1D Projections Readout and Track Reconstruction for the SONTRAC Instrument

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***Abstract*—Neutron spectroscopy and imaging has improved considerably over the last decade with the advancement of modern scintillating materials and compact, low power readout devices. Though challenging to detect, fast (>0.5 MeV) neutrons are ubiquitous, contribute to the radiation exposure of astronauts and space hardware, and have been effectively used to examine physical processes both locally and within our heliosphere at large. The SOlar Neutron TRACking (SONTRAC) instrument is designed to measure neutrons between 20-200 MeV with good angular sensitivity. SONTRAC consists of orthogonally stacked scintillating fibers readout by silicon photomultipliers to detect and track the recoil protons from double scatter neutron events. Proton tracking provides high-resolution imaging of fast neutrons at energies where the bulk of solar and planetary neutrons resides. The SONTRAC readout system, algorithms for track reconstruction, and tracking performance are presented.**

I. INTRODUCTION

FAST neutrons with energies greater than 0.5 MeV are produced from the interaction of energetic particles with planetary atmospheres, their surfaces or deep within the Sun's atmosphere. Together with gamma rays, neutrons propagate to Earth unhindered by the effects of transport and thus directly probe energetic processes within the solar atmosphere. Similarly, neutrons can be used to probe composition trends within planetary bodies. Finally, given that neutrons are highly penetrating, they constitute an important source of the radiation exposure in deep space for astronaut crew traveling to the Moon and Mars through the Artemis program.

Traditional neutron detection takes advantage of the double scatter technique (Frye et al. 1985) in which neutrons undergo elastic scattering within a detector multiple times imparting energy to the recoil nuclei, typically protons, along its path. A measure of the recoil proton position and momentum vectors provide information on the incident neutron direction and energy (see Ryan et al. 2003). Proton tracking can be accomplished with highly segmented scintillating optical fibers where the scintillation light is collected with modern light sensors, such as silicon photomuliplers (SiPMs).

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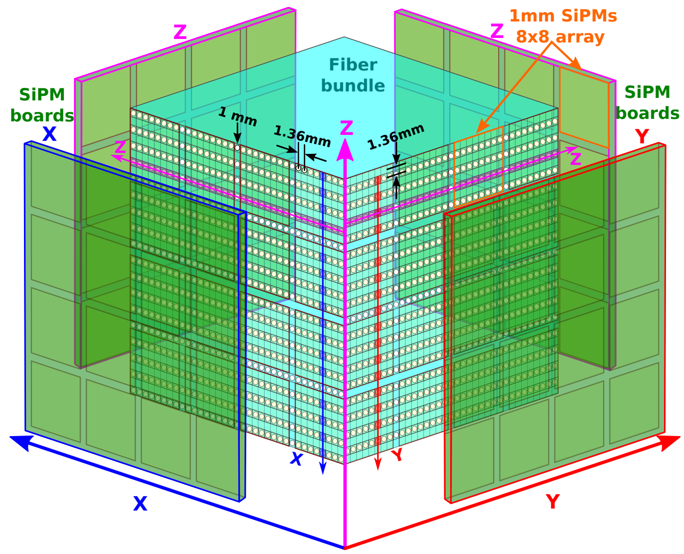


Fig. 1. Strip (1D Projection) readout with vertical (X and Y) and horizontal (Z) strips.

The SOlar Neutron TRACking (SONTRAC) instrument consists of orthogonally stacked scintillating fibers readout by fine-grained arrays of 1-mm SiPMs with signal processing from multi-channel ASICs (CAEN Petiroc2A) (Fig. 1). Details of the SONTRAC prototype and performance are discussed in de Nolfo et al., these proceedings. Track reconstruction of the recoil proton is accomplished by reconstructing three 1D projections of summed SiPM strips in each of the three bundle planes. A 1D projection in the remaining 4^{th} plane improves the resolution in the Z-direction. This novel strip readout design significantly reduces the number of channels required to reconstruct the recoil proton tracks. We discuss the techniques developed to fully implement track reconstruction based on strip readout and present preliminary results from laboratory studies of ground level muons.

II. APPROACH

The SONTRAC prototype is shown in Fig. 2. It contains a 35x35 cm^2 scintillating fiber bundle with a 1.36mm fiber pitch. Each of the fiber bundle sides is paired with a 32x32 array of 1 mm KETEK SiPMs with the same fiber pitch. Covering the four sides allows us to have a stereoscopic view of the particles interacting in the scintillator volume. As shown in Fig. 1, each of the 32x32 SiPM arrays (one of each side of

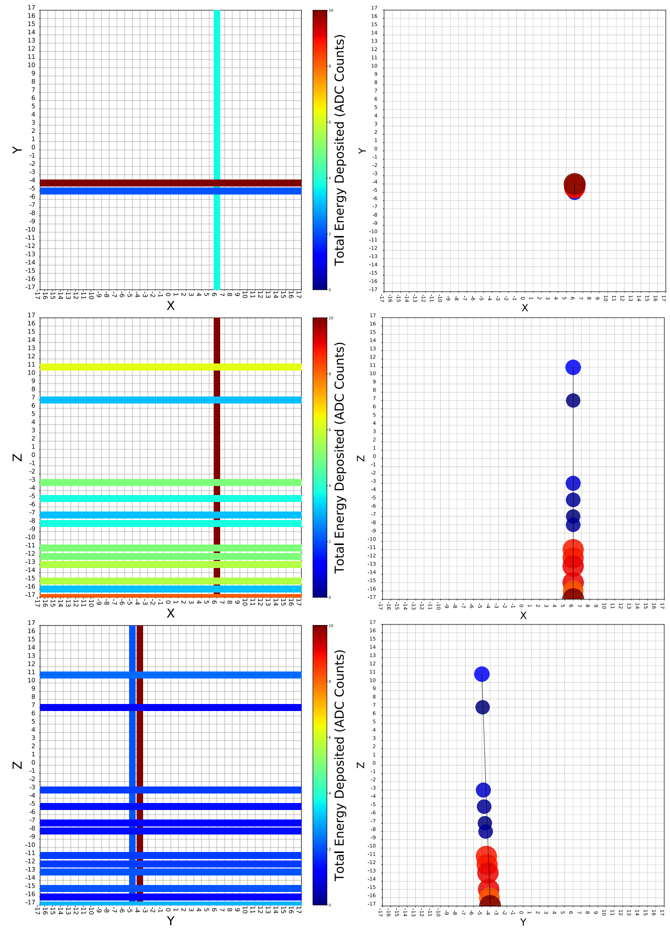
Fig. 2. New *SONTRAC* instrument prototype scintillator and 1mm SiPM detectors with 1.36mm pitch. SiPM board contains 32x32 1mm SiPMs with 1.36mm pitch and formed by a 16 KETEK carrier boards. The gap between the carriers is where the extra fibers (not being read) are located in the fiber bundle. The SiPMs are read out in strip (1D projections) to reduce the number of channels and encode the data.

the scintillator) will be configured in strips such that individual SiPMs are summed along strips. This reduces the total number of channels from 2048 (2 sides, 1024 per side) to 128 (4 sides, 32 per side). Highly integrated ASICs, the CAEN Petiroc2A, are used to read out the strips in all four planes. Utilizing one Petiroc2A ASIC per side, we can reduce the size, mass and power while still processing a large number of channels at a high rate.

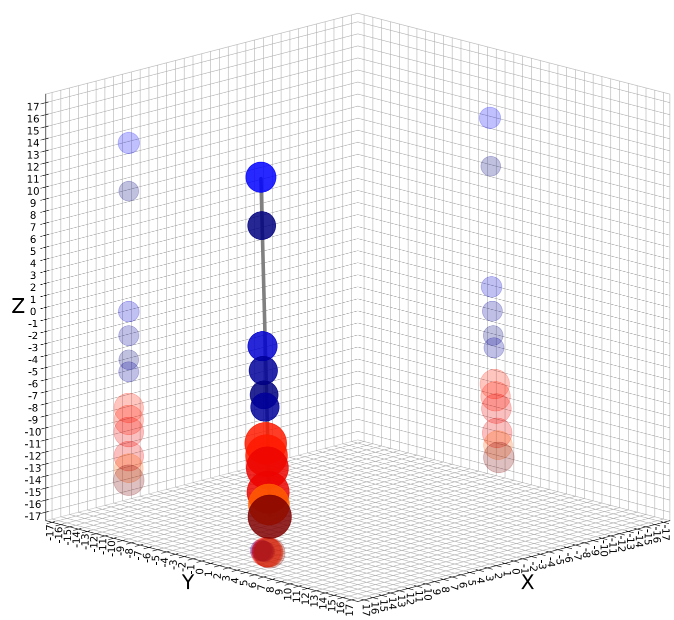
The strip readout technique takes advantage of *a priori* information about the particles tracks. Such techniques have been used extensively to reconstruct images with the Positron Emission Tomography (PET) scanner (e.g., Kim et al. 1999). We incorporate similar computed tomography techniques used in medical imaging to reconstruct recoil proton tracks for SONTRAC, incorporating other heuristic information about the recoil proton track (e.g., Bragg peak, electronic noise, etc).

III. Early Results & Future Work

The prototype instrument is undergoing testing with ground level muons in preparation for a proton/neutron accelerator run at Crocker Nuclear Laboratory, UC Davis. Fig. 3 shows a muon traversing the fiber bundle. The instrument was configured with external muon detectors above and below the fiber bundle to trigger on coincident events. The event was reconstructed from the 1D projections using the proposed back-projection heuristic track reconstruction algorithm. Future work includes an accelerator run to perform energy calibration and reconstruction for single and double scatter neutron events.



(a) Projections and 2D reconstruction



(b) 3D reconstruction

Fig. 3. Muon event traversing the fiber bundle and its reconstruction using aback-projection heuristic track reconstruction algorithm. Reading the fibers in strips (1D projections) encodes the track trajectory and requires reconstruction.

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