Tungsten Powder as an accelerator target

& In-Beam Testing

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(Apr. 4, 2013)

(RAL)
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(CERN)

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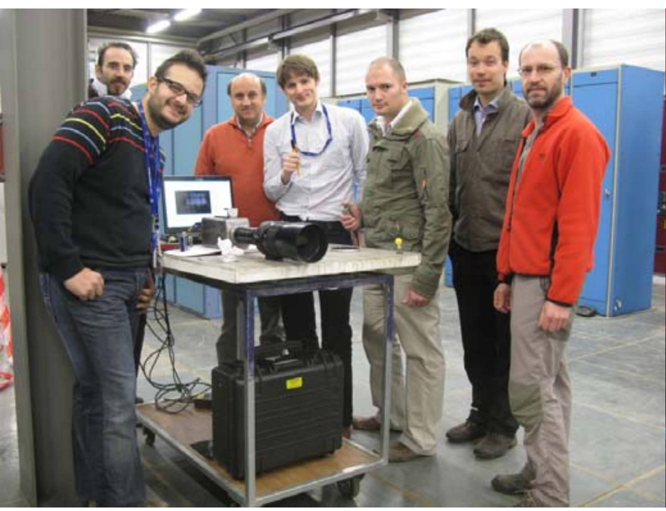
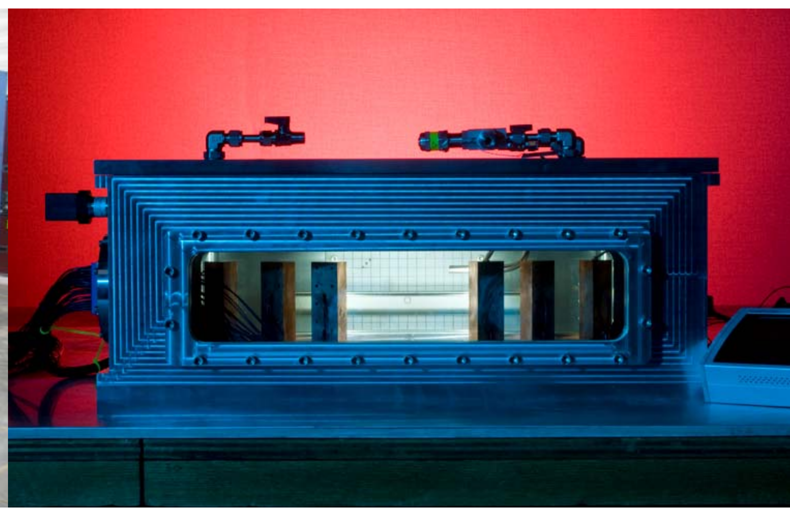
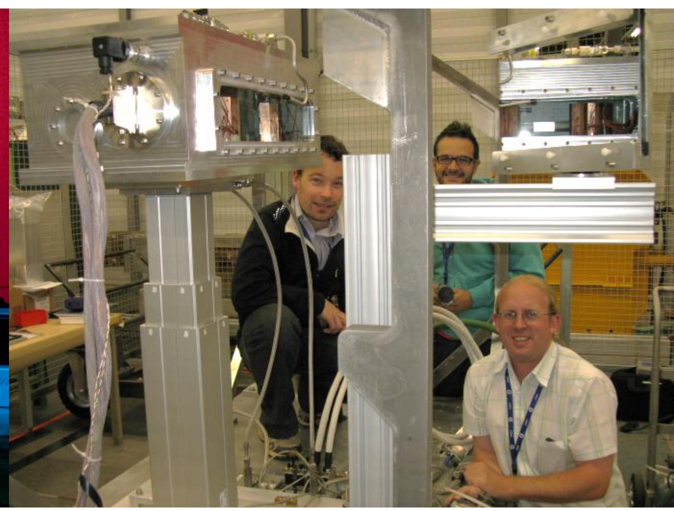
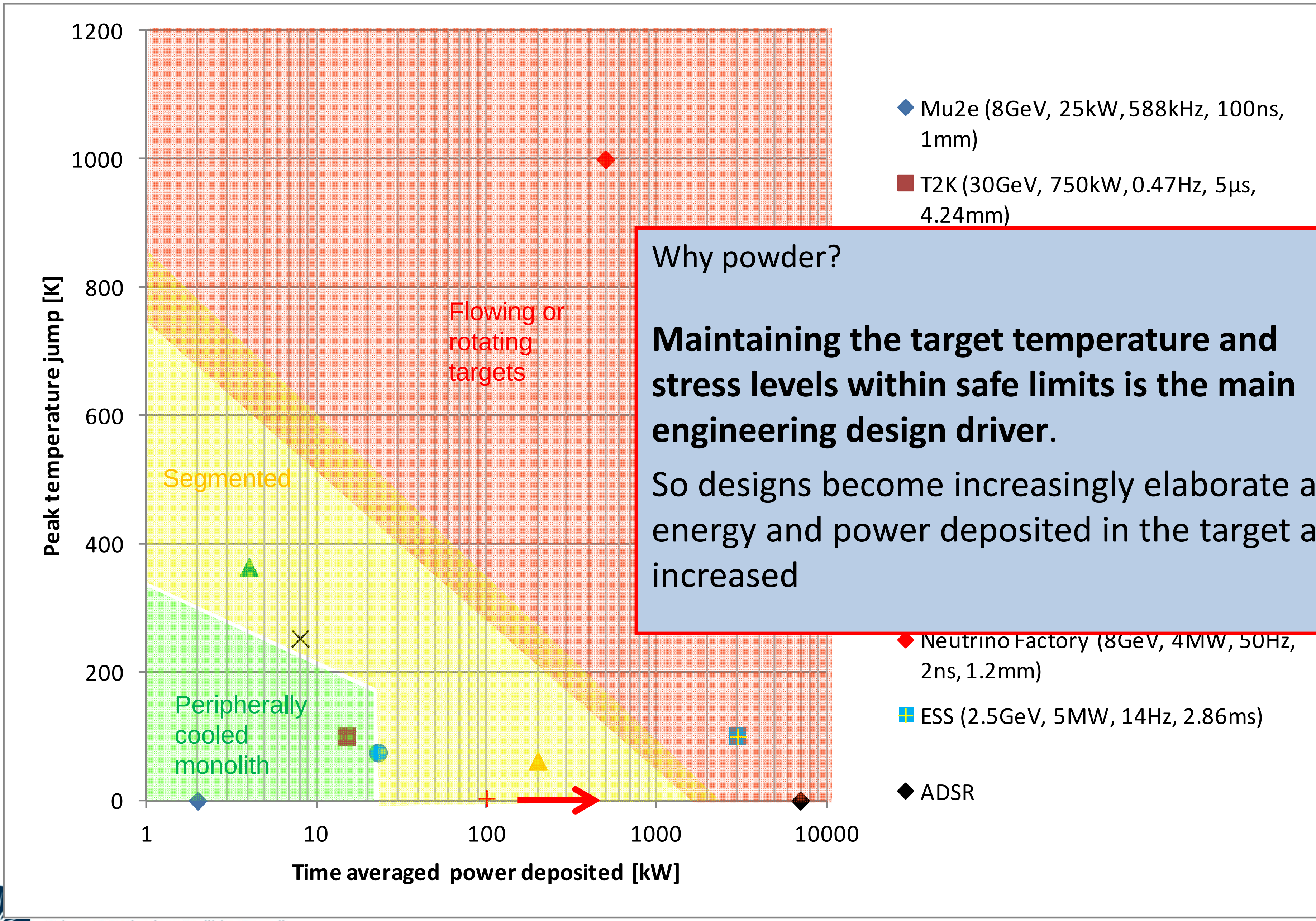




Davenne: Limitations of target technologies



Why powder?

Maintaining the target temperature and stress levels within safe limits is the main engineering design driver.

So designs become increasingly elaborate as energy and power deposited in the target are increased

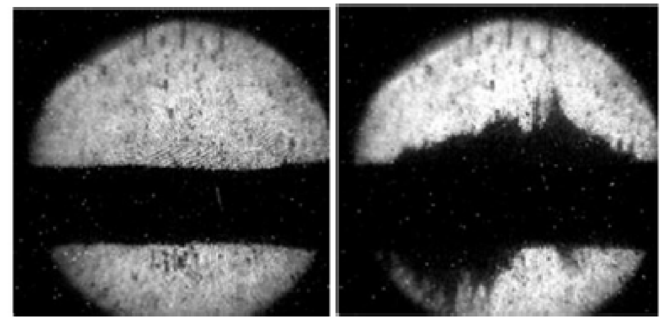
Candidate target technologies for a Neutrino Factory

1. Mercury

+ already exist, e.g. SNS

- toxic!

- reacts violently with beam



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

2. Moving Solid Tungsten Bars

+ studies on dynamic stress and strain-rate effects published

- Reliability in harsh environment?

- High static stress levels require much larger beam sigma than baseline beam parameters

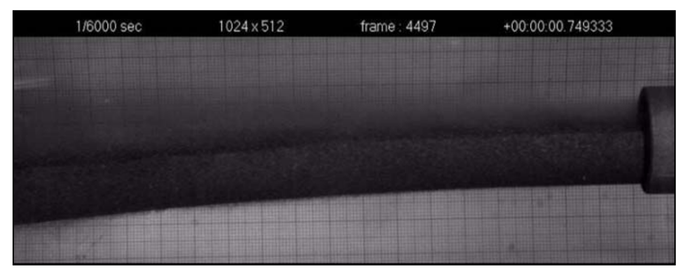
lifetime testing of tungsten wires in response to dynamic thermal loading, Skoro et al.

3. Tungsten Powder

+ Pneumatic conveyance of powder demonstrated

- wear of parts and powder

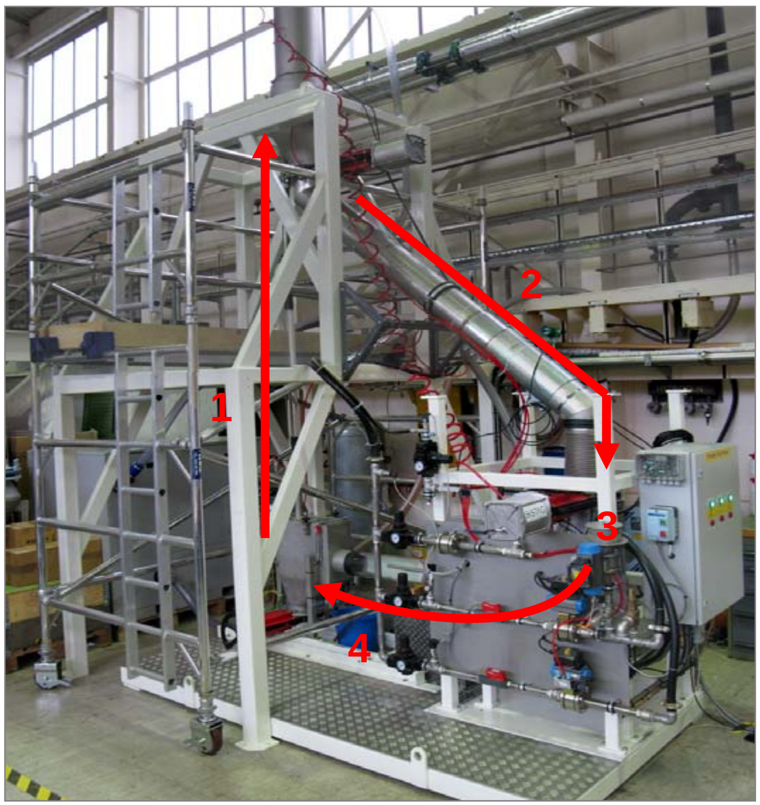
- Containment



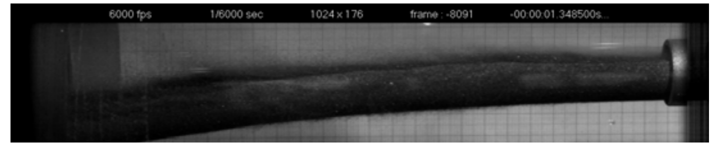
Pneumatically conveyed dense-phase tungsten powder jet, Caretta et al.

Tungsten Powder Test Programme in PASI-WP3 + ASTEC

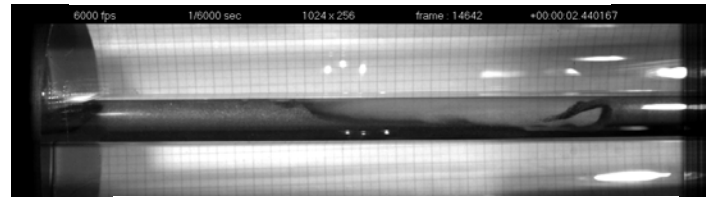
- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Containment / erosion
  - Heat transfer and cooling of powder



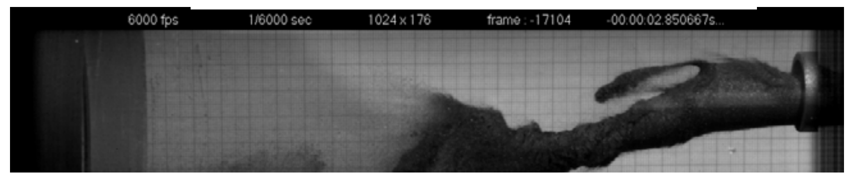
Dense-phase delivery



High speed image: tungsten powder jet

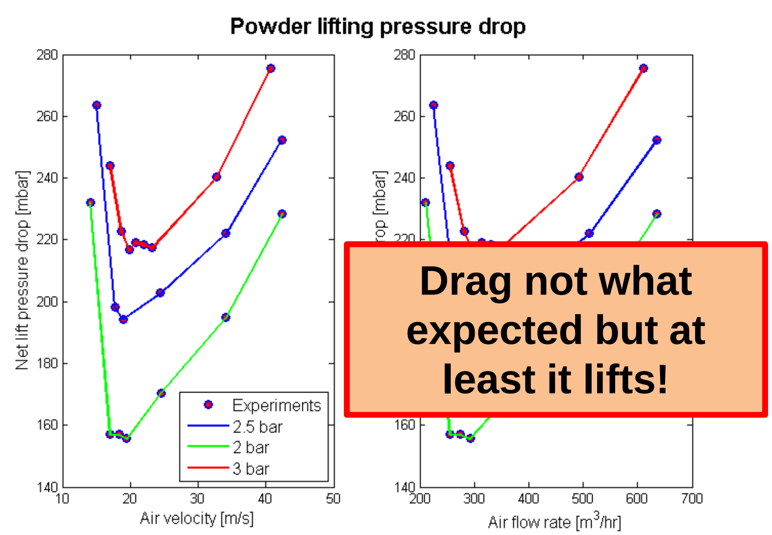


High speed image: tungsten powder flow in a pipe



Unstable tungsten powder jet

Lean-phase lift

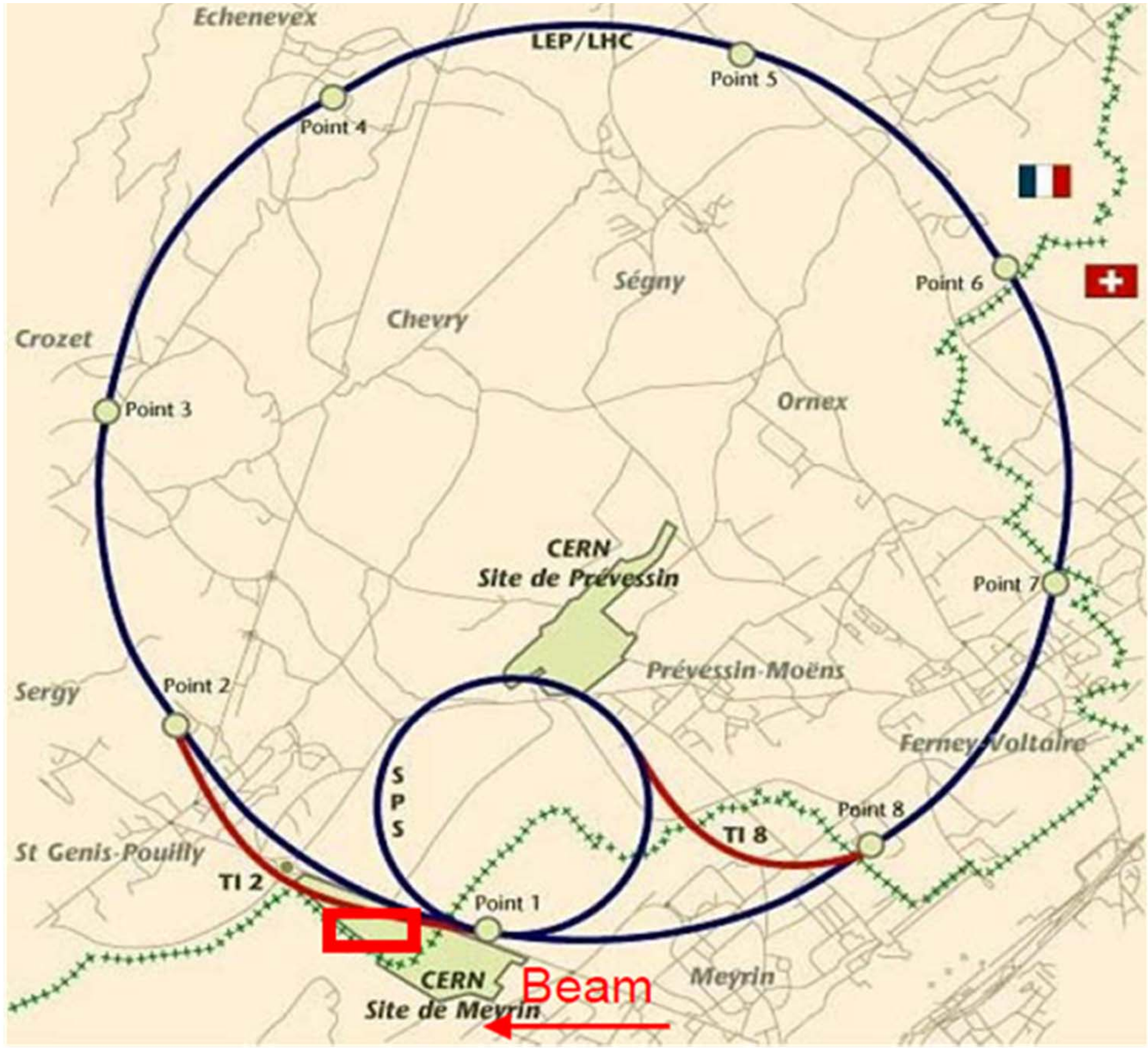


In-beam experiment Opportunity, June 2012

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 mm^2



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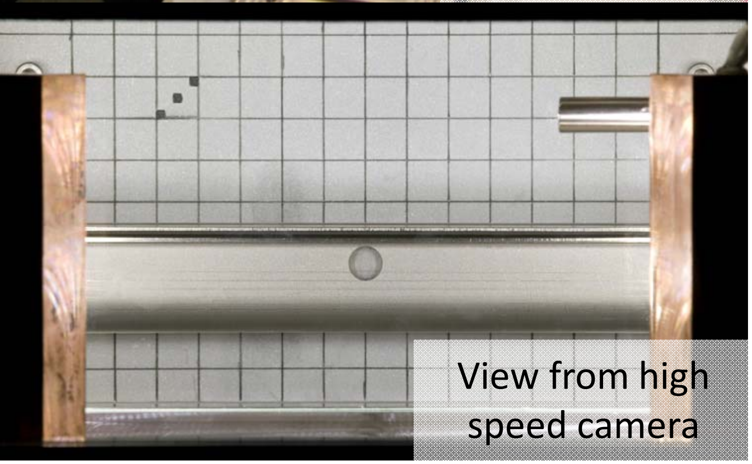
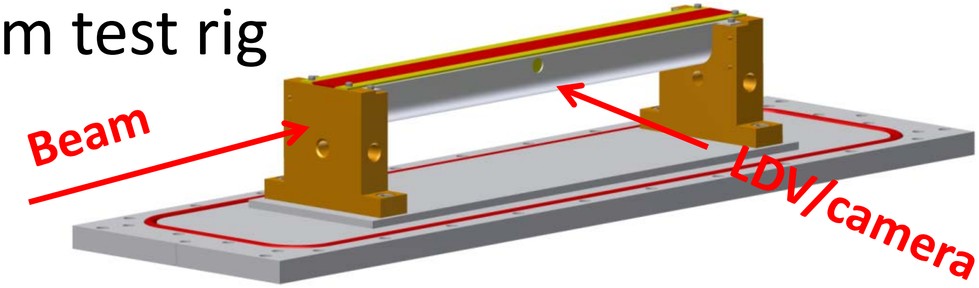
Open trough Assembly

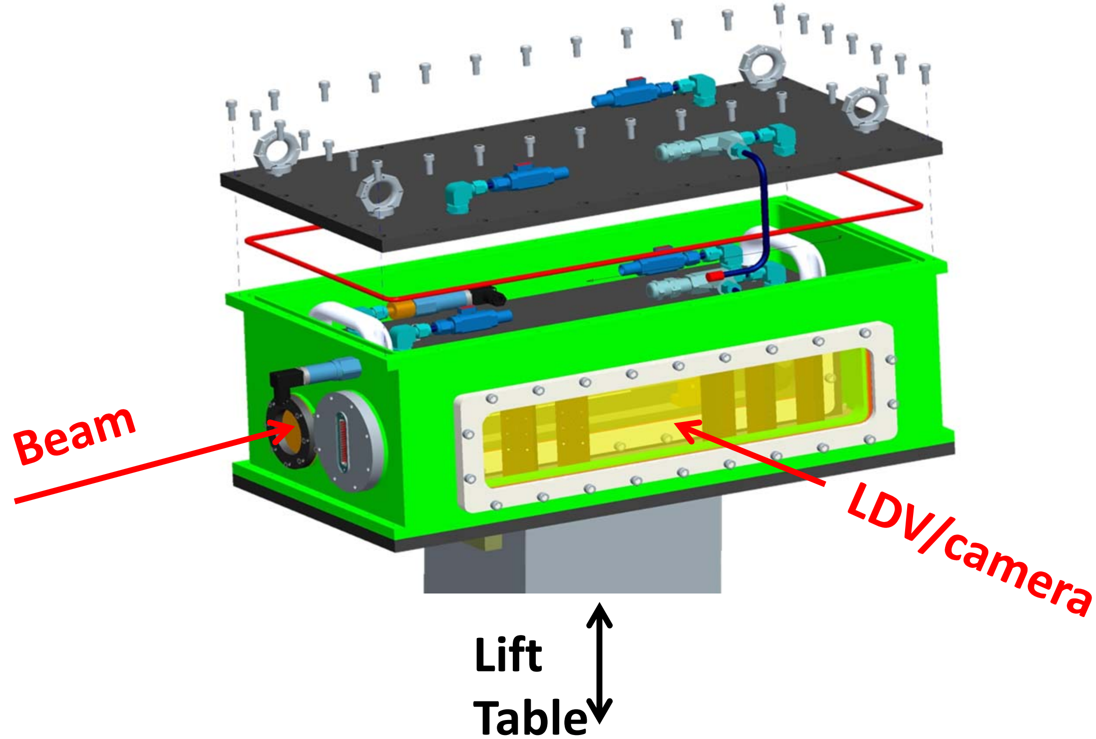
Filling with Tungsten Powder



View from high speed camera

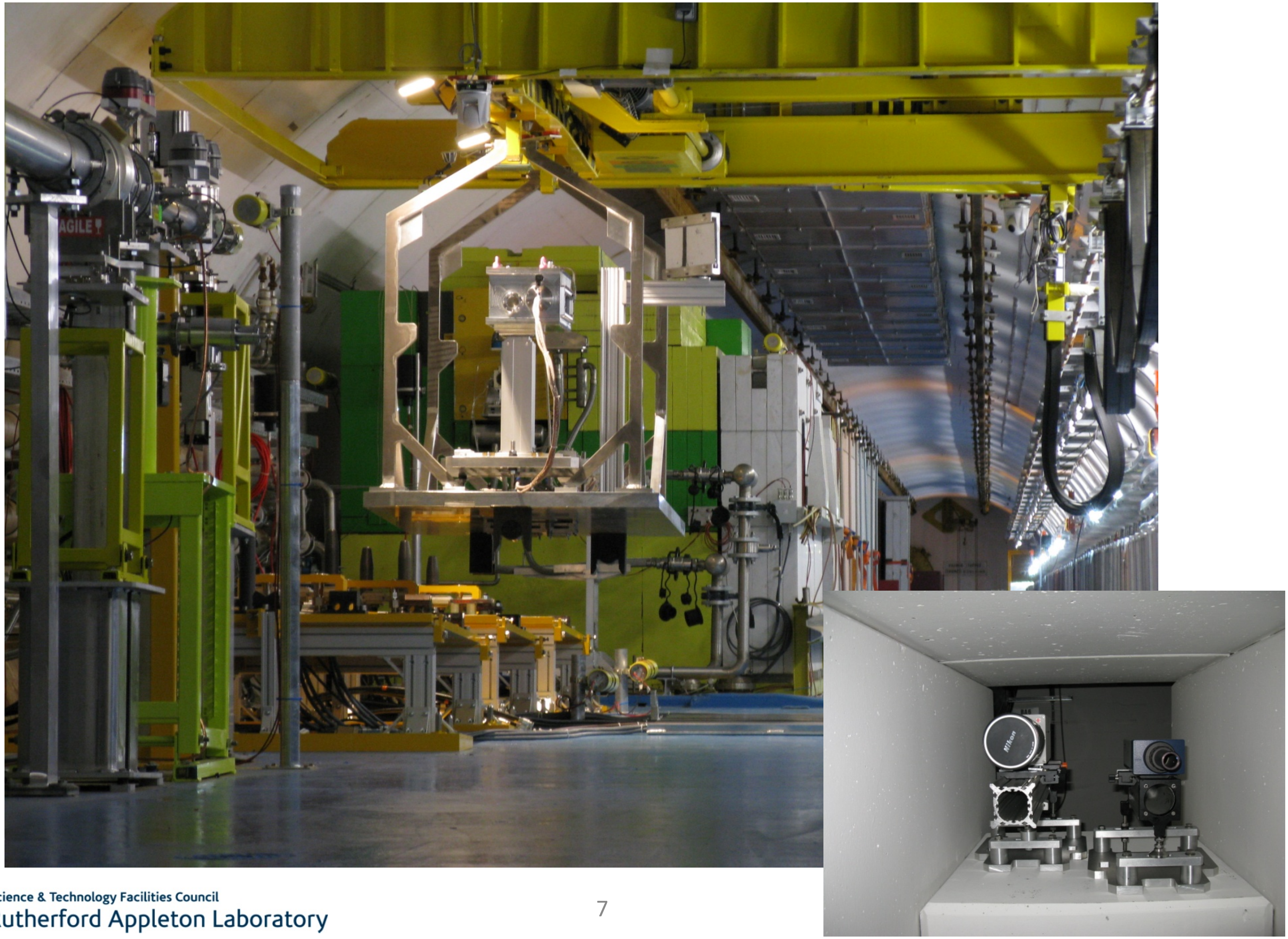
In beam test rig



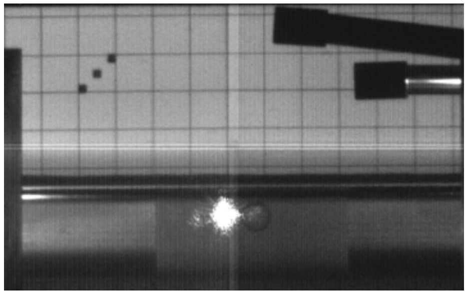


- Tungsten powder sample in an open trough configuration
- Helium environment
- Two layers of containment with optical windows to view the sample
- Remote diagnostics via LDV and high-speed camera

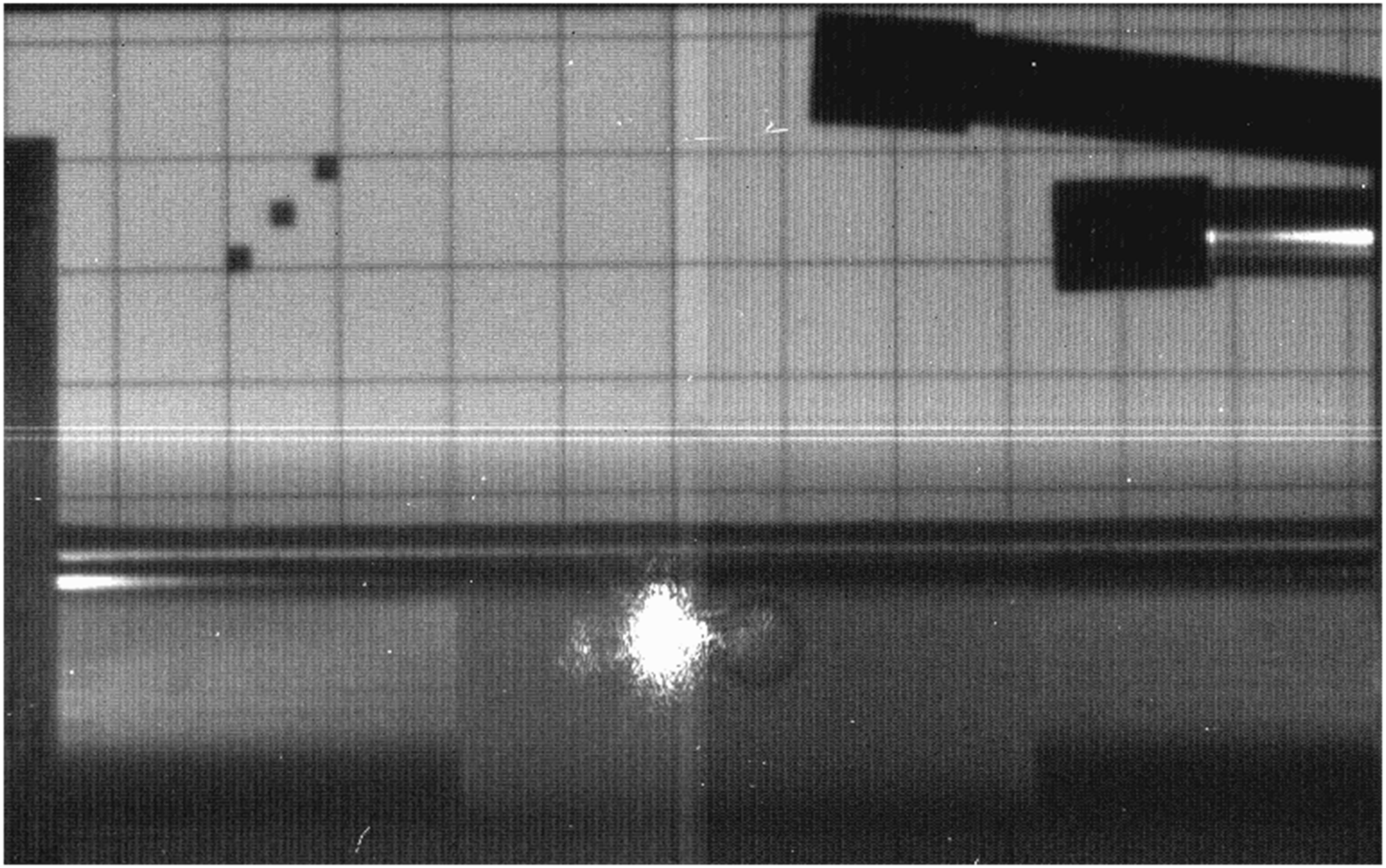
HiradMat Installation and Remote diagnostics



HiRadMat: Run 7



Intensity: 8.40E+10 PoT



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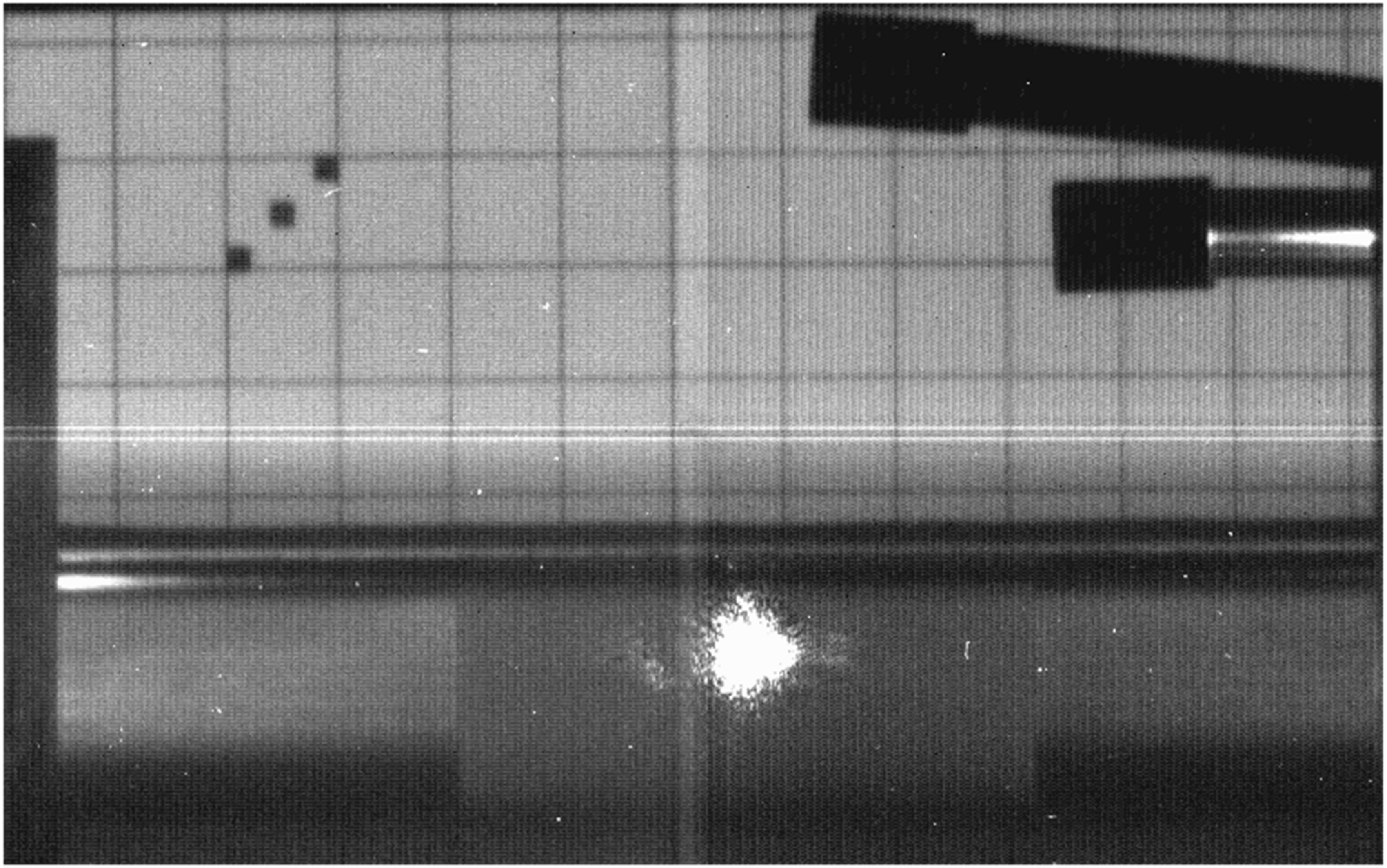
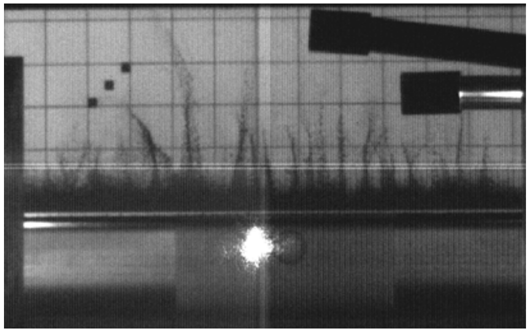
HiRadMat: Run 8

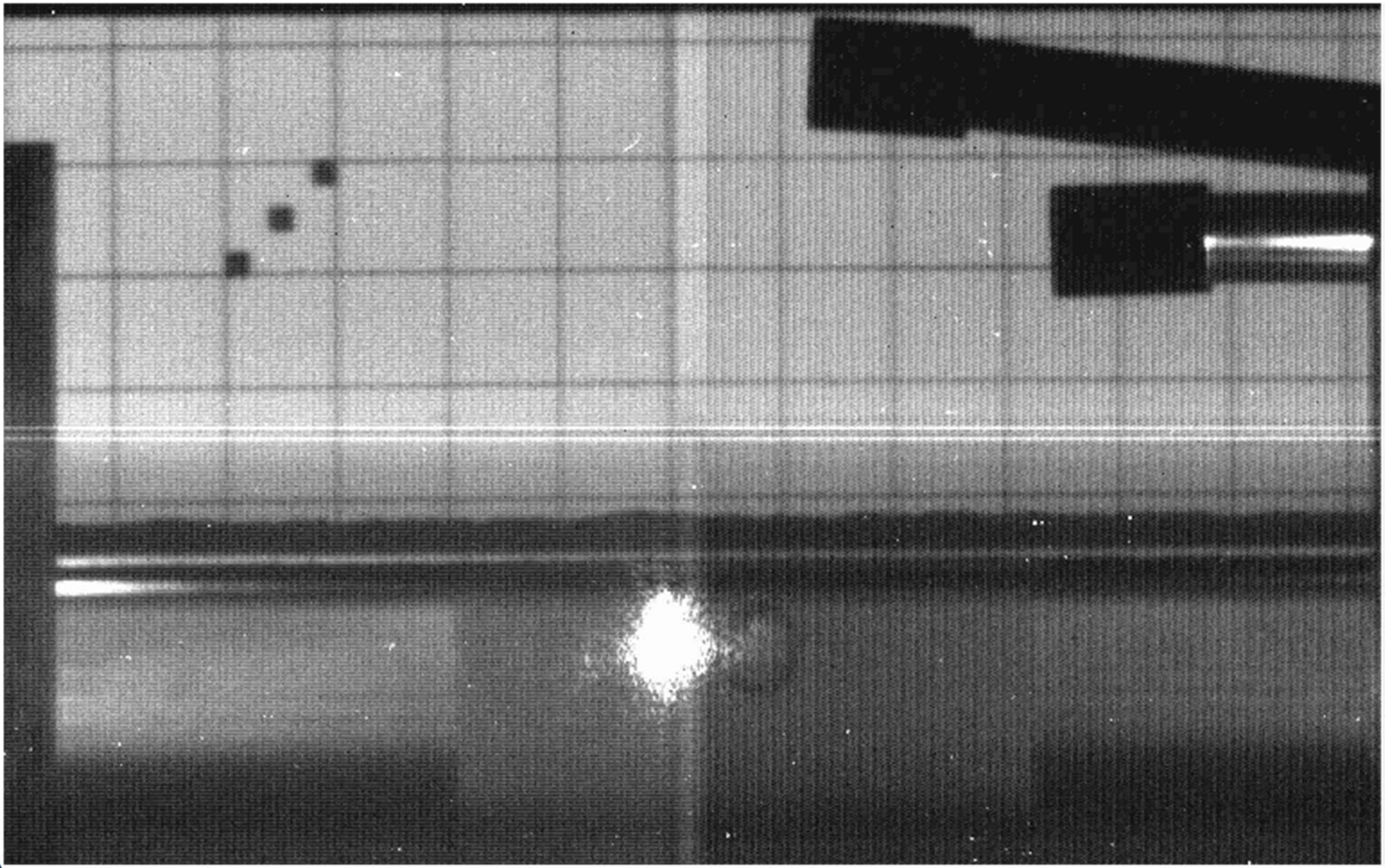
Intensity: 1.75E+11 PoT



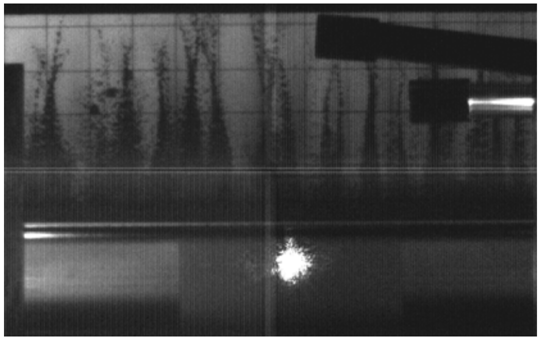
HiRadMat: Run 9



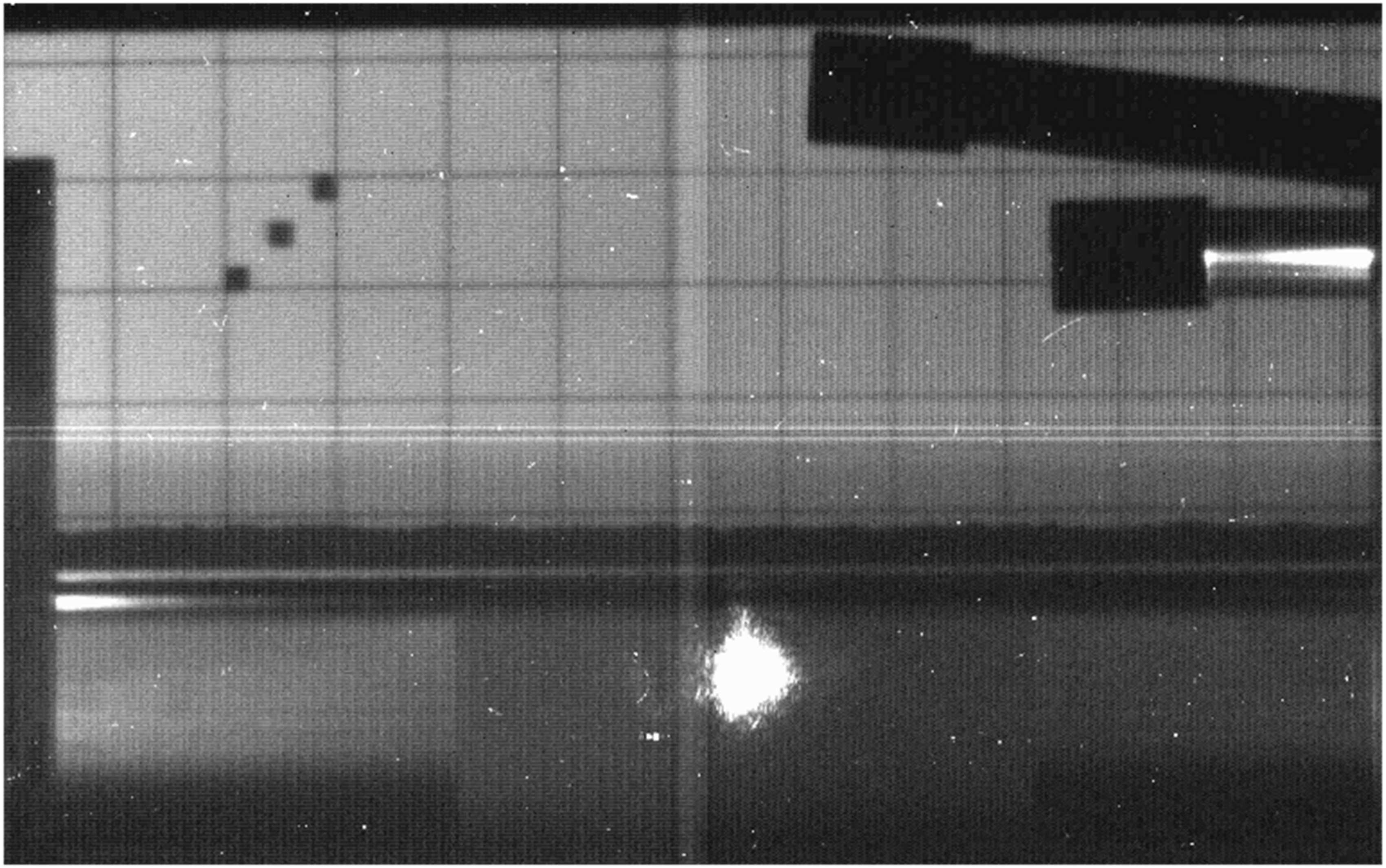
Intensity: 1.85E+11 PoT



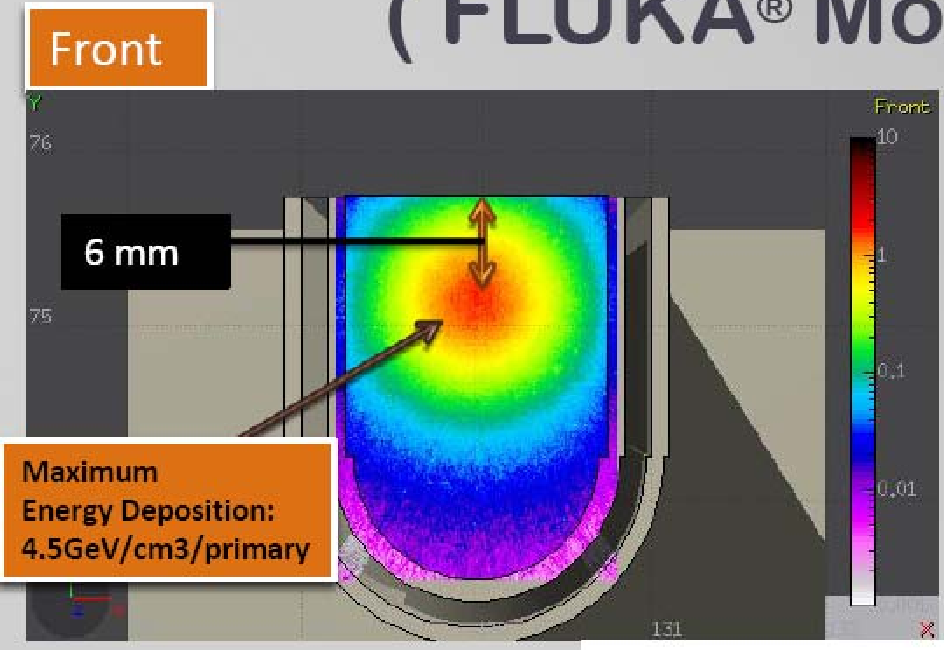
HiRadMat: Run 21

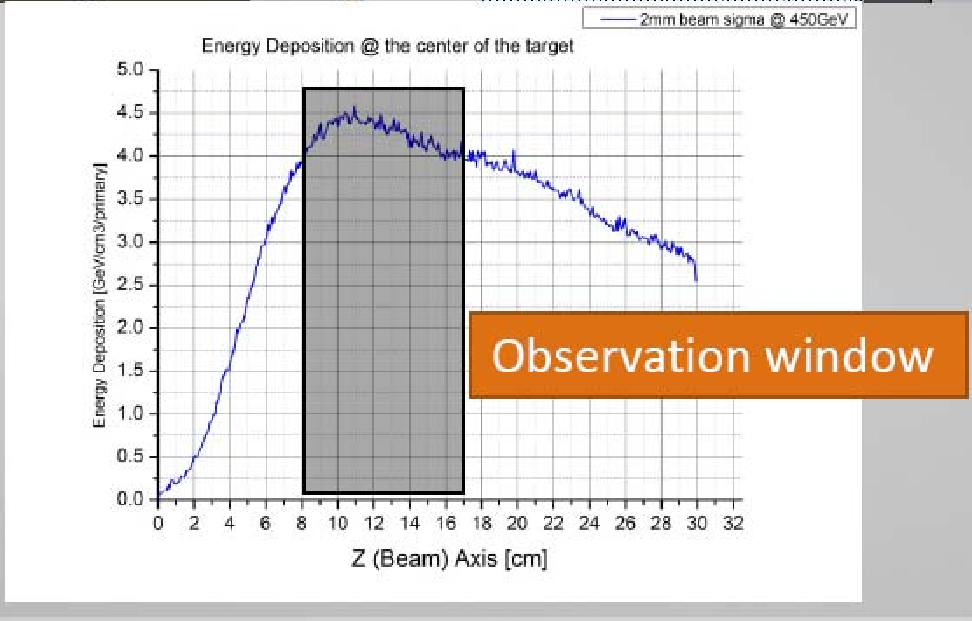


Intensity: 2.94E+11 PoT

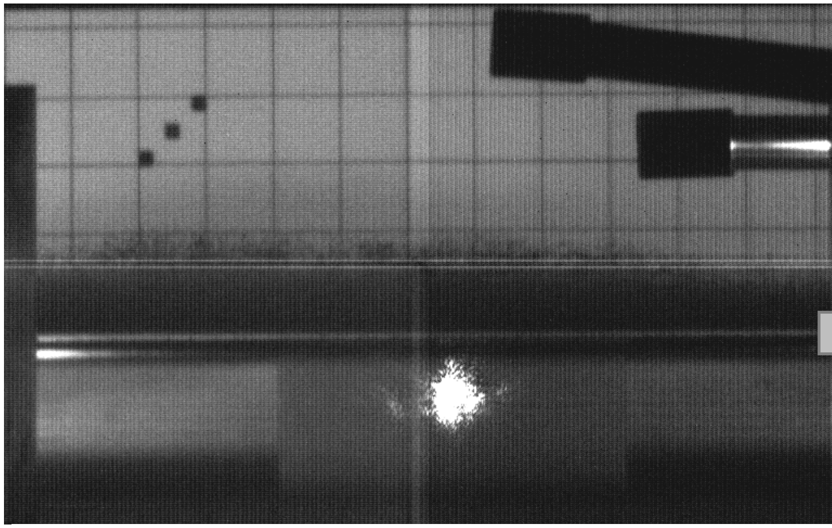


Prompt energy deposition/radiation (FLUKA® Monte – Carlo Code)



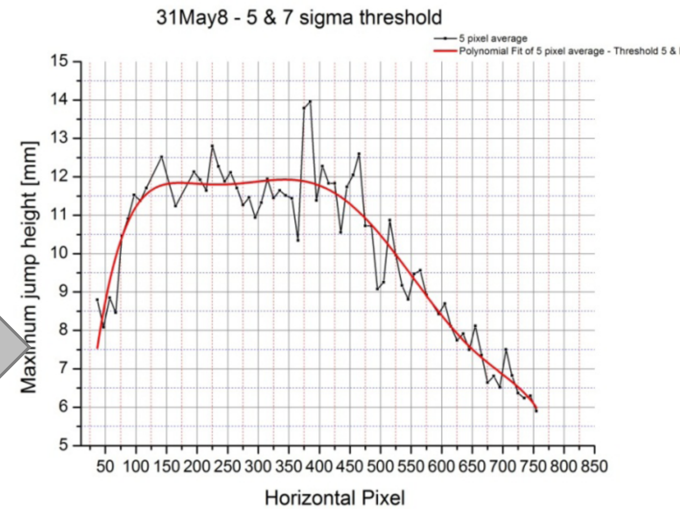


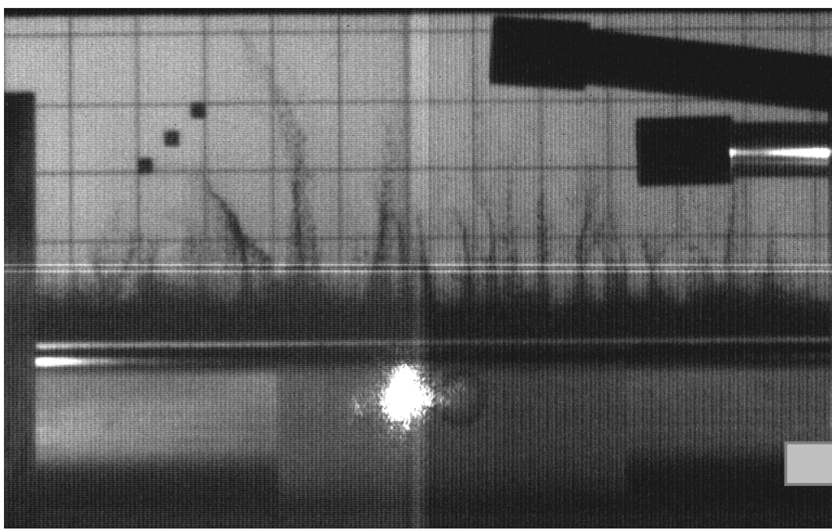
Charitonidis



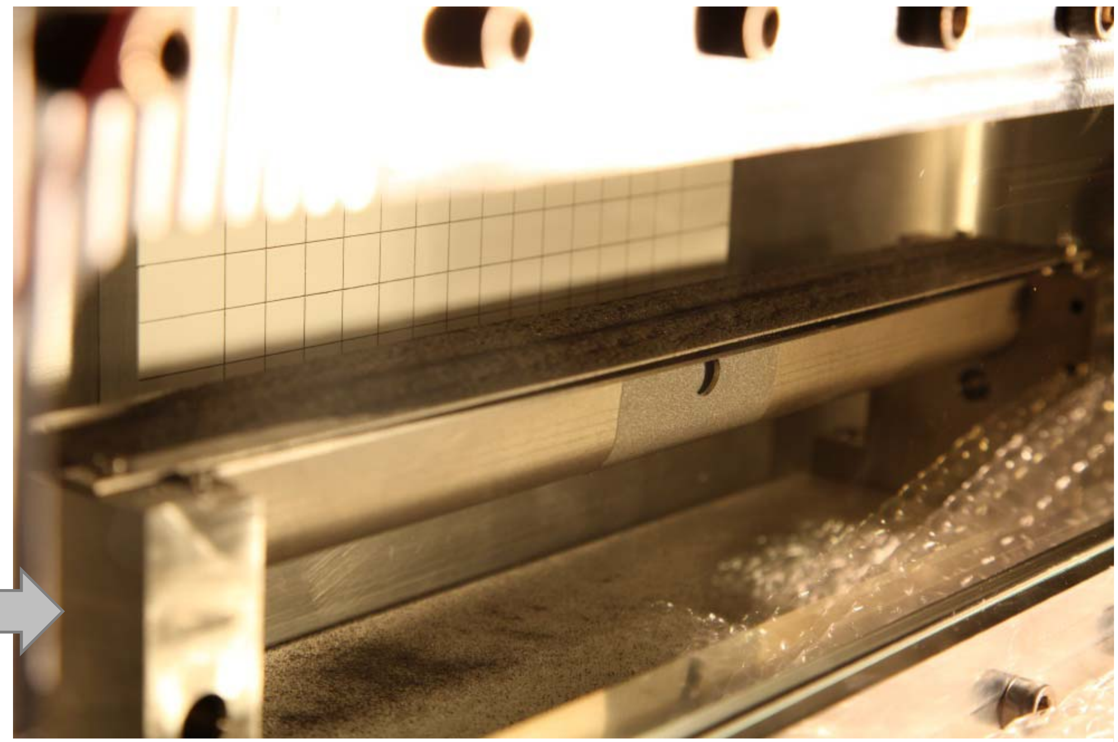
Shot #8, 1.75e11 protons
Note: nice uniform lift

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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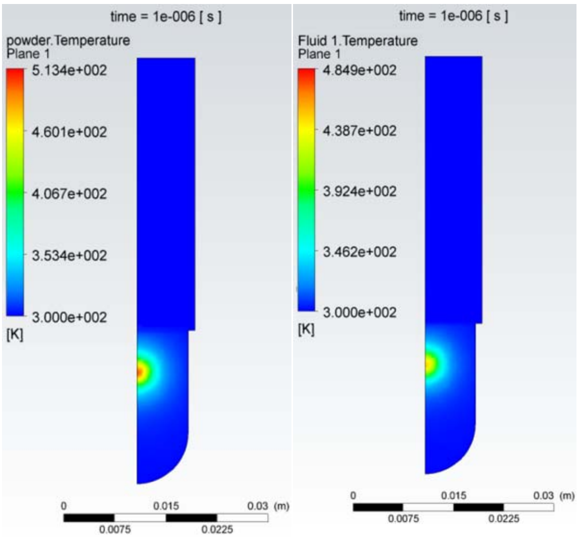
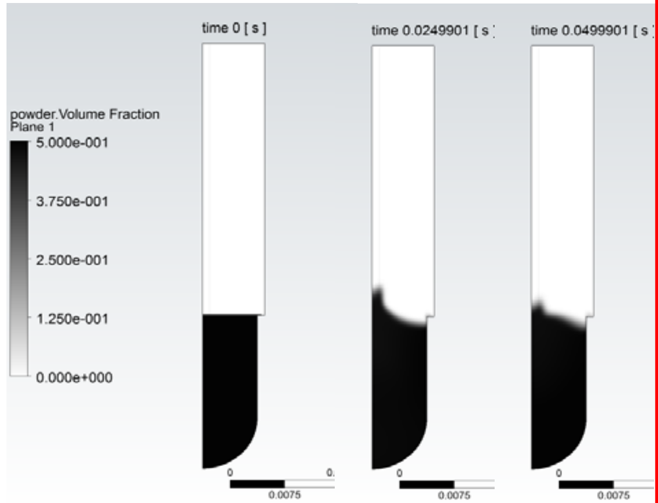
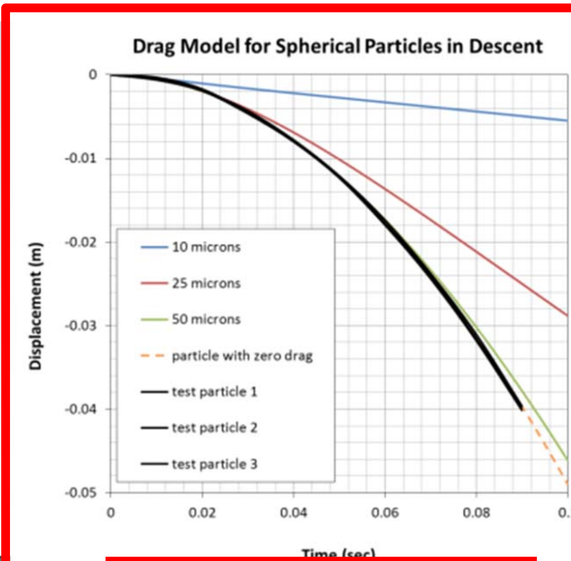
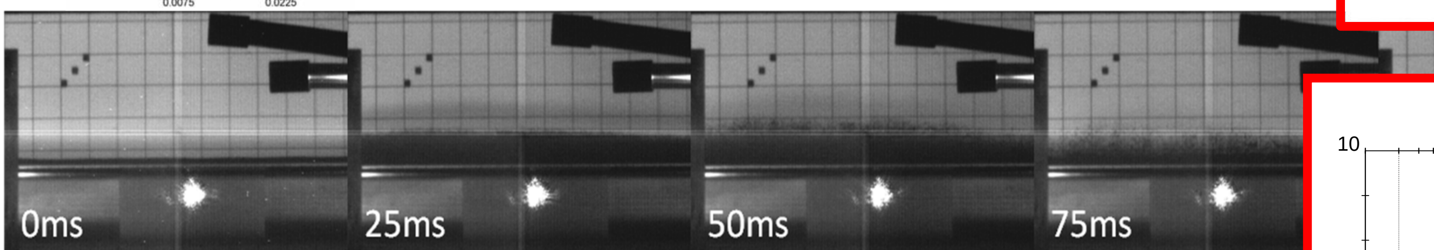
Davenne: CFD predictions/post fits

Beam heating



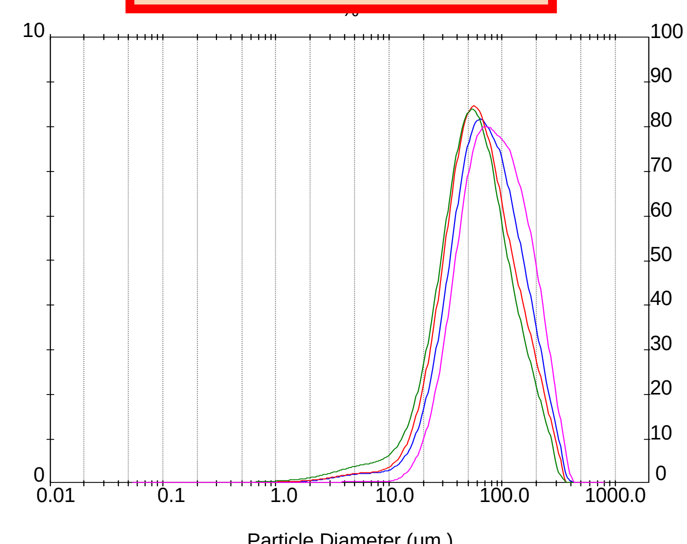


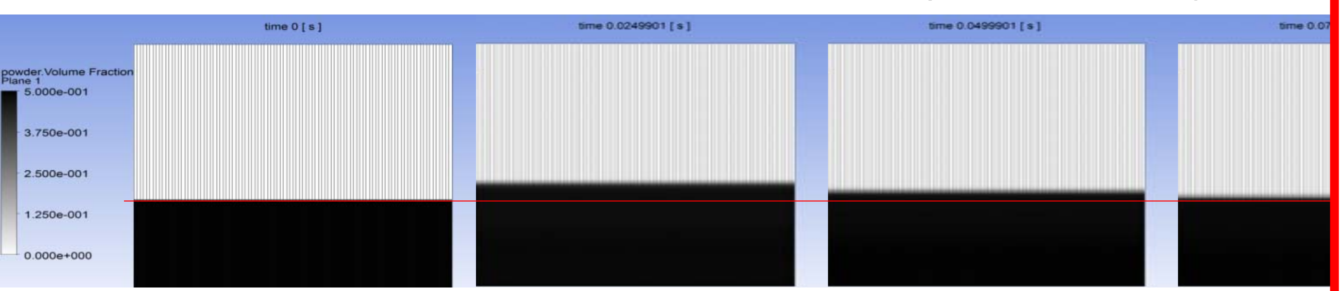




Test Results from Shot #8, 1.75e11 protons, beam sigma 0.75

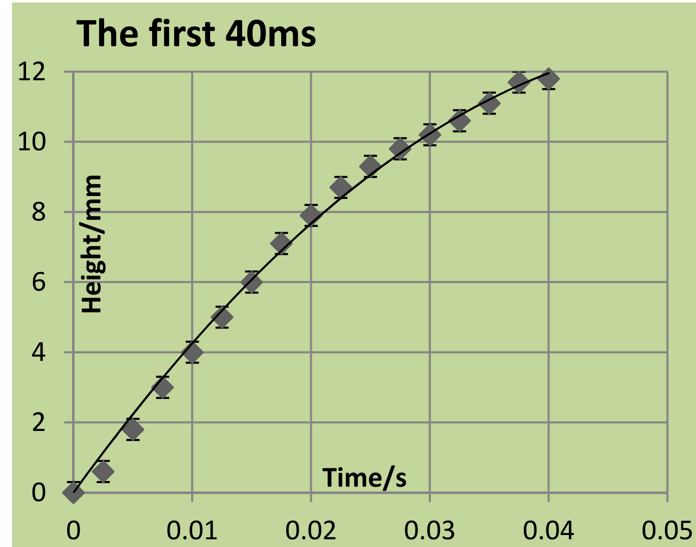
Average aerodynamic diameter ~30um





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

Speculating (stumbling in the dark!)

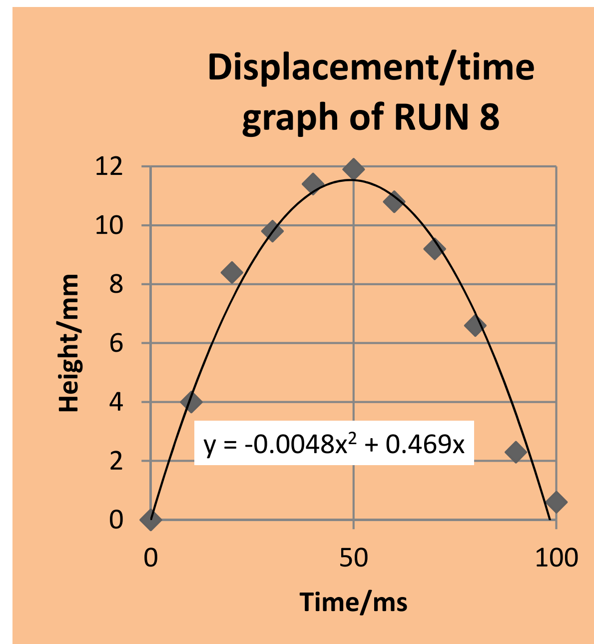


1. EXTERNAL STRESS

A kick from the trough?
Trough resonance perhaps too slow &
Trough does not appear moving in the HSV

2. GAS LIFT

Lift proportional to Energy deposition
CFD says yes but the energy/diameter is rather different.
Drag model is incorrect for W or
is it a different phenomenon?



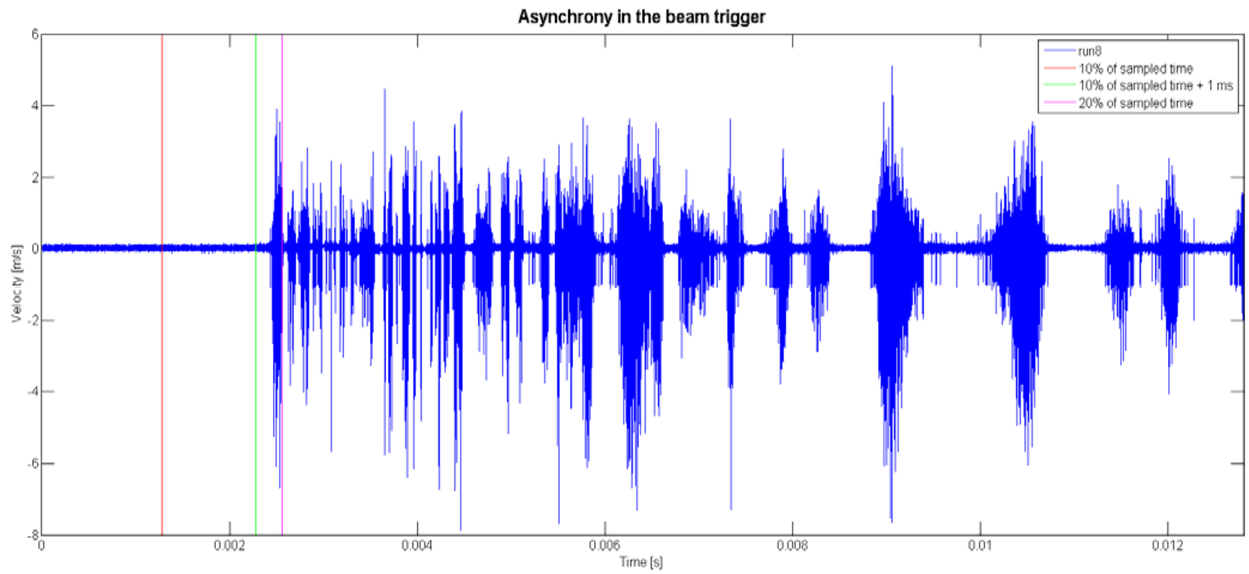
3. THERMAL STRESS PROPAGATION

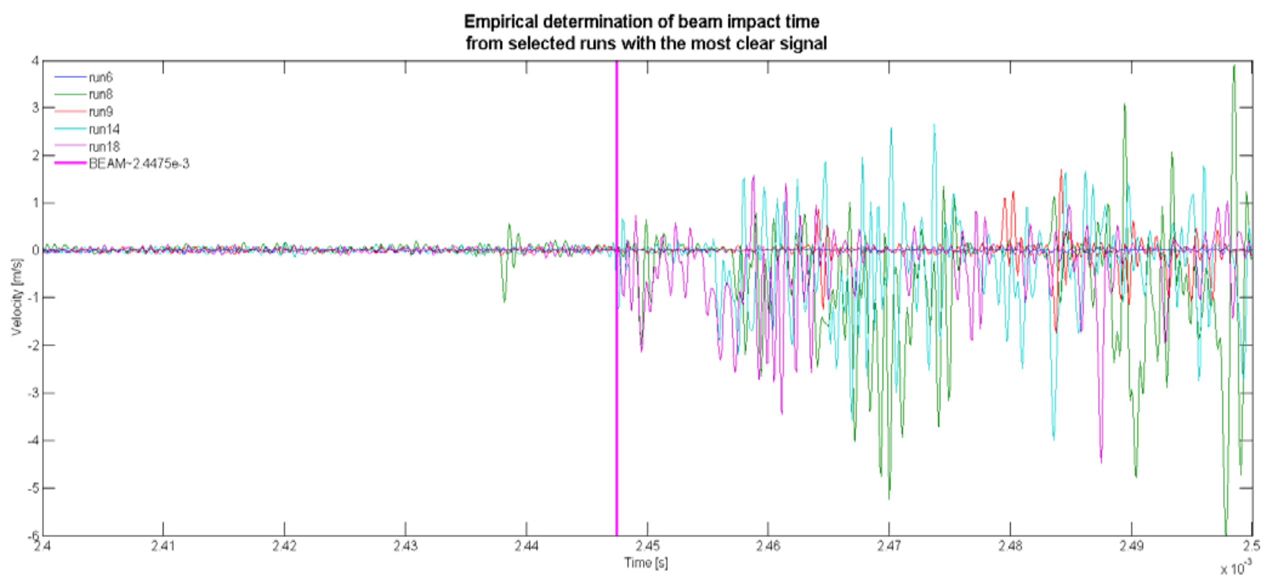
Lift proportional to Energy deposition
Too slow and too late compared with propagation
through a solid.
Peak ~40J/g (similar to MERIT) but
100 times lower velocities 0.5m/s.
Is this due to attenuation through the powder?

LDV: the problems *Part 1*

No reliable beam stamp: the gitter

i.e. no measurement of stress wave propagation time!





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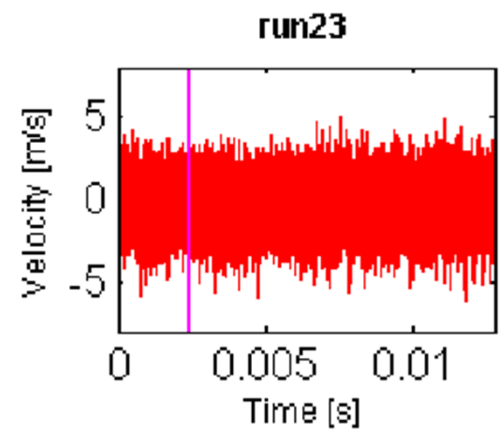
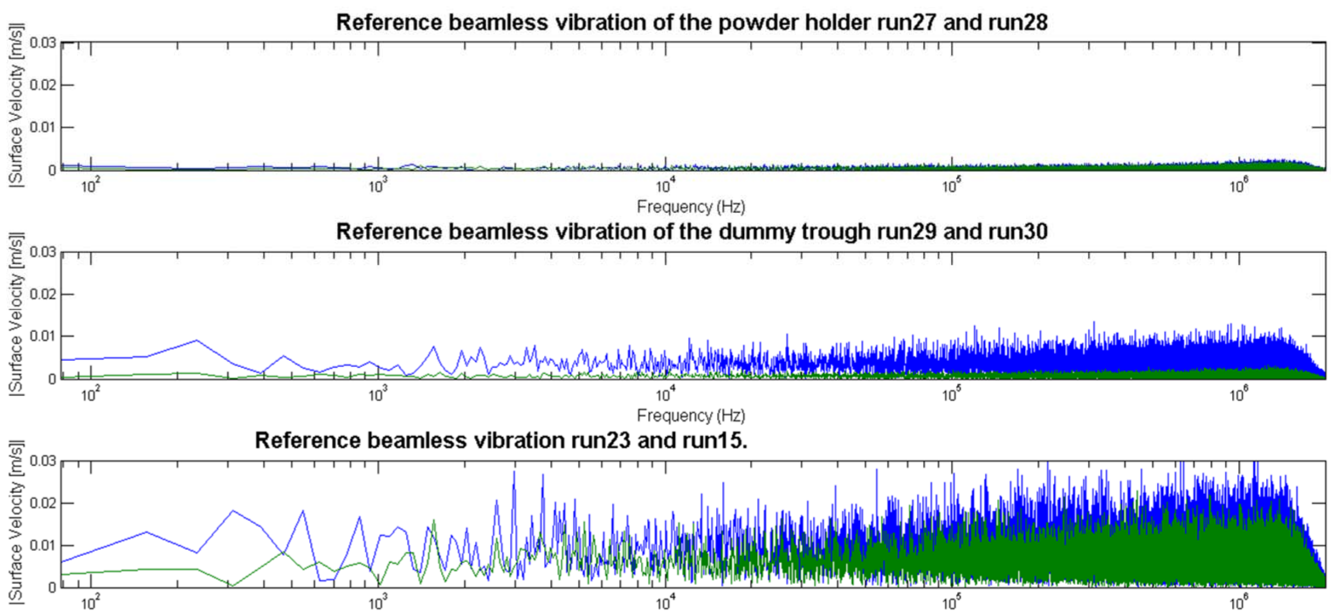
LDV: the problems *Part 2*

High frequency
high amplitude noise?!

Yet not in all the runs?!

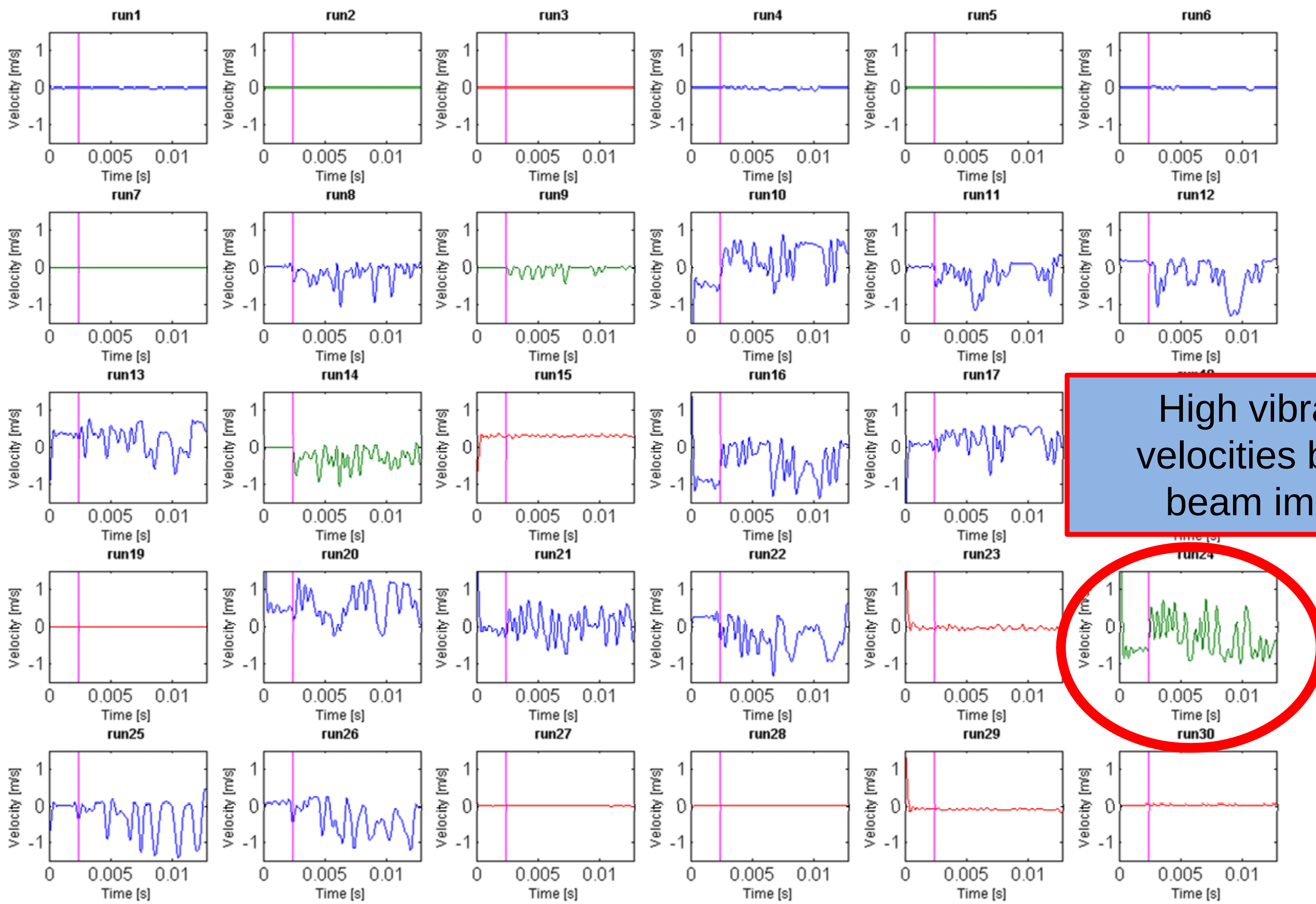
LDV vibration without beam





LDV: the problems *Part 3*

Doom: watch out for the drift!

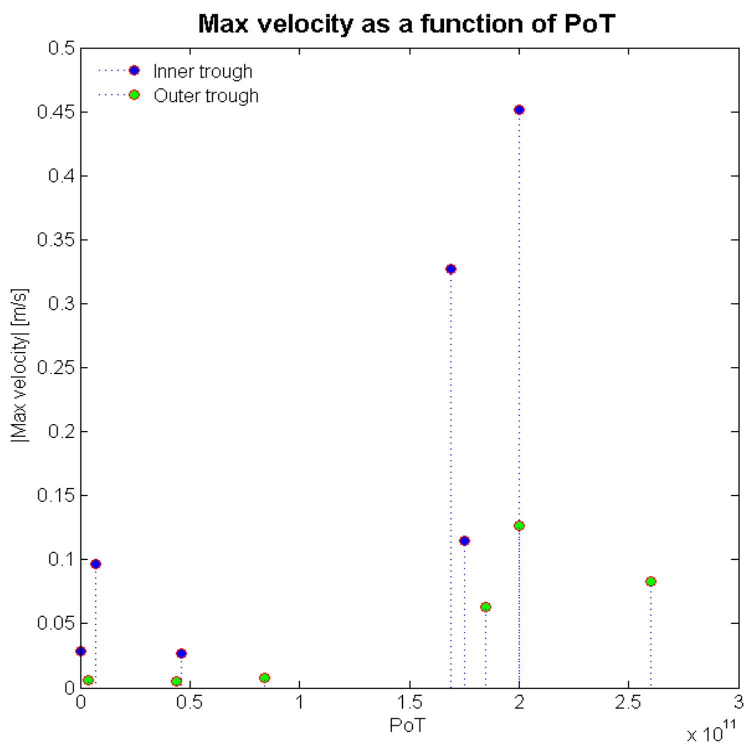


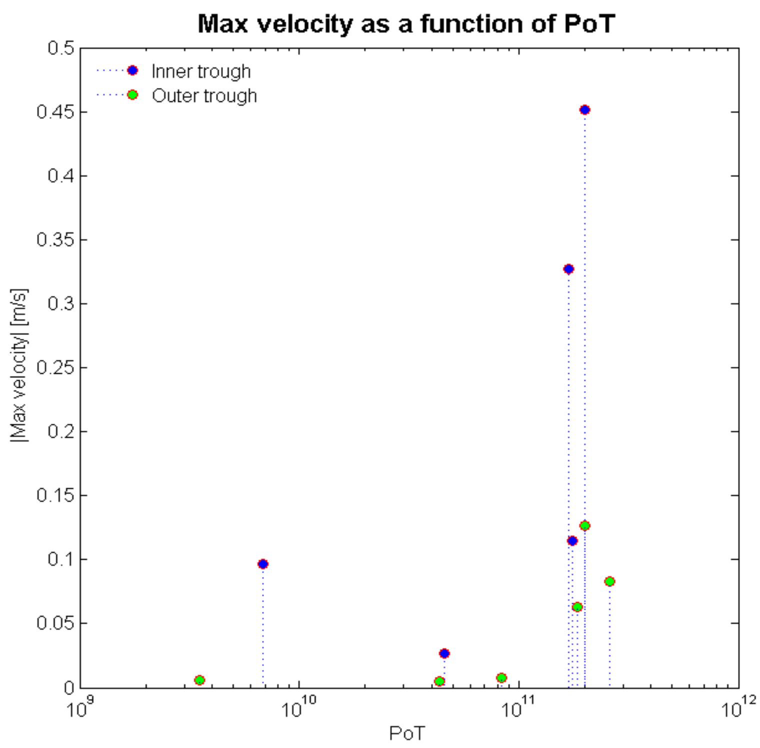
High vibration velocities before beam impact

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)





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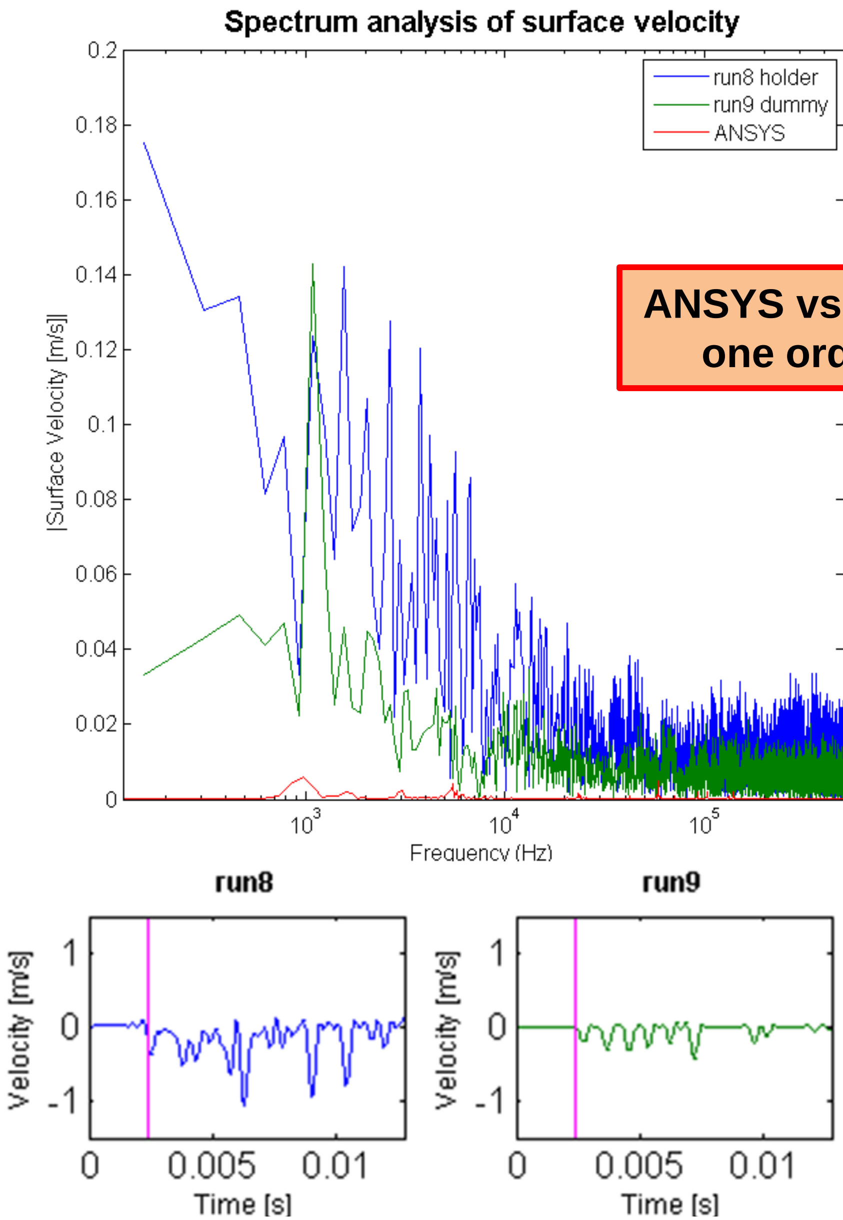
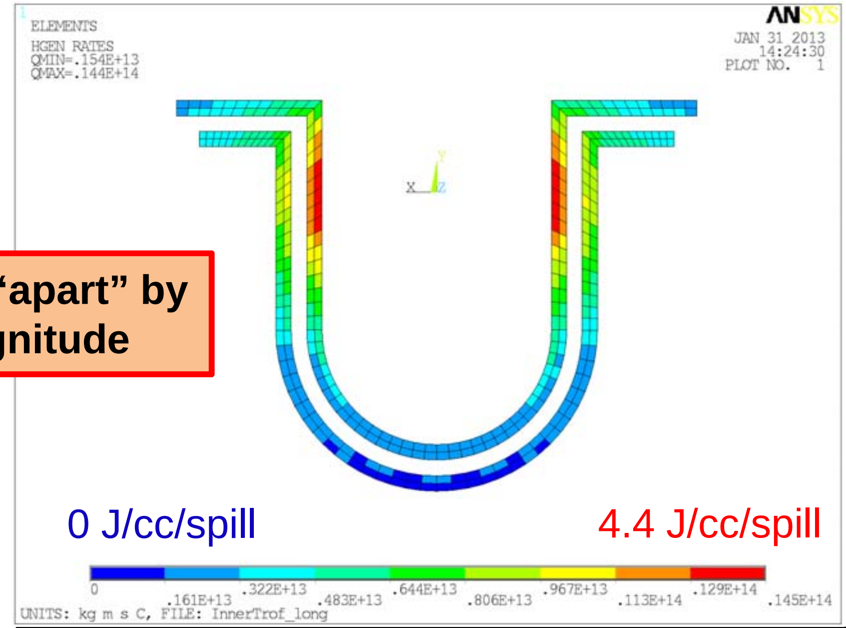
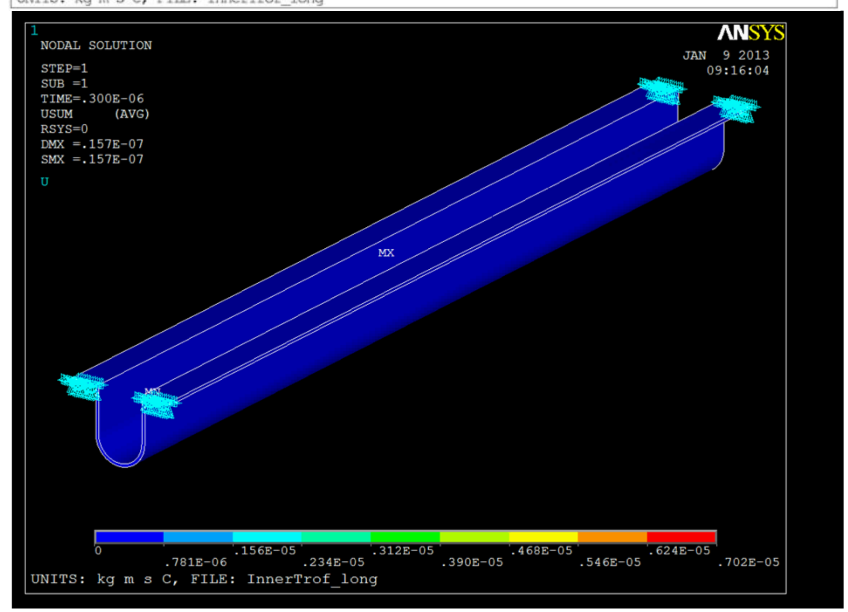
Loveridge: ANSYS predictions



ANSYS vs LDV are "apart" by one order or magnitude

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



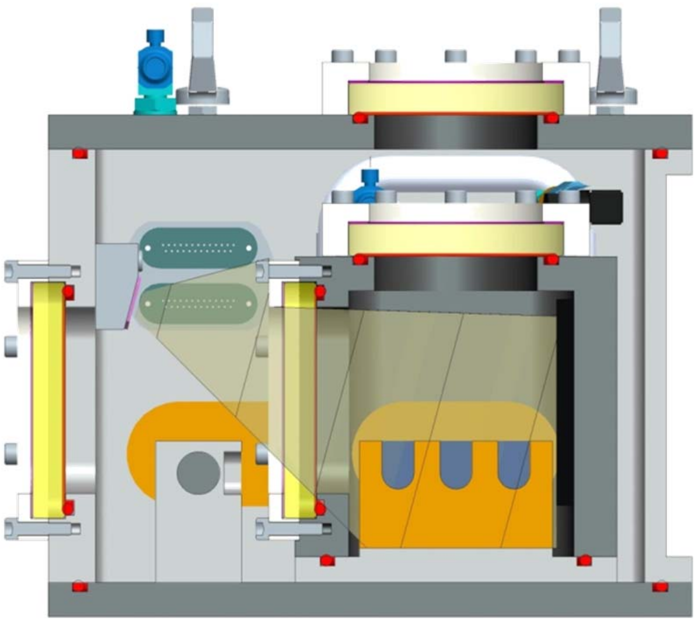


ANSYS simulation of secondary heat induced vibrations
Velocity ≈ 0.1 m/s

Lessons learnt and stuff left to do

HiRadMat mark 2 (after CERN shutdown)

1. Powder mono-size distribution
2. More samples (prevent interference between measurements)
3. Full length view of the sample
4. Repeat test in He and vacuum (separate Aerodynamic Lift vs momentum transfer)
5. LDV
   - calibrate signal in situ
   - use flat mirrors
   - Establish beam gitter
   - Watch out for windows interference



Other general powder work

1. Continue generic powder conveying study
2. Calorimetric heat transfer
3. Evaluate effect of magnetic field