Solid Target for a Neutrino Factory

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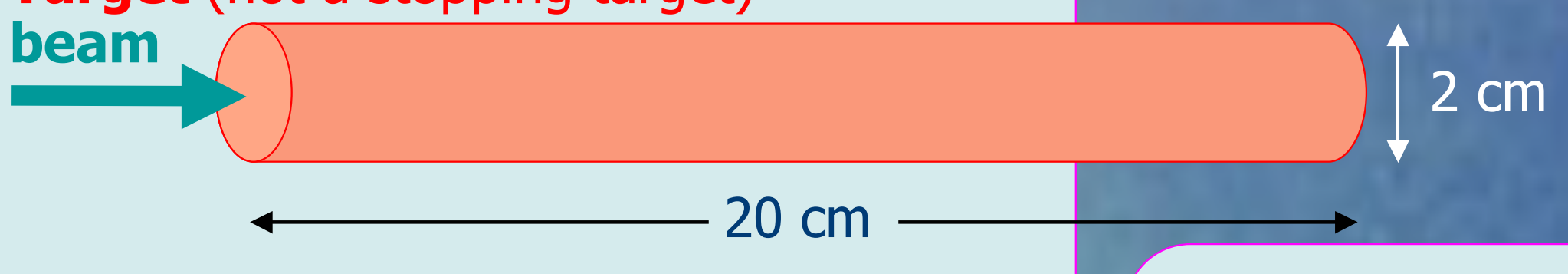
Neutrino Factory Target Concepts

Parameters of the Neutrino Factory Target

Proton Beam

pulsed	50 Hz
bunches	3 (2 ns rms)
energy	10 GeV
beam power	4 MW

Target (not a stopping target)



mean power dissipation 0.75 MW
energy density ~ 300 J/cm3

The target operates at very high mean power dissipation and extremely high energy density. This high power density creates severe problems in dissipating the heat and the short pulses produce thermal shocks due to the rapid expansion of the target material. These shocks can potentially exceed the mechanical strength of solid materials.

In addition, the pions and muons created in the target must be collected in a 20 Tesla solenoidal field.

This imposes strong restraints on the target and collector system which must ultimately be designed as a single entity.

Several targets which potentially can withstand the huge power density are currently being considered worldwide:
a. Mercury (or a liquid metal) jets
b. Contained flowing mercury (or a liquid metal)
c. Solid target – tungsten or tantalum bars
d. Granular solid target

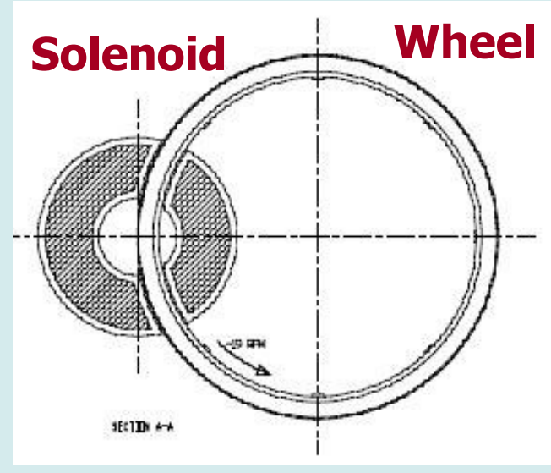
Solid Target Options

The UK is currently investigating solid targets. The solid target is simple in concept, but may be susceptible to **shock damage**. There are many examples of solids bombarded by proton beams at similar power densities and even targets operating at an order of magnitude higher power density have been shown to survive many pulses.

We have studied different options for Neutrino Factory target and almost all of them are based on the idea to have a number of individual (tungsten or tantalum) bars where a "new" bar would be presented for each beam pulse. The most interesting concept is a spokeless wheel with around 150 tungsten bars. In this case solenoid must be split (Helmholtz coil).

Wheel option has been already used at PSI…

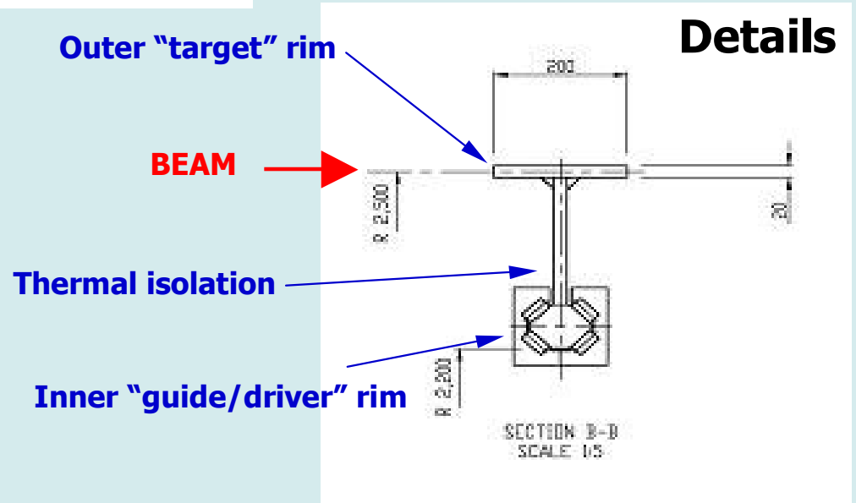
… and spokeless wheel in some amusement parks



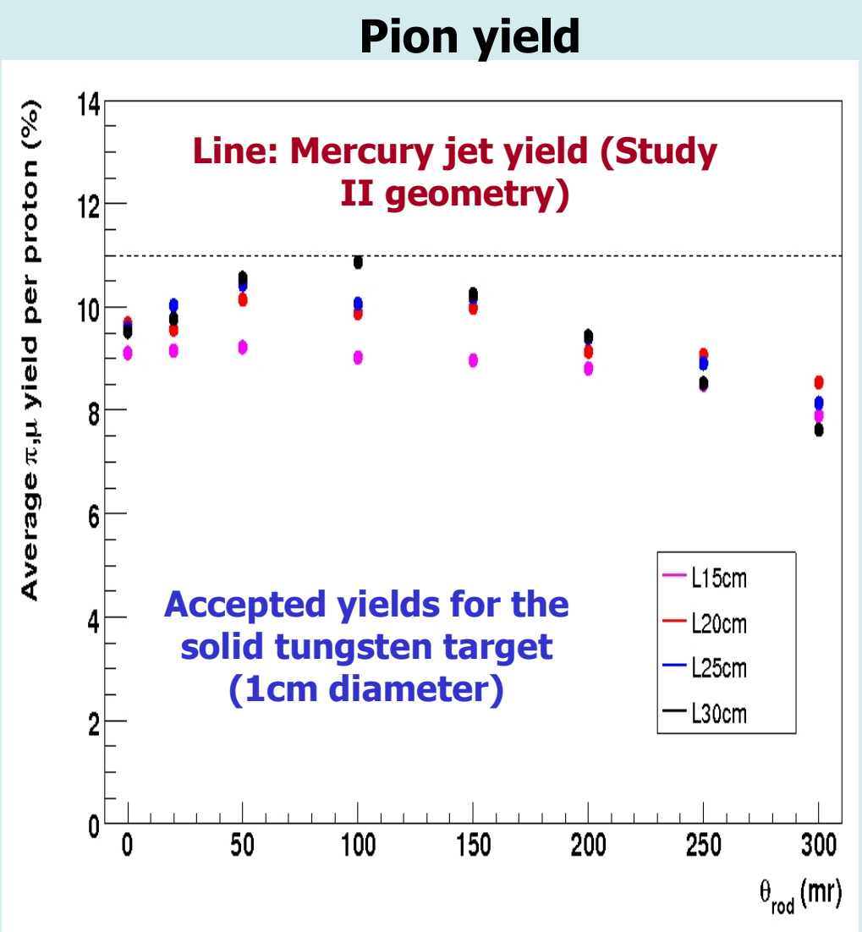
Dimensions

Outer diameter:	**5 m**
Speed at rim:	**5 m/s**
Revolution time:	**3.14 s**
Target spacing:	**100 mm**
# of targets:	**157**

Details

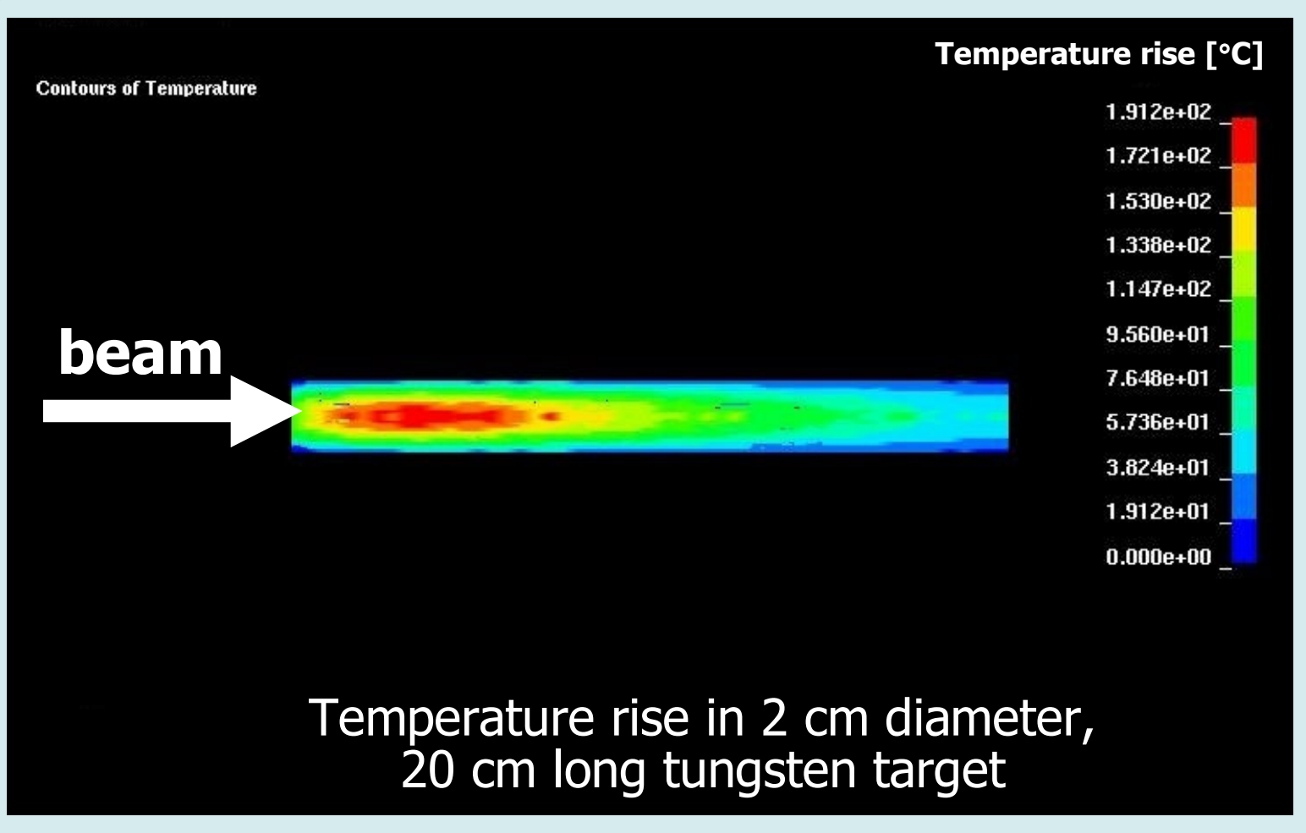


Pion yield

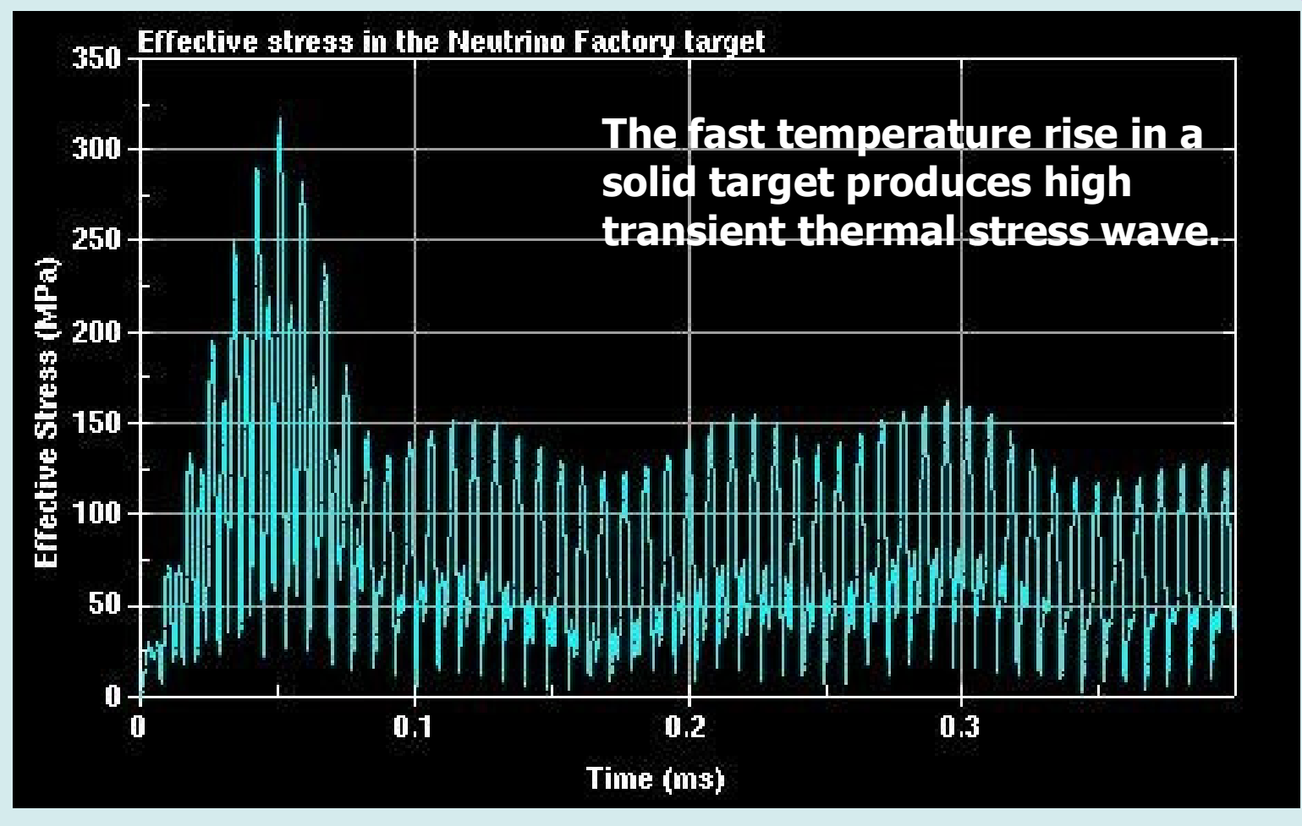


Thermal stress is a problem for solid targets so the shock studies are the main thrust of the UK activity.

Thermal Shock in Solids



Temperature rise in 2 cm diameter, 20 cm long tungsten target



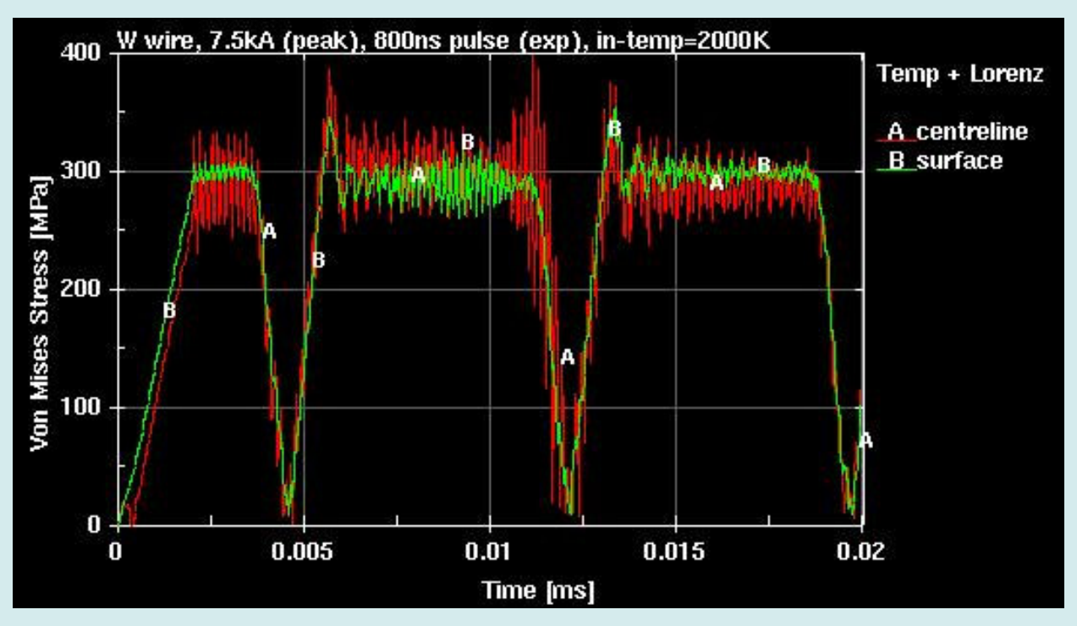
The fast temperature rise in a solid target produces high transient thermal stress wave.

Modern computer codes such as LS-DYNA can be used to simulate the material response in such situations.

For example, the induced thermal stress wave has an amplitude at the level of several hundreds of MPa resulting from the energy deposition of 10 GeV protons (4 MW beam power) in 2 cm diameter, 20 cm long tungsten target.

Ideally it would be best to do a full scale life test on a real size target in a beam over 1-10 years. However, beams of this power are not readily available for any length of time.

Fortunately, the very same level of stress can be induced in the material by passing a fast, high current pulse through a thin wire.

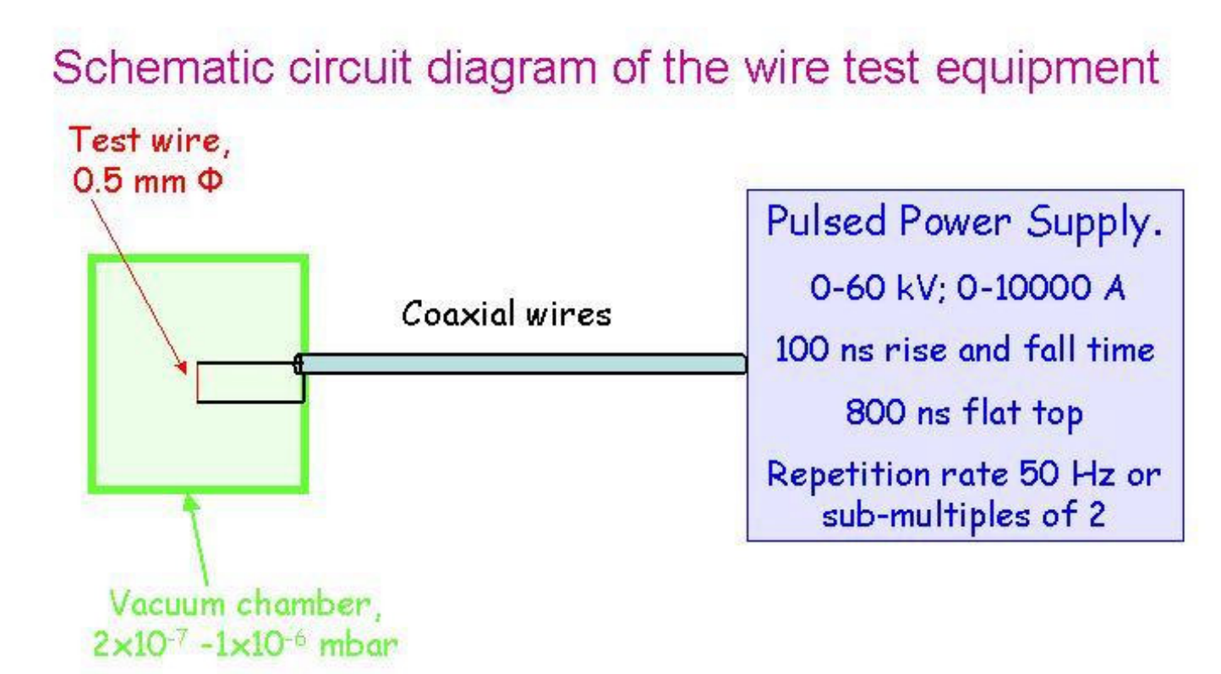


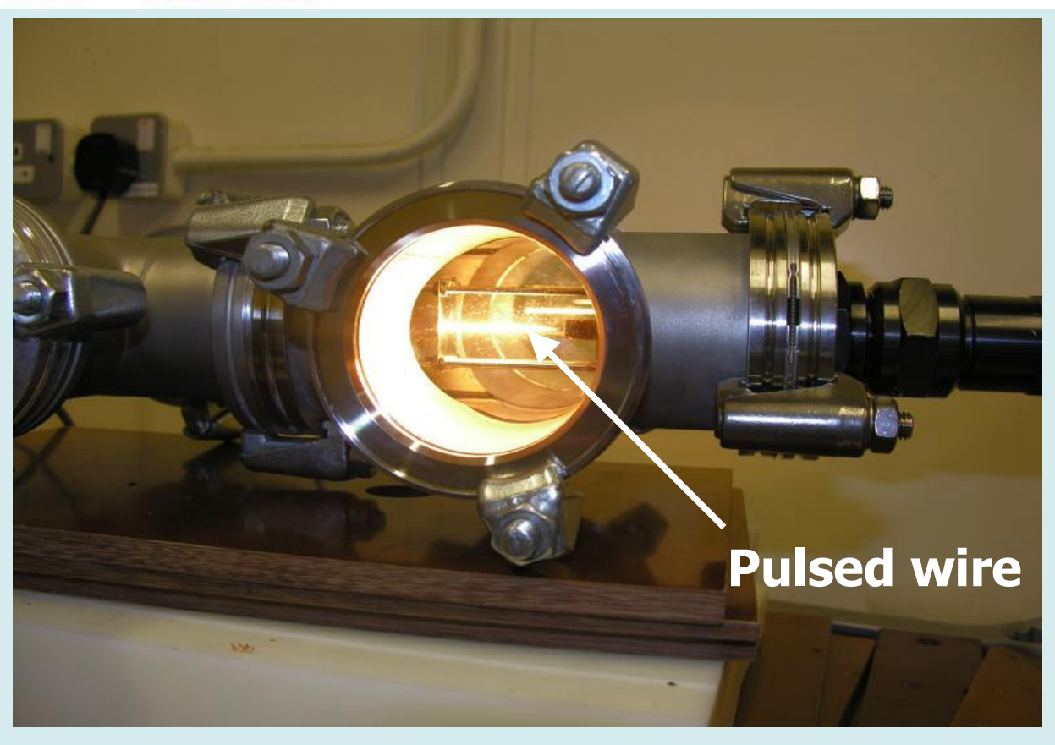
LS-DYNA result for a tungsten wire

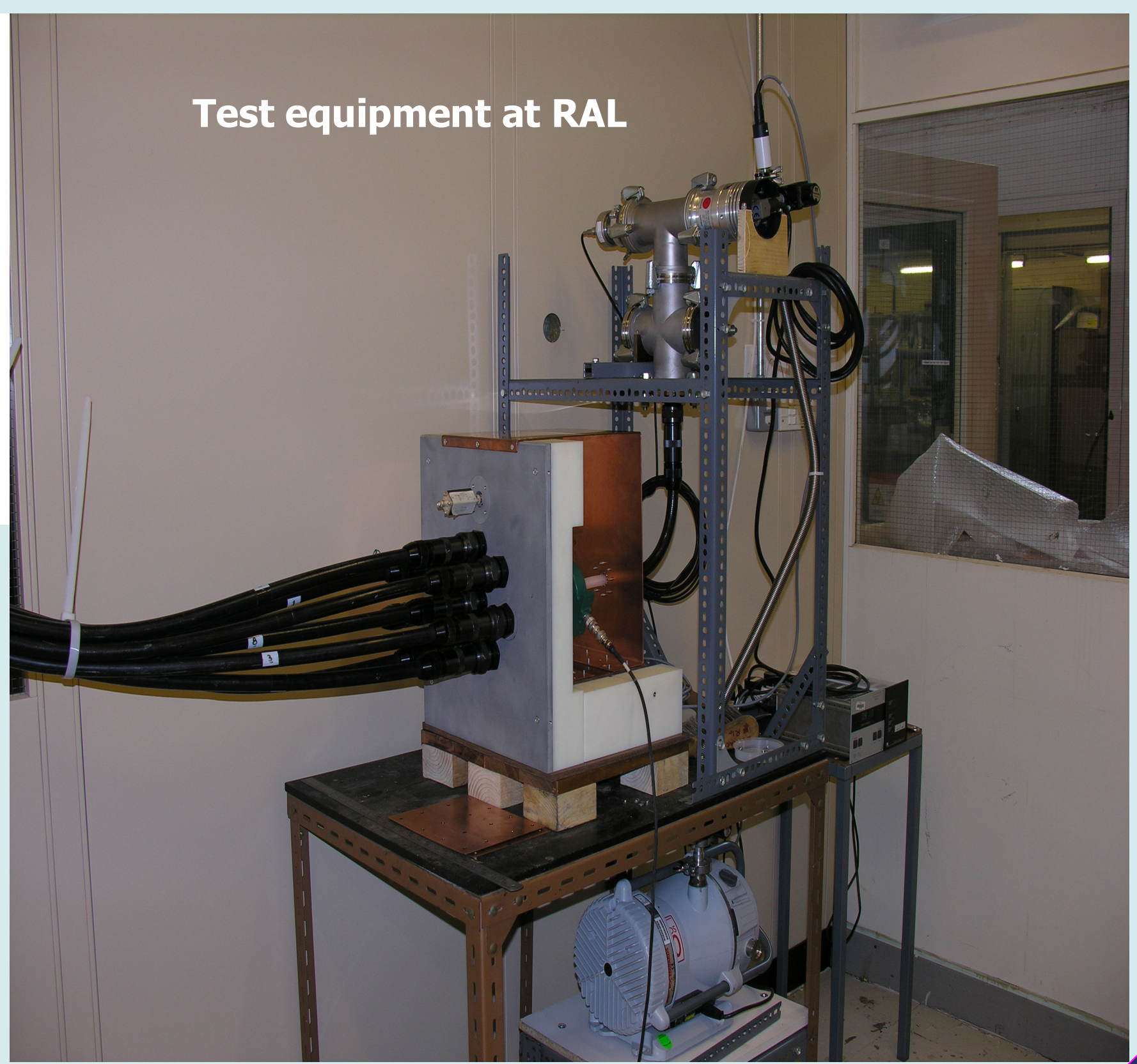
Current Pulse – Wire Tests at RAL

The pulsed heating of a small tungsten (tantalum) wire was proposed as a method for measuring the properties of the candidate materials under controlled laboratory conditions.

Schematic circuit diagram of the wire test equipment

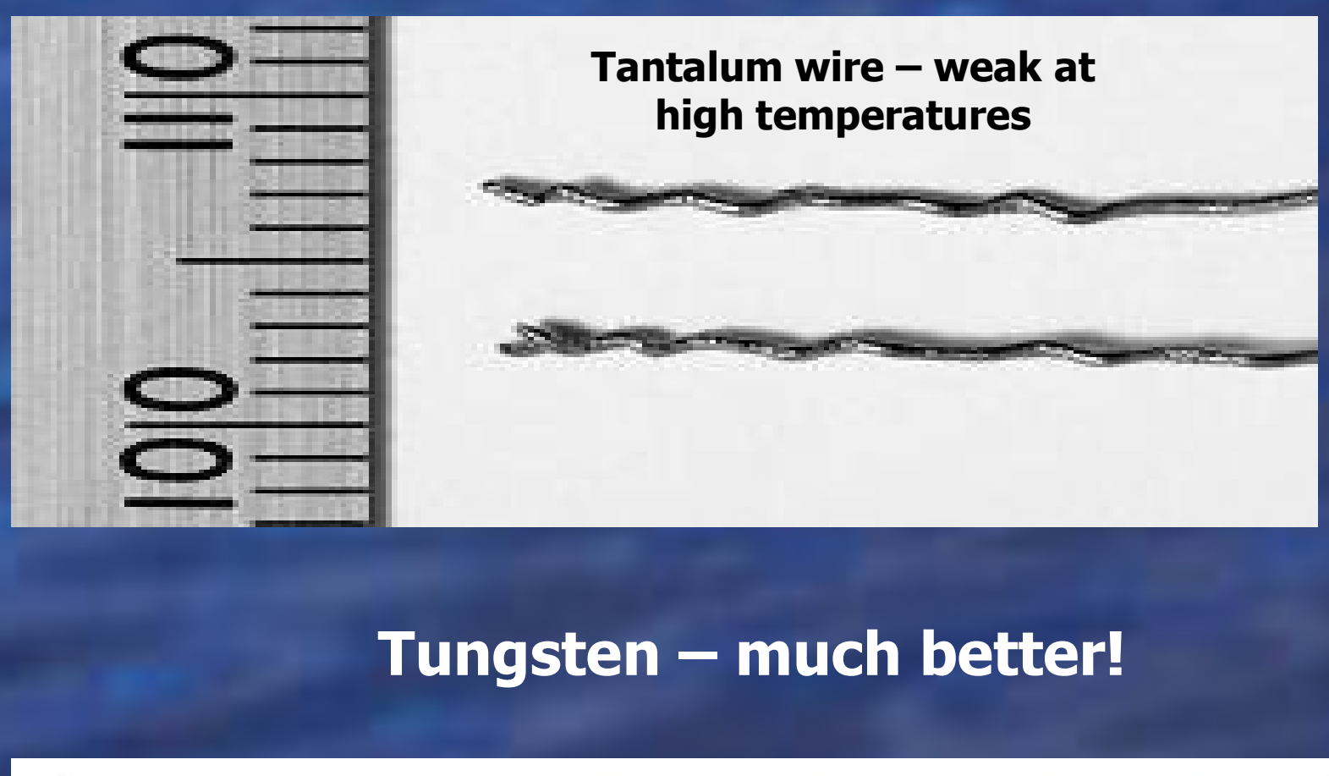






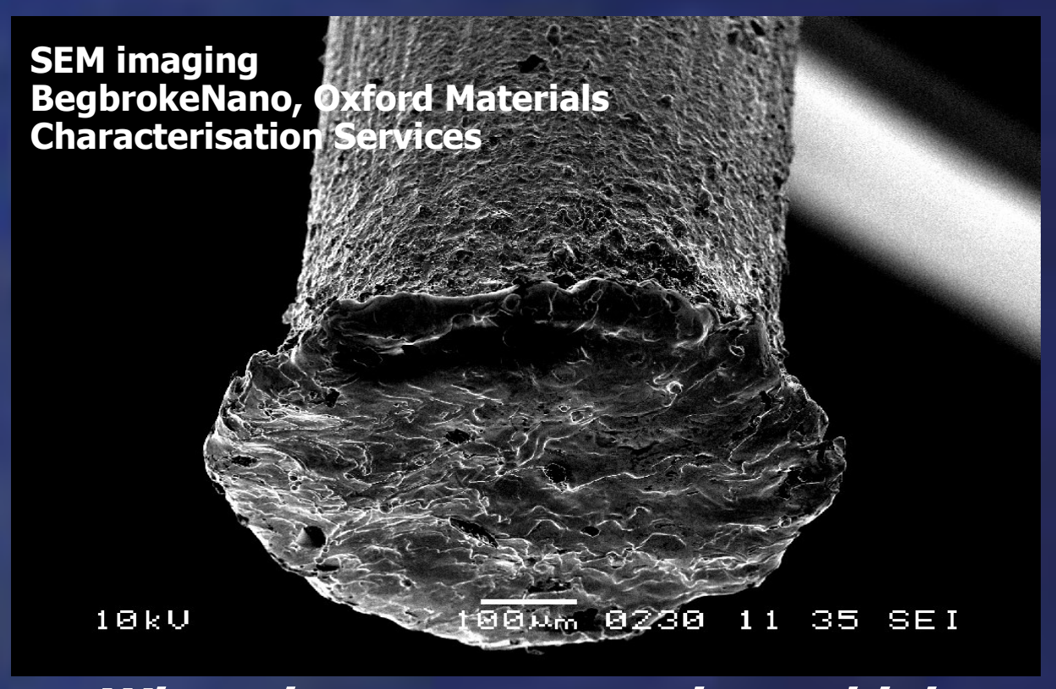
Test equipment at RAL

Lifetime/Fatigue Tests Results



Tantalum wire – weak at high temperatures

Tungsten – much better!



SEM imaging BegbrokeNano, Oxford Materials Characterisation Services

When the temperature is too high: end of the melted wire

Material	Current (A)	ΔT (K)	Max. T (K)	Pulses to failure	Eq. power
Tantalum	3000	60	1800	0.2x10^6	(MW)
Tungsten					
	5560	130	1900	4.2x10^6	2.7/5.0
Connector failed	5840	140	2050	>9.0x10^6	3.0/5.4
	7000	190	2000	1.3x10^6	4.3/7.8
	6200	160	2000	10.1x10^6	3.3/6.1
	8000	255	1830	2.7x10^6	6.1/>13
Cable #6 failed	7440	230	1830	0.5x10^6	5.2/11.4
	6520	180	1940	26.4x10^6	4.1/8.7
	4720	77	1840	>54.4x10^6	2.1/4.5
	6480		~600	>80.8x10^6	4.0/8.6

Equivalent power at Neutrino Factory (2cm/3cm diameter target)

More that 26 Million pulses at 4 MW

Better at lower temperature!

More than sufficient lifetime demonstrated:

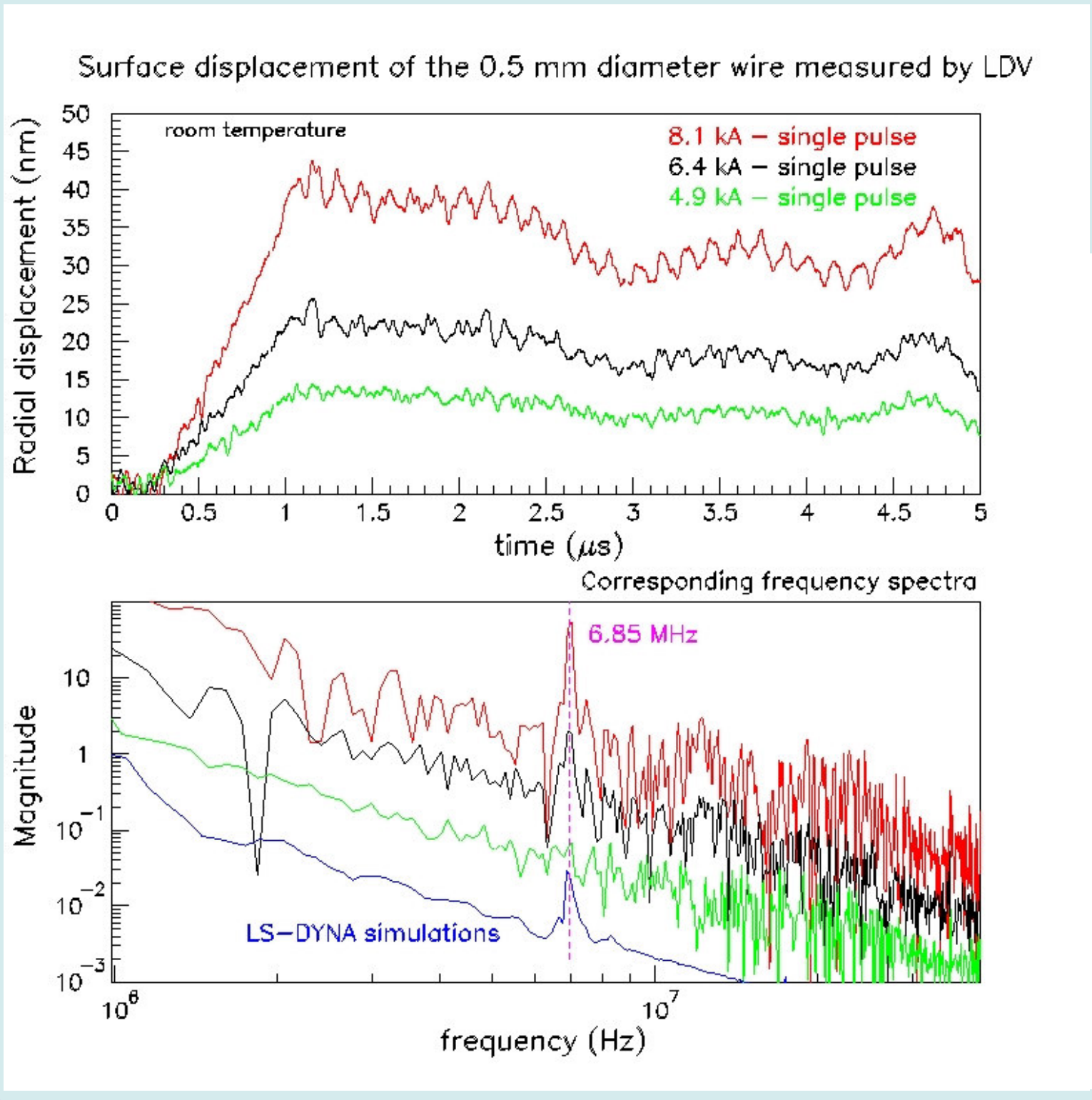
> 10 years for 2cm diameter target (> 20 years for 3cm diameter target)

LDV Tests

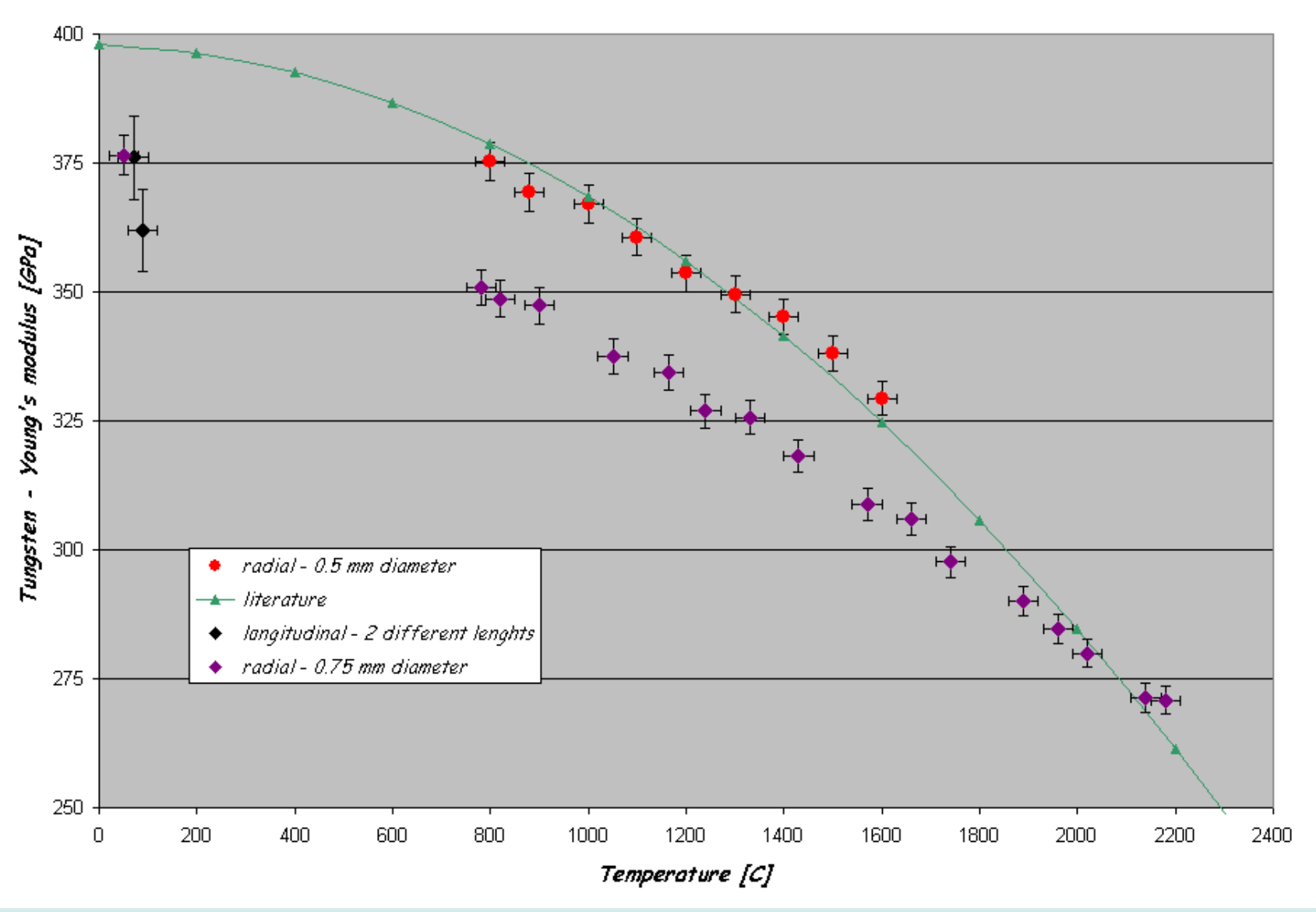
Measurements of the velocity and displacement of the surface of the wire using Laser Doppler Vibrometer will allow us to understand the behavior of the different candidate materials under shock conditions similar to that expected at the Neutrino Factory.

LDV: Laser Doppler Vibrometer

Thermal expansion of the wire as a function of applied current



Characteristic frequency of the wire vibration can be used to directly measure Young's modulus of tungsten as a function of temperature…



… and to confirm modelling results.