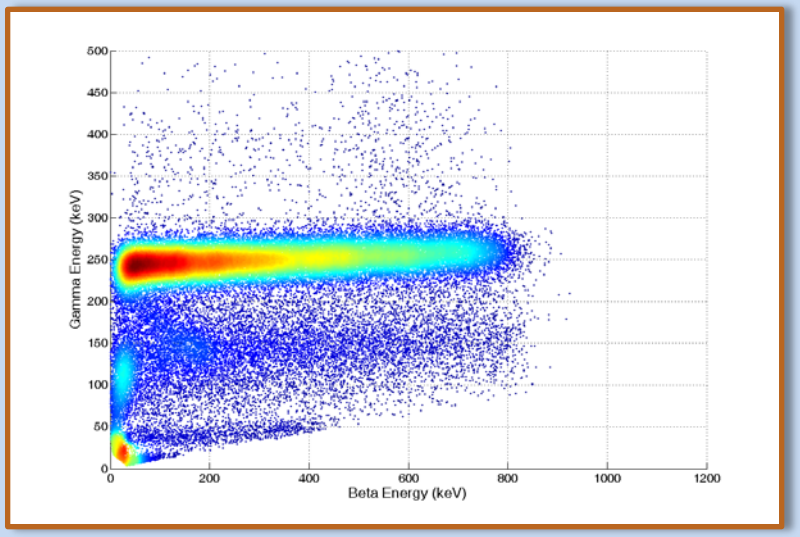
Development of Phoswich Detectors for Radioxenon Measurements



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INEST Fuel Cycle CORE Regional Outreach Meeting
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OUTLINE

- Radioxenon Detection
- Actively-Shielded Phoswich (ASP) Detector
- Compton Suppression Mechanism in the ASP Detector
- Digital Pulse Shape Analysis
- Suppression Factor
- Radioxenon Measurements
- Future Works

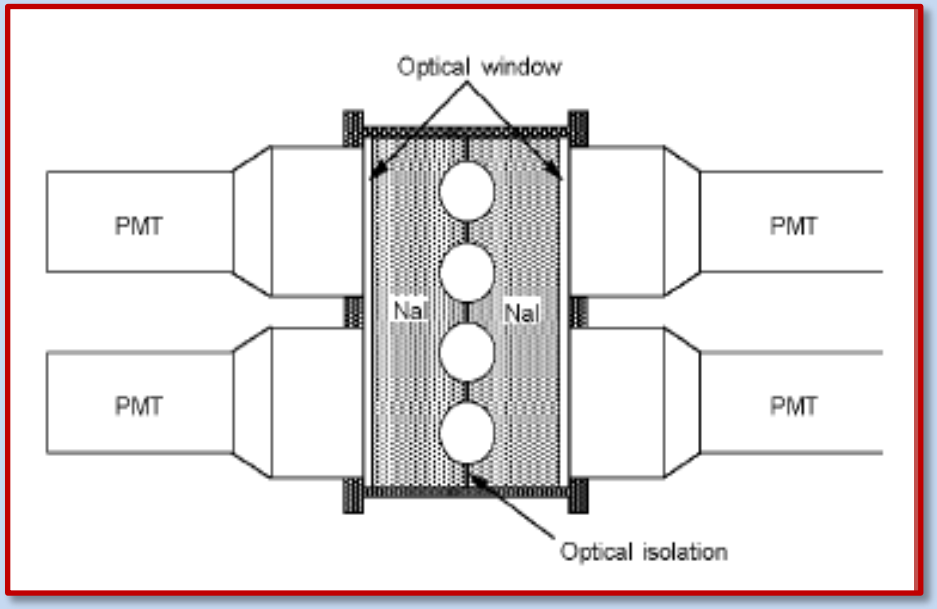
Radioxenon Detection

Electron and Photon Coincidence Measurements

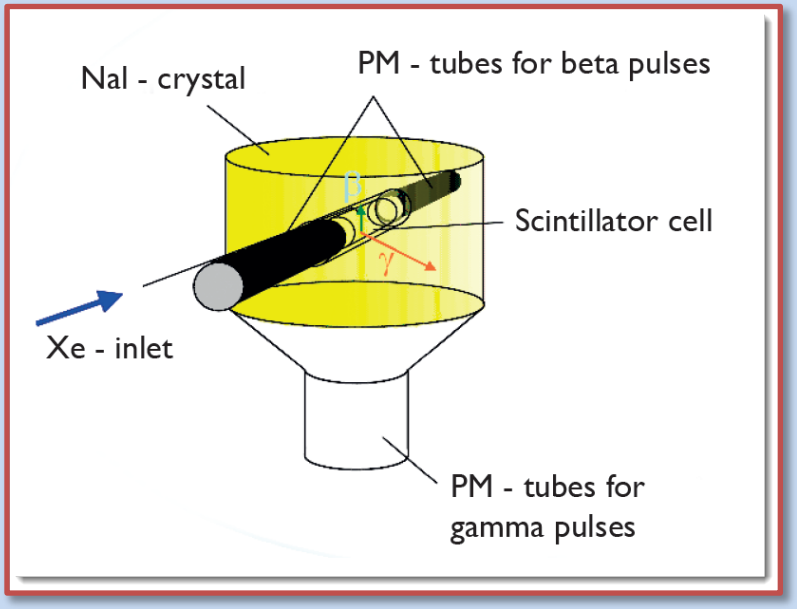
^{131m}Xe	→	**X-Ray** (30 keV)	**+**	**CE** (129 keV)
^{133m}Xe	→	**X-Ray** (30 keV)	**+**	**CE** (199 keV)
^{133}Xe	63% →	**X-Ray** (30 keV)	**+**	**β+CE** (45-391)
	37% →	**γ** (81 keV)	**+**	**β** (0-346 keV)
^{135}Xe	→	**γ** (250 keV)	+	**β** (0-910 keV)

Radioxenon Detection

- Radioxenon Detectors Based on **Beta-Gamma Coincidence Measurements**
- Low Background
- High Sensitivity
- Multiple PMT's, not easy to maintain energy calibration for a long time



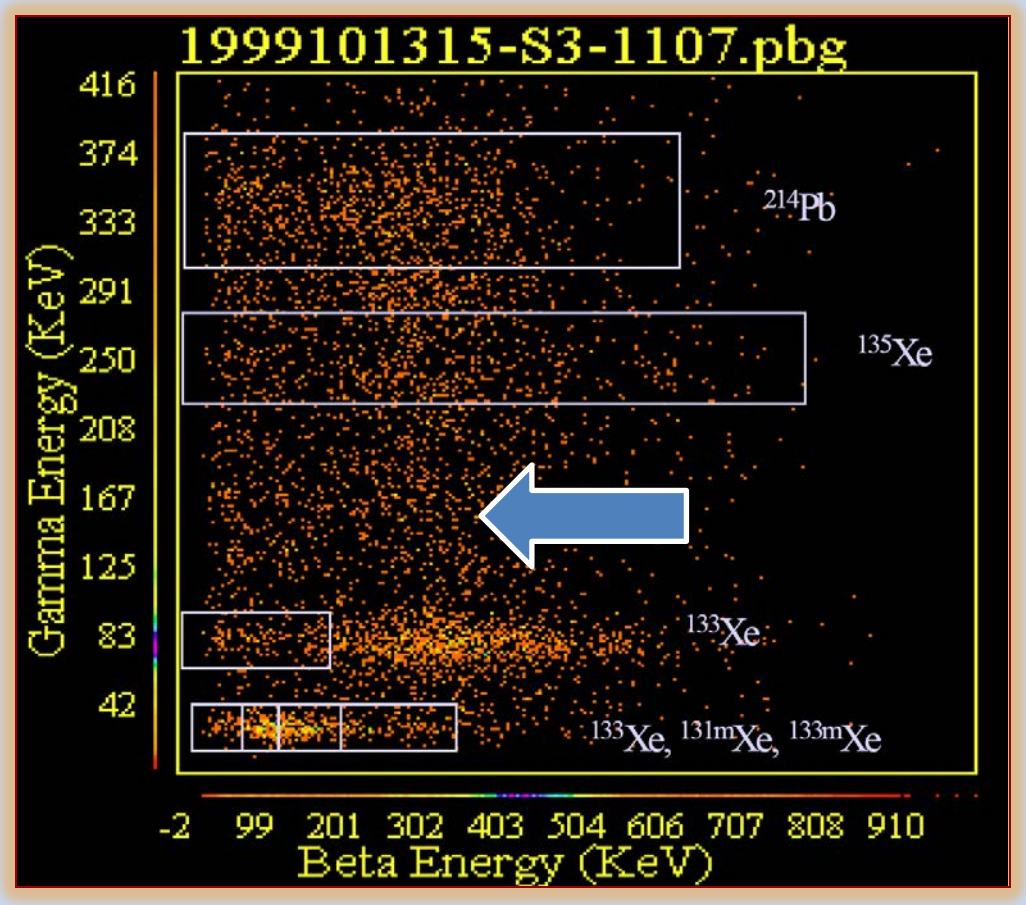
Automated Radioxenon Sampler/Analyzer (ARSA)



The Swedish Automatic Unit for Noble gas Acquisition (SAUNA)

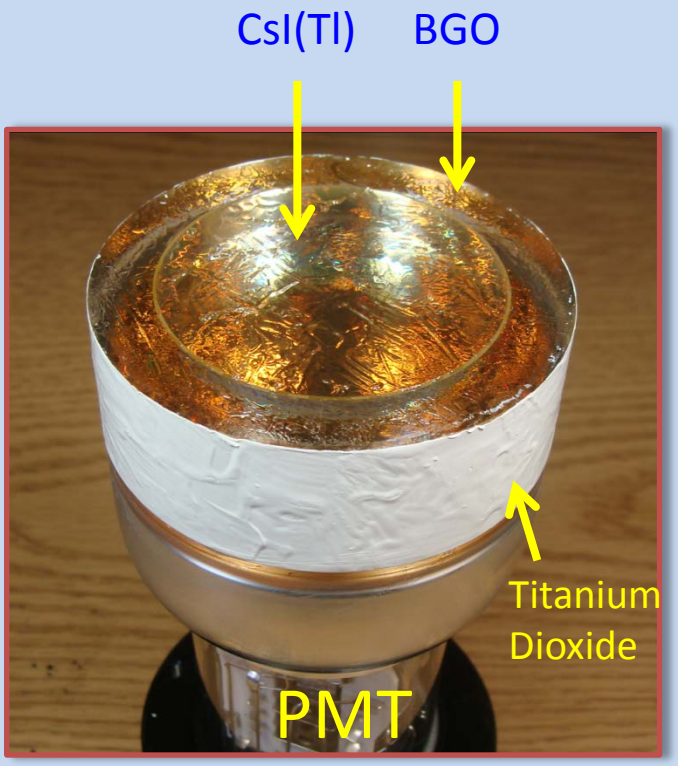
Radioxenon Detection

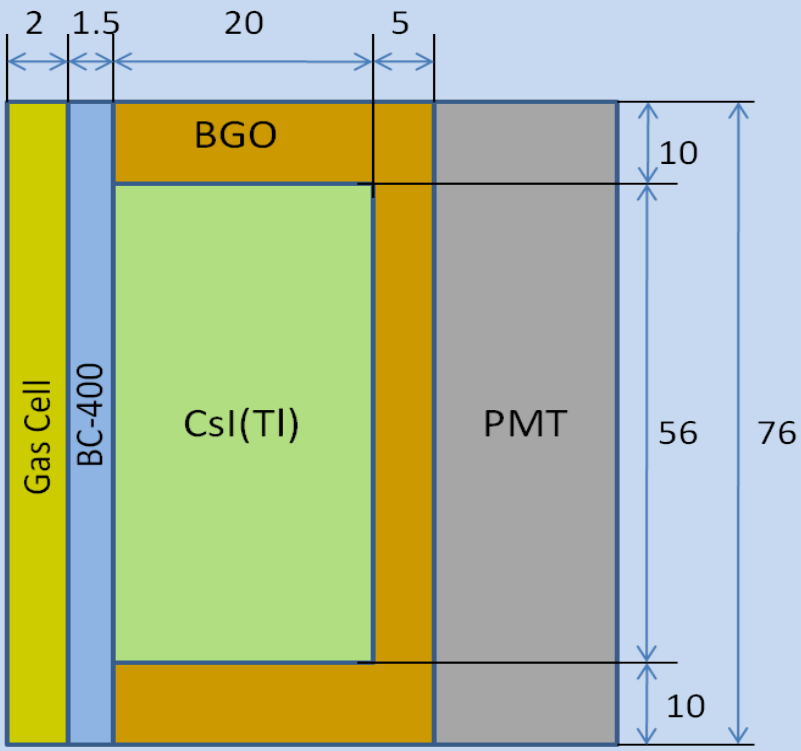
- Two-dimensional beta-gamma coincidence spectrum
- Background contribution from Compton continuum



Actively-Shielded Phoswich (ASP) Detector

- Detector Design
- Detection of beta/conversion electron in Plastic Scintillator (BC-400)
- Detection of X-ray/gamma-ray in CsI(Tl) scintillator
- Suppression of Compton-events using BGO scintillator (anti-coincidence with CsI(Tl))



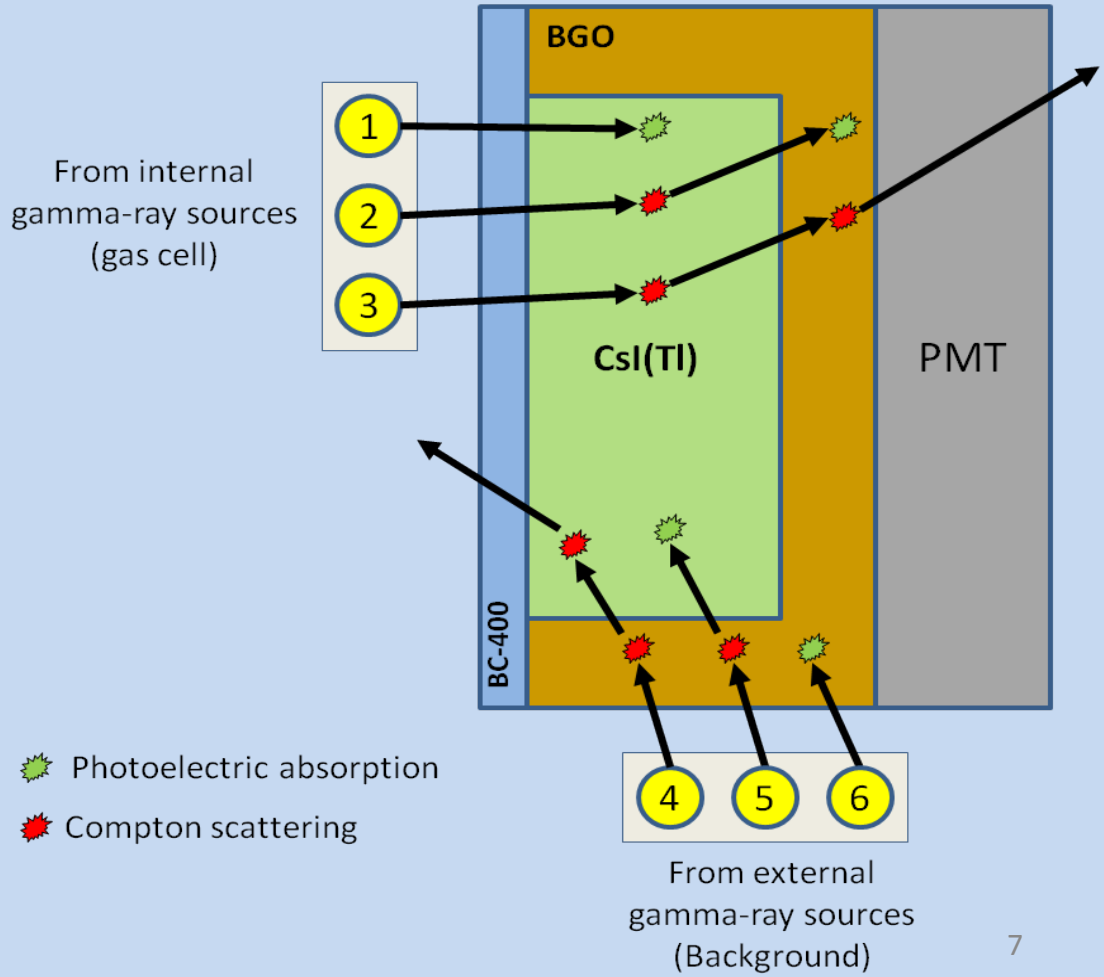


Schematic diagram of the phoswich detector. All dimensions are in mm.

Compton Suppression Mechanism in the ASP Detector

- Major gamma interaction scenarios in the phoswich detector from internal and external sources

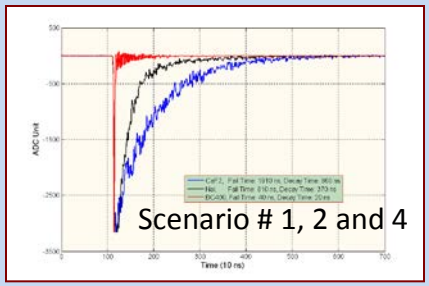
When accompanied with a coincident beta absorption in plastic scintillator, gamma interaction **scenarios 2 and 3** generate coincident pulses which are most likely responsible for Compton background in the two-dimensional beta/gamma coincidence spectrum.

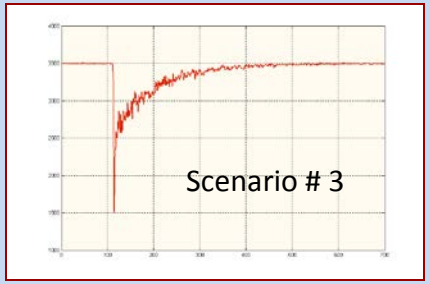


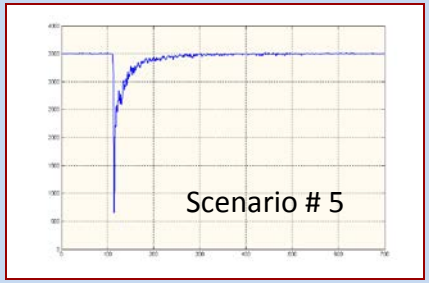
Digital Pulse Shape Analysis

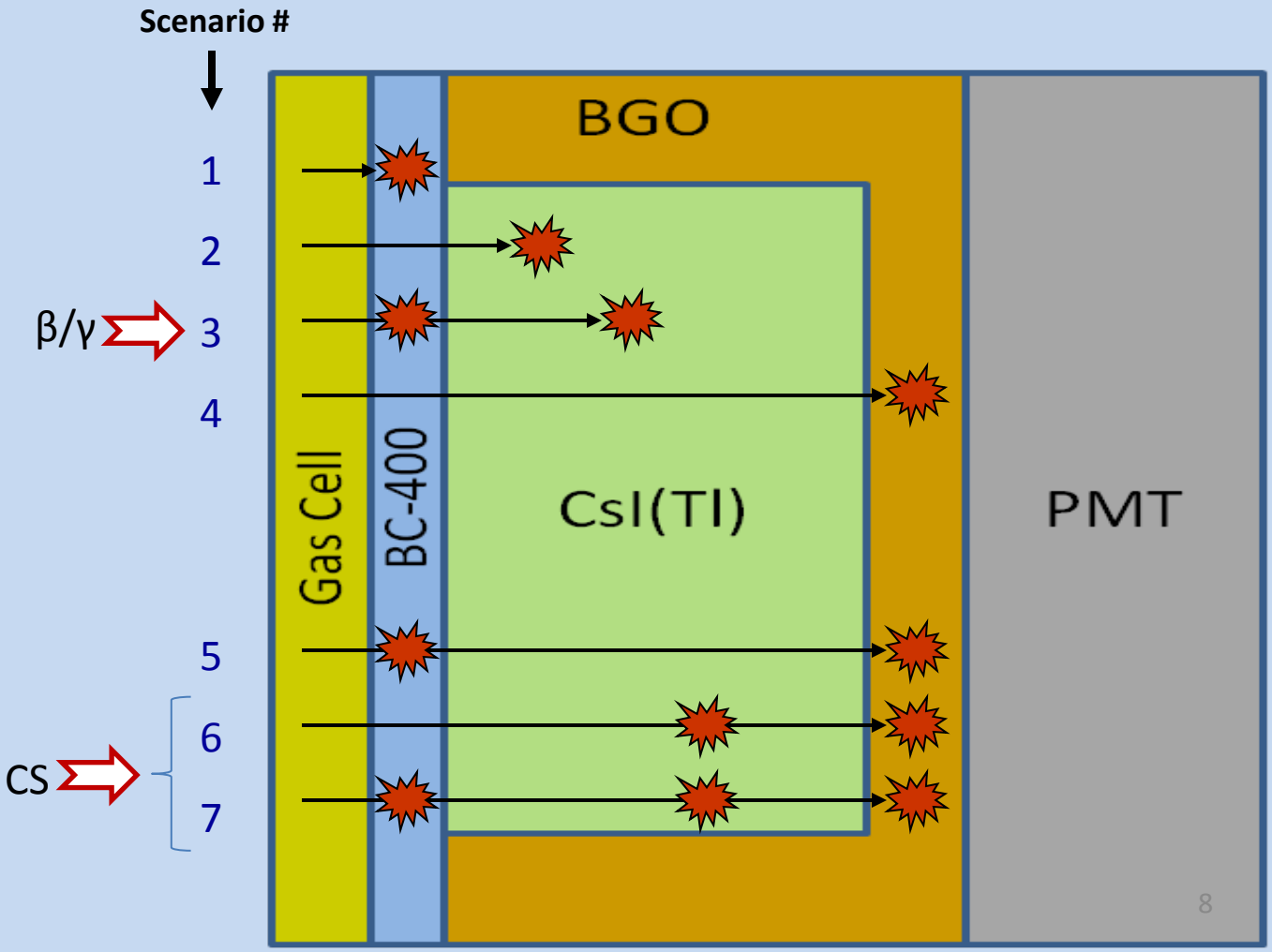
- From three scintillators, seven possible signal-pulse shapes or types could be generated.

Scintillator	Decay Time (nsec)
Plastic (BC-400)	1.2
BGO	300
CsI (Tl)	1000









Digital Pulse Shape Analysis

- **RX1200, User-Programmable Digital Spectrometer**
- **12-bit Resolution**
- **200 MHz Sampling Rate**
- **Dual-parameter Digital Pulse Shape Discrimination**
- **Digital Triangular Filters**

RX1200, Avicenna Instruments

$$Fast\ Ratio = \frac{A}{B}$$

$$Slow\ Ratio = \frac{B-A}{C-A}$$

Where

$A = \max(Pulse \otimes F1)$

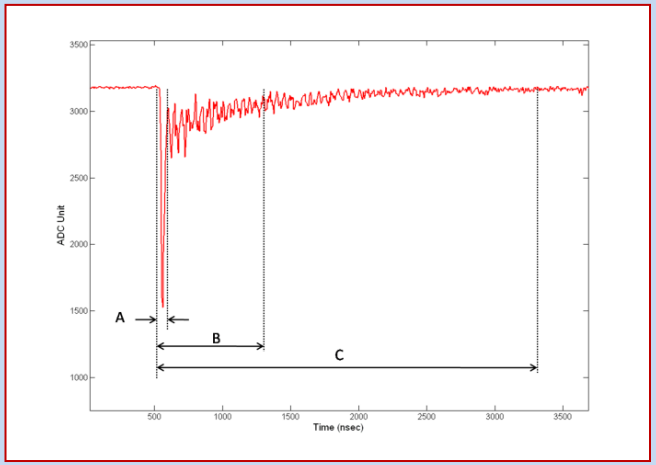
$B = \max(Pulse \otimes F2)$

$C = \max(Pulse \otimes F3)$

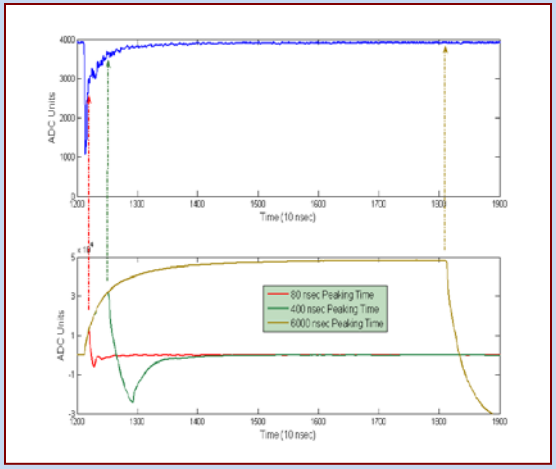
F1: Triangular Filter (80 ns)

F2: Triangular Filter (400 ns)

F3: Triangular Filter (6000 ns)



A, B and C Summation regions

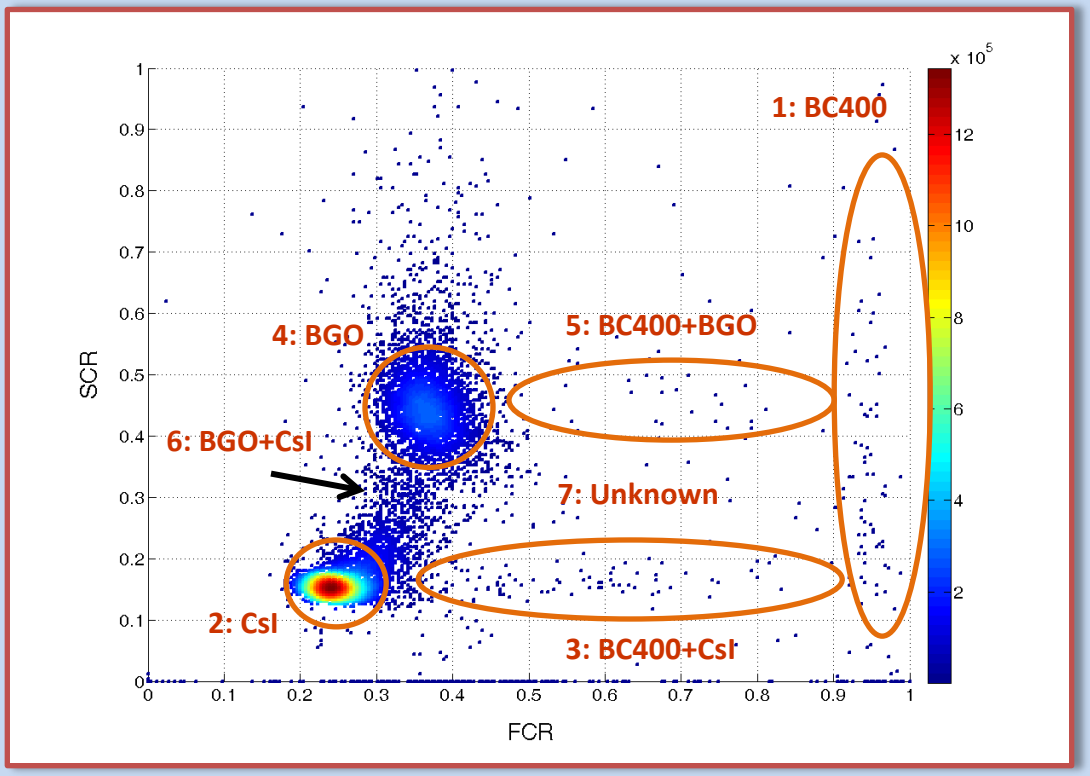


Responses of three triangular filters

Digital Pulse Shape Analysis

- Scatter of Fast and Slow Component Ratios from ^{137}Cs (shielded against beta)

- Seven marked regions correspond to seven pulse shapes, indicating how gamma-rays interact with the three layers of phoswich detector



Measurement Results

A. Suppression Factor

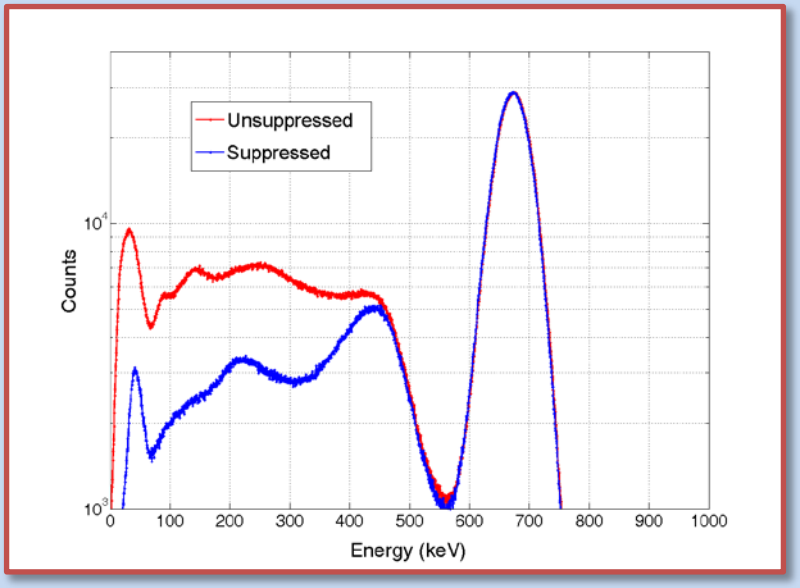
The suppression factor was defined as:

$$Suppression\,Factor\,(E) = \frac{C_u(E) - C_s(E)}{C_u(E)} \times 100$$

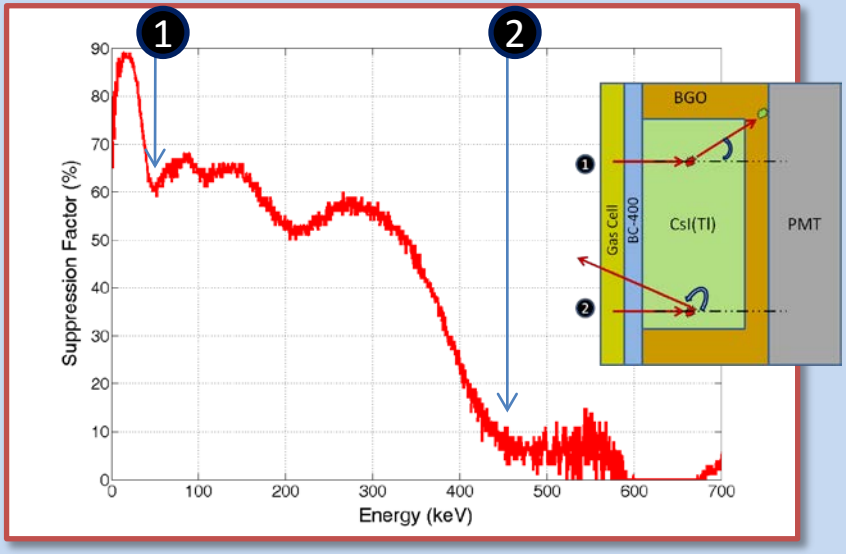
Where:

$C_u(E)$ is the number of counts in energy E of the unsuppressed spectrum and $C_s(E)$ is the number of counts in energy E of the suppressed spectrum.

The Compton suppression mechanism is more efficient (50%-60%) in low-energy part of the Compton continuum (<200 keV) than the higher energies close to the Compton edge (~477 keV).



Suppressed and unsuppressed gamma-ray spectra from ^{137}Cs. The whole digital pulse processing was implemented in a FPGA device.



Suppression factor as a function of photon energy.

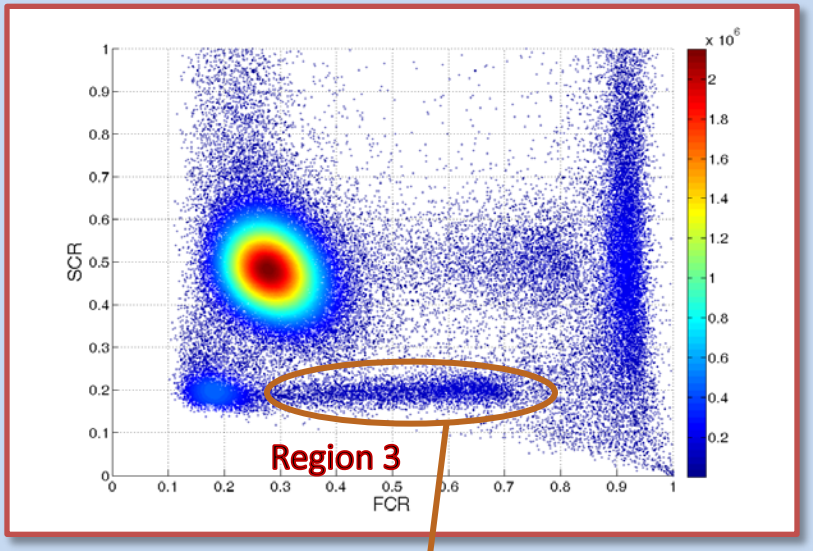
Measurement Results

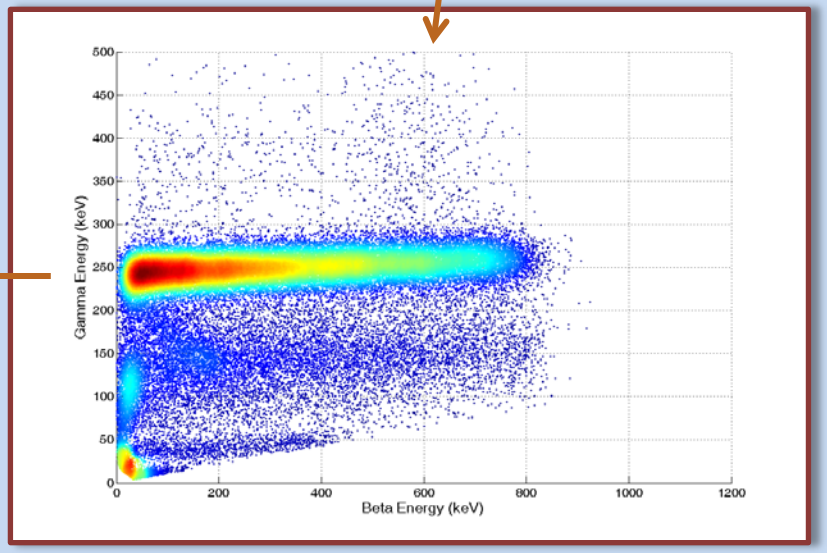
B. ^{135}Xe measurements

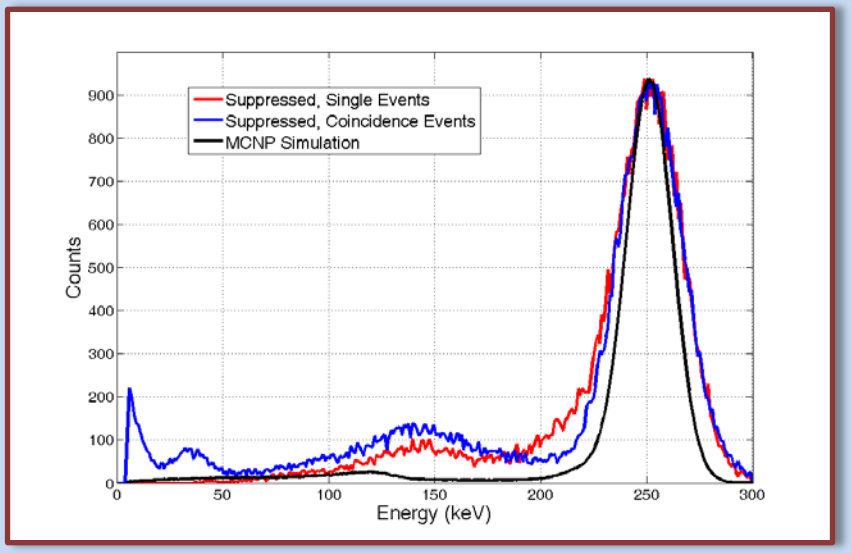
3 ml of stable and enriched (>99%) ^{134}Xe were irradiated in the thermal column of the TRIGA reactor for two hours
(Ø = 7x1010 n.cm^{-2}.sec^{-1}).

^{135}Xe was produced and injected into the gas cell.

Scatter of Fast and Slow Component Ratios from ^{135}Xe.







Gamma energy spectra in CsI(Tl) (coincidence with BC-400) from ^{135}Xe.

2-D beta-gamma coincidence energy histograms from ^{135}Xe.

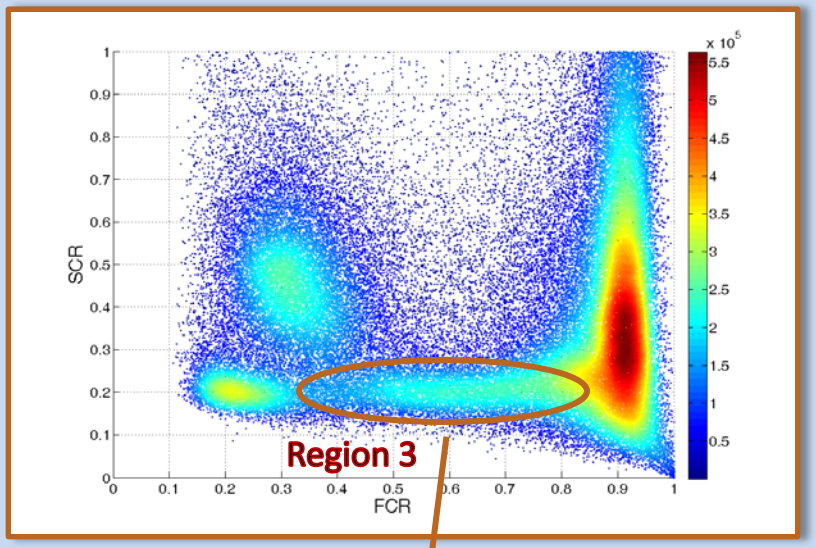
Measurement Results

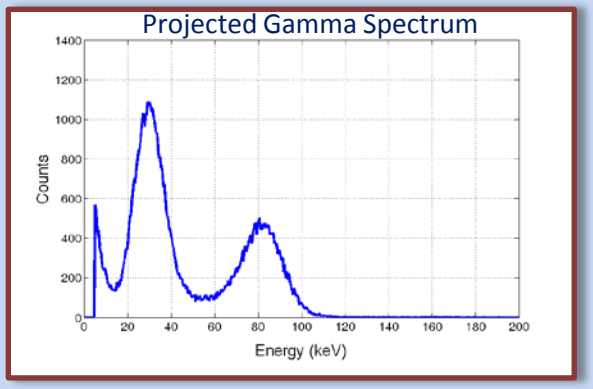
C. ^{133}Xe measurements

3 ml of stable and enriched (>99%) ^{132}Xe were irradiated in the thermal column of the TRIGA reactor for two hours (Ø = 7x1010 n.cm^{-2}.sec^{-1}).

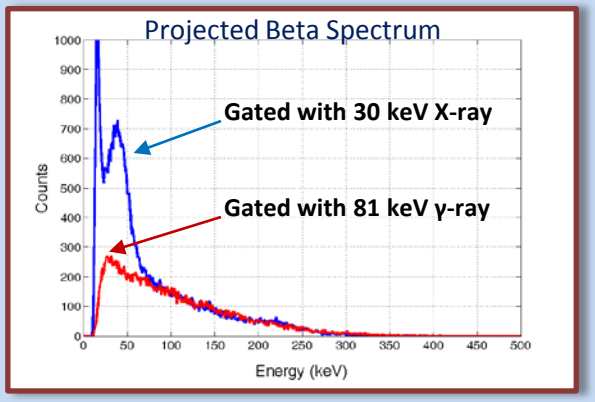
^{133}Xe was produced and injected into the gas cell.

Scatter of Fast and Slow Component Ratios from ^{133}Xe.

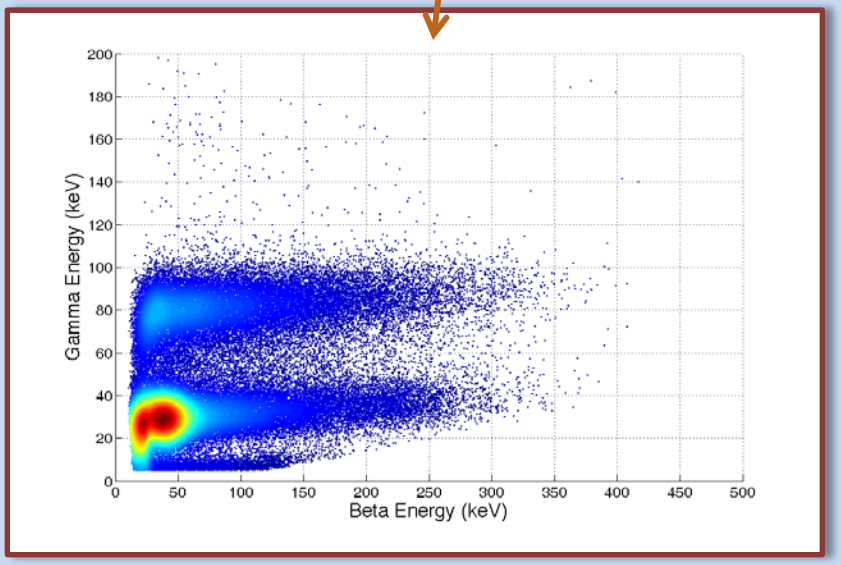




γ



β



2-D beta-gamma coincidence energy histograms from ^{133}Xe.

Future Works

- Characterizing the detector with ^{131m}Xe
- Developing full digital pulse processing in FPGA
- Building and characterizing a Well-type phoswich design

Questions?