Collimator Materials for LHC Luminosity Upgrade: Proposal of Irradiation Studies at BNL

Collimation Upgrade Specification Meeting
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Summary

1. Requirements LHC Collimators
2. Radiation Hardness Studies at KI and BNL
3. Goals of Irradiation at BNL
4. BNL Accelerator Complex & BLIP Target Station
5. Preliminary Analysis
6. Materials samples number, geometry and production
7. Next Steps
8. Conclusions

LHC Collimators General Requirements

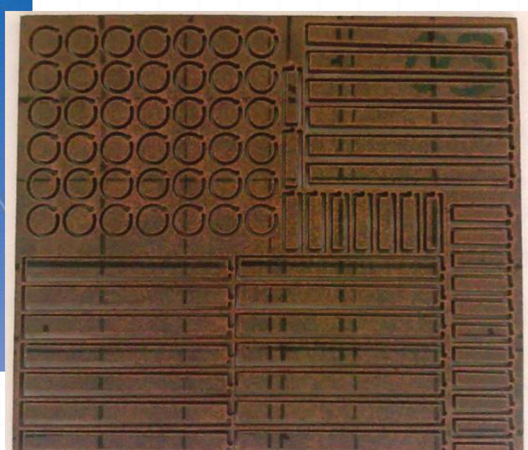
Key requirements for LHC Collimation System:

Intrinsic limitations **C-C** Collimators may ultimately limit LHC performances:

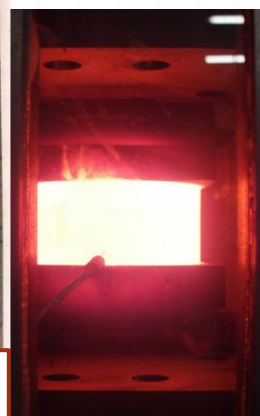
- **Low-Z** material (Limited Cleaning Efficiency)
- **Poor electrical conductivity** (High RF impedance)
- **Limited Radiation Hardness** (Reduced Lifetime)

➔ **Innovative Materials** are the key element for next-generation Collimators

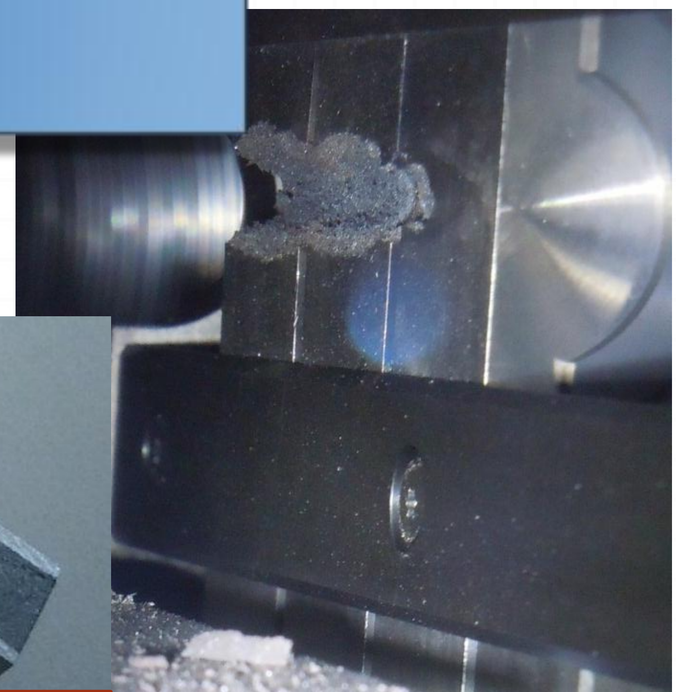
➔ **Need for new materials extensive Characterization**



CuCD Courtesy: **E. Neubauer, M. Kitzmantel** – RHP-Tech



MoGRCF – CERN - BrevettiBizz



Radiation Hardness Studies

- Radiation Hardness is a key requirement.
- Benefit from complementary studies in two research centers with different irradiation parameters, different materials and approaches
- Results Benchmarking

Ongoing Characterization Program in RRC-Kurchatov Institute (Moscow) to assess the radiation damage on:

- **CuCD**
- **MoCuCD**
- **MoGRCF (ex SiC)**

Features:

- Irradiation with protons and carbon ions at **35 MeV and 80 MeV** respectively
- Direct water cooling and T~100°C
- Thermo-physical and mechanical characterization at different fluencies (10^{16}, 10^{17}, 10^{18} p/cm^2)
- Theoretical studies of damage formation

Proposal for Characterization Program in Brookhaven National Laboratory (New York) to assess the radiation damage on:

- **Molybdenum**
- **Glidcop**
- **CuCD**
- **MoGRCF**

Features:

- Irradiation with proton beam at **200 MeV**
- Indirect water cooling and T~100°C (samples encapsulated with **inert gas**)
- Thermo-physical and mechanical characterization for fluence **up to 10^{20} p/cm^2**
- Possibility to irradiate with **neutrons** (simulate shower on secondary coll.)

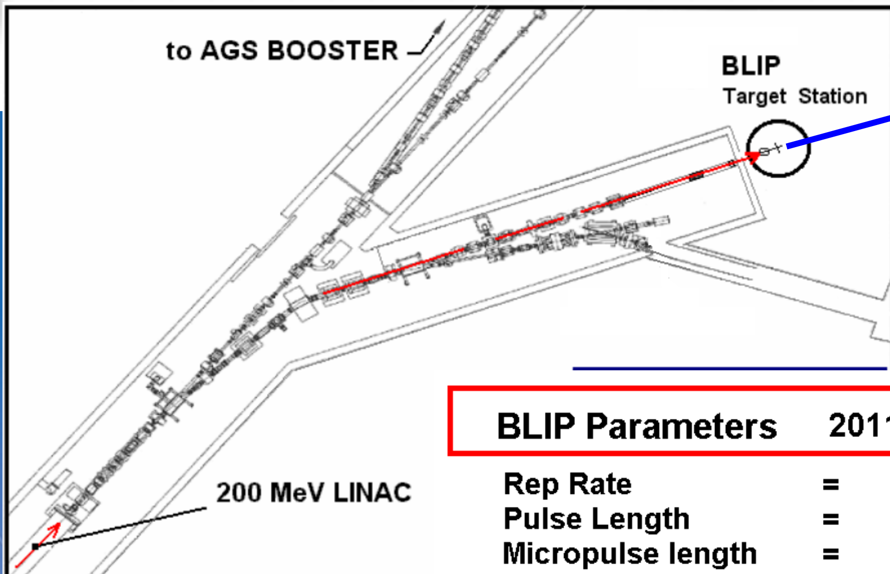
Goals of Irradiation in BNL

- Assess degradation of physical and mechanical properties of selected materials (Molybdenum, Glidcop, CuCD, MoGRCF) as a function of *dpa* (up to 1.0).
- Key physical and mechanical properties to be monitored :
  - Stress Strain behavior up to failure (Tensile Tests on metals, Flexural Tests on composites)
  - Thermal Conductivity
  - Thermal Expansion Coefficient (CTE) and swelling
  - Electrical Conductivity
  - Possible damage recovery after thermal annealing
- Compare *dpa* level to expected *dpa* level in LHC at nominal/ultimate operating conditions
- Is *dpa* a sufficient indicator to compare different irradiation environments?

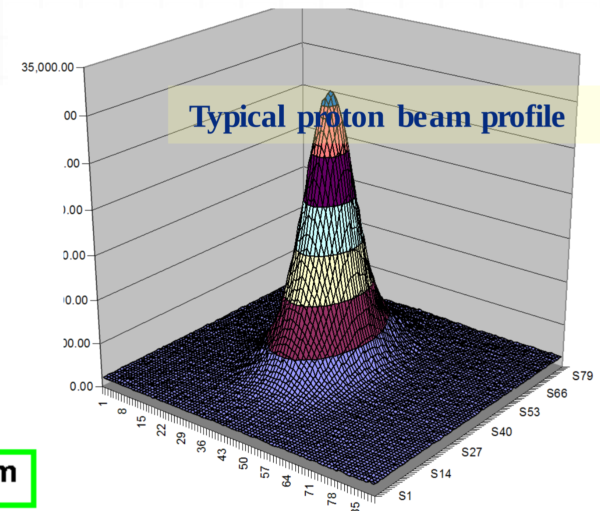
BNL Accelerator Complex

Irradiation at BLIP Target Station:
- Up to 200 MeV incoming proton beam
- Reduction of proton energy down to 112.4 MeV for further spallation neutron production

Power ~ 28 kW

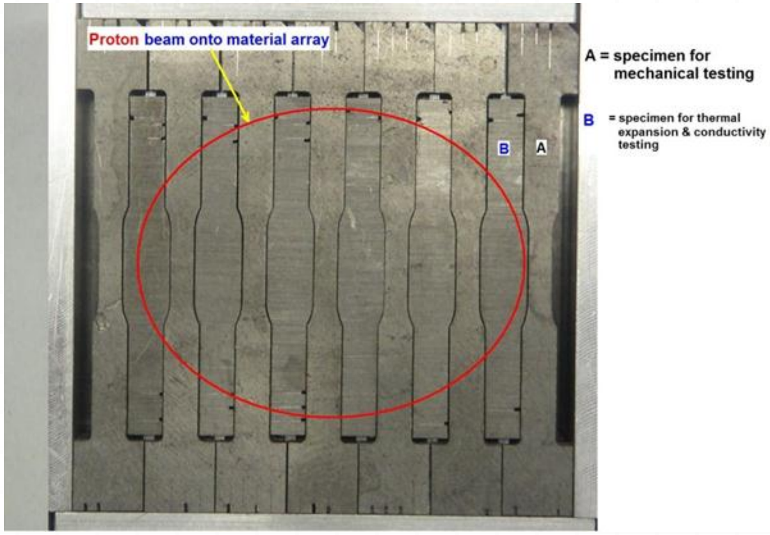


BLIP Parameters		2011 RUN
Rep Rate	=	6.67 Hz
Pulse Length	=	440 micro-secs
Micropulse length	=	5 ns
Micropulse structure	=	200.25 MHz
Average Current*	=	~105 micro-A
6 sigma beam within	=	2-inch diameter
Beam Gaussian	==>	1 sigma = 4.233 mm



Courtesy: N. Simos – BNL

BLIP Target Station



- Facility mainly to produce Isotopes and fast Neutrons.
- Possibility to irradiate materials.
- Incoming proton beam at 200, 181 or 164 MeV.
- Beam energy to be reduced after materials target station down to 112.4 MeV for optimal neutron production
- Samples arrangement not to significantly modify beam profile
- Optimal water cooling between capsules to maintain chosen irradiation temperature.
- **Identification of correct sample/supporting structure/cooling system geometry and layout, on the basis of analytical and numerical calculations.**

Steps to Material Irradiation

Preliminary assessment of specimen type, arrangement, thickness and number to reach Exit Energy of 112,4 MeV by simplified analytical calculations
➔ BNL + CERN

Montecarlo calculations to verify Energy Deposition on samples and structure + Exit Energy on Isotope Production Target
SRIM code at BNL +
FLUKA code at CERN

Ongoing

Thermo-mechanical numerical analysis to assess water coolant flow inside the gap between the capsules and irradiation temperature
➔ BNL

Ongoing

MCNPX Montecarlo analysis to assess isotope production and activation of samples and structures
➔ BNL

Not started

Present the results to Safety Committee

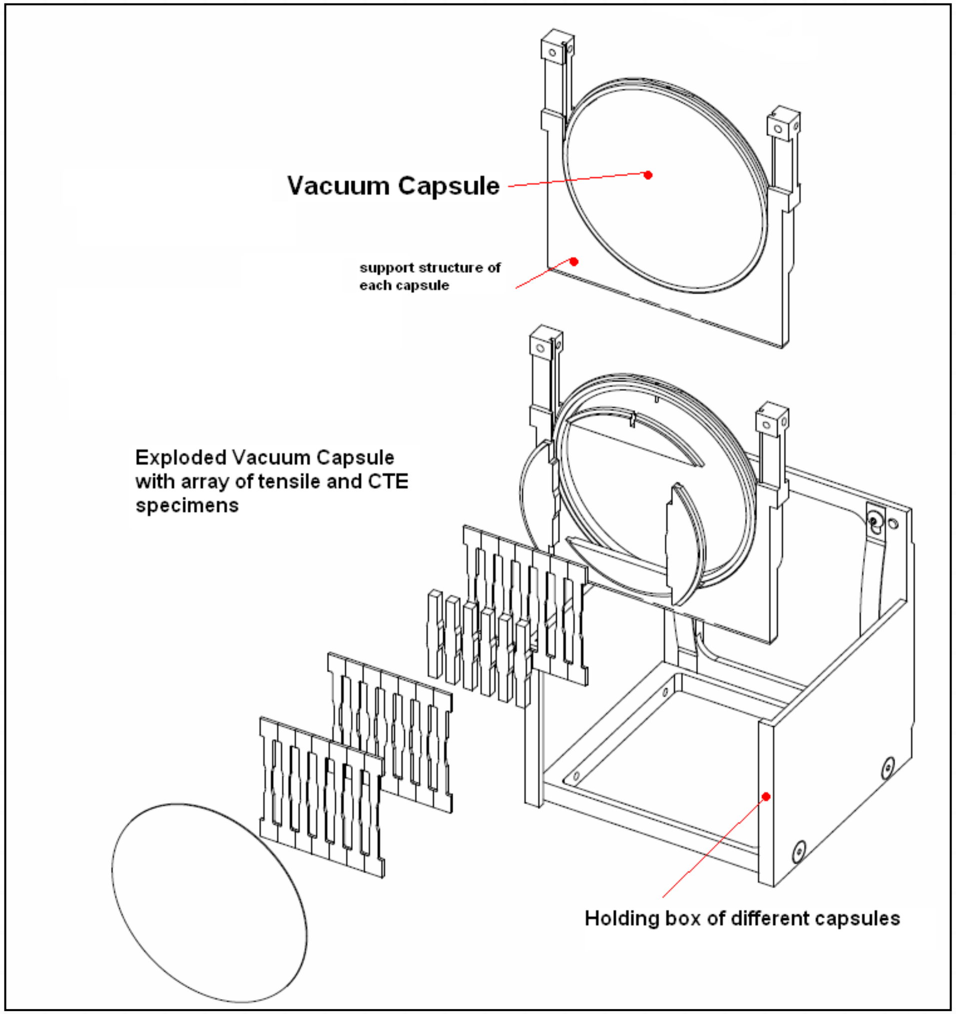
Materials Specimens Holding Box

The specimens are encapsulated into special vacuum tight capsules (vacuum or inert gas).

The different capsules are mounted into a Holding Box.

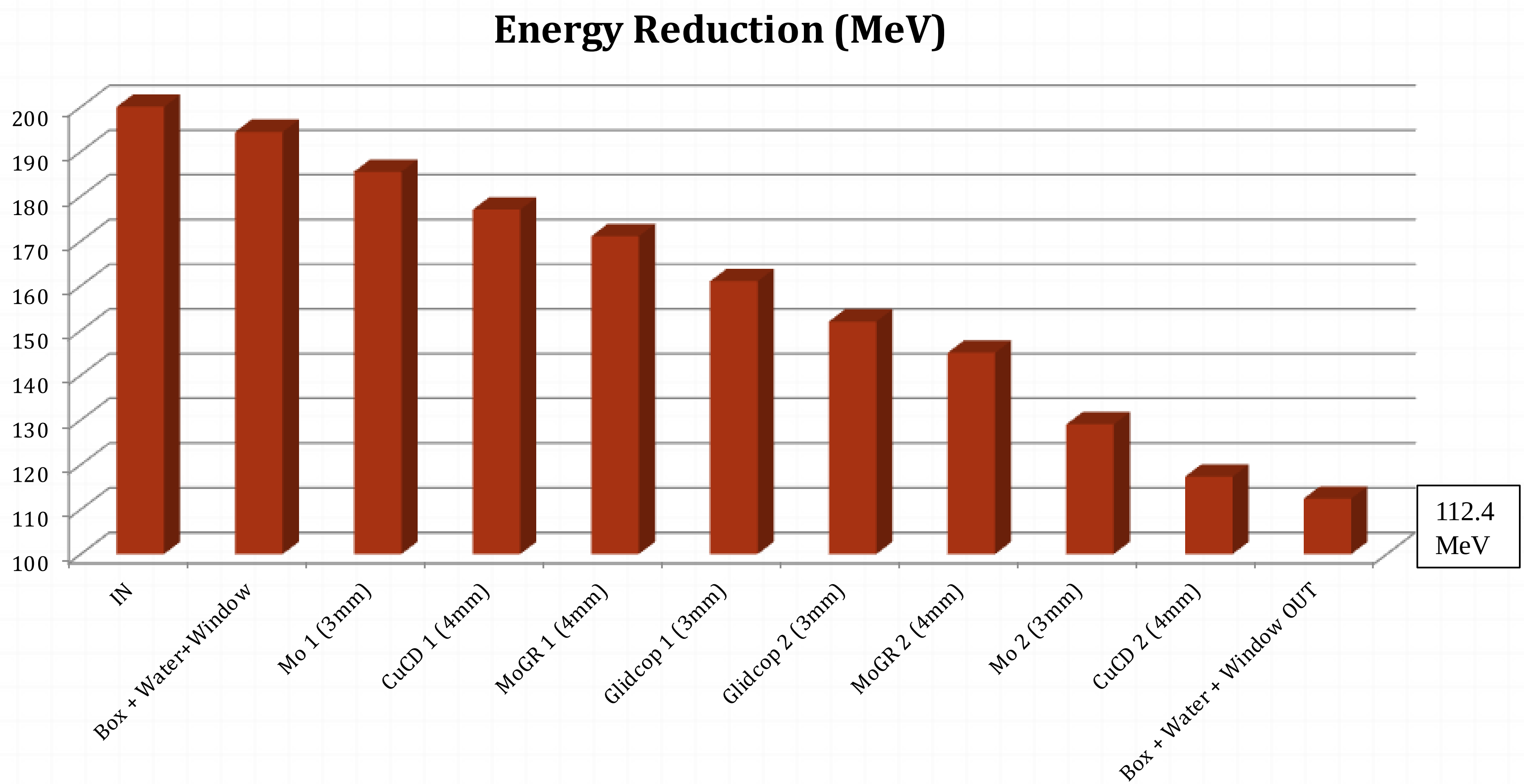
The cooling is made by water flow between adjacent capsules
➔ The samples must not leave gaps between material and capsule to assure heat conduction.

Foreseen layout:
- 1 Holding Box
- 8 capsules x Holding Box,
- each capsule capable to contain materials specimen up to 4 mm thick



Estimation of Energy Degradation

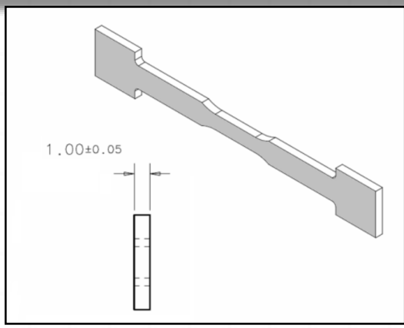
Preliminary analytical estimation shows smooth energy degradation through the foreseen sample and structure layout

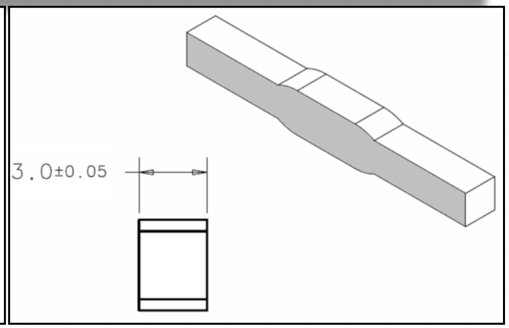


Specimens

Several Materials shapes exist for Metals and Composites
Different Sample manufacturing methods and tests techniques

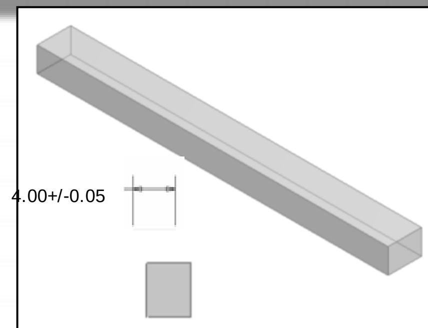
Metallic materials samples: Molybdenum + Glidcop





Tensile tests | **Other**

Composite materials samples: CuCD + MoGRCF



Parallelepiped shape for all tests

Material	Sample	Dimensions	Number X capsule	Total
Metals	Tensile	42x6x1 mm	21	42
	Physical	29x4x3 mm	6	12
Composites	Flexural	42x4x4 mm	8	16
	Physical	21x4x4 mm	4	8

Sample Preparation Advancement

Material	Availability	Piece Dimensions	Material Location	Sample Preparation
Glidcop	YES	1x Bar ~90x40x300 mm (waste piece)	CERN (R. Bebb)	CERN Atelier (P. Moyret)
Molybdenum	YES	2x Bar 65x50x10 mm (cut from Collimator stiffeners)	CERN (P. Francon)	CERN Atelier (P. Moyret)
CuCD	3-4 weeks	1x Plate 150x150x4 mm (to be produced at RHP)	RHP Technology (M. Kitzmantel)	Water Jet (tbd if at RHP or at CERN)
MoGRCF	3-4 weeks	2 x Plate 70x55x4 mm (to be produced at Brevettibizz)	BrevettiBizz (S. Bizzaro)	Water Jet (CERN)

Next Actions

BNL – Complete SRIM energy deposition calculations and MCNPX isotope production calculations

BNL – Complete Thermo-mechanical analysis of whole holding box

CERN FLUKA Team – perform FLUKA energy deposition calculations

BNL – Present the calculations to the safety committee

BNL – CERN: validate the proposed samples geometry and number

CERN – Launch composite materials production in RHP Technology and in BrevettiBizz;

CERN – Machine metallic samples at CERN Atelier.

Conclusions

Beam-induced material damages (both due to instantaneous high intensity impacts and long-term irradiation) are one of the most serious threats to High-energy, High-intensity accelerators.

A new generation of collimators embarking **novel advanced materials** will be likely required to reach expected HL-LHC performances.

A comprehensive R&D program to develop these materials is in full swing, giving important results (**CuCD, MoCuCD, MoGRCF**).

Irradiation studies have been carried out in past years at BNL and KI on Phase I Collimator materials giving evidence of **serious degradations of various materials**.

A first irradiation campaign is already ongoing at KI on selected composite materials for Phase II Collimators.

A new proposed irradiation campaign at BNL is paramount to complement the material characterization from the radiation hardness point of view for **future collimators design**.