Final Scientific/Technical Report

Section 3. Executive Summary

Our Columbia group, in collaboration with Brookhaven and SMU, has been carrying out R&D on tracking detectors in cryogenic liquids, including neon and helium. A cryostat purchased by this Grant capable of working temperatures down to 1 K and pressures above the critical point of neon and helium has been operated with a variety of noble fluids. Gaseous Electron Multipliers (GEM) with hydrogen additives have been operated with tracks of radioactive sources read out both by electrical charge detecting electronics, and an optical camera purchased by this Grant, measuring mobility, charge yield, transitions through phase boundaries, gain limitations, and other properties.
The goal is very high resolution in large volumes.

How the Research Adds to the Area Studied: Extension to Light Signals

1. The extension to measuring the light-emission from the tracks as well as charge offers great benefits for a system requiring a huge number of readout channels, since fast, low-noise cameras are now available with millions of detection elements. The cost of such cameras to universities has fallen within reasonable bounds, and our grant from DOE has allowed us to purchase a high performance camera, which we have used to examine charge tracks in a variety of configurations. The photons are emitted from the avalanche gain region of planar GEM detectors collecting the electrons drifting in a Time Projection Chamber in the noble liquid, and the gain allows a detector sensitive to very low energy tracks, such as those resulting from solar neutrino (or possibly dark matter) scattering events. We have observed these tracks and are now continuing to explore the parameter space of fluids: temperature, pressure, avalanche gain device, quenching additives, and types of tracks in our detector. Note that this is a "Final Report" for this Grant, which provided the camera, while the Final Report for the overall project of our collaboration, which will continue for one year, will cover the results now being gathered. The performance achieved promises to offer new possibilities in particle and astrophysics experiments.

Technical Effectiveness

2. Tracking by detecting the photons from charge on the tracks has performed as we hoped. The charge from the tracks is effectively focused into 50-micron holes in relatively large GEM or Micro Mega planes and the light is emitted from the center of the holes and focused into the camera. The spatial resolution is maintain in the camera readout, yielding a large number (order 10^5) of "pixels" from just one camera. Furthermore, the camera it read out serially so that if a Time Projection system a three-dimensional picture is obtained from just one output cable – practical in a low event-rate non-accelerator or pulsed beam environment. It is evident that this system,

profiting from an industrially developed system of great sophistication, can be much more cost effective in appropriate applications than a charge read-out scheme constructed in a typical physics institution.

Other Benefits

3. This development was driven by the needs of underground neutrino experiments, and as the concepts have been developed by experimental measurements and calculations, we have seen how the new techniques can be useful in other areas, including areas of benefit to the public. For example, we have been approached for advice by the management of a company using large numbers of detectors to examine possibly hazardous structures from a distance, to find out what materials they might contain. In the Final Report of our project, we will report to DOE HEP on the wider applications of our results.

Section 5, Summary of Activities

1. The scope of the project is the provision of a high performance camera and its installation in a cryogenic facility providing pressure up to 40 atmospheres and a temperature from ambient down to about 1 K. In this section we will address the goals and results having to do with this project and particularly the performance of the camera, and provide a summary of the status of the detector project. (We note that the camera in a powerful instrument that can be applied to a broad range of applications over a period of time.)

   The technical development of digital cameras has been dominated for the last forty years by the Charge-Coupled Device technology (CCD). This allows photon recording on very small pixels on silicon planes that provide high quantum efficiency in the visible spectrum, recording the charge generated by a single photon stored on one pixel with an area of order ten microns square. The area can be up to several centimeters squared, containing a million pixels or more. The stores charge is usually read out by manipulating voltage biases to shift the charge in each pixel over to the next, and eventually out of the array and sent to an external processor and memory. Mass production has brought the cost per channel down to very small values and allowed cameras to be integrated to many consumer products.

   Thermal noise becomes larger than one photon on a single pixel at good temperature, and demand night vision and other demanding applications has led to intense R&D over the years, and small coolers that maintain the CCD at temperatures of more than 100K below ambient are integrated into the camera package. These systems are sold in quantity to amateur

astronomers with the same silicon devices used in professional systems, provided long exposure times with less than one electron noise per pixel. In our particle readout, we are imaging a three-dimensional track drifting into the readout plane over time, and we need to read out one plane after another, and we need a high rate of pixel processing. For many years, the noise in the electronic amplifier matching the CCD to the external electronics led to noise levels of many electrons, much higher than in the CCD itself. A break-through was made by providing signal gain *inside* the CCD, connecting to the external line, by a Electron Multiplier CCD, http://www.andor.com/learning/digital_cameras/?docID=325, using a number of electron avalanche stages, each with a small, stable gain. This device was brought out just before out application for the present Grant, provided the last link in the development chain, which allowed out optical readout concept to be implemented at reason fact. In fact, we profited from the falling cost by delaying our order for about a year, which, together with the university discount, allowed us to proceed within our budget.

The camera we purchase from the firm ANDOR, which introduced the technique, comes with an extensive suite of software that allows the fast readout with different integration times, and makes a very convenient use in our application. We have been able to make images of the light signals coming from out GEM electron avalanche detectors under many conditions, with tracks of different particle types. We have reconfigured the system a number of times, using the results from the camera to learn how to change the TPC drift geometry and the GEM charge amplifier to improve performance, a process that is still going on. The camera purchase with this Grant has performed reliably and just as specified by the manufacturer and has been a trouble-free element of our larger product.

The ability of being able to vary the pressure and temperature over a wide range is very important for several reasons:

-we are able to choose a fluid density to make the best compromise between a range of low energy tracks long enough to measure, and higher density to minimize the detector size for a given rate;

-we can identify the density the allows the avalanche rate that provides sufficient signal to noise for the low-energy tracks we need to measure in a given application;

-we can operate at the optimum density and hydrogen admixture for light production.

A special cryostat was required to operate down to 1 K with pressures up to 40 Bar, well above the critical point of Neon. We needed a set of three windows to implement our optical readout, capable of standing the

pressure. A triple-wall vessel was required to yield a low heat load down to liquid helium temperatures, using a Nitrogen outer jacket and a main cooling system with liquid helium. We submitted this for safety certification at Brookhaven National Laboratory, to ensure that we had met the highest level of safety requirements. This vessel was purchased from this Grant from Ability Engineering Technology.

Final Summary of the Grant Activities

The Grant was based on the initial results of previous work on the electron-bubble detector development, to extend the concept to detect tracks optically. The technology of CCD cameras had recently advanced far enough at that time to make such a system feasible at reasonable cost. We purchased a very high performance camera as a standard product, and it met the specifications and proved very satisfactory. Our overall detector R&D project would have been impossible without this device, and with the cryostat vessel, which we expect to continue to use in the future.

Section 6, Publications etc.

1. Charge transmission through liquid neon and helium surfaces. R. Galea, J. Dodd, M. Leltchouk, W. Willis (Nevis Labs, Columbia U.) , P. Rehak, V. Chernyatin (Brookhaven) . 2007. Published in JINST 2:P04007,2007.

2. Gas purity effect on GEM performance in He and Ne at low temperatures. R. Galea, J. Dodd, Y. Ju, M. Leltchouk, W. Willis (Nevis Labs, Columbia U.) , P. Rehak, V. Tcherniatine (Brookhaven) , A. Buzulutskov, D. Pavlyuchenko (Novosibirsk, IYF) . Feb 2006. 4pp. Published in IEEE Trans.Nucl.Sci.53:2260-2263,2006.

3. GEM operation in helium and neon at low temperatures. A. Buzulutskov et al. Apr 2005. 13pp. Published in Nucl.Instrum.Meth.A548:487-498,2005.

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