12 years of Space Weather Monitoring With SATRAM

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2025 Spacemon Workshop - 11–13/06/2025

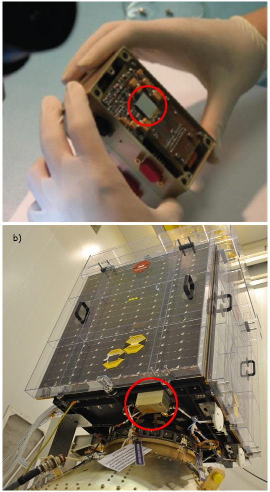
Space Application of Timepix Radiation Monitor (SATRAM)

First Timepix in open space

- 300 µm Si sensor, 256 × 256 pixel with 55 µm pixel pitch
- Operated in energy mode (ToT)
- Power consumption: 2.5 W
- Mass: 380 g; Dimensions: 107 mm × 70 mm × 55 mm
- Frame length: 2 ms, 200 ms, 2 s
- Platform technology demonstrator

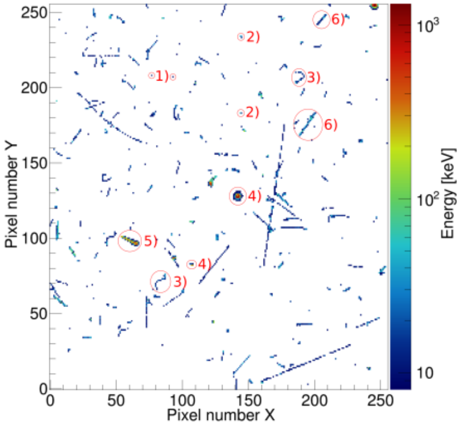
Proba-V

- Sun-synchronous at altitude 820 km
- Orbit duration: 101.21 min
- Inclination: 98.6°
- Launched 7 May 2013



Data Examples

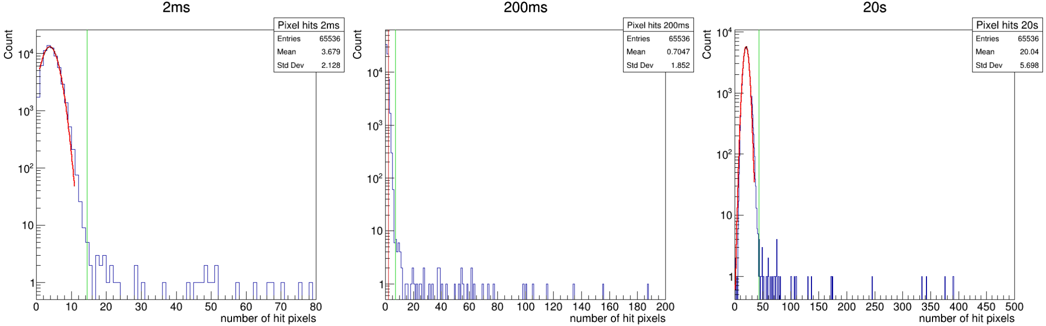
(1) Dot	Low energy X- and γ-rays, low energy electrons
(2) Small blob	X- and γ-rays, electrons
(3) Curly track	γ-rays and electrons (MeV)
(4) Heavy Blob	Highly ionizing particles with short range (α, protons, ...)
(5) Heavy track	Highly ionizing particles (protons, ions, ...)
(6) Straight track	Energetic light charged particles (μ, minimum ionizing light ions, ...)



B. Bergmann, St. Gohl, D. Garvey, J. Jelínek, and P. Smolyanskiy. Results and Perspectives of Timepix Detectors in Space—From Radiation Monitoring in Low Earth Orbit to Astroparticle Physics. Instruments, 8(1), 2024. ISSN 2410-390X. doi: https://doi.org/10.3390/instruments8010017.

Noisy Pixel Determination

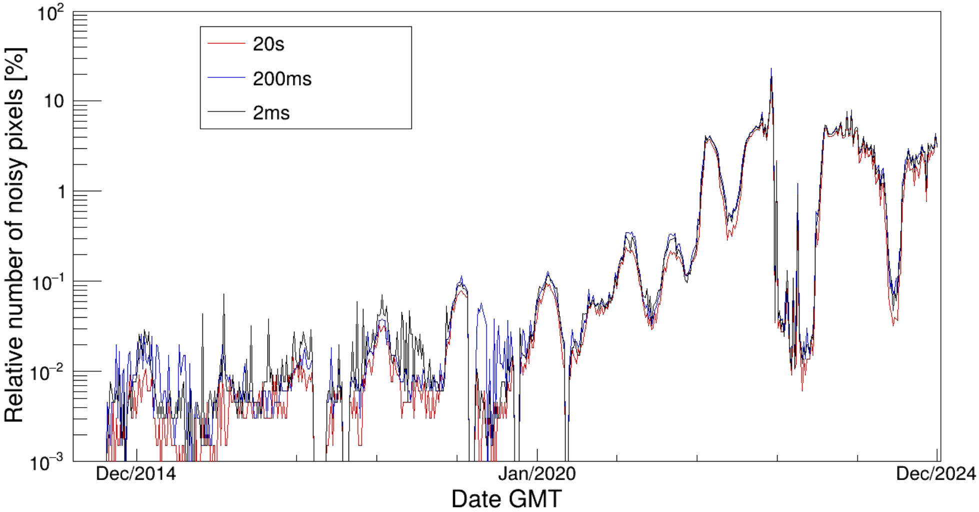
Counting number of hits per pixel over a week and fit with Gaussian



blue - data; red - fit; green - limit between not noisy and noisy pixels: mean + 5σ

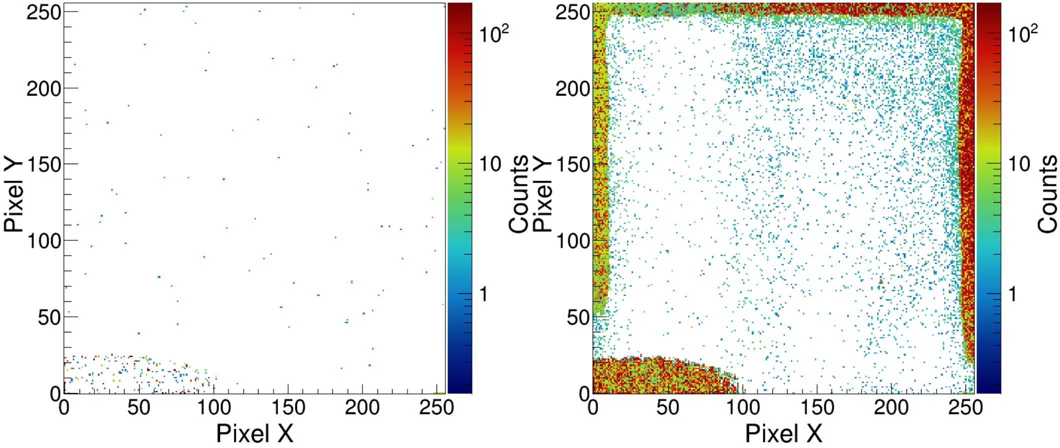
Pixel above limit → noisy

Noisy Pixels over the years

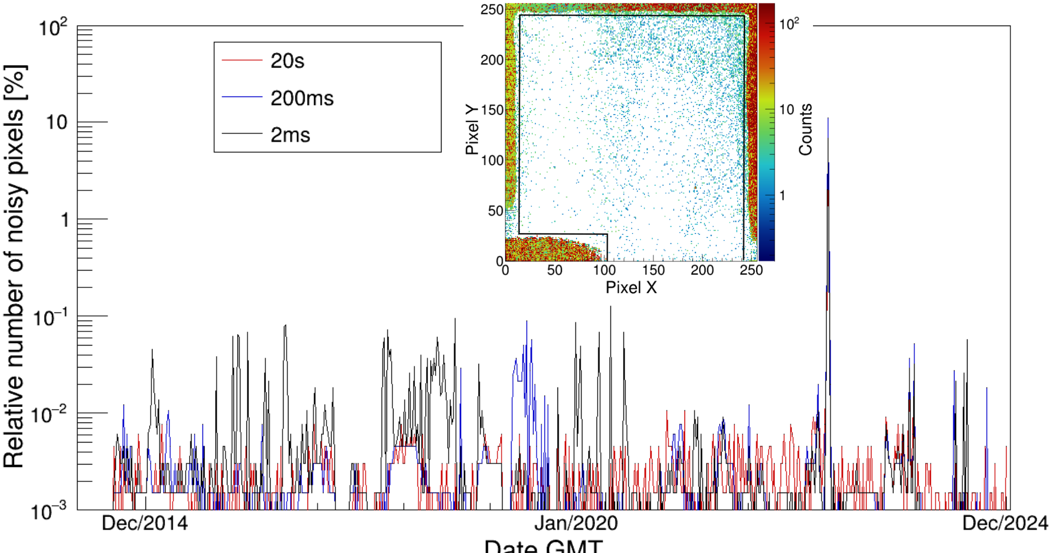


Pixel Matrix - 2015 vs 2022

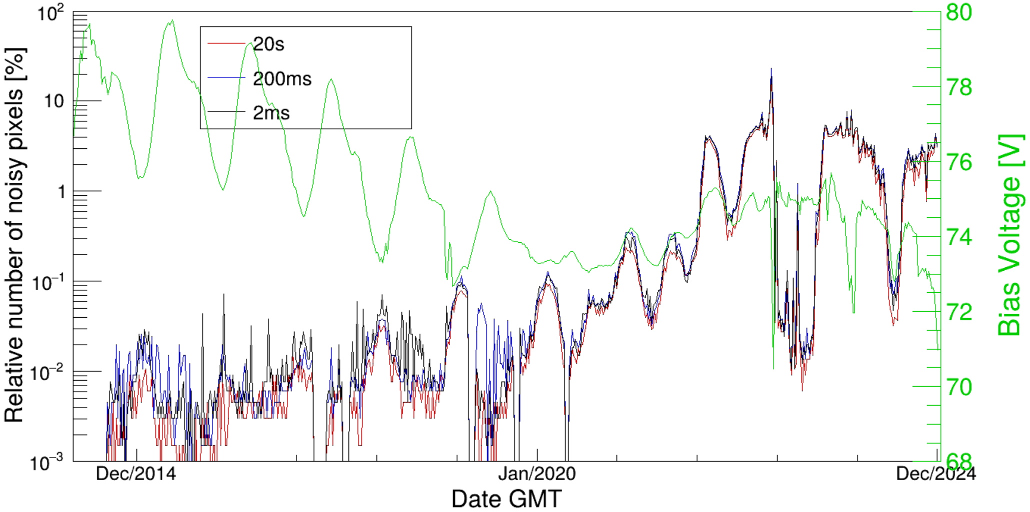
The more counts the more often pixel was considered noisy.



Noisy Pixels - Selected Area



Noisy Pixels - Selected Area



Bayesian Deconvolution

This method works by decomposing the stopping power "signal" of the field into its contributing particle signals, from which the particle's distributions can be inferred.

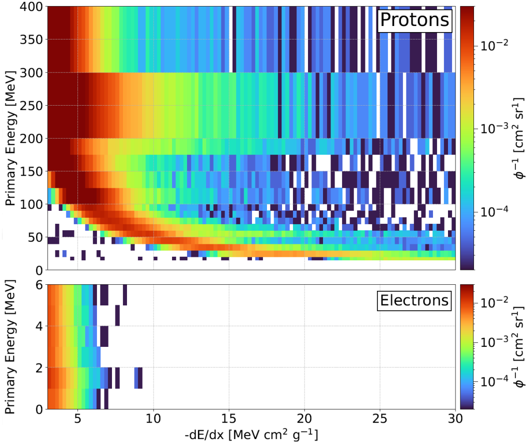
Response matrix

Particle spectrum

$$n(E) = R\,\Phi(c)$$

Measured dE/dx spectrum

$$\Rightarrow R^T n(E) = \Phi(c)$$

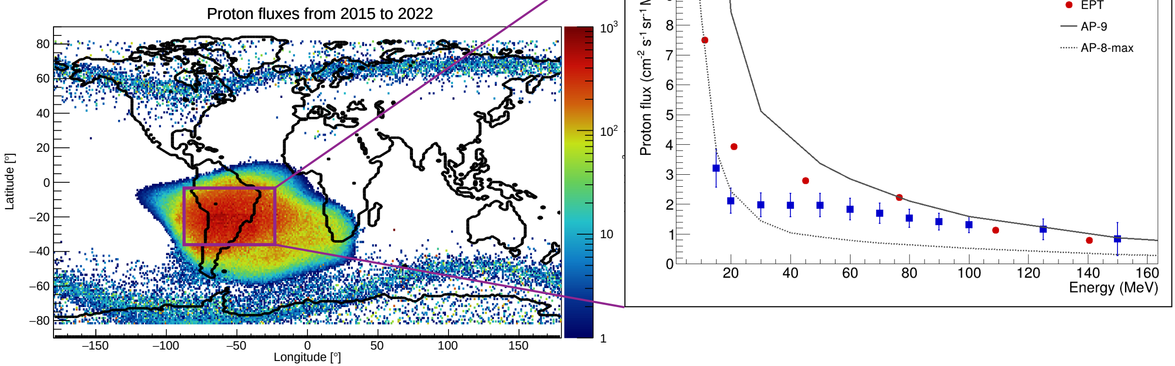


Methodology verification in monoenergetic proton beams

Bergmann, B.; Gohl, S.; Garvey, D.; Jelínek, J.; Smolyanskiy, P. Results and Perspectives of Timepix Detectors in Space—From Radiation Monitoring in Low Earth Orbit to Astroparticle Physics. *Instruments* **2024**, 8, 17. https://doi.org/10.3390/instruments8010017

Energy Spectrum of Protons Inside SAA

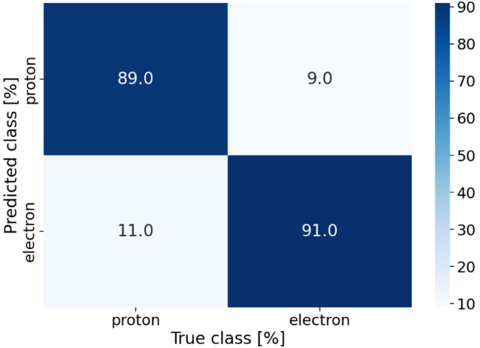
Usage only of frames with 2 ms to avoid overlapping tracks (the shortest frames available) resulting in a total measurement time of 46 s over 4 years



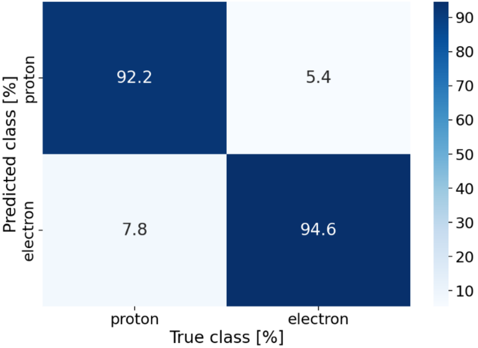
SAA Area: Longitude: [-70°,-25°], Latitude: [-40°,-12°]

Development of a new CNN

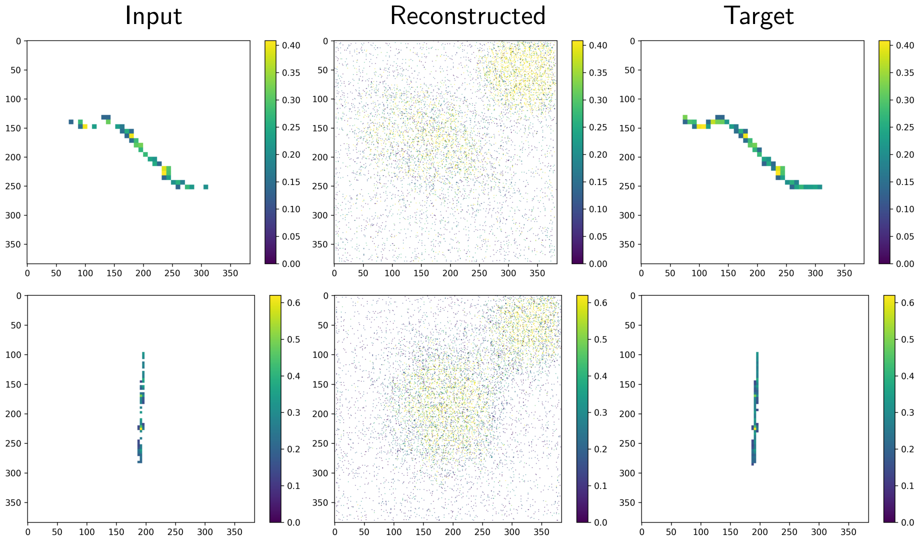
Previous: 90.2% accuracy
Feed-forward Neural Network
Trained with 7 features for particle identification: dep. energy, # of pixels, max energy, linearity, roundness, # of neighbouring pixels, 3rd order polynomial fit of cluster



New: 93.4% accuracy
Convolutional Neural Network with autoencoder structure (U-shaped net)
Training in 2 phases: 1. Unsupervised autoencoder pre-training; 2. Supervised training on simulated data



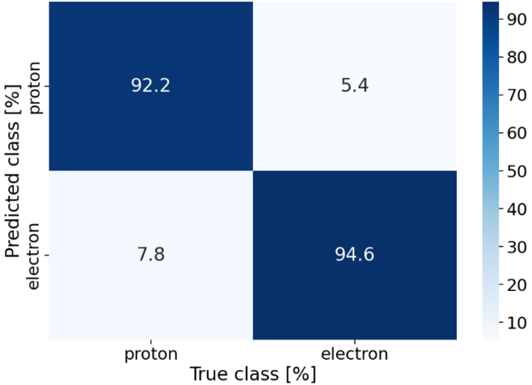
Reconstruction Examples



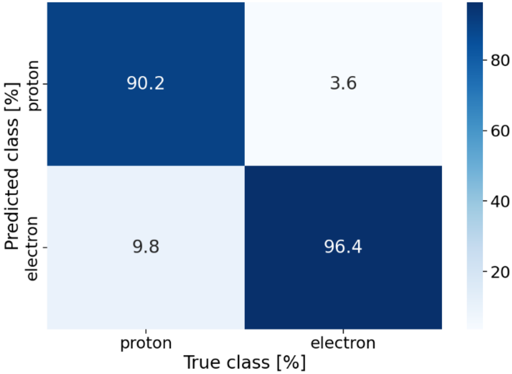
Constant Training Spectrum vs Model Spectrum

Trained with simulated data with energy distribution according to model spectrum (AP-8-max) instead of constant spectrum

Constant Spectrum: 93.4% accuracy



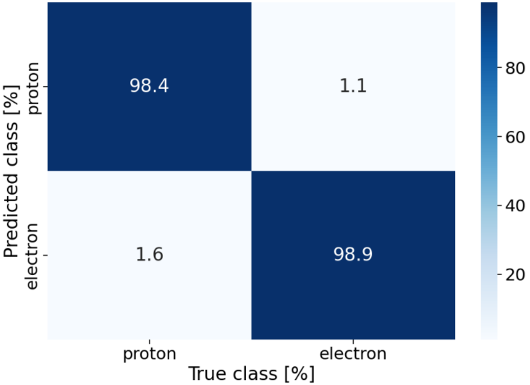
AP-8-max: 93.4% accuracy



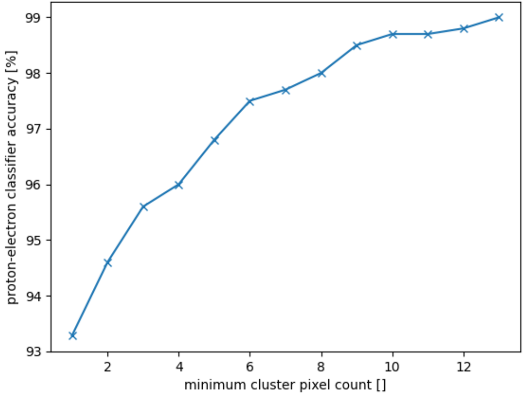
Cutting out Small Clusters

Excluding small clusters with $<$ 9 pixels improves accuracy

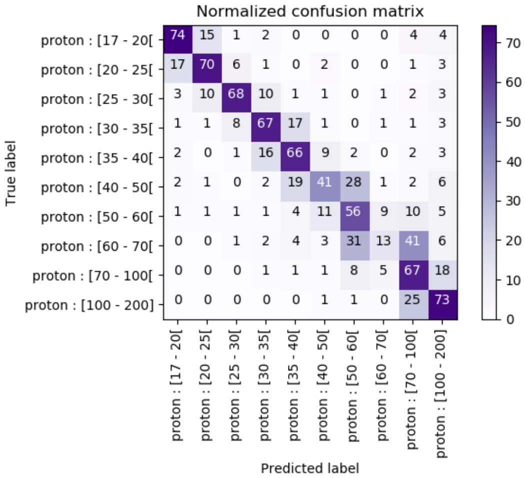
Accuracy: 98.65%

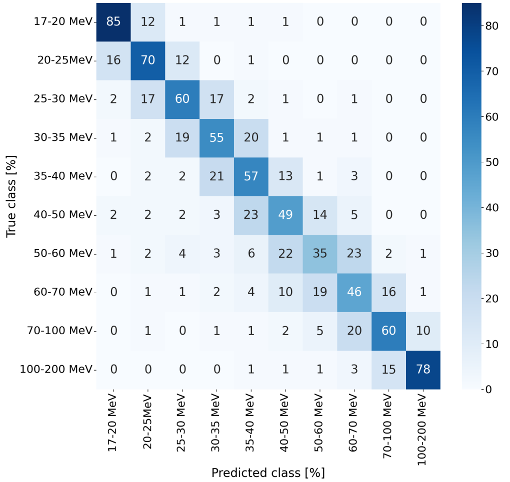


Accuracy vs Minimum pixel count



Energy Prediction

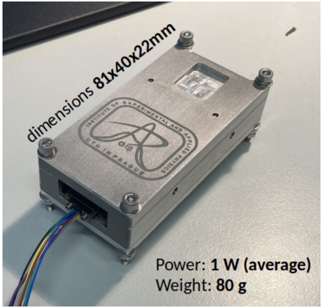


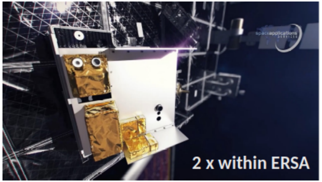


M. Ruffenach, S. Bourdarie, B. Bergmann, St. Gohl, J. Mekki, and J. Vaillé. A New Technique Based on Convolutional Neural Networks to Measure the Energy of Protons and Electrons With a Single Timepix Detector. IEEE Trans. Nucl. Sci., 68(8):1746–1753, 2021. doi: https://doi.org/10.1109/TNS.2021.3071583.

Hardpix: New Device - New Missions

- **SWIMMR1** D-Orbit ION satellite, 525 km altitude – launched June 2023
- **SWIMMR2** D-Orbit satellite orbit 330-1200 km – launched January 2025
- 2 modules outside of the Lunar Gateway as a part of the ESA **ERSA** (European Radiation Sensors Array)
- **HEKI** Study radiation field influence on a superconducting magnet by Robinson-Paihau research institute in New Zealand using 2x HardPix detectors on ISS.
- **Cassini** European Commission In-orbit demonstration mission. Managed by ESA and provided by ISISPACE 6U Cubesat
- **MAGPIE** Neutron Hardpix selected for the Mission for Advanced Geophysics and Polar Ice Exploration (`https://ispace-inc.com/news-en/?p=7621`)





Summary

- Noisy pixel level below 1% until end of 2022, since then up to 10% (except once: peak 22%)
- Removing pixels from edge after 2022 → smaller usable area but noisy pixel level below 1%

- Determination of average proton spectrum using a Bayesian deconvolution method using a single layer detector

- Using a new CNN that improves average electron-proton prediction to 93.5% or above 98% when excluding smaller clusters (<9 pixel per cluster)
- Need to be applied to SATRAM data in future

- Implement the new methods in onboard processing into new projects

Thank you for Attention!

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Successful launch and operation of SATRAM would not have been possible without Stanislav Pospíšil, Carlos Granja, and Alan Owens. The authors B.B. and D.G. are grateful for the funding received by the Czech Science Foundation (GACR) under grant number GM23-04869M.