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Tungsten Powder Target Experiments

In-Beam Testing

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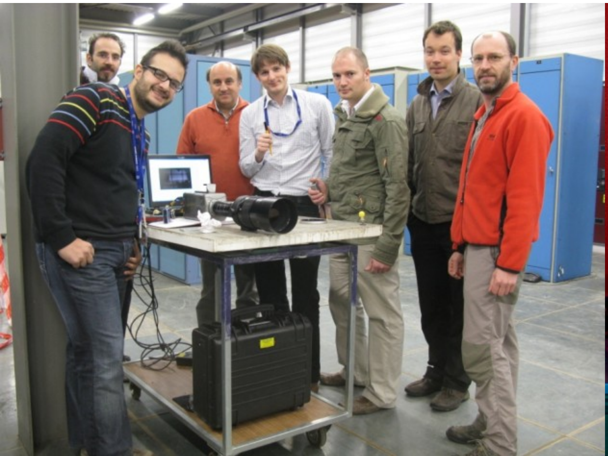
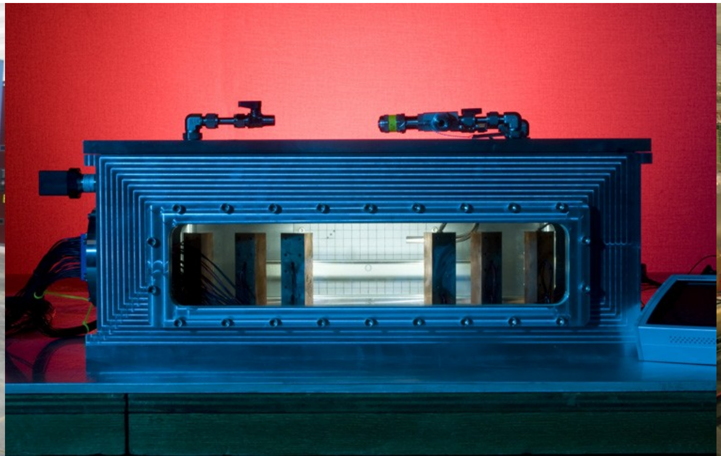
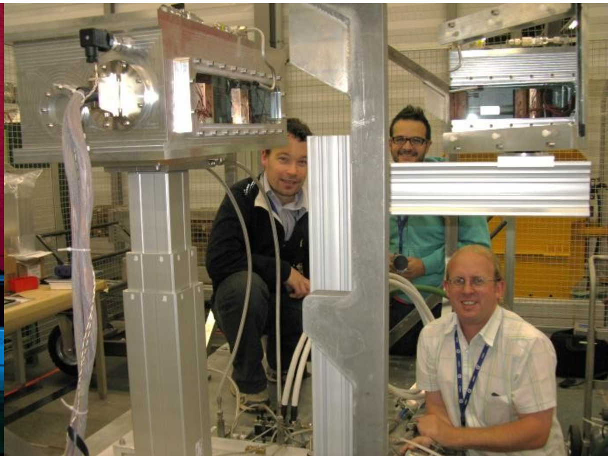
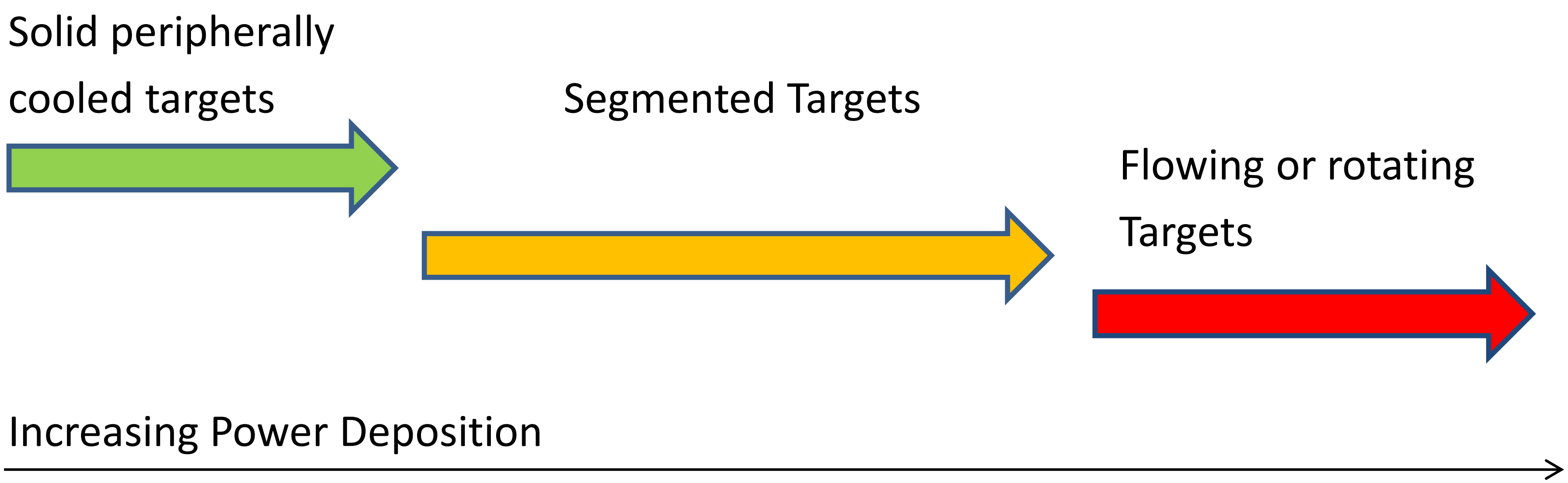




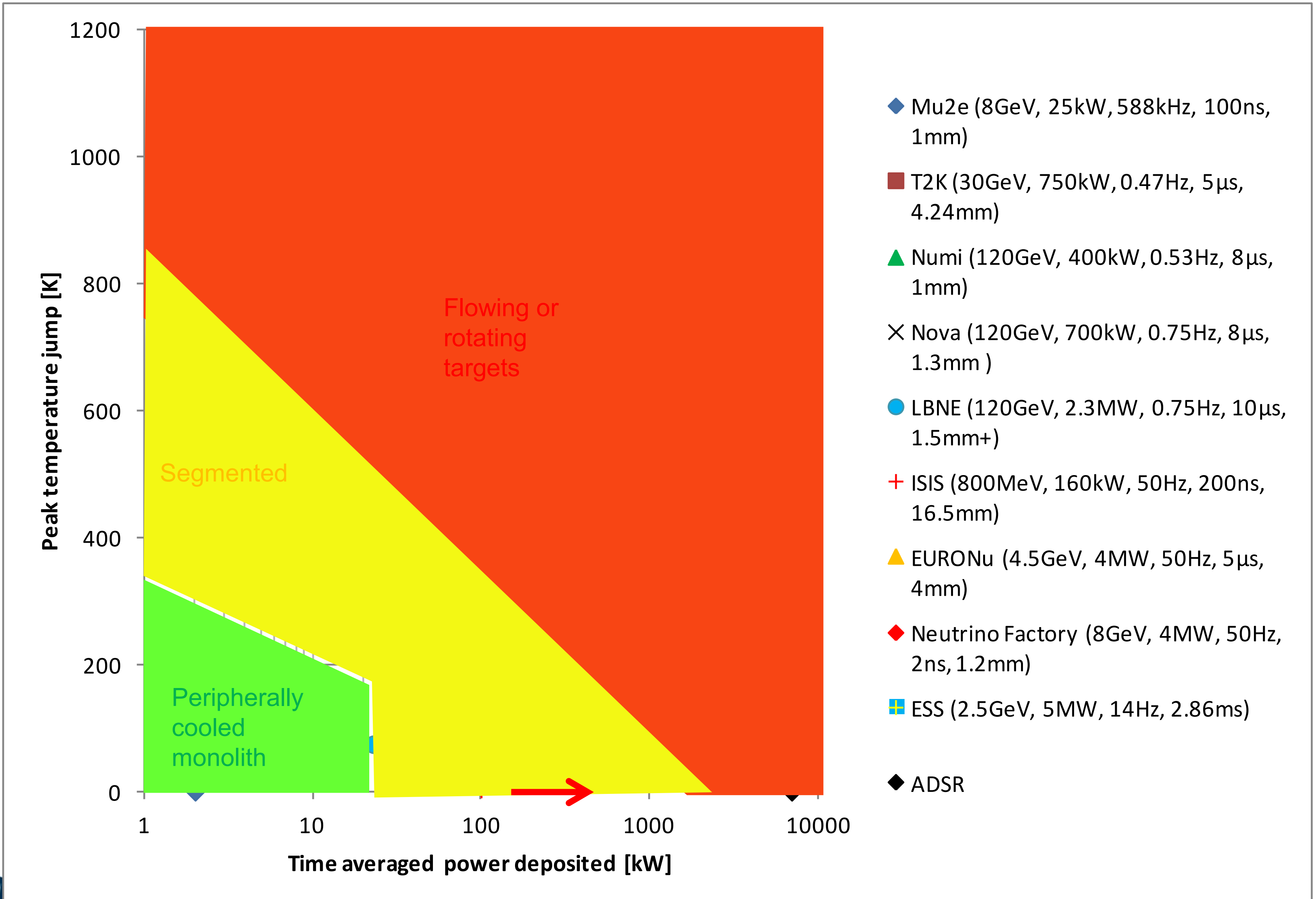


Motivation

- Designing targets for new accelerator based facilities is becoming more and more challenging due to increasing accelerator beam power and the associated power deposition in the target.
- Targets must sometimes accommodate significant power deposition in continuous form or sometimes as an intense pulse followed by an interval of cooling.
- Maintaining the target temperature and stress levels within safe limits is the main design driver and results in increasingly elaborate designs as time averaged and pulse power deposition are increased



Limitations of target technologies



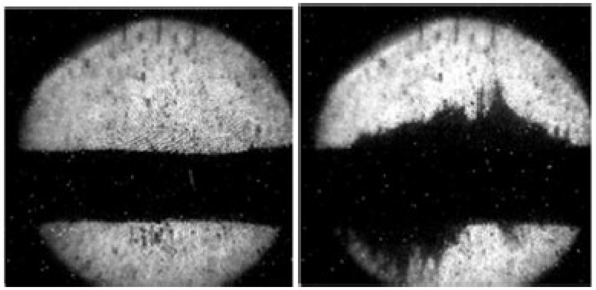
Example: Candidate target technologies for a neutrino factory

1. Mercury Jet

Liquid metal targets successfully implemented, e.g. SNS

Mercury boiling expected with baseline beam parameters

Significant beam induced splashing demonstrated in MERIT experiment



Mercury Jet in the MERIT experiment before (left) and after (right) a proton beam interaction, Kirk et al.

2. Moving Solid Tungsten Bars

Significant study on dynamic stress and strain-rate effects published

Mechanical reliability in harsh operating environment still in question

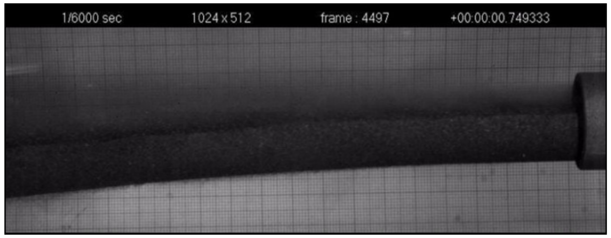
High quasi static stress levels, would require much larger beam sigma than baseline beam parameters

lifetime testing of tungsten wires in response to dynamic thermal loading, Skoro et al.

3. Tungsten Powder

Pneumatic conveyance of powder demonstrated in principle. Work continues to develop C.W. operation and erosion avoidance techniques

Response to proton beam heating was unknown hence this programme

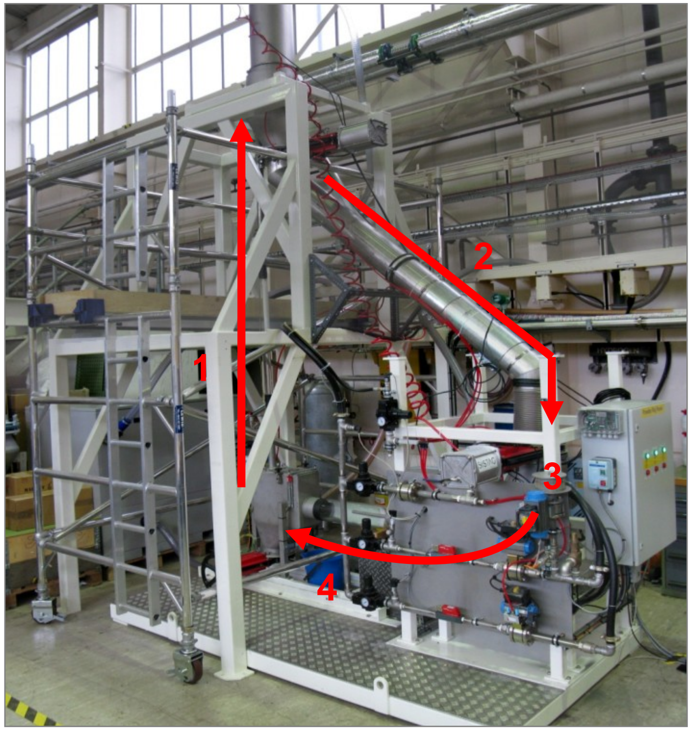


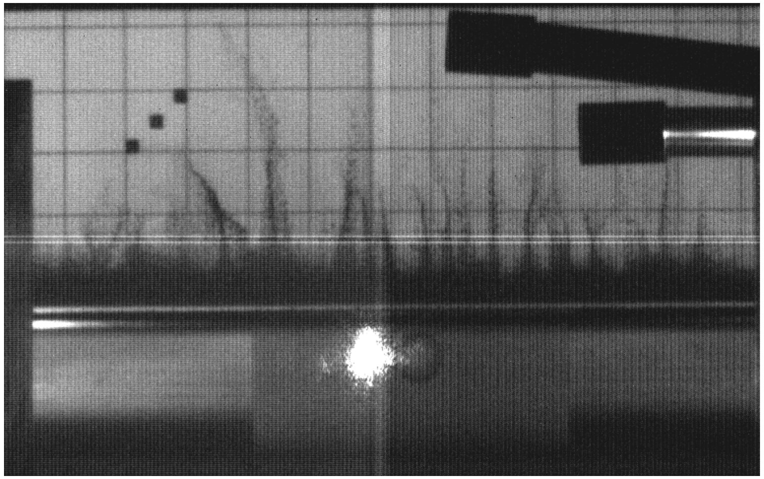
Pneumatically conveyed dense-phase tungsten powder jet, Caretta et al.

Tungsten Powder Test Programme in PASI-WP3

- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Diagnostics / process-control
  - Containment / erosion
  - Heat transfer and cooling of powder

- On-line testing
  - Will proton beam interactions cause a powder target splash/erupt?
  - Can you propagate a pressure wave through a powder target to its container?





Above: *tungsten powder response to a 440 GeV beam at HiRadMat (CERN)*

Left: *Powder conveying test rig (RAL)*

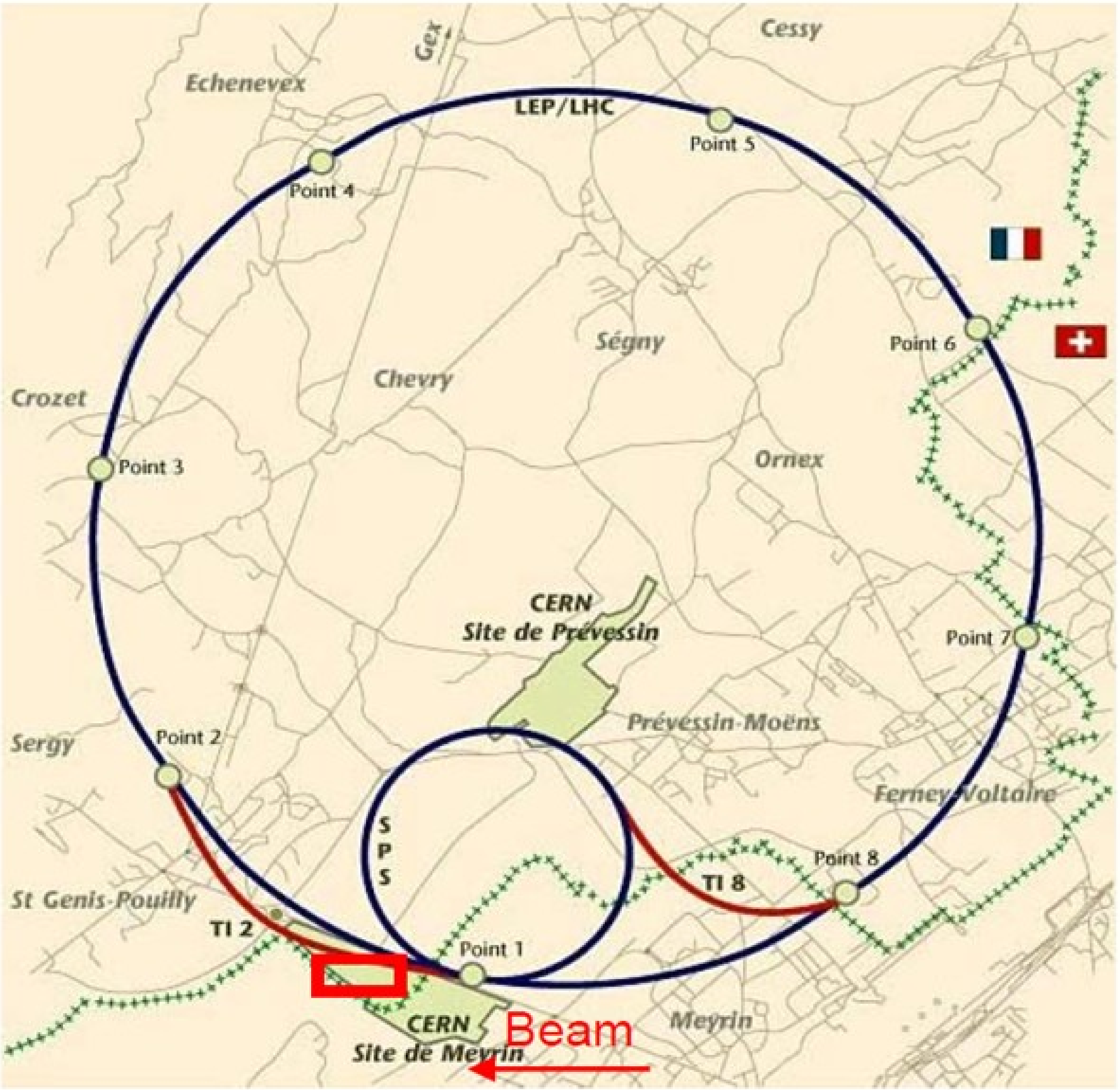
Location of HiRadMat

In-beam experiment Opportunity, June 2012

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 are summarised below:

Beam Energy 440 GeV
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
Beam size at target variable around 1 mm²



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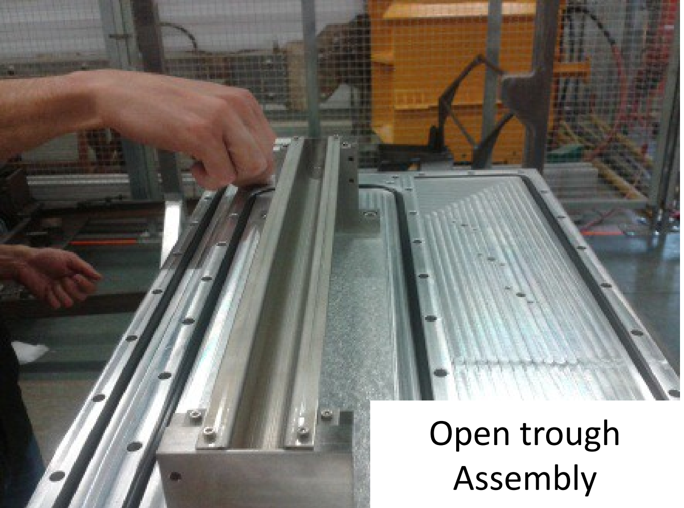
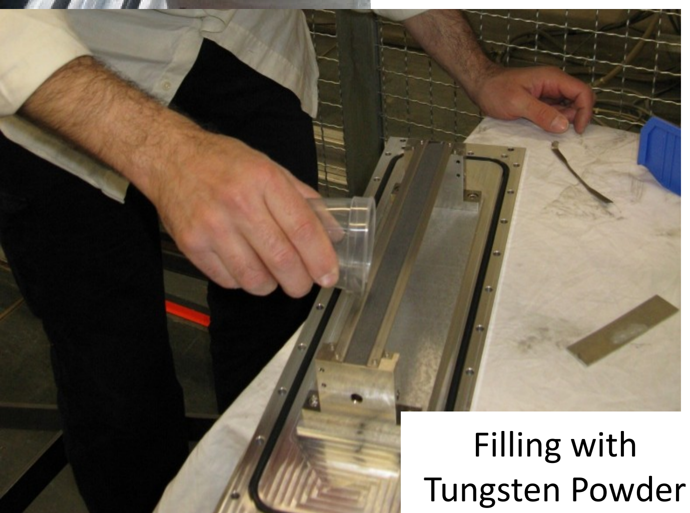
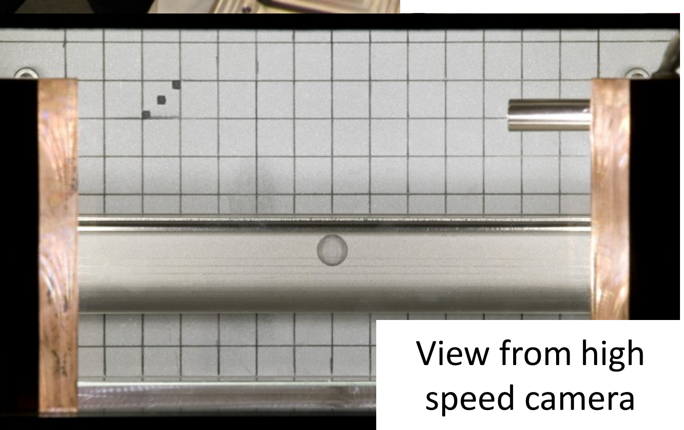
Appa



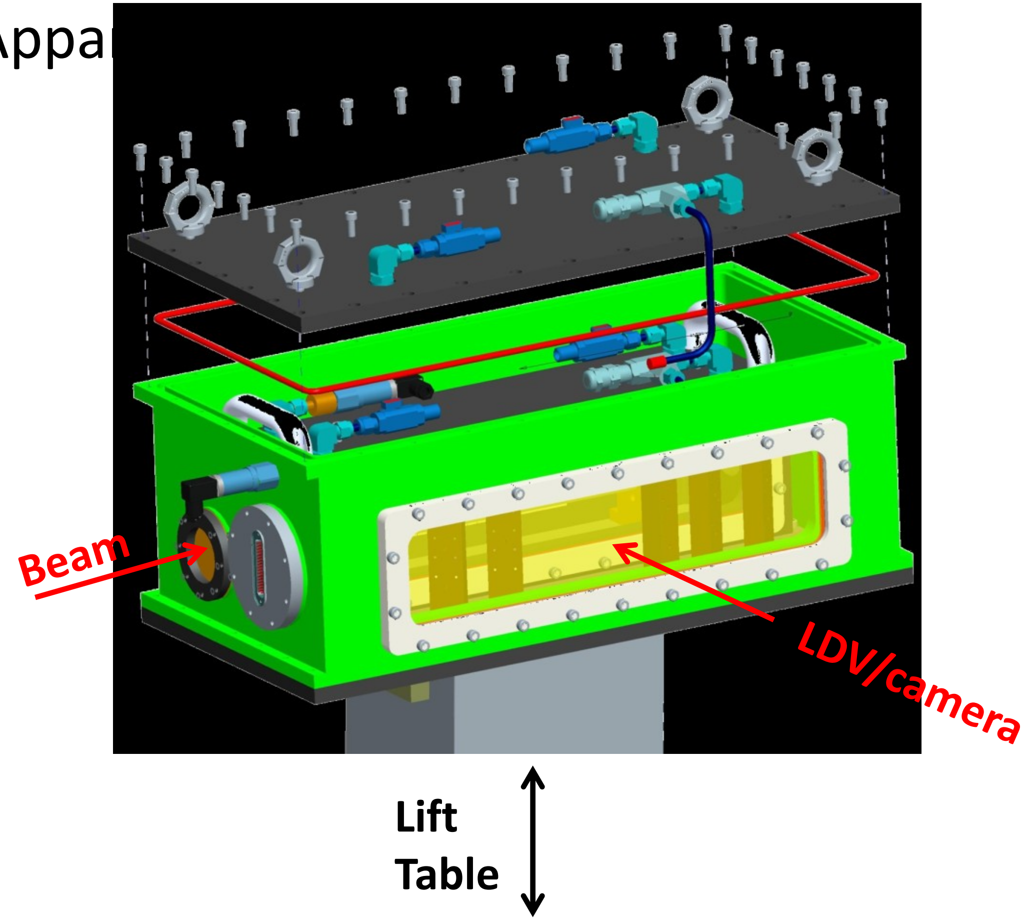
Open trough Assembly



Filling with Tungsten Powder

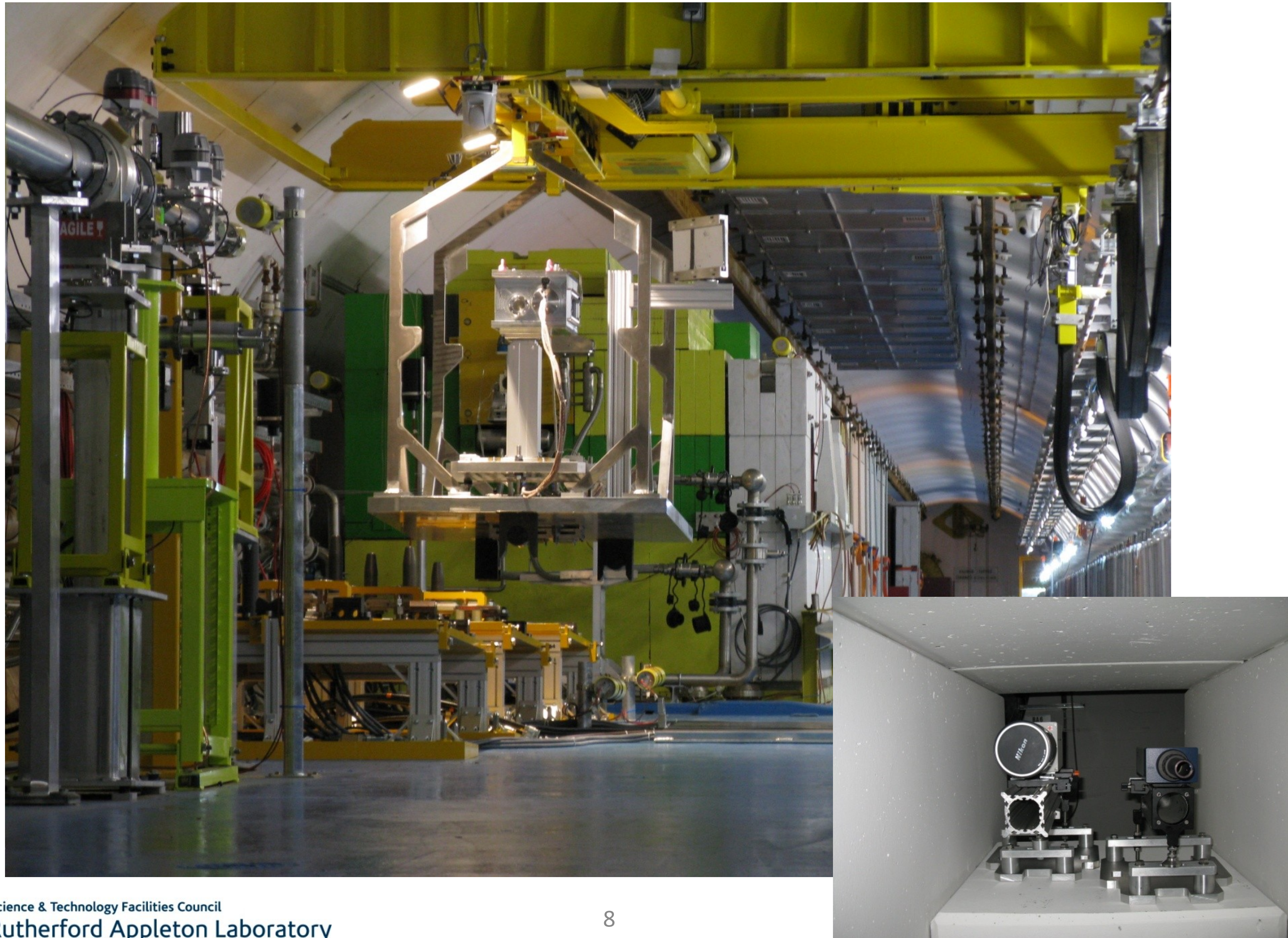


View from high speed camera



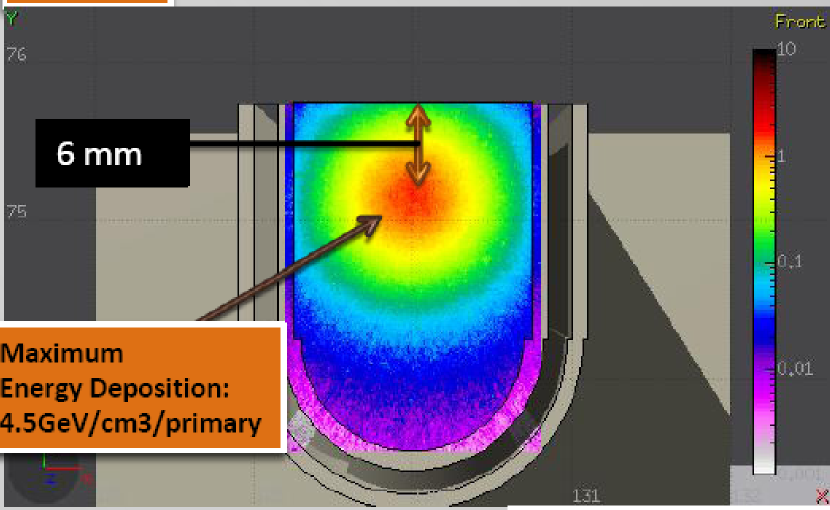
- Tungsten powder sample in an open trough configuration
- Helium environment
- Two layers of containment with optical windows to view the sample
- Remote diagnostics via LDV and high-speed camera

Installation and Remote diagnostics

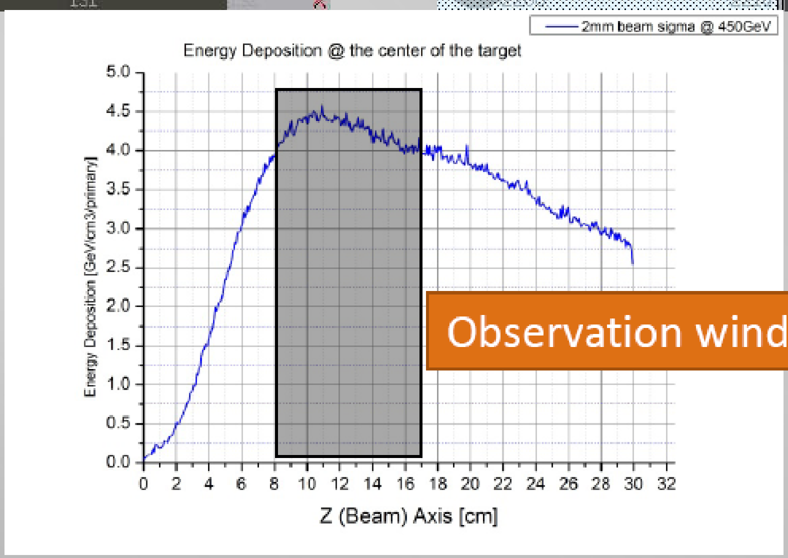


Prompt energy deposition/radiation (FLUKA® Monte – Carlo Code)

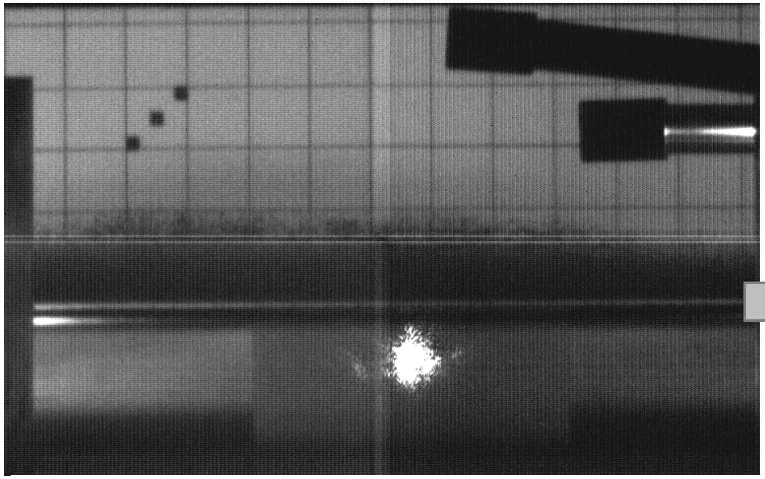
Front



Top

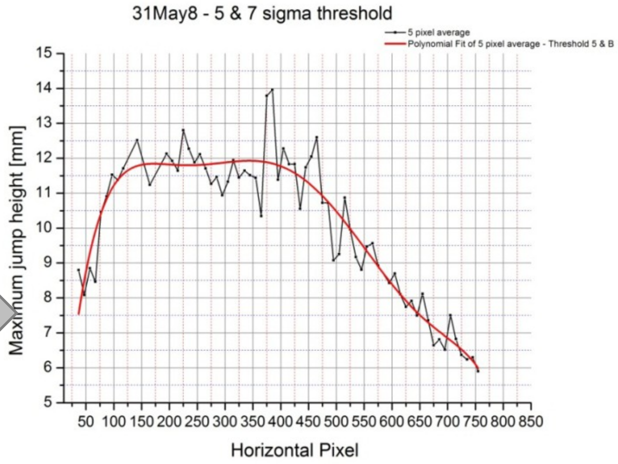


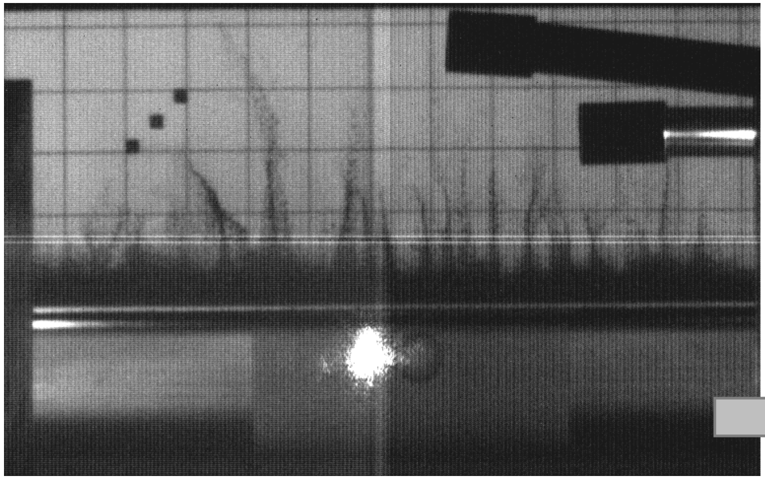
1st results



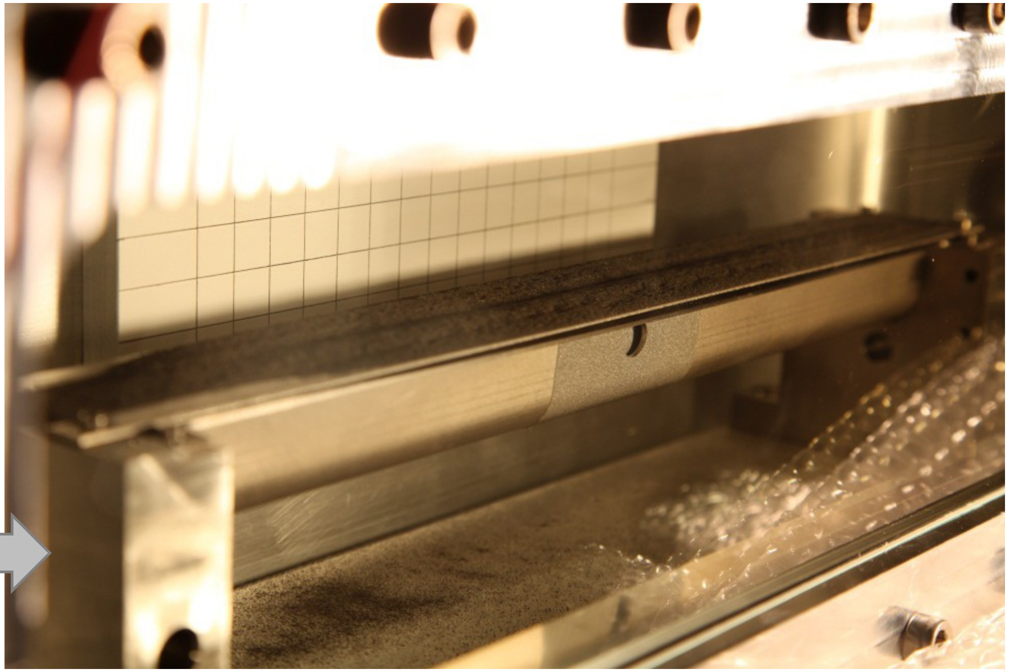
Shot #8, 1.75e11 protons
Note: nice uniform lift

Lift height correlates with deposited energy





Shot #9, 1.85e11 protons
Note: filaments!



Trough photographed after the experiment.
Note: powder disruption

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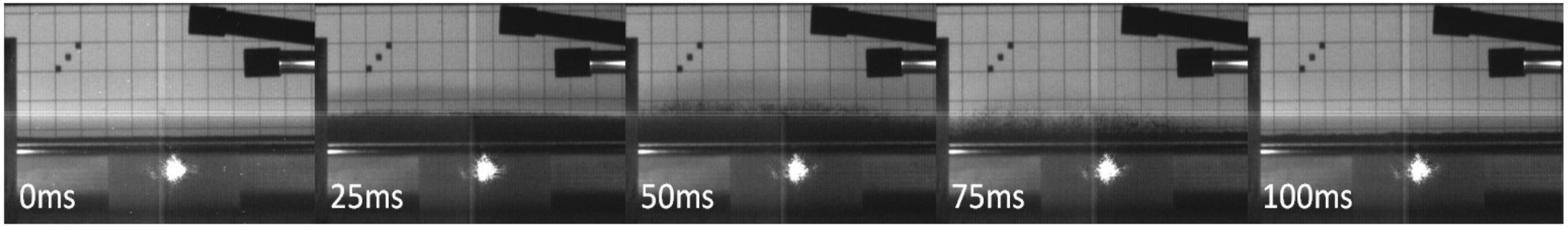
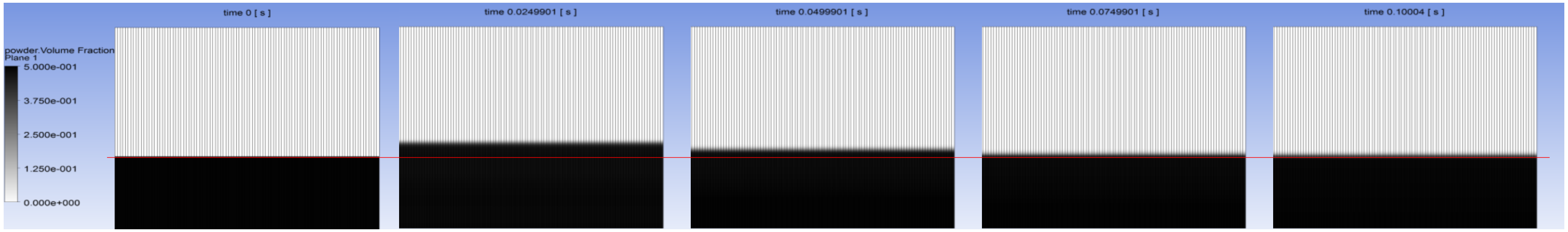
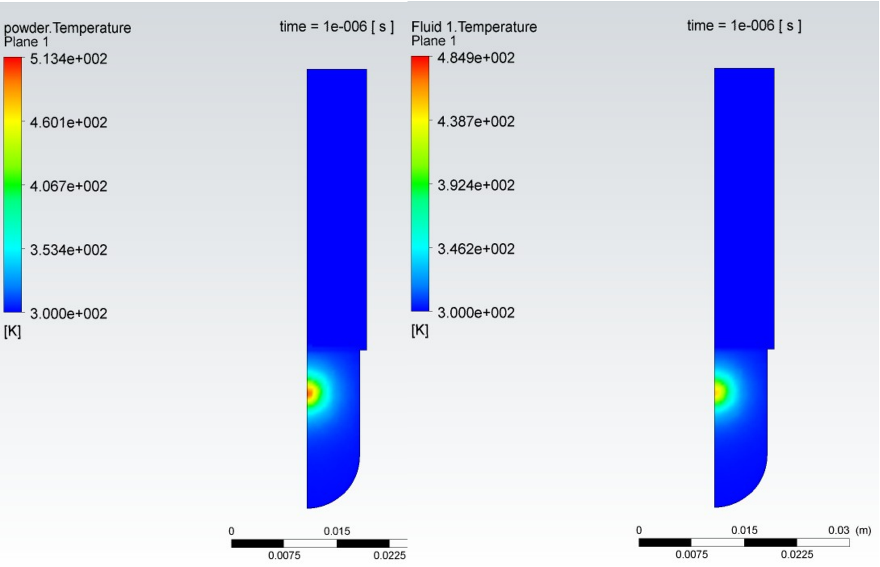
Eruption Threshold: Depends on Particle Size

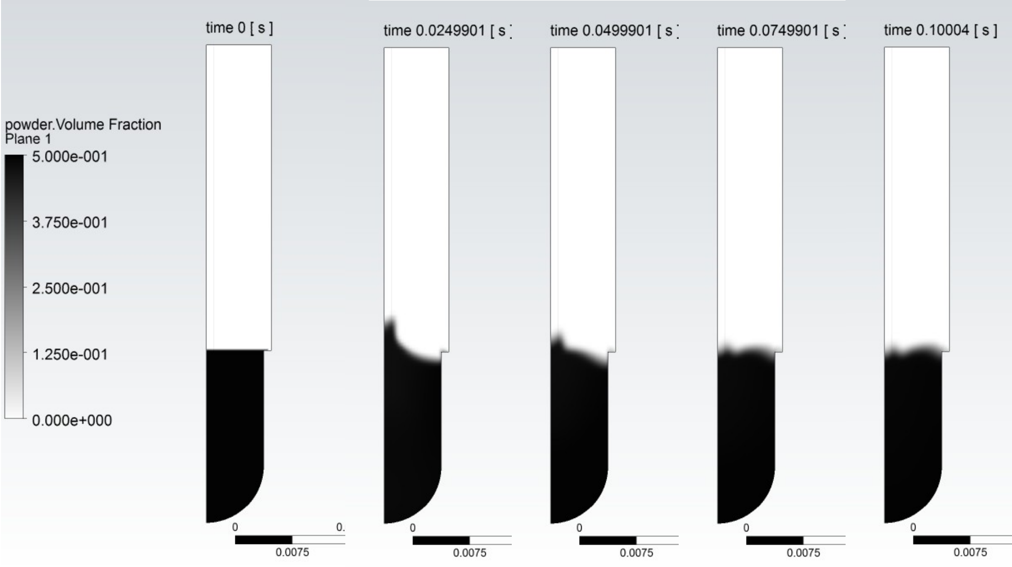


Test Results from Shot #8, 1.75e11 protons, beam sigma 0.75 mm x 1.1 mm

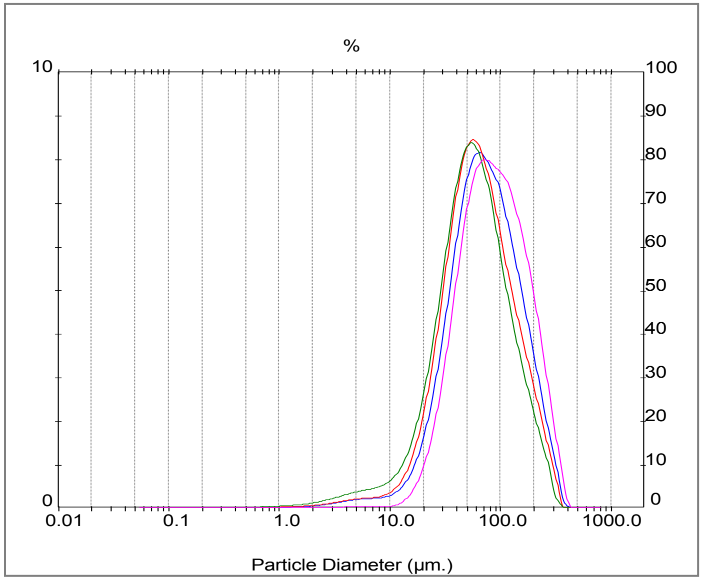


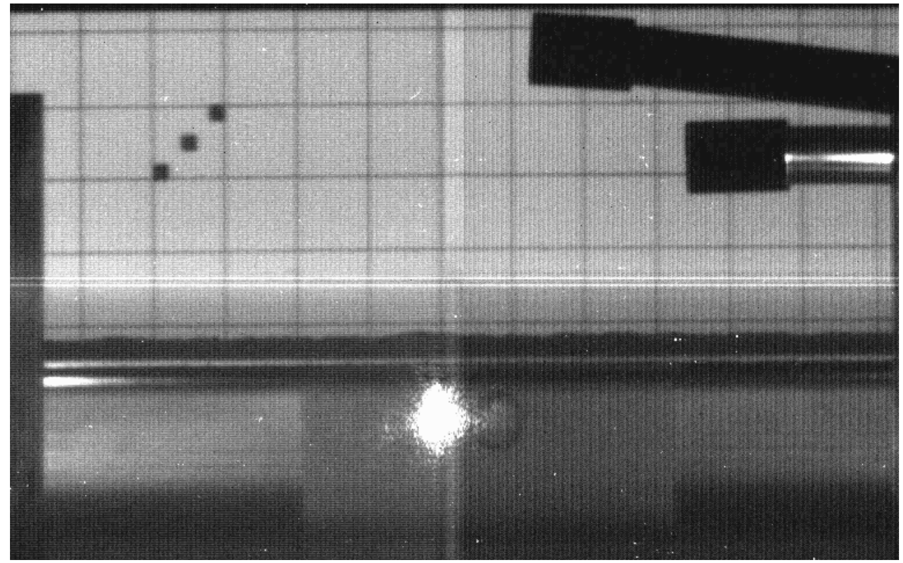
CFD simulation of Shot #8, assuming 1 micron particle size
(n.b. no lift with 25 micron particles at this intensity)



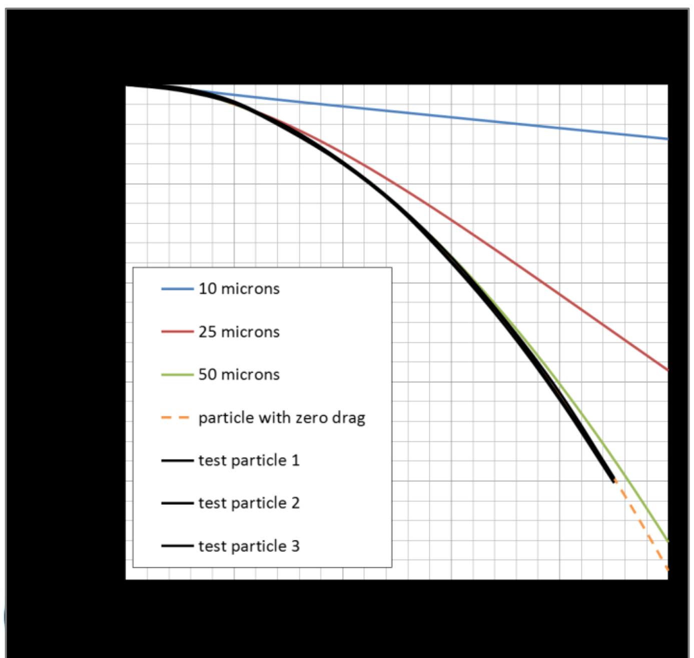


Grain Size Distribution



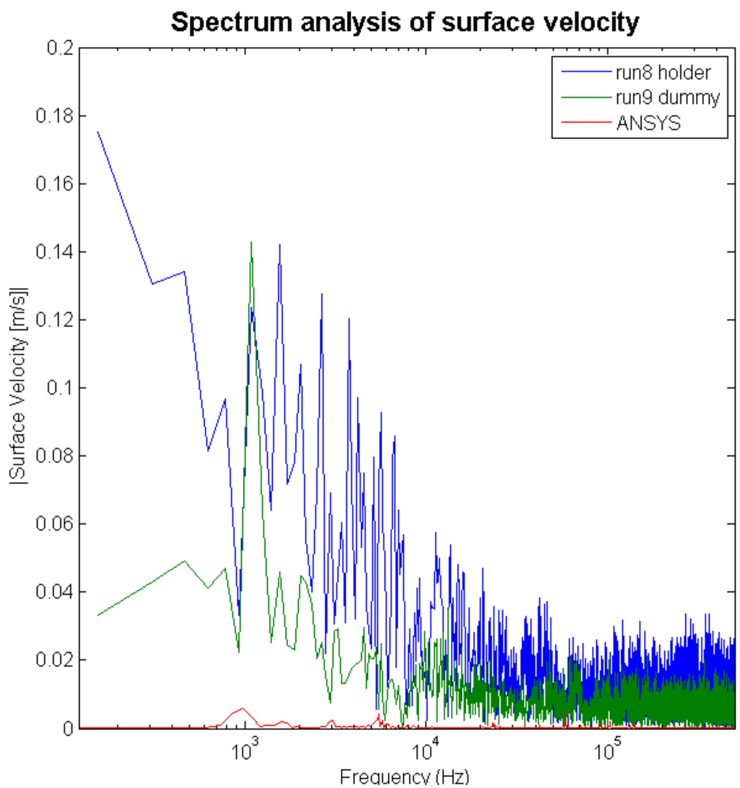


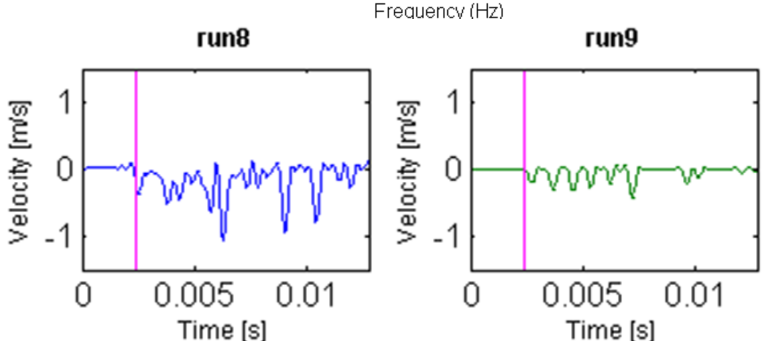
Shot #9, 1.85e11 protons



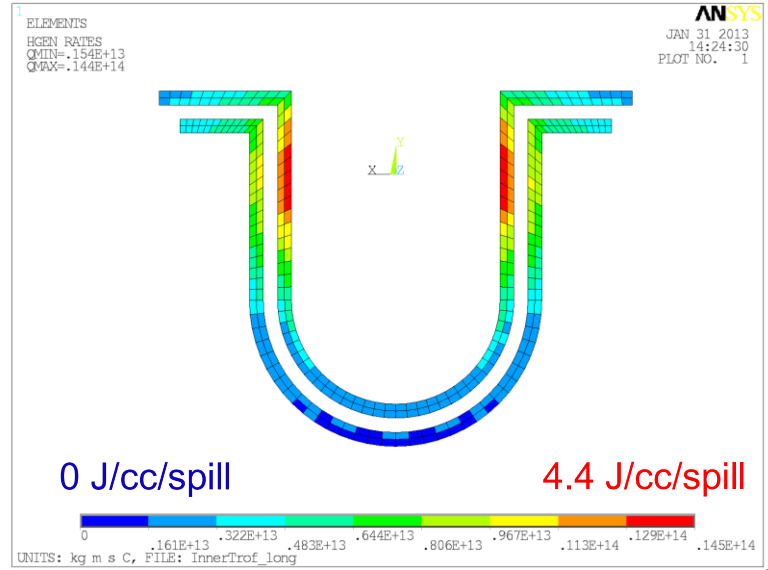
- Wide grain size distribution in sample (Maximum grain size is 300 microns)
- Video reveals that ***large*** grains are being lifted
- Leads us to believe the CFD simulation under-predicts the eruption threshold by an order of magnitude in intensity

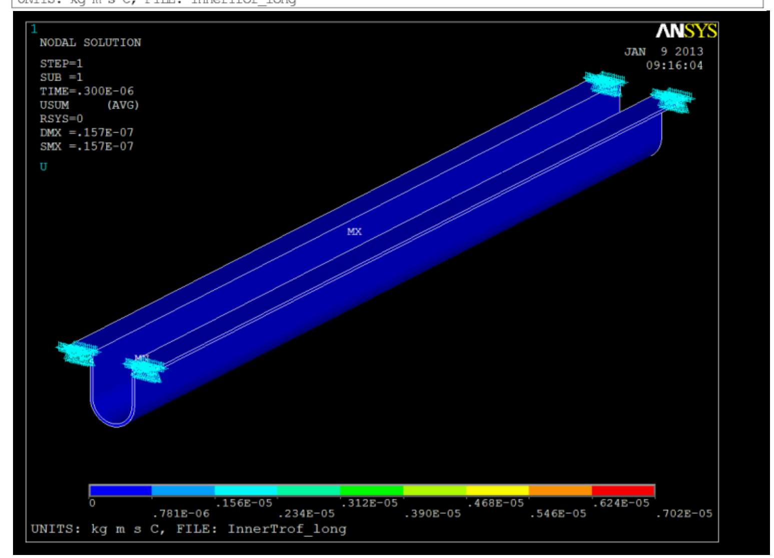
Trough-Wall Vibrations





LDV data, filtered and offset corrected
<Shot #8, 1.75e11 protons, inner trough>
<Shot #9, 1.85e11 protons, outer trough>
Velocity ≈ 1 m/s





ANSYS simulation of secondary heat induced vibrations
Velocity ≈ 0.1 m/s

What we Learned

1. Lift height

Correlates with deposited energy as expected

Could only see central part of the trough

2. Eruption threshold

Significant eruption seen at around 2e11 protons

Lift velocities of the order ~1 m/s

'Large' grains lifted – conflict with benchmark aerodynamic model

Observed threshold was an order of magnitude in intensity below expected

3. Trough Wall vibrations

Observed the ~1kHz resonant frequency of the trough

Inner trough response slightly larger than outer trough response in line with secondary heating model

Challenging measurement conditions (distance, mirrors, windows, noise)

Observed wall velocities an order of magnitude above those predicted by simulation

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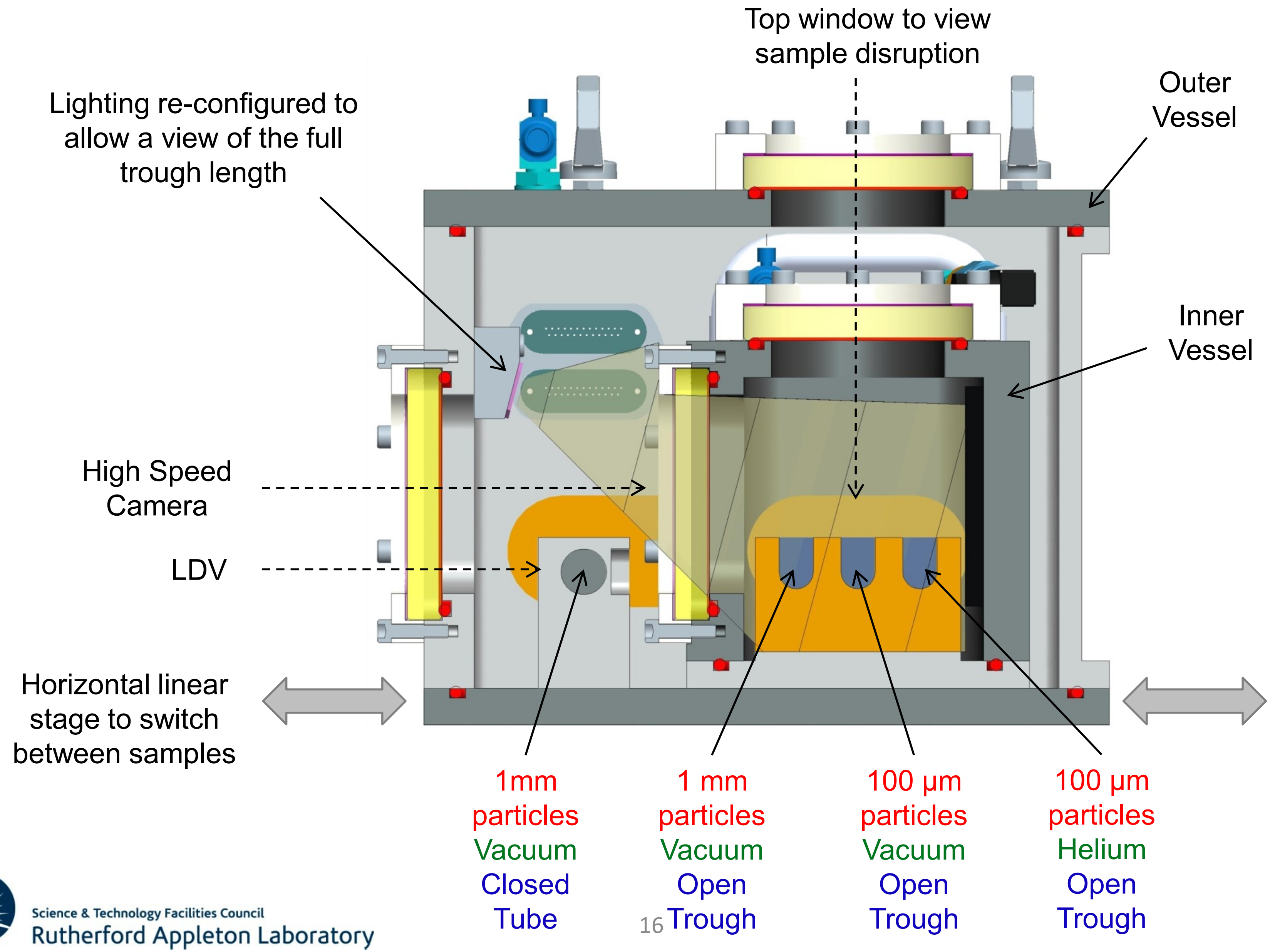
Question: is there something else going on, e.g. momentum transfer between grains?

HRM#2: Key Points

Opportunity for a 2nd HiRadMat test after CERN long shut-down (in 18 Months)

- Learn from experience of HRM#1
- Multiple samples with one shot per sample to eliminate the effect of sample disruption
- Separate aerodynamic effects momentum transfer effects – vacuum/helium environment
- Distinct particle sizing in samples to aid simulation benchmarking
- View full sample length, not just central 1/3 to better correlate lift with deposited energy

HRM#2: Multiple Sample Layout



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Summary

- Performed in-beam tests on a static tungsten powder sample at HiRadMat in June 2012

- Observed powder eruptions. Further questions raised.

- Opportunity for a 2nd HiRadMat test after CERN long shut-down (in 18 Months)

- Planning for a test which would allow us to separate the various different phenomena:
  - Particle size related effects
  - Aerodynamic Lift vs momentum transfer
  - Open trough vs closed container