ASC Conference 2022
4EOr2C - TES Workshop: Calorimeters IV

Effect of space radiation on TES detectors performance

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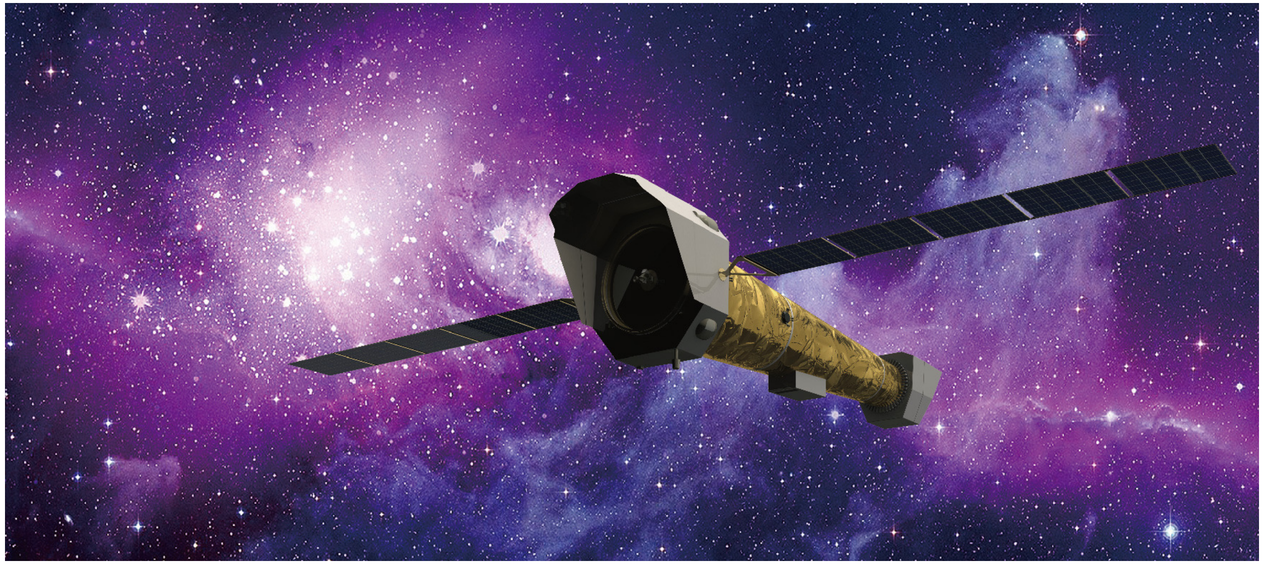
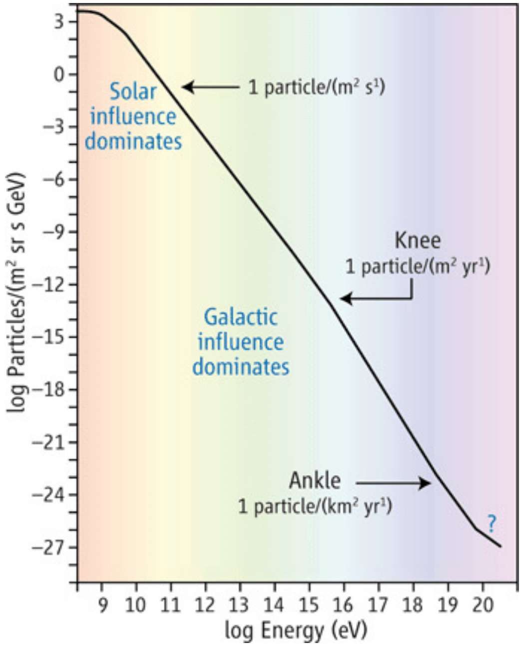
Introduction

- TES microcalorimeters developed at GSFC : for X-ray astrophysics mission
  e.g. : Athena

- Will be subject to space environment once in orbit at Lagrange point L1 :
  - Plasma radiations mainly from solar wind
    ↳ low flux protons (95%) and alpha particles (5%) with energies < 0.1 MeV
  - Energetic particle radiations from galactic cosmic rays & solar flares
    ↳ energetic protons, alphas, and electrons with energies up to 100s of MeV for H+ and the GeV for heavier ions



The Athena mission (Credit ESA/IRAP)



Cosmic ray spectrum (Credit Duldig,2006)

Potential radiation damage

- Depending on material, interaction particle and energy, different types of effect can occur :

Cumulative effects

- Ionization → oxide defects (charging effect in layer, interface traps)
- Dislocation damage → atomic displacement (defects creation)

Single event effects (SEE)

- Transients → Instantaneous effect induced by a single particle

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Ionization

oxide defects (charging effect in layer, interface traps)

- ❑ Membrane (Si_3N_4)
- ❑ Oxide layer (SiO_2)

Dislocation damage

atomic displacement (defects creation)

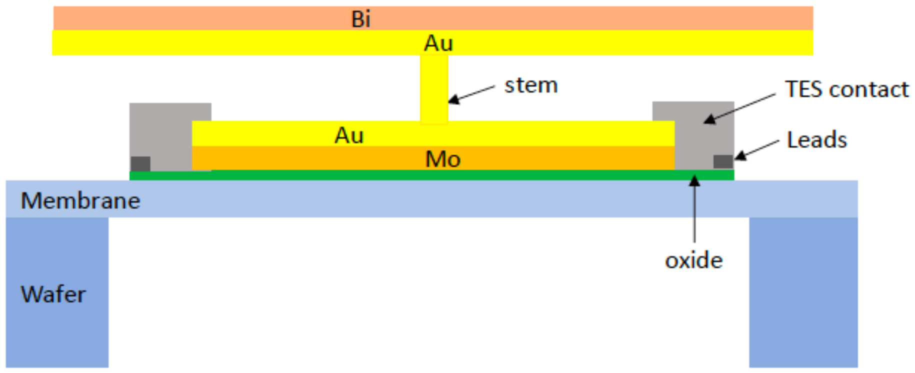
- ❑ TES bilayer
- ❑ Absorbers
- ❑ Leads

Single event effects (SEE)

Transients

Instantaneous effect induced by a single particle

- ❑ Superconducting films



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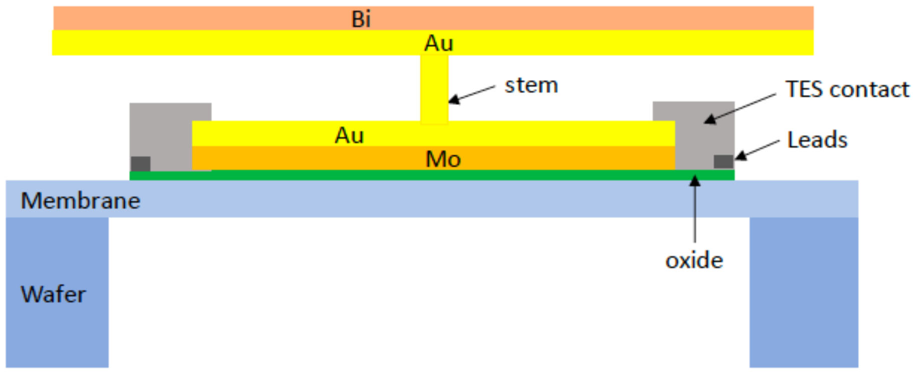
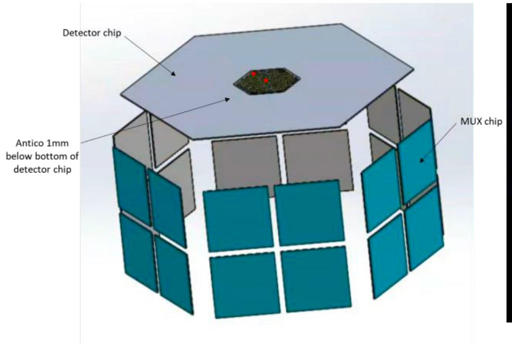


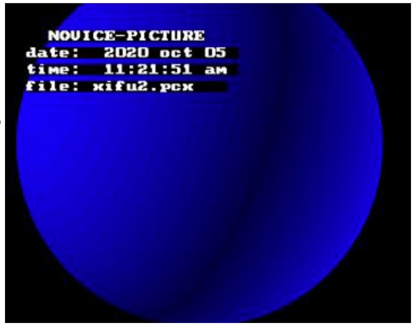
Radiation tests

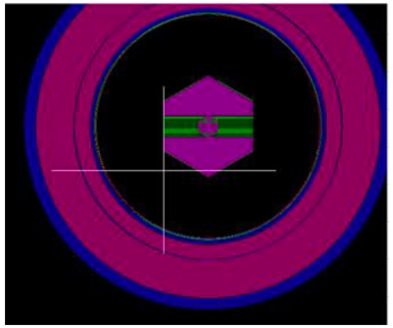
- Test design in close collaboration with Radiation Effect group from NASA GSFC
- X-IFU shielding analysis (***Courtesy of J.M. Lauenstein and her team***) :

➢ Adjoint Monte-Carlo simulation (with Novice)
  - Input spectra from solar and GCR protons
  - Input model with simplified geometries

  ⇒ Expected TNID & TID levels at various durations

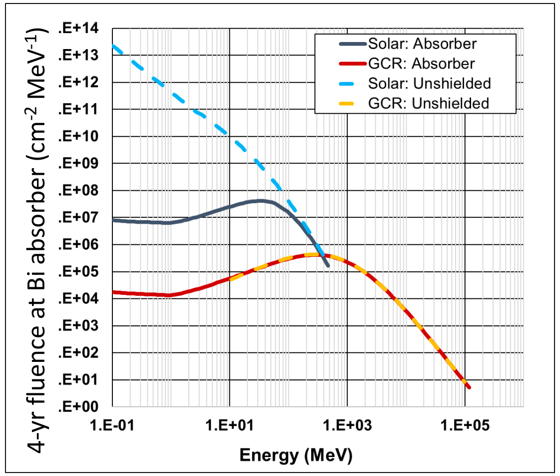


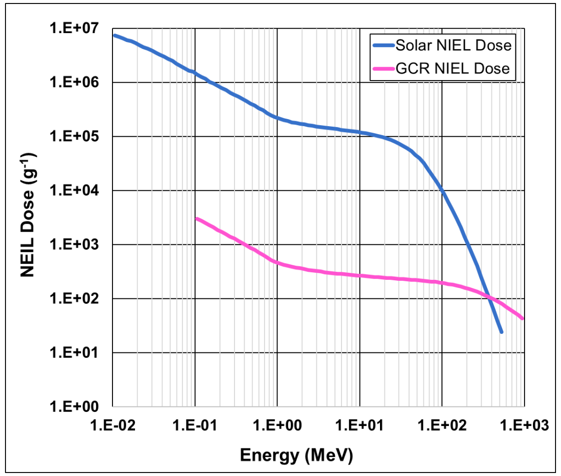




➢ Test proton energy selection guided by energy at highest differential flux
  - Want energy uniformity through layers
  - Want larger damage clusters as may be more disruptive

  ⇒ TES radiation test to use 64 MeV protons

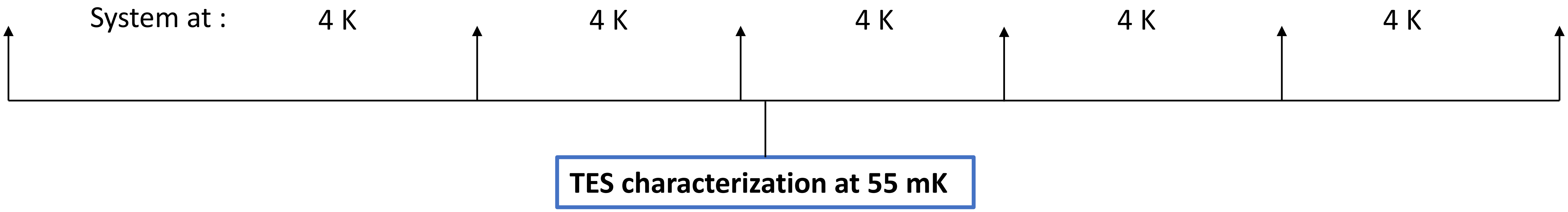




Radiation test design

- TES irradiation with 64-MeV Protons, in 5 dose steps
- Irradiation & testing must be done **cold** to avoid annealing effects ⇒ added complexity!

Mission duration	1 yr dose	2 yr dose	4 yr dose	10 yr dose	~25 yr dose
Exposure [min]	61.0	47.5	88.5	202.8	336.7
Flux [cm^{-2} s^{-1}]	4.87 E+05	1.25 E+06	6.70 E+05	5.00E+05	≤ 1.01E+06
TNID [MeV/g(Bi)]	1.67 E+06	3.33 E+06	6.67 E+06	1.24 E+07	3.05E+07
TID [rad(Bi)]	139	278	557	1032	2548



- Steps actually interleaved with MUX SQUIDs irradiation at 55 MeV and characterization in collaboration with NIST
  Not discussed here

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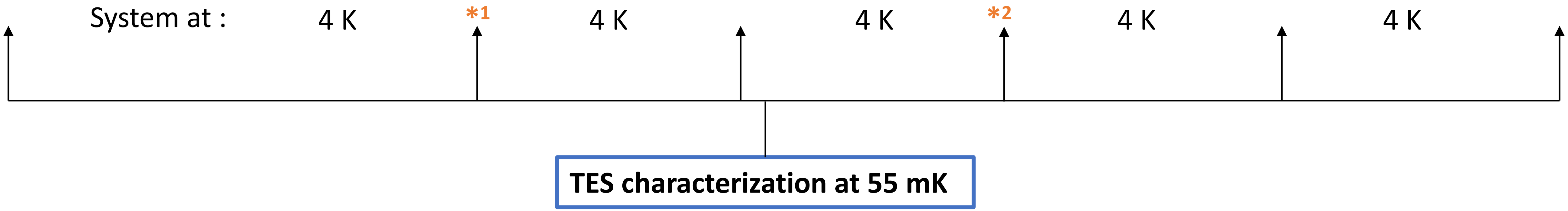


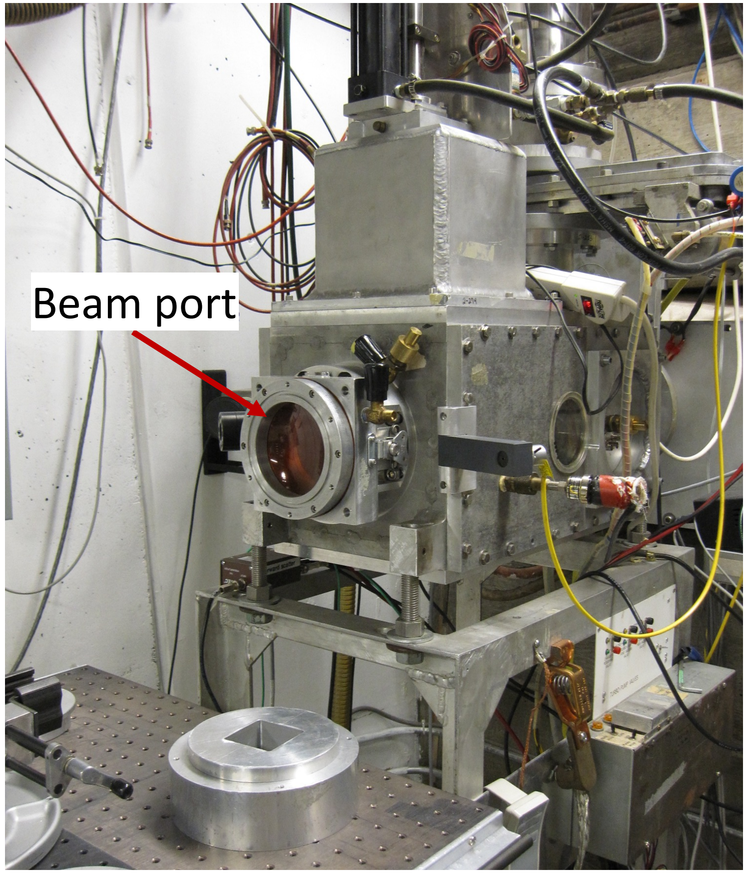
*1 Issue with cryostat –> Warmed up to room temperature ; Assumed all prior dose annealed

*2 Issue with trapped flux –> Warmed up to 20 K ; Assumed no annealing

Radiation test facility

- Testing during Fall 2021

- Univ. of California, Davis (UC Davis) - Crocker Nuclear Laboratory (CNL)
  ↳ 76” Cyclotron: Tunable proton beam energies continuously from 6.3 MeV to 67.5 MeV



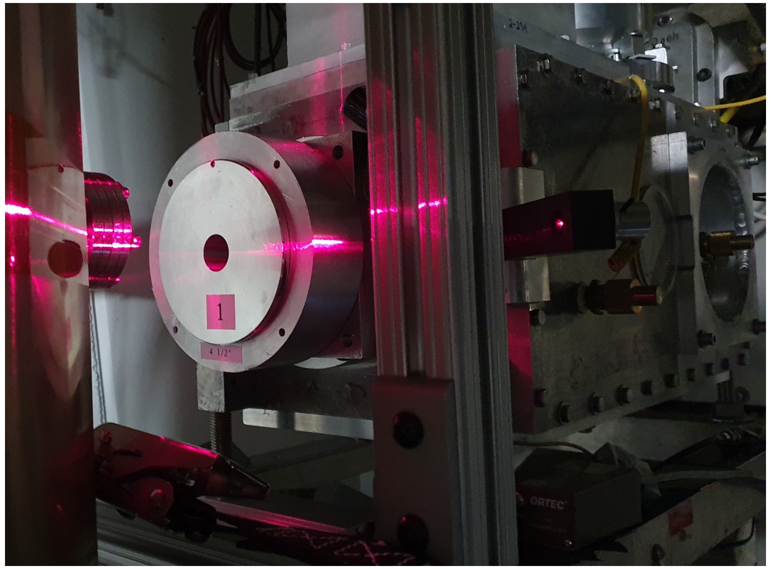
Installation at UC Davis

Setup and test pre-beam in high bay area

Detector characterization between dose steps

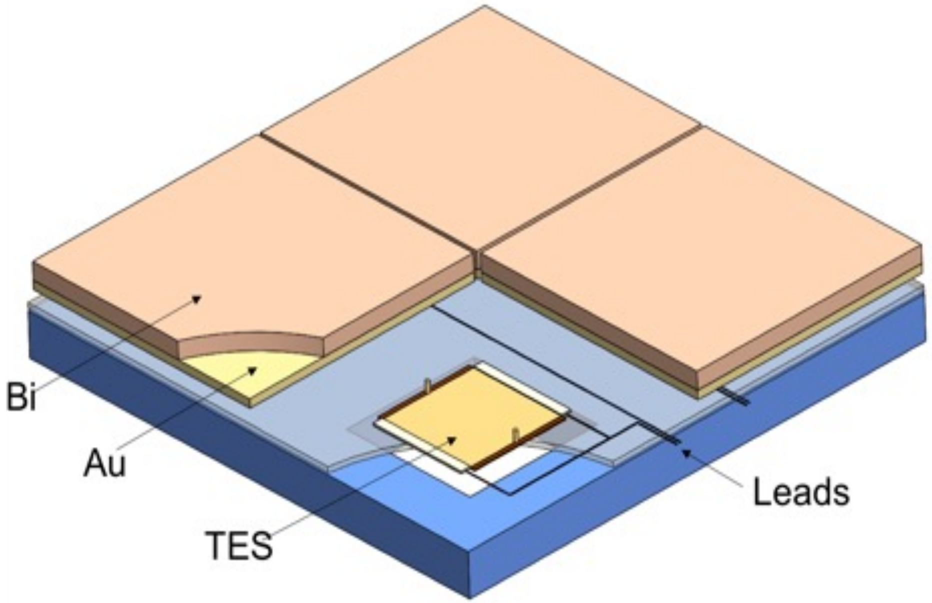
Installation at UC Davis

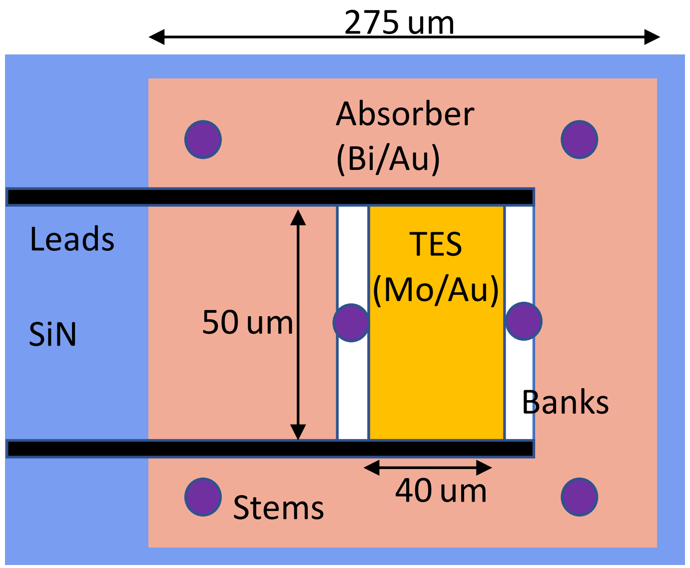
Cold irradiation



Warm irradiation

Test setup – TESs





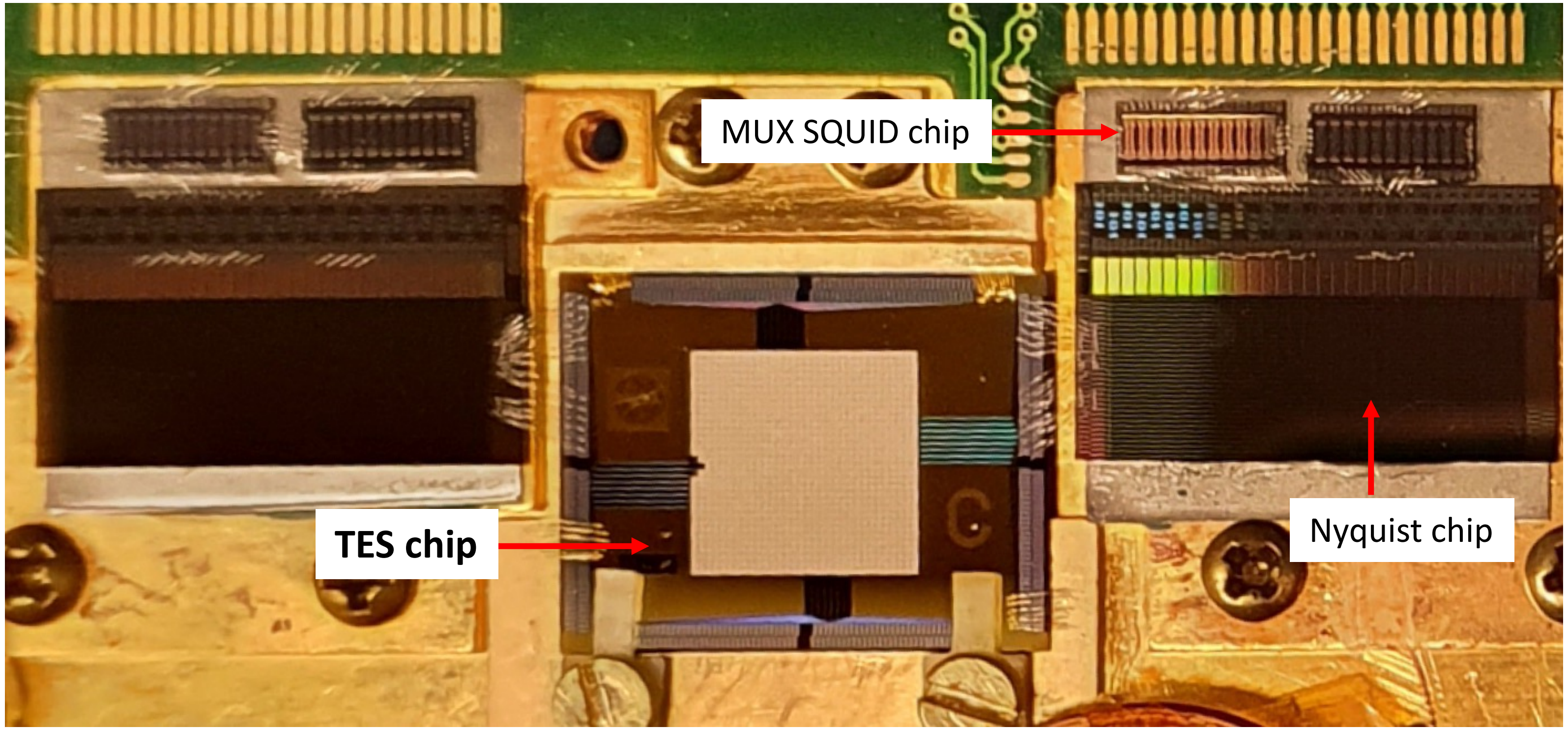
Absorber layer thicknesses	Au (1.3 µm) / Bi (3.1 µm)
TES design (bilayer aspect ratio & layer thicknesses)	50 x 40 µm (4 and 6 dots) Mo (47 nm) / Au (323 nm)
Tc	~ 98 mK
Array size	32 x 32
Number of pixels connected	18
Number of pixels tested	Up to 4 between dose steps (single readout)

Test setup – Cryostat and Read-out

- Cold electronics :
  - At 55 mK stage – detectors assembly housing 32x32 TES chips, Nyquist chips and MUX SQUID chips (both from NIST)
  - At 4 K stage – amp SQUIDs (from NIST)

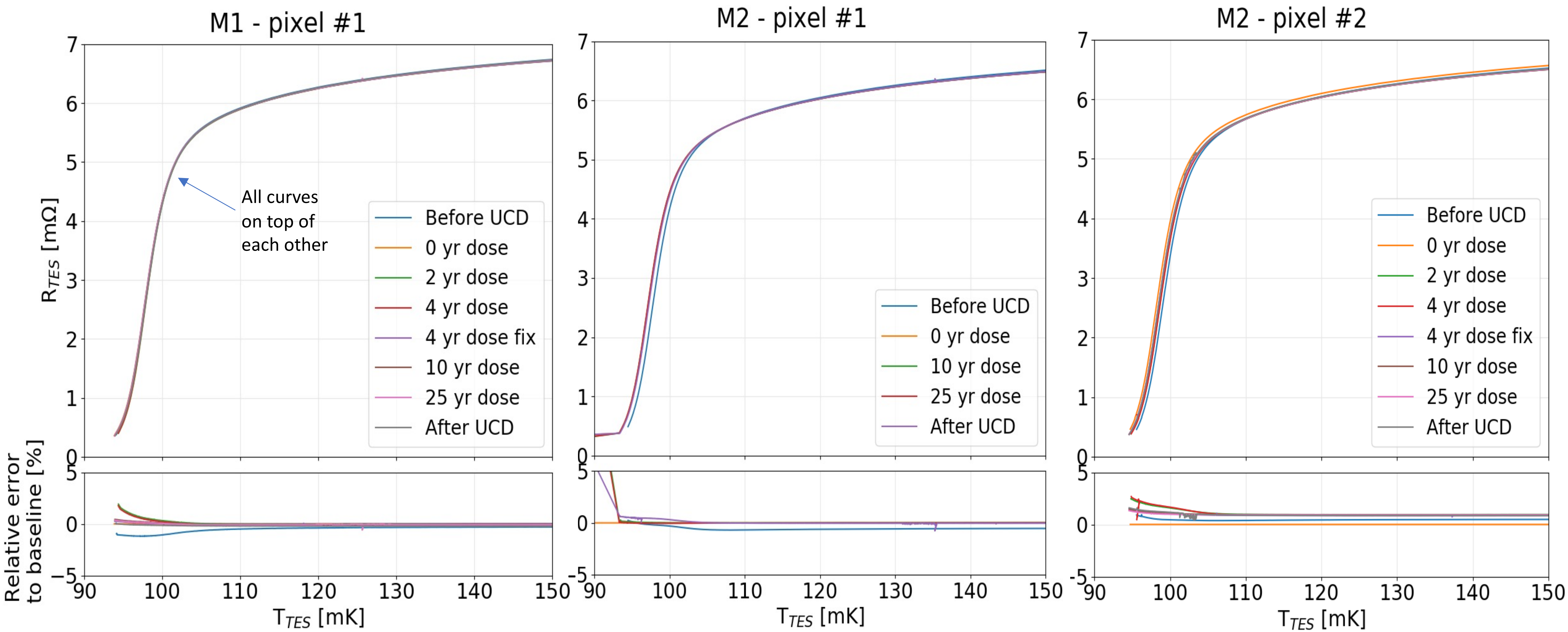
- Warm electronics :
  - Warm Front End Electronics from NIST (“tower”)
  - Digital Readout Electronics inhouse from GSFC

⇨ Single channel readout, for 2 columns



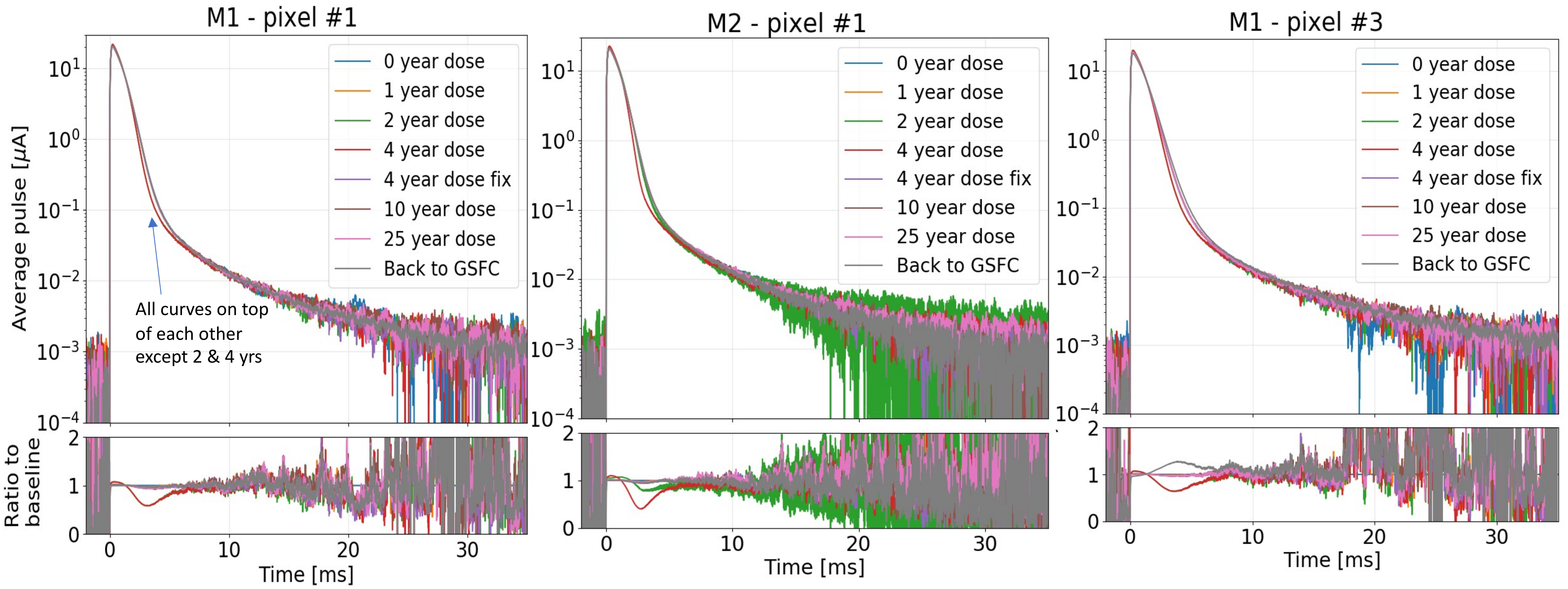
Test results – Transition shapes

- Transition very stable over the different irradiation steps
- **No apparent sign of Tc shift** due to radiations
- Small differences (less than 3%) with data from 1st day at UCD, attributable to changes in conditions (e.g. field environment)



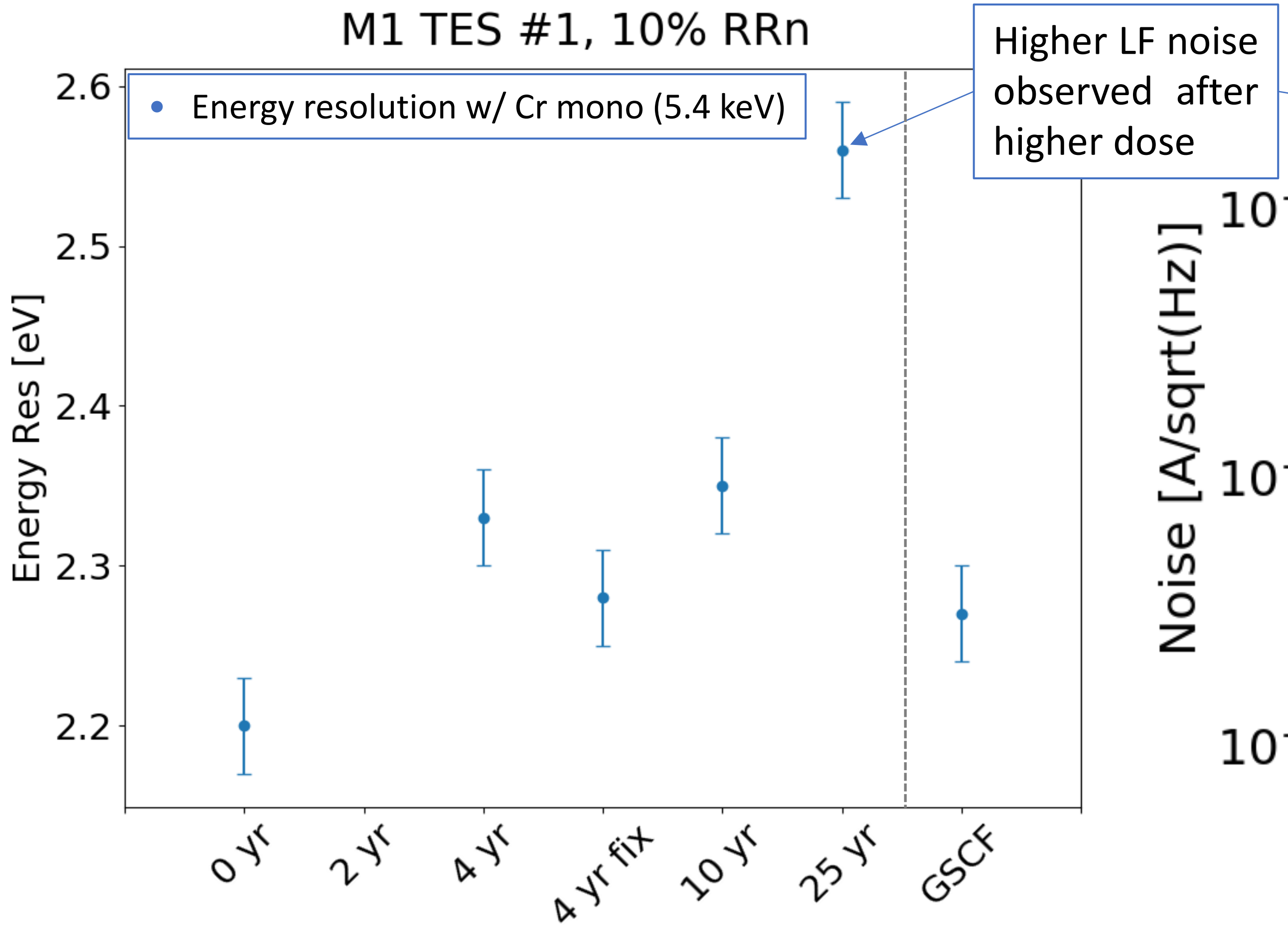
Test results – Pulse shapes

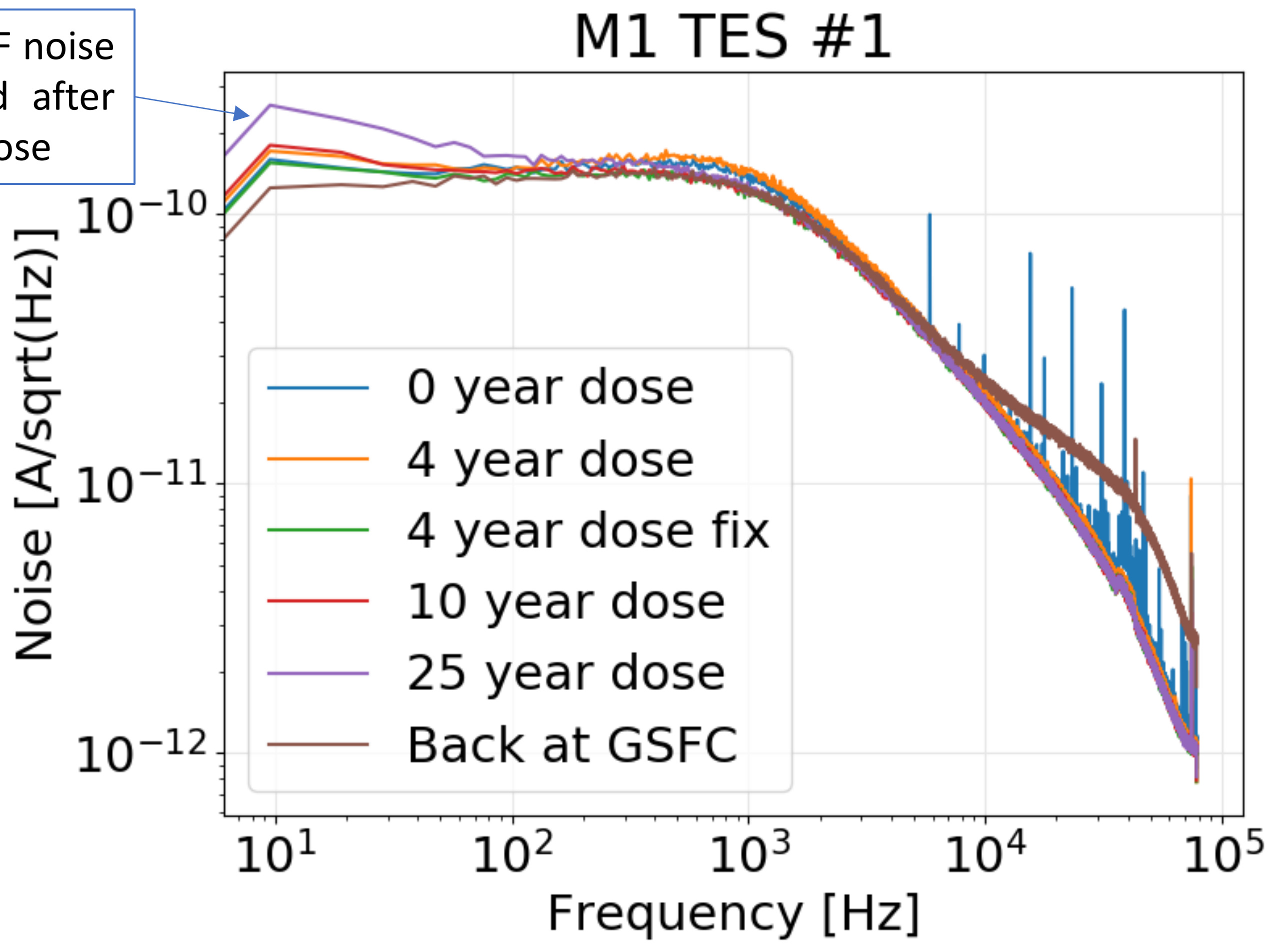
- Pulse shape stable over the different irradiation steps
  - Larger difference after 2- and 4-year dose where very strong suspicion of trapped field inside the Nb box
  - Small differences attributable to changes in conditions
- **No apparent sign of secondary tail** due to radiations



Test results – Energy resolution

- Energy resolution (FWHM) fairly stable over the different irradiation steps
  - Degradation after 25 years can be correlated with higher LF noise (higher background noise coming from the Nb box)
- **No sign of low energy tail** appearing on the data taken with the mono source



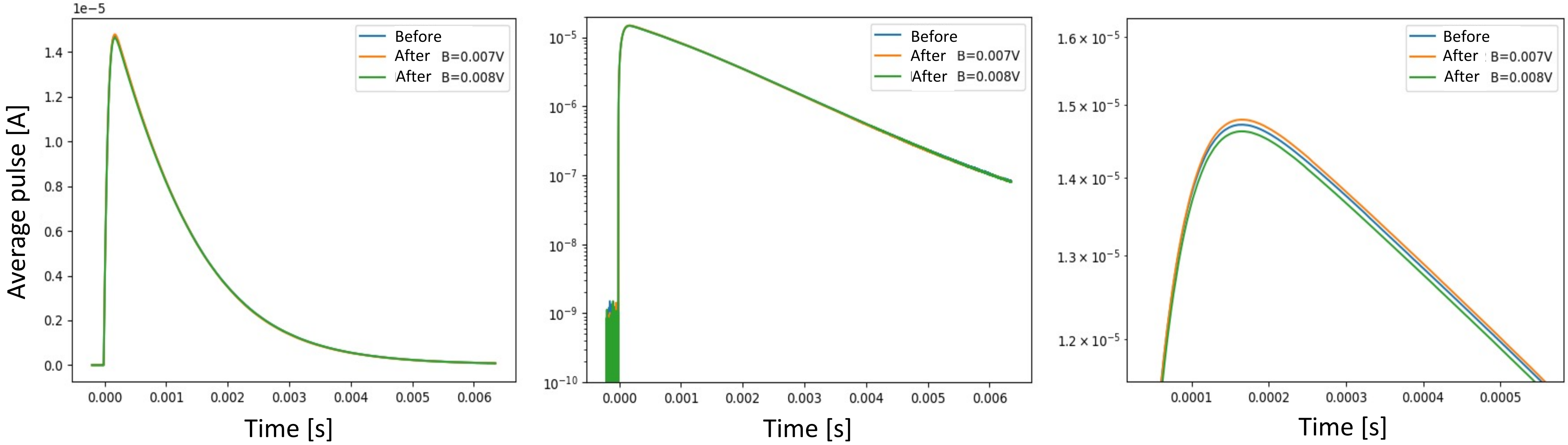


Test results ~ Warm irradiation

- Transition shapes, pulse shapes, and energy resolution compared before and after irradiation

- Consistently with the cold irradiation we observed :
  - No evidence of modification of the transition shape due to irradiation
  - No evidence of modification of the pulse shape due to irradiation
  - No change in energy resolution

- Some difference were, again as for the cold irradiation, visible but very likely due to changes in the environment.
  - This was checked by adjusting the offset field and comparing the pulse shapes as shown below



Conclusions

- From both the cold and warm irradiation tests, it seems no clear damage was inflicted to the TES detectors for a maximum dose of ~25 years (based on 11 mm of shielding from the spacecraft).

- I.e. no damage observed on : R vs T
  Pulse shape
  Energy resolution performance

- Some minor variations in transition or X-ray pulse shapes were observed
  ↳ within the range of the typical variability of pulse shapes and R vs T run-to-run variation due to small variations in the environment (e.g. B field, bias point)

Thank you for your attention

Any questions ?

Acknowledgments :
Part of the material presented is based upon work supported by NASA under award number 80GSFC21M0002