Testing particle impact on detectors.

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On behalf of the Milano Bicocca LiteBIRD Team

Workshop “CMB Day 2” @ ASI Oct 17th 2023

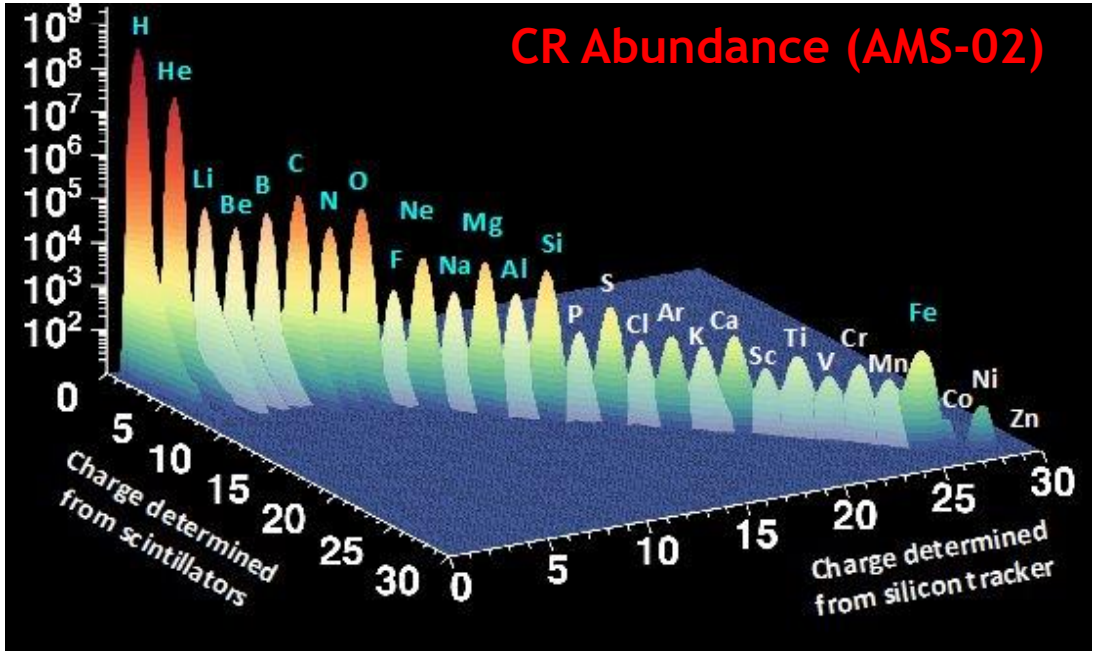
Outline

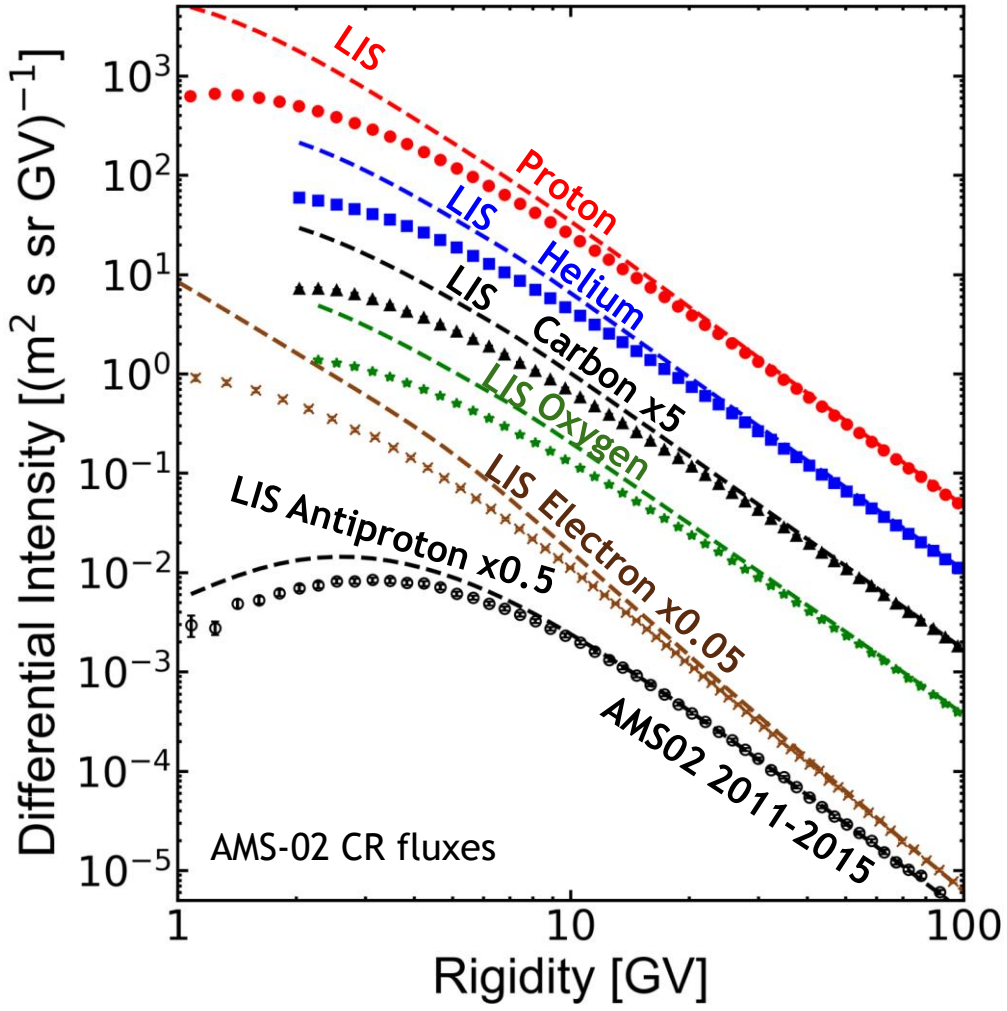
- CR Interactions with satellites
- CR-background in CMB studies
- CR impacts on TES in LiteBIRD detectors

Cosmic Rays (CR)

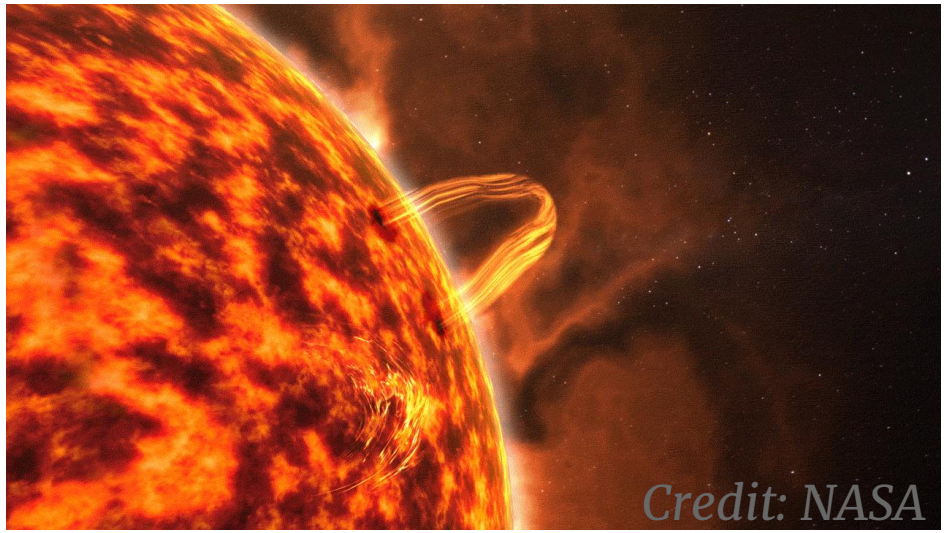
charged particles that propagate in the Interplanetary Medium:

- Galactic Cosmic Rays
- Solar Energetic Particles



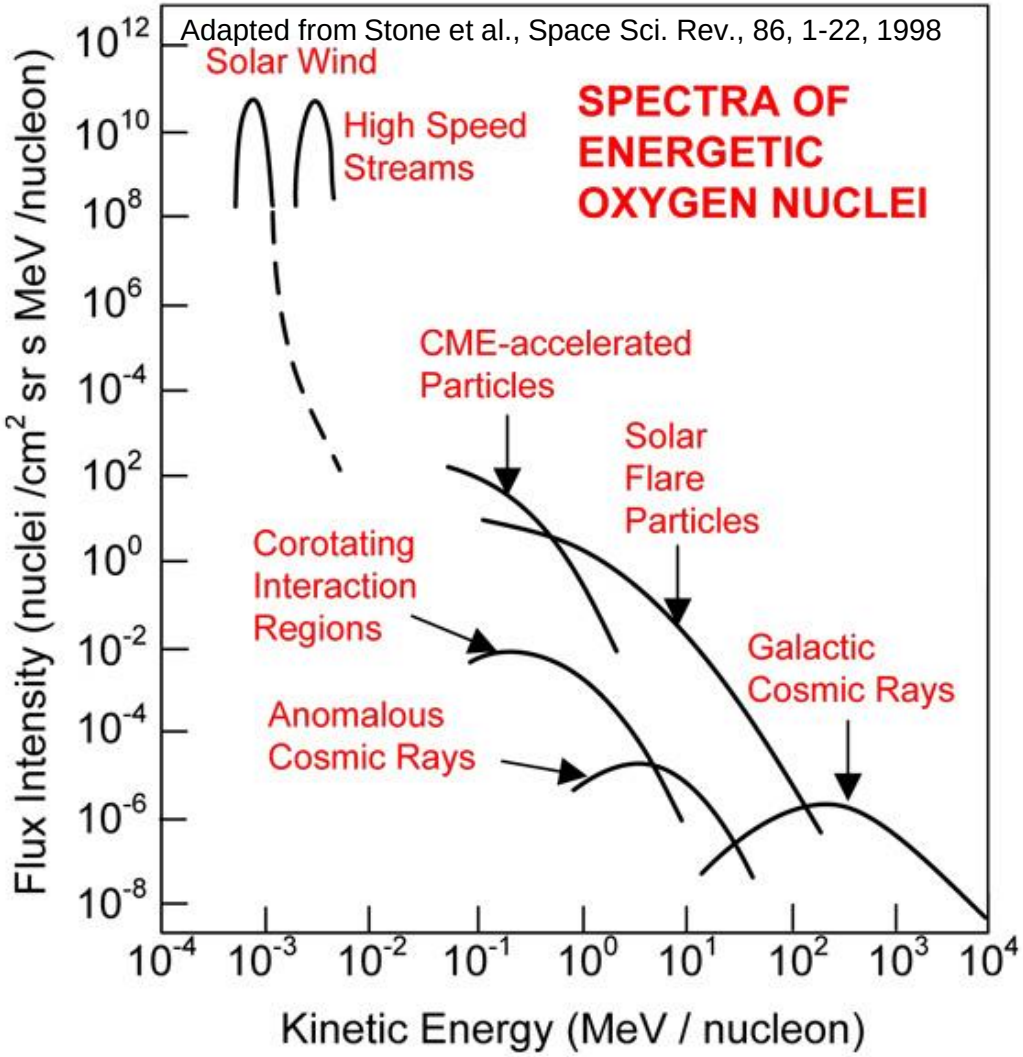


Cosmic Rays (CR)



Solar Energetic particle are randomly ejected from Sun with a probability that increase with solar activity level

High solar activity = high SEP emission probabability



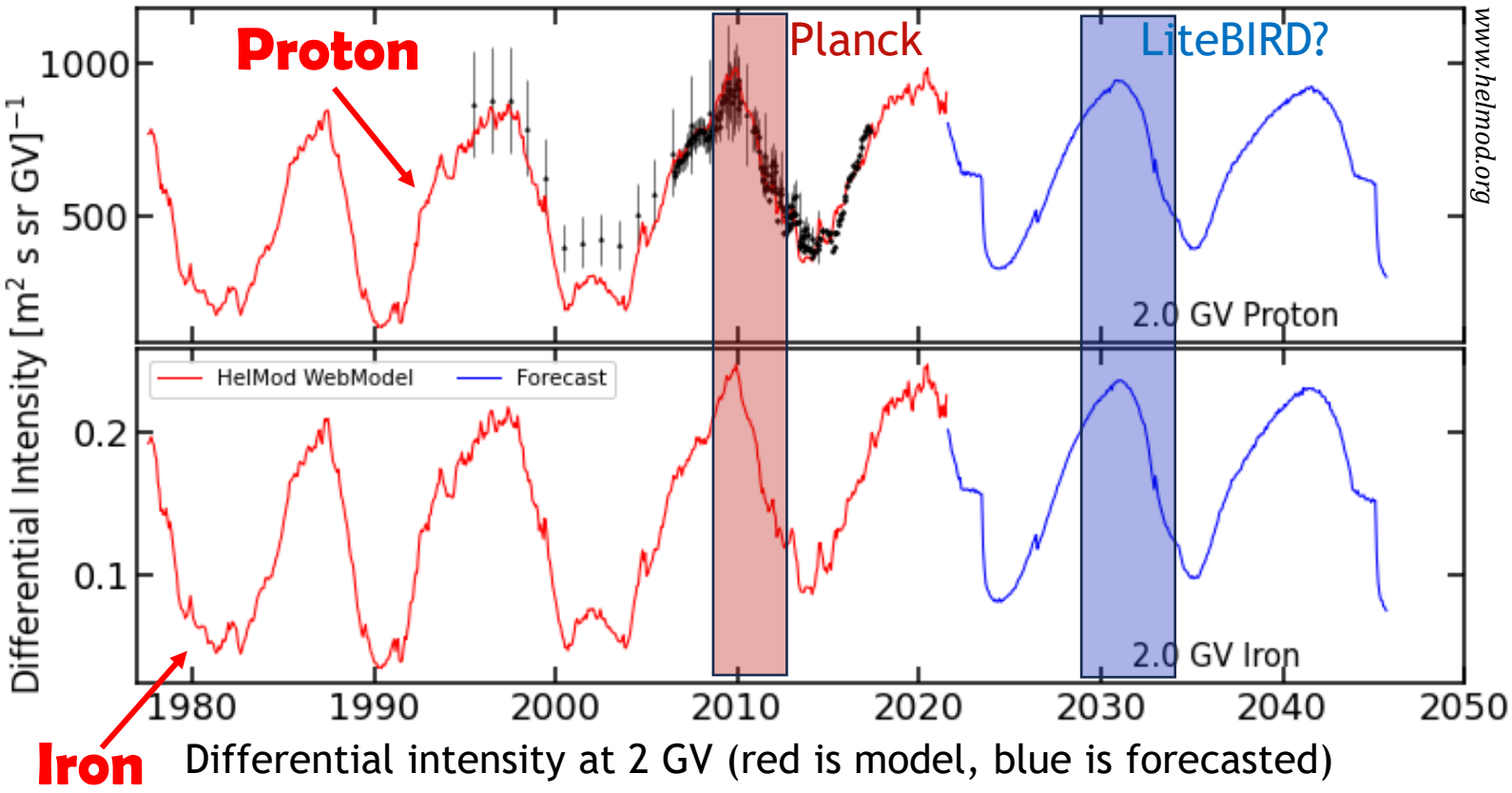
Cosmic Rays (CR)

Galactic Cosmic Rays are modulated in Energy and Time, in correlation with the 11yrs solar cycle:

low solar activity=high CR flux

Solar Energetic particle are randomly ejected from Sun with a probability that increase with solar activity level

High solar activity = high SEP emission probabability

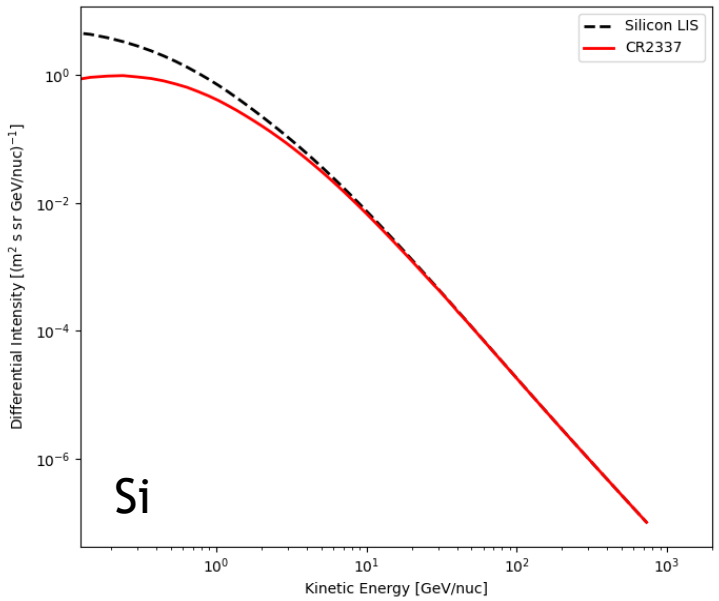


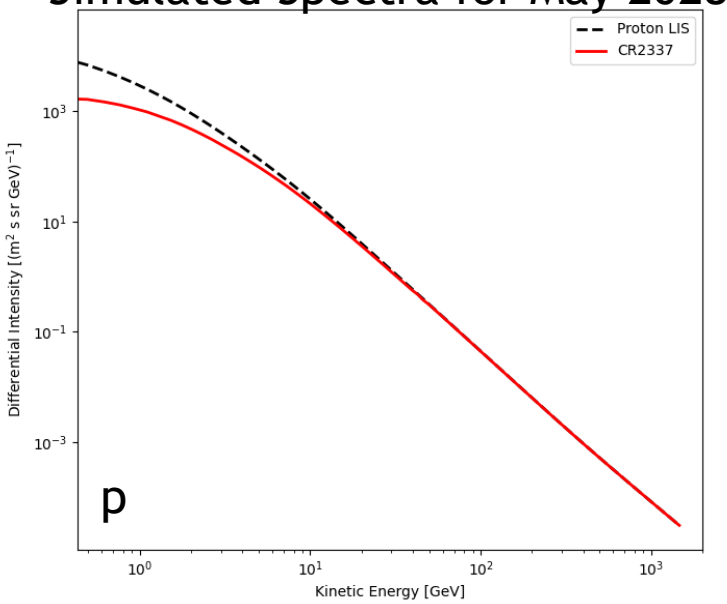
Space Radiation Environment al L2

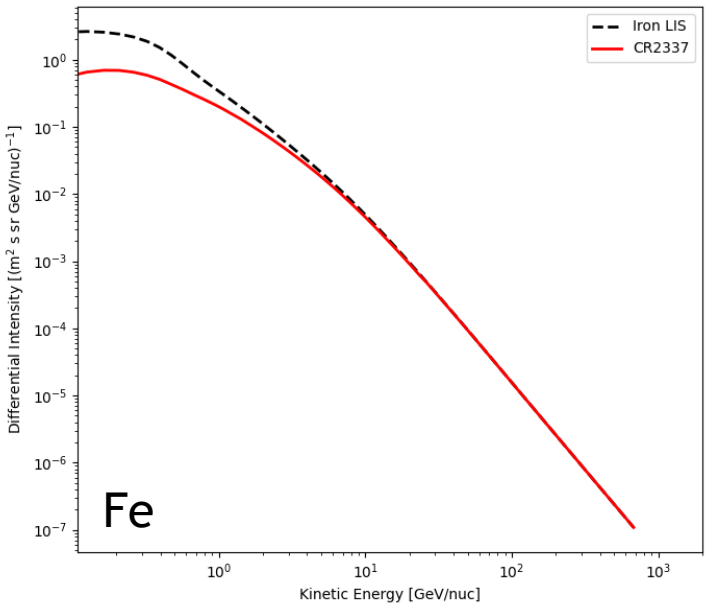
The space radiation environment, due to galactic cosmic rays, can be obtained by numerically solving the particle transport equation in Heliosphere.

The model is available as-a-service at www.helmod.org

Simulated Spectra for May 2028

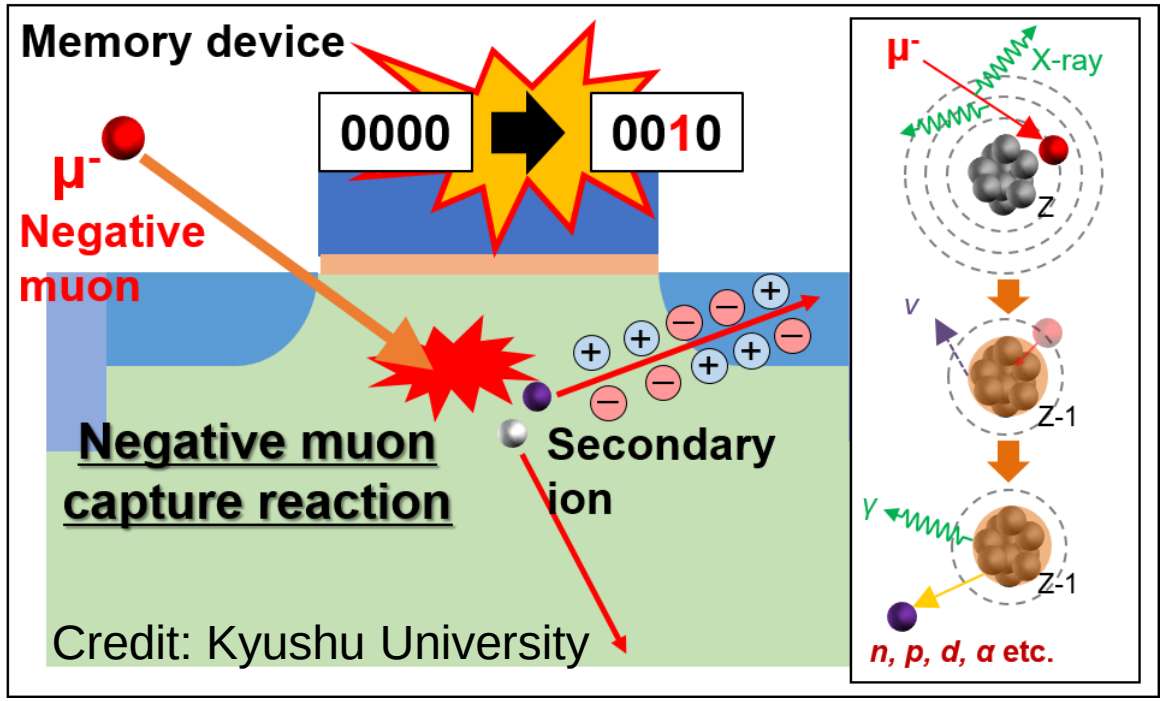


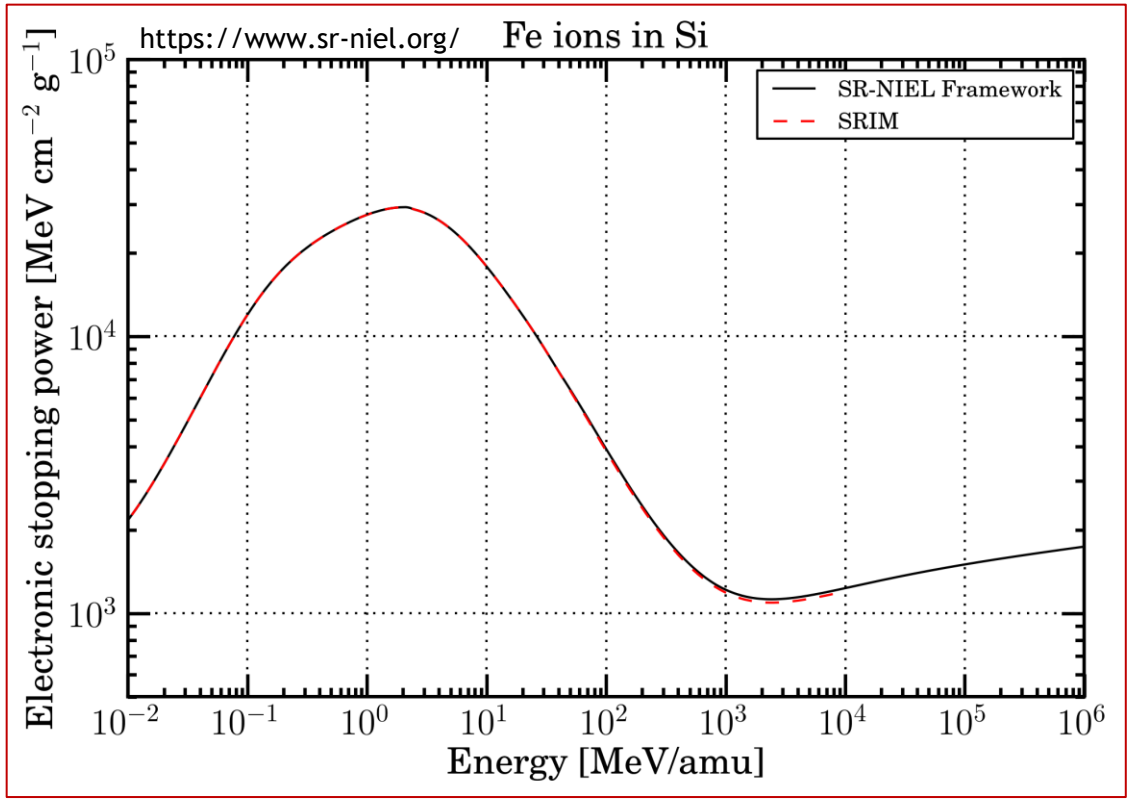




Cosmic Rays may interact with space electronics

CR may interact with detector material causing a **deposit of energy**

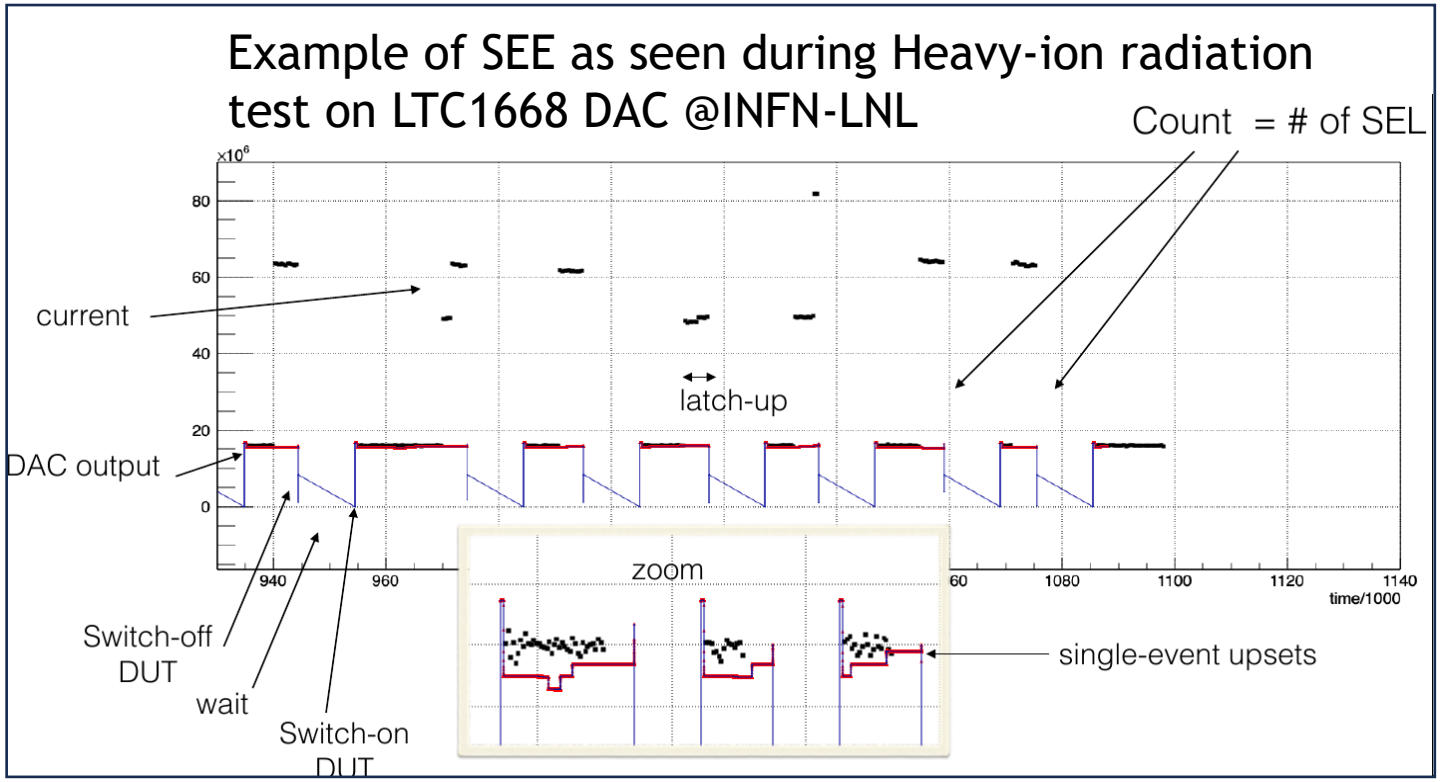




Cosmic Rays may interact with space electronics

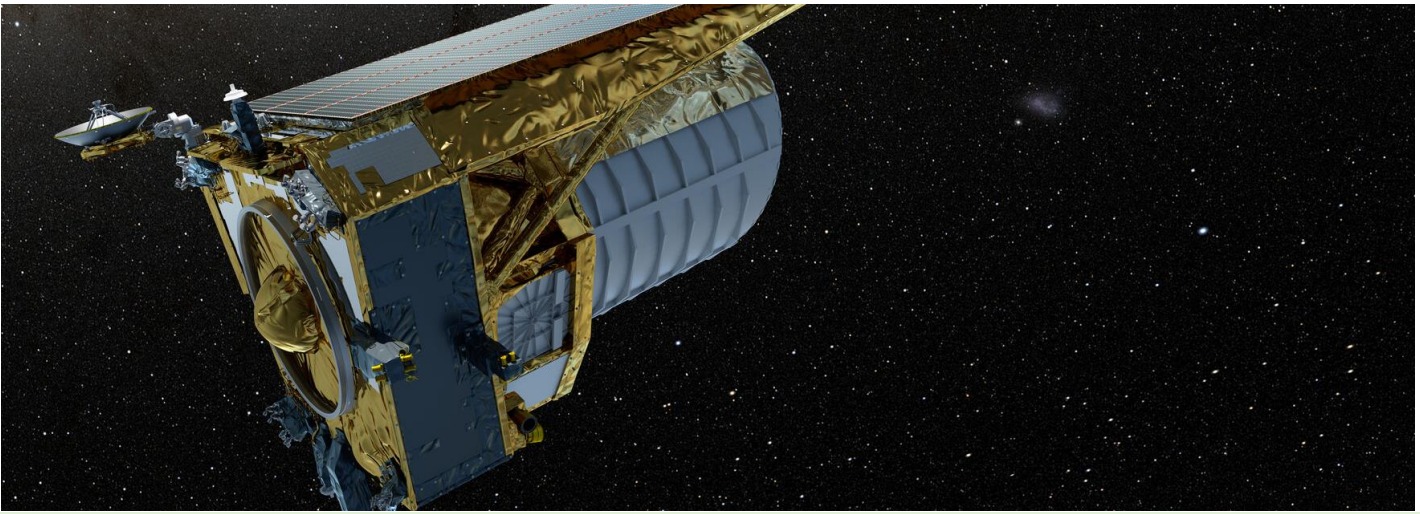
For Example, on electronics this may cause Single Event Effects (SEE): upsets, latch-ups, transient signals

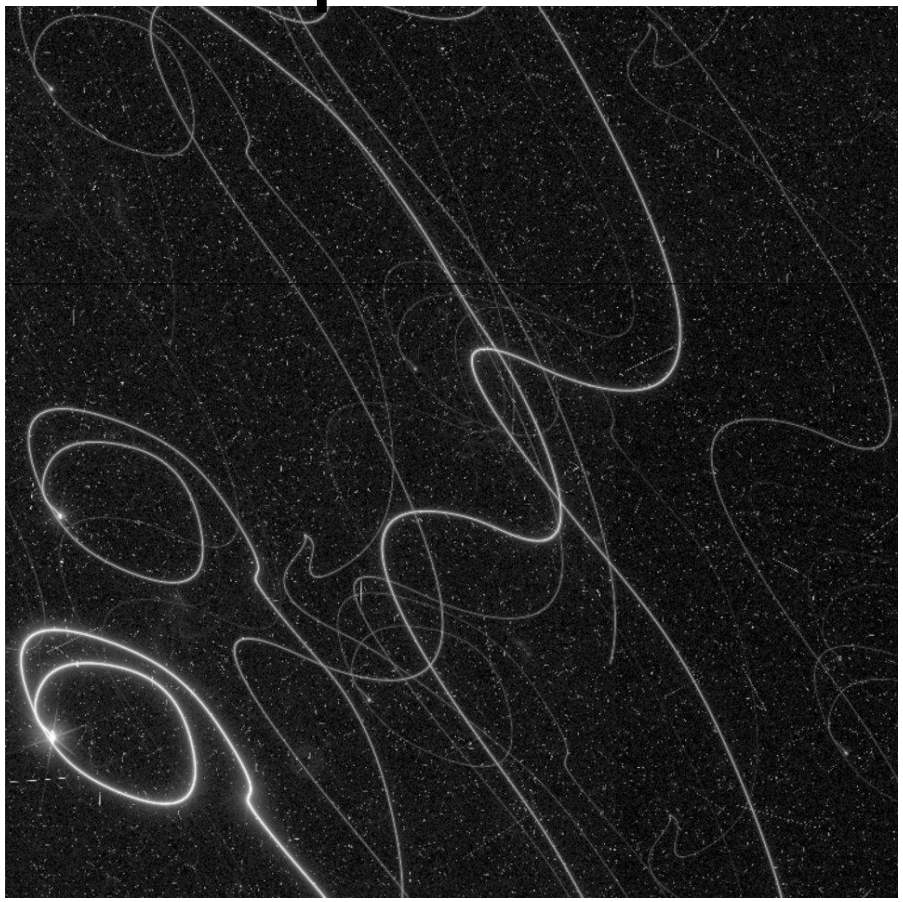
- Some SEE could be recoverable
- Others may cause severe damages



Cosmic Rays may interact with space electronics

Cosmic rays sometimes caused ‘artefacts’ or false signals to appear in Euclid's observations. These **false signals intermittently outnumbered real stars and Euclid's Sensor failed to resolve star patterns** that is needed to navigate. This led to some interesting test results!





Loopy star trails show the effect of Euclid's Fine Guidance Sensor intermittently losing its guide stars

https://www.esa.int/ESA_Multimedia/Images/2023/10/Loopy_star_trails_show_the_effect_of_Euclid_s_Fine_Guidance_Sensor_intermittently_losing_its_guide_stars

CR-background in CMB studies: The Plank experience

Planck operated during 2009 Solar Minimum, it was observed an *higher-than-expected rate of cosmic ray* ***glitches*** *and an associated* ***variability of the thermal load of the cold plate*** *of the instrument*.

They affect 90% of the data

PSD results with and without CR corrections

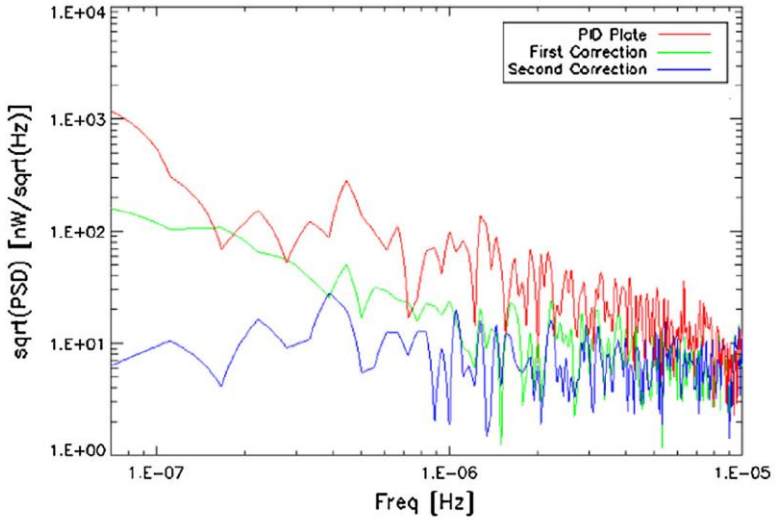


Fig. 3 *Top* correlation between the signal of the SREM (*red*) and the signal of the active regulation of the temperature of the bolometer plate. *Bottom* corrected data by subtraction of the SREM (*first*) and dilution fluctuation signal (*second*) (Color figure online)

J Low Temp Phys (2014) 176:773-786

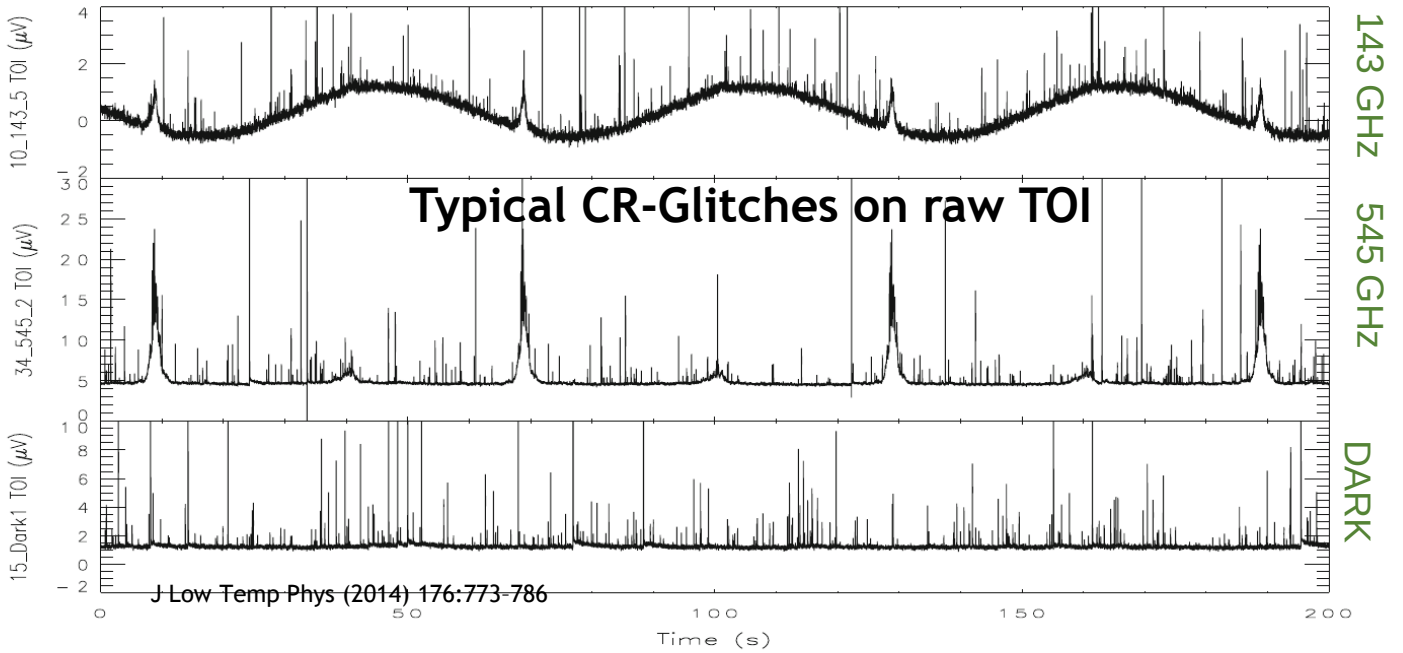


Fig. 4 Raw TOIs for three bolometers, 143 GHz (*top*), 545 GHz (*middle*), and a Dark1 bolometer (*bottom*) illustrating the typical behaviour of a detector at 143, 545 GHz, and a blind detector over the course of three rotations of the spacecraft at 1 rpm. At 143 GHz, one clearly sees the CMB dipole with a 60 s period. The 143 and 545 GHz bolometers show vividly the two Galactic Plane crossings, also with 60 s periodicity. The dark bolometer exhibits a nearly constant baseline together with a population of glitches from cosmic rays similar to those seen in the *two upper panels*. The typical maximum amplitude of a spike is between 100 and 500 mV depending on the bolometer

CR-background in CMB studies: The Plank experience

The *HFI Glitchology* was (almost) completely understood and includes:

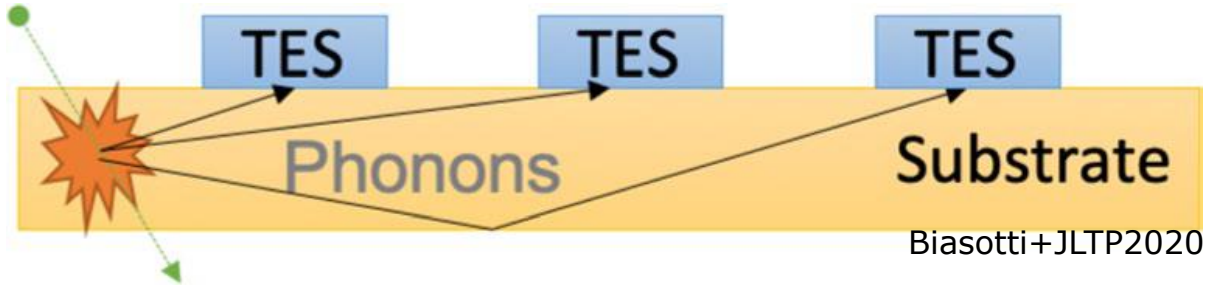
- Short Events --> due to CR impacts on grid or thermistor.
- Long Events --> due to CR hitting silicon die.
- Slow Events --> (prob.) due to heat transfer from PSBa feed-through -> silincon die -> thermistor

12-20% of the sample discarded due to glitch contamination

CR effects of HFI was studies extensively, e.g.:
Ade+ A&A 571, A10 (2014)
Catalano+ J Low Temp Phys (2014) 176:773–786
Catalano+ A&A 569, A88 (2014)

TES sensibility to cosmic rays

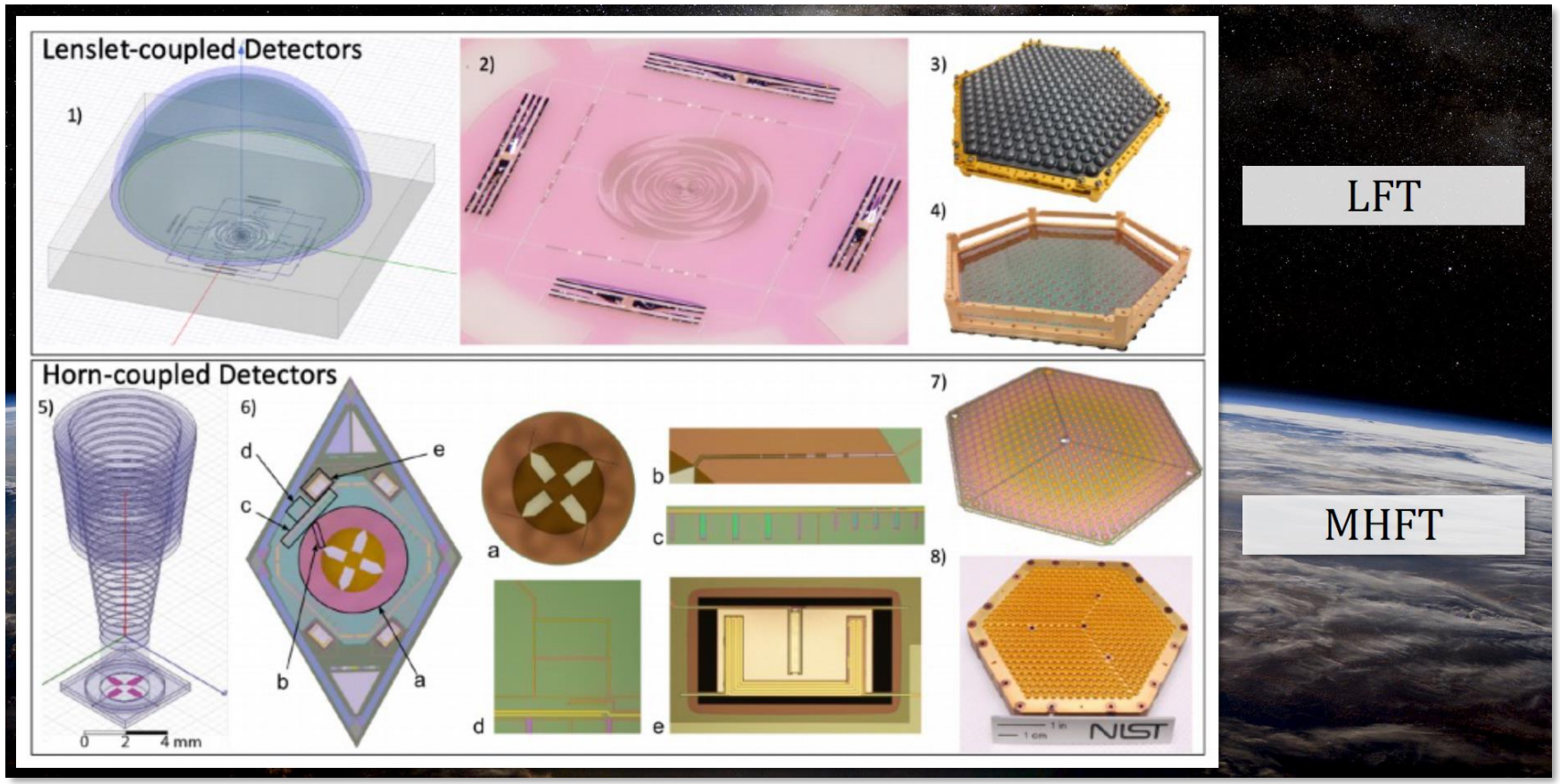
CR impacts on TES detectors result in an introduced noise from the thermal heating of the wafer or a direct hit on the detector



Biasotti+JLTP2020

Example of impacted detectors:
- ATHENA (X detector) Biasotti+JLTP2020
- SPICA/SAFARI (far infrared) Stockmans+JLTP2022
- LiteBIRD (CMB) Stever+JCAP2021

TES sensibility to cosmic rays

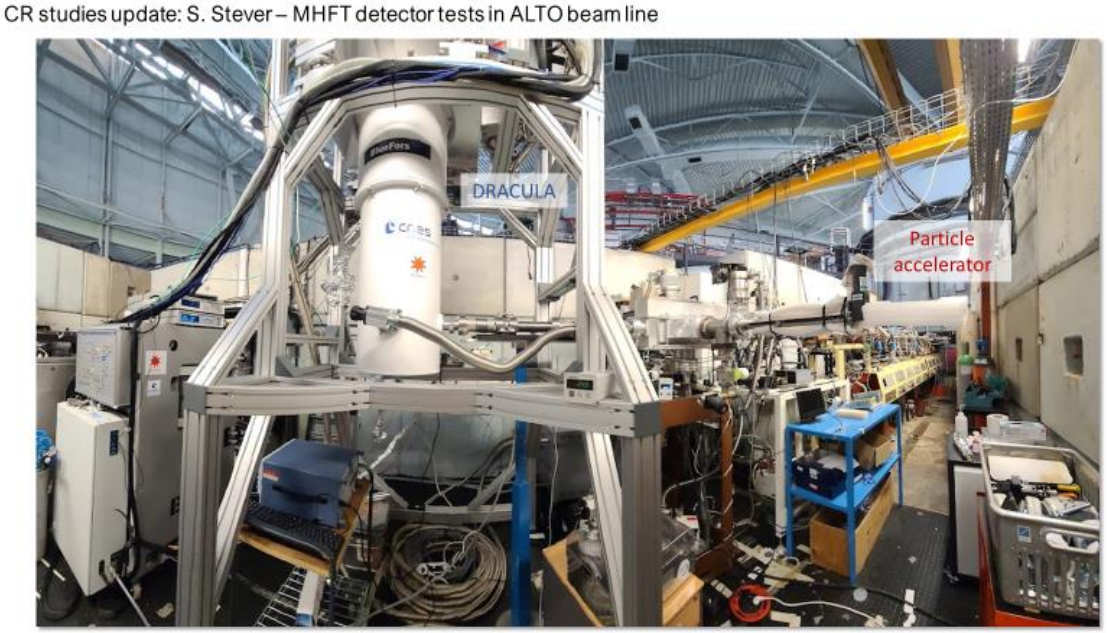


LiteBIRD extensively uses TES detectors (>4'000)

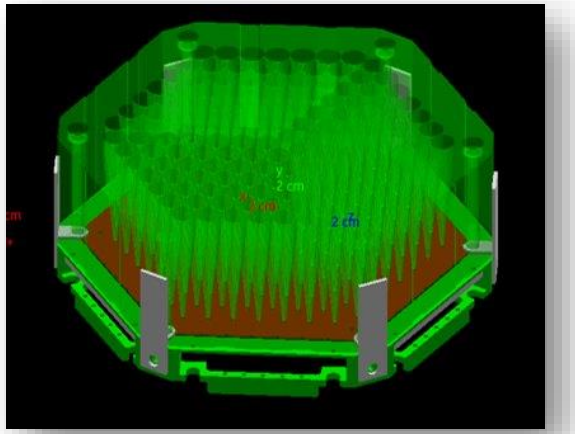
To assess the impact of CR both simulation and experimental activity are in progress

Experimental tests

- **Proposal for ALTO**: IAS lead + Pisa and Milano-Bicocca contribution to experiments and analysis
- NIST samples already sent to IAS, ready for packaging
- **DRACULA dilution fridge already tested** at the accelerator, with a successful outcome (= 100 mK test bench under proton irradiation is OK).



Simulation procedure (HFT)



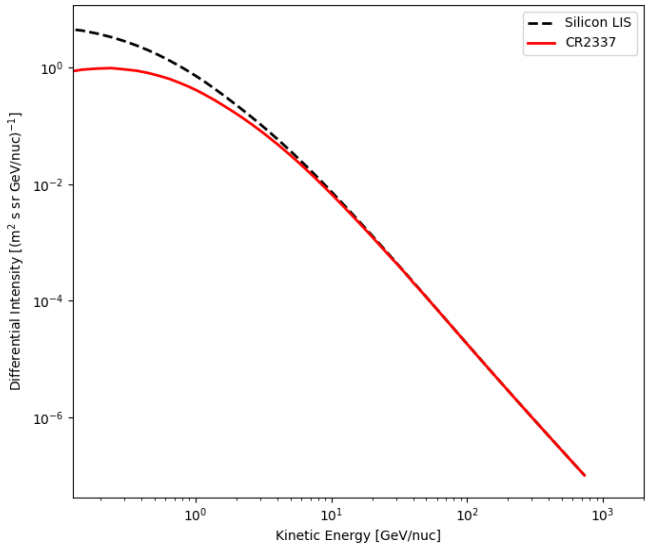
Adapted From Stever+2021

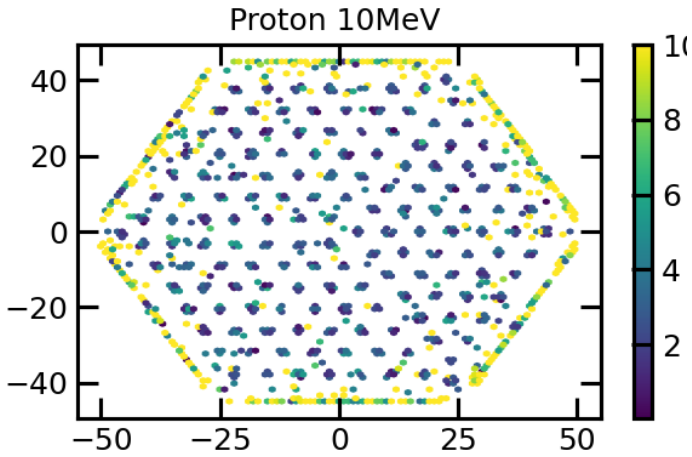
Space Radiation Environment at L2 2028-2030

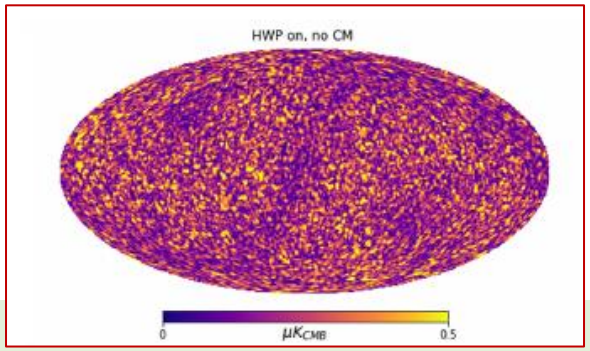
Simulation of Energy Deposition on detector (GEANT4)

Detector Thermal Model (COMSOL)

TOD Generation & Analysis

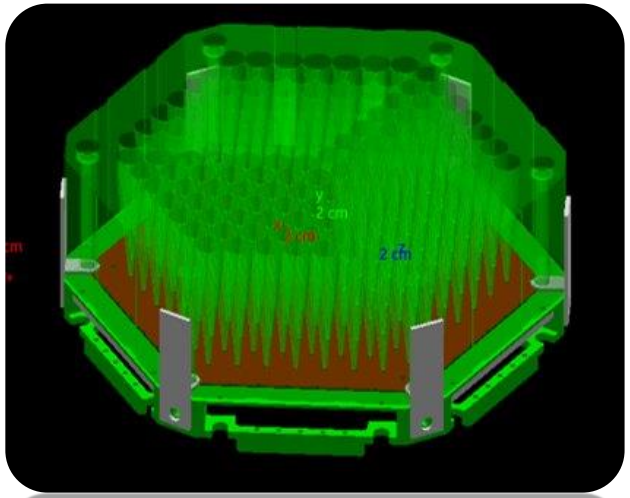


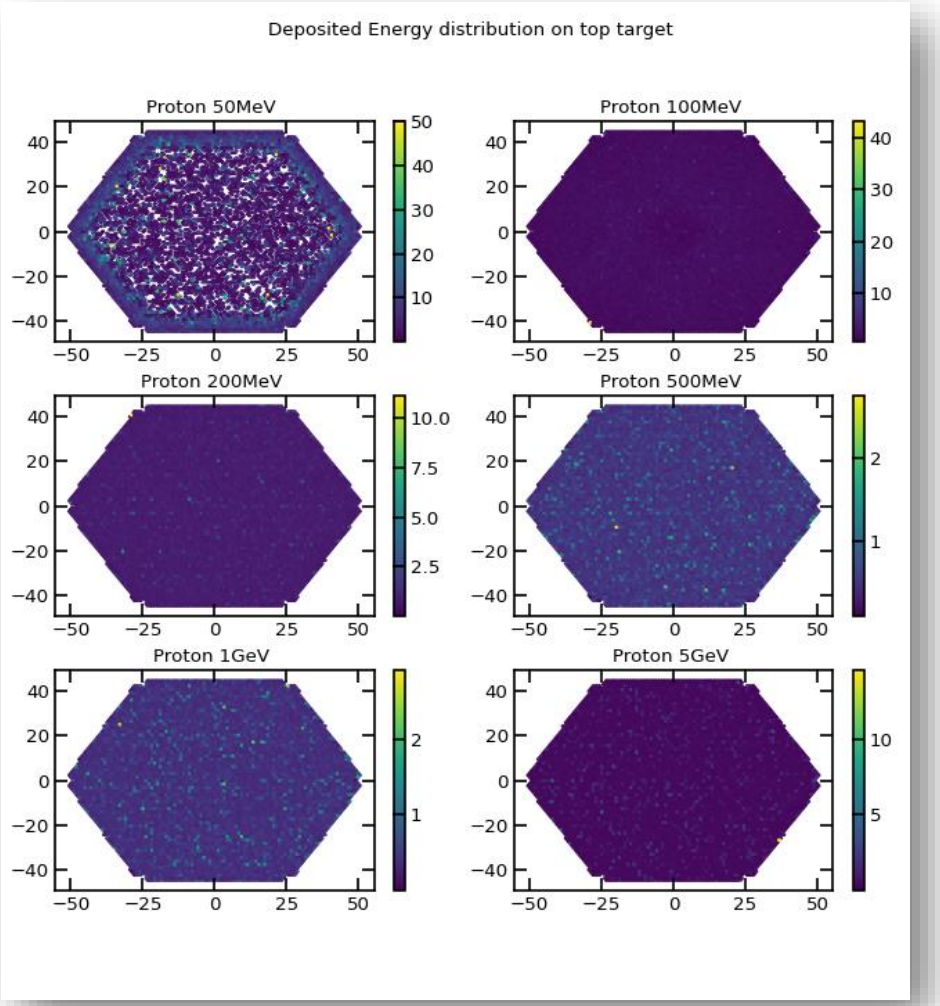




Energy distribution on HFT – GEANT-4 simulation

- We simulated 5M protons uniformly from a sphere of radius 7cm.
- QBBC physics,
- particle hits on sensible wafer

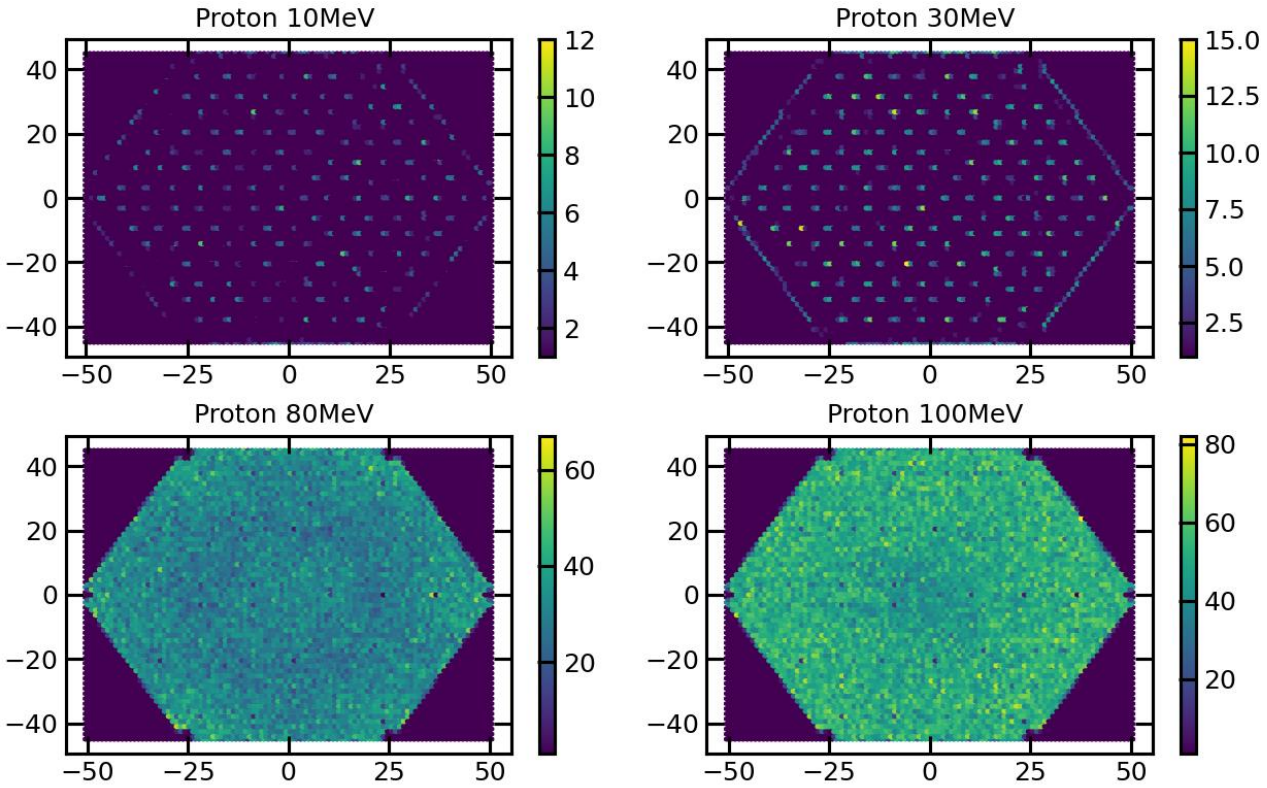




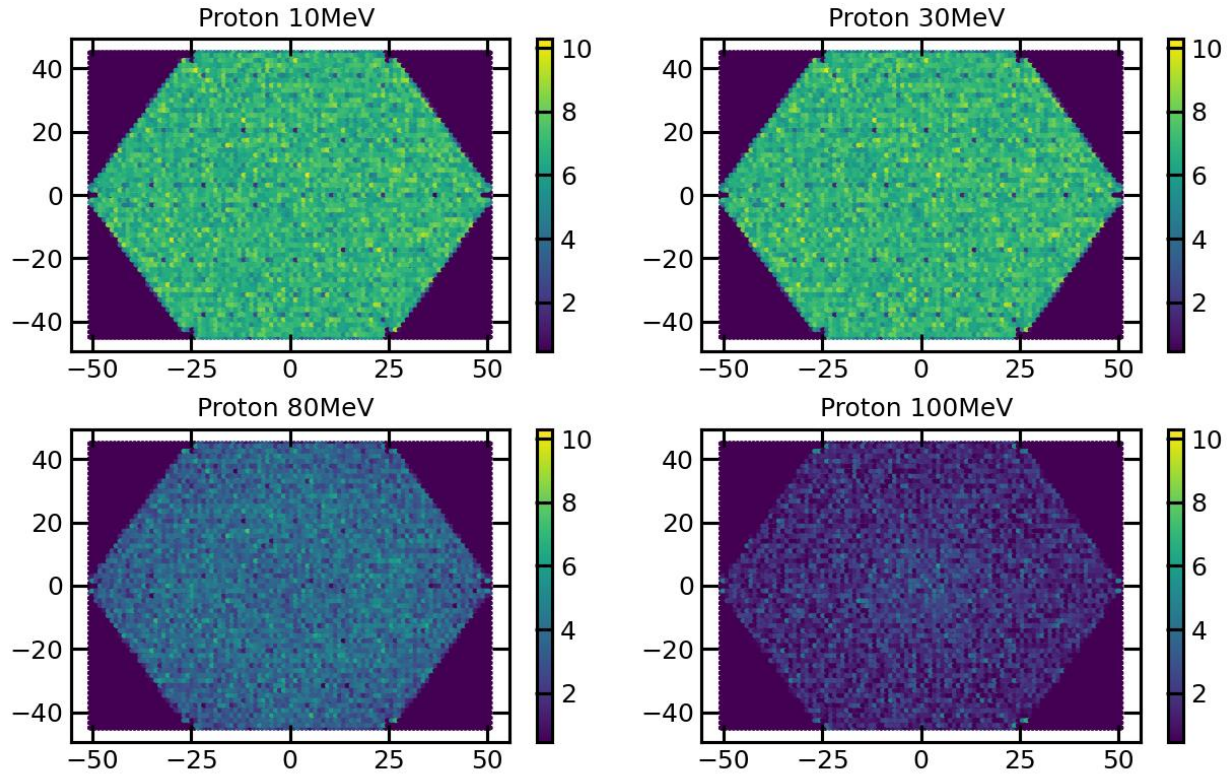
Energy distribution on HFT – GEANT-4 simulation

Preliminary results

Hit Distribution on top of HFT Wafer

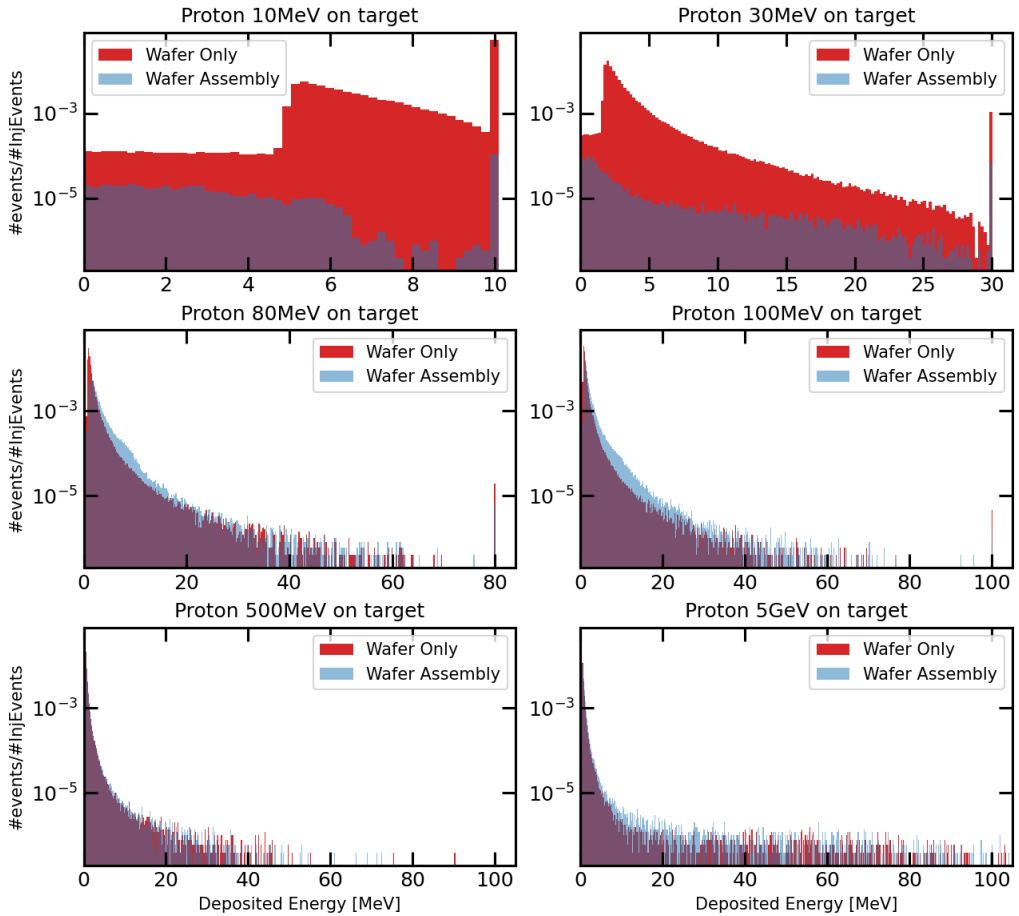


Difference of hit distribution with or without feedhorns



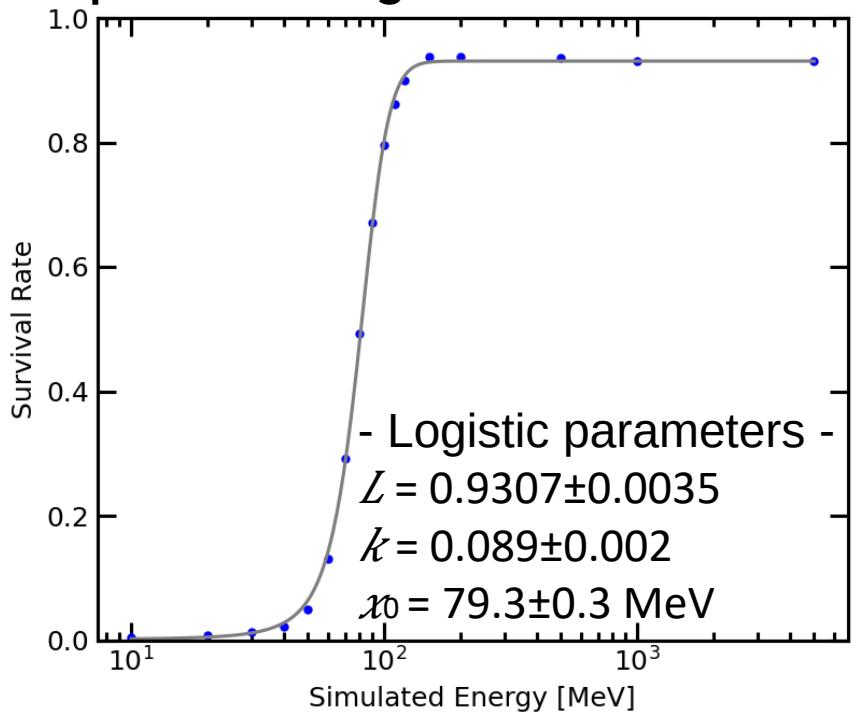
Energy distribution on HFT – GEANT-4 simulation

Deposited Energy distribution on HFT Wafer

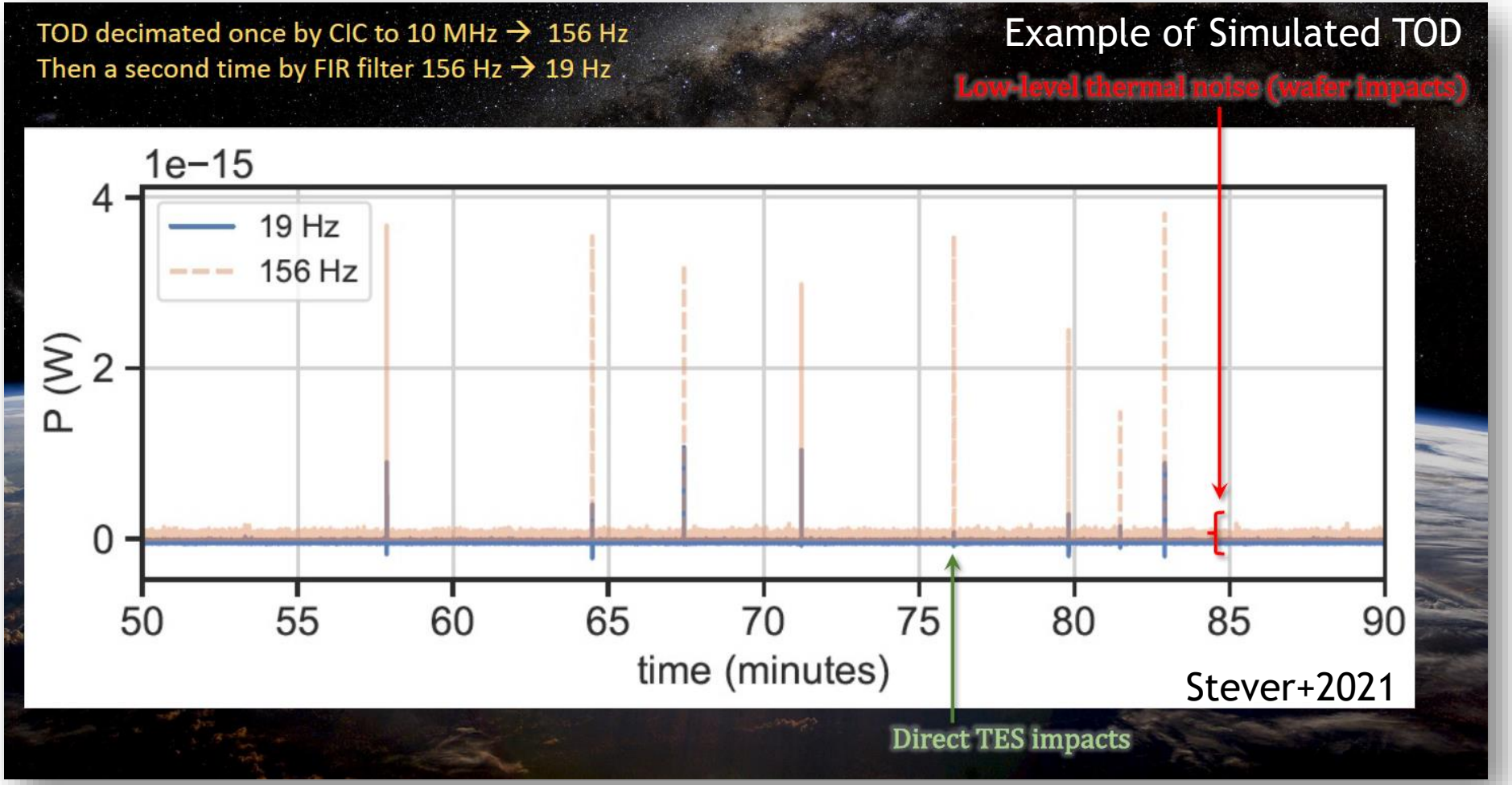


Preliminary results

Survival fraction of primary proton through the feedhorns



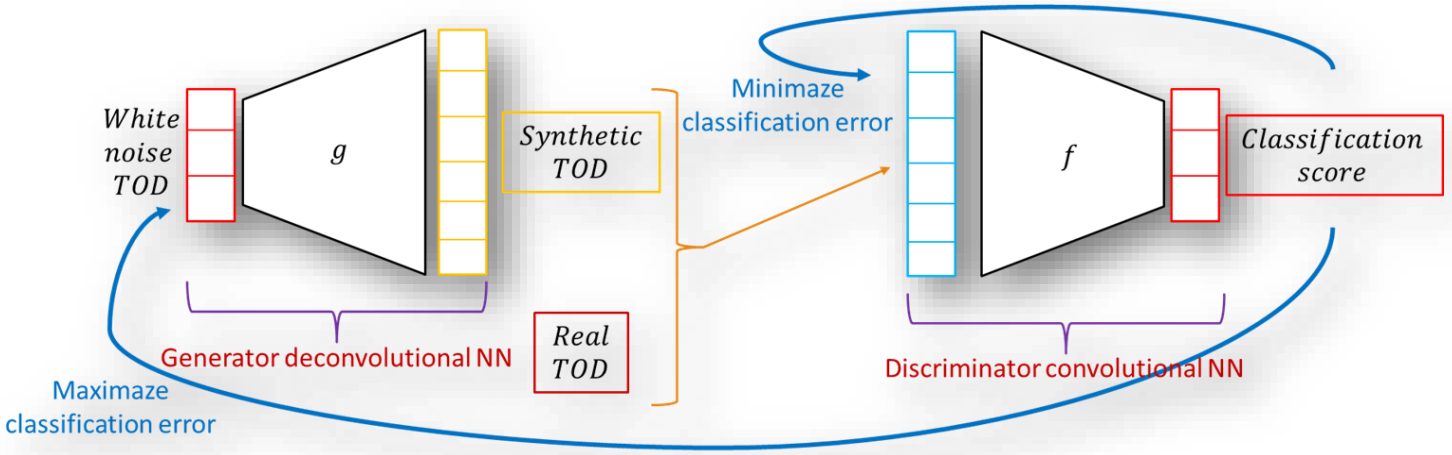
Simulation procedure (HFT)

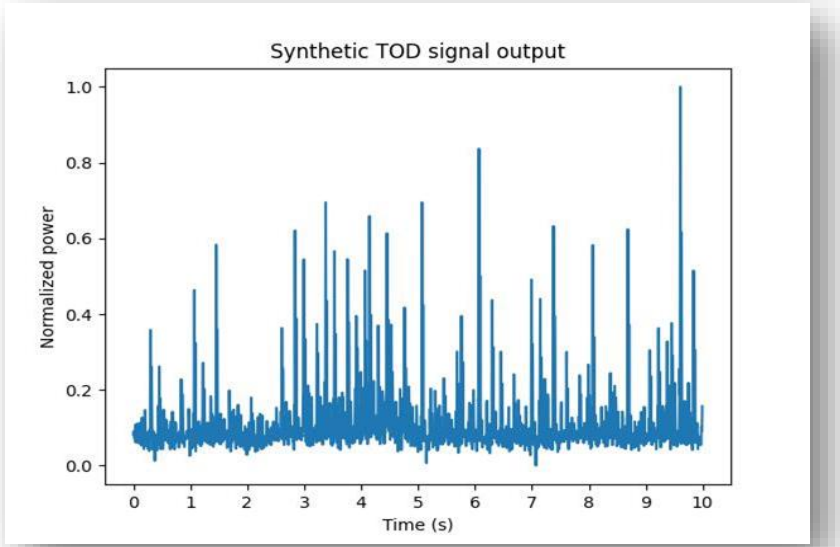


Simulation procedure (HFT)

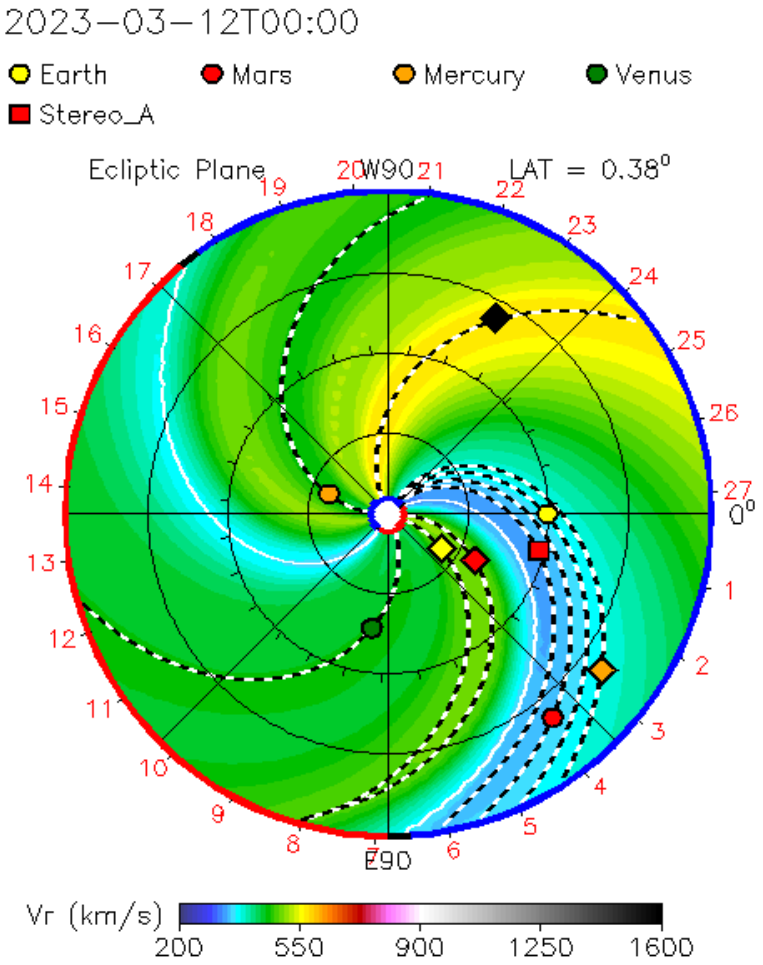
The CR systematics change along the 3 years mission of LiteBIRD and nowadays, **a representative sample of simulations is achievable only with data augmentation**. The developed GAN is an example of this technique.

We are developing a Generative Adversarial Network (GAN) model **to generate synthetic time series of the CR noise into the HFT response chain**. This reduces the simulation time with respect to the expensive traditional Monte Carlo chain of simulations.





A Final Remark
CR: problem or opportunity?



All Experiments in space have to deal with CRs

All Experiments in space potentially are CRs monitors

That may allow additional study for space weather application and particle propagation in the inner heliosphere

Better knowledge of the background induced by CRs

Conclusion

- We are studying the impact of CR on TES detectors for the LiteBIRD experiment
- Cosmic rays affects detectors in space causing radiation damages on electronics
- The impact of the space radiation environment on science data is a «must have» for all space missions. (False signal, noise,…)

AI Art for: *cosmic rays hitting litebird*

Thanks for your attention