# Development of Fused Silica Suspension Fibres for Advanced Gravitational Wave Detectors

TAUP Sendai

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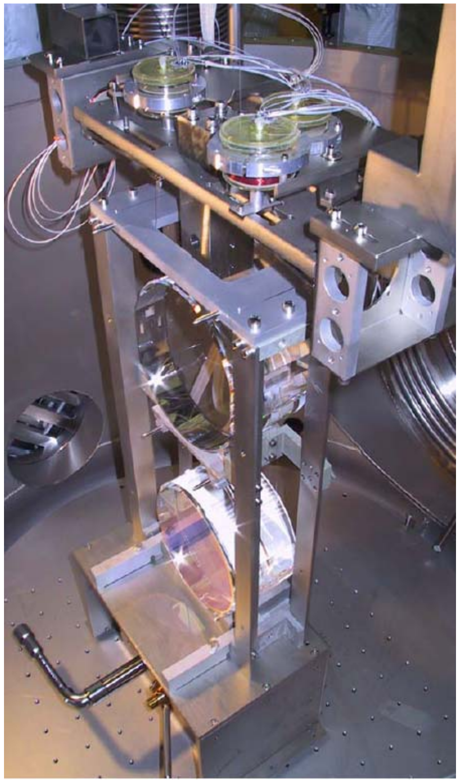
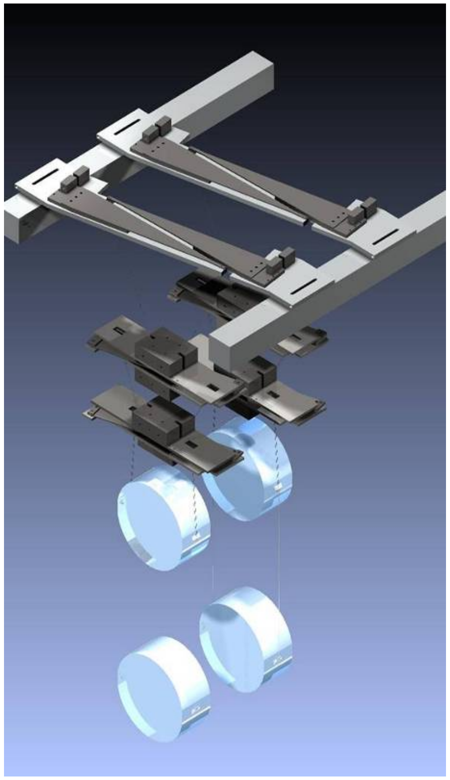
# Monolithic suspensions for advanced detectors

- Development of monolithic suspensions is based on experience from the GEO600 suspensions
- This talk will cover aspects of production and testing of suspension elements suitable for Adv. LIGO and upgrades to Virgo
- The criteria that must be met by ribbon fibres for Adv. LIGO:
  - Strength (x3 safety margin)
  - Thermal noise performance
- To meet these criteria we require
  - Breaking stress > 2.4 GPa
  - Intrinsic loss $<3 \times 10^{-11}/t$, where t is the thickness of the ribbon





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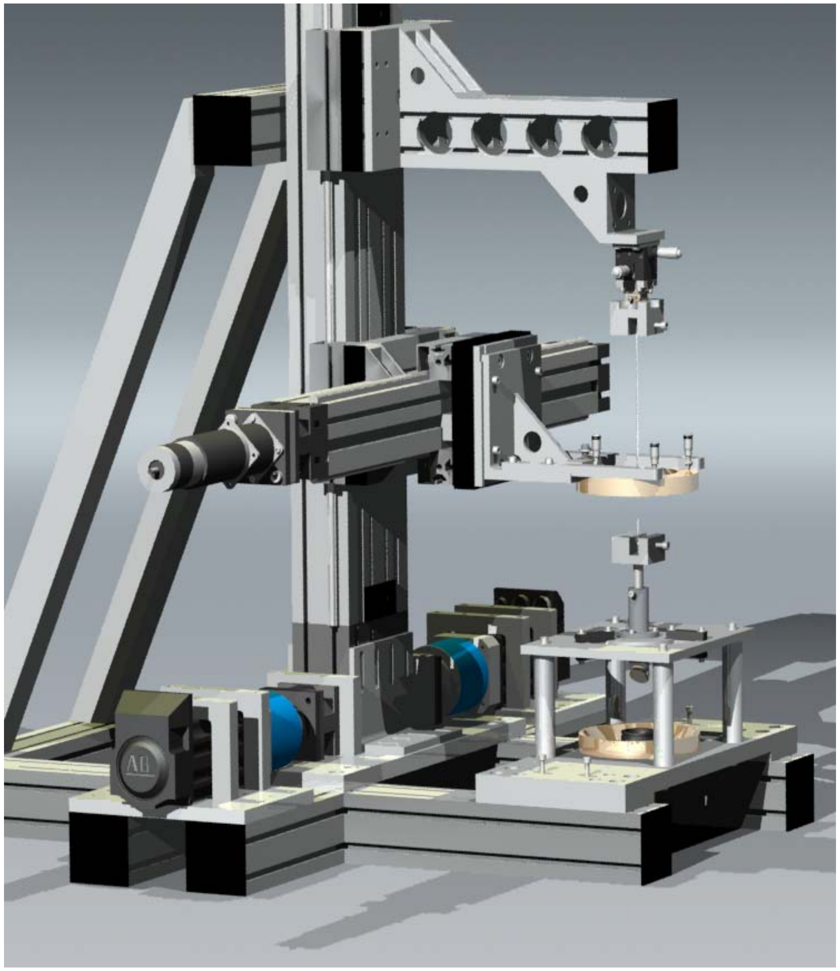
# Improving fibre pulling technology

- Advanced LIGO suspensions require ±1.9% tolerance on fibre dimensions.
- This is a slight increase on the ±2.1% achieved in GEO600.
- Repeatability and tolerance in flame pulling machines is limited by gas regulation and slack in mechanical parts.
- A new machine was developed in Glasgow using a $CO_2$ laser and high precision drive systems
- Designed for both ribbon and cylindrical fibre production to be suitable for both LIGO and Virgo upgrades.
- The machine is also capable of welding fibres.



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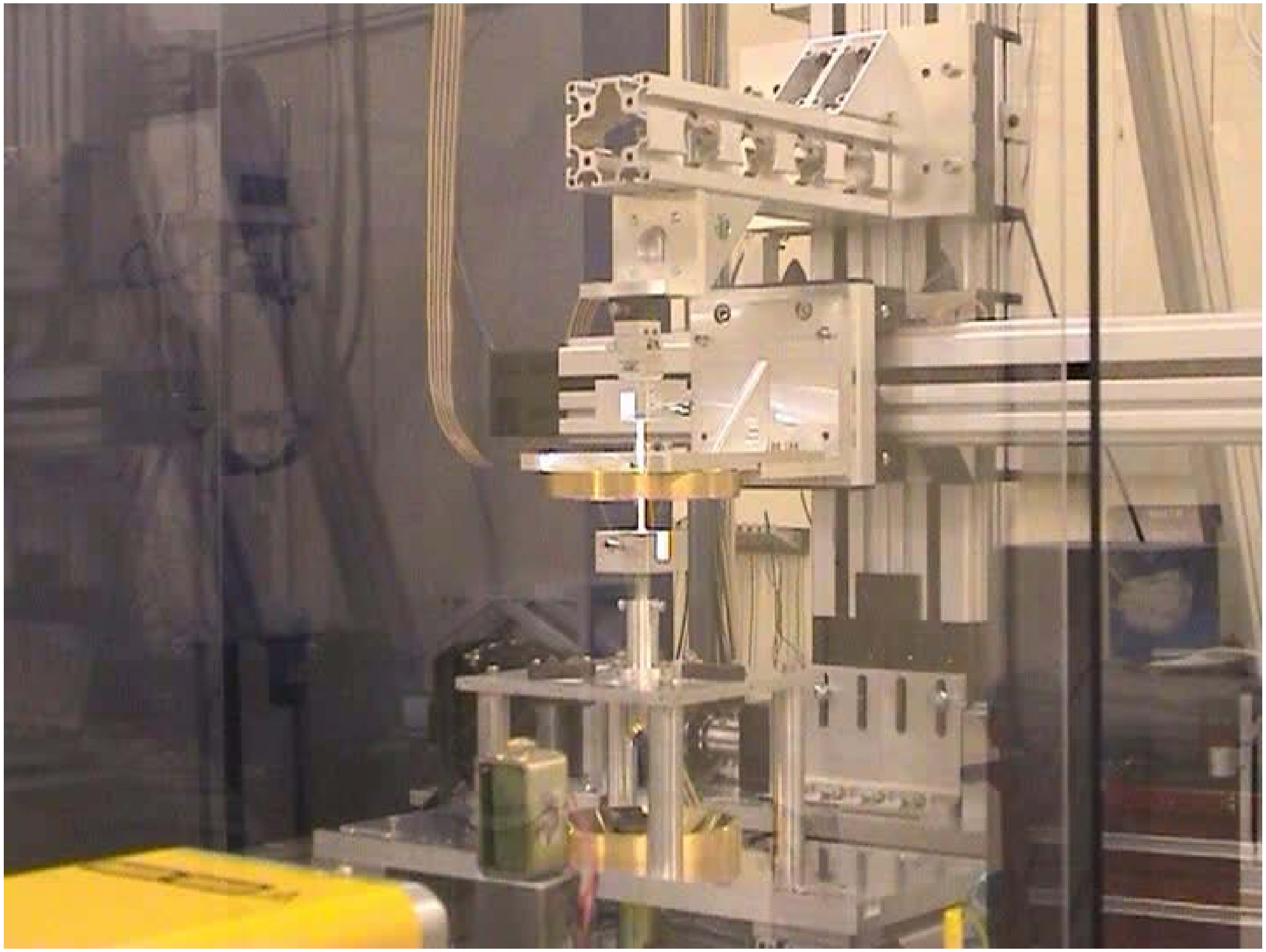
# Pulling fibres using the $CO_2$ laser



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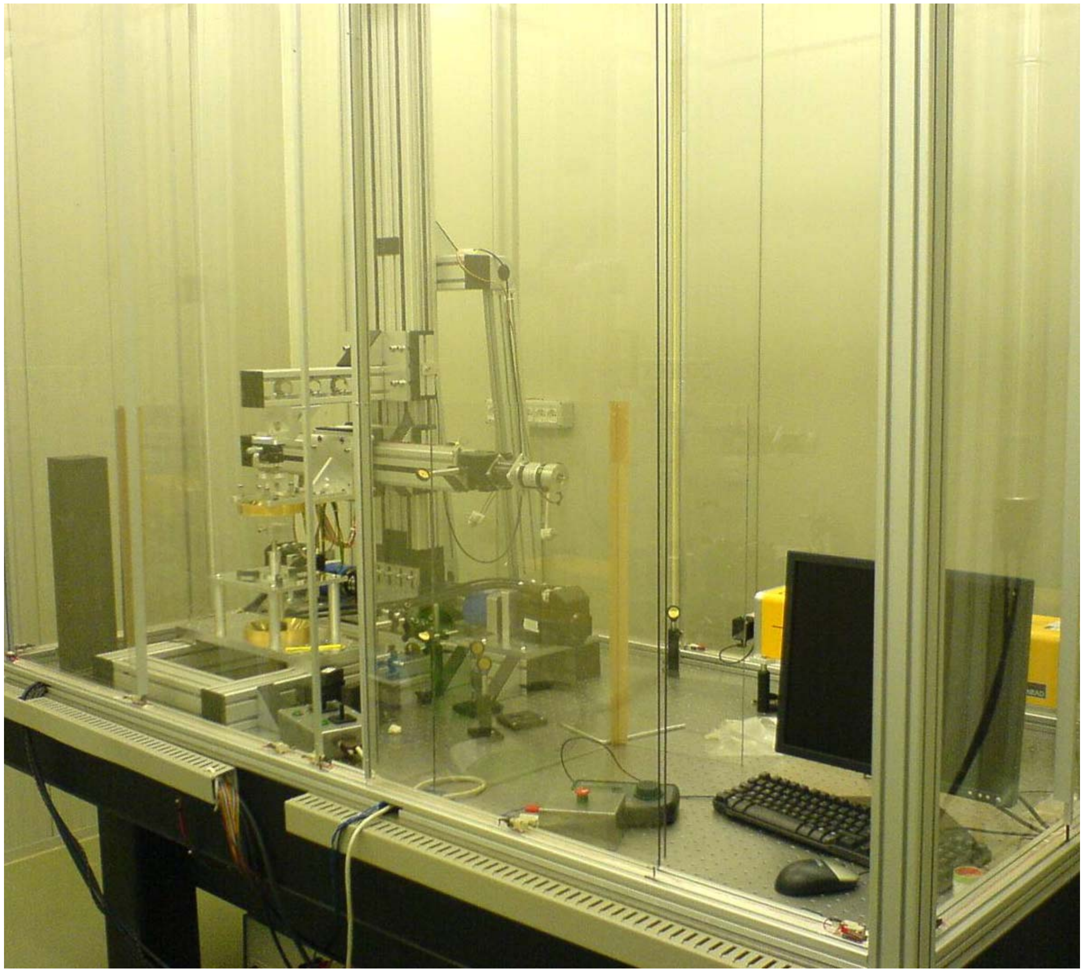
GEO 600

IGR

# Virgo laser pulling machine installation



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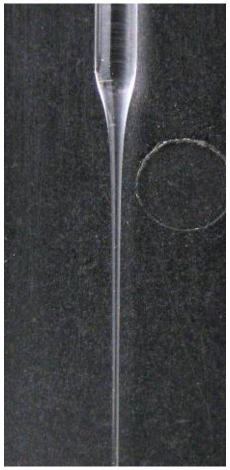
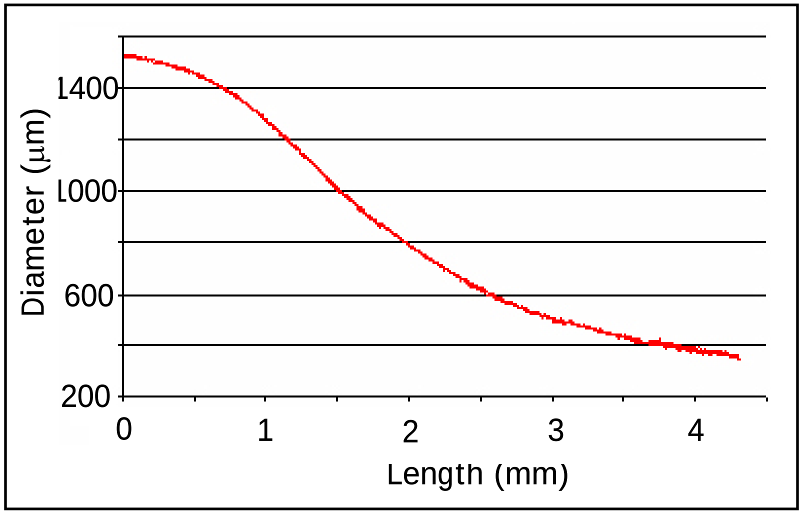
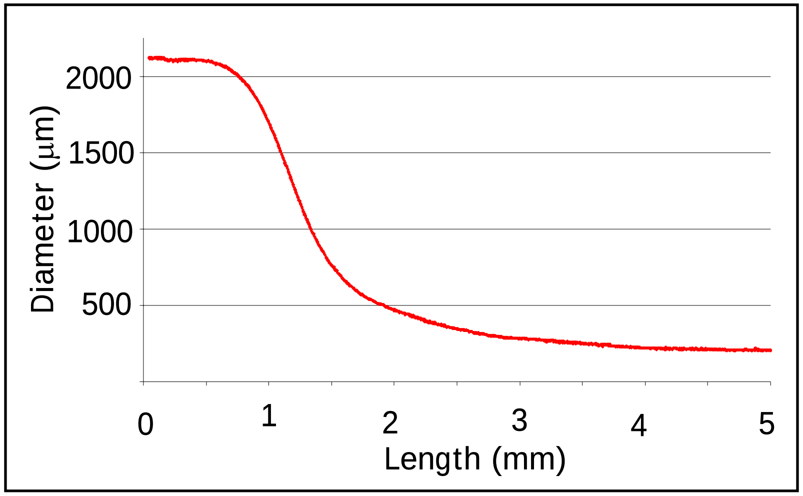
# Controlled shaping of the neck



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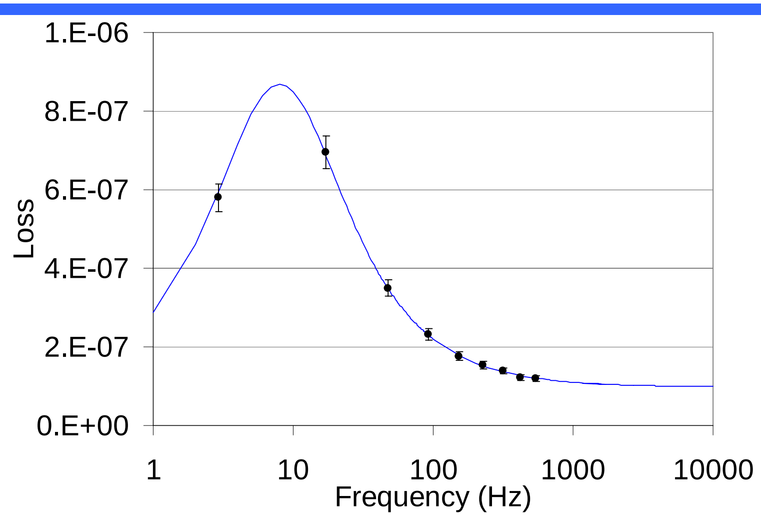
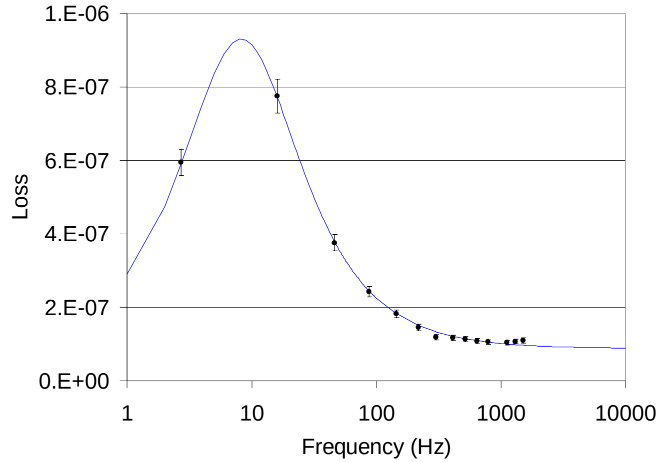
# Mechanical loss in $CO_2$ laser pulled fibres




- Four Suprasil 300 fibres of diameter ~470μm were measured
- Initial analysis of losses shows a surface loss consistent with:

$$h\phi_{surface} = 4.7\times10^{-12}\,\mathrm{m}$$

- From Penn et al we can calculate values:

for suprasil 2 $$h\phi_{surface} = 6.05\times10^{-12}\,\mathrm{m}$$

for suprasil 312 $$h\phi_{surface} = 3.25\times10^{-12}\,\mathrm{m}$$

- Suprasil 300 is not necessarily expected to be similar to 312 or 311 as it has a different manufacturing process and a lower OH content

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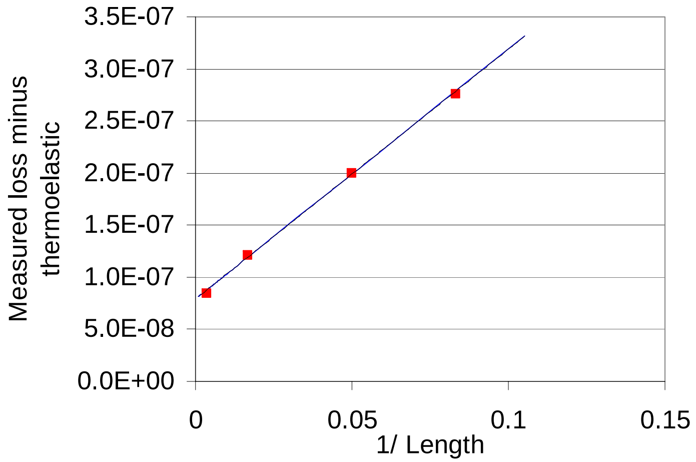
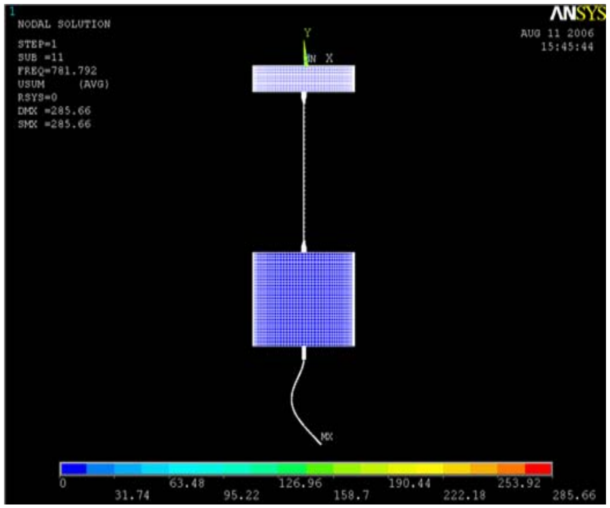
# Where does dissipation arise in our material?

- In order to reduce thermal noise we need to reduce dissipation.
- To do this we must first understand where it arises.
- Loss in fused silica is normally split into two categories
  - Bulk    A very low level dissipation in the body of the material recently shown to be due to the residual effects of dissipation due to a two level system
  - Surface    A much higher level of dissipation in the damaged surface layer
- The dominant loss mechanism depends on surface to volume ratio.
- This can now be controlled to a level acceptable for next generation detectors
- However a better understanding of the physics of these loss mechanisms is needed to reduce thermal noise for future detectors

# Recent measurements at Glasgow (1)

- Loss measurements made on laser pulled fused silica fibres have shown a length dependence to dissipation
- This is consistent with a source of loss close to the top of the fibre
- This has been shown analytically and using finite element modelling
- Source of loss thought to be due to welding
- This is a previously unknown source of loss – highly relevant for development of detector suspensions

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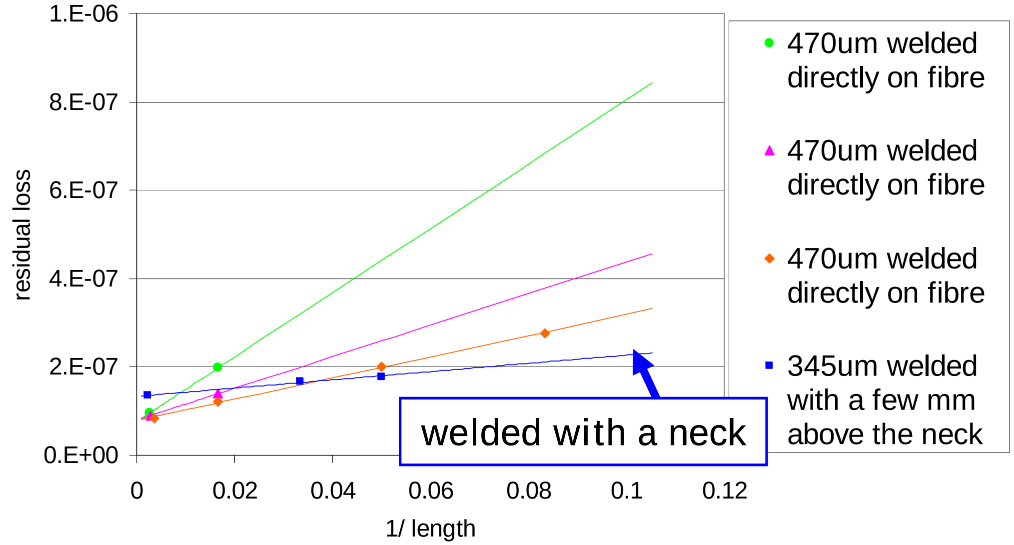
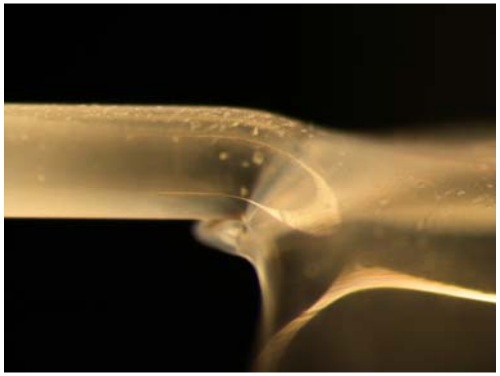
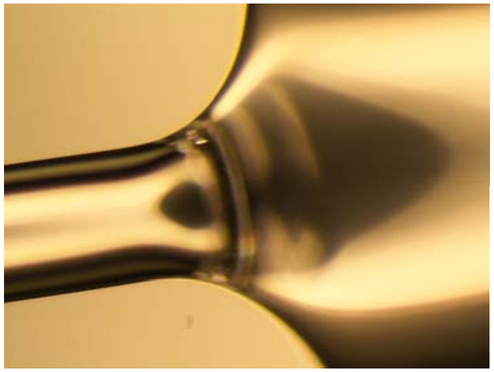
# Recent measurements at Glasgow (2)

- Each weld gives different value for loss
- When viewed under a microscope possible loss mechanisms can be seen
- Fibre attached using thick neck shows lowest loss as less energy stored in weld





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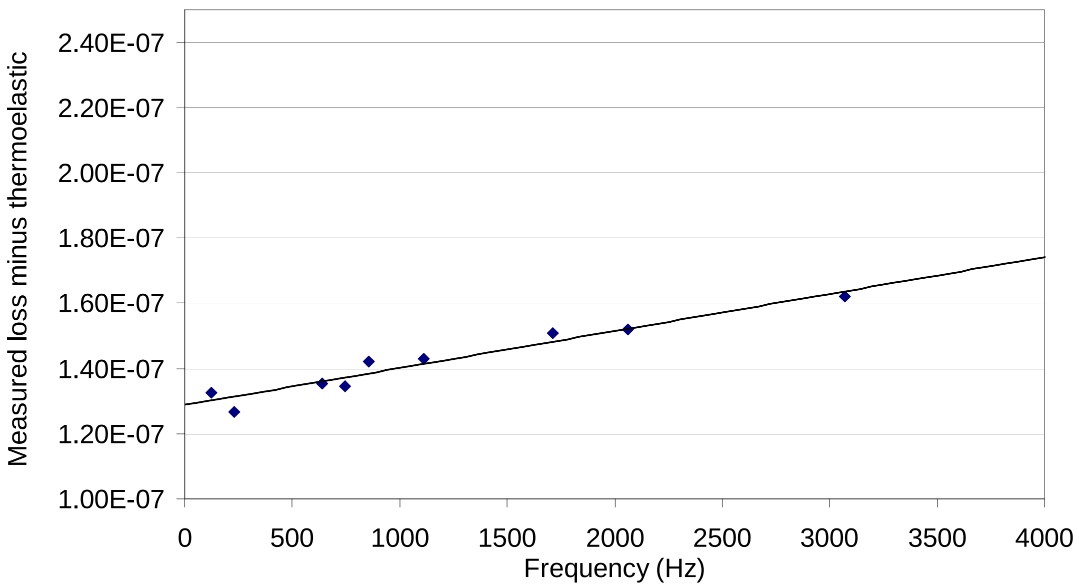
# Recent measurements at Glasgow (3)

- Analysis of dissipation in fibres has shown evidence of a frequency dependent bulk loss seen at a higher than expected level
- Approximately 10 times that seen in bulk samples
- At higher frequencies this contributes as much as 25% of loss

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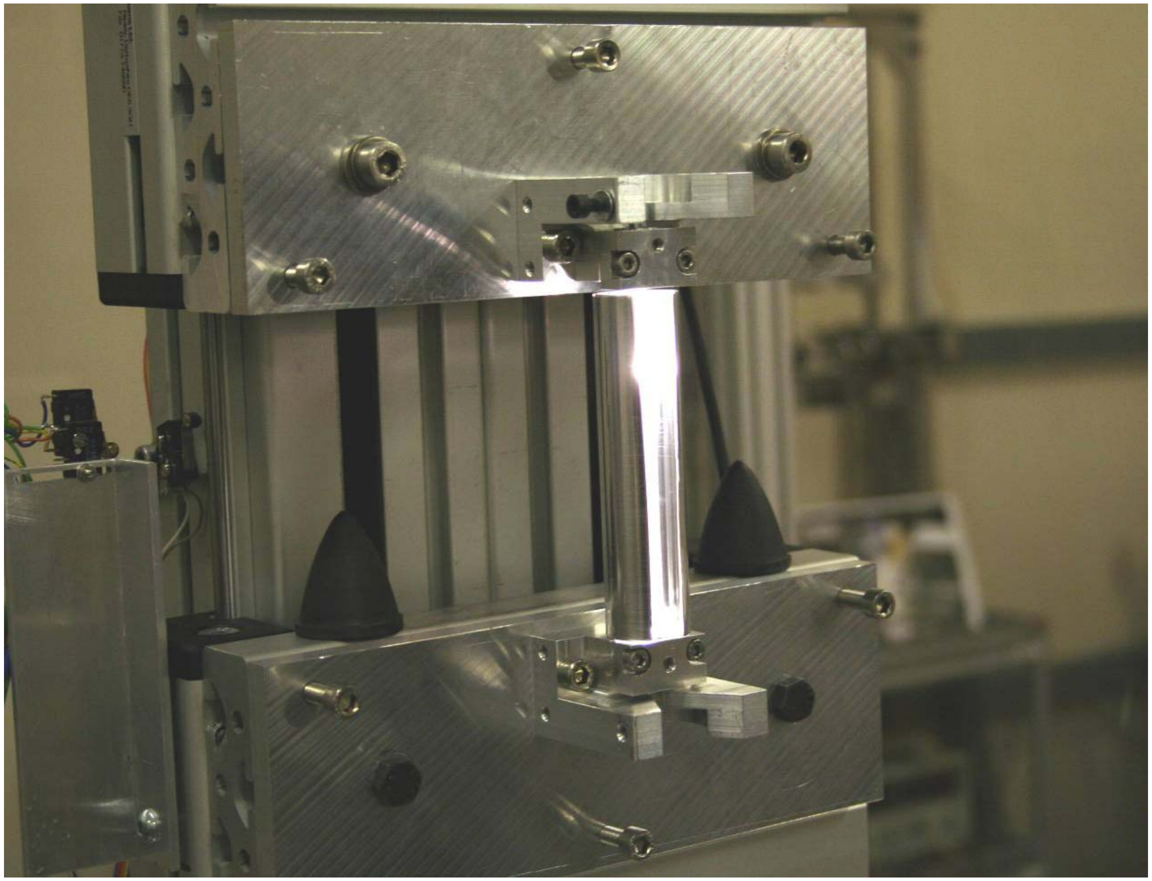
# Ribbon fibre development



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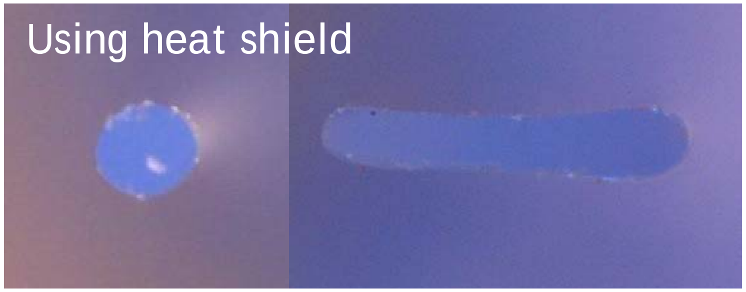
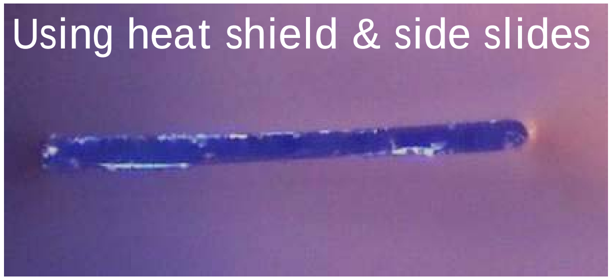
# Ribbon cross-sectional shape development

- First ribbon fibres pulled had a non-rectangular cross-section due to heat loss from edges.
- Laser was run at close to maximum power due to heat loss.
- Polished aluminium heat shield was developed to reflect heat back at edges.
- Further improvements to the symmetry of the fibre neck and cross section were achieved by using slides on either side to reduce the edge effects.
- Laser stabilisation has been significantly improved
  - Fast sensor
  - Wedged Brewster window for pick-off
- Profile of pull has been investigated to create good shapes for the neck regions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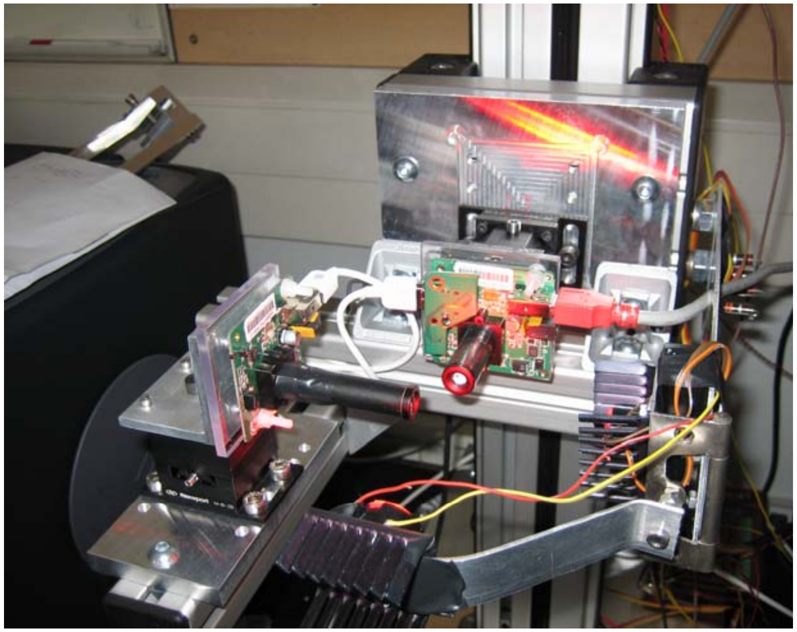
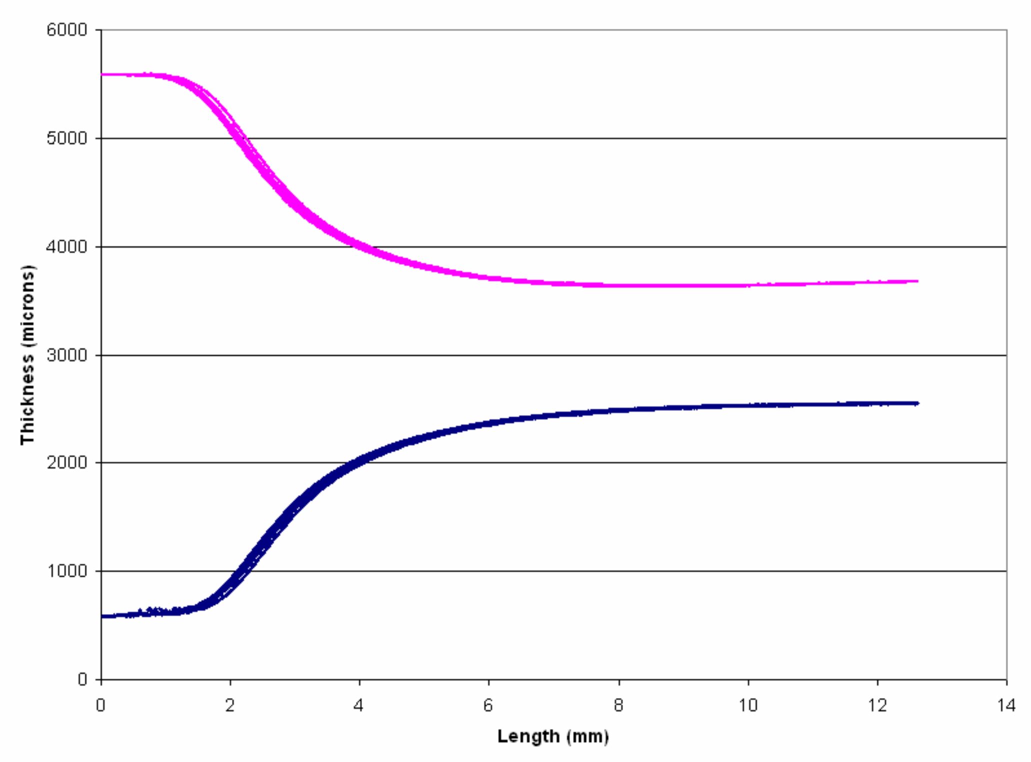
# Profiling of ribbon dimensions



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# Strength and bounce frequency testing

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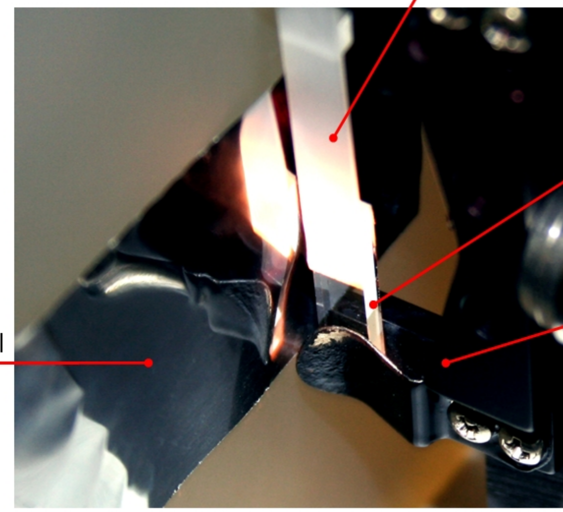
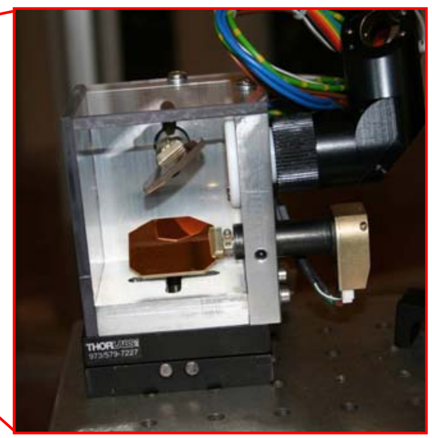
# Welding technology



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# Bonding test mass ears at LASTI (1)

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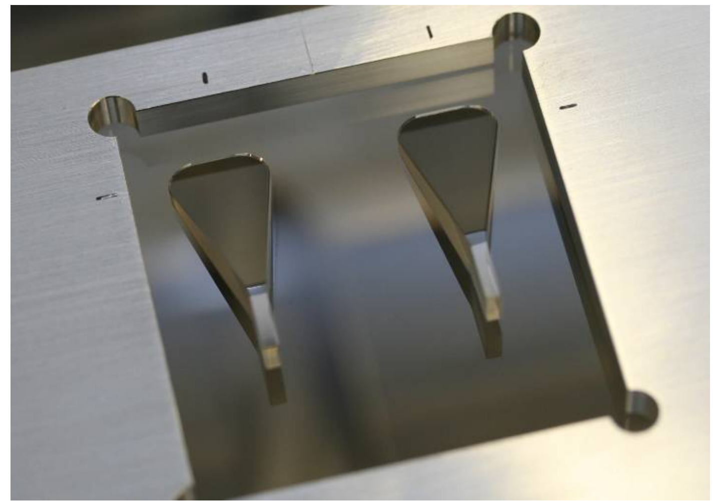
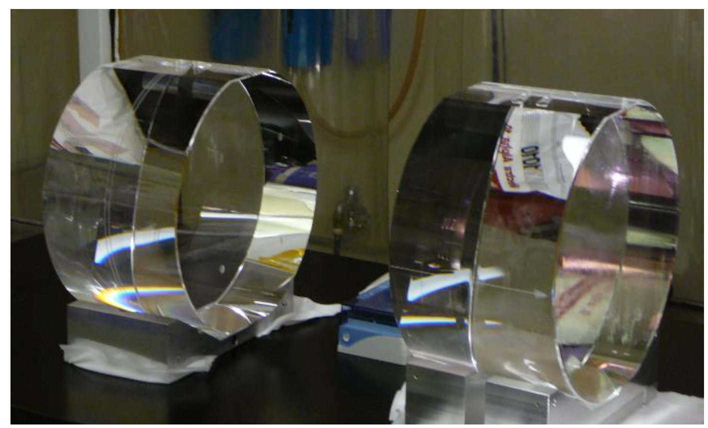
# Bonding test mass ears at LASTI (2)





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# Conclusions

- Based on the experience of the flame pulling machines used for the GEO600 suspensions we have designed and built new fibre pulling machines using $CO_2$ lasers
- Laser pulled cylindrical fibres have a surface loss at a similar level to flame pulled fibres
- Data shows evidence of length dependent loss which appears to be related to the quality of weld
- There is strong evidence of frequency dependence in residual loss of fibres studied
- This appears to arise due to dissipation in the bulk of the fibre material but at a higher level of loss than is seen for larger ‘bulk’ samples
- Both the above effects need included in any model of suspension thermal noise in monolithic silica suspensions
- Further studies in progress
- The construction of the monolithic pendulum stage for LASTI has begun, with successful bonding of the ears to both the penultimate and test masses