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Engineering Department

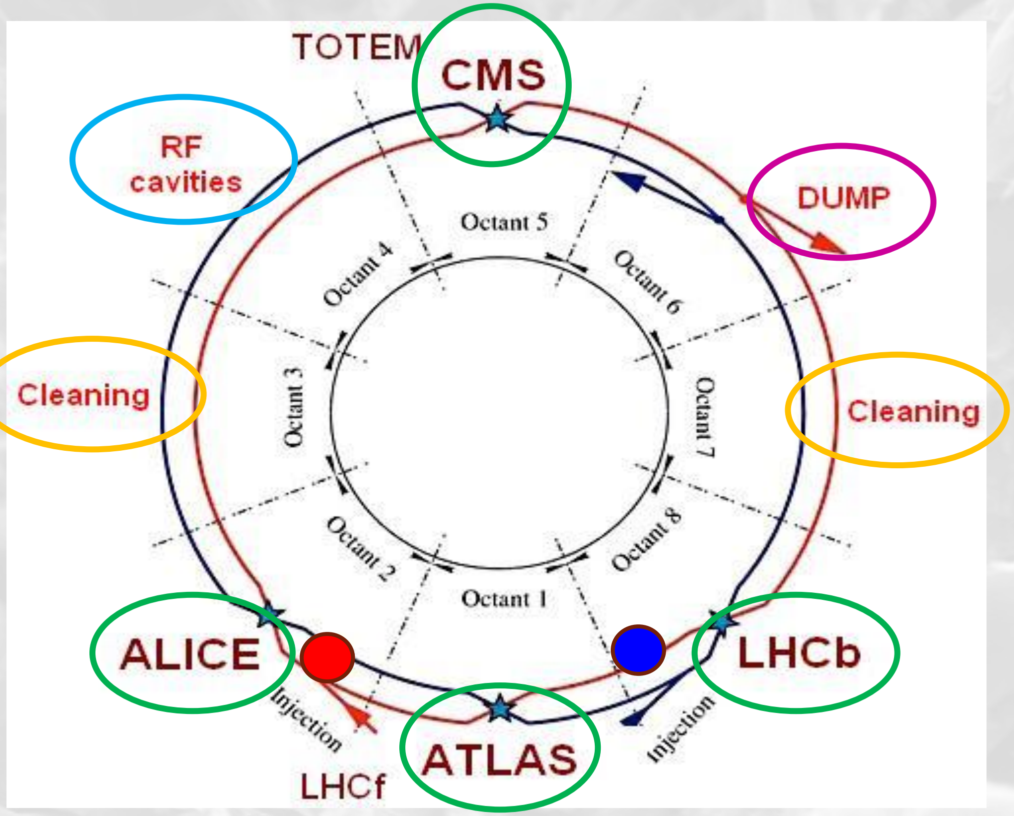
Innovative Ceramic Matrix Composites for Thermal Management: Molybdenum Carbide - Graphite

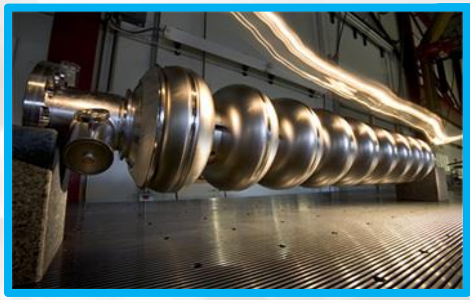
BREVETTI BIZZ

Recipe of the LHC ring

2 Proton beams
NB: bunched and counterrotating!

27 km Circular tunnel
- 8 curve sections (Arcs)
- 8 straight sections (Insertion Regions):
  - 4 Collision points
  - 2 Collimation regions
  - 1 Beam dump point
  - 1 Radio Frequency system





Provide energy to particles
450 GeV – 4 TeV – 7 TeV
(injection) (2012) (design)

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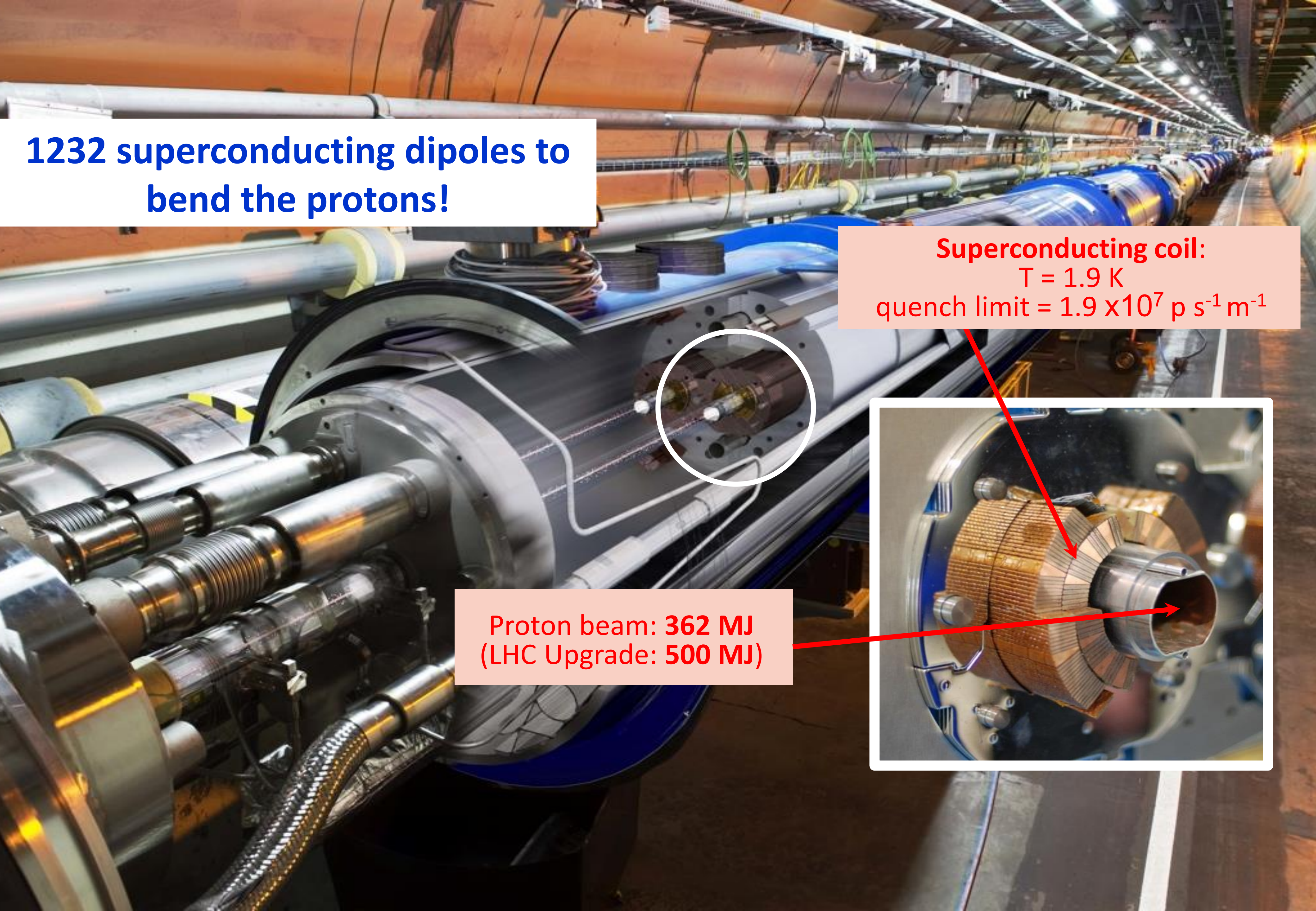

1232 superconducting dipoles to bend the protons!
Superconducting coil:
T = 1.9 K
quench limit = 1.9 x10^7 p s^-1 m^-1
Proton beam: 362 MJ
(LHC Upgrade: 500 MJ)

LHC stored energy challenge

- **LHC** stored energy: **360 MJ** in nominal conditions;
- It will soon reach **500 MJ** (**High Luminosity** upgrade)

1 LHC beam equivalent energy

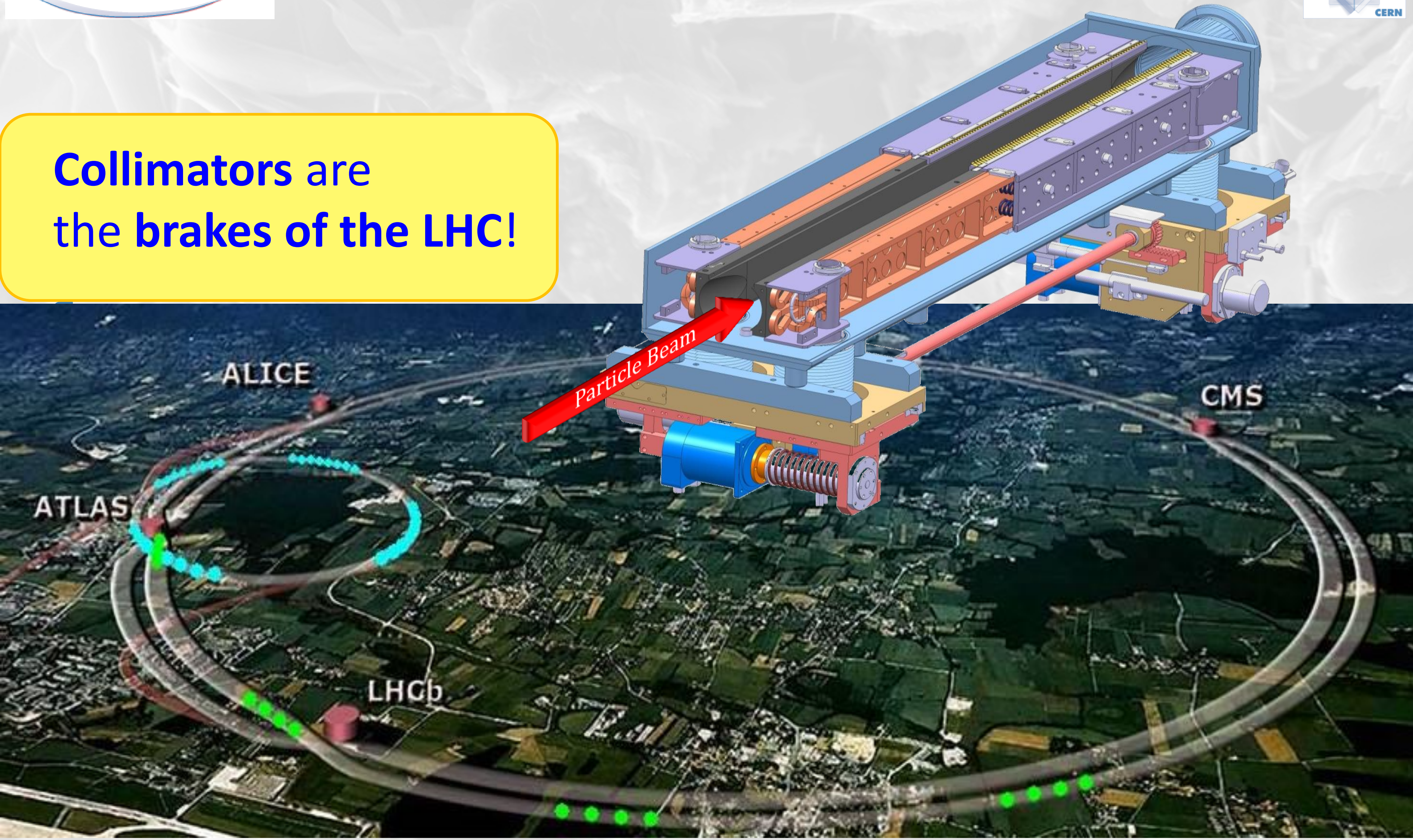
110 kg TNT

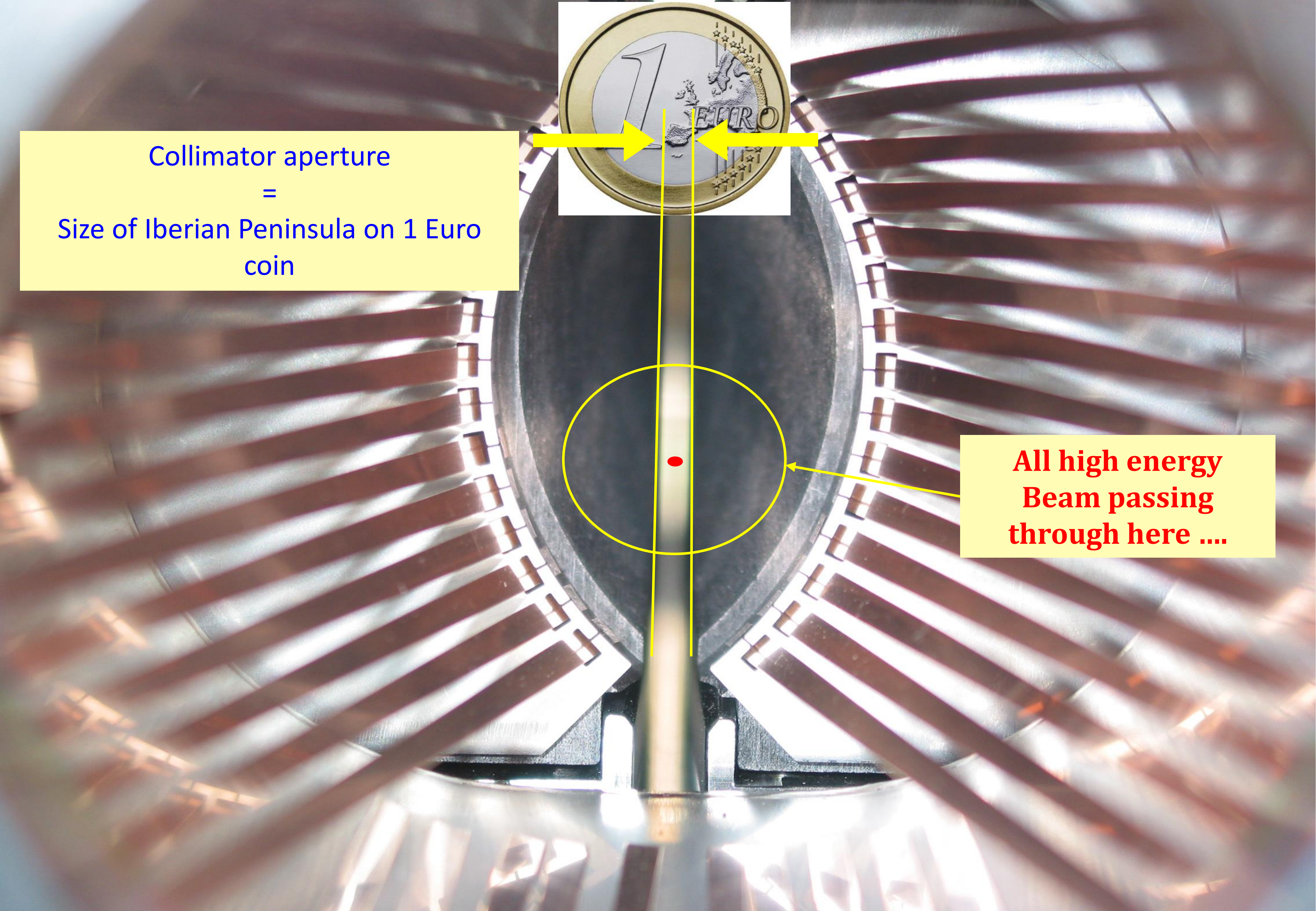
We Need the Best Brakes!

Good brakes allow you to **go faster and safer**!

We Need the Best Brakes!

Collimators are
the **brakes of the LHC**!

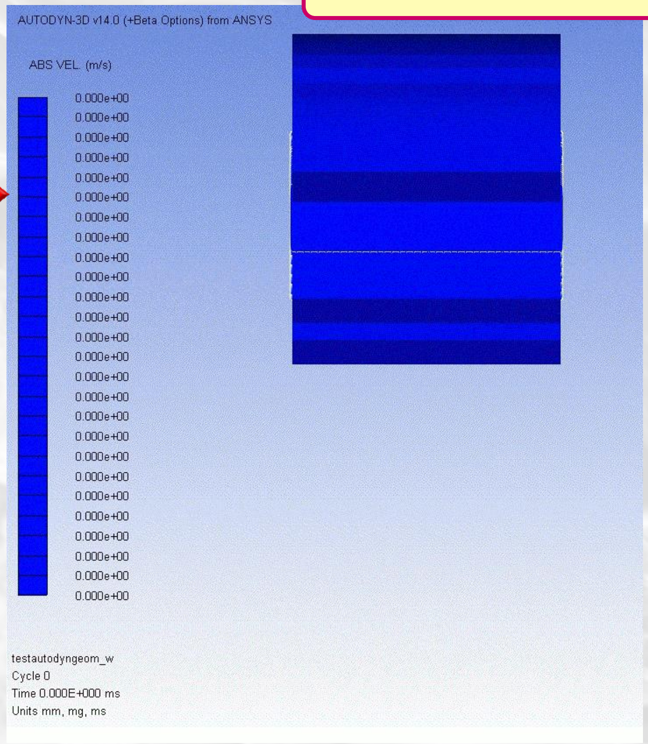



Collimator aperture
=
Size of Iberian Peninsula on 1 Euro coin
EURO
All high energy Beam passing through here ....

Effects of high intensity beam impact

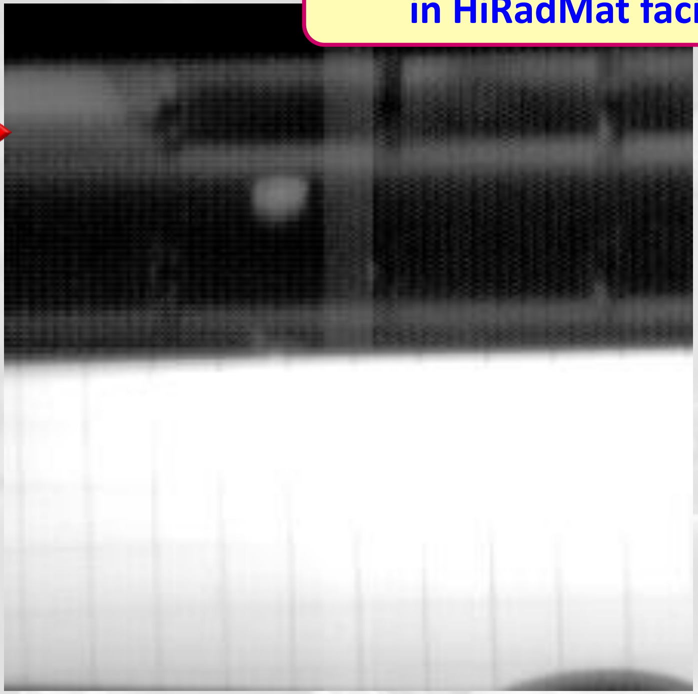
AUTODYN simulation

Beam



High-speed Video Camera in HiRadMat facility

Beam



316 m/s

~275 m/s

Very high challenge:

Fast & energetic phenomena!

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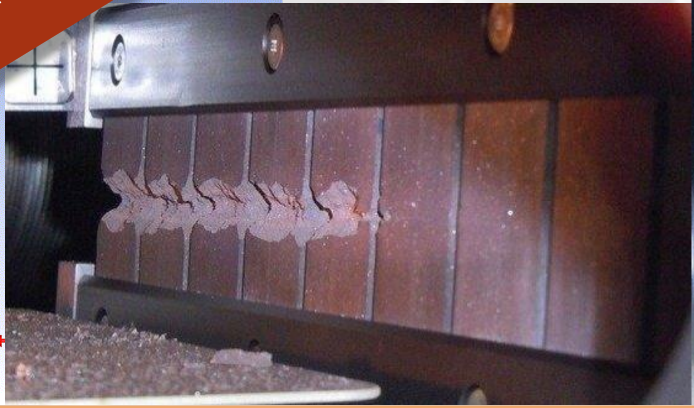
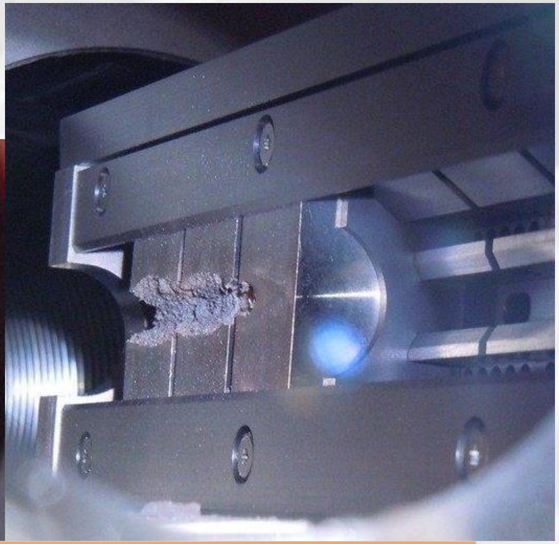
Context

- **Beam-induced accidents** among the most dangerous and sti… xplored events for particle accelerators.
- **Collimators** (and other **Beam Intercepting Devi**… sed to such extreme events.
- Collimators are the highest contribut… **ance**, potentially leading to serious **instabilities**.

Development of Novel advanced materials are instrumental in facing these challenges!





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Material Requirements

- Maximize **Electrical Conductivity**
- Maximize **Thermal Conductivity**
- Minimize **Coefficient of Thermal E…**
- Maximize **Strength** and **D…**
- Maximize **Op… …ure**
- Ens… **…ess**
- … **…rial feasibility** of large components
- Pr…uced at **affordable costs**

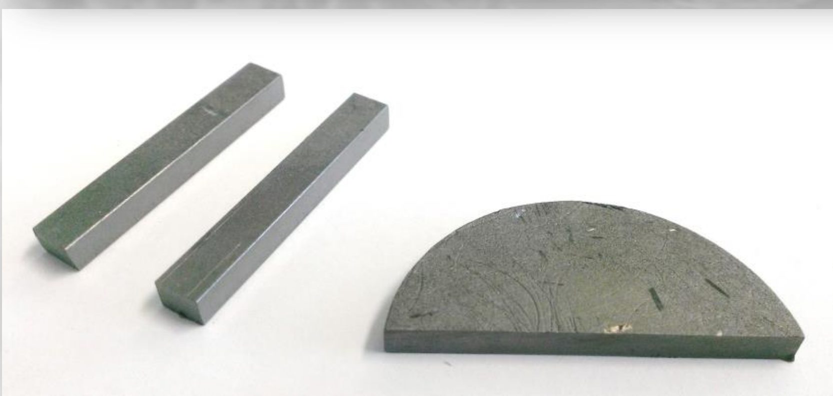
Many requirements **shared with** a broad range of **applications requiring efficient Thermal Management**

Molybdenum Carbide – Graphite (Mo-Gr) Composites

Key Features

- **Very high Melting Point**
- **Low Density**
- **Outstanding Thermal Conductivity**
- **Very low Thermal Expansion**
- **Highly stable** (forms MoC_{1-x} carbides)
- **Good electrical conductivity**
- **Fair Mechanical strength**

Co-developed by CERN and BREVETTI BIZZ



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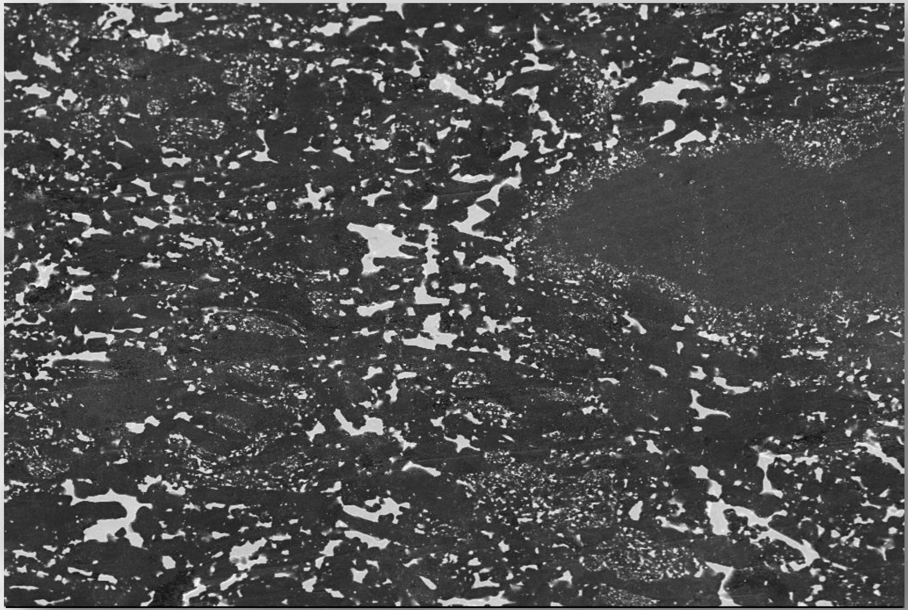
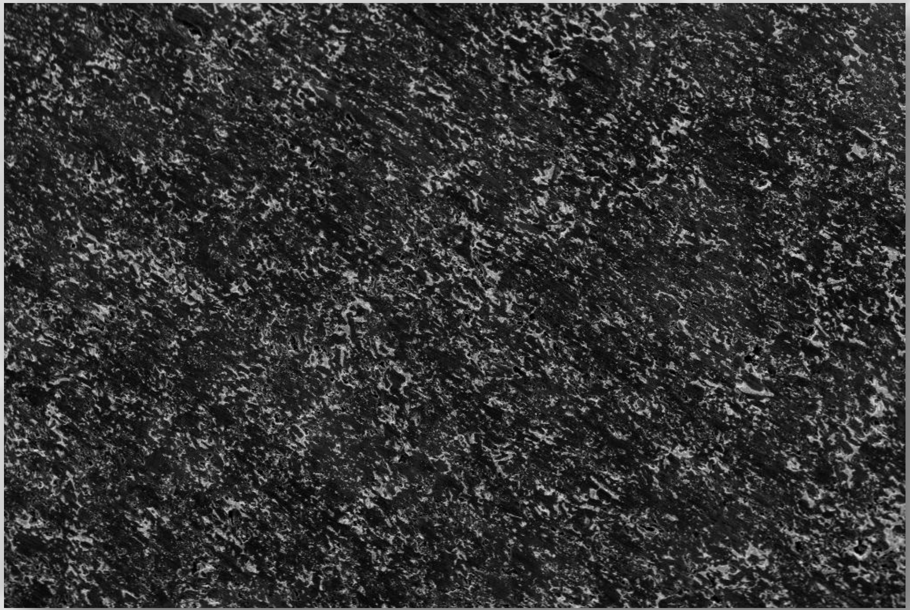
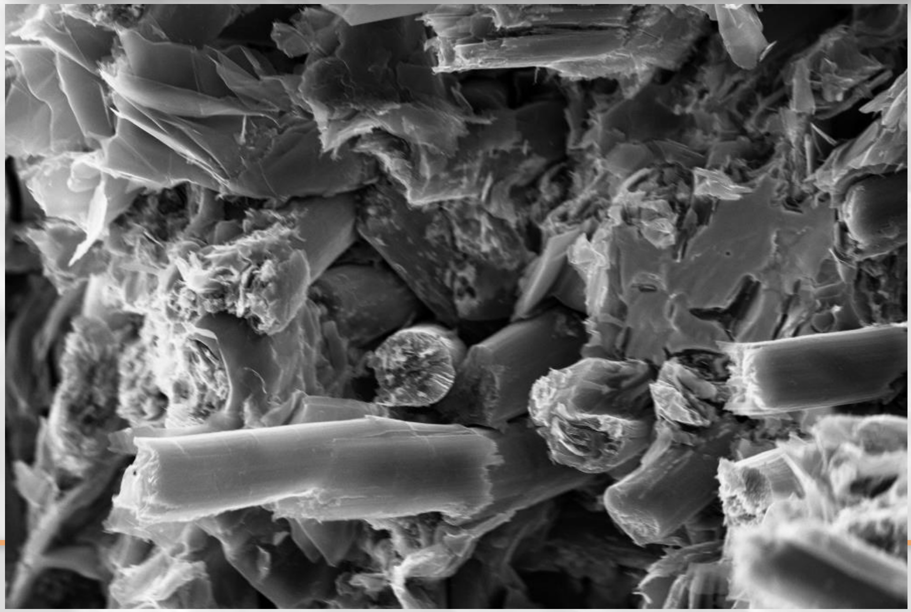
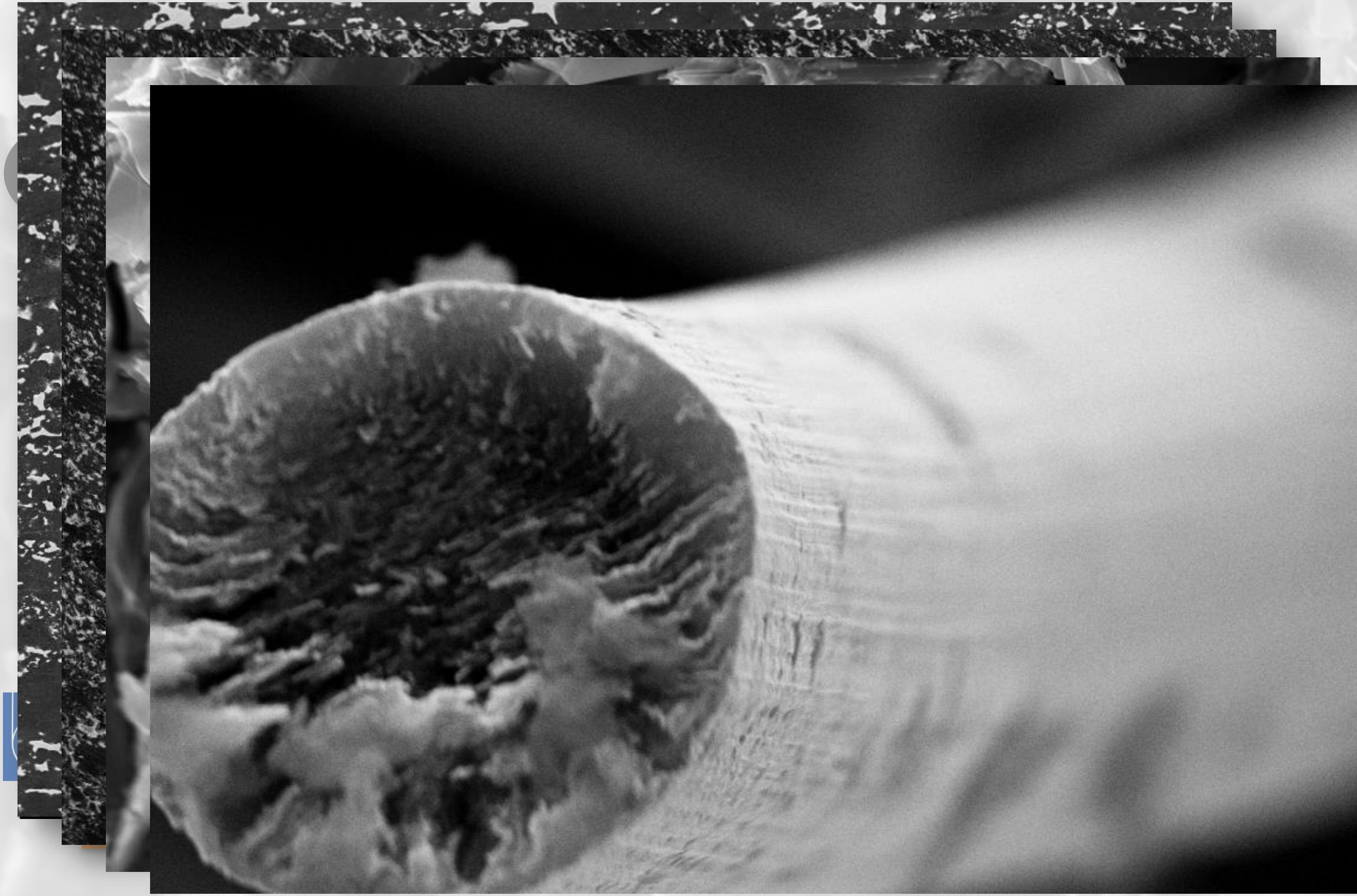
Molybdenun Carbide – Graphite Microstructure







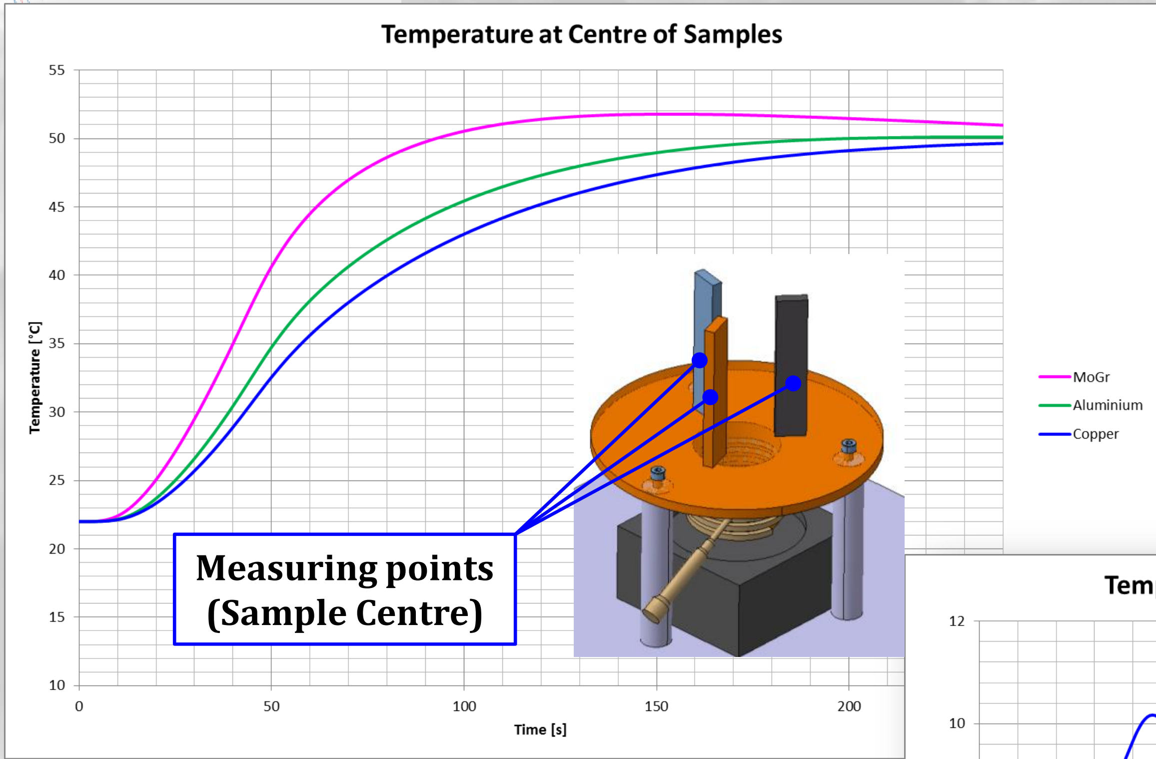
Molybdenun Carbide – Graphite Microstructure



Molybdenum Carbide – Graphite Key Figures

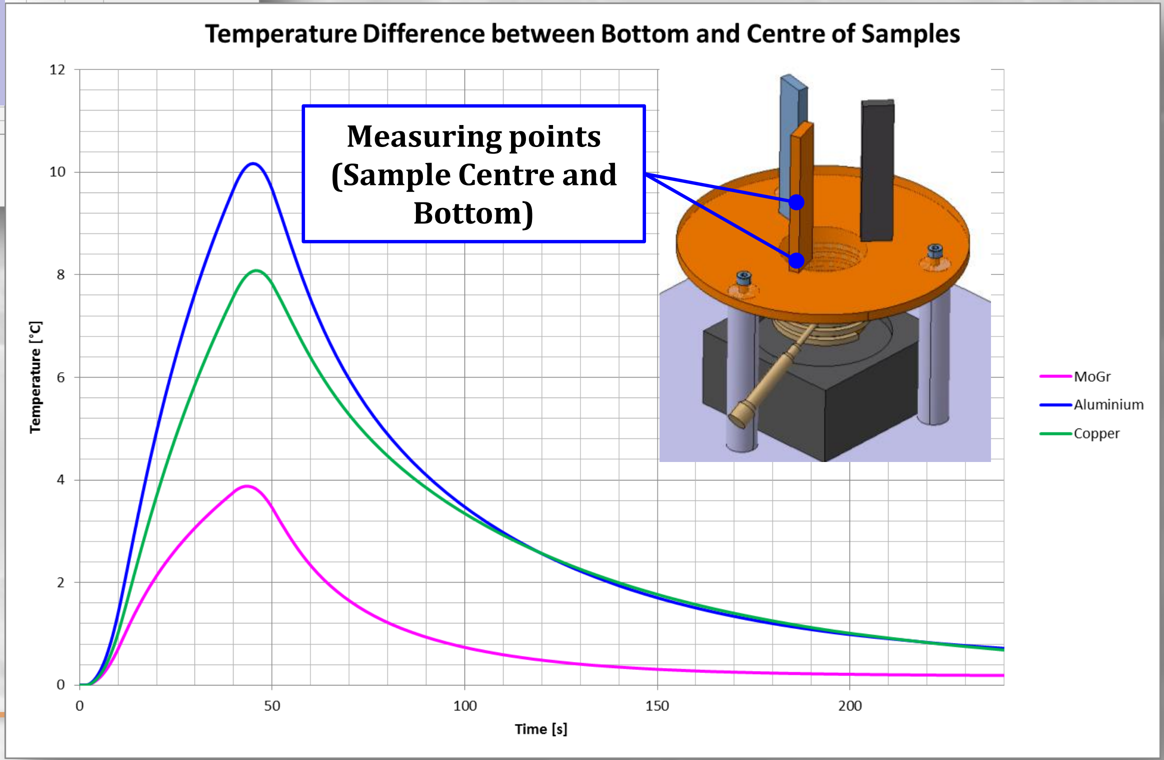
Properties *(Room Temperature, in plane)*	Values
Density [g/cm³]	2.65
Coefficient of Thermal Expansion [$10^{-6}K^{-1}$]	1.6
Thermal Conductivity [W/mK]	770
Electrical Conductivity [MS/m]	1.1
Young's Modulus [GPa]	53
Flexural Strength [MPa]	85

Materials Benchmarking



- **Mo-Gr** stands out for **thermal conductivity** and **thermal diffusivity** against very good conductors as **Copper** and **Aluminium**

- **Mo-Gr 770 W/mK**
- **Copper 385 W/mK**
- **Aluminum 240 W/mK**



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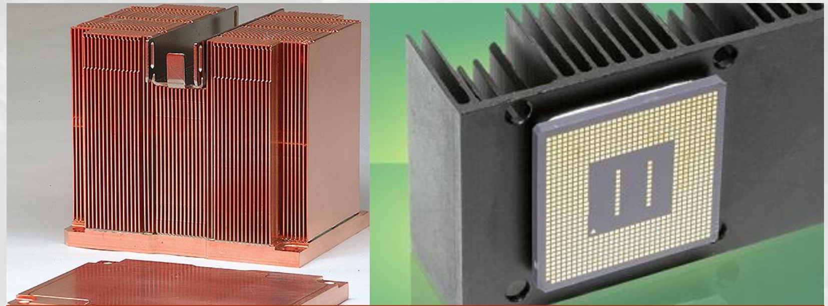
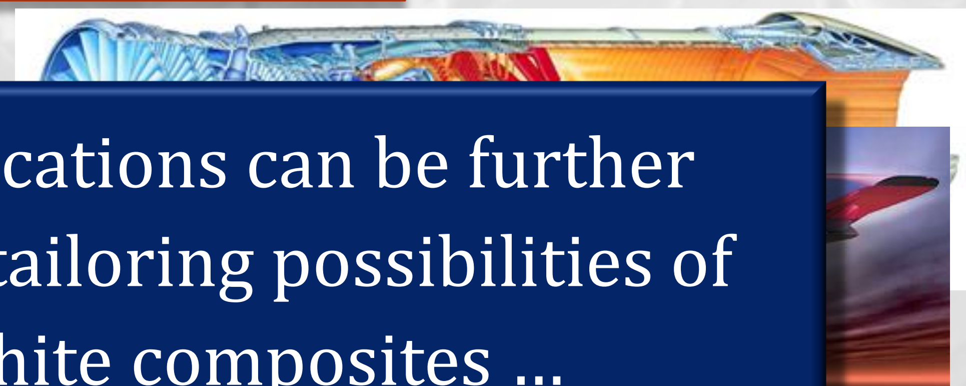
Mo-Gr Potential Applications …

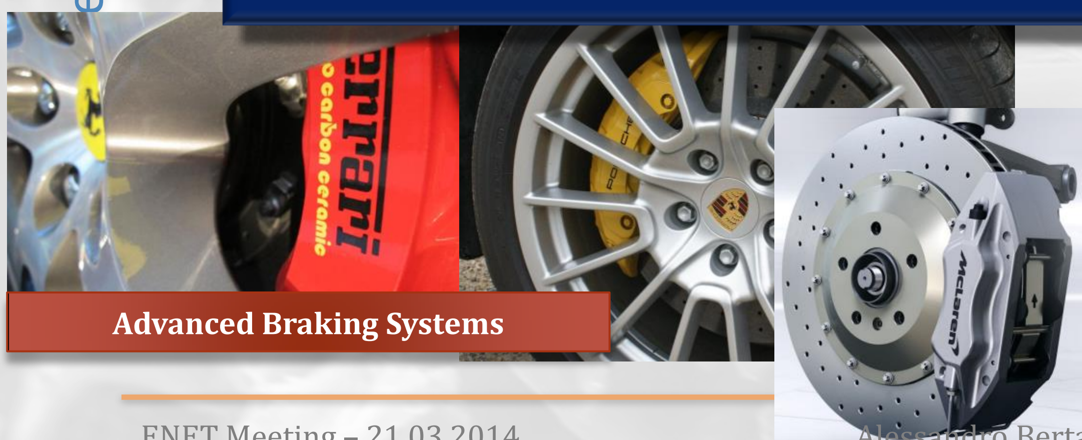


Thermal Management for High Power Electronics

Fusio…



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



Advanced Braking Systems

Solar Energy Applications

CERN