Collimator Materials for High Density Energy Deposition

Report from WP11

3rd EuCARD-2 Annual Meeting, MALTA, April 26-27, 2016

Adriana Rossi on behalf of

ColMat-HDED

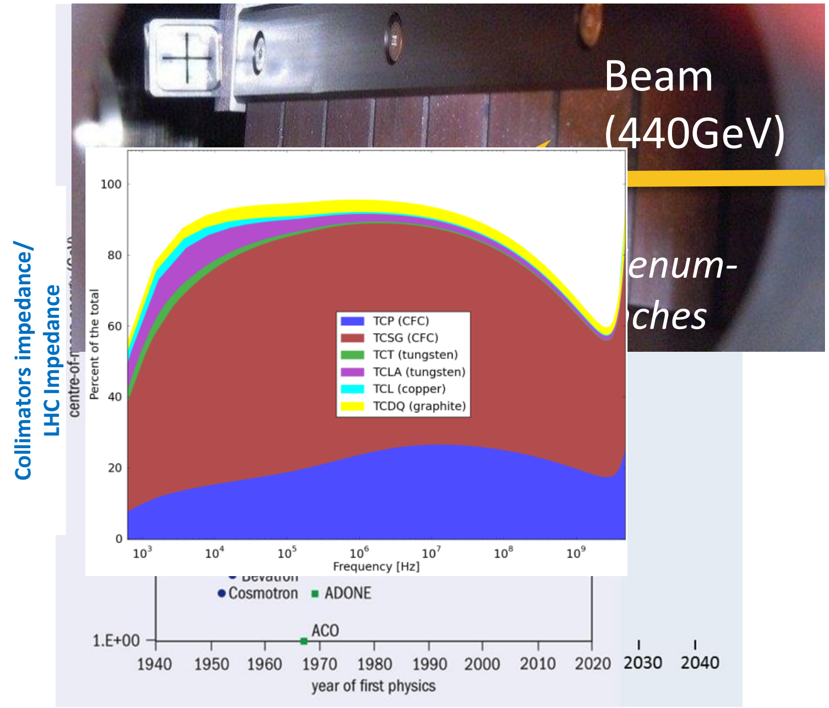
EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

outlook

- Brief overview on WP11
- Few breakthrough results
- WP11 topical meeting
- WP11 milestones and deliverables status

Our work

- The material work package supports progress with material developments for collimators and targets, where requirements for material shock resistance, electrical and heat conductance, in conjunction with radiation hardness push research onto challenging grounds.
  - Higher **robustness** (LHC beam energy density up to 15 GJ/mm2, 2-3 orders > other machines).
  - Lower **impedance** since collimators give, by far, the highest contribution to machine impedance, potentially leading to serious beam instabilities.
  - **Larger resistance to radiation** (1E16 p/y doses in LHC betatron cleaning insertion).
  - **Higher absorption** (clean efficiency for machine protection and lower background to experiments).



Our partners

BREVETTI BIZZ Partnership agreement with CERN (KN2045)

Mainly founded by the LHC Collimation Project

Collaboration CERN with US-LARP

Who does what

- Producing novel material samples (Brevetti-Bizz, RHP, CERN)
- Characterising mechanical properties (POLITO and CERN).
- Performing irradiation tests in M-branch (from 2011 in GSI) and HiRadMat (from 2012 at CERN), together with well-established irradiation facilities (NRC-KI and BNL) to measure radiation resistance and hardness. (CERN, GSI, UM, KUG, IFIC)
- Simulating mechanical properties (POLITO, NRC-KI, GSI, UM and CERN) and beam induced damage (CERN).
- Simulating radiation induced damage (NRC-KI, GSI and CERN).
- Integrating collimators into beam environment to give specifications and validate (CERN, HUD, UNIMAN, RHUL, IFIC).

Some of WP11 breakthrough results

- *Simulations of collimation upgrade scenarios with new materials for HL-LHC*
- *Production of CuCD samples and jaw blocks*
- *Radiation Induced Effects in Mo-Gr composites*
- *Simulation of radiation effects on Cu*
- *Collimator Design, Manufacturing and Testing*
- *Microphone as detection tools*

HL-LHC beam parameters pose strong concerns for present LHC collimators

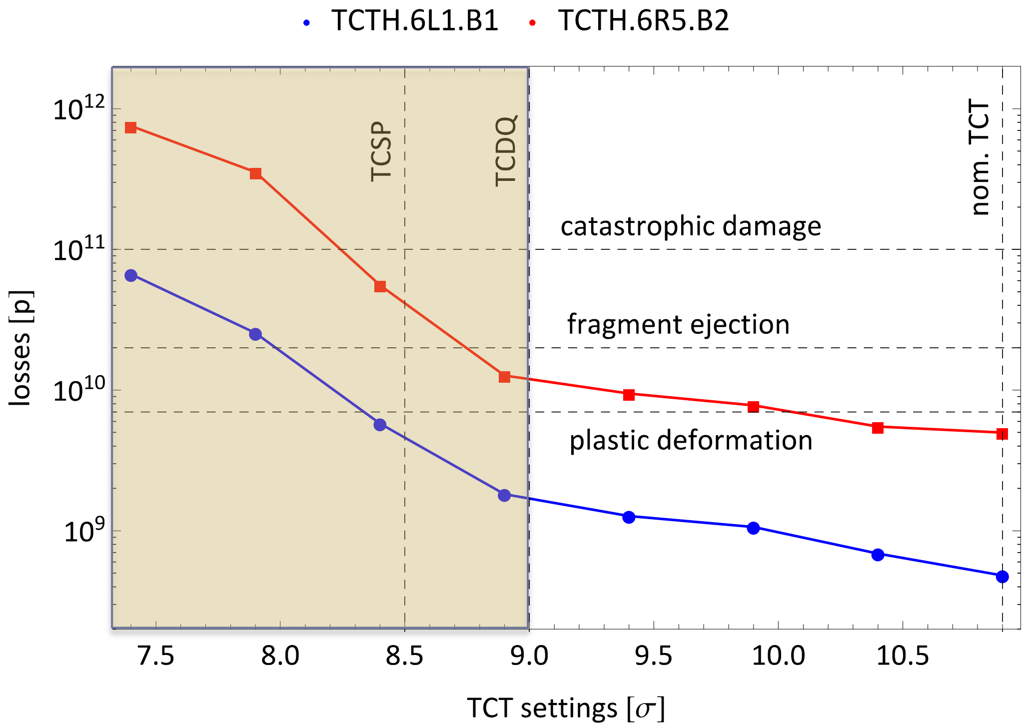
Limitations of the present LHC collimation system related to materials:

Limitation	Upgrade
High contribution of non-metallic collimators to machine impedance in cleaning insertion IR7 → beam instability	Low-impedance (high ro MoGr) collimators in IR7
High losses of off-momentum protons in high dispersion locations (e.g.: IR7 DS) → limitation to collimation cleaning	Robust DS collimators in IR7
Low robustness of collimators in the experiments insertion regions against fast beam losses → limitation in β^* and luminosity	Robus CuCD the exp ents

HL-LHC collimation upgrade

Robustness of tungsten tertiary collimators to fast beam losses

Closing down TCTs below dump protections (experimental insertion regions) more exposed to beam losses due to fast beam failures → W jaws risk to be severely damaged



Proposal of mitigate constraints from TCT robustness issues by replacing present Inermet180 with Cu-CD, after the successful HRM-23 test.

E. Quaranta, R. Bruce, A. Mereghetti, S. Redaelli – CERN:
Simulations of collimation upgrade scenarios with new materials for HL-LHC

EuCARD²

Collaborations with CERN

Courtesy of J. Guardia

CERN

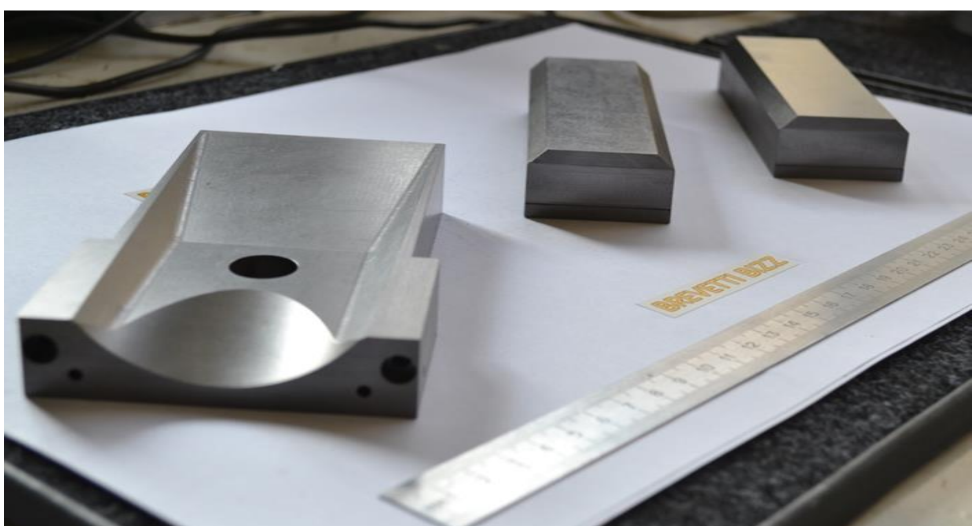
S. Bizzaro BREVETTI BIZZ

Absorber material for HL-LHC collimators

R&D on novel materials, very high-temperature processing and high-precision machining.

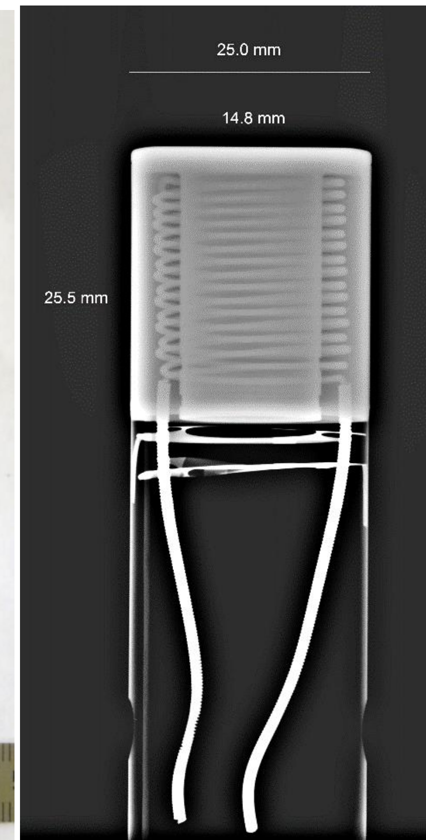
Molybdenum-graphite sintered plate
Dim.: 100x150x30mm

Tapering and blocks HRMT23 experiment



Cathode for CERN electron gun (HL-LHC hollow e-lens)

R&D on materials, density, doping elements and shape.



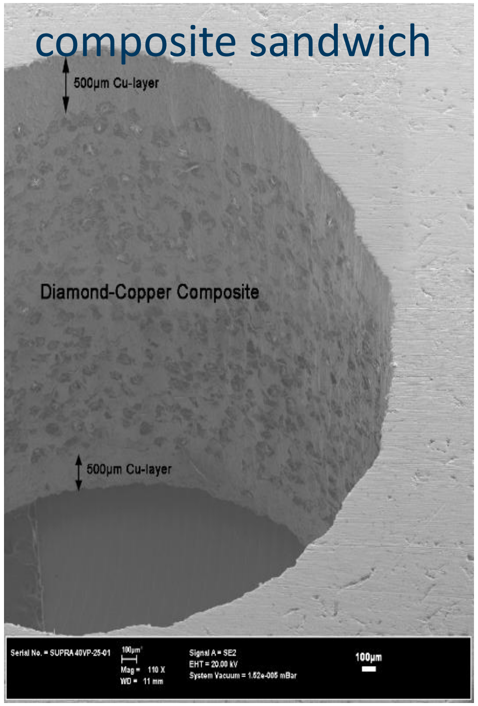
Tungsten cathode and X-Ray image.
Courtesy of Pascal Simon (CERN EN-MME)

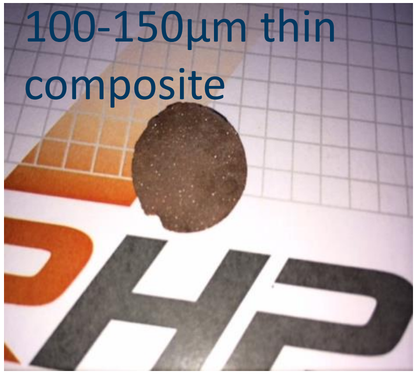
Metal-Diamond Composites

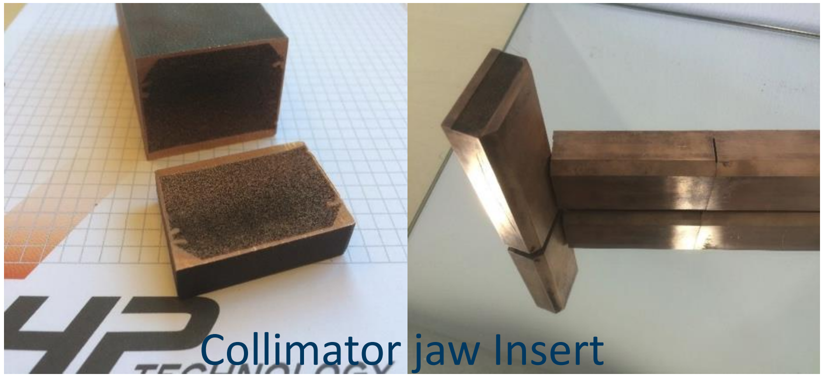
Diamond-containing materials are very difficult to machine. Processing challenging but successful in the required

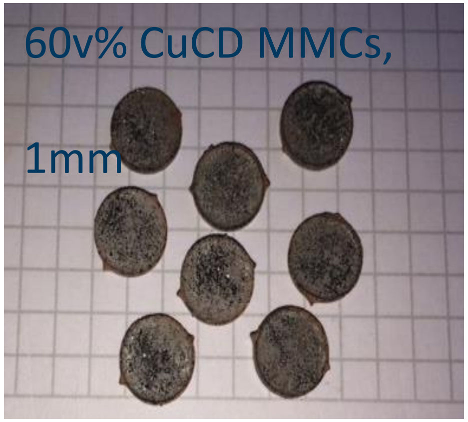
- geometries (semi finished parts)
- compaction of the composites and
- the tight geometrical tolerances.

Thickness for samples of 100-150µm challenging to achieve.



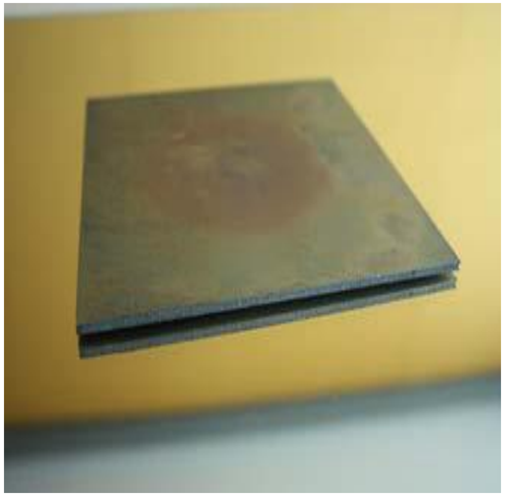


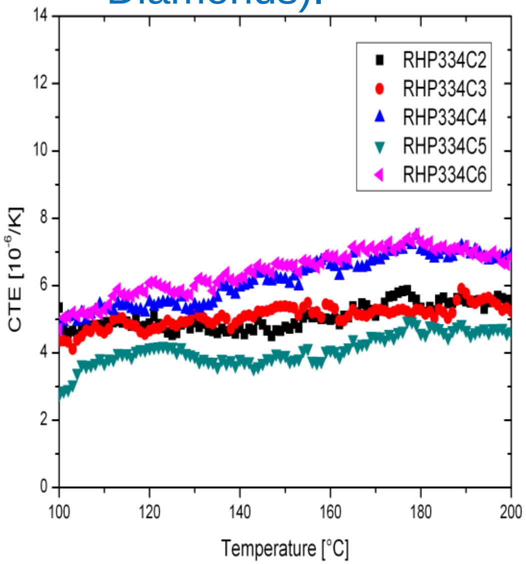


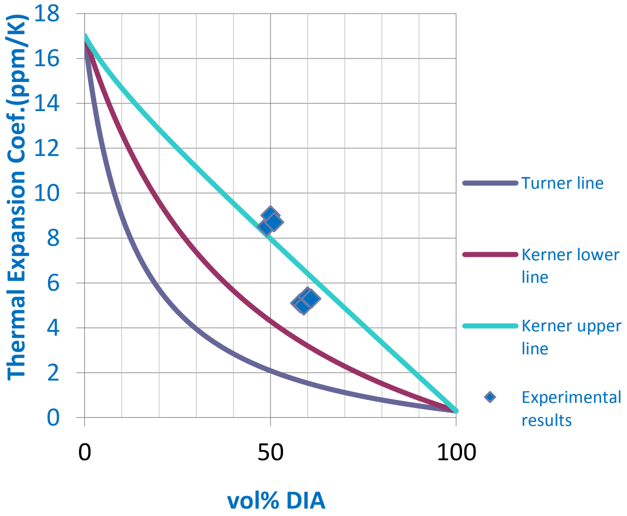


Characterisation of CuCD

- Thermal expansion was measured for samples with
  - 50vol% of Diamonds in the copper matrix (monomodal mixtures, Ø ~ 100µm)
  - 60vol% Diamond fraction (bimodal mixture, Ø ~ 100µm and Ø ~ 40µm).
- Multimodal was also investigated, but smaller Diamonds weaken the thermal conductivity and larger particles make it too hard to machine.
- Copper-Diamond Composites exhibit good thermal properties, although their degradation due to bake-out needs to be addressed (stability of the interface between Cu and Diamonds).





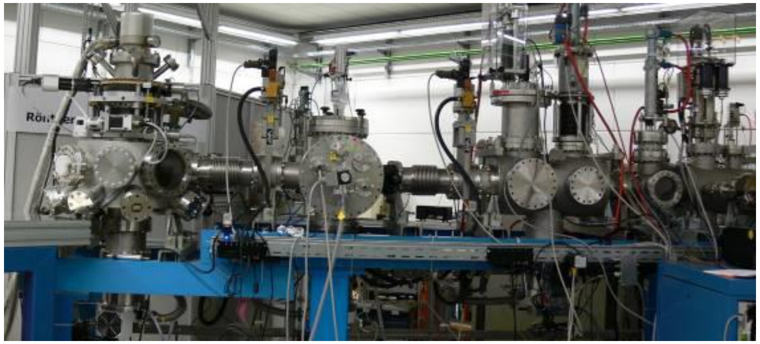


Top: CuCD plate and CTE samples

Left: Coefficient of thermal expansion (CTE)

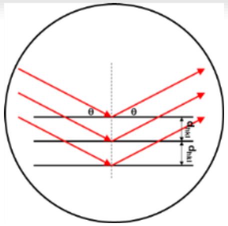
Middle: Theory vs. Experiment CTE

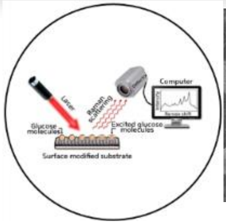
Irradiation of novel composites at GSI

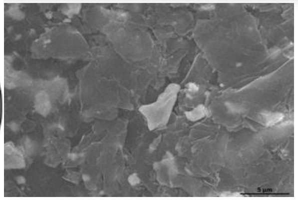


Ion irradiation: C – U
Energies: 70 MeV – 1 GeV
Fluence: up to $1x10^{14}$ ions/cm^2

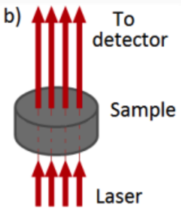
Structural characterization:
XRD, Raman spectroscopy, SEM

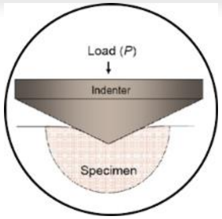


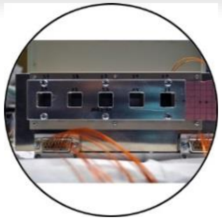




Functional properties degradation:
thermal, mechanical, electrical





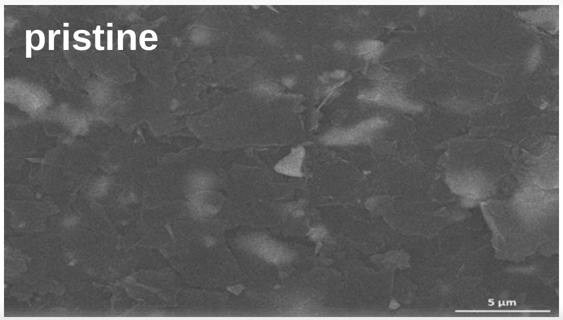


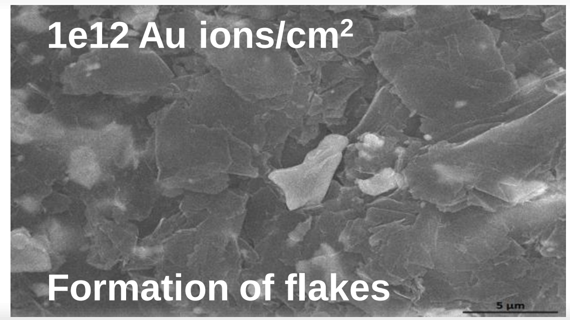
Material optimization

Beam induced structural changes in Mo-Gr

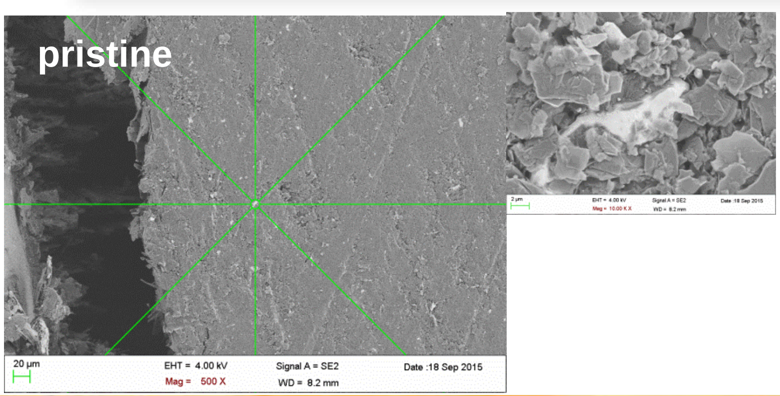
Structural characterization:

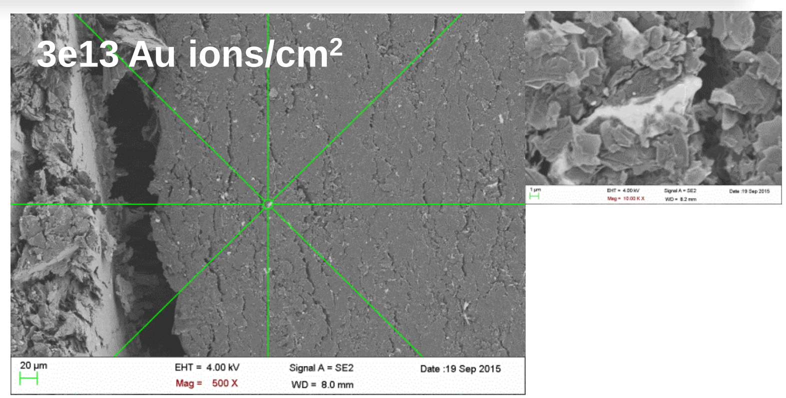
In-plane crystallite size reduction – SEM, Raman spectroscopy:





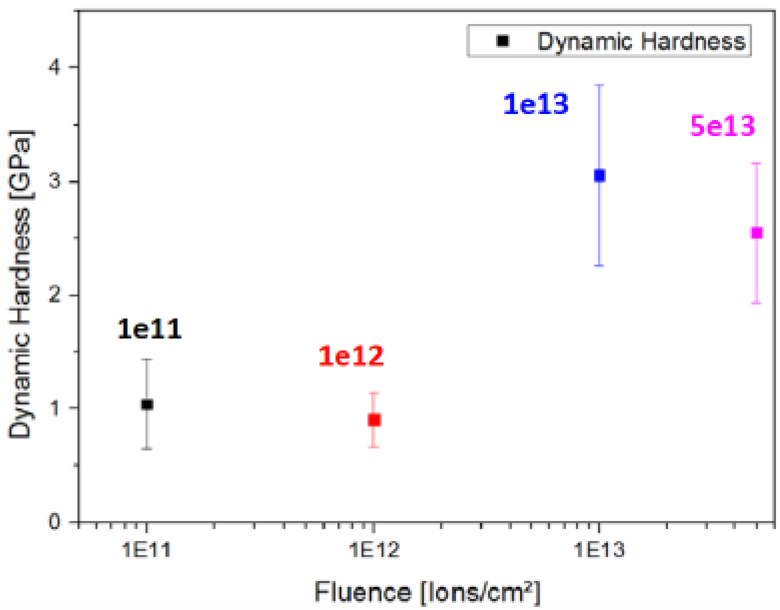
Swelling → Stress → Deformation → Cracks in the matrix
In situ SEM during irradiation





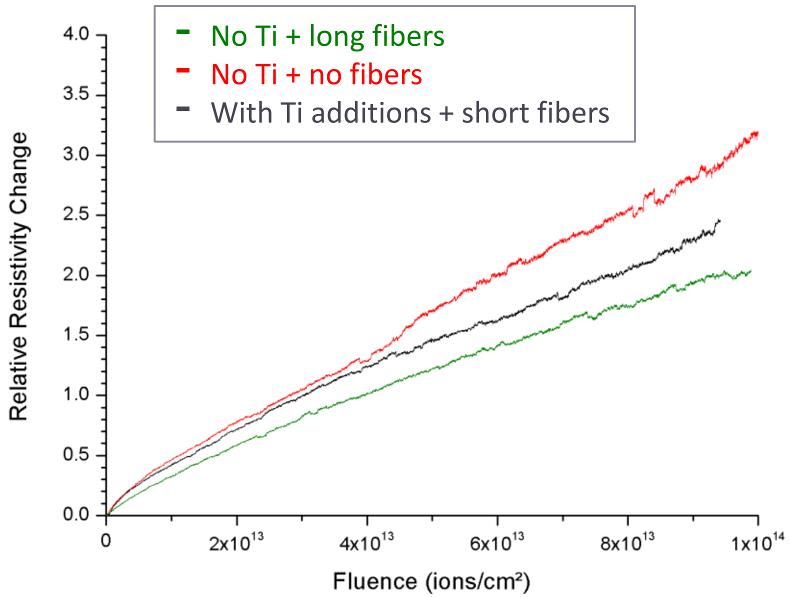
Radiation damage effect on properties degradation in Mo-Gr

Irradiation induced hardening
– dynamic harness:



- Hardness and Young's modulus increased with accumulated dose.
- Samples annealed at higher temperatures show less degradation

Increase of electrical resistivity
- online measurements during irradiation

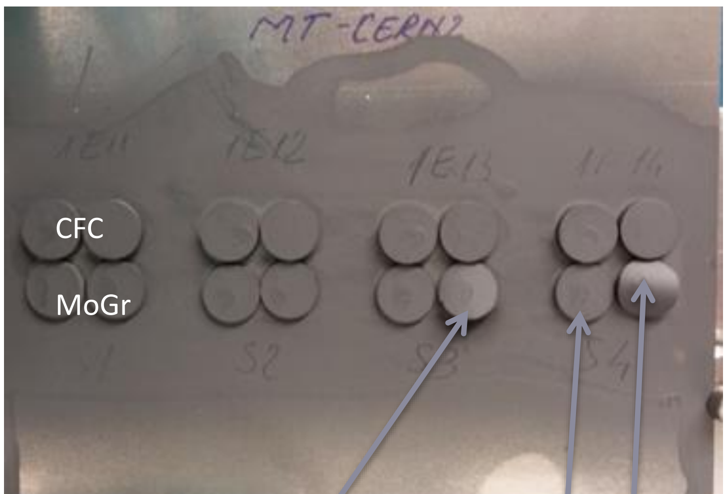


- Defect accumulation results in gradual resistivity increase
- Presence of carbon fibers reduces material's resistivity degradation

Irradiation induced deformation in Mo-Gr and mitigation

- Macroscopic bending was observed around 5×10^{12} U ions/cm²

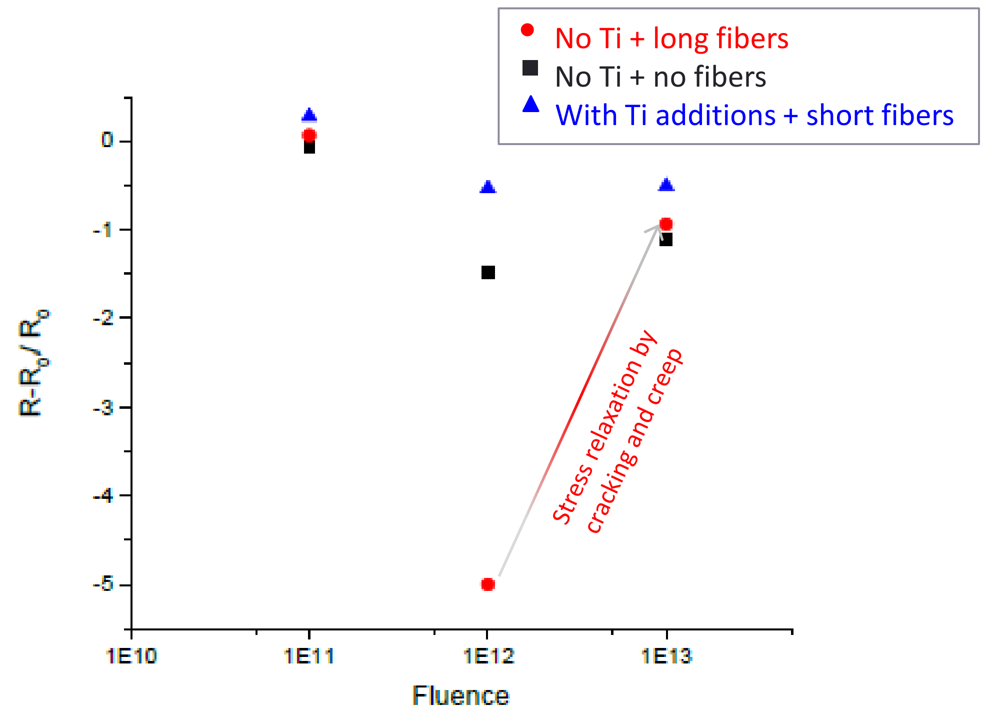
- Optimization of the material to avoid swelling and deformation: by annealing at very high temperature and modifying composition



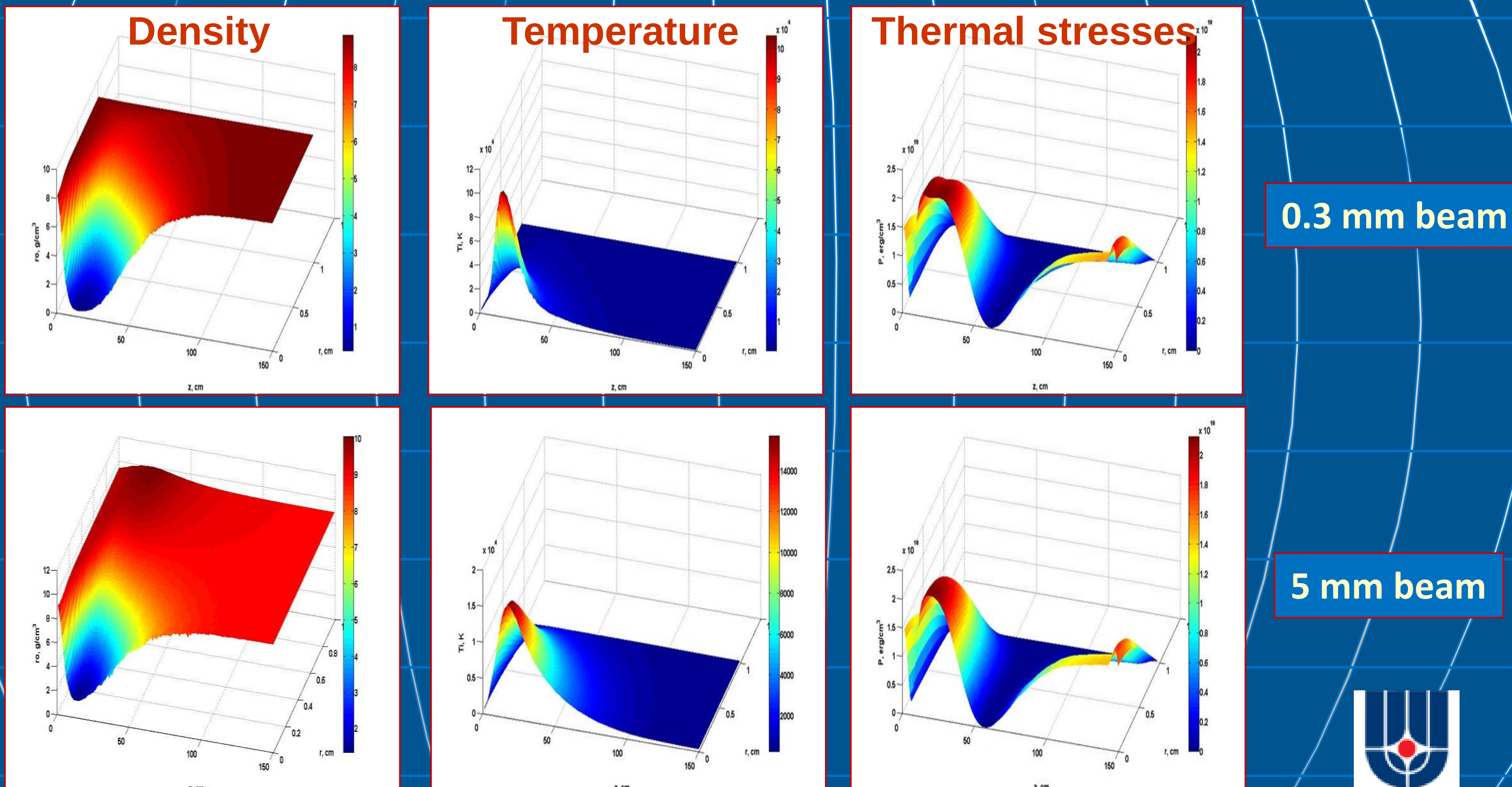
Not annealed

in plane

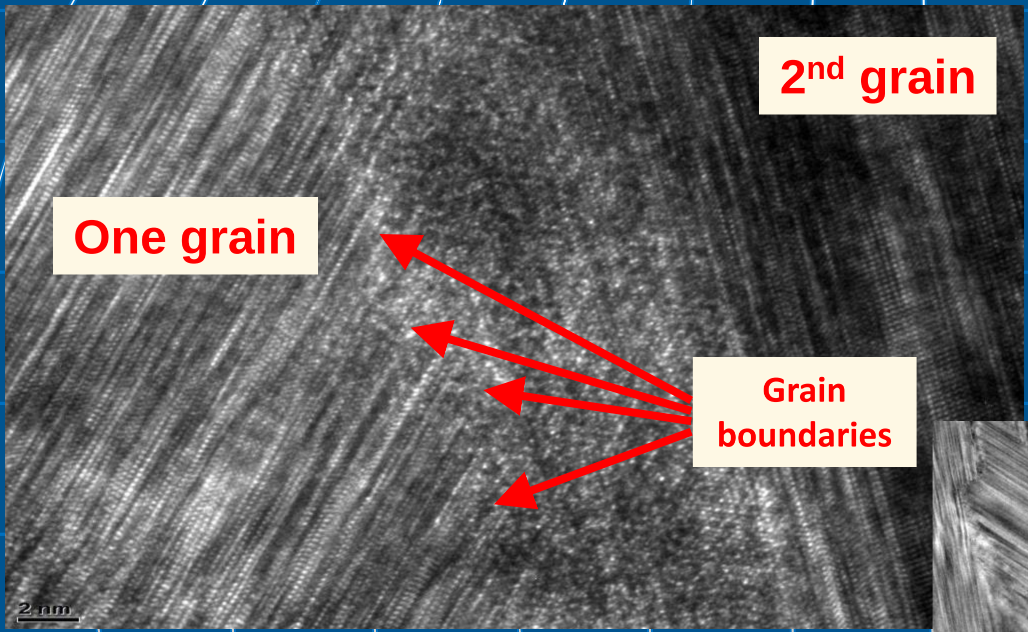
transverse

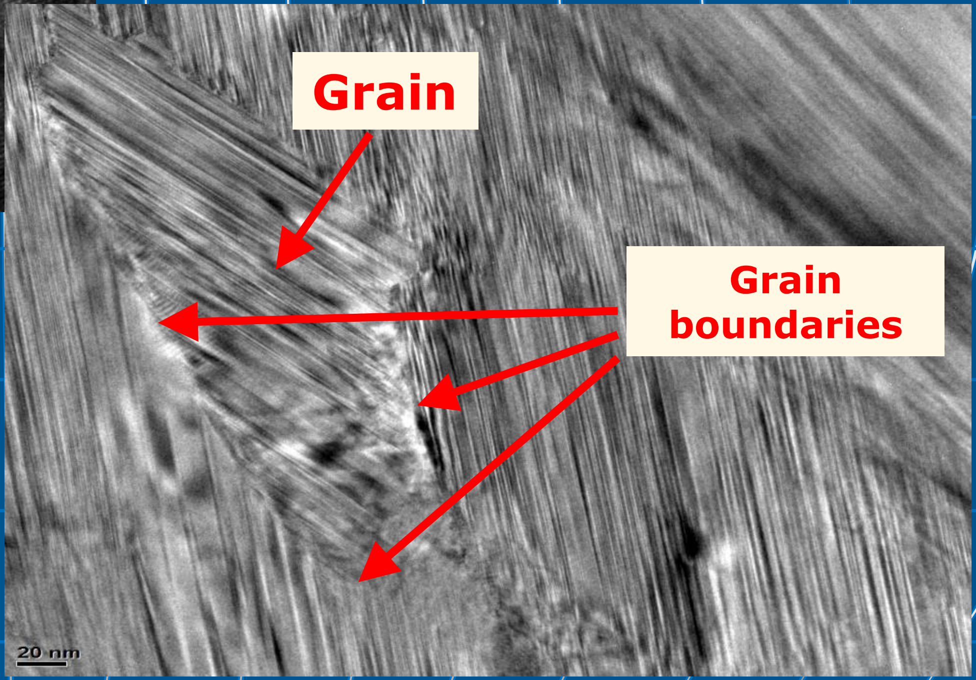


Density, Temperature and Thermal stresses distribution in Cu after irradiation by 1000 proton bunches of 450 GeV for 0.3 and 5 mm beam size using the free boundary conditions on irradiated material.



High resolution transmission electron microstructure of SiC before fast particle irradiation





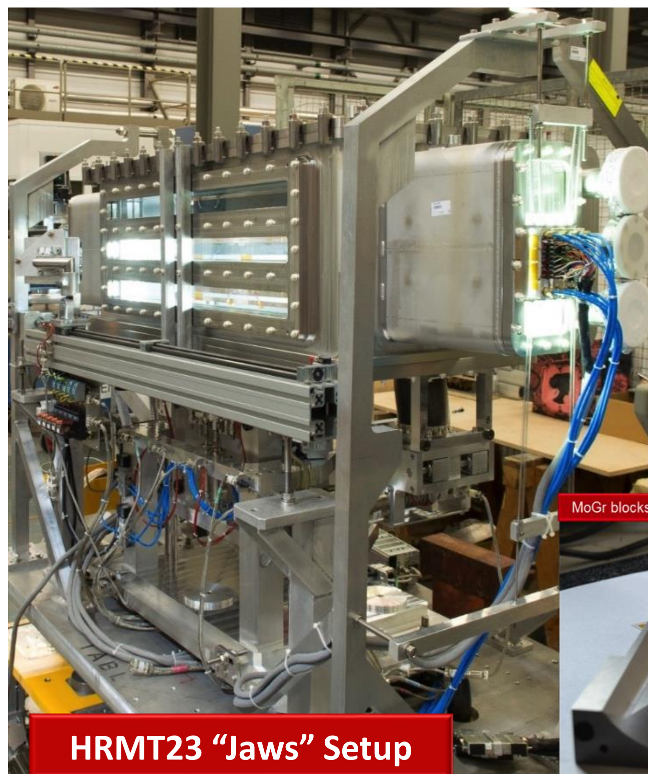
TCSPM : low impedance secondary collimators with BPM

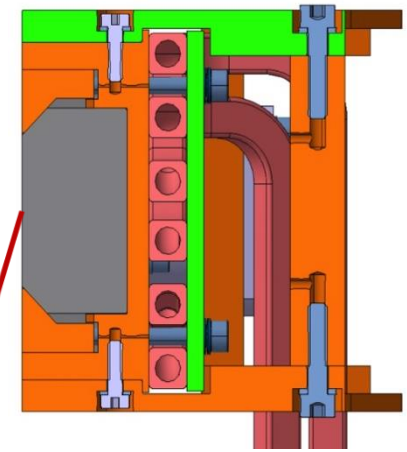
- New secondary collimator (TCSPM) designed using **novel materials** developed with Eucard2 and CERN partners (RHP, BrevettiBizz)
- **Modular design**, accepting different absorbers (e.g. MoGr, CuCD)
- **Two jaws built in 2015 and tested in HiRadMat** together with a CFC jaw

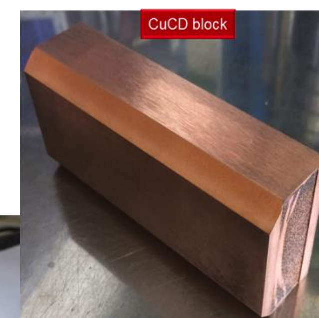

TCSPM MoGr

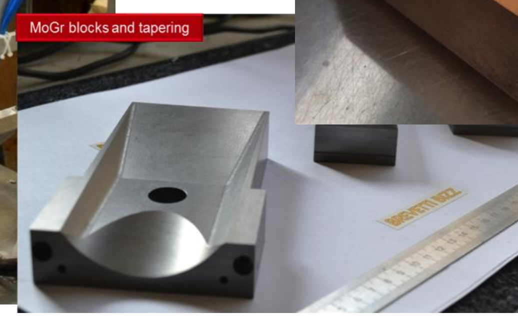

TCSPM CuCD


TCSP CFC


HRMT23 "Jaws" Setup


MoGr (high robustness)
CuCD (higher density)

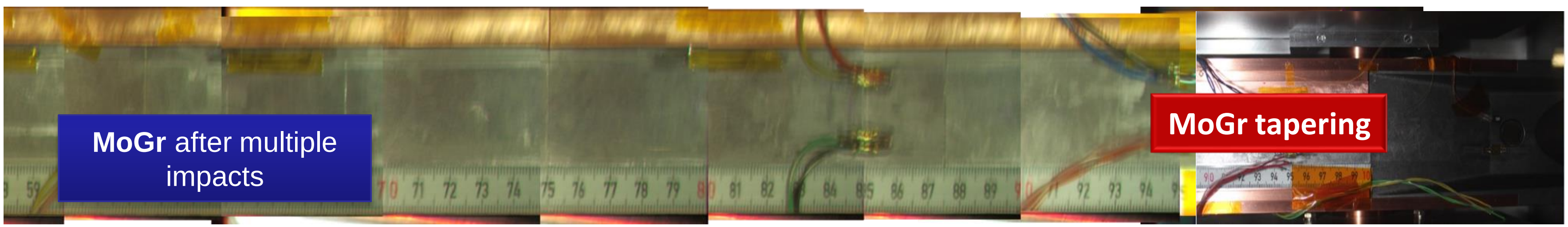


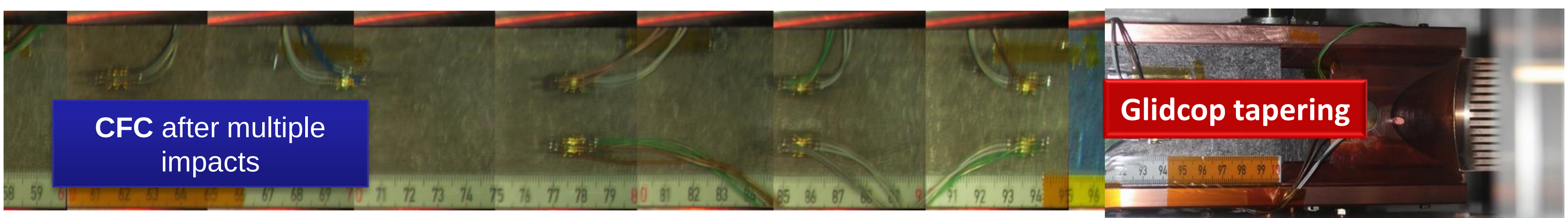


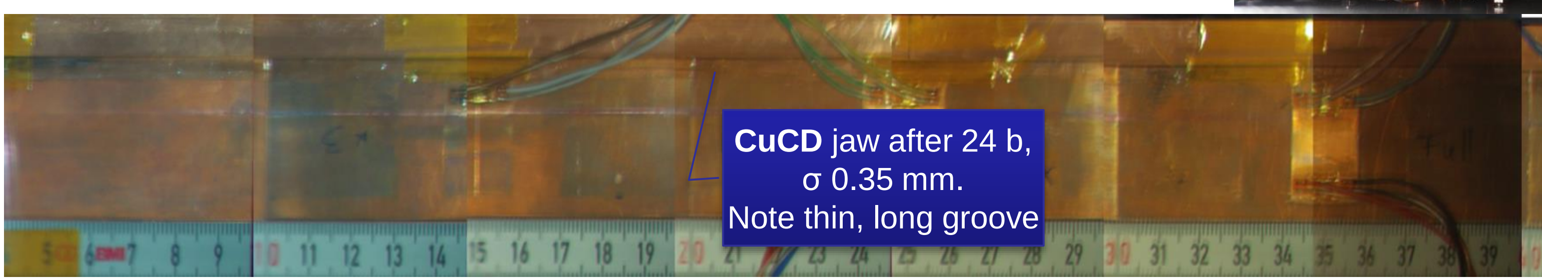
TCSPM: HiRadMat HRMT23 test

- **Two TCSPM** jaws (MoGr and CuCD) and **one TCSP** jaw (CFC) tested in HiRadMat in July 2015
- **MoGr** and **CFC** sustained the impact of multiple full SPS beams (288b, σ down to 0.35 mm – equivalent to HL-LHC and BCMS LIU failure scenarios) without experiencing failure
- **CuCD** survived to the 24b pulse, equivalent the worst accident scenario on a tertiary collimator

➢ **TCSPM MoGr prototype under fabrication at CERN for testing in the LHC during 2017**

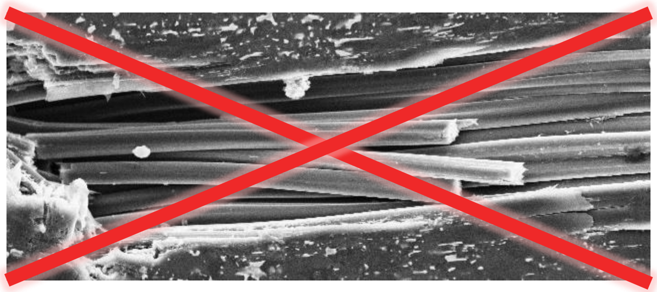






Advanced materials R&D at CERN

- Material R&D is continuing, aiming at improving radiation hardness and vacuum compatibility while maintaining or improving other of properties.
- Based on the results and fruitful discussions with GSI, in order to improve the radiation hardness, the development is pointing to the removal of the fibres and the addition of Titanium



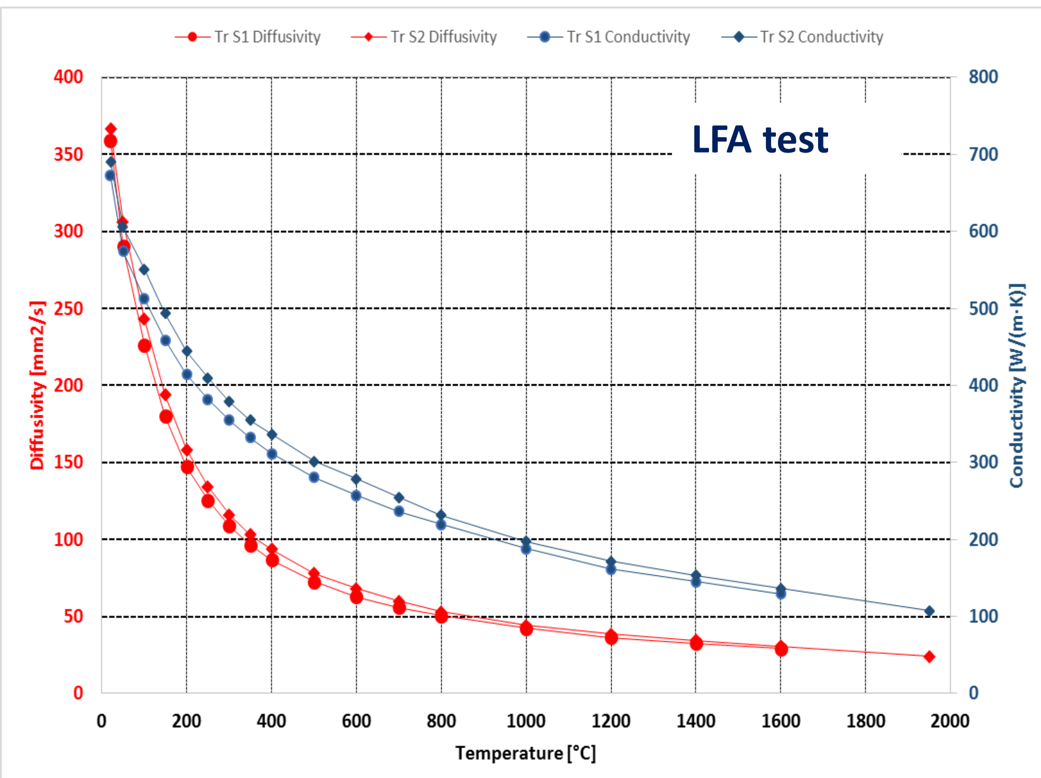
- Sintering aid
- Carbide phase stabilizer
- Better final properties

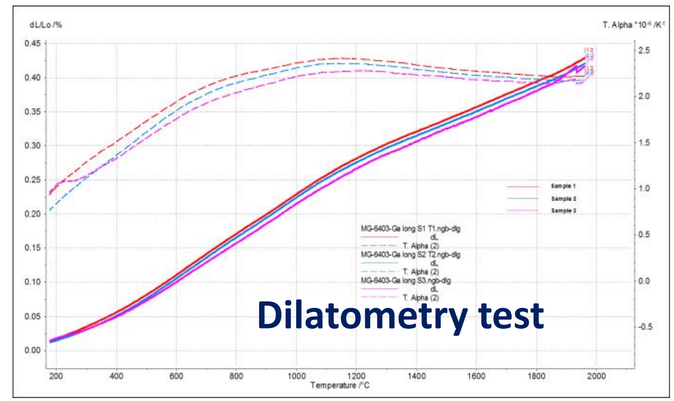
- New promising grade MG-6403 has been produced and characterized.
  - Composition: 95.3vol.%Gr, 4.5vol.%Mo and 0.2vol.%Ti
  - Sintering cycle: +2650ºC

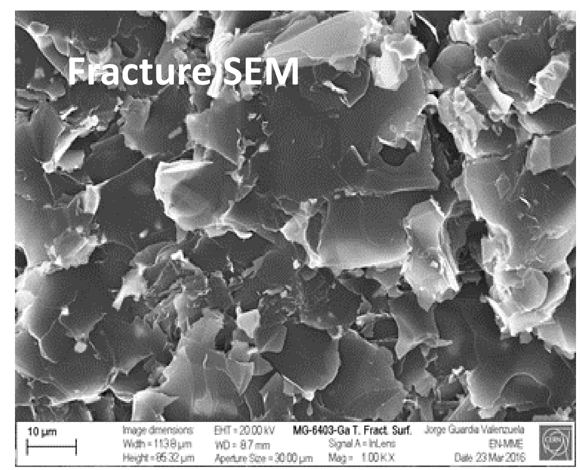
Advanced materials R&D at CERN

Grade **MG-6403-Ga (no fiber, Ti addition, different annealing cycle)**: The sintering cycle is being slightly optimized in order to meet vacuum requirements.
Thermo-mechanical properties have been improved with respect to previous grades.

- Highest thermal and electrical conductivities
- Very good strength and thermal expansion behaviour

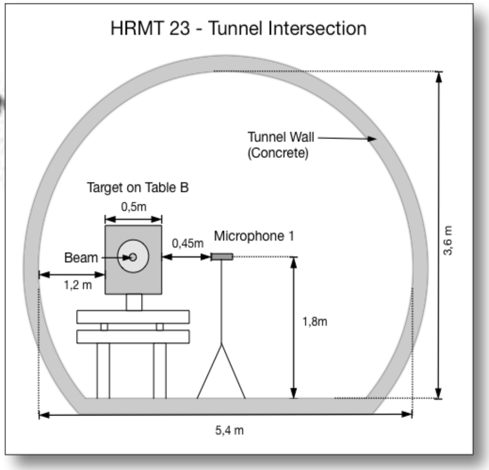


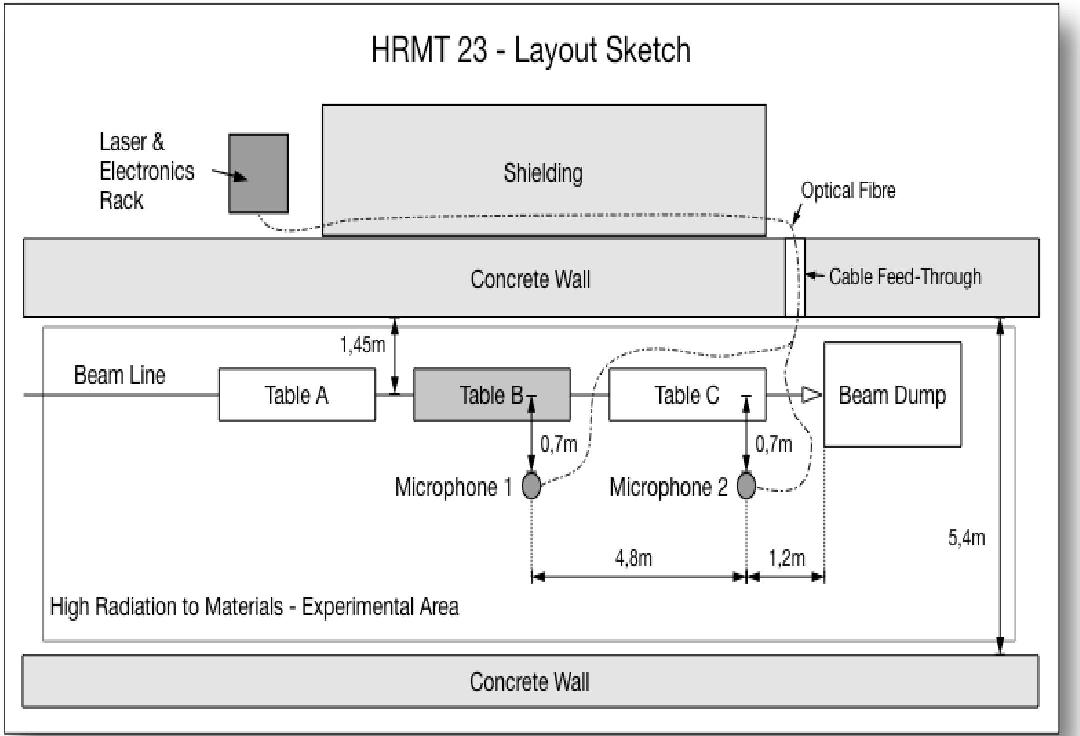




Microphone as detection tools: Experimental Setup

the employe
microphone





In cooperation with XARION Laser acoustics, we tested a new optical microphone sensor during HRMT23 (Collimator Jaw Materials)

Robert Höldrich (KUG)
Daniel Deboy (KUG)
Balthasar Fischer (XARION)

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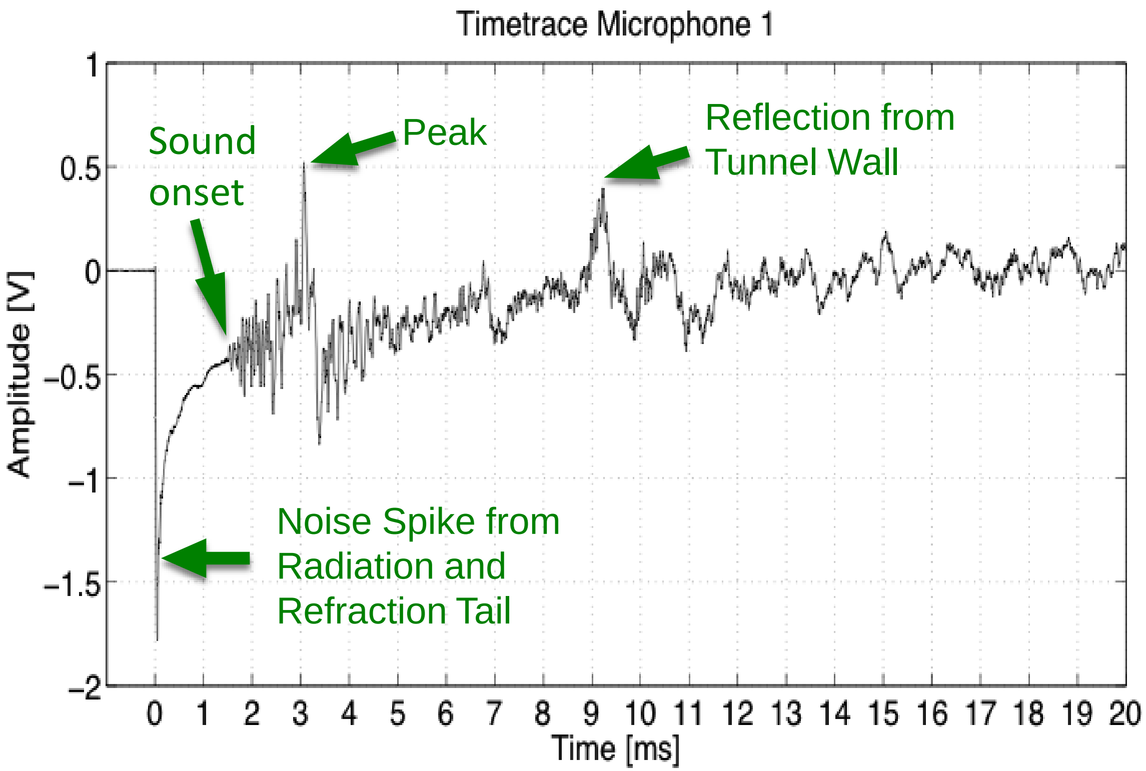
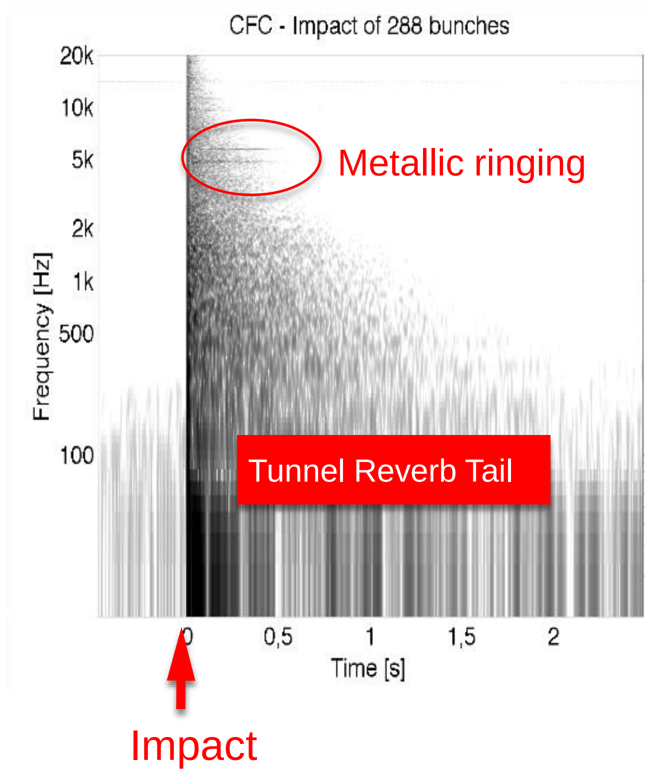
Microphone Signal during Beam impact





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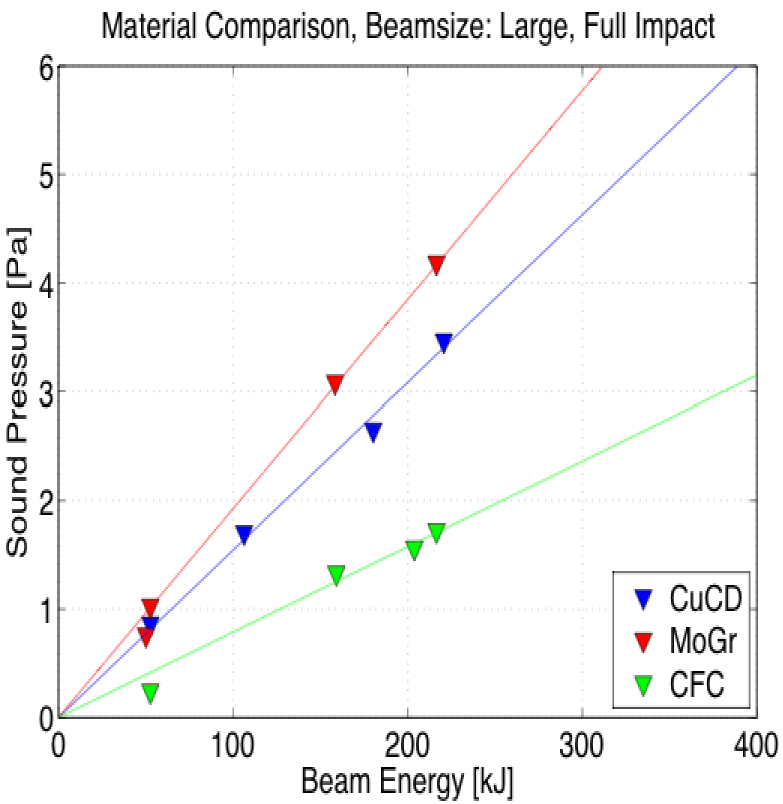
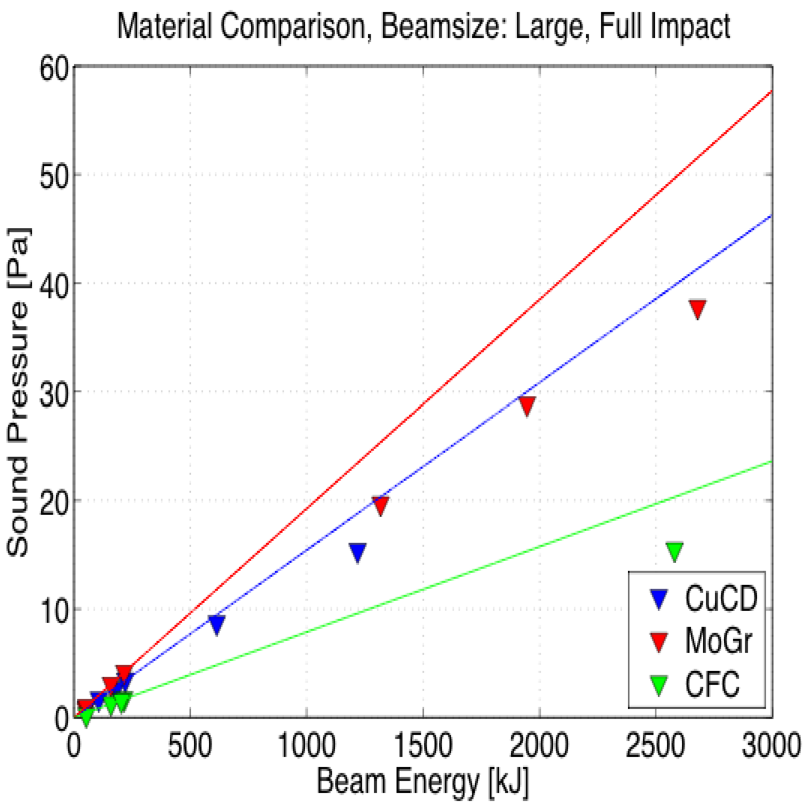
Sound pressure vs. Beam energy

Linear at low beam energy



Non-Linear with higher beam energy



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Outlook

Radiation induced noise:

- It is assumed that the provided **shielding** for the electronics was **not sufficient** (other users also reported problems with electronics in same area)
- New tests with electronics on surface foreseen in April/May 2016

Sound pressure vs. beam energy vs. material:

- Next step: Comparison to **deposited energy** as well as to **other sensor data** measured during HRMT23

WP2-WP11 WorkShop

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EuCARD-2 Workshop on Applications of Thermal Management Materials

06 November 2015, CERN

In the framework of EuCARD-2, an ambitious research program has been undertaken to investigate, process and characterise novel composite materials. These are intended to combine optimum mechanical, thermal and electrical properties, such as mechanical strength, melting temperature, thermal shock resistance, electrical conductivity, and energy absorption.

These materials are of particular interest for thermal management applications such as high power density electronic packaging, aerospace, automotive, nuclear fusion and solar energy. This EuCARD-2 meets industry event aims to bring together experts in the research and industrial sector, to exchange ideas on the latest developments in design, manufacture, testing and applications of Thermal Management Materials.

Please see more information and the possibility to register on the event webpage: http://indico.cern.ch/event/400452/

Archived news »

See Tim Tsarfati's talk

WP11 Topical meeting 28-29 April 2016

This topical annual meeting aims at a comprehensive review on

- Applications of collimator materials to LHC and HL-LHC
- Progress on material development and characterisation
- Outlines of production techniques
- Results of irradiation tests (ions, protons and high-energy impact protons)
- Comparison with FLUKA estimation of DPA to predict radiation induce degradation

Programme

THURSDAY 26th April 2016		
9:30	Introduction and scope (15'+5')	A. ROSSI – CERN
9:50	Overview of scenarios where new materials are required (20'+10')	R. BRUCE – CERN
10:20	Progress on material development and characterisation (30'+20')	J. GUARDIA VALENZUELA – CERN
11:10	COFFEE	
11:40	Material characterisation (30'+20')	L. PERONI – POLITO
12:30	CuCD production and novelties (20'+10')	M. KITZMANTEL – RHP
13:00	MoGr production and novelties (20'+10')	S. BIZZARO – BREVETTI-BIZZ
13:30	LUNCH (free)	
14:30	The HiRadMat 23 Experiments : results and analysis (30'+20')	F. CARRA – CERN
15:20	Ion irradiation results: variation of material properties with irradiation (30'+20')	M. TOMUT – GSI
16:10	COFFEE	
16:40	Proposal of upgrade scenarios based on tracking simulations with new materials (30'+20')	E. QUARANTA - CERN
17:30	Status and perspectives of proton irradiation tests at RRC-KI (30'+20')	A. RYAZANOV – RRC-KI
20:00	WP11 DINNER @ Michael's at the Civil Service Sports Club	
FRIDAY 27th April 2016		
9:00	Overview of radiation damage studies and the RaDIATE (Radiation Damage In Accelerator Target Environments) Collaboration (30'+20')	M. CALVIANI – CERN
9:50	FLUKA estimation of DPA for ion irradiation and update on IR7 DPA calculations for LHC operations (30'+20')	L. SKORDIS – CERN
10:40	COFFEE	
11:10	Studies of energy deposition for a proton absorbers for crystal collimators (30'+20')	S. GIBSON – RHUL
12:00	Status of proton irradiation tests at BNL and DPA estimation (30'+20’)	N.SIMOS – BNL
12:50	LUNCH (free)	
14:15	Presentation of the ARIES (after EuCARD2) programme for materials (30'+20')	A. ROSSI and M. TOMUT
15:05	Wrap up and future plans	

WP11 Milestones and deliveries
… a busy year ahead!

Milestones :

MS69 Irradiation of first samples	M12
MS70 Present results on material damage from irradiation	*M24*
MS71 Show new material development status	M24
MS72 Present results on material damage from simulation and compare to experiments	M45

Deliverables :

11.1 Result on simulations of new materials and composites	M36
11.2 Report on comparative assessment of beam simulation codes	M40
11.3 Irradiation test results	M46
11.4 Results on characterisation of new materials and composites	M46

THANK YOU FOR YOUR ATTENTION

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