Science & Technology Facilities Council

Tungsten Powder as an accelerator target

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(CERN)

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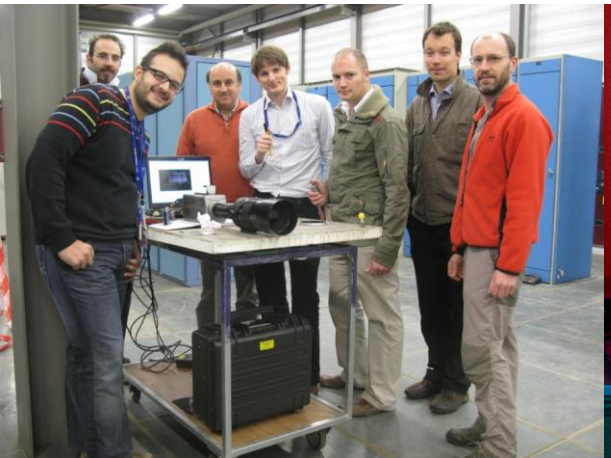
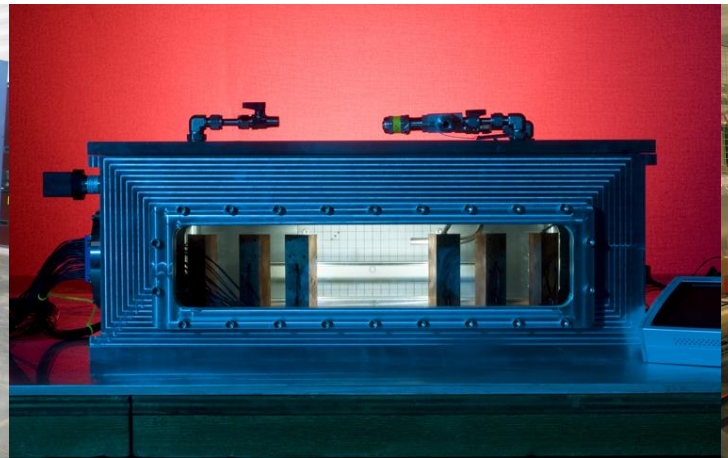
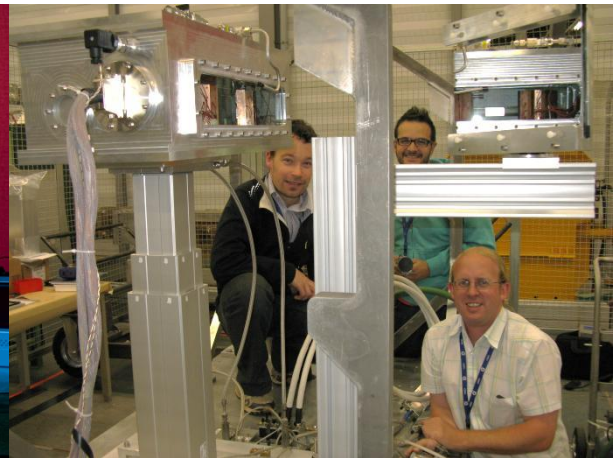
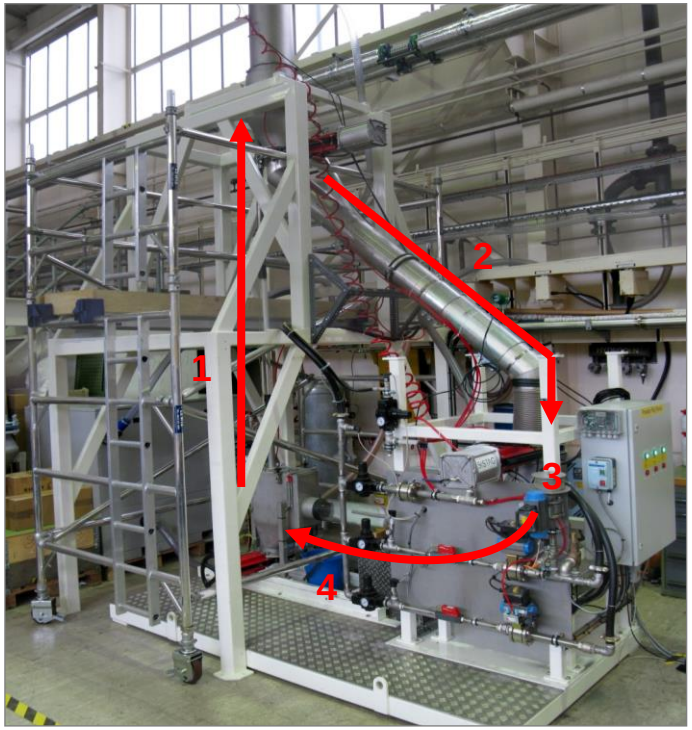




Tungsten Powder programme live areas of work

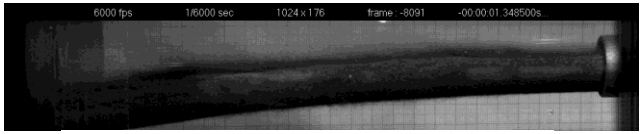
- **Rig improvement**
  - CW upgrade
  - Improving the receiver vessel
  - Improving diagnostic
  - Increasing the solid fraction
  - calorimetry
- **In beam tests HiRadMat**
  - Understanding factor/factors for beam powder lift
    - aerodynamic
    - stress propagation
    - Electrostatic
    - a combination of all the above!
- **Understanding fluidisation conditions and pressure loss**

Tungsten Powder Test Programme in PASI-WP3 + ASTEC

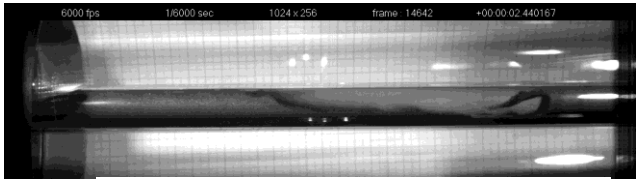
- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Containment / erosion
  - Heat transfer and cooling of powder



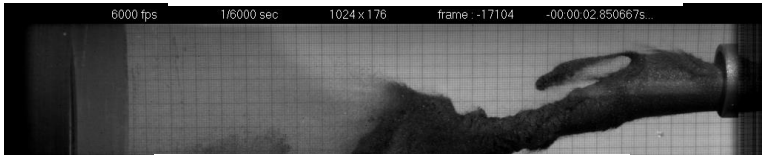
Dense-phase delivery



High speed image: tungsten powder jet

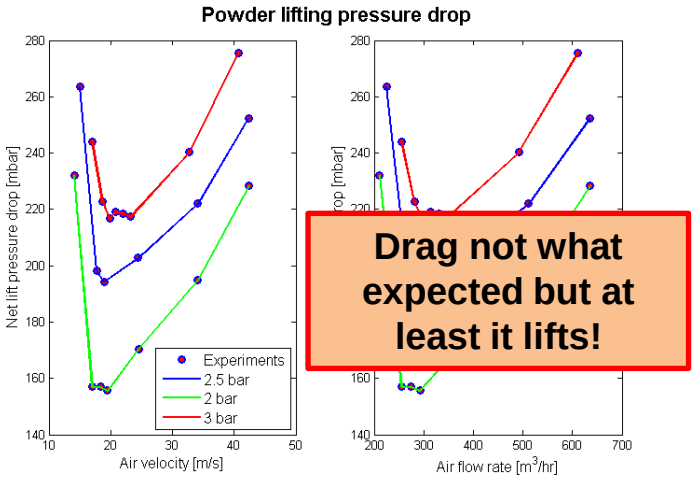


High speed image: tungsten powder flow in a pipe



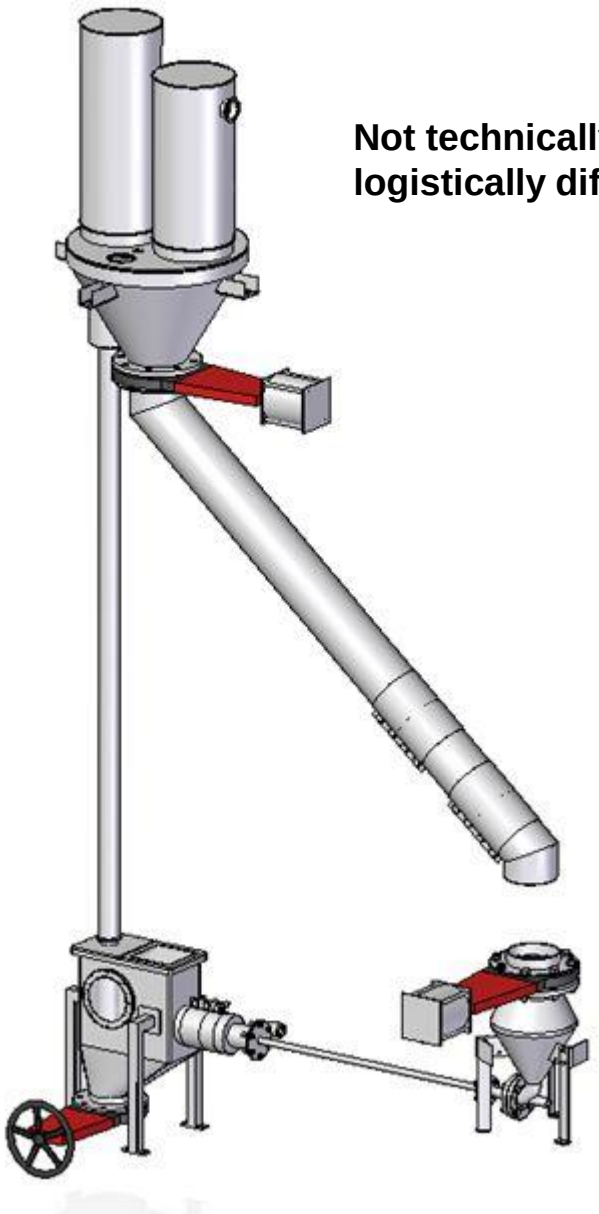
Unstable tungsten powder jet

Lean-phase lift

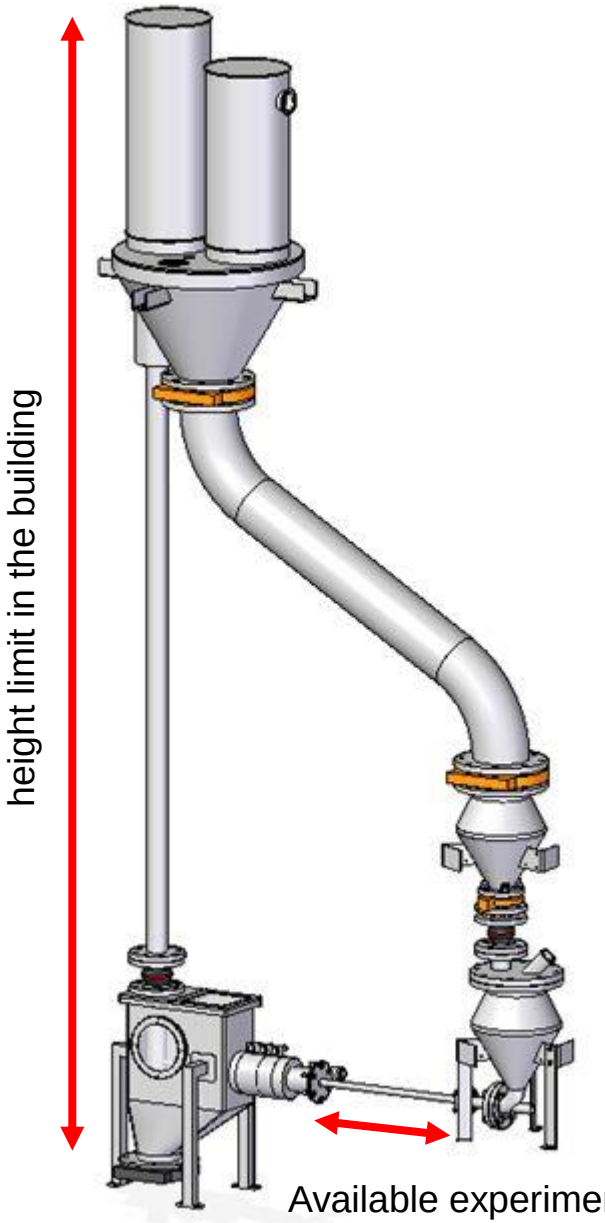


Drag not what expected but at least it lifts!

CW operation requires a few more components

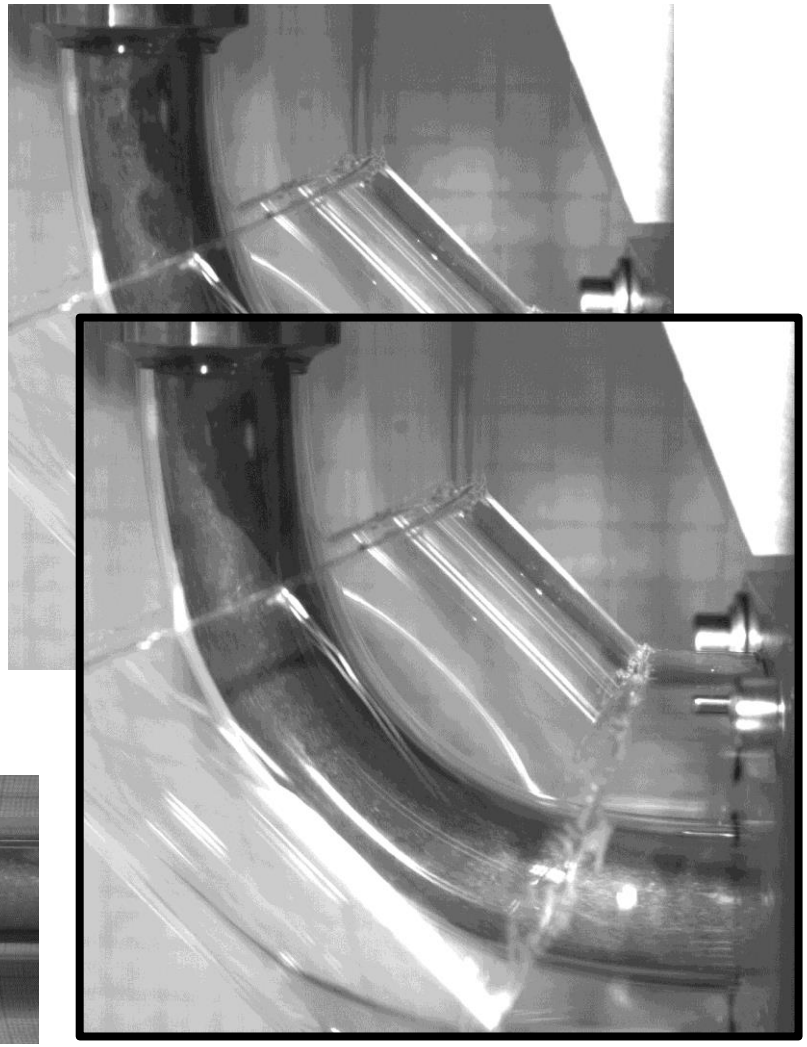


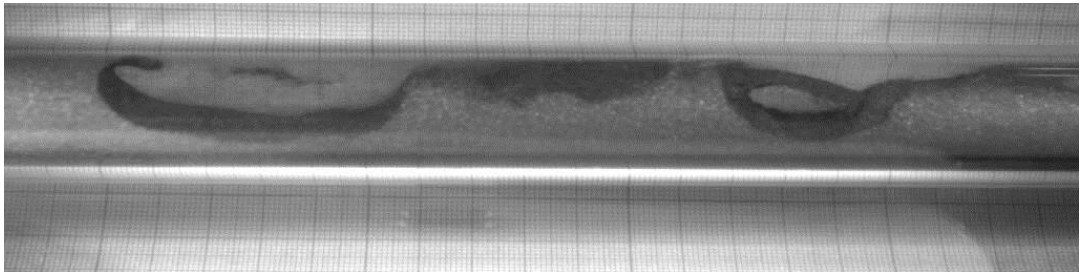
Not technically challenging but logistically difficult in R12



Dan Wilcox

Improving diagnostics to increase the solid fraction





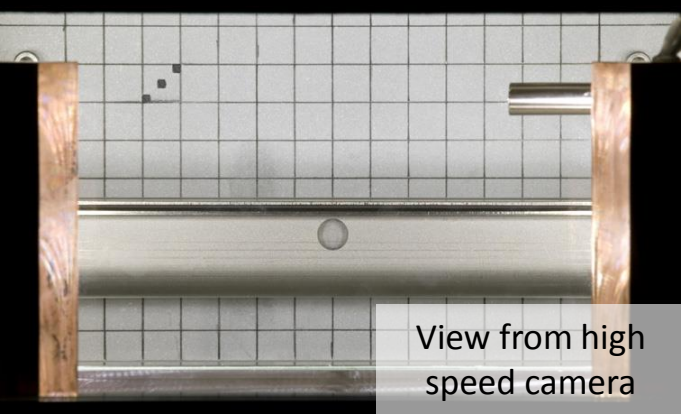
New glass parts show early stages of phase separation

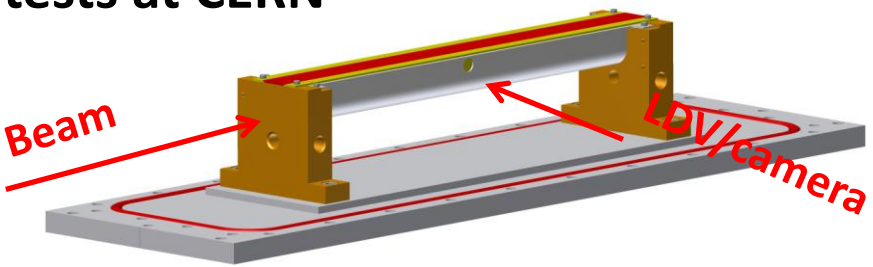
Phase separation diagnostic improvement

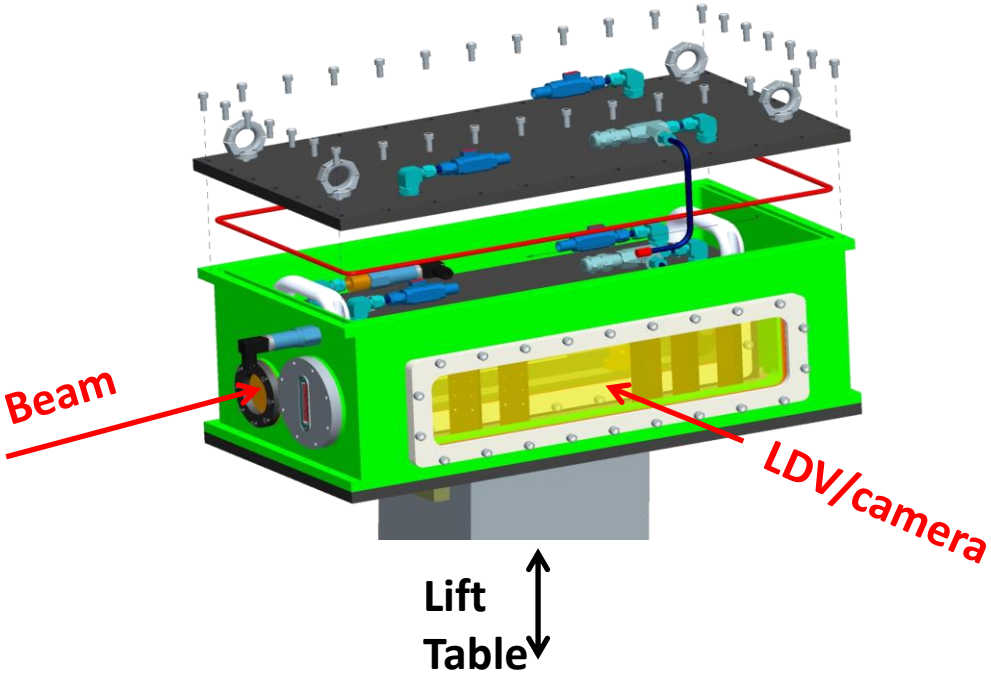
Next stages:

- Vary system characteristic pressure drop (i.e. pipe diameter and length)
- See how the powder flows through the dense phase hopper

In beam tests at CERN



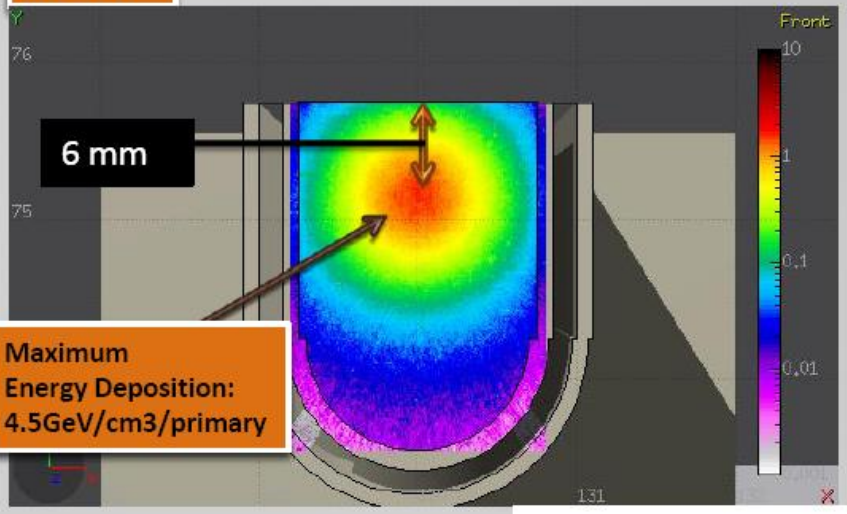




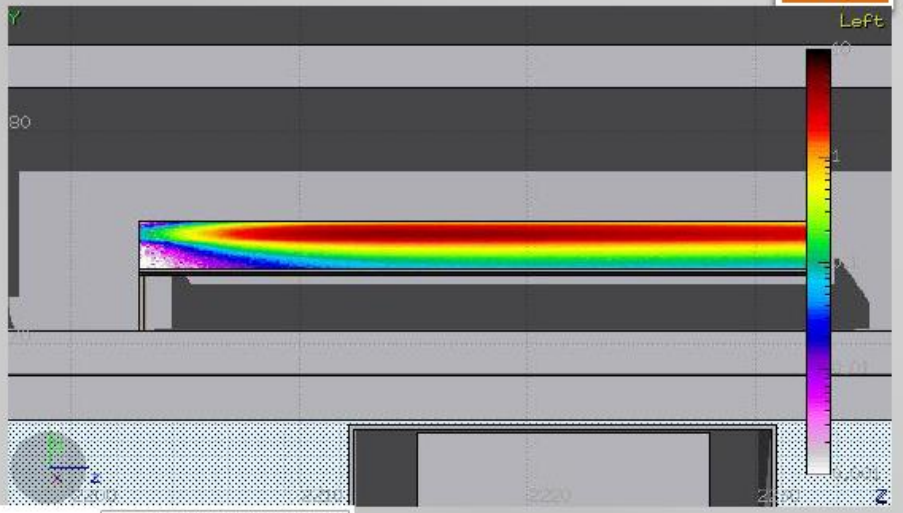
- Tungsten powder sample in an open trough configuration
- Helium environment
- Two layers of containment with optical windows to view the sample
- Remote diagnostics via LDV and high-speed camera

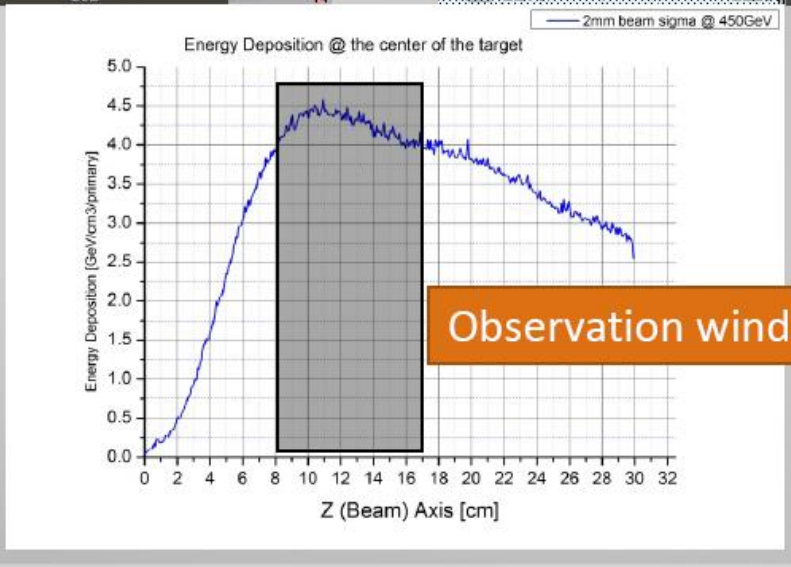
Prompt energy deposition/radiation (FLUKA® Monte – Carlo Code)

Front

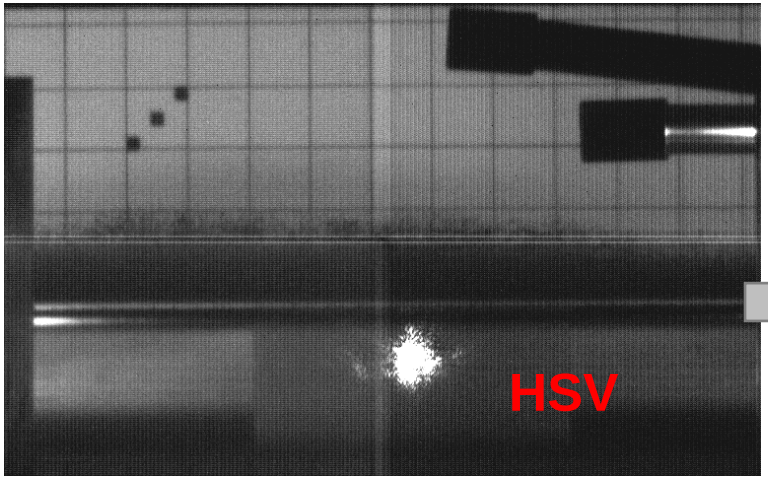


Top



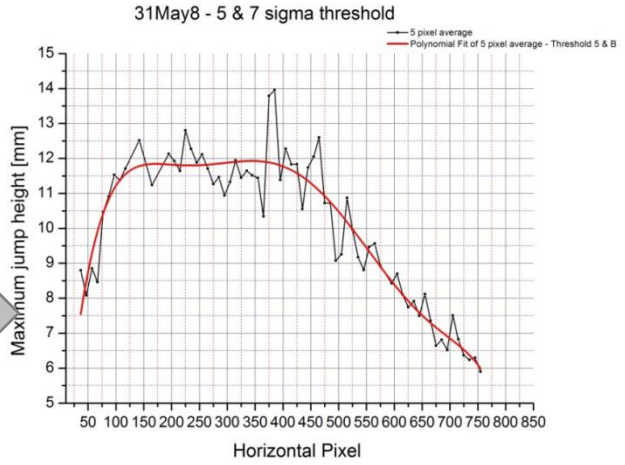


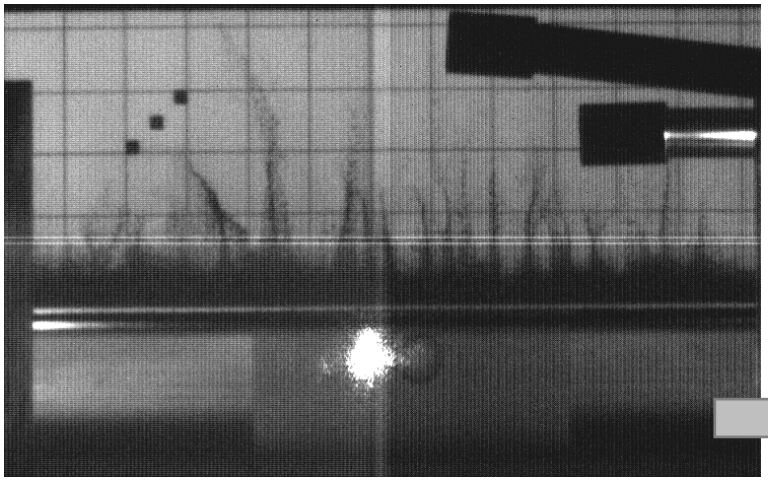
Charitonidis



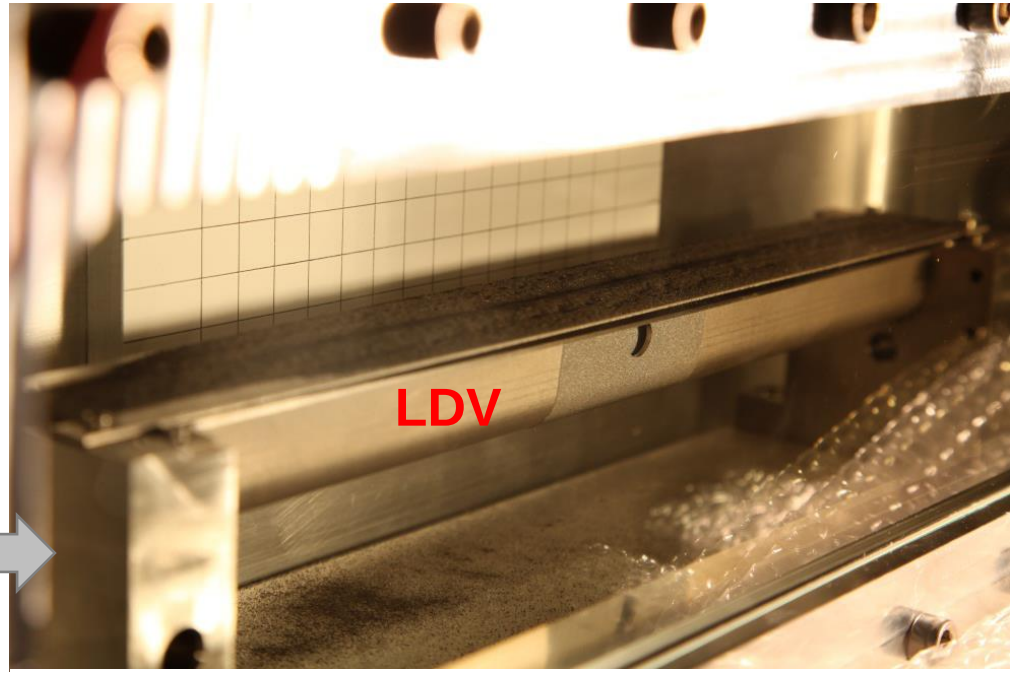
Shot #8, 1.75e11 protons
Note: nice uniform lift

Lift height correlates with deposited energy





Shot #9, 1.85e11 protons
Note: filaments!

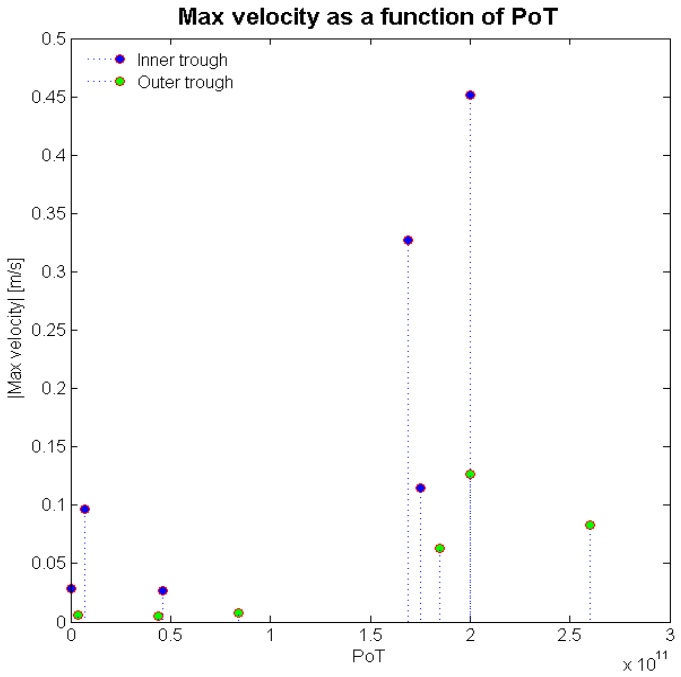


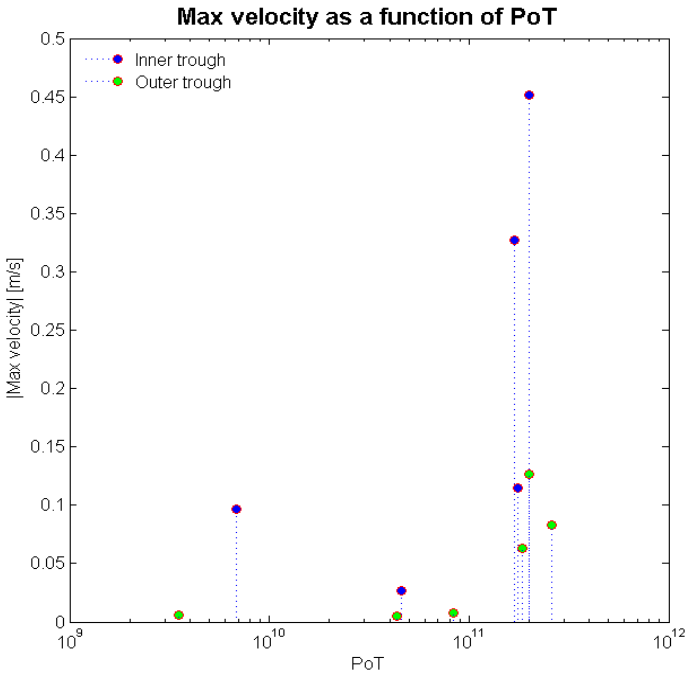
Trough photographed after the experiment.
Note: powder disruption

LDV: the good bits

Having taken all the bad data away (technically defined as data massaging!!)

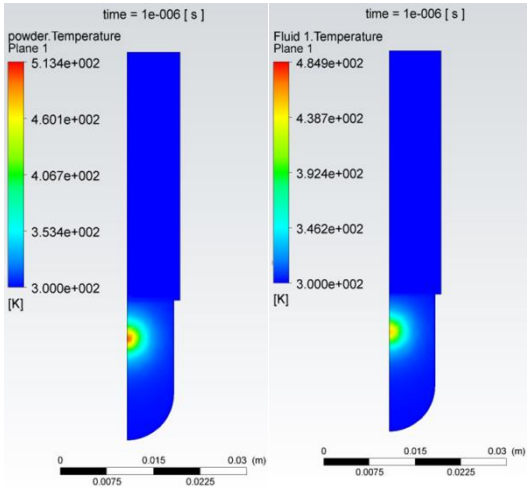
- the amplitude of vibration appears proportional to PoT
- Vibration amplitude is higher in the inner trough than on the outer trough
- There is a 1kHz resonant frequency peak (expected from trough resonance)

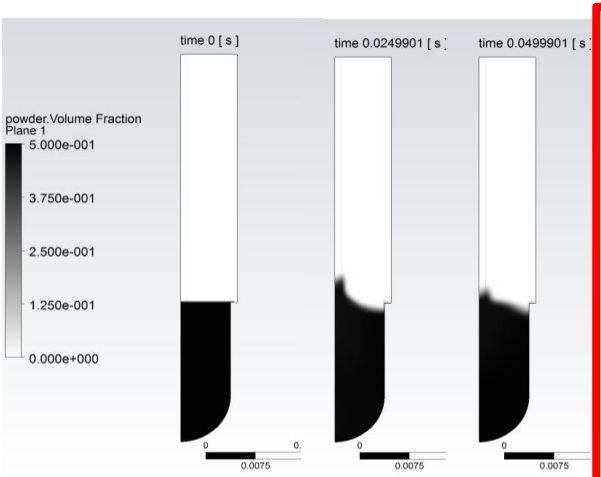


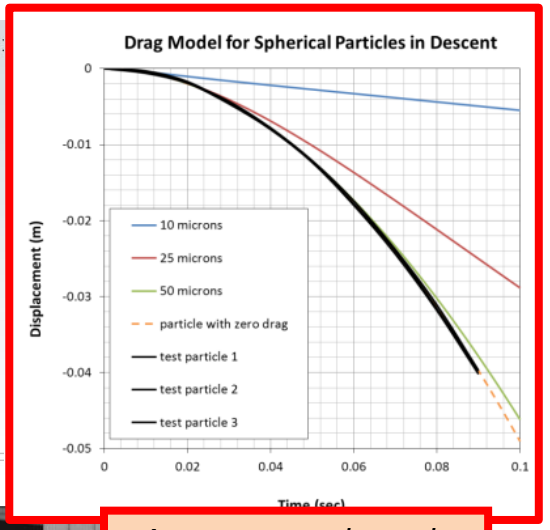


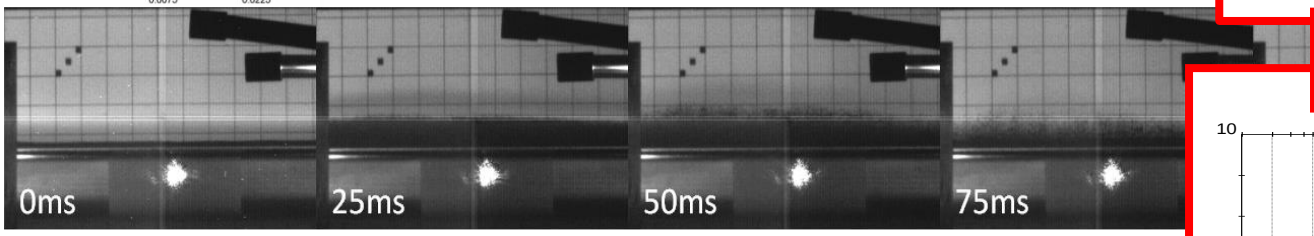
Davenne: CFD predictions/post fits

Beam heating

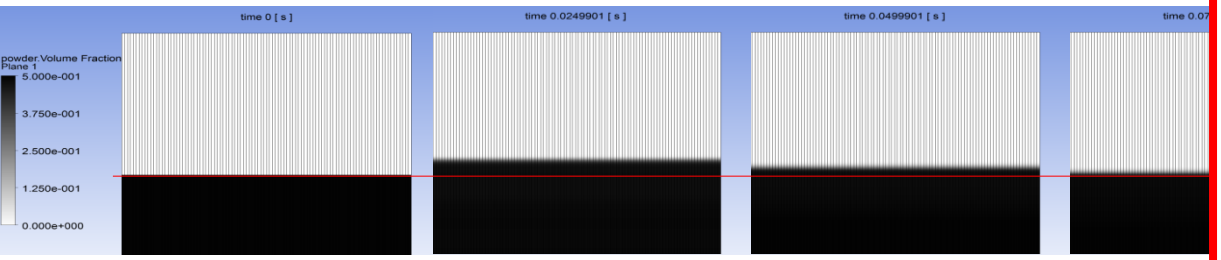






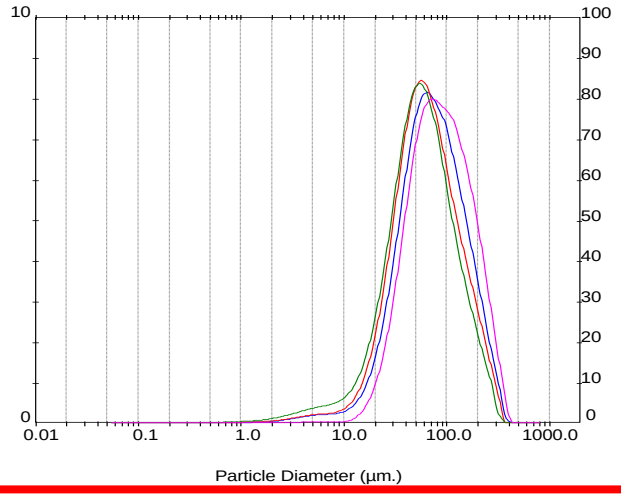


Test Results from Shot #8, 1.75e11 protons, beam sigma 0.75



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

Average aerodynamic diameter ~30um



Rachel Salter

Powder lift didn't match expectations..
So looking at the powder falling: Drag coefficient calculations

Appendix 1: Drag and equations of motion

D: drag force
Re: Reynolds number
C_d: Drag coefficient
v: Particle velocity
ρ: density of fluid
μ: viscosity of fluid
d: diameter of particle
a: acceleration of particle
x: displacement of particle from peak height
t: time
m: particle mass
B:Buoyancy
ρ_p: particle density
a: acceleration

$$Re = \frac{\rho v d}{\mu}$$

$$D = \frac{\rho v^2 \pi d^2 C_d}{8}$$

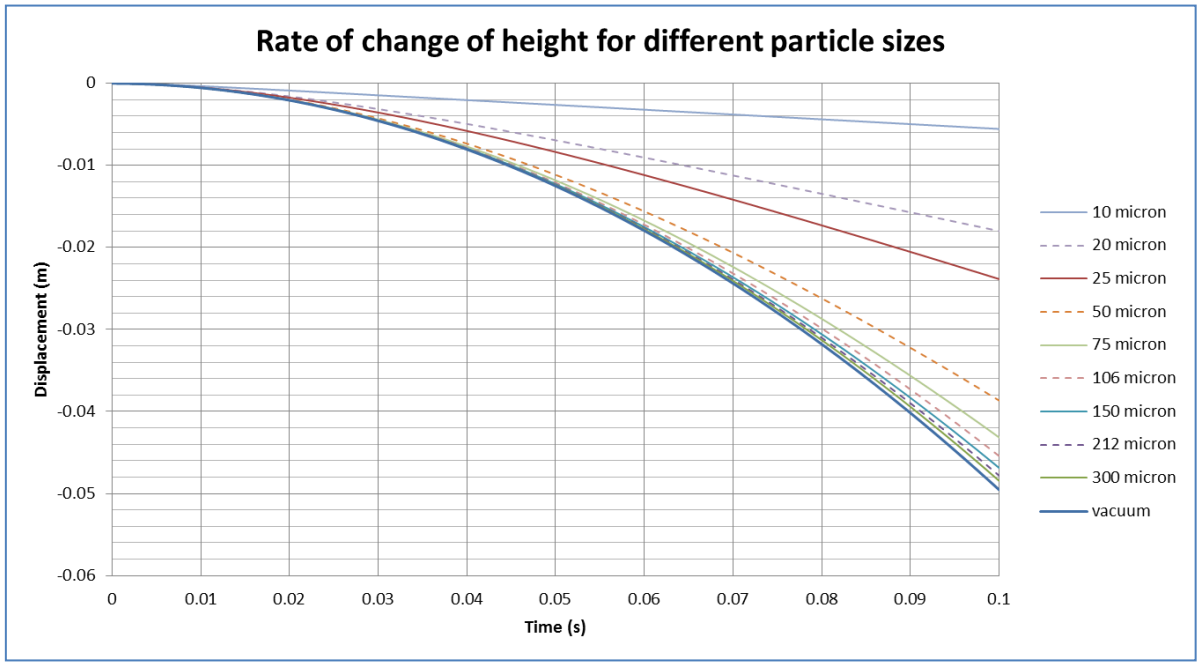
D+B

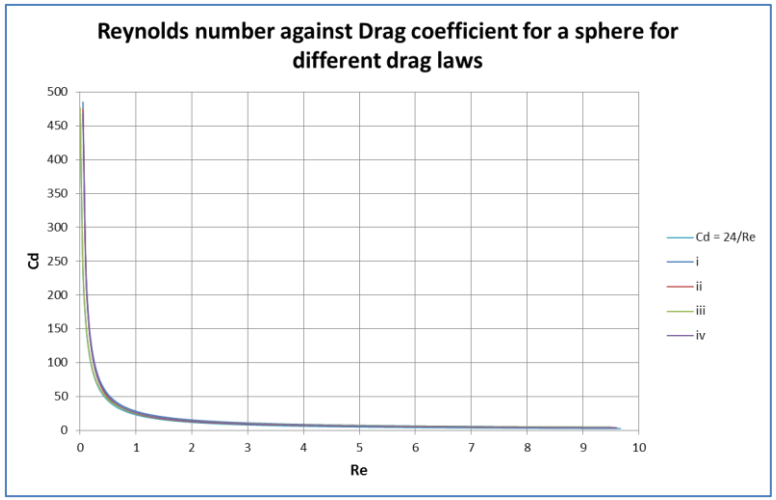
mg

$$B = \frac{m\rho a}{\rho_p}$$

D + B − mg = ma (defining up as positive)

$$x = vt + 0.5at^2$$





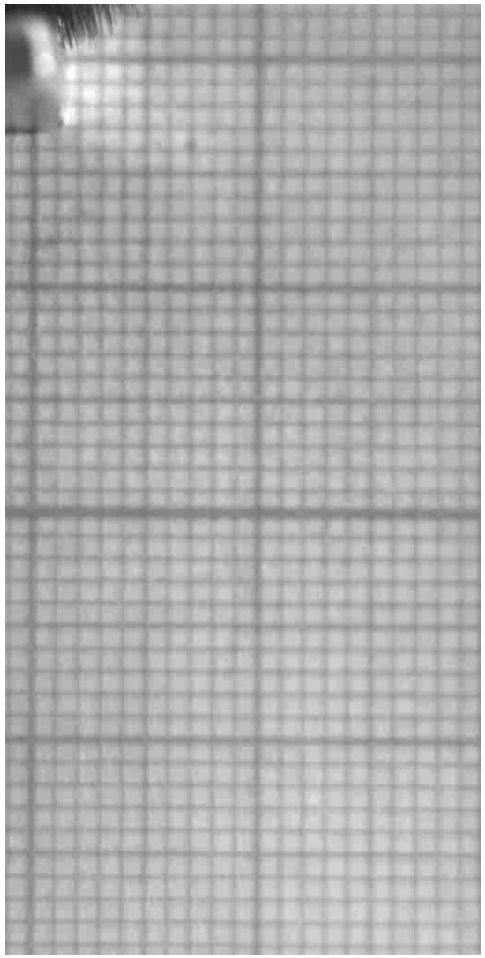
i) $C_d = \frac{24}{Re} + \frac{4}{Re^{0.33}}$ (valid for 1 < Re < 1000) (Ahmadi)

ii) $C_d = \frac{24}{Re} + \frac{\left(2.6 \times \frac{Re}{0.5}\right)}{1+\left(\frac{Re}{5}\right)^{1.52}}$ (there are two further terms that were considered negligible when investigating low Reynolds number) (Morrison, 2013)

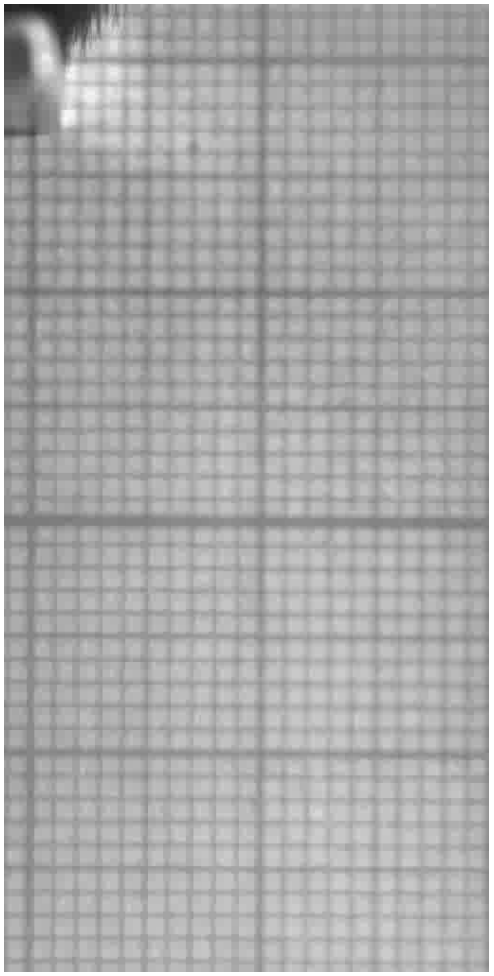
iii) $C_d = \frac{24}{Re}\left(1 + \frac{3}{16}Re\right)^{0.5}$ (for Re < 100) (Massey, 1989)

iv) $C_d = \left(0.63 + \frac{4.8}{Re^{0.5}}\right)^2$ (used by previous summer student (Gibilaro, 2001))

Tungsten powder drop tests



Particle size: 50 to 75 um

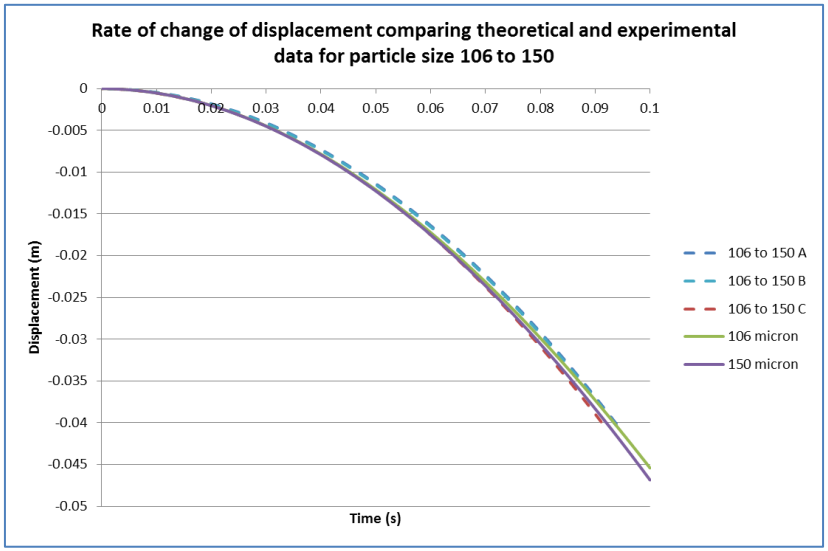


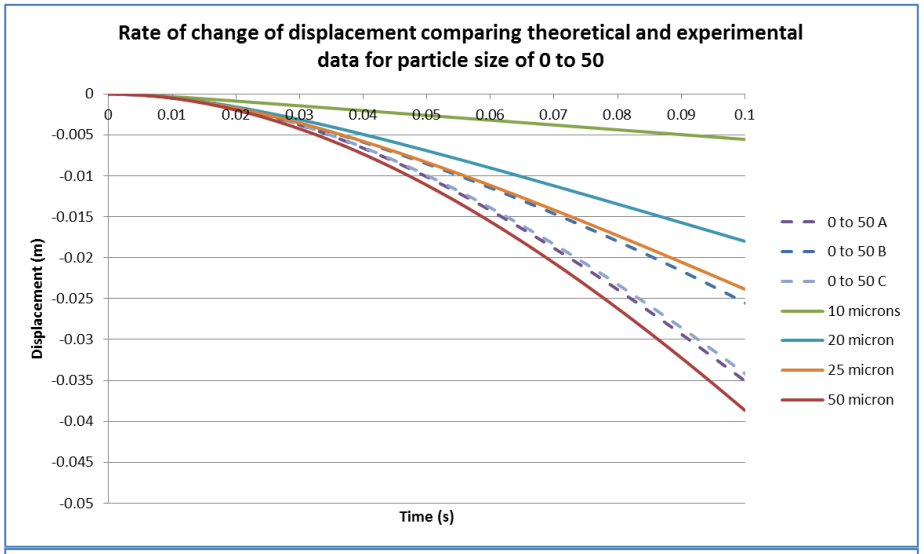
Particle size: 0 to 50 um

Agglomerates only appear to form when there are particles smaller than 50 microns present

- **Geldart Group C** particles
- For Tungsten powder, **20 microns** is the estimated threshold size for agglomeration

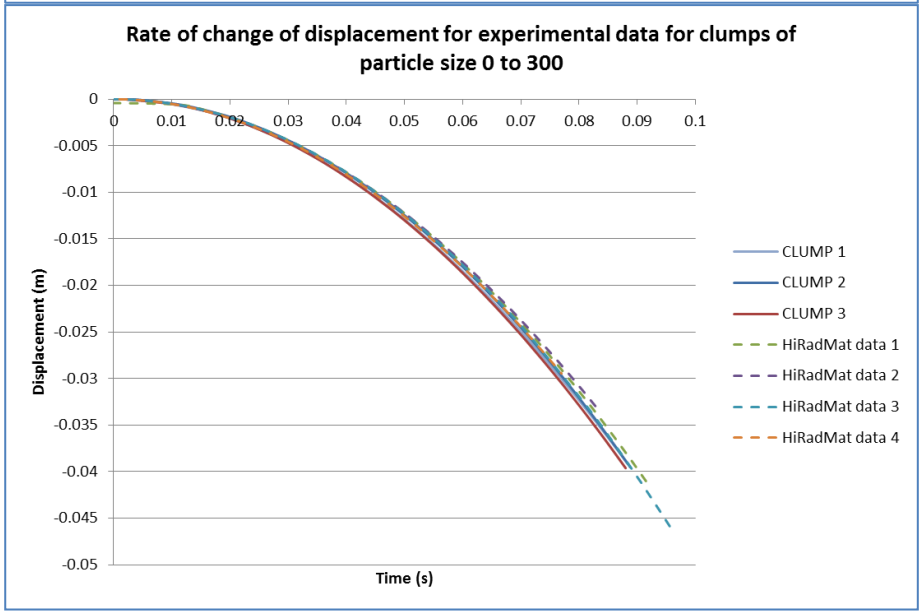
Tungsten powder drop tests (2)





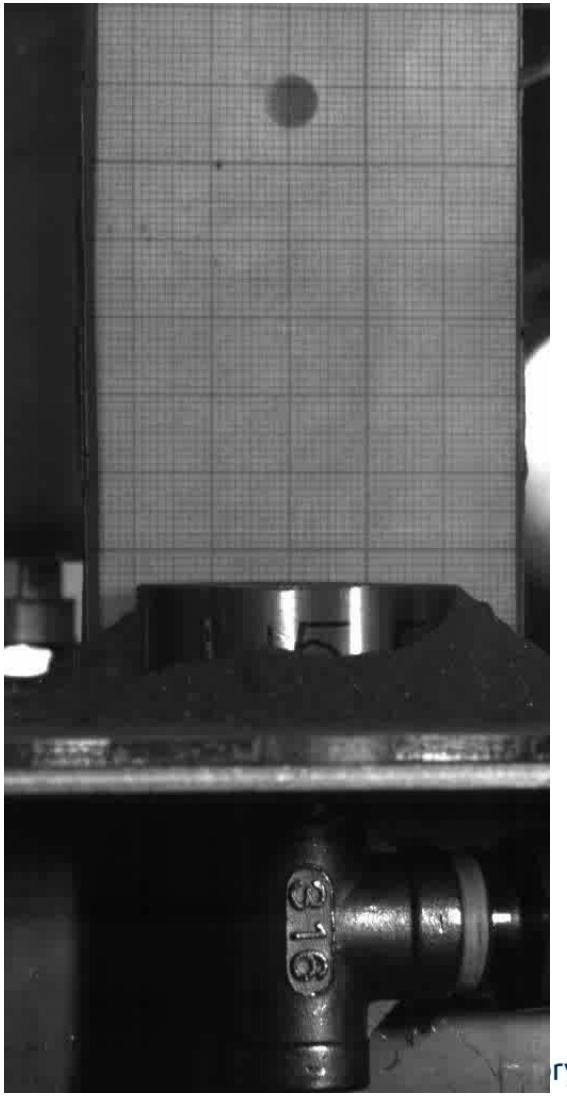
- Theoretical data fits quite closely to data obtained by tracking single particles- **drag equations** are therefore justified using **spherical** assumption

- HiRadMat data follows a similar trend to agglomerates tracked in the powder drop test- therefore more likely that **clumps of particles** were being tracked

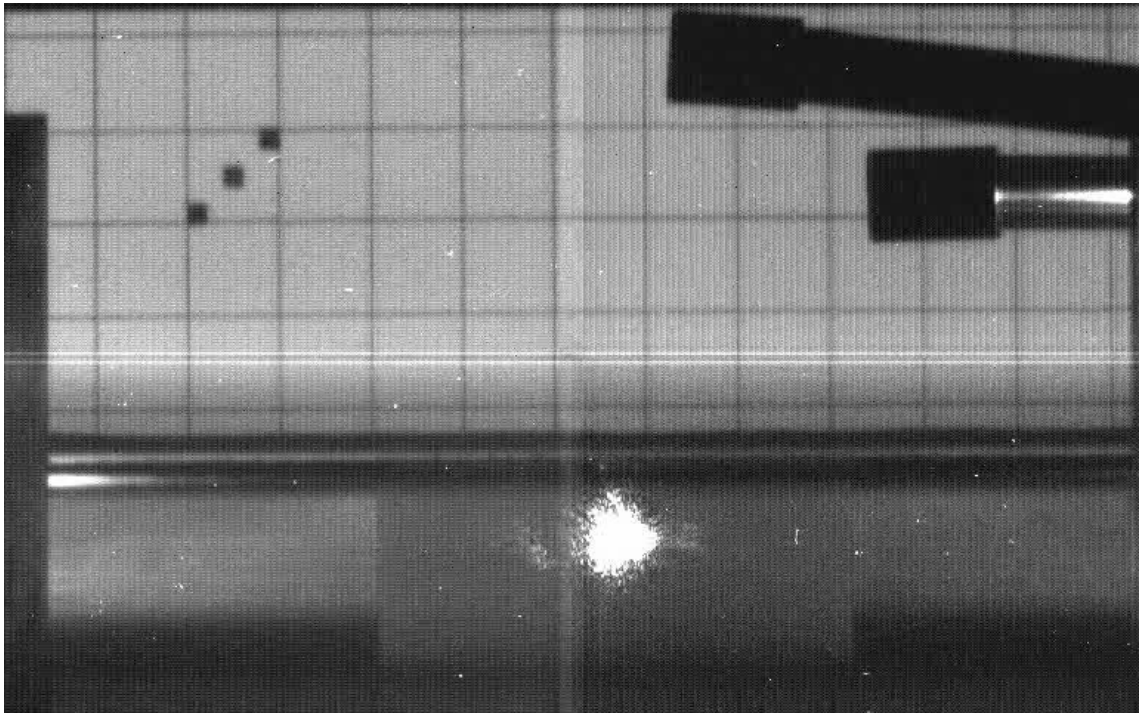


Tungsten powder puff experiment. Trying to understand the powder lift

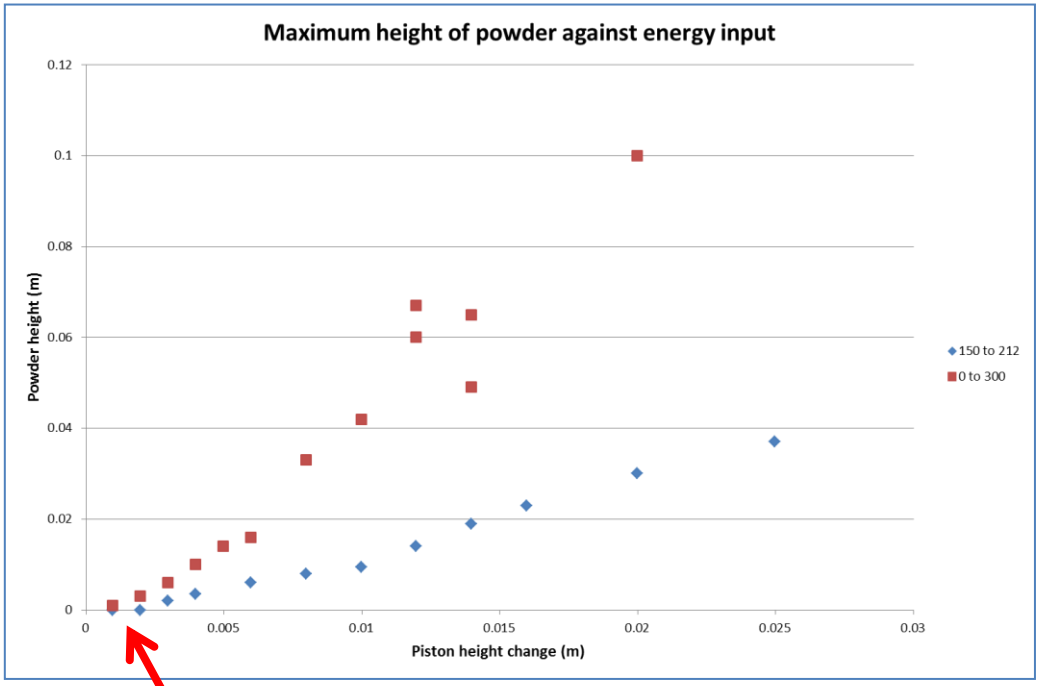
Tungsten powder puff experiment



- 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



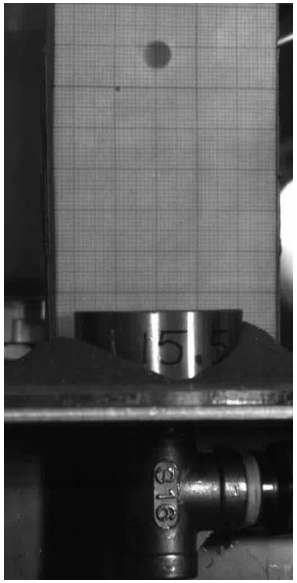
Tungsten powder puff experiment (2)



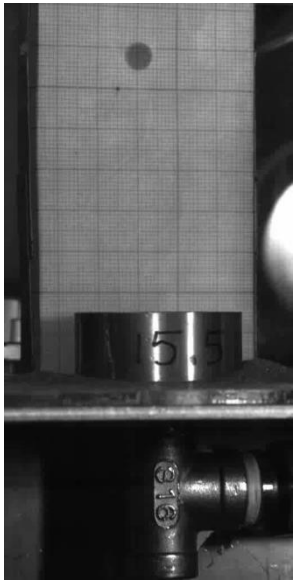
There is a threshold energy which has to be reached before the powder begins to lift. The threshold depends on the depth of the powder

- The maximum height reached by the powder is proportional to the energy put in by the compression of the piston
- The powder sample containing smaller particles was lifted higher than the sample containing only larger particles
- The acceleration is faster than can be captured with 1kHz HSV

0 to 300 um

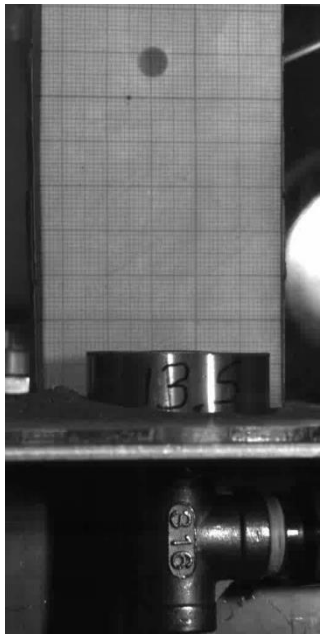


150 to 212 um

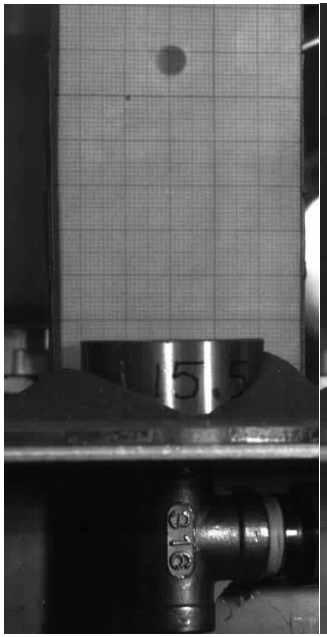


Tungsten powder puff experiment (3)

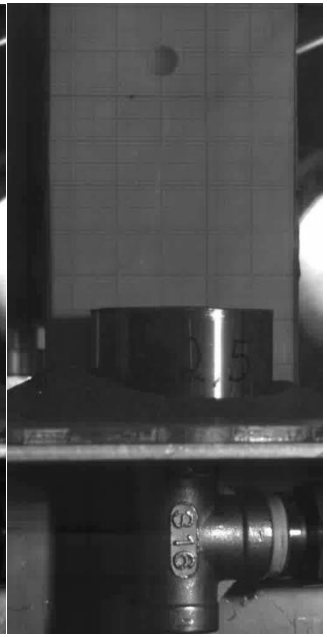
Powder depth = 13.5mm



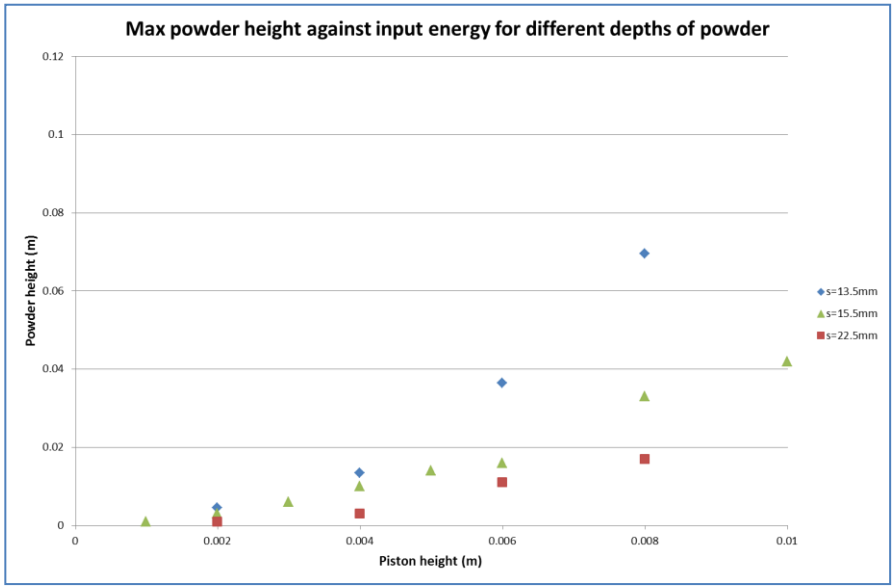
Powder depth = 15.5mm



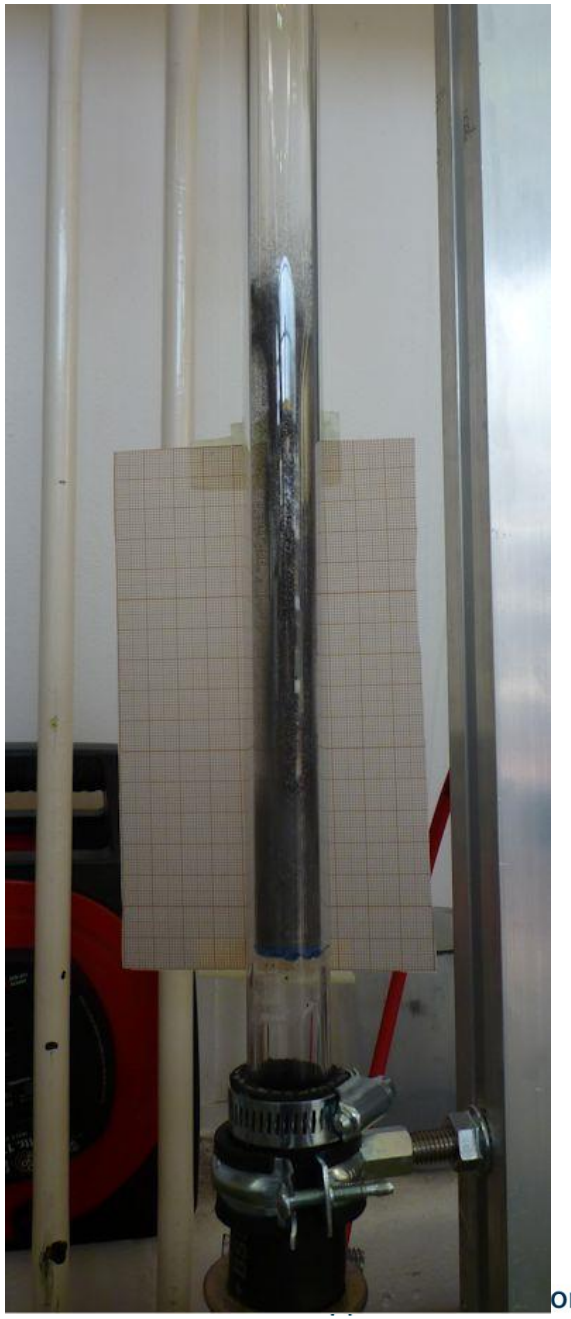
Powder depth = 22.5mm



- The smaller the depth of powder, the larger the maximum powder height reached



Understanding powder lift part 2



Pressure drop for air flowing through a bed of powder

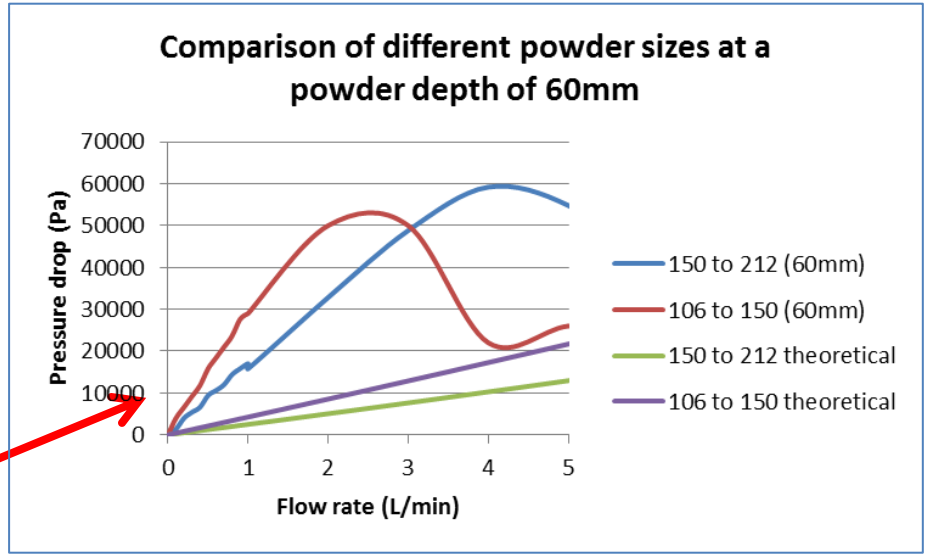
Atherton, Salter, Bennetton

Fluidised bed experiment (2)

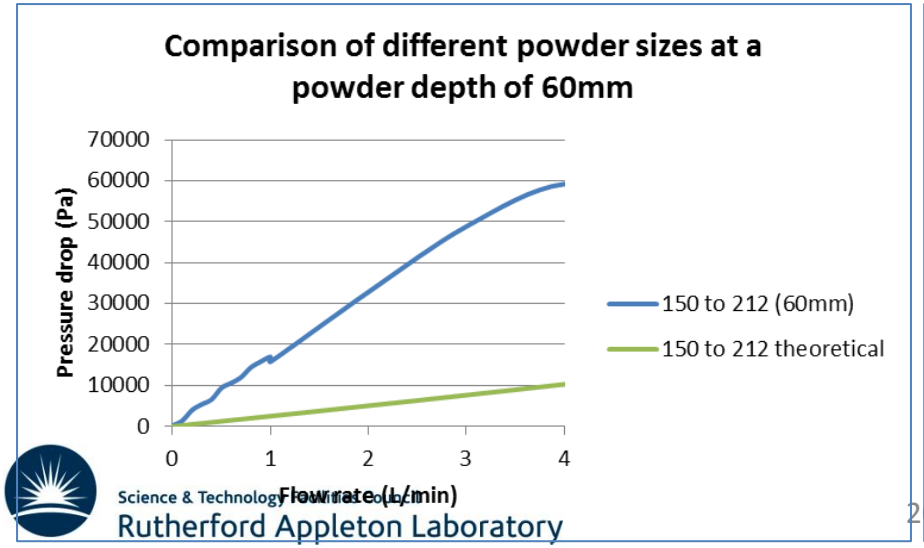
- The experimental change in pressure is consistently much larger than the expected change
- Theoretical calculations rely heavily on **shape factor** (ψ) and **void fraction** (ϵ), and are usually applied to much **less dense** material

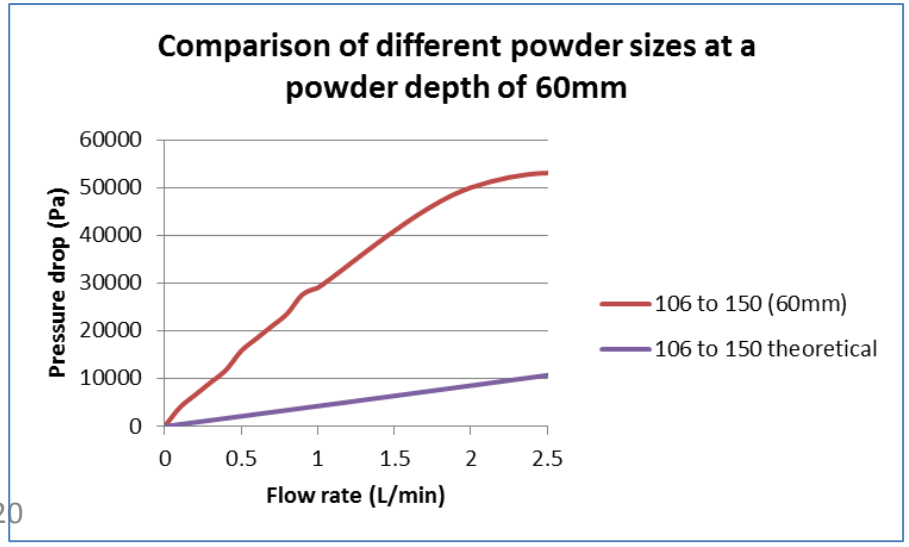
$$\frac{\Delta P}{h} = \rho_g U^2 \left[\frac{150(1-\varepsilon)}{Re_d \psi} + \frac{7}{4} \right] \frac{1-\varepsilon}{\psi \, d_p \, \varepsilon^3}$$

Linear region corresponds to regime before fluidisation has started



Both Ergun and Carman-Kozeny equations largely underestimate pressure drop





Future work to understand W powder dynamics

- Studying the effect of sphericity on flowability and on pressure drop
- Validating the fluidisation experiments on a lighter material (e.g. Glass)
- Investigating electrostatic effects