SnT 2023

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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19 TO 23 JUNE

Next Generation Beta-Gamma Coincidence Detectors with Increased Capability

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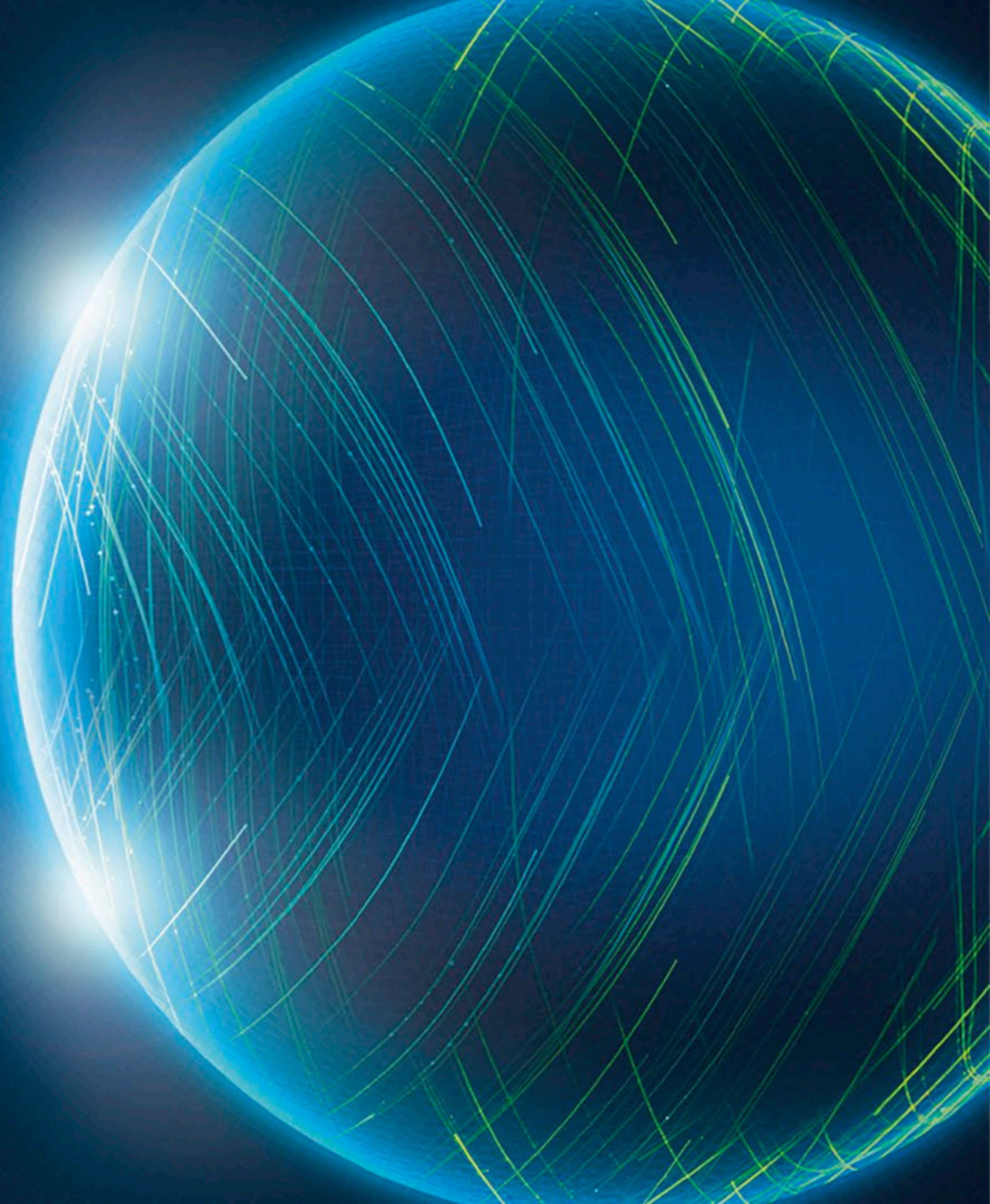
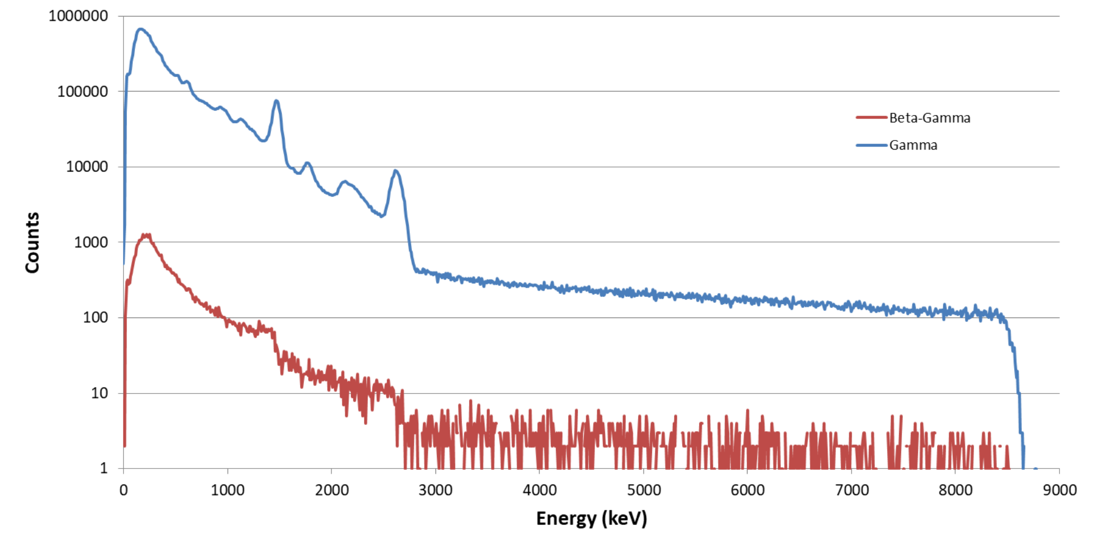
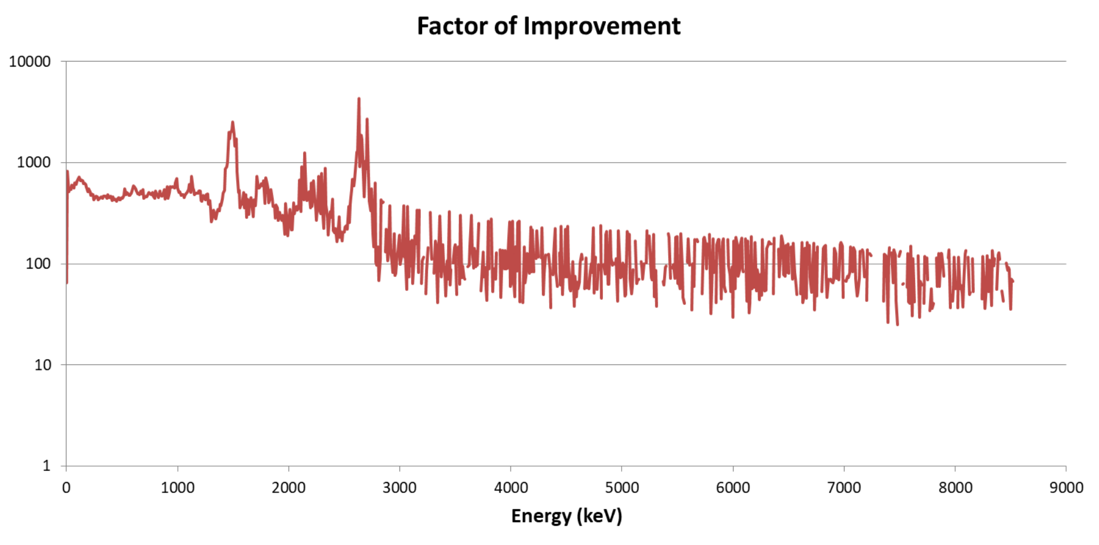


Beta-Gamma Coincidence for Radioxenon Detectors

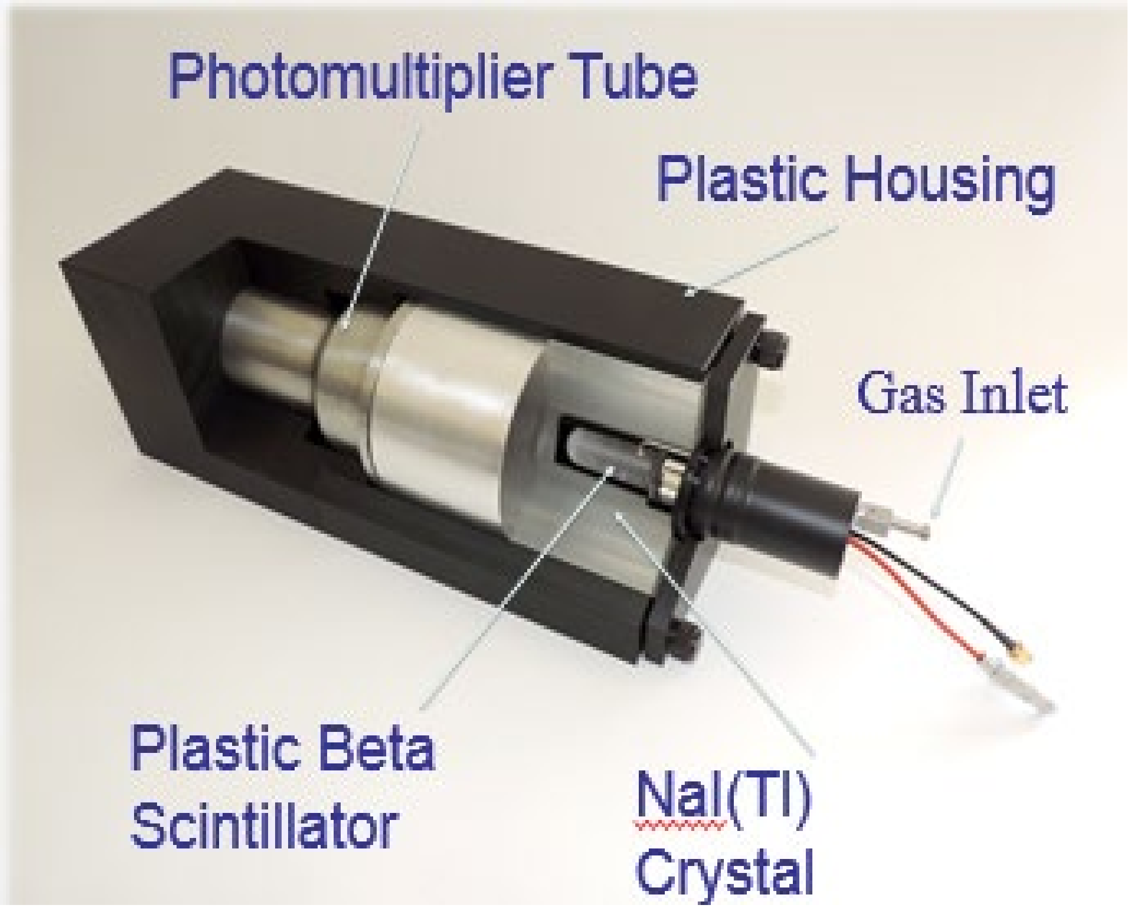
- Radioxenon is important for underground nuclear explosion monitoring
  - Noble gas, will escape and transport without much interaction
  - Half-lives of four isotopes are long enough to be detectable at long distances (^{131m}Xe, ^{133}Xe, ^{133m}Xe, and ^{135}Xe)
- Beta-gamma (electron-photon) coincidence offers good background reduction in xenon detectors
  - Improves minimal detectable activity (MDA)
  - Reduces shielding requirements





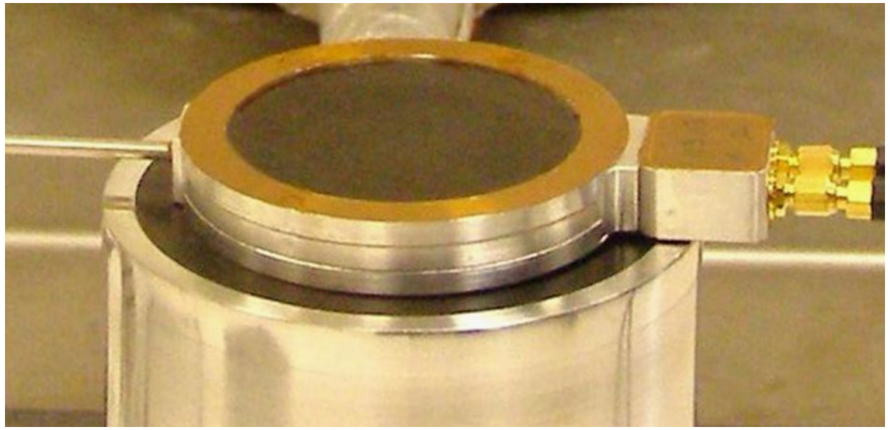
Radioxenon Detector Example

- Example radioxenon detector
  - Xenon International design
  - Gas contained in plastic scintillator (electron detector)
  - Surrounded by thallium doped sodium iodide (NaI [Tl]) photon detector
- Challenges
  - Plastic scintillator has poor resolution
  - Plastic scintillator absorbs xenon (memory effect)
    - Mitigated with Al_2O_3 coating
    - Research into glass scintillator (for example; University of Michigan)

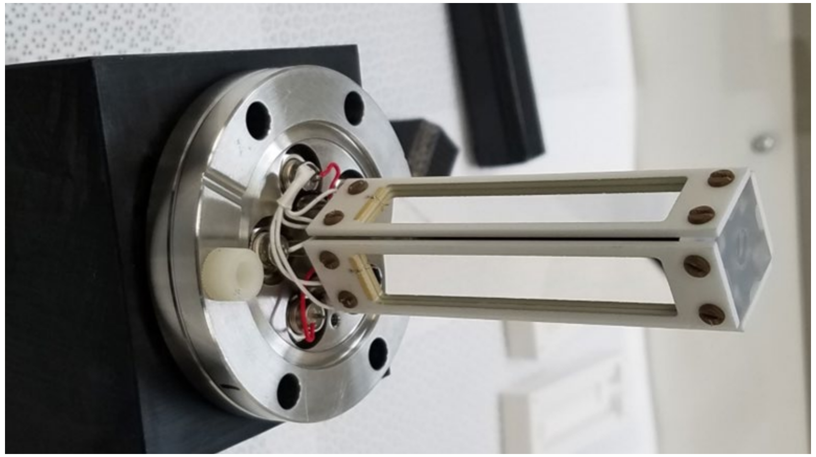


Recent Radioxenon Detectors

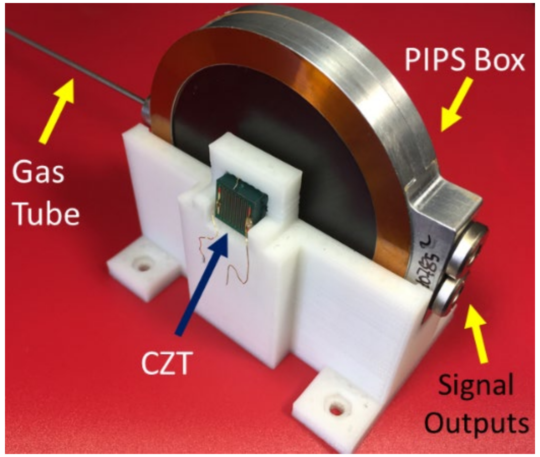
- Electron Detectors
  - Silicon
    - Better resolution and no/little memory effect compared to plastic scintillator
  - Photon Detectors
    - Cadmium-Zinc-Telluride (CZT)
      - Better resolution compared to NaI, but less than high purity germanium (HPGe)



SPALAX: PIPSBox on top of HPGe detector



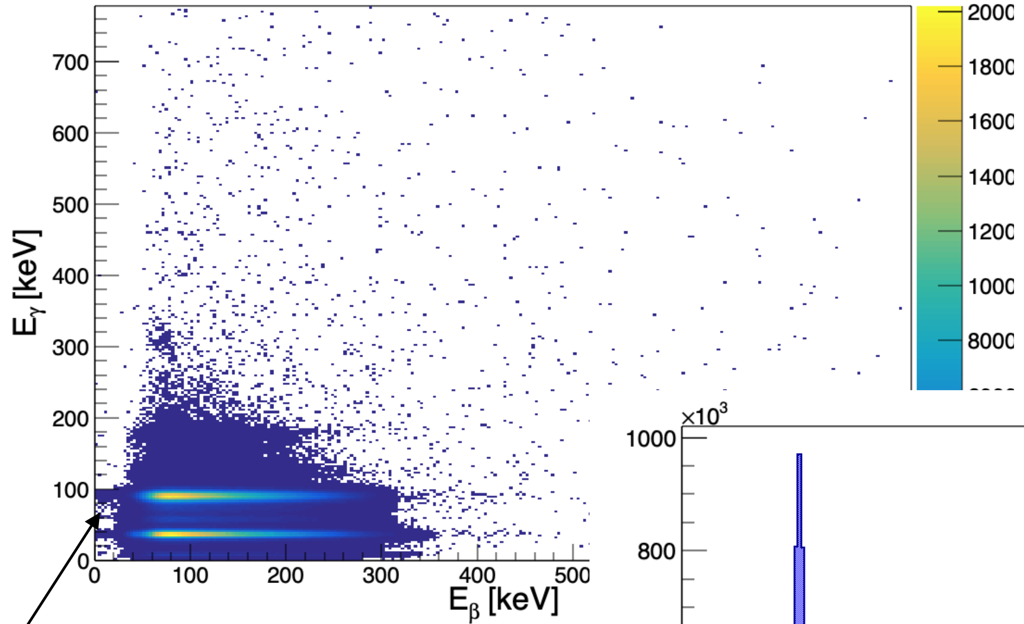
Silicon detector at PNNL



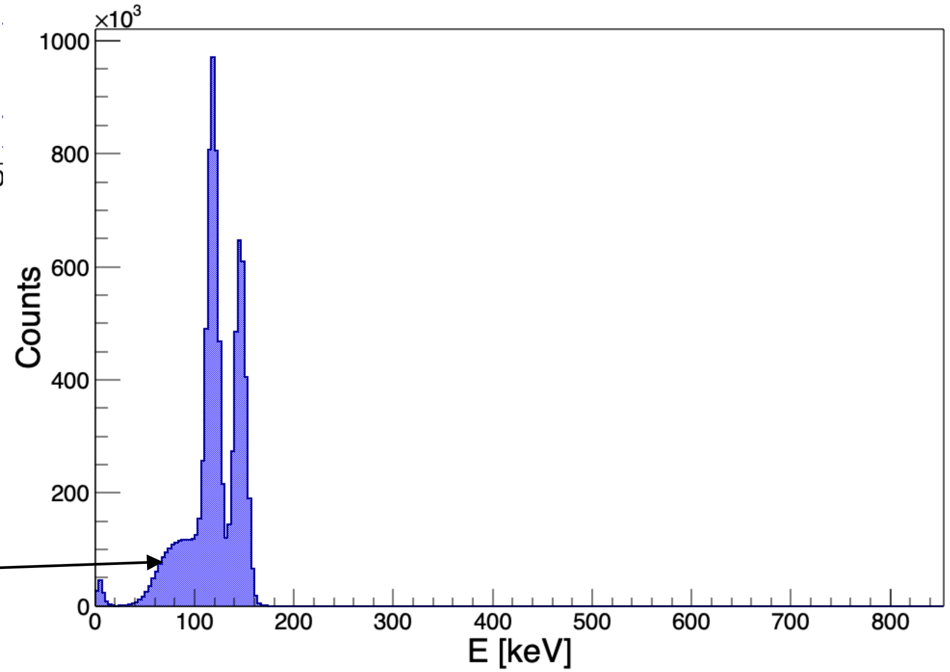
PIPS-CZT detector (Oregon State University)

Silicon Detector for Electron Detection

- Silicon provides better resolution
  - Smaller ROIs – less background – lower MDA
  - Low energy noise requires discrimination
  - Electron scattering



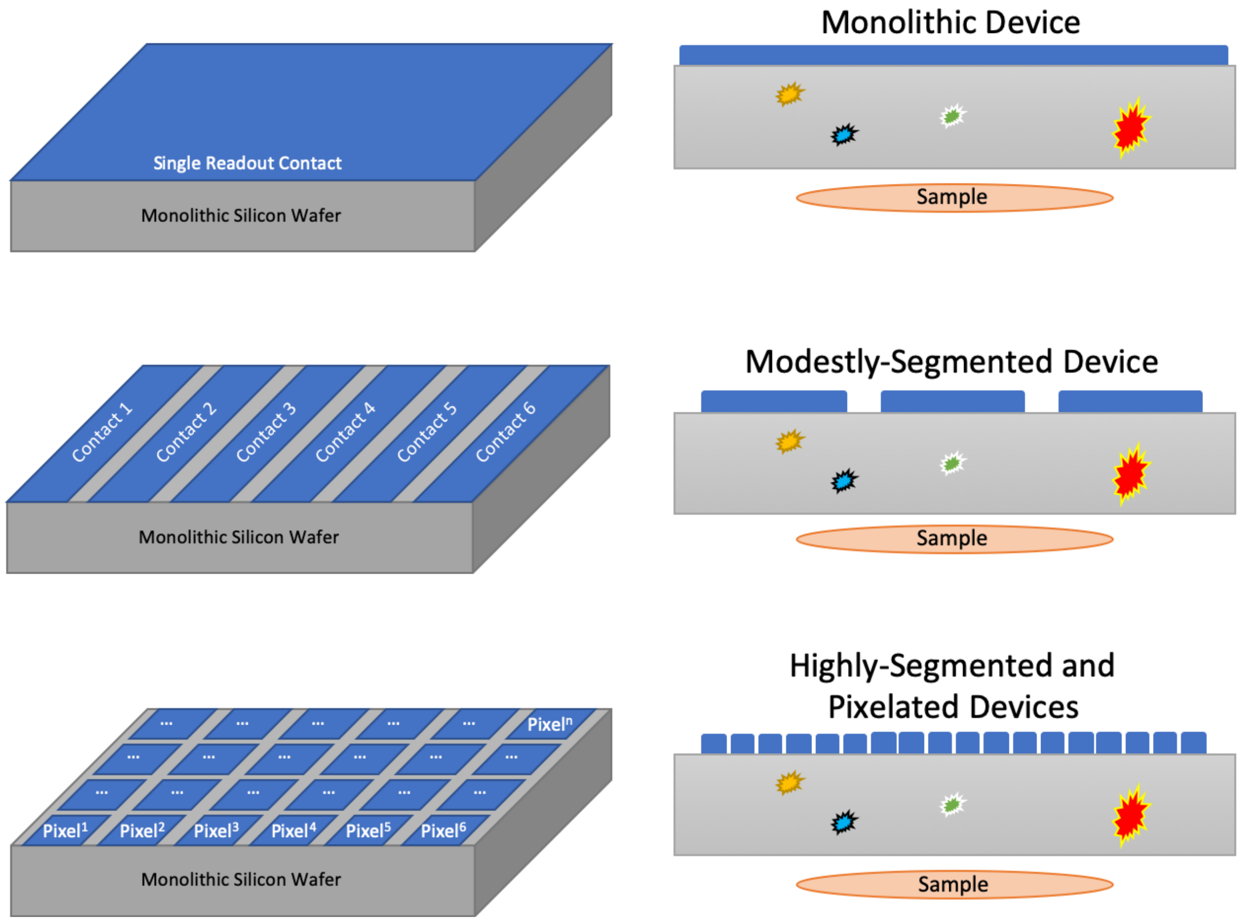
^{133}Xe: low energy electrons cut off



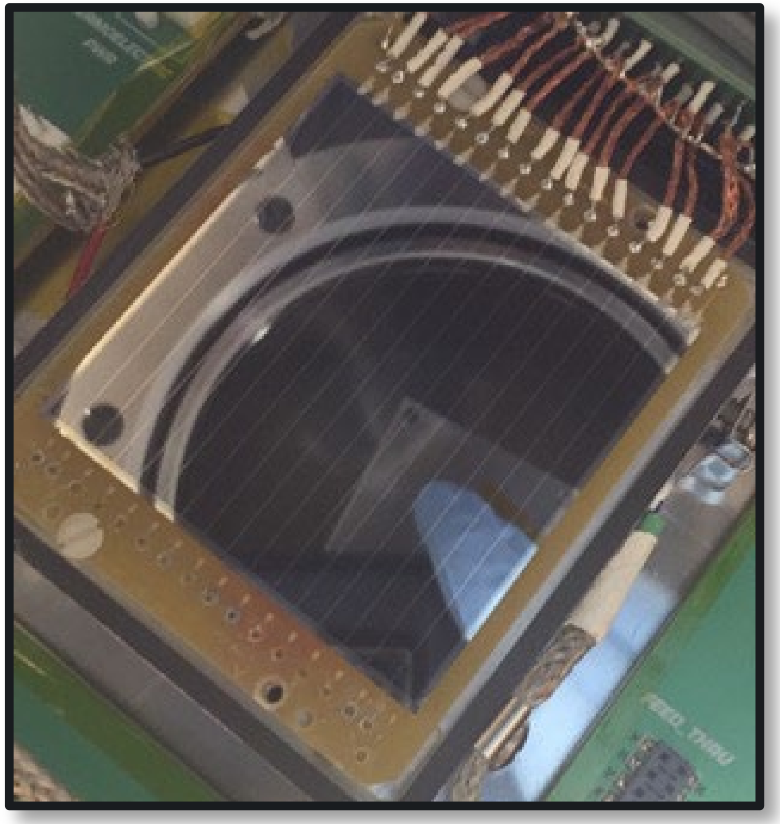
^{131m}Xe (singles): low energy tail from electron scattering

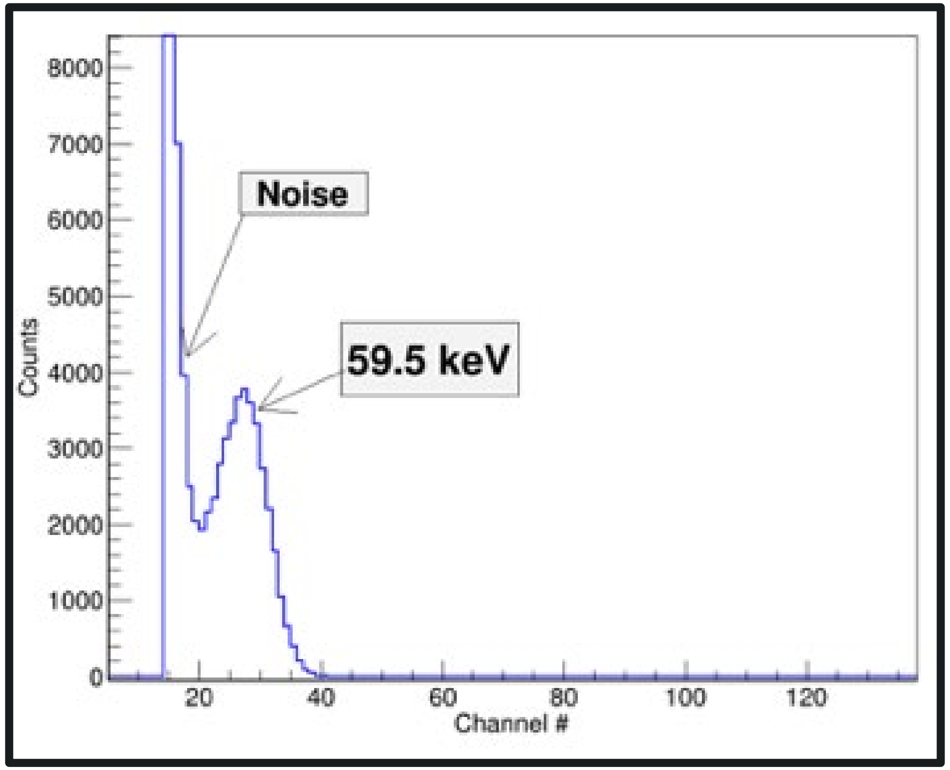
Reducing Noise

- Approach to reduce noise and lower threshold
  - Reduce capacitance of detector
  - Segmented detectors
    - Current detectors - some segmentation
    - Pixelation – maximum segmentation



Segmented Strip Detector Example

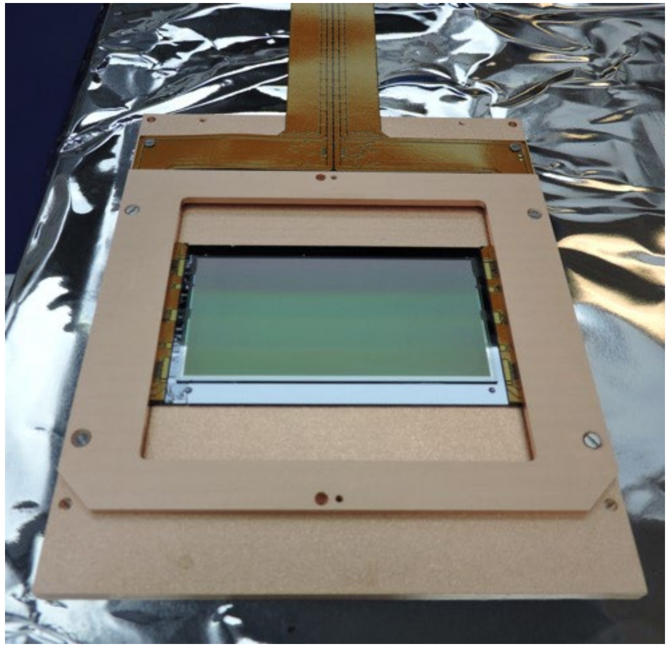


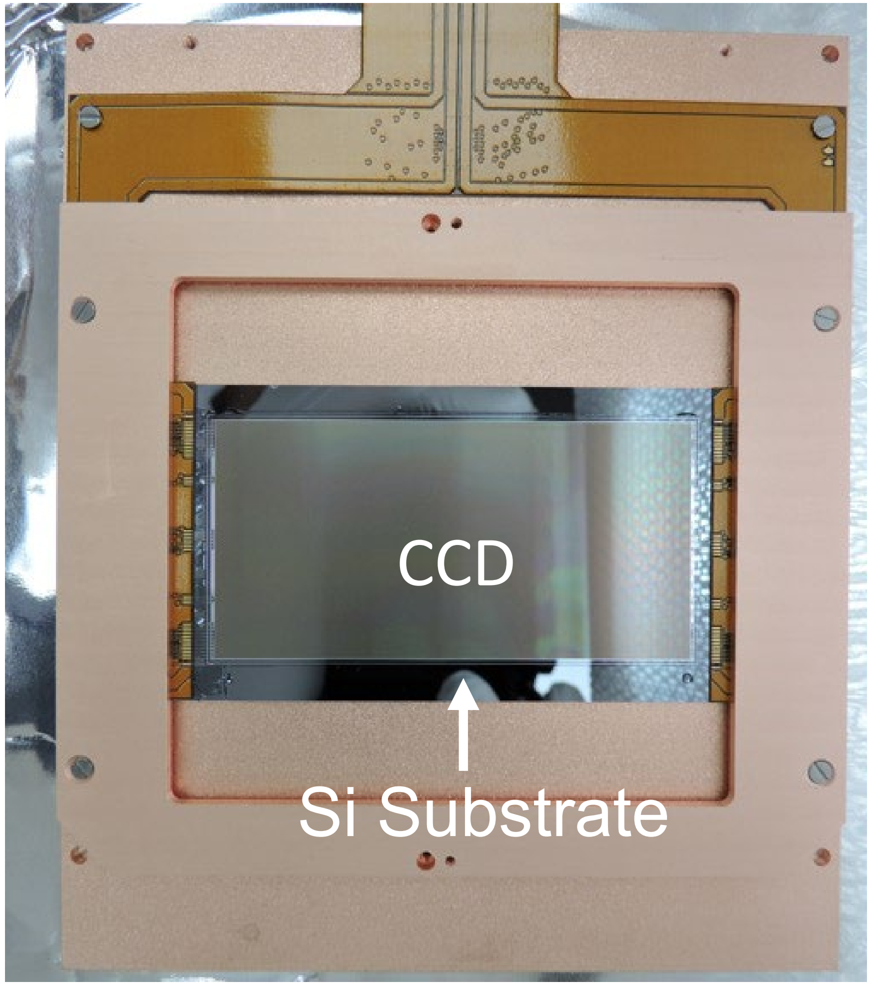


- 16-strip commercial detector; capacitance lower in each strip compared to monolithic detector
- Lower noise threshold (example of ^{241}Am source; noise below channel 20 or roughly 40 keV)

Thick Charge Coupled Devices (CCD)

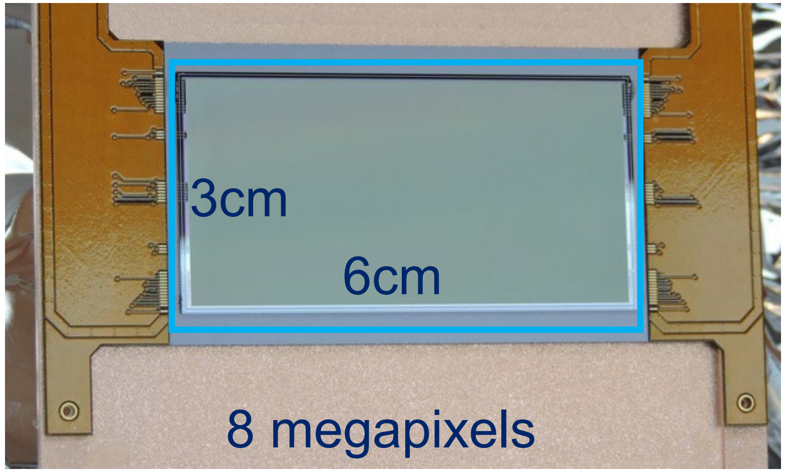
- Highly pixelated (15 micron pixels)
  - Large size possible (6 × 9 cm^2)
  - Thick – up to 675 microns



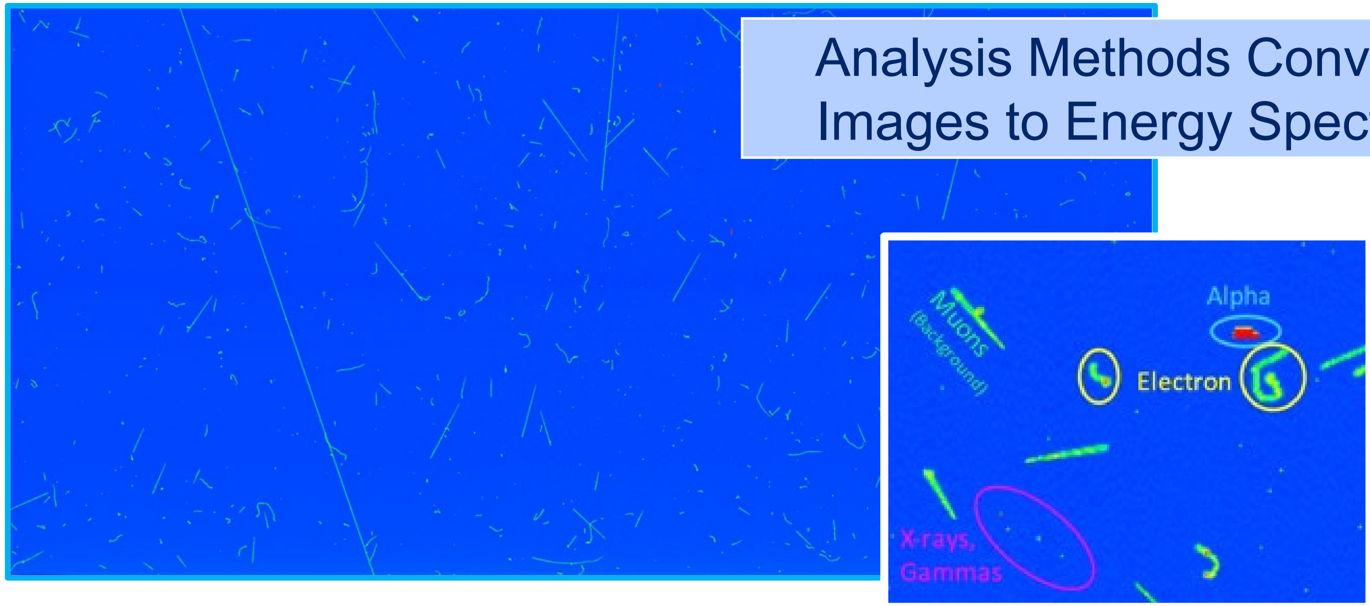


Large area CCDs developed at Lawrence Berkeley National Laboratory Microsystem Lab

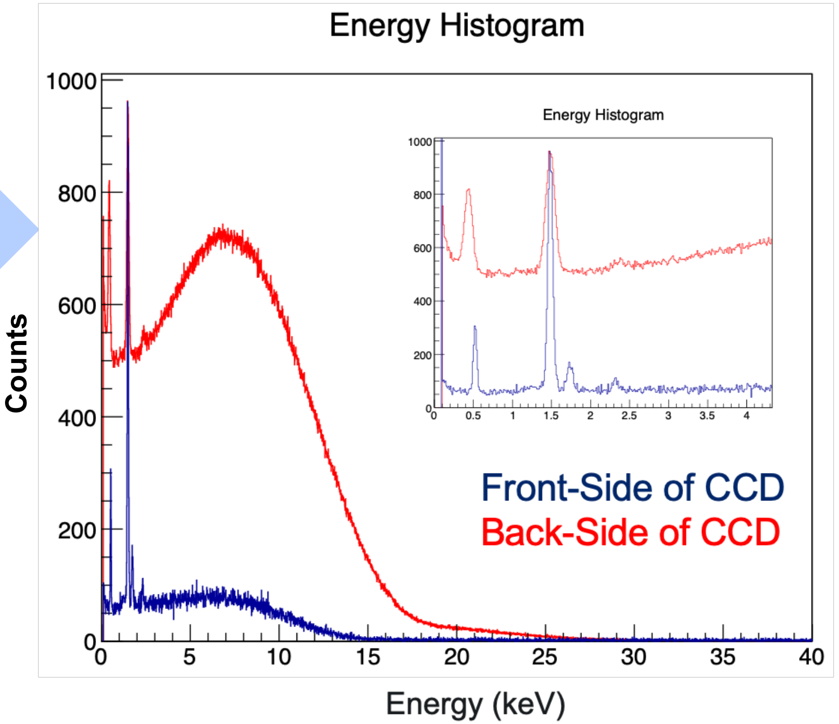
Ionizing Radiation Detection with CCD



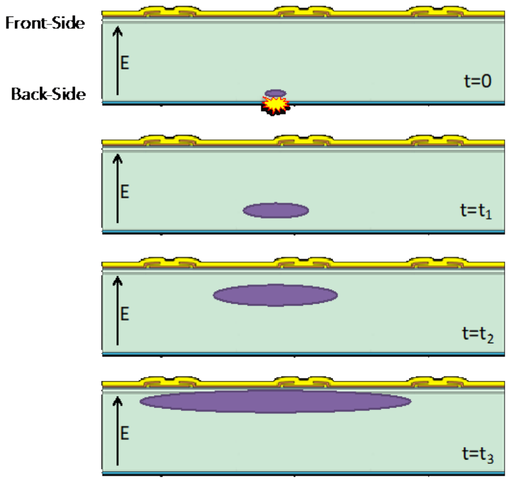
- Different particles produce different signatures

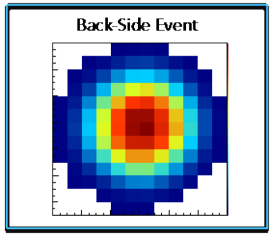


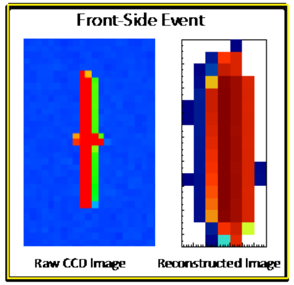
Analysis Methods Convert Images to Energy Spectra

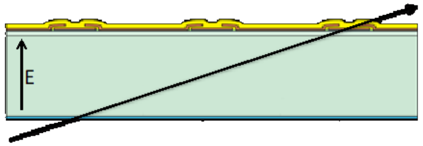


Particle Interactions in CCD

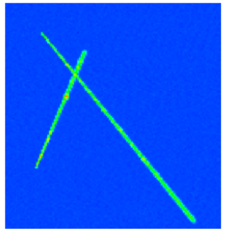




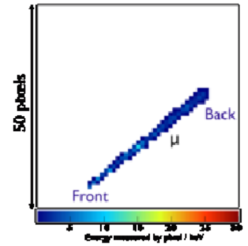




Muons or other minimum ionizing particles leave behind linear tracks

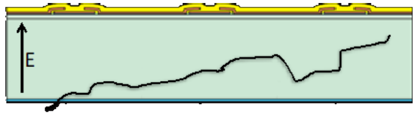


Raw CCD image of muon tracks

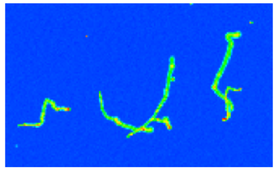


Reconstructed CCD image

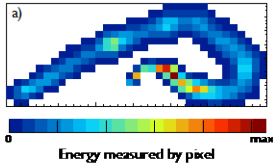
Beta



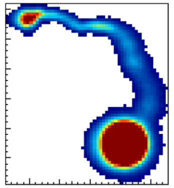
Beta events are characterized by the irregular tracks



Raw CCD image of beta tracks

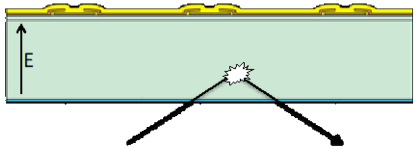


Reconstructed Image

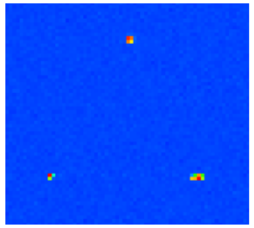


Alpha-Beta Event

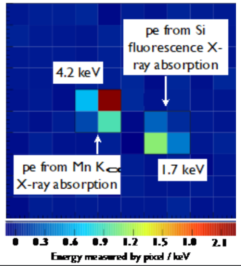
Gamma/X-ray



Gamma / x-ray events are characterized by diffusion limited events

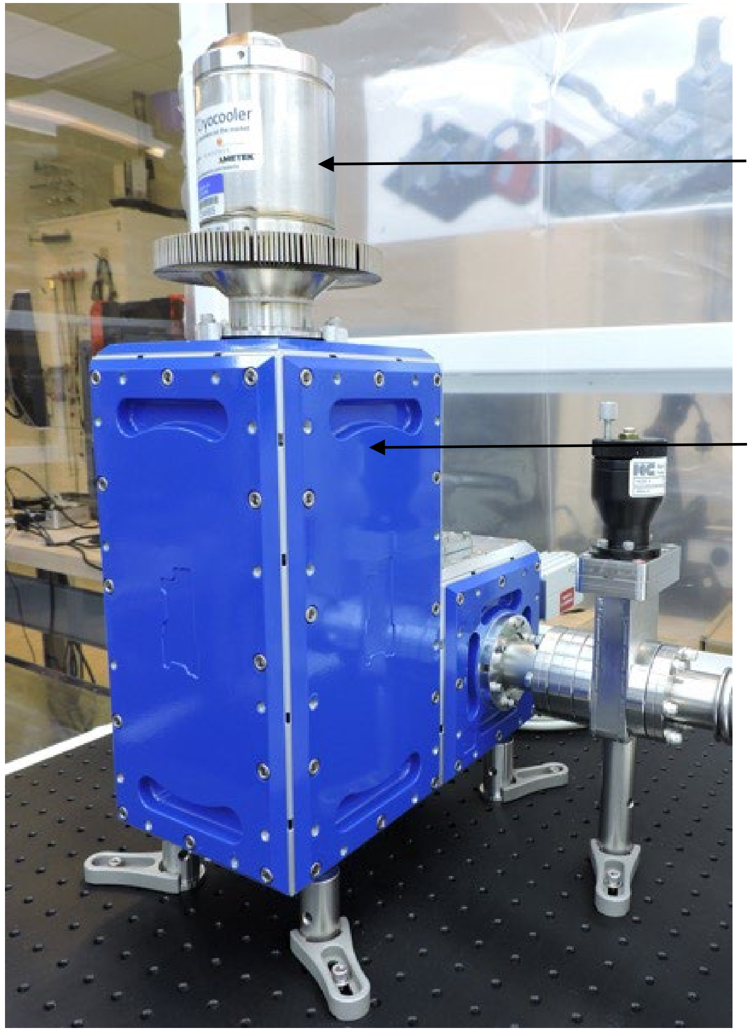


Raw CCD image of D.L. events



CCD Testing Systems at PNNL

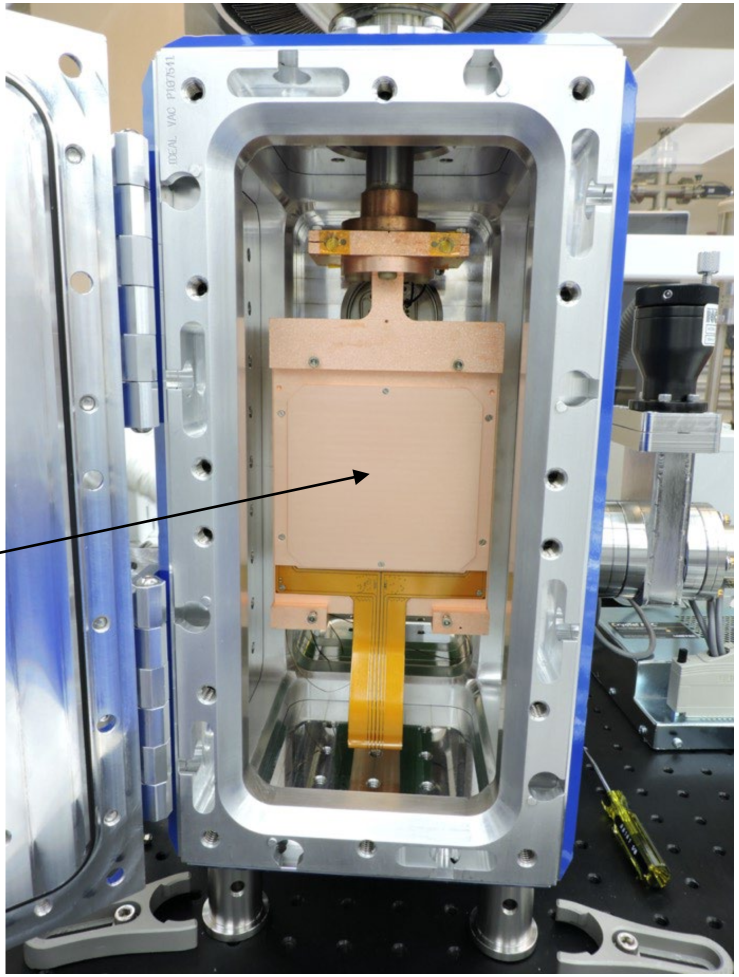
- This is not a field system! (yet…)



Mechanical Cooler

Vacuum Chamber

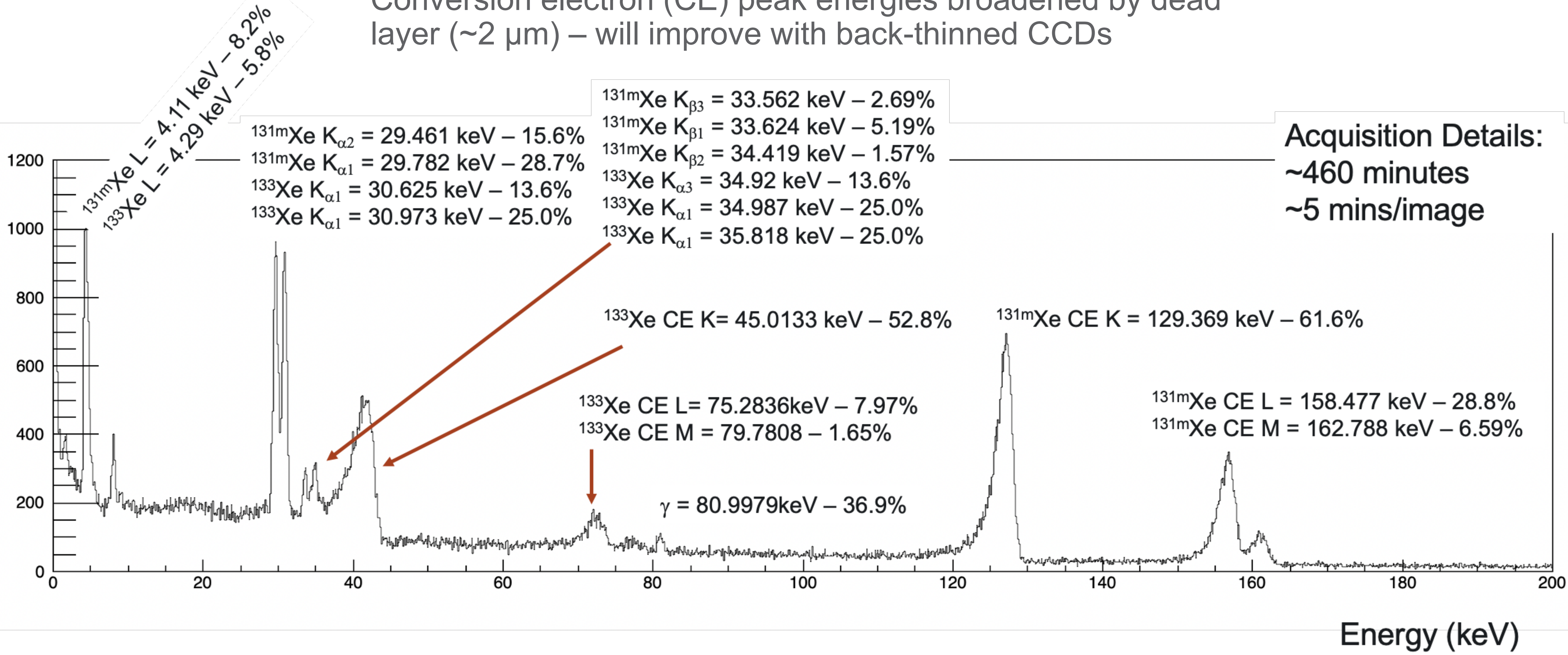
CCD Cover



Best noise performance at 140-160 K; need vacuum chamber and cooler

CCD Testing Systems at PNNL

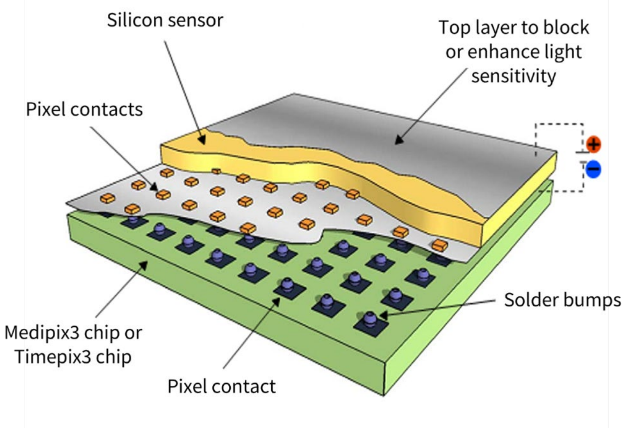
Conversion electron (CE) peak energies broadened by dead layer (~2 μm) – will improve with back-thinned CCDs

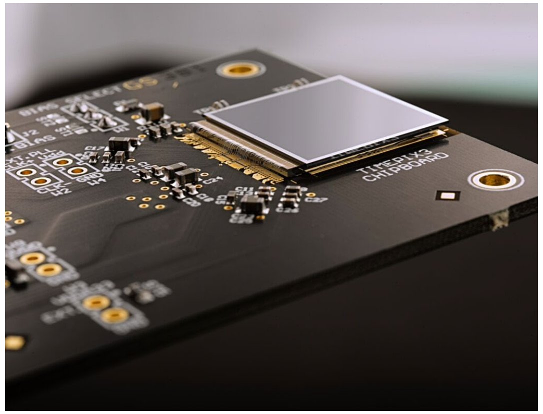


Latest back-thinned detectors have improved performance (down to 1.5 keV threshold) and are larger (54 cm^2)

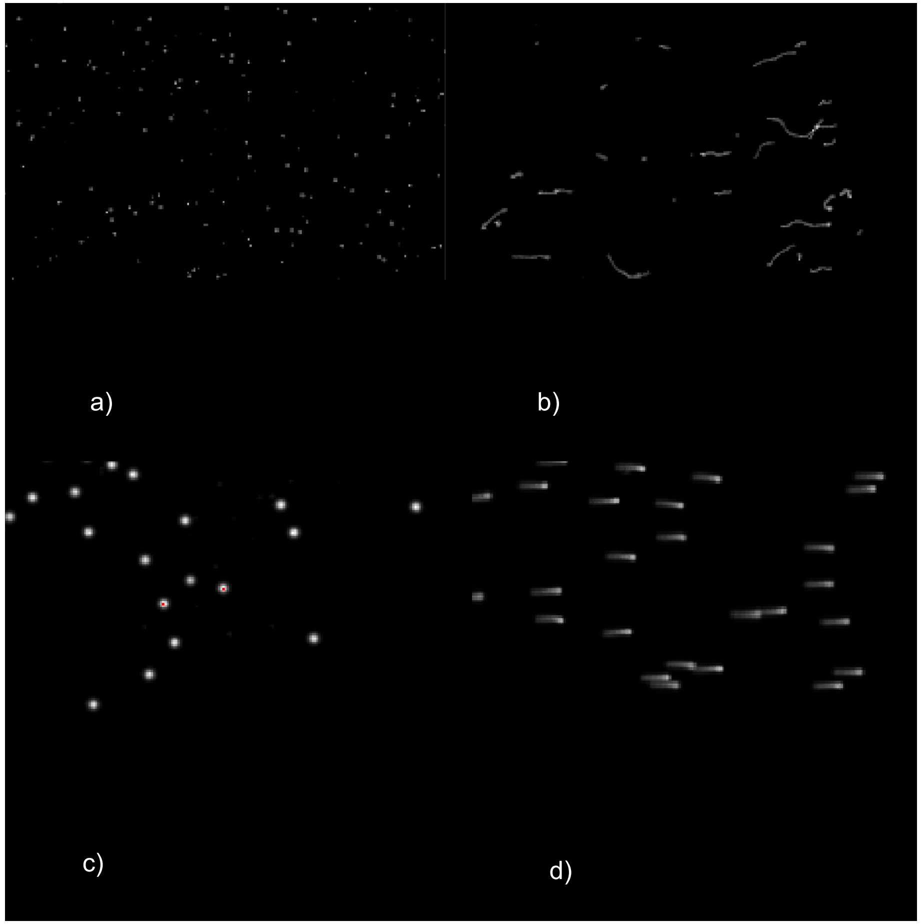
Room Temperature Approach

- TimePix3 silicon pixelated detectors
  - Developed at CERN; commercially available
  - Each pixel bump-bonded to ASIC readout
  - Low threshold (~ few keV)
  - TimePix3: timing (1.56 ns resolution), energy, x,y position





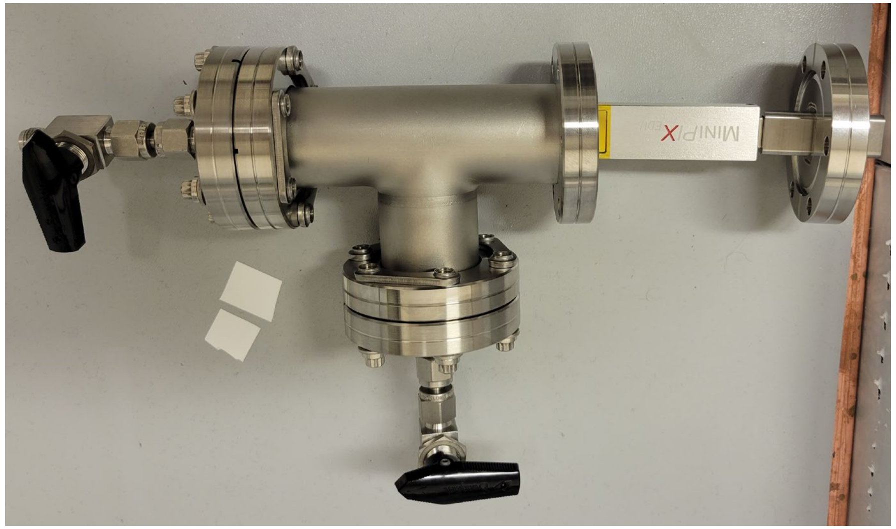
Amsterdam Scientific Instruments website
https://www.amscins.com/learn-more/technology/



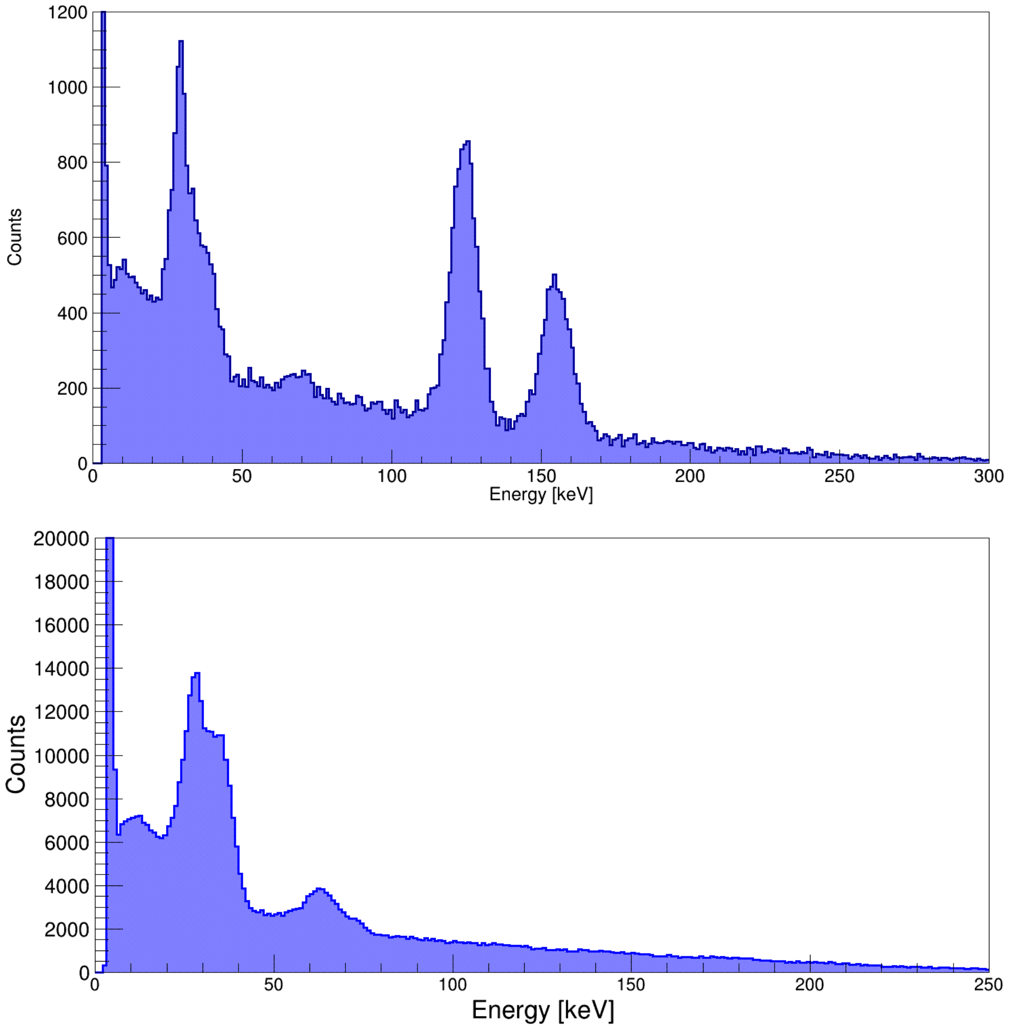
a) Gamma and x-rays, b) electrons, c) alphas, d) protons from left side.
From: “Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XI”, edited by Ralph B. James, Larry A. Franks, Arnold Burger, Proc. of SPIE Vol. 7449

Initial Measurements at PNNL

- Evaluating ADVACAM silicon detectors
  - Initial measurements with radioxenon (^{133}Xe and ^{131m}Xe)
  - Initial configuration with gas – no coincidence
  - Low thresholds observed (5-10 keV)



PNNL setup for measuring gas with the silicon detector (image is of MiniPix EDU)



ADVACAM TimePix3 spectra: Top figure: ^{131m}Xe, bottom figure ^{133}Xe

Summary and Conclusions

- Beta-gamma (electron-photon) coincidence; good background reduction and mainstay of xenon detectors
- New materials and detectors are being developed and evaluated
- Silicon is promising for electron detection and several implementations already
- Segmented or pixelated detectors offer additional information: spatial
  - Lowers noise threshold to access lower energy gamma and x-ray energies
  - Pixelated detectors have particle ID capability with track shape
  - Potential to lower background even further

Future improvements will increase sensitivity (lower detectable activity) and reduce size and weight (shielding requirements)

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