Status of R&D and Beam Plans for Low-Impedance Collimators

F. Carra[1,2]

A. Bertarelli, R. Bruce, A. Dallocchio, M. Garlasché, L. Gentini, P. Gradassi, M. Guinchard, , A. Manousos, E. Quaranta, S. Redaelli, A. Rossi, O. Sacristan de Frutos, V. Vlachoudis, and many others!

(1) CERN – European Organization for Nuclear Research, Geneva, Switzerland
(2) Politecnico di Torino, Turin, Italy

4th Joint HiLumi LHC-LARP Annual Meeting
KEK, Tsukuba, Japan– *19 November, 2014*

Outline

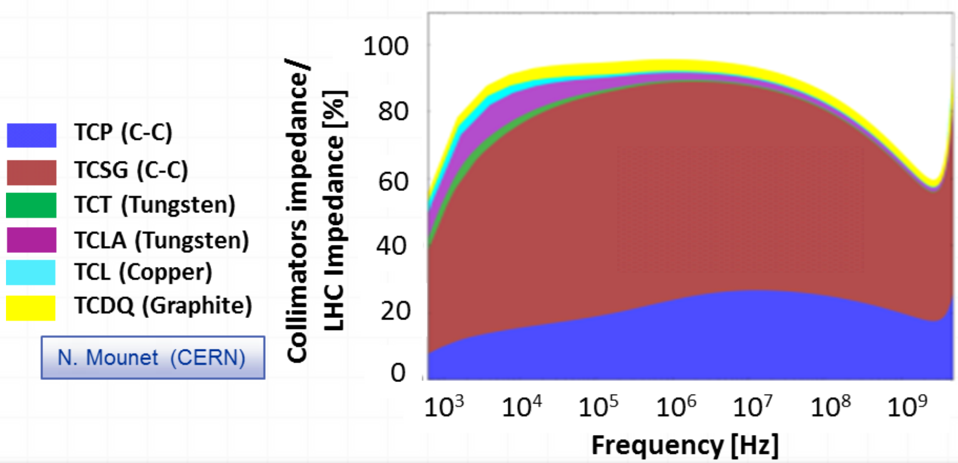
- R&D on novel collimator materials
- TCSPM collimator for HL-LHC era
- Future HiRadMat experiments
- Summary

Outline

- R&D on novel collimator materials
- TCSPM collimator for HL-LHC era
- Future HiRadMat experiments
- Summary

Context

- Future HL-LHC beam will store **unprecedented energy (678 MJ)** released, in case of impact on BIDs, in few **microseconds**!
- Collimator materials must **withstand such energetic beam impacts** as well as **guarantee jaw geometrical stability in standard operation**
- Collimators are also the highest contributors to **machine RF impedance**, which potentially leads to serious instabilities
- Resistive-wall impedance is decreased by **increasing the electrical conductivity** of jaw materials
- Further material requirements include **radiation hardness, UHV compatibility, industrial feasibility, machinability**



What is HL-LHC Energy equivalent to?

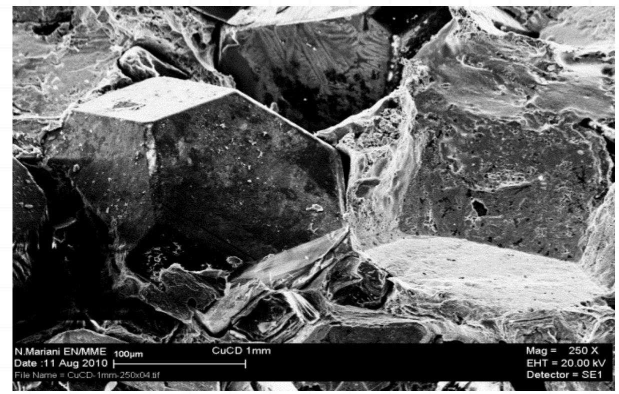
USS Harry S. Truman

TGV

160 kg TNT

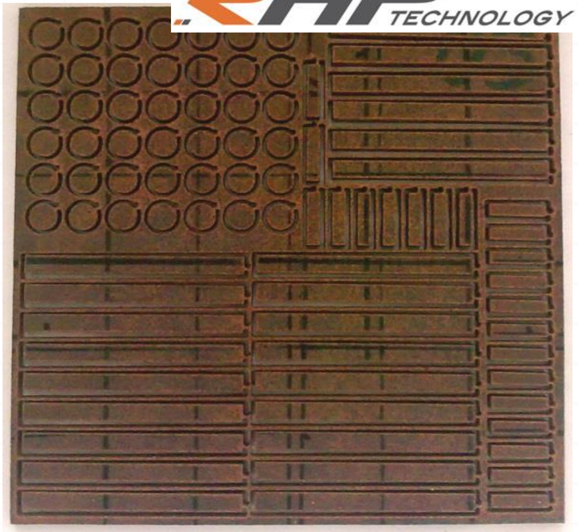
R&D on Novel Materials

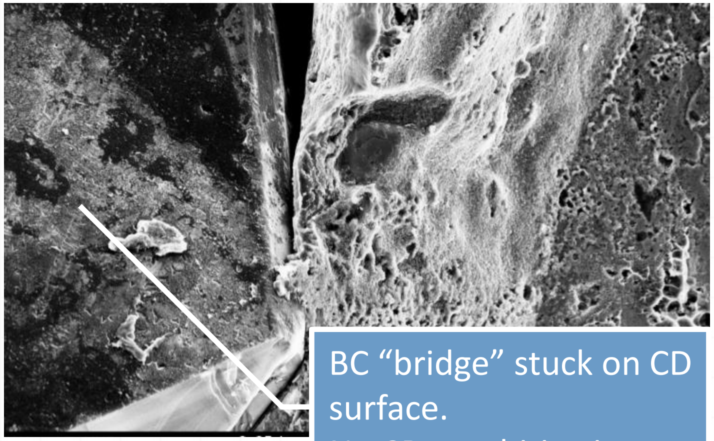
- Extensive **R&D program** launched at CERN in partnership with industries and other institutions
- Aim: explore/develop composites combining the properties of **graphite or diamond** (**low ρ, high λ, low α**) with those of **metals and transition metal-based ceramics** (**high R_M, good γ**)
- Amongst many investigated materials, most interesting are **Copper-Diamond** and **Molybdenum Carbide-Graphite**
- Production techniques include Rapid Hot Pressing, Liquid Phase Sintering and Liquid Infiltration



Copper-Diamond

- Developed by **RHP-Technology** (Austria)
  - Composition :
  - 60%v diamonds (90% 100 µm, 10% 45 µm)
  - 39%v Cu powder (45 µm)
  - 1%v B powder (5 µm)
    - No diamond degradation
    - Thermal (**~490 $Wm^{-1}K^{-1}$**) and electrical conductivity (**~12.6 MSm^{-1}**)
    - No direct interface between Cu and CD (lack of affinity) impairs mechanical strength. Issue partyl offset by limited bonding assured by Boron Carbide (**~120 MPa**)
    - Cu low melting point (**1083 °C**)
    - 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 Carbide-Graphite

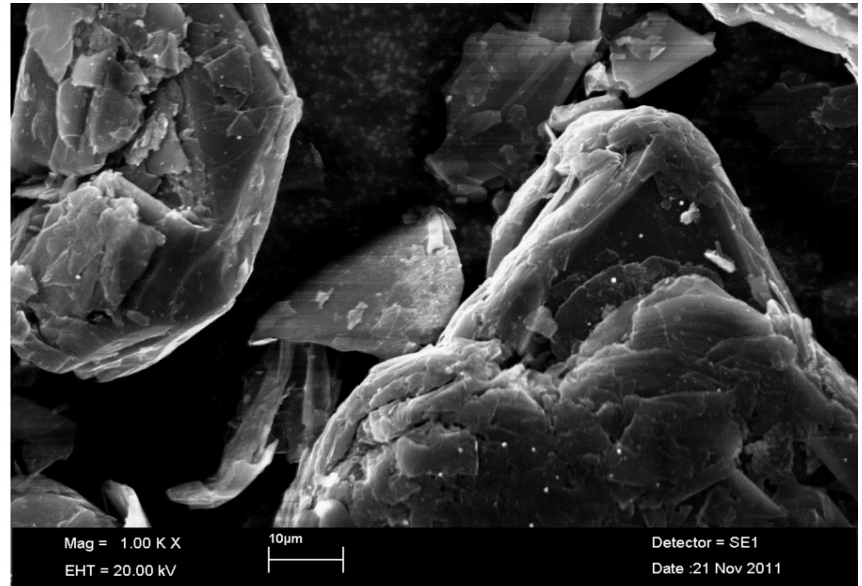
- Co-developed by CERN and Brevetti Bizz (Italy)

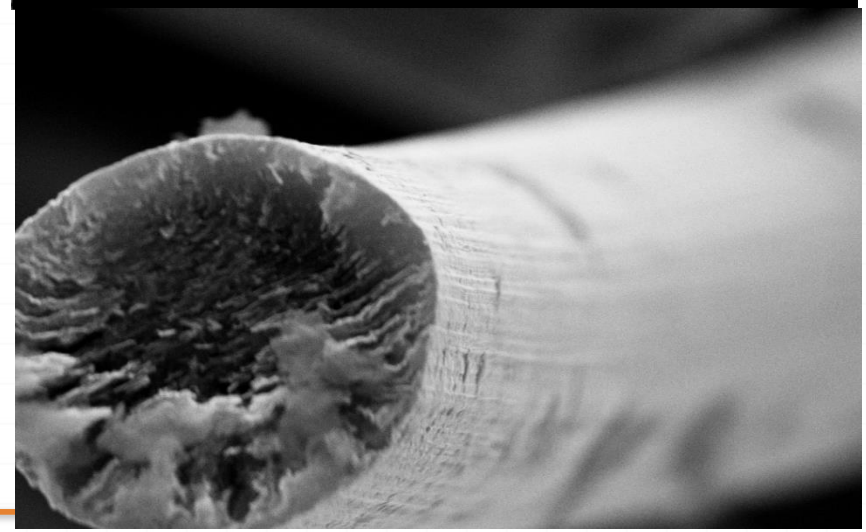
- Broad range of processes and compositions investigated (Molybdenum, Natural Graphite, pitch-based Carbon Fibers)

- **Why Molybdenum?**
  - Refractory metal
  - Density lower than Tungsten

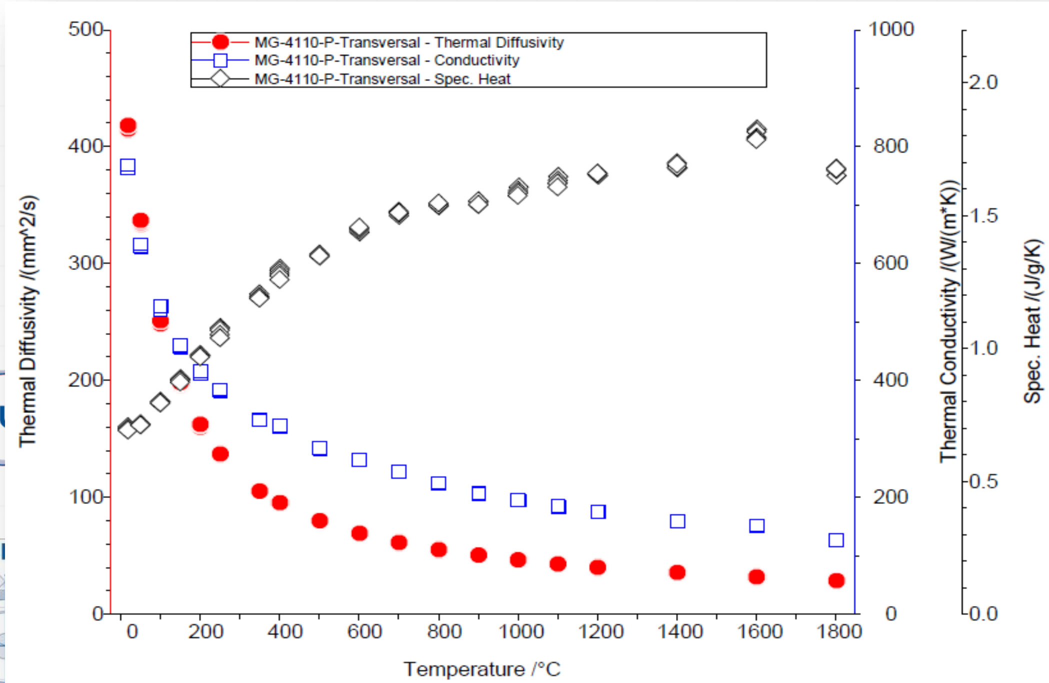
- **Why Natural Graphite?**
  - Low CTE (along basal plane)
  - High Thermal Conductivity (along basal plane)
  - Low Density
  - Very High Service Temperatures
  - High Shockwave Damping
  - Low cost

- **Why Mesophase Pitch-based Carbon Fibres?**
  - Increase mechanical strength
  - Contribute to Thermal Conductivity (highly ordered structure)

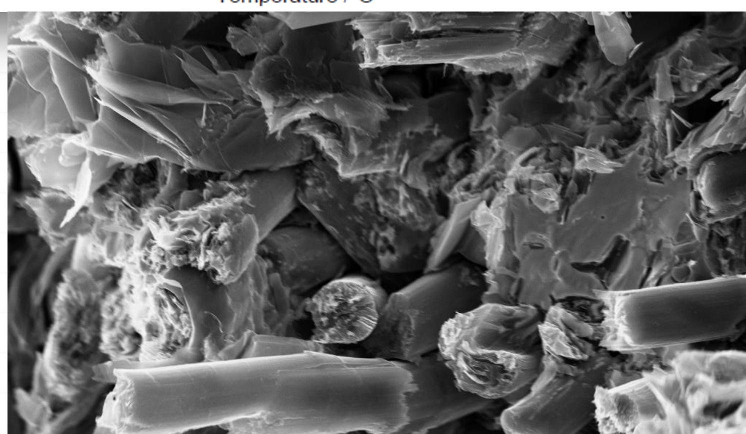




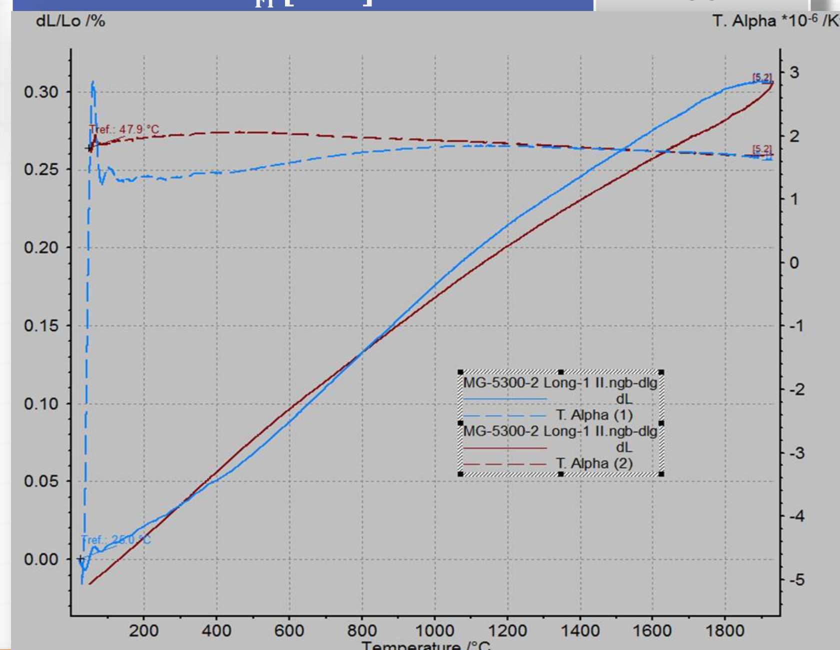
Molybdenum Carbide-Graphite



ρ [g/cm^3]	2.5
$\alpha_{\perp}$ (RT to 1000° C) [10^{-6}K^{-1}]	<1.8
$\alpha_{//}$ (RT to 1000° C) [10^{-6}K^{-1}]	12
$\lambda_{\perp}$ (RT) [W/mK]	>770
$\lambda_{//}$ (RT) [W/mK]	85
$\gamma_{\perp}$ (RT) [MS/m]	1÷18
$\gamma_{//}$ (RT) [MS/m]	0.3
E (Flexural) [GPa]	53
R_{Fl} [MPa]	85

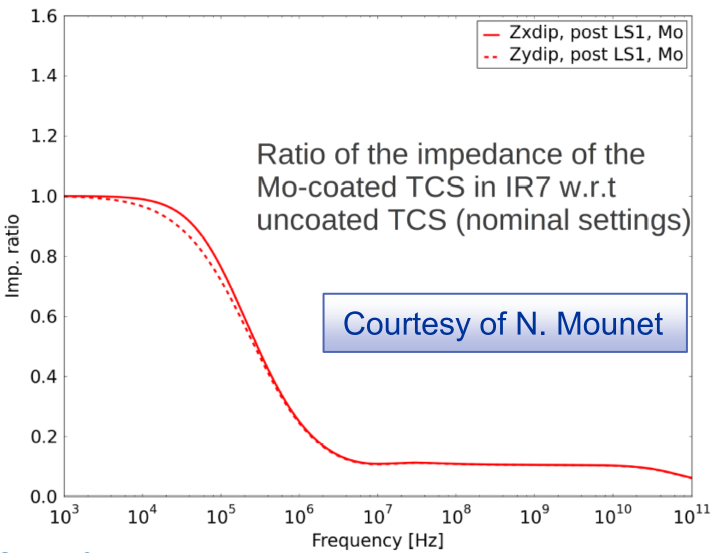


Fracture surface of MoGr with fibres



Molybdenum Carbide-Graphite

- Electrical conductivity (γ): **1 order of magnitude higher than CFC**
- Coating with **chemically-affine material** to further increase γ by another order of magnitude
- **Factor 100 in electrical conductivity → factor 10 in impedance reduction of the LHC collimators!**

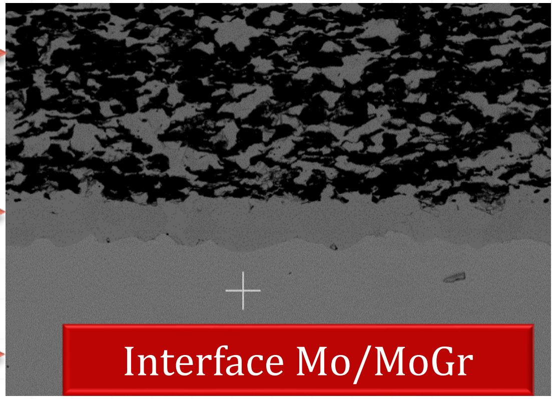


⇒ Impedance of these collimators decreased by a factor 10.

Core

Carbide layer

Mo Coating



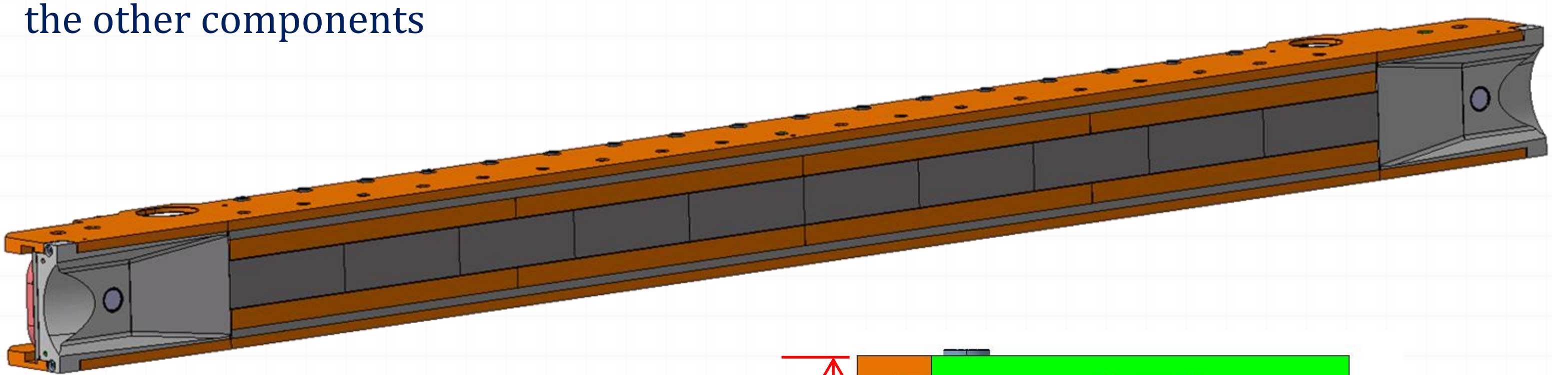
- **Mo coating**: promising in terms of γ and chemical affinity
- R&D ongoing on **low-Z, high-γ, refractory layers** to boost the coating resistance to particle beam impacts

Outline

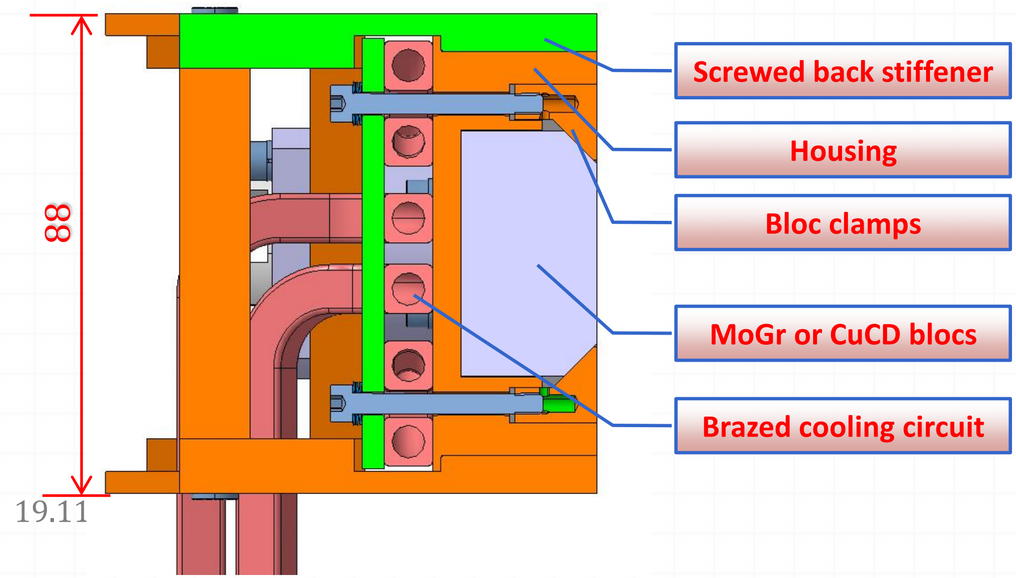
- R&D on novel collimator materials
- TCSPM collimator for HL-LHC era
- Future HiRadMat experiments
- Summary

TCSPM collimator

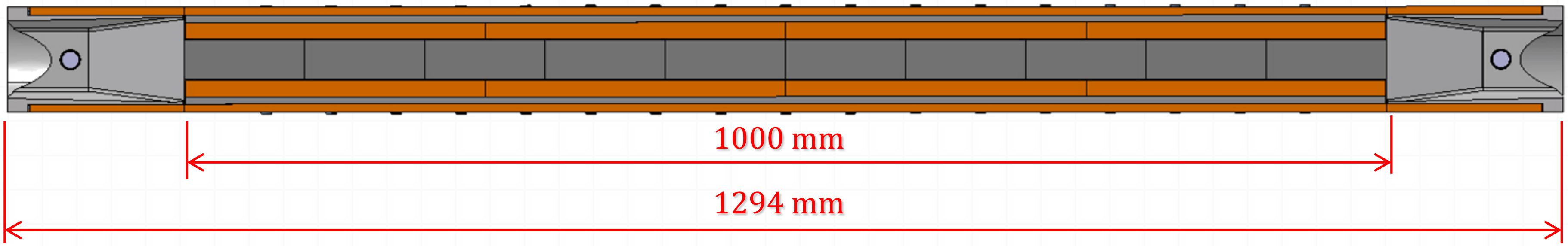
- **Main objective: install a new low-impedance secondary collimator prototype (TCSPM) in the LHC in early 2016**
- New design studied: the active jaw can be made of CuCD or MoGr without any modification to the other components



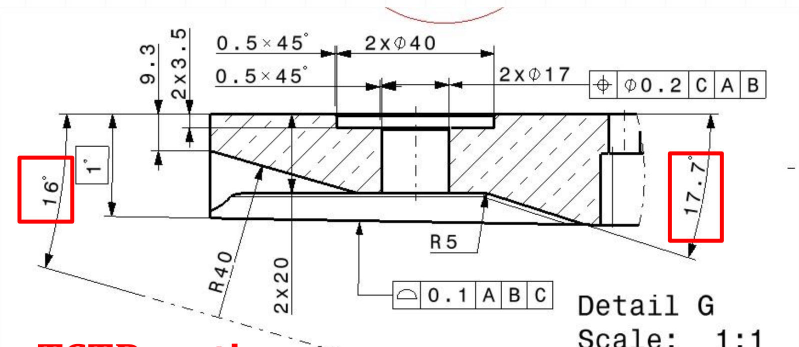
- 1m active jaw made of **10 composite blocs**
- **Clamped solution** to avoid stress concentration on the material, allowing sliding between components with different CTE
- **Brazed cooling circuit**
- **Screwed stiffener** to increase the geometrical stability of the jaw



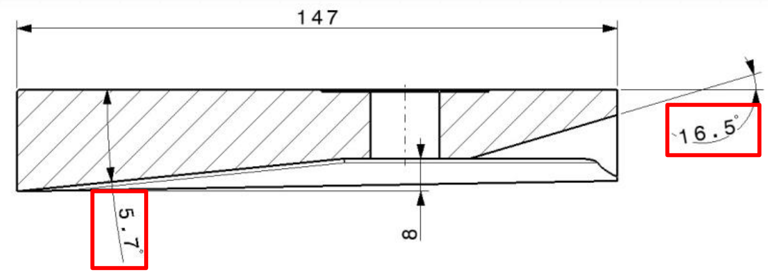
TCSPM collimator



- Jaw 100 mm longer than TCSP, allowing a reduction of the tapering angle to **further decrease the collimator impedance**
- The tapering will also be made of a novel composite, to **increase its robustness to particle beam impact**

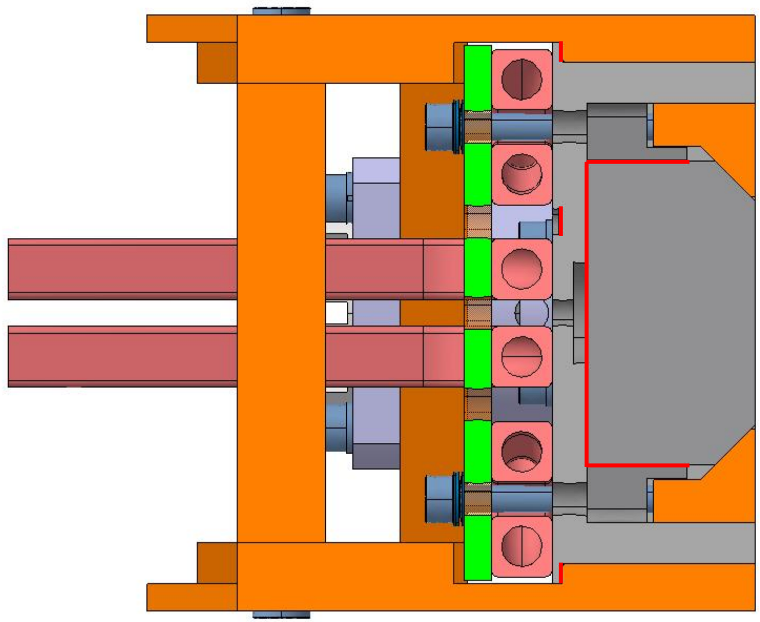


TCTP section



TCSX section

TCSPM assembling procedure



Outline

- R&D on novel collimator materials
- TCSPM collimator for HL-LHC era
- Future HiRadMat experiments
- Summary

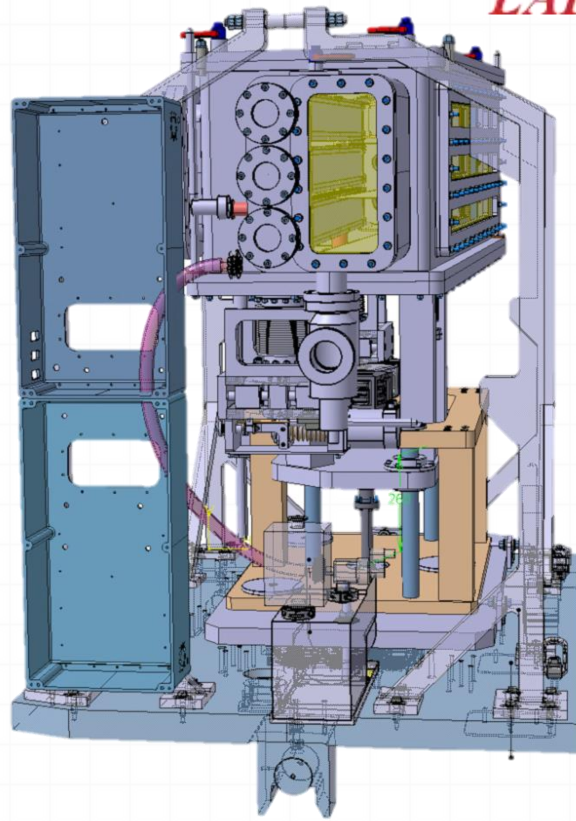
Future HiRadMat Experiments

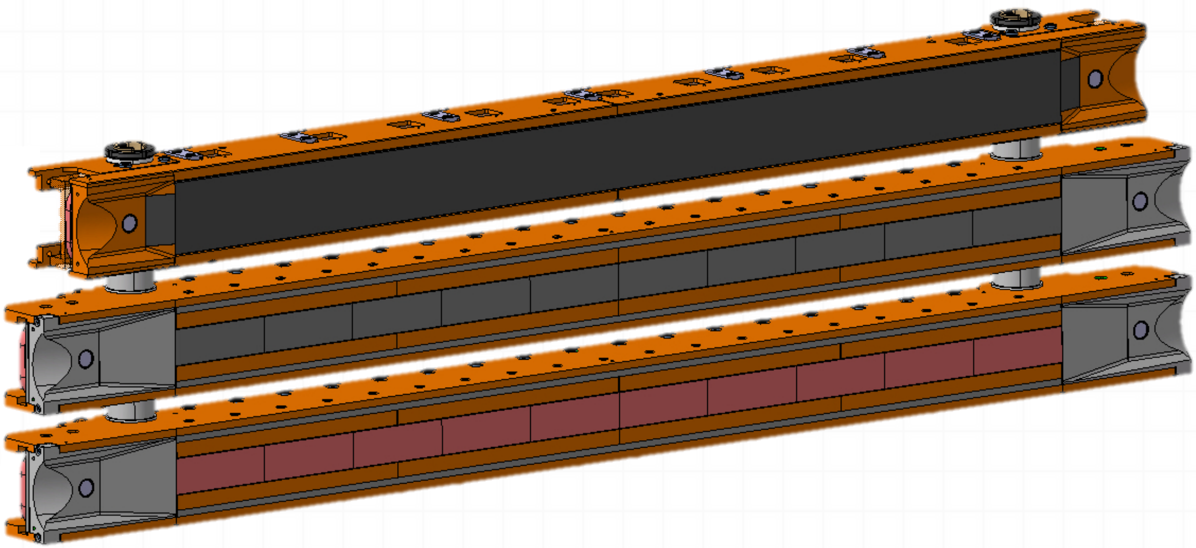
- The final choice of the active jaw material can be made only after a **robustness test** against particle beam impacts at the **highest possible intensity (ideally HL-LHC beam parameters)**
- With this goal, an experiment named **HRMT-23** will be performed in Spring 2015 in the **HiRadMat facility**
- Other objectives of the experiment include:
  - **Determine damage thresholds** for secondary collimators with BPM buttons (TCSP) and for TCSPM
  - **Acquire online data** about **response of complete jaws** to beam impact
  - **Assess impact consequences** on jaws components after irradiation
- Approved by the HiRadMat Scientific Committee and recently submitted to the HiRadMat Technical Board

Quick overview of HRMT-23 in the next slides: for more details on this and other future collimation-related tests in HiRadMat (SLAC collimator, MultiMat) please refer to the presentation: "Planned HiRadMat beam tests on collimation materials", **F. Carra et *al*. - WP5/7/14 Session**

HRMT-23 Experiment

- **3** separate **complete jaws** extensively instrumented.
- **Stainless steel vacuum vessel** (p > 10^{-3} mbar). Quick dismounting system to access and manipulate jaws in a glove box. On a standard HiRadMat table
- **Control system** derived from HRMT-14. Horizontal (jaws) and vertical (whole tank) movement enabled.
- Total expected number or protons **~ 3e14 p**

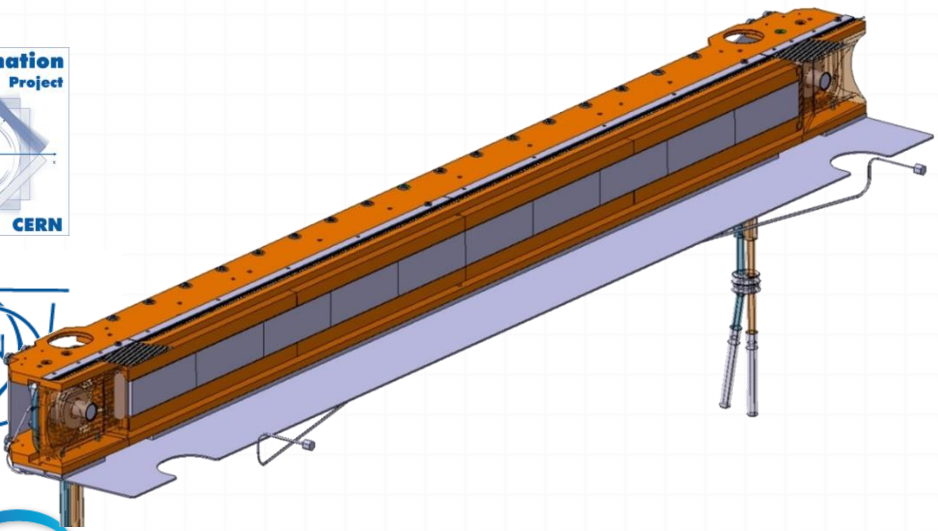


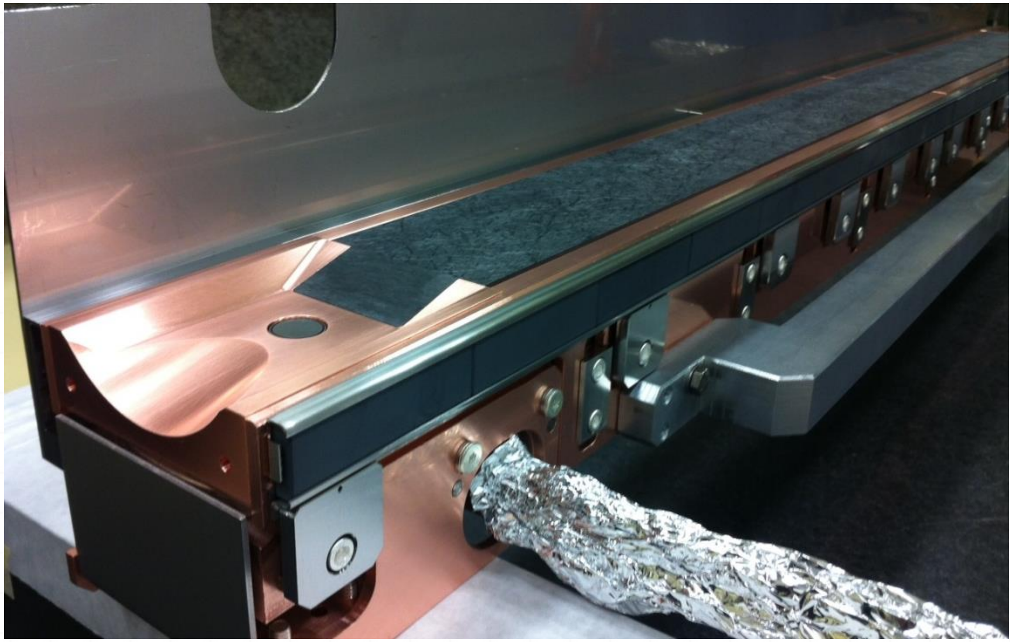


HRMT-23 Experiment

Currently envisaged proposal for Jaws:

1. **TCSPM** with 10 **Molybdenum Carbide–Graphite** inserts (some inserts possibly coated)
2. **TCSPM** with 10 **Copper–Diamond** inserts
3. **TCSP jaw**: to verify the resistance of C/C jaw, metallic taperings and BPM buttons to beam injection accident with HL-LHC parameters





Outline

- R&D on novel collimator materials
- TCSPM collimator for HL-LHC era
- Future HiRadMat experiments
- Summary

Summary

- Bringing LHC beyond nominal performances (HL-LHC) will require a new generation of collimators embarking **novel advanced materials**
- An ambitious R&D program is focusing on the development, simulation and test of such materials: the most promising are **CuCD and MoGr**
- In particular, the use of these composites would decrease the **collimators impedance by a factor of 10**
- A **new collimator design based on these two novel materials** has been studied: thanks to its flexibility, it permits a late choice of the active jaw material
- To provide indications about the material choice, and to validate the proposed design and the simulations performed, a **new experiment called HRMT-23 is scheduled in 2015 in HiRadMat**
- **On the basis of HRMT-23 results, a TCSPM prototype will be built and installed in the LHC in early 2016**

Thank you for your attention!