Science & Technology Facilities Council

Fluidised Tungsten Powder Target Research

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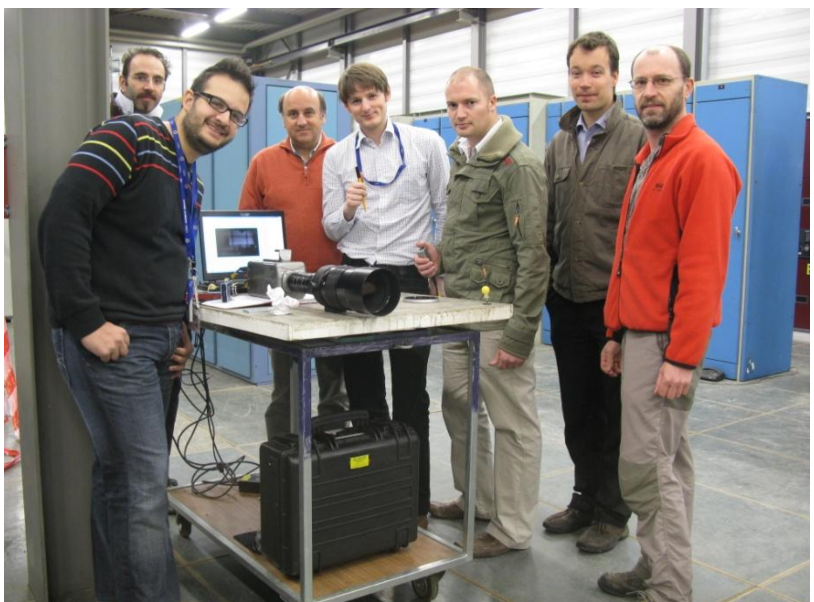
CERN



Experiment at HiRadMat CERN

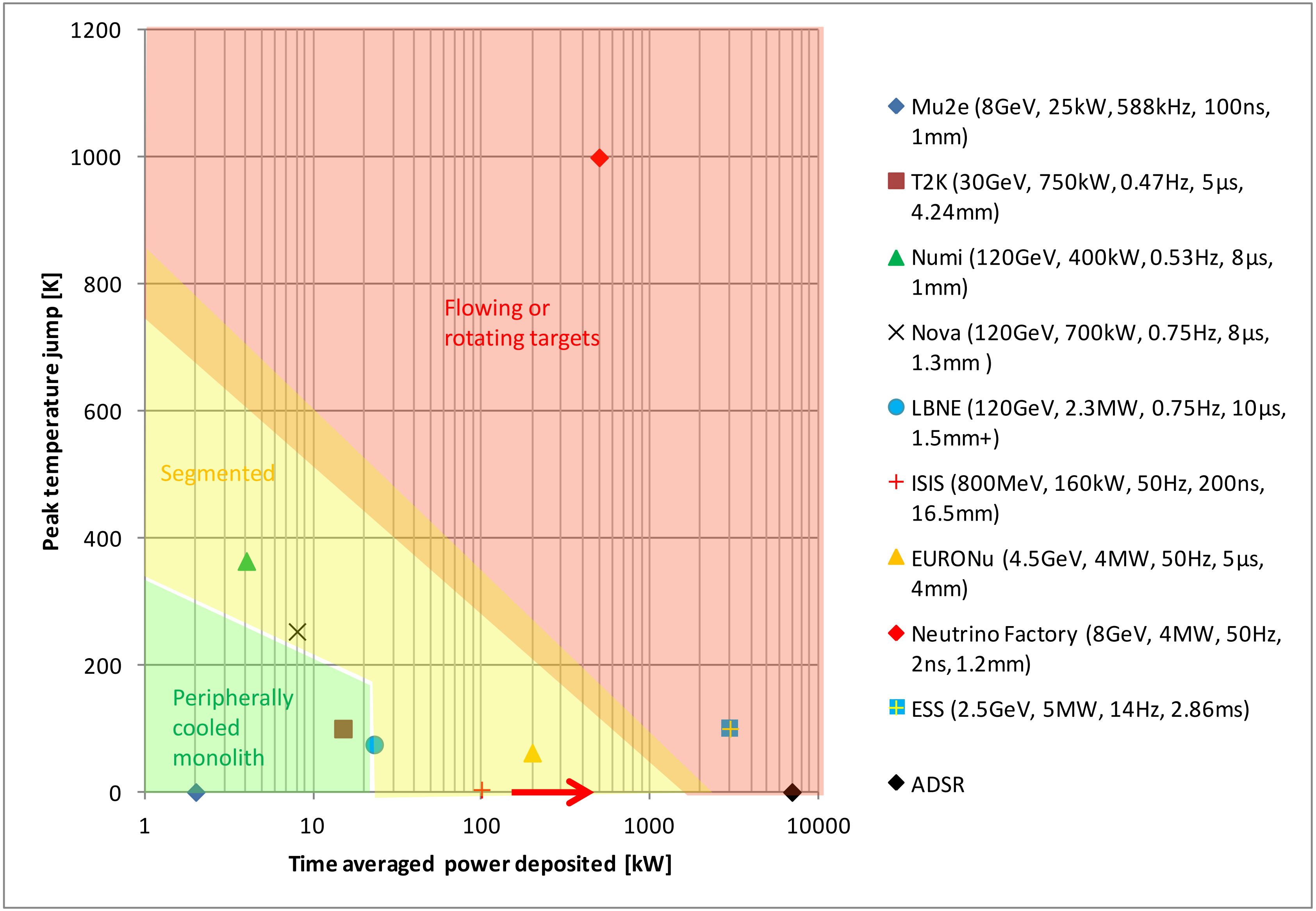
Funded by ASTEC, CERN subscript

High Power Targets

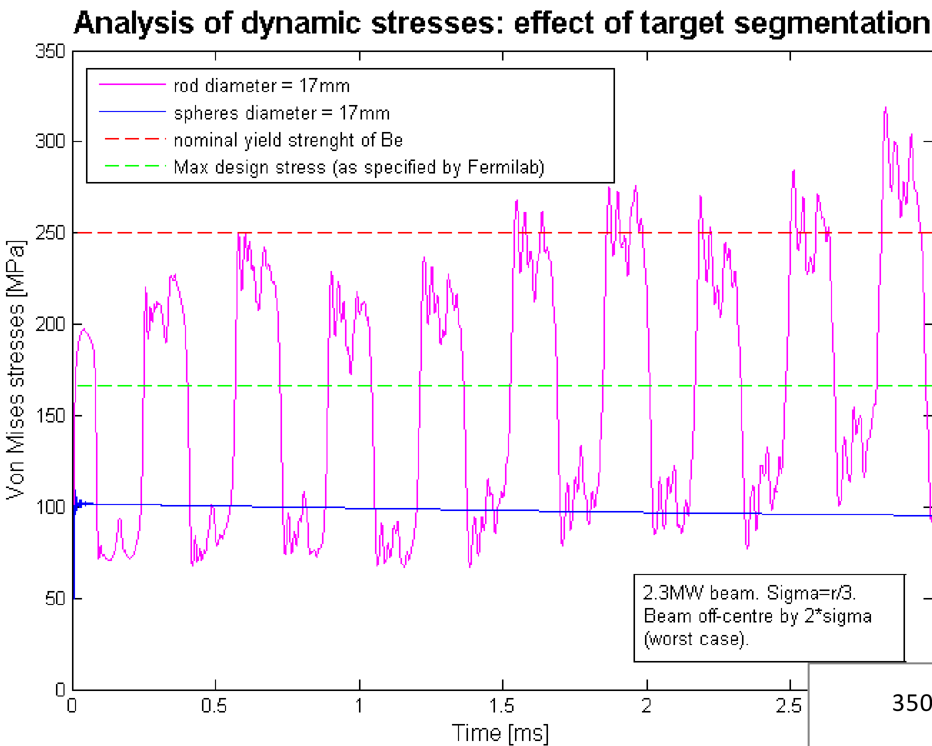
Current HPTG work programme

- T2K beam & target design & manufacture (STFC grant)
- Fluidised tungsten powder (ASTeC support)
- EUROnu (Superbeam) target and target station design study (FP7)
- LAGUNA-LBNO (Superbeam) design study (FP7)
- LBNE target study (FNAL contract)
- NuMI target study (FNAL contract)
- Mu2e target study (FNAL contract)
- NOvA target manufacture(FNAL contract)
- DiPOLE analysis (CLF)
- ESS target study (ESS contract)
- ISIS TS1 target development (ISIS support + STFC grant)
- RaDIATE -Radiation Damage in an Intense Accelerator Target Environment – PASI/FNAL

Limitations of target technologies



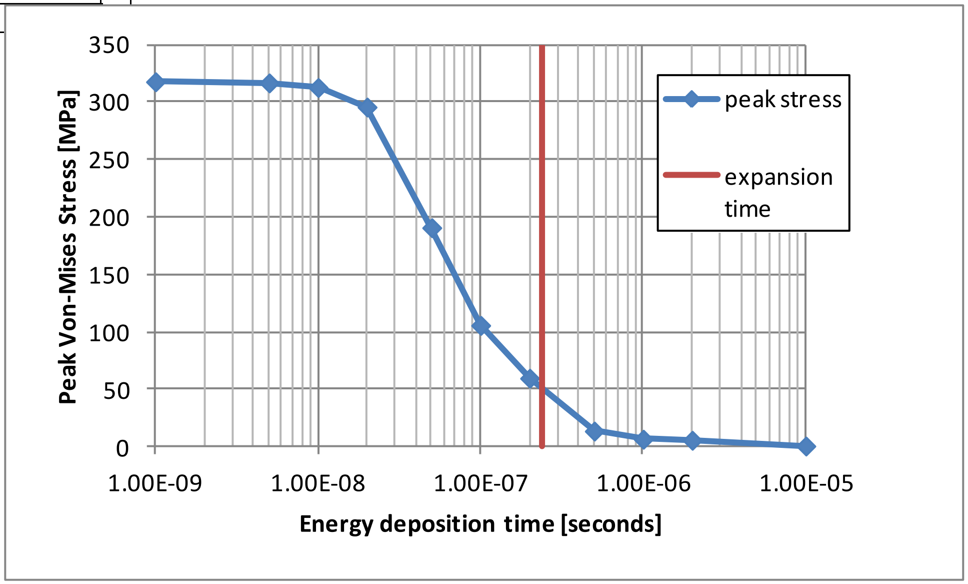
Thermal 'Shock' for a segmented target



Dynamic stresses in beryllium cylinder compared to beryllium spheres as a result of LBNE 2.3MW beam

Relationship between peak dynamic stress and energy deposition time for a sphere

Expansion time α target size



Three main candidate targets for a neutrino factory

Moving Solid Tungsten Bars (rotating or on a chain)

- Significant study on dynamic stresses and strain rate effects published
- Mechanical reliability in harsh operating environment still in question
- High quasi-static stress levels with baseline beam parameters

Mercury Jet

- Significant splashing as a result of pressure waves transmitted through the liquid
- Boiling of the mercury with IDS baseline beam parameters

Merit, Flowing mercury jet 14GeV proton beam Kirk et al.

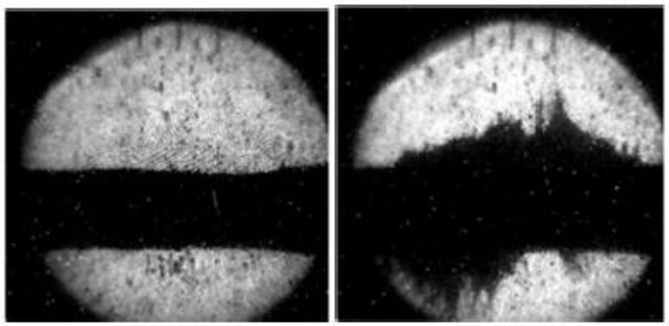
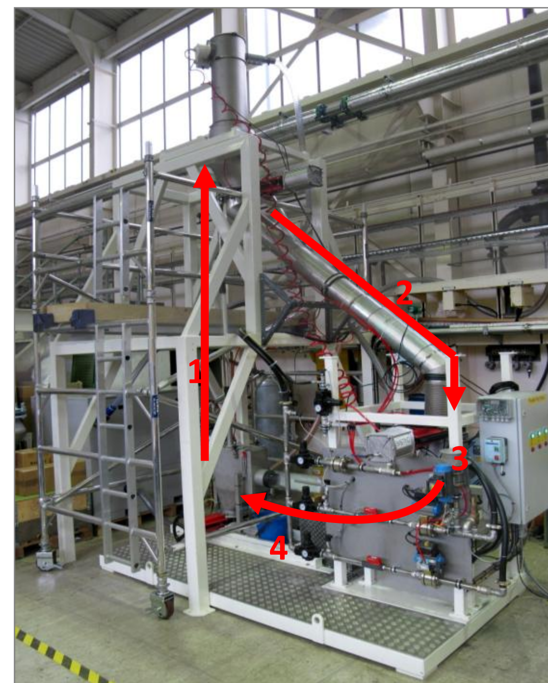


Figure 5: A proton beam/jet interaction as viewed in view port 2: Left image: before interaction; Right image: 350 μs after proton beam arrival.

Tungsten Powder

- Pneumatic conveyance of powder demonstrated in principle, on going work on developing continued operation and erosion avoidance techniques
- Response to proton beam heating untested



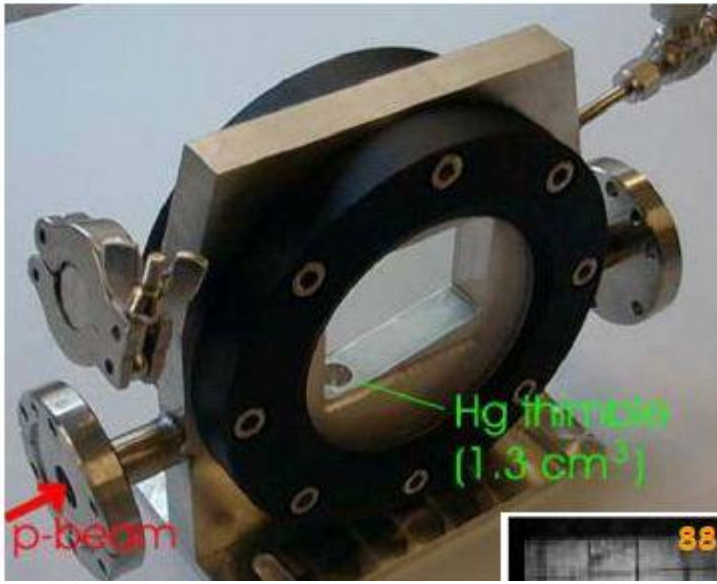
Motivation for in-beam powder test

- Splash and cavitation in a liquid (mercury) is a result of propagation and reflection of pressure waves through a continuous medium.
- It has been asserted that powder will not be subject to splashing or violent events because of its discrete nature. Individual powder grains do not easily transmit pressure waves to neighbouring grains and as such pressure waves tend to be contained within the grains.
- A mechanism for a powder eruption has been identified as a result of a beam induced pressure rise in the carrier gas. The expansion of the carrier gas may be violent enough to aerodynamically lift some powder. While this is a potentially interesting threshold to find we expect that it will confirm that eruption velocities are small compare to the splashing velocities observed with mercury.
- In order to confirm these assertions the response of a powder target to the proton beam must be tested to definitively answer the following two questions
- Will a powder target splash/erupt?
- Can you propagate a pressure wave through a powder target to its container?

Replicate mercury thimble experiment for tungsten powder

ISOLDE Hg-thimble test

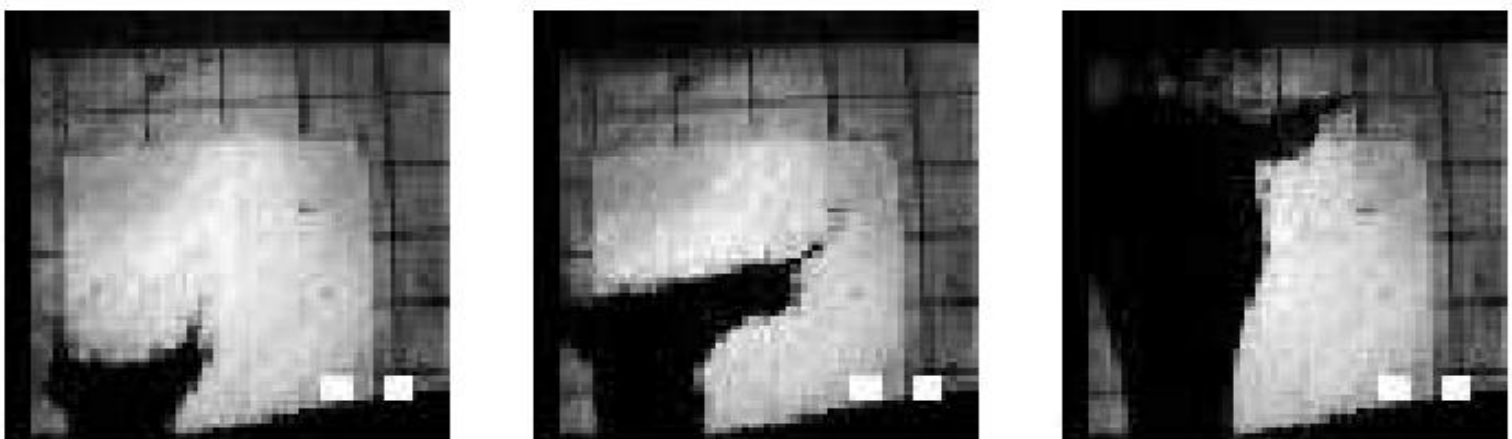
A. Fabich, M.Benedikt, J. Lettry



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.

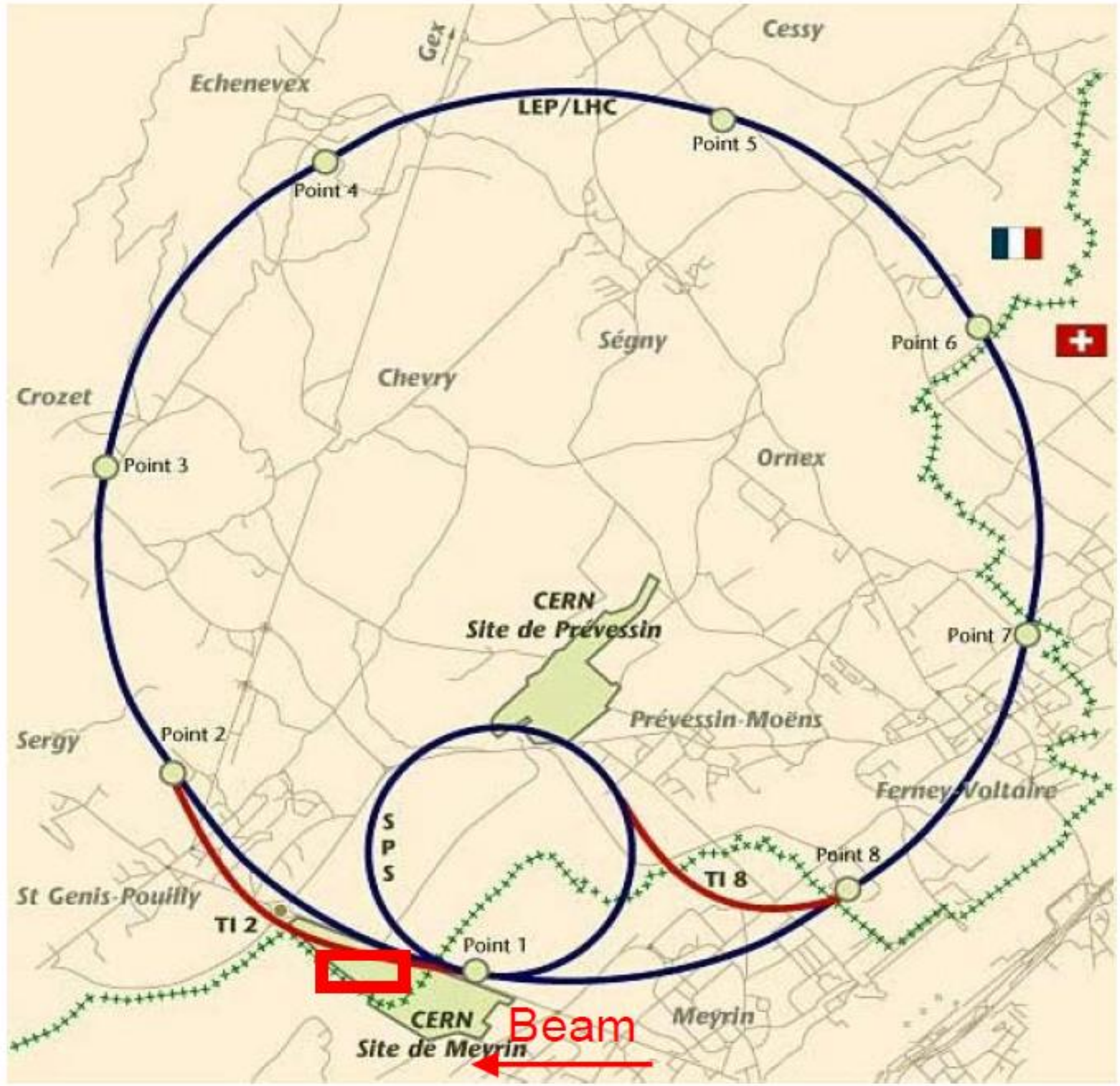
The Hg interaction with 1.4 GeV, 4 10^{12} p^+ is shown below.



Location of HiRadMat

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](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]



Tungsten Sample and Sample Holder

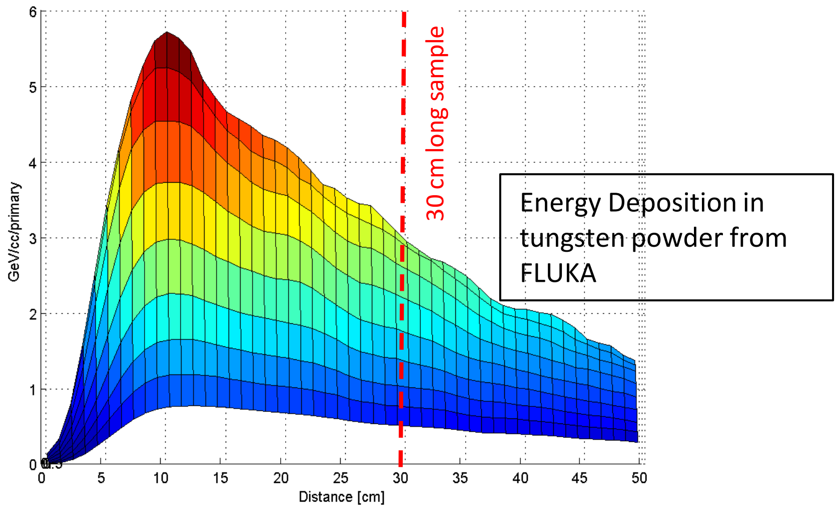


Figure 1 Energy deposition in a tungsten-helium compound (50% vol for each component)

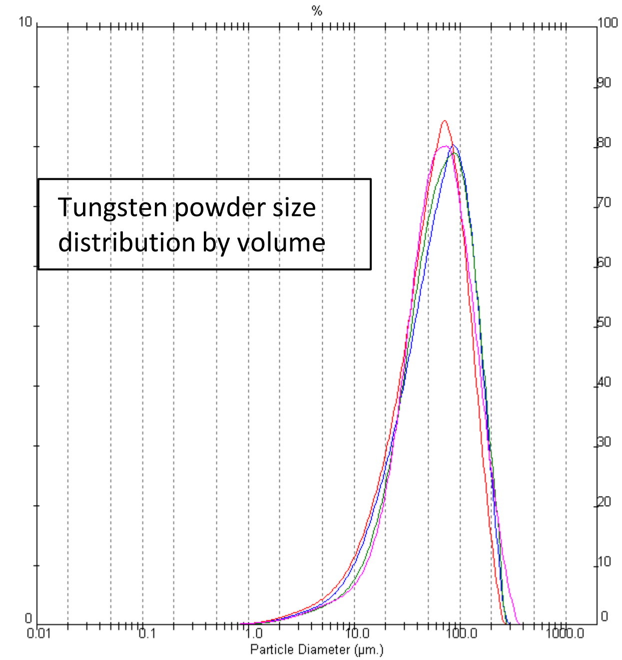
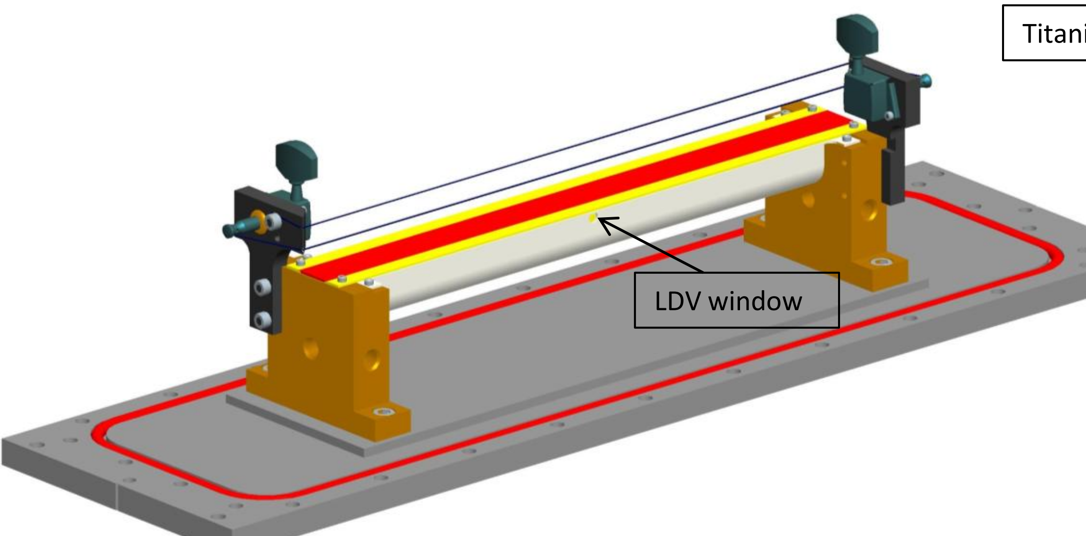
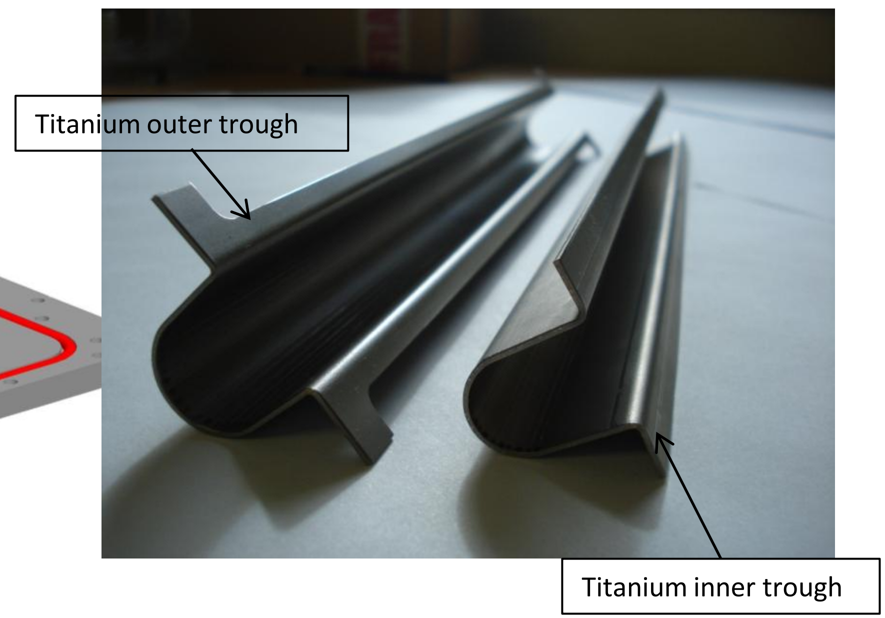
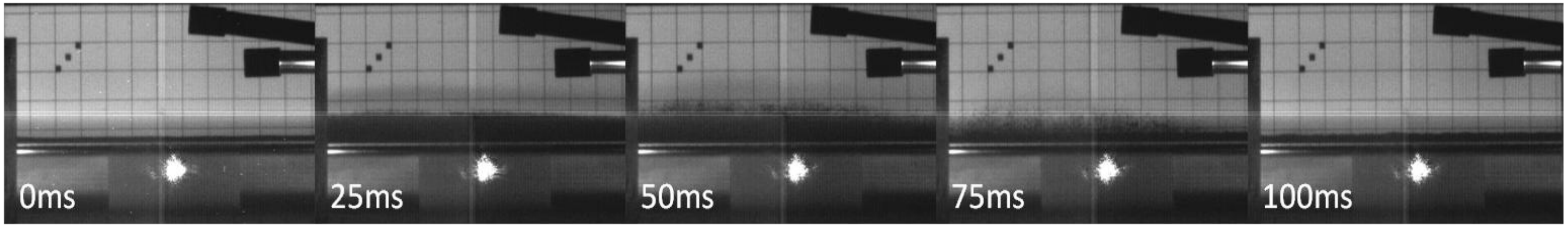


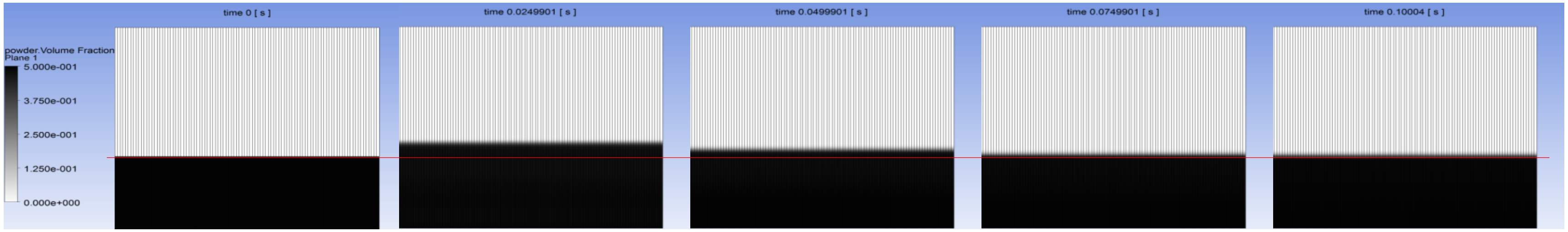
Figure 1. Variation of size distribution for different stirrer p

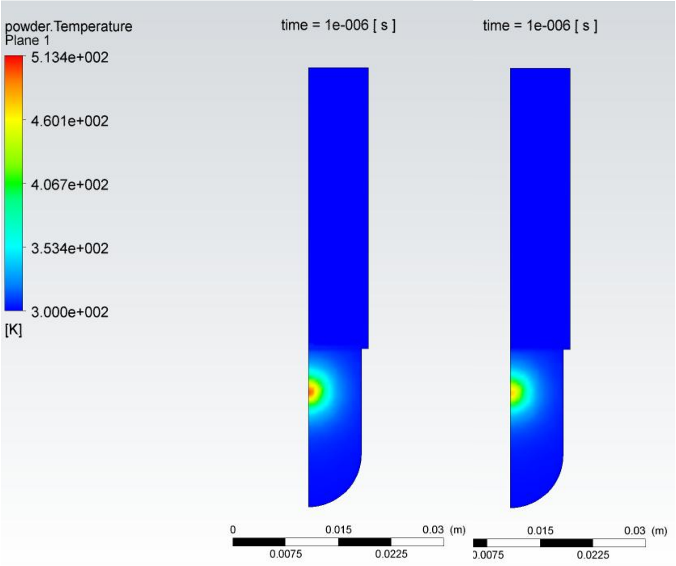


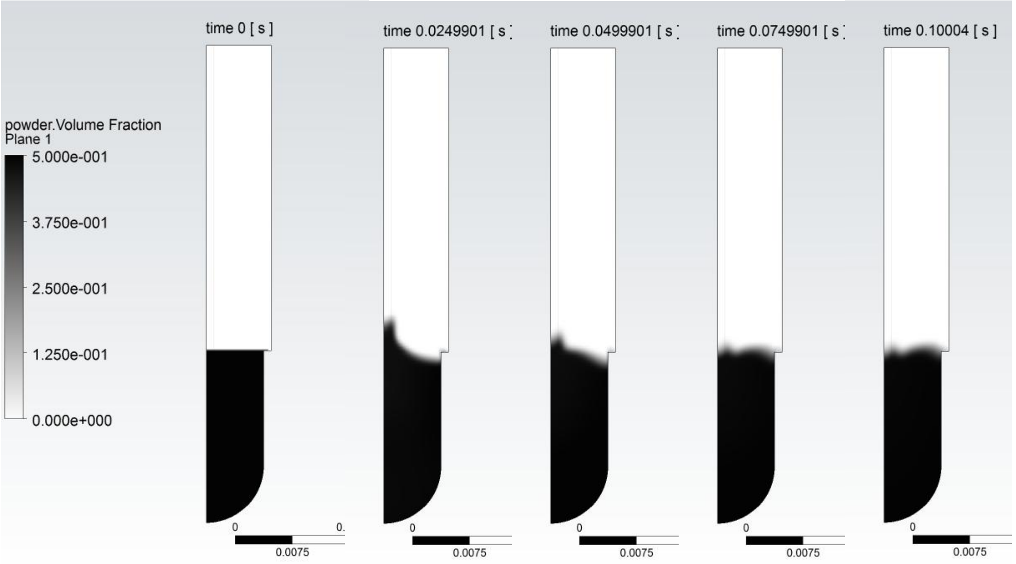


Pulse 8 - 1.75e11 protons; Beam Sigma = 0.75mmx1.1mm
Results vs CFD (1micron diameter particles)

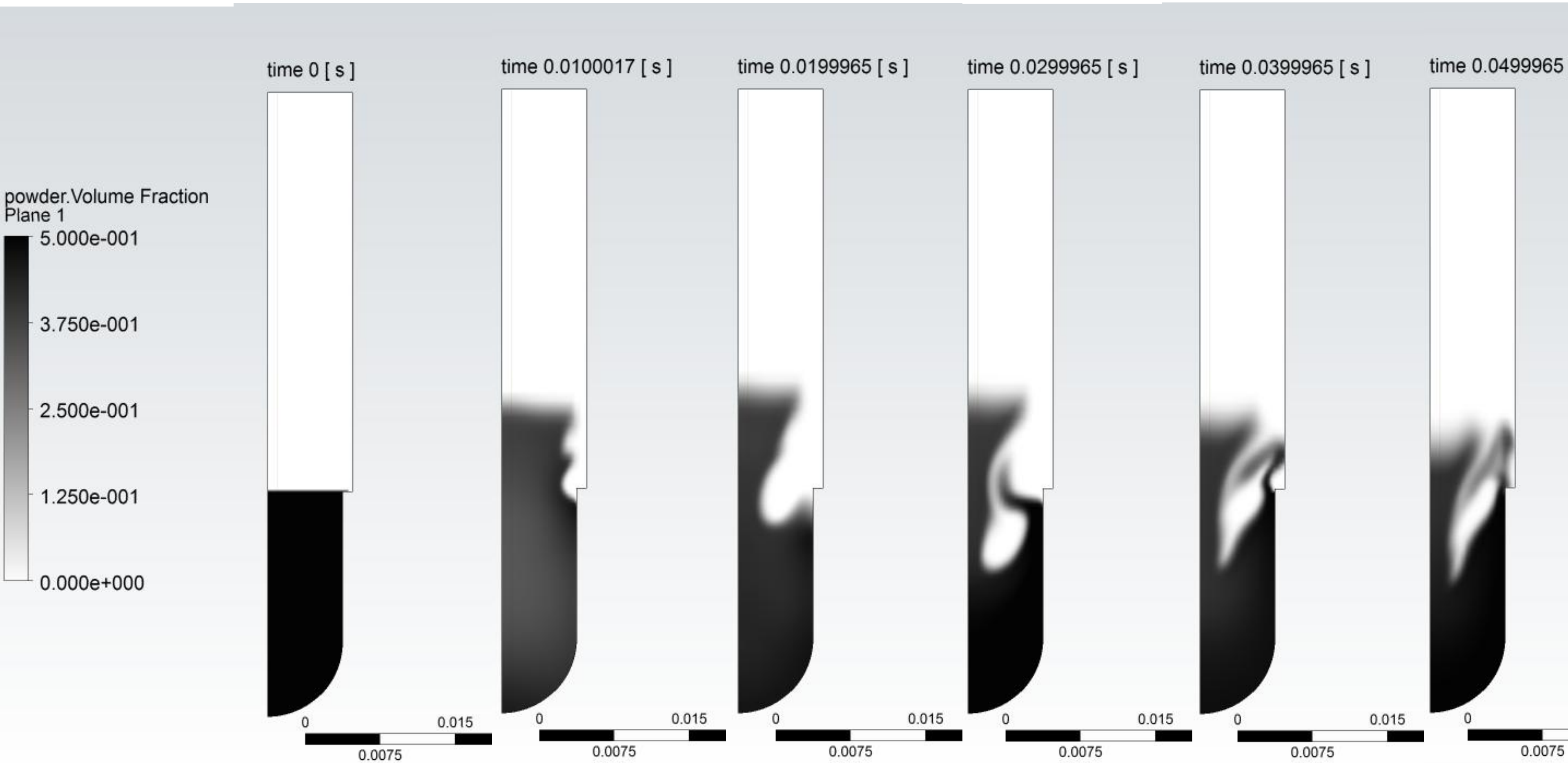








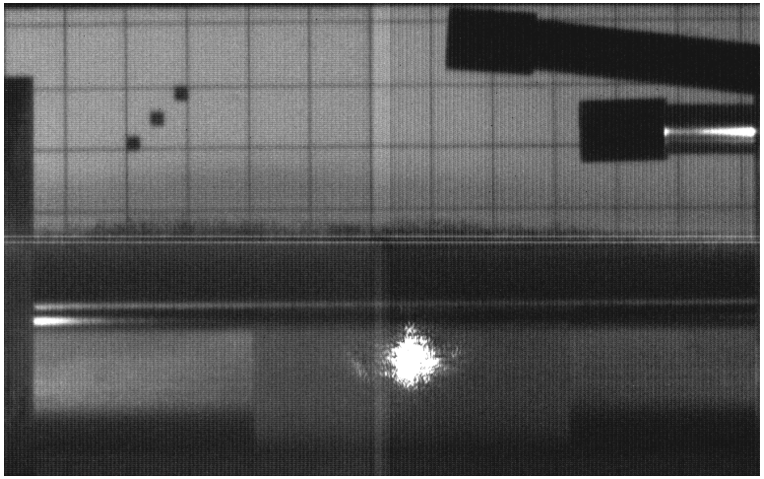
Simulating a more violent response intensity = 1.2e12 protons



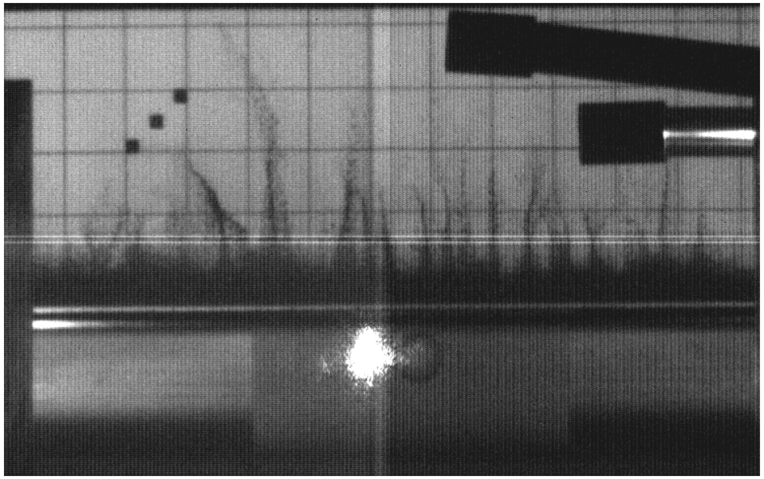
Effect of a perturbed powder surface?

Both after 30ms, at a similar intensity

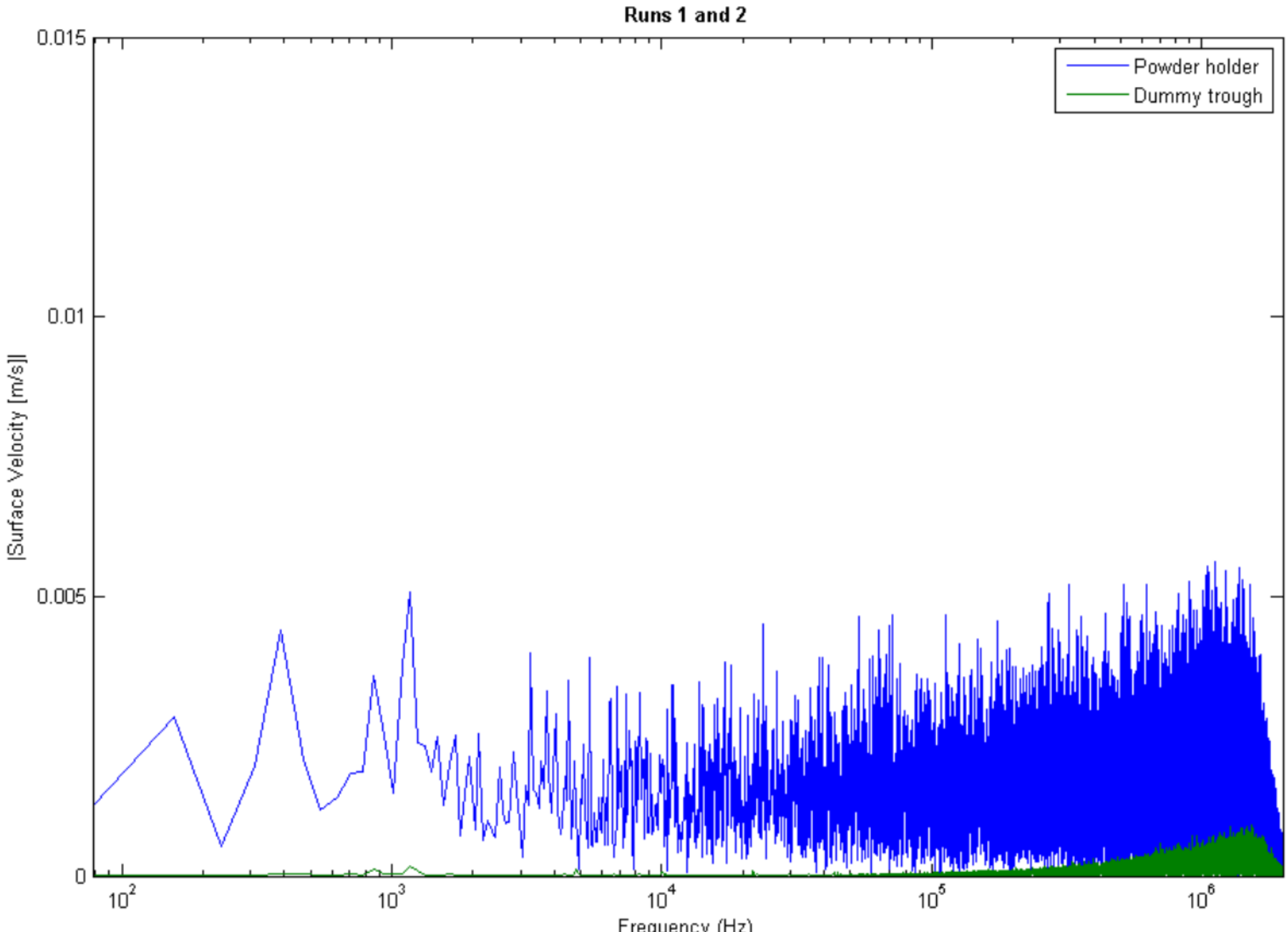
Pulse 8



Pulse 9



Laser Doppler Vibrometer results: 10^9 proton pulse



Interim conclusions

A recent experiment at the HiRadMat facility at CERN has demonstrated that there is a threshold proton pulse intensity above which a powder target will erupt

Eruption velocities seen here are at least an order of magnitude less than the splash velocities seen with previous Mercury in-beam experiments for the same pulsed power density

One mechanism for eruption is thought to be beam heated gas, aerodynamically lifting powder as it expands and escapes from the powder.

A CFD model simulating this mechanism is underway, however the effect observed appears greater than that expected, and larger grains are lifted rather than the smaller ones expected. Is another mechanism responsible?

Future work

- HiRadMat data analysis
  - LDV results interpretation
  - Powder eruption modelling
  - Planning for future experiment in vacuum to isolate gas lift from other effects
- Tungsten powder rig – considerable future development required
- Target station design layout & physics performance

Program of Experiments for novel target solutions

Offline powder conveying experiments

- Dense phase ejection
- Suction at same rate as ejection
- Complete recirculation in batch mode demonstrated
- CW operation
- Heat transfer tests

In-Beam tests

- Powder experiment #2 in vacuum
- Pebble bed target (for superbeam EUROnu / Laguna)
- Window survivability (single pulse failure tests)