Laser Ablation of Metal Doped Polymers with CO_2 Laser

EOARD Grant FA8655-03-1-3061

Properties of Laser Ablation Products of Delrin with CO_2 Laser

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OUTLINE

- Who is DLR – Institute of Technical Physics (TP)?
- Lightcraft Research at TP
- Experimental Setup and Sample Types
- Results: Flat samples in air
  3-D expansion
  Vacuum
  Comparison of different sample types
  Tests with a light concentrating structure
- Scanning electron micrographs
- Conclusions and proposal

DLR - INSTITUTE OF TECHNICAL PHYSICS

German Aerospace Center

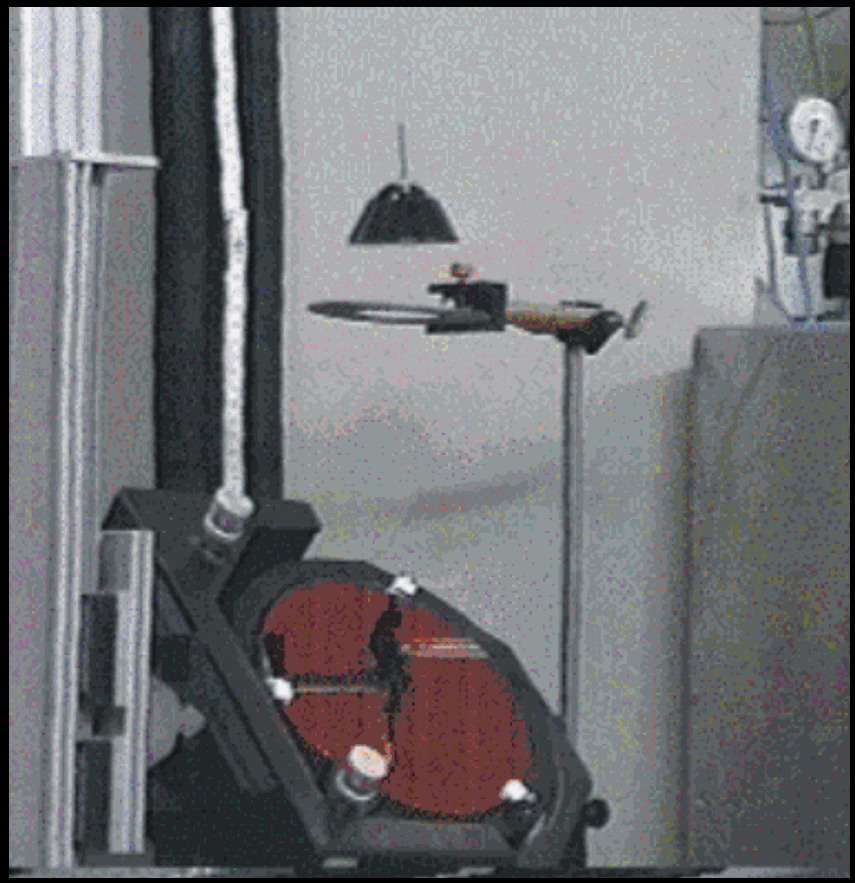
- Astronautics
- Traffic
- Energy
- Aeronautics

Institute of Technical Physics

HEL / COIL
SSL / NLO
Active opt. Systems

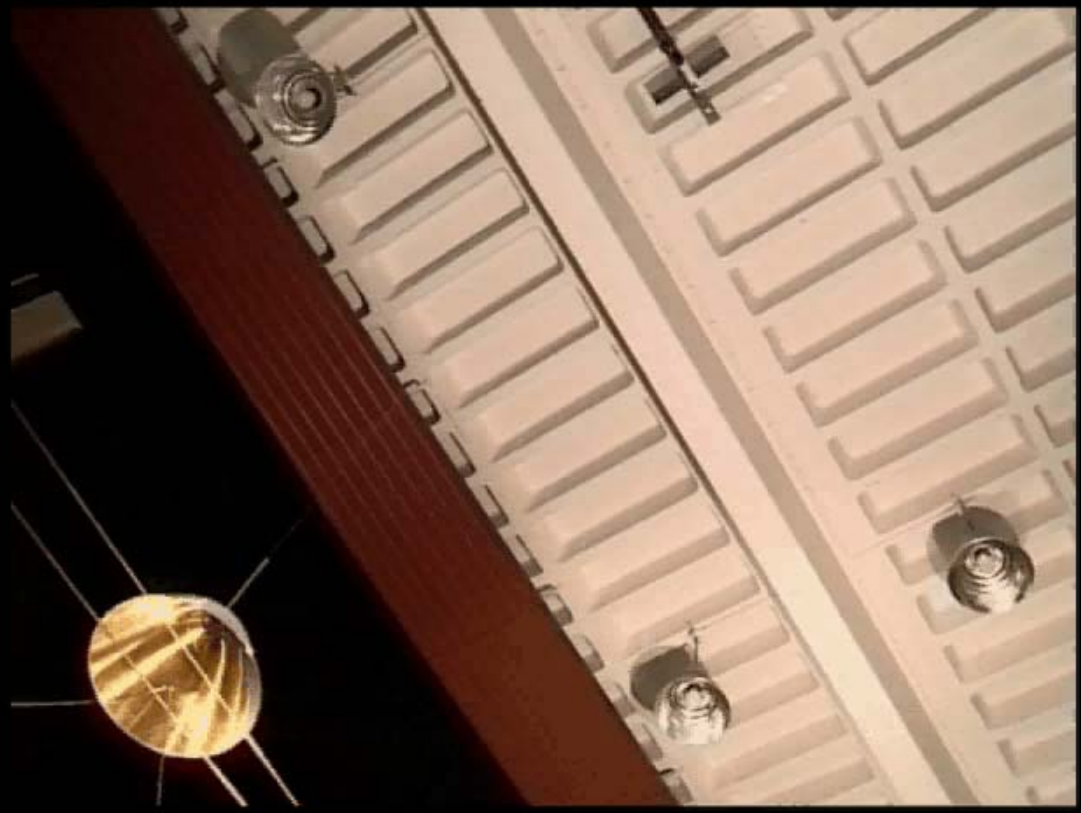
Studies & Concepts
Akquisition & Support

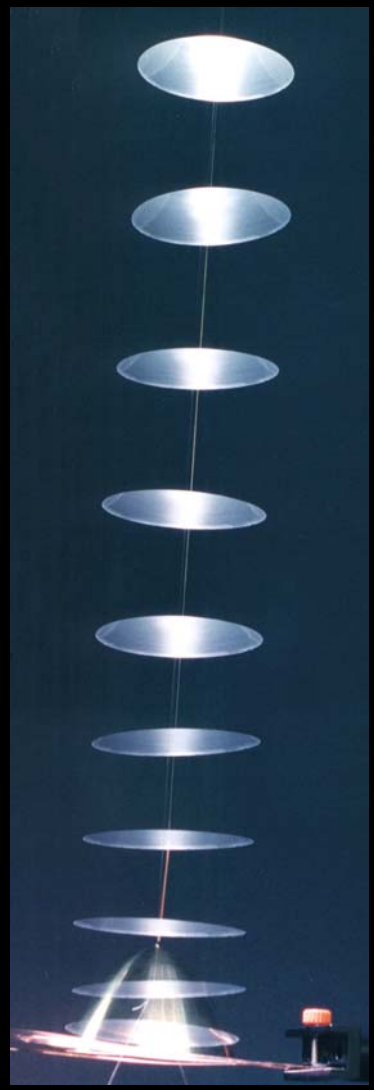
HOW IT ALL BEGAN ... (1998)



Bicycle Headlight Reflector

LIGHTCRAFT FLIGHT





ACKNOWLEDGEMENT

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Dr. Franklin B. Mead Jr. and **Dr. Carl W. Larson**

(AFRL – Propulsion Directorate, Edwards AFB, CA)

Dr. Ingrid Wysong (EOARD - London)

(and all the others in the background)

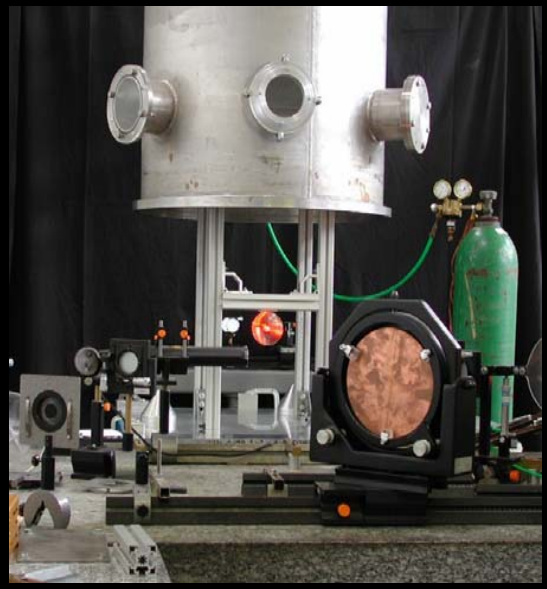
for making our research and this visit possible.

EXPERIMENTAL EQUIPMENT

Lightcraft

Parabola with
Diameter 10 cm
Focal Distance 1 cm

Vacuum Tank

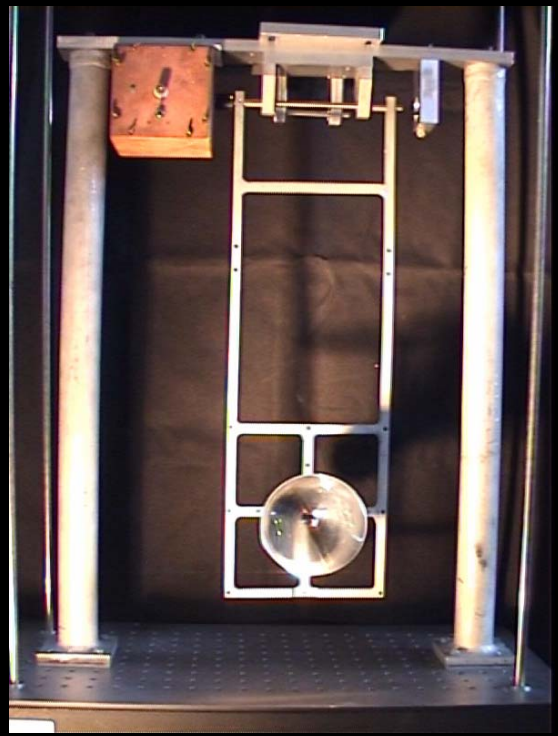


Diameter 80 cm
Height 110 cm

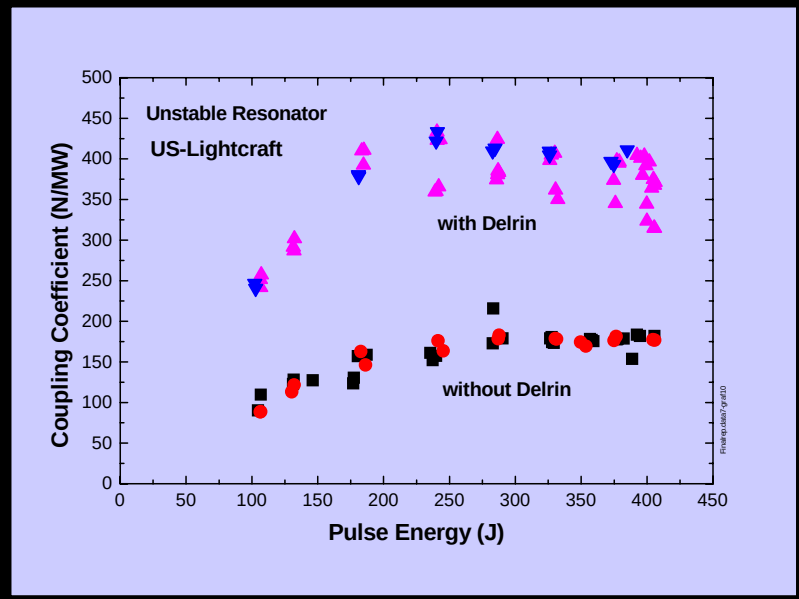
E-beam sustained CO_2 Laser

Pulse Energy ... 420 J
Repetition Rate ... 100 Hz
Wavelength 10.6 µm
Pulse Length 3 ... 12 µs

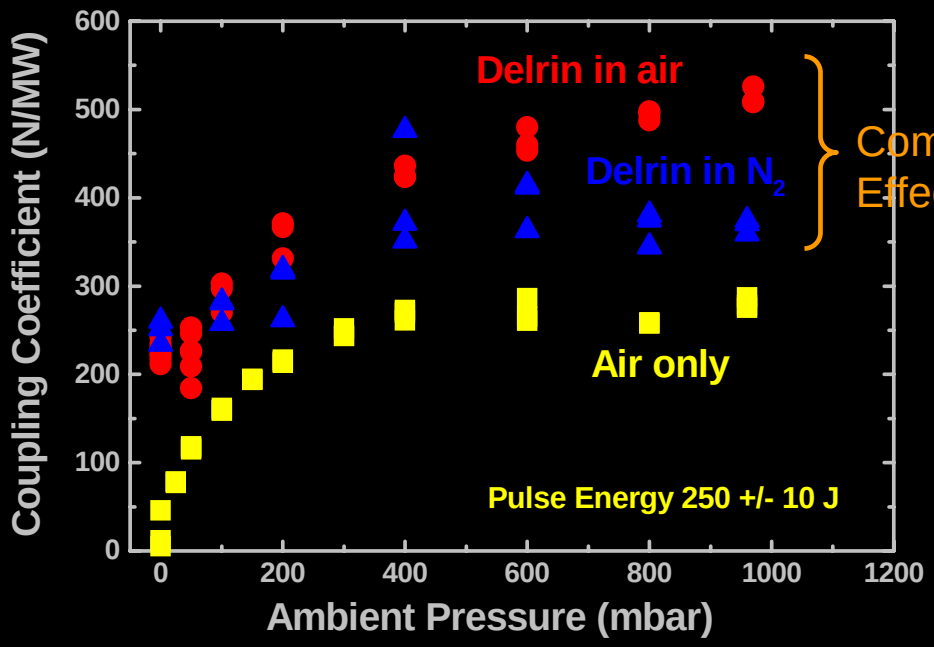
INVESTIGATIONS FOR EOARD (Phase I – 2002)

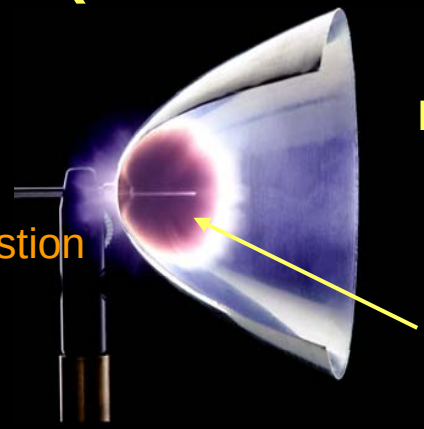


Comparison of measurement techniques and performance of US and German lightcraft

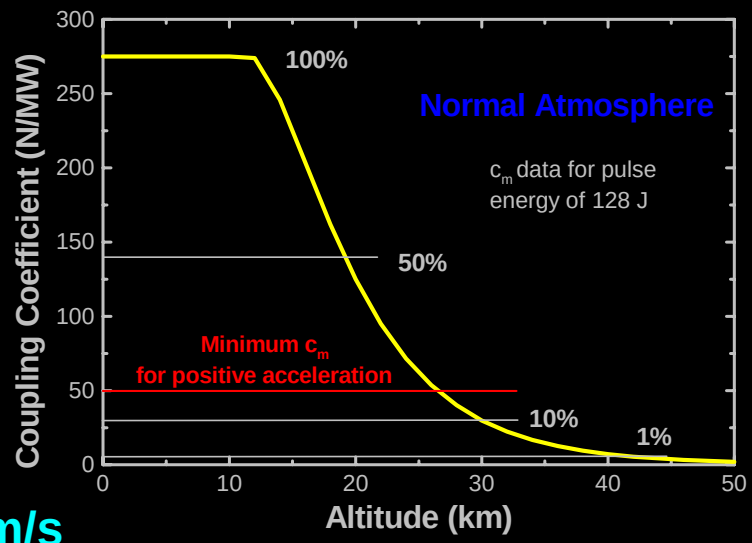


INVESTIGATIONS FOR EOARD (Phase II – 2003)





Delrin cylinder



Air breathing propulsion possible to altitudes of about 30 km !

With Delrin in vacuum v_{ex} = 2400 ± 200 m/s

LASER LAUNCH SYSTEM DEVELOPMENT ROADMAP

LASER POWER (kW)

10000
1000
100
10

2004 2006 2008 2010 2012 2014 2016 2018 2020

Laboratory flight tests

16 Mio Euro

Free flight testing

85 Mio Euro

Launch of sounding rockets

Launch of satellites

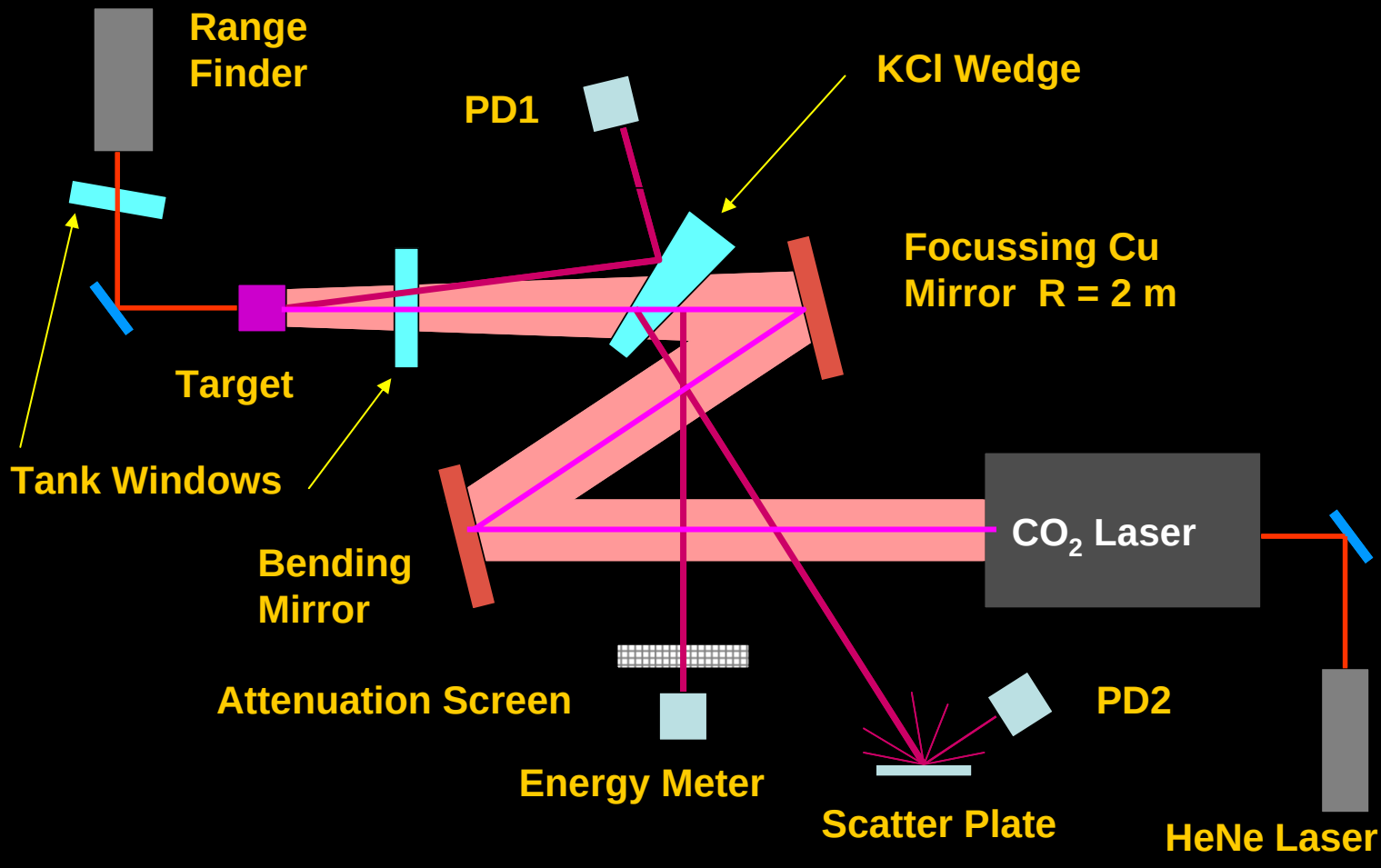
275 Mio Euro

Phase 1
Basic Research

Phase 2
Pre-Prototype

Phase 3
Commercial

EXPERIMENTAL SETUP



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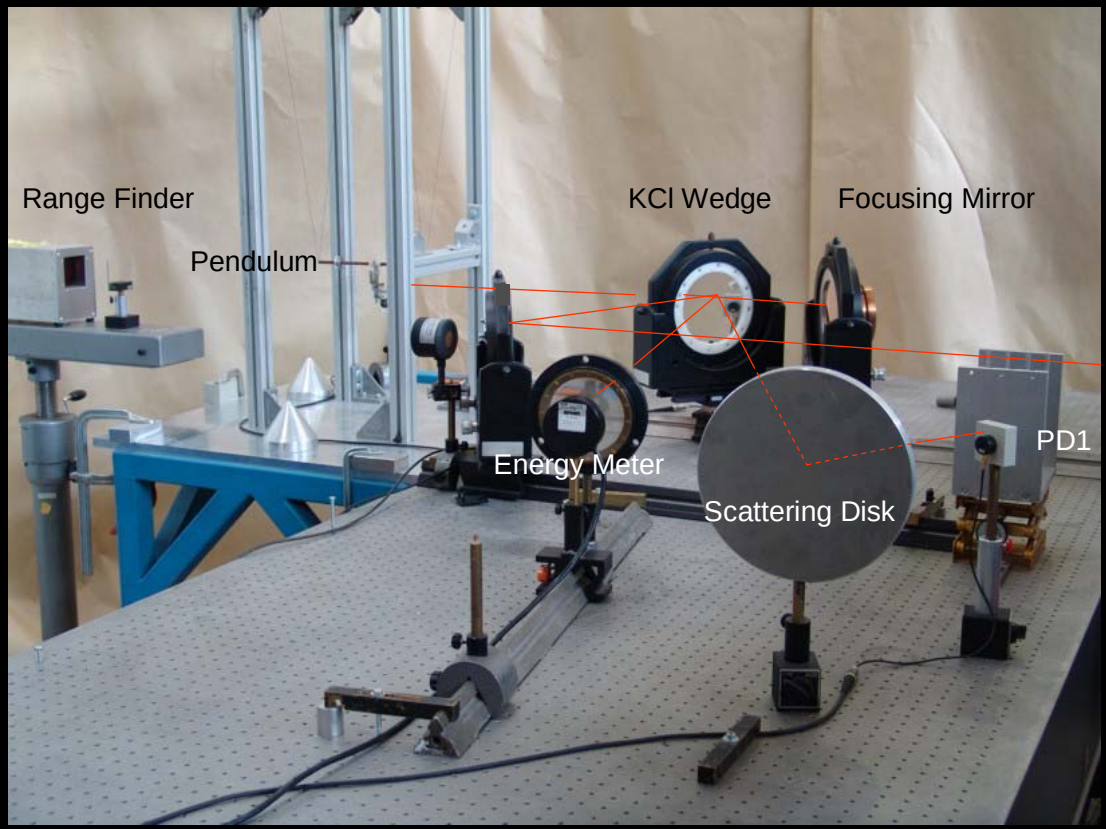
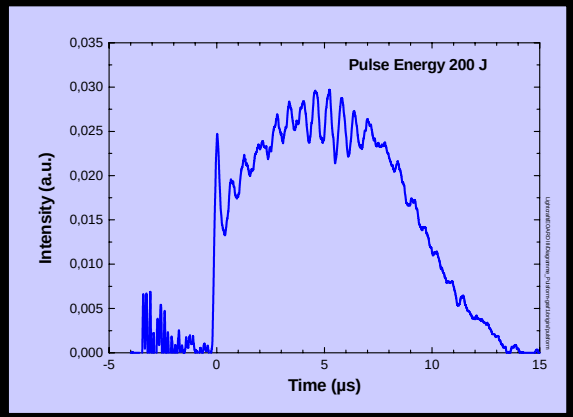
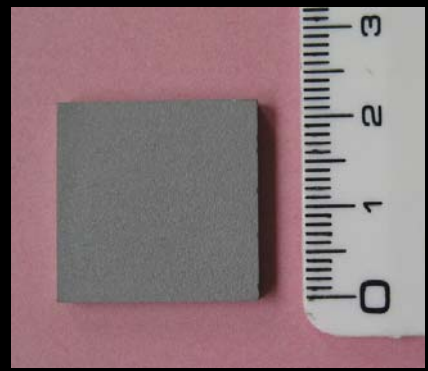


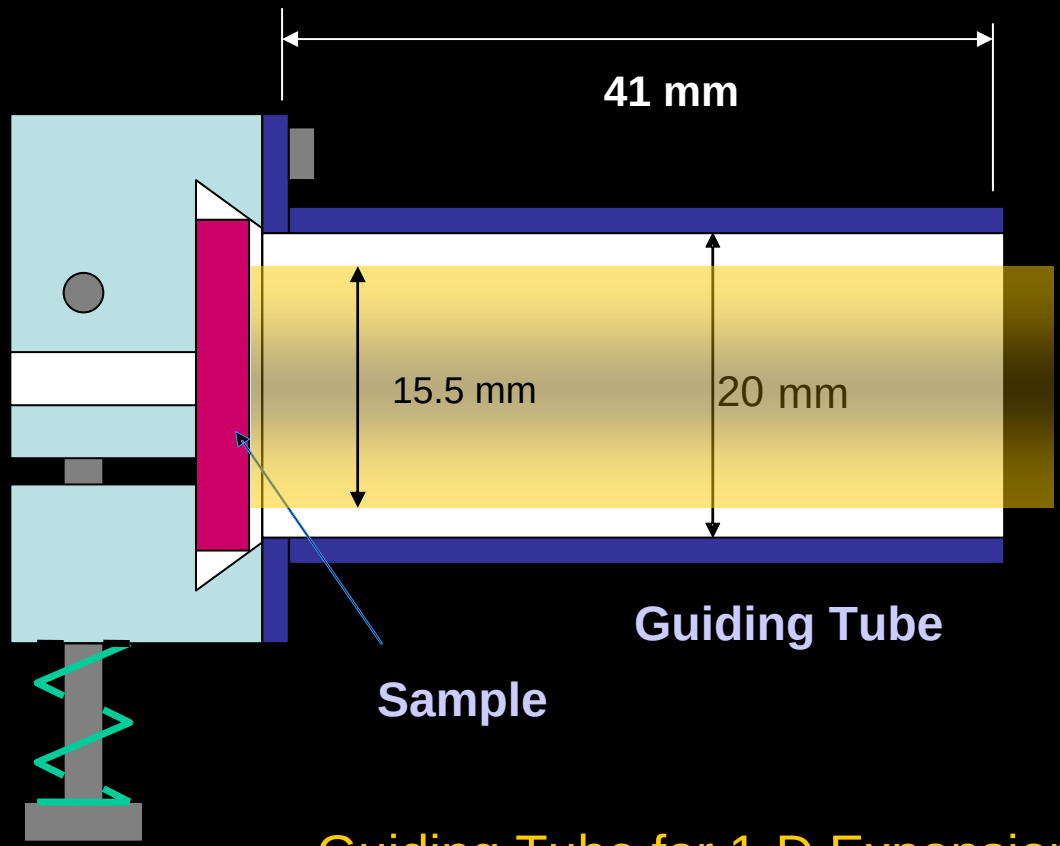
Laser Pulse Profile





Sample

SAMPLE HOLDER



Guiding Tube for 1-D Expansion

SAMPLE FORMULATIONS

POM = PolyOxyMethylene = Polyacetal = *Delrin*®

POM + Al	0, 20, 40, 60 % by wt.
Epoxy + Al	0, 3, 5, 10, 17, 30, 40, 50 % by wt.
Epoxy + Mg	0, 3, 5, 10, 17, 30, 40 % by wt.
Others:	Polybutadiene + Al, POM + Fe, POM + Ti

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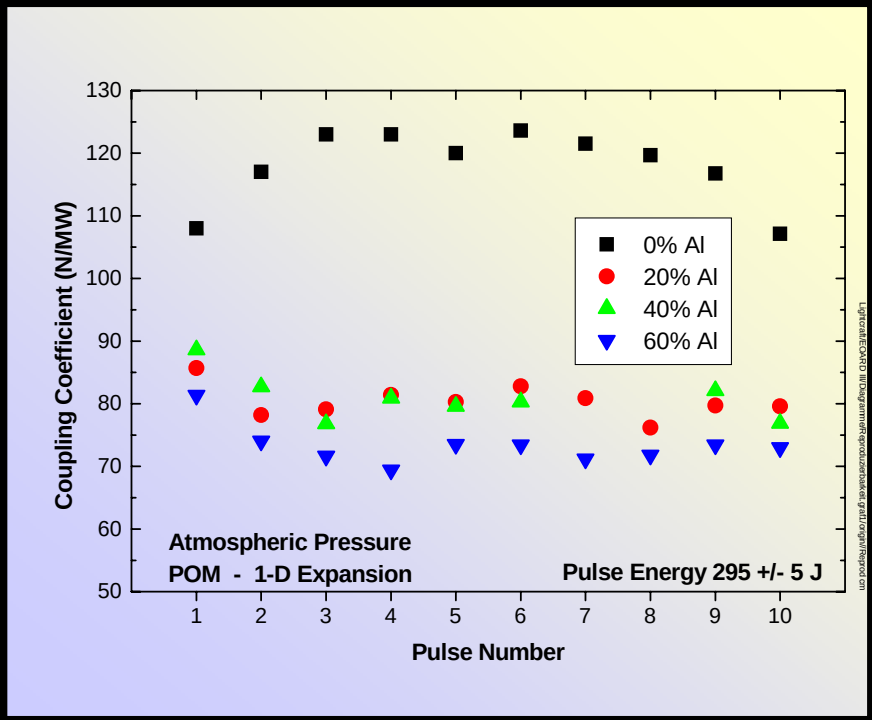
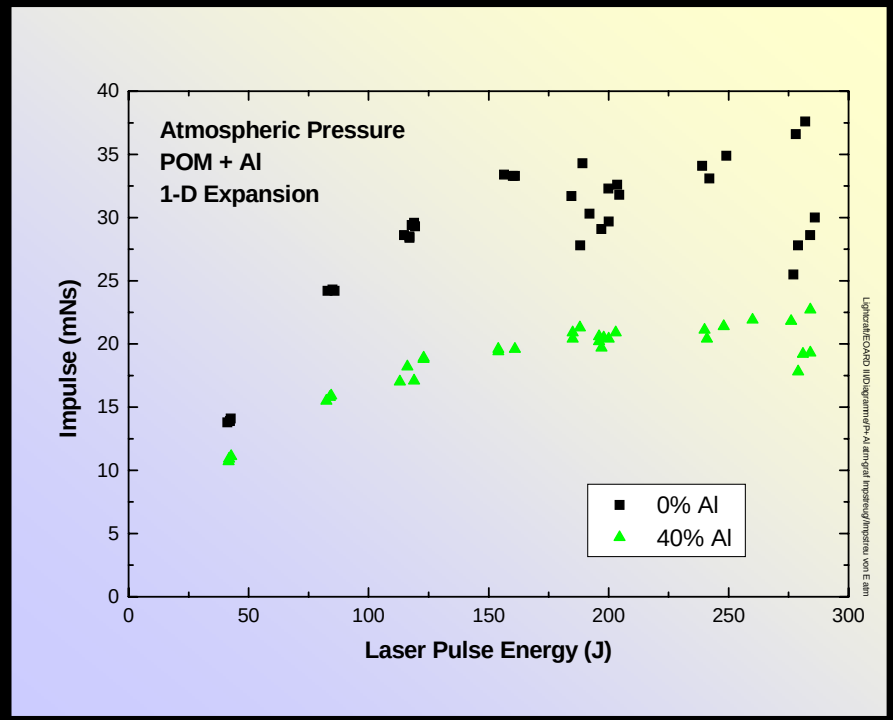
REPRODUCIBILITY

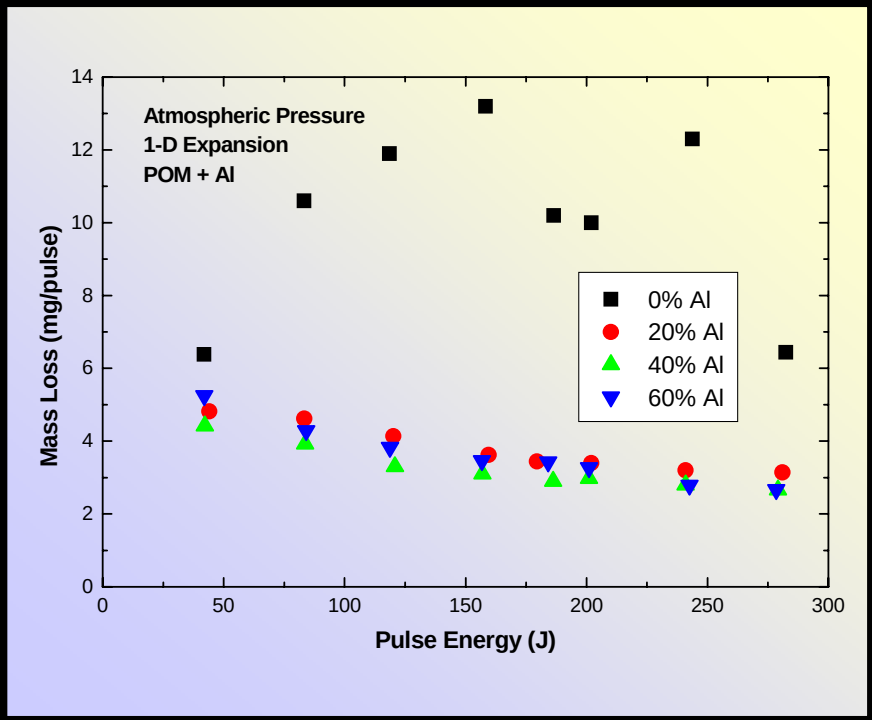


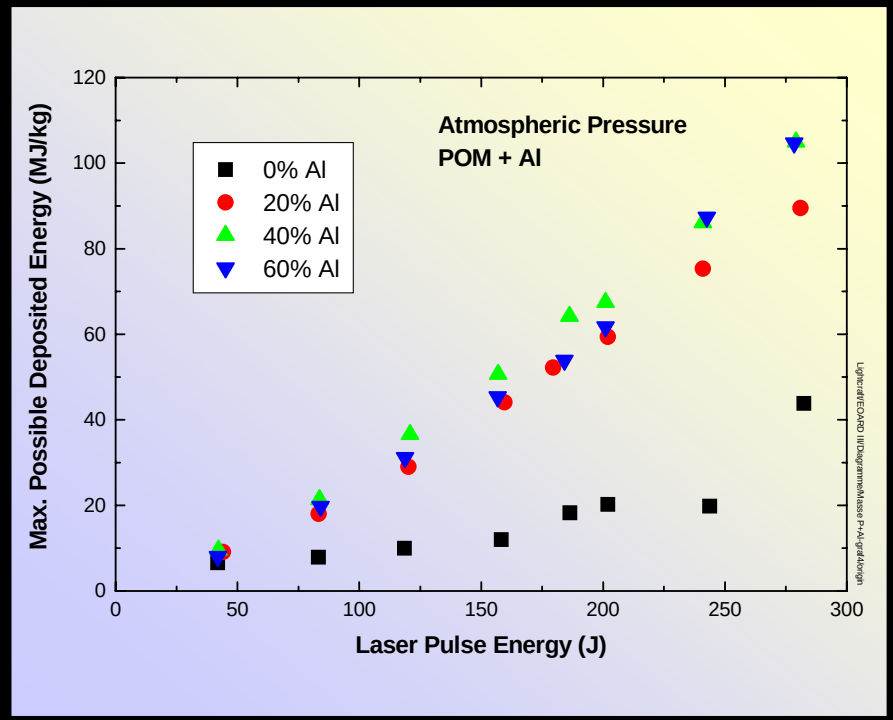


Shot to shot result on one sample

Scatter for individual shots

ABLATED MASS IN AIR



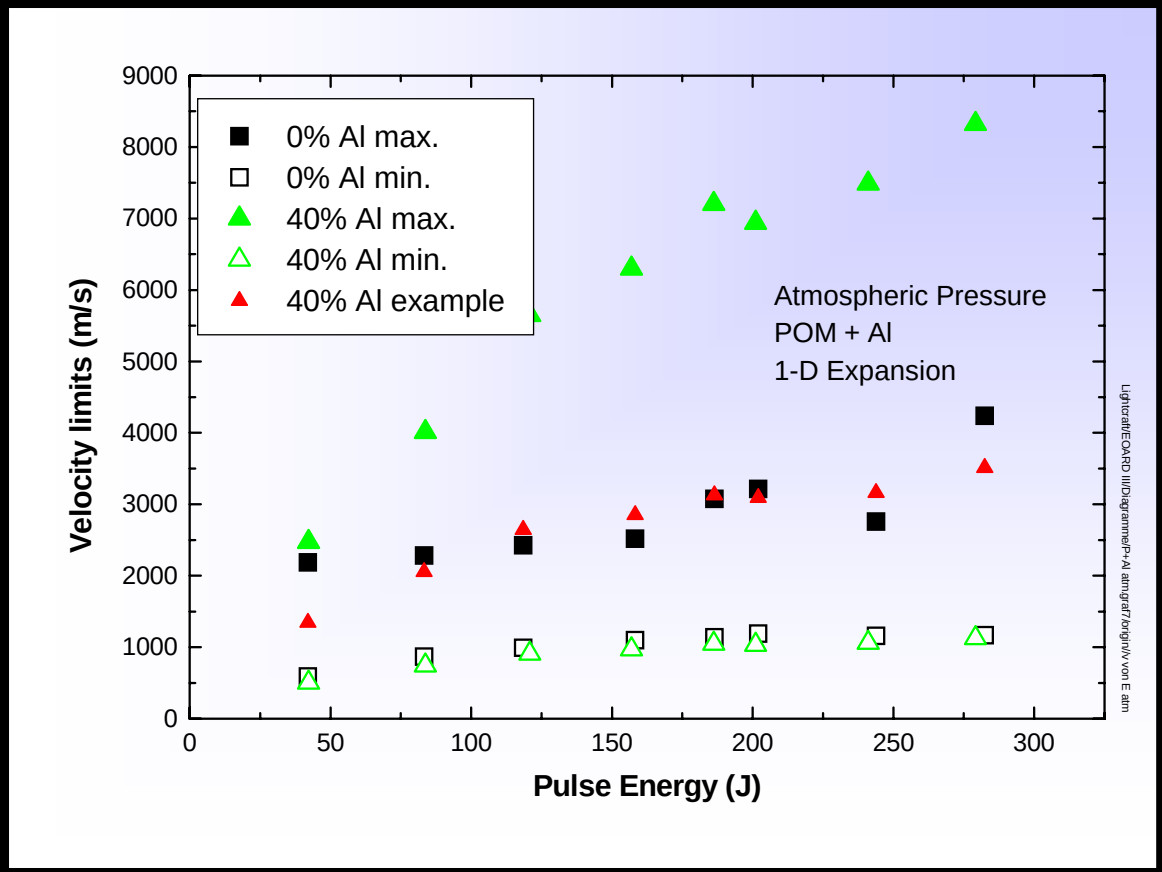


Ablated Mass vs. Pulse Energy

Apparent Deposited Energy

→ Upper limit

EXAMPLE: LIMITS TO THE VELOCITY



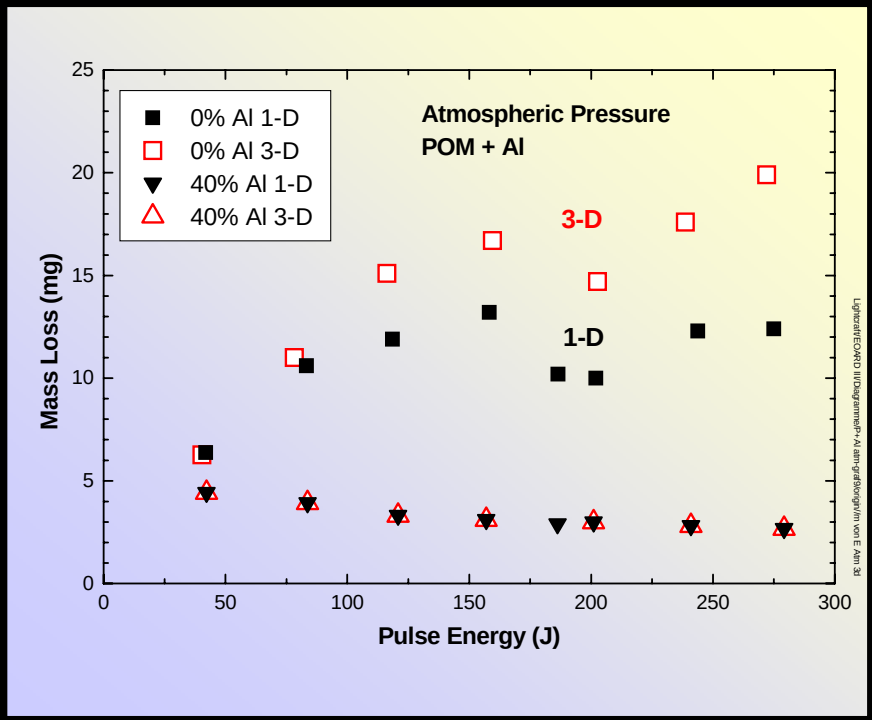
Upper Limit: 8500 m/s

No air exhausted

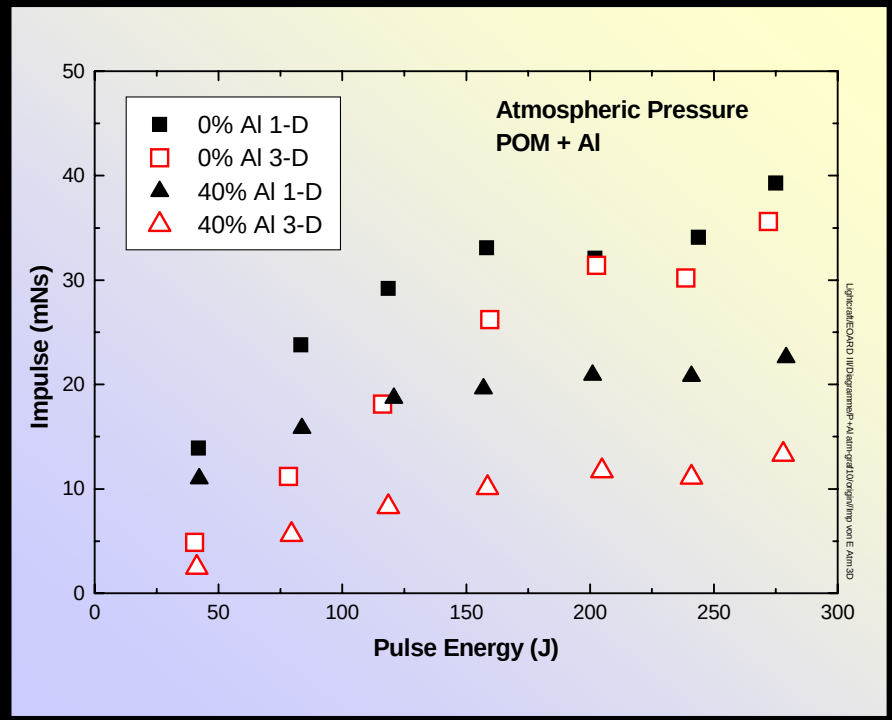
Lower Limit: 1200 m/s

All air in tube exhausted

3-DIMENSIONAL EFFECTS

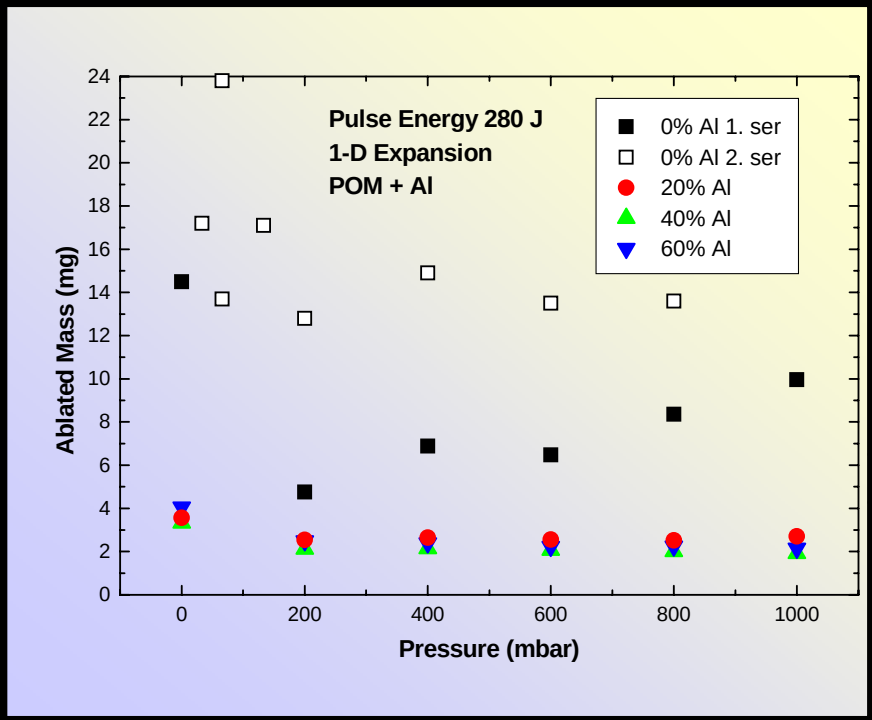


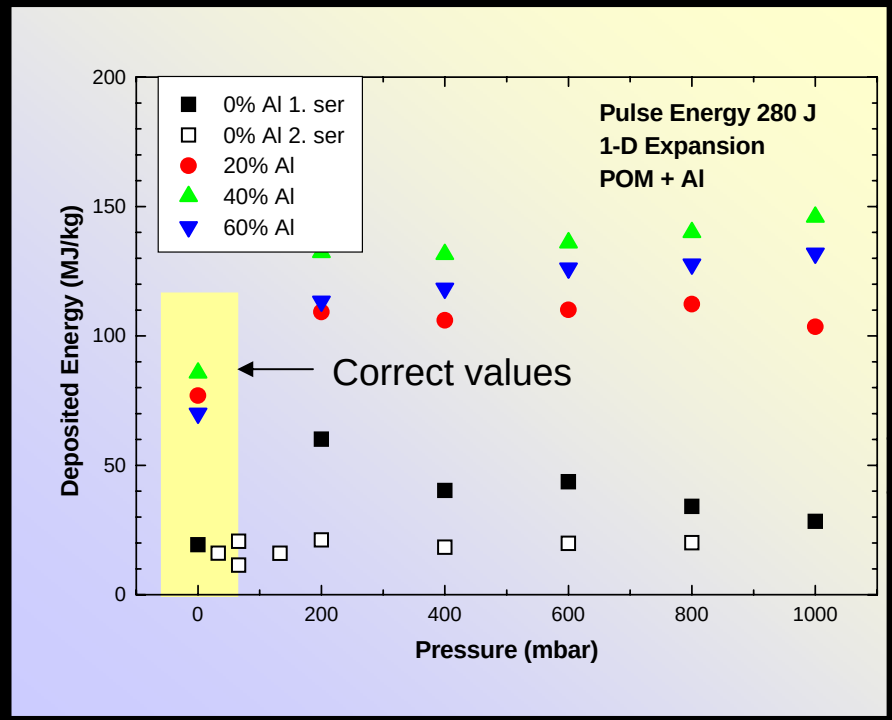
Mass Loss: 3-D vs. 1-D



Impulse: 3-D vs. 1-D

REDUCED PRESSURE



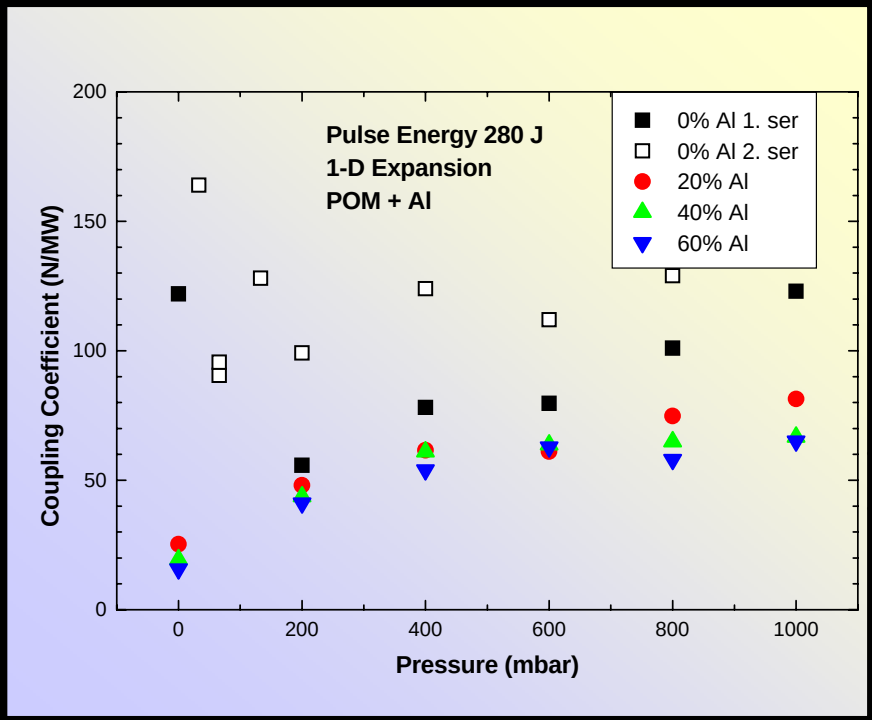


Ablated Mass vs. Pressure

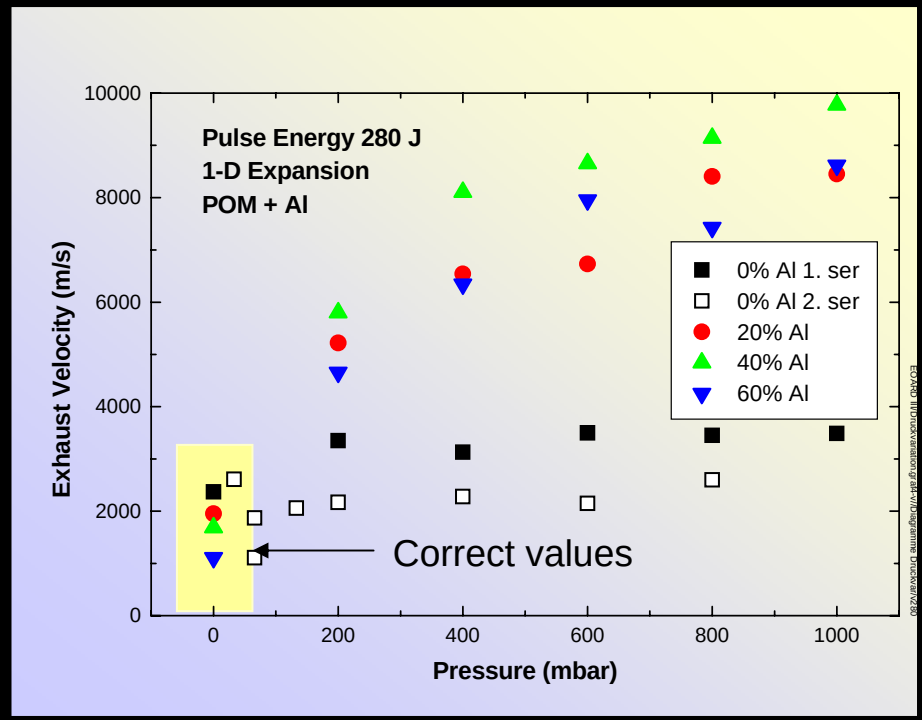
Apparent Deposited Energy

Correct only in vacuum

REDUCED PRESSURE



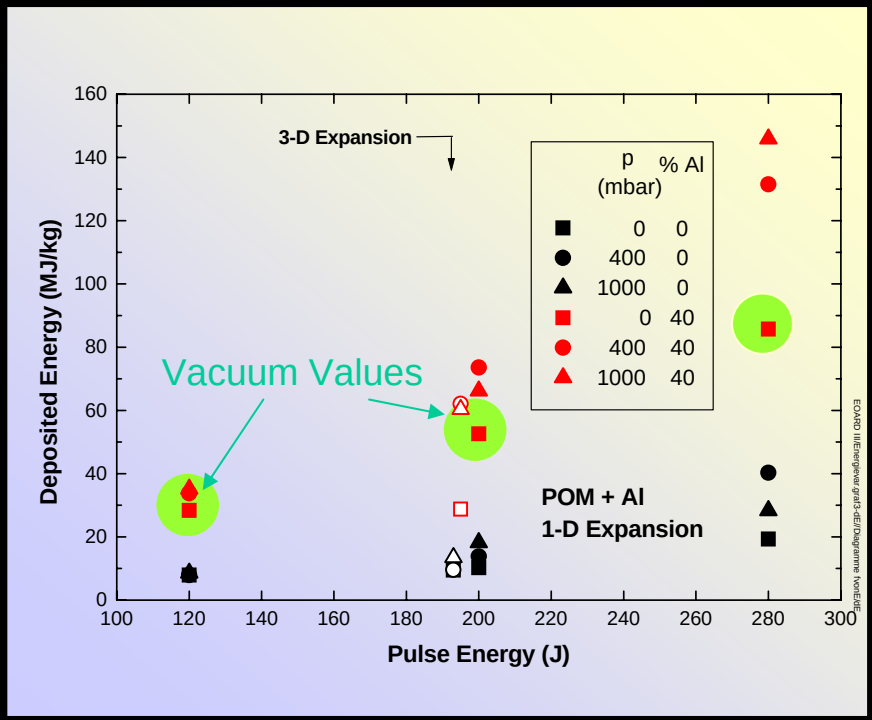
Coupling Coefficient vs. Pressure



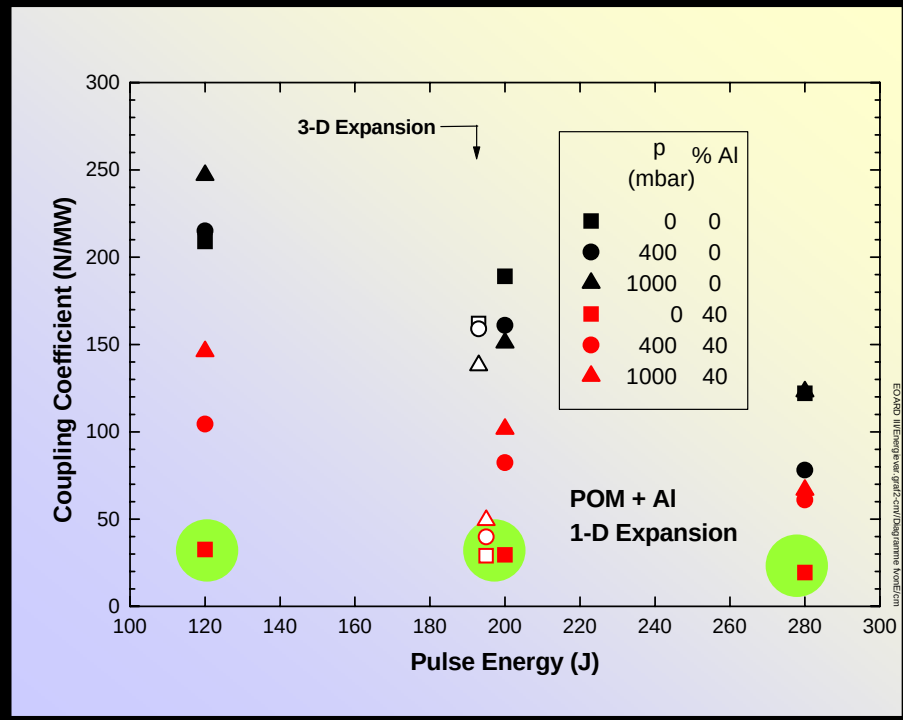
Apparent Jet Velocity

Jet Efficiency in vacuum < 0.03

REDUCED PRESSURE

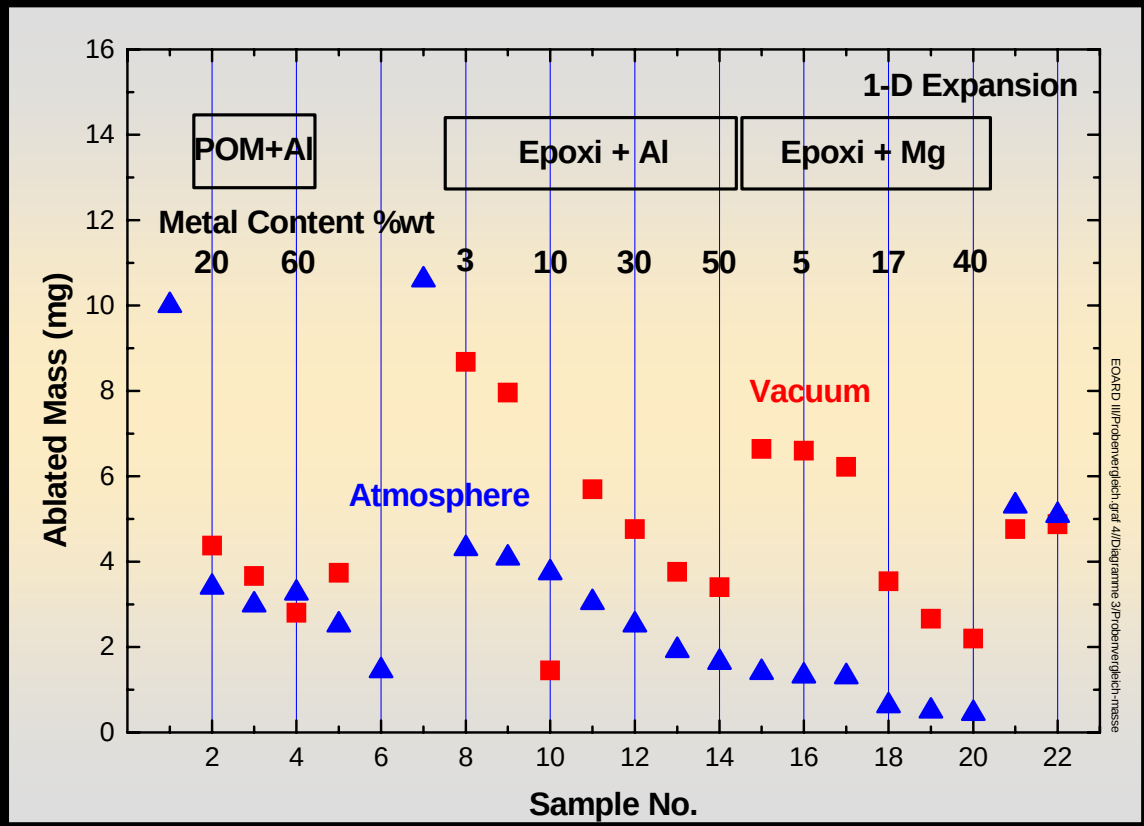


Deposited Energy vs. Pulse Energy



Coupling Coefficient vs. Pulse Energy

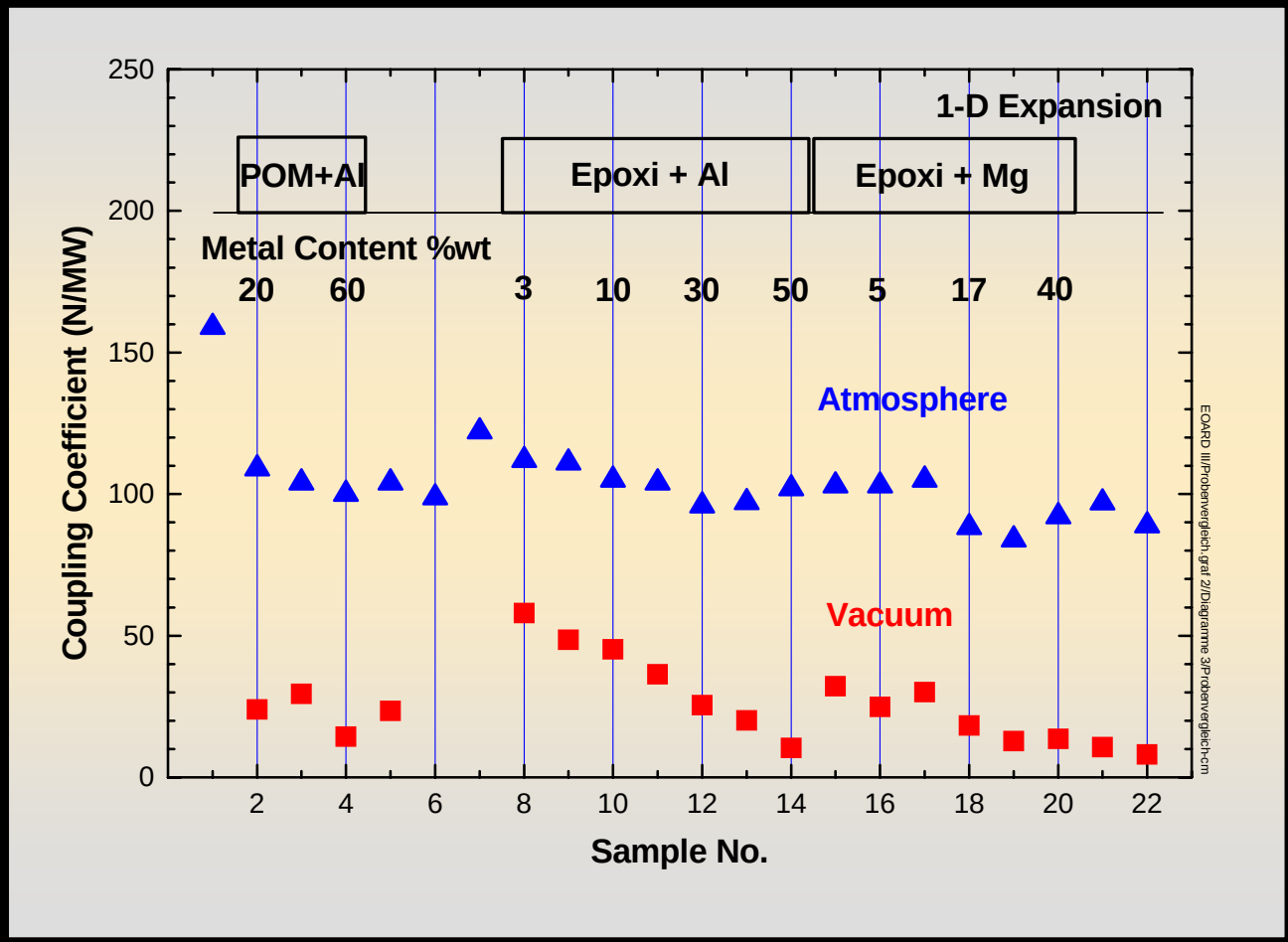
SAMPLE COMPARISONS - Ablated Mass



Pulse Energy
200 J

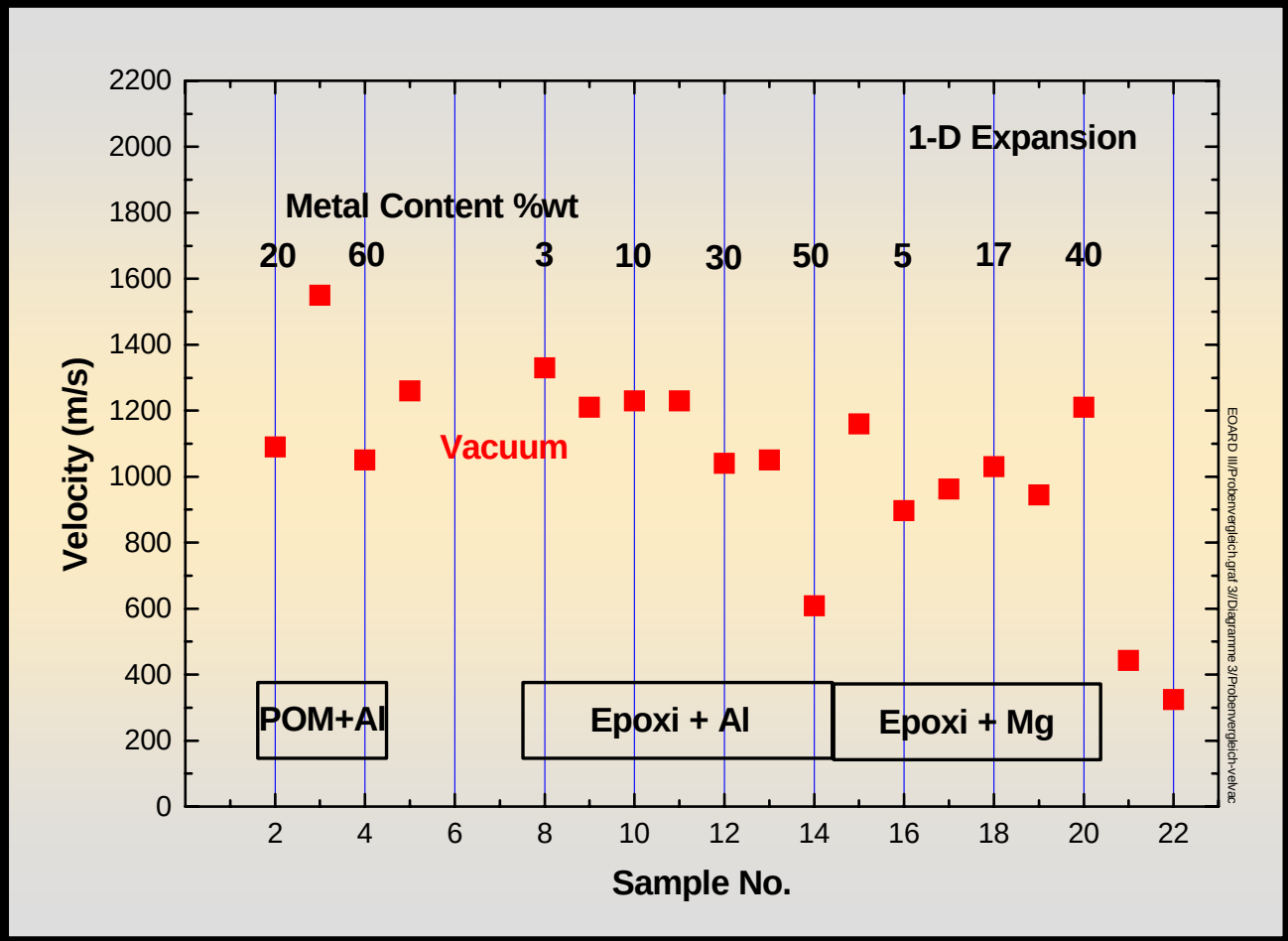
In Vacuum: Deposited Energy =
- 50 – 70 MJ/kg POM + Al
- 20 – 60 MJ/kg Epoxy + Al
- 30 – 90 MJ/kg Epoxy + Mg

SAMPLE COMPARISONS - Coupling Coefficient



Pulse Energy 200 J

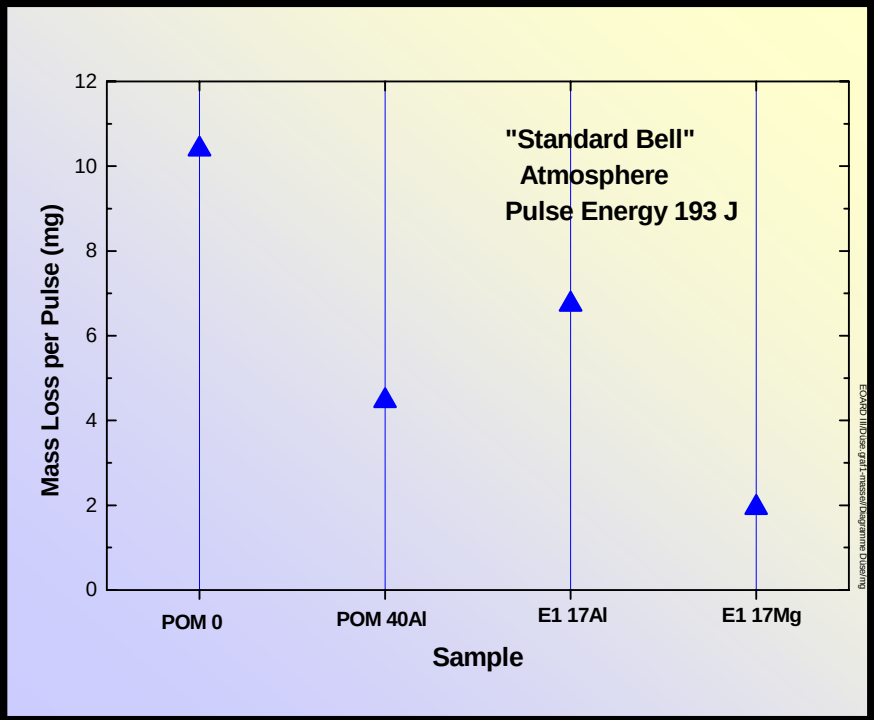
SAMPLE COMPARISONS - Jet Velocity

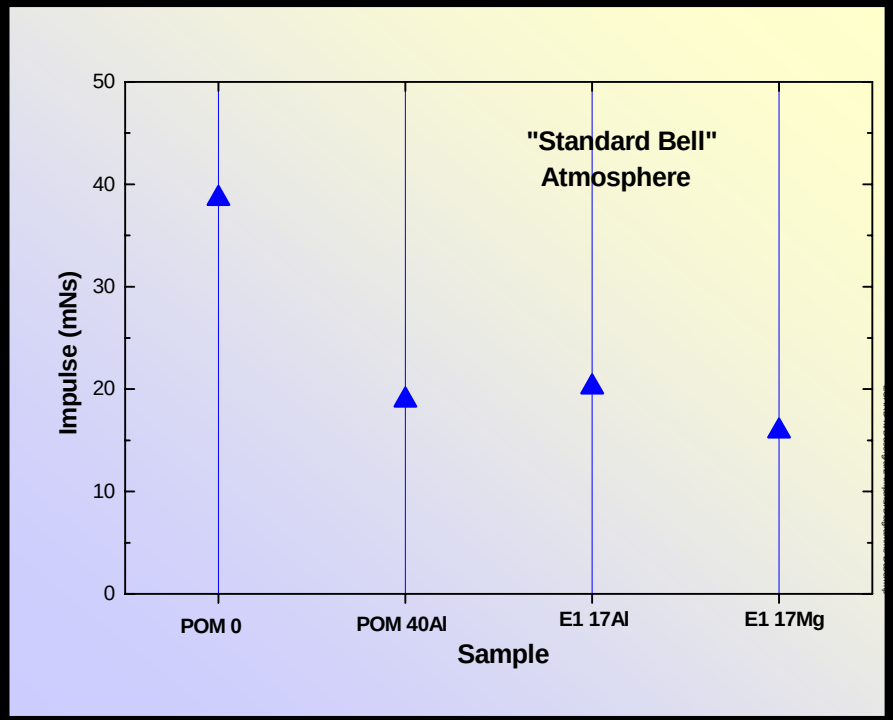


Pulse Energy 200 J

η < 0.03

COMPARISON WITH LIGHT CONCENTRATING STRUCTURE ("BELL NOZZLE") IN AIR – 200 J





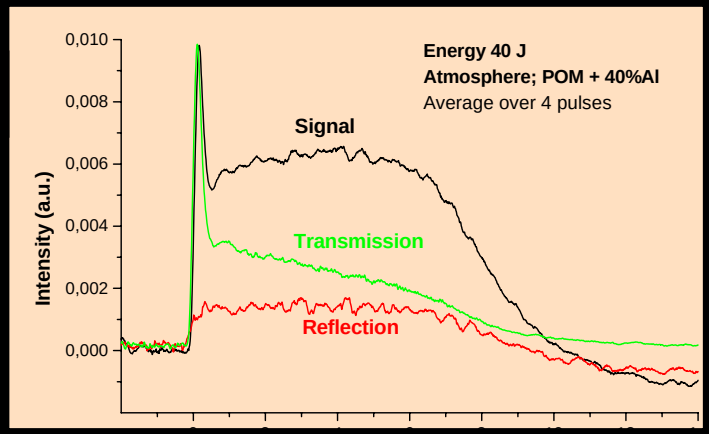
20 ... 50 MJ/kg **100 MJ/kg**
Apparent Deposited Energy

200 N/MW **100 N/MW**
Coupling Coefficient

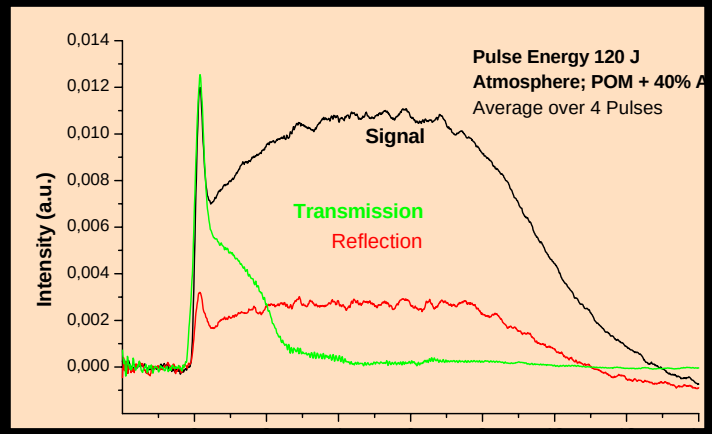
POWER PROFILES

POM + 40 % Al in air

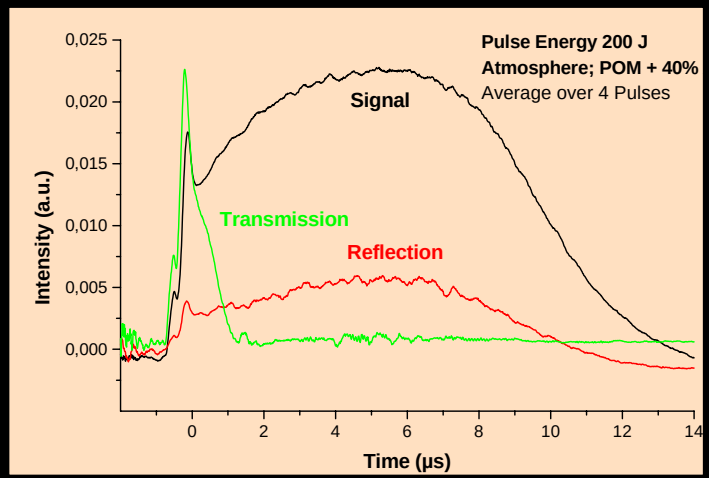
40 J



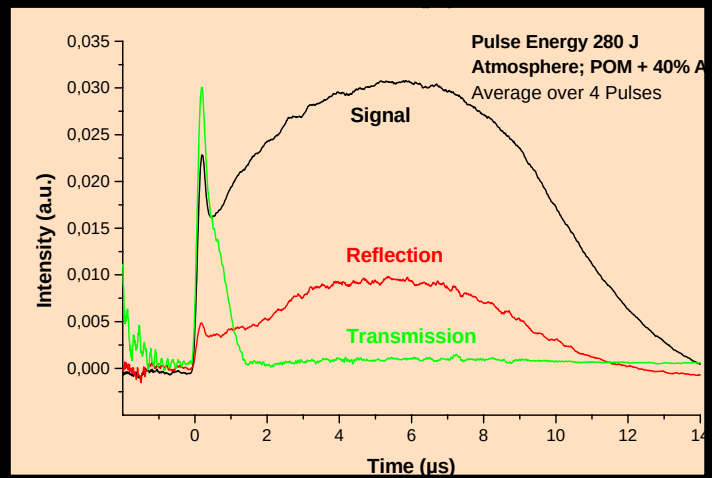
120 J



200 J



280 J



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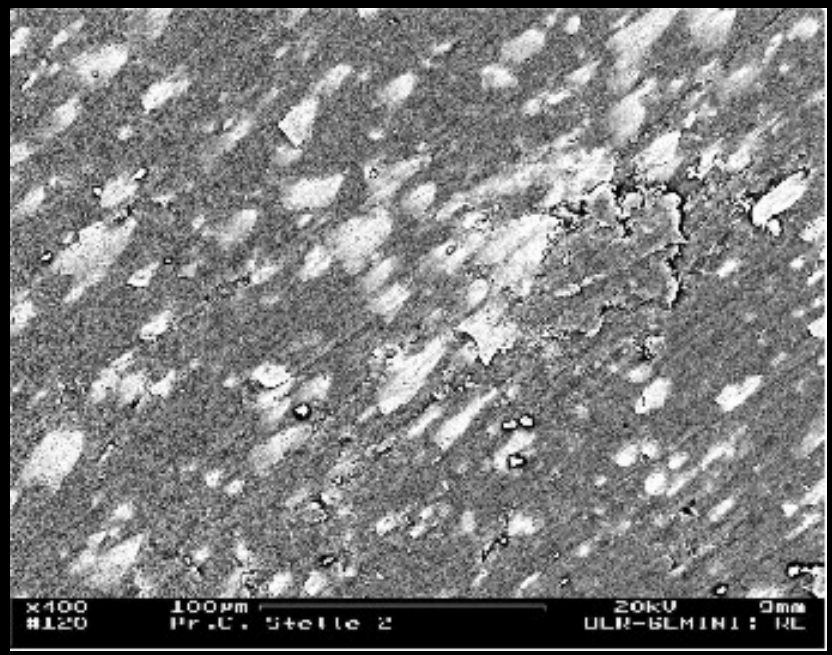
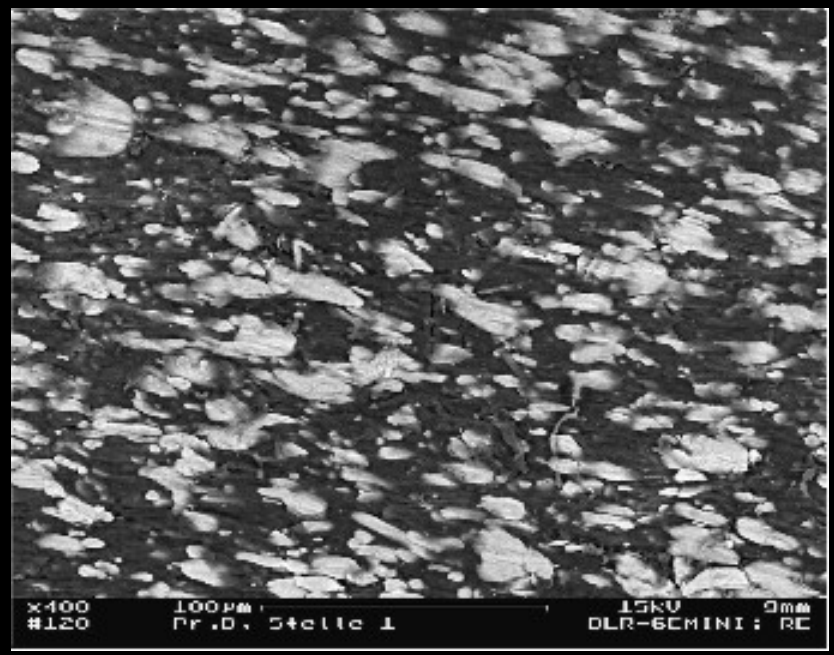
ELECTRON MICROSCOPE PICTURES

Before Laser Irradiation

RE-Mode





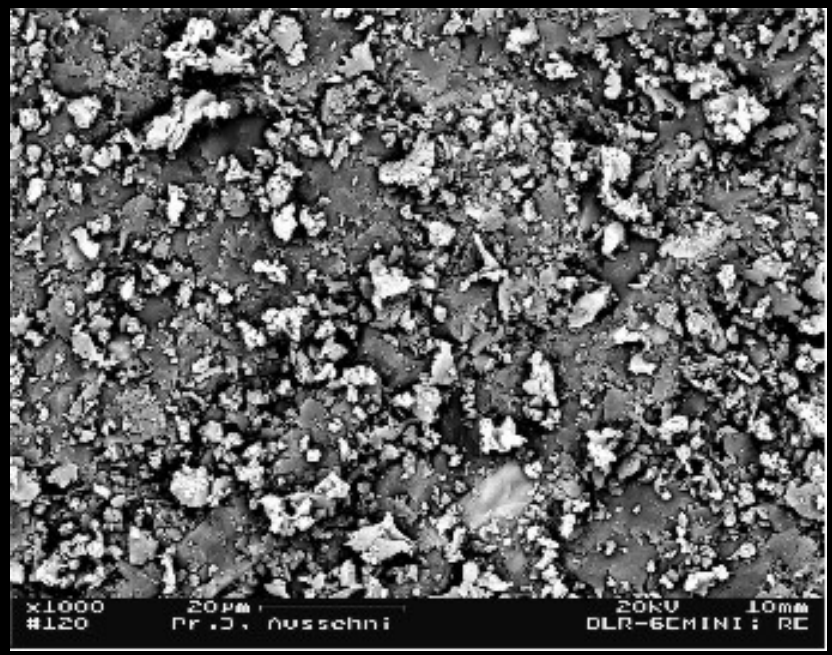
POM + 20 % Al **400x**

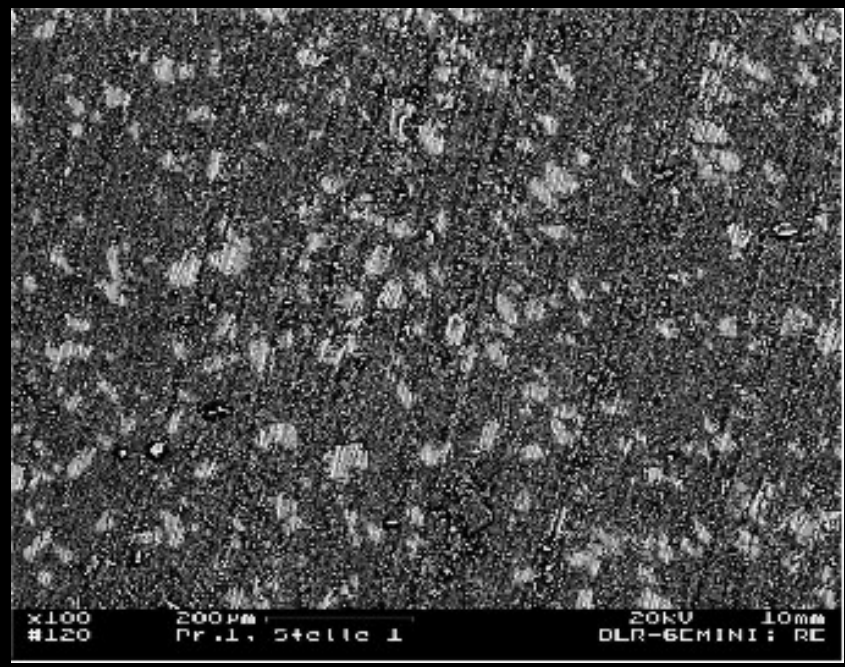
POM + 40 % Al **400x**

ELECTRON MICROSCOPE PICTURES

Before Laser Irradiation

RE-Mode





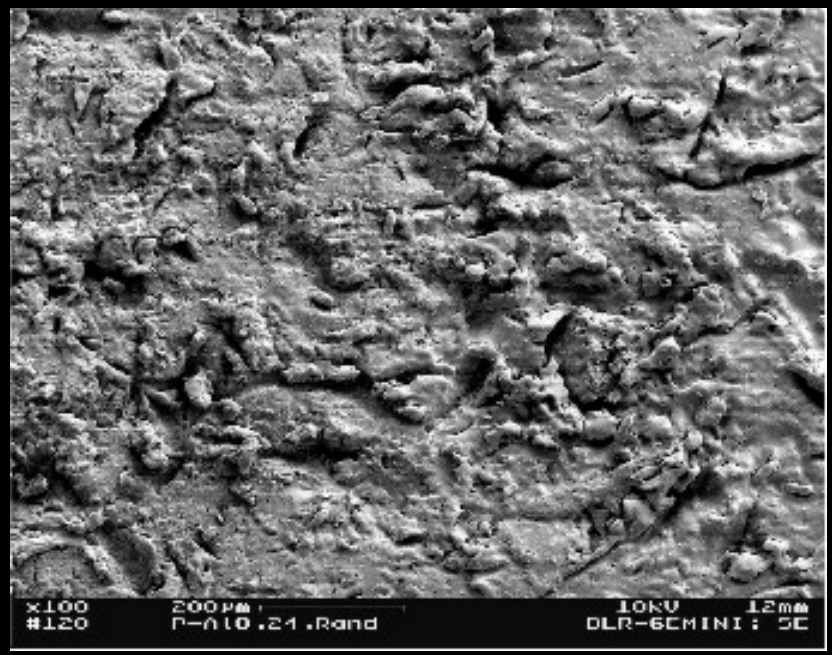
Epoxy + 17% Al 1000x

Epoxy + 17% Mg 100x

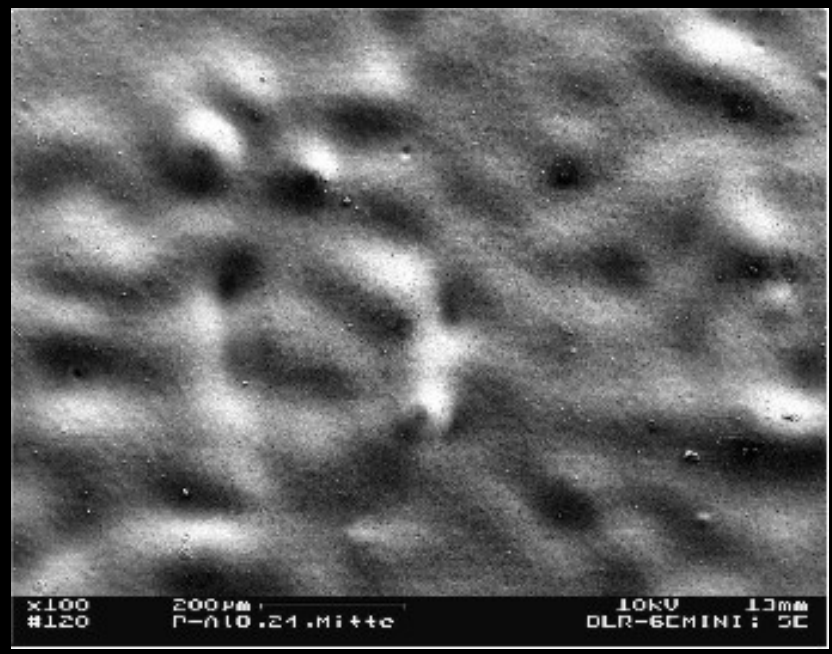
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation

SE-Mode



POM – edge 100x

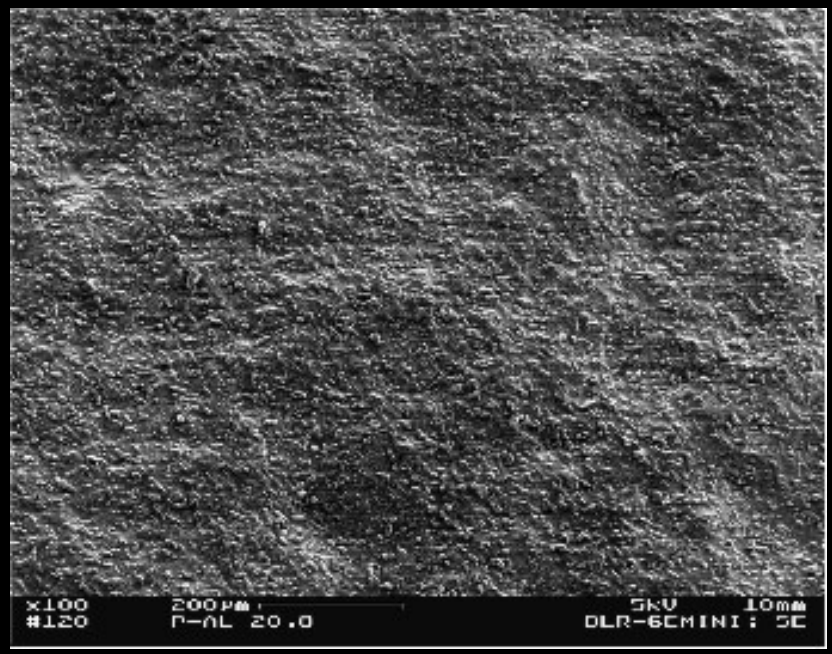


POM - center 100x

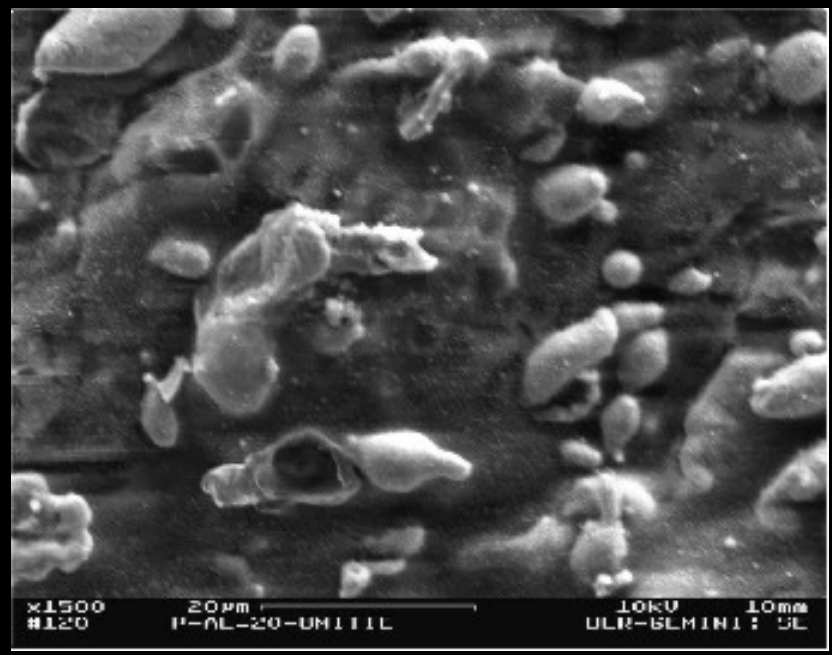
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation

SE-Mode 200 J vacuum



POM + 20 % Al - center 100x

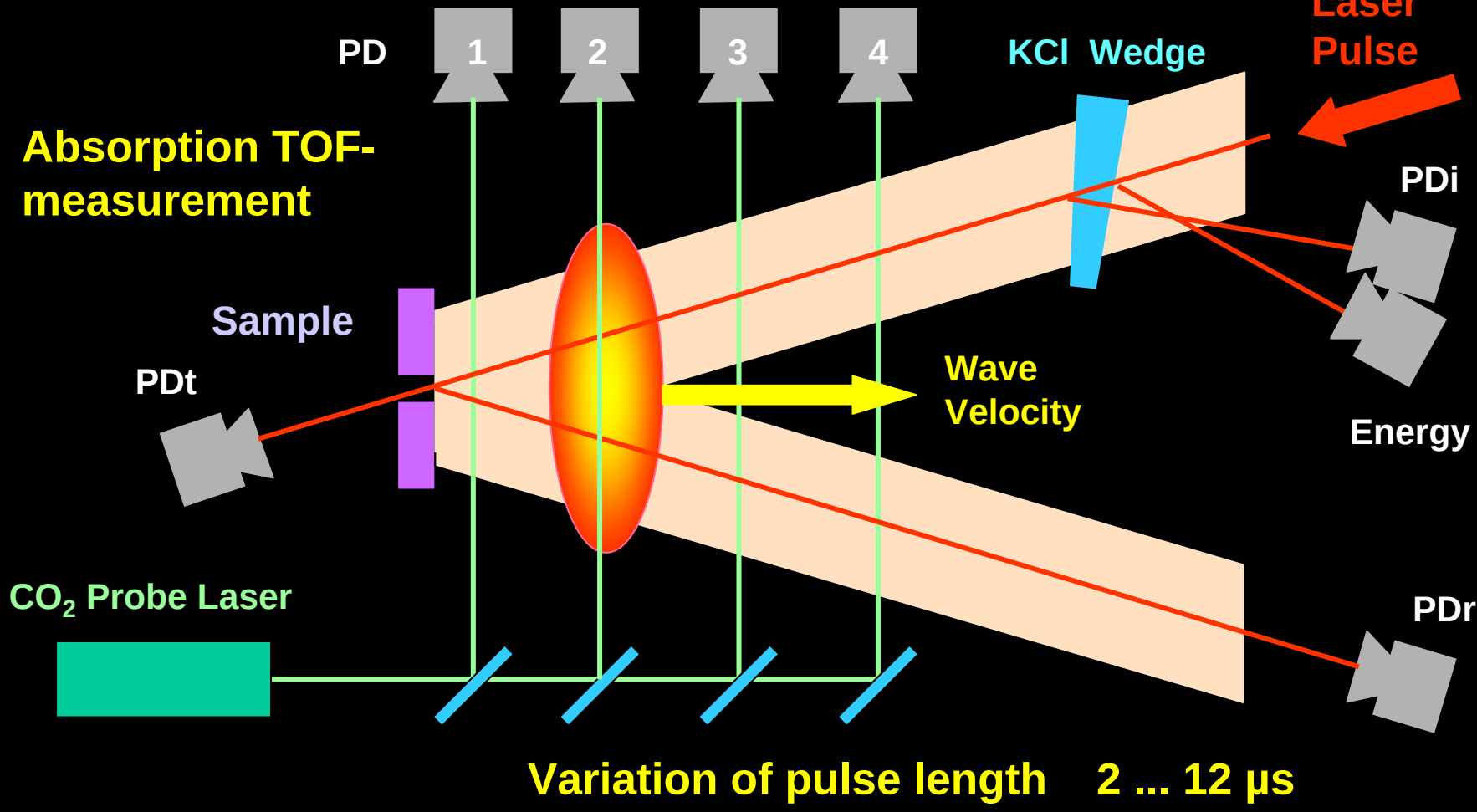


POM + 40 % Al 1500x

CONCLUSIONS

- Goals for I_s = 800 s not met
- In air → accelerated air fraction unknown
  → all related values are wrong
- In vacuum → deposited energy goes up with increasing metal fraction, but coupling coefficient decreases
- Strong evidence for large energy loss in a decoupled laser absorption wave
- Nature and characteristics of absorption wave need investigation
- Can shorter pulse lengths help prevent decoupling?

PROPOSAL FOR NEW EXPERIMENTS



Variation of pulse length 2 ... 12 µs

POM after laser irradiation 3000x