The Advanced Scintillator Compton Telescope (ASCOT)

Motivation, Balloon Flight, and Future Directions

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Collaborators

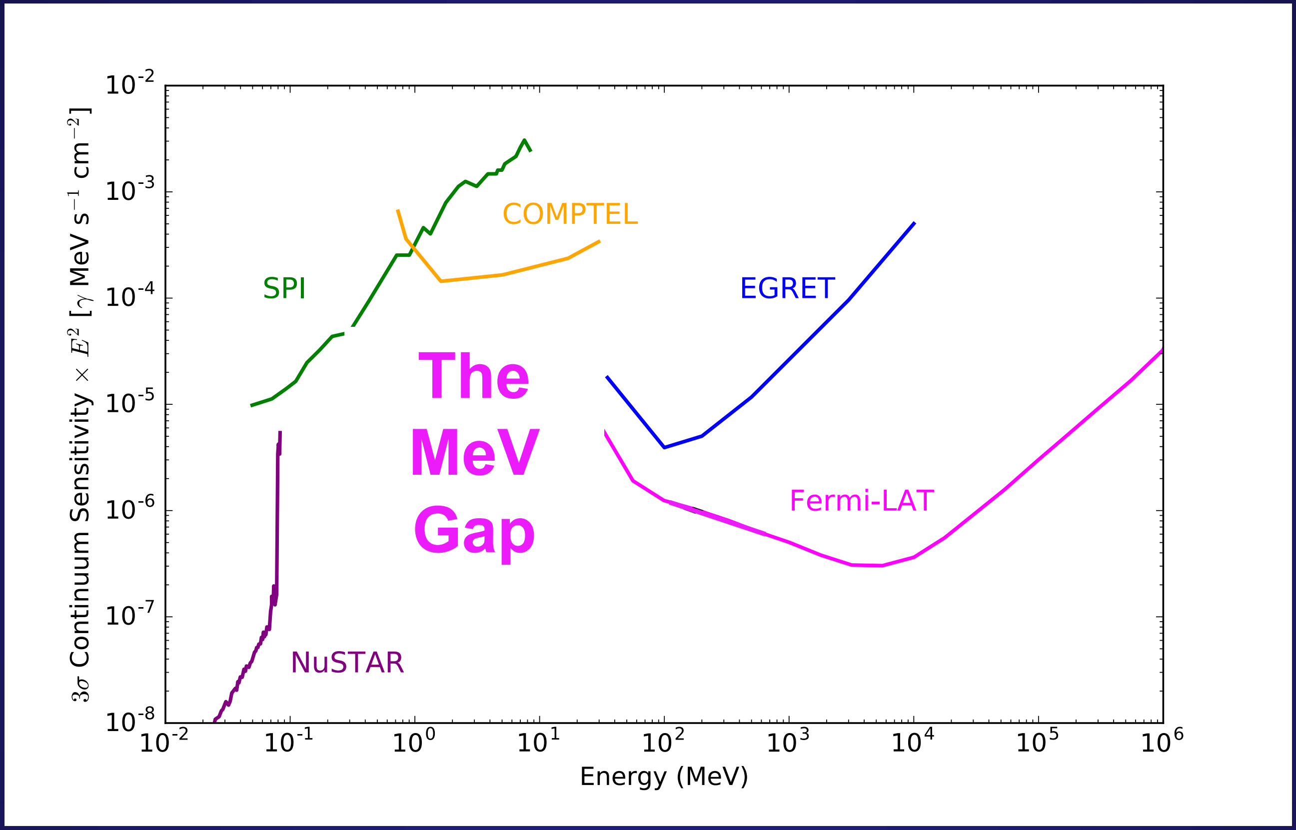
The work described in this talk was performed at the University of New Hampshire's Space Science Center, where I was on the Research Faculty until moving to LANL in December. My collaborators were:

<u>Tejaswita Sharma</u>
Jason Legere
Chris Bancroft
Colin Frost
Alex Wright
John Gaidos
Mark Widholm
Mark McConnell
James Ryan

And the rest of the UNH SSC technical and administrative staff

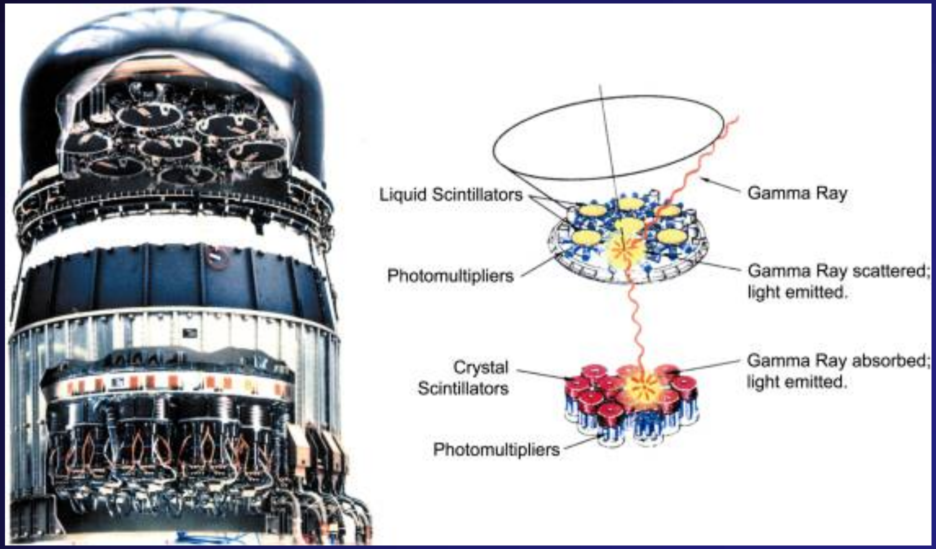
MOTIVATION

The MeV Gap: How Can We Improve Sensitivity in MeV Band?



COMPTEL was the first, and still only, Compton Telescope to fly in space with sufficient sensitivity to perform astronomical observations in the MeV band

COMPTEL and its Background



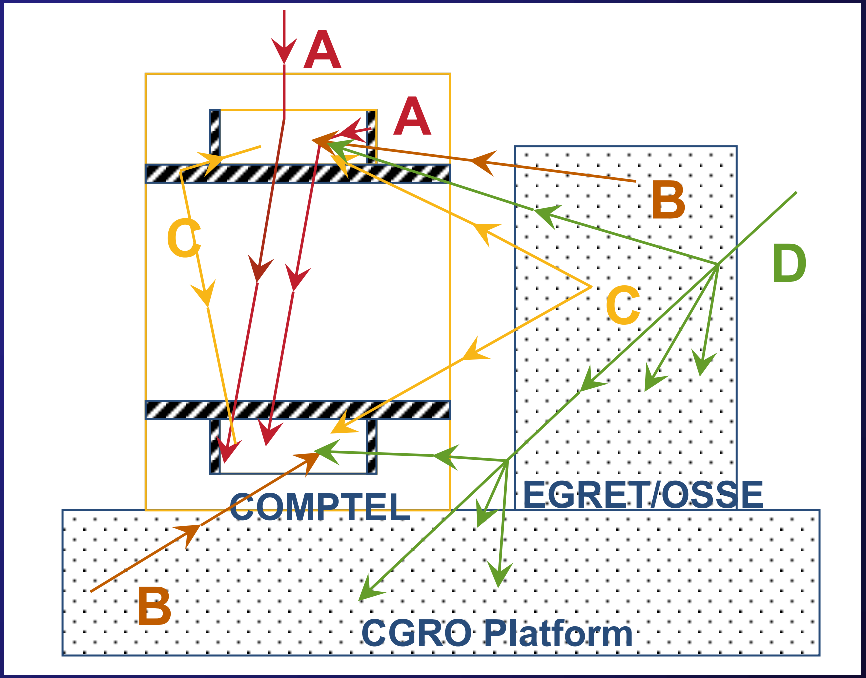
D1: organic liquid scintillator

D2: inorganic NaI scintillator

Photomultiplier Tube (PMT) readout

Measured E_1, E_2, Positions, PSD, ***Time-of-Flight***

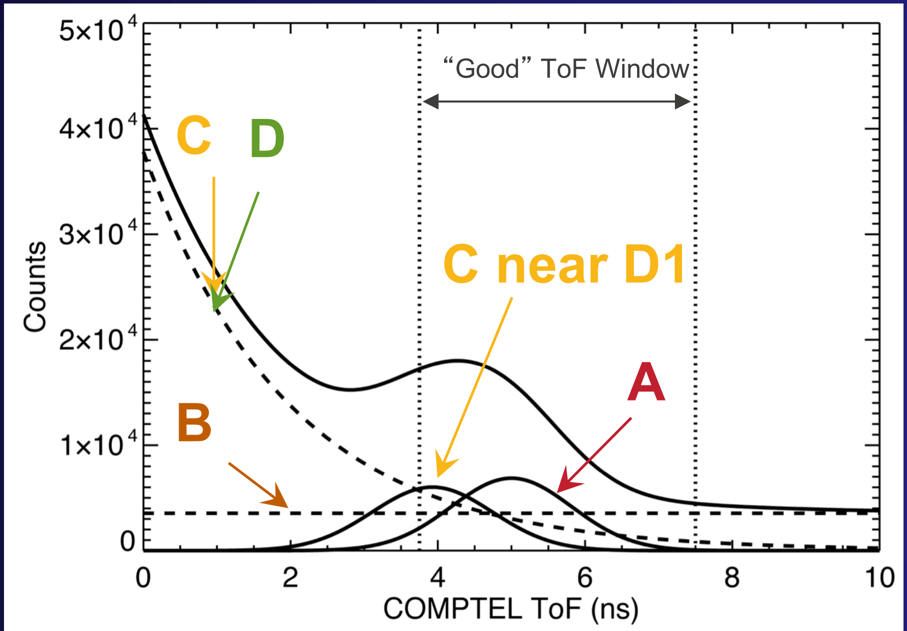
COMPTEL suffered intense background from particle interactions:

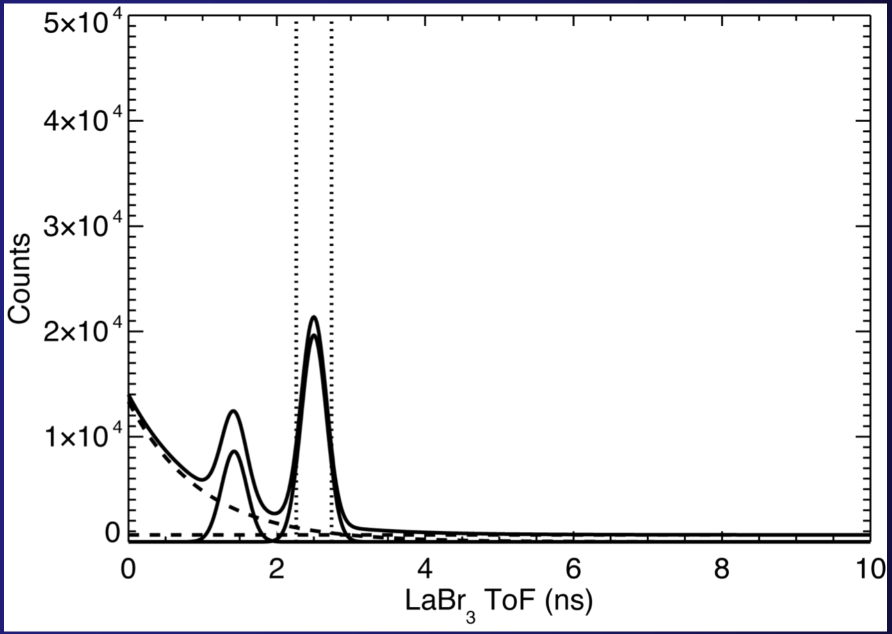


Kappadath, S. C., 1998, Ph.D. Thesis, University of New Hampshire

COMPTEL Background Rejection: ToF

ToF was *critical* to COMPTEL's sensitivity:





Kappadath, S. C., 1998, Ph.D. Thesis, University of New Hampshire

Improved ToF resolution will greatly reduce background in straightforward manner

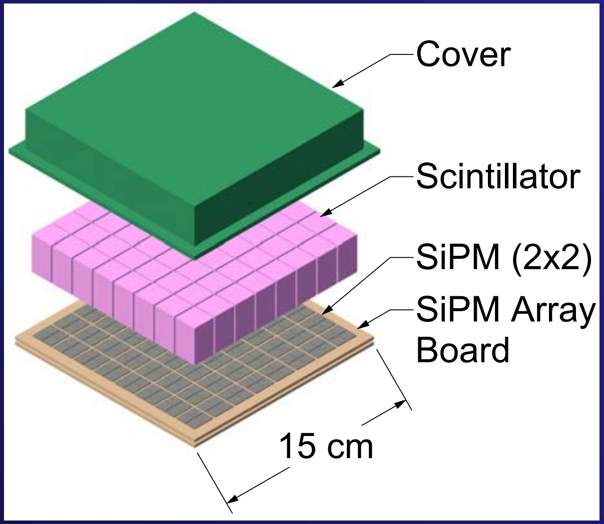
ASCOT Motivation

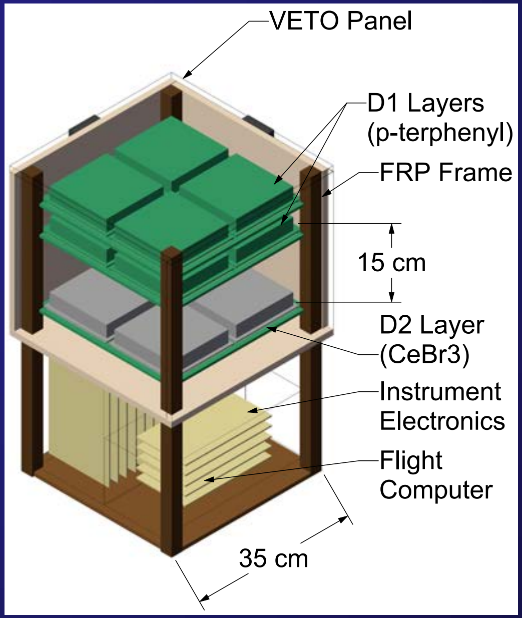
- The ASCOT project is motivated by the theory that the most cost-effective, low-risk way to implement an advanced, ***general-purpose*** Compton telescope is to build directly on the experience of COMPTEL
- A advanced, scintillator-based Compton telescope would use ***modern detector materials*** to improve efficiency, energy resolution, and time-of-flight (ToF) resolution for background rejection
- It would also use ***advanced light readout devices***, such as silicon photomultipliers (SiPMs), to reduce passive mass, volume, and power
- **<u>Project Goal</u>:** Demonstrate technology by imaging Crab Nebula during 1-day balloon flight

ASCOT INSTRUMENT

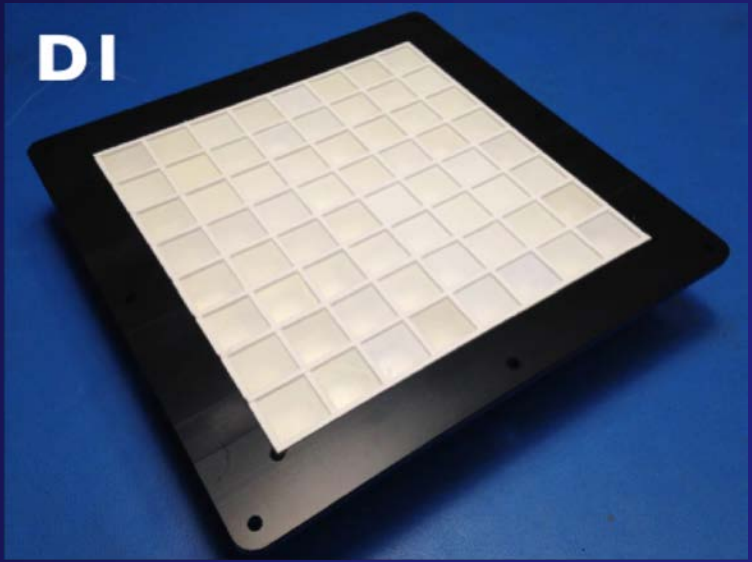
ASCOT Instrument Overview

- Instrument concept: basic “module” with 8 × 8 scintillator array optically coupled to a 8 × 8 SiPM array
- Each scintillator 15 × 15 × 25 mm^3
- Each scintillator read out by 2 × 2 SiPM array
- Detector layers each 2 × 2 array of modules
- Two D1 layers, one D2 layer (cost)





ASCOT D1: P-terphenyl

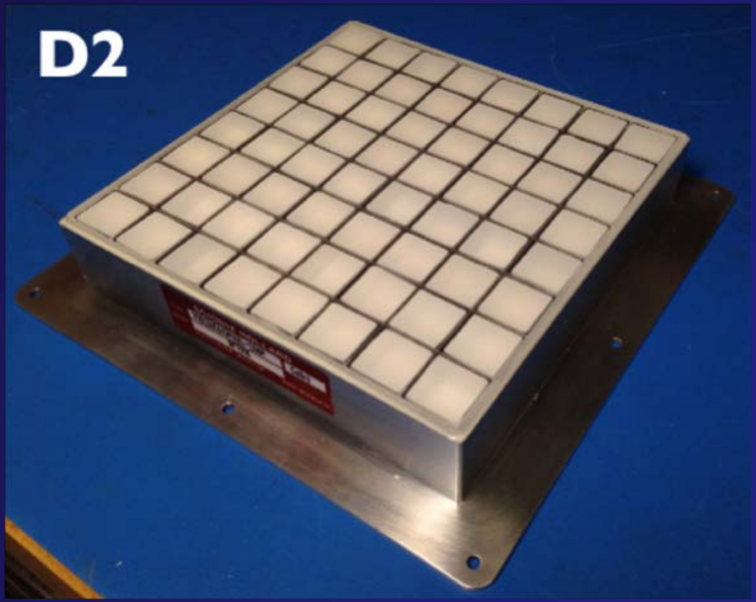


P-terphenyl for D1

- Low Z
- Fast Decay Time
- High light output
- Mechanically robust

- Scintillator elements purchased from Proteus, Inc., and screened by UNH undergraduate Alex Wright
- Elements assembled into 8 × 8 module arrays inside Delrin housings
- Separated by slats of white Gigahertz Optik material

ASCOT D2: $CeBr_3$



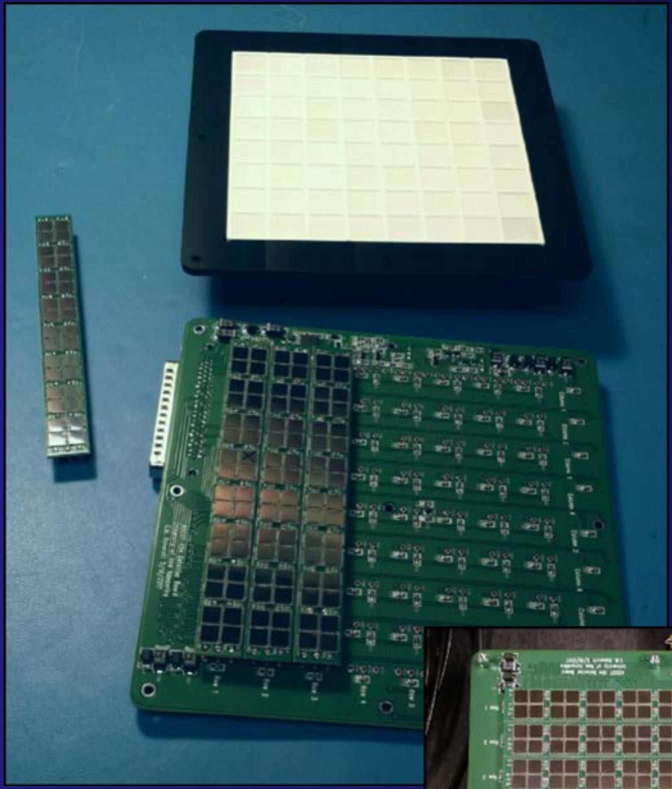
$CeBr_3$ for D2

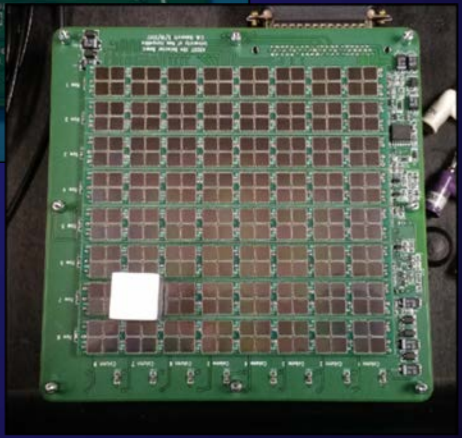
- High stopping power
- Fast timing
- Superior energy resolution

- 8 × 8 vacuum-rated arrays provided by BNC/Scionix
- Al housing with common optical window for all pixels – causes some optical cross talk, light loss

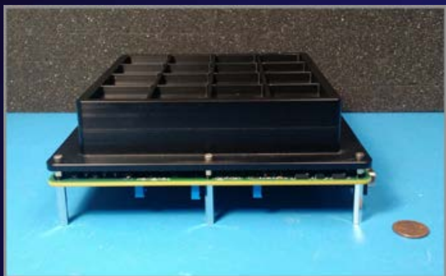
SiPM Readout

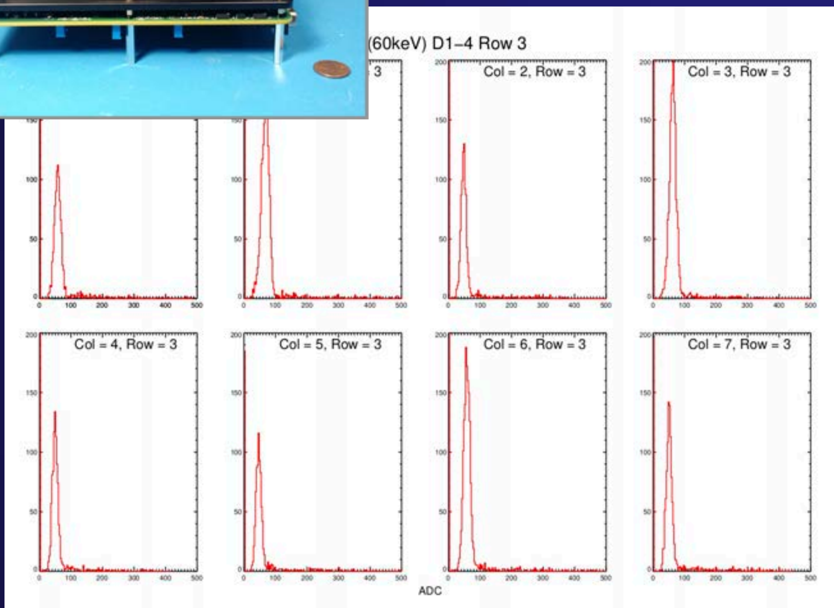
- Each scintillator element read out with 2 × 2 array of SensL MicroFC-60035-SMT 6-mm SiPMs
- SiPMs mounted on custom “strip” boards by IMS Corp (Manchester, NM): one strip per module row
- Strips plugged into module array board: FEE and bias voltage (~29 V) with passive temperature-based gain correction

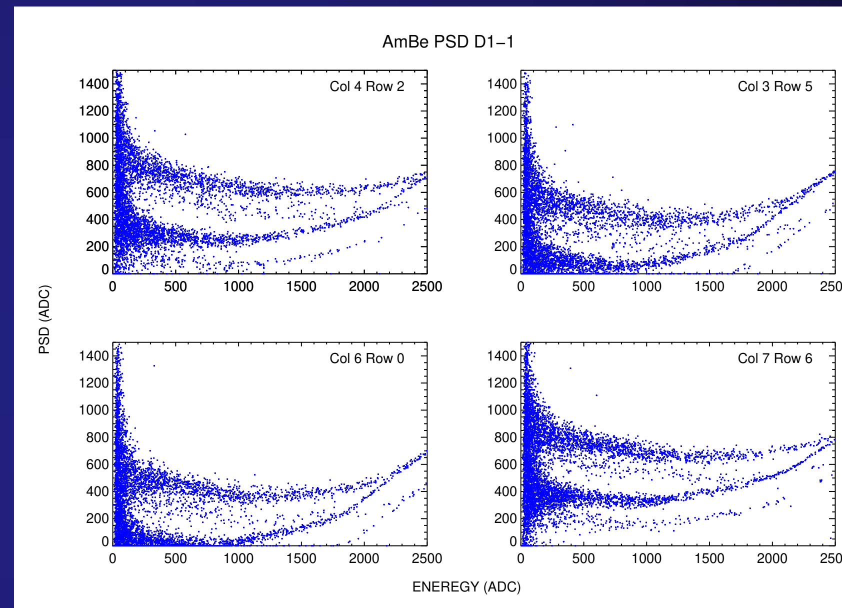




D1 Module Performance



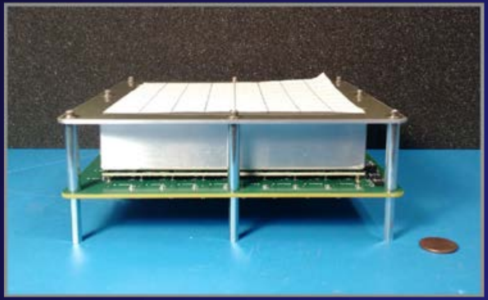


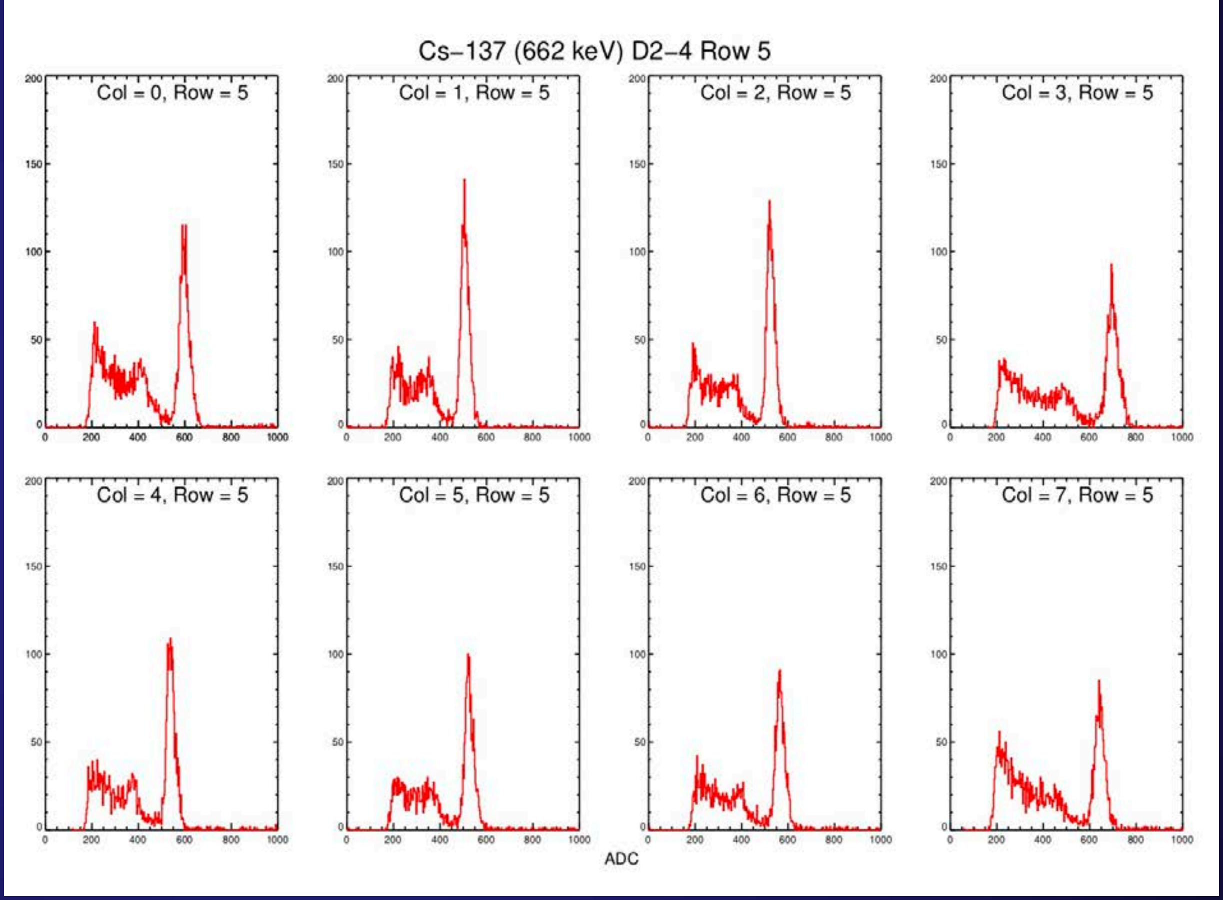


- 60 keV photopeak ~30% (FWHM) energy resolution
- Trigger threshold ~35 – 40 keV

- Pulse-shape discrimination (PSD) vs. pulse height
- Measured using AmBe source
- Can discriminate gamma-ray vs. neutron scatters

D2 Module Performance

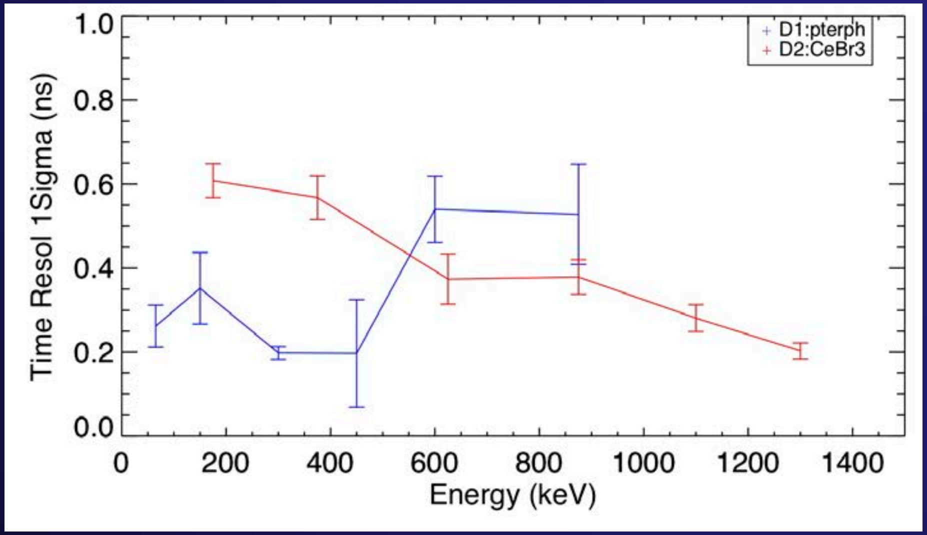


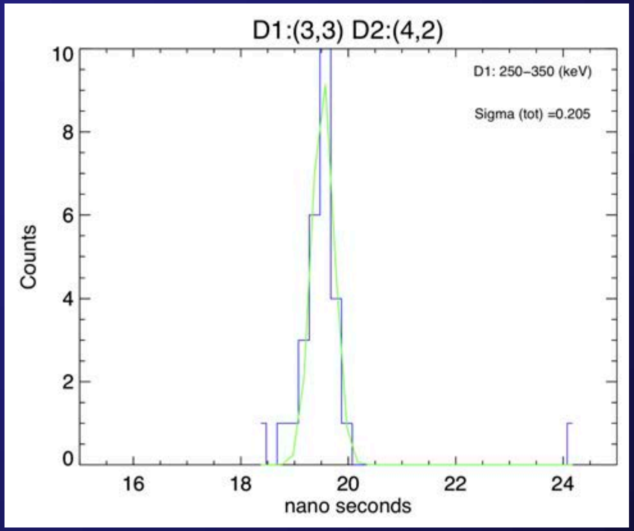


- 662 keV photopeak ~6% (FWHM) energy resolution
- Trigger threshold set at ~200 keV

Time of Flight

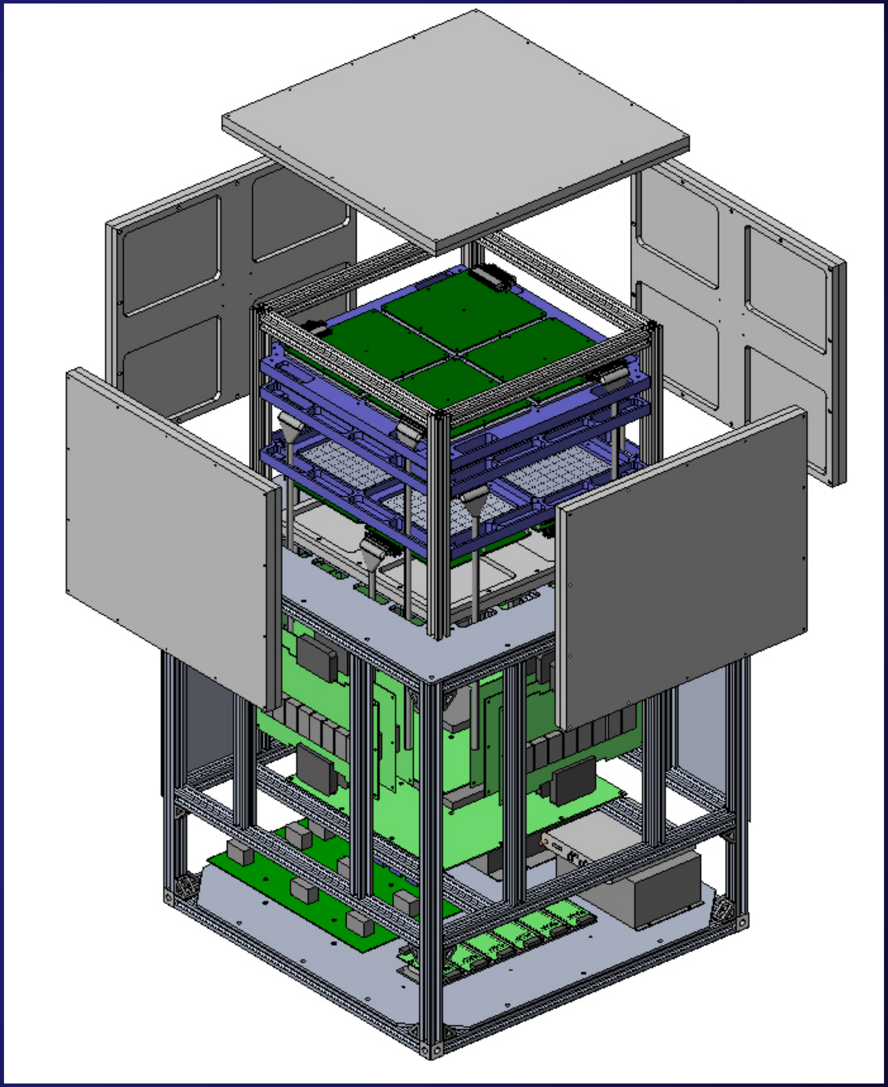
- Measured ToF resolution between D1 & D2 pixel pairs using ^{60}Co
- We see some PH-dependent walk in timing – fit and correct
- Timing resolution vs. energy measured in one detector by keeping other detector energy fixed
- For D1, resolution worsens above ~500 keV due to cross-talk between rows (timing dominated by low-light row)
- For ~300 keV in D1 & ~1400 keV in D2, get ~480 ps (FWHM)



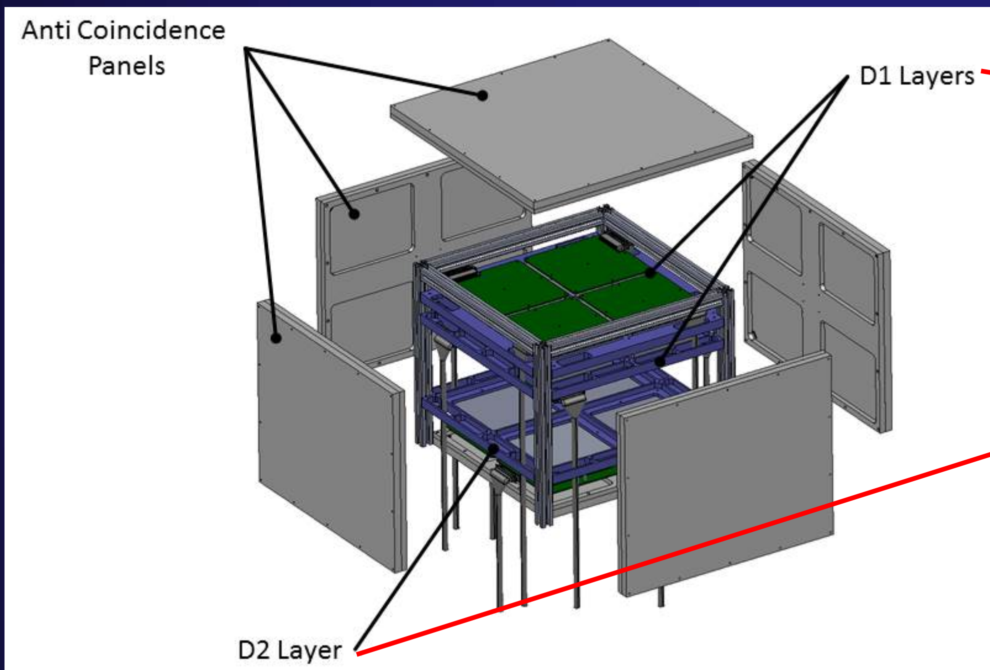


ASCOT Balloon Instrument

- Detector modules and VETO panels
- Electronics boards
- Flight computer
- Regulators, relay board, and science stack



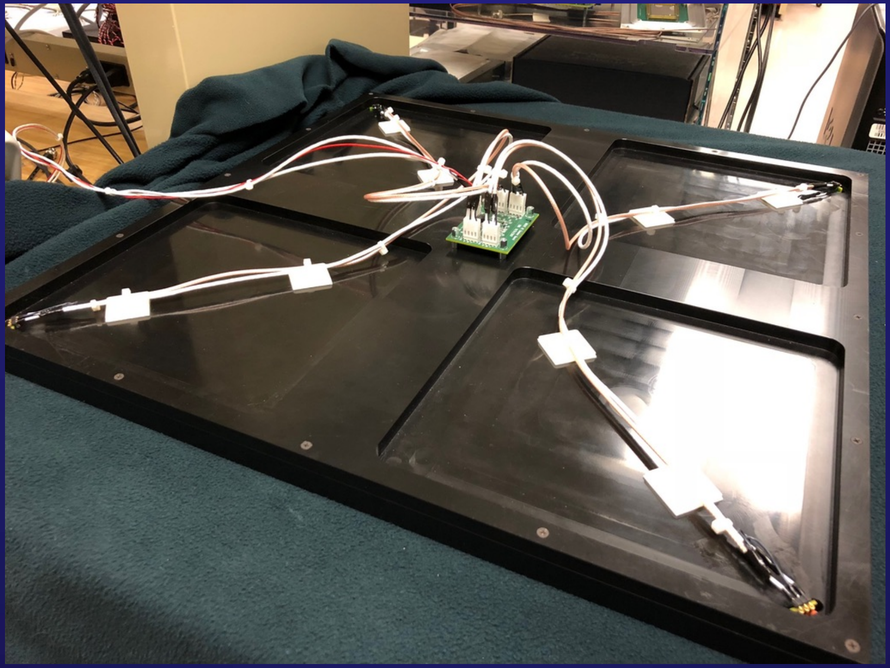
ASCOT Instrument Assembly



Instrument support structure made of plastic to reduce activation

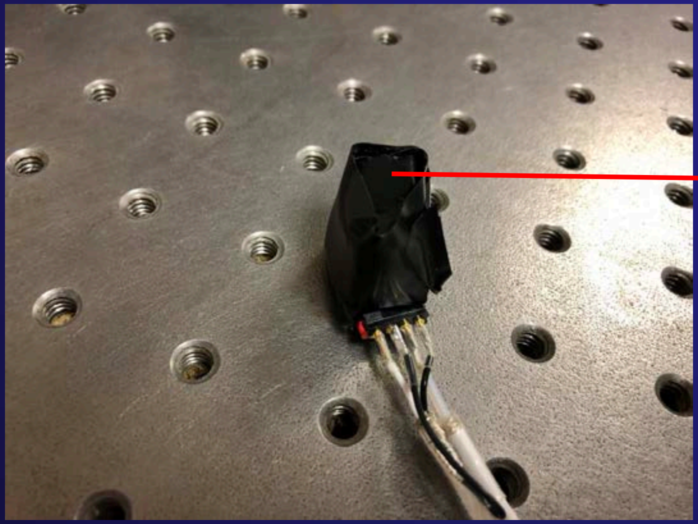
ASCOT Anti-Coincidence Panels

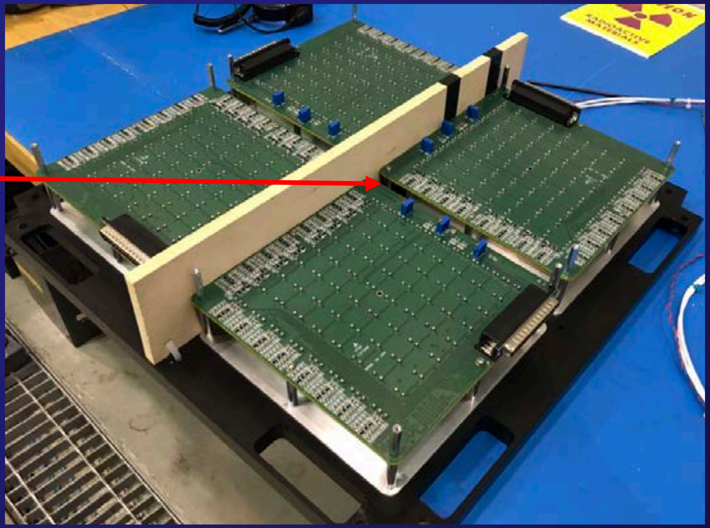
- Anti-panels surround detector modules on six sides to reject charge particle events
- 5-mm thick plastic sheets held in Delrin frames
- Read out by 6-mm SensL SiPMs on four corners



ASCOT Tagged Source

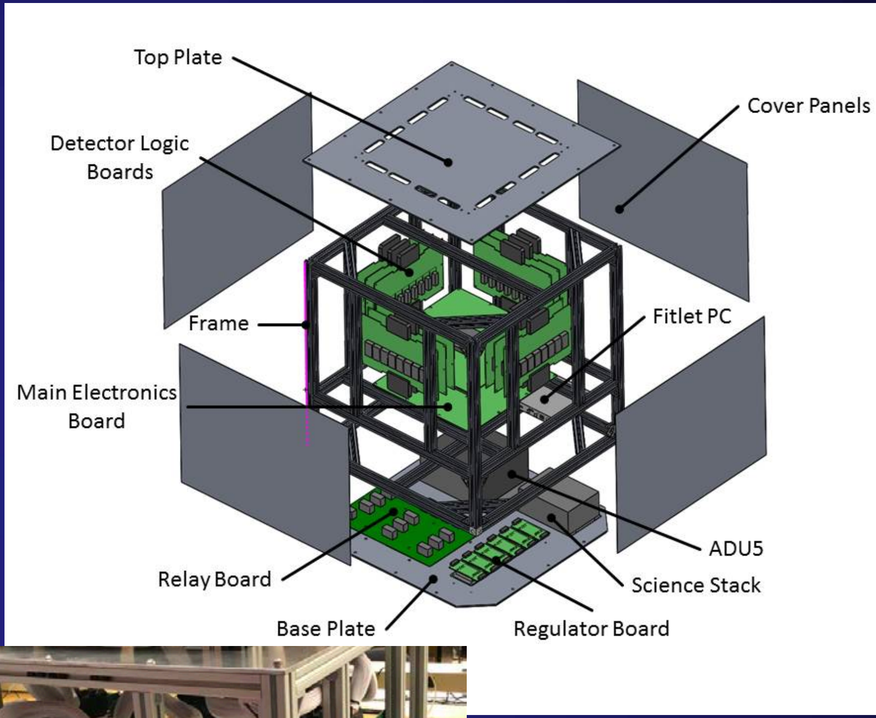
- A tagged source consisting of plastic scintillator infused with ^{60}Co (< 50 nCi) is located between the four D2 modules
- Light read out by another SensL SiPM
- Provided in-flight calibration

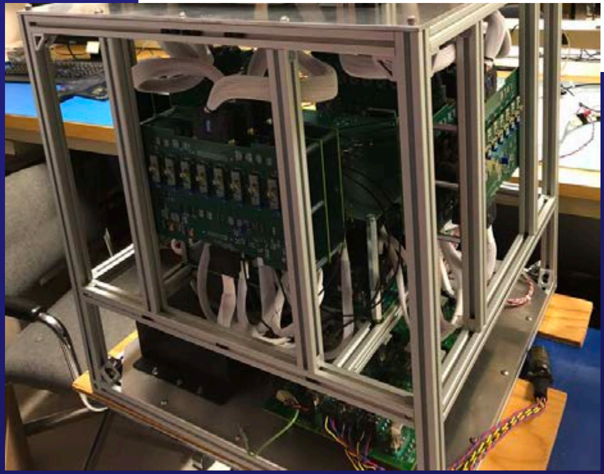




ASCOT Electronics

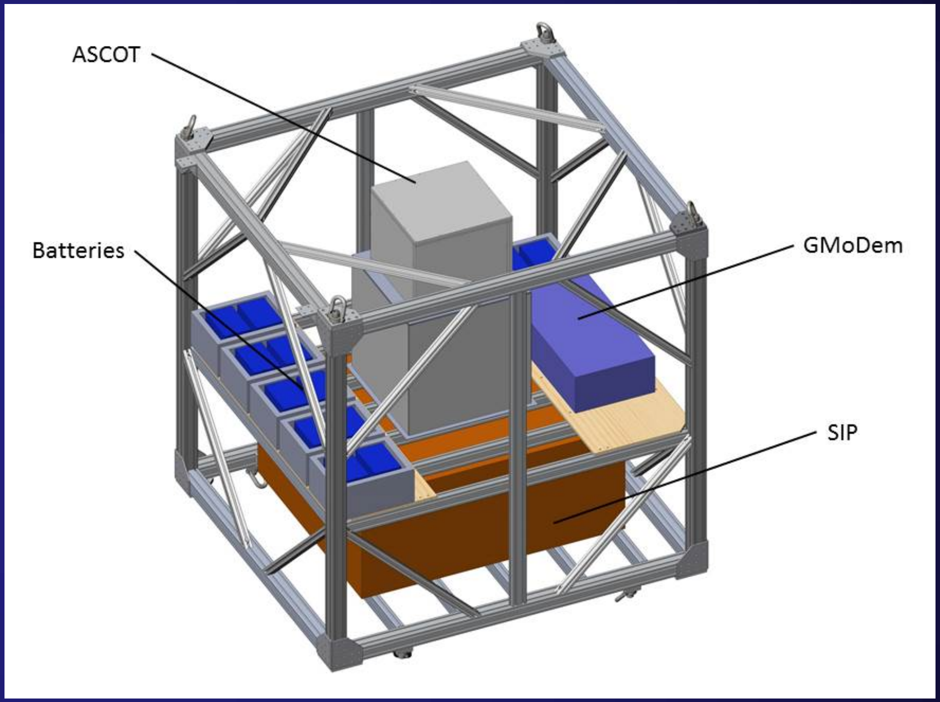
- Electronics box contains "logic board" for each module
- ToF board records timing
- Module interface board (MIB) contains FPGA for data acquisition
- Fitlet-H computer controls instrument, records data onboard, and sends to telemetry
- Relay board, controlled by science stack, interfaces batteries to regulators
- ADU5 GPS controller





ASCOT Payload

- Based on GRAPE payload (2011 & 2014)
- Instrument held in gondola frame made of 8020 extruded aluminum
- Batteries and GMoDem piggyback payload mounted on platform
- Mini-SIP mounted below
- ADU5 GPS provides attitude knowledge (no pointing)



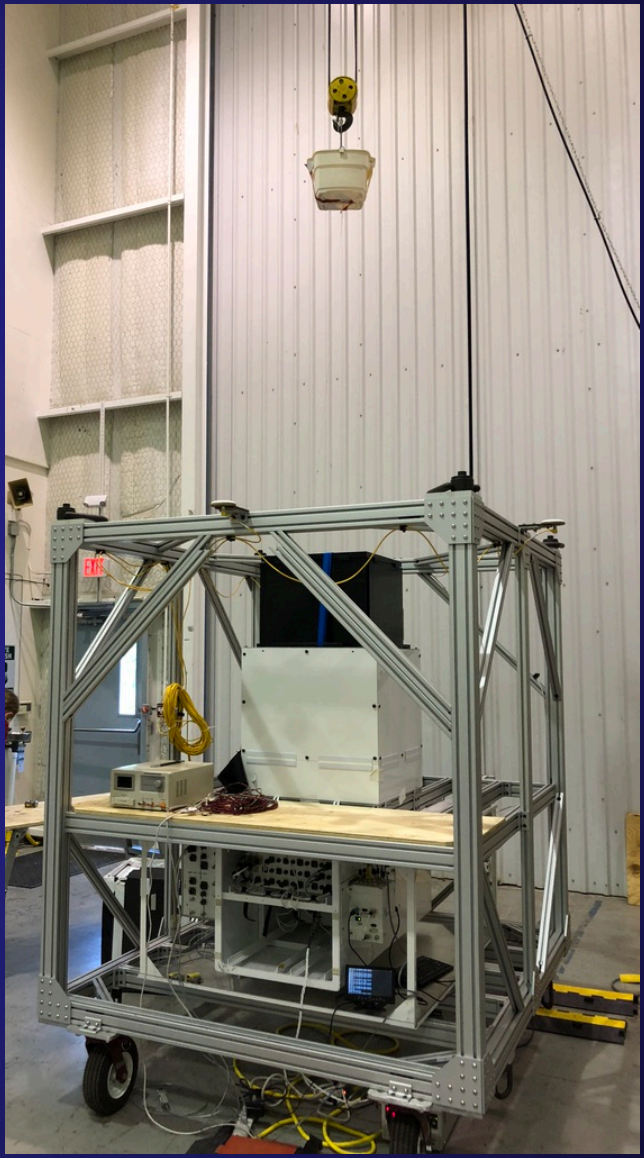
ASCOT BALLOON FLIGHT

ASCOT Balloon Campaign

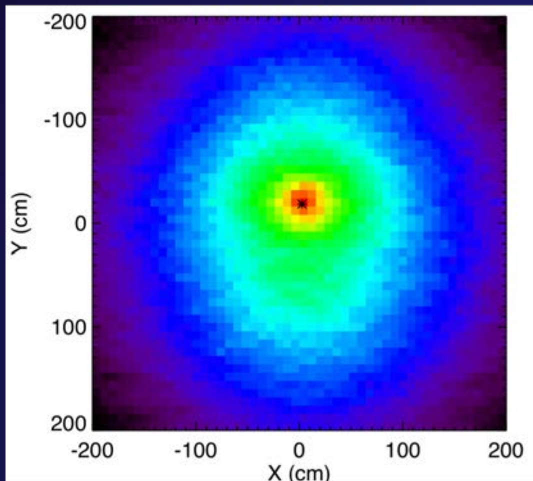
- Arrived at NASA/CSBF in Palestine, TX, on June 3, 2018
- Declared flight ready June 14
- Weeks of poor weather…

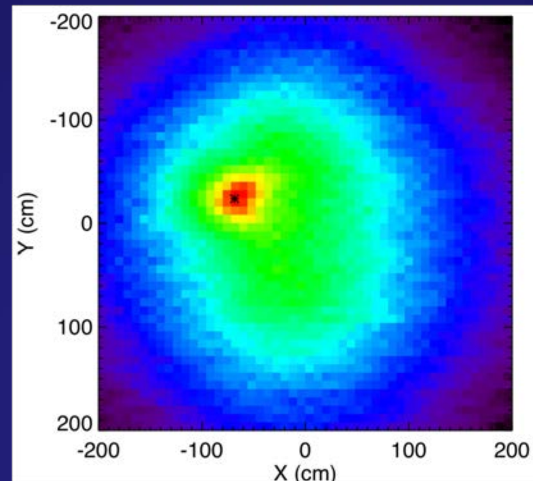
Imaging Tests

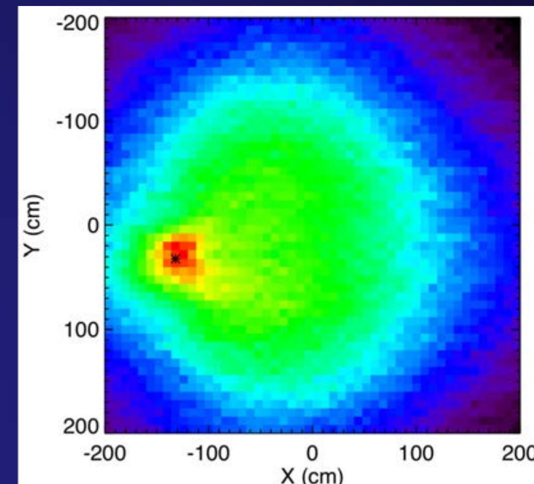
- While in the hangar, suspended ^{60}Co source above instrument using crane
- Recorded data with source in three different locations

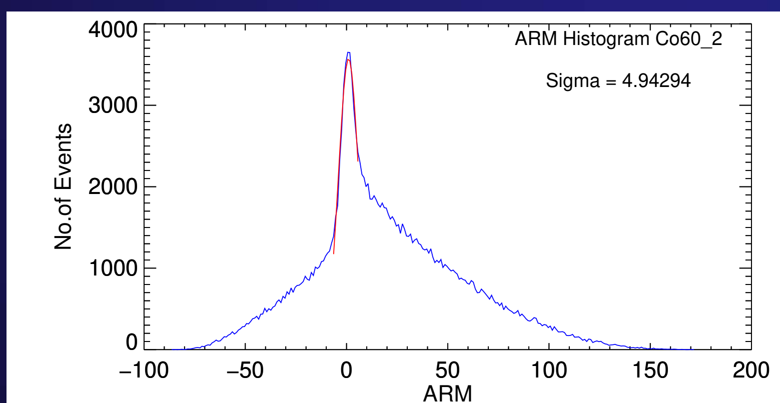


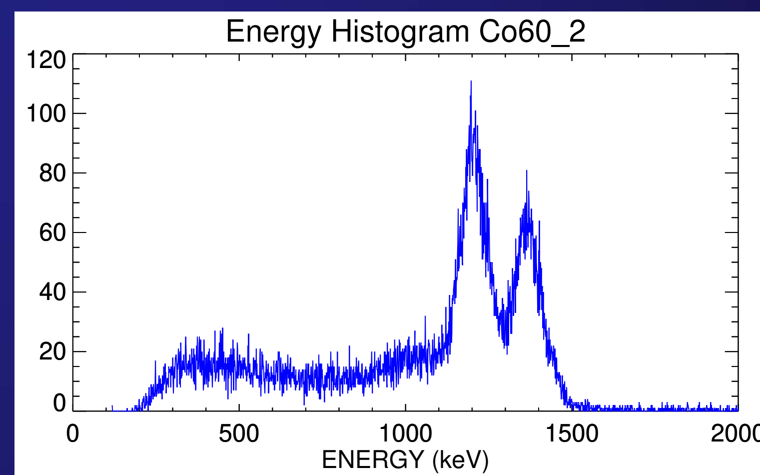
Imaging Tests









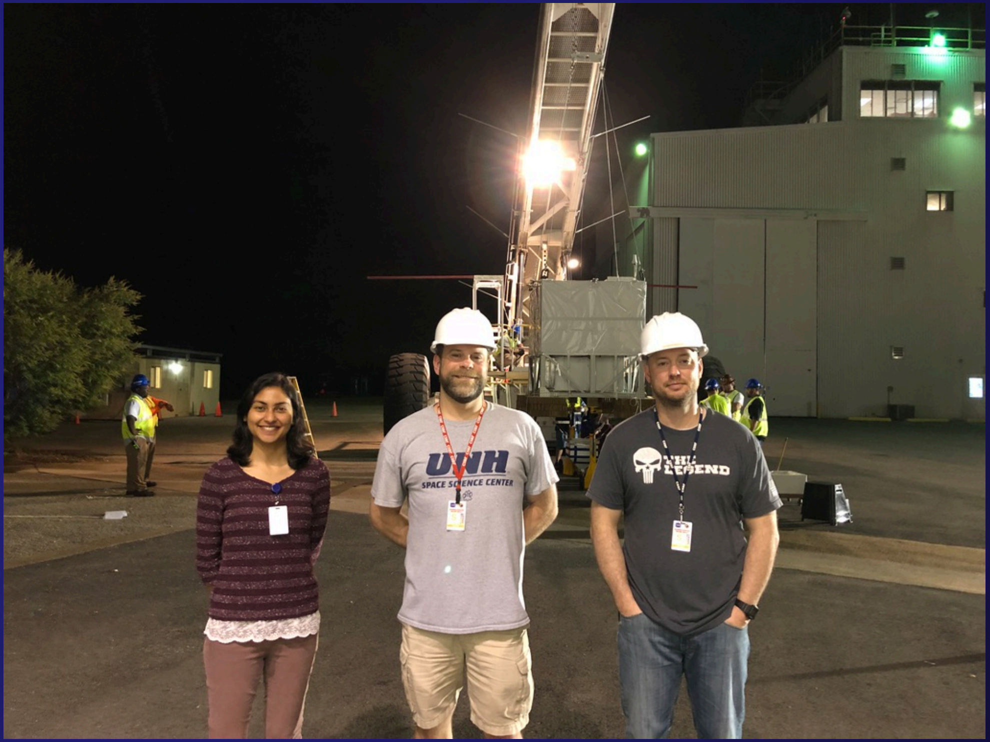


UNH energy calibration needs to be corrected using tagged source

ASCOT Balloon Launch

Launch attempts June 30, July 1, 2, 3

Finally got perfect conditions on July 5

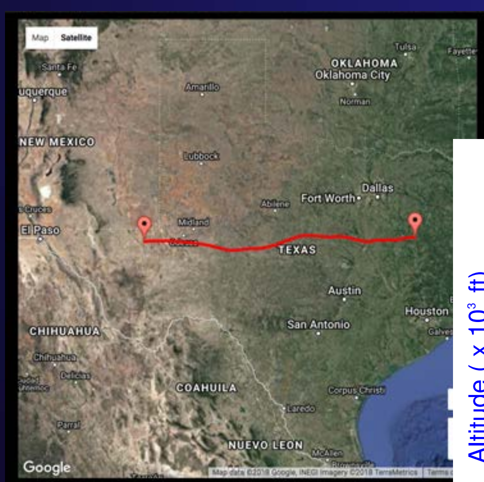


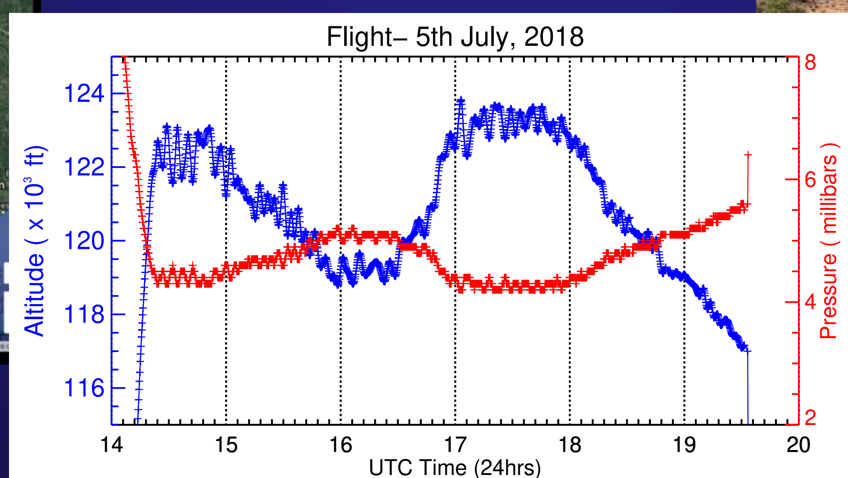
ASCOT Balloon Launch

Launched on July 5th at 7:12 AM CDT

ASCOT Balloon Flight

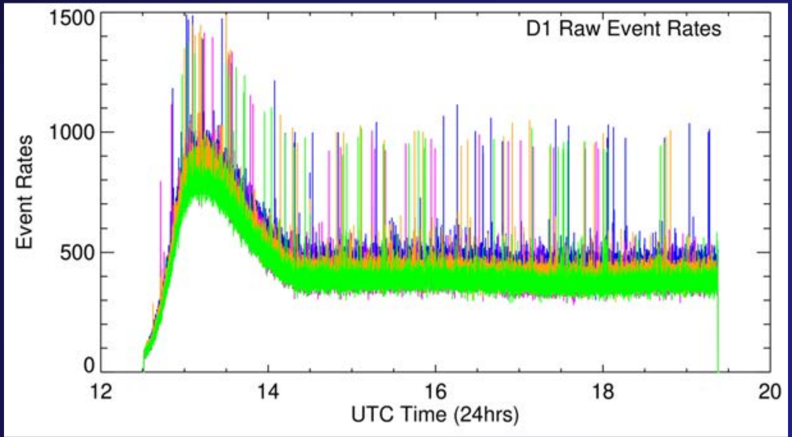
- Flight achieved float altitude of 119,000 – 123,000 feet
- Stayed at float for five hours while Crab was high in the sky
- Payload flew west at 50 – 75 kts, terminated in West Texas near Pecos
- Flight data and payload recovered with no issues

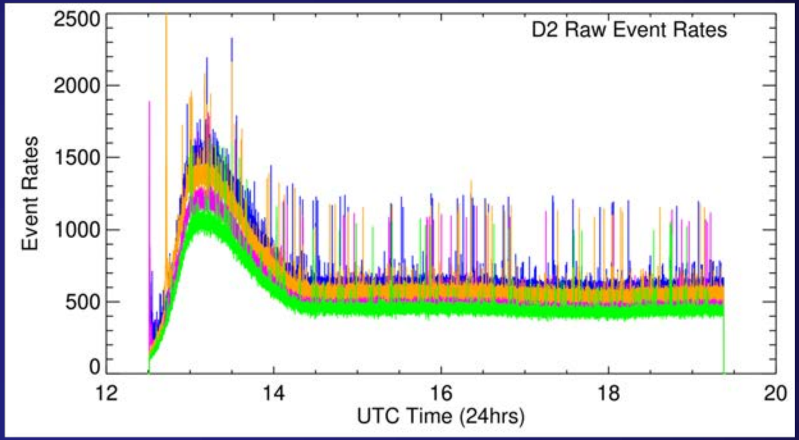




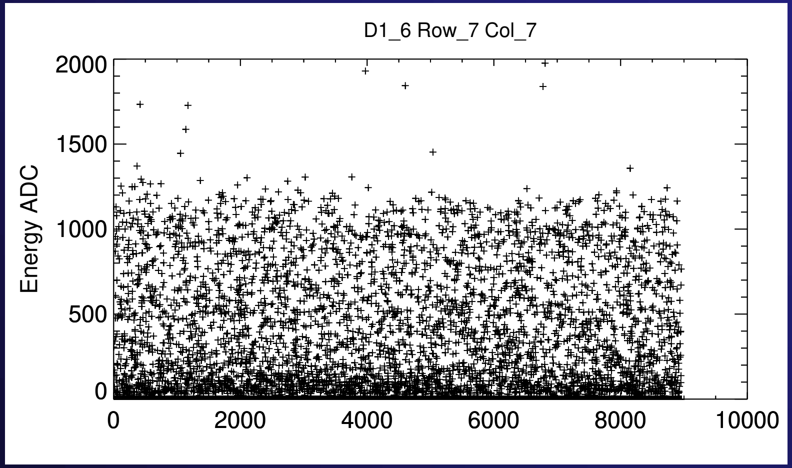
ASCOT Flight Data - Preliminary

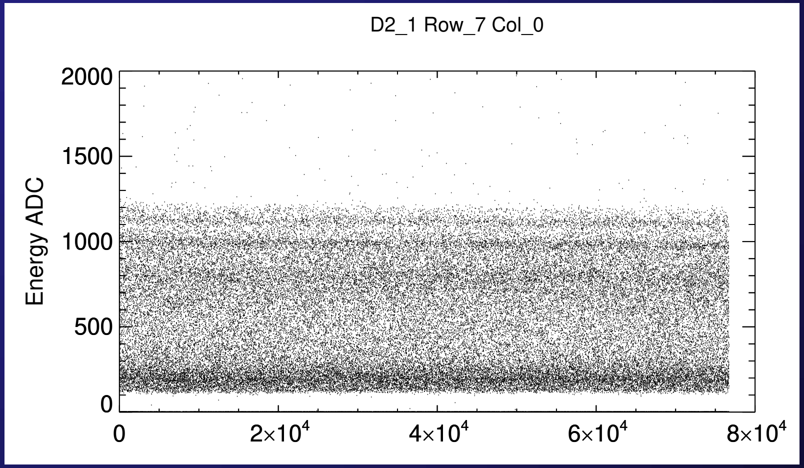
Early indications are that all detectors functioned well:





Tagged events show that the gain was ~stable:

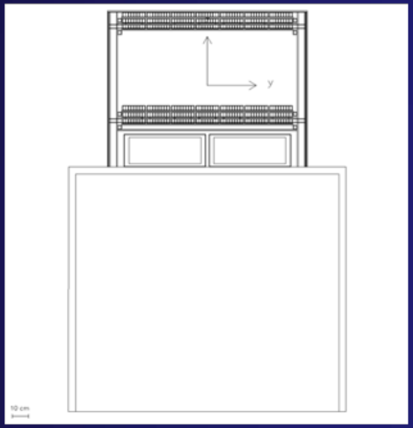


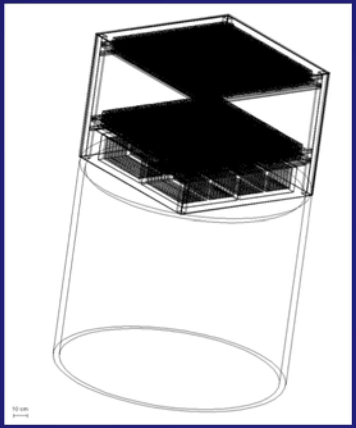


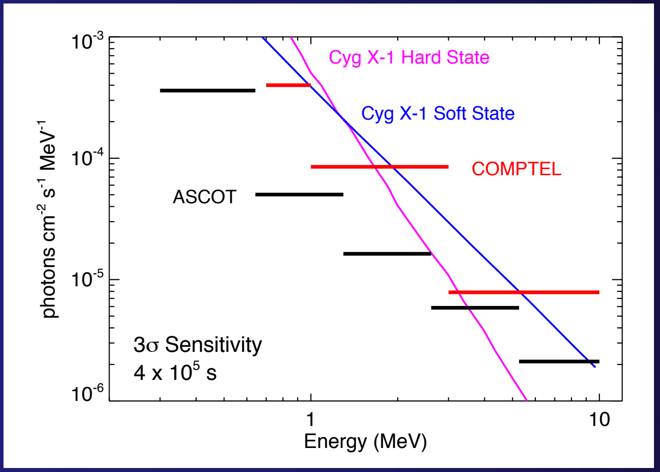
FUTURE DIRECTIONS

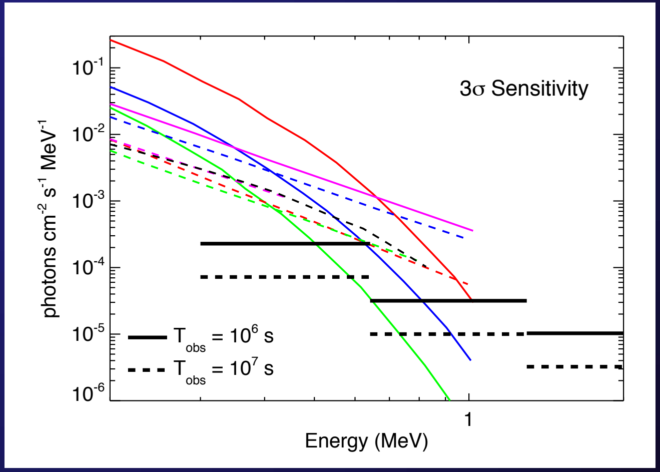
Simulation of Potential Explorer Mission

A few years ago, made a first stab at estimating performance of MIDEX:





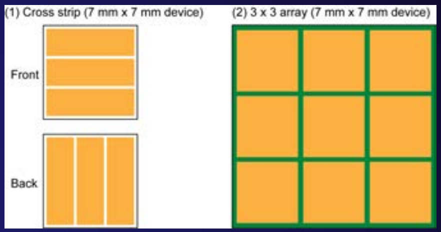


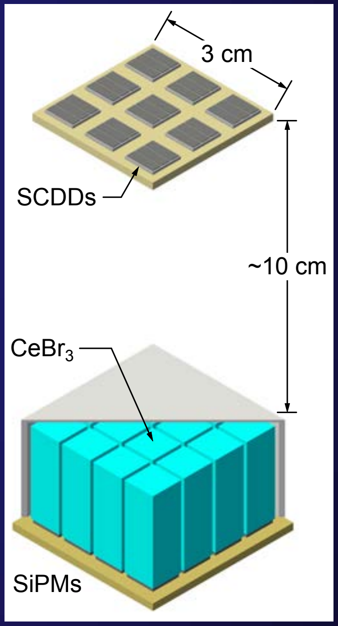


- Explorer-sized instrument concept
- Three D1 layers and three D2 layers, 50 cm separation
- Estimate 120 × 120 × 100 cm^3 instrument, ~1000 kg payload
- Simulate response and background
- ~8× better continuum sensitivity than COMPTEL

Diamond Detectors for D1

- Limiting factor currently is D1 organic scintillator: low light output causes poor energy and ToF resolution at low energy
- Low density requires large volumes for good efficiency
- Possible solution? **Single Crystal Diamond Detectors**
- Almost pure carbon, 3.5 g/cm^3, good position and energy resolution, very fast timing, radiation hard, light and temperature insensitive
- Currently very small (< 1 cm^2) and expensive
- Have recently begun APRA project (collaboration with SwRI) to study SCDD performance as Compton scattering elements for Compton telescopes
- If performance is a good as hoped, ***and if can be made larger/cheaper***, could enable even smaller MeV gamma-ray missions (SmallSats??)





Conclusions

- The recent ASCOT balloon flight has demonstrated the stable operation of scintillator/SiPM detectors in a near-space environment
- Flight data analysis has just begun – expect to image Crab Nebula ~0.2 – 2 MeV
- New detector technologies offer the potential for smaller-scale missions that will still accomplish exciting new science
- We may yet see medium-energy gamma-ray astronomy move forward in our lifetimes!