The Front-end and DAQ system of the Terzina instrument onboard the NUSES space mission

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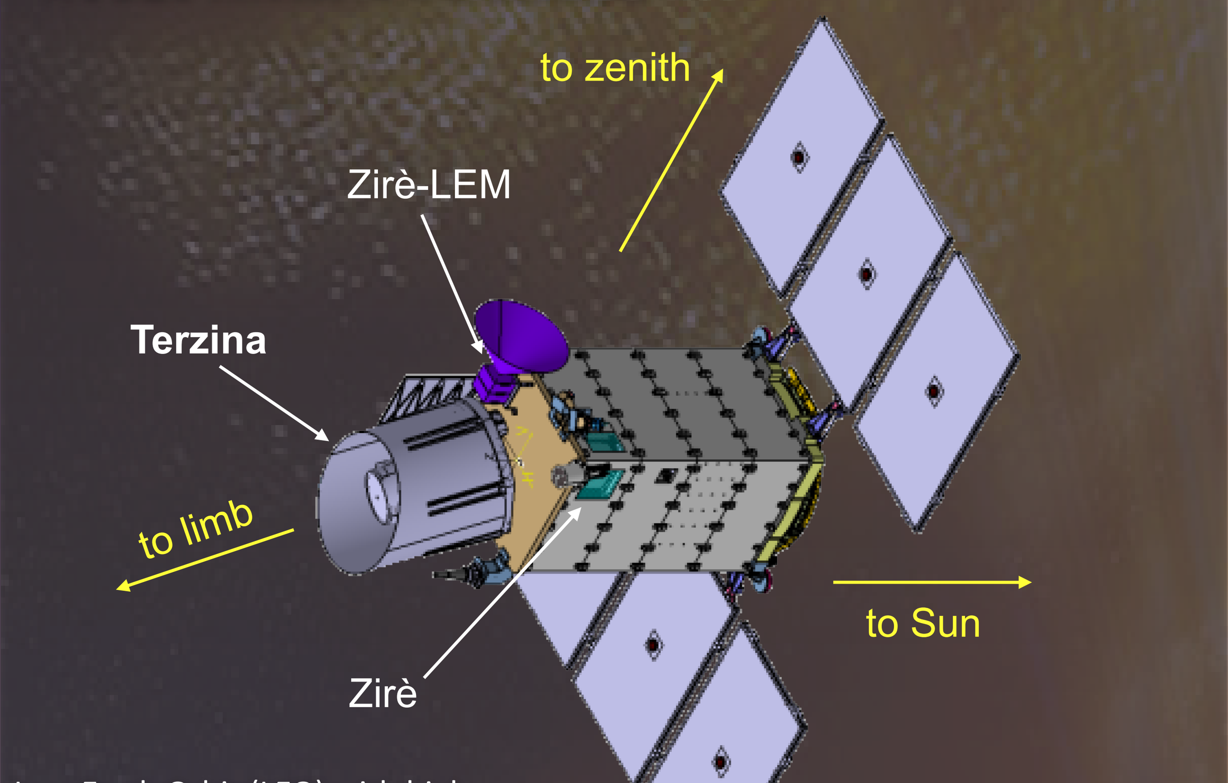
Abstract

The **Terzina** instrument has the scientific goal of detecting Ultra High Energy Cosmic Rays (UHECRs) surpassing 100 PeV and producing atmospheric showers (EAS). The instrument will be installed onboard a LEO (Low Earth Orbit) sun-synchronous orbit satellite in a space mission called NUSES, developed by a collaboration between universities, research institutes and private companies. A second challenging goal of the instrument is the detection of Earth-skimming neutrinos with energies above ~10 PeV. In order to detect such rare events, the SiPM (Silicon Photomultiplier - SiPM) sensor technology has been chosen to cover the foreseen dynamic range of the Cherenkov radiation (~320 to 550 nm). We present an overview of the innovative and custom front-end (FE) electronics and data acquisition (DAQ) system developed for the readout of the SiPM's output signals in Terzina.

NUSES mission: the satellite



Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (BoL altitude 535 Km)

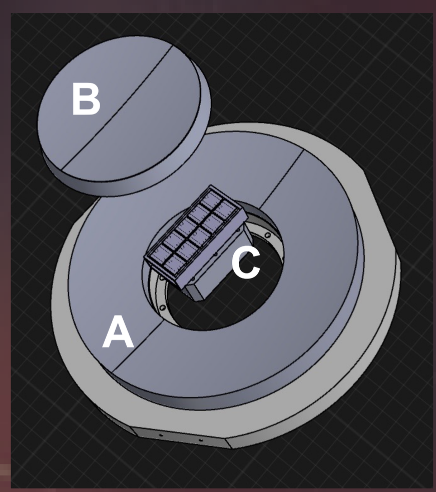
Mission Lifetime: 3 years

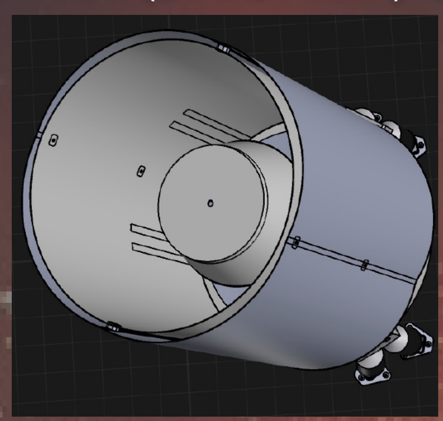
TERZINA: features and goals

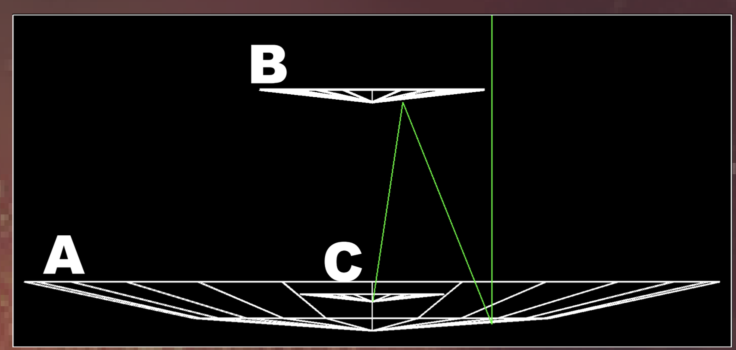
- The Terzina detector is composed by a near-UV-optical telescope, with Schmidt-Cassegrain optics, and a Focal Plane Assembly.
- Terzina is also a pathfinder of future missions, like POEMMA (Probe of Extreme Multi-Messenger Astrophysics).
- Observation of astrophysical **neutrinos** at energies > few PeV (only possible from space).
- Detection of high-energy **cosmic rays** (E > 1 PeV) through EAS Cherenkov emission.
- All sky monitor active in the range 10 keV - 30 MeV.
- Total weight of the Terzina payload: ~35 kg.

Optical system with Schmidt-Cassegrain reflector

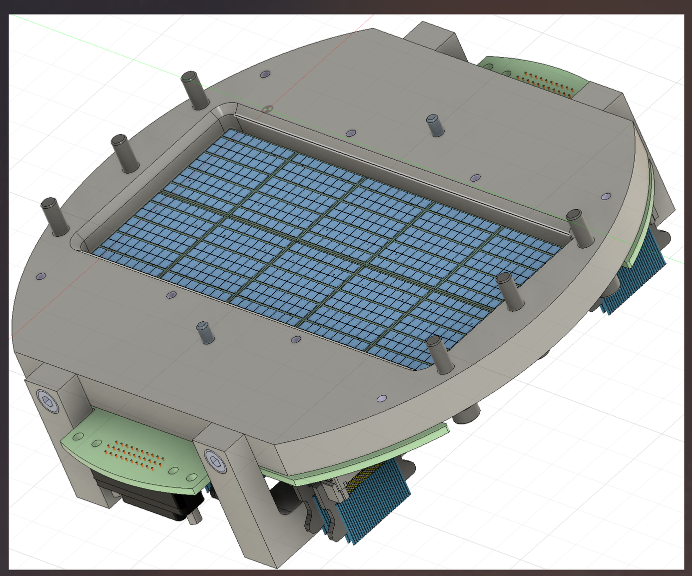
A: Primary mirror (394 mm radius, 0.1 m² area)
B: Secondary mirror (144 mm radius)
C: SiPM-based camera (2:5 aspect ratio, 640 pixels, 3 x 3 mm² pixel size, 10 x (24 x 24 mm²) effective area)



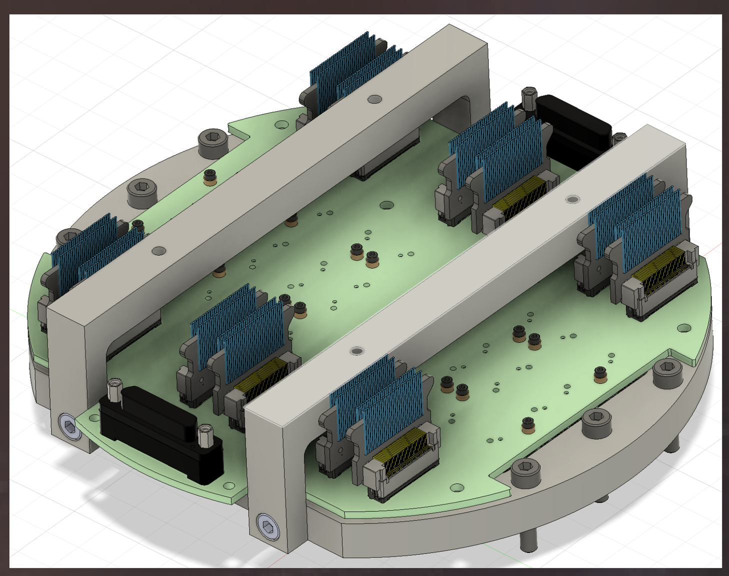




The Focal Plane Assembly (FPA)



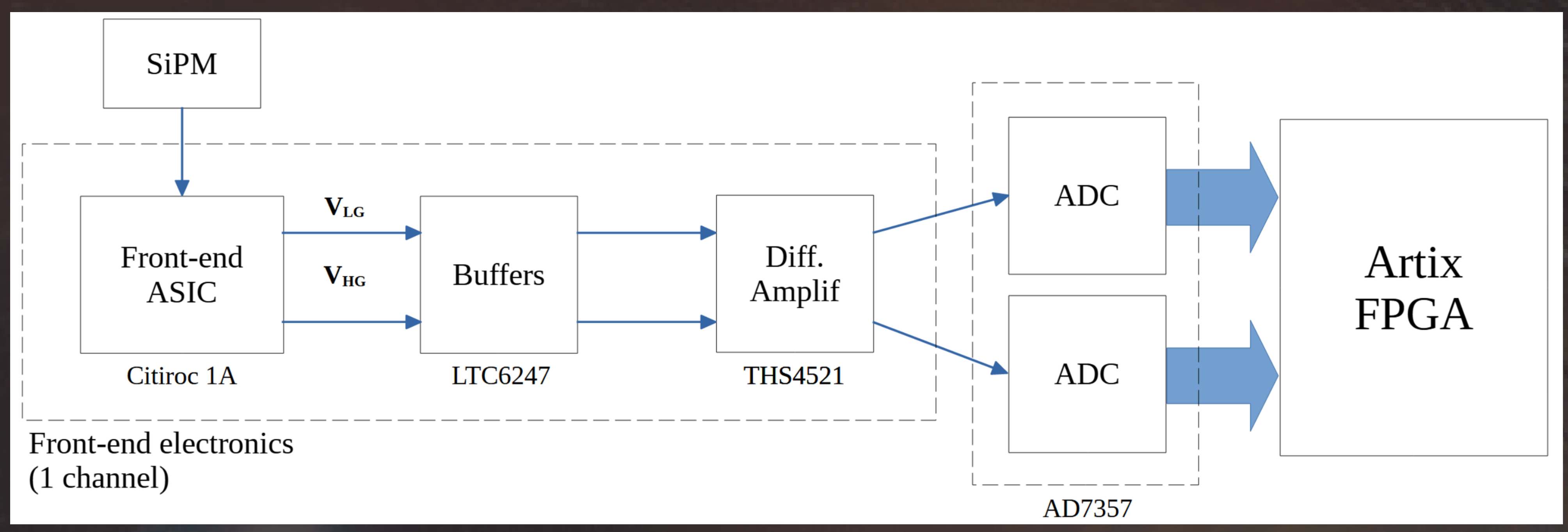
Top view of the SiPM-based camera (10 arrays of 8 x 8 SiPMs)



Bottom view of the interface board (connection SiPMs ↔ FE electronics)

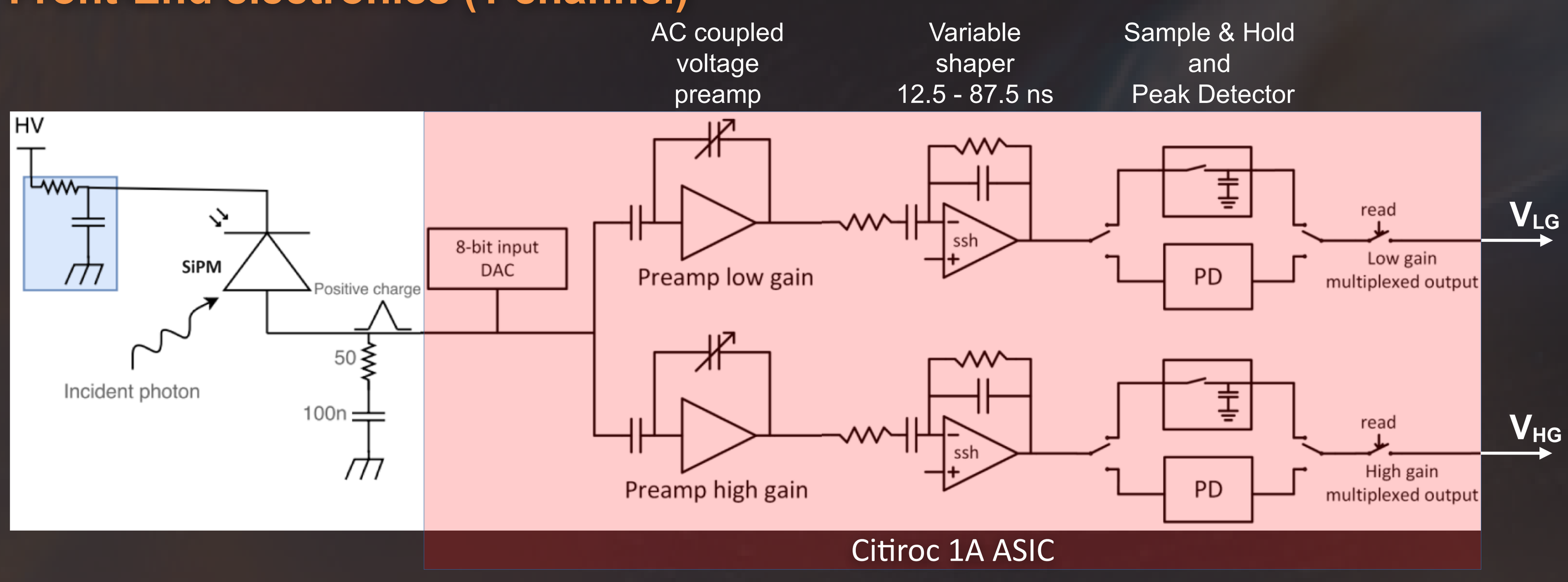
- NUV-HD SiPM technology by Fondazione Bruno Kessler (FBK)
- 35 µm cell size, DCR ≈ 100 kHz/mm², after-pulsing ≈ 5%, crosstalk ≈ 5% - 20%
- PDE (Photon Detection Efficiency) > 40% in the wavelength range 300 nm – 500 nm

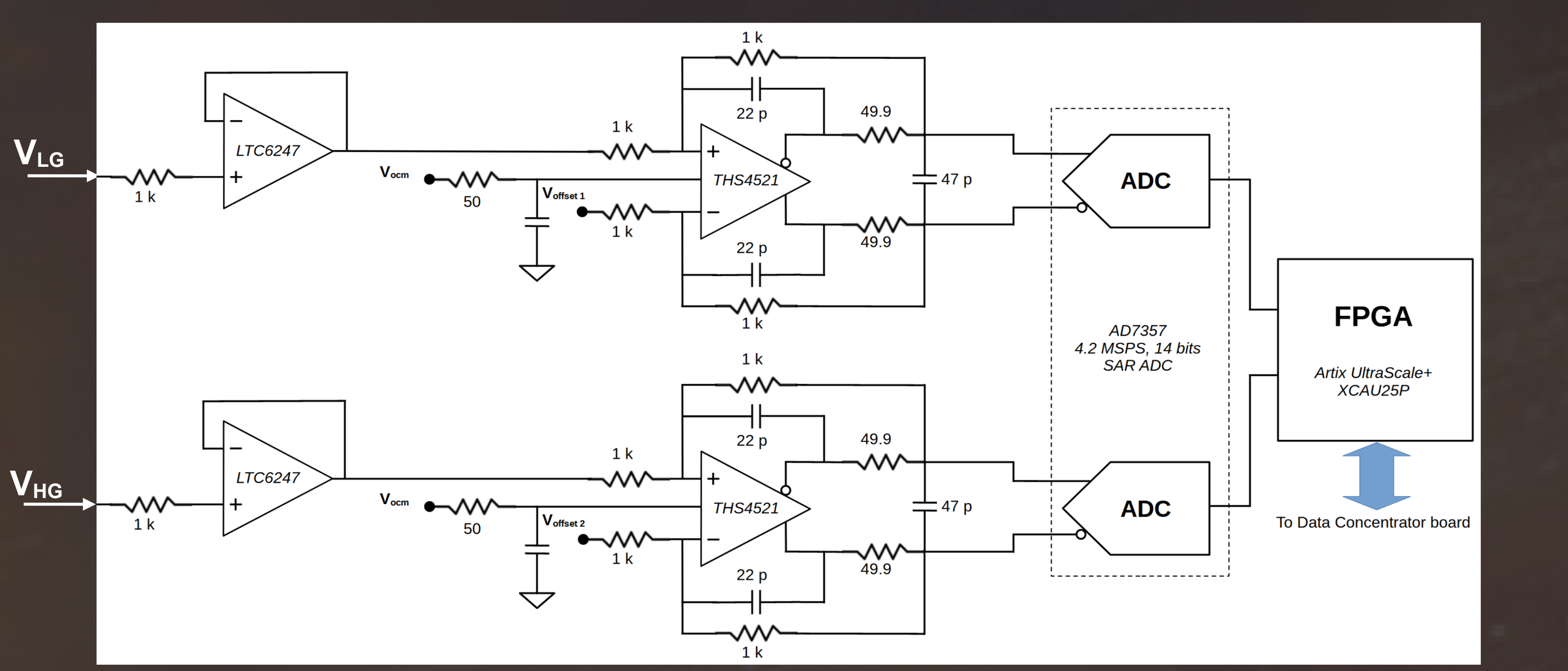
SiPM readout overview



- Custom electronics fully developed with commercially available off-the-shelf (COTS) devices.
- 32-channel front-end ASIC (Citiroc 1A) designed to readout SiPM for scientific applications.
- Differential input, dual-channel 14-bit SAR ADC with 4.2 MSPS througput rate at 36 mW power dissipation.

Front-End electronics (1 channel)

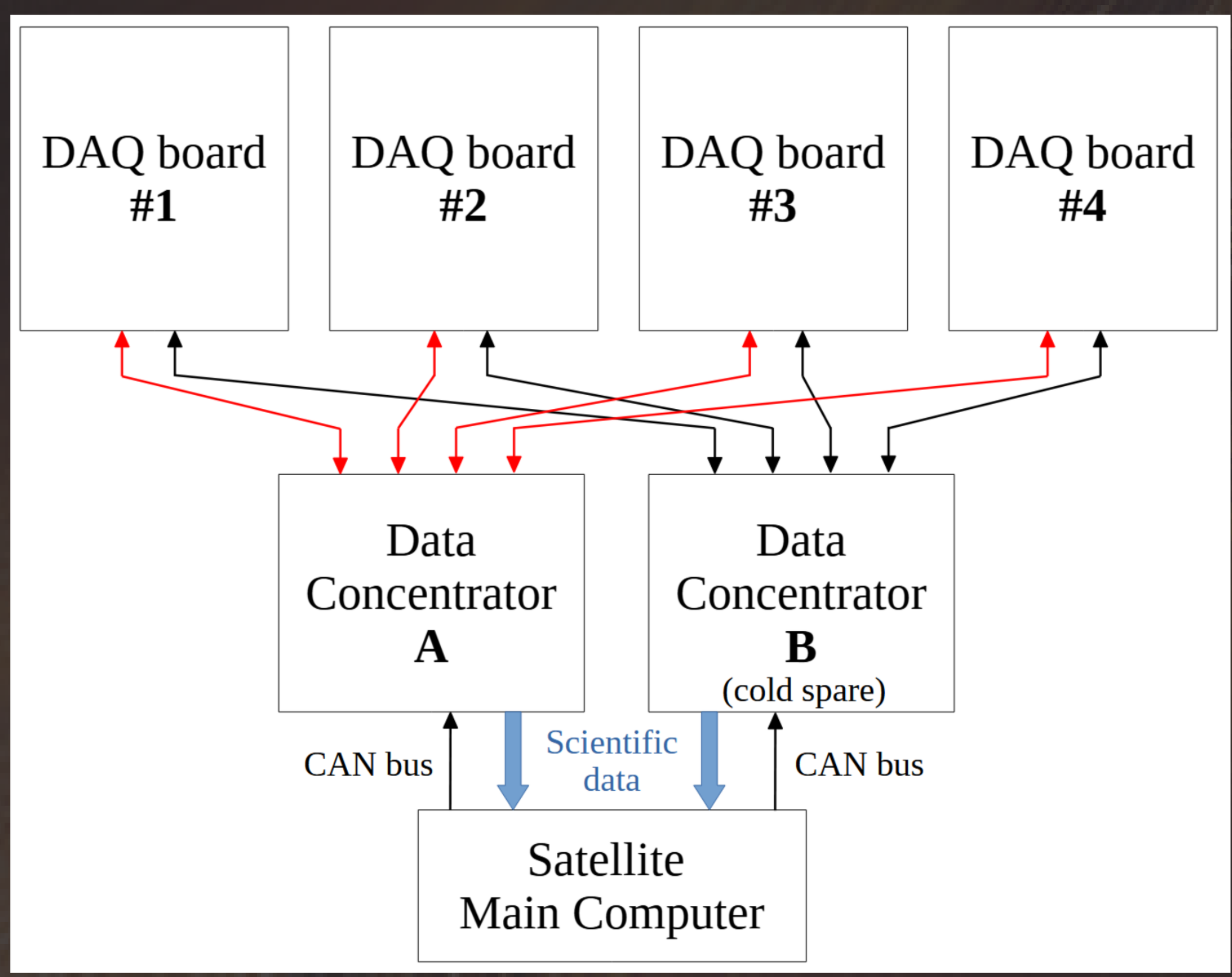




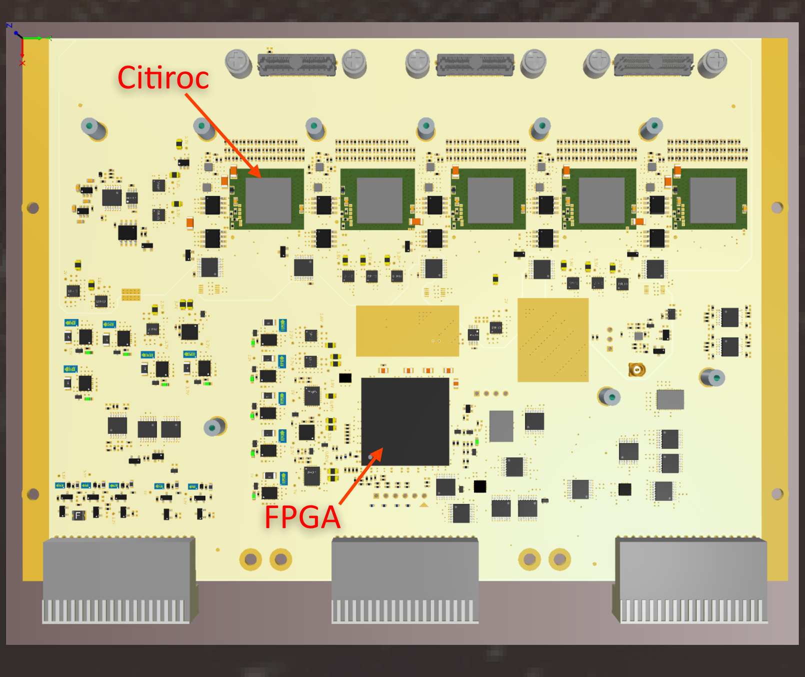
- Provide triggering down to 1/3 photoelectron and charge measurement with good noise rejection.
- Adjustment of each SiPM high-voltage is possible using a channel-by-channel Citiroc DAC.
- Two measurements paths with different gains (1 to 10 ratio) work in parallel to maximize the dynamic range – from **160 fC to 400 fC**.
- A variable shaper circuit, with adjustable *time constant*, filter the input signal bandwidth and optimize the signal-to-noise ratio (SNR).
- The signal can be sampled using either a *Sample & Hold*, controlled by an external signal, or a *Peak Detector* disabled by an external signal.
- The Citiroc output signals (Low and High gain) follow to a voltage follower for buffering, a single-to-differential conversion stage and finally the analog-to-digital conversion (ADC).

Data Acquisition System

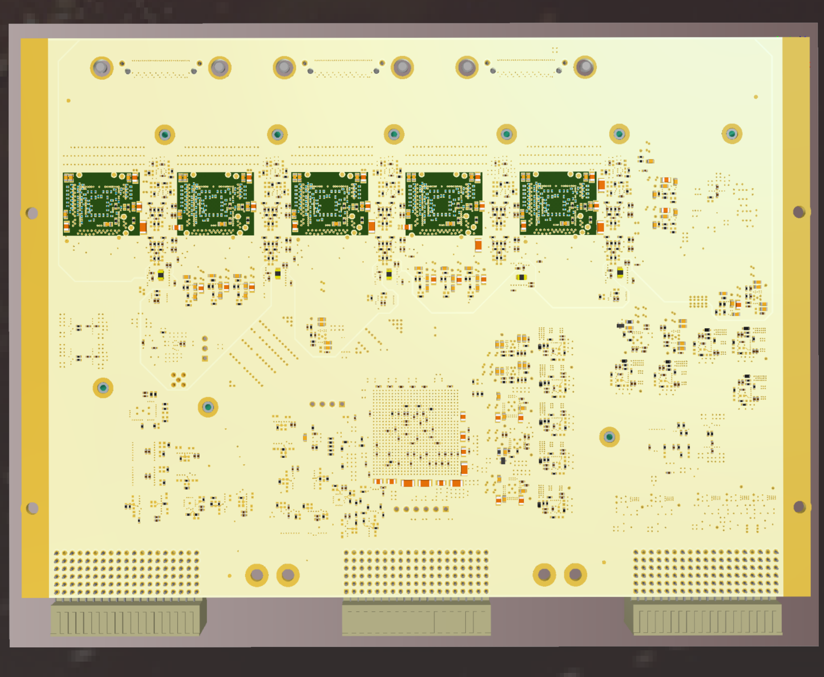
- The complete DAQ system is composed by:
  - DAQ boards (FE + ADC + FPGA), above diagram
  - Data Concentrator boards
  - Satellite Main Computer
- The Data Concentrator is designed with a SoC FPGA (Quad-Core ARM + logic).
- Two Data Concentrator boards used for redundancy (only one powered at a time).
- All interfaces between Data Concentrators and DAQ boards are redundant.
- The firmware of the entire Terzina payload is held by the two Data Concentrators.



The Terzina DAQ board (under development)



Top view (5 Citiroc's, 1 Artix FPGA)



Bottom view

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