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HRMT-23 "Jaws" Experiment at CERN HiRadMat Facility

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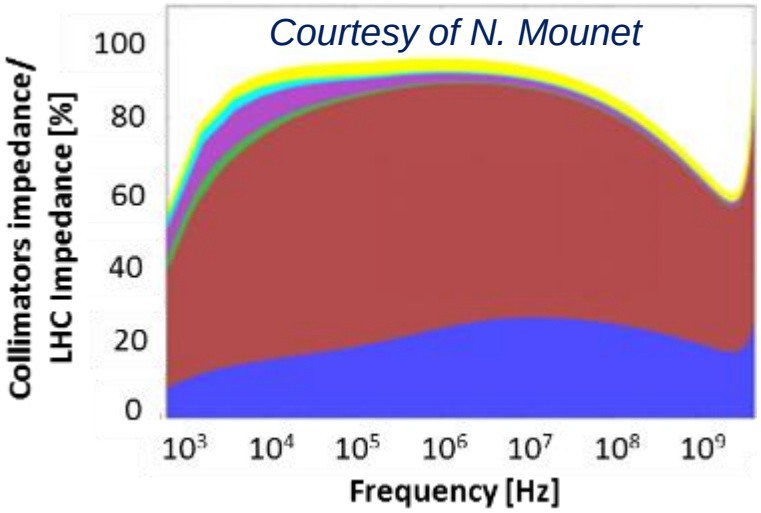
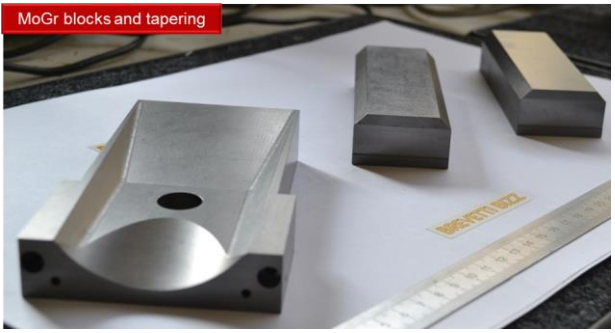
Outlook

- Context
- HiRadMat facility
- HRMT-23 “Jaws” Experiment
  - Experiment description
  - First results
  - Preliminary experimental/numerical benchmarking
- Summary and next steps

Context

- LHC collimation system: **robust, reliable, efficient!**
- However: HL-LHC beam stability can be guaranteed only **decreasing the RF impedance** of the system
- **New collimator design** studied in 2014/15, featuring **high-electrical conductivity** jaw materials
- Novel composites developed in the frame of **Eucard², WP11**, with **RHP (Copper-Diamond – CuCD)** and **BrevettiBizz (Molybdenum-Graphite – MoGr)**
- The new collimator should maintain or improve the performances in terms of **robustness, geometrical stability, radiation hardness, UHV compatibility**





***Molybdenum Carbide – Graphite** (**MoGr**), co-developed by CERN and Brevetti Bizz (IT): high thermo-mechanical properties and low electrical resistivity (factor 5 to 10 better than carbon).*

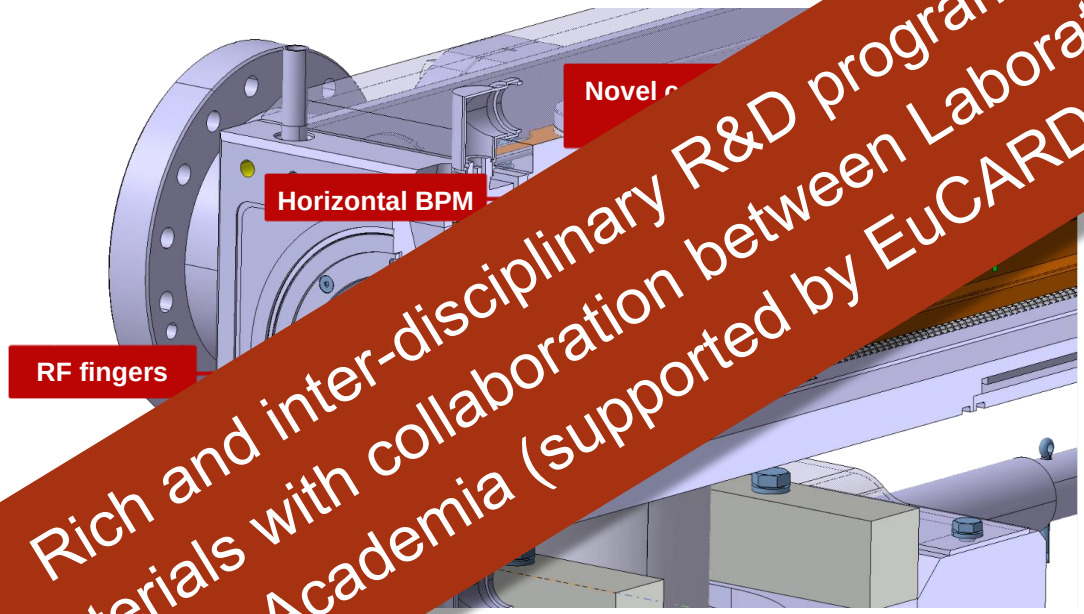
***Copper-Diamond** (**CuCD**), produced by RHP-Technology (AT): composite keeping most of Cu thermo-electrical properties, while reducing density and improving structural behavior.*

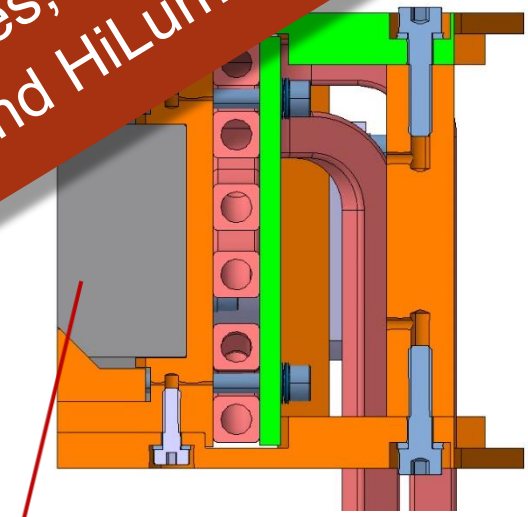
HL-LHC Collimator Design

- **Modular design** allowing to install 8 or 10 jaw inserts made of **adva** optimized RF features
- Design suitable for **primary, secondary** and **tertiary** coll

MoGr

Cu





MoGr (high robustness)
CuCD (higher density)

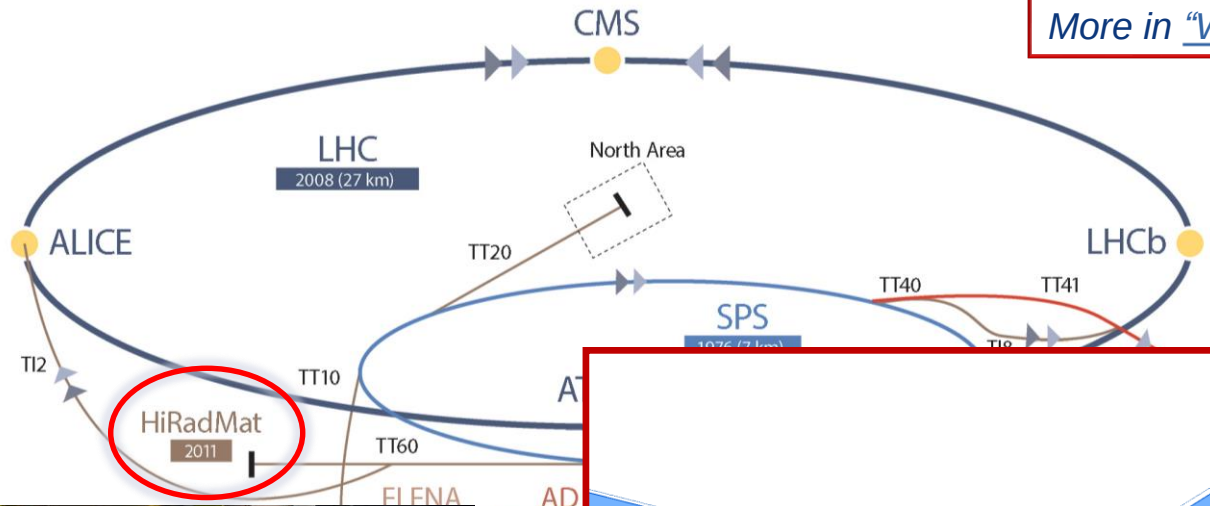
Rich and inter-disciplinary R&D program on novel collimator materials with collaboration between Laboratories, Industries and Academia (supported by EuCARD2 and HiLumi)

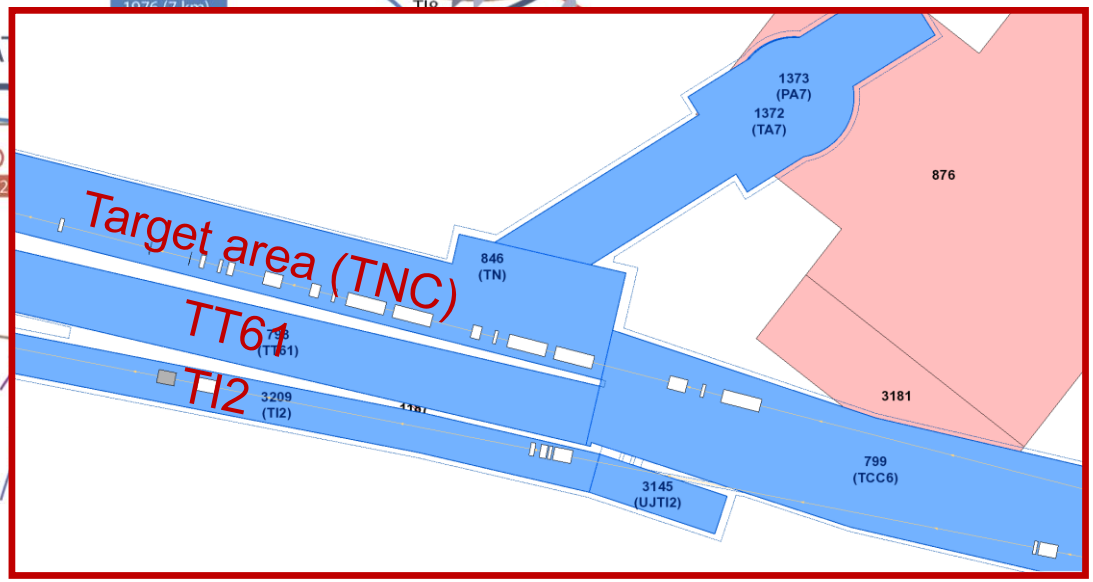
- A **full** **prototype** for beam tests in LHC in 2017 (approved by the ATS directorate after the 2013 review) aiming to produce a
- Pre-re**quisite**: full validation of **new design and material robustness** at CERN **HiRadMat facility → HRMT-23 "Jaws" experiment**

CERN HiRadMat facility

- Provides high-intensity pulsed proton beams to an irradiation area where material samples and accelerator components can be tested.

More in "WP9 - HiRadMat", A. Fabich

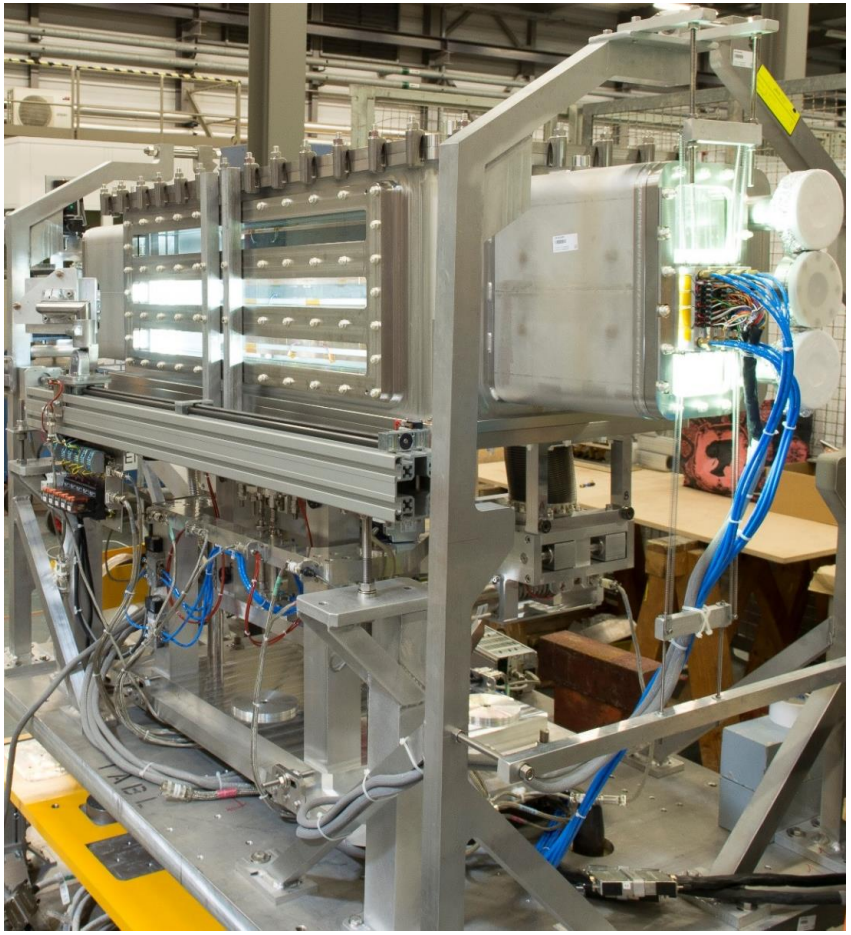




p (proton) ion neutrons p̄ (antiproton) electron proton/antiproton conversion

HRMT-23 “Jaws” Experiment

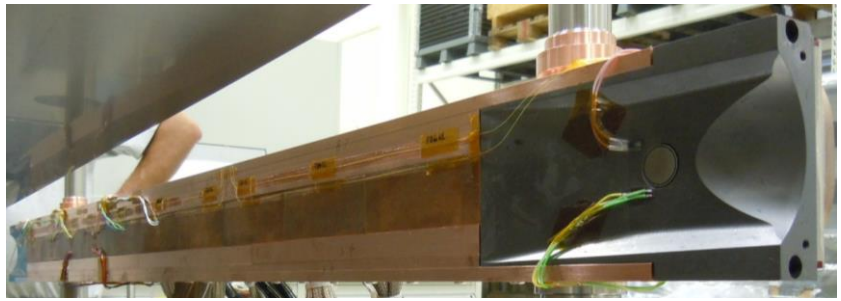
- **3** separate **complete jaws** extensively instrumented.
- **Stainless steel vacuum vessel** ($p > 10^{-3}$ mbar). Quick dismounting system to access and manipulate jaws in a glove box.
- **Be/CFC vacuum windows**: designed to withstand higher energy density and intensity
- **Horizontal actuation** inspired by collimator movable tables; Stroke (H): 35 mm
- **Vertical movement of the whole tank**; stroke (V) +/-140 mm. 3 separate windows sets for each jaw
- **Control system** derived from previous HRMT tests (2012)
- **Standard HiRadMat support table**:
  - Total envelope: 1.2(H) x 0.4(W)x 2.1(L) m^3
  - Total mass ~ 1600 kg



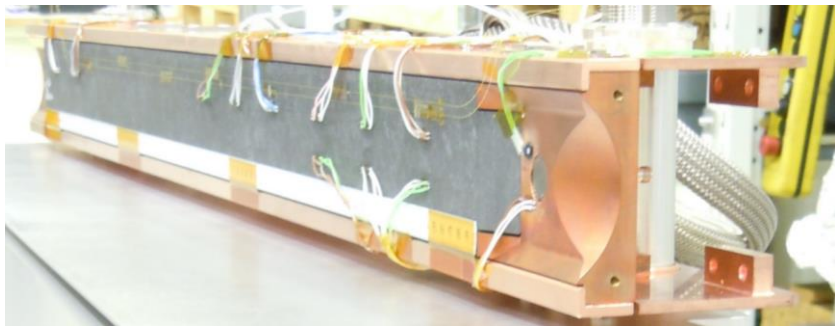
HRMT-23 “Jaws” Experiment

1. **HL-LHC Secondary Collimator Jaw** (TCSPM) with 8 **MoGr** inserts and taperings

2. **HL-LHC Secondary Collimator Jaw** (TCSPM) with 10 **CuCD** inserts (MoGr taperings)

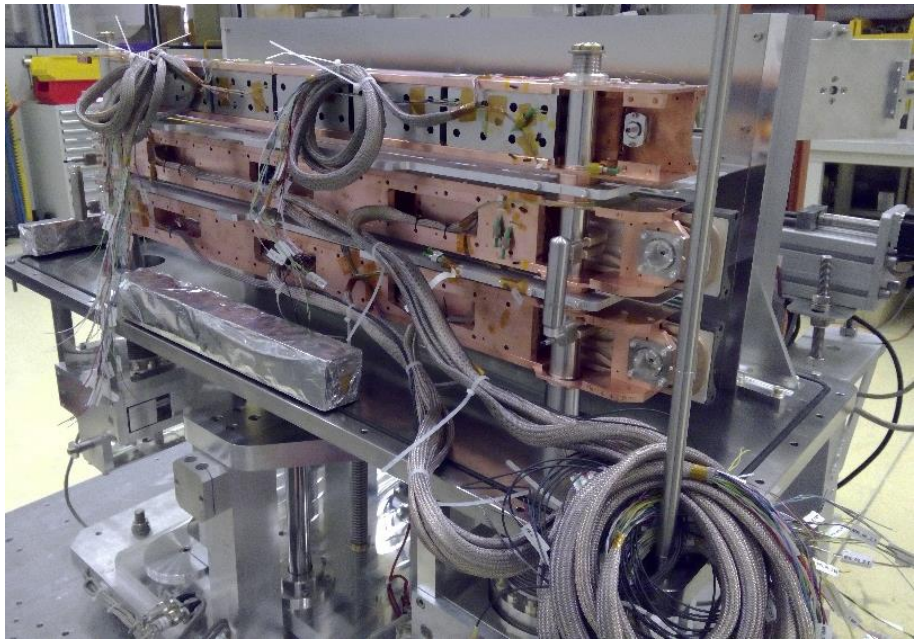


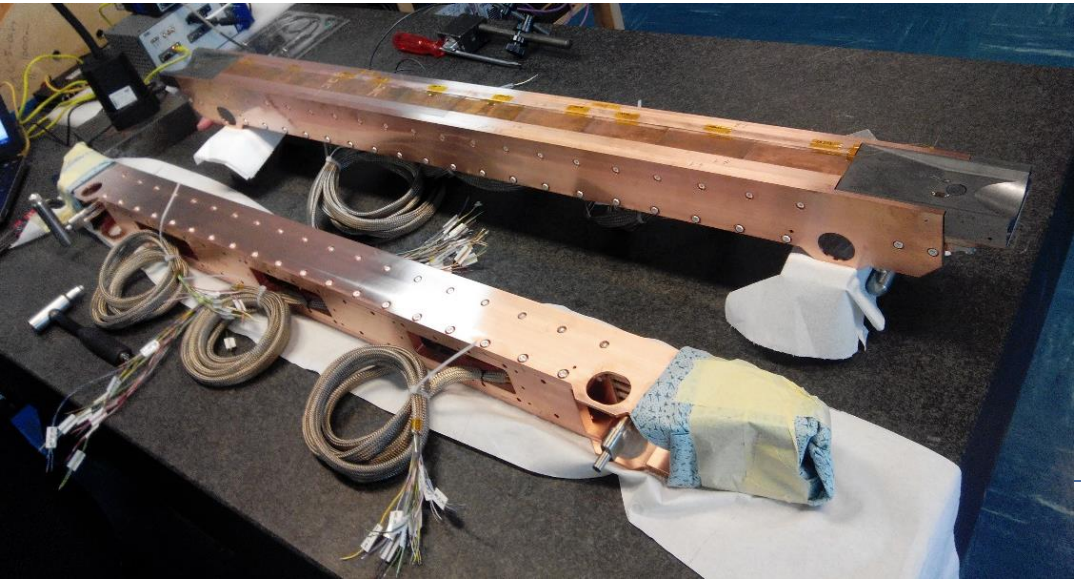
3. **LHC Secondary Collimator Jaw** (TCSP): to verify the resistance of Phase I CFC jaw to beam injection accident with HL-LHC parameters

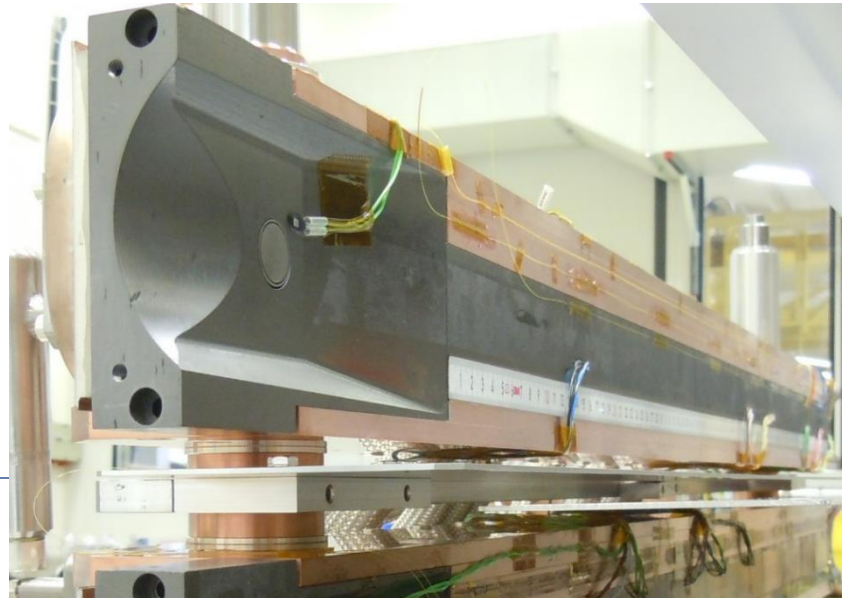


HRMT-23 “Jaws” Experiment

Experiment Instrumentation	Sampling frequency
126 electrical strain gauges	4 MHz
42 temperature probes	200 Hz
Laser Doppler Vibrometer	4 MHz
Water pressure sensor	100 kHz
60 strain Optical Fibre Bragg Gratings	500 Hz
Inspection HD Camera (4K)	-
High Speed Camera + LED lighting system	20 000 fps
In-jaw US probes (Omniscan)	-

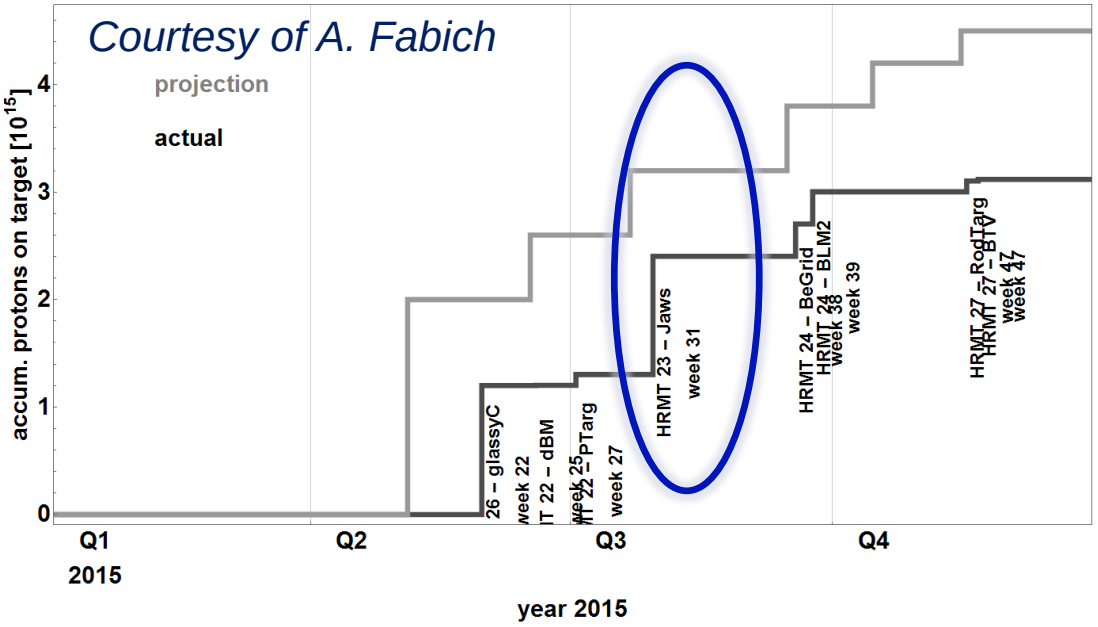


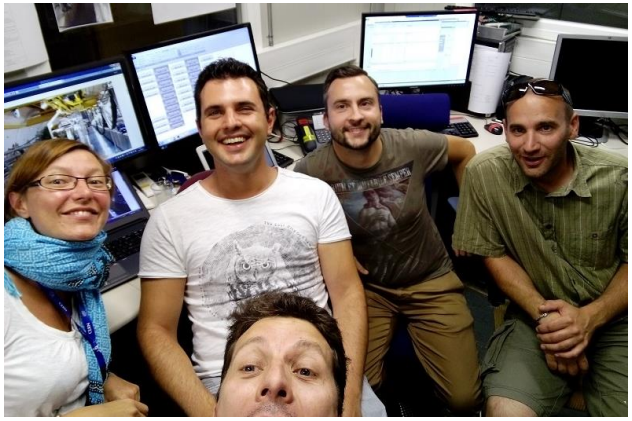




HRMT-23 Beam Parameters

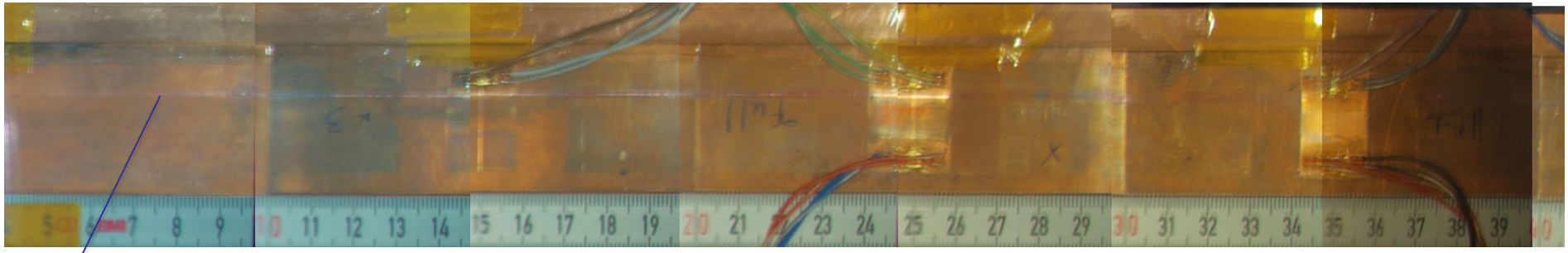
- Test Runs: **24-31 July 2015**
- Beam energy: **440 GeV**
- Bunch spacing: **25 ns**
- Protons/bunch: up to **1.32e11**
- 1 to **288 bunches** per pulse
- Beam size (σ): **0.35** to **1 mm**
- Different **impact positions**
- Total Pulses: **100** (excluding alignment)
- Total Bunches: **8110** (excluding alignment)
- Total Protons: **~ 1e15** (highest pot together with HRMT-22)



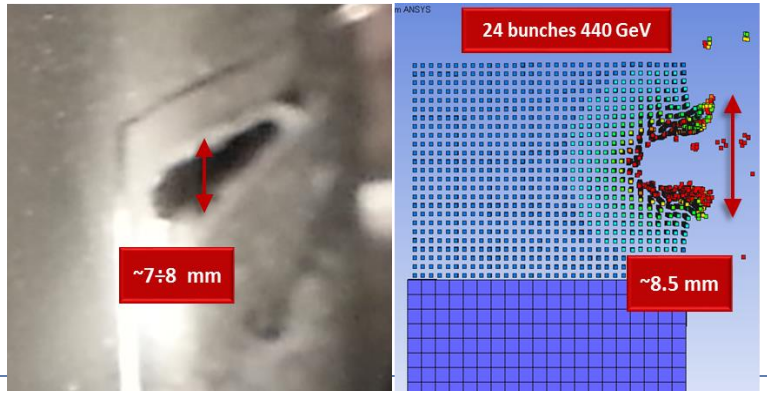


HRMT-23 first results CuCD

- **CuCD** on HL-LHC jaw survived (with a limited surface scratch on the Cu coating) the impact of **24 b**, **σ 0.35 mm** at 440 GeV, roughly **equivalent to 1 LHC bunch** at 7 TeV
- At **48 b** (~2 LHC 7 TeV bunches) the scratch is more severe, but the jaw appears globally undeformed
- This would qualify CuCD as an superior material for TCT jaws (presently in Tungsten alloy). Local damage induced by Asynchronous Beam Dump could be compensated by jaw shift with 5th axis



CuCD jaw after 24 b, σ 0.35 mm. Note thin, long groove



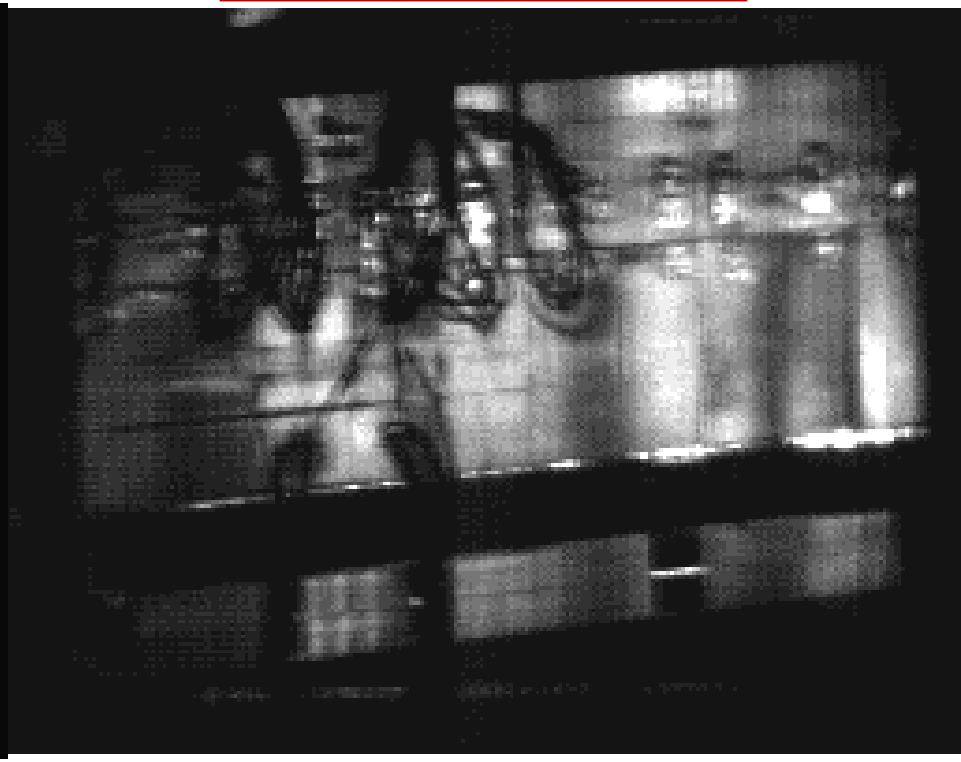
Groove caused on TCT by an SPS 24 b pulse (HRMT-09, 2012)

HRMT-23 first results CuCD

- CuCD 48 bunches, σ 0.35 mm, impact 0.5σ
- CuCD 144 bunches σ 0.61 mm, impact 5 σ

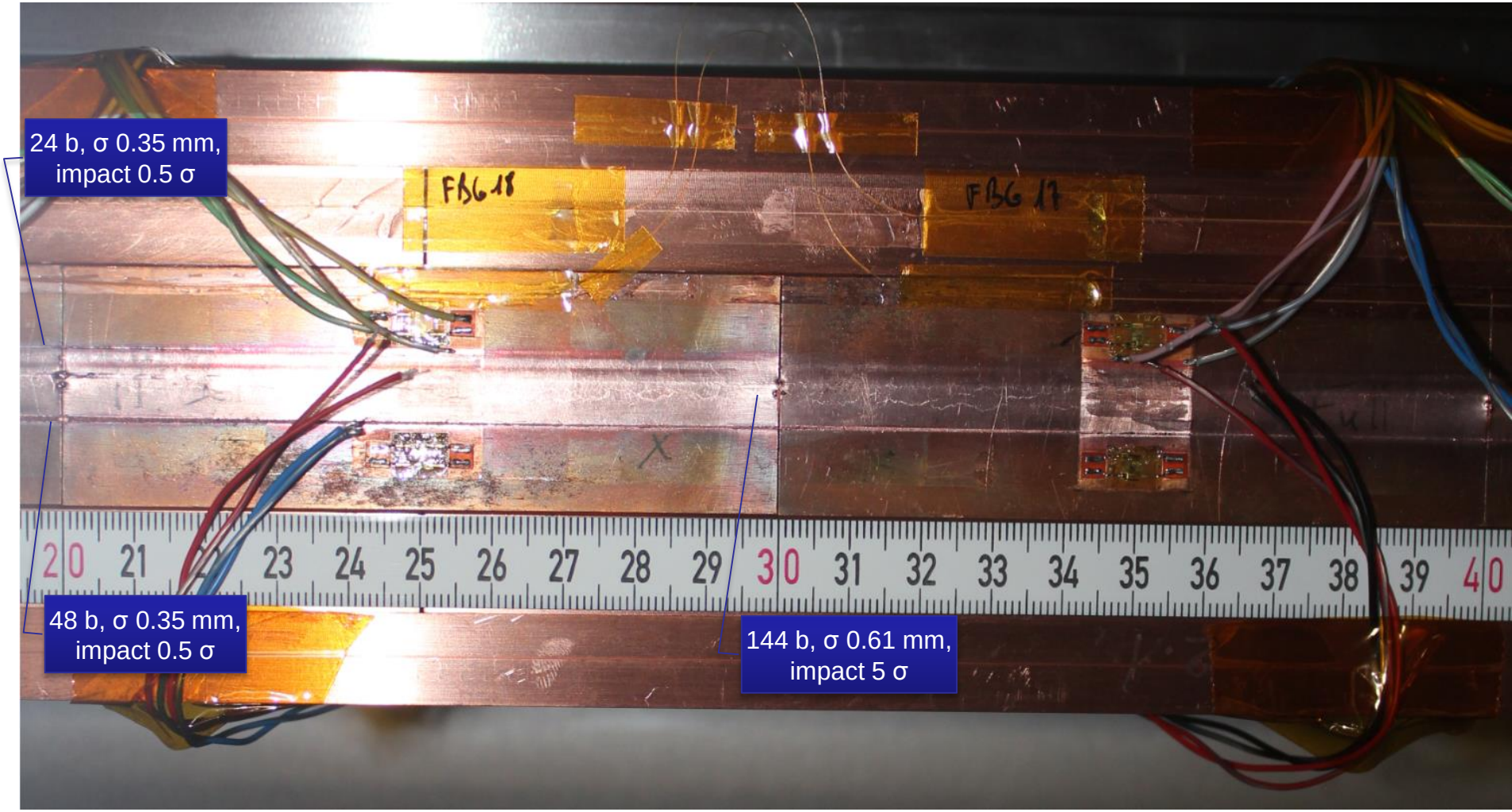
TCSPM CuCD 48 bunches

TCSPM CuCD 144 bunches



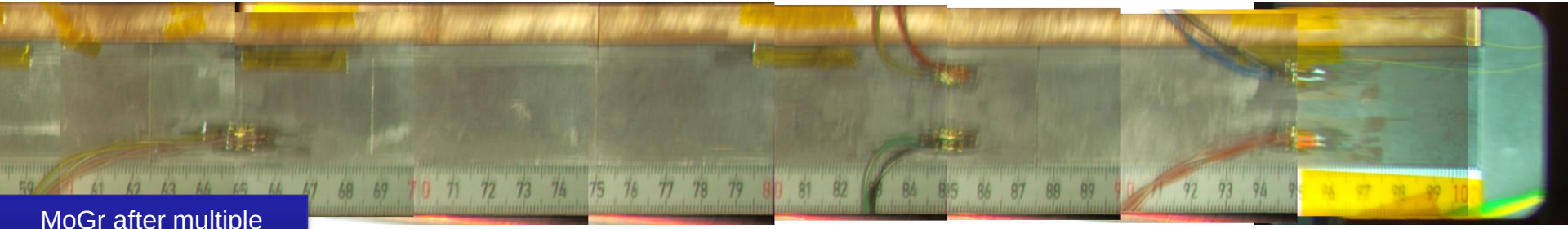
HRMT-23 first results CuCD

- **Post-irradiation visual inspection**

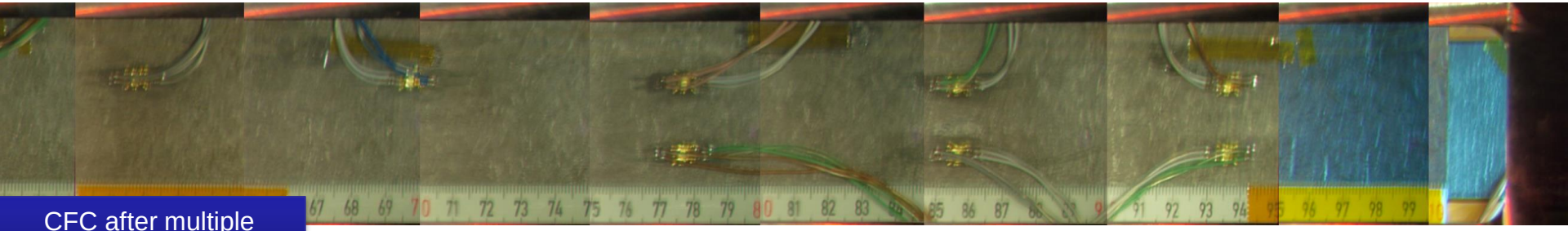


HRMT-23 first results MoGr & CFC

- **MoGr** on HL-LHC jaw survived the impact of several **288 b pulses** with σ down to 0.35 mm (**peak energy density slightly higher than HL-LHC injection error)**
- **CFC** on LHC jaw **survived the same impacts**
- Preliminary results would qualify MoGr (from robustness point of view) as an alternative to CFC with a factor 5 to 10 **gain in electrical conductivity**



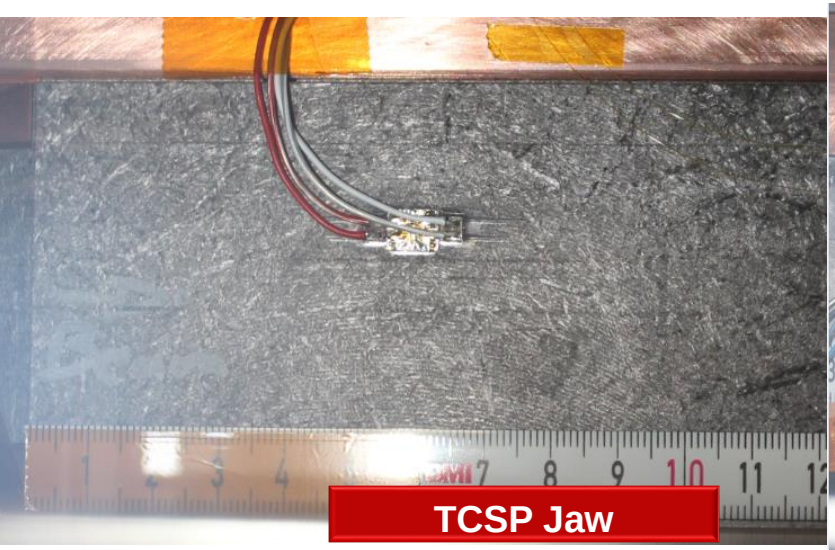
MoGr after multiple impacts



CFC after multiple impacts

HRMT-23 first results MoGr & CFC

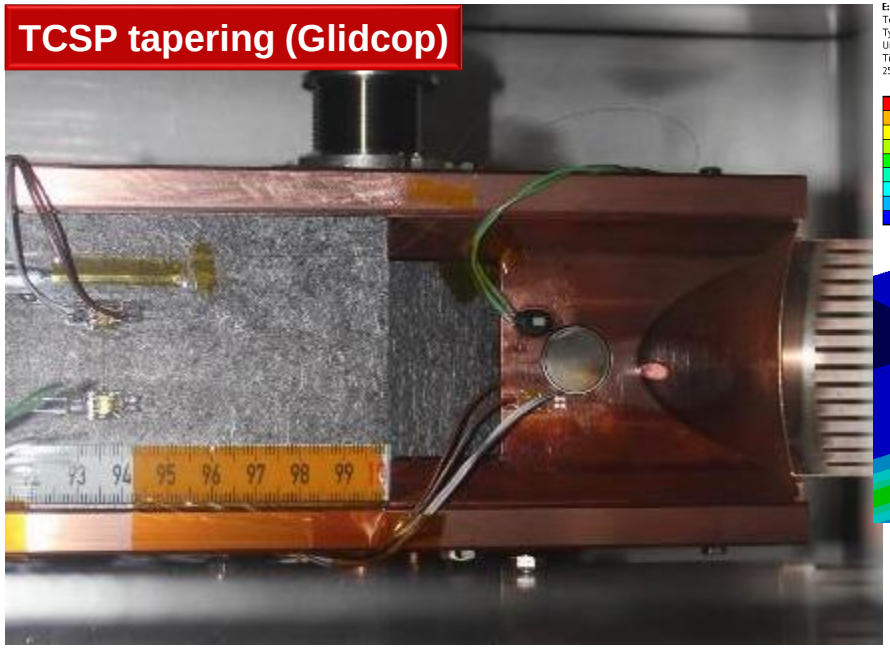
- Post-experiment observations also allowed to observe some marks on the CFC and MoGr surfaces
- The visibility of the marks changes with the light orientation
- Probably generated during the 0.5 sigma impacts by **detachment of the surface powders** (pencil-like surface typical of graphitic materials, no etching done before the experiment)
- **No cracks are visible**



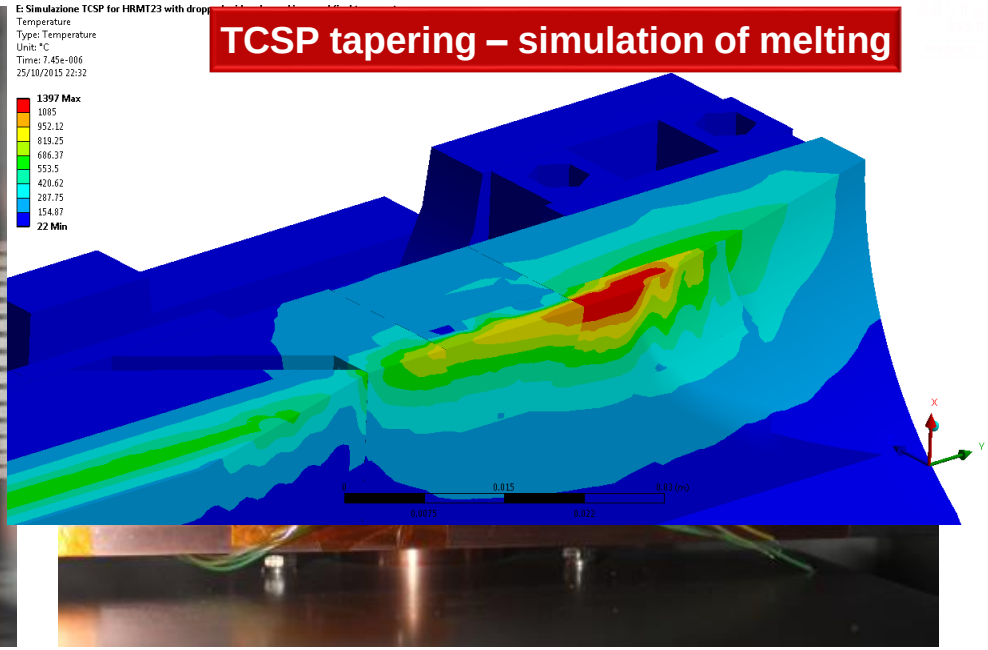
HRMT-23 first results MoGr & CFC

- Hole in the TCSP Glidcop tapering observed, two TCSPM jaw taperings, in MoGr, visually unscathed → **MoGr is a more robust option as a tapering material also for TCSP**
- The **electrical functionality of the BPM** embarked in the three jaws will be verified during the post-irradiation experiments, once opening the tank

TCSP tapering (Glidcop)

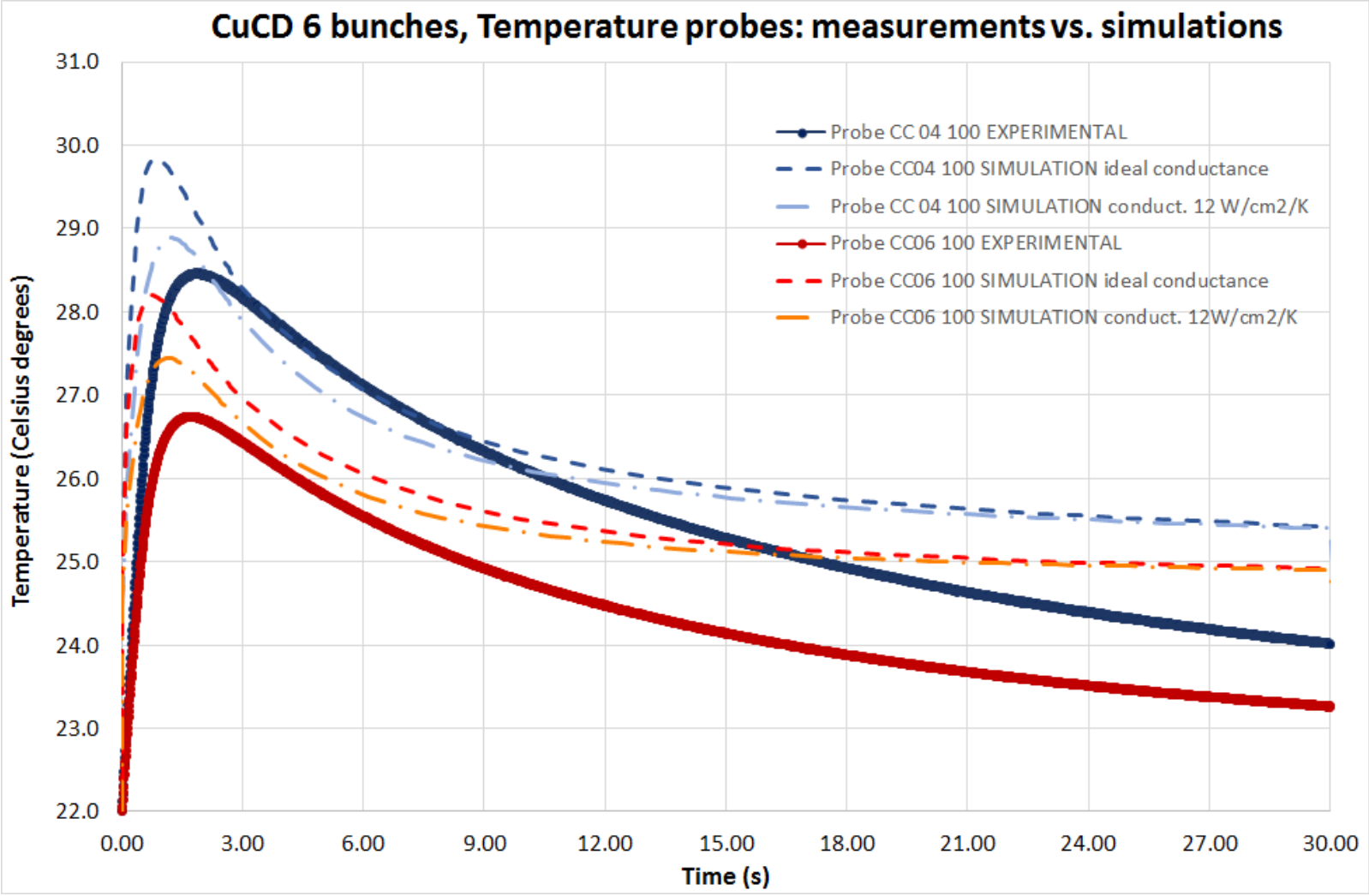


TCSP tapering – simulation of melting



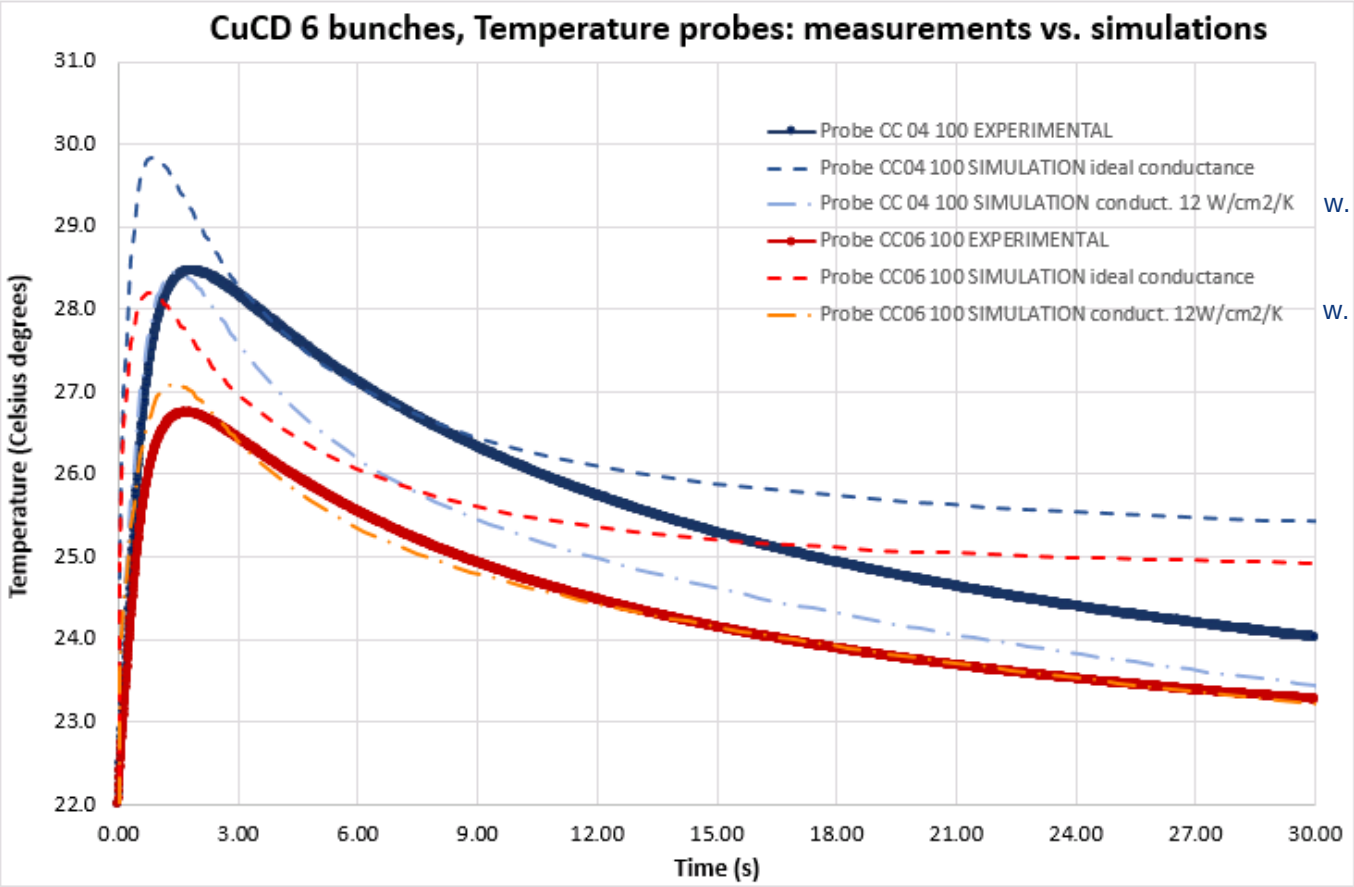
Numerical benchmarking – Thermal

- **THERMAL: CuCD 6 bunches, σ 0.61 mm, impact 5σ**



Numerical benchmarking – Thermal

- Cool-down simulated is much slower, **typical of forced convection** (nominal film coefficient of LHC collimators with circulating water!)
- **Shock-enhanced water forced convection?**

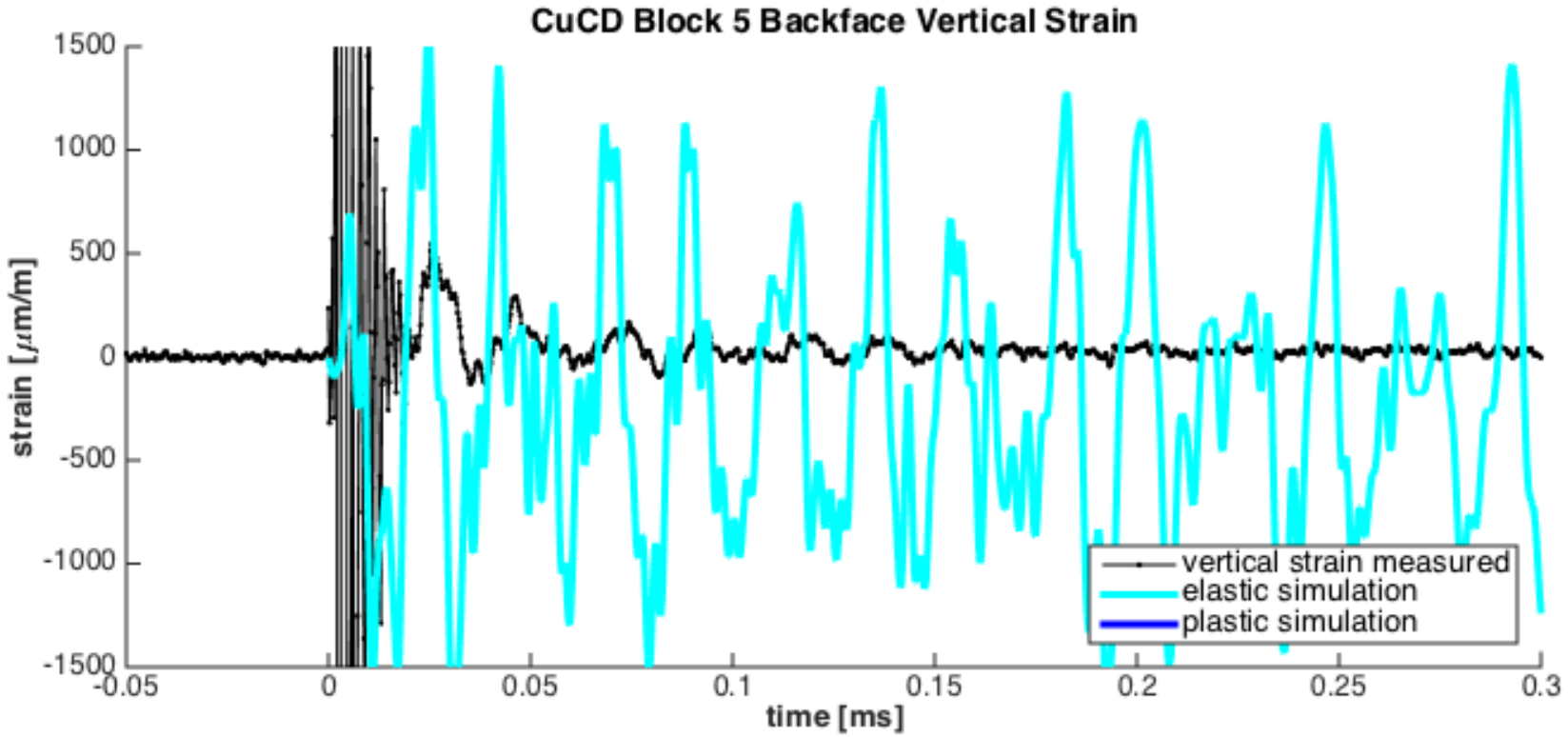


w. Forced convection

w. Forced convection

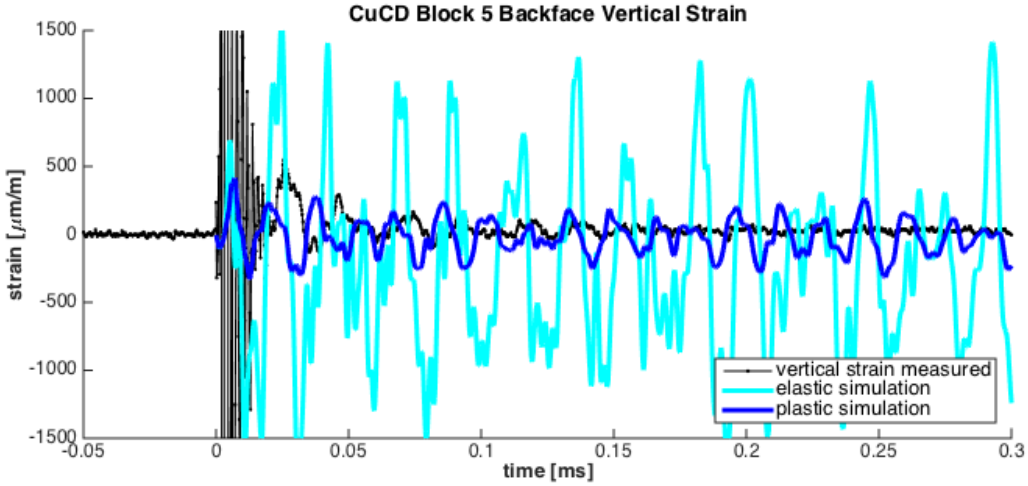
Numerical benchmarking – Structural, CuCD

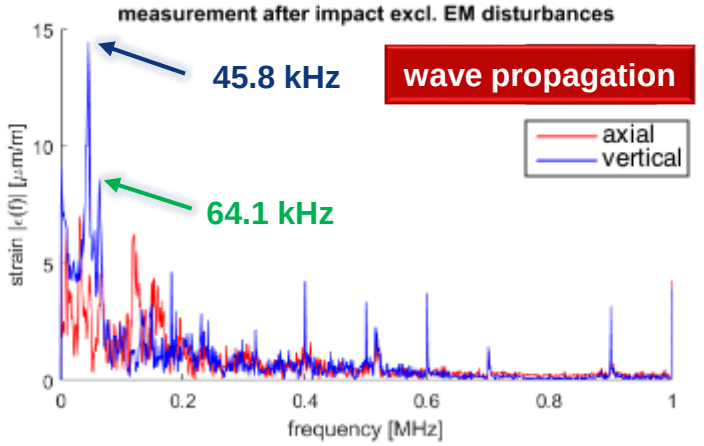
- Structural: **CuCD 24 bunches**, σ 0.61 mm, impact 5σ
- Reasonably **low noise levels**
- **Electromagnetic coupling beam/strain gauges** for the first microseconds after the impact

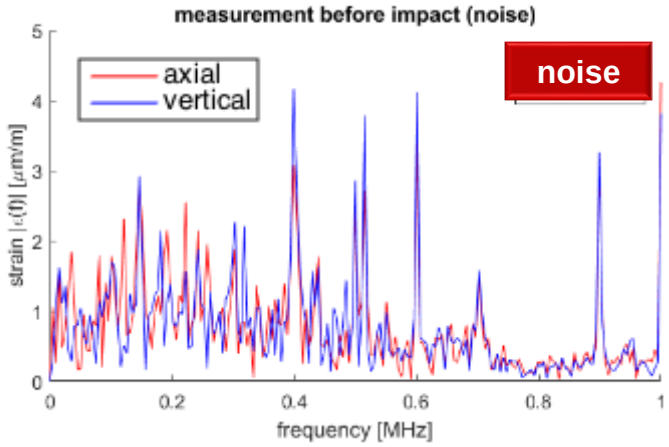


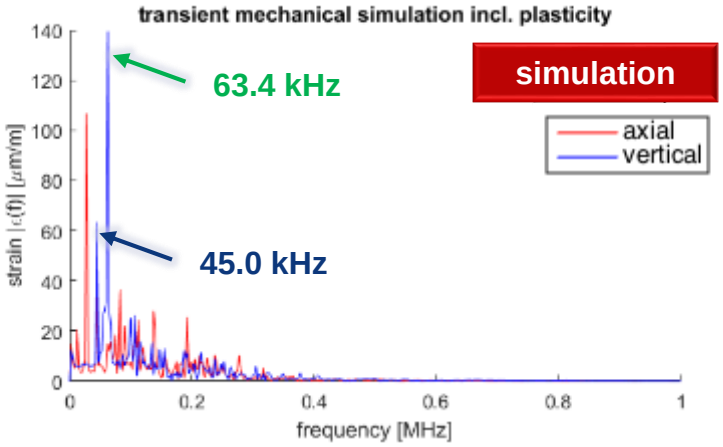
Numerical benchmarking – Structural, CuCD

- Structural: **CuCD 24 bunches**, σ 0.61 mm, impact 5σ
- Pseudo-plasticity of the material taken into account!





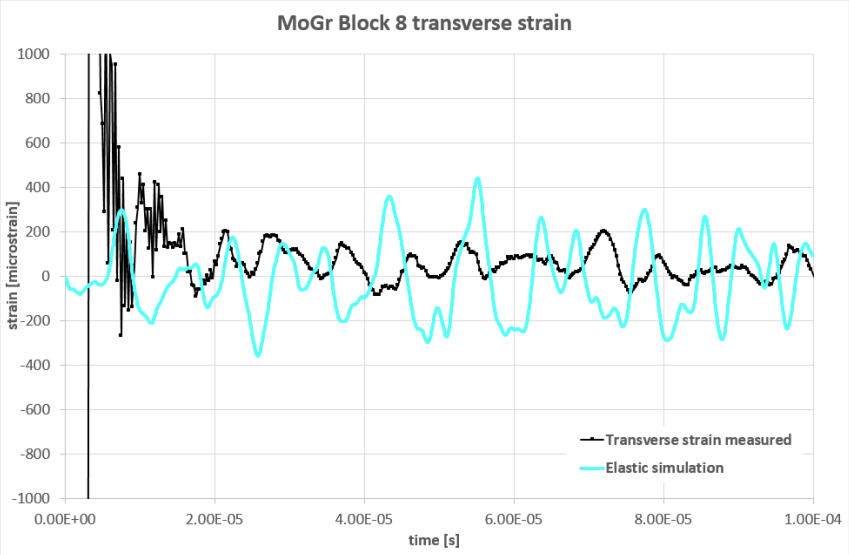


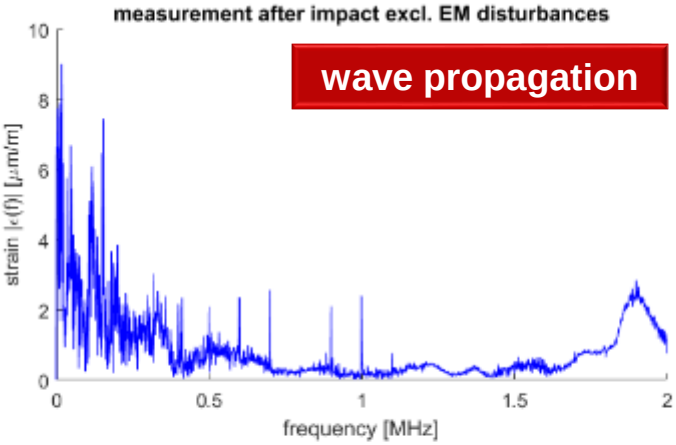


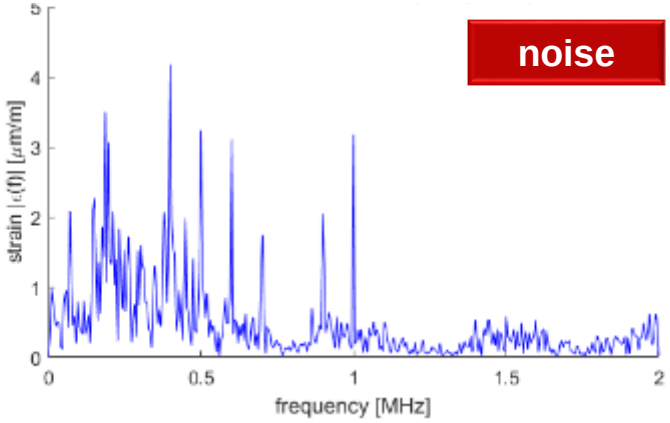
- Ongoing: **wave damping, phase, increased simulation duration** (to catch lower frequencies)

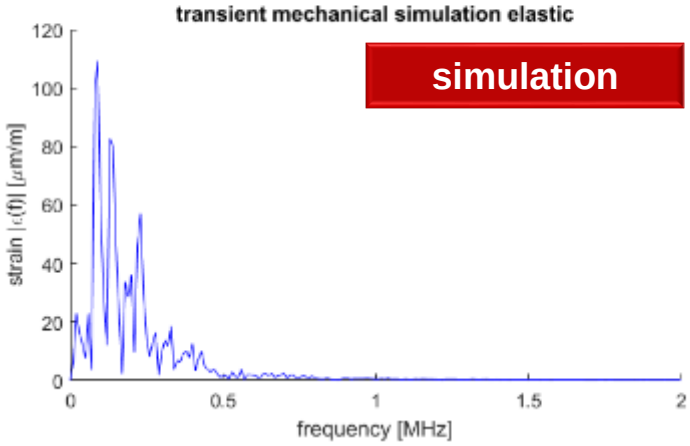
Numerical benchmarking – Structural, MoGr

- Structural: **MoGr 24 bunches**, σ 0.6 mm, impact 5σ
- **Elastic models for MoGr** so far: important to include plasticity! Difficult, because **anisotropic material**









Summary

- New materials developed in EuCARD^2, WP11: **MoGr** and **CuCD**
- Proposed as solutions for **HL-LHC collimators** (low-impedance primary and secondary, high-robustness tertiary)
- HiRadMat test (**HRMT-23**) in August 2015 to demonstrate the validity of the two HL-LHC collimators, and to test a TCSP at the energy density of HL-LHC injection error
- **CFC** and **MoGr survived** all impacts up to 288 b, σ 0.35 mm, grazing and deep impacts, **slightly in excess of peak energy density of HL-LHC and LIU BCMS Beam Injection Error**
- **CuCD survived** (with surface scratch) by 24 b, σ 0.35 mm roughly **equivalent to 1 full LHC bunch (asynchronous beam dump failure)**
- **TCSP Glidcop tapering locally melted**, **MoGr taperings** of TCSPM jaws **survived** unscathed the beam impacts → MoGr taperings to be considered also for all the other future collimators
- After HRMT-23, **green light for the construction of a prototype of secondary HL-LHC collimator (TCSPM) to be tested in the LHC in 2017** → production well ongoing

Next steps

- **Numerical/experimental benchmarking:**
  - **The plastic model proposed for CuCD seems to work well**, still few points to be addressed (material damping, signal phase, full-scale model)
  - Plastic model to be extended also to **CFC** and **MoGr** (so far, anisotropic elasticity considered) → wrt CuCD, further difficulty is due to the **material orthotropy**
  - More sophisticated signal analysis ongoing (e.g. **wavelet analysis**)
- **Post-irradiation campaign**:
  - **Tank opening** to be coordinated with RP, once activated dose will be low enough
  - With respect to past HiRadMat tests (HRMT-09 and HRMT-14) **lower level of contamination**
  - **Non-destructive** and **destructive tests** once opened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Thank you.