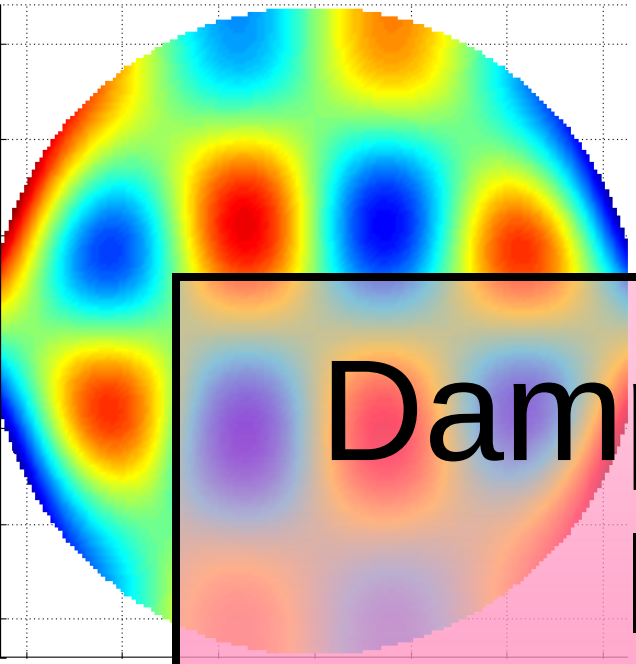
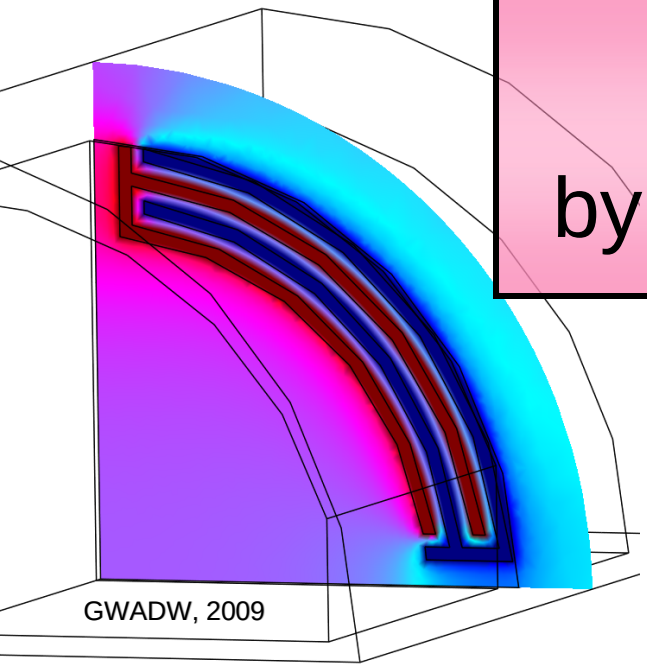


Damping Parametric Instabilities

research at MIT

by John Miller and Natania Antler



GWADW, 2009

Matthew Evans, MIT

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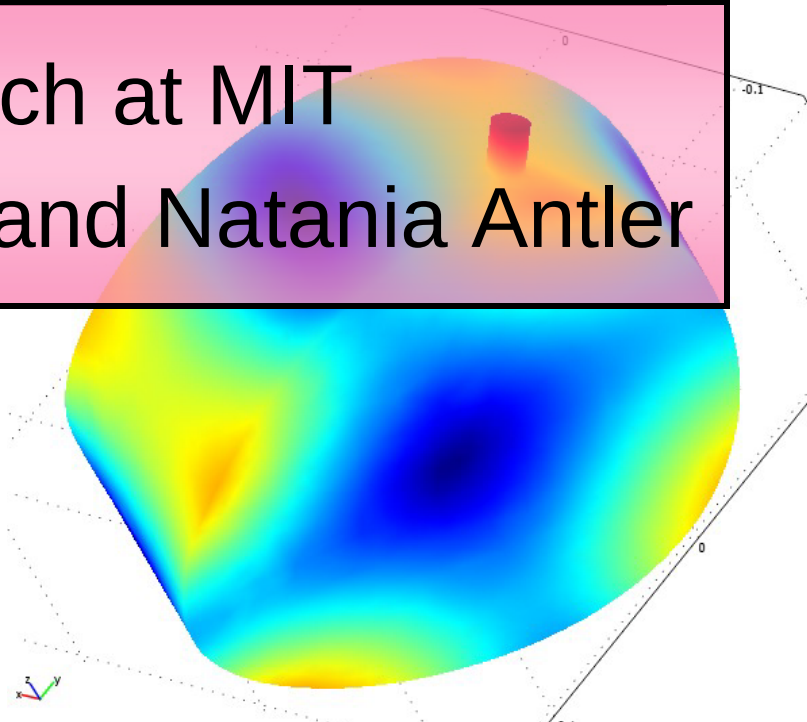
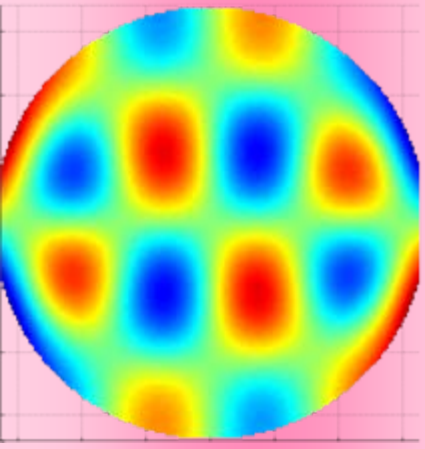
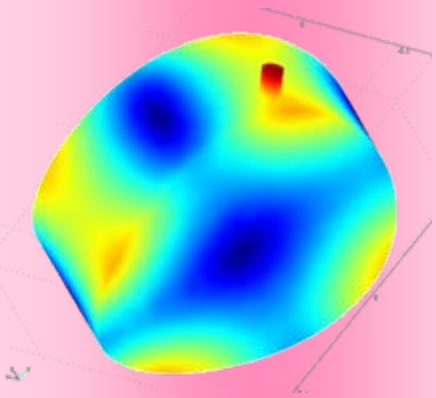
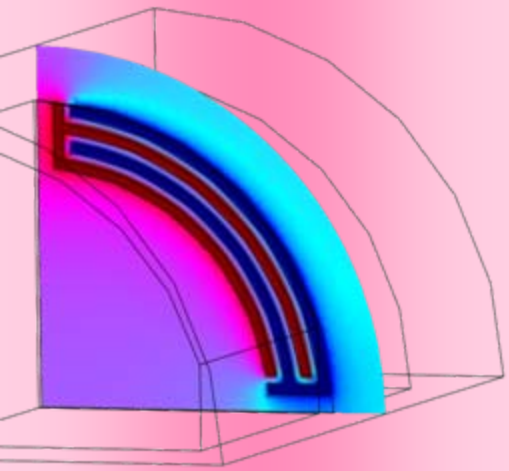


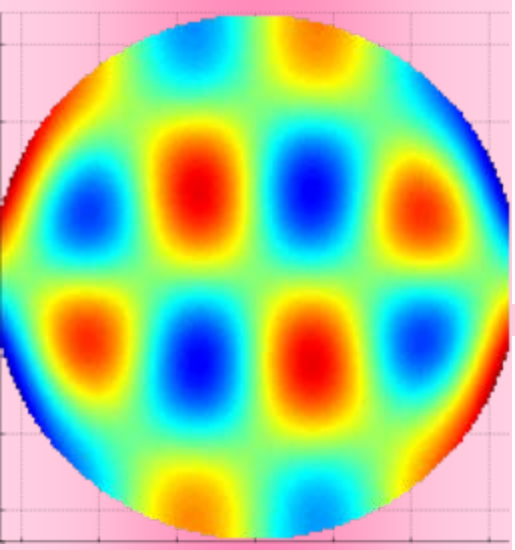


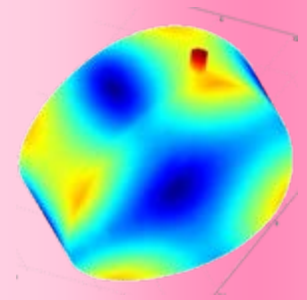


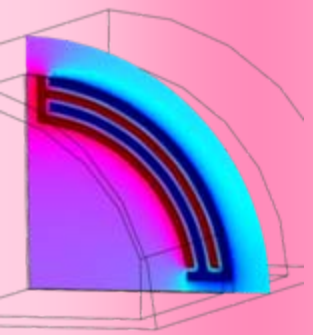


Outline

- Parametric Instability
  - What, when, where, why…
  - A general, classical approach
- Passive Damping
  - work by Natania Antler
- Active Damping
  - work by John Miller

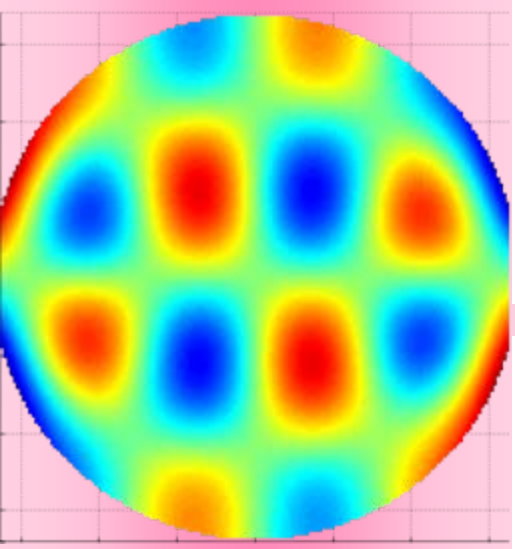


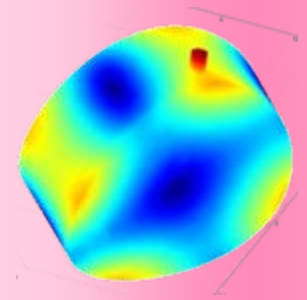


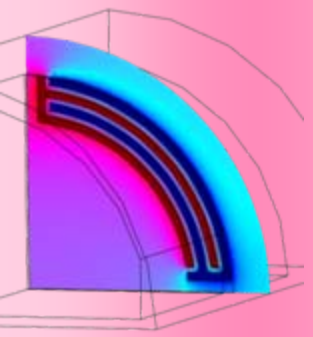


Parametric Instabilities

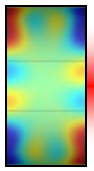
- Opto-mechanical instability that may arise in advanced detectors
  - High stored power (~ 1MW)
  - High Q mechanical modes (>1M)
- Due to energy transfer from stored optical power to mirror mechanical modes
  - Transfer is driven by mechanical mode amplitude
  - Can lead to instability



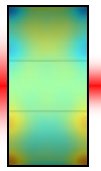




Parametric Gain

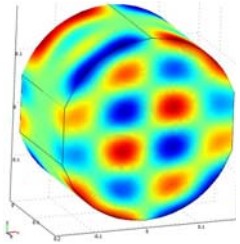


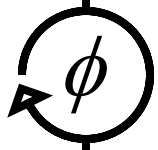
High Finesse Cavity

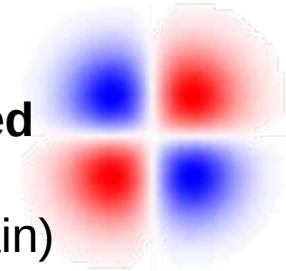


Nascent Excitation

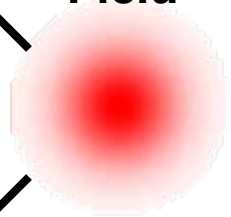
Mechanical Mode





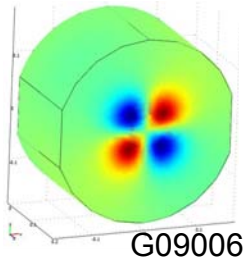


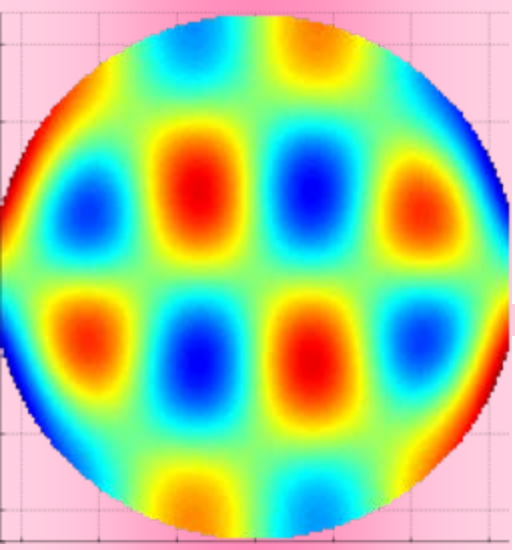
Pump Field

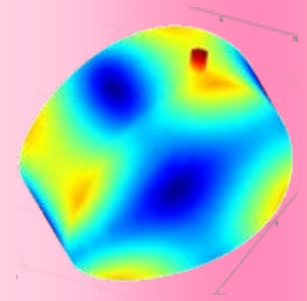


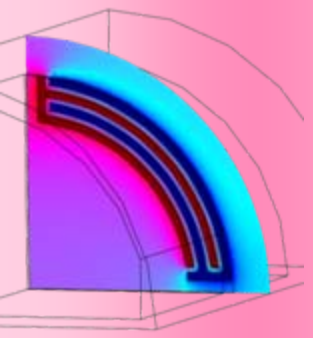
Scattered Field (cavity gain)

Radiation Pressure









Parametric Gain

- Opto-mechanical feedback
  - X_mechanical starts at X_initial
  - Converts E_pump to E_nm
  - Beats with E_pump to make F_nm
  - Drives X_mechanical
- Open-loop gain

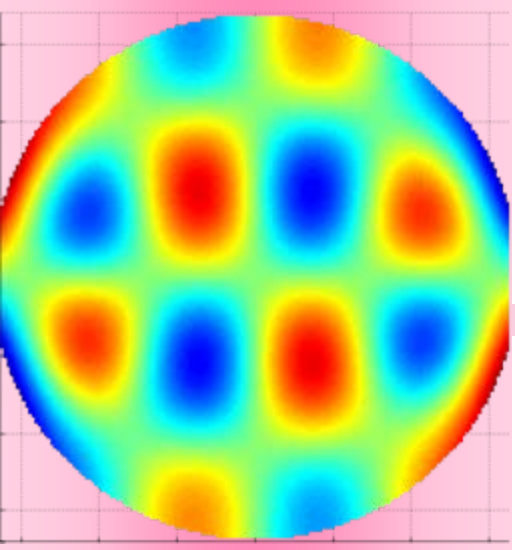
$$R = \frac{Q}{m\omega^2}\frac{2P_0}{c}\sum_i B_i^2 G_i$$

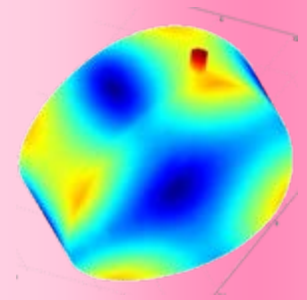
Sum over optical modes

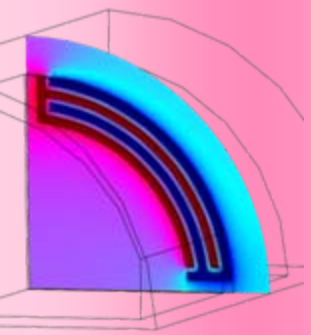
Mechanical Mode

Radiation Pressure

Scattered Field and Cavity Gain

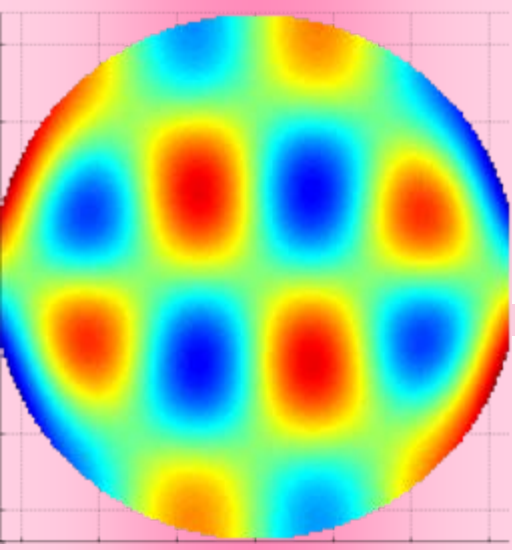


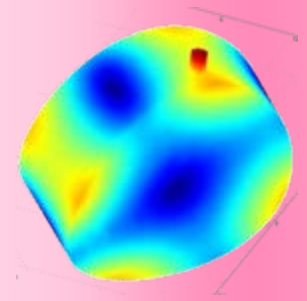


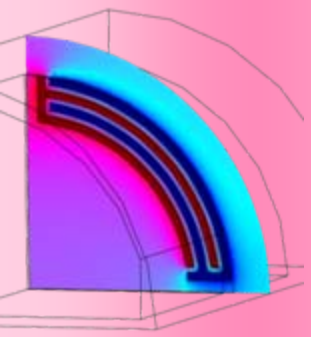


Parametric Gain, Worst Case

- Curvature uncertainty
  - Make optical resonances wider
  - Ignore optical modes with negative gain
- Assume high mechanical Q
  - 10M assumed for all modes
- For Advanced LIGO…

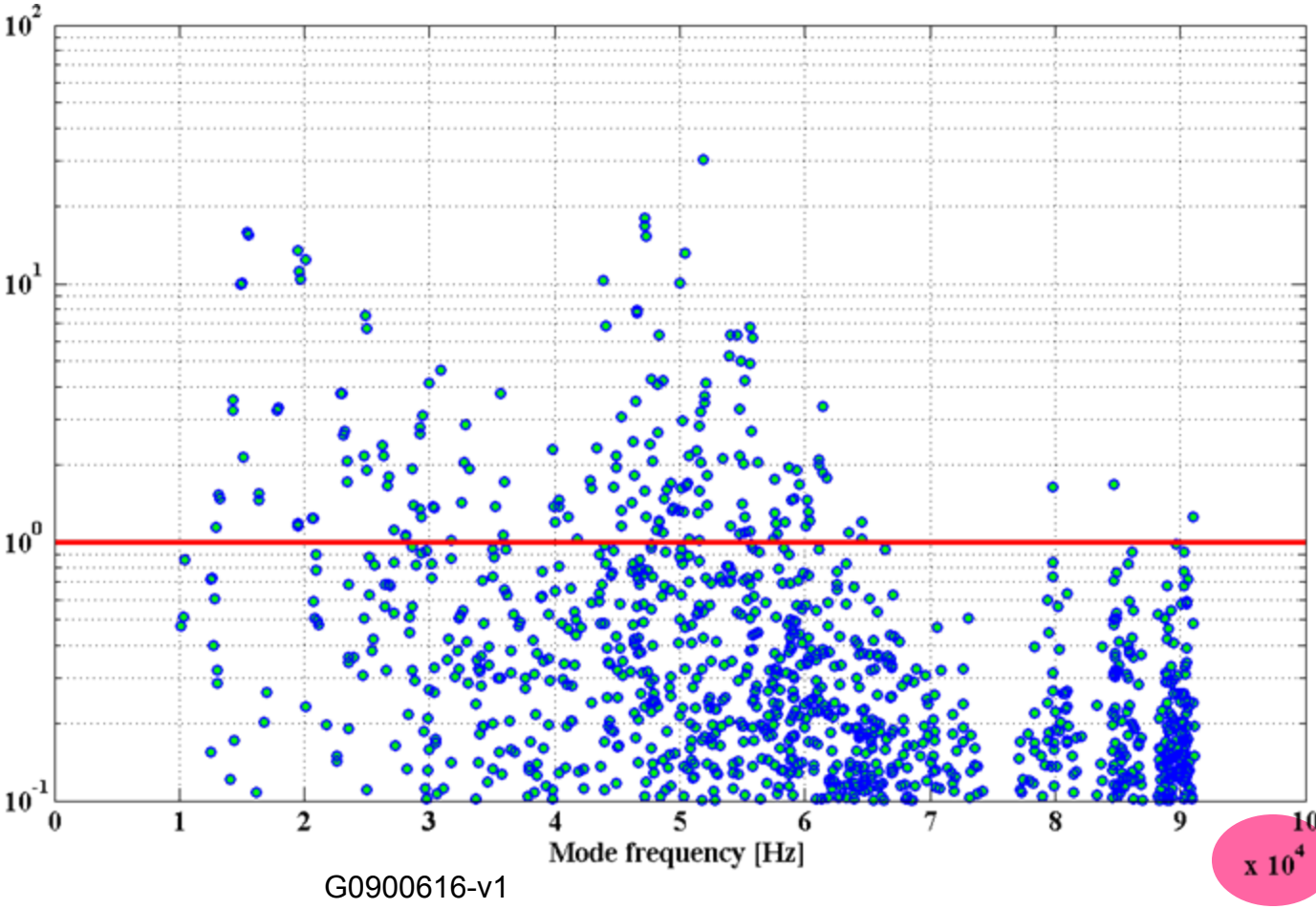


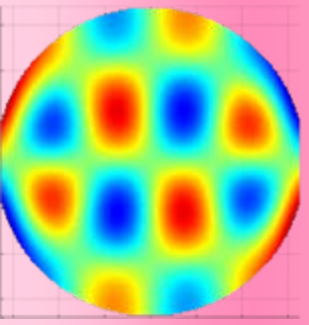


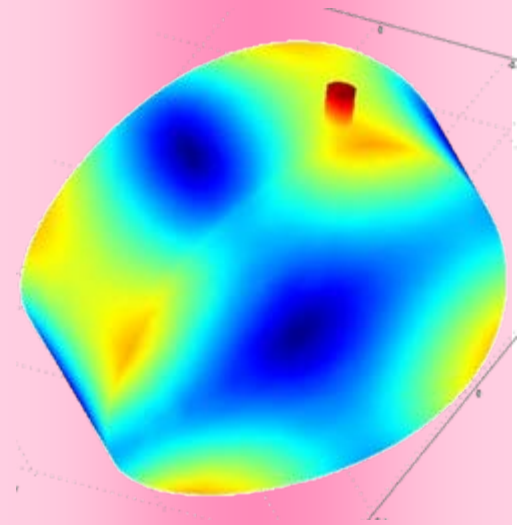


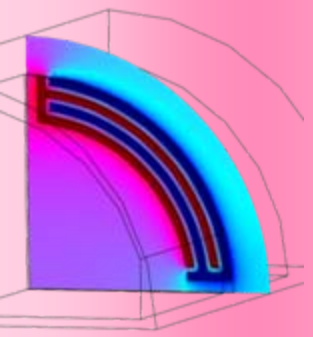
Parametric Gain, Worst Case

- Worst Case R values



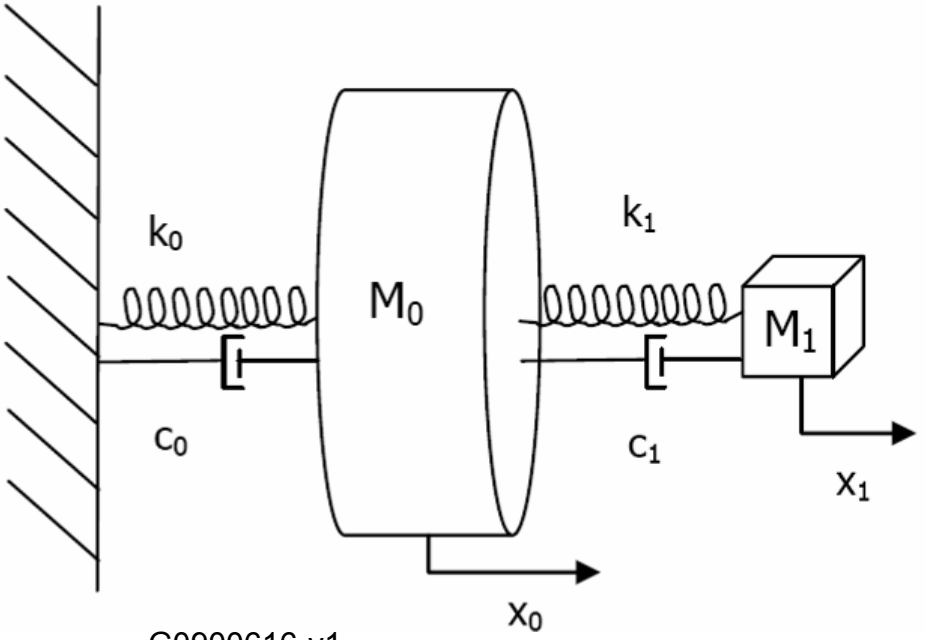


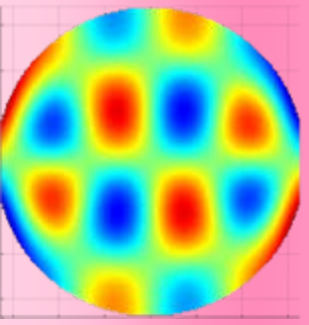




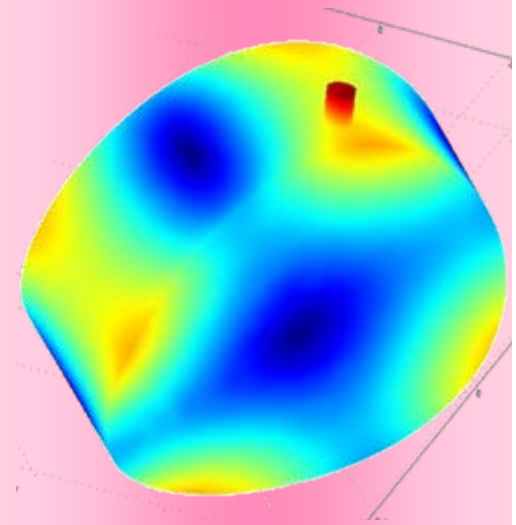
Passive Damping

- Resonant damping
  - Add a few mechanical dampers
  - Resonant frequencies > 10kHz

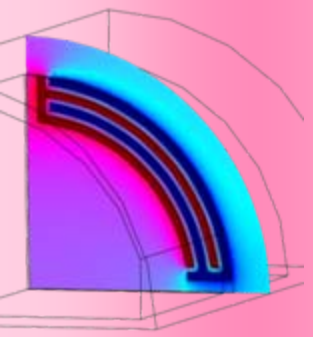


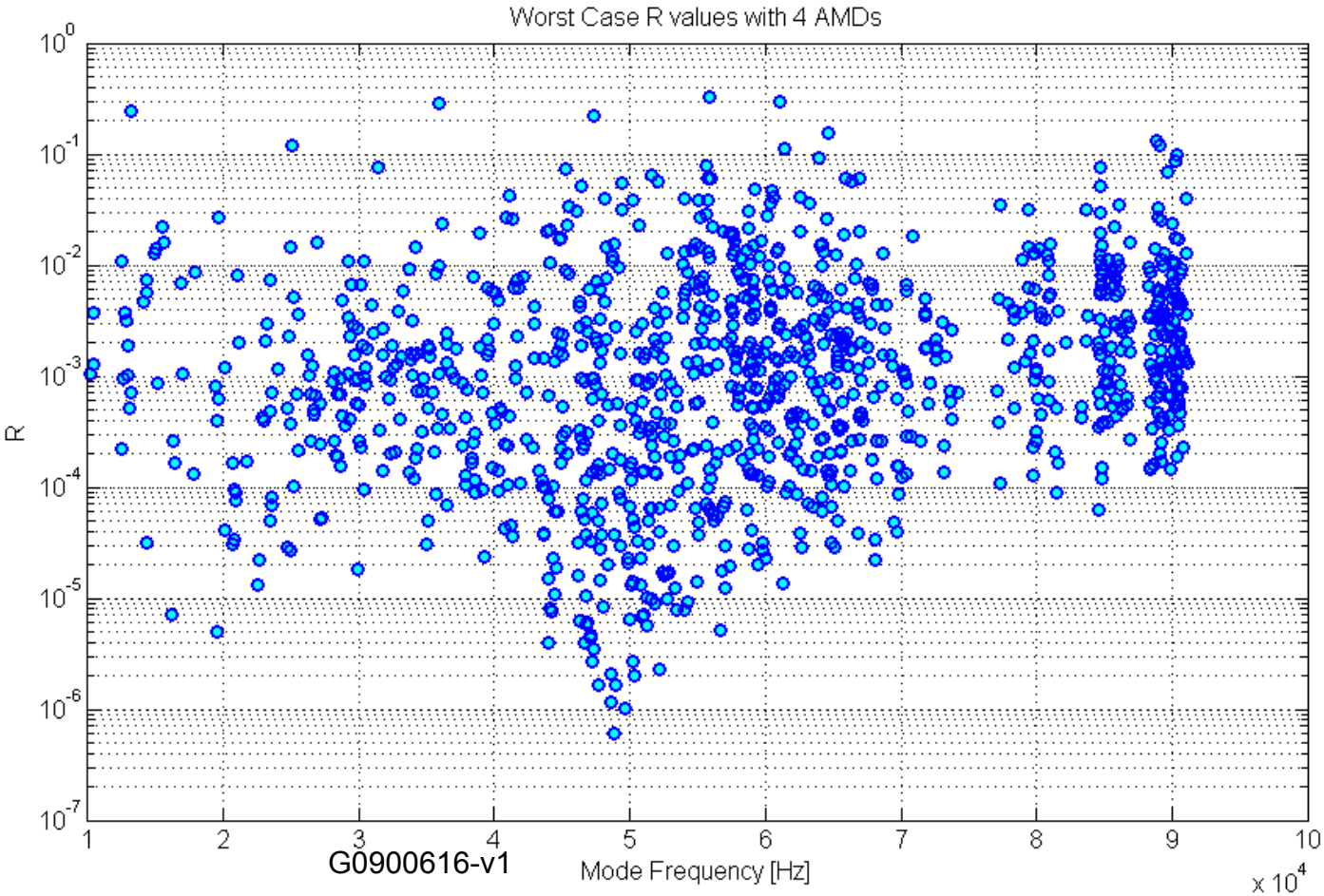


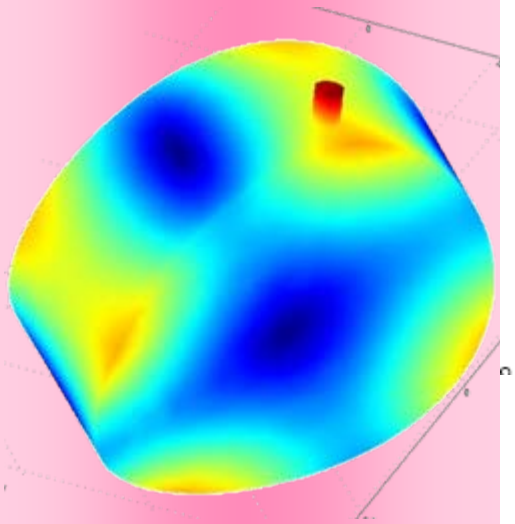
Passive Damping, Performance

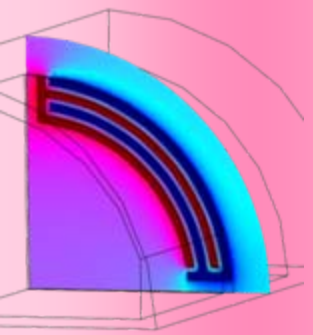


- With 4 resonant dampers

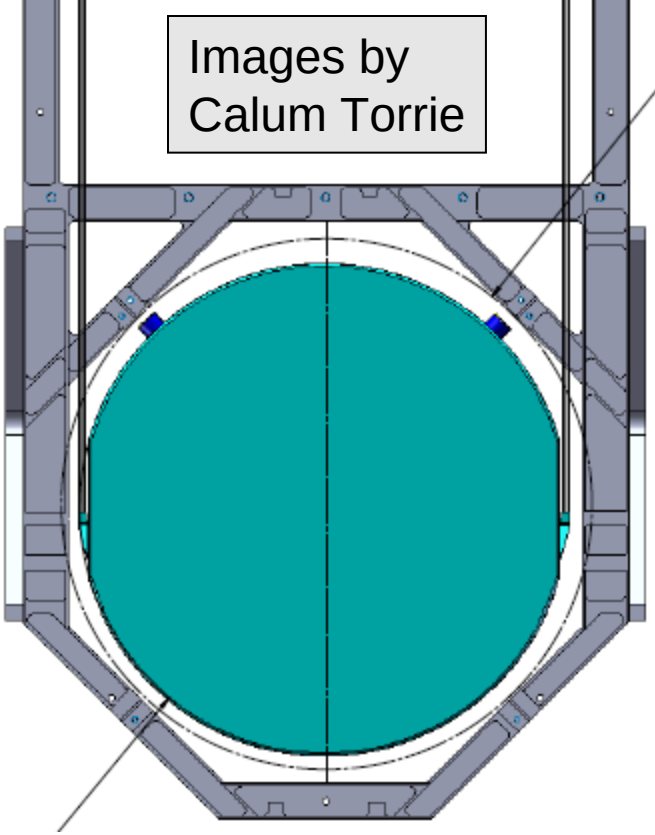


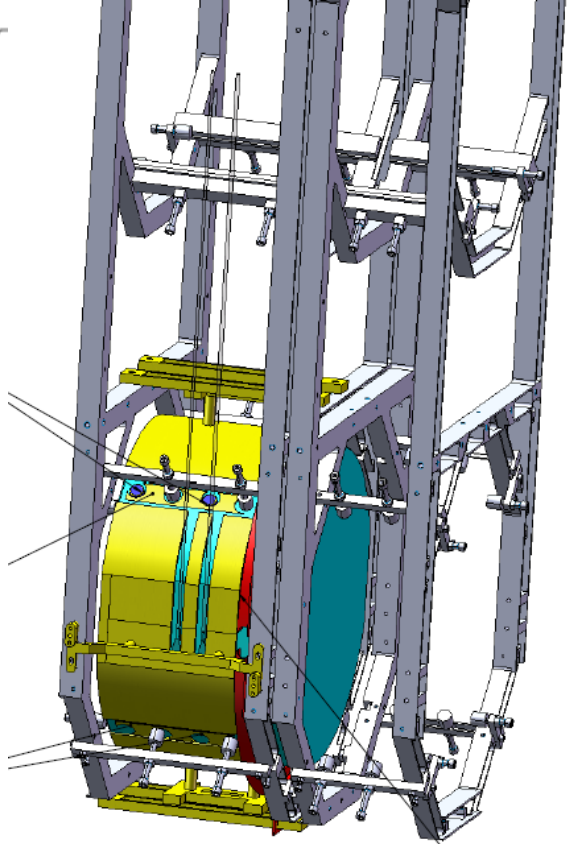


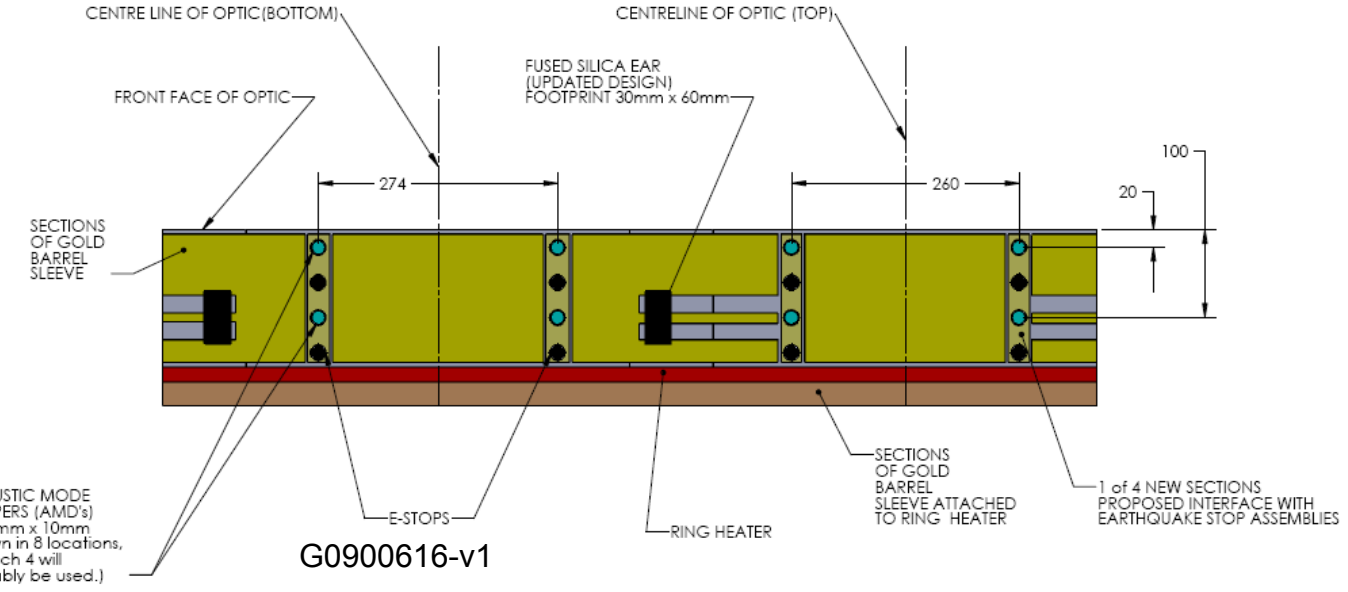




Images by
Calum Torrie







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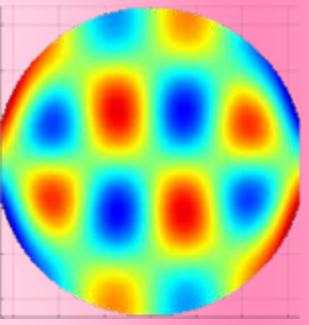
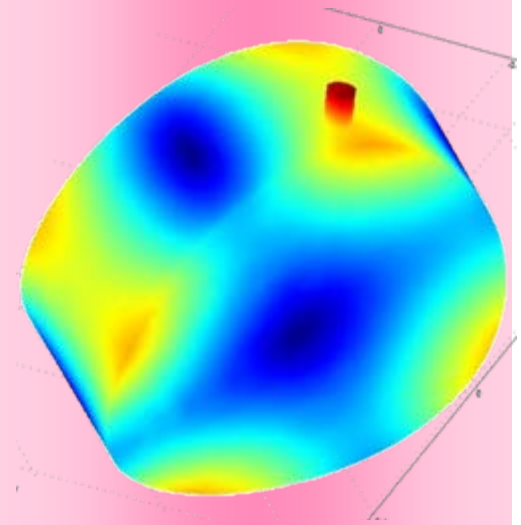
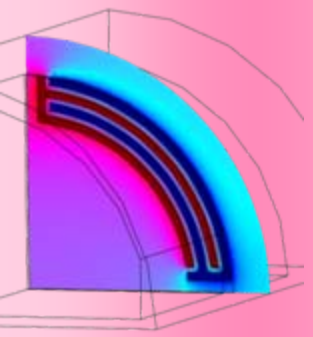


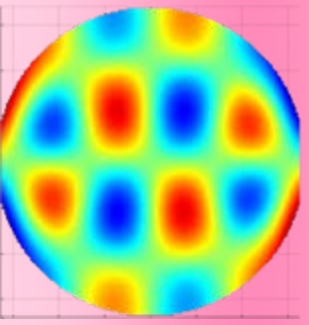




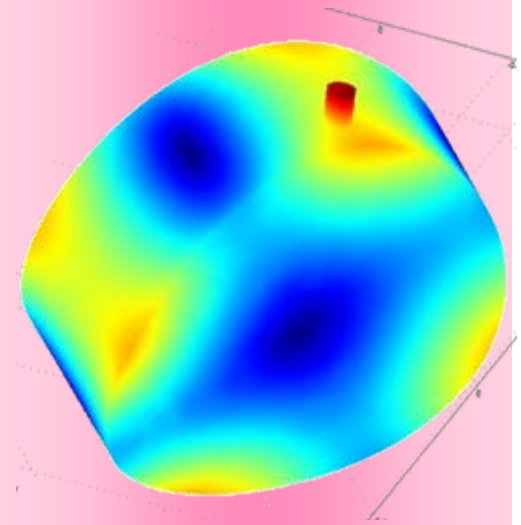
Passive Damping, Noise

- What is the thermal noise implication?
- The damper is rigid at 100Hz
  - Loss in the resonant damping is negligible
- And the glue?
  - Dennis Coyne says (at 100Hz)

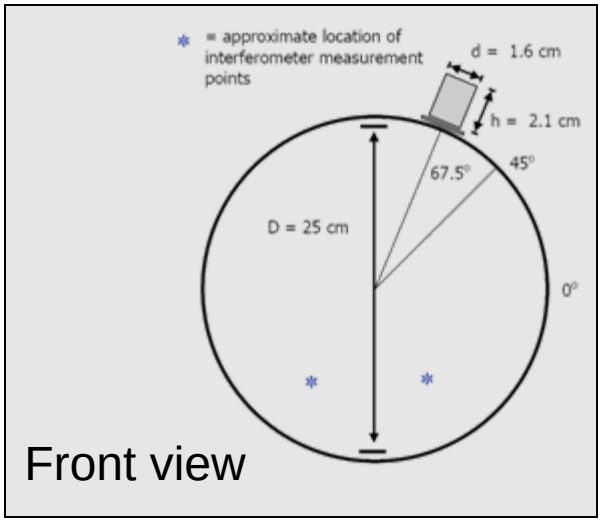
$$S_x < 2.5\times10^{-22}\sqrt{\frac{A}{cm^2}}\frac{m}{\sqrt{Hz}} << 10^{-20}\frac{m}{\sqrt{Hz}}$$

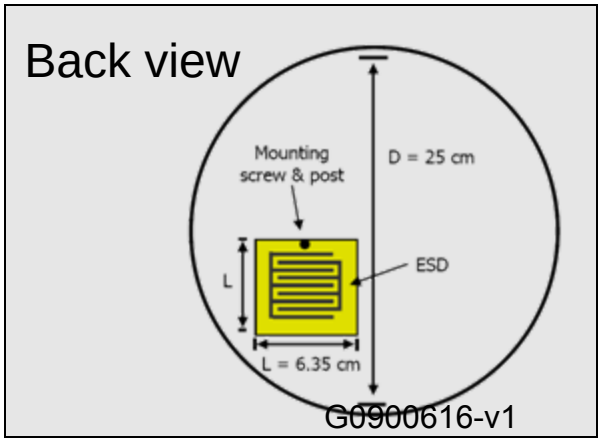


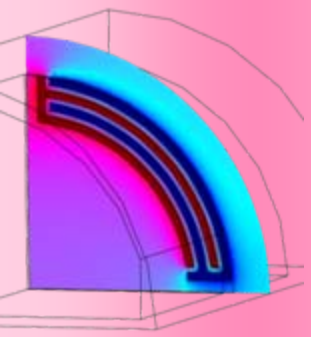
Passive Damping, at MIT



- Experiment by Natania Antler

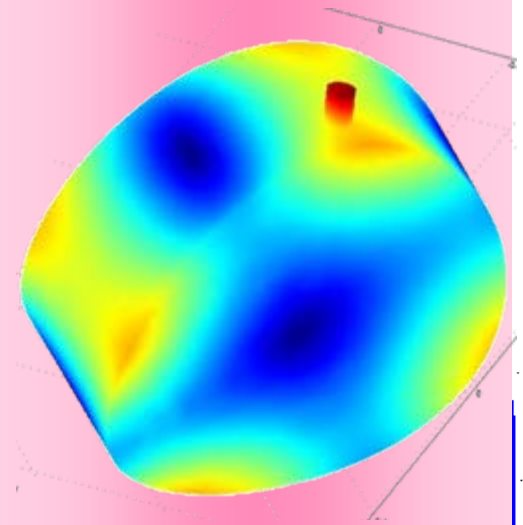


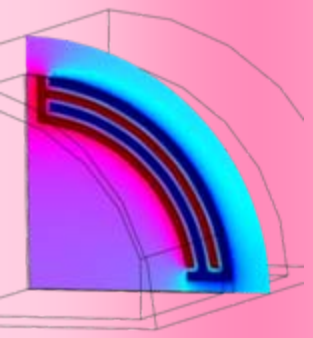


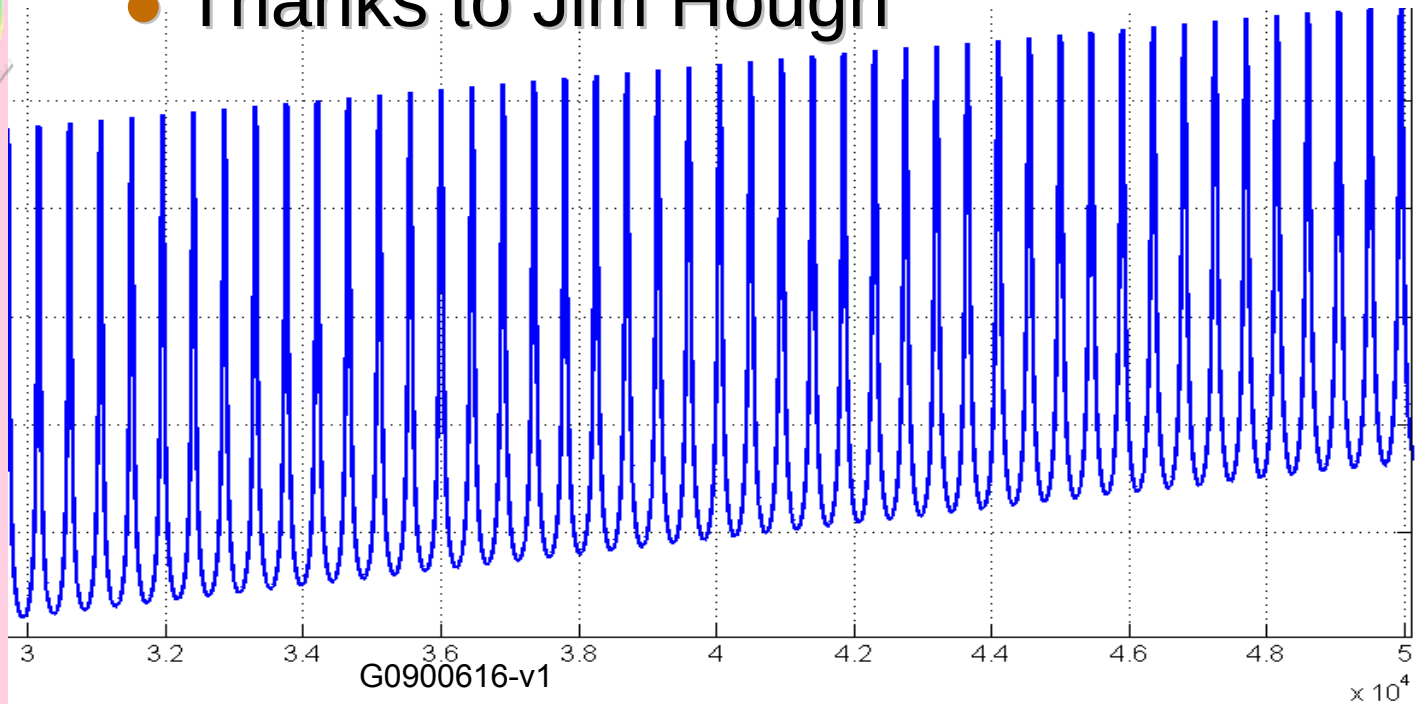


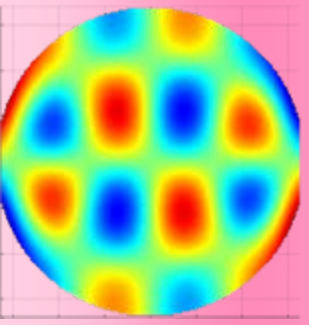
Passive Damping, for free?

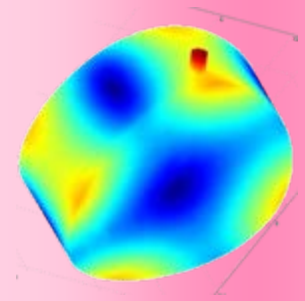
- From the violin modes
  - GEO modes have Q ~ 1M
  - May be due to violin modes
  - Thanks to Jim Hough

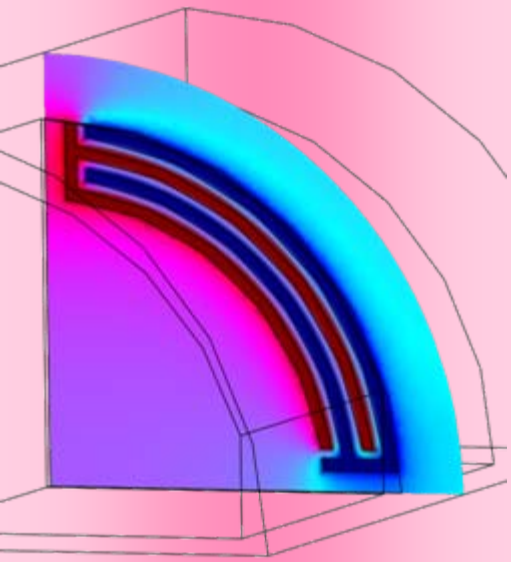






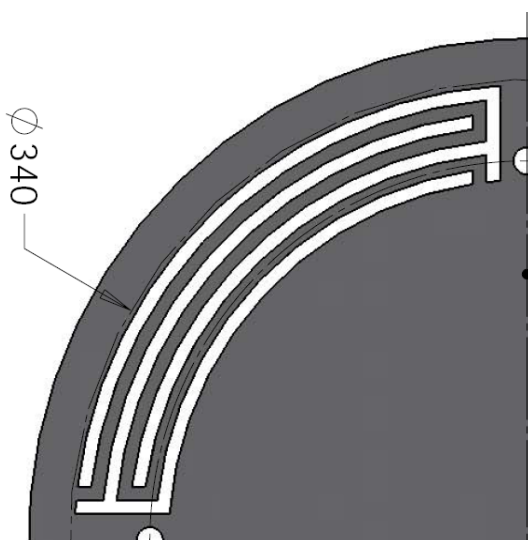


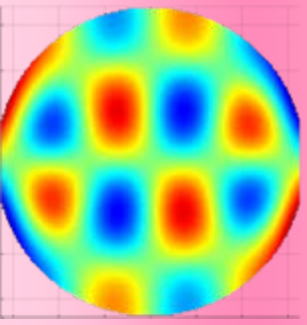


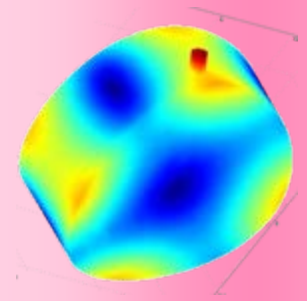


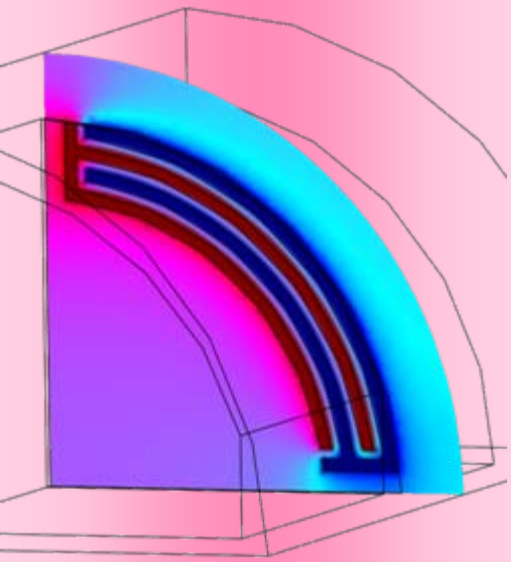
Active Damping

- Active feedback damping
  - Use existing optical readout
  - Use existing electro-static drive
- Shape loop
  - Eliminate in-band noise
  - Tune loop phase



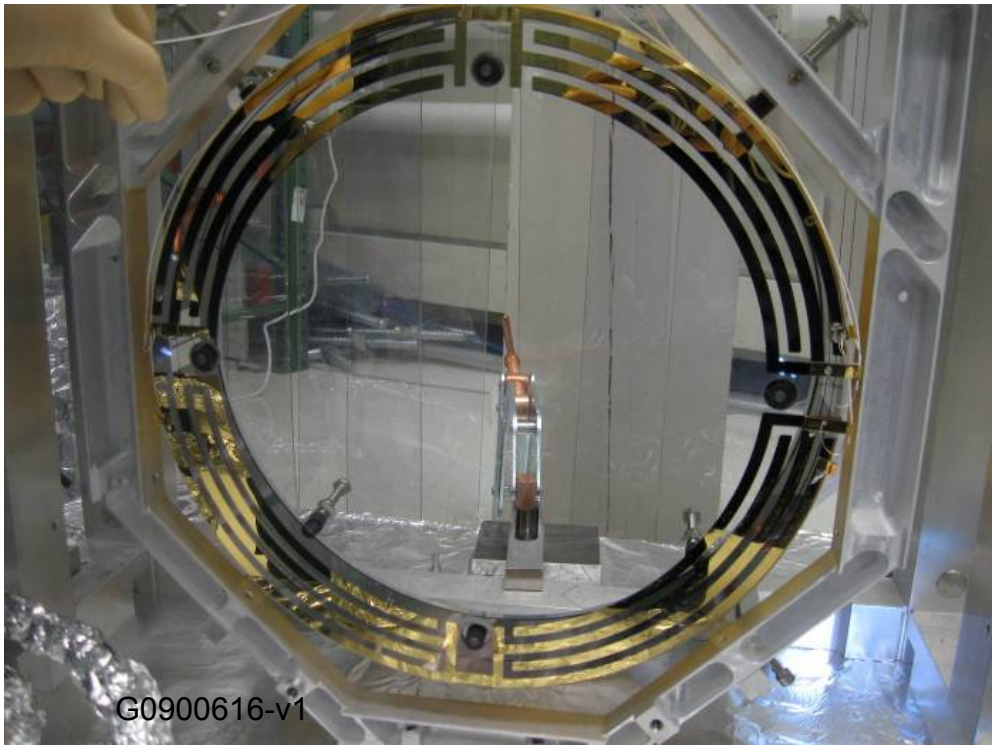






Active Damping, the ESD

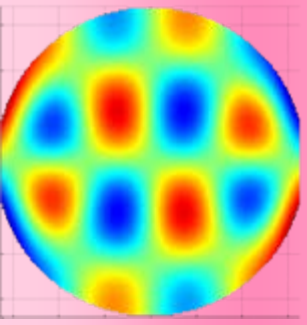
- How much force is needed?
- How much can the ESD deliver?
- What is the coupling?

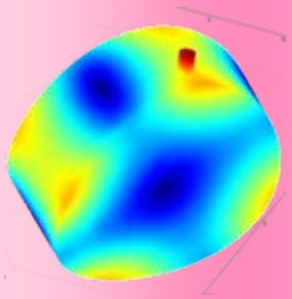


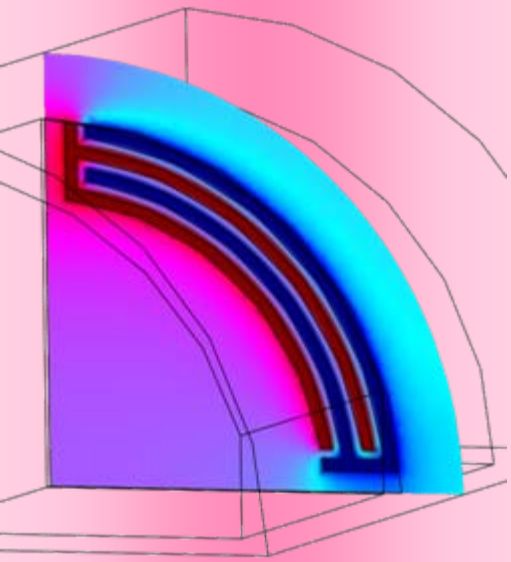
LASTI prototype compensation plate

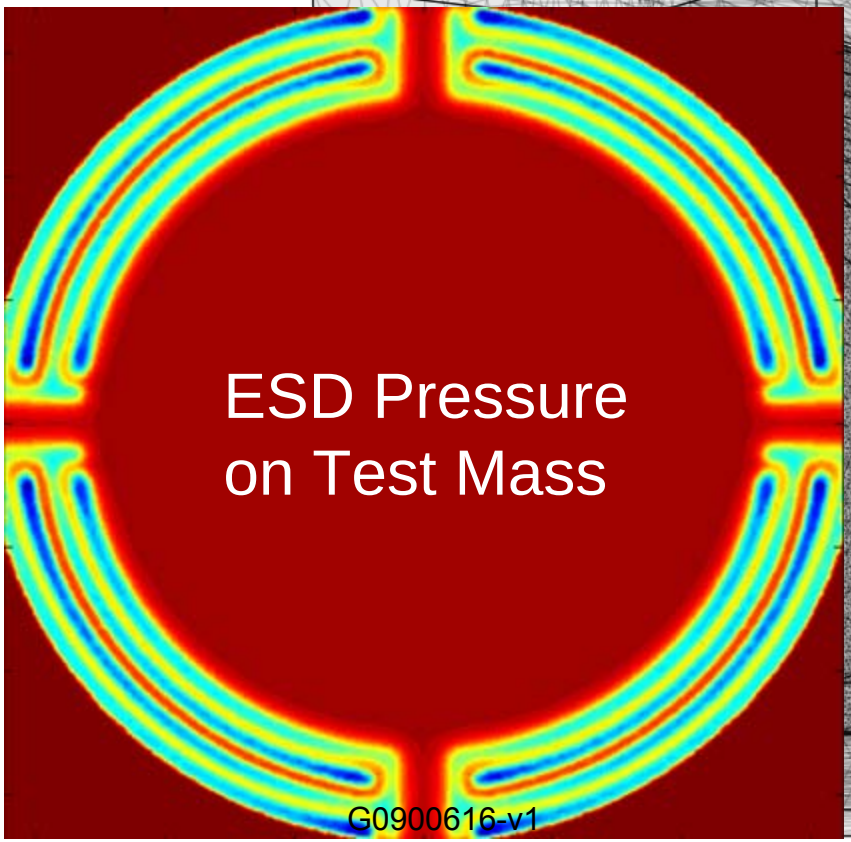
Active Damping, the FEM

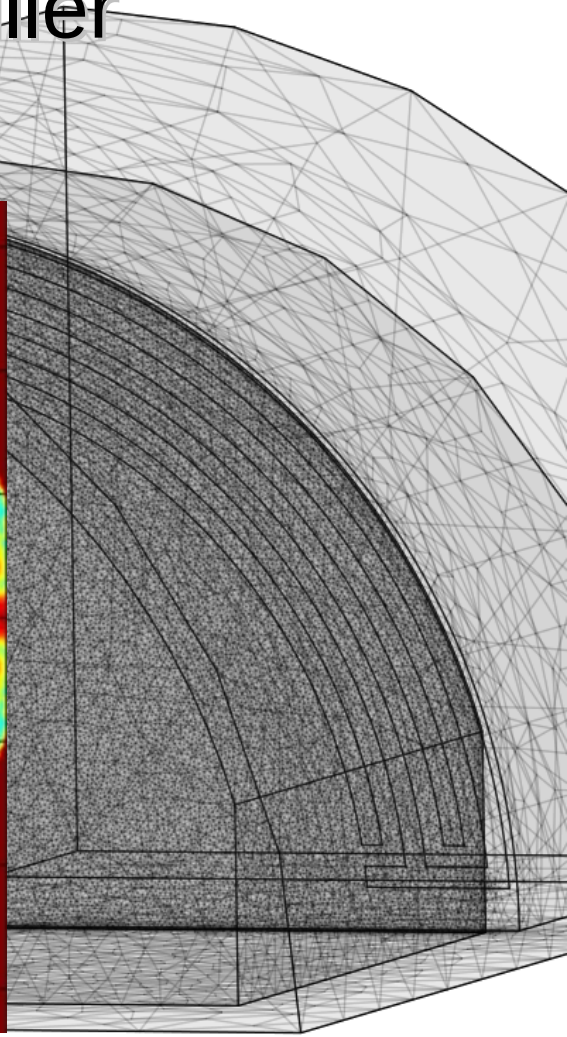
- Analysis by John Miller

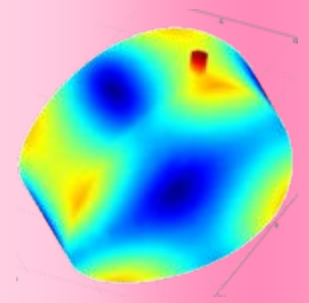


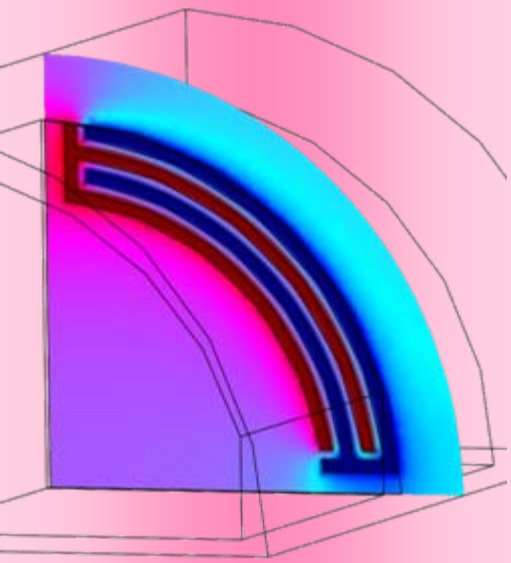






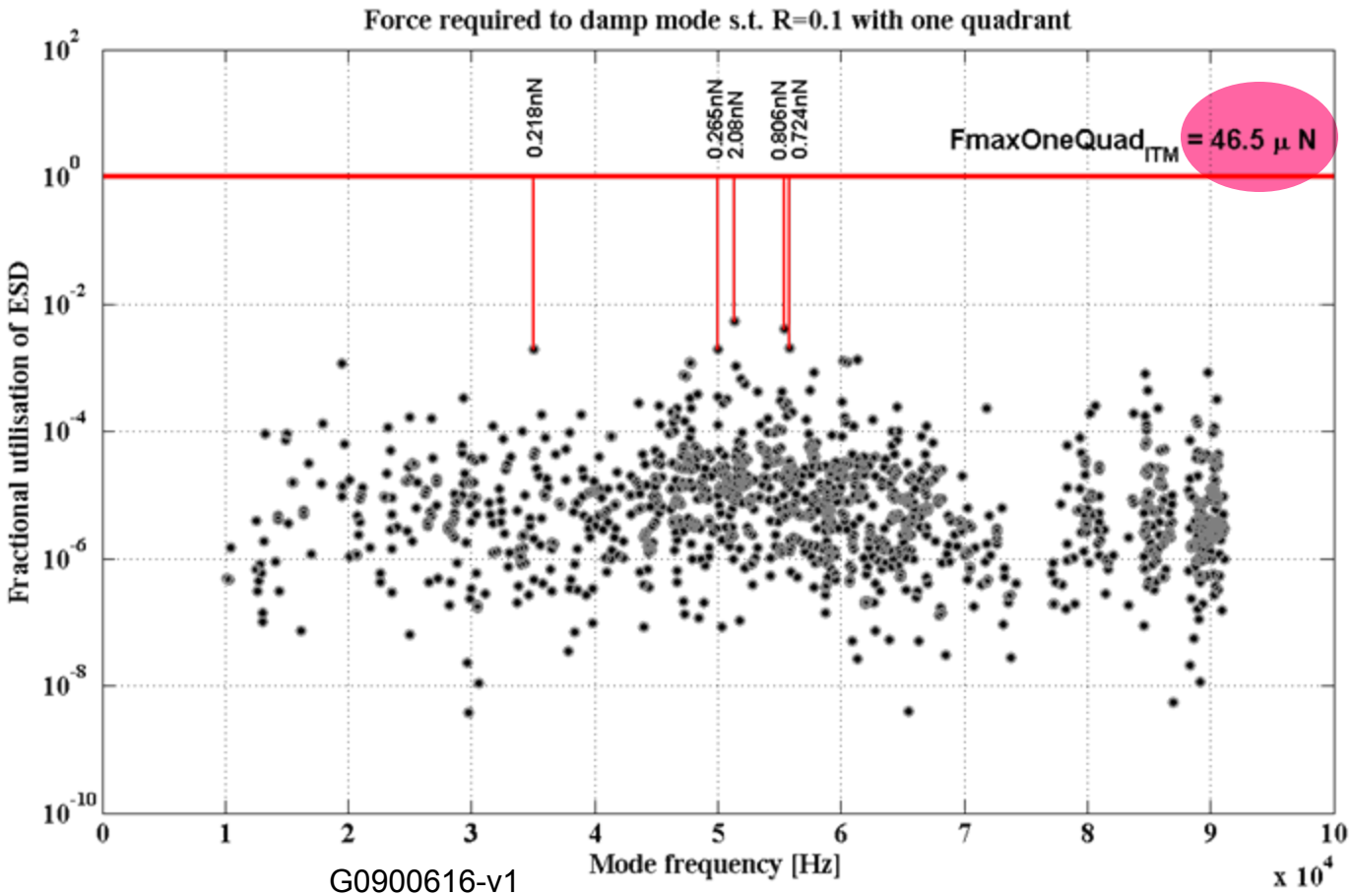


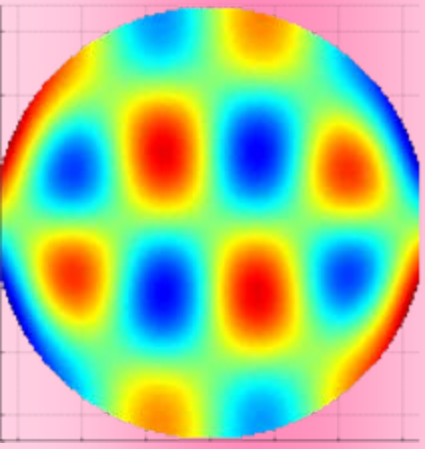


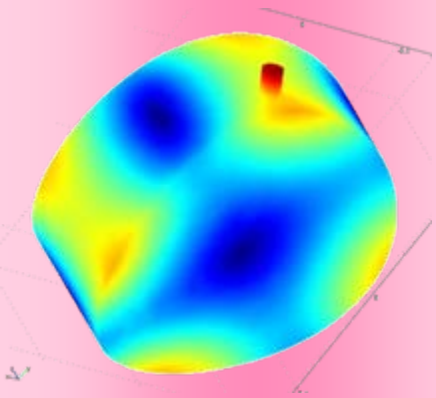


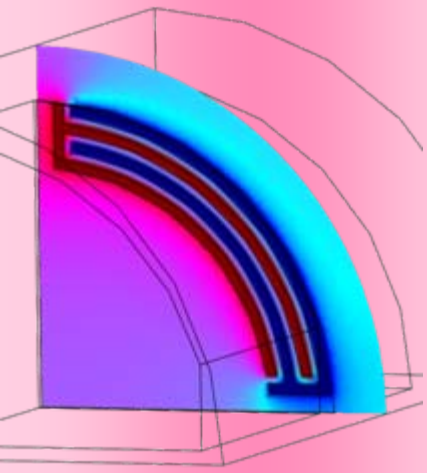
Active Damping

- All modes can be damped…



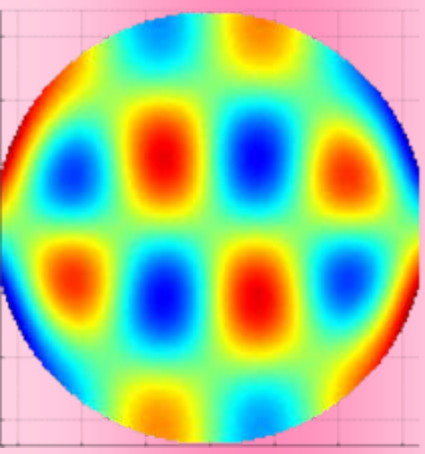


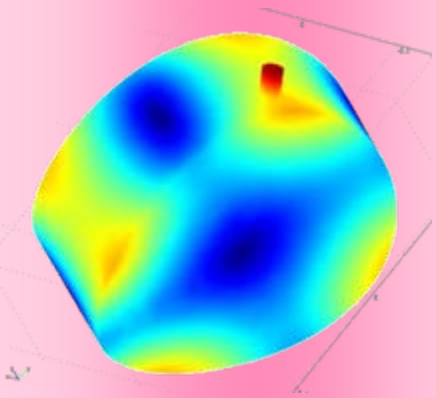


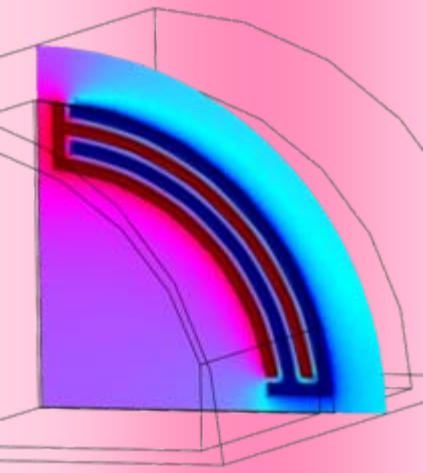


Conclusion

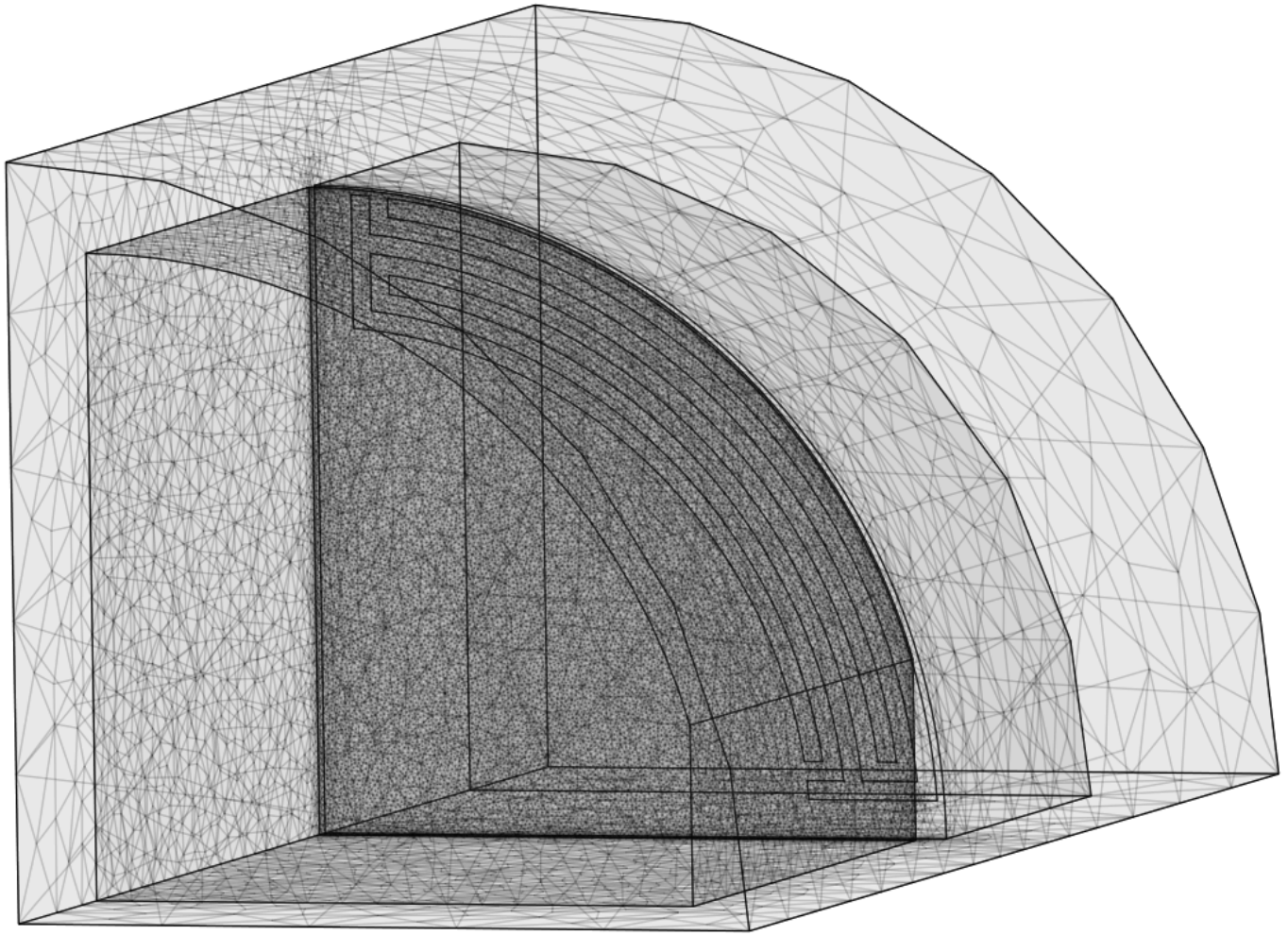
- Parametric Instability
  - Easy to understand
  - Depends on high mechanical Q
  - … which is easy to spoil
- Passive damping
  - Easy, low cost
  - No extra thermal noise
- Active Damping
  - No added hardware
  - May be time consuming







The End



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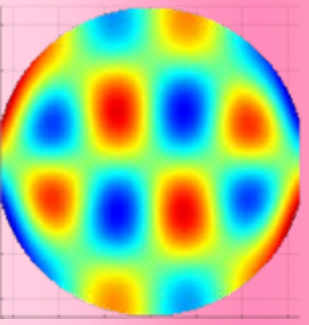
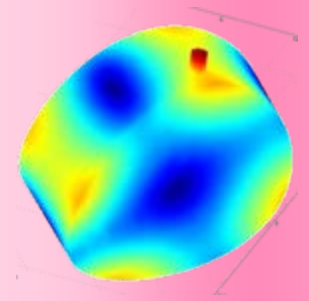
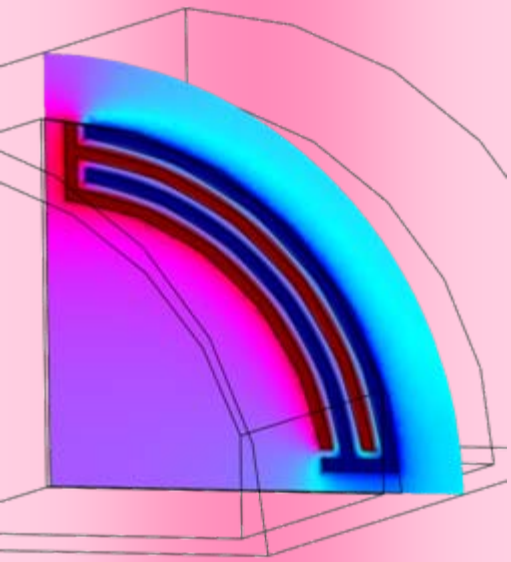






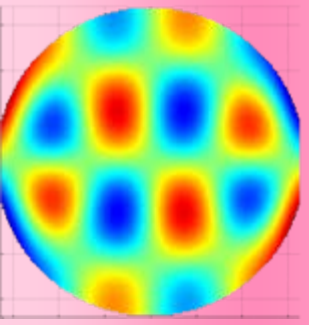
Active Damping, Force

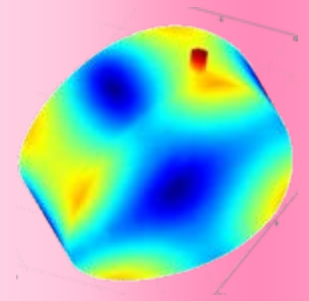
- FEM by John Miller

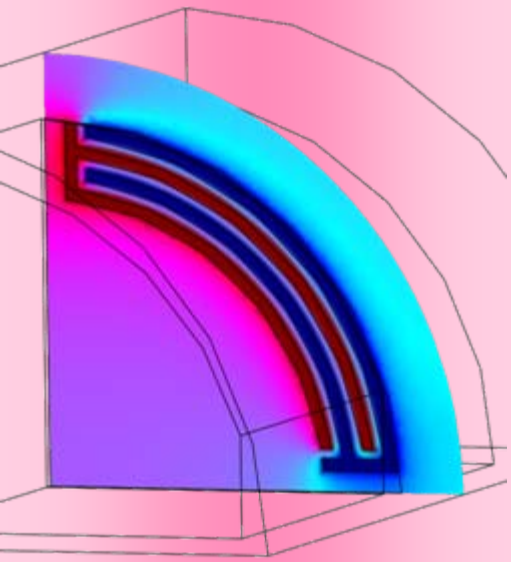
$$F_{ESD} = \frac{\omega_m^2 \cdot M_m}{\Gamma_m \cdot Q_m} \cdot x_m^{rms}$$

for thermal excitation…

$$= \frac{\omega_m}{\Gamma_m \cdot Q_m} \cdot \sqrt{M_m k_B T}$$

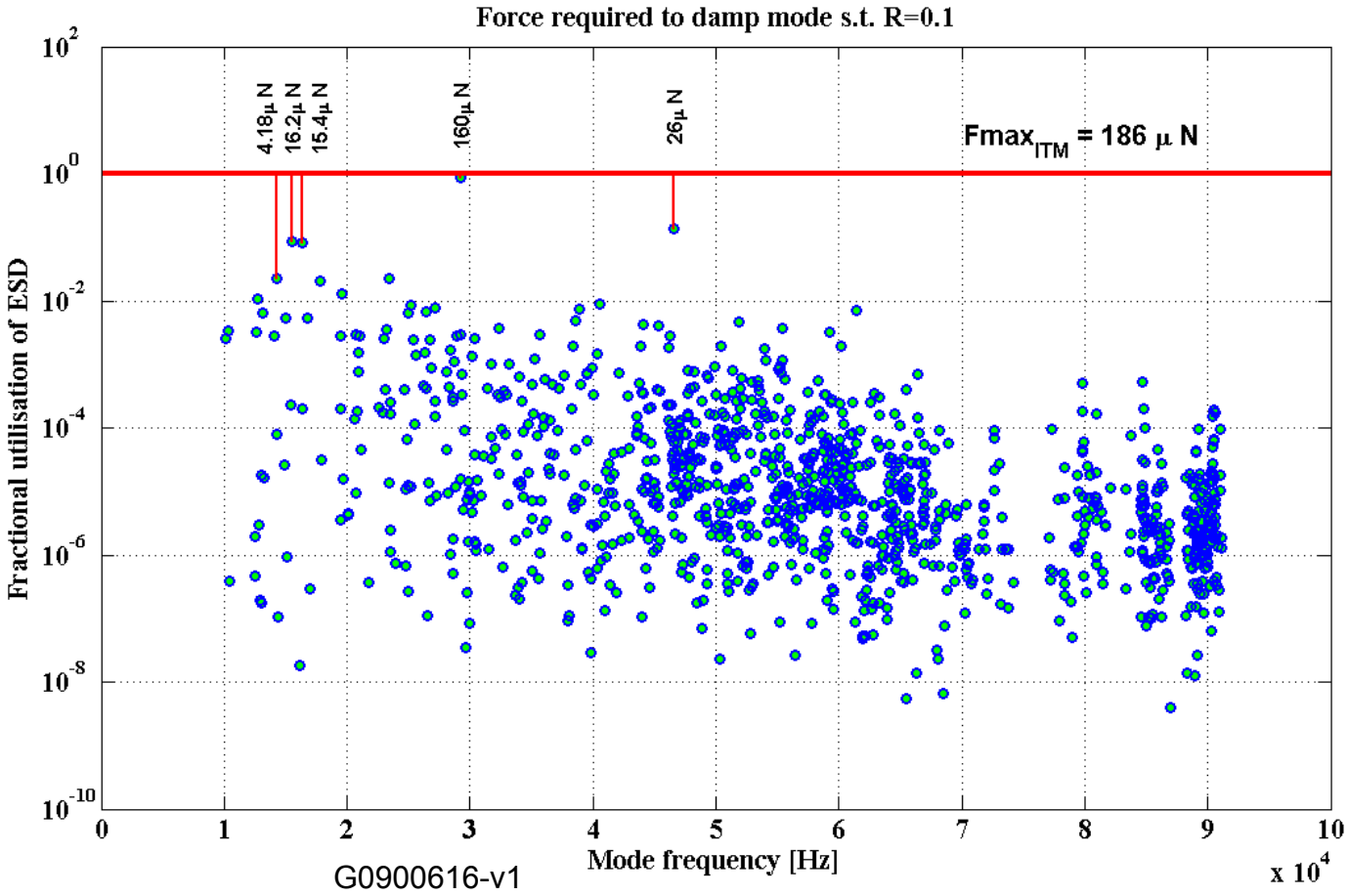


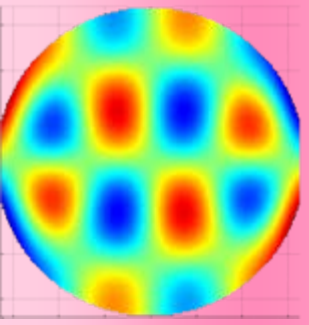


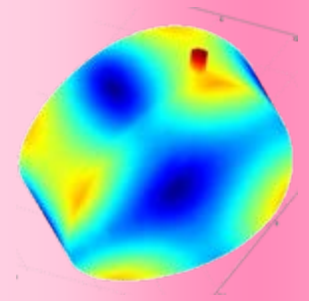


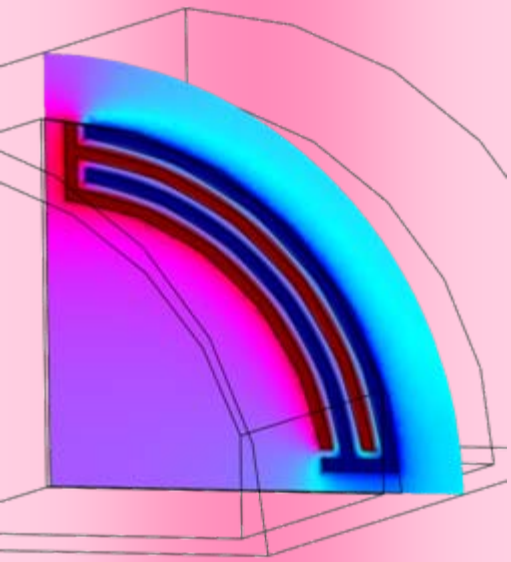
Active Damping, Force

- If you use all for ESD quadrants



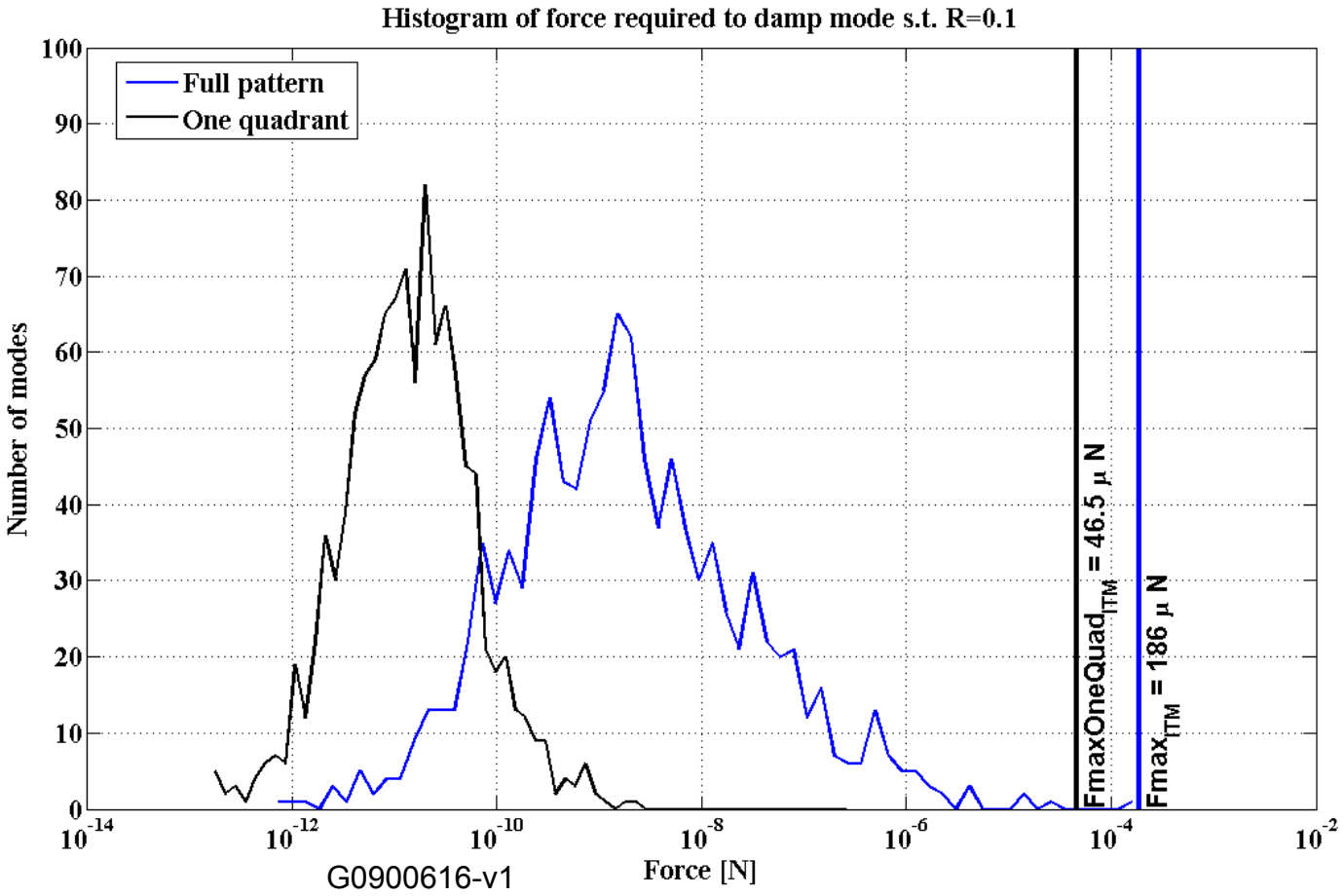


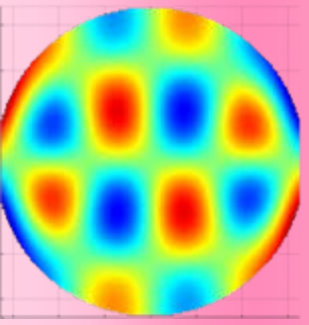


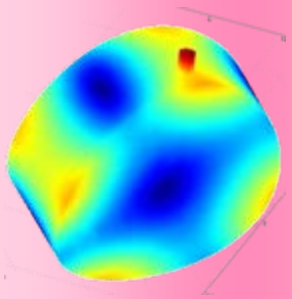


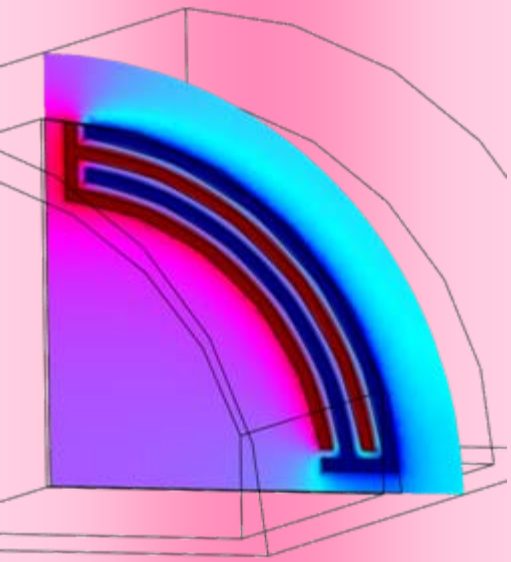
Active Damping, Force

- All quads, or just one?



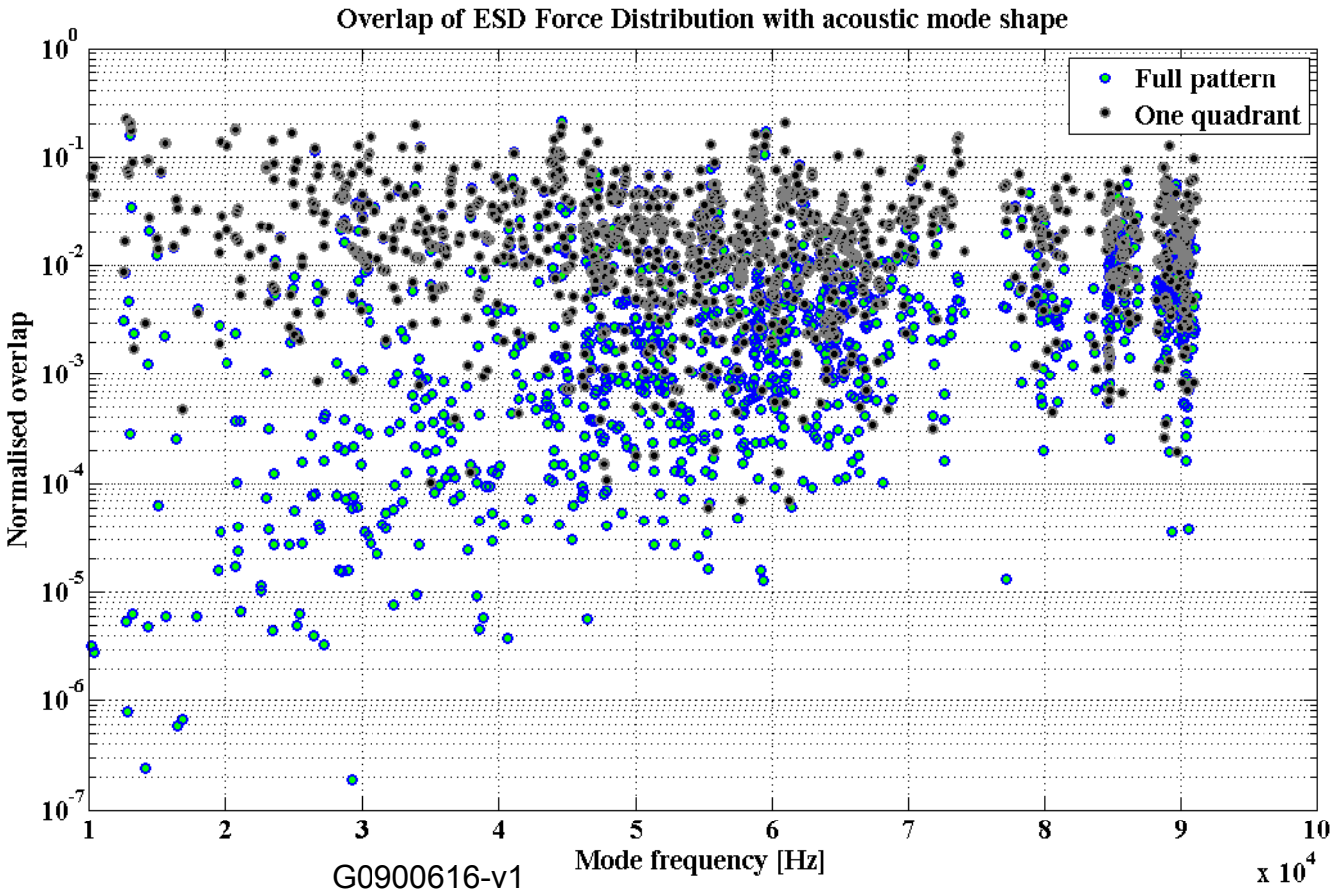


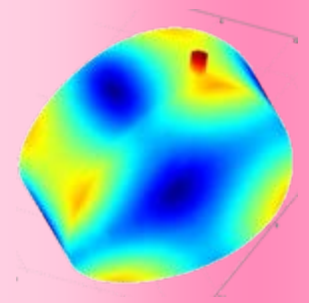


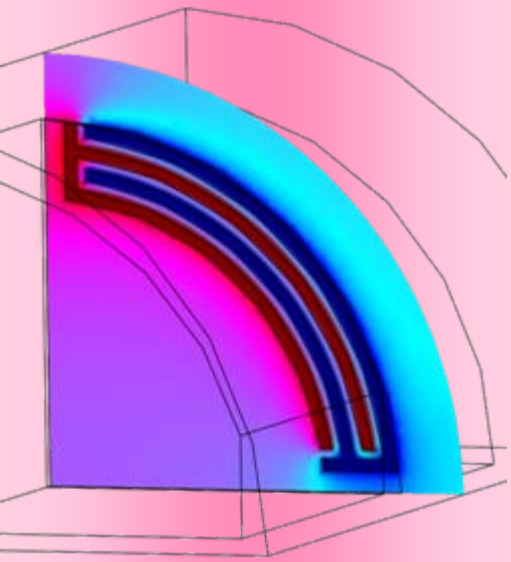


Active Damping, Force

- All quads, or just one?







Active Damping, ETM ESD

- ETM ESD pattern
  - To be changed