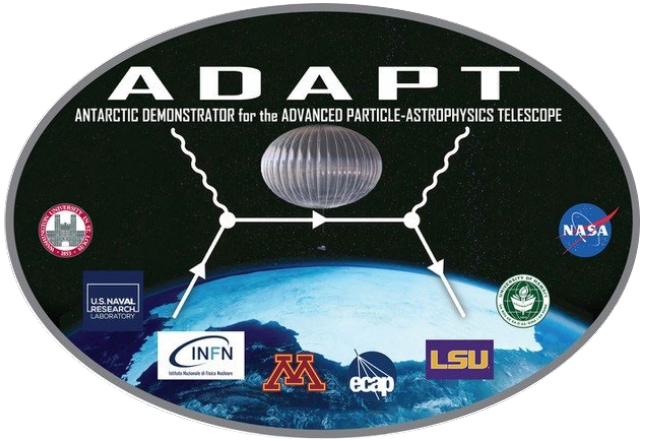
The Antarctic Demonstrator for the Advanced Particle-astrophysics Telescope (ADAPT)

https://adapt.physics.wustl.edu/

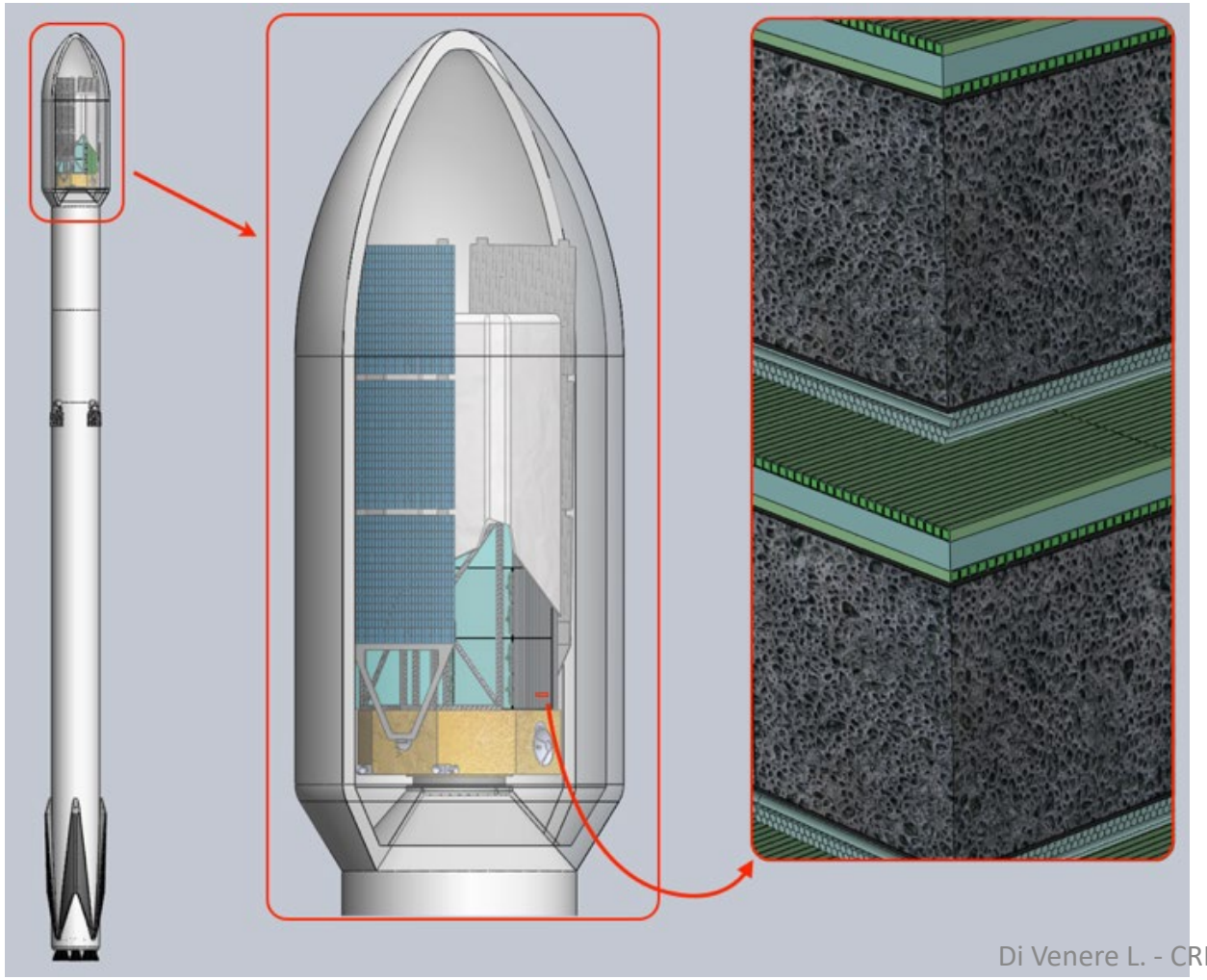


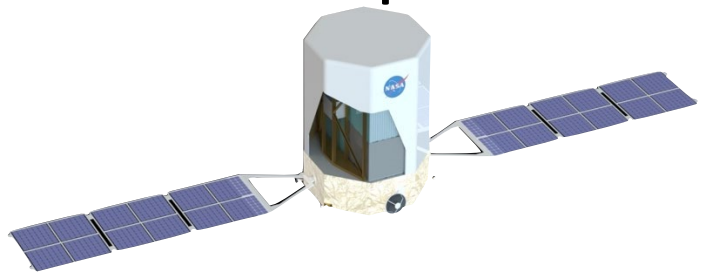
Di Venere Leonardo[1]
for the APT collaboration

[1]INFN Bari

Trapani, June 20, 2024

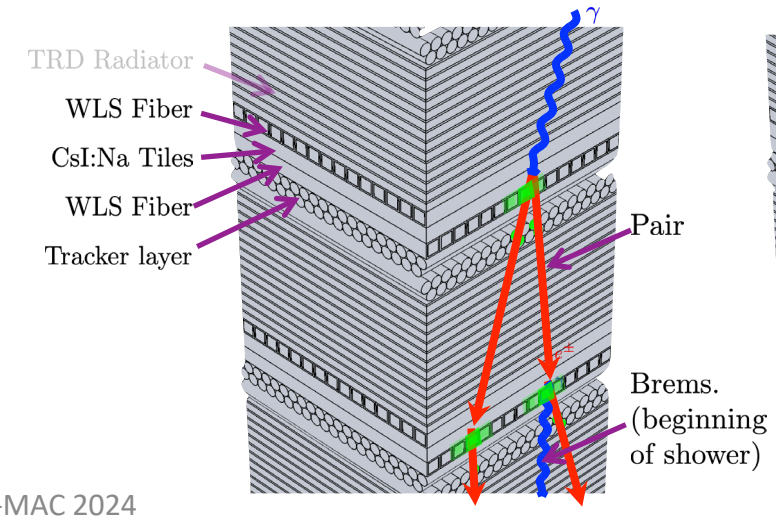
The Advanced Particle-astrophysics Telescope (APT) mission concept



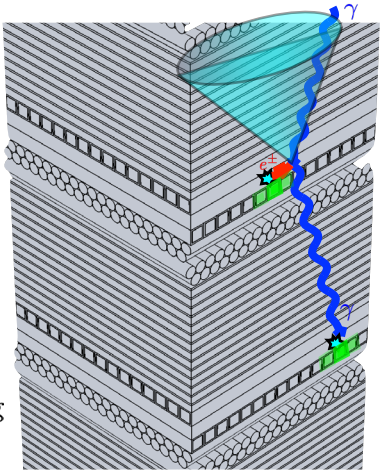


- Large effective area
  - 3m x 3m x 2.5m detector
- Combine a pair and Compton telescope in one design

Pair telescope



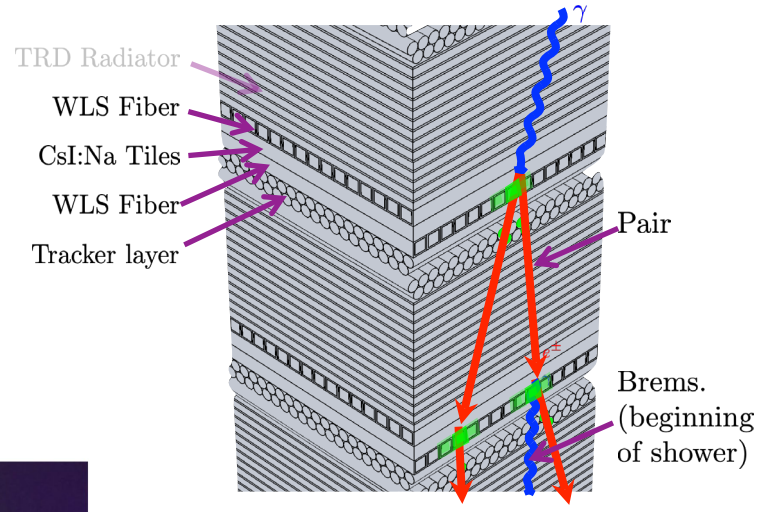
Compton telescope



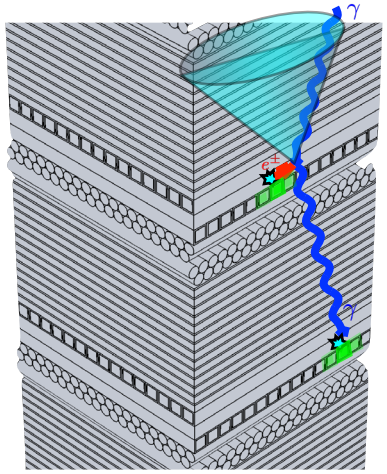
The Advanced Particle-astrophysics Telescope (APT) mission concept

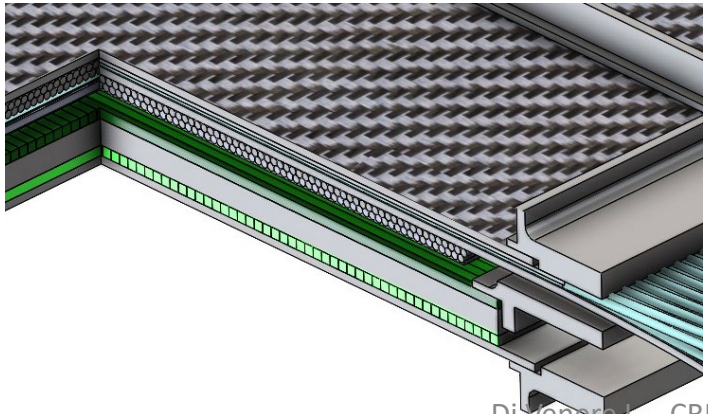
- 20 layers of 5-mm thick CsI(Na) with crossed wavelength shifting fiber (WLS fiber) readout
- 20 XY scintillating optical fiber tracker (SOFT) layers using interleaved 1.5mm round scintillating fibers
- Top-bottom symmetry doubles FoV (in L2 orbit)
- Fiber readout on the sides with SiPMs and analog signal digitization

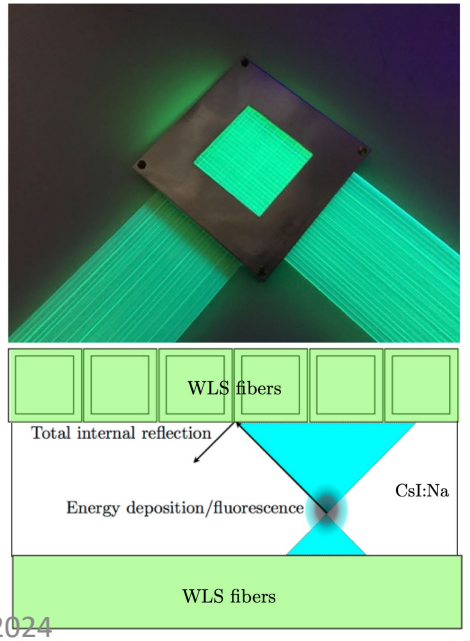
Pair telescope



Compton telescope

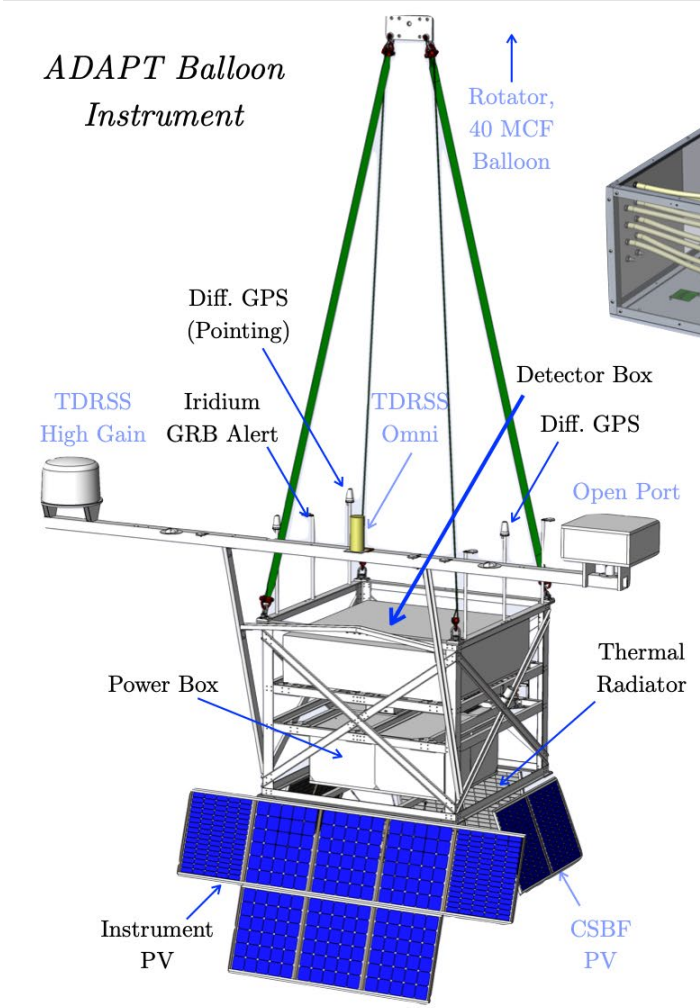


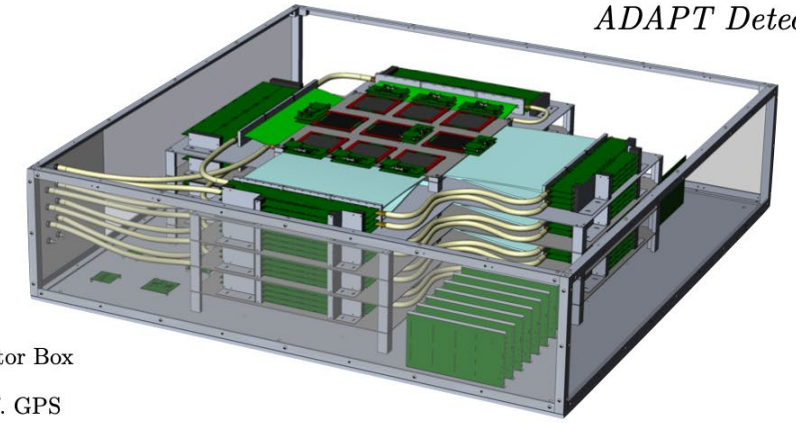


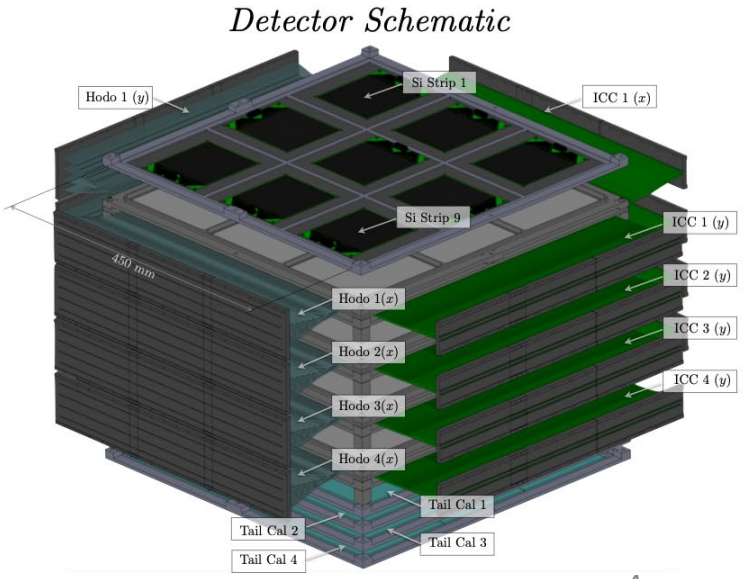


The Antartic Demonstrator for APT

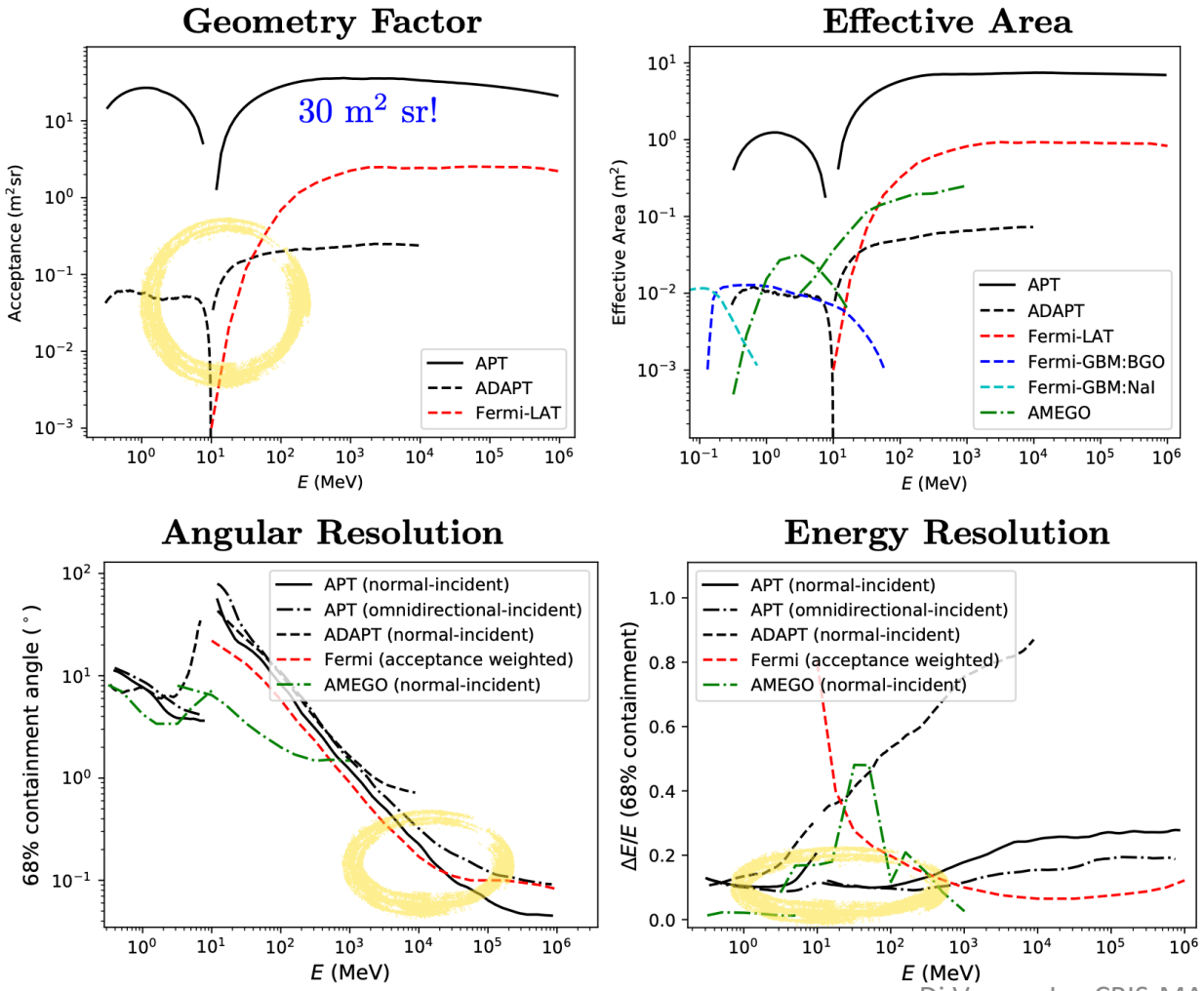
- NASA grant to develop a full suborbital mission
- Long-duration flight on a 60 million-cubic-foot balloon flight from Antarctica in the FY25 season







APT and ADAPT expected perfomrmance



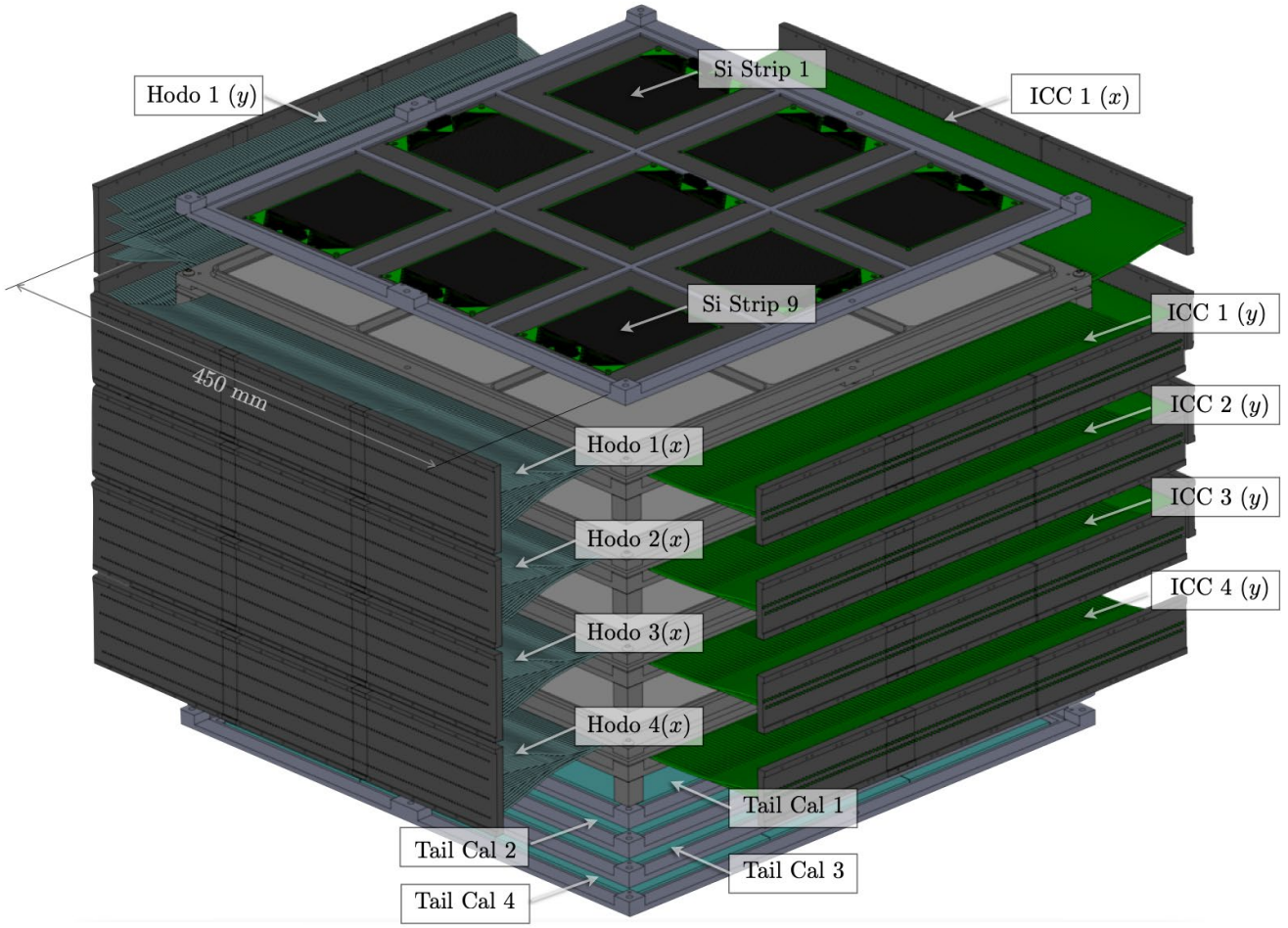
- Higher acceptance compared to Fermi-LAT
- Comparable angular resolution, but less precise wrt silicon-based trackers
- Energy resolution worse at higher energies due to the ‘light’ detector concept, but better at lower energies thanks to the absence of passive materials

ADAPT detector stackup

- **4 layers**
- **3x3 modular design for 45x45cm² active area**

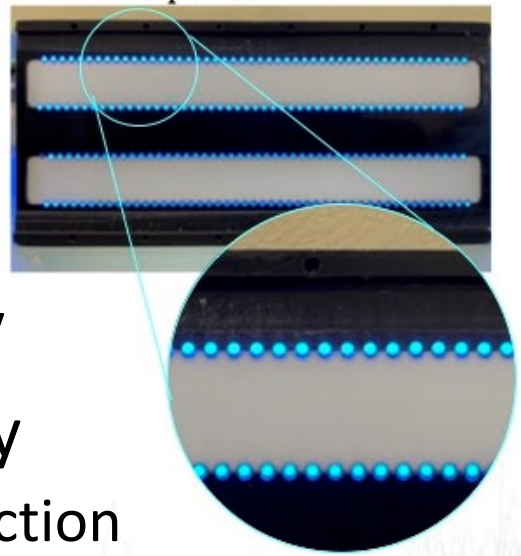
Detector stackup

1. **SSDs:** *Silicon Strip Detectors* for CR charge identification, Compton.
2. **ICCs:** *Imaging CsI Calorimeter* modules. CsI:Na tiles with crossed 2mm WLS fiber+SiPM readout and SiPM CsI *Edge Detectors.*
3. **Hodoscope:** *Scintillating Fiber Tracker* modules, crossed interleaved 1.5 mm scintillating fibers+SiPM readout.
4. **Tail Counters:** Integrating CsI modules with Edge Detectors only

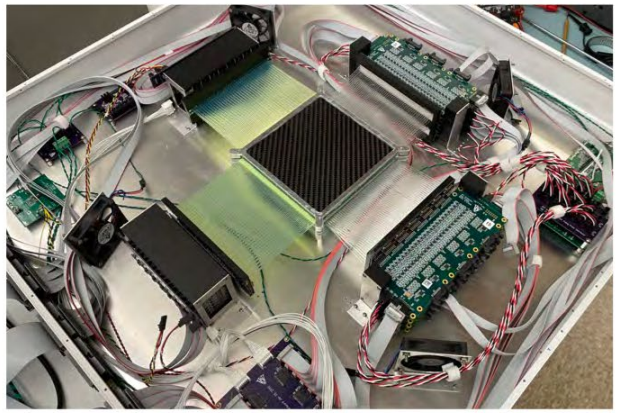


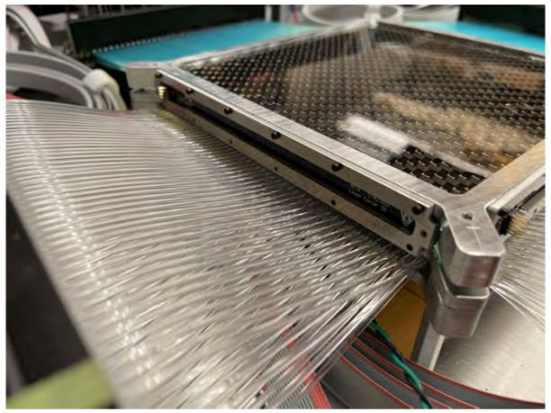
Fiber + SiPM readout

Hodoscope 1.5mm fiber ends

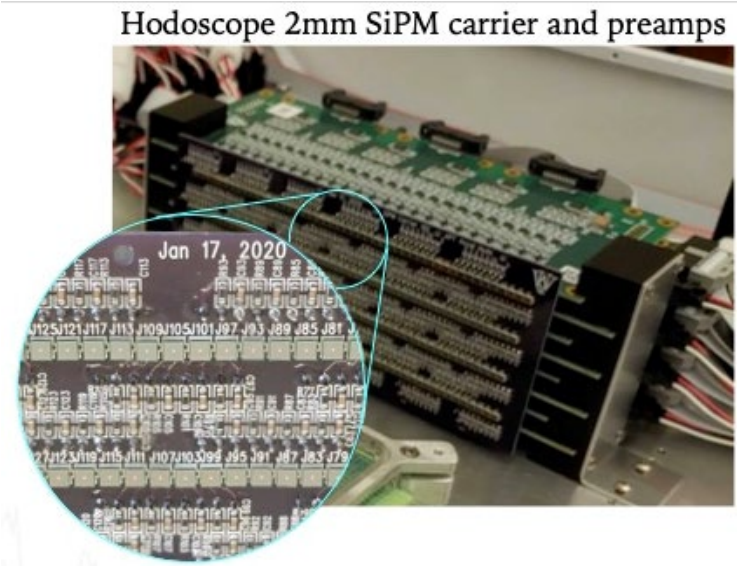


- WLS and scintillating fibers are bundled into a linear array
- SiPM carrier boards designed to match the fiber geometry
  - One fiber readout by a single SiPM → easier position reconstruction

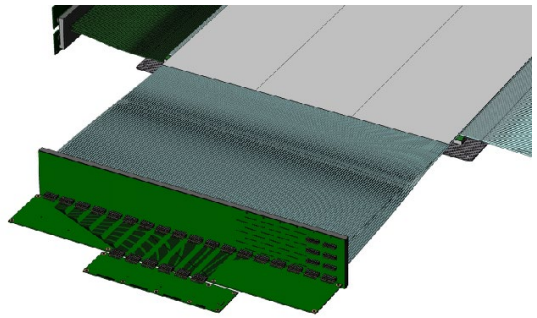




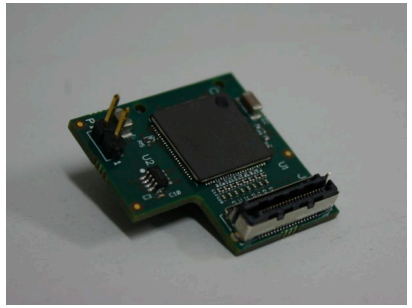
Hodoscope 2mm SiPM carrier and preamps



Readout electronics for Hodoscope and ICC

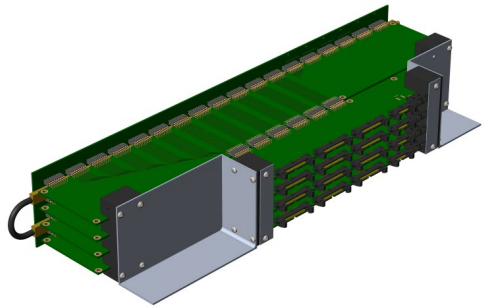


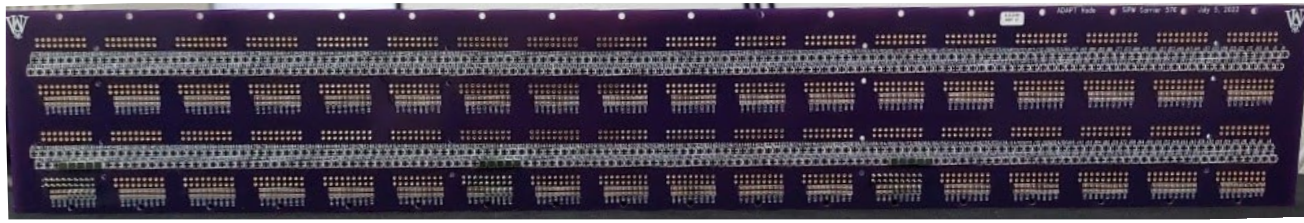
- Hamamatsu SiPMs coupled to WLS/scintillating fibers
  - 3x3mm^2 CsI SiPM (S13360-3050CS)
  - 2x2mm^2 Tracker SiPM (S13360-2050VE)
- Multiplexing boards to sum up 3 SiPMs from different tiles
  - Reduce the number of readout channels
  - Still keep position identification capabilities thanks to the edge detectors
- Preamplification stage based on the SMART ASIC preamplifier
  - Developed for Schwarzschild-Couder Telescope project for CTA
- Waveform digitizer to readout SiPM signal waveforms



Hodo Electronics

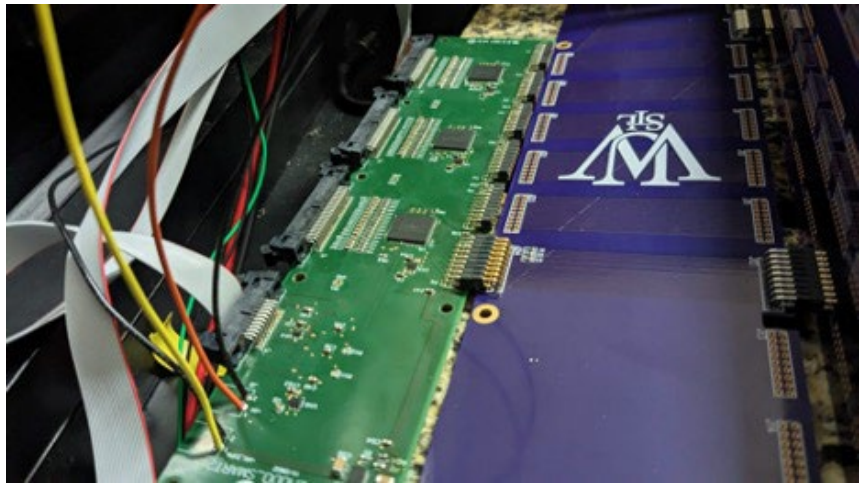
- SMART preamp board hosting 3 ASICs designed (48 channels)
- Prototype boards produced and tested in 2023



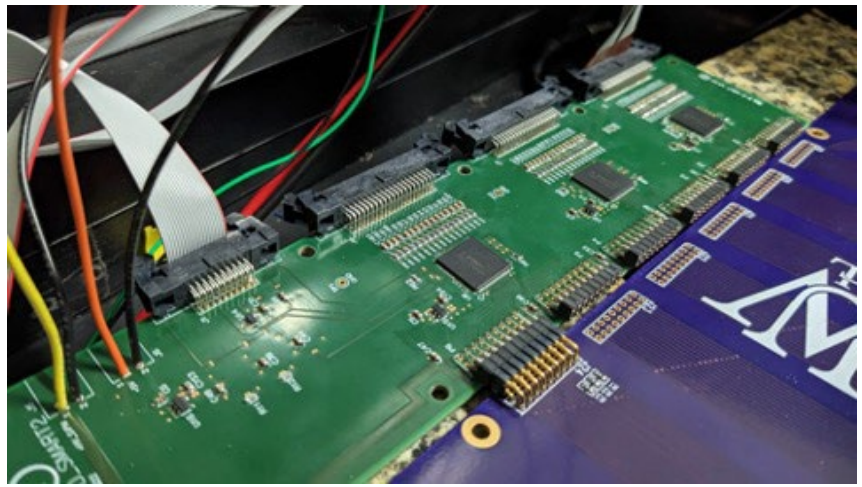


SiPM Carrier

MUX+SiPM Carrier



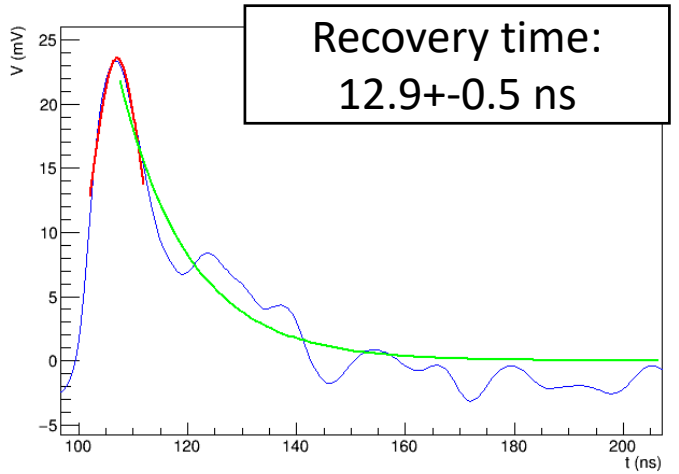
Hodo SiPM + MUX + Preamp

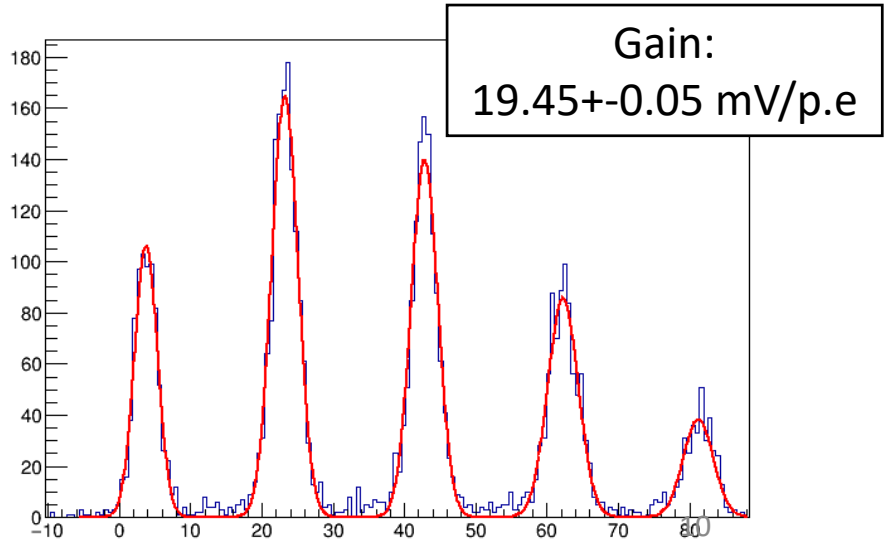


Hodo SMART Preamp Board

Hodo preamp tests

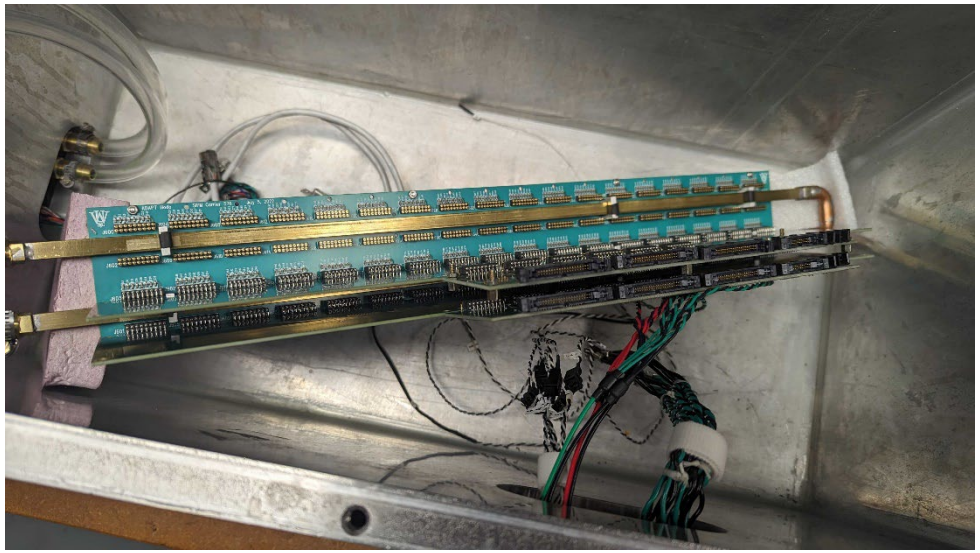
- Several configuration tested to explore SMART configuration parameters (gain, pole-zero)
  - Gain up to 20 mV/pe with signal-to-noise ratio ~20
  - Pulse shape with FWHM and recovery time up to 20 ns
- Compared performance with and without the MUX board (1 vs 3 SiPMs)
  - Gain slightly lower for 3 SiPM configuration
  - Longer signals (FWHM up to 20 ns)

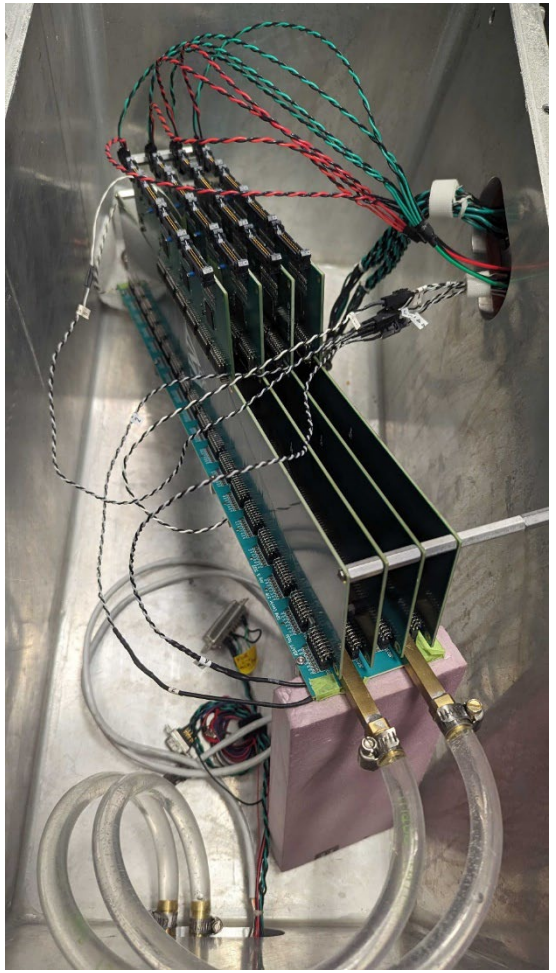




Hodo Electronics

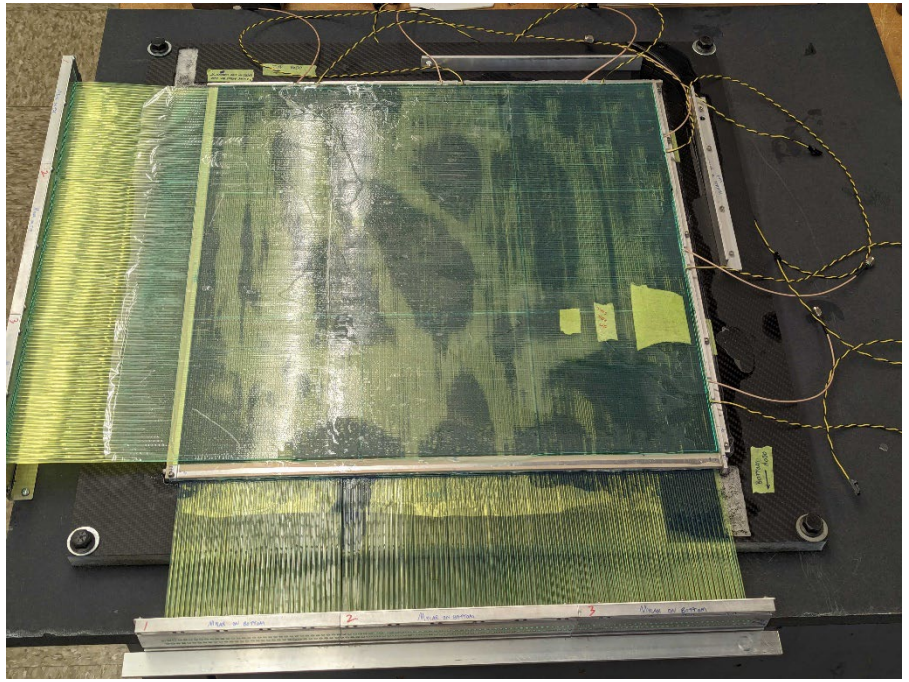
- Hodo SiPMs and electronics for full ADAPT instrument produced and tested
- First vacuum and thermal tests conducted
- Integration ongoing





Imaging CsI Calorimeter (ICC)

- CsI scintillator tiles coupled with WLS fibers + SiPM array
- Scintillator + WLS fibers assembly ongoing
- SiPM Edge detector for triggering and charge measurement

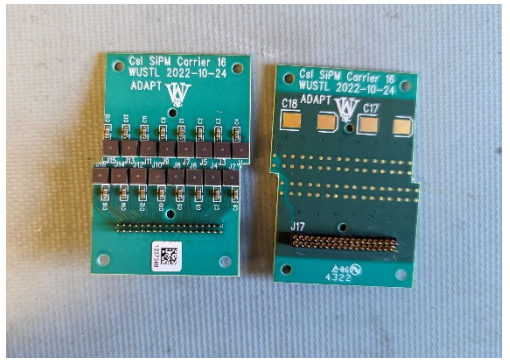


ICC CsI tile with WLS fibers

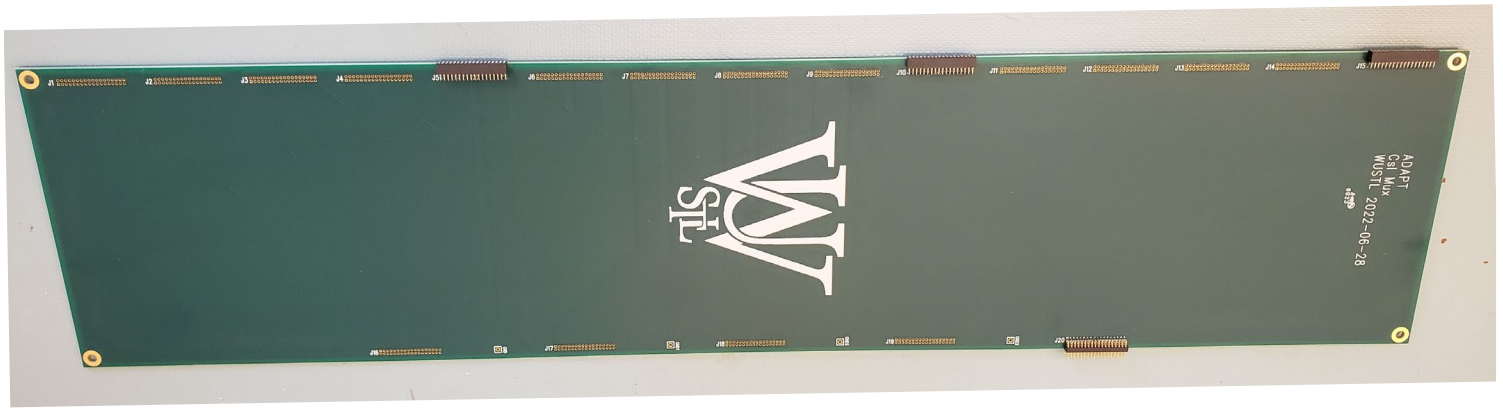
ICC SiPM Edge detector

ICC Electronics

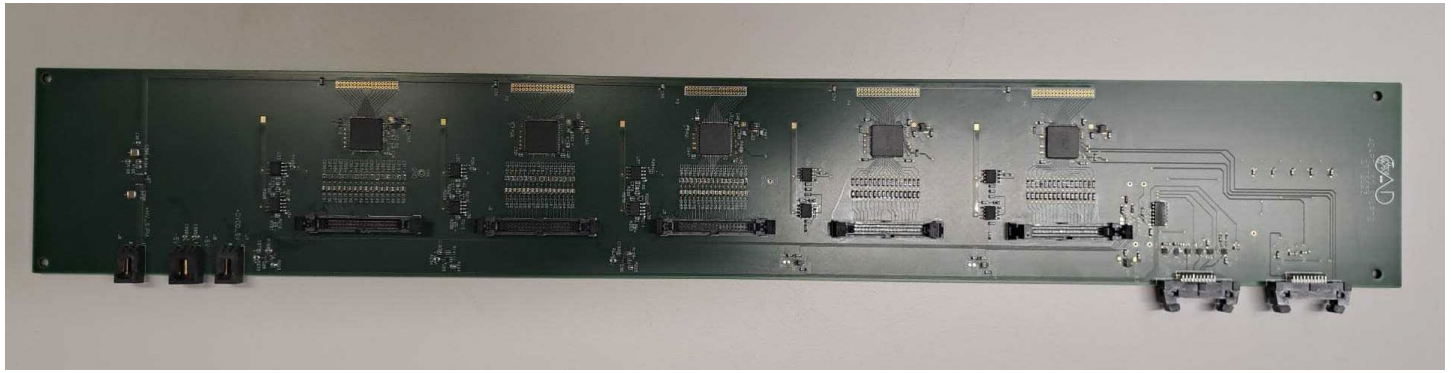
- Similar concept to the Hodo electronics
- SiPM array to realized a one-to-one coupling with WLS fibers
- MUX board to sum up three SiPMs on the same electronics channel
- SMART electronics board hosting 5 ASICs (80 channels)
- Prototype boards produced and tests ongoing



ICC (CsI) SiPM carrier



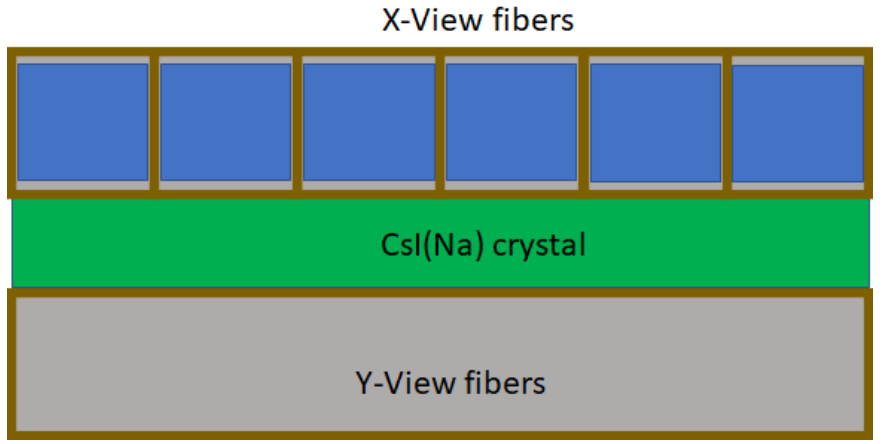
ICC (CsI) MUX



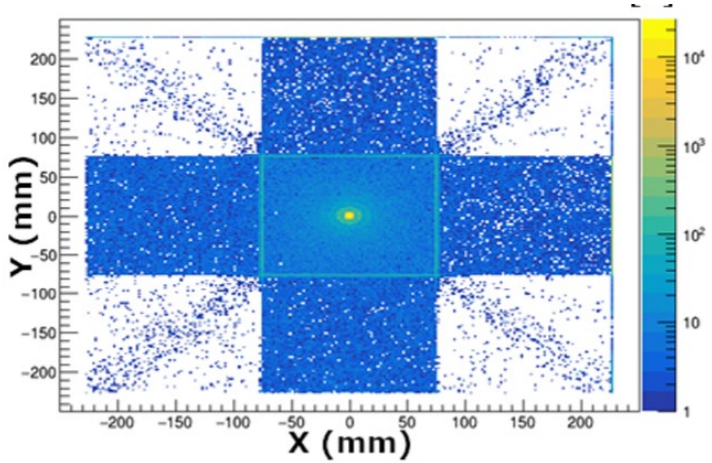
ICC (CsI) SMART Preamp board

ICC simulation

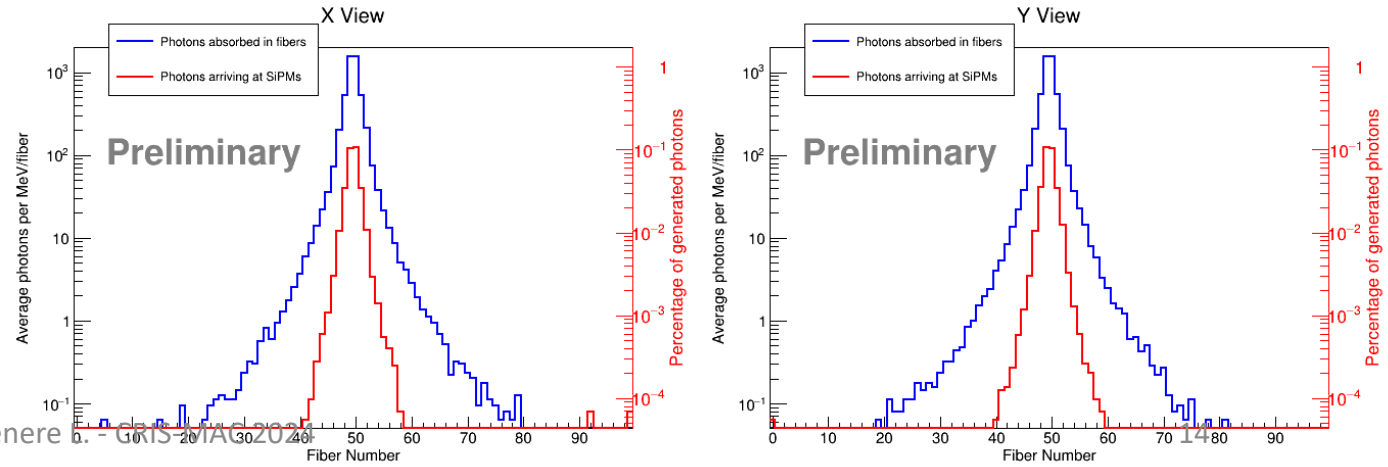
- GEANT4 simulation framework
- Scintillation light simulation with photon propagation in CsI:Na crystal and WLS fibers
  - 5 mm-thick 20×20cm^2 CsI:Na crystal tile
  - Sandwiched between two layers of 2x2mm^2 WLS fibers
  - SiPM at the end of each fiber
  - SiPM edge detector at the edge of tiles



Scintillation photon propagation in CsI

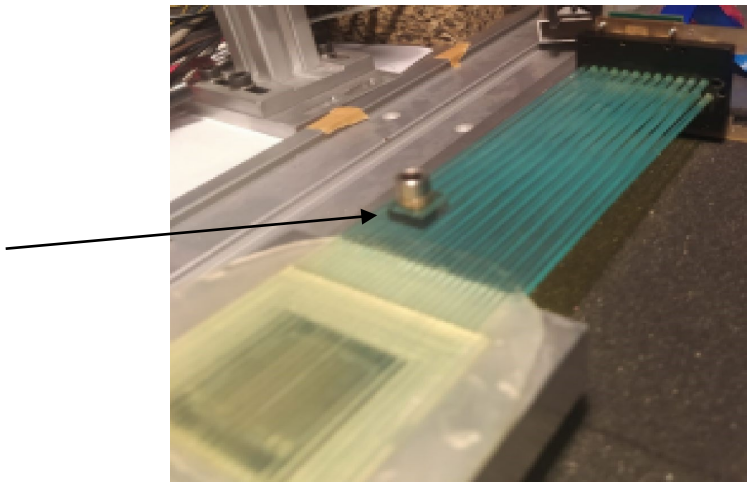


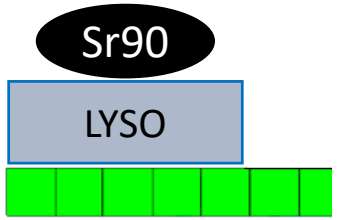
Scintillation photon collected in WLS



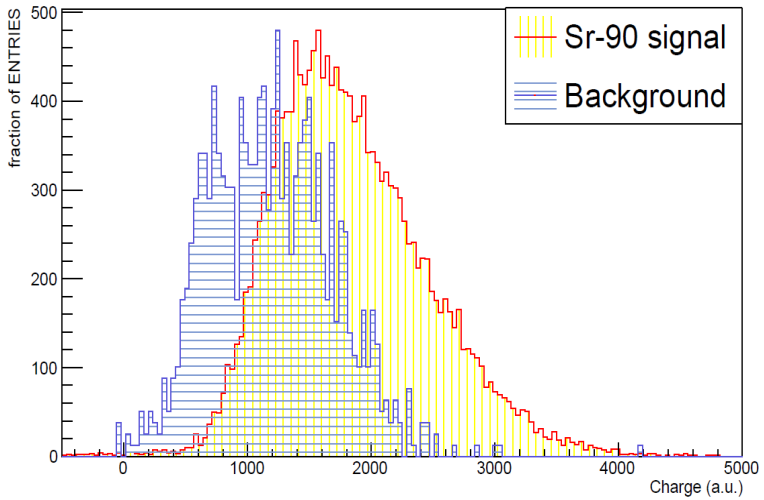
ICC lab prototype

- 5-mm thick LYSO crystal with a square cross section of 1 x 1cm^2
- 2x2mm^2 WLS fibers
- LYSO crystal was covering 5 WLS fibers
- Sr-90 source on top of the LYSO crystal
- Same readout electronics of the ADAPT instrument
- Trigger on one WLS fiber

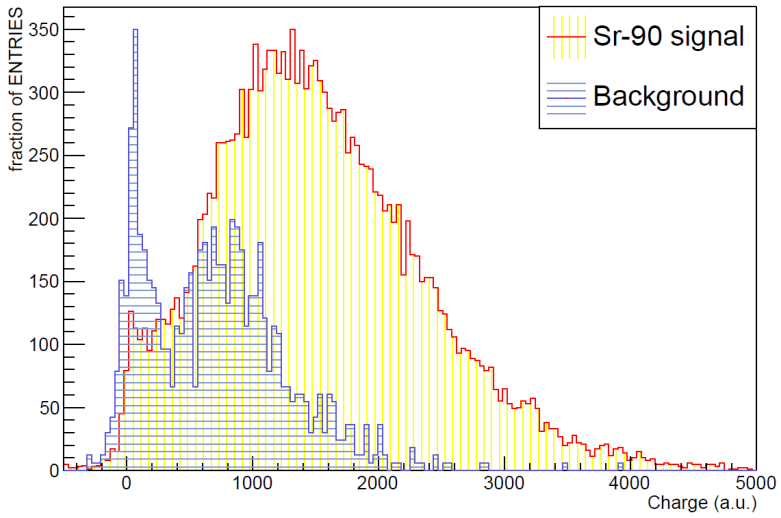


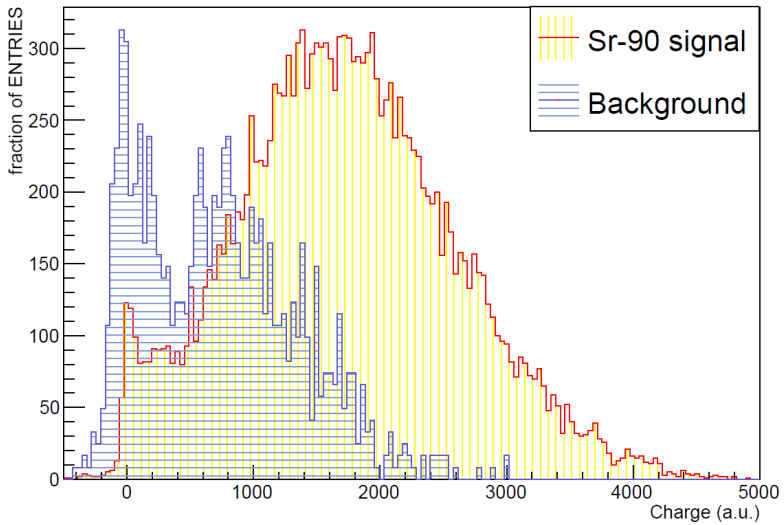


Trigger channel



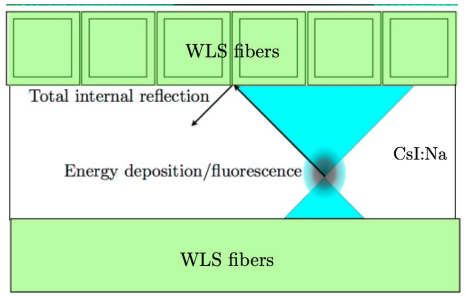
Channel of fibers at the left and at the right of the source



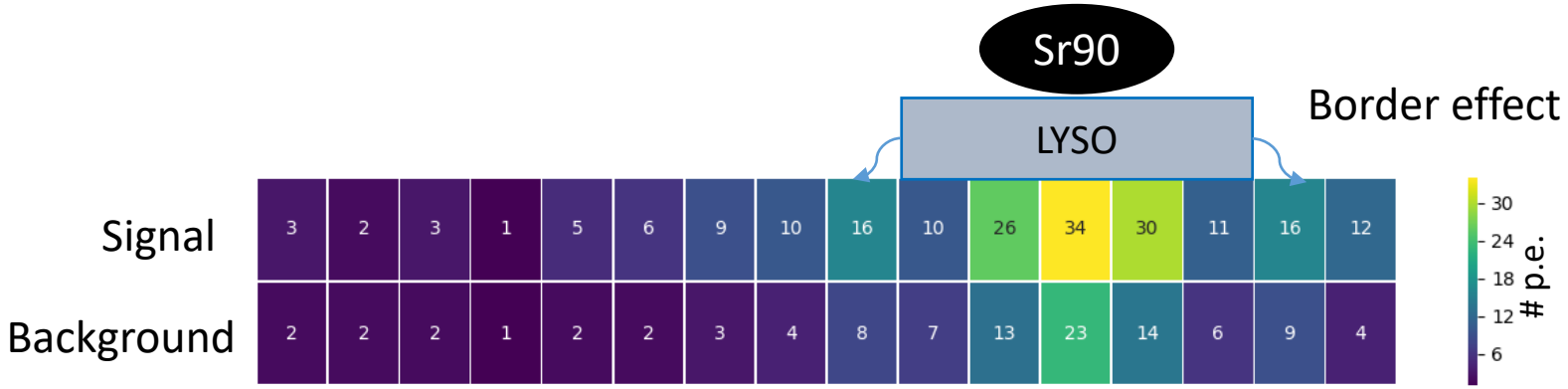


Signal is clearly present also in channels close to the triggered fiber as expected

Preliminary position reconstruction

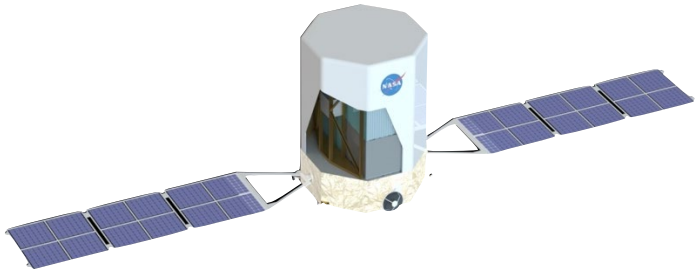


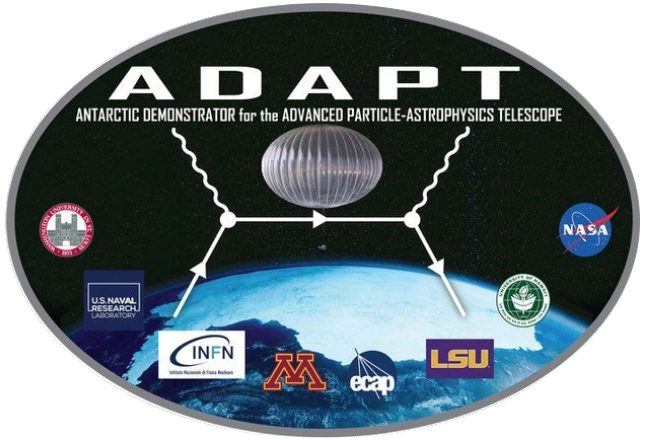
We calculate the average number of photo-electrons in each fiber
Information on the x-coordinate of the event



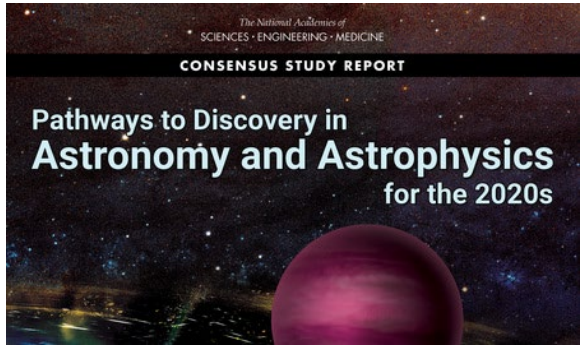
Only three fibers show a signal above background → compatible with aperture cone in 5 mm thick LYSO (taking into account that coupling with fibers is not optimal)

Conclusions



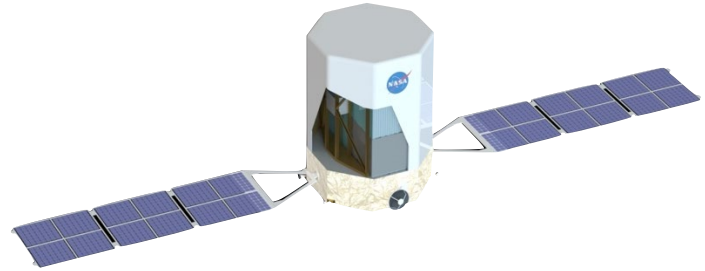


- APT is a proposed mission for gamma-ray detection combining Compton and pair regimes
- NASA APRA funded project for a demonstrator (ADAPT)
  - Sub-detector tests and integration ongoing
  - Balloon flight expected at the end of 2025
- APT mentioned in Decadal Survey among the proposed mid-scale gamma-ray missions

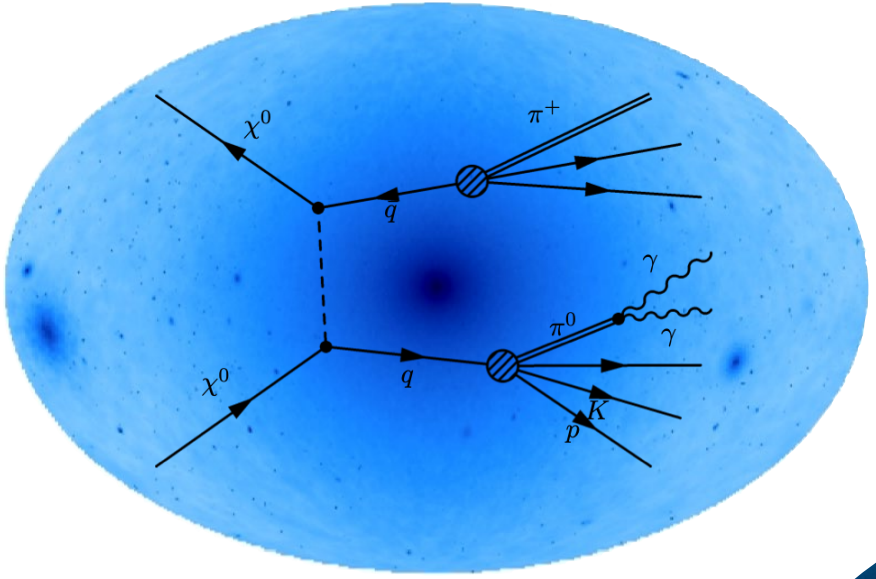


Backup

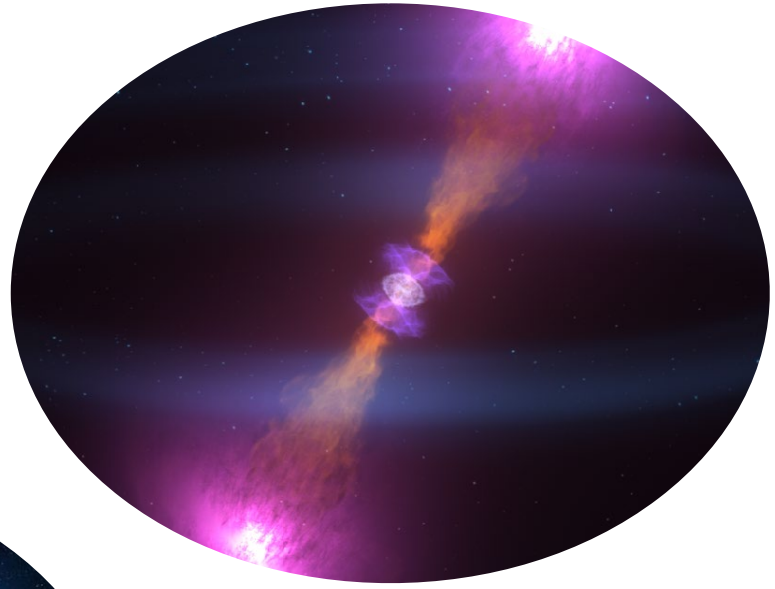
The APT and ADAPT science



Dark matter searches



Multimessenger Observations

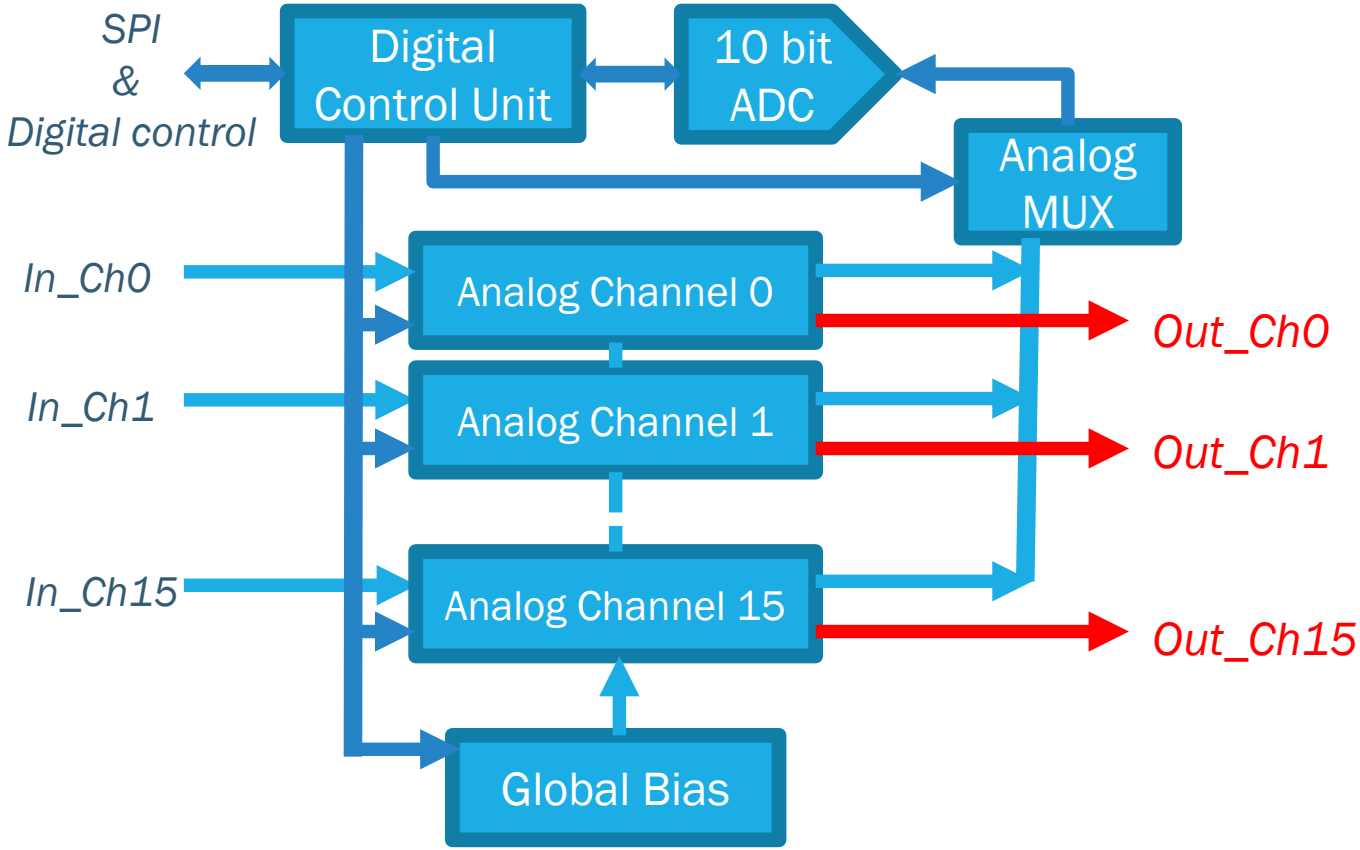


Origin of the Heavy Elements

SMART: a **S**iPM **M**ultichannel **A**sic for high **R**esolution Cherenkov **T**elescopes

Pre-amplifier designed for photon counting for the Cherenkov Telescope Array project

- 16-channel trans-impedance amplifier
- 20-bit global adjustment: gain (8 bits), bandwidth (6 bits), Pole-Zero (6 bits)
- 8-bit DAC for SiPM bias fine tuning (1 DAC per channel)
- Slow monitoring of SiPM current (10-bit ADC)
- 1 MHz LVDS SPI interface



Designed by F. Licciulli & G. De Robertis at the Electronics CAD INFN Bari

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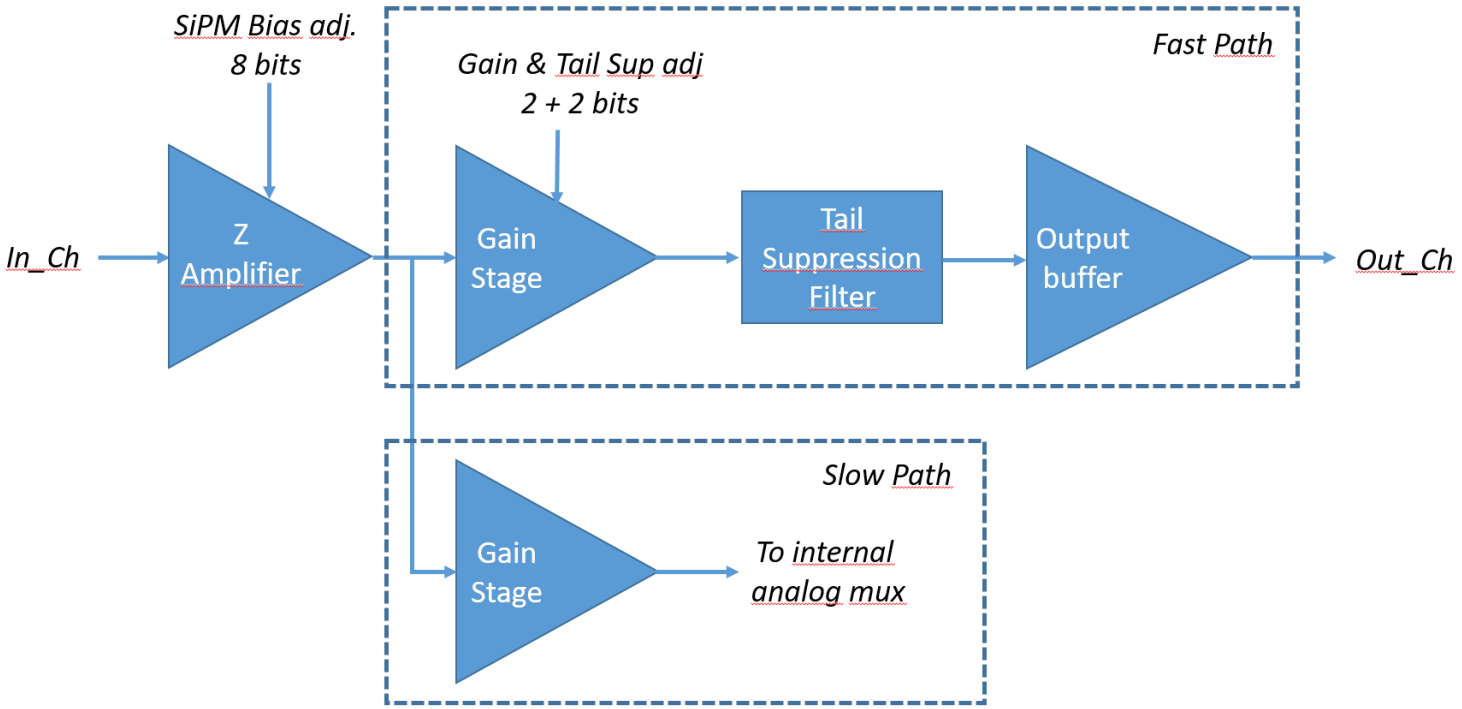
SMART Channel Architecture



Channel features:

- Fast path gain: 2-8 mV/ph
- Tail suppression:
  pulse duration ~ 10ns
- Output buffer impedance: 12.5Ω
- Power consumption:
  20mW/channel
- SiPM bias fine tuning: LSB = 12.5mV
- Slow path output & 10 bit ADC:
  LSB = 2MHz