Mapping the Radiation Degradation of Perovskite Solar Cells

Team Particle Partners

Shiven Sood, Anay Dhawan, Shaurya Jani, Vihaan Bhagwat
, Shaurya Gangrade, Yashee Shinde, Arpita Chougule

Experiment and Outreach proposal for the Beamline for Schools competition

NES International School Mumbai

Mapping the Radiation Degradation of Perovskite Solar Cells

Under GeV-Scale Proton Irradiation at CERN T9

1. Motivation to Participate

India's space programme is expanding rapidly ISRO's current and planned missions will rely on solar panels that survive years of energetic proton bombardment in deep space. Perovskite solar cells have grown from 3% to over 26% power conversion efficiency in under a decade [1] and are now serious candidates for next-generation satellite power, offering far greater specific power than the silicon panels currently used [2]. However, a critical measurement gap exists: no study has characterised how perovskites degrade under GeV-scale protons, the dominant radiation in real deep-space environments [3]. As students from Mumbai with backgrounds in physics and electronics and with ISRO's deep-space ambitions as direct motivation we want to fill this gap using CERN's T9 beamline, one of the only facilities on Earth where this measurement is physically possible.

2. The Experiment

2.1 The Scientific Problem

Satellites in geosynchronous and interplanetary orbits encounter protons spanning energies from ~100 MeV to several GeV [3]. All published radiation hardness data for perovskite solar cells uses protons at energies of 50 keV to 68 MeV sourced from hospital cyclotrons and research accelerators [4,5,6]. This is a fundamental mismatch: a low-energy proton stops inside the cell and deposits all its energy at a single point via the Bragg peak, while a GeV proton passes entirely through, depositing a small, distributed dose by ionisation and nuclear collisions. The damage mechanisms are physically incomparable, and existing data cannot be extrapolated to the real space environment [3,7]. Despite this, GeV-scale perovskite irradiation data does not exist in the literature. This experiment will produce it for the first time.

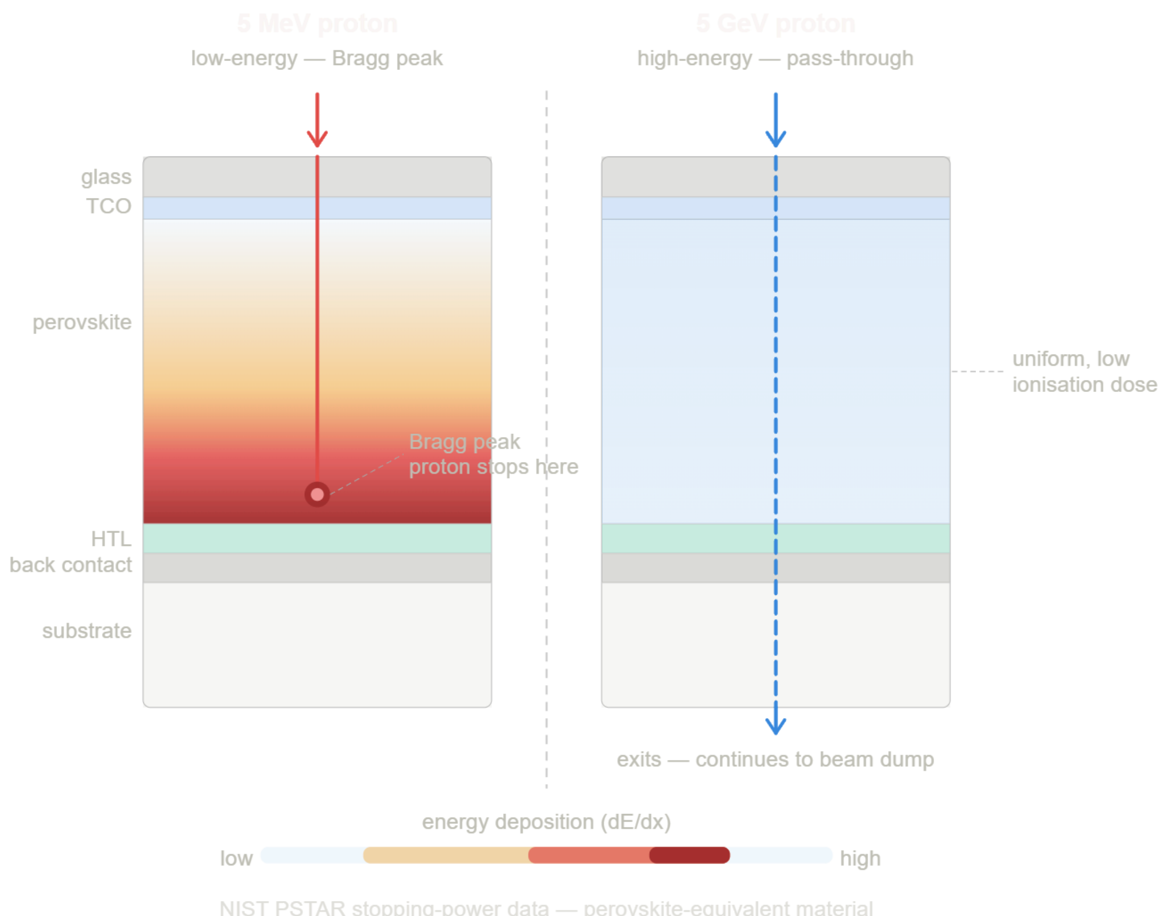

Fig. 1 Why low-energy lab tests do not represent the real space radiation environment [7]

2.2 Why CERN T9 is Essential

CERN's T9 secondary beamline produces a beam of hadrons (protons, pions, kaons) with momenta selectable between 0.5 and 15 GeV/c. At momenta above 3 GeV/c, beam protons and pions pass entirely through a thin perovskite sample, depositing energy as space protons do. This energy regime is inaccessible at hospital cyclotrons (max ~250 MeV) and at no research facility available to Indian high-school students. The experiment is only possible at CERN [8].

2.3 Samples

We will bring or obtain 18 samples (six per type), each 1×1 cm, epoxy-encapsulated non-toxic, non-biological, T9-compliant:

- $MAPbI_3$ (methylammonium lead iodide) perovskite solar cell baseline composition, most studied in radiation literature [4,5]

- FAMAPbI$_3$ mixed-cation perovskite   higher efficiency and thermal stability, leading space candidate [6,9]
- Crystalline silicon reference cell   well-characterised radiation response, validates our protocol against published non-ionising energy loss (NIEL) damage curves [7]

2.4 Experimental Setup

Fig. 2   Experimental layout at T9 using standard BL4S detectors [8]

The setup uses exclusively standard BL4S detectors:

- Two scintillation counters in coincidence (S1, S2)   beam trigger and particle fluence counting
- Two Delay Wire Chambers (DWC1, DWC2)   confirm beam hits the active cell area with positional accuracy
- Sample mount: 3D-printed holder, cell perpendicular to beam, spring-loaded electrical contacts
- Calibrated LED (~1 sun equivalent, stable)   illuminates cell during I-V sweeps without interfering with beam
- Source-measure unit (SMU, Keithley 2400)   sweeps current-voltage characteristics

- Fibre-coupled spectrometer at cell edge records photoluminescence (PL) spectrum, a sensitive crystal-damage indicator [9]

2.5 Measurement Protocol

Full baseline characterisation of all 18 samples precedes irradiation. We then irradiate to three cumulative fluence levels representing realistic satellite mission doses:

Fluence	Dose (protons/cm²)	Space mission equivalent
F1	1×10^{10}	~1 year, low Earth orbit
F2	1×10^{11}	~5 year, medium Earth orbit
F3	1×10^{12}	~10 year deep-space mission

After each fluence step, the beam is gated off and we re-measure: open-circuit voltage (Voc), short-circuit current density (Jsc), fill factor (FF), power conversion efficiency (PCE), and PL peak intensity and wavelength.

2.6 Analysis and Expected Results

Primary output: normalised PCE (η/η_0) vs. $\log_{10}$(fluence) for each cell type the degradation curve. We extract the critical fluence F½ (fluence at which PCE drops to 50% of baseline) as a single radiation hardness figure of merit. Separating trends in Voc, Jsc, and FF identifies the dominant damage mechanism: bulk recombination, grain boundary defects, or increased series resistance [9,10]. PL quenching tracks lattice damage independently of the electrical measurement [9]. The silicon reference, whose NIEL damage curves are well-published, validates the entire measurement chain [7].

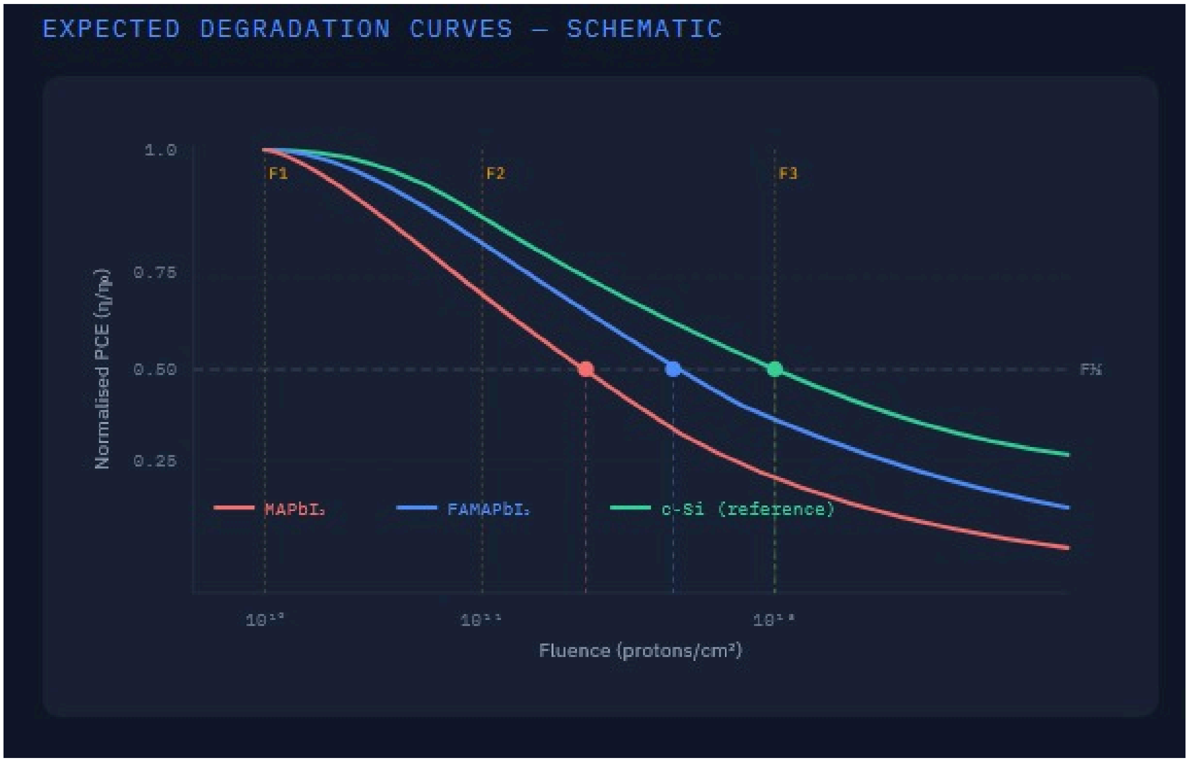

Fig. 3 Expected form of degradation curves; silicon reference validates protocol against established NIEL data [7]

All data will be published openly for the space photovoltaics community.

3. What We Hope to Take Away

We aim to leave CERN with the first published GeV-scale proton degradation curves for $FAMAPbI_3$ perovskite data that does not currently exist and that ESA and NASA mission designers explicitly need [3]. We will write up our results for submission to a peer-reviewed journal (e.g. *Progress in Photovoltaics* or *Solar Energy Materials and Solar Cells*) with guidance from contacts at IIT Bombay. We will share our findings with ISRO's Space Applications Centre. Beyond the science: we want to demonstrate that high school students from Mumbai can produce research that the global space industry actually uses.

4. Outreach Proposal

We will build and publicly release a free bilingual (English and Hindi) website that lets any student anywhere simulate our CERN experiment in their browser. No login, no download, no cost.

The site has three layers. First, an interactive particle simulator where students fire virtual protons at a perovskite solar cell, adjust the energy using a slider, and watch in real time how the crystal lattice responds to defects appearing at low energies, the damage curve flattening at GeV scale. The physics is accurate; the visual is immediate. Second, a live data page displaying our actual measurements from T9, updated as we run the experiment, so students follow along in real time from their classrooms. Third, a plain-language explainer with no jargon, illustrated covering what a particle accelerator is, what perovskite is, and why space solar panels matter for India's future in space.

We will share the link directly with physics teachers across fifty Mumbai schools through our school network and submit it to CERN's own educational resources directory. The site will remain live permanently after the competition ends.

Everything will be open-source on GitHub so other student teams worldwide can adapt it for their own BL4S experiments.

References

[1] Green, M. A. et al. Solar cell efficiency tables (version 63). Progress in Photovoltaics: Research and Applications 32, 425–441 (2024). https://doi.org/10.1002/pip.3750

[2] Ho-Baillie, A. W. Y. et al. Deployment opportunities for space photovoltaics and the prospects for perovskite solar cells. Advanced Materials Technologies 7, 2101059 (2022). https://doi.org/10.1002/admt.202101059

[3] Kirmani, A. R. et al. Countdown to perovskite space launch: guidelines to performing relevant radiation-hardness experiments. Joule 6, 1015–1031 (2022). https://doi.org/10.1016/j.joule.2022.03.004

[4] Lang, F. et al. Radiation hardness and self-healing of perovskite solar cells. Advanced Materials 28, 8726–8731 (2016). https://doi.org/10.1002/adma.201603326

[5] Hughes, D. et al. Proton radiation hardness of perovskite solar cells utilising a mesoporous carbon electrode. Energy Technology 9, 2100928 (2021). https://doi.org/10.1002/ente.202100928

[6] Miyazawa, Y. et al. Tolerance of perovskite solar cell to high-energy particle irradiations in space environment. iScience 2, 148–155 (2018). https://doi.org/10.1016/j.isci.2018.03.020

[7] Berger, M. J. et al. PSTAR: Stopping-Power and Range Tables for Protons. NIST Physics Laboratory (2017). https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

[8] CERN Beamline for Schools Team. Beams and Detectors Document BL4S 2026. CERN (2025). https://beamlineforschools.cern/useful-documents/

[9] Afshari, H. et al. Unraveling radiation damage and healing mechanisms in halide perovskites using energy-tuned dual irradiation dosing. Nature Communications 15, 709 (2024). https://doi.org/10.1038/s41467-024-44876-1

[10] Kirmani, A. R. & Sellers, I. R. Are metal-halide perovskite solar cells really radiation tolerant? Joule 9, 101823 (2025). https://doi.org/10.1016/j.joule.2025.101823