# The Project on LHC Collimation

R. Assmann, CERN-SL

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

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

1. Why must we worry about collimation?

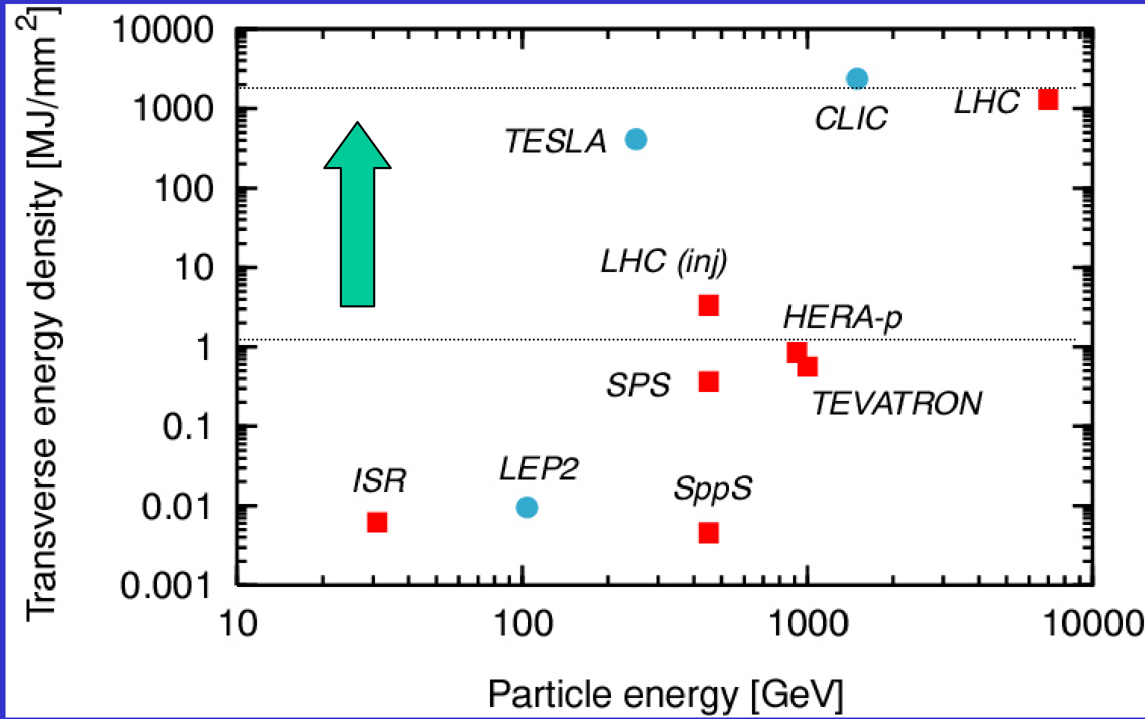
2. The collimation project

3. Changes under study – What can you expect?

4. Required input from you

# The High Power 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: | **350 MJ** |
| *Injection:* | |
| Proton energy: | 450 GeV |
| Transv. Beam size: | 1 mm |
| Bunch length: | 18.6 cm |




Factor 1000 in transverse energy density!

**At 0.1 % of its intensity the LHC will enter new territory!**

**Note: HERA collimators have been strongly damaged!**

# The Real Question: What Luminosity?

Physics Potential =
Energy and Luminosity:

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

Increase transverse energy density

d = demagnification
$N_p$ = protons per bunch
$f_{rev}$ = revolution freq.
$E_b$ = beam energy

The luminosity (transverse energy density) in the LHC may be limited by:

- **Rate of quenches (cleaning efficiency): decrease bunch intensity, number of bunches**
- **Tight tolerances in the collimation system: increase $\beta^*$**
- **Protection of elements close to the beam (collimators, ...): decrease bunch intensity, number of bunches**

**We need to do a much better job than Tevatron, HERA, RHIC!**

# Material Damage

*Destruction limits*

| Case | Destruction threshold [nominal intensity] | |
|---|---|---|
| Copper | 1.9e-3 | **1.8e-5** |
| Beam screen | **1.6e-3** | 7.0e-5 |
| S.C. coil | 4.2e-3 | 14.0e-5 |

This made the **reconsideration of present collimator jaw materials** necessary! We cannot use Copper!

5-12 nominal bunches at injection

0.05-0.4 nominal bunches at top energy

No safe operating point for LHC (top) without protection!

# Super-Conducting Environment

Proton losses into cold aperture

⇩

Local heat deposition

⇩

Magnet can quench

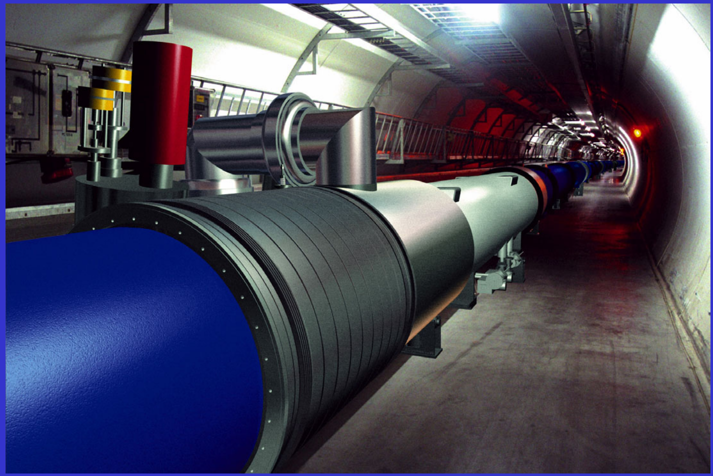


*Illustration of LHC dipole in tunnel*

| 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)*

# Concept of LHC Collimation

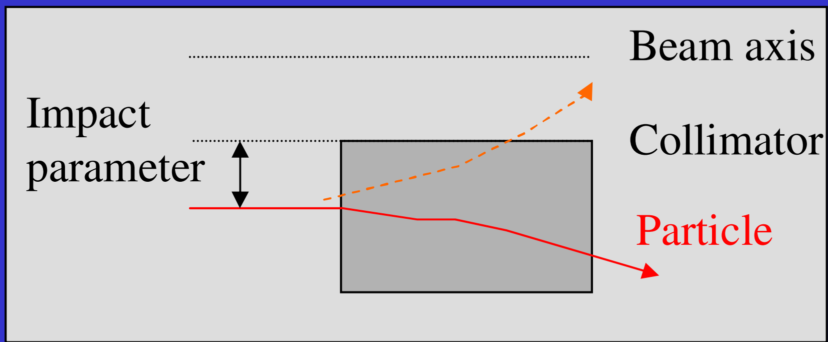
"Conventional" jaws (blocks of appropriate solid materials).

"Exotic" schemes (e.g. crystal collimation) not foreseen in baseline solution.
Unusual mechanical solutions can be envisaged ("consumable" jaws, connected jaws).

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



# Requirements for Collimator Settings

Reminder: Normalized available LHC aperture specified to be about $10\sigma$ at injection (arcs) and top energy (triplets).

+ 3-4 mm for closed orbit, 4 mm for momentum offset, 1-2 mm for mechanical tolerances

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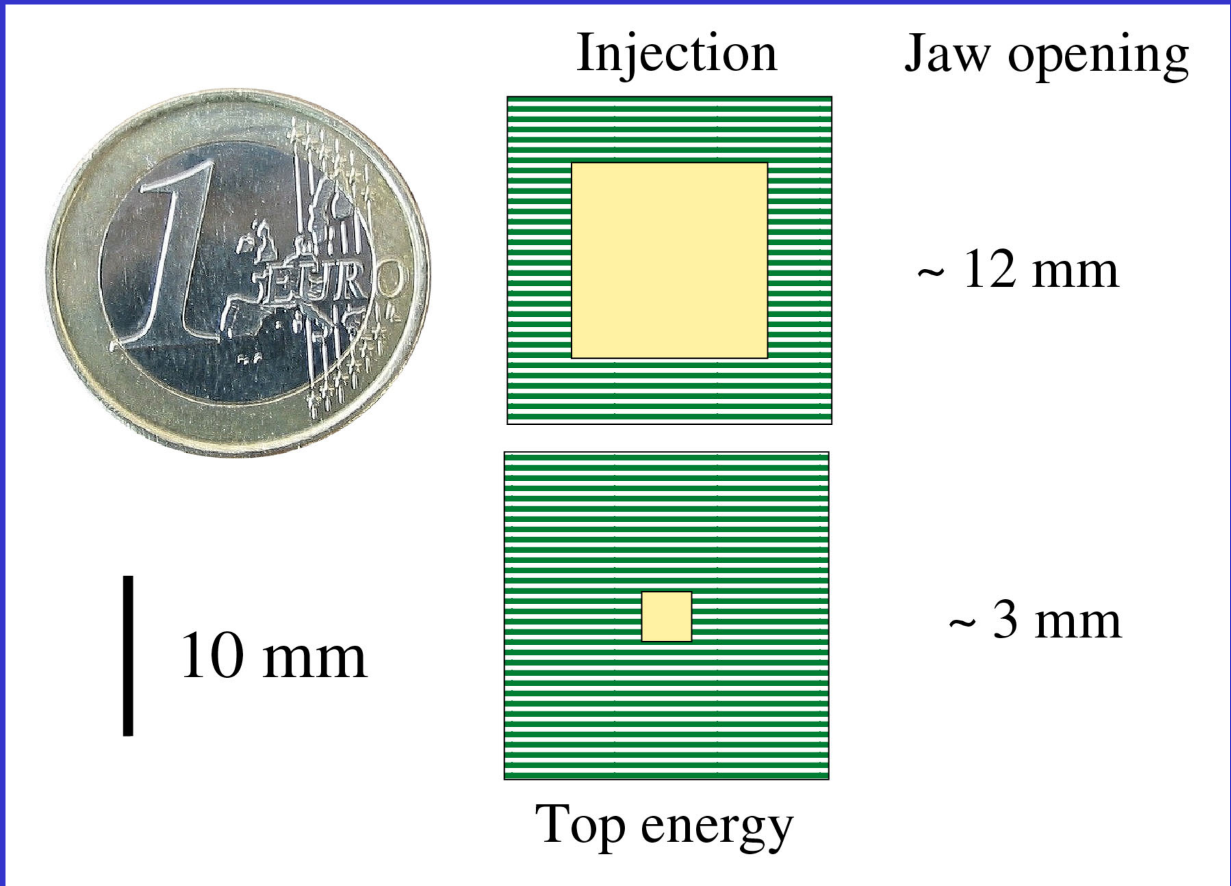



Collimator settings:

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

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

Number of protons reaching $10\sigma$:

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

# LHC collimators must be robust and precise!

Survival of jaws with 7 TeV proton impact (no melting, cracks, dust formation, …).

- 2 $10^{12}$ p (2.2 MJ) in 0.5 $\mu$s over area of 1 mm (full width) × 0.2 mm (rms)
- 4 $10^{12}$ p (4.5 MJ) in 10 s over area of 0.03 mm (rms) × 0.2 mm (rms)

0.7 MJ to melt one kg Cu

Excellent cleaning inefficiency.

- Local losses ~$10^{-5}$ of primary beam halo.
- Deformations of ~1.5m long jaws < 25 $\mu$m.
- Control/maintain beam-jaw position/angle to ~0.1 mm, ~60 $\mu$rad.
- …

… and available from day 1 of LHC operation (10% intensity still far beyond handled so far)

RA; IR7 Pos 6/12/02

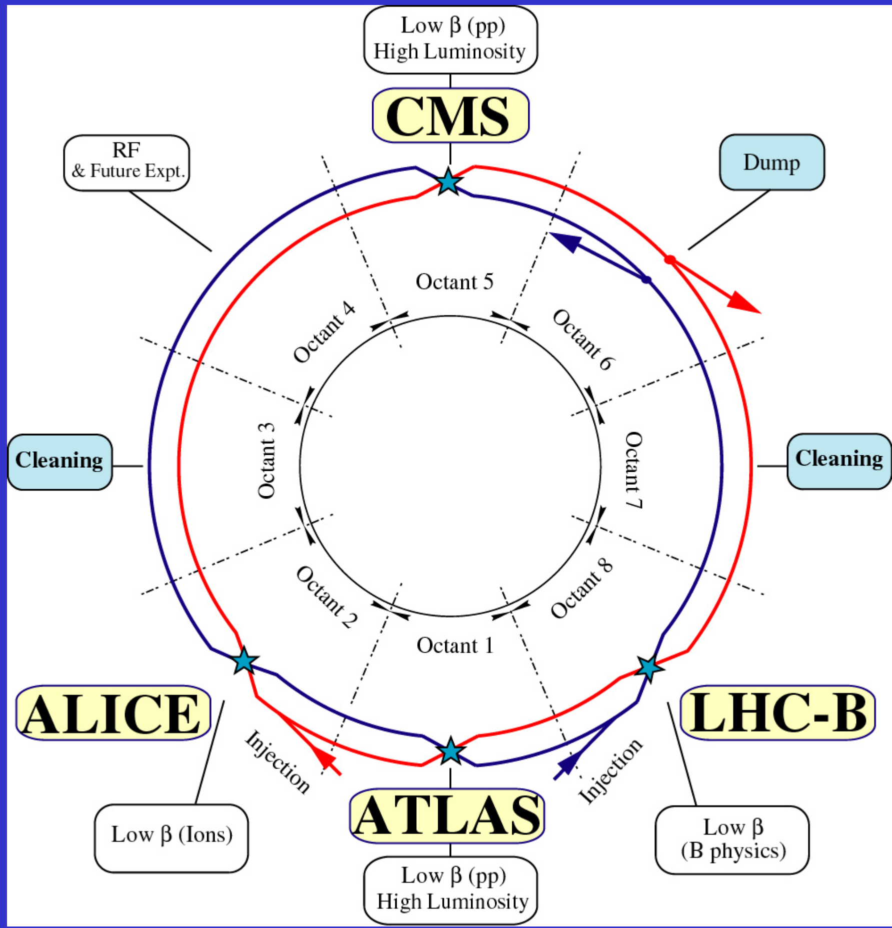
# Two Dedicated LHC Insertions

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*

Full system: 66 collimator tanks + 12 spares

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# Mandate and Required Schedule

**Finalize the design** of the LHC collimation system in IR3 and IR7, taking into account all relevant requirements concerning **robustness, performance, fabrication, installation, maintenance, machine protection, and beam operation**.

Produce **prototype collimator tanks** for TCP, TCS, and TCL type collimators and verify their performance.

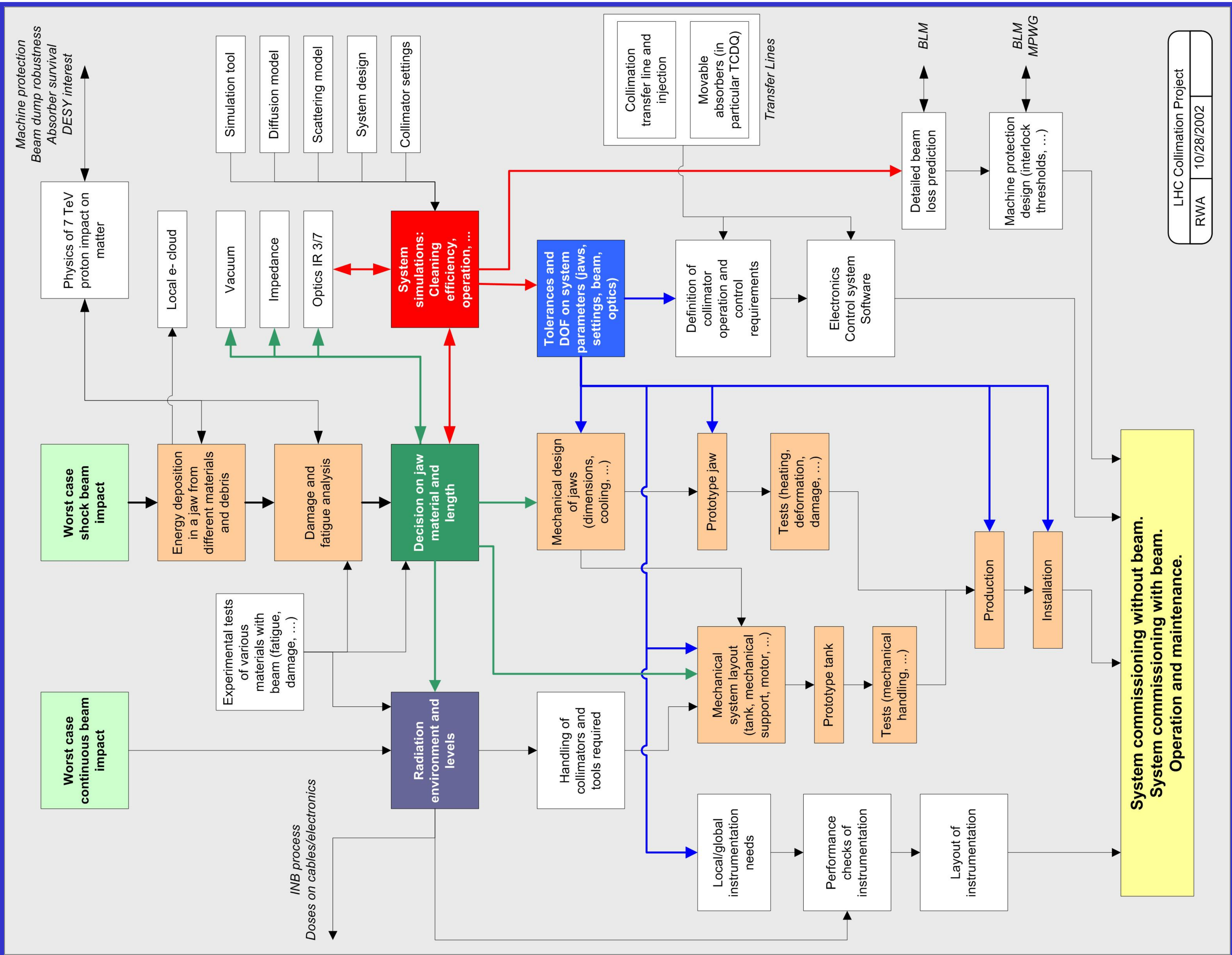
Supervise **production and installation** of the full system.

**Commission** the system without and with beam.

**Support routine operation**.

Demanding schedule:

| | |
|---|---|
| end 2003 | prototypes |
| 2004/05 | production |
| 2006 | installation |
| 2007 | commissioning |

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# Present Status

**Beam scenarios defined**: Requirements for LHC collimators specified in detail (published).

**Studies of energy deposition started**. Material pre-selection: Ti, C, Be, C with Ti coating, BN, Cu, …

**Damage/fatigue analysis will start very soon.**

| | |
|---|---|
| Milestone 1: | **Selection of material and length.** |
| Milestone 2: | Final system design (layout, efficiency, optics). |
| Milestone 3: | Detailed mechanical design. |
| Milestone 4: | Prototype and tests (end 2003?!). |

# Route 1: Materials

| | Be | C | BN | Ti |
|---|---|---|---|---|
| Low Z for survival | + | + | + | -- |
| Experience | + | + | -- | + |
| Toxicity | -- | + | + | + |
| Short length | - | - | - | + |
| Good impedance | + | -- | - | + |
| No coating | + | -- | - | + |
| Good vacuum (local e-cloud) | + | -- | - | + |

**No ideal material, no obvious solution!**

*Detailed studies P. Sievers, A. Ferrari, …*

# Present estimate (guess) for secondary collimators (see JBJ):

| | Low Z (2denC) | Cu (V6.4) |
|---|---|---|
| Length of jaw: | 100 cm | 50 cm |
| Tapering: | 20 cm | - |
| Overhead tank: | 20 cm | 20 cm |
| Remote handling: | - | - |
| Movable shielding: | - | - |
| Vacuum ports: | 25 cm/side | 25 cm/side ← **Possible gain?** |
| Total (2 side port): | **190 cm** | **120 cm** |

For example: 3 secondary collimators (TCS) inside quadrupole

Length for three TCS: 3.1 m (V6.4) ➡ ~ 5.2 m

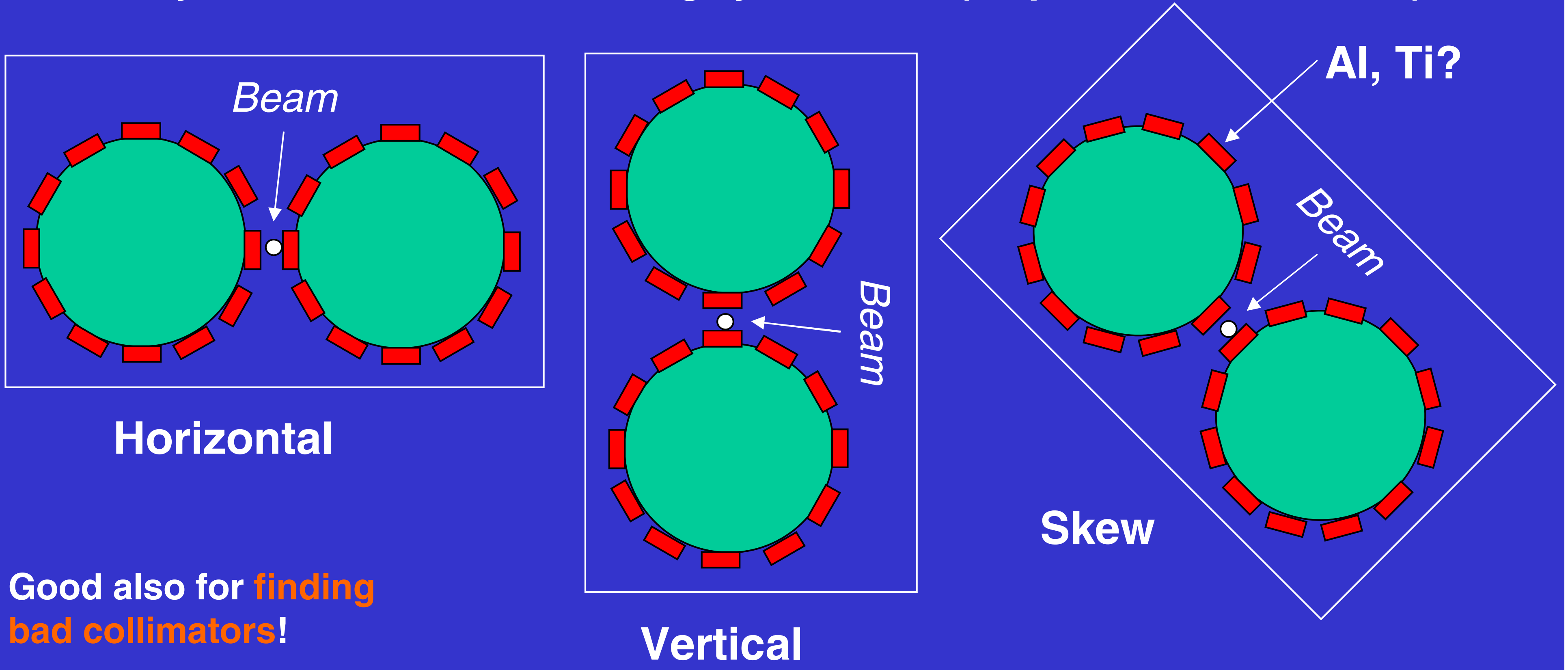
Quadrupoles could move by **~ 2 m** at specific locations (maintain symmetry)!?

**Movements even where no collimators** are (maintain symmetry of optics)

# Route 2: Mechanical Engineering

As materials cannot be tested anyway for LHC densities:

Assume jaws are broken and change jaw in situ ("repairable" collimator):




Good also for finding bad collimators!

Adjust collimator gap, angle beam-jaw, rotation with tight tolerances (complicated)!

Estimate rate of jaw consumption (should hold all run)!

# Route 3: Operationally Robust System

**Concept:** Add up to 12 primary collimators to close phase space to oscillations (0,45,90,135 degree).

Secondary collimators can never become primary collimators (excluding local IR7/IR3 errors).

Insensitive to orbit, beta beat errors. More relaxed tolerances for jaw properties.

Secondary collimators can be made simple, as they are always protected by primary collimators.

Most likely not possible any more due to length (phase advance) limitations!

# You should expect

Changes in magnet positions of up to 2 m, even where no collimators are.
This is a guess and can become larger!

A few additional secondary collimators to close the phase space for machine protection (present orbit can reach 10 $\sigma$ for collimators at 6/7 $\sigma$).
A clean spot will not necessarily remain a clean spot.

The ordering and installation of cables for the collimators, once they have been specified.
A second installation campaign is needed anyway.

Separate cooling circuits for the collimators? Remote handling? Movable shielding?

Additional requirements from detailed engineering design?

| Demanding schedule: | end 2003 | prototypes |
|---|---|---|
| | 2004/05 | production |
| | 2006 | installation |
| | 2007 | commissioning |

# Crash program to freeze IR7?

Thorough study:

Decide material by July 03.

Decide remote handling: July 03.

First rough design: July 03.

Know length.

Redesign IR7 optics/coll system: Oct 03
(3 months for +- 1m changes)

**System with optimal performance.**

Crash program:

Guess maximum length required per collimator (e.g. 3 m).

Match **“placeholder” optics** that should accommodate any final design. (Mar 03)

**Pay with cleaning efficiency.**

# What we need from you:

Feedback on the constraints from your side:

**Scheduling, design choices, installation, space constraints, …**

# References

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