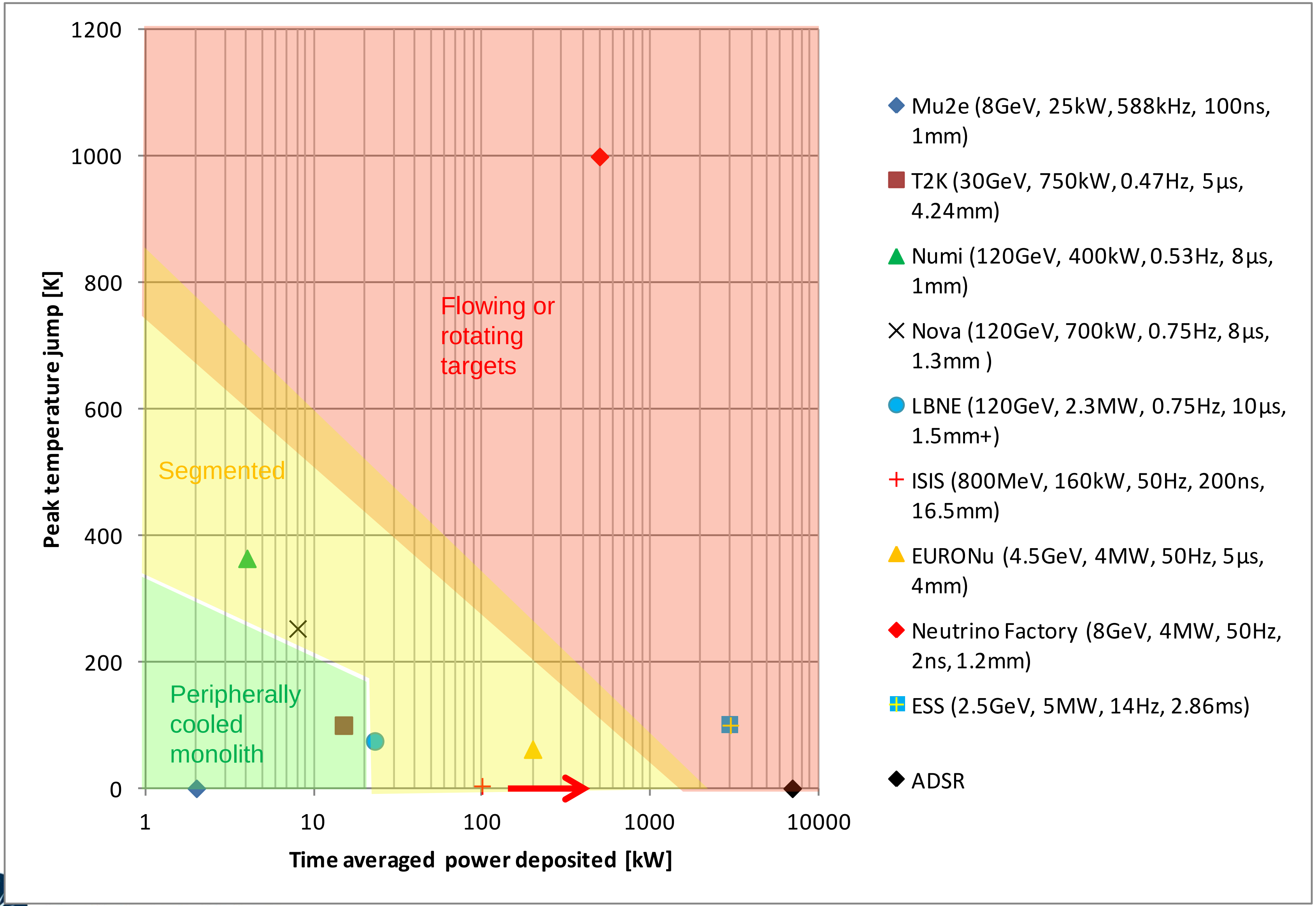
Fluidised powder target research

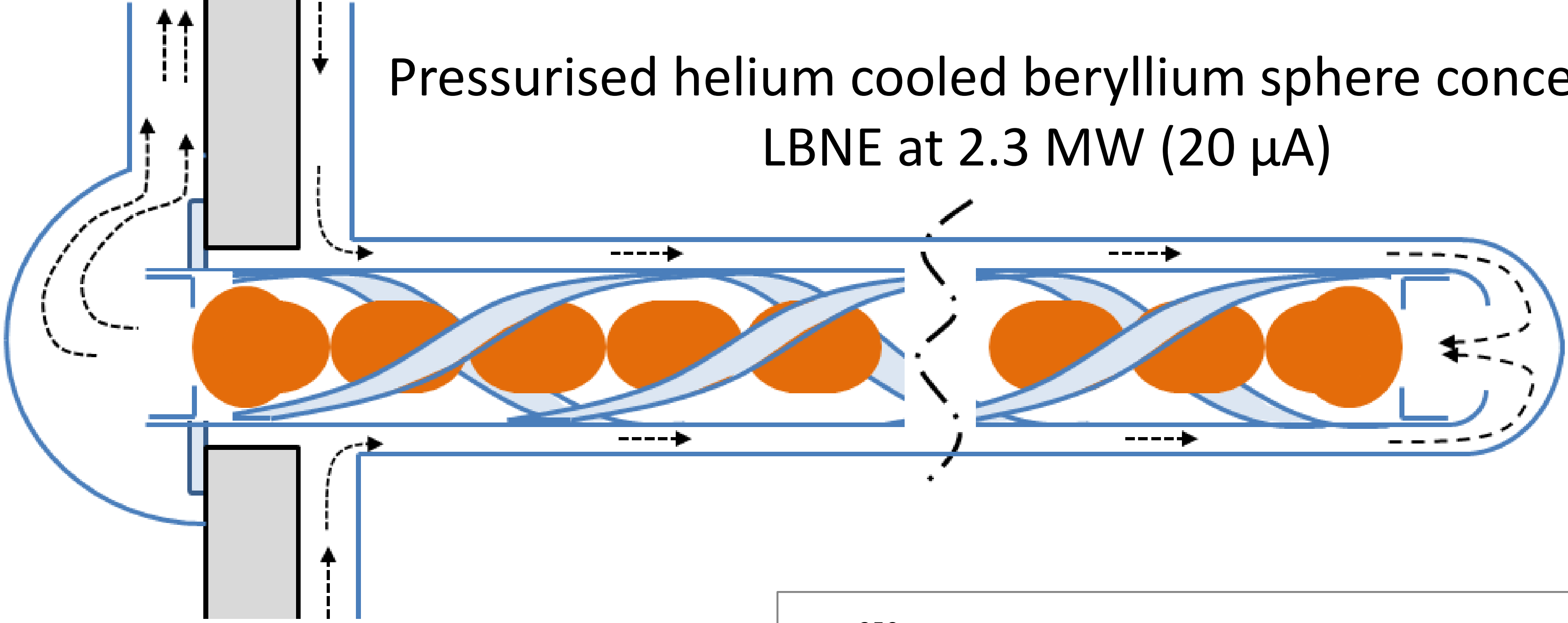
Chris Densham, Ottone Caretta, Tristan Davenne, Peter Loveridge,
Andrew Atherton, Luke Fry, Mike Fitton,
Joe O’Dell, Dan Wilcox, Jennifer Wark
(RAL)

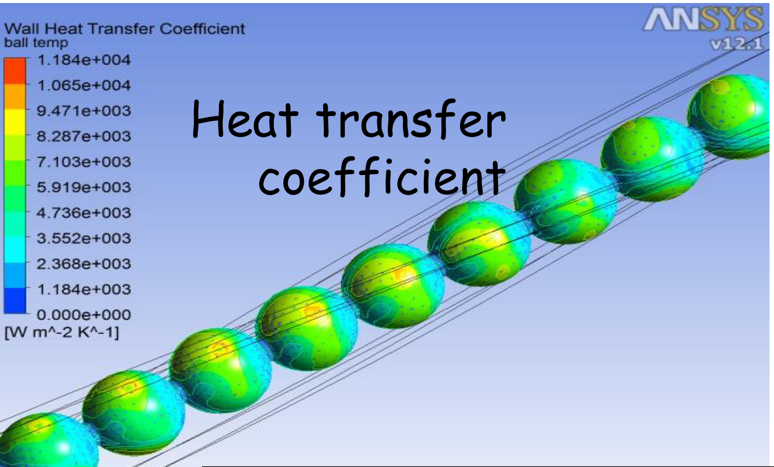
Ilias Efthymiopoulos, Nikolaos Charitonidis, Adrian Fabich
(CERN)

Heat Removal and Thermal Stress Summary

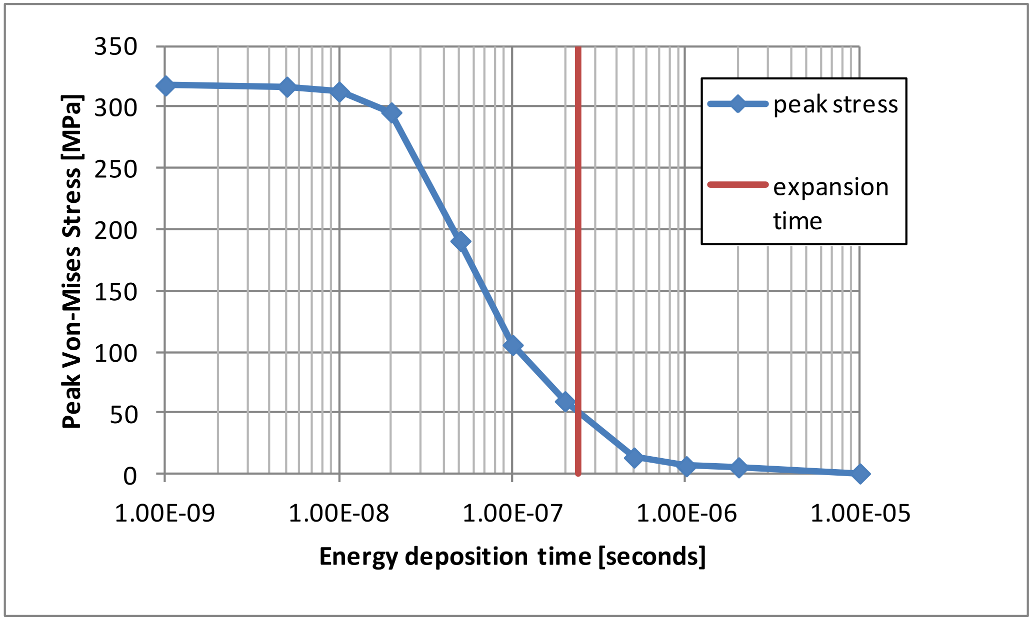


Pressurised helium cooled beryllium sphere concept for LBNE at 2.3 MW (20 µA)





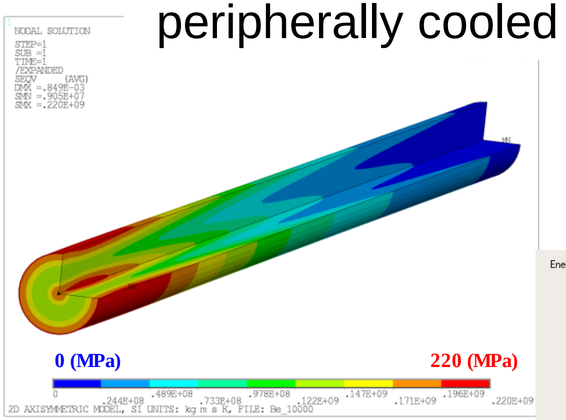
Heat transfer coefficient

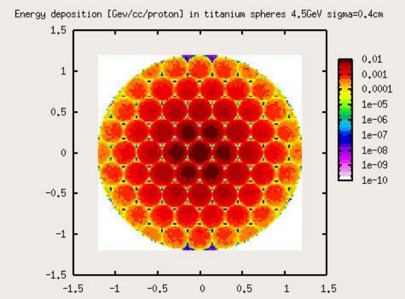


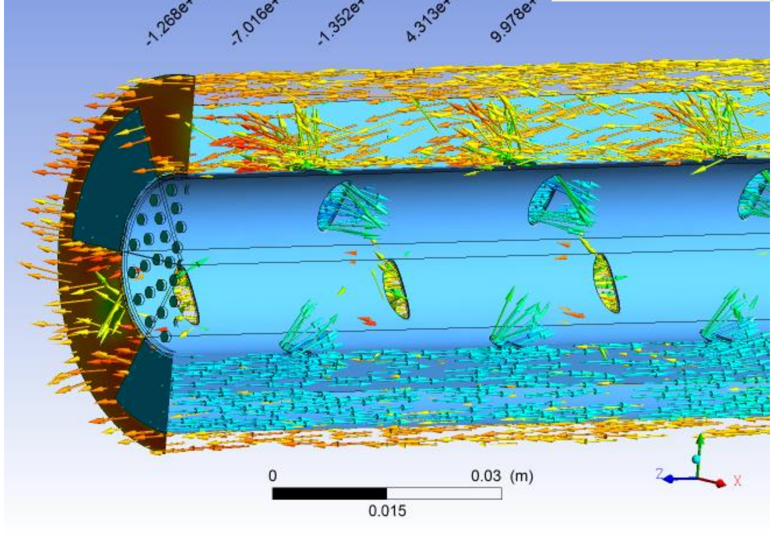
Stress vs beam spill length for fixed radius sphere

Packed bed target (EUROnu study for SPL-Superbeam)

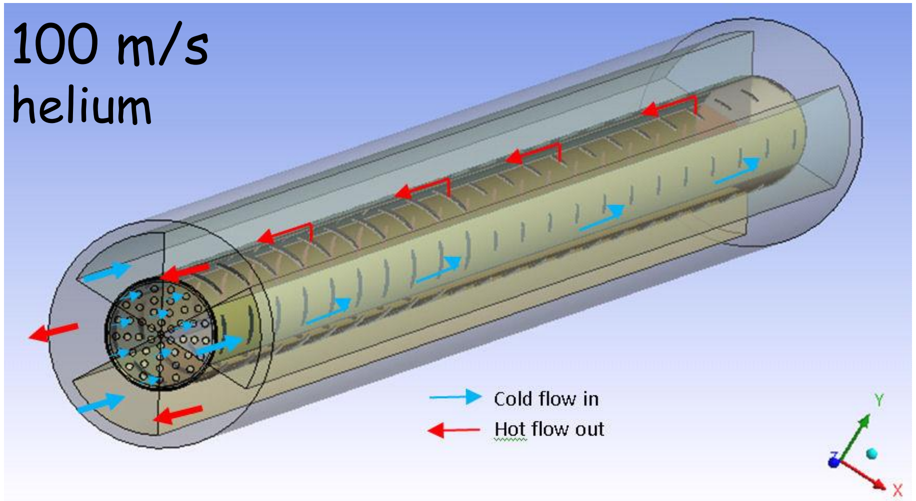
Stress limit reached for solid peripherally cooled target



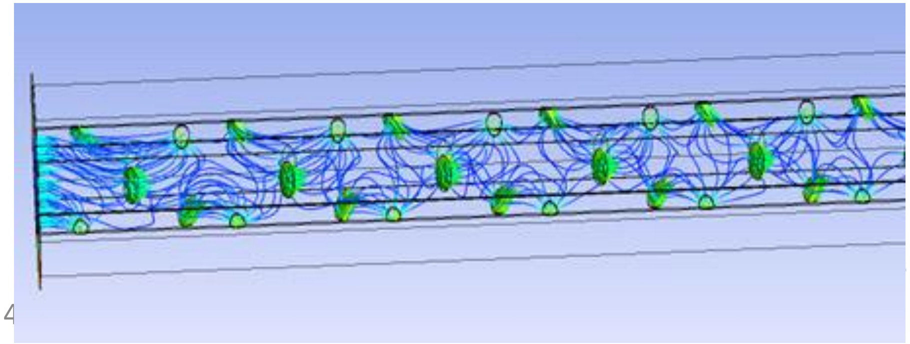




Increased surface area. Coolant reaching maximum energy deposition region

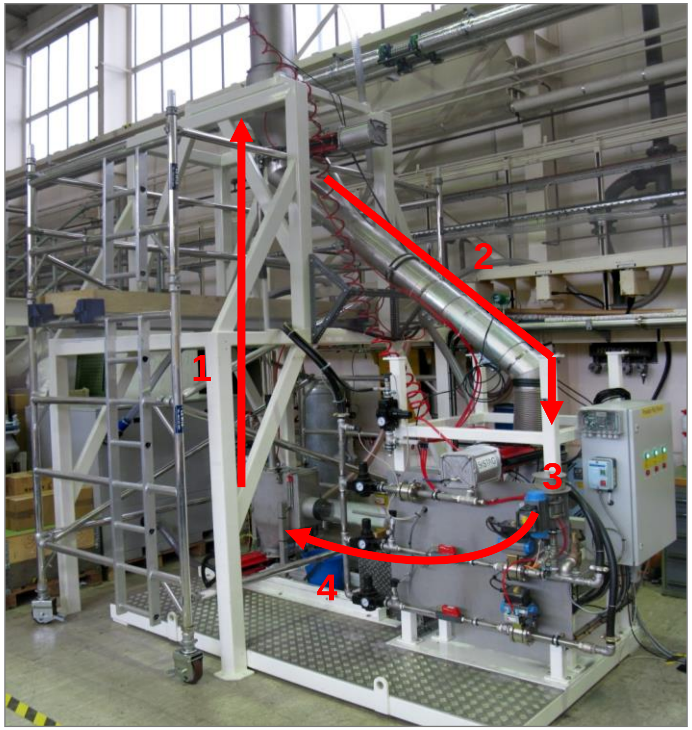


Packed bed target concept for 1 MW (200 μA per target) Limit for static target?

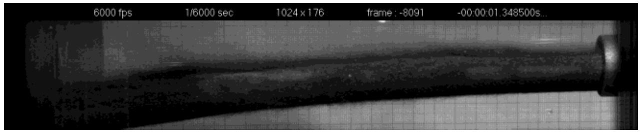


Fluidised tungsten powder target off-line test rig

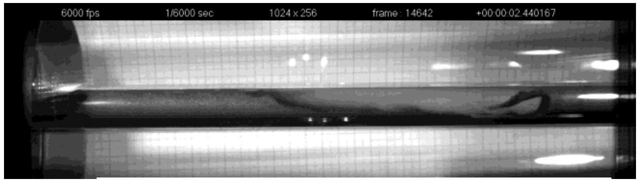
- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Containment / erosion
  - Heat transfer and cooling of powder



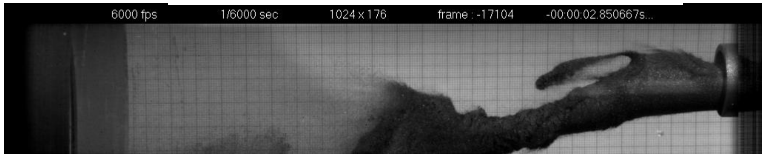
Dense-phase delivery



High speed image: tungsten powder jet

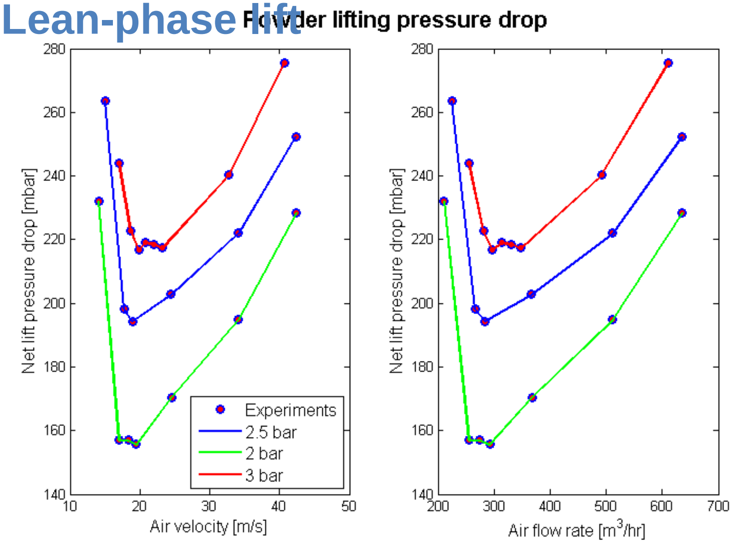


High speed image: tungsten powder flow in a pipe



Unstable tungsten powder jet

Lean-phase lift



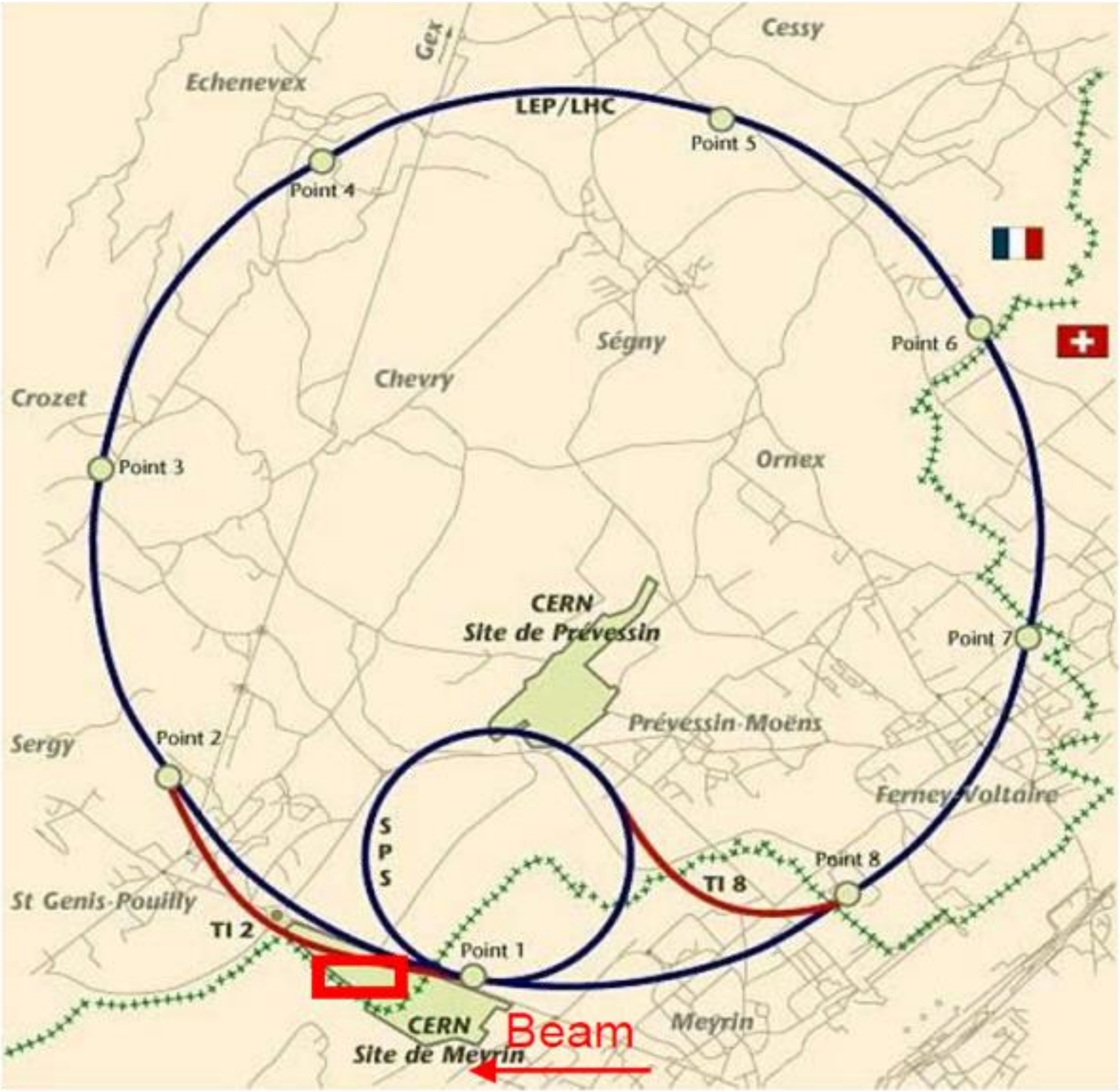
Location of HiRadMat

Pulsed-beam experiment June 2012

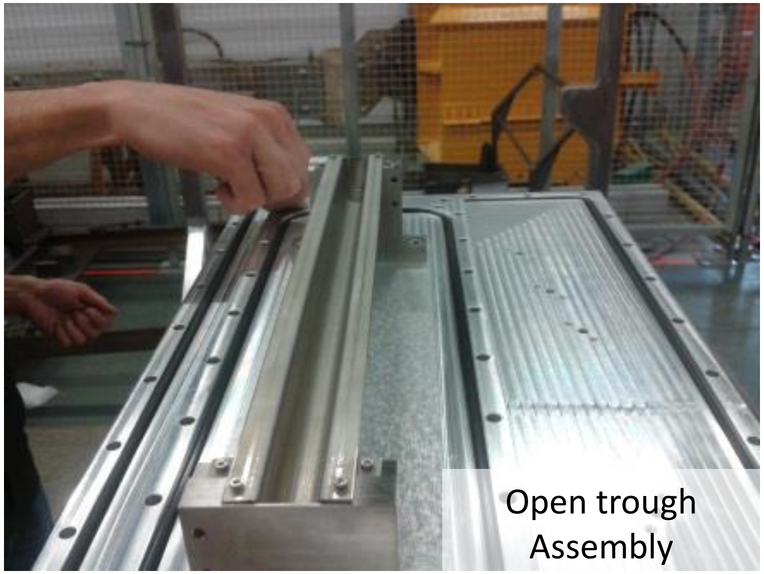
HiRadMat Beam Parameters:

A high-intensity beam pulse from SPS of proton or ion beams is directed to the HiRadMat facility in parasitic mode, using the existing fast extraction channel to LHC..

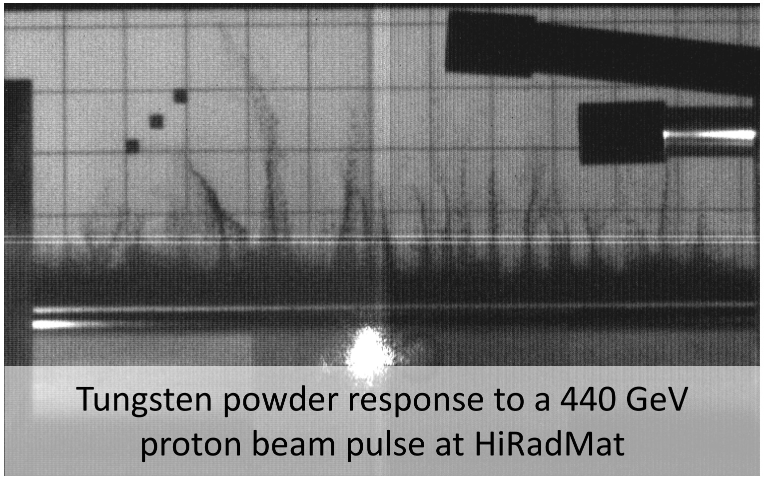
Beam Energy 440 GeV
Pulse Energy up to 3.4 MJ
Bunch intensity $3.0 \cdot 10^9$ to $1.7 \cdot 10^{11}$ protons
Number of bunches 1 to 288
Maximum pulse intensity $4.9 \cdot 10^{13}$ protons
Bunch length 11.24 cm
Bunch spacing 25, 50, 75 or 150 ns
Pulse length 7.2 µs
Beam size at target variable around 1 mm^2



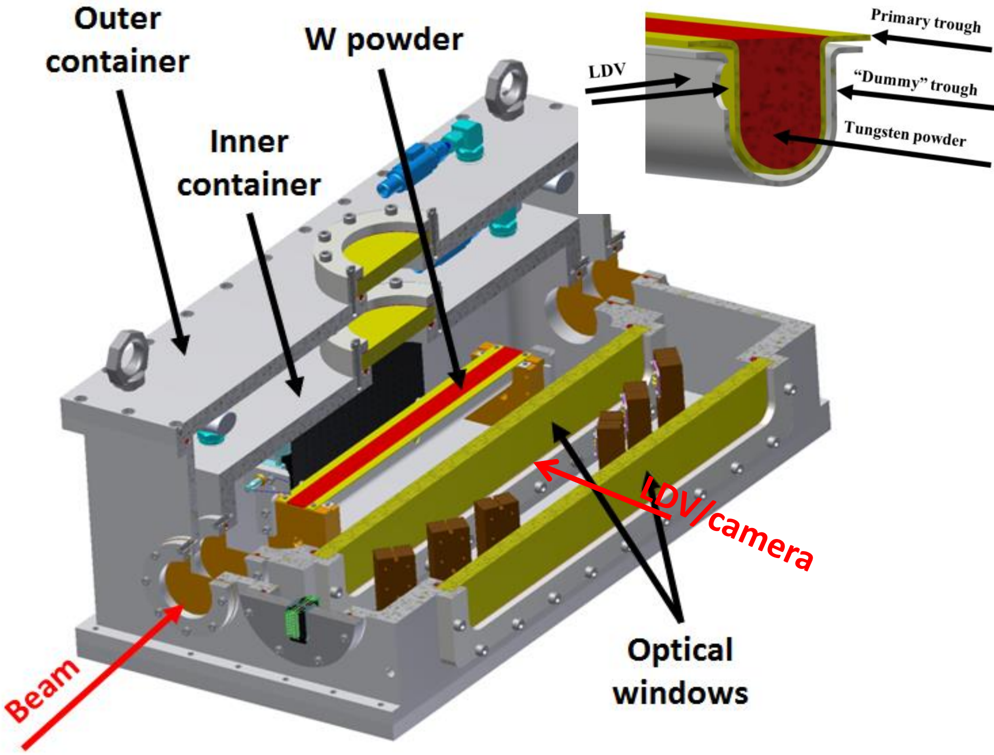
In-beam experiment at HiRadMat, CERN



Open trough Assembly



Tungsten powder response to a 440 GeV proton beam pulse at HiRadMat



- ❑ Single tungsten powder sample in an open trough configuration
- ❑ Helium environment
- ❑ Remote diagnostics via LDV and high-speed camera

HRMT-10: *What We Learned*

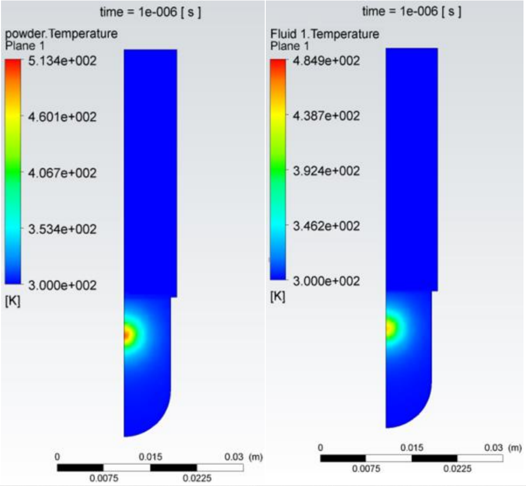
- Identified an Energy threshold, beyond which significant eruption of the powder occurs
- Lift height correlates with deposited energy
- Eruption velocities are low when compared to liquid metal splashes

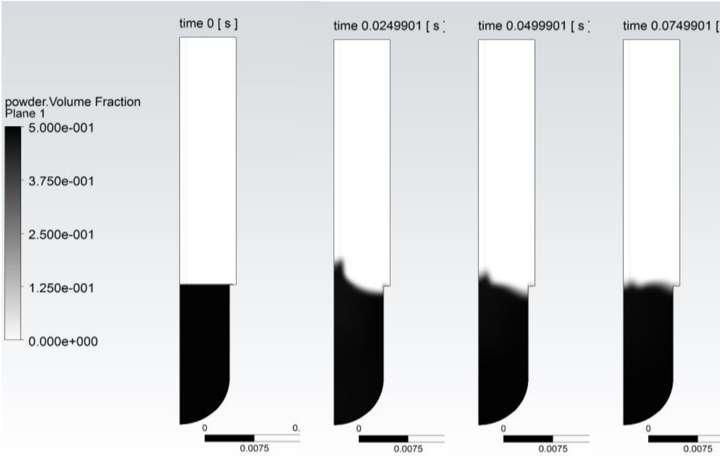
HRMT-10: *Open Questions*

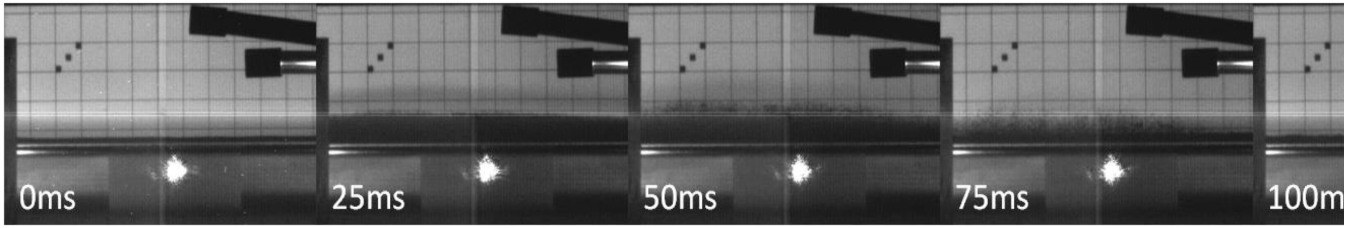
- Can Aerodynamic processes alone be shown to account for the observed response? Or is there something else going on?
- Can we rule out other mechanisms such as:
    - i. direct momentum transfer between grains (i.e. shock-transmission through the bulk solid)
    - ii. An electrostatic mechanism
    - iii. Trough Wall vibrations exciting the powder
- **-> Off-line test programme**
- **-> New experiment at HiRadMat**

Davenne: CFD predictions/post fits

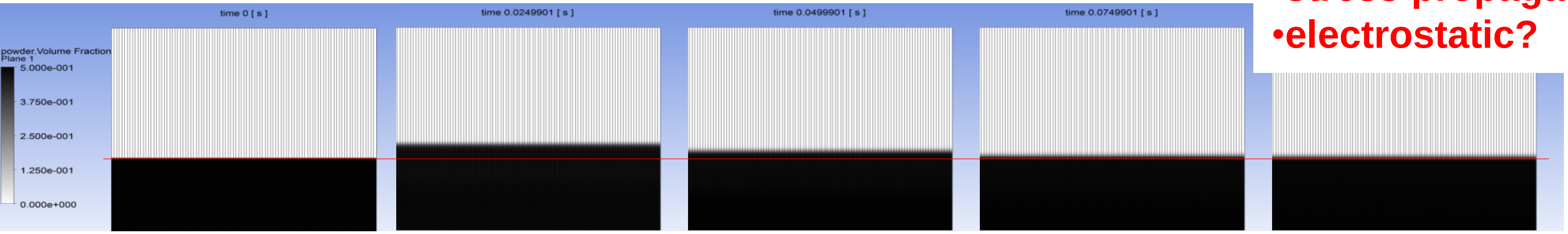
Beam heating







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



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

Powder lift was predicted by CFD

However the threshold intensity to lift the powder was found in the experiment to be an order of magnitude lower than predicted

So is the lift:

- **aerodynamic?**
- **stress propagation?**
- **electrostatic?**

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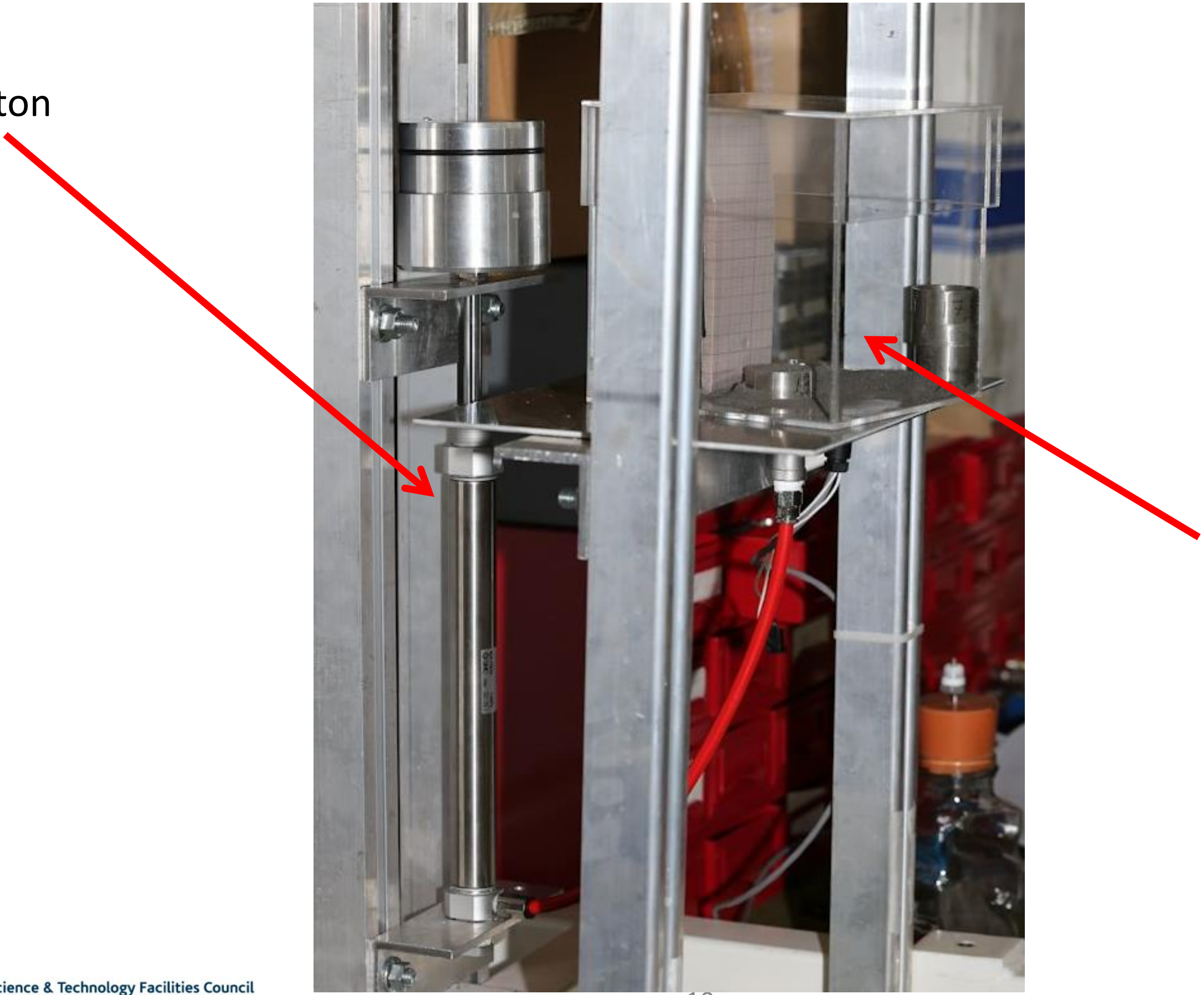
Tungsten powder puff experiment: understanding the powder lift

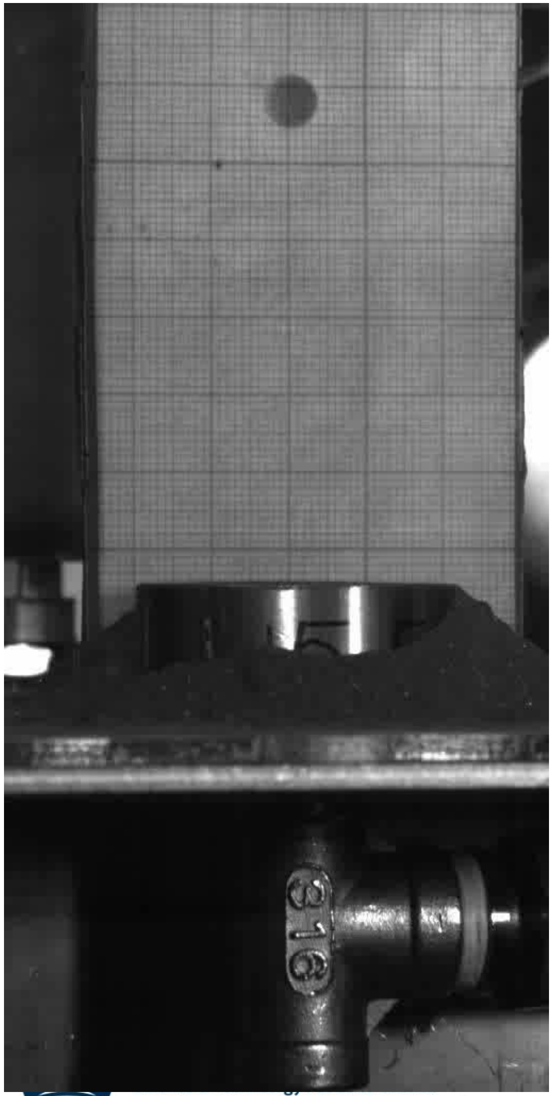


piston

Puff cell

Tungsten powder puff experiment

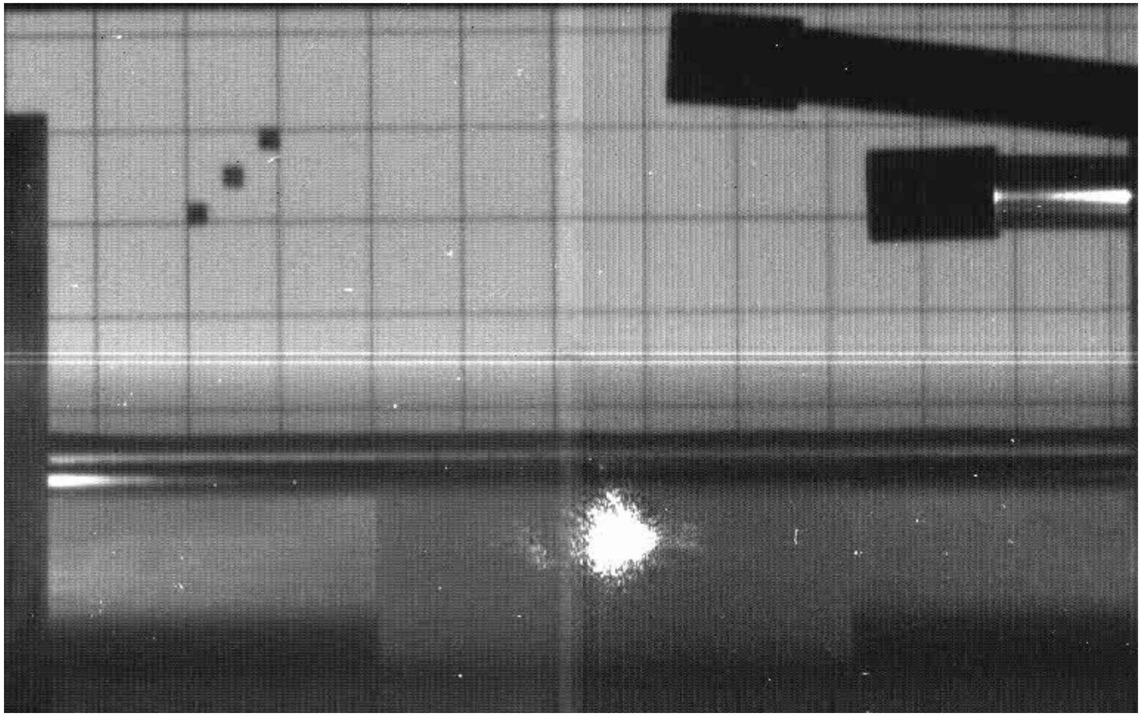
Off-line test



- Aim: To compare behaviour of Tungsten powder after a short pressure spike against the behaviour in the HiRadMat experiment

- Method: Use a short pressure pulse to lift the powder

On-line test



Understanding powder lift

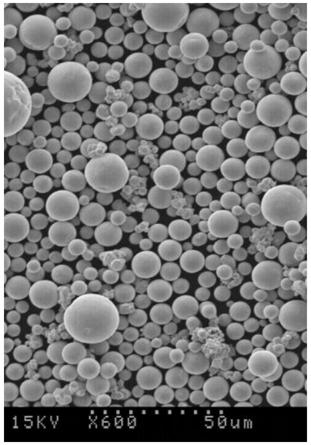
Pressure drop for air flowing through a bed of powder

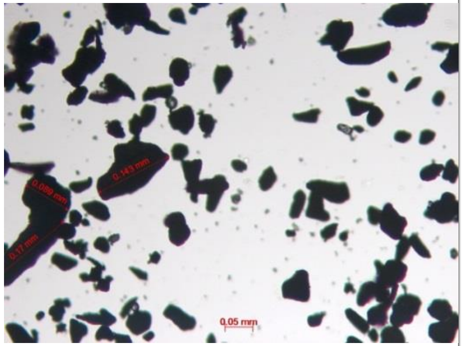
Atherton, Davenne

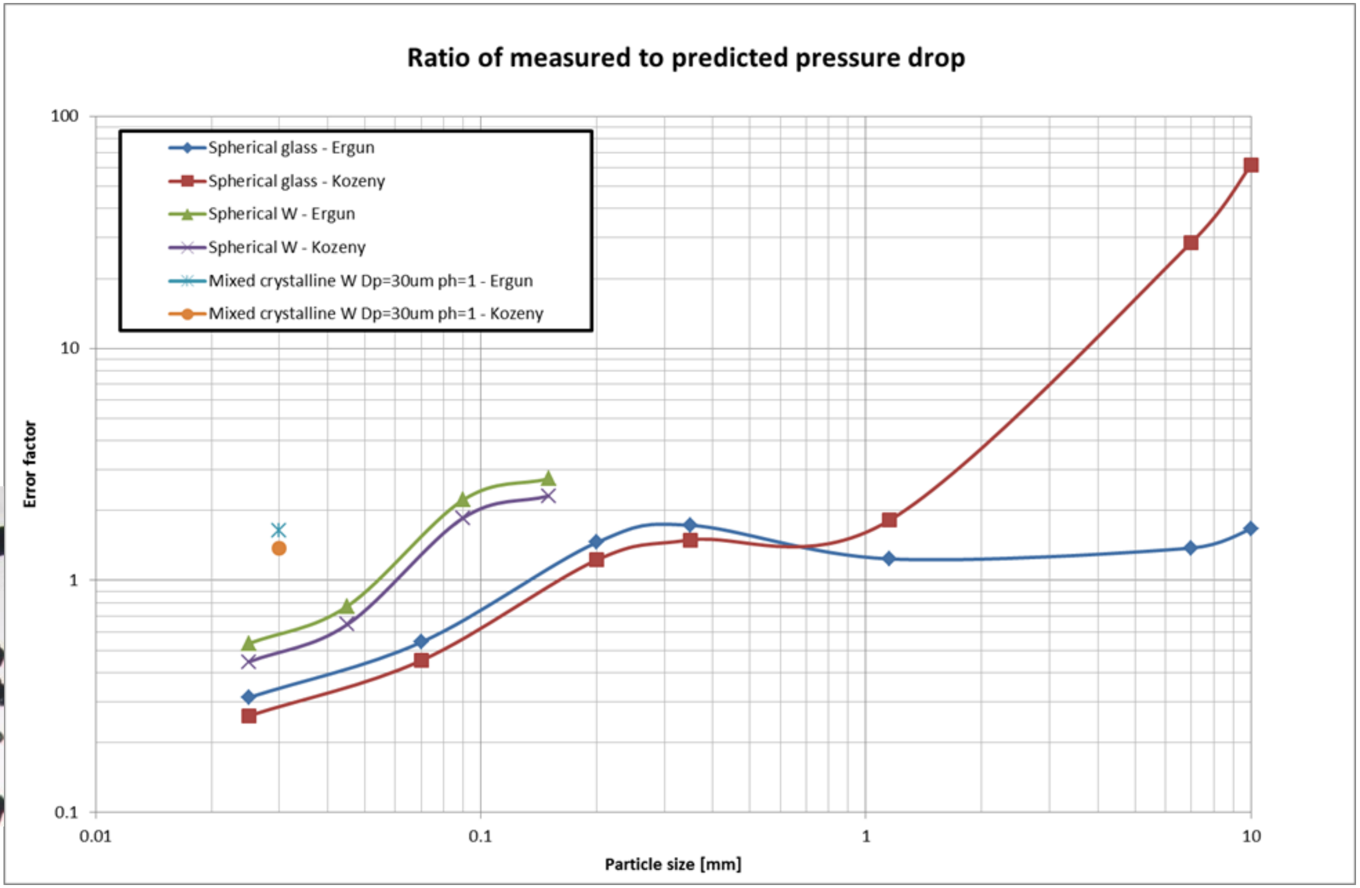
Packed bed experiment

Experimental pressure drop measured across a packed bed of W powder is in line with the analytical pressure drop given by Ergun (employed by CFX)

$$\frac{\Delta P}{h} = \rho_g U^2 \left[\frac{150(1-\varepsilon)}{Re_d \psi} + \frac{7}{4} \right] \frac{1-\varepsilon}{\psi \, d_p \, \varepsilon^3}$$







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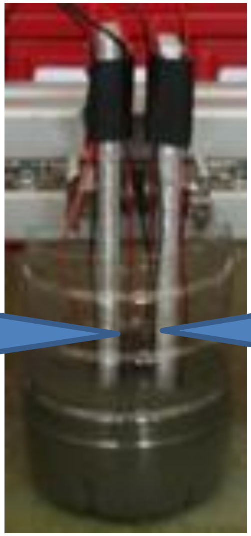
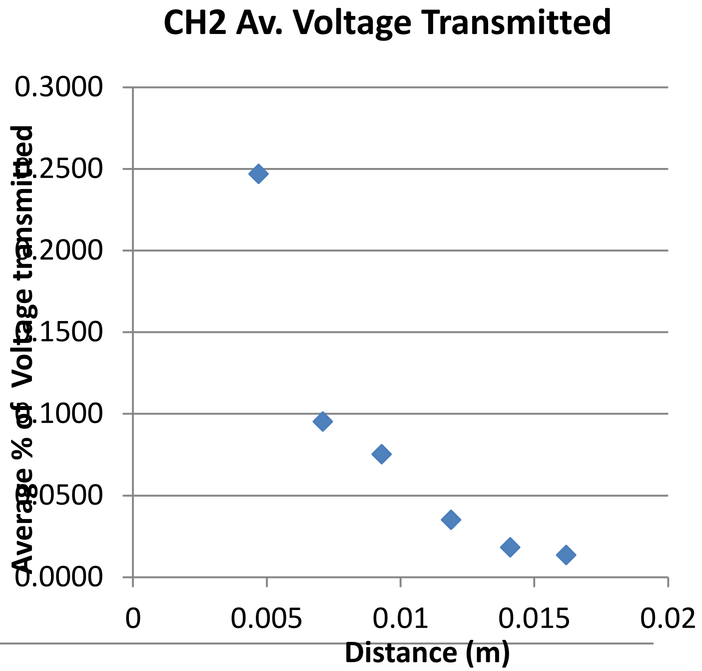
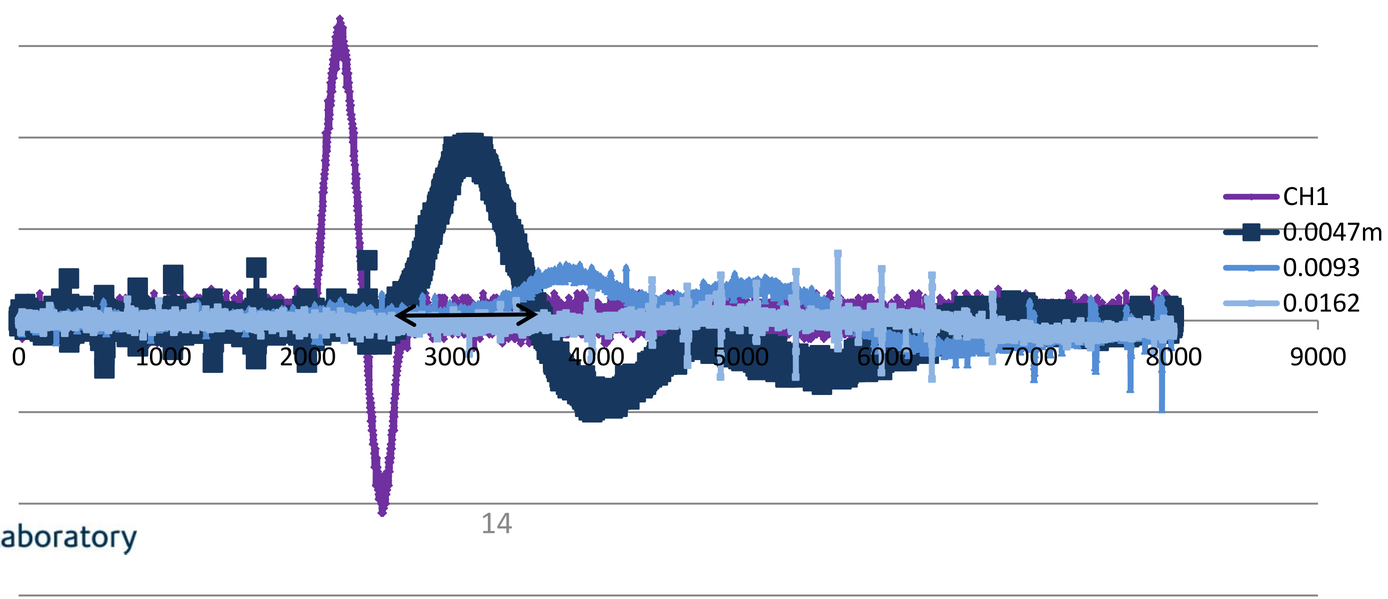
Sound propagation velocity and attenuation through granular materials

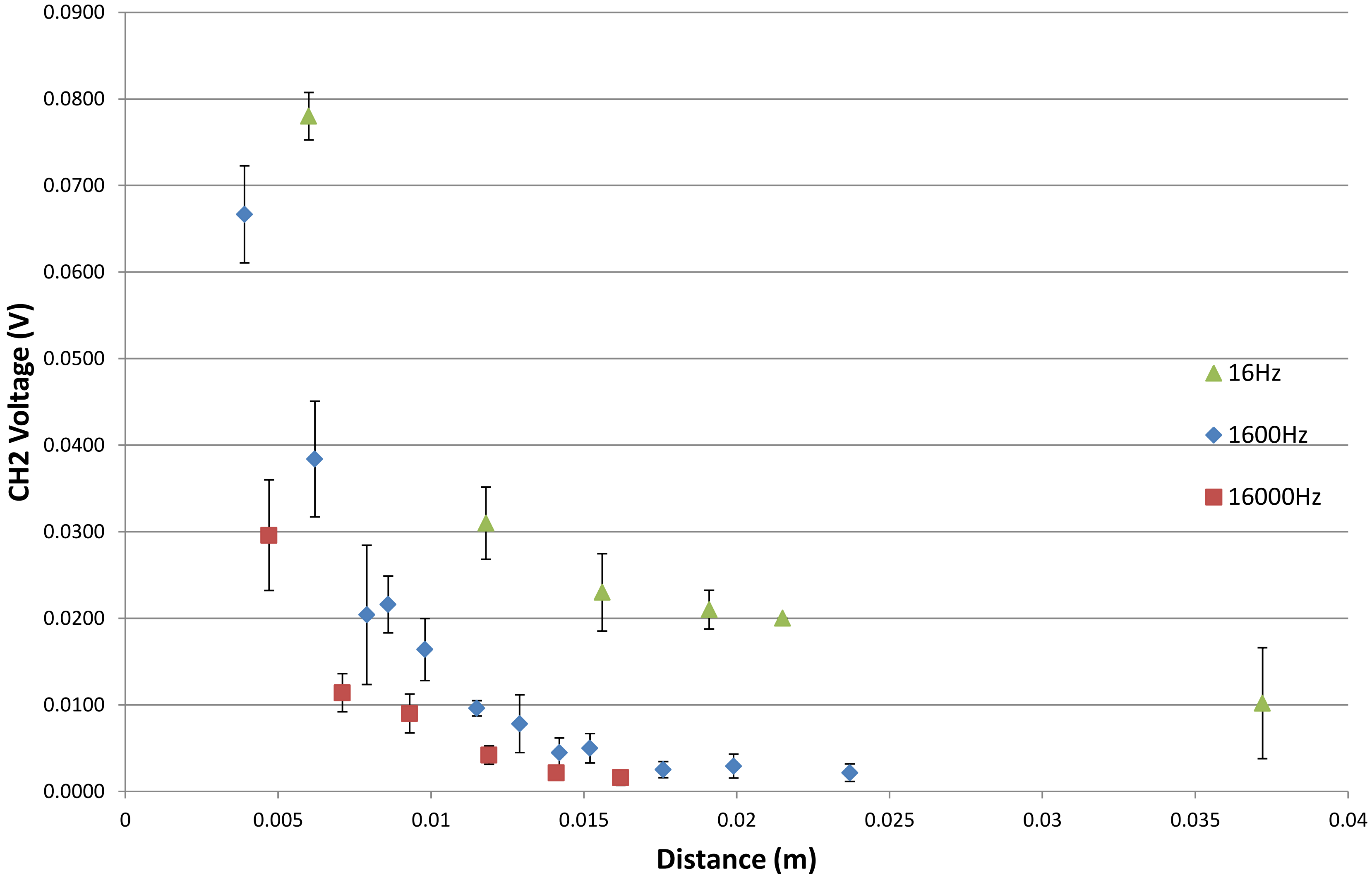




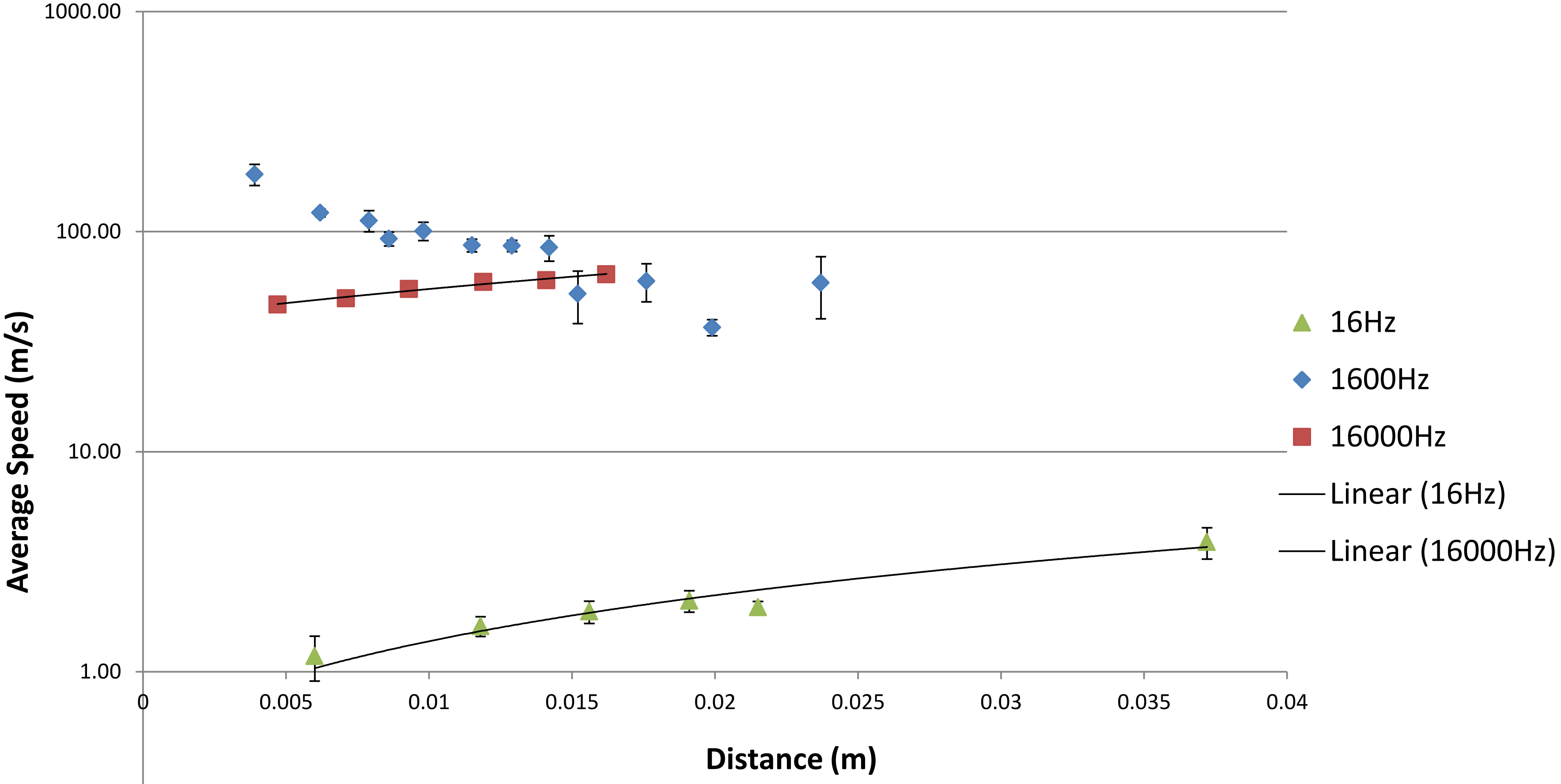
12 V signal generator



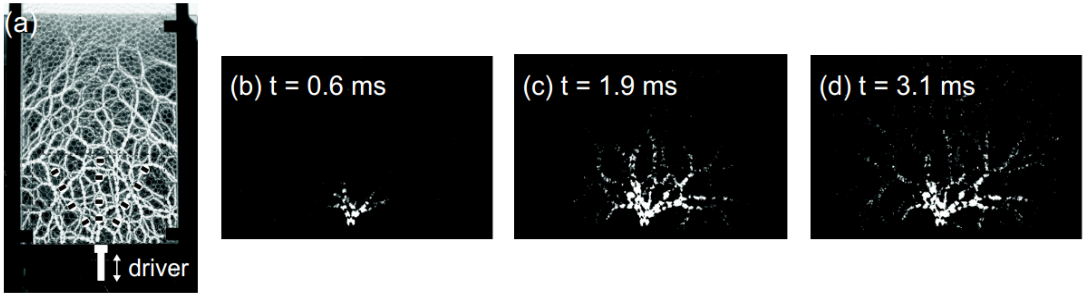
Attenuation of sound waves at different frequencies



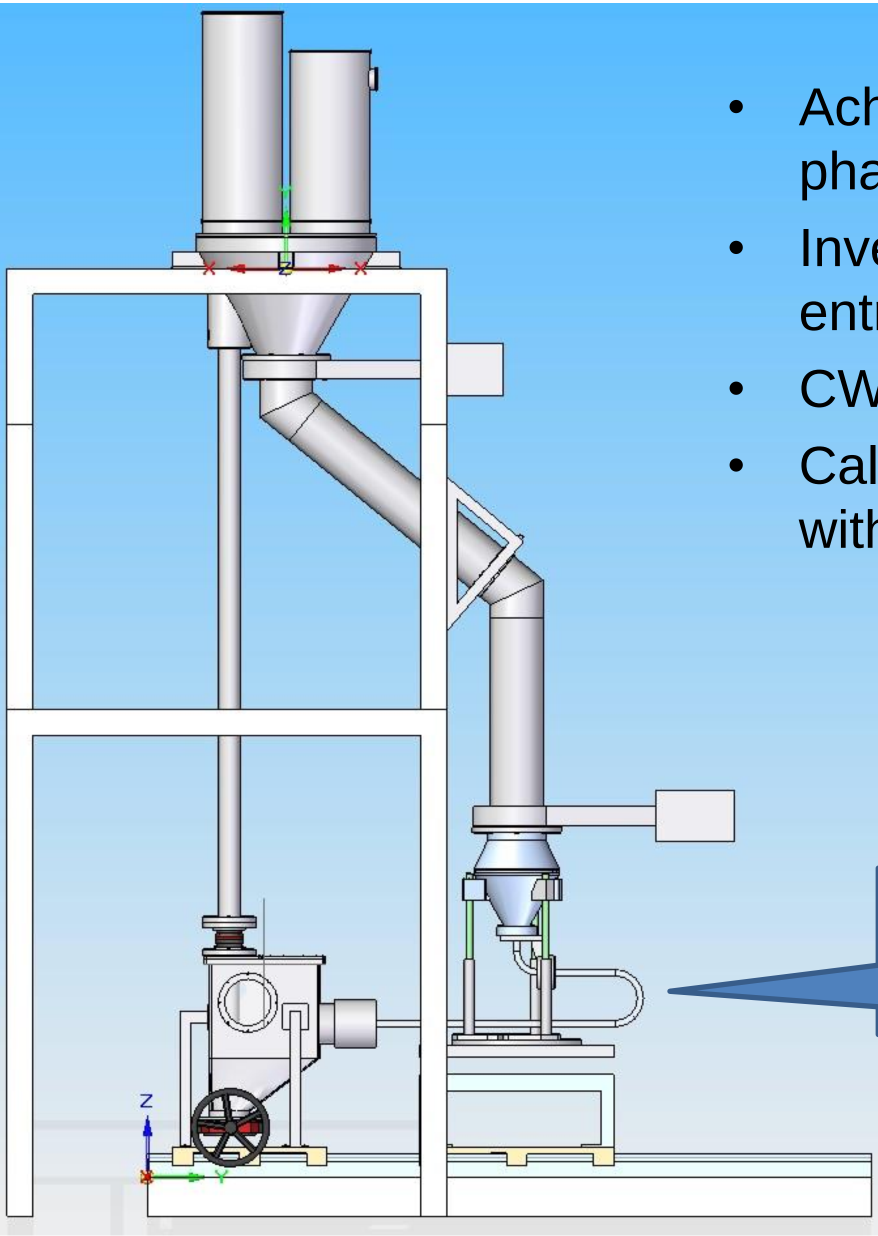
Average Speed comparison at different Frequencies



‘The propagation of acoustic signals is facilitated along strong force chains in granular materials via the increased contact area at strong contacts’ (Danielle S. Bassett, 2012).



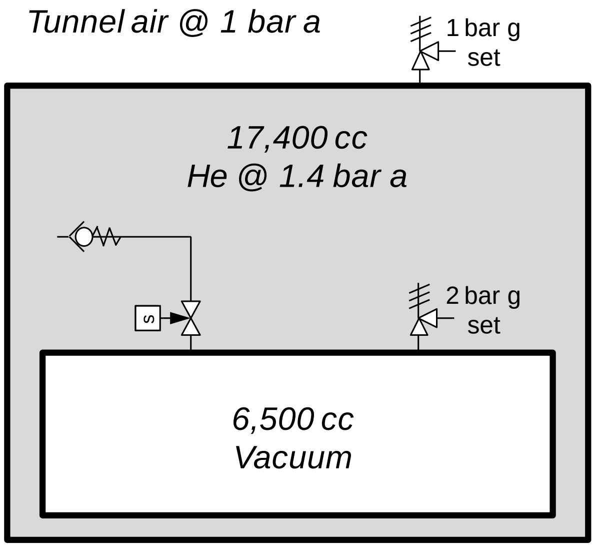
Fluidised powder test rig development



- Achieving solid dense-phase flow
- Investigation of 180° re-entrant pipe geometry
- CW upgrade
- Calorimetry – heat transfer with pipe wall

180° re-entrant pipe test – compatible e.g. with NuFACT solenoid geometry

Key Developments for the HRMT-22 Experiment (Approved)



1. ***Test in both vacuum and helium environments***

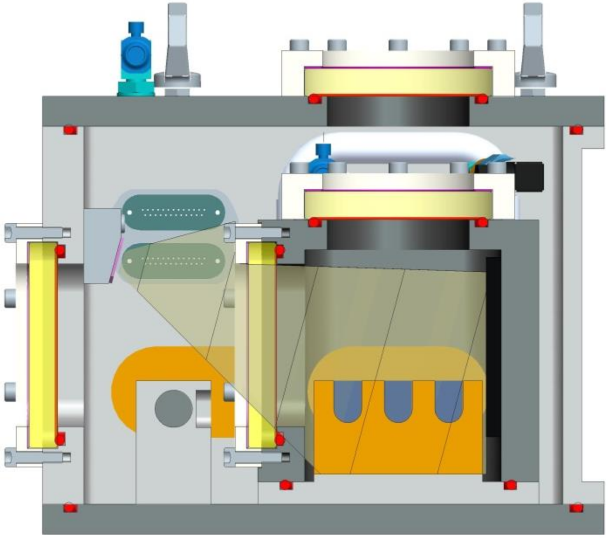
   If we see an eruption in vacuum then it cannot be due to an aerodynamic mechanism!

2. ***Vessel updates***

   Elongated beam windows to facilitate hitting multiple samples. Extra optical window in the lid permits a view of the disrupted sample from above.

3. ***New Trough Concept***

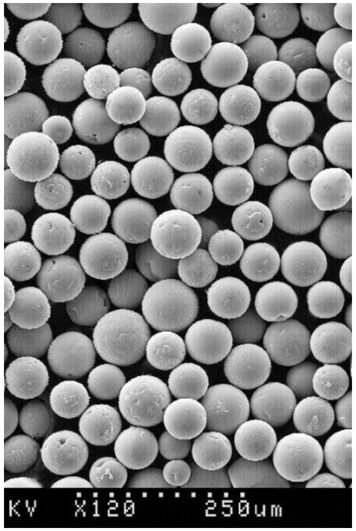
   multiple samples, stiff (high natural frequency) to separate trough/powder disruption effects.

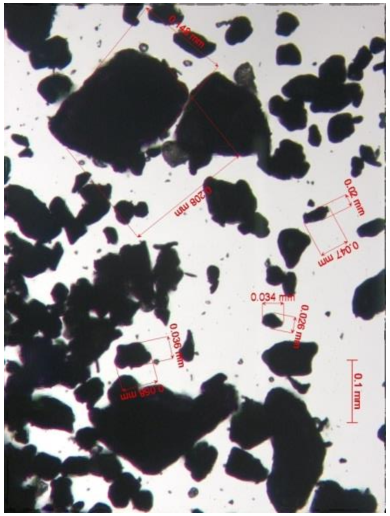


Key Developments for the HRMT-22 Experiment (Approved)

4. ***Use mono-dispersed spherical tungsten powder***

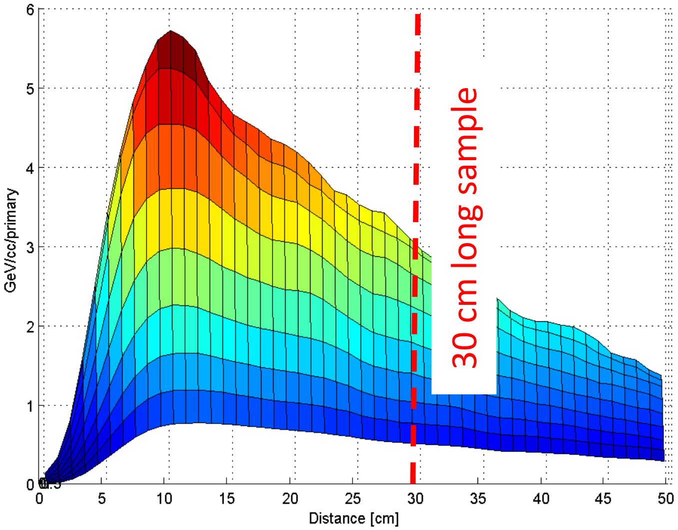
   To make the experiment fit the model(!)





5. ***Reconfigure the lighting rig to permit a view along the full length of the trough***

   To allow better correlation of lift vs energy deposition as the shower builds up along the sample



Energy deposited in a tungsten powder sample from FLUKA simulation

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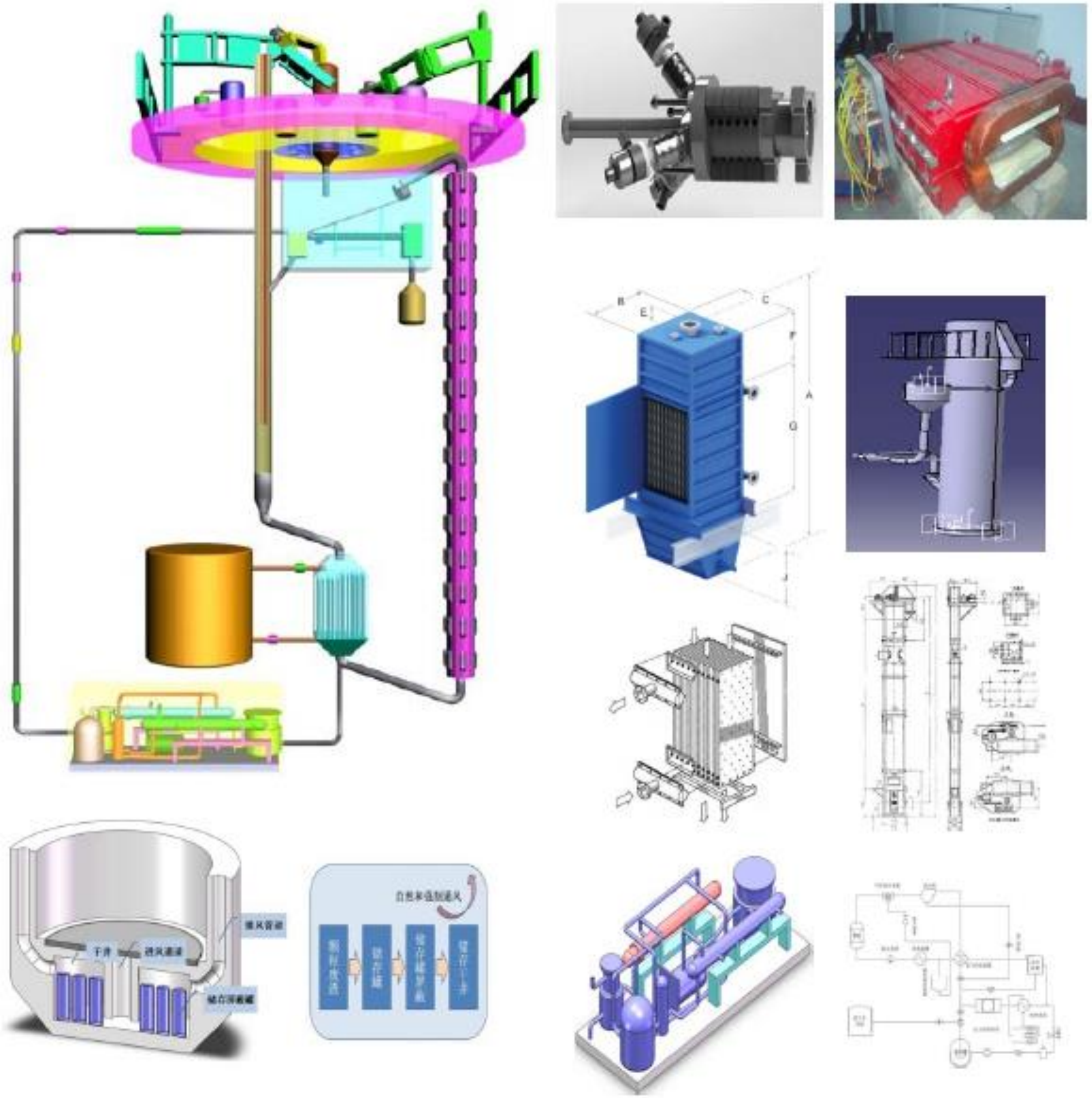
Granular target concept design for CIADS

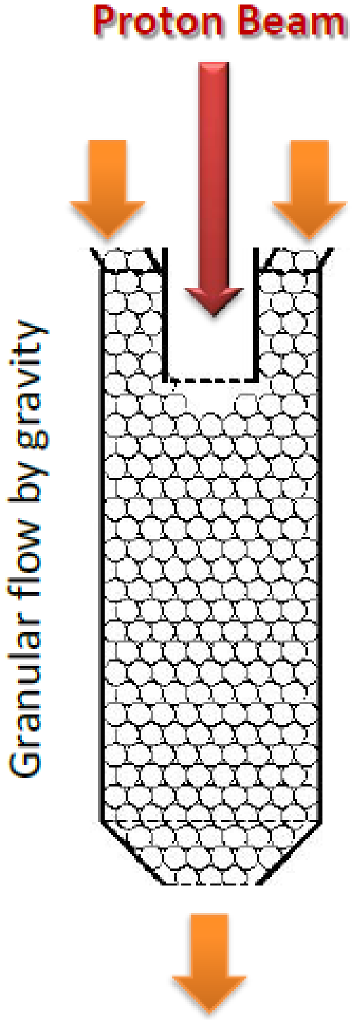


parameters	
Granular material	Tungsten/Tungsten alloy
Structure material	Tungsten alloy/SiC
Granular size	~5mm
Inlet temperature	~250 C
MAX Outlet temperature	~650 C
Proton beam	250eV@10mA=2.5MW
Intensity of beam	>100 μA/cm^2
Diameter of beam spot	~10cm
Average velocity of granular flow	~0.5m/s

*International patent

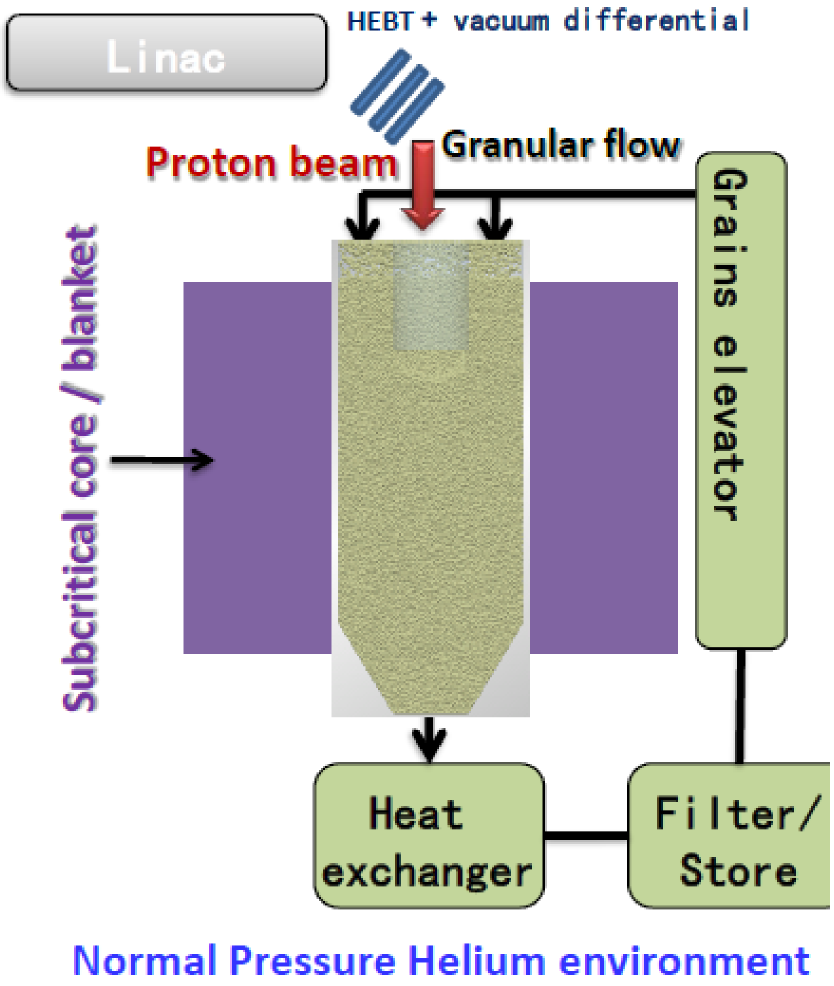
Granular target (windowless) system concept: Dense Granular flow target by gravity

Sand Clock: domed interior is sand sand bucket, sand and time is proportional to the amount of outflow relationship, based on the stock of sand and sand can know the time.



Proton Beam

Granular flow by gravity



Linac

HEBT + vacuum differential

Proton beam

Granular flow

Grains elevator

Subcritical core / blanket

Heat exchanger

Filter/ Store

Normal Pressure Helium environment

Lei Yang et al

Conclusions

Peripherally cooled cylindrical **monolith targets** have limited heat dissipation capability and experience high steady state and dynamic stresses.

Segmented internally cooled stationary targets can accommodate much higher heat loads and higher power densities.

A **pebble bed target** such as that proposed for EURONu or ESS-SB is probably the ultimate segmented target and may be relevant for other facilities where a solid cylindrical target is not viable. R & D in pebble bed and other segmented targets would be beneficial for future neutrino facilities and neutron sources alike.

At higher beam powers it may become necessary to employ **flowing** (powder and liquid metals) or rotating targets and that is why research in this area is required.

Physics performance is a function of reliability as well as optimum particle yield so the simplest target design possible is often the best choice.