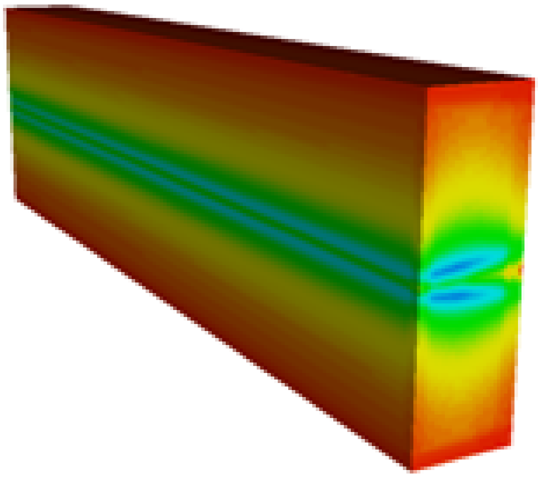
Workshop on Materials for Collimators and Beam Absorbers

Monday 03 September 2007 - Wednesday 05 September 2007

CERN



Book of Abstracts

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Accelerometer and microphone measurements of the LHC collimator

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Sound and vibration measurements of the LHC collimator were performed with various accelerometers and a microphone during collimator robustness tests in 2004 and 2006. The collimator jaws were hit by 450 GeV protons beam of up to 3.5x10e13, equivalent to a total energy of about 2.4 MJ (0.65% of the nominal LHC beam at 7 TeV). It was demonstrated that these measurements can be used to detect beam impacts of LHC beams on the collimators and hence possibly damaged collimators. In this talk the experimental layout is presented and detailed frequency analysis of the measured vibration signals are presented.

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Beam absorbers for Machine Protection at LHC and SPS

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Beam impact on collimator materials: Studies for LHC and SPS using BIG

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Beam impact on collimator materials: Studies for LHC by Kurchatov Institute

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Theoretical models and numerical calculations are presented here to understand an influence of the impact of a 7 TeV proton beam on the physical-mechanical properties of collimator materials (C, Cu) used
in the LHC. Here we develop the theoretical model for shock wave propagation and theoretical model for calculations
of primary radiation damage formation including calculations of a generation rate of point defects and atomic
cascades in collimator materials under 7 TeV proton beam irradiation. In our calculations we assume that each
7 TeV proton bunch has 1.1x1011 protons with a bunch length of 0.5 ns and a bunch spacing of 25 ns. The high
energy stored in each bunch can produce a shock wave and radiation damage near the impacting proton beam in these materials.
The theoretical model for the investigations of shock wave propagation in the collimator materials takes into
account ionization, electronic excitation, and energy transfer from excited electronic subsystem of material
to the ionic subsystem. The changes of some physical properties of the collimator materials during shock
wave propagation are considered here. The deposited energy is calculated with the FLUKA program.
The numerical results of the microstructure changes in collimator materials produced by shock wave propagation
near 7 TeV proton beam are presented for different numbers of bunches. This allows investigating changes of
density and internal pressure, the distributions of atomic and sound velocities, and the temperature profiles in
electronic and ionic subsystems of materials near the front of shock wave. These results are very relevant
for the understanding the behavior of collimator materials used in LHC when hit by a 7 TeV proton beam.
The new theoretical models and computer tools are developed for investigations of radiation damage formation: point defects, cascades and sub-cascades near a 7 TeV proton beam in collimator materials: Cu and
Graphite, taking into account electronic excitation, energy loss, elastic and inelastic collisions in materials
induced by interaction of 7 TeV proton beam with collimator materials. The numerical calculations for generation
rates of point defects are based on the numerical calculations of displacement cross sections for point defect
production taking into account primary knocked atom (PKA) energy spectra for nuclear products and neutron
spectrum near 7 TeV proton beam obtained using FLUKA program.

Co-authors: SEMENOV E.v. (Kurchatov Institute), KOZLOVA O.a. (Kurchatov Institute), ASSMANN Ralph (CERN), FERRARI Alfredo (CERN), SCHMIDT Rudiger (CERN)

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Carbon-metal composites for thermal management

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Carbon-metal matrix composites are a very attractive materials for thermal applications, given their very high
thermal conductivity in at least two planes.
Therefore, in an attempt to obtain a good thermal conducting material as well as a low Coefficient of Thermal
Expansion (CTE), a mixture of reinforcements (graphite and carbon fibre) was infiltrated with liquid alloys.
The role of two reinforcing materials are following: while graphite reinforcement increases thermal conductivity in the plane direction, the carbon fibre helps to reduce the CTE of the alloy in the same direction.
In the present work, graphite-carbon fibre preforms were infiltrated with Al/Si and Ag/Si alloys by means
of gas pressure to produce an anisotropic composite.
The influence of the volume fraction in the thermal conductivity and CTE was evaluated. The experiments
determined that the manufactured composites has a adequate thermal behaviour to be used as low cost materials in heat spreaders.
Co-Authors: LOUIS Enrique (Alicante University), MOLINA Jose Miguel (Alicante University), PRIETO Richard (Alicante University).

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Copper based composites reinforced with carbon nanofibers

Author: René NAGEL[1]

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The Powder Technology Center of the Austrian Research Centers GmbH is working since several years on
the development of materials with advanced thermal properties. Different Cu and Al based fiber or particle
reinforced composites have been studied. As reinforcement materials carbon fibers, carbon nanofibers (nanotubes),
SiC or diamond particles have been used to prepare materials with high thermal conductivity and reduced
coefficient of thermal expansion. Such materials are of interest for heat sinks or heat spreaders in electronic´s cooling.
One material with a high potential - but big challenges - are copper reinforced by carbon nanofibers.
Carbon nanofibers are a promising reinforcement material for copper based composites. The high thermal
conductivity of the carbon nanofibers (up to 2000 W/mK) is expected to improve the thermal properties of the
composite material. One main problem is the lack of any interfacial reaction between copper and carbon
based materials, which requires either a pre-treatment of the nanofibers and/or modification of the
matrix (e.g. via alloying). The influence of both possibilities on the thermal performance (thermal
diffusivity/conductivity and Coefficient of Thermal Expansion) of the material will be shown. In addition
microstructure analyses are carried out in order to assess the nanofiber distribution and the quality of the interface.

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Design and testing of ILC Beam Delivery System collimators

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Development and manufacturing status of diamond-based composites

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Co-authors: Ravi BOLLINA [1] ; Tobias MROTZEK [1]

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Advanced metal diamond composites with Silver, Aluminum and Copper matrices exhibit high thermal conductivity
in the range of 400-700 W m-1 K-1 and low CTE of about 7 – 9 ppm/K. A gas pressure assisted infiltration process
has been developed for cost-efficient industrial production of diamond composite substrates and heat sinks.
The composite microstructure and interface morphology determine the thermal properties and reliability during thermal
cycling and represent the key to advanced composite formation. An industrial scale pilot production has been installed
and the product has reached a degree of maturity allowing the application for current and future high end thermal
management applications. The status of product development as well as thermal and mechanical properties and
results of thermal cycling tests will be reviewed.
Co-authors: BOLLINA Ravi (PLANSEE SE), MROTZEK Tobias (PLANSEE SE)

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Diamond-based Metal Composites

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High end applications as the beam collimators for the LHC or first wall materials in fusion reactors require not only
innovative engineering of the assembly and the structural parts but require also unique property combinations
of the materials they are made of, e.g. good electrical conductivity, high thermal conductivity, low absorption of
elemental particles, low coefficient of thermal expansion (CTE), high stiffness, high strength etc.. Some of these
requirements may even be mutually exclusive in monolithic materials.
A common strategy to cope with such unprecedented property combinations is to use a composite approach,
which is essentially a structural solution on the micron scale. In this talk materials combining diamond
particles and metallic matrices are presented that combine low CTE, high thermal and electrical conductivity,
and high stiffness. A few fundamental issues concerning the potential and the limitations of these

materials as
well as possibilities to manufacture such materials and current challenges in the development will be discussed.

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Discussions and closing remarks

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Dynamic structural analysis of absorbers with spectral-element code ELSE

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The dynamic structural behavior of beam diluter elements TCDS (LHC) and TPSG (SPS), protecting the extraction
septum magnets in the event of an asynchronous firing of the extraction kickers, has been studied. The
deposited energy densities, estimated by the high-energy particle transport code FLUKA, were converted
to internal heat generation rates according to the time dependence of the extracted beam. The transient response
to this thermal load was obtained by solving the power deposition and subsequent structural deformation by
using the spectral-element code ELSE.
This presentation gives a short overview of the used method and descibes the spectral-element code ELSE.
Furthermore we presents the results of the TCDS and TPSG analysis and finally conclude with some thoughts
on the materials and numerical simulations.
Co-authors: KADI Yacin (CERN), ROCCA Roberto (CERN), WETERINGS Wim (CERN)

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Dynamic vacuum - Collimator technology for suppression and control of desorption gases

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During operation with low charge state heavy ions (e.g. U28+) in the GSI synchrotron SIS18, fast beam losses
have been observed in experiments. At the same time, a dynamic behaviour of the residual gas pressure was
observed. To evercome these problems, a collimator system has been devoped and is now in the final
preparation for installation into two of the twelve sectors of SIS18 in the shutdown this year. It incorporates
the use of the CERN developd NEG coating as well as low desorption rate materials found out by systematic
studies using the ERDA (Elastic Recoil Detection Analysis) technology at GSI. The collimator system will both
reduce the desorption rate as well as control the not avoidable produced desorption gases. Simulation
studies using the code STRAHLSIM as well as construction details are presented.
Co-Authors: SPILLER Peter (GSI)

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Experience with implicit and explicit codes in analysing beam-induced thermo-mechanical shock

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In an effort to extrapolate the interaction of intense proton pulses with materials to power levels beyond
those achieved to-date in accelerators, computational schemes based on finite element formulation are being
widely employed. While the long-term interaction between radiating particles and materials result in the degradation
of the ability of a material to absorb the induced shock, a concern addressed in parallel studies that is coupled with
shock resistance, it is the rapid heating and shock generation in a material that results from short exposure to
intense pulses that poses a serious concern and, for the power levels under consideration, is accompanied
with serious uncertainties. Experimental studies at power levels generated by currently operating accelerators
have been used to benchmark the computational processes which will be used to extrapolate the material response
to desired, but yet to be achieved power levels.
Different computational schemes that may serve different stages of the interaction problem may be utilized.
The choice of such scheme is inherently bound between accuracy and computational cost. This presentation
will discuss both the similarities as well as differences between implicit and explicit numerical formulations
applicable to the thermo-mechanical shock problem where realistic description of the problem itself requires

high-fidelity modeling or descretization and high computational cost regardless of the scheme selected.
Experience from the benchmarking of numerical schemes against experimental results will also be presented.

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Experimental methods for material measurements at high strain-rate

Authors: Lorenzo PERONI[1] ; Massimiliano AVALLE[1]

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The detailed mechanical characterization of a material is the very first step in the design of structural components.
Depending on the type of application (dynamic, impact, thermal loading, fatigue…) different types of tests,
experimental methods, and testing equipments are required. After a general introduction about the effects of dynamic
loading on material behaviour, several related test methods will be outlined and discussed. The experimental
equipment, available at the Reliability and Safety Laboratory of Politecnico di Torino for static and dynamic
characterization of materials, will be described in detail and some examples of the most interesting results will be
presented, with particular attention to metals, polymers, and various types of composites and joints.
Co-authors: PERONI Lorenzo (Politecnico Di Torino)

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FE simulation of 450 GeV injection error test

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Dynamic phenomena provoked by the rapid interaction of energetic particle beams with slender structures
usually known as thermally induced vibrations are presented. Specific regard is given to the analysis of the accident case triggered by a beam injection error at 450 GeV, recently tested at CERN on LHC collimator prototypes.
A simplified analytical method, which was previously developed, has proved useful to obtain a preliminary
estimation of the vibrations induced on a collimator jaw.
A 3D Finite Element model for thermo-structural fast-transient elastic-plastic analysis has been fully studied.
The numerical method is carefully described with particular attention to initial conditions, boundary conditions
and integration scheme.
Numerical results are in good agreement with experimental measurements performed via Laser

Doppler Vibrometer.
Co-authors: BERTARELLI Alessandro (CERN)

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Finite Element Methods for the Thermo-mechanical analysis of the Phase I Collimators

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The functional requirements of the LHC Collimators impose, for the start-up of the machine and the initial
luminosity runs (Phase 1), a collimation system with a very high dimensional stability in nominal operating conditions, under considerable thermal loads and, at the same time, maximum robustness in
case of accidental beam impacts.
In order to meet these requirements and to optimize the complex mechanical design, the extensive use of in-depth numerical analyses was essential. Given the number and the detail of the elements which
had to be taken into account in the collimator model, the recourse to a general-use, comprehensive, multiphysics finite-element code was necessary: ANSYS Multiphysics proved very effective in dealing
with the coupled thermal/structural problems which were typically encountered and the disparate nature of used materials. The methods used and the approaches developed to correctly apply the thermal loads and to study coupled-field problems in the steady-state and transient domains, using both
fully elastic and elastic-plastic material properties will be presented.
Co-authors: DALLOCCHIO Alessandro (CERN)

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Generic studies of radioactivity induced by high energy beams in different absorber materials

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Generic studies of radioactivity induced by high energy beams in different absorber materials

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A rigorous campaign of benchmark measurements for materials typically used at accelerators
has shown the high accuracy of FLUKA calculations for isotope production and residual dose rates.
Accurate estimates of both quantities are important during all phases of an accelerator, i.e., design, operation and decommissioning.
A detailed implementation of geometries and accurate consideration of loss assumptions allows optimizing the layout of components
and performing detailed intervention planning starting already efficiently during the design phase.
Recent design modifications have shown the need to derive practical scaling coefficients in order to quickly asses
how estimated results can be roughly scaled for different assumptions affecting the calculated quantities, e.g.: chosen materials;
beam energies and particles; loss conditions, cooling times and beam impact parameters.
This talk gives an overview of dedicated generic simulations and the comparison of residual dose rates
for different chosen representative configurations.
Furthermore, the major contributing isotopes are derived
and obtained results are compared to those of dedicated simulations (TDI, IR7 collimators, etc).
Co-authors: ROESLER Stefan (CERN), FORKEL-WIRTH Doris (CERN)

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Irradiation damage in LHC beam collimating materials

Authors: Nick SIMOS[1] ; Nikolai MOKHOV[2]

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Demand for high-performance materials that can safely intercept the LHC proton beam has prompted an
extensive experimental study focusing on material degradation due to long radiation exposure. Given the
multi-MW class of the beam interception process at LHC combined with the stringent positional requirements
on the intercepting elements, the envelope of the current knowledge regarding material behavior and endurance
for both short and long exposure needs to be extended. For the collimating structures intercepting the halo of
an intense beam under normal or the entire beam during off-normal conditions, performance issues are essential
and directly tied to materials and their ability to maintain key properties and absorb beam-induced shock.
The limitations of most materials in playing such pivotal roles have led to an extensive search and experimentation
with new alloys and composites that appear to possess the right combination of properties.
Post-irradiation analysis results following exposure to the 200 MeV protons at the end of the BNL Linac will be
presented. In addition, preliminary results of estimated neutron-induced damage on LHC materials will be

discussed as a result of experimentation with a "unique" neutron source at BNL.
Co-authors: MOKHOV Nikolai (BNL)

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Issues Raised by the Design of the LHC Beam Dump Entrance Window

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The LHC beam dump entrance window consists of a carbon-carbon composite structural sheet backed by a thin stainless steel foil for leak tightness.
The design of this window has highlighted issues that merit further investigation.
The use of the bulk coefficient of thermal expansion coefficient for the composite should be questioned
where there is a significant temperature gradient between individual fibres.
Differential thermal expansion between fibre and matrix could lead to thermally induced fatigue.
The validity of the analytical dynamic stress model used should be confirmed by finite element or experiment.
After a brief description of the window design, I will outline the issues. From this I will draw some conclusions
about further analysis and the possible advantages of using windows to perform material and structural experiments.

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LHC Collimators (Phase II): What is an ideal material?

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The collimation system which is being installed has been designed to ensure high robustness during the LHC start-up and initial luminosity runs (Phase I). However, RF studies predict that the Phase I collimator
impedance will prevent the machine from attaining its nominal luminosity. Hence, from the early phases of
design, it has been envisaged to complement this system with a series of Secondary collimators (Phase II),
allowing to overcome the impedance issue and increase the collimation efficiency. One essential parameter
to meet such an ambitious goal will certainly be the type of material chosen for the new collimator jaws.
Given the Phase II collimation requirements, this "ideal" material shall have a low electrical resistivity and
a relatively high mass density. On top of this, a close-to-zero Coefficient of Thermal Expansion, high yield strength
and high thermal conductivity are desirable. The figures of merit which allow to identify the best candidate and
the rationale which is behind these figures will be illustrated.

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LHC requirements for collimation

Author: Ralph ASSMANN[1]

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LHC foresees a staged implementation of collimation. The first stage is presently being constructed and installed.
A second stage should allow an even higher performance reach and shoul address several possible limitations in
the initial installation. Collimators are the closest elements to the high-intenisty LHC beam and must be designed to
directly intercept beam particles. The question of material with high power load and high activation is a crucial ingredient
in the studies towards an upgraded collimation system. The open questions and required boundary conditions for
jaw materials in the LHC collimation system are presented.

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Lattice optimization for low charge state heavy ion operation - Collimation concepts for beam ions after a charge change

Authors: Carsten OMET[1] ; Jens STADLMANN[1] ; Peter SPILLER[1]

[1] *GSI*

We present a new lattice design concept for heavy ion synchrotrons which is optimized for the control
of beam loss by projectile ionization.
The lattice cells of the FAIR SIS100 synchrotron has been designed as charge separators. Thereby
ionized projectiles are well separated from the reference beam. The generated peaked loss
distribution enables the operation of a highly efficient scraper system.
The main purpose of the scraper system is to suppress and controle the production of desorption
gases and thereby stabilize the residual gas pressure dynamics.
Co- Authors: OMET Carsten (GSI), SPILLER Peter (GSI)

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Measurement of shock waves and vibrations

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Numerical tools for the design of beam intercepting devices

Author: Luca Bruno[1]

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Beam intercepting devices (collimators, targets, absorbers) capable of sustaining high-intensity beams are key elements to meet the future physics needs. The highly non-linear phenomena involved in their
design study (cavitation, transient magnetic-hydrodynamic effects on liquid metal jets, phase change, fluid-structure interactions) require advanced simulation tools at the forefront of today's numerical technology. This goes beyond the software usually available which uses numerical techniques not capable
of modelling effectively or even unable to study such complex phenomena.

In order to address this issue, a technical survey has been performed to investigate the state-of-the-art
in numerical simulations. The capabilities of existing advanced numerical tools has been assessed and a
code has been identified which combines comprehensive equations of state, strength and failure material
libraries, phase transition models and simulation techniques (meshless finite element methods) indispensable
to satisfy the design needs.

The presentation will focus on the rationale for this choice by examples and a benchmark with experimental
results on liquid metal targets performed at CERN.

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Objectives and questions

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Overview of FLUKA Energy Deposition and Design Studies for the LHC

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In order to assess the energy deposition in sensitive LHC components,
extensive simulations were performed with the Monte Carlo cascade code FLUKA.
In many cases specialized solutions needed to be found, challenging in

several aspects, i.e., from the calculation as well as from the design point-of-view.
Depending on the problem, detailed geometrical implementations, an accurate consideration of magnetic fields, tracking of particles over hundreds of meters, grazing angles and special biasing need to be considered.
This presentation gives a brief overview over the performed calculations, points out important input- and output parameters and the respective assumptions in the simulation as well as tries giving an overview of related uncertainties, the latter being of statistical and systematic nature.
Co-Authors:
FERRARI Alfredo (CERN), LARI Luisella (CERN), MAURI Marco (CERN), SARCHIAPONE Lucia (CERN),
VLACHOUDIS Vasilis (CERN), CERUTTI Francesco (CERN).

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Phase II Collimators for LHC Upgrade at SLAC - Material Issues

Author: Eric Doyle[1]

Co-authors: Jeffrey Smith [1] ; Leonard Anzalone [1] ; Lewis Keller [1] ; Stephen Lundgren [1] ; Thomas Markiewicz [1] ; Yunhai Cai [1]

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A rotatable collimator as developed at SLAC for NLC was proposed for LHC's Phase II upgrade to provide a low
impedance metal collimator, able to recover from several damaging hits by the beam. This talk reviews the
technical problems involved, the FLUKA/ANSYS simulations which have guided our design decisions and the
materials considered for the jaws. It focuses on the the reasons for the choice of Glidcop, copper and molybdenum
for the jaws and the ongoing material issues relating to the jaws and ancillary components.
Co-authors: ANZALONE Leonard (SLAC), CAI Yunhai (SLAC), KELLER Lewis (SLAC), LUNDGREN Stephen (SLAC),
MARKIEWICZ Thomas (SLAC), SMITH Jeffrey (SLAC)

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Simulating radiation damage effects in LHC collimators (code development status)

Author: George SMIRNOV[1]

Co-authors: Alfredo FERRARI [1] ; Hans BRAUN [1] ; John JOWETT [1] ; Ralph ASSMANN [1] ; Simone GILARDONI [1] ; Vasilis VLACHOUDIS [1]

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The current status of the code development for simulating the structural damage of the graphite jaws of the
LHC collimators produced by 7 TeV protons is presented. The technique, which is being developed in the framework
of the Monte Carlo code FLUKA, combined with the results of experimental tests of carbon-carbon composite
materials in radiation hard environment will be capable of evaluating lifetime of the collimation system.
Co-authors: ASSMANN Ralph (CERN), BRAUN Hans (CERN), FERRARI Alfredo (CERN), GILARDONI Simone (CERN),
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Studies of radiation effects on graphite collimator materials

Author: Alexander RYAZANOV[1]

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The effect of the 7 TeV proton beam irradiation on degradation of physical mechanical properties of graphite
collimator materials for LHC is very important for the understanding of stability the collimators during operation
of the LHC. At such high energies the carbon atoms in graphite collimator materials of LHC can get also
very high energy with primary knock on carbon atoms (PKA) reaching an energy of up to hundred GeV due to
elastic collisions with secondary particles formed in nuclear reactions. Carbon PKA atoms with such high energy
will produce radiation damage. The radiation resistance of graphite collimator materials will be determined by
the microstructure change under irradiation and defect cluster formation in atomic collision cascades. The main
aim of these investigations is to measure the effect of fast particle irradiation (carbon ions) on physical-mechanical
property changes of different graphite materials: thermal conductivity, thermal expansion coefficient, mechanical
properties (including the measurements of compression ultimate tensile stress, dynamic elastic module, static elastic module),
electrical resistivity, lattice constant and microstructure change.
Samples of various types of graphite collimator materials prepared by different firms for CERN were investigated:
C-C composite graphite REC, C-C composite graphite material AC and high-density graphite material R4SSO.
The obtained results for the measurements of initial physical-mechanical properties of these materials and
effect of irradiation of carbon ions with an energy of 5 MeV on radiation swelling and radiation erosion of these

materials are discussed here. The microstructure investigations of irradiated samples have been performed as
a function of the irradiation dose of fast carbon ions up to total dose of carbon ions 1018 cm-2. The performed
investigations shown that best radiation resistance properties including dose dependence of radiation swelling
at room temperature has composite material R4SS0. Other C-C composite materials such as REC and AC
have not so high radiation resistance properties that were confirmed by the dose dependence of radiation swelling.

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TT40 collimator – Deformation measurement after beam test

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Tevatron Collider Collimators and Absorbers

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Beam collimation is mandatory at any superconducting collider to protect components against excessive
irradiation, minimize backgrounds in the experiments, maintain operational reliability over the life of the machine,
and reduce the impact of radiation on environment, both at normal operation and accidental situations.
Highly-efficient two-stage collimation system at Tevatron reliably serves these purposes.
The system evolution over 25 years is described. Recent developments include marble shells and crystal collimation.
The later, gives a possibility to test channeling techniques in a collider as an interesting option for LHC.
External and internal Tevatron collider beam absorbers are described. They also exhibit high performance.

Session 1: Introduction – collimators and beam absorbers for different accelerators - Board: 1 / **0**

Welcome and introduction to the workshop

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