Collimator Materials for High Density Energy Deposition

Adriana Rossi on behalf

ColMat-HDED

LHC Collimation Project CERN

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

Outlook

- EuCARD2 for materials: collaboration
- A brief overlook on accelerators
- Motivation of material studies and methodology

ColMat-HDED collaboration and beyond

- ColMat-HDED partners

- Partnership agreement with CERN (KN2045)

BREVETTI BIZZ

- Collaboration CERN with US-LARP

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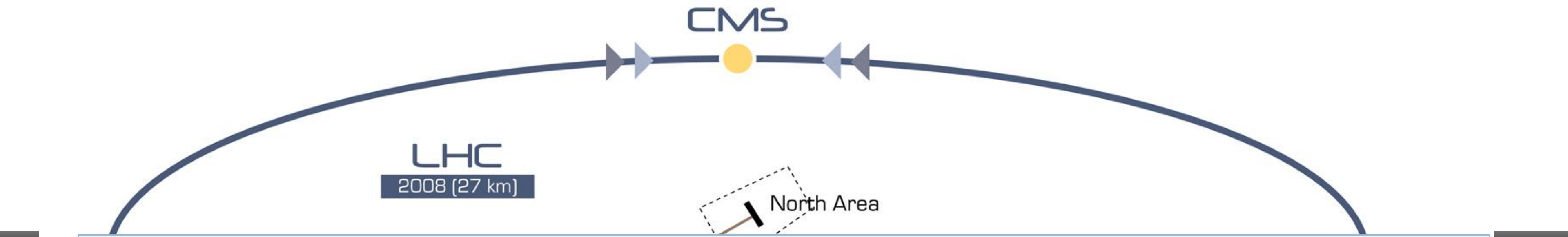


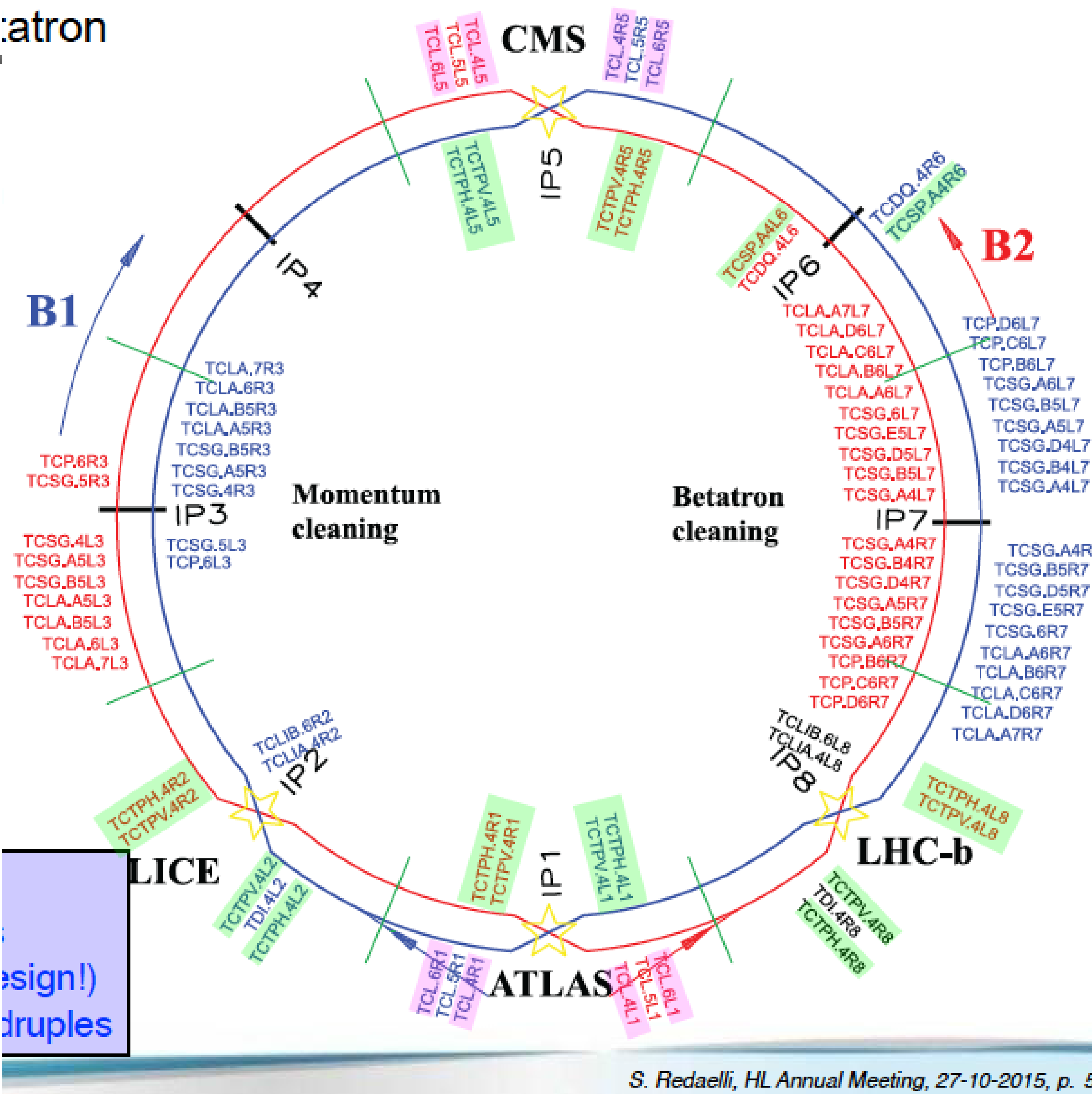
- Our goal is to investigate the dynamics and structure of matter.
- To study the collisions of quarks with each other, scientists resort to collisions of nucleons, which at high energy may be usefully considered as essentially 2-body interactions of the quarks and gluons of which they are composed.
- We accelerate charged particle beams to extremely high energy, in a confined way and make them collide.
- Particles travel in a ultra-high vacuum tube and are guided by magnetic fields (in the LHC SC magnets)

LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF-3 Clic Test Facility CNGS Cern Neutrinos to Gran Sasso ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight

EuCARD²

LHC



- LHC beam energy density up to 15 GJ/mm²
- Collimation system to ‘clean’ beam halo (regular losses)
- Protect machine (accidental losses)
- Beam dump

Robustness

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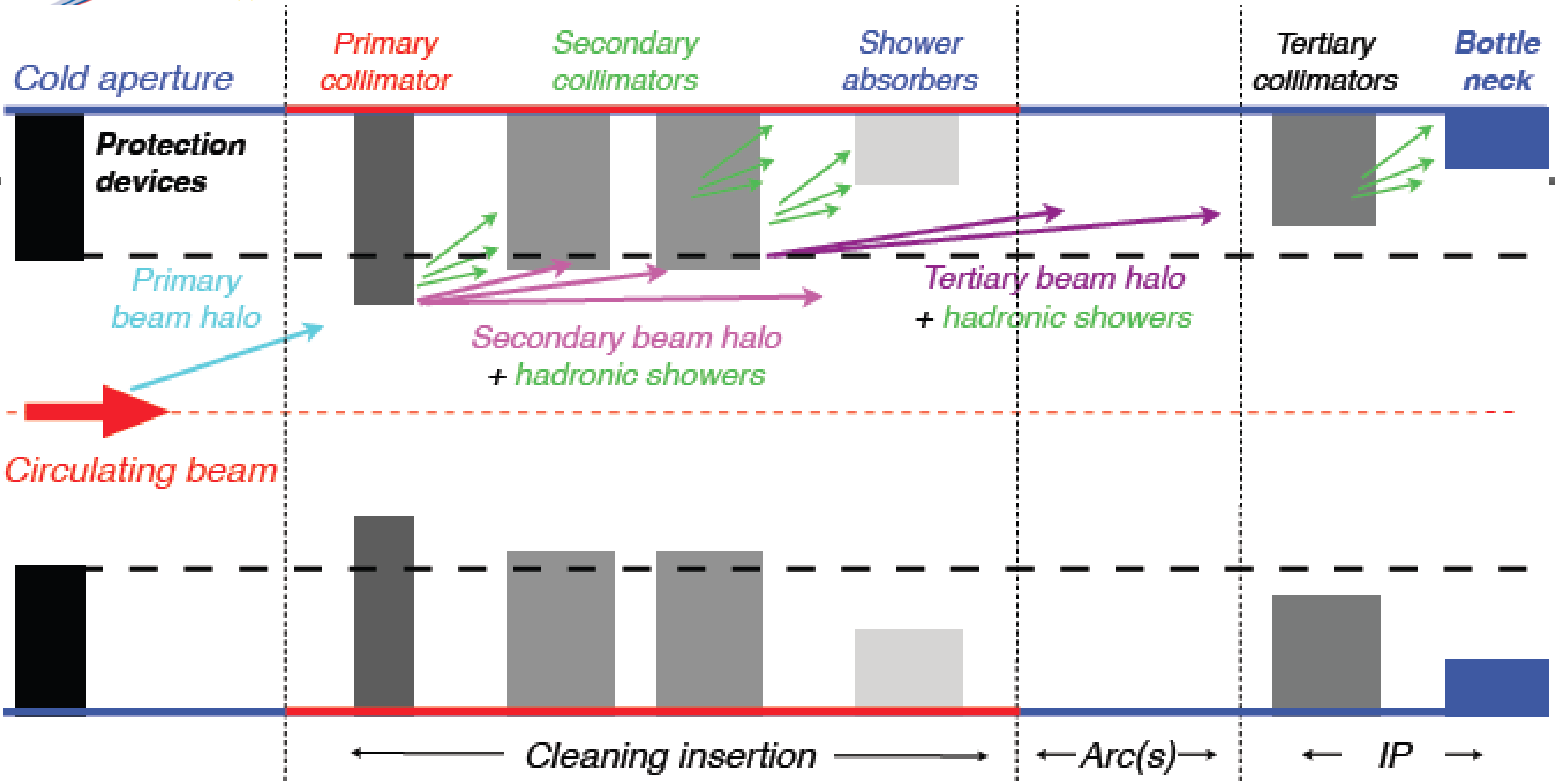


Including protection devices, a **5-stage cleaning** in required!

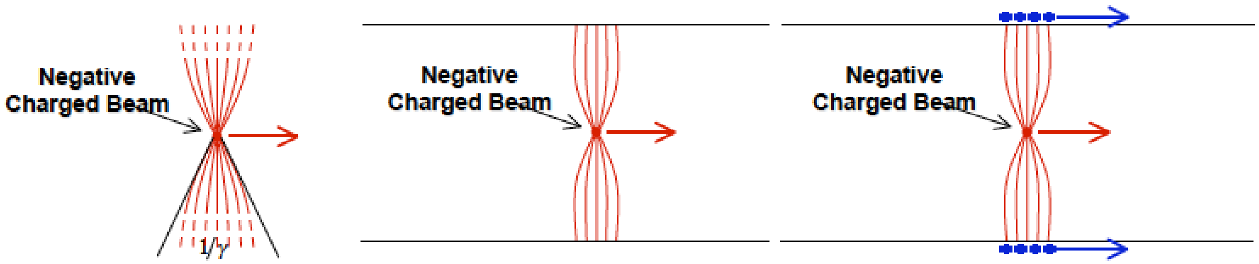
The system performance relies on achieving the well-defined **hierarchy** between collimator families and machine aperture.

Impedance:

Impedance in Accelerator Physics is a quantity that characterizes the self interaction of a charged particle beam, mediated by the beam environment

- In the lab frame, the EM field of a relativistic particle is transversely confined within a cone of aperture of ~ $1/\gamma$
- Particle accelerators operate in an ultra high vacuum environment provided by a metal *vacuum chamber*
- By Maxwell equations, the beam's E field terminates perpendicular to the chamber (conductive) walls
- An equal image charge, but with opposite sign, travels on the vacuum chamber walls following the beam

Image from a US Particle Accelerator School: William A. Barletta



- As long as image current travels at c, forces cancel out
- Resistive walls slow image current =>> wakefield interacts with beam and modifies particle motion
- Need of low impedance materials

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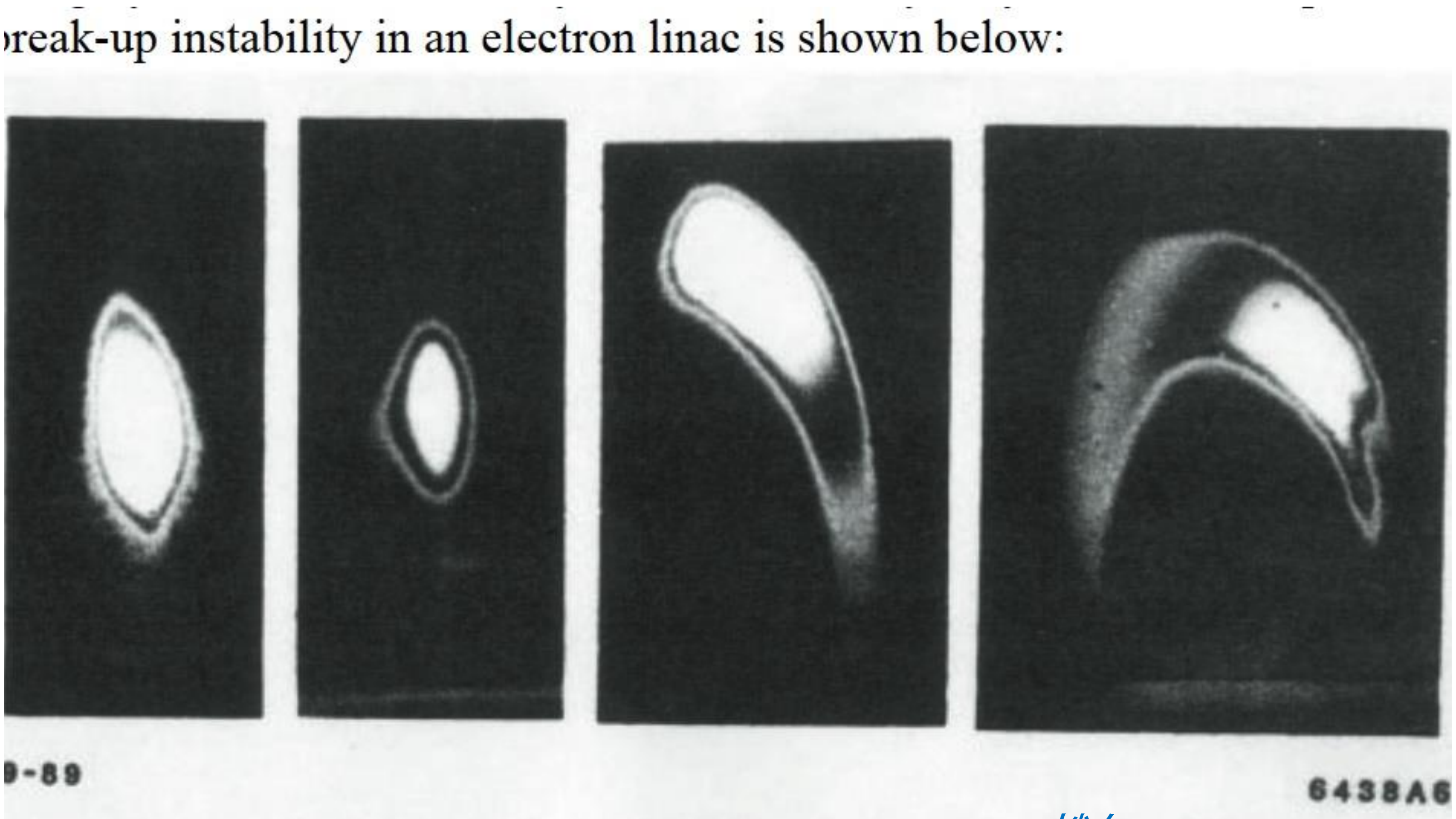
Beam instability

- Instability could be driven by impedance (amongst all different causes)



From: Collective Instabilities in Accelerators Alex Chao 趙午
OCPA School 2010

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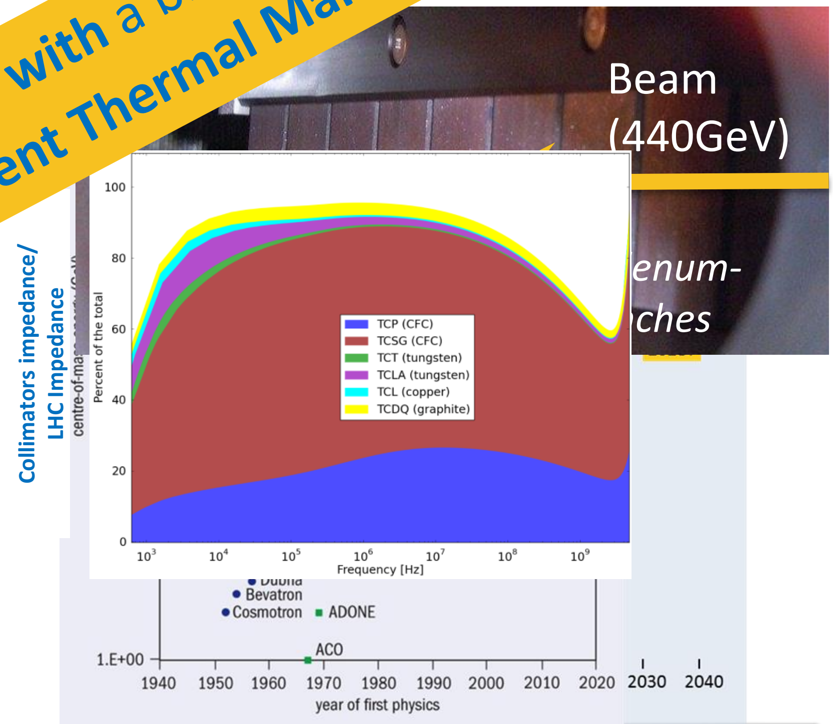
Motivations

- Accelerator performance with ever increasing beam brigh[…]ess and stored energies pushes **material requirements for co[…]s** into more challenging grounds: Collimators (and all B[…]ing Devices) are inherently exposed to extreme […]
  - Higher **robustness** (LHC beam energy density up to 15 GJ/mm^2, 2-3 orders > oth[…] machines).
  - Lower **impedance** […]ive, by far, the hig[…]o machine i[…]ially leading to se[…]ities.
  - Large[…] to radiation (1E16 p/[…]ses in LHC betatron cleaning insertion)
  - **Higher absorption** (clean efficiency for machine protection)

Many requirements shared with a broad range of applications requiring efficient Thermal Management



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Material studies

Experimental:

- Material characterisation (pristine)
- Irradiation
- Beam impact
- Thermo-mechanical tests

Thermo-mechanical and beam simulations

Radiation damage simulations

Material studies

- Materials being investigated are **Copper-Diamond (Cu-CD)**, **Molybdenum-Diamond (Mo-CD)**.
- **Molybdenum-Graphite (Mo-Gr)** is particularly appealing for it can be coated with a Mo layer dramatically increasing electrical conductivity , easily machined, has better thermal properties …
- R&D program still ongoing to further improve physical properties, particularly mechanical strength of **Graphite.**

High-Z Collimators

Low-Z Collimators

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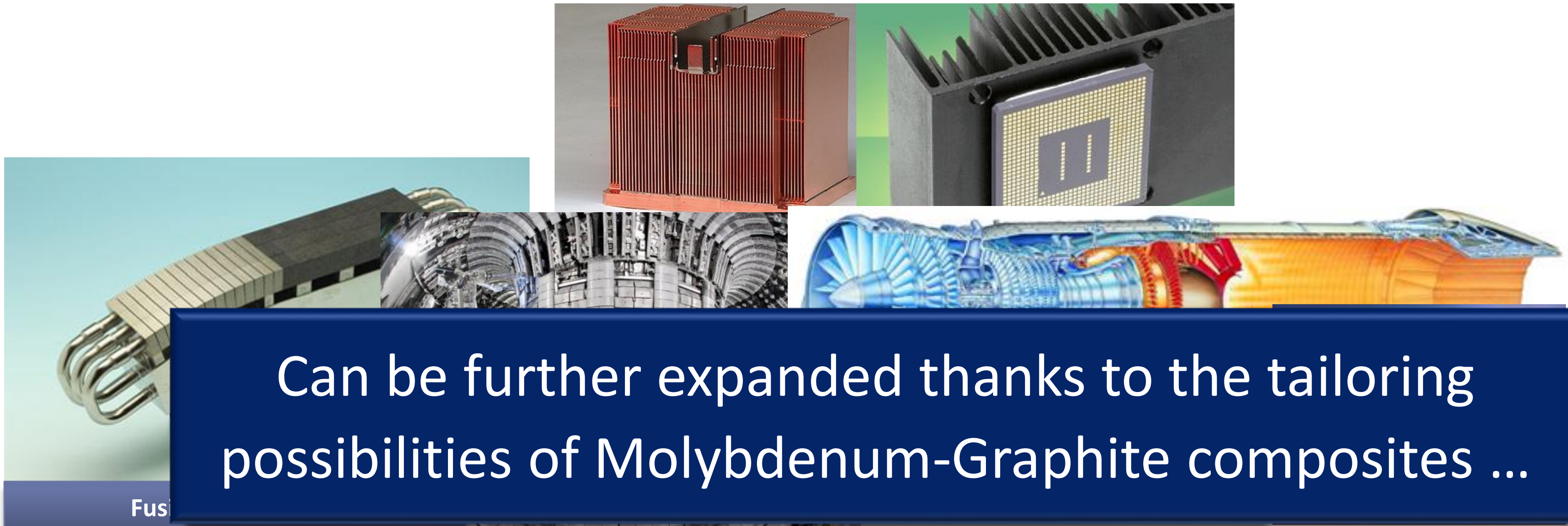
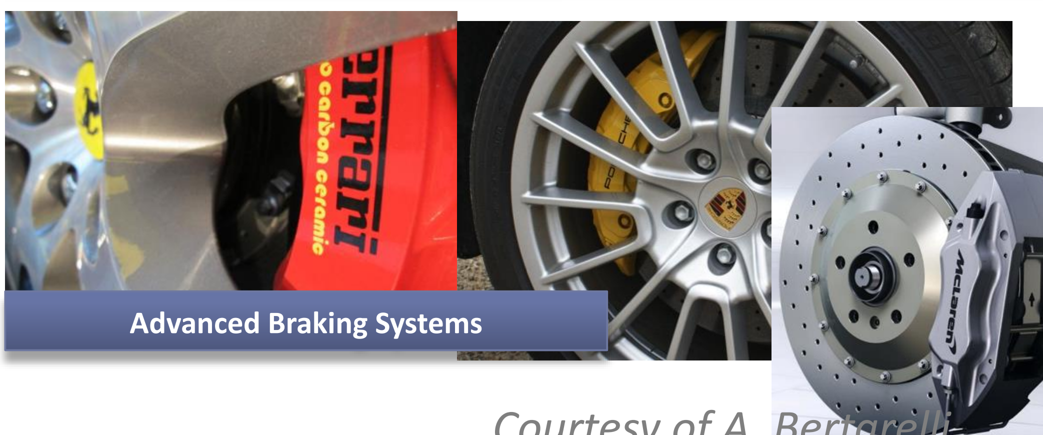
Potential range of applications outside accelerators



Can be further expanded thanks to the tailoring possibilities of Molybdenum-Graphite composites …



Courtesy of A. Bertarelli

Later presentation will show methodology and results

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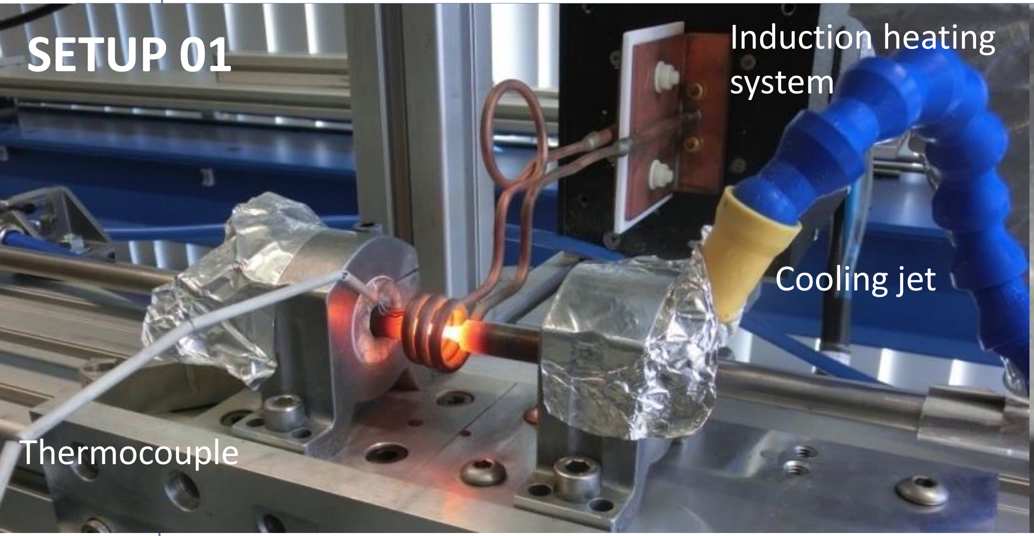
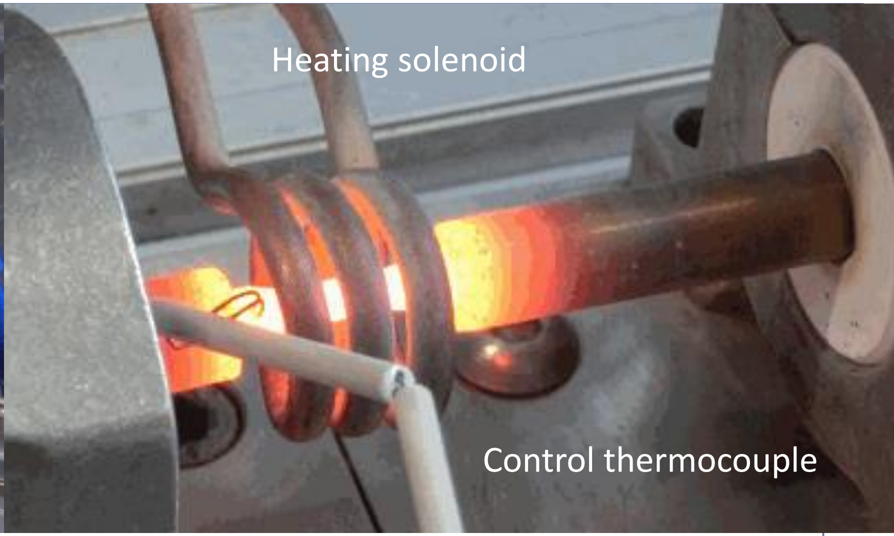
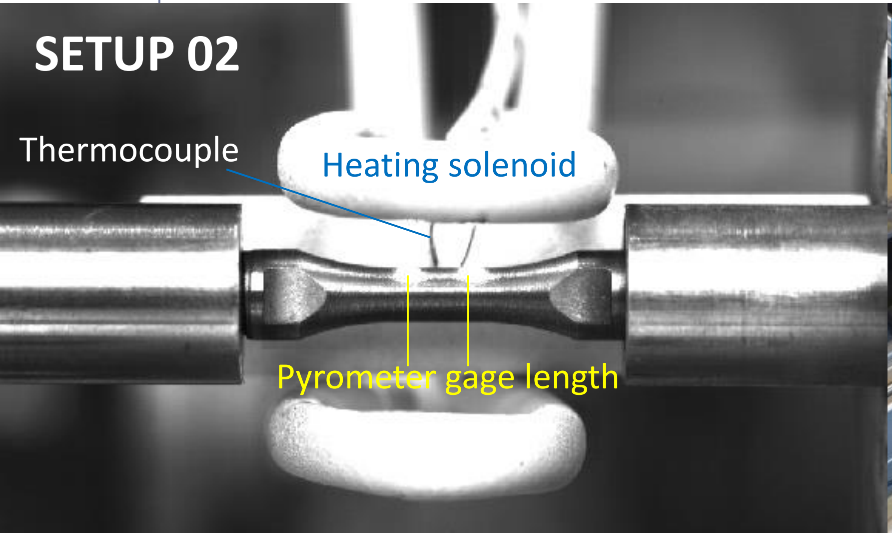
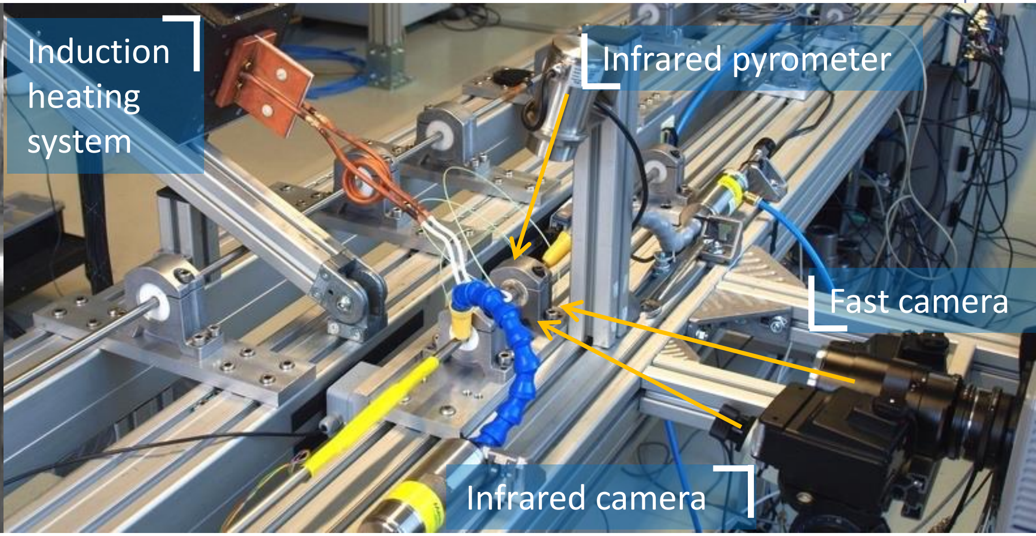
Back up slides







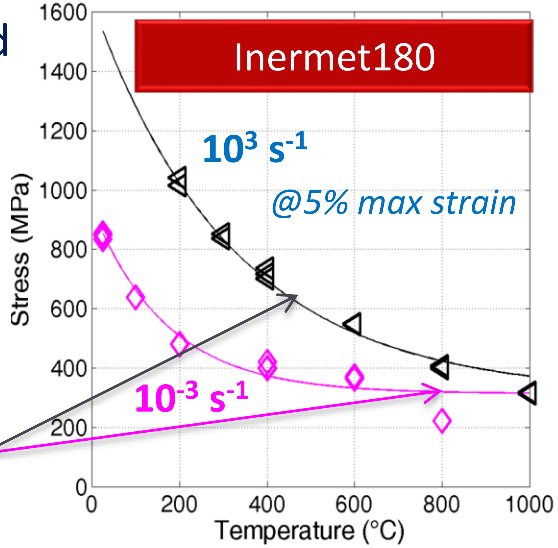


Experimental setup

Mechanical characterization – Dynamic

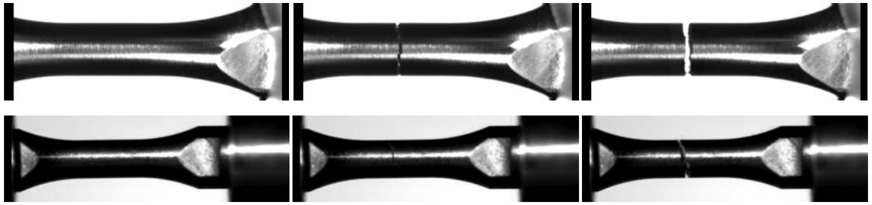
- At **Politecnico di Torino**, dynamic measurements performed to determine the **effects of temperature and strain rate on the material behaviour**
- Characterization of metallic alloys with the Split-Hopkinson bar experimental setup:

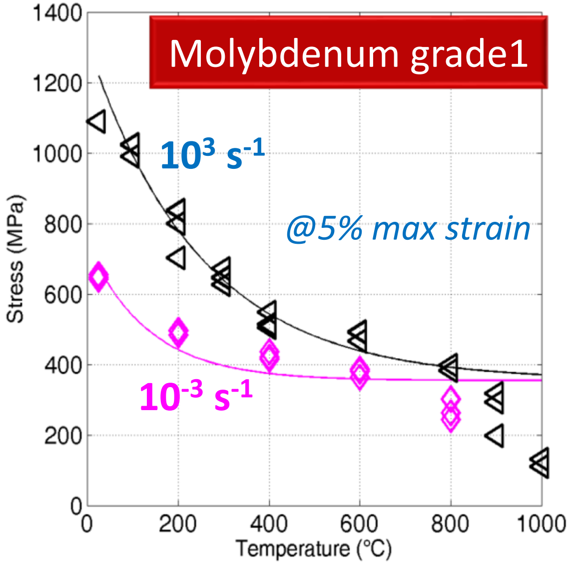
Constitutive models to be used to predict material behaviour under extreme conditions (high strain rate, high temperature)



IT180

Mo



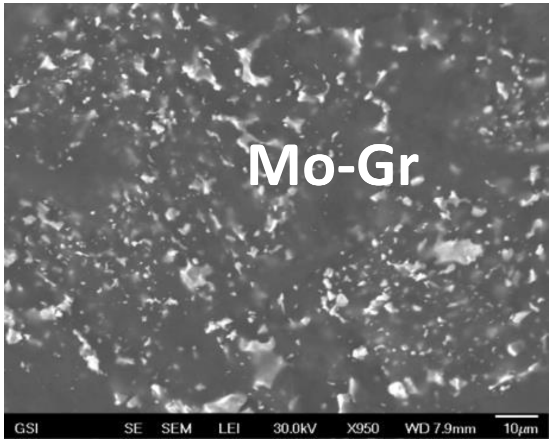


L. Peroni (POLITO)

Irradiation tests @GSI

- Irradiation tests to study ion-induced modifications with ion fluencies and perform.

Microstructural studies – SEM



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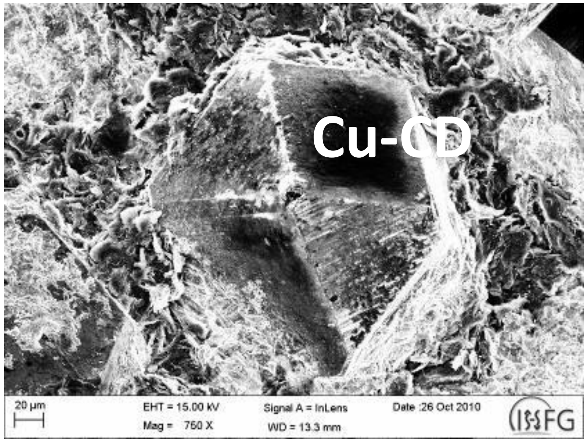

RHP TECHNOLOGY

Courtesy of M. Tomut

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Experimental characterisation

- GSI irradiation tests with swift heavy ions

In-plane and transverse **MoGr** samples irradiated at ≈ Bragg peak energy with Au ⟶ U ions, with doses from 1E11 to 5E13 ions/cm^2.

- All investigation methods (Laser Flash Method, Raman Spectroscopy, SEM, X-ray diffraction) show better stability if samples annealed prior exposure (so far 1150°C and 1300°C - 1800°C yet to be measured).
- There seem to be a threshold dose for damage (to be understood).
- Maximum irradiation dose should not be reached at LHC.
- Irradiation above ion track formation.

At higher accumulated doses the transverse samples are deforming, whereas the in-plane samples experience no change of the shape. Optimization of radiation hardness of these samples has been done by pre-irradiation annealing.

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After 5.10^{13}ions/cm^2 – Au 5.9 MeV/u Transverse cut

Courtesy of M. Tomut (GSI)

- All 3 grades exposed to 5.10^{13} Au ions/cm^2 broke due to beam induced deformation.
- At 2.10^{13} Au ions/cm^2 samples show different degree of deformation, depending on the C fiber content.
- Analysis is ongoing

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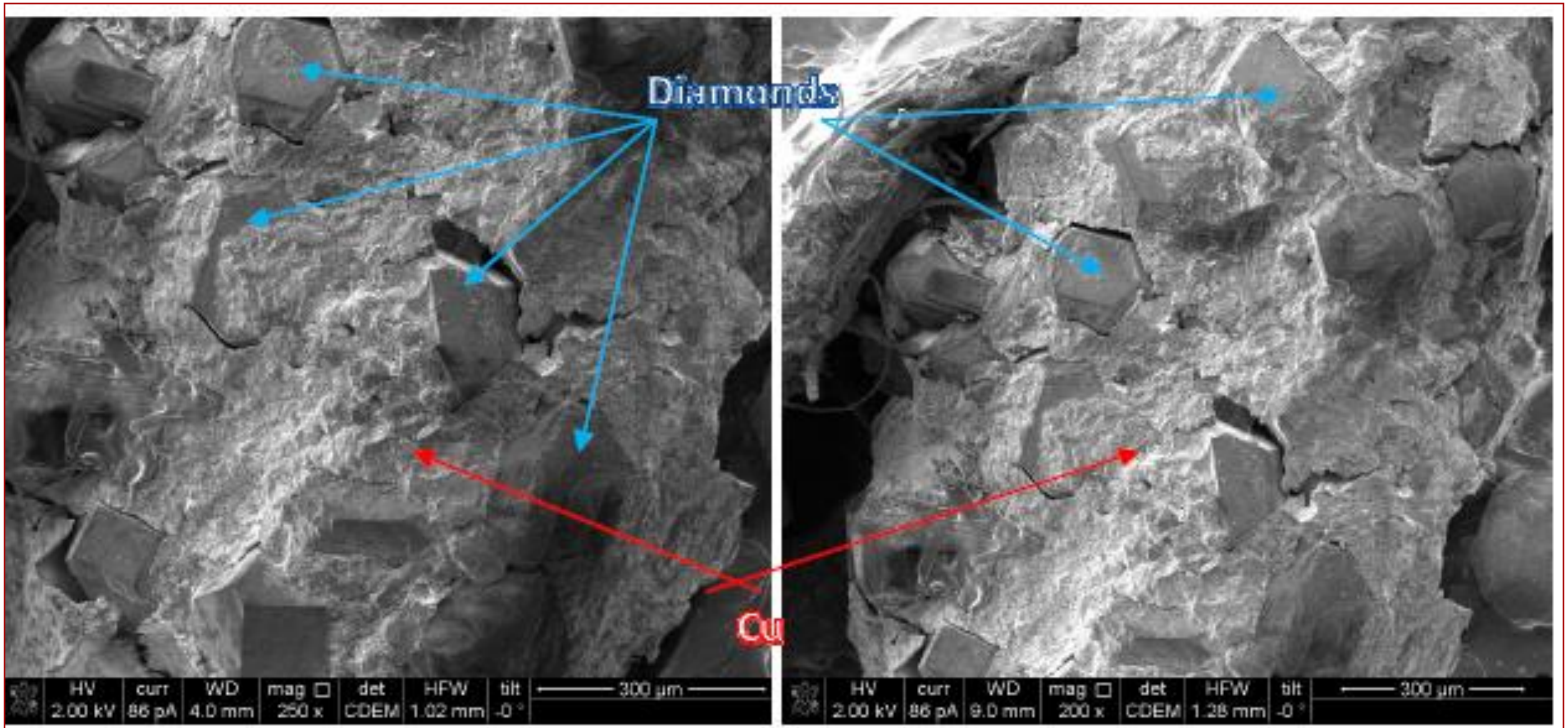
Irradiation tests @ NRC-KI

SEM images of the Cu-CD composite after p+ irradiation at 30 MeV and dose of 10^{17}p/cm^2 with (a) – high and (b) – low magnifications



(a) (b)

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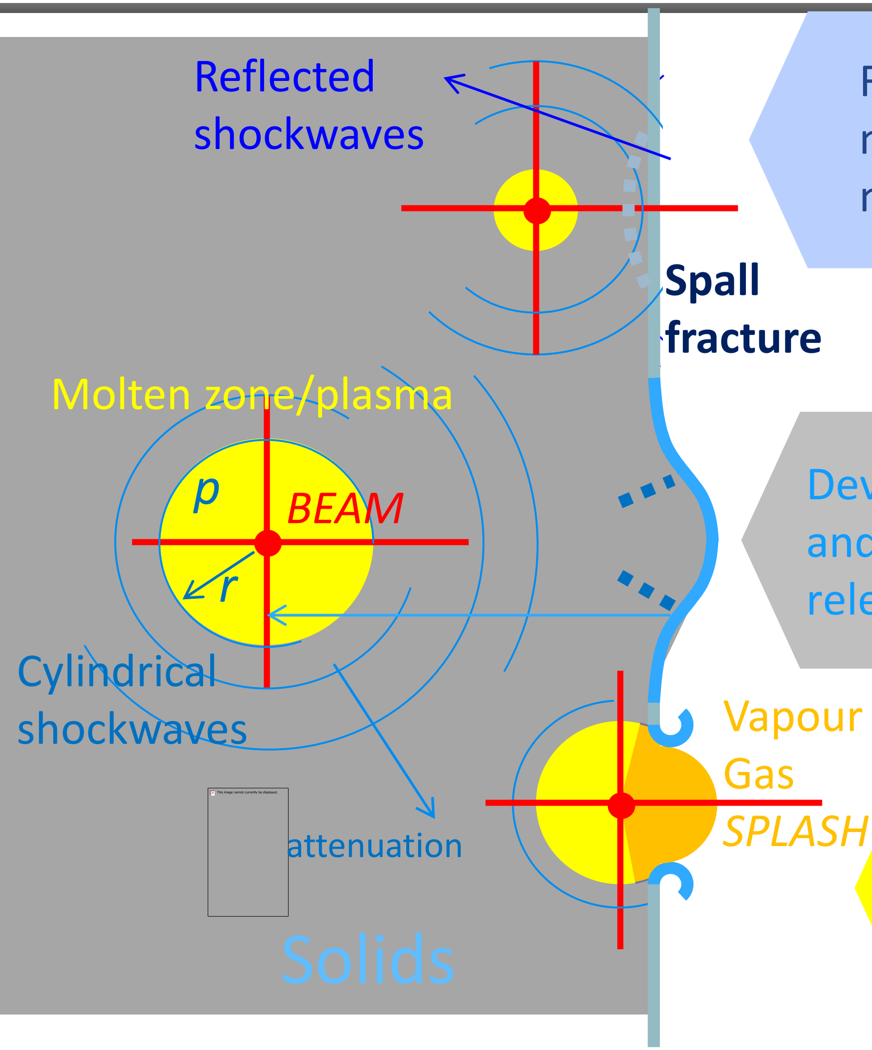
Studies @POLITO

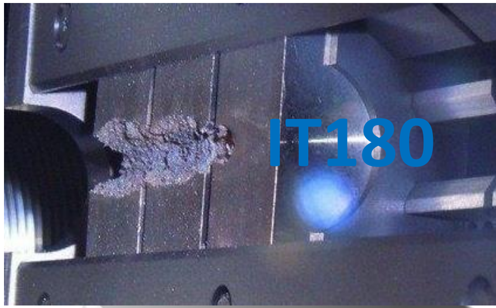
POLITECNICO DI TORINO
DIMEAS



Fracture analysis of novel composites materials

Development of strength and failure models for relevant materials

Contributions to the development of Equations of State for relevant materials



Courtesy of L. Peroni

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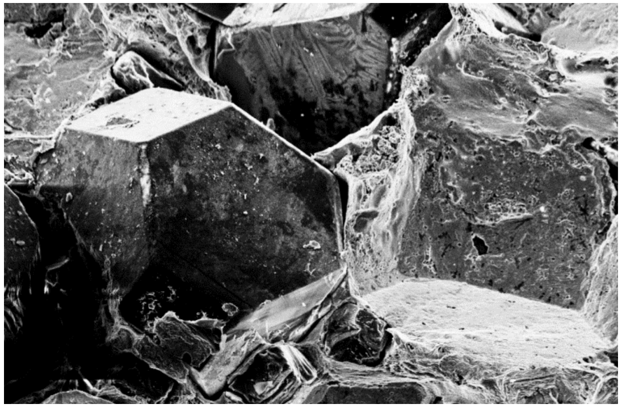
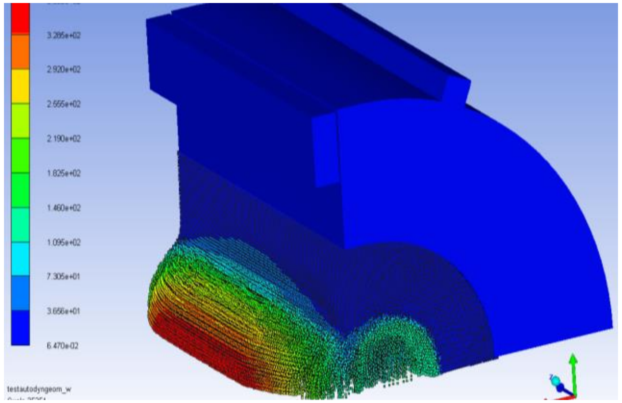
Extract of A. Beratrelli's slide

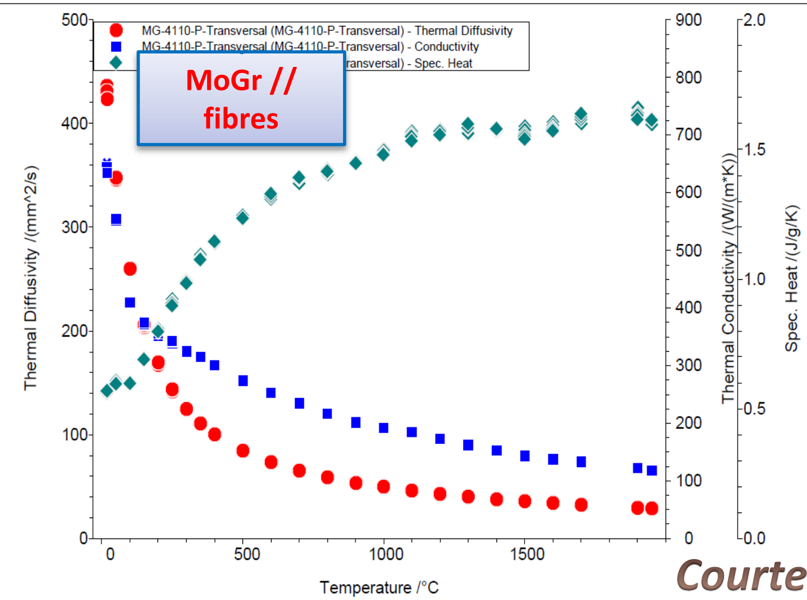
- **Novel, composite materials** are under development to meet these challenges.
- New sophisticated and powerful **numerical tools** (**Hydrocodes**) are used to simulate accidental events.
  Limitations exist as to material constitutive models.

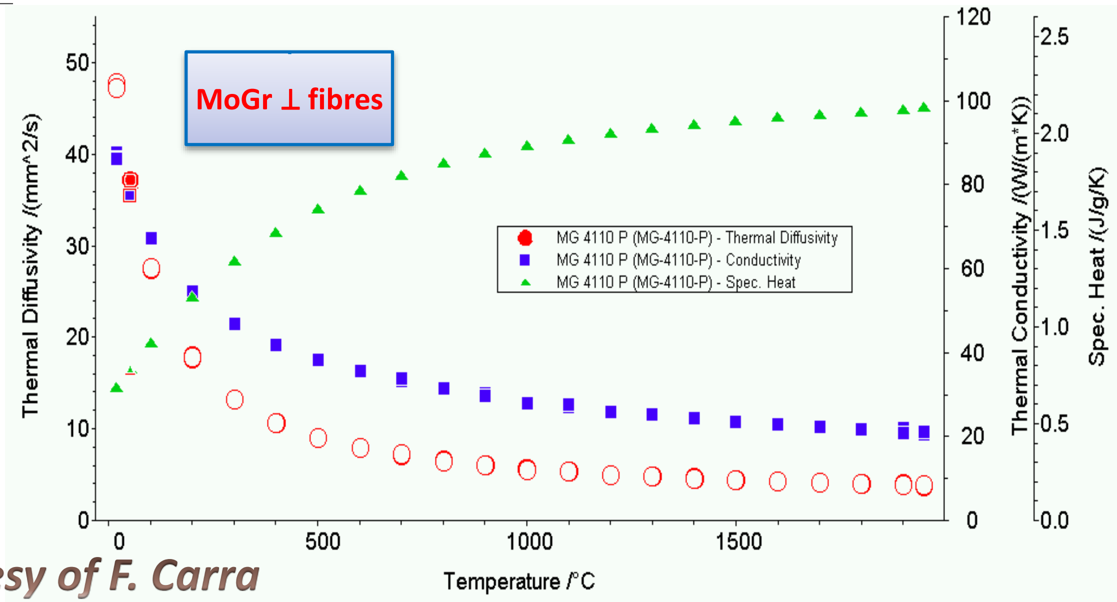




Thermo-mechanical measurements @CERN

- **State-of-the-art machines** purchased by CERN to measure thermal properties of advanced materials
- **Temperature range**: T_{room} up to **2000 ˚C** (lower limit **-180 ˚C** with ad-hoc setup)
- **Laser-Flash**: thermal diffusivity, specific heat and thermal conductivity
- **Dilatometer**: Coefficient of thermal expansion

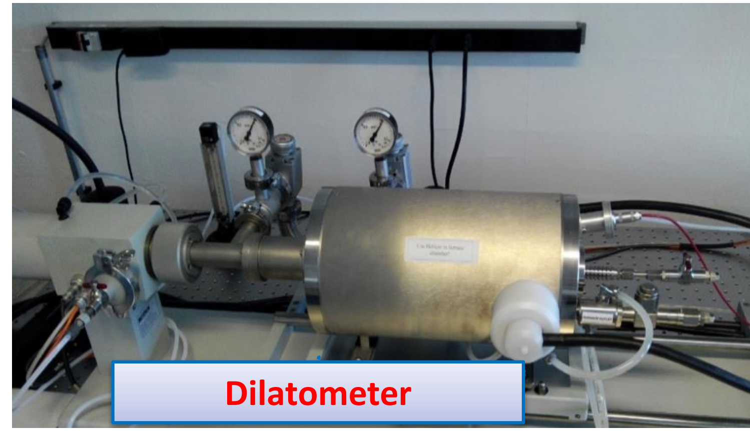


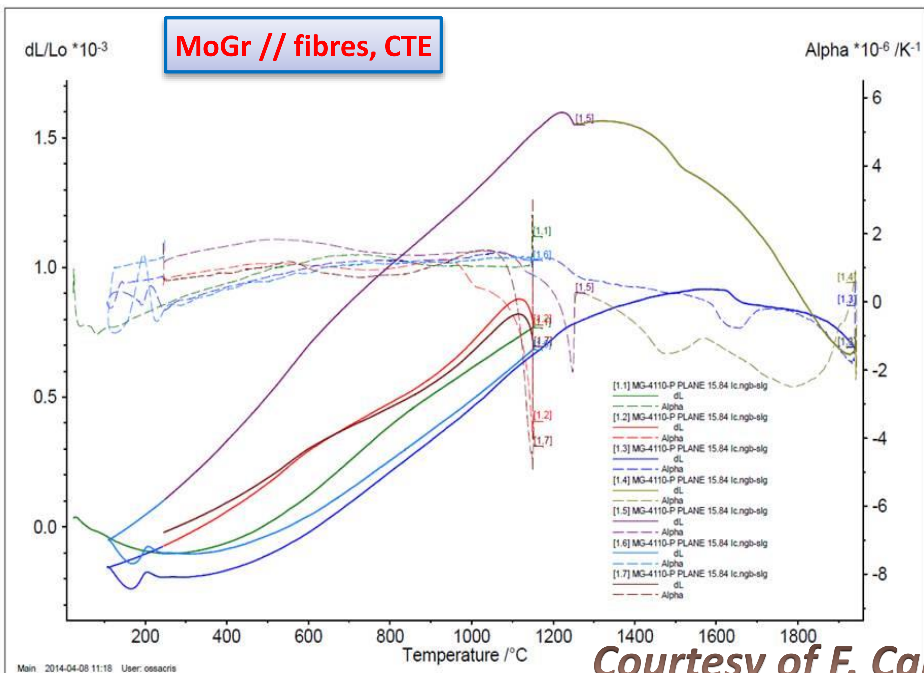


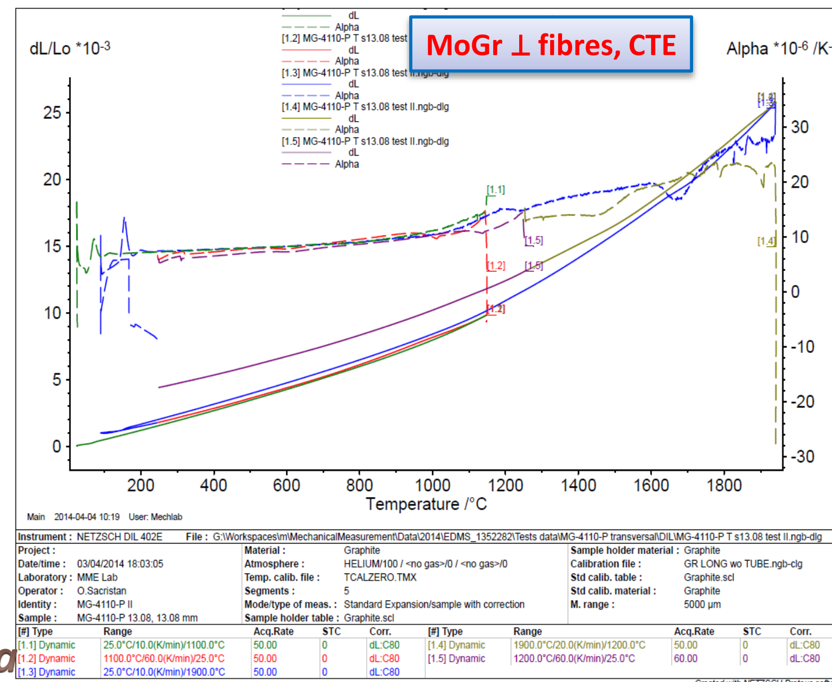
Courtesy of F. Carra

Method to measure material properties @CERN

- **CTE measurements: measurements performed in the two directions, after heating/cooling cycles**
- **Dotted lines: CTE**
- **Continuous lines: linear expansion**







Courtesy of F. Carra

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