Radiography of gas-gun impact experiments using an X-pinch

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first light

Motivation

- First Light Fusion (FLF) is researching ICF with novel target designs utilising strong shocks driven by hyper-velocity projectiles and EM launchers.
- Proprietary target designs are being developed and understood using our in-house front tracking hydrodynamics code Hytrac.
- Experiments designed to deliver proof-of-concept and numerical benchmarking data are being conducted and generate conditions opaque to probing with optical light.
- X-ray radiography of the dynamic density structures occurring during target impacts has been achieved by coupling an X-pinch X-ray source to the FLF two-stage light gas-gun launcher (2SLGG)[1].
- This is the first time dynamic radiography has been done on a gas-gun using an X-pinch and is already providing valuable experimental shock density information (see Fig. 1).

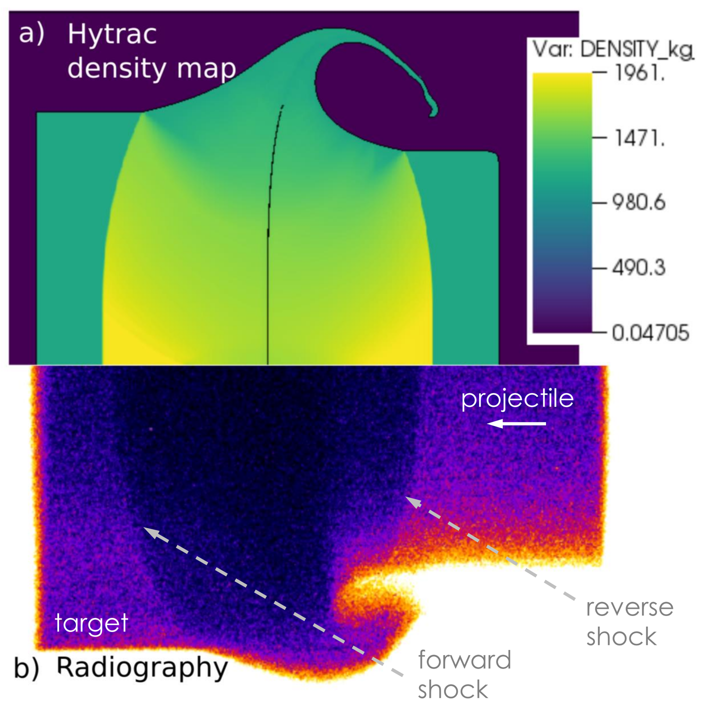


Fig. 1: Hytrac simulation (top) of planar impact of a PMMA projectile with target, moving right to left. X-pinch radiograph of equivalent experiment shown alongside (bottom).

X-pinch X-ray Source Characterisation

- X-pinches are pulse-power driven point X-ray sources. A large pulsed current (>1 kA/ns) [2] is applied to a pair of crossed fine wires that form an 'X' shape (Fig. 3, 6) and a burst of X-rays is emitted (Fig 2):
  - Thermal plasma hotspot (HS): soft X-rays (<10 keV, <1 μm, <<1 ns)
  - E-beam acceleration (non-thermal)(after HS breakup): harder X-rays (>10 keV, >10 μm, >10 ns)
- FLF targets require 10 -15 keV X-rays to probe through cm-scale targets, therefore the hard X-ray source.
- The X-pinch is driven by a 70 kA, 70 ns Marx bank and pulse-forming line pulsed power device on loan from Imperial College London. Six 0.3 μF capacitors are charged to ±60 kV, and provide a stored energy of 3 kJ.

Source Size	:	200 μm
Energy Range	:	Broadband up to ~20 keV
Energy	:	~20 mJ, > 8 keV
Duration	:	20 ns
Resolution	:	100 μm

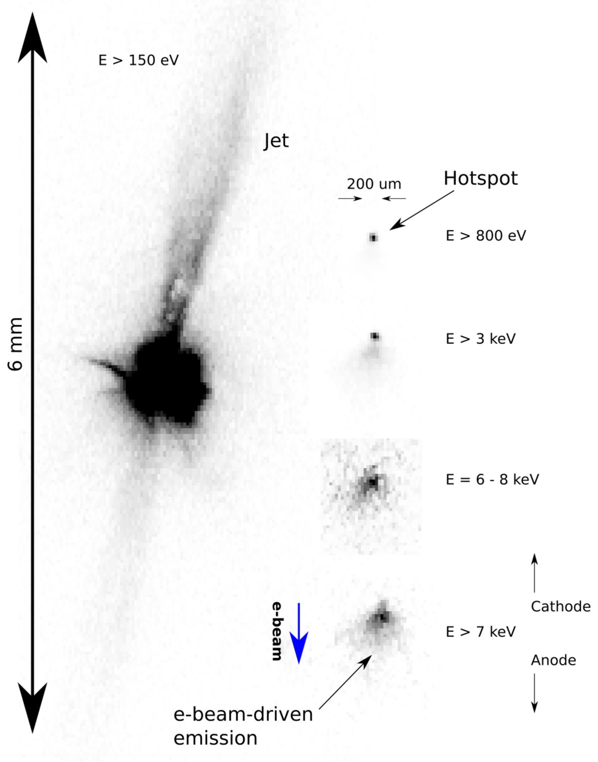


Fig.2: Time-integrated pinhole images of a 4 x 7.5 μm tungsten (W) X-pinch in different spectral bands. Spatial scale constant and limited by 150 μm pinhole

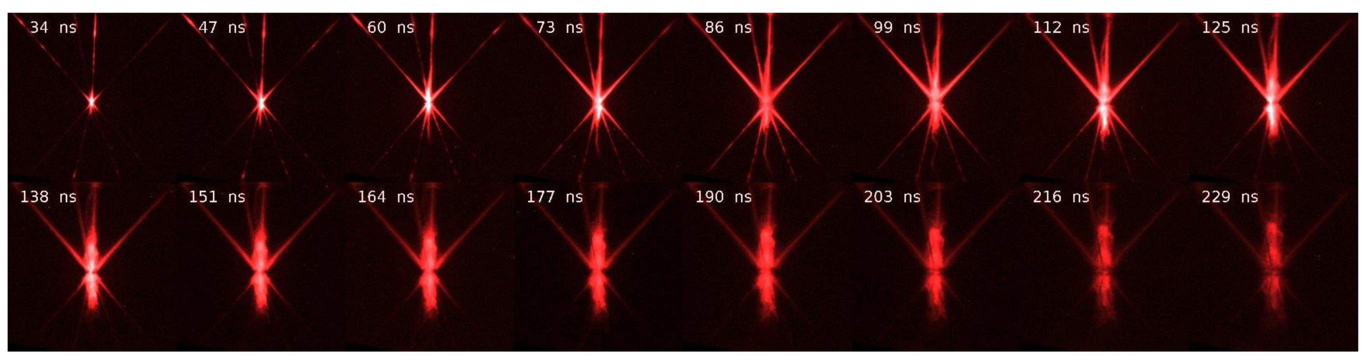


Fig.3: Optical emission temporal sequence from a 4 x 7.5 μm tungsten (W) X-pinch, shown as a composite of two different contrasts.

- The source imaging quality has been characterised using a number of techniques:
  - Differentially filtered pinholes image the source in different spectral bands (Fig 2).
  - Fast gated optical imaging gave the temporal evolution of optical emission (Fig 3)
  - A slit-step wedge gives time-integrated 1D spatial resolution across multiple energy bands (slit width = 100 μm, magnification = 4.7)(Fig. 4a) and point-projection using a steel grid gave 2D resolution and source size (Fig. 5)
  - A crystal spectrometer gives detailed higher resolution spectral information (Fig. 4b,c)

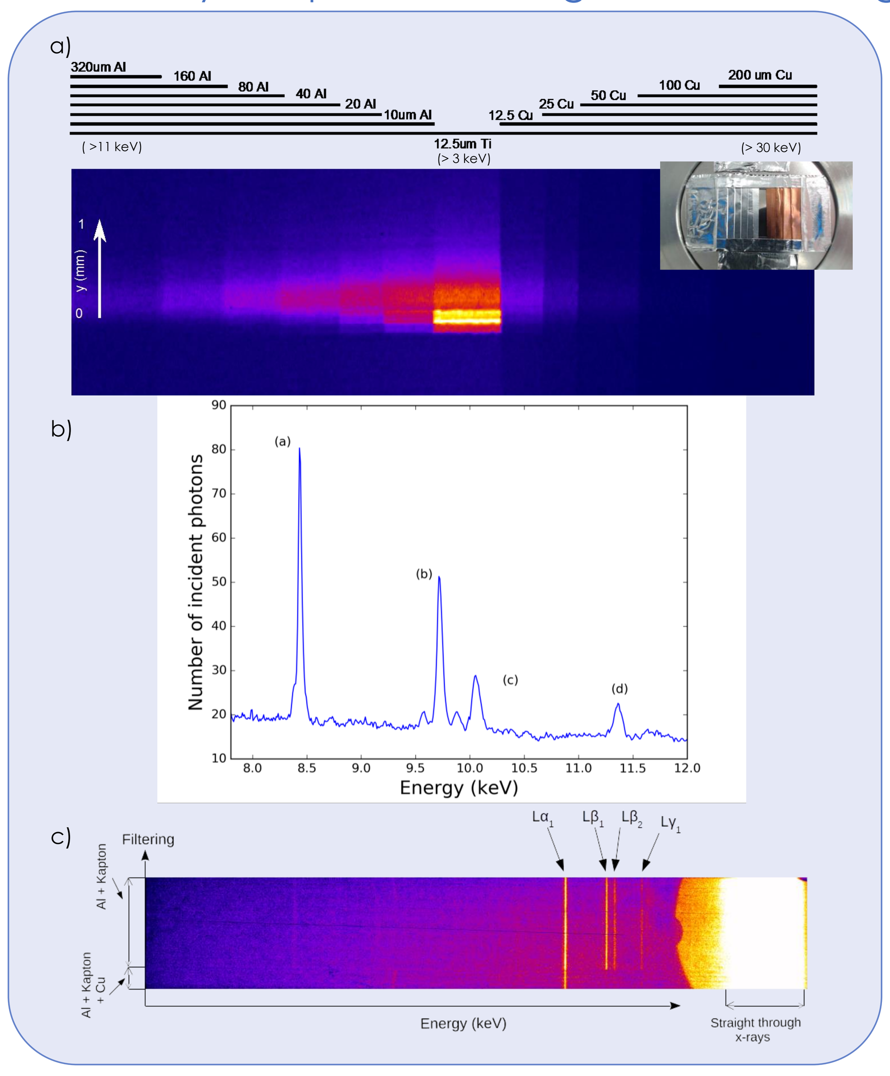


Fig.4: Raw X-pinch spectral information from slit-step wedge data (a) and from a crystal spectrometer (from CEA) (c) with the corrected spectral plot (b).

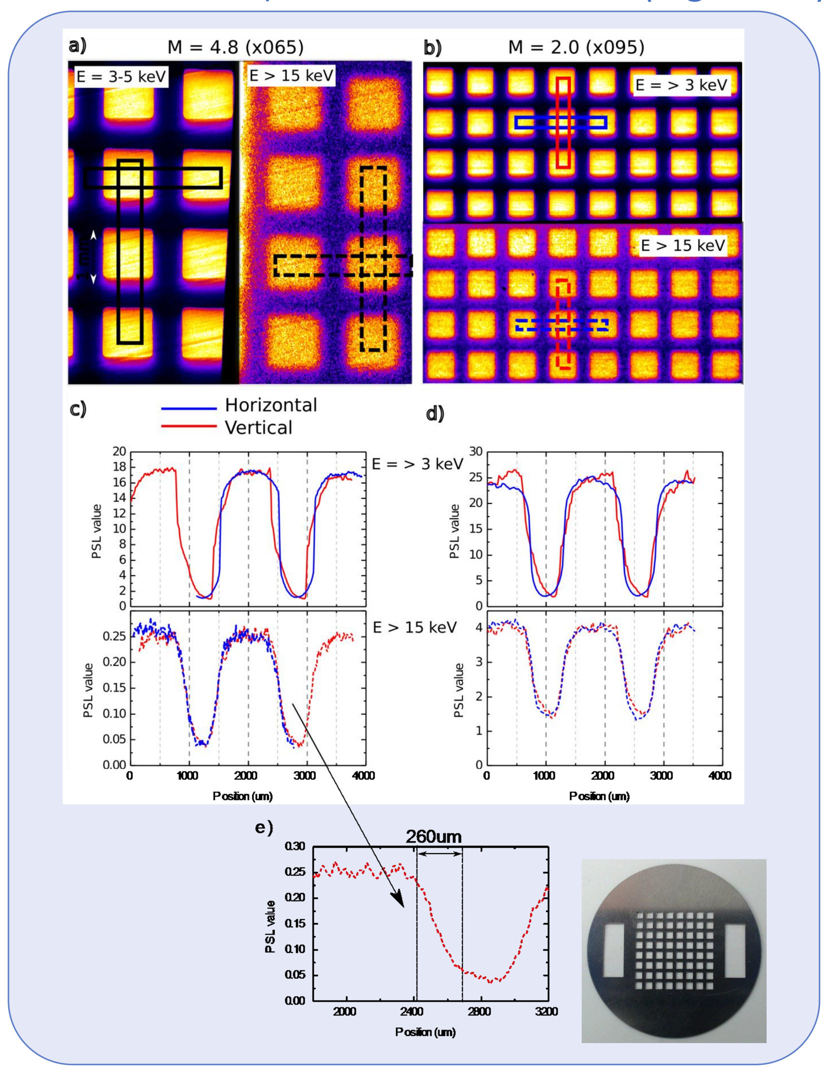
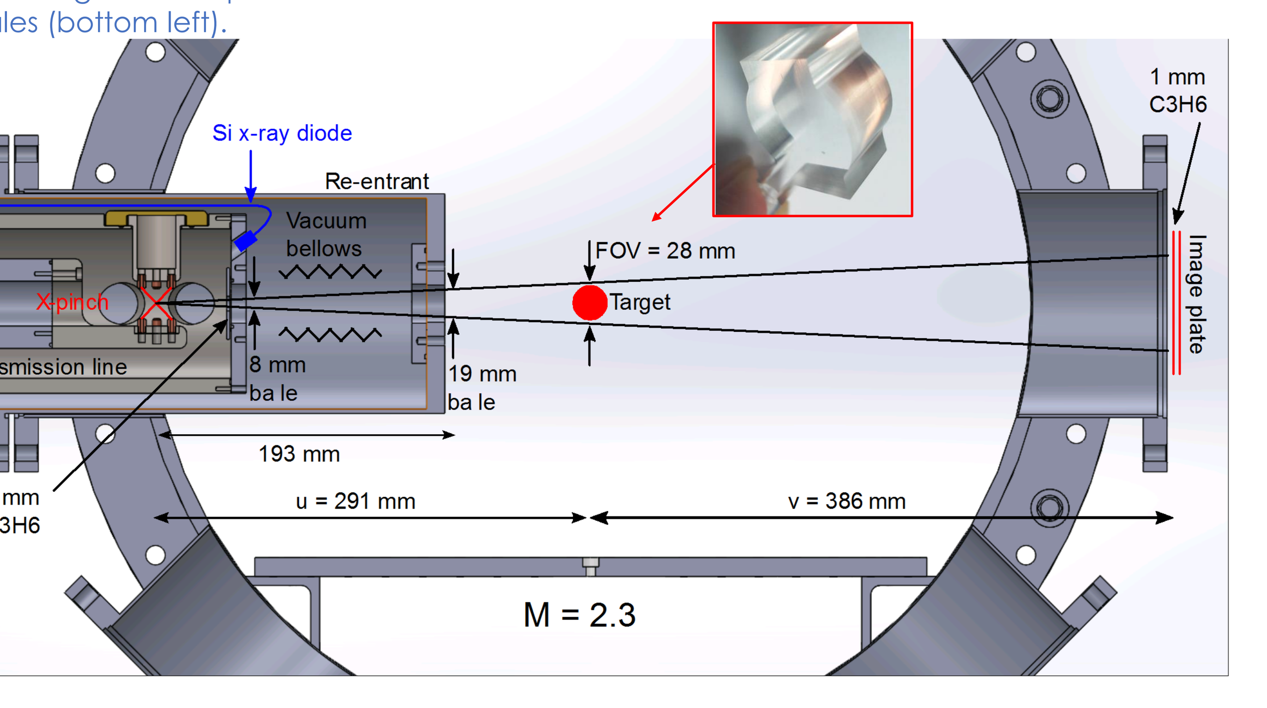


Fig.5: Point projection of a steel grid at different magnifications for two filtered energies: E > 3 keV (12.5 μm Ti) & E >15 keV (12.5 μm Ti + 1 mm Al)

Dynamic Imaging

- Radiography of a dynamic gas-gun impact has been undertaken for the first time using an X-pinch X-ray source.
- A re-entrant tube was used to get the X-pinch close enough to the target to ensure the necessary flux (Fig. 6)
- The X-pinch was triggered off the gas-gun main trigger and the timing jitter can be seen in Fig. 6 to be quite reasonable for gas-gun timescales (bottom left).
- The X-pinch and target chambers were connected with a vacuum bellows. A 1 mm thick plastic window enabled a high vacuum within the X-pinch and gave protection against debris.
- Image plate is used for X-ray detection with 1 mm of CH for debris protection.



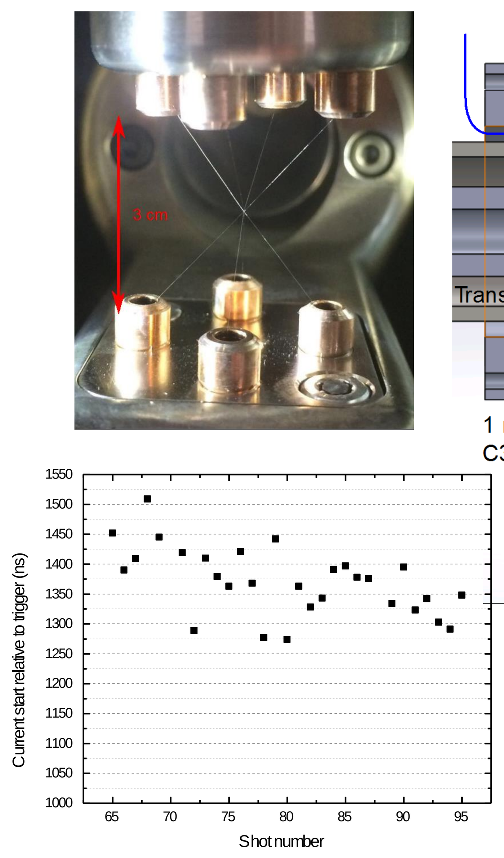


Fig. 6: X-ray backlighter within the target chamber. The point projection geometry produces a magnification of 2.3 (top right). Photograph showing a standard 4-wire 7.5μm Tungsten X-pinch (top left). Trigger jitter between current start and gas-gun trigger (bottom left), X-pinch stand alone jitter is ± 10 ns.

- Solid PMMA targets (Fig. 6-top insert) have been imaged orthogonally (Fig. 7) in both X-ray (a) and optical (b)(saturated and un-saturated) during a 6.5 km/s impact with a polycarbonate projectile from the FLF gas-gun.
- The internal forward and reverse shock structure can be seen clearly in the X-ray data and only the shadow of the shock can be seen in the optical.
- Open-backed hemisphere cavity targets have also been imaged at different stages of jet formation (Fig. 8). The forward and reverse shocks can be seen along with the density structures within the jet.
- Frames 1 and 2 show impacts with a aluminium tipped projectile to show the density difference, which can be clearly seen in the radiograph.

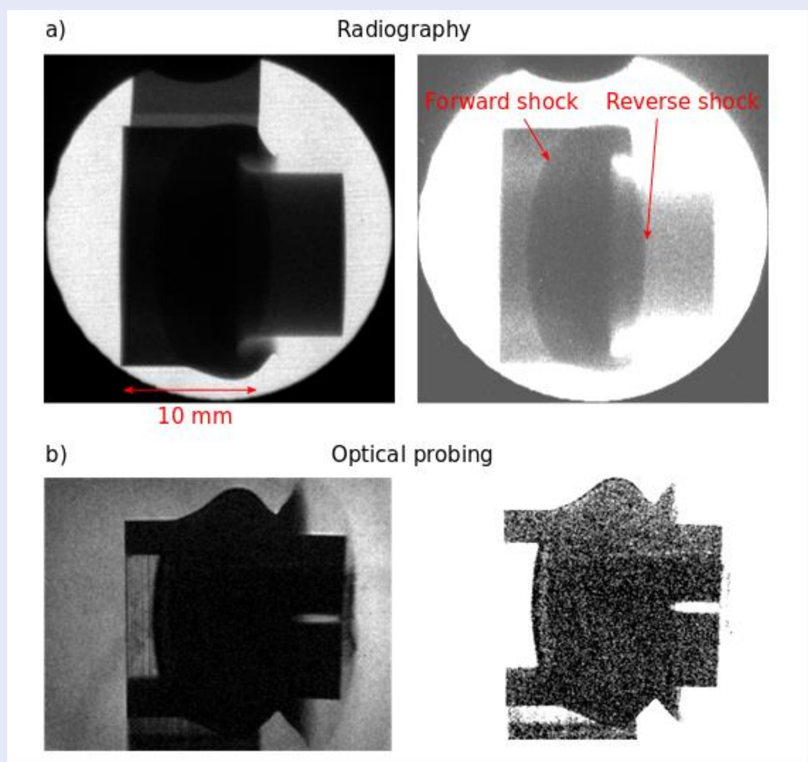


Fig. 7: Radiography (a) and optical backlighting (b) of a planar driven shock from a 12.7 mm diameter projectile impacting with a plane PMMA at 5.4 km/s, showing the shock density structures can only be resolved with radiography.

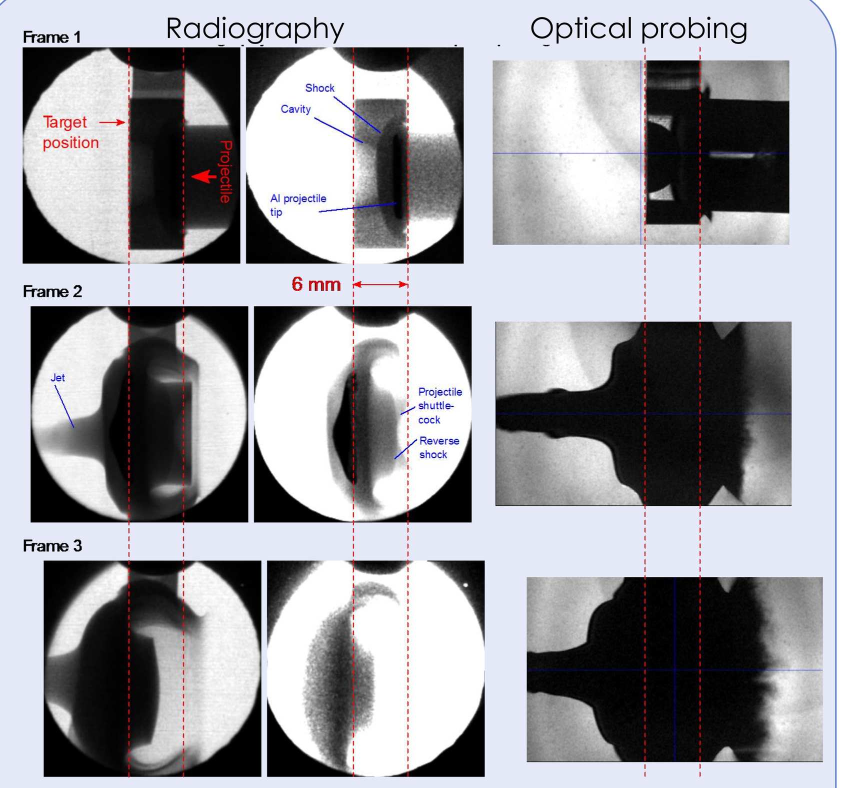


Fig. 8: Time series of 4 mm radius open-back cavity radiography (two contrast levels shown on left). Projectile travelling from right to left. Red lines indicate initial position.

Active and future work

- Extracting density profiles is possible using an abel transformation (Fig. 9.d)
- Abel transformation requires the target and impact to be axially symmetric along the flight direction. It also requires the spectral attenuation to be well characterised. (Fig. 9c)
- The first abel transform from dynamic X-pinch radiography of a gas gun impact shock release is shown in Fig. 9d.

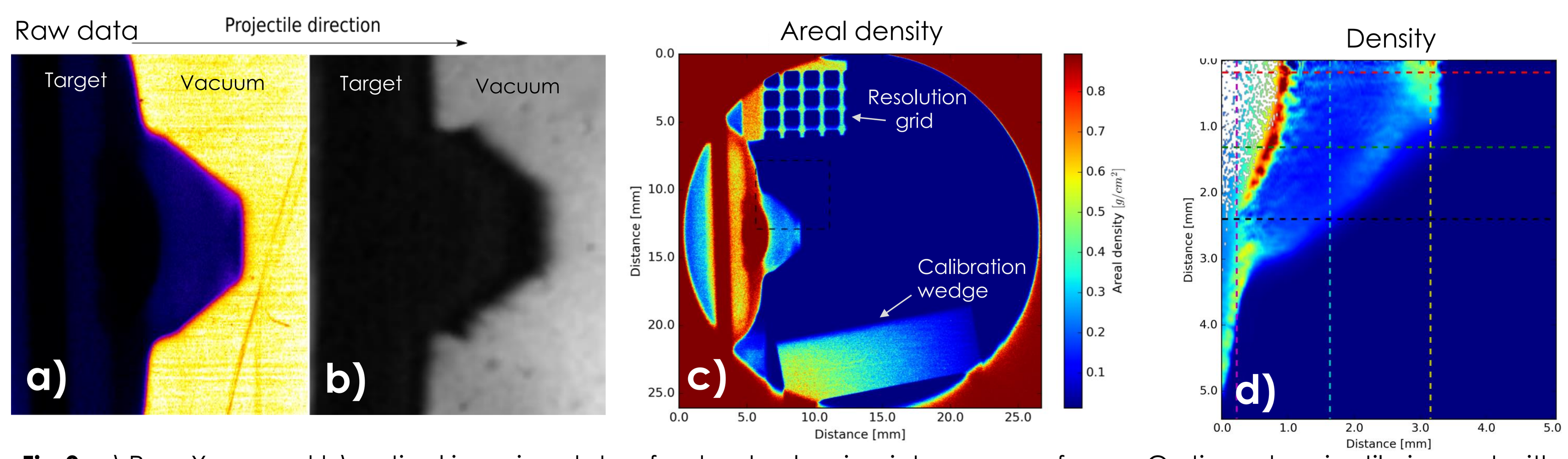


Fig.9: a) Raw X-ray and b) optical imaging data of a shock releasing into vacuum from a Cu tipped projectile impact with aluminium (impact from left to right), c) resolution grid and attenuation calibration wedge to confirm resolution and spectral attenuation, d) abel transform of region shown in (a) revealing the hidden density structures within the release material.

In development:

- Upgrade of X-pinch for increased current.
- Use on new M3 launcher (under construction)
- Data use for equation of state validation
- Development of X-pinch as potential source for scattering experiments
- Development of hybrid pinch for smaller source sizes and fewer multiple bunches.

References

1. Ringrose et al. Procedia. Eng. 204 (2017)
2. Pikuz, PPR 41, 4 (2015)