Design and thermal noise modelling of cryogenic sapphire suspension for KAGRA detector

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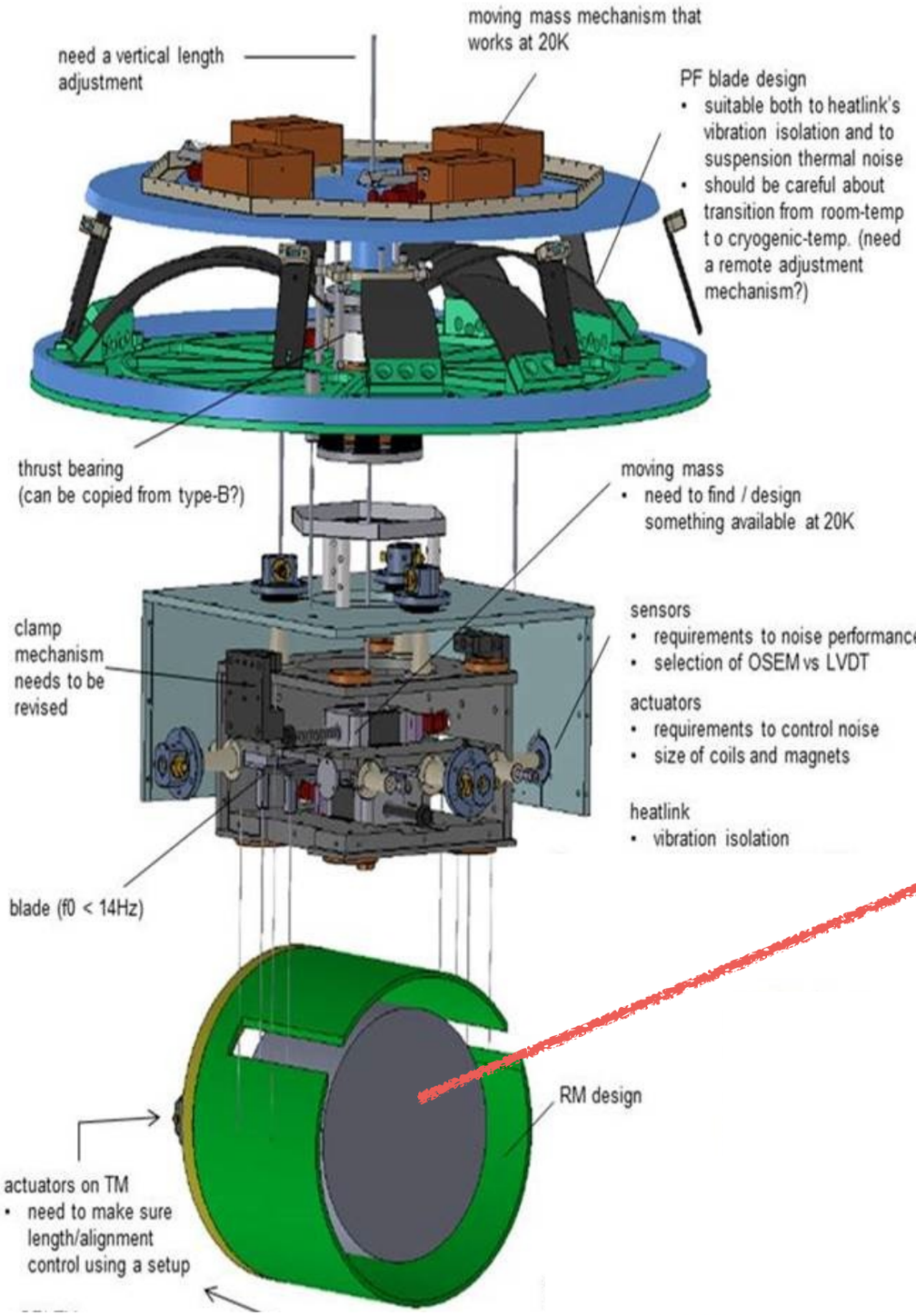
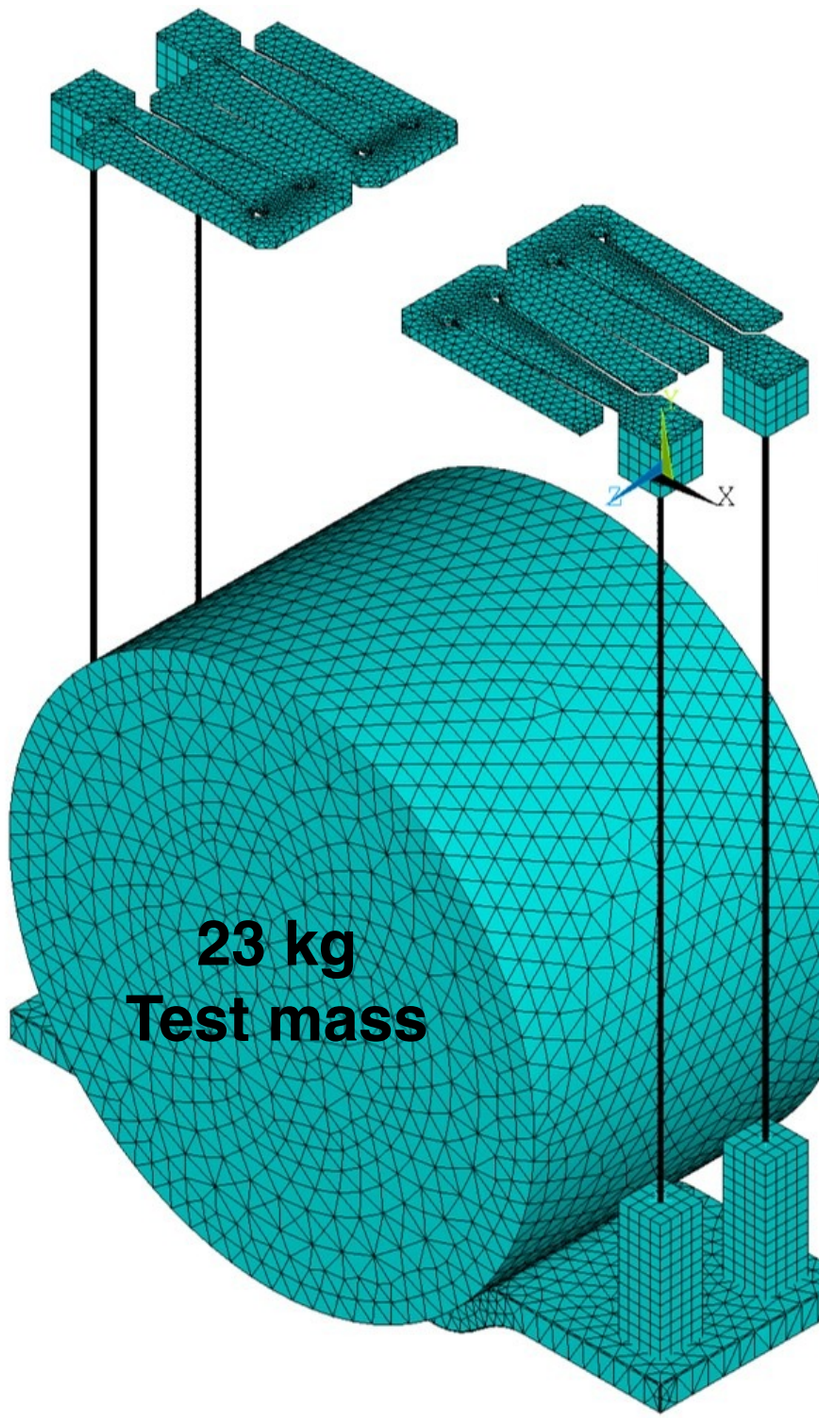
Outline

- Layout of the cryogenic payload
- Cradle suspension
- Sapphire blade springs
- Thermal noise modelling (FEA)
- Ongoing/future work
- Conclusions

Cryogenic payload





Sapphire fibre
length 300 mm
diameter 1.6 mm

Cradle suspension (prototype)

- Plan to fabricate the first prototype cryogenic payload system in ICRR (in 2014)

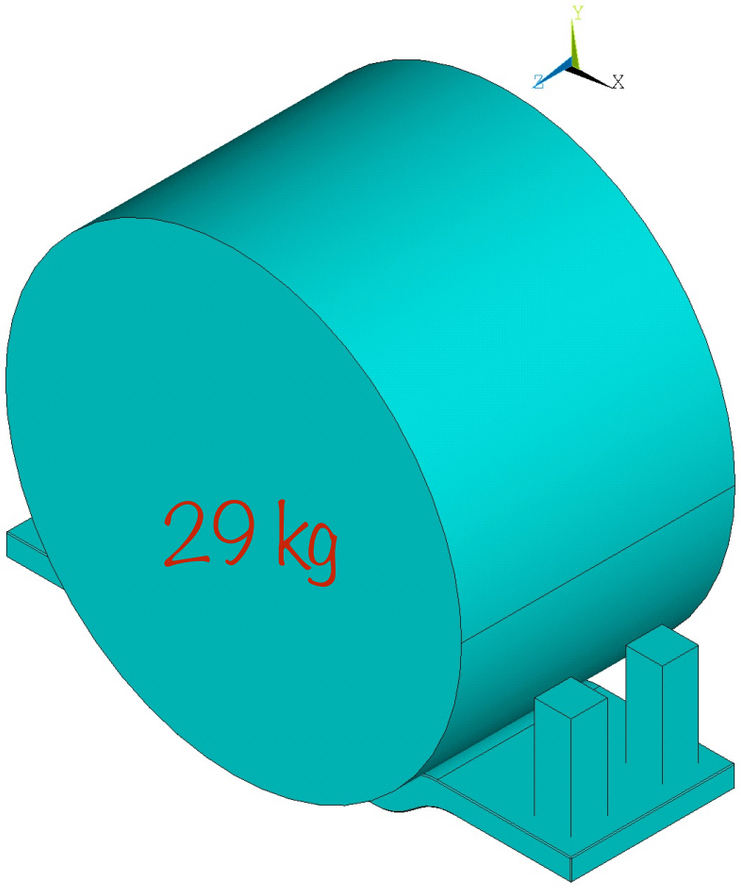
- Cradle suspension is the first phase towards the final design

- Includes sapphire fibres, sapphire cradle test mass and sapphire blade springs

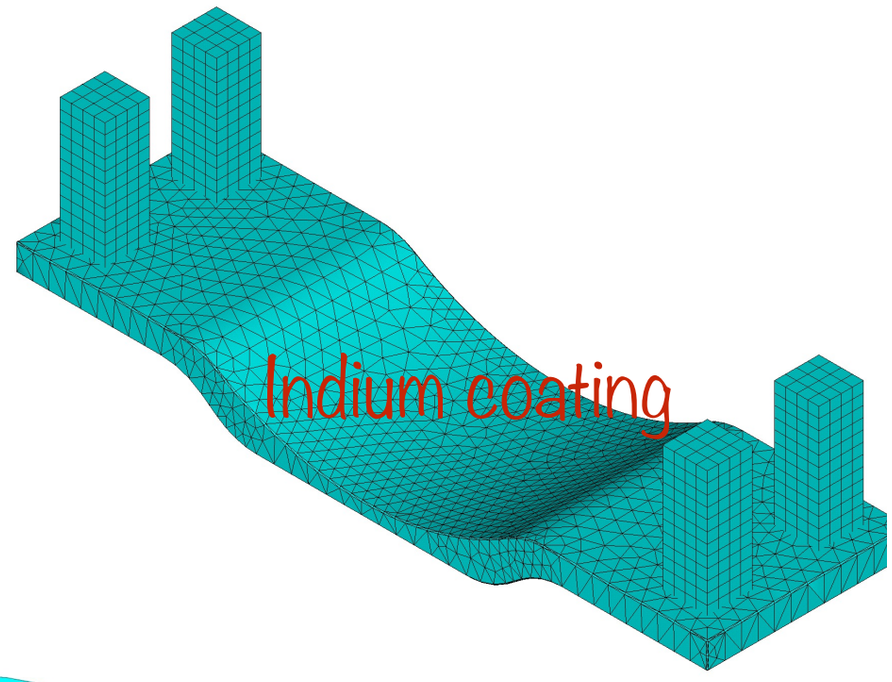
- 30 kg test mass will used for the cradle test suspensions

- Develop assembly procedure, perform cooling test (20 kelvin), test and characterisation of various components (example blade springs, fibres, connections etc.)

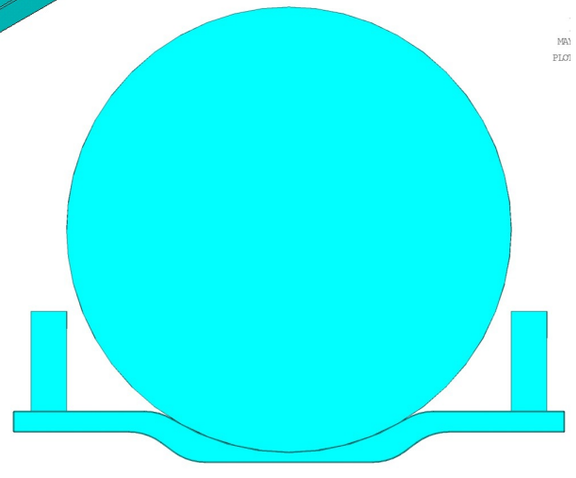
Cradle test mass



We have a spare test mass (29 kg) in ICRR for use

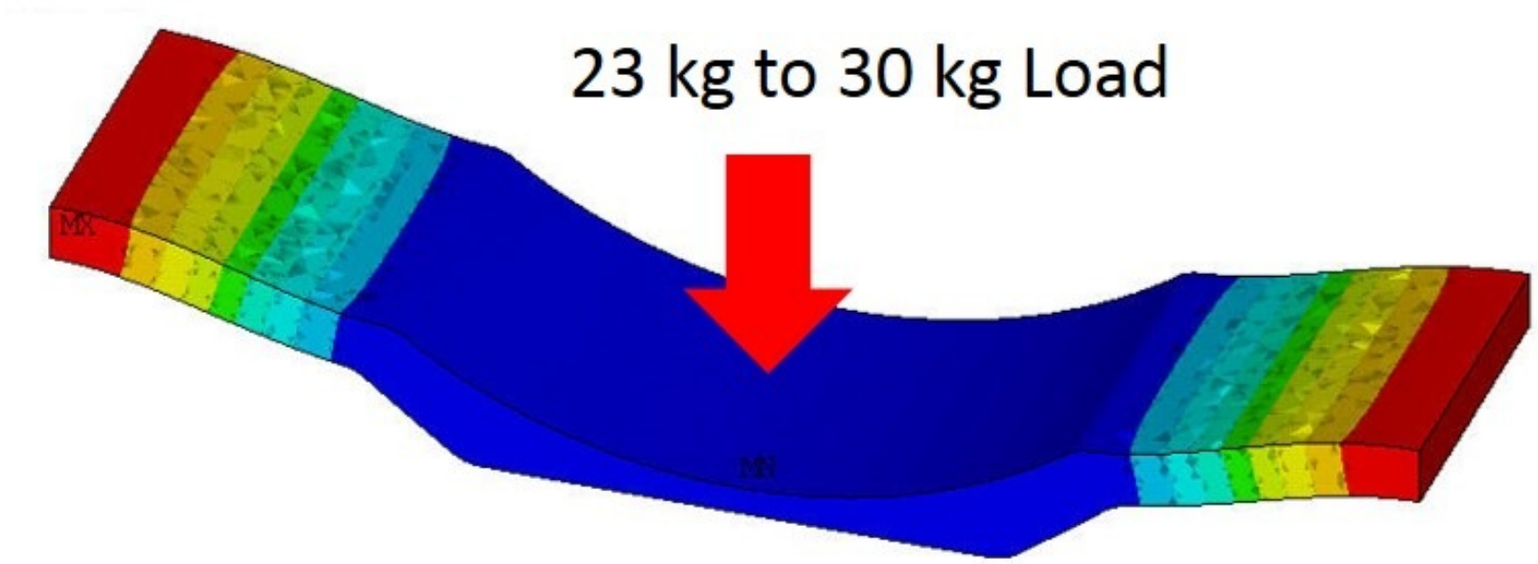


sapphire cradle (1 kg)



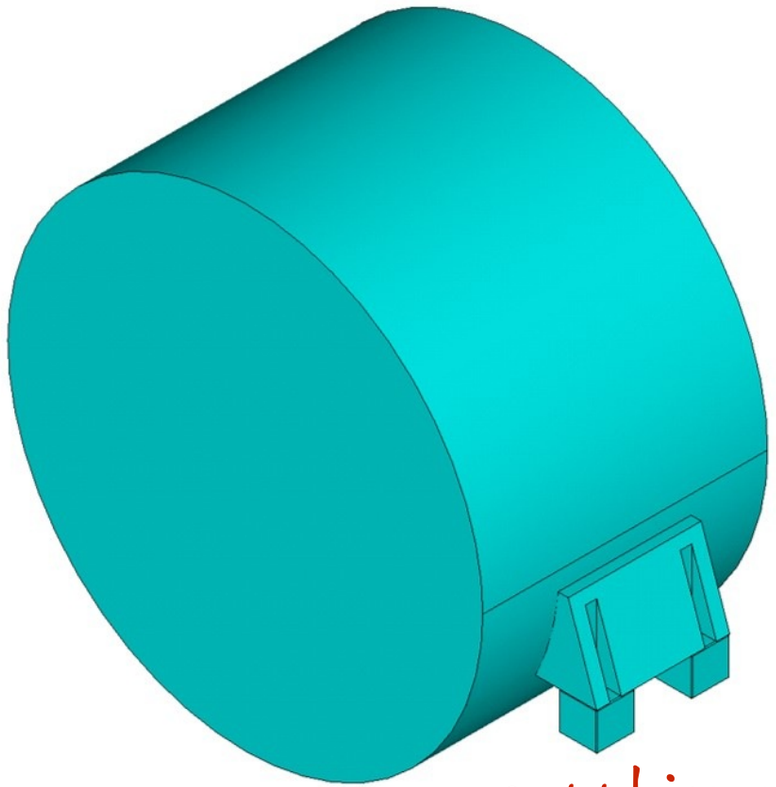
front view of the test mass

FEA modelling (cradle)



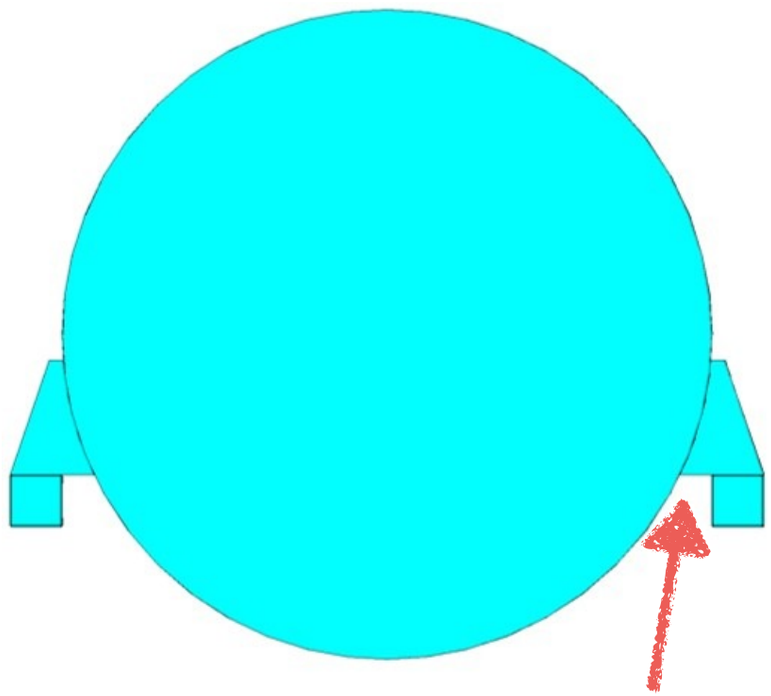
- Maximum deformation - 1.3 microns
- Maximum equivalent stress - 7 MPa
- No internal modes observed till 2 kHz

Test mass with ears



sapphire ear

Nail head of the fibre will be hooked under the ears



position of the ear can be moved depending on bending length of the fibre

Sapphire blade springs

- **Why do we need them?**

- Reduce the vertical (bounce) mode to below 15 Hz (Vela Pulsar is at 22 Hz)

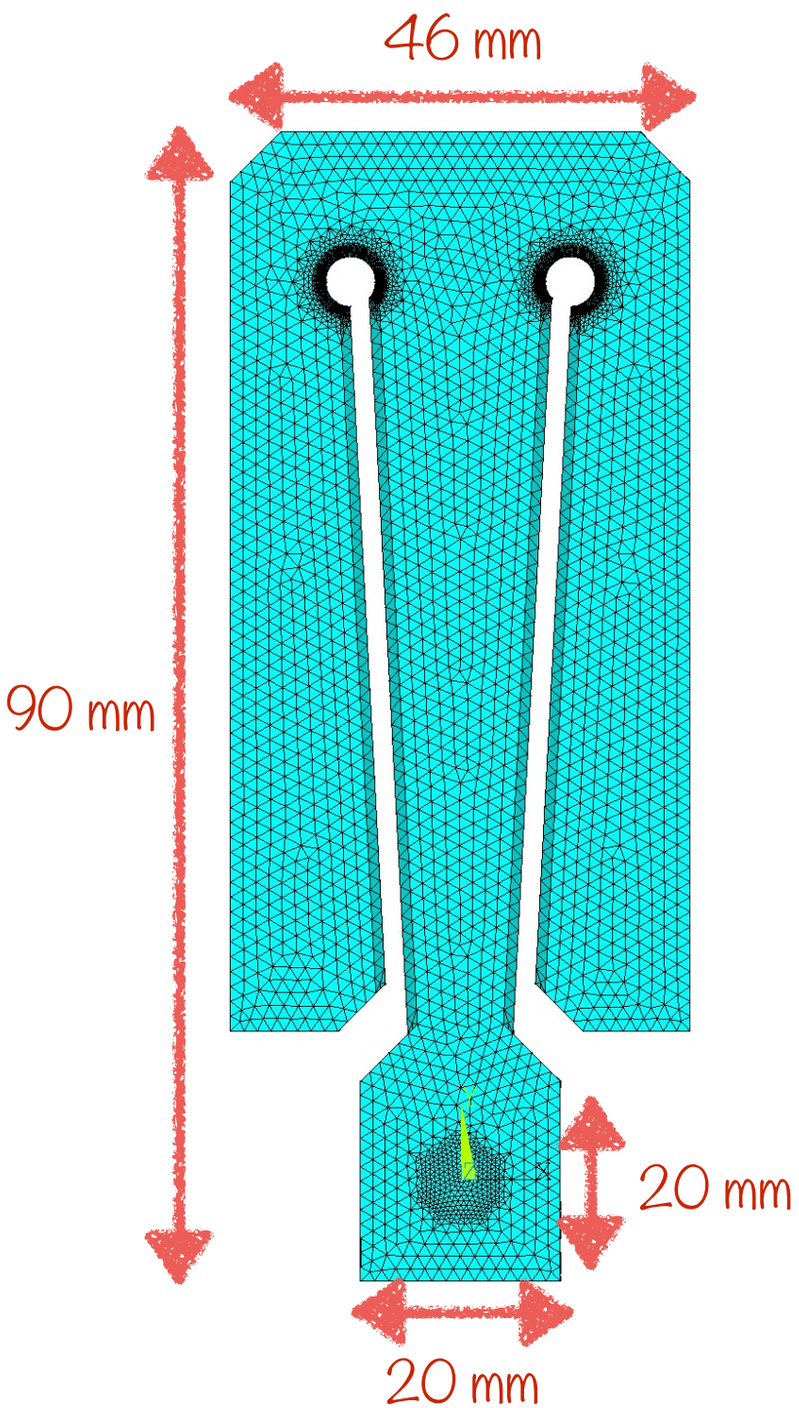
- Length compensation of the sapphire fibres

- Reduce the frequency spread of the fundamental violin mode (less than 5%)

- **Sapphire breaking stress**

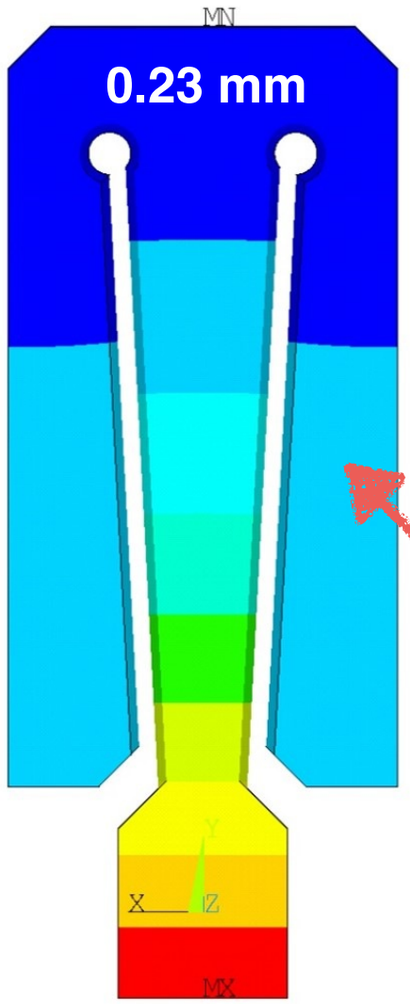
- Average breaking stress of 450 MPa (thermo polished sample) - as shown by Giles Hammond (Glasgow) in the ELiTES meeting 2013. (Poster d-4)

Blade design

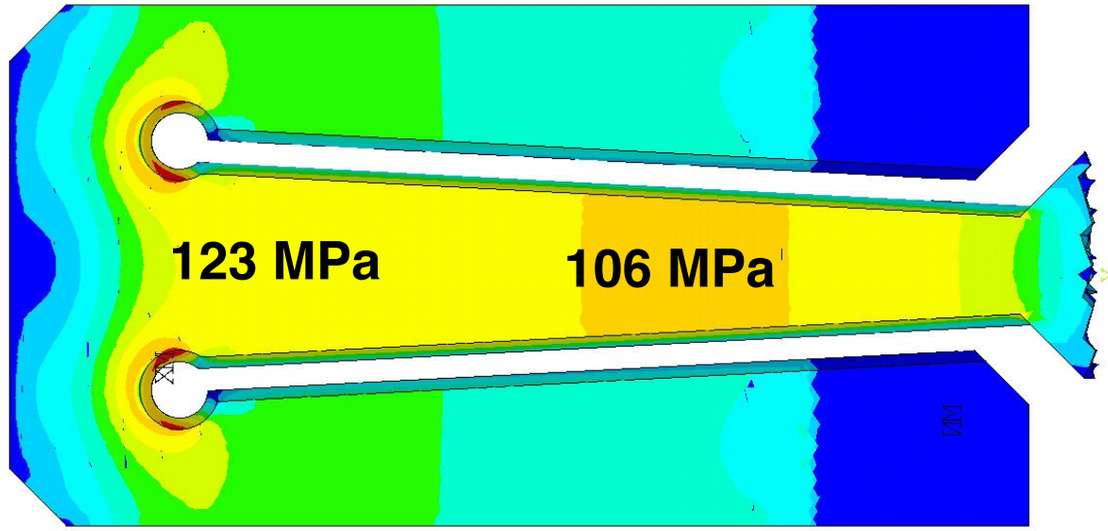


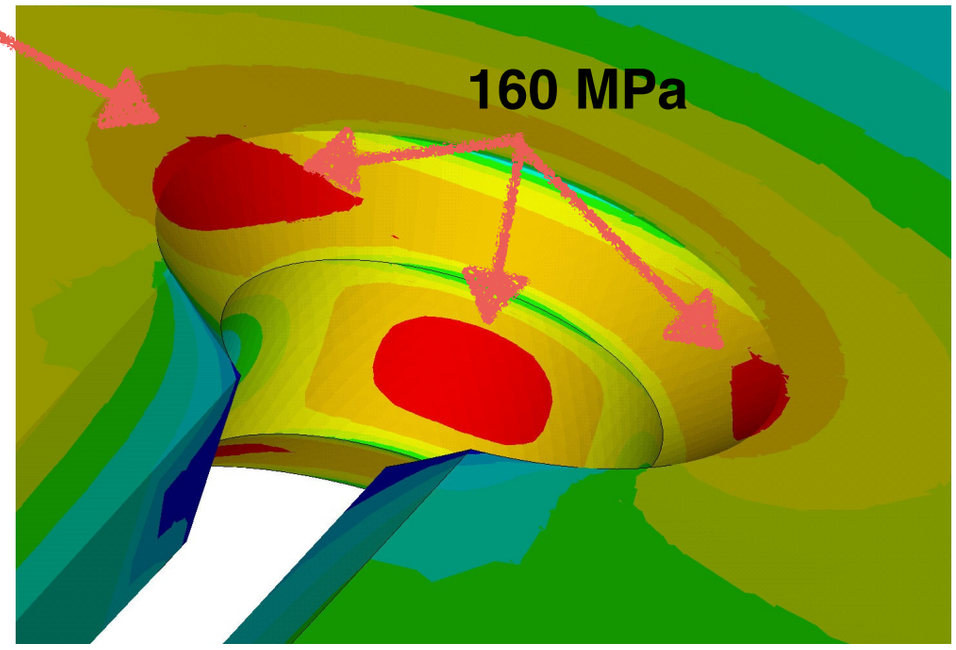
Chamfers for stress distribution

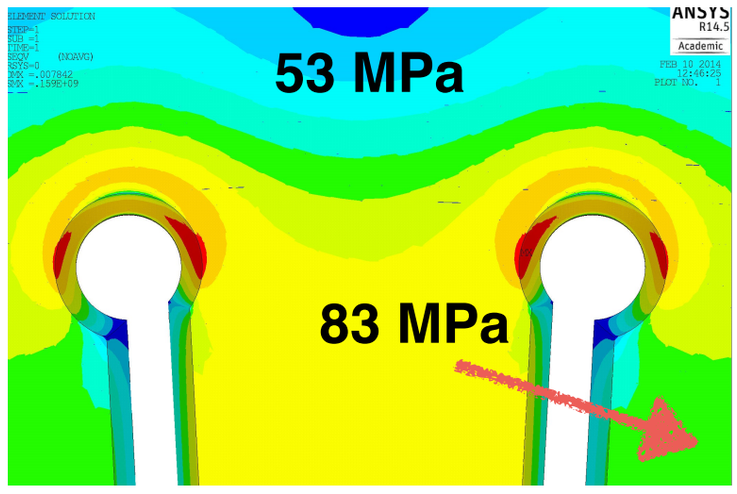
Static deformation



Equivalent stress

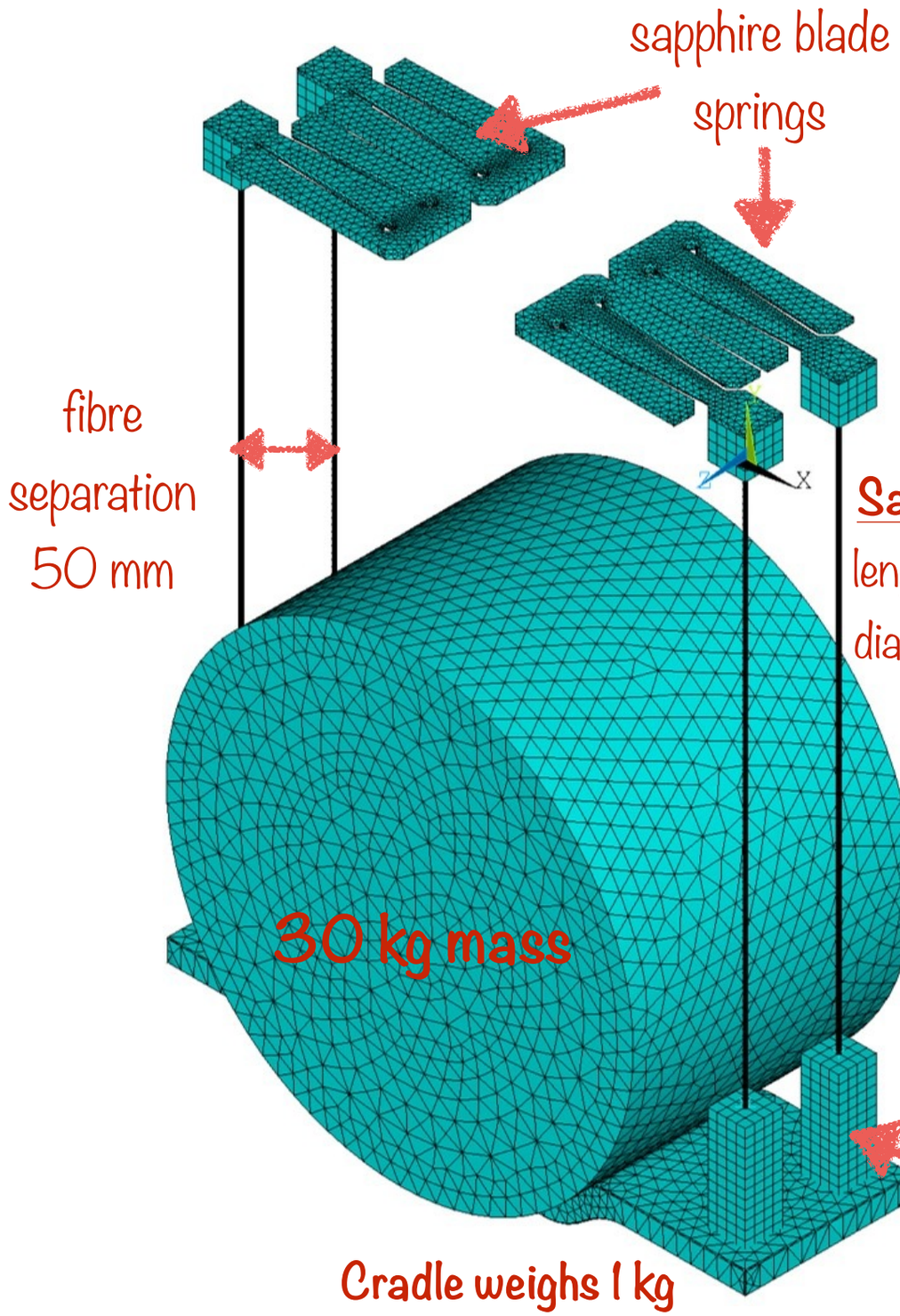


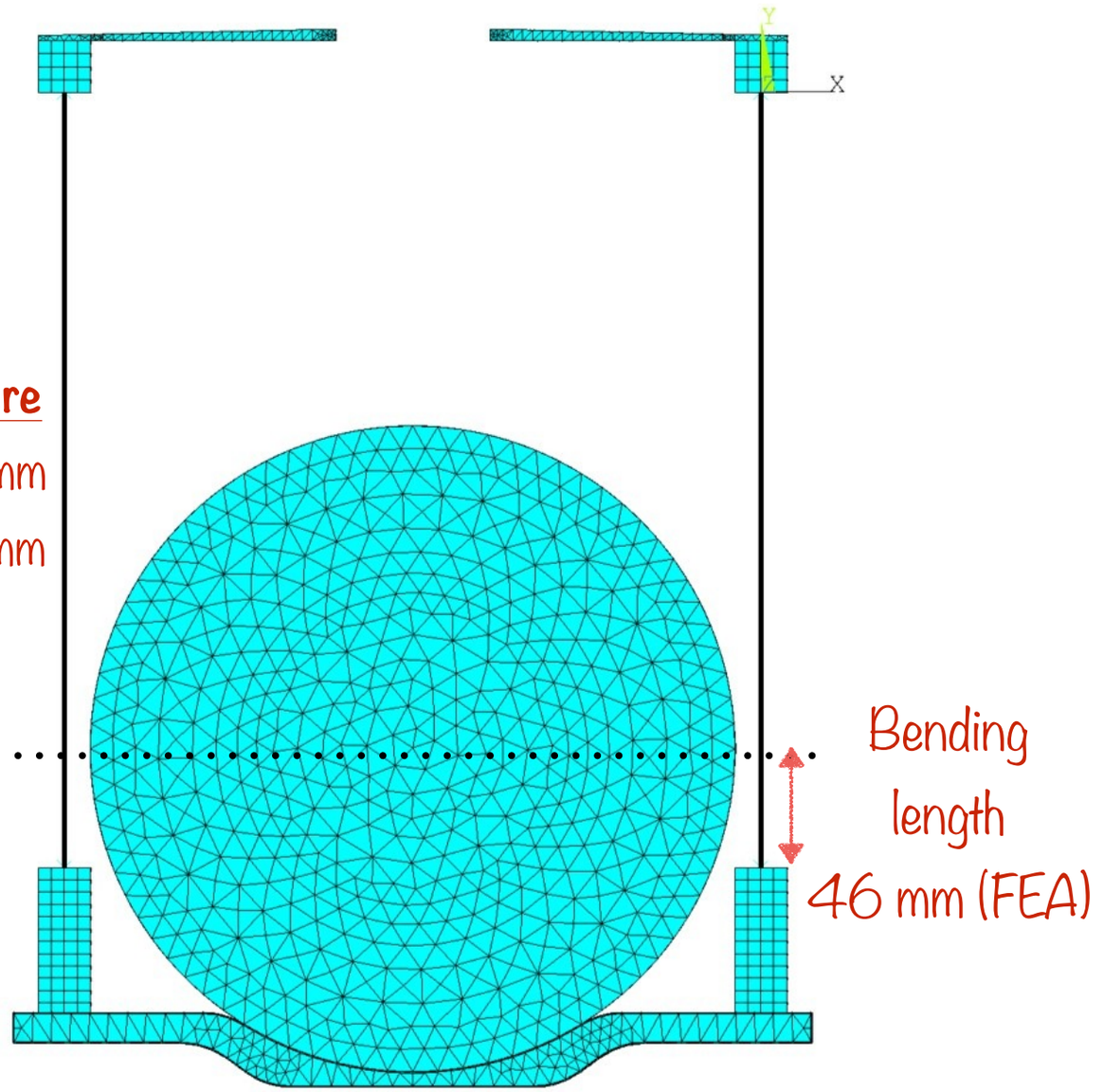




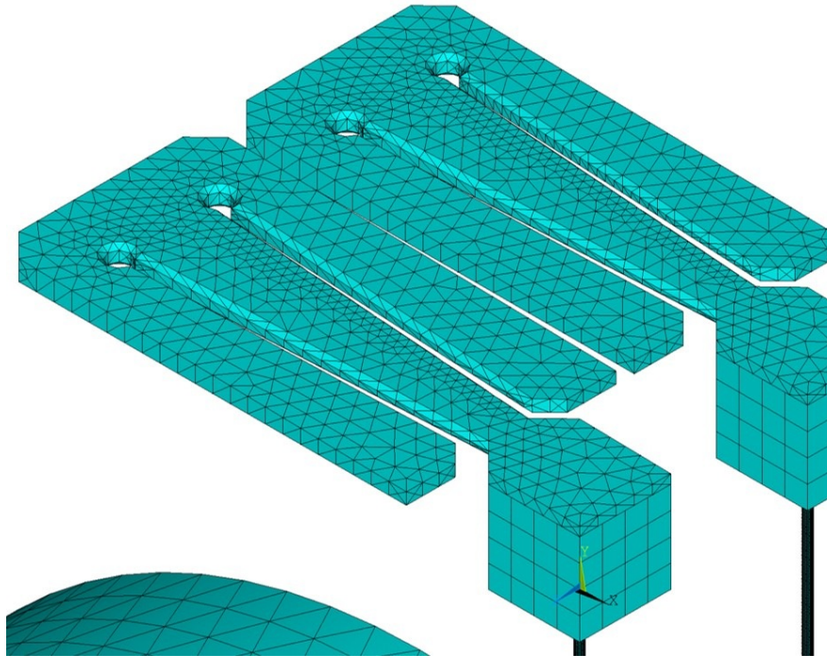
- Vertical (bounce) frequency: 14.5 Hz
  (drops from 108 Hz)
- First internal mode at 550 Hz

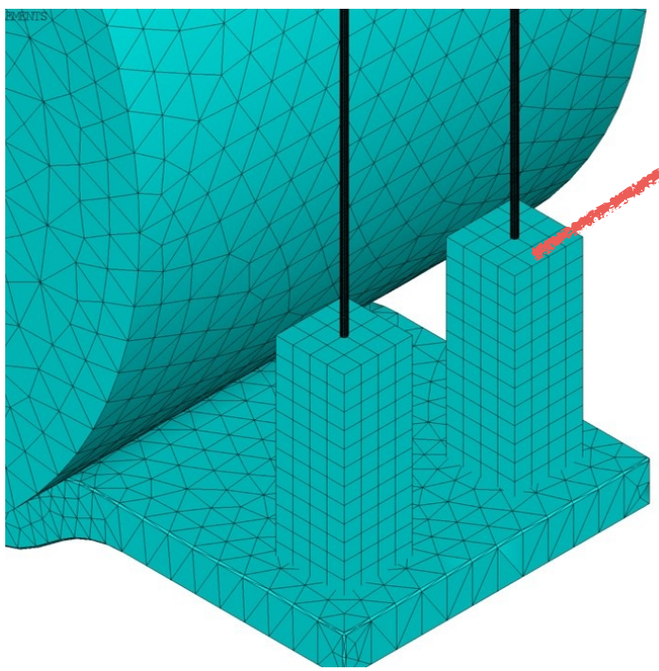
FEA - cradle suspension



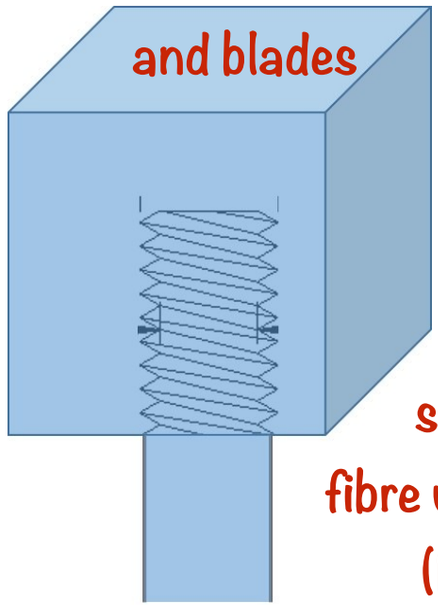


Connections…

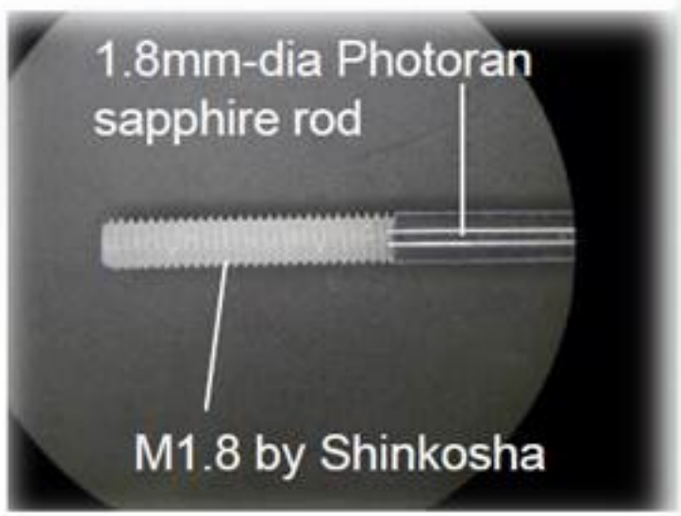




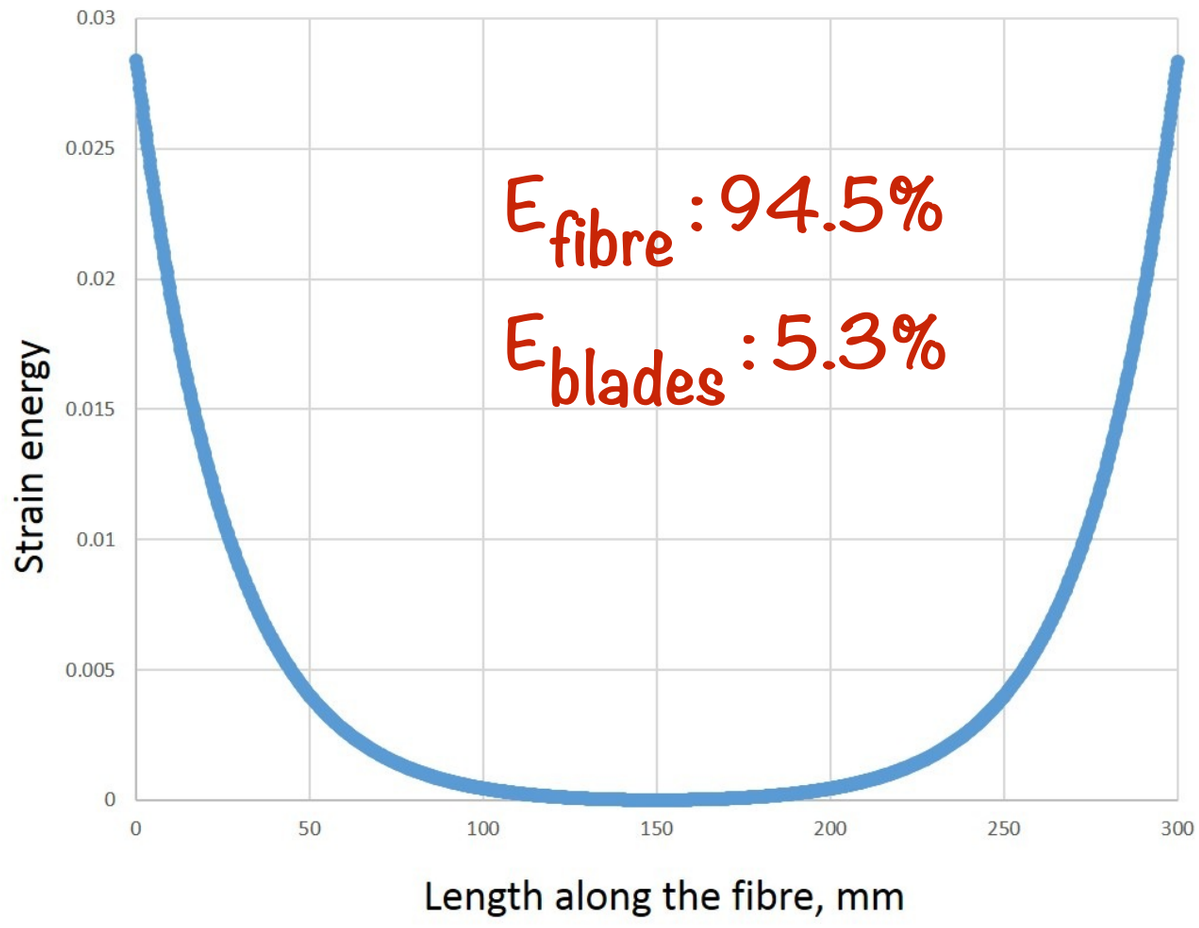
bolted connection
between nail head
and blades



sapphire
fibre with threads
(1.8 mm)



Results from FEA (ANSYS)

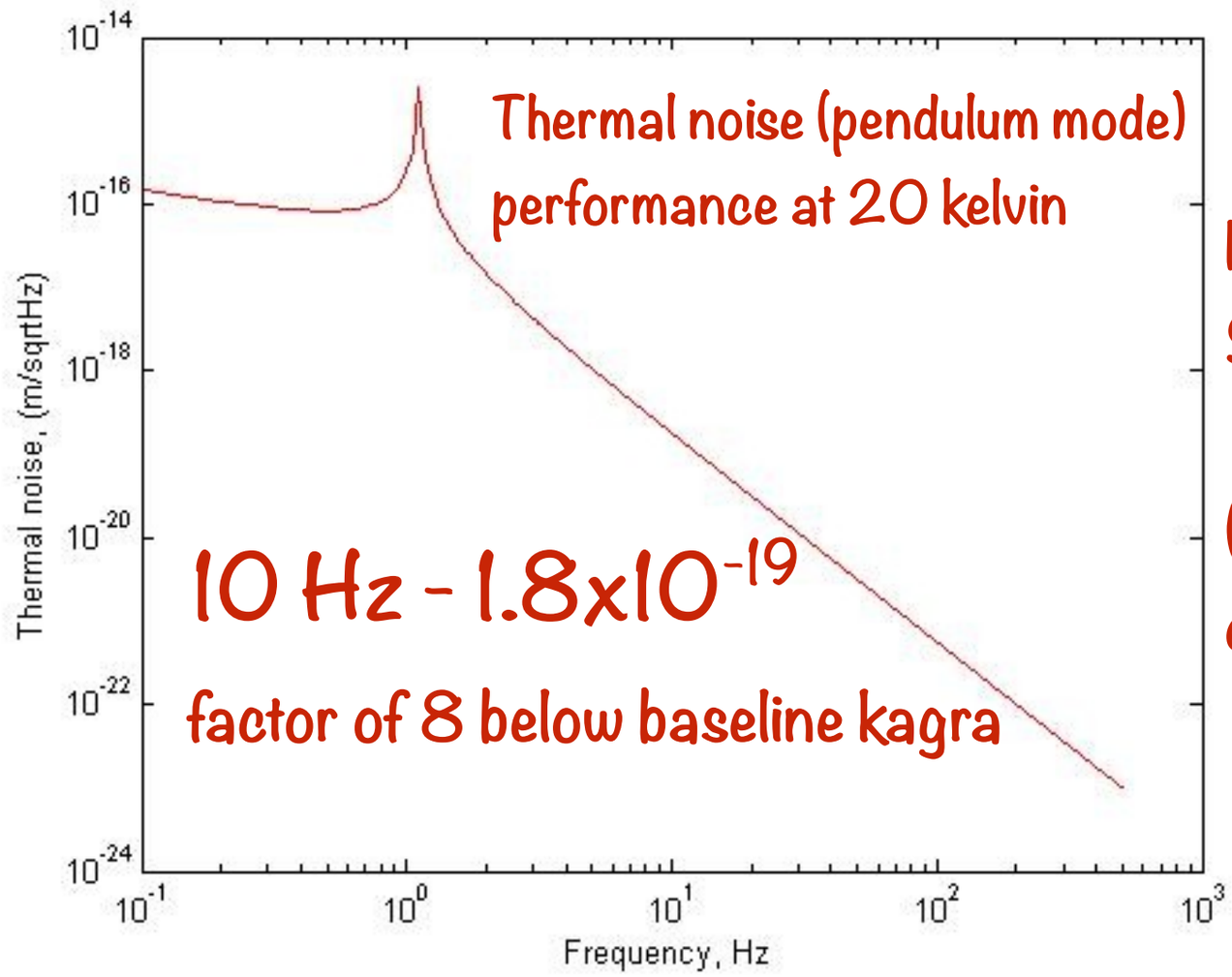


Dissipation dilution: 6

ratio of gravitational energy (pendulum motion) to the elastic energy (in fibres)

- Thin (400 microns) fibres usually bends right at the two ends
- Thick (1.8 mm) fibre stores more energy (elastic) along the length

Thermal noise



Dominant loss term:
Surface loss

(surface depth over which loss occurs: 100 microns)

Mechanical loss of sapphire fibres - 1.56×10^{-7}

see Dan's poster: e-1

Ongoing/future work

- Optimisation of the cryogenic pendulum design
- Estimation of thermal noise contribution from connections (fibre threads & bolts) using FEA
- Thermal noise from **the Indium layer between the test mass & cradle**
- Comparison of noise performance: **cradle vs ear suspension** (including noise from various joints - threads, HCB, Indium)
- **Cradle suspension fabrication** - sapphire blade springs, cradle and sapphire fibres with threads being fabricated by Shinkosha.
- Characterisation of the cradle suspension at 20 kelvin (comparison with results from FEA)

Conclusions

- R&D for the cradle & ear type suspension is ongoing
- Cradle suspension design will enable us to re-use the sapphire test mass
- We now have a sapphire blade spring design as per KAGRA requirement
- Sapphire blade springs have a maximum stress of 160 MPa and bounce mode frequency of 14.5 Hz
- Results from FEA shows that the cradle suspension design looks feasible for fabricating a prototype suspension
- Pendulum mode thermal noise is estimated to be 1.8×10^{-19} $m/\sqrt{Hz}$ at 10 Hz
- Various components for the cradle suspension are being fabricated for building the prototype cryogenic system in 2014.

Thank you