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A MODULAR X-RAY DETECTOR FOR BEAMLINE DIAGNOSTICS AT LANL*

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Abstract

An X-ray detector is being developed for diagnostic measurement and monitoring of the Drift Tube LINAC (DTL) at the Los Alamos Neutron Science Center (LANSCE) at Los Alamos National Lab. The detector will consist of a row of X-ray spectrometers adjacent to the DTL which will measure the spectrum of X-rays resulting from bremsstrahlung of electrons created in vacuum by the RF. Two types of spectrometer modules are being developed. A large number (near 100) of inexpensive LYSO+SiPM-based modules will be deployed to measure the rate and energy of gammas along the beam and at different azimuthal angles. A smaller number of LaBr+PMT-based modules (one or two per DTL tank) will precisely measure the energy of X-rays at specific drift tube gaps in addition to reporting event rates.

Initial prototypes were tested during a beam development period at the LANSCE DTL just prior to this conference (July 30-Aug 3) and also during the RF conditioning in April 2022. An MFR proposal has been submitted for the funding of further development and deployment of this X-ray detector.

Bremsstrahlung X-rays

The detectors will monitor the bremsstrahlung spectrum of field emission electrons (FEE). FEE are generated in RF cavities and undergo bremsstrahlung in collision with the beampipe and other structures, as illustrated in Fig. 1 [1].

Work in Ref. [2] demonstrated that a set of temporarily deployed LYSO+SiPM-based detectors adjacent to the beam line could be used to find the location of arcing in the DTL. The proposed X-ray detector would be a permanent installation to monitor the entire length of the DTL, which will be feasible due to small, lightweight, and inexpensive spectrometers which can be mounted directly onto the DTL.

LaBR+PMT-BASED PROTOTYPE

For the PMT-based prototype, shown in Figs. 2 and 3, LaBr crystal and a LYSO crystal are coupled to the two visible PMTs. Two PMTs beneath those also have NaI crystals, though our work has determined that LaBr is likely the preferable material due to its superior energy resolution and small form factor (10 mm long and 10 mm in diameter). Spectra measured with known radioactive sources are shown in Fig. 4.

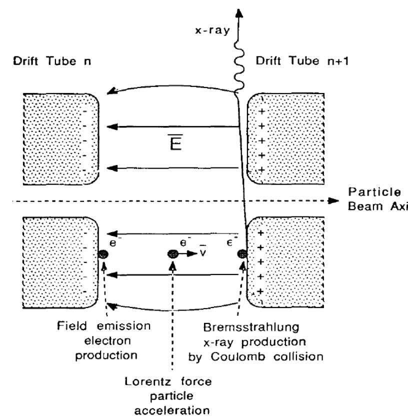

Figure 1: Diagram of FEE and resulting X-rays from Ref. [1].

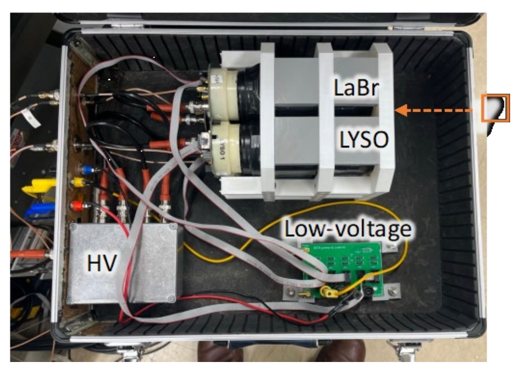

Figure 2: Interior of the LaBr+PMT-based prototype.

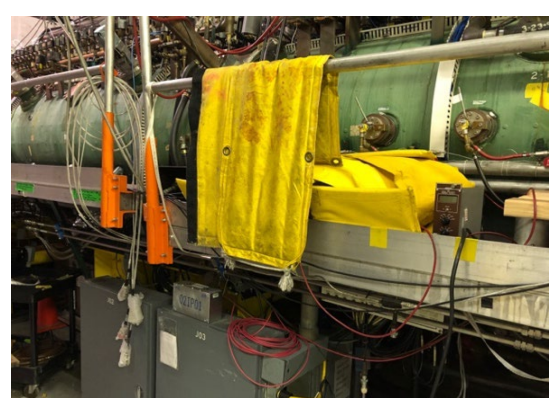

Figure 3: LaBr+PMT-based prototype at the LANSCE DTL with Pb blankets (yellow) to shield from background radiation arising from other DTL tanks.

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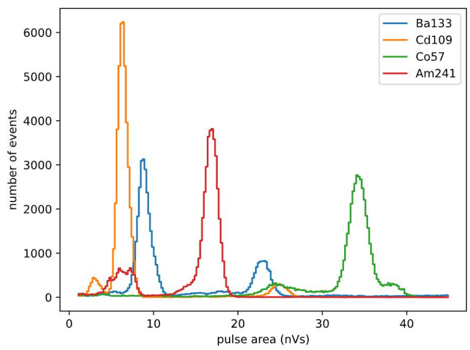

Figure 4: Spectra measured with known calibration sources and the LaBr+PMT spectrometer.

The LYSO provides a tagged gamma source with three peaks that are used for calibration of the LaBr (or second LYSO crystal.) In testing with the PMT-based spectrometer at the LANSCE DTL, in-situ self-calibration spectra matched ex-situ calibration well, up to a scaling factor, as shown in Figs. 4 and 5, despite a background of bremsstrahlung X-rays from the RF.

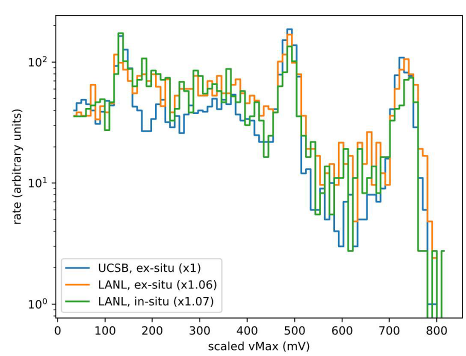

Figure 5: Scaled LYSO calibration spectra in-situ (at LANL DTL with background RF) and at ex-situ (labs at LANL and UCSB). The events are selected to have the 176Lu gamma rays tagged by a coincident hit in the LYSO.

LYSO+SIPM-BASED PROTOTYPE

As shown in Fig. 6, the LYSO+SiPM-based X-ray detector modules are composed of a pair of 4x4x22 mm LYSO scintillators. The LYSO scintillators are each mounted on a 4x4 mm SiPM which is read out with custom-built electronics including a digitizer and amplifier PCB. Data collection with a DRS4 was also used during testing.

This prototype is small to allow for lightweight and inexpensive shielding, such as a Pb tape (see Fig. 7) or Tungsten-polymer. The efficacy of shielding with Pb tape was compared to that with an additional housing of Pb bricks that is shown in Fig. 8. The Al foil-wrapped module has only the Pb tape for shielding, whereas the one wrapped in Cu is housed in Pb bricks for better shielding. The Pb blankets were placed on top after the photograph in Fig. 8 was taken.

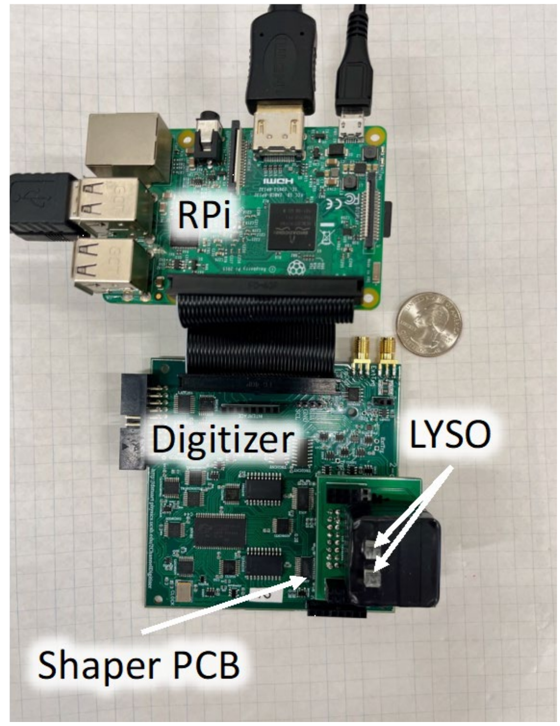

Figure 6: Photograph of the X-ray detector module prototype with Raspberry Pi to control the SRAM digitizer and read out the (uncovered) LYSO+SiPM.

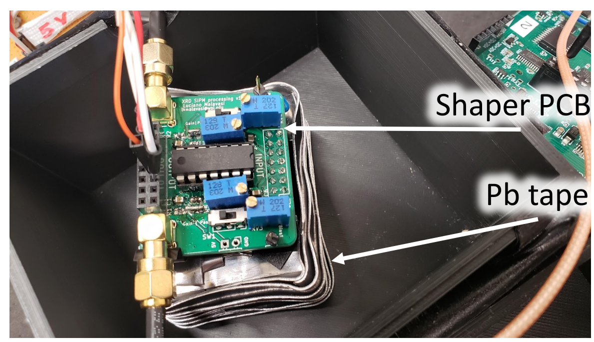

Figure 7: The SiPM-based prototype wrapped in Pb tape for radiation shielding inside its Faraday cage. There is no Pb tape on the front of the crystals.

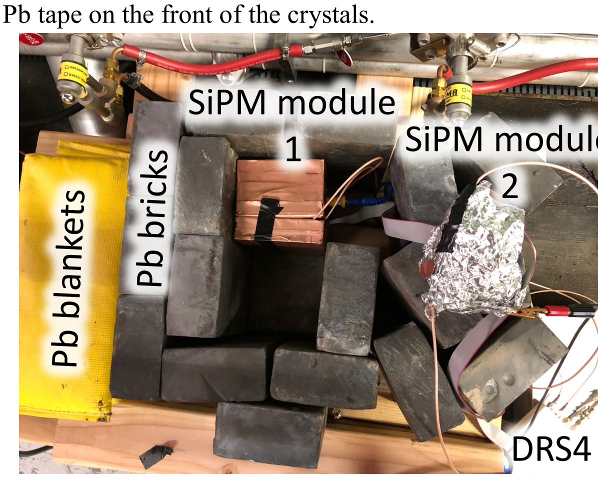

Figure 8: Two LYSO+SiPM-based prototypes at the LANSCE DTL.

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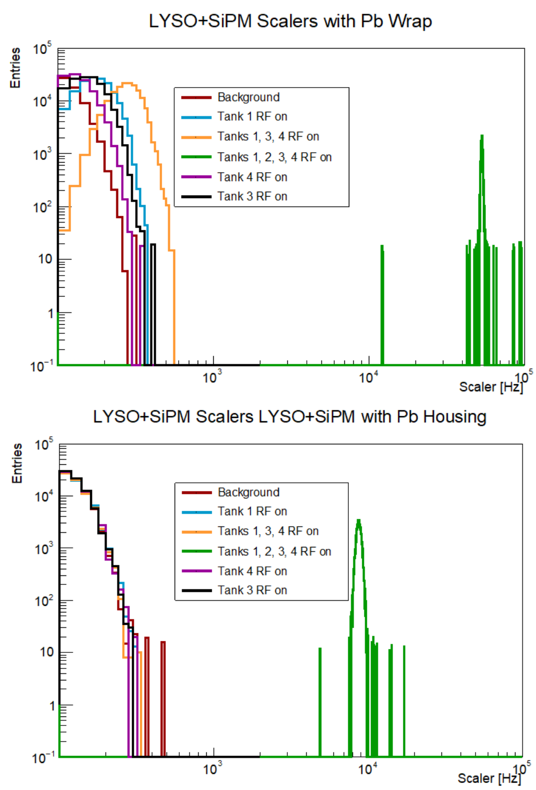

Figure 9: Hardware scalers (trigger rate without dead time) for the LYSO+SiPM modules in different RF conditions. The top (bottom) plot is for the lightly (heavily) shielded module.

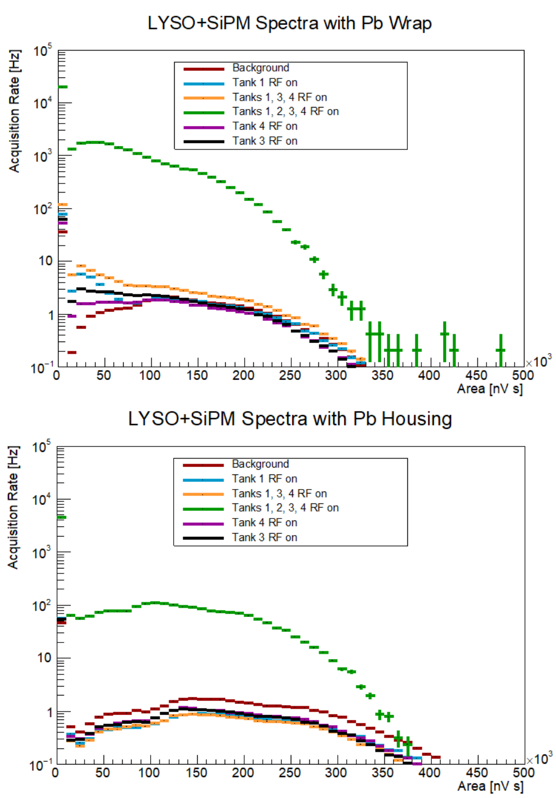

Figure 10: Scaled pulse area spectra (uncalibrated) for the LYSO+SiPM prototypes for different RF conditions. The top (bottom) plot is for the lightly (heavily) shielded.

As shown in Figs. 9 and 10, for both heavily and lightly shielded modules, the background rates due to the RF in tanks 1, 3, and 4 are comparable to the background rate, and the rate measured with the tank of interest on, tank 2, dominates.

Custom-built SRAM Digitizer

A prototype of the electronics has been built and tested and is shown in Fig. 6; it samples the waveform from each SiPM with an ADC written to an SRAM at 33 MHz and then readout via a Raspberry Pi (RPi) for each trigger. The trigger logic is configurable to allow flexible sampling of single channel triggers for the DTL monitoring and coincident triggers for the in-situ calibration. Software on the RPi handles waveform recording, with real-time pulse finding. It is designed to collect data automatically, needing only simple network communication. The use of commodity scintillators, SiPMs, and a simple readout system makes each detector module inexpensive so that they can be widely deployed.

For the results shown here, DRS4 evaluation boards were used for the sake of reliability and in light of time constraints. Future versions of the detector will be tested with the custom-built electronics.

CONCLUSIONS AND OUTLOOK

The results from the recent beam development demonstrate that the background of other tanks can be rejected while measuring tank 2 of the LANSCE DTL with relatively lightweight and inexpensive shielding around the LYSO+SiPM modules. A similar result would be expected for a smaller PMT-based LaBr/LYSO detector, which is to be developed. The feasibility of in-situ calibration with the LaBr+PMT-based module was also demonstrated.

Testing during an upcoming beam development at LANSCE and deeper analysis of the recently acquired data will explore:

- Measurement with the custom-built readout electronics (digitizer).
- In-situ calibration with LYSO+SiPM modules.
- Optimized mechanical and shielding design for both types of modules.

An MFR proposal has been submitted for development of the X-ray detector as a diagnostic at LANSCE. If the detector is developed, deployed, and proves to be an effective diagnostic, such a detector would be applicable to other DTLs, and possibly in diagnostics of other accelerator systems.

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[2] M. Sanchez Barrueta, G. O. Bolme, J. T. M. Lyles, R. Z. Pinsky, and J. E. Zane, "X-Ray Detector Array for Spatial and Temporal Diagnostic at the LANSCE Linac", in *Proc. NAPAC'19*, Lansing, MI, USA, Sep. 2019, pp. 47-50. doi:10.18429/JACoW-NAPAC2019-MOYBB6

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