LHC Collimation Project CERN

EN Engineering Department

Report from WP 11: Collimator Materials for Fast High Density Energy Deposition (ColMat-HDED)

Alessandro Bertarelli (CERN)

33rd ColUSM Meeting
CERN, *24 January, 2014*

Outline

- **Context**
- Partners (WP11 and beyond)
- WP11 Tasks and Deliverables
- WP11 Status and upcoming activities
- Summary and Perspectives

Context

- **LHC** is reaching unprecedented **beam brightness** and **energy** leading to extreme **energy density (15 GJ/mm²)**
- At such energy densities **Beam-induced accident**… among the most dangerous events for particle… accelerators.
- **Collimators** are inherently expos… events (**β^* reach** is determin…
- Collimators are, by far… machine **impeda**… **instabilities**…

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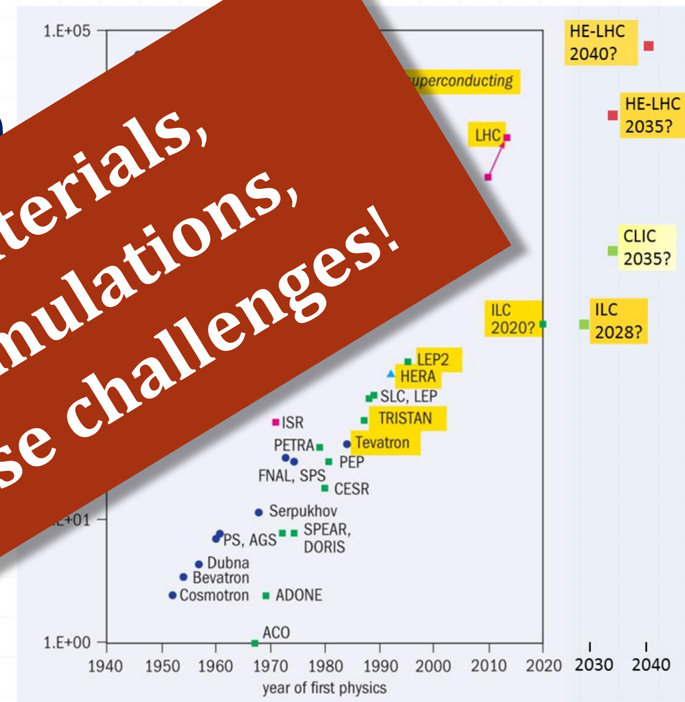
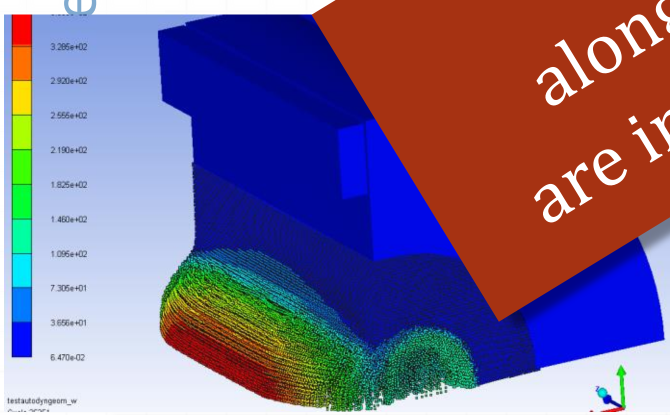
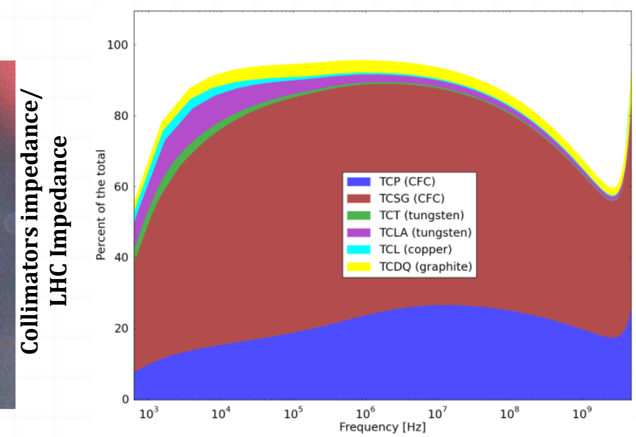
Development of **advanced materials**, along with **state-of-the-art simulations**, are instrumental in **facing these challenges!**







Metal Matrix Composites

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- Materials investigated are **Copper-Diamond (Cu-CD)**, **Molybdenum-Diamond (Mo-CD)**, **Silver-Diamond (Ag-CD)**, **Molybdenum-Graphite (Mo-Gr)**
- Most **promising materials** are **Cu-CD** and **Mo-Gr**.
- Ag-CD and Mo-CD are, by now, sidelined as they are limited by (relatively) low melting temperature (Ag-CD) and insufficient toughness (Mo-CD).
- **Mo-Gr** is particularly appealing as it is **easy to machine**, is **versatile** and can be **coated with** a **Mo layer** dramatically **increasing electrical conductivity** …

Copper-Diamond Composite

- Developed by **RHP-Technology** (Austria)

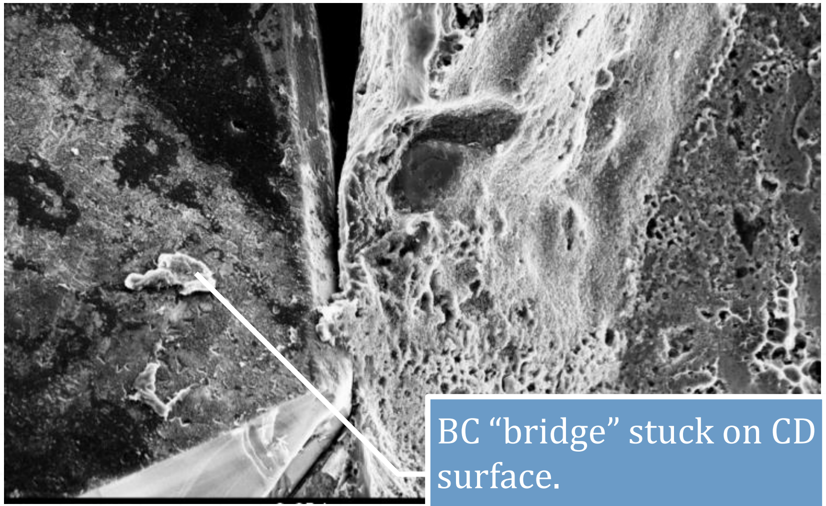
⬆ No diamond degradation (in reducing atmosphere graphitisation starts at **~ 1300 °C**)

⬆ Very good thermal (**~490 Wm^{-1}K^{-1}**) and electrical conductivity (**~12.6 MSm^{-1}**).

⬌ No direct interface between Cu and CD (lack of affinity). Partial bonding bridging assured by Boron Carbides limits mechanical strength (**~120 MPa**).

⬇ Cu low melting point (**1083 °C**) may limit Cu-CD applications for highly energetic accidents.

⬇ CTE increases significantly with T due to high Cu content (from ~**6 ppmK^{-1} at RT** up to **~12 ppmK^{-1} at 900 °C**)



BC "bridge" stuck on CD surface.
No CD graphitization

Molybdenum-Graphite Composites

- Co-developed by **CERN** and **Brevetti Bizz**.

Why Graphite?

- Low CTE
- Low Density
- High Thermal Conductivity (natural graphite flakes)
- Very High Service Temperatures (also allowing elevated processing temperatures)
- High Shockwave Damping

Composite Features

- ↑ Very high melting point (**2500+°C**)
- ↑ Low Density (can be tailored)
- ↑ **Very high thermal conductivity**
- ↑ Highly stable (forms MoC_{1-x} carbides)
- ↔ Fair electrical conductivity
- ↓ Mechanical strength to be improved …

Why Molybdenum?

- Refractory metal
- High mechanical strength
- Density lower than Tungsten

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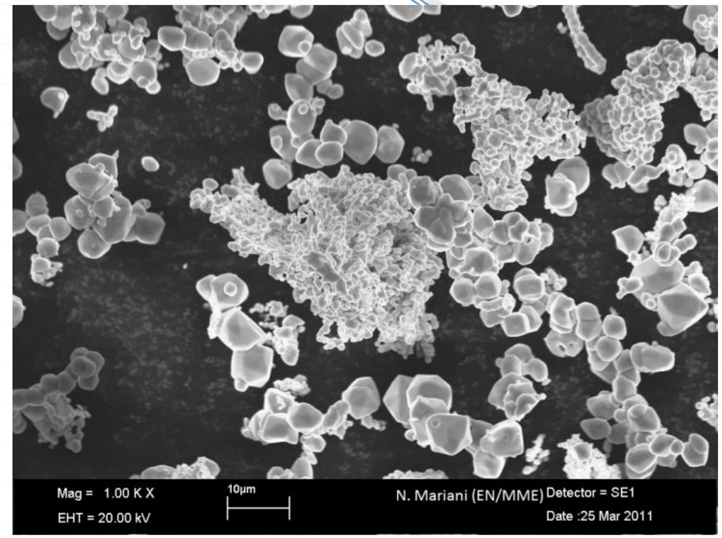
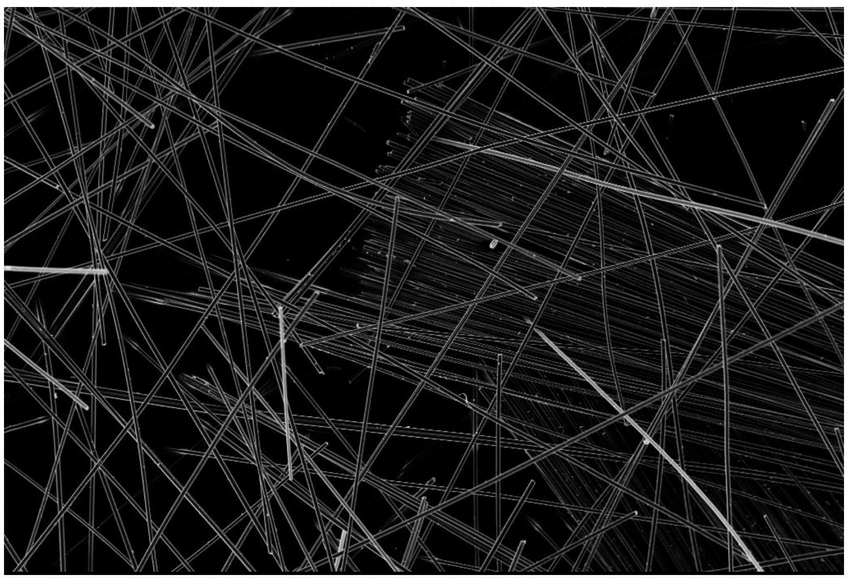
Molybdenum-Graphite Composites

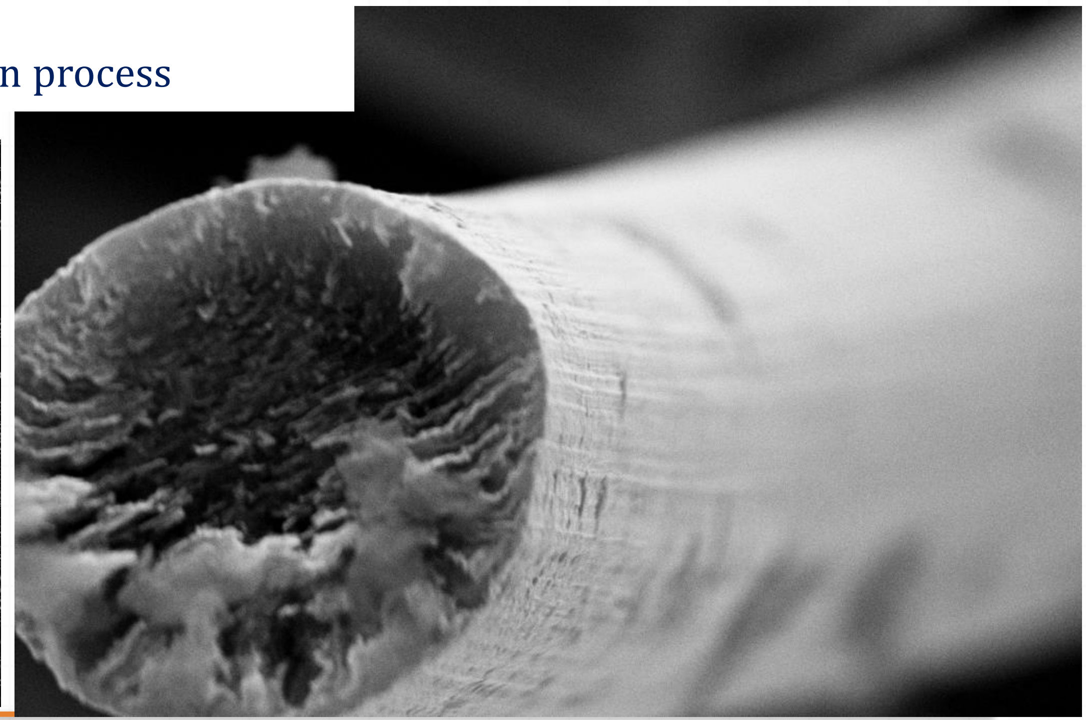
- Addition of **mesophase pitch-base carbon fibers**
- **Liquid Phase** Spark Plasma **Sintering (>2500° C)**



Advantages of Carbon Fibers addition

- Increase mechanical strength
- Contribute to high thermal conductivity (mesophase pitch grade)
- Along with MoC_{1-x} , catalyze graphitization process





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Mo-Gr-CF Microstructures

- Homogeneous distribution of graphite, fibers and fine MoC_{1-x} grains
- Recrystallization of graphite and CF
- Highly Oriented **Graphene** planes
- Strong fiber-matrix bonding

→ **Improved Mechanical St**

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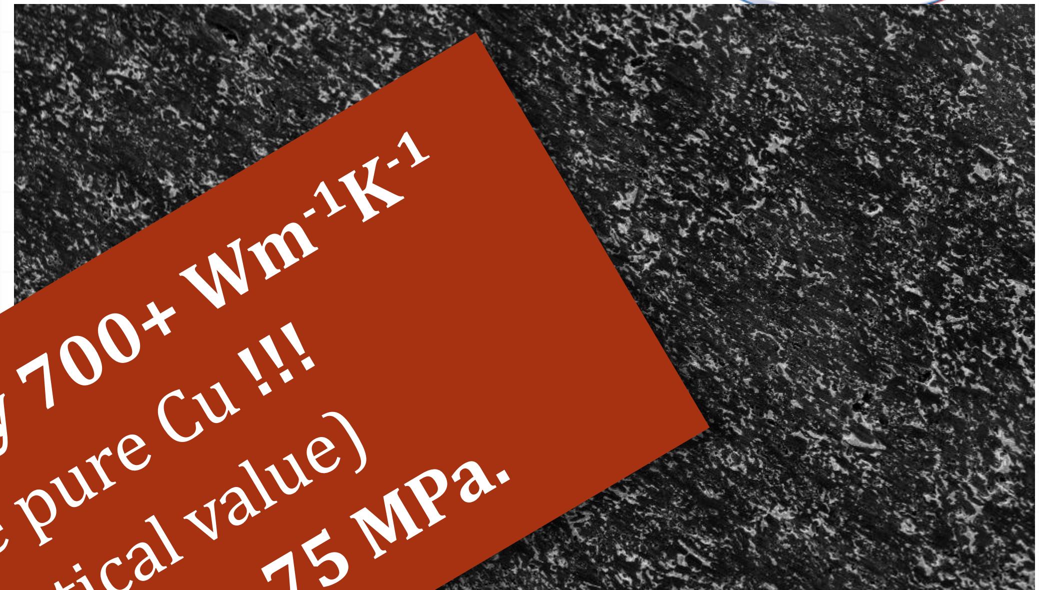
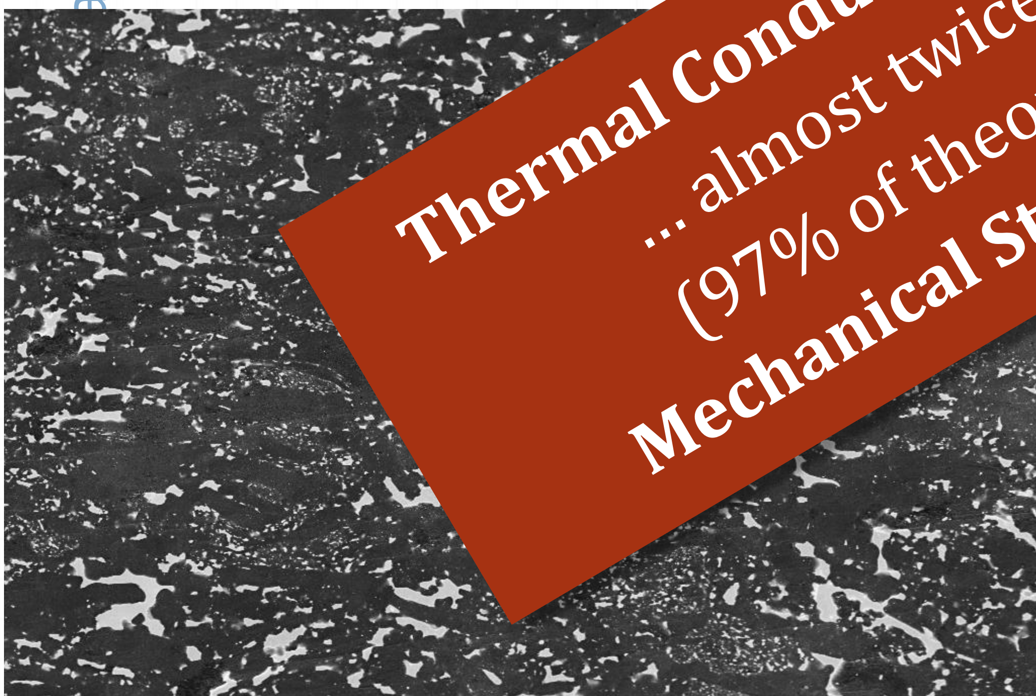
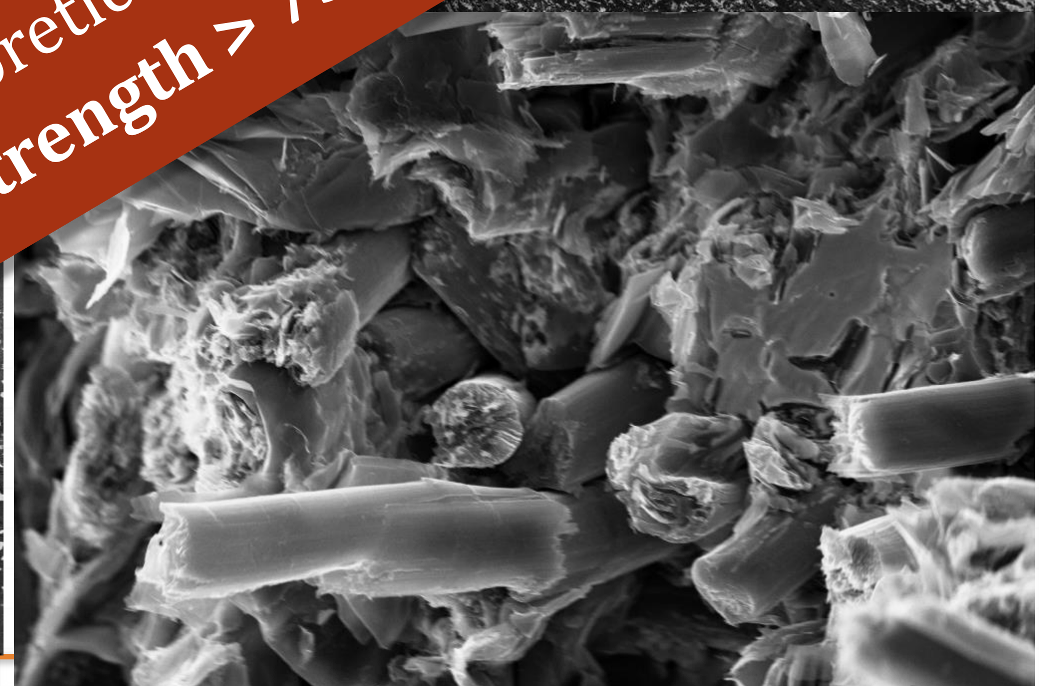






Thermal Conductivity 700+ $Wm^{-1}K^{-1}$

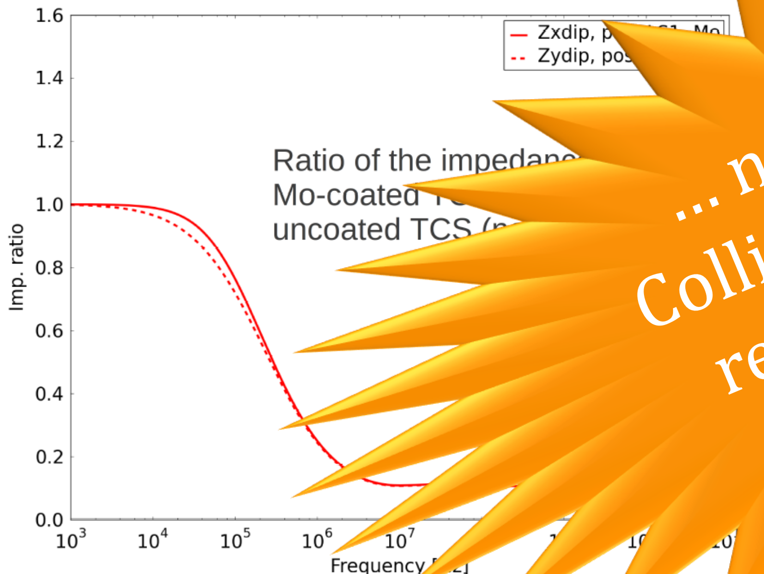
… almost twice pure Cu !!!

(97% of theoretical value)

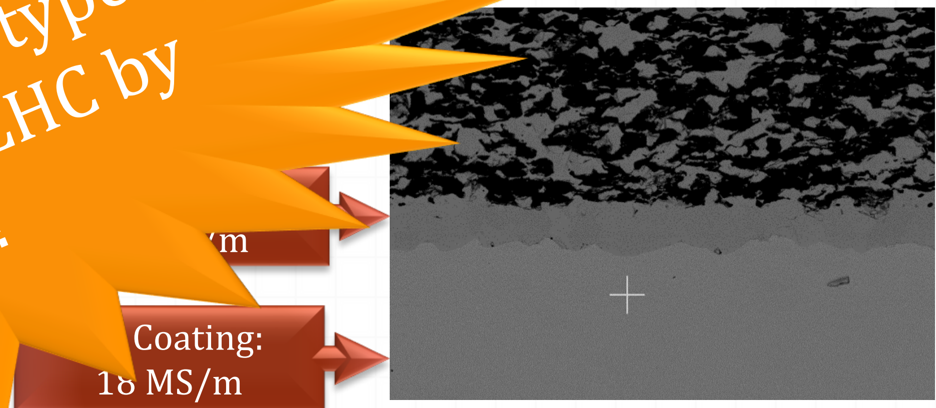
Mechanical Strength > 75 MPa.

Mo-coated Mo-Gr

- Co-developed by **CERN** and **Brevetti Bizz**.
- Molybdenum – Graphite core with **pure Mo cladding**.
- **Sandwich structure** drastically increases **el ctrica co   cti   y**
- Excellent adhesion of Mo cladding tha ks to



... no surprise a full Collimator prototype is requested in LHC by 2016!



- Collimator **impedance reduced by a factor 10** through Mo-coated Mo-Gr.

Outline

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- Context
- **Partners (WP11 and beyond)**
- WP11 Tasks and Deliverables
- WP11 Status and upcoming activities
- Summary and Perspectives

The Partners (WP11 and beyond)

- **WP 11 Partners (ColMat-HDED)**

ColMat-HDED

- **Partnership agreement with CERN (KN2045)**

BREVETTI BIZZ

- **Collaboration with US-LARP**

BROOKHAVEN NATIONAL LABORATORY

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WP11 Tasks and Deliverables

- **Work Package subdivided in 4 Tasks**

1. **Coordination and Communication**
   (A. Rossi and J. Stadlmann)
2. **Material testing for fast energy density deposition and high irradiation doses**
   (A. Bertarelli)
3. **Material mechanical modelling**
   (A. Bertarelli)
4. **Material Specification** (A. Rossi)

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WP11 Tasks and Deliverables

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EuCARD²

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Deliverables and Milestons

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D11.1	Results on simulations of new materials and composites	12	30.00	R	PU	36
D11.2	Report on comparative assessment of beam simulation codes	1	20.00	R	PU	40
D11.3	Irradiation test results	20	23.00	R	PU	46
D11.4	Results on characterisation of new materials and composites	26	30.00	R	PU	46

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS69	Irradiate first sample	26	12	Report
MS70	Present results on material damage from irradiation	26	24	Report
MS71	Show new material development status	20	24	Publication of results achieved
MS72	Present results on material damage from simulation and compare to experiments	26	45	Report

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WP Time Framework

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- **"Global" Collimation objectives (relevant to WP11) and (very aggressive) timing**
  - Choose a novel, robust (low-Z) material for HL-LHC Primary and Secondary Collimators (TCSx) – **Mid 2014**
  - Design, build and install a test bench for one or more HL-LHC Collimator full jaws in HiRadMat² – **Early 2015**
  - Investigate alternative, more robust materials for Tertiary Collimators and Absorbers – **Mid 2014**
  - Design, build and install a test bench to assess and qualify a palette of materials samples in HiRadMat² – **Mid/Late 2015**
  - Design, build and install in the LHC a prototype of HL-LHC Secondary Collimator embarking novel advanced materials – **2016**

Task 11.1: Status and Next Events

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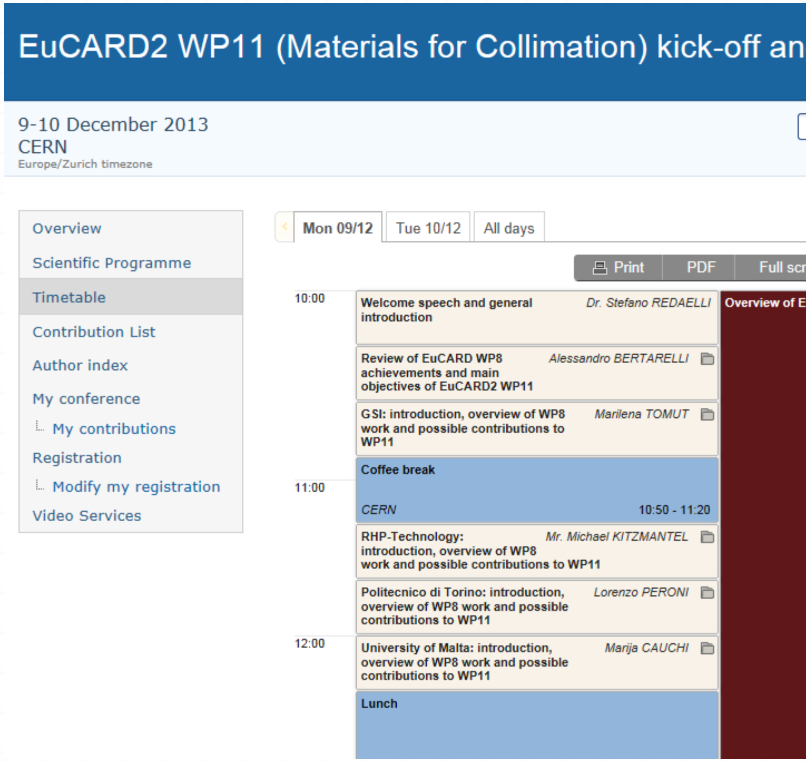
- Kick-off Meeting held on 9.12.13
- Participation (direct or remote) by all partners (20 participants)
- Indico Site online (https://indico.cern.ch/conferenceTimeTable.py?confId=286096#20131209)



EuCARD2 WP11 (Materials for Collimation) kick-off and tasks meeting

9-10 December 2013
CERN
Europe/Zurich timezone

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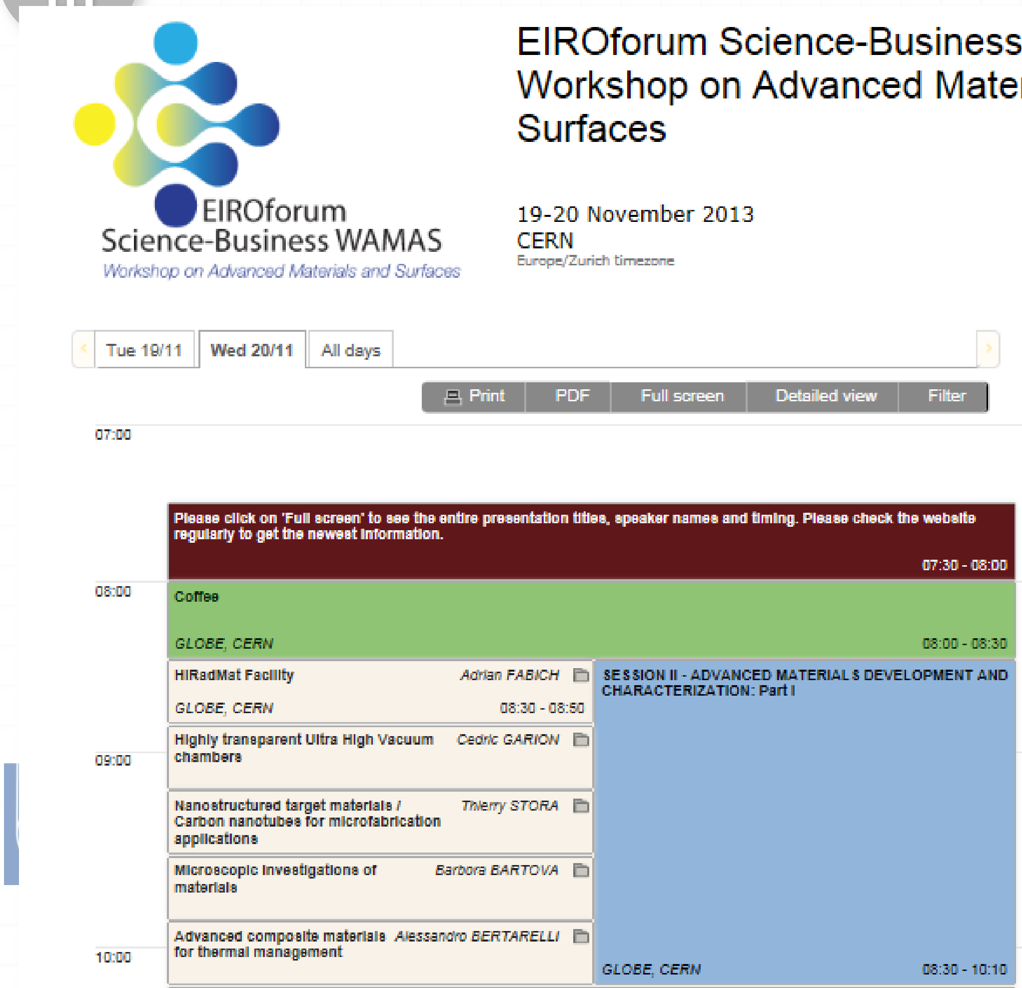
10:00	Welcome speech and general introduction	Dr. Stefano REDAELLI
	Review of EuCARD WP8 achievements and main objectives of EuCARD2 WP11	Alessandro BERTARELLI
	GSI: introduction, overview of WP8 work and possible contributions to WP11	Marilena TOMUT
11:00	Coffee break — CERN	10:50 - 11:20
	RHP-Technology: introduction, overview of WP8 work and possible contributions to WP11	Mr. Michael KITZMANTEL
	Politecnico di Torino: introduction, overview of WP8 work and possible contributions to WP11	Lorenzo PERONI
12:00	University of Malta: introduction, overview of WP8 work and possible contributions to WP11	Marija CAUCHI
	Lunch	

Overview of E

Task 11.1: Status and Next Events

- Participation to WAMAS (Workshop on Advanced Materials and Surfaces).
- WP 11 website online: https://lhc-collimation-upgrade-spec.web.cern.ch/lhc-collimation-upgrade-spec/WP11.php

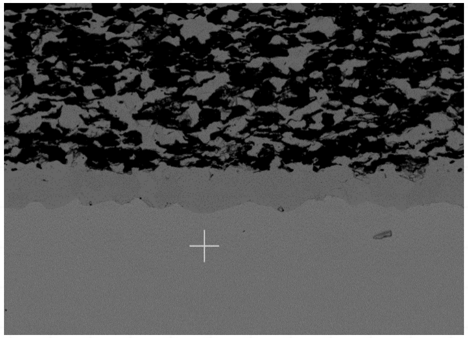


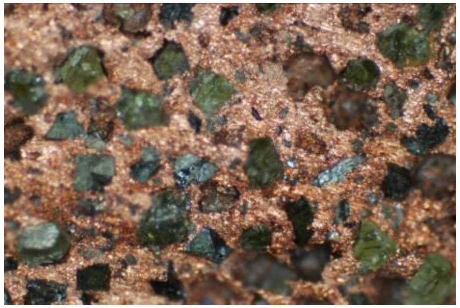
Roughly 1 BEUR for Materials R&D

Task 11.2: Next Activities (~6 ÷ 8 mo)

Research and Development of Novel Materials

- Continue development of **Mo-Gr** and **Mo-coated Mo-Gr** in view of optimizing performances and identifying optimal grade by Summer 2014 (**CERN / Brevetti Bizz**)
- Produce specimens of **Mo-Gr** and **Mo-coated Mo-Gr** for irradiation tests in GSI starting in February 2014 (**CERN / Brevetti Bizz**)
- Produce specimens of **Cu-CD** for irradiation tests in GSI starting in February 2014 (**RHP Technology**)
- Continue investigations on existing "traditional" materials (particularly Carbon-based) (**CERN / GSI**)

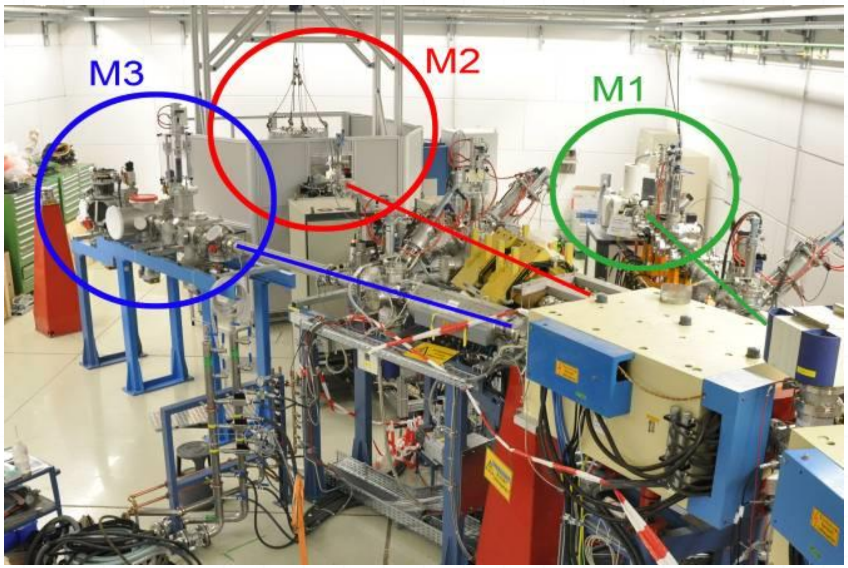


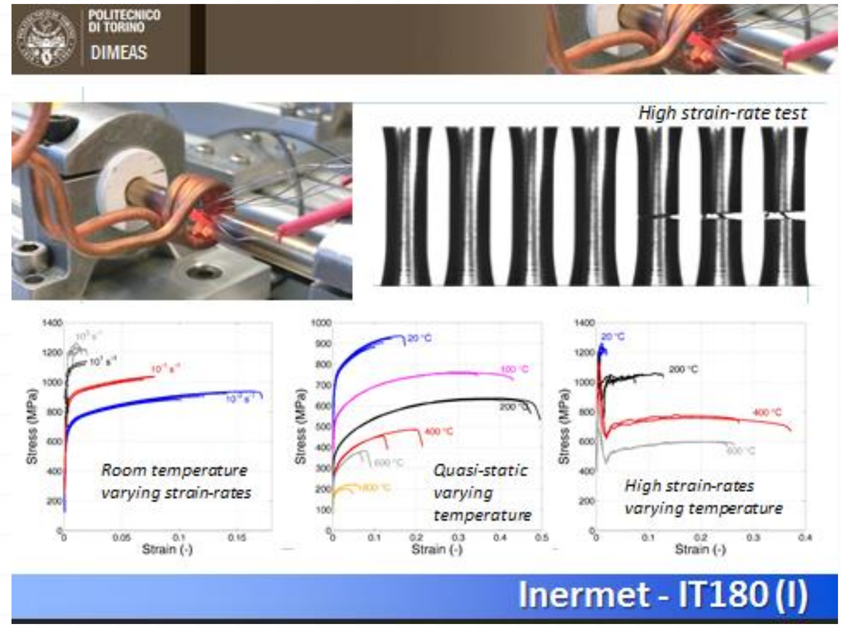


Task 11.2: Next Activities (~6 ÷ 8 mo)

Characterization and physio-mechanical testing of Collimator Materials (novel and existing)

- Microscopic Analyses (**CERN**)
- Thermo-physical characterization up to 2000° C (**CERN**)
- Mechanical Testing of Mo, Inermet and Graphite (**Polito**)
- Irradiation and radiation damage characterization in situ and off-line as of **February '14** (**GSI**) – **Milestone 69**)





Task 11.2: Next Activities (~6 ÷ 8 mo)

Irradiation Campaign in GSI

- High Energy Ion Irradiation (300 MeV/u) on **C/C**, **Mo-Gr** and **Cu-CD**
  - **Block 1** (Au and/or U): **19 February - 9 March '14**
  - **Block 2** (Au or Xe): **April '14**
  - **Block 3** (Au): **July '14**
  - **Block 4** (Pb): **September '14**
- Evolution of properties to be measured with dose:
  - Thermal Conductivity
  - Thermal Diffusivity
  - Hardness
  - Swelling

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Task 11.2: Next Activities (~6 ÷ 8 mo)

EuCARD²

- **CERN** to prepare **80 C/C discs** Ø10 mm x 2 mm, by 20.02.2014. Additionally, a number of carbon fiber samples (Phase 1 and present).

- **Brevetti Bizz** to prepare 65 Mo-Gr specimens:
  - 20 discs Ø10 mm x 1 mm available at GSI by 19.02.2014
  - 15 discs Ø20 mm x 30 mm available at GSI by 19.02.2014
  - 5 discs Ø32 mm x 30 mm available at GSI by 19.02.2014
  - 20 discs or squares 10 mm x 1 mm available at GSI by 07.04.2014
  - 5 discs Ø10 mm x 3 mm by September

- **RHP-Technology** to prepare **65 Cu-CD s**pecimens:
  - 20 discs Ø10 mm x 1 mm available at GSI by 19.02.2014
  - 15 discs Ø20 mm x 30 mm available at GSI by 19.02.2014
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  - 5 discs Ø10 mm x 3 mm by September

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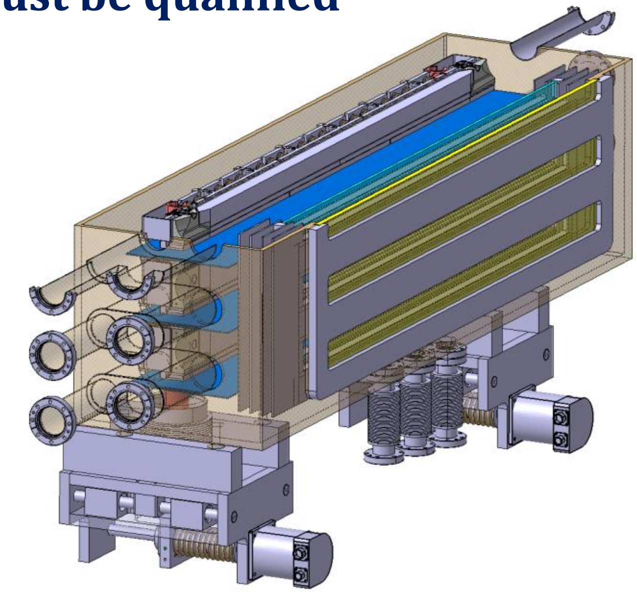
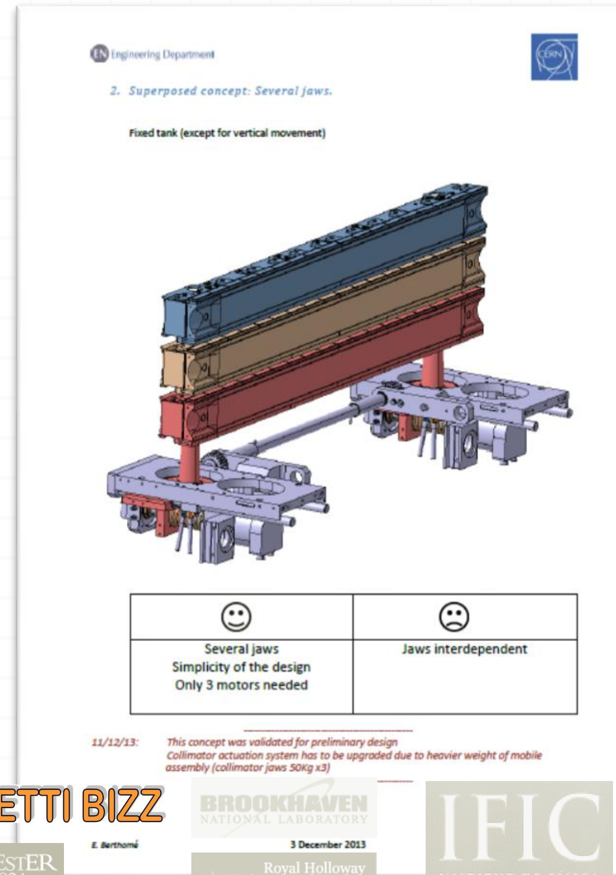
Task 11.2: Next Activities (~12÷15 mo)

Experimental tests at HiRadMat²

- 2012 experiments in HiRadMat (HRMT-14 and HRM-09) were very successful and useful …… e.g. they allowed to define new beam limits for Tertiary Collimators.
- However a number of improvements is due, particularly for low-Z materials (having "weak" responses to beam impacts).
- **A number of novel materials is yet to test …**
- **New designs must be qualified**





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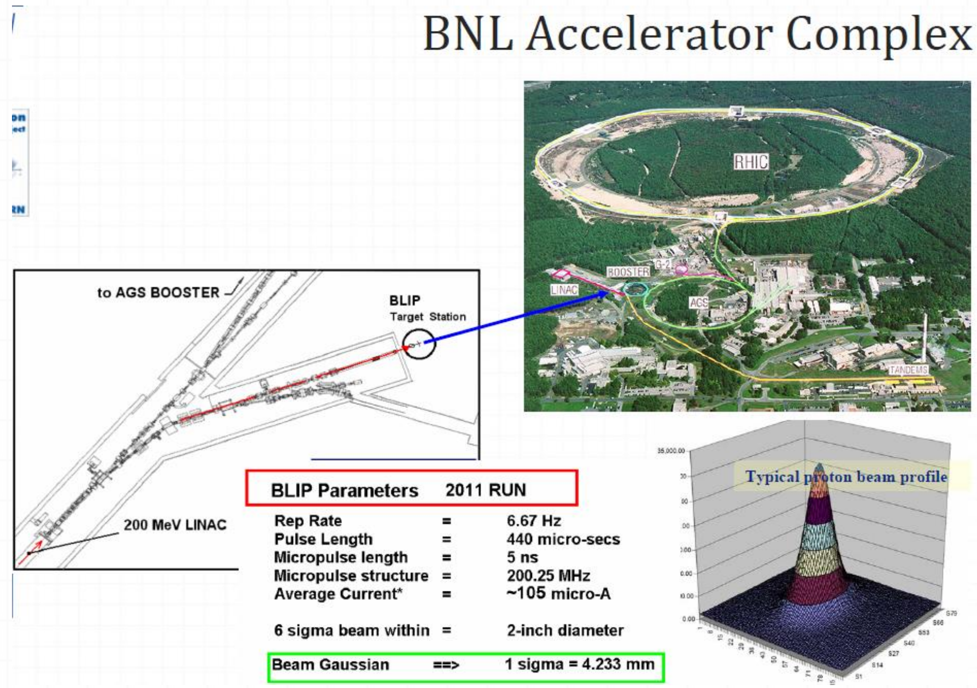
Task 11.2: Ongoing/Next Activities

Long-term irradiation tests and assessment of material property changes

- Continuation of Irradiation studies at KI-RRC and reports
  - Cu-CD
  - MoCuCD
  - SiC
- Continuation of Irradiation studies at BNL and reports
  - Cu-CD
  - Mo-Gr
  - Molybdenum
  - Glidcop
- **Open issue is the scalability of results for 10÷100 MeV to the TeV level ...**



Tasks 11.3: Ongoing/Next Activities

- Theoretical modelling of materials and novel composites (Equations of State, Strength models, Failure models).
- Energy deposition calculations (FLUKA) and coupling with hydrocodes.
- Modelling of dynamic phenomena (stress and shock waves, spall, melting, fragmentation, tunnelling …) induced by fast abnormal beam loss events.
- Modelling of long-term radiation damage. Equivalence between high fluence, low energy and lower fluence, high energy irradiation with various species.
- Benchmark numerical results with experimental data.

Task 11.4: Status and Next Activities

- **Material specification (Beam simulation codes)**
  - Ad-hoc meeting in Daresbury on 15 November after HiLumi 3rd meeting
  - Comparison between SixTrack, Merlin and FLUKA.
  - Implement cross-sections for novel materials and composites.

Potential EUCARD2 in Manchester

The Cockcroft Institute of Accelerator Science and Technology

The MERLIN code has been developed for LHC collimation as part of the HiLumi-LHC project and EUCARD project.

The results for the LHC are very promising, and starting to bear fruit.

Potential areas of work in EUCARD2 are the following (but collaboration would be important to achieve these)

- Simulate the potential of new collimator materials like Mo-Graphite
- Comparison between, SixTrack, Merlin and FLUKA (ongoing)
- Implement cross-sections for novel materials and composites.

EuCARD2 WP11 kick-off: Royal Holloway contribution

Prospects for WP11

- Detailed simulations of LHC are underway to understand beam backgrounds and tune the collimator configuration for HL-LHC.
- BDSIM is being further developed for LHC studies as part of HiLumi and EuCARD2 projects.
- Novel collimator materials (Mo-graphite) could be readily simulated in BDSIM through Geant4 material description.
- Would enable characterization of new materials and through collaboration allow ongoing comparison with other codes: SixTrack / FLUKA and Merlin.

JAI John Adams Institute for Accelerator Science — *Stephen Gibson* — 10

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Summary and Perspectives

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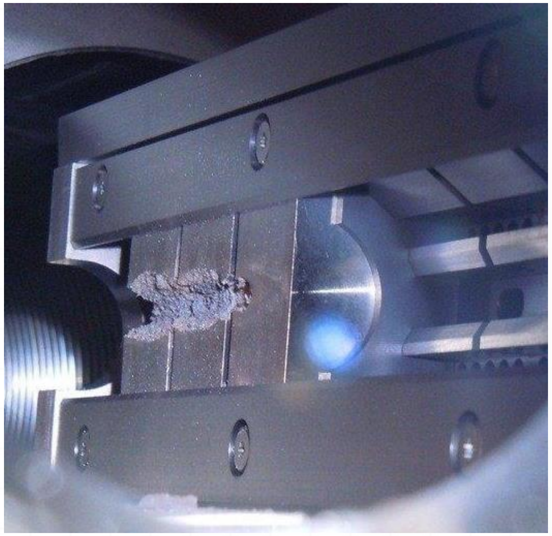
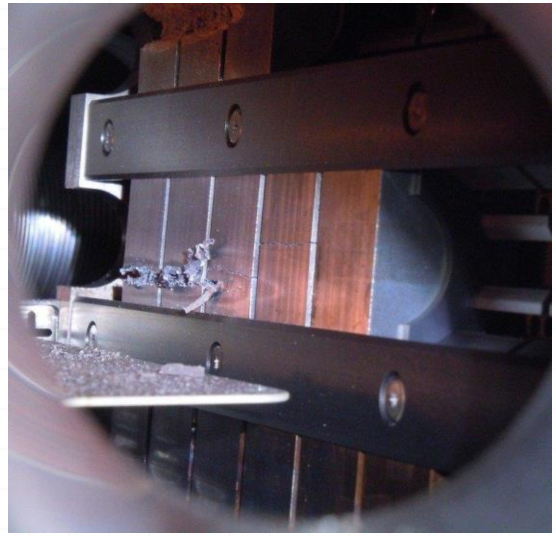
- WP11 is up and running with and ambitious program aiming at the development … tion of collimators.
- Very motivat … plus 2 "external" ones).
- 1st WP meeti … particular to materials irr…
- Very intense … ARD2 deadlines but also by "… mator with new materials to …
- Contribution … nging goals in a framework o … n sight …
- Materials bei … ge of industrial applications and have the potential for a real impact on society …

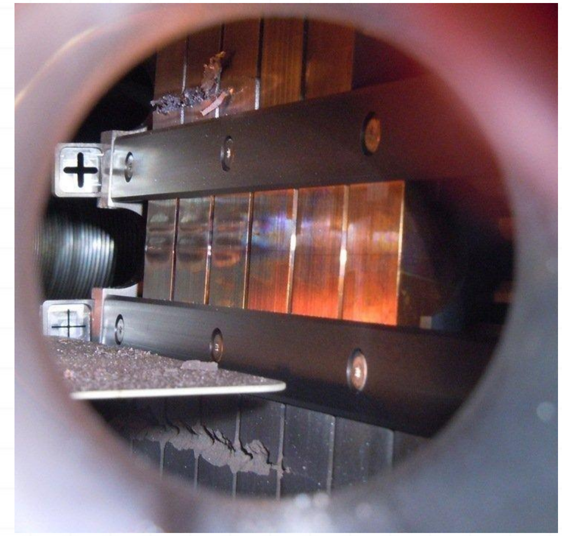
Thank you for your attention!

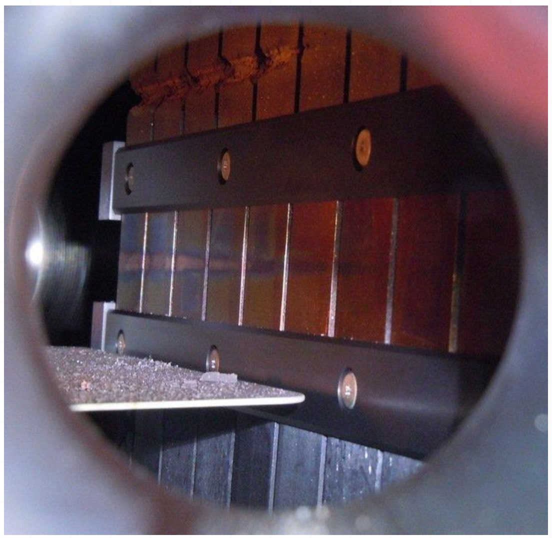
LHC Collimation Project

HRMT14: High Intensity Tests

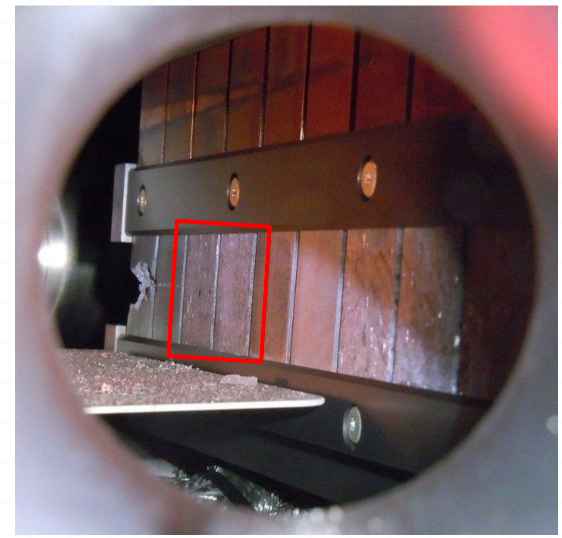

Inermet 180, 72 bunches


Molybdenum, 72 & 144 bunches


Glidcop, 72 bunches (2 x)


Copper-Diamond
144 bunches


Molybdenum-Copper-Diamond
144 bunches


Molybdenum-Graphite (3 grades)
144 bunches

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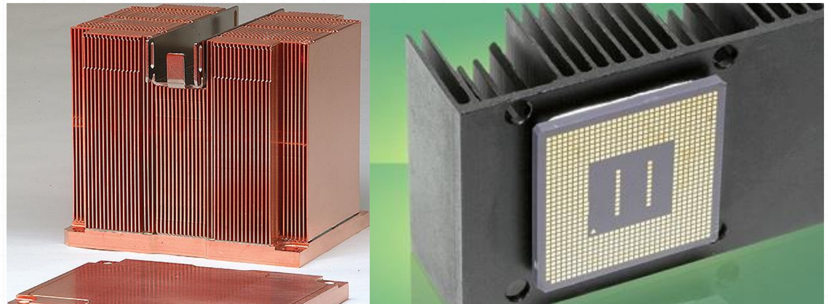
Novel Materials Future Application?



Thermal Management for High Power Electronics

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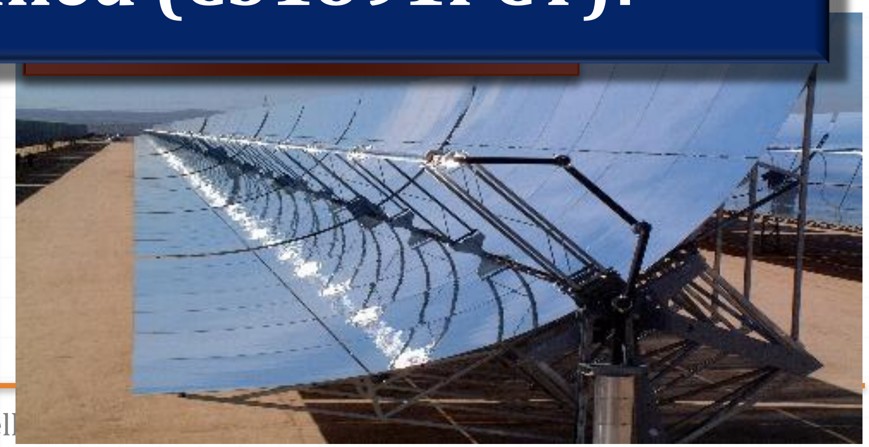
Potential range of applications can be further expanded particularly thanks to the tailoring possibilities of Molybdenum-Graphite composites

…

International Patent filed (C31891PCT)!

Advanced Braking Systems



GSI Irradiation: Specimens

CERN to prepare **80 C/C discs** Ø10 mm x 2 mm, by 20.02.2014. Additionally, a number of carbon fiber samples from Phase 1 and present R&D.

Brevetti Bizz to prepare **65 Mo-Gr specimens**:

a. 20 discs Ø10 mm x 1 mm available at GSI by 19.02.2014
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