Experimental measurements of TPa shock structure on exit from a planar shock amplification system

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First Light Fusion

First Light Fusion Ltd. is a privately funded company researching ICF target designs that are driven by strong shocks from high velocity projectile impacts.

Fig. 1: Schematic of fusion method.

Fig. 2: The large light gas gun facility at First Light Fusion Ltd.

- A projectile driven by a large light gas gun impacts a shock amplifier at 6.5 km/s.
- The amplifier is designed to increase the velocity and pressure of the shock travelling through it and was used to achieve fusion on the large light gas gun in early 2022.
- A 32 km/s, ~ 1 TPa, shock exits the amplifier and impacts the target where fusion conditions occur.
- The planarity, profile, temperature and velocity of the shock exiting the amplifier is essential knowledge for
  - validation of amplifier simulations.
  - optimisation of fusion targets.
- The amplifier can be used as a platform for reaching high pressures in EOS experiments.

Measuring Shock Velocity

- The velocity of the shock exiting the amplifier into a plastic block has been experimentally measured. It has been simulated by in house multi-material parallel resistive MHD code B2, in 2D.
- The measured velocity is ~ 2 km/s slower than that predicted by simulations. A velocity peak shown in the simulation is not recreated in the experiment due to 3D effects.
- The slower velocity measured could be due to the large tilt of 3.6° of the projectile impacting the amplifier.
- See VISAR measurements of the velocity in J. Read's poster TP11.00076 and measurements of velocity in gas in E. Escauriza's talk TO05.00013.

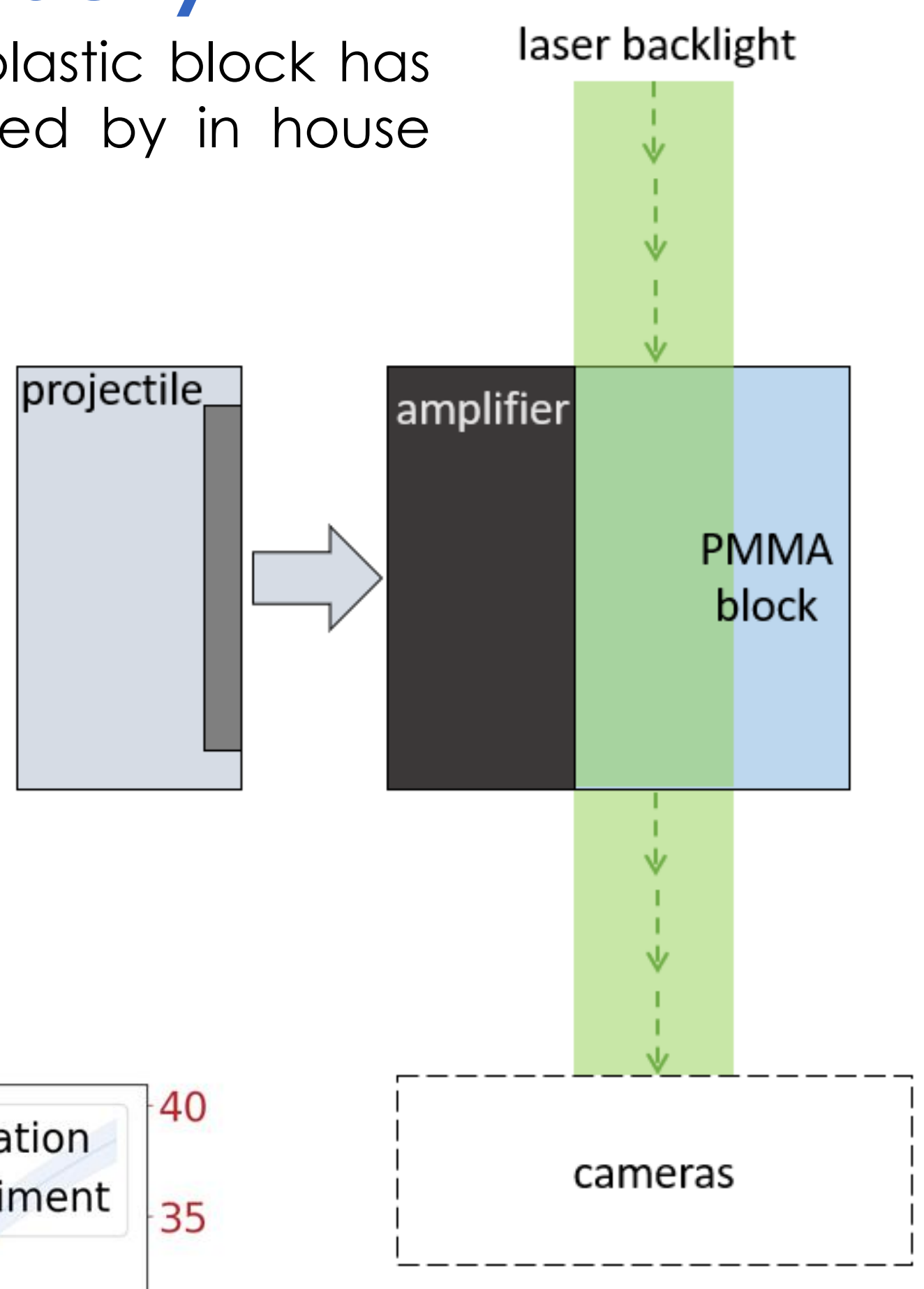

Fig. 4: Diagram of the shock velocity measurement experiment. The shock exiting the amplifier is backlit by a 532 nm laser.

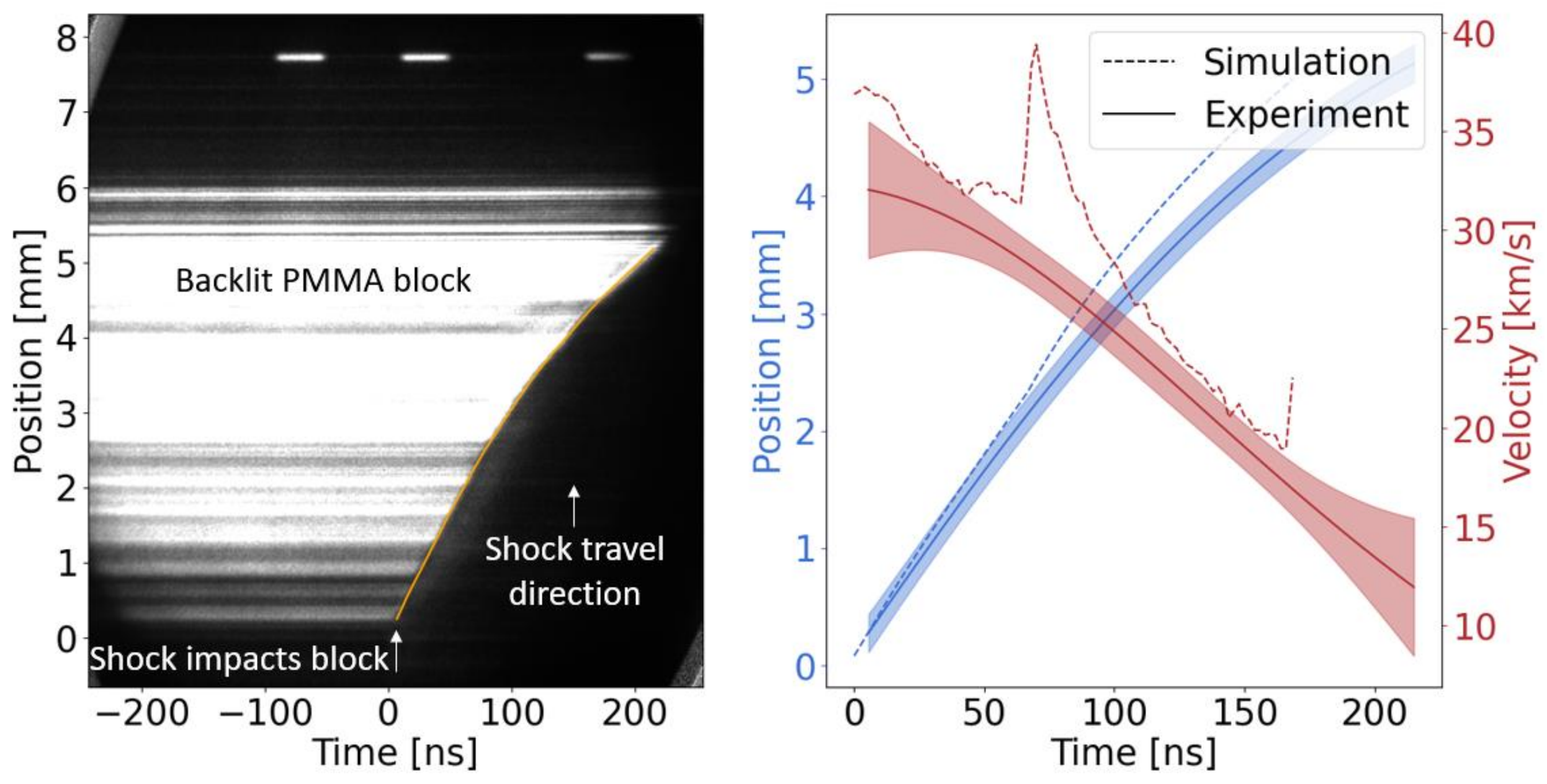

Fig. 3: Experimental measurement of the position of a shock from an amplifier entering a plastic block. Positions have been differentiated to obtain a velocity.

Measuring Shock Profile and Temperature

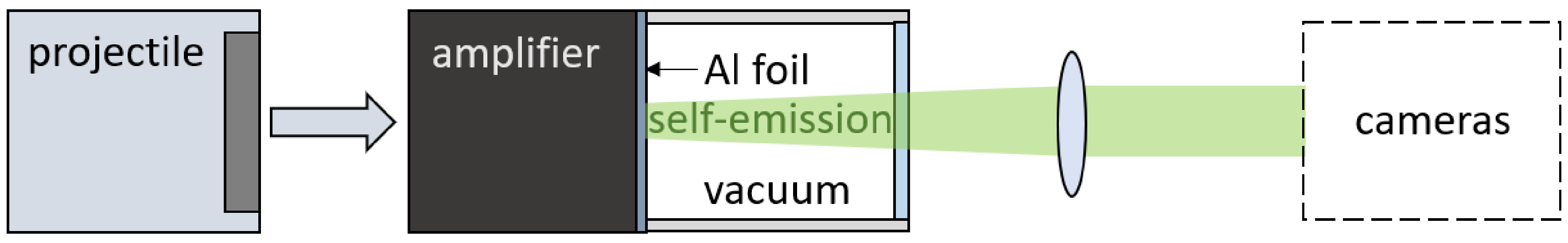

Fig. 5: Diagram of the shock planarity and temperature measurement experiment.

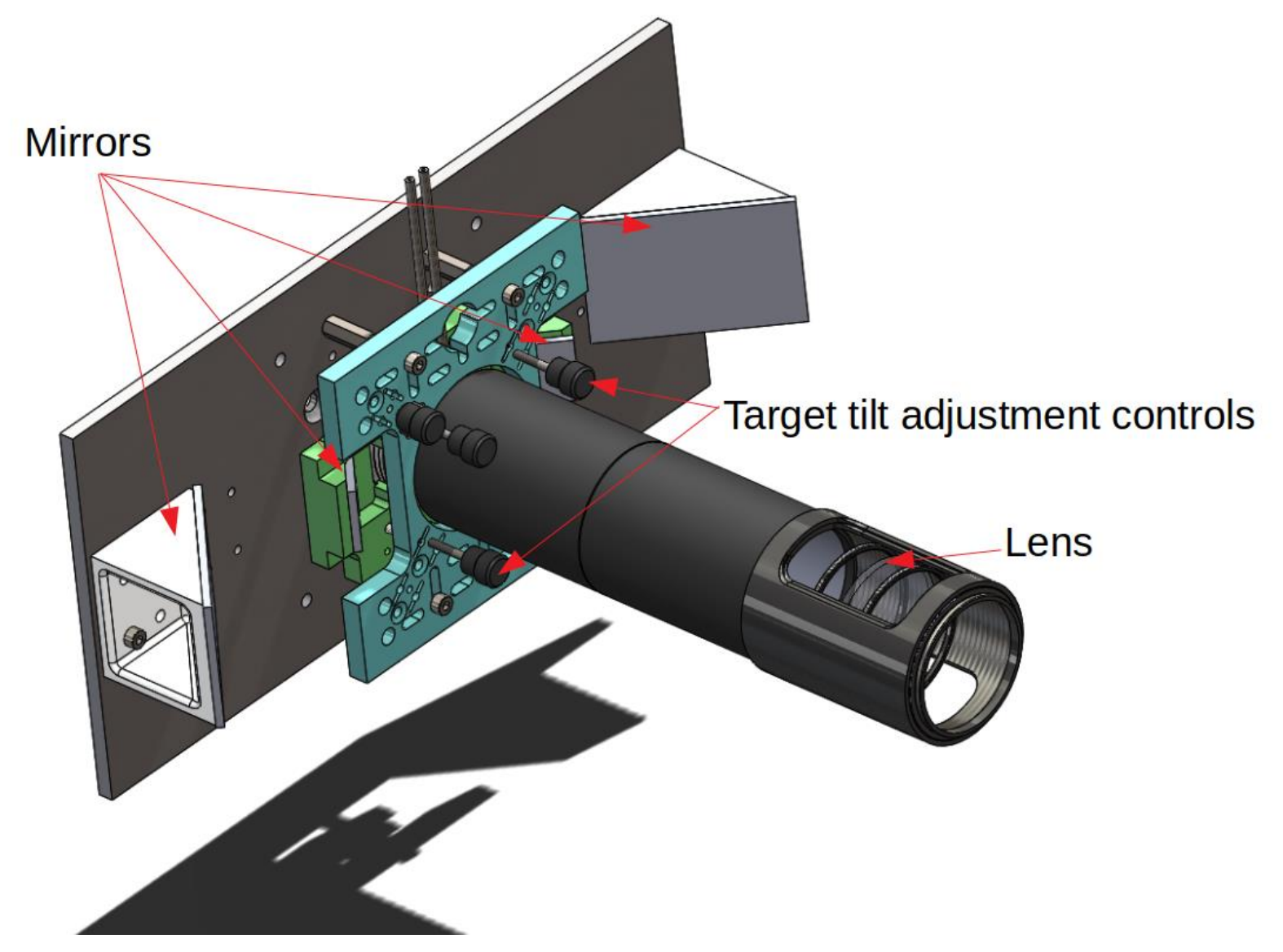

Fig. 6: CAD of the planarity measurement target.

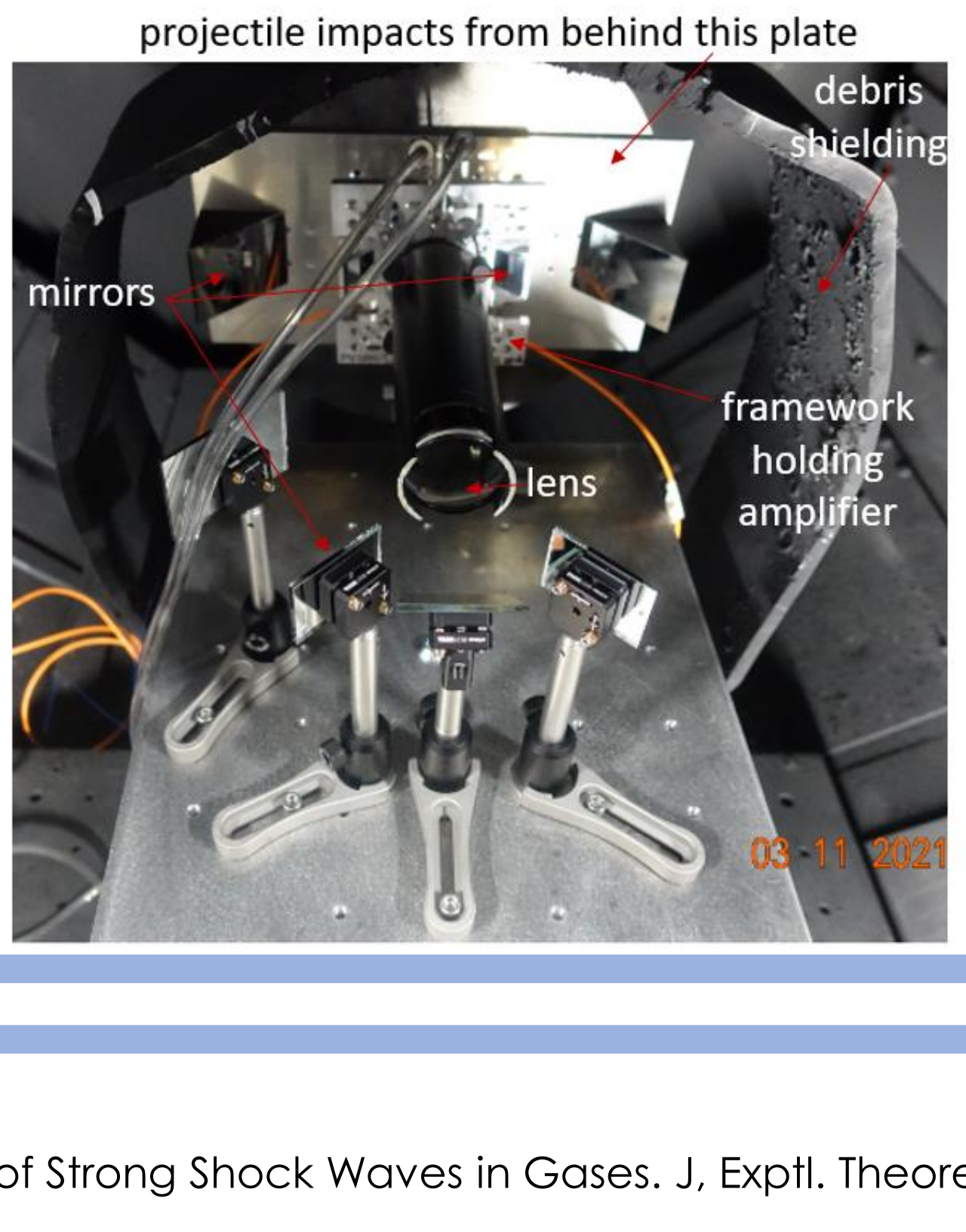

Fig. 7: A target ready to shoot in the vacuum chamber of the large light gas gun. Mirrors were used to direct light into and out of the chamber.

References

1. I. Sh. Model' (1957). Measurement of High Temperatures of Strong Shock Waves in Gases. J, Exptl. Theoret. Phys. (U.S.S.R.) 32, 714-726.

Measuring Shock Profile and Temperature

- Planarity measurements were taken on the large light gas gun facility.
- A projectile travelling at 6.5 km/s impacts an amplifier. A shock travels through the amplifier and exits directly into a 100 micron Al foil. As the shock breaks out of the foil, the self emission is captured by an imaging system.
- The profile, brightness and timing of the emission give information about the dynamics inside the amplifier and the conditions of the releasing shock.
- The spectrum emitted by the metal foil is given by

$$I_B(\lambda, T_B) = \frac{\varepsilon(\lambda, T_B) C_1 \lambda^{-5}}{e^{\frac{C_2}{\lambda T_B}} - 1},$$

where ε is the emissivity of the body, C_1 = 1.19x10^{16} Wm^{2}sr^{-2}, C_2 = 0.0144 Km, λ is the wavelength of the radiation and T_B is the temperature of the body [1].

- If the system is absolutely calibrated with a black body source of known temperature, the temperature of the emitting foil can be obtained, if the emissivity of the foil is known. The emissivity can be taken as constant in λ if a grey body spectrum is assumed.

Experimental Results

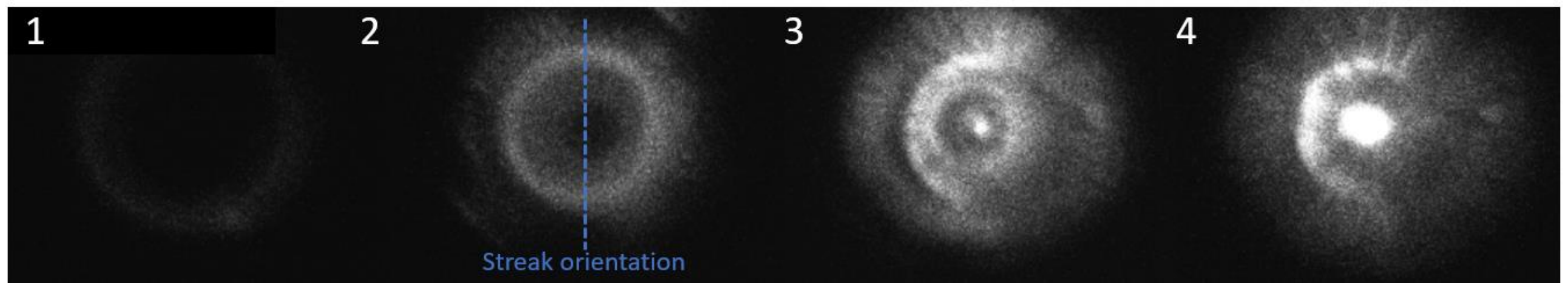

Fig. 8: 2D images of the shock breaking out of the metal foil, shot 58. Images are separated in time by 7 ns. Frame 2 indicates the orientation of the streak cameras for figures 9 and 10.

- B2 was used to create a synthetic image of the brightness emitted as the shock breaks through the foil on the streak camera.
- Differences in breakout time from one side of the shock to the other suggest the shock is sometimes exiting tilted. This is believed to be due to the projectile impact being tilted and could significantly affect fusion yield.

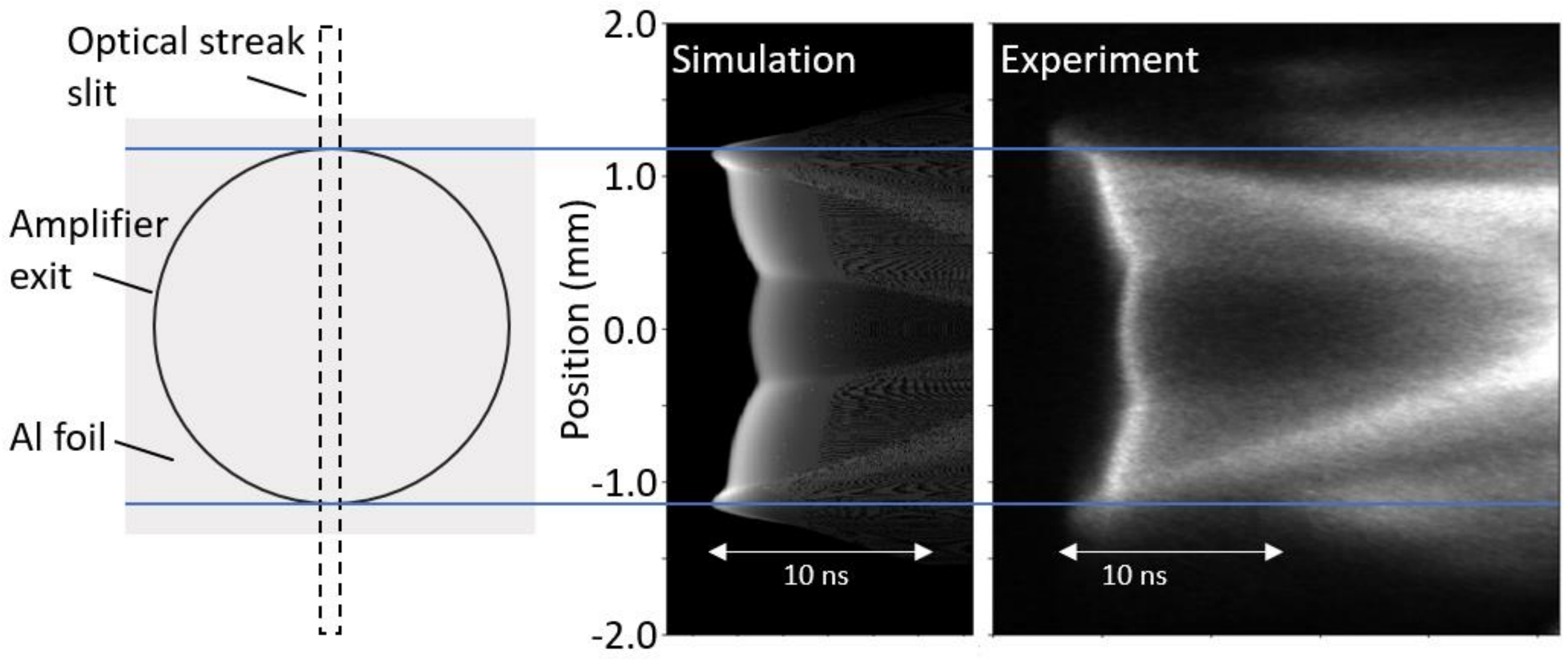

Fig. 9: Shot 58 experimental results compared to simulation results from in house code B2.

- Experimental data for non tilted shots is in excellent agreement with simulation data.
- Temperature measurements of the shock were not obtained due to difficulty absolutely calibrating the optical system.
- Alternative calibration methods including taking images with 2 different wavelengths of light are being investigated for future experiments.

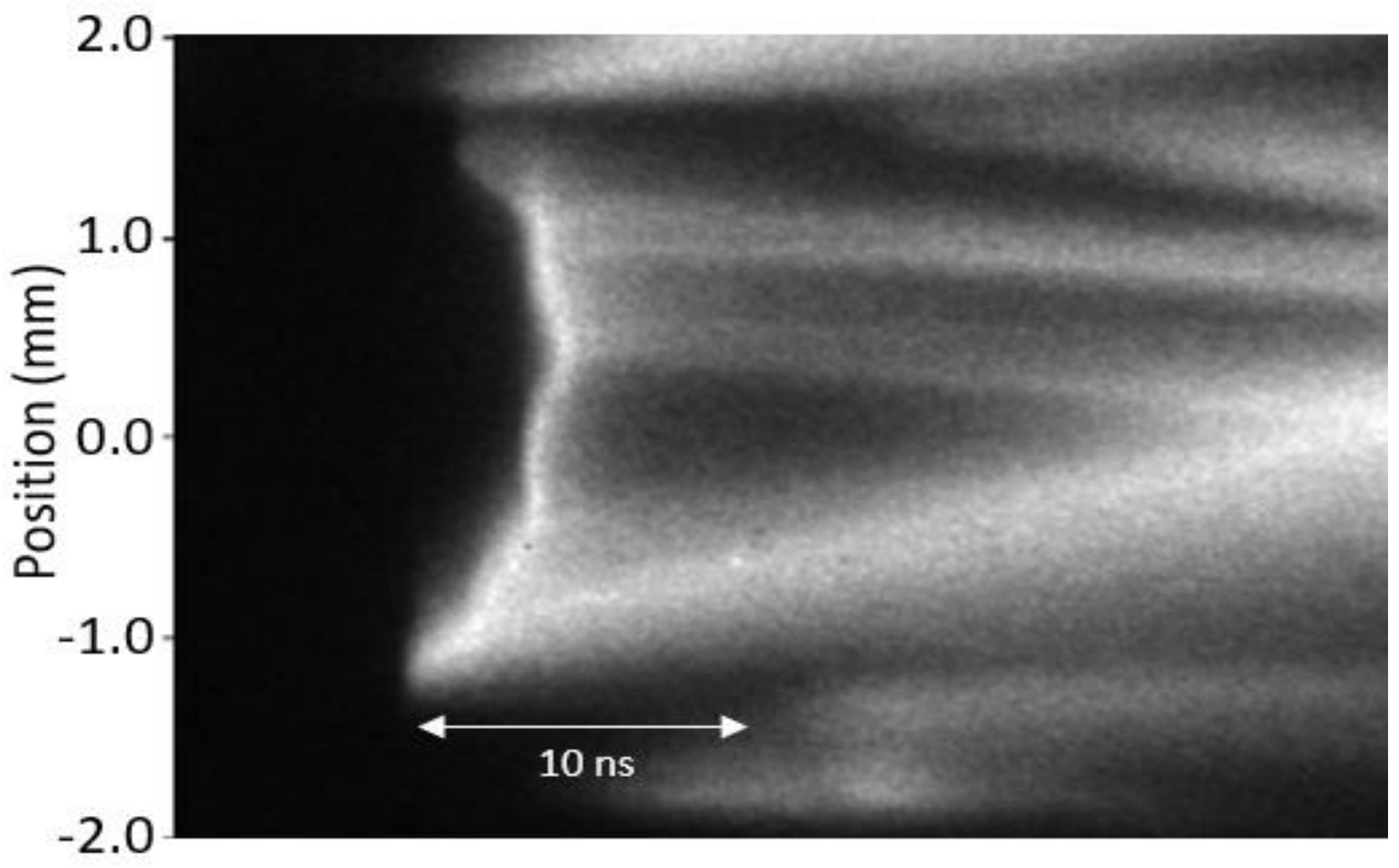

Fig. 10: Shot 60 experimental results: this shot has a tilt of 1.1°.

Summary and Future Work

- The velocity and planarity of a 1 TPa shock exiting a First Light Fusion amplifier was successfully measured and showed excellent agreement with simulations.
- The temperature of the shock was not obtained due to difficulty calibrating the system.
- Future experiments will improve the temperature measurement by capturing the shock at multiple wavelengths or using a brighter calibration light source.
- The input and output tilt of the amplifier should also be measured in future.

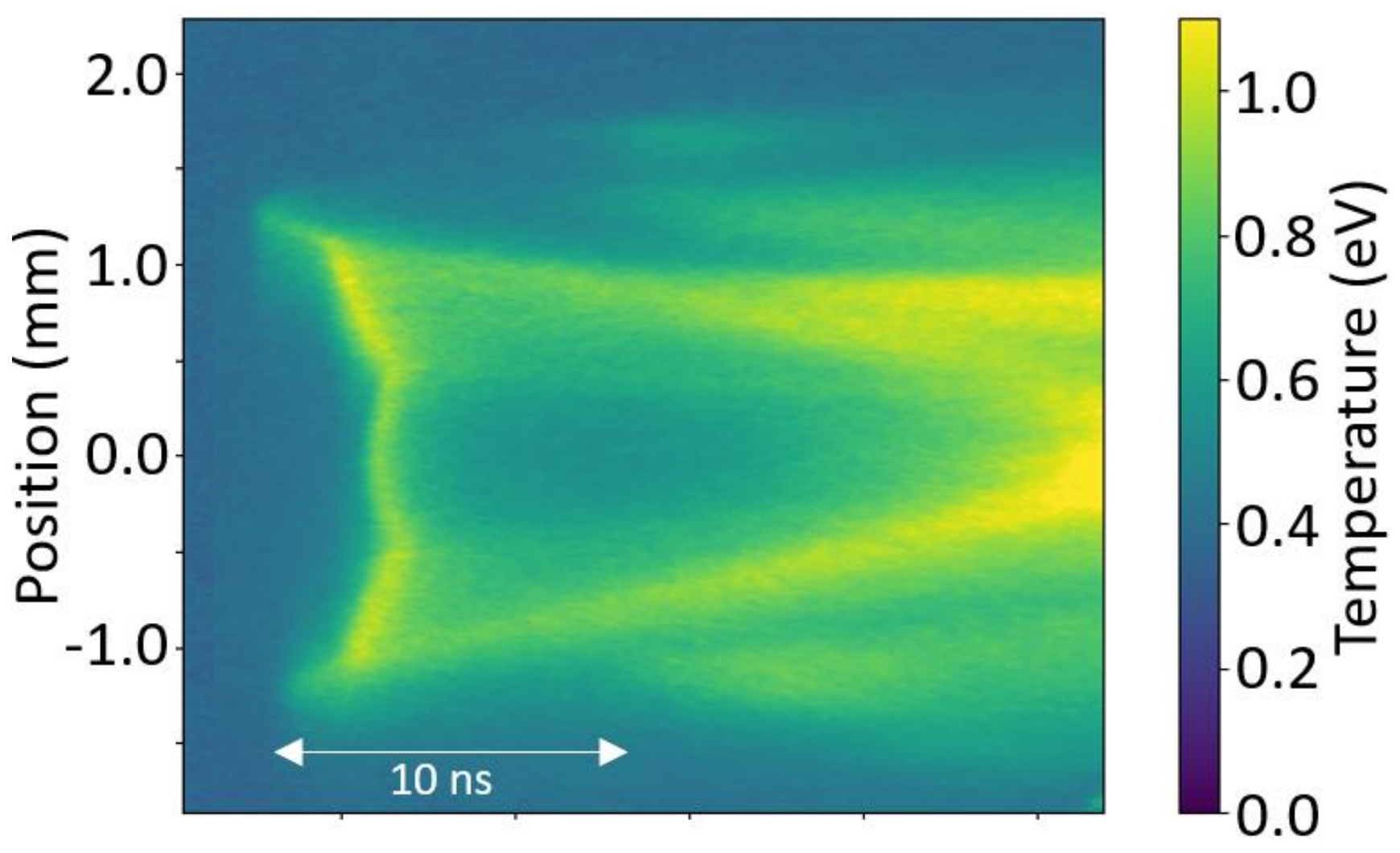

Fig. 11: Temperature measurements from shot 58 are not reliable due to problems calibrating the optical system.

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