The Advanced Scintillator Compton Telescope (ASCOT) Balloon Project

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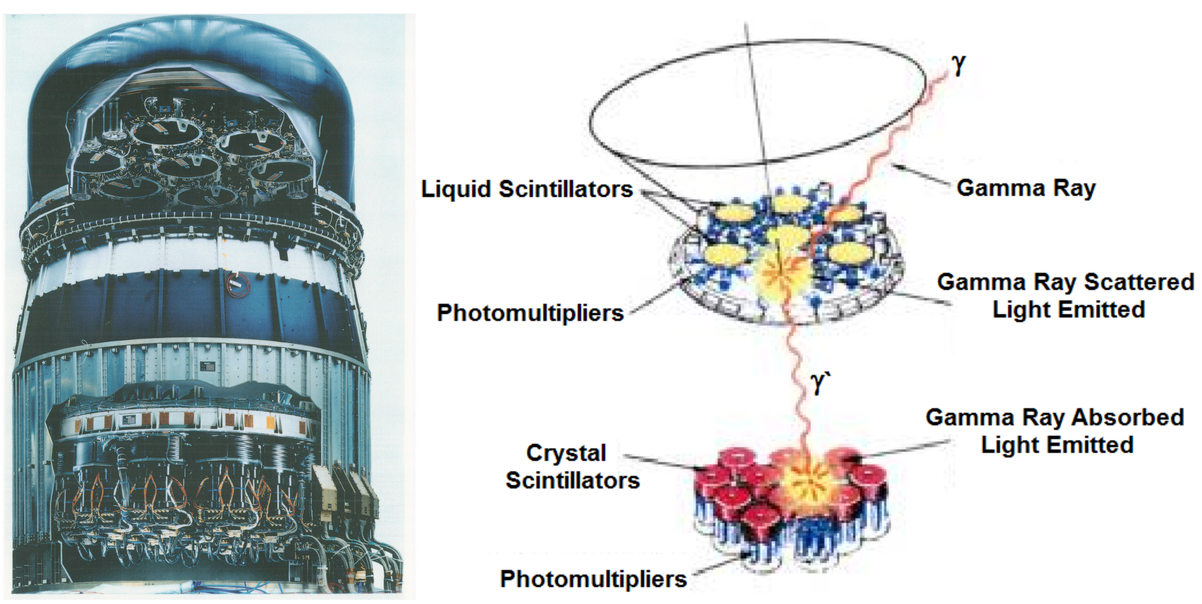
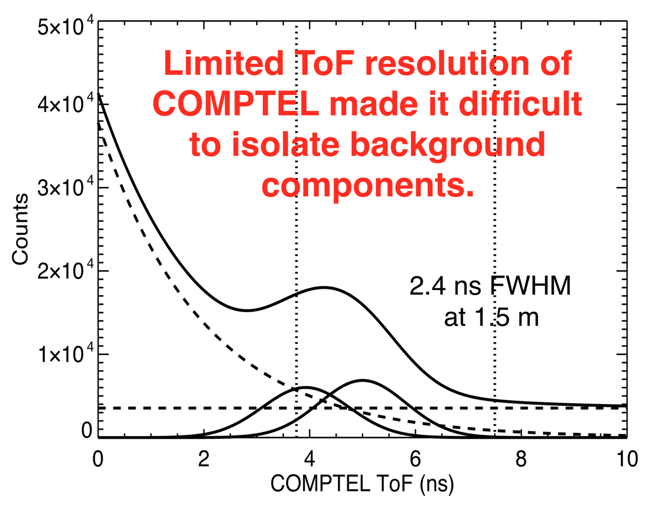
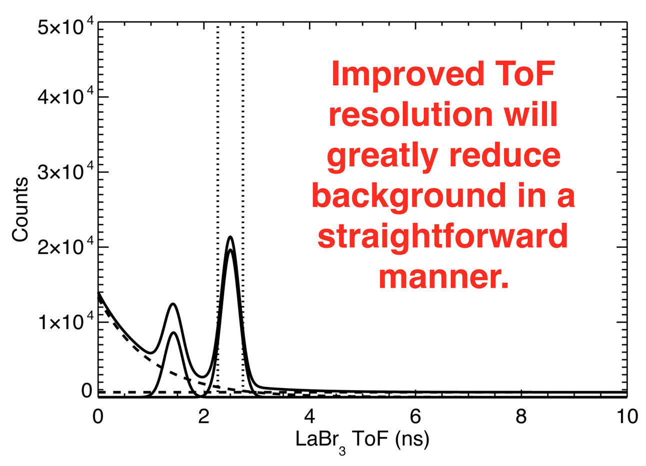
There is an urgent need in high-energy astronomy for a medium-energy gamma-ray mission covering the energy range from approximately 0.4 - 20 MeV to follow the success of the COMPTEL instrument on CGRO. We believe that directly building on the legacy of COMPTEL, using relatively robust, low-cost, off-the-shelf technologies, is the most promising path for such a mission to become reality. High-performance scintillators, such as Lanthanum Bromide ($LaBr_3$), Cerium Bromide ($CeBr_3$), and p-terphenyl, and compact readout devices, such as silicon photomultipliers (SiPMs), are now commercially available. We have conducted two balloon flights of prototype instruments to test these technologies. The first, in 2011, demonstrated that a Compton telescope consisting of a liquid organic scintillator scattering layer and a $LaBr_3$ calorimeter effectively rejects background under balloon-flight conditions using time-of-flight (ToF) discrimination. The second, in 2014, showed that a telescope using an organic stilbene crystal scattering element and a $LaBr_3$ calorimeter with SiPM readouts can achieve similar ToF performance. We are now beginning work on a much larger balloon instrument, an Advanced Scintillator Compton Telescope (ASCOT), with the goal of imaging the Crab Nebula at MeV energies in a one-day flight. If successful, this will demonstrate that the energy, timing, and position resolution of this technology are sufficient to achieve an order of magnitude improvement in sensitivity in the medium-energy gamma-ray band, were it to be applied to a ~1 cubic meter instrument on a ULDB or Explorer platform.

CGRO / COMPTEL and ToF

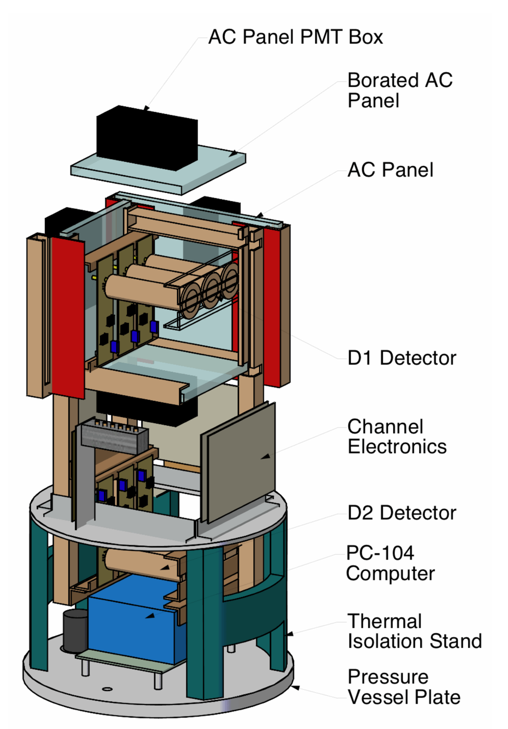


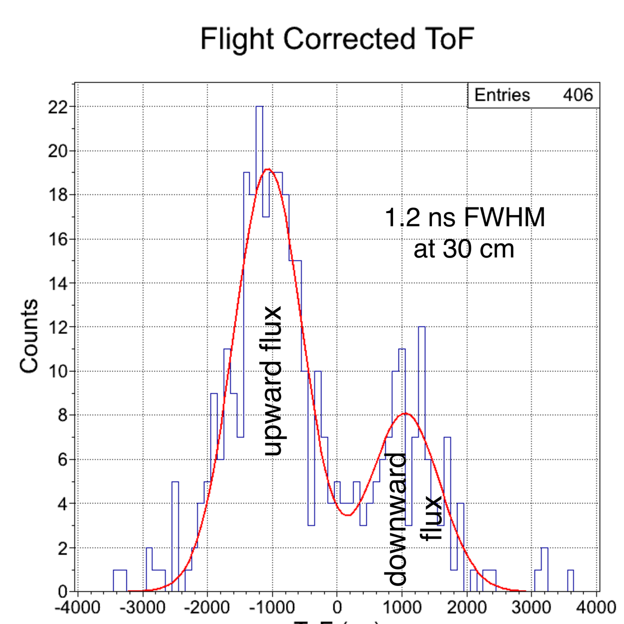


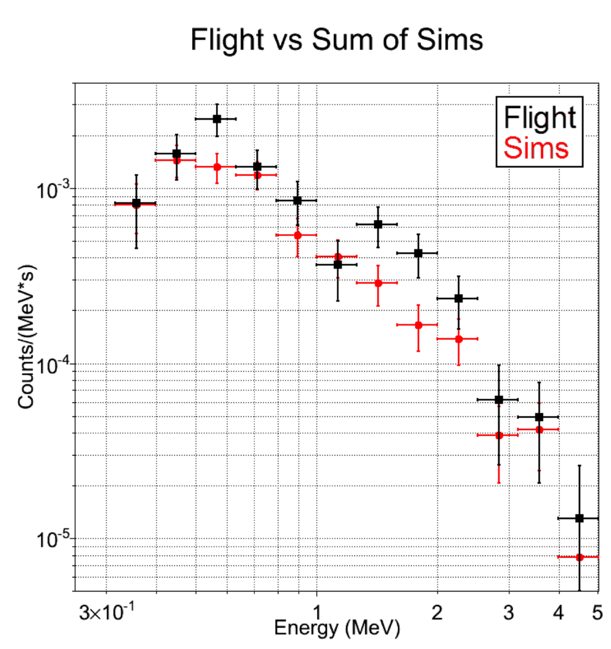


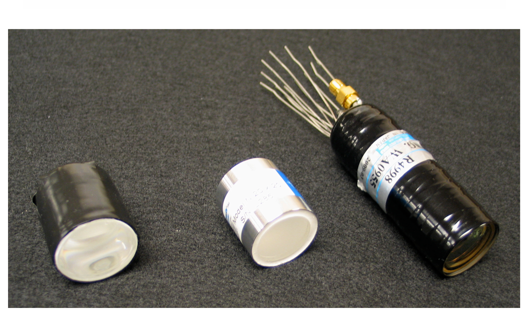
The COMPTEL instrument on CGRO was a double-scatter instrument (D1 - liquid scintillator D1 / D2 - NaI(Tl)) capable of imaging 0.75-30 MeV gamma rays. With a D1-D2 separation of 1.5 m, it relied on both pulse shape discrimination (PSD) and Time-of-Flight (ToF) to identify and reject various background components (e.g., neutrons and activation of passive materials). The ToF proved to be a crucial aspect of COMPTEL data analysis. We believe that ToF techniques utilizing the latest technologies offer a significant advantage for future Compton telescopes.

2011 Balloon Flight - FACTEL









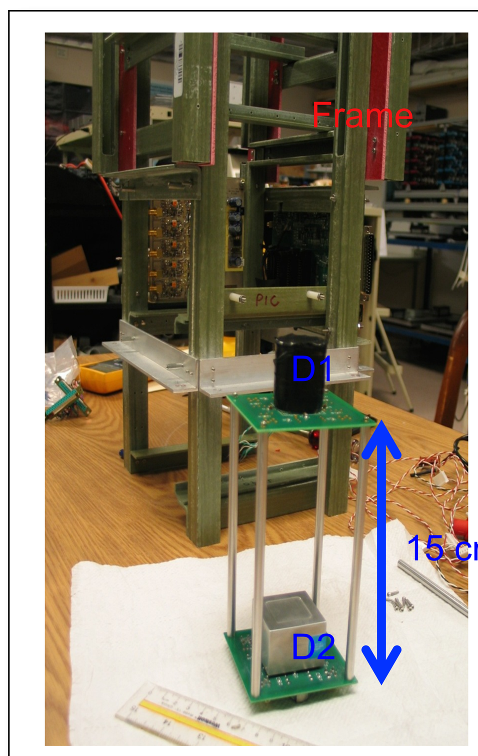
liquid LaBr₃ PMT

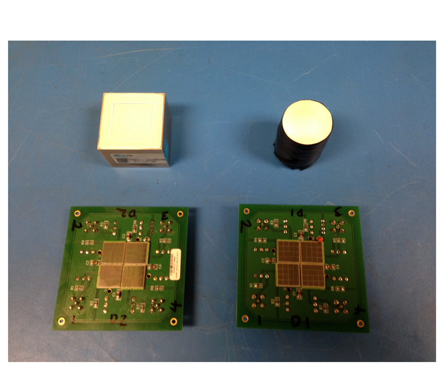
Fast Compton Telescope (FACTEL)

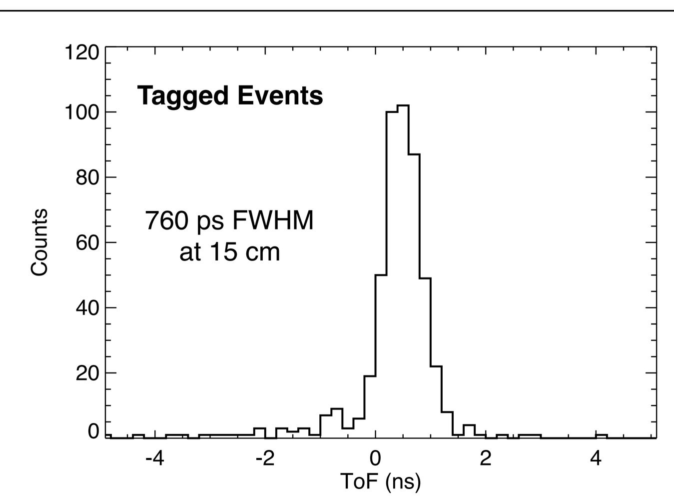
Demonstration of New Scintillator Technology ($LaBr_3$)

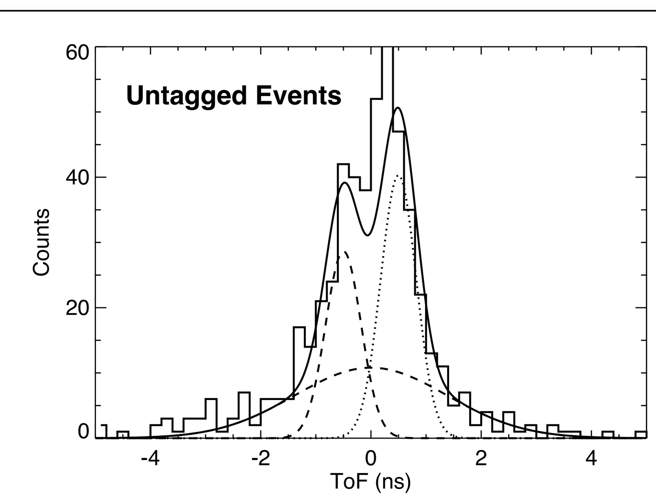
Compton telescope consisting of three 1-inch liquid organic scintillators (D1) and three 1-inch $LaBr_3$ scintillators (D2). Both very fast scintillators (3 ns and 16 ns, respectively), all read out by fast PMTs. Payload remained at float for 26 hours. ToF spectrum clearly separates upward and downward fluxes, even at 30 cm separation. Flight background consistent with simulated spectrum.

2014 Balloon Flight - SolCompT









Solar Compton Telescope (SolCompT)

Demonstration of New Readout Technology (SiPM)

Silicon photomultipliers (SiPMs) offer fast readout in a compact, low-power, rugged package, ideal for space applications. SolCompT was a small Compton telescope consisting of one D1 detector (1-inch organic stilbene with 5 ns decay time) and one D2 detector (1-inch $LaBr_3$ with 16 ns decay time), both read out by SiPMs (Hamamatsu S11828-3344 MPPCs). A tagged ^{60}Co source (~240 nCi) was used to monitor gain and energy resolution throughout the 3.5 hour flight. Background ToF spectrum somewhat harder to interpret due to small separation (15 cm).

New Scintillators and SiPMs

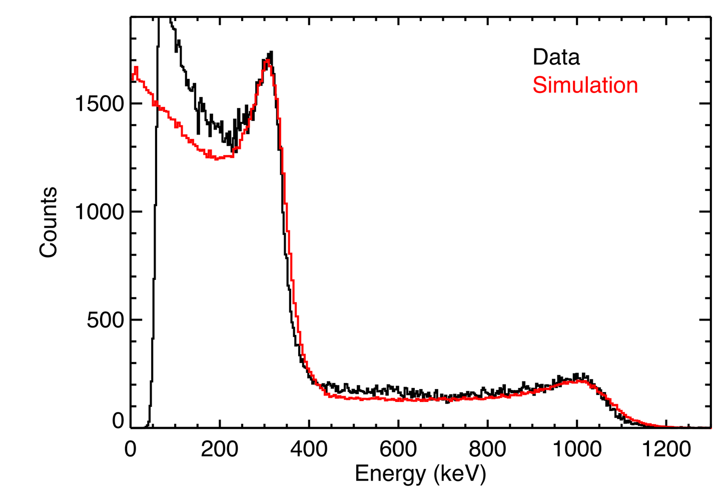
The ASCOT instrument will make use of the latest commercially available scintillators and SiPMs:

D1: The D1 layer will be composed of organic p-terphenyl crystals. P-terphenyl is more robust than stilbene, has a decay time of ~3 ns, and shows good PSD performance.

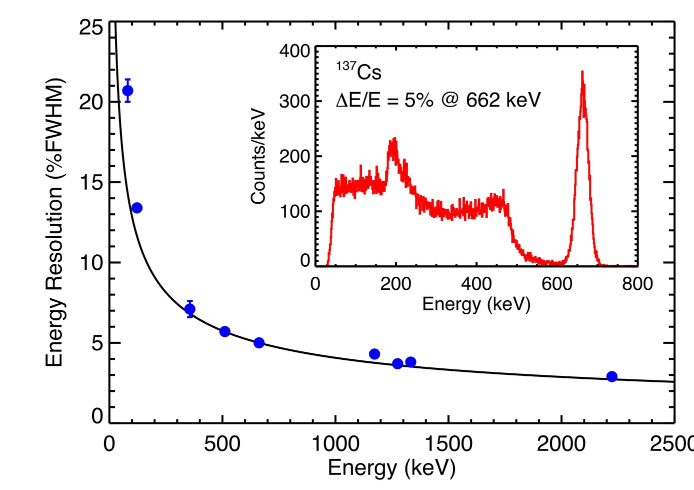
D2: The D2 layer will be composed of inorganic $CeBr_3$. $CeBr_3$ was chosen because it is more easily obtained and has lower intrinsic background than $LaBr_3$.

SiPMs: We have chosen the MicroFC-60035-SMT SiPMs from SensL. These feature low noise, good sensitivity to blue light, and a "fast" output for good timing performance.

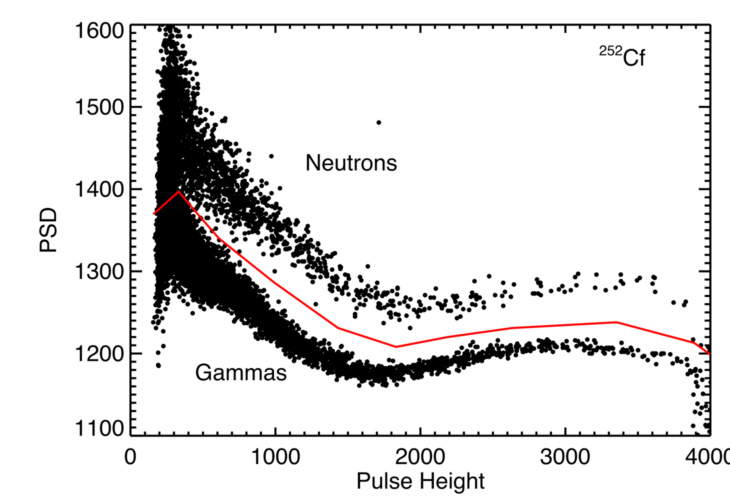
Laboratory test results from single detector elements (using $LaBr_3$) are shown below:



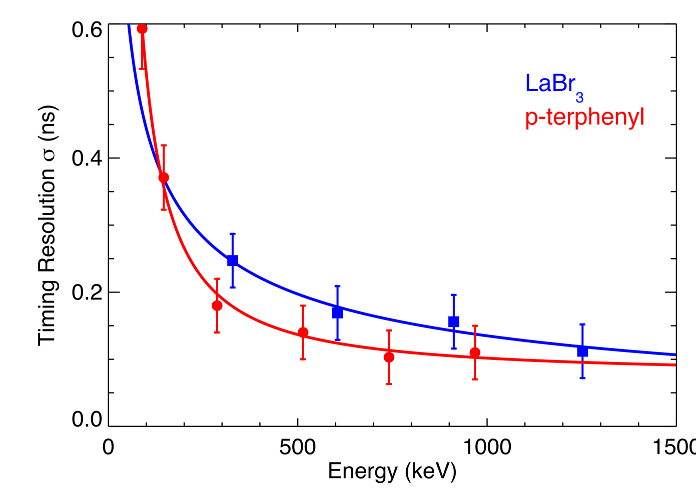
P-terphenyl energy response determined by gamma measurements combined with simulations.



$LaBr_3$ calibrated up to 2.2 MeV with gamma ray calibration sources.

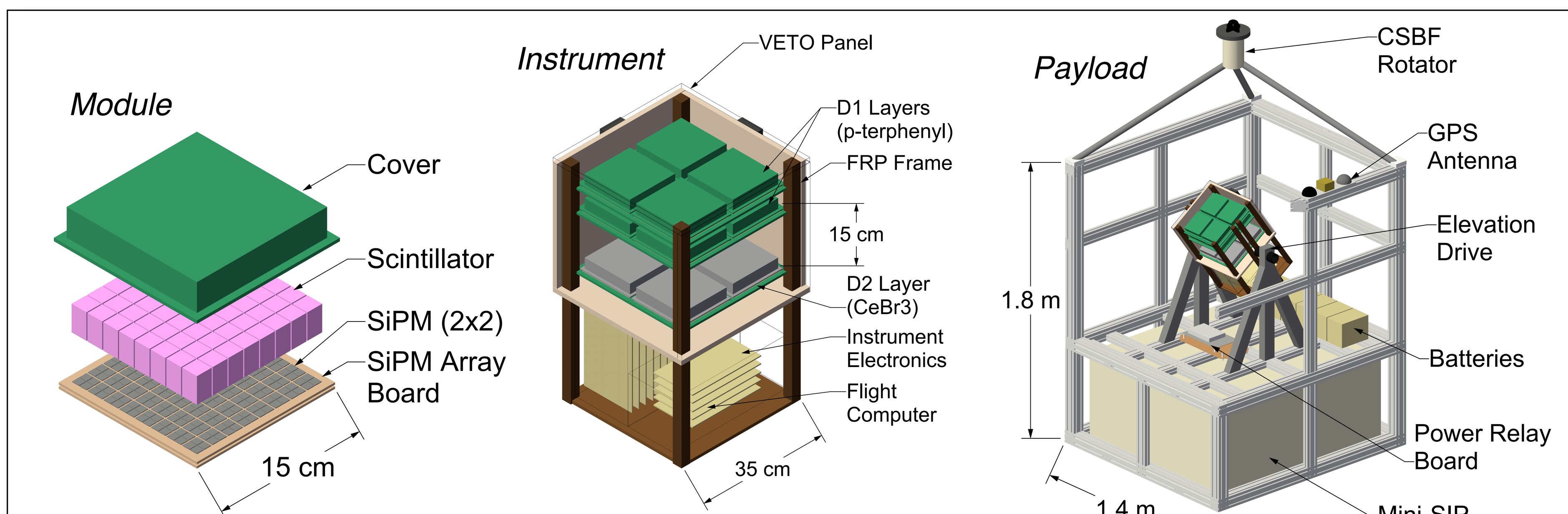


P-terphenyl PSD response determined with ^{252}Cf fission source.



ToF contribution from individual scintillator elements based on calibrations using coincident gamma rays from ^{60}Co source.

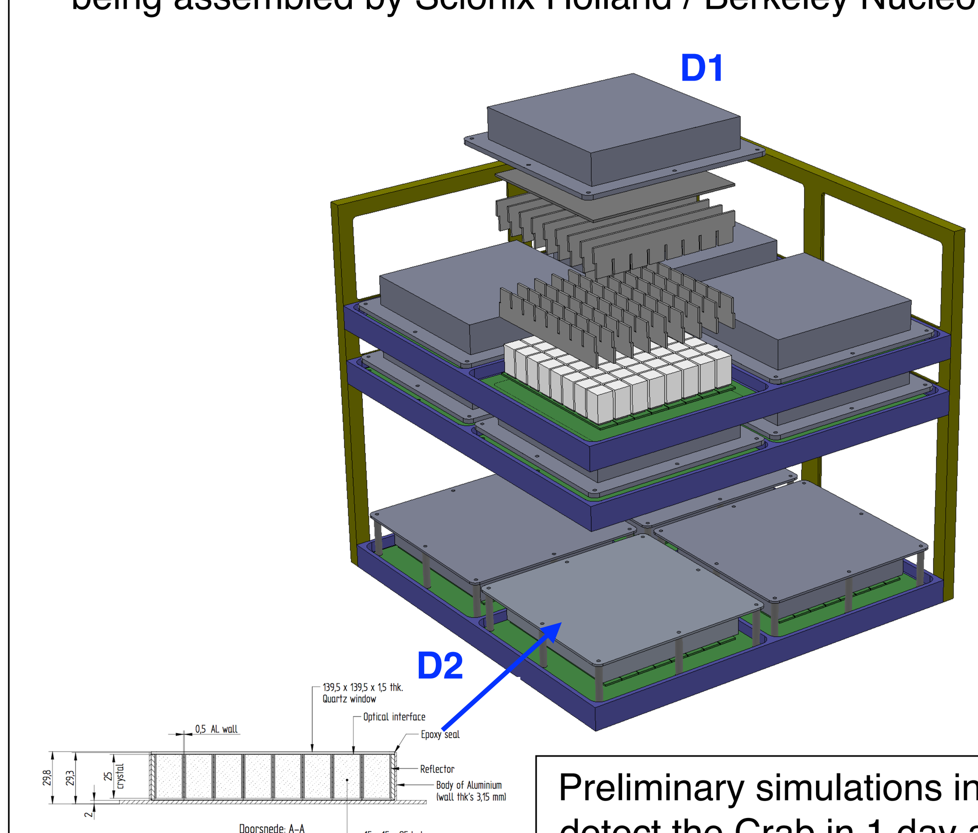
ASCOT Balloon Instrument (2017)

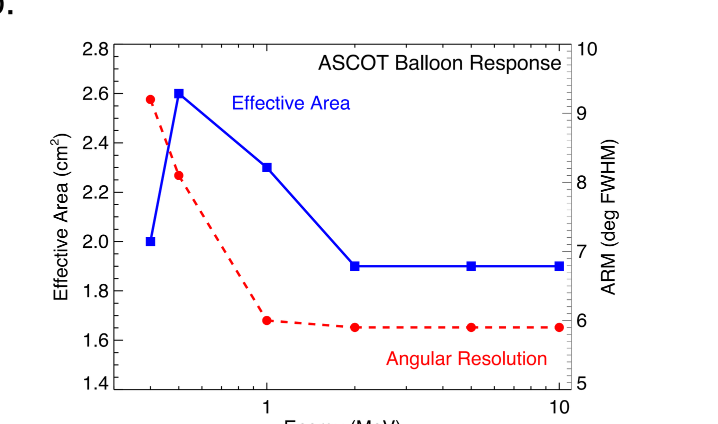


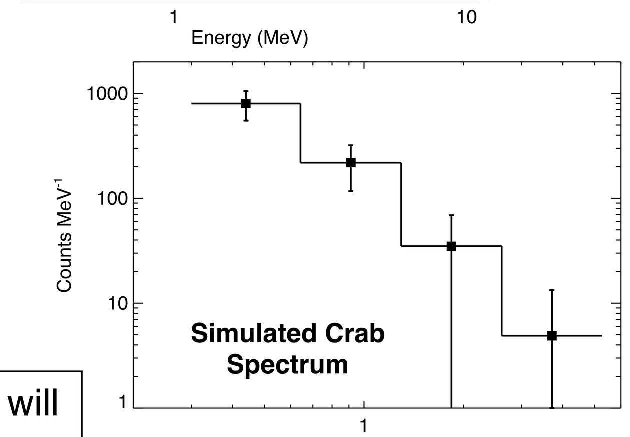
Advanced Scintillator Compton Telescope (ASCOT)

Scientific Validation of the Design

Balloon payload (to be launched in 2017) will be capable of measuring the Crab in a 1-day flight. The telescope consists of two D1 layers (p-terphenyl) and one D2 layer ($CeBr_3$) separated by 15 cm. Smaller separation increases both the effective area and the FoV. Each detector module consists of an 8 x 8 array of scintillator elements (each of which is 15 × 15 × 25 mm³). Scintillator array is read out by an 8 x 8 SiPM array (composed of 8 x 8 array of 2 x 2 SensL SiPM subarrays). Each detector layer consists of a 2 x 2 array of detector modules. The p-terphenyl is being purchased from Proteus, Inc. The $CeBr_3$ arrays are being assembled by Scionix Holland / Berkeley Nucleonics Corp.







Preliminary simulations indicate ASCOT will detect the Crab in 1 day at ~4σ significance

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