

Experimental Characterization of Explosives and Their Effects: A University Perspective

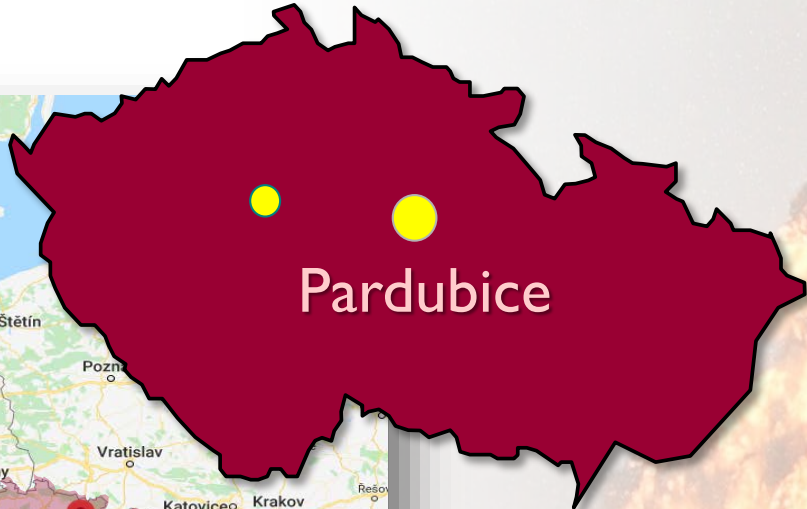
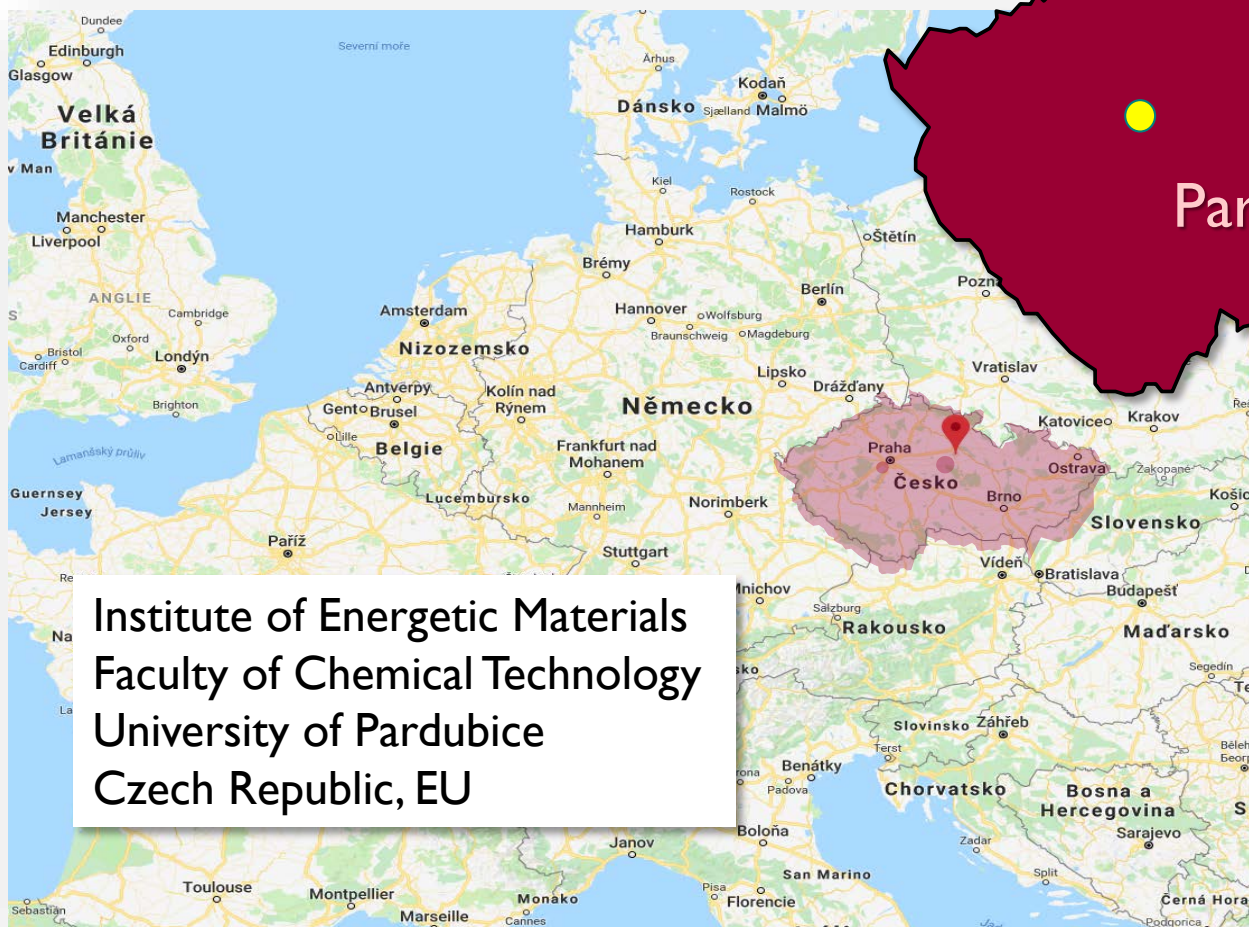
Jiří Pachman

online presentation, February 9th, 2021

AVT-340 Research Workshop on Preparation and Characterization of Energetic Materials



Brief introduction



Institute of Energetic Materials
Faculty of Chemical Technology
University of Pardubice
Czech Republic, EU

Brief introduction

Institute of Energetic Materials
~15-20 students (10% foreigners)

Pardubice
regional capital
~ 90k inhabitants



Faculty of Chemical Technology
~1400 students (10% foreigners)

Brief introduction - funding

- Ministry of Education, Youth and Sports
- Ministry of Industry & Trade
- Ministry of the Interior
- Technology Agency of the Czech Republic
- Czech Science Foundation
- JRC European Commission
- Industry



AUSTIN POWDER



Brief introduction -people

- Professor 1 + external Professors
- Assoc. Professors 4 + external assoc. Professors
- Assist. Professors 3
- Technical staff 3
- Group of veterans
- 5-10 PhD students (internal, external)
- 5-10 undergraduates

Overlap of teaching & research



Teaching activities

Bachelor program (participation of lecturers)

- Teaching general courses – Safety engineering

Master (M.Sc.) & Doctoral (Ph.D.) program

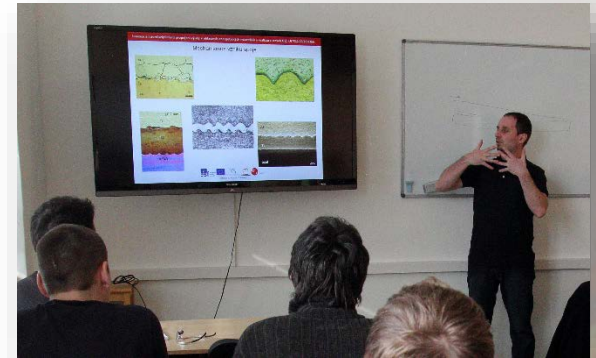
- Engineering of Energetic Materials (Czech & English)

Non degree programs

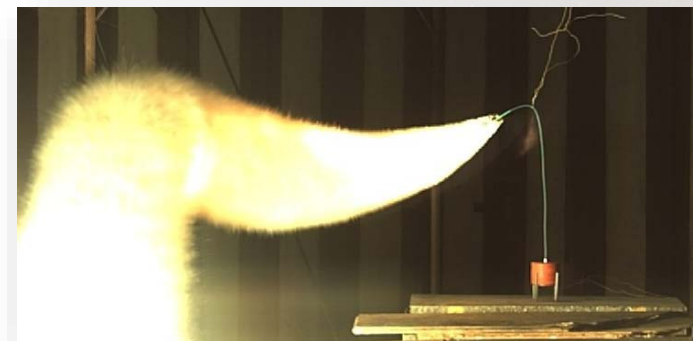
- Theory and Technology of Explosives
- Rock Blasting

Specialised training (participation of lecturers):

- police EOD
- military EOD



From laboratory to the field - scope



Experimental Characterization of Explosives and Their Effects

Synthesis

Chemical and physical properties

Stability and sensitivity

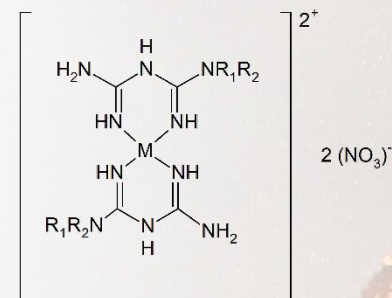
Formulation

Detonation parameters

Explosive effects



Synthesis – laboratory scale



- High nitrogen molecules for gas generating pyrotechnics
- Ballistic modifiers for various type of propellants
- Lead-free primary explosives for initiators



Sellier & Bellot

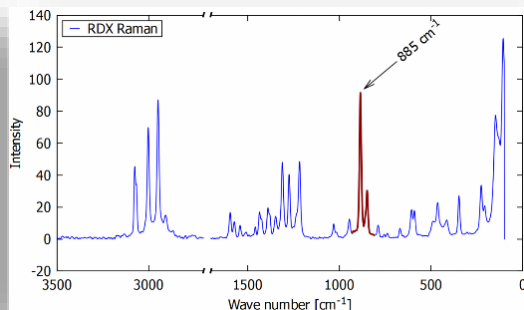
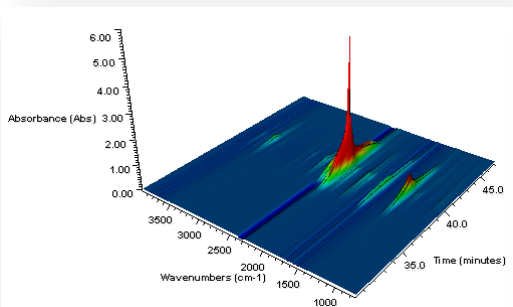
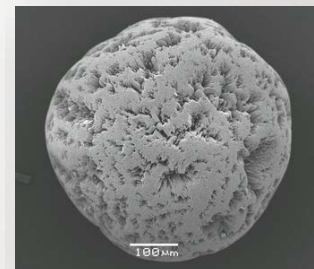


Chemical and physical properties

In house techniques

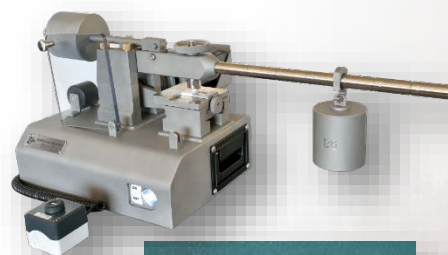
- separation techniques – chromatography (HPLC)
- spectral techniques – FTIR, Raman, UV/VIS spectroscopy
- thermal analysis – differential TA, TG, calorimetry (DSC, ARC, combustion)
- decomposition – vacuum stability (VST), elemental analysis
- density by He pycnometry

All other techniques available at our faculty



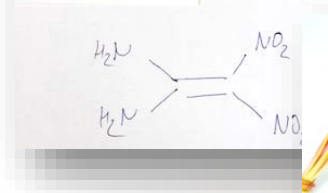
Stability and sensitivity

- Heat
 - fast heating - cook-off
 - slow heating VST, ARC, cook-off
- Mechanical stimuli
 - Impact
 - Friction
 - Shock wave – GAP test
- Electrostatic discharge

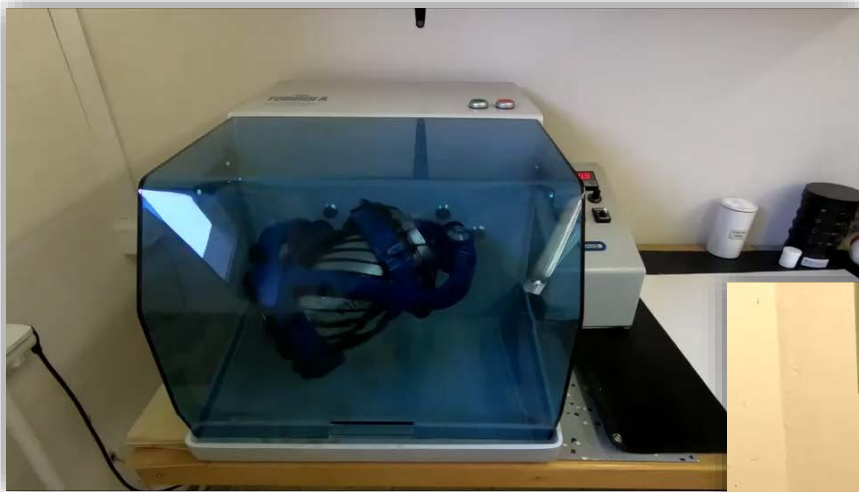


Explosive characterization

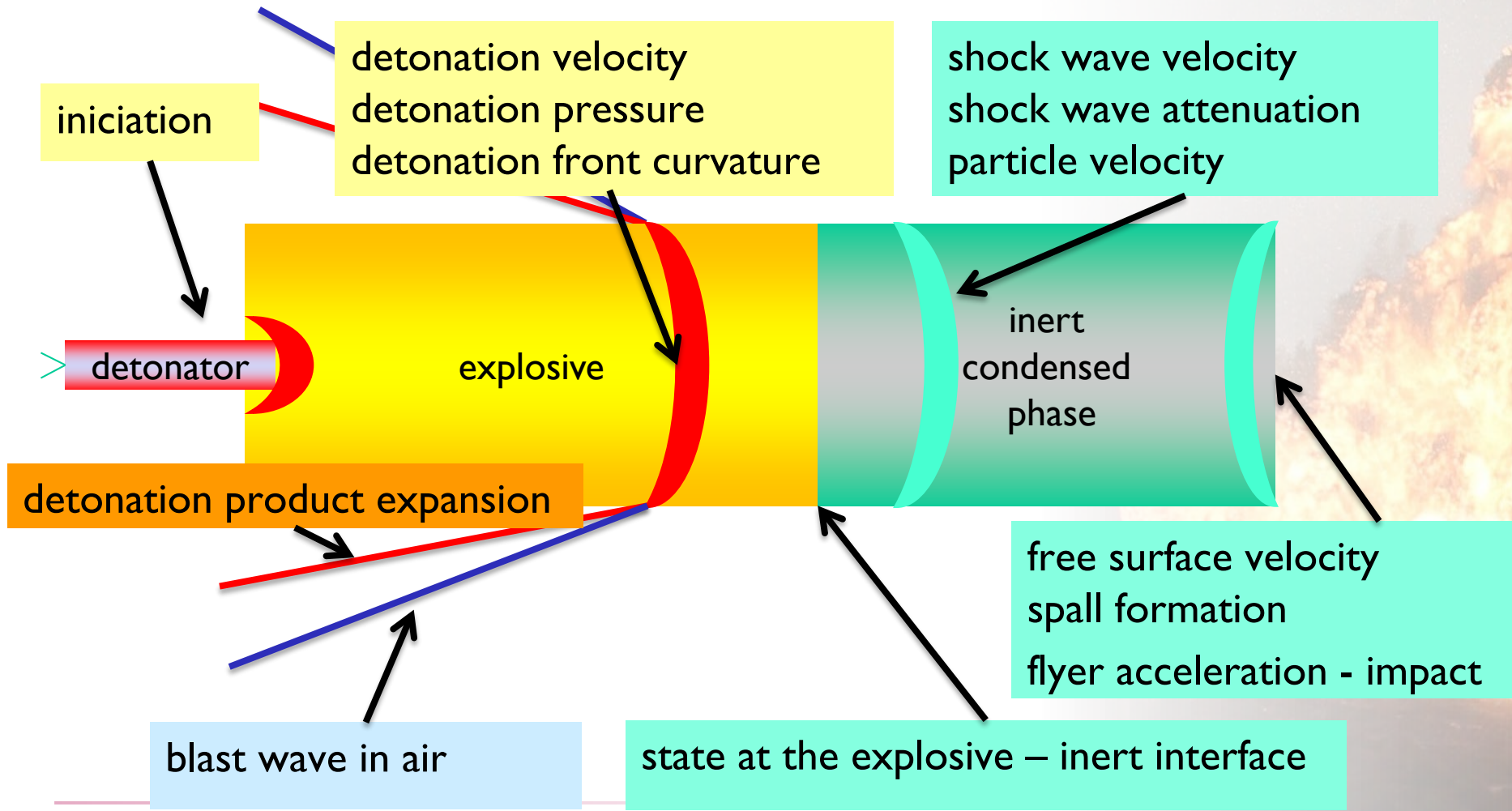
- „Test tube“ type characterization
 - all chemical analysis tests
 - most sensitivity tests
 - many stability tests
- Charge characterization
 - phenomena inside the explosive
 - combined: explosive-confiner interaction
 - phenomena outside the explosive



Formulations – mixing, pressing



Characterization of explosive charge



Characterizing explosives

detonation parameters of the charge

Detonation velocity
Detonation pressure
Detonation front curvature
Detonation products EOS

Characterization by effects



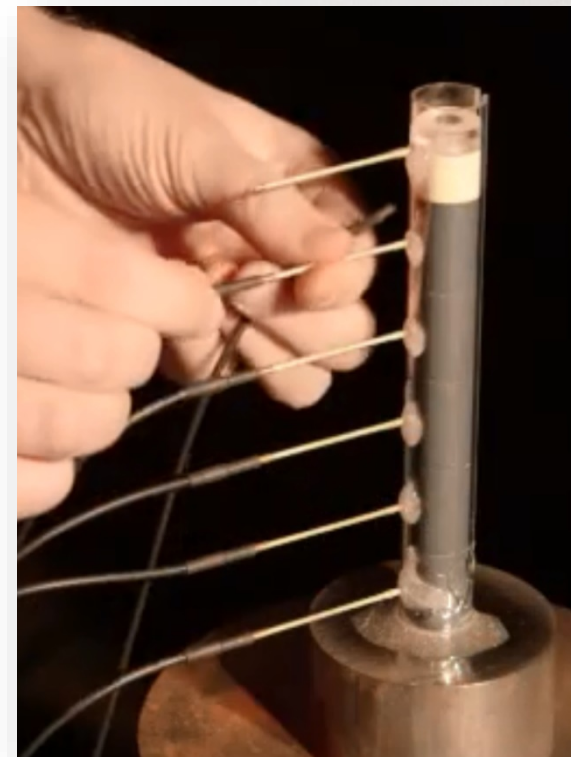
Detonation velocity

Discontinuous methods

- Ionization probes
- Piezoelectric pins („rate stick experiment“)
- Passive optical probes
- Ultrahigh speed framing camera

Continuous methods

- Handi Trap a MicroTrap
- Streak camera
- RF reflectometry

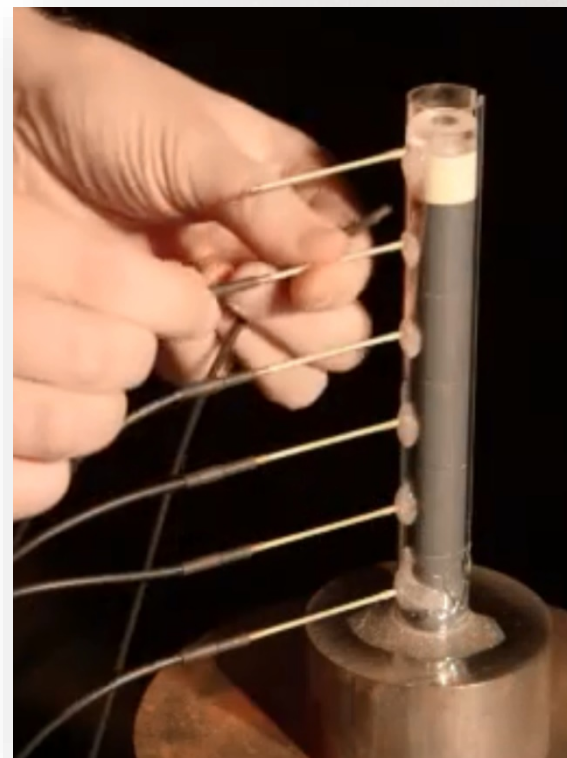


Cornell, R., Wrobel, E., Anderson, P. E. Research and Development of High-performance Explosives. *J. Vis. Exp.* (108), e52950, doi:10.3791/52950 (2016).

Detonation velocity - issues

Piezoelectric pins („rate stick experiment“)

- Example: 6 probes
- first 2 are not useful for VOD
- price: 25 USD/ probe + 25 USD / cable
- good for well controlled environment, short cables, large charges, nearly ideal explosives
- on top of that we do 10-15 shots per day with students



Cornell, R., Wrobel, E., Anderson, P. E. Research and Development of High-performance Explosives. *J. Vis. Exp.* (108), e52950, doi:10.3791/52950 (2016).

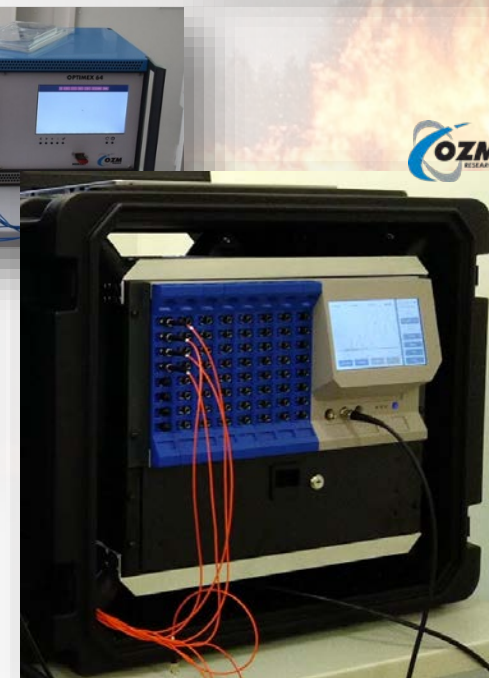
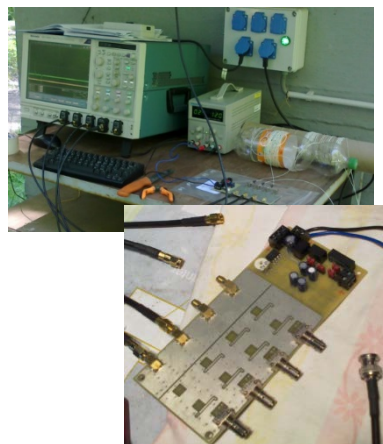
Detonation velocity - issues



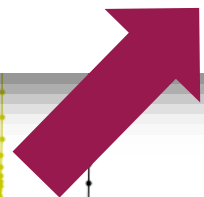
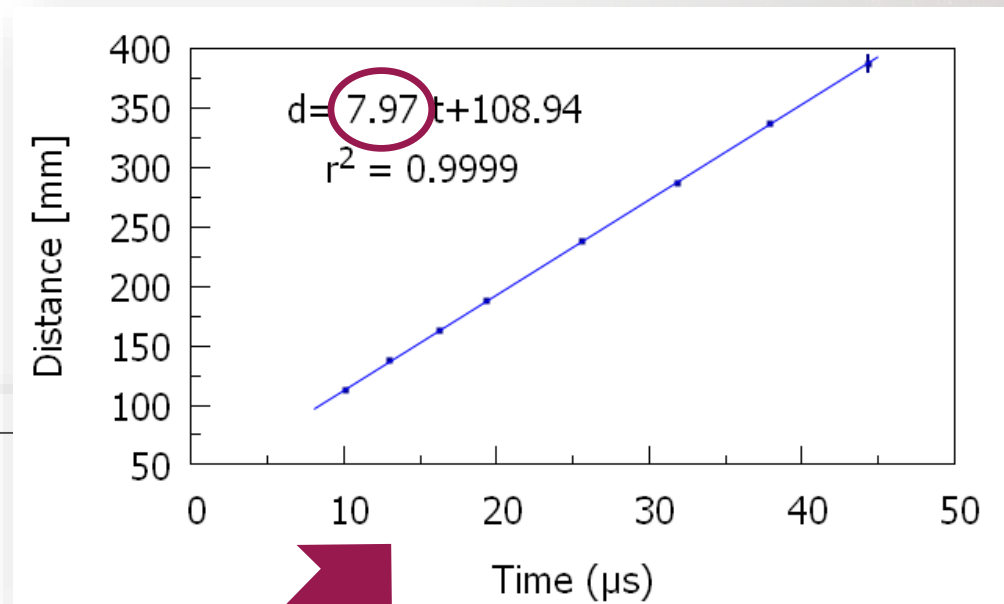
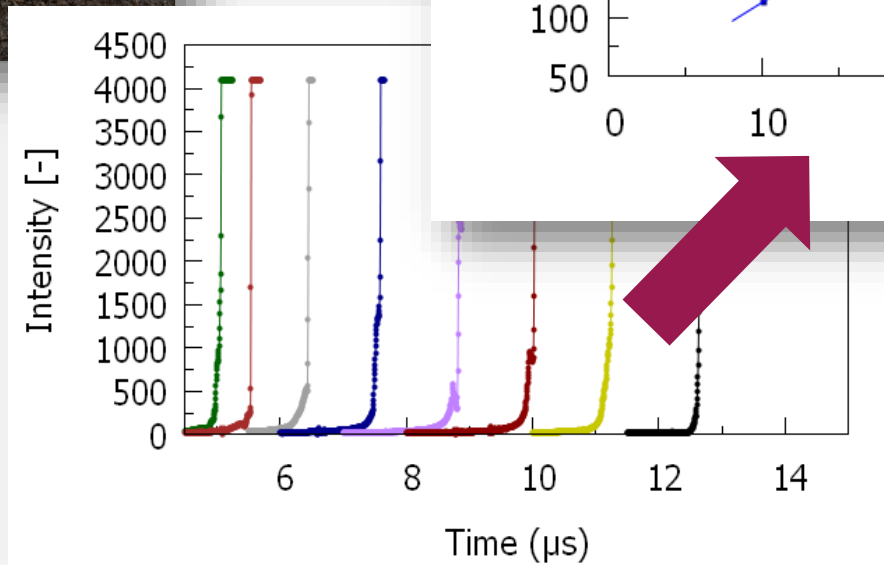
fiber optic methods

OPTIMEX

- relatively robust
- relatively cheap
- relatively broadly applicable



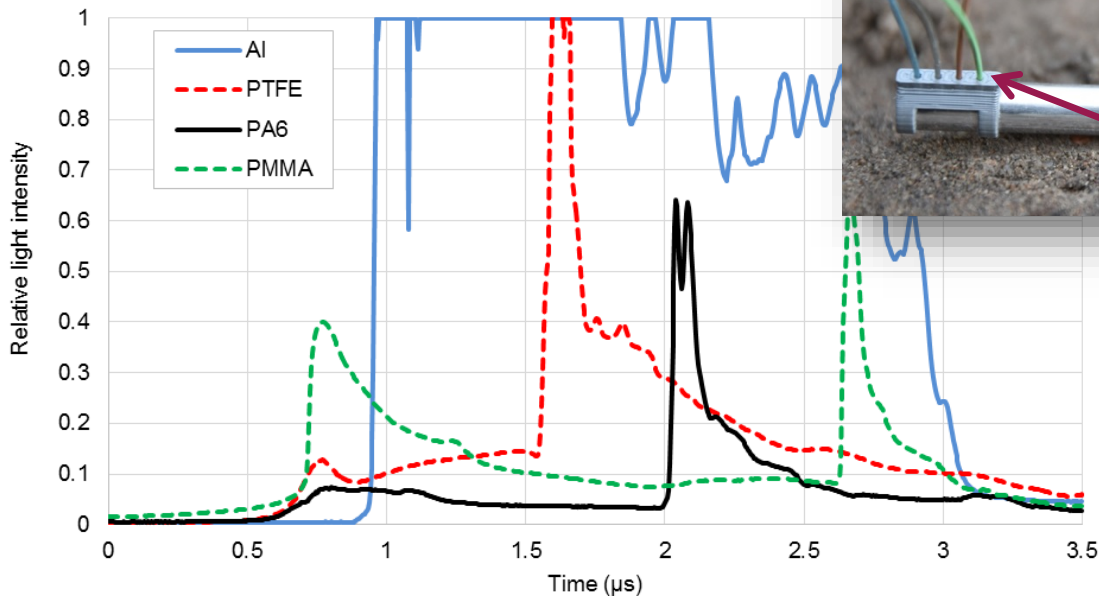
Detonation velocity – fiber optics



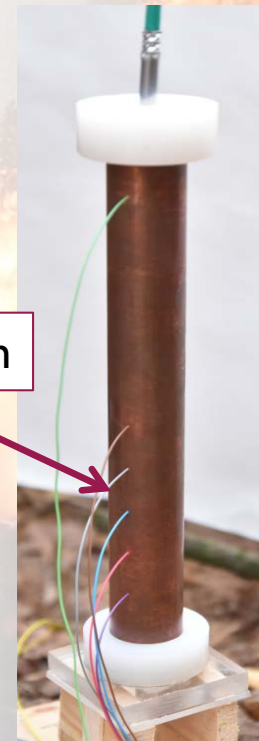
Detonation velocity – fiber optics

- David Williamson (personal communication at workshop on explosives, Tours, CEA), something like:

„If you hit the end of the fiber strong enough, it gives you a light pulse“



not through



Fiber optic probe – fiber with holes

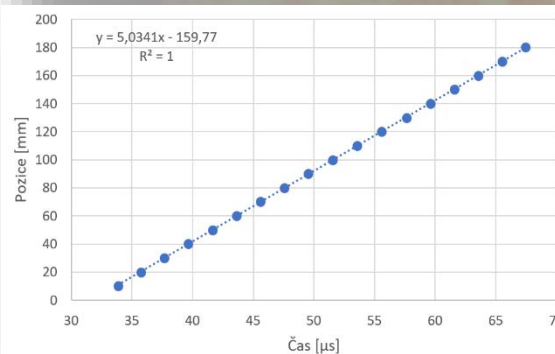
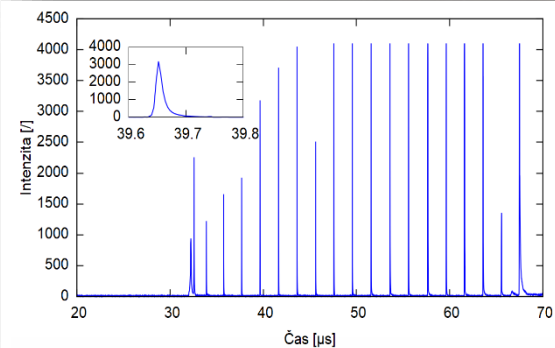
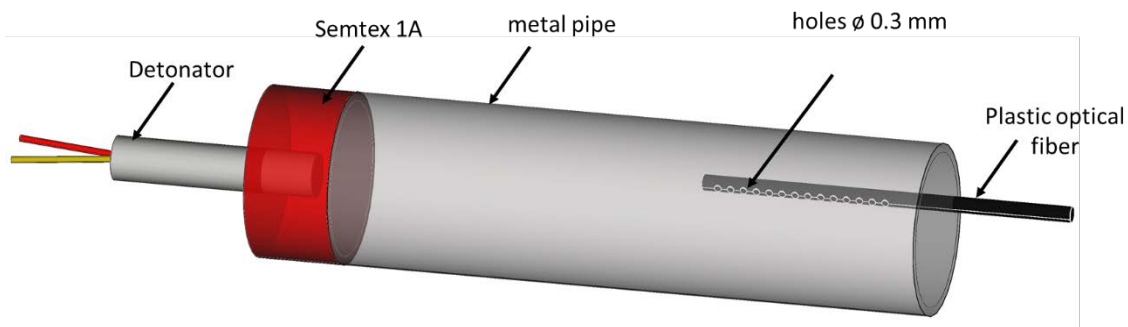
- technique published by TNO „Fiber Optic Probe (FOP)“ →
- Using standard I/2.2mm POF
- Hole 0.5 mm
- Too much light requires attenuation ↓



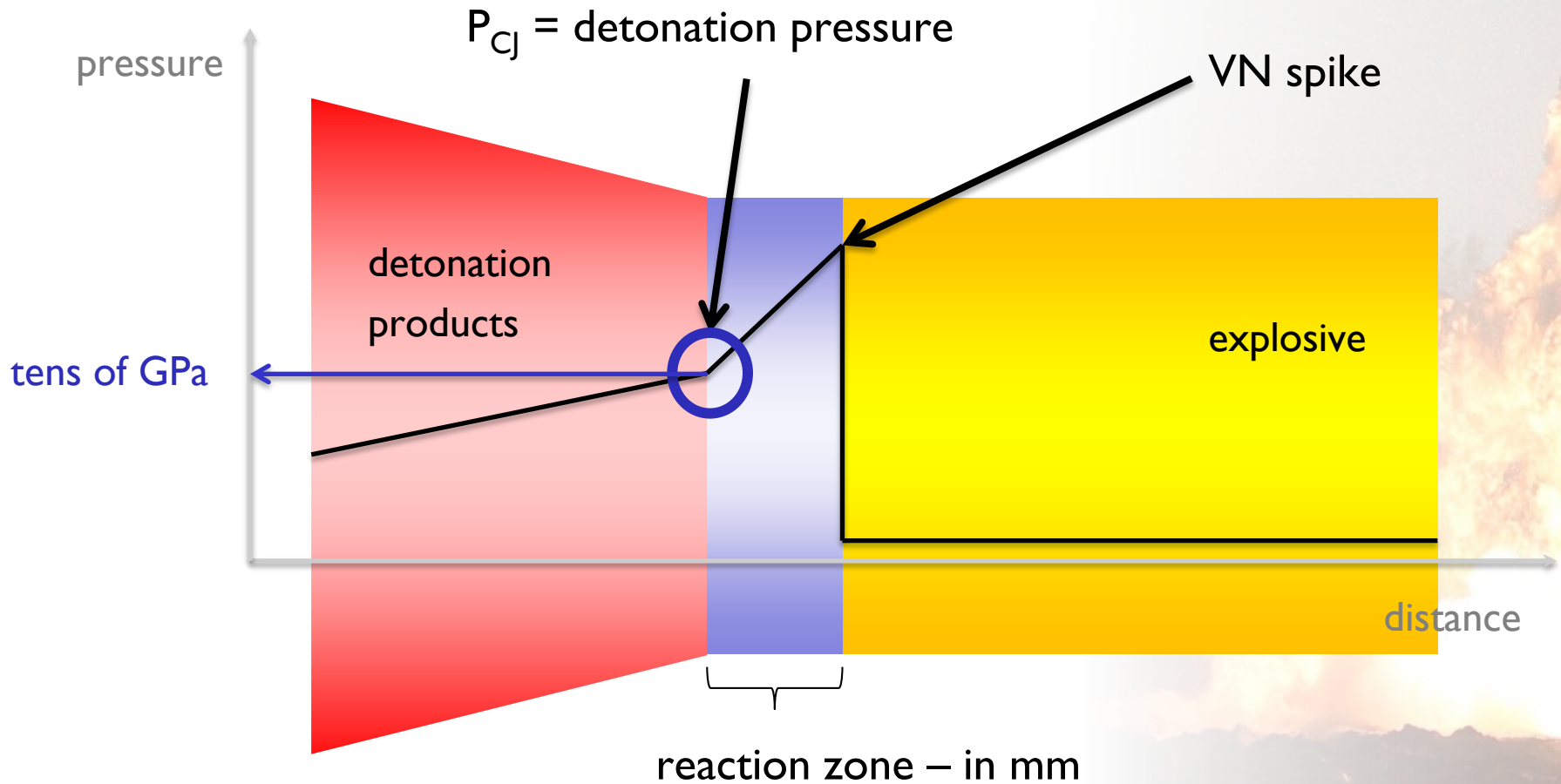
Van Rooijen, M., et al. *Comparison of methods to measure detonation velocity. Ionization pins, resistance wire, and fiber optic probe.* in *28th International Annual Conference of ICT.* 1997. Karlsruhe, Germany: Fraunhofer-Institut für Chemische Technologie. p. 129/1 - 129/10.



Detonation velocity – FOP



Detonation pressure

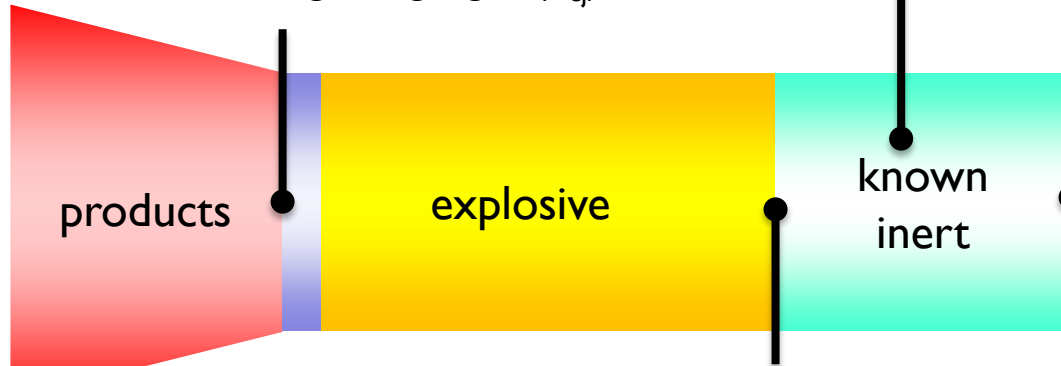


in an ideal case this is where explosive changes to detonation products

Detonation pressure

Measurements in explosive:

- x-ray (u_{cj})
- electromagnetic induction (u_{cj})
- manganin gauges (P_{cj})



Measurements at the explosive – inert interface:

- interferometry (u_{cj})
- manganin gauges (P_{cj})

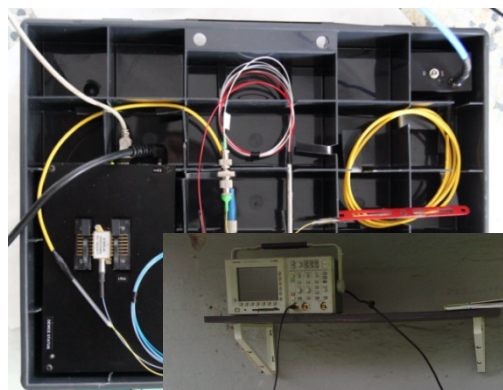
Measurements in inert:

- high speed cameras (U_i)
- contact probes (U_i)
- optical probes (U_i)
- manganin gauges (U_i, P_i)
- interferometry (u_i)

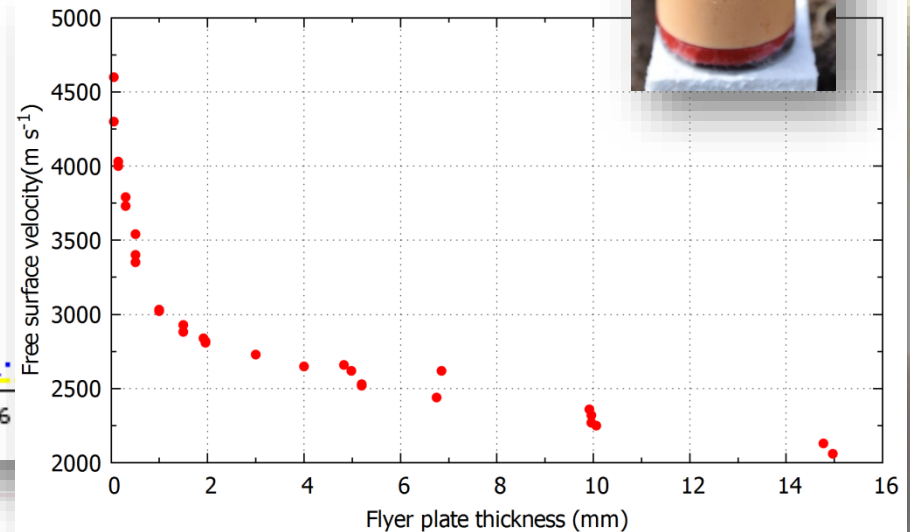
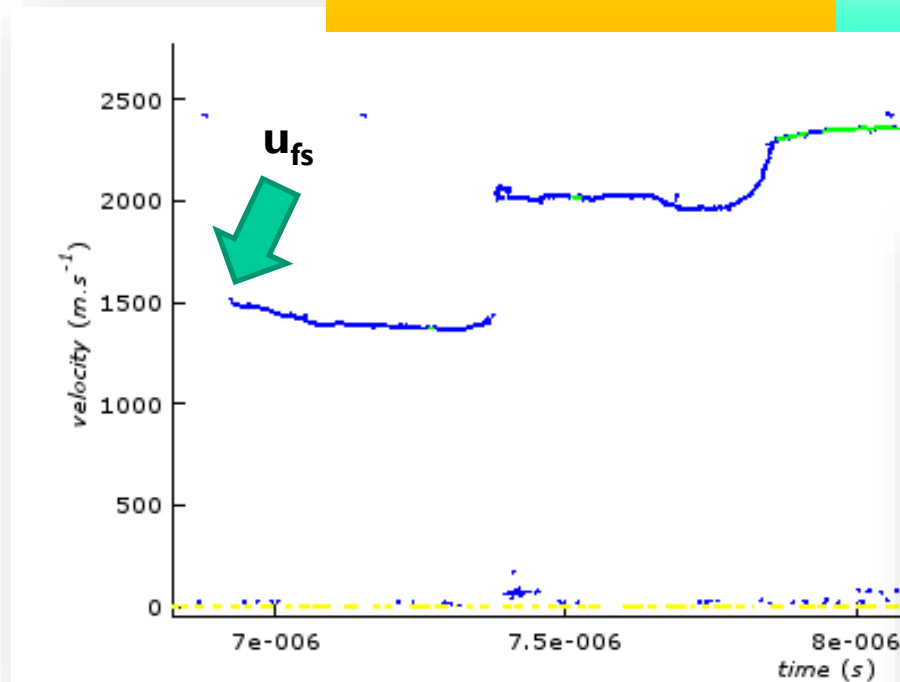
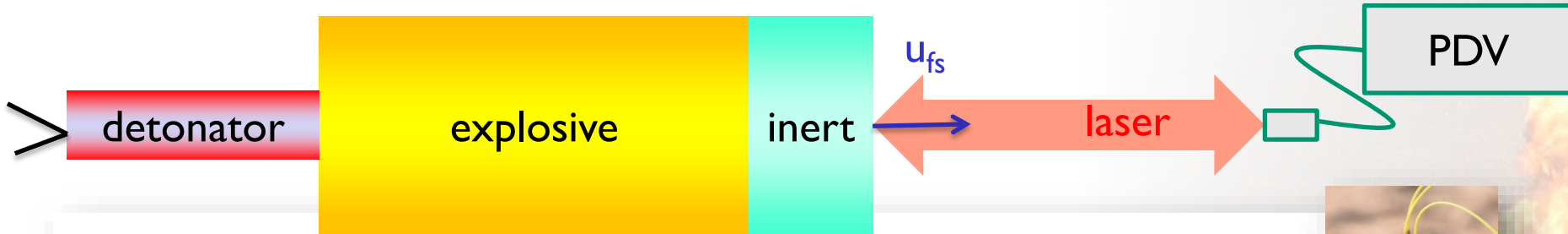
Measurements on the surface:

- interferometry (u_{fs})
- contact pins (u_{fs})

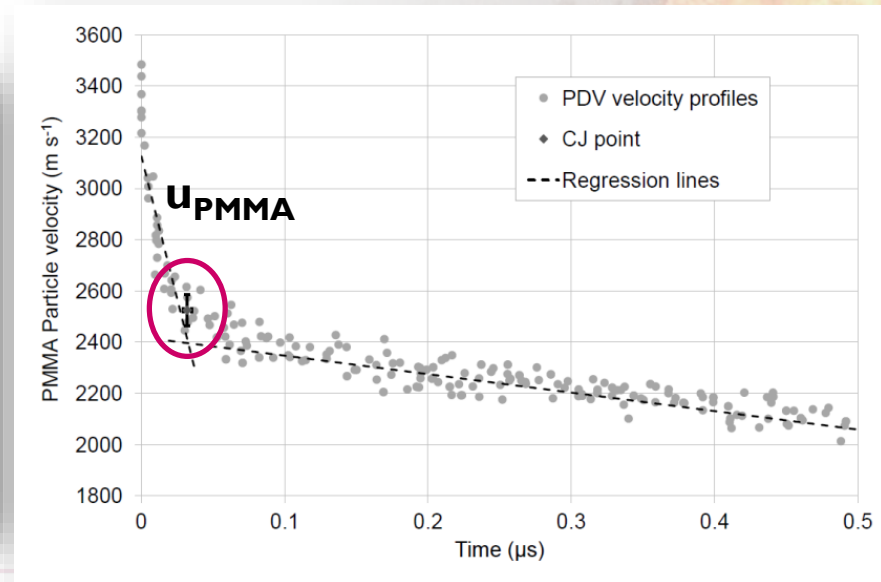
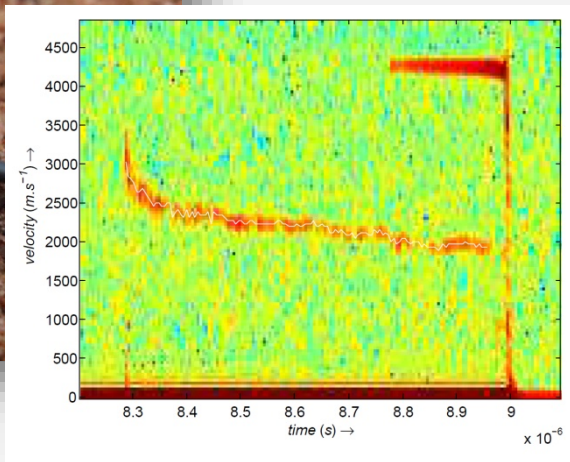
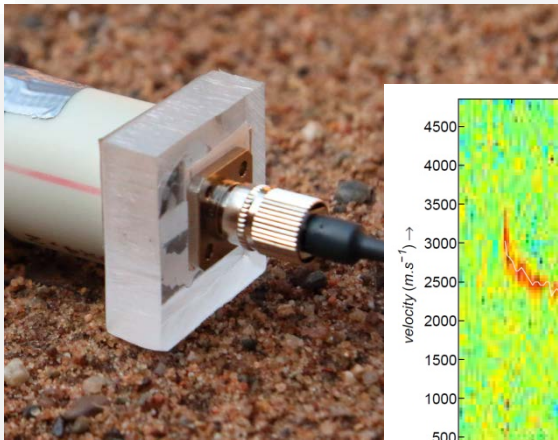
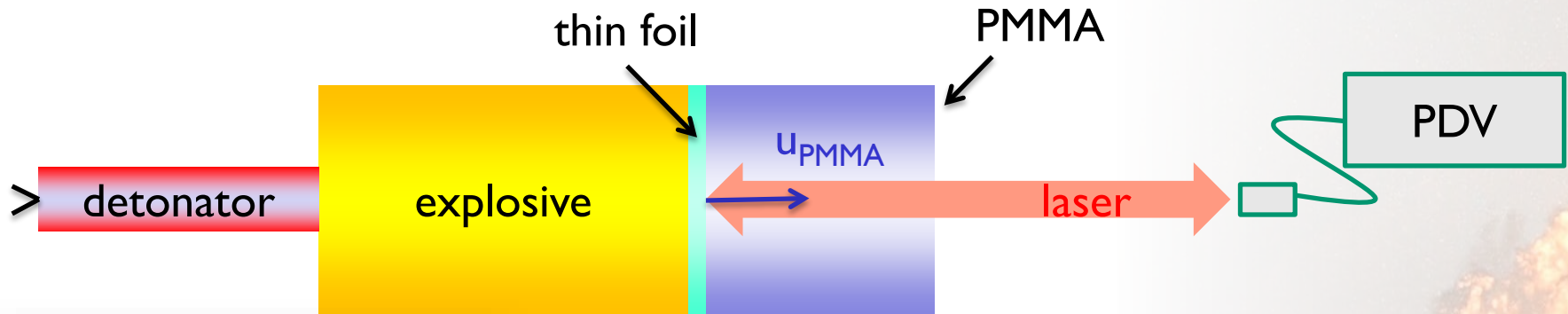
Photonic Doppler Velocimetry - PDV



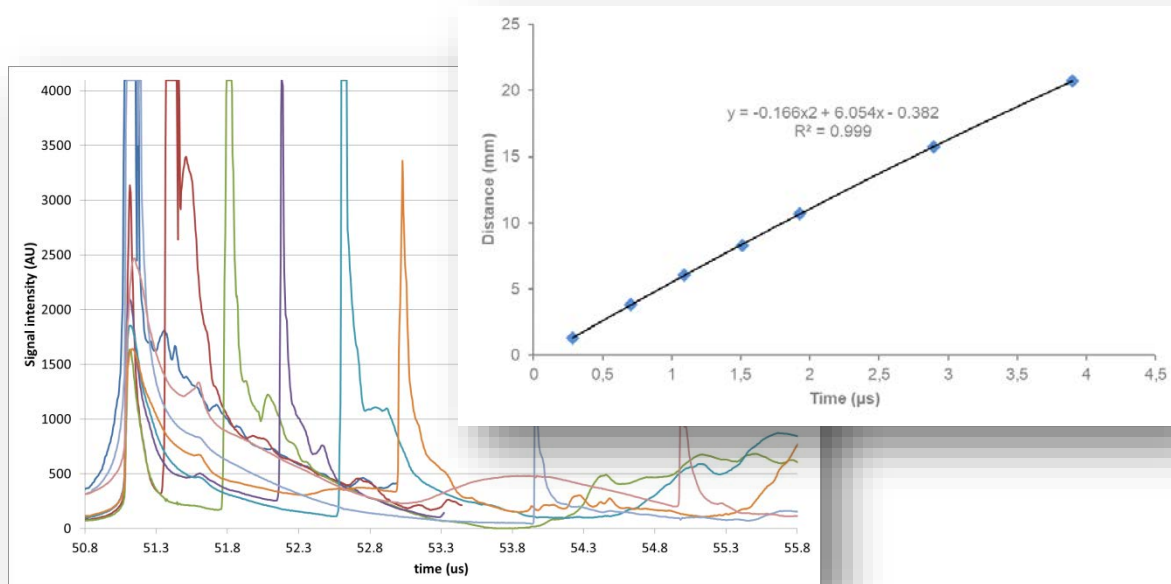
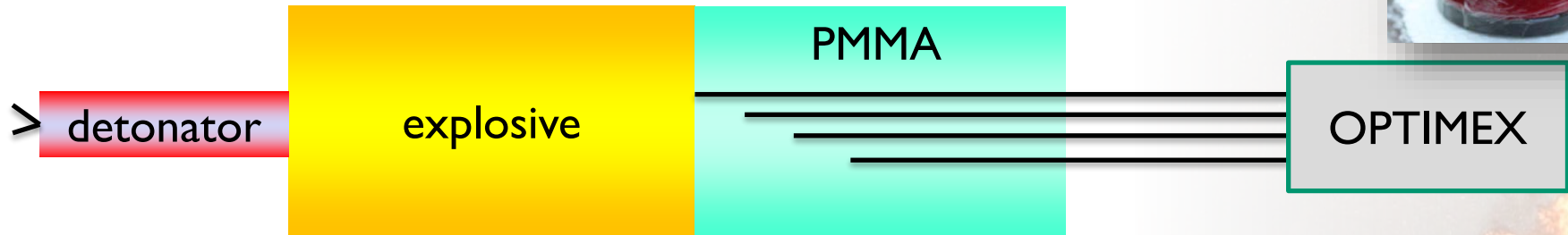
Detonation pressure from u_{fs}



Detonation pressure from u_{PMMA}



Detonation pressure from U_{inert}

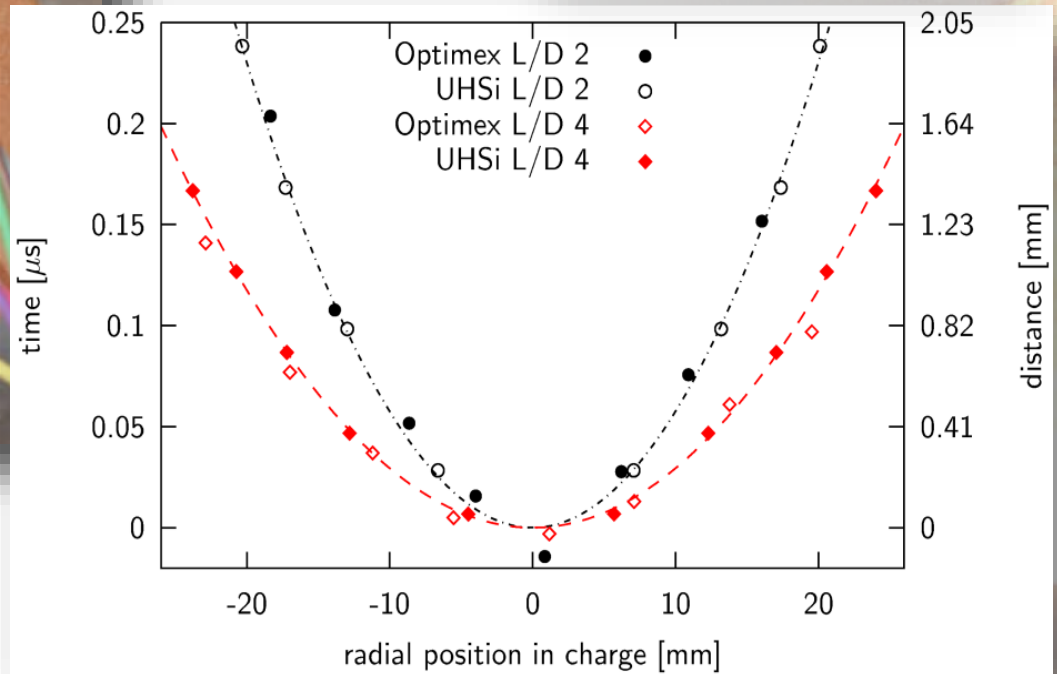
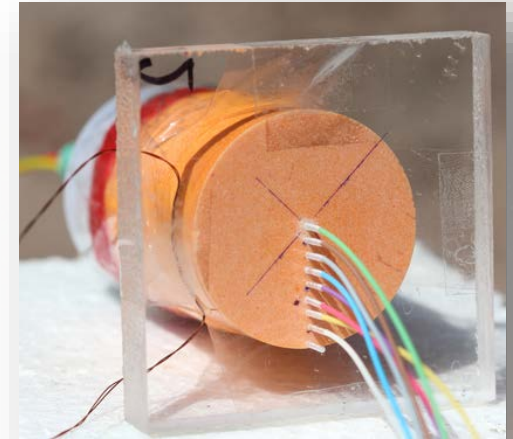
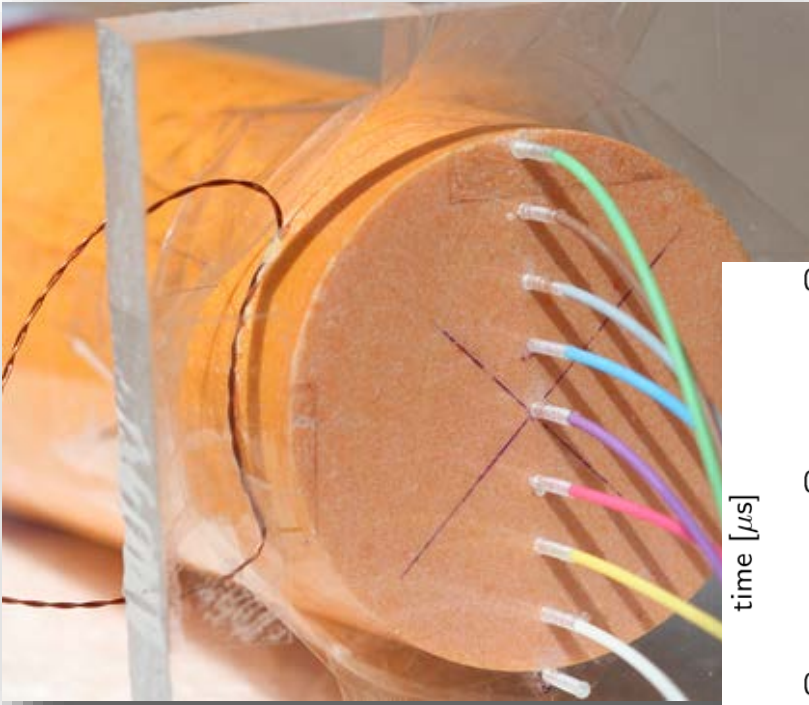


PMMA: $U_s = 2.598 + 1.516u_p$
 for $U_s = 6.054$ km/s
 is $u_p = 2.28$ km/s

other U_{inert} based techniques:

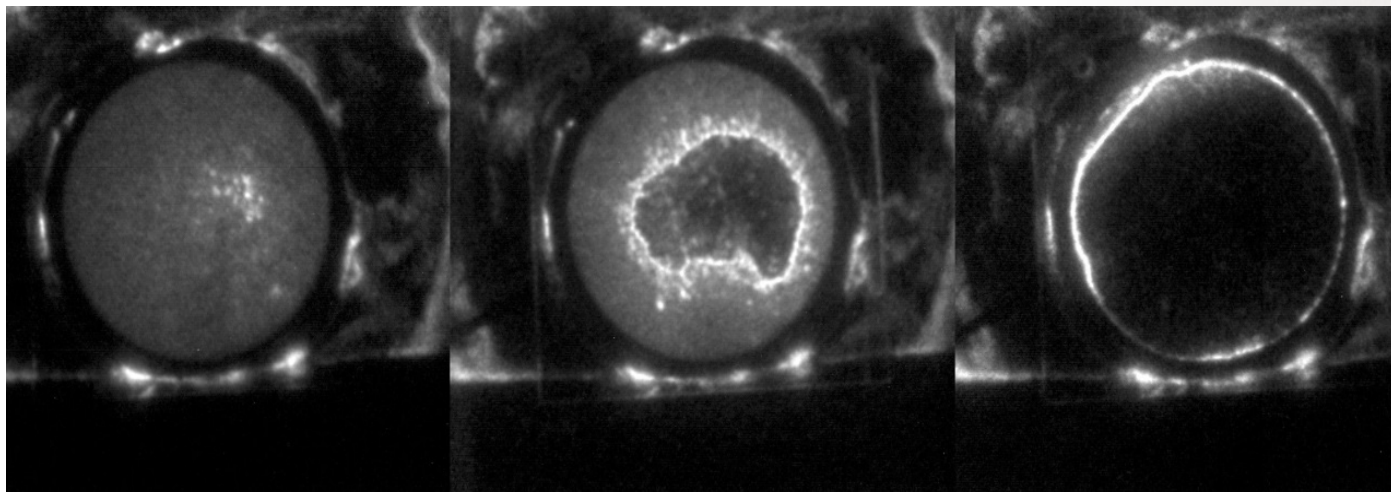
- high speed cameras
- detonation electric effect

Detonation front curvature



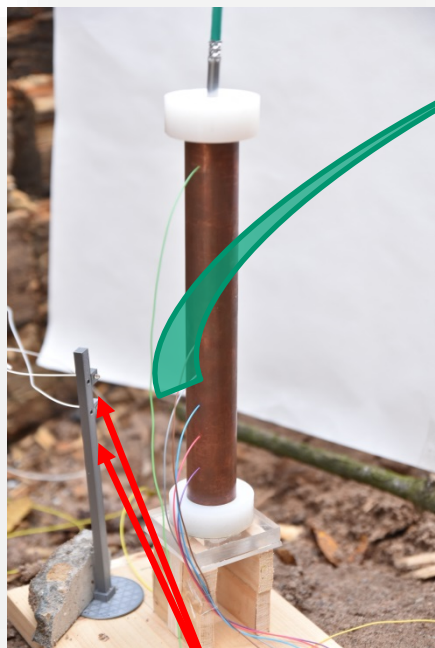
Detonation front curvature - issues

- works well only for „homogeneous“ charges



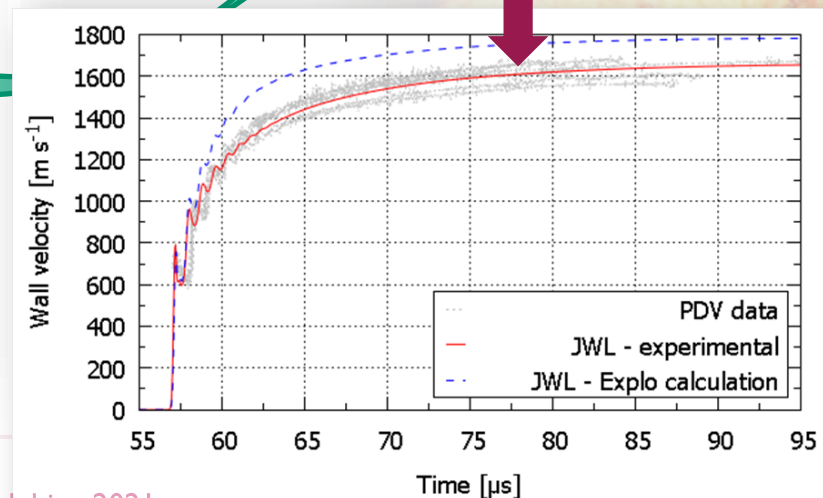
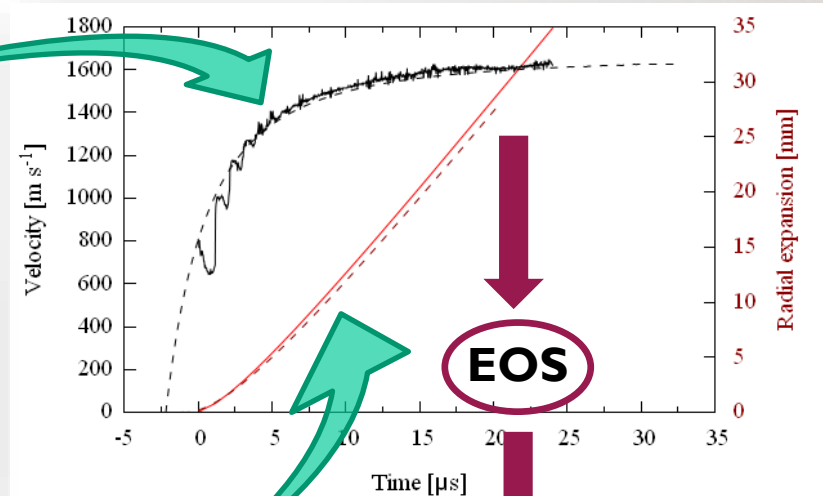
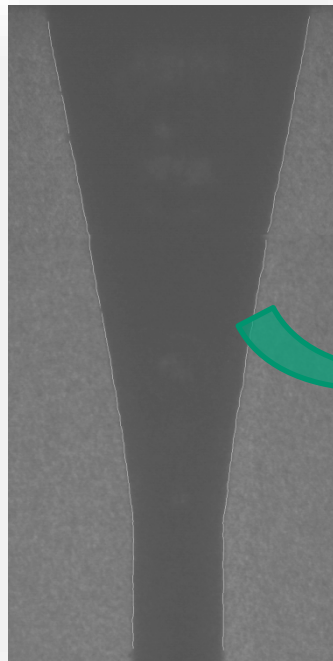
cylindrical charge of Semtex 1A (350 g) in a polypropylene tube,
diameter 46 mm, charge length 150 mm, exposure 25 ns,
18M FPS, time after trigger 0-110-330 ns

EOS – cylinder test

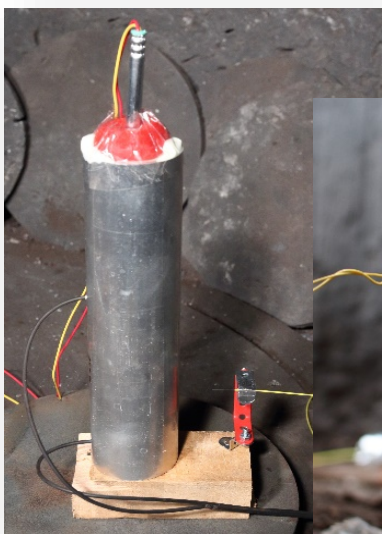


PDV probes

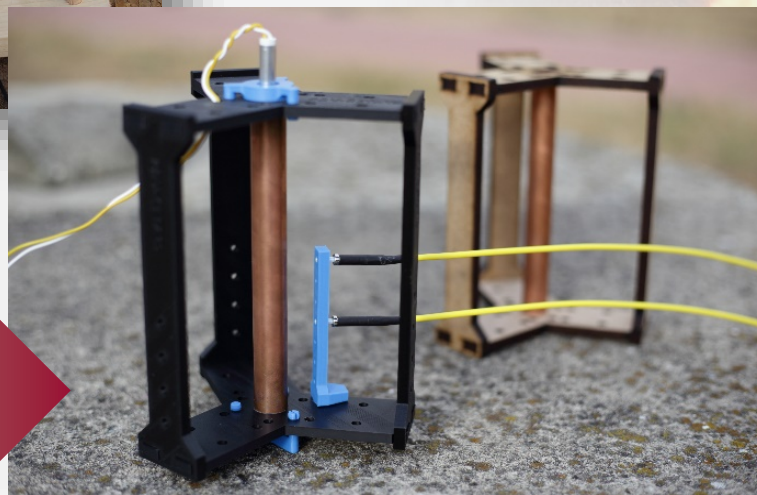
High-speed camera



Cylinder test - history

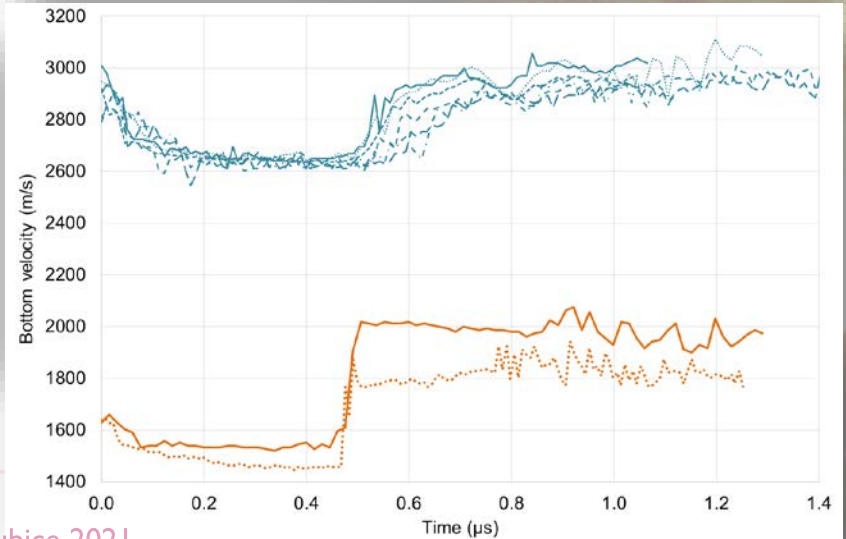
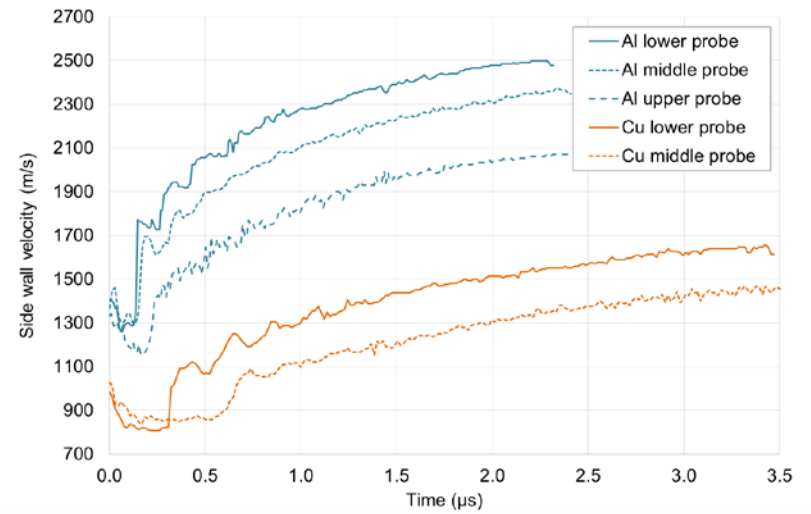
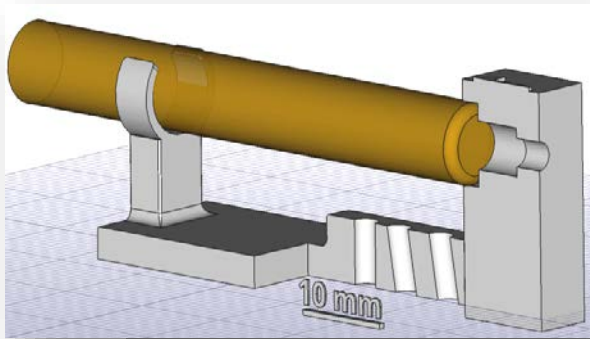


J. Kucera design



M. Kunzel design

Detonator tube expansion



Explosive effects

knowing the explosive & looking at the effects

Contact loading

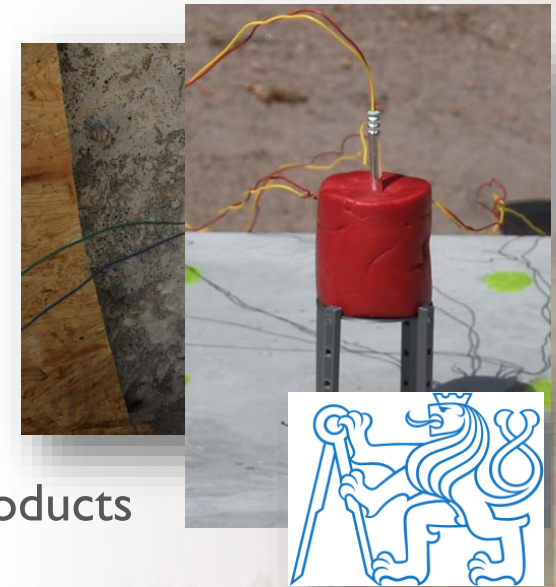
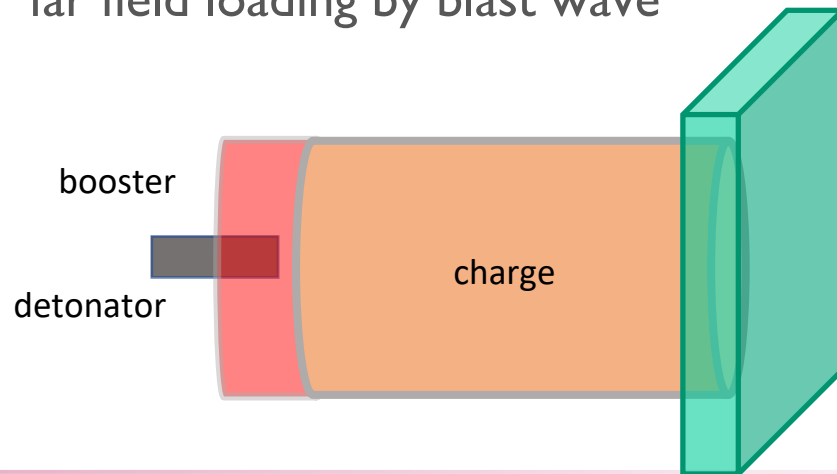
Blast waves in air

Blast loading of structures



Explosive inert interaction

- explosive and material in contact
loading by shock wave and detonation products
- explosive and material separated by an air gap
near field loading by blast wave and detonation products
- explosive separated from material by large air gap
far field loading by blast wave



concrete – M. Foglar

Explosive effects

knowing the explosive & looking at the effects

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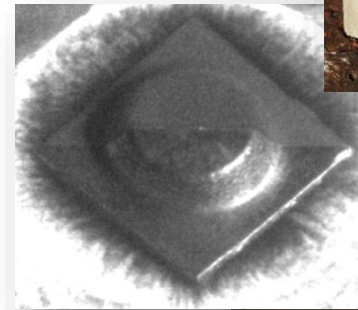
Direct explosive loading

Application in small scale experiments

- detonation parameters (P_{cj} , Gurney)
- performance (cylinder test, brisance, PDT)
- sensitivity (GAP test)

- material response
metals, concrete, rocks, composites

- plane wave generators
- explosive welding



Almost the entire production of high explosives is used in contact applications.

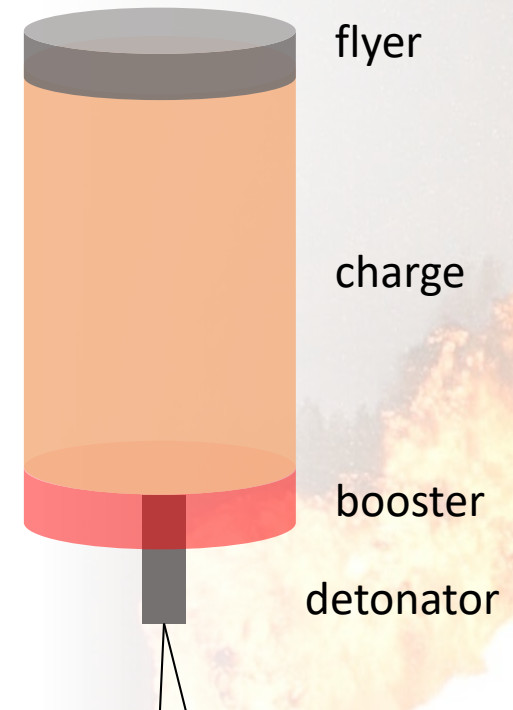
Explosive flyer

Explosive

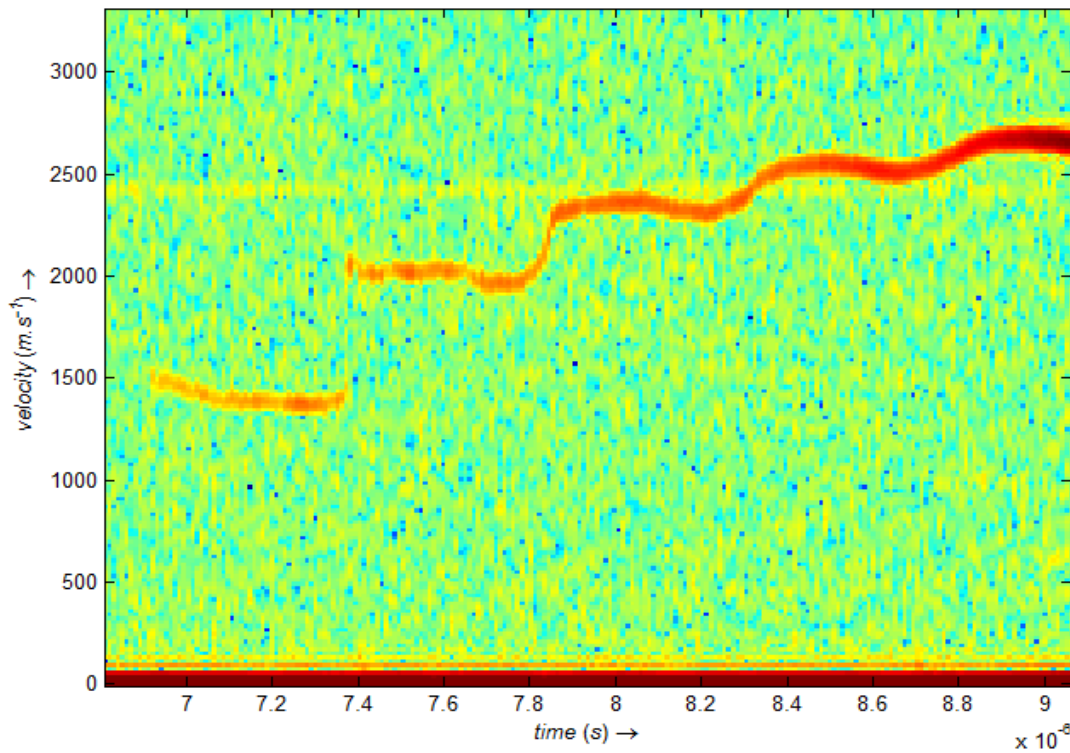
- A-IX-1 (RDX/wax)
- cylindrical geometry
diameters 40mm and 50mm
- booster – Semtex 1A
- detonator – Rock Star, Austin Detonator

Flyer

- Al or Cu discs
- various thicknesses



Direct explosive loading of flyer

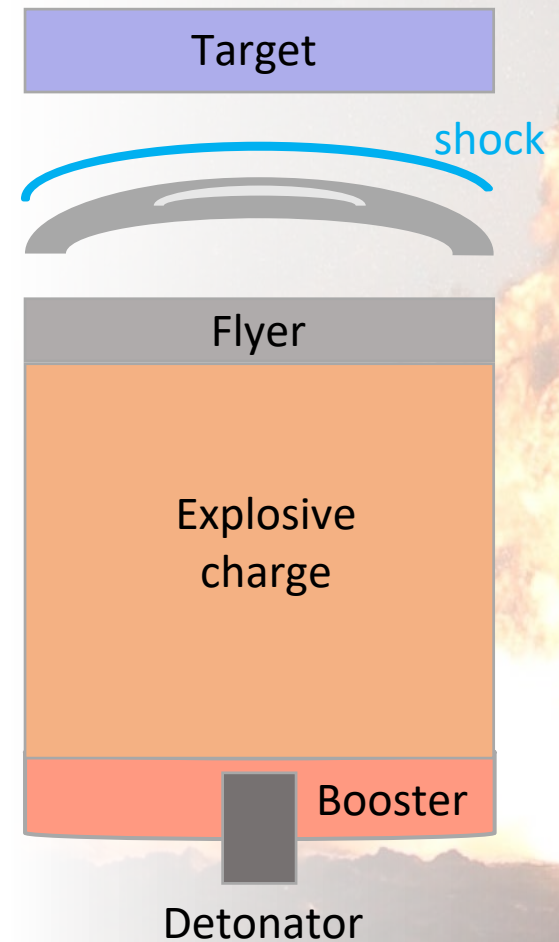


Useful in determination of detonation pressure



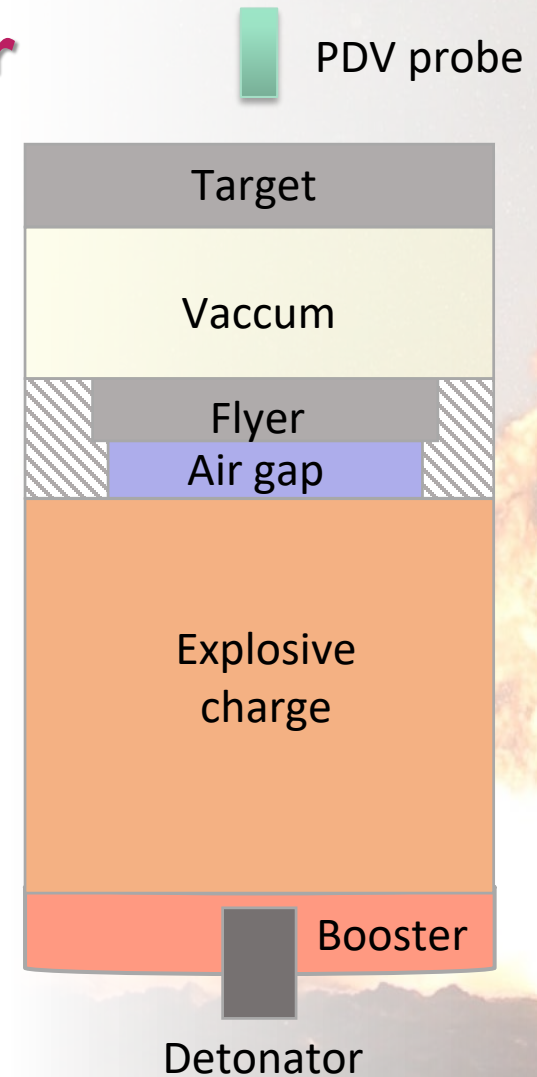
Direct explosive loading of flyer

- spall formation in flyer
- shock reverberation in flyer
- flyer deformation
 - curved detonation front
 - rarefaction waves from the side
 - air drag (air friction)
- flyer heating
- shock wave formation in air ahead of flyer

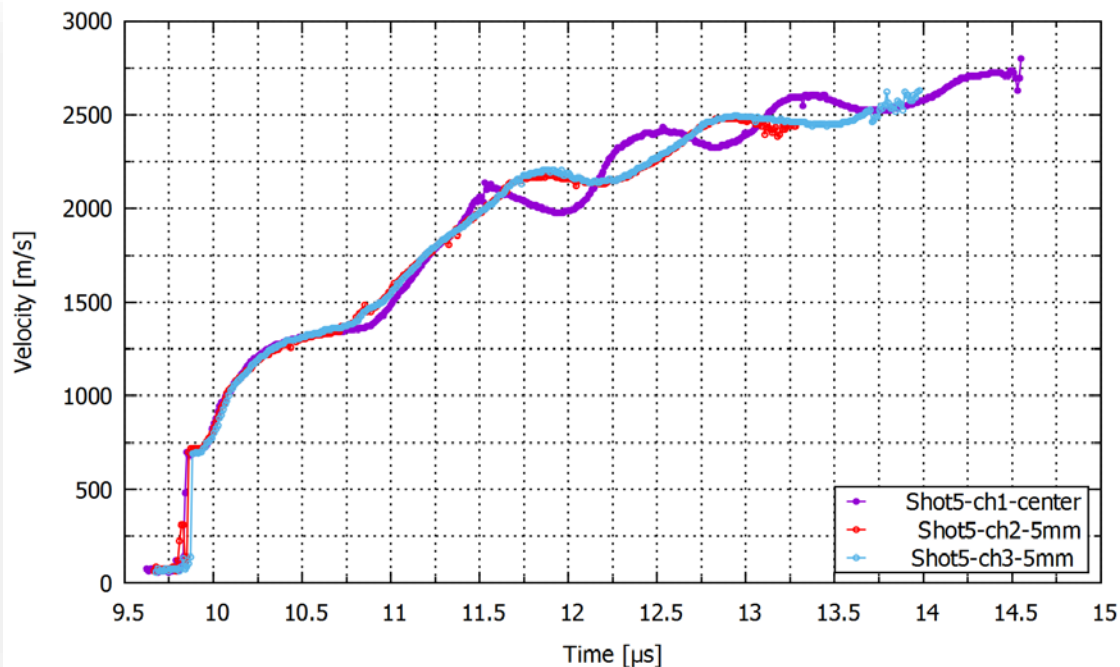


Indirect explosive loading of flyer

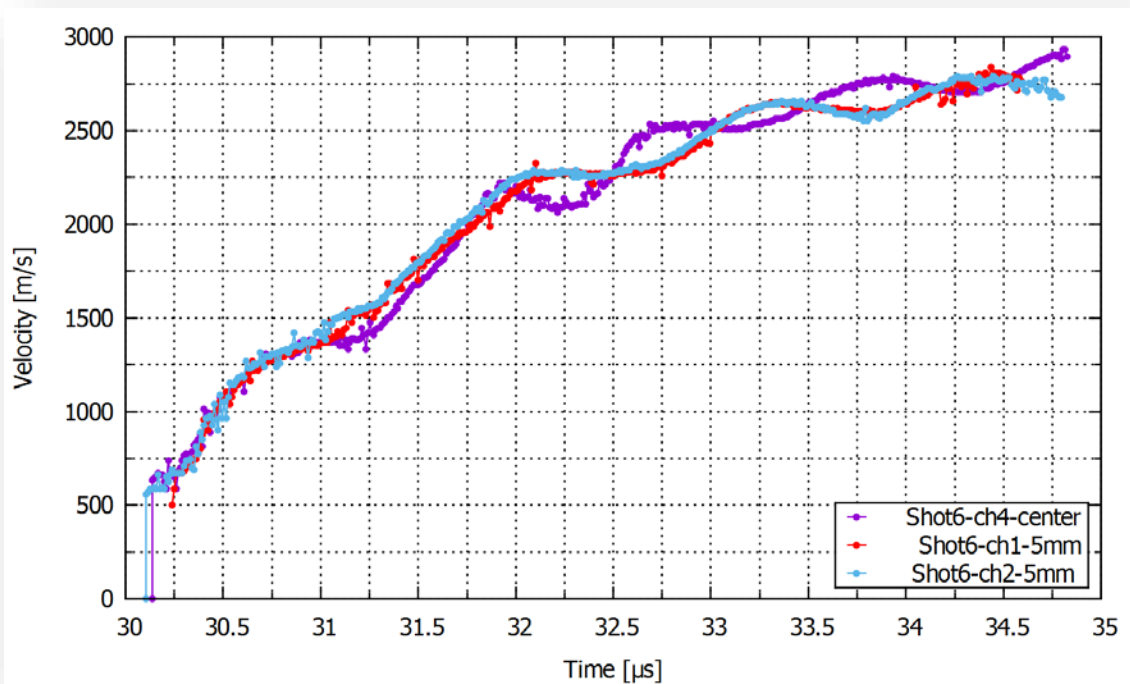
- spall formation in flyer
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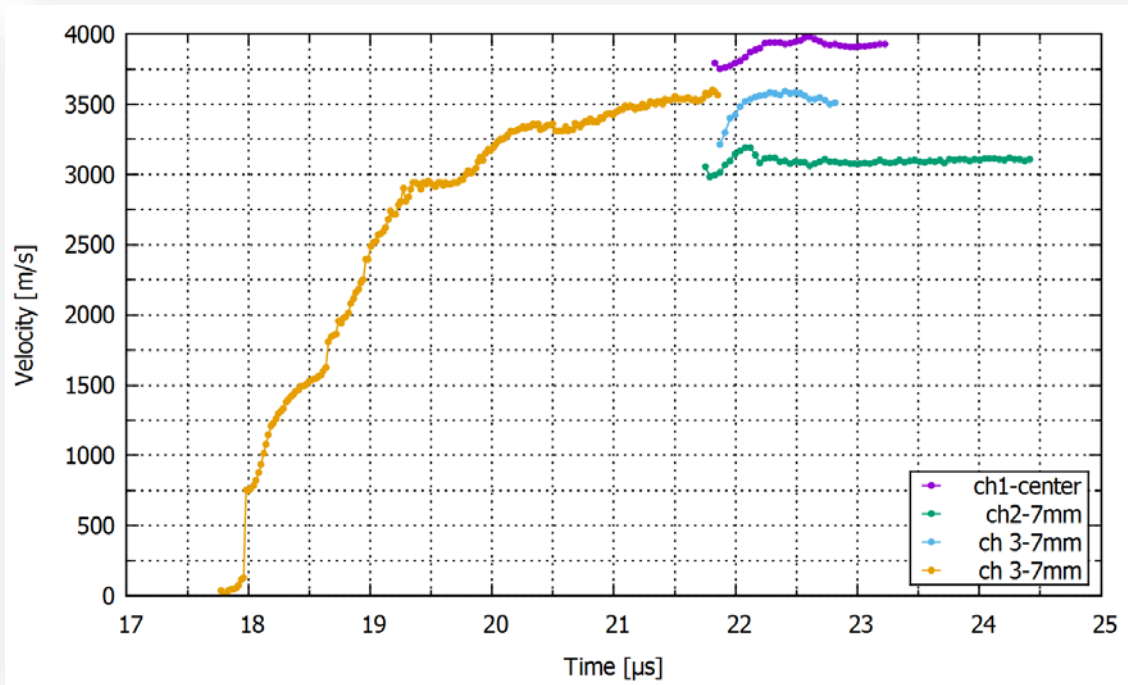
Indirect explosive loading flyer velocity in air



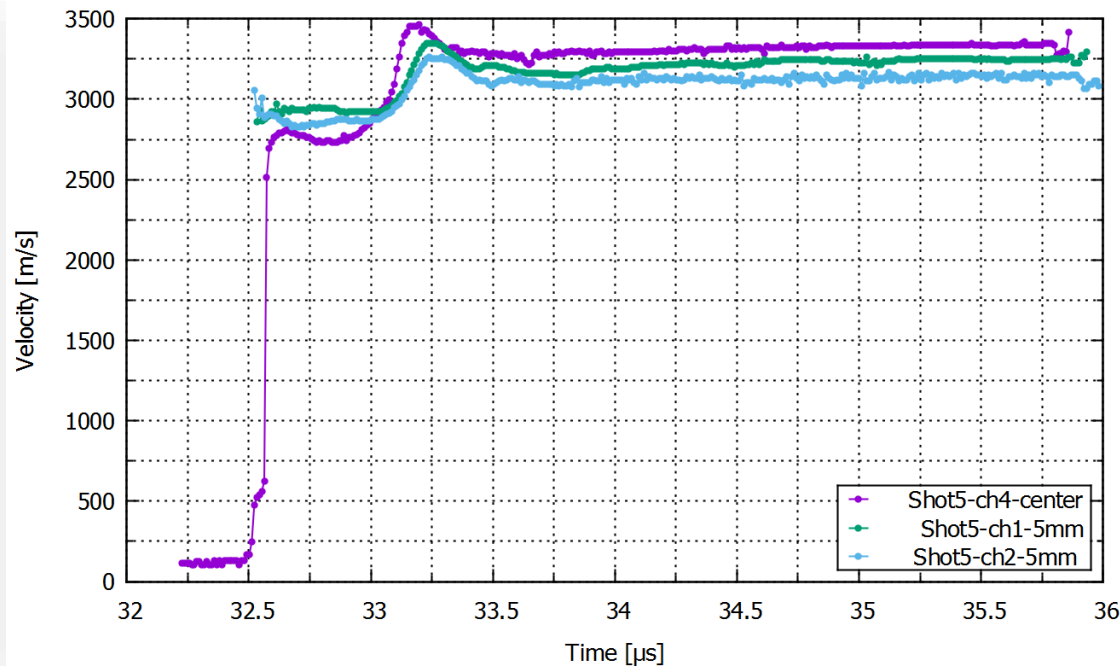
Indirect explosive loading flyer velocity in vacuum



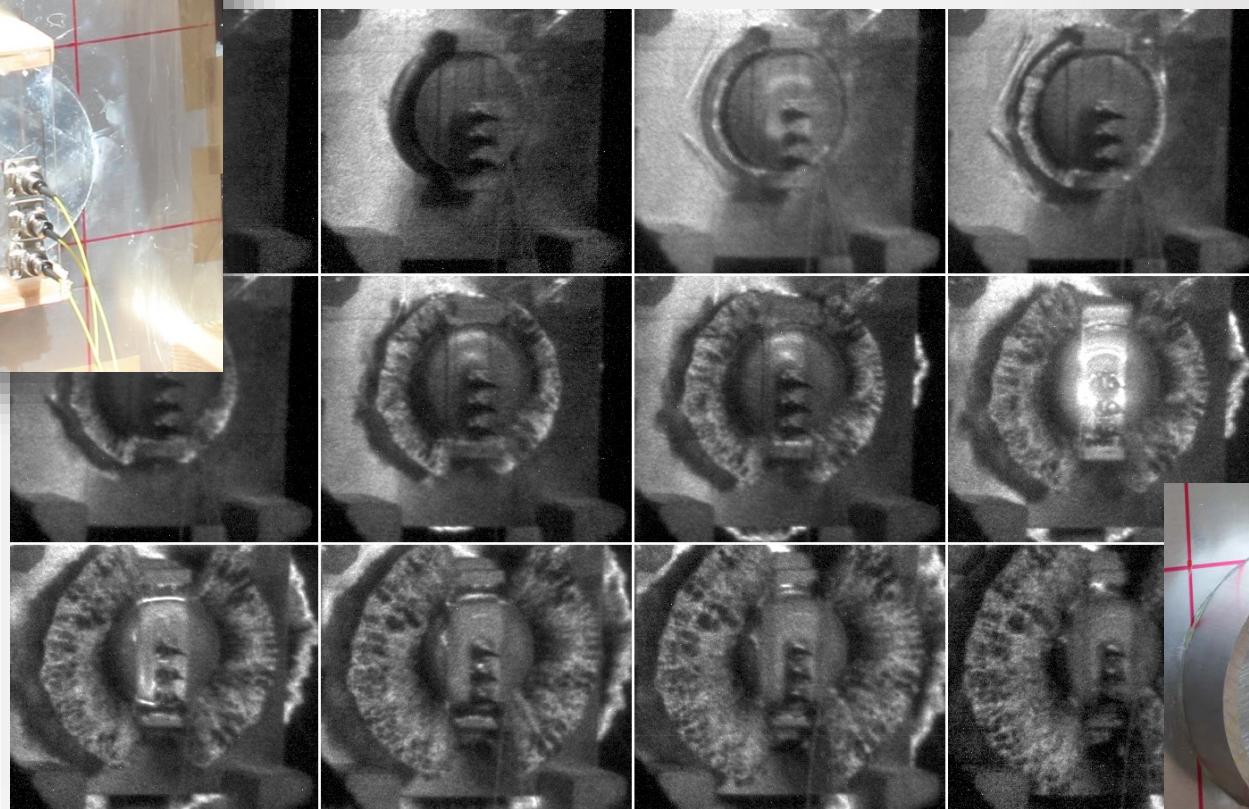
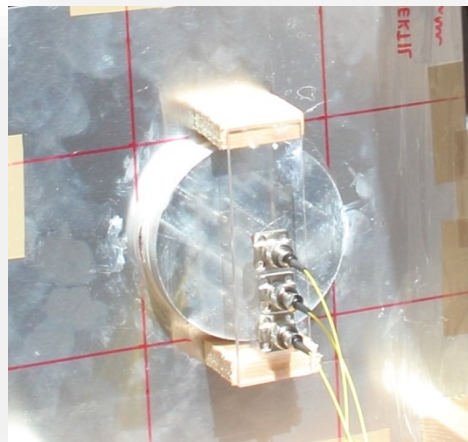
Indirect explosive loading flyer impact in air



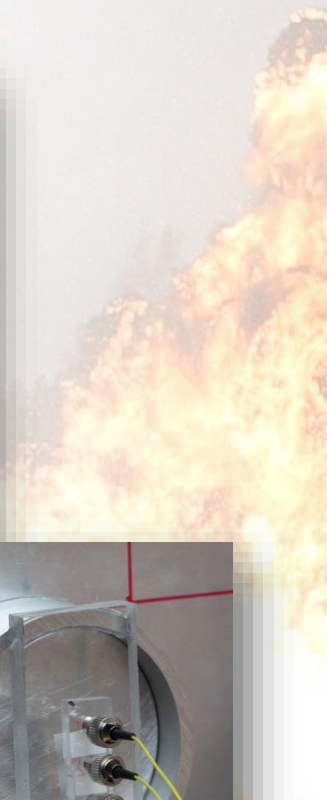
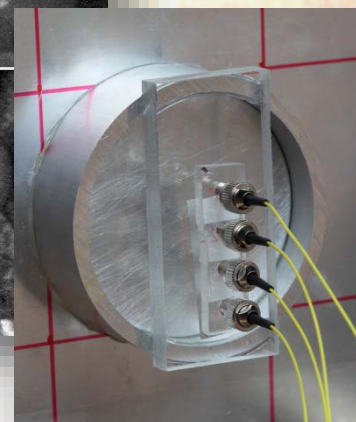
Indirect explosive loading flyer impact in vacuum



Large diameter flyer

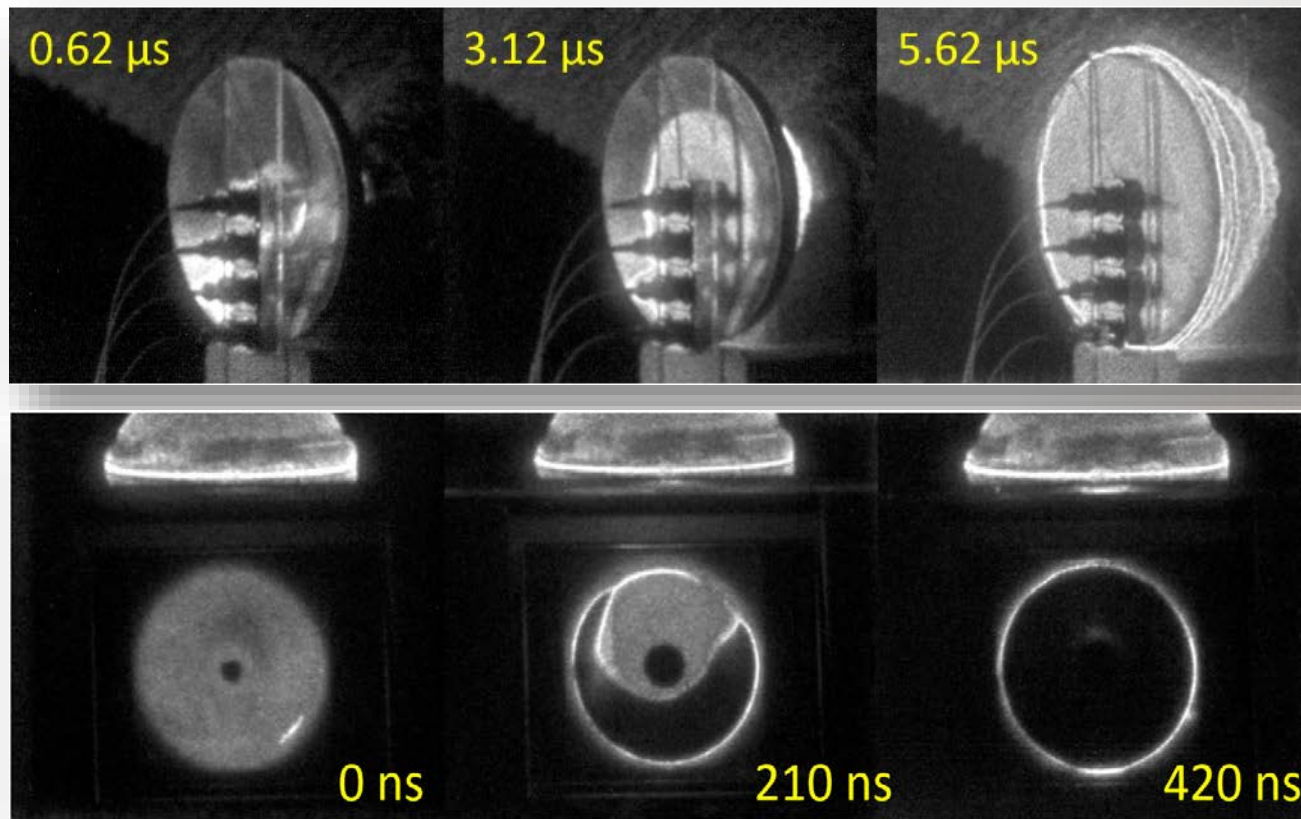


100 ns exposure



Large diameter PWG

D. A. Philippart idea, 1993



Explosive effects

knowing the explosive & looking at the effects

Contact loading

Blast waves in air

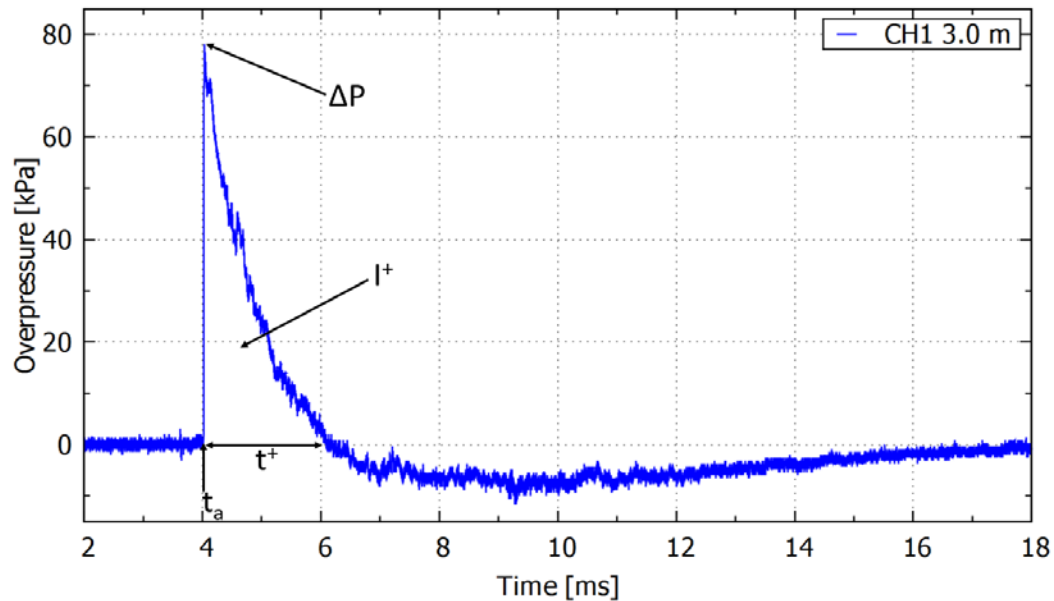
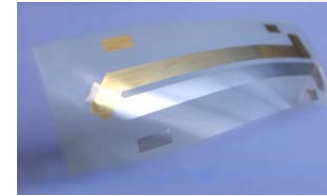
Blast loading of structures



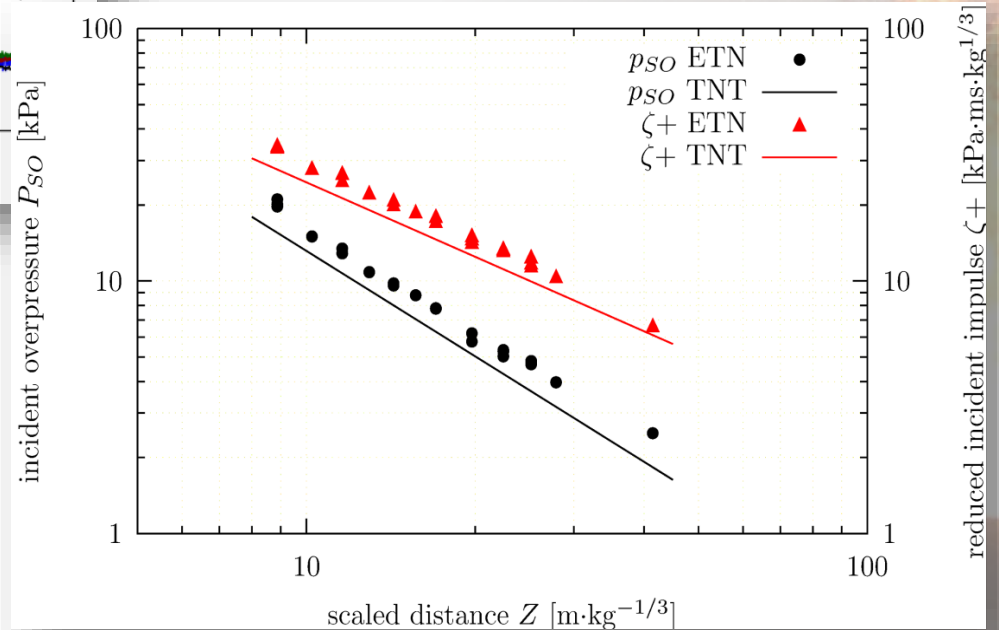
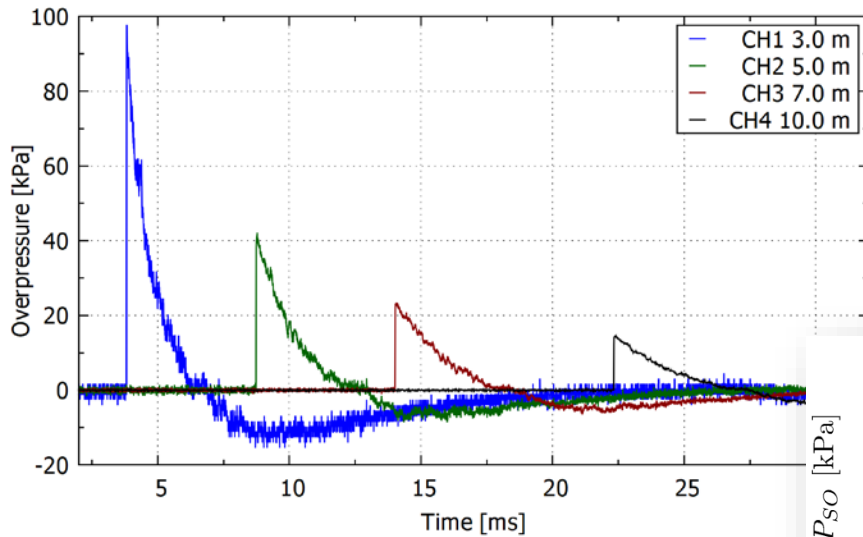
Experimental characterization of blast waves



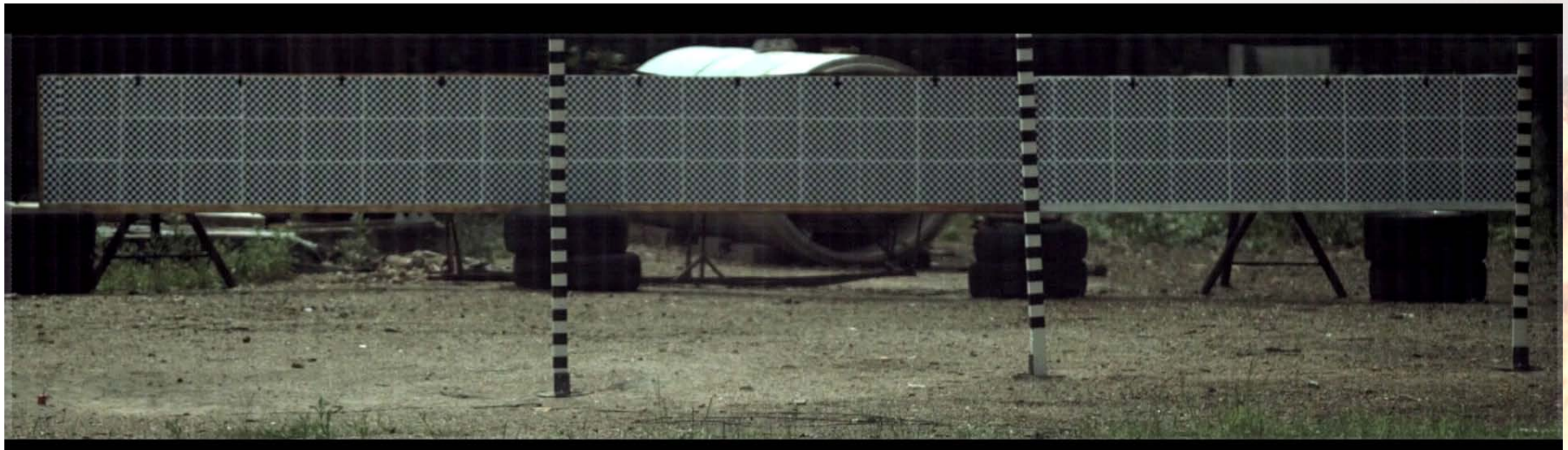
Explosively generated blast waves



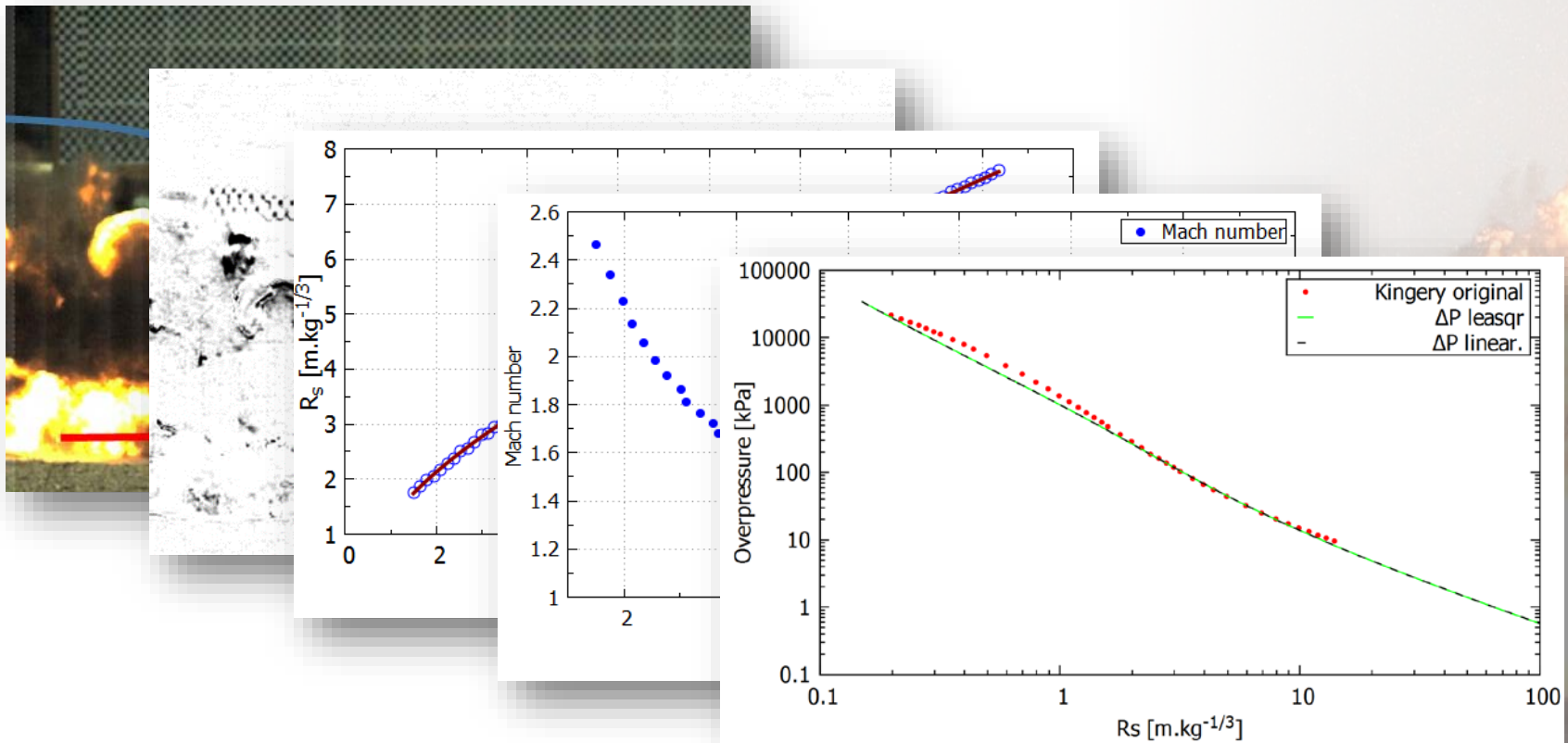
Explosively generated blast waves



Blast waves – photogrammetry



Blast wave parameters from arrival time



Blast waves - characterization



Explosive effects

knowing the explosive & looking at the effects

Contact loading

Blast waves in air

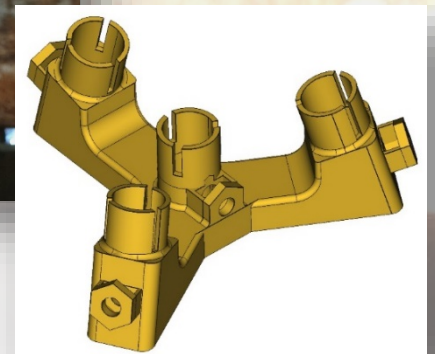
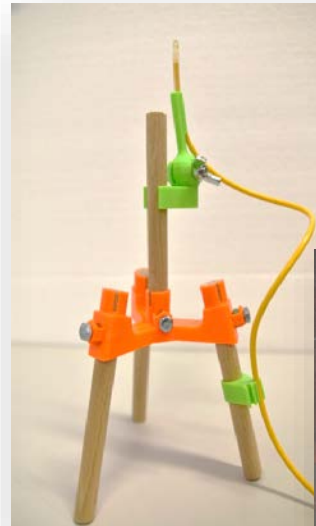
Blast loading of structures



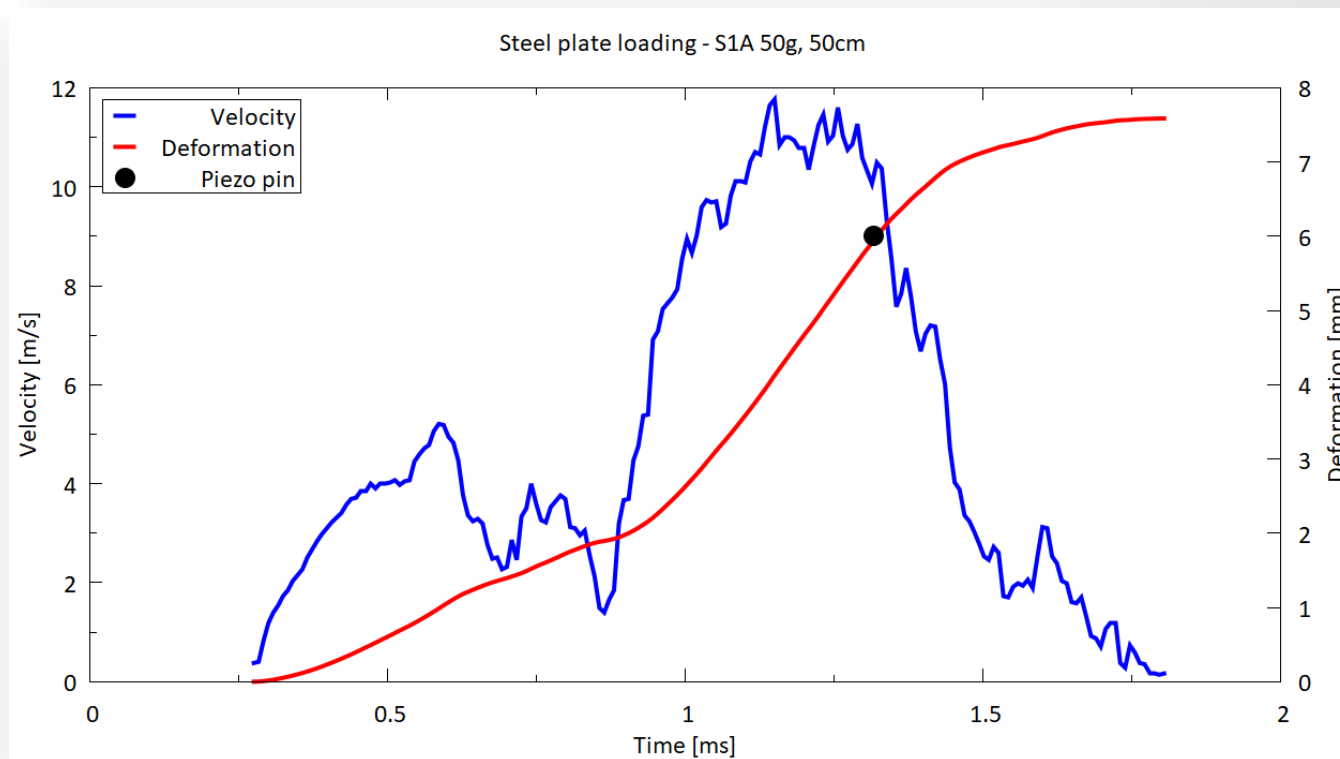
Blast loaded metal plate



Blast loaded metal plate

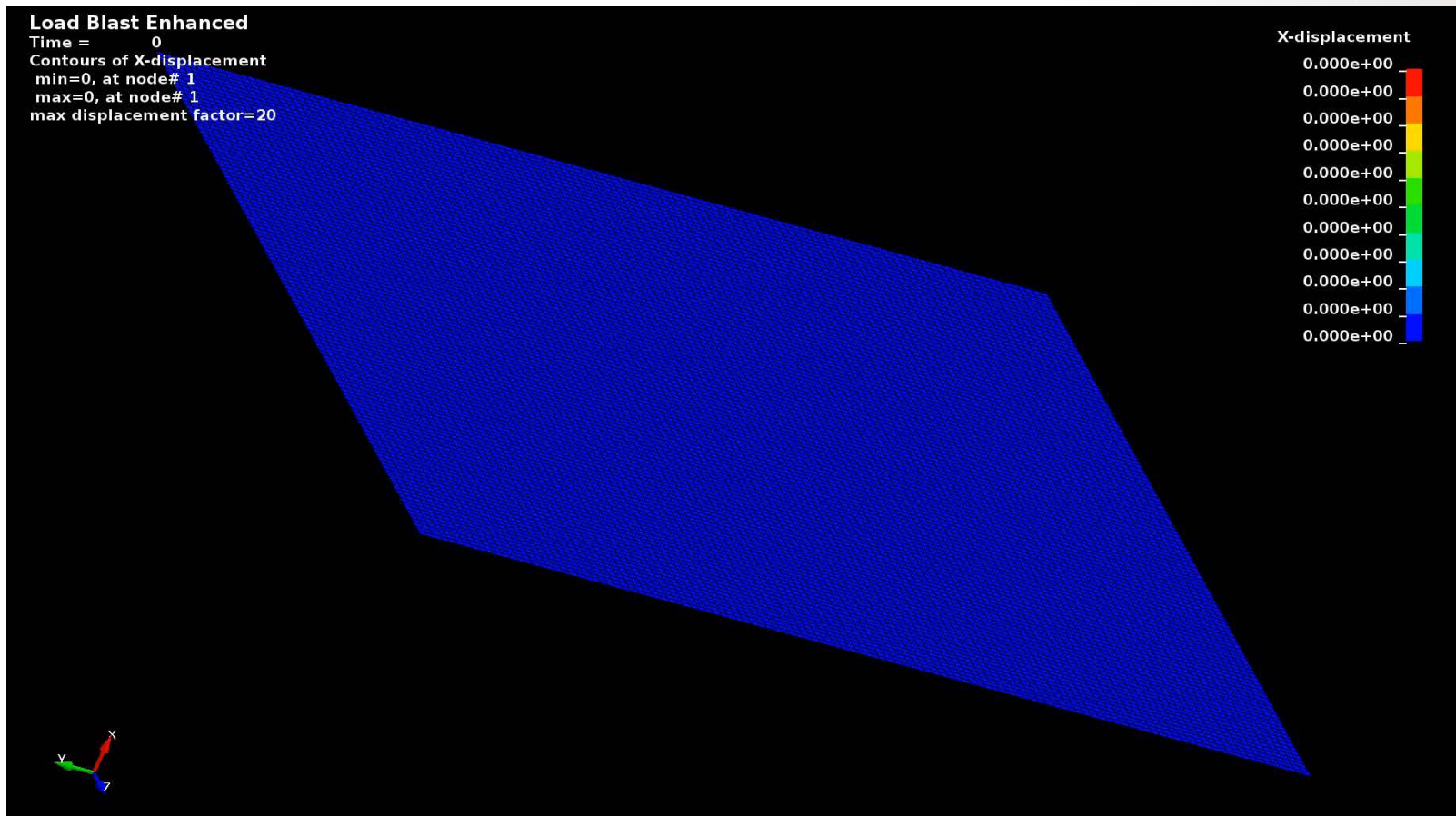


Blast loaded metal plate





Blast loaded metal plate



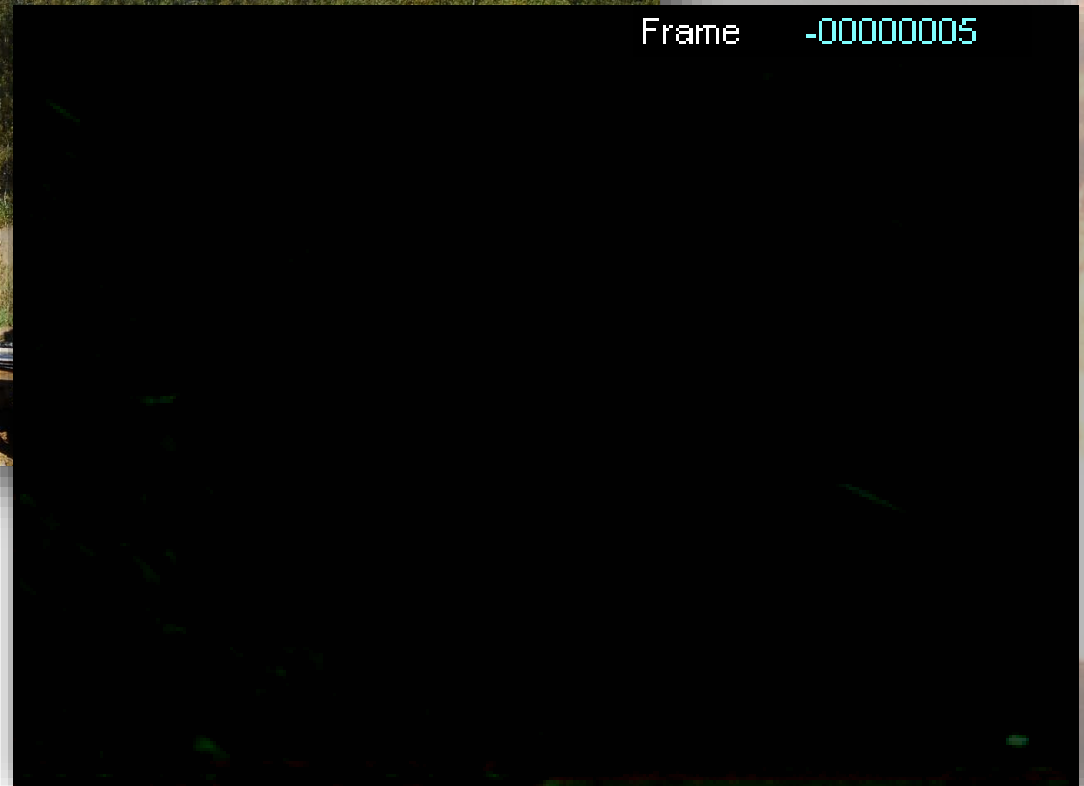


Effects of blast waves





„Blast wave“ interaction with structures





Thank you, questions?