HiRadMat tests on collimator elements

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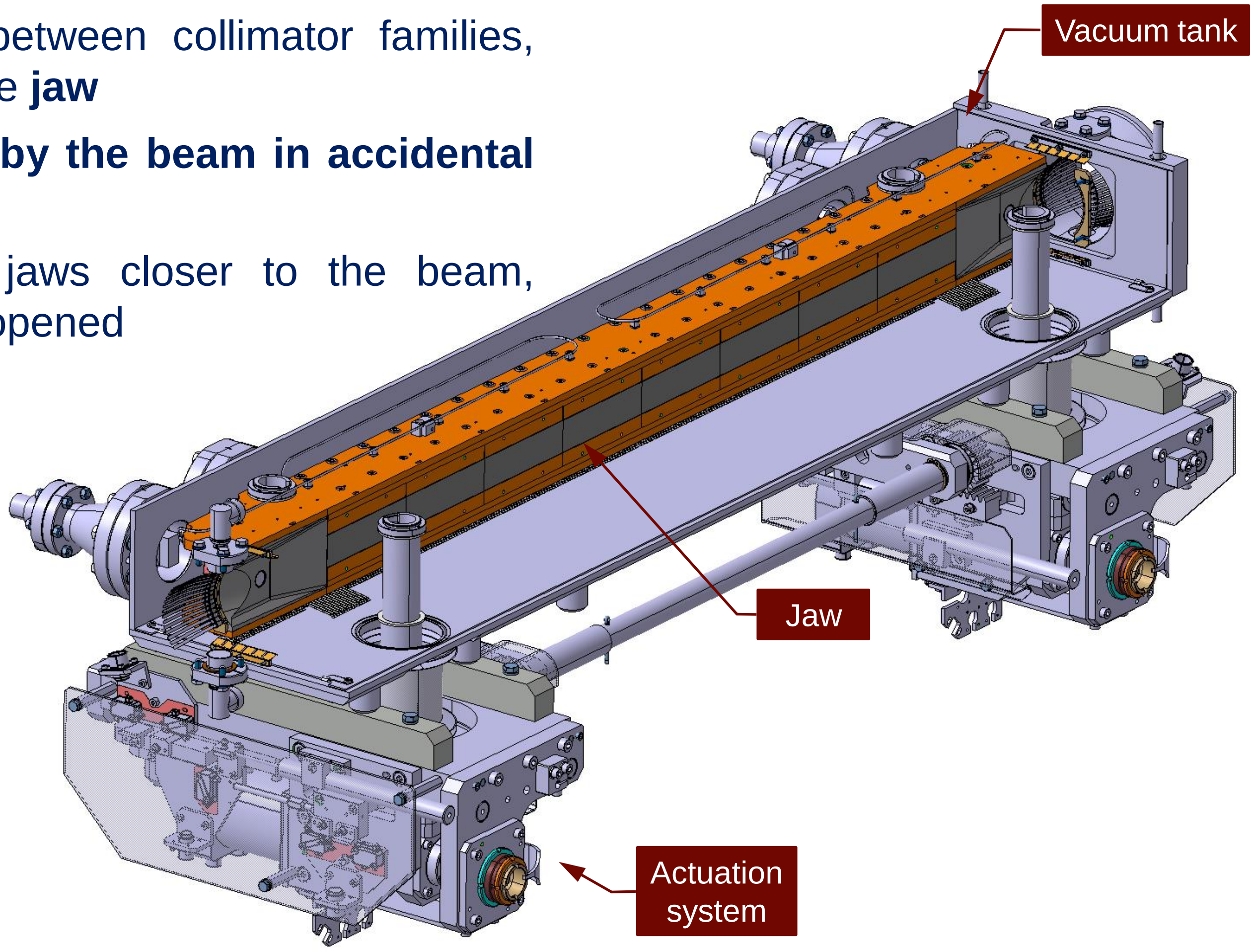
Outline

- LHC collimators
- Beam impact tests on collimators
  - Categories of tests
  - Before HiRadMat
  - With HiRadMat
- What tests do we need for HL-LHC?
- Conclusions

LHC collimators

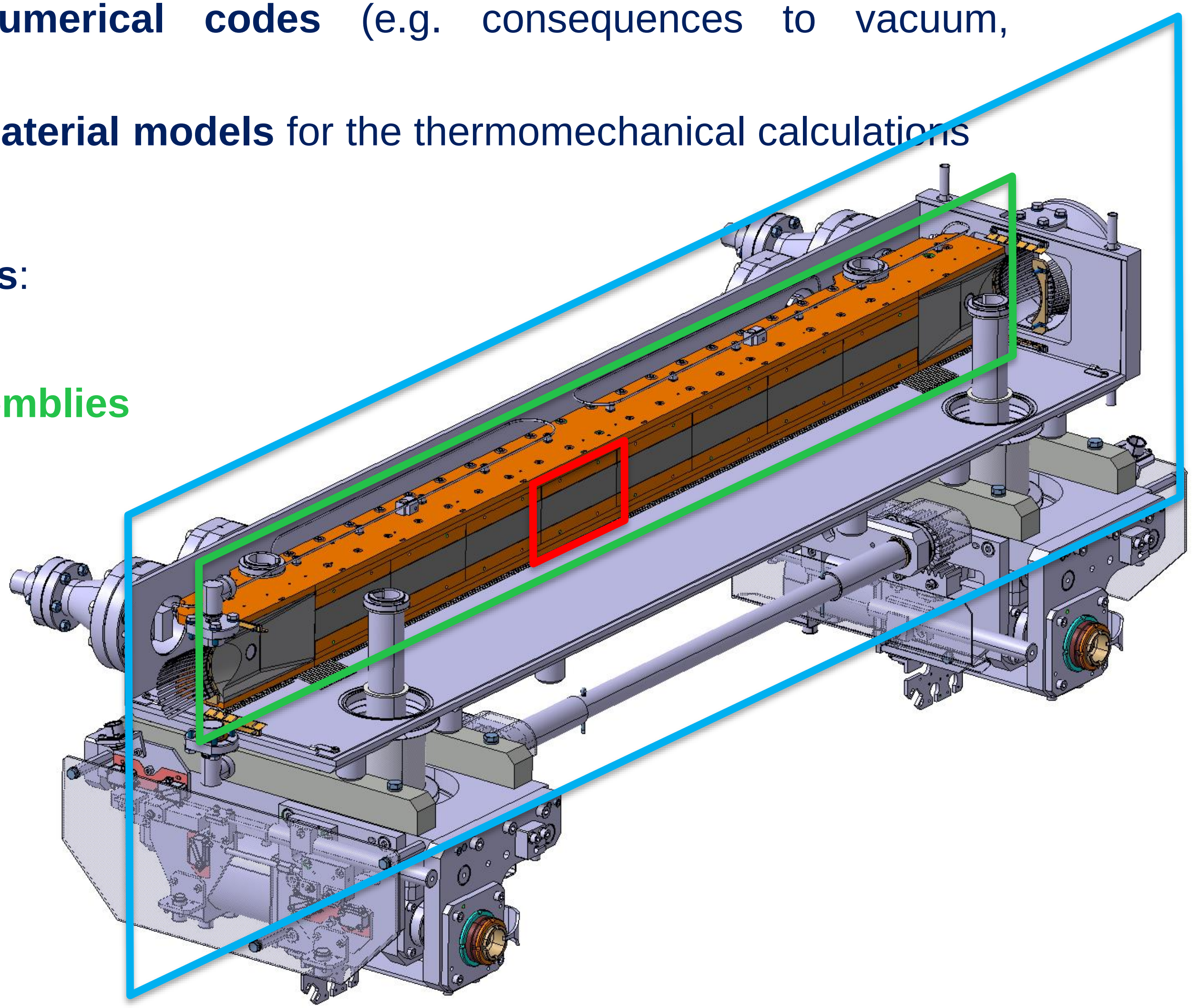
- Two main functions:
  - Beam cleaning
  - SC magnet protection
- Design quite similar between collimator families, main changes are in the **jaw**
- **Potentially impacted by the beam in accidental scenarios**
- Lighter materials for jaws closer to the beam, heavier for jaws more opened



Beam impact tests

- Advanced numerical analysis in the design phase must be complemented by experimental tests
- Necessary to assess **consequences of an impact to the structure unpredictable with numerical codes** (e.g. consequences to vacuum, contamination, etc.)
- Also, need of **deriving material models** for the thermomechanical calculations

- **Three main test categories**:
  - A. Material samples
  - B. Collimator sub-assemblies
  - C. Full collimators



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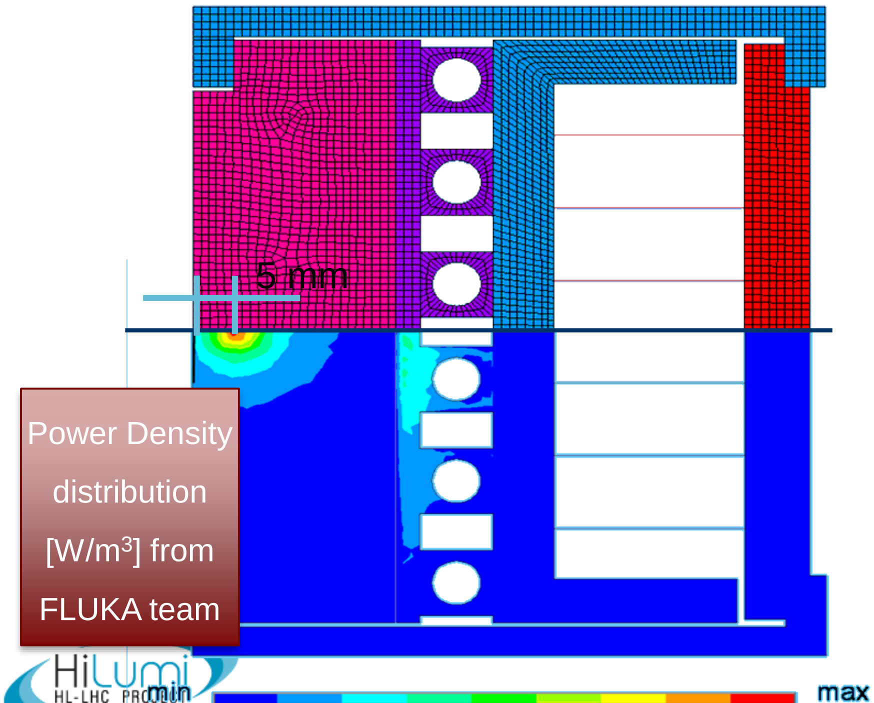
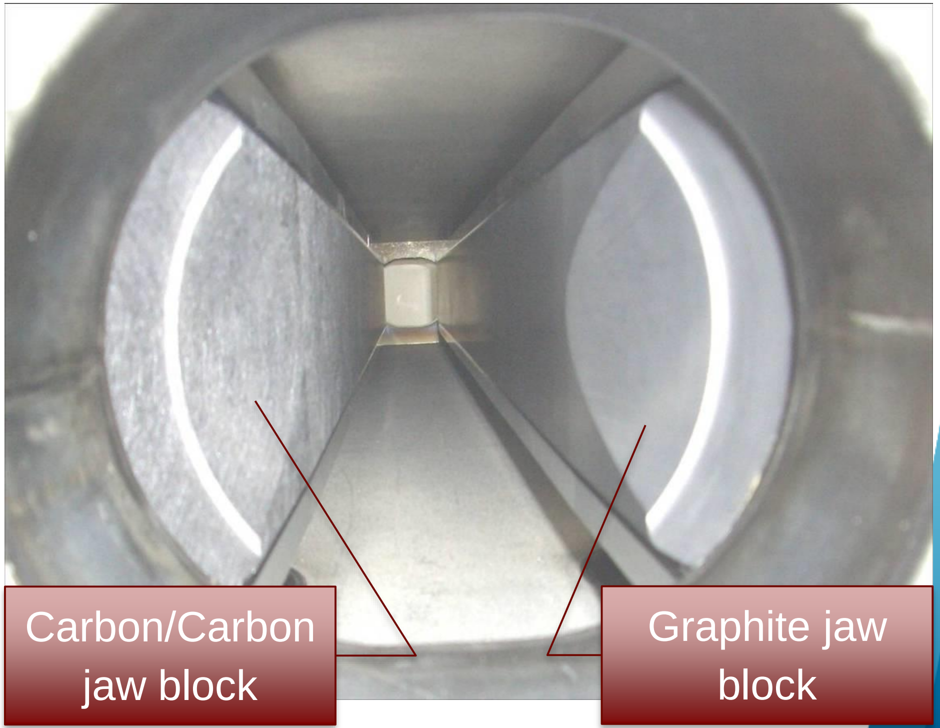
Before HiRadMat

- Before availability of the HiRadMat facility, tests on collimator **sub-assemblies (B)** (CFC and graphite jaws, with copper and Glidcop housing) in TT40 and TT60 (2004 and 2006)
- Impacts of 288 b, 450 GeV, σ = 1 mm^2 → design accidental scenario (**beam injection error**)
- Very important to assess the robustness of **graphitic materials**
- Allowed to choose **Glidcop over copper for the metallic structure**

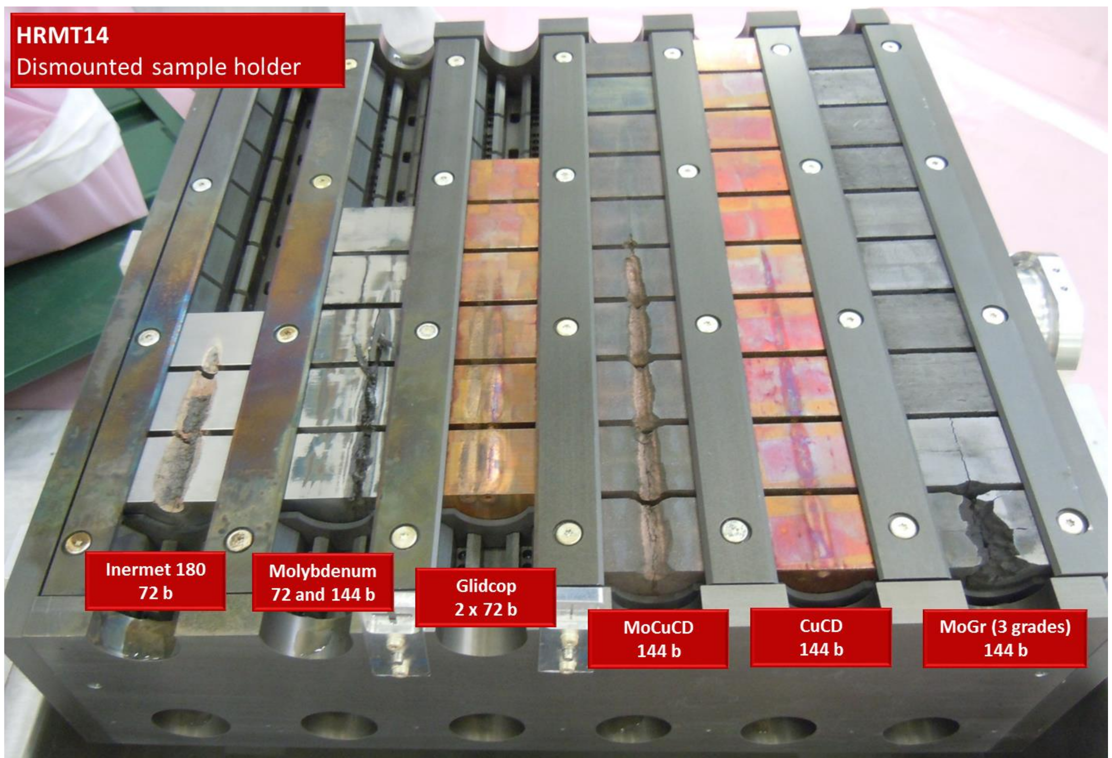
Typical collimator cross-section





With HiRadMat: tests on material samples (A) – HRMT14 (2012)

- Test of specimens from 6 different materials: Inermet180, Mo, Glidcop, MoCuCD CuCD, and MoGr (very old grade with high density, 5.4 g/cm3)
- Allowed **characterization of materials of interest for collimators**
- **Tuning of numerical models, with very good benchmarking between measurements and simulations**



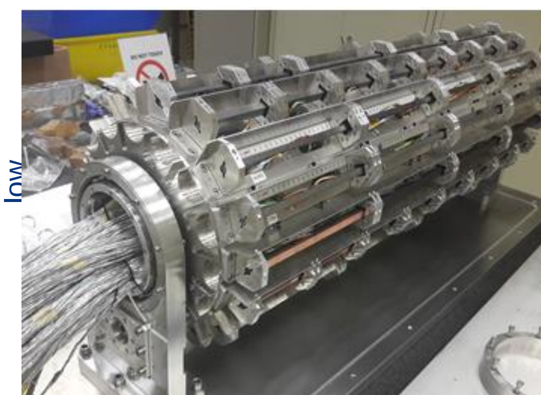
- *A. Bertarelli et al. (2013). An experiment to test advanced materials impacted by intense proton pulses at CERN HiRadMat facility. Nucl. Instr. Meth. Phys. Res. B 308:88–99.*

With HiRadMat: tests on material samples (A) – HRMT36 (2017)

#	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	✓	5μm TiN
9	ND-7401-Sr	2.52	✗	
10	MG-6530Aa	2.50	✓	2μm Cu
11	MG-6541Fc	2.49	✓	8μm Mo
12	TPG	2.26	✗	
13	TG-1100	2.19	✗	
14	R4550	1.90	✓	2μm Cu
15	CFC AC150K	1.88	✓	8μm 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)

- Test on 16 target stations, including **coated and uncoated material targets (rods)** and electronic devices
- Specimen geometry chosen to:
  - Generate easily detectable **uniaxial signals**
  - Enhance **maximum energy per section** (factor 2-3 above HL-LHC!) thanks to sample section ~1/10 of collimator jaw section
  - **Energy density peak** enhanced by squeezing the beam (30-50% above HL-LHC)



With HiRadMat: tests on material samples (A) – HRMT36 (2017)

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With HiRadMat: tests on collimator sub-assemblies (B) – HRMT23 (2015)

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- Test on **three collimator jaws: CFC (LHC design), MoGr and CuCD (HL-LHC design)**
- Allowed validation of **absorber jaw materials, as well as additional elements** (taperings, BPM, housing, cooling circuit, brazing)

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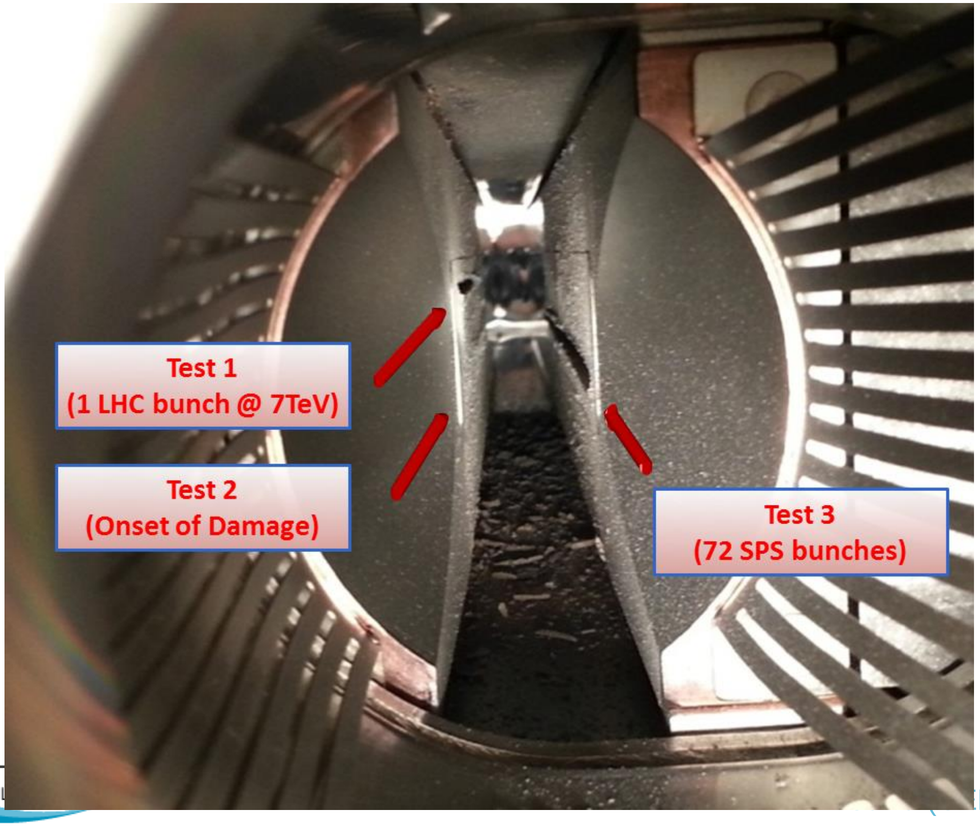
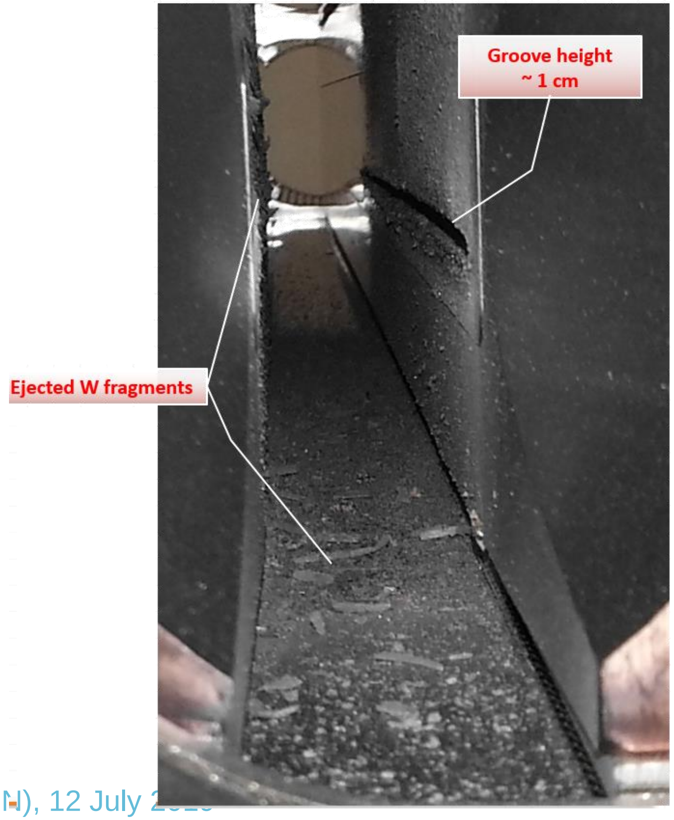
With HiRadMat: tests on full collimators (C) – HRMT09 (2012)

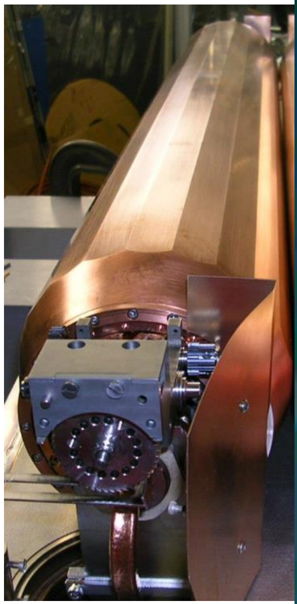
- Testing of a spare **TCT full collimator**
- Allowed to derive **damage limits for tertiary collimator jaws** (Inermet180)
- Highlighted **additional potential machine protection issues on top of mechanical damage**, due to projection of fragments and dust (UHV degradation, contamination of vacuum chambers, complication of dismounting procedure)

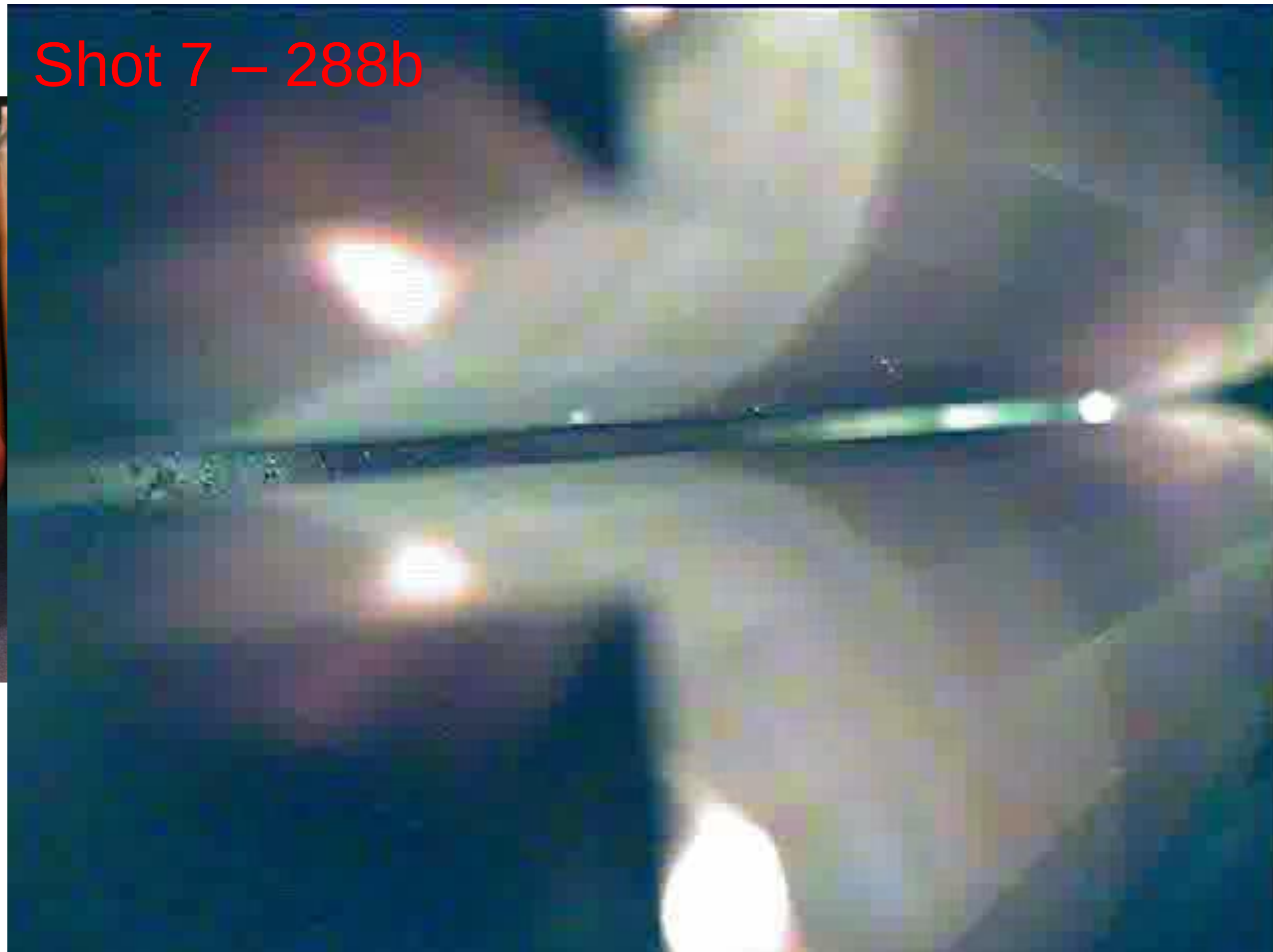




With HiRadMat: tests on full collimators (C) – HRMT21 (2017)

- Test on **SLAC rotatable collimator** (Glidcop)
- **Low-impedance secondary collimator** capable of withstanding 7 TeV failures





ent total energy

of plastic damage
ted to be around
@ 440GeV (141kJ)

mediary shots

n failure at 7Tev
@ 440GeV (1MJ)

C injection error
@ 440GeV (2.4MJ)

Future tests for HL-LHC

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- With LIU and HL-LHC, the bunch intensity will go up by **almost a factor of 2** (1.3E11 p → 2.2E11 p)
- So far, the HL-LHC **energy density peak** has b… e beam
- However, HL-LHC … samples (…
- … **onset of**
- … **…gy shower on collimator elements** … **…ary protons** (housing, taperings, BPM, pipes,

Future tests (categories A, B, C) in HiRadMat with the HL-LHC ultimate bunch intensity are of paramount importance for the Collimation Project, and of strong interest for the scientific community for extending the validity of material models

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Future tests for HL-LHC

- Aim is **re-using as much as possible the expensive elements** of previous test benches (mirrors, windows, feedthrough, pumps, supports, etc.)
- For experiments of category A (material samples), **multi-purpose tank with rotatable barrel to host up to 16 samples of desired geometry**

- For experiments of category B (sub-assemblies), we will see if we can re-use a tank adopted for past experiments
- For the tests of category C (full collimators), **prototypes at the end of their qualification lifetime** will be adopted

Conclusions

- **HiRadMat allowed to push tests on collimator elements** with respect to previous experiments in the SPS transfer lines (more extensive instrumentation, cameras, online diagnostics, controlled beam size and parameters)
- In the time period 2012-2017, important experiments were run in HiRadMat, providing **key elements for the design of new collimators, and for the improvements of the understanding of the beam/matter interaction and simulations**
- In view of the increase of beam stored energy in HL-LHC, as well as in future accelerators under design (FCC, CEPC-SPPC, etc.), we believe that **continuing the experimental studies in a future HiRadMat run is of paramount importance for the Collimation project, as well as for similar beam intercepting devices**
- The material models that could be extended are of **relevant scientific interest in all applications were dynamic loads are involved**

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Thanks for your attention!

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