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Target challenges for the next generation of Neutrino Facilities

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(RAL)

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2015-05-20 High Power Target workshop at FermiLab

Inputs to High Power Target design envelope

Cyclic stresses (fatigue)

Creep

Heat load removal

Stress endurance

Quasi-static stresses

Dynamic inertial stresses

High power proton beam

HP Target

Disposal

Operational safety

Material props Rad. Damage

Toxicological

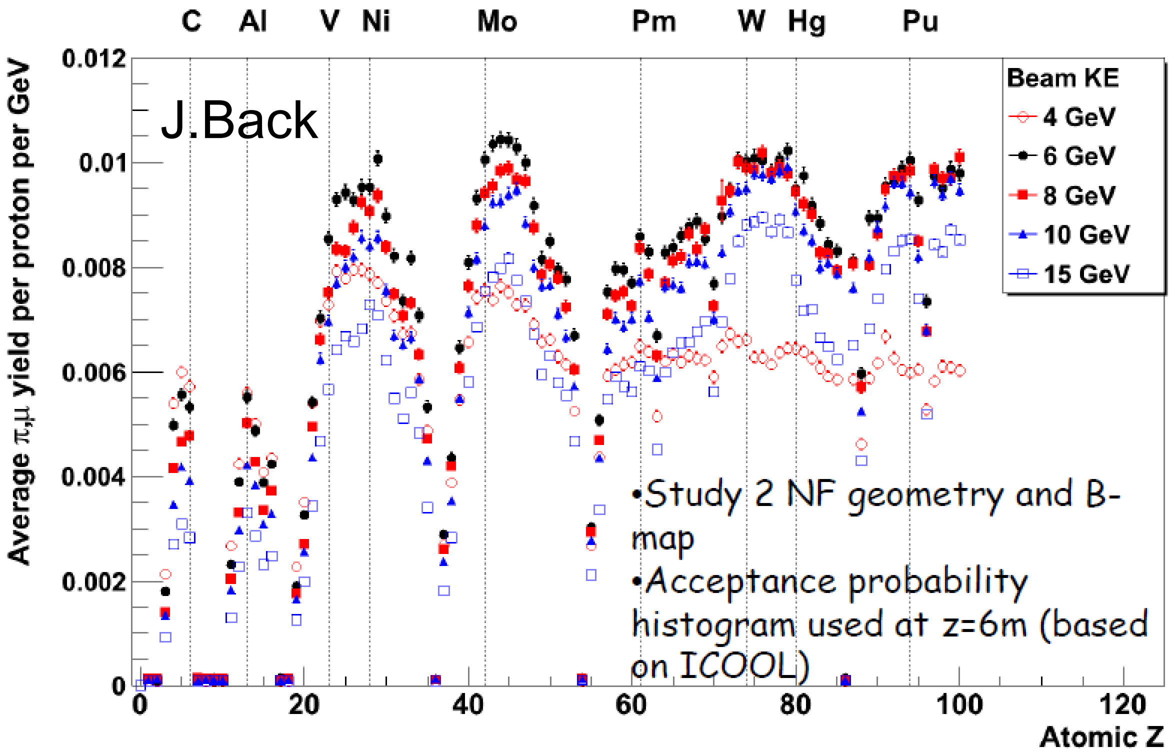
Radiological

Physics performance

Remote handling

Operational reliability

Yield or Productivity?!

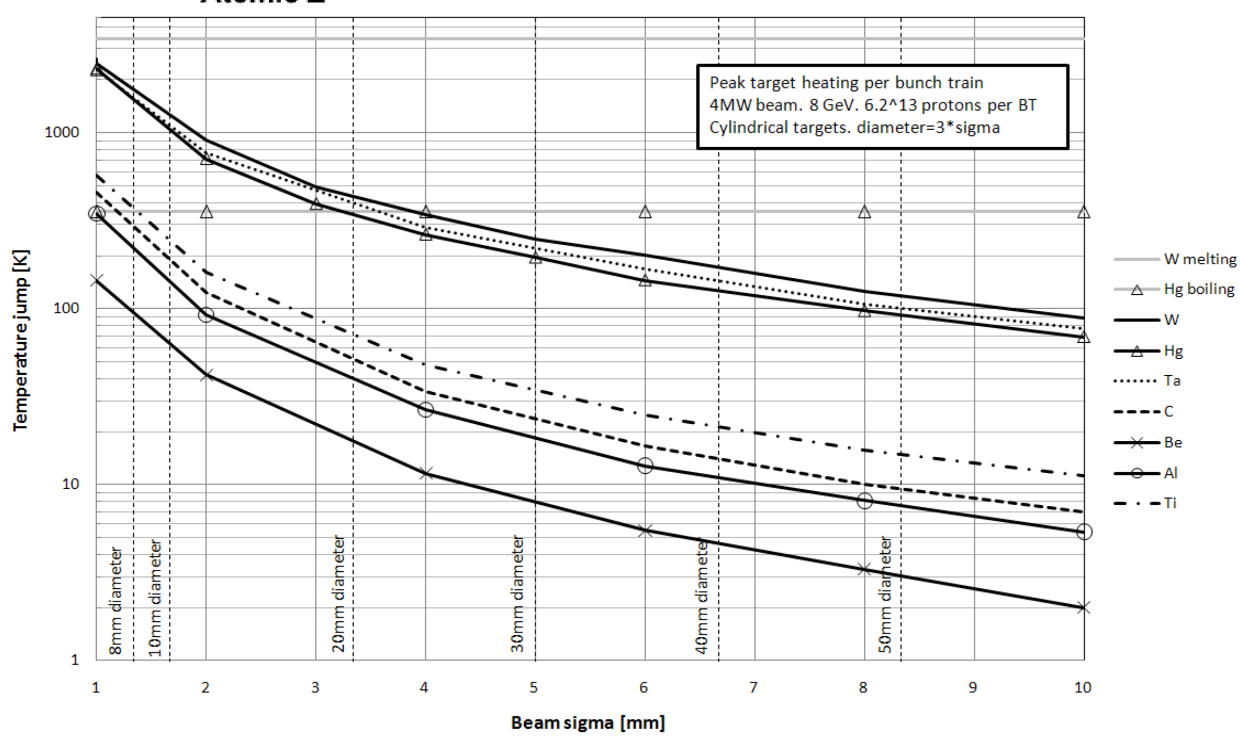


See NF yield in W with that in C (left) and see respective peak temperature jump (below)

Reliability in engineering

$R_f = r_1 * r_2 * r_3 * \ldots r_n$

Where $r_n <= 1$ is the reliability of a given component



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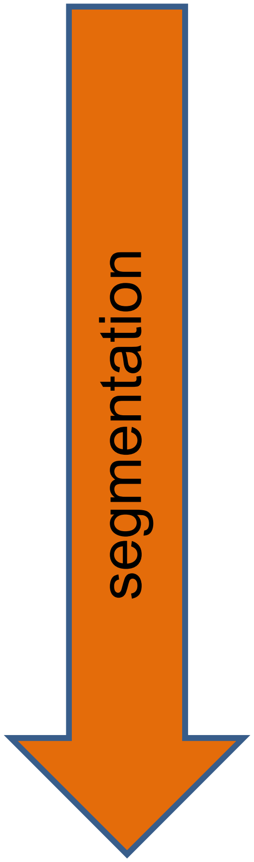
Heat Removal and Thermal stresses

Target	Power Deposited [kW]	Peak Temperature Jump [K]	Existing or proposed solution
Mu2e	2	0.0014	Peripherally cooled cylinder
T2K	15	100	
Numi	4	364	Peripherally cooled segmented
Nova	8	253	
LBNE	23	75+	
ISIS	100	3.8	Segmented with cooling through core
EuroNu	200	62	
Neutrino Factory	500	1000?	Flowing or rotating target
ESS	3000	100	Rotating target with cooling through core of target



T. Davenne

Segmentation is a powerful tool to improve cooling and reduce stresses although there's no such thing as a free ride..

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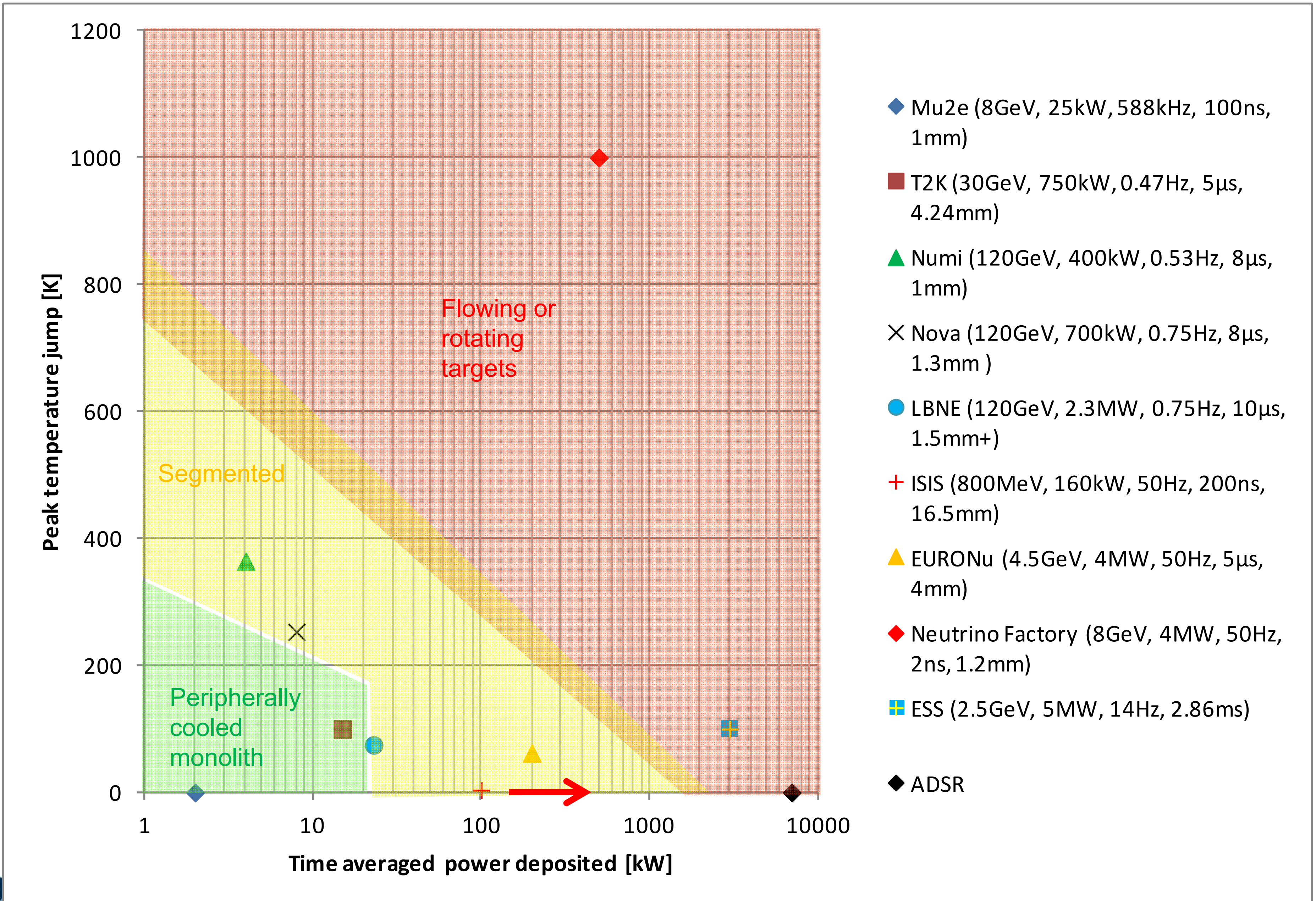
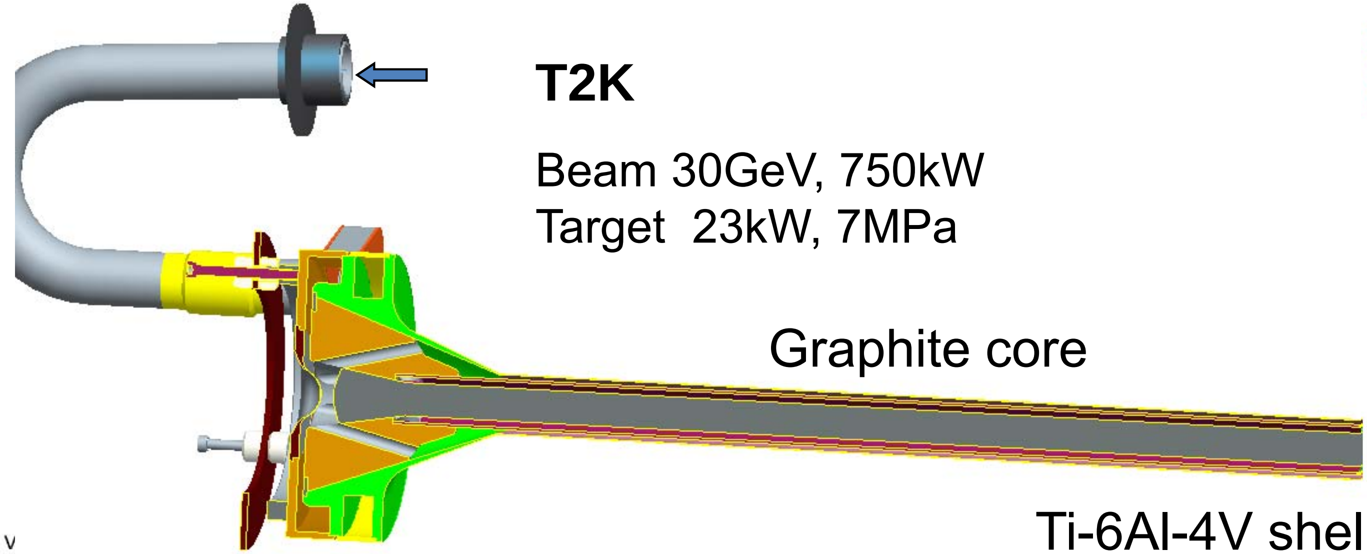
Heat Removal and Thermal Stress Summary

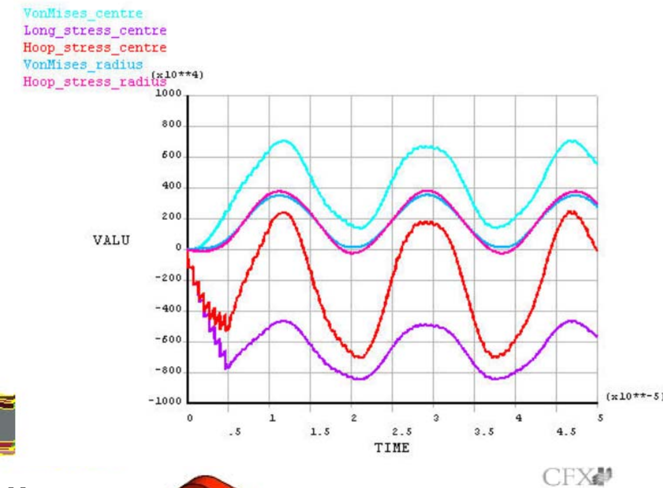


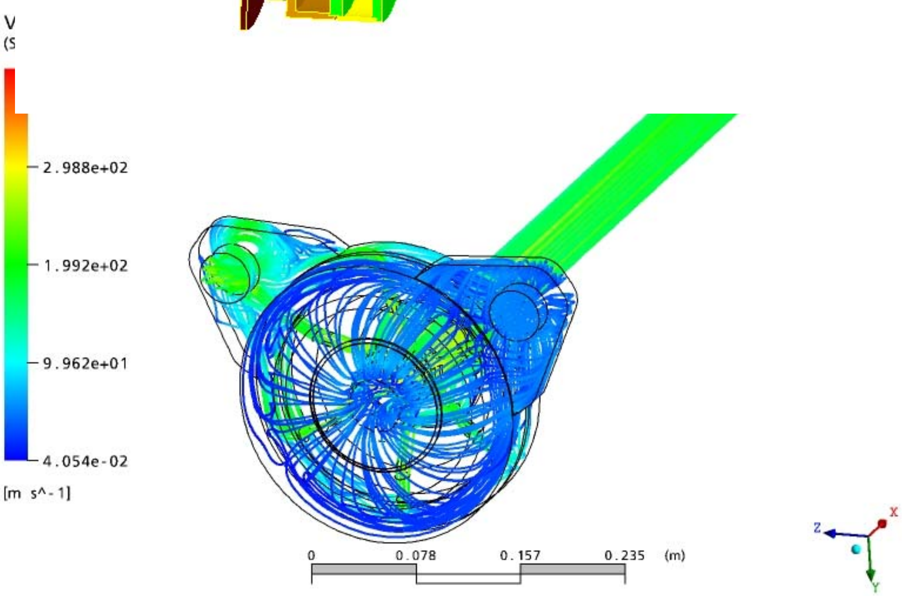
Monolithic (peripherally cooled) target: T2K

T2K

Beam 30GeV, 750kW
Target 23kW, 7MPa

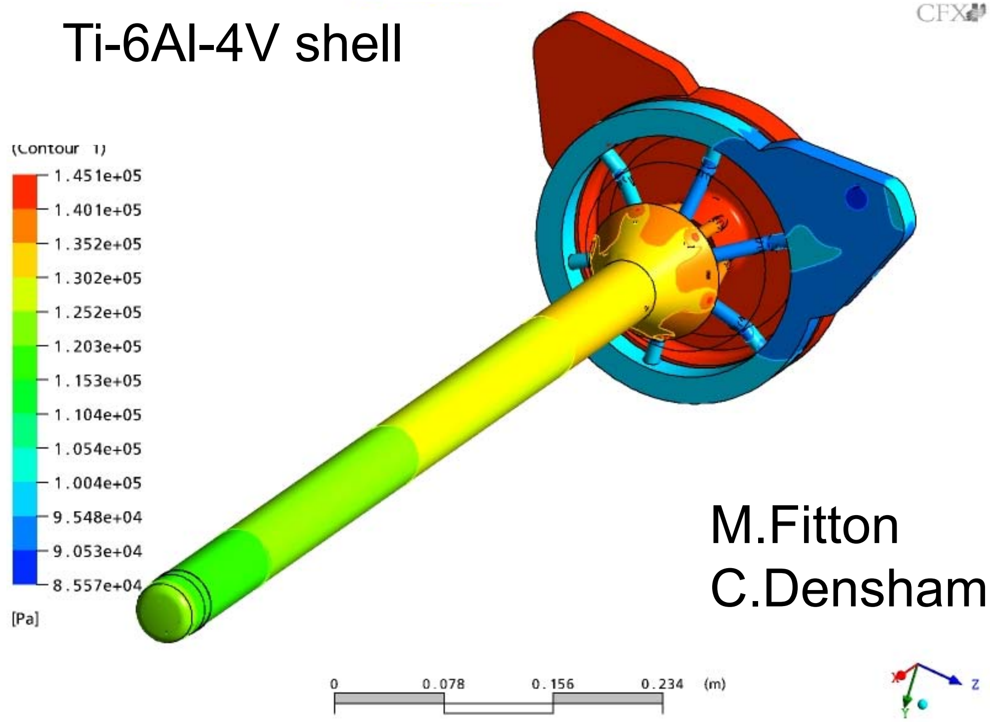






Helium cooling velocity streamlines

Maximum velocity = 398 m/s

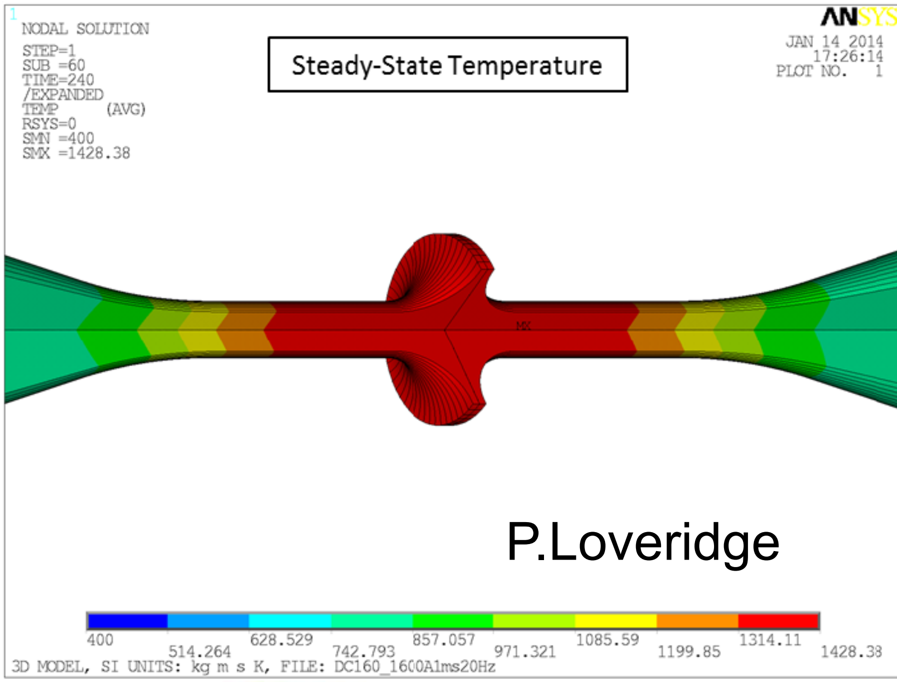


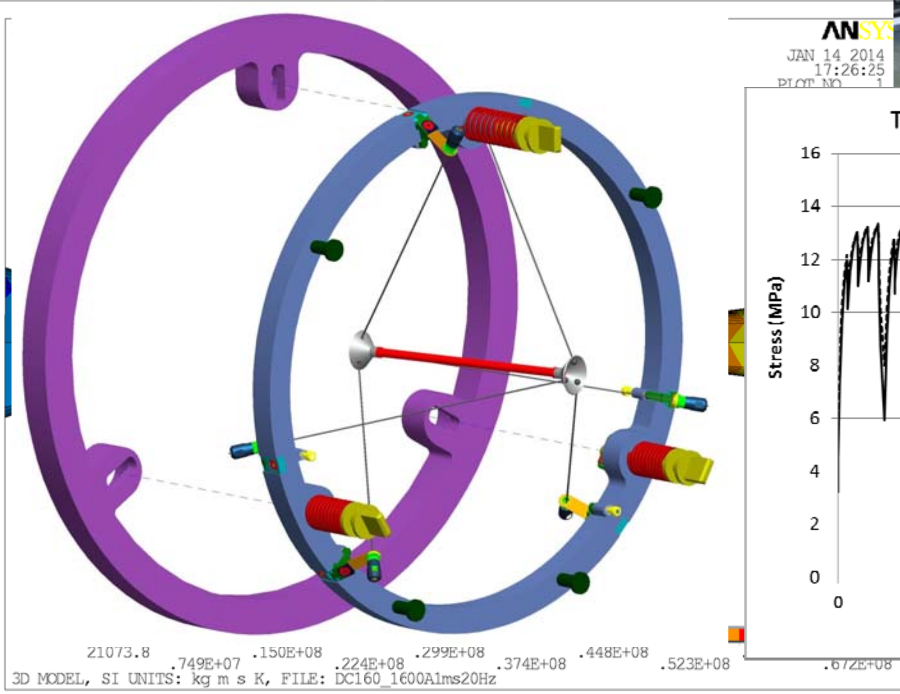
M.Fitton
C.Densham

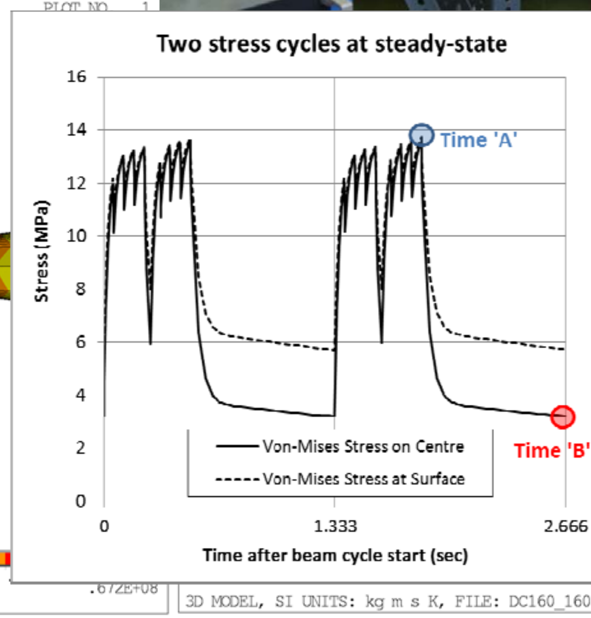
Pressures (gauge)

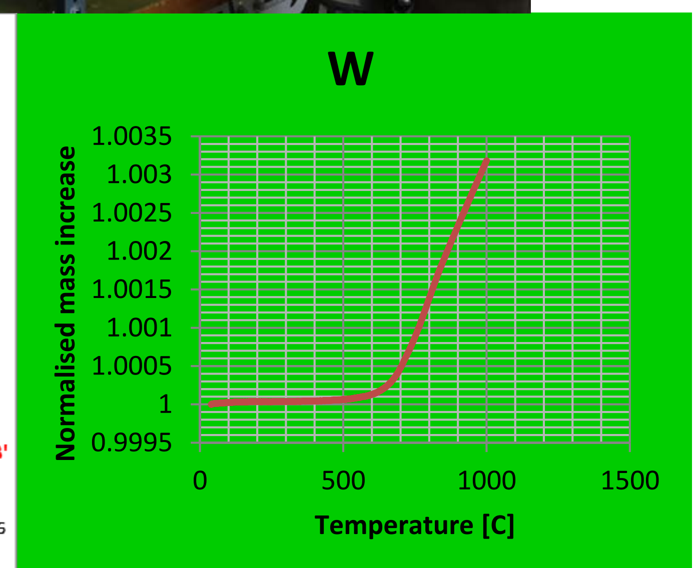
Pressure drop = 0.792 bar

Monolithic radiation cooled target: Mu2e





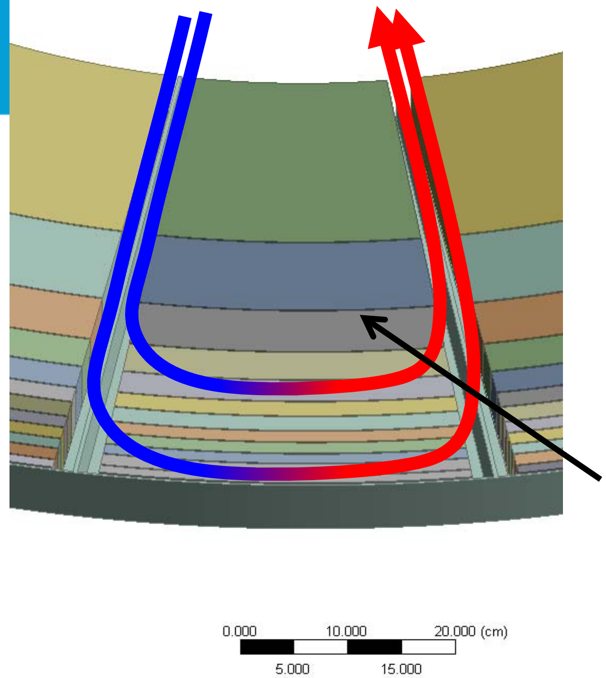


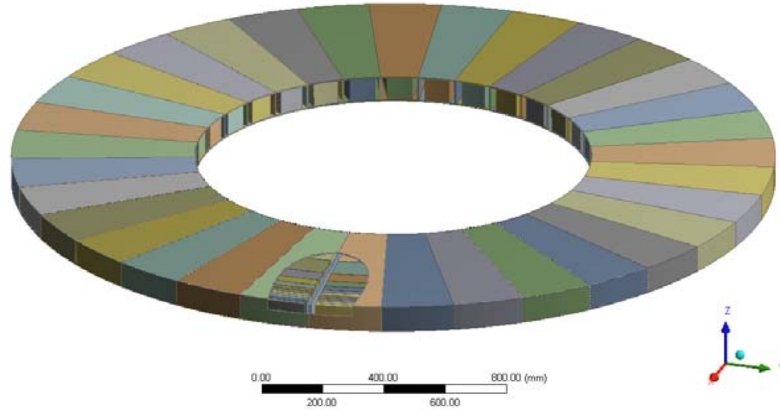


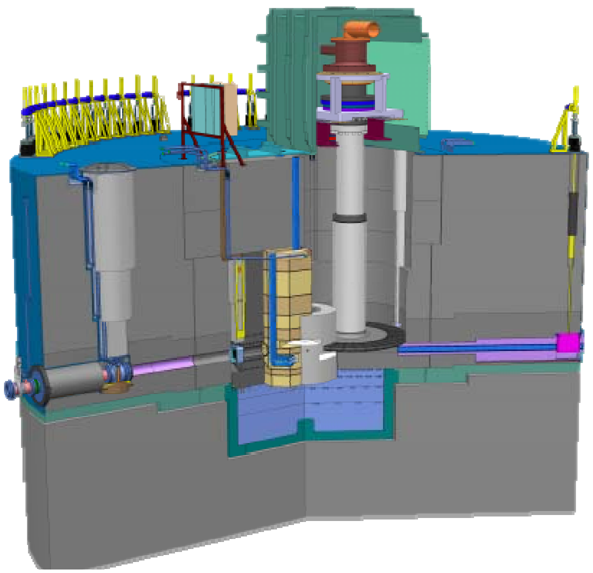
EUROPEAN SPALLATION SOURCE

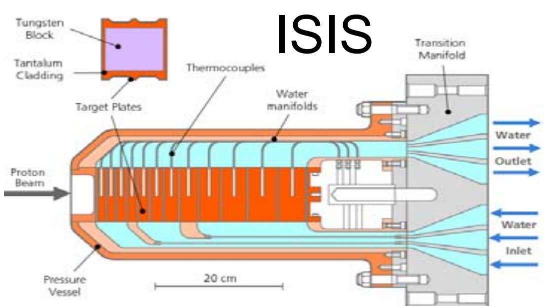
Segmented target: ESS wheel

5 MW target: helium cooled tungsten wheel



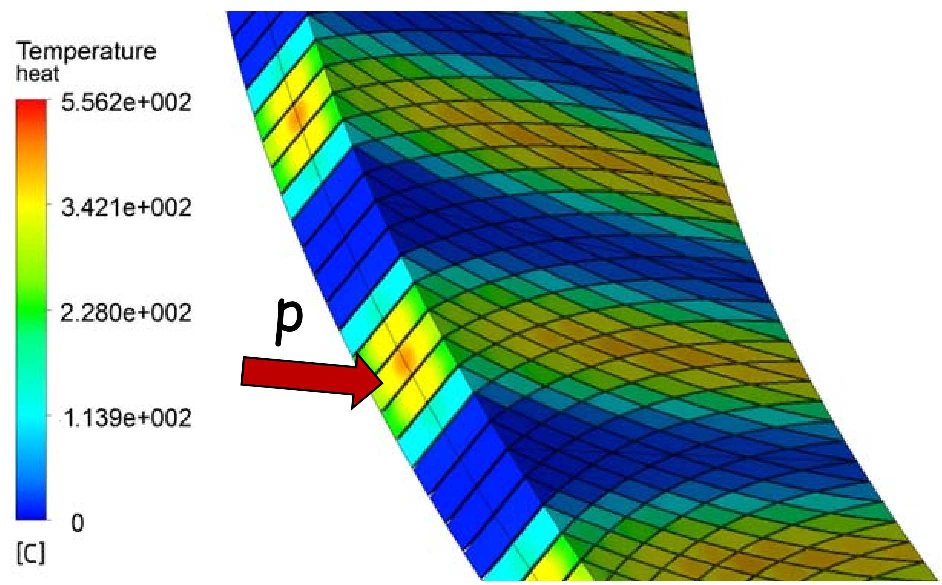






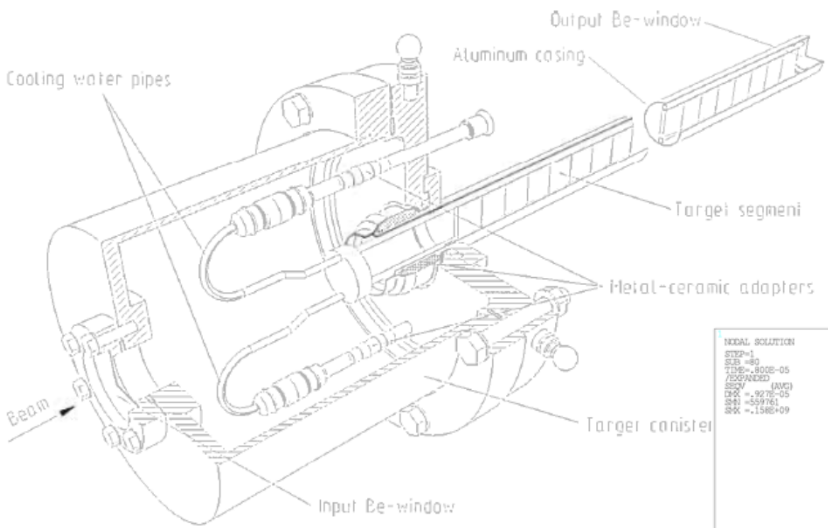
ISIS

Segmentation is necessary to remove the heat and a higher degree of segmentation may be required to reduce the peak stresses

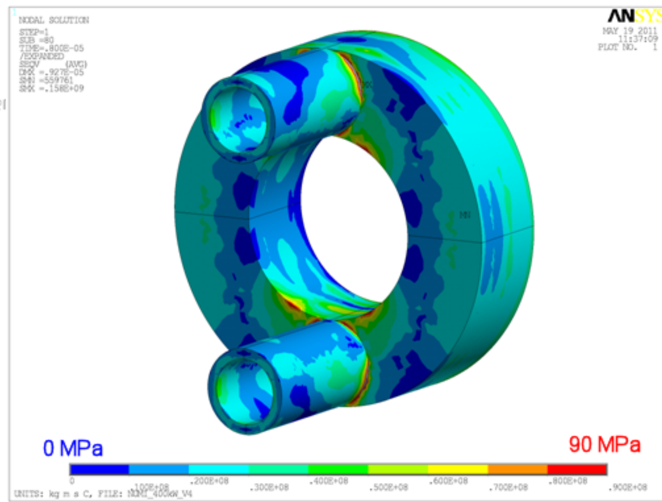


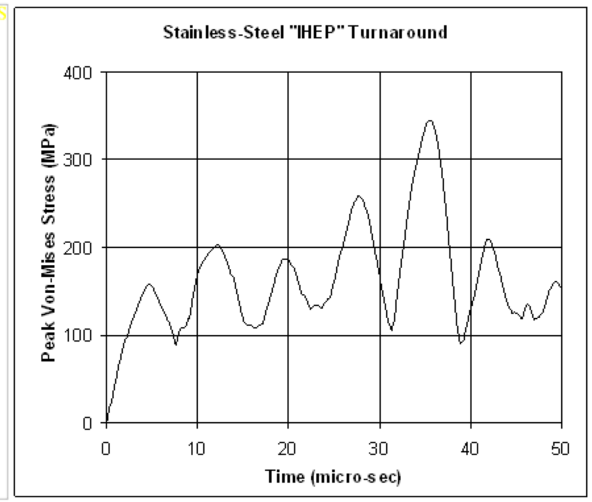
Segmented Target: NuMi

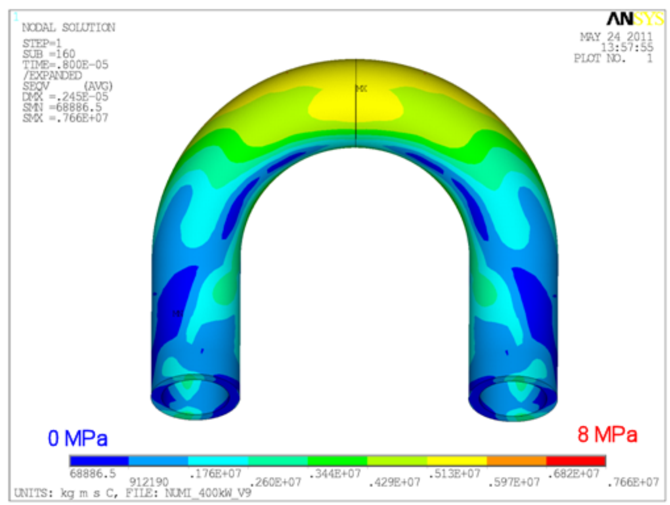
P.Loveridge
M.Fitton.
G.Burton

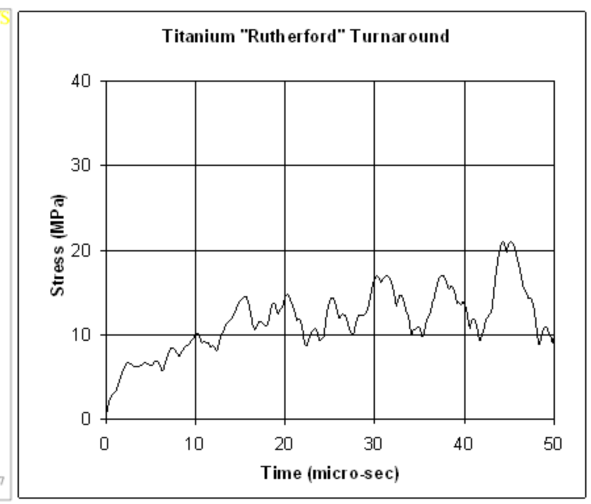


5K temperature jump in water
40K temperature jump in Steel cooling tubes



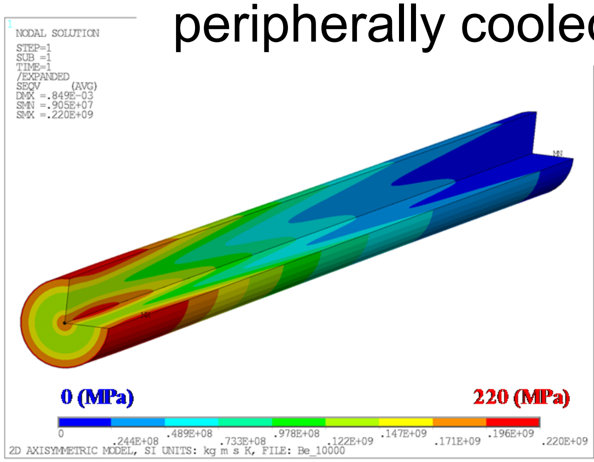




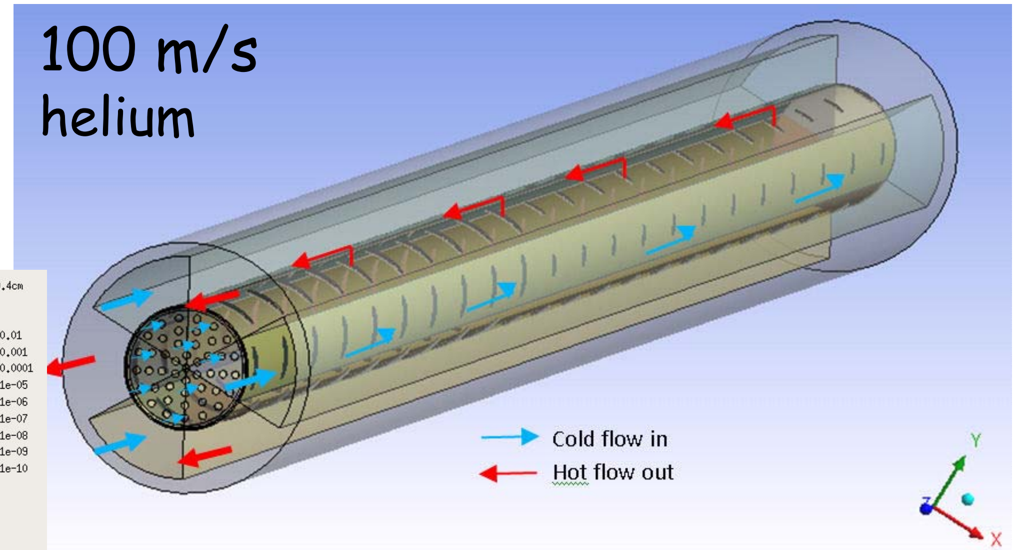


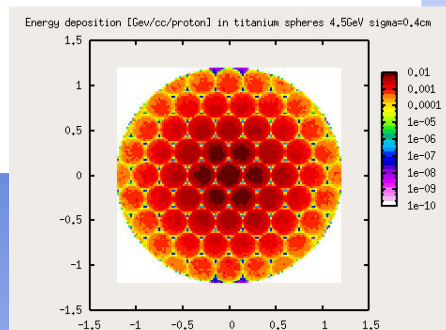
Segmented Target: EURONu

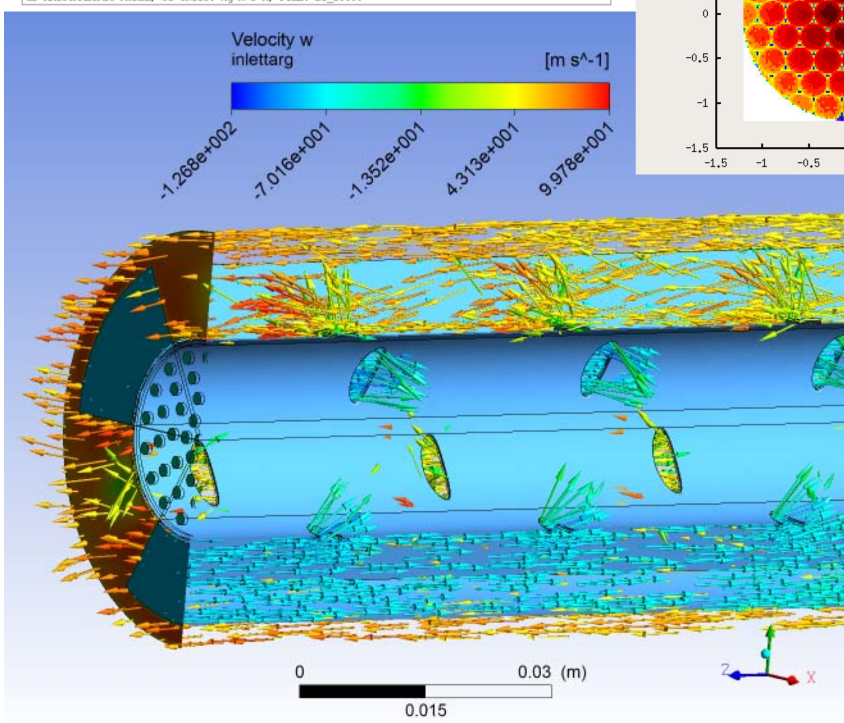
Stress limit reached for solid peripherally cooled target



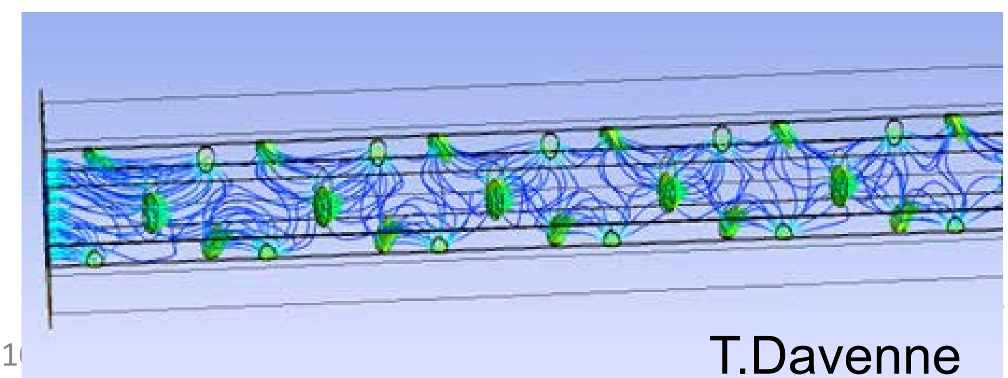
Increased surface area. Coolant reaching maximum energy deposition region



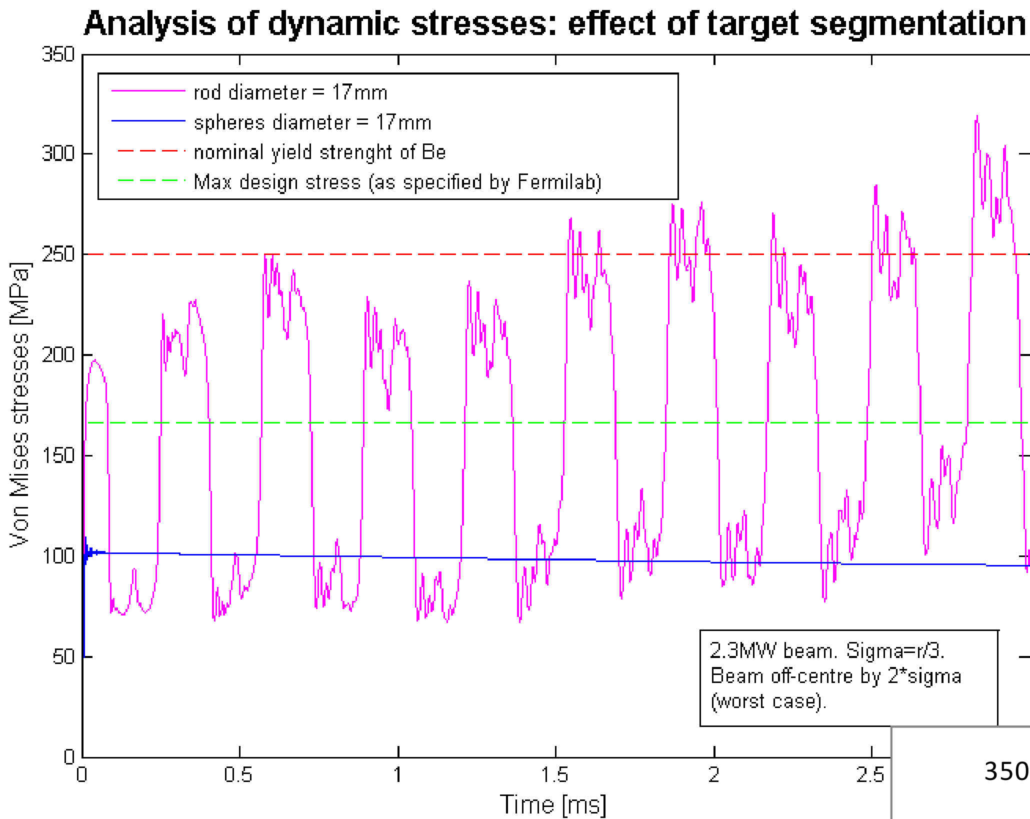




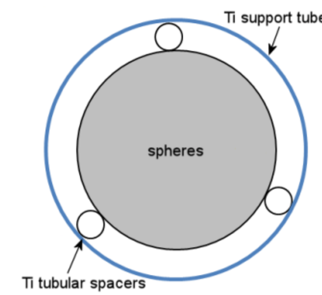
Packed bed target concept for 4 MW Neutrino Superbeam study (EUROnu)



Segmented target: LBNE

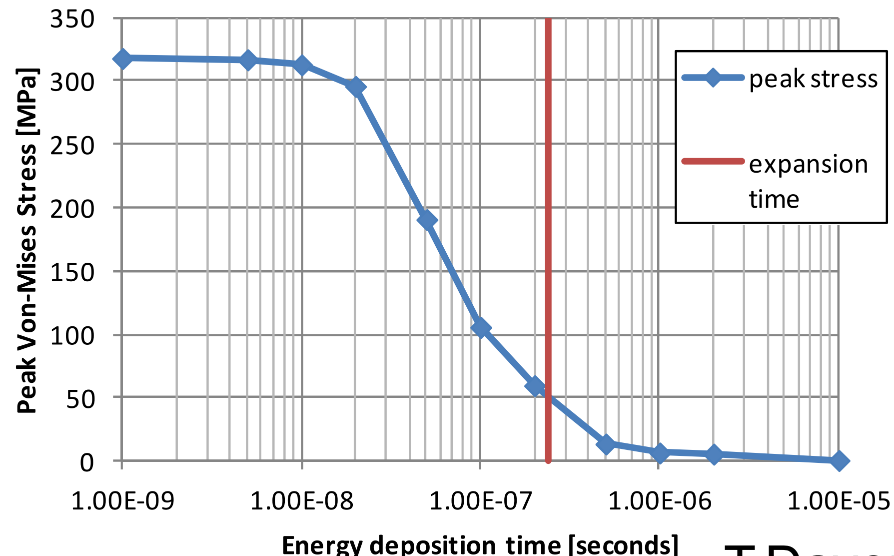


Dynamic stresses in beryllium cylinder compared to beryllium spheres as a result of LBNE 2.3MW beam



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

Expansion time α target size



T.Davenne

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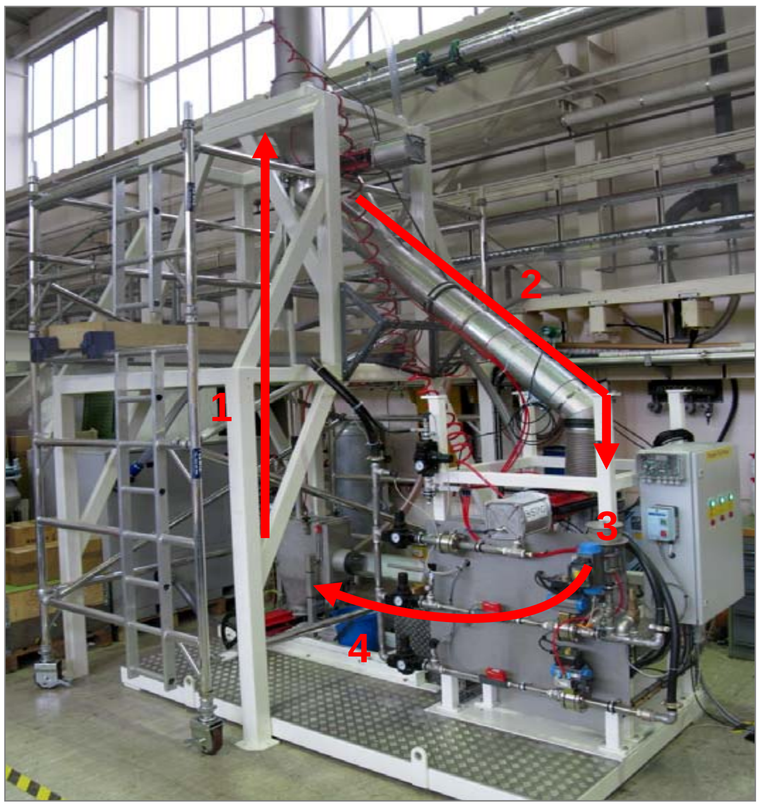
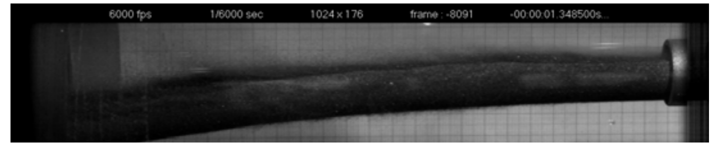
Fragmented high Z flowing target: W powder rig

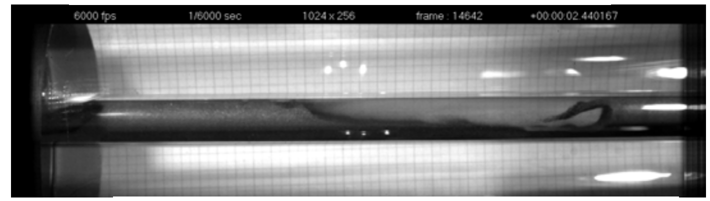
- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Containment / erosion
  - Heat transfer and cooling of powder



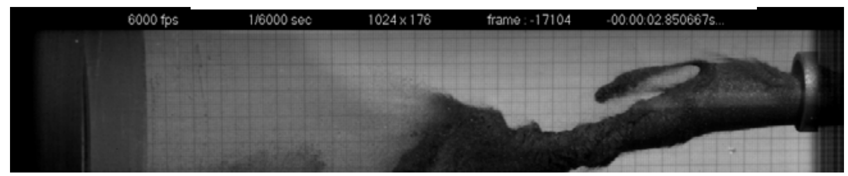
Dense-phase delivery



High speed image: tungsten powder jet

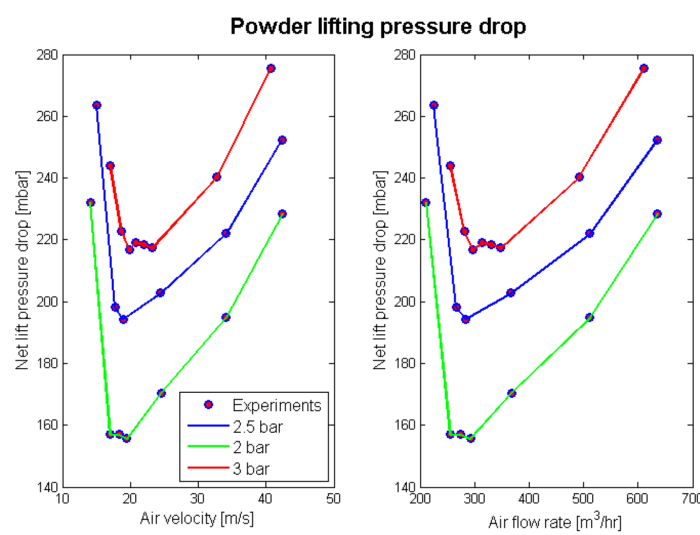


High speed image: tungsten powder flow in a pipe



Unstable tungsten powder jet

Lean-phase lift



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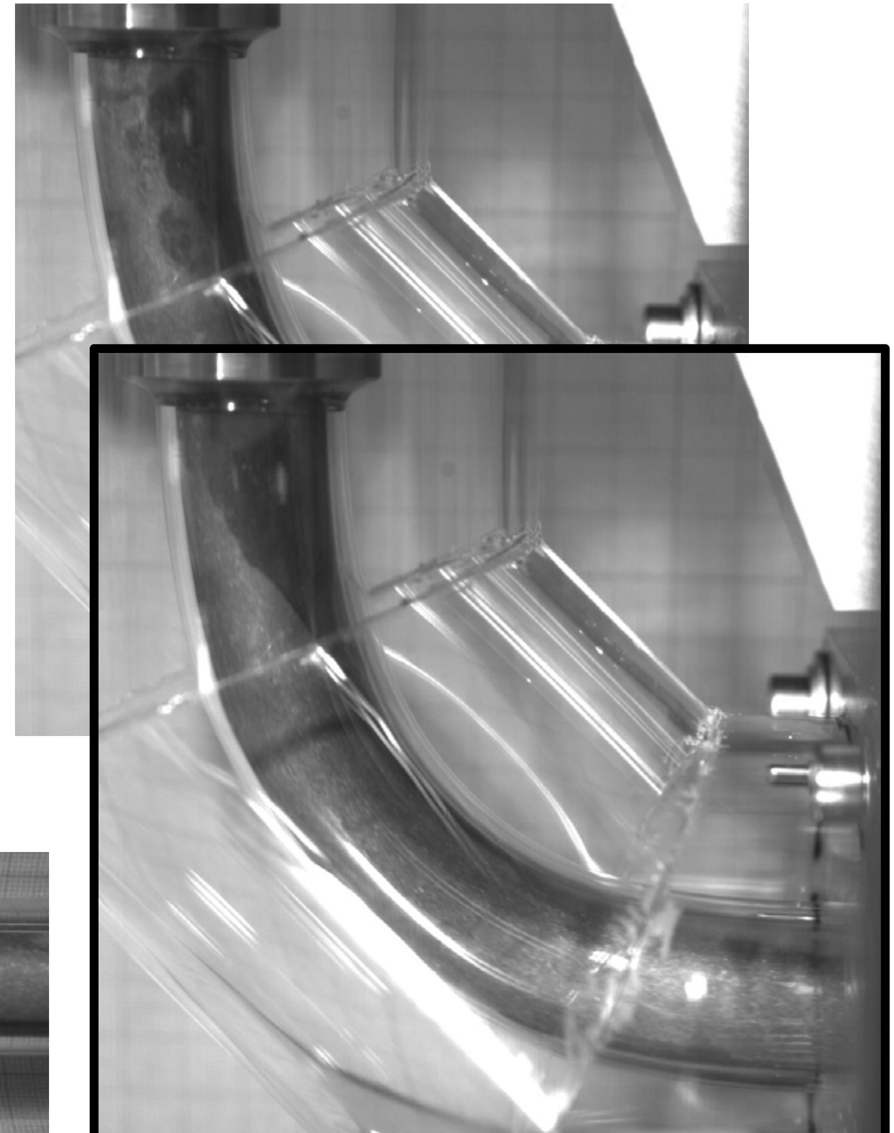
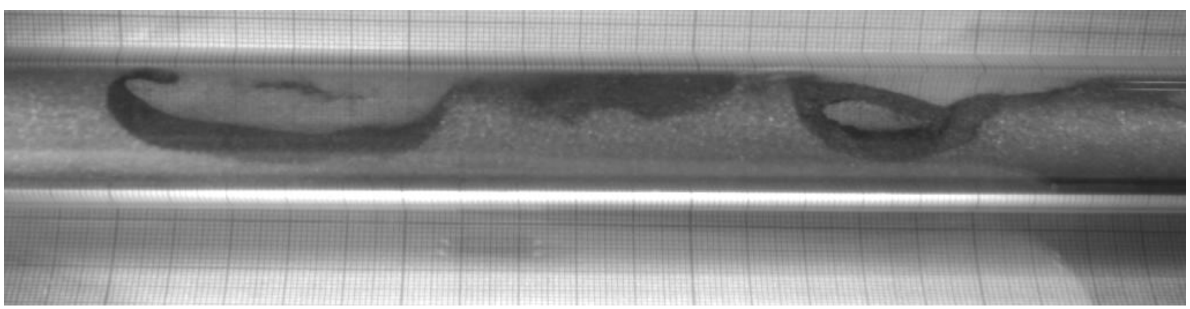
Improving diagnostics to increase the solid fraction





glass parts tube show early stages of phase separation

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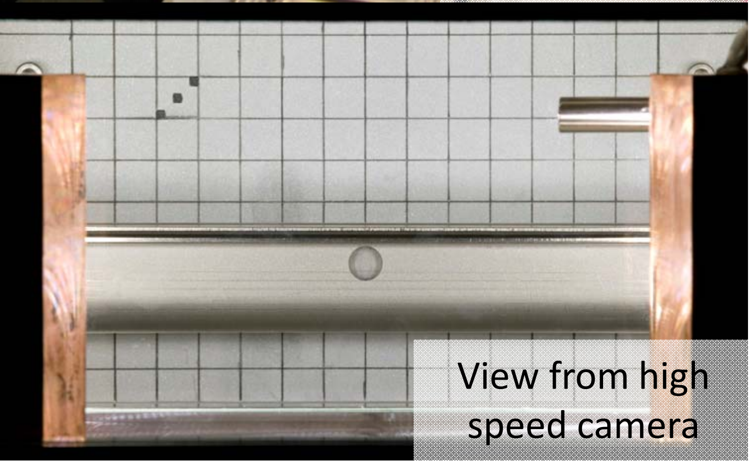
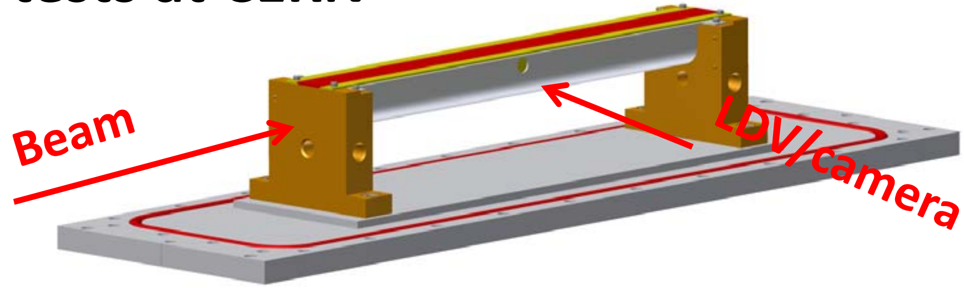
O'Dell - Loveridge

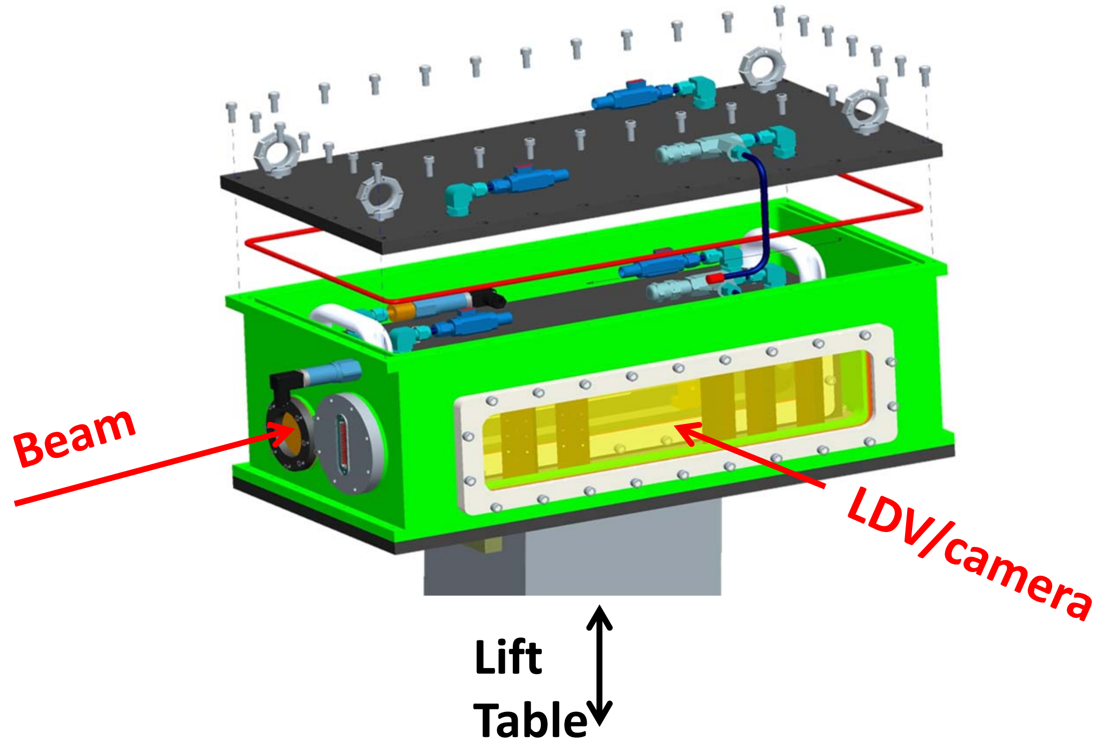
In beam tests at CERN


Open trough Assembly


Filling with Tungsten Powder

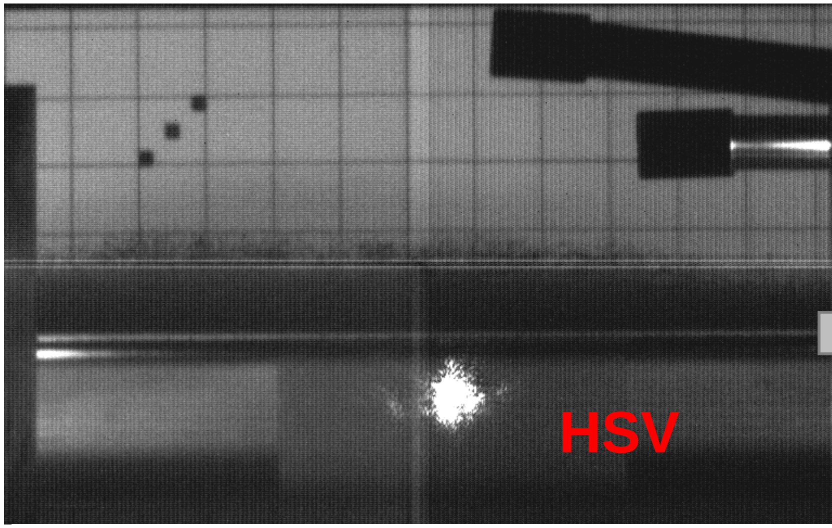

View from high speed camera





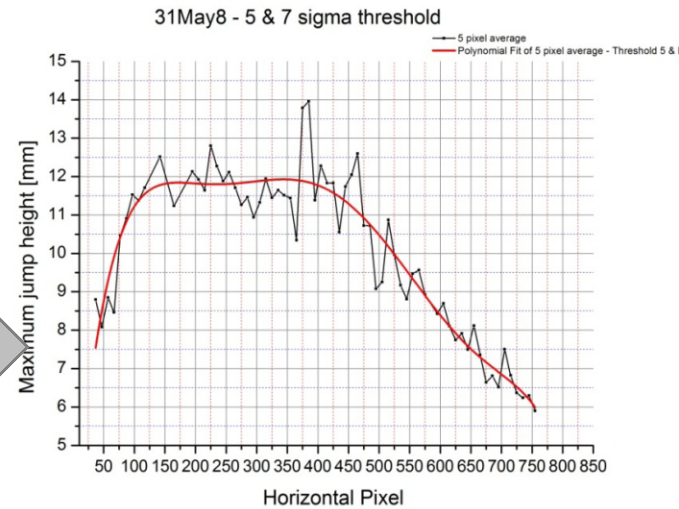
- Tungsten powder sample in an open trough configuration
- Helium environment
- Two layers of containment with optical windows to view the sample
- Remote diagnostics via LDV and high-speed camera

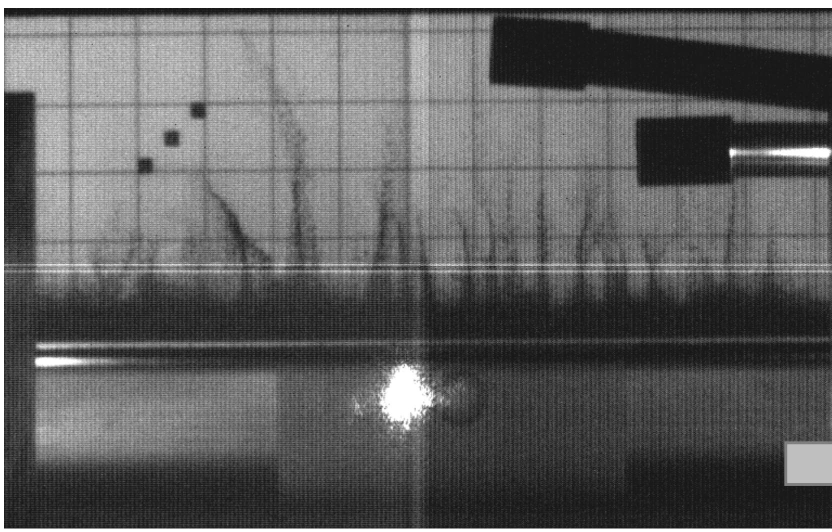
Charitonidis



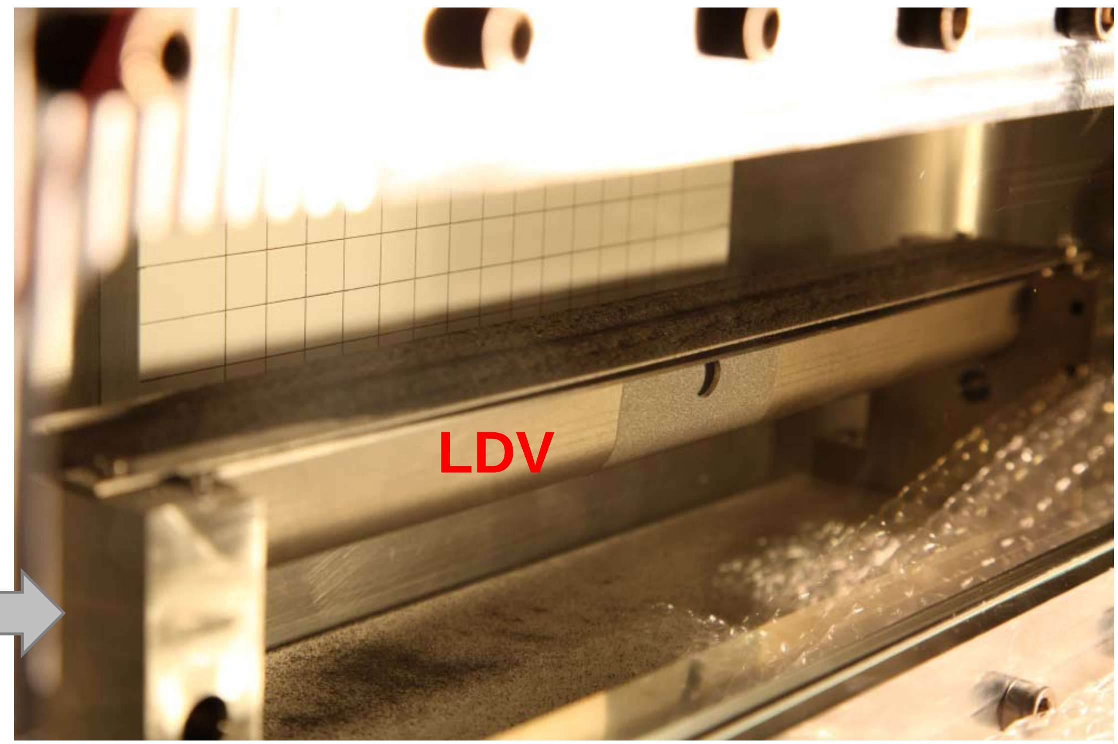
Shot #8, 1.75e11 protons
Note: nice uniform lift

Lift height correlates with deposited energy





Shot #9, 1.85e11 protons
Note: filaments!



Trough photographed after the experiment.
Note: powder disruption

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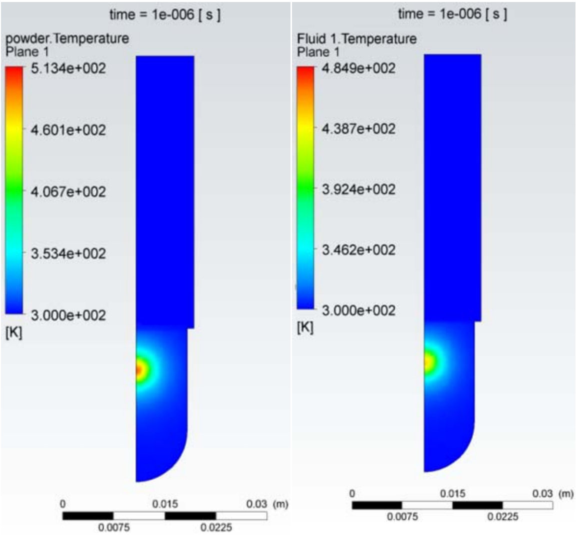
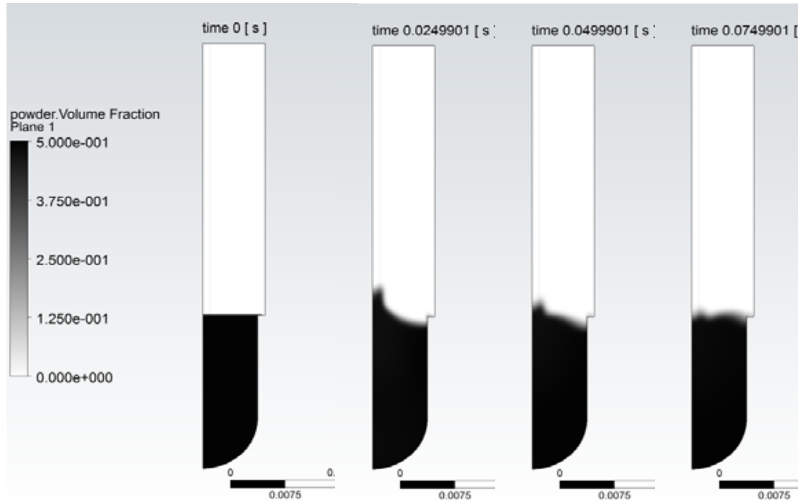
Davenne: CFD predictions/post fits

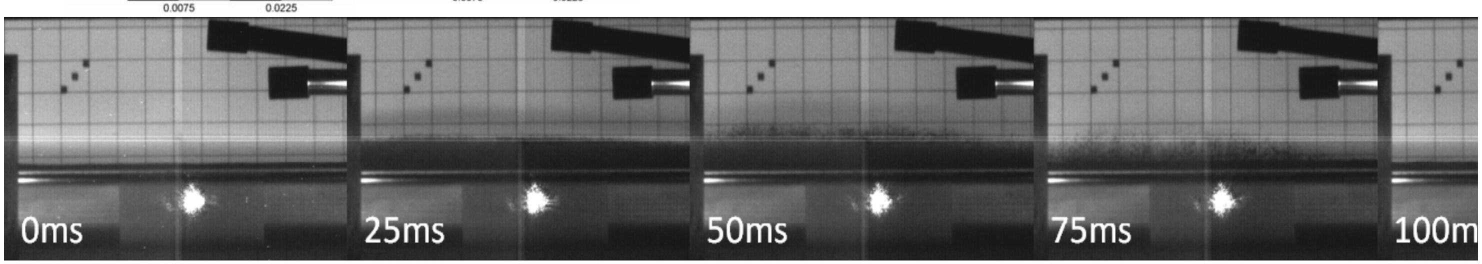
Beam heating





Powder lift was predicted by CFD

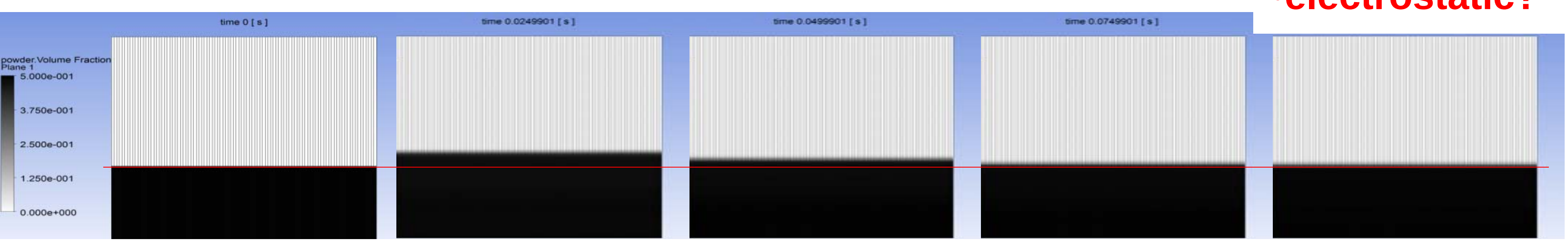
However the energy to lift the powder was found in the experiment to be an order of magnitude smaller than predicted



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

So is the lift:

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



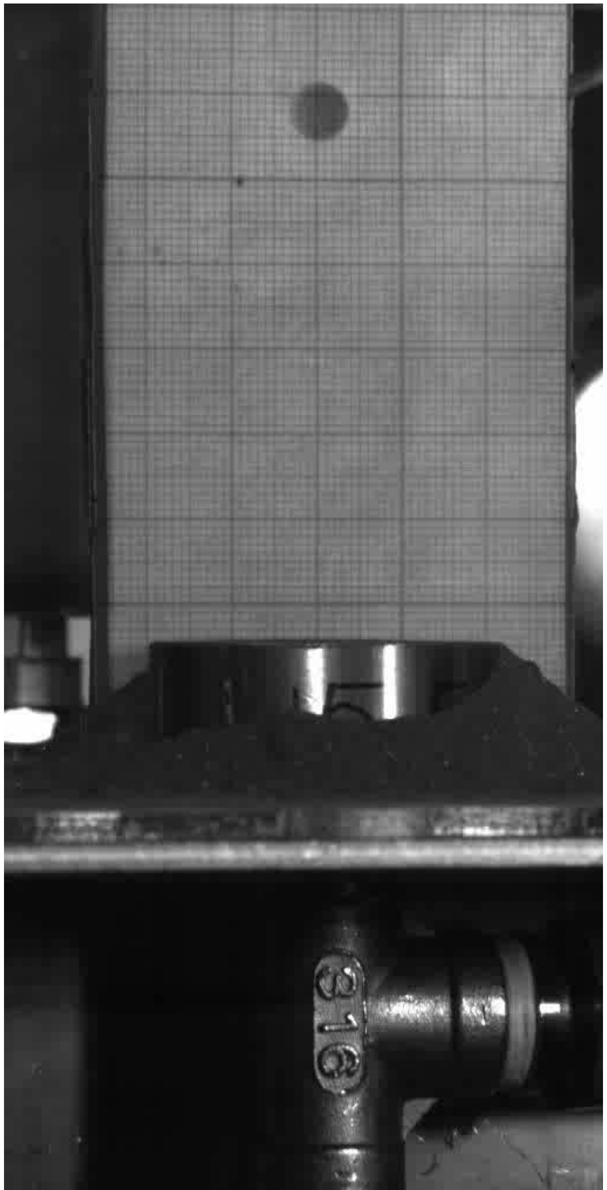
CFD simulation of Shot #8, assuming 1 micron particle size
(n.b. no lift with 25 micron particles at this intensity)

Tungsten powder puff experiment: understanding the powder lift

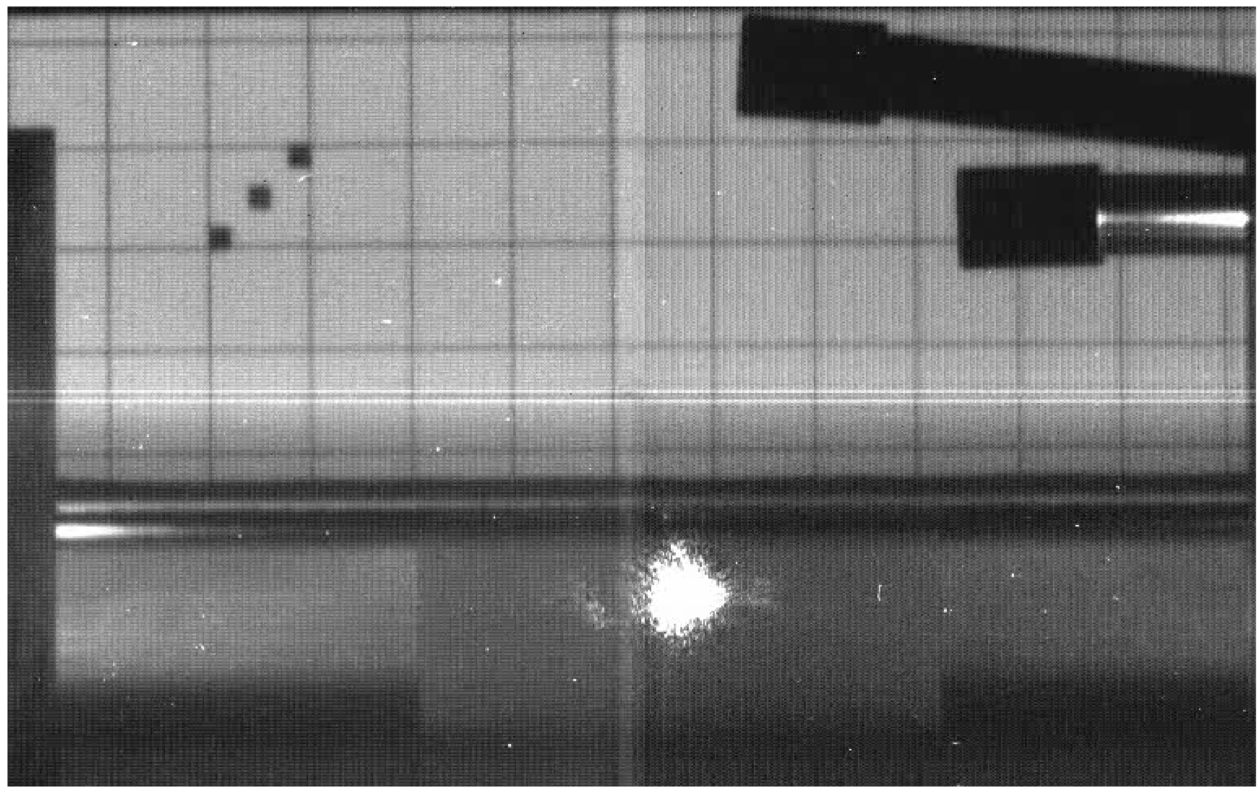
piston

Puff cell

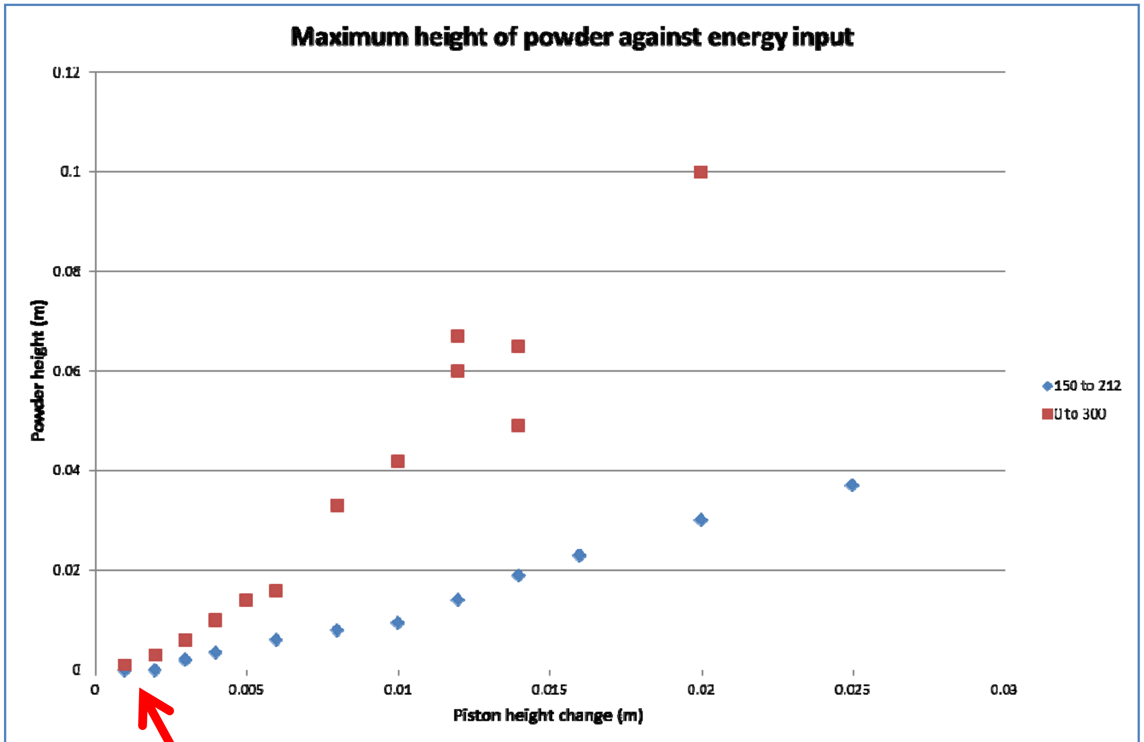
Tungsten powder puff experiment



- 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



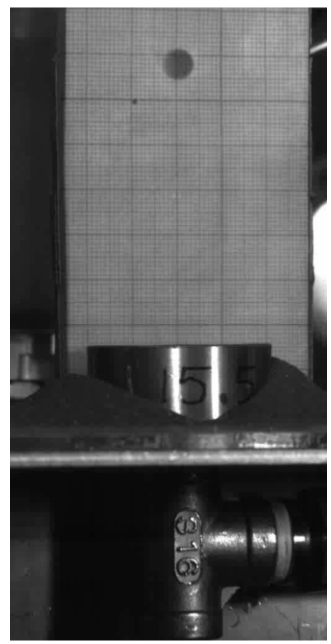
Tungsten powder puff experiment



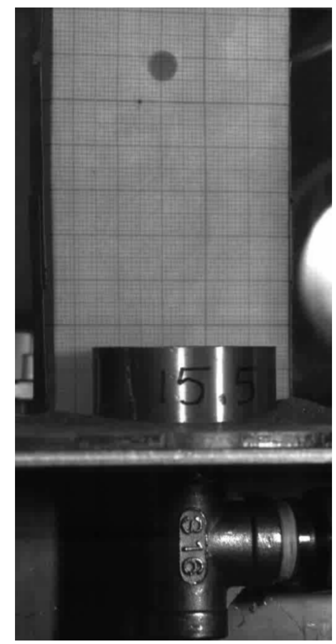
There is a threshold energy which has to be reached before the powder begins to lift. The threshold depends on the depth of the powder

- 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 that can be captured with 1kHz HSV

0 to 300 um



150 to 212 um

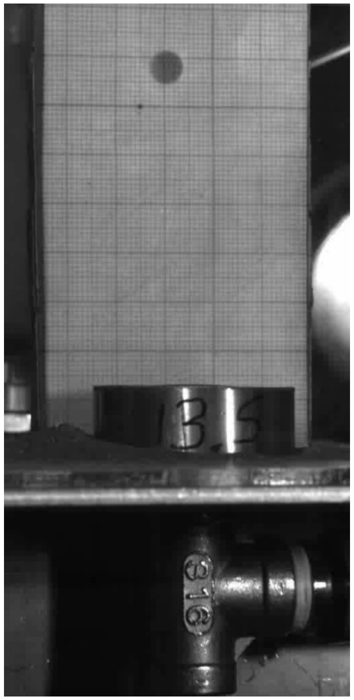
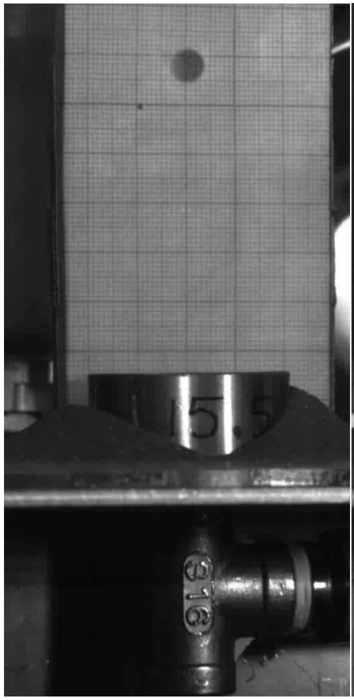
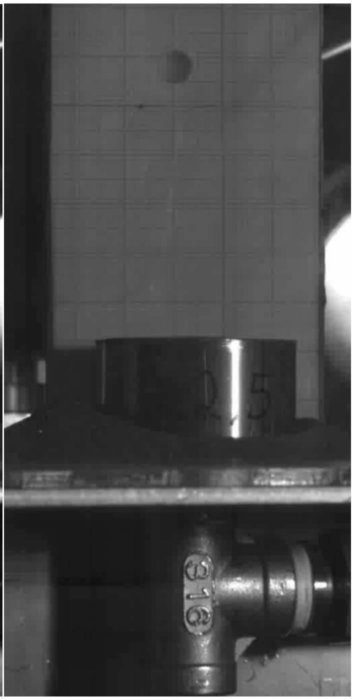


Tungsten powder puff experiment

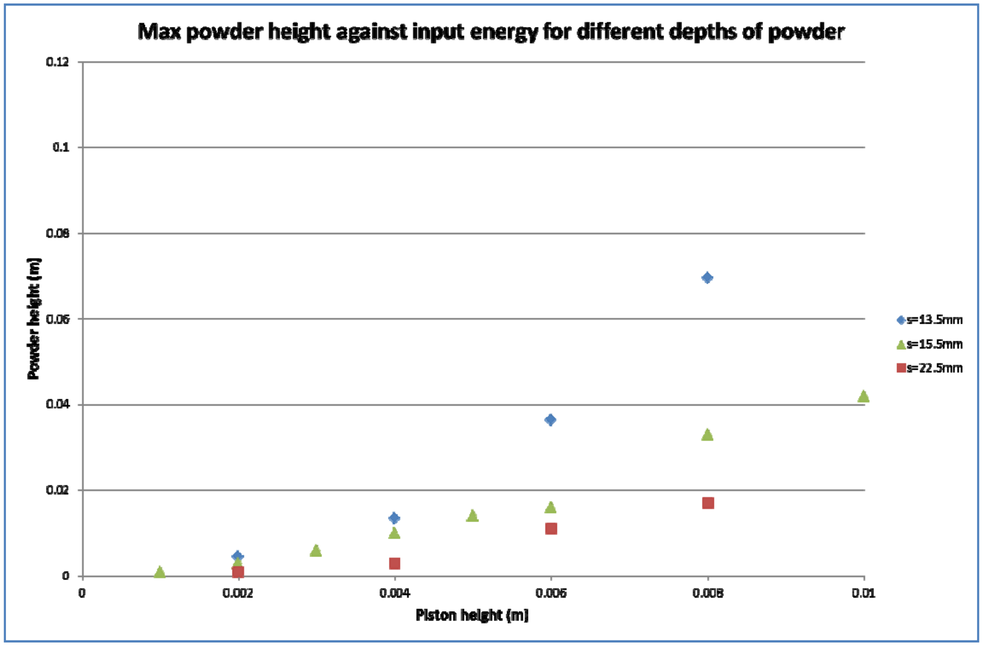
Powder depth = 13.5mm

Powder depth = 15.5mm

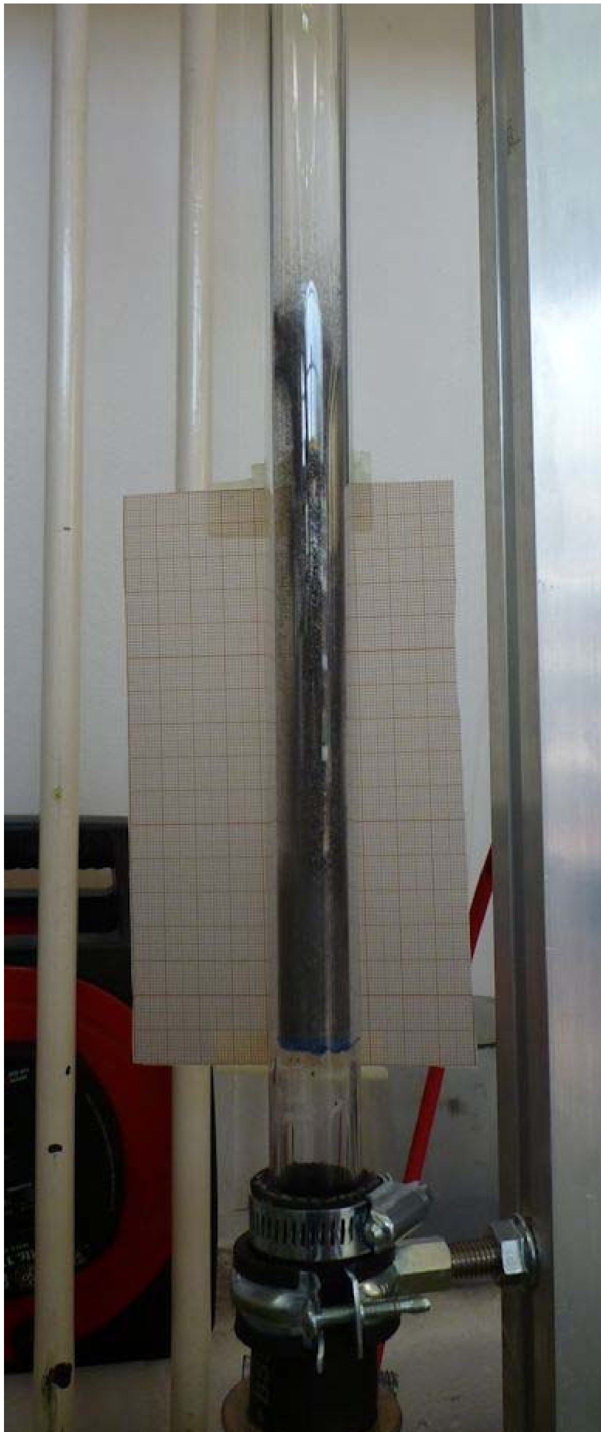
Powder depth = 22.5mm

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



Understanding powder lift



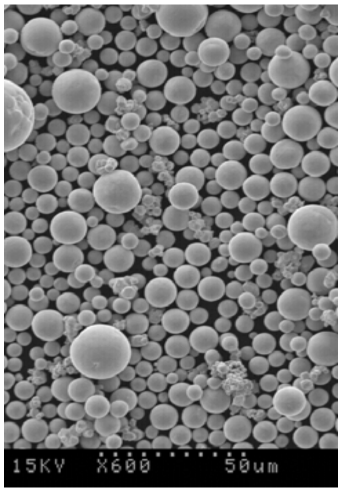
Pressure drop for air flowing through a bed of powder

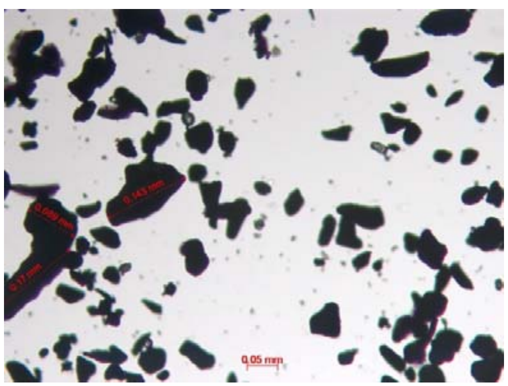
Atherton, Davenne

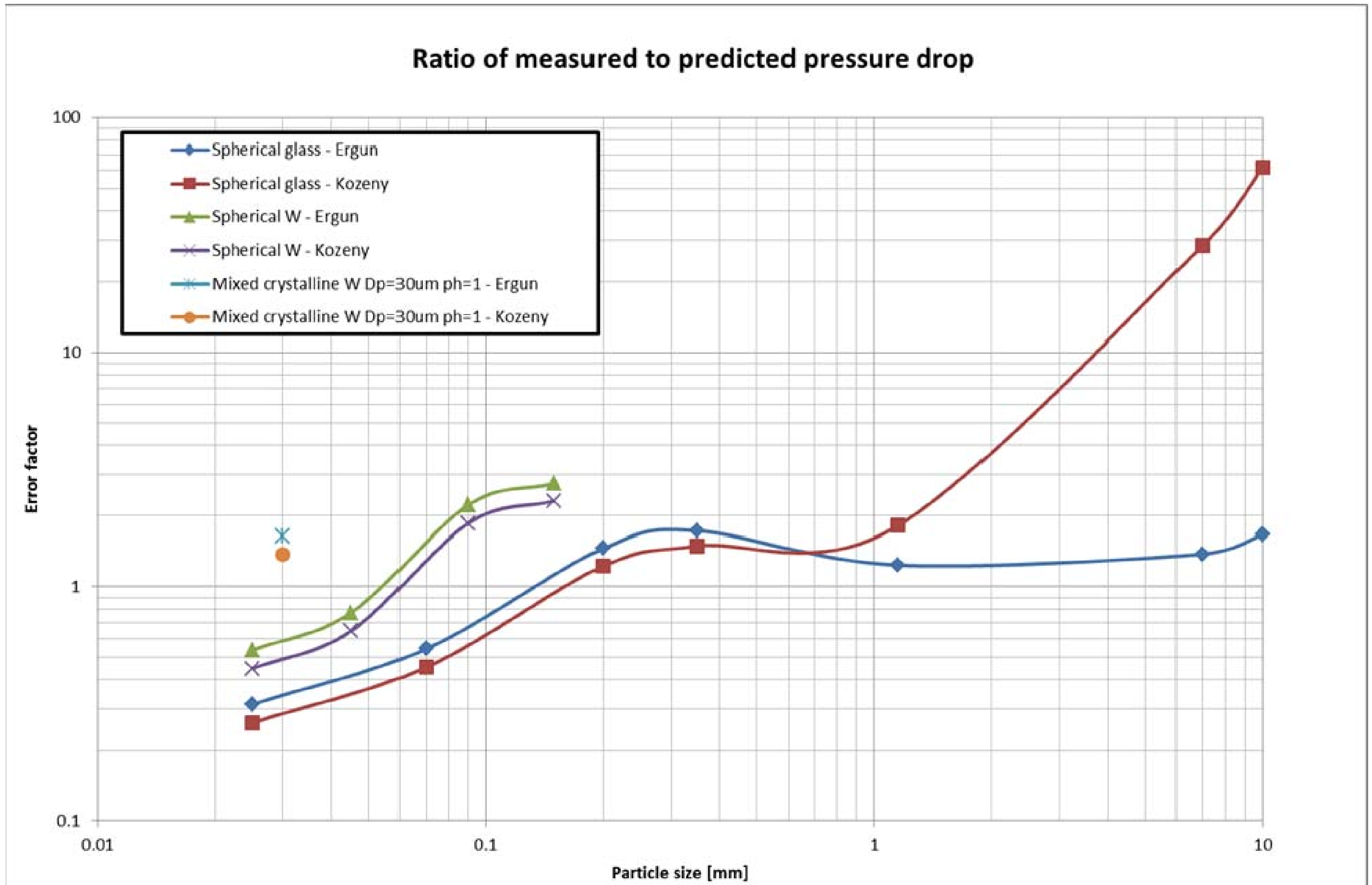
Packed bed experiment

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)

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







Tungsten Powder programme live areas of work

- **Rig improvement**
  - Increasing the solid fraction
  - CW upgrade
  - Calorimetry
- **In beam tests HiRadMat**
  - Understanding factor/factors for beam powder lift
    - aerodynamic
    - stress propagation
    - Electrostatic
    - a combination of all the above

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 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 beneficialfor 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.