Progress on the monolithic suspension work in Glasgow and at MIT since April 2009

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On behalf of the monolithic suspension team

NSF Review, Livingston (Louisiana), 14th – 16th April 2010

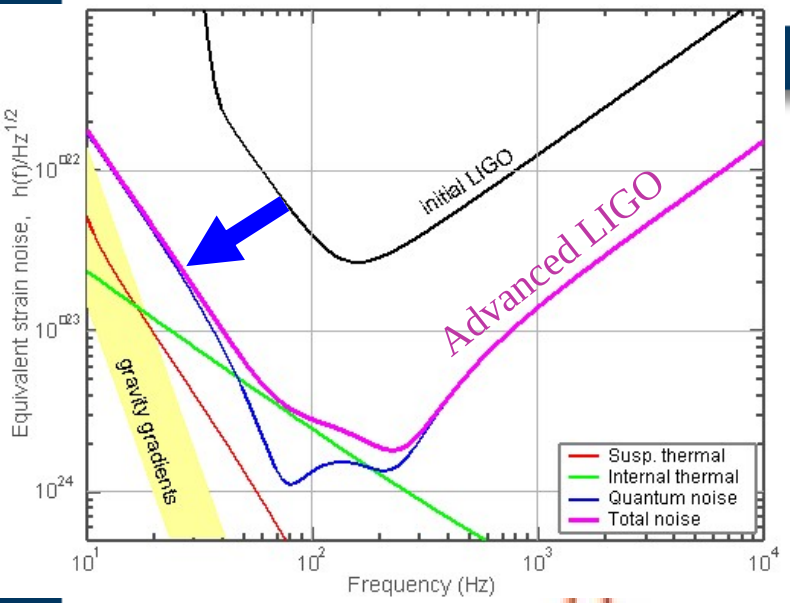
LIGO-G1000436-v3

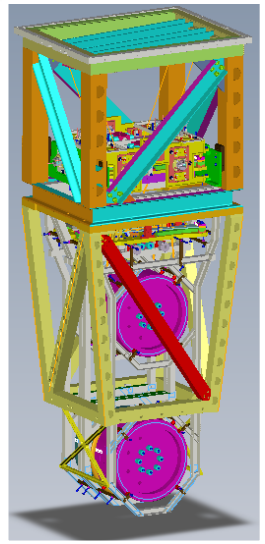
Overview of the presentation

- Introduction to the monolithic suspension
- Monolithic suspension procedure
- Overview of test suspension work in the past year
- Some images of the preparation of the monolithic suspension in April 2010
- Current schedule towards monolithic suspension at MIT

University of Glasgow

Quadruple suspension





- The input test masses (ITM) and end test masses (ETM) of Advanced LIGO will be suspended via a quadruple pendulum system

IGR

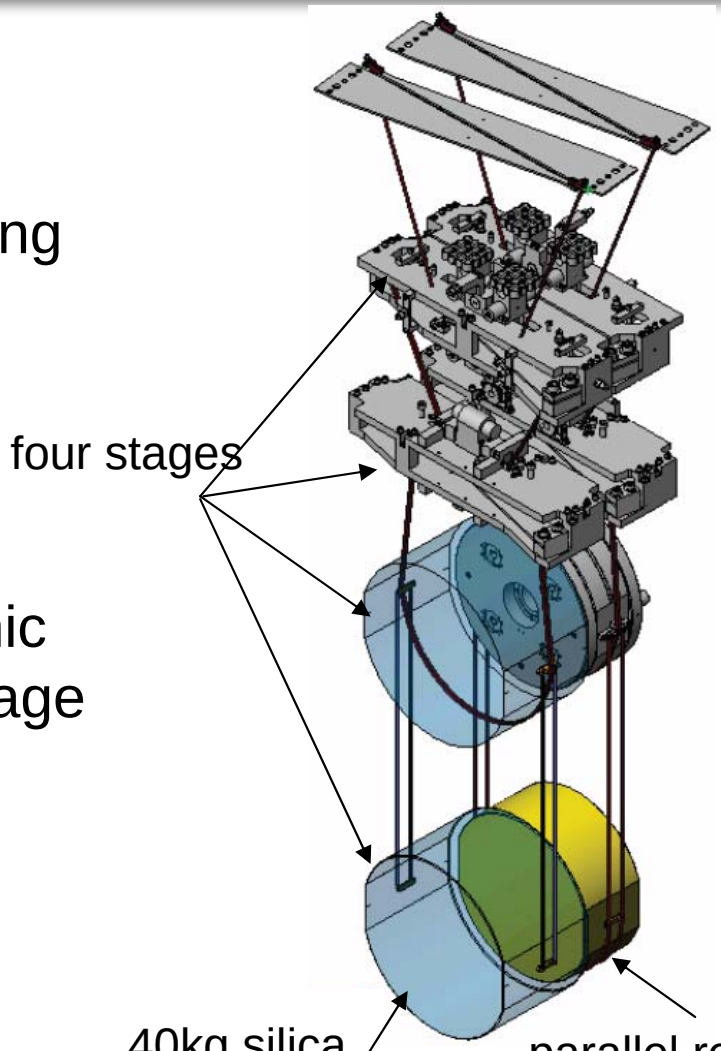
SUPA

16t

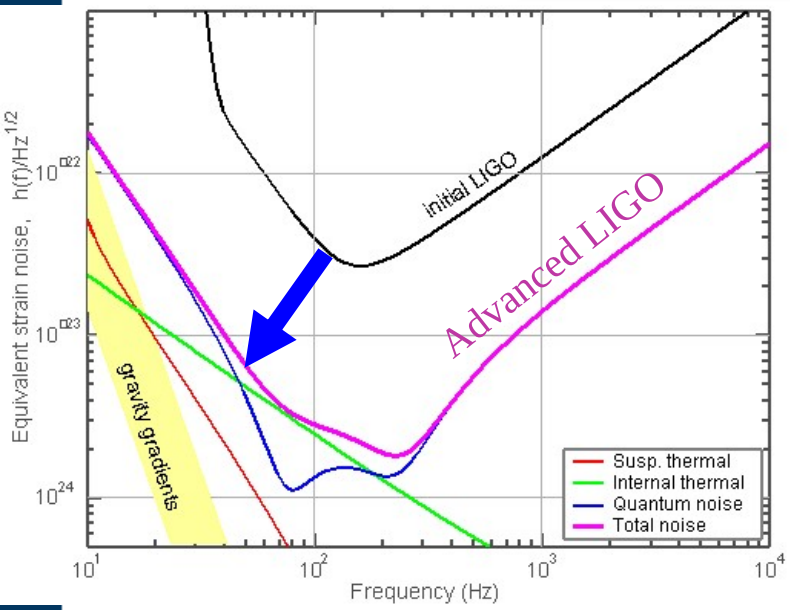
Quadruple suspension

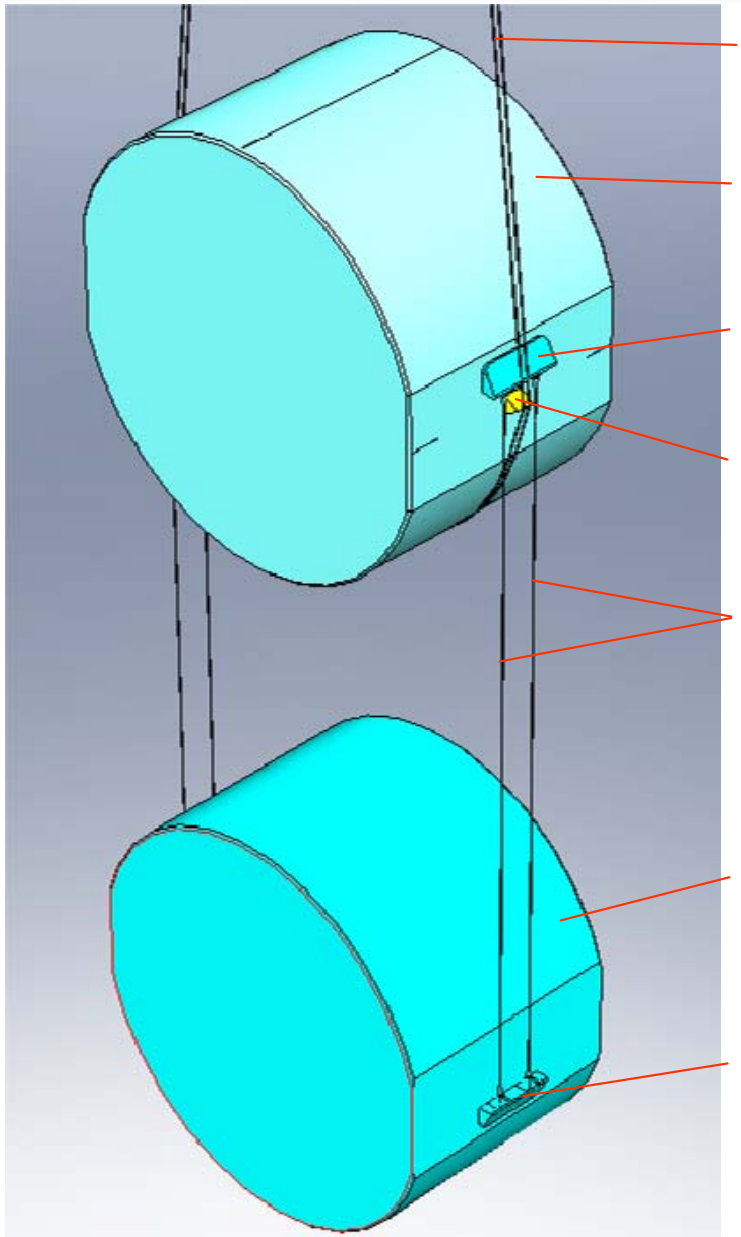
- Seismic isolation: use quadruple pendulum with 3 stages of maraging steel blades for enhanced vertical isolation

- Thermal noise reduction: monolithic fused silica suspension as final stage - low pendulum thermal noise and preservation of high mirror quality factor
  - *silica fibre loss angle ~ $3 \cdot 10^{-7}$,*
  - *c.f. steel ~$2 \cdot 10^{-4}$*



Monolithic final stage of the quadruple suspension





Monolithic suspension procedure

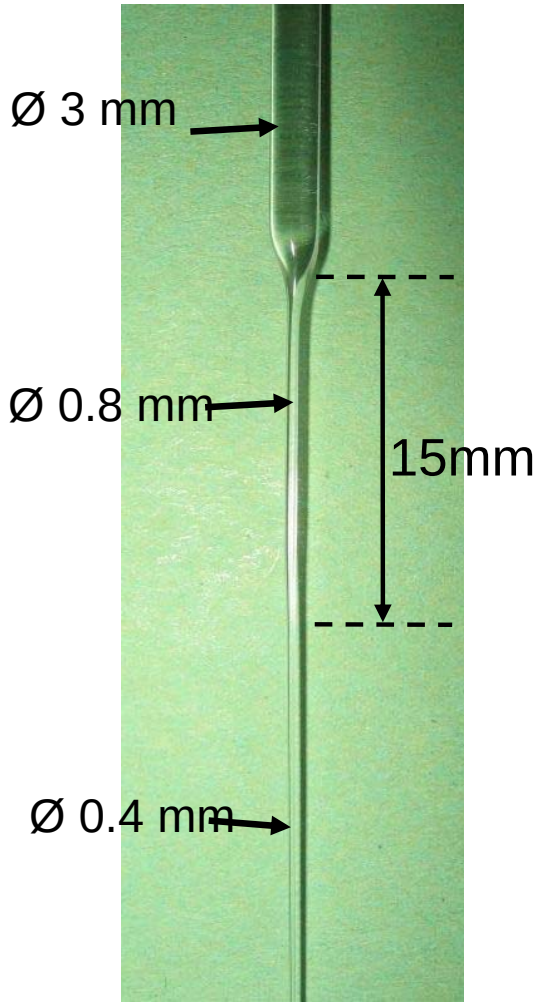
3 main stages

- Preparing masses by hydroxide catalysis bonding of the ears to:
  - the test mass and
  - the penultimate mass
- Manufacturing of the fibres
  - fabricate by laser pulling
  - Characterisation (profiling, bounce test, proof test)
- Installation of fibres using laser welding

Monolithic suspension procedure (2)

Manufacturing and characterising the fibres

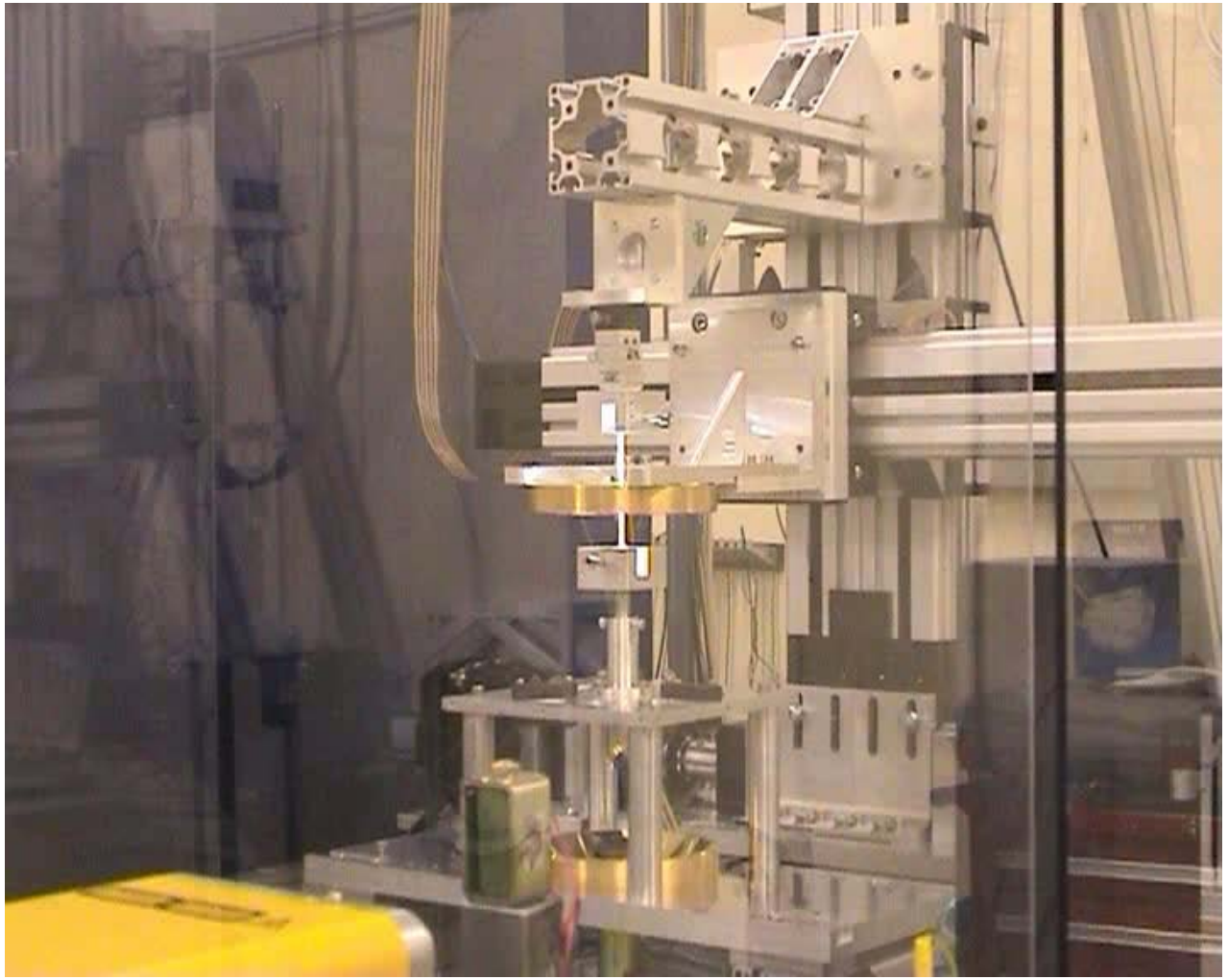
- Pull fibres with a laser pulling machine
  - Dumbbell shape for thermo-elastic noise optimisation*



*Cumming et al. Classical and Quantum Gravity 26 (2009) 215012

Monolithic suspension procedure (3)

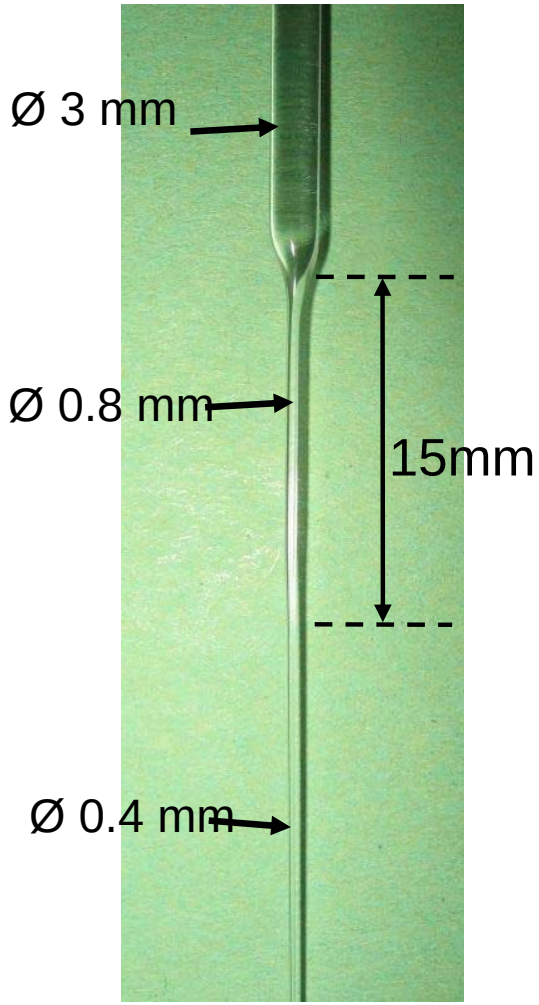
Manufacturing and proof testing fibres



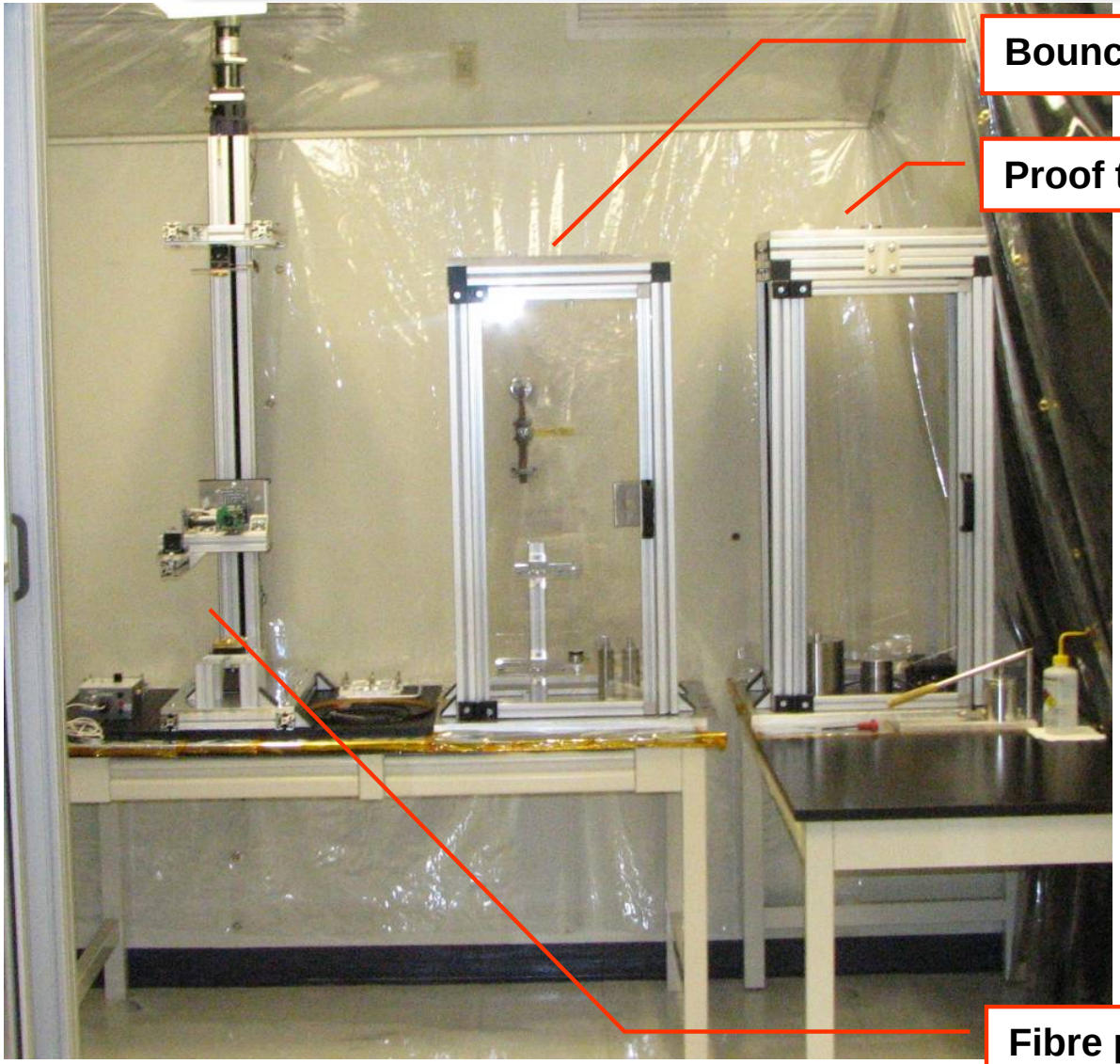
Monolithic suspension procedure (4)

Manufacturing and characterising the fibres

- Pull fibres with a laser pulling machine
  - Dumbbell shape for thermo-elastic noise optimisation
- Proof test fibres
  - Load fibres with 15 kg for 5 min
- Measure the fibre profile
- Bounce test fibres
  - To determine the bounce frequency and therefore the stiffness of the fibres



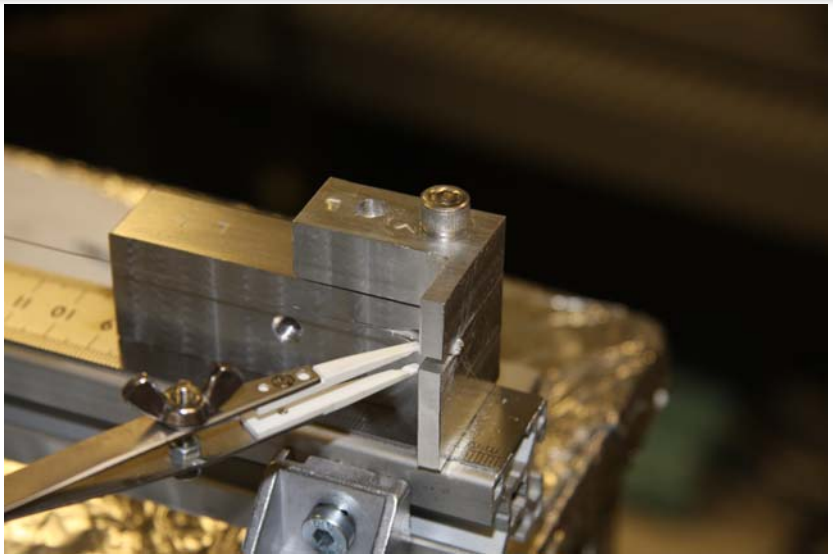
Monolithic suspension tooling

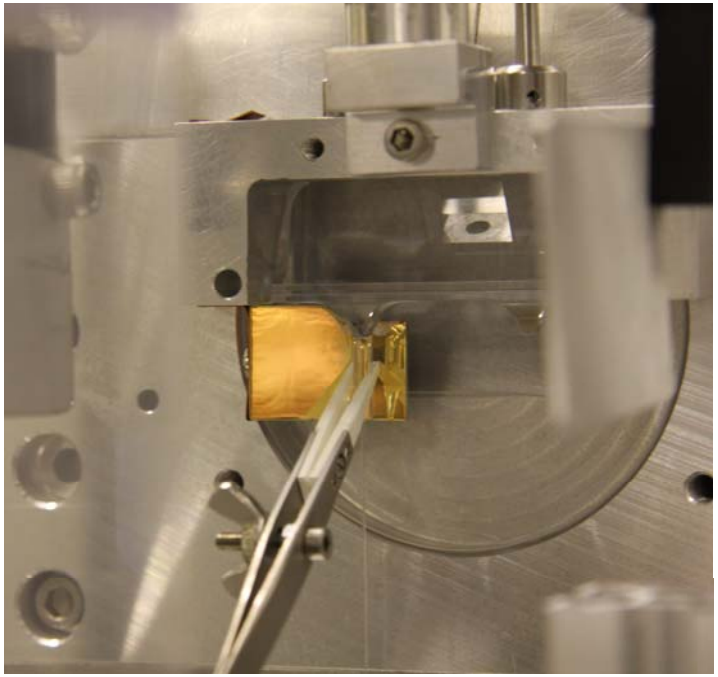


Monolithic suspension procedure (5)

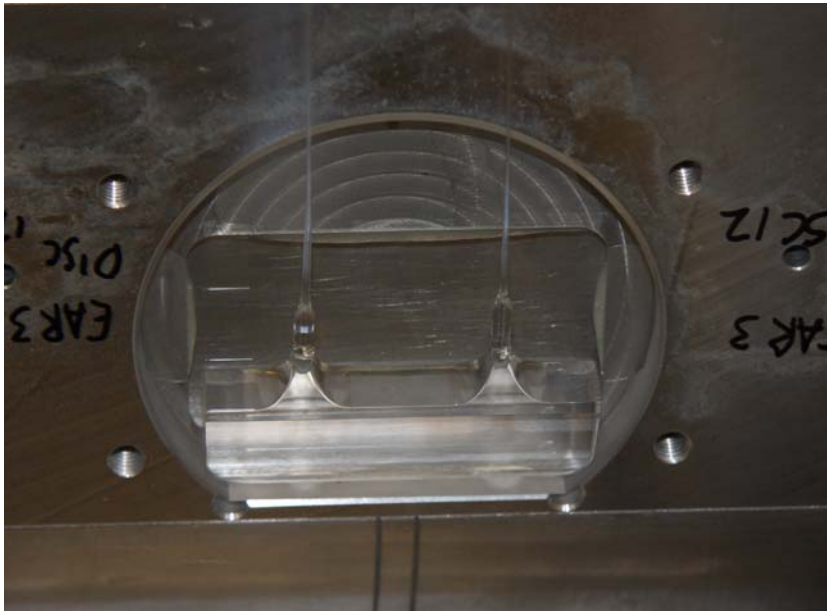
Some steps involved in welding in fibres

Cutting the fibre to length





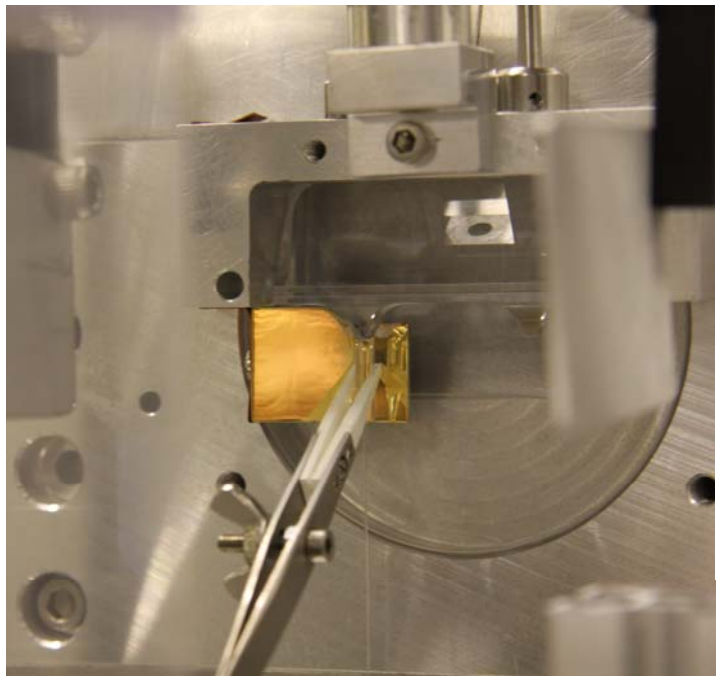
Still holding the fibre just after welding



2 fibres welded onto an ear

Monolithic suspension procedure (6)

Some steps involved in welding in fibres



Still holding the fibre just after welding

Vapour extraction pipe in place

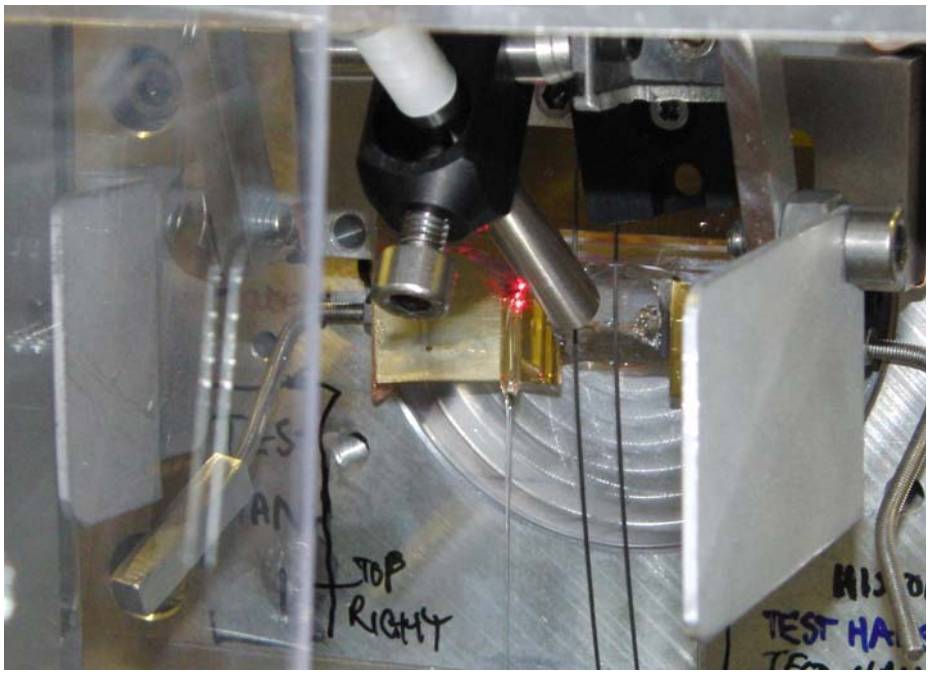
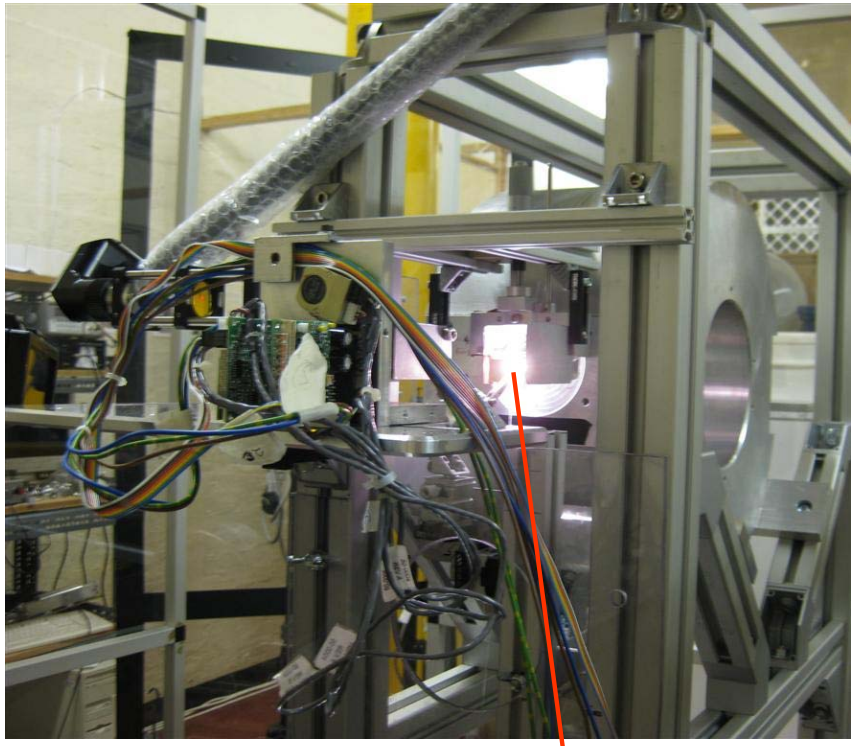


Image taken during stress relief and annealing stage for removing surface damage

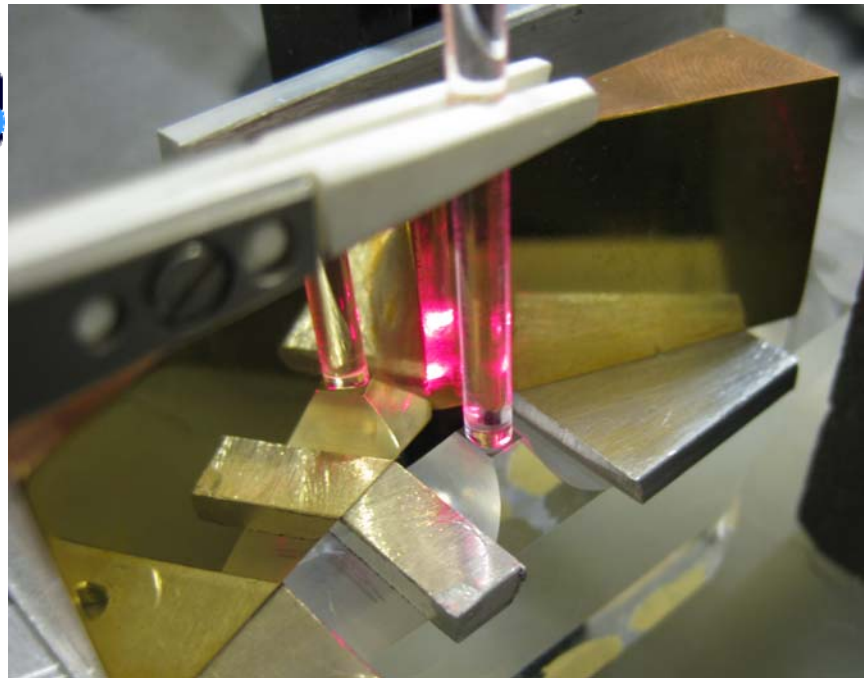
Monolithic suspension procedure (7)

Installation of fibres

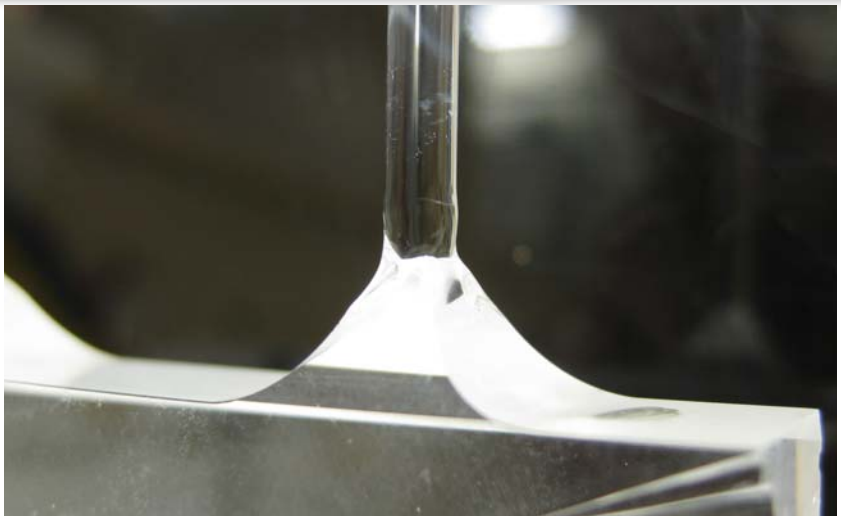


Status April 2009: 1 year ago

Just welded silica stock onto an ear



Welding mirrors behind ear horn



Welded ear

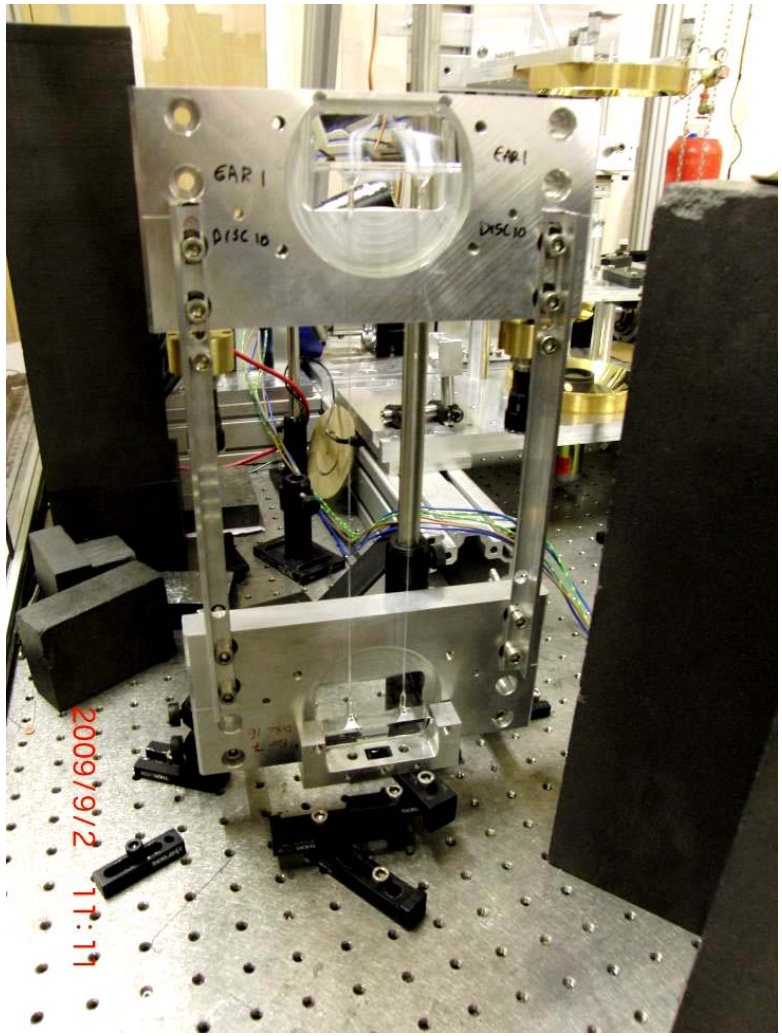
Since April 2009 …

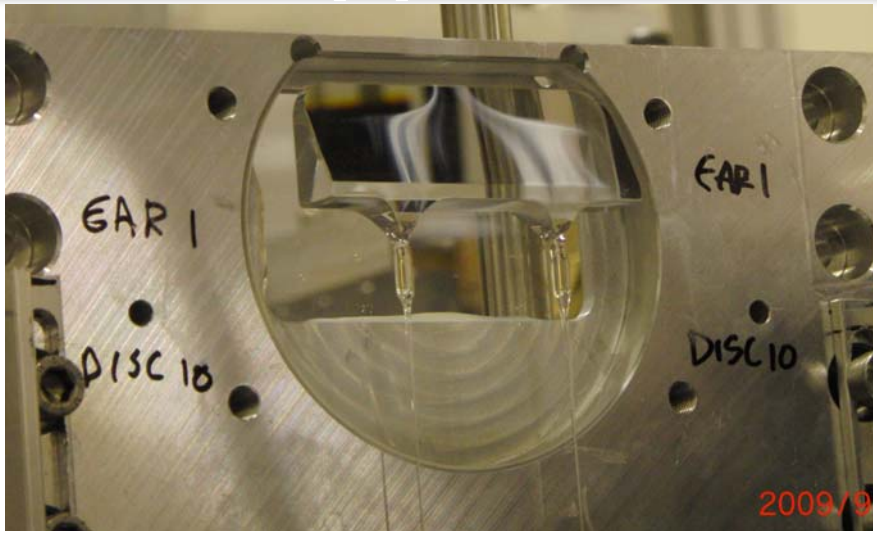
Task	May	Jun	Jul	Aug	Sep	Oct
Double fibre weld strength tests to actual ears	■				■	
1st full test suspension in Glasgow (successful, 2nd June)		■				
Preparations test suspensions LASTI			■			
2 test suspensions at LASTI (not successful)				■		
5 full test suspensions Glasgow + experiments					■	■

Since November 2009 …

Task	Nov	Dec	Jan	Feb	Mar	Apr
5 full test suspensions Glasgow + experiments (all successful)	■	■				
Preparations for test suspensions at LASTI			■			
2 full test suspensions LASTI (both successful)				■ ■		
Monolithic suspension LASTI preparations					■	■ ■
1 full test suspensions Glasgow					■	■ ■

Double fibre weld tests (1)

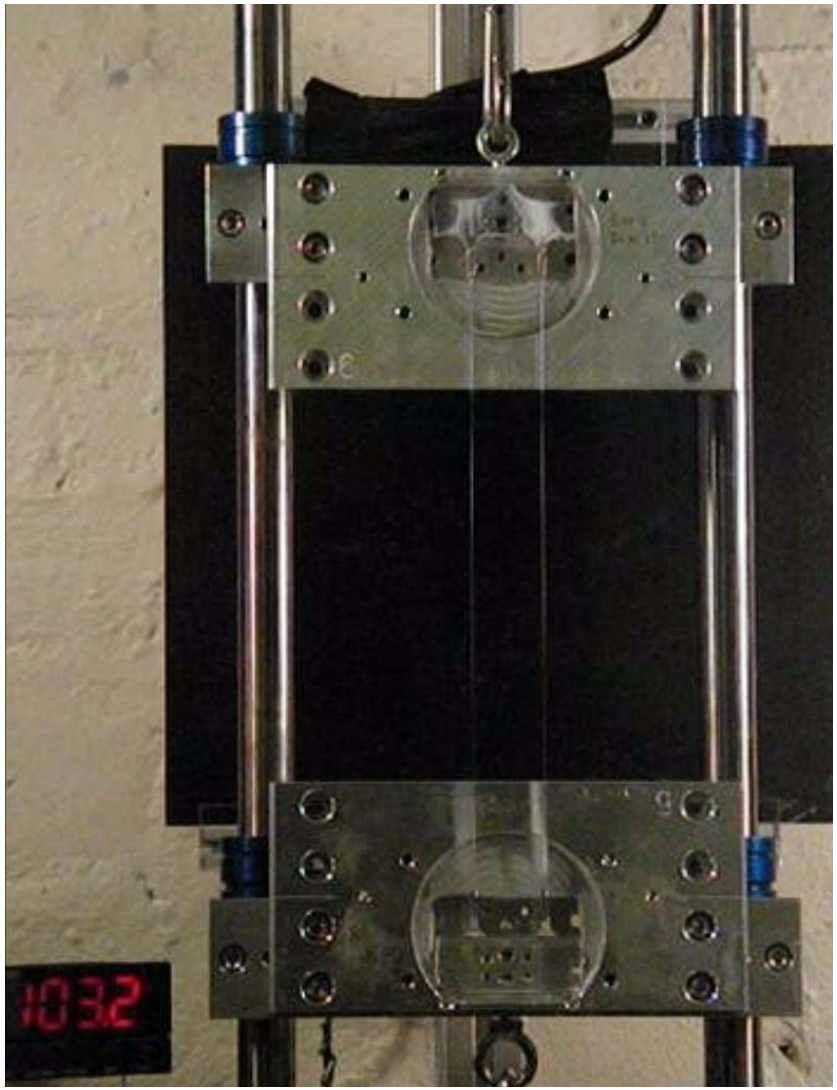




Top ear with welded fibres

2 fibres welded to ears in disc inserts on a double cartridge

Double fibre weld tests (2)

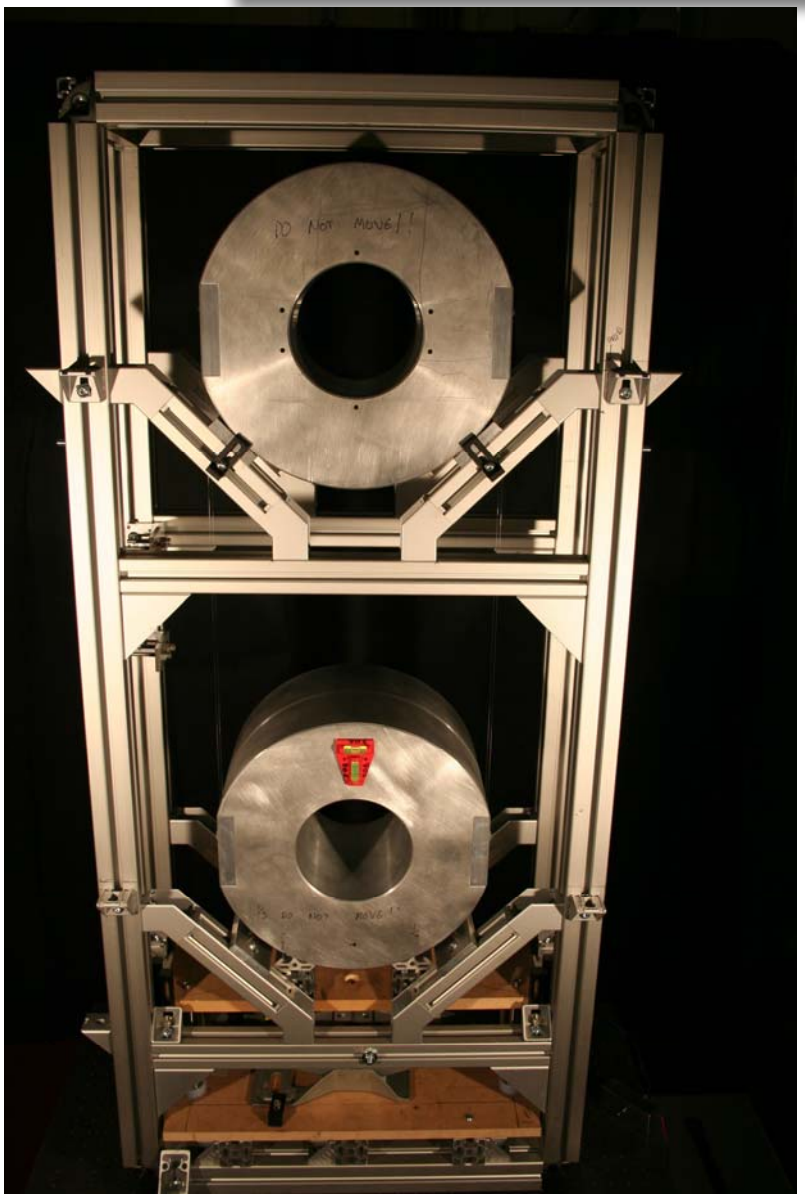


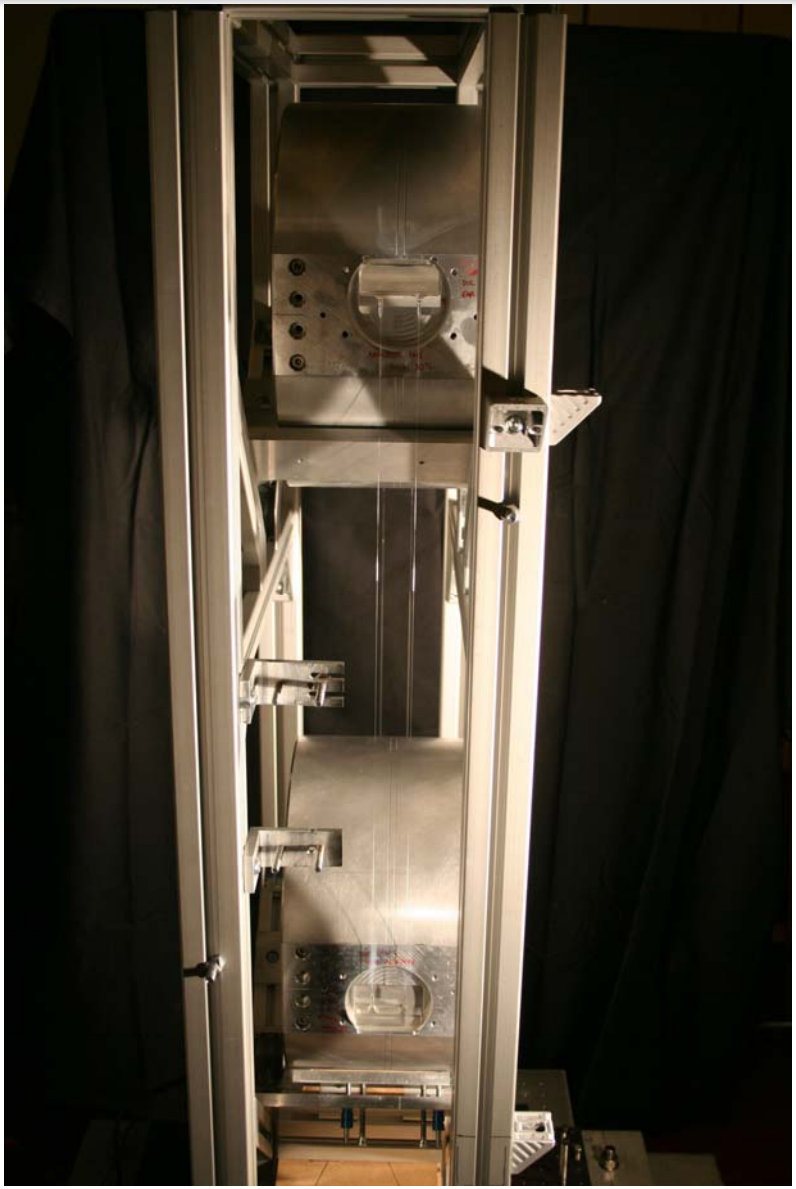
Results of double fibre tests (nominal load for 1 fibre = 10 kg)

Strength test of double fibre just before break at 103 kg

1st Full test suspension Glasgow (1)

Successful!





1st Full test suspension Glasgow (2)

Successful!

1st Full test suspension Glasgow (3)

Successful!

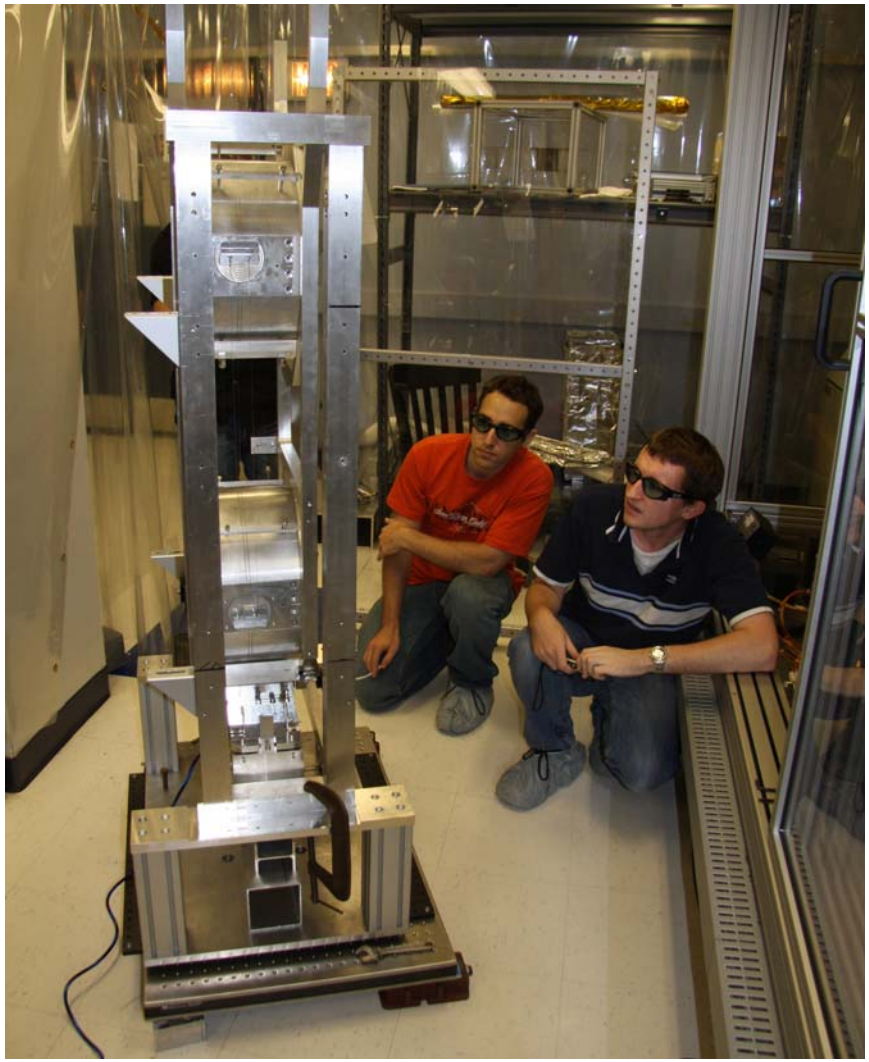
- First 40 kg test mock ‘monolithic’ suspension was successfully accomplished in Glasgow on the 2nd of June
- It was suspended for 2 weeks and then intentionally broken
- Experiments have been conducted to measure the resonances of the suspension

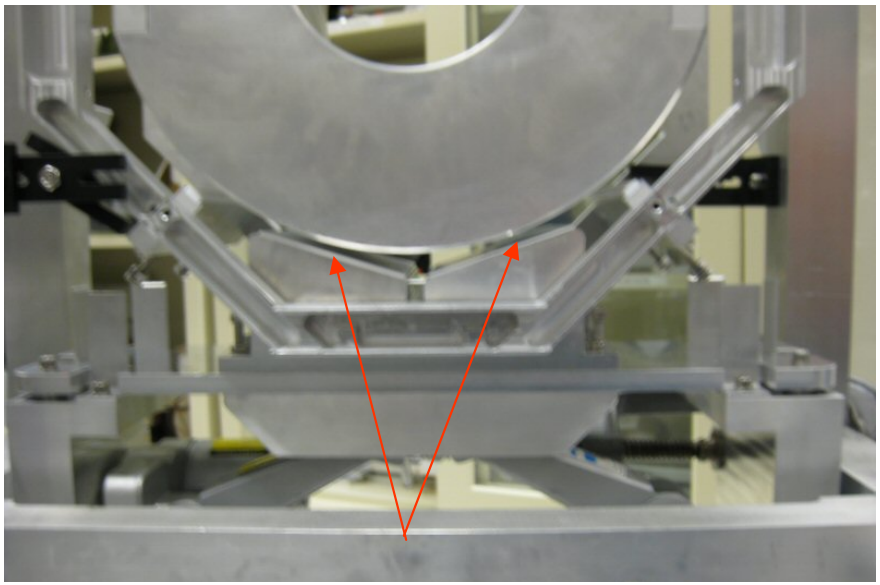
Mode	Modelled frequency (ANSYS) [Hz]	Measured frequency [Hz]
Pendulum	0.65	0.64
Pitch	1.09	1.03
Yaw	1.09	1.08
Bounce	7.00	6.42
Violin	452.2	452.6, 450.9, 453.4, 450.5

Two test suspensions at LASTI

Unsuccessful

Brett and Alan are waiting to see if the first test suspension works





It was suspended for ~1 minute, but then failed …

Second suspension failed during loading

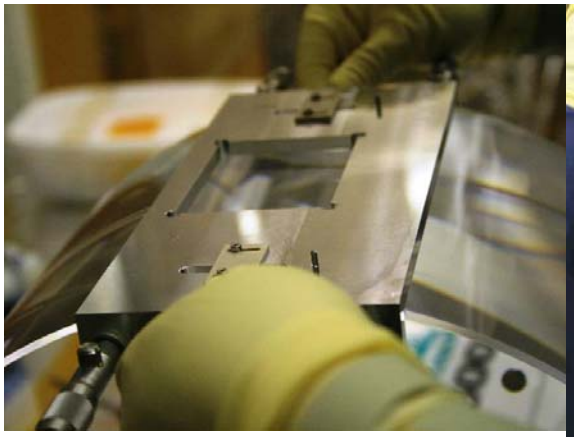
Likely causes: touched fibre, possibly chipped ear, but mainly procedures needed further development and care

Successful full test suspensions

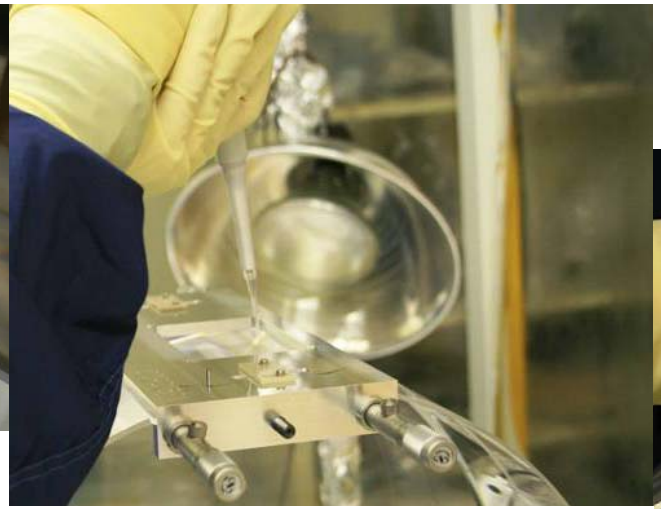
We have made 7 successful full test suspensions in Glasgow and 2 at MIT:

- Perfecting the procedure a bit more every time
  - Fibre preparation procedure – reducing risk
  - Improvements on the weld tooling
- Making measurements of modal frequencies
- Subjecting the suspensions to high loading conditions:
  - Shake and mallet tests (shake, roll, bounce)
  - Shock tests
  - Transportation of locked down suspension both in Glasgow and at MIT

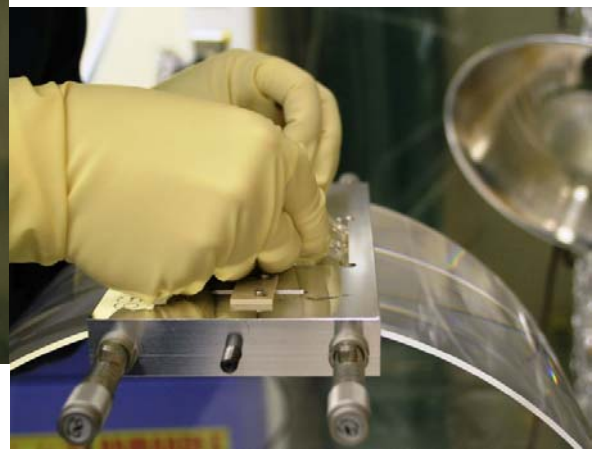
Preparations for the monolithic suspension at LASTI – bonding ears and prisms



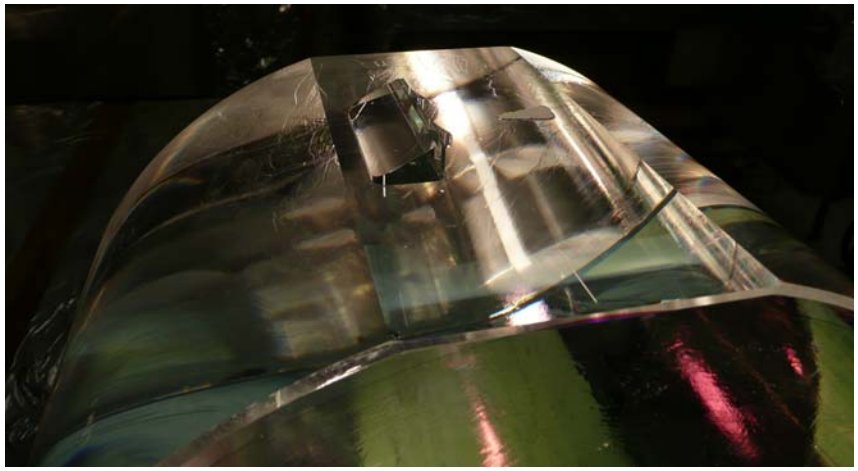
Placing bonding jig



Applying bonding solution

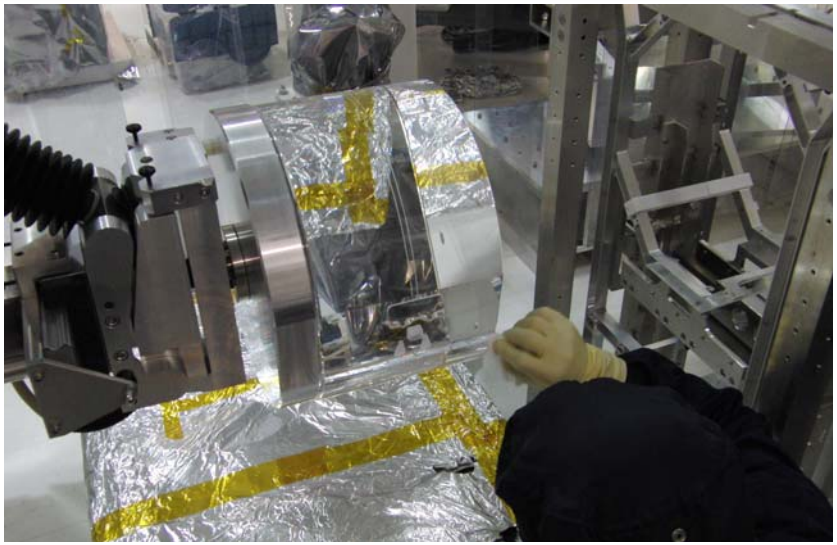


Aligning the ear



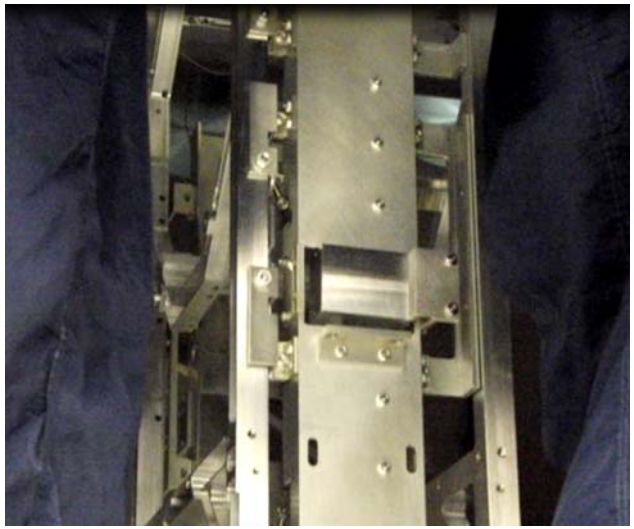
Ear bonded to test mass

Preparations for the monolithic suspension at LASTI – setting up masses and pulling fibres



Inserting penultimate mass into the structure

Masses inserted into the main chain



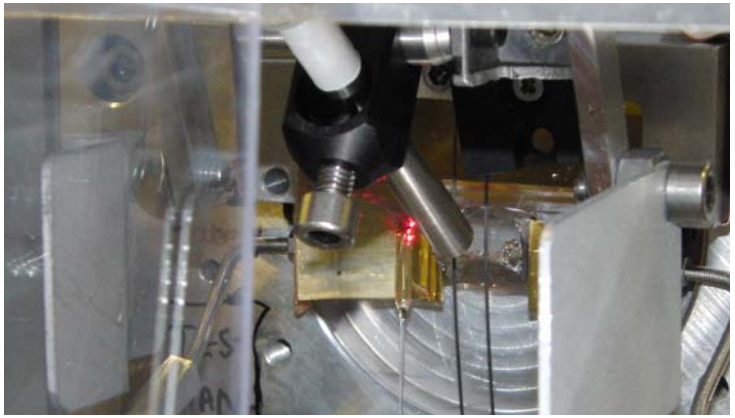
Testing inserting the chains into the vacuum tank

Fibre guard

Latest test suspension in Glasgow

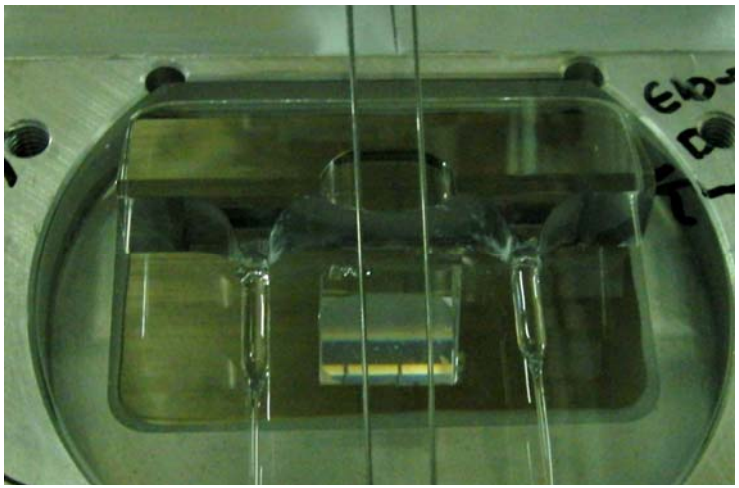
- with vapour extraction and full clean room gear

Inserting fibre bow in full clean room gear



Vapour extraction still in place after welding

Welding with face mask and goggles



Almost no vapour deposited on top ear

Conclusions

- We have made 11 test suspension tests of which 9 were successful including 2 suspensions at LASTI
- We have learned that:
  - Fibre and welding preparation through a well thought through procedure is the key to success
  - Only people experienced enough should get close
  - Once the suspension has been welded and suspended it is very robust
- We are now preparing for the monolithic prototype suspension which is scheduled for May
- After that a final design review will follow and the UK will continue to provide support

Next 6 months

Task	May	Jun	Jul	Aug	Sep	Oct
Welding monolithic suspension and insertion into BSC	■					
Preparation for and actual final design review monolithic	→	→	→	→		
Training LIGO personnel			■	■		
Support to LIGO for installation first monolithic suspensions					■	■