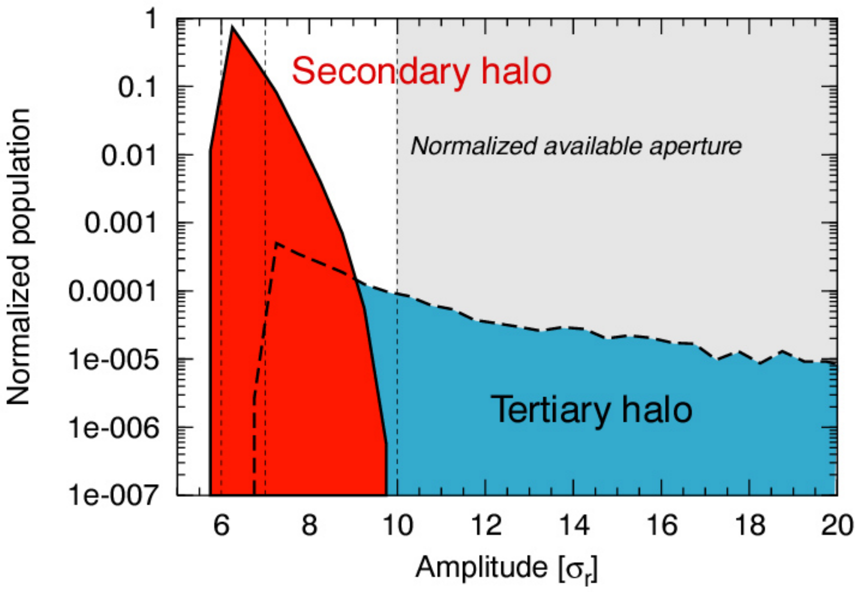


Set-up of tools, thinking about operation started

Tools:	SIXTRACK with collimators
	Comparison of scattering physics
	Interface of halo prediction to BLM studies
Operation:	Operational strategies
	Orbit feedback
	Machine protection
	Required accuracy for beam diagnostics
	Allowed deterioration of beam parameters

All ongoing… (fast results when mechanical properties decided)

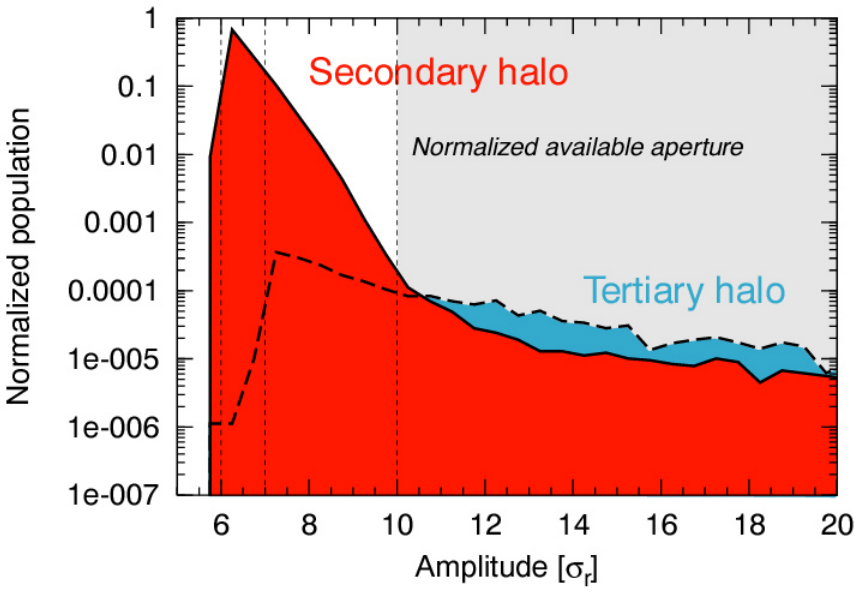
Secondary and tertiary beam halos



Scattering in collimator jaws (at 6/7 σ)

Transverse scattering angles + momentum loss

Halo at zero dispersion



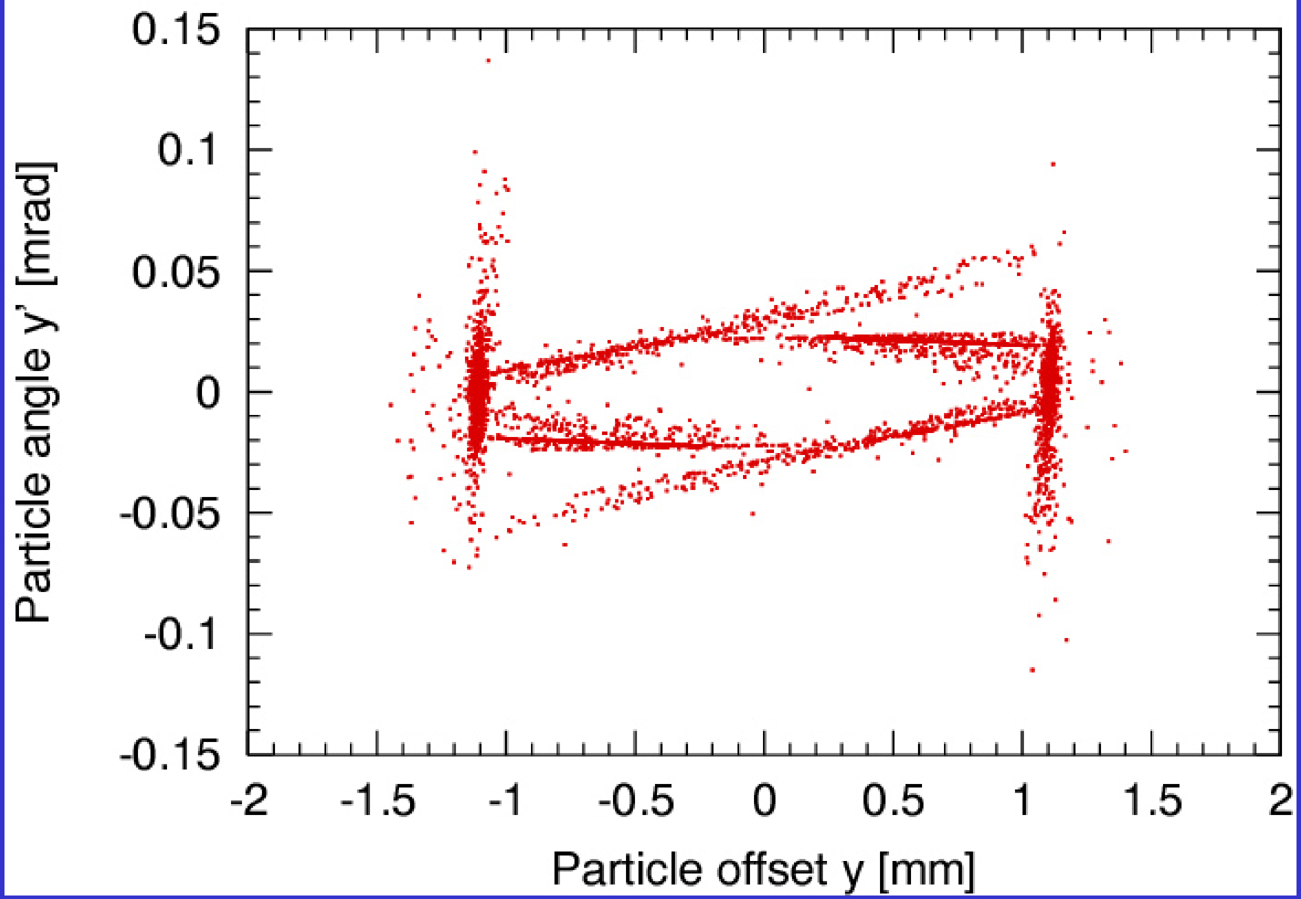
Halo at max dispersion

Local inefficiency [1/m]:

Integrate halos above 10σ

Divide by dilution length (50 m)

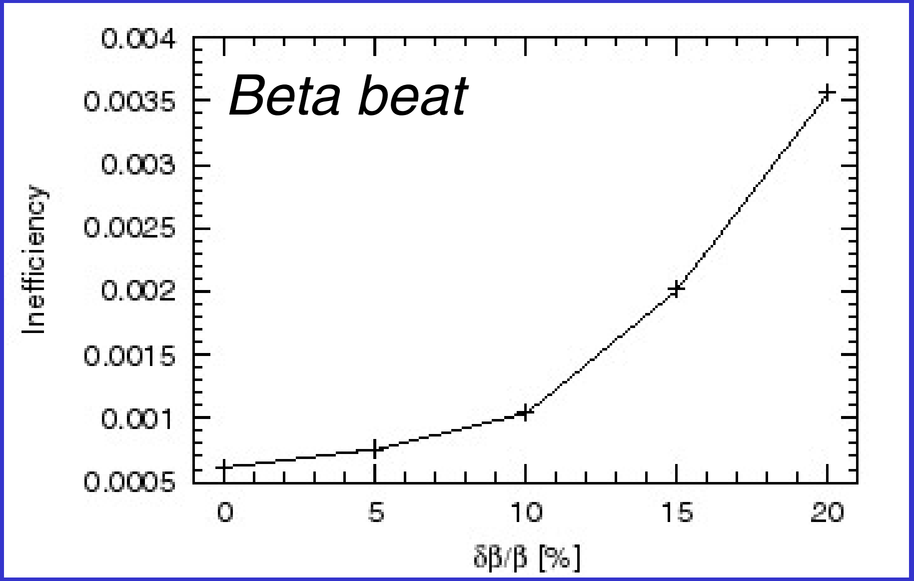
Tertiary halo in phase space

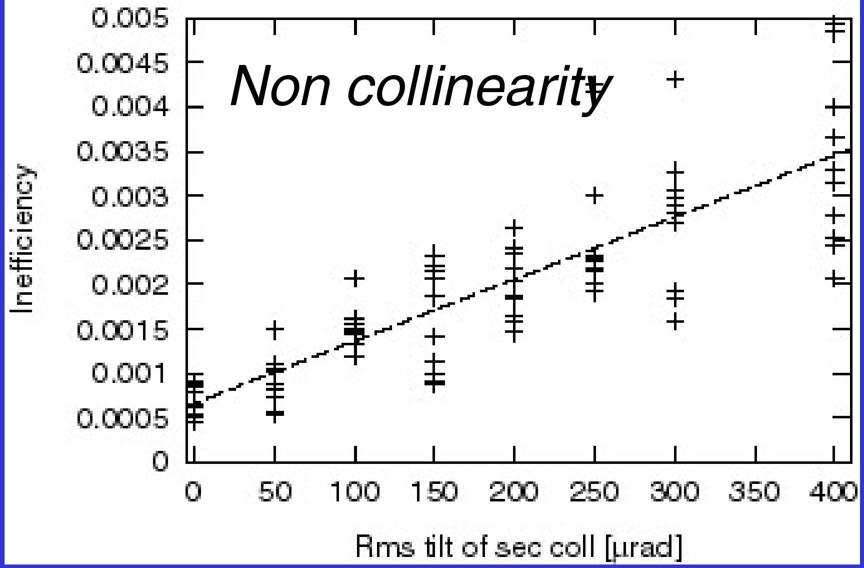


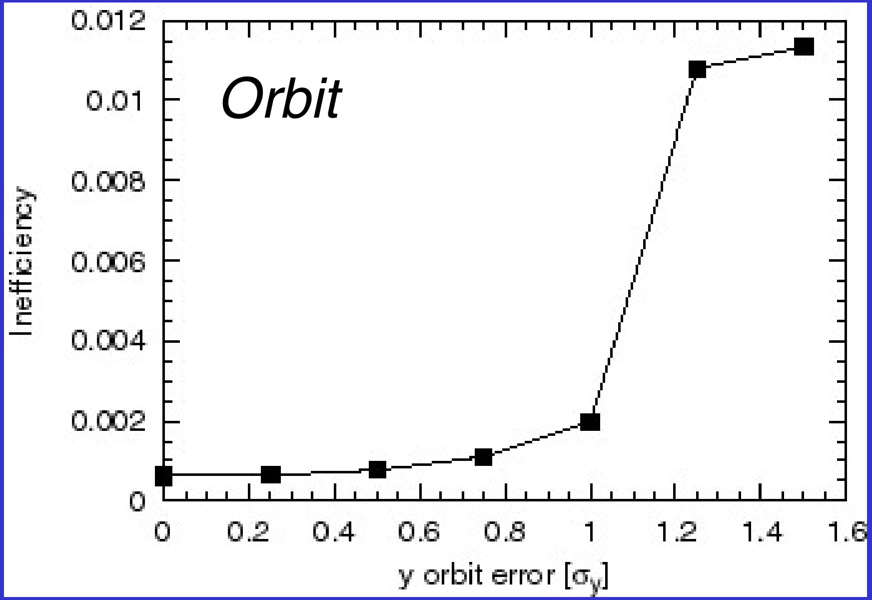
Halo generated
at specific
phase space
locations!

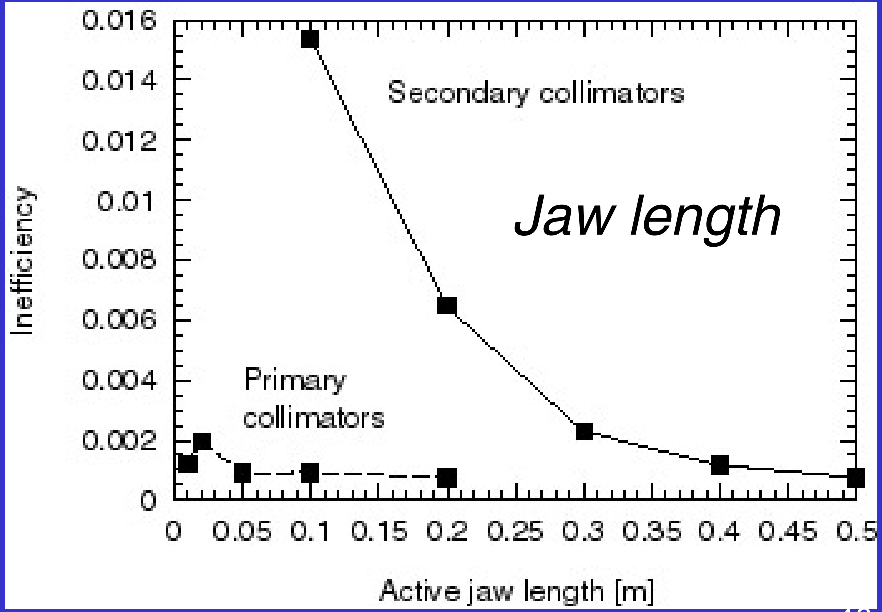
Input to studies of **local loss distribution** (dilution, expected signals of Beam Loss Monitors BLM).

Inefficiency versus imperfections

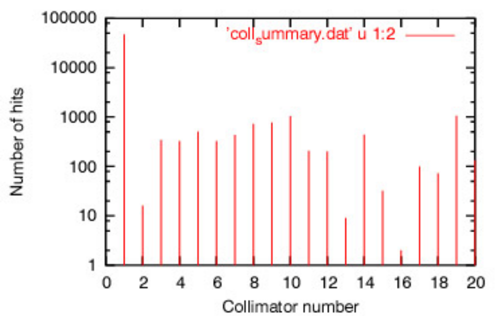


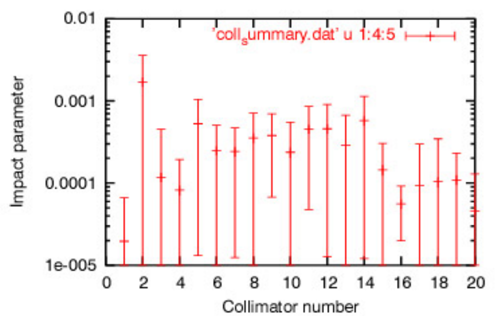


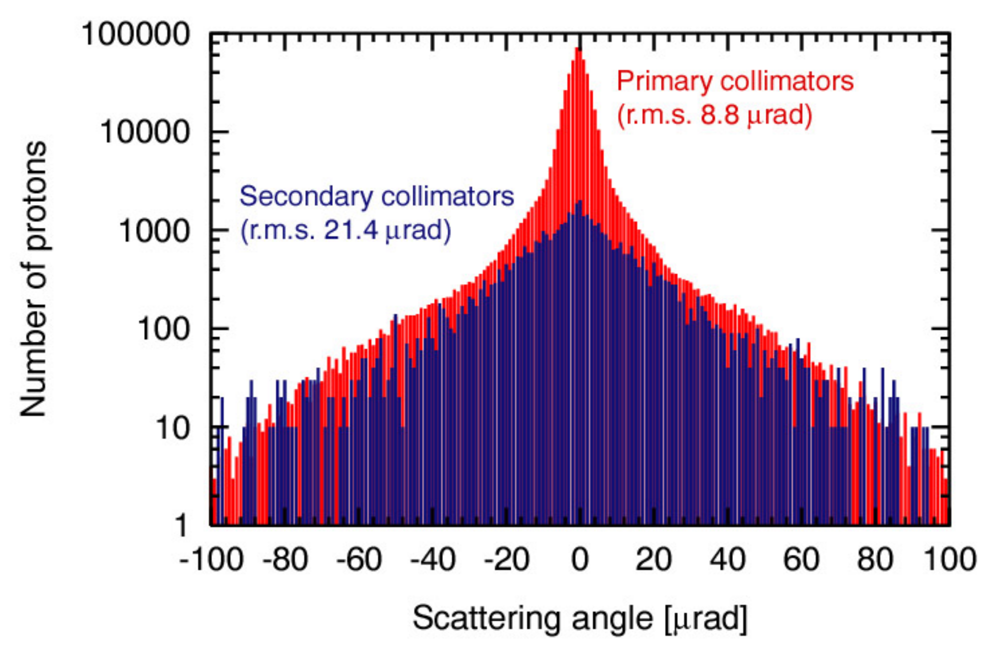


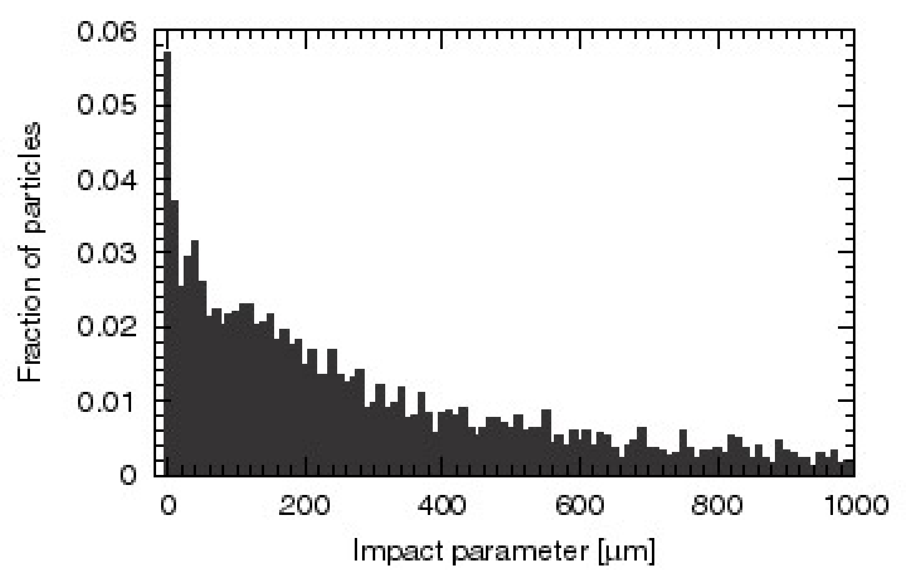


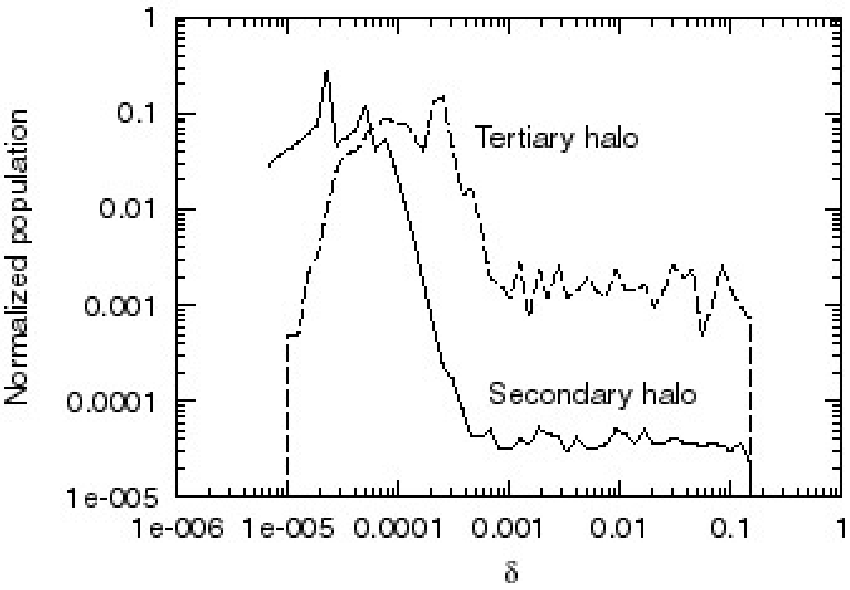
Scattering physics



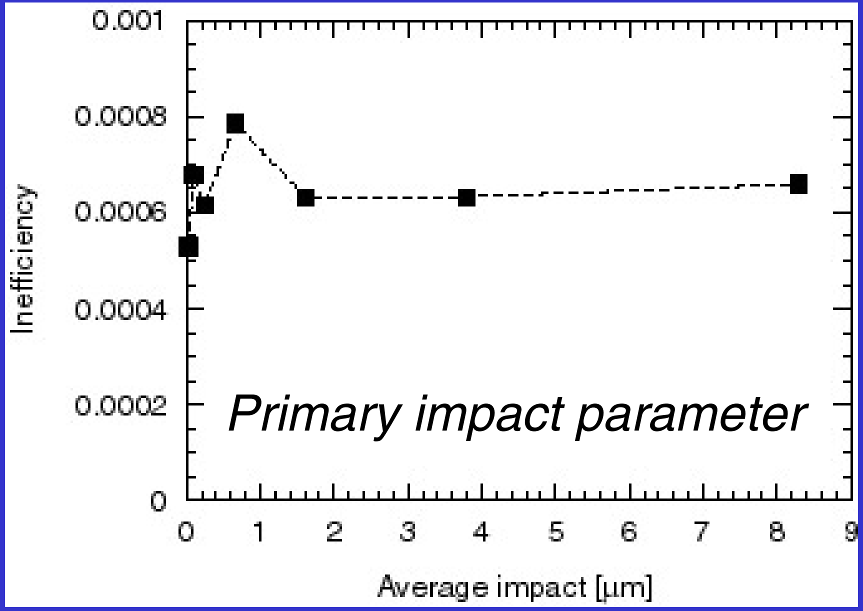


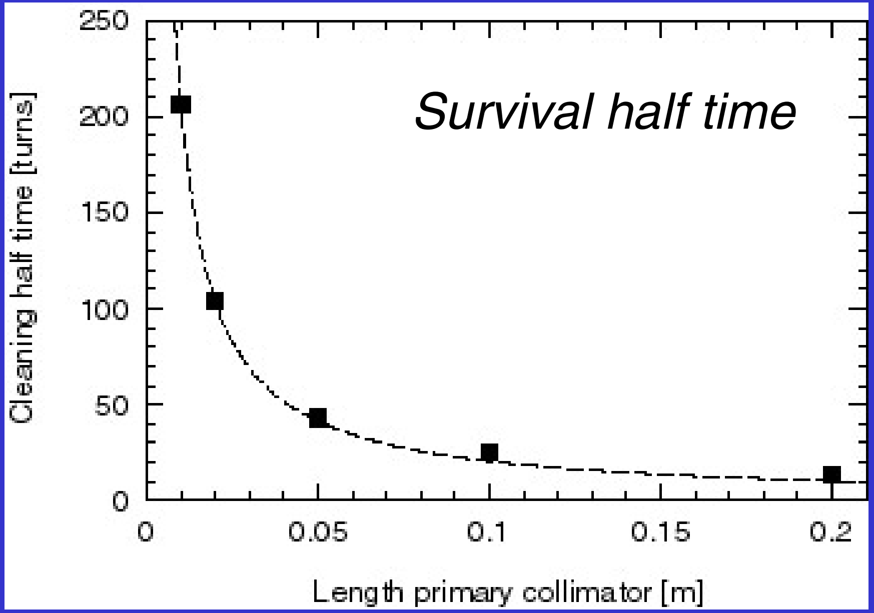


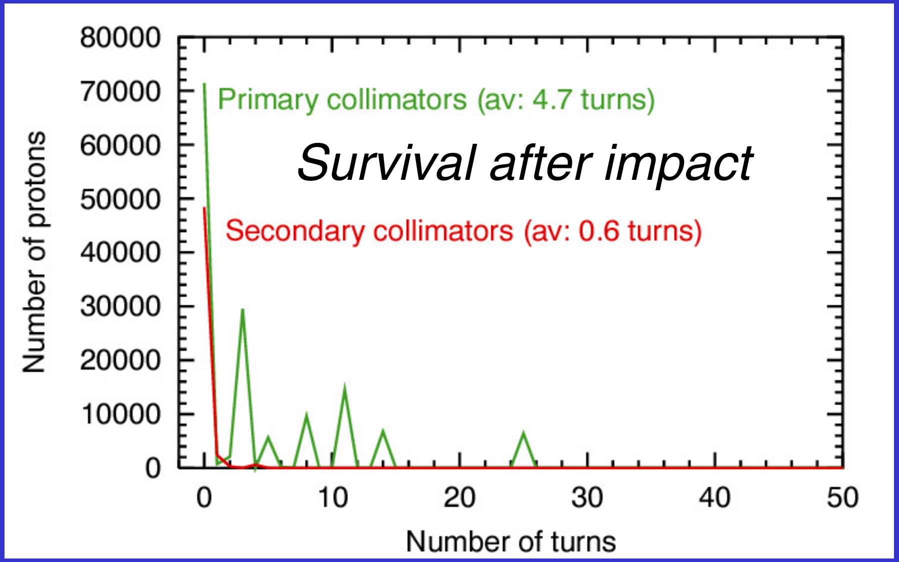


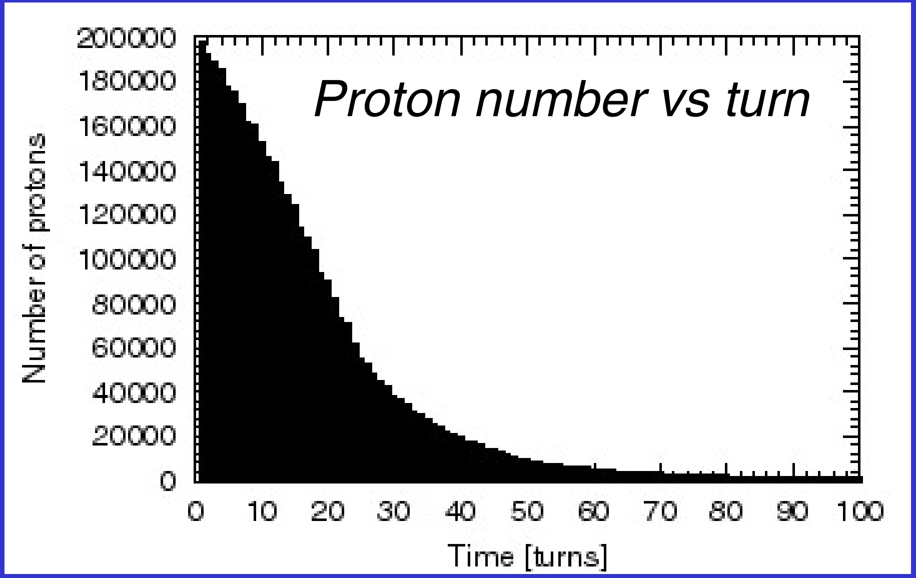


Multi-turn properties and impact parameter









Super-Conducting Environment

Proton losses into cold aperture

⇓

Local heat deposition

⇓

Magnet can quench

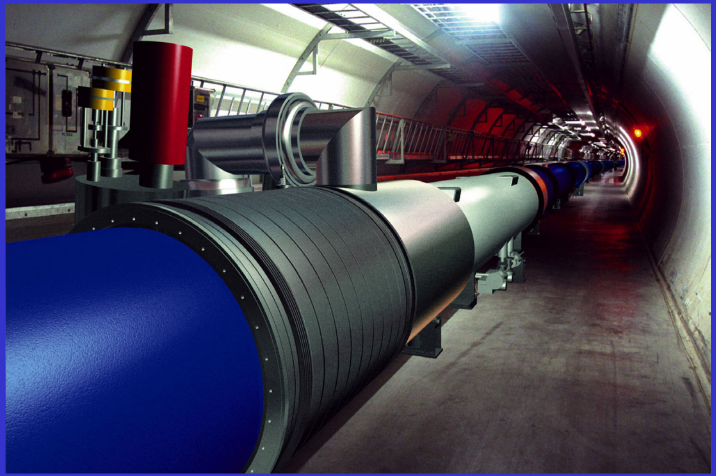


Illustration of LHC dipole in tunnel

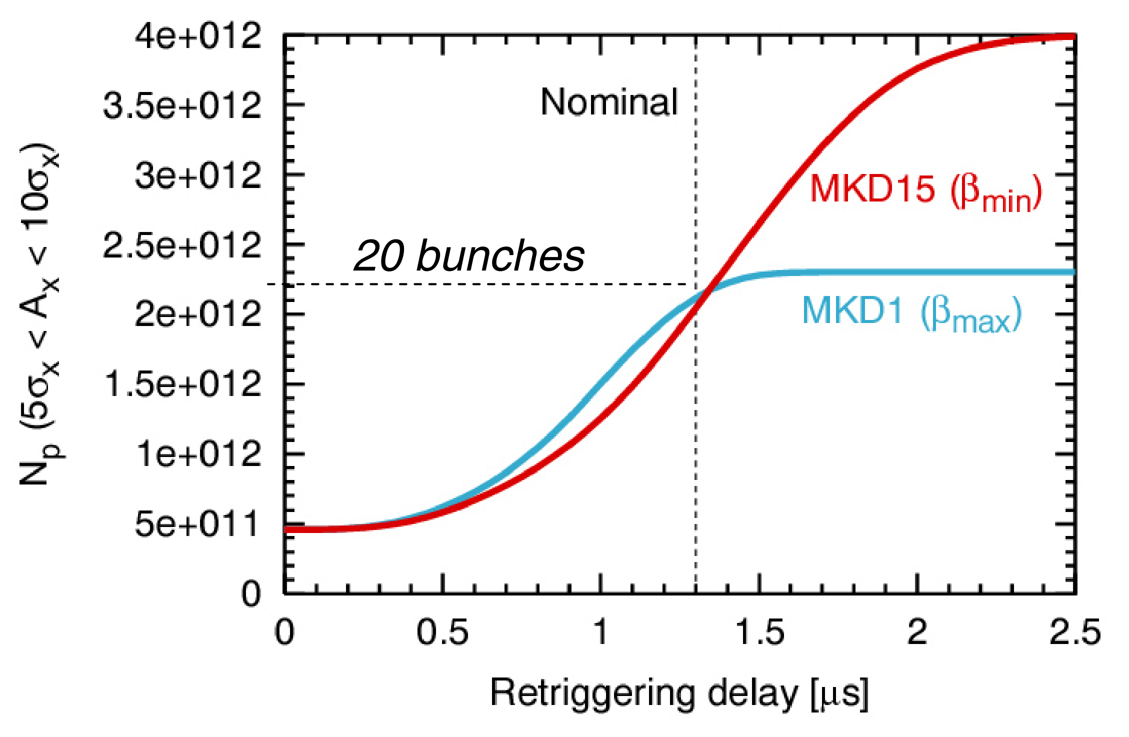
Energy [GeV]	Loss rate (10 h lifetime)	Quench limit [p/s/m] (**steady losses**)	Cleaning requirement
450	8.4e9 p/s	7.0e8 p/s/m	92.6 %
7000	**8.4e9 p/s**	**7.6e6 p/s/m**	**99.91 %**

Control **transient losses (10 turns)** to ~1e-9 of nominal intensity (top)!

Capture (clean) lost protons before they reach cold aperture!

Required efficiency: **~ 99.9 %** *(assuming losses distribute over 50 m)*

Ease requirements from dump system?



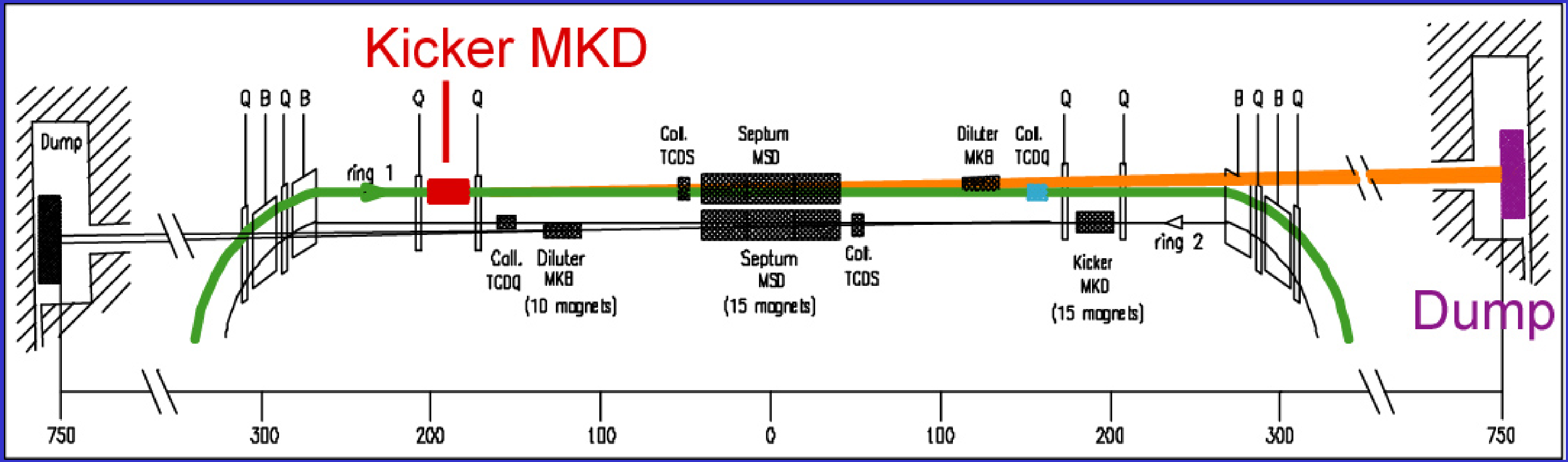
One module pre-fire depends on details of dump kicker design (pulse form, number of magnets, re-trigger design)!

Possible remedies are being studied (require modifications to dump system).

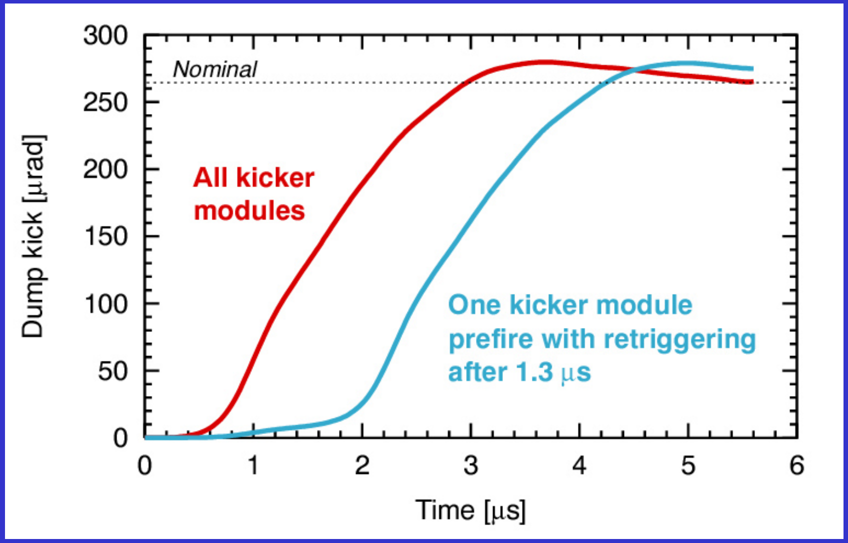
Collimators should withstand this impact without damage!

Consequences for choice of material, jaw length, operation, exchange facilities, setting of TCDQ (10σ), distribution of radioactivity, …

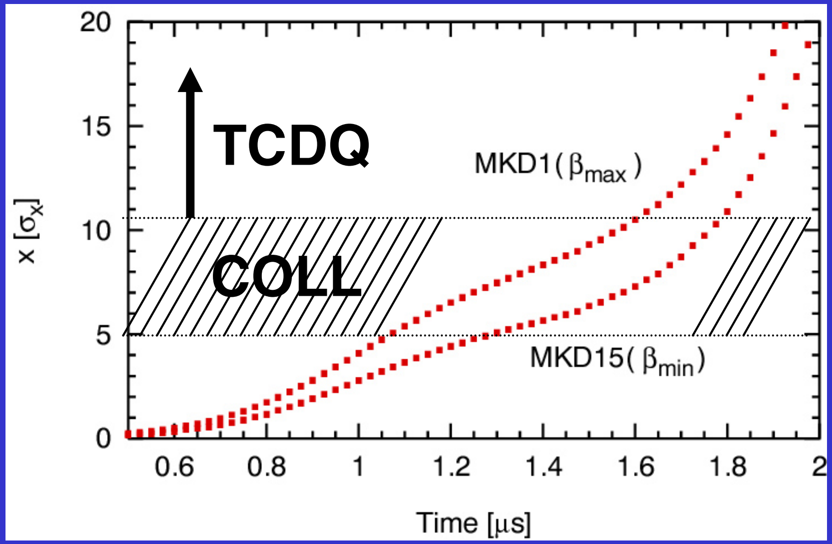
Abnormal dump actions



Kick [μrad]



Downstream offset [σ]



One module pre-fire

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CERN-LHC-PROJECT-REPORT-599: REQUIREMENTS FOR THE LHC COLLIMATION SYSTEM. By R.W. Assmann, I. Baishev, M. Brugger, L. Bruno, H. Burkhardt, G. Burtin, B. Dehning, C. Fischer, B. Goddard, E. Gschwendtner, M. Hayes, J.B. Jeanneret, R. Jung, V. Kain, D. Kaltchev, M. Lamont, R. Schmidt, E. Vossenberg, E. Weisse, J. Wenninger (CERN & Serpukhov, IHEP & TRIUMF).

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LHC-PROJECT-NOTE-293: The consequences of abnormal beam dump actions on the LHC collimation system *by:* Assmann, R ; Goddard, B ; Vossemberg, E ; Weisse, E ; (2002)

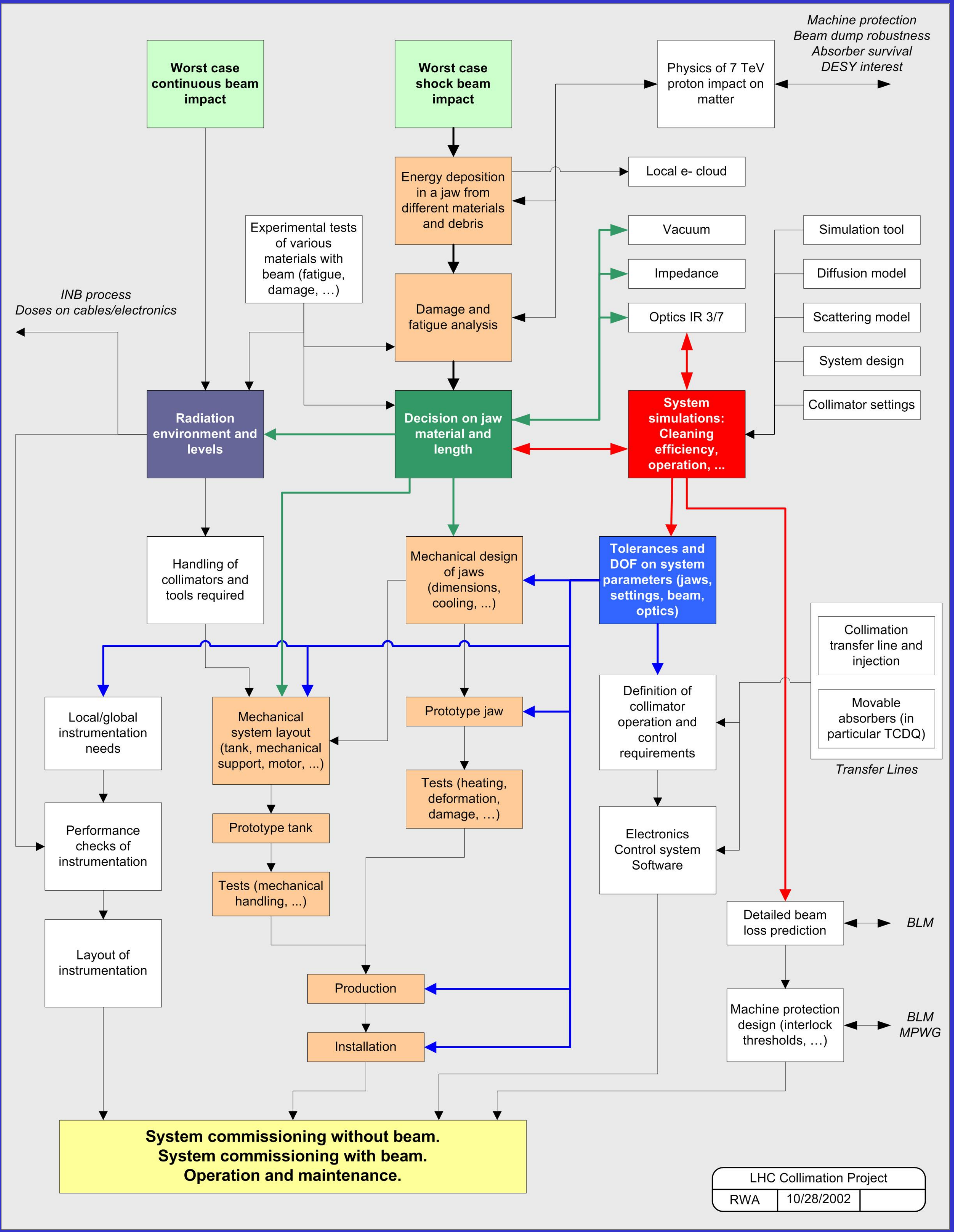
LHC-PROJECT-NOTE-282: Summary of the CERN Meeting on Absorbers and Collimators for the LHC *by:* Assmann, R ; Fischer, C ; Jeanneret, J B ; Schmidt, R ; (2002)

LHC-PROJECT-NOTE-277: Preliminary Beam-based specifications for the LHC collimators *by:* Assmann, R ; (2002)

Collimators & absorbers at 7 TeV:

Region	Type	Orientation	Material	Number	Length	Setting
IR1	TCL (Q5)	X	Cu	2	1.0 m	10.0 σ
	TAS	Round	Cu?	2	1.8 m	12.0 σ
	TCL (D2)	*X*	*Cu*	*2*	*1.0 m*	*10.0 σ*
IR3	TCP	X	Al	1	0.2 m	8.0 σ
	TCS	X, Y, XY	Cu	6	0.5 m	9.3 σ
IR5	TCL (Q5)	X	Cu	2	1.0 m	10.0 σ
	TAS	Round	Cu?	2	1.8 m	12.0 σ
	TCL (D2)	*X*	*Cu*	*2*	*1.0 m*	*10.0 σ*
IR6	TCDQ	X (1 side)	C	1	9.5 m	10.0 σ
IR7	TCP	X, Y, XY	Al	4	0.2 m	6.0 σ
	TCS	X, Y, XY	Cu	16	0.5 m	7.0 σ

- Numbers are for Al, Cu system. Length is given per collimator
- All collimators two-sided except noted.
- Number is per beam.
- TCL (D2) is an upgrade for LHC ultimate performance.
- Table is for 7 TeV.
- Settings are for nominal luminosity and nominal β^* (n_1 = 7 in the triplet).
- For injection add TDI, TCL (inj), and TCDS. All around 10 σ. IR1 and IR5 settings could be open for injection, others remain at similar settings.



Machine protection
Beam dump robustness
Absorber survival
DESY interest

Worst case continuous beam impact

Worst case shock beam impact

Physics of 7 TeV proton impact on matter

Energy deposition in a jaw from different materials and debris

Local e- cloud

Experimental tests of various materials with beam (fatigue, damage, …)

Vacuum

Impedance

Optics IR 3/7

Simulation tool

Diffusion model

Scattering model

System design

Collimator settings

INB process
Doses on cables/electronics

Damage and fatigue analysis

Radiation environment and levels

Decision on jaw material and length

System simulations: Cleaning efficiency, operation, ...

Handling of collimators and tools required

Mechanical design of jaws (dimensions, cooling, ...)

Tolerances and DOF on system parameters (jaws, settings, beam, optics)

Collimation transfer line and injection

Movable absorbers (in particular TCDQ)

Transfer Lines

Local/global instrumentation needs

Mechanical system layout (tank, mechanical support, motor, ...)

Prototype jaw

Definition of collimator operation and control requirements

Tests (heating, deformation, damage, …)

Prototype tank

Performance checks of instrumentation

Tests (mechanical handling, ...)

Electronics Control system Software

Detailed beam loss prediction

BLM

Layout of instrumentation

Production

Installation

Machine protection design (interlock thresholds, …)

BLM
MPWG

System commissioning without beam.
System commissioning with beam.
Operation and maintenance.

LHC Collimation Project
RWA 10/28/2002