TES pixel optimization for the ATHENA X-IFU instrument

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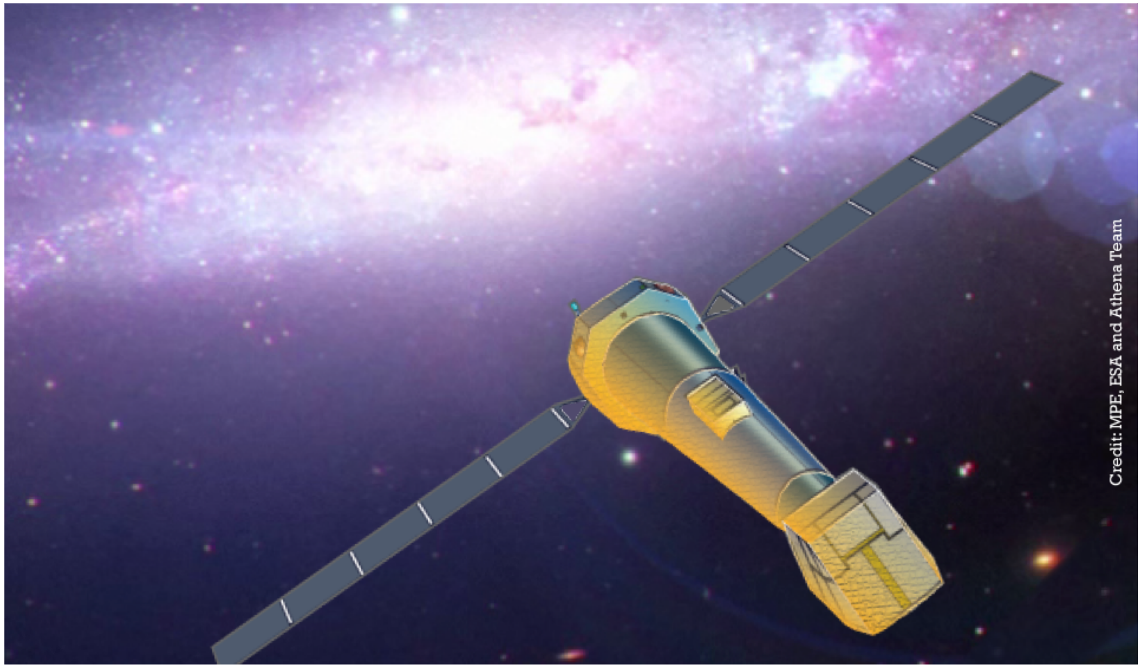
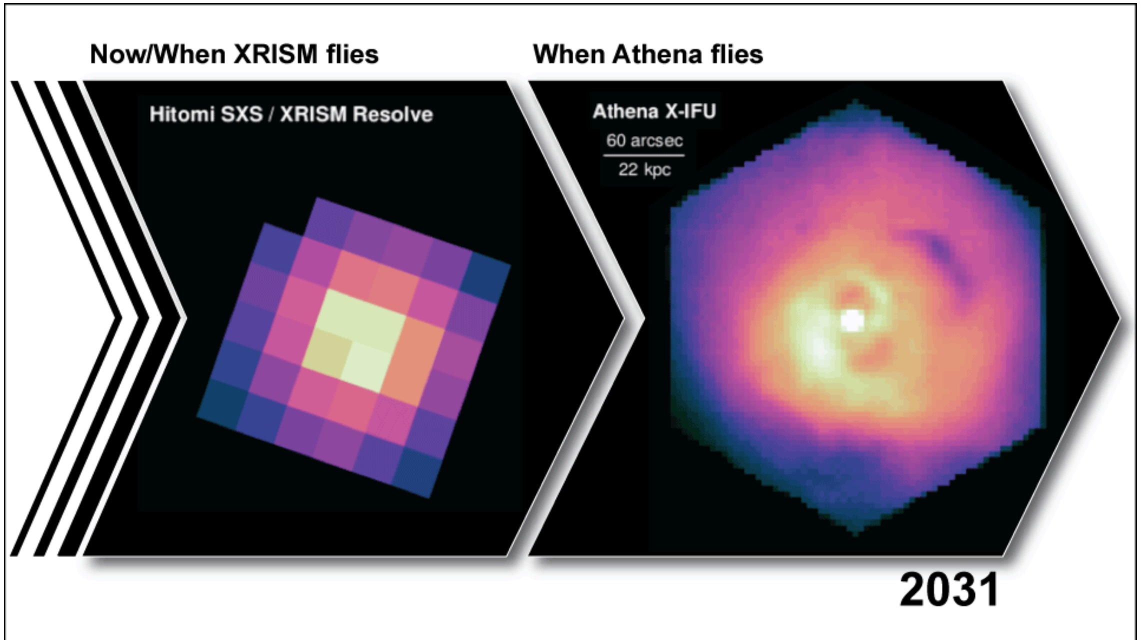
ATHENA

ATHENA is a European led x-ray observatory due for launch in the early 2030s

- The X-ray Integral Field Unit (X-IFU) instrument on ATHENA will have an array of 3168 TES microcalorimeters
- 2.5 eV resolution (at 7 keV)
- 5 arc second angular resolution and a 5 arc minute field of view
- As one example, will allow unprecedented views of composition and dynamics of galaxy clusters



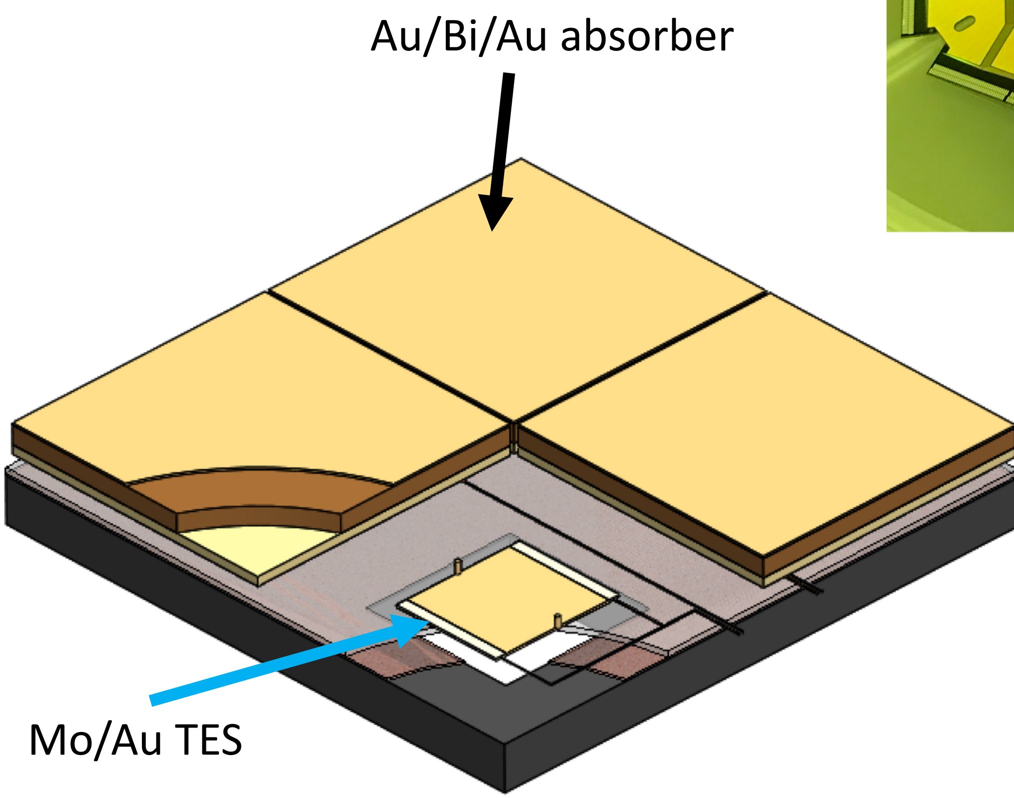
Bulk velocity in Perseus galaxy cluster

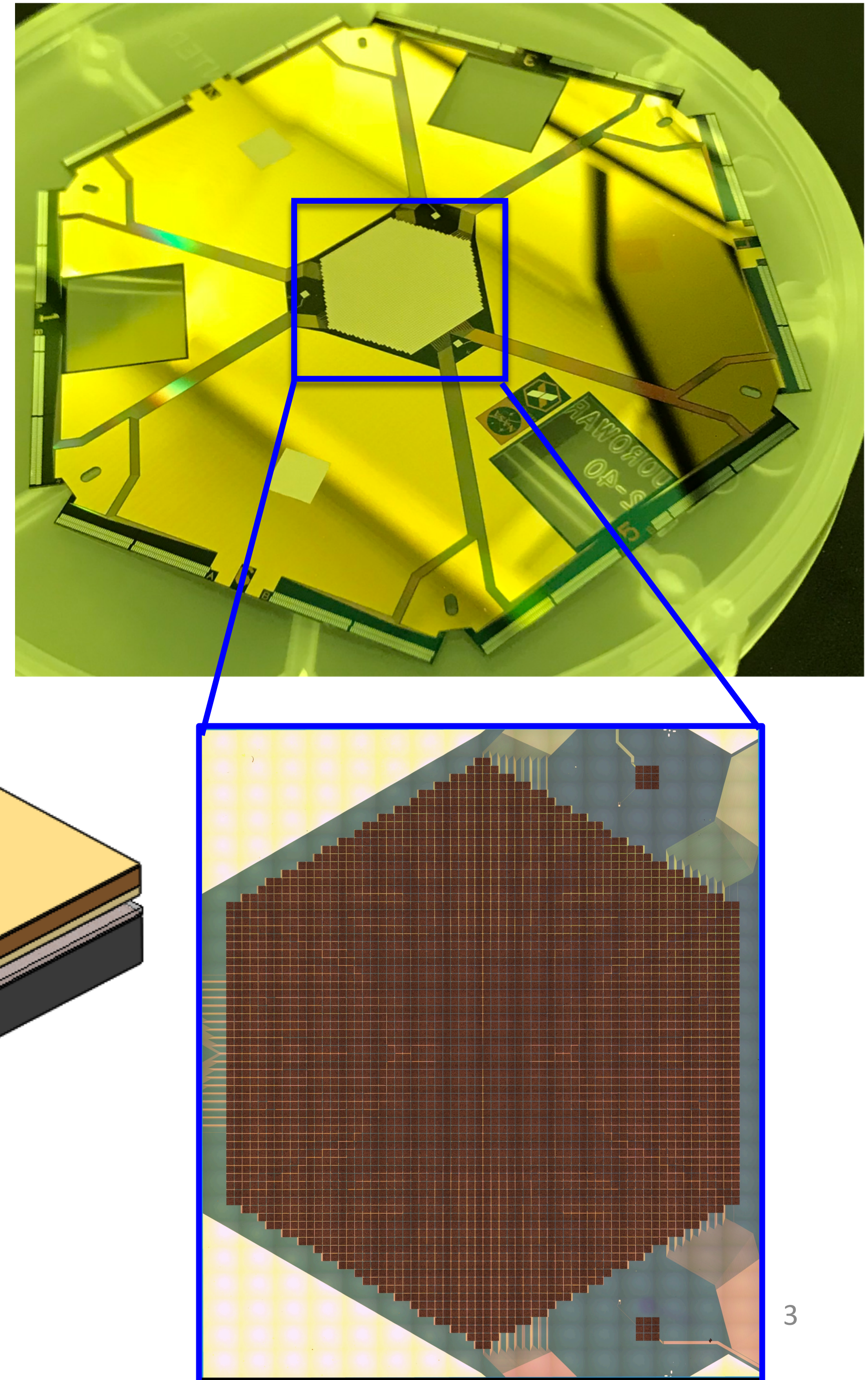


Credit: Jeremy Sanders (MPE), Composition: ACOTeam

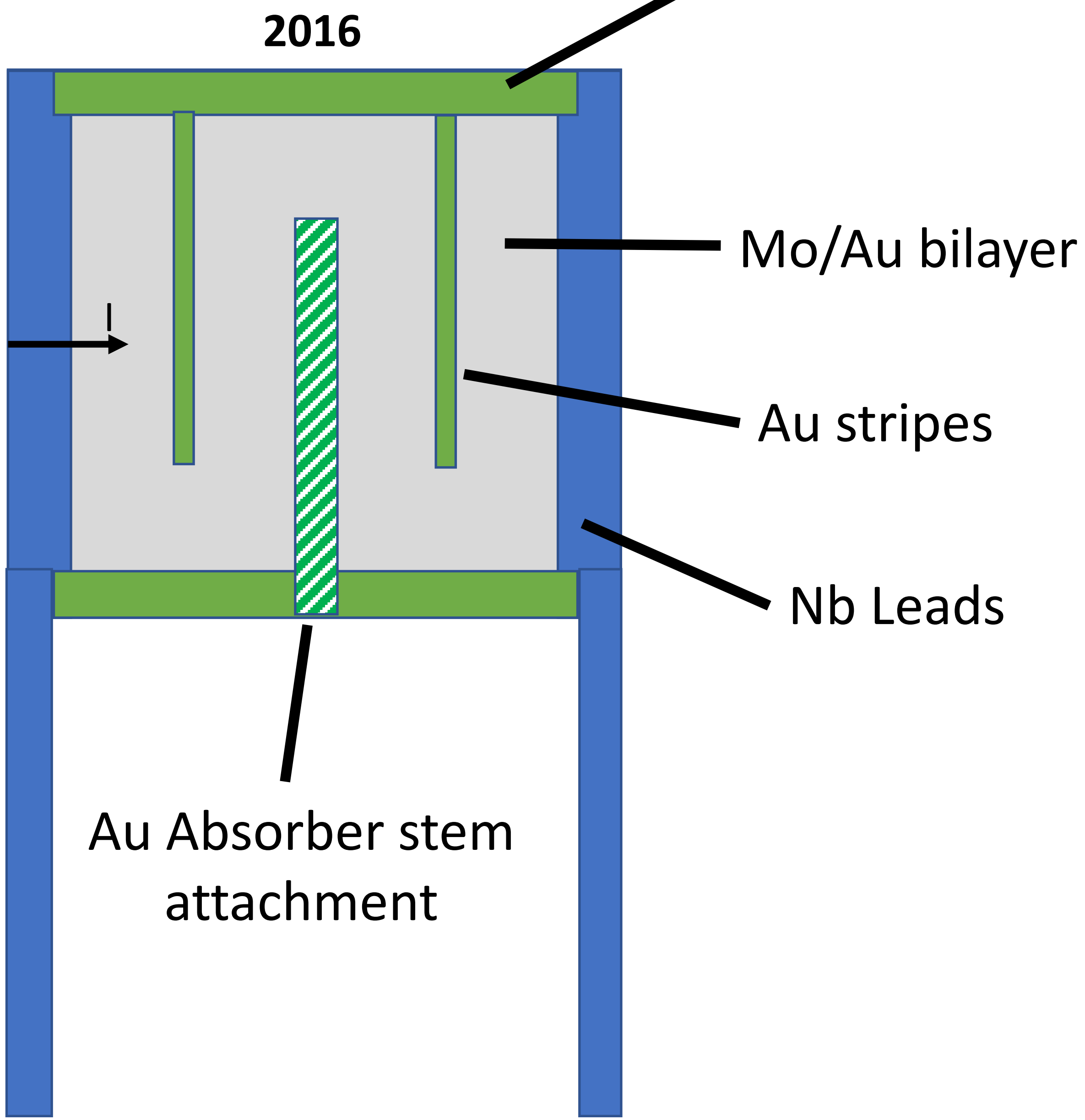
X-IFU Detector array

Hexagonal array of 3168 TES microcalorimeter pixels





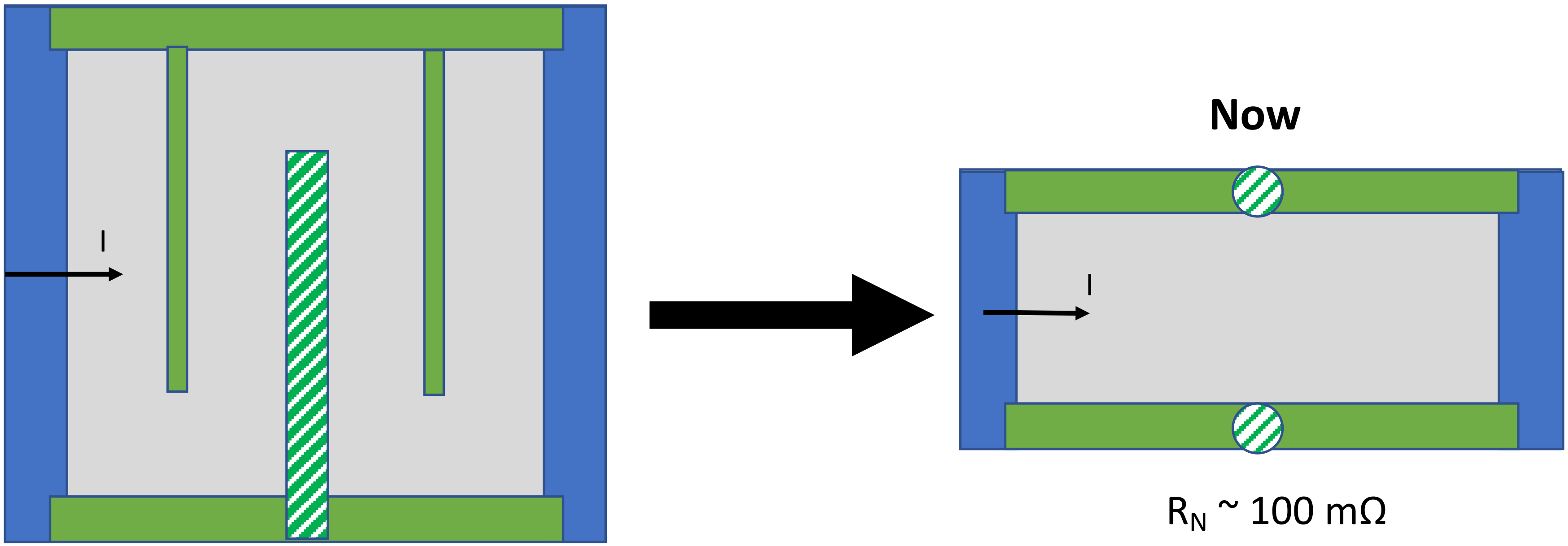
Focus on TES design



Focus on TES design

2016

Now



R_N ~ 100 mΩ

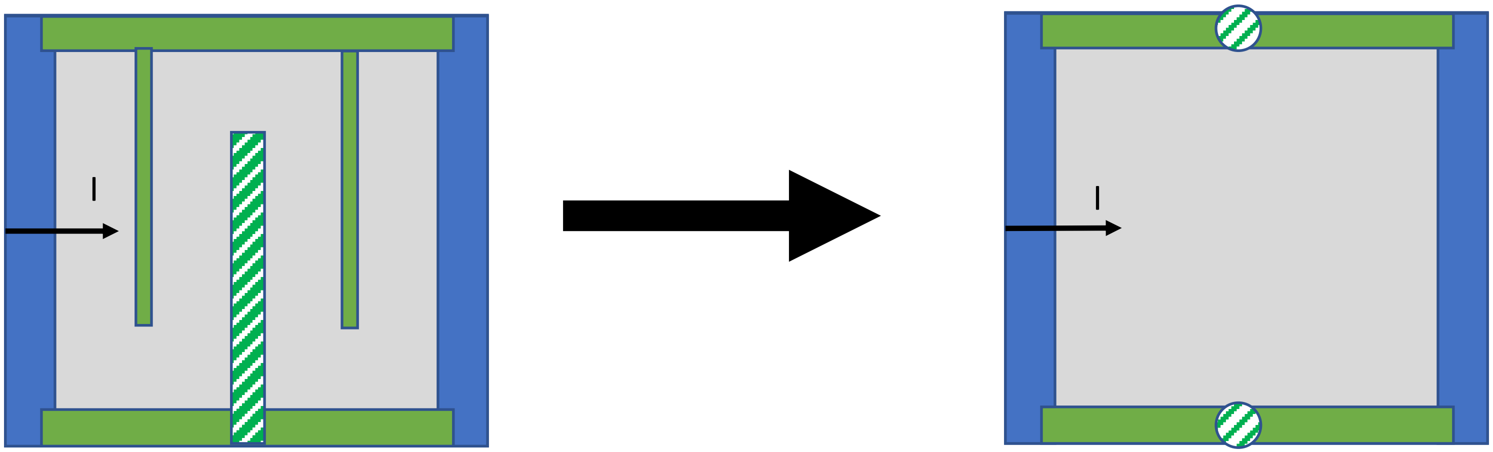
R_N ~ 10 mΩ

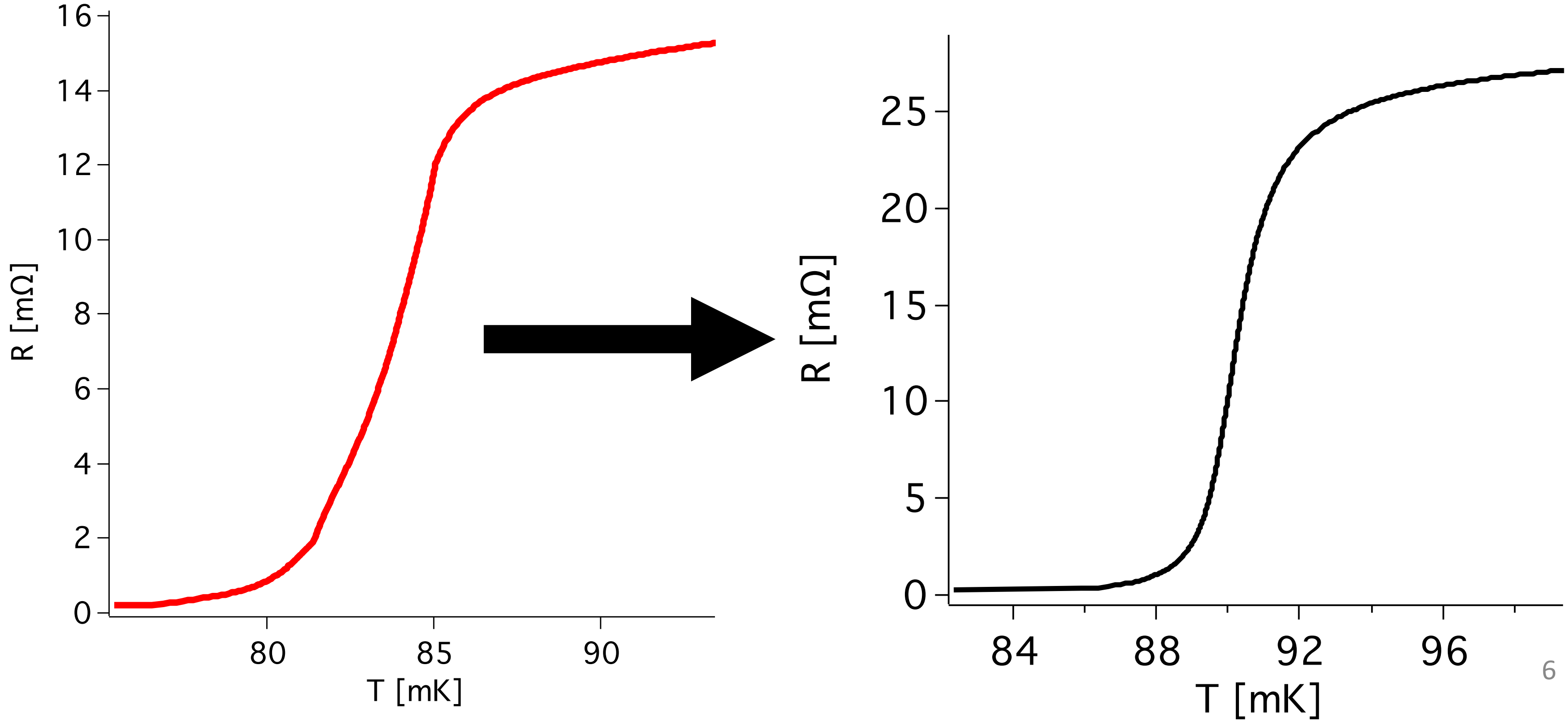
Over the last few years the TES design has evolved:

1. Removed stripes
2. Increased bilayer sheet resistance, R_s
3. Changed aspect ratio

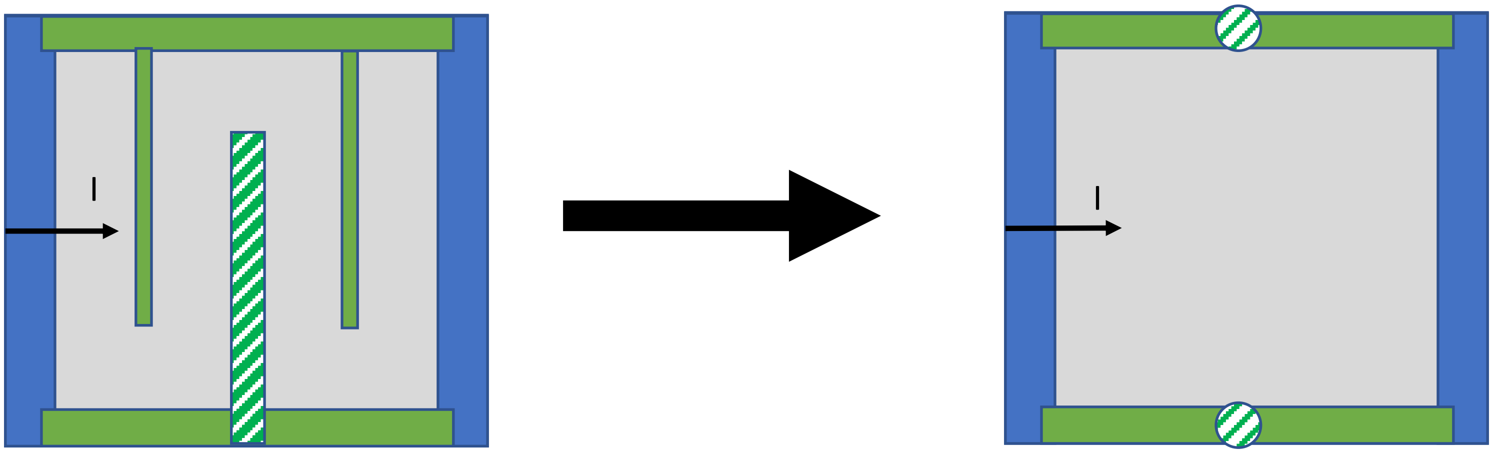
Why have we made these changes?

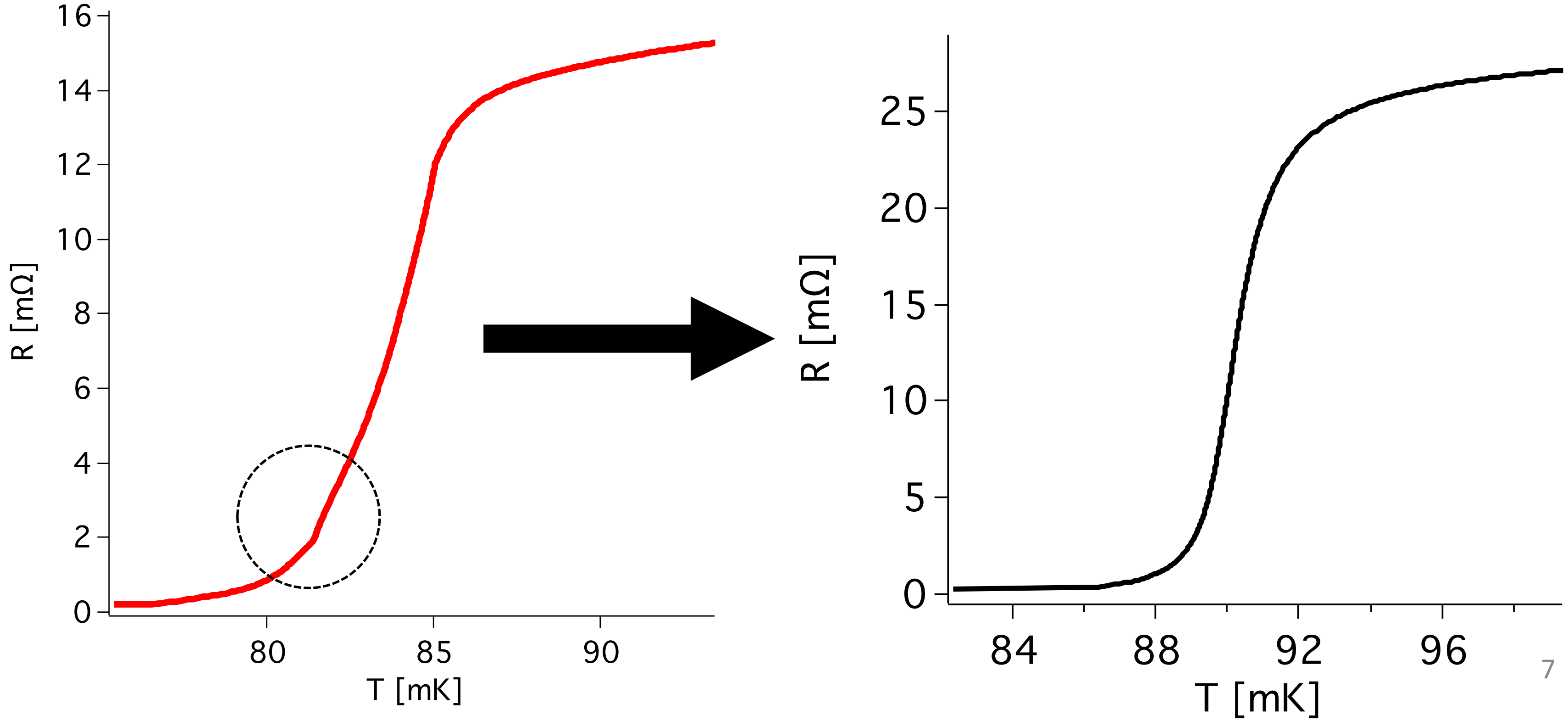
1) Removed stripes





1) Removed stripes





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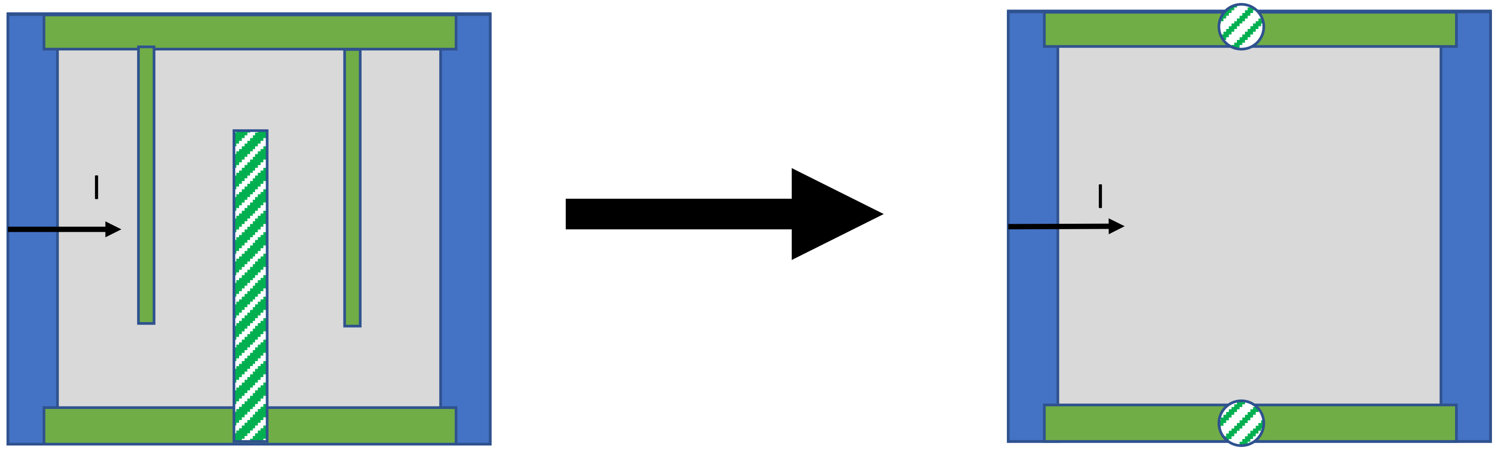

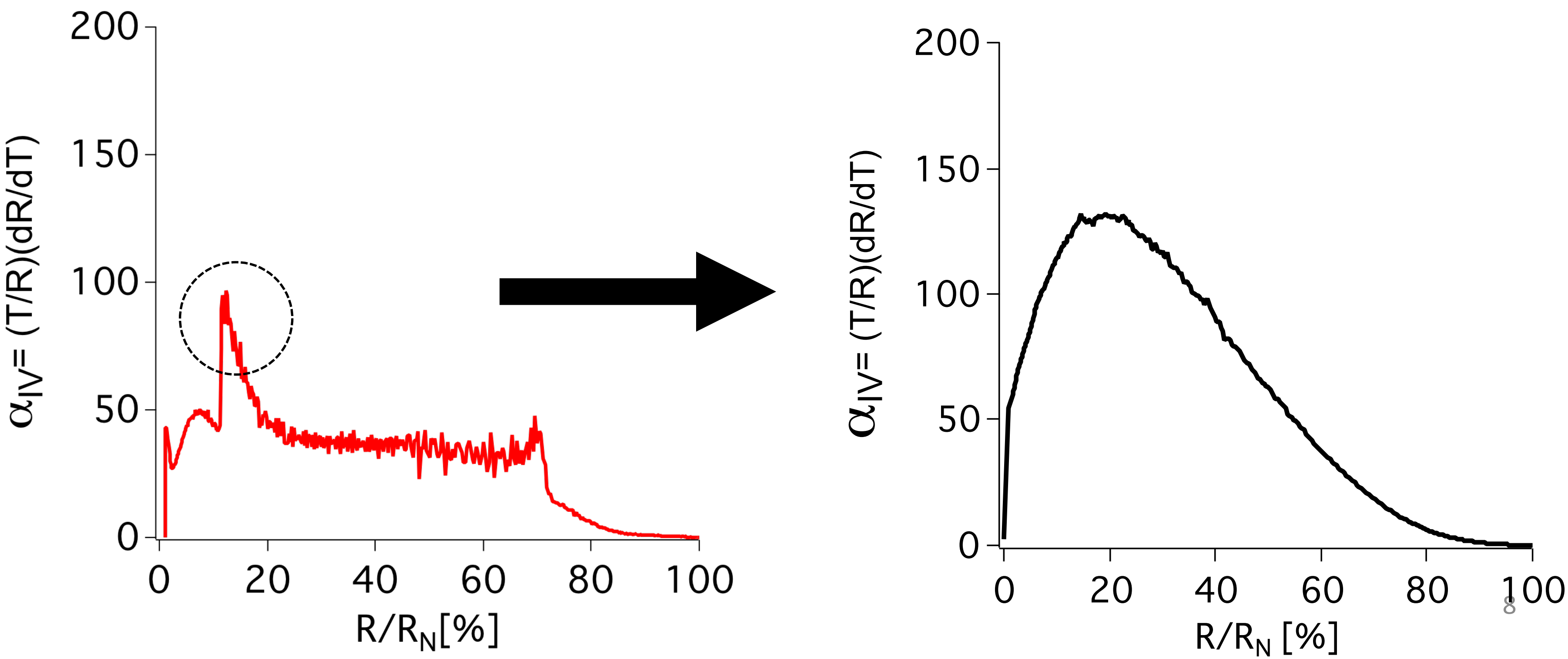

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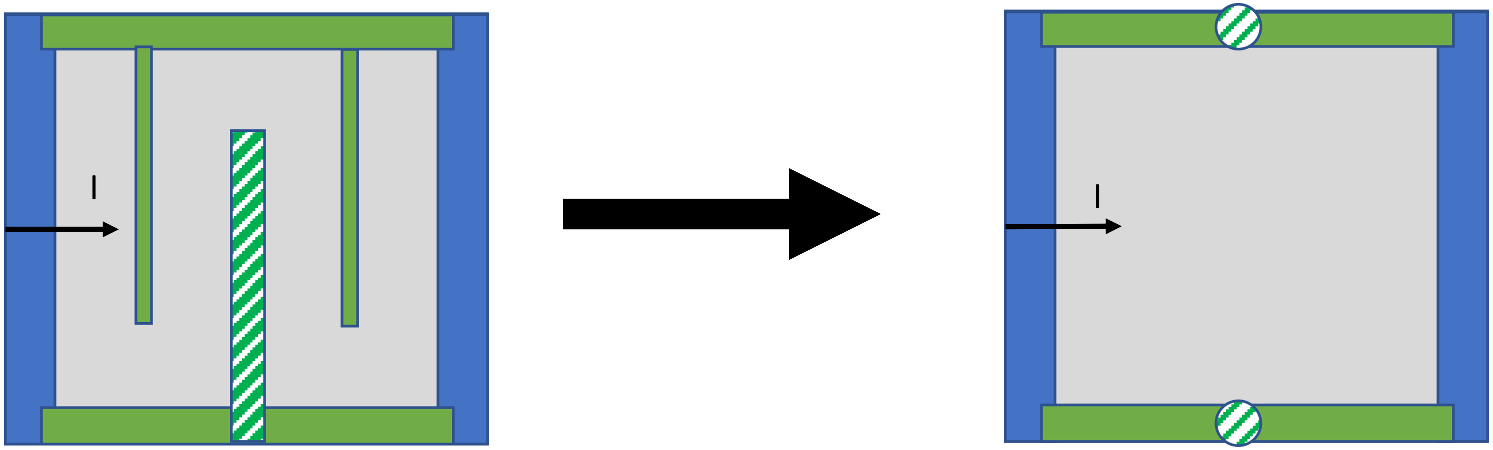
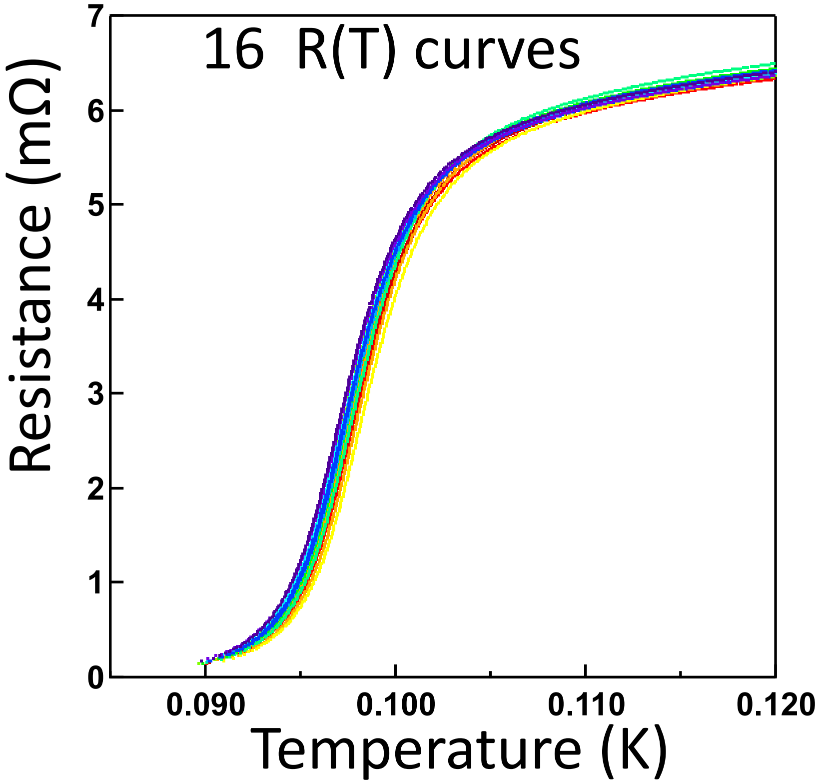
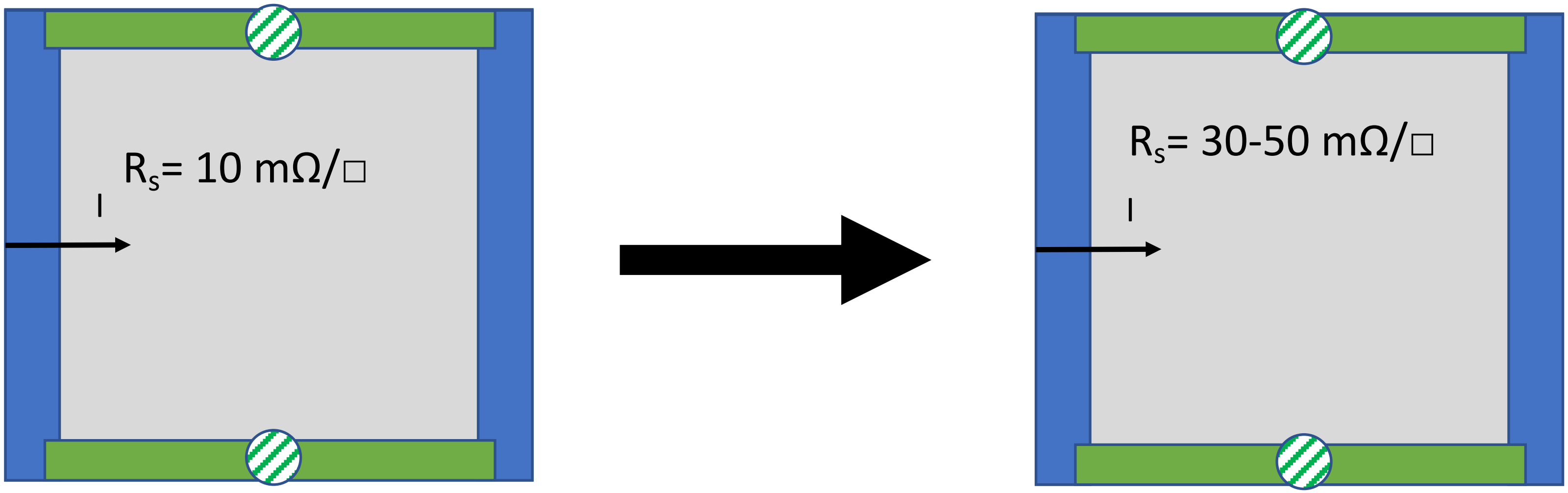


- Improved transition shape
- Improved transition uniformity
- Attributed to changes in magnetic field dependence

Wakeham et al. J. Low Temp. Phys. 193, 231 (2018)



2) Increased R_s



- Multiplexed readout scheme for X-IFU is Frequency Division Multiplexing (FDM)

- Pixels are biased using an Alternating Current (AC) with a different frequency for each pixel in a column

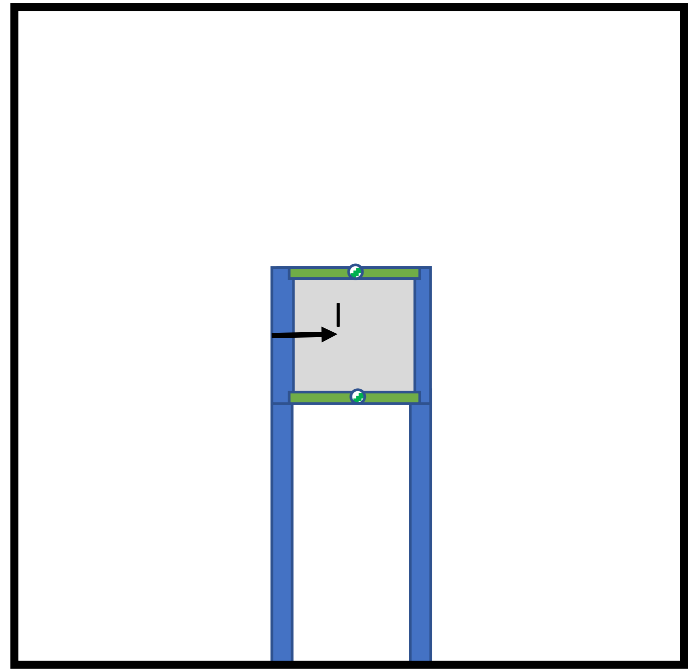
- AC bias frequency range ~1-5 MHz

- Devices originally designed for DC Bias
- AC biasing has a significant effect on the behavior of the TES.
  - Particularly in two ways : a) AC loss
    b) Josephson Oscillations

2) Increased R_s

a) AC loss

- AC induces eddy currents in the normal metal regions causing dissipation
- Dominant effect is coupling from leads to the absorber.
- Dissipation in the absorber acts like an additional series resistor, R_{Loss}.



Sakai et al. J Low Temp Phys (2018) 193: 356.

- AC loss broadens the effective resistive transition under AC bias - reduced performance
- Mitigation strategy is to increase R_s and therefore R_N
- R_{Loss} is then a smaller fraction of R
- Therefore, predicted to have less impact on the transition

2) Increased R_s
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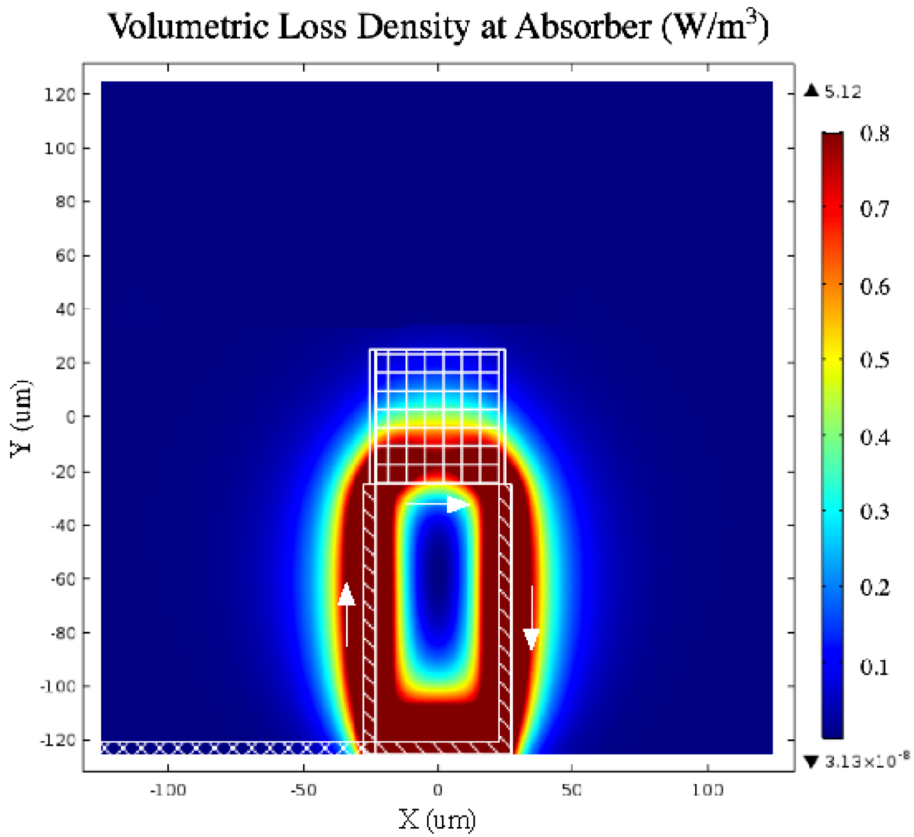

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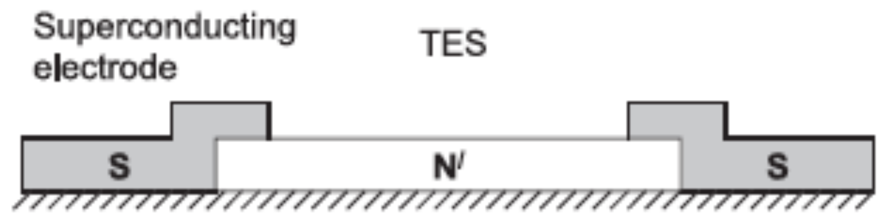
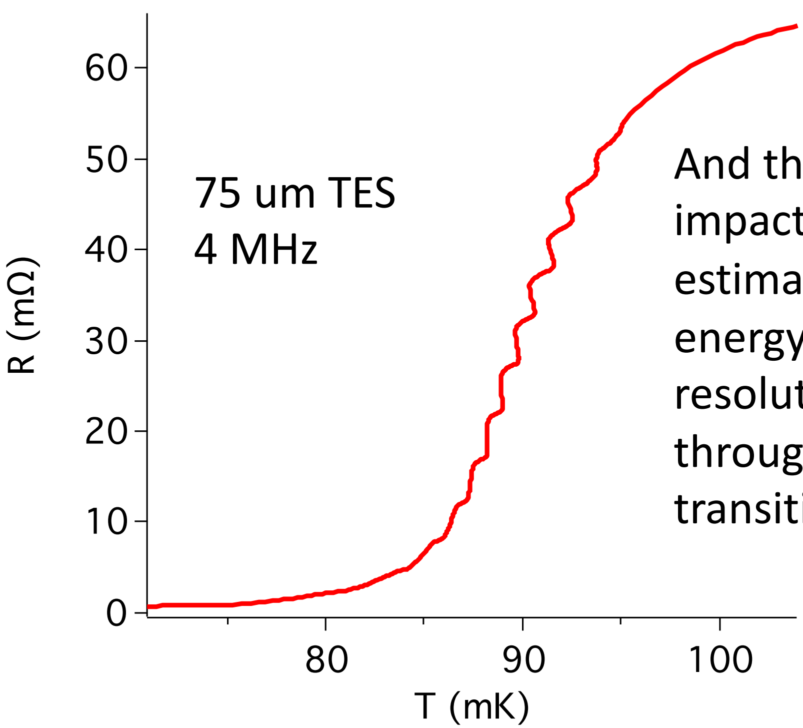
2) Increased R_s
b) Josephson Oscillations

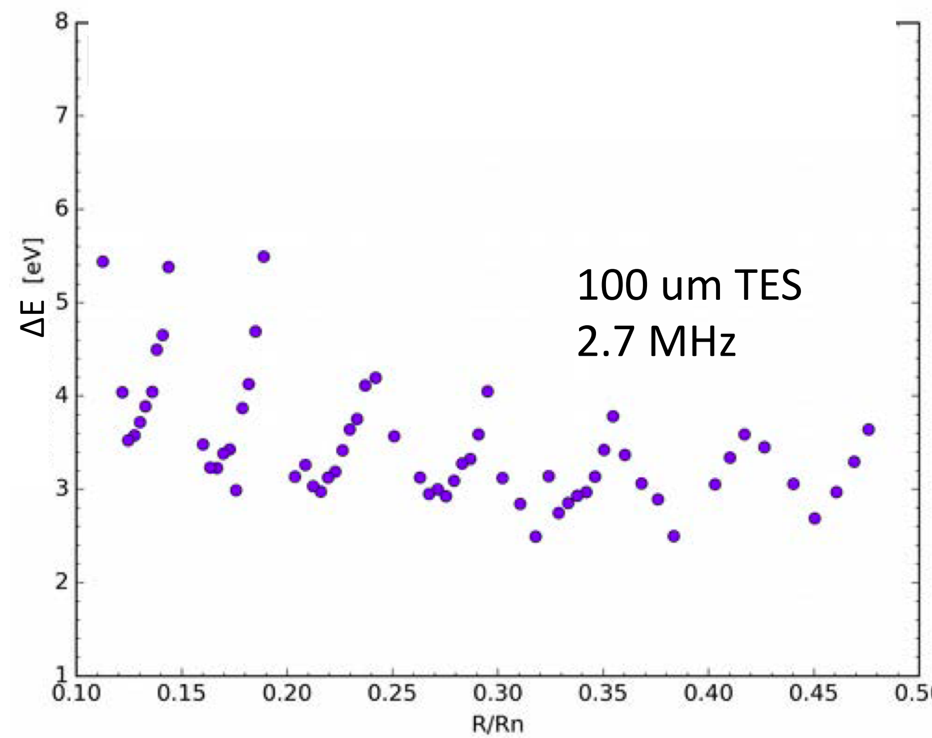
- Because of the superconducting leads the TES behaves as a Josephson junction



- Therefore under AC bias TES cannot just be treated as a purely static resistive component
- This manifests as oscillatory features in the R(T) curves – **POSTER: L. Gottardi 79-97 Tues**



And this impacts the estimated energy resolution through the transition

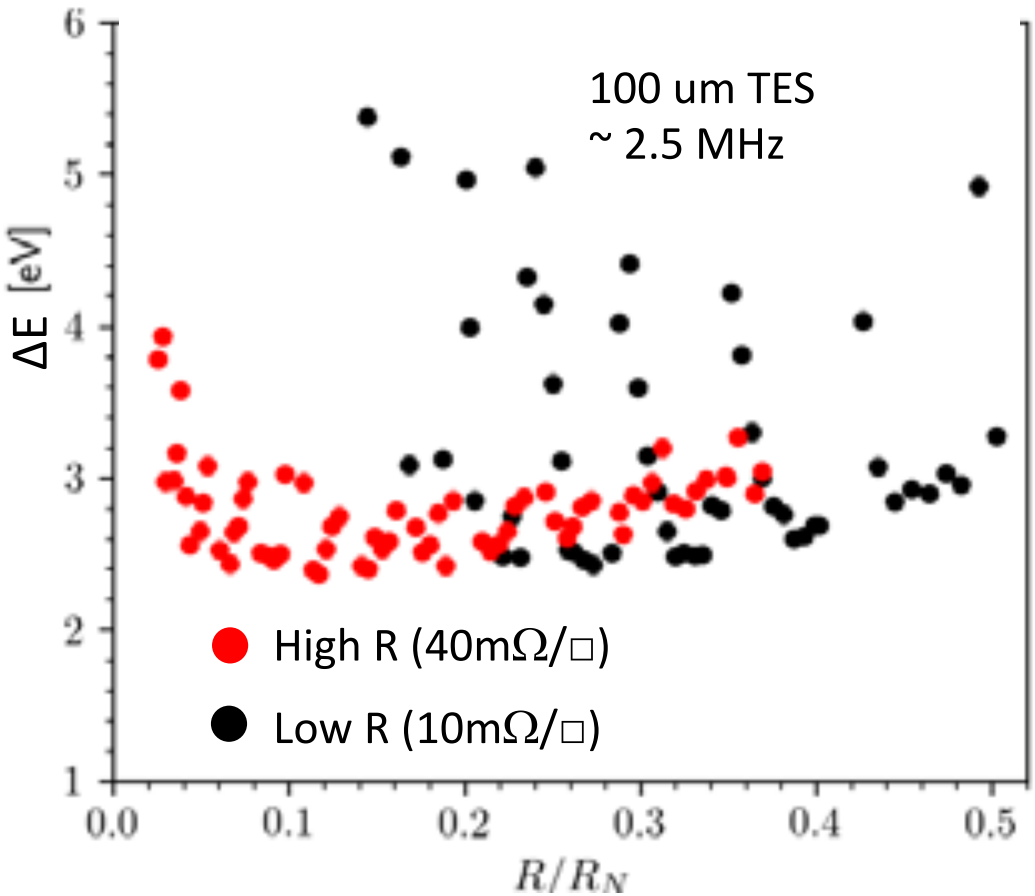


2) Increased R_s

b) Josephson Oscillations

Strength of these oscillations is predicted from RSJ model to scale with $1/\sqrt{(P_{Joule}R_N)}$
Gottardi et al. J Low Temp Phys (2018) 193: 209

Therefore by increasing R_s (and R_N) we reduce the amplitude of the oscillations
POSTER: L. Gottardi 64-99 Thursday



Two-body model

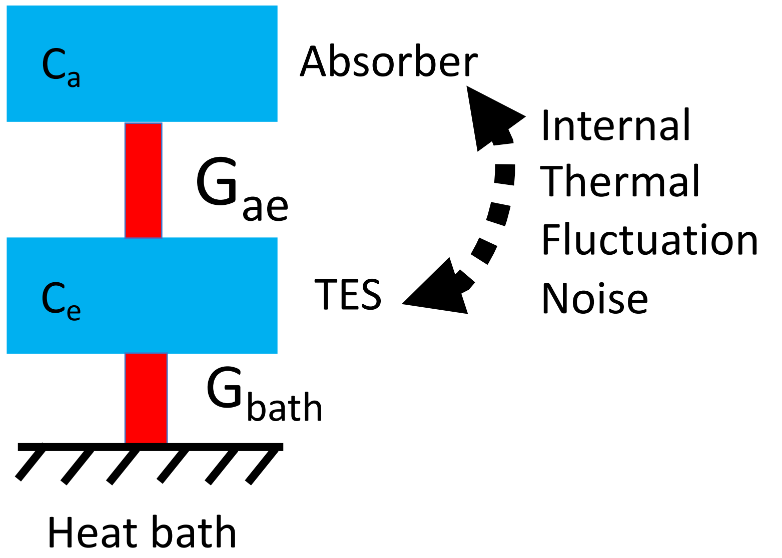
Shown experimentally under DC bias small noise penalty for this R_s increase

Using a two-body electro-thermal model we've shown:

- Internal thermal fluctuation noise between the TES and the absorber is significant

- Thermal conductance of the TES bilayer (and therefore R_s) is important

Wakeham et al. J. Appl. Phys 125, 164503 (2019)



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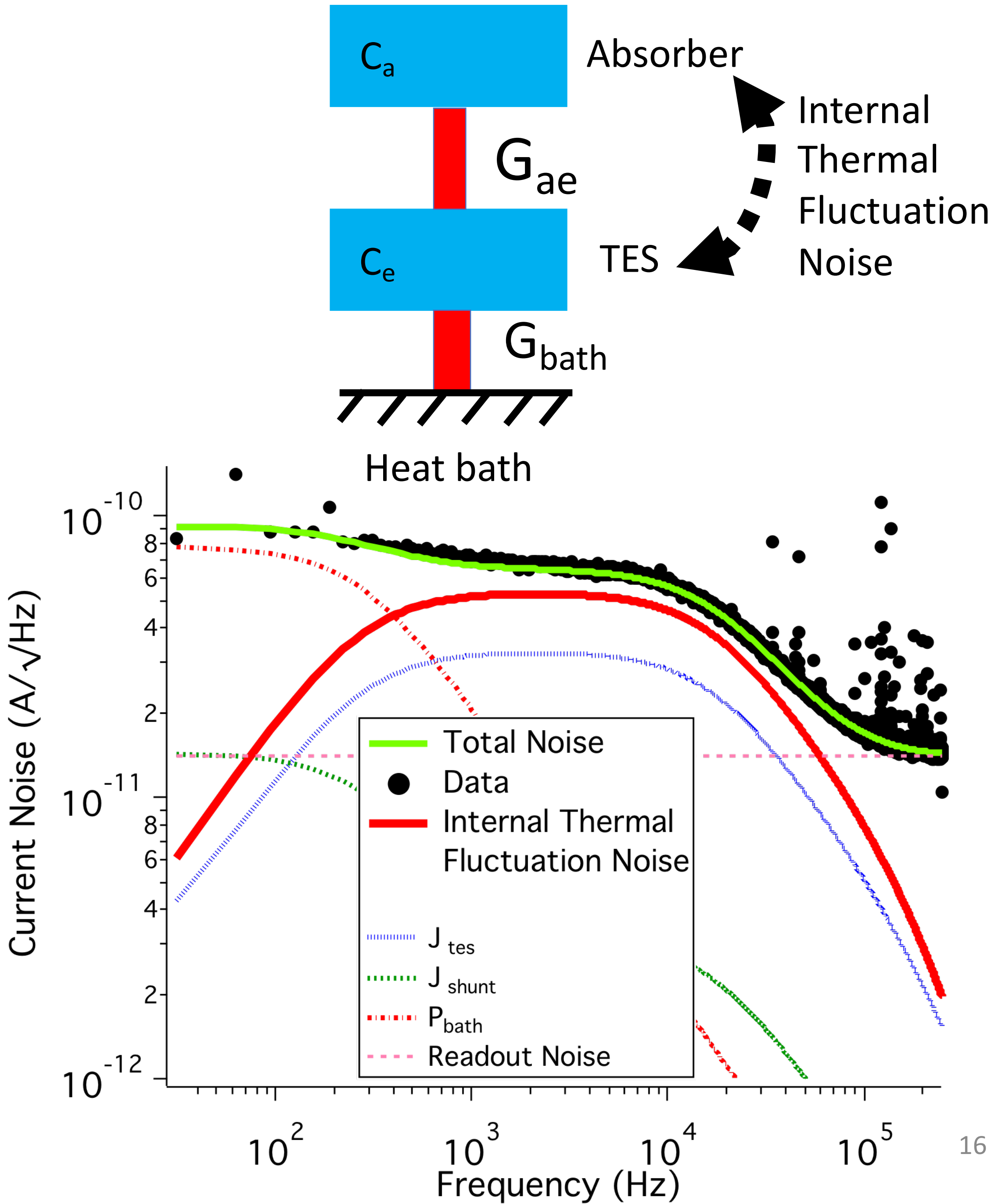
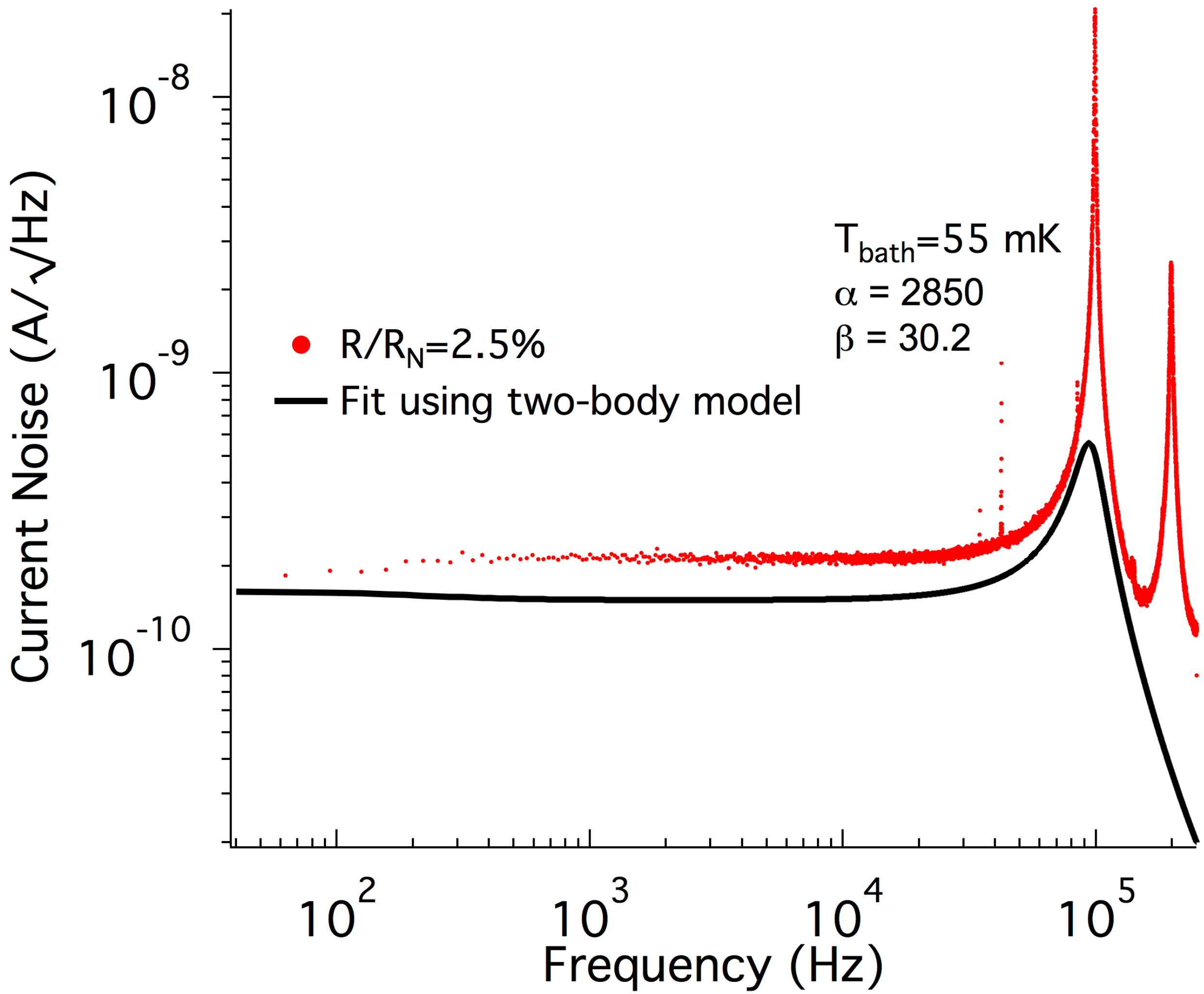


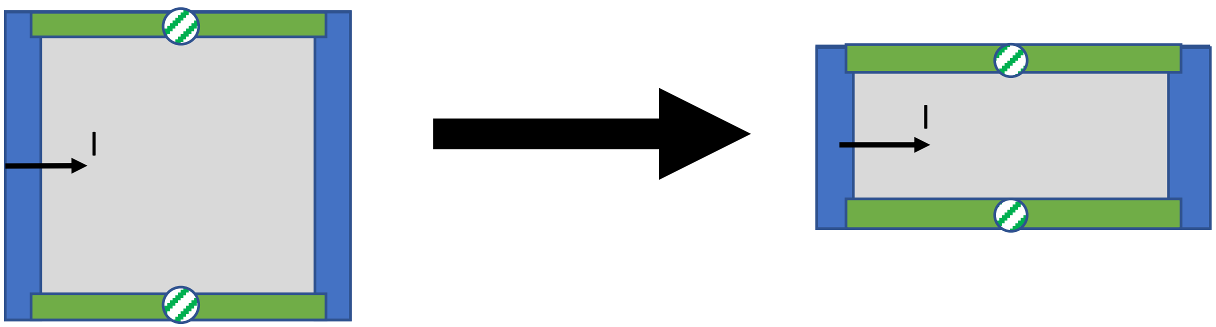
Two-body model

We have recently observed in extreme cases this can give rise to noise peaks
This can be qualitatively explained as under damping in the two body model

Wakeham et al. Submitted to J. Low Temp. Phys.



3) High Aspect Ratio



$R_N \sim 40\ \text{m}\Omega$ → $R_N \sim 100\ \text{m}\Omega$

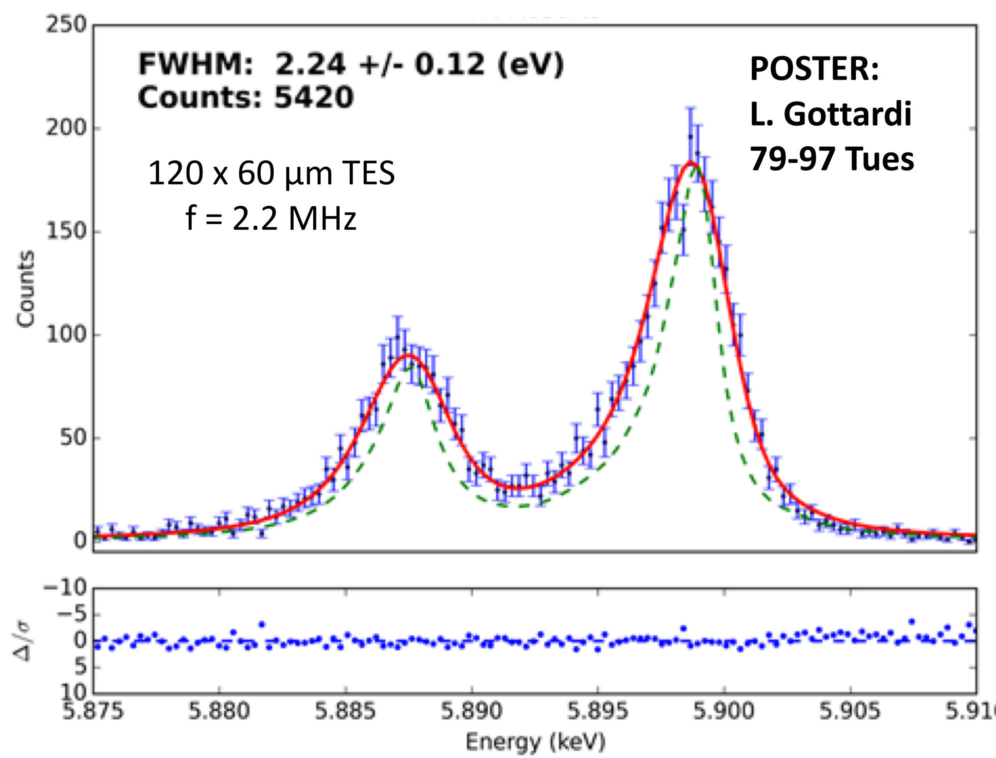
Josephson oscillation magnitude scales with $1/\sqrt{(P_{Joule}R_N)}$

R_N increase is beneficial for transition properties

But G_{bath} decreases, means P_{Joule} decreases

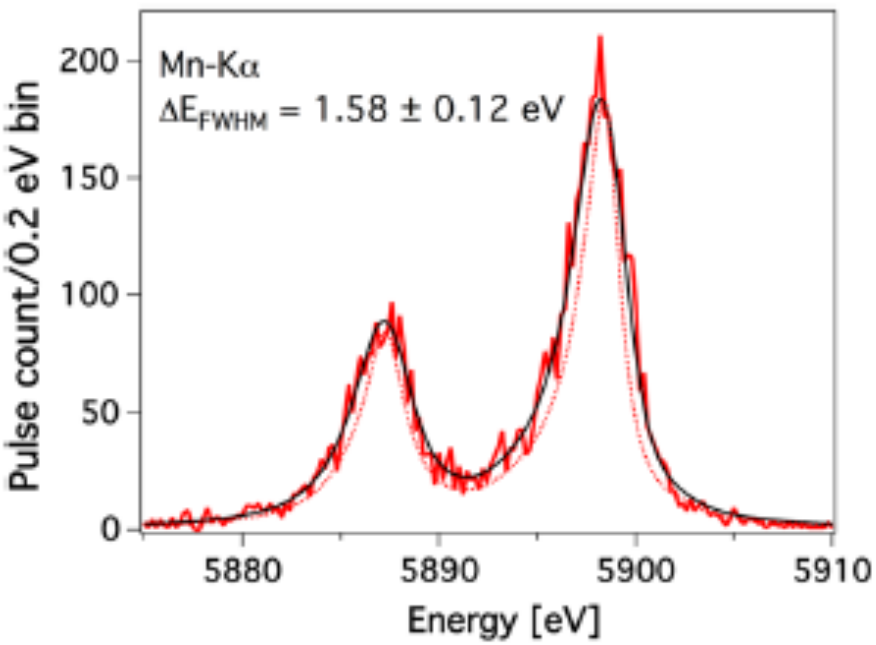
- Prediction is still net improvement
- Lower G_{bath}, pixels desirably slower
- **TALK: H. Akamatsu. Today 18:40.**

Ongoing – but already seeing excellent results from these devices

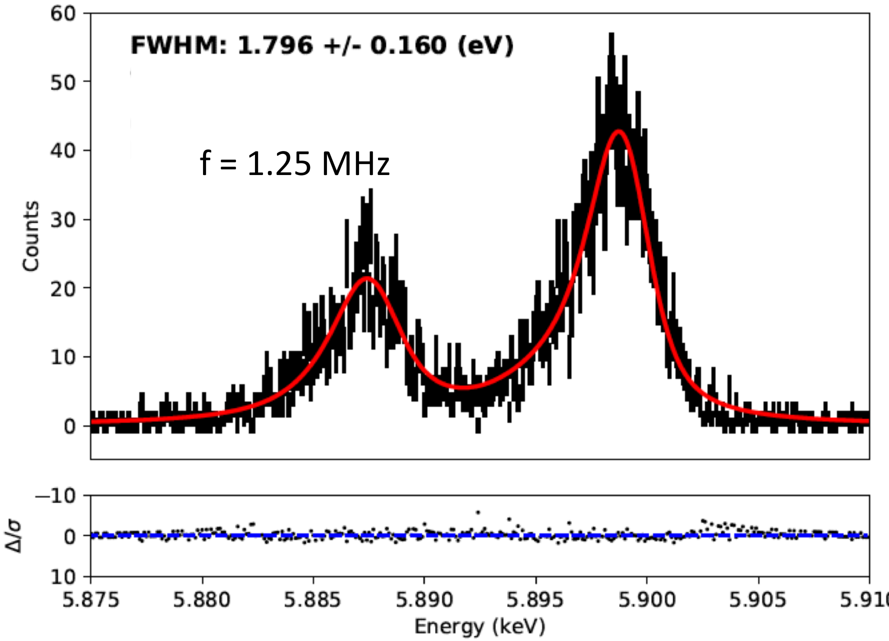


- With these changes AC bias resolution is now much closer to DC bias

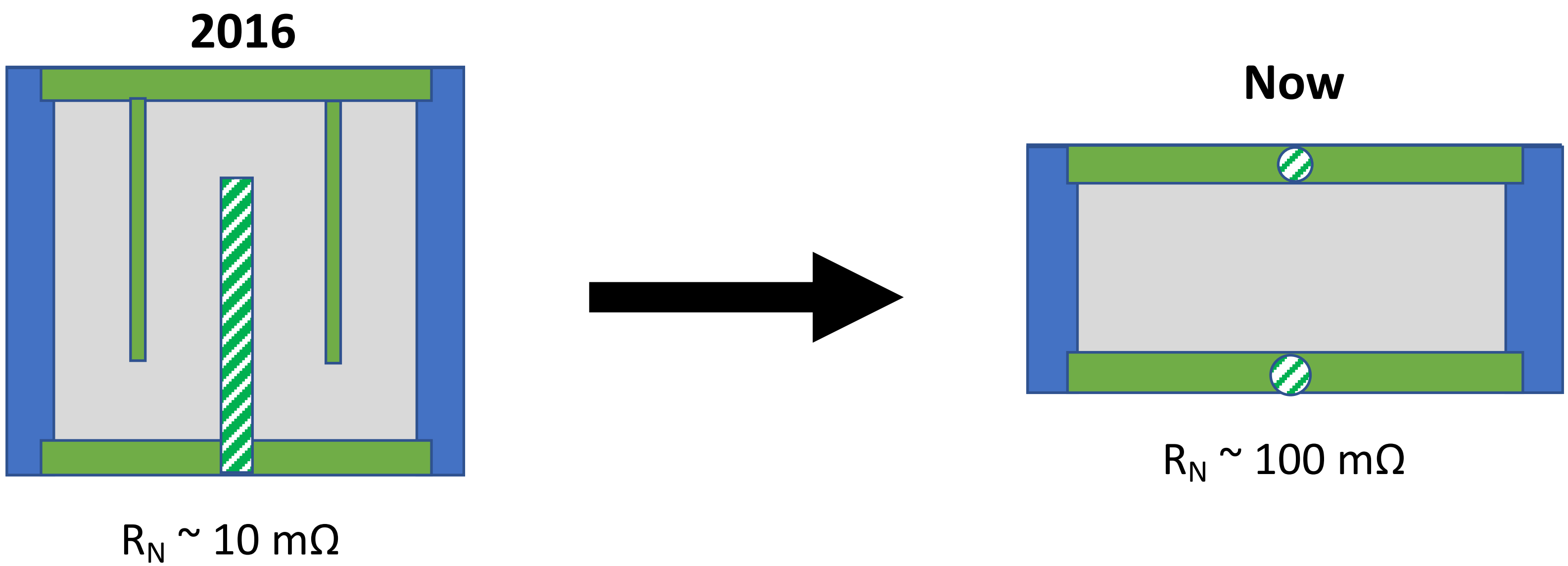
DC bias



AC bias



Conclusion



Over the last few years the TES design for X-IFU has evolved:

1. Removed stripes
   - Improved AC and DC bias transition

2. Increase bilayer sheet resistance
   - Improved AC bias transition

3. Changed aspect ratio
   - Improved AC bias transition and G_{bath}