Two recent developments have led us to propose a new type of Compton telescope in compact geometry with time-of-flight, for gamma-ray astronomy in the energy regime of 0.2–20 MeV. First, the technology of vacuum ultraviolet photo sensors for efficient and fast readout of liquid xenon (LXe) scintillation light has improved dramatically over the last few years, and new developments are underway. A LXe Advanced Compton telescope would consist of two detector arrays of LXe time projection chambers in compact geometry, with time-of-flight (ToF) between detector modules at a resolution of order 100 ps. Second, the previously achieved moderate energy resolution in LXe, a significant drawback for gamma-ray line spectroscopy, has been found to be limited by a strong anti-correlation of ionization and scintillation in LXe. Efficient measurement of both charge and light enables us to improve energy resolution greatly. A factor of three improvement over a previous prototype, LixGRT, has already been achieved, and the measured underlying physics indicates the possibility of achieving energy resolution below 1% FWHM at 1 MeV. We are vigorously working on improving light and charge readout to realize this potential in a practical detector. Here, we report on the status and prospects of our current NASA research and development program.

Concept for LXeTPC for the Advanced Compton Telescope

Shown in the schematic to the right is an example of an LXe Time Projection Chamber (TPC) in a compact geometry that would be used on the ACT [7]. Each module is a two layer array of square Hamamatsu PMTs for efficient light collection. The upper TPC will contain 3 cm of LXe while the lower TPC will contain 7 cm of LXe.

Avalanche Photodiodes (APD, left) have been used as an alternative to Photomultiplier Tubes since they have a higher QE and are insensitive to vacuum ultraviolet magnetic fields. APD use semiconductor technology, as a weak pulse of light passes through the upper layer (p-type) it creates an ionization track. This enables operation as a Compton telescope, where Compton ionization and scintillation light in the detector. Scintillation light from the incoming γ-ray is detected by Ultraviolet Photomultiplier Tubes (UV PMT) across the detector.

New Developments in Photodetection

Hamamatsu R8520 was measured to have a QE of 34%+/-5% for 175 nm light. The top-right plot shows signal gain versus bias voltage across the APD. Dark current was much reduced at the operating temperature of LXe and a maximum stable gain of 5600 was achieved. The bottom-right graph plots APD energy resolution as a function of gain from scintillation in LXe. The minimum energy resolution was 5.3% rms at a gain of 160 [5]. This is due to light collection variations for different positions of LXeTPCs in compact geometry with ToF.

Silicon Photomultiplier Tubes (SPM, center) use a 34x34 array of micro APDs (right image) representing individual pixels (1156) in a compact area (2x2 mm). Each pixel (micro-APD) has an area of 30 x 30 μm and operates in Cocker model to help reduce noise levels and yields a high gain > 10^5. We are planning measurements to test their use in LXe. We expect excellent timing and high QE with low noise.

A Compact Liquid Xenon Compton Telescope with High Energy Resolution and Time-Of-Flight

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Abstract

Motivation for Gamma-Ray Astronomy

An Overview of Radiation Detection in LXe

LXeTPC Combined with Time-Of-Flight

Current Research

Ionization versus Excitation in LXe

Overview

References

We are collaborating with the University of Milan to design an ultra-low noise pre-amplifier with the FET front end inside LXe and will test it in the Rice TPC. Future projects include development of a 3D sensitive TPC module with enhanced light/charge collection and very good energy resolution [6].


Gamma-ray astronomy/astrophysics is still one of the least known about and less explored regions of the energy spectrum, yet many of the mysteries of the universe may be revealed from these energetic photons. Nuclear γ-rays line transitions allow individual isotopes to be identified, allowing us to better understand the nuclear forces of the universe. Gamma-ray photons are highly penetrating, often traversing the length of entire galaxies before a single interaction. The precision of LXeTPCs has always been limited primarily by background noise. More efficient detection mechanisms at greater energy resolution and sensitivity are needed [7].

NASA is planning to launch the Advanced Compton Telescope circa 2015 to replace COMPTEL and CGRO. Its main goals are to study Sn Ia supernovae [4] and the antimatter universe. In each interaction, a dense cloud of electrons is created through ionization. The charges are drifted in an electric field of 1 kV/cm until they pass through wire grids which determine the X-Y coordinates. The energy is measured on an anode where charges are collected or alternatively on the wires.

The figure on the right shows a large area APD from Radiation Monitoring Devices Inc. in the task chamber. Opposite the APD in the TPC die is an imbedded Pd-210 source and is between a calibration LED. This APD was measured to have a QE of 34%+/-5% for 175 nm light. The low-light output signal is amplified using a low-noise charge sensitive pre-amplifier which will be sampled by a Flash ADC system at ~100 kHz. Light signals will be digitized using a fast amplifier (700 MHz) 12 bit Flash ADC board on a VME system. A 365 nm UV LED will be used to calibrate the PMTs. Fast measurements are expected in the next few months.

The effect of combining charge and light is shown in the figure on the upper left. In the regions where light and charge are combined yield a narrower FWHM than by charge or light collection alone. An improved measurement is shown on the right. The challenge is to maximize light collection and at the same time minimize electronic noise. Both problems are being tackled in our R&D program (boxes below).