Friedrich-Alexander-Universität
Erlangen-Nürnberg

ECAP contribution to the Small-Sized Telescope Camera for CTAO

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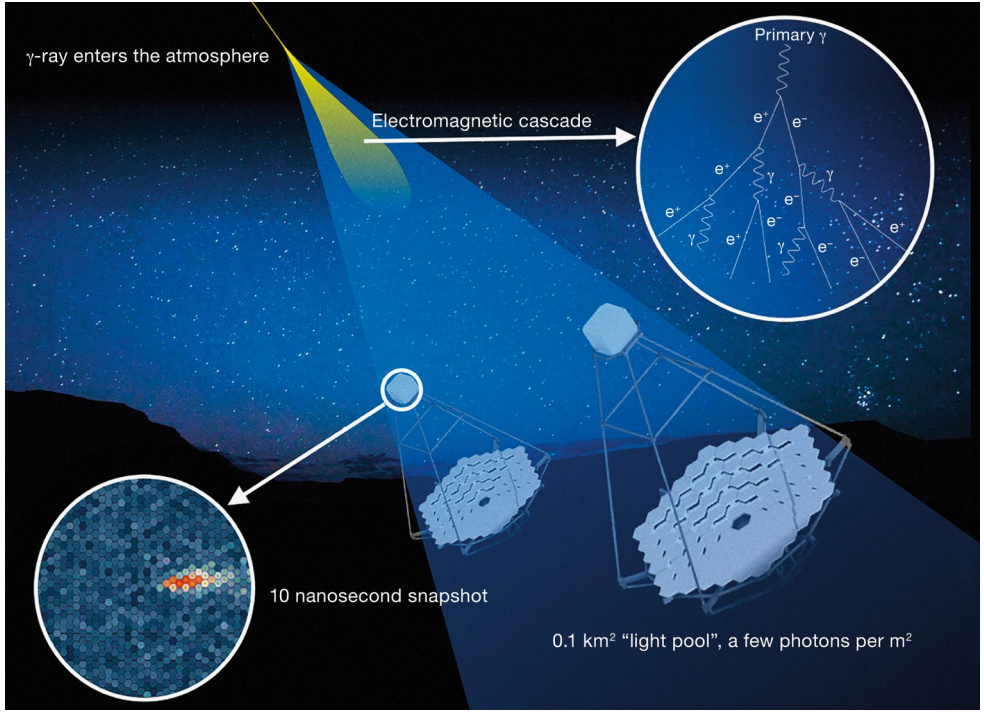
Würzburg, 20.07.2026

Group members: Dr. Adrian Zink, Dr. Benjamin Schwab, Prof. Dr. Stefan Funk

Cherenkov Telescope Array Observatory

Prospects



Credit: CTAO/ESO

- **Multiple telescopes** enable stereoscopic perception.
  - > 60 ensure better energy reconstruction.
  - → Better sensitivity.
- Southern + Northern hemispheres.
  - **Full-sky scan**.
  - → More sources.
- Telescopes of **different sizes**:
  - → Larger energy coverage (20 GeV – 300 TeV).
    - Large-Sized Telescopes (LST)
    - Medium-Sized Telescopes (MST)
    - Small-Sized Telescopes (SST)

Small-Sized Telescopes (SSTs)

Prospects

Designed to detect **VHE gamma rays**.

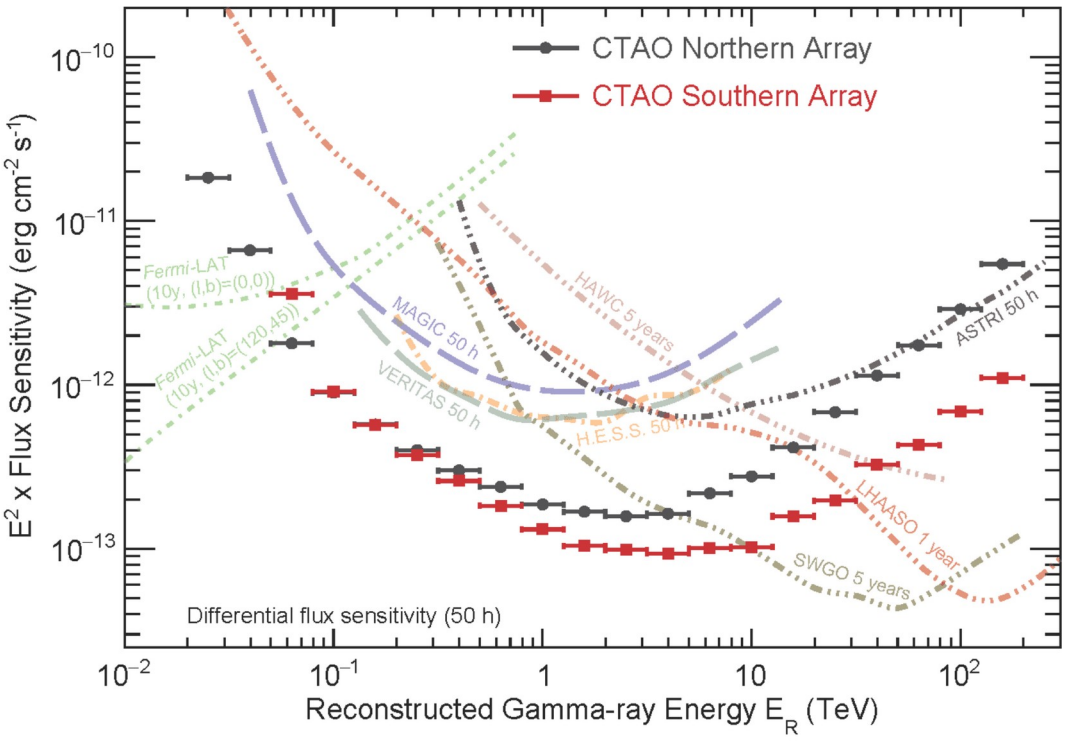
Cherenkov light flashes properties:

- Rare (effective collection area ~ 10^4 m^2).
- Wide range of intensity.
- Fast (pulses last ~ 10 ns).

Telescopes characteristics:

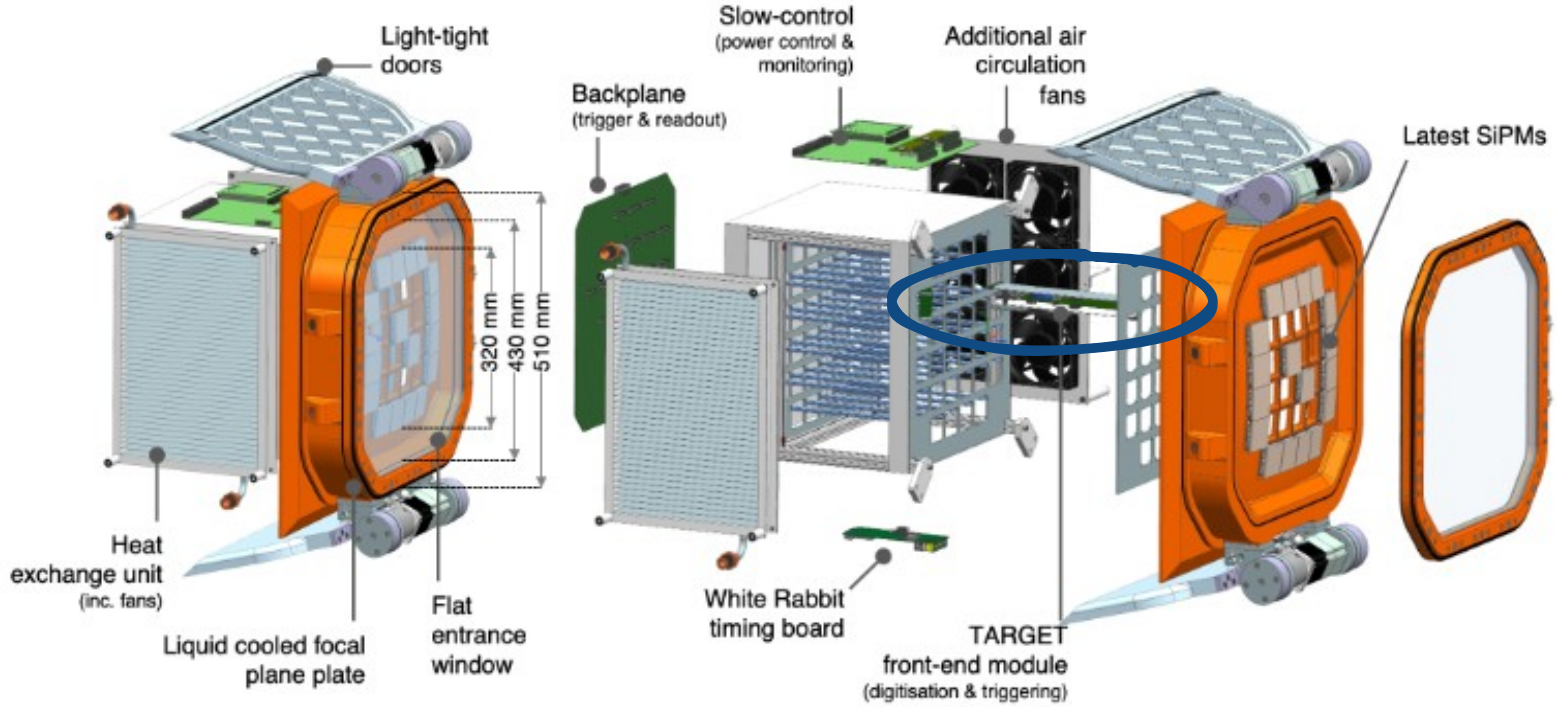
- Small size (~ 4 m)
  - → Possibility to **produce many** (~ 40).
  - → Higher detection probability.
- **Large dynamic range**.
- **Fast-sampling** cameras (~ 1 Gsa/s).

Credit: CTAO - Cherenkov Telescope Array Observatory



Small-Sized Telescope Camera

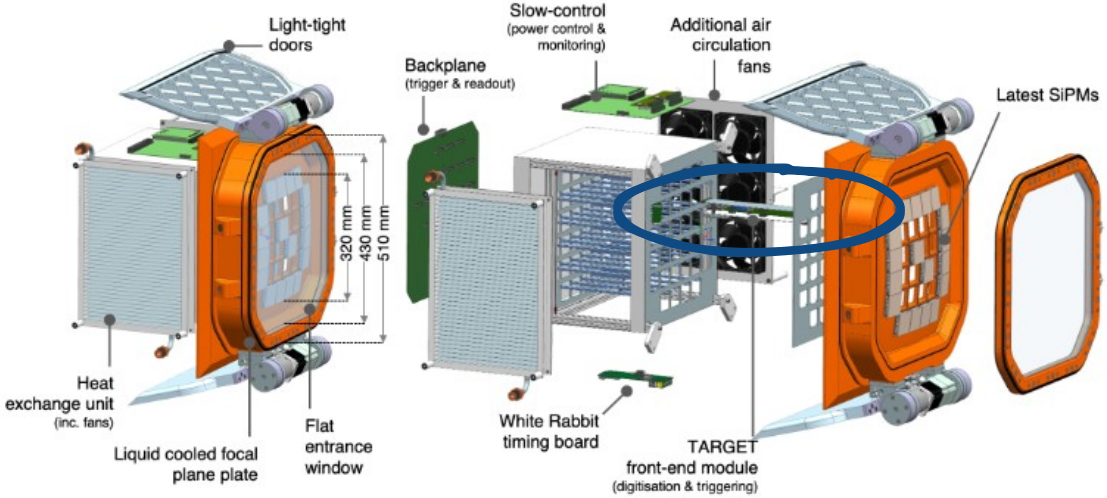
Components



SST Camera. Credit: White, R (2021)

Small-Sized Telescope Camera

Components

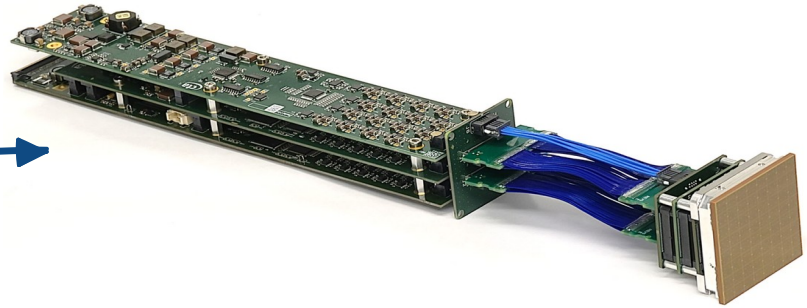


SST Camera. Credit: White, R (2021)

Requirements:

- Compact and cost-efficient.
- Fast-sampling (~ 1 Gsa/s).
- Large dynamic range.
- Good charge resolution.

TARGET Module. Credit: A. Antonelli (2024)



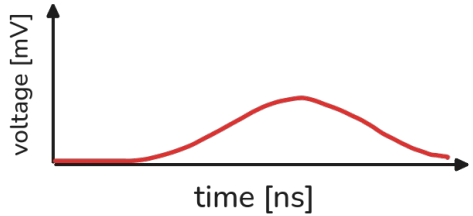
TARGET modules

Read-out electronics

One SiPM tile has 64 pixels ⟶ 64 input channels per TARGET module.

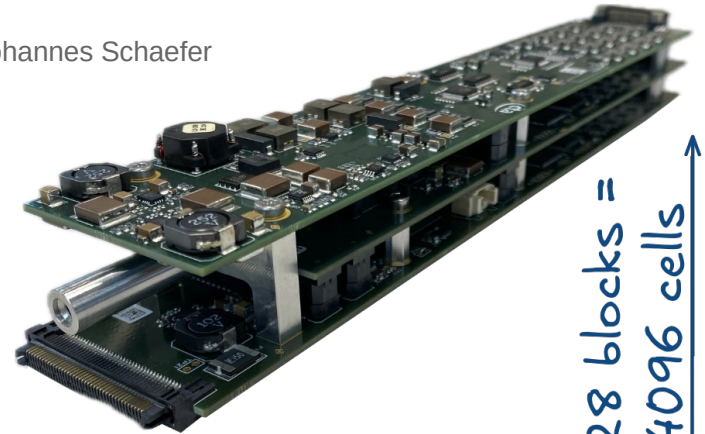
For each channel, the TARGET module:

Samples, triggers and **digitizes** the incoming signal.

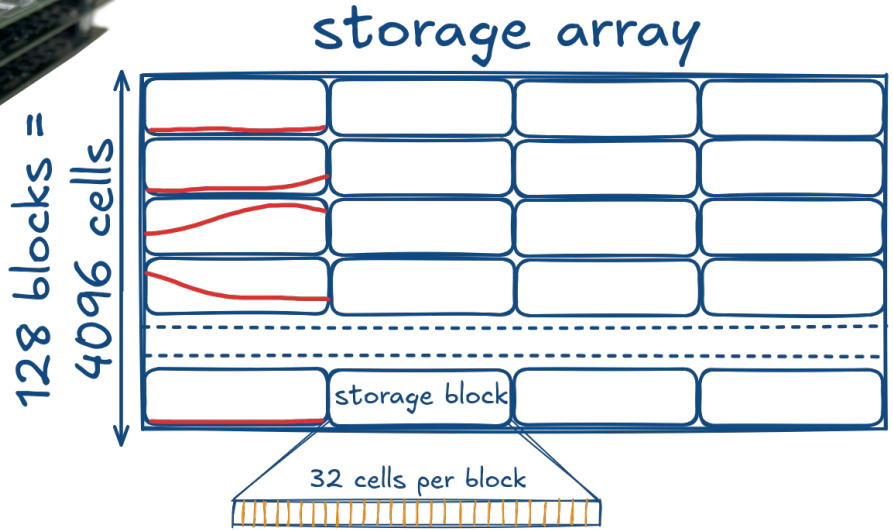


Analog signals from SiPM

TARGET Module. Credit: Johannes Schaefer

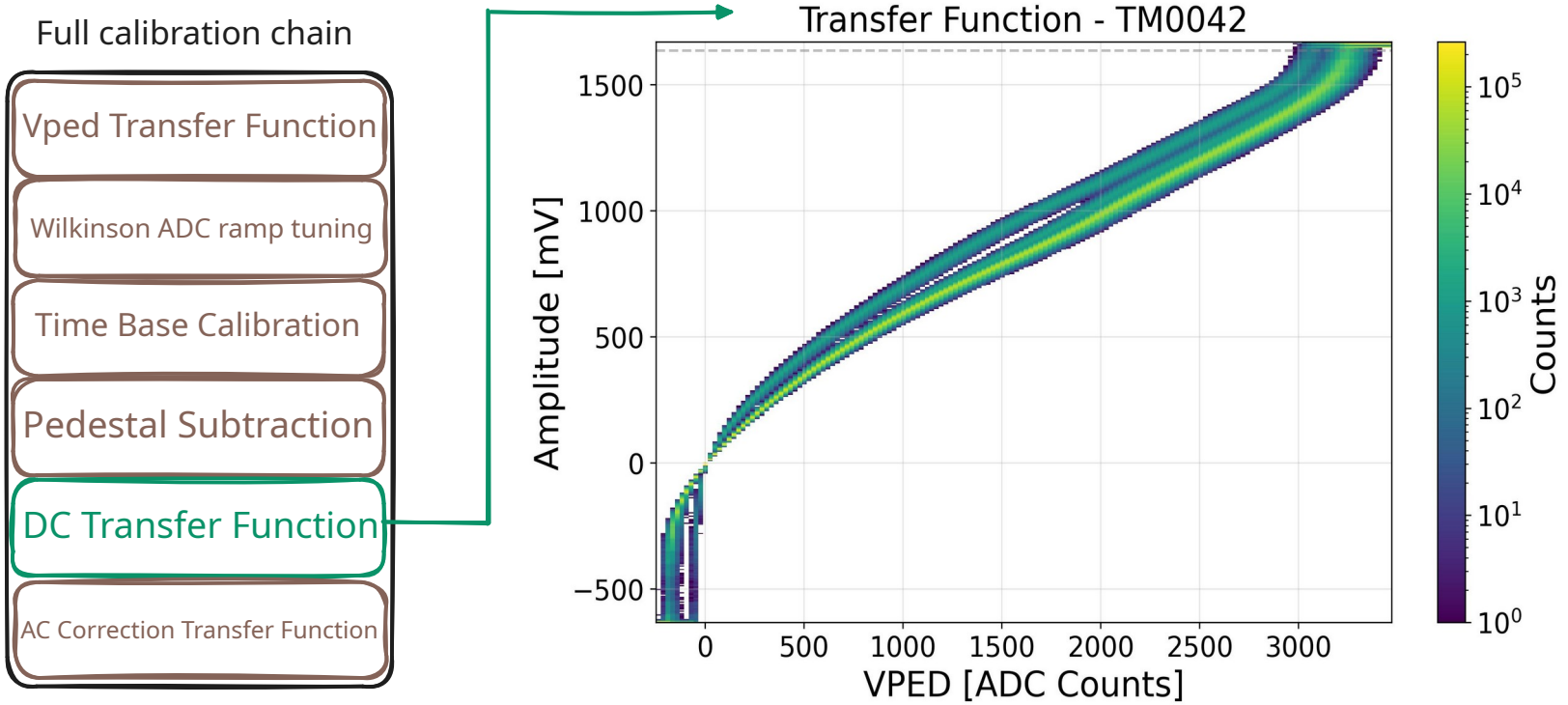


Digital signals to the backplane



Previous work

ECAP led the full design, calibration, and performance validation of the TARGET modules.



Current needs

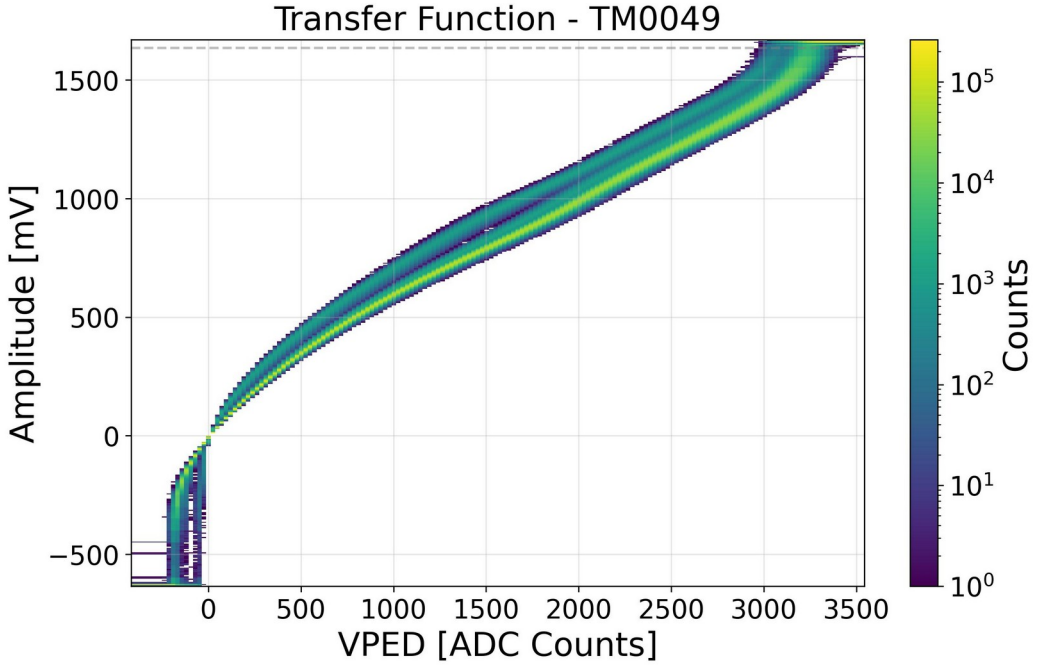
Time-efficient quality testing

The number of TARGET modules being tested is scaling up (~ 1200 TMs require quality testing and calibration).

Time-efficient quality testing

- Full dynamic range for all storage cells.
- Average baseline around 0 ADC counts.

⟶ Ensure wide range of intensity.

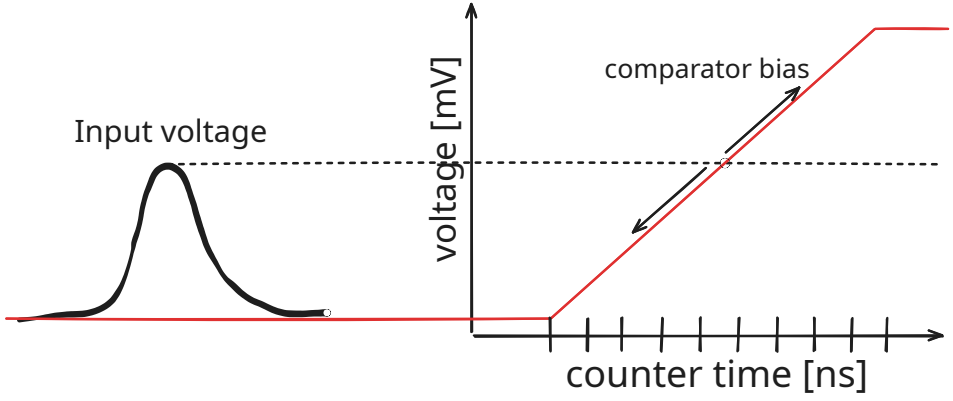


Current needs

Tuning the Wilkinson Analog-Digital Converter (ADC)

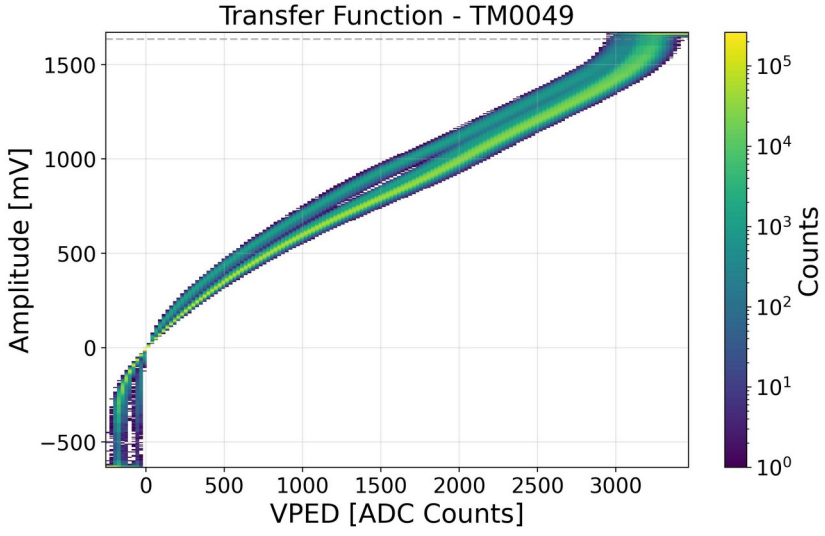
Signals are digitized through a **Wilkinson ADC**.

Operating principle:



The **comparator** is a component that flips when the ramp reaches the input voltage.

After the comparator bias tuning:



Current needs

Fast and precise calibration

The number of TARGET modules being tested is scaling up (~ 1200 TMs require quality testing and calibration).

Time-efficient quality testing

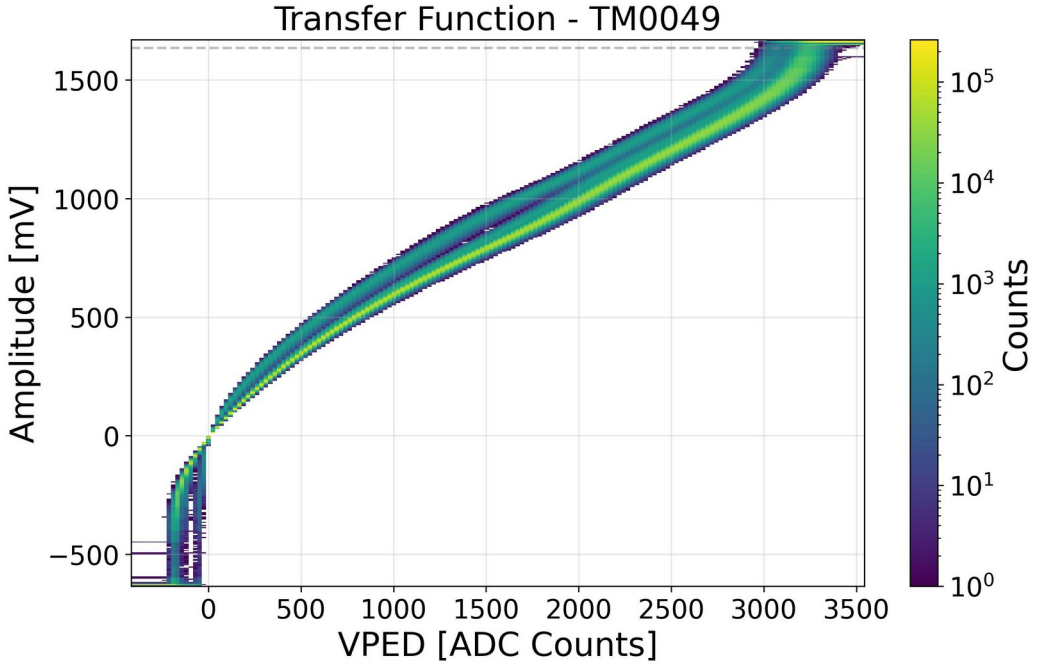
- Full dynamic range for all storage cells.
- Average baseline around 0 ADC counts.

→ Ensure wide range of intensity.

Fast and precise calibration

- Similar DC TF between cells.
- Similar DC TF between modules.

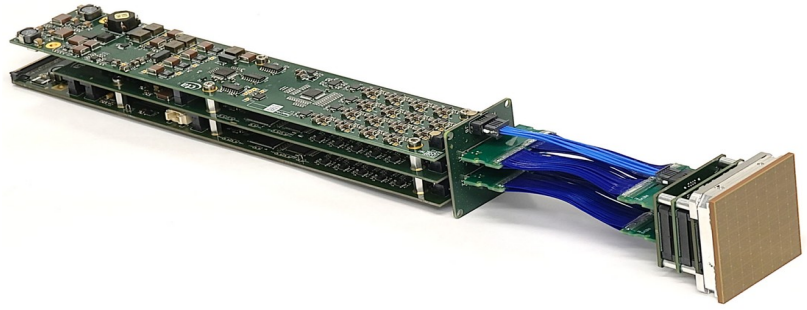
→ Ensure best energy resolution possible within computational limits.



Summary and prospects

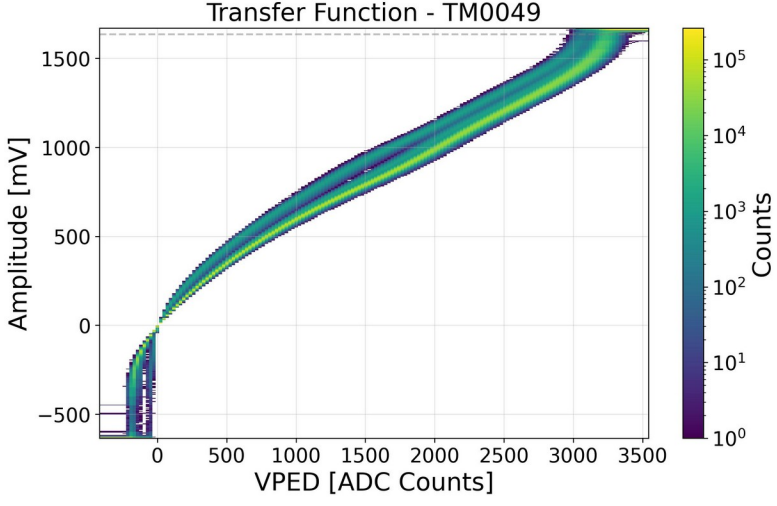
Summary:

- Previous work assessed that TARGET modules satisfy the CTAO's requirements.
- Hardware testing brings up unexpected work everyday.



Future prospects:

- ► Implement fast and reliable quality-tests, with standard diagnostic plots.
- ► Simplify the tuning process.
- ► Optimize calibration to improve efficiency while maintaining current energy resolution.



Thank you for your attention!

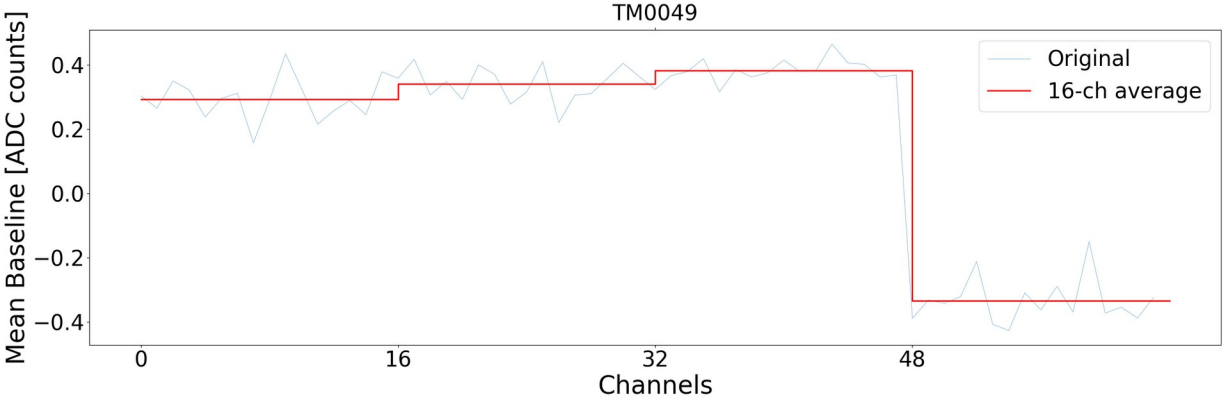
Back-up

Current needs

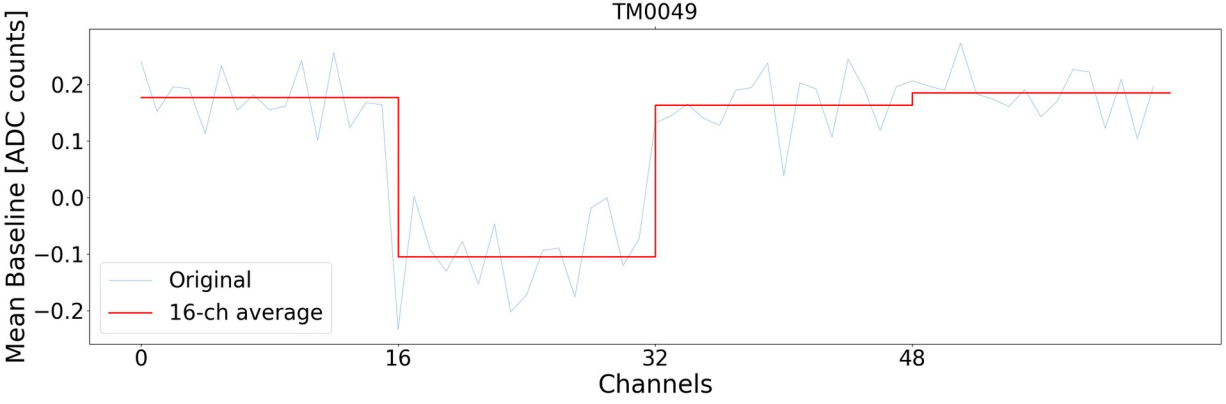
Tuning the Wilkinson Analog-Digital Converter (ADC)

After tuning the comparator bias, we check if the average baseline drifted:

Before tuning:

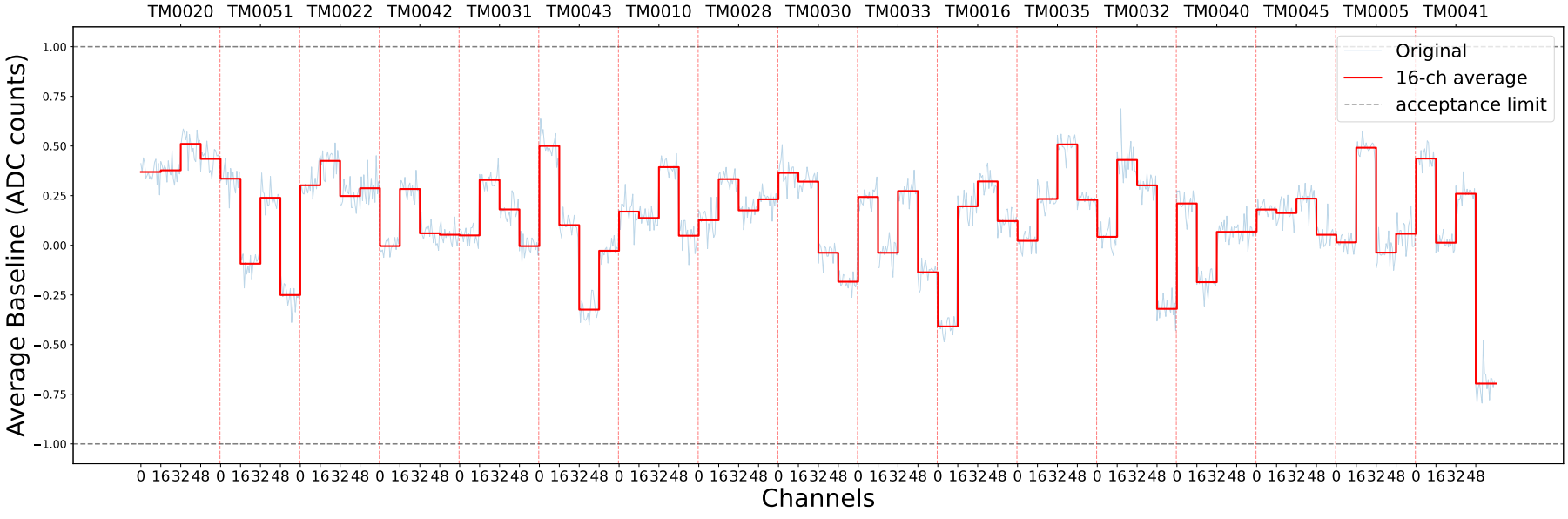


After tuning:



Current needs

Average baseline across multiple modules



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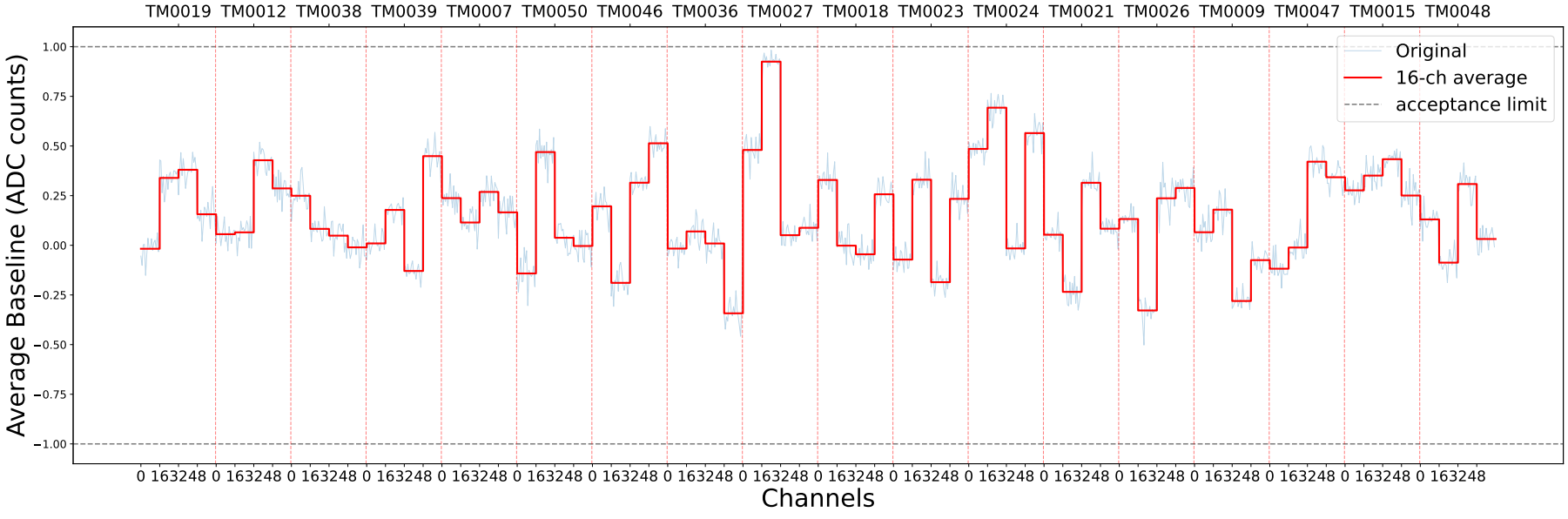


CTA science cases

Higher energies and larger sky coverage

- **Origin of relativistic cosmic rays.** Sources, mechanisms, ultimately, their role in star formation.

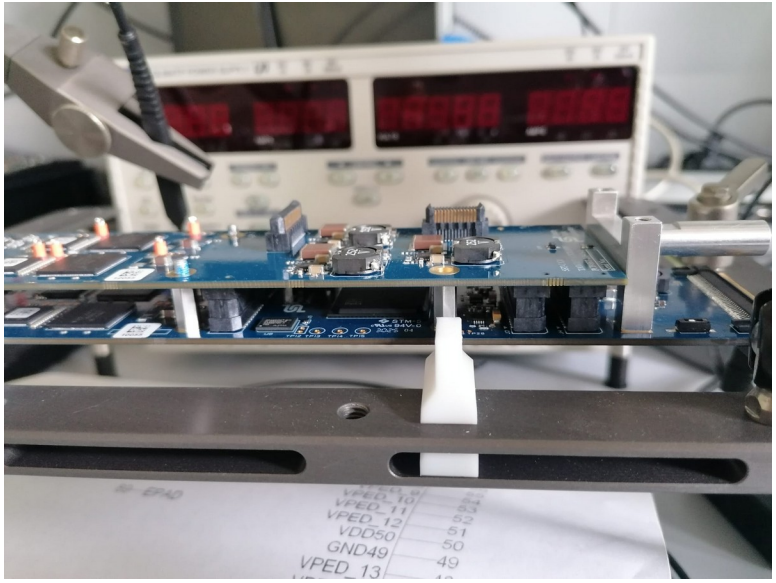
- **Extreme environments.** Neutron stars and black holes, how magnetic fields evolve in cosmic times.

- **Physics frontieres.** Nature of DM, its distribution.

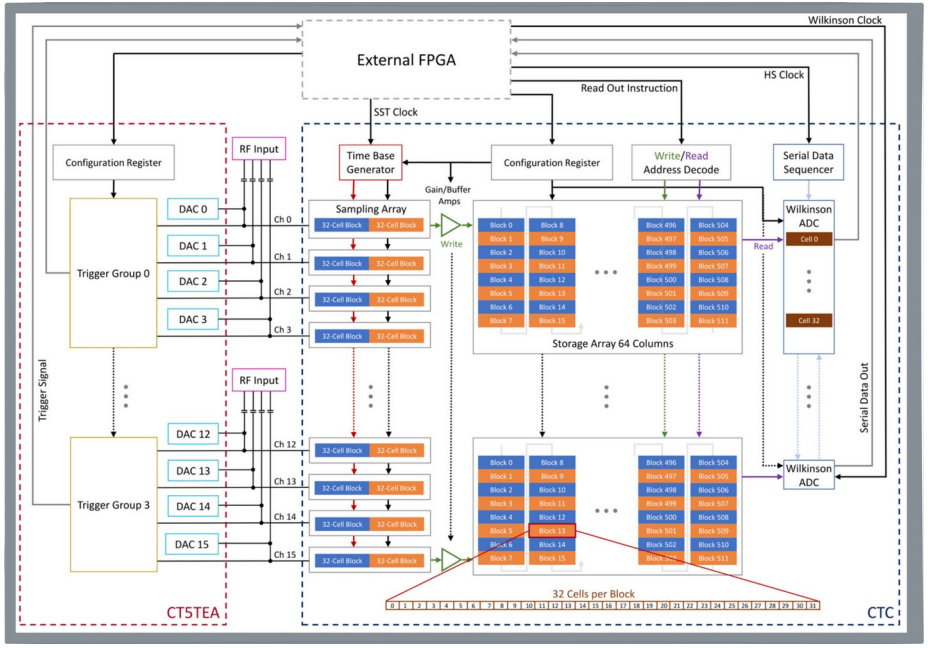
TARGET Modules

Readout system

1) FPGA (Field-Programmable Gate Array) – configuring and controlling the ASICs
2) CT5TEA (Cherenkov Target 5 Trigger Extension Asic) – trigger ASIC
3) CTC (Cherenkov Target C) – sampling ASIC



Schwab, B. (2024)



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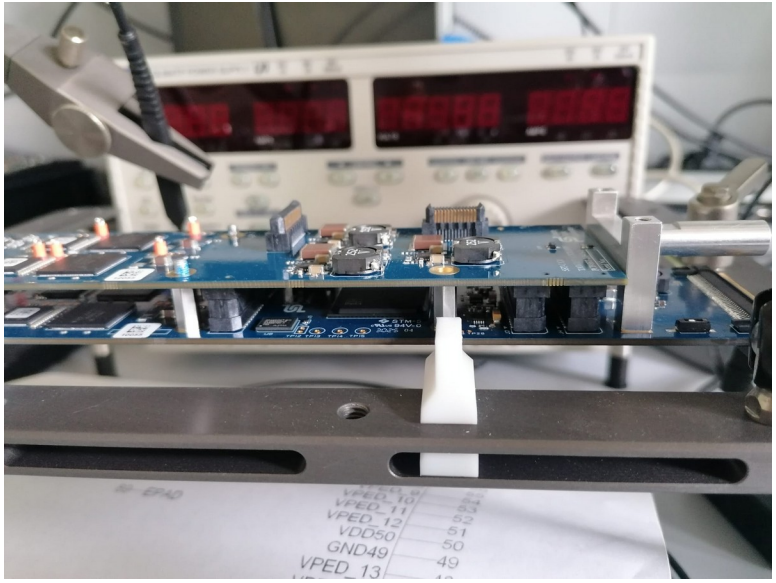

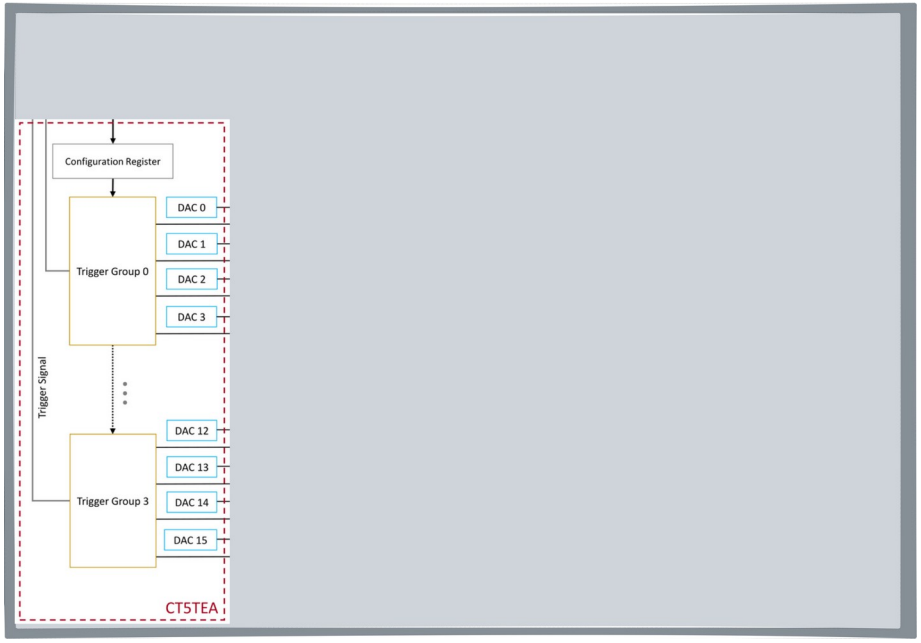

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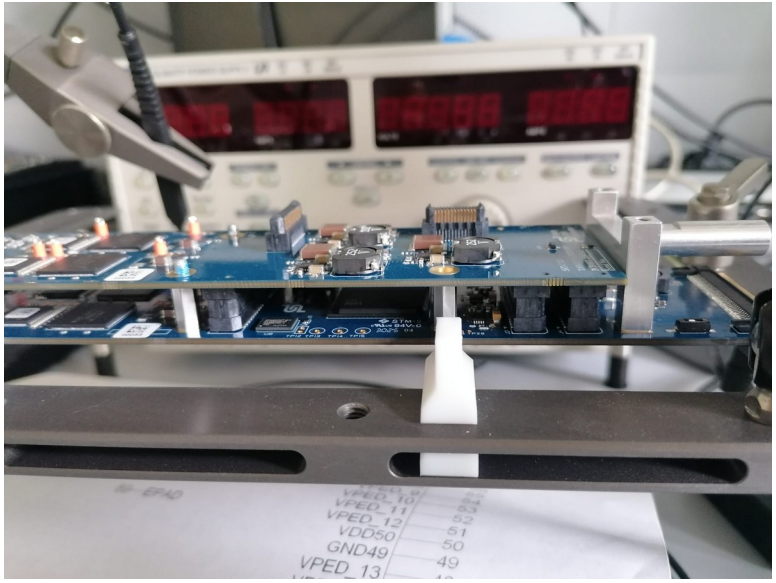
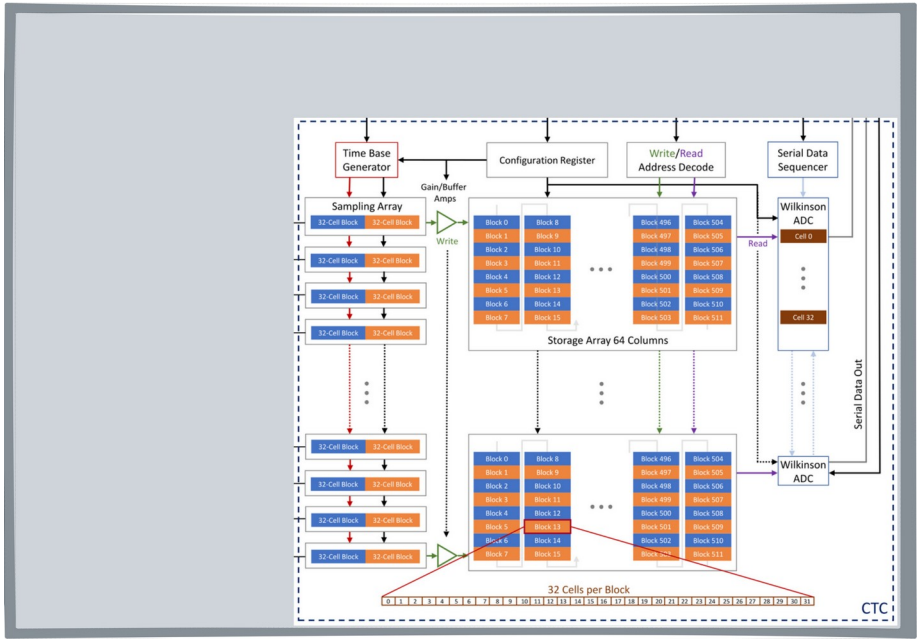




TARGET Modules

Previous work

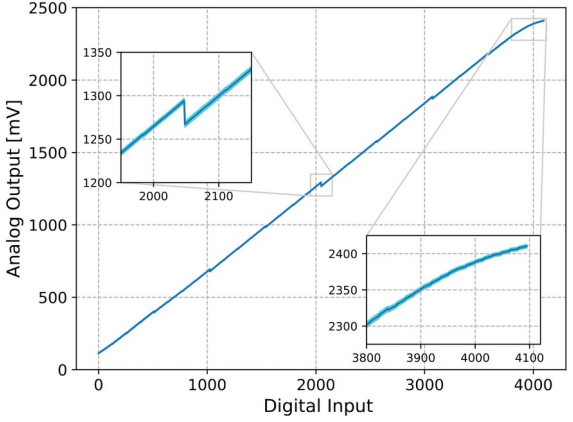
1. Vped Transfer Function

Purpose: Characterize the DACs that set the **operational pedestal voltage** for each channel.

Method:

DAC output voltages are probed at the test point in front of CTC.

Measurements taken with a Multimeter over 512 different DAC settings.

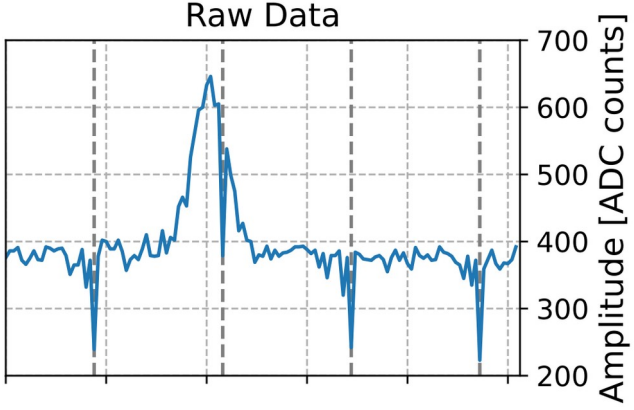


Temperature stability: Deemed sufficiently stable for use in the SST camera. At the operational pedestal voltage of 750 mV, temperature-induced offset scales with ~0.08 mV/K, which is negligible relative to the SCA's required voltage margins.

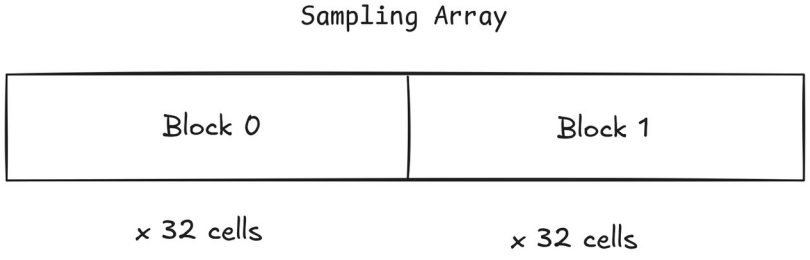
Future improvements

The CTC ASIC uses a dual-block Switched-Capacitor Array (SCA) in ping-pong mode. Each block contains 32 sampling cells.

Were noticed downward spikes in digitized waveforms:



Schwab, B. (2026) [PhD Thesis]



- Delay to start/stop transit to next cell address
- Delay to start/stop writing the voltage

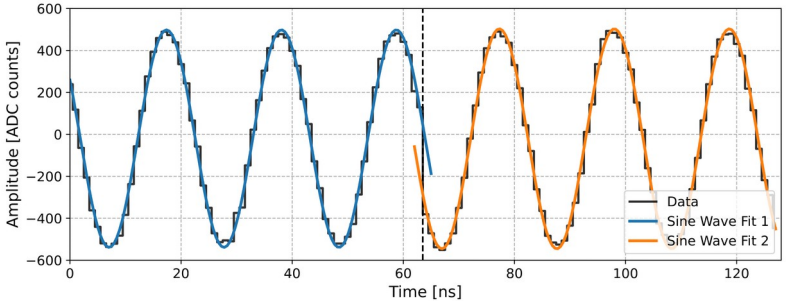
Previous work

Calibration chain development

Pre-operational Calibration:

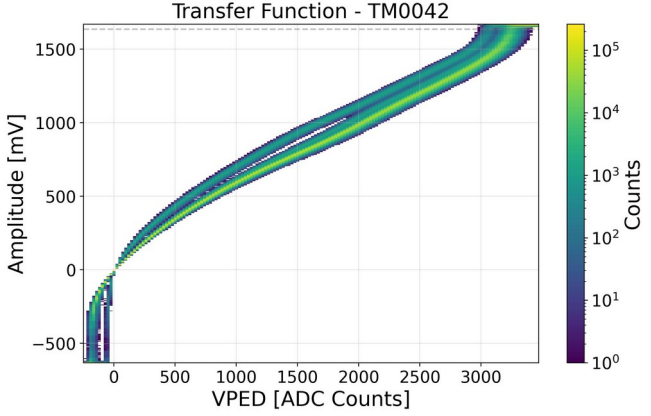
- DAC tuning: a stable **working point** (Vped) was set to 750 mV.
- The length of individual sampling cells was fine tuned to have a transition from second to first block in sync with the FPGA clock.
- The Wilkinson **ADC ramp**'s slope and zero point were tuned to reach operational range of [0.2 V, 2.4 V]

Schwab, B. (2024)



In-Situ Calibration:

- Pedestal subtraction
- DC transfer function using the internal DACs of the CT5TEA. This allows the camera to correct for temperature-dependent performance drifts without requiring external test equipment.



Current needs

Average baseline across multiple modules

Some target modules might need detailed verification.