This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

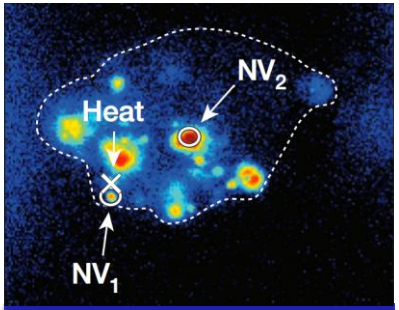
New Technologies: New Materials for Extreme Thermal Management – PowerMat (WP17)

ARIES Kick-off Meeting, CERN Geneva 04.05.2017

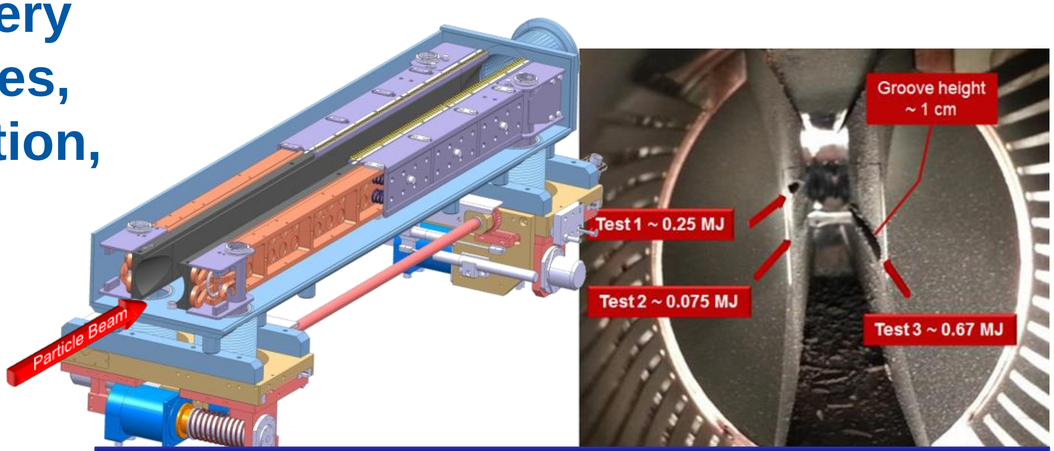
Alessandro Bertarelli (CERN), Marilena Tomut (GSI)

What is Extreme Thermal Management?

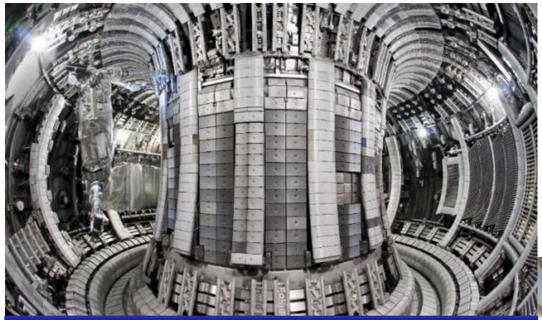
- **Applications dealing with very high temperatures, pressures, strain rates, particle irradiation, in harsh environments …**



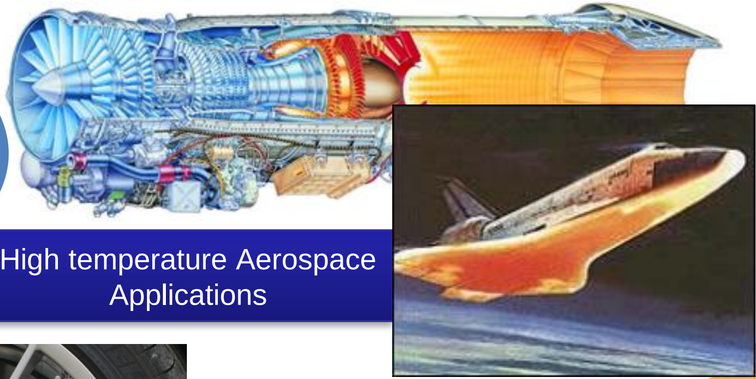
Medical Imaging



Particle Accelerators (Beam Intercepting Devices)



Fusion Engineering



High temperature Aerospace Applications

Advanced Braking Systems

PowerMat in a Nutshell

- Push forward **R&D** of **novel Ceramic Matrix and Metal Matrix Composites** based on graphite and diamond reinforcements with various dopants
- **Simulate** and **test** materials under **extreme thermal shocks** (particle- or **laser-beam induced**) and **particle irradiation**
- Investigate **radiation damage** from theoretical, numerical and experimental standpoint
- Identify materials for a broad range of **accelerator applications** (high power collimators, beam targets, beam windows and luminescence screens …)
- Explore **societal applications** in advanced engineering, medical imaging, quantum computing, energy efficiency, aerospace …

PowerMat Partners

- Strong interaction with **WP14** (Promoting Innovation) – **Task 14.4**
- WP17: **6 main beneficiaries**, **1 associate** (**NIMP**)
- WP14: **1 beneficiary industry** (**RHP-Technology**), **1 associate industry** (**Brevetti Bizz**) in Task 14.4

CERN

POLITECNICO DI TORINO 1859 1906

GSI

POLITECNICO MILANO 1863

eli Nuclear Physics

UNIVERSITY OF MALTA
L-Università ta' Malta

INFM

RHP TECHNOLOGY

BREVETTI BIZZ

ARIES

PowerMat Partners

Work Package Organization

- **PowerMat JRA** is organized in 5 Tasks:
  - 17.1: **Communication & Coordination**
    A. Bertarelli, CERN; M. Tomut, GSI
  - 17.2: **Materials development and characterization**
    A. Bertarelli, CERN
  - 17.3: **Dynamic testing and online monitoring**
    L. Peroni, POLITO
  - 17.4: **Simulation of irradiation effects and mitigation methods**
    A. Lechner, CERN
  - 17.5: **Broader accelerator and societal applications**
    M. Tomut, GSI
- Within **WP14** (**Promoting Innovation**):
  - 14.4: **Industrial production of materials for extreme thermal management**
    F. Carra, CERN

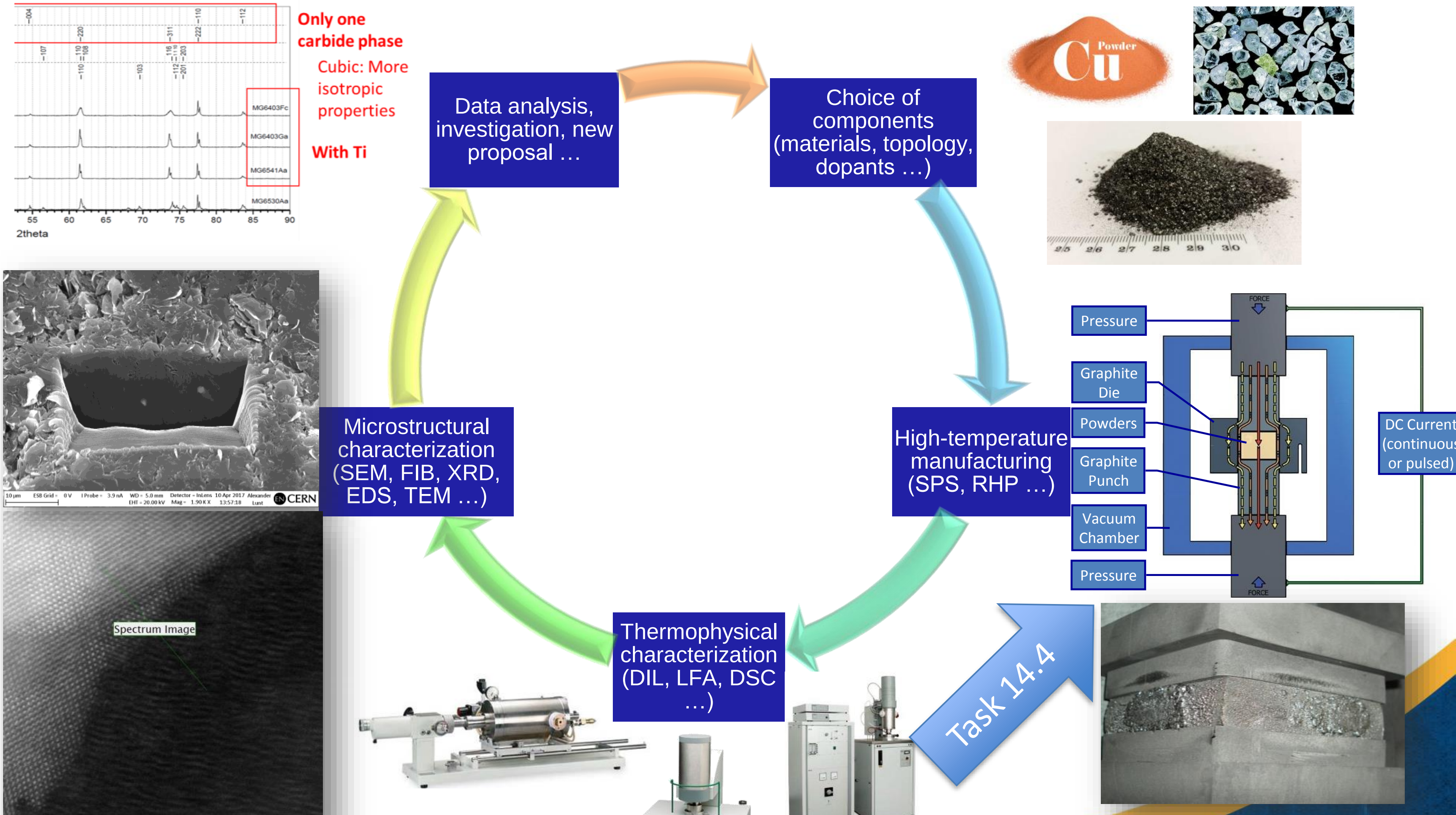
Task 17.2: Materials development and characterization

Coordinator: A. Bertarelli, CERN

Participants: CERN, GSI, NIMP, POLIMI, POLITO, UM (plus **Brevetti Bizz, RHP-Technology** through WP14)

- Research, investigation, development and characterization of **novel CMC and MMC** based on graphitic, carbide or diamond reinforcements and dopants (in collaboration with Task 14.4).
- Study and development of **electrically conductive coatings**, resisting the impact of high intensity particle beams.
- Characterization of **thermophysical and outgassing properties**, **microstructural analyses**, **study of phases** and of their change under various environments …

Task 17.2: Materials development and characterization

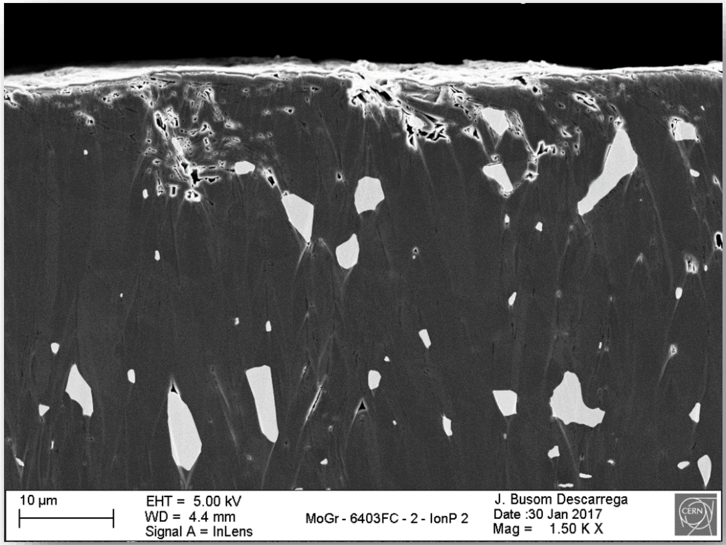


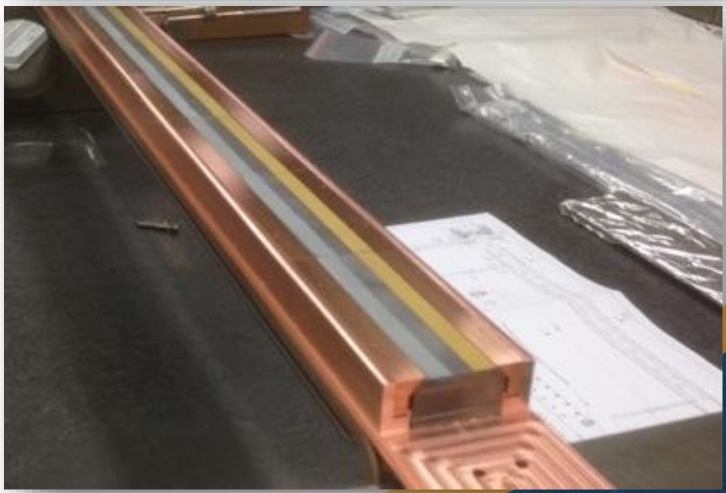
in collaboration with University of Zaragoza (SP)

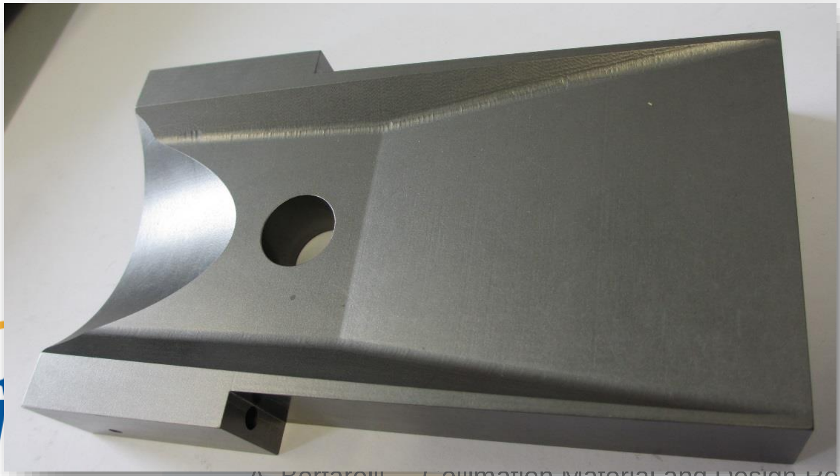
Task 17.2: Materials development and characterization

Example of Ceramic Matrix Composite: Molybdenum Carbide – Graphite (MoGr)

- Co-developed by CERN and Brevetti Bizz
- Produced by **Pressure-assisted Electric Current Sintering** attaining **liquid phase** of carbides **(T ≅ 2600°C)**
- Excellent crystalline structure of carbonaceous phase with **highly-oriented Graphene planes.** Graphitization favored by the **catalyzing effect** of molten carbides!
- **Excellent thermal properties (up to 4 times Cu diffusivity)!**
- **Electrical conductivity: factor of 10 higher than isotropic graphite!**
- Can be produced in **large components (150 x 100 x 25 mm^3)** and easily **machined**
- **Can be coated** with metals (e.g. Mo) and ceramics (e.g. TiN)



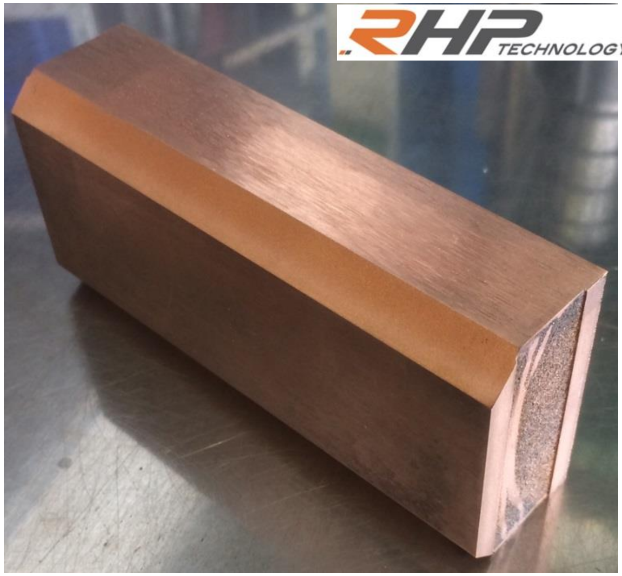


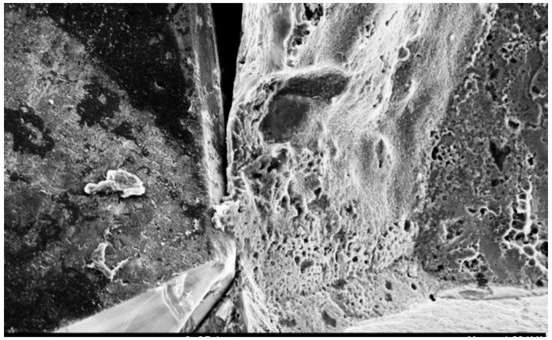


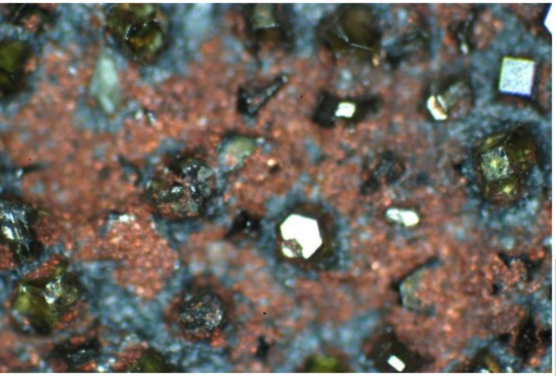
Task 17.2: Materials development and characterization

Example of Metal Matrix Composite: Copper – Diamond (CuCD)

- Developed by **RHP-Technology**
- Produced by **Rapid Hot Pressing (T ≅ 1000°C)**
- **Excellent electrical conductivity**, **very good thermal conductivity**
- Shock and Radiation resistant
- Can be cladded with pure copper

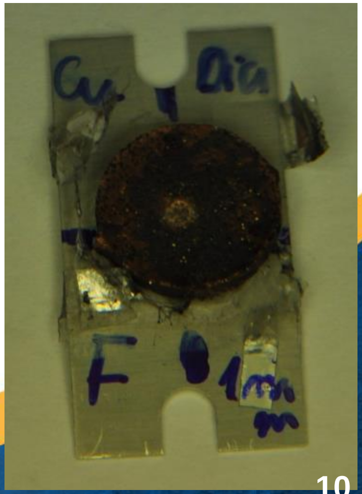






Laser shock experiment - GSI:

Pulse duration:	0.7-20 ns
energy:	0.3-1 kJ
Max. Intensity:	10^{16} W/cm^2



Proton beam HiRadMat, CERN:

Task 17.3: Dynamic testing and online monitoring

Coordinator: L. Peroni, POLITO

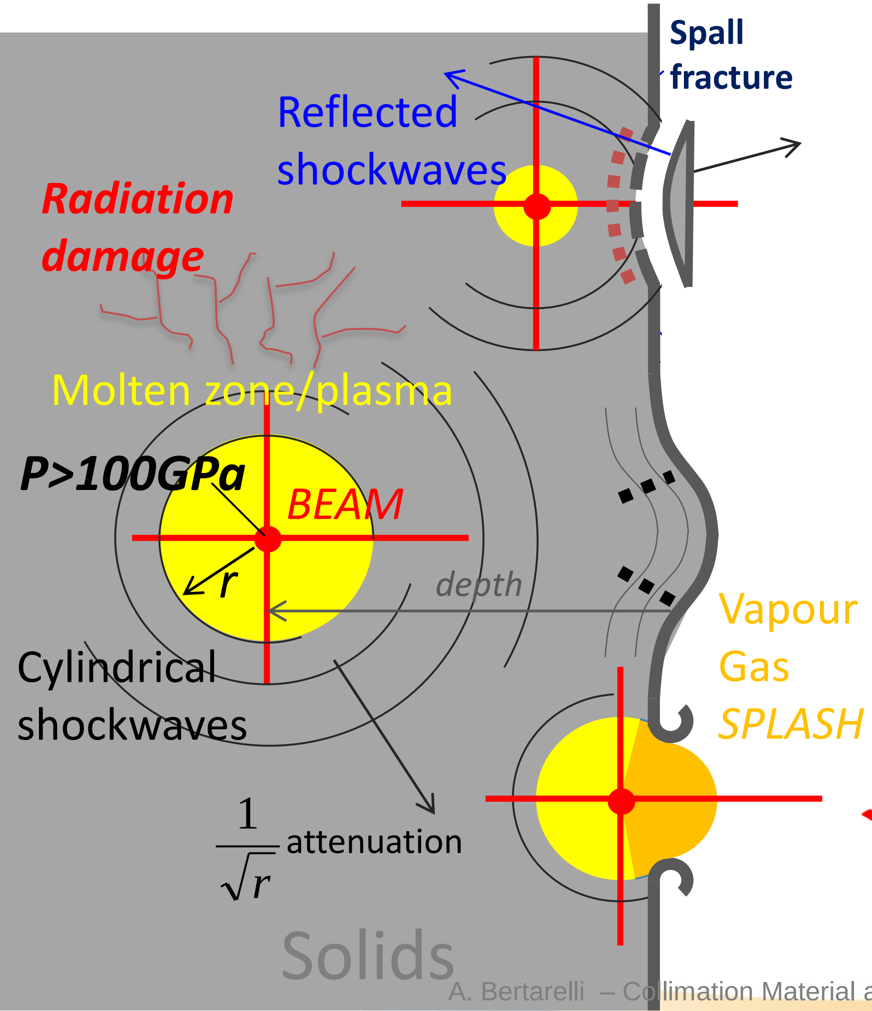
Participants: CERN, ELI-NP, GSI, POLIMI, POLITO

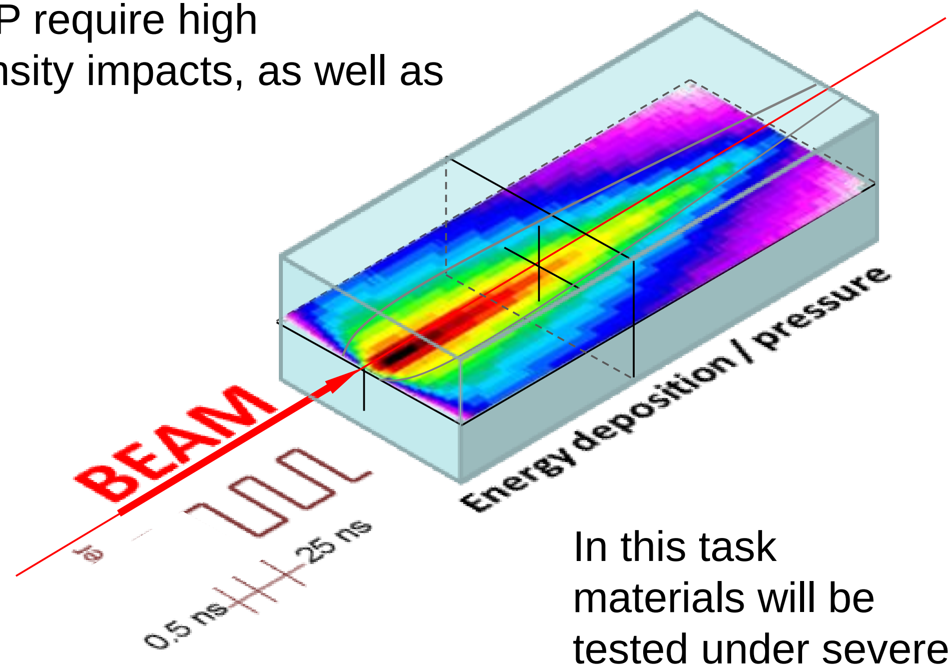
Testing of material samples in a broad range of environments:

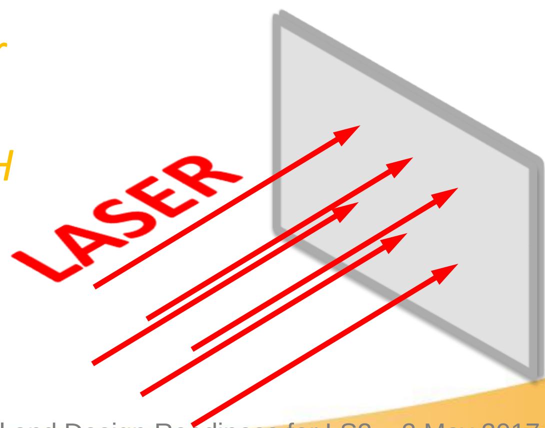
- Mechanical testing in quasi-static and dynamic conditions, at various temperatures
- Tests under very high power laser beams
- Irradiation tests with online monitoring of properties evolution
- Hydrodynamic simulations of experiments – Equations of State, Spall Strengths for new materials

Task 17.3: Dynamic testing and online monitoring

Applications of materials studied in this WP require high resistance to high energy, high energy density impacts, as well as radiation.



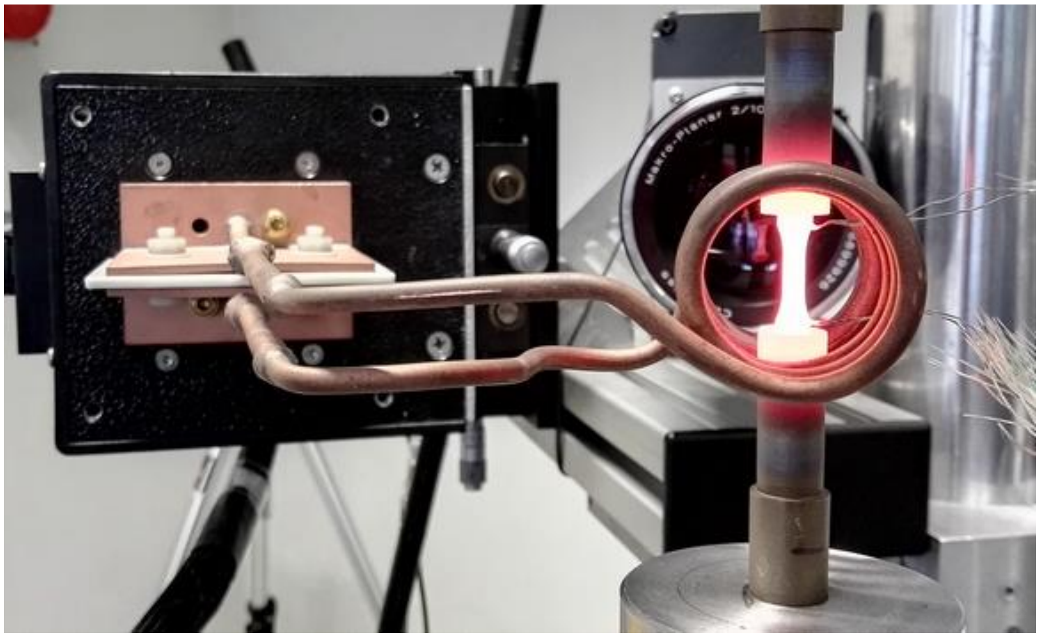


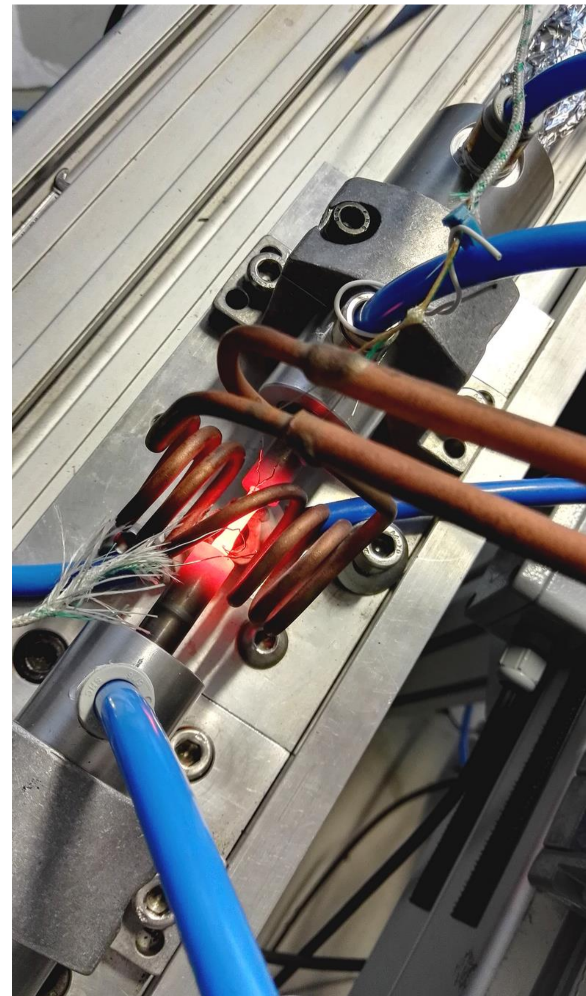


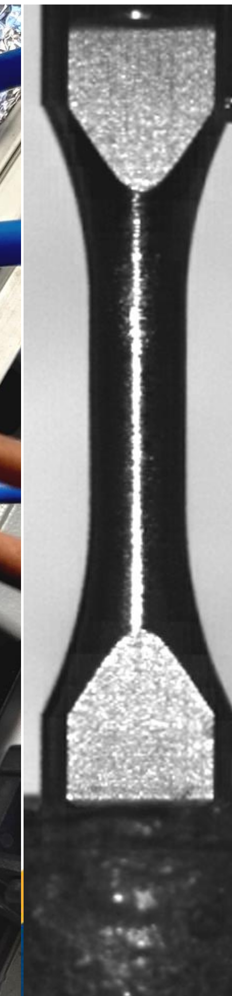
In this task materials will be tested under severe conditions such as high strains or energy density deposition, as well as irradiate them with protons, ions and laser beam.

Task 17.3: Dynamic testing and online monitoring

Mechanical testing in quasi-static and dynamic conditions, at various temperatures





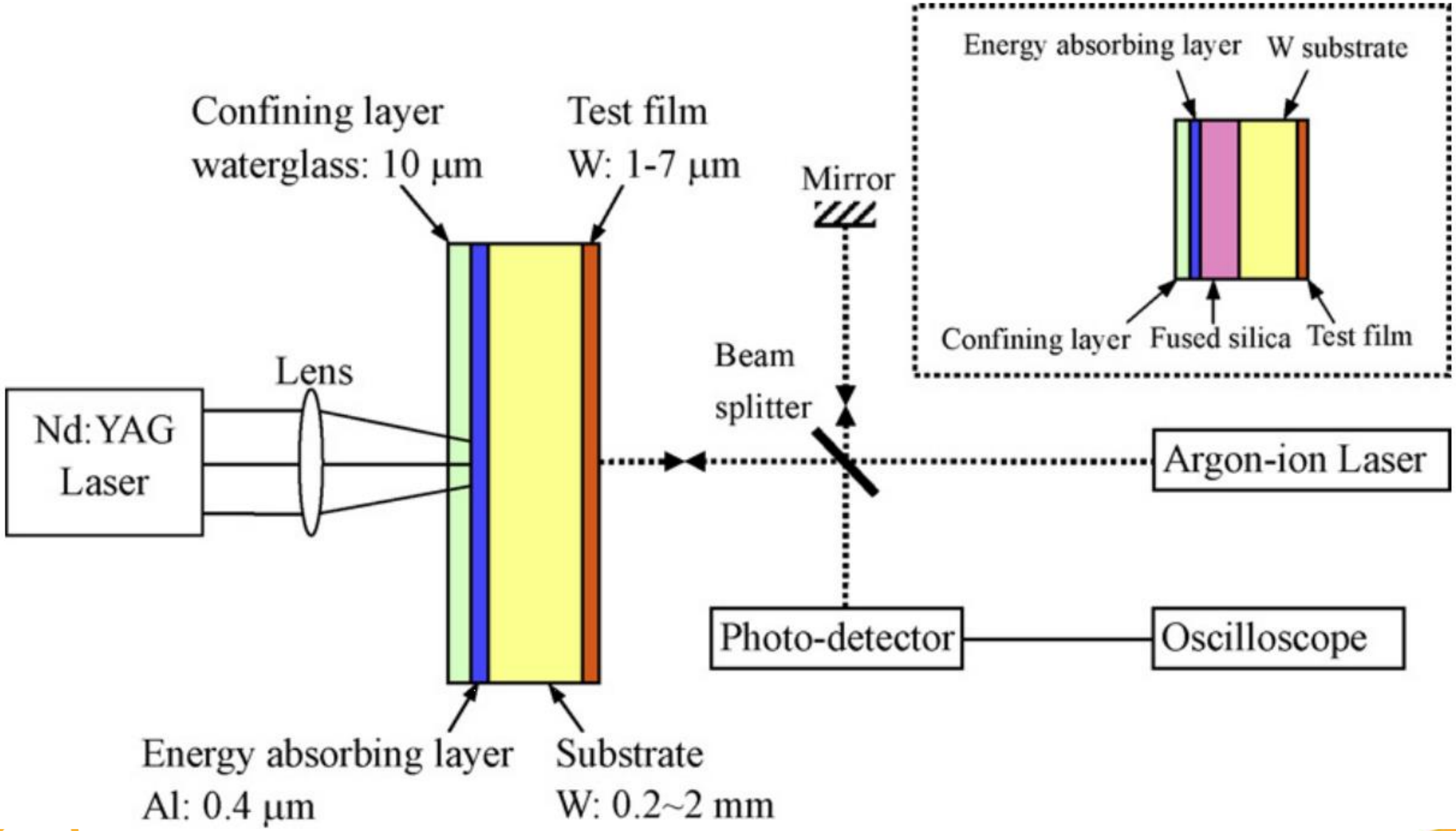


Task 17.3: Dynamic testing and online monitoring

Tests under very high power p⁺ and laser beams (GSI, ELI-NP)

p^+ from **HiRadMat**, CERN and ELI-NP

Explore VH intensity (**Phelix**, GSI), multi PW **laser facility** (**ELI-NP**)



Lili Hu, Phillip Miller, Junlan Wang (2009)

High strain-rate spallation and fracture of tungsten by laser-induced stress waves

Task 17.4: Simulation of irradiation effects and mitigation methods

Coordinator: A. Lechner, CERN

Participants: CERN, GSI, POLIMI

- Investigation and simulations of material damage induced by irradiation with protons and ions at various energies and doses
- Quantify Displacement per atom (DPA), gas production, nuclear transmutations for equipment in complex accelerator environments and provide a relationship with radiation experiments at lower energies and/or different particle species
- Ideally, relate radiation damage quantities (e.g. DPA) with change of relevant macroscopic material properties
- Open to co-operation with other international collaborations such as RaDIATE – (Radiation Damage In Accelerator Target Environment)

Task 17.5: Broader accelerator and societal applications

Coordinator: M. Tomut, GSI

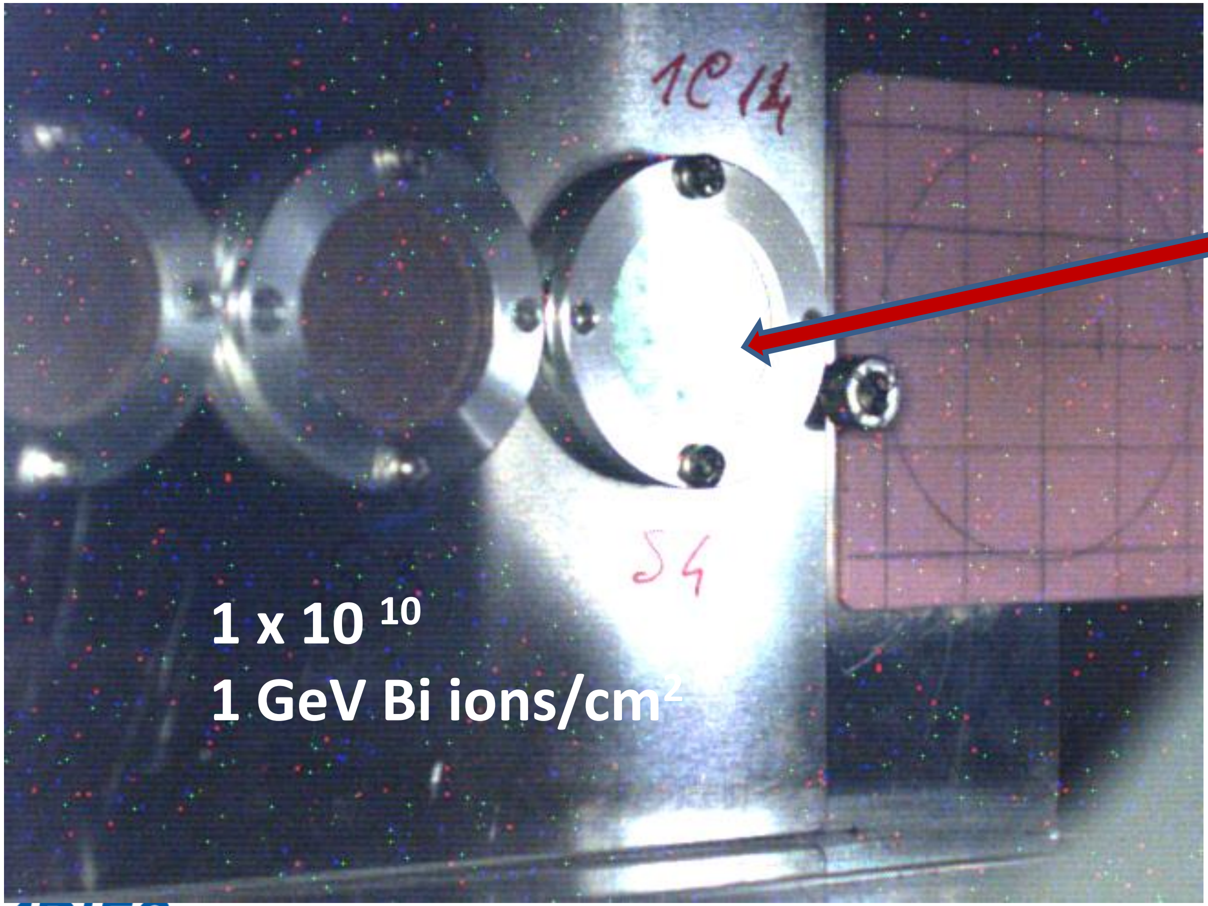
Participants: CERN, GSI, NIMP, (plus **Brevetti Bizz, RHP-Technology** through WP14)

R&D towards broader applications of new materials for high-power accelerators, space, society (energy, medicine, computing)

- Exploit irradiation-induced defect centres in diamond for luminescent screens, medical imaging and quantum computing
- Optimize materials compositions for high power targets, beam catchers, beam windows.
- Explore use of intense ion pulses for materials processing
- Explore synergies and applications for energy, medicine, biotechnology, aerospace and advanced technologies

Task 17.5: Broader accelerator and societal applications

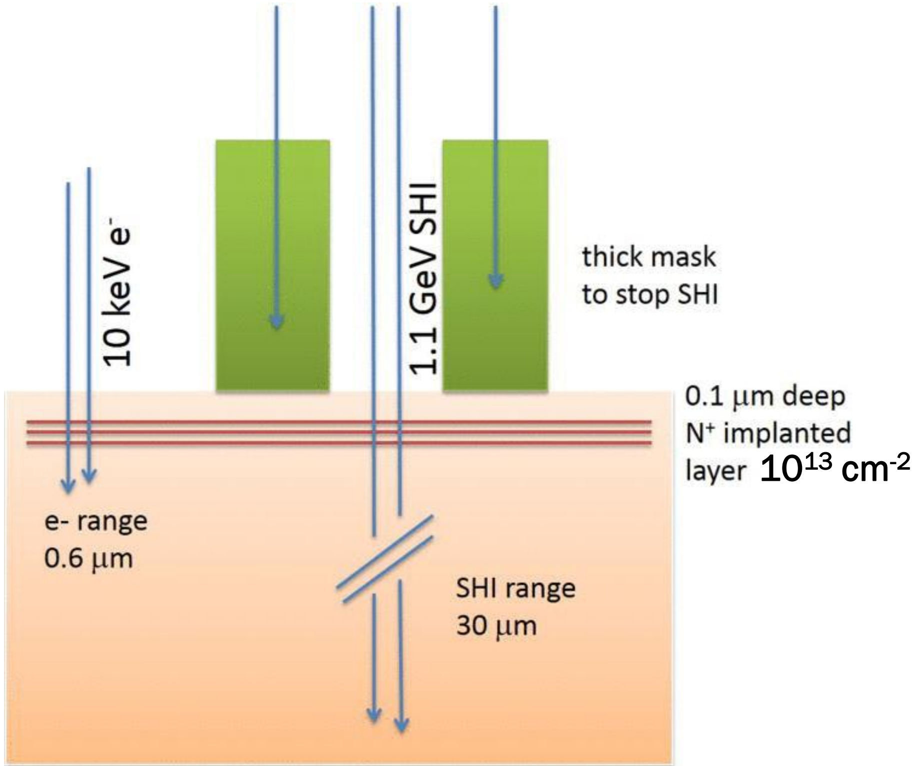
Evolution of ion induced luminescence in Cu-CD composites with dose

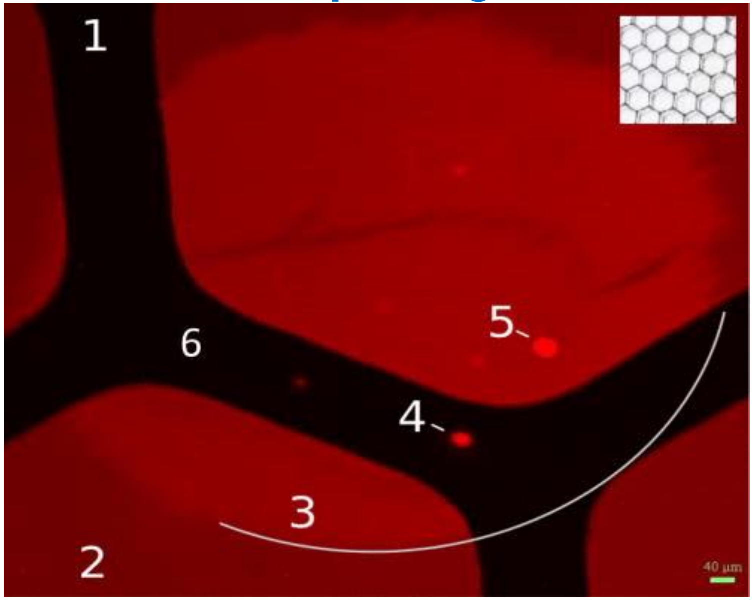


Beam-induced luminescence in CuCD: withstands beam intensities 3 orders of magnitude higher than traditional Chromox

Task 17.5: Broader accelerator and societal applications

Nitrogen-Vacancy formation by electronic excitation from passage of ions through diamond?





	Nitrogen implant	heavy ions	e^- beam	See NVs ?
1	No	No	No	No
2	No	Yes	No	No
3	**Yes**	**Yes**	**No**	**Yes !**
4	Yes	No	Yes	Yes
5	**Yes**	**Yes**	**Yes**	**Yes**
6	Yes	No	No	No

- Swift heavy ions, 5 MeV/u Uranium-ions, 5×10^{11} cm^{-2}
- Electronic stopping power: ~50 keV/nm (Bragg peak)
- delta-electrons up to ~10 keV

J. Schwartz, et al., J. Appl. Phys., 2014

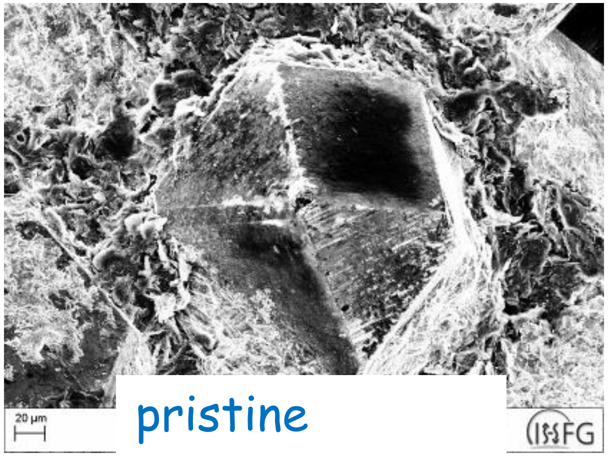
Task 17.5: Broader accelerator and societal applications

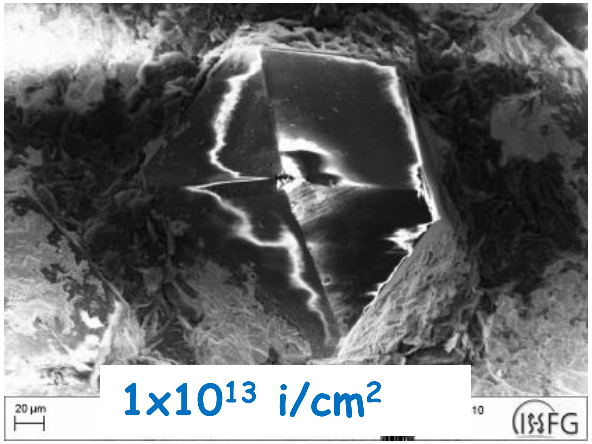
In situ analysis of radiation damage effects

M1-GSI
Electron Microscopy

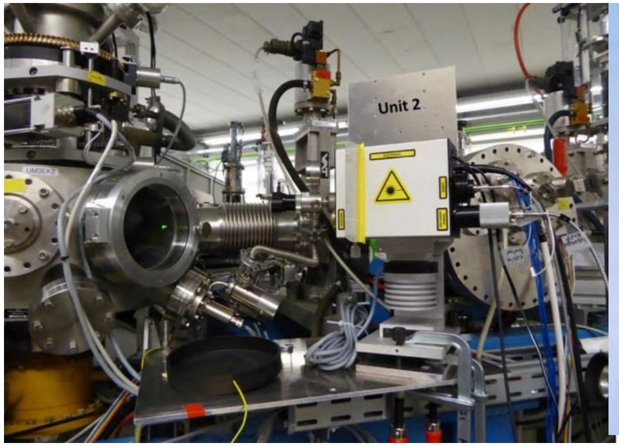
in collaboration with University of Stuttgart

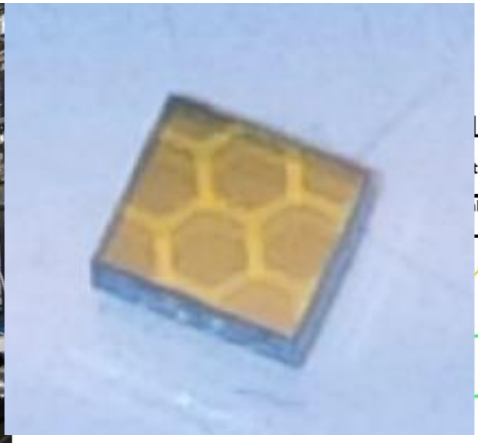
HR-SEM

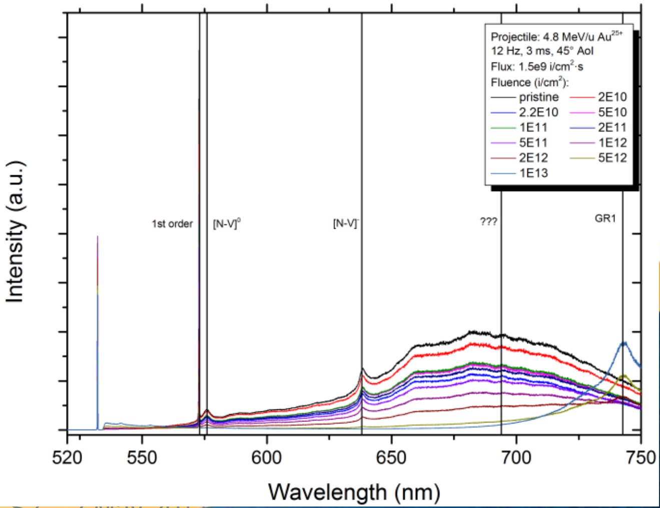




Raman spectroscopy







in collaboration with University of Heidelberg

PowerMat WP Summary and Outlook

- **PowerMat** is an **integrated and comprehensive research activity** with challenging and **innovative objectives**:
  - **R&D** and **optimization** of **advanced materials** for a broad range of application in HEP and advanced engineering …
  - **Innovative numerical** and **experimental methods** to test materials at **extreme energy density conditions** (beyond HL-LHC) in more accessible experimental facilities and producing less activation.
  - Assessment of **radiation damage** in materials and **results scalability** between different irradiation conditions (short, low energy tests vs. long-term, high energy in real accelerators)
  - **Control and exploitation** of **irradiation-induced effects** in novel materials (e.g. **diamond luminescence**) for new monitoring techniques in accelerators as well as exploration of **unconventional applications in society** (medicine, biotechnology, quantum computing …)
- **Strict co-operation** with **WP 14 (Task 14.4)**
- **PowerMat** is already **up and running**: WP **kick-off meeting due tomorrow**, following a **preparation meeting on 1 February 2017**!

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

Thank you!

Deliverables

- Task 17.2 Comparative compendium of the developed materials [month 40]
- Task 17.4) Report on simulations on irradiation effects [month 44]
- Task 17.3) Irradiation test results: Beam impact on new material and composite [month 46]
- Task 14.4) Production of material samples (as large as possible for each industry to demonstrate workability) [month 24]

Milestones

- Task 17.1) Organisation of PowerMat kick-off meeting, with publication of talks on Web [month 6]
- Task 17.2) Material characterisation, with publication of results on Web [month 18-24]
- Task 17.3) Irradiation, with publication of report on web[month 27]
- Task 17.4) Irradiation effects analysis, with publication of report on web[month 36]
- Task 17.5) Report on studies, with publication of report on web, [month 46]
- Task 14.4) Prepare first samples [month 12]

Deliverables and Milestones

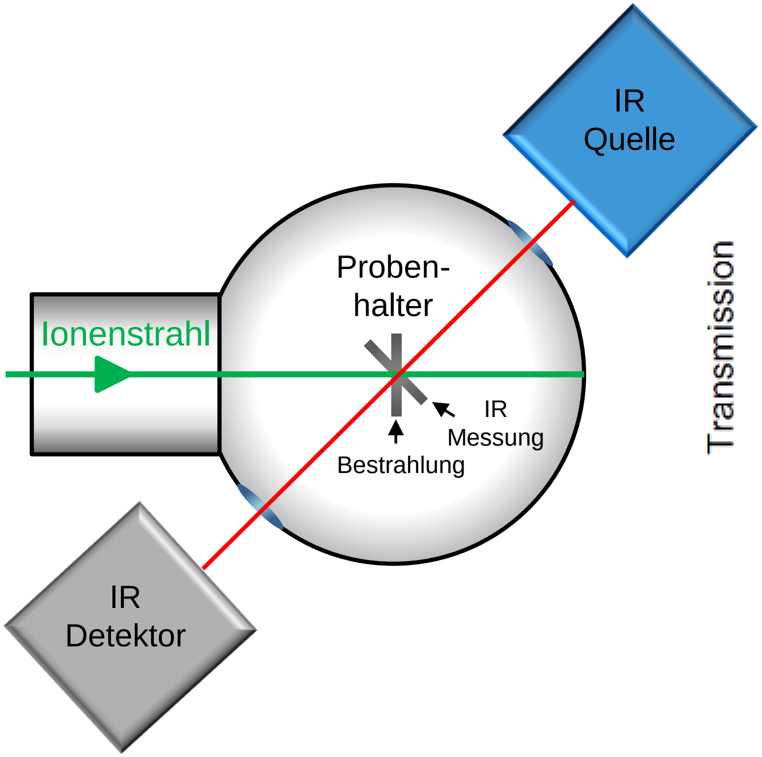
Task	Year 1				Year 2				Year 3				Year 4			
	Q1	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*	*Q1*	*Q2*	*Q3*	*Q4*
17.1		M														
17.2							M						D			
17.3									M							D
17.4												M		D		
17.5																M
1.4				M				D								

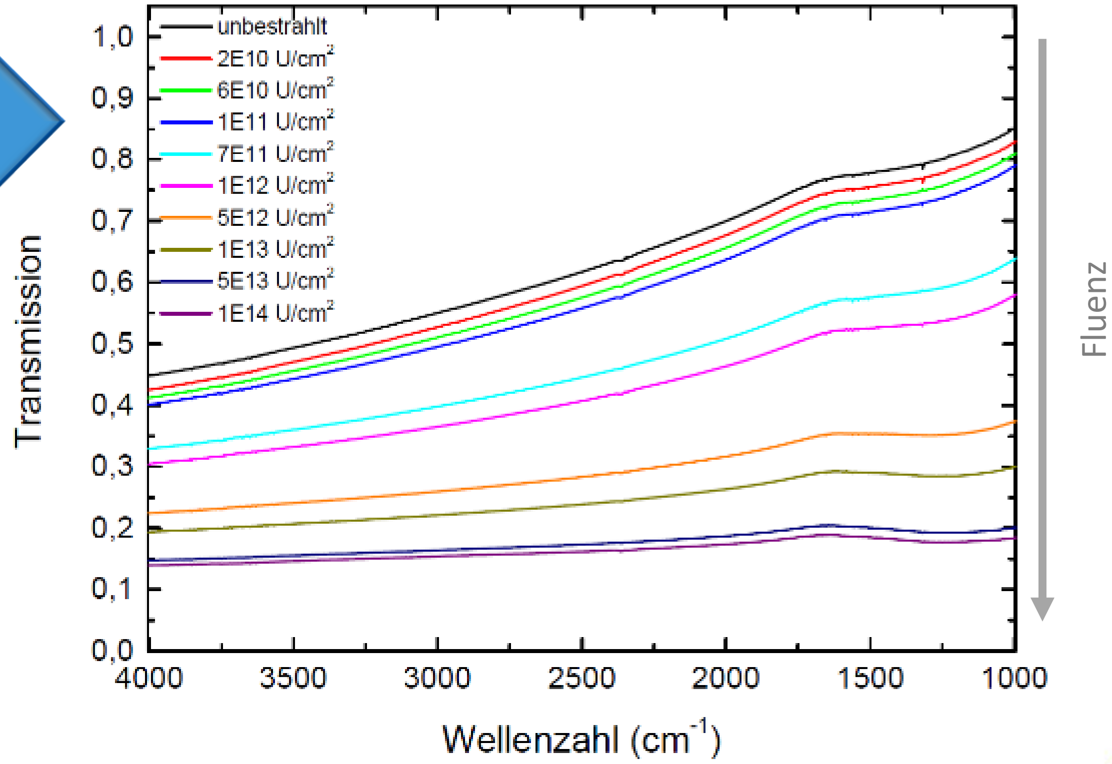
Task 17.1 Coordination and Communication

Coordinators: A. Bertarelli, CERN; **M. Tomut, GSI**

- **Coordination** of JRA tasks, **interface** with other work packages (specifically WP14), public outreach, knowledge transfer etc.
- **Budget management**
- **Monitoring task progress**. Adherence to milestones and timely **reporting of deliverables**

Irradiation tests with online monitoring of properties evolution (GSI)

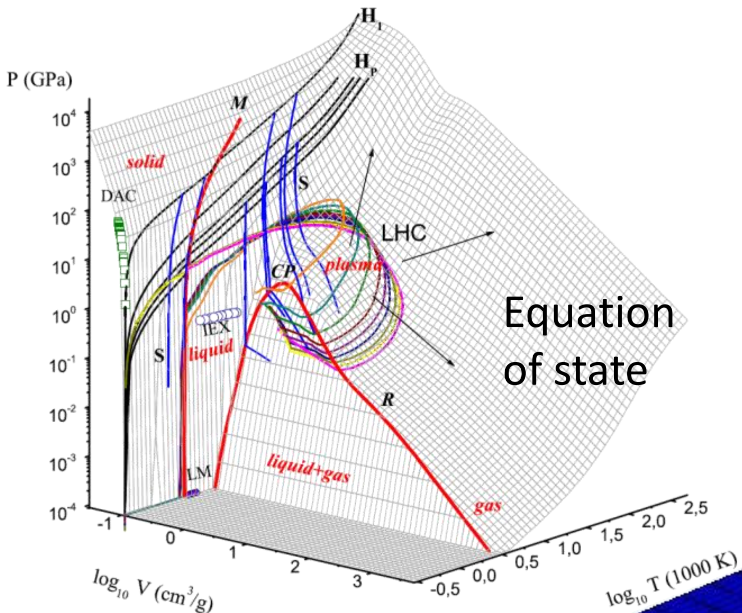




sp^3 → sp^2

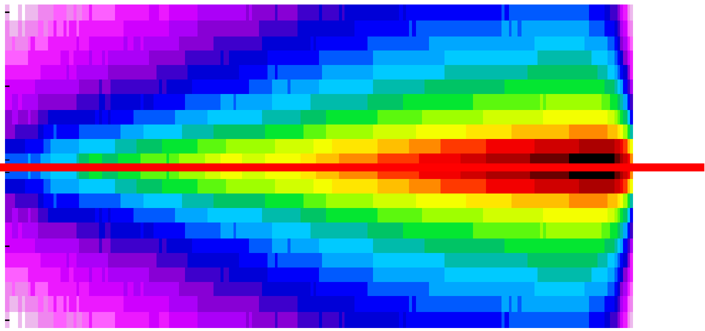
ARIES

Hydrodynamic simulations of experiments - EOS, spall strengths for new materials



Equation of state

Energy deposition



Particle beam