Replication of near-supersonic, runaway electron induced dust-wall impacts using a two-stage light-gas gun

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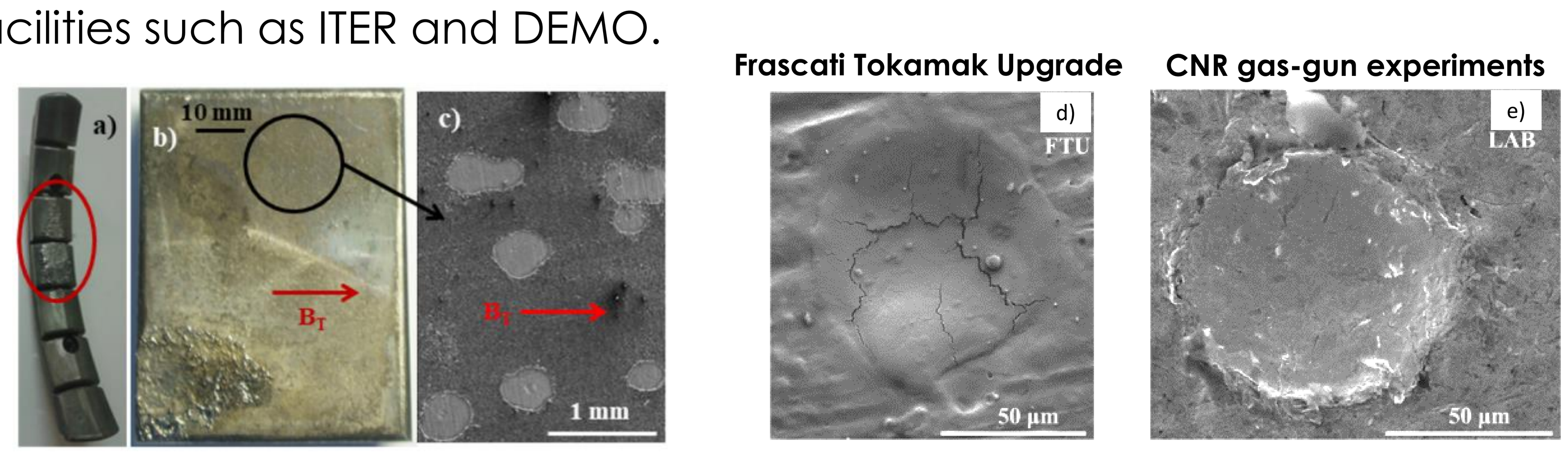
Dust-wall mechanical impacts in tokamaks

Tokamak disruptions can generate relativistic runaway electrons which terminate on plasma-facing components leading to bulk melting [1], material explosion and the release of fast solid debris [2].

The solid dust particles are ejected with speeds of the order of ~km/s and their impacts on the vessel yield further delocalized damage [3].

Understanding dust-wall mechanical impacts is critical for fusion research facilities such as ITER and DEMO.



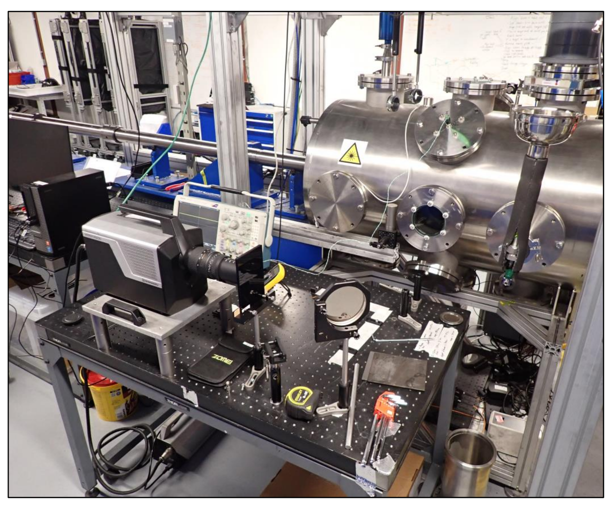
(a) Direct, relativistic-electron induced damage on the poloidal limiter tiles at FTU.
(b,c) Indirect damage due to dust impacts on the line-of-sight toroidal limiter tiles.
(d,e) Reproduction of craters in gas-gun experiments at CNR allows identification of dust size and speed [2].

Experiments using First Light Fusion's two-stage light-gas gun

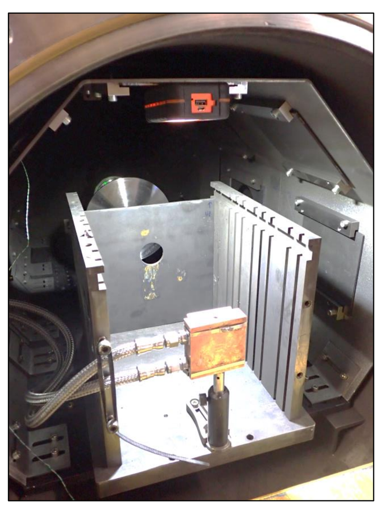
The dust-wall mechanical damage at FTU was replicated by accelerating solid molybdenum particles into a cryogenic TZM target using FLF's "small" gas-gun [4].

- 7.5 m long, 12.7 mm diameter bore, powder driven
- Can accelerate a ~3 g projectile up to ~7 km/s

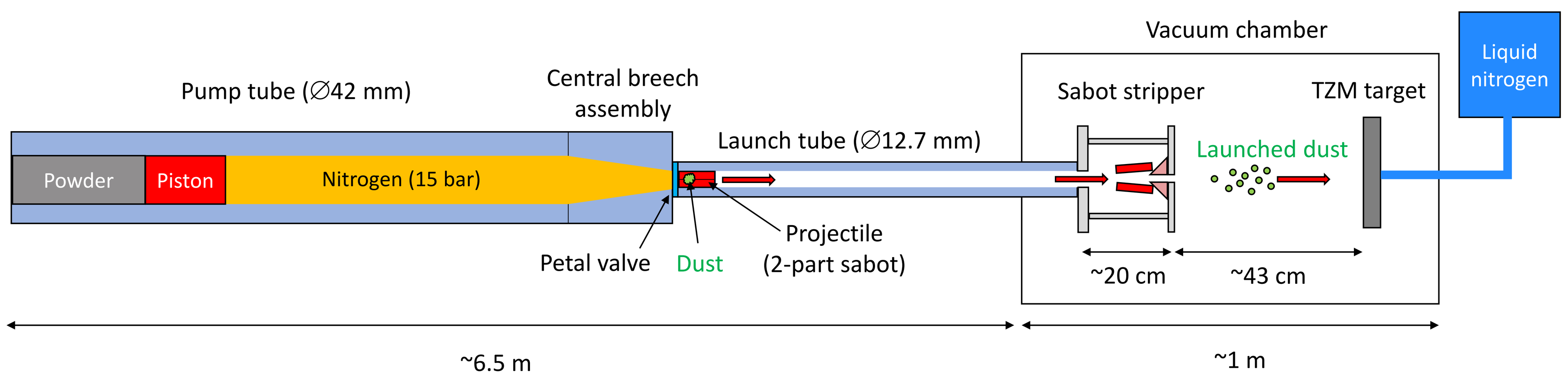
FLF's small gas-gun.



Fast-framing optical camera diagnostic.



Cryogenic TZM target.

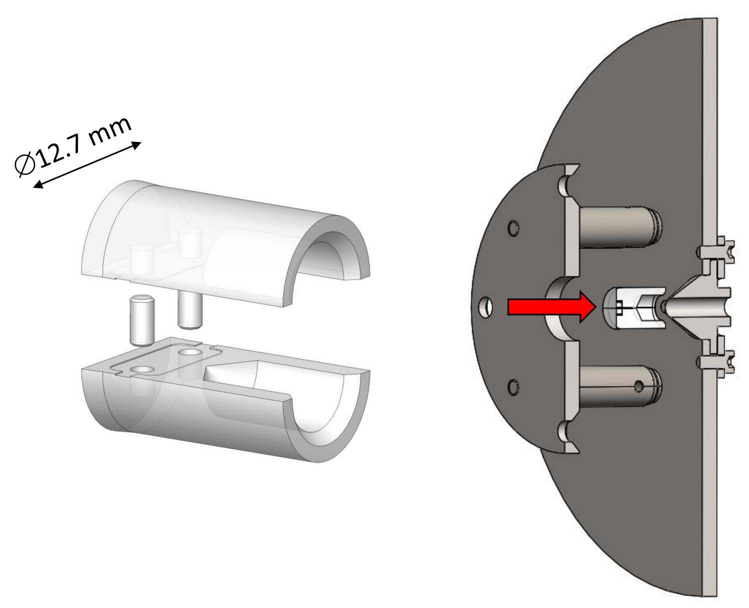


Schematic experimental setup to launch dust particles into a cryogenic TZM target.

Two-part sabots and a sabot-stripper were designed and tested.

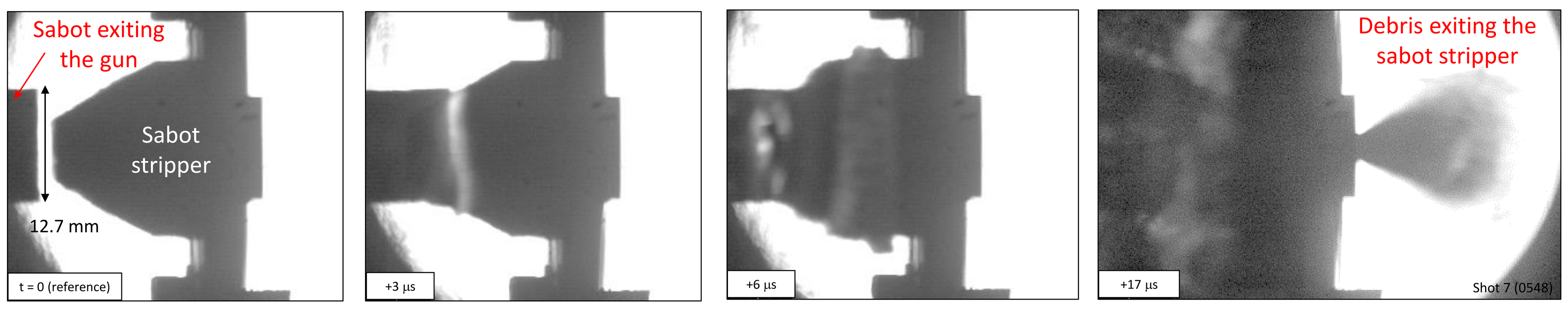
The sabot exiting the gun's barrel was imaged optically (128 frames, 500 ns interframe, 200 ns exposure).

An optical laser (λ = 632 nm, 30 μs pulse duration) was used to perform side-on backlighting imaging.

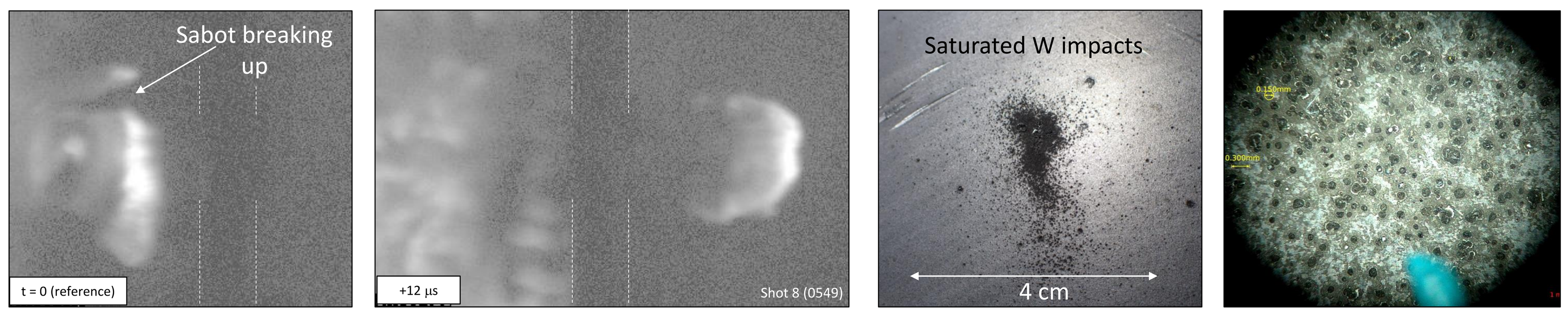


Two-part sabot and cut-view of the sabot stripper.

Testing two-part sabots



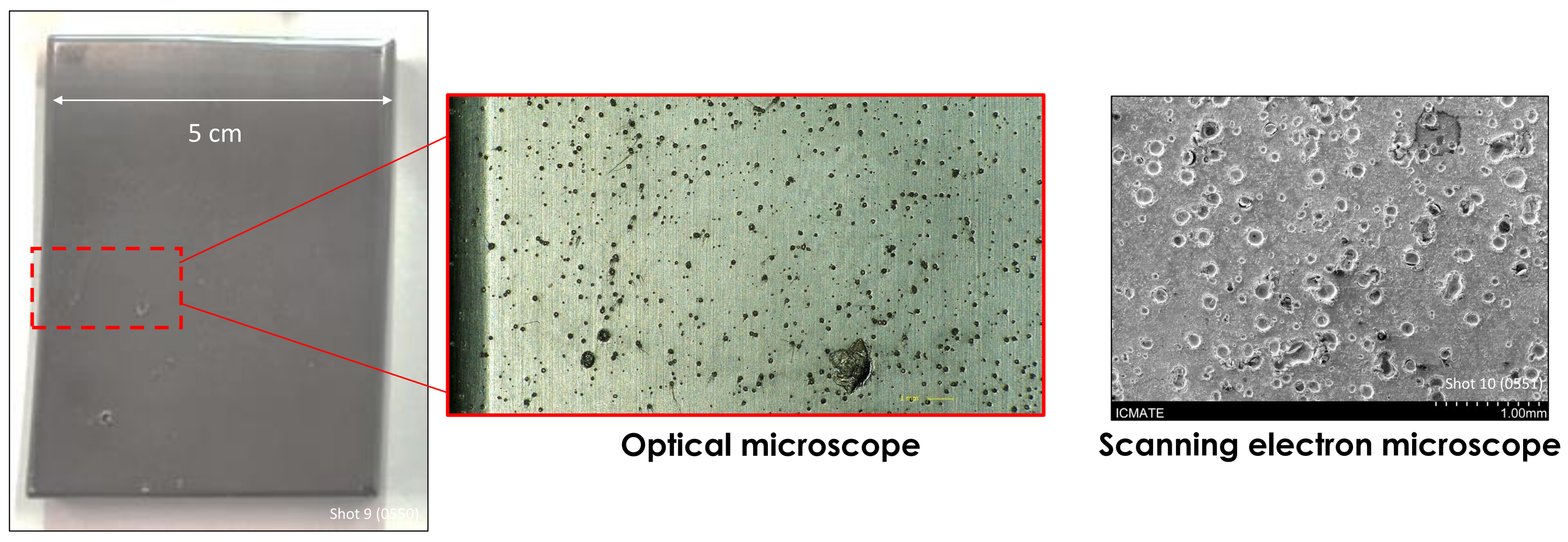
Optical laser backlighting showing the two-part sabot in flight towards the sabot stripper.



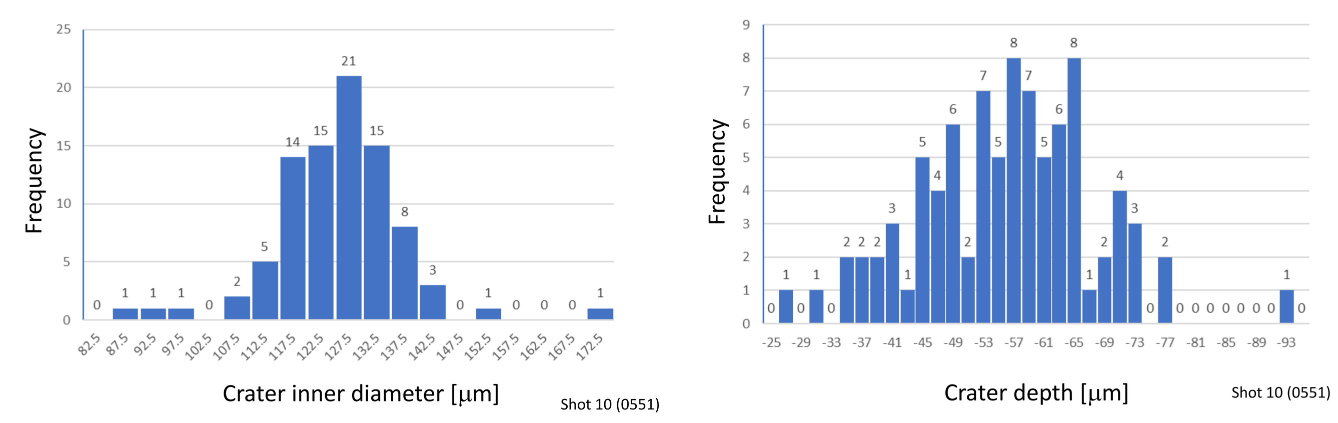
Optical self-emission showing the two-part sabot breaking up. This test experiments used unmeshed ∅ 45-90 μm diameter tungsten dust, resulting in saturated crater impacts.

Crater analysis from Mo dust impacts into cryogenic TZM tiles

Molybdenum dust particles (Ø71 um diameter) were placed inside the sabot and accelerated to ~2 km/s before impacting a TZM (Ti-Zr-Mo) tile cryogenically cooled to ~170K (-100 C).



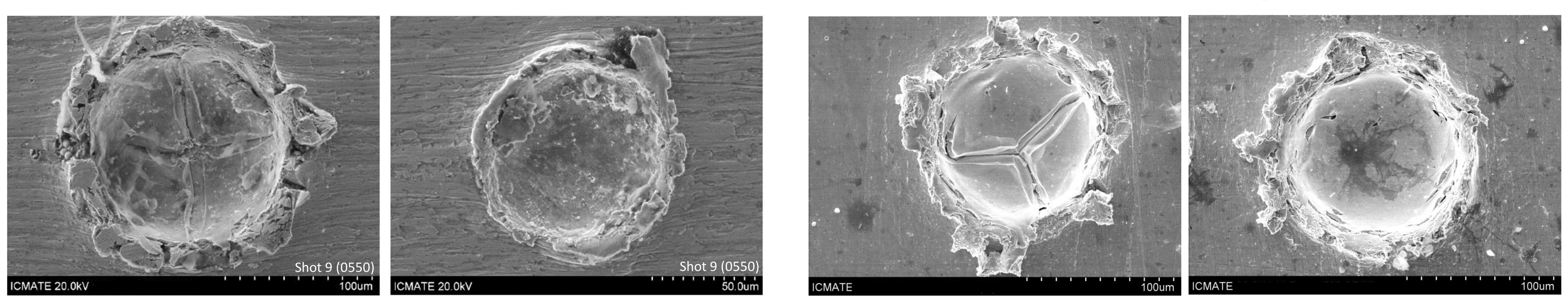
Post-shot TZM tile showing craters from Mo dust impacts.



Distribution of crater inner diameter and depth from SEM images of a cryogenic target at FLF.

The crater morphology between cryogenic and room temperature experiments is very similar, despite the -80 C ductile-brittle transition temperature (DBTT) of TZM.

Data from FLF's gas-gun TZM at -100 C | **Data from CNR's gas-gun TZM at room temperature**



SEM images comparing Mo impacts on TZM tiles at cryogenic and room temperatures.

Summary

- New capabilities were developed on FLF's two-stage light-gas gun: Open sabots and a sabot stripper to study solid dust impacts.
- Impacts from molybdenum particles at ~2 km/s into TZM targets at -100 C were obtained, aimed at replicating the damage of plasma facing components on the cryogenically cooled FTU tokamak.
- Preliminary comparison between cryogenic and room temperature impacts reveals similar crater morphology and small differences in the crater diameter and depth.

References

[1] G.F. Matthews et al., Physica Scripta **T167**, 014070 (2016)
[2] M. De Angeli et al., Nuclear Fusion **63**, 014001 (2023)
[3] P. Tolias et al., Fusion Engineering and Design **195**, 113938 (2023)
[4] T. Ringrose et al., Procedia Engineering **204**, 344-351 (2017)