

A Fast Scintillator Compton Telescope for Medium-Energy Gamma-Ray Astronomy

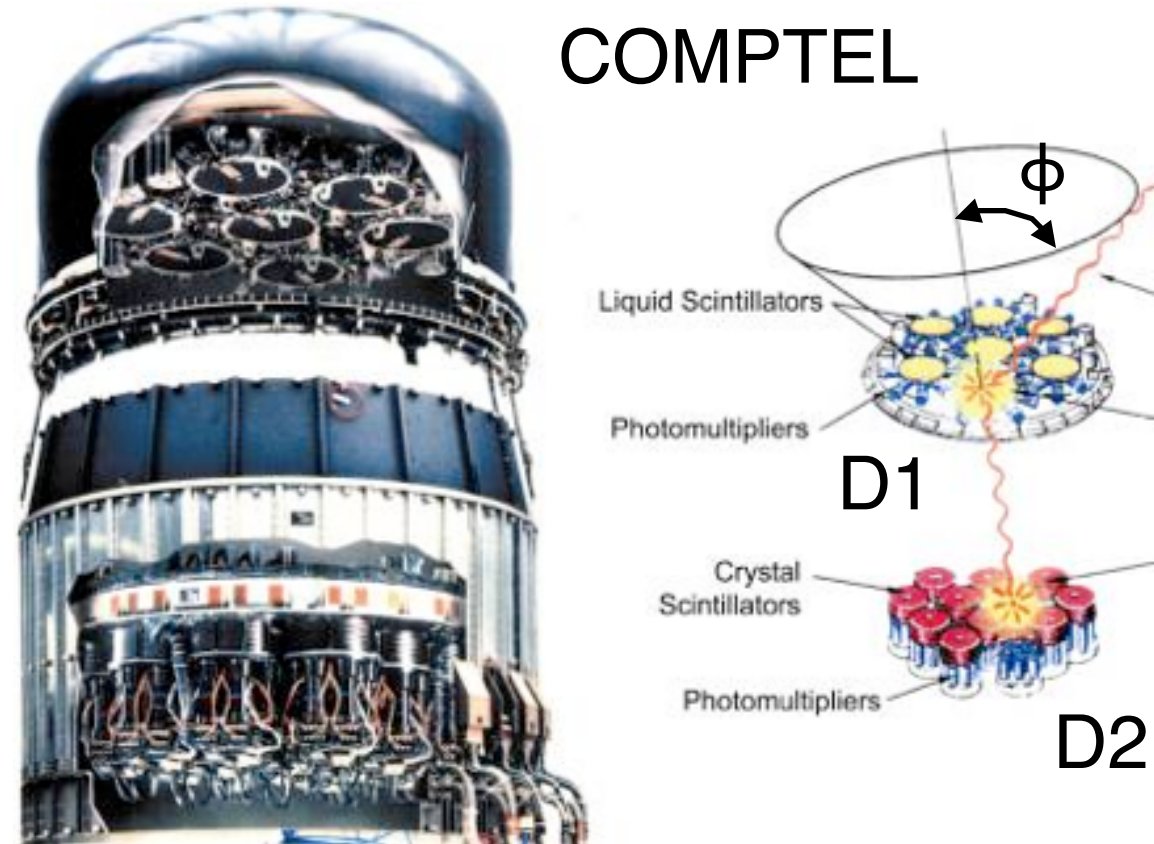
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The field of medium-energy gamma-ray astronomy urgently needs a new mission to build on the success of the COMPTEL instrument. This mission must achieve a sensitivity significantly greater than that of COMPTEL in order to advance the science of relativistic particle accelerators, nuclear astrophysics, and diffuse backgrounds and bridge the gap between current and future hard X-ray missions and the high-energy Fermi mission. This must be accomplished within the constraints of an Explorer-scale mission. Such an increase in sensitivity can only come about via a dramatic decrease in the instrumental background. We are currently developing a concept for a low-background Compton telescope that employs modern scintillator technology to achieve this increase in sensitivity. Specifically, by employing Lanthanum Bromide scintillators for the calorimeter, one can take advantage of the unique speed and resolving power of this material to improve the instrument sensitivity and simultaneously enhance its spectroscopic performance and thus its imaging performance. We present the design and calibration results for a small prototype of such an instrument, the **FAst Compton TELeSCOpe (FACTEL)**, scheduled to fly on a balloon test flight in the Fall of 2011.

Introduction

Compton telescopes are the instruments of choice for spectroscopic imaging of the sky in the difficult energy range of 500 keV to 10 MeV. This is mainly so because the coincidence requirement greatly reduces the intrusion of single photon and single particle radioactive decays and scatters into the data. The intrinsic directionality of Compton telescopes further reduces background.

The "classical" Compton telescope, COMPTEL (Schönfelder et al., 1993, *Astrophysical Journal Supplement Series*, 86, 657), employed two detecting arrays separated by 1.6 m, with a good event being one with near simultaneous interactions in the two detectors. Compton scatters in the forward detector D1 were measured for location, energy deposit and pulse shape. D1 was composed of **liquid organic scintillator**. Location and energy deposit were measured for scatters into the rearward detector D2 and the time-of-flight (ToF) was measured between the detector triggers. D2 was composed of **NaI(Tl)**. From the positions and energy deposits in the two detectors, the source of the incident gamma-ray photon could be constrained to lie on an "event circle" on the sky using the Compton scattering formula. The coincidence requirement greatly reduced the effective area of the instrument, but reduced the background even further, yielding a net improvement in sensitivity over single detector systems.



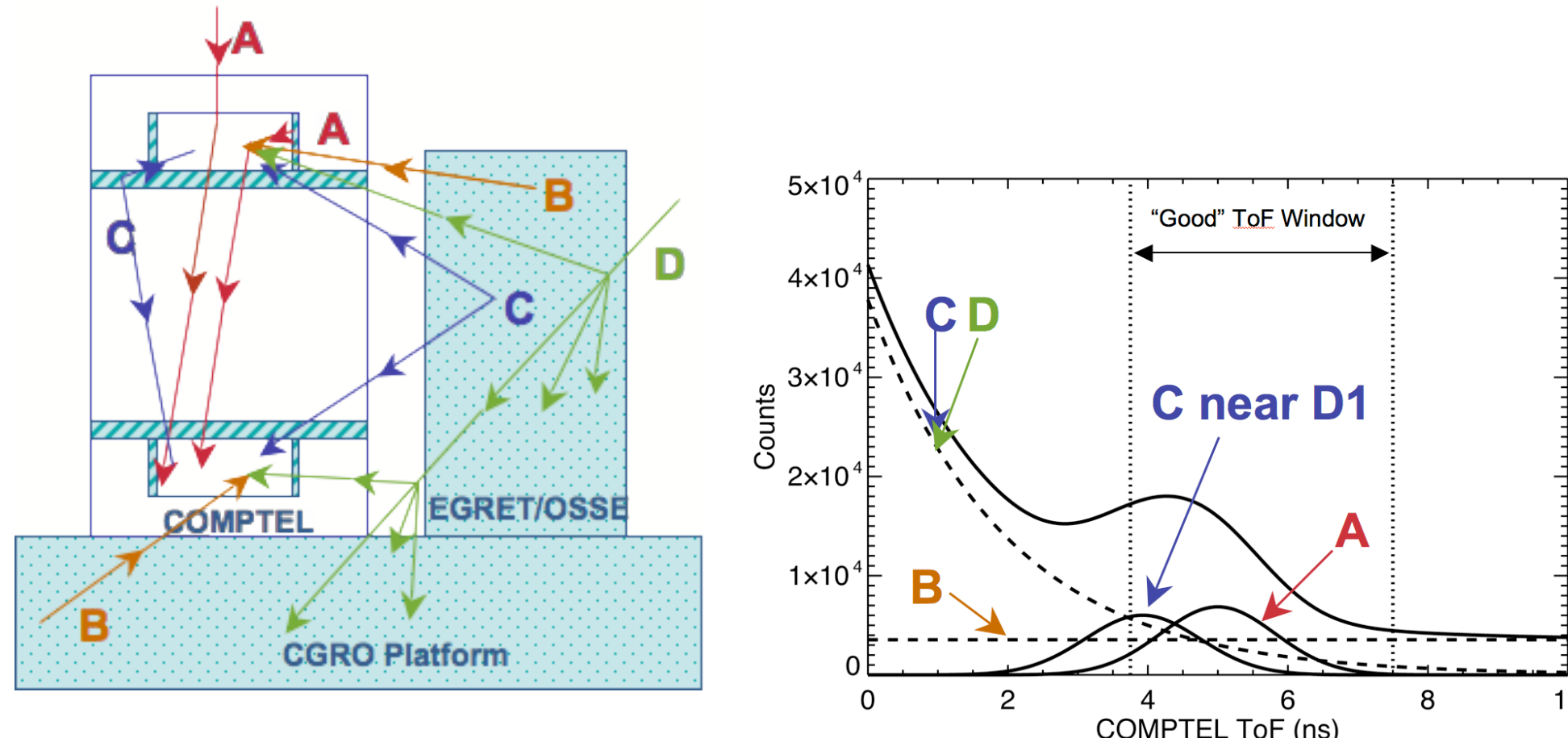
$$E_o = E_{scat} + E_e$$

$$\cos \phi = 1 - m_0 c^2 (1/E_{scat} - 1/E_o)$$

COMPTEL Background

The scientific return of COMPTEL was ultimately limited by the unexpectedly large instrumental background encountered in low Earth orbit. The COMPTEL background was caused mainly by activation of passive material by cosmic rays and neutrons. Different background components may be identified by their ToF signatures, as illustrated below (adapted from Kappadath, S. C., 1998, Ph.D. Thesis, University of New Hampshire). "Good" events are selected from the 3.75 ns ToF window:

- Photons (e.g., 2.2 MeV neutron capture) that scatter from D1 to D2
- Random coincidences (either cosmic photons or radioactive decays) in the ToF window
- Double-photon radioactive decays (e.g., ^{24}Na) that mimic the correct ToF
- Multiple photons from cosmic ray-induced showers that mimic the ToF

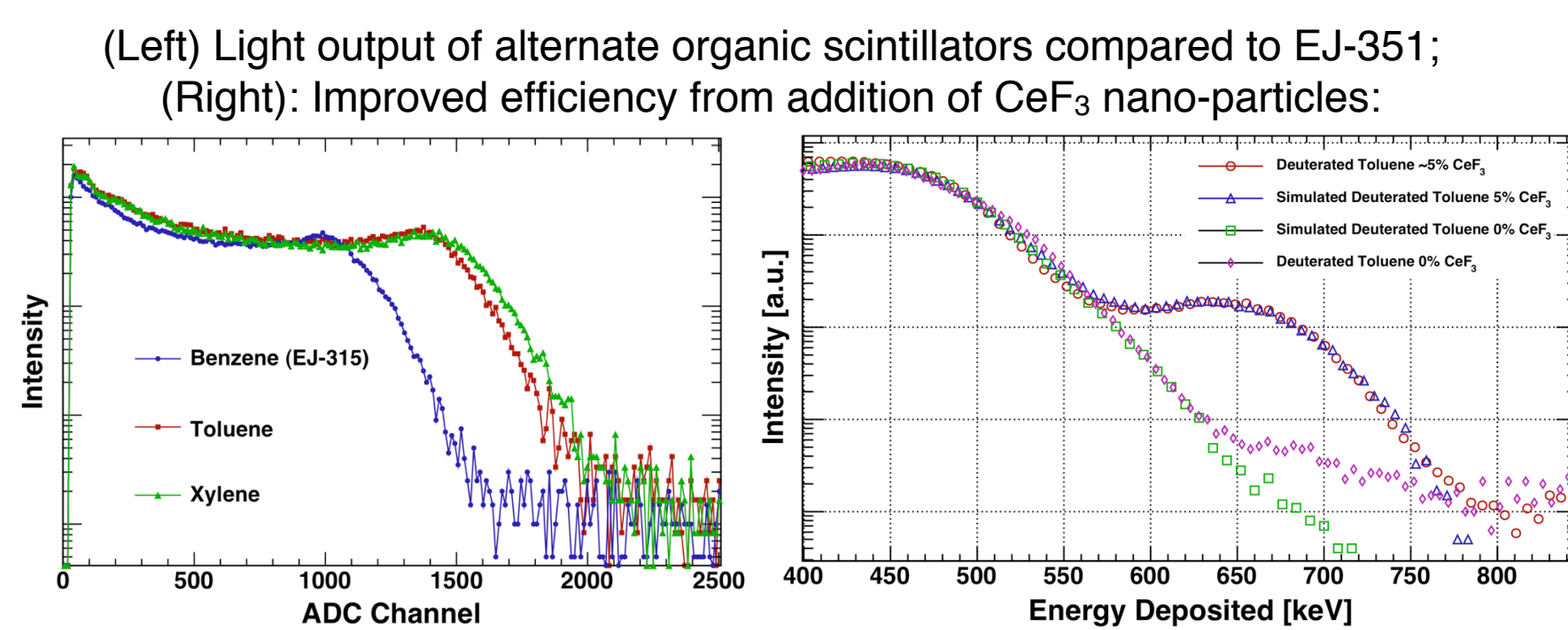


ToF was *critical* to the success of COMPTEL!

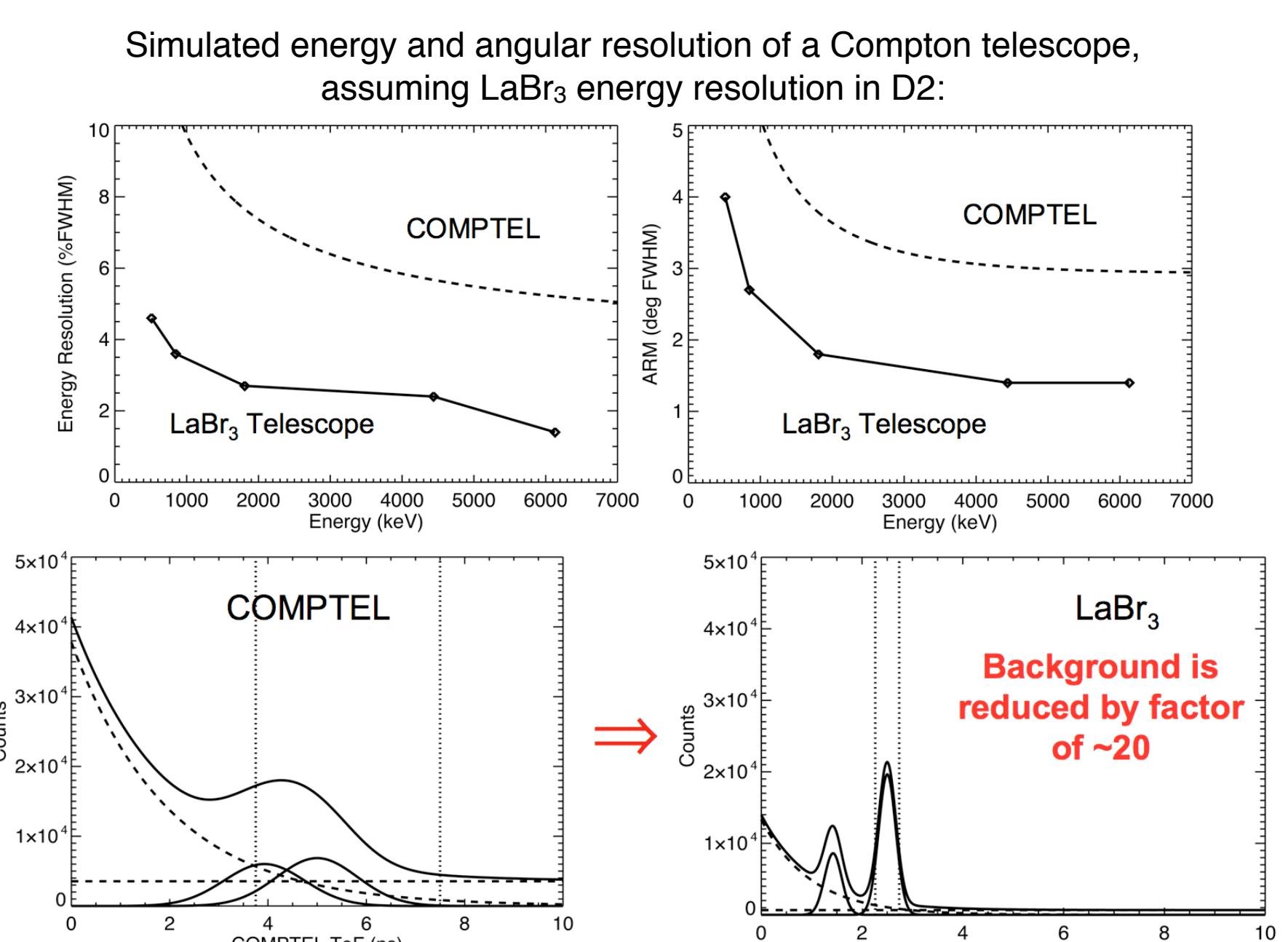
Advanced Scintillators

The use of **modern scintillator materials** would greatly improve the performance of a Compton telescope over that of COMPTEL:

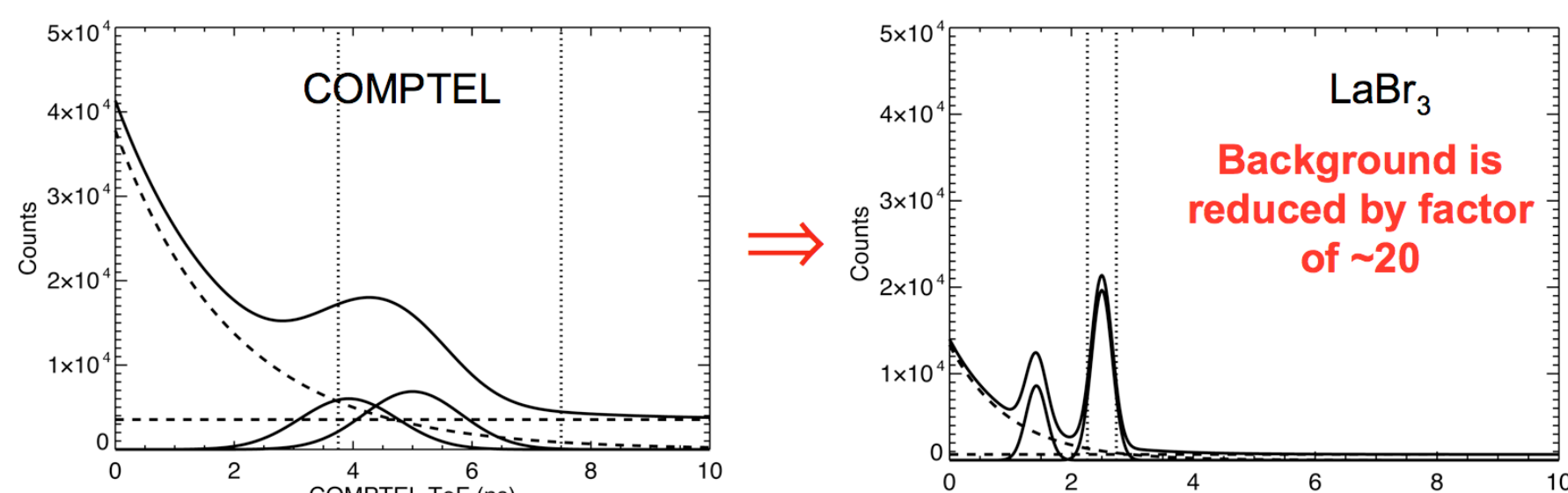
Deuterated liquid (e.g., EJ-315) for D1 will greatly suppress internal 2.2 MeV background from thermal neutron capture. **Alternate materials**, including inorganic **nano-particles**, offer improved light output and interaction cross section:



Fast, bright inorganics (e.g., $\text{LaBr}_3:\text{Ce}$) for D2 will greatly improve response via better stopping power and energy resolution:



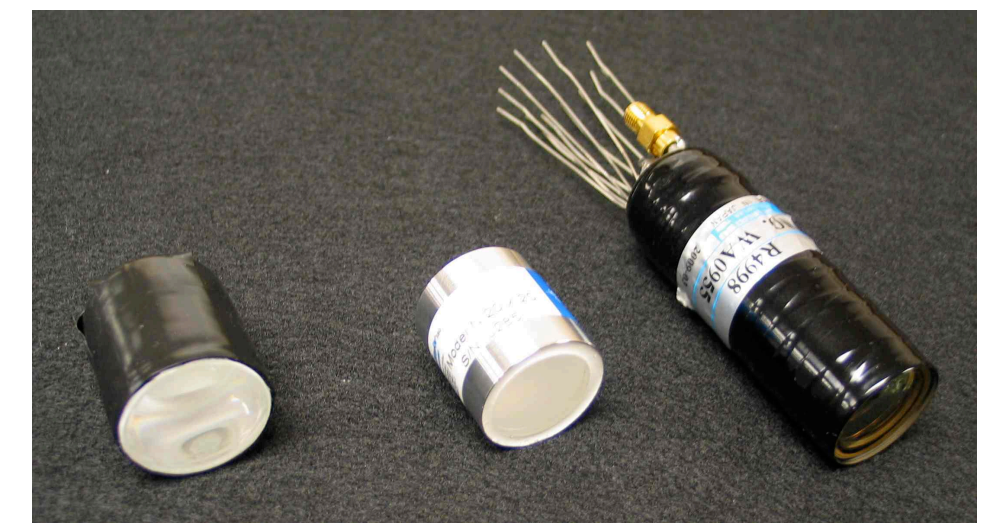
Fast, bright inorganics in D2 also greatly suppress background by reducing the width of the good ToF window to ≈ 500 ps:



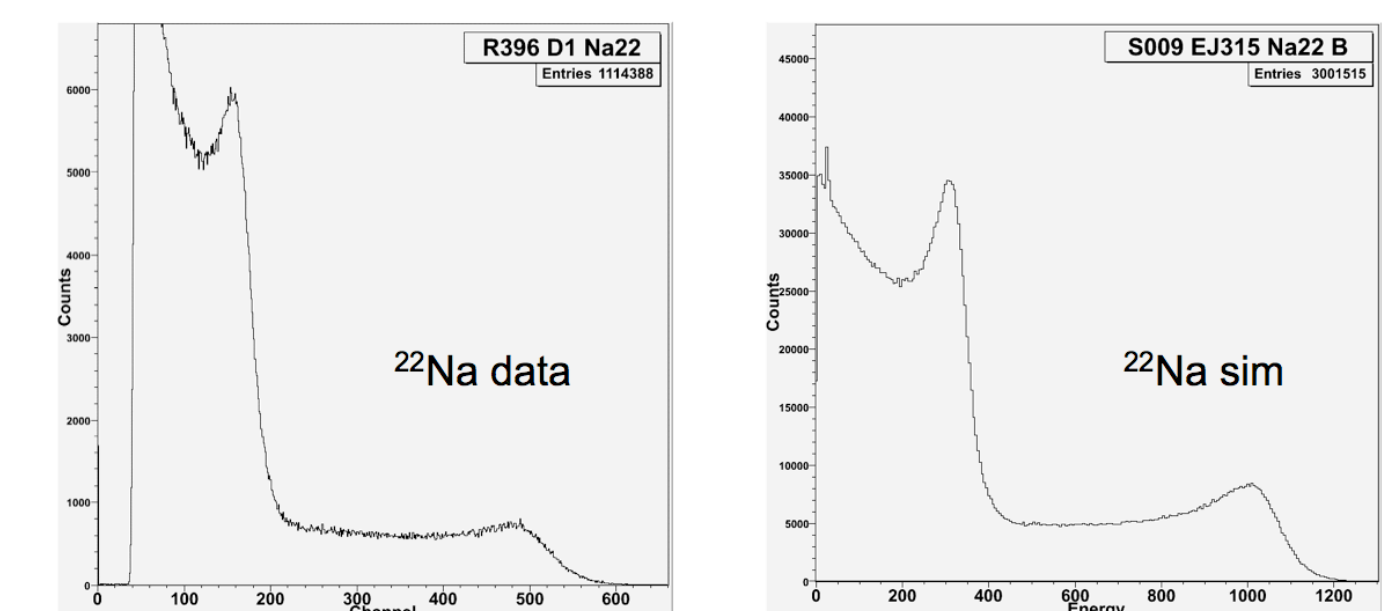
Laboratory Development

A prototype of a FAst Compton TELeSCOpe (FACTEL) using advanced scintillators is currently being tested in the laboratory:

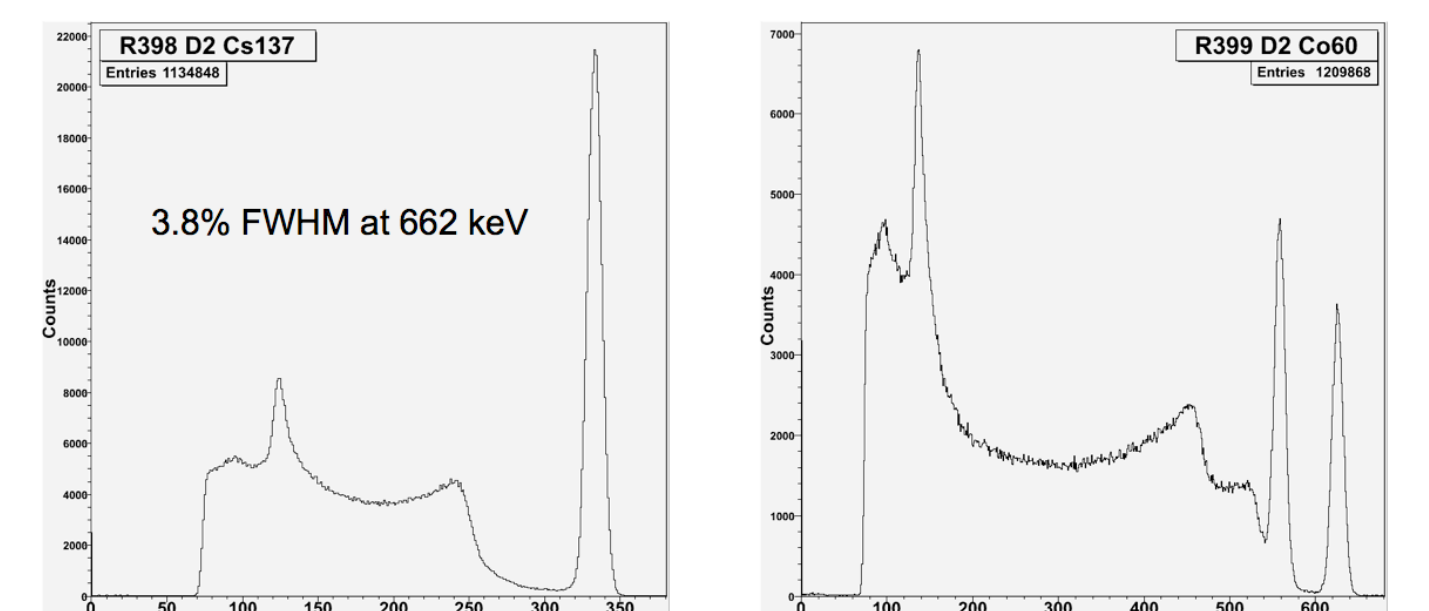
- D1: 1" x 1" cylinders of deuterated liquid (Eljen EJ-315) in glass housing
- D2: 1" x 1" cylinders of LaBr_3 (Saint-Gobain BrillanCe™ 380)
- D1 and D2 read out by Hamamatsu R4998 1" fast photomultiplier tubes (PMTs)
- Custom HV supplies and preamp boards
- Standard lab electronics (CFD, amplifiers, TAC, ADCs) and LabVIEW DAQ used for initial calibration and test



D1 calibrated using combination of low-energy photopeaks and Compton edges, in conjunction with Geant4 simulations:



D2 calibrated using gamma-ray photopeaks:

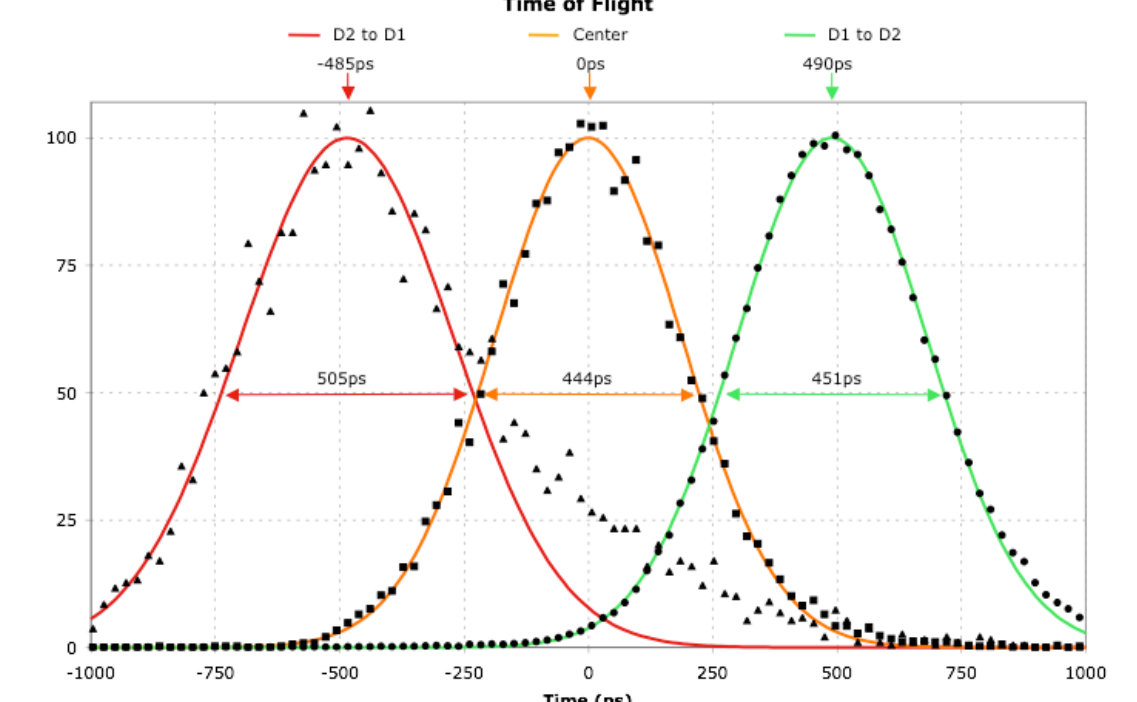


Time-of-Flight measured using ^{22}Na source placed between D1 and D2:

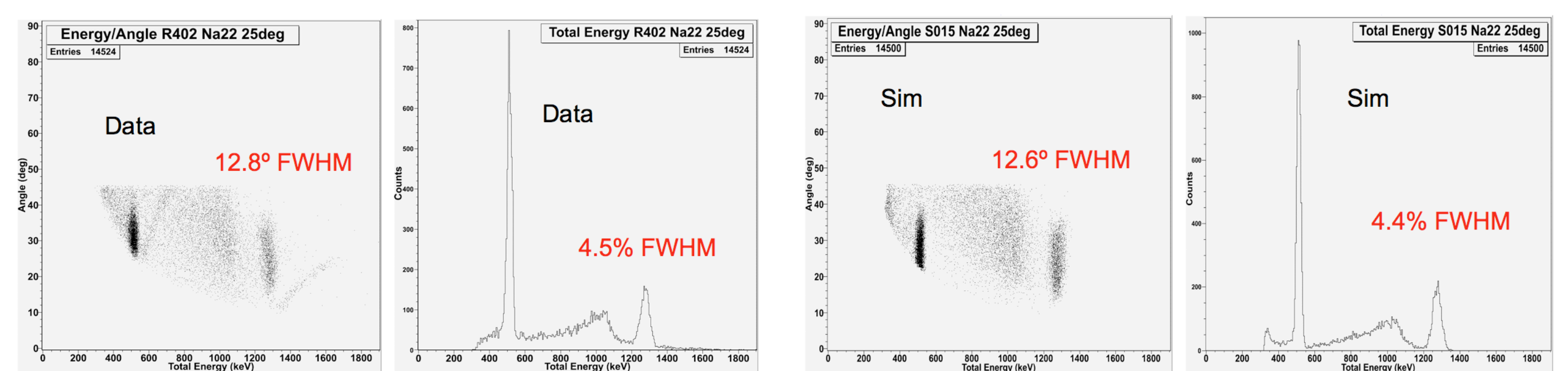
- Select on 511 keV photopeak in D2 and Compton edge (~340 keV) in D1
- Source moved over ~15 cm

⇒ ToF resolution of 450 ps (FWHM)

COMPTEL: 1.9 ns



Telescope energy and angular resolution were measured using ^{22}Na source (0.511 and 1.275 MeV) scattered at $\sim 25^\circ$ between single D1 and D2 cells 20 cm apart. A 1 ns ToF window was applied:

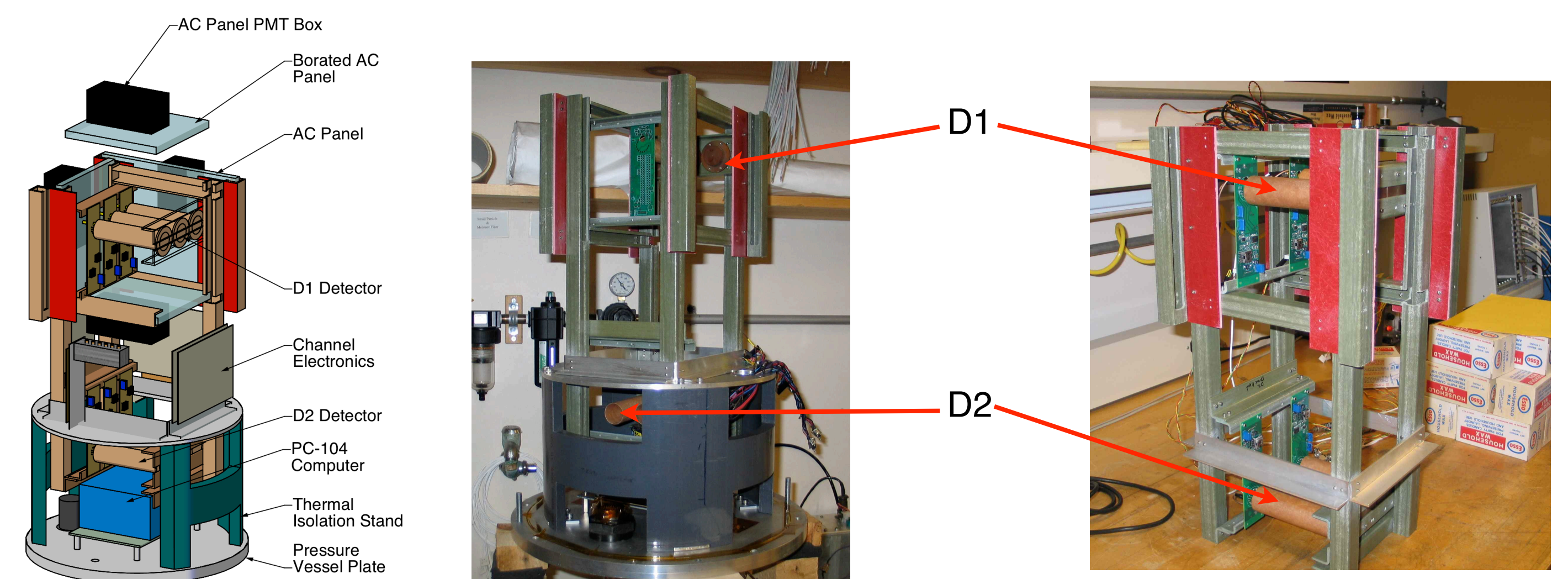


Laboratory timing and energy resolution are already **significantly better** than COMPTEL. Geant4 simulations are in **good agreement** with lab data. This validates simulations showing a LaBr_3 Compton telescope outperforms COMPTEL.

Balloon Flight Test

We are preparing a small prototype of the FACTEL payload for a piggyback balloon flight from Ft. Sumner, NM, in August 2011 in order to test the robustness of the hardware and to demonstrate its background rejection ability.

- D1 will include two 1" EJ-315 cells, plus a third cell of experimental organic scintillator from LANL
- D2 will include three 1" LaBr_3 cells from Saint-Gobain
- Custom channel electronics boards controlled by a PIC processor are being tested
- The payload includes a pressure vessel, plastic anti-coincidence shields, PC/104 computer, heaters, and cables previously flown (2007) as part of the GRAPE project
- Top anti-coincidence panel made of boron-loaded plastic to suppress 2.2 MeV emission



From the flight data and ongoing simulations we will continue to explore the potential scientific return of an advanced scintillator Compton telescope on either a long-duration balloon (LDB) or Explorer-class satellite platform