# TES proton irradiation result analysis for future space applications


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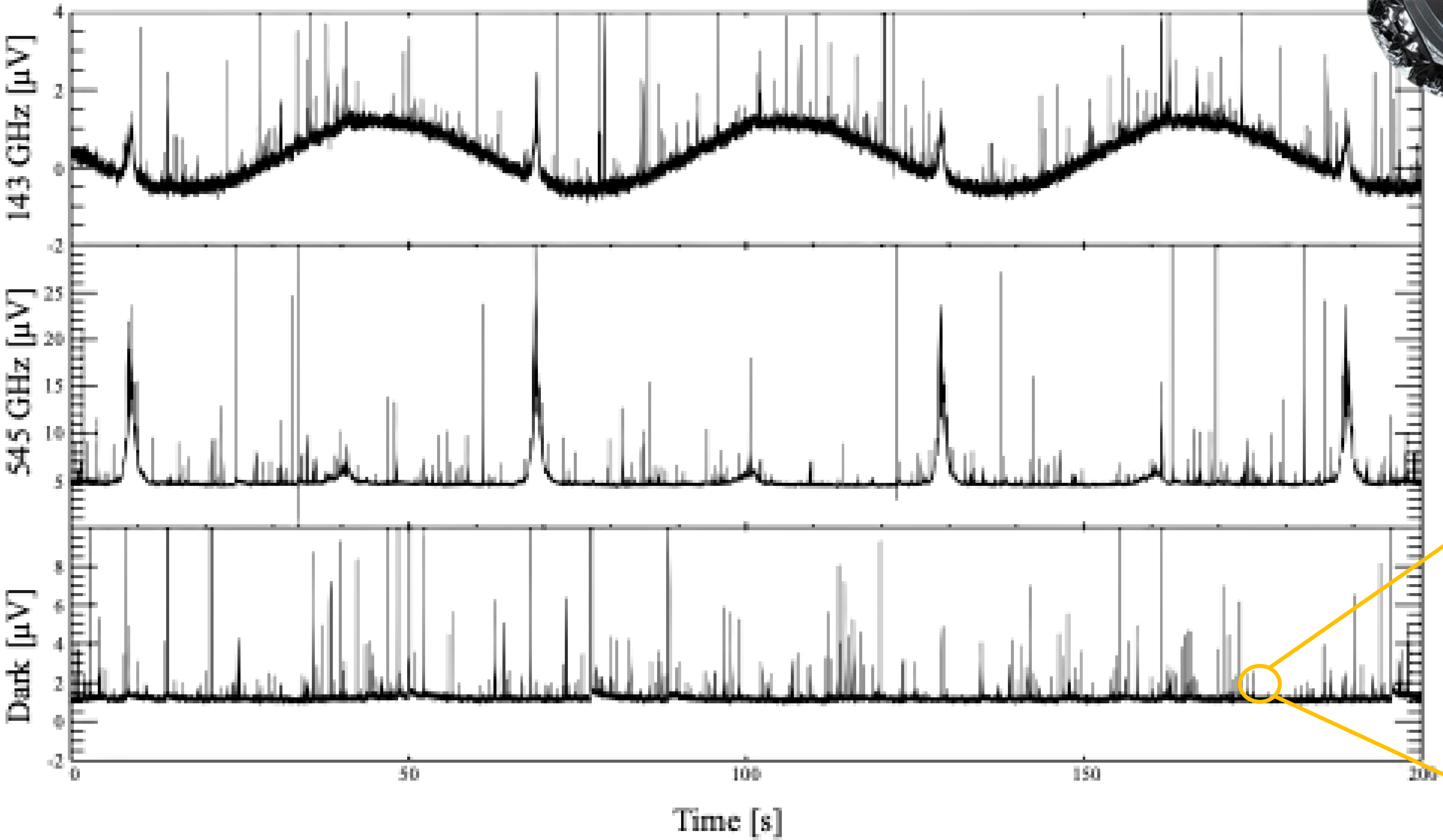
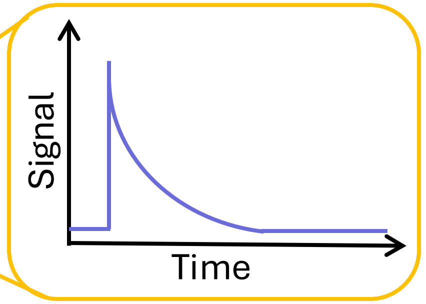
# Cosmic-rays problematic




Signals from Planck HFI's detectors (top : 143 GHz, middle : 545 Ghz, bottom : dark)

- Impacts of cosmic-rays (CRs) on Planck bolometers (@ 100 mK)
  ⇢ several years of post-data treatment to clean data

Few % of the data unusable even after glitches cleaning A.Catalano et al. – 2013

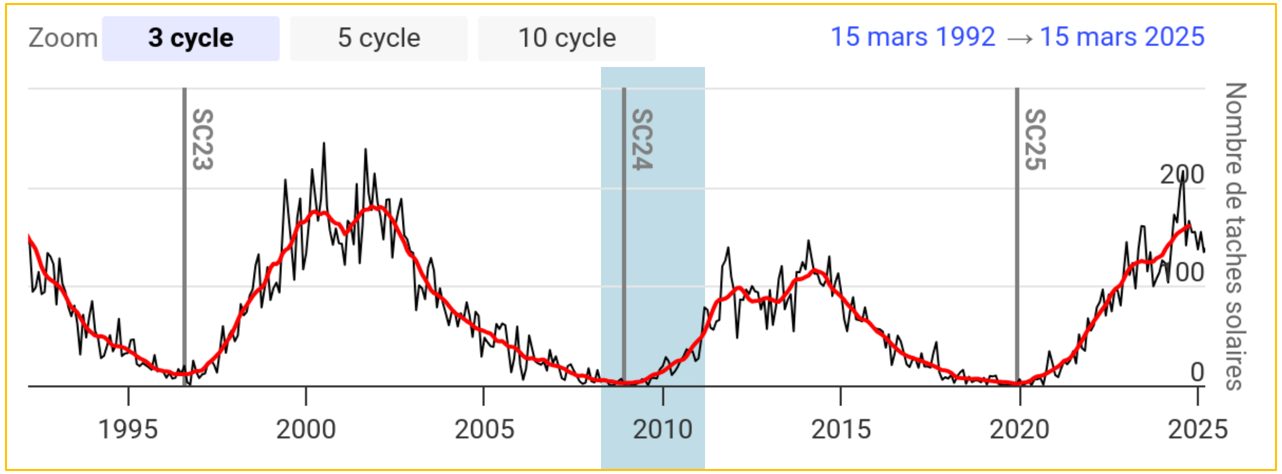
# Prepare the future

**After Planck ?**

⟹ IAS started to explore the impact of cosmic rays (SYMBOL) **S.L.Stever** – 2019

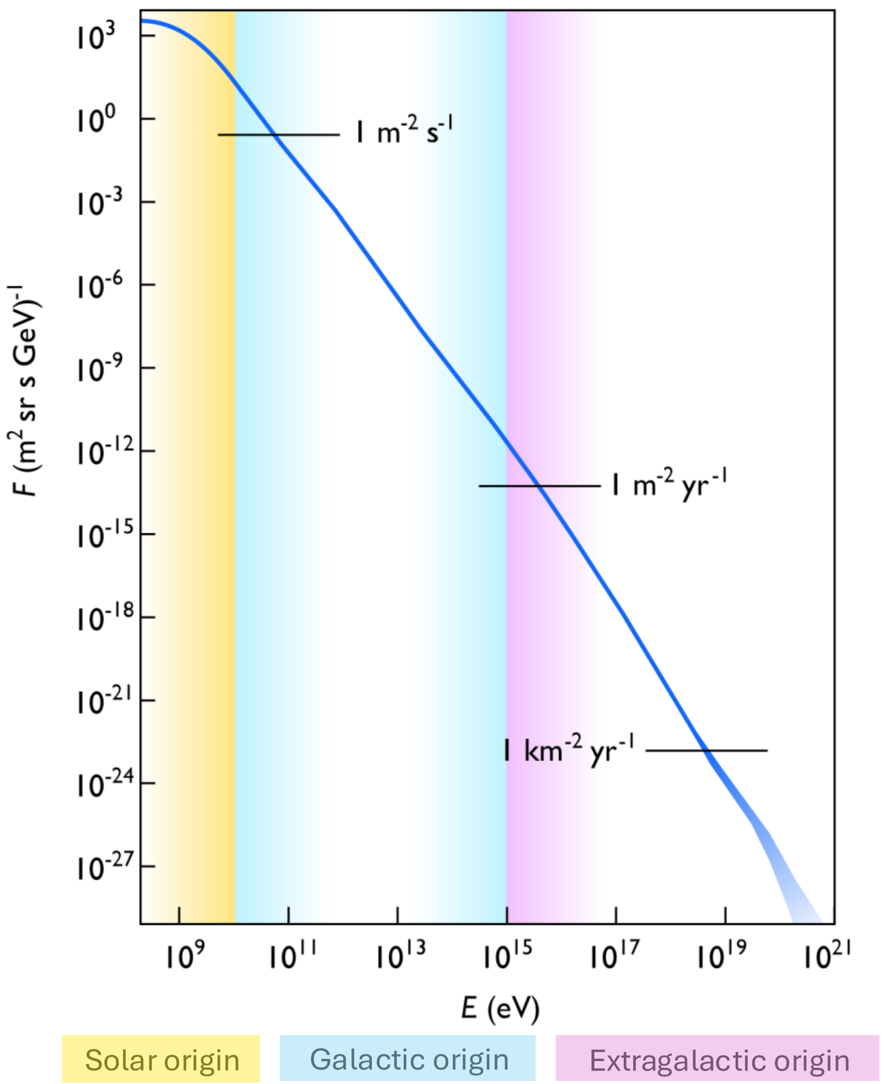
- CRs at L2 : mainly protons and $\alpha$-particles ~ GeV

⇢ Galactic origin
⇢ Solar origin
(LiteBIRD ~2036: solar maximum)




Planck

CRs flux vs particle energy



# Prepare the future

**After Planck ?**

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- CRs at L2 : mainly protons and $\alpha$-particles ~ GeV

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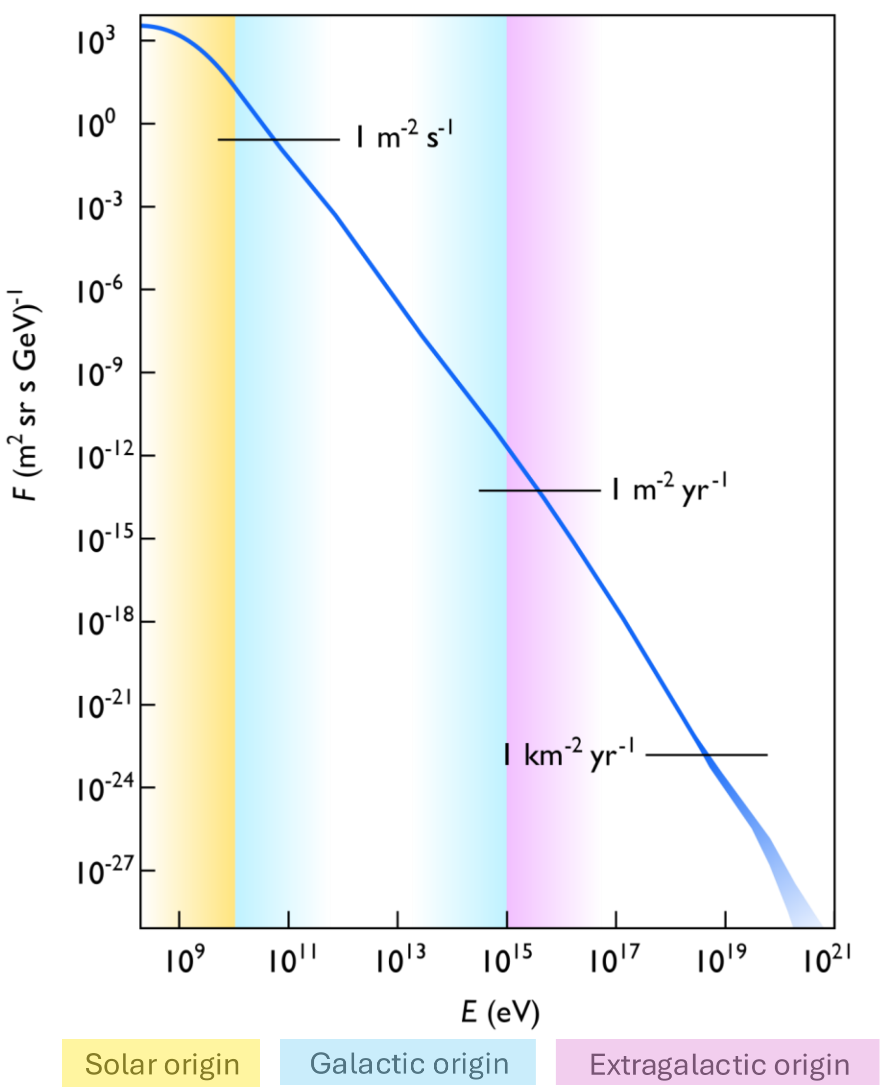
⇢ Solar origin
(LiteBIRD ~2036: solar maximum)

- Future CMB missions :

❑ Higher sensitivity
❑ Larger detection surface

**⟹ There is a real need to characterize the impact of the CRs on detector prototypes**

CRs flux vs particle energy



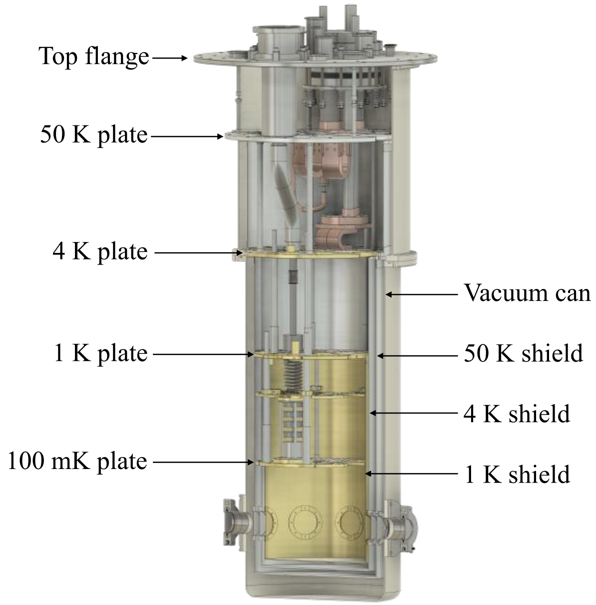
# Presentation of the test facility

## Cryogenic facility

DRACuLA (**D**etector ir**RA**diation **C**ryogenic faci**L**ity for **A**strophysics) : developed to simulate the impact of CRs on detectors and part of focal planes

**Adaptable to particle accelerators**

- 500 µW @ 100 mK
- Experimental plate $\phi$ 25 cm
- Mobile : compact frame with wheels
- Includes micro-vibration attenuators
- 4 KF-50 ports (at 0º, 45º, 90º & 180º)
- 24 low-pass RF-RC filtered lines
- Superconducting coax wires for KIDs
- SQUIDs for TESs
- 4 temperature measurement bridges




Anatomy of DRACuLA

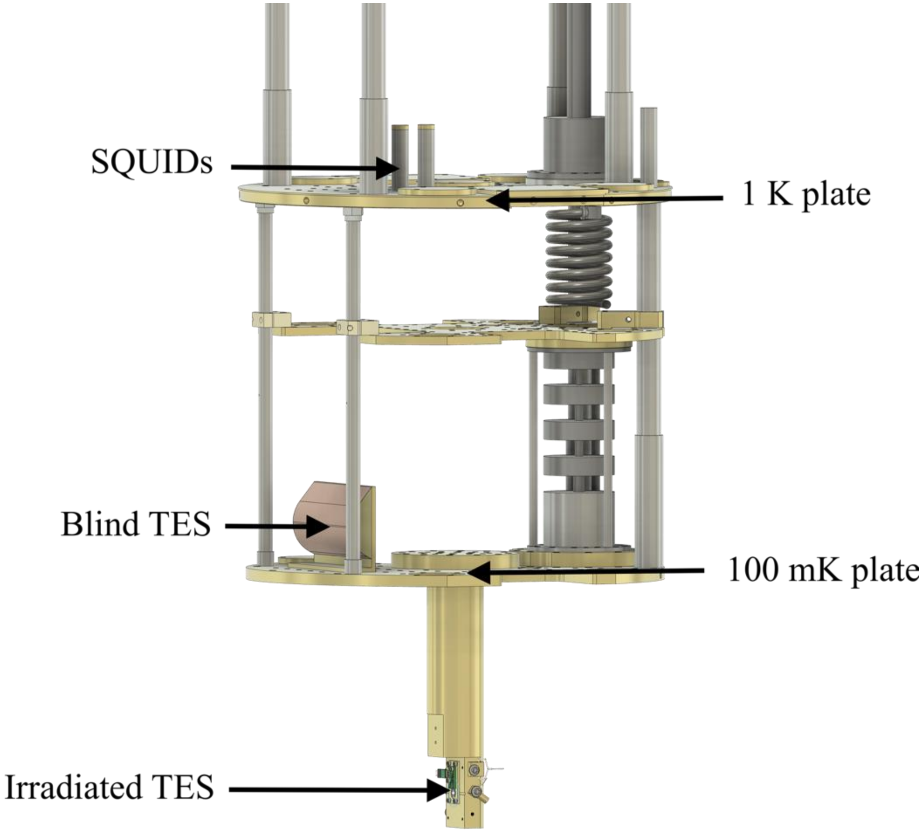
DRACuLA

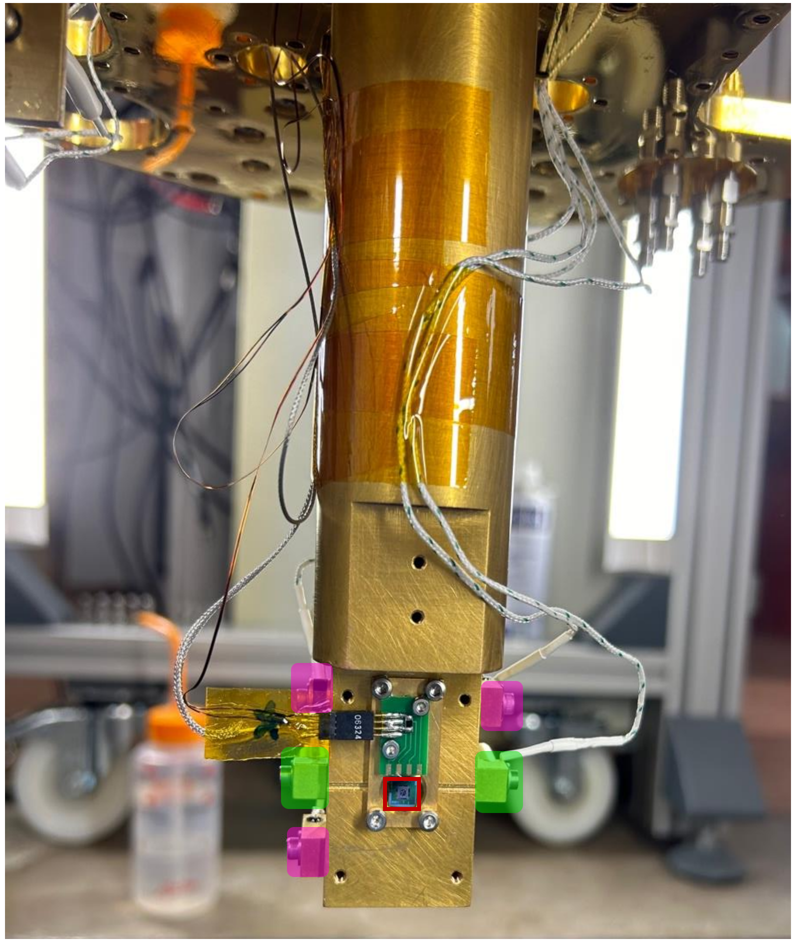
**More details on DRACuLA facility and its temperature stability**

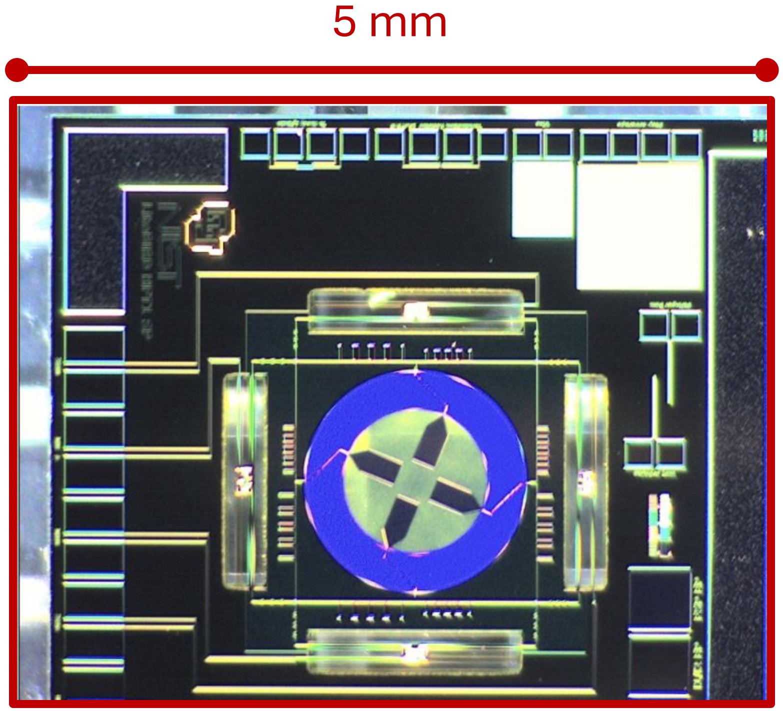
A.Besnard et al. – 2024

# Preparation of the campaign

**Experimental set-up**



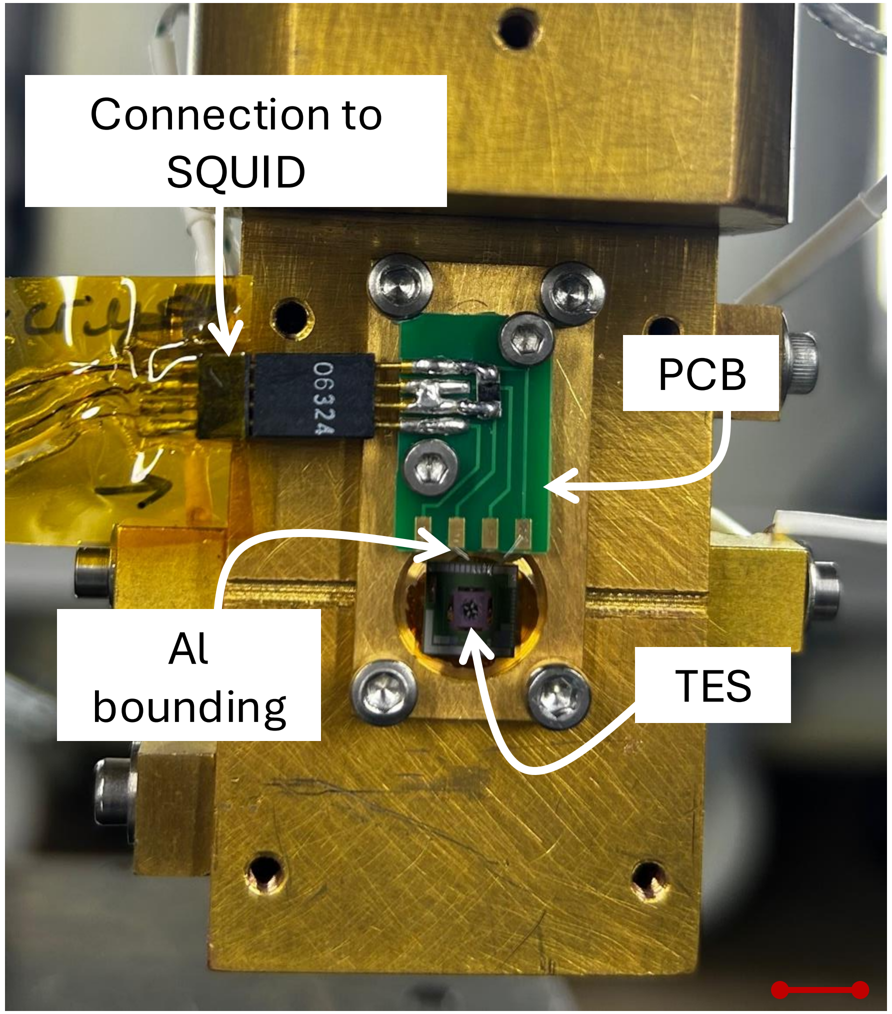



Heaters

Thermometers

# Preparation of the campaign

**Transition Edge Sensor (TES)**



TES installed in DRACuLA

Scale = 5 mm

For a $\Delta T$ change : $\Delta R = \alpha R \Delta T$

Detector with a sharp transition phase between a superconducting state and a normal state

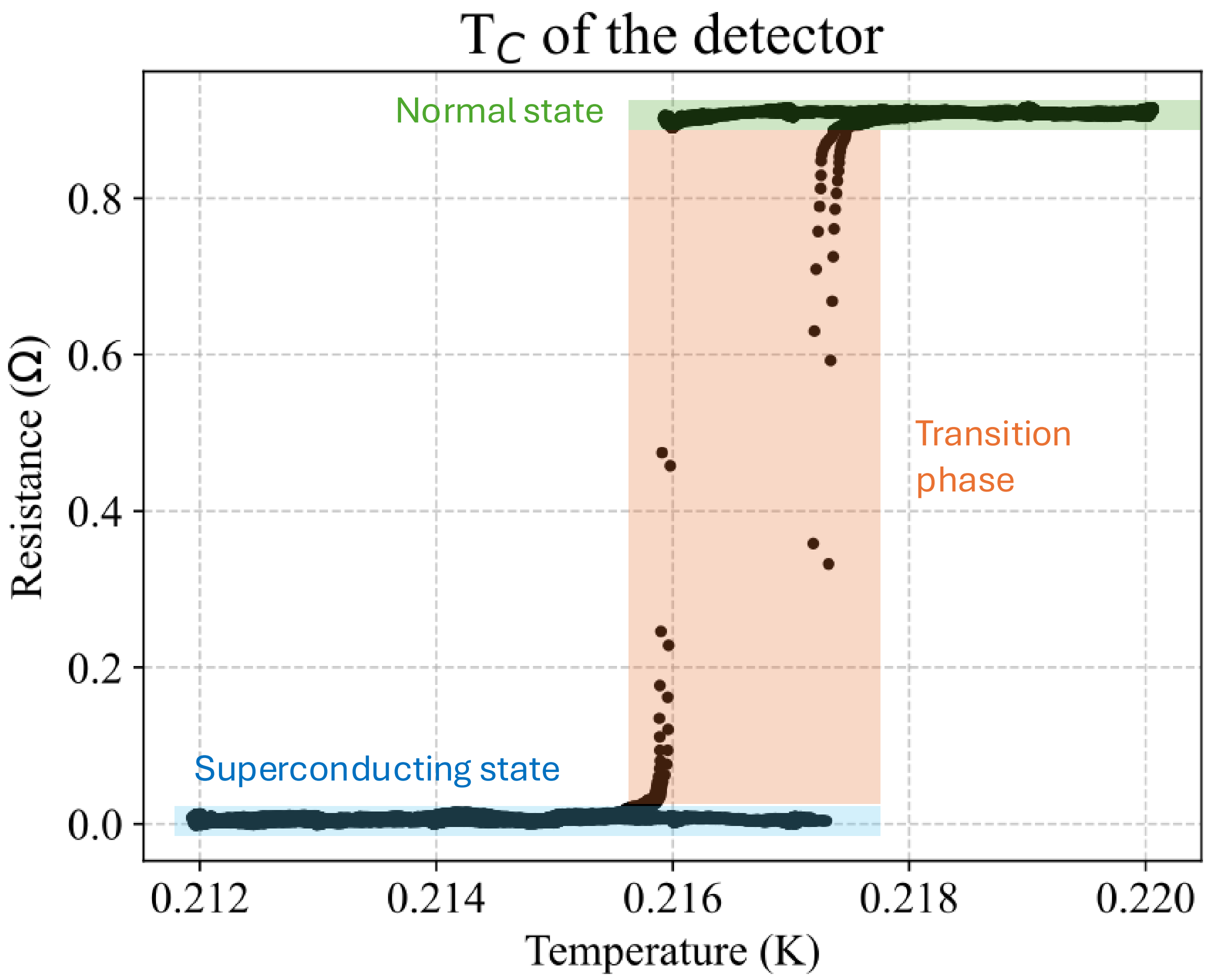
⇢ TES from NIST M.Lueker et al. – 2009

**Installation :**

- SQUID readout system (lent by INFN Pisa)
- Designed PCB to connect with SQUID @1K and bounded to TES with 25 µm Al wires (Stefanos Marnieros from IJCLab)
- Blind detector (TES 2) not facing the beam

# TES characterisation

**Transition Edge Sensor (TES)**




$2^{nd}$ campaign with TES

**Determination of the $T_C$ :**

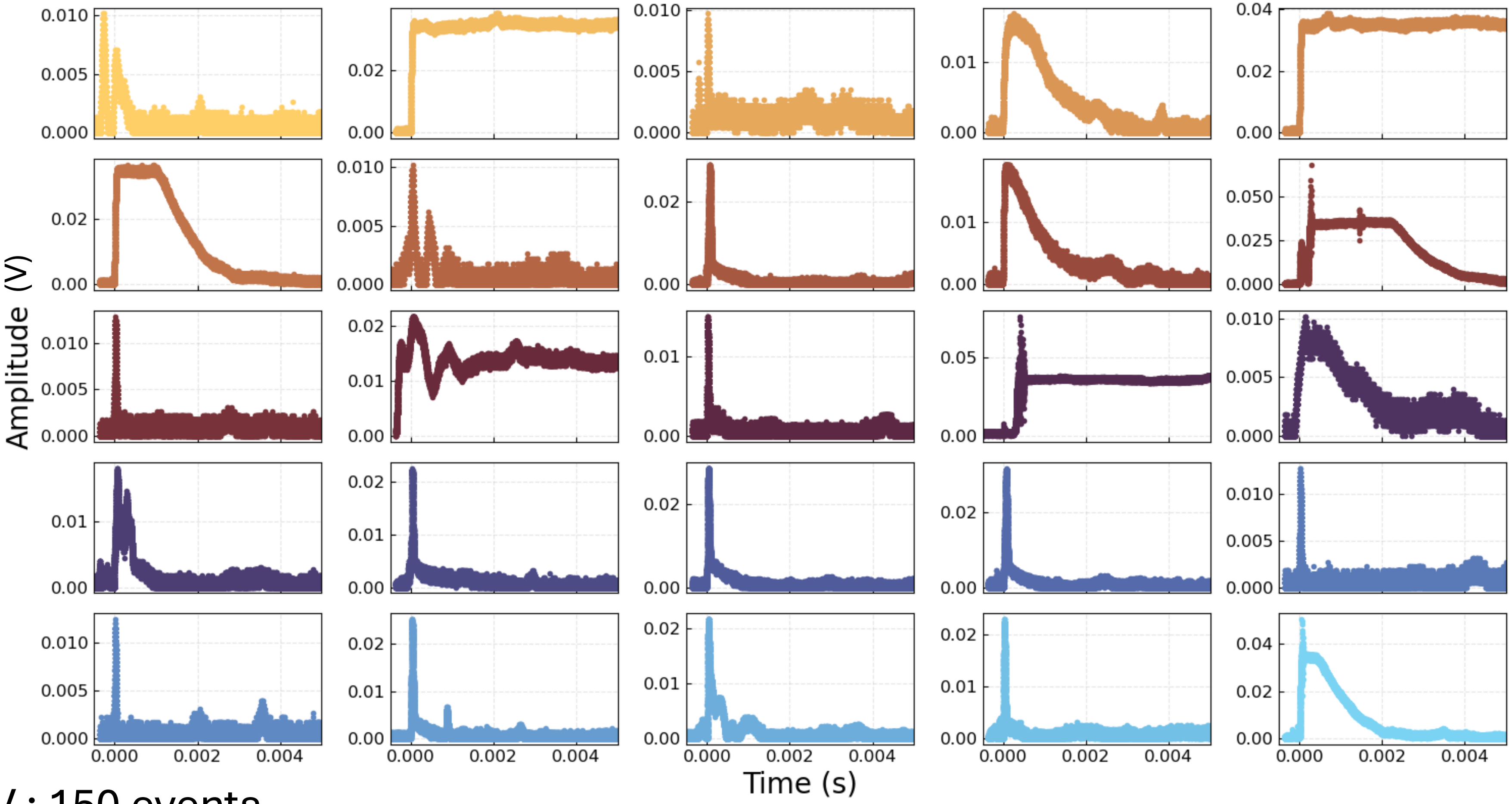
- 1st detector : ~212 $\pm$ 1 mK
- 2nd detector : ~217 $\pm$ 1 mK

→ Impact of irradiation on the TES's $T_C$ measured after the campaign **P.dal Bo et al.** (submitted)

**First tests with an internal $\alpha$-source ~5.4 MeV** ✅

# Alpha irradiation - raw data

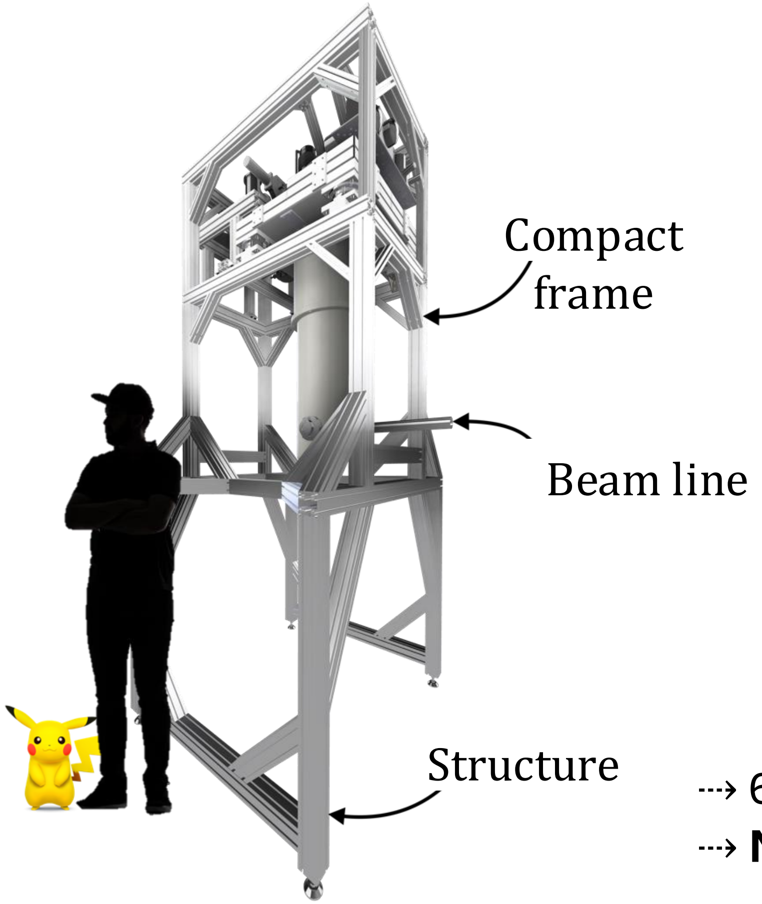
**Alpha source**



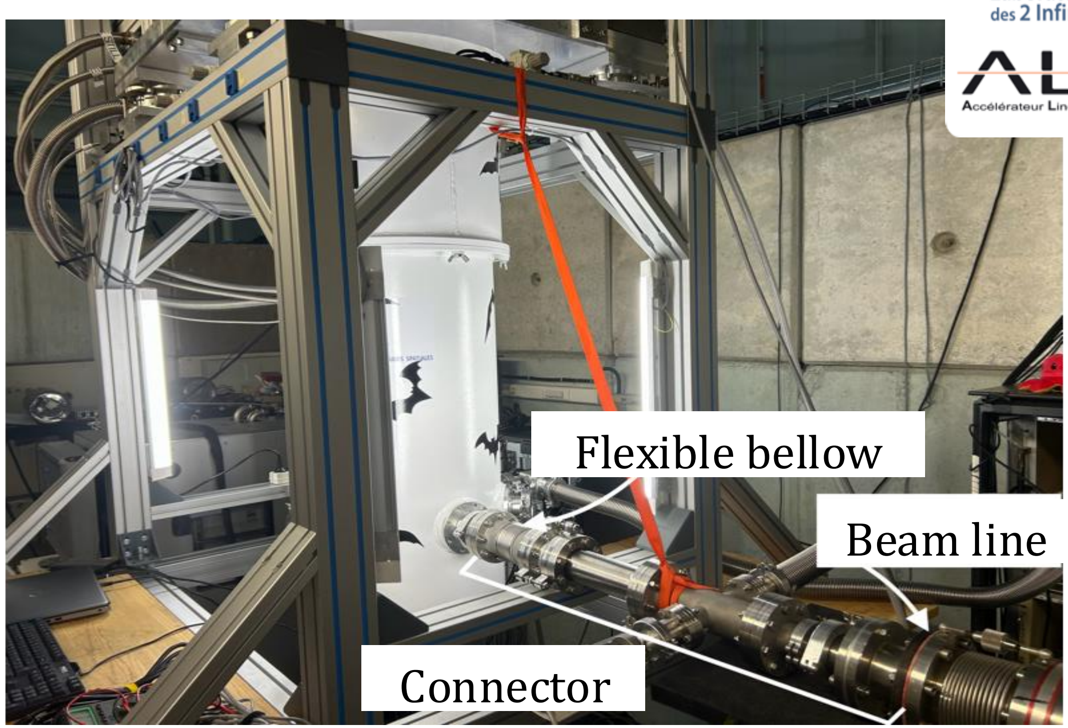

- @ 5.4 MeV : 150 events
- First measurements done in the lab with alpha particles to ensure TESs are sensitive to glitches

# Installation at TANDEM

**Cryostat/beamline interface**




Structure holding the cryostat




Connection between the cryostat and the beam particle

⇢ 60 µm **polypropylene window** between the vacuum can and the connector
⇢ **Mylar filters** on 4 K & 1 K shields

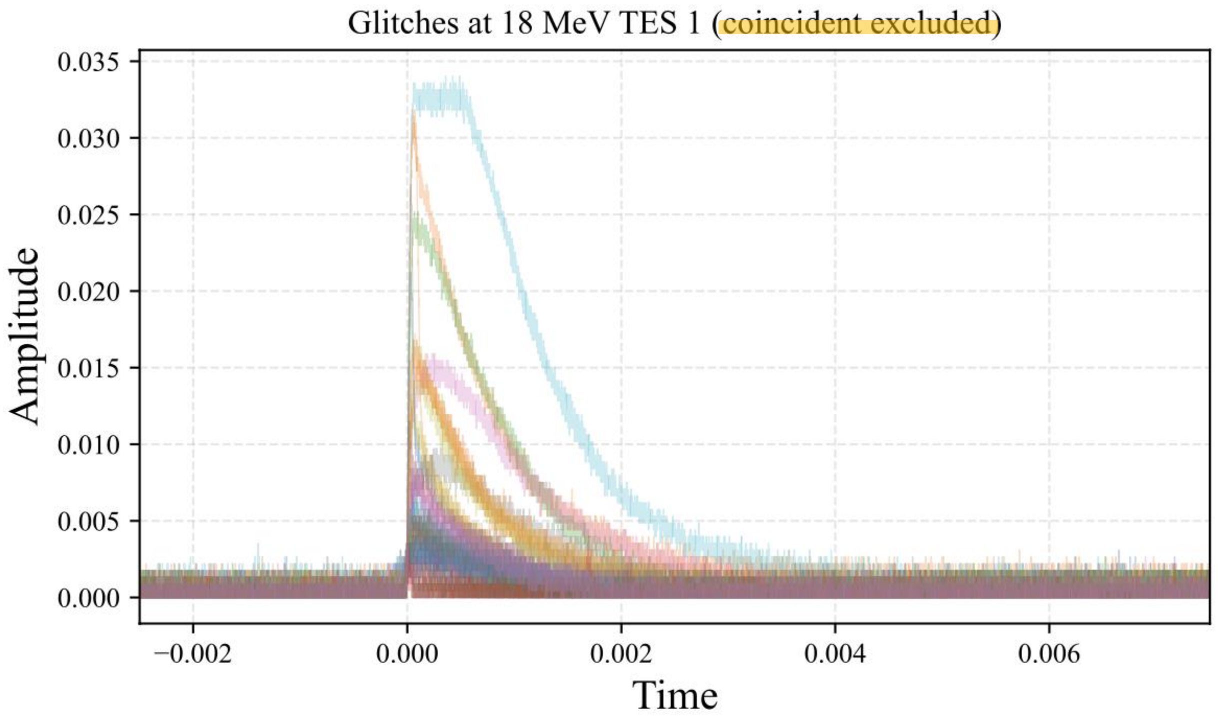
- 1st campaign at ALTO (Orsay) was conducted in 2021 to assess the facility's capabilities using a bolometer

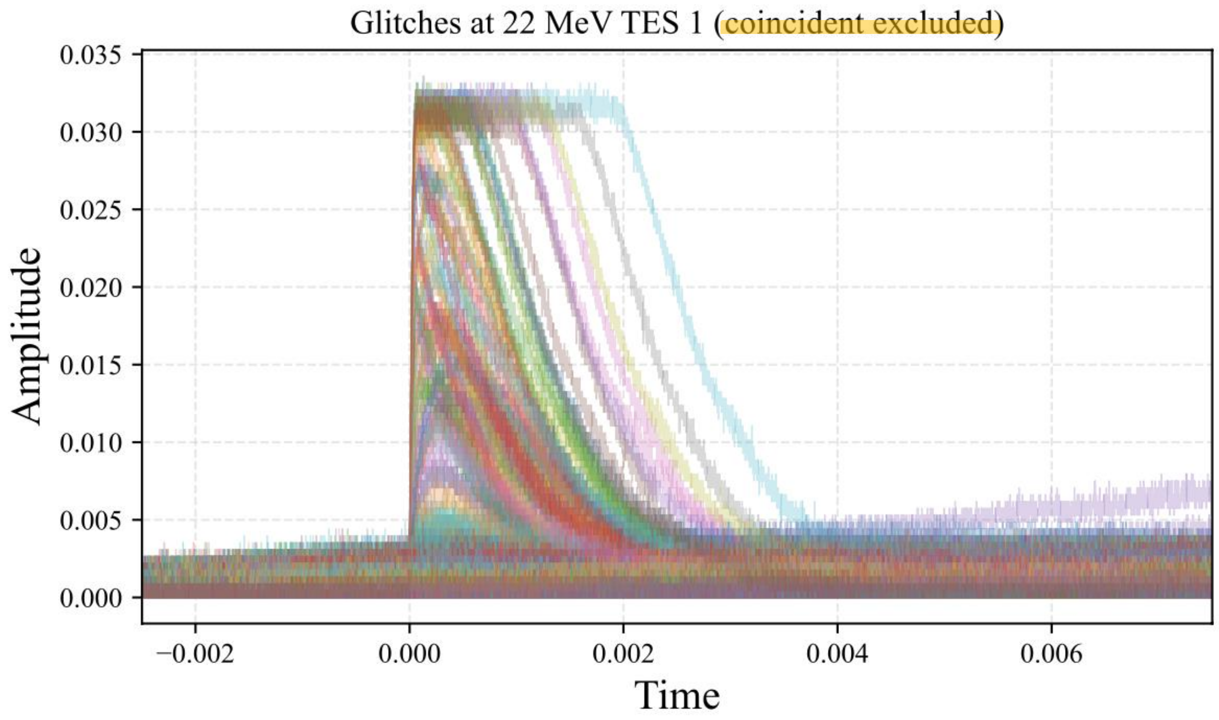
# Proton irradiation - raw data

**2nd campaign in May 2024 :**

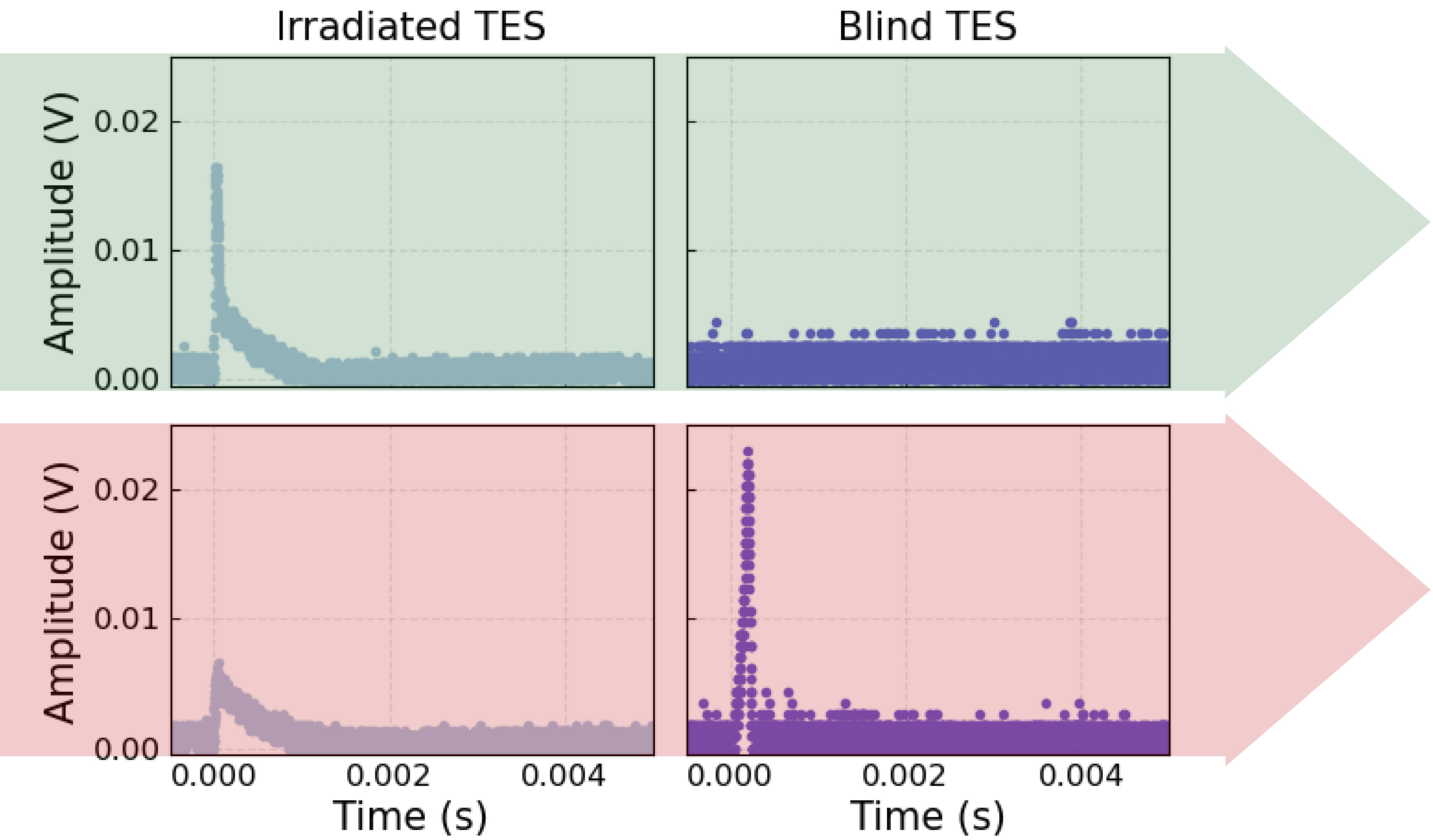
- 2x8 hours of irradiation
- @ 18 MeV : 51 events
- @ 22 MeV : 2885 events

Coincident glitch = event detected by both TESs (blind and irradiated)



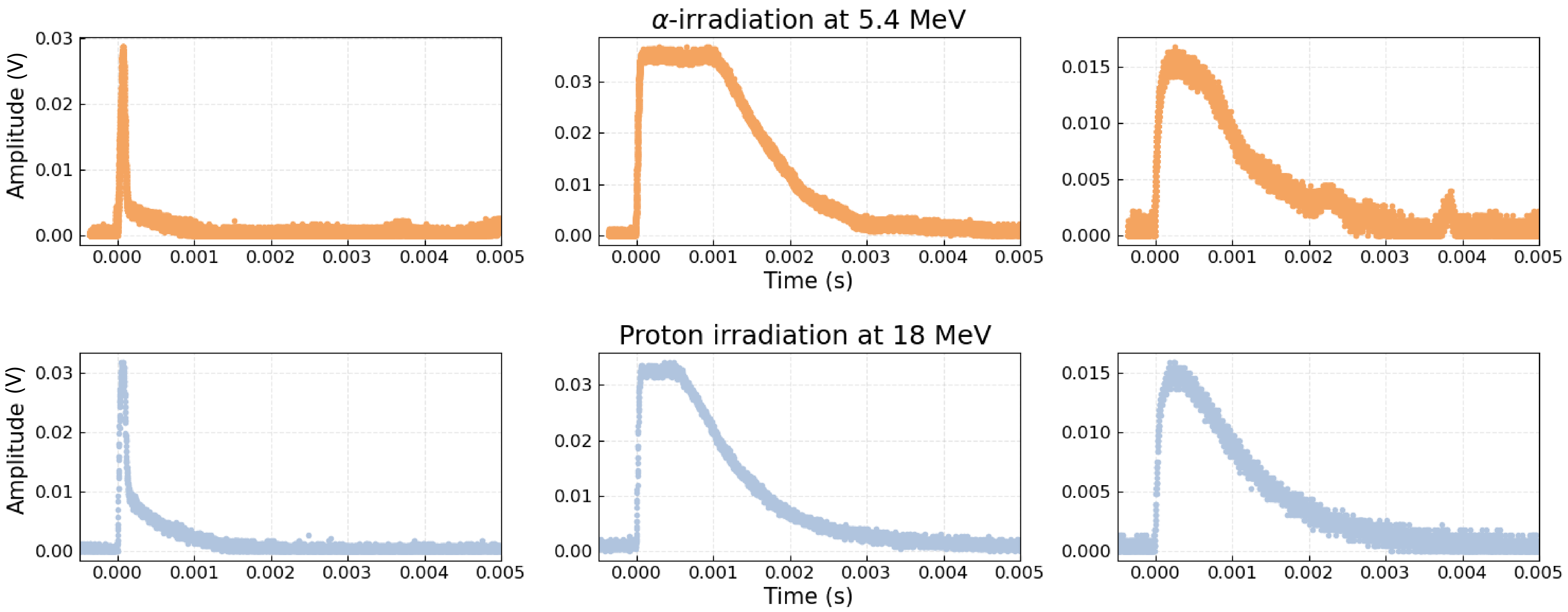
# Proton irradiation - raw data




**No coincident glitch**
resulting from direct particle hit on irradiated TES
⇒ **GOOD**

**Coincident glitches**
resulting from secondary particles or electronics
⇒ **DISCARDED**

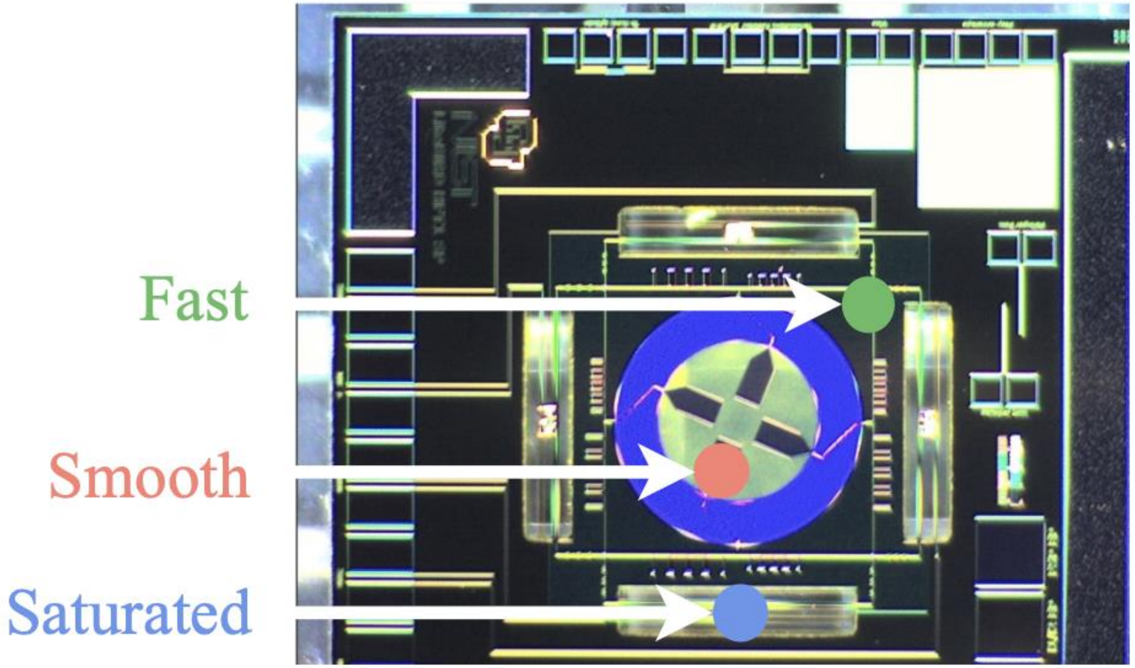
# Different type of shape

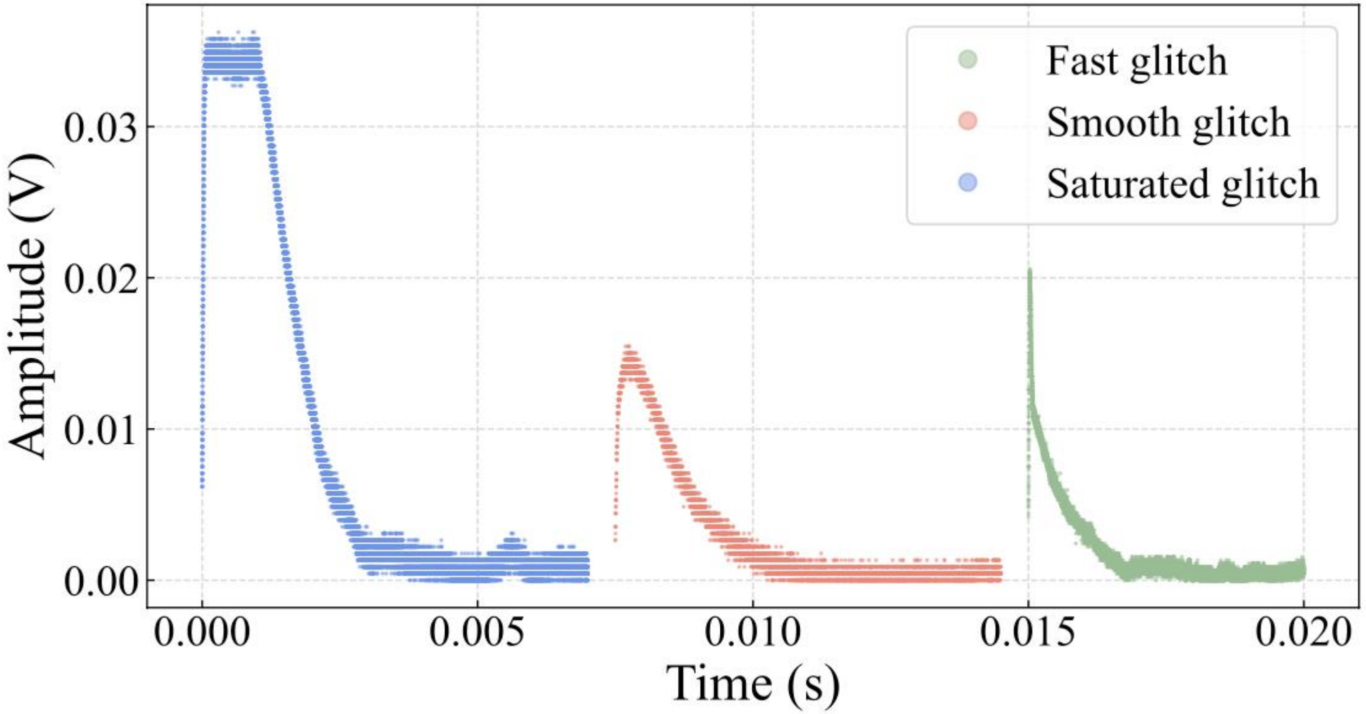


# Different type of shape

**Relation between shape and irradiated zone on chip ?**

- Direct hit on TES ?
- Hit on antenna ?
- Somewhere in between ?

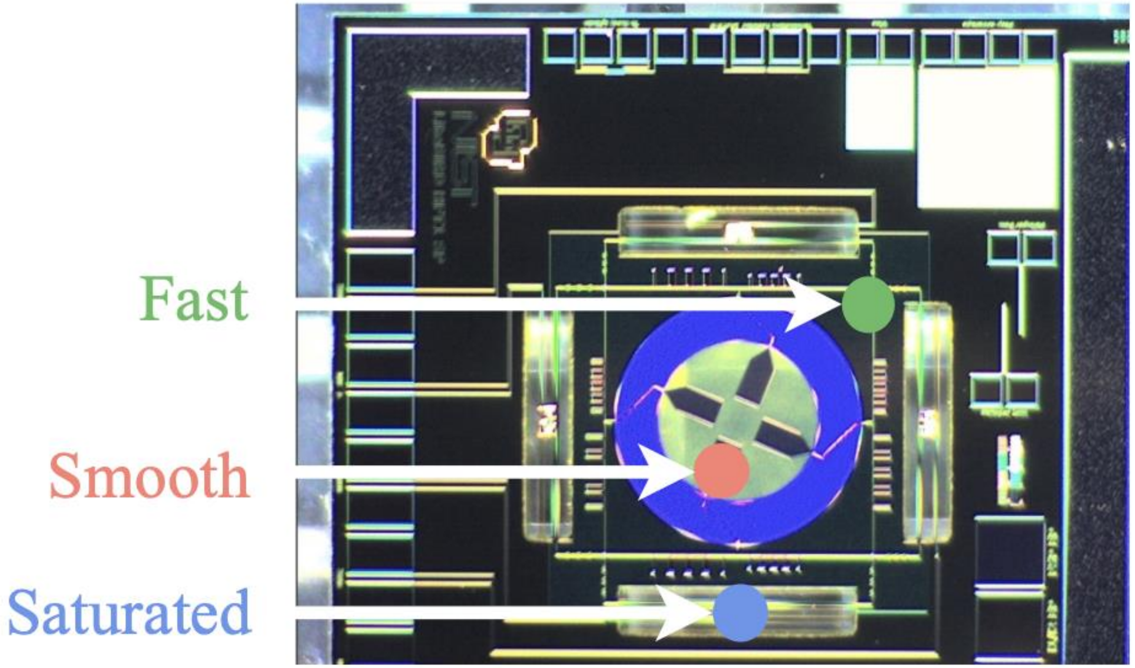


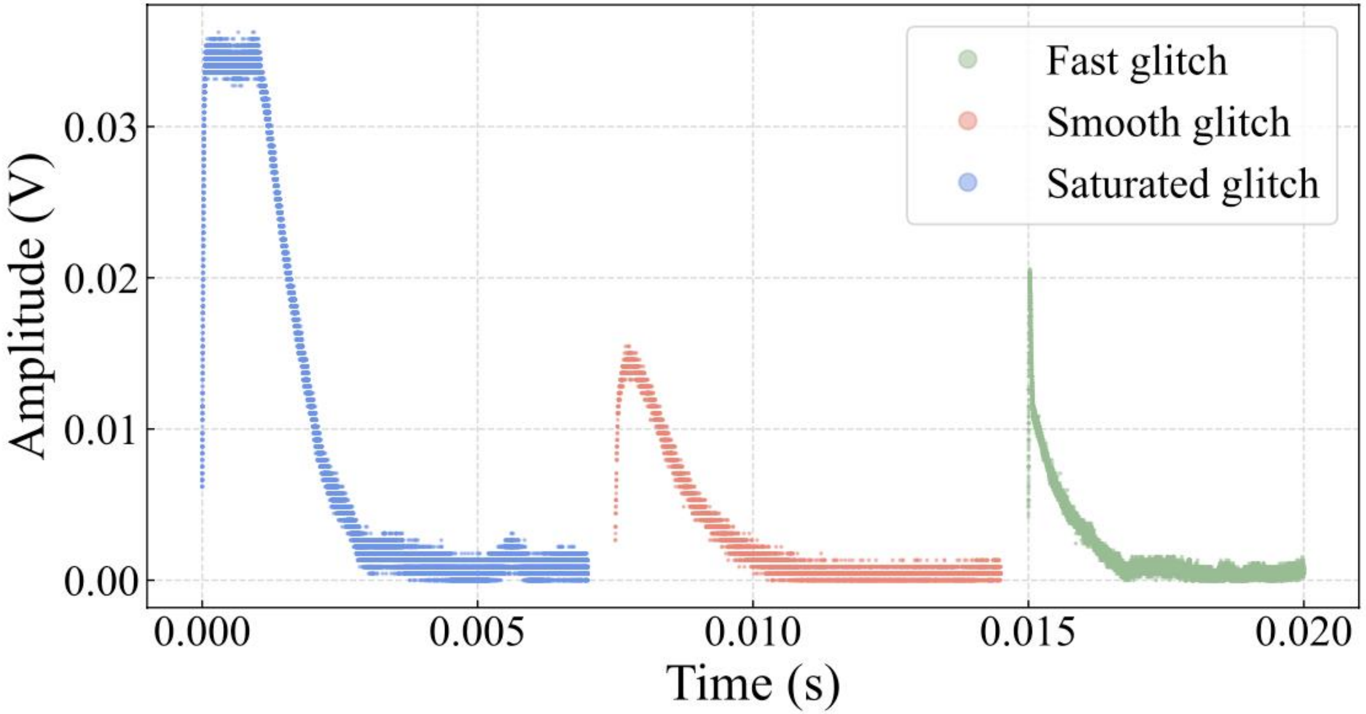




**⟹ To be confirmed with further analysis and simulations**

# Different type of shape

| Shape | 5.4 MeV | 18 MeV |
|---|---|---|
| Fast | 580 µs | 520 µs |
| Smooth | 510 µs | 453 µs |
| Saturated | 500 µs | 480 µs |

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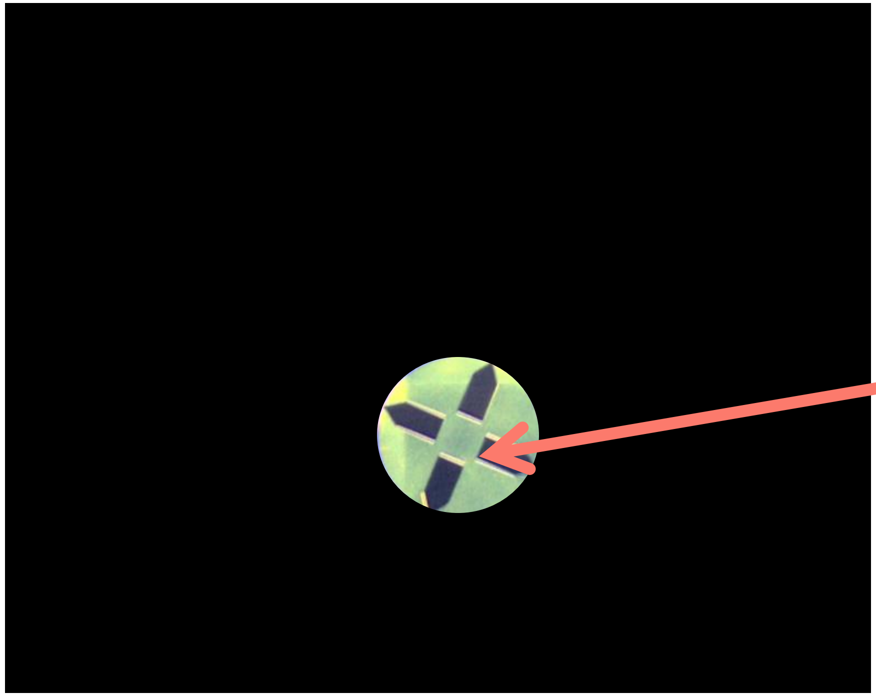
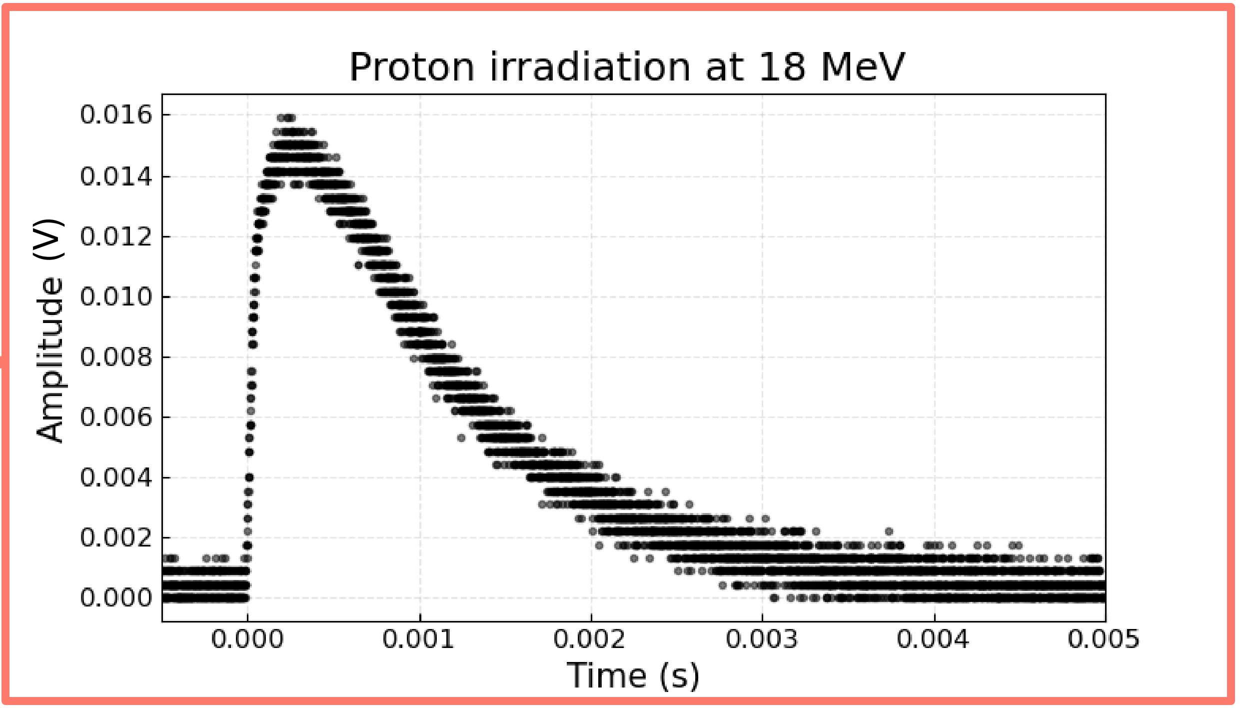
# Glitch on OMT antenna

**<u>Detector chip in operation</u>**

- TESs covered
- Only antenna exposed

⟹ <u>Hypothesis</u> : shield thickness to avoid energy deposition elsewhere than antenna probes



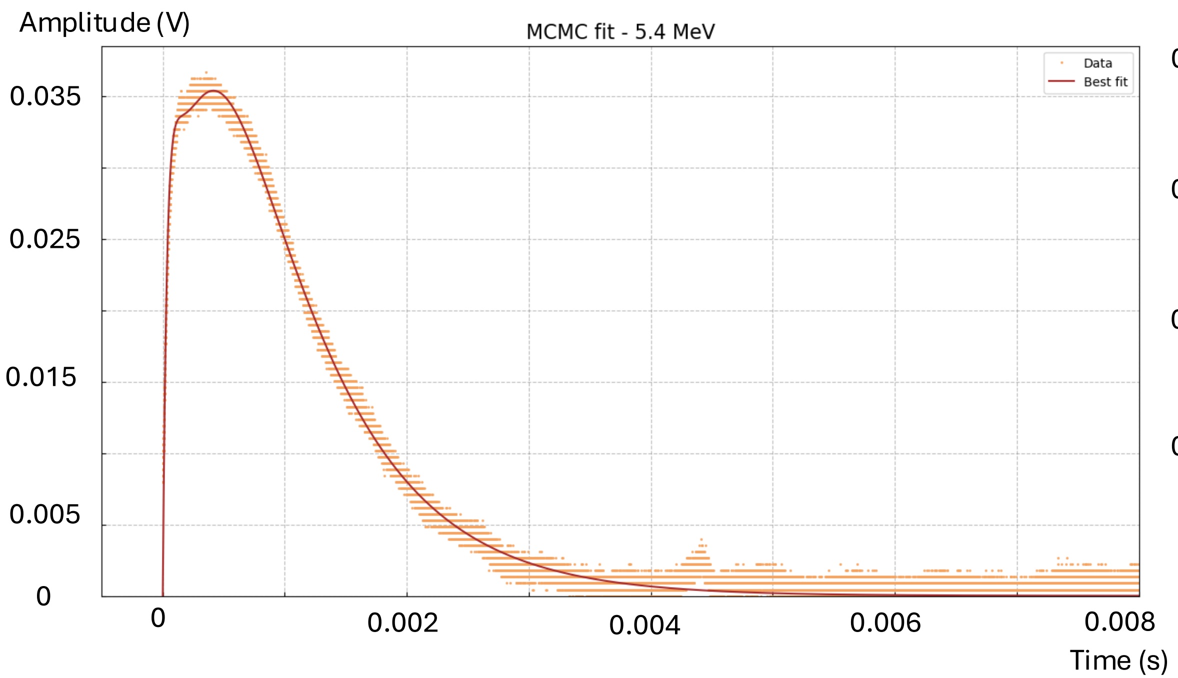


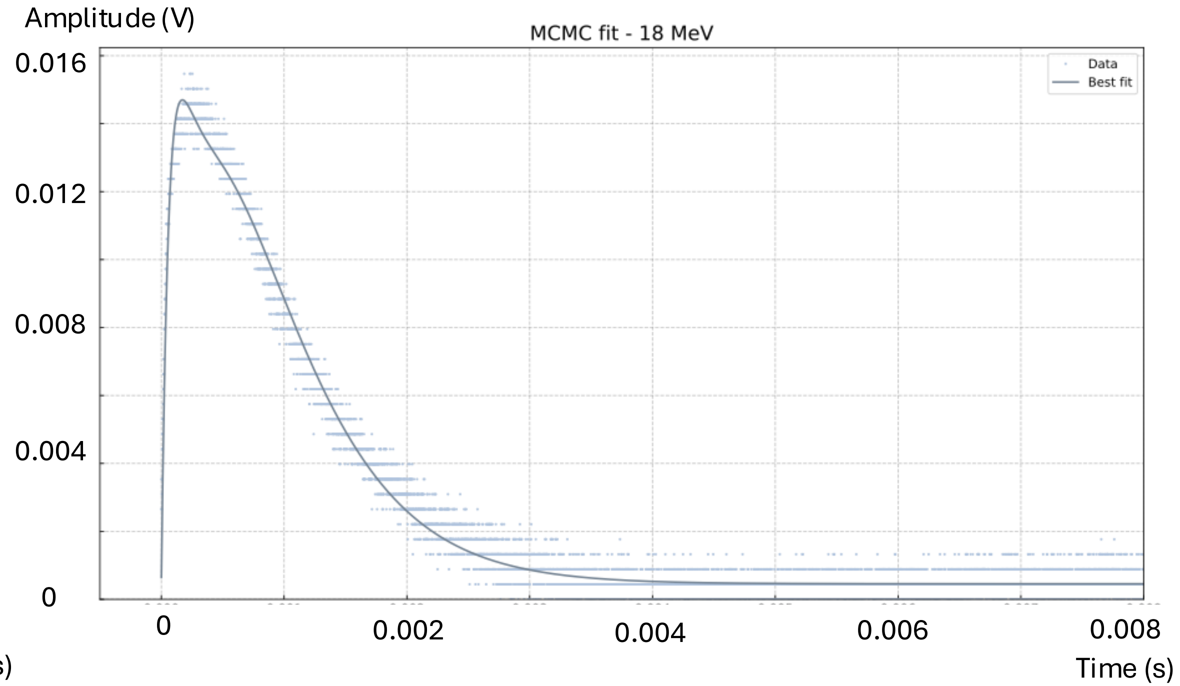

**⟹ To be confirmed with further analysis and simulations**

# Glitch on OMT antenna

$$P = A_{ath}\frac{t}{\tau_{ath}}e^{1-\frac{t}{\tau_{ath}}} + A_{th}\frac{t}{\tau_{th}}e^{1-\frac{t}{\tau_{th}}} + K$$

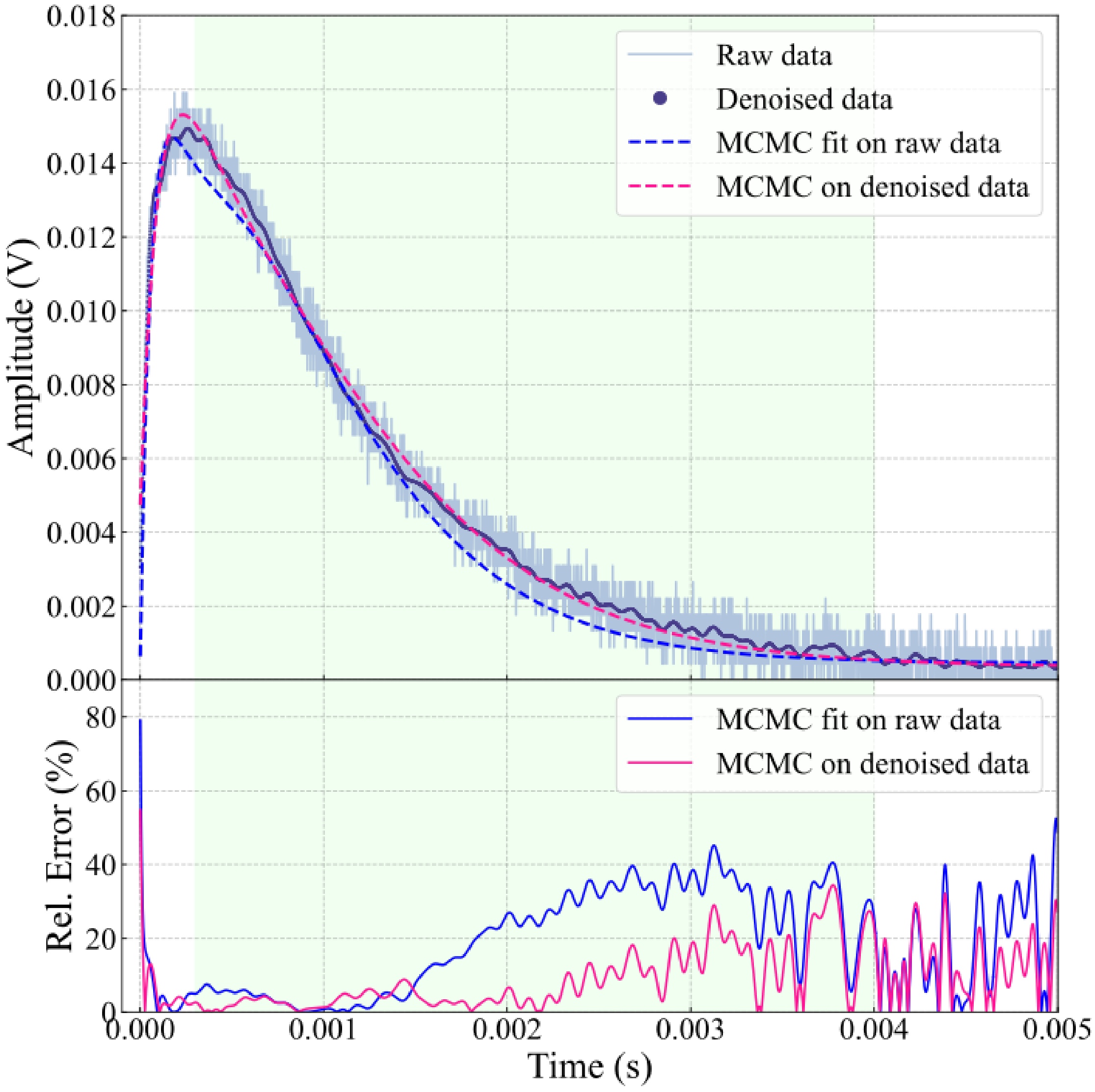
Adapted from « The Cryogenic Anti-Coincidence detector for ATHENA X-IFU: pulse analysis of the AC-S7 single pixel prototype», **M. D'Andrea et al.**




| | **5.4 MeV** | **18 MeV** |
|---|---|---|
| $\tau_{ath}$ | $75.30^{+0.02}_{-0.02}$ µs | $95.09^{+0.2}_{-0.2}$ µs |
| $\tau_{th}$ | $505.90^{+0.03}_{-0.03}$ µs | $485.76^{+0.3}_{-0.3}$ µs |

# Glitch on OMT antenna




**Denoising glitch :**

FFT

↓

Identify and filter stochastic noise contribution

↓

iFFT

+ $\Delta t$ = 99 μs on the thermal component

| **MCMC fit on raw data** |
| --- |
| $\tau_{th} = 485.76^{+0.3}_{-0.3}\ \mu s$ |

| **MCMC fit on denoised data** |
| --- |
| $\tau_{th} = 584^{+0.35}_{-0.32}\ \mu s$ |

# Conclusion

**Summary :**

- ✓ Functional set-up allowing to simulate detectors' susceptibility to cosmic rays

- ✓ Glitches observed at : 5.4 MeV, 18 MeV & 22 MeV
  - Different shapes
  - Hypothesis on shape VS chip zone hit

- ✓ Very similar time constants at 5.4 MeV and 18 MeV
  ⟹ « TES proton irradiation result analysis for future space applications » - **A.Besnard et al.** (submitted)
- ✓ Total dose calculations and IV Curves performed on the TES irradiated
  + Migth be a change in $T_C$ value of the detectors of a few mK ⇒ under investigation
  ⟹ « Preliminary assessment of Total Integrated Dose effects on LiteBIRD TES » - **P.dal Bo et al.** (submitted)

**Next steps:**

- ❑ COMSOL's simulations to compare the shape with hits

The author wants to express her gratitude to François Couchot for his great help on the understanding of the particles' interactions with matter.