Updates on the Developments of Compact Cherenkov Proton Detectors

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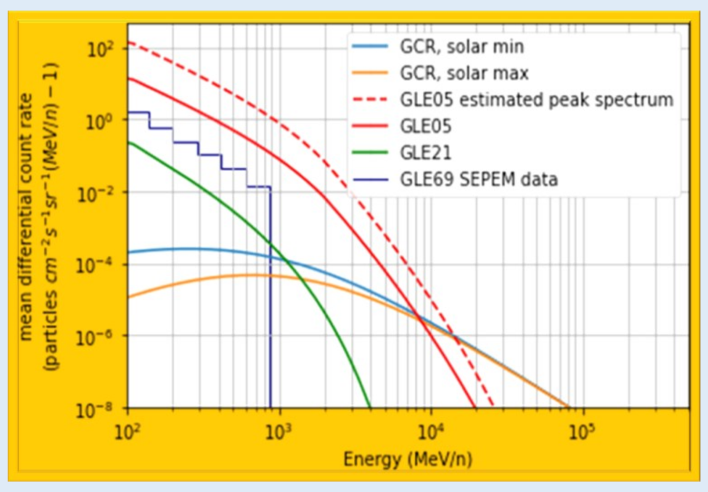
Introduction

The Cosmic Ray and Trapped Proton Environment

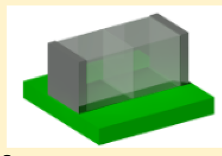
- Galactic CR: up to TeV and beyond,
- Solar CR/SEP: up to ~10s GeV
- Trapped protons: ~ 100s of MeV.
- Past experiments are either focused on the low energy (<100 MeV, e.g., GOES,VAP) or very high energies (> GeVs, e.g., AMS-02)
- There is a noticeable gap with experiments dedicated to the measurements of energetic SEPs/GLEs



Novel Cherenkov Proton Detector and Telescope

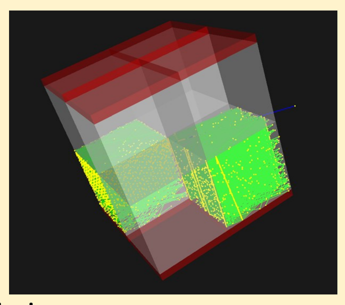
HEPI - High Energy Proton Instrument

- Pair of compact Cherenkov detectors
- > 300 MeV Solar energetic protons
- Operated individually and in coincidence
- Geomagnetic shielding as a means for spectroscopy
- Targeting CubeSats in a LEO constellation deployment

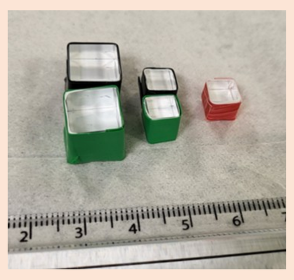


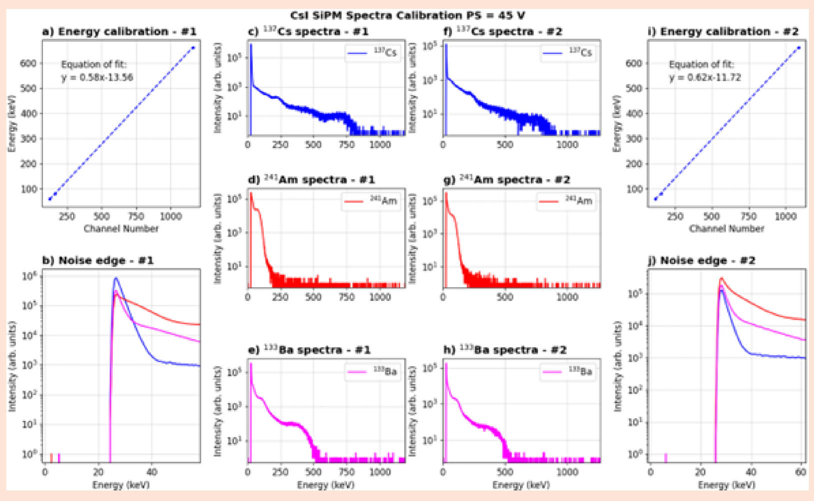
HEPTEL – High Energy Proton Telescopes

- Multiple radiators
- Telescope configurations
- Spectroscopy
- Directionality
- For operational or scientific missions



HEPI Detector Implementation [1]





Base unit:

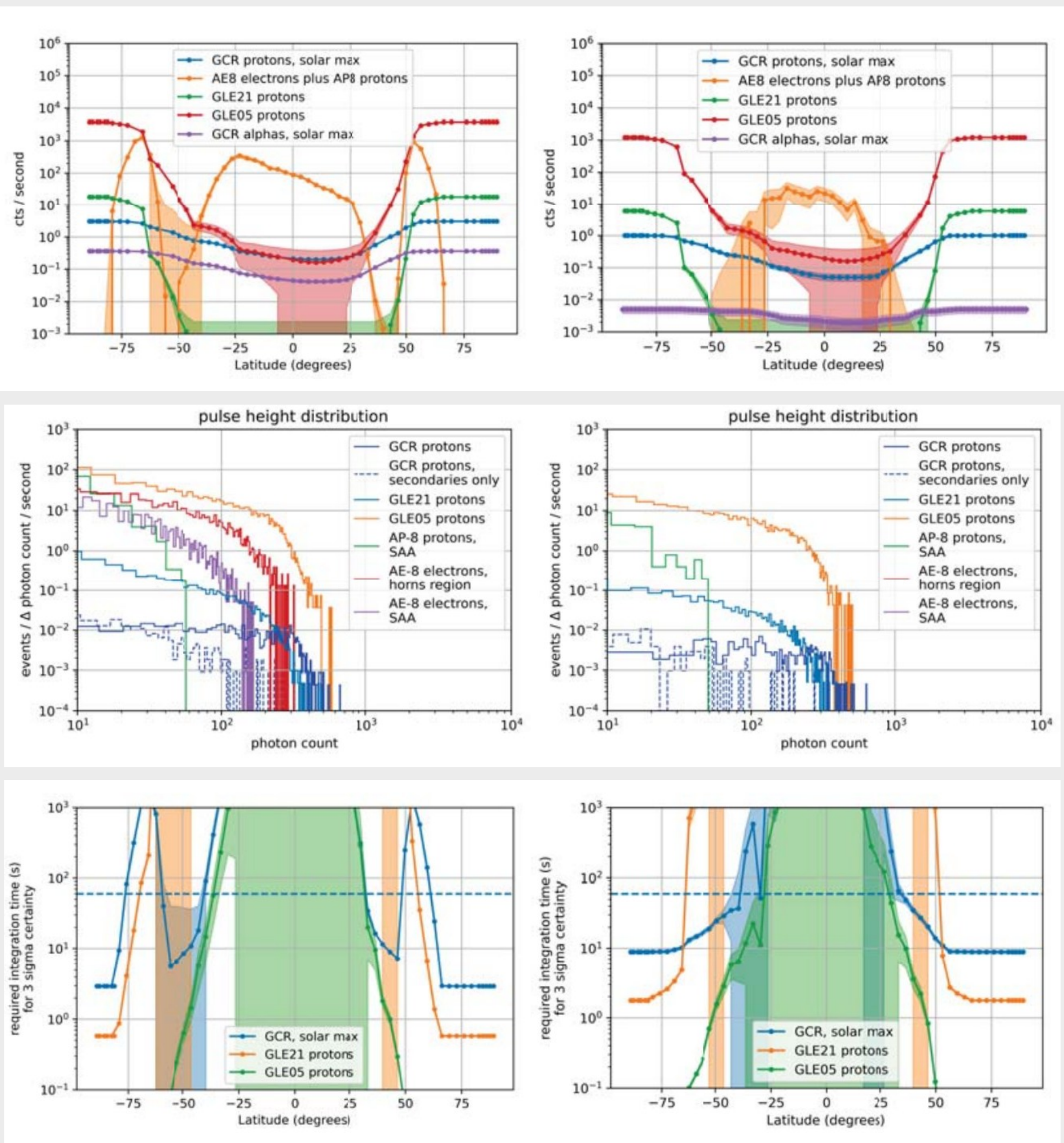
- 10x10x10 mm radiator
  - $SiO_2/PbF_2/MgF_2$
- SiPM optical readout
  - Broadcom NUV-MT 6x6 mm
- Shielding/Housing
  - 2mm Al + 0.5 Ta

HEPI baseline:

- 2 baseline units
- Individually and in coincidence

Performance Simulations [3]

- **GRAS/Geant4 based, inc. optics**
  - Baseline design, 20 pho. Threshold
  - Pulse height spectra and counting rates
- **LEO (worst case 450km polar orbit)**
  - GCR p; SEPs(GLE5, GLE21), Trapped p, e-
  - Act as source of signal or background



(a) No coincidence (b) With coincidence

Beam Test Results [2]

A: Examples of the test run spectra:

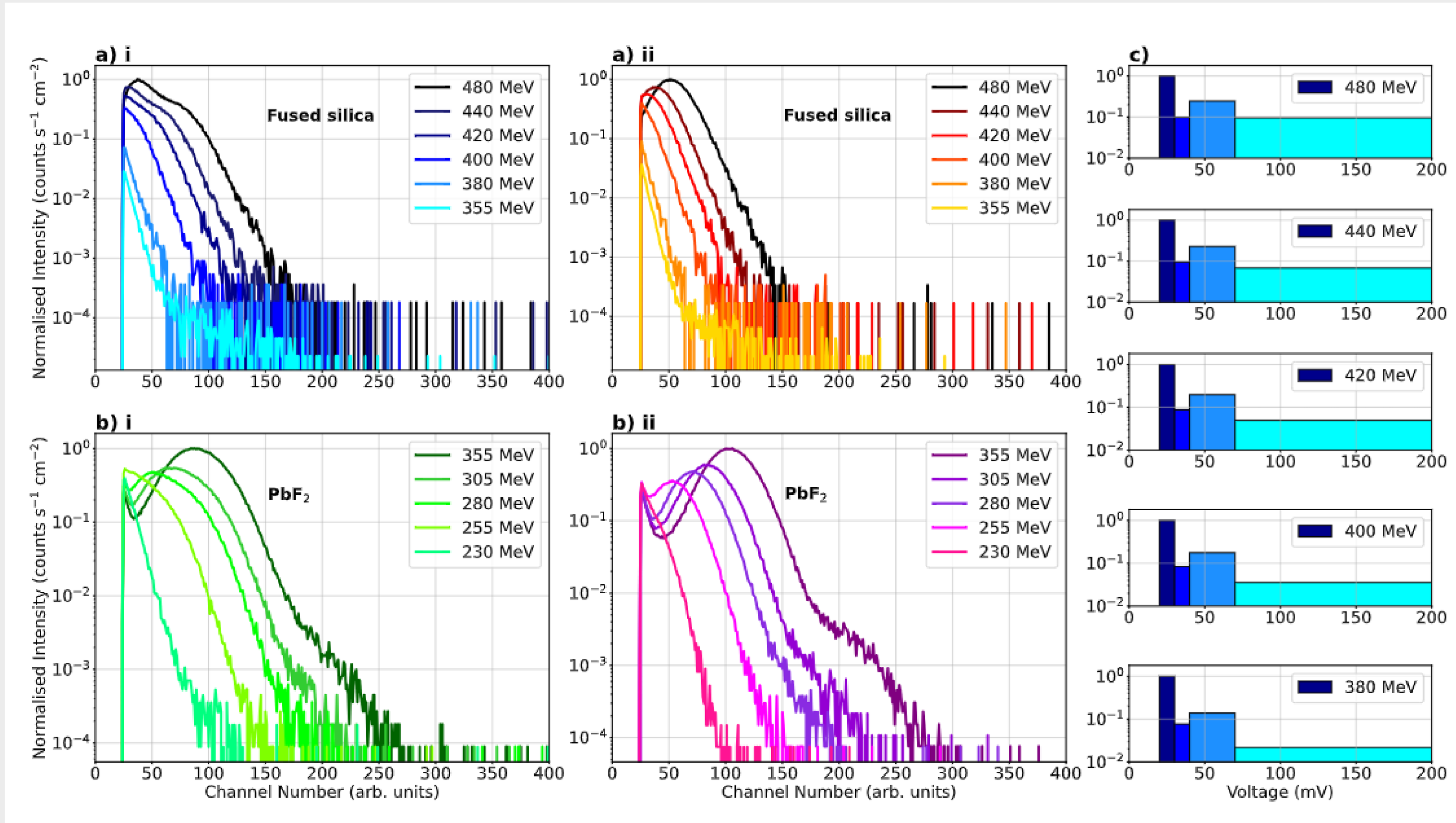


Figure 3: Normalised Cherenkov spectra of two a) fused silica (n=1.50, E_{th}=320 MeV, E_{beam} = 355-480 MeV), b) PbF_2 (n=1.89, E_{th}=167 MeV, E_{beam} = 230-355 MeV) radiators, gated on coincident signals. i) Spectra from the forwards facing SiPM 1, ii) spectra from the backwards facing SiPM 2. c) Normalised Cherenkov spectra of a PbF_2 radiator (E_{beam} = 355-480 MeV). Data processed via satellite-based SPB.

B: Determination of the Cherenkov Thresholds:

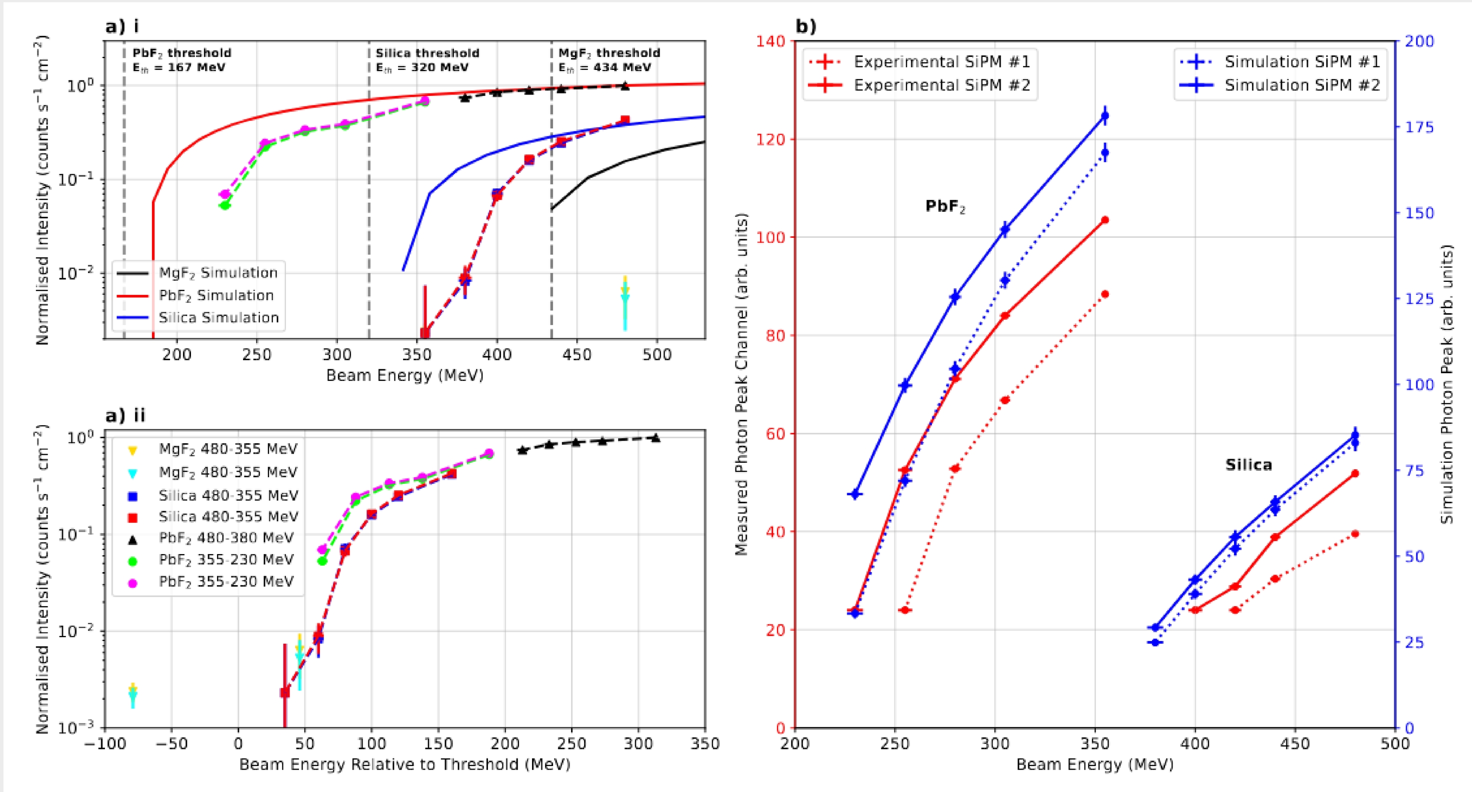


Figure 4: a) Normalised proton-induced Cherenkov intensity for MgF_2, fused silica and PbF_2 radiators as a function of proton beam energy. i: The minimum detectable energies for the three materials are marked, as are the simulated intensities for each material. ii: The data plotted as a function of beam energy relative to each material's calculated threshold. b) Proton peak position as a function of beam energy for the PbF_2 and fused silica measurements, from both the measured and simulated spectra.

480 and 355 MeV proton beam at the TRIUMF PIF

Summary & Outlook

Main Achievements:

- Established the key requirements
- Completed the breadboard implementation
- GRAS/Geant4 based simulator for in orbit performance evaluation
- Successful beam tests at TRIUMF:
  - Precise measurements of the Cherenkov thresholds
  - Coincidence technique for direction and background rejection

Further Studies:

- Further lab tests with e^- source
- Rad effects on SiPM performance
- Optimization of detector optics and front-end electronics

Future Plans:

- Continue development in the ASPIRE project (ESA-EU)
- IODs
  - Jovian-1 mission (UK)
  - UK astronauts mission (AXIOM)
  - VMMO mission (ESA)

[1] J. O'Neill, F. Lei, K. Ryden, P, Morris, B. Clewer, F. Baird, P. Sellin, C. Dyer, M. Heil, P. Jiggens, G. Santin, The High-Energy Proton Instrument (HEPI), a Compact Cherenkov Radiation Space Weather Monitor, JSWSC,Vol.15, 2025. DOI: https://doi.org/10.1051/swsc/2025023

[2] J. O'Neill, F. Baird, B. Clewer, C. Dyer, F. Lei, P. Morris, K. Ryden, P. Sellin, M. Heil, P. Jiggens, G. Santin, Characterisation of the high-energy proton Cherenkov response approaching the energy threshold for miniaturised space-borne detectors, NIM-A, 2025, https://doi.org/10.1016/j.nima.2025.170535.

[3] C. S. W. Davis, F. Lei, K. Ryden, C. Dyer, G. Santin, P. Jiggens, M. Heil, Background in Low Earth Orbiting Cherenkov Detectors, and Mitigation Strategies, JGR Space Physics, 2025, submitted.