HPTW 2014

5th High Power Targetry Workshop

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Simulations of Proton Impacts on Beam Intercepting Devices and Methods for an Experimental Characterization

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Abstract

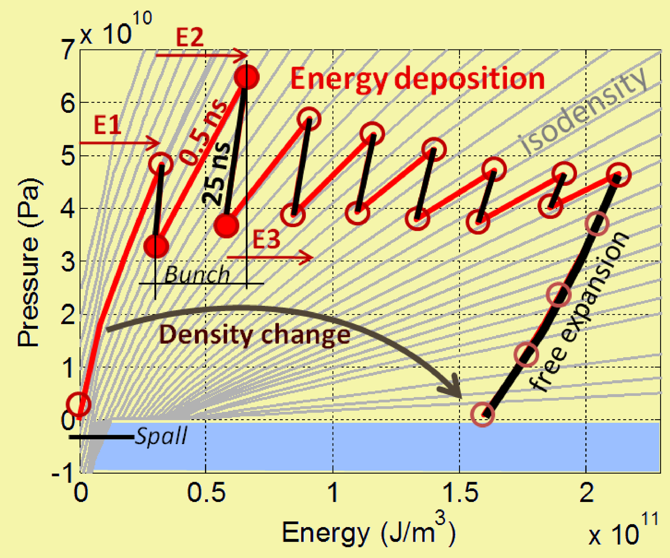
In recent years, state-of-the-art numerical methods, involving the use of Autodyn and LS-Dyna wave propagation codes, have been developed at CERN and at Politecnico di Torino in order to simulate the impact of a particle beam on solid accelerator devices such as collimators, windows, targets, dumps and absorbers. These methods were adopted by the authors in 2011 to analyze the consequences of an asynchronous beam abort on LHC Tungsten Collimators (TCT). In order to validate the material constitutive models, in 2012 and 2013 a vast characterization campaign has been launched, entailing advanced beam impact tests in the HiRadMat facility and high-speed mechanical measurements at Politecnico di Torino with the Hopkinson bar setup. The experiments confirmed the effectiveness of numerical methods to reliably predict beam-induced damages, also allowing to improve the material models. New simulations were then performed, adopting the refined material models and the updated accident scenarios; damage limits were also redefined, to identify the threshold of incipient plastic damage on the tungsten jaw.

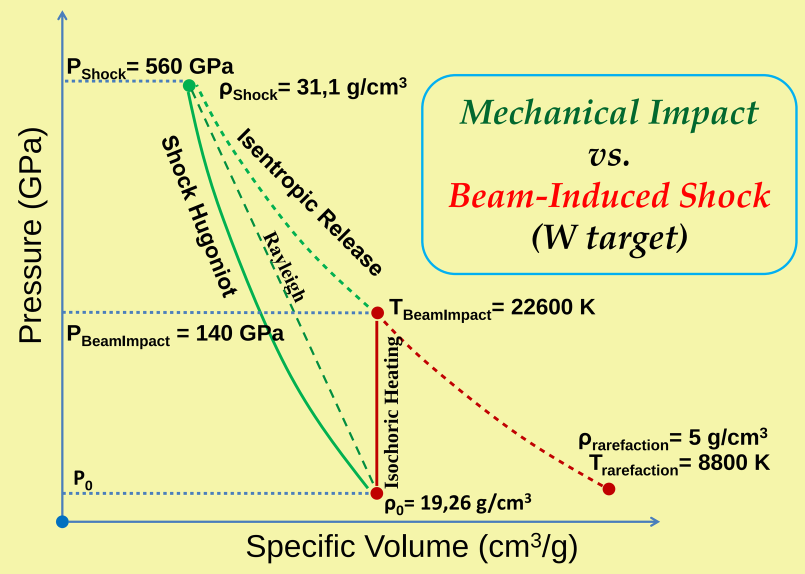
Particle Beam Impact on Solid Targets

*High-energy particle beams impacting a solid target provoke fast isochoric heating, generating intense **cylindrical shock-waves**.*

- ***Mechanical shock**: melting occurs only during the release phase following extremely intense mechanical impacts*
- ***Beam-induced shock**: melting occurs already during the isochoric heating (material in compressive state) at relatively low pressures*

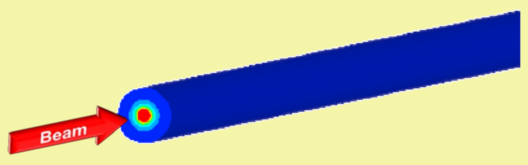
The two phenomena allow exploring completely different regions of the EOS:

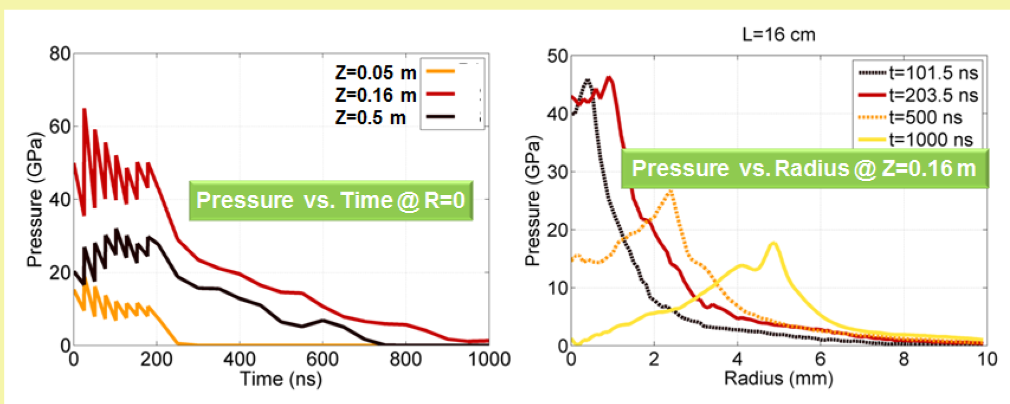




Cylindrical Cu OFE Target

EOS: Cu SESAME 3320



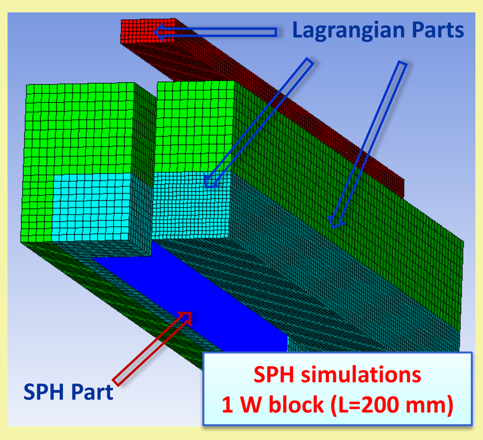


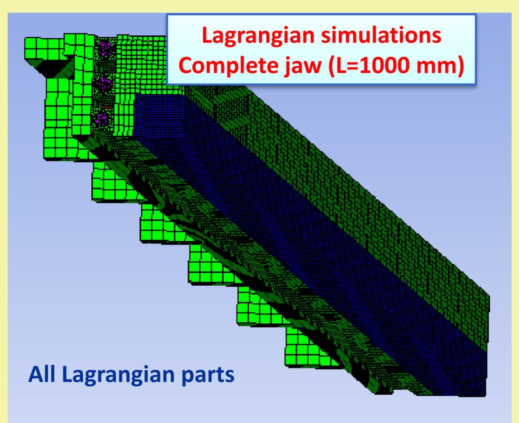
Numerical Simulations at CERN

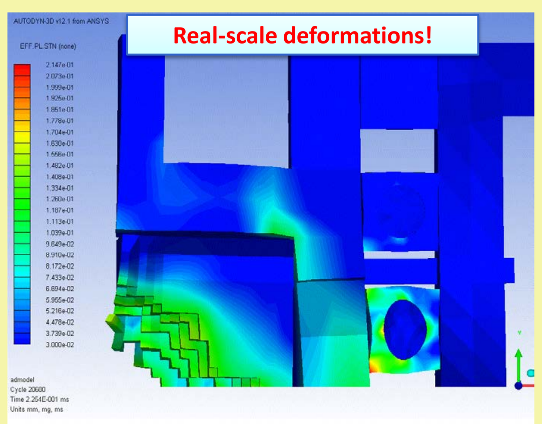
*Numerical methods to simulate beam-impact scenarios on accelerator devices have been developed at CERN in recent years. Extreme phenomena such as **phase changes, spallation, explosions** are studied with wave propagation codes such as Autodyn®.*

Catastrophic failure scenario on a tungsten collimator

*During Chamonix Workshop 2011, a study of asynchronous beam abort on a tungsten collimator was presented. The catastrophic scenario leading to water leakage on the cooling pipes and dramatic jaw deformation occurs **at 5 TeV energy** and **1x10¹² p. pulse intensity**.*





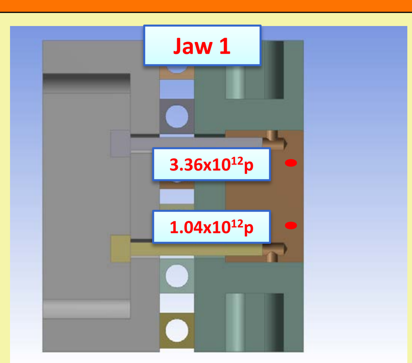


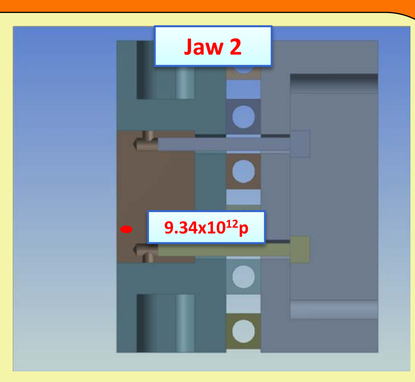
Experimental Benchmarking: HiRadMat

*In order to validate the material models used in the explicit simulations, two different particle-beam impact tests were performed in 2012 in the **HiRadMat facility** at CERN (SPS beam: 450 GeV, intensity up to 2x10¹³ protons).*

HRMT09 experiment

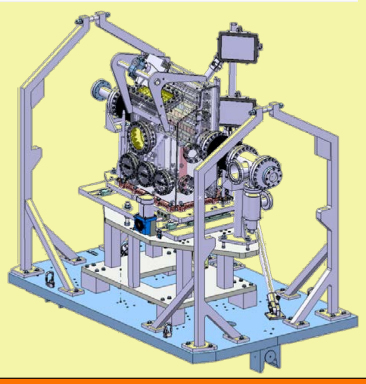
LHC spare TCT impacted in 3 different spots with increasing pulse intensity.

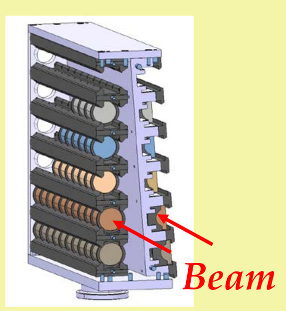




HRMT14 experiment

Sample holder to test 6 materials (2 different shapes, for tests at medium and high intensity).





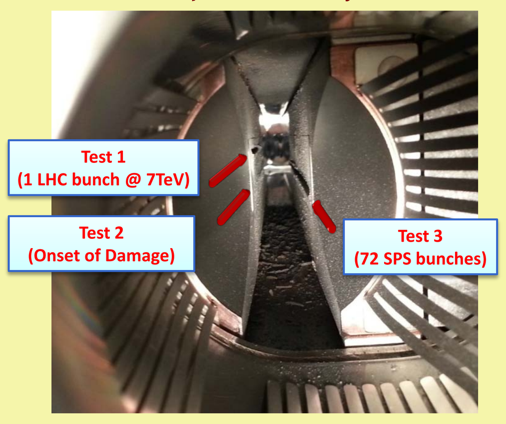
Experimental Benchmarking: HiRadMat

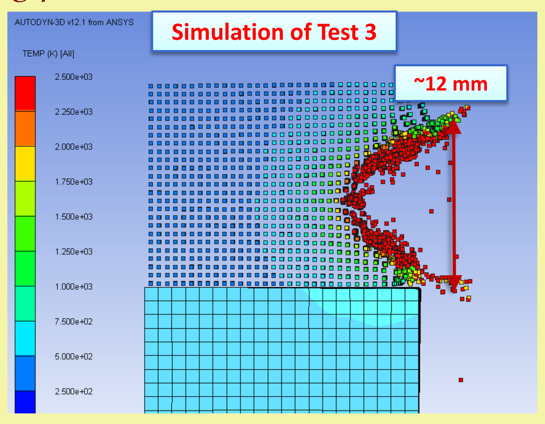
Both experiments wholly successful: they confirmed the effectiveness of numerical methods and material models to reliably predict beam-induced damages (error band < 25%).

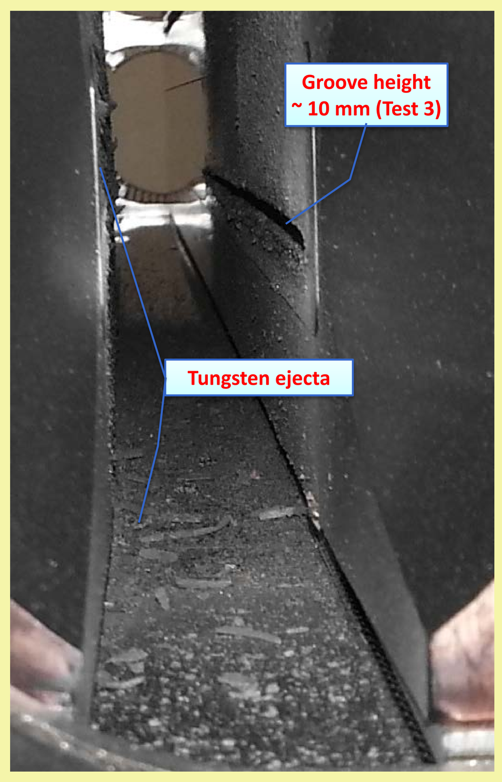
HRMT09

*The experiment highlighted additional potential machine protection issues, on top of mechanical damage, due to the generation of **tungsten ejecta**:*

- *UHV degradation*
- *Contamination of tank, bellows, vacuum chambers …*
- *Complication of dismounting procedure*

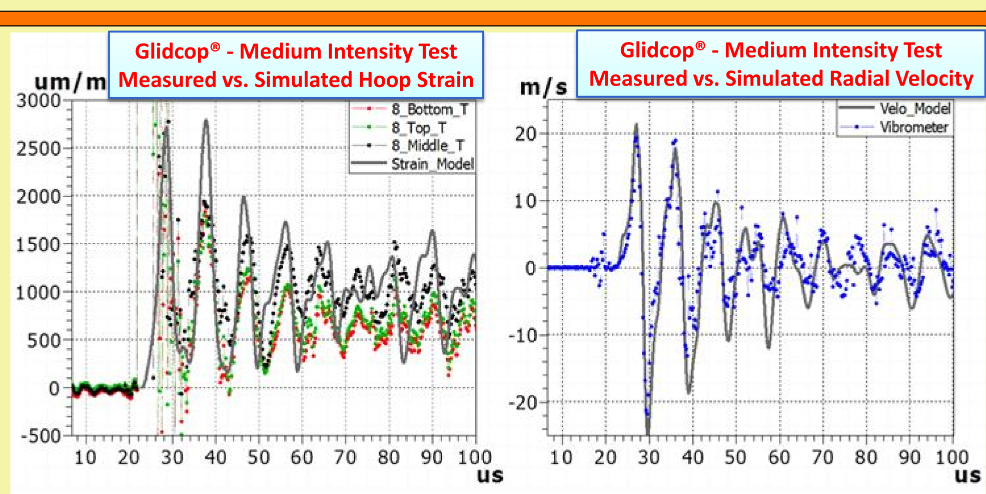


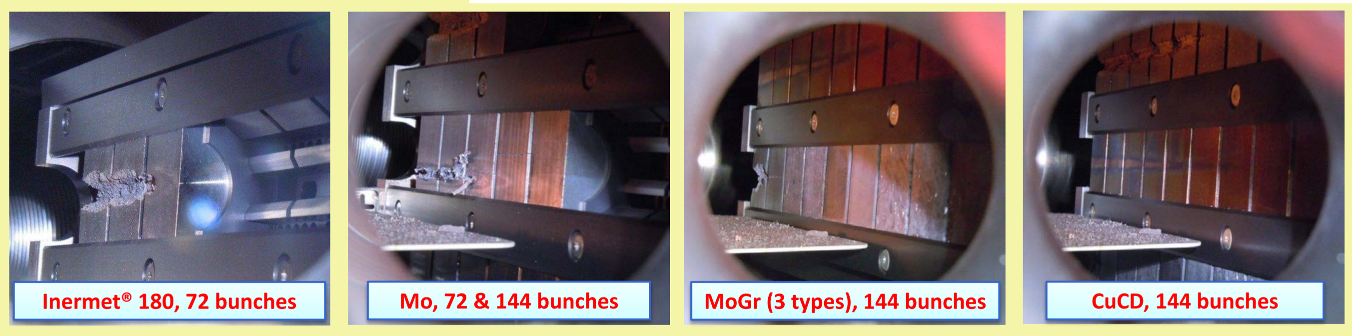




HRMT14

- *Excellent behavior of the instrumentation in a harsh environment*
- *Good benchmarking measurements/simulations!*
- *Large amount of data to derive constitutive models for less known composite materials*



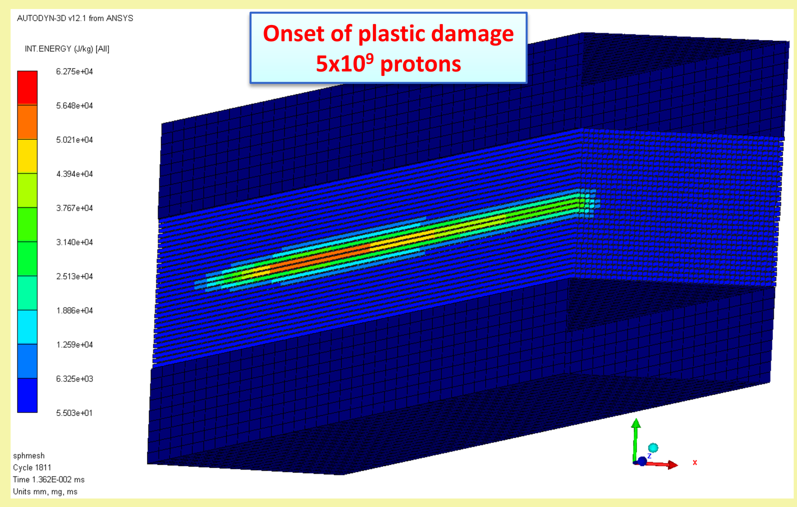


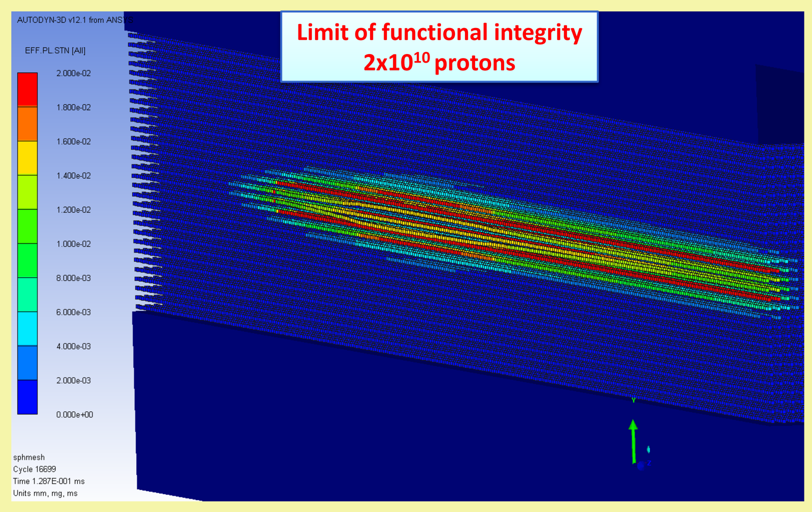
Updated TCT Robustness Limits

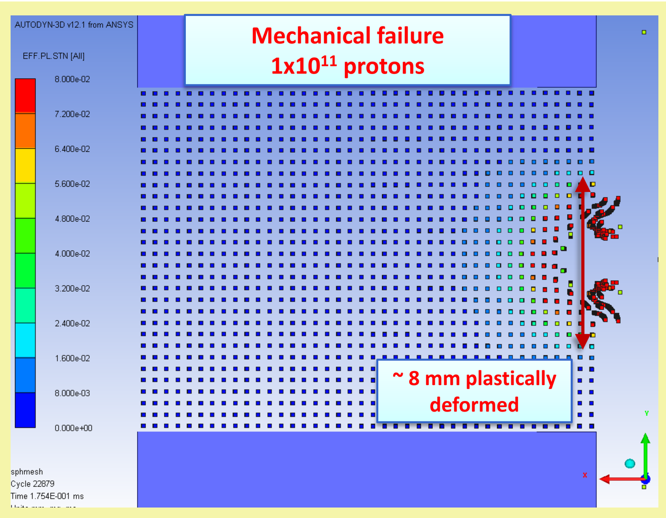
Follow-up of Chamonix 2011: new Autodyn® simulations performed considering one bunch with variable intensity impacting the jaw with a likelier impact parameter; models updated on the basis of HiRadMat results.

Three questions to address:

1. *What is the initial **damage threshold** (onset of plastic damage) at 7 TeV?*
2. *What is the limit of **functional integrity** (no generation of ejecta) at 7 TeV?*
3. *What is the intensity at 7 TeV which induces a **mechanical failure of the collimator?** (radius of the removed W volume > 8 mm → cannot be compensated by moving the jaw vertically)*







	Onset of damage	Limit of functional integrity	Mechanical failure
Energy [TeV]	7	7	7
Impact depth [mm]	0.5	0.5	0.5
Beam size [s_x x s_y mm²]	0.5 x 0.5	0.5 x 0.5	0.5 x 0.5
Number of bunches	1	1	1
Jaws gap [mm]	20	20	20
Pulse intensity [p]	5 x 10⁹	2 x 10¹⁰	1 x 10¹¹

LHC pilot bunch intensity!

LHC CERN