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Silicon beta cell performance improvements using silicon photomultiplier well detectors for beta-gamma radioxenon systems

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INTRODUCTION

Improvements were made to a prototype silicon beta cell for beta-gamma coincidence counting of radioxenon.

METHODS/DATA

The original configuration, while meeting targeted noise and threshold targets, could clearly be improved with the adoption of new hardware.

START

RESULTS

Thresholds were successfully dropped from nearly 45 keV to just under 22 keV with improvements also made to the reliability and ease of operation of the detector.

CONCLUSION

Improvements to detector response were readily made with the selection of new hardware components. Refinement of the design would likely provide further benefits and increase the spectroscopic range of the system.

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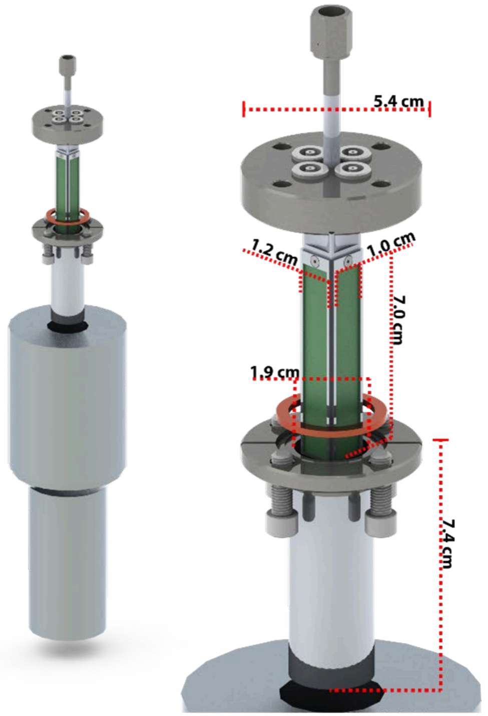
Beta Cell Introduction

Prior efforts in developing a silicon beta cell as a potential improvement to scintillating plastic in beta-gamma systems resulted in a design with high resolution, capable of resolving different conversion electron energies in the metastable radioxenons, but a higher threshold that cut off low energy x-rays. Switching from a photomultiplier tube based NaI well detector to a low-voltage silicon photomultiplier (SiPM) based detector resulted in a significant improvement to the energy threshold from nearly 45 keV to below 30 keV. When combined with changes to the high voltage bias supply, energy thresholds on the beta cell have been reduced to below 22 keV. The SiPM well detector also drastically improved run-to-run reliability by eliminating noise dependence on beta cell positioning.



(Right) Silicon chips mounted to ceramic holders and wired to the vacuum flange feedthroughs.
(Left) Concept drawing of silicon beta cell with vacuum cover in tandem with PMT based NaI well detector.

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Initial Results and Expectations

Initial Setup:

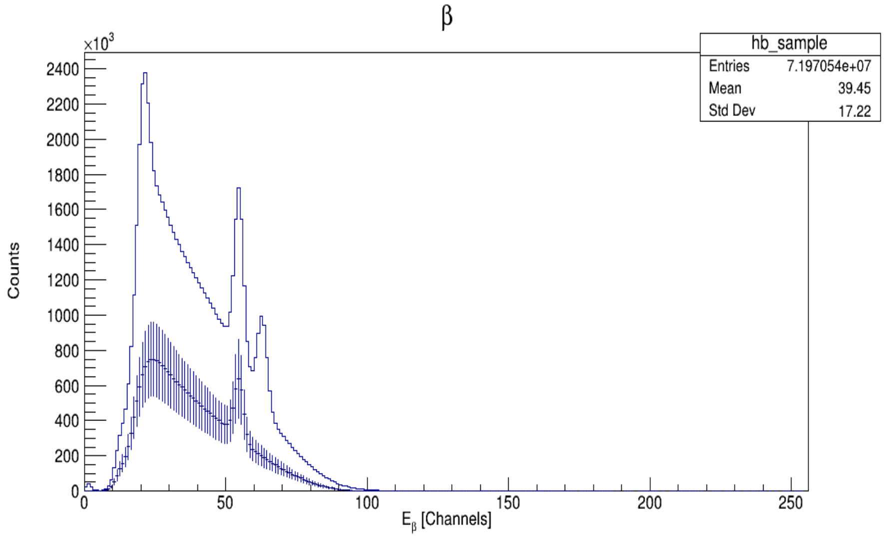
- Beta cell of four monolithic silicon chips
- In parallel with Scionix well detector with PMT base
- Caen charge sensitive A1422 preamplifier
- Caen N1490 NIM HV power supply
- XIA Pixie4 DAQ readout
- Room temperature operation

Measurement Campaign:

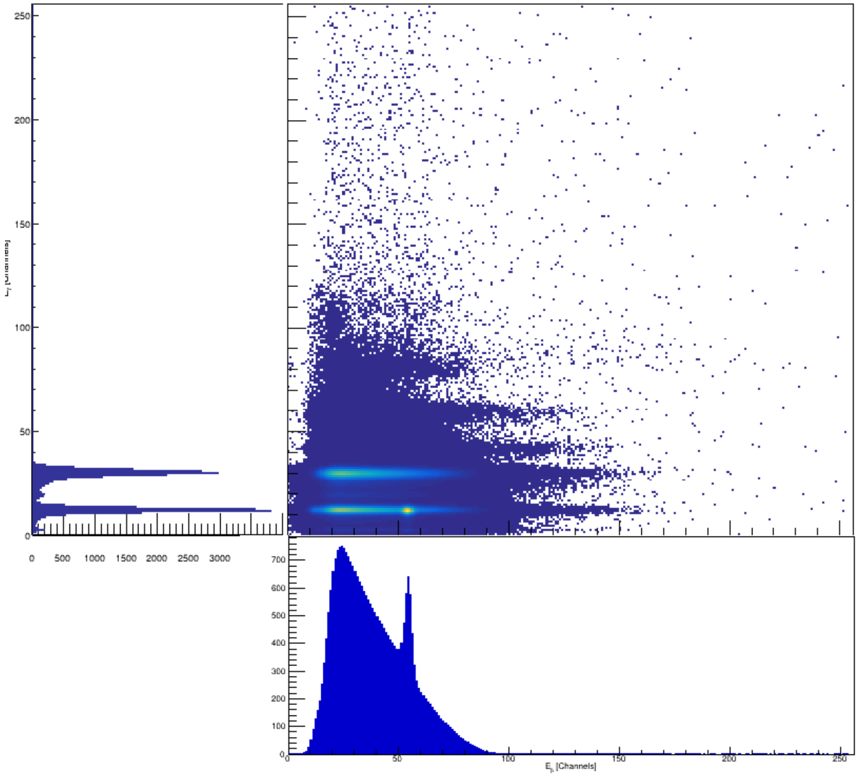
- Xe-131m, Xe-133, Xe133m, and Xe-135

Threshold was found to be low enough to partially capture the 45keV CE from Xe-133 (left, singles). Initial testing goal was met but a reduced threshold would be advantageous for low energy x-rays and conversion electrons.

Silicon beta cell in NaI well detector.



Silicon beta cell histogram of Xe-133m with beta singles as a solid line and coincidence counts as a dashed line. The two CE's of Xe-133m are clearly distinguishable in the beta singles while the 45keV peak from Xe-133 is only partially captured.



Beta-gamma coincidence measurement of Xe-133m with Xe-133. Beta coincidence is projected along the x-axis and gamma along the y-axis. A single peak in the beta coincidence is observed for the 199 keV CE.

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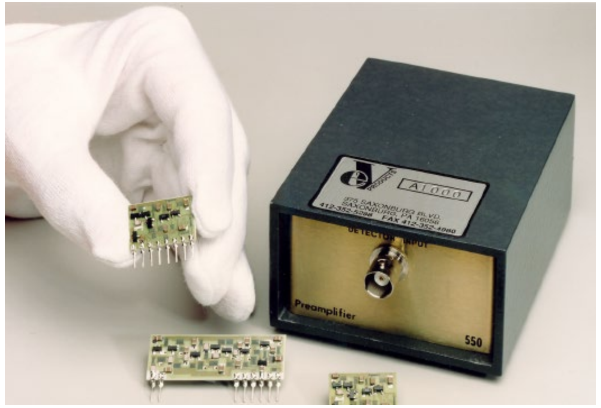
Noise Reduction Through Hardware Changes

Hardware improvements:

- Moved to SiPM based NaI well detector (Scionix 83BP76/SIP-E3-X)
  - Eliminated noise from positional dependence of beta cell within well detector
  - Immediately lowered noise threshold to fully capture the 45 keV CE peak.
- Changed HV power supply to Caen DT5485P
  - Lower V_{pp} ripple in bias voltage
- Kromek EV-5093 preamplifier
  - Lower gain at 5-158 mV/MeV vs. 400 mV/MeV
  - Modestly reduced keV noise per pF of detector capacitance
- Refrigeration added as a last step in testing
  - Cooled to 46 °F (7.8 °C)

Original Caen preamplifier with 400 mV/MeV charge sensitivity



Promotional photograph of Kromek model 550 preamplifier box.

SiPM based NaI well detector.

Silicon beta cell partially inserted into the SiPM based well detector.

New Caen desktop SiPM power supply used to bias silicon beta chips.

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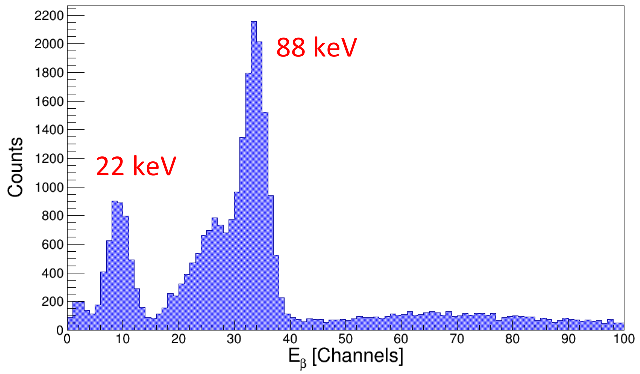
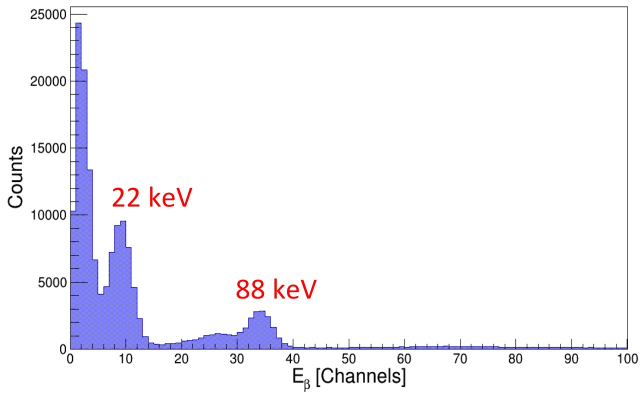
Performance Improvements

Hardware improvements impact:

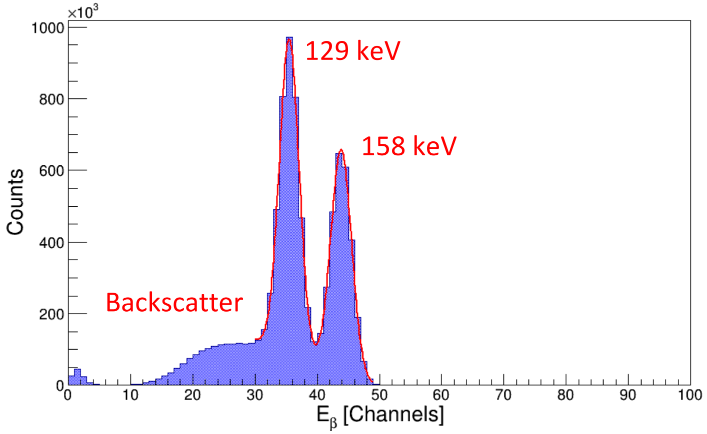
- Lowered noise threshold significantly
  - The 22 keV threshold of Cd-109 was observed. Altering the threshold changed the efficiency significantly.
- Modest improvement to the peak energy resolutions of Xe-131m
- Reliability and ease of operation significantly improved with removal of positional dependence of beta cell within NaI well
- SiPM NaI well detector required low ripple power source for comparable performance to PMT based detector



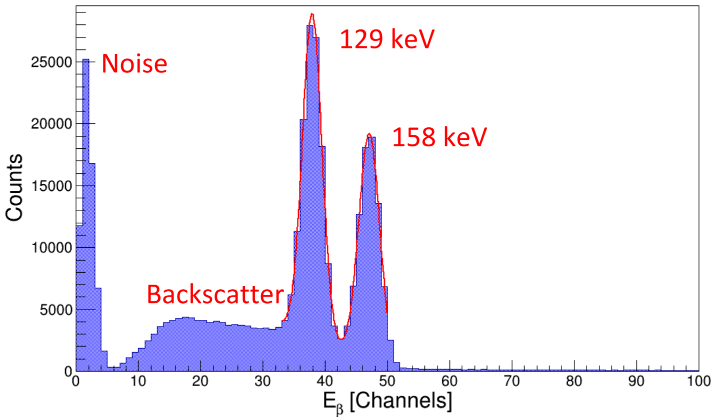
Beta singles from Cd-109 with hardware improvements. The 22 keV x-ray peak is partially captured.



Cd-109 with lowered threshold showing improved efficiency of 22 keV x-ray.



Original beta singles from Xe-131m calibration.



Beta singles from Xe-131m calibration with hardware improvements. The backscatter continuum extends to much lower channel values

Table of resolutions from the CE's of Xe-131m from the original calibration measurement and the improved hardware calibration. Modest improvements in resolution are observed, which is anticipated.

Isotope	Peak Energy [keV]	Resolution [%]	Original Resolution [%]
Xe-131m	129	9.80 ± 0.04	10.33 ± 0.01
Xe-131m	158	8.40 ± 0.07	9.59 ± 0.01

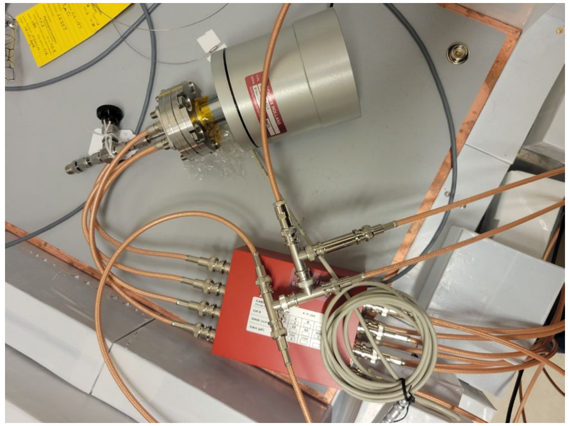
Conclusion

Lessons Learned:

- Performance of the silicon beta cell for radioxenon measurements can be impacted by the choice of paired well detector, bias supply, and preamplifier.
- PMT based NaI well detectors introduce noise in silicon beta cells. Switching to SiPM readouts eliminates the noise problems associated with positional dependence as well as improving the threshold limit.
- Incremental improvements exceeded the radioxenon measurement performance requirements and potentially place low energy x-rays and CE's in range of observation.

Opportunities:

- Installing Kromek preamplifiers directly onto the gas manifold housing is a promising step forward.
- Integrating a cooler into the manifold to stabilize temperatures at lower than ambient.
- Dedicated low noise power supplies for preamplifiers and SiPM well detector.



(Left) Silicon beta cell with SiPM well detector while wired to a single HV bias channel from the SiPM power supply.

(Bottom) Beta-gamma performance with improved hardware during Xe-131m calibration. The extent of backscatter continuum is clearly evident in the coincidence histogram to low energies.