Progress towards a Solid Target for a Neutrino Factory

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Outline

1. Requirements.
2. A little history.
3. "SHOCK" in solids.
4. Lifetime and Strength of Tungsten.
5. Further work and tests. Target changing.

Requirements

Proton Beam:

Energy	6-8 GeV
Average beam power	4 MW
Pulse length	2-3 ns
Repetition rate	50 Hz

Target:

Material	Heavy metal
Dimensions	20 cm long x 1 cm diameter

A little history:

Initial thoughts were to use

many solid targets

with

radiation cooling.

A solid target is a relatively simple and well tried solution with minimum problems of radiation contamination compared to liquid or powder targets.

But

To move target bars into the beam at 50 Hz (one every 20 ms) is difficult.

Also, the target needs to be ~2 cm diameter to reduce the temperature and the stress.
The larger diameter reduces the pion yield.

However,
a bigger problem was considered to be -

THERMAL SHOCK

A shock wave
usually travels faster than
the speed of sound in the material.

In our case
we do not have shock.

BUT
it is possible to exceed the
STRENGTH OF THE MATERIAL.

Lifetime and Strength Studies

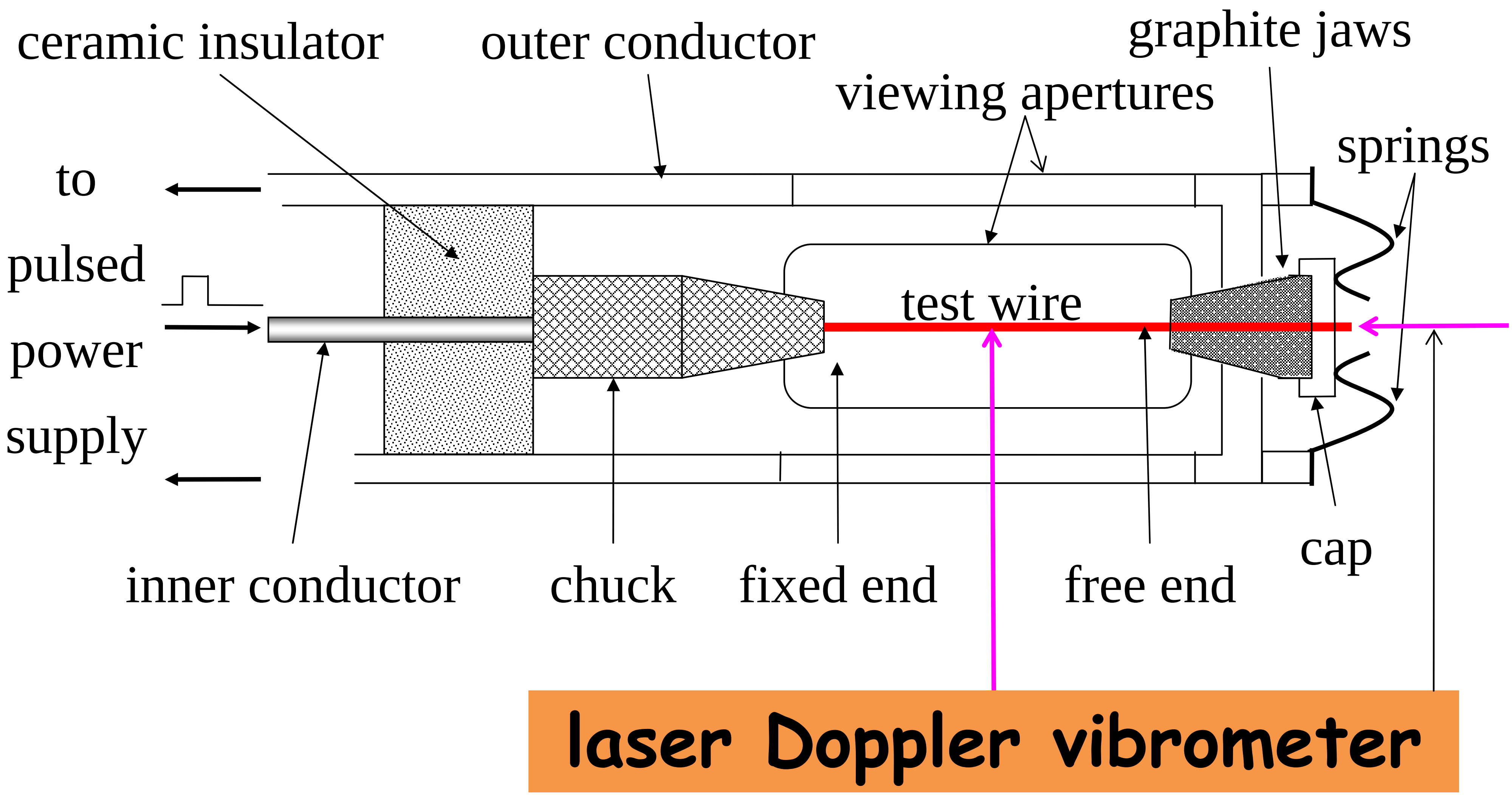
Unfortunately it is impractical to test a full size target in a proton beam –

So –

Tests on thin wires carrying a fast current pulse.

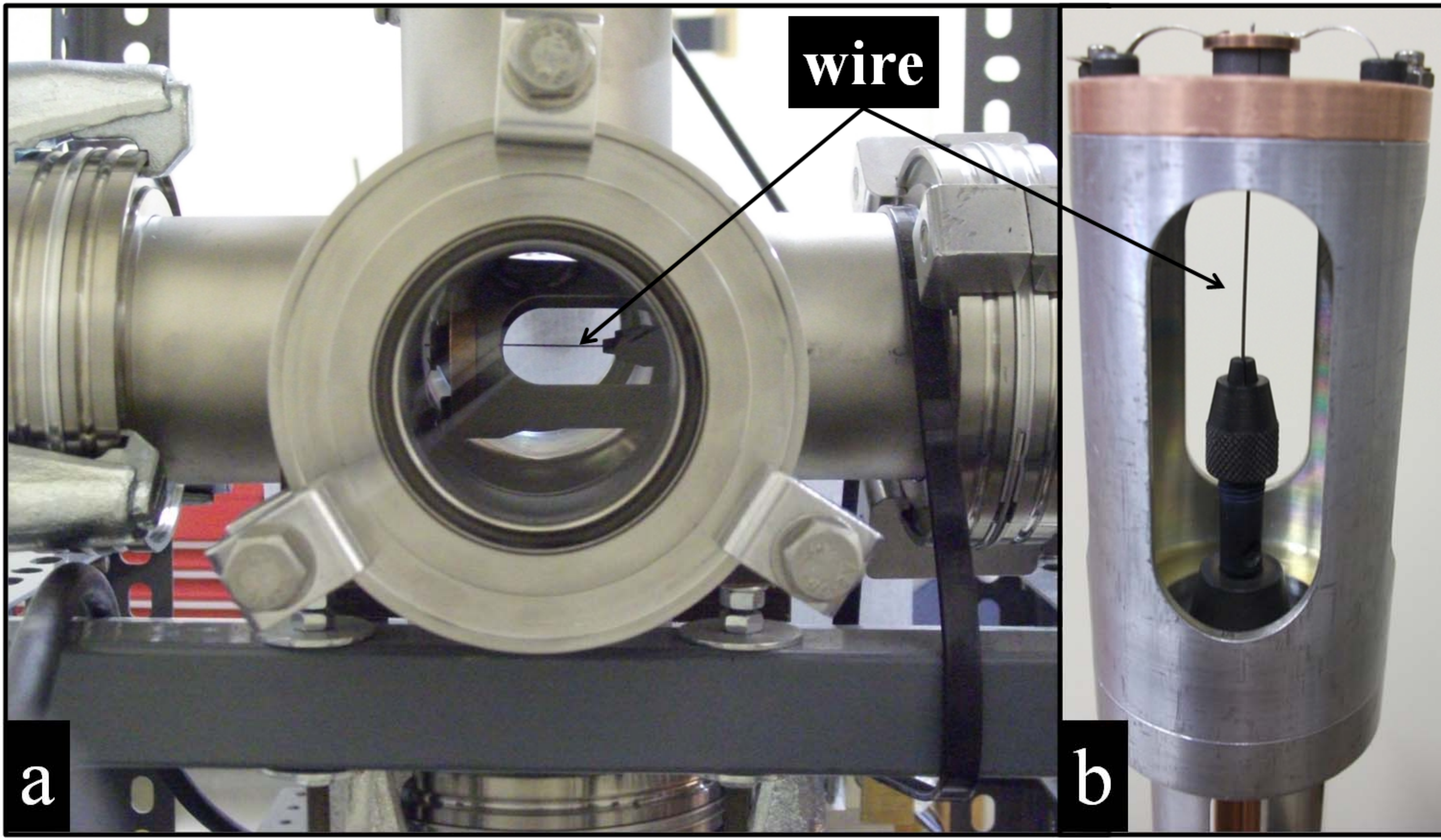
Note that it is important to test under dynamic conditions.

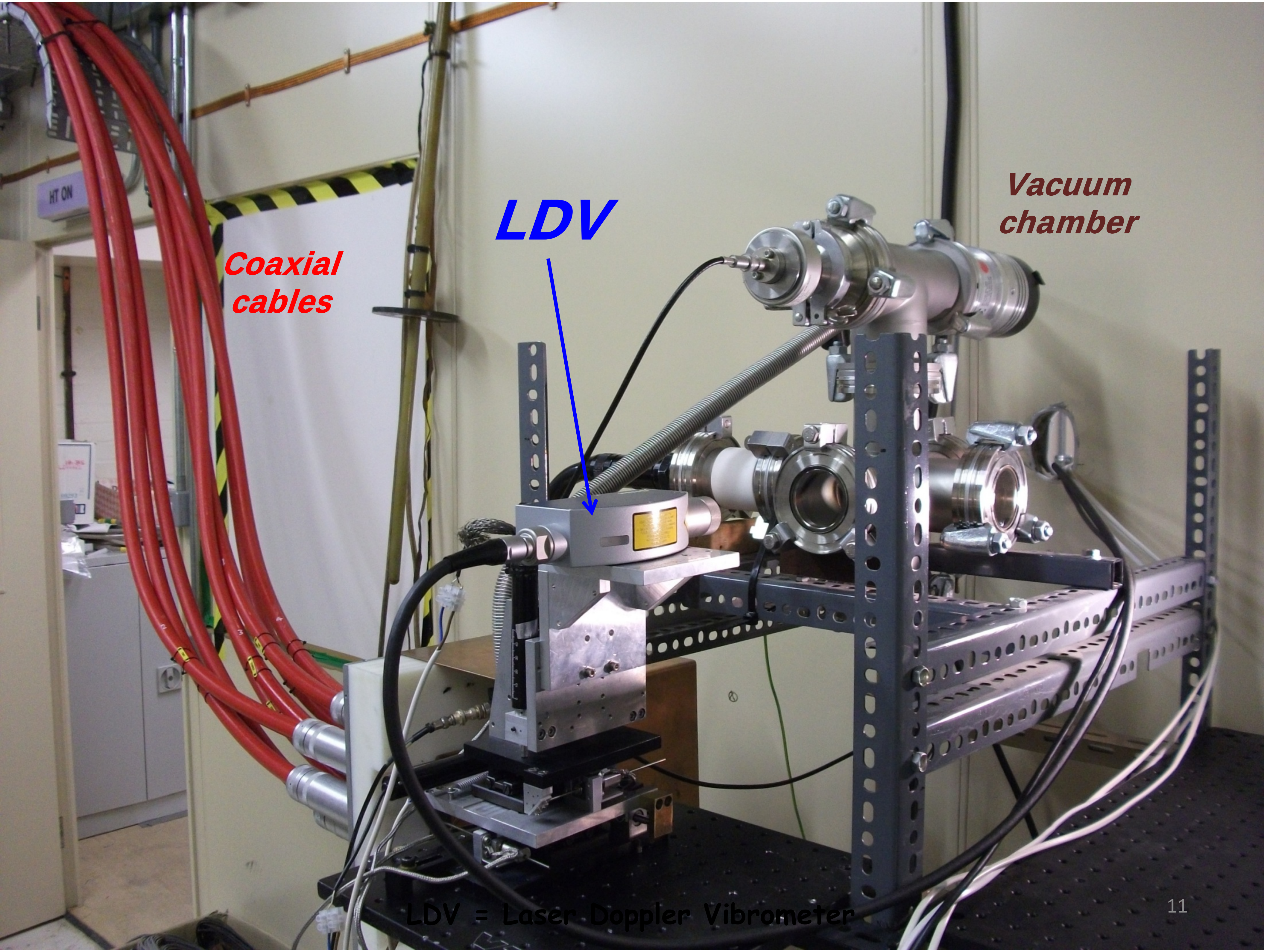
1. The strength of materials varies with the strain rate.
2. The stress/strain curve is very different from that of a conventional quasi-static measurement.



Schematic diagram of “The Little Wire”

“The Little Wire” Equipment

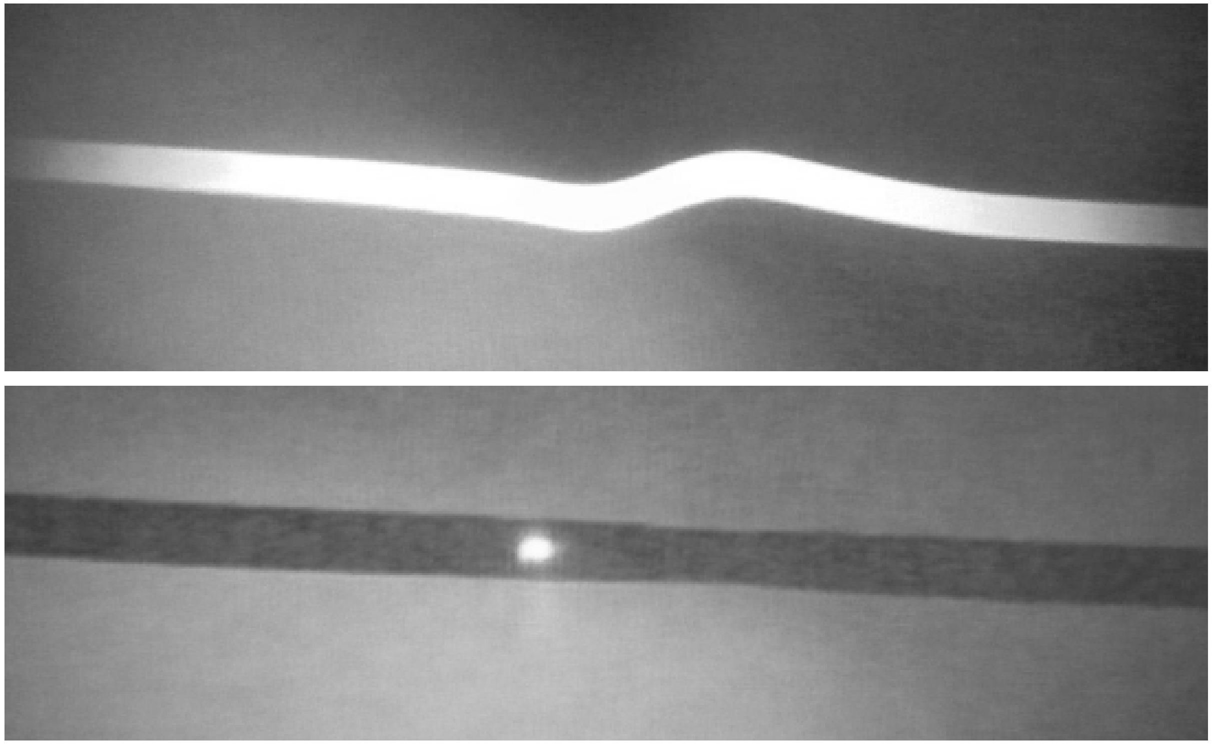



Coaxial cables
LDV
Vacuum chamber
HT ON
LDV = Laser Doppler Vibrometer

OPERATION

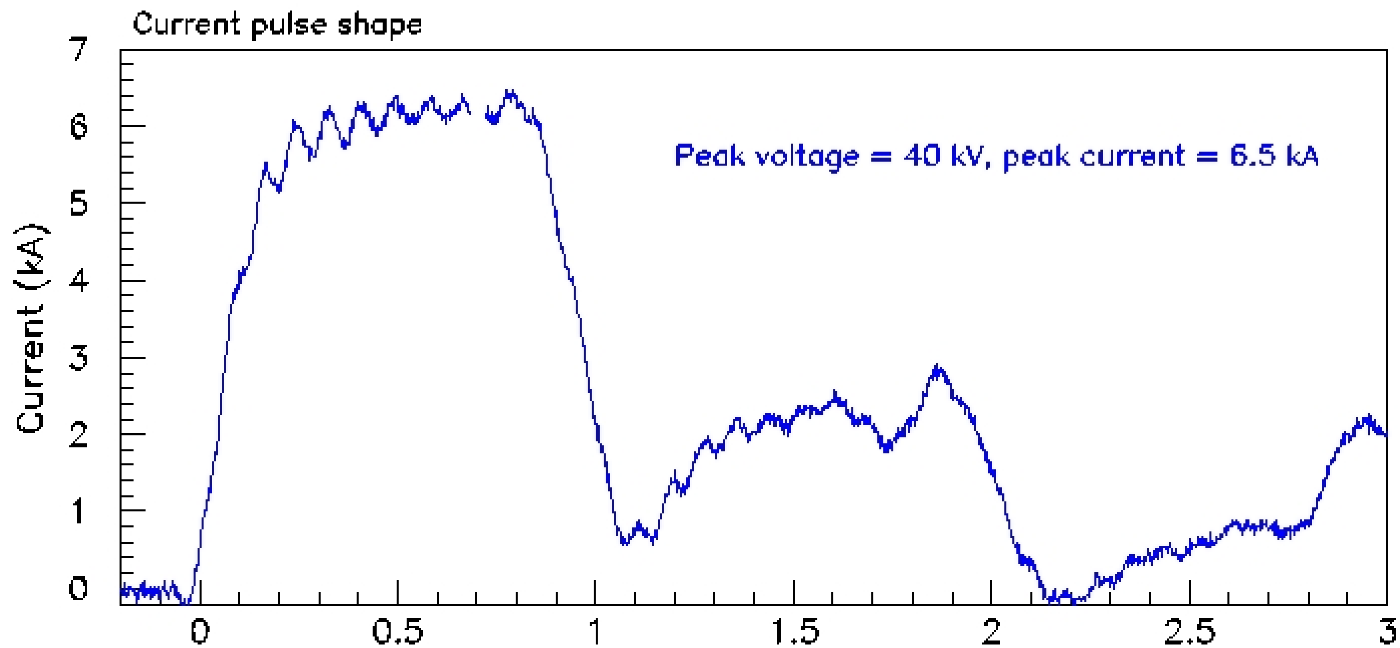
1. Pass a short current pulse through the wire.
   The current determines the temperature rise and mechanical stress in the wire.
   The pulse frequency determines the mean temperature of the wire.
2. Measure the radial velocity of the wire as a function of time with the Vibrometer.
3. Measure the peak temperature of the wire at the measuring point with an optical pyrometer.
4. Analyse the Vibrometer signal to find the radial resonant frequency.
5. The radial frequency gives Young's modulus of elasticity.
   Measure Young's modulus as a function of temperature and stress.
   The modulus is found to be independent of stress (below breaking).
6. Vary the amplitude of the current pulse at a given temperature to find the stress at which the wire starts to deform (or break) within a few pulses. The Vibrometer signal becomes incoherent at this point, due to the wire becoming plastic.
7. Calculate the stress in the wire using commercial computer codes.
8. Plot the Stress at which the wire breaks versus the Temperature.
   This gives typical *Strength versus Temperature curves.*
   The measurements are at high strain rate.

Note that it is important to measure Young's modulus under the conditions – high stress, temperature and strain rate – since it is used to calculate the stress in the wire in the tests.

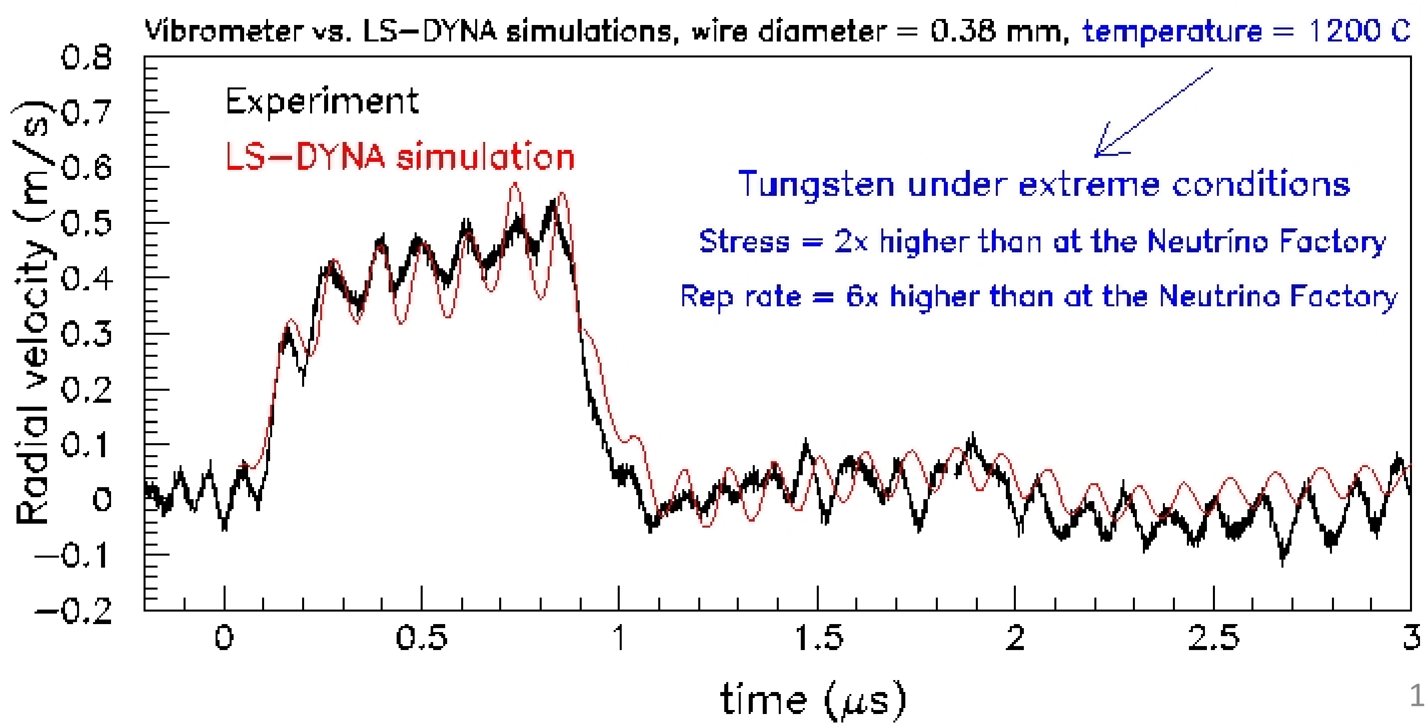


Two tungsten wires, 0.5 mm diameter, about to fail in bending (top picture, hot wire) and stretching (bottom picture, cold wire showing the laser spot from the vibrometer on the wire).

Current Pulse.

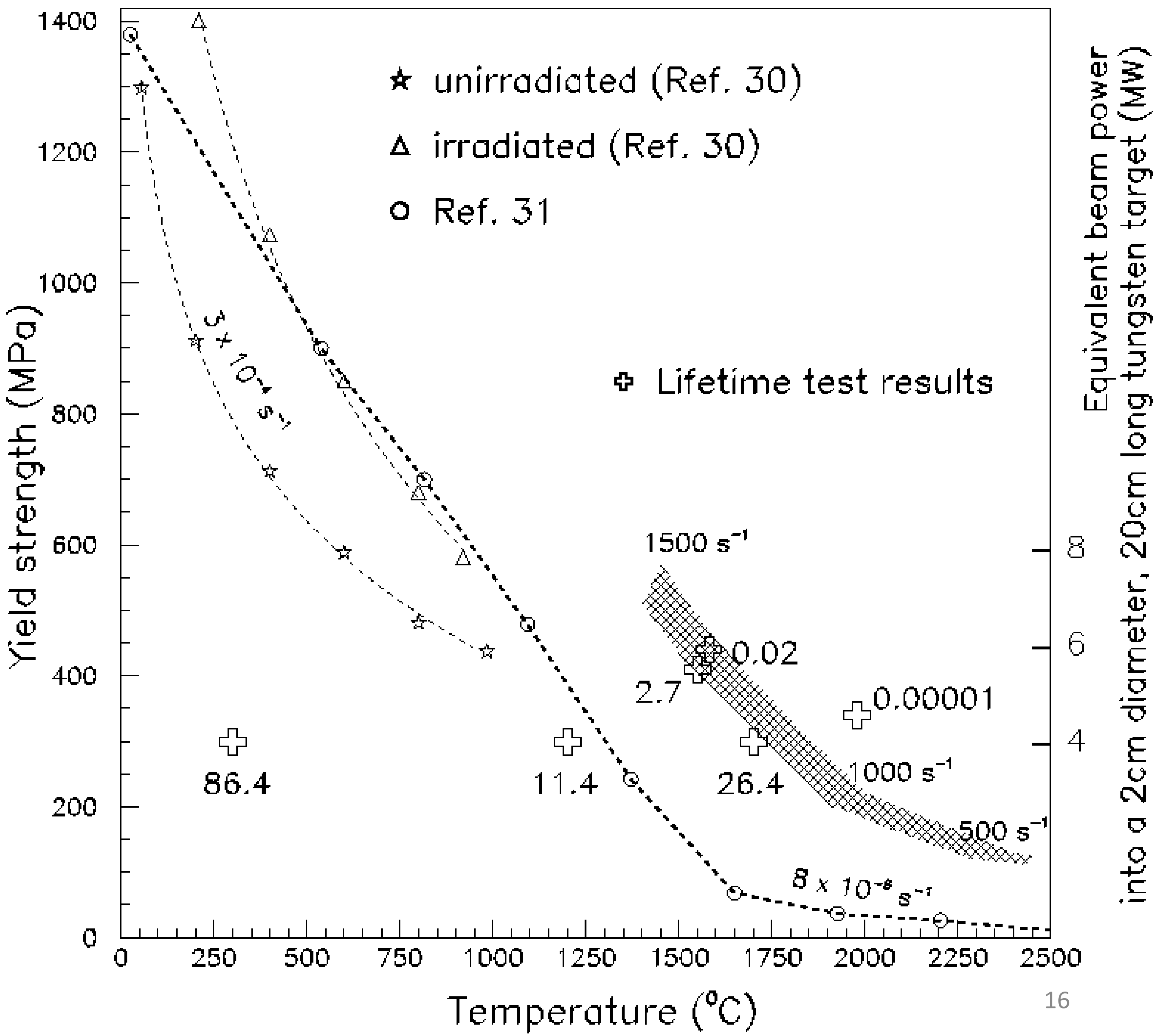


Vibrometer measurement (black line) and calculation (red line).



Strength of Tungsten versus Temperature and Lifetime, ✙ in Millions of Pulses

Strain rates shown in s^{-1}.



The test wires are drawn but the targets will be hot forged.

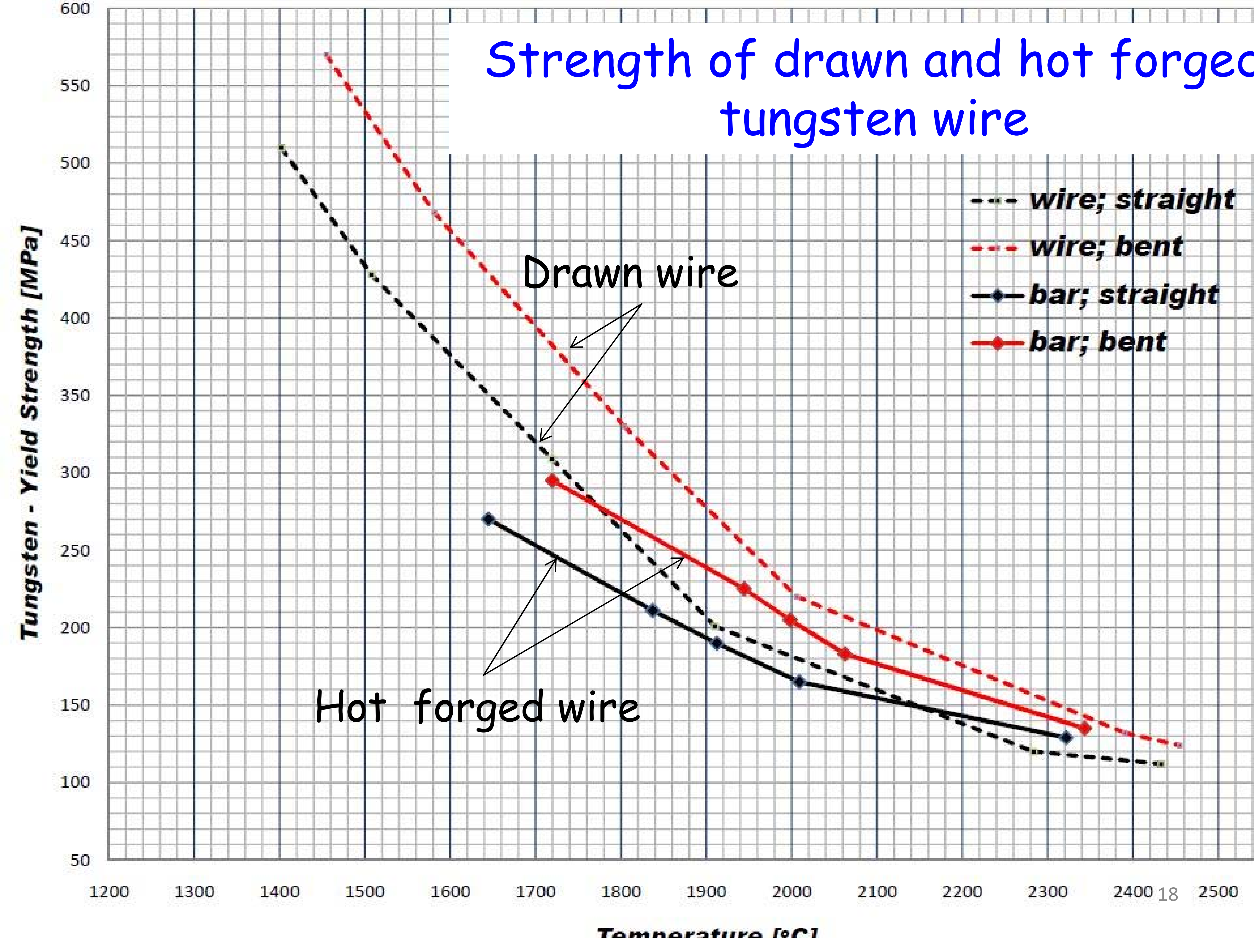
Drawn tungsten is stronger than forged.

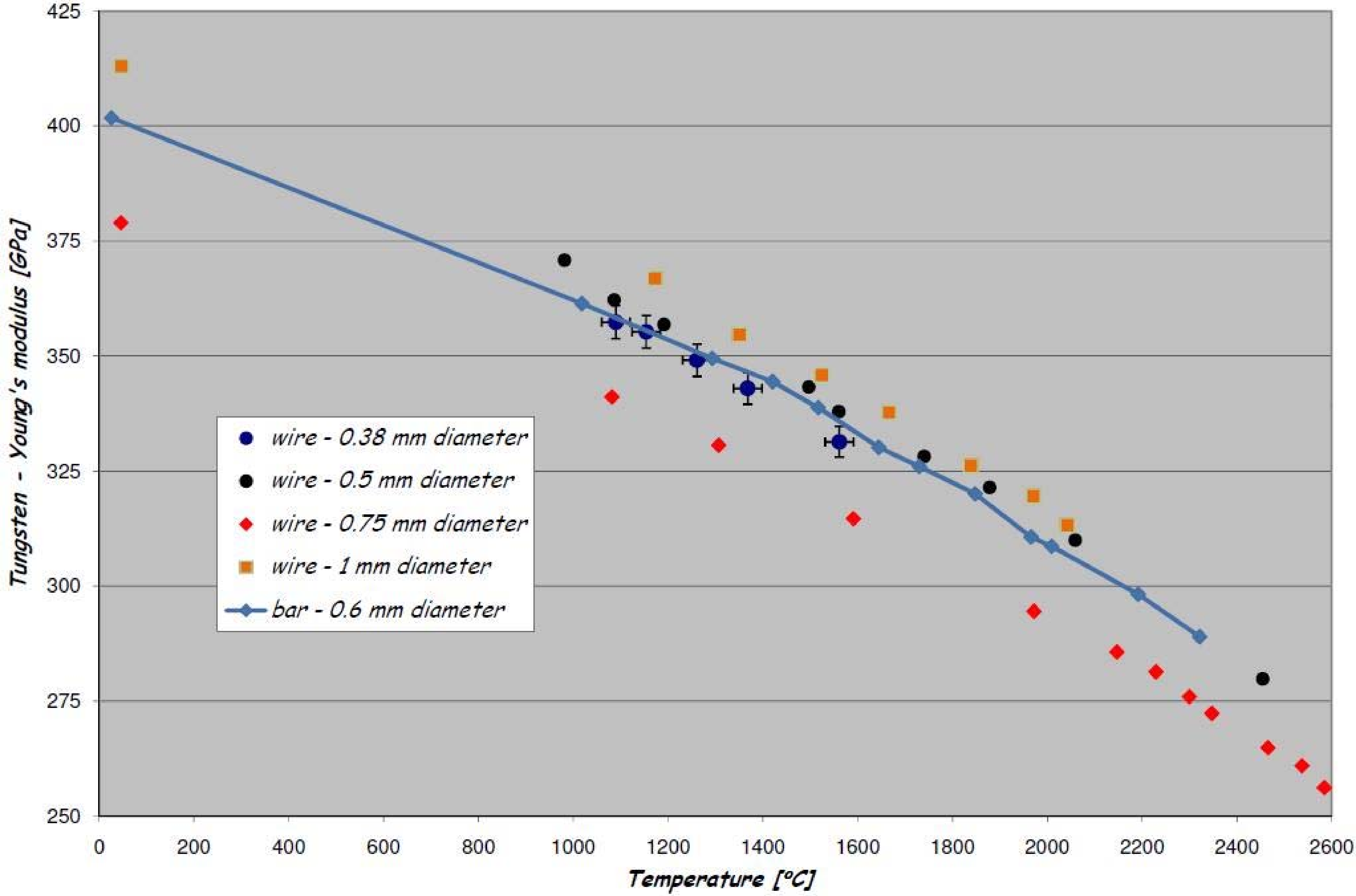
Currently we are testing hot forged 0.6 mm wires.

They (maybe) show only a marginal reduction in strength.

The value of Young's modulus is the same as drawn.

Strength of drawn and hot forged tungsten wire





Measured Young's modulus versus temperature for various wire diameters.

The 0.6 mm diameter wire is hot forged and centreless ground.

Conclusions

The Strength of Tungsten at High Temperature & Stress:

- We've done this to death!

  But the target still lives!

- We don't believe there is a problem.

So we conclude:-

- Can operate the target at 4 MW & 1200° C for at least 10 years.
- Can reduce the target radius to 0.75 cm. But - will need more than 500 targets to remove the heat.
- Probably can operate at 10 MW, 1200° C.

Future Work and Tests

1. Radiation damage to tungsten
   - No evidence of damage to ISIS W targets up to 12 dpa.
   - Want to do proton irradiations at CERN next year.
2. Target mechanism
   - Design and Test
3. Collection solenoids (an existing slight problem)
4. Target station
   - Design and cost

Target Change Mechanism

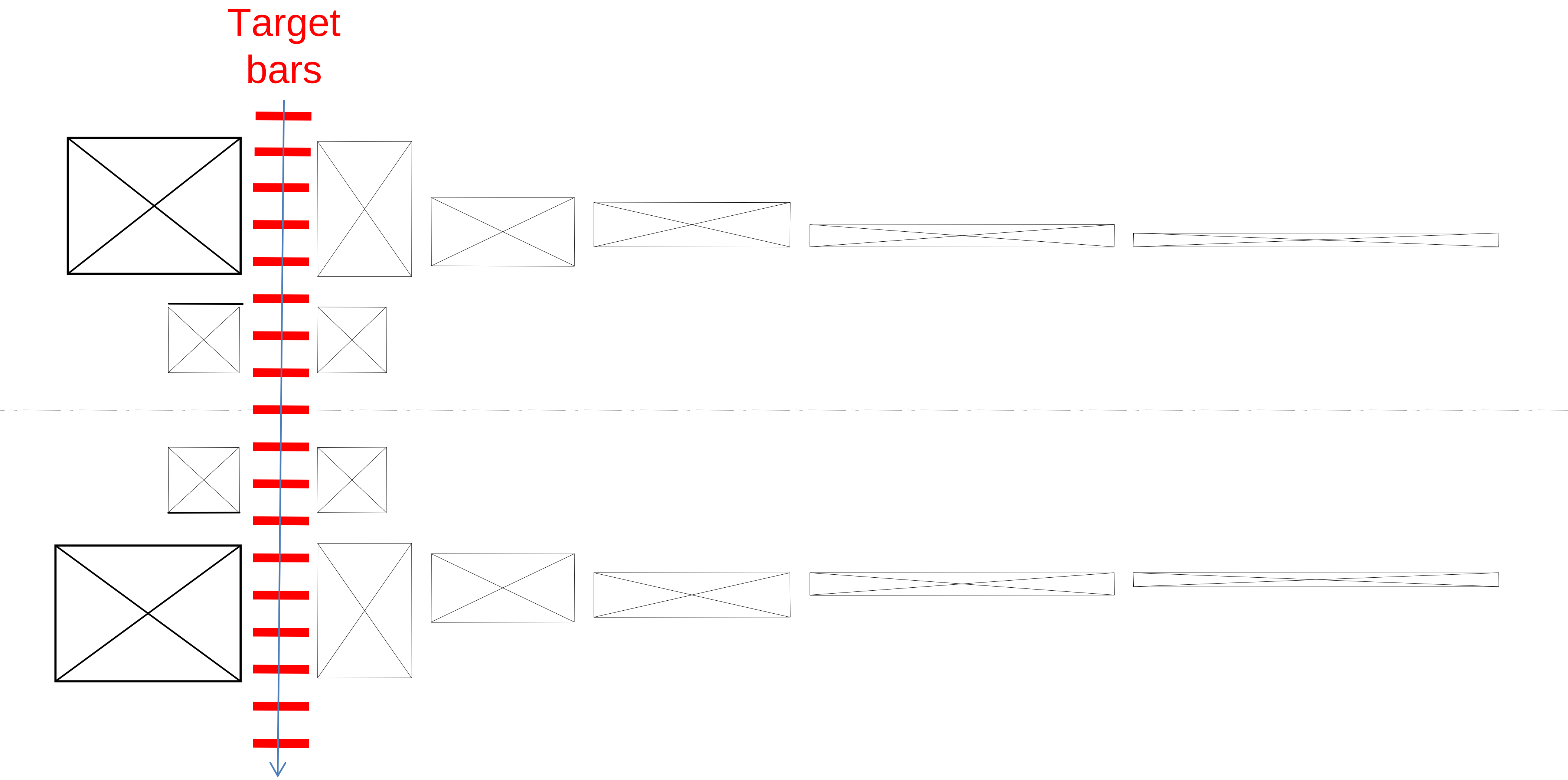
Targets must be changed every beam pulse at 50 Hz.

In addition there must be

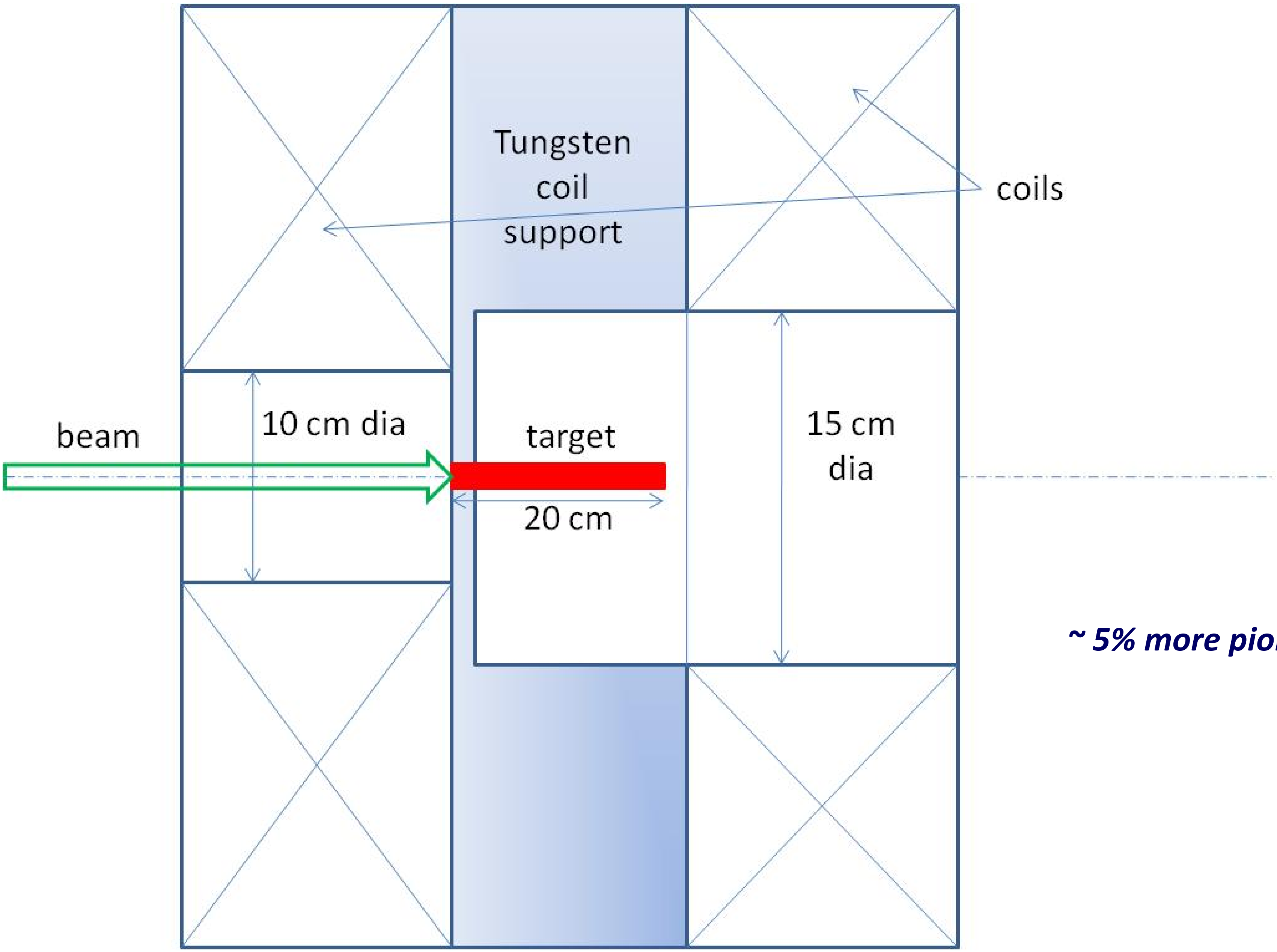
- minimal impact on pion production
  - minimal effect on shielding
  - simplicity of design
  - excellent reliability
  - replacement of targets remotely
  - no damage by heat or radiation
  - use, as much as possible, of existing technology

NF Capture Coil

Helmholtz Coil Geometry

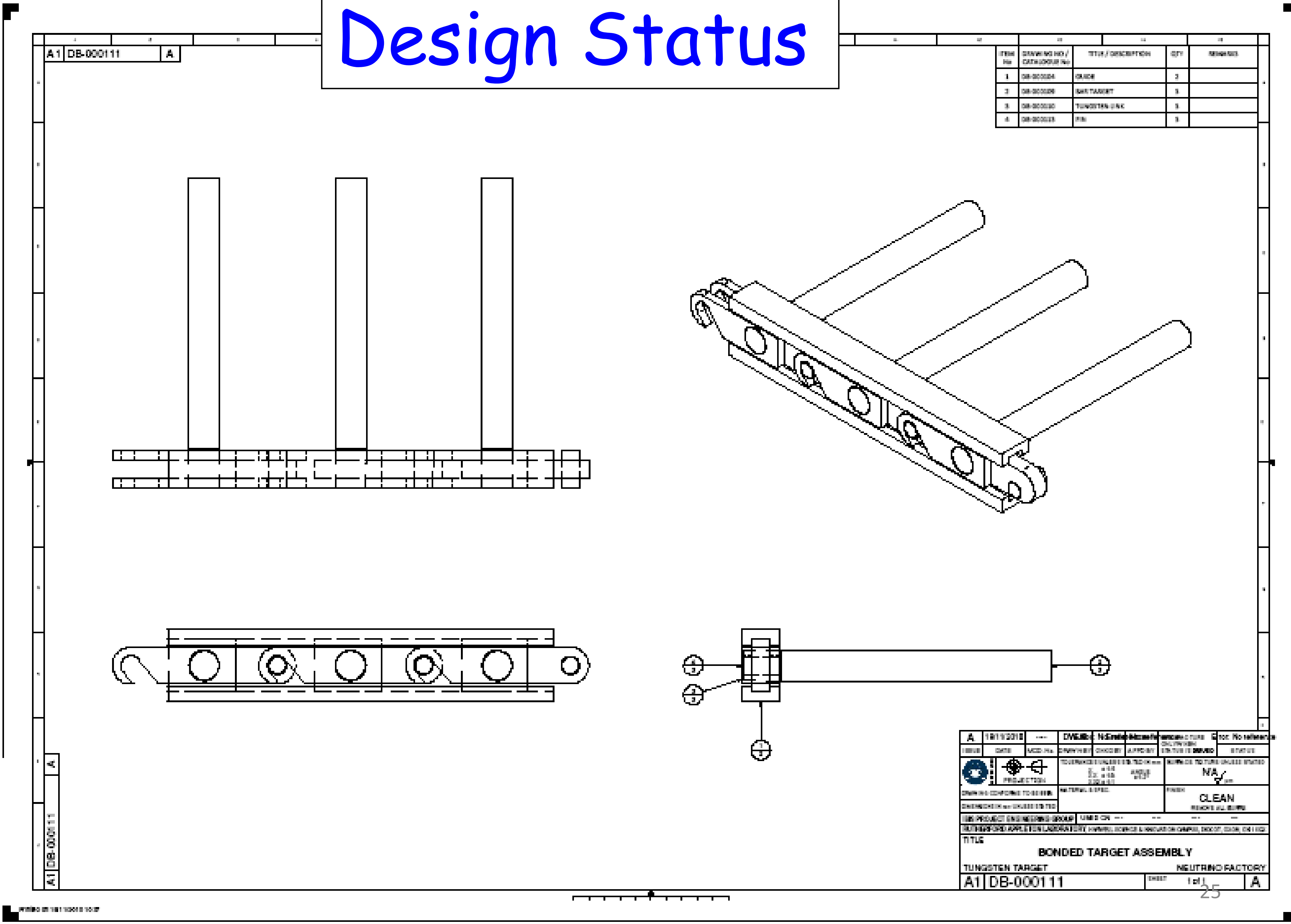


Target change – a chain

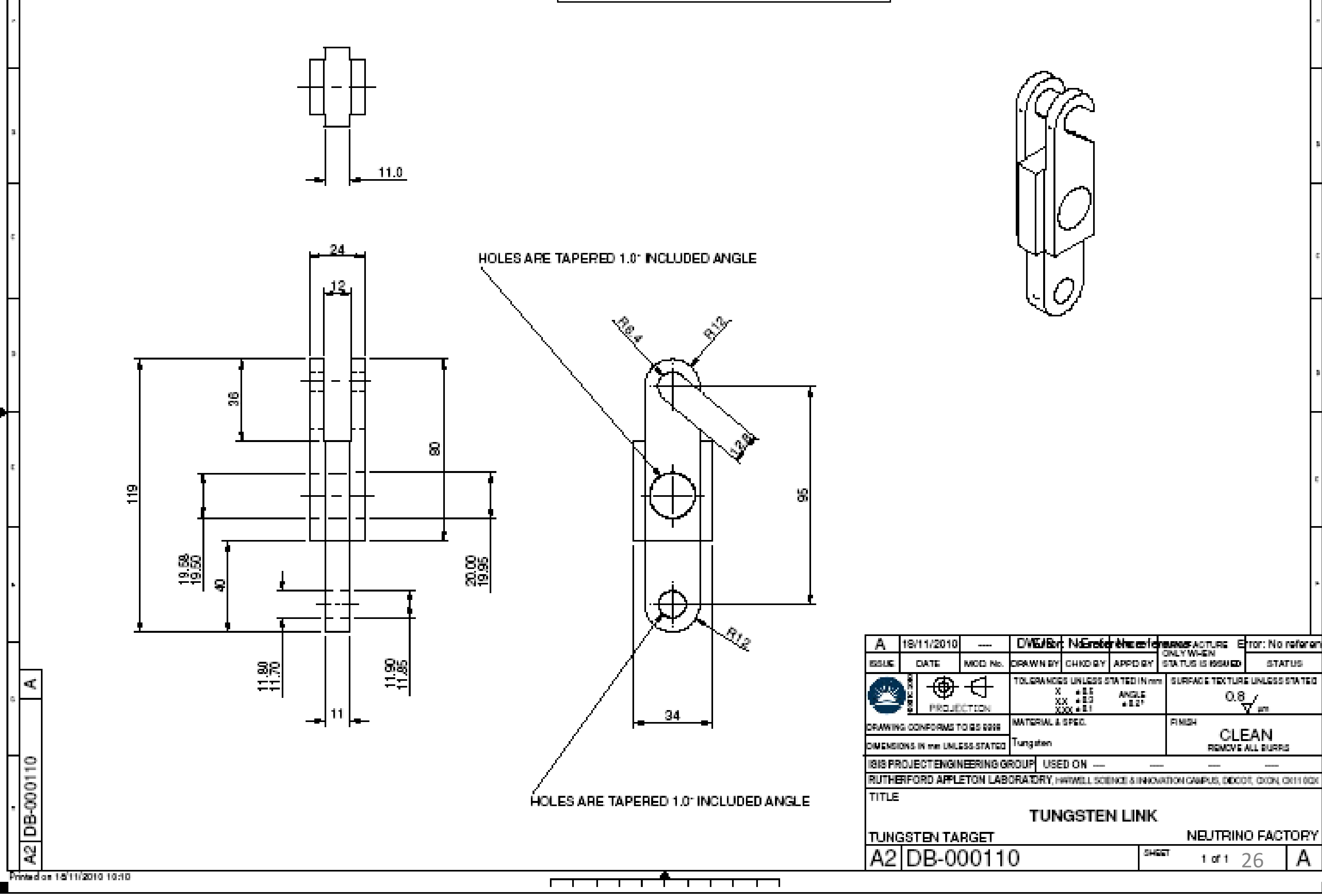


~ 5% more pions

Design Status



Link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R8.4
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TUNGSTEN LINK
TUNGSTEN TARGET
NEUTRINO FACTORY
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Diffusion bond the target bars (tapered) and the pins into the links.

Enquiries to manufacturers for:

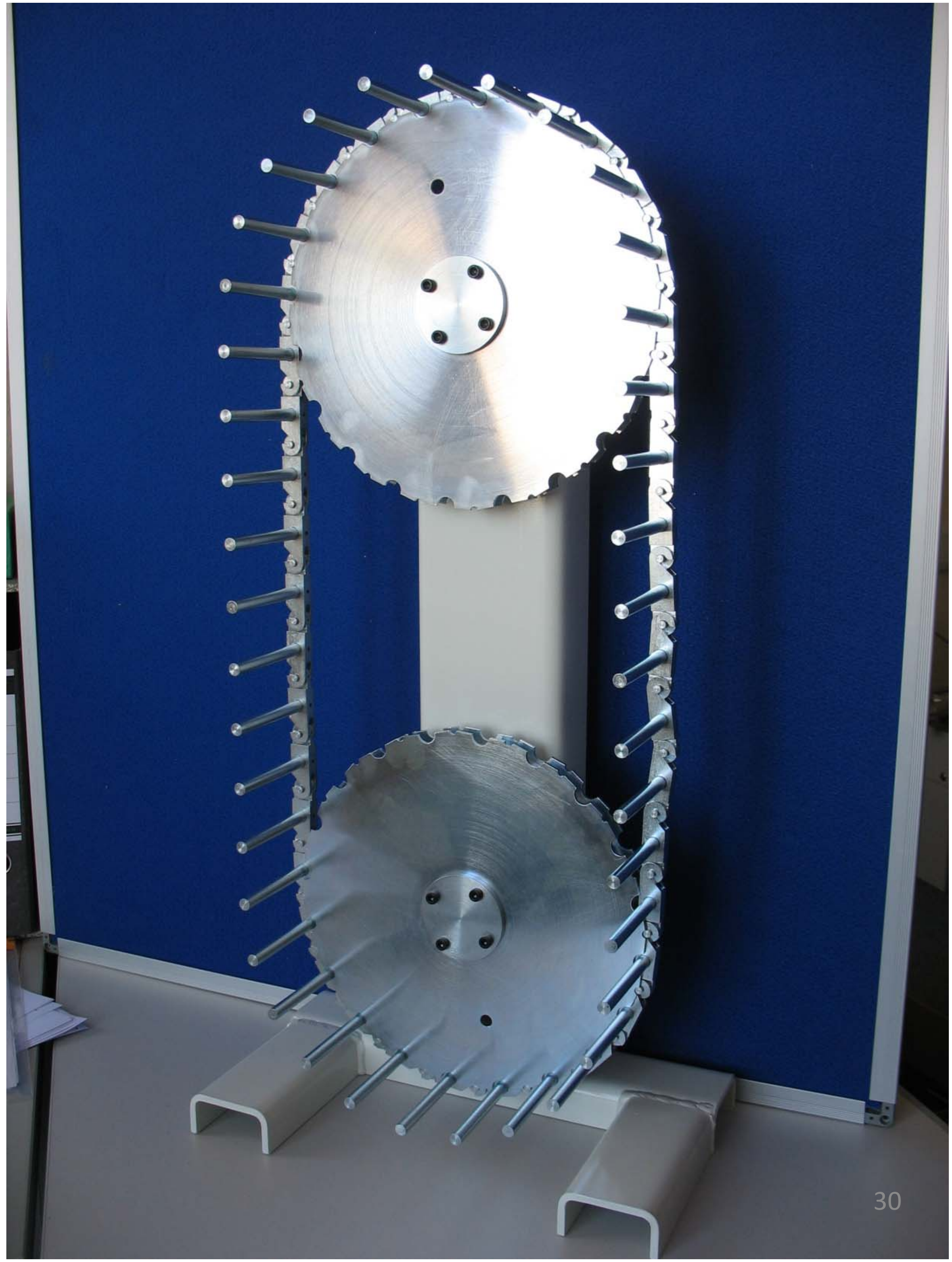
- diffusion bond tests.
- manufacturing ease, practicality and costs.

Full sized model of a target bar and chain link in mild steel

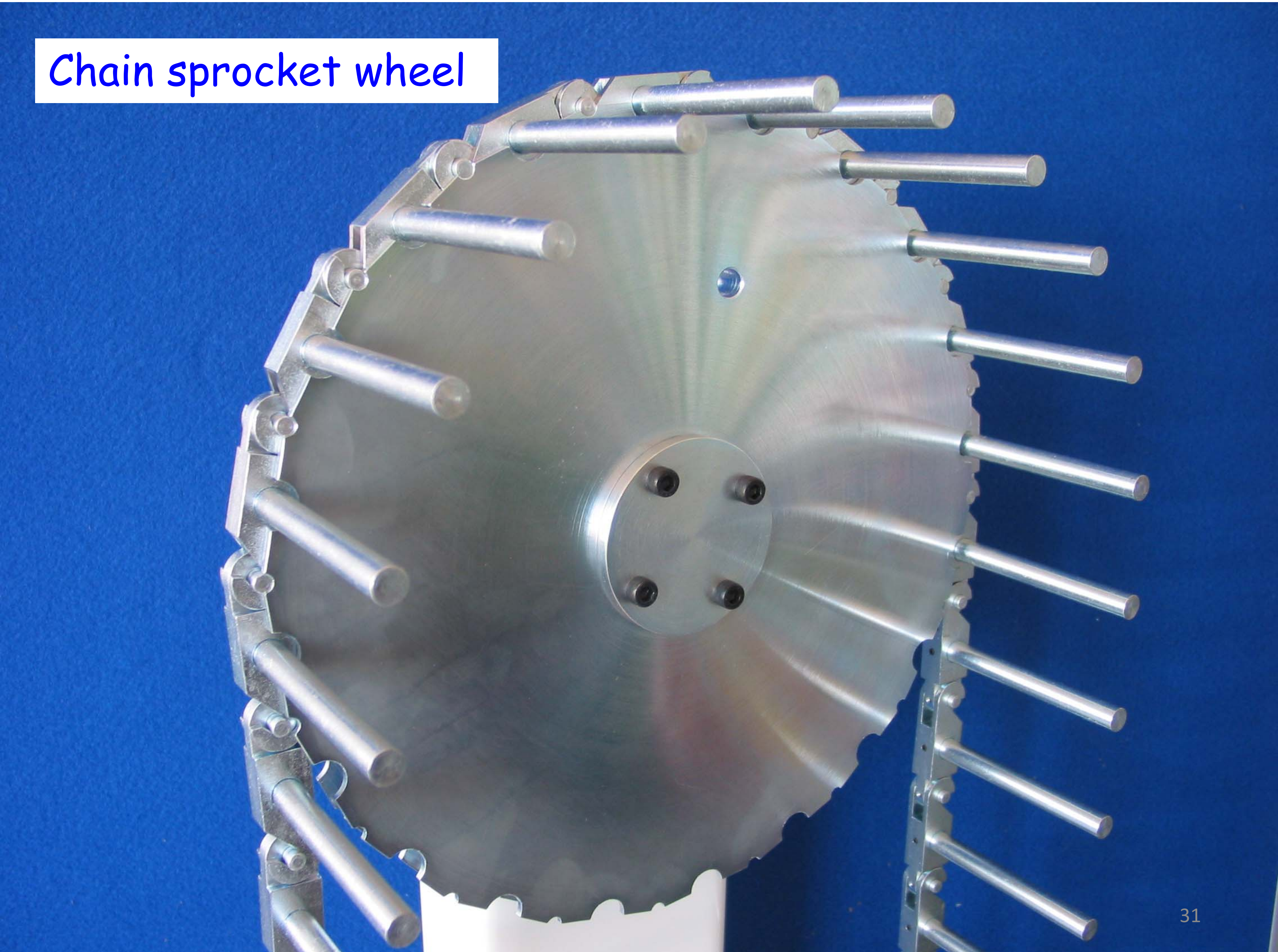
3 target bars and chain links

Half-Scale Model

40 targets/chain-links, mounted on two chain wheels.



Chain sprocket wheel



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