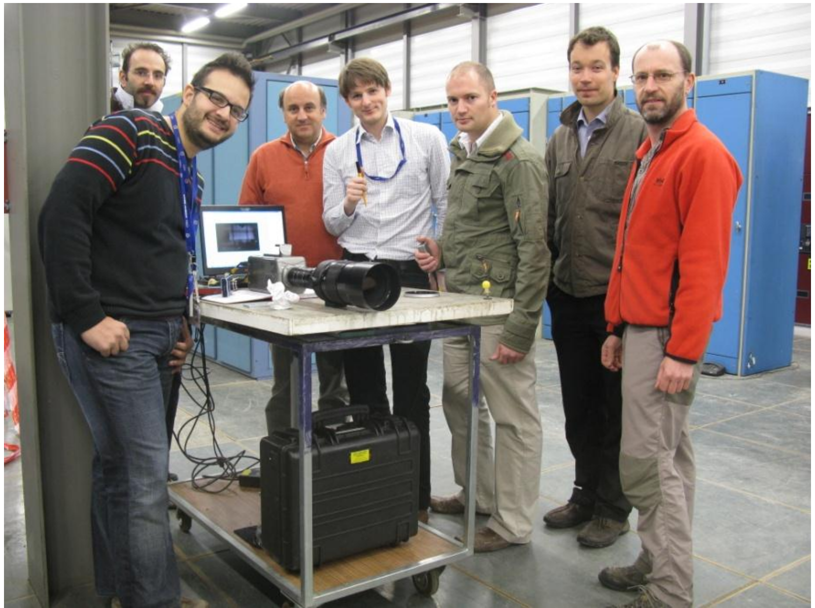
Simulations of Tungsten Powder Experiment at HiRadMat CERN

Tristan Davenne, Peter Loveridge, Joe O'Dell, Otto Caretta, Mike Fitton
& Chris Densham (High Power Targets Group, RAL)
Ilias Efthymiopoulos, Nikolaos Charitonidis (CERN)



High Power Targets

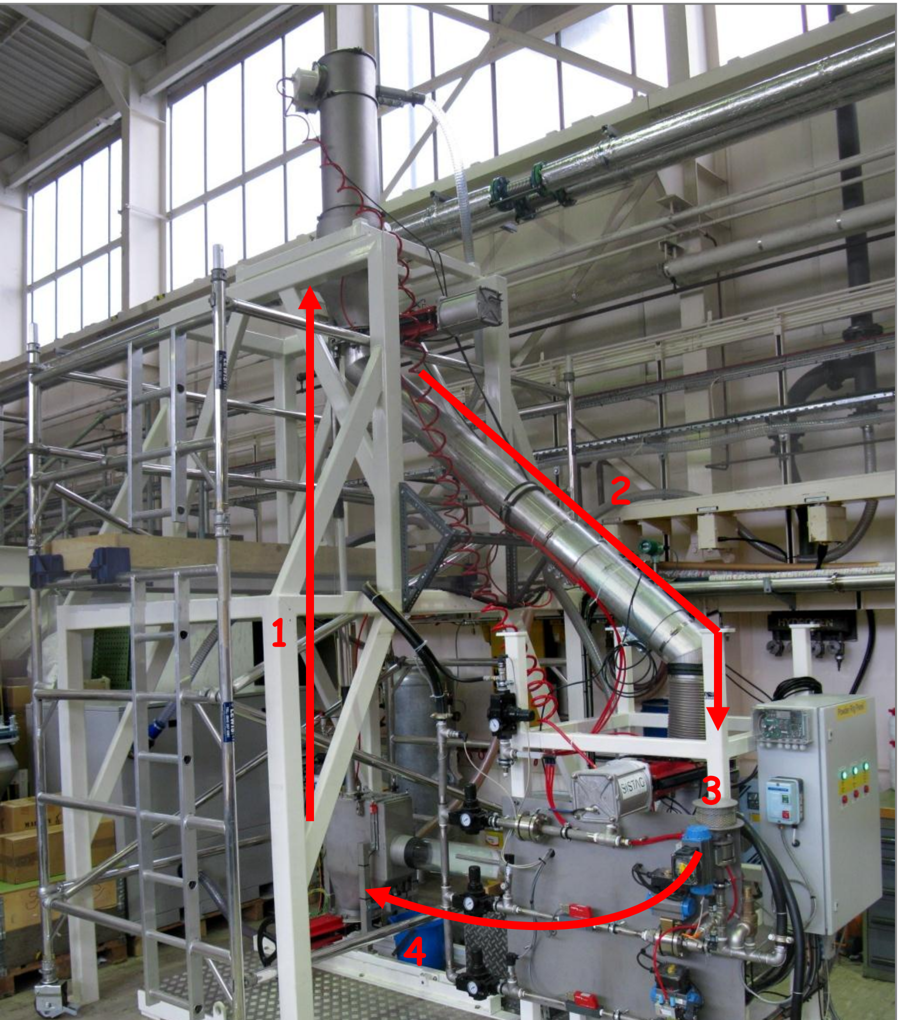
Science & Technology Facilities Council
Rutherford Appleton Laboratory

Fluidised tungsten powder target technology

- Pneumatically recirculated tungsten powder (use helium in online facility)
- A new generic target technology
- Potential solution for applications requiring highest pulsed beam powers on high-Z target material
- E.g. proposed as alternative to Neutrino Factory liquid mercury jet
- Technology has been demonstrated off-line in test rig at RAL
- HRM-10 first in-beam experiment

High Power Targets

Fluidised tungsten powder test rig flow regimes

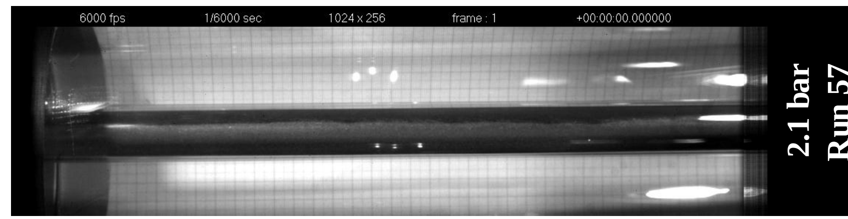


1. Suction / Lift
2. Load Hopper
3. Pressurise Hopper
4. Powder Ejection and Observation

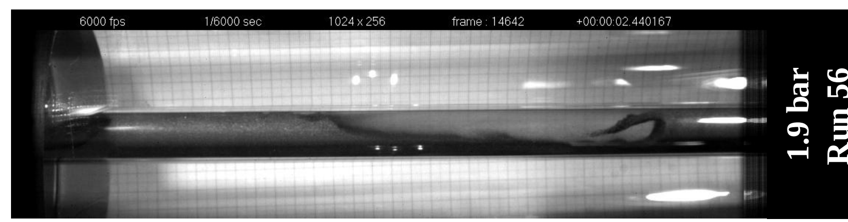
A. Lean Phase: done

- Low fraction of solid material
- High velocity -> potential erosion
- Used in (1) vacuum recirculation line

B. Continuous Dense Phase: done



C. Discontinuous Dense Phase: done



D. Solid Dense Phase: not done yet

Pipeline full of material, 50% v/v
Low velocity
Not yet achieved in test rig – > future work

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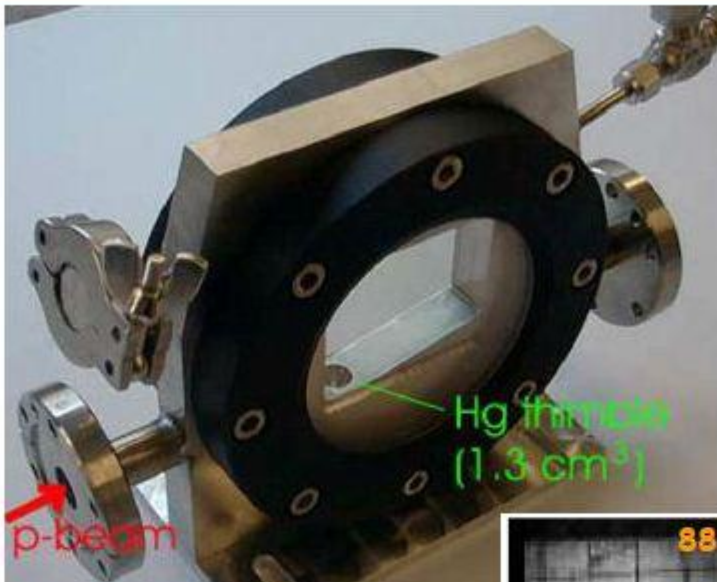
Objective: Replicate mercury thimble experiment for tungsten powder

ISOLDE Hg-thimble test

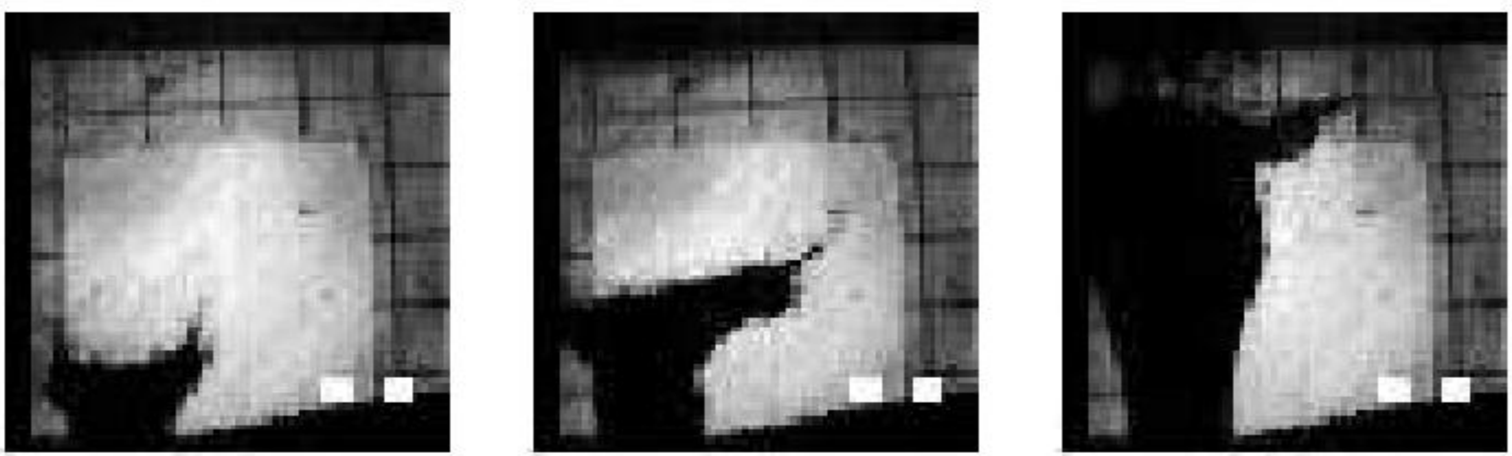
A. Fabich, M.Benedikt, J. Lettry



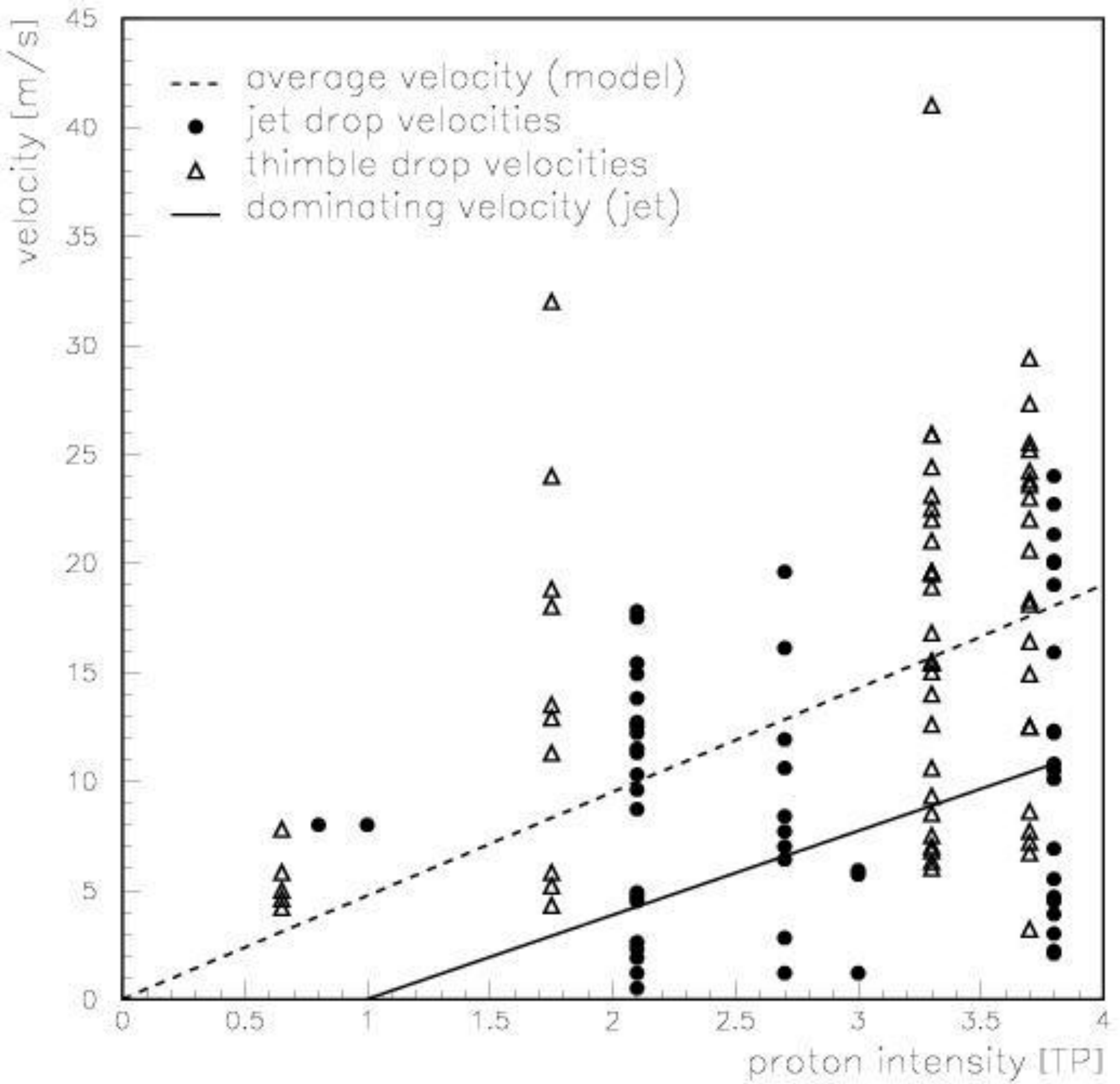
Hg-thimble set-up. Two quartz windows make it possible to view the p$^+$-Hg interaction process.

The Hg receptacle consists of a half sphere (r = 6mm), a vertical cylinder (r = h = 6mm), and a meniscus .The mercury has a free surface, where it can expand into an atmosphere of 1 bar Argon.

The Hg interaction with 1.4 GeV, 4 10^{12} p$^+$ is shown below.



Mercury thimble velocity results vs proton intensity (Fabich, Benedikt, Lettry)



Tungsten Powder Sample and Holder

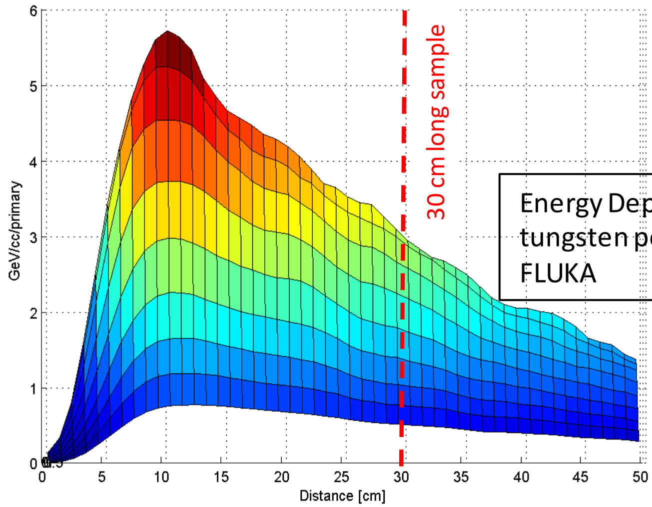


Figure 1 Energy deposition in a tungsten-helium compound (50% vol for each component)

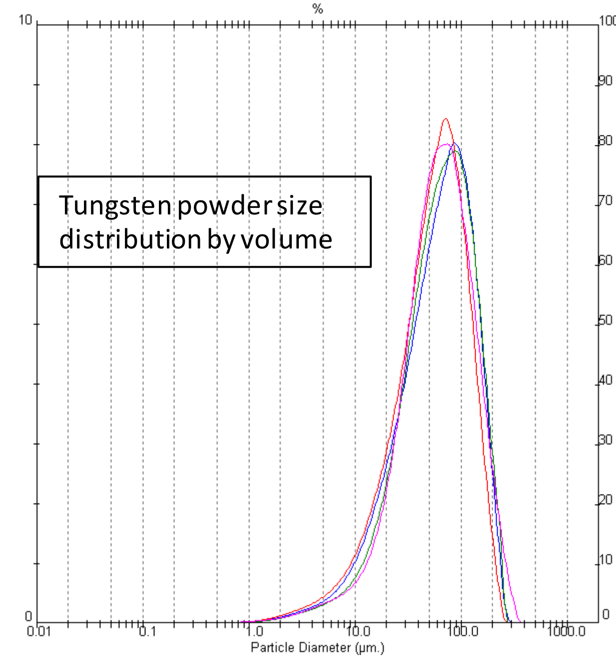
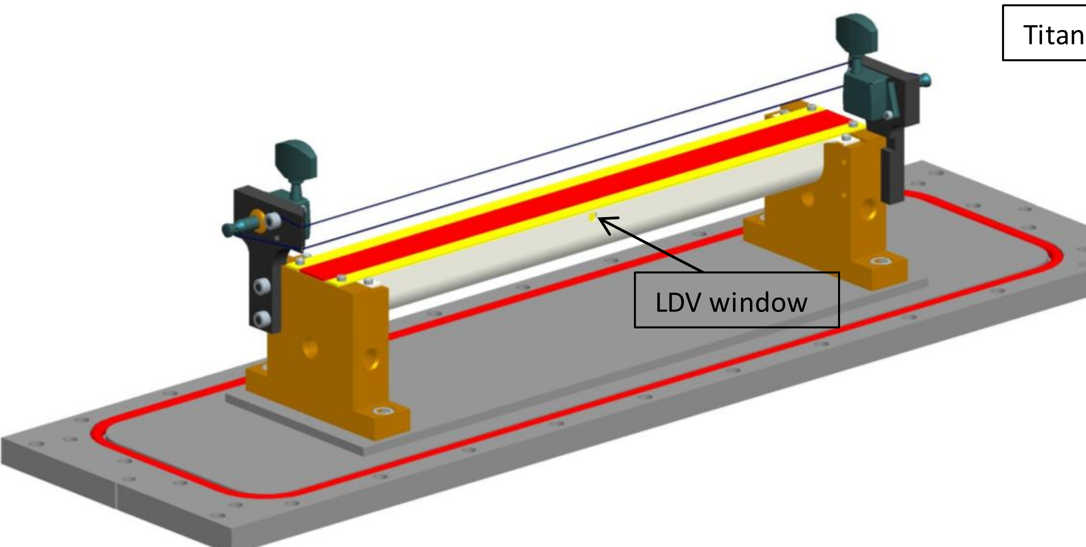
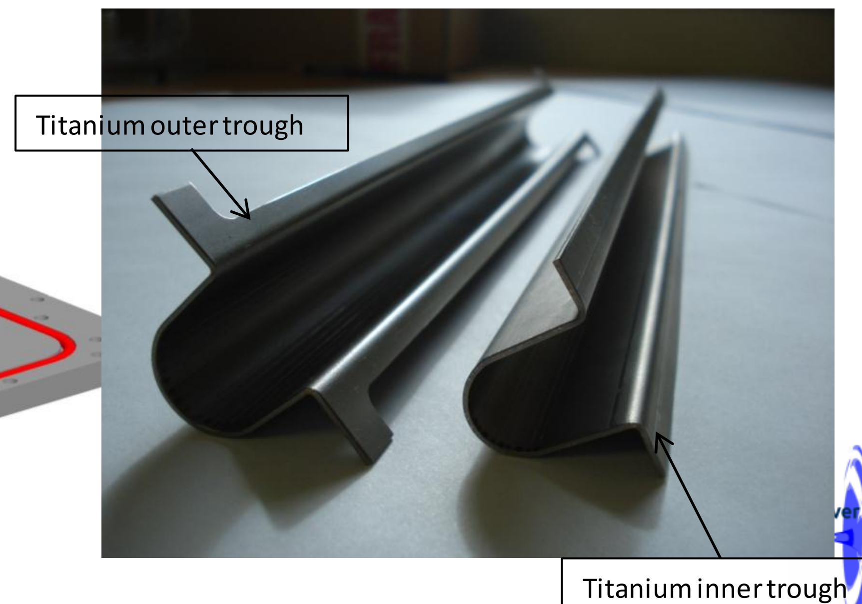


Figure 1. Variation of size distribution for different stirrer





Powder response questions for experiment

1. Is force propagation through the powder negligible?
2. How severe is beam induced gas expansion as a mechanism for eruption?

Proposed beam Induced gas expansion mechanism:

- Beam interaction causes sudden heating of powder sample
- Gas pressure rises as a result of rapid heating
- Gas expands and escapes through powder to the surface
- If temperature and pressure is high enough particles can be lifted by aerodynamic force applied by the escaping gas
- It was postulated that a threshold exists for powder eruption

  -below which the expanding gas escapes without disrupting the powder

  -above which the expanding gas lifts powder grains as it escapes through the powder

Experiment design

- Double-walled trough of tungsten powder
- High speed camera can view powder eruptions from surface
- Laser Doppler Vibrometer can measure vibrations of inner and outer container
  - \> Possible to differentiate between effect of powder on wall and secondary heating effects
- Same powder size distribution as used in test rig

CFD Model used to simulate mechanism

- Ansys CFX v13 & v14
- Inhomogeneous two phase model – Helium Ideal gas & Tungsten dispersed solid spheres
- Interphase drag force – Gidaspow
- Heat transfer between phases – Hughmark
- Gravity - y direction
- Initial condition for powder sample – 50% tungsten, 50% helium by volume

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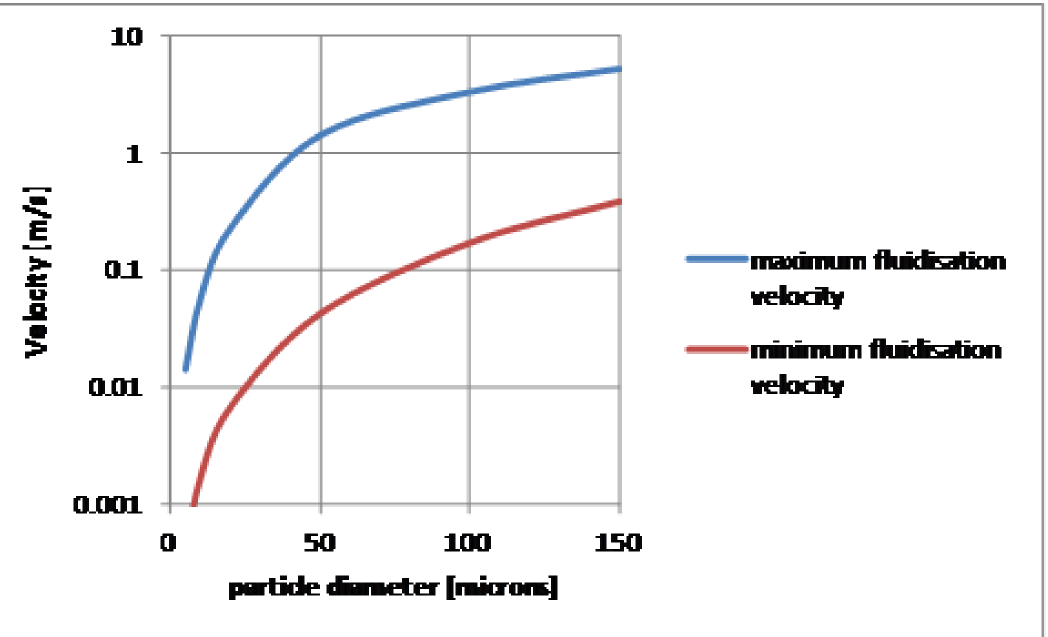
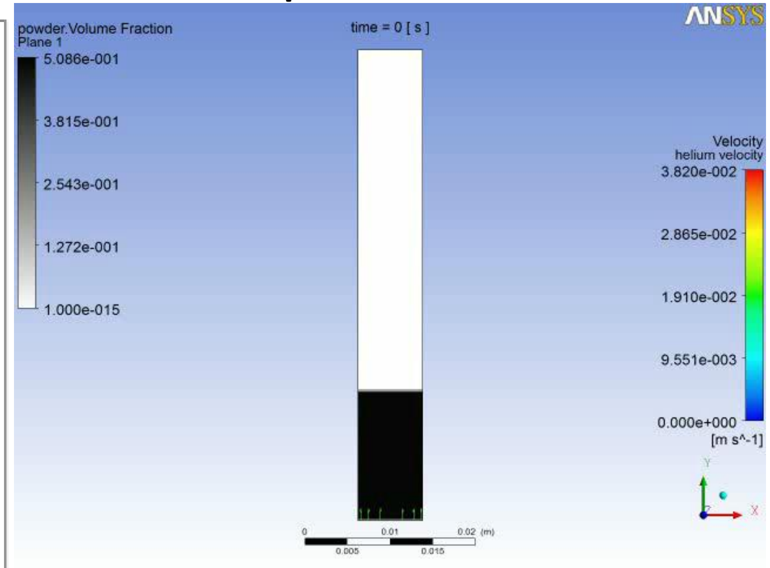
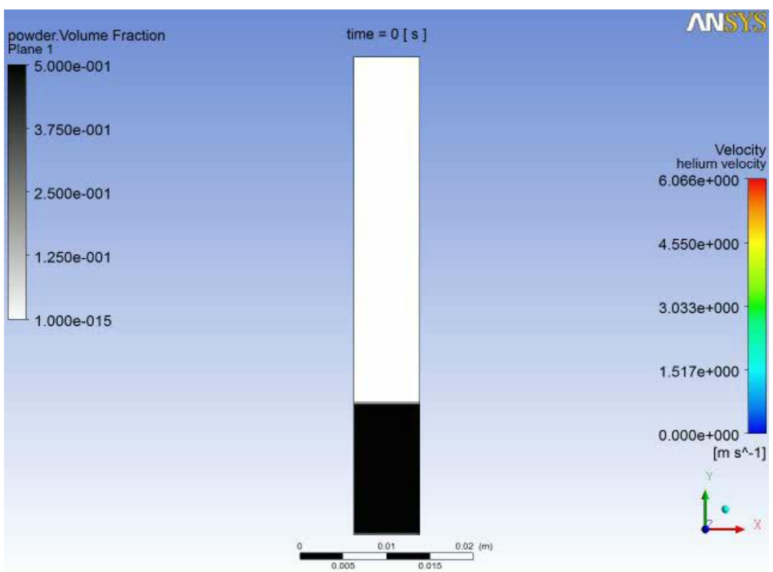
Fluidisation theory and CFX model for 50 micron particles in helium

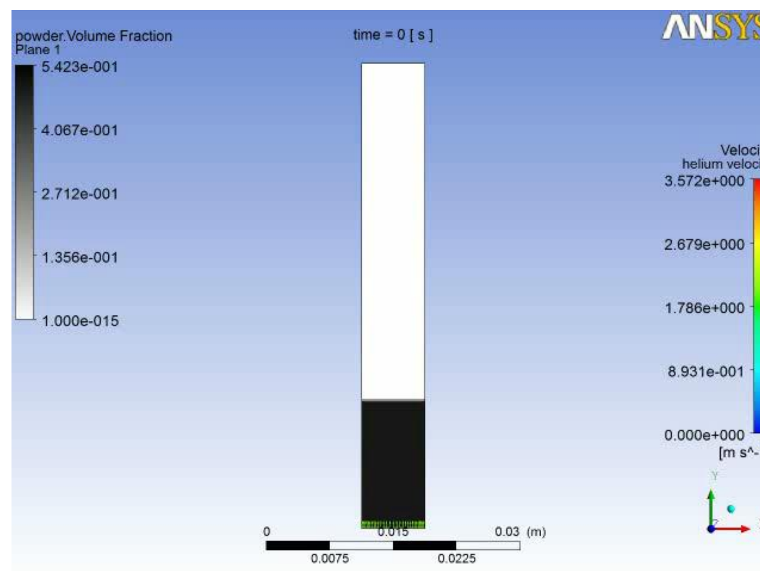




Vertical velocity =0.02m/s



Vertical velocity =0.2m/s



Vertical velocity =2m/s

CFD simulations used to predict threshold prior to experiment

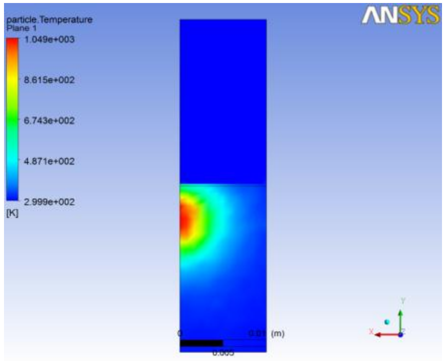


Figure 1 Example of Temperature jump in the powder

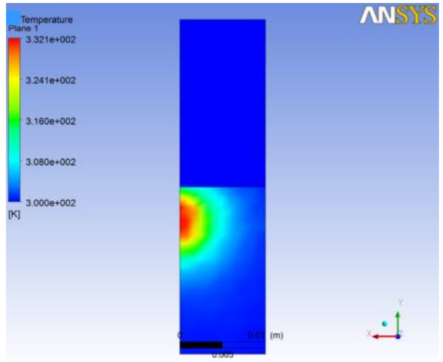


Figure 2 Example of temperature jump in the helium

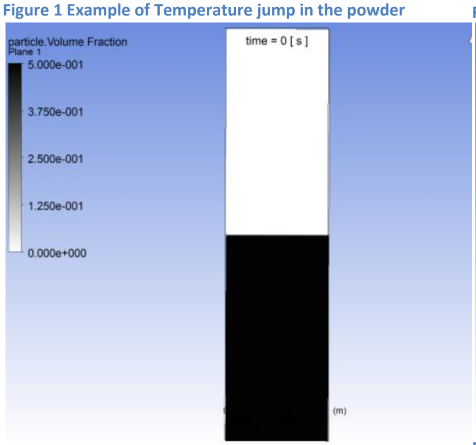


Figure 3 Tungsten powder volume fraction at time=0

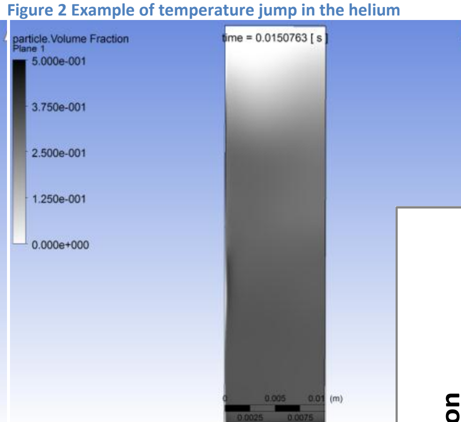
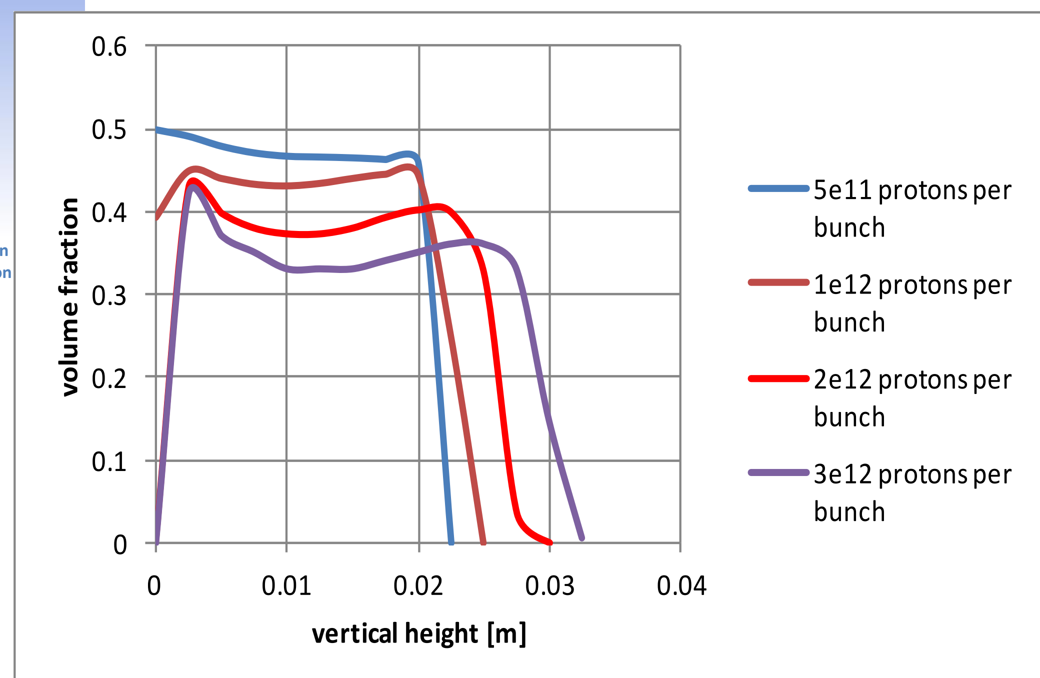


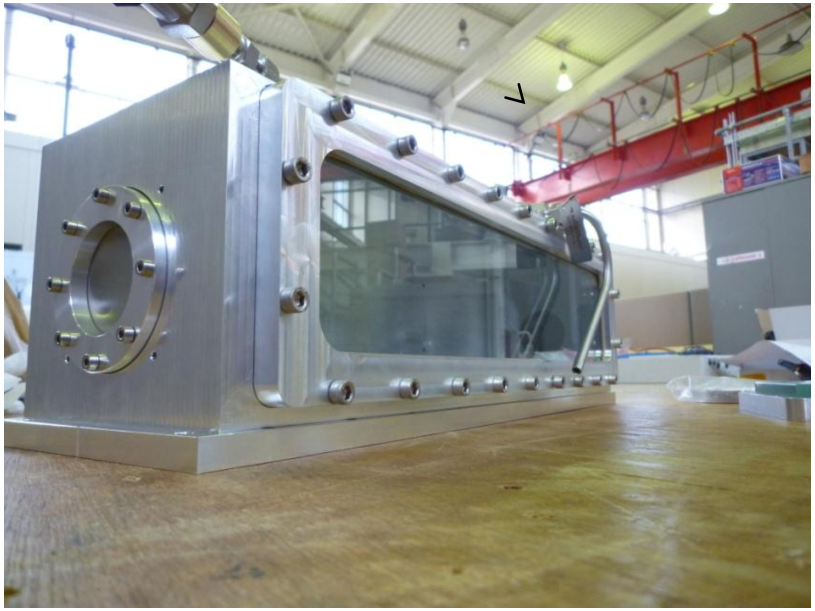
Figure 4 Tungsten powder volume fraction 15milliseconds (particle size = 5microns, proton =2e12)

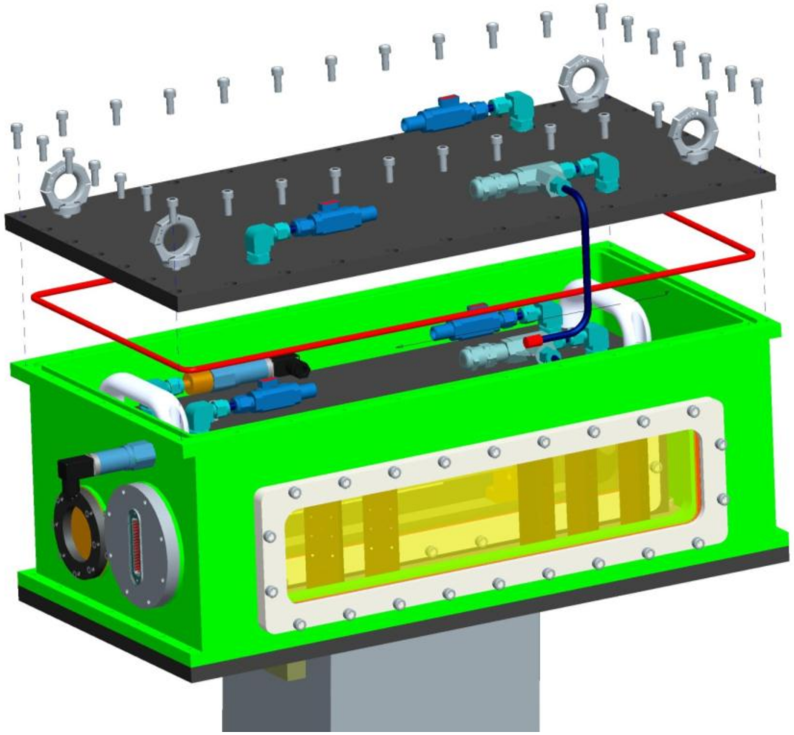
- For 50 micron diameter and 2mm beam sigma >1e12 protons required for significant eruption
- Time scale for eruption of order 30 ms
- Velocity scale of order 1 m/s



Clear model and predictions to test against powder response

Experimental Vessel





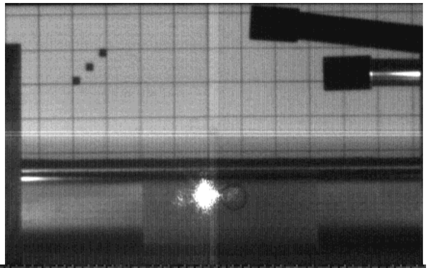
Key Features

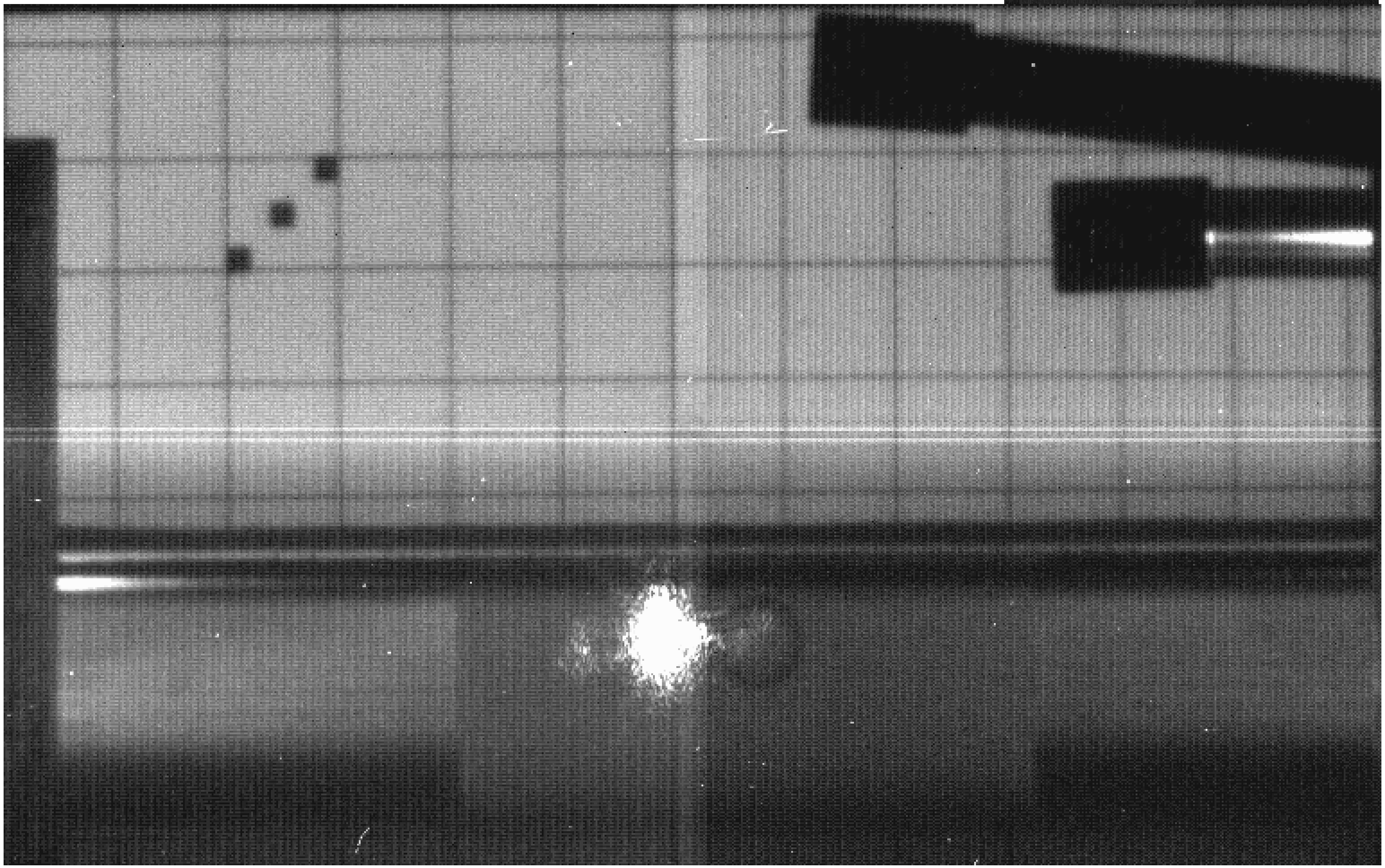
- Open trough to contain tungsten powder
- Double containment for safety
- Titanium beam windows
- Optical windows for high speed camera and LDV
- Powerful LED lighting array for high speed camera
- Pressure and temperature sensors
- Helium filled

High Power Targets

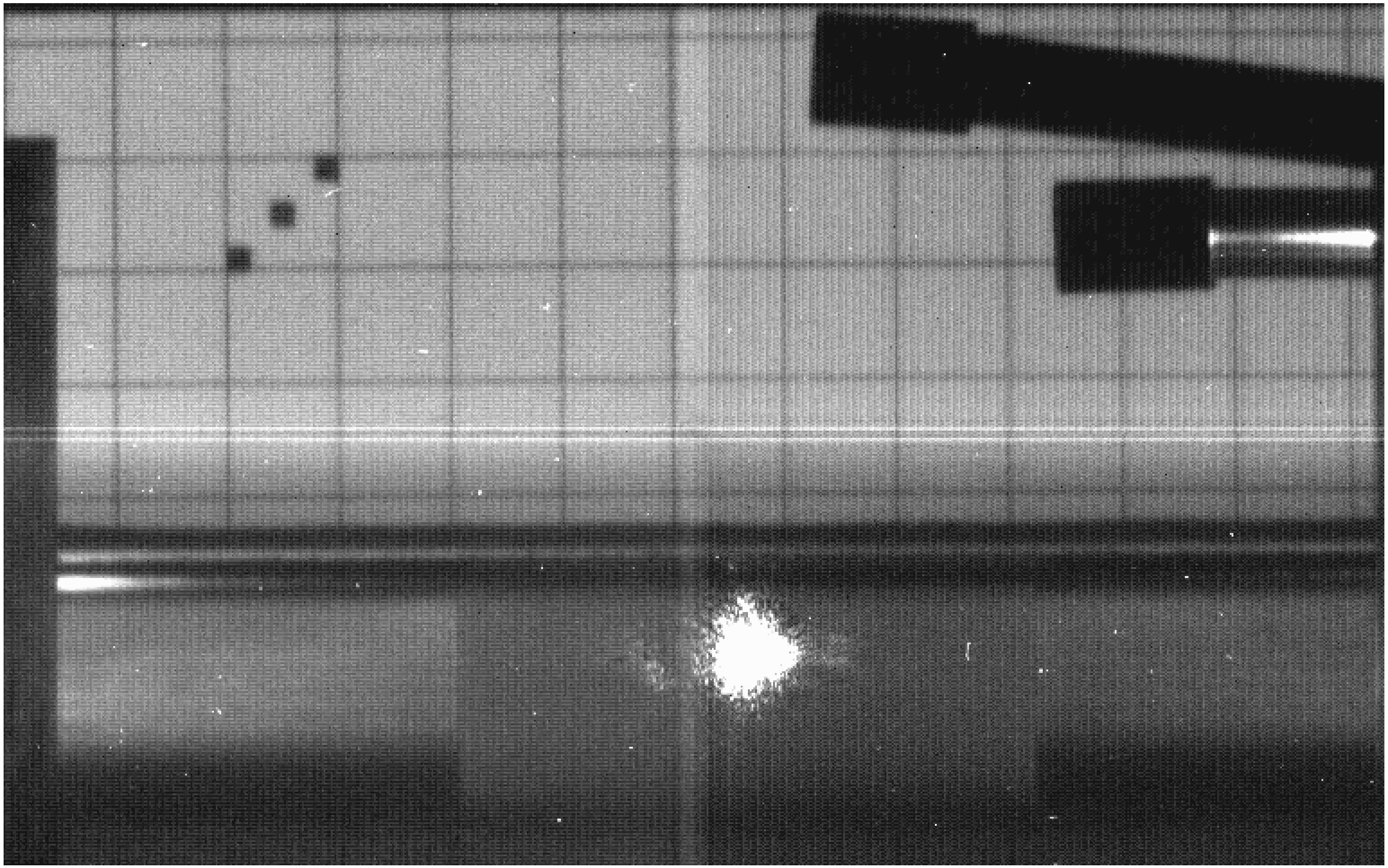
pulse 7 – last pulse below threshold

Intensity: 8.40E+10 protons



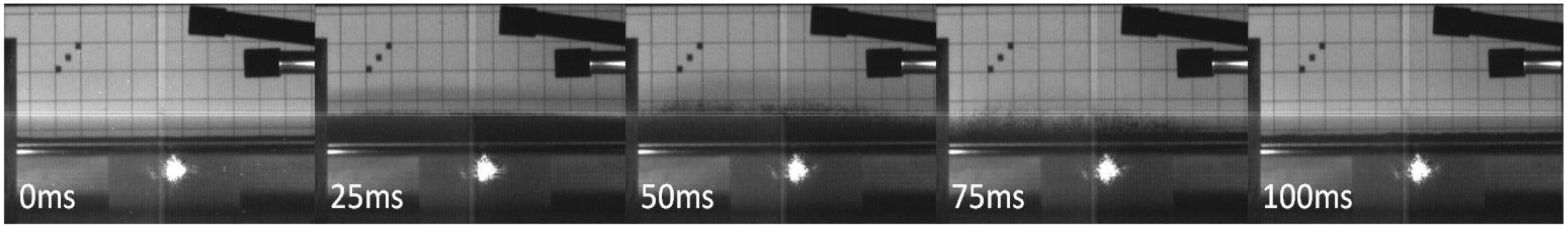


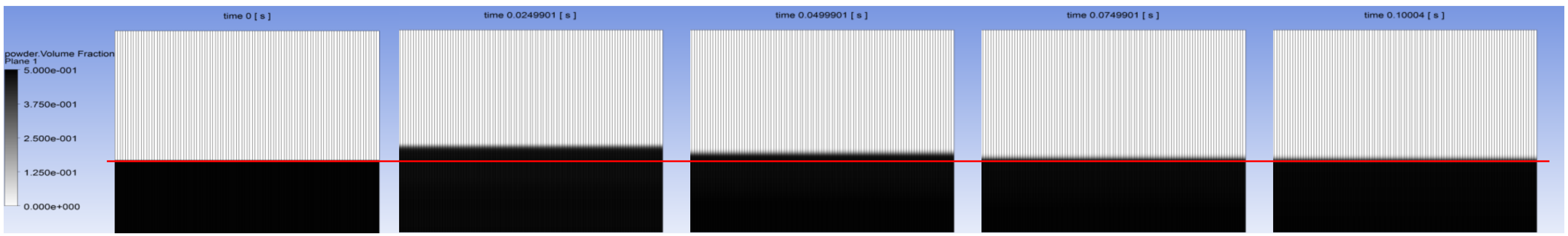
pulse 8 first pulse above threshold

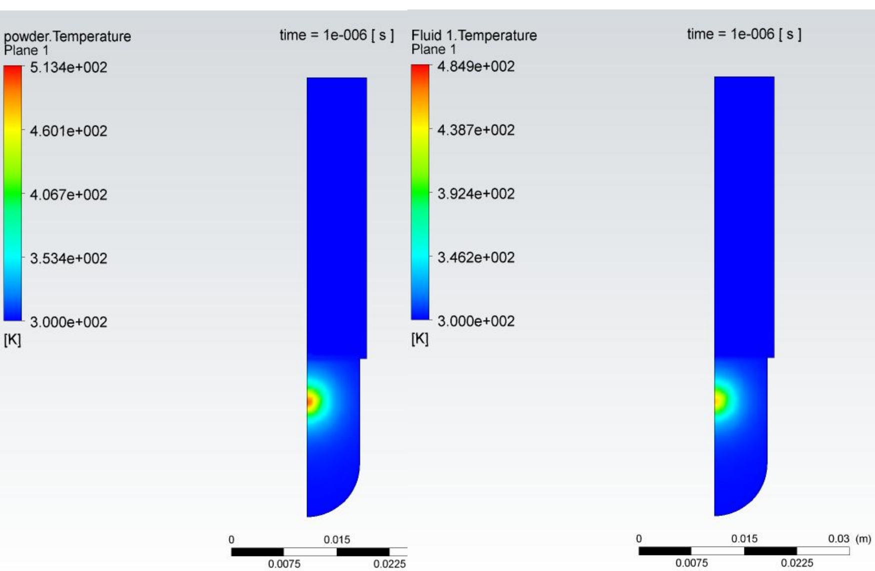


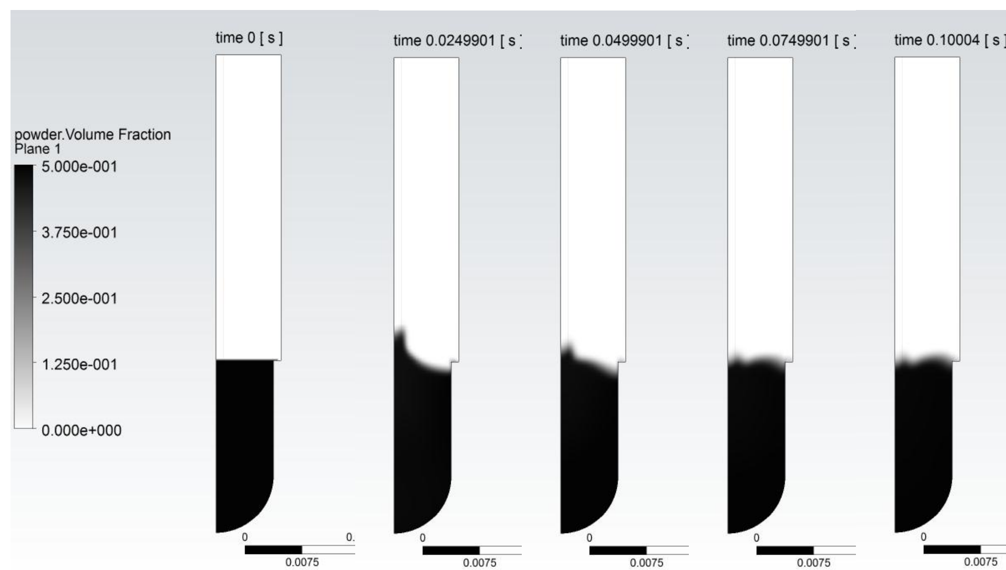
Intensity: 1.75E+11 protons

Results vs CFD with 1 micron diameter particles
Pulse 8 - 1.75e11 protons; Assumed Beam Sigma = 0.75mmx1.1mm
(N.B.no lift expected with >25micron particles at this intensity)



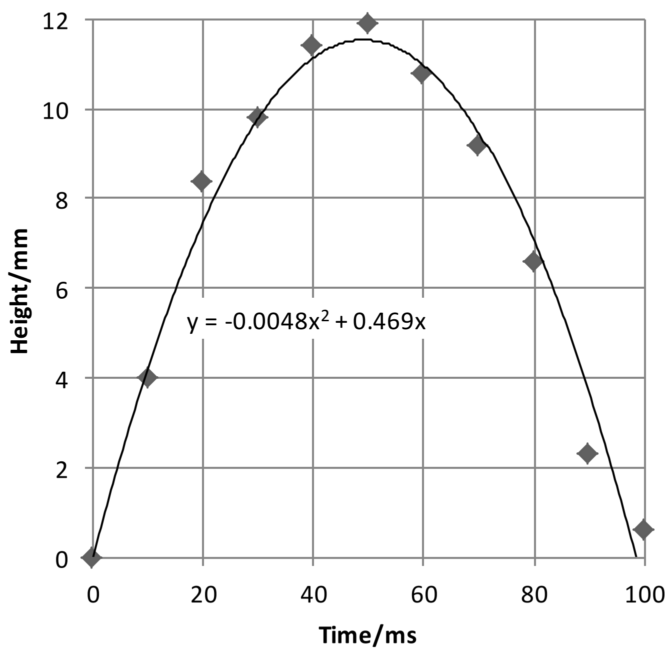






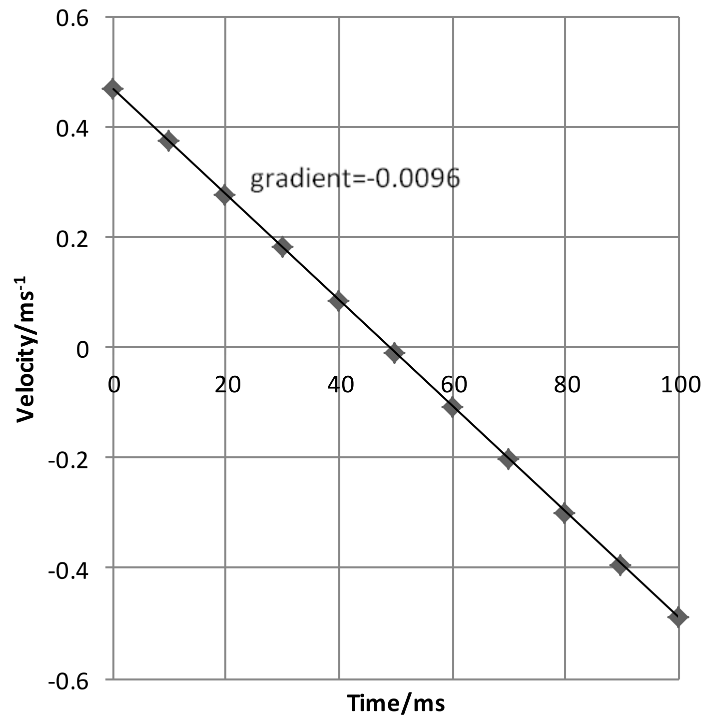
Analysis of high speed video footage for pulse 8

Displacement/time graph of RUN 8



Maximum height= 11.5mm

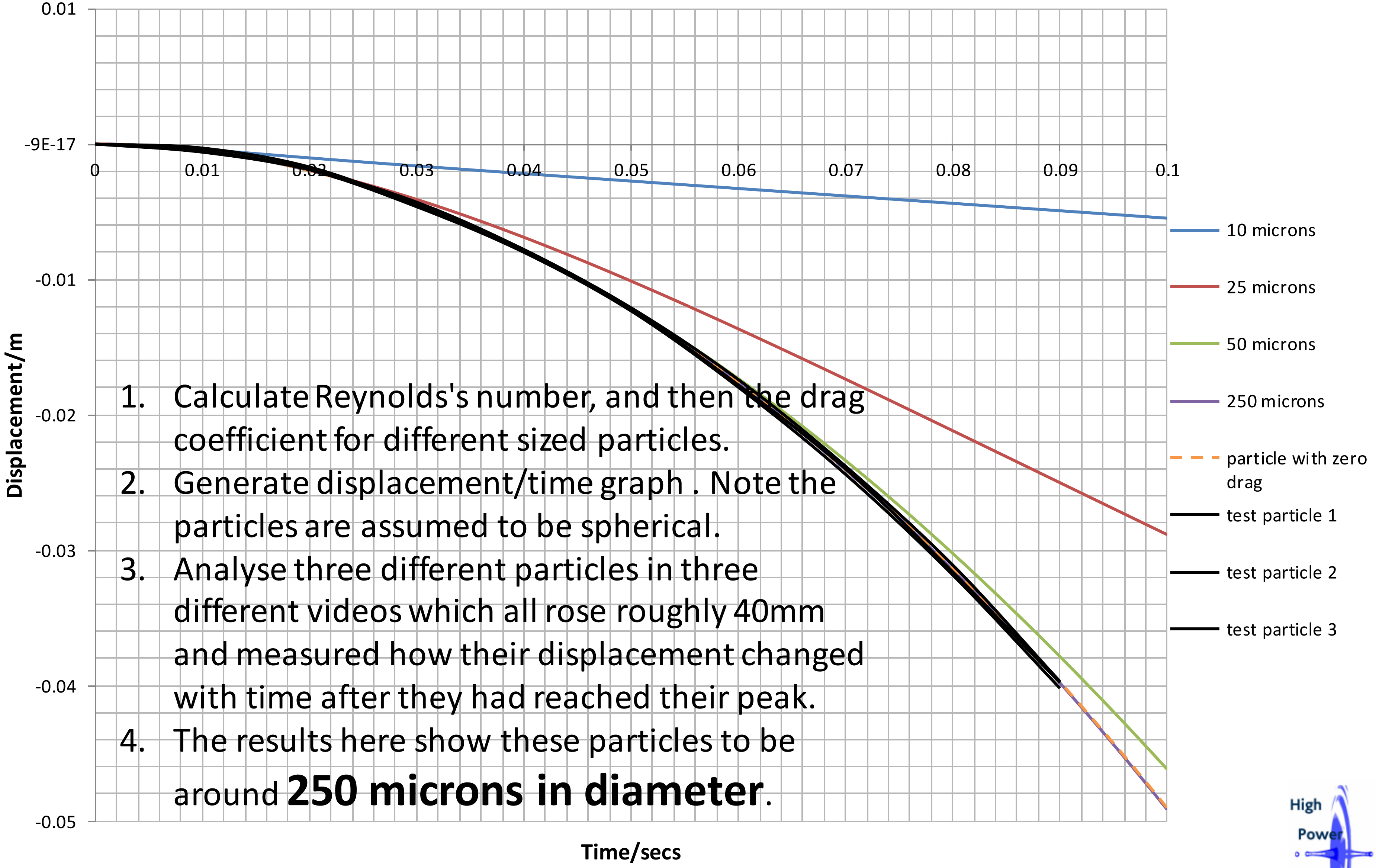
Velocity/time graph of RUN 8



Initial velocity= 0.469ms^{-1}

High Power Targets

Observation of particle falling rate indicates that particles are greater than 50microns in diameter



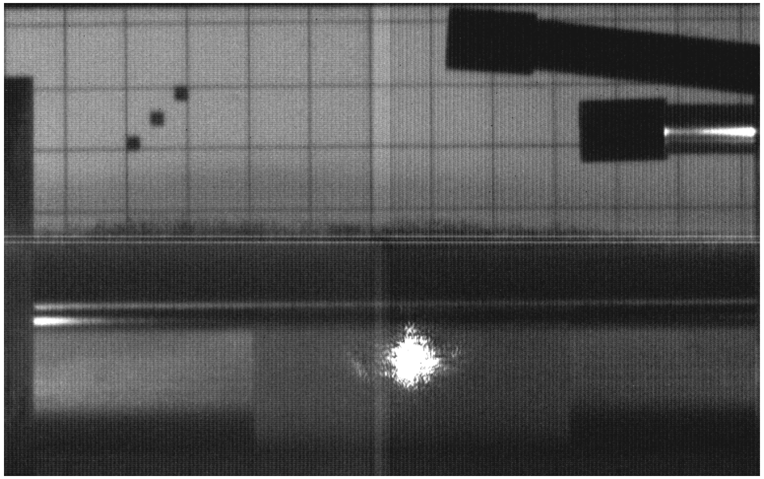
1. Calculate Reynolds's number, and then the drag coefficient for different sized particles.
2. Generate displacement/time graph . Note the particles are assumed to be spherical.
3. Analyse three different particles in three different videos which all rose roughly 40mm and measured how their displacement changed with time after they had reached their peak.
4. The results here show these particles to be around **250 microns in diameter**.

High Power Targets

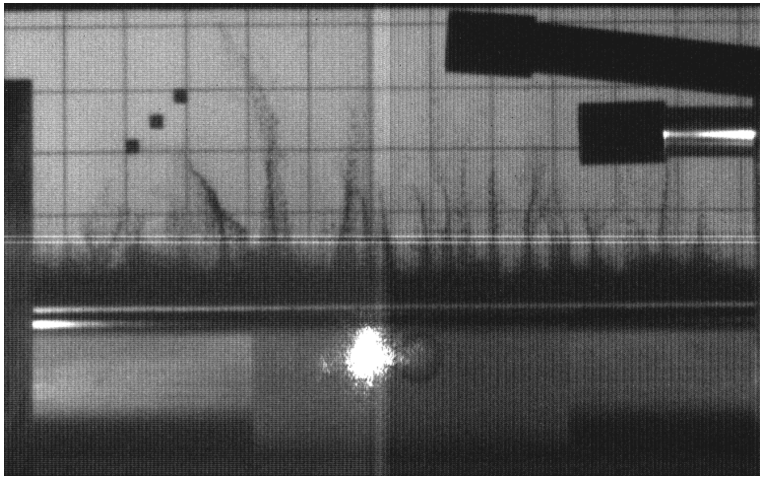
Effect of a perturbed powder surface?

Both after 30ms, at a similar intensity

Pulse 8

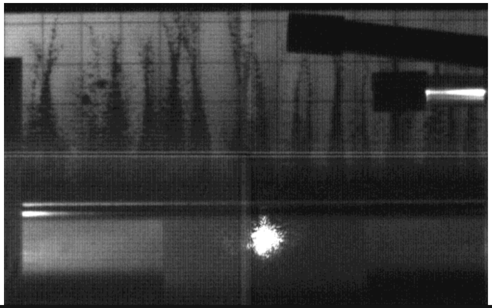


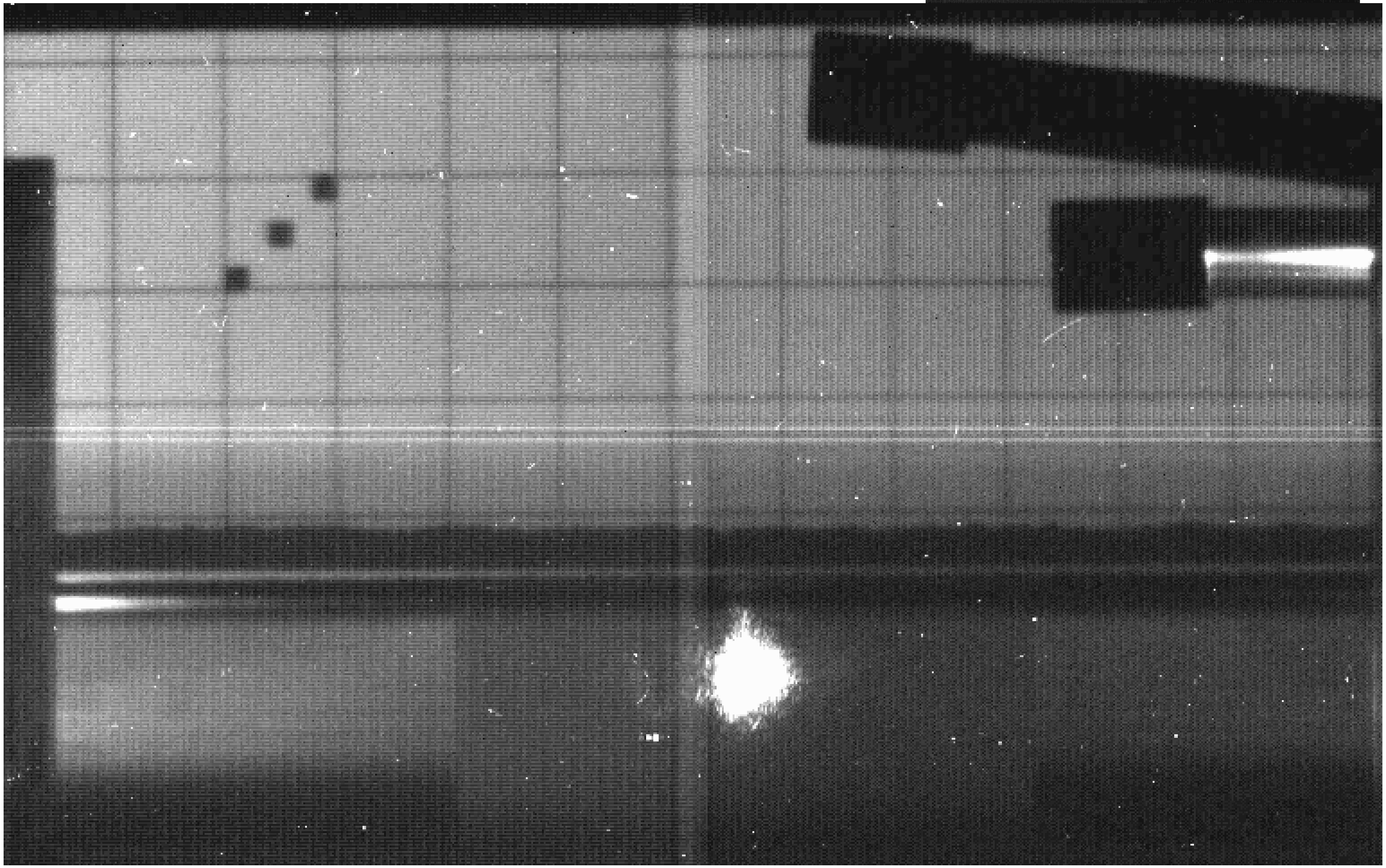
Pulse 9



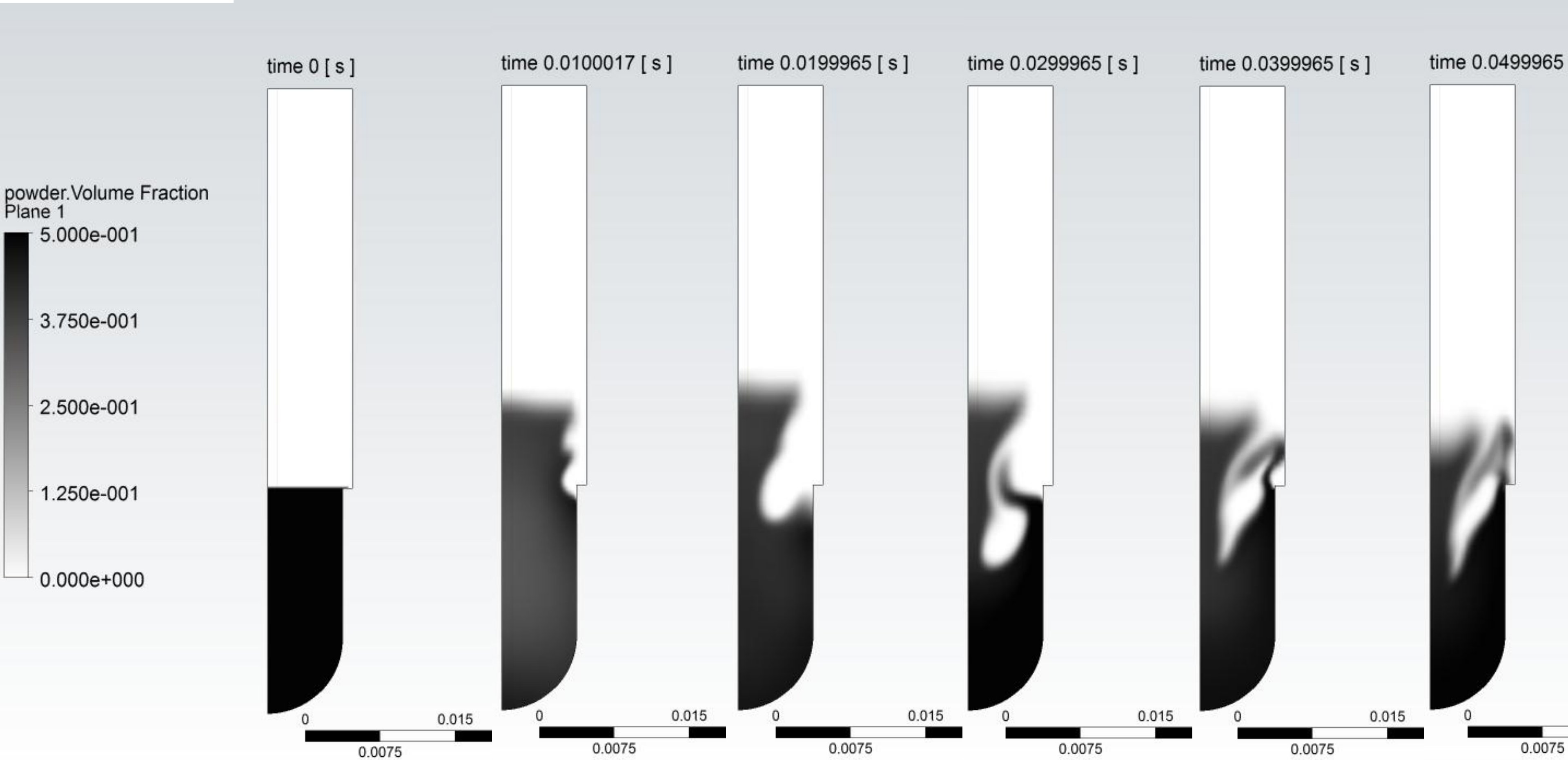
Pulse 21 – more violent response

Intensity: 2.94E+11

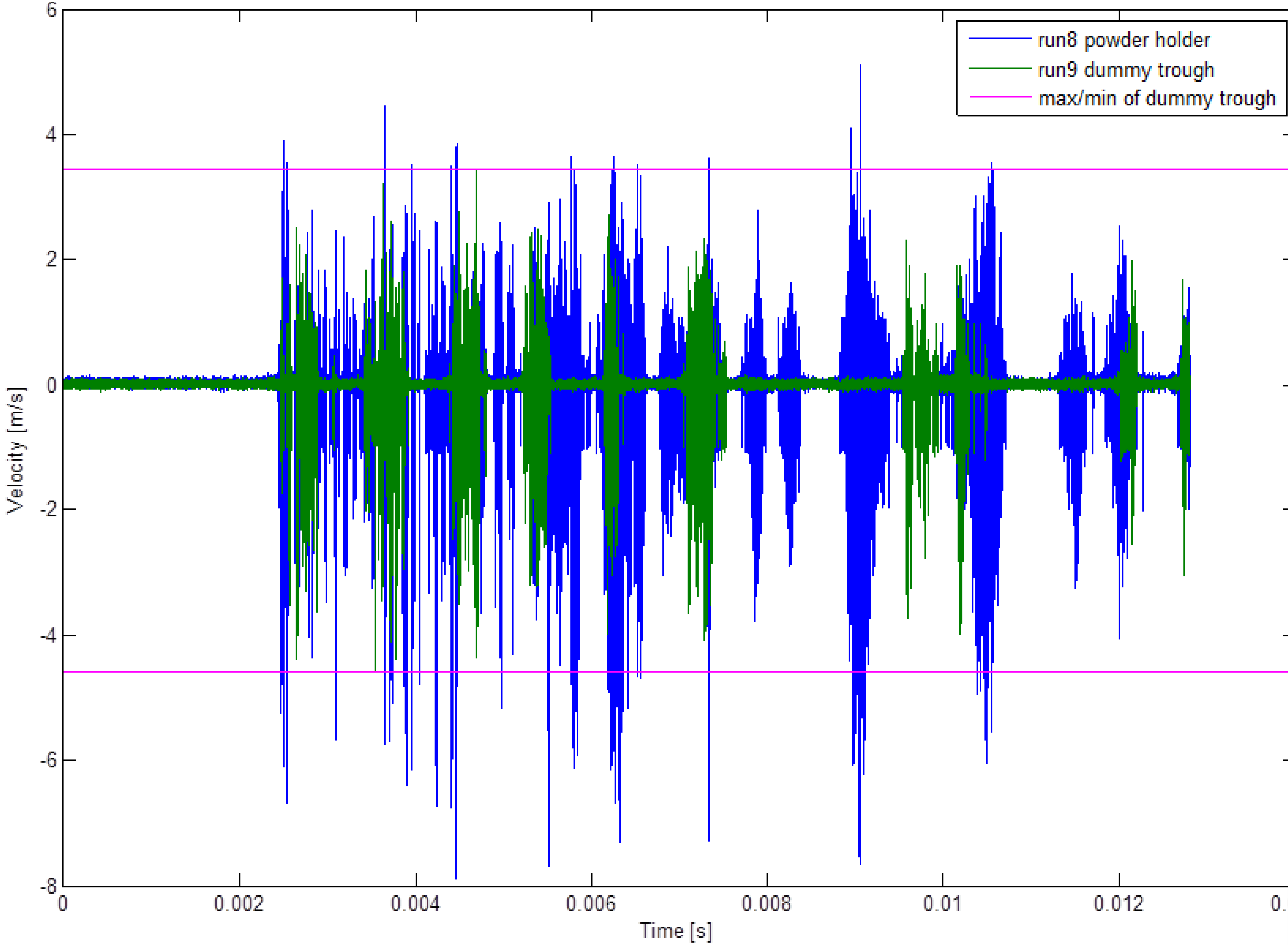




Simulating a more violent response
intensity = 1.2e12 protons

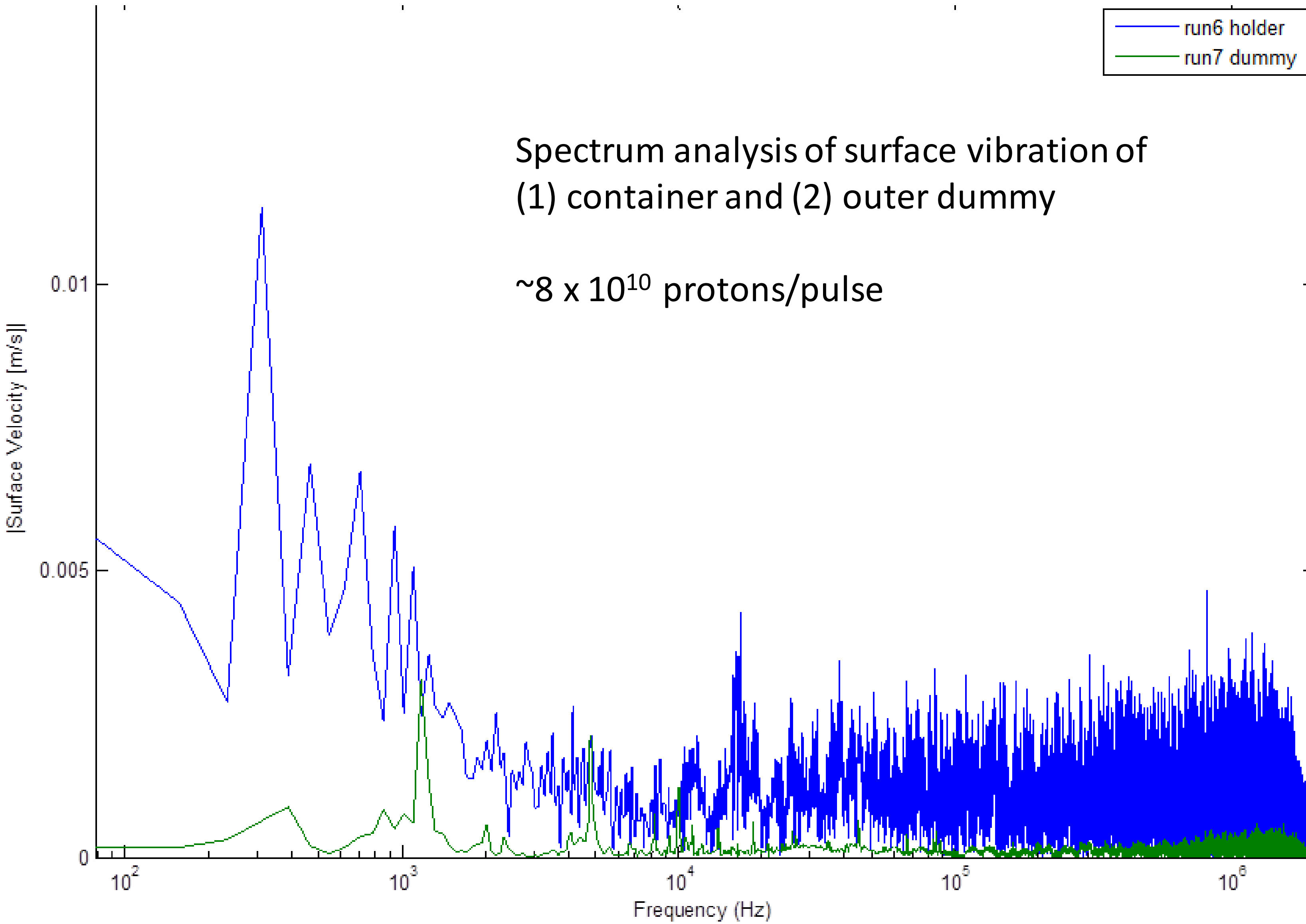


Preliminary Laser Doppler Vibrometer Results



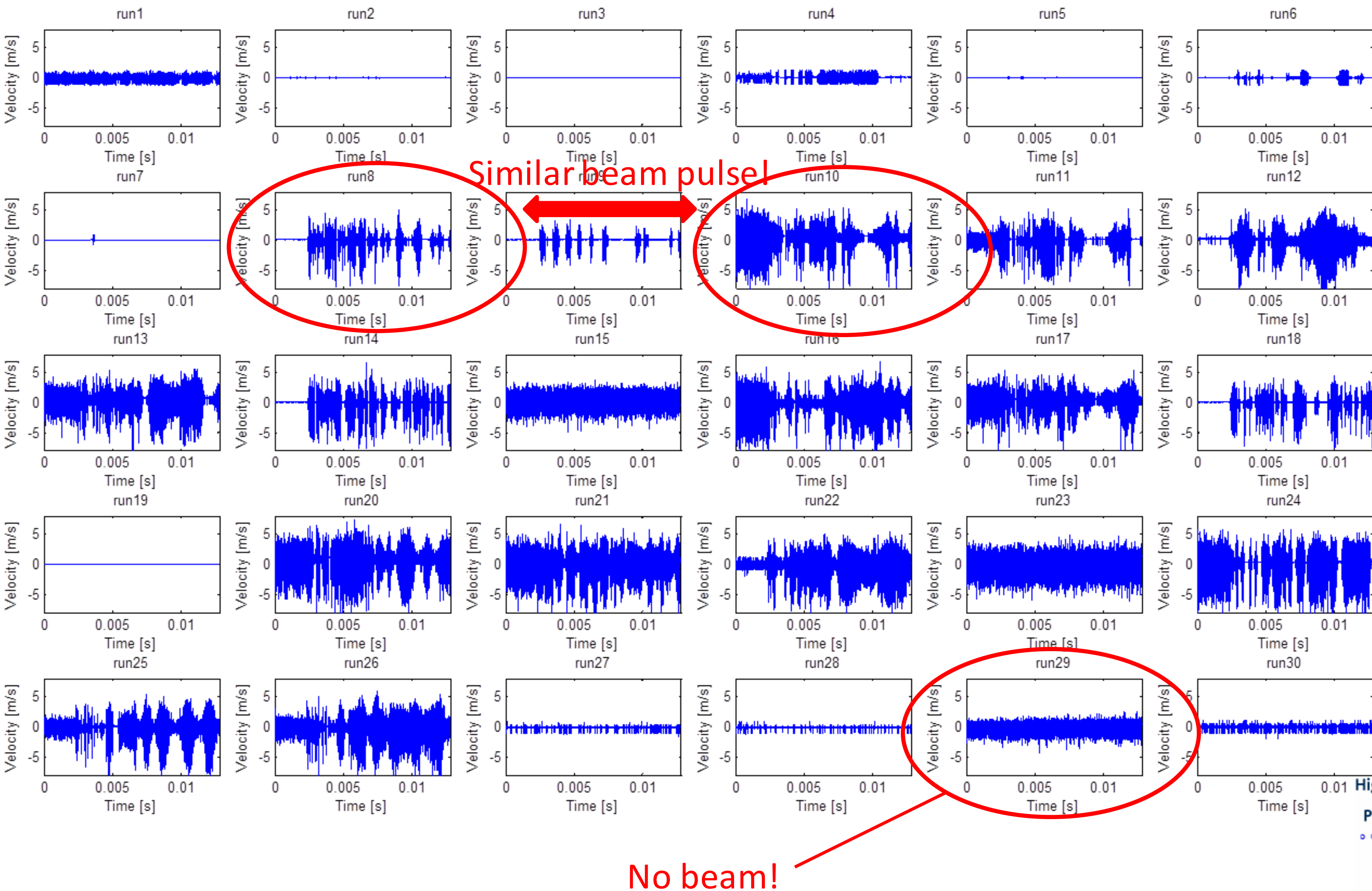
High Power Targets

Preliminary Laser Doppler Vibrometer Results

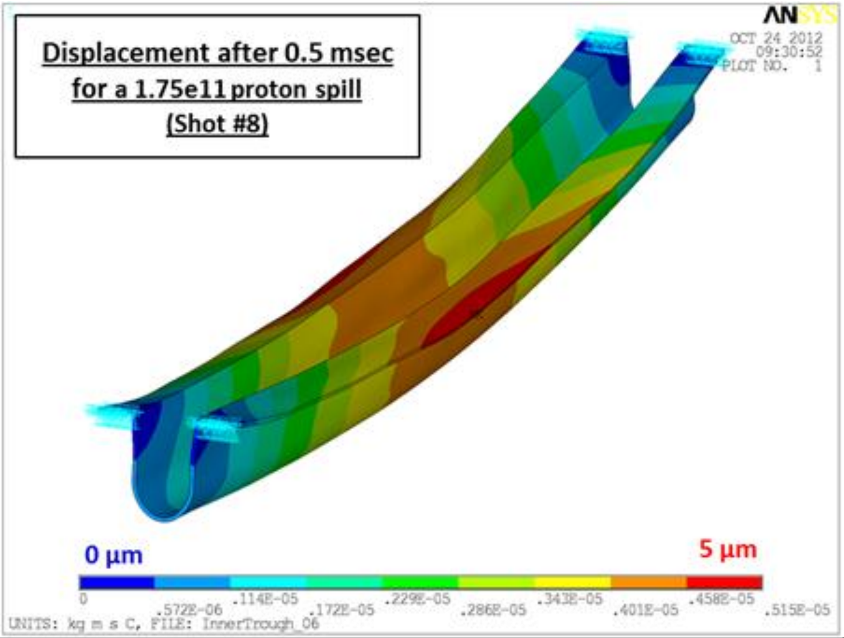


High Power Targets

Now the confusing bit: LDV results for all shots



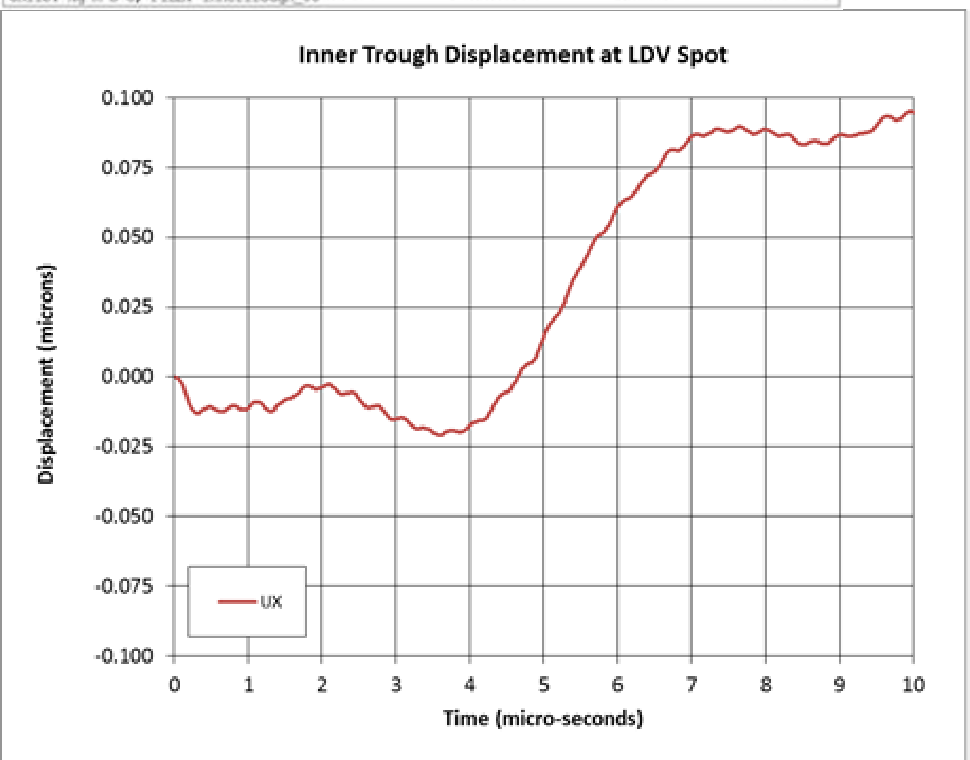
High Power Targets

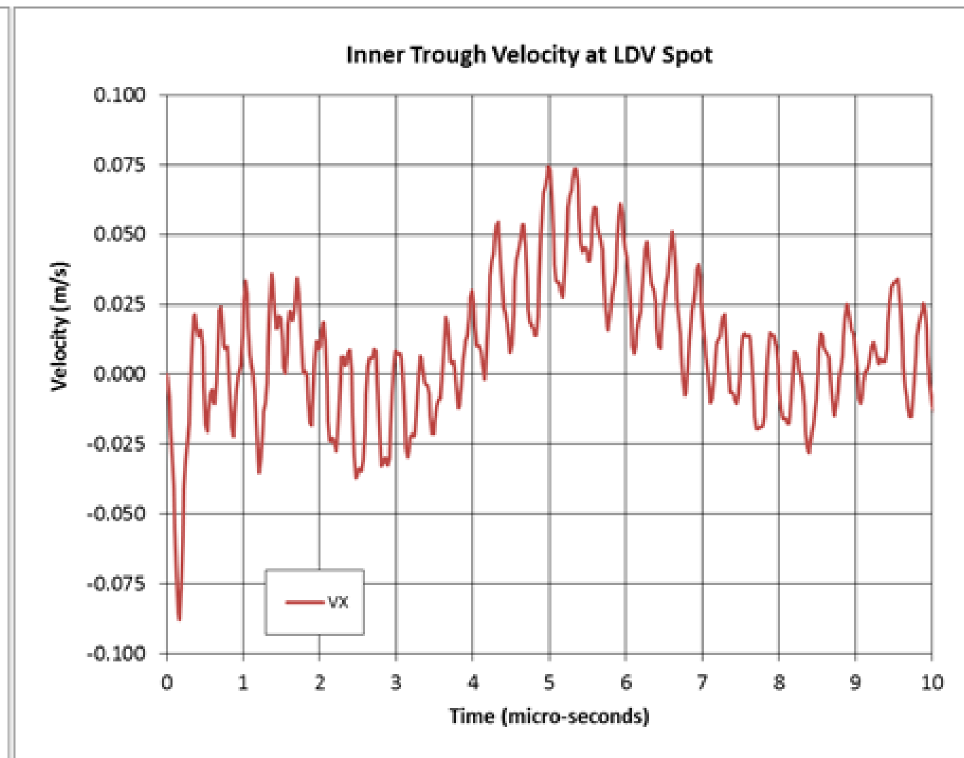


Is secondary heating causing vibration of sample container?

Could be responsible for extra powder lift vs CFD result

Mechanism not obvious





Interim Conclusions

- Pulsed proton beam induced eruption of a sub-100 μm tungsten powder sample in helium was observed.
- Eruption threshold observed of c.1.75 e11 ppp, σ = 1.17 mm
- A CFD model simulating a gas expansion eruption mechanism predicts threshold of c. 1 e12 ppp, σ = 2 mm
- This discrepency/mechanism is not understood
- LDV data indicates greater response from trough in contact with powder than external 'dummy'
- LDV contains many anomalies and is being studied (help welcome!)

High Power Targets

Future experiment planned to investigate mechanism of powder eruption

- Experiment design:
  1. More rigid sample holder
  2. Initial operation in vacuum to see if eruption still occurs, and if so what is threshold
  3. Helium then used to backfill target containment to determine effect of more rigid sample holder c.f. thin double-walled container for HRM-10
  4. Different powder size distributions along length
  5. Any other bright ideas?

High Power Targets

HiRadMat Beam Parameters

A high-intensity beam pulse from SPS of proton or ion beams is directed to the HiRadMat facility in a time-sharing mode, using the existing fast extraction channel to LHC. The SPS allows accelerating beams with some 1013 protons per pulse to a momentum of 440 GeV/c.

Details of the primary beam parameters and focusing capabilities can be found in the EDMS Document [1054880](), and summarized below.

Protons:

Beam Energy 440 GeV [a]

Pulse Energy up to 3.4 MJ

Bunch intensity $3.0 \cdot 10^9$ to $1.7 \cdot 10^{11}$ protons

Number of bunches 1 to 288

Maximum pulse intensity $4.9 \cdot 10^{13}$ protons

Bunch length 11.24 cm

Bunch spacing 25, 50, 75 or 150 ns

Pulse length 7.2 μs

Minimum cycle length 18 s[c]

Beam size at target variable around 1 mm^2 [b]