High-resolution Exotic Atom (x-ray spectroscopy) with Transition-Edge Sensors

HEATES

High energy background event identification using local group trigger in a 240-pixel X-ray TES array

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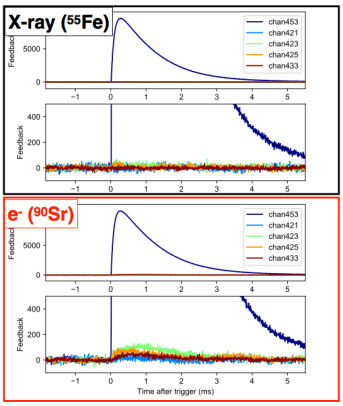
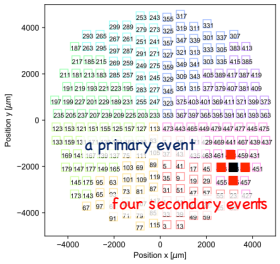
1. ABSTRACT

A novel triggering function developed for 240 pixel NIST Transition-Edge Sensors[1] is demonstrated under the high rate of particle background. The function is integrated into the standard data acquisition system in the NIST TES framework. It enables any type of combination of trigger pattern when a pixel is triggered, which is called "group trigger". As a practical implementation, the primary trigger is distributed to the four physically nearest pixels. The group trigger function was utilized throughout the entire one-month J-PARC experiment[3] for the measurement of the Kaonic-atom X-rays. This trigger allowed us to confirm that the increased background and degraded energy resolution we observed when operating the TES array in the presence of an ion beam are the result of thermal crosstalk from charged particles[4]. We show that the maximum of the peak values among the four neighboring pixels is useful event selection parameter. We use cuts based on this parameter to improve the peak-to-background level in a measured x-ray energy spectrum by a factor of 2.5, while keeping 95% of measured events. This flexible group triggering technique allows us to improve the signal to noise on the very faint Kaonic Helium x-ray lines we are measuring, better understand our experiment environment, and we believe this technique may prove useful in other ground and space based TES applications.

2. INTRODUCTION





"group trigger"
a function of sending triggers to nearby pixels.

It is similar to "GRADE" of CCD used in X-ray astronomy.

High-energy charged particles deposit energy in Si frame of TES chip[5].
Need to know thermal-crosstalk pulses that degrade the energy resolution.

3. IMPLEMENTATION

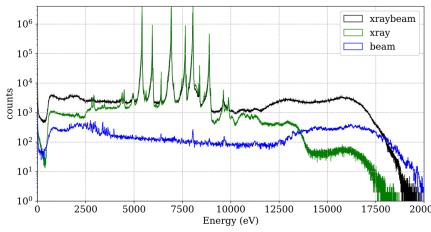
The 240-pixel NIST TES array is read out with the time-domain multiplexing (TDM) system[1]. Each TES consists of a superconducting bilayer of thin Mo and Cu films with an additional 4μm thick Bi absorber. The detector stage is cooled with a pulse-tube-backed adiabatic demagnetization refrigerator (ADR). The ADR's bath temperature is regulated to 75 mK with 5μKrms. The TES pixels are then electrically biased to their superconducting critical temperature of T_c of 100 mK. The time-division-multiplexing readout system samples the current signal of the 240 sensors through 8 SQUID columns[2]. The sampling time of each pixel is 7.2μs (=240nsx30 pixels), and thus the effective sampling rate is 139 kHz. All the sample is transferred to the host PC through PCIe bus. The software package called "Matter" is the main engine of the pulse processing running on the host PC, where the most part of the implementation is the internal functions of it. The main routine is summarised as the following step.

1) load the waveform until the minimum of timestamps in the latest all-pixel events
2) scan the waveform for primary triggers according to the trigger setting
3) distribute the primary triggers to the receivers referring to the look-up table
4) save all the records for the trigger queues with a flag of primary and secondary
5) trim the waveform by the maximum of timestamps in all the processed triggers

4. RESULT

(1) The spectra taken at J-PARC E62 experiment

Pure Cr, Co, and Cu used as X-ray generator for the energy-scale calibration



RUNID	X-ray	Beam	Duration (sec)	rate/array (Hz)	Remark
135	ON	OFF	4.8k	~ 210	gain cal. for beam only
136–139	OFF	ON	21k	~ 20	beam only
^{3}He,^{4}He^{ad}	ON	OFF	~ 0.8M	~ 190	X-ray only
^{3}He,^{4}He^{ad}	ON	ON	~ 0.5M	~ 210	X-ray & beam

Xraybeam = Cr, Co, Cu X-rays + charged particles

Xray = Cr, Co, Cu X-rays

beam = charged particles.

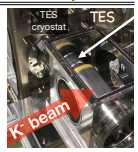
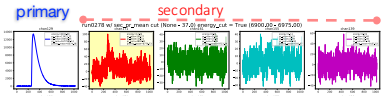
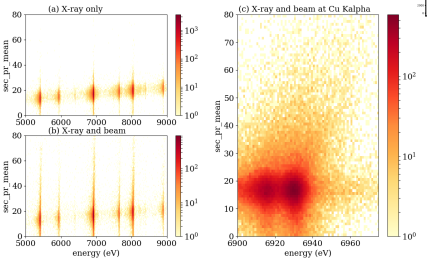


Fig.1) The entire spectra obtained during (1) X-ray and beam on, (2) X-ray only, and (3) beam only, shown in black, green, and blue, respectively. The bin size is 2 eV for (1) and (2), while 10 eV for (3).

(2) The primary and secondary events

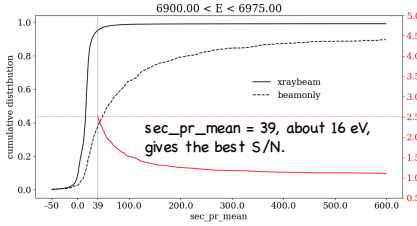




sec_pr_mean = the maximum pulse height over the pulse region among the group-triggerred pixels. It is a good indicator of the themral cross talk

Fig. 2) Energy vs. sec_pr_mean of pixel 129. (a) X-ray only, (b) X-ray and beam, and (c) is a magnified one of (b) to clarify it around Cu Kα lines. The bin size of the energy is 2 eV, while that of sec_pr_mean is 1.

(3) Optimize the event selection parameter



To save 95% events from X-ray and beam data over 6.9 keV to 6.975 keV, the criteria requires sec_pr_mean to be 39, and the signal to noise, a ratio of the cumulative curve of the X-ray plus beam to beam only, becomes 2.5.

Fig. 3) The cumulative distributions of sec_pr_mean for X-ray plus beam (solid) and beam only (dot) are plotted in the left axis. The ratio of the two is shown on the right. The point where the signal reaches 95% of the total and its corresponding ratio are indicated as the vertical and horizontal line, respectively.

(3) The effect of the group-trigger event cut

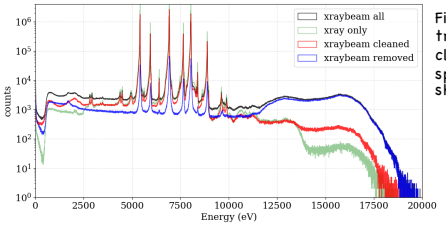


Fig. 4) The excluded components by the group trigger cut is shown in blue, while the cleaned one in red. The black and green spectra are the same as figure 1, which are shown for comparison.

photos @J-PARC 2018, July

5. SUMMARY

We presented the implementation of the group trigger for the first time, and its successful use at the one-month experiment at J-PARC. The cut selection is optimized to obtain 95% signal acceptance and achieved the improvement of the signal to noise ratio by a factor of 2.5. We have only used a scalar value for the analysis, but utilizing a waveform in the neighbor could potentially restore the energy resolution as well. It could also let us notice a possible change in the environment (e.g., noise, crosstalk, or any change of detector response), which could be useful for the future space mission such as Athena, Lynx, and Super DIOS. Further application of the TES into the severe environment would help it more mature.

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