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Development and Testing of the AMEGO Silicon Tracker System

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The All-sky Medium Energy Gamma-ray Observatory (AMEGO) is a probe-class mission in consideration for the 2020 decadal review designed to operate at energies from $\sim$ 200 keV to $>$ 10 GeV. Operating a detector in this energy regime is challenging due to the crossover in the interaction cross-section for Compton scattering and pair production. AMEGO is made of four major subsystems: a plastic anticoincidence detector for rejecting cosmic-ray events, a silicon tracker for measuring the energies of Compton scattered electrons and pair-production products, a CZT calorimeter for measuring the energy and location of Compton scattered photons, and a CsI calorimeter for measuring the energy of the pair-production products at high energies. The tracker comprises layers of dual-sided silicon strip detectors which provide energy and localization information for Compton scattering and pair-production events. A prototype tracker system is under development at GSFC; in this contribution we provide details on the verification, packaging, and testing of the prototype tracker, as well as present plans for the development of the front-end electronics, beam tests, and a balloon flight.

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1. Context

The region of the electromagnetic spectrum between 100 keV and 100 MeV has, to date, had very limited observations due to the challenging nature of detecting the gamma-ray photons, and is often referred to as the “MeV Gap”. The most sensitive instrument to operate in this energy regime was the *Imaging Compton Telescope* (*COMPTEL*) [1] aboard the NASA Compton Gamma-Ray Observatory (CGRO), which operated at energies between 0.75 MeV and 30 MeV. *COMPTEL* used the Compton scattering technique to reconstruct an image of the gamma-ray source. However, this experiment offered limited angular resolution and low sensitivity, making detailed reconstruction of an all-sky source map challenging due to source confusion.

One of the difficulties in constructing a detector to operate at these energies is that above $\sim$ a few hundred keV, gamma-ray interactions are dominated by Compton scattering, and at higher energies e^+/ e^- pair production is the dominant process, with a crossover at $\sim$ a few MeV. An instrument designed to work in this energy regime must be optimized for both Compton and pair-production events; several designs have been proposed in the past to accomplish this (e.g. [2, 3]).

2. AMEGO

The *All-sky Medium Energy Gamma-ray Observatory* (*AMEGO*) is a probe-class mission concept designed to operate from $\sim$ 100 keV to above 10 GeV being submitted to the 2020 Decadal Survay. *AMEGO* comprises of four major subsystems: a plastic anticoincidence detector for vetoing cosmic-ray events, a silicon tracker system for measuring the particle tracks, a CZT calorimeter for measuring the direction and energy of Compton scattered photons, and a CsI calorimeter for measuring the position and energy of pair-production events. The hardware design is given in Figure 1; a more complete overview of instrument and simulated performance can be found in Refs. [4] and [5], respectively.

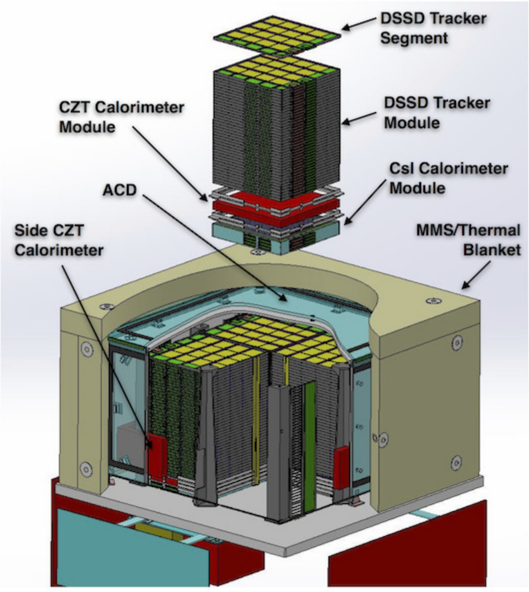

Figure 1: Hardware design for AMEGO [4].

3. The Tracker

3.1 Event Types

Operating in both the Compton- and pair production regime presents some design challenges pertaining to the silicon tracker subsystem.

A traditional Compton telescope reconstructs the arrival direction of the incident photon as a cone on the sky according to the traditional Compton scattering equation by measuring the energy of the scattered electron and photon:

$$\cos\theta = 1 - \frac{m_e c^2}{E_\gamma} + \frac{m_e c^2}{E_e + E_\gamma} \tag{3.1}$$

However, it is also possible to use the direction information of the scattered photon and electron to reconstruct the arrival direction of the primary gamma-ray:

$$\vec{e}_i = \frac{\sqrt{E_e^2 + 2E_e m_e c^2}\vec{e}_e + E_\gamma \vec{e}_\gamma}{E_e + E_\gamma} \tag{3.2}$$

Events where the scattering direction of the electron is known are called "tracked events"; these events significantly reduce the uncertainty in the arrival direction from an annulus to an arc (*i.e.* the convolution of the previous direction reconstructions), which increases the sensitivity of the instrument at low energies.

Pair-production telescopes use a high-Z (e.g. tungsten foil on the *Fermi*-LAT) material in order to ensure that gamma-rays are converted to e^+/e^-pairs which can then be tracked as they pass through the detector. However, the use of additional material between silicon layers greatly increases the chances of Compton scattered electrons being absorbed in the conversion layer, adversely affecting the performance of the instrument at low energies. *AMEGO* uses the silicon layers themselves as the pair-production material. This presents an optimization problem: the silicon must be sufficiently thick to ensure pair production occurs but thin enough so that Compton electrons can still penetrate multiple layers. Examples of the two different event types is shown in Figure 2.

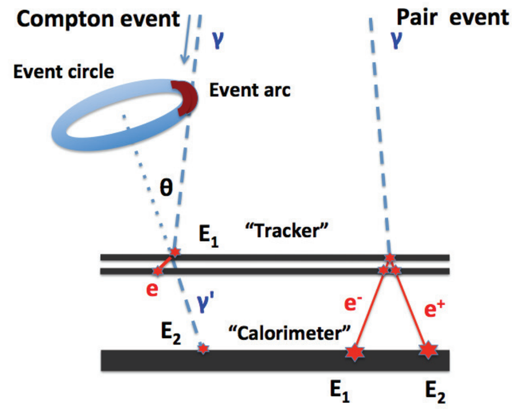

Figure 2: Depiction of the different event types for *AMEGO*. A Compton event with a tracked electron allows for the Compton event circle to be reduced to an arc. The conversion material for pair-production events is the silicon tracker layers themselves. For low-energy pair production events, the energy of the e^+/e^- pair can be determined using pulse-height information from the tracker.

In order to maximize sensitivity to Compton events, dual-sided silicon detectors (DSSDs) are required to yield position information on two axes simultaneously; low-energy Compton electrons may not be able to penetrate two single-sided detectors. The CZT calorimeter, which encases the bottom $\sim$ half of the silicon tracker, provides energy measurements for Compton scattered photons.

In the pair-production regime ($\gtrsim 10\,\mathrm{MeV}$), *AMEGO* has been optimized for lower energies. However, the CsI calorimeter (comprised of several layers of scintillator bars) is deep enough to extend the energy range of *AMEGO* to GeV energies. This is significantly greater than that of previous proposed detectors, which typically extended to $\sim 100\,\mathrm{MeV}$. The CsI bars are read out using silicon photomultipliers which increases their performance at low energies. The use of DSSDs also allows for polarization measurements of pair-production events to be made.

3.2 Design

The *AMEGO* tracker comprises 60 layers of DSSDs vertically separated by 1 cm connected in a 4×4 configuration, referred to as a “tower”. Each wafer is a 10 cm square, 500 µm thick with a strip pitch of 500 µm, yielding 192 strips per side per wafer. The detector readout electronics are located along two edges of each wafer (one for the x and y directions). The full *AMEGO* tracker has four identical towers; this modular design allows for four identical towers to be used, simplifying integration and allowing for for spare components.

The strips are read out by an ASIC; tentatively, the prototype detector will use the IDEAs VATA460.3 [6], a combined pre-amplifier and pulse-height-measuring digitizer. The pulse-height information is required to measure the energy of the scattered electron for Compton events and for measuring the energy of the particles in low-energy pair-production events. A custom readout system (front-end) is also under investigation.

3.3 Testing

Upon their receipt, each wafer will undergo testing before being integrated into one of two different test configurations, discussed later. The first two or three wafers will undergo extensive testing: full C-V and I-V curves for each channel in each direction will be made to verify the depletion voltage of the silicon, the parasitic capacitance of the detector and leakage currents with respect to the manufacturer’s specifications. This procedure is relatively time consuming (estimated to be at roughly two weeks per wafer), so results of the first few wafer tests will be used to decide the testing strategy for subsequent wafers (e.g. is testing only a subset of channels sufficient; when fully assembled, *AMEGO* will have ~ 1.5 million strips, making it impractical to test every single one).

Seven wafers will be used in a 4×3 configuration “L-shape” in order to verify whether or not the parasticic capacitance (which is a dominant source of readout noise) is sufficiently low. Readout electronics will be connected on each side of the corner of the “L” (similar to the case of the full detector); this configuration will make it possible to test the position resolution in both $x-$ and $y-$ directions using an XY positioner and radioactive sources.

A second configuration of vertically-stacked detectors will also be built; this configuration will be instrumented with readout electronics and similar tests with radioactive sources will be tested. This configuration also allows for particles to be tracked as they pass through multiple silicon layers, allowing for track reconstruction algorithms to be developed and tested. This configuration will also be tested in a particle beam and flown on a balloon.

4. Conclusions

A silicon tracker system is currently under development. The design will allow *AMEGO* the be sensitive to both Compton scattering and pair-production events. Over the course of the next year, a test setup will be assembled and tested at GSFC and will be beam tested and flown on a balloon to test its functionality.

References

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