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Dynamic Response of Graphitic Targets with Tantalum Cores Impacted by Pulsed 440-GeV Proton Beams

2nd Annual Meeting of ARIES WP17

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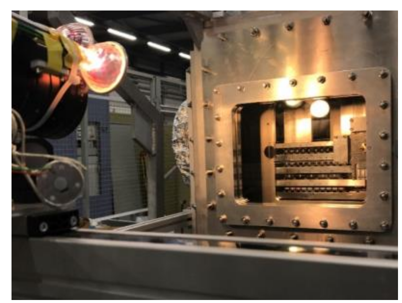
HRMT-38 “FlexMat”

- HiRadMat Experiment performed in May 2018
- Measured dynamic response of a wide variety of graphite grades (0.5 – 2.25 g/cm3), polycrystalline graphite, glassy carbon, CFC, foam, TPG…
  - All relevant for beam intercepting devices
- Overall 46 samples in 6 target stations with <=10 samples in-line

→ Overview presentation at the 1st annual meeting in Malta 2018

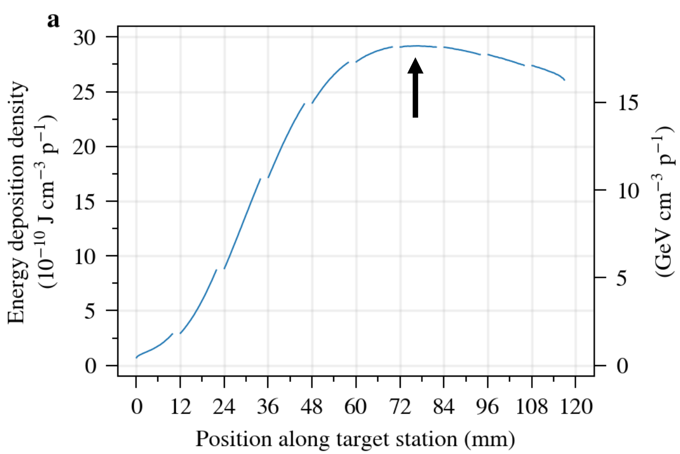
- Dedicated target station of ⌀10 mm graphite samples with a press fit ⌀3 mm tantalum (Z=73, ρ=16.67 g/cm^3) core
  - Use higher specific energy deposition in tantalum to induce potential failure in the surrounding graphite

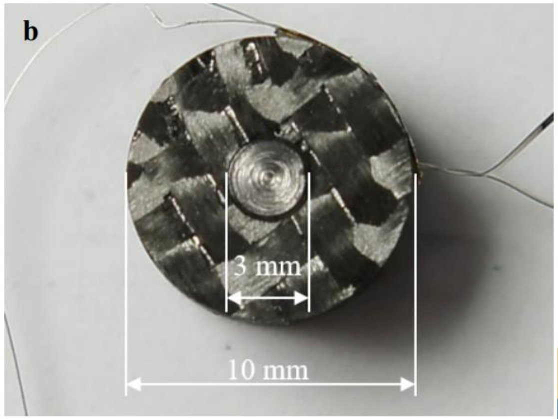


FlexMat / Target Station 6

- 10 Samples with embedded tantalum „core“
- Tantalum has shown excellent robustness towards beam impact in comparable conditions
  - Tested extensively in HRMT-27 RodTarg
- Max. specific energy deposition (100 mm target):
  Graphite, 1.83 g/cm³: ~1 GeV/cm³ p (σ = 0.25 mm)
  Tantalum, 16.67 g/cm³: ~18 GeV/cm³ p (σ = 1.5 mm)

#	Target Material	Density (g cm^{-3})	Flexural strength (MPa)	Peak energy deposition in Ta core (10^{-10} J cm^{-3} p^{-1})
1	SGL R6650 (PG, 10 µm)	1.84	67	1.7
2	SGL R6300 (PG, 20 µm)	1.73	51	5.5
3	POCO ZEE (PG, 1 µm)	1.77	146	12.9
4	SGL Premium PyC (Pyrolized 2D-CFC)	1.59	∥: 123 ⊥: 290	20.7
5	SGL Premium (2D CFC)	1.55	∥: 106 ⊥: 225	26.1
6	SGL R6650 (PG, 10 µm)	1.84	67	28.5
7	ArianeGroup Sepcarb (3D CFC)	1.5	∥: 145 ⊥: 186 [30] 17	29.1
8*	ø 7mm SGL Sigraflex (EG)	1	—	28.8
	ø 10 mm Sepcarb (3D-CFC)	1.5	—	
9	SGL Sigraflex (Expanded graphite)	1	—	27.9
10	POCO FOAM (Graphitic foam)	0.5	3	26.9





- This induces up to ~100 MPa stress in the graphite at beam intensities of ~2-6×10¹¹ ppp

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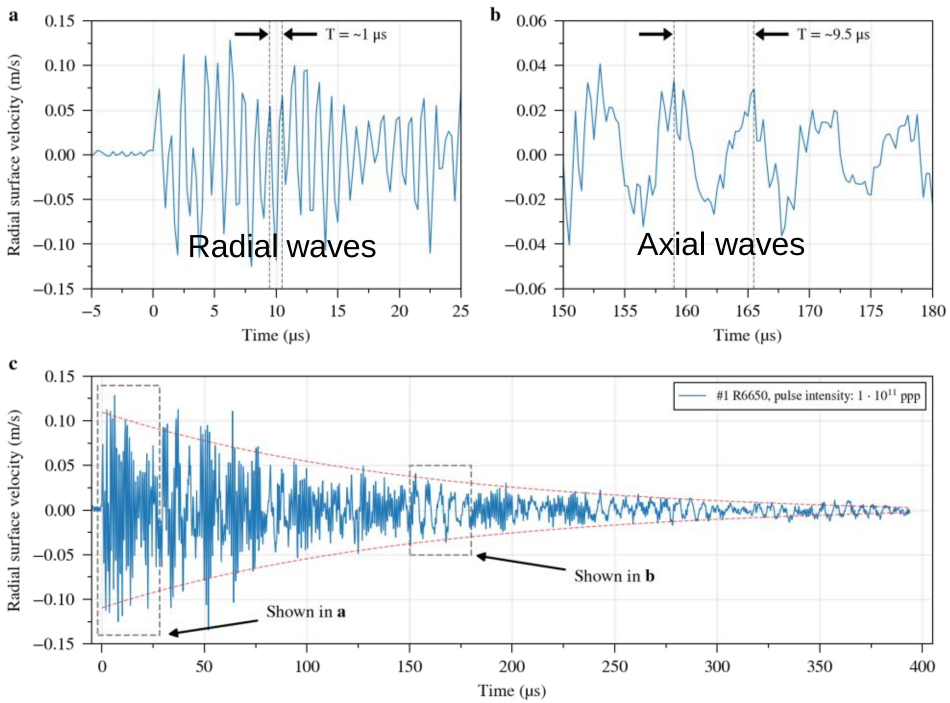
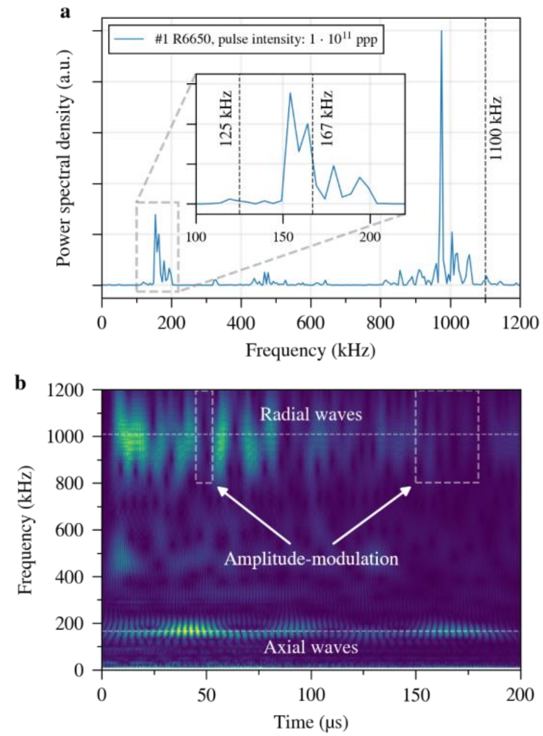
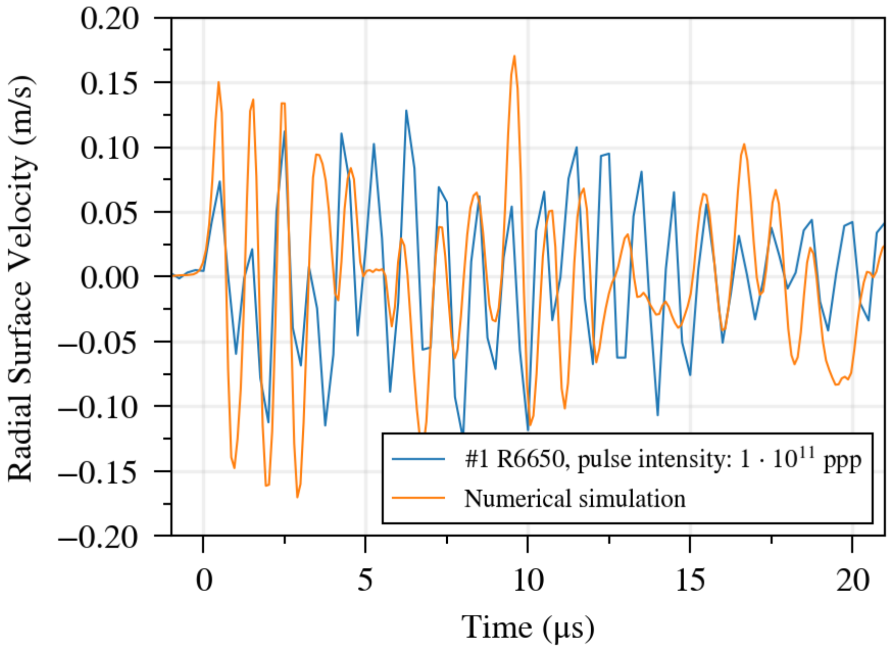
Sample #1 R6650 / 1×10^{11} ppp

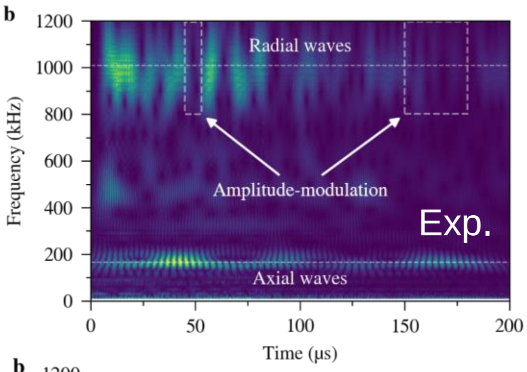


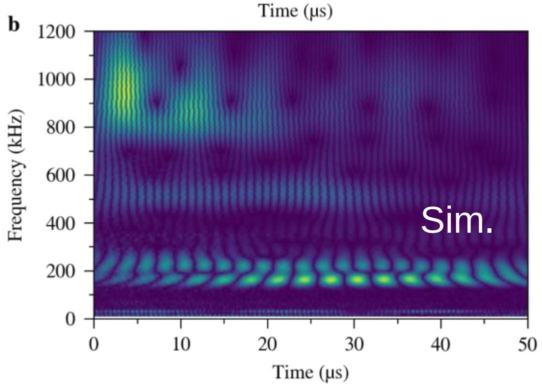


- Clear identification of radial and axial waves
- Signal dominated by dynamic response of tantalum core
- Considerably faster damping of dynamic response in comparison to bare metal

Sample #1 R6650 / 1×10^{11} ppp

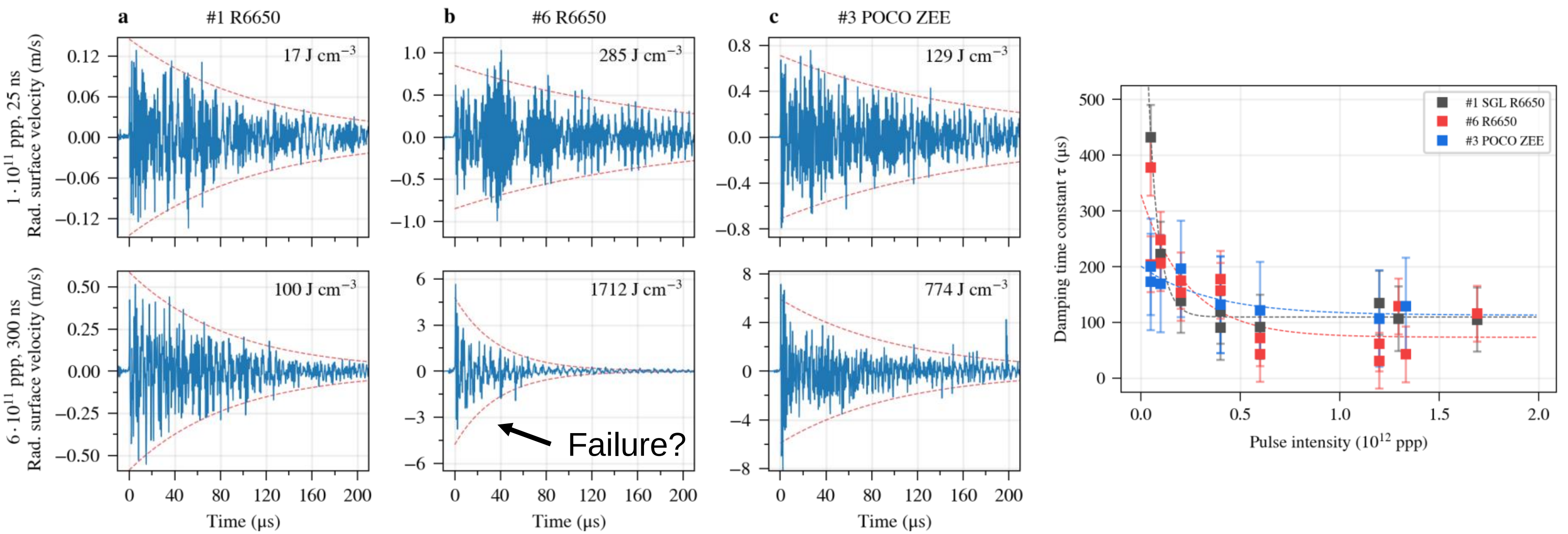






- Simulation using ANSYS Workbench w/ FLUKA input
  - Material parameters from supplier datasheets
  - No plasticity, fully bonded contact

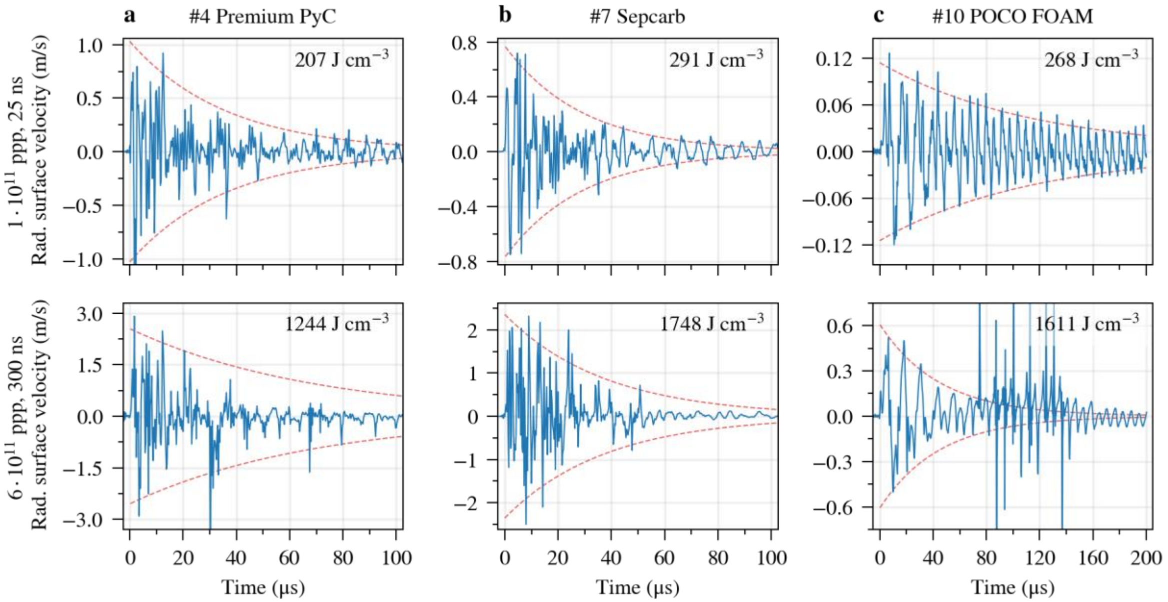
Polycrystalline Graphites



- No correlation between microstructure (grain size) and damping behaviour
  - Damping time constant decreases systematically with pulse intensity

- Deformed wave structure hints to first signs of failure in target #6 at 6×10^{11} ppp

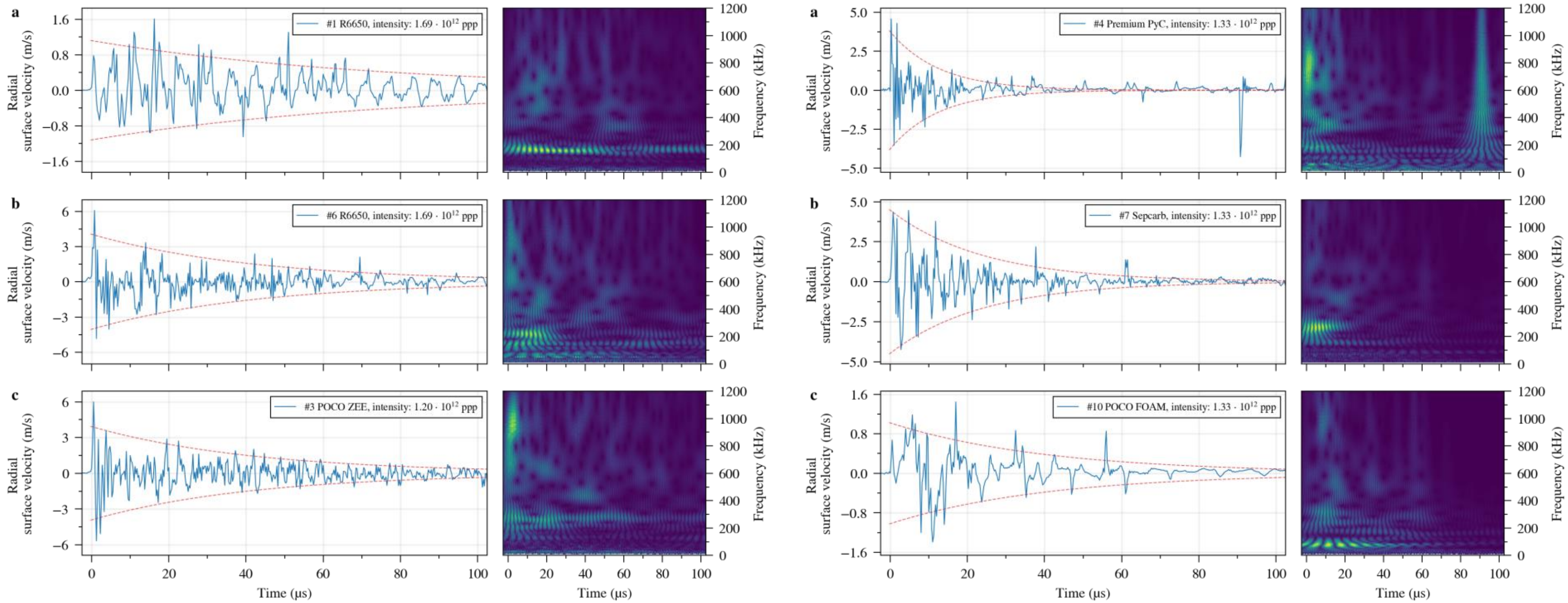
CFCs + Graphitic Foam



- Possible failure in CFCs below 2 kJ/cm^3 in tantalum core?
- Somewhat unexpected due to large strength of the material

- Foam response very clear, even at higher beam intensities

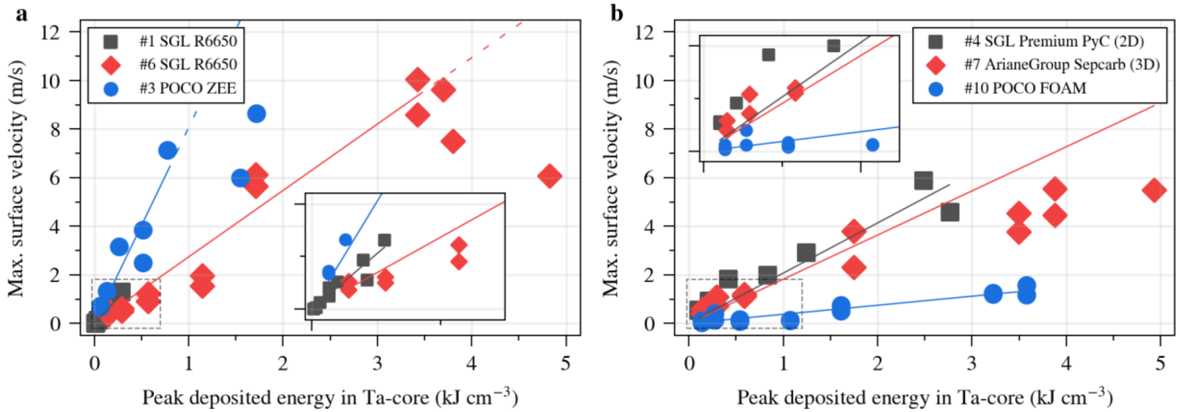
High intensity / 1.3 – 1.7×10^{12} ppp

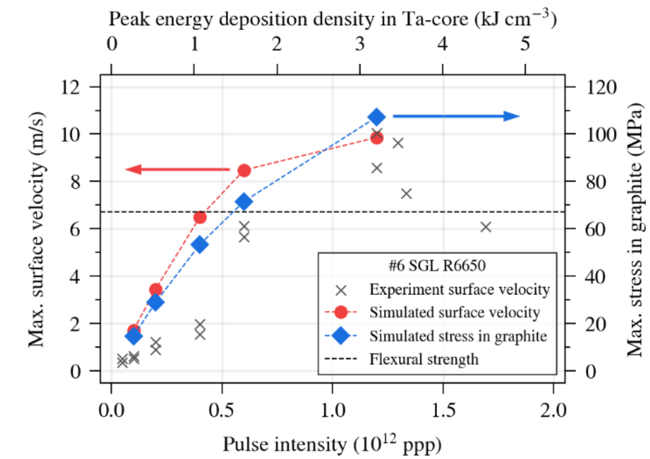


- Failure in nearly all samples (graphite + tantalum core)
  - Beam-induced stresses in the cores ~2x higher than during RodTarg

- Out of the large energy deposition samples (starting from sample #4) Sepcarb shows the „cleanest“ response

Summary





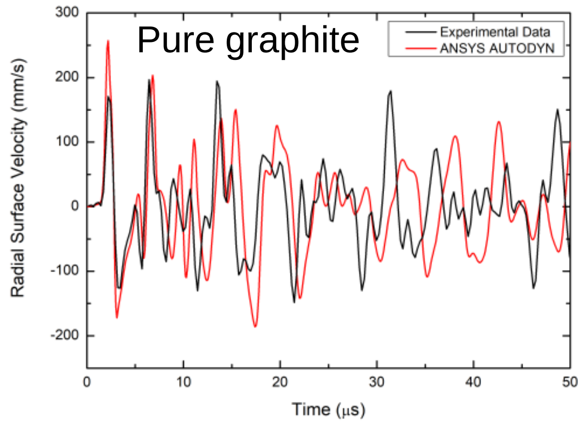
- Slopes are proportional to CTE of the materials
- Polycrystalline graphites show clear signs of failure:
  - Velocity doesn‘t increase with beam intensity at a certain point
  - #6 R6650: agrees well with stresses expected from ANSYS

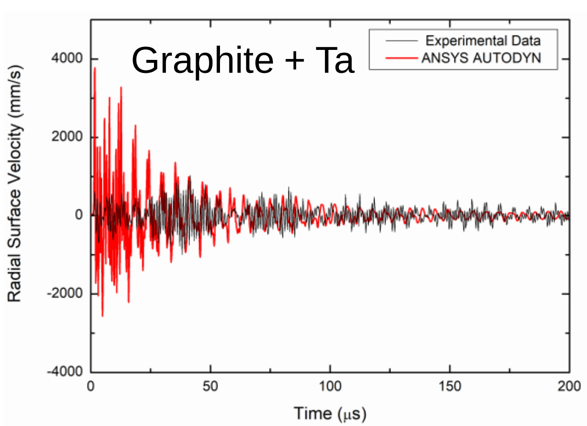
- CFCs have a more peculiar behaviour with apparently two regimes:
  - Linear response <1 kJ/cm^3
  - Decreased slope >1 kJ/cm^3
  - Fiber delamination? Failure of the low strength matrix? (tensile strength 17 MPa in Sepcarb)

- Very interesting results for POCO FOAM

Outlook

- Simulations with AUTODYN:





- Foam in Workbench:

(AUTODYN produces error at 0.5 g/cm³ ☹)