Response of TESs to charged particle impacts and analysis technique for exotic atom X-ray spectroscopy

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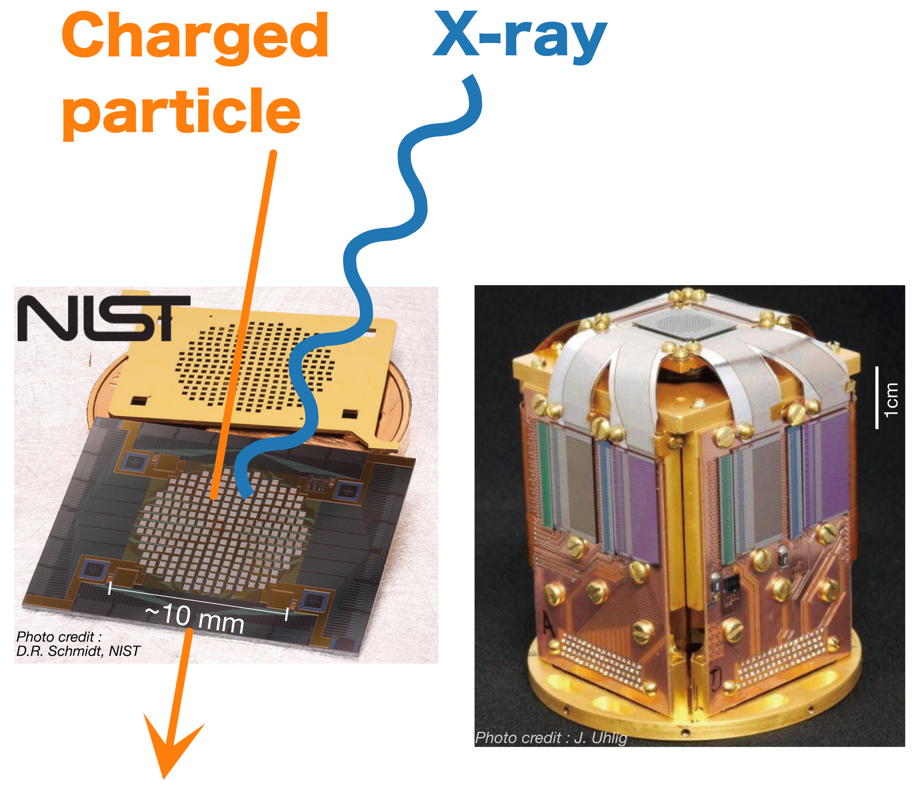
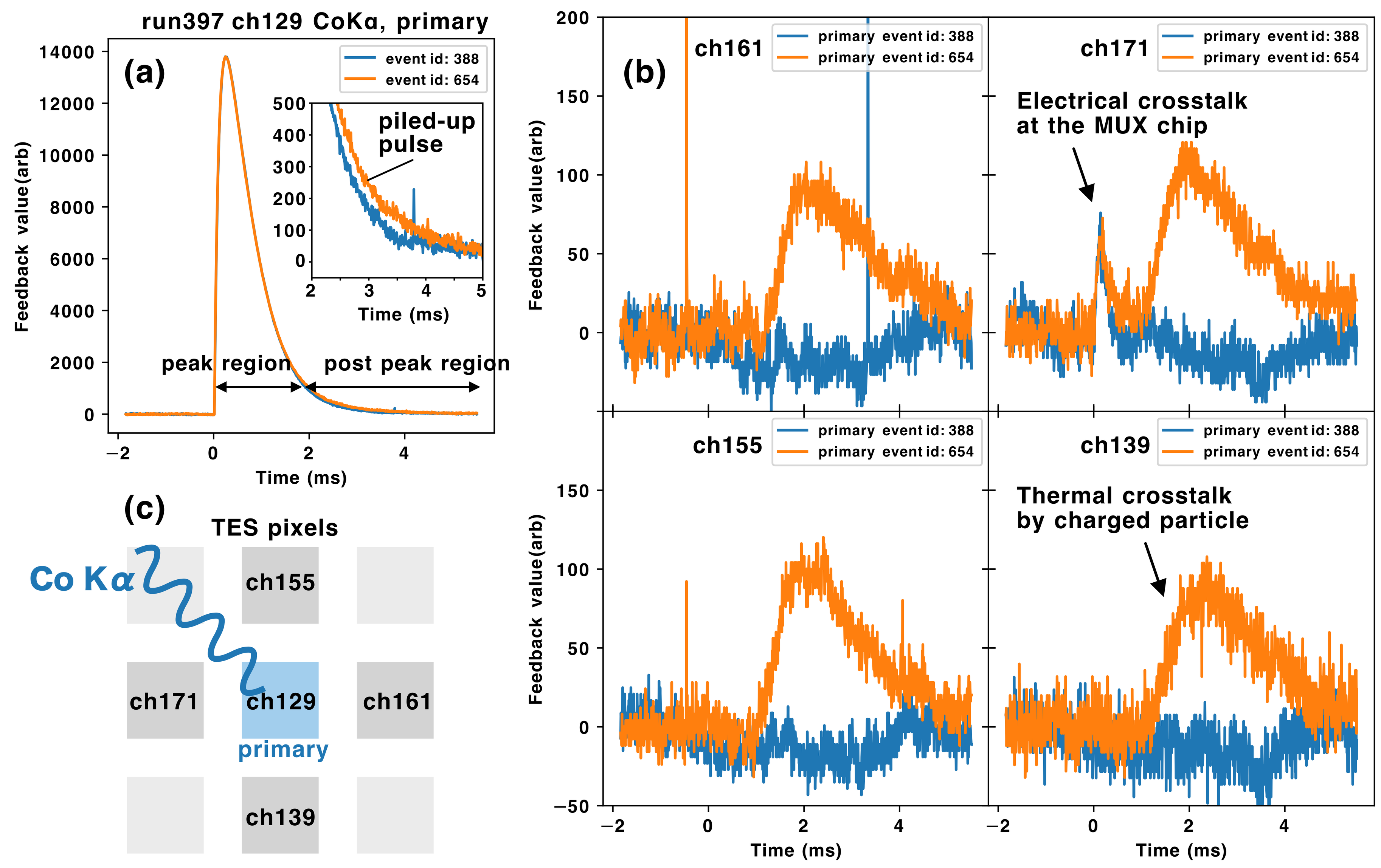
1. Identification of charged particle events



Left: The 240-pixel Mo-Cu bilayer TES array, each pixel is covered with the 4-μm thick Bi absorber. The total active area is 23 mm² with the gold-coated silicon collimator. *Right*: Time-division-multiplexing (TDM) readout system through 8 SQUID columns.

The application of TESs at the charged-particle-beam environment requires non-trivial analysis techniques. Investigating the charged particle impacts on the TES array is important to perform precision X-ray spectroscopy. The energy deposits of charged particles on the array, especially on its silicon substrate, can cause small thermal crosstalk pulses in all TESs. The pileup of the thermal crosstalk and normal X-ray pulses degrades the energy resolution due to poor pulse-height estimation via optimal filtering, moreover the additional low-energy and high-energy tail components are needed to fit the X-ray peaks.

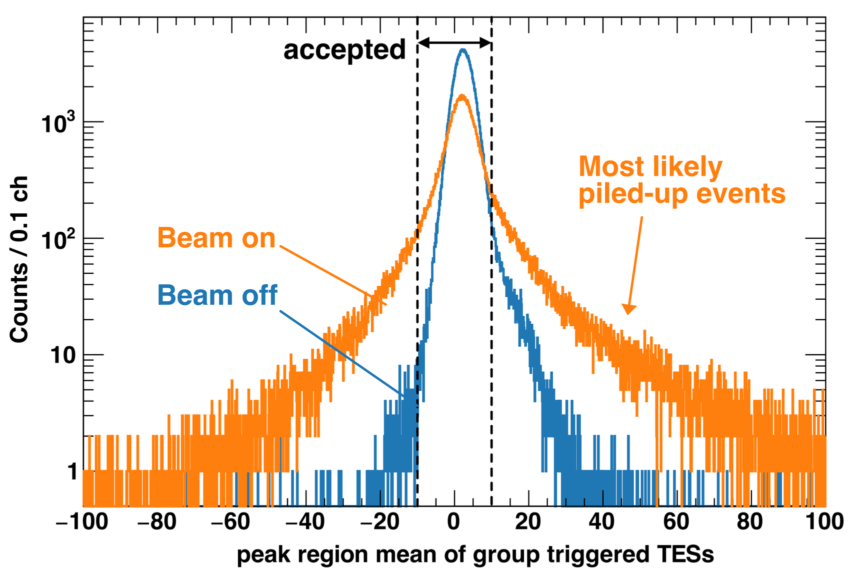
The group trigger is used to aid in the identification of thermal crosstalk. A TES pulse triggers the recording of that TES (primary records) and the four adjacent TESs (secondary records).



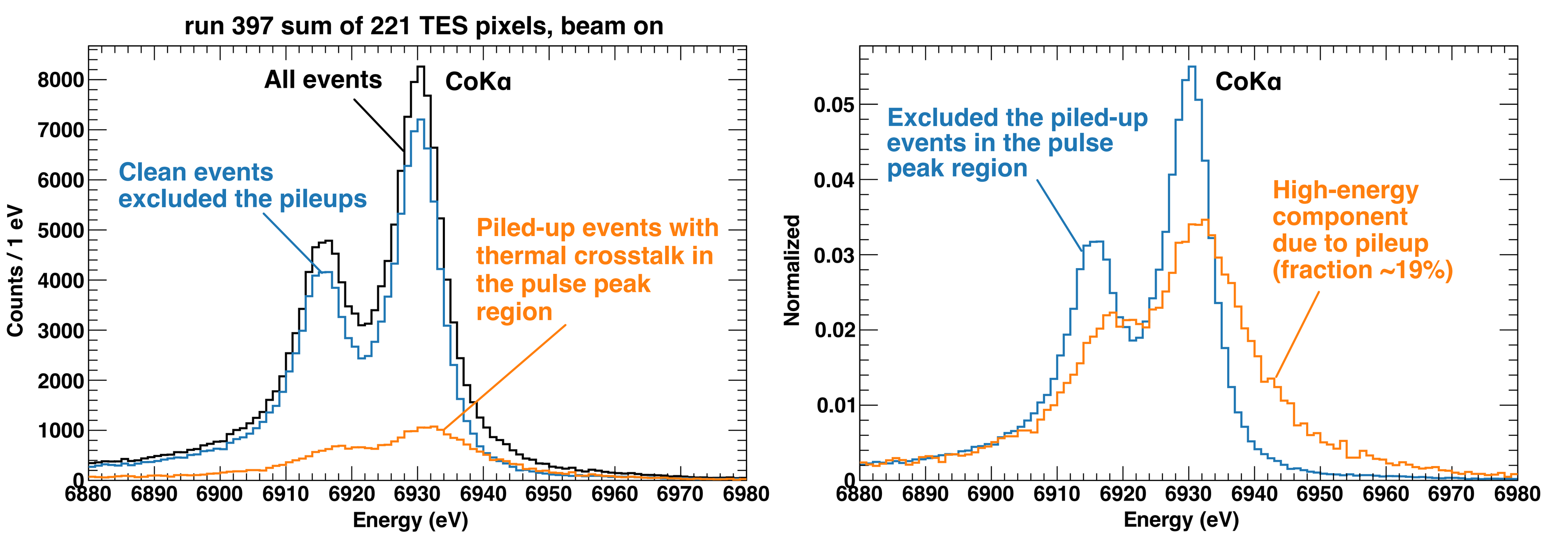
2. Thermal crosstalk effects in pulse peak region

Thermal crosstalk in the pulse peak region is identified using secondary event records from the four adjacent TES pixels. We define the pulse peak region as 256 samples from the primary trigger (1 sample is 7.2 μs) and can evaluate the peak-region-mean value (PRMV) for each TES. Abnormally high PRMV indicated that an X-ray event is affected by the pulse-peak-region thermal crosstalk.

The high-energy component of the X-ray peak is excluded by the PRMV cut. There is no need for the empirical high-energy tail function to fit the X-ray peaks.

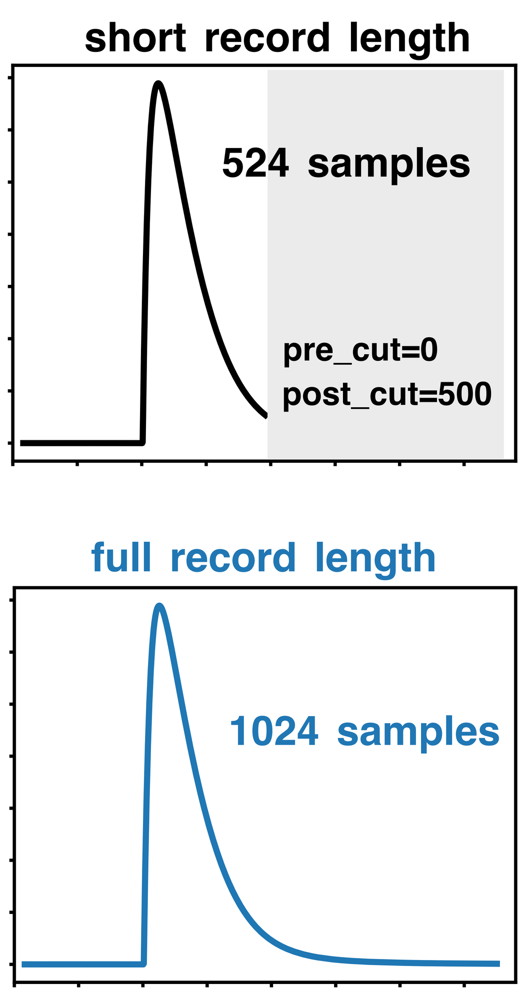


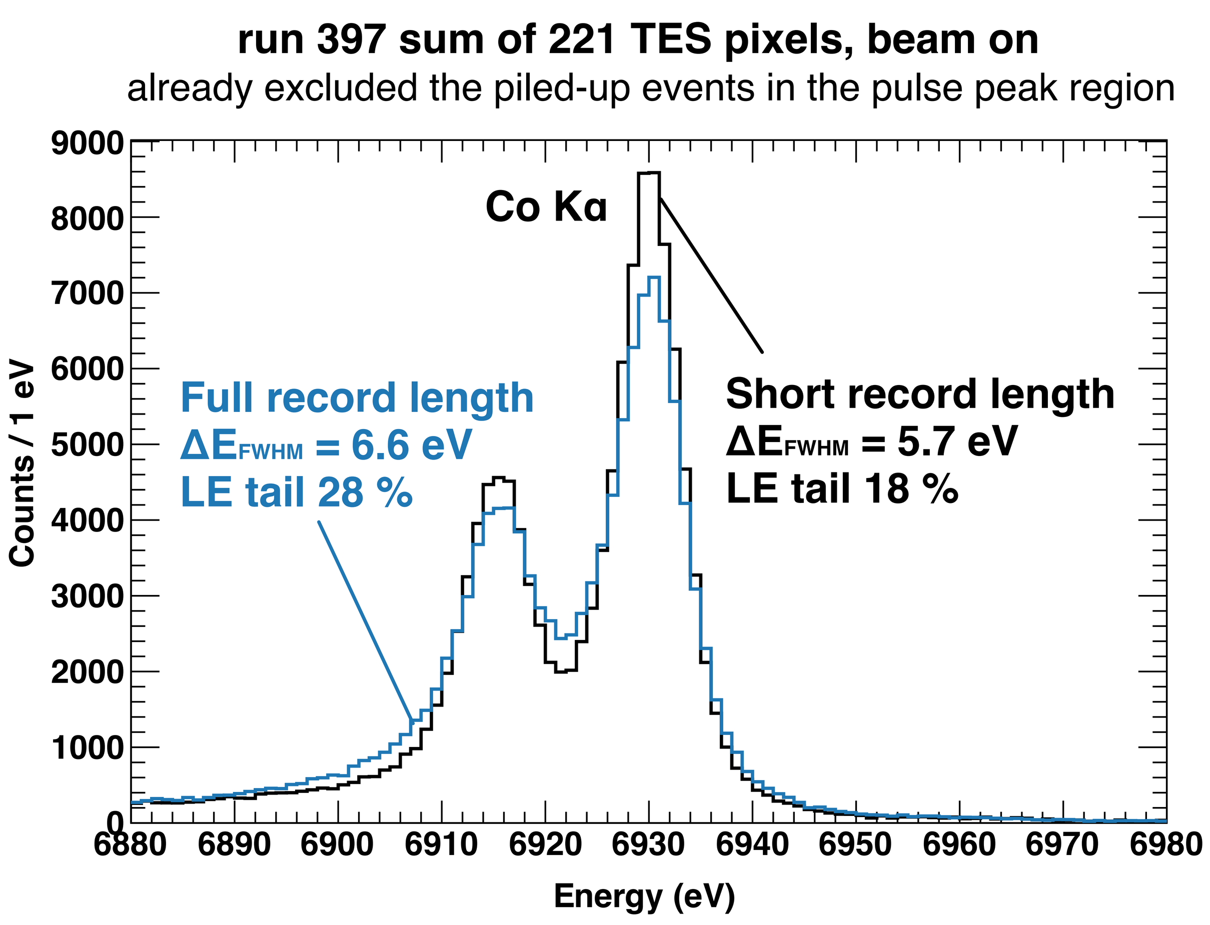
Beam-on and off PRMV distributions of the adjacent TESs (secondary records). Events affected by the thermal crosstalk are identified by the condition |PRMV|≥10 (19 % of all pulse records).

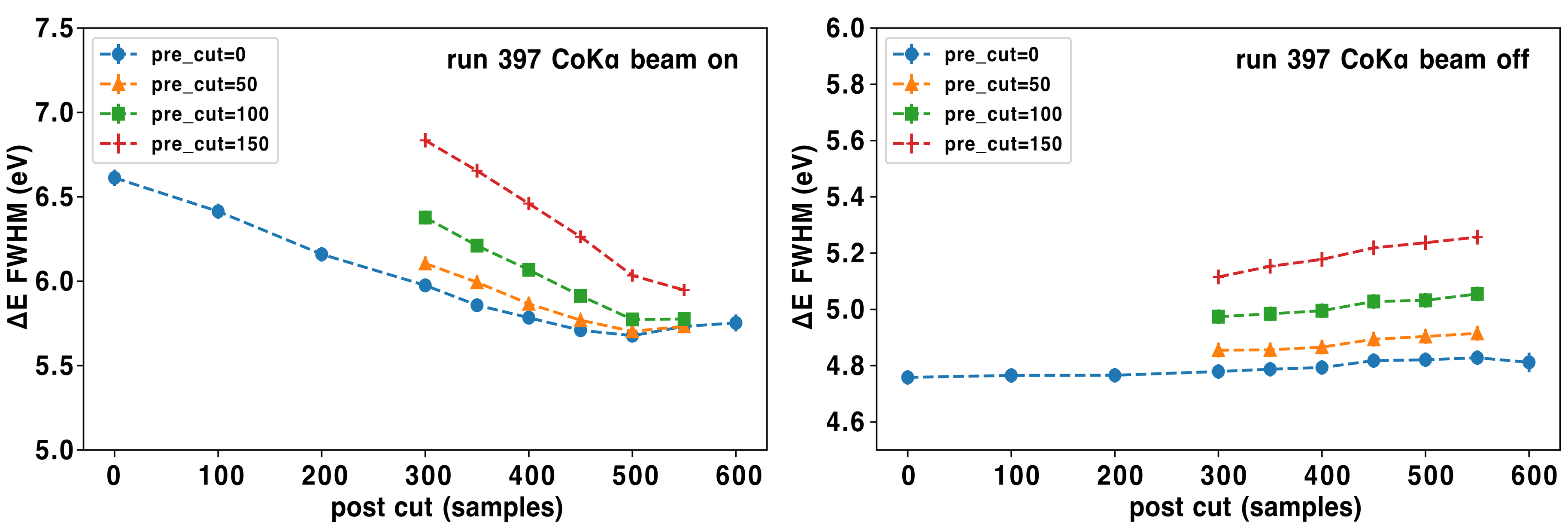


The beam-on energy spectra of Co Kα X-rays summed over 221 TES pixels. *Left*, the energy spectra of all events (black), events affected by the thermal crosstalk in the pulse peak region (orange), and clean events not affected by the thermal crosstalk in the pulse peak region (blue). *Right*, the normalized spectra of events not affected by thermal crosstalk (blue) and affected (orange) in the pulse peak region. The orange histogram has a visible high-energy component.

3. Short record length analysis and the piled-up events in the post peak region

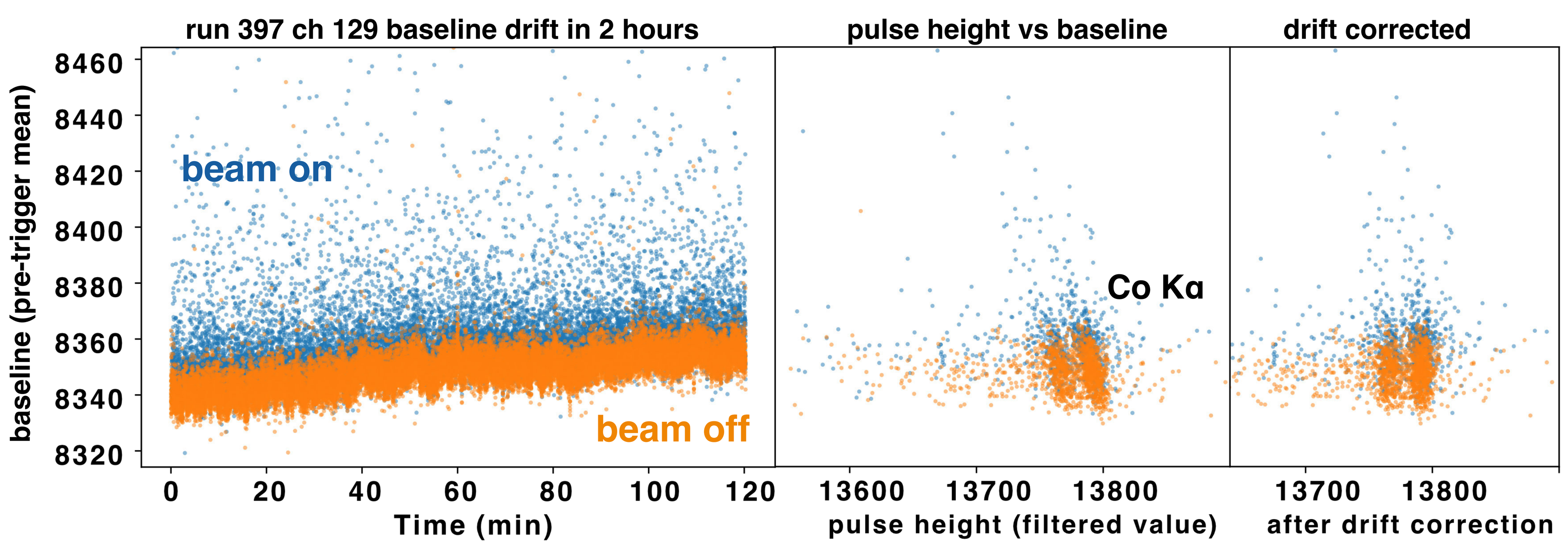






The use of the shorter record lengths improves the FWHM energy resolution from 6.6 eV to 5.7 eV at the Co Kα and reduced the LE tail fraction from 28 % to 18 % without losing any events. The record-length dependence of the energy resolution shows the optimal point at the post cut=500 and pre cut=0. In our case, the charged particle hit rate on the TES array is ~40 cps/array.

4. Baseline shift, gain drift, and drift correction



The baseline is slightly changing when beam is on in addition to the gain drift, because the heat from the charged particles energy deposits heats the TES pixels. The beam-on and beam-off correlation between baseline and pulse height could be slightly off. If the energy calibration curve is shared, the beam-on X-ray peak position may shift by 0.2 eV.

5. Summary

- Developed the analysis techniques to identify the piled-up events with the thermal crosstalk and to reduce the pileup effects.
- The high-energy and low-energy components of the X-ray spectra are excluded by using the pulse-peak-region analysis with the group trigger and the shorter record-length analysis to discard the piled-up record timing, respectively.
- These methods improve the energy resolution from 6.6 eV (FWHM) to 5.7 eV at 6.9 keV and enable simpler fits of X-ray spectra, which leads to precise and accurate energy calibration.

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