



Diamond Scattering Detectors for Gamma-Ray Astronomy

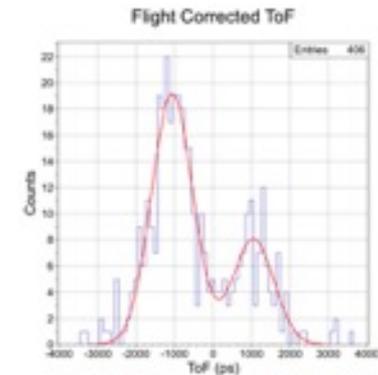
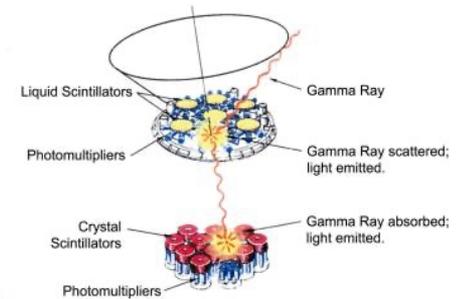
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Los Alamos National Laboratory

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Motivation I

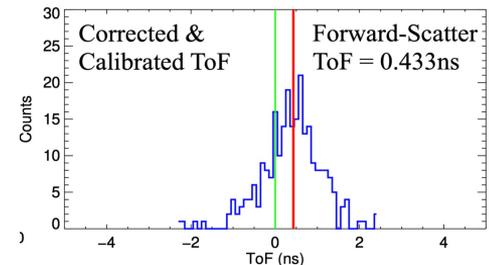
- Overall goal is more sensitive soft-to-medium energy ($\sim 0.1 - 10+$ MeV) gamma-ray instrumentation
- The most successful Compton telescope to date (COMPTEL) relied on **time-of-flight (ToF)** to reject background
- Most modern concepts (COSI, AMEGO) utilize semiconductors for greatly improved energy and position resolution, make compact for efficiency, and use complex event reconstruction, electron tracking, etc. to reject background
 - ToF not possible with these concept
- But, modern detector materials also make improved ToF discrimination possible - keep looking at this!



Liquid organic D1 and LaBr₃ D2

Motivation II

- P. Bloser previously led APRA-funded ASCOT project at University of New Hampshire to try and demonstrate Advanced Scintillator Compton Telescope using p-terphenyl for D1 and CeBr₃ for D2, both with SiPM readout
- Basically worked, though home-brewed SiPM readout only achieved ~1.5 ns (FWHM) ToF resolution
 - Could do better with modern ASIC readout
- **Organic scintillator D1 has fundamental limitations**
 - Low density, requiring large volumes for efficiency
 - Low light output, resulting in energy and timing resolution degradation at low energies
 - Poor position resolution for both reasons
 - Rad tolerance of scintillator and SiPMs

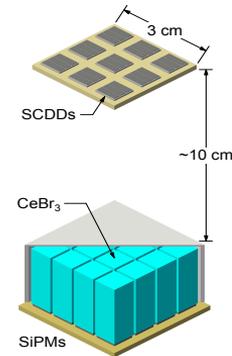
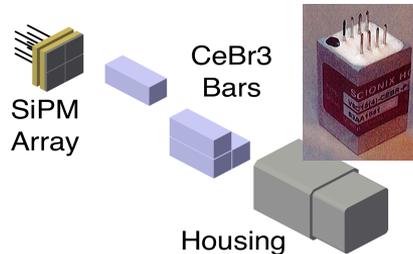
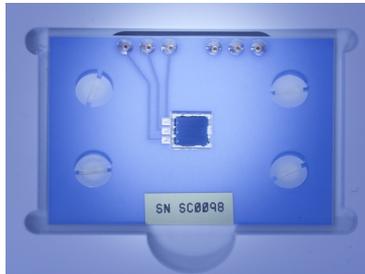


Advantages of Diamond

- Single-crystal diamond detectors (SCDDs) offer many potential **advantages** for Compton scattering instruments:
 - Energy and position resolution (~mm) similar to Si SSDs
 - Low-Z material (carbon) for high Compton cross section compared to Si
 - High density (3.5 g/cm³) compared to organic scintillator or Si for good efficiency
 - **Fast timing** for ToF capability (~ns rise time)
 - Light and temperature insensitive
 - Radiation hard
- Are also **disadvantages** of course:
 - Very expensive
 - Very small/thin detector volumes so far
 - Primary traditional supplier (Element Six) not interested in improving technology

SCDD Development Project #1: 2018 APRA

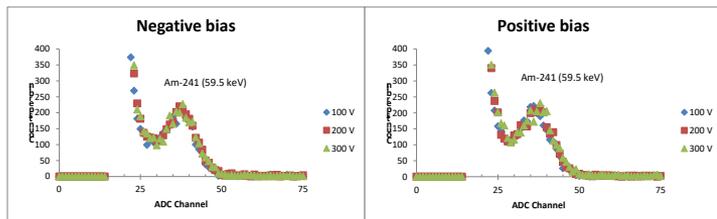
- Collaboration between P. Bloser at UNH and K. Ogasawara at SwRI
- Attempt to demonstrate small prototype diamond-CeBr₃/SiPM Compton telescope
- SwRI has procured two SCDDs (4.5 mm × 4.5 mm × 0.5 mm) from Micron Semiconductor (material from Element Six)
 - 3 × 3 cross strip readout, mounted on custom board
- LANL (via UNH) procured four fast scintillator (CeBr₃) calorimeter units with SiPM readout from Berkeley Nucleonics Corp.
 - Read out with TOFPET2 ASIC evaluation kit



SCDD Development Project #1: 2018 APRA

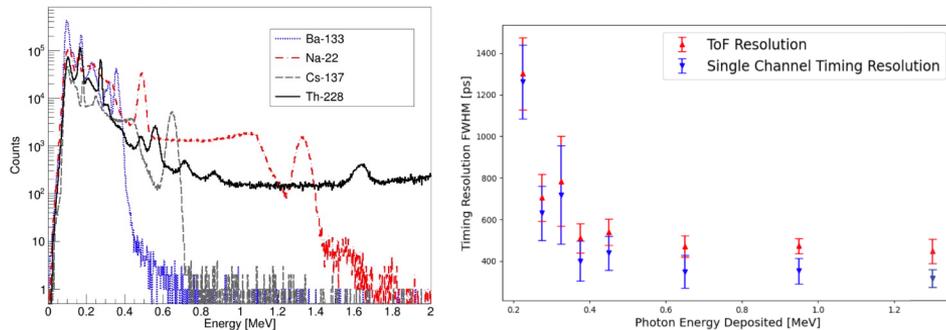
- COVID-19 wreaked havoc with this project
- Using “slow” shaping amp, SwRI showed good energy response of SCDDs
 - Couldn’t get dual energy-timing readout working
- UNH used Petsys TOFPET2 ASIC to achieve decent energy and timing resolution from CeBr_3 channels
 - Lots of non-linear response ASIC response to correct, complex analysis

SCDD



~30 keV threshold, 35% FWHM at 60 keV

$\text{CeBr}_3/\text{SiPM}$



~6.7% FWHM at 662 keV, 400 ps FWHM > 400 keV

SCDD Development Project #2: LANL Internal Material Evaluation



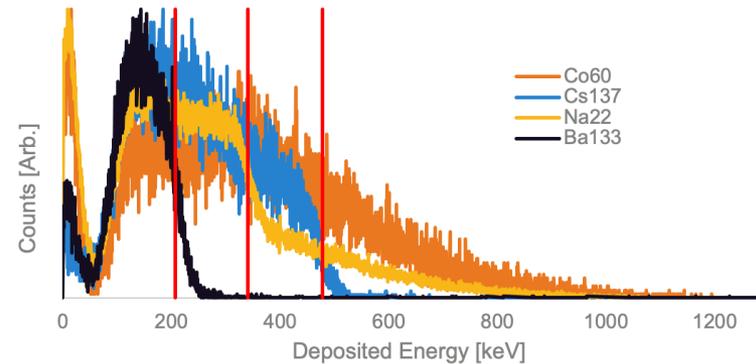
- Collaboration between Space Science and Applications Group (ISR-1) and accelerator science (i.e., beam monitor applications) group
- Evaluated material from Element Six vs. new domestic vendors
- Developed detector fabrication (cross-strip electrode deposition) techniques
- Two vendors, **Great Lakes Crystal Technologies** (Michigan) and **Innovative Carbon** (Illinois) look promising, interested in trying to produce detectors larger than standard $4.5 \times 4.5 \times 0.5 \text{ mm}^3$
- Commercial fast amplifiers work for 5 MeV alpha particles, but too noisy for $<100 \text{ keV}$ threshold needed for Compton scattering instruments



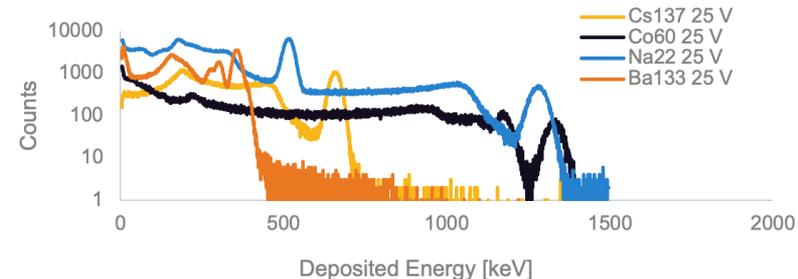
SCDD Development Project #3: LANL Internal Compton Telescope Test

- D. Poulson led project to demonstrate diamond-CeBr₃/SiPM Compton scattering measurement
- Used Pixie-Net digitizing readout with trapezoidal filter
- SCDD too fast for Pixie-NET – required CAEN shaping amp with ~50 ns rise time which destroyed timing for ToF
- BUT, got good linear energy response

Element 6 Single-Crystal Diamond Spectra

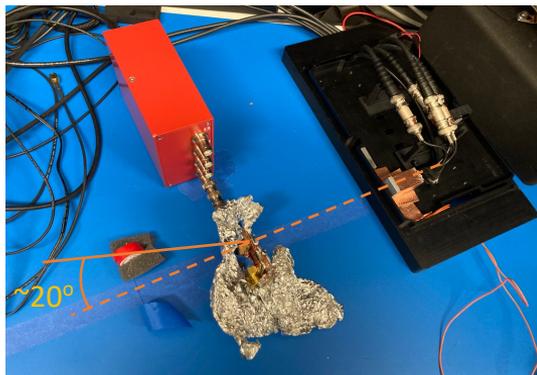


CeBr3 Channel 1

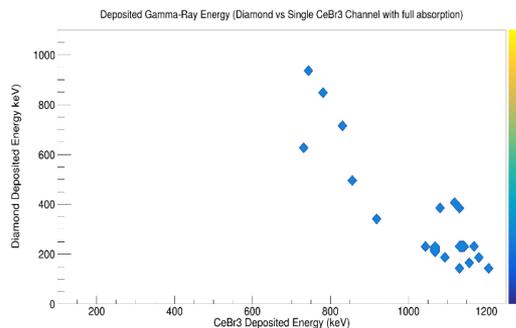


SCDD Development Project #3: LANL Internal Compton Telescope Test

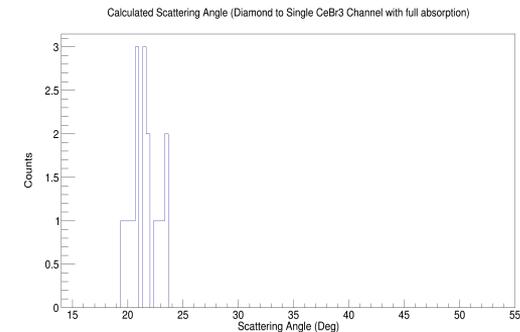
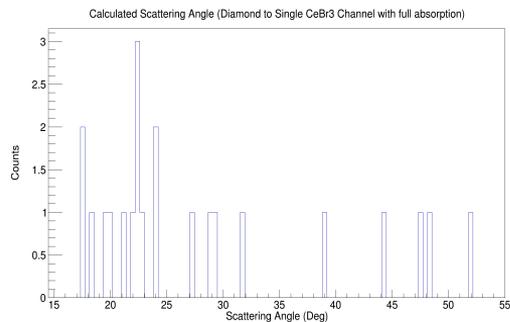
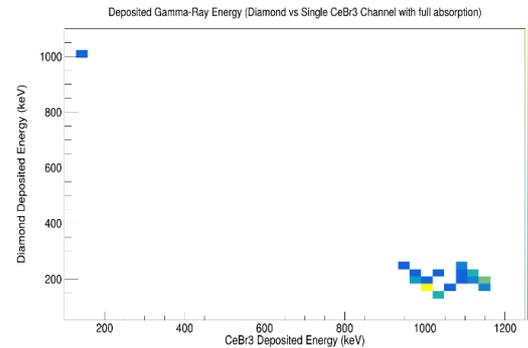
Simple Compton scattering test (without utilizing ToF) showed good agreement with Geant4 simulations:



Data



Simulation



SCDD Development Project #4: 2024 APRA

- D. Poulson is leading new APRA at LANL to develop **optimized low-noise, fast front-end electronics readout** for diamond
- Were given 1 year of funding to produce proof-of-concept
- Will use existing Element Six diamond to start, eventually want to start using larger SCDDs from GLCT

Potential Applications

- Diamond-Fast Scintillator Compton Telescope
 - Potential for ToF background rejection, good position and energy resolution in D1, maybe electron tracking as well
 - Lots of work obviously needed on FEE and ASIC implementation
 - Also on SCDD size, cost!
- Compact Compton Polarimeter
 - Envision stack of SCDD with ~mm electrodes for compact, efficient 3D Compton polarimeter (GRBs)
 - Very small coincident window allows for high rates, good 3D event reconstruction
- Fast Neutron Imaging Spectrometer
 - Diamond also good for elastic neutron scattering up to ~5 MeV
 - E.g., compact, rad-hard instrument for solar flare neutron measurement from inner heliosphere; low SWaP planetary science (SwRI has proposed latter)