CTA小口径望遠鏡用
焦点面検出器の試作器開発

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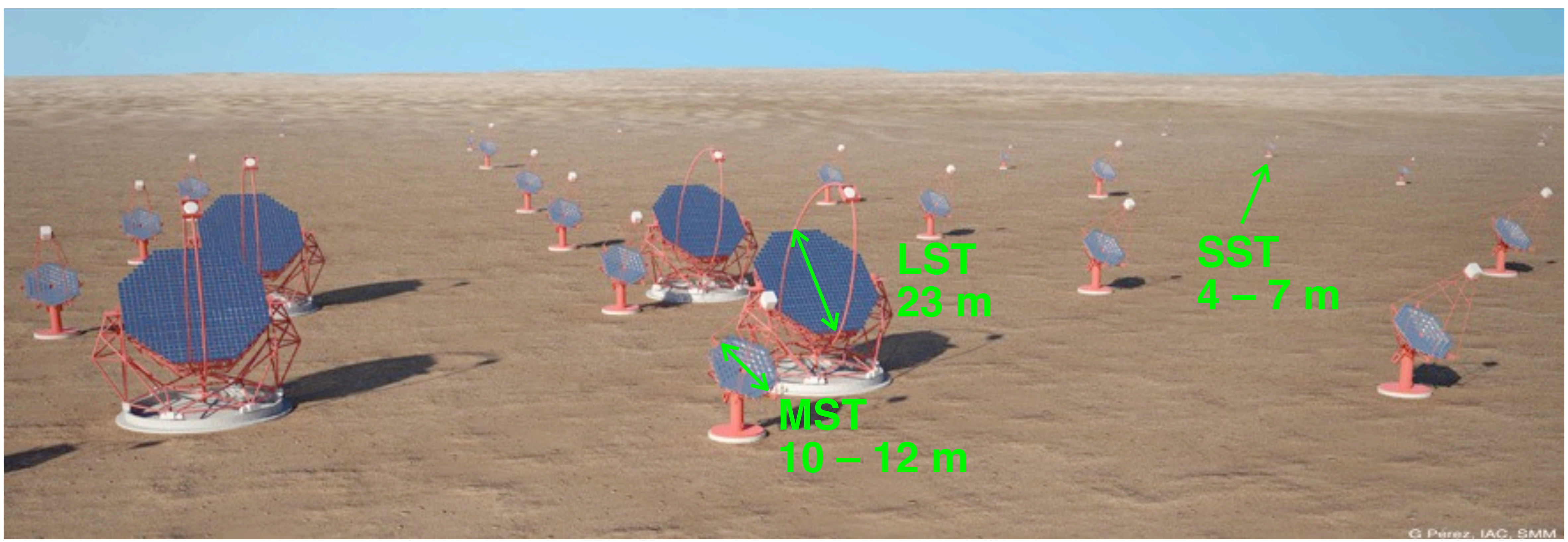
JPS meeting
Waseda University

Cherenkov Telescope Array

- **Observations of gamma rays in 20 GeV – 100 TeV band**
  - **Cherenkov light from electromagnetic shower produced by interaction of gamma rays with atmosphere**
- **Large collection area by placing many telescopes**
  - **x10 better sensitivity**
- **Wide energy band coverage by three different sizes of telescopes**
  - **Large-sized telescope (LST): Φ = 23 m, 20 GeV – 1 TeV, 4 telescopes**
  - **Medium-sized telescope (MST): Φ = 10 – 12 m, 0.1 – 10 TeV, ~20 telescopes**
  - **Small-sized telescope (SST): Φ = 4 – 7 m, 1 – 100 TeV, 30 – 70 telescopes**



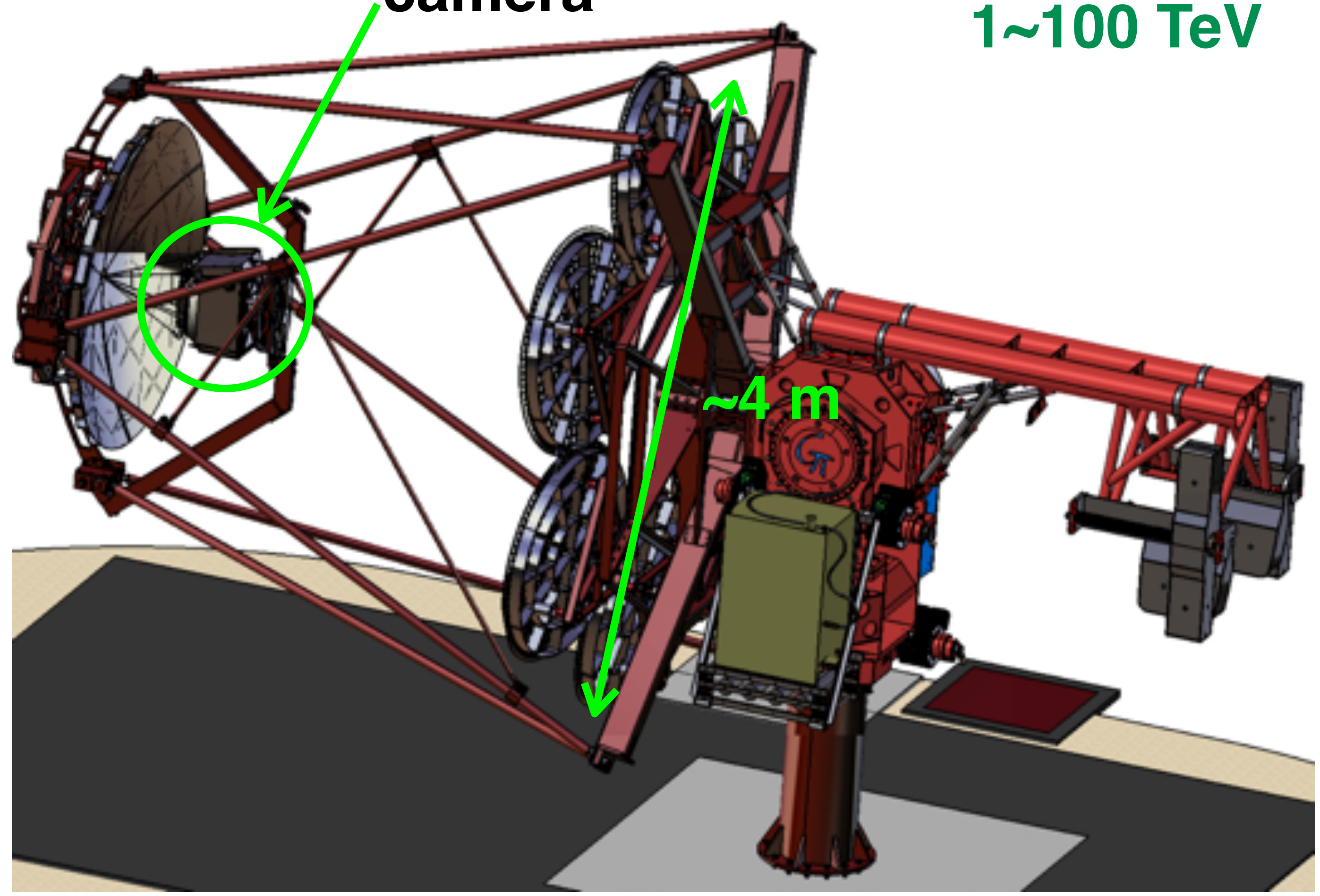
SST-2M Design Concept

❖ Dual mirror design with small pixel photon sensor

- ✤ Small pixel (~6 mm) photon sensor to reduce camera cost
  - ◉ Multi-anode photomultiplier or SiPM
  - ◉ High density readout electronics (ASIC)
- ✤ Schwarzschild-Couder (SC) optics
  - ◉ Short focal length to realize small plate scale
    - Technically challenging
  - ◉ Large field of view
    - Longer telescope spacing (larger collection area)

❖ Gamma-ray Cherenkov Telescope (GCT)

- ✤ Collaboration of Australia, France, Germany, Japan, Netherland, UK

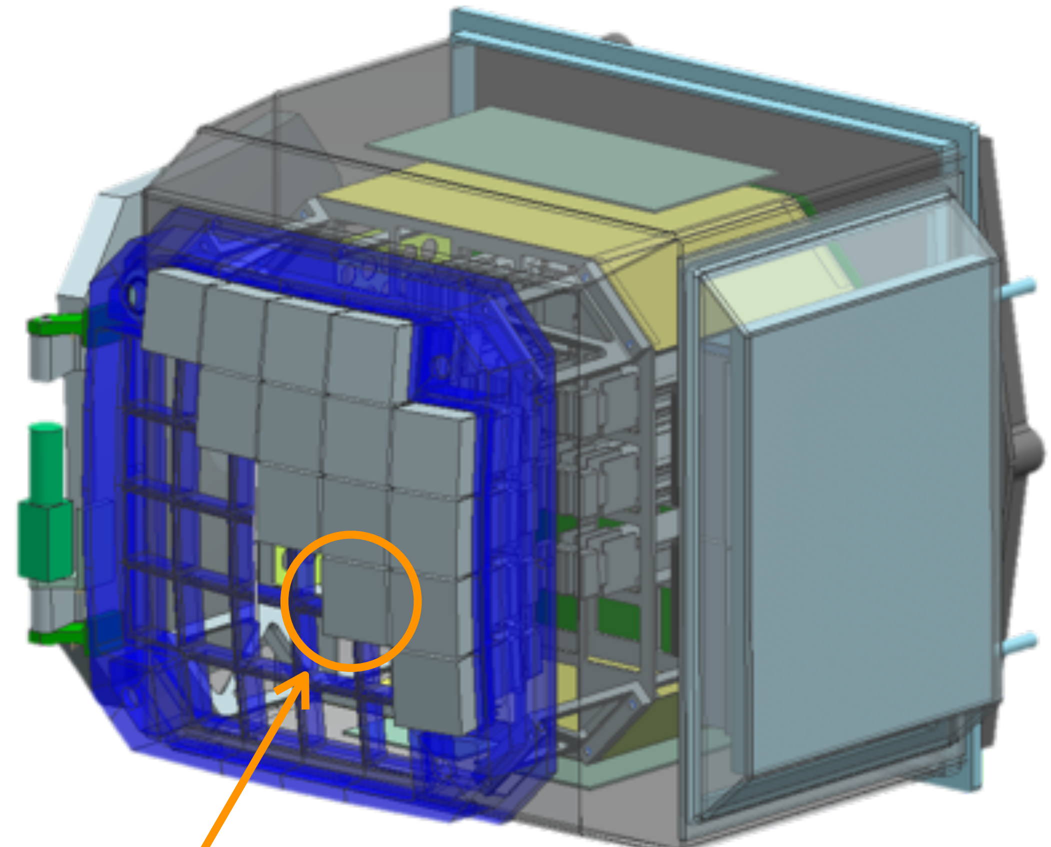


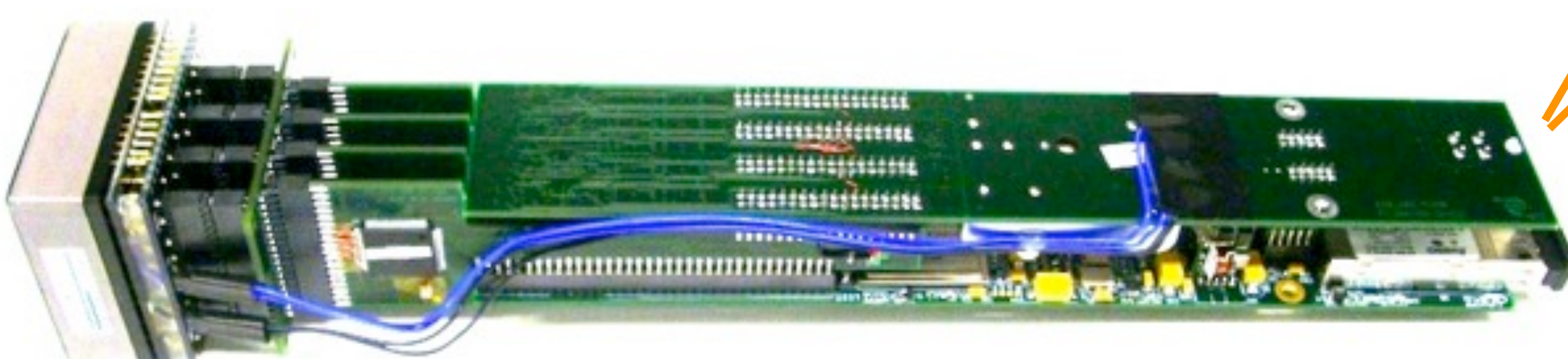
SST-2M Camera Design

❖ SST-2M camera parameters

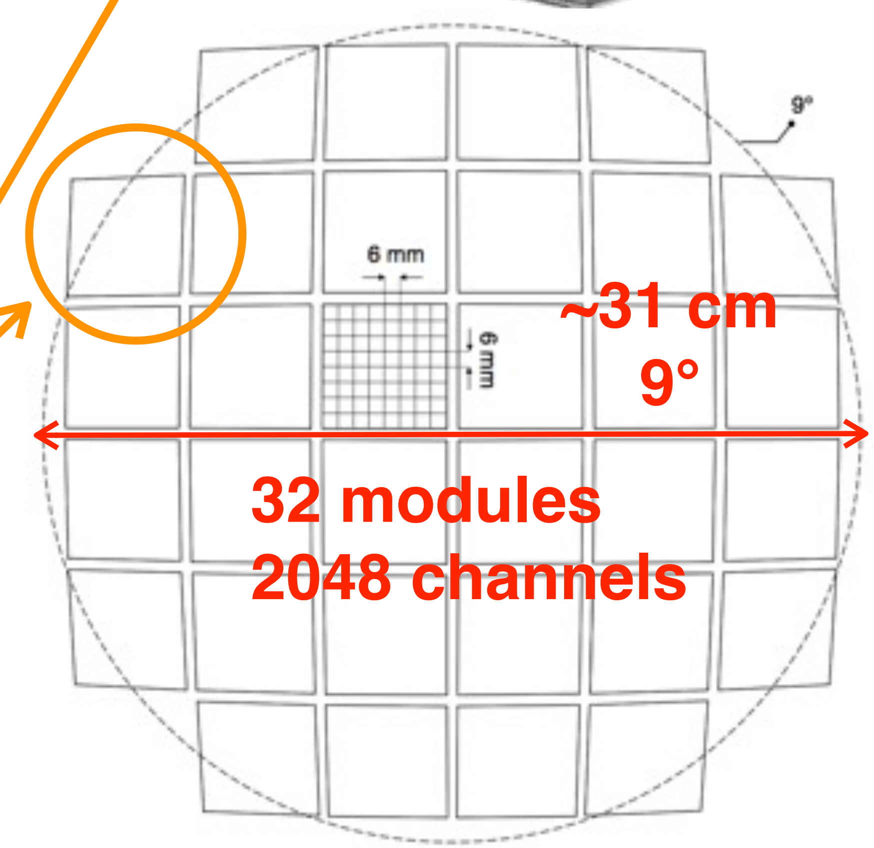
	32 mod
FOV for 0.18°/pixel (36 mm/°)	8.6°
FOV for 0.28°/pixel (23 mm/°)	13.4°
Angular pixel size for FOV=10°	0.21°
# of pixels per camera	2,048
Power consumption per camera (FE)	350 W
Weight per camera (FE+SiPM)	11 kg
Total cost (FE+SiPM) for 50 CAMs*	$7.2M

*Assuming $20/ch, which does not explicitly include labor for mechanical module assembly and calibrations



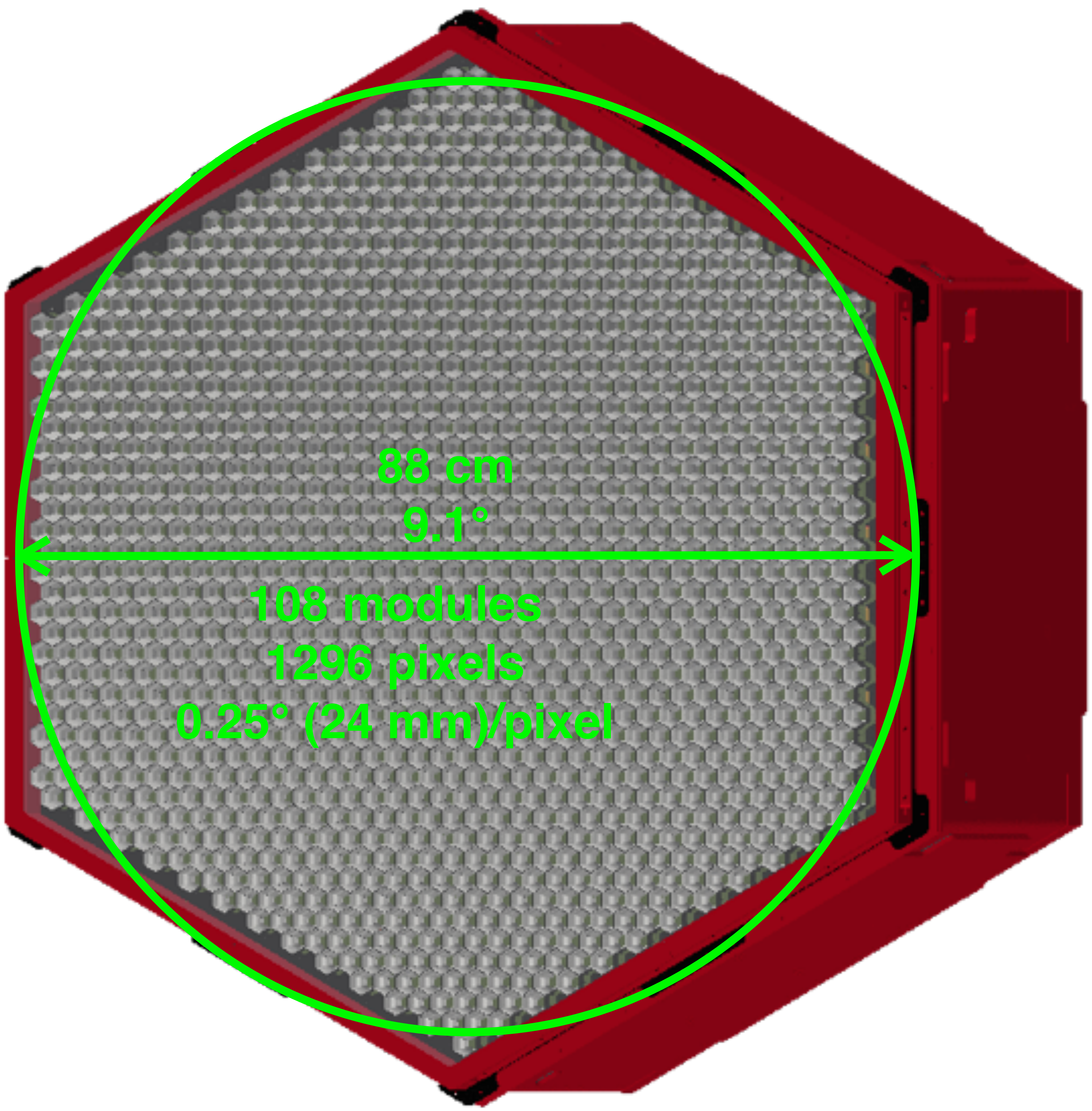


Front-End (FE) electronics module



Comparison with Single-Mirror Camera

SST-1M camera

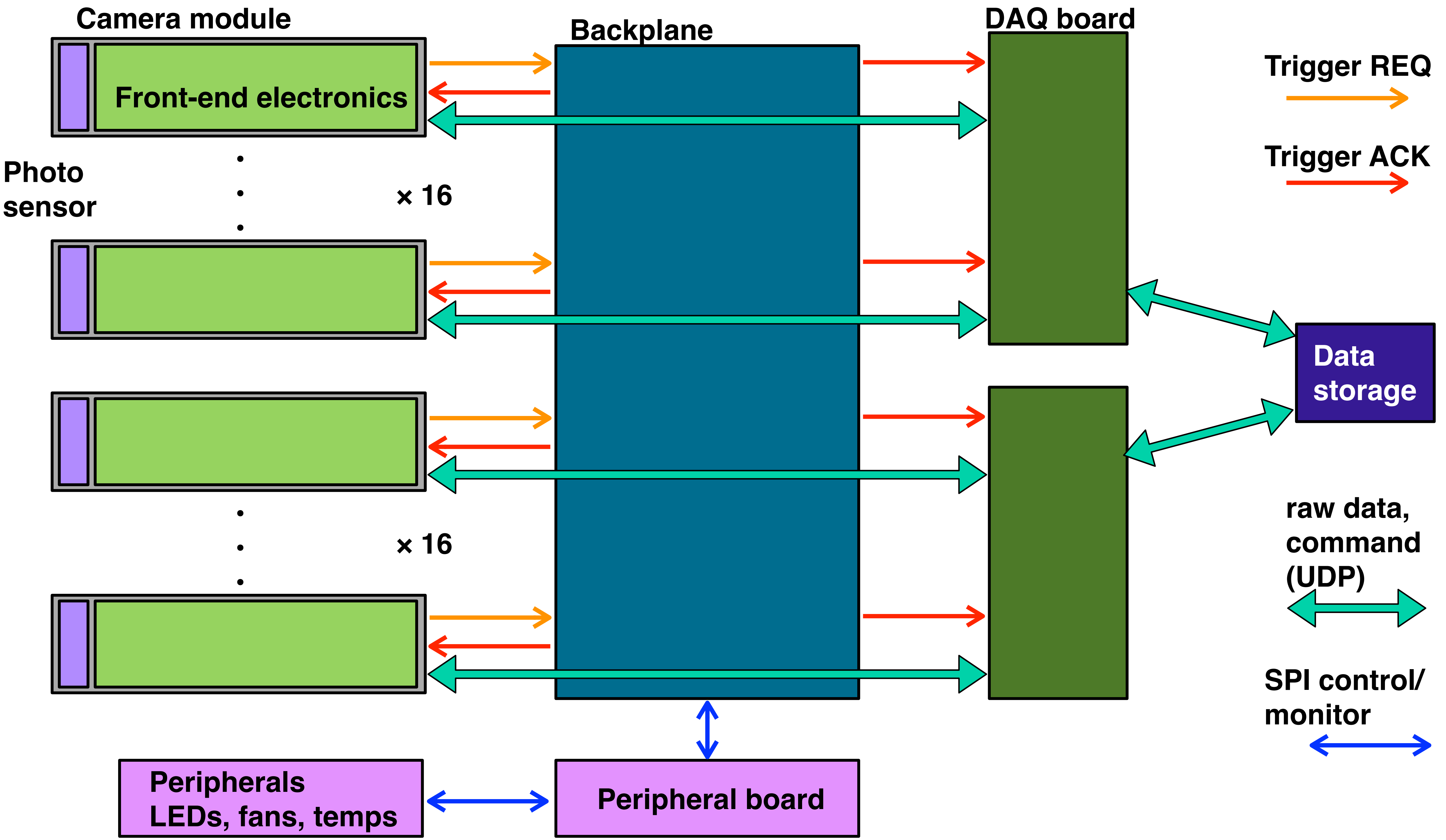


SST-2M camera

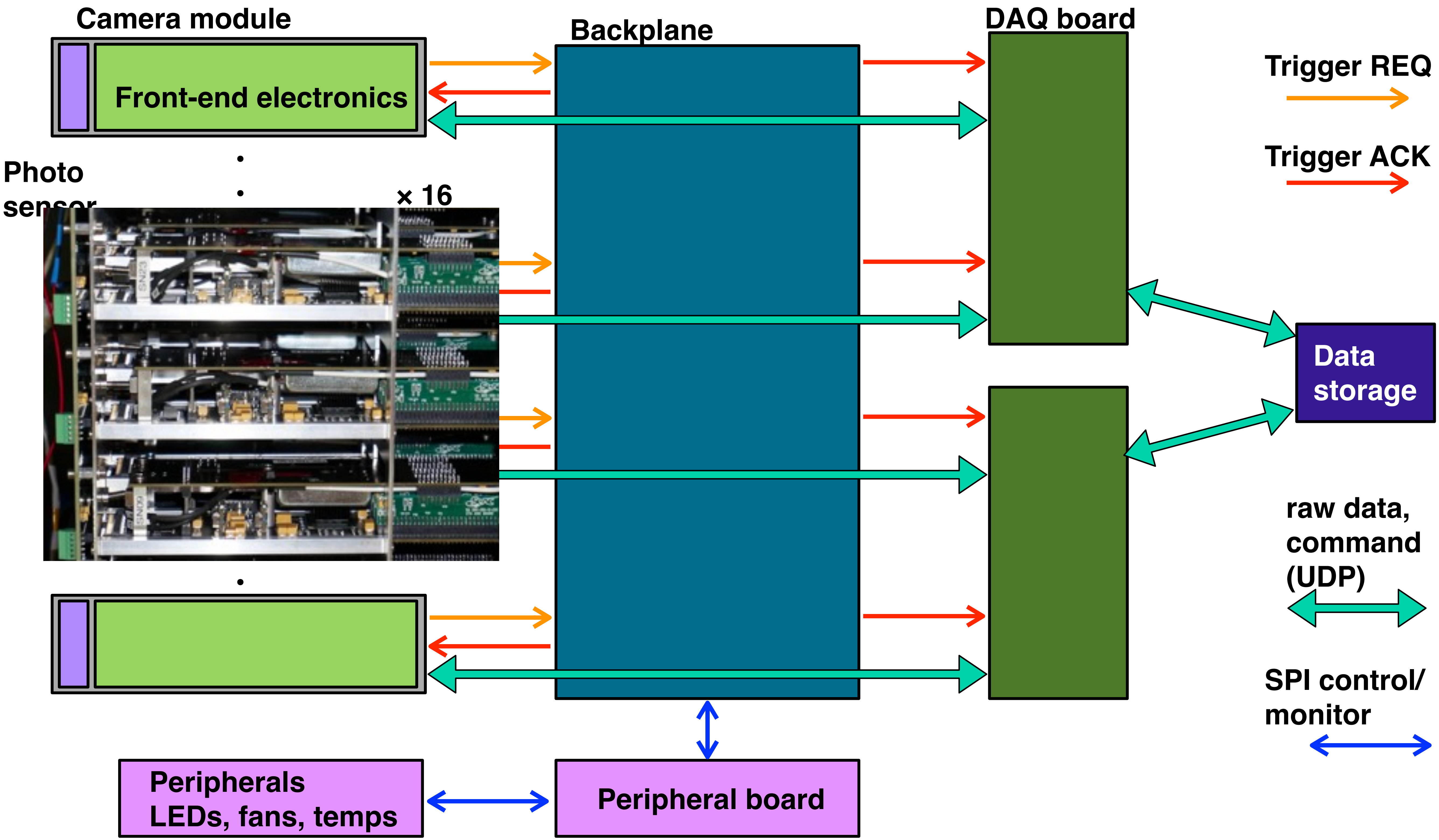
~31 cm
9°

32 modules
2048 channels
0.18° (6.2 mm)/pixel

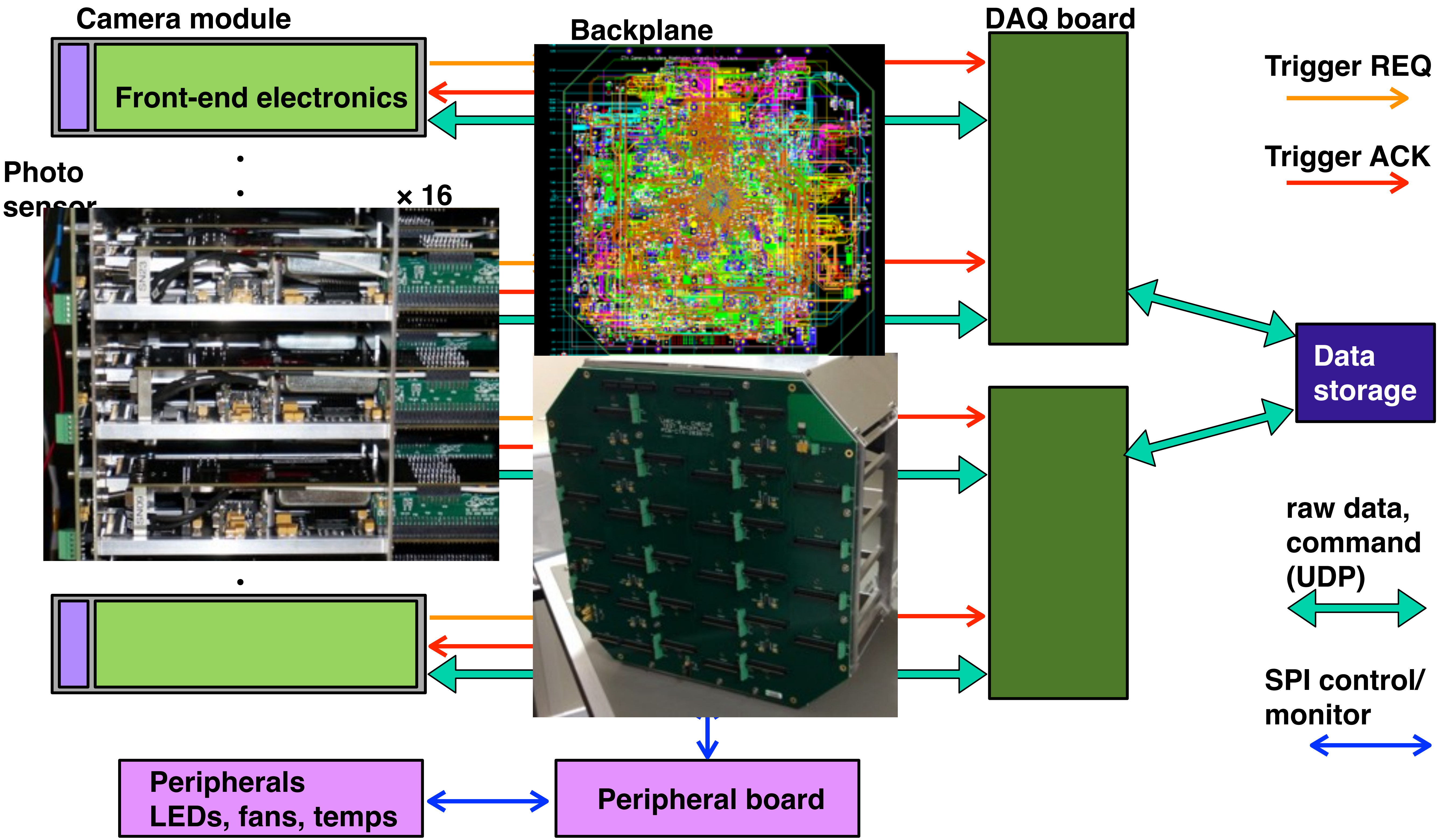
GCT Camera Electronics



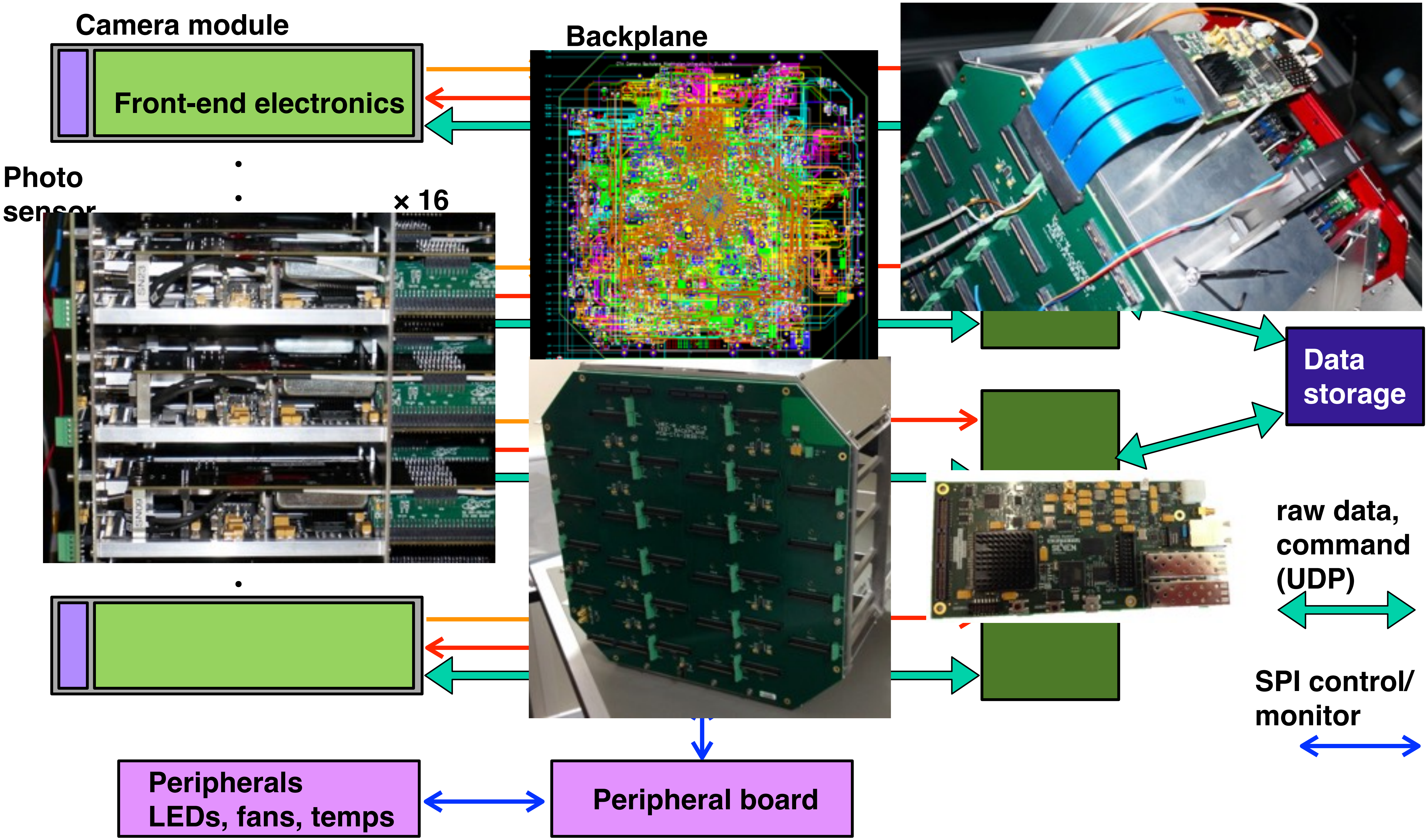
GCT Camera Electronics



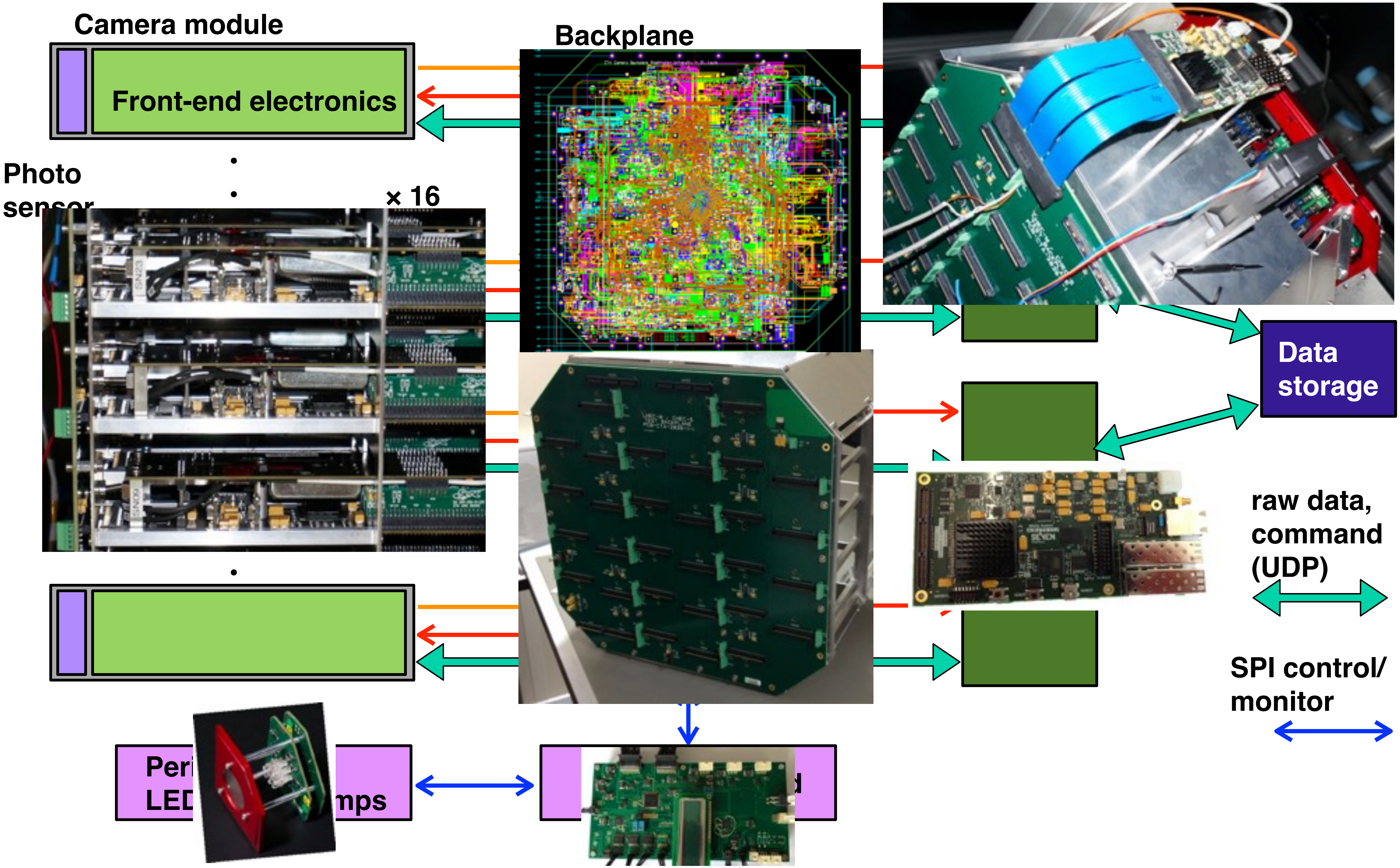
GCT Camera Electronics



GCT Camera Electronics

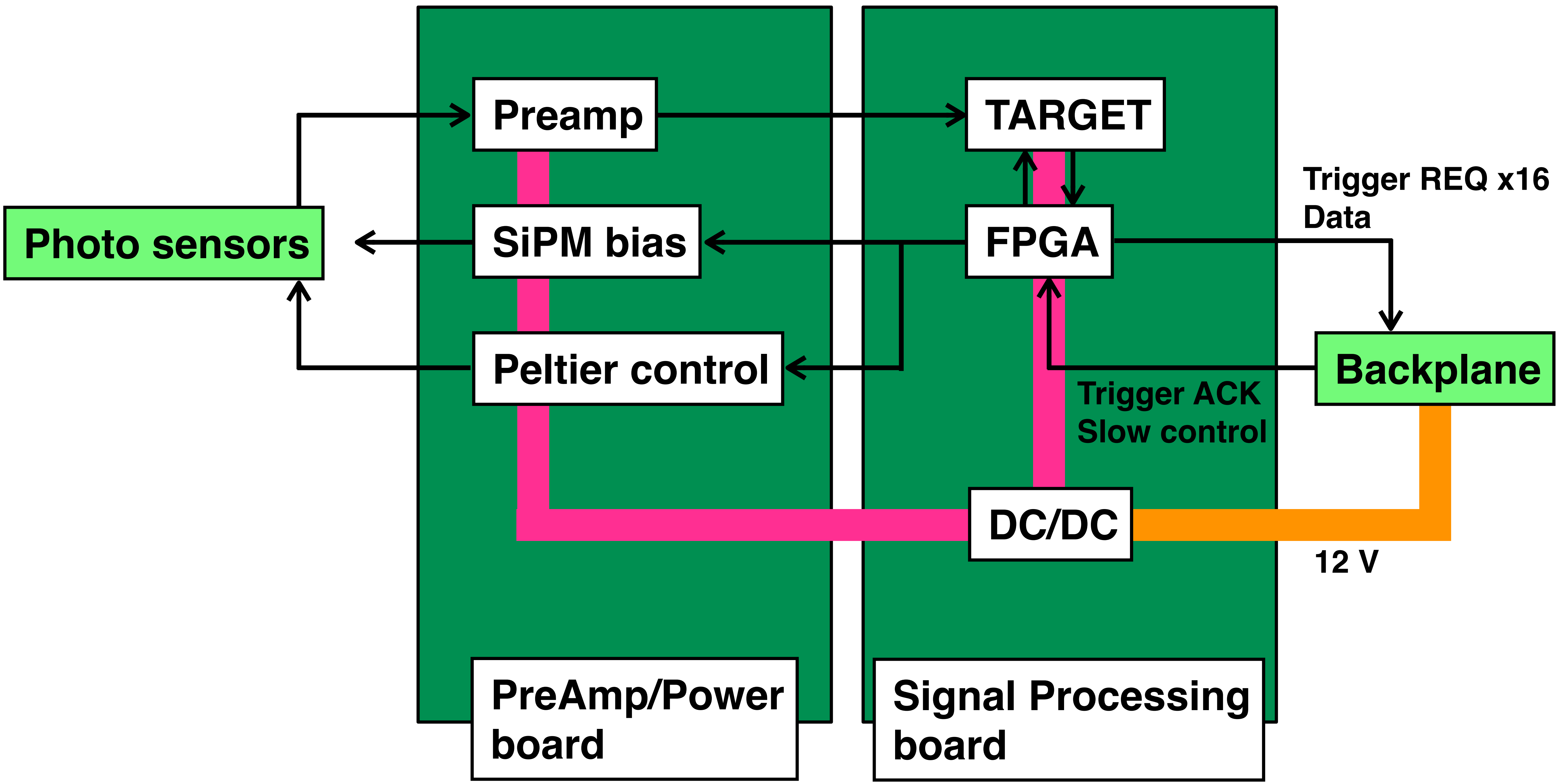


GCT Camera Electronics

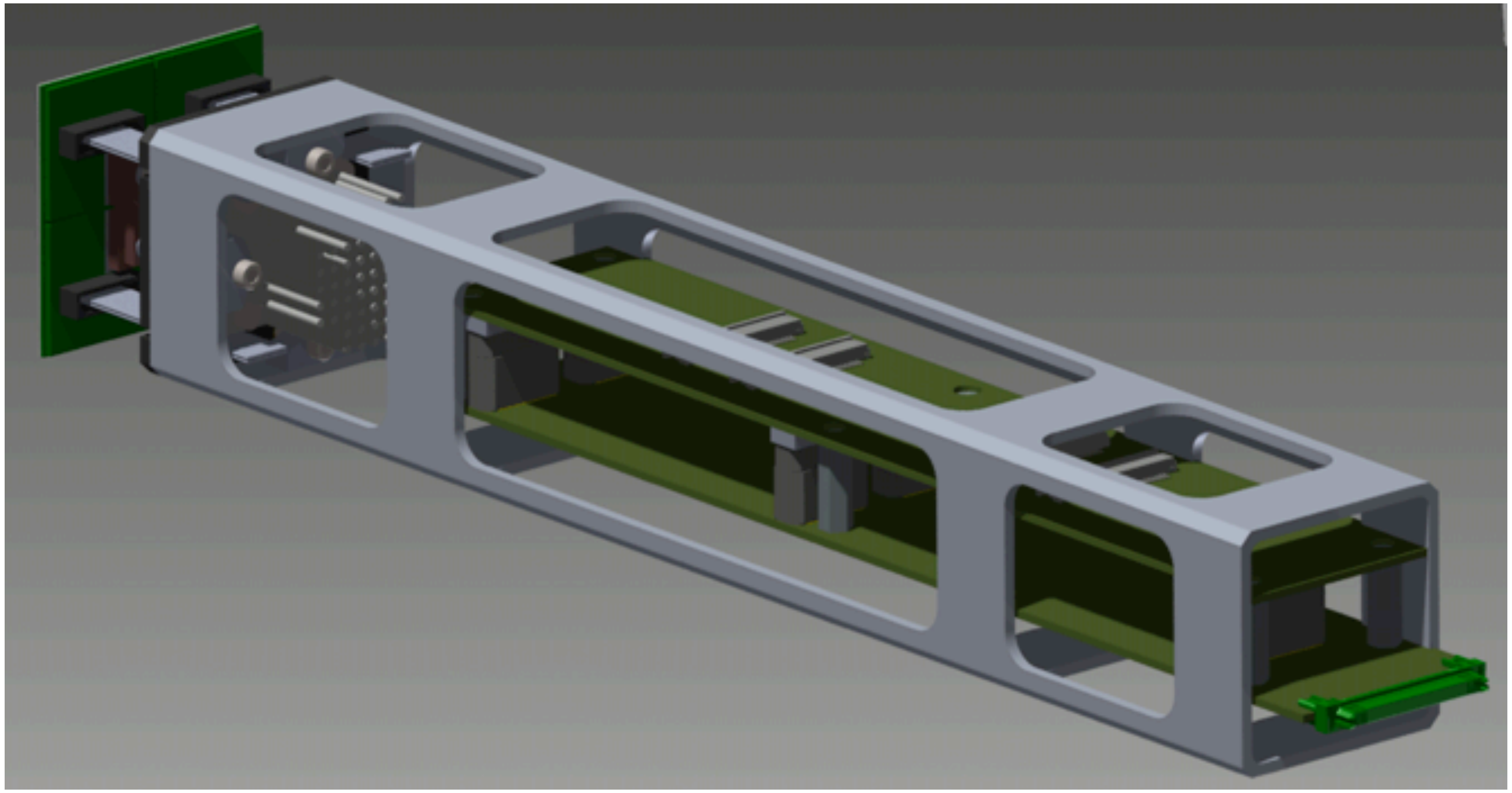


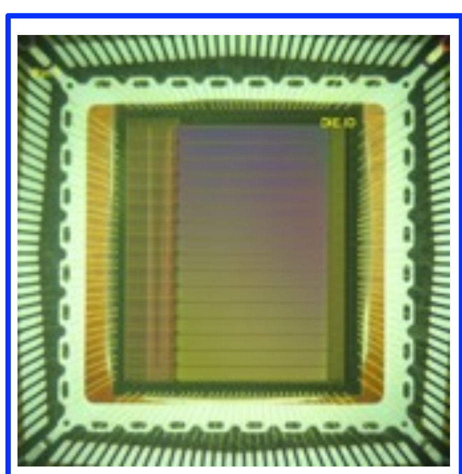
GCT Camera FEE Function Diagram

GCT Camera Front-End Electronics (FEE)

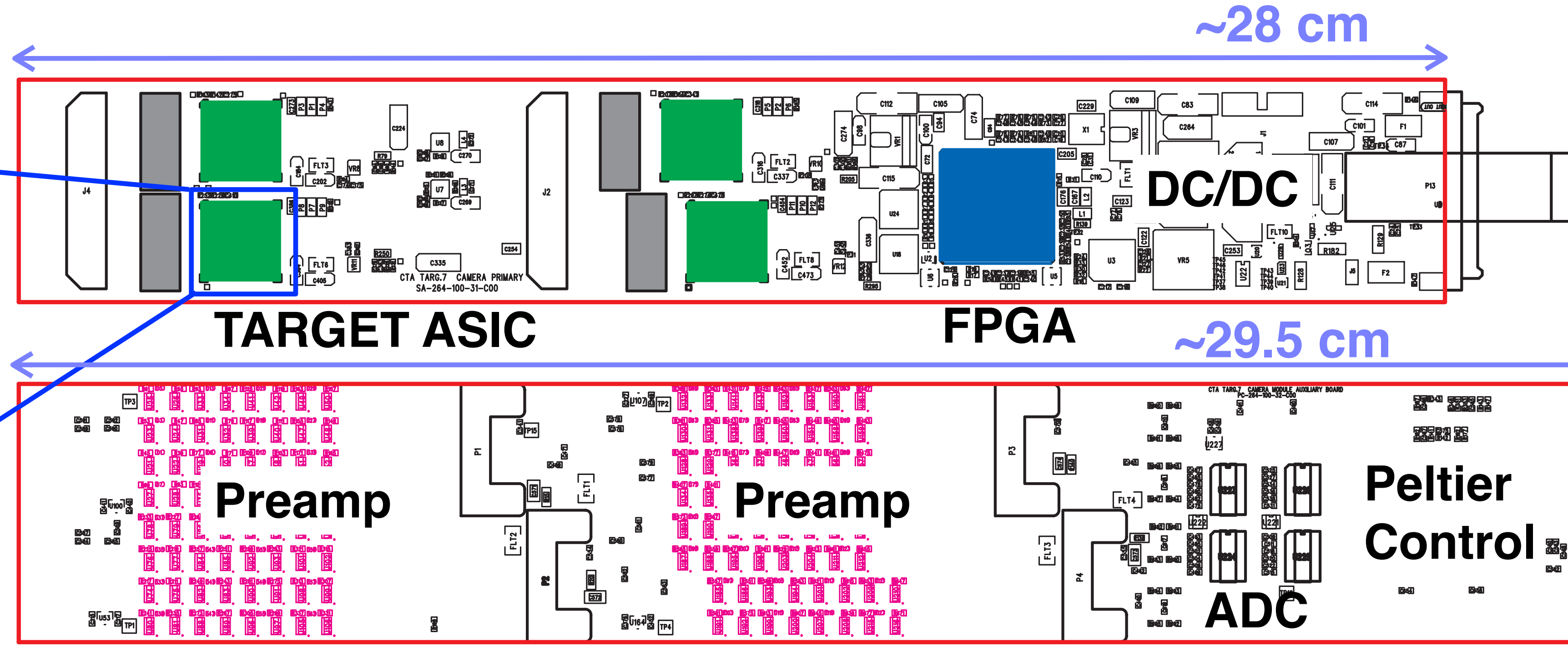


GCT Camera FEE Design

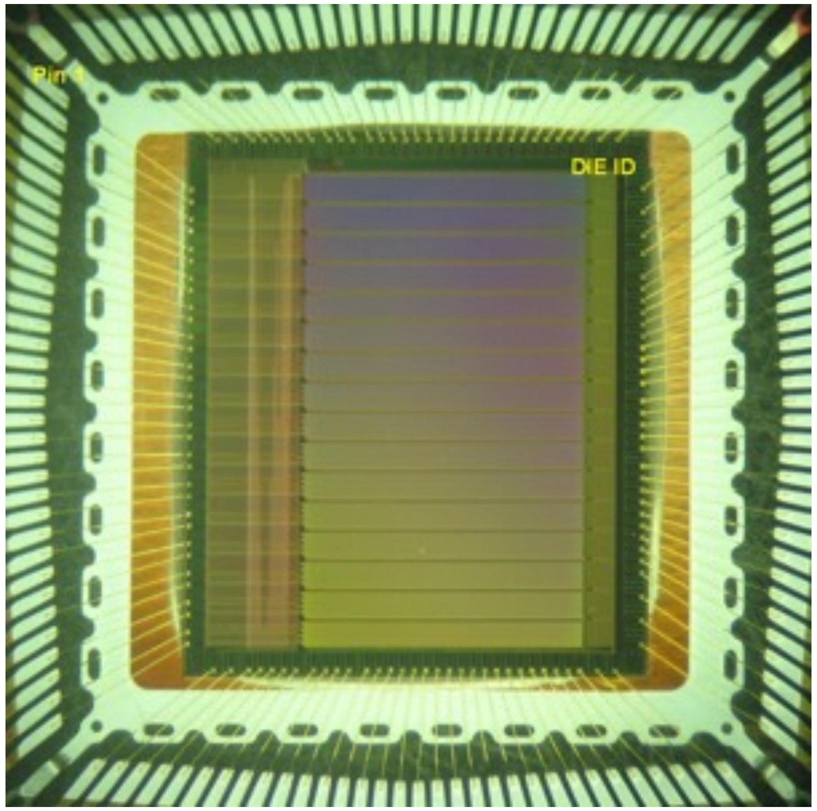




designed by G. Varner (Hawaii)



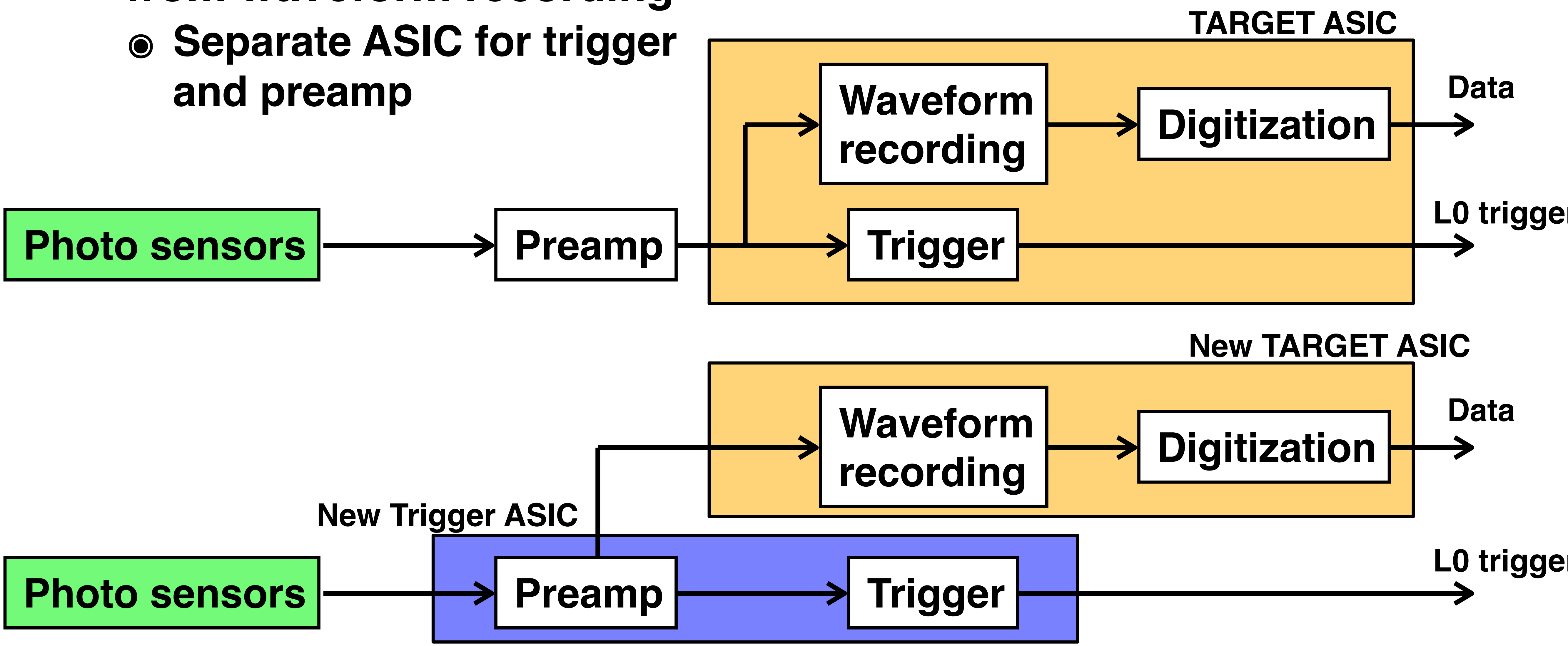
GCT Camera FEE Specifications



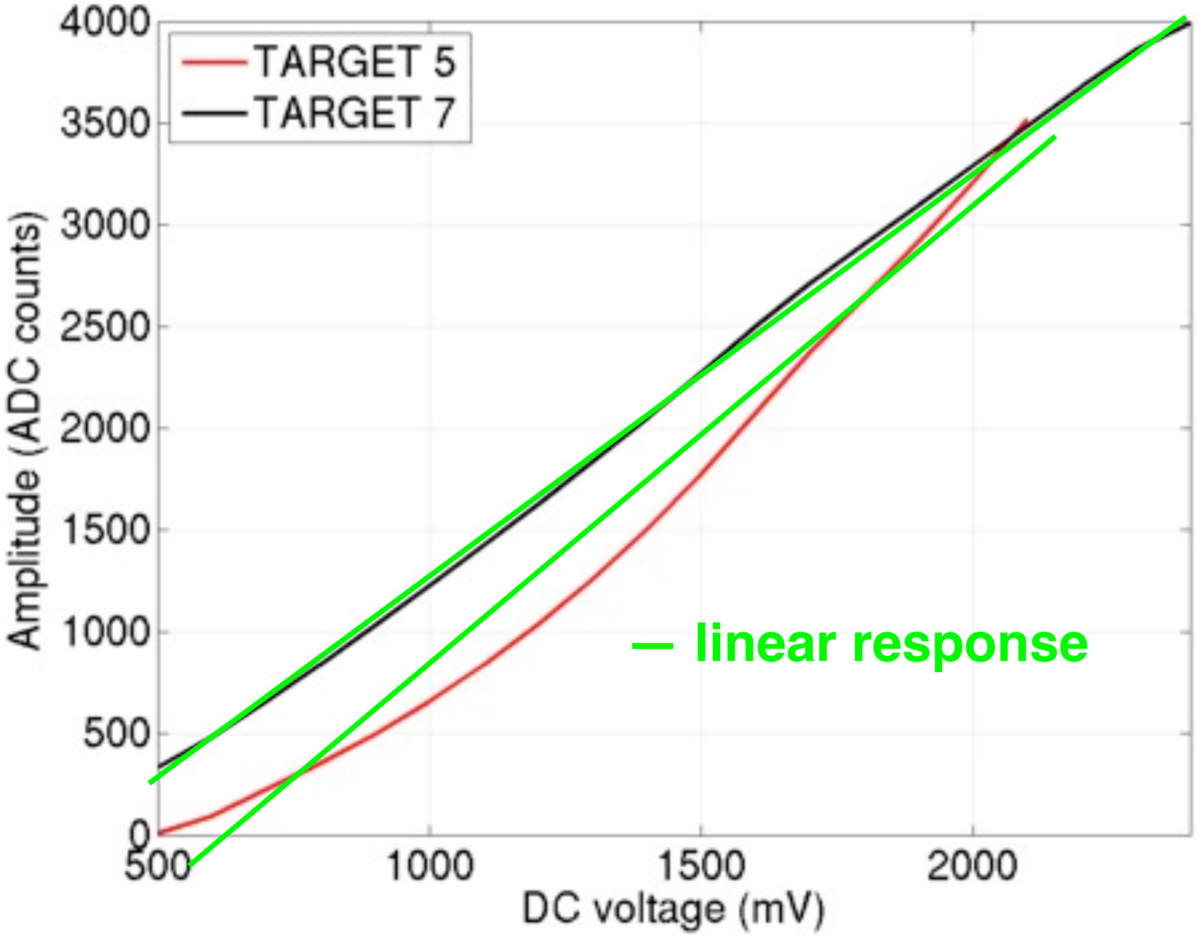
- **Requirements**
  - Waveform sampling at ~ 1 GSa/s
  - Signal bandwidth > 380 MHz
  - Cross-talk < 1%
  - Look-back time: > 12 μs
    - For coincidence between telescopes
  - Dynamic range: > 9 bits
  - Readout (dead) time: < 30 μs
  - Trigger timing: < 4 ns
  - Trigger segment: 0.1° x 0.1° ~ 0.2° x 0.2°
- **TARGET ASIC**
  - Switched capacitor array for high speed waveform sampling
  - Integrated digitization circuits and trigger circuits
    - Reduction of components and cost, increase reliability
  - Internal bias generator
    - All digital interface
  - Low power consumption: ~70 mW/channel including FPGA

TARGET ASIC Development

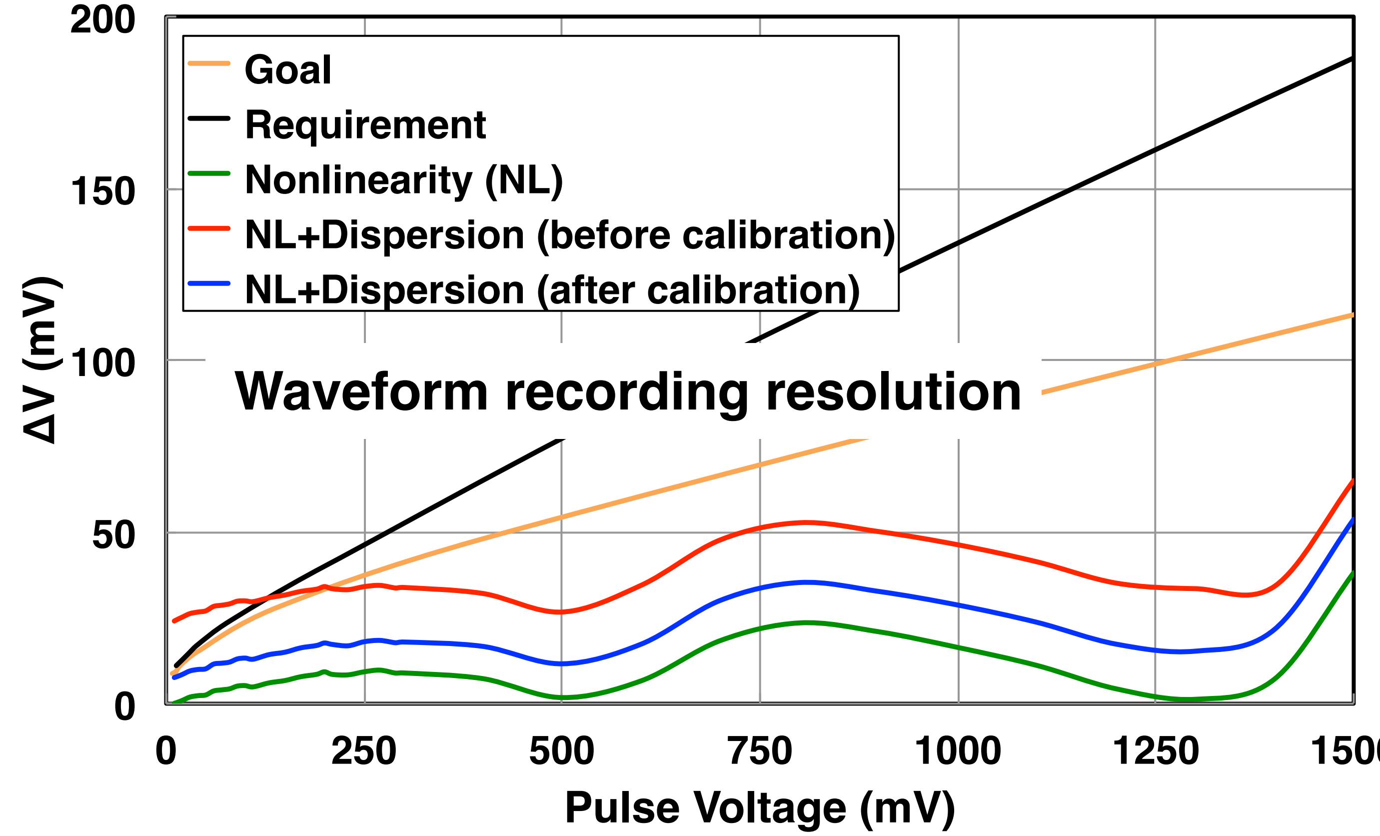
- **TARGET ASIC is required to minimize cost and PCB space**
  - **while realizing GHz sampling and digitization, and trigger**
- **Current status of development**
  - **Waveform recording and digitization satisfy requirements**
  - **Trigger performance needs improvements due to interference from waveform recording**
    - **Separate ASIC for trigger and preamp**

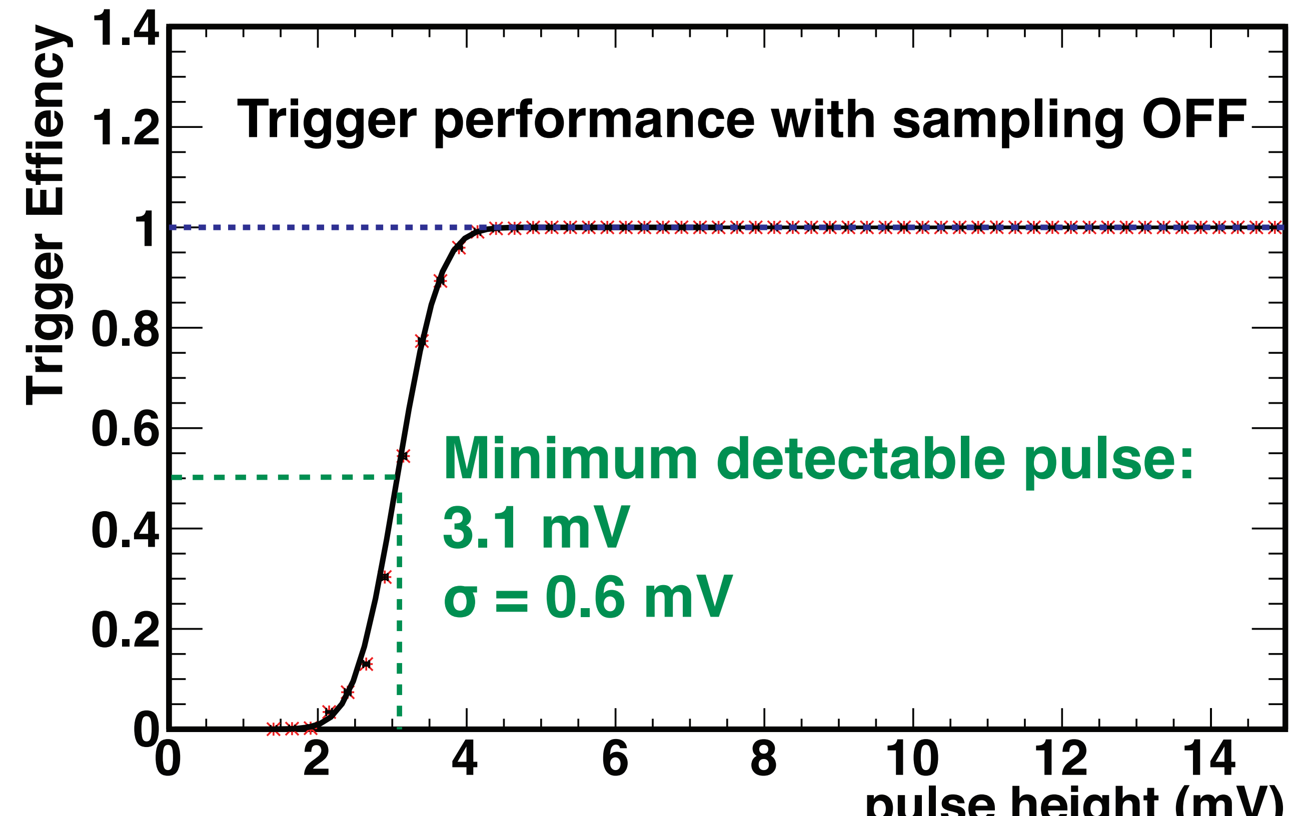


TARGET Performance



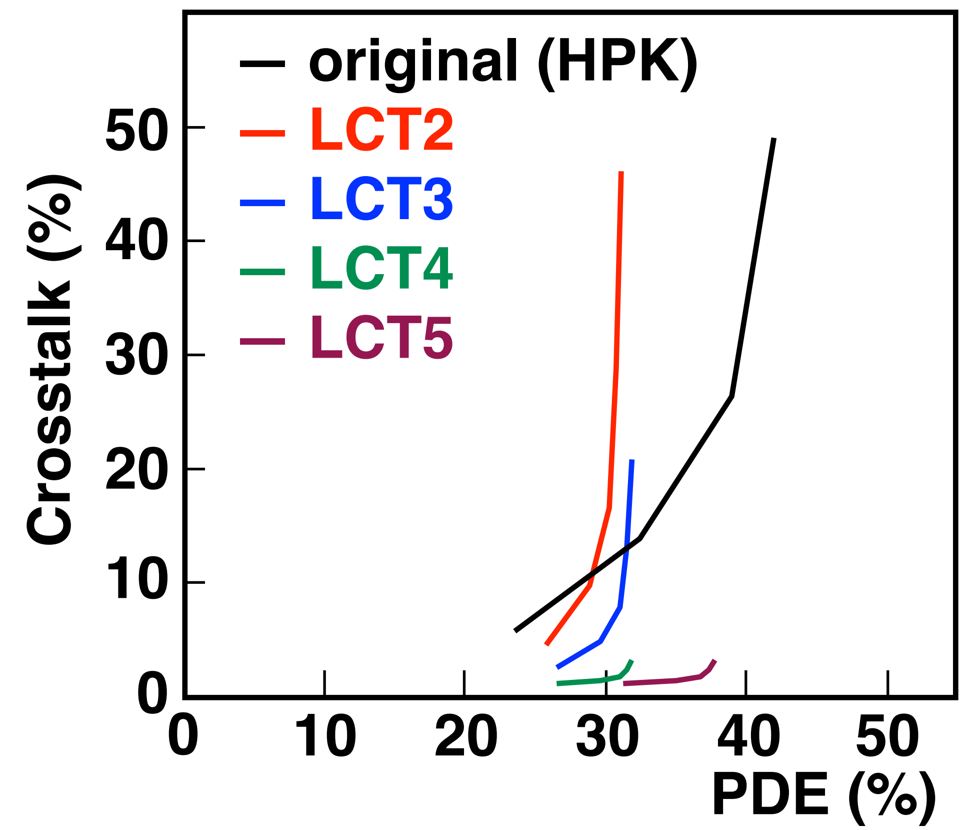
Waveform recording linearity

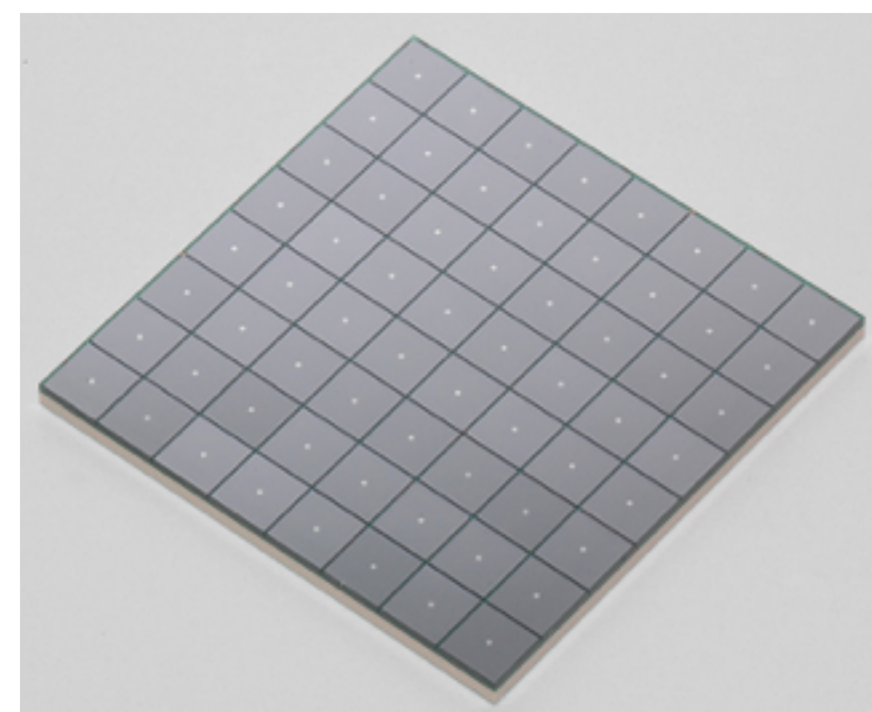




Development of Photo sensor

- **Silicon photomultiplier**
  - High photon detection efficiency (PDE)
  - Low bias voltage (50–70 V)
  - Robust compared with phototubes
  - Crosstalk needs improvement
    - Trade off with PDE
    - Factor of >10 improvement with 10-15% loss of PDE
  - Packaging density is getting better with Through Via Silicon technology
    - 4-side buttable
    - 200 μm gap between pixels
  - It is a default choice for all dual-mirror telescopes in CTA
- **R&D is almost over**
  - 6 mm sensor is being evaluated
  - Prototype with correct pixel size (6.3–6.7 mm) will be fabricated and tested





DAQ and Slow Control Software

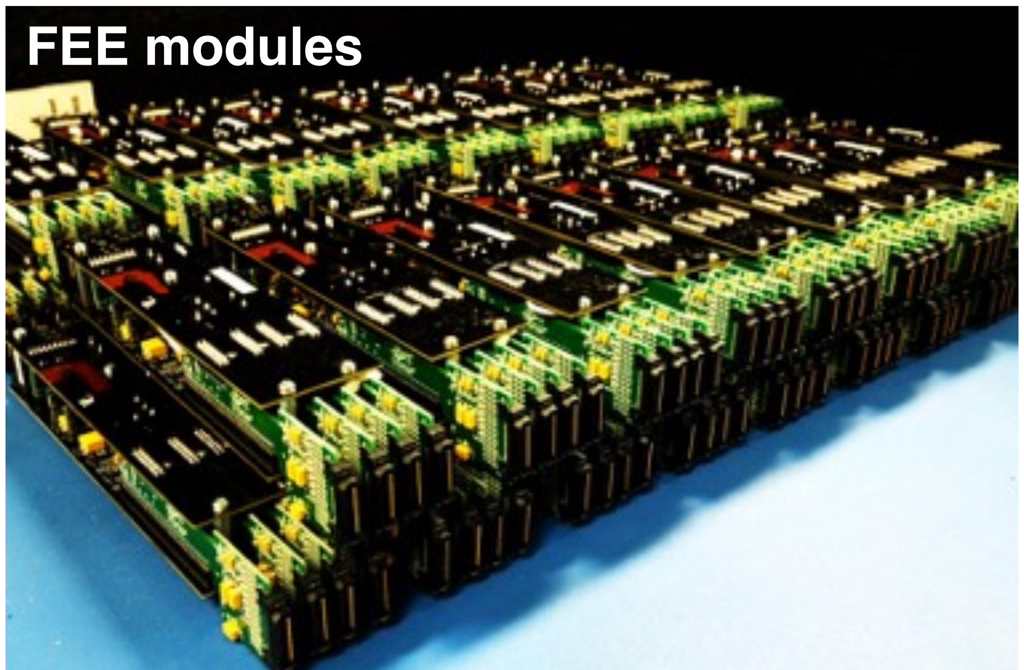
- **libTARGET (2013 –)**
  - C++ and Python libraries for lab tests of TARGET ASICs
  - Was not designed for multiple modules or high trigger rates
- **libCHEC (2014 –)**
  - Based on libTARGET, but fast DAQ, slow control, and event display functionality was written from scratch
  - C++ and Python libraries
  - Makes use of C++11, CMake, Boost, CFITSIO, ROOT6, SWIG, Google Protocol Buffer, and ZMQ
  - 32 UDP sockets are connected to 32 camera modules
    - For raw data transfer and slow control of camera modules
  - Still under development, being tested with CHEC-M in a lab

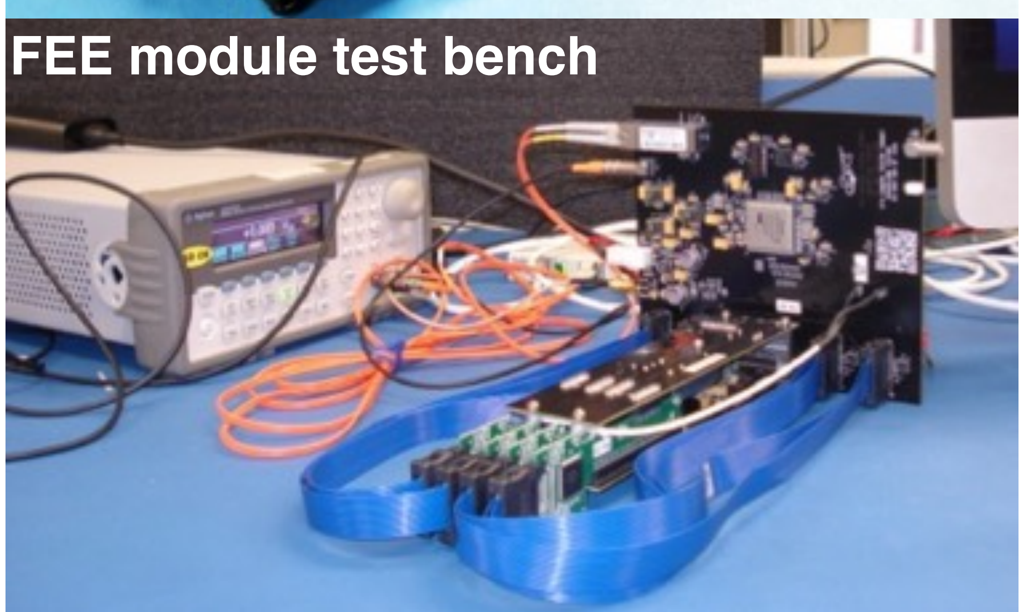
Camera Commissioning

❖ **First GCT camera prototype is assembled and being tested**

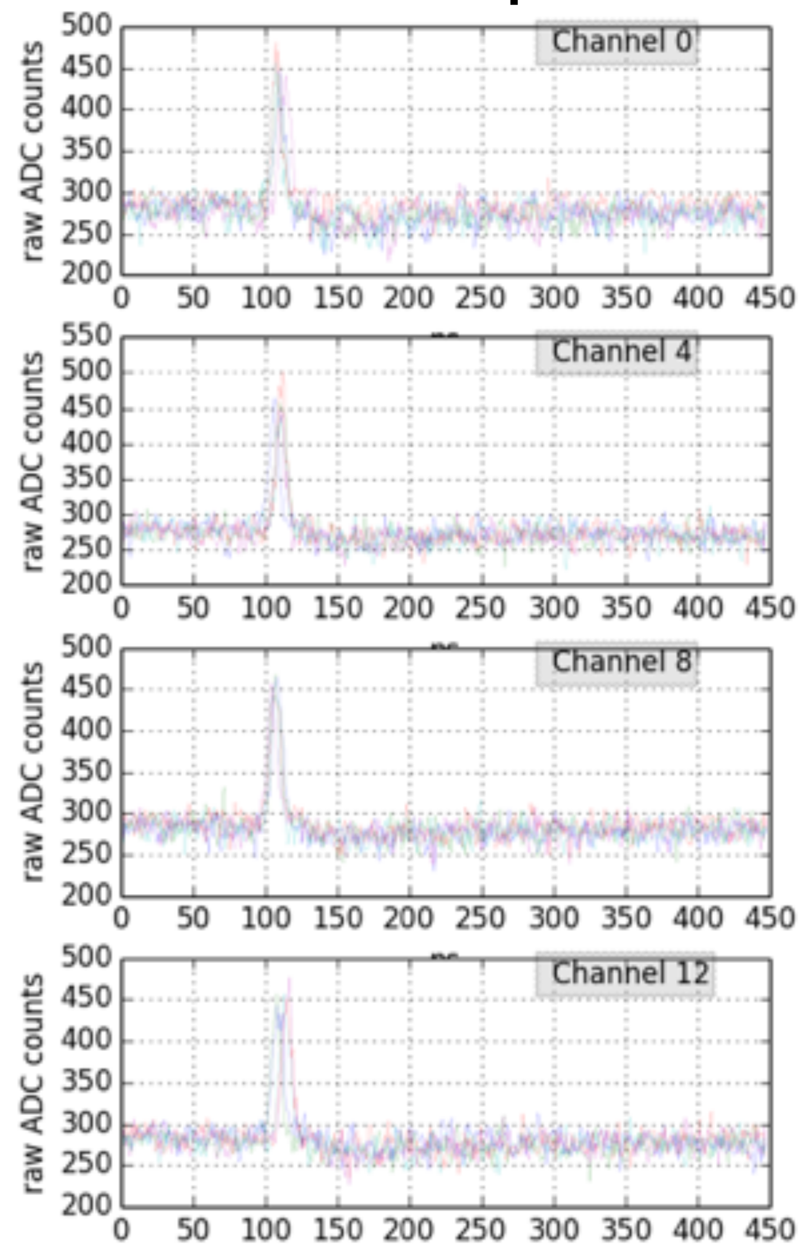
✤ **FEE module level tests completed**

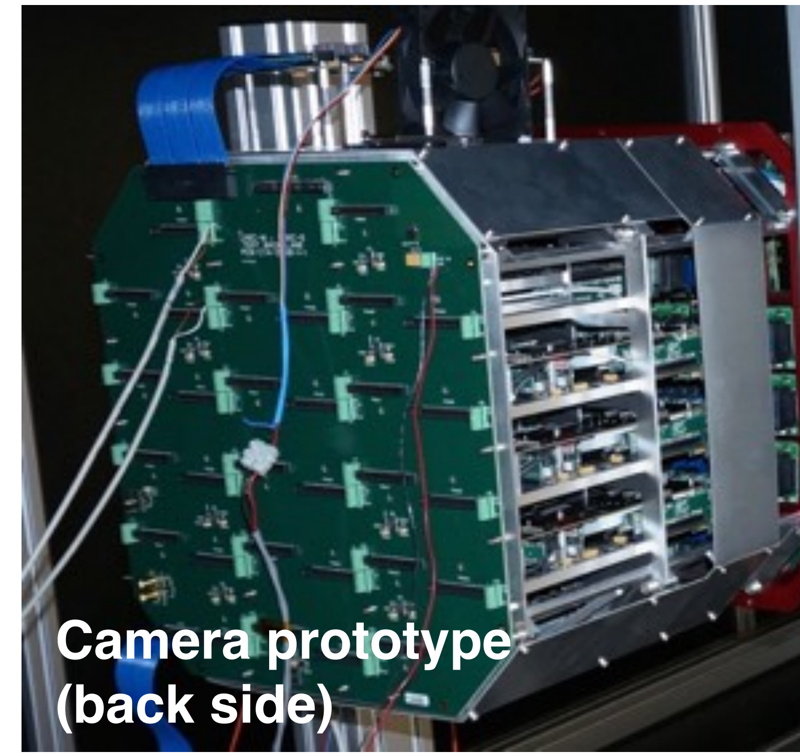
✤ **Integrated camera test in progress**

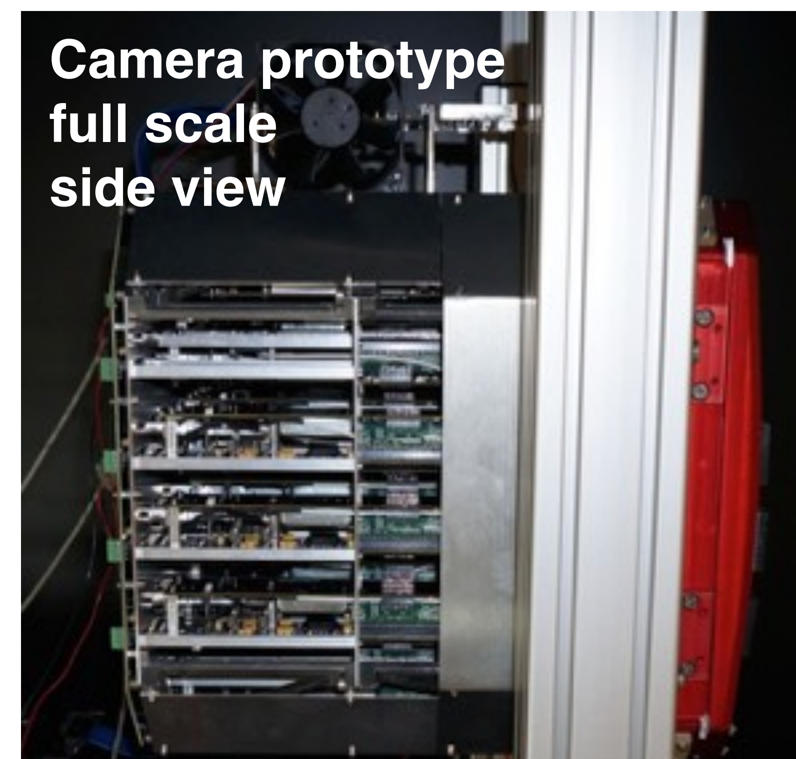




Test bench output







Camera Commissioning

- First GCT camera prototype is assembled and being tested
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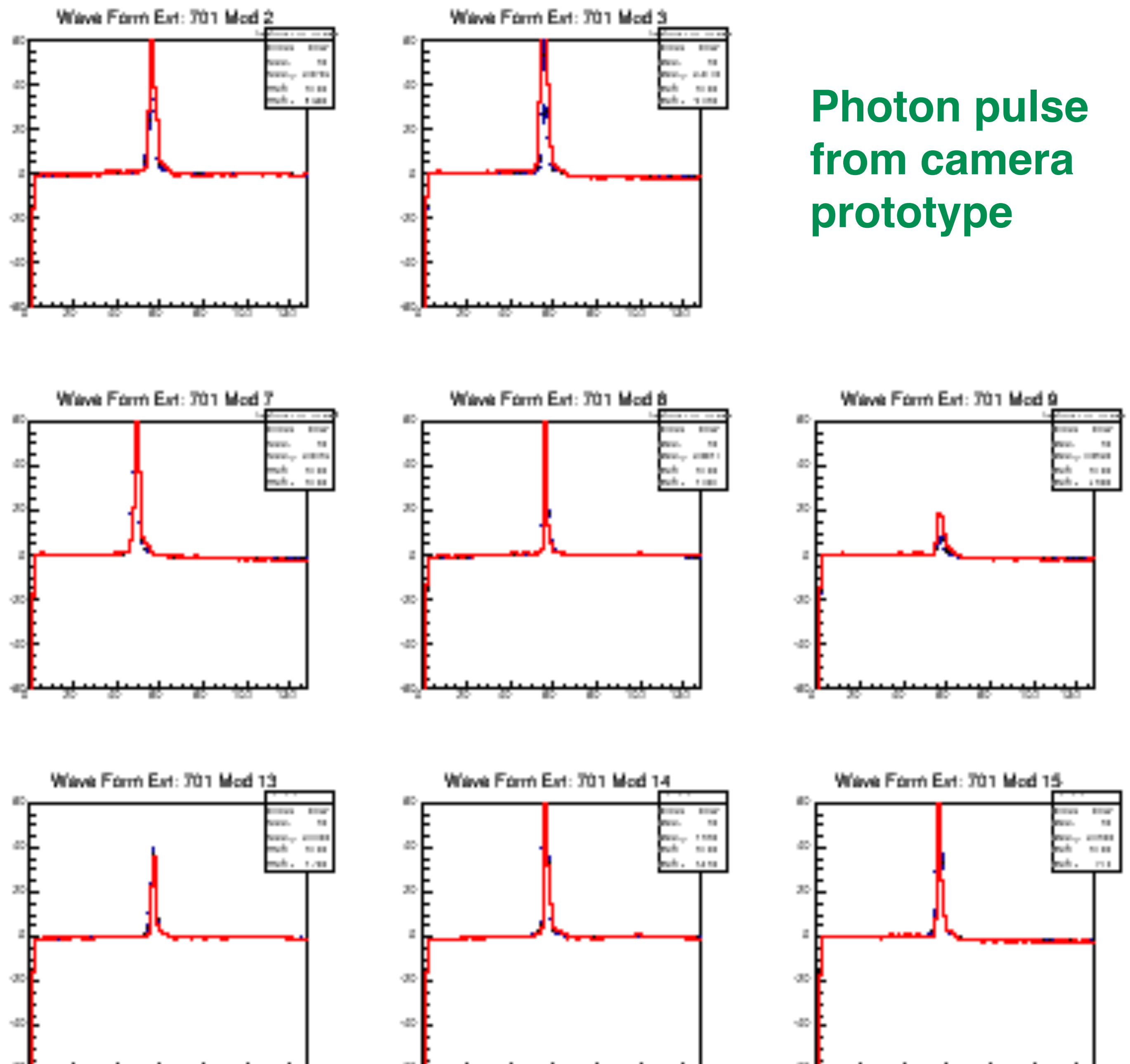
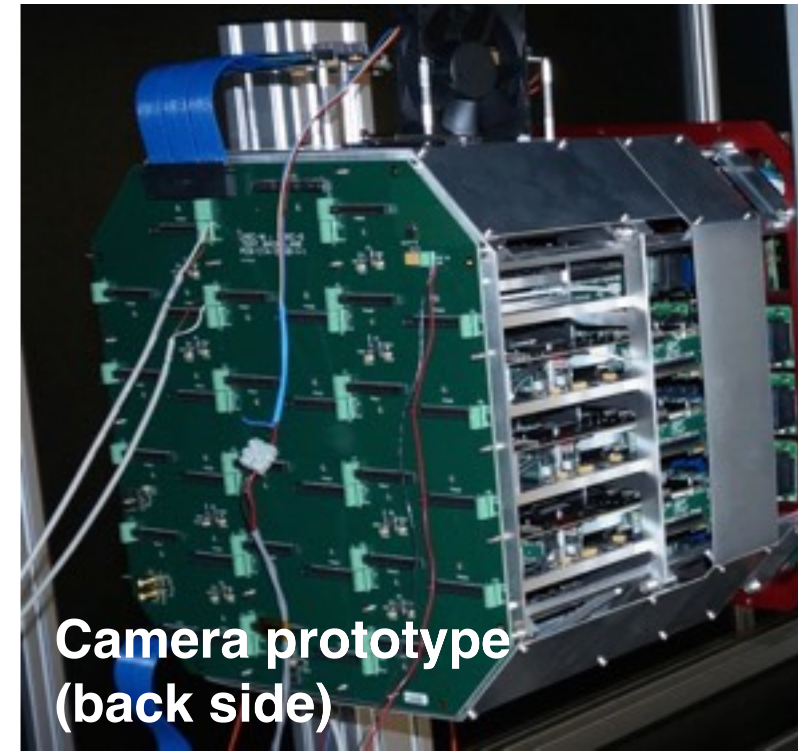
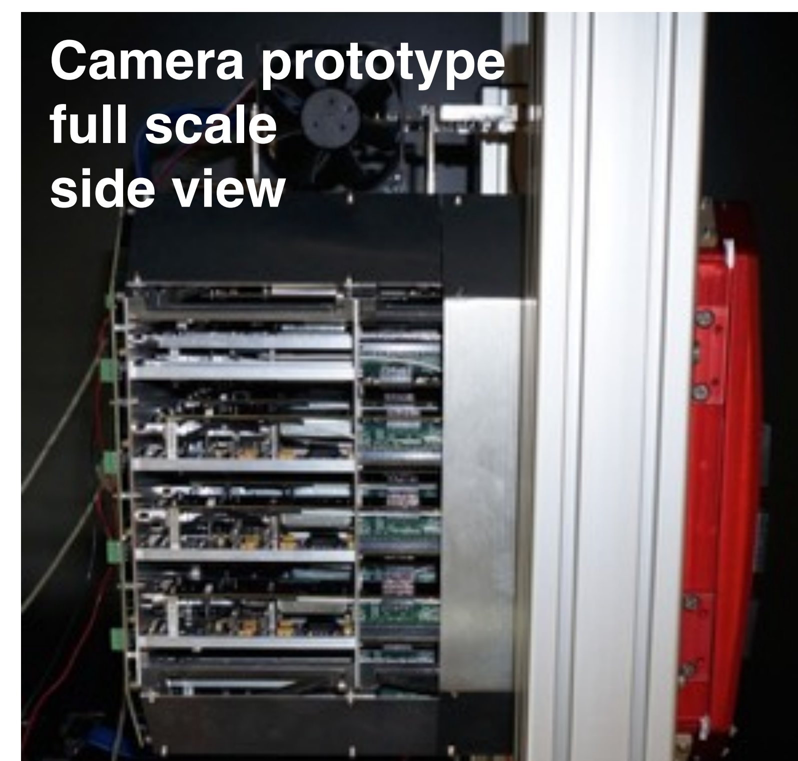
FEE modules


FEE module test b



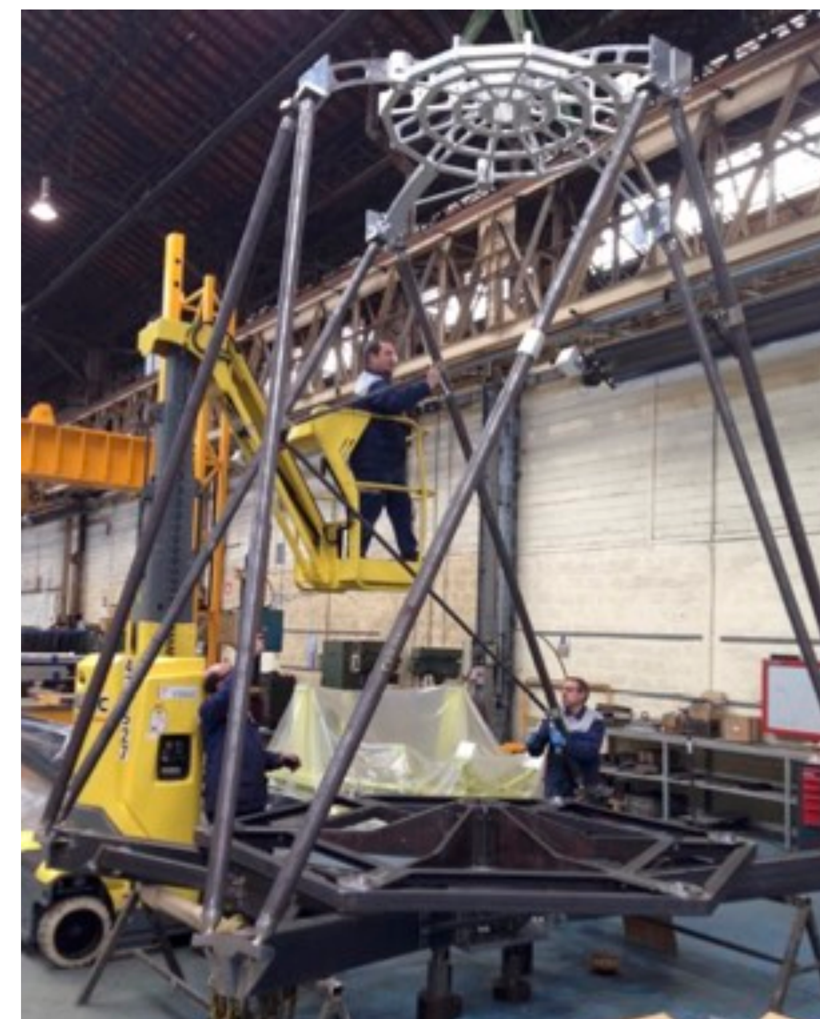
Photon pulse from camera prototype


Camera prototype (back side)


Camera prototype full scale side view

Summary and Plans

- ❖ **Waveform sampling capability of TARGET-7 is satisfactory**
  - ✤ Trigger performance will be fixed by CCTV
- ❖ **Characterization and improvement of SiPM ongoing**
  - ✤ R&D is almost over
- ❖ **System test ongoing for the first camera prototype**



GCT telescope structure

- ❖ **Plans**
  - ✤ CCTV is out of fab and will be tested soon
  - ✤ Prototype sensor will be fabricated after completion of 6 mm sensor testing
  - ✤ Prototype production of complete GCT telescope ongoing