Collimator Upgrades to LHC

16 July 2009
SLUO LHC Workshop
Jeff Smith, SLAC
Review of LHC Collimation and Why we Need an Upgrade
LHC stored energy corresponds to **80 kg TNT per beam**!

Dangerous beam!
Preventing Quenches

- Maximum **beam loss at 7 TeV**: 1% of beam over 10 s

- **Quench limit** of SC LHC magnet:

  8.5 W/m $\Rightarrow$ 230 kW

  evenly over 27 km

This is a job for Collimators!
“Phase 1”

Momentum Collimation

“Final” system: Layout is 100% frozen!

Betatron Collimation

from: R. Assmann
LHC Collimation Requirements

• For performance metrics focus on:
  – “Transient” bursts corresponding to ~1.4% beam loss in 10 sec
    • beam lifetime $\tau = 12$ min or
    • Particle loss rate $= 4 \times 10^{11}$ p/s
    • Energy loss rate $= 450$ kW
    • abort if lasts $> 10$ sec
  – Note that “steady state” engineering loss rate is 5x less (1 hour beam lifetime)
  – Long term beam loss rate another x10-20 less (10-20 hour beam lifetime)

• $\sigma \sim 200\mu$m for collimators (collision energy) and secondary collimators are at $7\sigma$

• Accident Scenario:
  – Beam abort system fires asynchronously with respect to abort gap
  – 8 full intensity bunches impact collimator jaws
  – 1 MJoule incident energy
The LHC “TCSG” Collimator

3 mm beam passage with RF contacts for guiding image currents

Designed for maximum robustness:

Advanced CC jaws with water cooling!

Other types: Mostly with different jaw materials. Some very different with 2 beams!
MOTIVATION FOR UPGRADE: HIGHER COLLIMATION EFFICIENCY

- High Z materials improve system efficiency but generate more heat

- Copper eventually selected for SLAC Phase II design because of its high thermal conductivity and ease of fabrication

- Available length for jaws is about 1 meter, although gain after ~50cm is minimal

- Global inefficiency x3.6 better for Cu over C, but does nothing for Intensity Limit of particles lost in dispersion suppressor

Similar SIXTRACK results by Abmann, Bracco
LHC Impedance Dominated by Collimator Resistive Wall for both Graphite and Copper

Elias Métral, Conceptual Design Review LHC Phase II Collimation, CERN, 02-03/04/2009

from: E. Metral
Switch to Copper helps but still not quite good enough on its own.

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**STABILITY DIAGRAM (3/3)**

- Scan of the resistivity of the secondary collimators

![Graph showing stability diagram](image)

- **1.7 \(10^{-8}\) \(\Omega\)m (copper)**
- **10\(^{-10}\) \(\Omega\)m**
- **10\(^{-5}\) \(\Omega\)m (nominal)**
- **No secondary collimator**

From Landau octupoles at max.

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Elias Métral, Conceptual Design Review LHC Phase II Collimation, CERN, 02-03/04/2009
1. Collimation in first bend dipoles downstream of straight betatron collimation section to absorb single diffractive scattered particles

2. Higher Z secondary collimators
   1. Flat metallic (directly replacing graphite in phase I)
      • Risk beam impact destroying collimator
   2. Flat exotic material (Diamond Graphite, advanced composites, ceramic)
      • Unproven materials
   3. Rotatable metallic collimator
      • Garden variety material
      • Easily recover from beam impact

3. Changes to betatron cleaning optics that allow for the secondaries to be further away from the beam

4. Crystal collimation
   • Increases collimation efficiency with secondaries at greater sigma

5. Hollow electron lens
   • Beam scraping below 6 sigma
   • Pull primaries and secondaries further away from the beam

Secondary collimator solution will be based on LHC beam experience, have to wait...
Rotatable Copper Collimator
LHC Rotatable Phase II Collimators

SLAC Developed & Prototyped for NLC a “Consumable” Primary Collimator to Handle Infrequent e- Beam-Impact Events

In 2003 SLAC suggested to CERN & LARP that this “Rotatable” concept might be the basis of an LHC Phase II Secondary Collimator

Rotating "Wheel" Collimator

Damage zone ~1mm
Only 6mm thick
NO COOLING!!

Thin Cu with micron scale hole drilled by beam
LHC Phase II Base Concept

Glidcop Jaw - Cu Mandrel wrapped with CuNi coil – Hollow Glidcop
Hub / Molybdenum Shaft with 2mm gap from Mandrel

• Beam spacing: 136mm OD
• Length 1.47 m flange–flange:
  • 930mm overall
  • 2 x 38mm 15° tapers
  • 854mm long facets

20 facets

Glidcop    Cu    Mo

Hub area

Cantilever Mo shaft @ both ends

2mm gap between shaft OD and mandrel ID

Helical cooling channels 23mm below surface with 16m long 10mm square CuNi tube

Cu coolant supply tubes twist to allow jaw rotation

Molybdenum Shaft

Copper Mandrel

Copper tubing wound in groove
Rotatable Design: 1st Collimator: 4E11 p/s

LARP

At $\tau = 12$ min, each jaw of Coll#1 in IR7 absorbs 3kW if C or 60kW if Copper

• Temperature rise and differential heating cause jaw to distort
  – Loss of efficiency as lose flatness
  – Swell closer to beam core

Thermal distortion is a function of materials, jaw OD & ID, length, cooling & support design

Study energy deposition with FLUKA & mechanical response with ANSYS
TT60 Beam Impact tests

• The TT60 Extraction line off the SPS is planned to be converted into a beam impact test facility
• up to 2.4 MJ or greater than the collimator accident scenario
“RC0” First Full Length Jaw Finished May 2008
Tests with first prototype

- Thermal test with 10kW resistive heaters to verify ANSYS
- Vacuum Bakeout
- CMM Flatness measurements
- Rotation mechanism tests
- RF impedance measurements
Future Schedule

• 2010: Construction of first full collimator for tests in SPS
  • Test integrated Beam Position Monitors
  • Measure impedance contributions
  • Test operation in a live machine
• 2011: Beam impact studies in TT60 test facility
  • Confirm recovery from direct beam impact
    • How much damage?
  • On our side could be done by the end of the year but facility needs to be constructed at CERN first!
• ~2012: Tests In LHC
  • Confirm operation LHC
  • Collimation upgrade choice after tests
• Future: Build up to 40 rotatable collimators and install in LHC!
Full part of LHC Collimation team

- SLAC’s Rotatable Collimator group is fully integrated into the larger LHC Collimation group at CERN.
- We have regular teleconferences and videoconference.
- Regular visits to CERN
- Our technology is on “equal” footing with CERN’s on-site options
Working with CERN

• As a postdoc early in my career:
  • Provides an opportunity to work with the only high energy accelerator being commissioned.
  • CERN is (unfortunately) the center of the high energy physics universe and my presence is directly known within this community.
  • World-wide exposure and networking

• As a SLAC employee
  • Technology and solutions developed in our program can be applied to future projects at SLAC and elsewhere