THU Gamma Ray Integrated Detectors

An Effective Calibration Method for GRID:

a Student-driven NanoSat Constellation for GRB Observation

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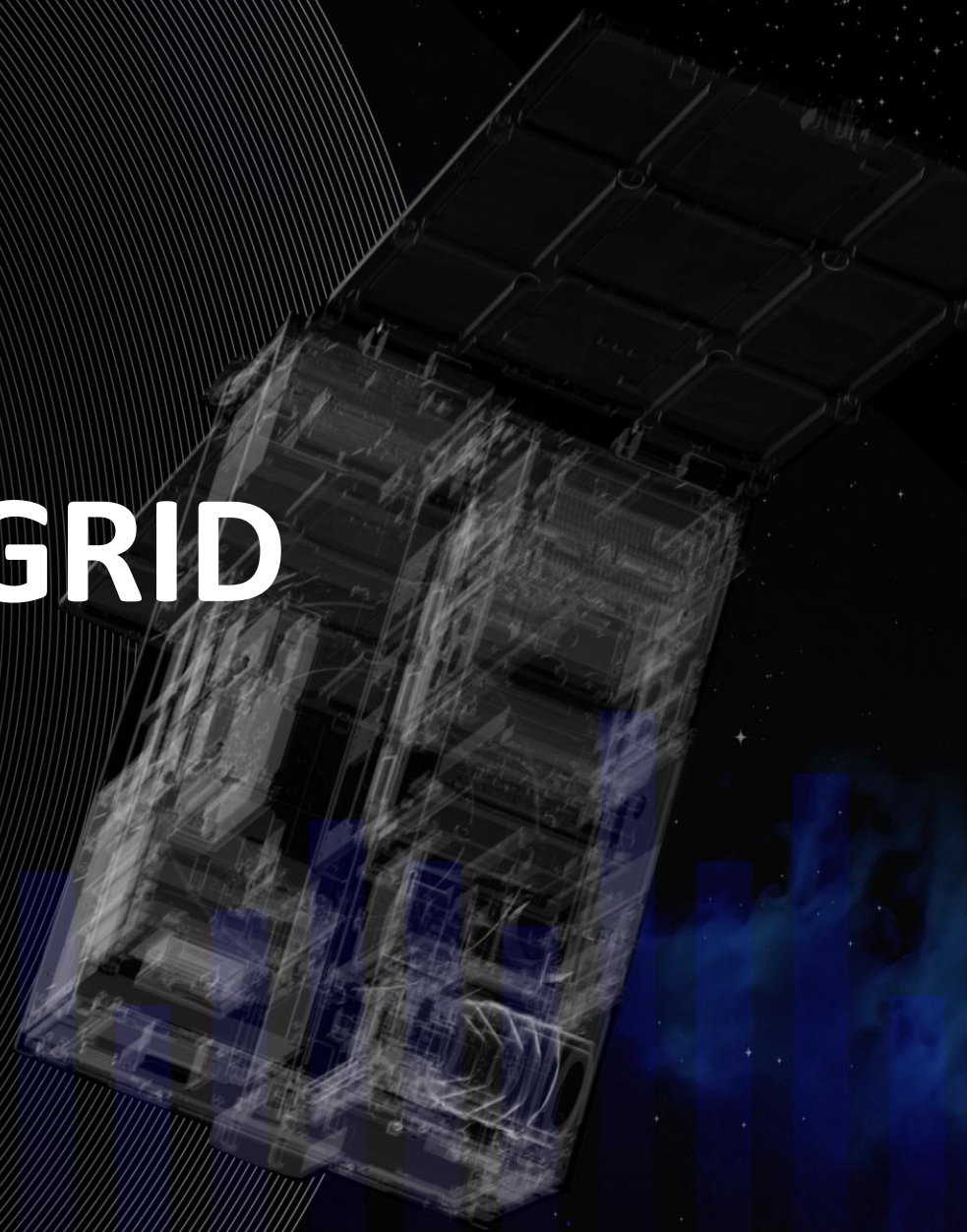
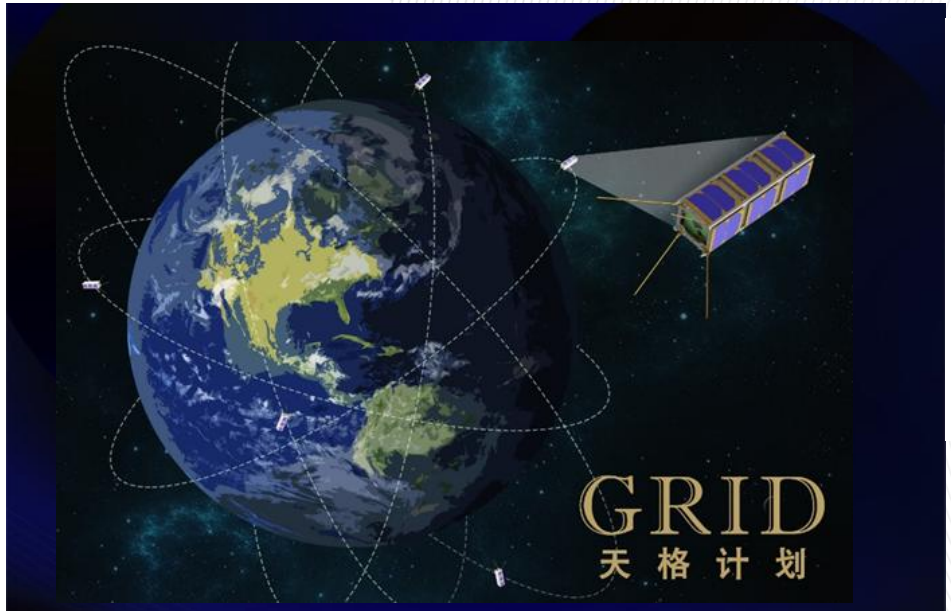
Overview of GRID

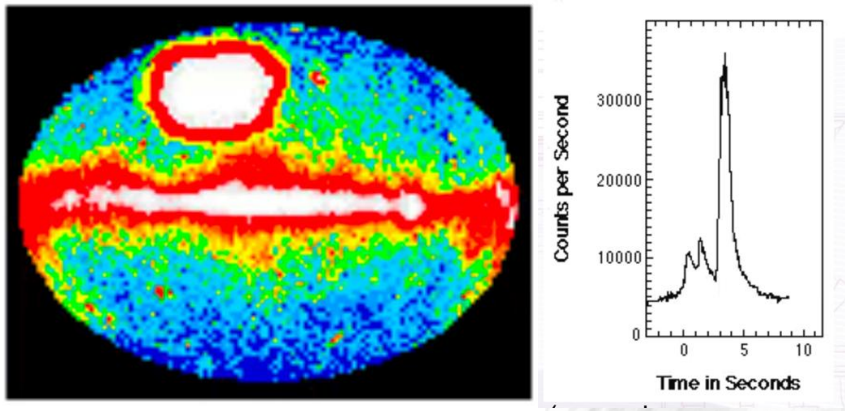


Concepts

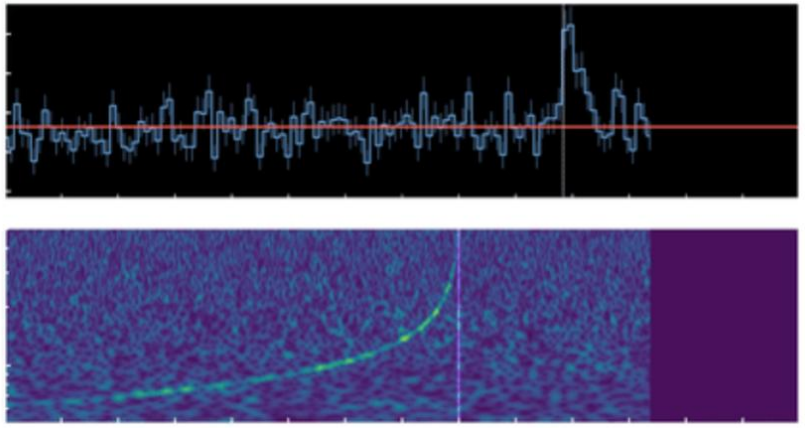


Gamma Ray Integrated Detectors (GRID)

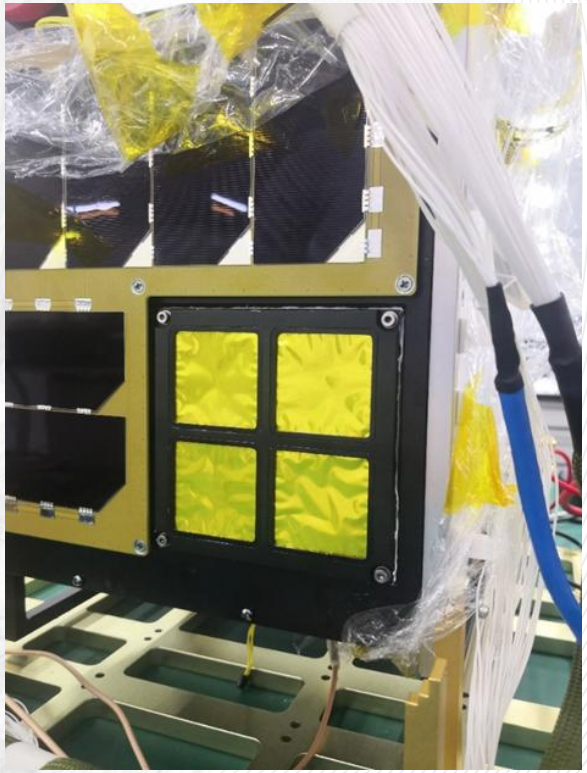
- Detection of GRBs associated with future NS-NS mergers and other gamma ray transients.
- NanoSats scattered in low Earth orbits[1], aiming at full-time all-sky monitoring and localizing.
- Compact gamma ray detectors



NASA: Gamma-Ray Burst(GRB) and its lightcurve



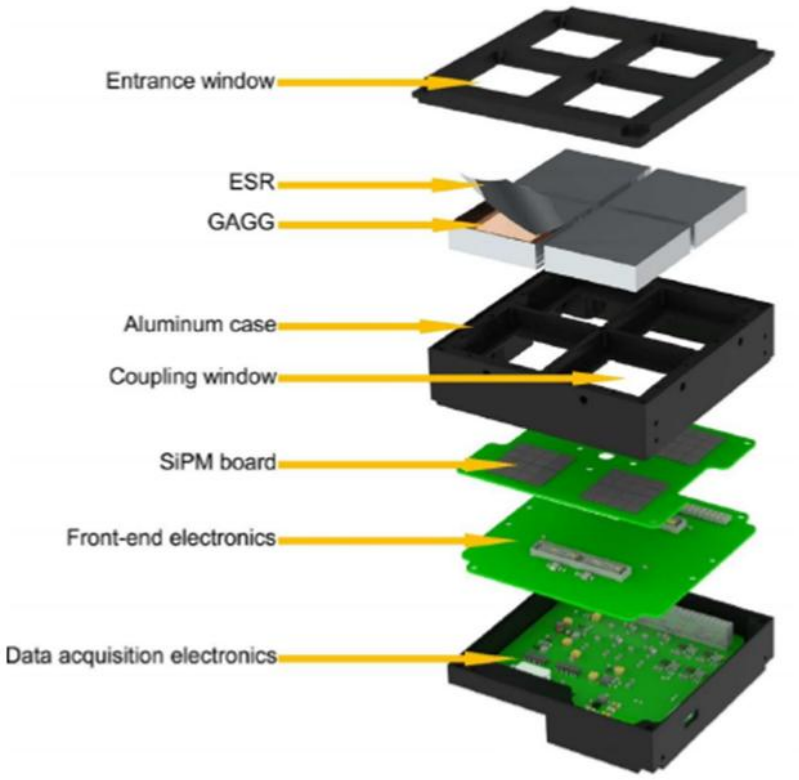
Joint, multi-messenger detection of GW170817 and GRB 170817A[2]



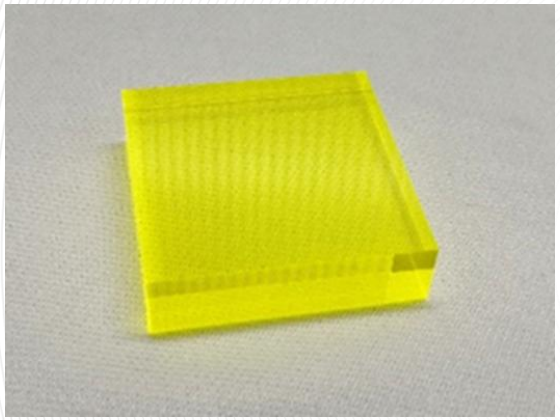
GRID-02
installed on the NanoSat

[1] Wen, J.,et al. 2019 [2] B. P. Abbott et al. 2017

Compact Detector Design

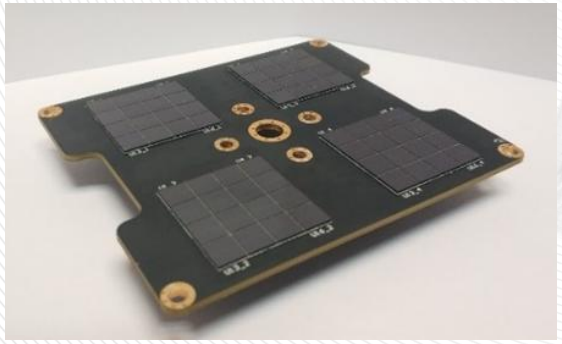


GRID type-A detector design[3]



GAGG:Ce* scintillator

*Cerium-doped Gadolinium Aluminum Gallium Garnet



GRID SiPM* array board

*Silicon photomultiplier SensL MicroFJ-60035

Specifications of scintillator

Scintillator size	**3.8×3.8×1cm³ For single channel**
Density	6.6g/cm³
Light Yield	54,000ph/MeV
Decay Time	150ns
Radiation Hardness	10^7rad
Deliquescence	no

Specifications of SiPM

Breakdown Voltage	24.2~24.7V
OverVoltage (V_{ov})	1~6V
Gain	6.3e6@+6V V_{ov}
Dark Count Rate	150 kHz/mm² @+6V V_{ov}

[3] Wen, J.,*.et al.* 2021

GRID Constellation

GRID-ID	Launch Date	Ownership	Spacetrack catalog No.	Control Unit	Dead time	Power consumption
GRID-01	2018/10/29	THU	43663	MCU	~20us	~2W
GRID-02	2020/11/06	THU	46838	MCU	~15us	~2W
GRID-03B	2022/03/11	THU	51830	FPGA	~5us	~7W
GRID-04	2022/03/11	THU	51830	MCU	~15us	~2W
GRID-05B	2023/01/15	THU	55254	FPGA	~5us	~7W
GRID-06B	2023/01/15	NJU&SCU	55252	FPGA	~5us	~7W
GRID-07	2023/01/15	BNU	55261	MCU	~15us	~2W
GRID-08B	2023/01/15	NJU&SCU	55261	FPGA	~5us	~7W
GRID-10B	2024/06/22	THU&SCU	60088	FPGA	~5us	~7W
GRID-11B	2024/11/11	THU&SCU	61897	FPGA	~5us	~7W
GRID-12B	2024/11/27	THU	62112	FPGA	~5us	~7W
GRID-13B	2024/11/27	THU	62111	FPGA	~5us	~7W

BNU: Beijing Normal University SCU: Sichuan University NJU: Nanjing University THU: Tsinghua University

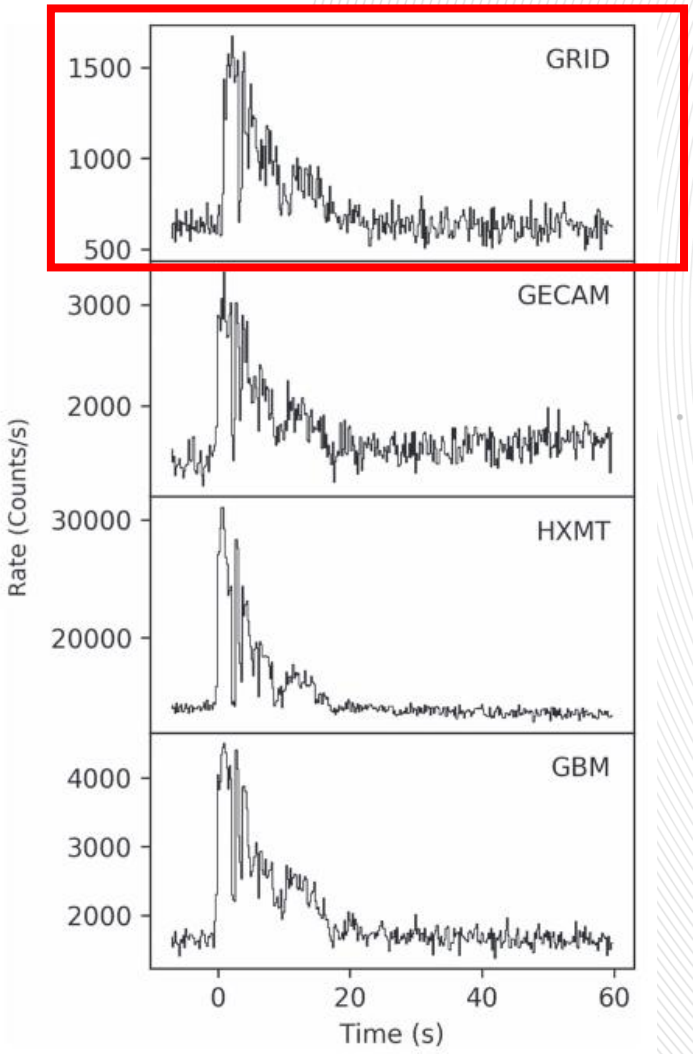
The Student Team

The 2016 student team

The 2025 student team

Observation Results

*General Coordinate Network



GRB 210121A: first GRB observed by NanoSat detector[4]

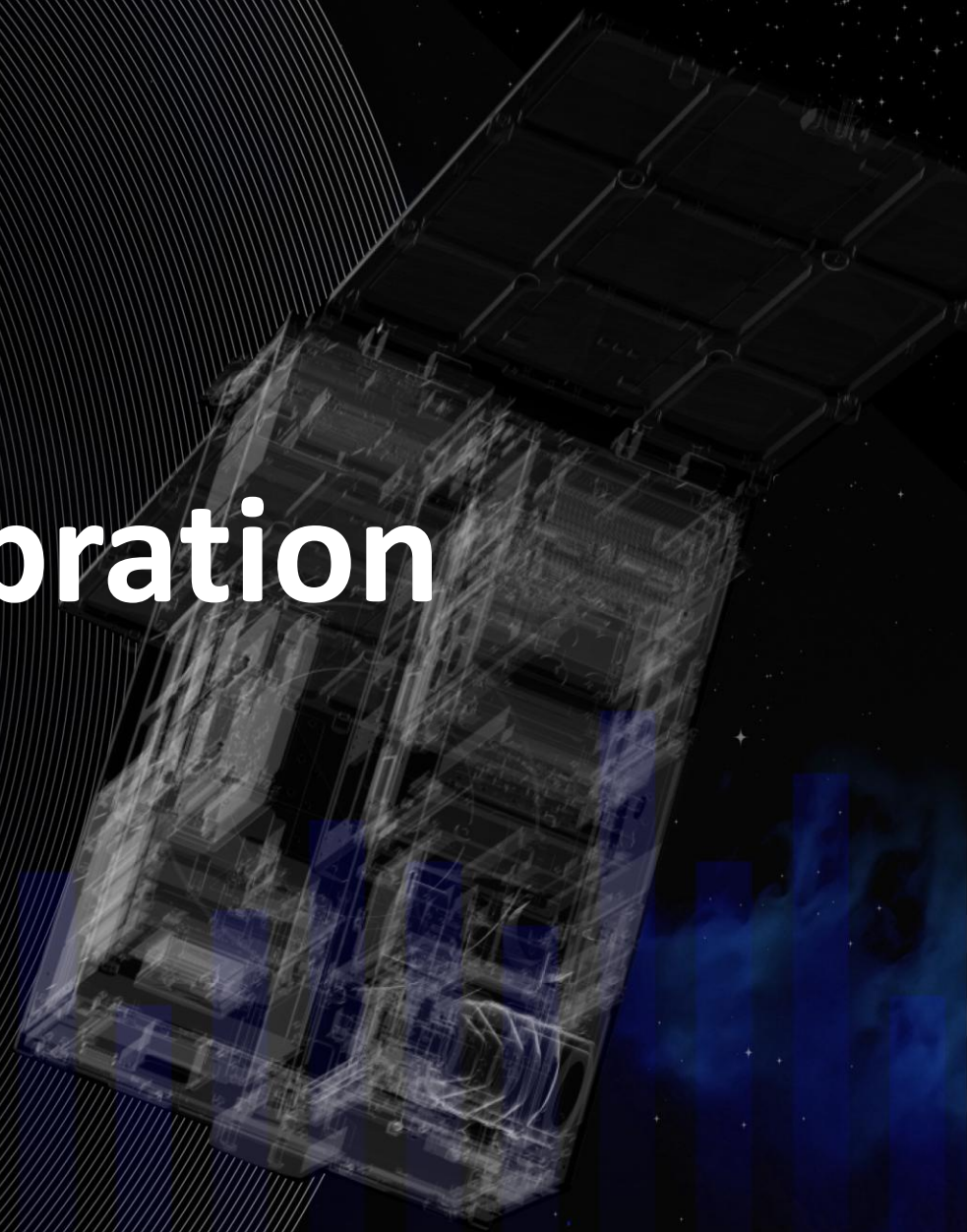
Some GCN* Circulars Submitted by GRID

No.	GRID-ID	Trigger time	GRB	Circular
01	03B	2023-06-25T18:23:57	230625A	34149
02	07	2023-06-28T17:36:23	230628C	34171
03	03B/04/07	2023-07-03T22:53:07	230703A	34188
04	03B	2023-08-18T23:27:30	230818A	34523
05	03B/04	2023-08-27T18:17:41	230827A	34642
06	03B/04/07	2023-10-04T18:56:58	231004A	34868
07	04	2023-10-20T18:56:58	231020A	34903
08	07	2023-12-05T02:25:11	231205A	35402
09	03B/04	2023-12-05T16:43:49	231205B	35403
10	04	2023-12-05T09:47:18	231215A	35413
11	04	2023-12-30T01:29:08	231230A	35559
12	03B/04	2024-02-29T14:07:08	240229A	35904
13	03B	2024-03-06T06:45:48	240306A	35930

GRID Catalog is in progress

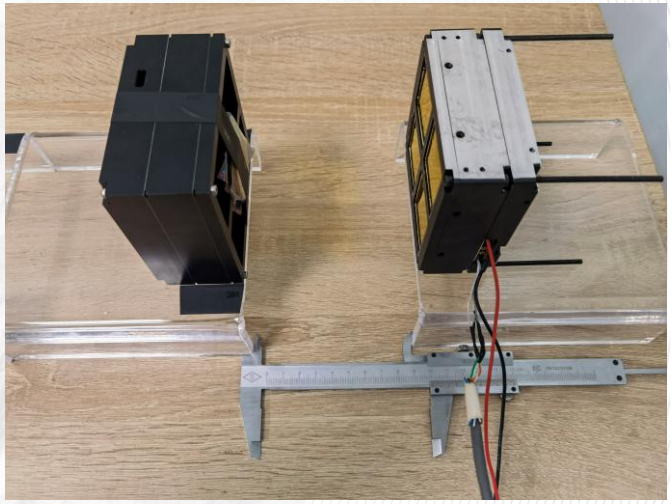
[4] Wang, X. I., 2021.

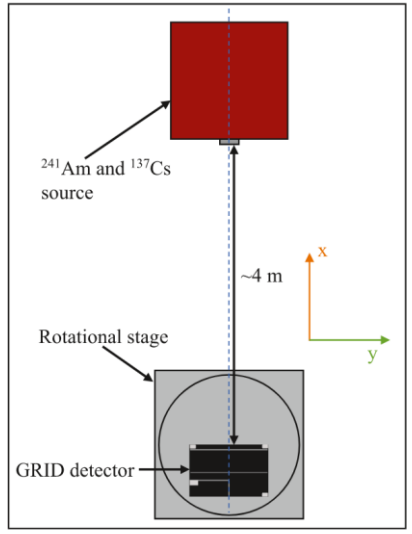
On Ground Calibration

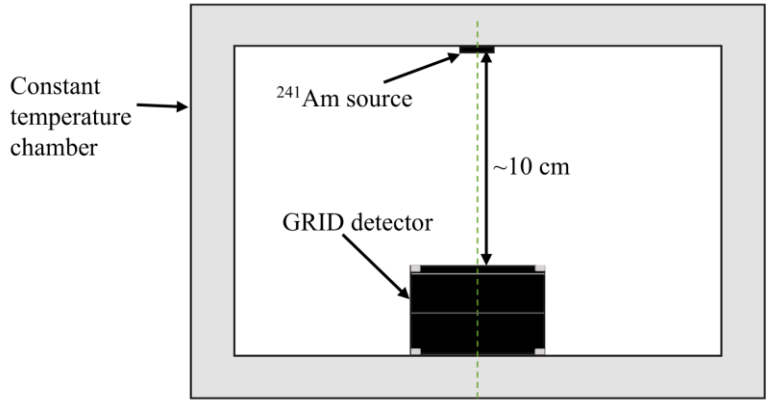


Calibration Campaign

- Energy response
  - X-ray beam(20-120 keV)
    - NIM. in Beijing
  - Radioactive source(59-1332keV)
- Angular response
  - Measurements are obtained from 0°to 360°
  - angle cadence of 15°
- Temperature Bias dependency
  - 27V to 29V
  - -20 ℃ to 40 ℃



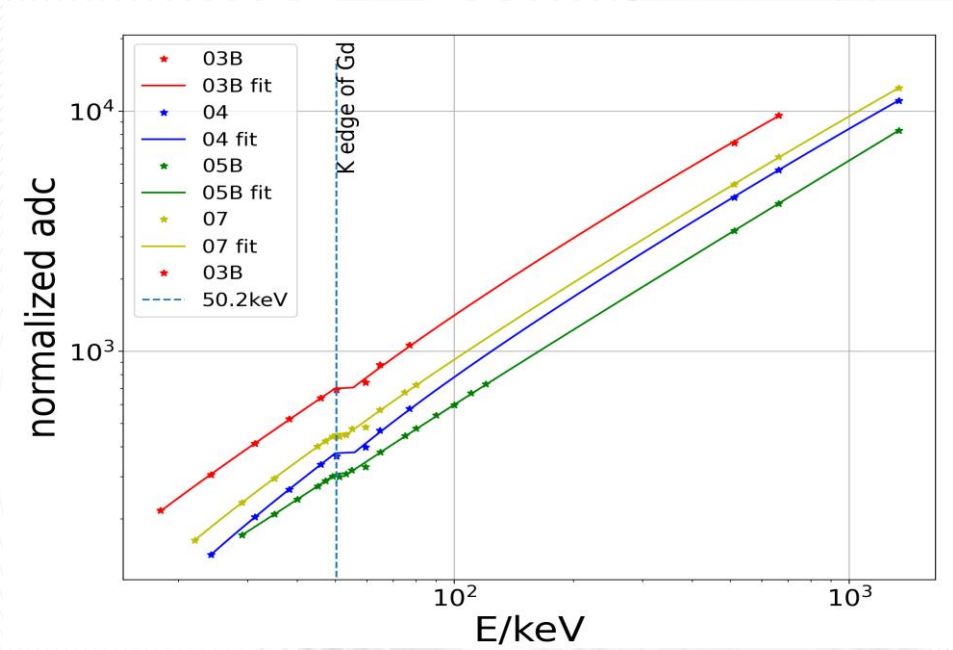


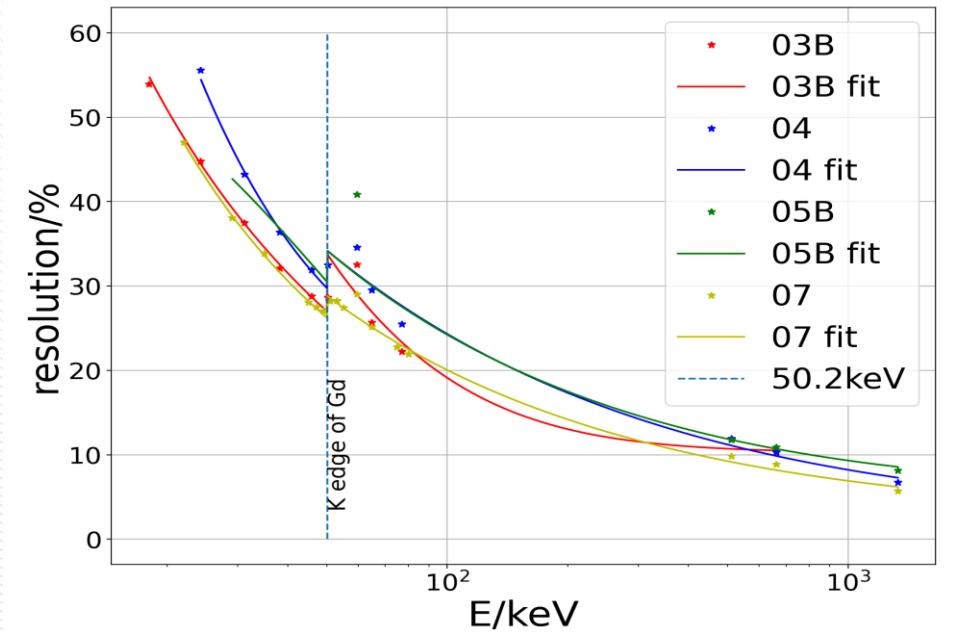


[5] Gao, H.,et al. 2021.

Energy Response

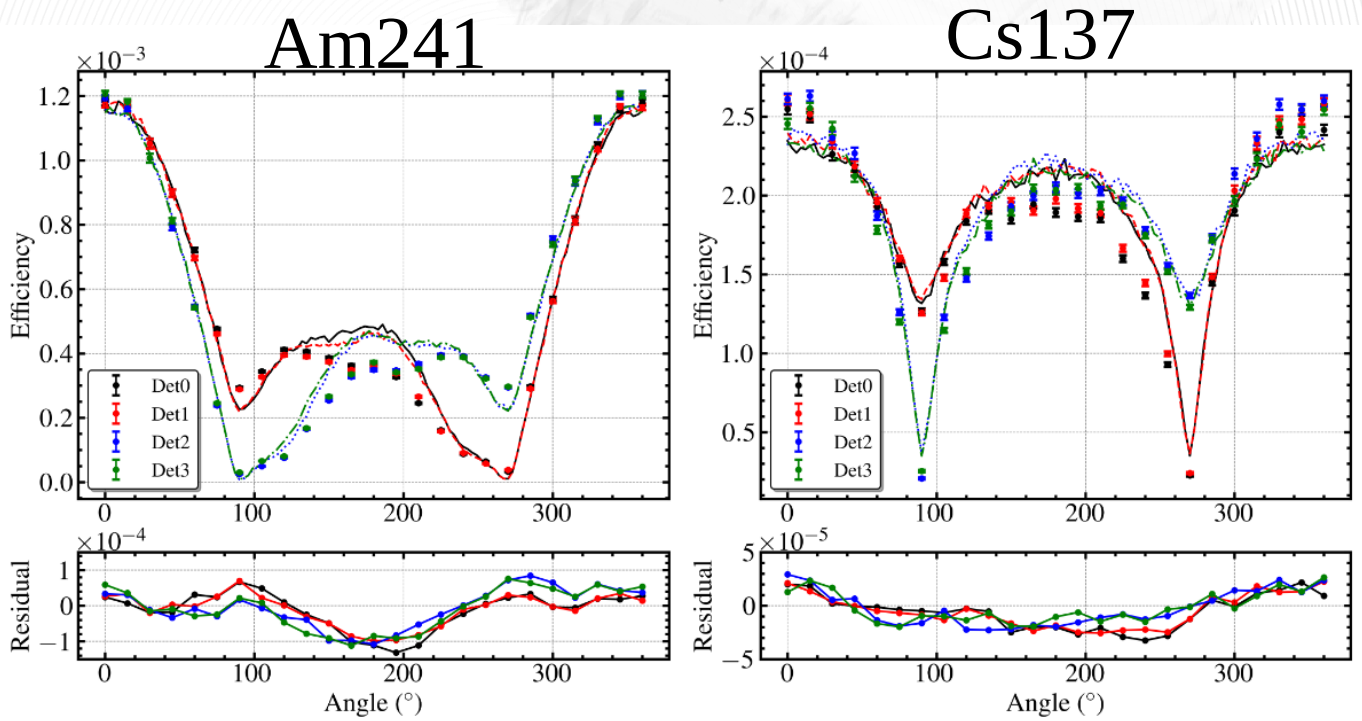
- Energy-Channel
  - quadratic function
- Energy resolution
  - $\text{resolution} = \frac{\sqrt{a \cdot \mathrm{E}^2 + b \cdot \mathrm{E} + c}}{\mathrm{E}}$
- Segmented fitting
  - K-edge of Gd: 50.2 keV
  - Light yield drop of GAGG
- Consistency across detectors





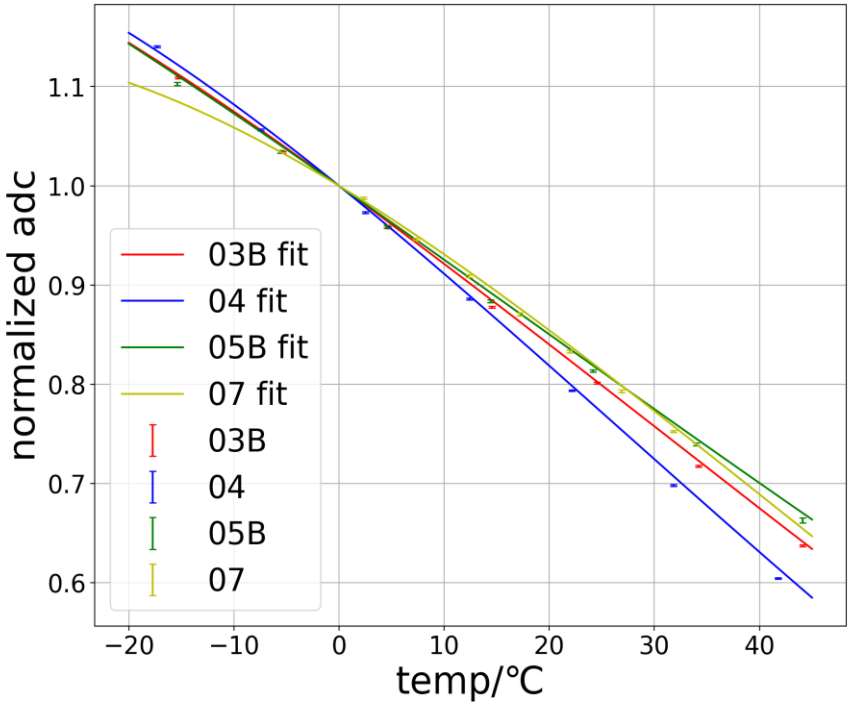
Angular Response

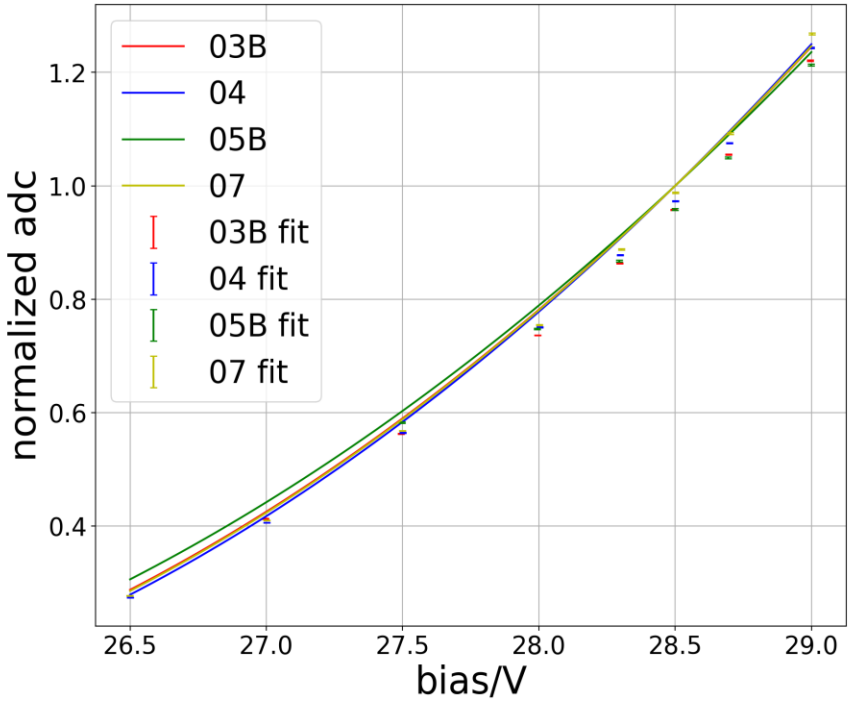
- The number of direction is limited
- Geant4 simulation
- The experimental data are in good agreement with the simulation
  - Am241, Cs137
- Angular response will be generated for the target direction when a GRB is found



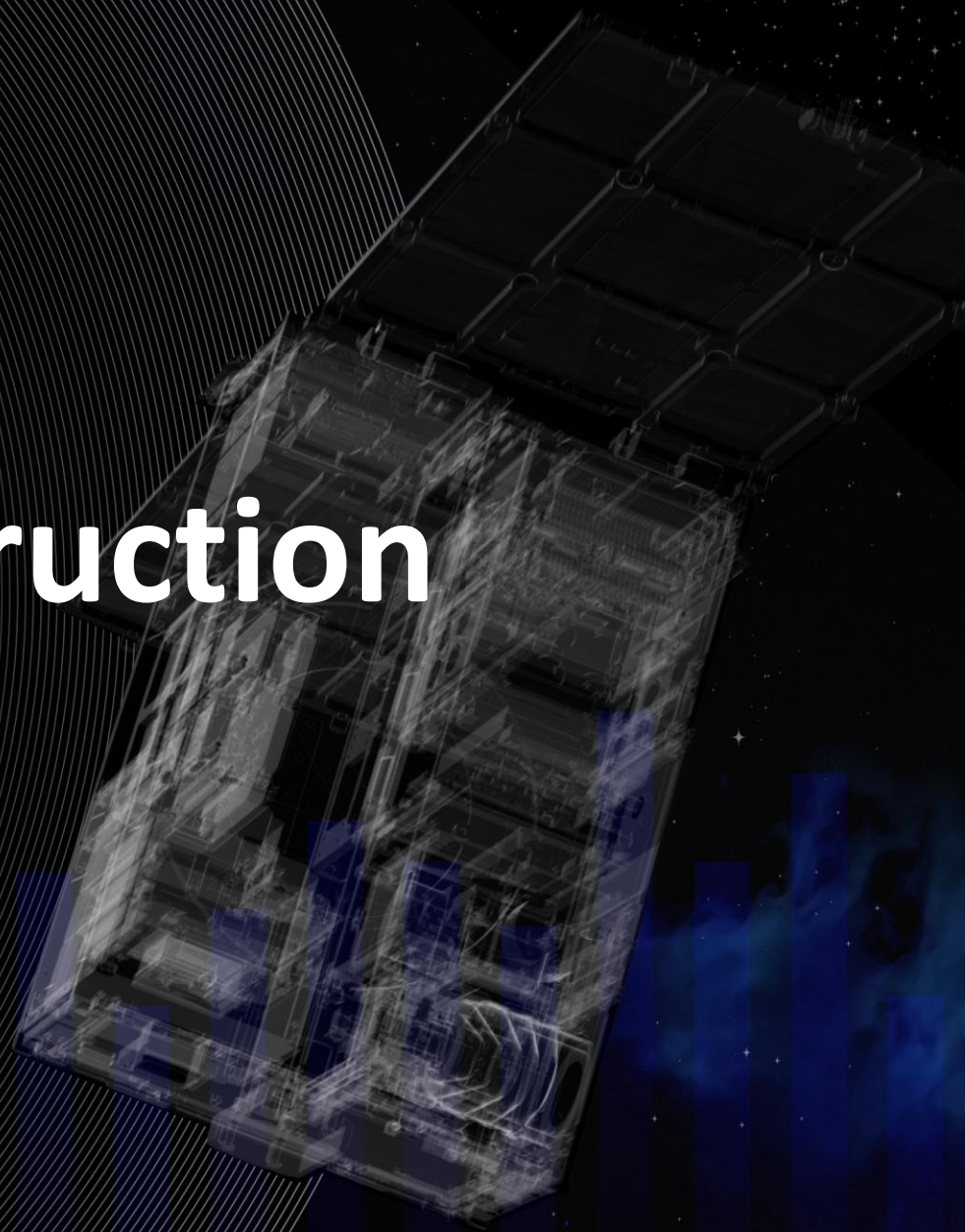
Temp Bias Dependency

- Gain variation
  - Bias
  - Temperature
- Non-negligible change
  - ~10% gain variation
    @ 10℃ fluctuation
  - ~20% gain variation
    @ 0.5V fluctuation



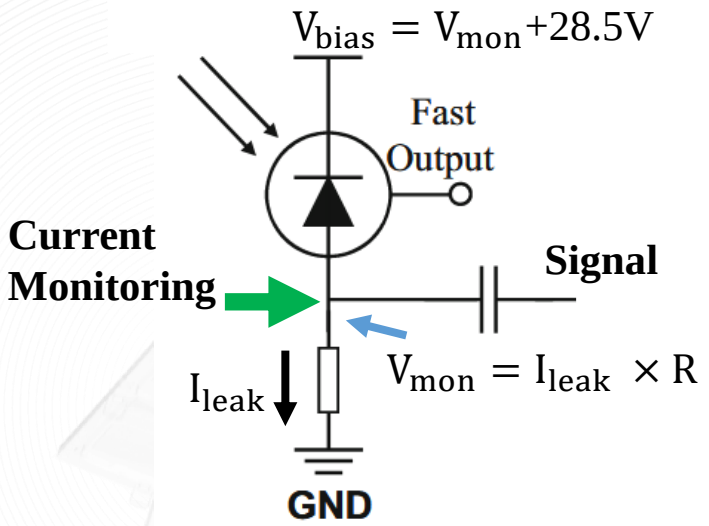


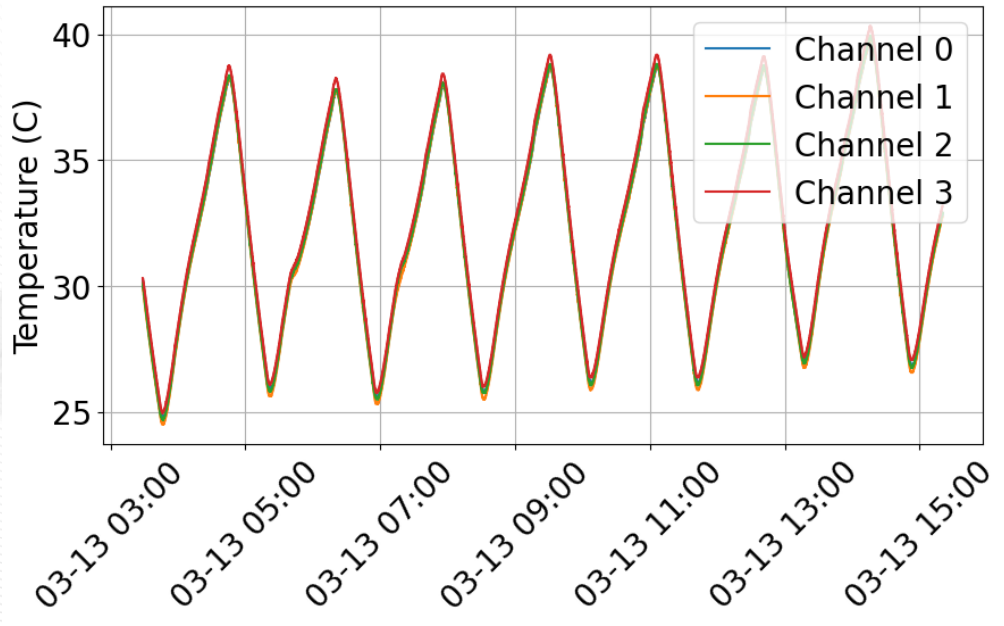
Energy Reconstruction



Operating Strategy

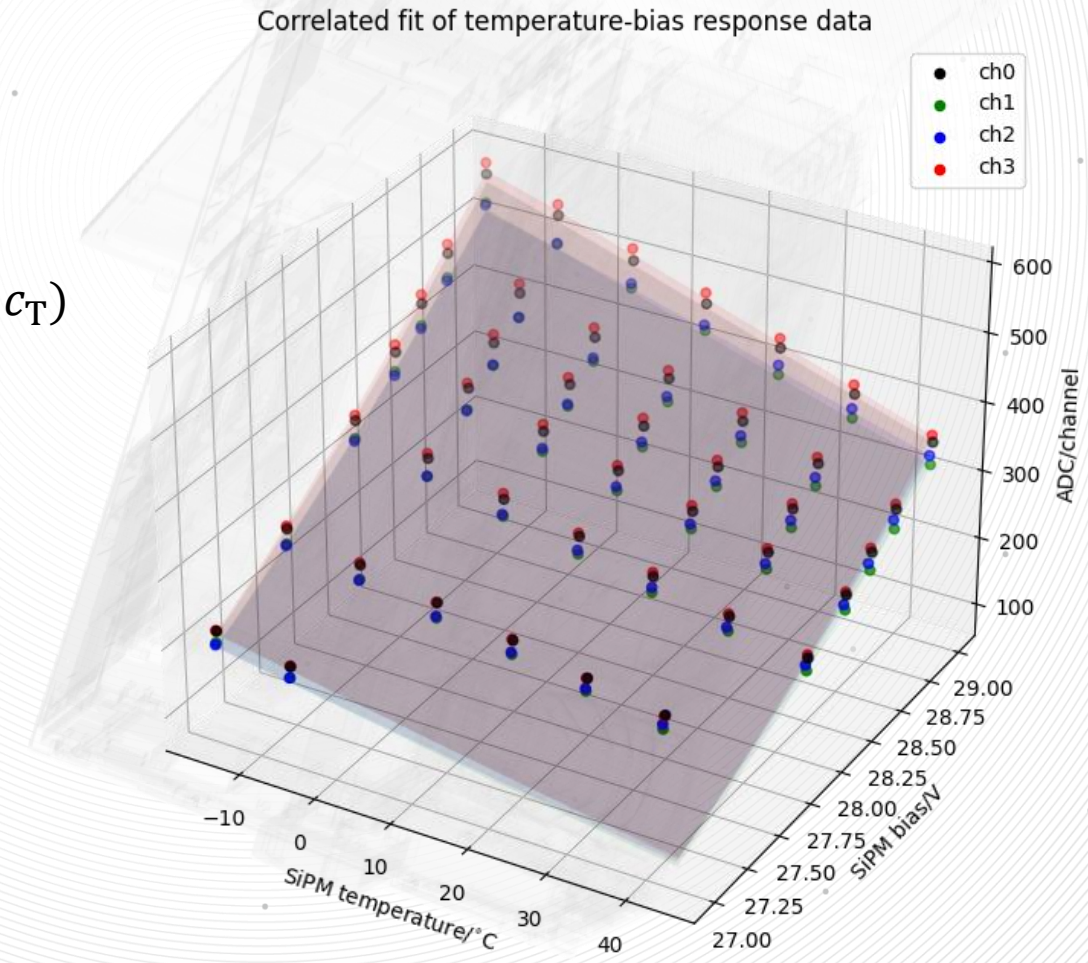
- G_{det} is sensitive to both **temperature** and **bias voltage**
- Operating Strategy:
  - Monitoring the leakage current
    - Radiation damage
    - Temperature
  - Stabilize the bias voltage
    - with PID algorithm
  - Record temperature real time
    - temperature monitoring chip near the SiPM
  - reconstruct gain of each photon event
    - Dedicated bias & recorded temperature
    - **Calibration result**





2D Temp Bias Response

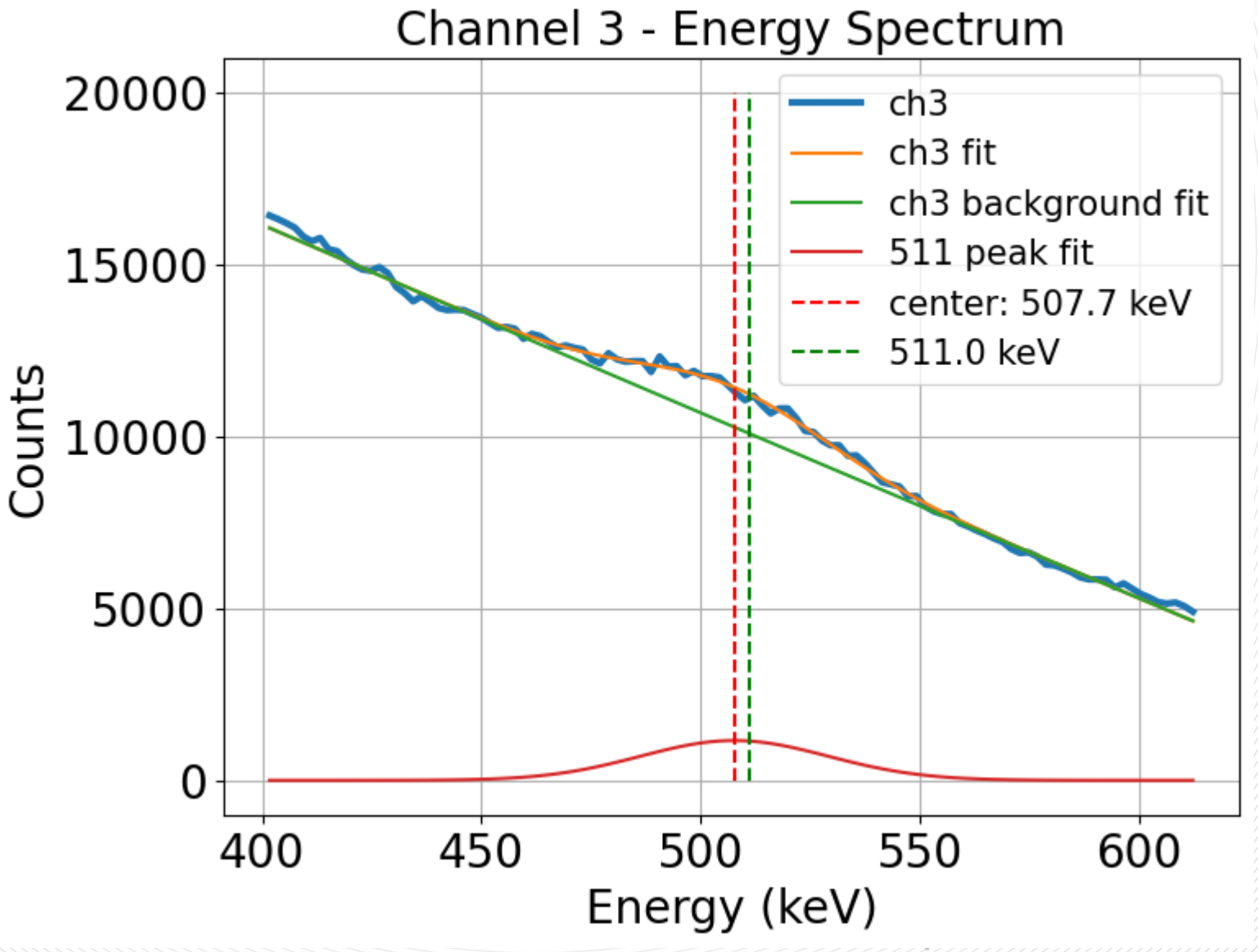
- Gain model for entire detector
- $$G_{\mathrm{det}}(T, V_{\mathrm{b}}) = \mathrm{LY}_{\mathrm{GAGG}} \cdot \mathrm{PDE} \cdot G_{\mathrm{SiPM}} \cdot G_{\mathrm{elec}}$$
$$= G_0 \cdot (V_{\mathrm{b}} - k \cdot T - V_{\mathrm{BD0}})^2 \cdot (-T^2 + b_{\mathrm{T}} \cdot T + c_{\mathrm{T}})$$
  - With on ground calibration data
- Correct signal amplitude
  - To reference temperature, bias
    - 28.5V, 20℃
  - photon by photon



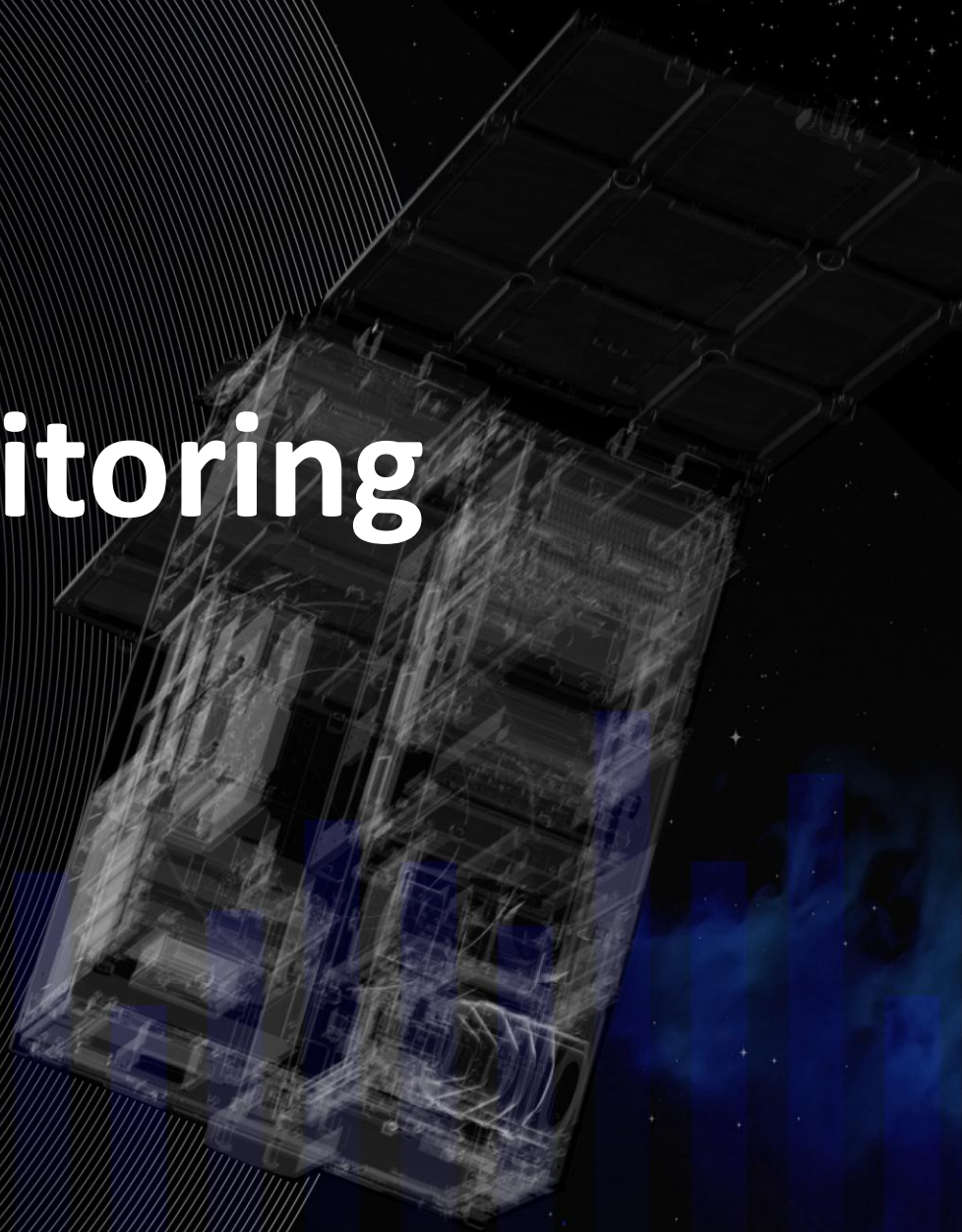
[5] Gao, H.,et al. 2021.

In Orbit Calibration

- Long-term gain shift
  - 511 keV correct
- <10% before and after rocket launch
- Long term around 1%

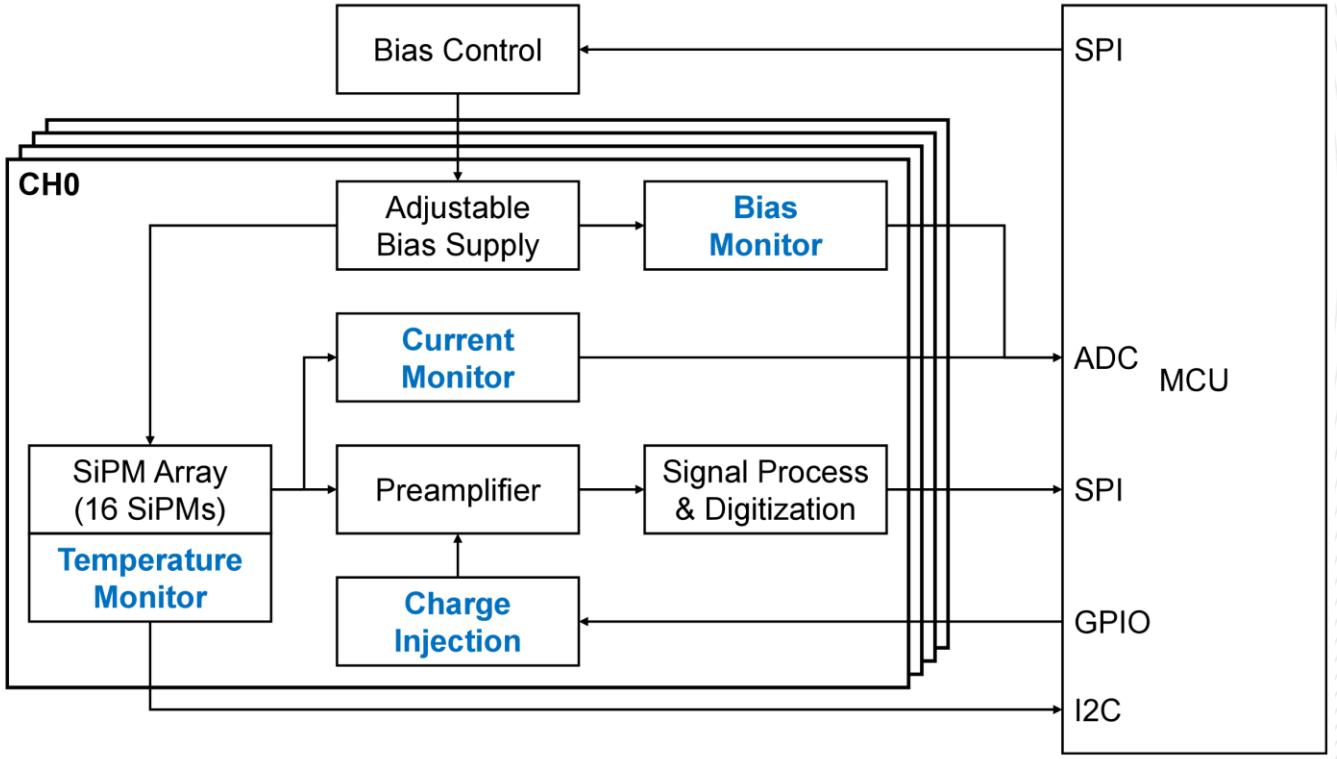


Long Term Monitoring of SiPM



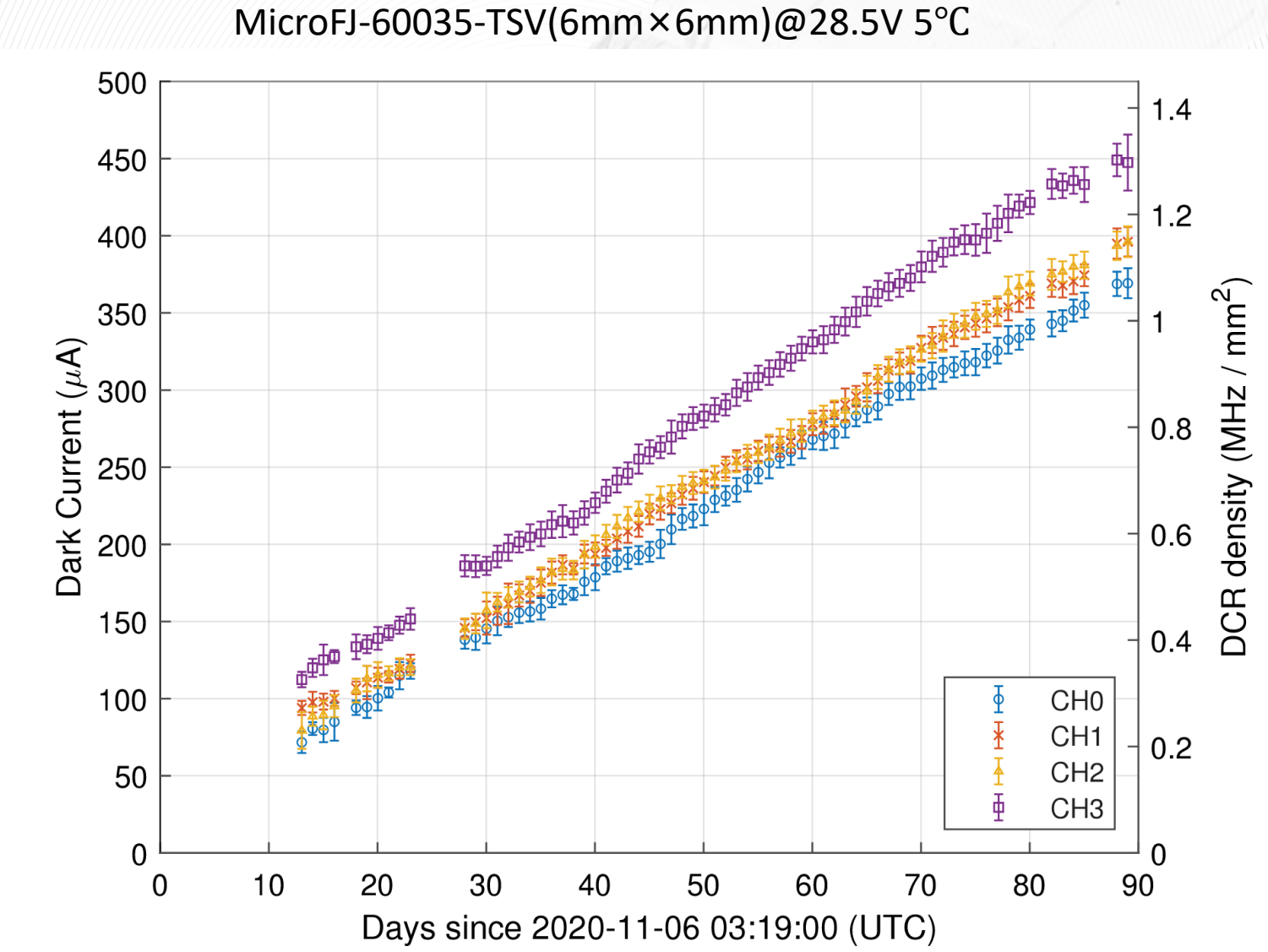
SiPM Monitoring

- GRID circuit design
  - Temp bias record in real time
  - IV scan for breakdown voltage
  - Charge Injection
    - with and without bias voltage
    - Total noise including
      - SIPM dark count noise
      - electronics noise
- Accumulated data more than one year
  - ~900 days for GRID-03B



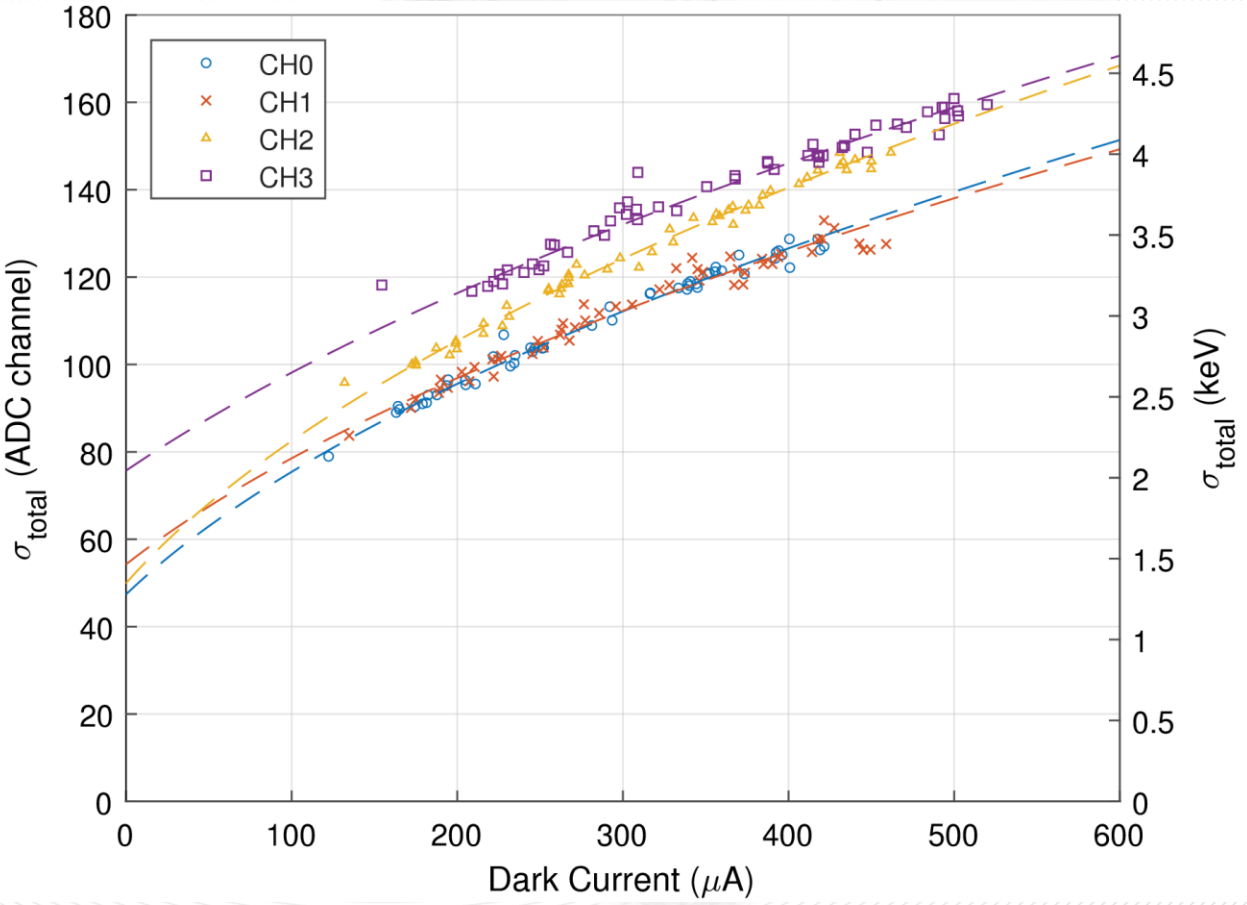
Leakage Current

- Keeps increasing due to radiation damage
- Linear growth
  - Proportional to accumulated dose



Charge Injection

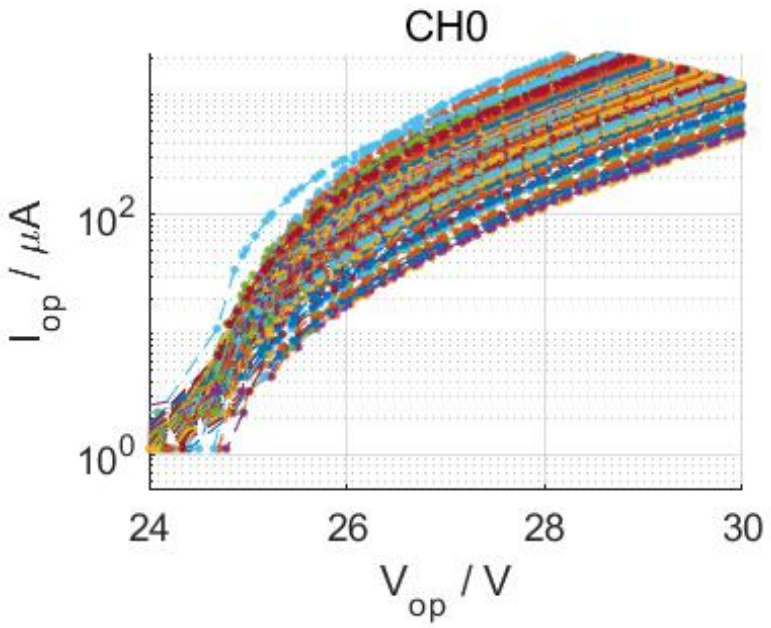
- $\sigma_{\mathrm{total}}^2 = \sigma_{\mathrm{DC}}^2 + \sigma_{\mathrm{elec}}^2$
  - Dark count noise of SiPM
  - σ_{elec} shows no significant change in GRID data
- $\sigma_{\mathrm{total}} = \sqrt{a_{\mathrm{n}} \cdot I_{\mathrm{dark}} \cdot (V_{\mathrm{bias}} - V_{\mathrm{bd}}) + b_{\mathrm{n}}}$
  - Measurement of radiation damage

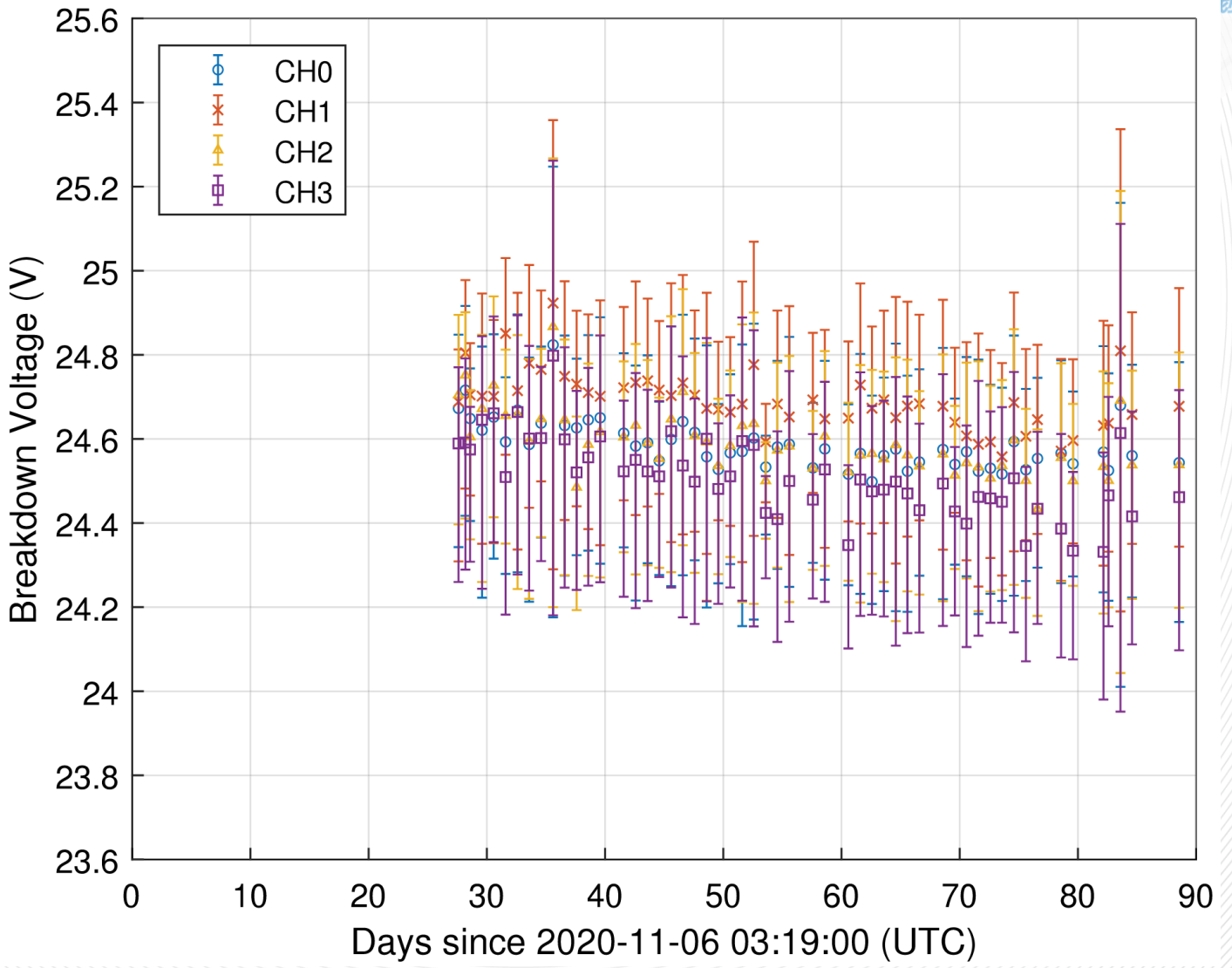


[7]X. Zheng et al. 2022

SiPM IV Scan

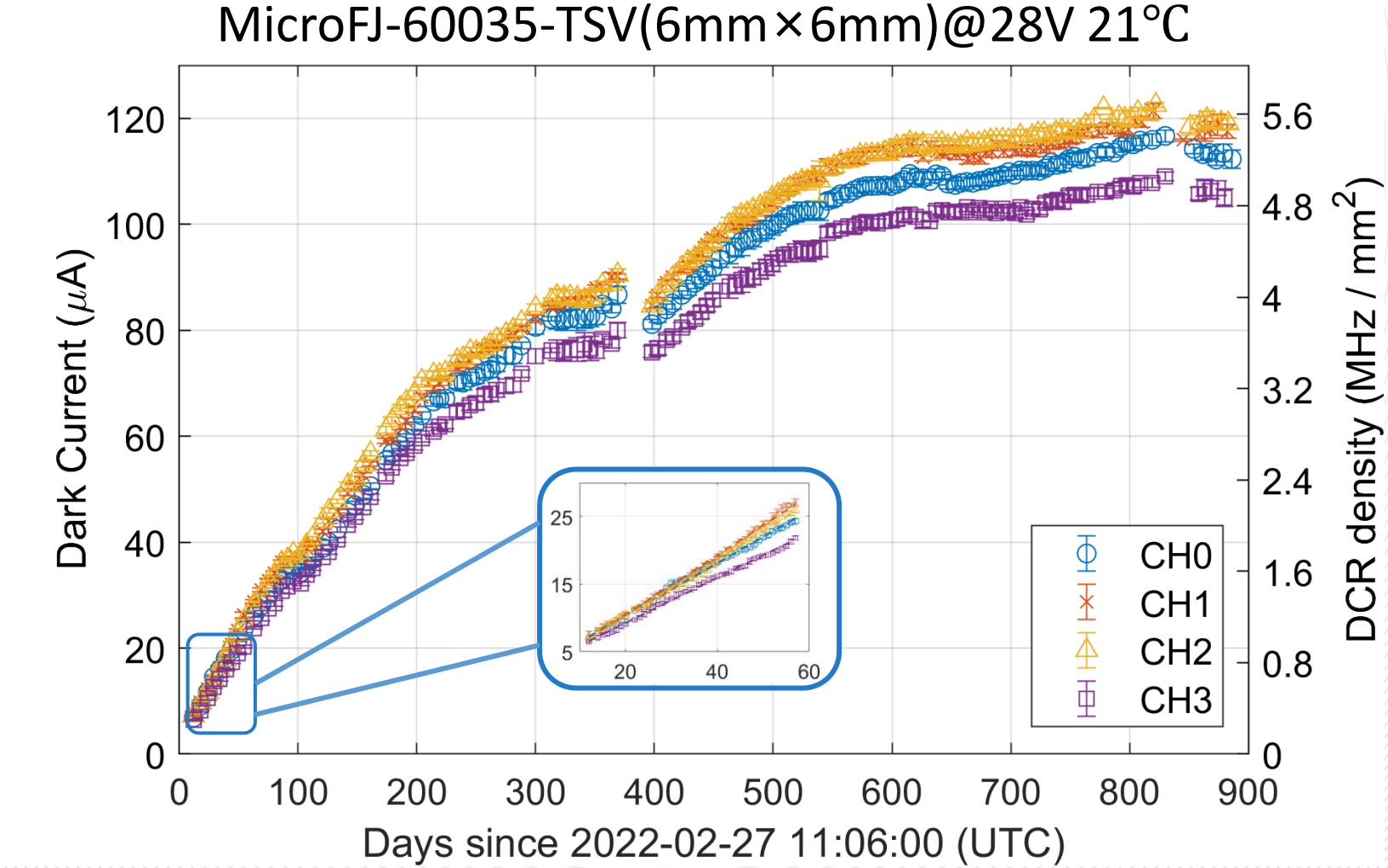
- Breakdown voltage
  - Not affected by radiation damage





Leakage Current Growth in Long Term

- Linear growth
  - at early time
- Saturation in long term
  - Annealing effect



Conclusion

- GRID is a NanoSat mission for GRB observation, with both scientific and education purpose, with considerable contribution from undergraduate students.
- 12 GRID detectors have been successfully launched, and some scientific results have been published.
- An effective calibration method has been applied to GRID detectors and it’s promising for SiPM-based detector on NanoSat.
- GRID provides long-term in-orbit monitoring of SiPM, which is beneficial to its space application.
- GRID is a collaboration with open hardware and open data, welcome to join!

The GRID Collaboration

Reference

[1] J. Wen et al., “GRID: a student project to monitor the transient gamma-ray sky in the multi-messenger astronomy era,” Experimental Astronomy, vol. 48, no. 1, pp. 77–95, Aug. 2019, doi: 10.1007/s10686-019-09636-w.

[2] B. P. Abbott et al., “Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A,” The Astrophysical Journal, vol. 848, no. 2, p. L13, Oct. 2017, doi:10.3847/2041-8213/aa920c.

[3] J.-X. Wen et al., “Compact CubeSat Gamma-ray detector for GRID mission,” Nuclear Science and Techniques, vol. 32, no. 9, Sep. 2021, doi: 10.1007/s41365-021-00937-4.

[4] X. I. Wang et al., “GRB 210121A: A Typical Fireball Burst Detected by Two Small Missions,” The Astrophysical Journal, vol. 922, no. 2, p. 237, Dec. 2021, doi: 10.3847/1538-4357/ac29bd.

[5] H. Gao et al., “On-ground calibrations of the GRID-02 gamma-ray detector,” Experimental Astronomy, vol. 53, no. 1, pp. 103–116, Dec. 2021, doi: 10.1007/s10686-021-09819-4.

[6] Q. Liu et al., “Monte Carlo simulation of angular response of GRID detectors for GRID mission,” Journal of Instrumentation, vol. 20, no. 03, pp. P03017–P03017, Mar. 2025, doi: 10.1088/1748-0221/20/03/p03017.

[7] X. Zheng et al., “In-orbit radiation damage characterization of SiPMs in the GRID-02 CubeSat detector,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 1044, p. 167510, Sep. 2022, doi: 10.1016/j.nima.2022.167510.

Thanks for listening!