AWE NUCLEAR SECURITY TECHNOLOGIES

Dynamic tests with simultaneous Broadband Laser Ranging and Photonic Doppler Velocimetry

Alex Cardy

alex.cardy@awe.co.uk

17th October 2024

PDV Workshop

Las Vegas, NV, USA

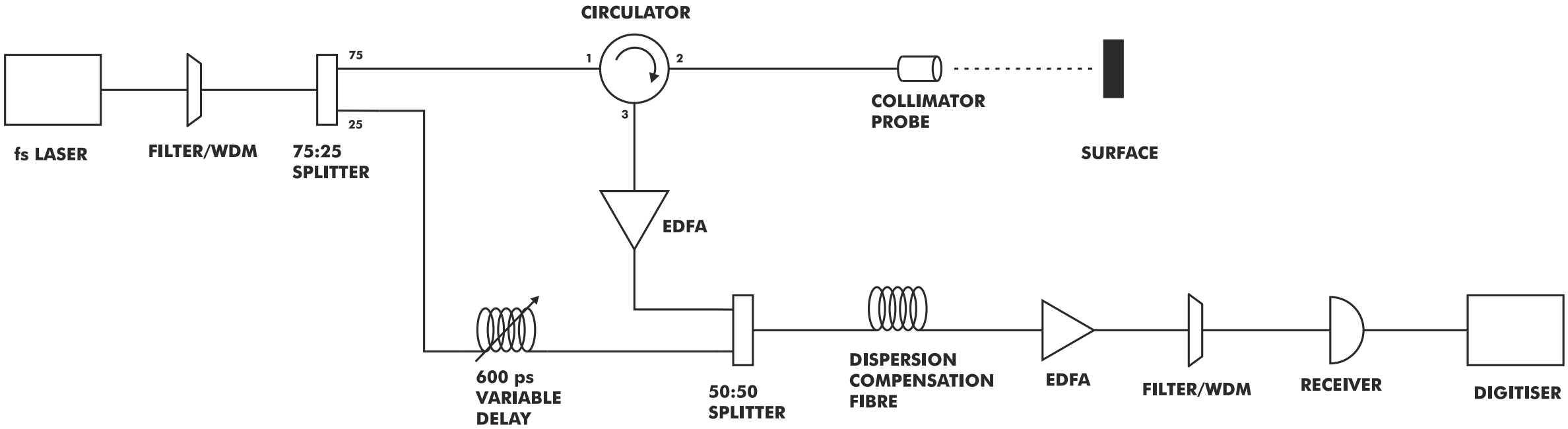
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Broadband Laser Ranging (BLR)

- Broadband femtosecond pulsed time-of-flight diagnostic
- Surface pulse and reference pulse temporally combined with spectral dispersion to generate distance-dependent beat frequency
- Compliments existing Photonic Doppler Velocimetry (PDV) systems – combined on the same probe using an Optical Add/Drop Multiplexer
- A series of explosive firings were carried out to evaluate a Michelson interferometer BLR architecture
  - Previous work involved dynamic tests with a Mach-Zehnder system
- A frequency-upshifted PDV system was fielded simultaneously

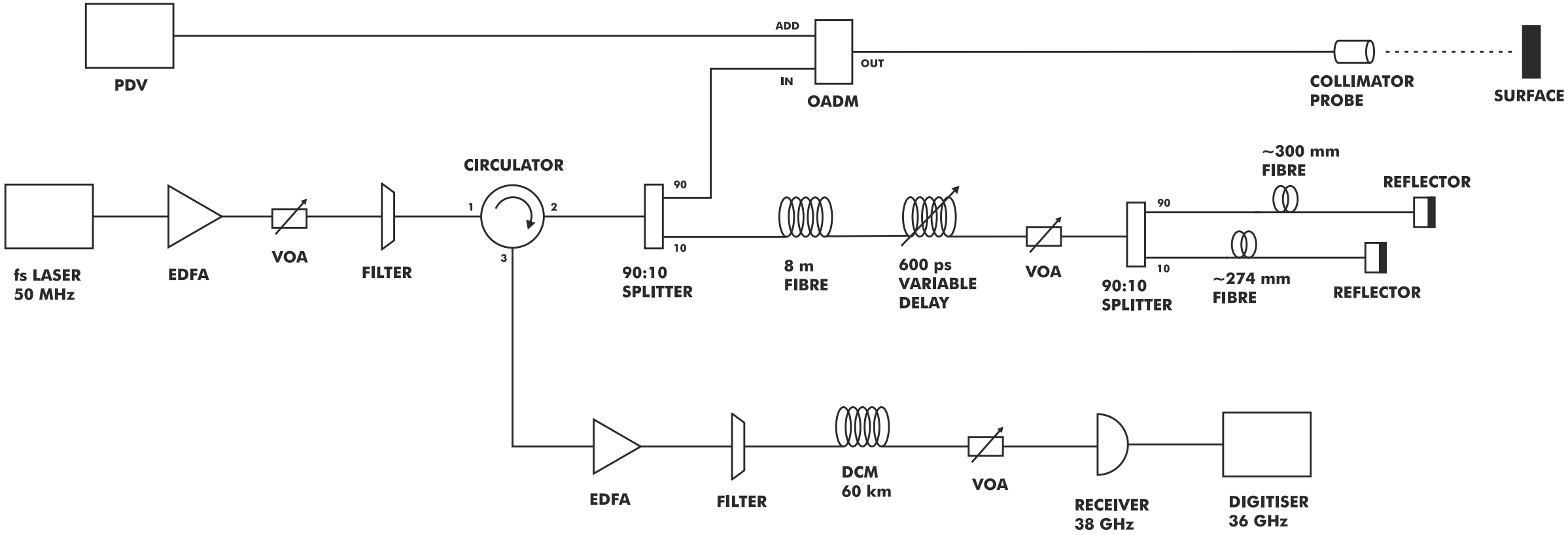
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Previous BLR system: Mach–Zehnder interferometer



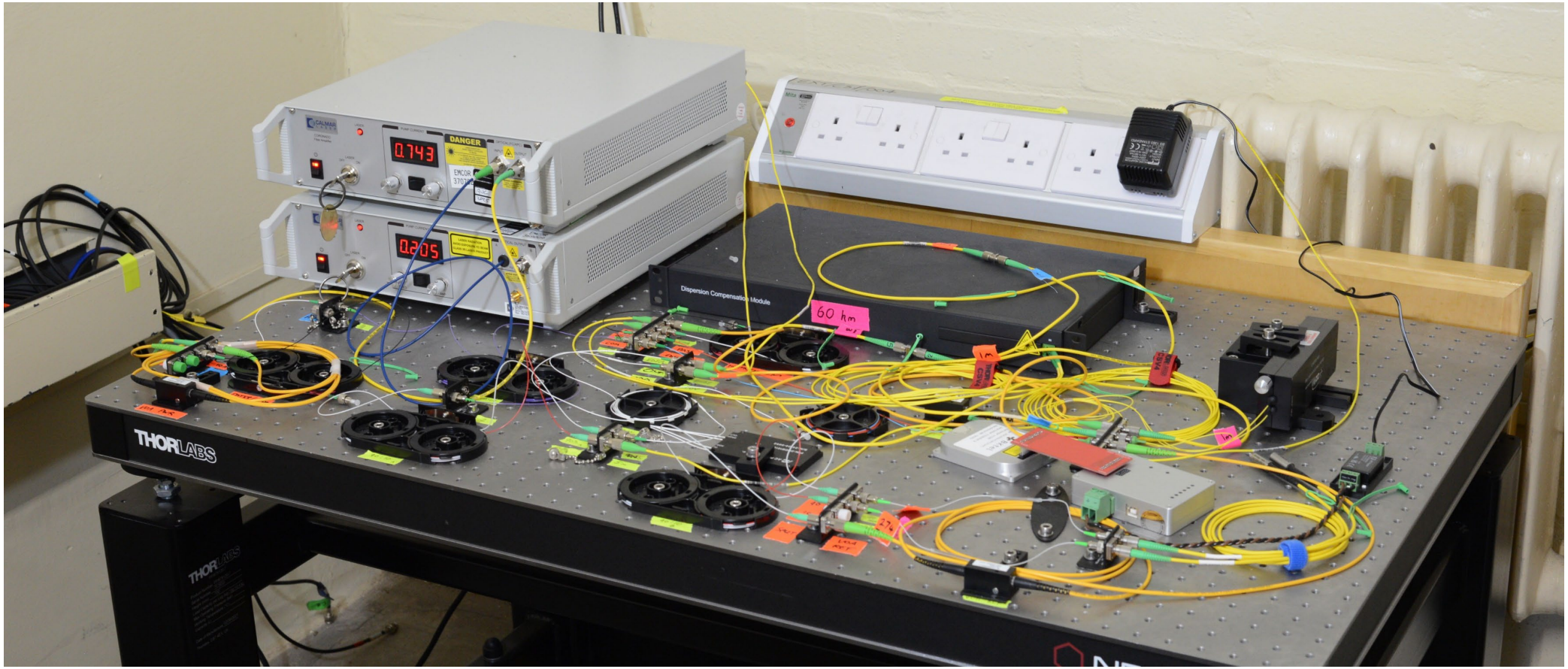
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Current BLR system: Michelson interferometer



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

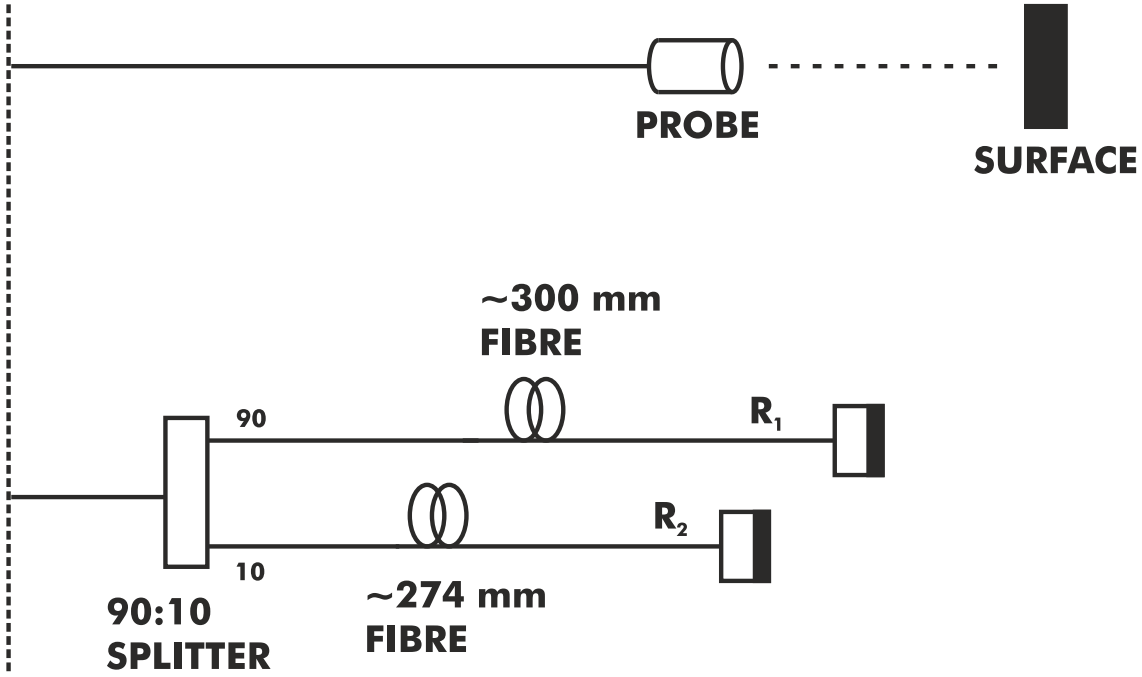
Current BLR system: Michelson interferometer



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

In-situ calibration

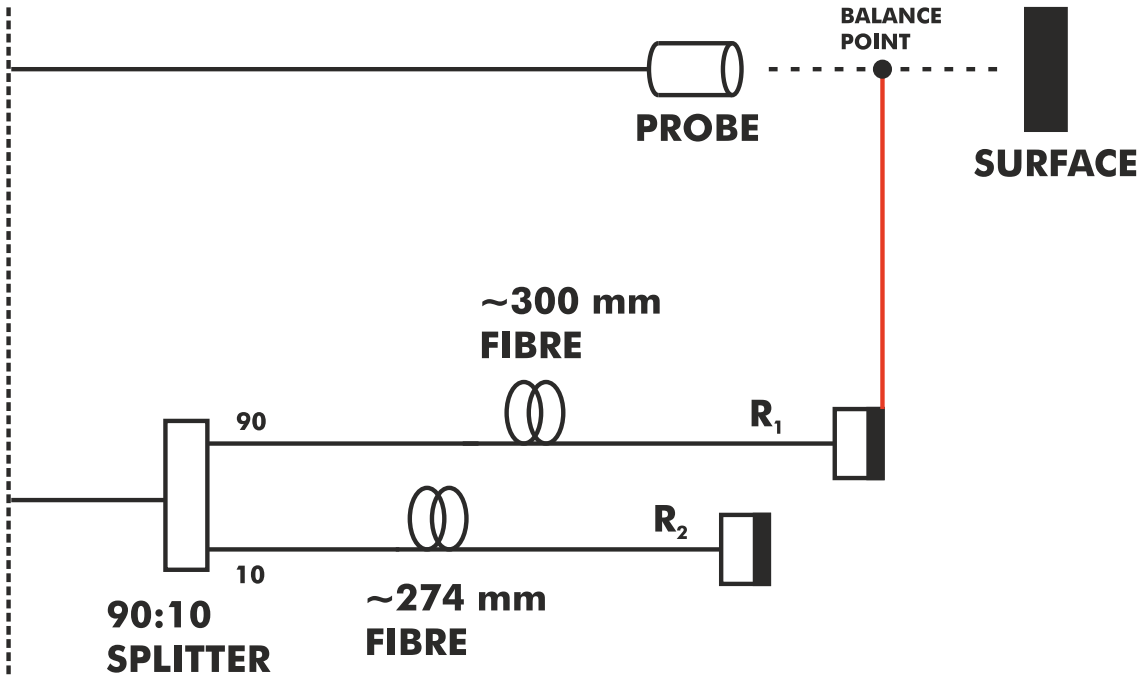
- Fixed path length difference between R_1 and R_2
- Path length difference 29.8 mm per Optical Backscatter Reflectometry (OBR) measurement
- 34.9 GHz beat frequency
- (29.8 mm * 1.4682) / 34.9 GHz = 1.25 mm/GHz system sensitivity
- R_2 is shorter than main path to delay beat frequency between surface and R_2 until after surface has reached the balance point



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Reference length

- Set reference path length halfway between probe and surface for double-ended operation
- 600 ps adjustable delay provides 1.2 ns round-trip adjustment of reference leg
- Time domain check carried out first with DCM bypassed (i.e. no dispersion), then FFT for fine tuning of path length



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Time domain check

- R_1 pulse should come 100s of picoseconds before surface pulse in time domain with the DCM bypassed
- R_1 identified by adjusting variable optical attenuator on reference path
  - Reference pulse will change in amplitude while surface pulse remains constant
- Surface can be identified using retroreflective tape

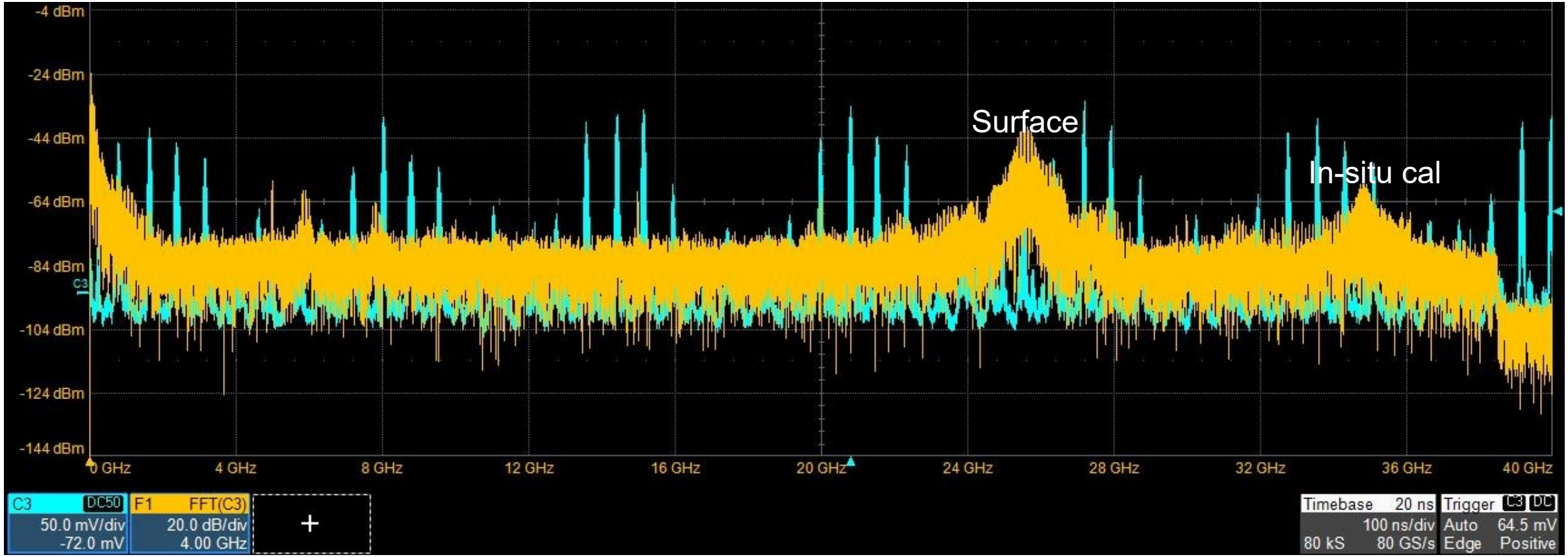
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Frequency domain check

- Run FFT on digitiser
- In-situ cal. line should peak at 34.9 GHz
- Surface peak will be visible, assuming time domain check was successful
- Move surface towards probe slowly – surface peak will go to 0 GHz and back (double ended)

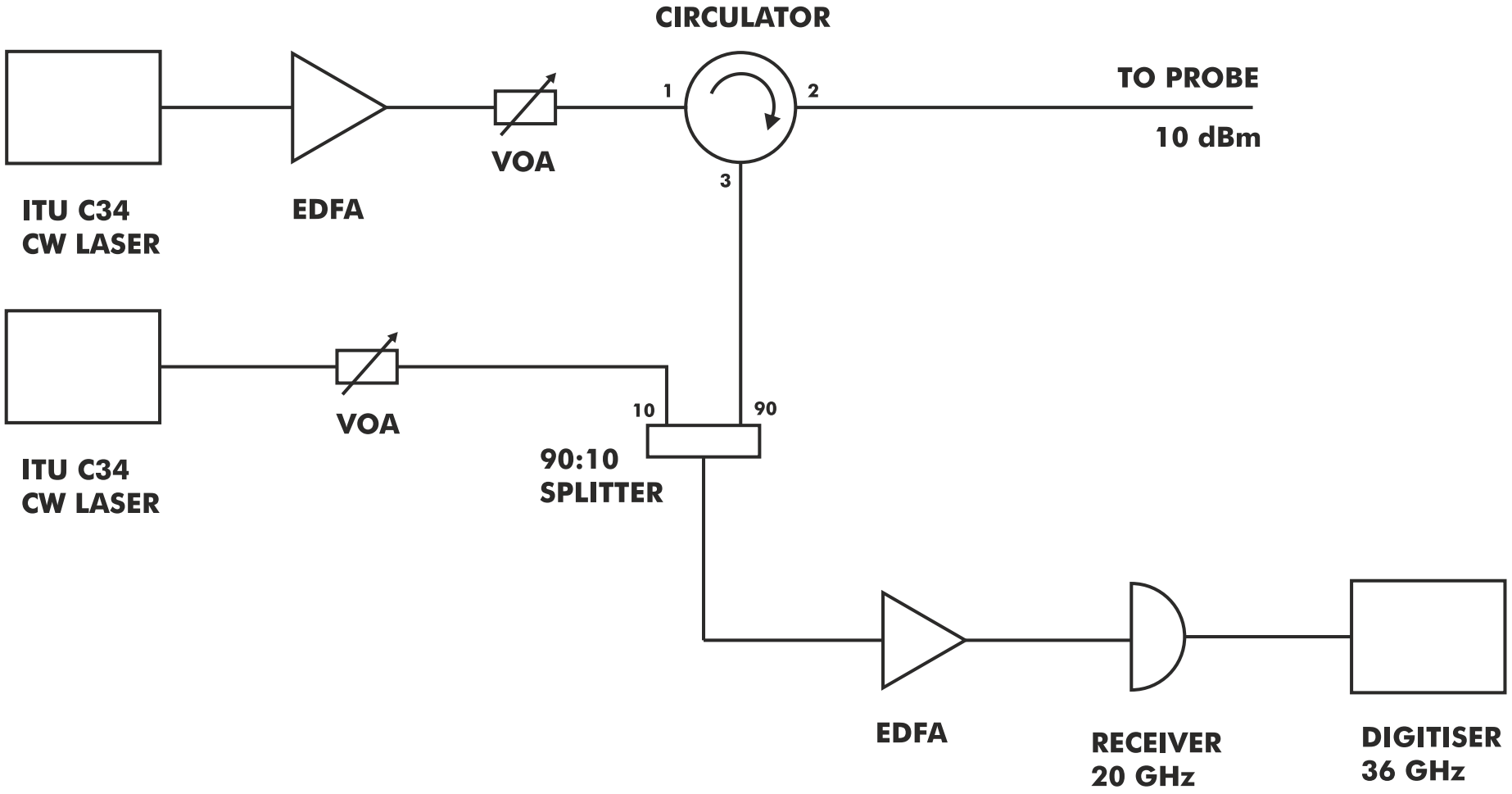
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Frequency domain check



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

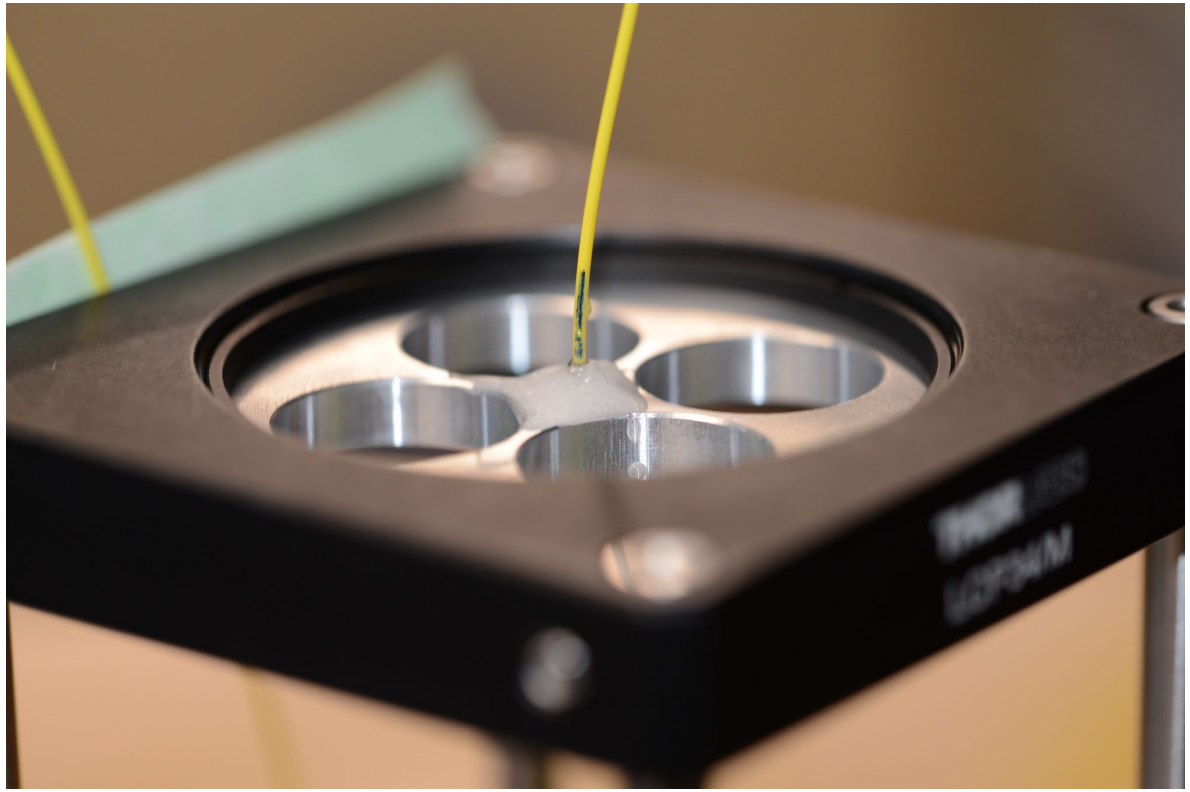
Simplified PDV system diagram



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiments

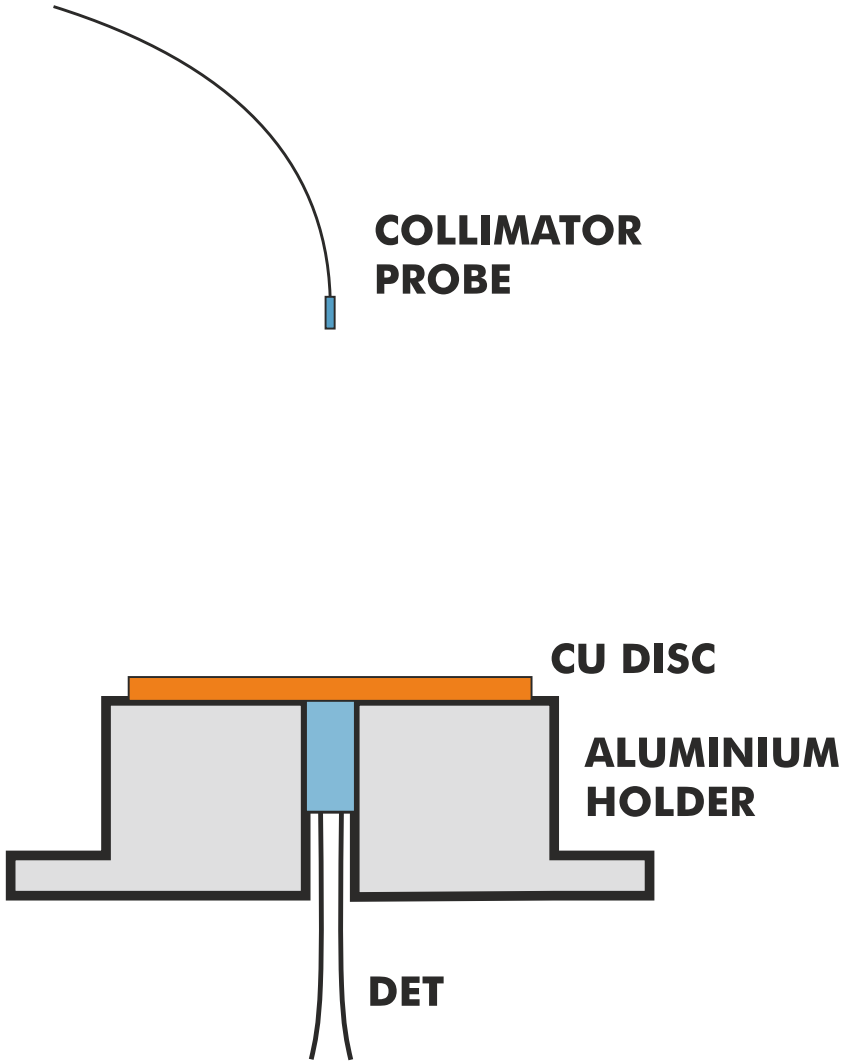
- 60 mm optomechanical cage system used to hold parts in alignment
- Collimator ~220 µm beam diameter
  - Attached with two-part epoxy or two-part epoxy putty
  - Aligned using visible laser to a hole in another cage plate to ensure measurement along cage axis



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiment 1: Cu Disc

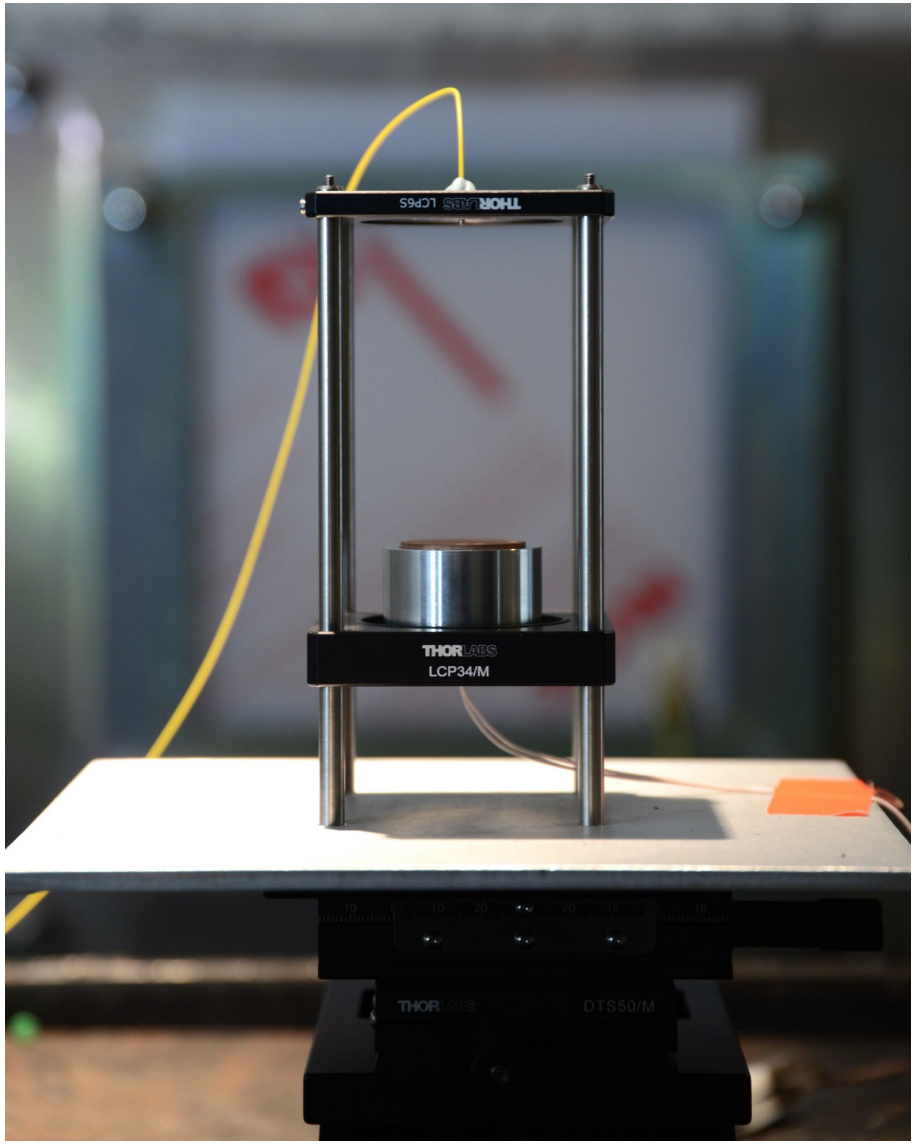
- Detonator drives 2 mm thick, 30 mm diameter copper disc
- Disc surface bead blasted for consistent return signal
- Probe aligned to centre of disc
- Disc expected to fragment



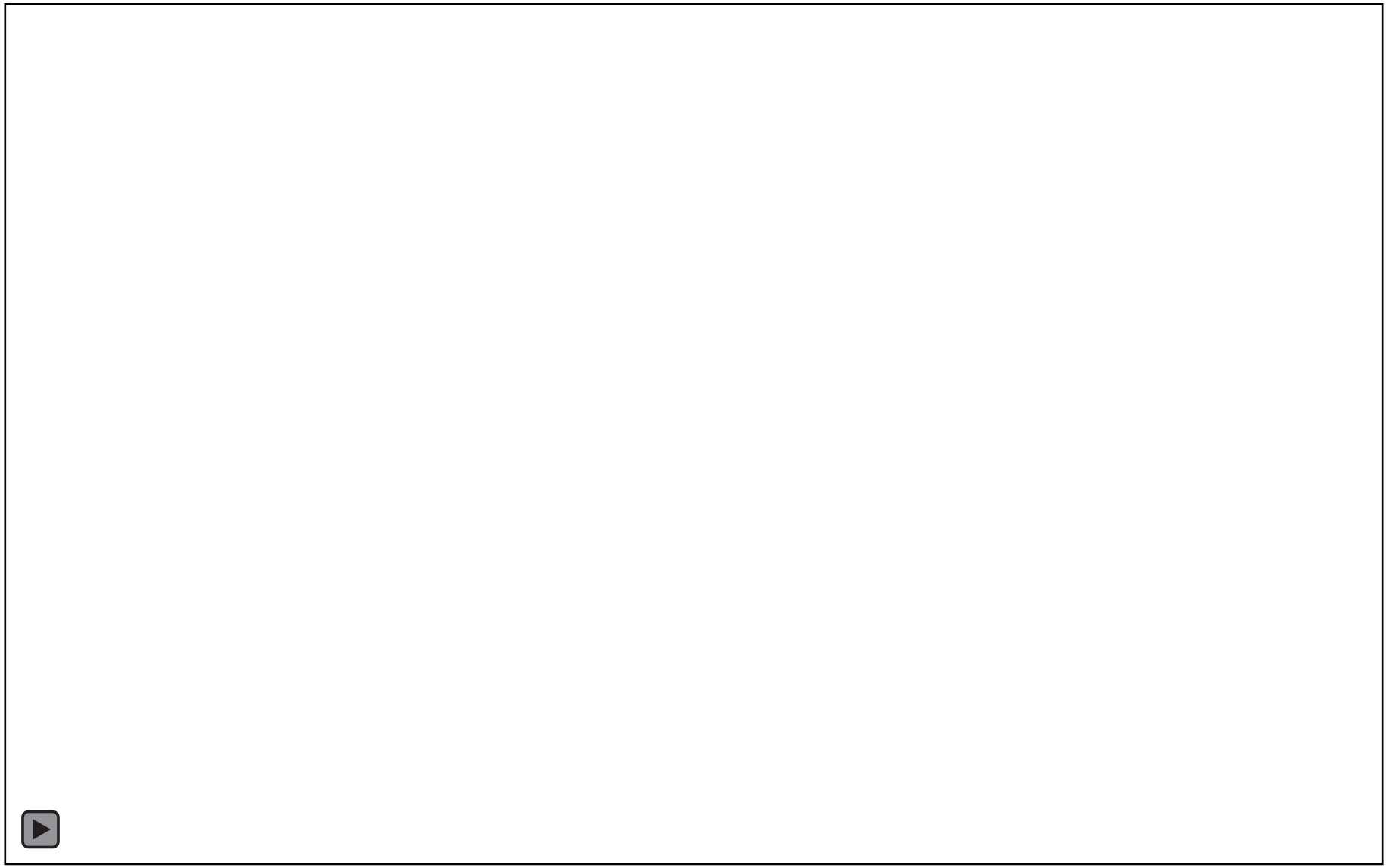
B. M. La Lone, B. R. Marshall, E. K. Miller, G. D. Stevens, W. D. Turley, L. R. Veeser; Simultaneous broadband laser ranging and photonic Doppler velocimetry for dynamic compression experiments. *Rev. Sci. Instrum.* 1 February 2015; 86 (2): 023112.

UK Ministry of Defence © Crown Owned Copyright 2024/AWE

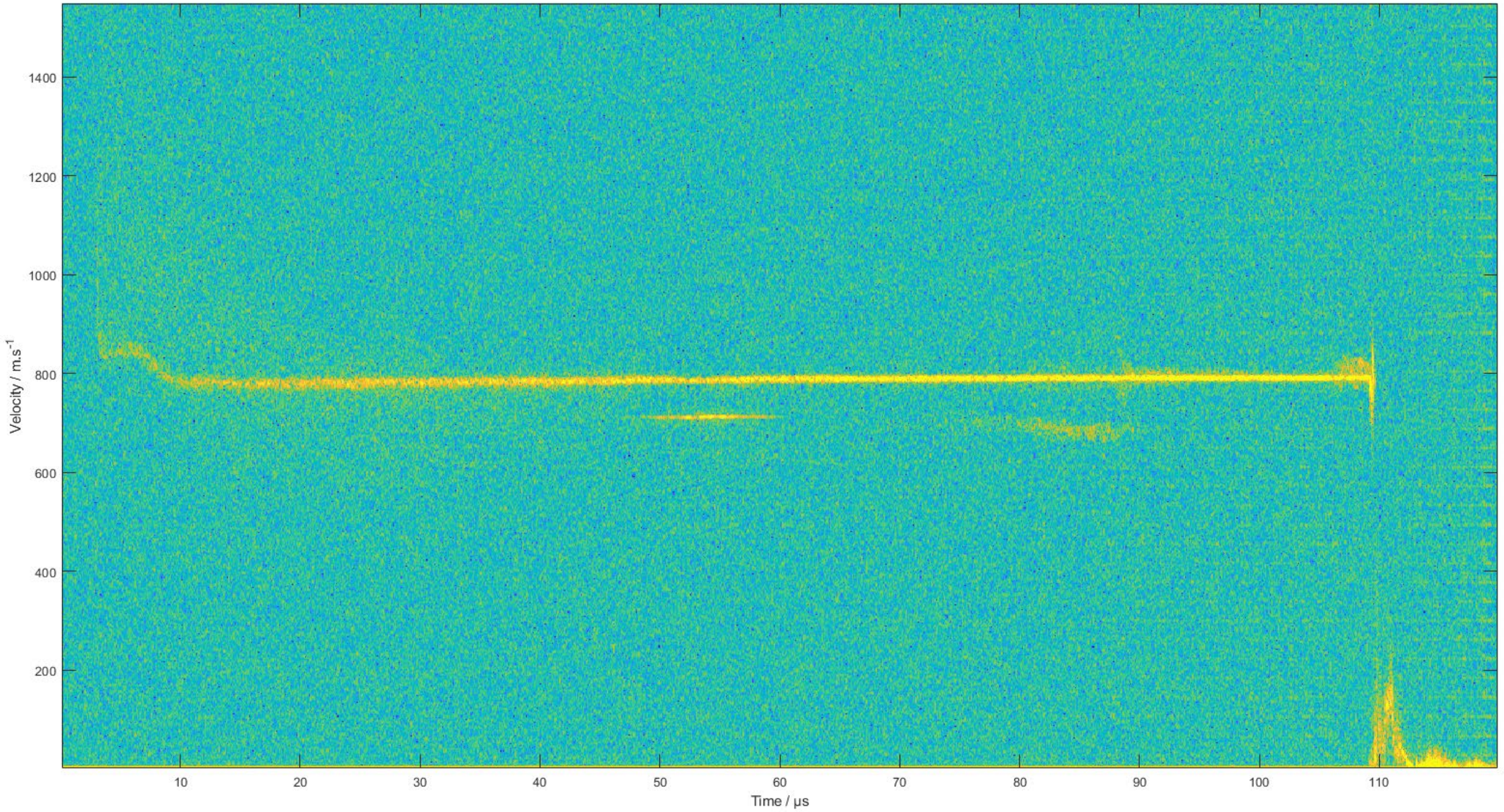
Experiment 1: Cu Disc



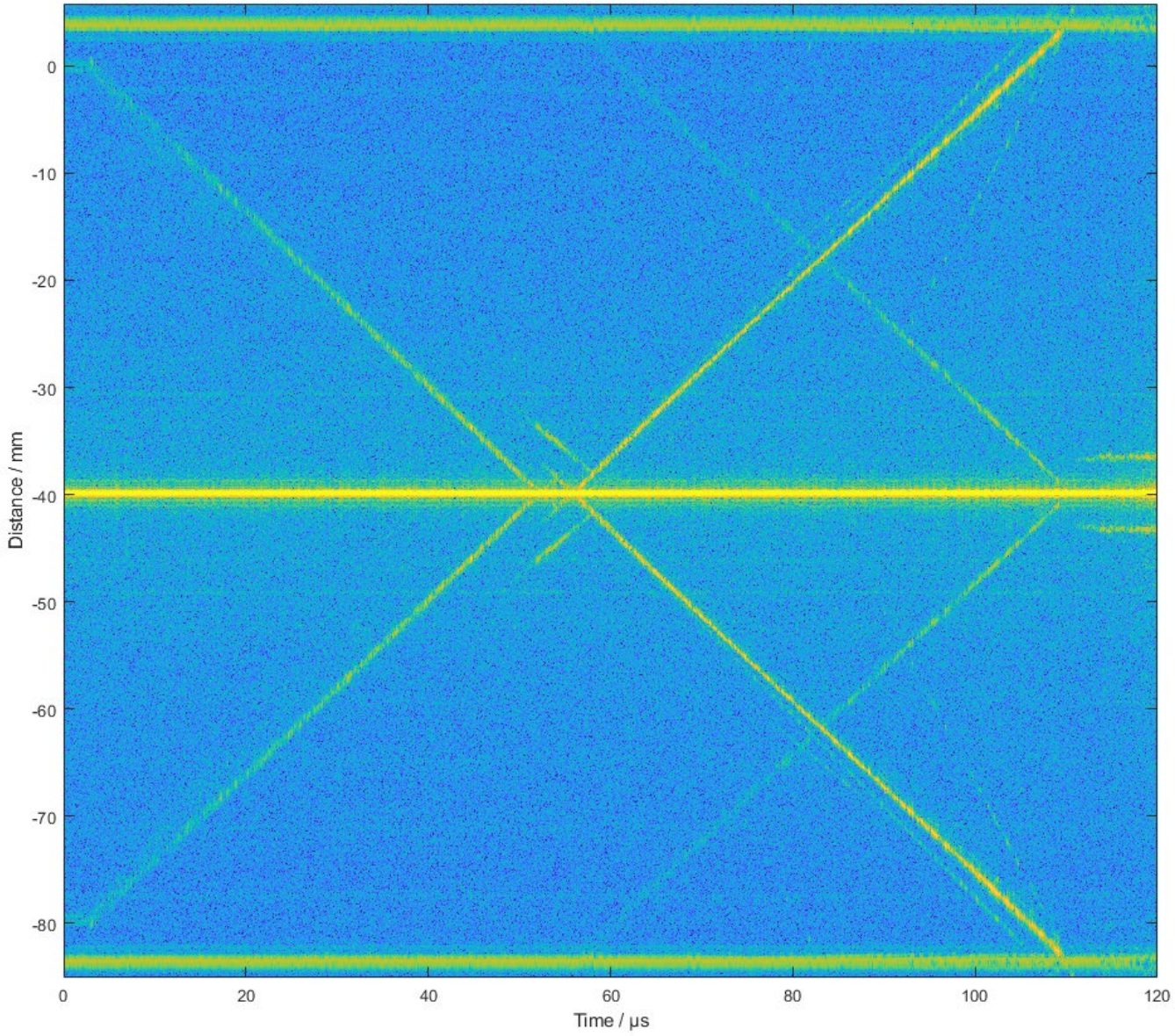
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



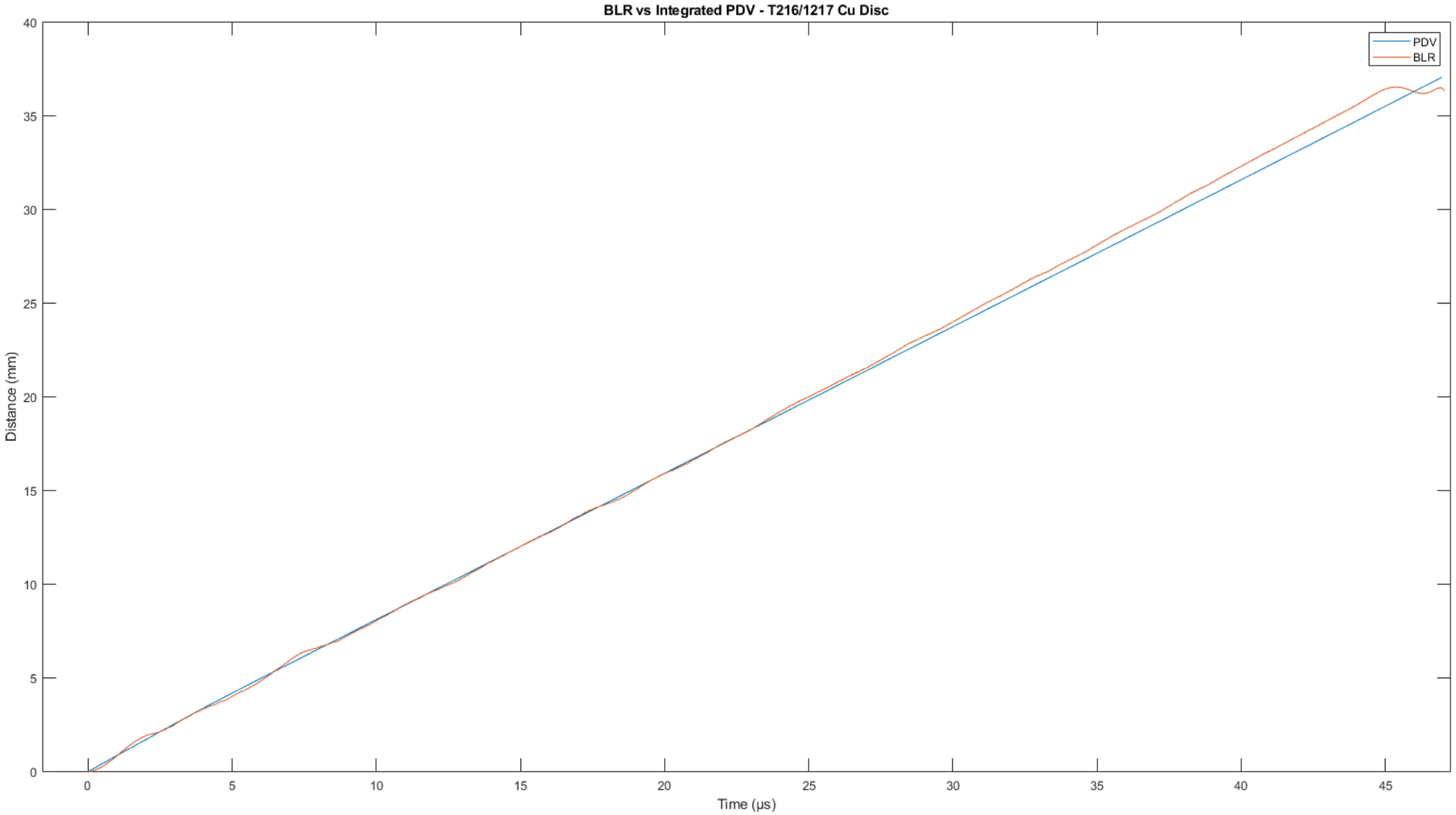
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



UK Ministry of Defence © Crown Owned Copyright 2024/AWE



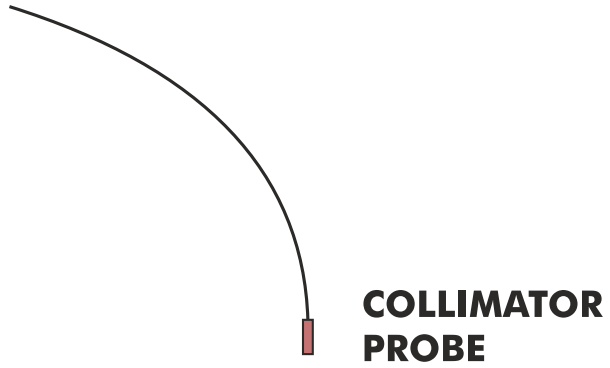
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

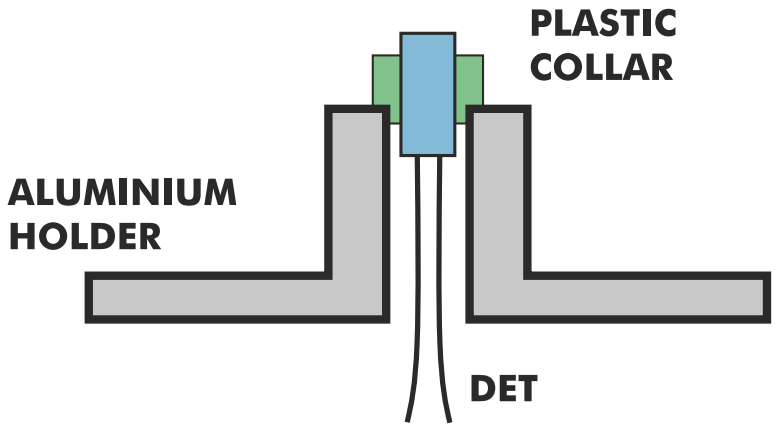


UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiment 2: Detonator

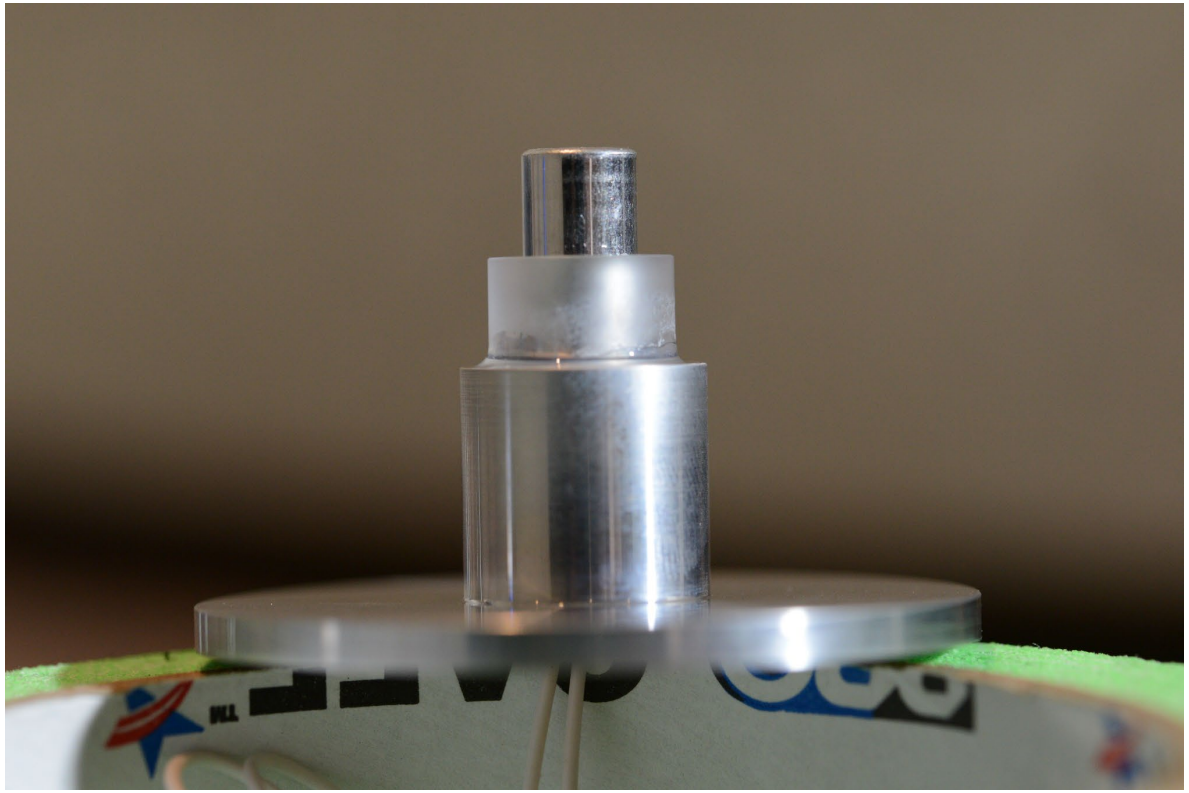
- Detonator glued into plastic collar
- Probe pointed at centre of detonator output

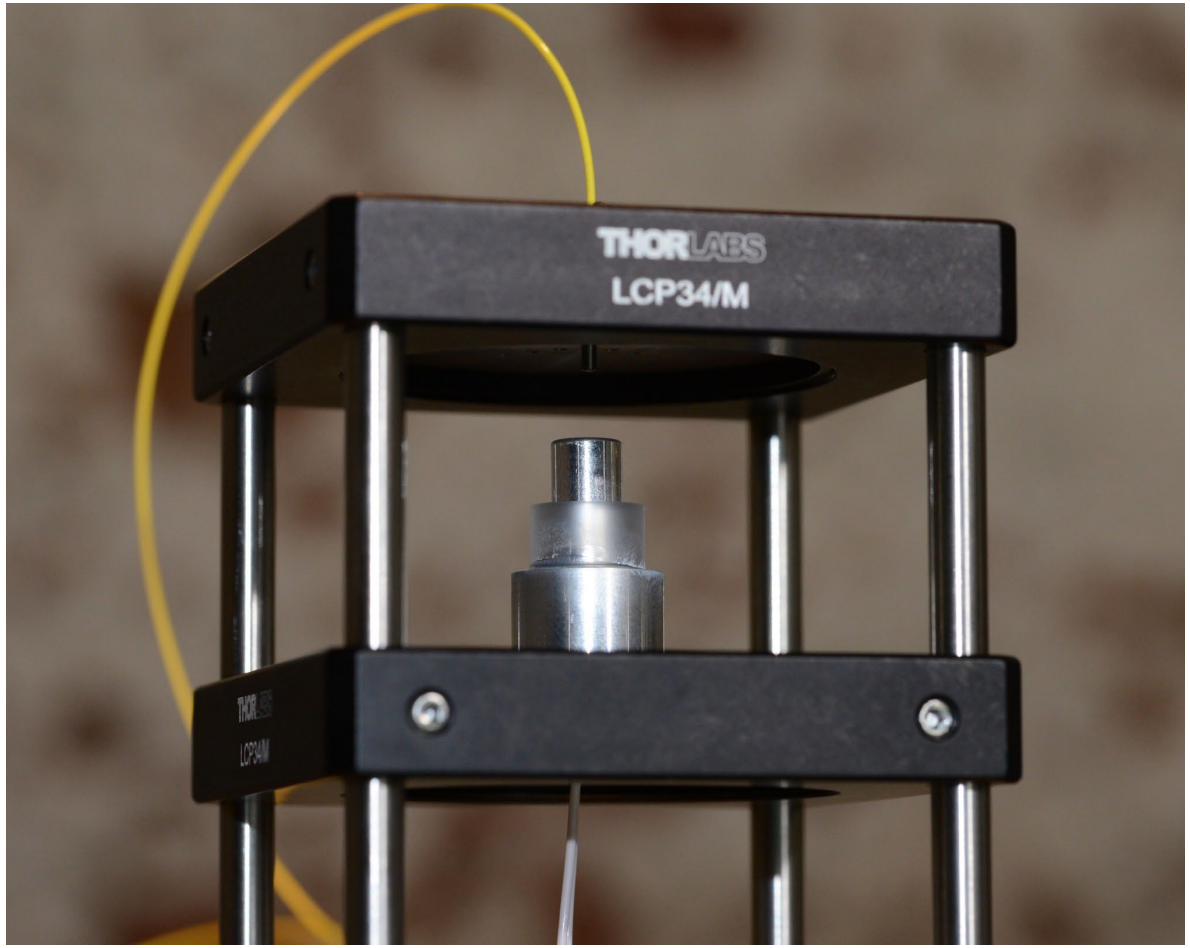




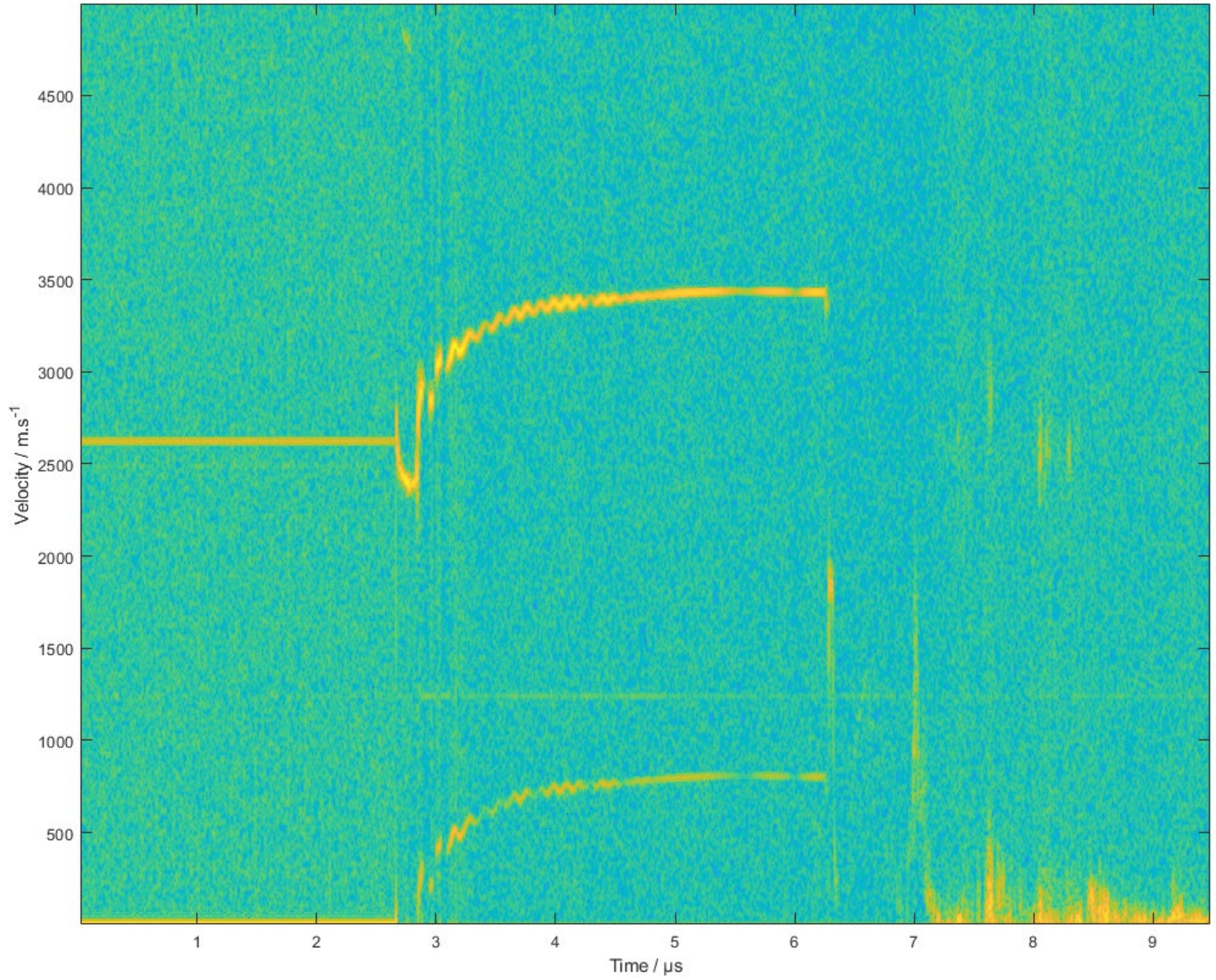
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiment 2: Detonator

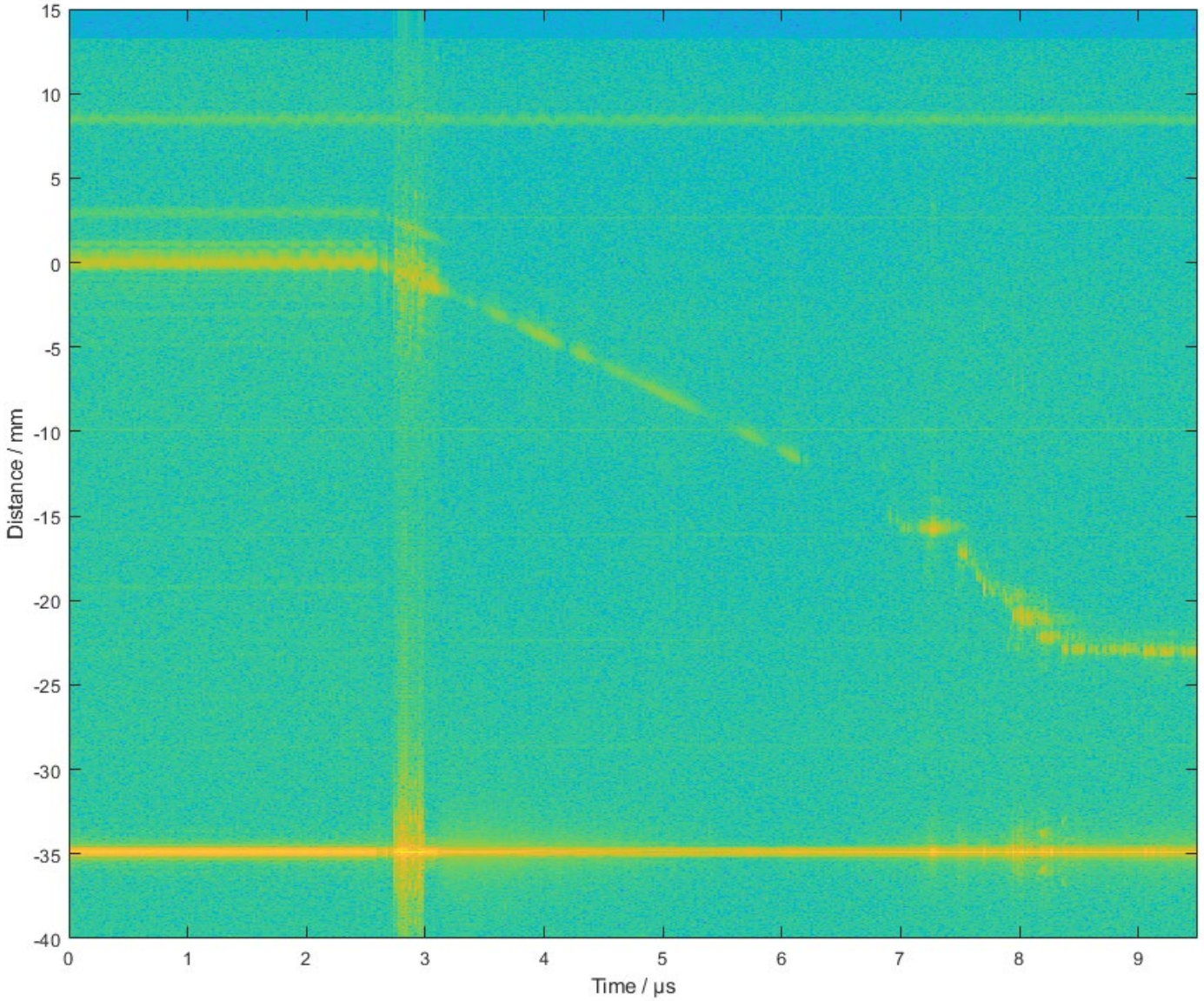




UK Ministry of Defence © Crown Owned Copyright 2024/AWE



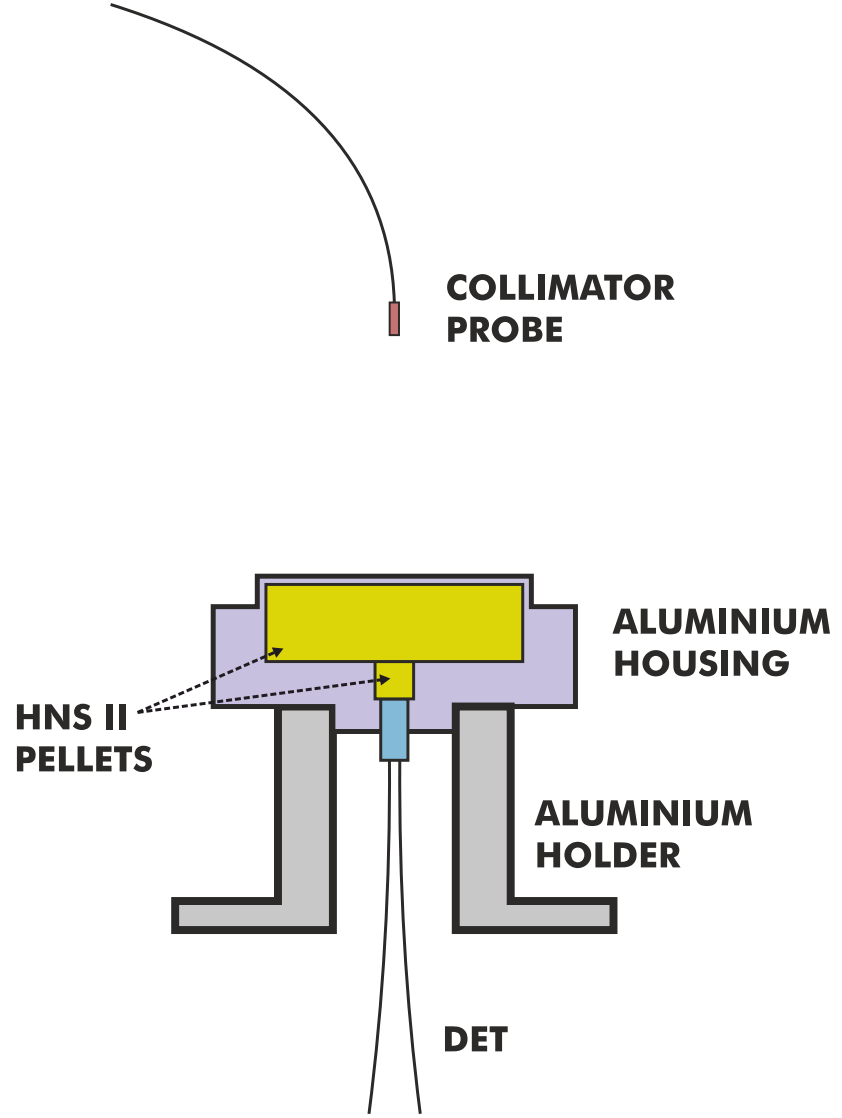
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

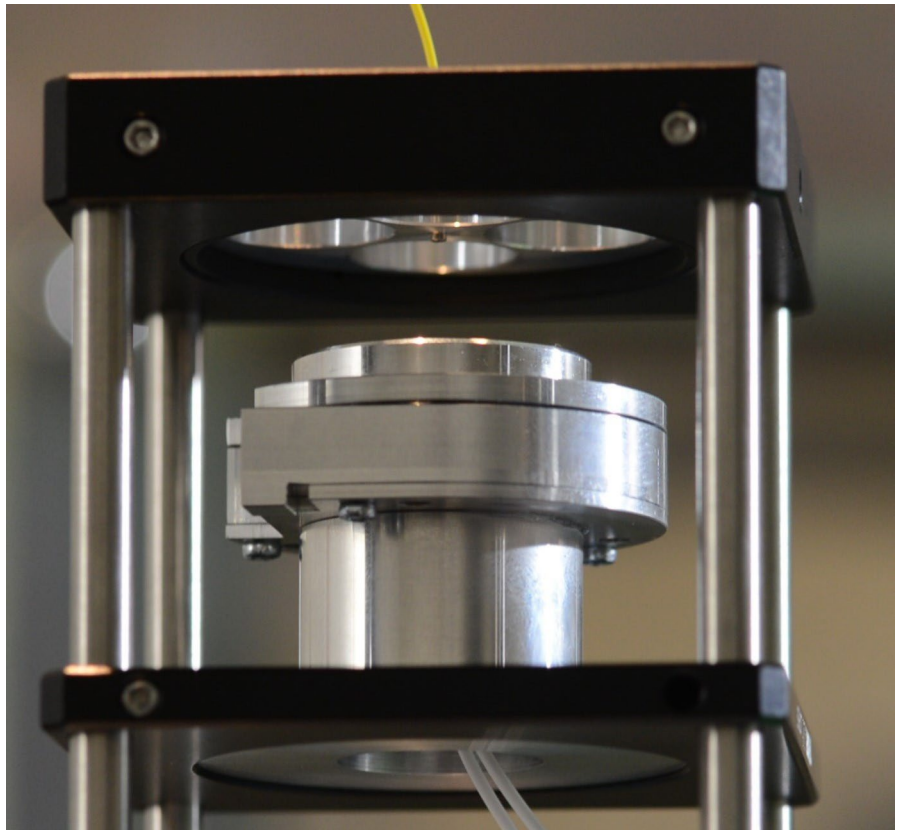
Experiment 3: Pellet Housing

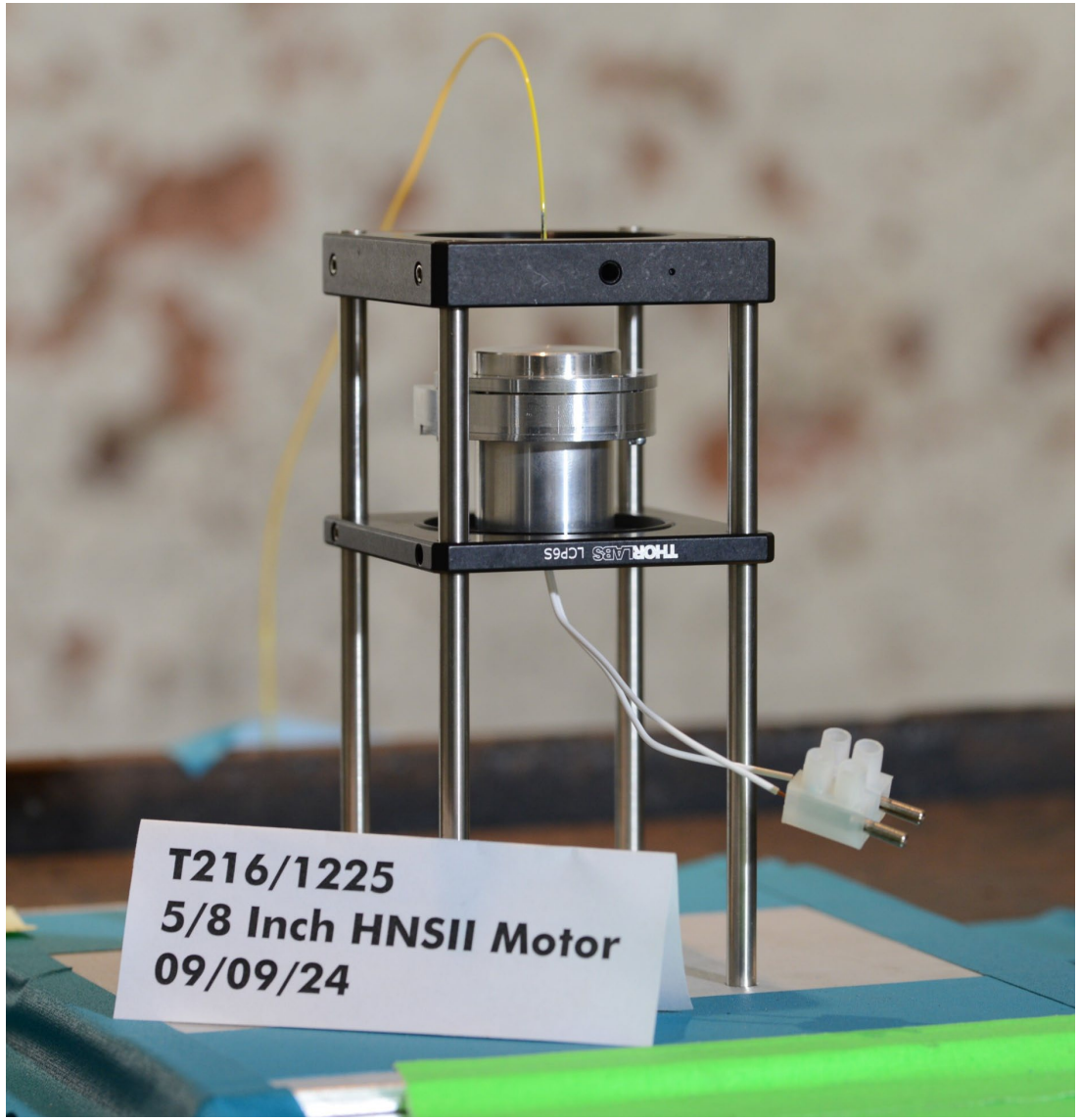
- 5/8″ diameter Hexanitrostilbene II (HNS II) output pellet in thin aluminium housing
- 6 mm diameter intermediate pellet initiated by detonator



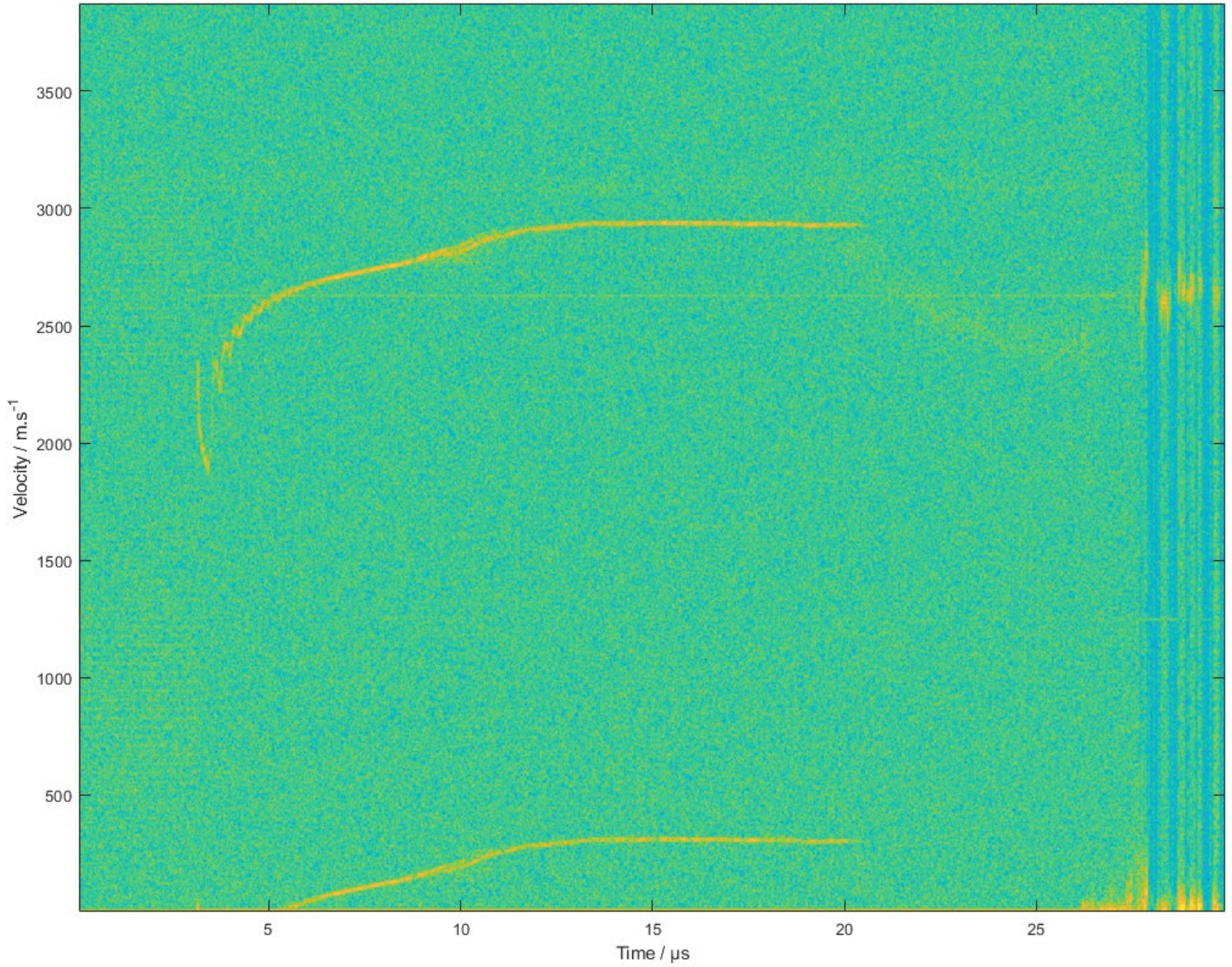
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiment 3: Pellet Housing

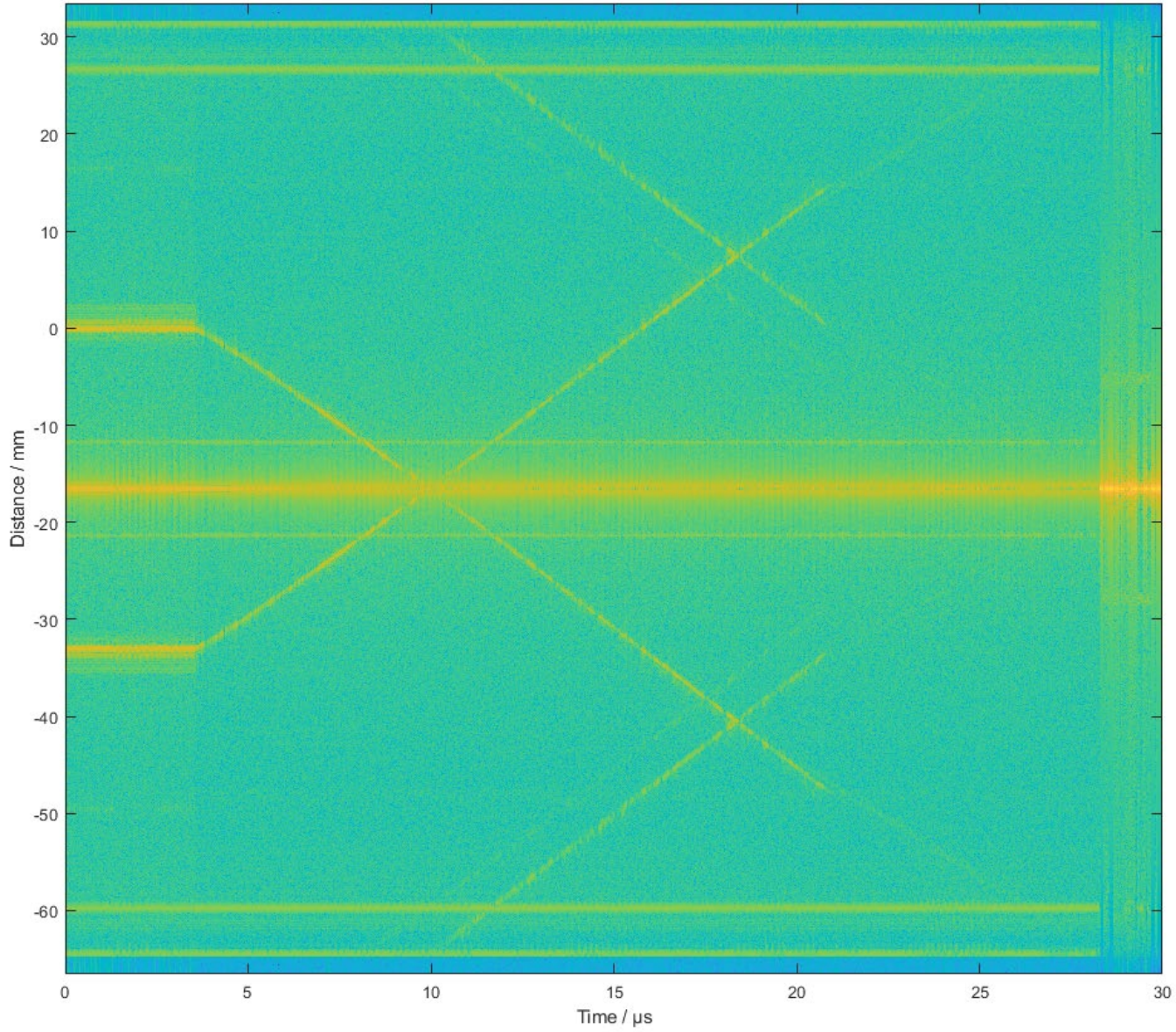




UK Ministry of Defence © Crown Owned Copyright 2024/AWE



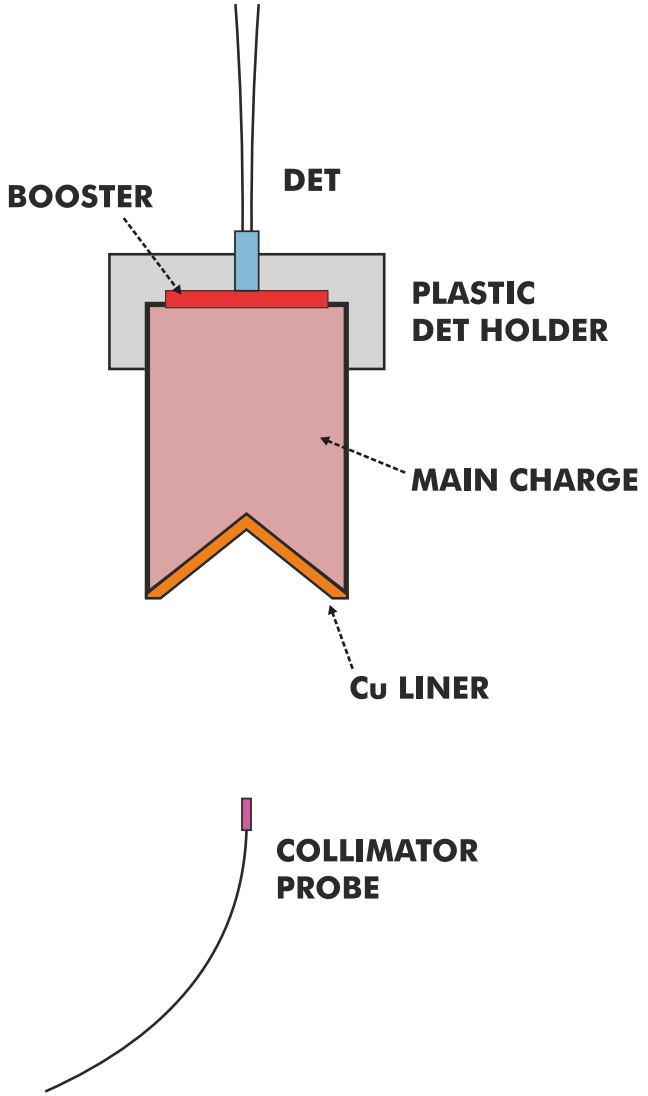
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

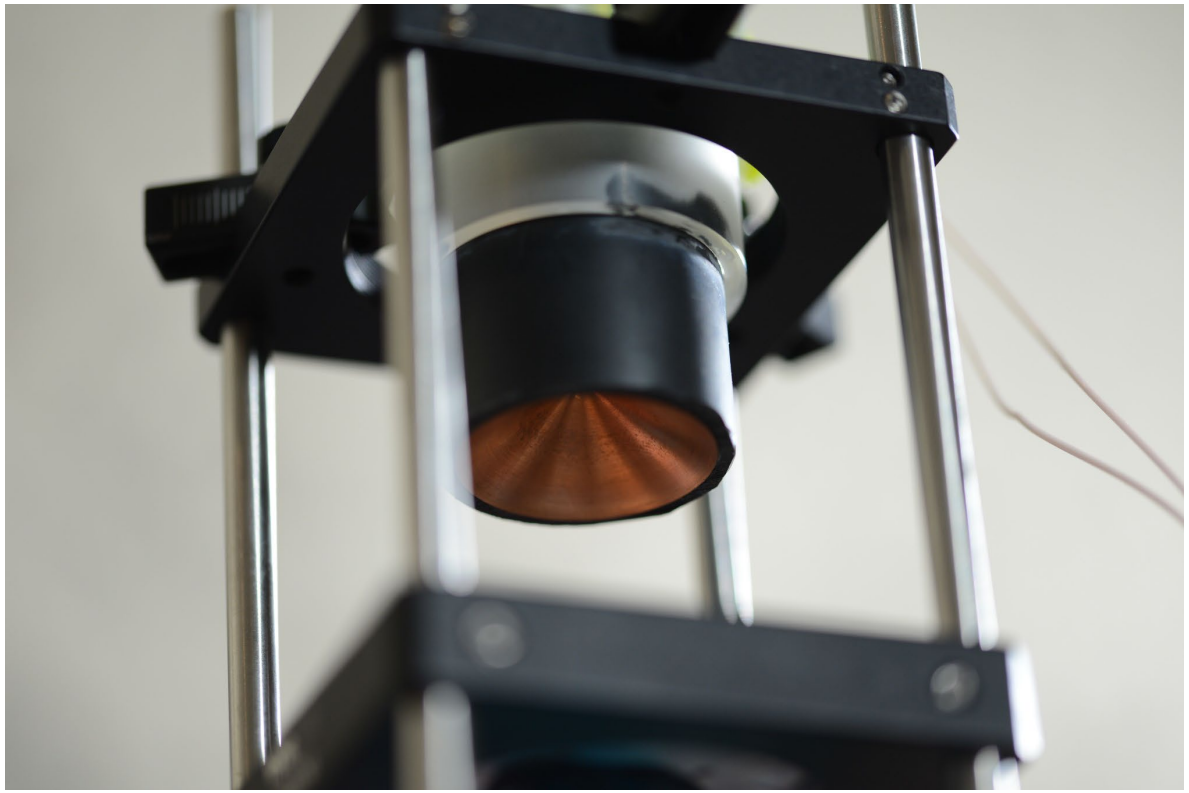
Experiment 4: Shaped Charge

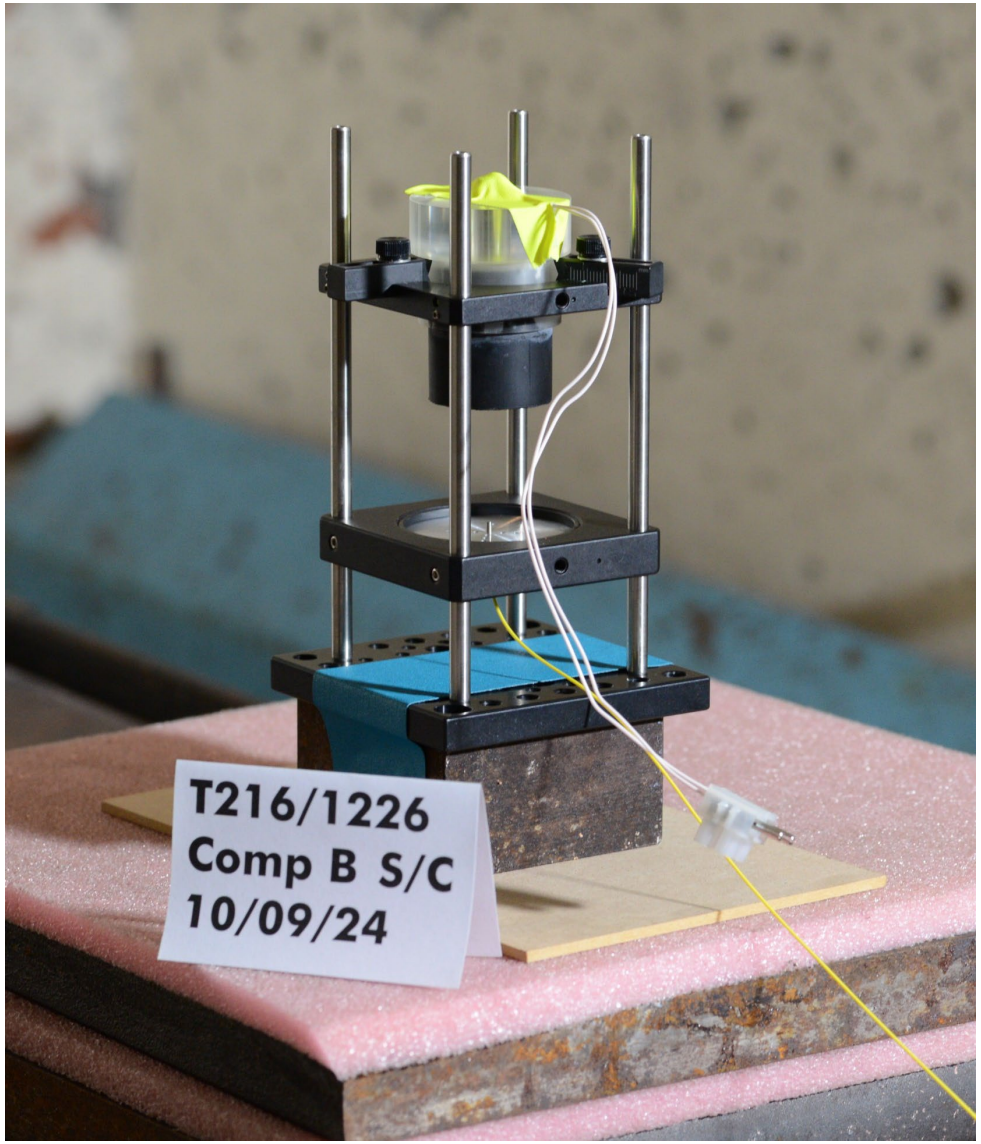
- 30 mm diameter shaped charge
- Conical copper liner
- Composition B (RDX/TNT) cast fill
- End-initiating detonator with PETN sheet explosive booster
- Probe pointed at liner apex, along charge axis



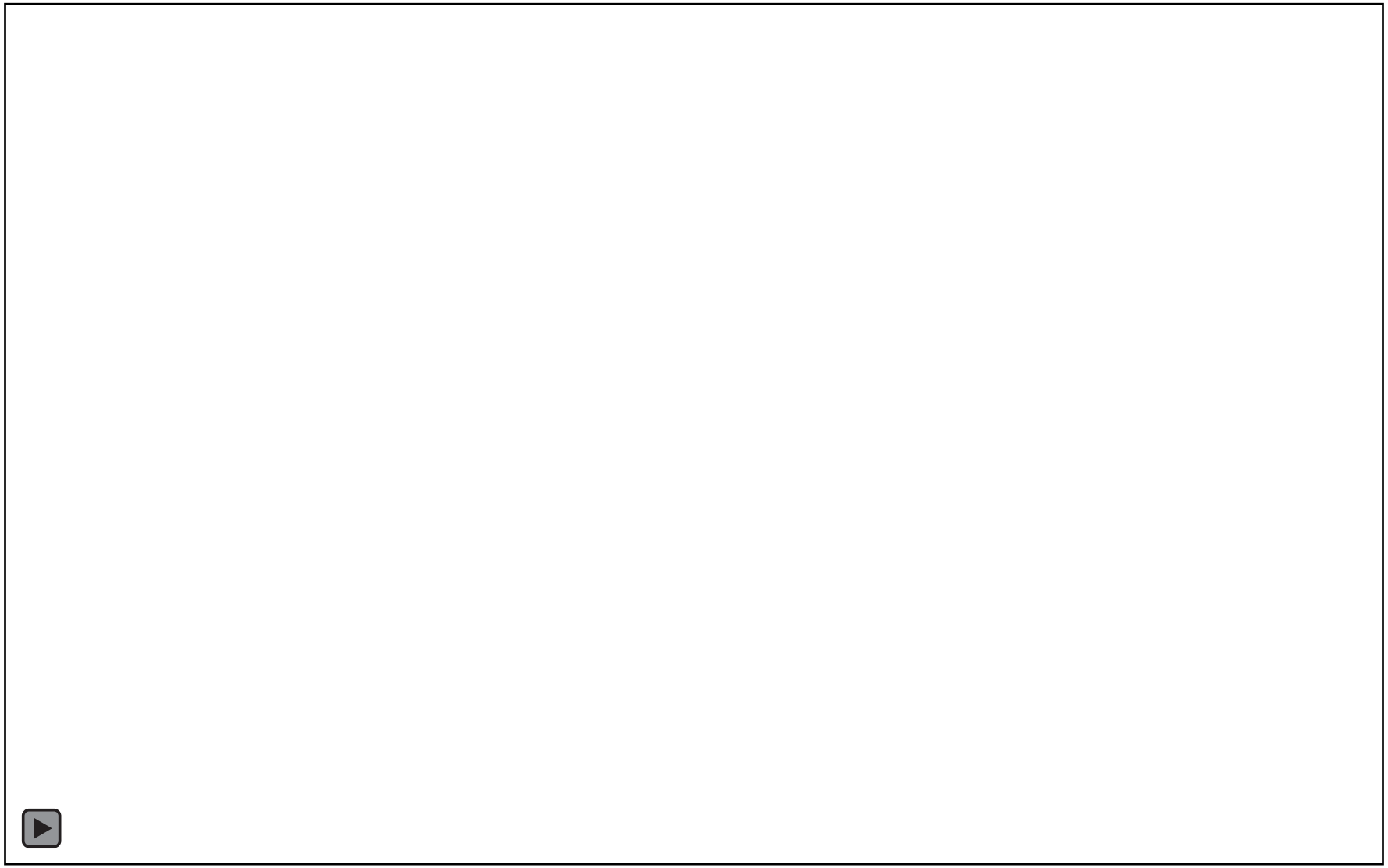
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Experiment 4: Shaped Charge

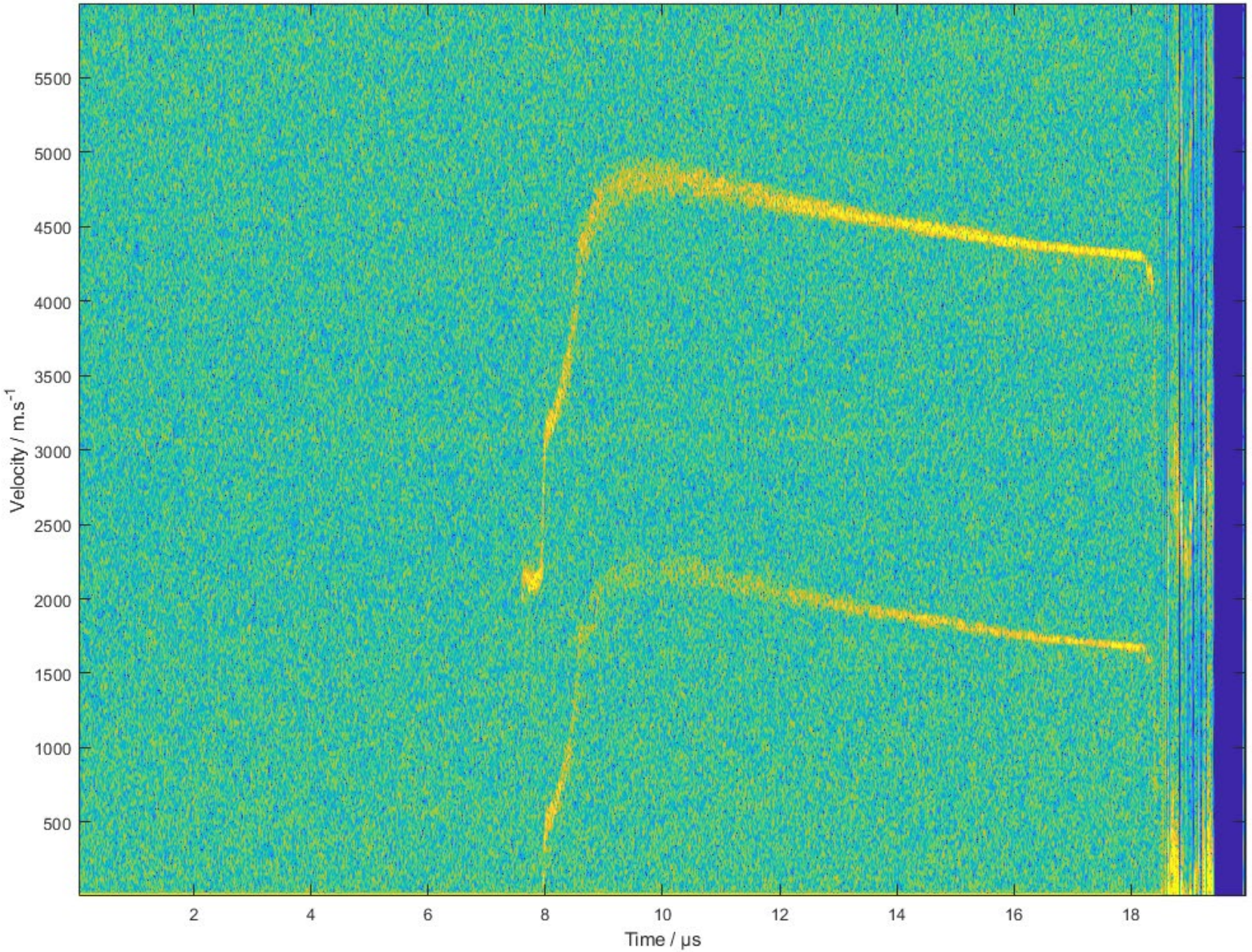




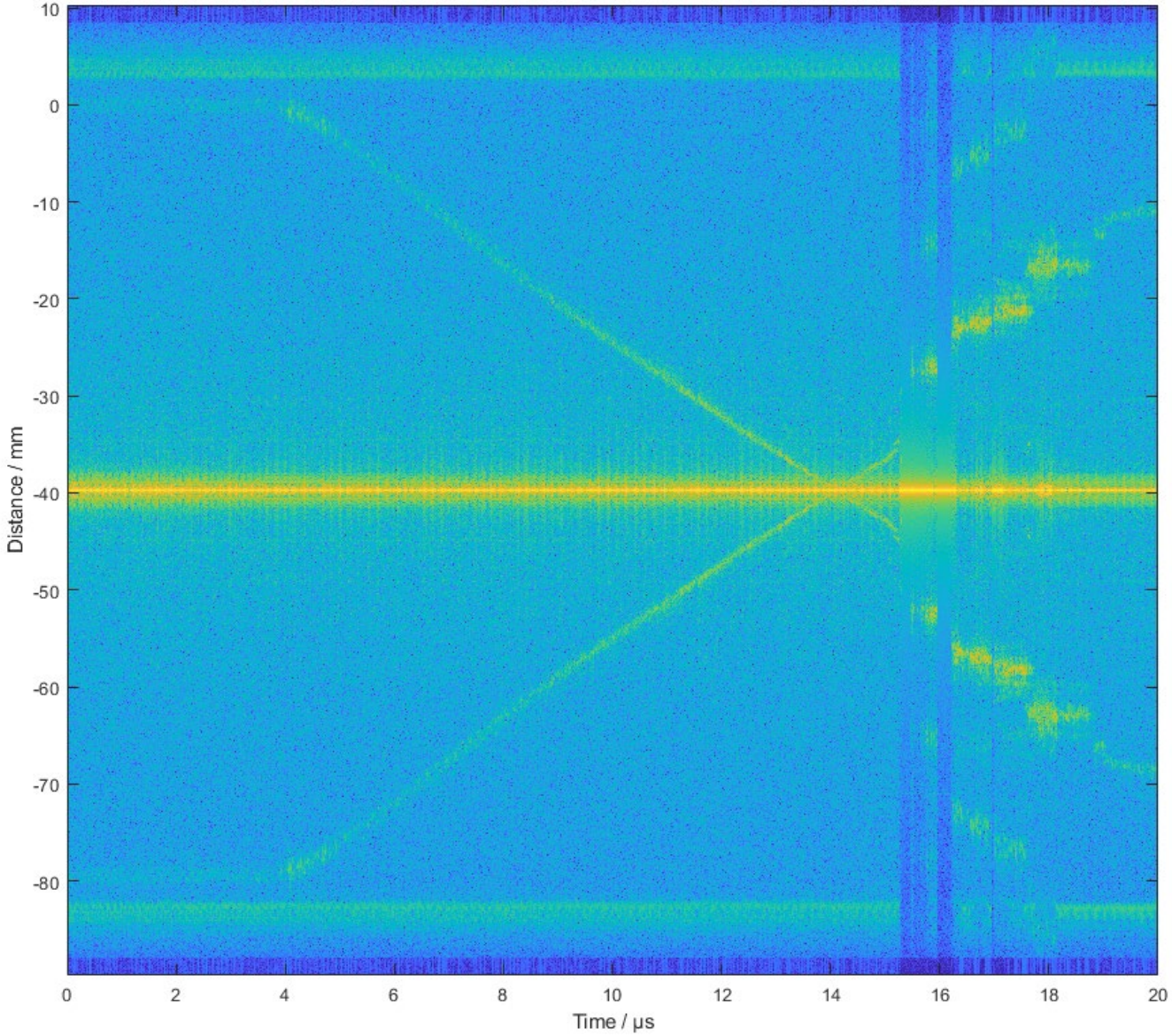
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



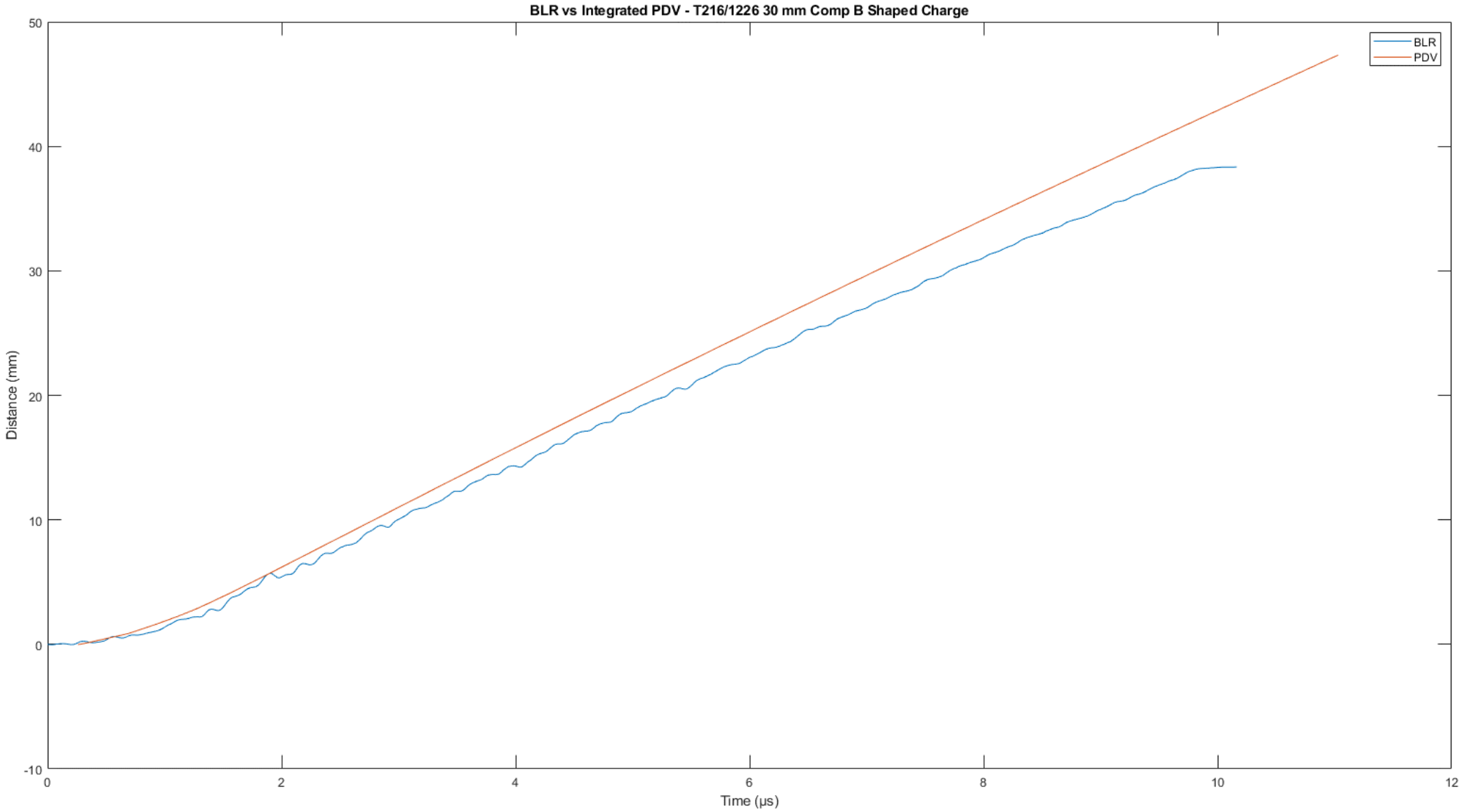
UK Ministry of Defence © Crown Owned Copyright 2024/AWE



UK Ministry of Defence © Crown Owned Copyright 2024/AWE



UK Ministry of Defence © Crown Owned Copyright 2024/AWE



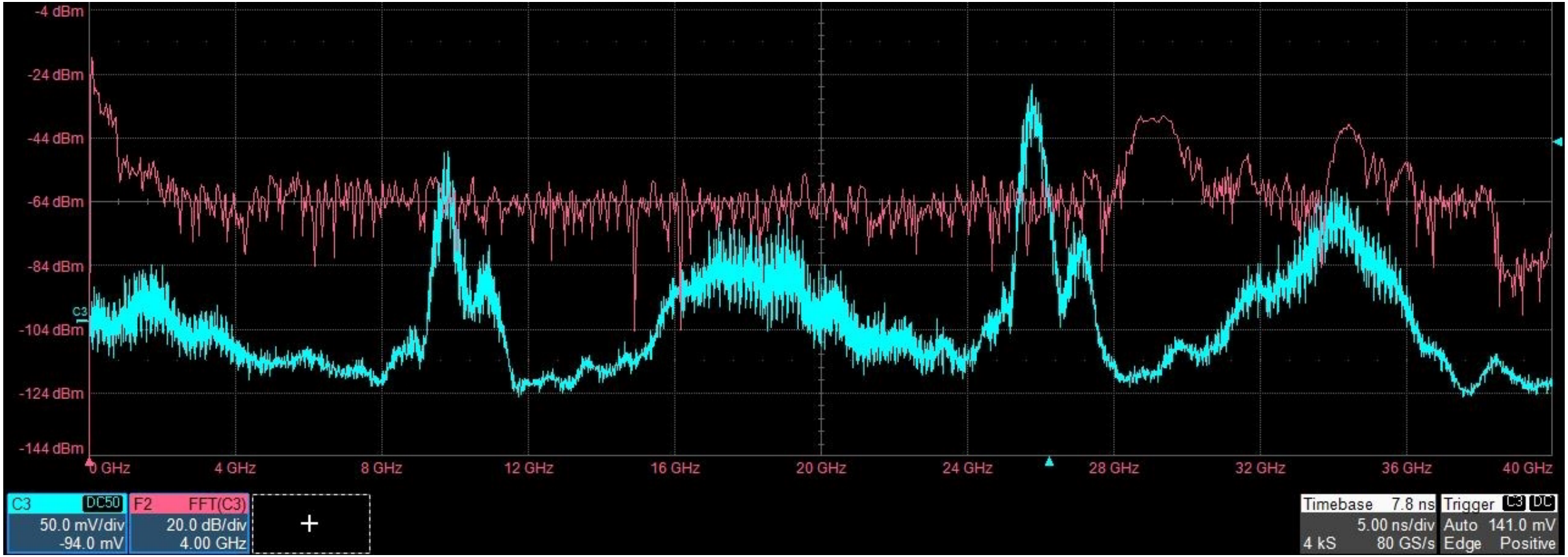
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Issues and Improvements – BLR

- Implement polarisation control to improve SNR
- Characterise seed laser pump current dependent wavelength shift using spectrometer – this is seen on digitiser FFT
  - Filters are for 1533 – 1564 nm pass band
- Add a pulse picker
  - Reduce setup time by making correlating pulses easier when single-triggered
  - Allow reduced rep rate during experiments
  - At 50 MHz this system is close to overlapping pulses
- Replace EDFA with Raman amplifier scheme using DCF – benefits?

UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Issues and Improvements – BLR SNR



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Issues and Improvements – BLR

- Dispersion compensation fibre in DCM causes a time delay relative to PDV channels
  - Approximately 40 μs in this system
- Add a fiducial pulse during experiment for PDV and BLR channel cross-timing
- Measure probe standoff using OBR every time so movement can be measured relative to probe position if required
- Package system in 19″ rack chassis for mobility

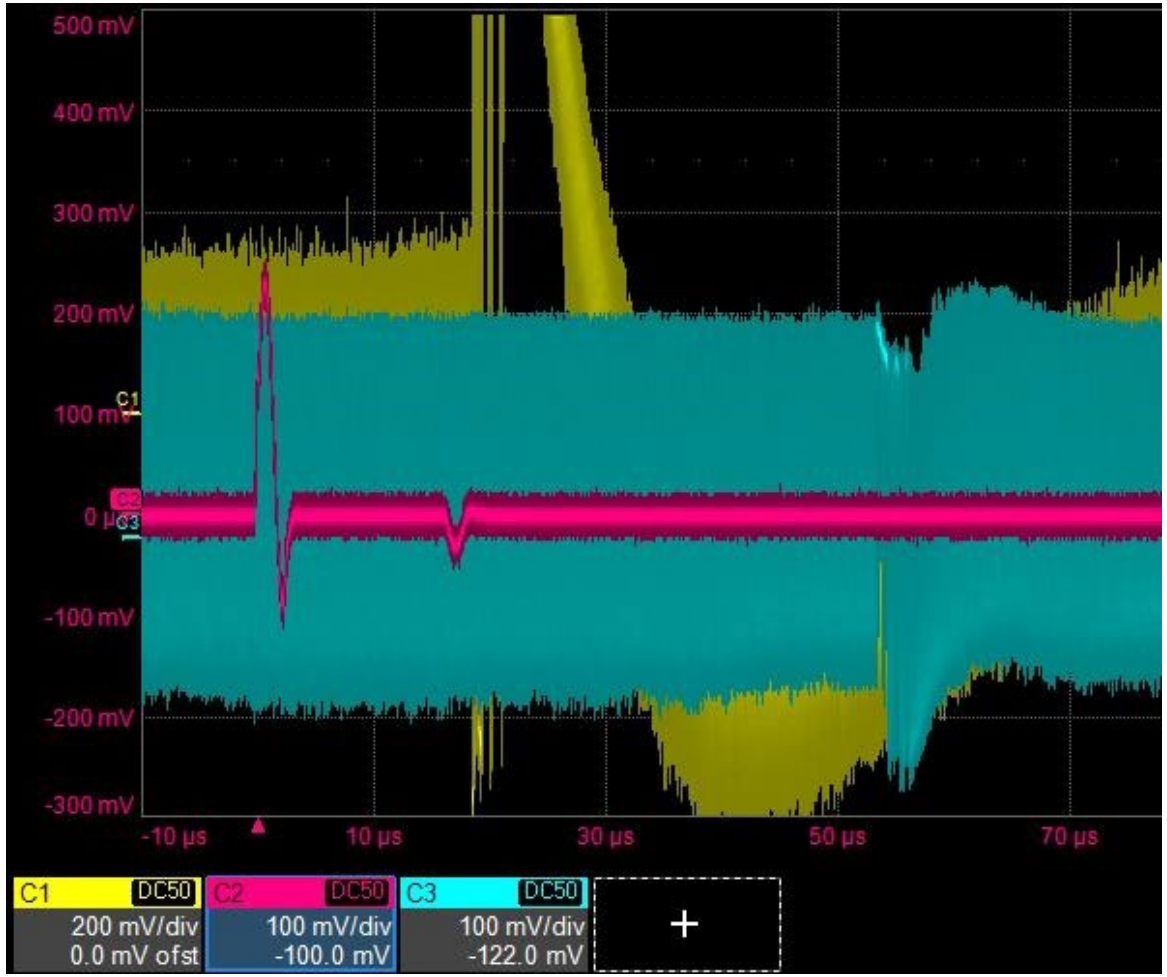
- Dechirp in analysis
- Find in-situ calibration frequency automatically

UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Issues and Improvements – PDV

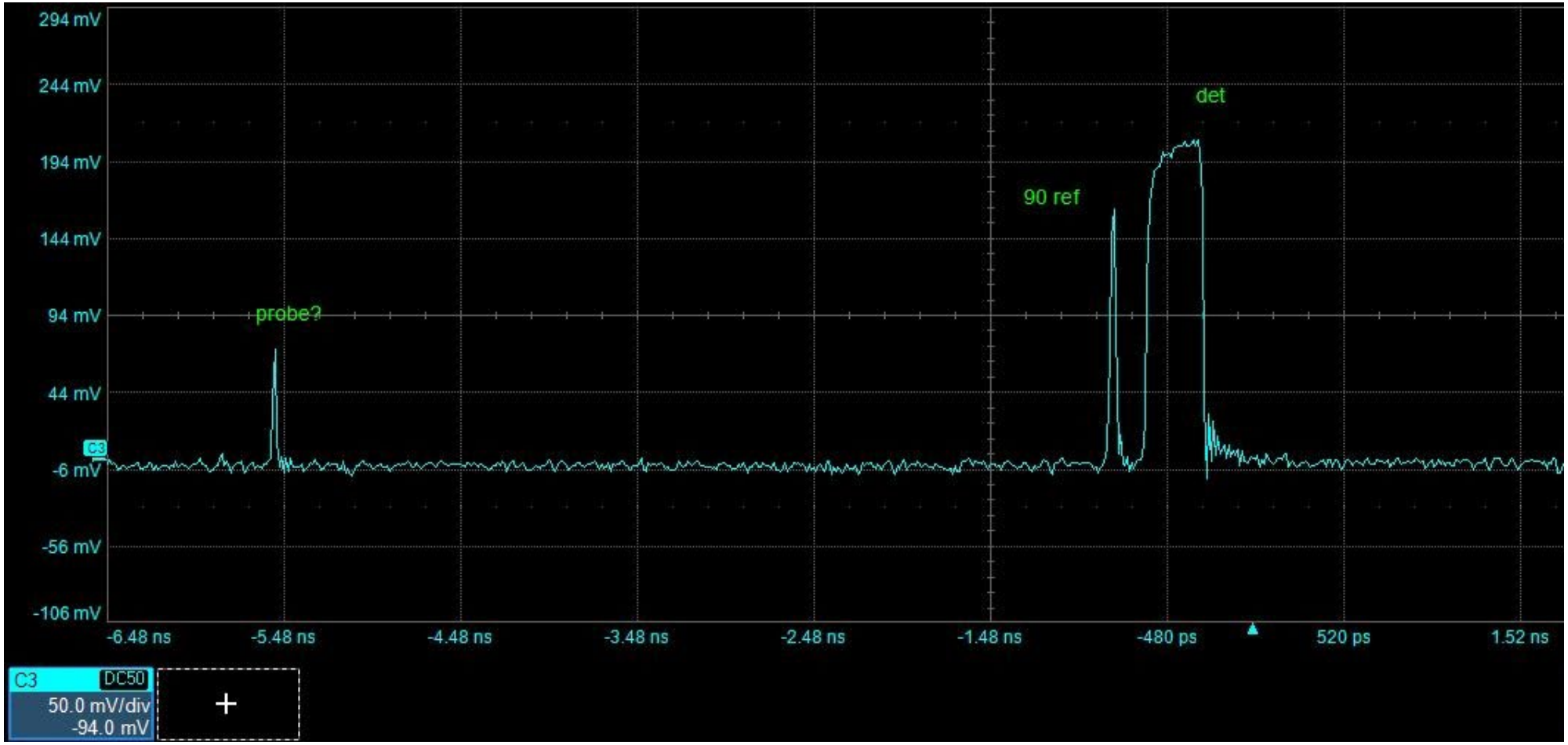
- 20 GHz receiver behaviour upon sharp drop in return signal
  - Bias takes tens of microseconds to recover
  - Causes clipping

- PDV should be upshifted more to separate main signal from 0-referenced signal



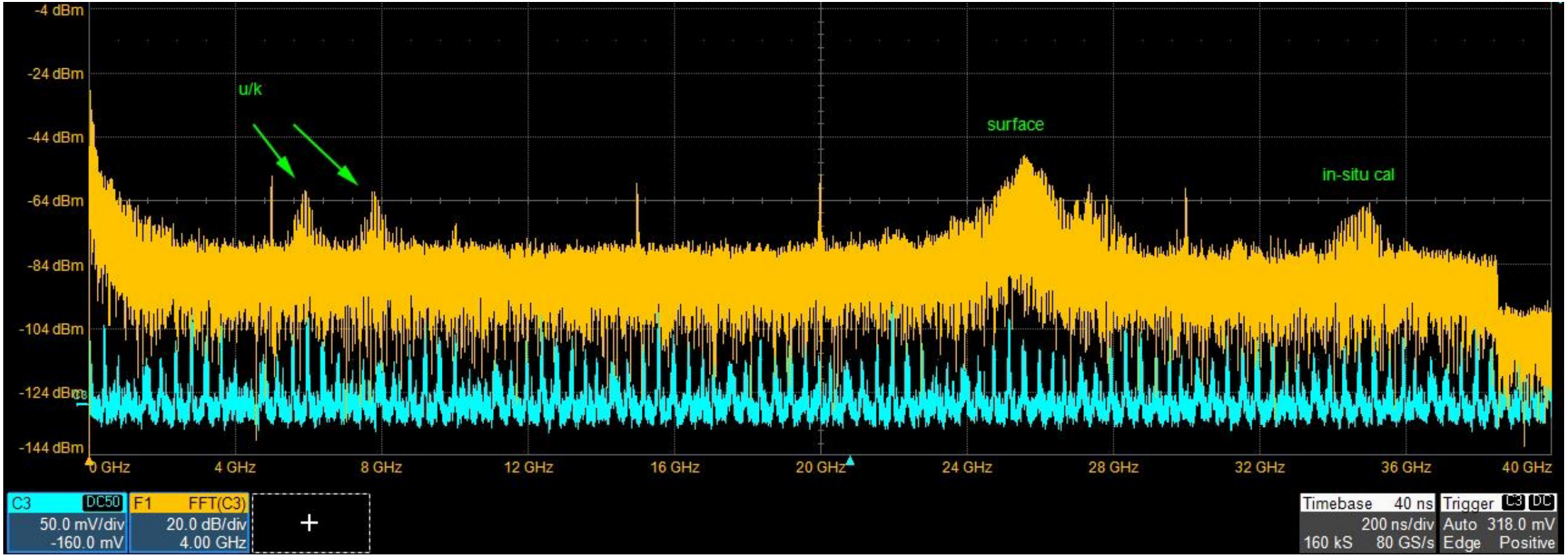
UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Appendix – where does this pulse come from?



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Appendix – extra frequency peaks



UK Ministry of Defence © Crown Owned Copyright 2024/AWE

Acknowledgements

- Callum Pryer, AWE

BLR system design and construction, analysis software

- Alice Keeble and Eloise May, AWE

Construction of in-situ calibration fibres

- Tom Ota, AWE

Development of previous iteration of BLR

- Instrumentation Team, Counter Terrorism & Security Division, DSTL

High-speed imaging

- Firing officers & technicians, AWE

UK Ministry of Defence © Crown Owned Copyright 2024/AWE

AWE NUCLEAR SECURITY TECHNOLOGIES

www.awe.co.uk

© British Crown Owned Copyright 2024/AWE

AWE Nuclear Security Technologies is the trading name for AWE plc. AWE is a Non-Departmental Public Body owned by the Ministry of Defence. Registered in England and Wales. Registration no. 02763902

AWE plc Aldermaston, Reading, Berkshire, RG7 4PR