Australian Government
Department of Defence
Defence Science and Technology Group

Novel instrumentation technique to derive critical diameter in PBXN-111

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Problem

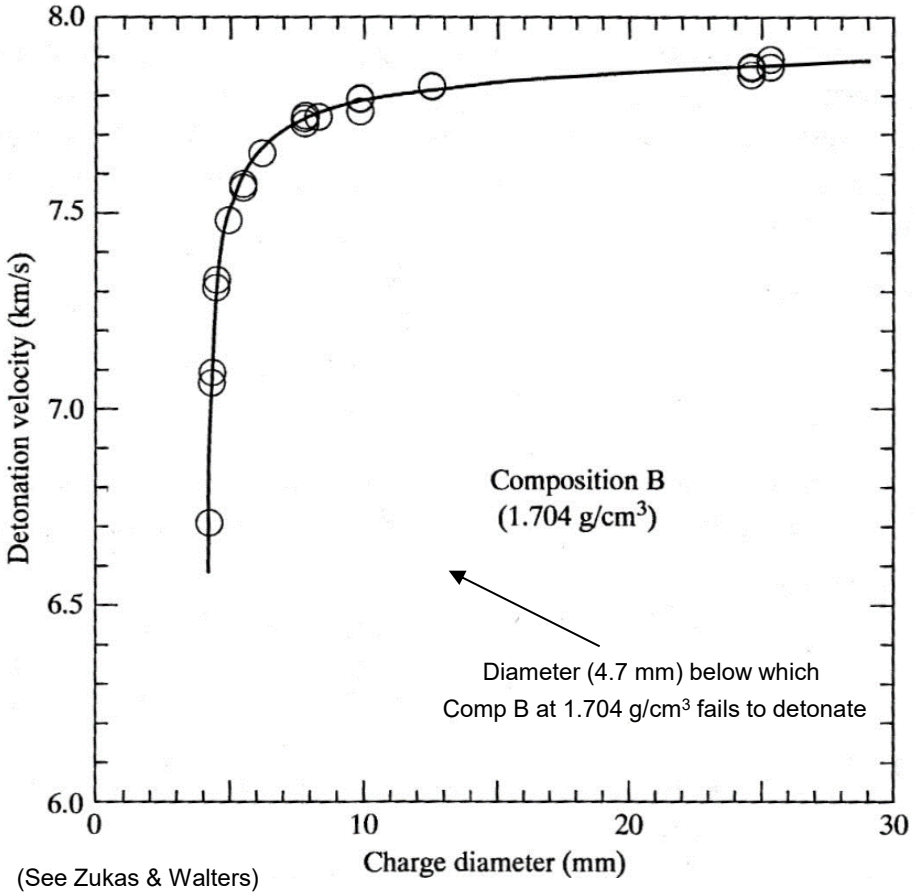
- Critical diameter is an essential parameter for qualification of explosive for service according to STANAG 4170. An explosive of interest to the GWEO enterprise, PBXN-111, has a large critical diameter, 60-80 mm, which requires a large amount of material to be tested.

Suggested solution

- Conduct the tests with a smaller, subcritical-diameter explosive charges measuring the run-to-failure distance, verifying the computational model, and deriving the critical diameter from the computational model.

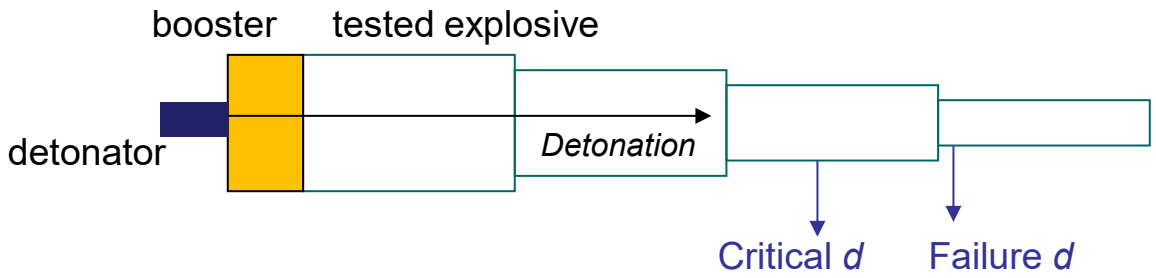
Critical diameter definition

- Critical diameter is the minimum diameter at which a cylindrical explosive charge sustains a high-order steady-state detonation



(See Zukas & Walters)

The measurement technique



Examples of critical diameter measurements in DSTG explosive chamber

- Indentation in metal plate occurs due to high pressure of detonation products

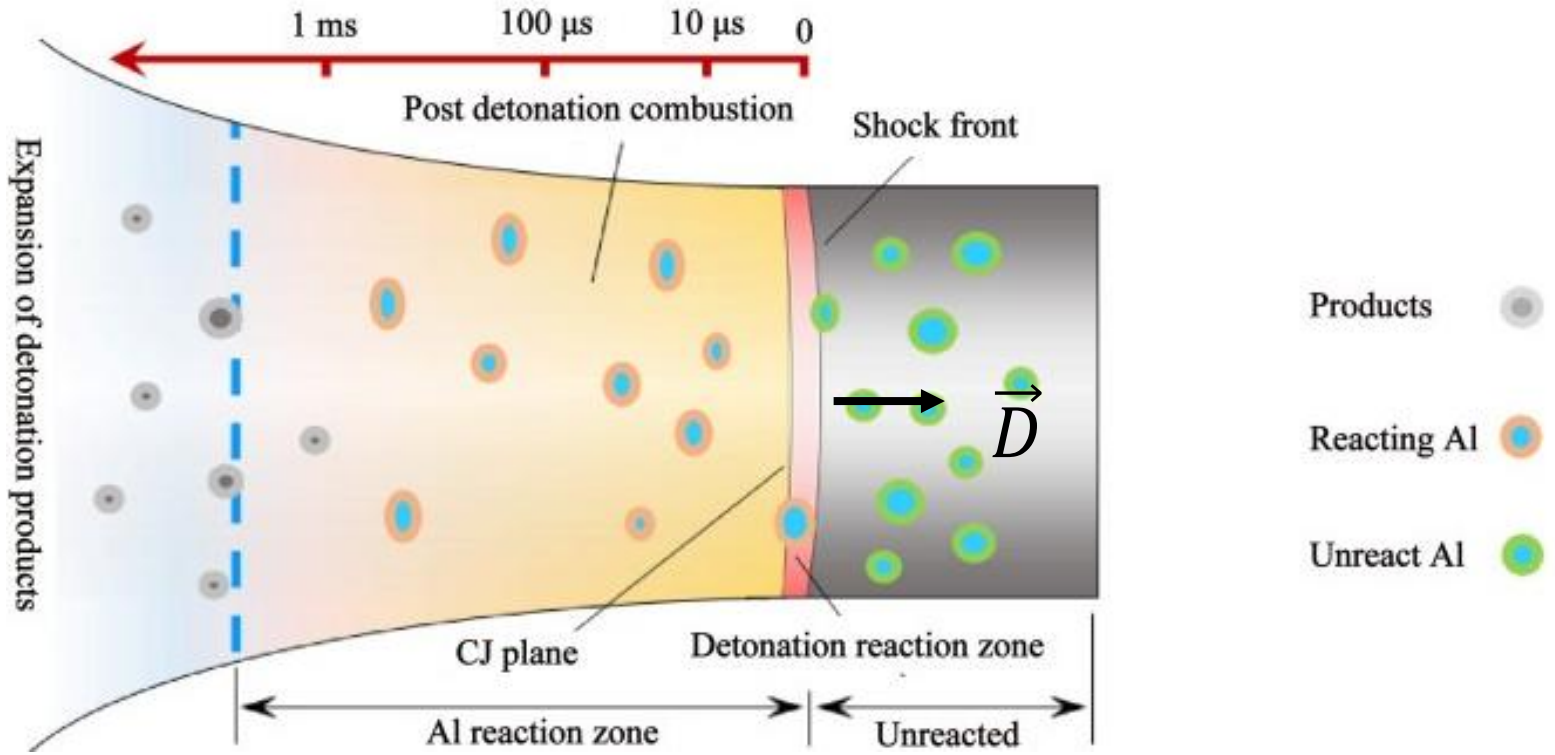




Method does not work for PBXN-111

Chemical reaction zone structure of aluminised explosive

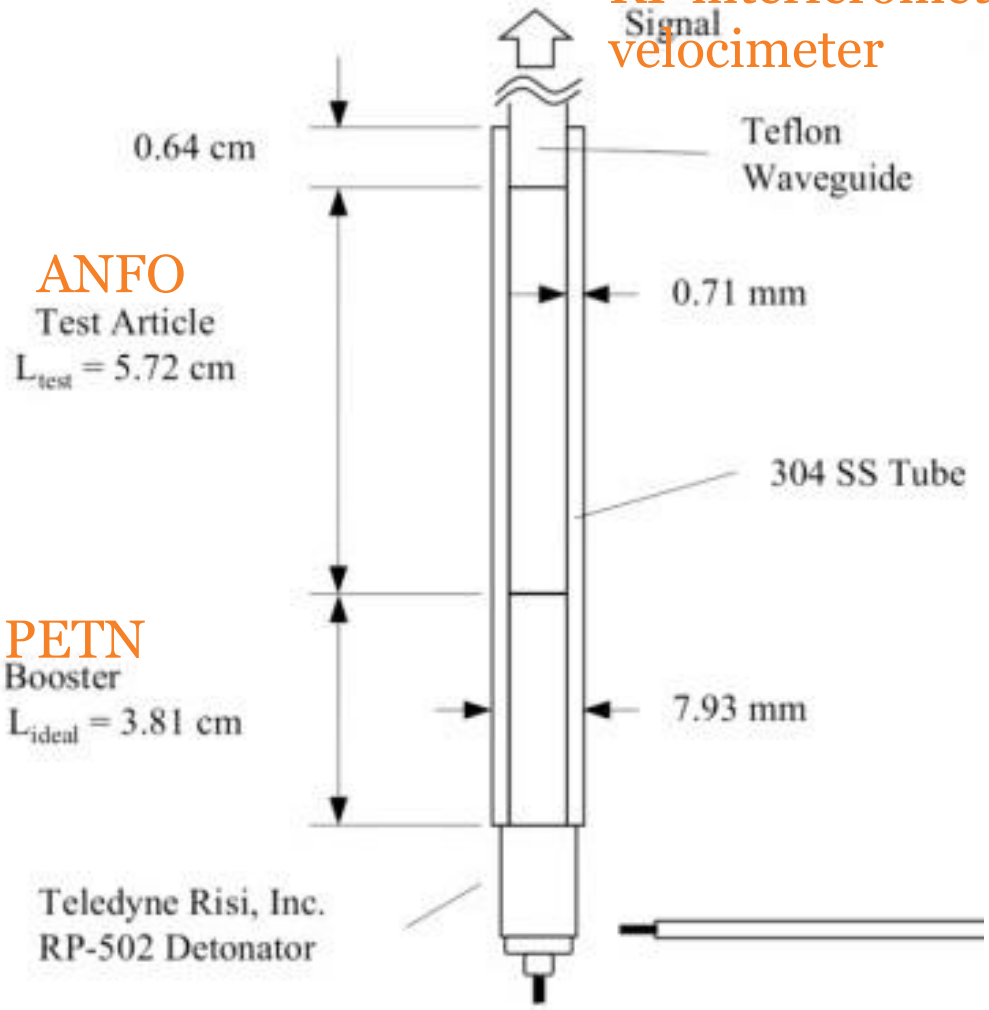
- PBXN-111: 20% RDX, 43% ammonium perchlorate, 25% aluminium, 12% HTPB

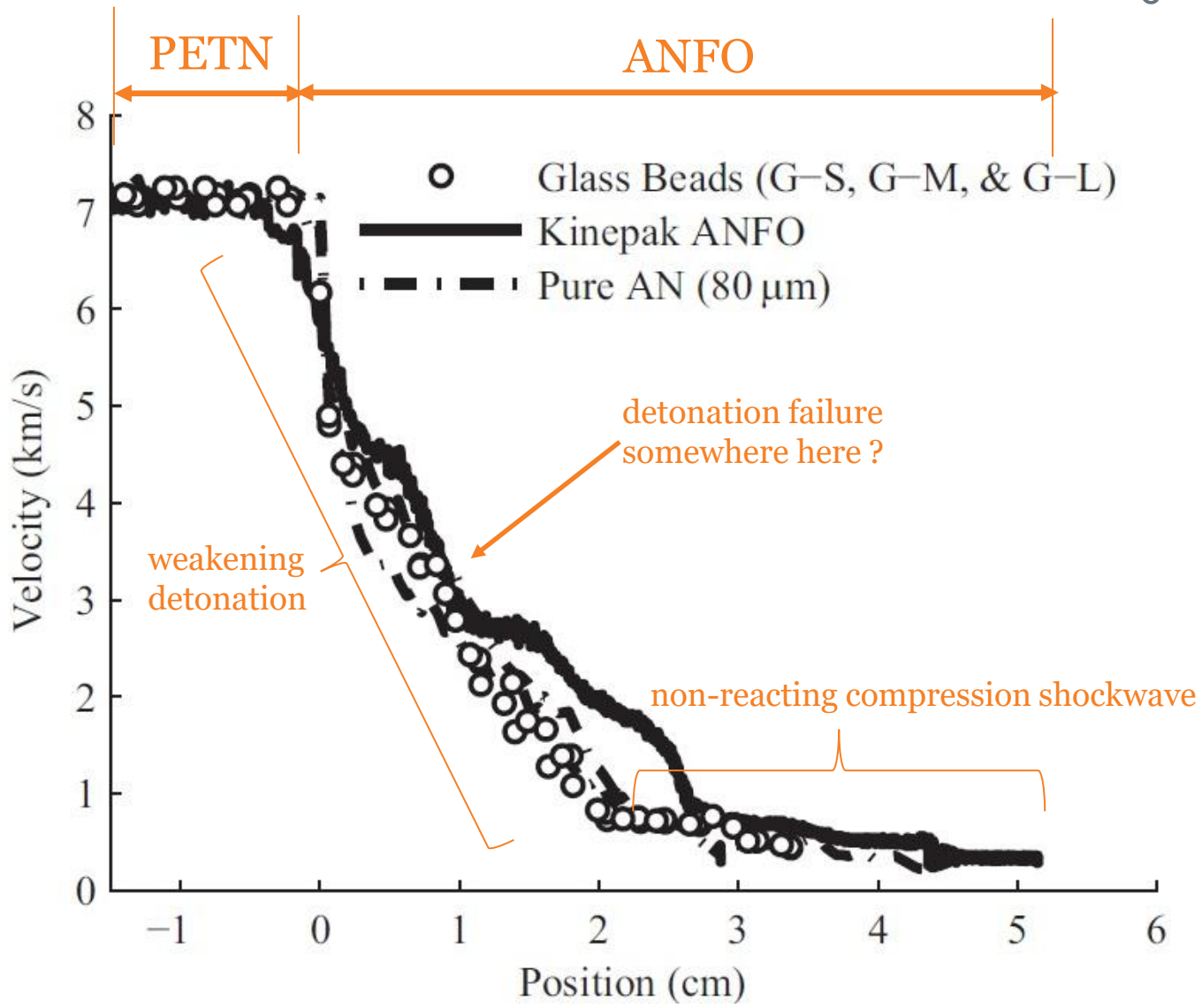


Light emission probes or ionization gauges do not point to the CJ plane location in a long chemical reaction zone (several cm). How to identify the position of CJ (detonation) plane ?

Prior art

RF interferometric velocimeter



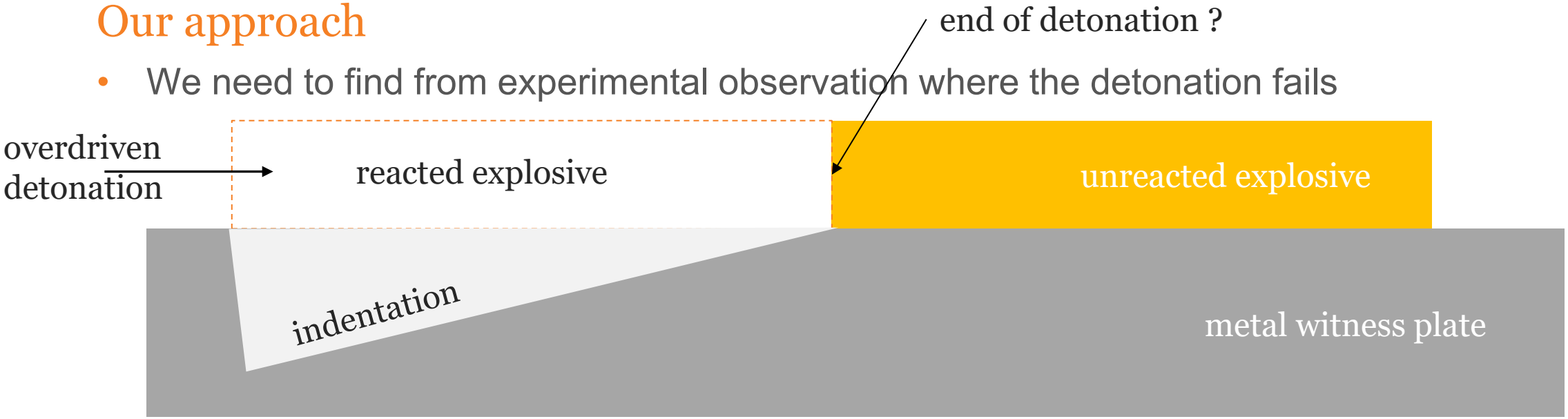


N.R. Cummock, J.O. Mares, Jr., I.E. Gunduz, S.F. Son, "Relating a small-scale shock sensitivity experiment to large-scale failure diameter in an aluminized ammonium nitrate non-ideal explosive". *Combustion and Flame*. **194**. 271 (2018).

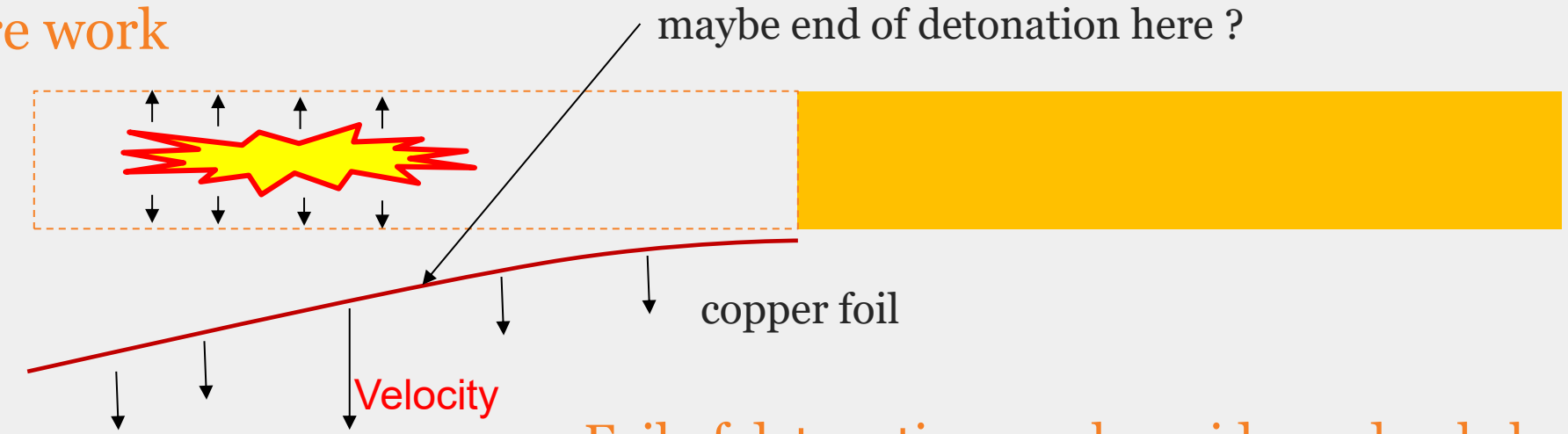
Modelling conducted, EoS derived, critical diameter confirmed ~8 cm

Our approach

- We need to find from experimental observation where the detonation fails



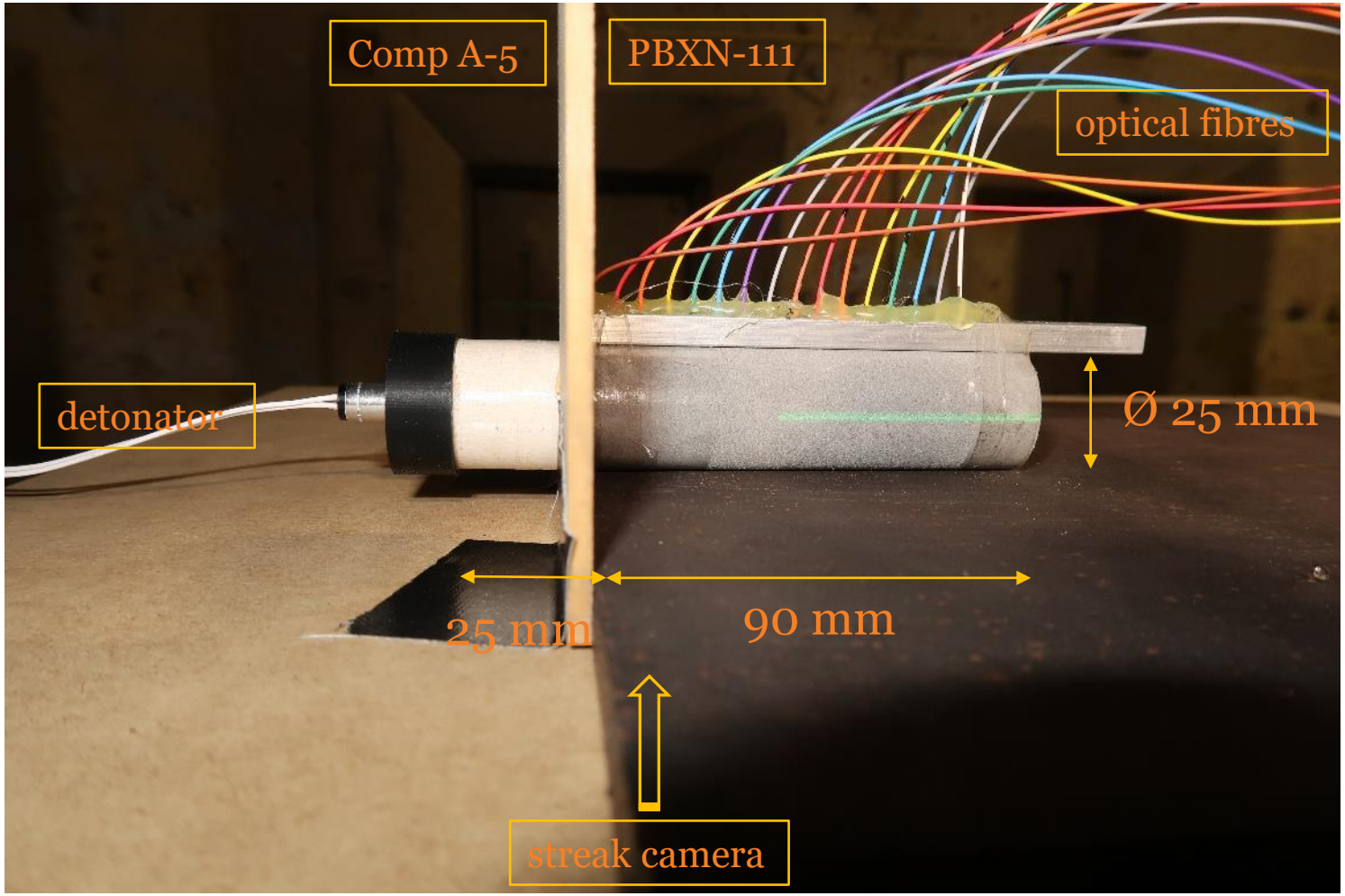
Future work



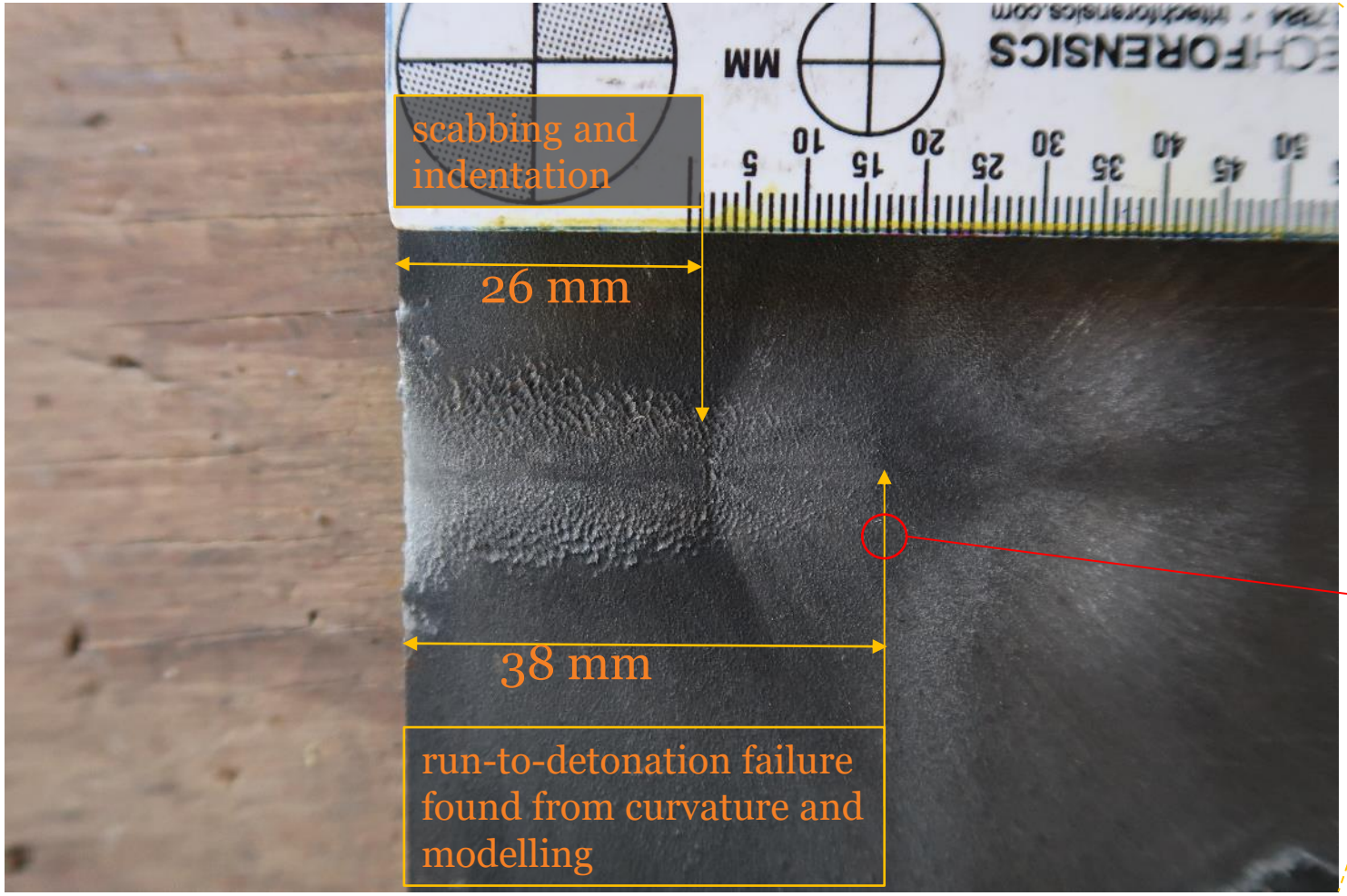
Fail of detonation can be evidenced only by drop of pressure

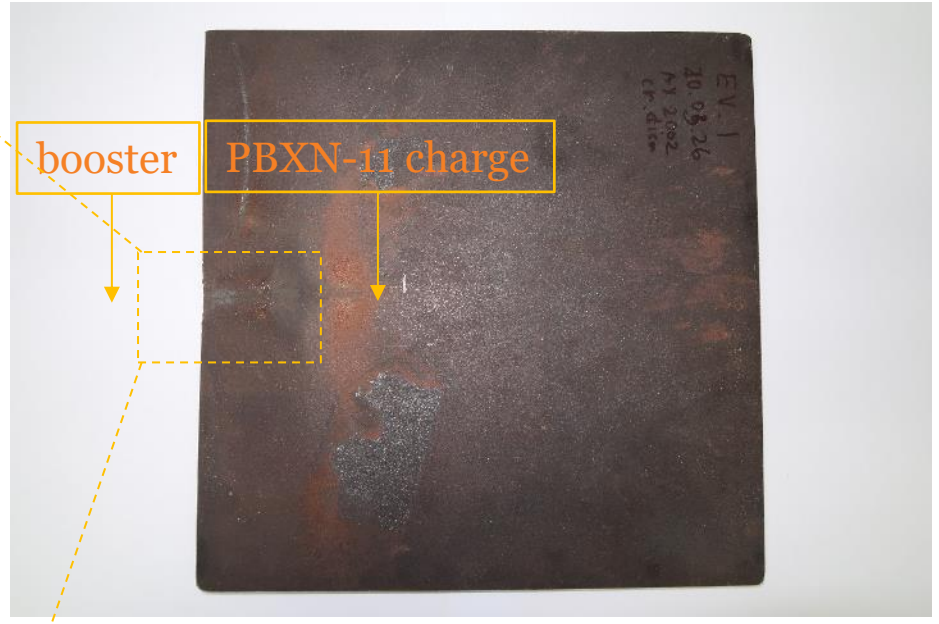
Experimental setup

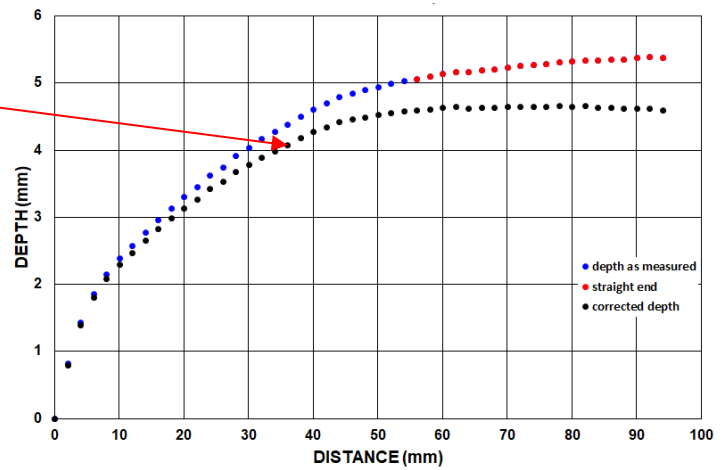
- Velocity of detonation front is measured by optical fibre and streak camera



Witness plate indented from explosive charge blast



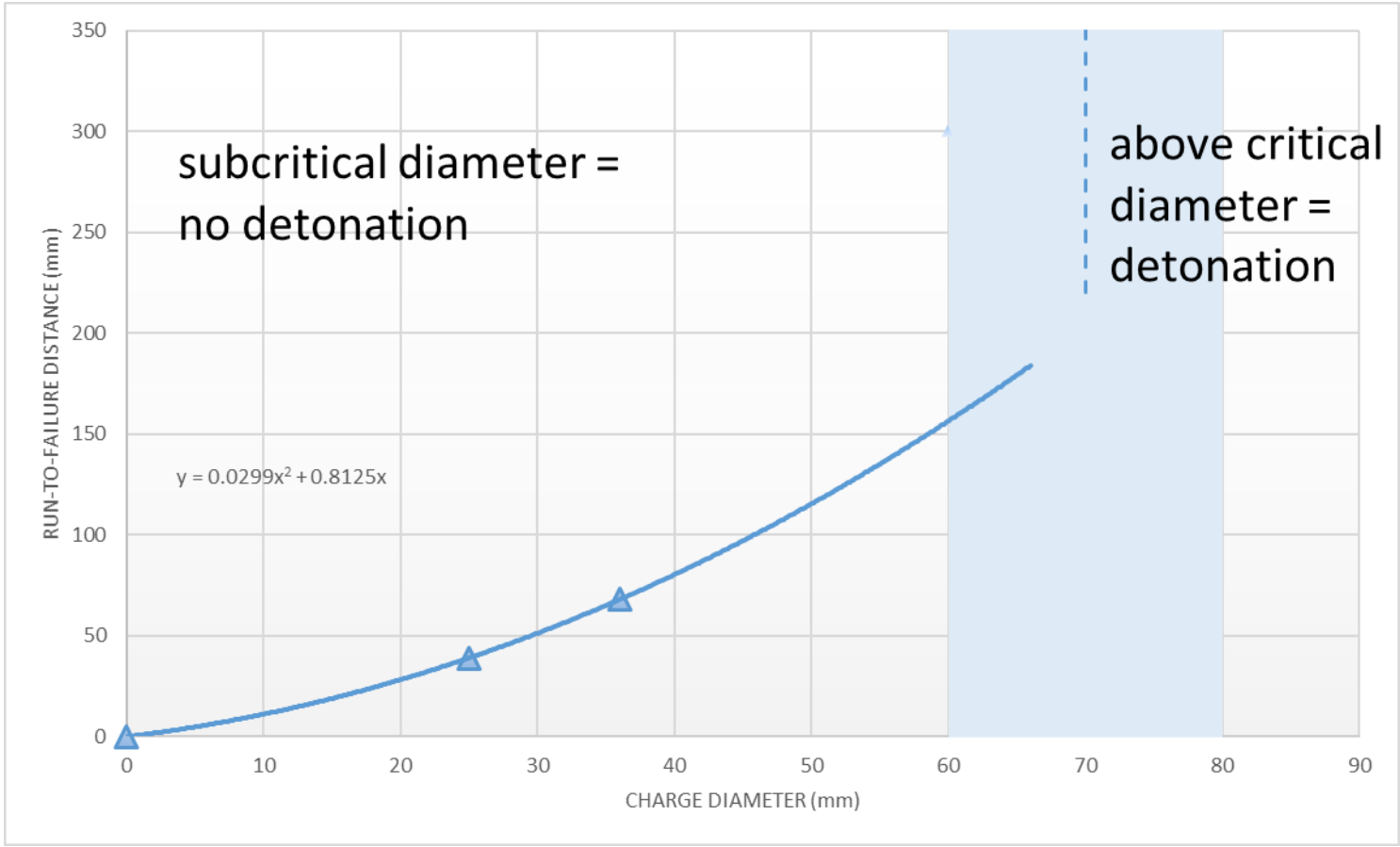




In non-ideal explosive PBXN-111, correlation between detonation and indentation fails

Run-to-failure distance vs charge diameter

- Failing detonation was observed in the charges Ø25 mm and Ø36 mm.



As charge diameter increases, the failing detonation can run farther

Modelling methods

- CTH is a multi-material, large deformation, strong shock wave hydrocode developed at Sandia National Laboratories (USA).
- High explosive detonation is modelled by the programmed burn model. Products of detonation are modelled by the Jones-Wilkins-Lee equation of state. A special model is available for moving fragments smaller than a computational cell with the statistically correct velocity, which is used in experiments with witness plates.

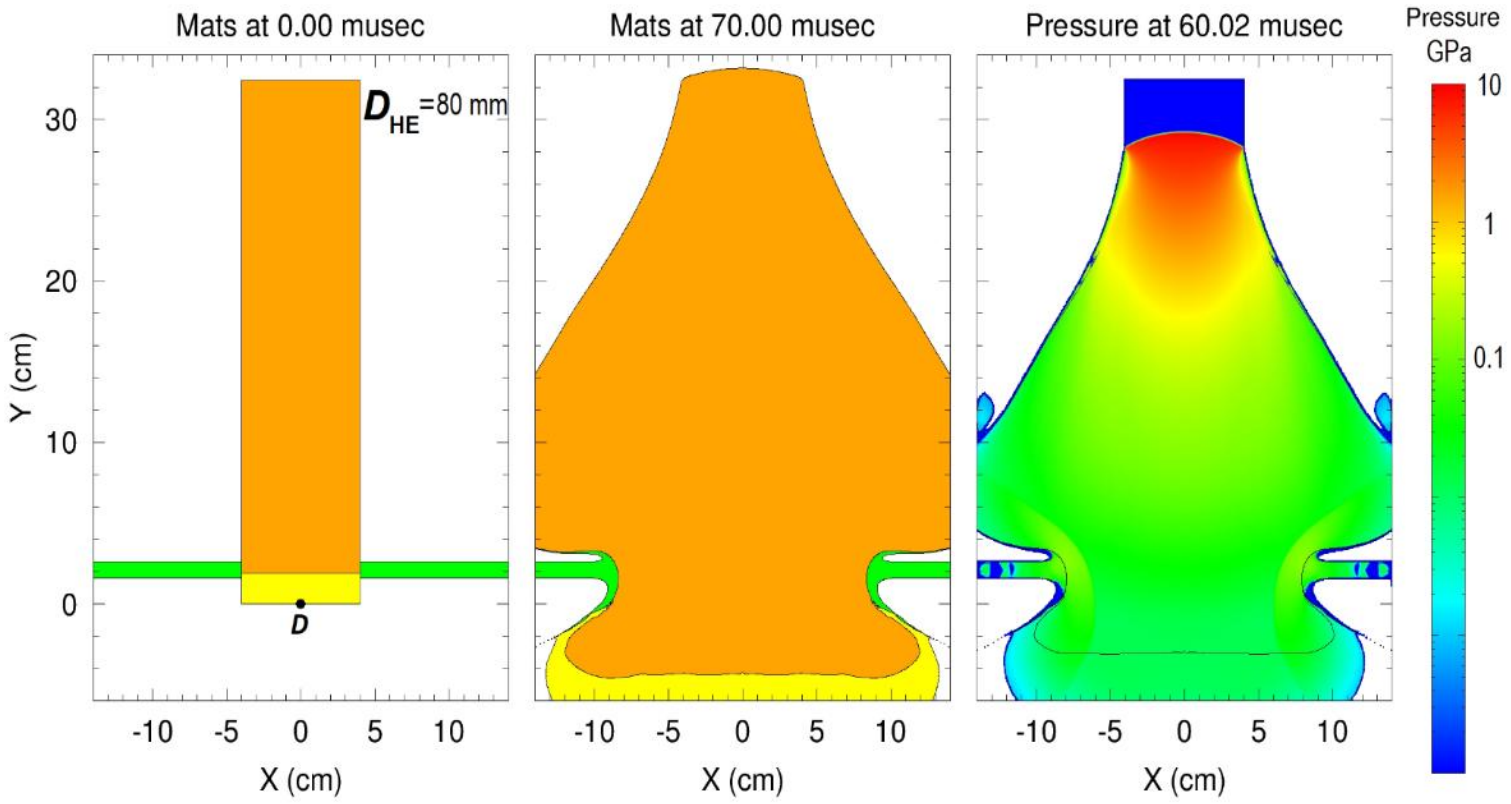




- Modelling performed by Dr Resnyansky

Modelling results

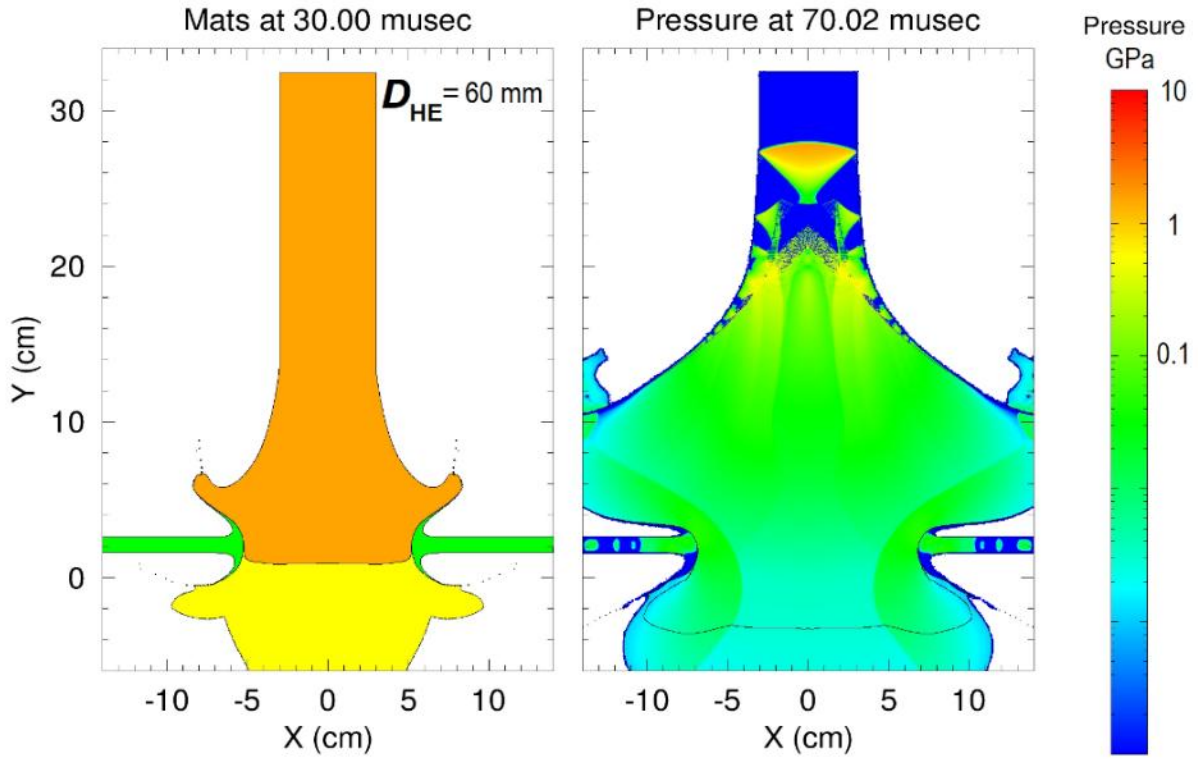
- 2D material contours and pressure in Ø80 mm PBXN-111 charge
- Ø80 mm is above critical diameter – detonation is expected



Modelling shows detonation occurs within the whole explosive charge

Modelling results

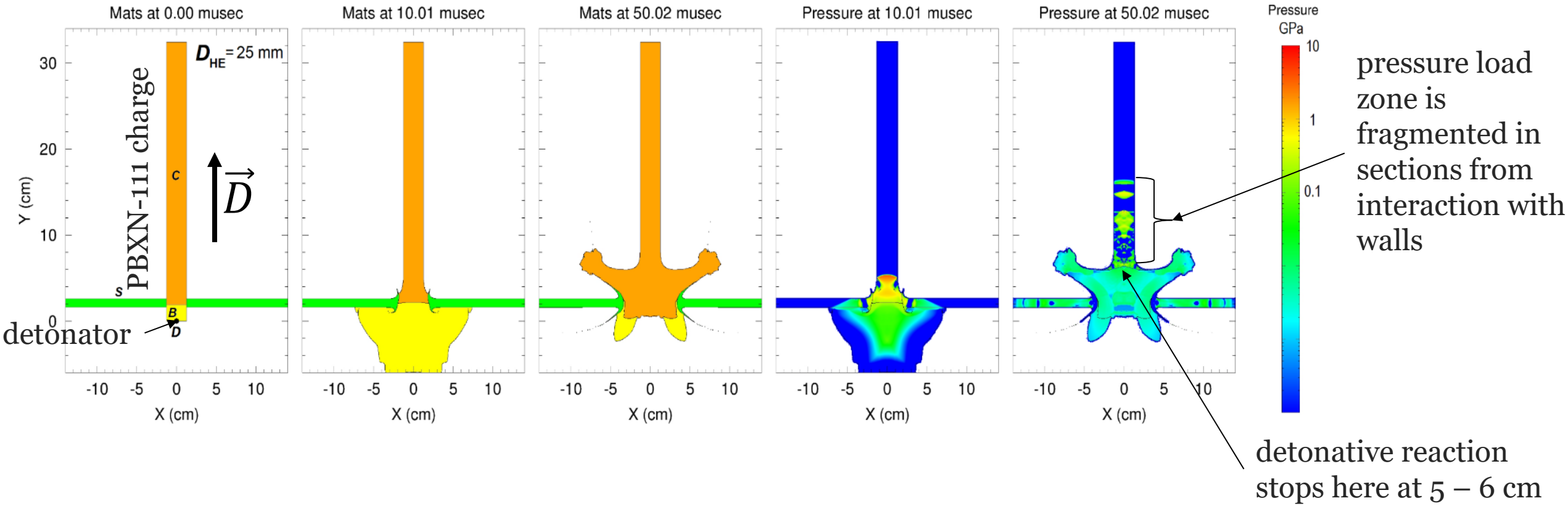
- 2D material contours and pressure in Ø60 mm PBXN-111 charge
- Ø60 mm is at critical diameter or slightly less – interruption of detonation



Modelling shows detonation starts to fail past 20 – 22 cm after 50 µs from booster initiation

Modelling results

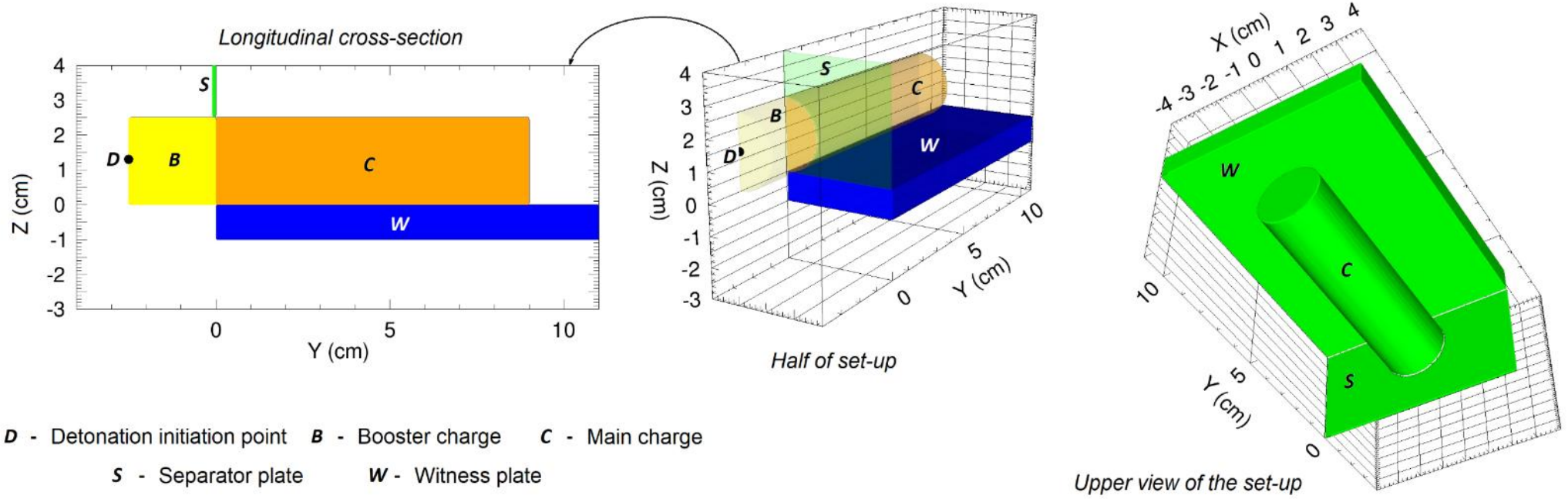
- 2D material contours and pressure in Ø25 mm PBXN-111 charge
- Ø25 mm is diameter well under critical – subduing of overdriven detonation is expected



Modelling shows no reaction occurs past 5 – 6 cm after 20 µs from booster initiation

Setup of CTH model

- 3D model of the experiment with the booster and charge on top of metal plate

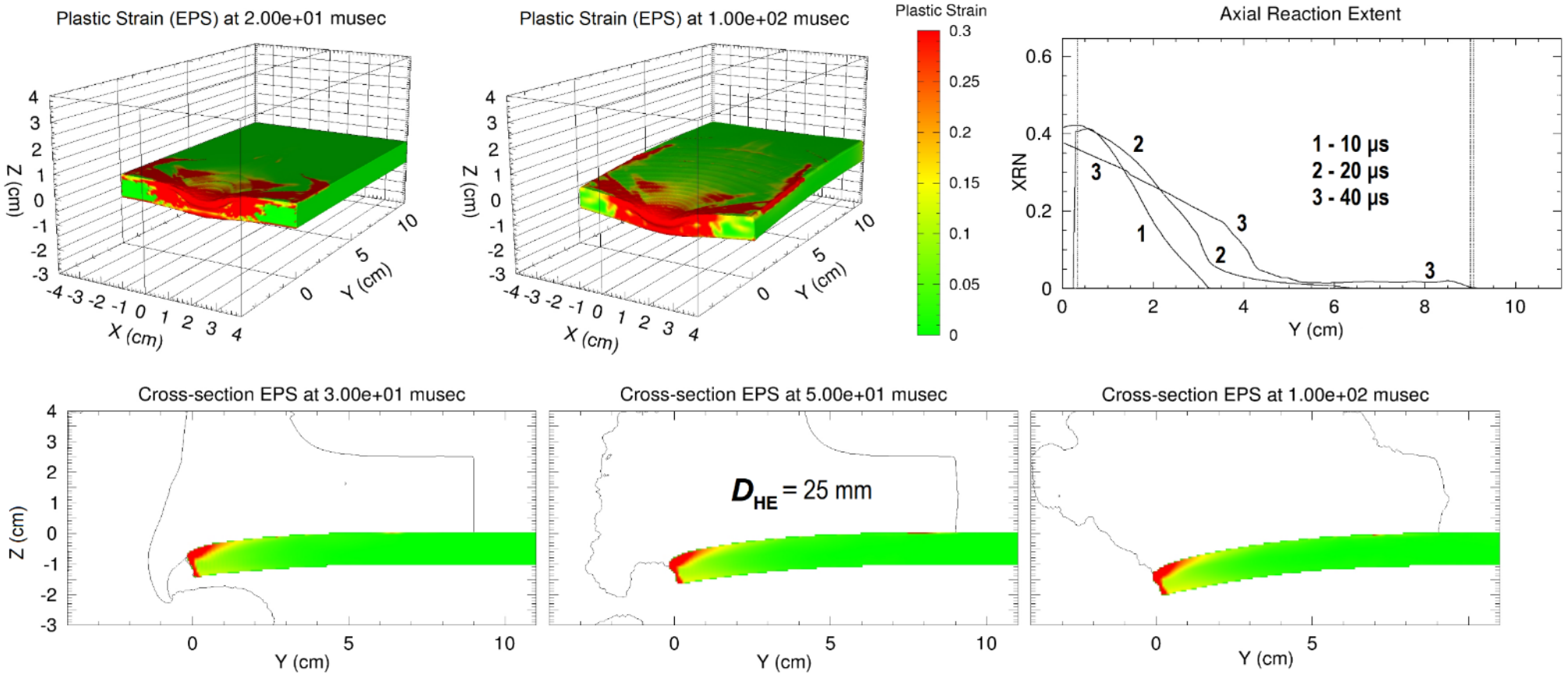


D - Detonation initiation point **B** - Booster charge **C** - Main charge

S - Separator plate **W** - Witness plate

Modelling results

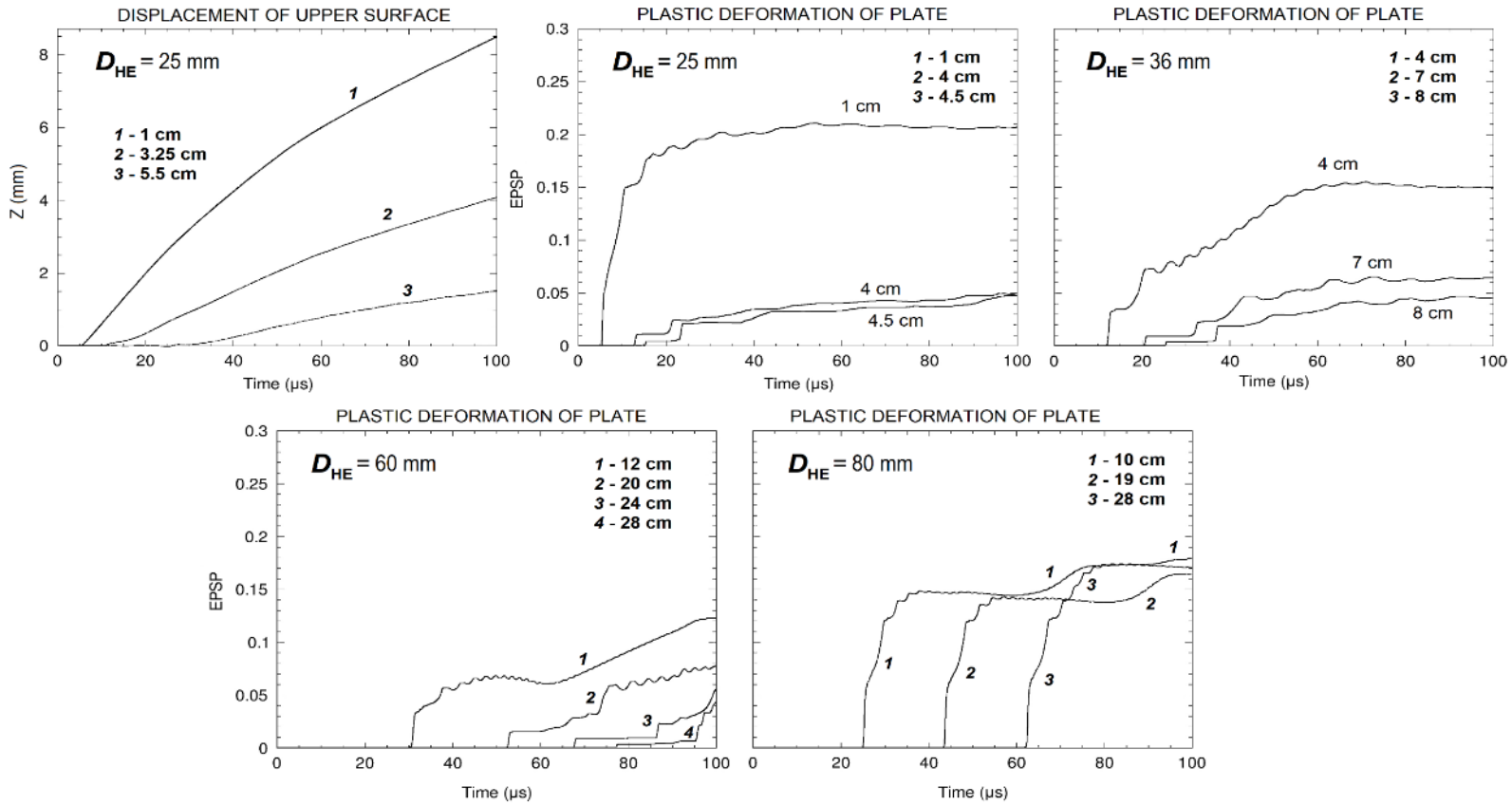
- Plastic strain in the metal witness plate under the Ø25 mm diameter charge



Plastic deformation in plate due to shockwave pressure load is much higher in the areas under detonative reaction

Evolution of plastic deformation

- 3D modelling shows profiles of plastic deformation of witness plate under charges Ø25, Ø36, Ø60, and Ø80 mm



Visible deformation of metal plate under shock load is not indicative of detonation

Resume of the method

1. Measure velocity of detonation in explosive charges of a diameter of 25, 36, 60, and 80 mm => Find out Ø80 mm is the rough critical diameter.
2. Modify *Ignition & Growth (I&G)* model kinetic, so that detonation occurs completely at Ø80 mm, and ceases at < Ø80 mm in 2D CTH model.
3. Measure the bending deflection in witness plate from detonation for the charge diameters 25, 36, 60, and 80 mm.
4. Evaluate the run-to-failure distance, and corresponding indentation in the metal witness plate.
5. Calculate in 3D model the deflection in witness plate at that run-to-failure distance with the modified *I&G* model.
6. Compare the experimentally-measured and computational deflection.
7. The 3D CTH model now got the correct *I&G* kinetic, and allows to calculate critical diameter.

Conclusions

- Modelling work has shown that the critical diameter of the experimentally-investigated explosive PBXN-111 has a critical diameter of 60 – 80 mm.
- This corresponds to the reported critical diameter of PBXN-111.
- Experimental approaches are identified that will allow a tighter determination of the critical diameter by modelling.
- A unique method was developed to characterize the failure dynamics of aluminised explosives with small sample sizes.
- The predictive, laboratory-scale work will allow to minimize the large-scale field trials thus saving financial resources.
- This work allows to bridge the gap between imported formulations and local chemical synthesis.

Acknowledgements

Authors thank the colleagues for assistance:

- Mark Reynolds for conducting the firings
- Sam Marmion for metal plate profile measurements