Proceedings of the CERN Meeting on Absorbers and Collimators for the LHC

January 25th, 2002 at CERN

G. Arduini, R. Assmann, D. Brandt, L. Bruno, H. Burkhardt, C. Fischer,
B. Goddard, C. Hauviller, N. Hilleret, J.B. Jeanneret, R. Jung,
R. Schmidt, H. Schönauer, P. Sievers, G. Stevenson

The proceedings of the LHC collimation day contain copies of the talks presented plus preliminary conclusions as presented at the LHC Commissioning Committee. A detailed written summary of the meeting is under preparation. The meeting was jointly organized by R. Assmann, J.B. Jeanneret, C. Fischer, and R. Schmidt.

List of participants:

G. Arduini, R. Assmann, I. Baishev, D. Brandt, M. Brugger, L. Bruno, H. Burkhardt, E. Chiaveri, B. Dehning, L. Evans, A. Ferrari, C. Fischer, B. Goddard, E. Gschwendtner, C. Hauviller, W. Herr, N. Hilleret, G. von Holtey, J.B. Jeanneret, J. Jowett, R. Jung, J.P. Koutchouk, T. Kurtyka, M. Lamont, J. Lettry, V. Maire, M.S. Merce, V. Mertens, S. Myers, S. Redaelli, T. Risselada, S. Roesler, F. Ruggiero, R. Schmidt, H. Schoenauer, P. Sievers, G. Stevenson, R. Veness, A. Verdier, J. Wenninger, F. Zimmermann

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CERN Meeting on Absorbers and Collimators for the LHC Beam on 25.1.02

Preliminary Summary

R. Assmann, SL/AP

Complete summary being prepared by R. Assmann, C. Fischer, J.B. Jeanneret, R. Schmidt (meeting yesterday).

Goals:

- Bring together the CERN expertise on collimators and absorbers.
- Confront the requirements with this expertise.
- Collect ideas on solutions and most urgent studies.

Part of the activity of the LHC Beam Cleaning Study Group.

Our input:

LHC Project Note 277

January 24, 2002

Ralph.Assmann@cern.ch

Preliminary Beam-based Specifications for the LHC Collimators

R. Aßmann, I. Baishev, M. Brugger, H. Burkhardt, G. Burtin, B. Dehning, S. Fartoukh, C. Fischer, E. Gschwendtner, M. Hayes, J.B. Jeanneret, R. Jung, V. Kain, D. Kaltchev, M. Lamont, R. Schmidt, J. Wenninger

Keywords: Collimation, Beam Loss, Machine Protection

Expertise from SL/AP, SL/BI, SL/OP, AC/TCP, TIS/RP, and collaborators.

Response to our initiative: **Strong interest and support**

(~ 45-50 participants)

We asked for: **Short talks (5-15 min) for quick summary of relevant experience and knowledge.**

Great support from CERN experts… (all agreed to give a talk)

20 talks ranging from the ISR …

… over the Booster, ISOLDE, SPS, LEP…

… to the LHC.

- *Requirements from the Beam Cleaning SG, Machine Protection, impedance, vacuum.*
- *Materials (from Be, C to fiber reinforced ceramics, Boron Nitride). Beryllium OK?!*
- *Technical solutions for handling the LHC beam for injection and dump.*
- *Experience with damage and fatigue.*
- *Computer tools.*
- *Possibilities for experimental tests.*

Talks will be put on web. **Valuable archive of CERN expertise…**

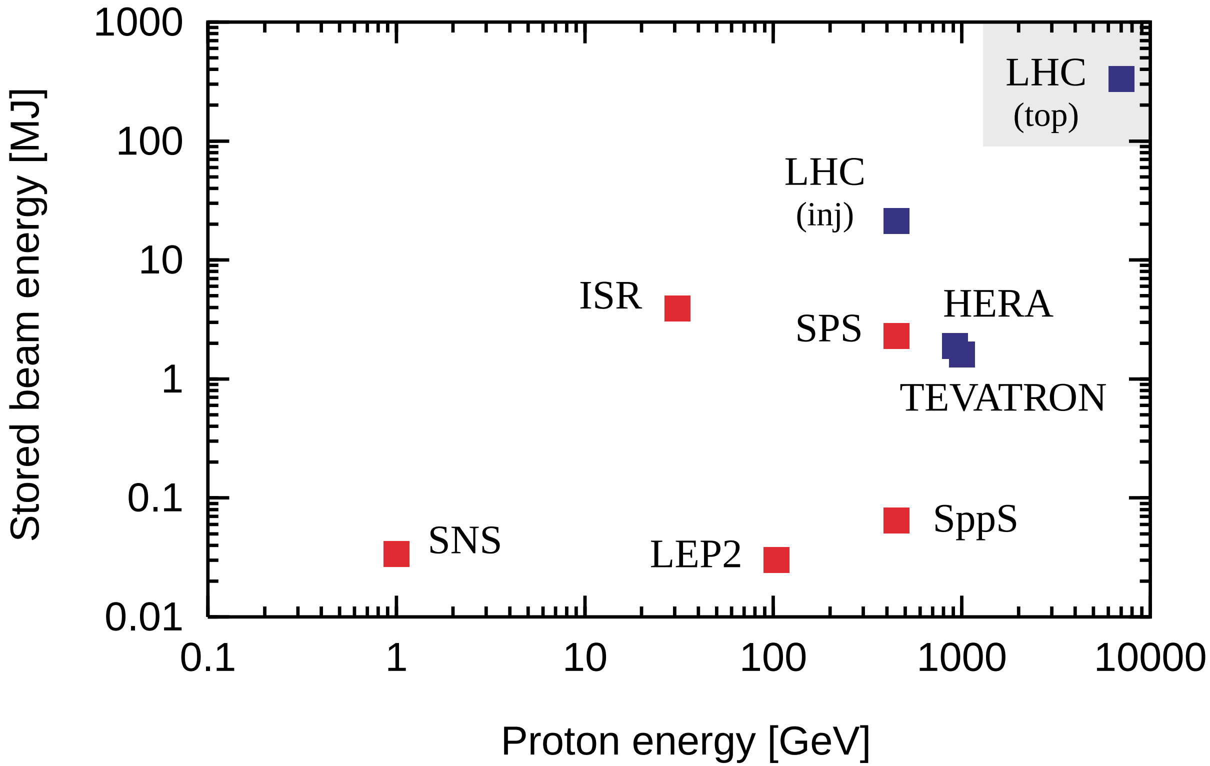
The Challenge:

Talks explaining the challenge and the specific requirements:

J.B. Jeanneret
R. Schmidt
C. Fischer
R. Assmann

Complemented by talks on impedance and vacuum issues:

D. Brandt
N. Hilleret



Step from previous accelerators:

Factor 7	in proton energy
Factor 100	in stored beam energy

The powerful LHC beam must be handled in sensitive super-conducting environment!

Beam and Power Deposition During Regular Operation:

Relax with slower ramp!

Lifetime reductions during machine cycle (ramp, squeeze, …) and tuning…

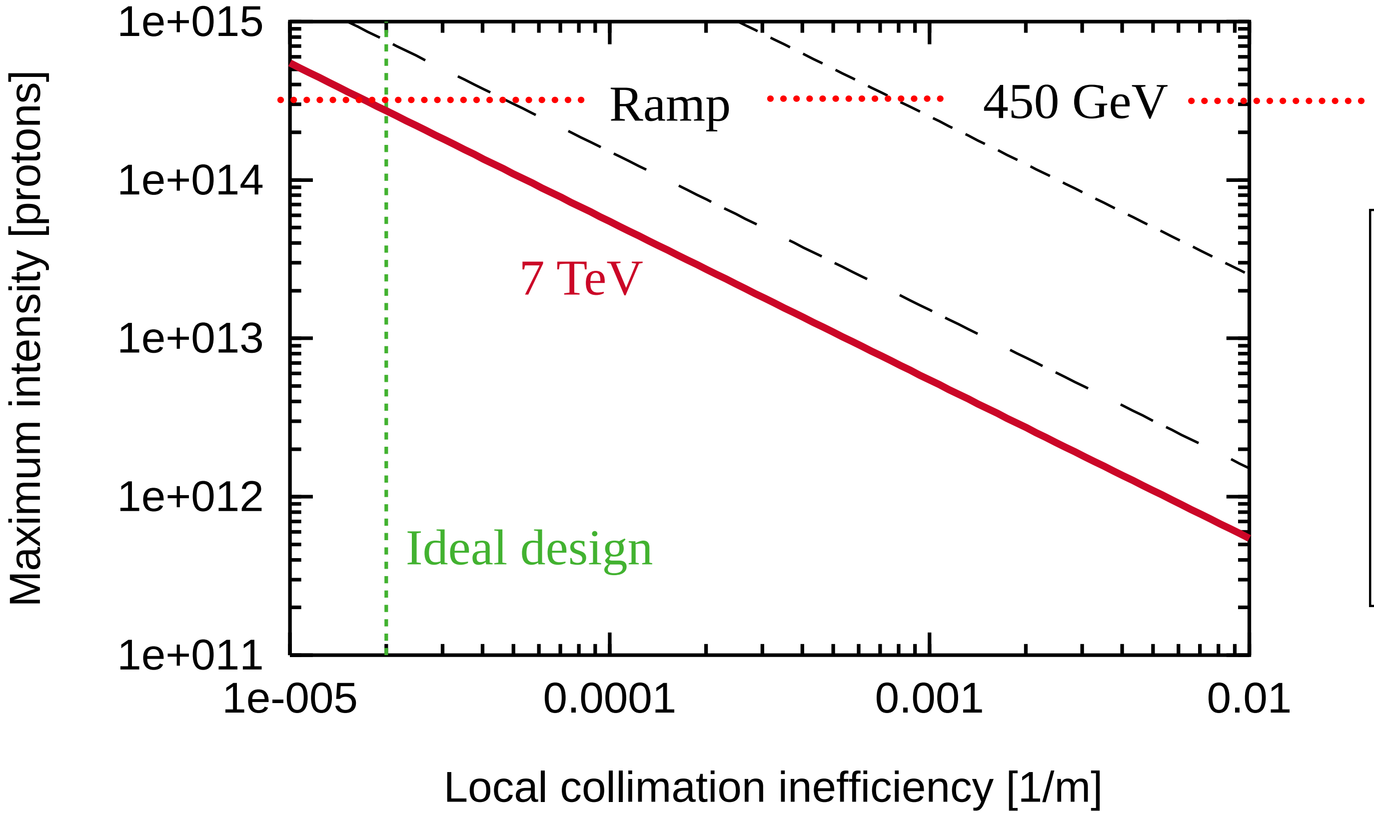
Mode	Energy [TeV]	Duration [s]	Req. min. lifetime [h]	Beam deposition [protons/s]	Power deposition [kW]
Injection	0.45	cont	1.0	0.8×10^{11}	6
		10	0.1	8.2×10^{11}	60
Ramp	0.45-7.00	10	0.1-0.2	$8.2\text{-}4.1 \times 10^{11}$	60-465
	0.45	≈ 1	0.006	1.3×10^{13}	1000
Top energy	7.00	cont	1.0	0.8×10^{11}	93
		10	0.2	4.1×10^{11}	465

Most severe: Top energy (up to 0.5 MW) to be absorbed in collimators and down-stream material. Dump beam below 0.2 h (top).

Ensure: Keep tolerance for collimation efficiency **(~ 100 μm flatness)**. (important DIFFERENCE to BT absorbers)

Cleaning Efficiency:

Quench levels of magnets require **excellent cleaning of beam halo** from injection all the way to top energy.



Maximum Intensity
(for a beam lifetime of 0.2 h at the quench limit)

versus

Cleaning Inefficiency

Good efficiency with "good" collimators (cannot run with damaged/deformed collimators)!

E.g.: tolerance on surface flatness: **~ 100 μm**

mm "mountains" on HERA-p collimators…

Failures:

Failure description	Beam energy [TeV]	Intensity deposit [protons]	Energy deposit [kJ]	Transverse dimensions [mm×mm]	Impact duration [ns]
Injection oscillation	0.45	2.6×10^{13}	1875	1.0×1.0	6250
Asynchronous beam dump (all modules)	0.45	1.1×10^{12}	78	***5.0*** $\times 1.0$	275
	7.00	2.8×10^{11}	311	***1.0*** $\times 0.2$	75
Asynchronous beam dump (1 out of 15 modules)	0.45	1.1×10^{12}	78	***5.0*** $\times 1.0$	275
	7.00	6.0×10^{11}	667	***1.0*** $\times 0.2$	150

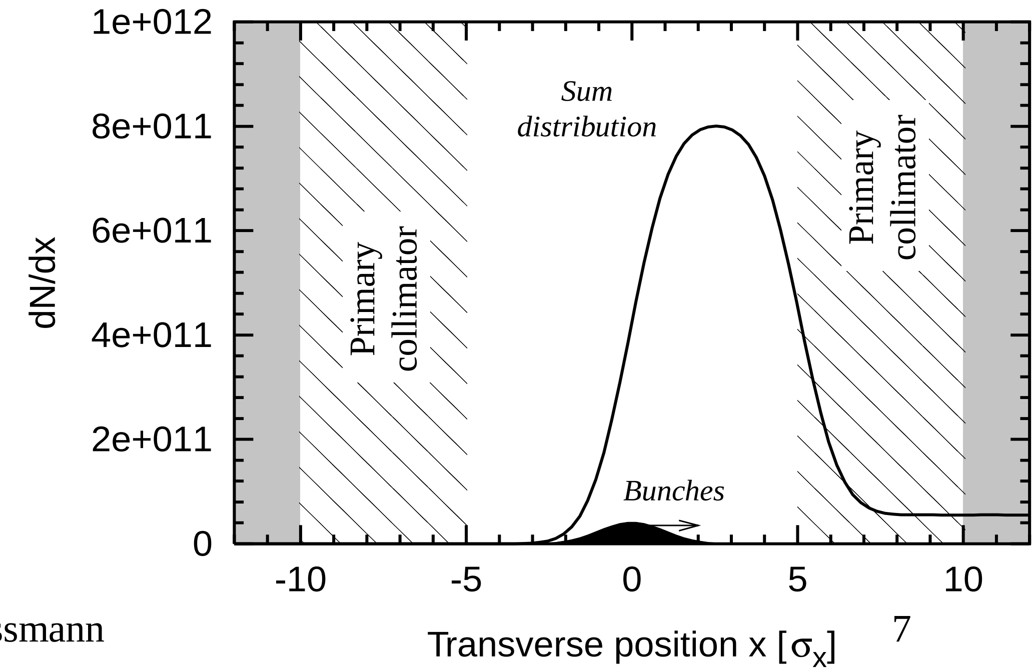
Relax with coll. system in transfer line!?

About 6 full LHC bunches:

- 0.2% of LHC beam
- 30% of HERA-p beam
- 2200% of LEP2 beam

Our goal:

Collimator jaws that can withstand this beam impact.



Preliminary summary: (final summary from JBJ, RS, CF, RA)

- Preliminary beam-based requirements presented as a **basis for hardware choices**. (Propose a talk in LCC on this issue in 4 weeks time).
- Several materials appear promising (**Be**, **C**, Boron Nitride, fiber reinforced ceramics?, diamond coating?). Would coating or plating be an option for collimators?
- Worries on materials (toxicity, brittleness, conductivity, **shock resistance, flatness control, dust, thermal expansion, surface cracks,** fatigue). Careful trade-off required.
- Damage mechanics (**shock waves, fatigue**) are crucial! Tools and expertise available…
- Experimental tests (**tests with beam**) are mandatory: ISOLDE, SPS?
- Collaborate with **vacuum** group on choice of material!
- **Do not consider constraints from impedance** for now (coating for insulator).
- Think on methods to **find damaged collimator** (tomography, RF, temp., beam based,…).
- Protection of LHC collimators require **TCDQ (BT) at 10σ**! Ensure consistency!
- Other concepts: wire septum, non-linear collimation, increased beta functions?

The **damage/deformation and fatigue of collimators** will depend on the **machine running**:

- **Collimation depth (aperture)**
- **Machine protection (beam dump)**
- **Intensities, bunch schemes**
- **Beam lifetimes**
- **Flashes of beam loss (start of ramp)**
- **Failures**

Close **interconnection** between: **accelerator physics**
operational scenarios
machine protection
radiation issues
collimator hardware design

Beam Cleaning Study Group + further collimation meetings?

The present LHC collimation system
Achievements and problems

LHC Collimation Day, 25th January 2002
CERN, Geneva, Switzerland

J.B. Jeanneret, CERN

/Coll/2002/heat_data/coll_day/talk1.tex

OutLine

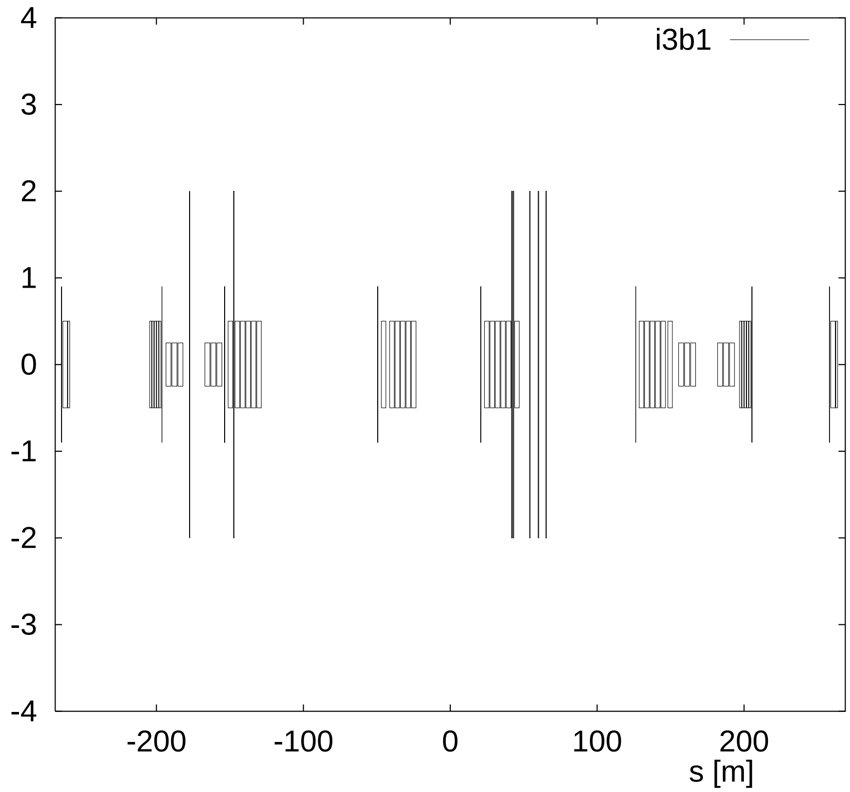
- Rapid description of the LHC collimation system
- Quench prevention data
- Heat and mechanical issues for the collimators

Table 1: Correlated phase advances μ_x and μ_y and $X - Y$ jaw orientations α_{Jaw} for three primary jaw orientations α and four scattering angles ϕ with $\mu_o = \cos^{-1}(n_1/n_2)$.

α	ϕ	μ_x	μ_y	α_{Jaw}	
0	0	μ_o	-	0	mom. coll.
0	π	$\pi - \mu_o$	-	0	mom. coll.
0	$\pi/2$	π	$3\pi/2$	μ_o	mom. coll.
0	$-\pi/2$	π	$3\pi/2$	-μ_o	mom. coll.
$\pi/4$	$\pi/4$	μ_o	μ_o	$\pi/4$	
$\pi/4$	$5\pi/4$	$\pi - \mu_o$	$\pi - \mu_o$	$\pi/4$	
$\pi/4$	$3\pi/4$	$\pi - \mu_o$	$\pi + \mu_o$	$\pi/4$	
$\pi/4$	$-\pi/4$	$\pi + \mu_o$	$\pi - \mu_o$	$\pi/4$	
$\pi/2$	$\pi/2$	-	μ_o	$\pi/2$	
$\pi/2$	$-\pi/2$	-	$\pi - \mu_o$	$\pi/2$	
$\pi/2$	π	$\pi/2$	π	$\pi/2 - \mu_o$	
$\pi/2$	0	$\pi/2$	π	$\pi/2 + \mu_o$	

Real LHC optics: an adequate approximation of this perfect case

Schematic layout of the Momentum Cleaning Insertion



$\overline{RF}$ at ramping

Table 2: Expected Nominal losses at ramping, compared to inefficiency and quench limits

Transient Quench limit (450 GeV)	$\Delta N_q = 2.5 \times 10^{10}$ p/m
3% of coast off-bucket	$\Delta N = 10^{13}$ p
Collimation inefficiency	$\eta \simeq 10^{-4}$ m^{-1}
Margin factor	$m = \Delta N_q \,/\, (\Delta N \times \eta) = 25$

Continuous losses in collisions

Table 3: Expected Nominal losses steady losses in collision, compared to inefficiency and quench limits

Continuous Quench limit (7 TeV)	$\dot{n}_q = 6 \times 10^6$ p/m/s
Beam Lifetime $\tau_{beam} = 40$ hrs	$\dot{N} = 3 \times 10^9$ p/s
Collimation inefficiency	$\eta \simeq 10^{-4}$ m^{-1}
Margin factor	$m = \dot{n}_q \,/\, (\dot{N} \times \eta) = 20$

Additional points

- Collimation efficiency little dependent on jaw material
  - low-Z primary jaw twice better than high-Z
  - marginal dependence with Z of secondary jaw provide that the length of secondary jaw is $> 3\lambda_{abs}$
- Full freedom to satisfy at best Heat load issues

Summary (and work for today)

Presently under control

- optics and insertion layout , betatronic and momentum
- quench prevention for 'nominal losses' (with margin factor > 10)

Still under study

- Heat deposition in jaws (removal, mechanical stress)
- Losses more severe than nominal
  $\Leftrightarrow$ ease of operation, performance
- Erratic dump trigger

The role of the LHC Collimation System in Machine Protection

At 7 TeV and nominal intensity, energy in each LHC Beam: 350 MJ

Energy in one beam could melt about 550 kg of copper

- A small fraction of the beam could damage equipment
- The entire beam would cause massive damage of equipment

Collimators for operating the machine

- Absorb the beam halo to avoid quenches of the superconducting magnets
- Collimator adjustment is critical - need to be close to the beam

Collimators for machine protection in case of failure

- Protect the accelerator elements and experiments from beam loss after a failure
- Absorbers need to limit the aperture - adjustment is less critical

Failures of machine equipment to be anticipated

The LHC is the most complex accelerator that has ever been constructed

- There are about 7000 magnets (most of them superconducting), powered in 1700 electrical circuits, each circuit powered with one power converter
- The protection of the sc elements (magnets, busbars and current leads) requires more than 5000 detectors

- A quench in a superconducting magnet would lead to beam loss
- A failure of a power converter is likely to lead to beam loss

Examples:

- at 7 TeV, one orbit corrector magnet fails that operates at 40% of its strength: beam deflection by about 4 sigma
- quench of one dipole magnet: beam deflection by about 4 sigma after about 60 ms - and 45 sigma after 0.4 s

The beams will (MUST) always touch the collimators first!

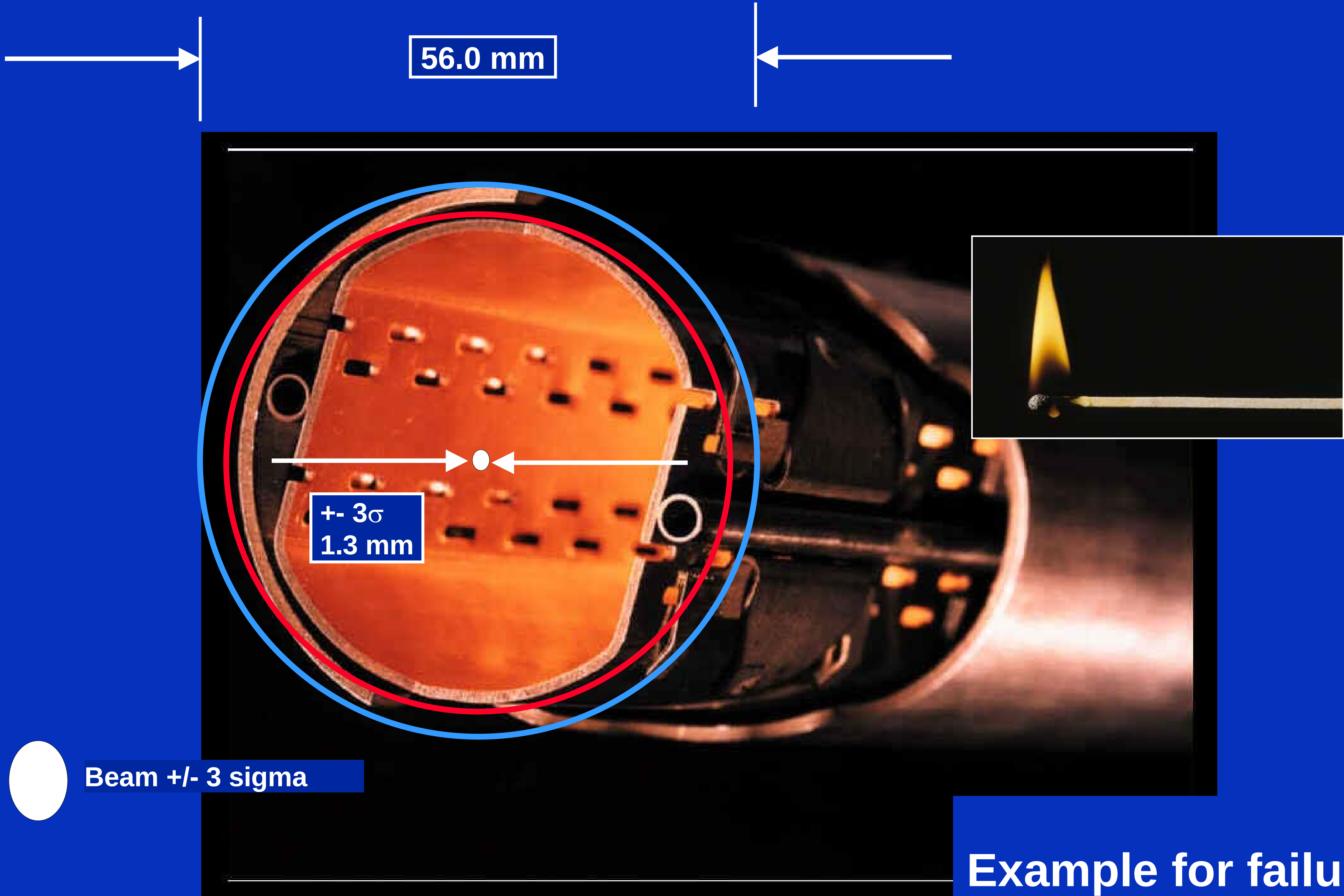
Tasks of the collimation system in machine protection

Task 1: Capture beam losses that could damage LHC equipment in case of a failure before the beam dump fires

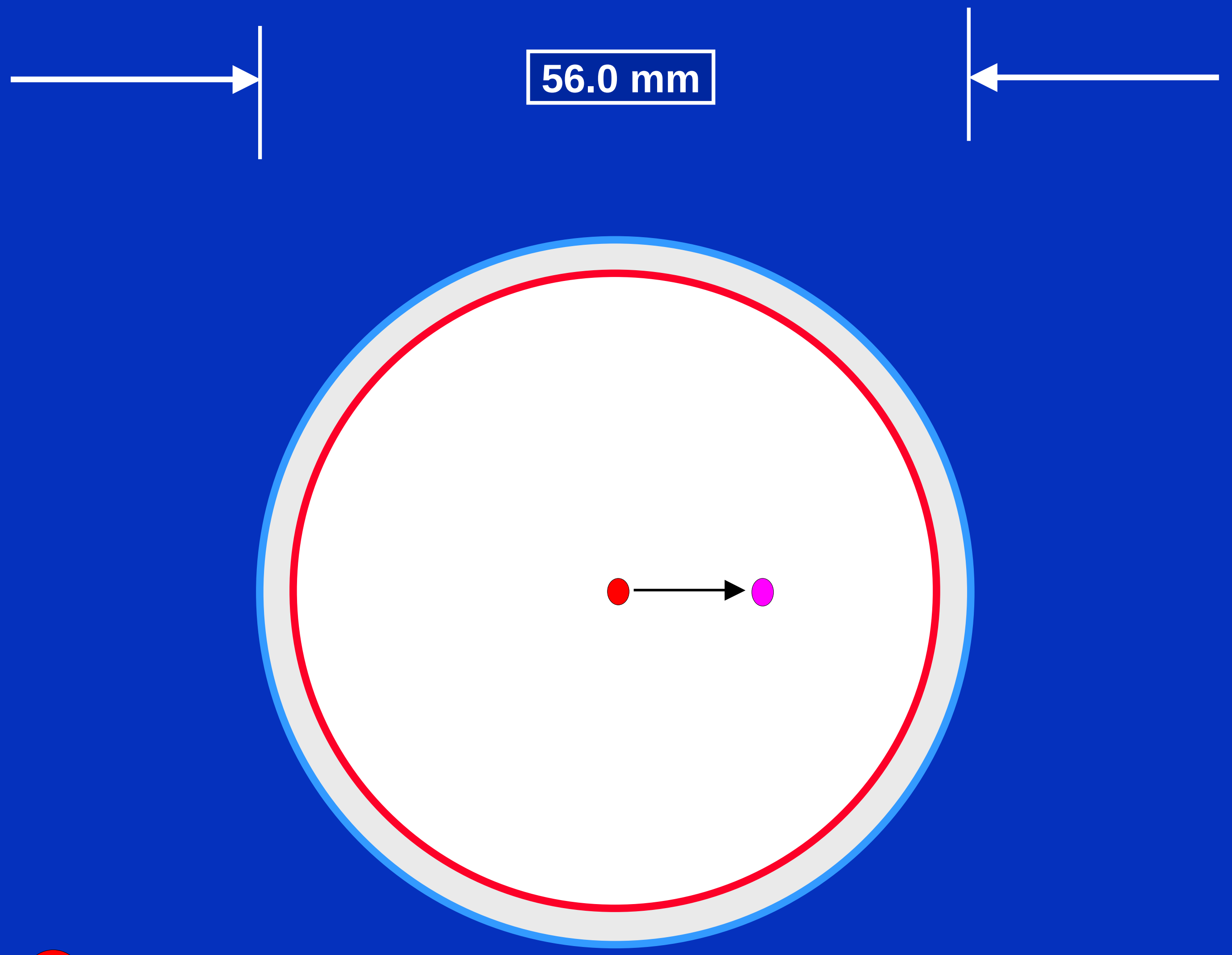
Task 2: Together with the Beam Loss Monitors produce a fast and reliable signal to dump the beam if beam losses become unacceptable

The beam dump block is the only systems that can stand the full 7 TeV beam

- The beam dump is an **active system -** it requires **a trigger** to dump the beam
- The collimators must be the elements that limit the aperture when operating with “high” intensity - high intensity is already in the order of 10^{-3} of the total beam intensity
- The threshold of the monitors to dump the beam should be below the destruction level of the collimators
- Quality and reliability of the beam dump system can not be better than the quality of the trigger



Example for failure at 7 TeV energy

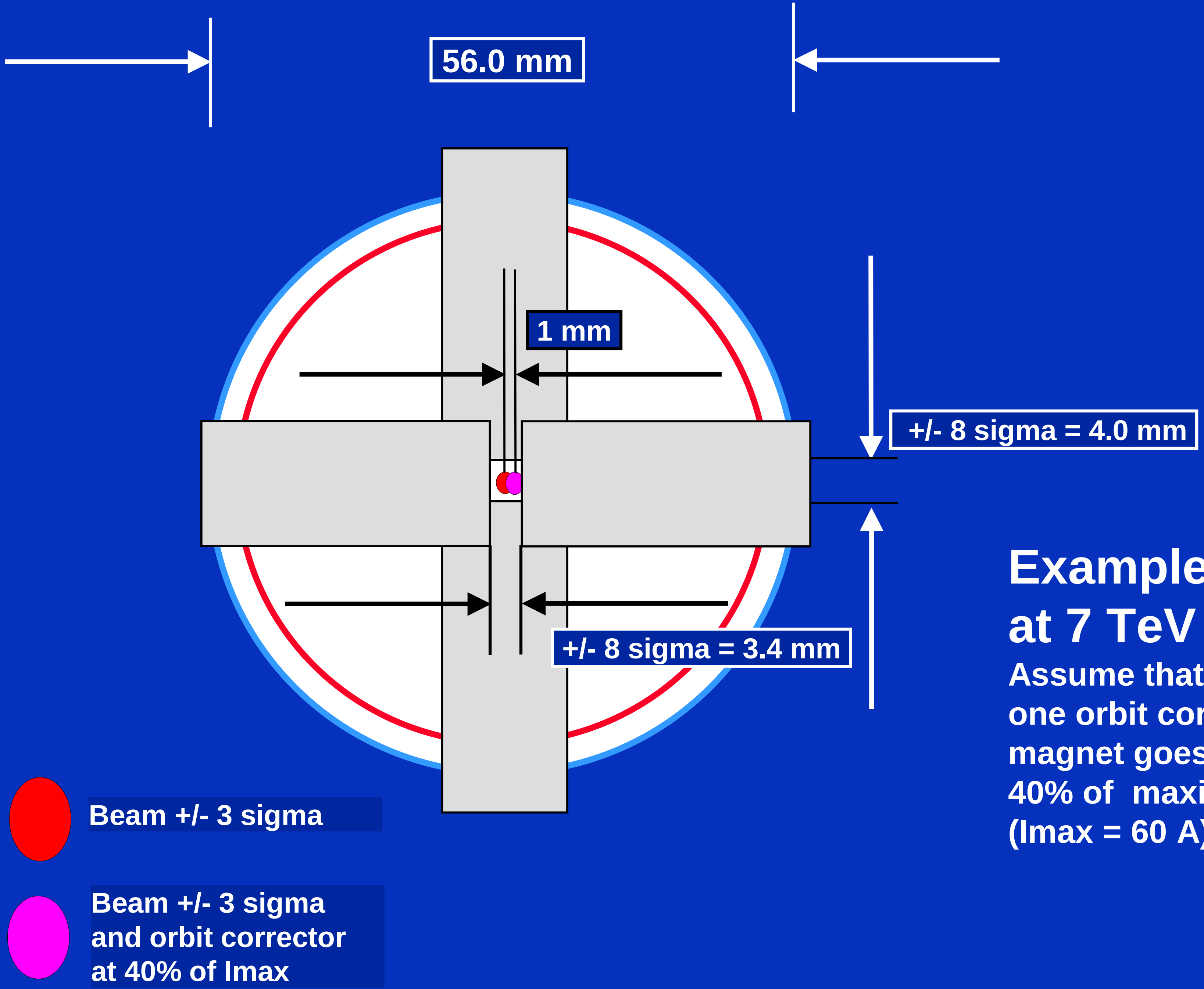


Beam +/- 3 sigma

Beam +/- 3 sigma and dipole magnet quench

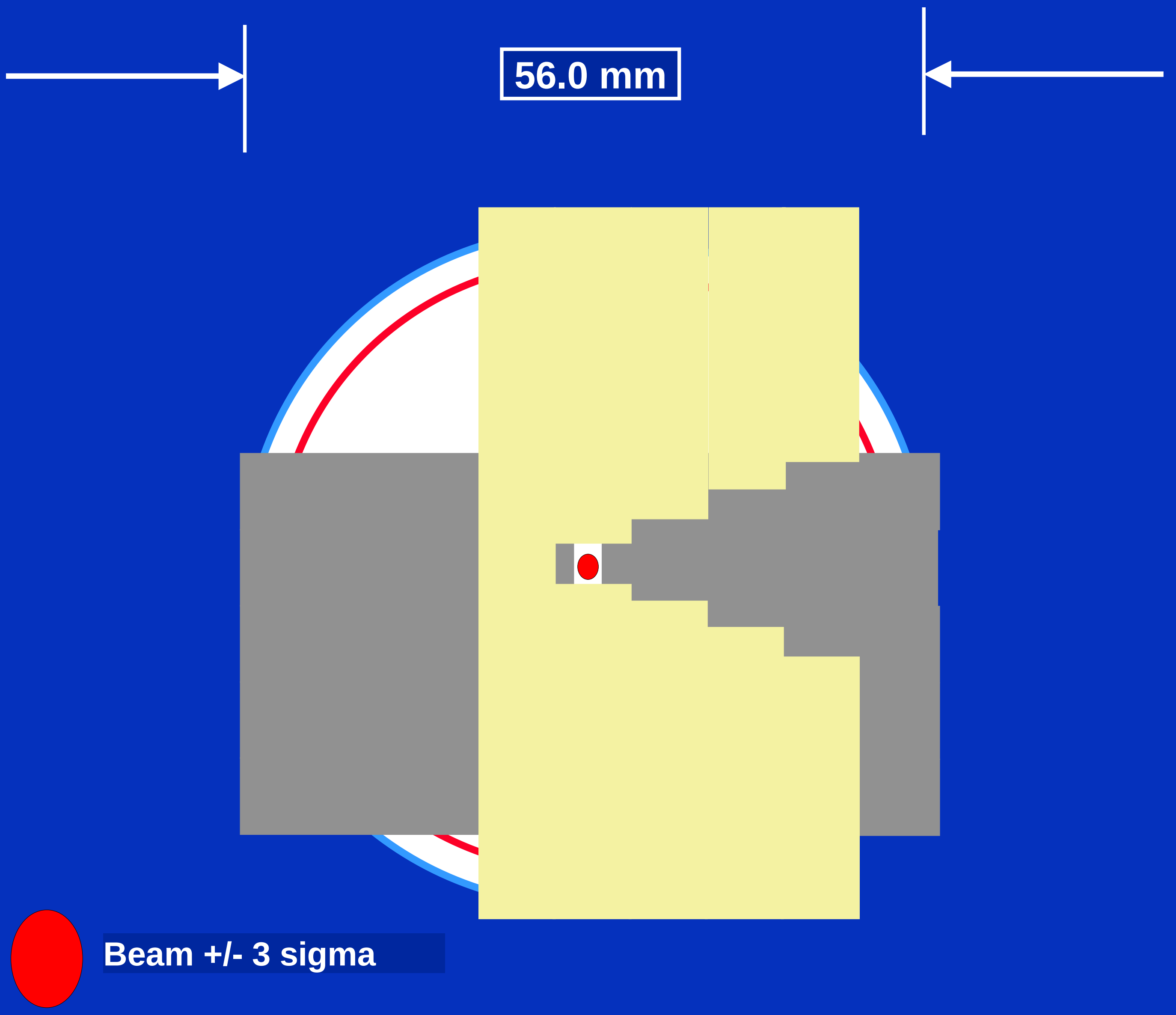
Example for failure at 7 TeV energy

Assume that a dipole magnet quenches



Example for failure at 7 TeV energy

Assume that the current in one orbit corrector magnet goes off to 0 from 40% of maximum current (Imax = 60 A)



No preconception for the collimator design

LHC COLLIMATION DAY

The BI Project

C. Fischer - CERN - SL/BI

Collimator Specification

Collimator Specification at the BI review — November 20, 2001

Kinds of collimators

- Low Z better (efficiency,energy density vs. impacting flux)
  → *OK for primary collimators: Al*
- Secondary ones must absorb → Be, Al : 160 cm ,Cu : 60 cm (4 abs. length)
  compromise with mech.precision/simplicity → **Cu**
  but stategy against destructive events need more work, see below
- Present choice :

PRIM :	Aluminium	20 cm
SEC :	Copper	50 cm
SINGLE PASS, inj+exp :	Copper (Al?)	100 cm
SINGLE PASS, dump :	Low Z	to be studied

JBJ,BI review, 20th Nov 2001

Collimator Specification at the BI review — November 20, 2001

Number of collimators per beam and total

Function	Prim	Sec	Single Pass	beams
β-coll.	4	16	-	2
δ_p-coll.	1	6	-	2
IP2,8-inj	-	-	2	2
IP1,5-exp	-	-	4	2
DUMP	-	-	2?	2
Total:	10	44	12 + 4?	-
Total tanks:	66 + 4?	(all kinds)		
Total motors:	132 + 8?	(all kinds)		

? : low-Z against dump failure, to be studied /decided

JBJ,BI review, 20th Nov 2001 — page 11

From that table, 3 main families:

- **β and δ_p cleaning insertions:**
  - **10 primary collimators: H,V, skewed**
  - **44 secondary collimators: H, V, skewed**

- **Injection IPs and High Lumi. IPs**
  - **12 single pass collimators: H,V**

3 different studies and series assumed

- ***H,V, skewed: difference at supporting level only***
- ***Same vacuum chamber interface (diameter) ?***

Possible time scale, (months),

after specification work completion

Design study	6	
Prototype	4	
Call for tender	10/12	
Production /	6 (10 units) –	12 (40 units)
Reception	2	2
Installation	0.5	1
	28.5	35

By staggering installation (planning)

* second and third design studies will be shorter (4 months)
* several series in parallel ? (design, manufacturers)

$\Rightarrow$ 3.5 to 4 years in total

Budget consideration

- **65 kSF/ collimator $\Longrightarrow$ 5 MSF for collimation**

  based on evaluation from LEP experience

- **Special LHC tolerances and contingencies**

  $\Longrightarrow$ **cost increase per unit ?**

Collimator control consideration

❧ **Severe tolerances ⇒ associated diagnostics needed**

$\sigma \cong$ 200 µm at 7 TeV

- Require precise knowledge of

- **beam size**
- **orbit**
- **loss monitoring**

- Positions to be controlled during beam energy ramping and machine optics adjustments

Requirements for an Improved System: Expected Beam and Power Deposition

R. Assmann, SL/AP

CERN Meeting on Absorbers and Collimators for the LHC Beam

25.1.2002

LHC Beam Cleaning Study Group:

Started in Sep. 2002 to coordinate further design and study of the LHC collimation system. Expertise from SL/AP, SL/BI, SL/OP, AC/TCP, TIS/RP, and collaborators.

This meeting is part of our activities towards an improved collimation system.

Our input:

LHC Project Note 277

January 24, 2002

Ralph.Assmann@cern.ch

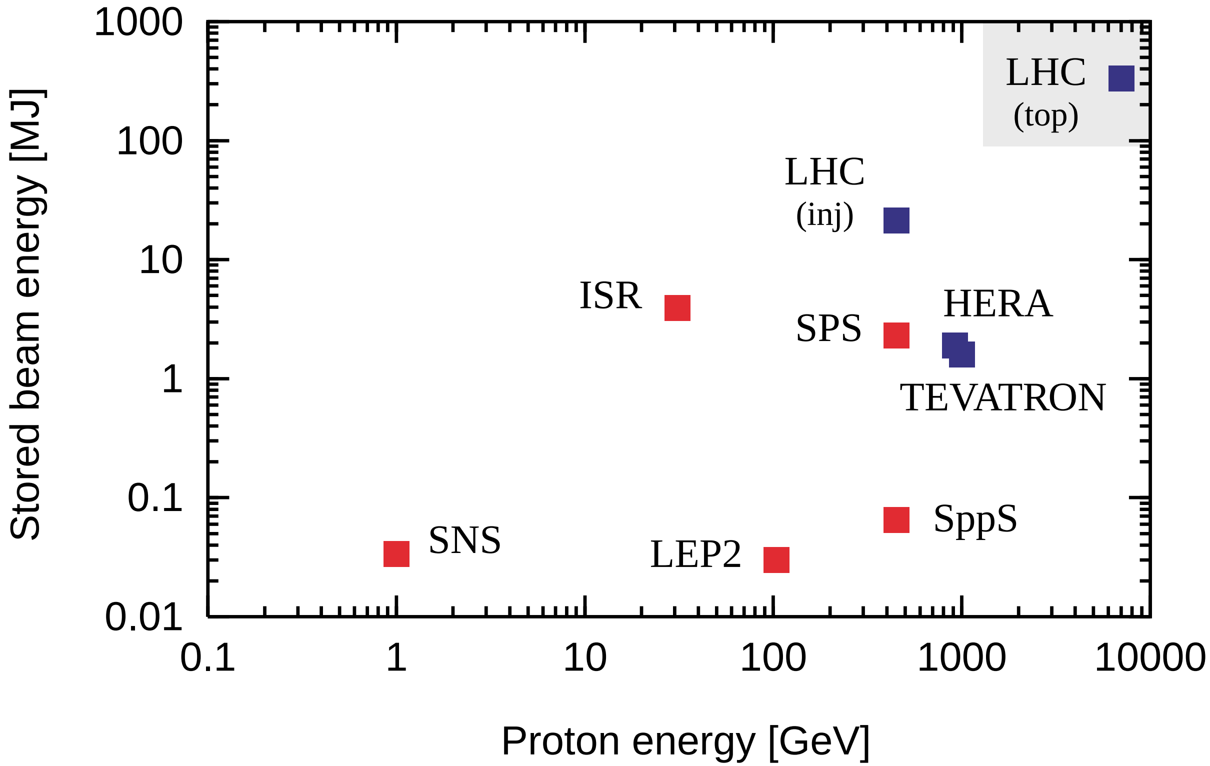
Preliminary Beam-based Specifications for the LHC Collimators

R. Aßmann, I. Baishev, M. Brugger, H. Burkhardt, G. Burtin, B. Dehning, S. Fartoukh, C. Fischer, E. Gschwendtner, M. Hayes, J.B. Jeanneret, R. Jung, V. Kain, D. Kaltchev, M. Lamont, R. Schmidt, J. Wenninger

Keywords: Collimation, Beam Loss, Machine Protection

The LHC Beam:

Number of bunches:	2808
Bunch population:	1.1e11
Bunch spacing:	25 ns
Top energy:	
Proton energy:	7 TeV
Transv. beam size:	0.2 mm
Bunch length:	8.4 cm
Stored beam energy:	331 MJ
Injection:	
Proton energy:	450 GeV
Transv. Beam size:	1 mm
Bunch length:	18.6 cm



Step from previous accelerators:

Factor 7 in proton energy
Factor 100 in stored beam energy

The powerful LHC beam must be handled in sensitive super-conducting environment!

Beam and Power Deposition During Regular Operation:

Lifetime reductions during machine cycle (ramp, squeeze, …) and tuning…

Relax with slower ramp!

Mode	Energy [TeV]	Duration [s]	Req. min. lifetime [h]	Beam deposition [protons/s]	Power deposition [kW]
Injection	0.45	cont	1.0	0.8×10^{11}	6
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Top energy	7.00	cont	1.0	0.8×10^{11}	93
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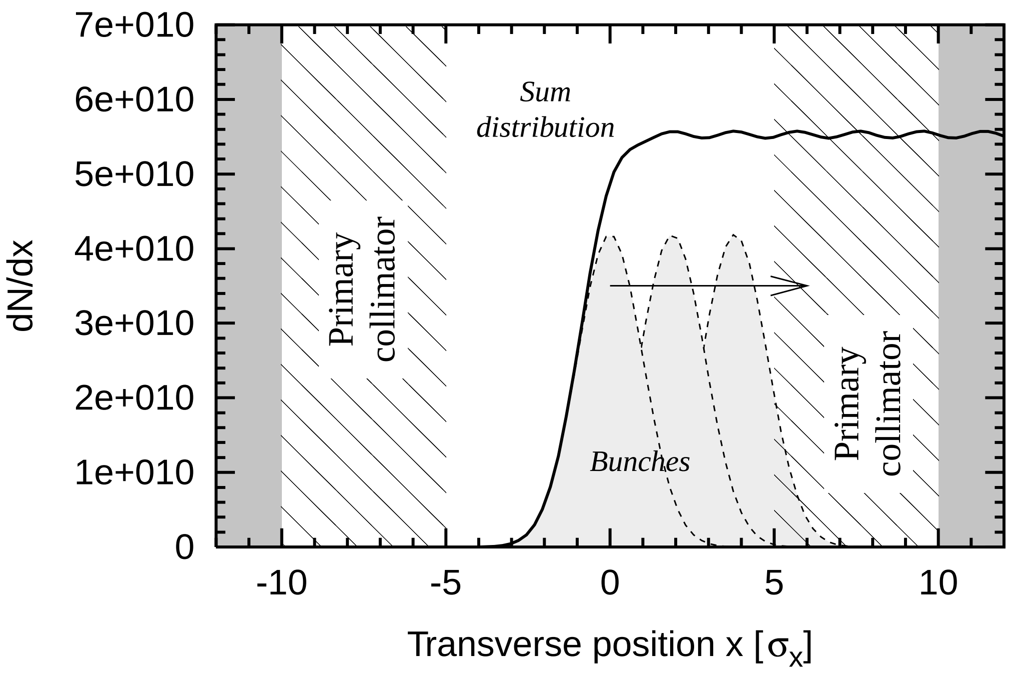
Most severe: Top energy (up to 0.5 MW) to be absorbed in collimators and downstream material. Dump beam below 0.2 h (top).

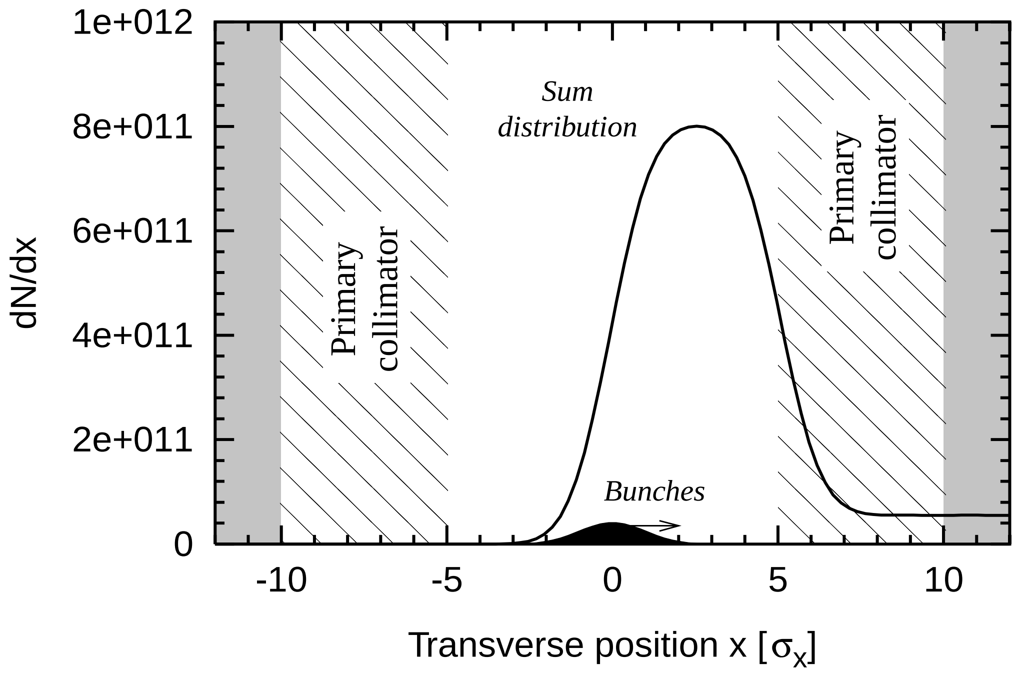
Beam Impact During Failures (single turn):

Things can and will go wrong (e.g. beam dump out of phase with dump gap)…

Collimators will be first to intercept the perturbed beam (desirable for passive protection).

Ensure reasonable collimator robustness (cannot replace every few months).





Asynchronous firing of all 15 dump kicker modules

Asynchronous firing of one dump kicker module with the rest kicking in after 1 µs.

R. Assmann

Failure description	Beam energy [TeV]	Intensity deposit [protons]	Energy deposit [kJ]	Transverse dimensions [mm×mm]	Impact duration [ns]
Injection oscillation	0.45	2.6×10^{13}	1875	1.0×1.0	6250
Asynchronous beam dump (all modules)	0.45 7.00	1.1×10^{12} 2.8×10^{11}	78 311	***5.0*** $\times$ 1.0 ***1.0*** $\times$ 0.2	275 75
Asynchronous beam dump (1 out of 15 modules)	0.45 7.00	1.1×10^{12} 6.0×10^{11}	78 667	***5.0*** $\times$ 1.0 ***1.0*** $\times$ 0.2	275 150

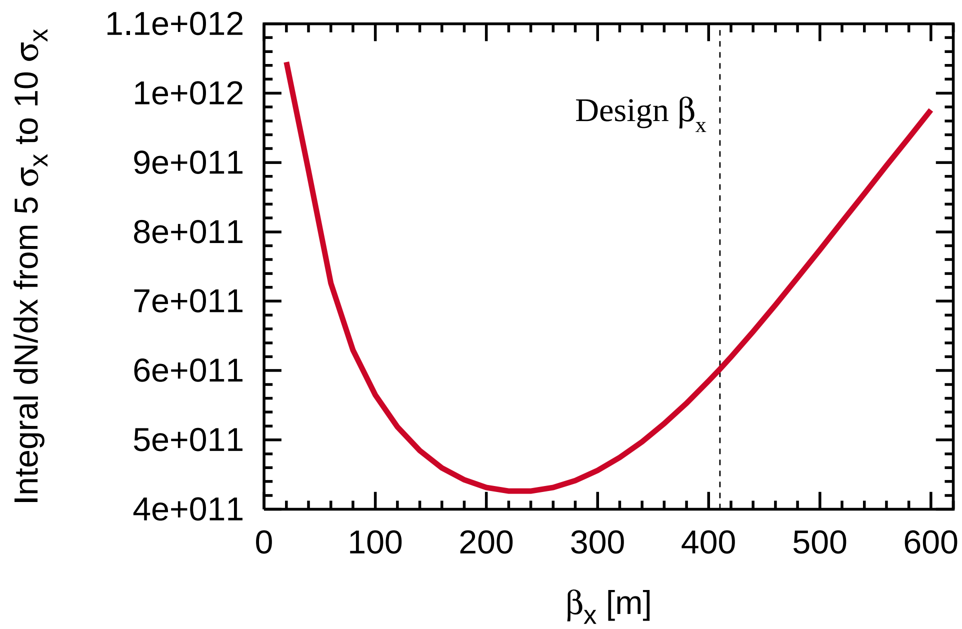
Relax with coll. system in transfer line!?

About 6 full LHC bunches:

- 0.2% of LHC beam
- 30% of HERA-p beam
- 2200% of LEP2 beam

Our goal:

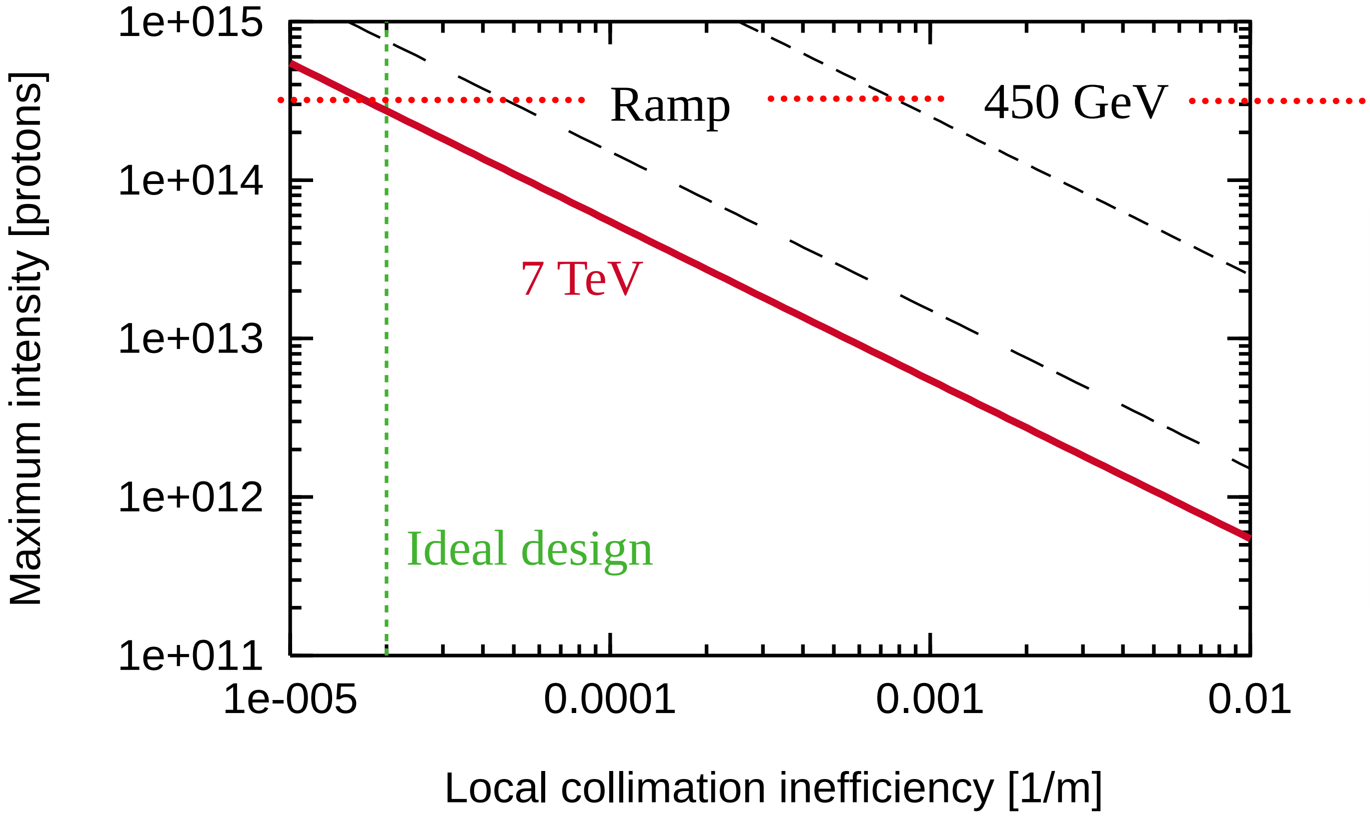
Collimator jaws that can withstand this beam impact.



(at dump kicker)

Cleaning Efficiency (multi-turn):

Quench levels of magnets require **excellent cleaning of beam halo** from injection all the way to top energy.



Maximum Intensity
(for a beam lifetime of 0.2 h at the quench limit)

versus

Cleaning Inefficiency

Good efficiency only with "good" collimators (cannot run with damaged collimators)!

E.g.: tolerance on surface flatness: **~ 100 μm**

mm "mountains" on HERA-p collimators…

Our questions: (given our preliminary beam-based specifications)

What are the most promising materials? (impedance, vacuum, radiation, robustness, …)

Is there a "best" geometry? (distribute losses, dissipate shock waves, …)

Are composite materials a way to go?

How can we best determine the damage threshold?

What is our knowledge on thermo-dynamic properties (shock waves)?

What is our knowledge on surface properties?

What are the best solutions for heat conduction and cooling?

Can we predict deformations of the jaw surface?

We come back to those questions in the brain-storming session…

INITIAL CONSIDERATIONS CONCERNING THE COLLIMATORS VACUUM

Main parameters influencing the design of collimators will be described from the point of view of vacuum performance and operation

N. HILLERET

CERN - LHC/VAC

Outgassing:

Dictated by surface preparation and treatments:

Sources of outgassing:

Static outgassing: less important

Stimulated desorbtion :

Electron bombardment -> electron induced desorption (E.S.D.) -> cleaning

Ion bombardment (I.I.D.) -> ion induced pressure bump   -> pressure instability

Photon induced desorption

Metals equivalent for comparable surface treatments e.g. bake out temperature

But bake out temperature determined by mechanical properties and geometrical precision required

Exotic materials C, BN,… properties less clear strongly dependant on their preparation

specific measurements needed appropriate cleaning and outgassing methods to be studied

Applicable Treatments:

Chemical cleaning

Vacuum firing

In situ vacuum bake-out

Glow discharge cleaning

Secondary electron emission

Determinant for the generation of electron cloud

Detrimental effect on beam properties, pressure increase by E.S.D.

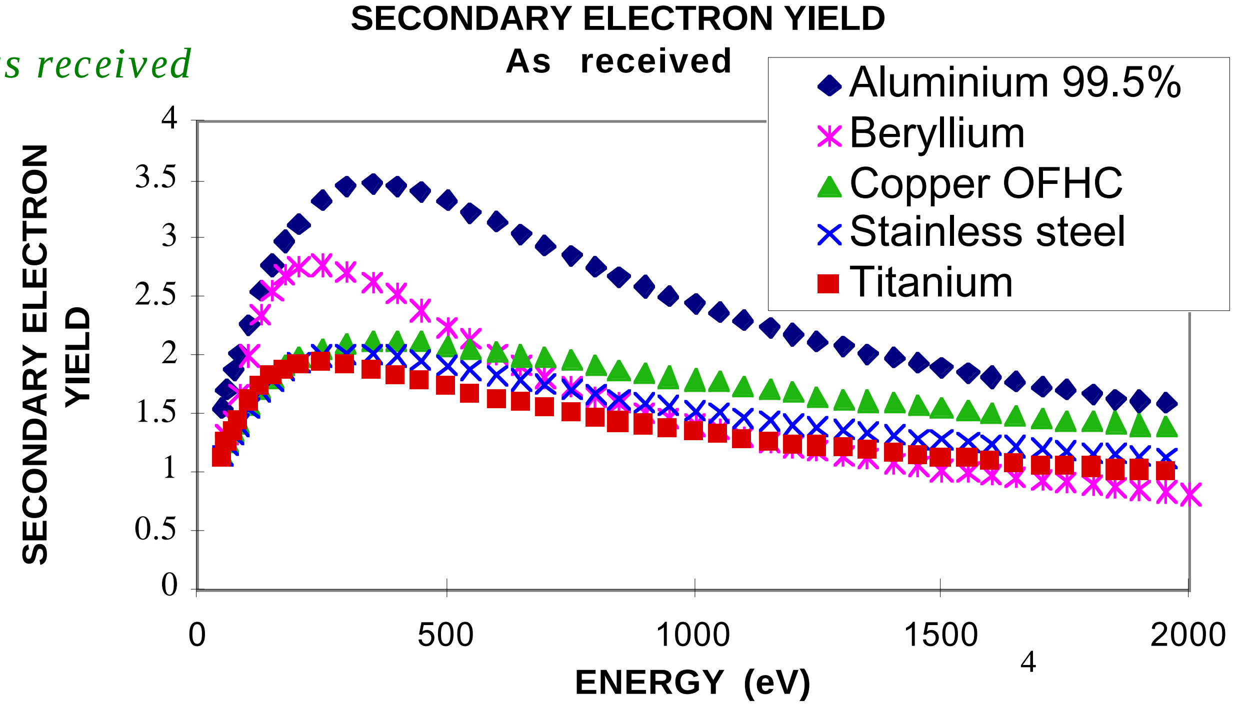
Secondary electron yield

Also determined by surface properties : hence mainly by surface preparation

BAD: > 3. Al, Be as received

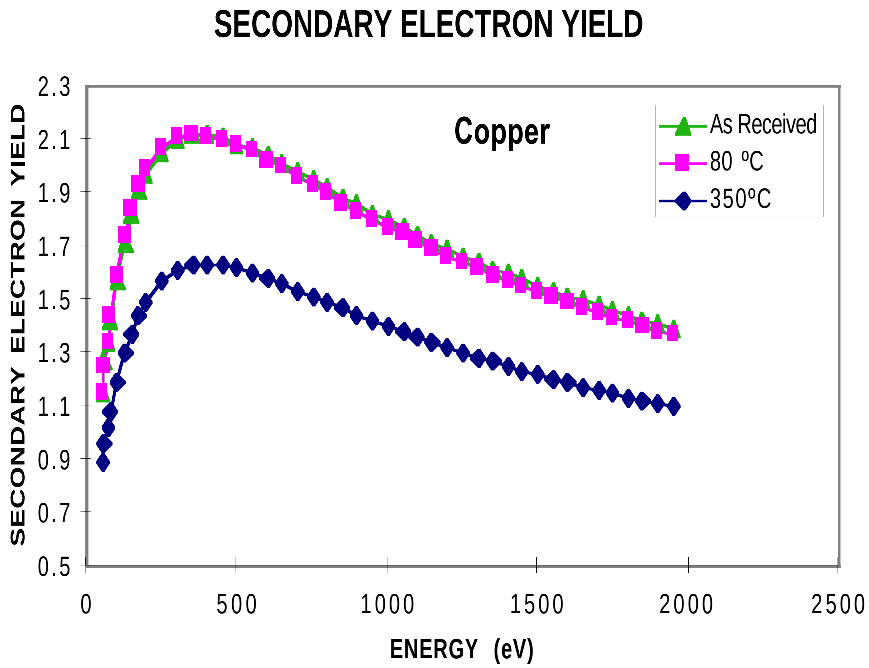
GOOD:< 1.3 no significant electron cloud

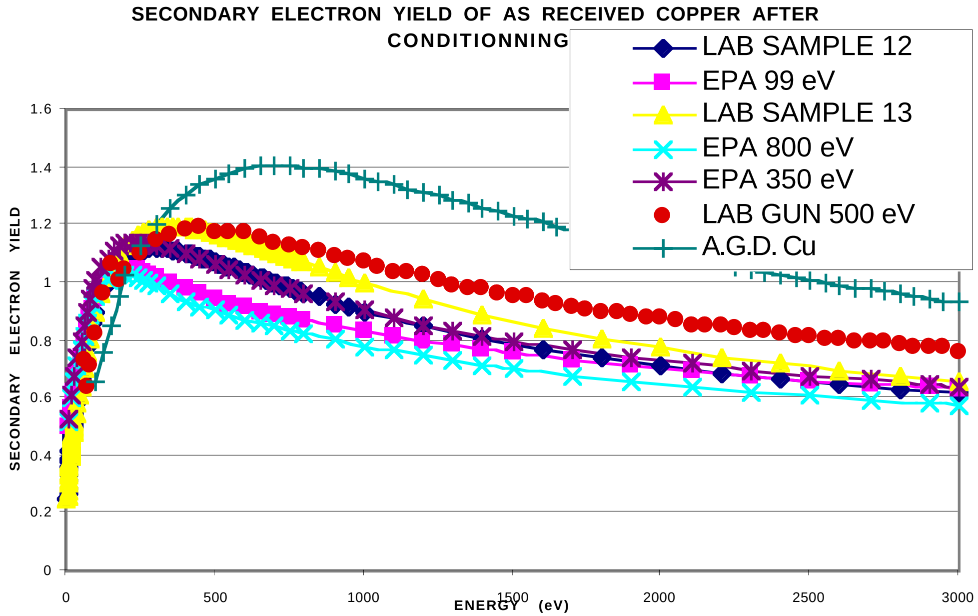
USUAL: Nb, Ti, Fe, Cu ~2 as received



TREATMENTS :

Bake out improves δ : ~1.6





Conditionning δ ~ 1.3 (1 mCb/cm^2) for most usual metals

For Al and Be special coatings needed

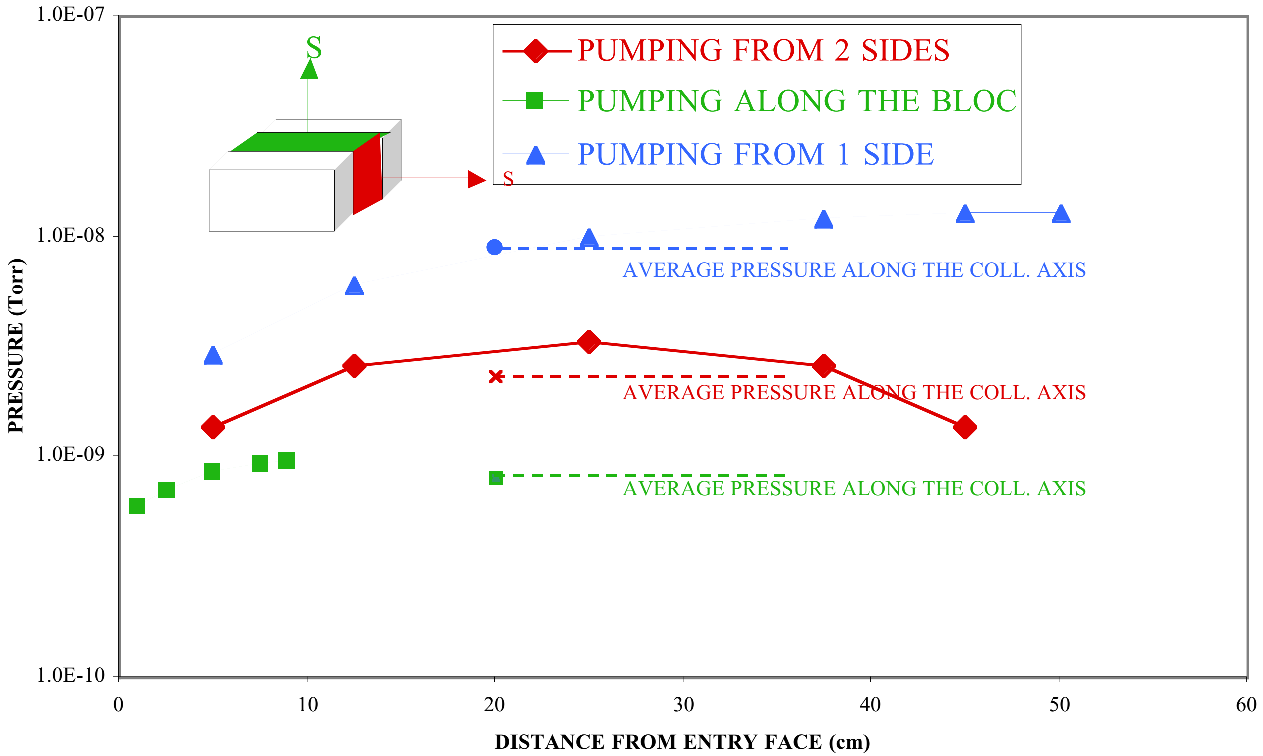
Coatings: NEG, TiN

PUMPING

Must cope with the large gas load generated during the operation of the collimator

Unusual configuration of LHC collimators : small gap

PRESSURE DISTRIBUTION



Position of the pump determinant : more efficiency if pumping distributed along the blocs

INSTALLATION AND MAINTENANCE

Radiation exposure important:

Reduce worker exposition to radiation:

good access, high reliability, robust material (e.g. type of pump), remote handling ???

CONCLUSION

Tight collaboration during the design phase to choose:

appropriate materials

appropriate treatments

good design for accessibility

adequate pump type and performance

Boundary Conditions from Impedance

- **Material**
- **Surface state**
- **Shape / Geometry**

D. Brandt and L. Vos

Impedance boundary conditions:

Impedance for collimators: **2 aspects**:

- Low-frequency **transverse impedance**: ⇒ **material**
- Longitudinal impedance (**Inductance (Z/n)**): ⇒ **Geometry** (material)

Transverse Impedance

- Choice of the **convenient** material is **difficult** enough ...

$\Rightarrow$ Impedance aspects **not prioritary!**

- In case **more than one** candidate:

$\Rightarrow$ contact SL/AP

- Likely to select the **lowest possible resistivity**.

Longitudinal Impedance: Geometry

- No proposal so far ⇒ **no impedance budget**.
- Try to get something **similar** to what has been done for **LEP** (with tapers).
- **Optimize** design for **closed position at 7 TeV** (worst case).

Longitudinal Impedance: Material

- **No firm recommandation** at this stage, **BUT:**

- If **“insulator”** selected (e.g. ceramic or TDI-like),

  ⇒ **thin metallic layer required** (e.g. a few microns Ti).

- **Reduce inductance (Z/n)**.
- **Avoid charging up the ceramic**.

ISR and LEP collimation

What can be learned for LHC?

R. JUNG, SL/BI

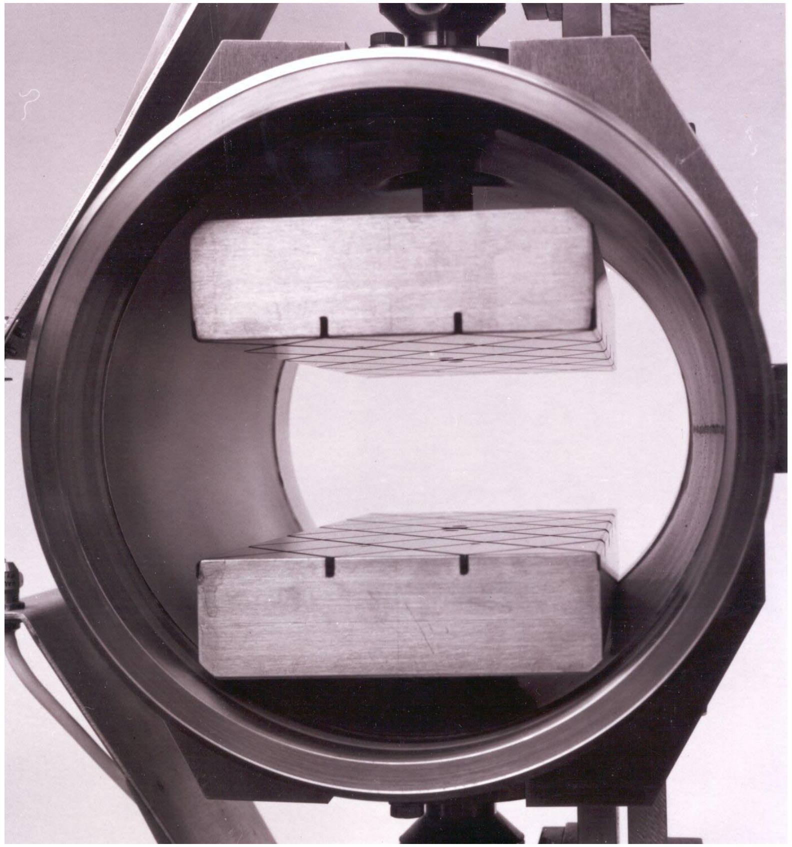
for the ISR and LEP collimation teams

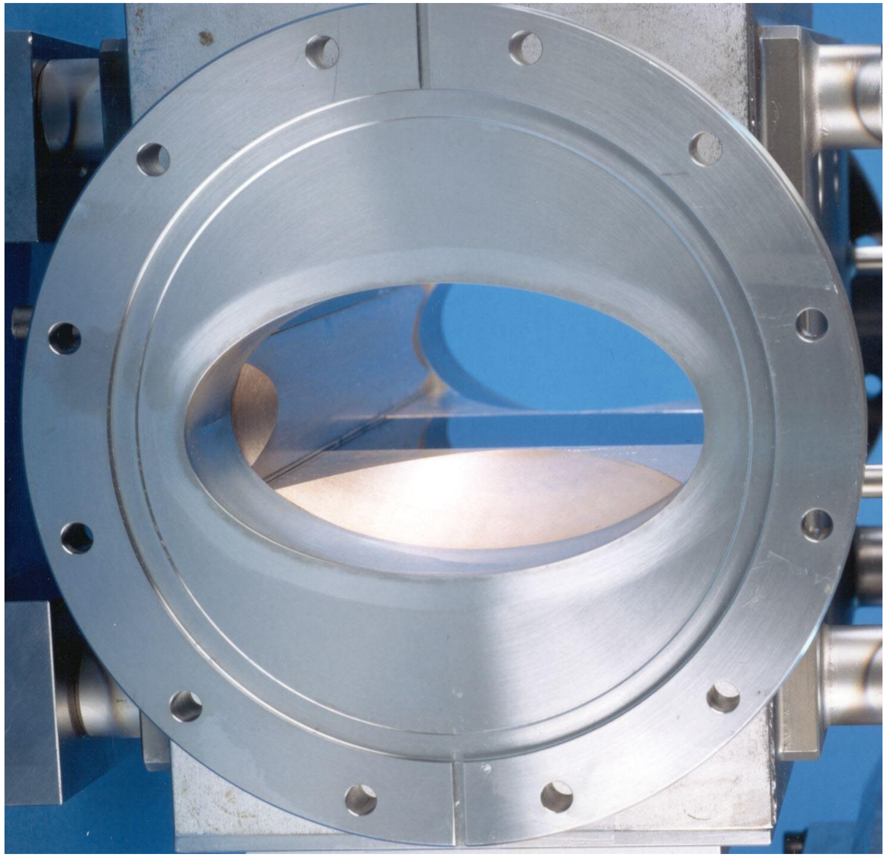
ISR and LEP Collimation

What was behind the concept of a "BI collimator"?

- A machined block of dm dimension
  - in general with high density material
  - exception: Al blocks in LEP's BBCA
- designed to protect the experiments from background
- positioned with a μm precision
- with independent position readout of ~ same precision
- in the ring UHV
- interacting possibly with the stored beam
- in a high radiation environment (MGy)
- with temperature monitoring
- with beam interlock (ISR)

ISR and LEP Collimators





ISR and LEP Collimation

What have we learned?

- **ISR: high intensity proton beams: MJs**
  - **Critical points:**
    - **Block/machine protection**
    - **precision controls/ beam protection**

- **LEP: short bunches: cm & high SR pwr: kWs**
  - **Critical points:**
    - **short bunches (12mm): HOM: innovative mechanical design**
    - **high SR pwr: kW: careful block design**
    - **large numbers: planning/ industrial production/ installation**

ISR collimation: DC Beams

E beam [GeV]	I beam [A]	Nb particles	Energy [MJ]	^ Power [MW]
26	50	$1\ 10^{15}$	4	1 300
31	30	$6\ 10^{14}$	3	930

ISR collimator features

- **Blocks: 10/beam, 20 total: 1ary and 2 aries**
  - **material:**
    - **stainless Steel**
    - **Tungsten**
    - **Molybdenum**
  - **shapes: nothing special, cooling: none**
  - **temperature monitoring for block protection**
  - **contacts for impedance reduction**

- **Tanks: DC beams:**
  - **standard vacuum tank: cylinders**
  - **pumping ports**

ISR collimator control

Due to

- **the high beam power,**
- **the long time to obtain physics beams with long lifetime,**
- **the computer/manual way to control the collimators with operator feedback on background of the experiments,**
- **the high radiation environment:~1 MGy expected over lifetime**

special care had to be taken for the controls:

- **position control: stepping motors: 5 μm increments**
- **position check: independent & absolute: resolvers: 20 μm**
- **beam loss interlock on DCCT:**
  - **beam touched:** slow down
  - **beam loss > 0.5A in 10s, i.e. lifetime < 10 min:** stop

ISR collimators: Results

- **Users: I don't remember of any dis-satisfaction**

- **Reliability record: 1977-1984:**
  - **Accumulated dose: ~0.2 MGy**
  - **No collimator to be replaced**
  - **No stepping motor or resolver failure**
  - **Temperature monitoring: useful?**

LEP collimators

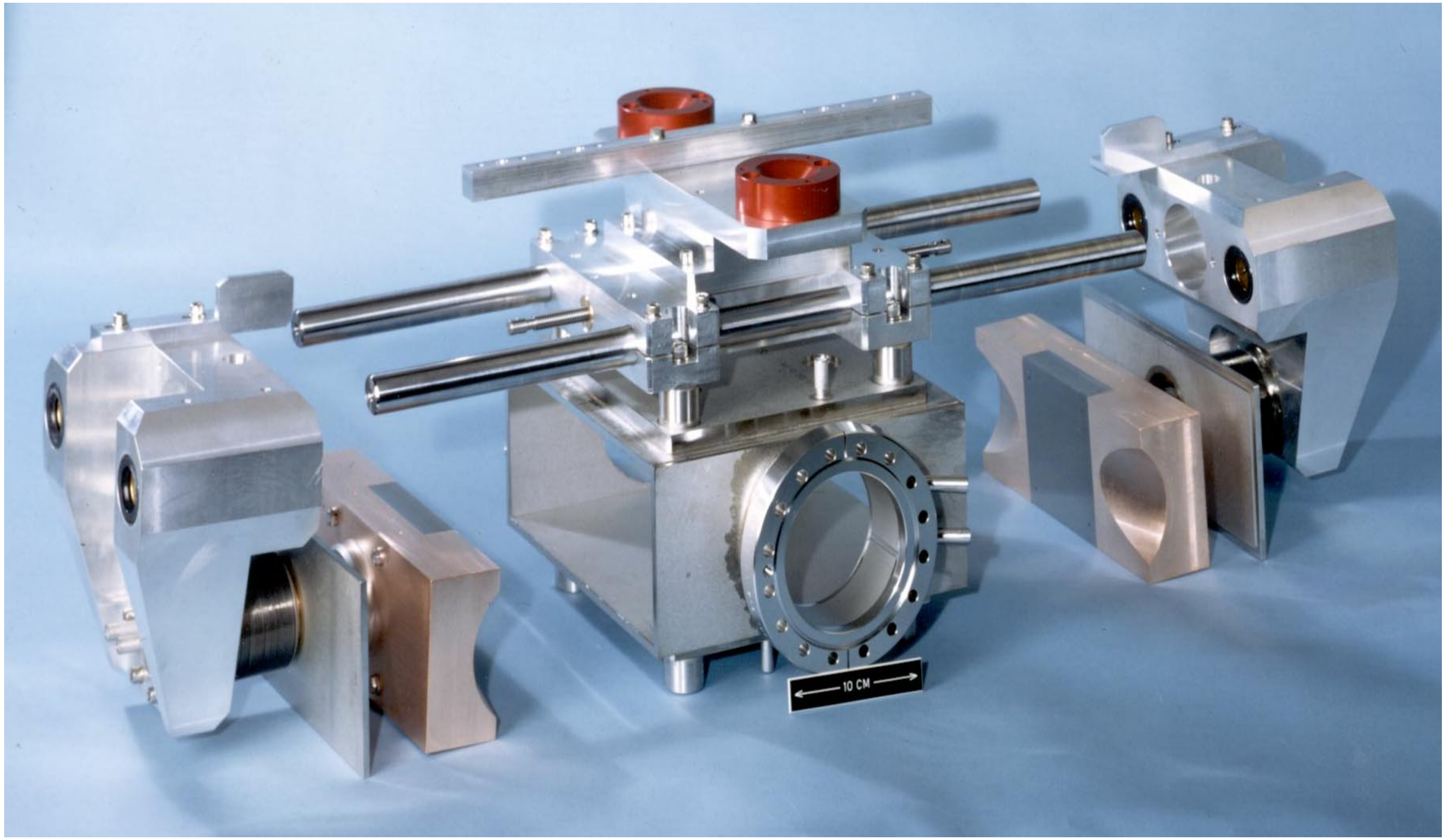
- **From the ISR experience, it was obvious that:**
  - the blocks would be controlled with Stepping motors and the positions checked with resolvers with 5 μm resolution
  - it was un-economical to have the possibility to control all motors at exactly the same moment: sequence: ~200 kCHF
- **From the LEP beam characteristics:**
  - an effort had to be made to cope with the short bunches
  - the large continuous SR power had to be evacuated
  - the implementation had to be a joined project effort
- **From the large number: >200 blocks:**
  - most of the manufacturing had to be done in industry

LEP: Short bunches

The collimator should define a variable aperture while presenting a permanent smooth transition to the nominal vacuum chamber!

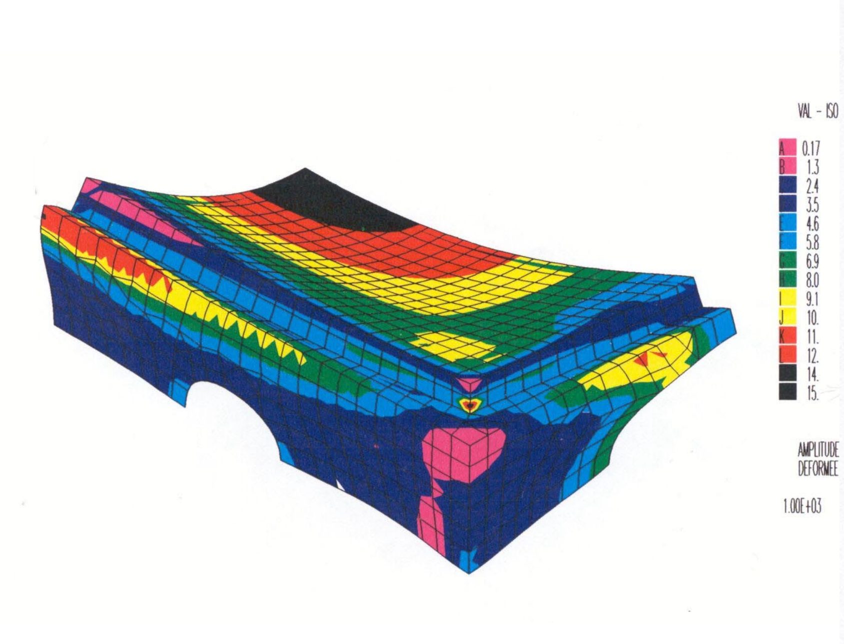
- **A priori : NO SOLUTION!**
- **BUT there is a good compromise for the HOM, while being a “heretic” mechanical vacuum vessel design:**
  - **“cubic” tank with clever (economical) machined blocks for minimising the loss factor over the useful stroke: needs mechanical and loss factor calculations**
  - **composite block:**
    - **W: minimum quantity (cost) for good SR (& e) absorption**
    - **Cu for economical transition and heating control**

LEP: collimator "toolkit"

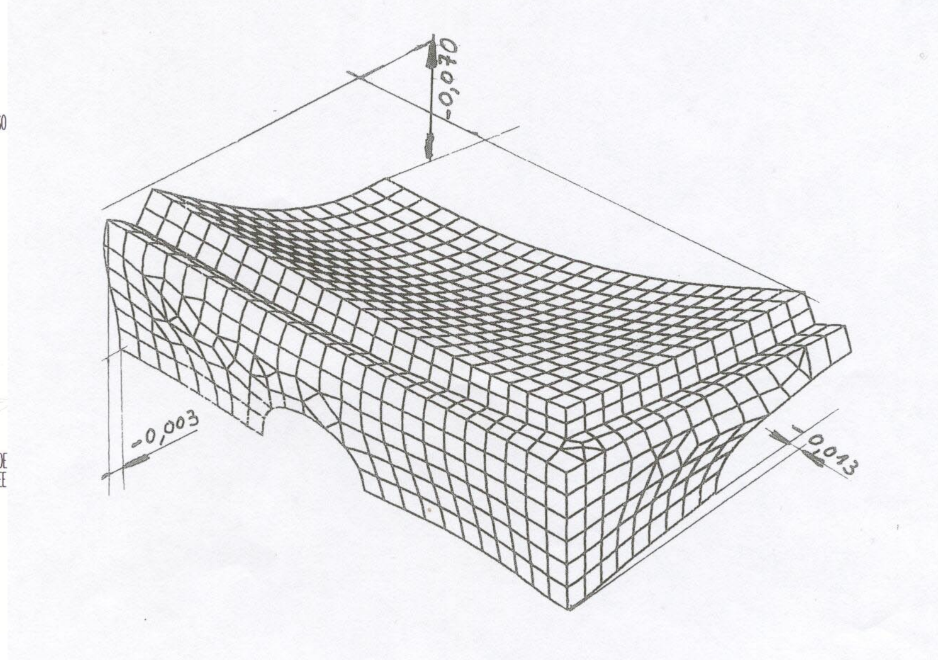


BRCH tank deformation

Stresses

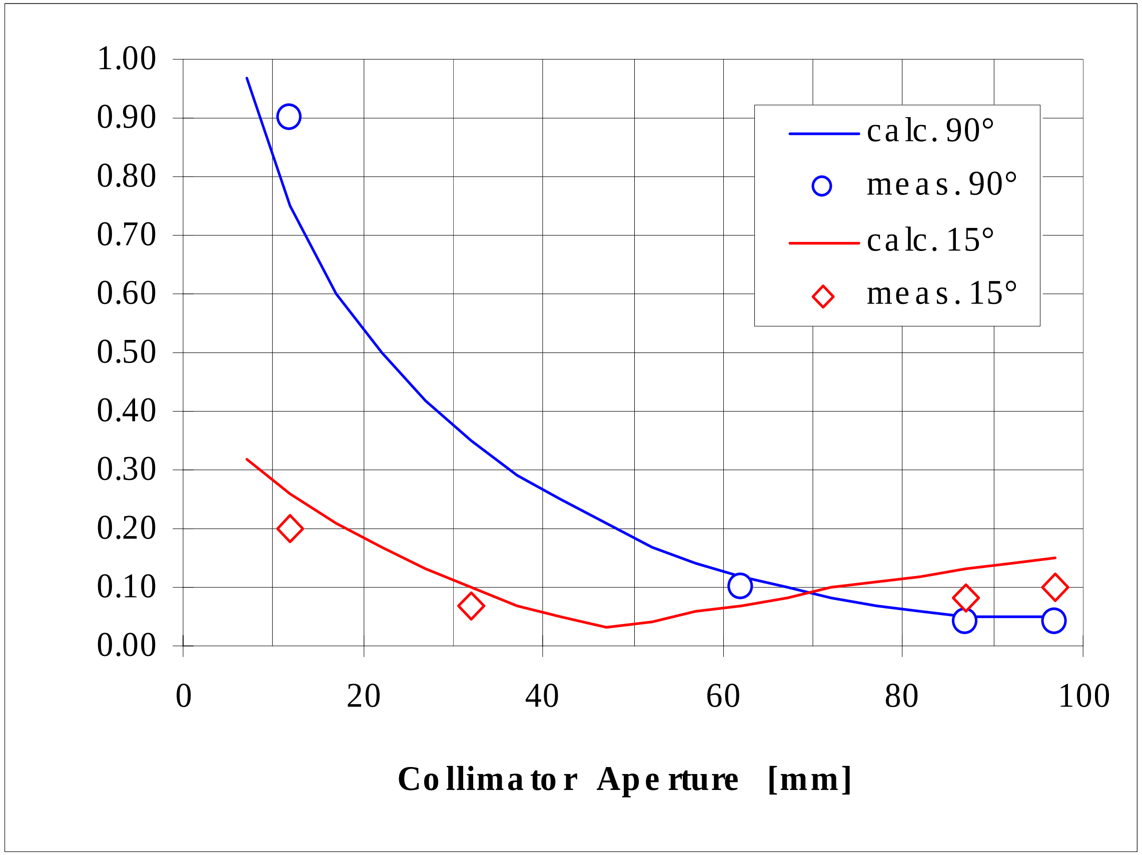


Deformation [mm]



BRCH collimator loss factor

- Block optimised around nominal position
- good agreement btw simulation and measurement



LEP: High Power

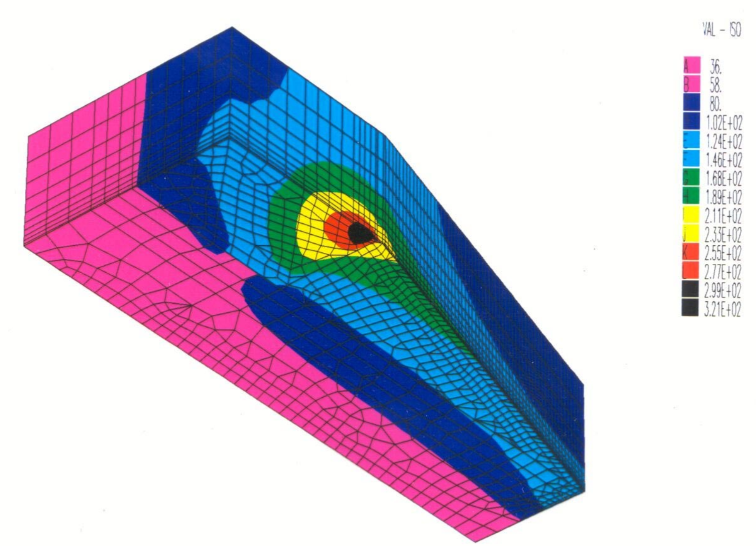
Two power sources:

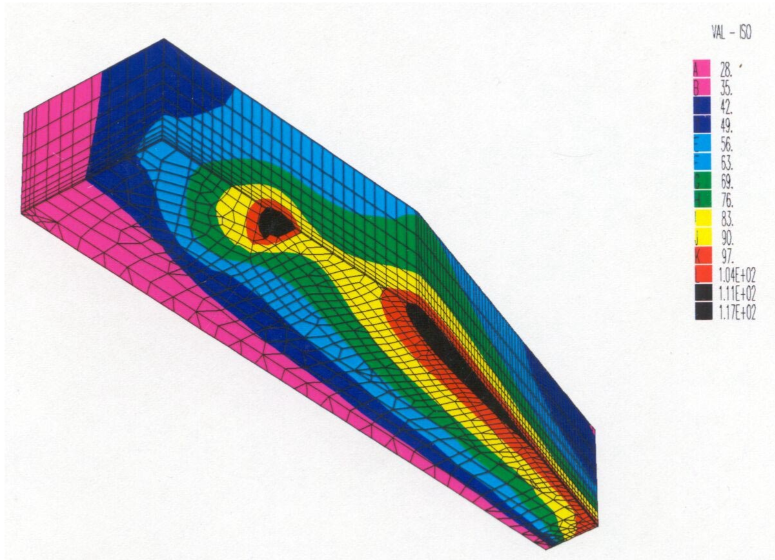
- **RF losses: 600W lost from beam**
  - **needs water cooling of tank and block**
- **SR power deposition: Horizontal & Outside: up to 10kW over a couple of mm height**
  - **Outer Block for horizontal collimators: up to 10kW: adapt design of composite block to spread the pwr deposition mostly in Cu and not in W, while keeping the collimation efficiency high, the loss factor and the price low: see BRCH block design**
  - **Block: temperature/water flow monitoring**
  - **Tank for V blocks: 500 W: unacceptable on stainless steel: Cu absorber/ Steel wall/ Water Cooling**

High SR pwr [10 kW] block design

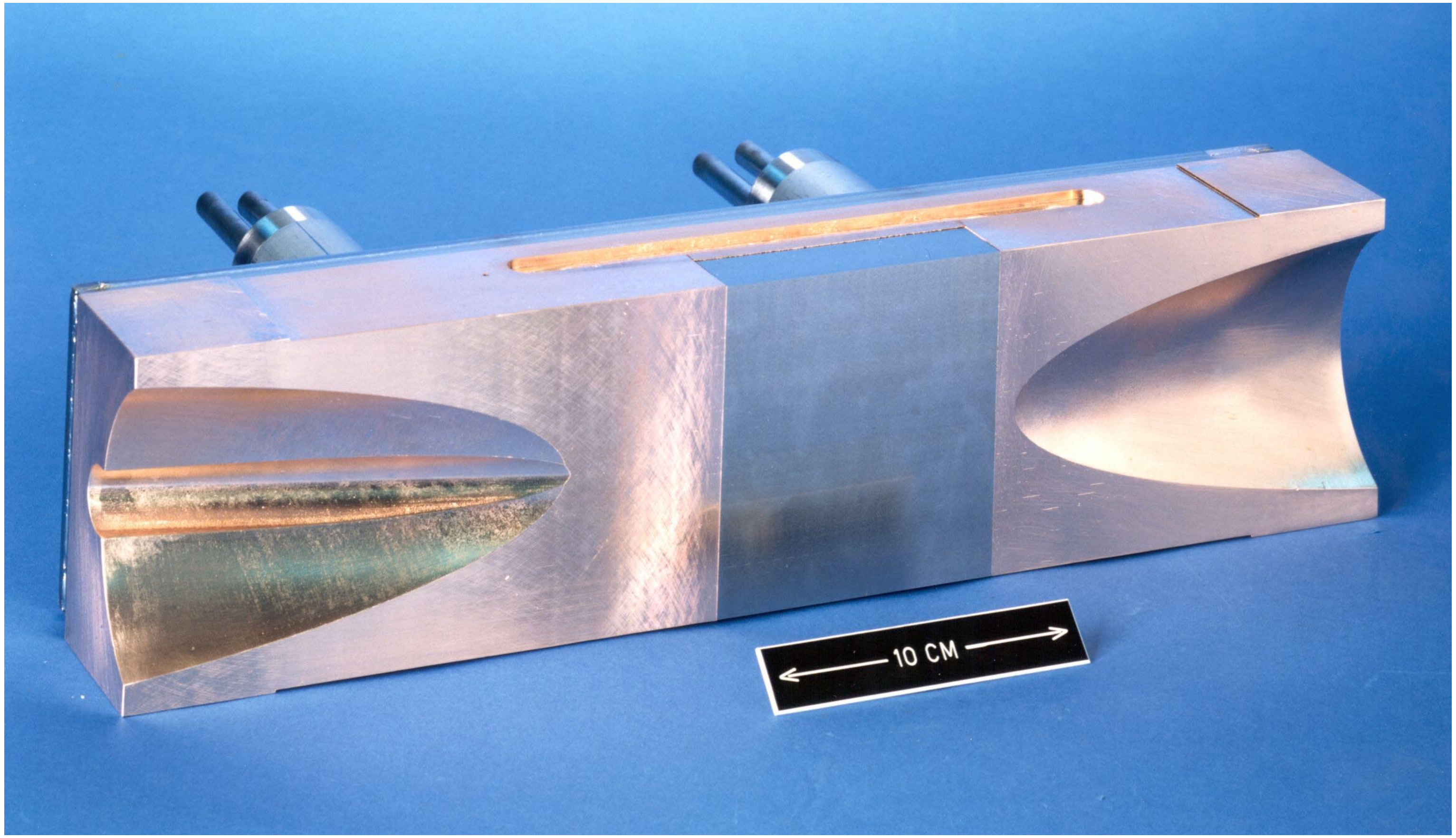
Std design: 320° hot spot in W

Modified : 117° spread out in Cu & W





LEP High SR PWR [10 kW] block



LEP: collimation system

- **For LEP1 and LEP2, in order to:**
  - **minimise the total loss factor due to collimators**
  - **satisfy special requirements such as:**
    - **Bhabha detectors integrated into collimator blocks**
    - **10m curvature radius of some W blocks**
    - **multi-layers of Cu/ Ag/ W on some blocks**
    - **Al blocks to catch off-momentum e^-**
- **270 blocks housed in 136 collimators:**
  - **with 1, 2, 4 jaws**
  - **of 14 different types**
- **had to be designed, produced, tested and installed in two relatively short periods, for an amount of ~ 5 MCHF**

LEP: Collimator Project Partners

- **This BI effort was done in collaboration with :**
  - G. von Holtey for the collimation specification
  - H. Henke for the loss factor part: excellent collaboration
  - the LEP design office: 1 engineer + up to 3 draughtsmen
  - the CERN central workshop for prototype, small quantities production, repair/expertise wrt industry, metrology
  - European industry for quantity production:
    - Interatom [D] (41)
    - CERCA [F] (19)
    - Philips [NL] (17)
    - Ingovi [E] (17)
  - FI, LEP/SU, LEP/VA, ST/Transport and those I have forgotten…., for procurement, preparation and installation.

LEP: Experience

- **To our knowledge, the users were satisfied**
- **There have been, over the 10½ years of LEP:**
  - **no collimator replacement**
  - **no motor/resolver failure with 10 MGy integrated dose**
  - **two occasions where LEP has been stopped:**
    - **on a Sunday when “somebody” had closed a cooling valve (which demonstrated the necessity of cooling!)**
    - **on a Saturday night when the Section was at the farewell party of one of its eminent members and a pin (out of ~ 10’000) in a cable [which had been replaced by an outside contractor because of radiation damage] no longer made contact.**

In both cases the length of the stop depended on the time to find BI people, as there was no “piquet” service, thanks to the very high reliability of the collimators.

ISR and LEP Collimation

What have we learned which should be useful for LHC?

- Collimation is a multi-disciplinary activity needing a good collaboration between various groups of specialists
- collimation is a staged activity over time:
  - system definition & specification
  - beam-material interaction
  - beam E-M fields-collimator interaction
  - model & prototype work
  - detailed mechanical collimator design
  - precision controls, including interlocks and monitoring
  - industrial production
  - preparation and installation
- To get a good collimation system ready on DAY 1, needs time, some of it uncompressible, be it for LEP or LHC.

ISR and LEP Collimators

- **The CERN ISR collimator system**

T. Risselada, R. Jung, D. Neet, H. O'Hanlon, L. Vos, PAC 79

- **Design and construction of LEP collimators**

F. Bertinelli, R. Jung, PAC 87

- **Design of a new generation of collimators for LEP200**

R. Jung, R. Perret, R. Valbuena, PAC 93

C. HAUVILLER
02/01/25

The ISR new beam dump

Description

Pre-design and design tools

If I would have to build a new ISR beam dump today?

Description

Energy, Power *
Internal beam dump
UHV 300°C bake-out Stopping material outside
Ejection through a Titanium window
Protection of the vacuum chamber with a fixed Copper collimator
Cascade dumped in slotted plates (Titanium and Stainless Steel)
Embedded in a stainless steel massive block

IEEE Transactions on Nuclear Science,

THE NEW ISR ABSORBER BLOCKS

Claude Hauviller

Summary

With the continual improvement of the ISR, one may hope that proton beams of intensities greater than 50 A (2.5 times the design value) will soon be obtained. The kinetic energy stored will then be 4 MJ and the instantaneous power at dumping greater than 1.3 Terawatt. New absorber blocks, able to stop 26 GeV/c beams of intensities up to 80 A, have been installed in the ISR in 1979. This paper describes the technical solutions adopted taking into account space, vacuum and operational constraints. Choice of materials criteria for the block itself, the vacuum chamber and the associated collimator are also presented.

these blocks should be changed. This report gives a description of the design of the newly installed absorber blocks, which are able to stop 26 GeV/c beams of intensity up to 80 A.

2. General

Design parameters have been extrapolated from their past and present values. Circulating beam sizes remain unchanged: rectangular-shaped horizontal distribution over 70 mm and Gaussian vertical distribution with a minimum value of the standard deviation σ_v of 1.2 mm. At dumping, the beam is spread by the kick and σ_v increases up to 1.7 mm. Higher beam intensities are obtained by increasing the longitudinal density up to 1.8 A mm^{-1}. The beam energy taken for most of the computations in this report is 26.6 GeV/c.

ture increase ΔT and an estimation of the thermal stresses σ:

$$\Delta T = \frac{E_0 \, n}{\rho \, c} ,$$

$$\sigma = E \, \alpha \, \Delta T ,$$

where:

- n = number of incident protons,
- ρ = material density,
- c = specific heat,
- E = Young's modulus,
- α = thermal expansion coefficient.

The uncertainties at all the steps of the computation lead to the choice of a simple criterion: the elastic limit of the material is compared to the computed thermal stress. Excluding beryllium for safety reasons,

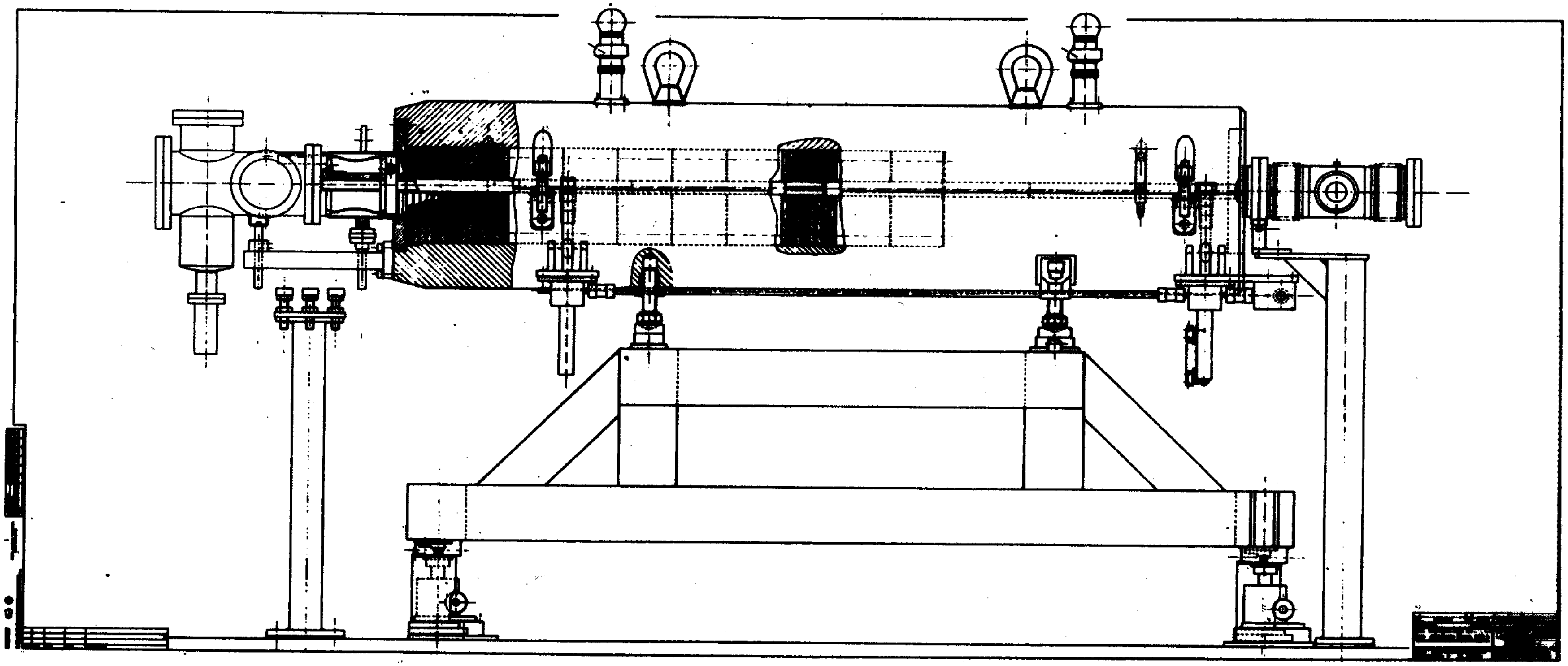
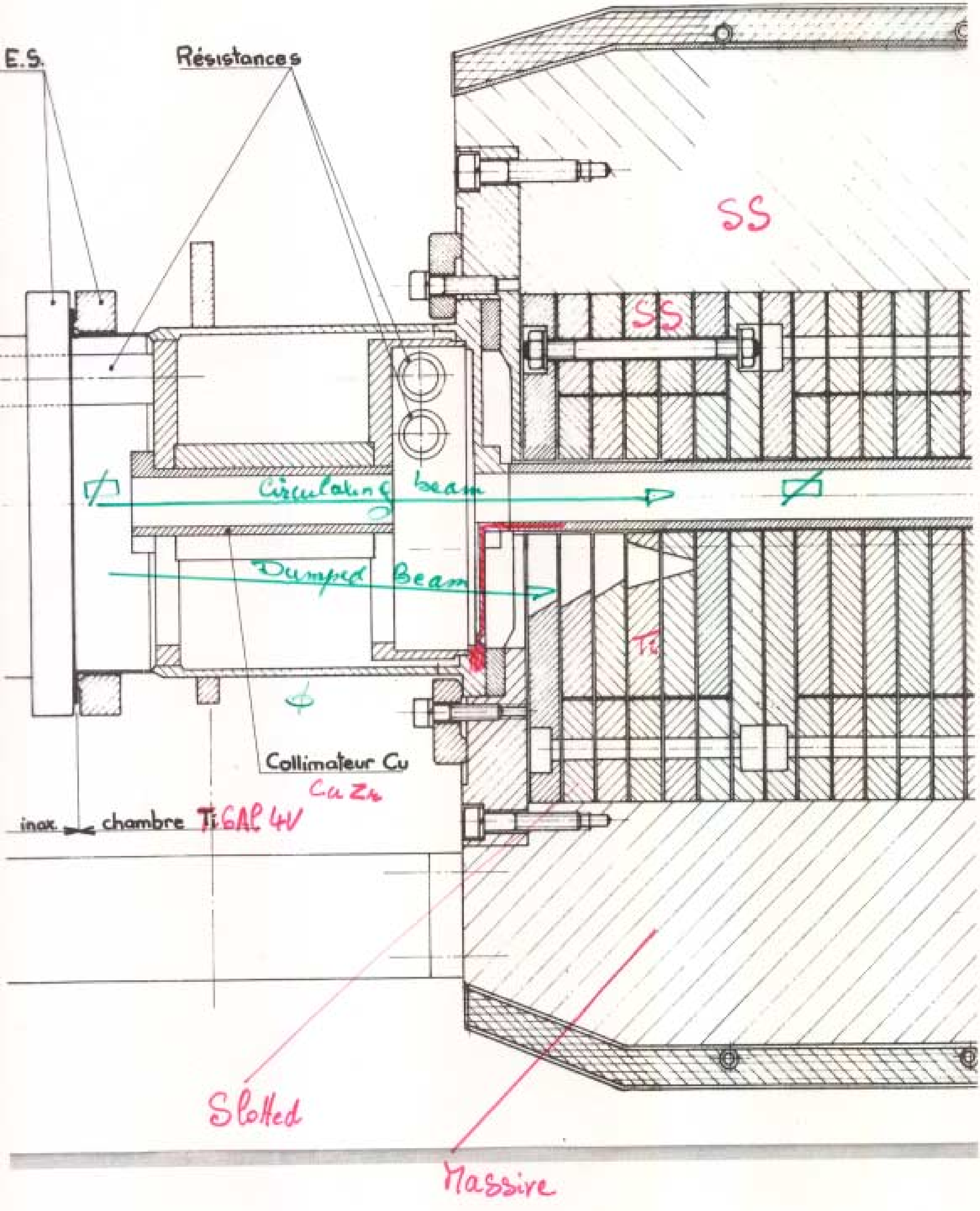


Fig. 1 Overall View of the Absorber Block Assembly

ISR Division, CERN
CH-1211 Geneva-23

0018-9499/79/0600-4134$00.75 © 1979 IEEE



E.S.
Résistances
SS
SS
Circulating beam
Dumped Beam
Ti
Collimateur Cu
Cu Zn
inox
chambre
Ti6Al 4V
Slotted
Massive

Pre-design and design tools

Cascade computations: CYLKAZ with modified input/output
Radiations analysis
Thermal analysis:

- **hand-computations (Eo, dE/dx)**
- **FEM software DOT**

Mechanical analysis:

- $s = E\ a\ DT / [1-(n-1)n]$ **n number of dimensions**
- **FEM software SAP** **static analysis**
- **FDM software REXCO** **shock wave analysis**
- **Fracture propagation (marginal)**

If I would have to build a new ISR beam dump today?

Design

Same design principle: avoid heating inside the UHV chamber
Same pre-design method
Updated design tools available in-house: StarCD, ANSYS
Improved study based on damage mechanics

Materials

Still avoid pure Beryllium (if possible)
Use more sophisticated materials to lower density:

- **High performance composites:**
  carbon-carbon
  metallic (Mg and Al based)
  metallic honeycomb
  fiber-reinforced ceramics
- **Metallic foams**
- **Diamond coating (high conductivity, high strength,…)**
- **Beryllium alloys (?)**

Beam Obstacles

Experience and Expertise in the SL Beam Transfer Group

Luca Bruno

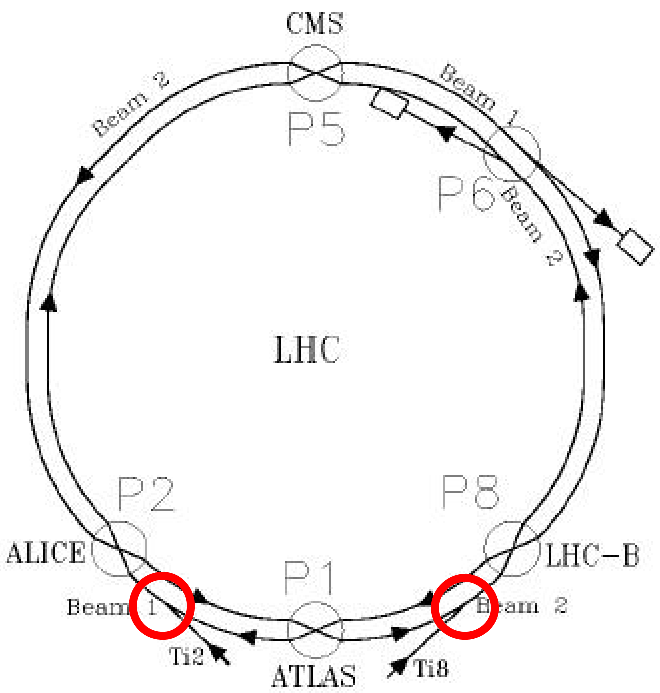
SL/BT **Target Section**

Outline

What can be said in ~20 minutes ?

- **List of Beam Obstacles (BO) dealt with by the SL/BT Target Section;**
- **Design sketches of selected BO ;**
- **Assumptions & specifications;**
- **Engineering Issues & Choices in BO design ;**
- **Bibliography .**

TDI - Assumptions and specifications



TDIs & TCDD Locations

Beam clearance: ± 10 s (~10 mm)

Max length : 5 m TDI / 1 m TCDD

Non-flatness : < 300 µm

Op. conditions :

Normal goal: no magnet quench

1 centred pilot bunch / 16 s

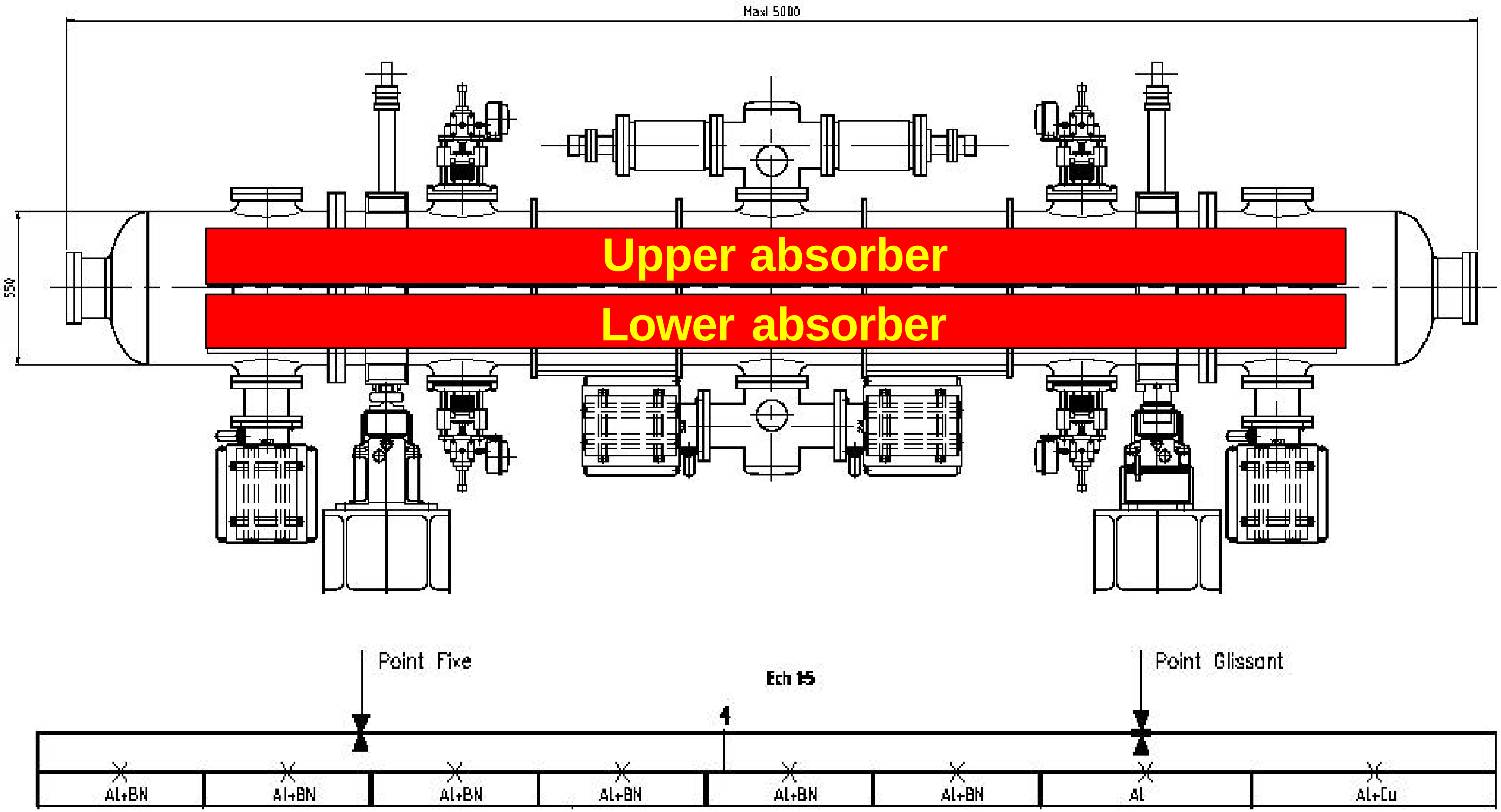
Upset goal: no magnet damage

1 full train centred (several/year)

swept bunches (several/year)

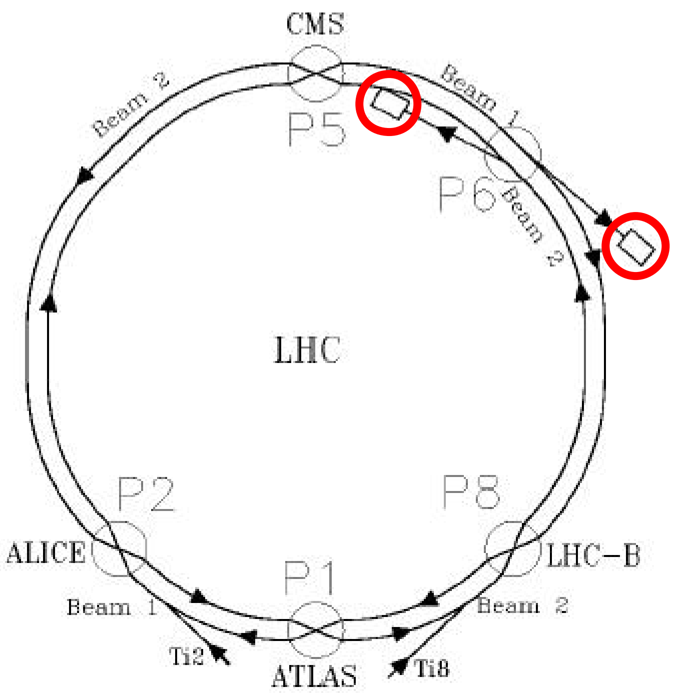
grazing bunches (1/10 years)

TDI - The Injection Beam Stopper



Upper absorber

TDE - Assumptions and specifications



TDEs Locations

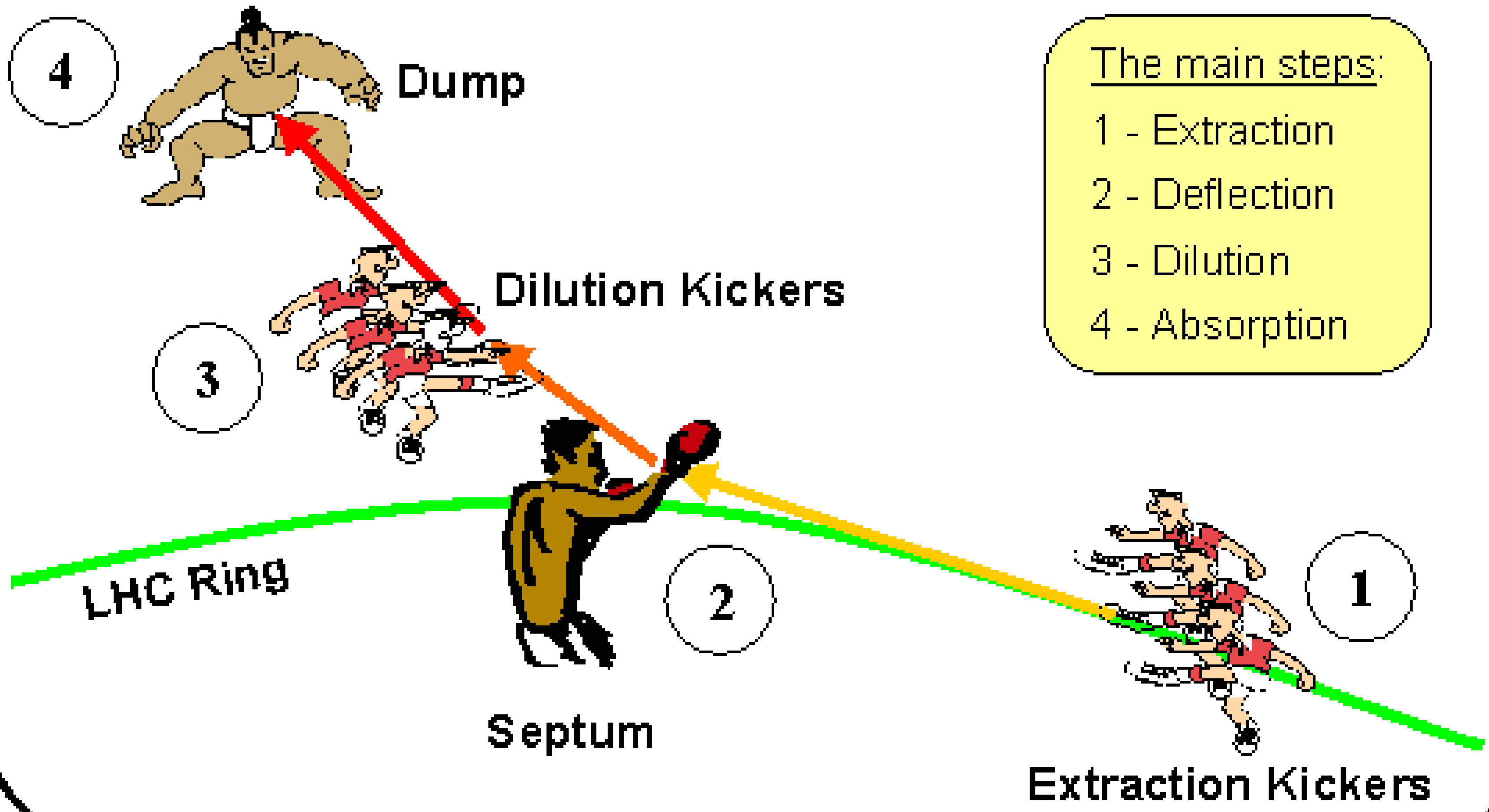
Beam energy	540 MJ (482 Tp)
Absorption time	86 µs
Beam shift	± 50 mm

Op. conditions

Normal goal: full beam absorption at ultimate intensity every 8 h;
beam dilution system active

Off-normal goal: no damage to the extraction line; no unrecoverable damage in the dump cavern
partial dilution (several/year)
total dilution failure

Introducing the LHC Dumping System



The main steps:

1 - Extraction

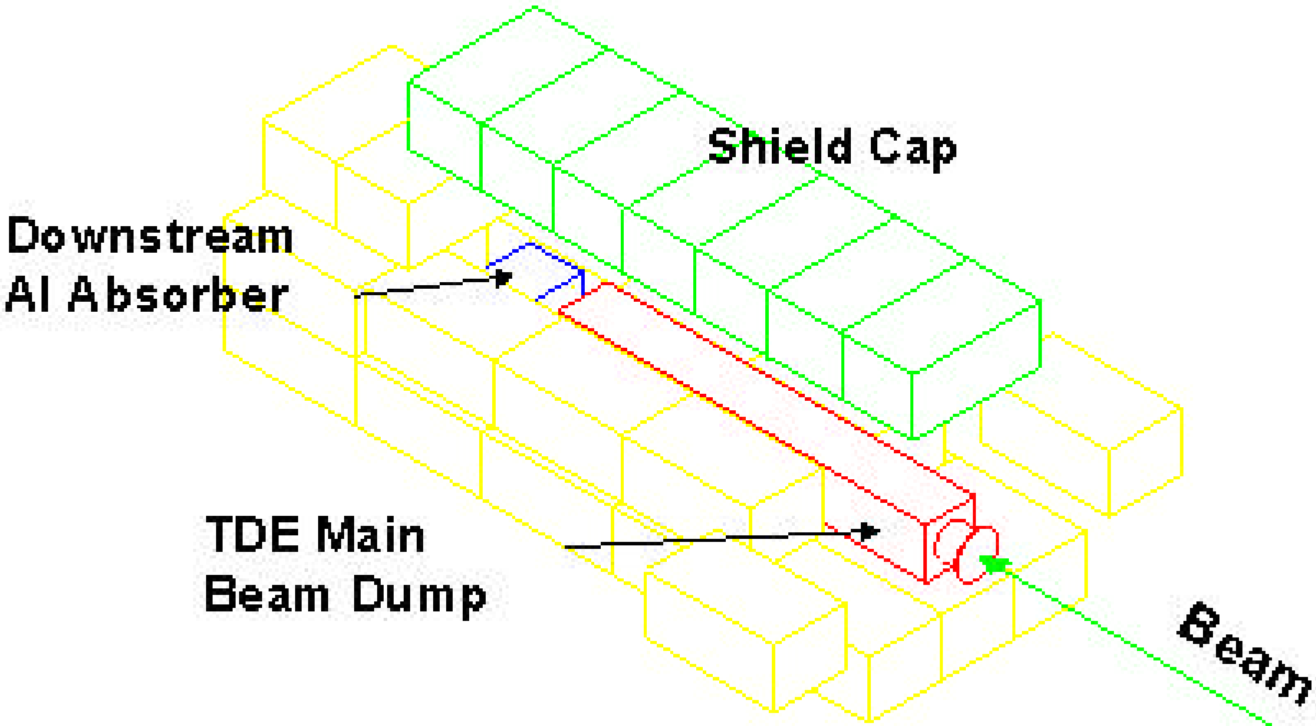
2 - Deflection

3 - Dilution

4 - Absorption

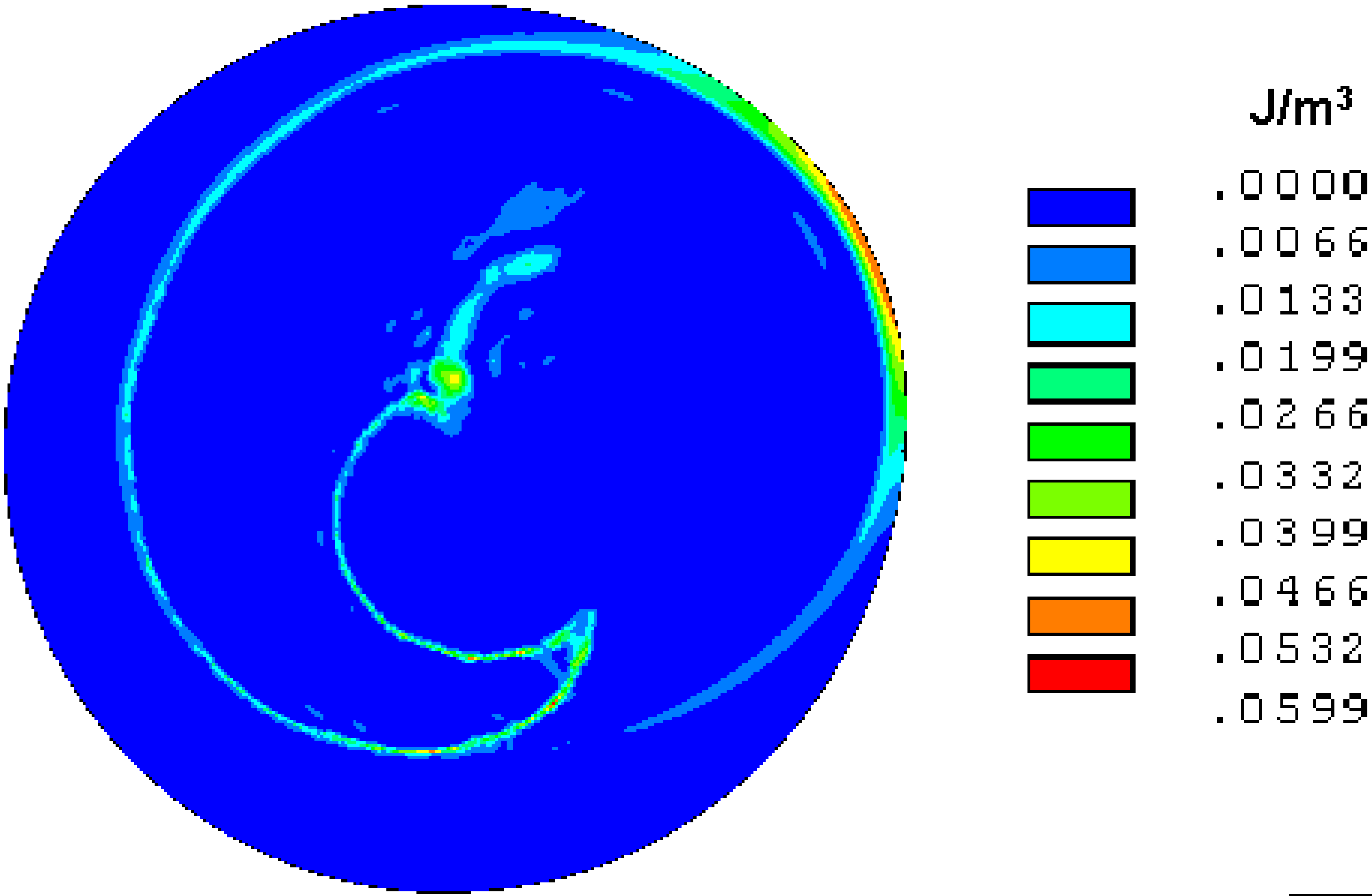
Assembly Sketch of the

LHC Beam Dump (TDE)



Kinetic energy density

at the end of beam absorption (t=85.8 μs, z=250 cm)



Invitation

Wednesday, January 30th, in room **865/1-D17** at **9:30** two Century Dynamics representatives will report on the

Study of the structural behaviour of the

LHC Beam Absorber (TDE)

in the case of a total beam dilution failure

Engineering Issues

Issue		Consequence
Extremely high thermal loads	→	**New material choices are required to cope with the specifications**
↓		
Complex, non-linear phenomena	→	**The know-how to perform complex numerical studies is neither available at CERN nor can be acquired in the medium term**
↓		
Safety Issues	→	**A commonly agreed and sound engineering approach to deal with machine safety is needed**

Engineering Activities

Material choice

An R&D activity is being performed on industrial ceramics (hBN in part.)**, test procedures** (vacuum, thermal shock, mech. properties) **and metal coating** (Ti)

Complex, non-linear phenomena

Partners outside CERN have been selected for short term support (Century Dynamics) **and long term collaboration** (CRS4) **on numerical studies**

Safety Issues

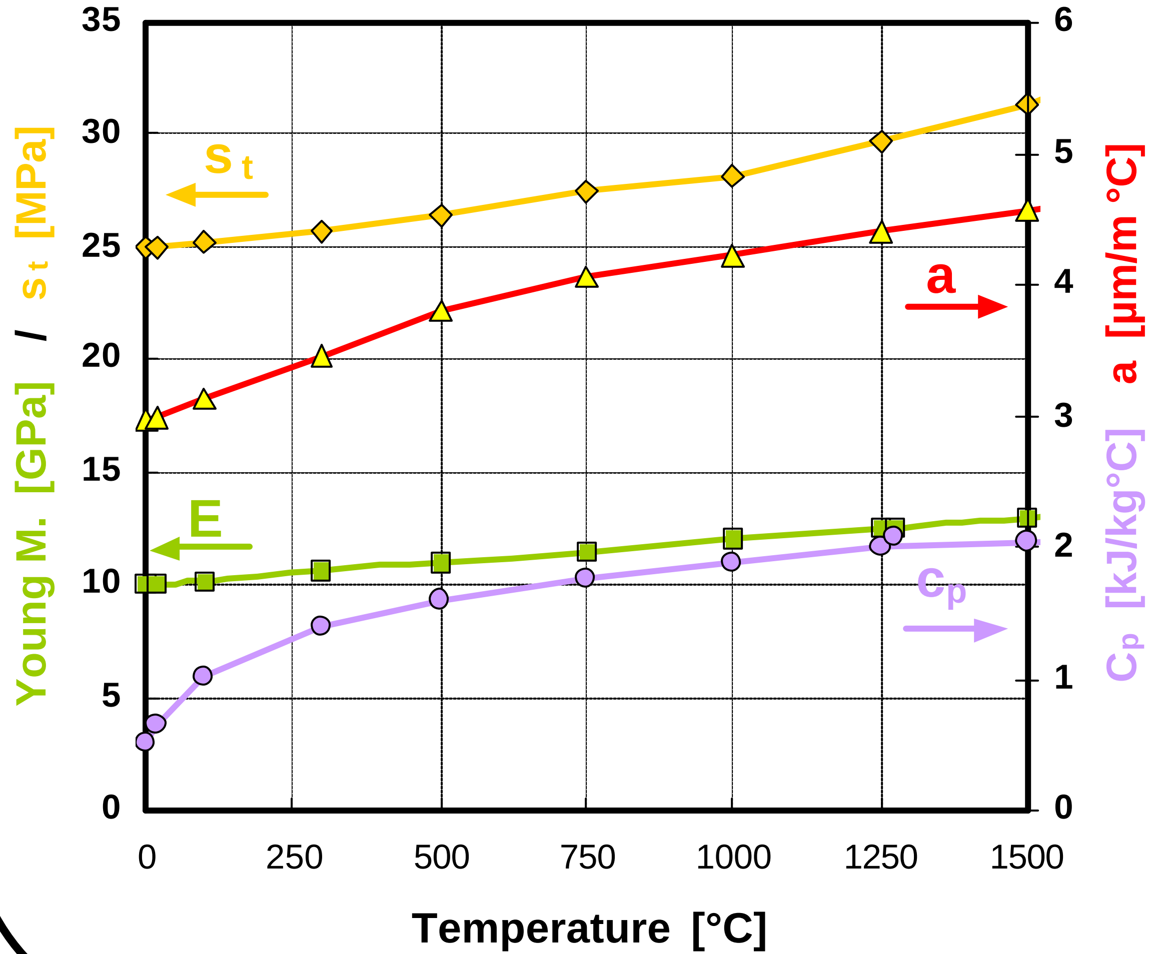
Safety & risk analyses procedures used in (nuclear) industry are being investigated

Material Choice

Graphites and hBN - Material Properties at 20 °C										
Property	**Unit**	**Carbone-Lorraine**			**SGL**				**POCO**	**h-BN**
		1940	2020	2333	R7500	CZ3	CZ5	CZ7	ZXF-5Q	AX05
Apparent Density	g cm^{-3}	1.76	1.77	1.86	1.77	1.73	1.84	1.88	1.78	1.91
Open Porosity	%	16	9	10	13	14	10	10	16	
Avg. Grain size	µm	12	16	5	10	20	10	3	1	
Young Modulus	Gpa	10	9.2	10	10.5	10	11.5	14	14.5	30
Thermal exp. Coeff.	µm/m °C	4.7	3.5	6	3.9	3.8	5.1	5.8	8.1	0.5
Thermal Conductivity	W/m°C	81	75	90	80	65	100	100		71/121
Electrical resistivity	µΩ m		16.5		14	18	13	13	19.5	$> 10^{14}$
Specific heat	J/kg °C	710	710	710	710	710	710	710	710	800
Flexural strength	MPa	45	41	76	50	40	60	85	115	22
Compressive Strength	MPa	91	100	167	120	90	125	240	195	23
Tensile strength	MPa	30	27	50	33	26	40	56	76	15
Ratio σ_c/σ_t	-	3.1	3.7	3.3	3.6	3.4	3.2	4.3	2.6	1.5
$K \sim (\sigma_t C_p)/(E \alpha)$	-	0.45	0.60	0.59	0.57	0.49	0.48	0.49	0.46	0.80

A wide range of materials is nowaday available. The table shows a selection of graphite grades as compared to hexagonal boron nitride.

Graphite Properties



Thermo-mechanical Efficiency

$$K \propto \frac{s_t\, C_{p,avg}}{E\, a}$$

The change of properties with temperature is to be considered in the comparison between the different materials.

Beam Obstacles - Short Bibliography

Conceptual Optimisation of the TDI and TCDD protections for LHC Injection lines / *Péraire, S.; Sala, P.R.*; in preparation;

Beam Dumps and Beam Stoppers for LHC and CNGS Transfer Lines / *Péraire, S.; Sala, P.R.*; LHC Project Report 465. Geneva, CERN, 7 Feb 2001.

LHC Beam Dump Design Study - Part I: Simulation of energy deposition by particle cascades; implications for the dump core and beam sweeping system / *Péraire, S.; Zazula, J.*; LHC Project Report 80;

LHC Beam Dump Design Study - Part II: Thermal analysis; implications for abort repetition and cooling system / *Péraire, S.; Zazula, J.*; LHC Project Report 87;

LHC Beam Dump Design Study - Part III: Off-normal operating conditions; / *Bruno, L.; Péraire, S.; Ross, M.; Sala, P.R.*; LHC Project Note 217;

Protection against ~~LHC dump errors~~ *Unsynchronised Dump*

TCDS and TCDQ

Brennan GODDARD, SL/BT

Acknowledgement

The work reported in this talk is based on the efforts of the following people:

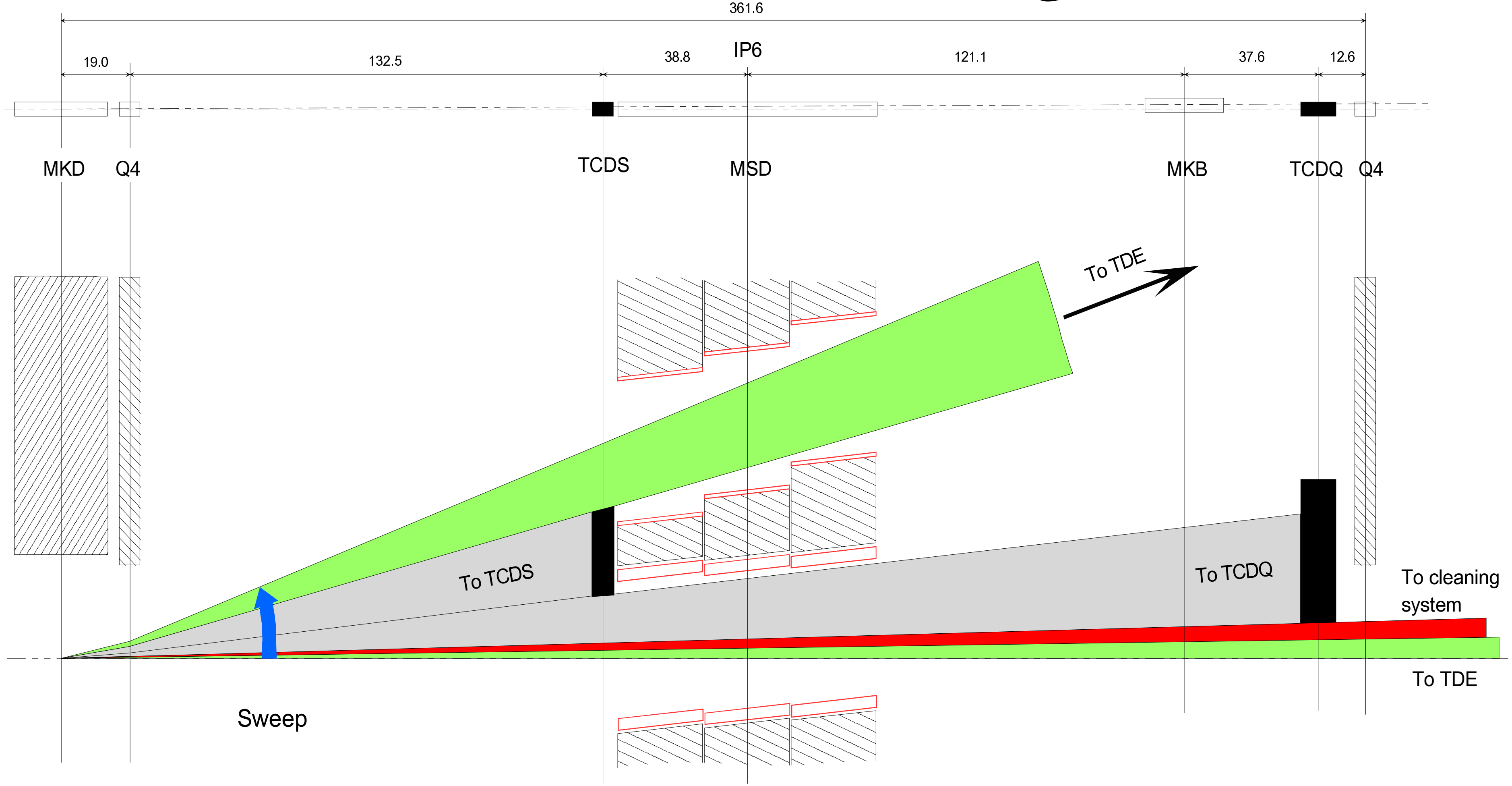
A. Drozhdin*, M. Gyr, M. Sans Merce, N. Mokhov* I. Rakhvo* and E. Weisse

**Fermilab National Laboratory*

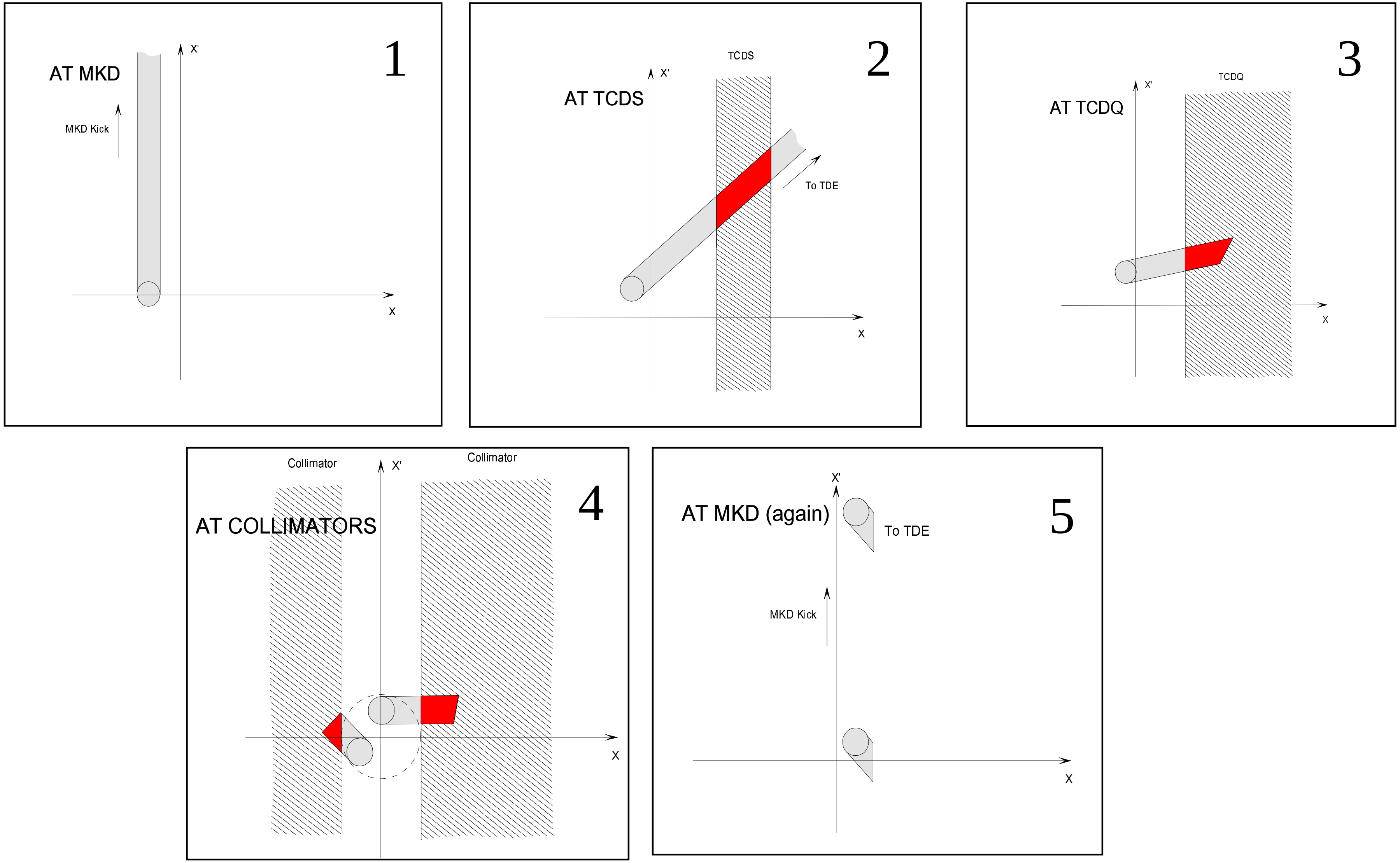
Warning!

Engineering of the TCDS and TCDQ is still in its early stages, and so <u>all</u> figures must be treated as provisional.

Extraction Protection Elements TCDS and TCDQ



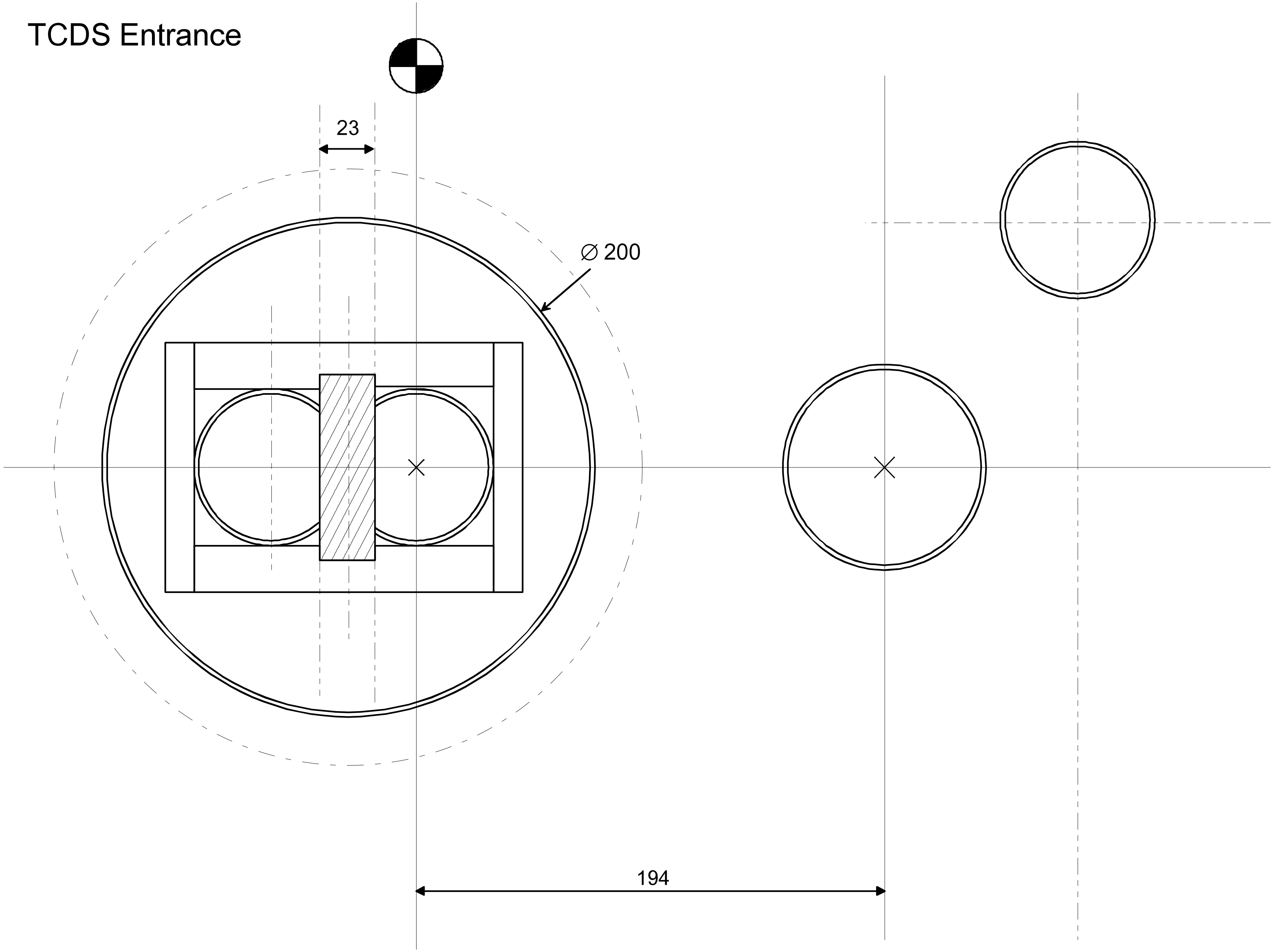
Where do the bunches go?



TCDS (Target Collimator Dump Septum)

- Fixed collimator (diluter) block to protect MSD septum from destruction in the event of unsynchronised firing of MKD kickers (sweep). 2+1
- Still in conceptual study phase. Will be designed to cope with LHC ultimate beam (1.7 x 10^{11} protons per bunch at 7 TeV).
- Block made of carbon (or BN) ~23mm wide, ~6m long.
- All inclusive tolerance on installed position to better than ±1mm.
- Protects MSD from MKD sweep only.

TCDS concept (section)

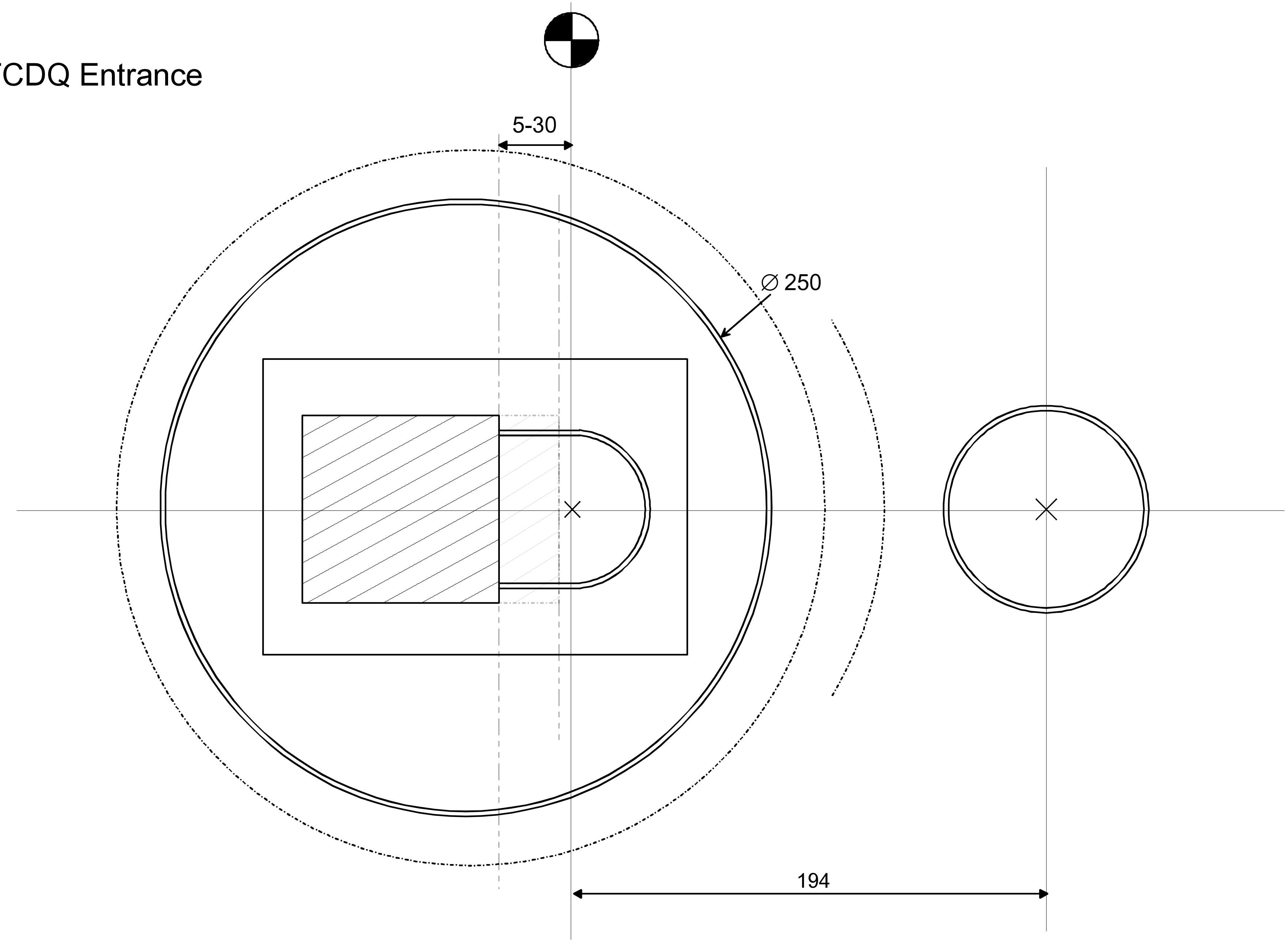


TCDQ (Target Collimator Dump Quadrupole)

- Collimator (diluter) to protect Q4 and IP5 insertion from destruction in event of unsynchronised MKD firing (quenches inevitable in point 6). 2+1
- Still in conceptual study phase [1]. Will cope with LHC ultimate beam.
- Mobile single-jawed block of carbon (BN?) + aluminium ~9.5m long. To be positioned outside cleaning collimators by several sigma i.e. could be closed to 10 sigma (plus what is needed for orbit…).
- Vacuum vessel(s) supported either directly on mobile support girder or floor (depending on choice of movement). Total length ~11m.

TCDQ concept (section)

TCDQ Entrance



Heat loads and peak local temperature rises in various elements (preliminary figures*!!)...

Element	Heat load (KJ)
TCDS	1120
MSD1	1340
MSD6	20
MSD15	3
TCDQ1	1640
TCDQ2	528
TCDQ3	60
Q4	22
Q5	4.6
MBA-1	3
MBB-1	0.64
Q8	0.11
MBA-2	0.3
MBB-2	0.17

Element	Material	Delta T (K)
TCDS	C	554 (>>?)
MSD1	Fe	98
MSD6	Fe	1.3
MSD15	Fe	0.07
TCDQ1	C	456
TCDQ2	C	155
TCDQ3	Al	5

*from Mokhov et al

Note: for low density (~1.1) C only, not BN

Non-nuclear engineering considerations/constraints

Vacuum:	Materials choice Bakeout Conditioning Surface coatings Dust in vacuum? Electron cloud ? …	**Impedance:**	Materials choice RF contacts Shields Coatings Transition tapers Bunch structure …
Mechanical aperture:	Orbit Tolerances Movement… Vac. chambers Alignment Stability …	**Performance:**	Instrumentation Logging Activation Cooling/recovery Spotting damage Upgrades? …

Note: contents of different boxes are inter-dependant!

Protection in Transfer Lines

- **Why passive protection in the transfer lines TI 2,8 ?**

  the inj. lines to the LHC are pulsed

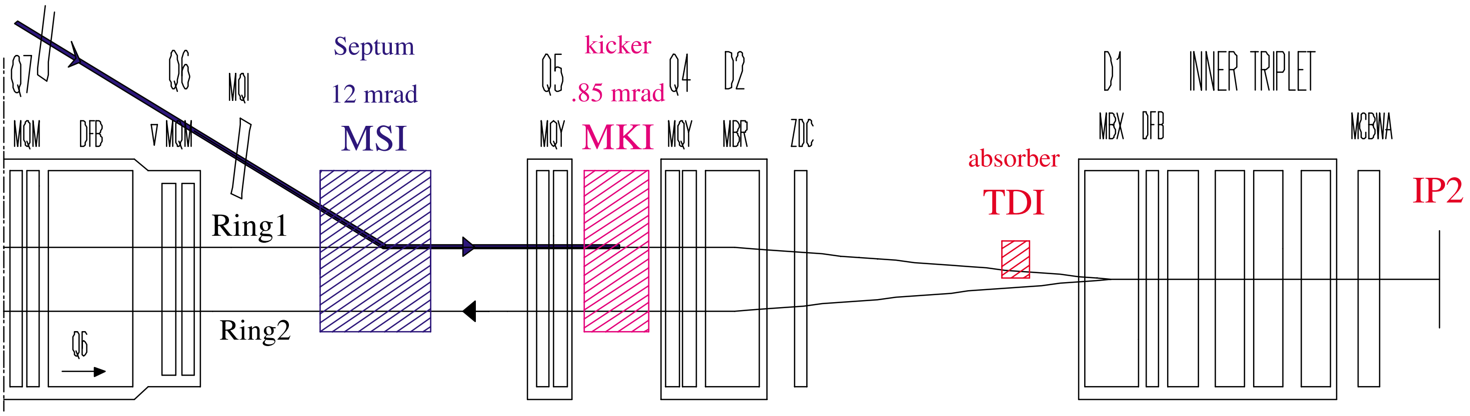
  single batch (2.6e13 protons, 450 GeV) can do serious damage

- **protect LHC from bad injection**

  TDI only effective in the vertical plane for kicker failures

  passive protection in the transfer lines should also limit horizontal inj. oscillations

  depending on LHC collimator design, transfer line protection could also reduce risk of damage of collimation devices in the LHC



- **Main idea**

  passive protection in front of the septum (MSI)

  complemented by further device(s) at $\Delta = 90^{o}$ phase

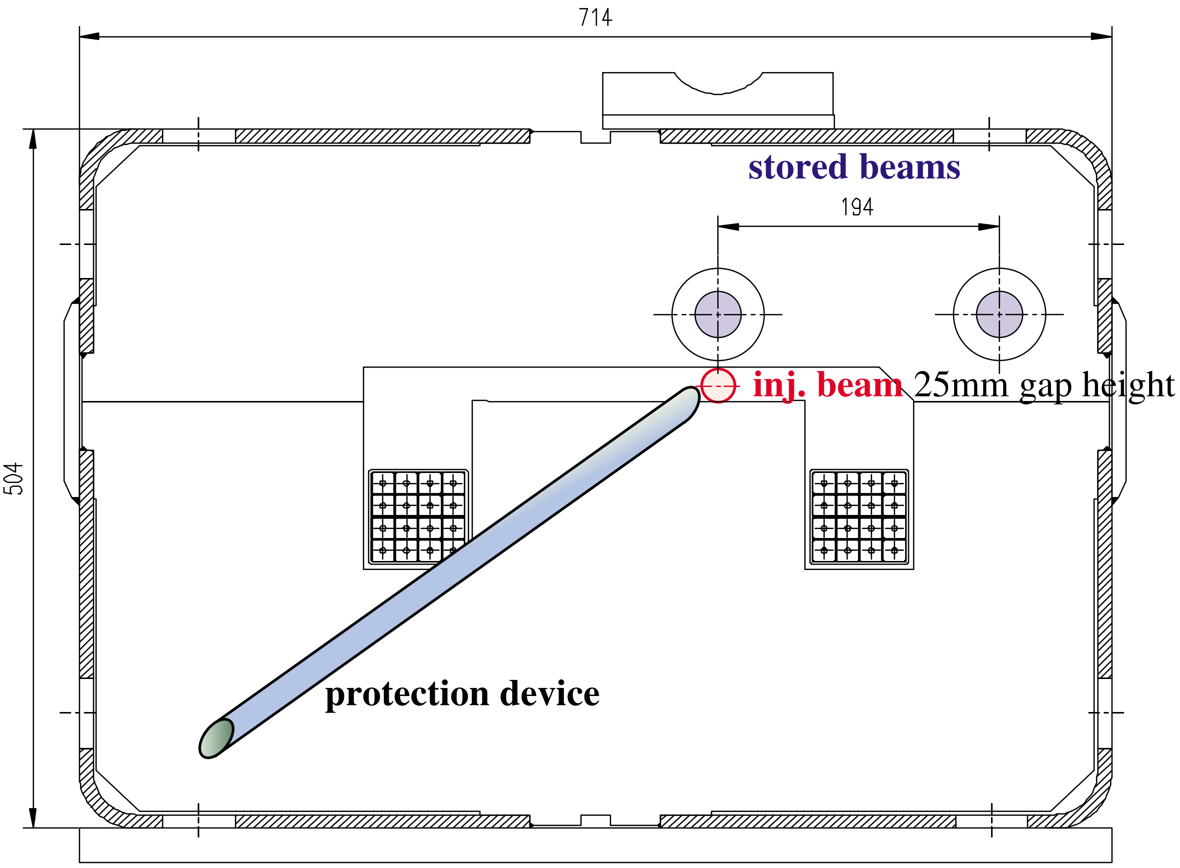
  also consider momentum collimation at beginning of the lines

- **Look for best compromise between**

  simple, cheap, effective (narrow fixed pipe/collimators)

  easy operation/setup of injection (sufficient aperture for setup with pilots)

1) passive protection of the septum



Septum (MSI) made of 5 magnets, 12 mrad total horizontal deflection
25 mm gap height, physical aperture for beam at best ~ 12 mm radius

optics parameters, (nominal beam $\varepsilon = 7.8$ nm, $\Delta p/p = 0.47e\text{-}3$)

H $\beta =$ 52 m D = 0.07 m $1\sigma = 0.64$ mm

V $\beta = 216$ m D = 3.0 m $1\sigma = 1.9$ mm (1/3 from $\Delta p/p$)

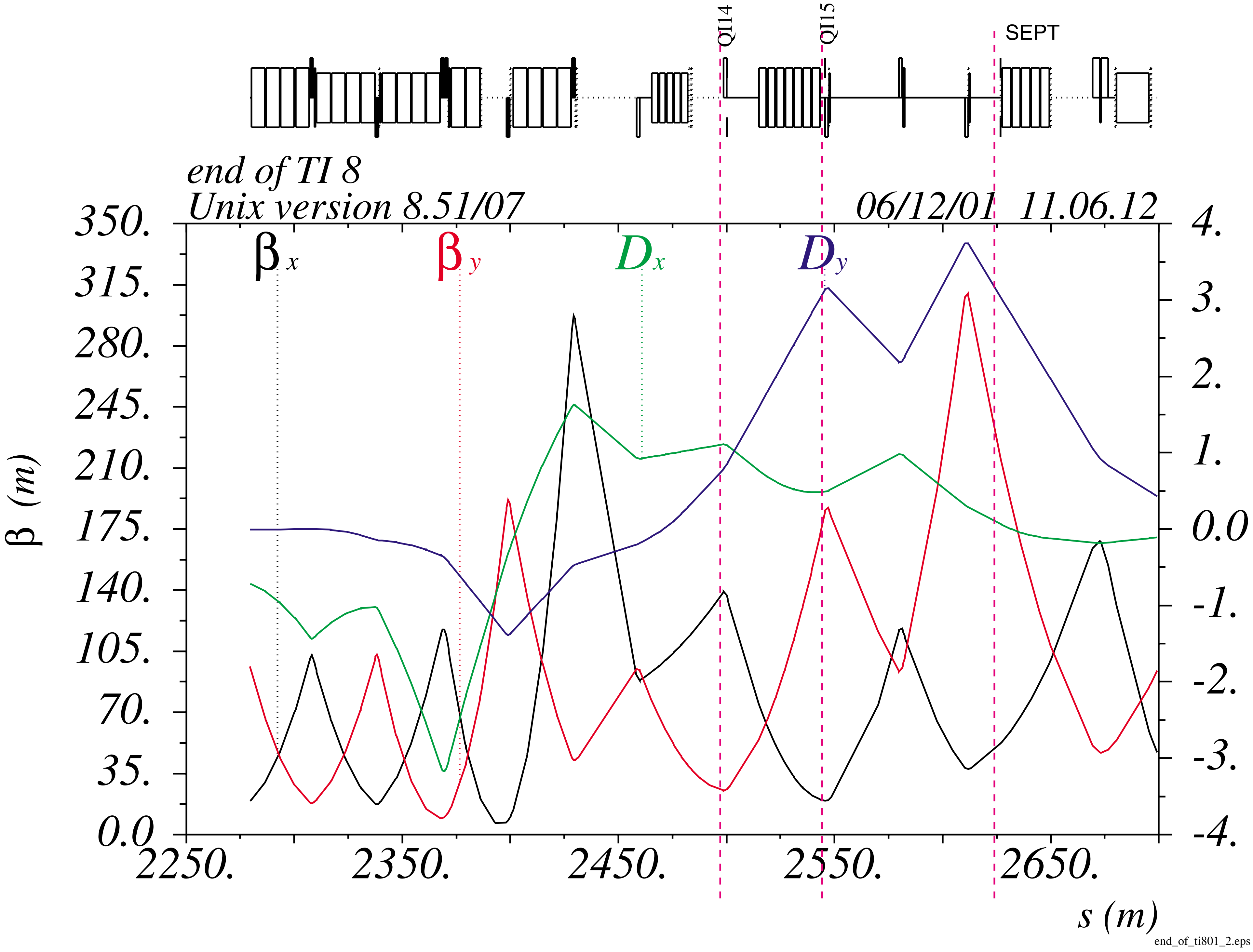
protection at 5σ would correspond to

$\pm$ 9.5 mm in V

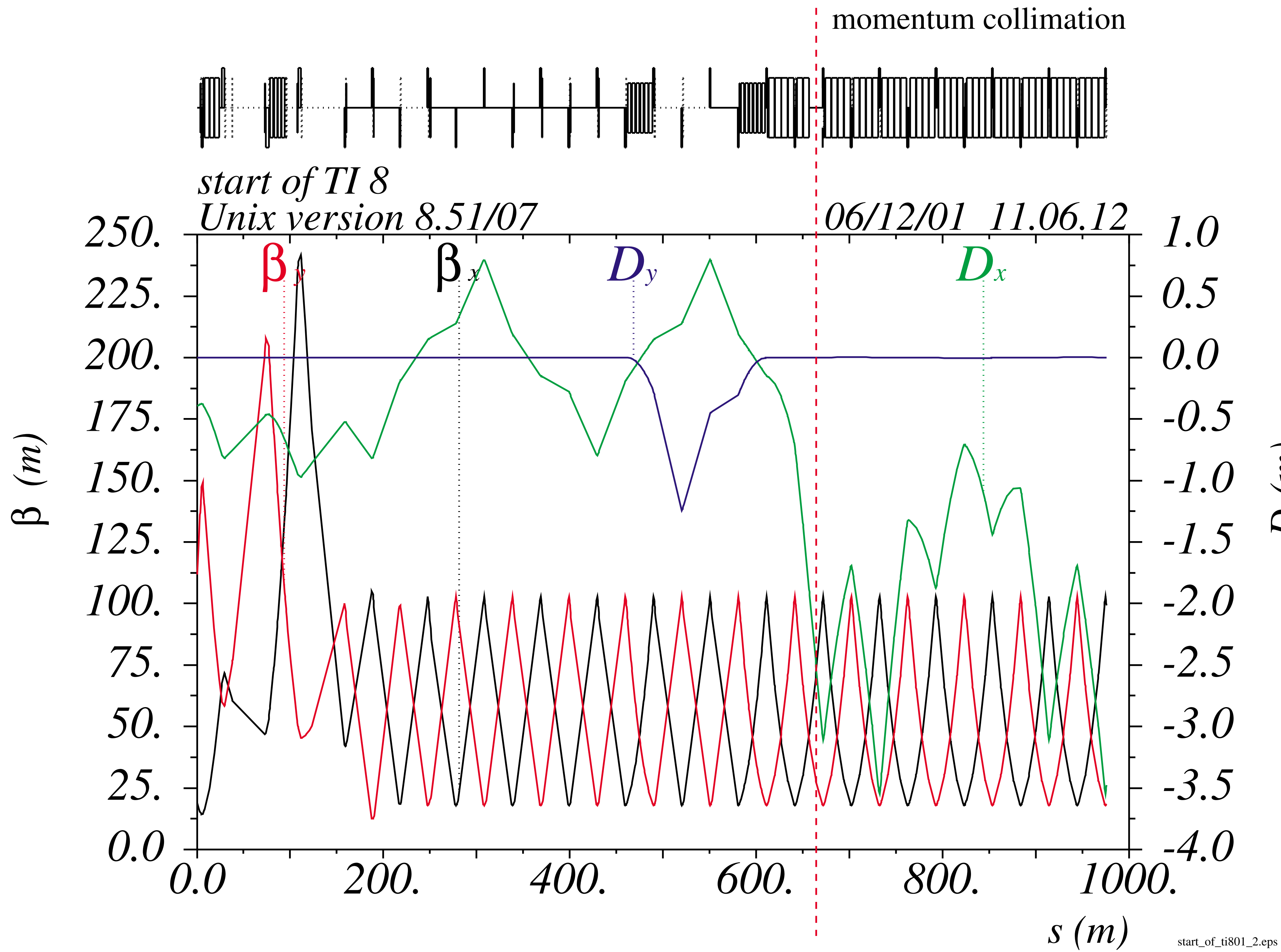
$\pm$ 3.2 mm in H (±10 mm in H is 15.6σ or rather poor protection in LHC)

Consider: 3-4 m pipe with inside rings of low Z high temp. materials like Graphite or Boronnitrit

lhcinj/septum.eps



QI14
QI15
SEPT
end of TI 8
Unix version 8.51/07
06/12/01 11.06.12
βx
βy
Dx
Dy
β (m)
D (m)
s (m)
350.
315.
280.
245.
210.
175.
140.
105.
70.
35.
0.0
4.
3.
2.
1.
0.0
-1.
-2.
-3.
-4.
2250.
2350.
2450.
2550.
2650.
end_of_ti801_2.eps


momentum collimation
start of TI 8
Unix version 8.51/07
06/12/01 11.06.12
β y
β x
D y
D x
β (m)
D (m)
s (m)
250.
225.
200.
175.
150.
125.
100.
75.
50.
25.
0.0
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
0.0
200.
400.
600.
800.
1000.
start_of_ti801_2.eps

Currently considered and simulated tracking (Mad V6.2)

passive devices, narrow pipes exchangeable or movable

1) H momentum cleaning at beginning of the line
2) V about 90^o from Septum
3) H about 90^o from Septum
4) Septum protection

with number for optics in Ti8:

Name H	s, m	βx, m	Dx, m	σx, mm	frac disp	μx	Δμx	Δφ, ^{0}
COLLMOM	671.144	101.157	-3.078	1.693	2.62	2.518	0	
COLLQI14	2500.071	137.089	1.101	1.157	0.25	10.017	7.499	158^o
COLLQI15	2545.685	19.263	0.49	0.451	0.35	10.191	7.673	95^o
COLLMSI	2626.801	52.068	0.068	0.639	0.00	10.456	7.938	

V	s, m	βy, m	Dy, m	σy, mm	frac disp	μy	Δ μy	
COLLMOM	671.144	18.175	-0.001	0.377	0.00	2.485	0	
COLLQI14	2500.071	25.788	0.845	0.598	0.78	9.998	7.513	70^o
COLLQI15	2545.685	185.696	3.145	1.902	1.49	10.113	7.628	29^o
COLLMSI	2626.801	215.791	3.043	1.928	1.20	10.193	7.708	

5σ collimation would imply rather narrow apertures
H ± 2.3 mm at QI15
V ± 3.0 mm at QI14

Summary

Passive protection devices in the transfer lines important to protect septum region and LHC first turn

Relatively cheap narrow pipe devices can likely do the job
(possibly 3-4 m pipes with inside rings of low-Z high T material)

Protection of collimators in LHC needed ?

Good protection requires rather narrow apertures
they should be easily exchangeable or movable to allow for easy operation/setup

Session 4 - Knowledge on Tools for Collimator/Target Studies

Thermal Stress and Thermo-Acoustic Waves Implications for Choice of Material

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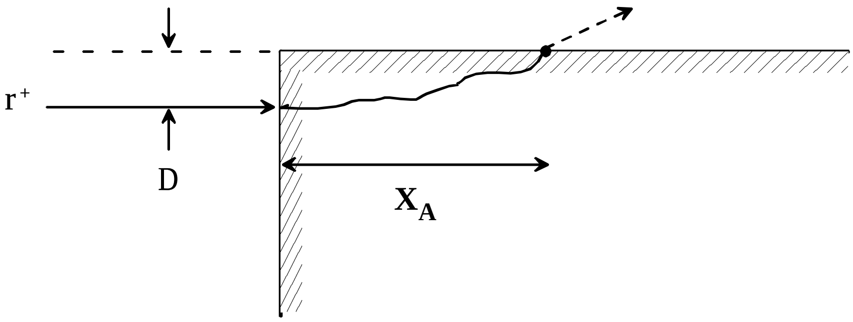
Peter SIEVERS / CERN-LHC

Collimation Day 25.1.2002

Choice of Collimator Materials
(Lab. II/BT/74-5)



Lateral Displacement due to Multiple Scattering Δ:

$$\Delta \sim X^{3/2} / X_R^{1/2} \;;$$

Radiation Length $X_R : X_R \sim \mathrm{A} / \mathrm{Z}^2 r$

Absorption Length $X_A : X_A \sim A^{1/3} / r$

Grey Zone : Δ reached after length X_A

$$\Delta_A \sim X_A^{3/2} / X_R \sim Z / r$$

	Be	C	Ti	Cu	W
Δ_A	2.2	3.3	4.4	3.2	3.8

However: At TeV Lateral Displacement Δ ~nm !

Coll. Efficiency defined mainly by X_A

and thus by Geometry + Alignment.

Beam Heating and Stresses

Cascade $dE(r,z)/\mathrm{dV}$

Depends on Beam : P_0, s

on material : A, r, Z

"Fast Heating"

Heating time $(\sim ms)$ << Thermal Diffusion Time (~ ms)

$$T(r,z) = \frac{1}{cr}\,\mathrm{dE}/\mathrm{dV}$$

In general $T(r,z)$ non uniform $\rightarrow$ Thermal Stress

e.g. Radial Symmetry $(Gauss\ s\ , \mathrm{Uniform}\ \mathrm{r} < \mathrm{r}_0)$ of Cylinder (R):

$$s\,(r=0) \approx \frac{EaT(r=0)}{2(1-n)}$$

E : Young's Modulus
a : Th. Exp. Coefficient
n : Poisson Ratio ~ 1/3

$$s\,(r=R) \approx \frac{EaT(r=0)}{1-n} \cdot 2s^2/R^2$$

Example

SL-93-47(BT) and TIS-RP/IR/93-10

	Be	C	Al	Ti	Cu	W
α [10^{-6}/k]	13	3.5	24	10	18	5
E [GPa]	230	9.2	70	100	120	400

450 GeV/c; σ = 1 mm; $10^{11}p^+$

T_0	0.8	3.3	7.1	28	22	171
$E\alpha T_0$[MPa]	2.4	0.1	12	28	48	342

7.3 TeV/c; σ = 0.35 mm; $10^{11}p^+$

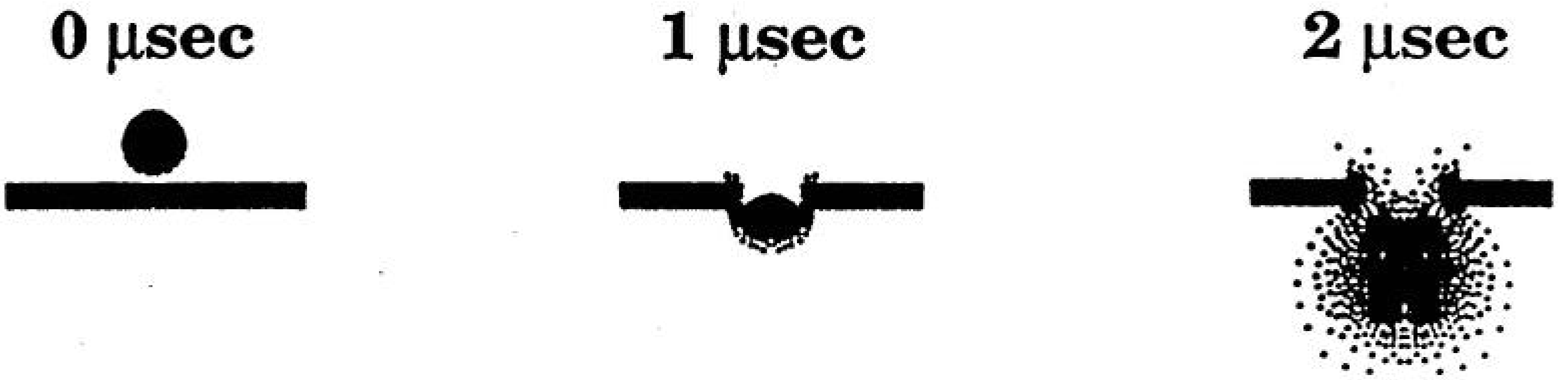
T_0	55	300	340(!)	1750!	4000!	29000!
$E\alpha T_0$[MPa]	165	9.1	574	1750	8727	58000

s_{ult} [MPa]	300	28	400	1000	800	1500

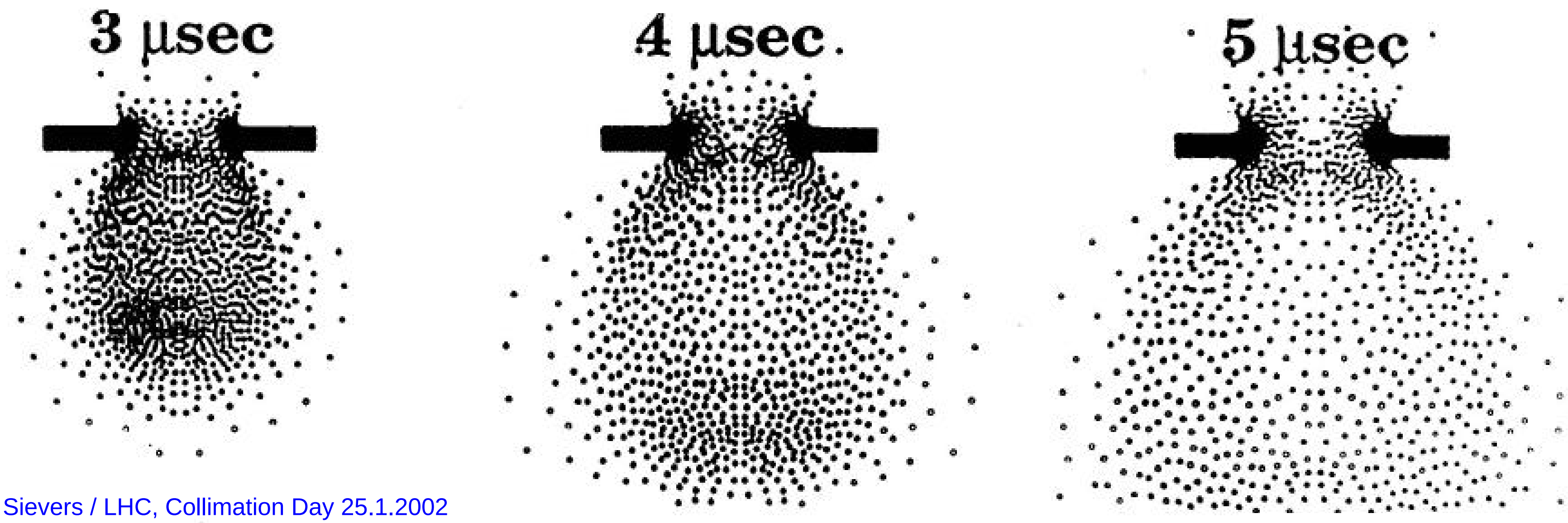
c_s[mm/µs]	10.7	2.3	5.0	4.5	3.7	4.5

20 km/sec Pb-Pb Impact

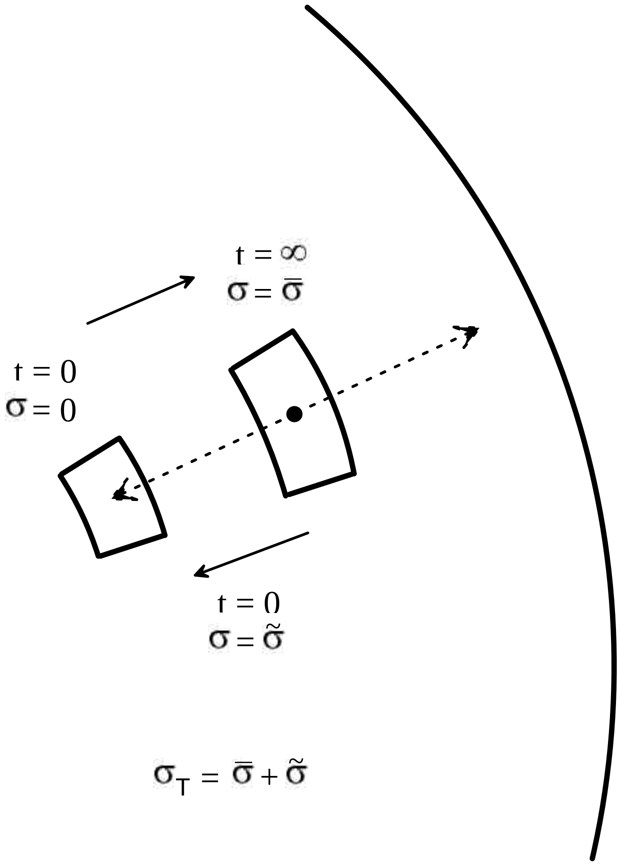
20 mm / ms

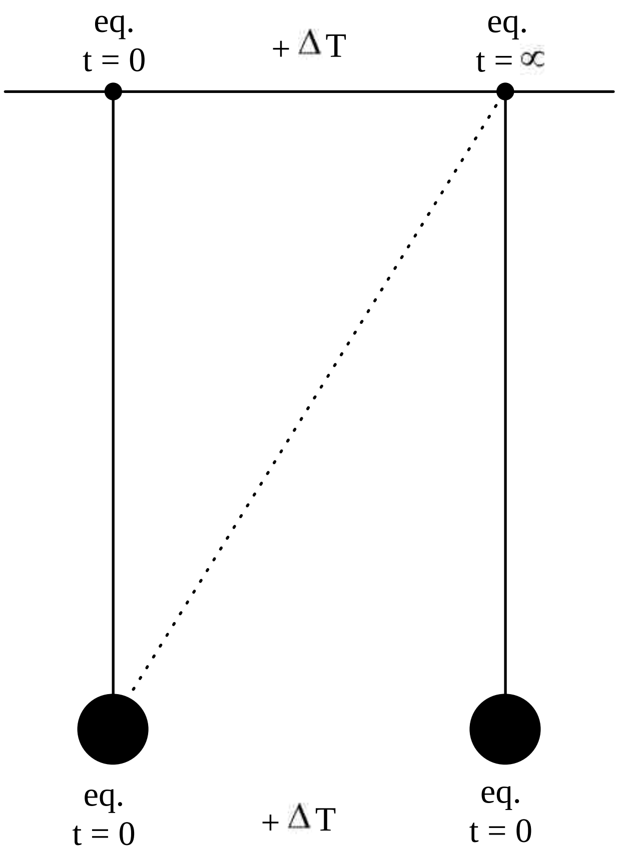


A PROTON BUNCH IS NOT A BULLET



Los Alamos


t = ∞
σ = σ̄
t = 0
σ = 0
t = 0
σ = σ̃
$\sigma_T = \bar{\sigma} + \tilde{\sigma}$


eq.
t = 0
+ ΔT
eq.
t = ∞
eq.
t = 0
+ ΔT
eq.
t = 0

Classical Solution of Wave equation

$$r\ddot{r} \sim \frac{\partial P}{\partial r} \; ; \; \mathrm{P} \sim \frac{\partial u}{\partial r} \;\text{and}\; \frac{u}{r}$$

$$\nabla^2 u = \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} \quad ; \quad \text{u : displacement}$$

- One dimensional

$$\frac{\partial^2 u}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2}$$

$$u(x,t) = f(x - ct) + g(x + ct)$$

- Spherical Symmetry

$$\frac{\partial^2 u}{\partial r^2} + \frac{2}{\mathrm{r}}\frac{\partial u}{\partial r} - \frac{2\mathrm{u}}{\mathrm{r}^2} = \frac{1}{\mathrm{c}^2}\frac{\partial^2 u}{\partial t^2}$$

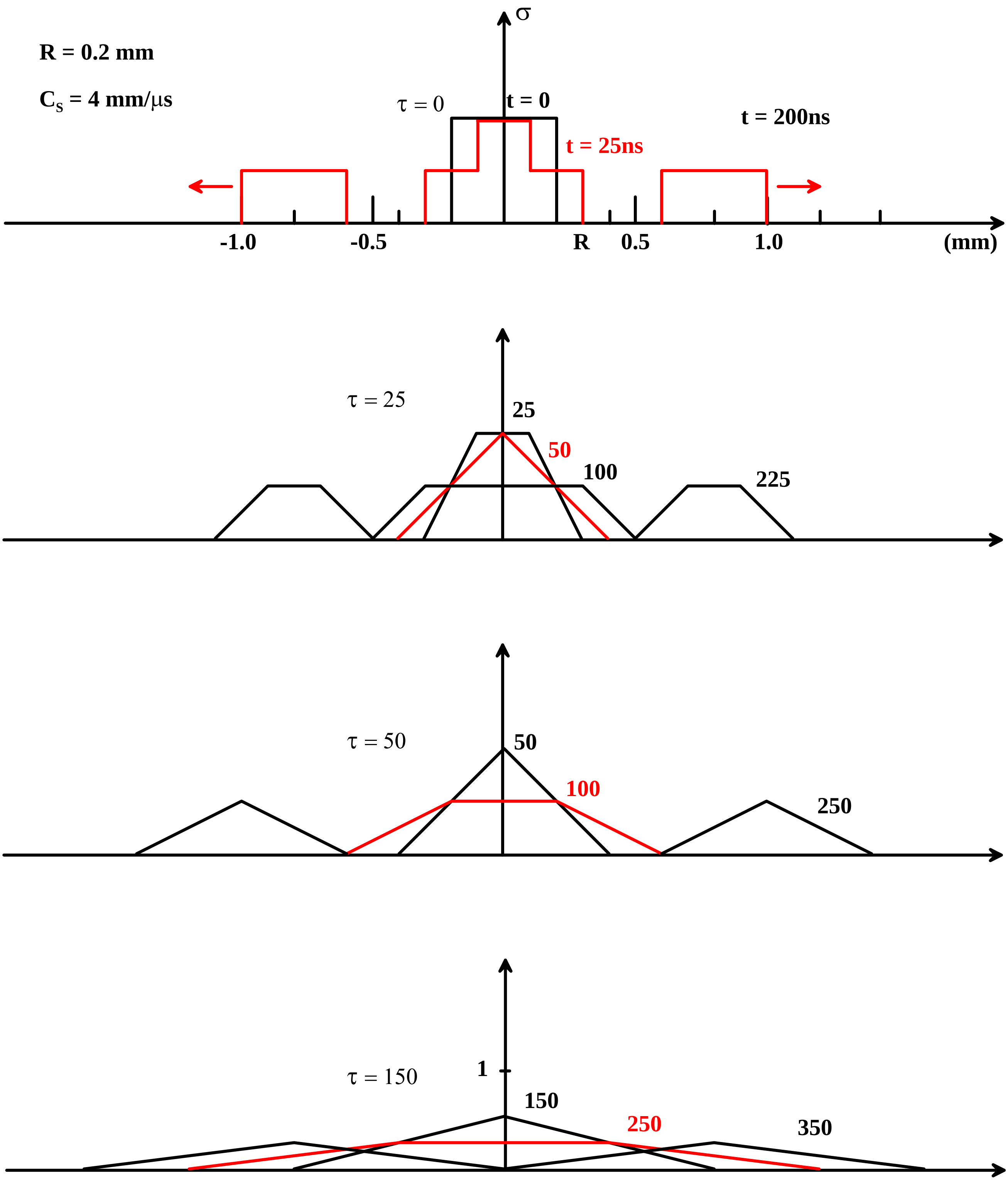
$$u(r,t) = f\,\frac{(r - ct)}{r} + g\,\frac{(r + ct)}{r}$$

- Cylindrical Symmetry

$$\frac{\partial^2 u}{\partial r^2} + \frac{1}{\mathrm{r}}\frac{\partial u}{\partial r} - \frac{\mathrm{u}}{\mathrm{r}^2} = \frac{1}{\mathrm{c}^2}\frac{\partial^2 u}{\partial t^2}$$

$$u(\mathrm{r},\mathrm{t}) = \sum_{\mathrm{n}=1}^{\infty} \mathrm{c_n} J_1(e_n x)\cos(e_n q)$$

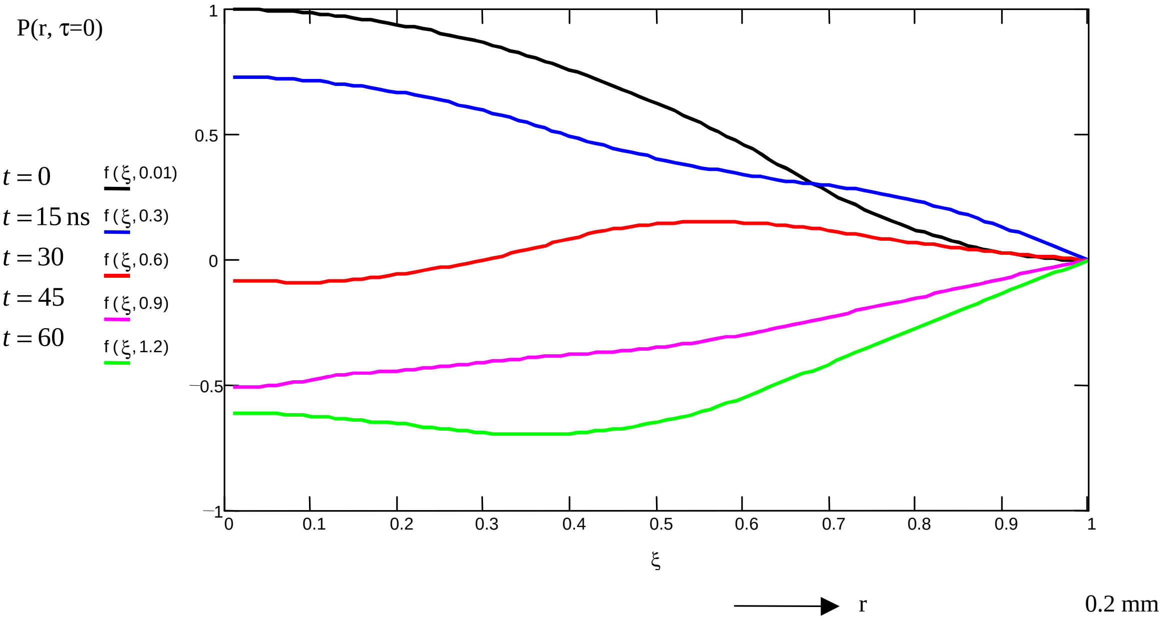
$$x = r/R, q = ct/R$$



R = 0.2 mm
C$_s$ = 4 mm/µs
σ
τ = 0
t = 0
t = 25ns
t = 200ns
-1.0
-0.5
R
0.5
1.0
(mm)
τ = 25
25
50
100
225
τ = 50
50
100
250
τ = 150
1
150
250
350

Liquid with free boundary conditions, Extended Parabolic Profile

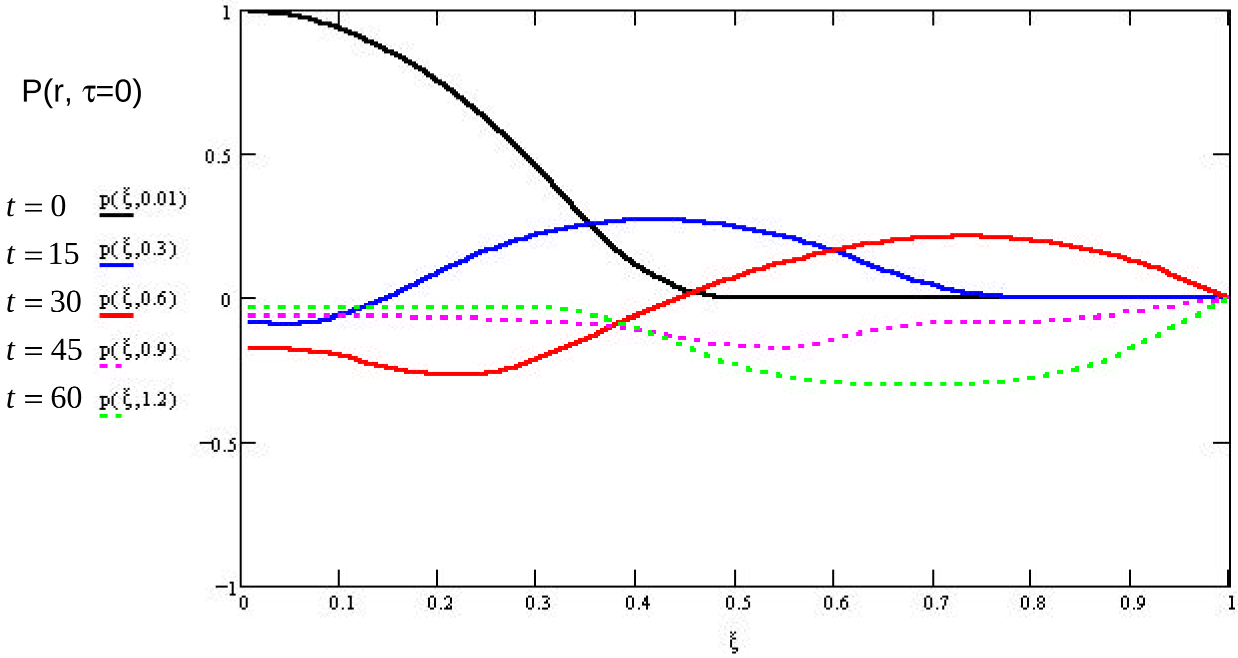
C = 4 mm / μs



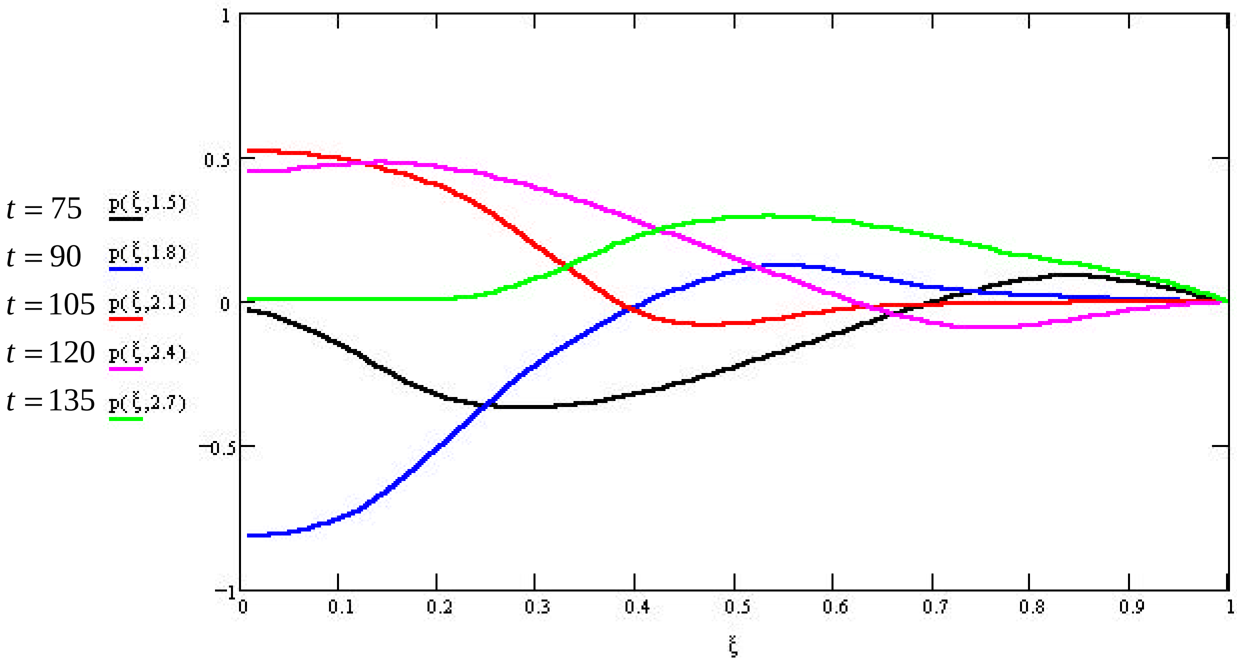
Liquid with free boundary conditions, Extended Parabolic Function

$\xi_i = 0.5$

P(r, τ=0)



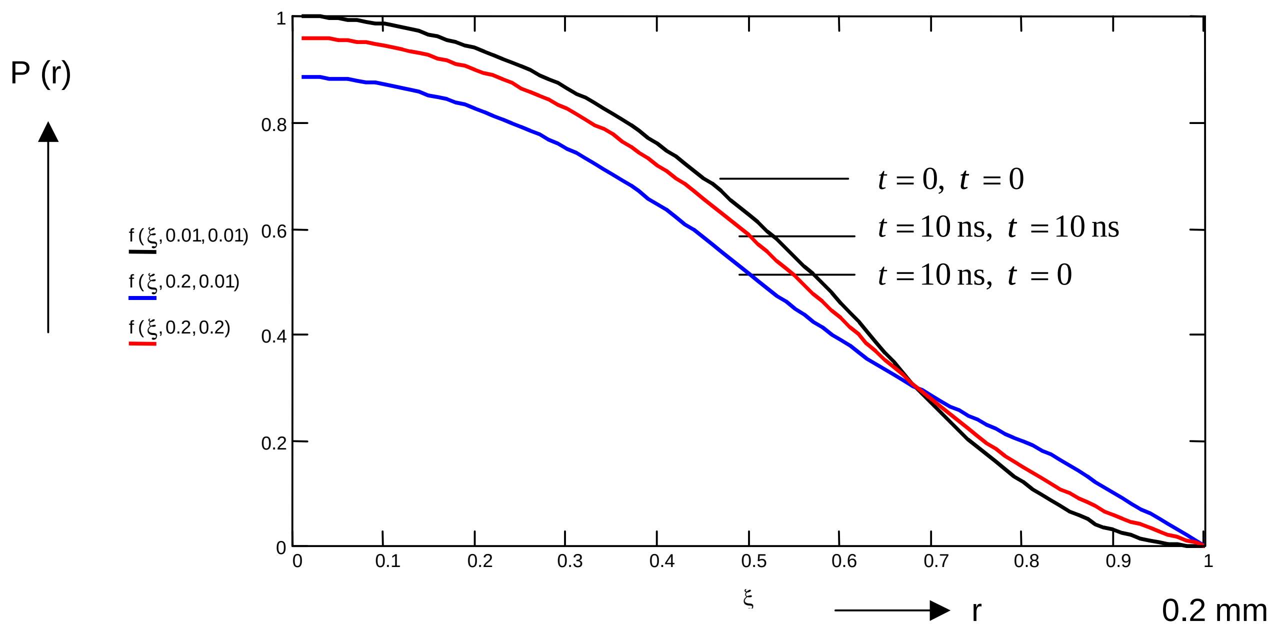
0.1 mm 0.2 mm



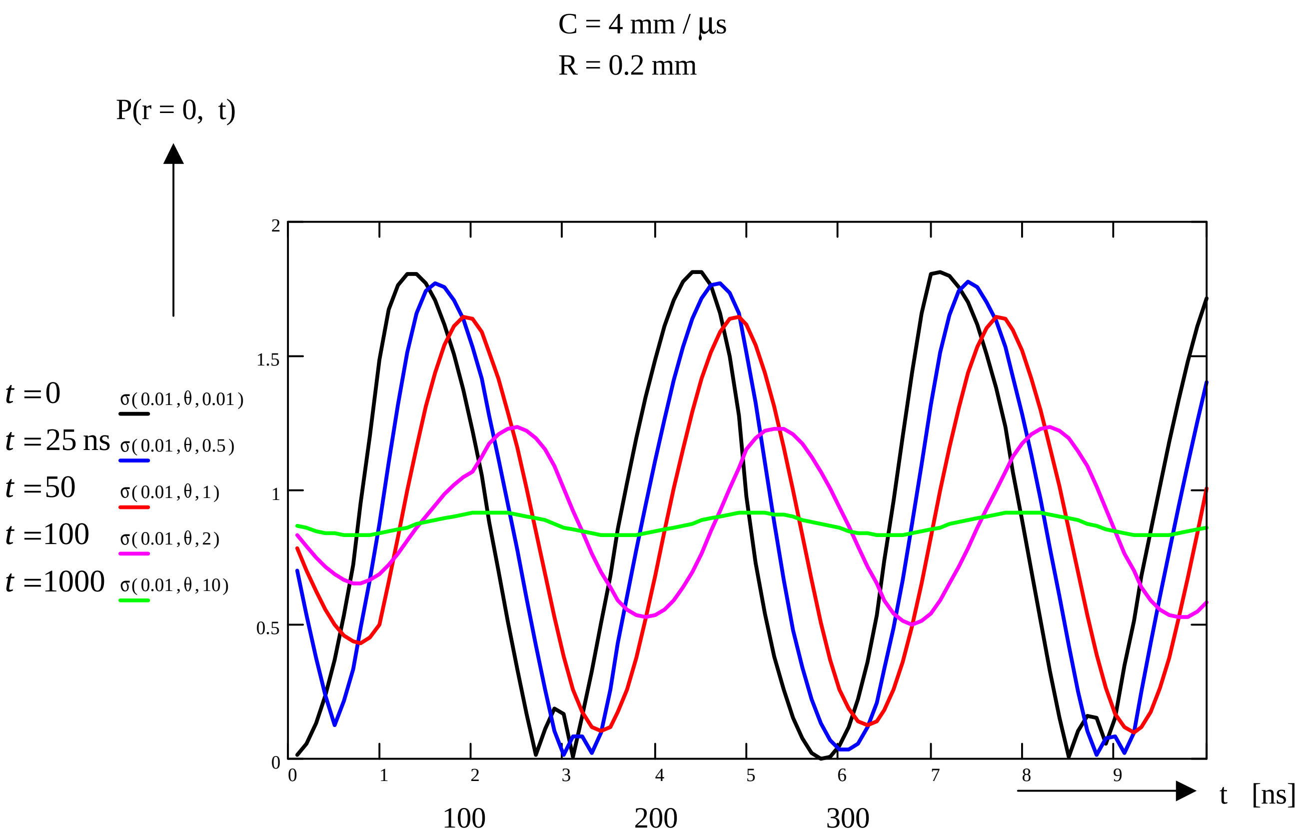
0.1 mm 0.2 mm

Liquid with free boundary conditions, Extended Parabolic Profile
Effect of the heating pulse length

C = 4 mm / μs



P. Sievers / LHC, Collimation Day 25.1.2002
P. 11/16



<u>Fig. 1</u>: Equivalent v. Mieses stress (in relative units of $E a_L \Delta T_0$) vs. time q (q in relative units of *R/c*) in the center of a solid target. In addition to the black curve, which is for infinitely fast heating, also oscillations are shown for uniform heating over the durations $q_0 = 0.5, 1, 2$ and 10 (q_0 in units of R/c).

Cylindrical Symmetry

- Infinitely fast heating

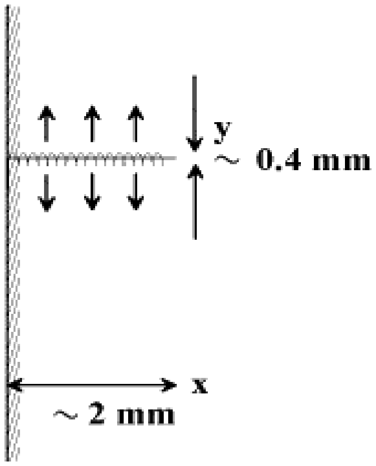
  Initial Condition $\rightarrow$ Wave Equation

- Not so fast heating

  Wave runs away while heating continues

  Long continuous Burst $\equiv$ Series of short superposed "Mini-Bursts": Folding Integral

  Simultaneous heating of total strip



Rule of the Game:

$$\hat{s}(Y=0, t=t) = \begin{cases} \tilde{s}_0 & \text{for } t \le t_0 \\ \tilde{s}_0 \cdot \dfrac{2}{1+2t/t_0} & \text{for } t > t_0 \\ \tilde{s}_0 \cdot t_0/t & \text{for } t \gg t_0 \end{cases}$$

t = Burst Duration

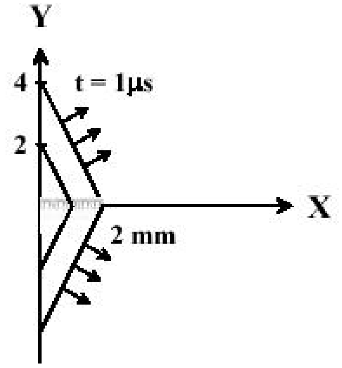
$t_0 = \Delta Y / c_s$ Time it takes for the sound to transit heated zone

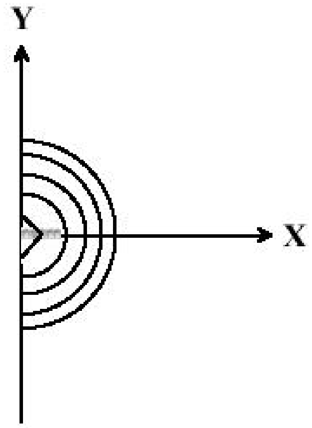
$\tilde{s}_0 \approx EaT(r=0)$ $\quad$ $t_0 = 100\ \text{ns}$

$\Delta Y = 0.4\ \text{mm}$ $\quad$ $t \sim 1 ms$

$c_s = 4\ \text{mm}/ms$ $\quad$ $\hat{s} \sim \tilde{s}_0/10$

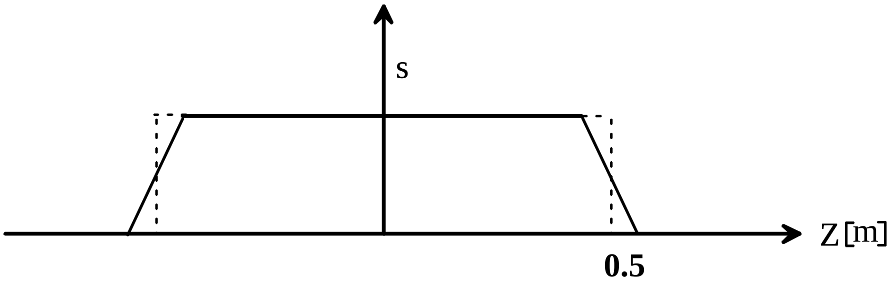
Moving Energy Deposition in (v ~ 2 mm/µs)
X-Direction: Each Bunch $s = \tilde{s}_0$ during 100 ns ?





Uniformly heated Rod

Longitudinal Vibrations in Z-Direction:

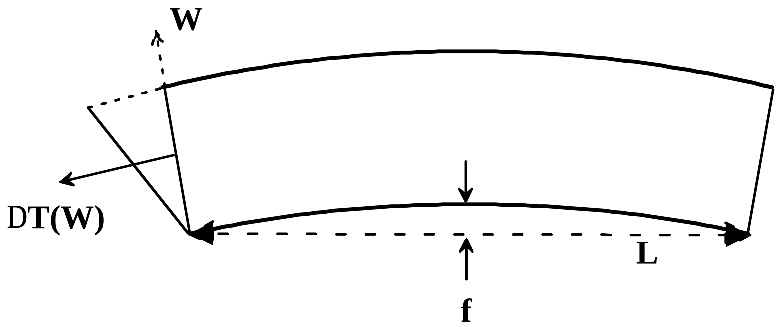


$t_0 \cong 500 ms >> t; \;\; n \approx 1\,\mathrm{kHz}$

$\hat{s} = \tilde{s}_0$

In collimator shock energy escapes laterally "easier" than in longitudinal direction !

Bending of Collimator Jaw in "Steady State":



$$f = \frac{a \Delta T \, L^2}{8W}$$

Cu, L = 1 m, ΔT = 10 K, W = 20 mm, H = 20 mm,

Q = 4 kW

f = 1.1 mm

Dynamic Bending Vibrations due to "fast" heating:

Collimator Jaw at t=0 not in its equilibrium, bent state.

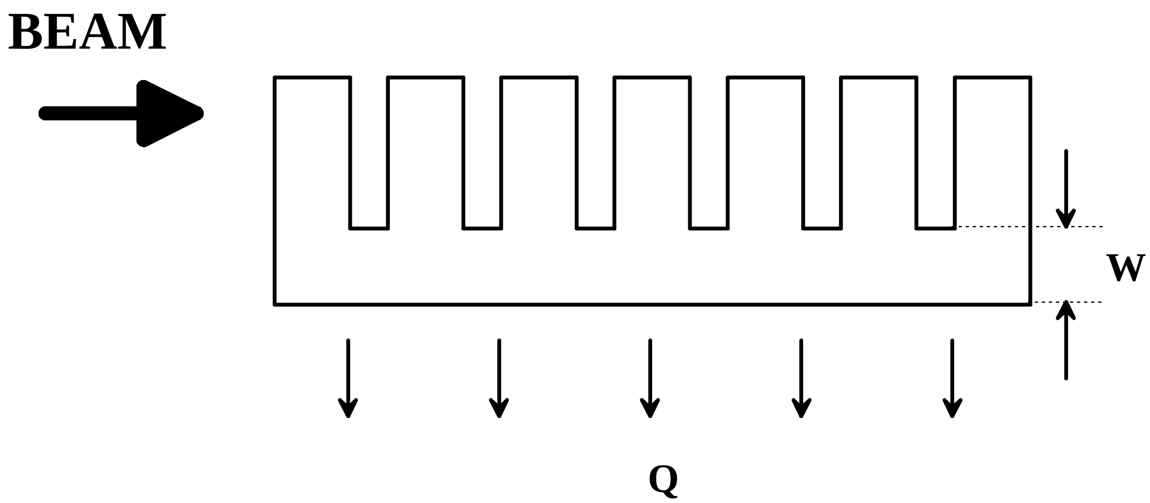
Fundamental Frequency

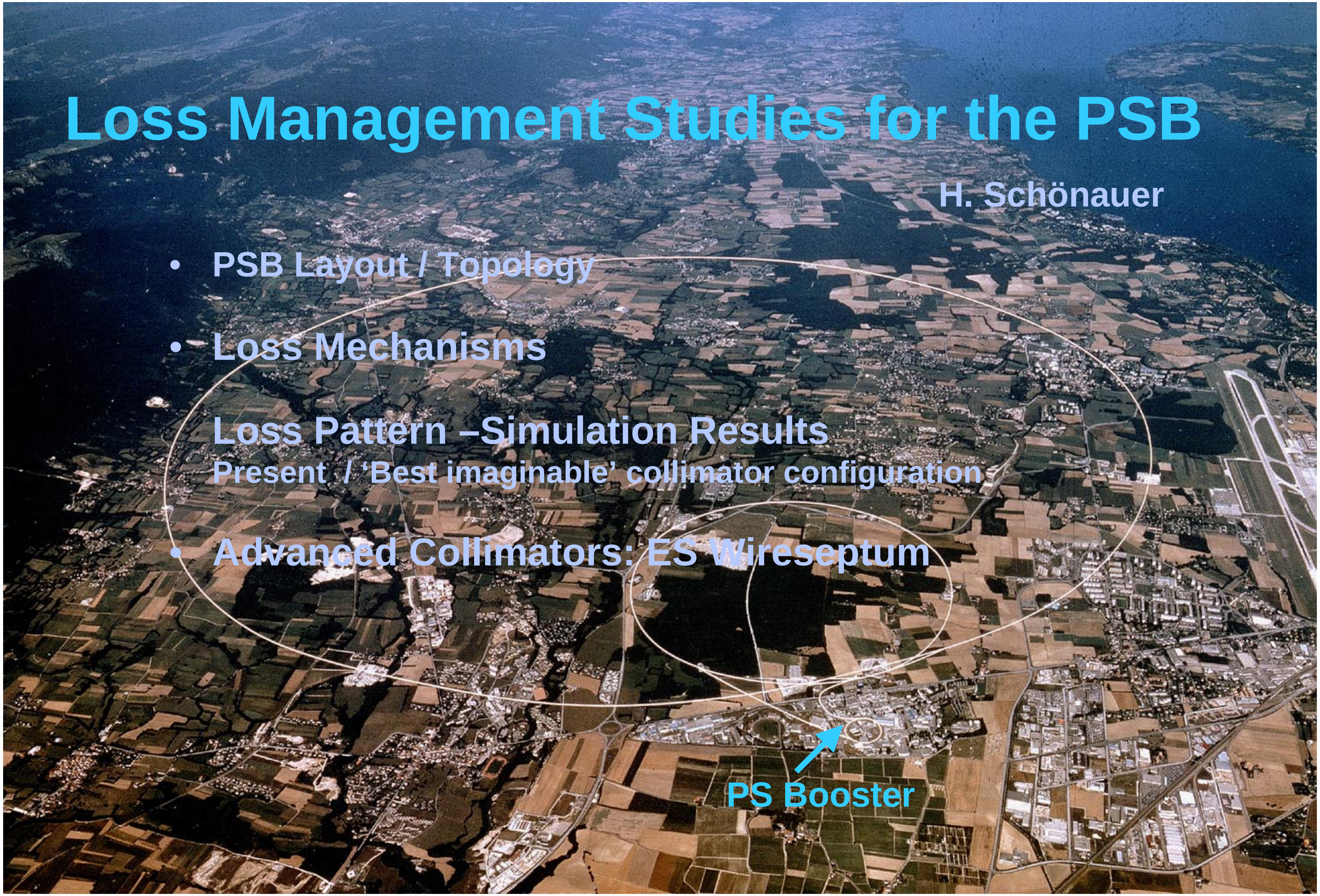
$$n_l = \frac{c_s W p}{\sqrt{3}\, 4 L^2} = 33.5 \text{ Hz}$$

Fast : $t \le 8$ ms

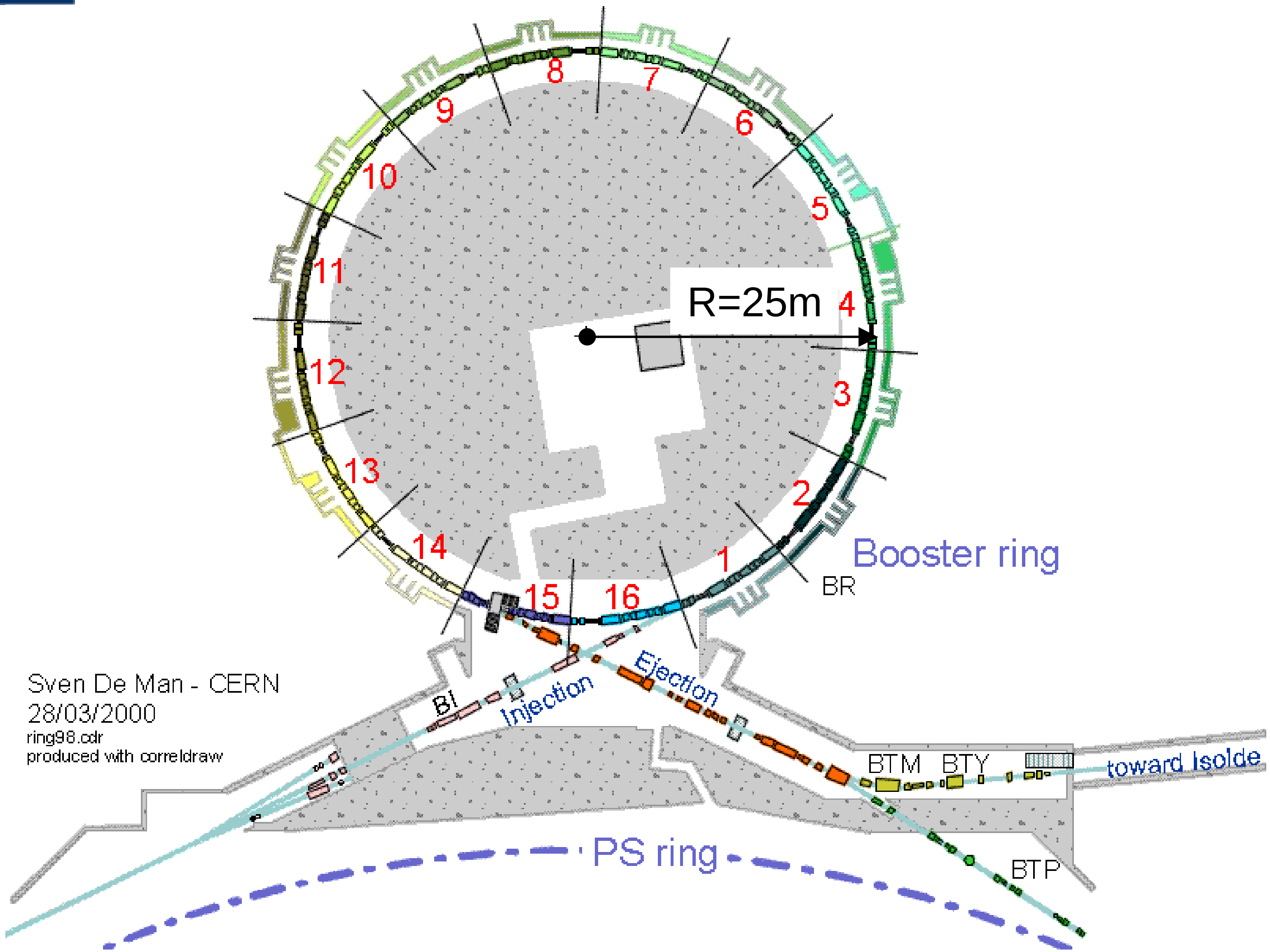
Recipe against : Long. Vibrations

Lateral Bending and Oscillations



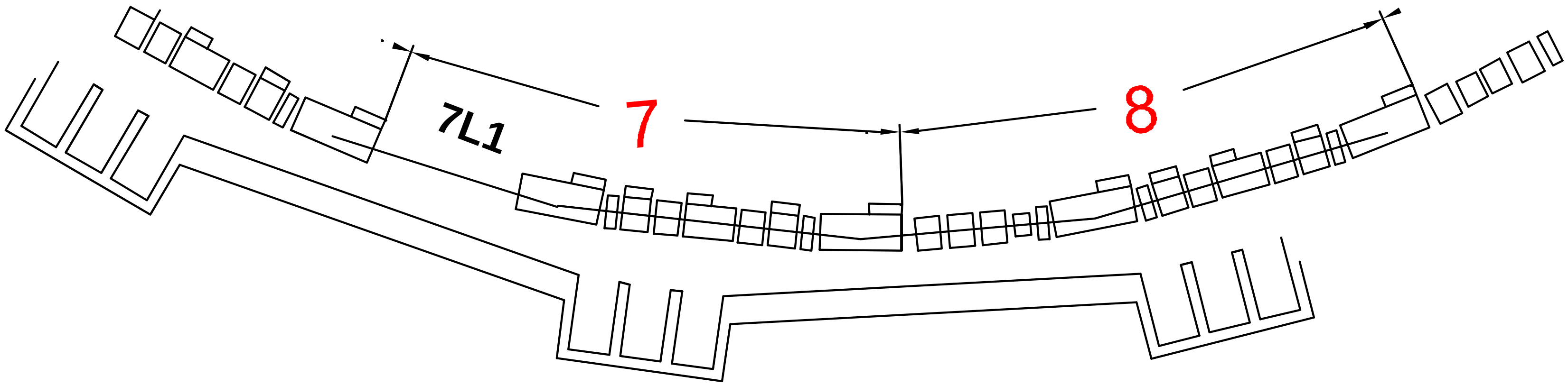

Loss Management Studies for the PSB
H. Schönauer
• PSB Layout / Topology
• Loss Mechanisms
• Loss Pattern –Simulation Results
Present / 'Best imaginable' collimator configuration
• Advanced Collimators: ES Wireseptum
PS Booster

PSB Layout



Sven De Man - CERN
28/03/2000
ring98.cdr
produced with correldraw

Nomenclature of Straight Sections and Lattice Elements of a PSB Machine Period n



n L1 | BHZn1 | nL2 | QFOn1 | n L3 | QDE n | n L4 | QFOn2 | n L5 | BHZn2 | (n+1)L1

Beam direction ⇒

Only 'L 1'
Sections (~2.5 m)
are long enough
for collimators

n = 1 - 16

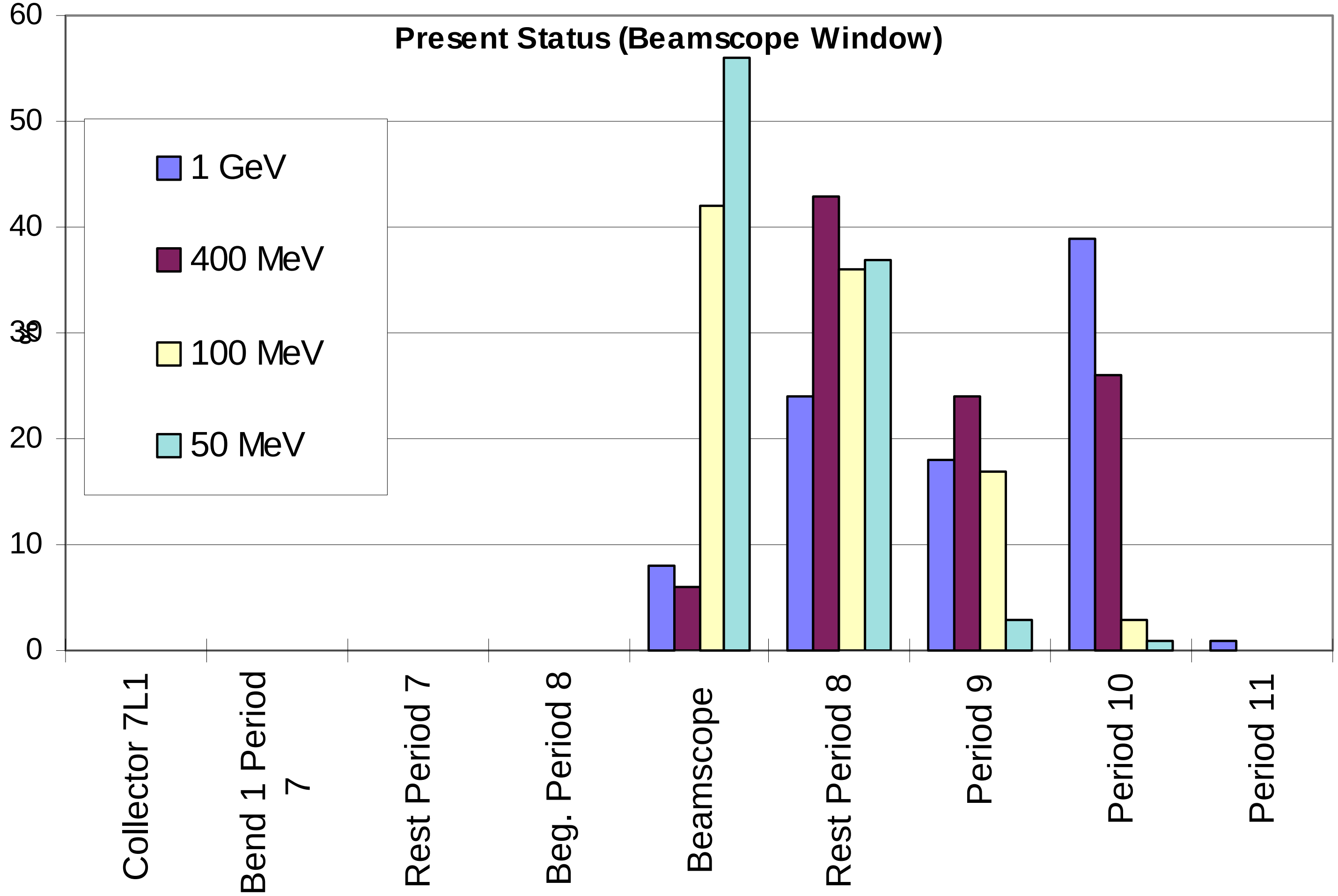
Loss Mechanisms in PSB

#	Type	%	Occurrence	Cure
1	Injection	40	Septum, 1st Bending	none
2	Capture	10	Beamscope Aperture[1]	High debuncher voltage
3	Stopbands	15	< 150 MeV	Compensation done as far as possible
4 4 a	Long. Instab. Dual RF syst. marginal stab.	5-10 >10	0.4-1 GeV ; Beamscope Aperture [2].	**New RF system h=1 & 2 (1998)**
5	Slow Loss	3-5	Diffusion out of bucket Spurious transverse inst.	h=5, h=10 voltage & phase programs Transverse Feedback[3]
6	R4 "µwave" instability	0-5	590 MeV; Beamscope Aperture [2].	h=10 voltage, phase shaking **Shielding of pump manifolds (1998)**
7	Ejection Loss	< 1 3-4	Halo scraped on inner sept. face, outer edge: kicker voltage, flat top	less important Improved max. kicker ampl. **New Septa (1998)**

1) not too bad at low energy
2) insufficient at a few 100 MeV
3) New kicker cables constitute higher coupling impedances; some possible effects observed in Ring 4

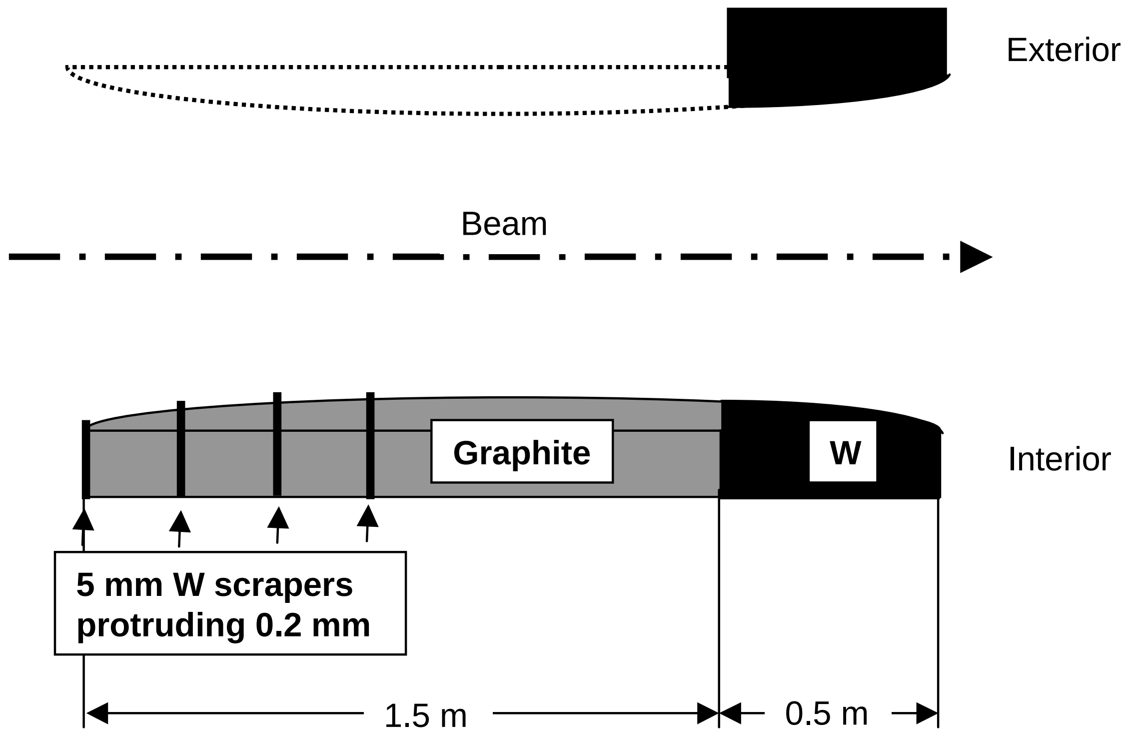
Distribution of momentum losses in the present ‘collimation system’, the Beamscope Aperture in 8L2 (%)

(T.Trenkler 1995)



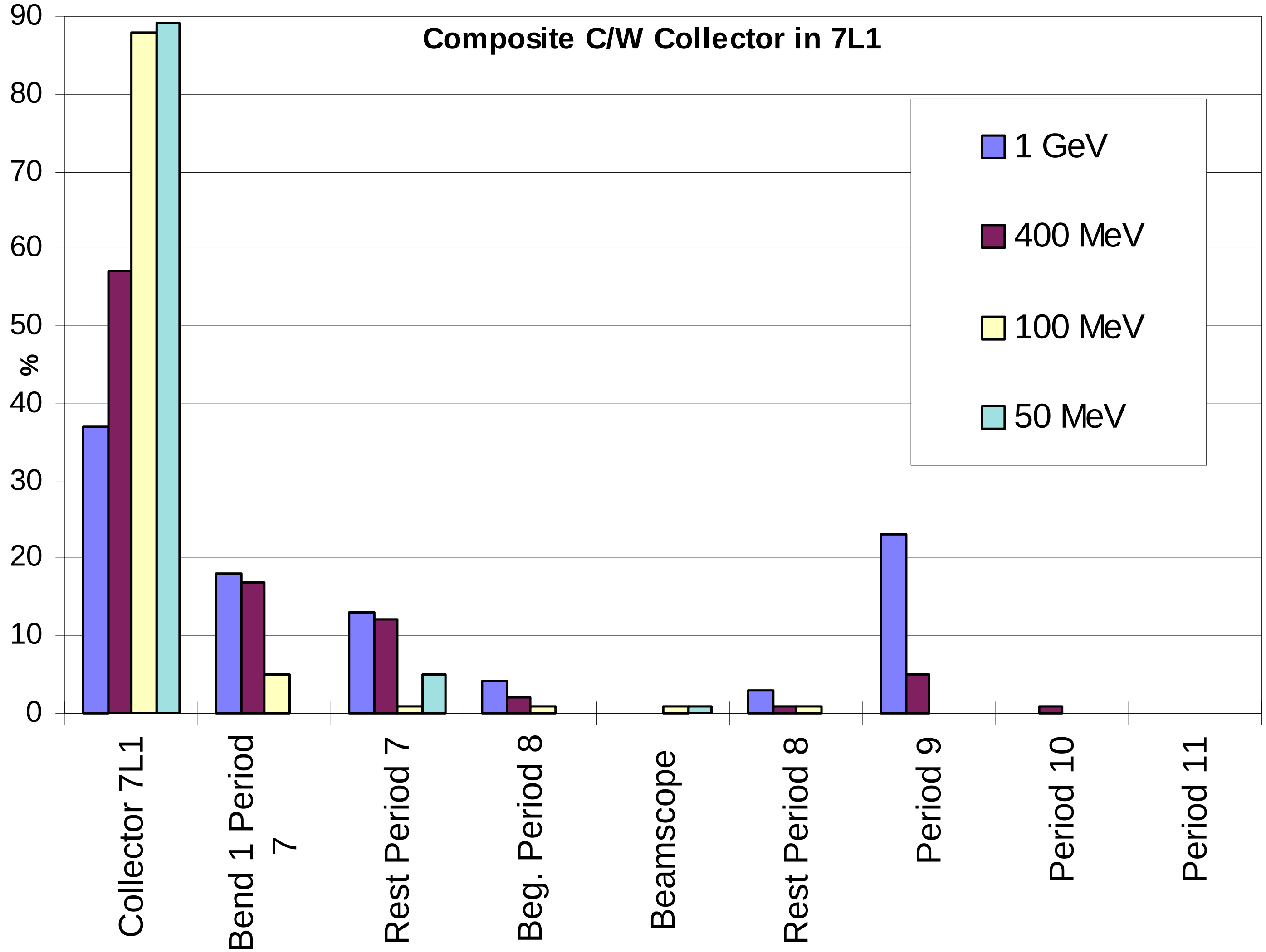
Composite C / W Momentum Collimator in SS 7L1 (HOR)

$A_h = 320\ \pi\ \mu m$ (~ 3 σ at 50 MeV)



Distribution of losses for the 'best imaginable' momentum collimator : Composite C / W in 7L1

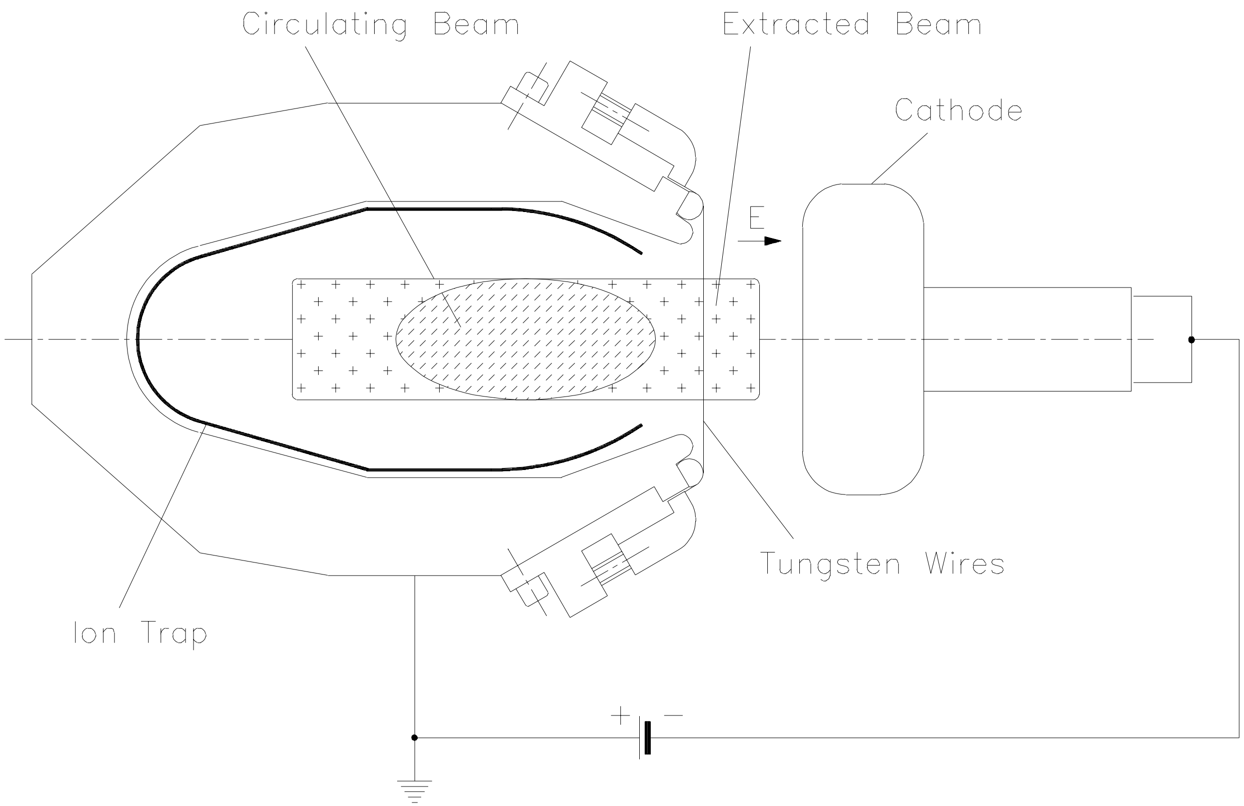
(T.Trenkler 1995)



Advanced collimator :
Electrostatic Wire Septum in 7L1
ACCSIM Simulations 1995

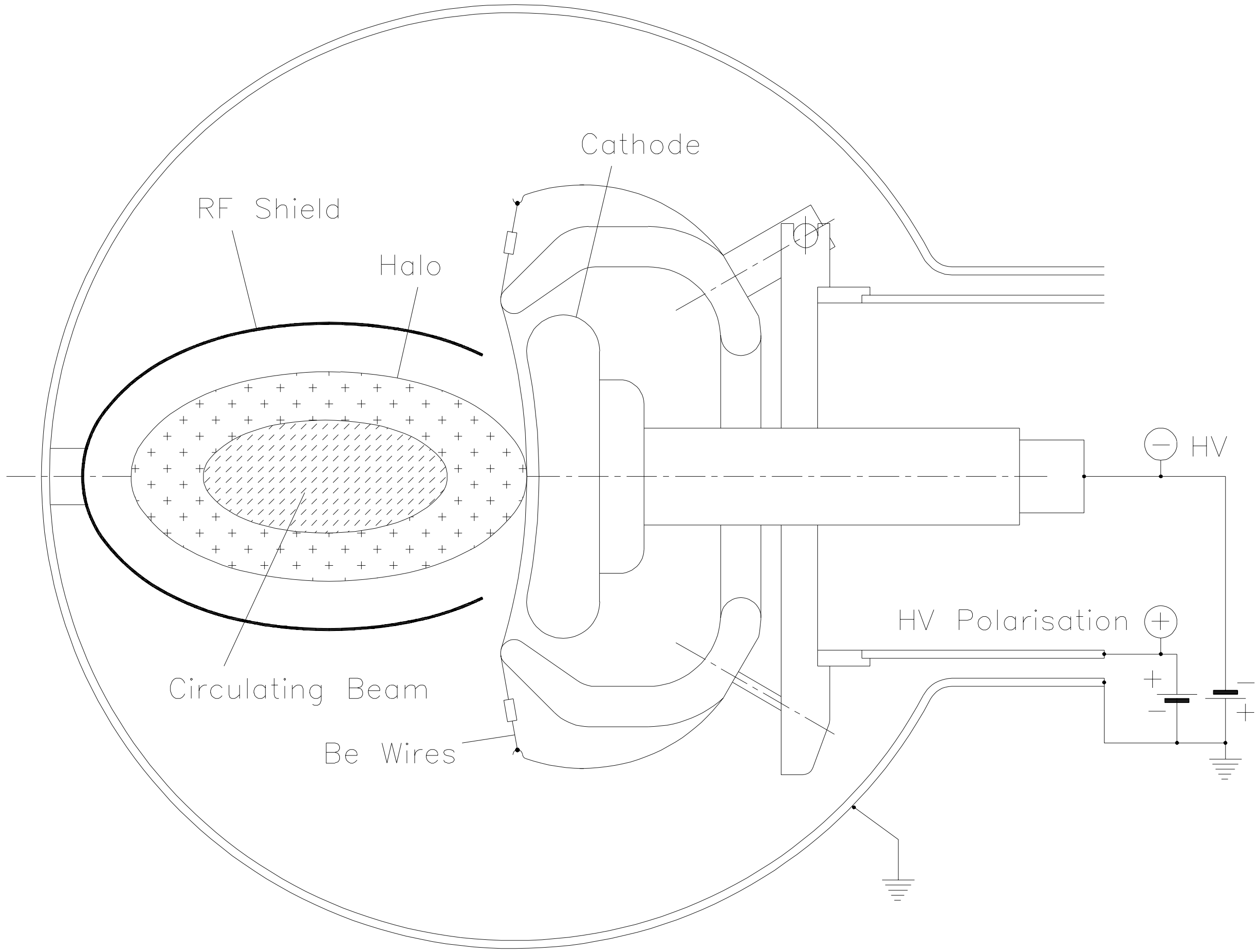
Energy [MeV]	Fraction stopped in W-Collector %	Fraction into Bending 7RB1 - potentially stoppable by a shield %	Fraction lost in Rest of Period 7 and Period 8 %
50	99	1	-
100	100	-	-
400	84	11	5
1000	60	15	15

Schema of a classic Extraction Wire Septum

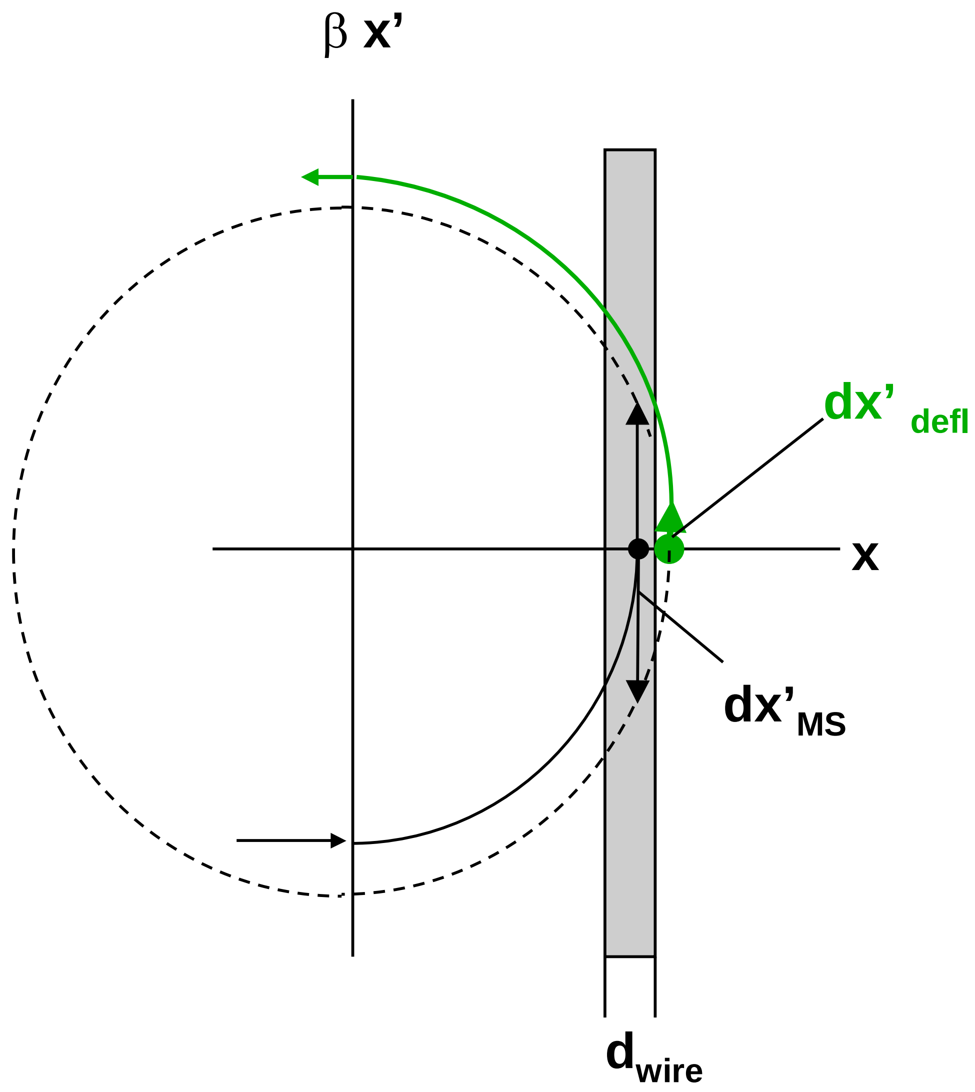


H. Schönauer

Schema of a (1st) ES Collimator Septum



Principle of ES Collimator Septum



Elementary Formulae

The deflection angle θ_s of an electrostatic wire septum is given by

$$\theta_s = (eE_0\, l)/(\beta pc)\ .$$

With the maximum field $E_0 = 5$ MV/m assumed for metal cathodes, the deflection per m septum length is

$$\theta_s\,' = 5\ \text{MeV}/(\beta pc)\ .$$

In low-energy machines ~1 GeV a length of l ~ 1 m suffices.

The gap width necessary to allow multiple passages is about 10 mm, limiting the cathode potential to 50 kV, still within simple HV technology.

The wire polarisation potential is given by

$$V_W = (1/2\pi)\, E_0\, a \ln (a/d\pi) = 13.7 \text{ kV}$$

for d = 0.05 mm diameter Be wires at a = 5 mm distance.

The force on each wire is

$$F_x = \varepsilon_0\, a\, E_0^2/2 = 0.028 \text{ N/m}$$

and the maximum deflection

$$x_B = \varepsilon_0\, a\, E_0^2\, h^2/(16T) = 3.45 \text{ mm}$$

for a tensioning force T of 0.2 N corresponding to 20% of the breaking strength of Be, and a septum height h = 100 mm.

The importance of this bulging, which can attain even more impressive values for machines with large apertures, necessitates a hollow cathode shape. The hollow shape of the collimation aperture is no disadvantage, as inclined collimator faces in connection with the inevitable linear coupling are desirable.

From elementary multiple-scattering theory one obtains the r.m.s. scattering angle for one wire (the average path length per wire is $d\pi/4$) :

$$\theta_{1,MS} = [13.6\ \text{MeV}/(p\beta c)]\ [d\pi/(4X_0)]^{1/2}$$

X_0 … radiation length (350 mm for Be, 188 mm for C).

The deflection for one wire is

$$\theta_{1,s} = (eE_0\, a)/(\beta pc)\ ,$$

and the ratio between the two

$$\theta_{1,MS} / \theta_{1,s} = [13.6\ \text{MeV}(eE_0\, a)]\ [d\pi/(4X_0)]^{1/2} \cong 6$$

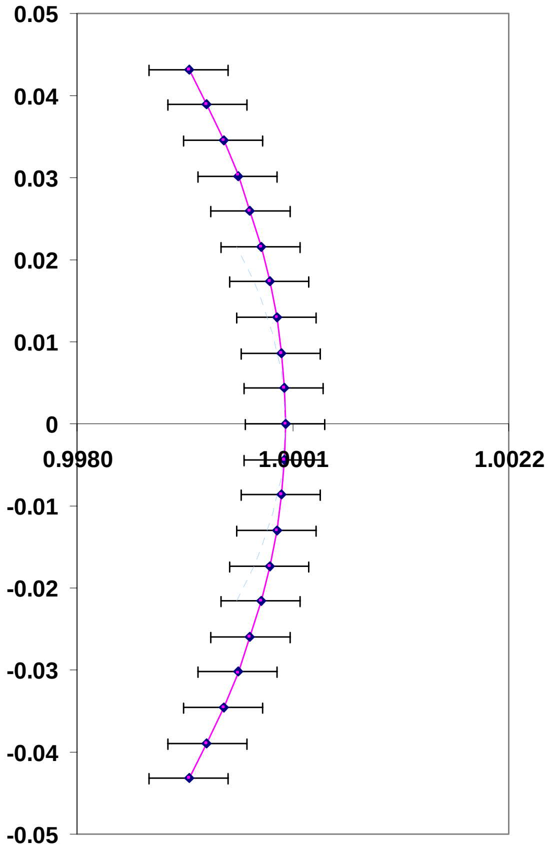
(≅5.8 for 50 μm Be, ≅6.4 for 33 μm C).

All angles scale with *(pβc)*, i.e. the relation given above holds at all energies. Although for the single wire multiple scattering dominates, for a row of ***N = l / a***
wires, this ratio goes down with **1/√N**.

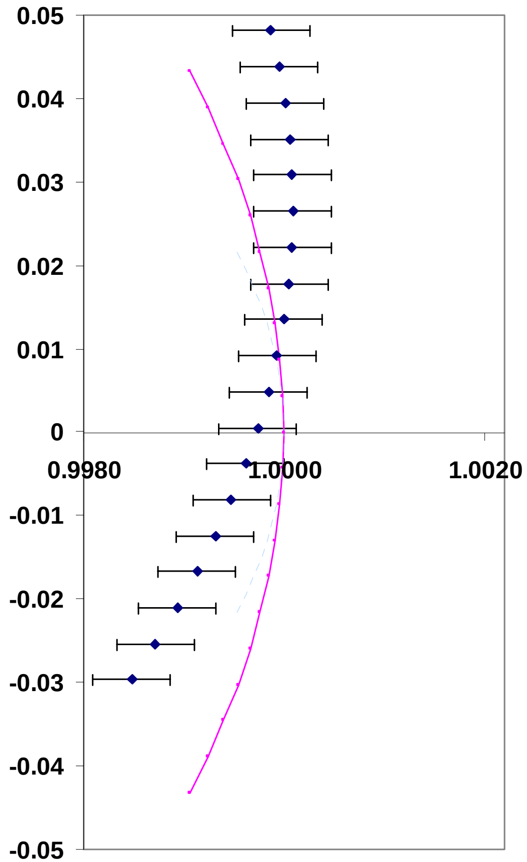
Phase Space Representation of the Wire Septum

A_h = 320 π μm, β_x= 5.78 m.
L = 0.5m, x-Error bars: Wire diam. = 0.033 mm

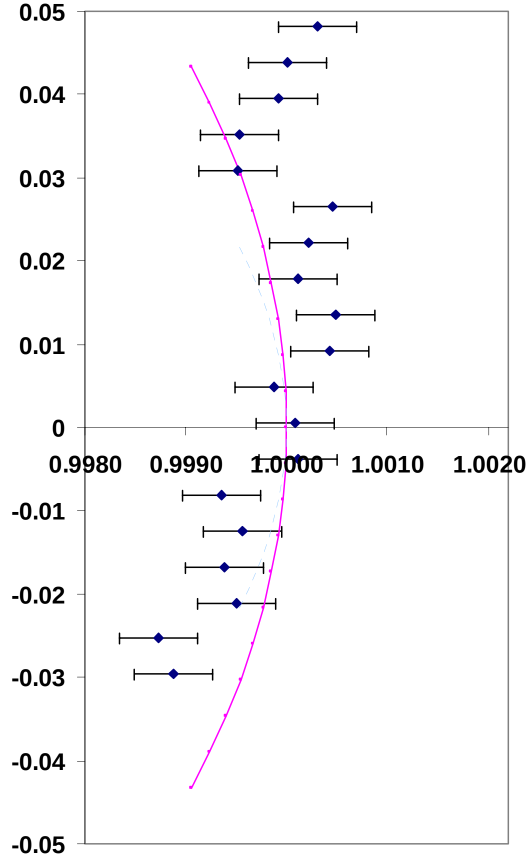
Aligned Septum



Sept. misalign. 0.1 mrad



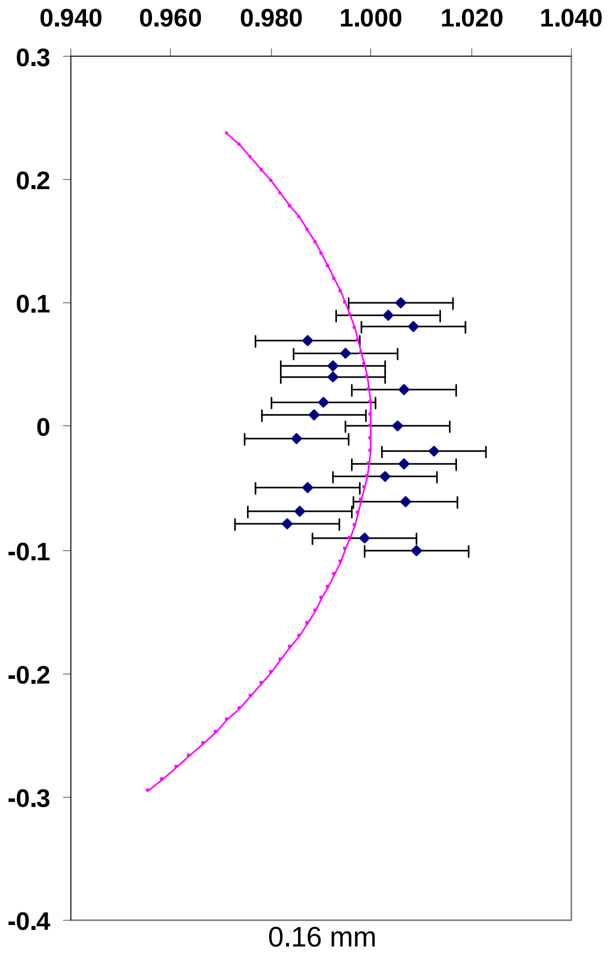
Sept. misalign. 0.1 mrad
wires ±0.05 mm



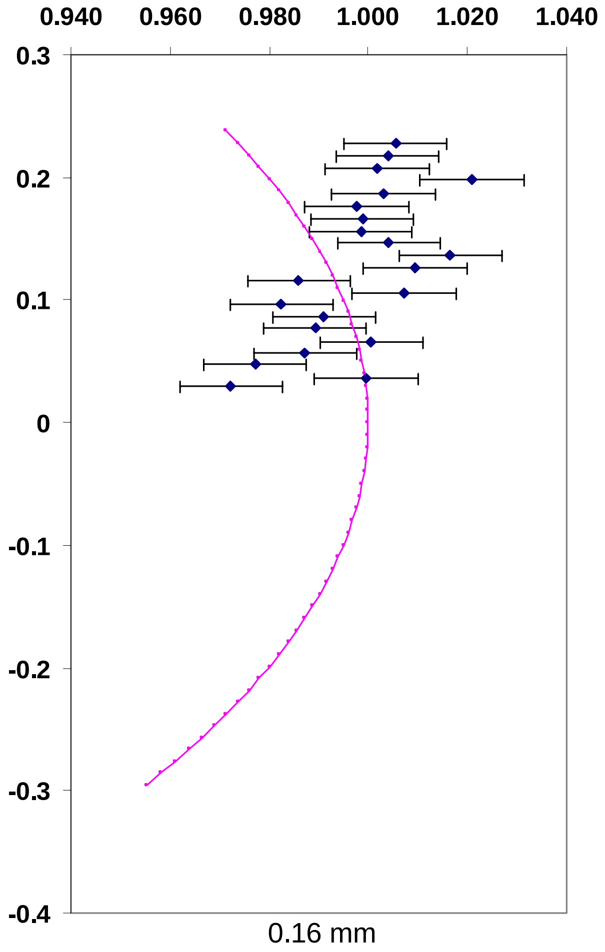
Phase Space Representation of the Wire Septum

A_h = 0.0125 π μm, β_x= 200 m.
L = 40 m, x-Error bars: Wire diam. = 0.033 mm

Aligned Septum, wires ±0.05 mm



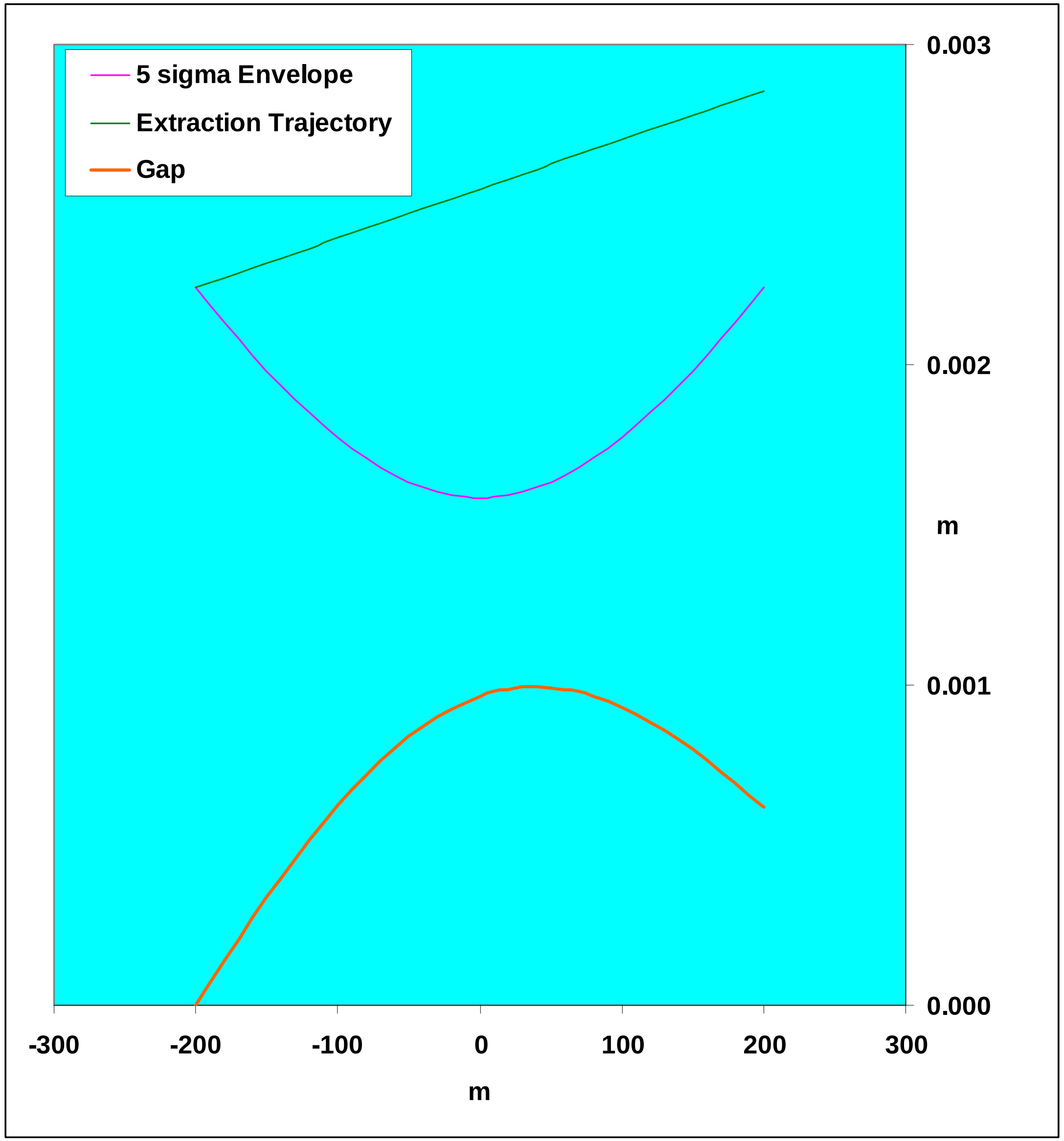
Sept. misalign. 1 μ rad, wires ±0.05 mm



Electrostatic Wire Septum in LHC...

Gap between extracted trajectory and the 5σ - envelope (7 TeV) for a **10 m long** ES septum in a long SS.

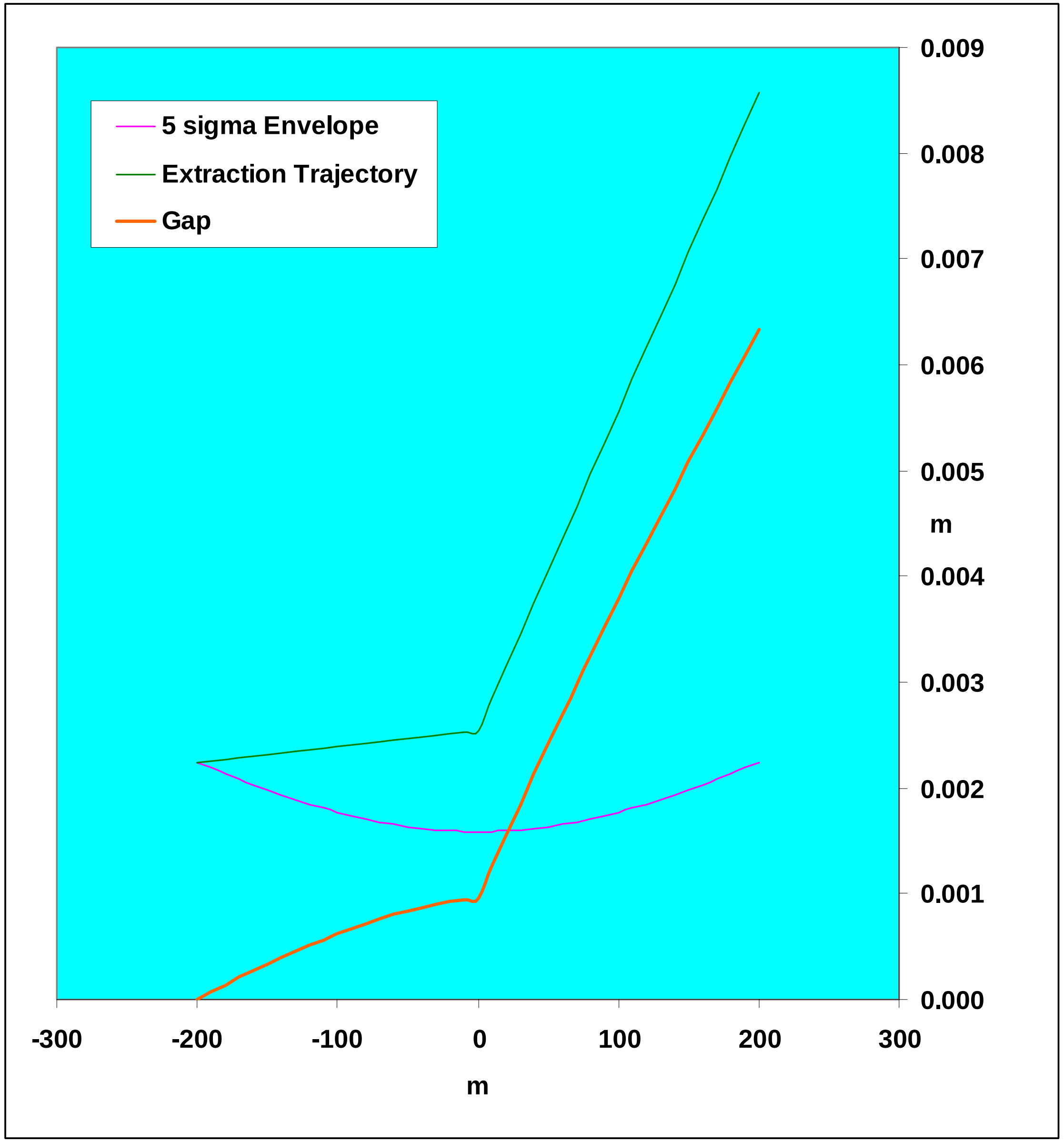
β_0= 200 m, β_{max} =400 m



H. Schönauer

Electrostatic Wire Septum in LHC...

Same as previous, with a 2nd **40 m long** ES septum 200 m downstream



H. Schönauer

Electrostatic Wire Septum in LHC - Why not use a Bent Crystal Instead?

This a good question indeed. G. Arduini asked it in private during the meeting.

In fact, bent crystals as scrapers have been suggested some time ago. There have been experiments at the SPS and at IHEP.

Cf. for instance:

Afonin et al., Progress in crystal extraction and collimation, 18th International Conference on High Energy Accelerators, Tsukuba, Japan, 26 - 30 Mar 2001

A.Chesnokov et al., Progress of Crystal Channeling Technique for Beam Extraction and Collimation at IHEP, LHC Project Note 248

Collimation Day

The LHC Scraper System, 25th January 2002

ENERGY DEPOSITION BY LHC BEAMS IN TARGETS OF DIFFERENT MATERIALS

CERN/TIS–RP/IR/93–10

Graham R. Stevenson
TIS/RP

Summary of the Presentation

- FLUKA simulations of the cascades induced in different materials by LHC beams have been made.
- Energy deposition was determined as a function of target size.
- These calculations provide a basis for determining the suitability of different materials for the construction of scrapers, *etc.*.
- The aim of was to provide basic data in an easily-available form while not intending to be a design-study for such devices.
- As a conclusion I will show some “incidents” I have known.

Introduction

- The spatial development of a cascade depends essentially on three parameters:
  1. the high-energy hadron inelastic interaction length which controls the development of the purely hadronic part of the cascade,
  2. the radiation length which governs the development of the associated electromagnetic cascades originating from π^0 decay and
  3. the density which governs the physical extent of the cascade.
- The complex inter-relation between these three parameters means that there is no simple empirical expression which allows one to deduce the maximum energy deposition as a function of the atomic number of the irradiated material.
- Hence the need for studies such as the present one.

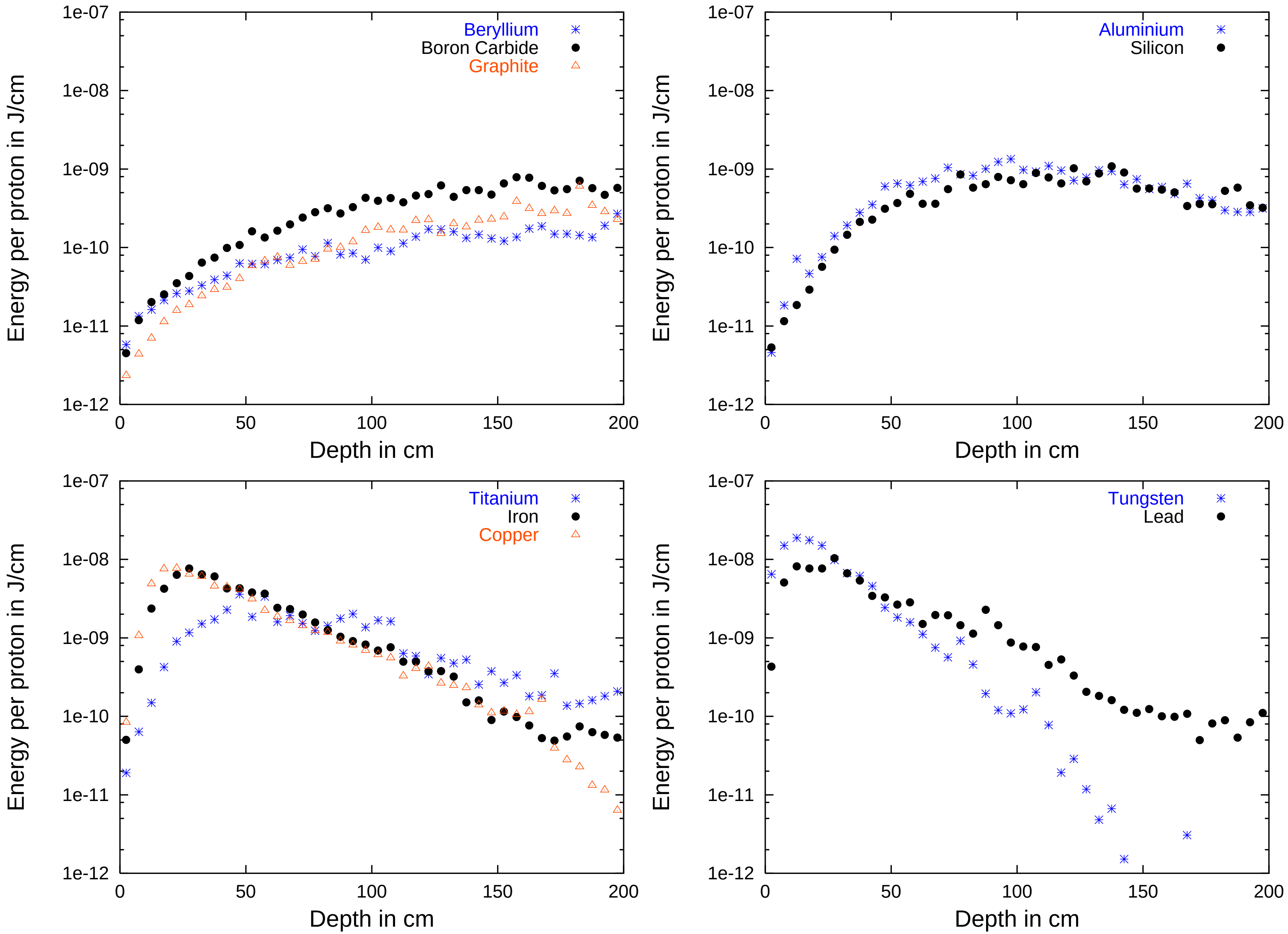
Simulation details

- The cascades were initiated by 7.3 TeV protons in targets of different materials.
- The radial beam size chosen for these studies was that of the LHC beam at the position of the scraper system proposed in IR3. The standard deviation of the projected beam distribution was expected to be 0.35 mm.
- The cascade was simulated in targets of 5 cm radius and 2 m in length.
- Energy deposition was determined as a function of radius and depth in both a coarse and fine radial bin structure. Both sets of bins were 5 cm in depth; the radial bin size of the coarse set was 1 mm whereas that of the fine set was smaller than the radial size of the incident beam, *viz.* 0.1 mm.
- Charged hadrons were followed down to an energy of 10 MeV; for electrons and positrons this limit was lowered to a kinetic energy of 1 MeV. Neutrons were also followed down to an energy of 1 MeV whereas the cut-off for photons was taken as 100 keV.

Graham R. Stevenson

Longitudinal energy deposition

target radius 5 mm



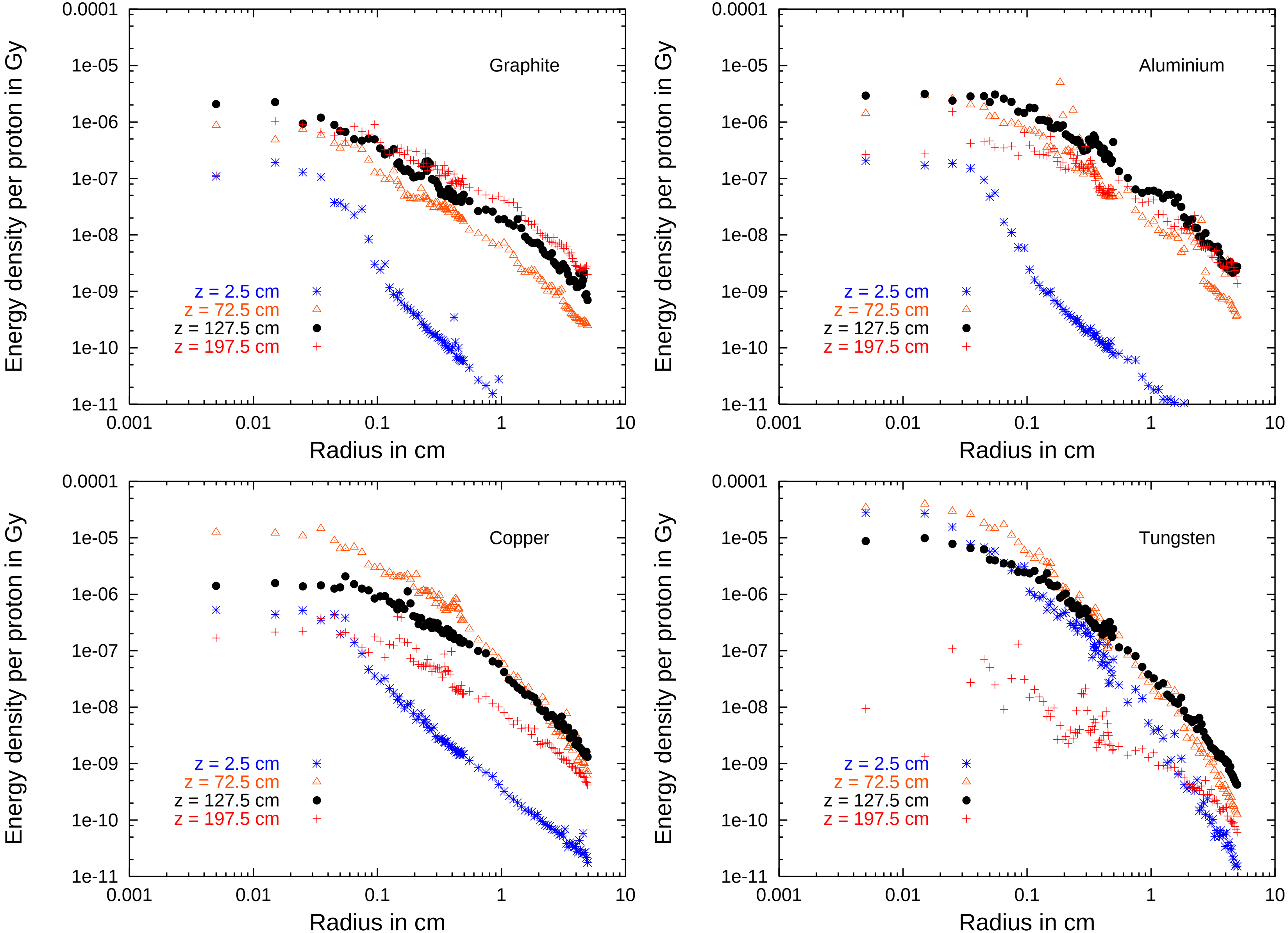
Longitudinal energy deposition – Summary

Maximum energy deposition in a target of 5 mm radius

Material		Density (g/cm^3)	Maximum energy deposition (J/cm)
Beryllium	Be	1.85	2×10^{-10}
Boron carbide	B_4C	2.6	7×10^{-10}
Graphite	C	1.75	3.5×10^{-10}
Aluminium	Al	2.7	1×10^{-9}
Silicon	Si	2.3	9×10^{-10}
Titanium	Ti	4.5	3×10^{-9}
Iron	Fe	7.88	8×10^{-9}
Copper	Cu	8.96	8×10^{-9}
Tungsten	W	19.3	2×10^{-8}
Lead	Pb	11.35	1×10^{-8}

Graham R. Stevenson
Collimation Day: 25.01.02

Radial energy deposition



Max. energy deposition on the beam axis

Material	Specific Heat (J/°C.kg)	Maximum energy deposition (J/kg) per proton	Temperature rise for 10^{11} protons °C	Melting point °C
Be	1800	1.0×10^{-6}	55	1280
B_4C	1850	2.5×10^{-6}	130	2350
C	670	2.0×10^{-6}	300	3500
Al	880	3.0×10^{-6}	340	660
Si	750	2.5×10^{-6}	330	1410
Ti	460	8.0×10^{-6}	1750	1680
Fe	440	1.0×10^{-5}	2300	1540
Cu	380	1.5×10^{-5}	4000	1080
W	140	4.0×10^{-5}	29000	3380
Pb	125	1.5×10^{-5}	12000	330

- Care must be taken in interpreting the on-axis values deep in the cascade because of the statistical fluctuations inherent in these calculations.
- Values of the maximum adiabatic temperature rise for a single bunch of 10^{11} protons are given and are compared with the melting points of the different materials.
- The difficulties of materials heavier than the transition metals in supporting such an irradiation is evident.

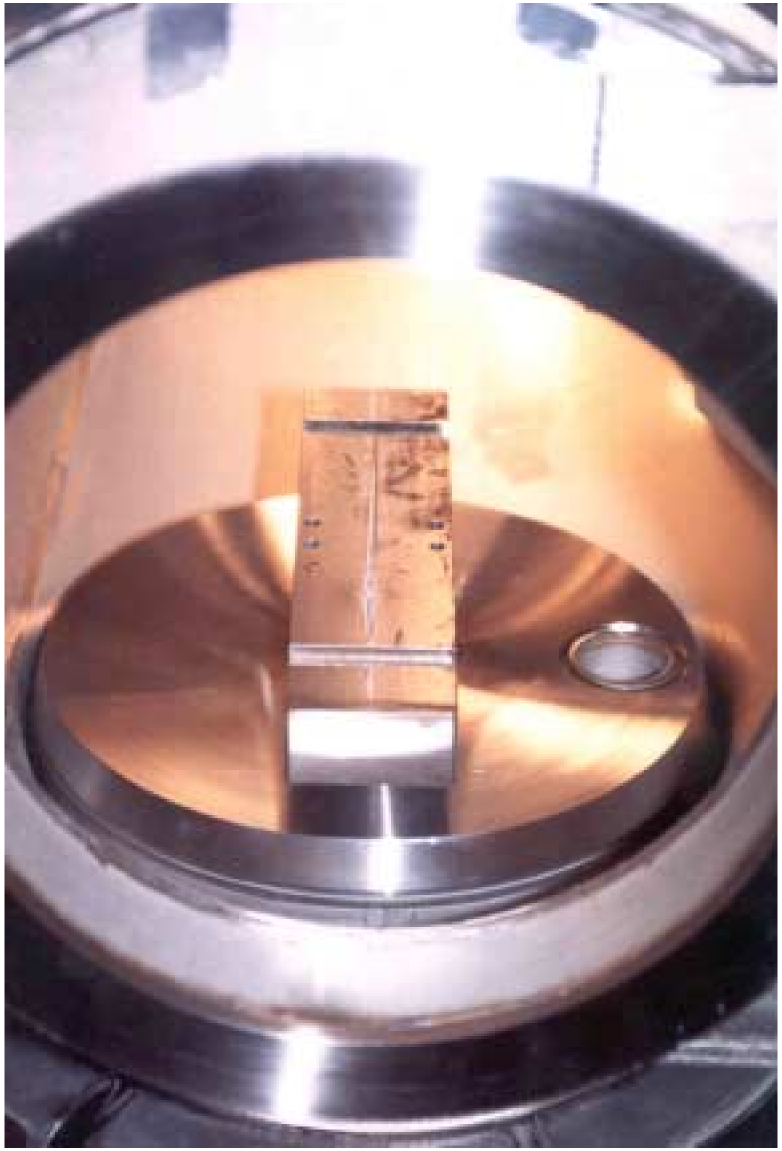
Deposited power

Power in watts deposited in targets of different materials and radii for 10^9 interacting protons per second

Material	5 mm radius Target length				5 cm radius Target length			
	5 cm	20 cm	50 cm	200 cm	5 cm	20 cm	50 cm	200 cm
Be	0.03	0.28	1.5	20	0.04	0.52	3.6	100
B_4C	0.02	0.31	2.4	70	0.03	0.57	6.2	280
C	0.012	0.13	0.9	31	0.014	0.19	2.0	130
Al	0.02	0.7	9	120	0.03	1.0	20	480
Si	0.03	0.32	5.5	97	0.04	0.57	12	400
Ti	0.10	3.3	5.1	200	0.15	5.9	134	680
Fe	0.25	35	210	330	0.40	57	430	860
Cu	0.42	70	240	330	0.70	110	500	870
W	33	290	510	550	38	390	820	960
Pb	2	110	290	400	3	170	550	890

SPS Tungsten Collimator

- A tungsten collimator was pushed too close to the circulating beam during a stored-beam machine development run at the SPS.

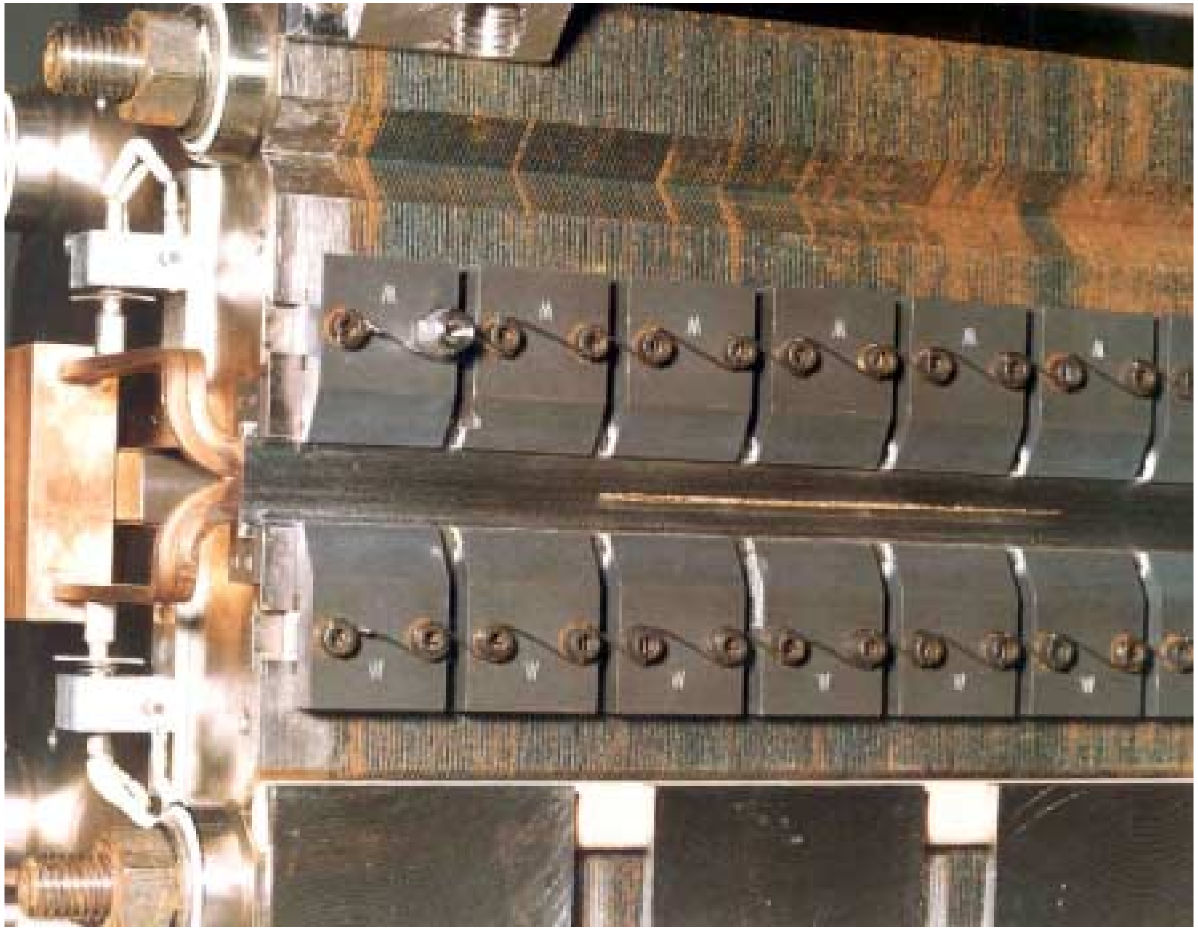


One-shot fast extraction

- A bending magnet was not powered during a fast-slow extraction to the WANF target.
- The beam entered the coil through the flange to the left of the vacuum chamber.
- The cascade melted the vacuum chamber at the maximum of the cascade.
- All magnet currents are now part of an interlock system!

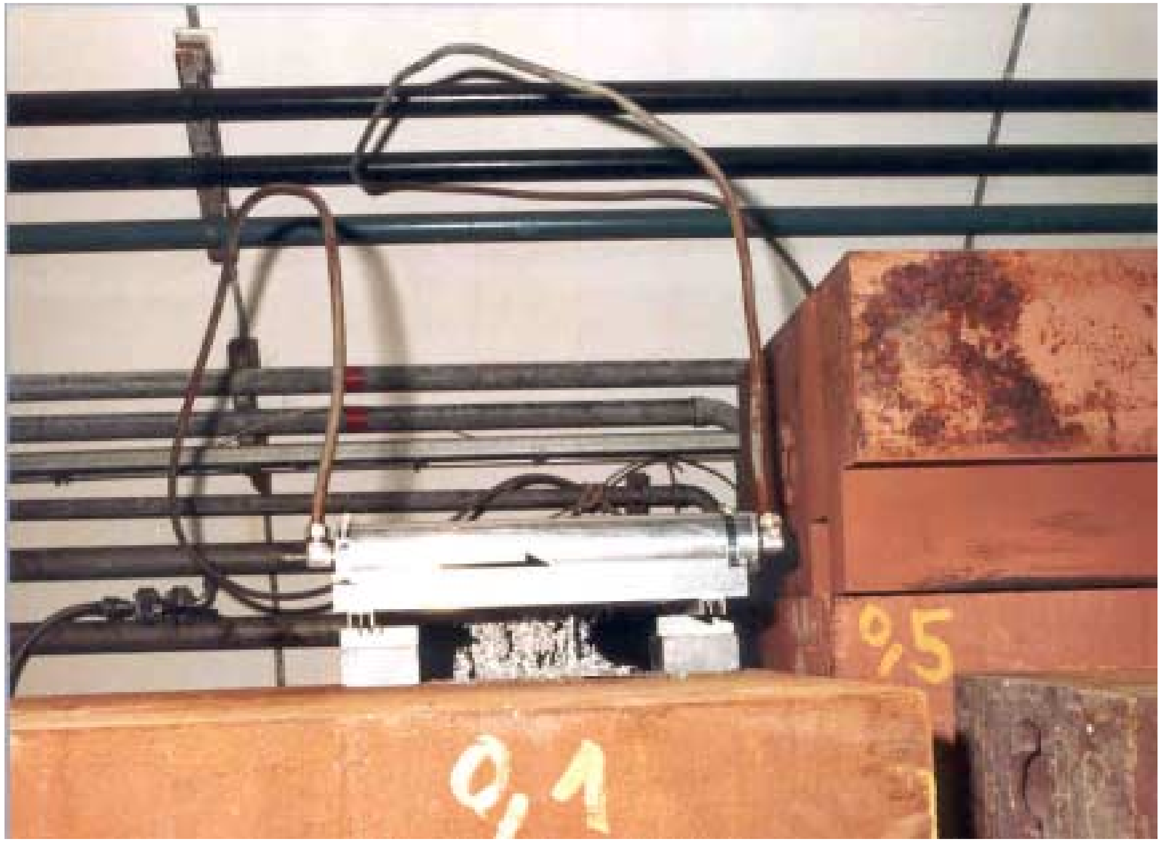
SPS Thin Magnetic Septum

- The thin magnetic septum is downstream of the initial electrostatic septum.
- A spark occurred in the electrostatic septum just during extraction.
- The beam struck the water-cooled coils, ripping them apart at the maximum of the cascade.



Pirate Neutrino Experiment

- A lead block was used to counterbalance a heavy metal target placed in the secondary pions downstream of the WANF target.
- Unfortunately the block was placed directly in the beam of protons passing through the neutrino target.
- A manipulator was needed to cut apart the experiment and clean up the mess.



Collimator Heating and Materials

LHC Collimation Day, 25th January 2002

CERN, Geneva, Switzerland

I. Baishev, IHEP and J.B. Jeanneret, CERN

/Coll/2002/heat_data/coll_day/talk2.tex

OutLine

- We must survive to as much as possible transient losses
- Present worst case : erratic trigger of the dump kicker

Therefore:

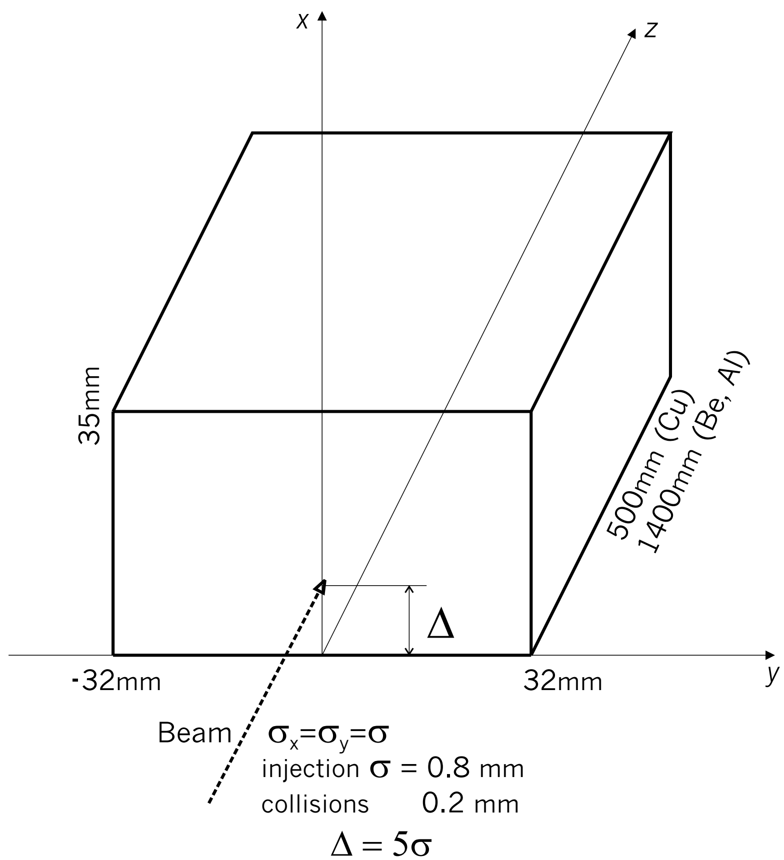
- Evaluate Thermo-mechanical properties of a few elements and Allowed HEAT DEPOSITION DENSITY
- Use EM-hadronic shower code to get ENERGY DEPOSITION DENSITY/proton
- Compare allowed to expected losses
- Issue preliminary conclusions, submitted to your appreciation

Table 1: Criteria for allowed losses - heat/mechanics of jaws. Consider losses on one jaw & Superimposed bunches, Short time $\Rightarrow$ no heat diffusion.

Events	Criterion	Allowed Occur.
Stay under Ultimate	$\Delta T < \frac{\sigma_{uts}(1-\nu)}{\alpha Y}$	$10^4 - 10^6$?
Tensile Strength	$(\Delta T = \Delta Q/\overline{c_v})$	
Possible reduction of	ΔT	100 ?
Mechanical Properties	$< 0.7 T_{melt} - T_{room}$?	
Begin damage	$T_{max} = T_{melt}$	< 1 ?

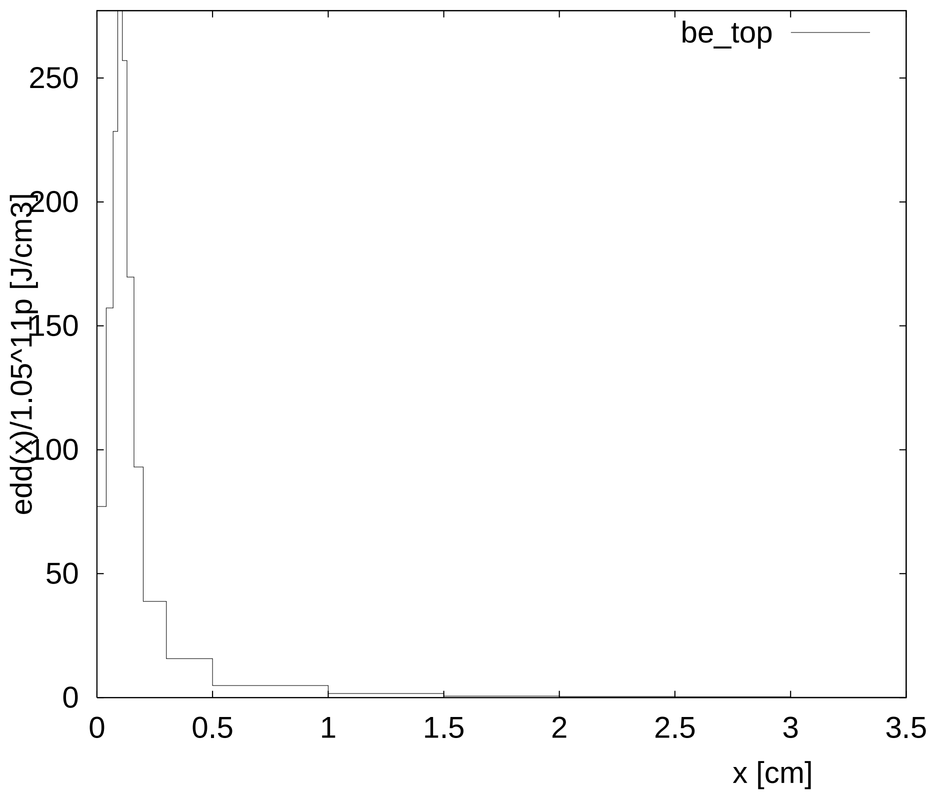
Energy deposition maps - MARS code

EM + Hadron Shower with thin mesh (scale $\sigma_\beta = 200\ \mu$m)



Results for Beryllium at 7000 GeV

Jaw 1400 mm long, X profile at Y=0 and Z=1400 (max. of amplitude)



Nuclear and E-M parameters vs. Atomic Number

Material	Z	L_r [cm]	λ_{nuc} [cm]	λ_{nuc}/L_r
Be	4	35.3	40.6	1.15
C	6	18.8	38.1	2.02
Al	13	8.9	39.4	4.4
Cu	29	1.4	15.0	10.7

The lowest ratio λ_{nuc}/L_r minimises the Energy Density

Allowed number bunch of bunches lost

Superimposed - No diffusion $\Rightarrow$ Fast deposition

Injection	Material	Safe	Occasional	Begin local damage
	Be	190	1100-1500	1300-2100
	C	230	500-800	500-800
	Al	30	80-130	110-180
	Cu	1	10-13	13-19
Top energy	Material	Safe	Occasional	Begin local damage
	Be	2.6	16-20	18-29
	C	2.5	5-9	5-9
	Al	0.2	0.3-0.8	0.7-1.2
	Cu	0.01	0.1-0.11	0.1-0.16

♣ Integrated heat deposition $\rightarrow \Delta T \sim 15$ K in the worst case of the table

Heating during RF losses at ramping (5% of coast)

- Duration of RF losses lasts ~ 1 s
- Use multiturn tracking
- Use energy deposition map in the most exposed secondary collimator
- $\Rightarrow$
  - Copper : $\Delta T = 650$ K (safe: $\Delta T_{uts} \sim 100$ K)
  - Beryllium : $\Delta T = 10$ K

Compare expected (dump kicker case) to allowed

Criterion : Occasional occurence (once/year)

	N [bunches]	
Expected	10	40% margin
Allowed for:		
Beryllium	$16-20$	
Graphite	$5-9$	
Copper/Aluminium	$0.1/0.5$	

Conclusion

- Need to secure preliminary limits for materials

Collimator jaws, need

- Low-Z
- High stiffness (μm precision)
- Good (or really null) elec. conductivity
- Beryllium sole oustanding element (+ stiffer than steel)
- But toxicity of Be (allergies) must be carefully considered

The SPS as a possible Test-Bed for LHC collimators?

G. Arduini SL/OP

SPS basic parameters

- Energy: 14 – 450 GeV
- T_{rev} ~ 23 μs (7/27 $T_{rev\ LHC}$)
- Phase advance/cell ~ 89°
- $\beta_{min/max}$~ 20/100 m

Beams (LHC)

- 26 – 450 GeV/c
- 3-4 x 72 bunches (~1.8μs) separation~225ns
- Bunch spacing: 25 ns
- I_{bunch}~1.1×10^{11}p (done 5×10^{10} p @450 GeV/c)
- I_{total}~3.2×10^{13}p (done 1.5×10^{13}p @450 GeV/c)
- Max stored energy: 2.3 MJ (1.1 MJ)
- $\sigma_{rms\ (@450GeV/c,\ \beta=100m)}$: 0.85(H)/0.85(V) mm
- Foreseen 1 fast extr. to TT40/TT60

Beams (CNGS)

- 14 – 400 GeV/c
- 2x2100 bunches (10.5μs)– 2 holes ~1μs each
- Bunch spacing: 5 ns
- I_{bunch} ~1.1x10^{10} p (aiming for 2x10^{10} p)
- I_{total} ~4.8x10^{13} p (aiming for 8x10^{13} p)
- Max stored energy:3.1 MJ(5.1 MJ)(circ.beam)
- $\sigma_{rms\ (@400GeV/c,\ \beta=100m)}$: 1.6(H)/1.3(V) mm
- Foreseen 2 fast extr. (~10.5 μs each) to TT40

Fixed target with FS extraction

- 14 – 450 GeV/c
- 2x2100 bunches (10.5μs)– 2 holes ~1μs each
- Bunch spacing: 5 ns
- I_{bunch} ~0.9x10^{10} p
- I_{total} ~3.8x10^{13} p
- Max stored energy: 2.7 MJ (circulating beam)
- σ_{rms} (@400GeV/c, β=100m) : ~ 1(H)/1.3(V) mm
- 2 fast-slow extr. (~5 ms each) to TT60

SPS Scrapers/Collimators(2002)

- BSHV.51459 – H/V fast scraper (few ms)
- BRCV.51699 – Collimator V
- BRCH.51702 – Collimator H
- BRCZ.51931 – Collimator V
- BRCZ.51932 – Collimator H

- All these systems are not water cooled
- This system (to be tested in 2002) is intended only for tail scraping (before extr. to LHC)
- LSS5 is a ‘NON-radioactive area’ mainly used for BI and VAC instrumentation

Boundary conditions

- All the fast-extraction kickers have been taken out from the machine
- Fast - Extraction in the East (LSS4 – towards TI8) will be possible in 2003 (HW-wise) according to the present planning but very likely at low intensity?
- 2002 run cut by ~25 % (same in 2003?)
- Are we going to run in 2004?

Conclusions

- A collimation test-bench is installed but not designed to stand high intensities. Tail scraping. It is located in a 'clean' area.
- Destructive tests in the SPS ring are not advisable. The most radioactive areas are in the injection and extraction zones and contain delicate equipment (inj. kickers, ES septa, etc.).

Conclusions

- Destructive tests could be (to be studied more in detail) foreseen in the TT40 extraction line, but very likely not before the end of 2003 or in TT60 with a fast-slow extraction (to be re-commissioned)
- All these studies would require dedicated time (long MDs) and would demand specific installations.