Status of the LHC Collimation System

Towards a More Robust System

R. Assmann, CERN-AB/ABP

for the LHC Collimation Project Team

LHC Machine Advisory Committee
13.3.2003

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!

O. Aberle	AB/ATB	D. Kaltchev	TRIUMF
R. Assmann	AB/ABP (Project Leader)	M. Lamont	AB/OP
I. Baichev	IHEP	M. Mayer	EST/ME
M. Brugger	TIS/RP	H. Preis	AB/ATB
L. Bruno	AB/ATB	T. Risselada	AB/ABP
P. Bryant	AC/TSC	F. Ruggiero	AB/ABP
H. Burkhardt	AB/ABP	F. Schmidt	AB/ABP
E. Chiaveri	AB/ATB	R. Schmidt	AB/CO
B. Dehning	AB/BDI	P. Sievers	AT/MTM
A. Ferrari	AB/ATB	V. Vlachoudis	AB/ATB
J.B. Jeanneret	AB/ABP	J. Wenninger	AB/OP
M. Jimenez	AT/VAC	F. Zimmermann	AB/ABP
V. Kain	AB/CO		

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:

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

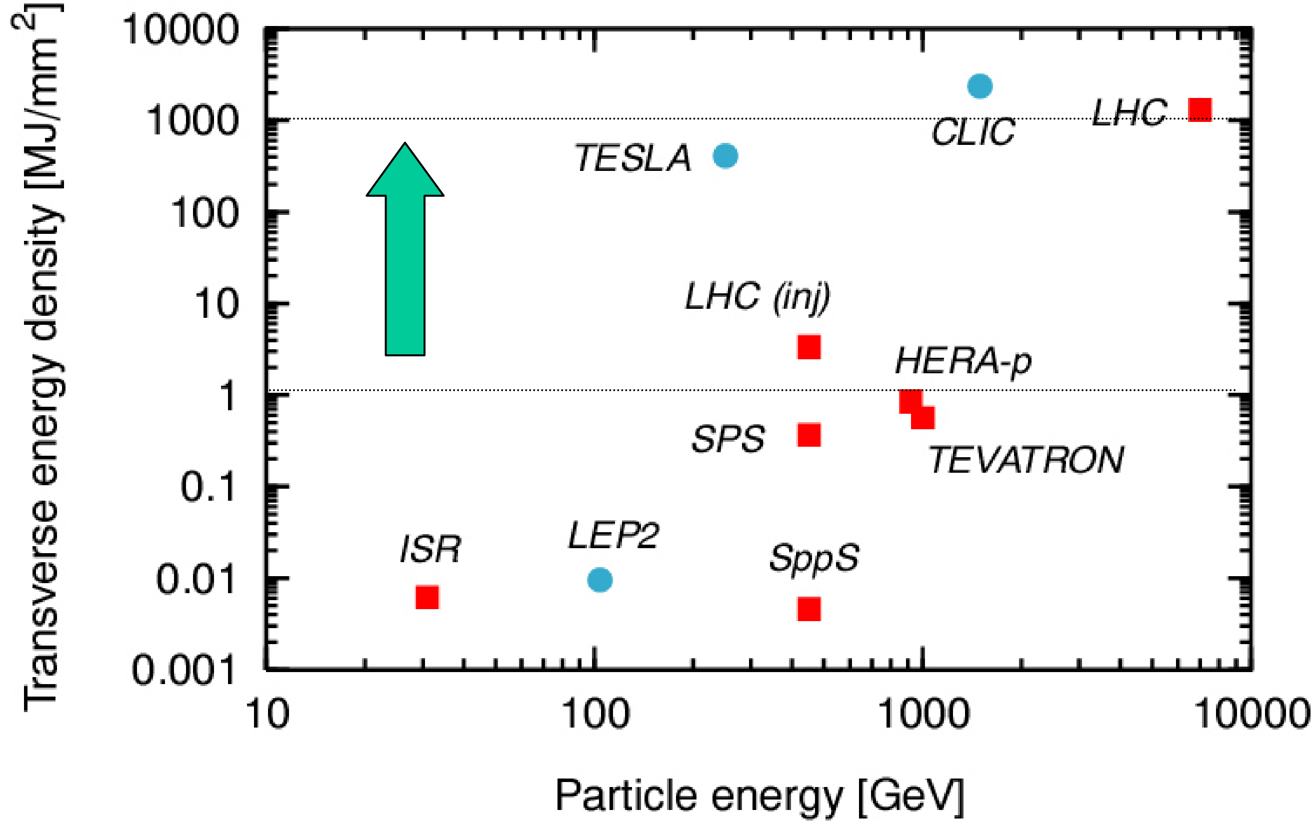
d = demagnification (β_{coll}/β^*)
N_p = protons per bunch
f_{rev} = revolution freq.
E_b = beam energy

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:

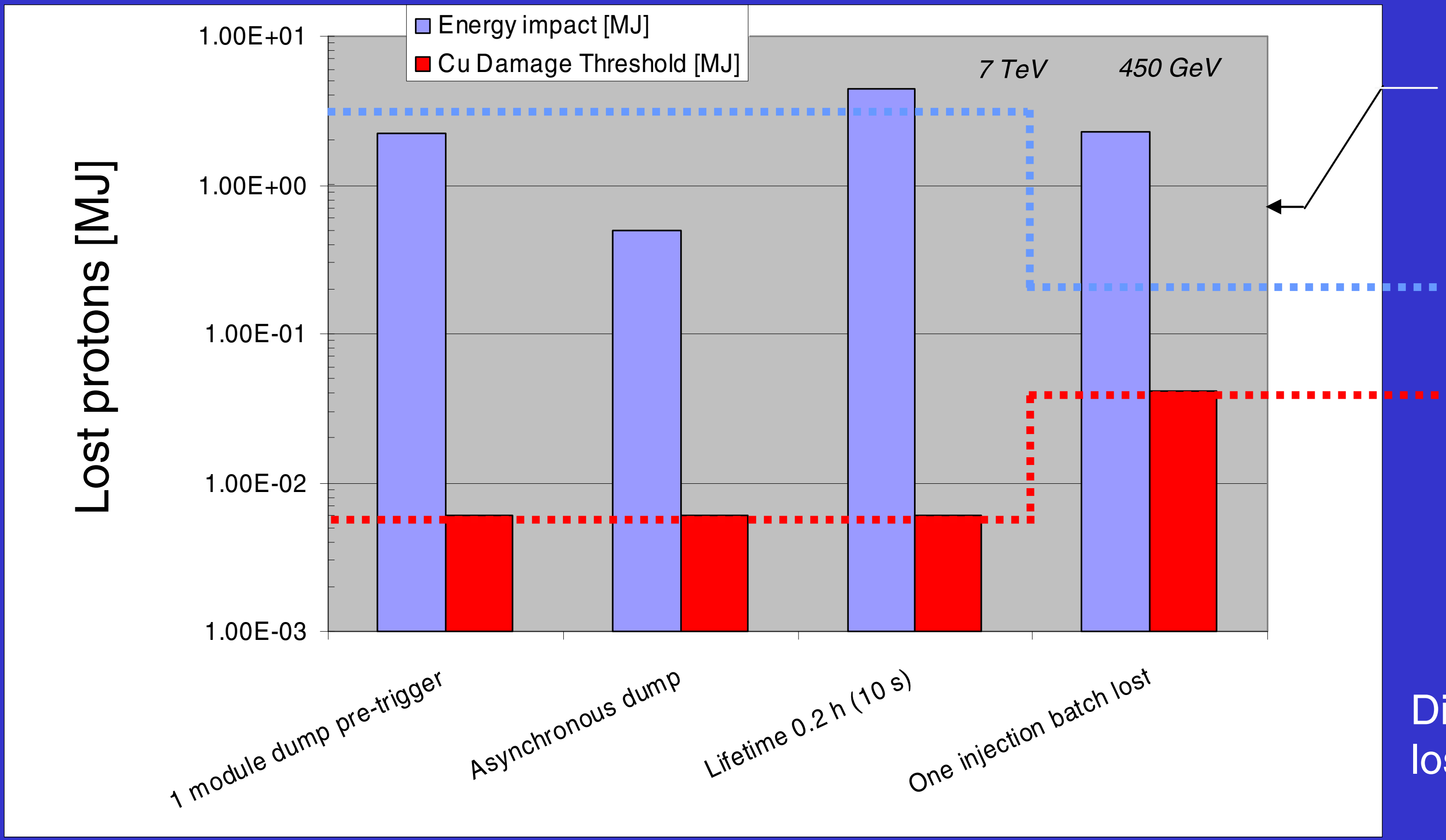
Number of bunches: Bunch population: Bunch spacing:	**2808** **1.1e11** 25 ns
Top energy: Proton energy: Transv. beam size: Bunch length: Stored beam energy:	 **7 TeV** **0.2 mm** 8.4 cm **350 MJ**
Injection: Proton energy: Transv. Beam size: Bunch length:	 450 GeV 1 mm 18.6 cm

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 on the 0.001% level. **Factor 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).

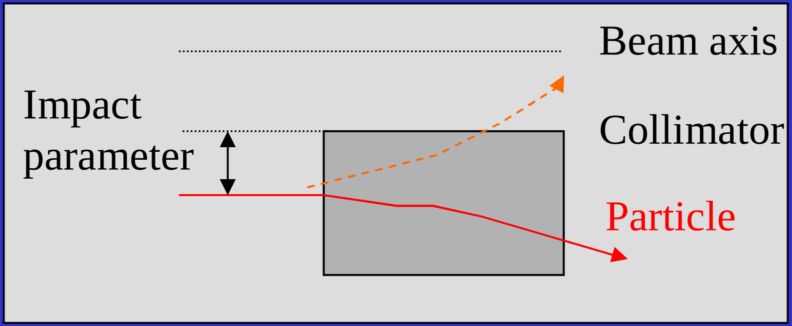
Two stage cleaning systems:

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

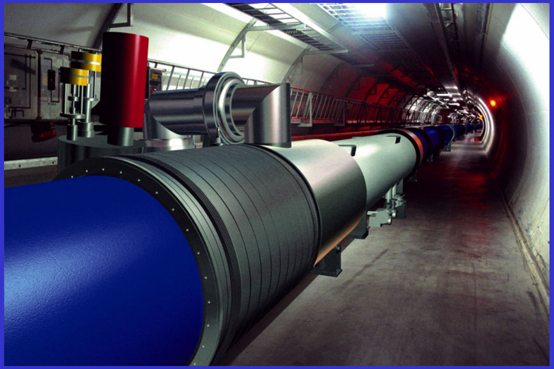


Illustration of LHC dipole in tunnel

Allowed intensity

Quench threshold
(7.6 ×10⁶ p/m/s @ 7 TeV)

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

Cleaning inefficiency

=

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

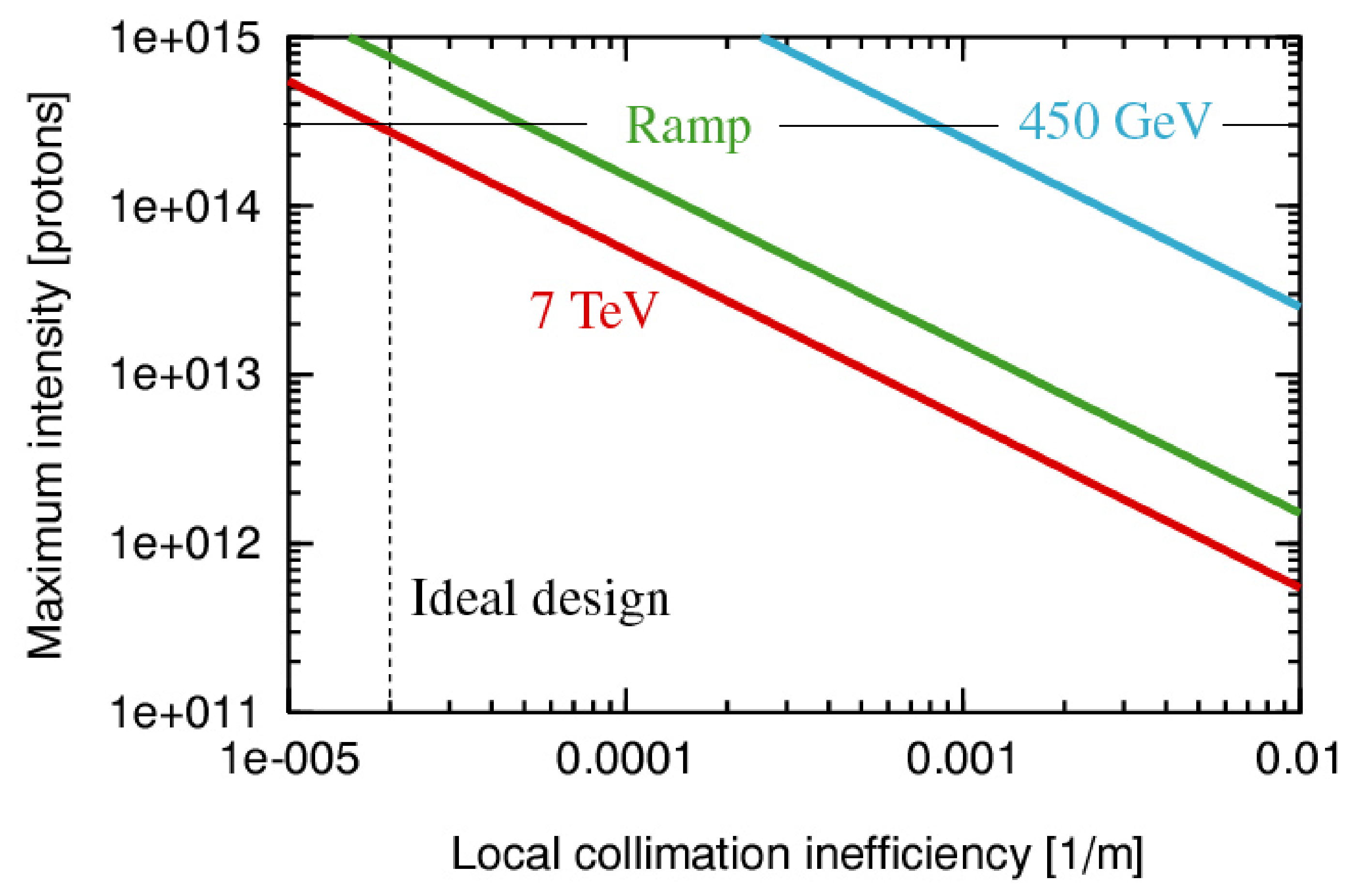
Beam lifetime
(e.g. 0.2 h minimum)

Dilution
length
(50 m)

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

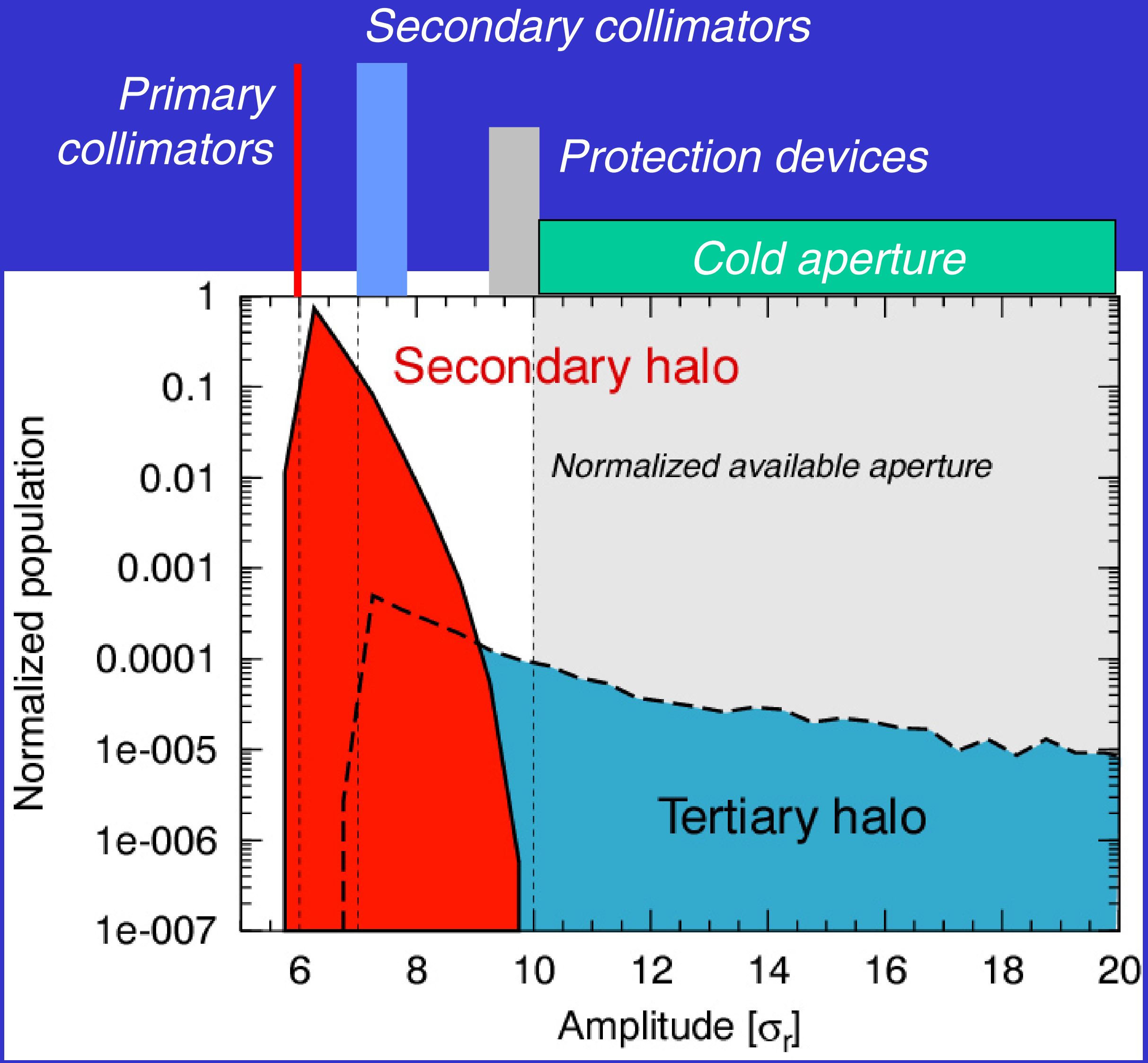
Collimator setting (prim) required for triplet protection from 7 TeV secondary halo:

$$a_{coll} \leq a_{triplet} \cdot \overbrace{\sqrt{\frac{\beta_{coll}}{\beta_{triplet}}}}^{\sim 0.15} \cdot \overbrace{\left(\frac{A_{primary}^{max}}{A_{secondary}^{max}} \right)}^{\sim 0.6}$$

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)



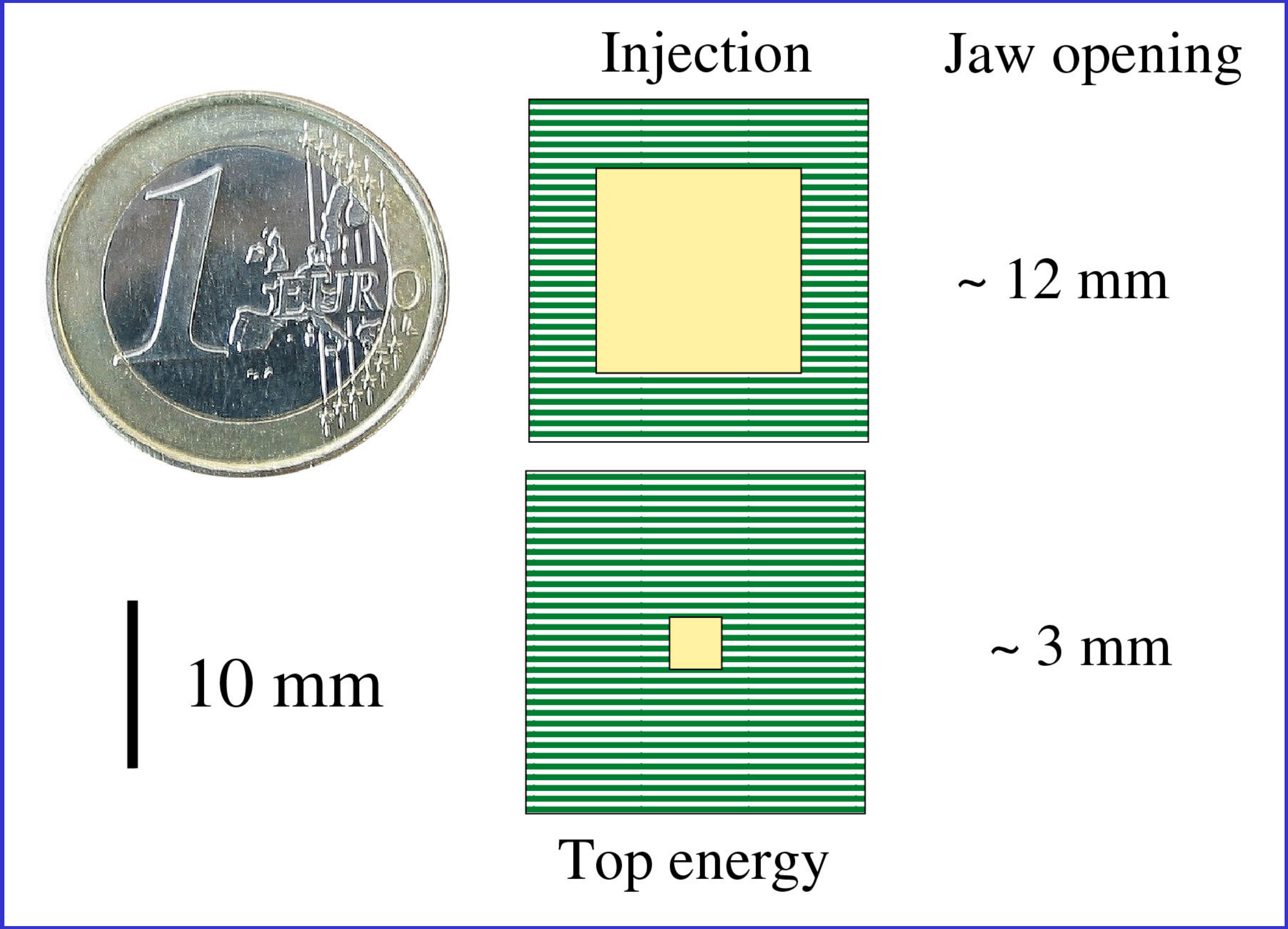
Strategy:

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:

$5 - 6\ \sigma$ (primary)
$6 - 9\ \sigma$ (secondary)

$\sigma \sim 1$ mm (injection)
$\sigma \sim 0.2$ mm (top)

Number of protons reaching 10σ:

10^{-4} of p at $6\ \sigma$

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):

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

Care required to avoid any limitation of this kind!

The Challenge…

Design and build a collimation system …

… that absorbs the beam halo

… of the high power LHC beam

… such that the quenches are avoided

… and the equipment is protected

… in the tight LHC cold aperture

… ensuring collimator survival

… respecting AP, vacuum, radiation boundary conditions

… and compatibility with operation

Much more critical than in existing accelerators (background is a side issue)!

New territory without trivial solutions!

Contents

I. The Challenge

II. The V6.4 Collimation System

III. Towards a System with Low-Z Jaws

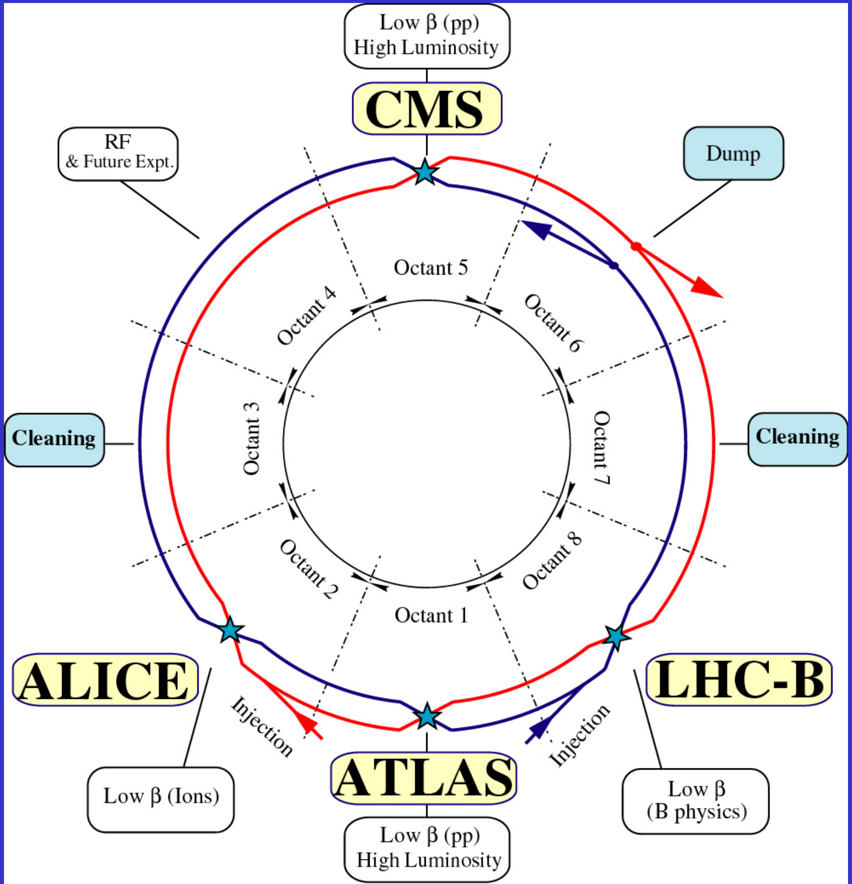
IV. Outlook

The LHC Cleaning Insertions

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.

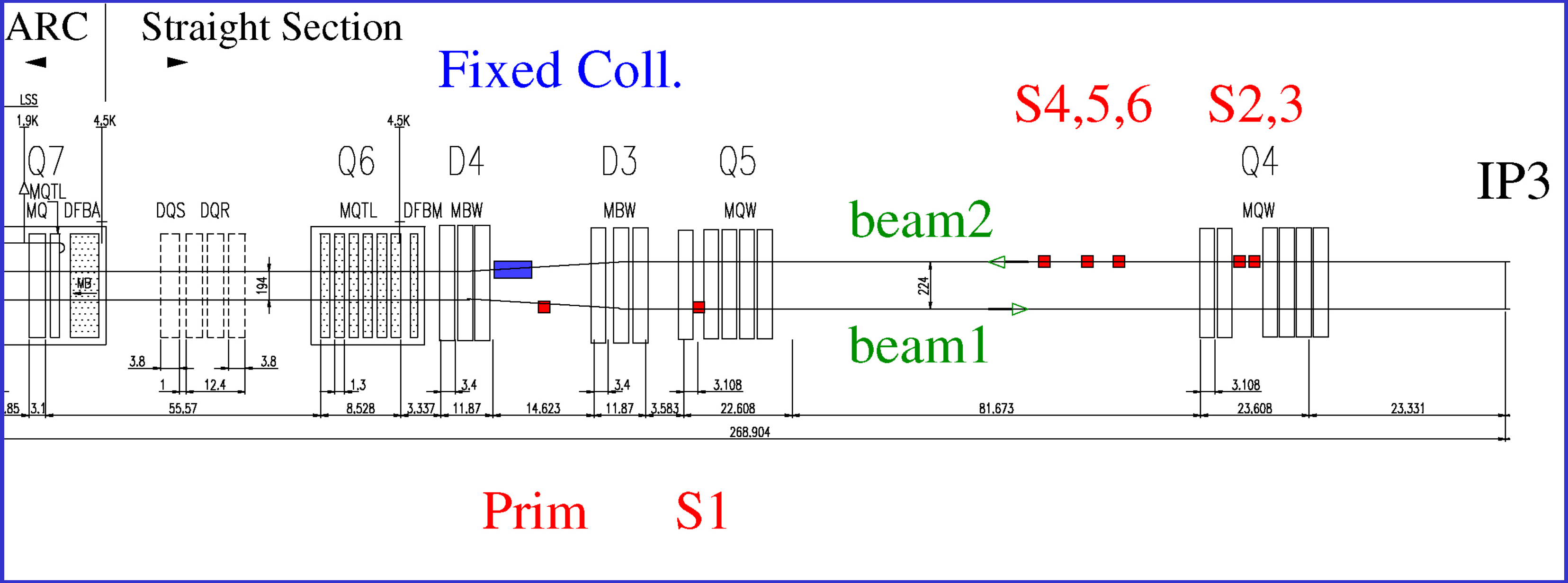


54 movable collimators for high efficiency cleaning, two jaws each *+ other absorbers for high amplitude protection*

Significant system: ~ 200 degrees of freedom!

Layout of Cleaning Insertion IR3

Present layout half IR3:



[Special optics] requirements (phase advance, dispersion)

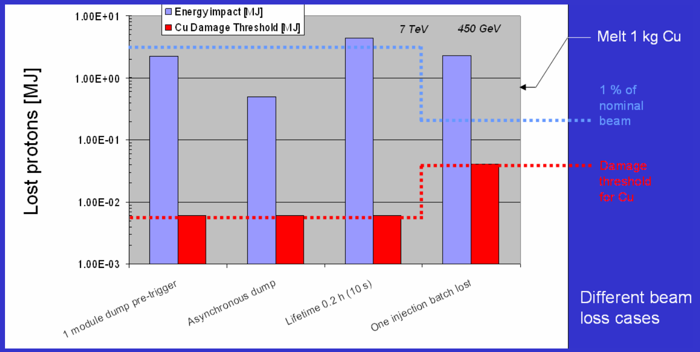
Importance of LHC collimation reflected by the fact that two insertions are dedicated to it!

Concept and basic layout developed and verified over last 10 years.

V6.4 Solution: Achievements and problem

Basic system design (two stage system, two cleaning insertions) works.

Required cleaning efficiency is provided.



LEP based material choices (Al/Cu) are not adequate:

- Detailed calculation with measured kicker waveform yields *higher beam impact* on collimators than assumed.
- Frequency of *abnormal beam dumps* (several times per year) higher than previously assumed.
- Shorter *beam lifetimes* (as low as 0.2-1.0 h) must be accepted (40 h was assumed).
- Loss of an *injected batch* must be accommodated.

System must accept 400 times higher losses than the Al/Cu system could.

New technical solutions are being pursued (low Z material, CERN meeting on collimators and absorbers, 2002).

Contents

I. The Challenge

II. The V6.4 Collimation System

III. Towards a System with Low-Z Jaws

IV. Outlook

The set-up and schedule

Sep 2001	LHC Beam Cleaning Study Group
Jan 2002	Consensus to consider low Z material (impedance presented as non-critical)
Jun 2002	Consensus on detailed requirements First tolerances
Oct 2002	Project LHC Collimation, new ATB group
Jan 2003	Full simulation chain: *Beam – FLUKA – ANSYS* Cleaning efficiency and optics with low Z Review of impedance, other constraints

April 2004	Prototype collimator
2004/2005	Production
2006	Installation

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).

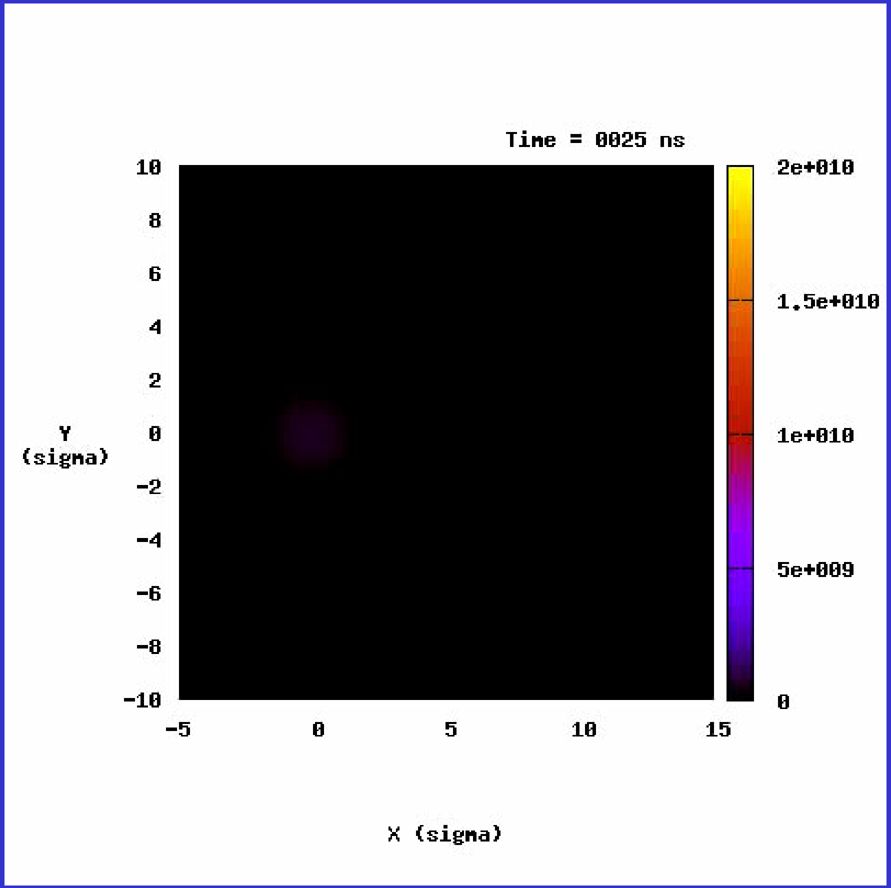
Failure modes:

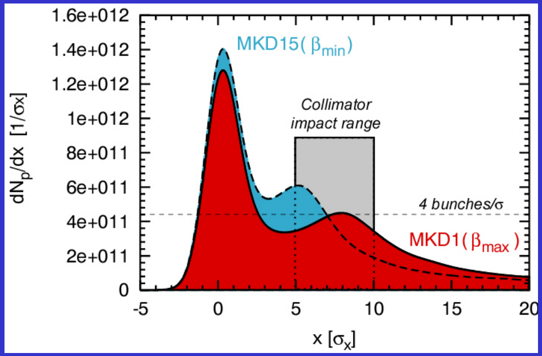
- Total failure of dump or dump trigger (> 100 years).
- Dump action non-synchronous with dump gap.
- Dump action from 1 of 15 modules, others retriggering after 1.3 μs.

}

Difficult to predict

Assume at least once per year!



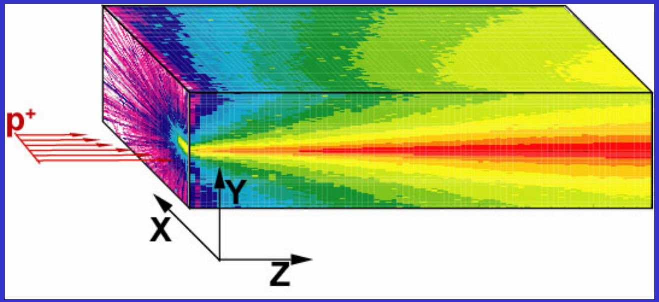


1 module pre-fire with re-triggering of 14 others after 1.3μs:

20 bunches over 5 σ

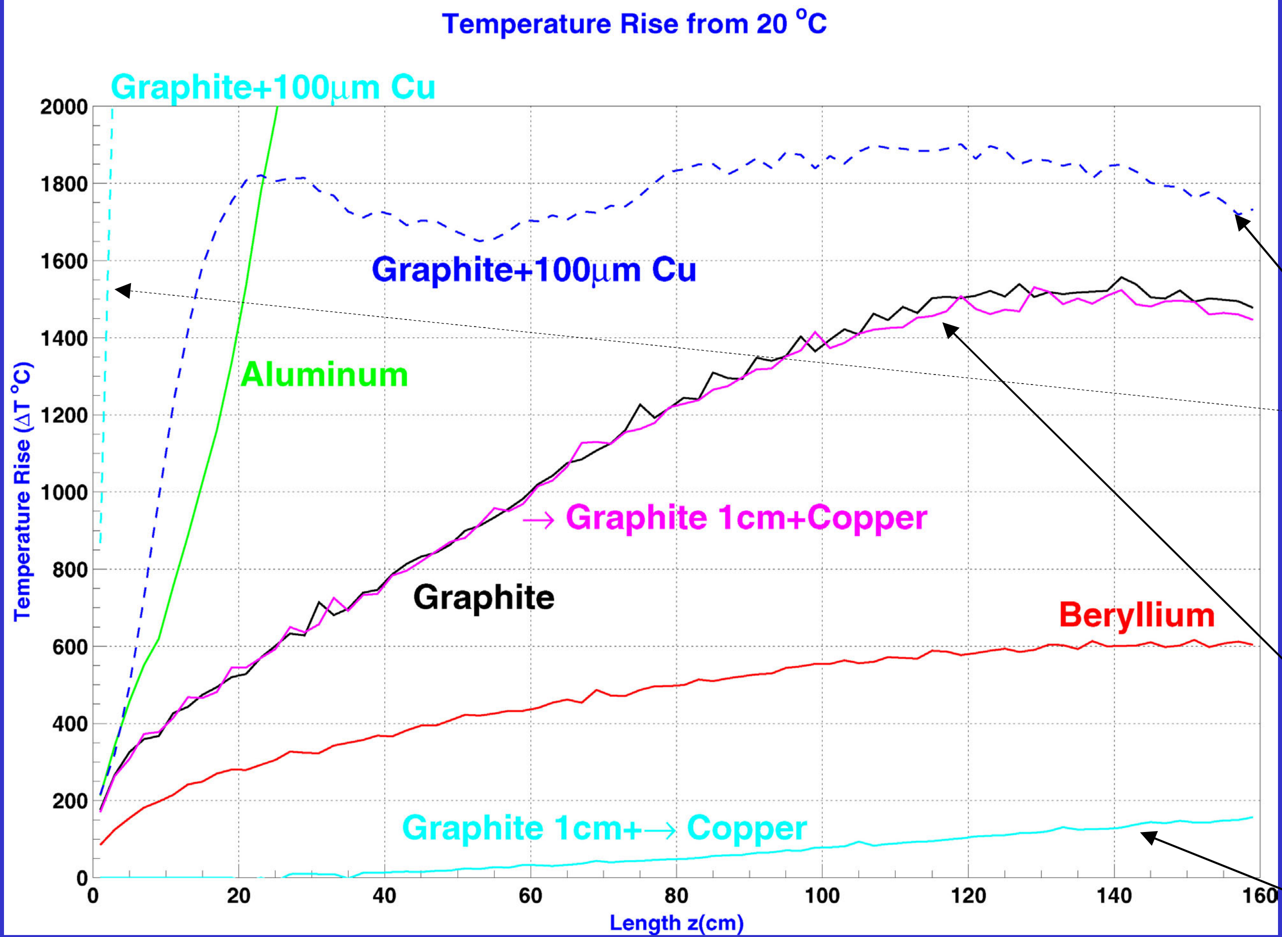
Peak: **6 bunches in 1 σ**

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



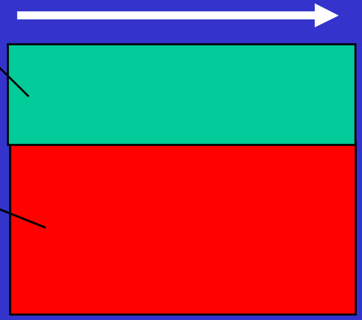
A. Ferrari, V. Vlachoudis

Different cases:

1) Block of material

2) Graphite + 100μm coating of Copper

3) 1 cm Graphite plate on Copper



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 ^{o}K 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

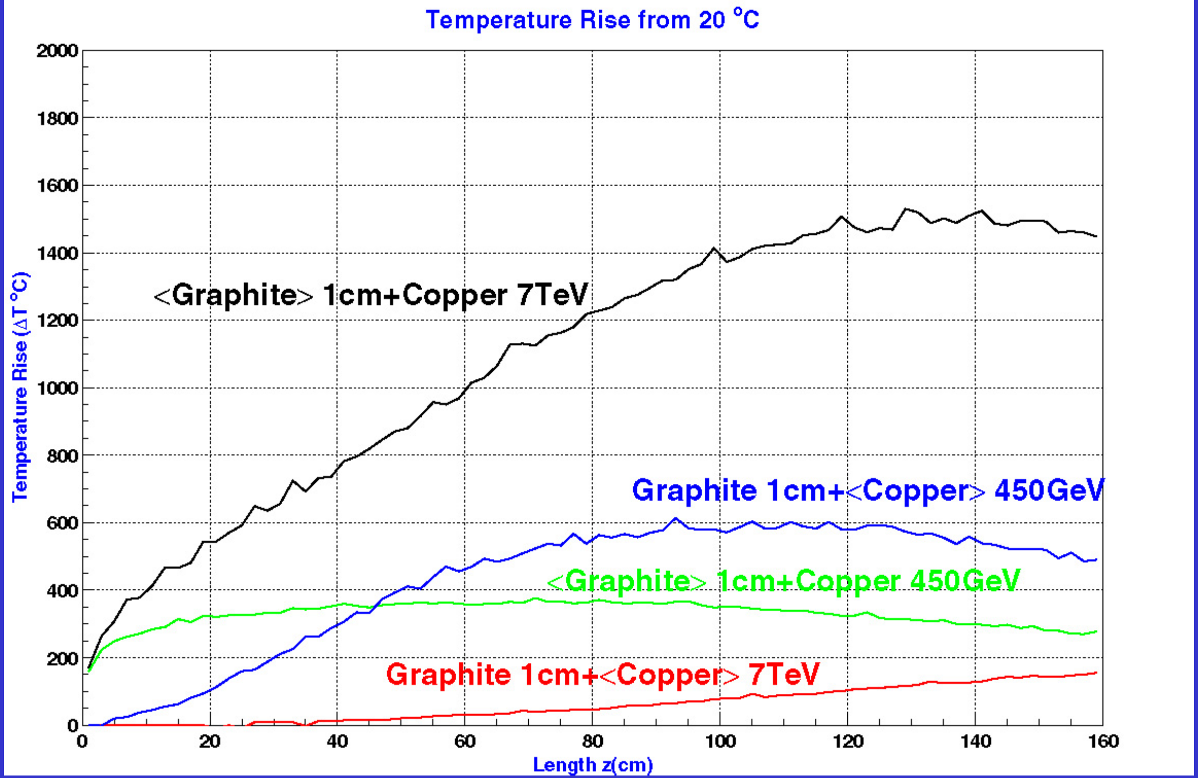
A. Ferrari, V. Vlachoudis

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)

Temperature rises for Graphite plate on Copper: 7 TeV and 450 GeV



A. Ferrari, V. Vlachoudis

450 GeV case:

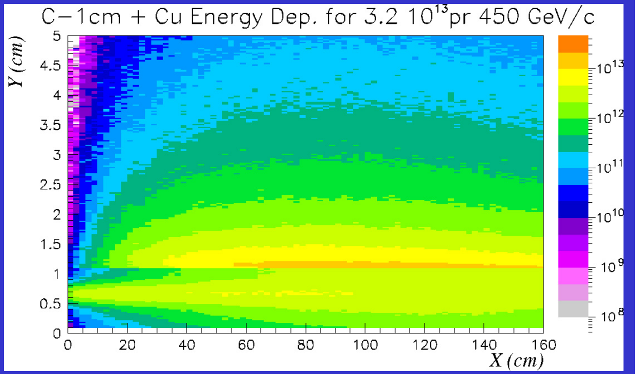
Impact of one full injected batch!

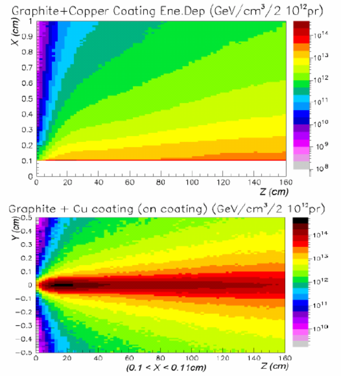
Observation:

450 GeV less critical for Graphite plate

450 GeV more critical for Cu support (larger impact area due to beam size)

Graphite plate must have more than 1 cm!





Input to ANSYS

Damage and Fatigue Analysis

Further cases under preparation: Slow losses and ions

Slow loss:

Uniform "emittance" blow-up

Beam lifetime: **0.2 h**

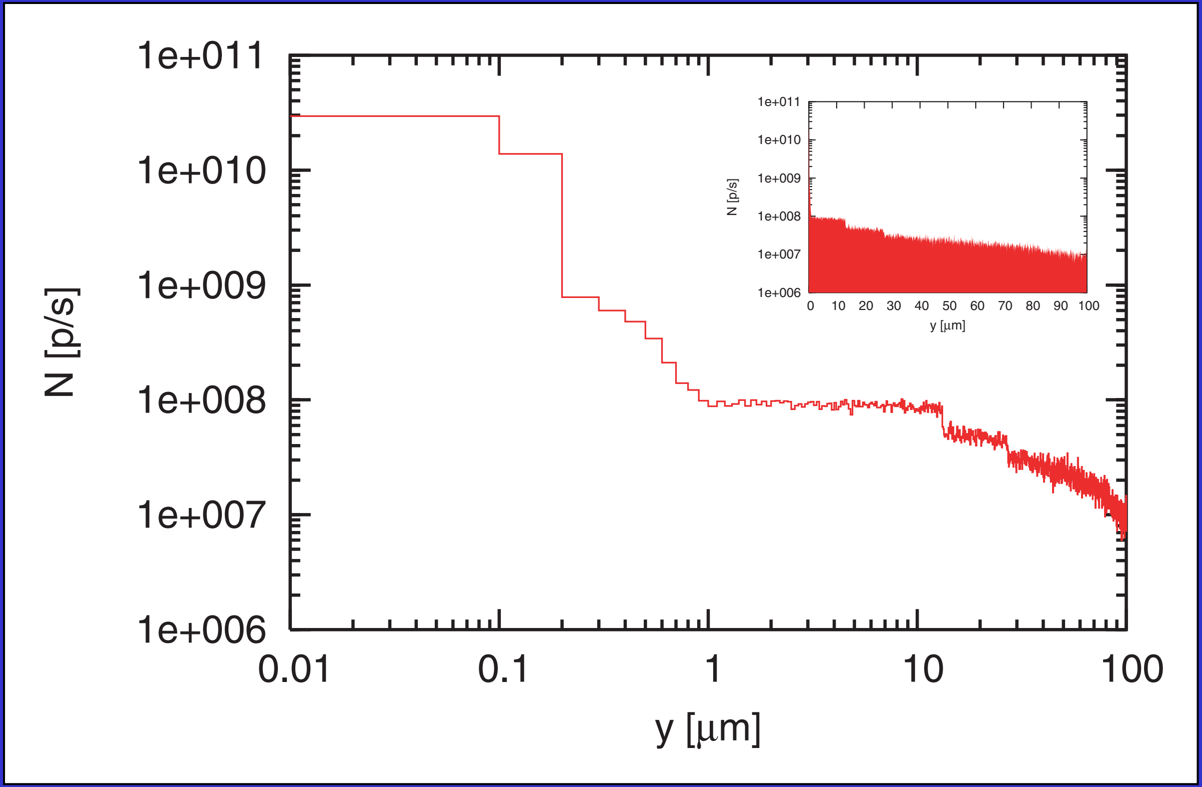
Loss rate: 4.1e11 p/s

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

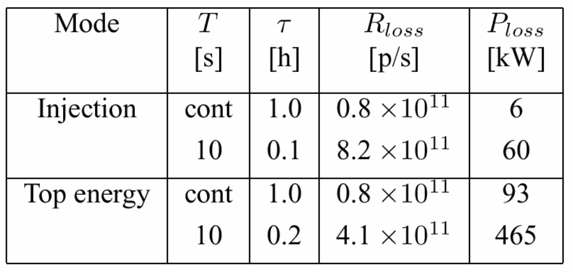
(~ 40 bunches)

Assume drift: 0.3 sig/s

5.3 nm/turn (sigma = 200 micron)



R. Assmann



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

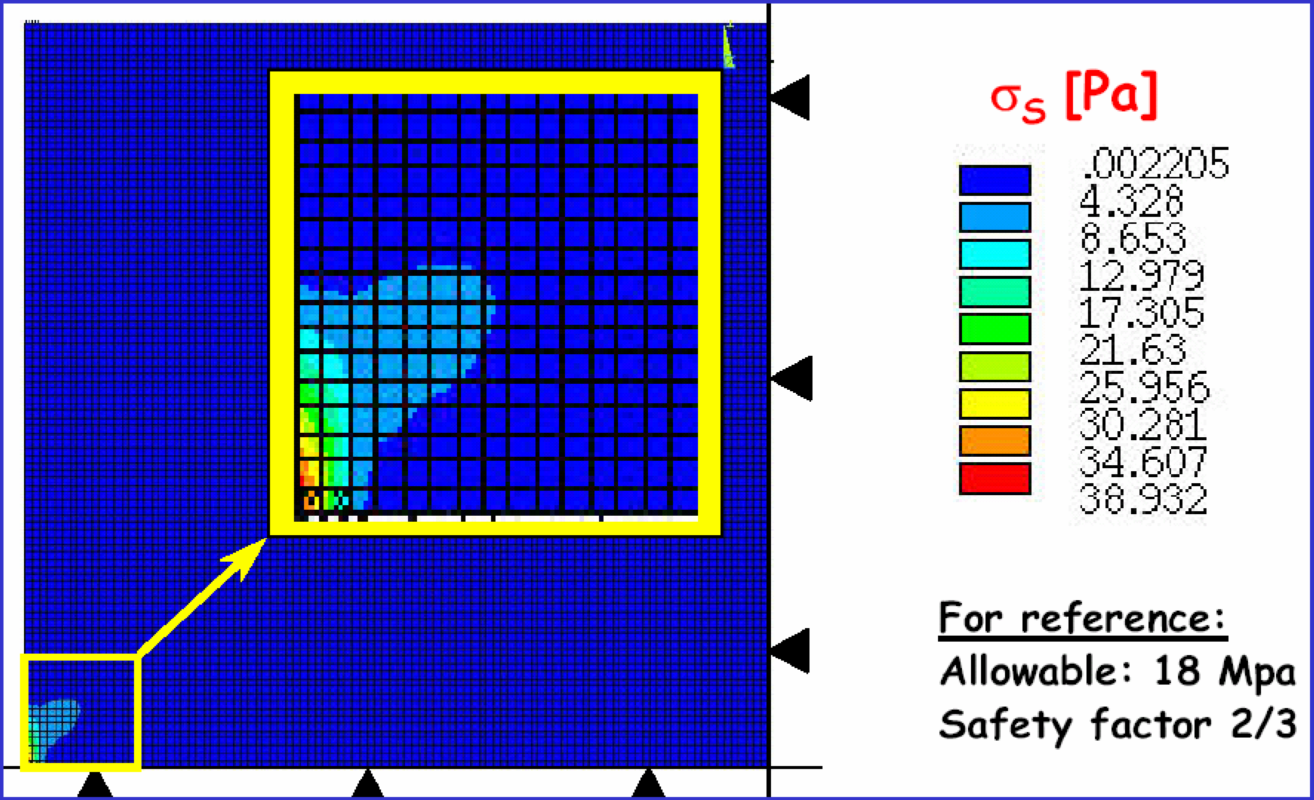
Transverse impact parameter

Almost all particles impact with

$y \leq 0.2$ µm

Surface phenomenon!

Stress analysis for 7 TeV 1 module pre-trigger



For reference:

Allowable: 18 Mpa

Safety factor 2/3

O. Aberle, L. Bruno

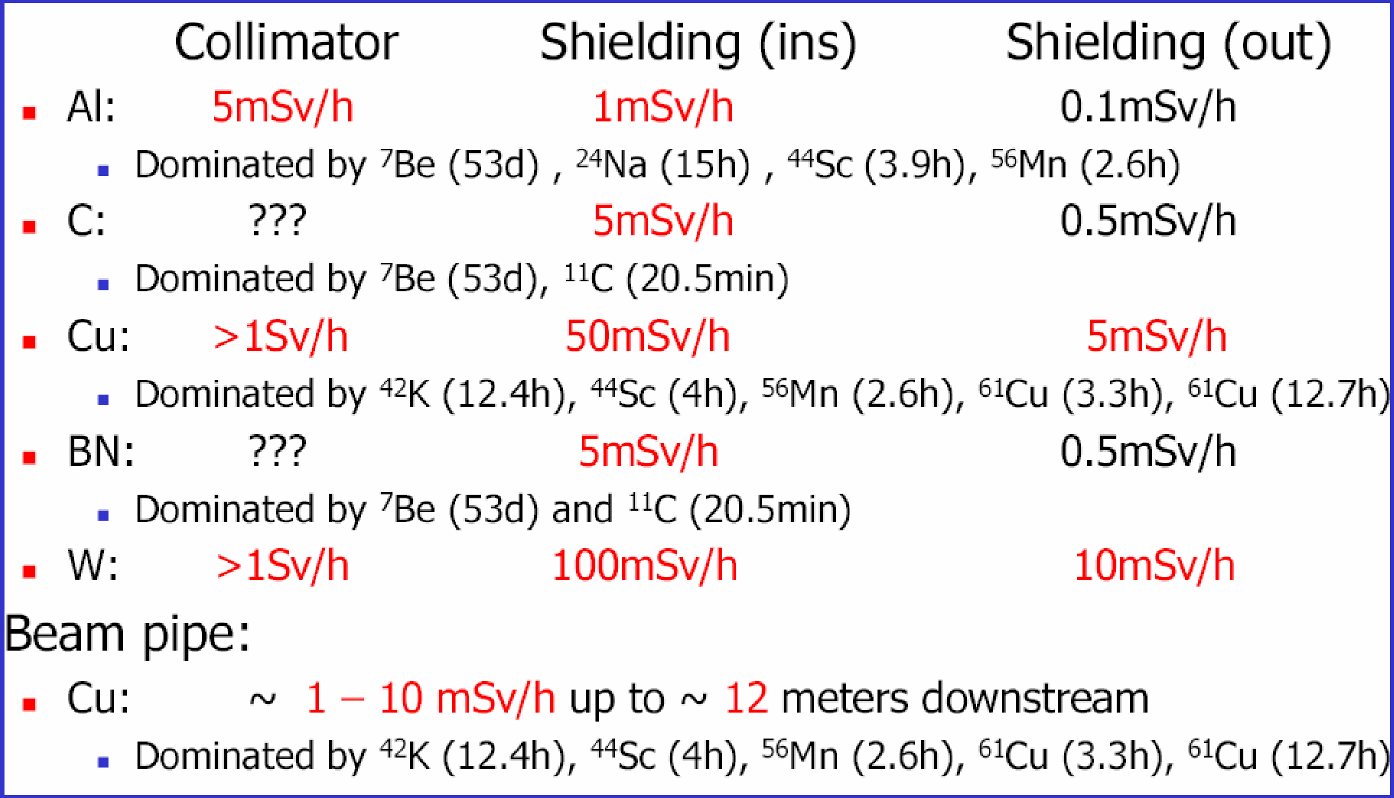
Calculated stress in simple Graphite about a **factor of 4 beyond** the allowable value!

This would almost be **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 seems not possible due to **large stress.**

Radiation studies for different materials (mock-up C collimation system)



	Collimator	Shielding (ins)	Shielding (out)
Al:	5mSv/h	1mSv/h	0.1mSv/h
Dominated by ^{7}Be (53d) , ^{24}Na (15h) , ^{44}Sc (3.9h), ^{56}Mn (2.6h)			
C:	???	5mSv/h	0.5mSv/h
Dominated by ^{7}Be (53d), ^{11}C (20.5min)			
Cu:	>1Sv/h	50mSv/h	5mSv/h
Dominated by ^{42}K (12.4h), ^{44}Sc (4h), ^{56}Mn (2.6h), ^{61}Cu (3.3h), ^{61}Cu (12.7h)			
BN:	???	5mSv/h	0.5mSv/h
Dominated by ^{7}Be (53d) and ^{11}C (20.5min)			
W:	>1Sv/h	100mSv/h	10mSv/h

Beam pipe:

- Cu: ~ 1 – 10 mSv/h up to ~ 12 meters downstream
  - Dominated by ^{42}K (12.4h), ^{44}Sc (4h), ^{56}Mn (2.6h), ^{61}Cu (3.3h), ^{61}Cu (12.7h)

M. Brugger, S. Roesler

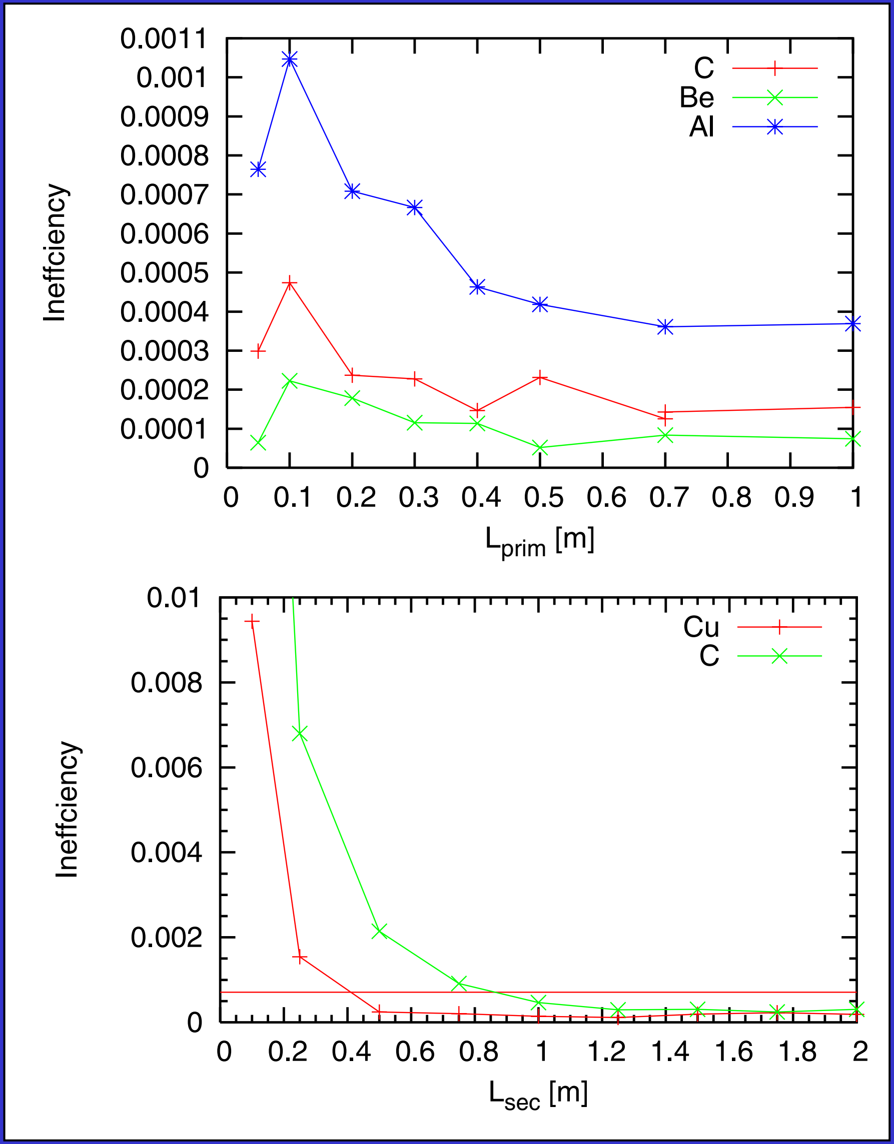
Low Z jaws are **less activated**.

Difficult **radiation environment**. *Interventions must be justified and optimized (> 100 µSv/h).*

Remote handling requirements are relaxed but still worrying.

More activation downstream!

Required lengths of low Z jaws:



R. Assmann, J.B. Jeanneret

1) Keep secondaries (0.5 m Cu) and vary material and length of primary collimators!

Observations:
Win factor two for 0.2 m graphite (C)!
Stay with 0.2 m length for primary

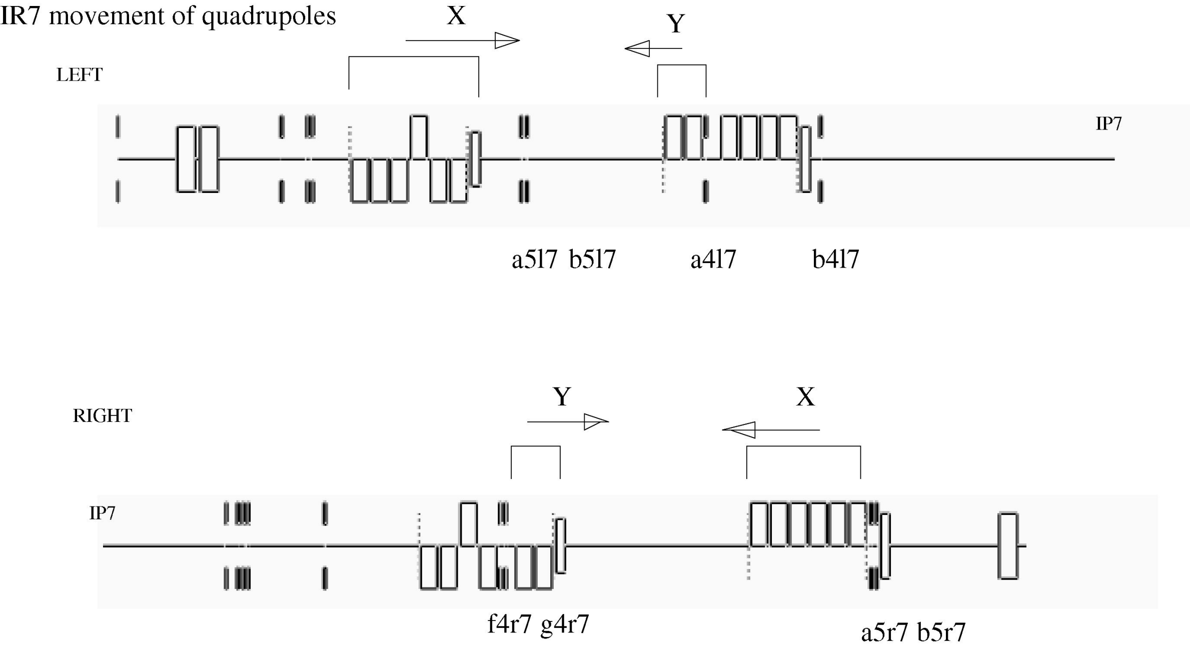
2) Choose 0.2 m C for primary collimators and vary material and length of secondary collimators!

Observations:
Secondary C collimators of 1 m length will restore the cleaning efficiency of the old system.

C system: 0.2 m and 1.0 m jaws!

Space for longer jaws in the cleaning insertions:

D. Kaltchev, TRIUMF



Two moves of groups of quadrupoles to provide space for longer jaws.

X is actually not needed, if f4r7 and g4r7 are simply shifted to the right ..

Y makes space for longer a5r7 and b5r7

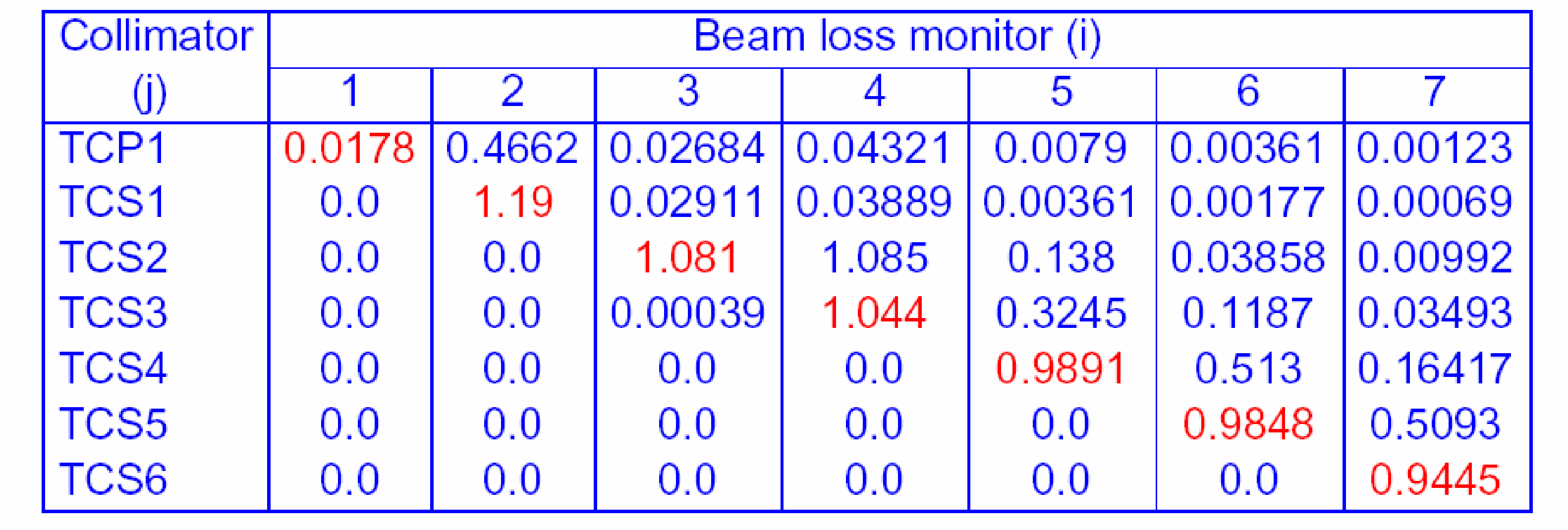
DJ result for delta=0:

	tunes0	tunes0	0.001	same tunes0
X , Y [m] =	0 , 0	1 , 2	0 , 2	0 , 2
Amax	9.22	9.24	9.15	9.37
Ax,max	7	7.13	7.1	7.1
Ay,max	7.1	7.23	7.15	7.17

Preliminary re-match done for up to 2 m quadrupole movements in IR7 (allowing for 1 m C jaws). Maximum escaping amplitude **almost maintained**.

Showering studies for BLM system (mock-up C collimation system)

Question: What do the BLM signals measure?
Can the BLM signals be used to tune the collimator settings?



Collimator (j)	Beam loss monitor (i)						
	1	2	3	4	5	6	7
TCP1	0.0178	0.4662	0.02684	0.04321	0.0079	0.00361	0.00123
TCS1	0.0	1.19	0.02911	0.03889	0.00361	0.00177	0.00069
TCS2	0.0	0.0	1.081	1.085	0.138	0.03858	0.00992
TCS3	0.0	0.0	0.00039	1.044	0.3245	0.1187	0.03493
TCS4	0.0	0.0	0.0	0.0	0.9891	0.513	0.16417
TCS5	0.0	0.0	0.0	0.0	0.0	0.9848	0.5093
TCS6	0.0	0.0	0.0	0.0	0.0	0.0	0.9445

I. Kouroutchikov (IHEP), B. Dehning, J.B. Jeanneret

Non-diagonal response matrix of the BLM system for the collimation system in IR7.

Good decoupling for the two beams.

Non-trivial tuning of collimator settings with BLM’s.

Further studies ongoing (response to settings, operational conditions, …).

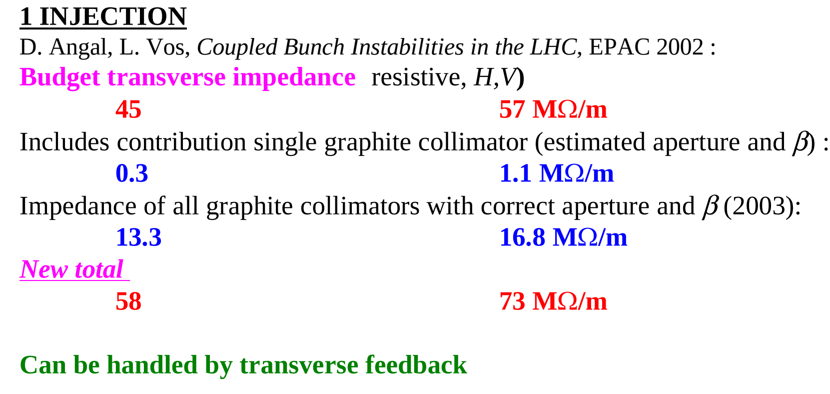
Can we use a C-based system for the LHC?

Results show that Graphite looks promising (required robustness at reach with a factor ~4 missing)…

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

$$\begin{aligned}\frac{Z_\perp^{\mathrm{coll}}}{Z_\perp^{\mathrm{arc}}} &\sim \frac{(L^{\mathrm{coll}}/L^{\mathrm{arc}}) \times \sqrt{\rho^{\mathrm{coll}}/\rho^{\mathrm{arc}}}}{(a^{\mathrm{coll}}/a^{\mathrm{arc}})^3} \sim \\ &\sim \frac{(20\,\mathrm{m}/20\,\mathrm{km}) \times \sqrt{\mathrm{RRR} \sim 30}}{(1.8\,\mathrm{mm}/18\,\mathrm{mm})^3} \sim \\ &\sim \frac{10^{-3} \times 5}{10^{-3}} \sim 5!\end{aligned}$$

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**

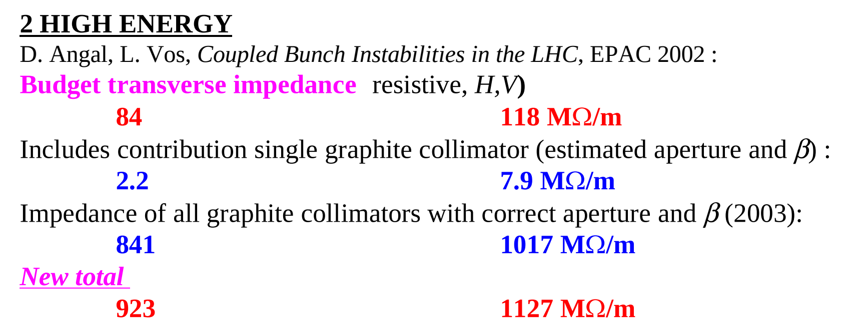
Impedance of all graphite collimators with correct aperture and *β* (2003):

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**

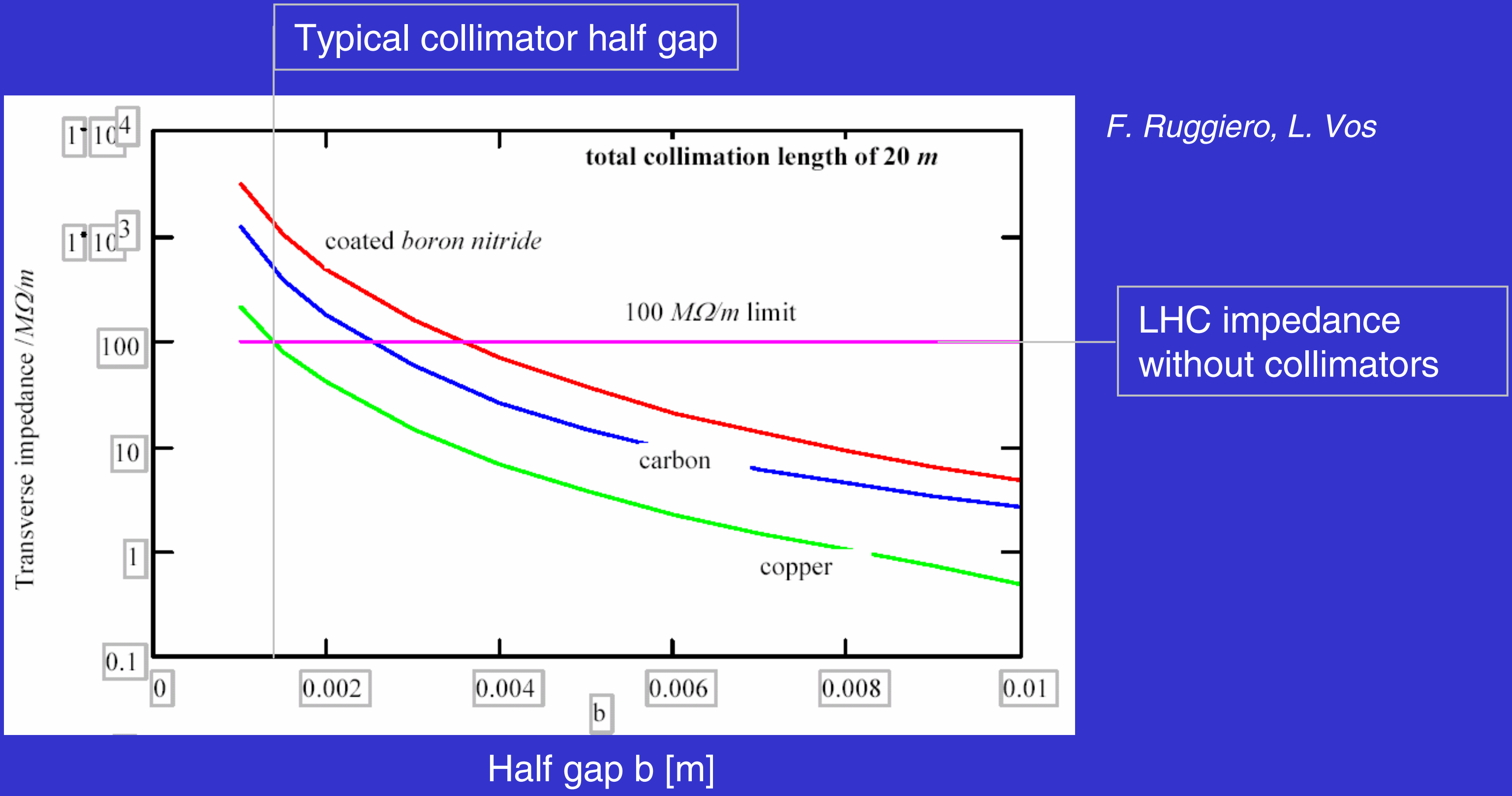
New total

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:



F. Ruggiero, L. Vos

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!

IV. Outlook

Beam impact requirements analyzed (failure modes and operational requirements) for a robust and efficient LHC collimation system! Tolerances established.

Detailed engineering design has started: appropriate materials (low Z), lengths, mechanics, cooling, damage and fatigue analysis, tolerances, …

Additional concerns are studied: Impedance, vacuum, local e-cloud, radiation impact.

Concentrating for now on a low-Z system based on Graphite (simplest solution):

- *Required robustness at reach (factor ~4 missing)!*
- *Jaw lengths remain quite reasonable!*
- *Space is available and optics can be re-matched!*
- *Activation is reduced and collimator remote handling requirements are somewhat relaxed!*
- *Vacuum group does not rule out C!*
- *Resistive impedance is large, consequences are under study (feedback)!*

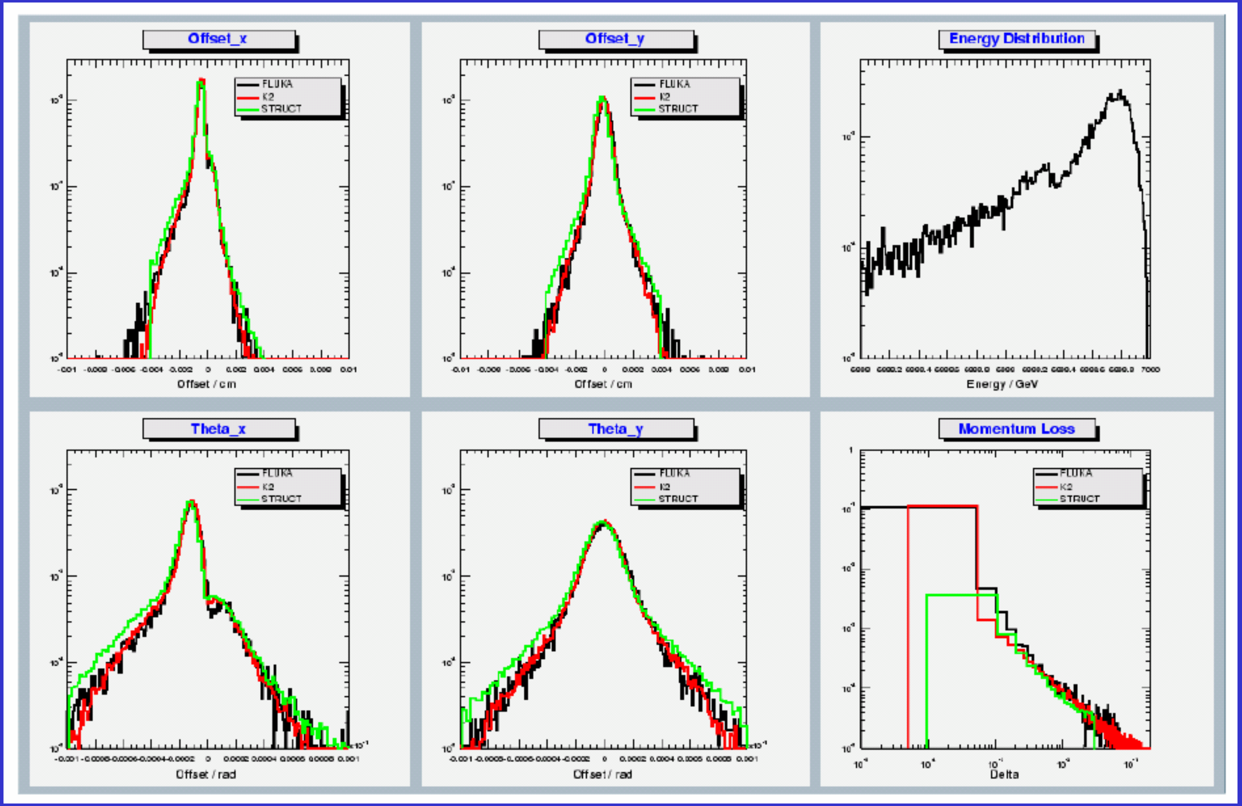
If this system is not feasible other solutions will be studied:

- *Low-Z system based on Beryllium (seems not easily feasible).*
- *Tertiary collimators at triplets to allow opening secondary collimators.*
- *Short high-Z jaws with easy remote diagnostics and repair/exchange. They could be damaged frequently.*
- *…*

Additional slides

Other supporting activities:

Work on numerical tools. Establish systematic errors.



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

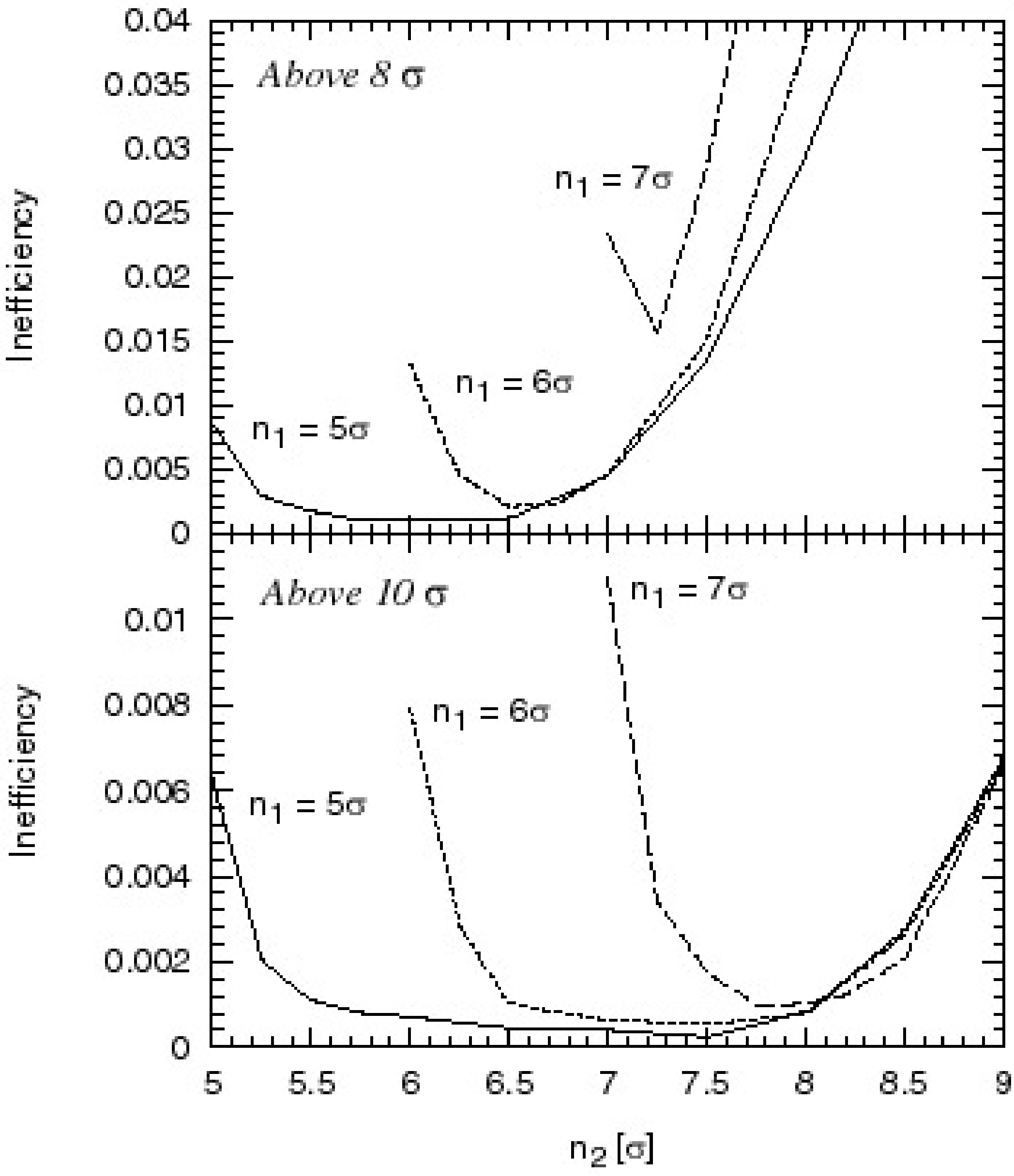
Collimator scattering and tracking with collimators in SIXTRACK:

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

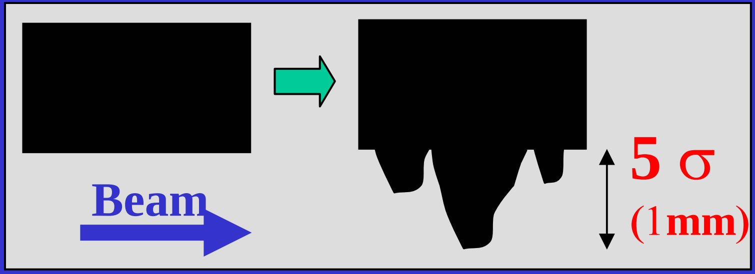
Error	Tolerance
Orbit	0.6 σ
Beta beat	8%
Longitudinal angle	50 μrad
$\Delta L/L$ (prim)	75%
Surface flatness (prim)	10 μm
$\Delta L/L$ (sec)	20%
Surface flatness (sec)	25 μm
Setting accuracy (prim)	-1.0/+0.5 σ
Setting accuracy (sec)	$\geq \pm 0.5\ \sigma$

Preliminary estimates:

Combined effect can make tolerances more severe!

Collimators need not only be robust, but also precise!

HERA experience:



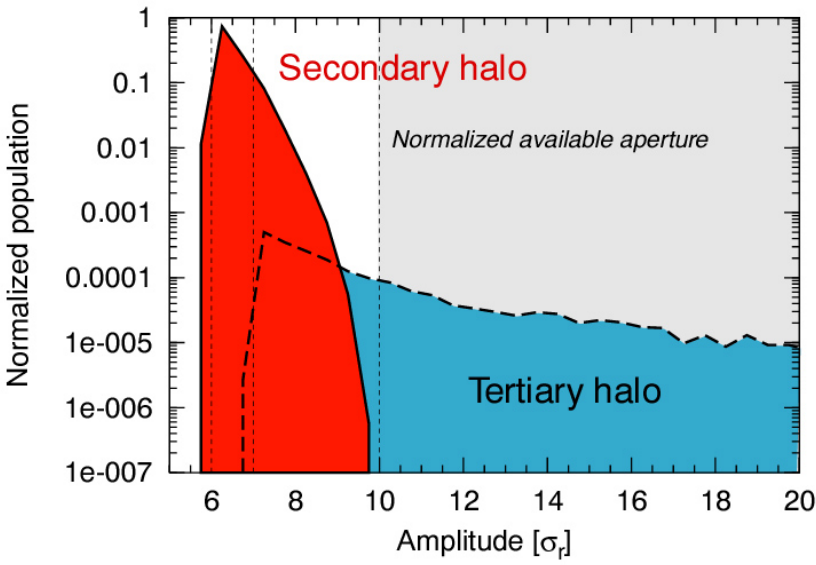
Set-up of tools, thinking about operation started

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)

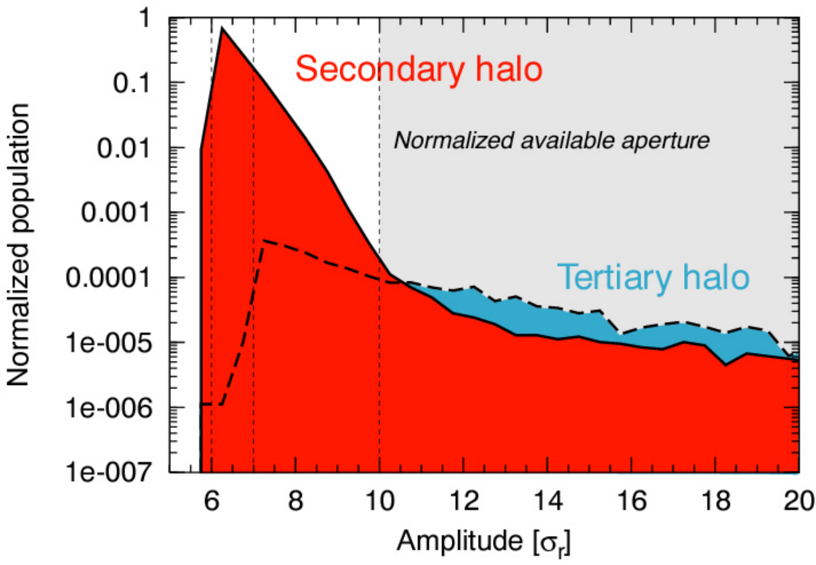
Secondary and tertiary beam halos



Scattering in collimator jaws (at 6/7 σ)

Transverse scattering angles
+ momentum loss

Halo at zero dispersion



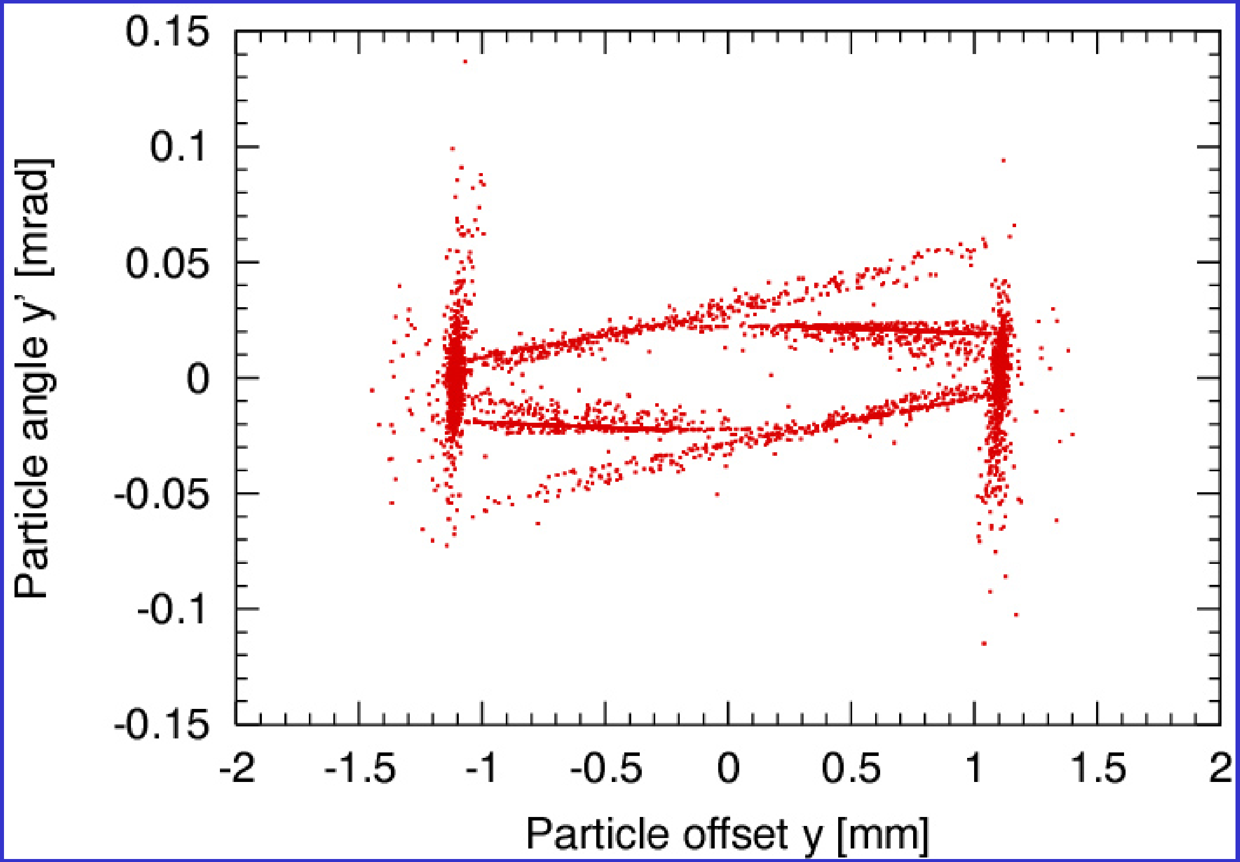
Halo at max dispersion

Local inefficiency [1/m]:

Integrate halos above 10σ

Divide by dilution length (50 m)

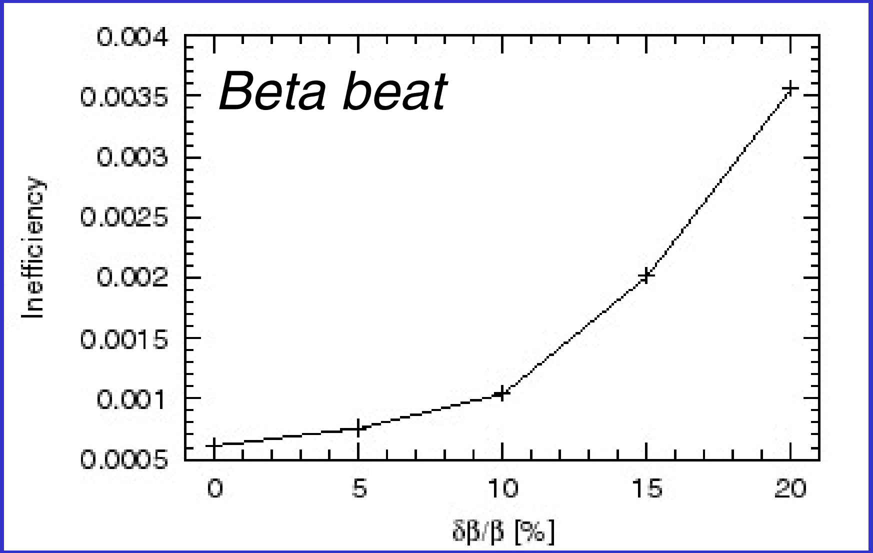
Tertiary halo in phase space

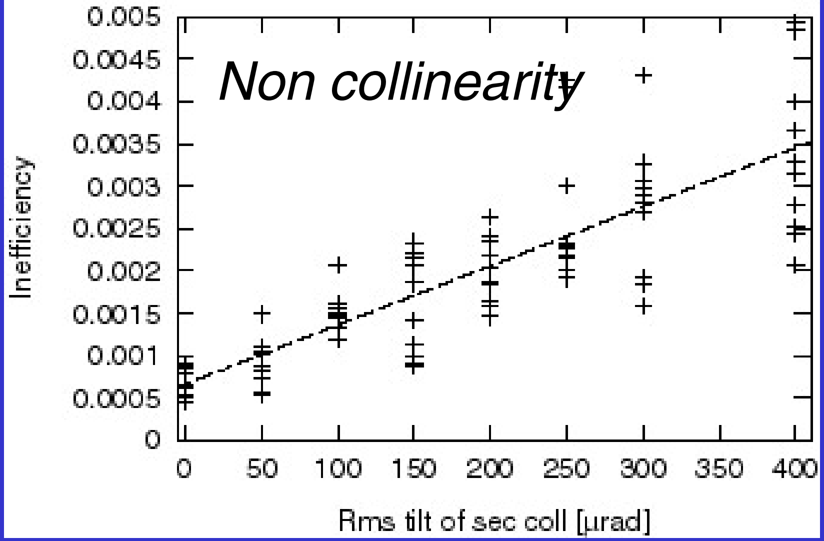


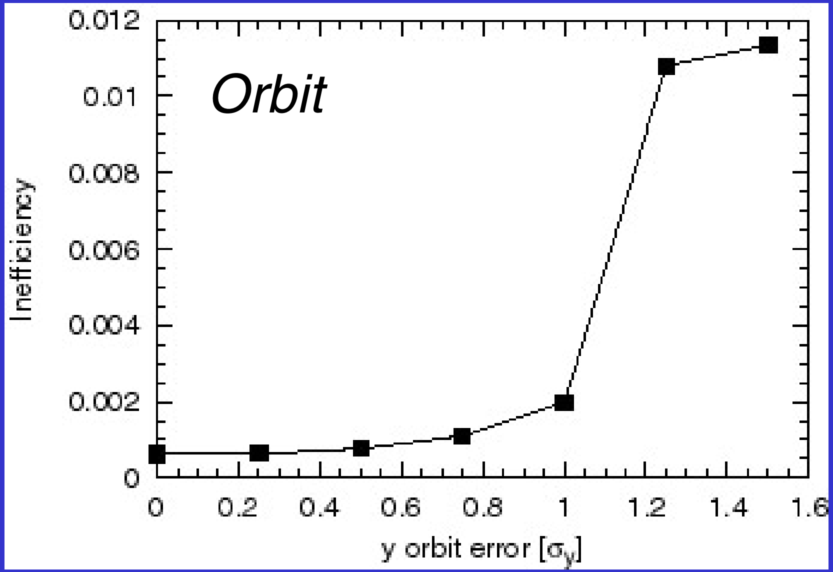
Halo generated at specific phase space locations!

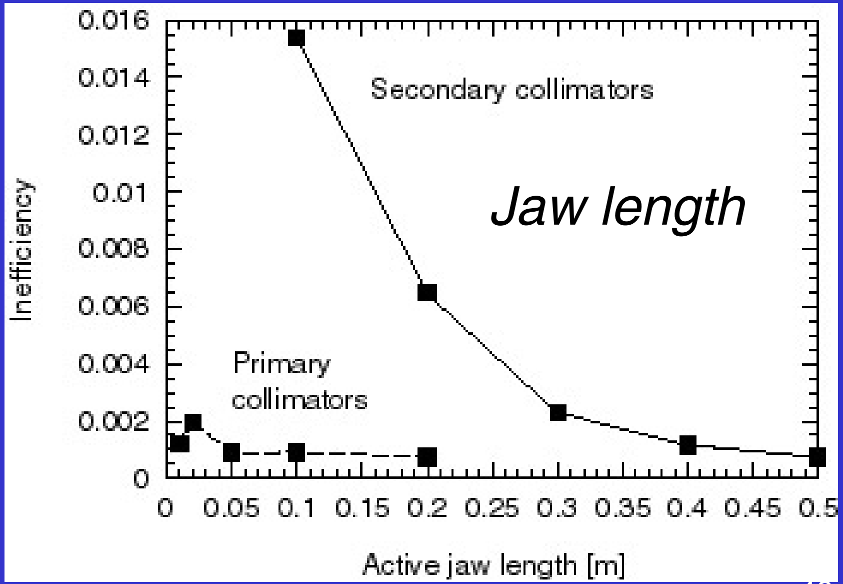
Input to studies of **local loss distribution** (dilution, expected signals of Beam Loss Monitors BLM).

Inefficiency versus imperfections

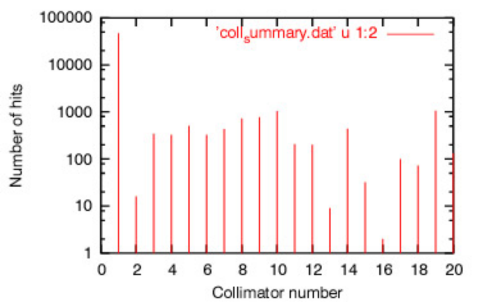


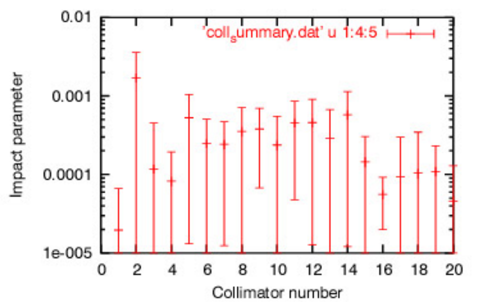


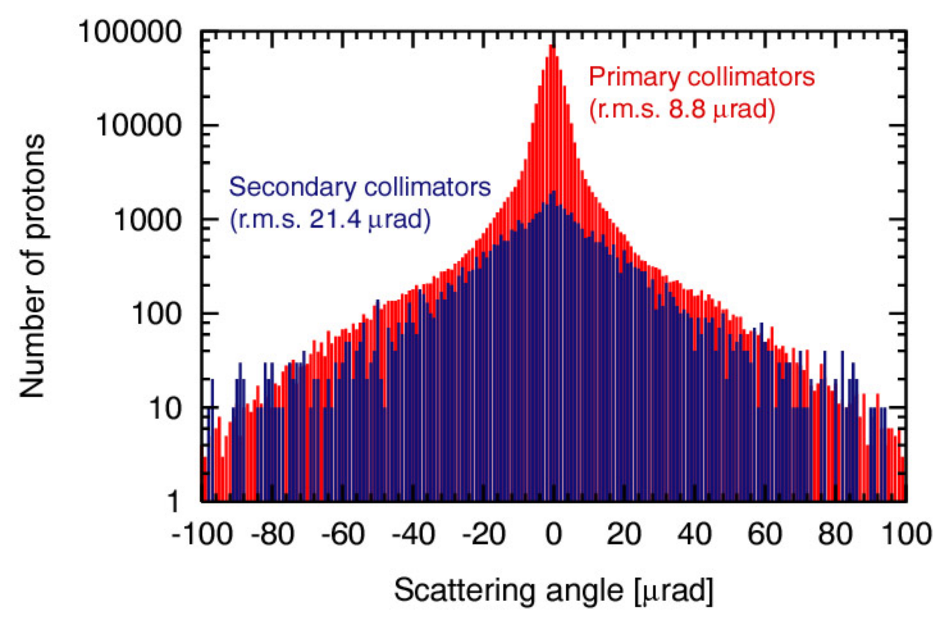


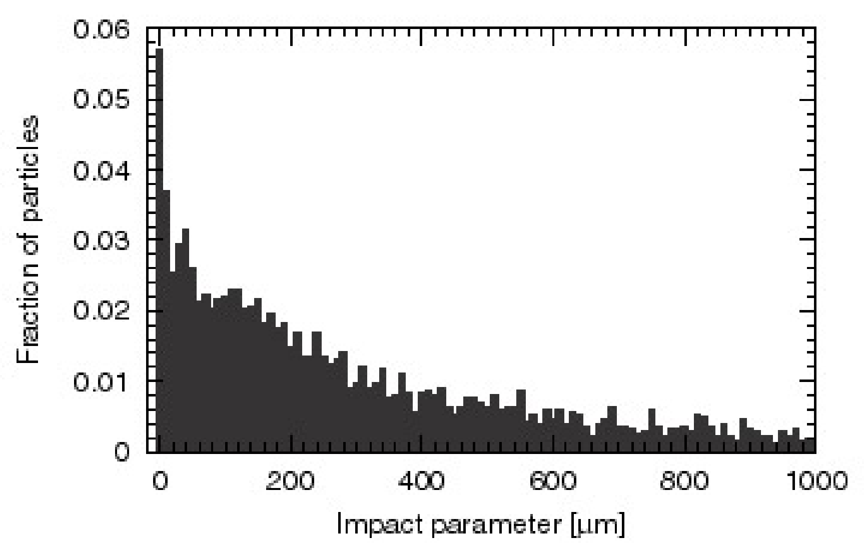


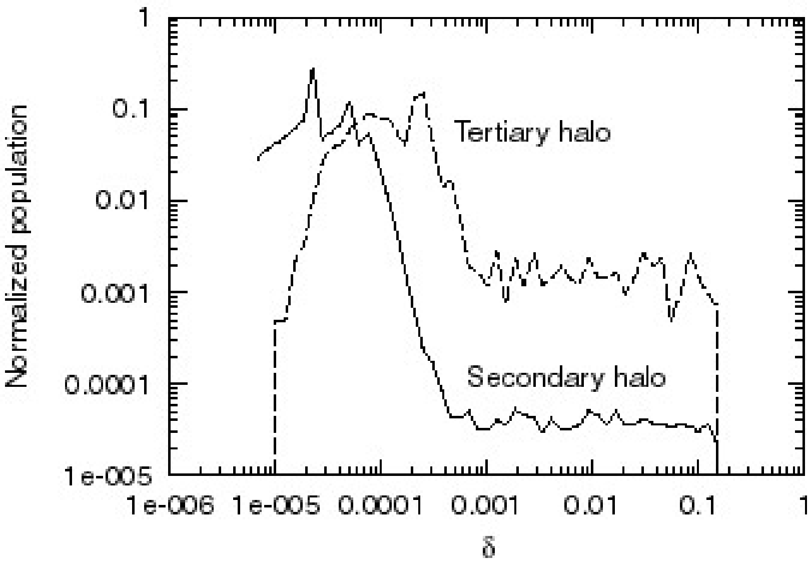
Scattering physics



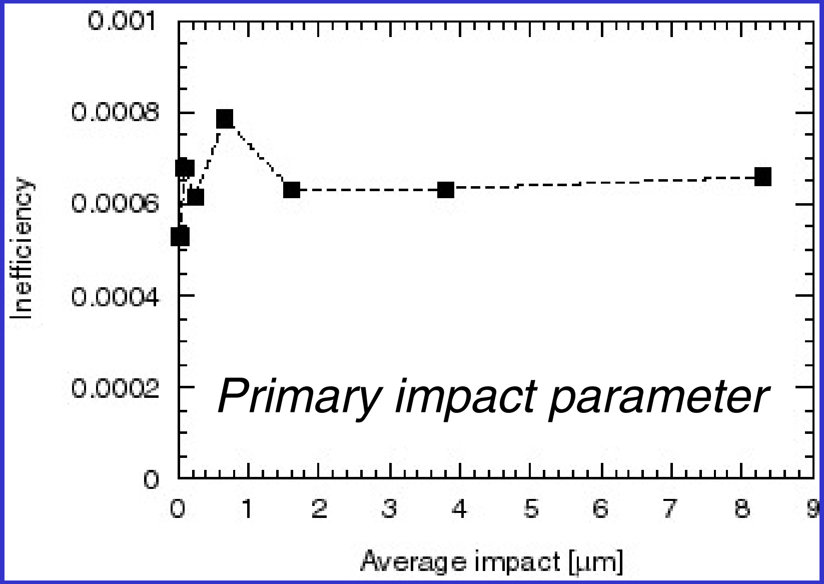




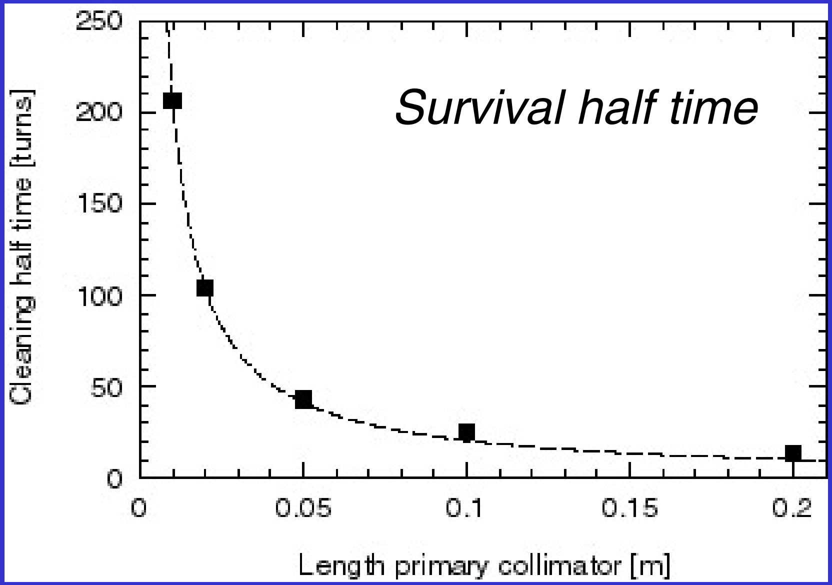




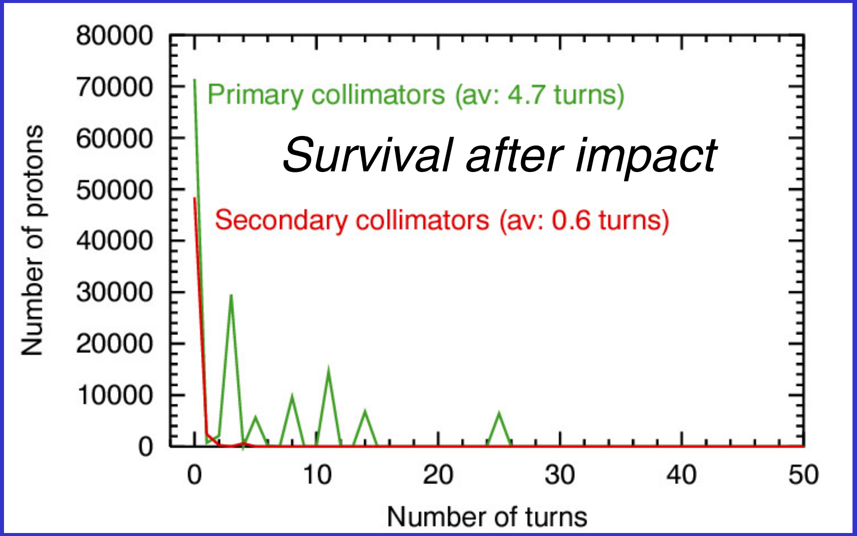
Multi-turn properties and impact parameter



Primary impact parameter



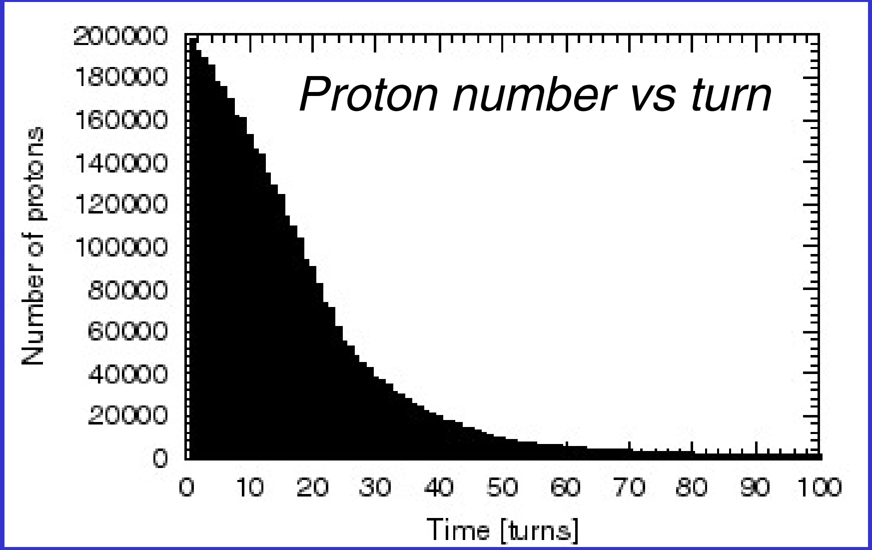
Survival half time



Survival after impact

Primary collimators (av: 4.7 turns)

Secondary collimators (av: 0.6 turns)



Proton number vs turn

Super-Conducting Environment

Proton losses into cold aperture

⇩

Local heat deposition

⇩

Magnet can quench

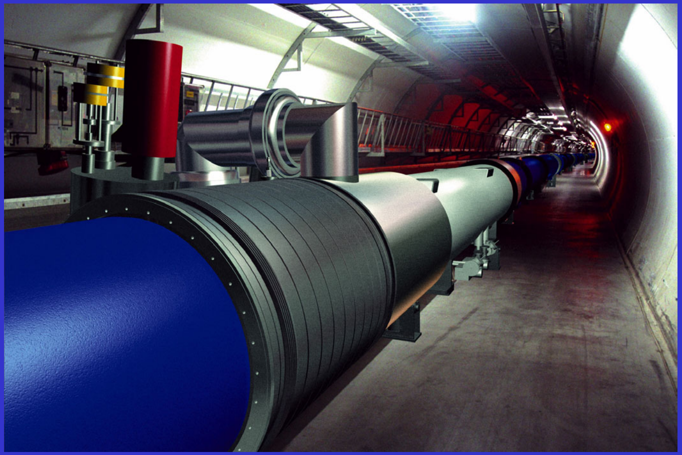


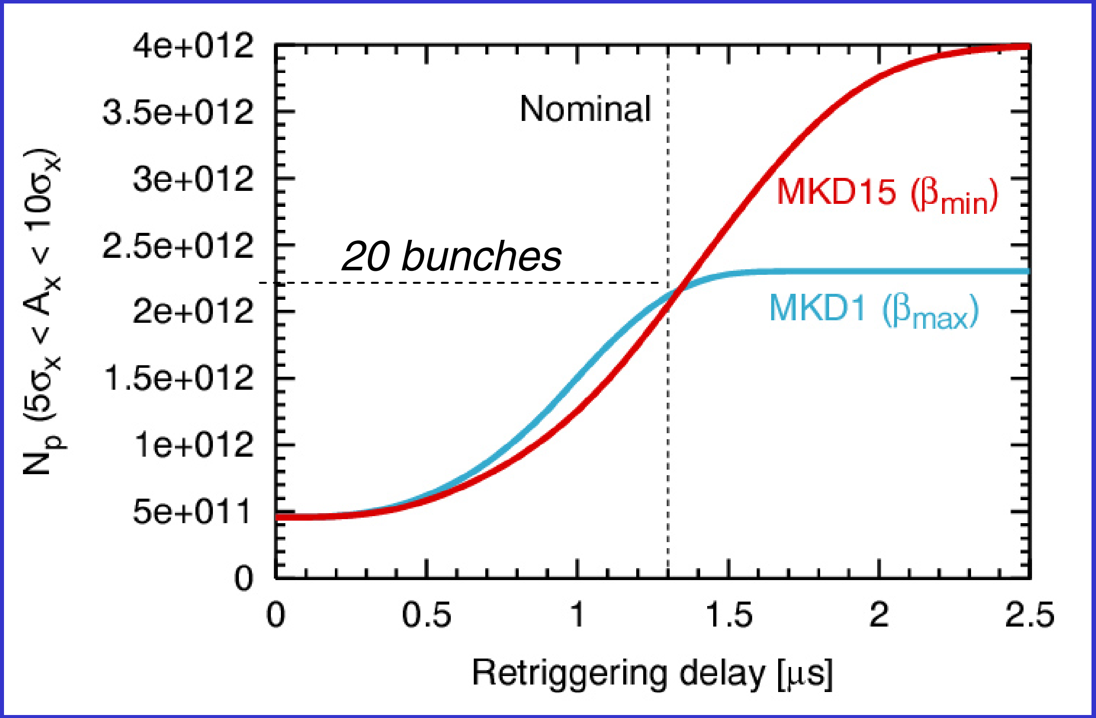
Illustration of LHC dipole in tunnel

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?



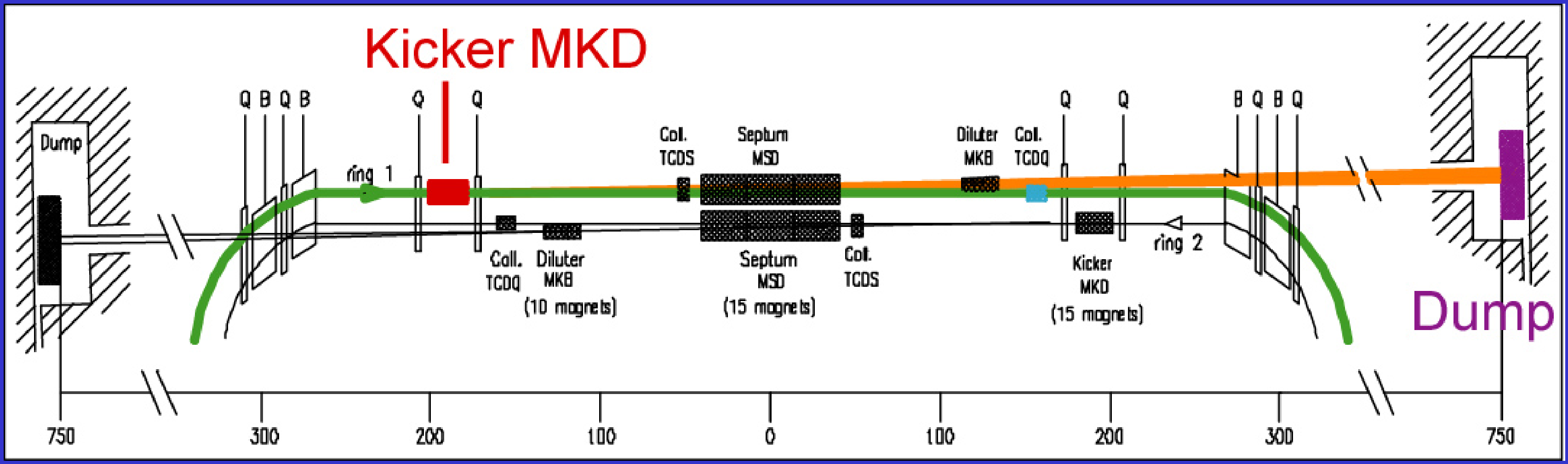
One module pre-fire depends on details of dump kicker design (pulse form, number of magnets, re-trigger design)!

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

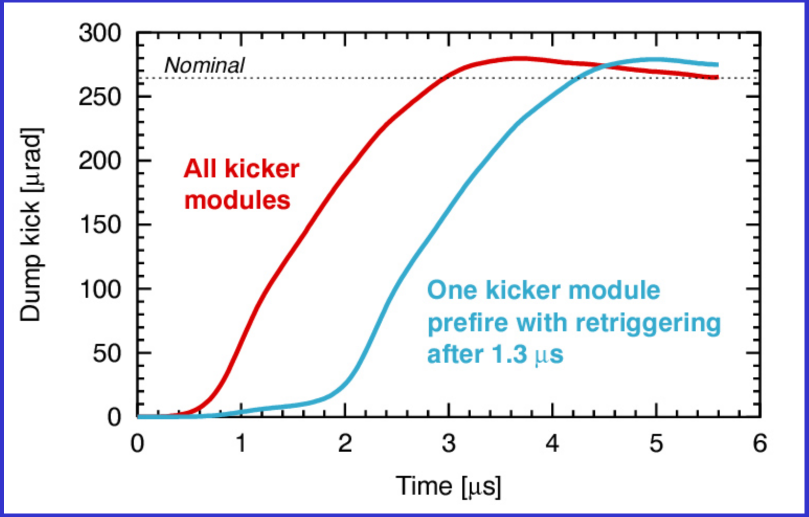
Collimators should withstand this impact without damage!

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

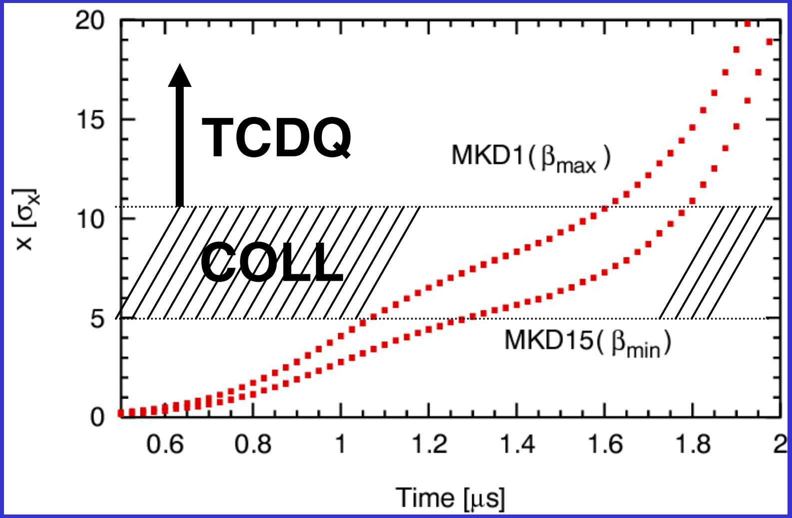
Abnormal dump actions



Kick [μrad]



Downstream offset [σ]



One module pre-fire

References

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).

CERN-LHC-PROJECT-REPORT-598: EFFICIENCY FOR THE IMPERFECT LHC COLLIMATION SYSTEM.

By R.W. Assmann, J.B. Jeanneret, D. Kaltchev (CERN & TRIUMF).

CERN-LHC-PROJECT-REPORT-592: EQUILIBRIUM BEAM DISTRIBUTION AND HALO IN THE LHC. By R. Assmann, F. Schmidt, F. Zimmermann, M.P. Zorzano (CERN & I.N.T.A.).

CERN-LHC-PROJECT-REPORT-589: TIME DEPENDENT SUPERCONDUCTING MAGNETIC ERRORS AND THEIR EFFECT ON THE BEAM DYNAMICS AT THE LHC. By R. Assmann, S. Fartoukh, M. Hayes, J. Wenninger (CERN).

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)

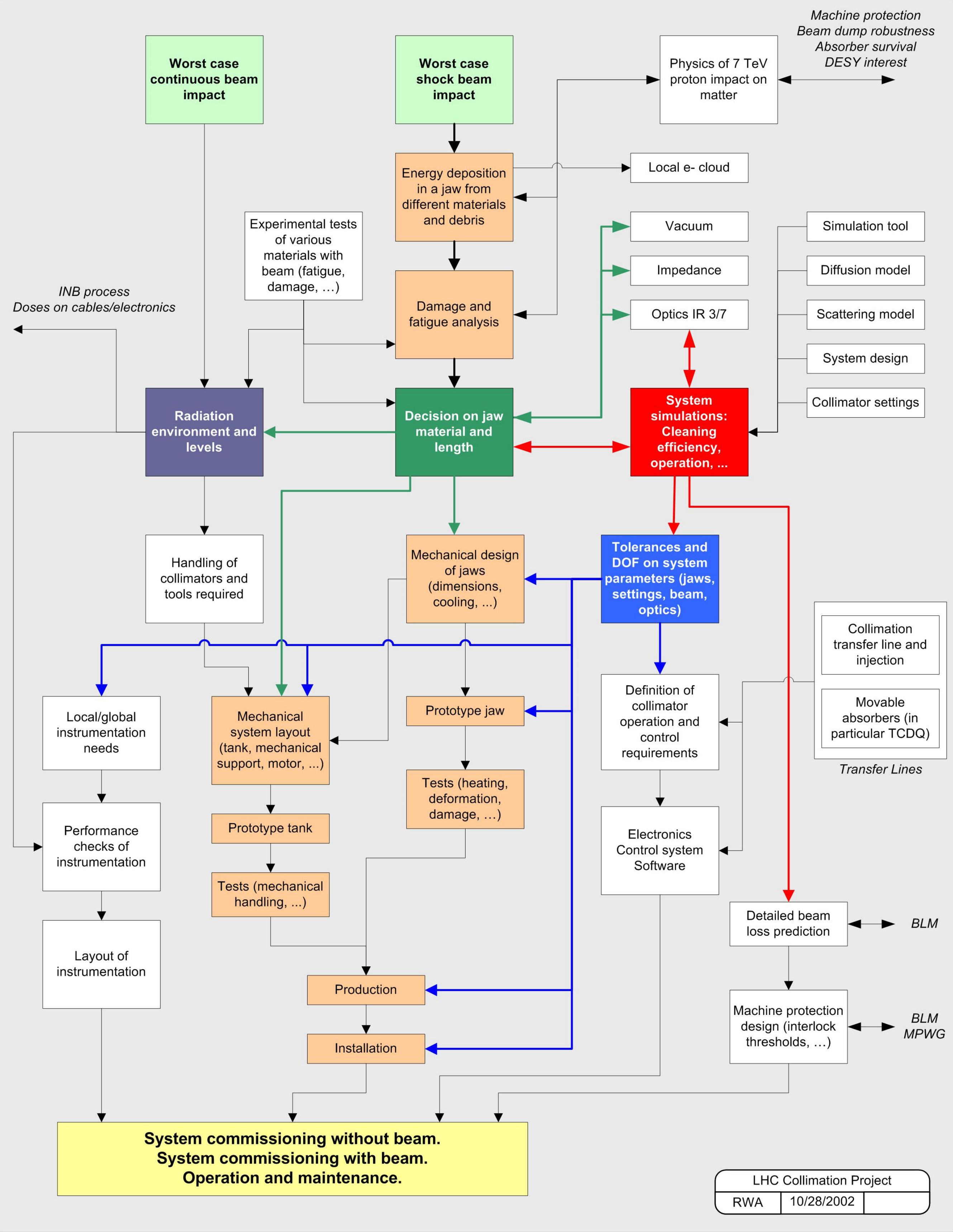
LHC-PROJECT-NOTE-282: Summary of the CERN Meeting on Absorbers and Collimators for the LHC *by:* Assmann, R ; Fischer, C ; Jeanneret, J B ; Schmidt, R ; (2002)

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.



Worst case continuous beam impact

Worst case shock beam impact

Physics of 7 TeV proton impact on matter

Machine protection
Beam dump robustness
Absorber survival
DESY interest

Energy deposition in a jaw from different materials and debris

Local e- cloud

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

Damage and fatigue analysis

Vacuum

Impedance

Optics IR 3/7

Simulation tool

Diffusion model

Scattering model

System design

Collimator settings

INB process
Doses on cables/electronics

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, …)

Performance checks of instrumentation

Prototype tank

Electronics Control system Software

Tests (mechanical handling, ...)

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