Preliminary results from HiRadMat "Multimat" experiment

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Objectives

- **Assess/validate materials** for HL-LHC
- Offer a single, flexible platform to test **specimens** of a large **palette of materials (**including **coatings, anisotropic materials, foams, AM etc.)** used in **Collimators** (and other **Beam Intercepting Devices**) under high brightness beams (as close as possible to HL-LHC and LIU/BCMS)
- Dedicated target stations to **assess behaviour of components** (sensors, electronic devices, beam diagnostics, etc.) in close vicinity of high intensity beams
- Acquire **online material dynamic responses** and **derive / extend constitutive models** (to be reused in simulating full scale devices) **without** reaching **extensive material degradation** (with the **possible exception of coatings**)
- **Benchmark** complex numerical **simulations** with little known constitutive equations
- Allow **rapid** specimens **disassembling** in view of **Post Irradiation Examination** completing material characterization

Configuration

- **Al** vessel hosting **16 target stations** on a **rotatable barrel**. Each target station equipped with several **specimens** of **18 materials**
- Vessel cooled by forced **Ar inert gas**
- **Comprehensive Acquisition system** based on Strain Gauges, Temperature probes, LDV, Rad-hard Camera

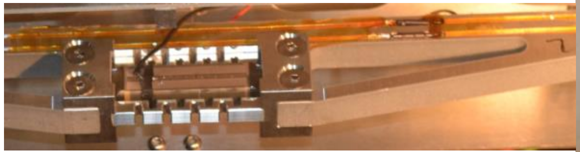
- Specimens of simple geometry (**slender bars, length 120 or 248 mm**) to generate simple wave signals, relatively easy to acquire and benchmark. Some low-Z samples coated (Mo, Cu, TiN)
- **Simply supported bars**, axially free to expand
- Mainly **square cross section** (8×8 to 12×11.5 mm^2) to disentangle anisotropy and simplify PIE

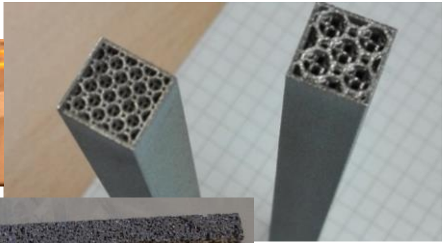
Specimens

#	Material	Density [g/cm³]	Coated	Coating Material
1	IT180	18.0	✗	
2	Ta10W	16.9	✗	
3	Ta2.5W	16.7	✗	
4	TZM	10.0	✗	
5	CuCD IFAM	5.40	✗	
6	CuCD RHP	5.40	✗	
7	SiC	3.21	✗	
8	MG-6403Fc	2.54	✓	TiN
9	ND-7401-Sr	2.52	✗	
10	MG-6530Aa	2.50	✓	Cu
11	MG-6541Fc	2.49	✓	Mo
12	HOPG	2.26	✗	
13	TG-1100	2.19	✗	
14	R4550	1.90	✓	Cu
15	CFC AC150K	1.88	✓	Mo
16	Ti6Al4V (AM)	1.62	✗	
17	CFOAM	0.40	✗	
18	Al 6082-T651 (UoHud)	2.70	✗	

high density (1–4); medium density (5–7); low density (8–17); Dedicated setup (18)

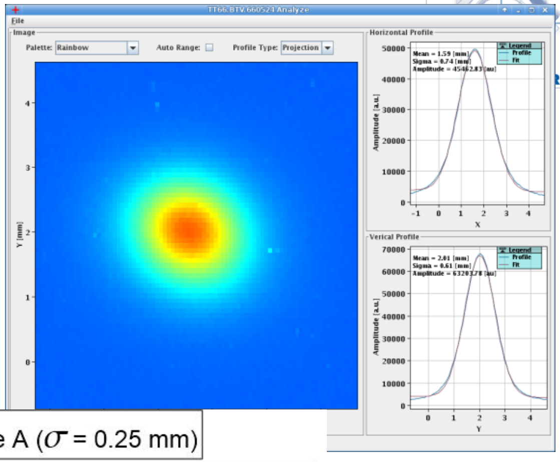
- 18 materials/grades to be tested.
- **4 grades of MoGr from 2 manufacturers** (BB and Nanoker)
- **3 coatings, Cu, Mo (CERN) and TiN (DTI)**
- Different combination of surface and thermal treatments (48h firing, CO_2 blasting, US cleaning);
- 2 grades of **CuCD** from 2 suppliers (RHP and IFAM)
- **Novel carbon-based materials** as HOPG (Highly-Ordered Pyrolitic Graphite) and Titanium-Graphite (TG-1100)
- Additively Manufactured **Titanium samples** (Ti6Al4V);
- **Actively controlled** (via piezoelectric transducers) Al samples (UoH)

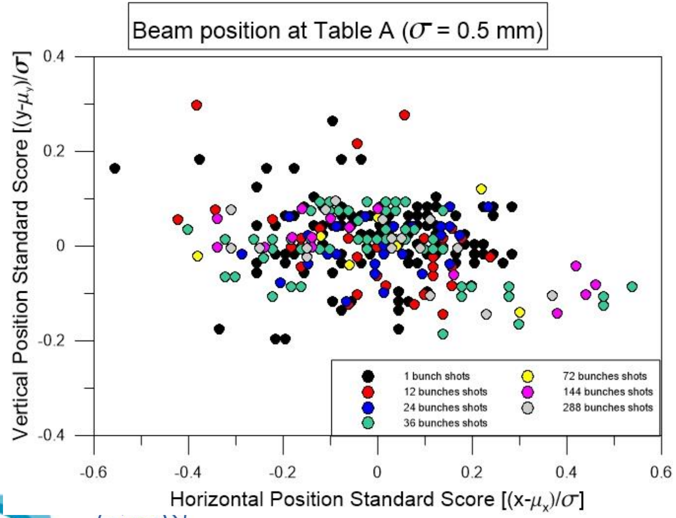


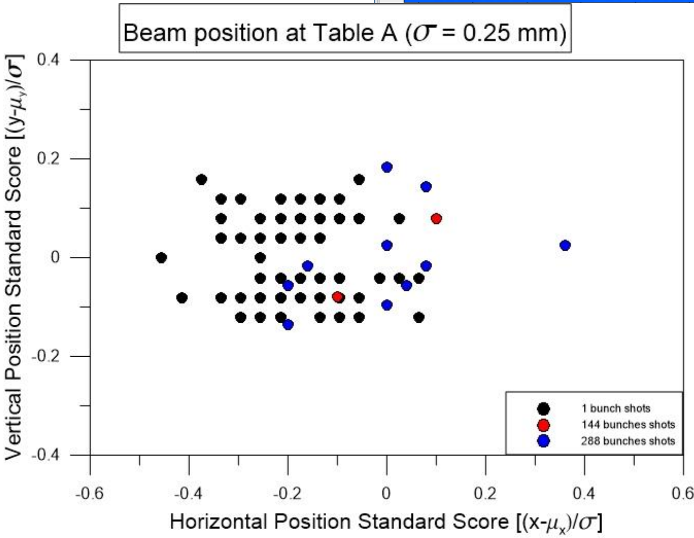


Experimental run

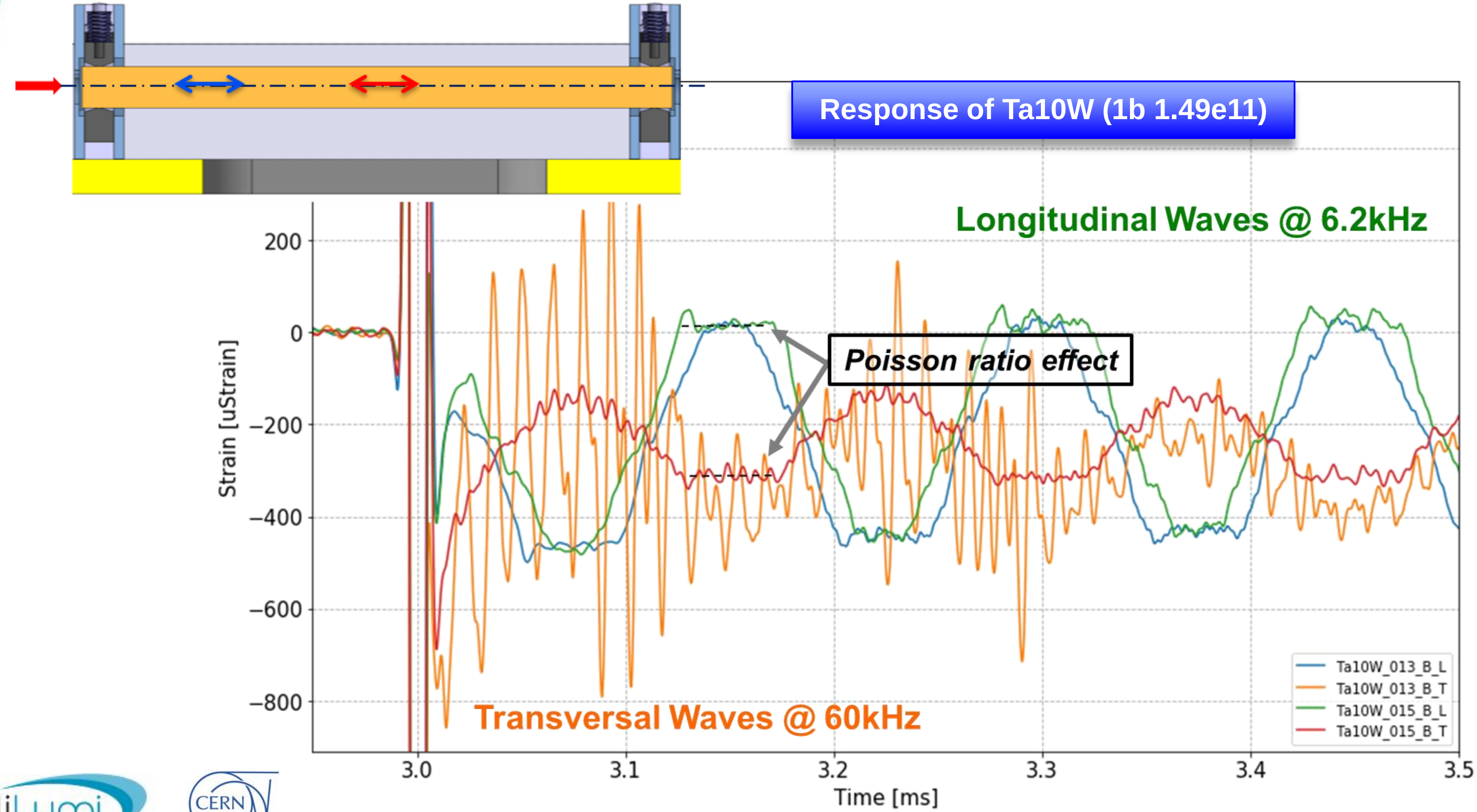
- Installed 2 October
- Experimental runs from **3 October to 17 October**
- 478 pulses (including BBA and parking position). **2.25×10^{15} POT**
- Intensity ranging from **1 b to 288 b**, typically 1.3×10^{11} p/b
- Beam rms size (nominal): 0.25×0.25, 0.5×0.5, 2×2 mm^2
- **Good beam stability and repeatability**, particularly important for grazing impacts



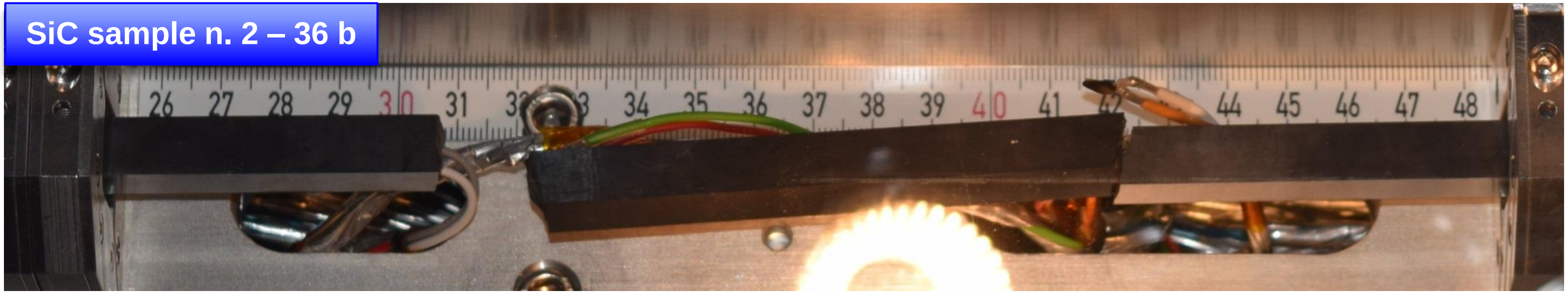


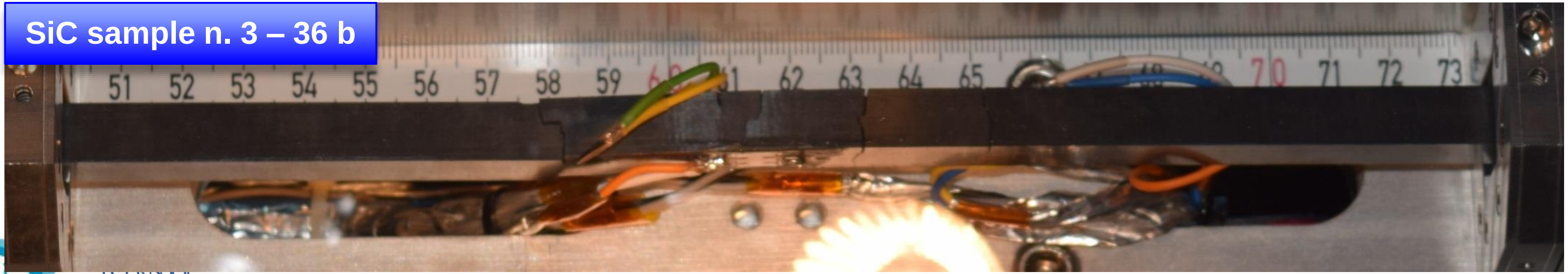


Results – Centred impacts

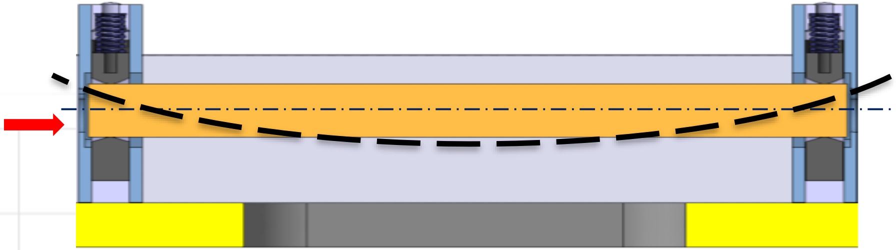


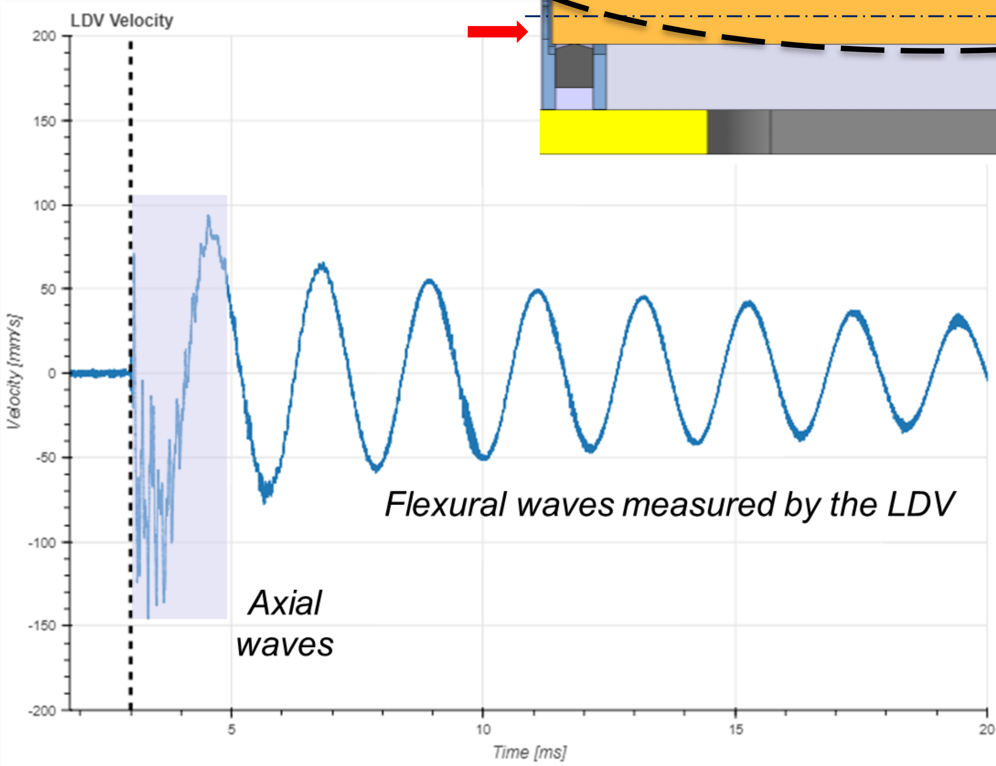
Results – Centred impacts





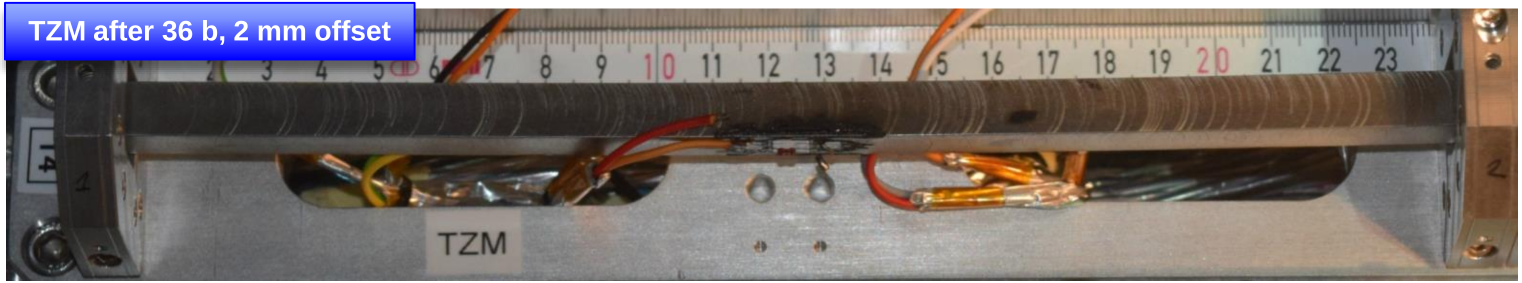
Results – Offset impacts



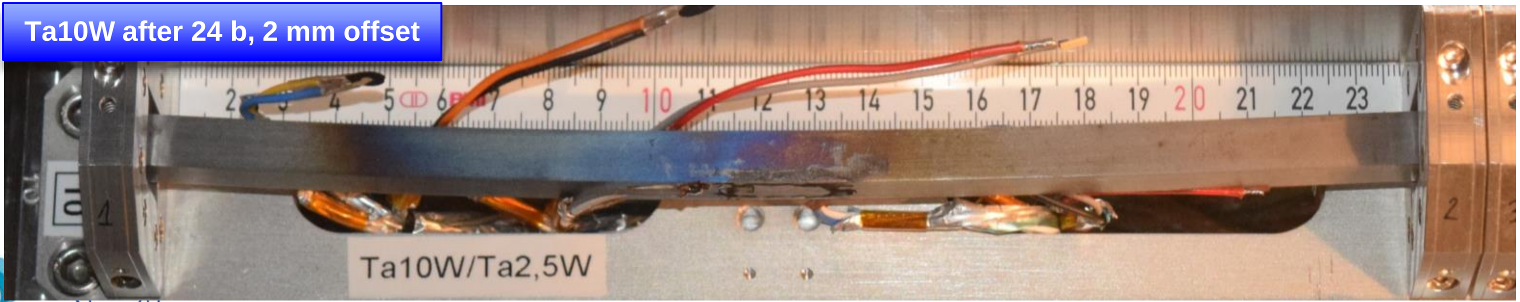


Results – Offset impacts

IT180 after 24 b, 2 mm offset



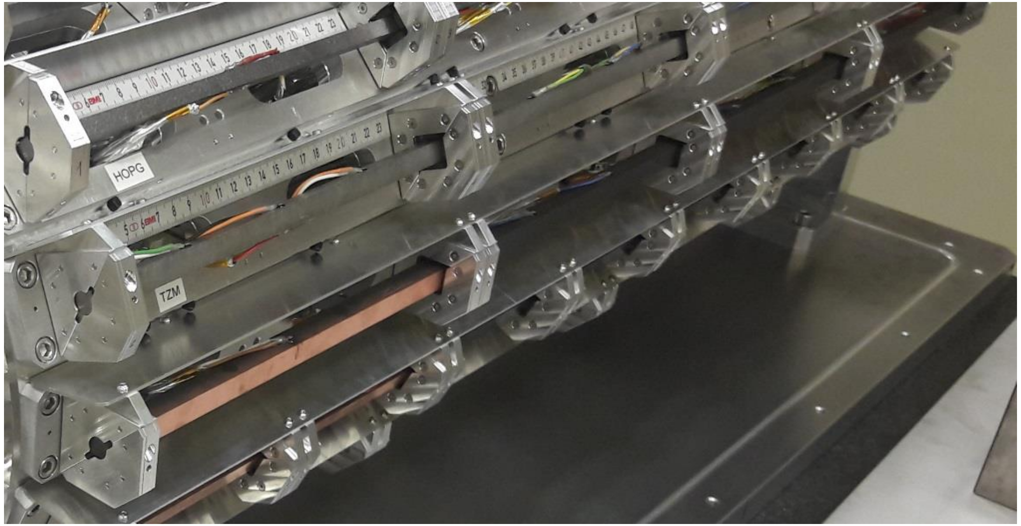
TZM after 36 b, 2 mm offset

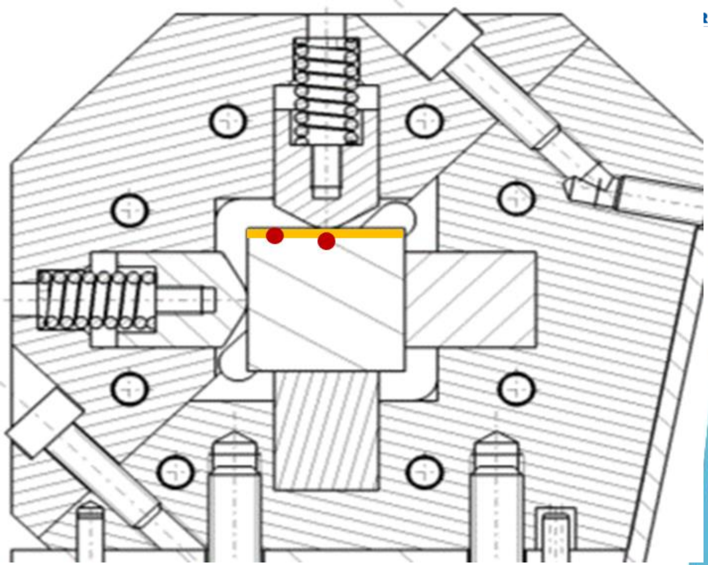


Ta10W after 24 b, 2 mm offset

Results – Grazing impacts

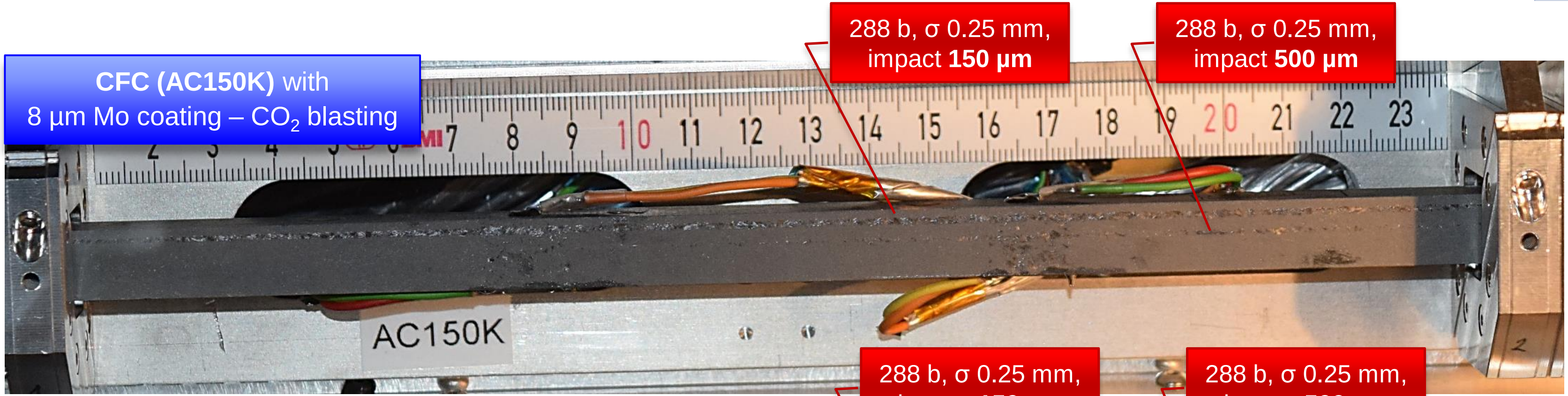
- Goal: assess coating strength (Cu, Mo, TiN) and surface damage.
- Coating on first specimens for a total coated length of ¼ m
- Smallest available beam size (**0.25×0.25 mm²**) at max bunch intensity (**1.4e11 p/b**) to mimic or exceed **HL-LHC energy density**
- Impacts at **144** (on Cu) and **288 b** (all) at different spots

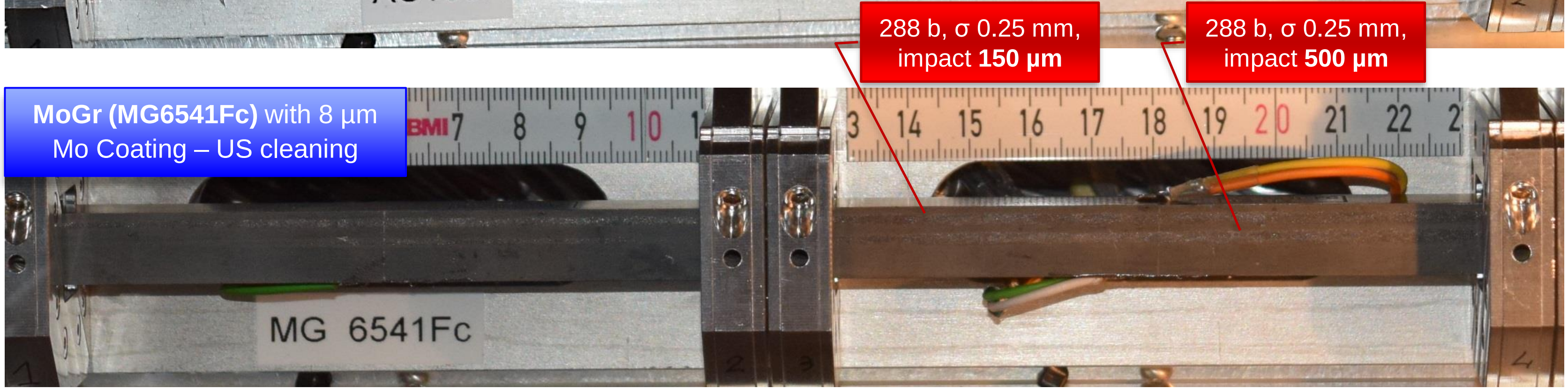




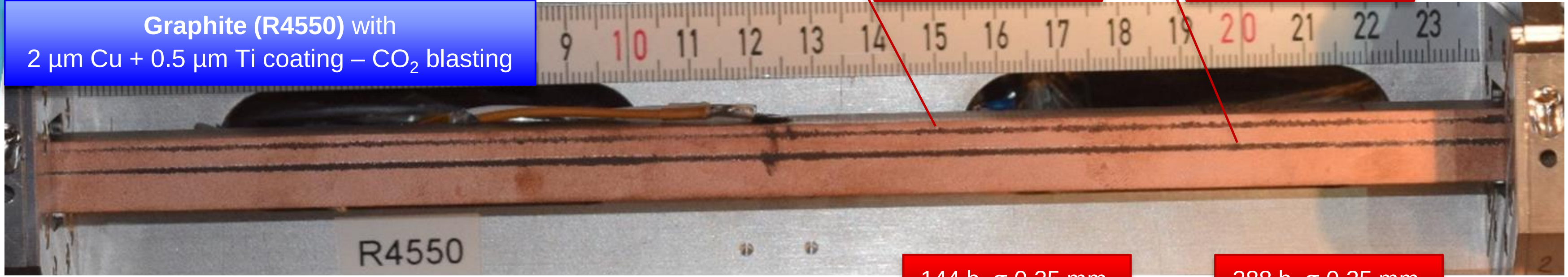
- 2 impact parameters: **150 µm** and **500 µm**
- Target alignment by BTV combined with Beam-based alignment

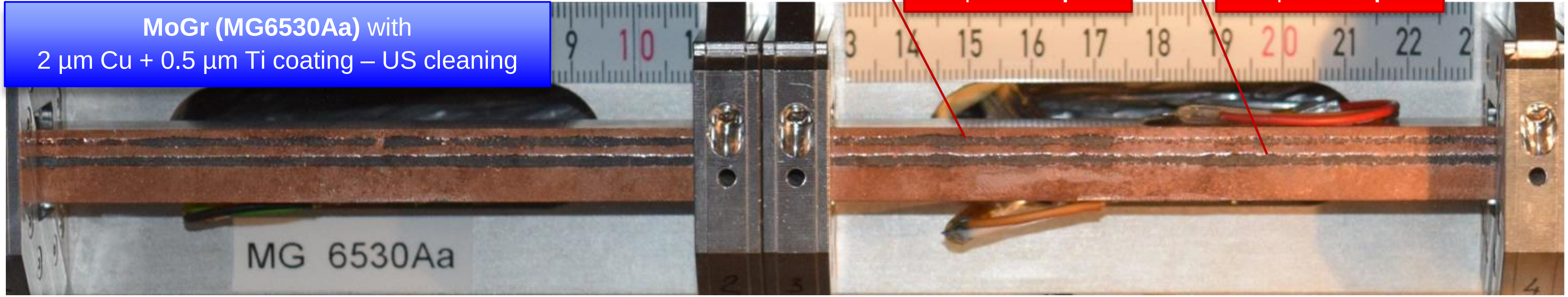
Results – Grazing impacts, Mo coatings



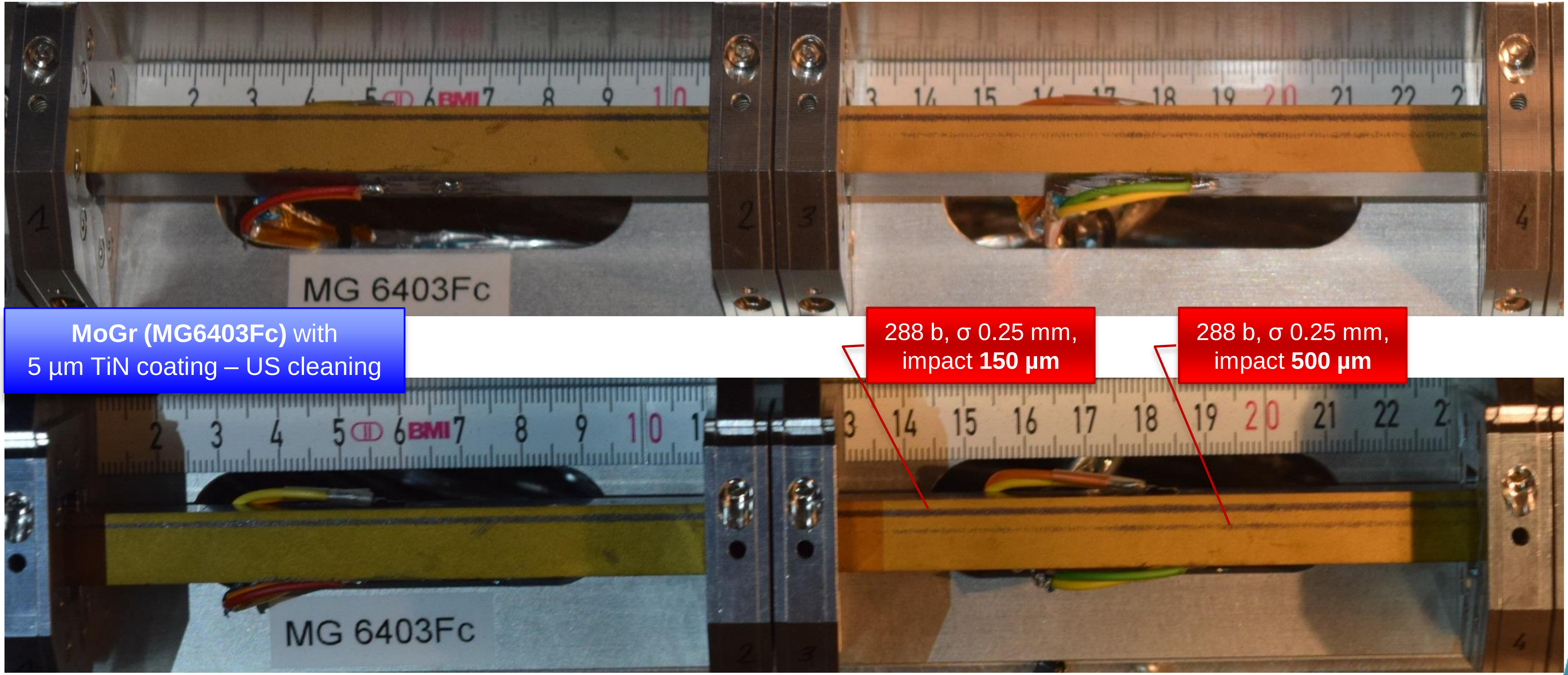


Results – Grazing impacts, Cu coatings





Results – Grazing impacts, TiN coatings



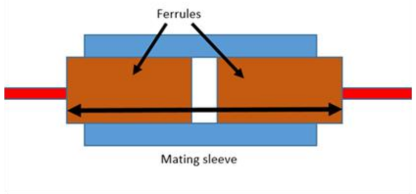
MoGr (MG6403Fc) with
5 µm TiN coating – US cleaning

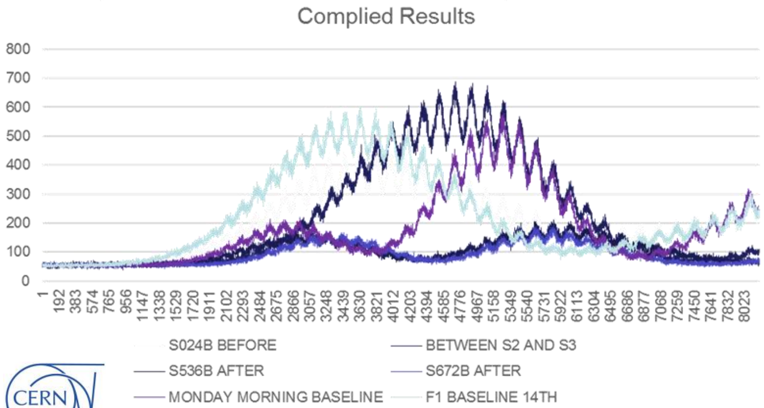
288 b, σ 0.25 mm,
impact **150 µm**

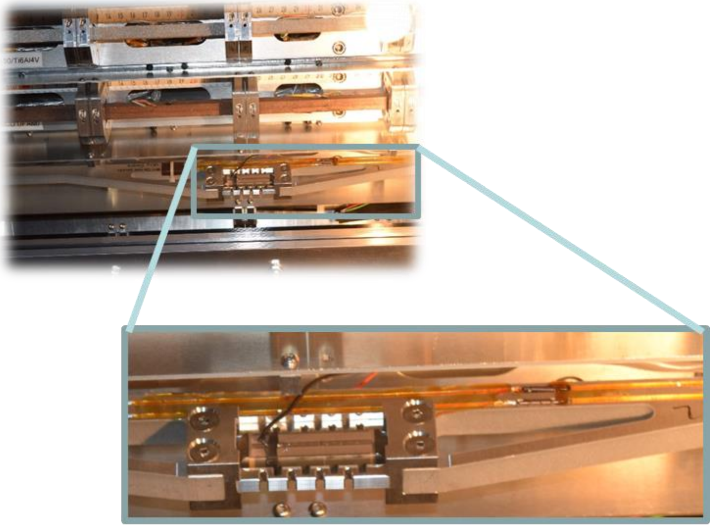
288 b, σ 0.25 mm,
impact **500 µm**

Results – MACS (UoH)

- **Multimat Adaptive Collimator System (MACS)**
- Fibres survived with same returned light intensity as started
- Piezo actuators still operational – observed by increased noise in signal response
- Noisy results on flexural response: UoH working on new algorithm to cope with low intensity data.
- Termination cavity issue solved as future fibres will be fusion spliced.

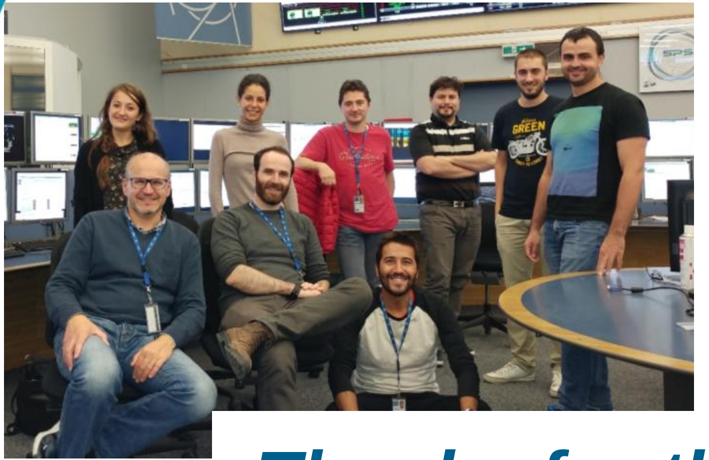


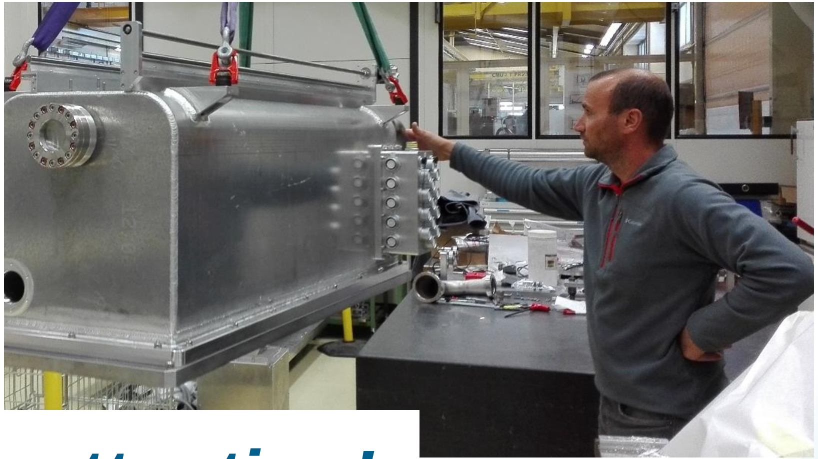




Summary

- MultiMat experiment was **successfully concluded** in October 2017 totalling ~2.3e15 POT
- **Good stability and repeatability** of delivered pulses
- All **carbon-based materials** (C Foam, CFC, Isotropic Graphite, HOPG, MoGr, TiGr) **survived impacts at maximum available intensities**, in all conditions
- **Unexpected failure was only achieved in SiC**. A **TZM** sample failed possibly because of fabrication defect
- **Plastic permanent deflections** induced in **high-Z materials**
- **Surface damage was induced on coatings**: larger in Cu coatings (lower melting point), smaller in Mo and TiN. Damaged stripes ~ 1÷3 mm wide
- A number of unknown materials properties can be derived: dynamic constants, damping, viscoelastic parameters, dynamic strength … lots of work ahead!
- **MACS still operational after high intensity impact**: low signal to noise ratio makes assessment of flexural response difficult. System to be improved in next demonstrator





Thanks for the attention!