Single Layer Timepix3 Compton Camera

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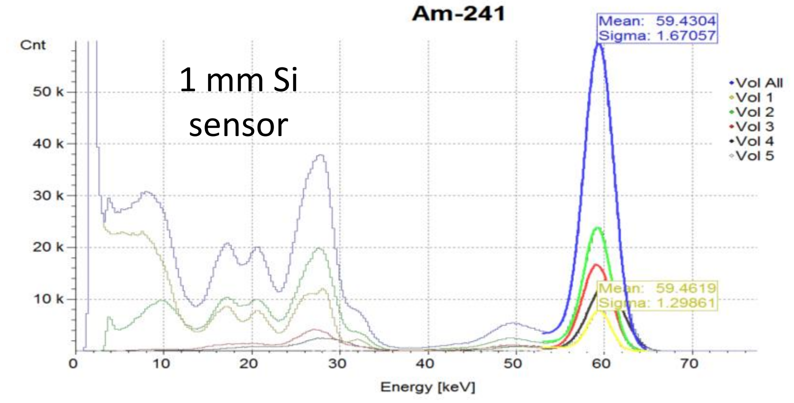
Timepix3 detector

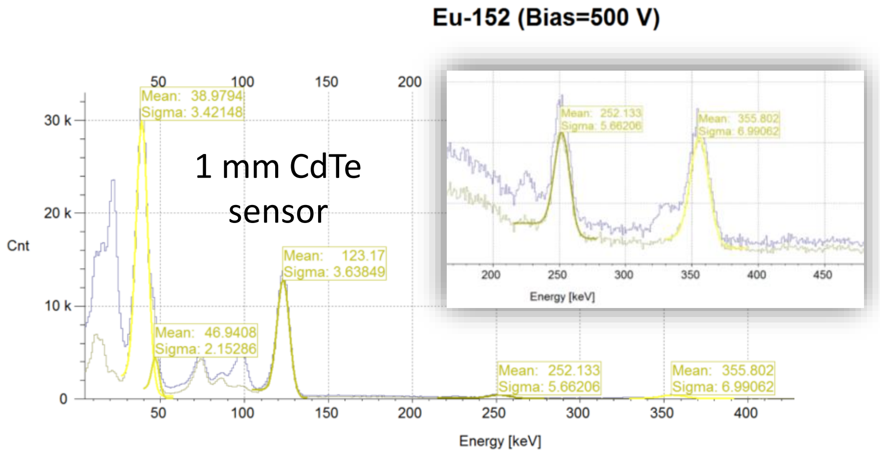
Timepix3:

- Successor of Timepix: 256x256 pixels, 55 µm pitch
- **Event based readout** (Not frame based as for Timepix): Each hit pixel transmits the hit information immediately.

⇒ No dead-time for readout of complete frame.

- Ability to measure Energy (ToT) and Time of arrival (ToA) concurrently.
- Time is measured with precision of 1.56 ns
- Chip can produce data stream of 5 Gbit/s.



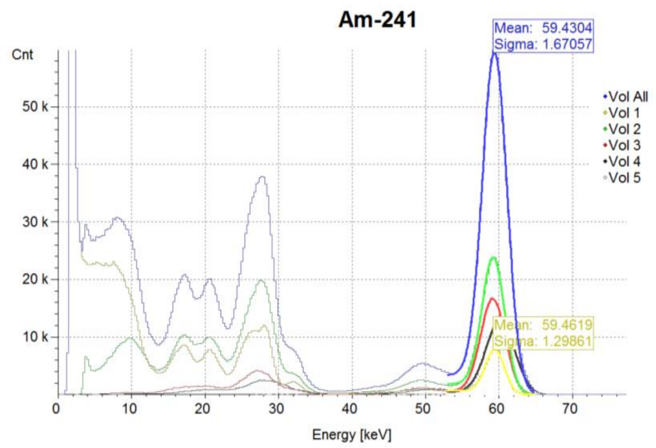


Timepix3 + different sensor types

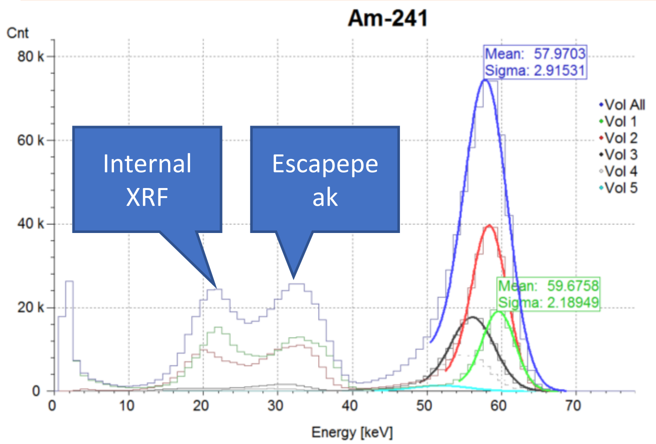
Supported sensor types:

- Silicon 100-1000 µm thick: Particle tracking, electron microscopy …
- CdTe 1000 and 2000 µm thick: Hard X-rays, Gamma, PET, SPECT …
- CZT 2000 µm thick
- GaAs 625 µm thick

1 mm Si

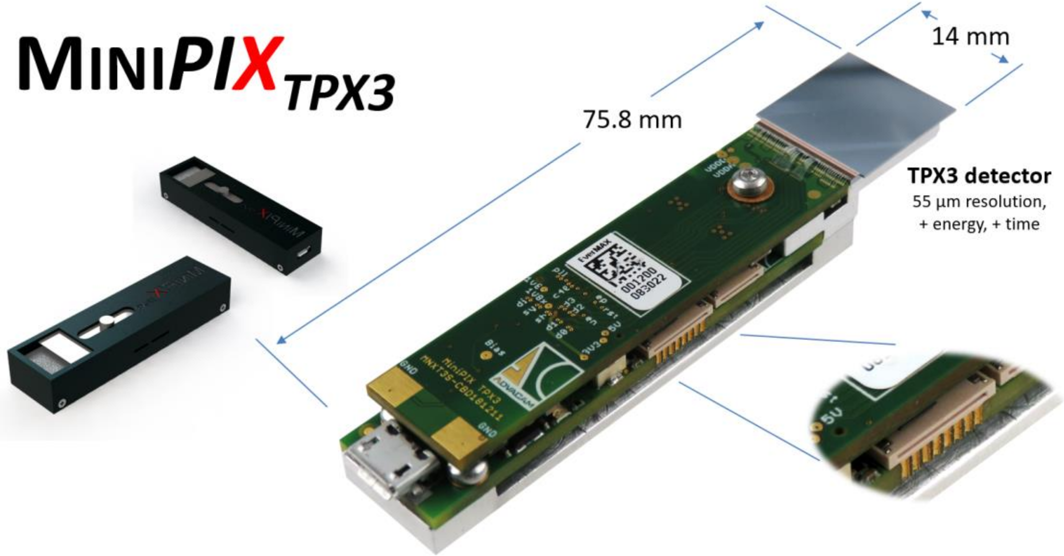


1 mm CdTe

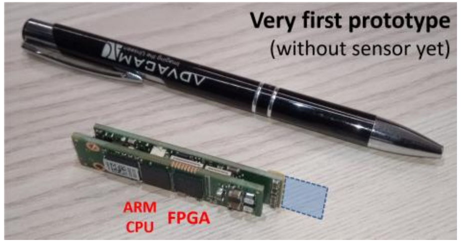


MiniPIX TPX3 - Miniaturized spectral camera supporting Si and CdTe sensors

- Miniaturized and compact device
- Vacuum compatible
- USB 2.0 device
- Bias source from –500 to + 300 V
- FPGA and ARM processor
  - ARM processor – flexible - can be programmed to work autonomously
- Sync. communication among multiple devices
- Possible to combine with different sensors
  - Si (100 – 1000 um),
  - CdTe (1 mm)
  - CZT (2 mm) – coming
- Maximal frame rate: 16 frames / s

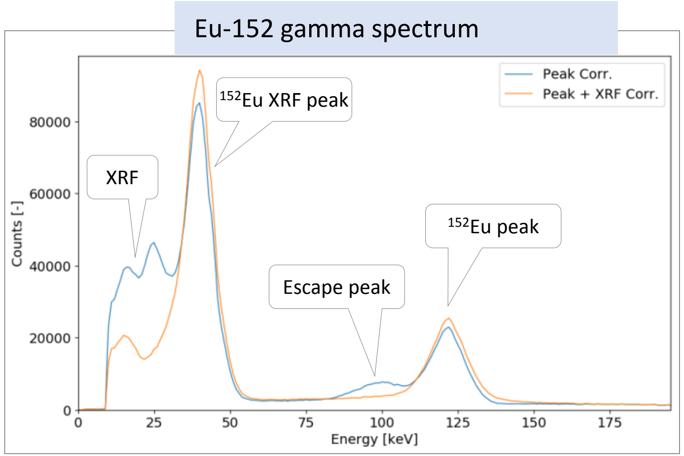


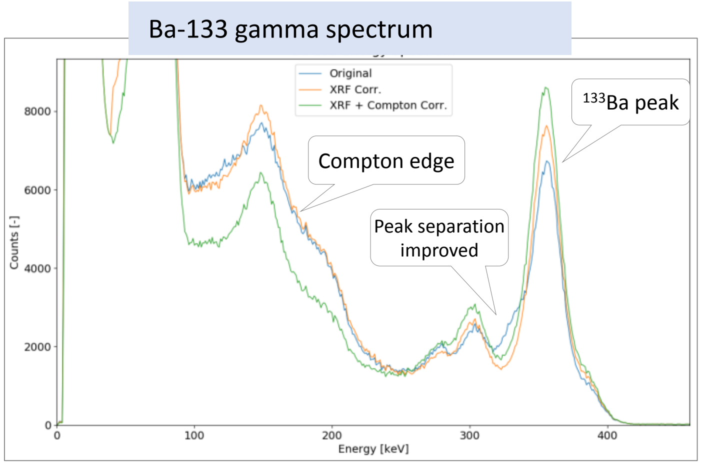
Its really small ..



Gamma spectrum reconstruction for CdTe

- 2 mm thick CdTe sensor: Efficiency for 120 keV of about 70%
- Coincidence technique removes artifacts and suppresses internal Compton scattering





Internal XRF reconstruction:

1. Coincident events E1, E2 recognized
2. One of them fits to XRF energy of Cd or Te say E2
3. Event E2 is removed.
4. Energy E=E1+E2 is assigned to E1.

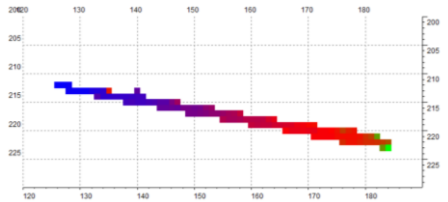
Compton effect reconstruction:

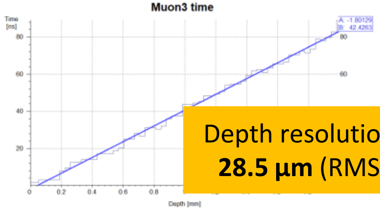
1. Coincident events E1, E2 recognized
2. Compton and Klein-Nishina formula evaluated for E1 and E2
3. More likely scattering scenario is chosen
4. Energy E=E1+E2 is assigned to correct point.

Depth difference measurement in CdTe

- Pair of events occurring in different depths of the sensor
- Use time of charge collection
- Calibration with cosmic muons

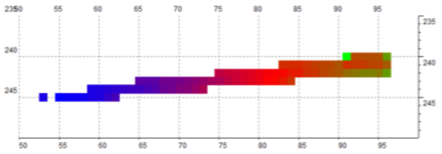
Bias voltage of **450 V**: Time domain

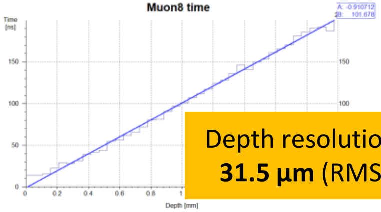




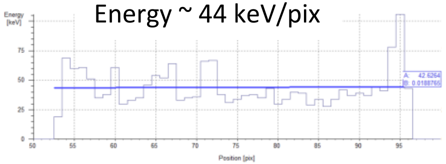
Depth resolution:
28.5 μm (RMS)

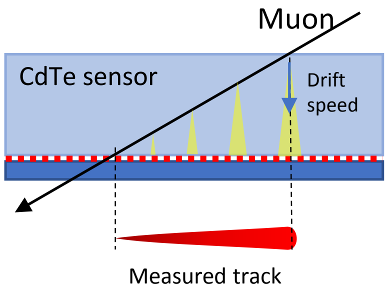
Bias voltage of **200 V**: Time domain

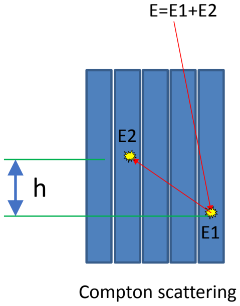


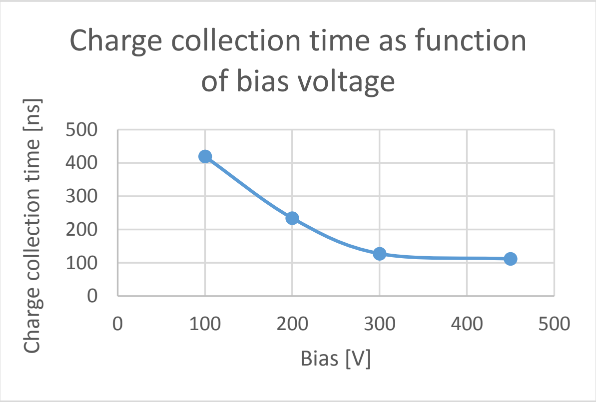


Depth resolution:
31.5 μm (RMS)





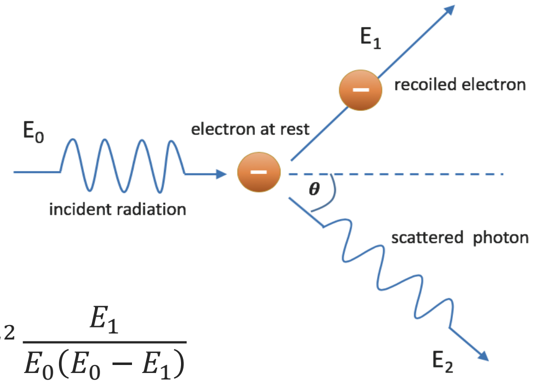




Compton Scattering and Compton Camera

Compton scattering

- Scattering of photon by a charged particle (electron) in a material
- Decrease in energy of the photon
- Part of the energy transferred to the recoiling electron



$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_0(E_0 - E_1)}$$

$$E_0 = E_1 + E_2$$

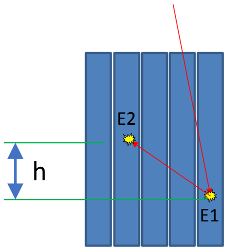
Compton camera principle

- Typically two detectors
- First detector scatterer
- Second detector absorber
- Reconstruction of cones, their intersection

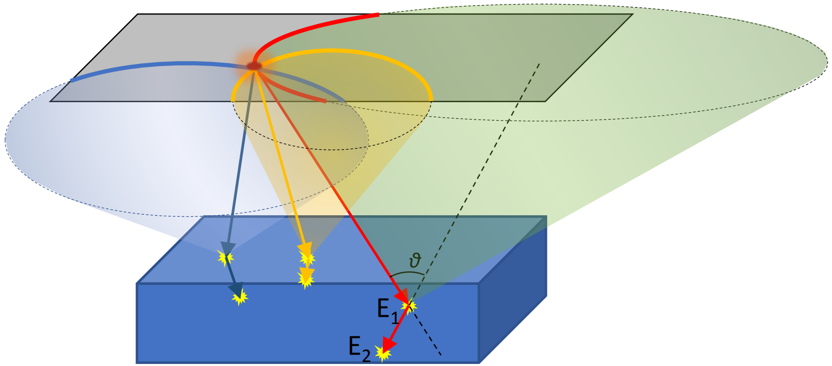
For each Compton scattering event we can:

- Detect coincidence
- Measure both energies: E_1 and E_2
- Measure both positions in 3D

=> We can reconstruct Compton cone:

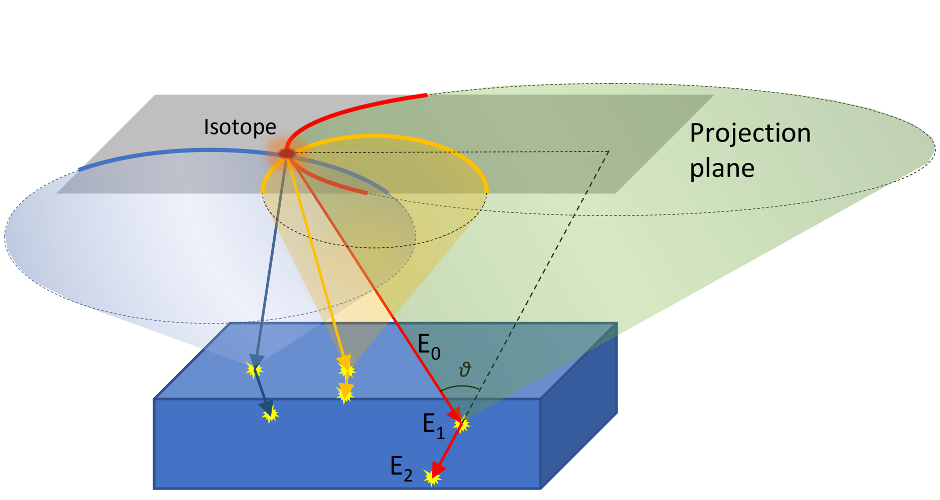


Compton scattering



Timepix3 CdTe detector

Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe



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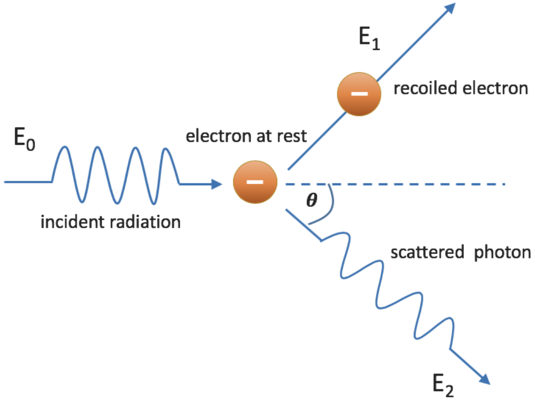

$$E_0 = E_1 + E_2$$

$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}$$

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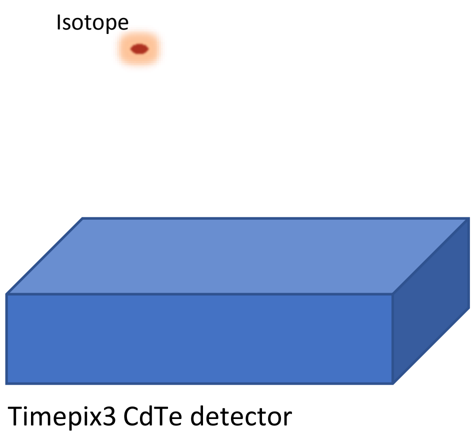

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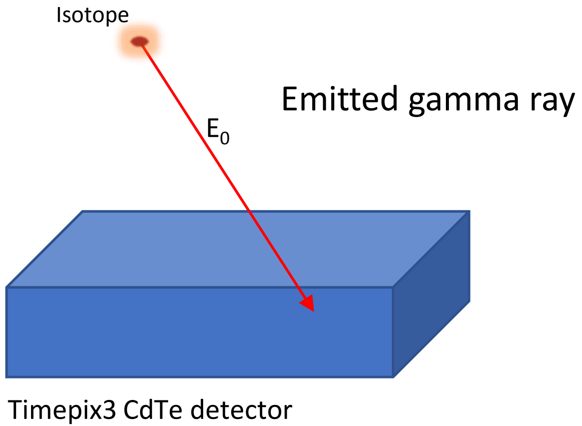

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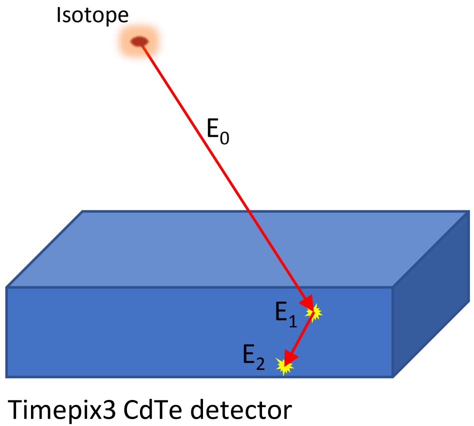
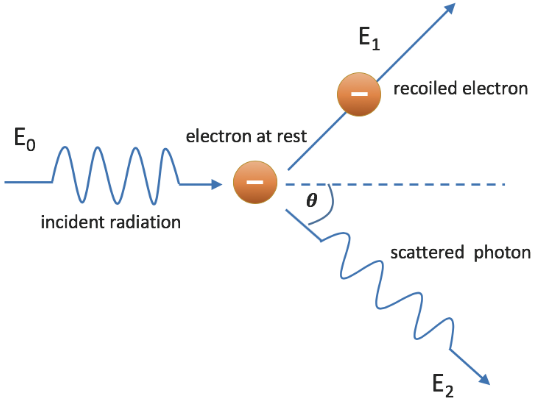


Compton scattering
=> two hits detected

$$E_0 = E_1 + E_2$$



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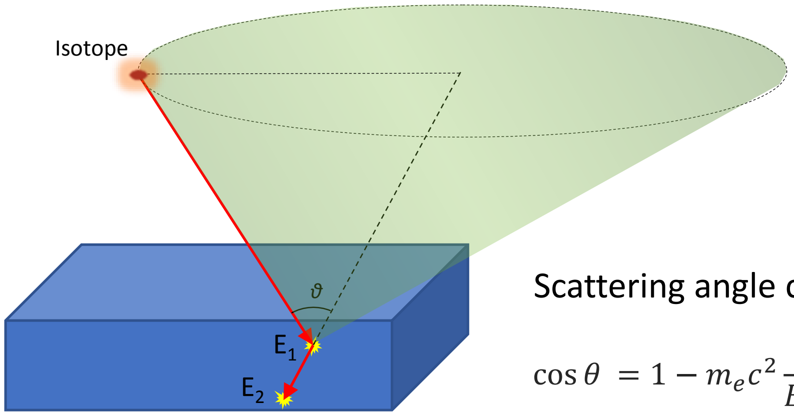
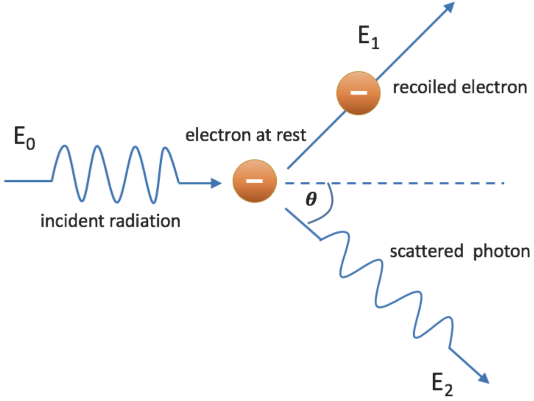


Timepix3 CdTe detector

Scattering angle calculated:

$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}$$



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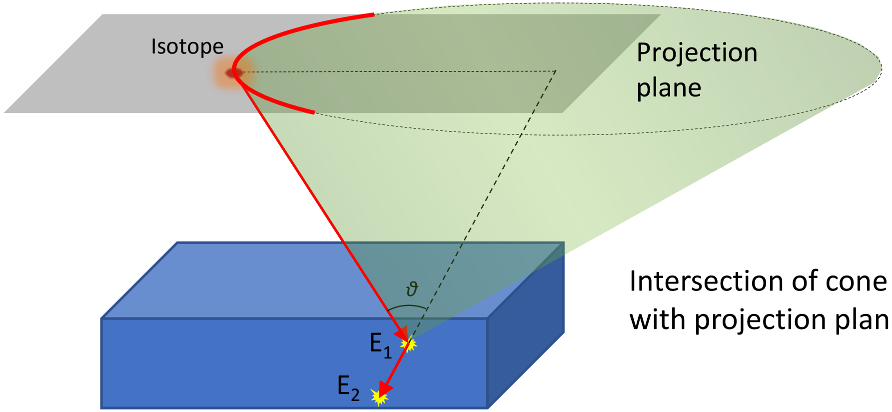

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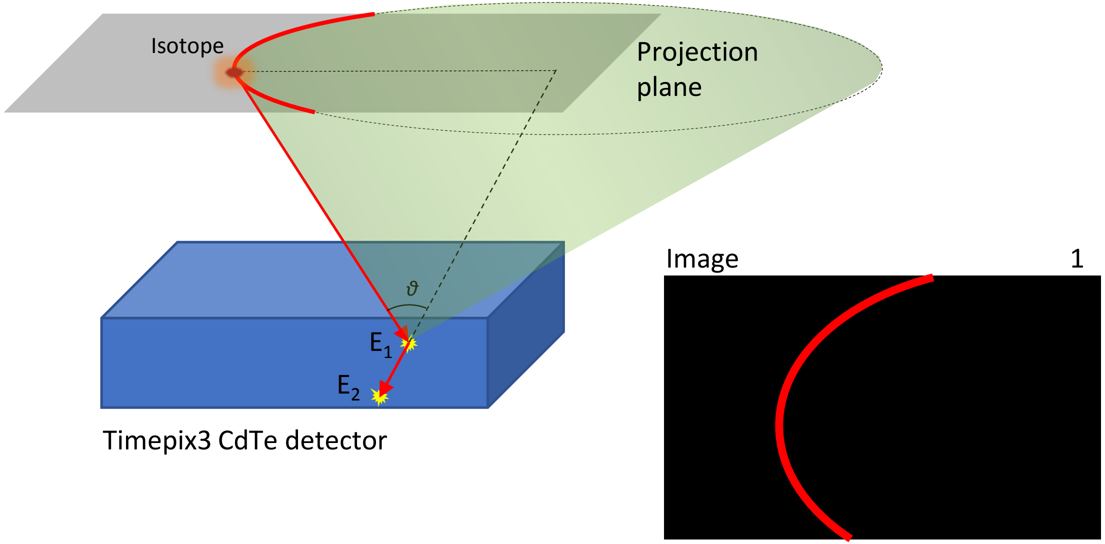

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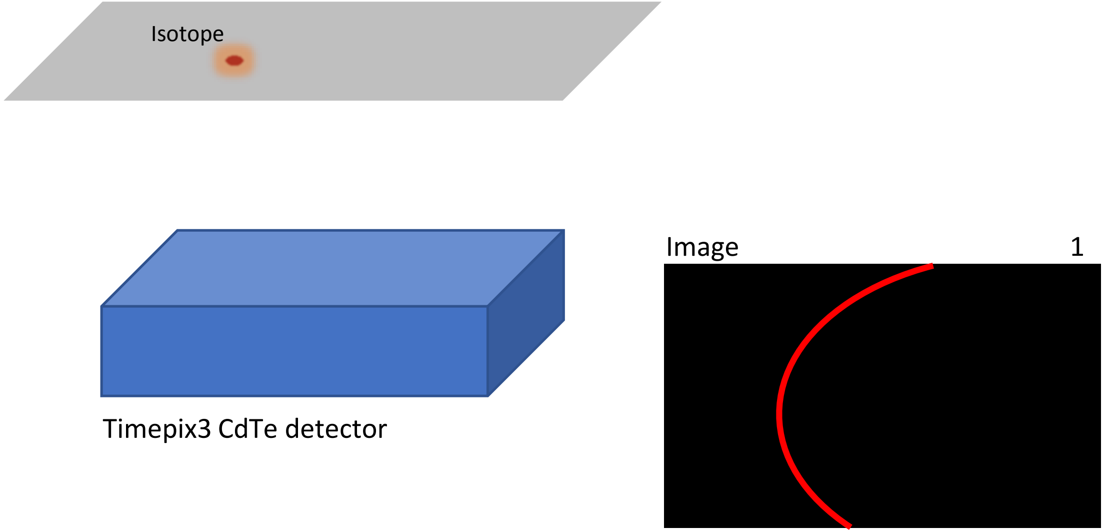

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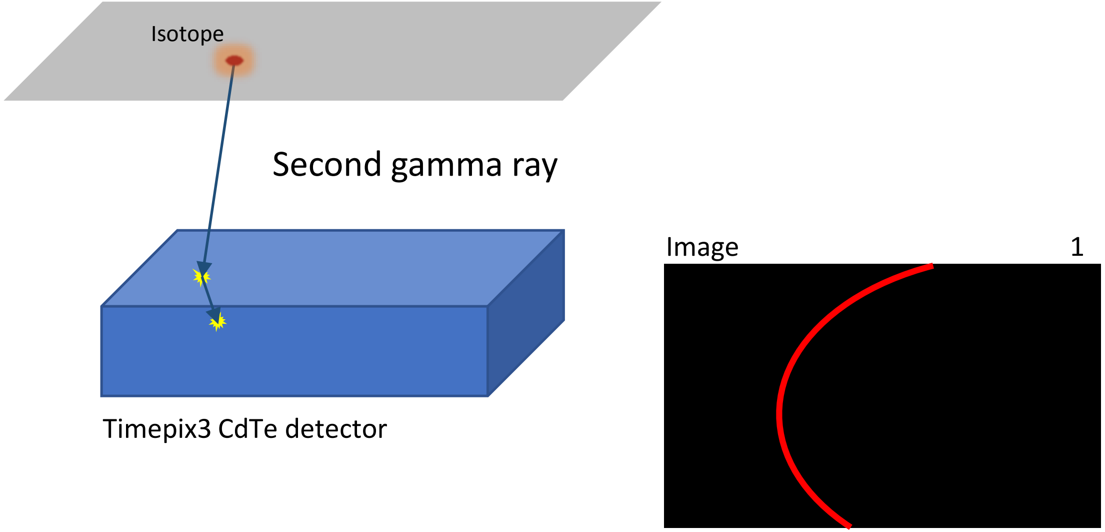

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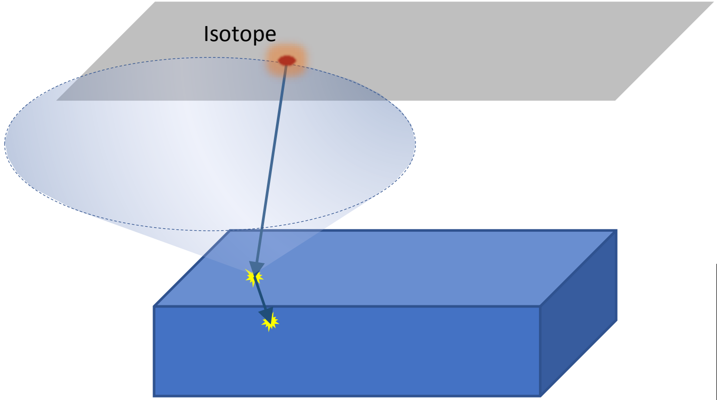

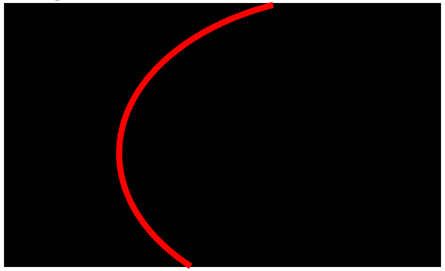

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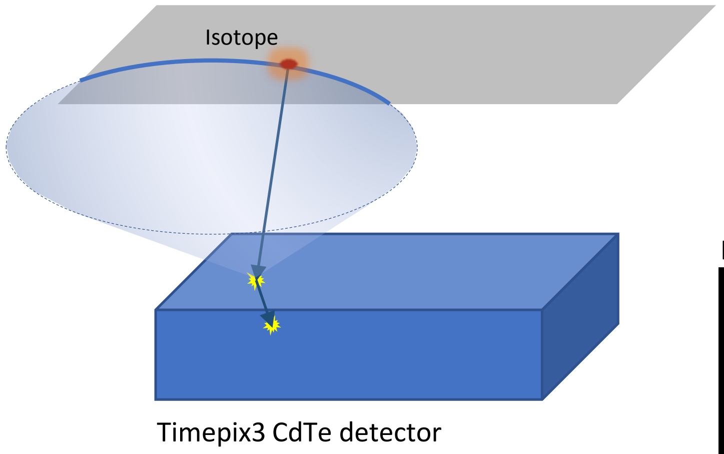

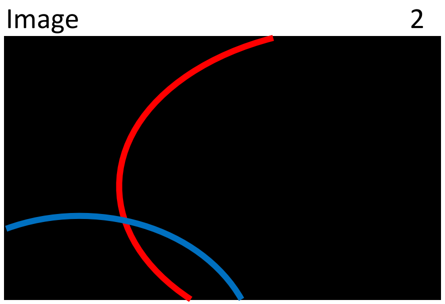

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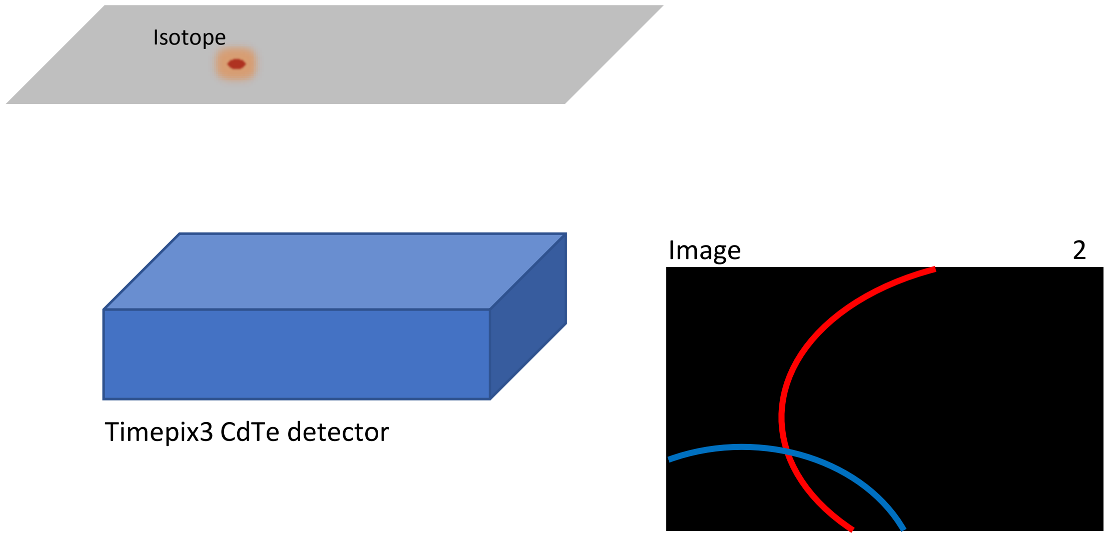

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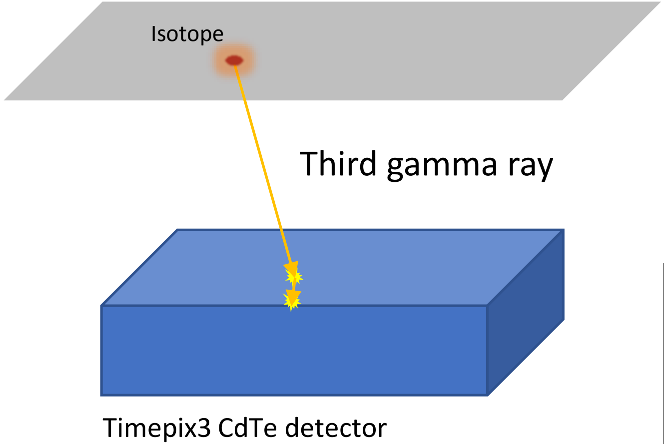
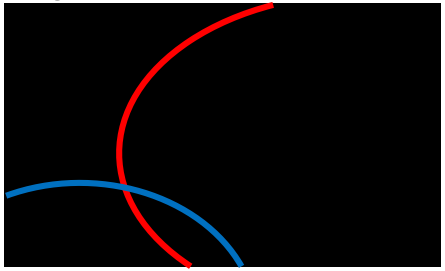


Image



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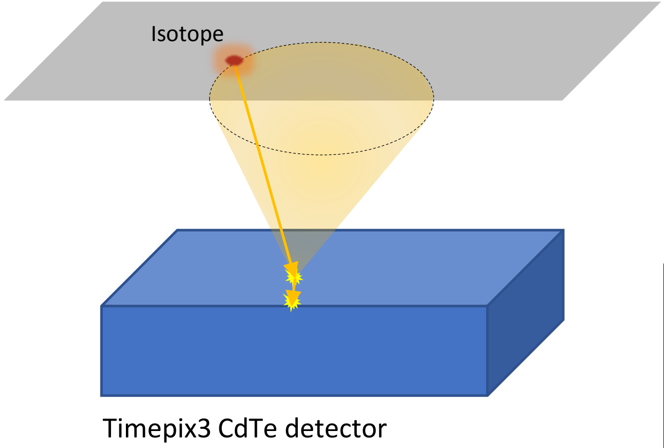

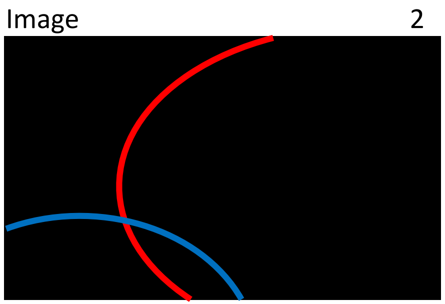

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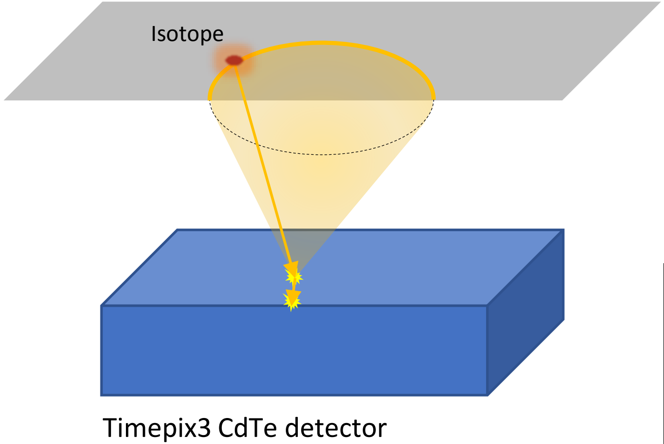

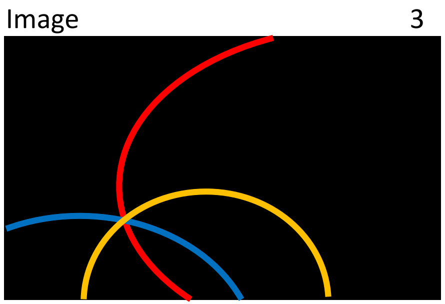

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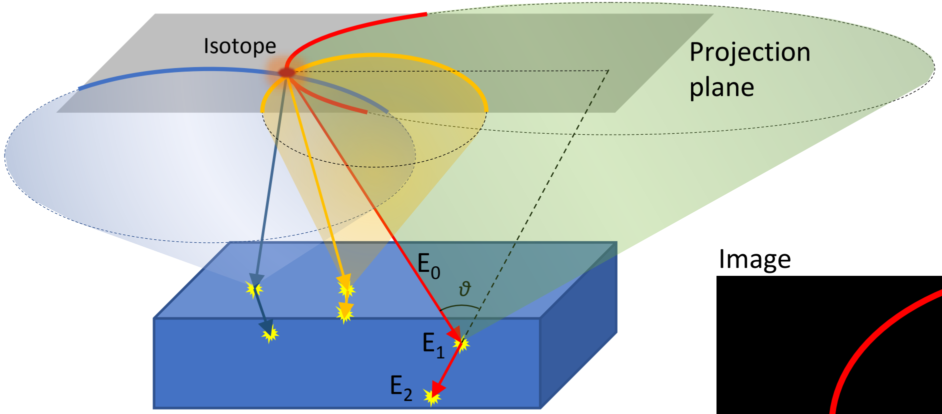
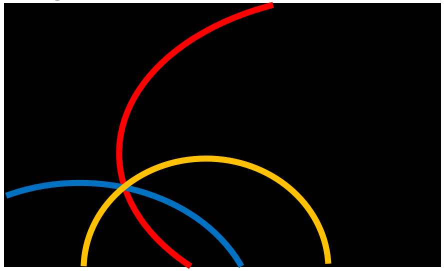


Timepix3 CdTe detector

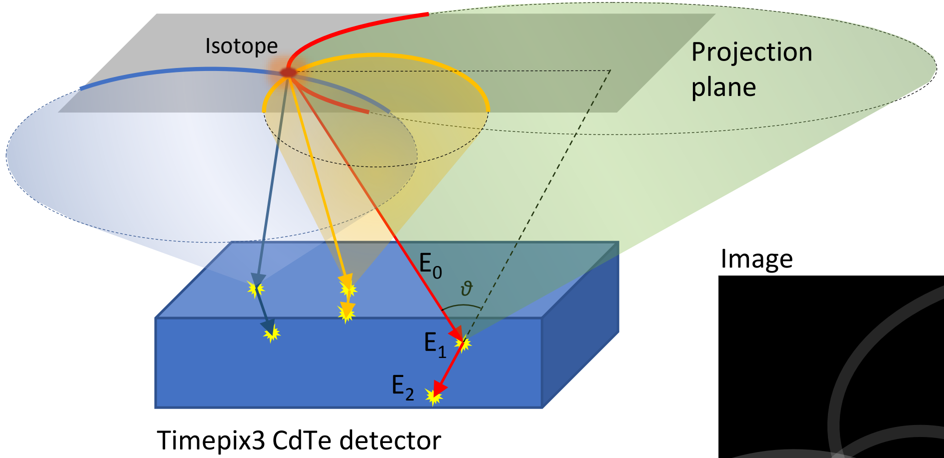
Image 3



$$E_0 = E_1 + E_2$$

$$\cos\theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}$$

Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe



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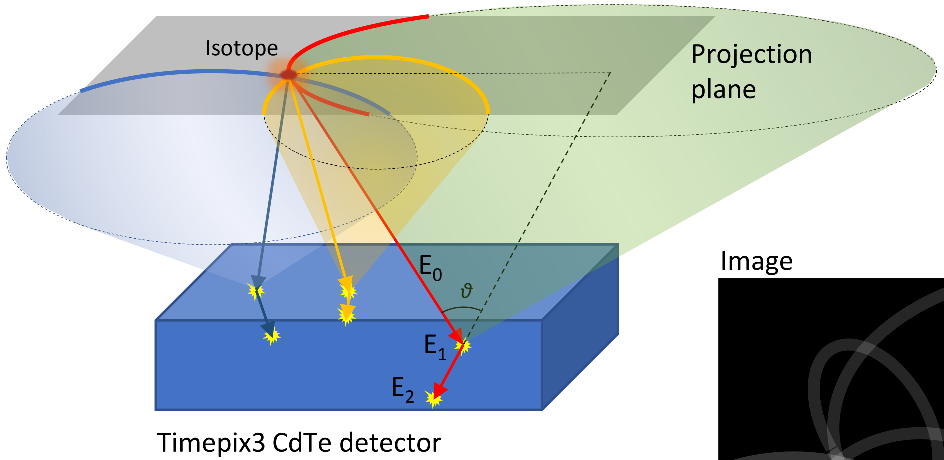

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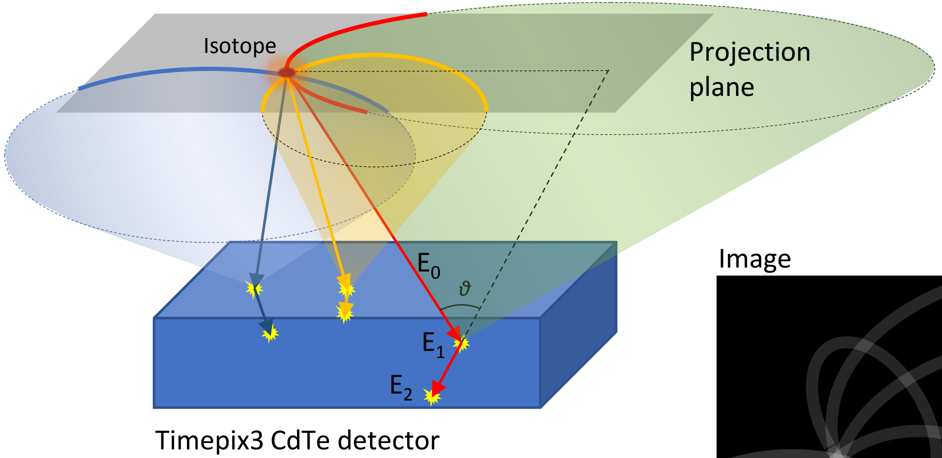

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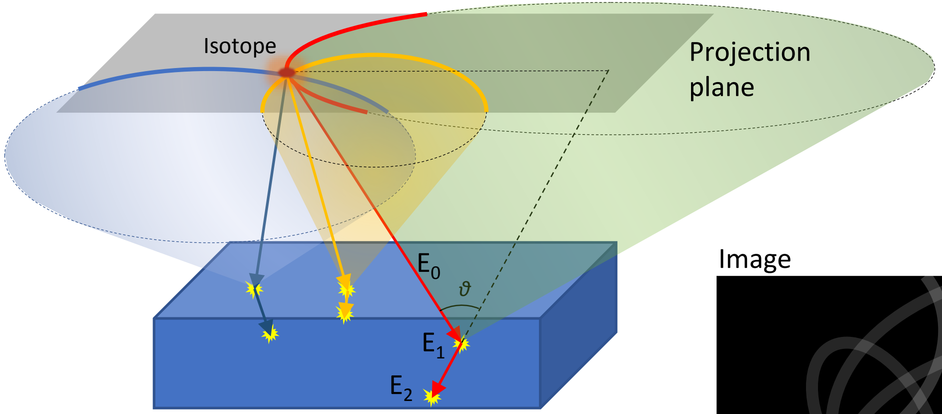
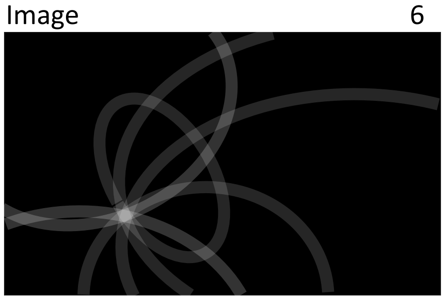
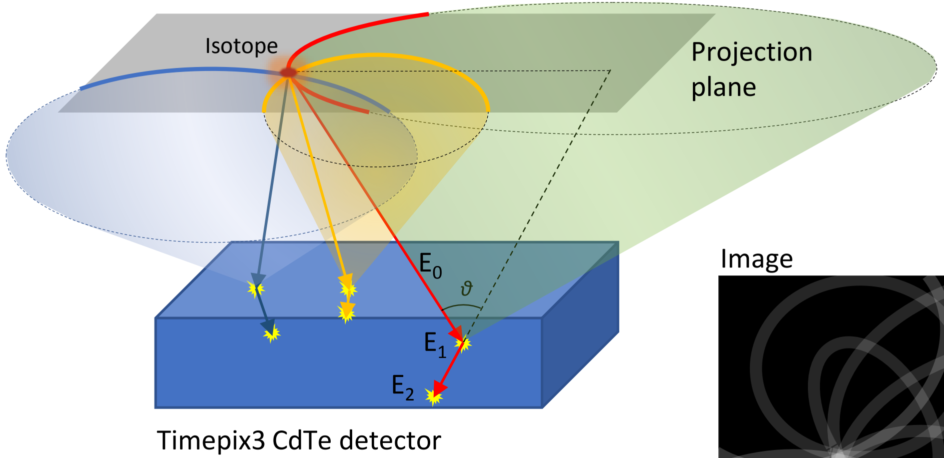
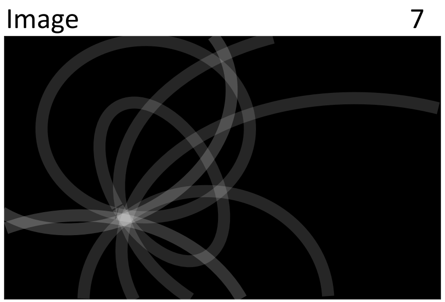


Timepix3 CdTe detector

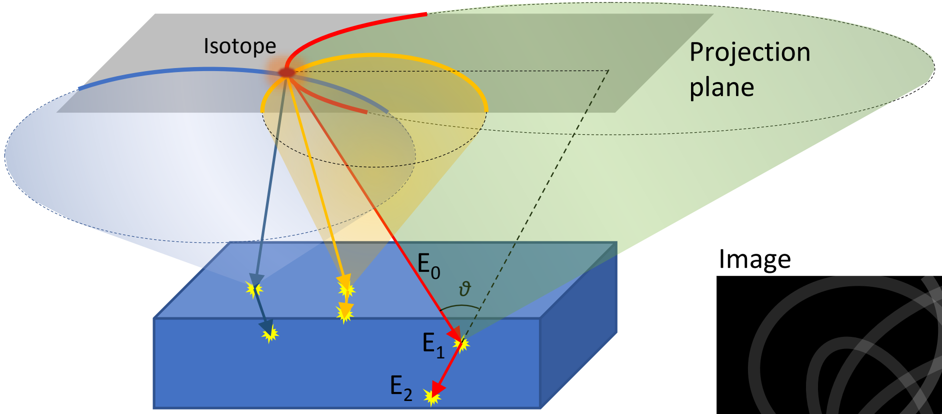


Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe



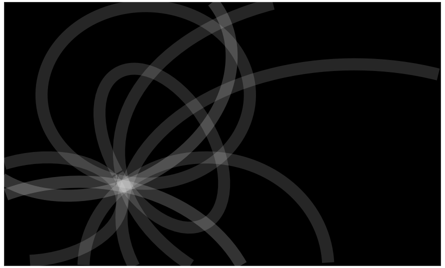


Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe



Timepix3 CdTe detector

Image 8



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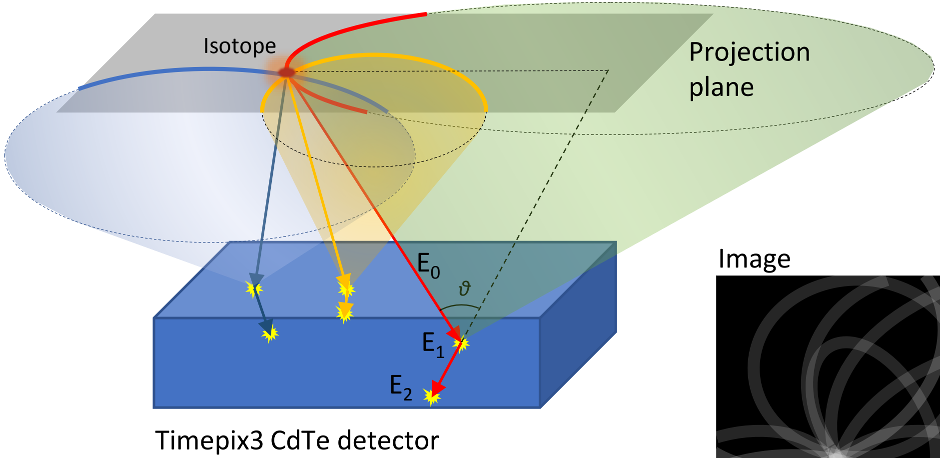

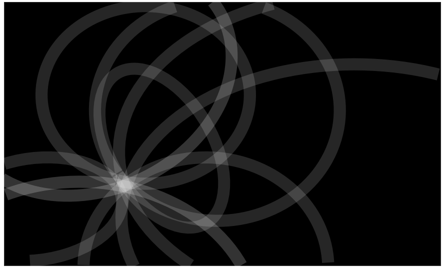

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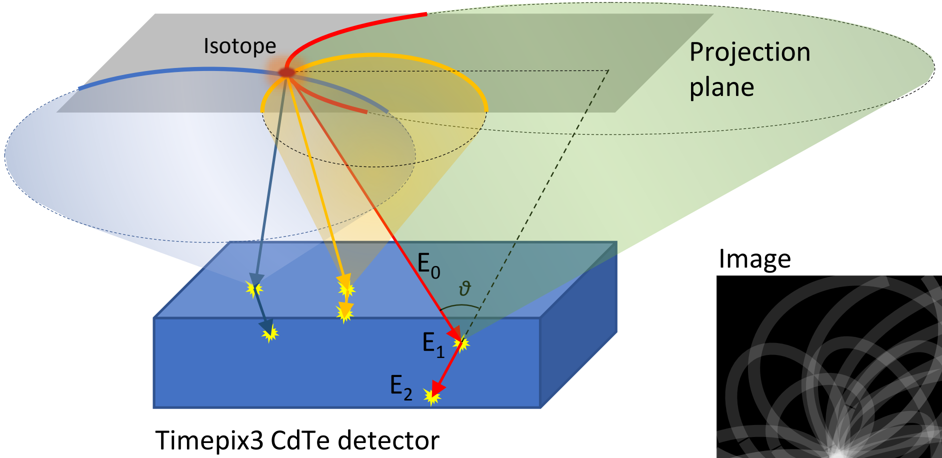
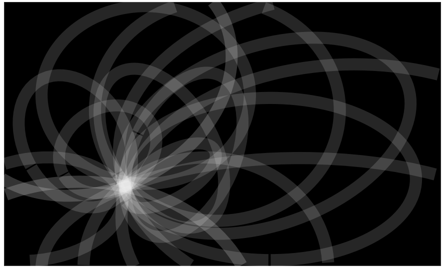
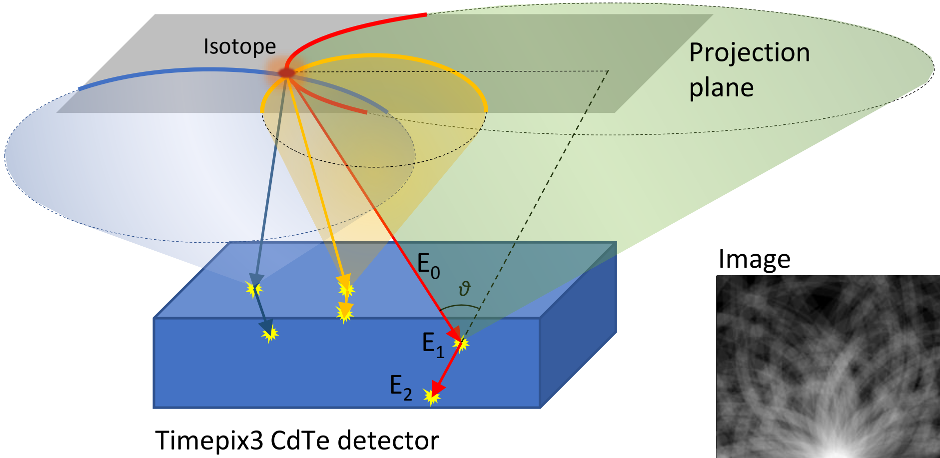
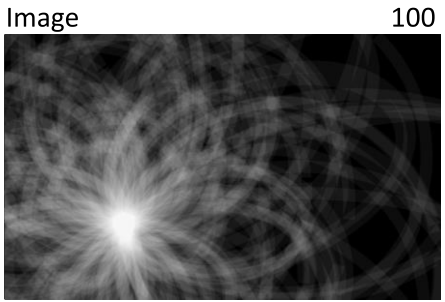




Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe





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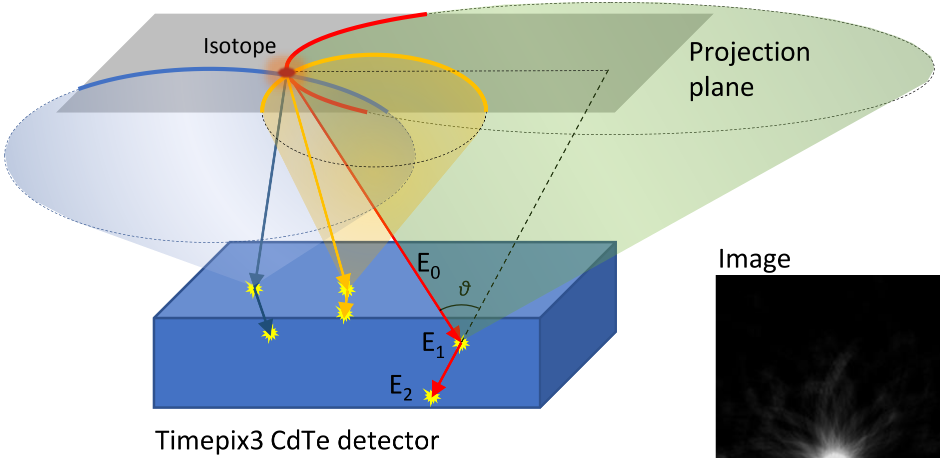

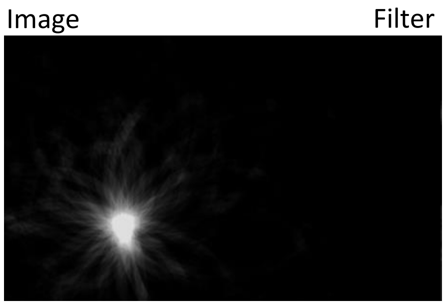

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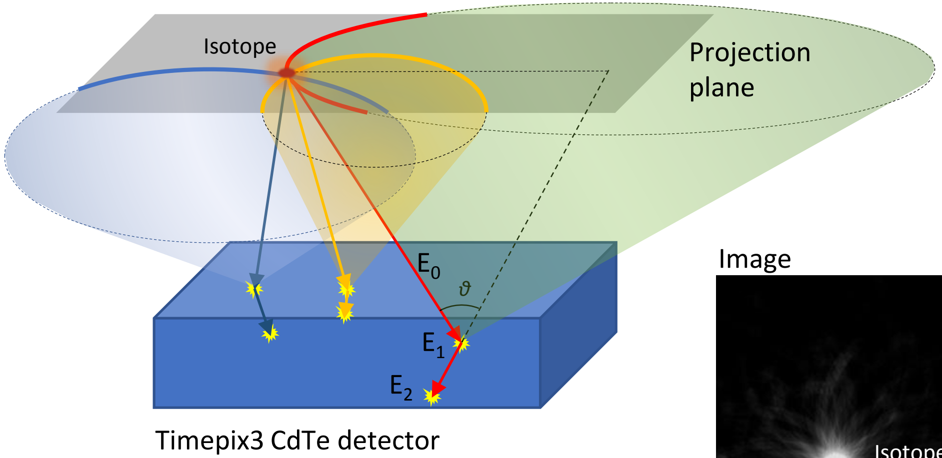
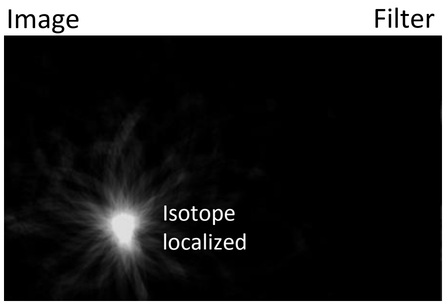
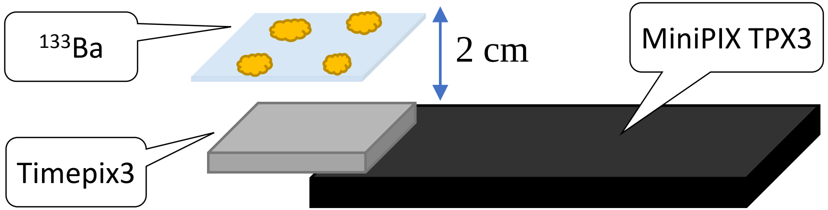


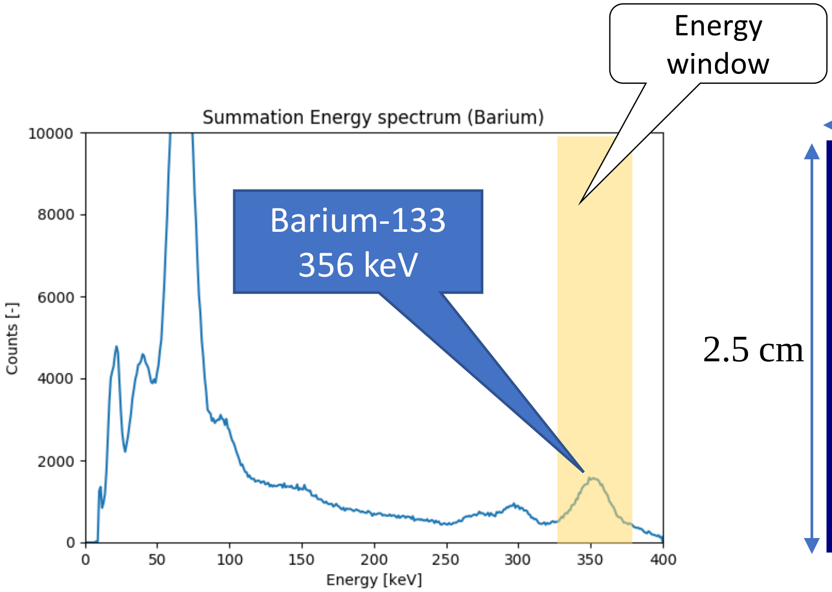


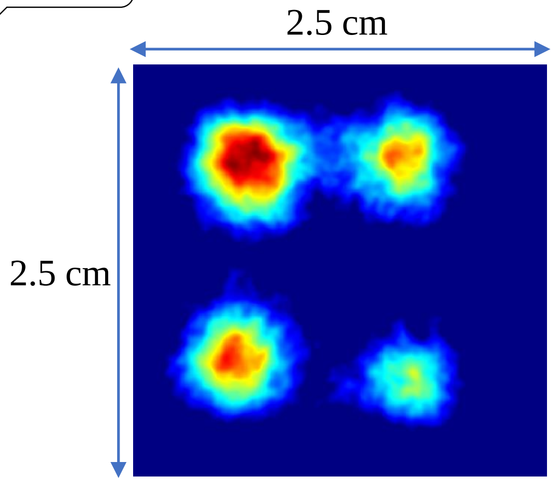
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe – 133Ba source

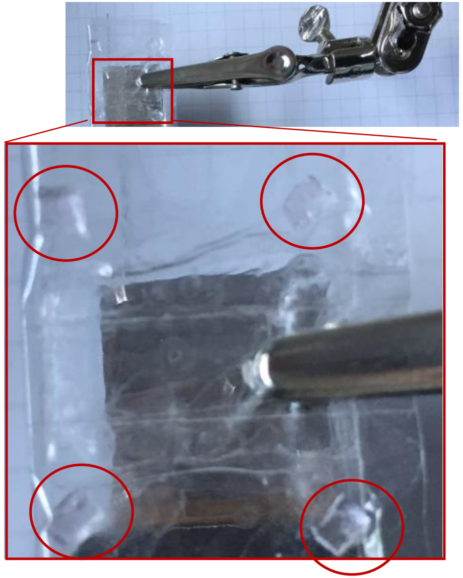
First tests – ^{133}Ba gamma source

- Small piece of Barium in silicon
- 4 different pieces positioned on top of the detector (2 cm)









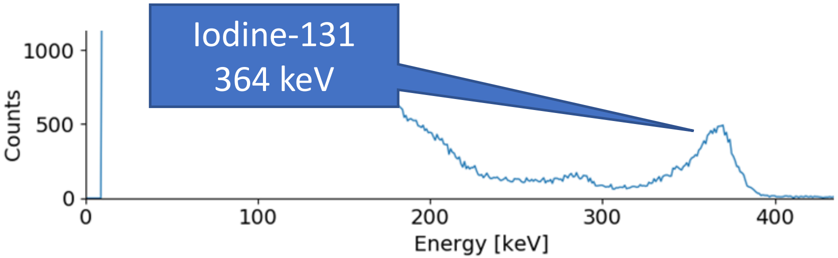
Reconstruction of position of 4 ^{133}Ba gamma sources (356 keV)

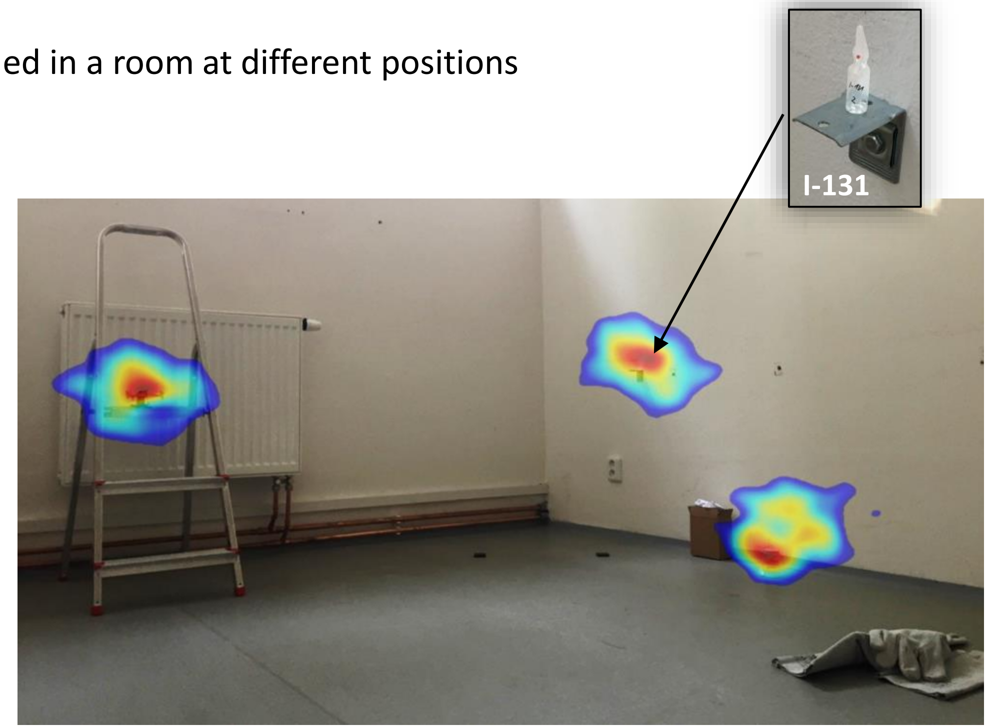
Single Layer Compton Camera with MiniPIX TPX3 – 131 Iodine source

Second test – ^{131}Iodine gamma source

- 3 different Iodine solutions in small bottles positioned in a room at different positions
- Distance from detector 3.5 m
- Mapped on photograph of the room
- Sources located correctly

Energy Spectrum of ^{131}I



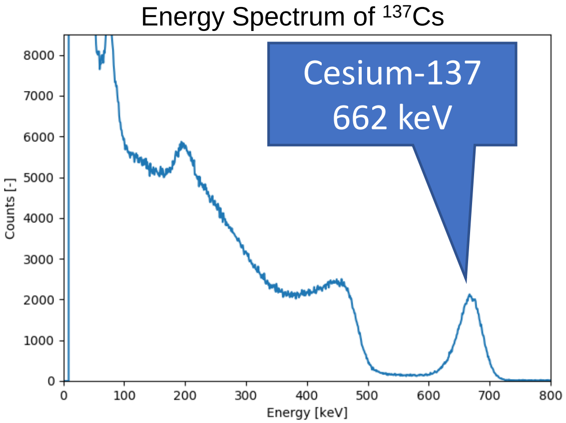


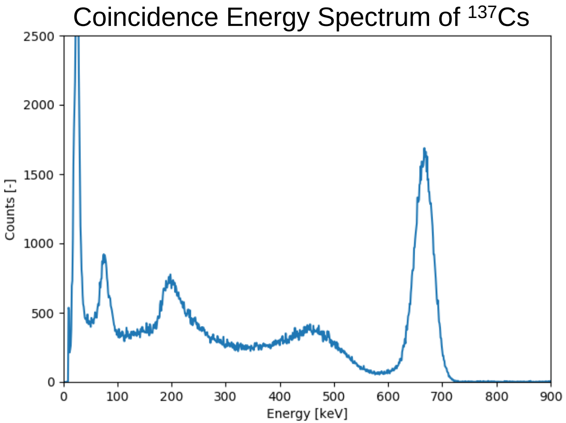
Reconstruction of position of three ^{131}I gamma sources (364 keV)

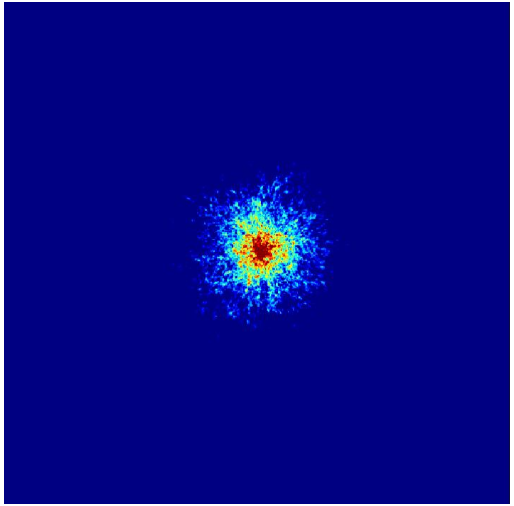
Single Layer Compton Camera with MiniPIX TPX3 – 137 Cesium source

Third Test – ^{137}Cesium gamma source

- Weak source – 100 kBq
- Distance from detector 10 cm
- Source localized



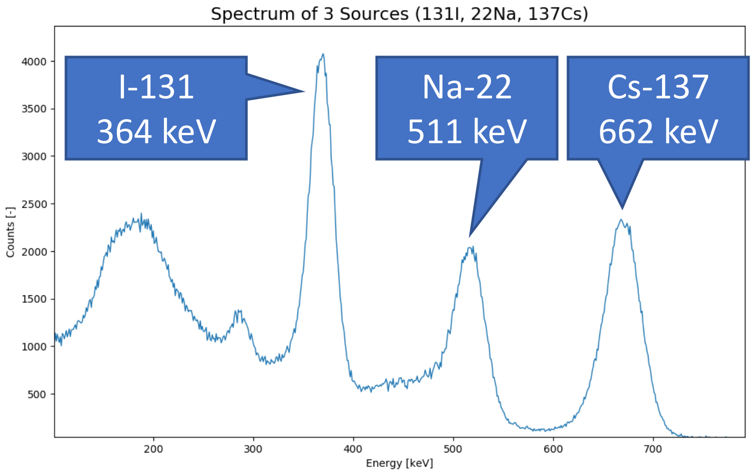


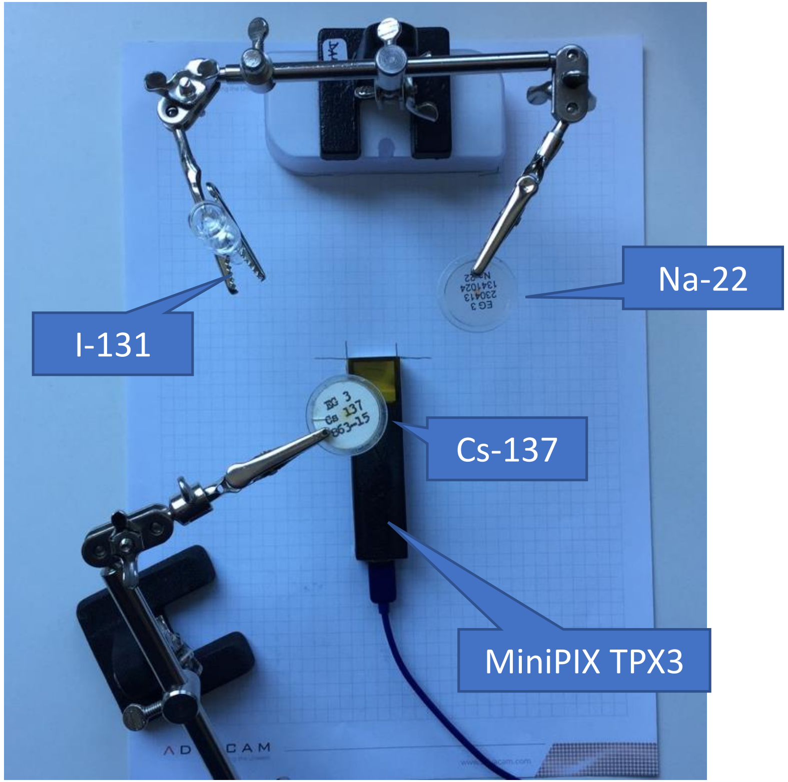


Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

Fourth Test – 3 different gamma sources ^{137}Cs, ^{22}Na, ^{131}I

- Distance from the detector 7 cm
- Different energies (364 keV, 511 keV, 662 keV)

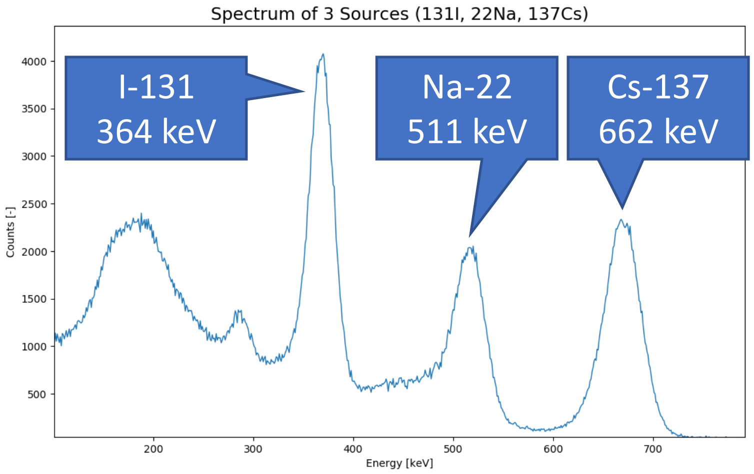


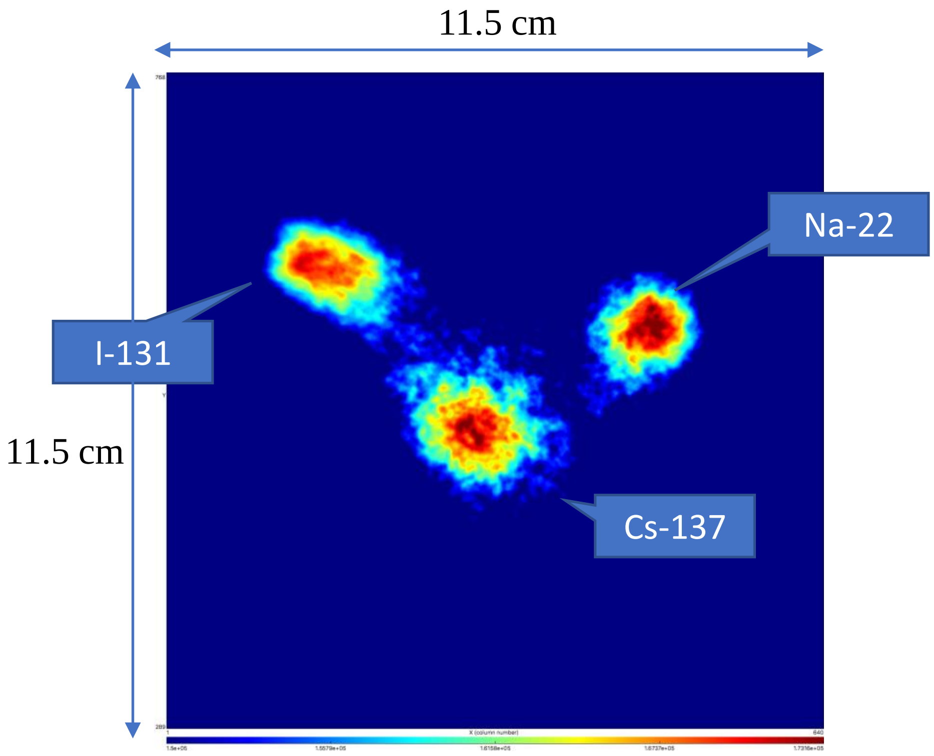


Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

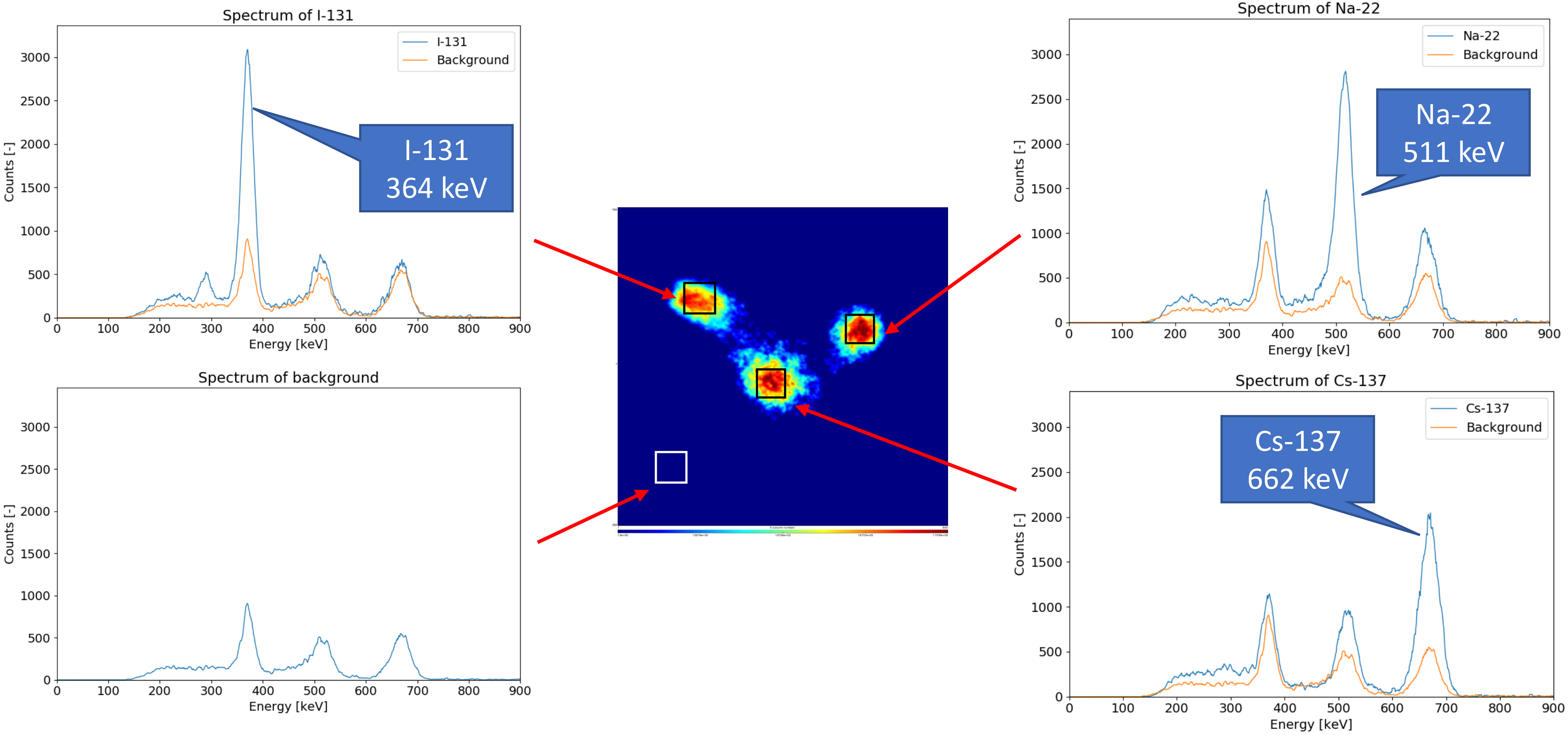
Fourth Test – 3 different gamma sources ^{137}Cs, ^{22}Na, ^{131}I

- Distance from the detector 7 cm
- Different energies (364 keV, 511 keV, 662 keV)
- Sources localized correctly



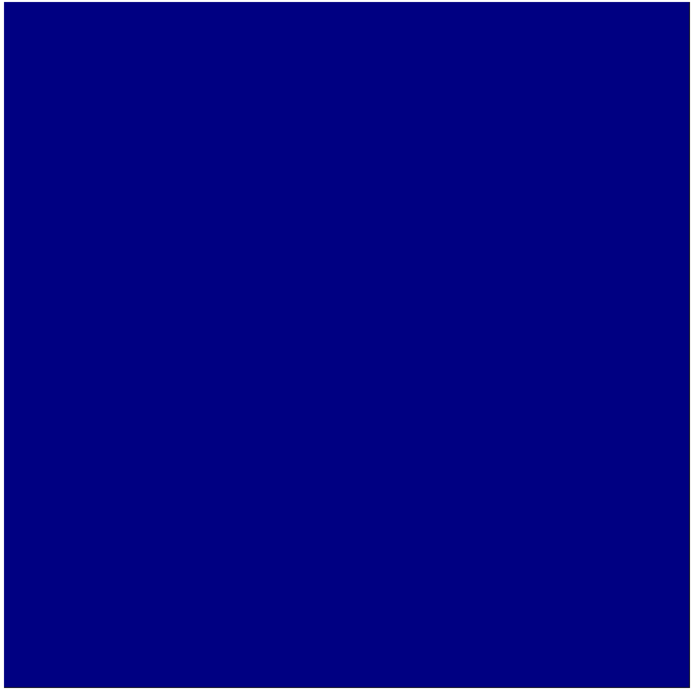


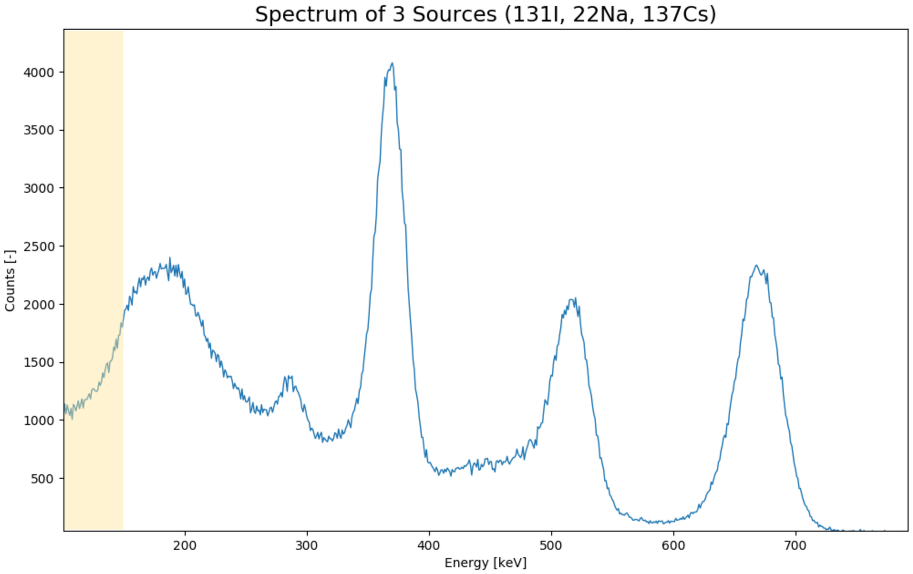
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources



Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

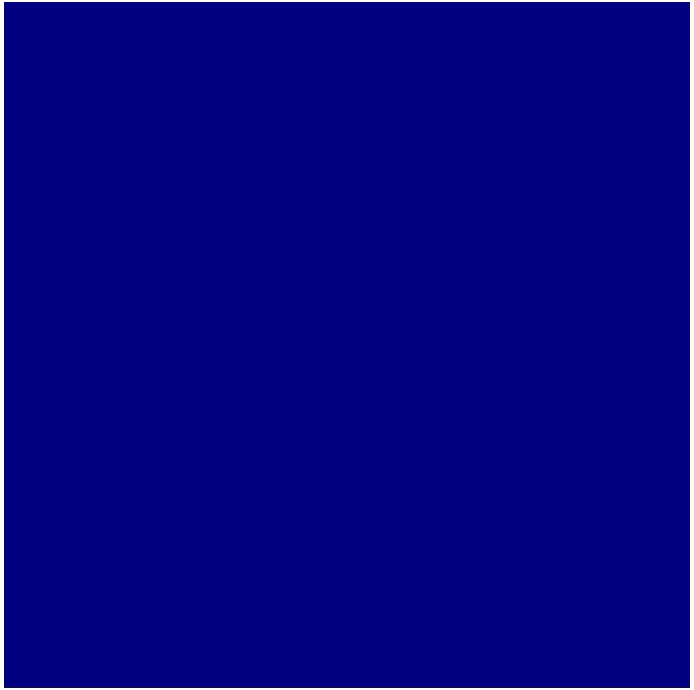
100 – 150 keV

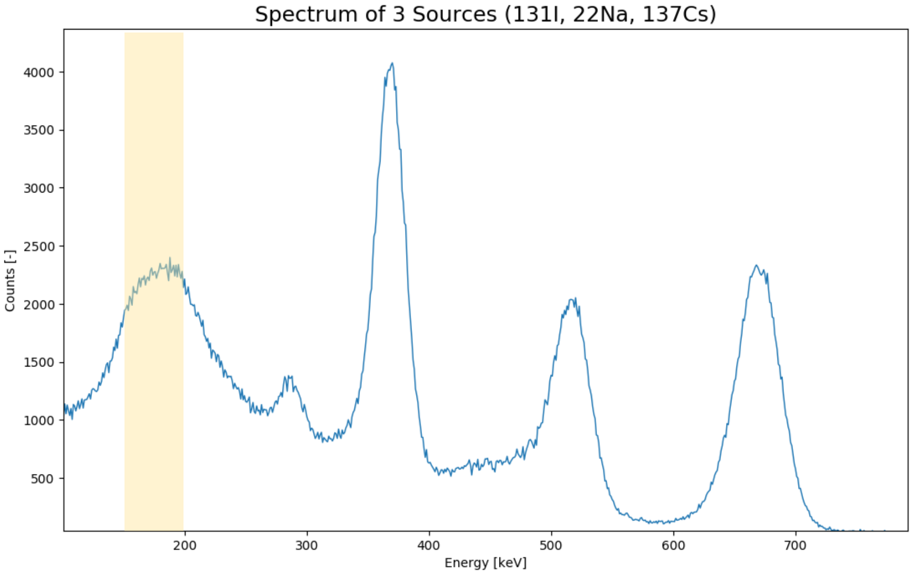




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

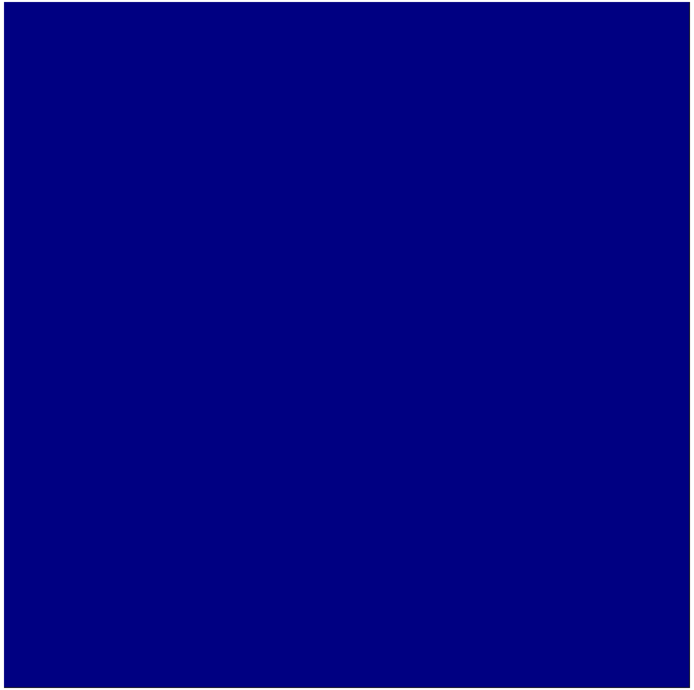
150 – 200 keV

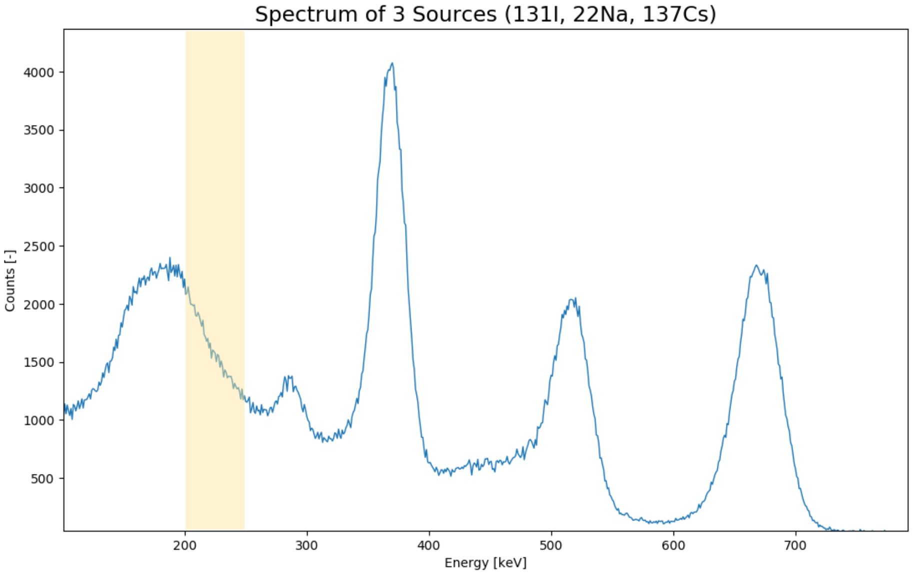




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

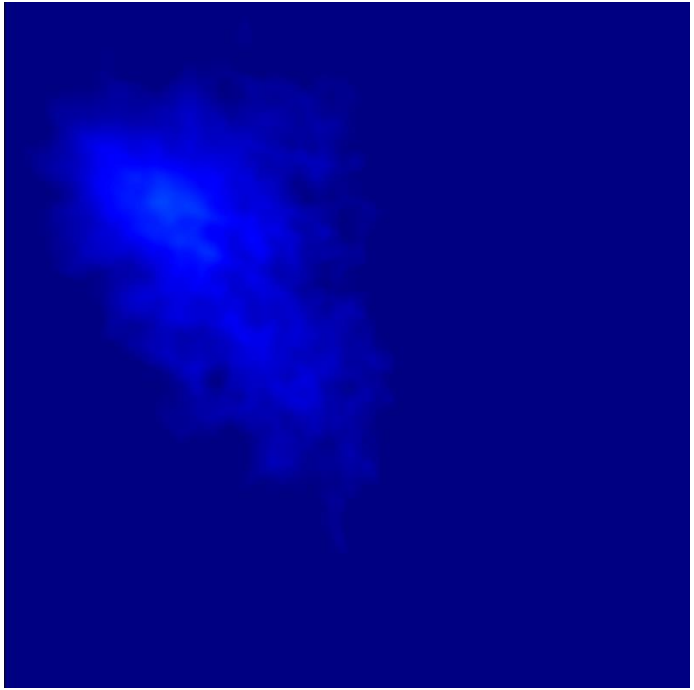
200 – 250 keV

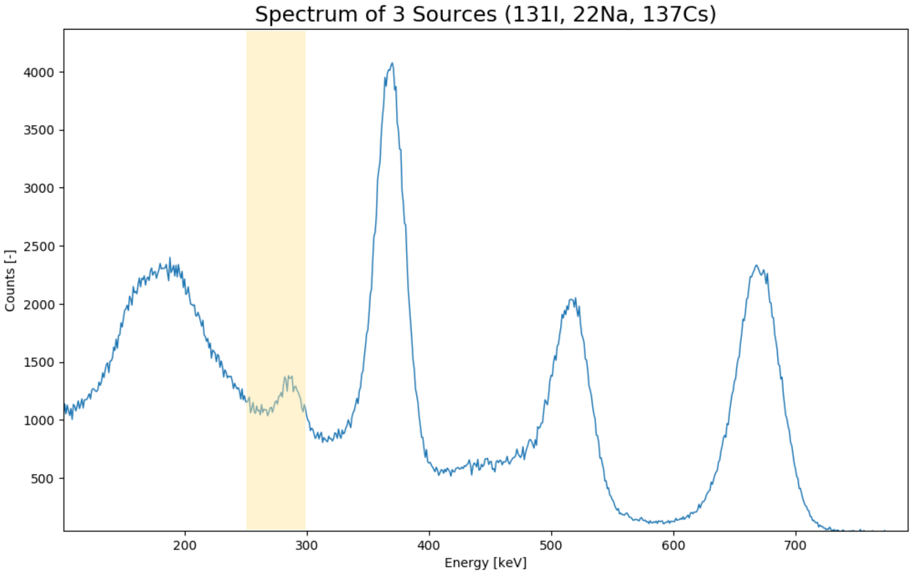




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

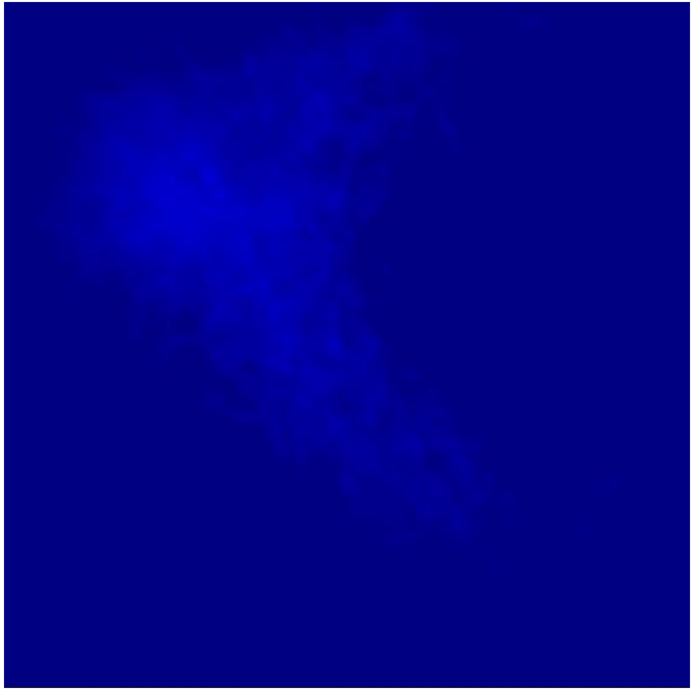
250 – 300 keV

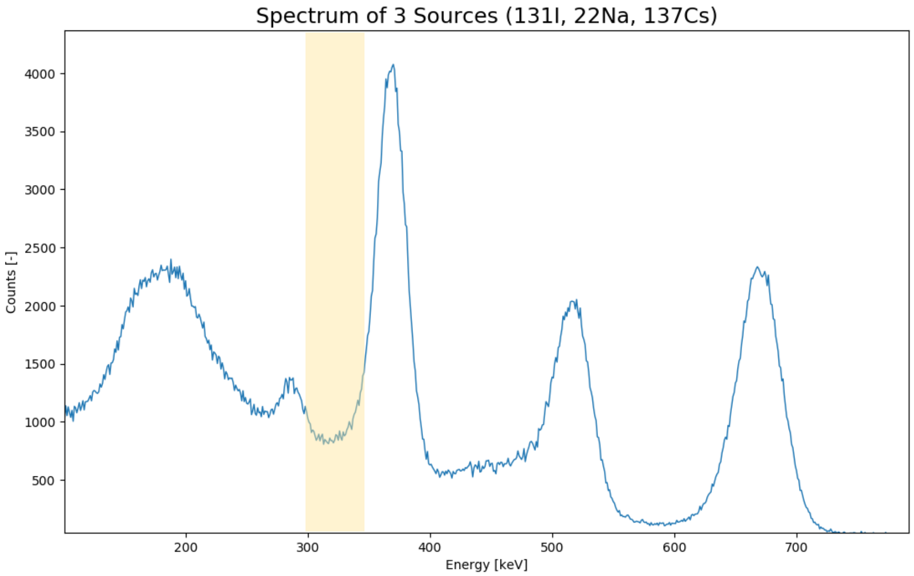




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

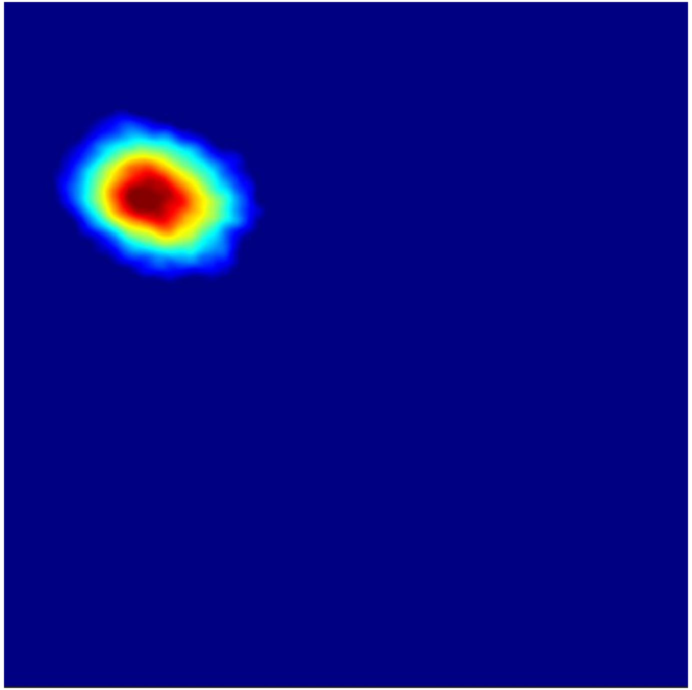
300 – 350 keV

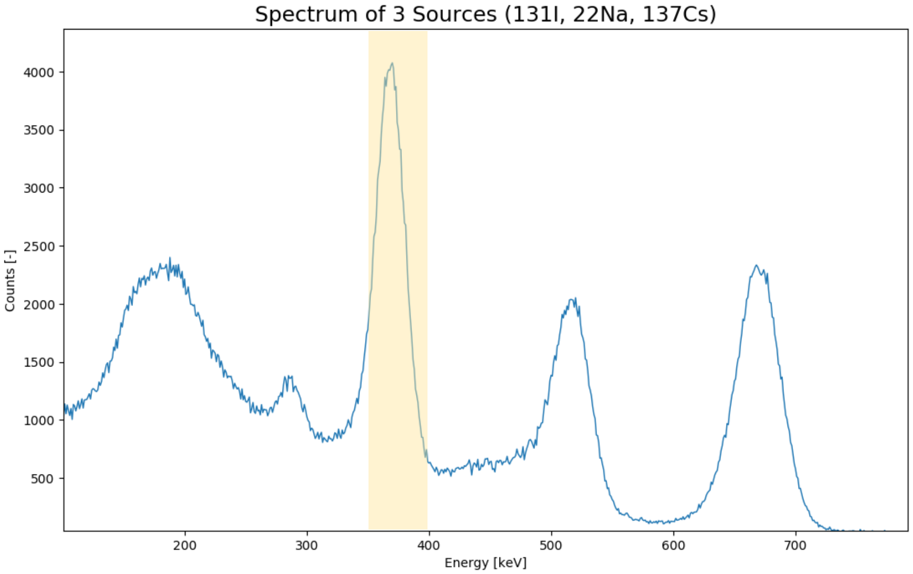




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

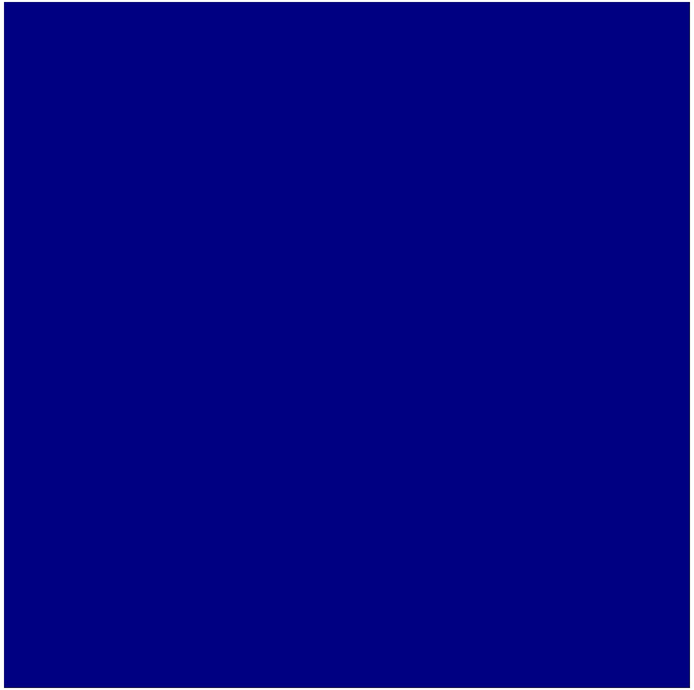
350 – 400 keV

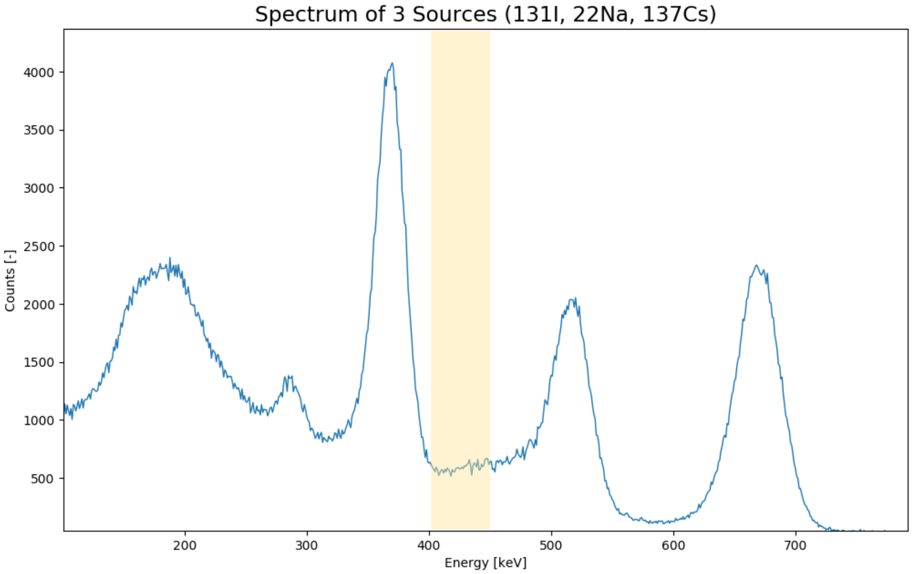




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

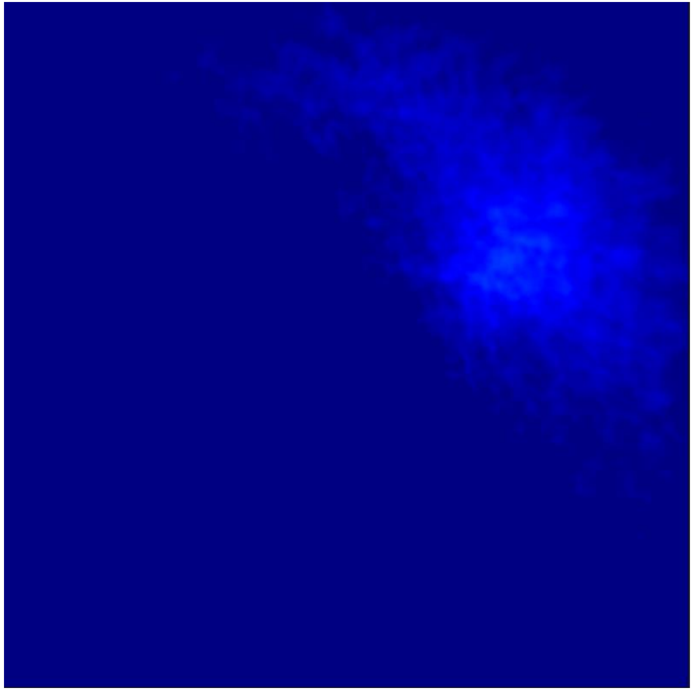
400 – 450 keV

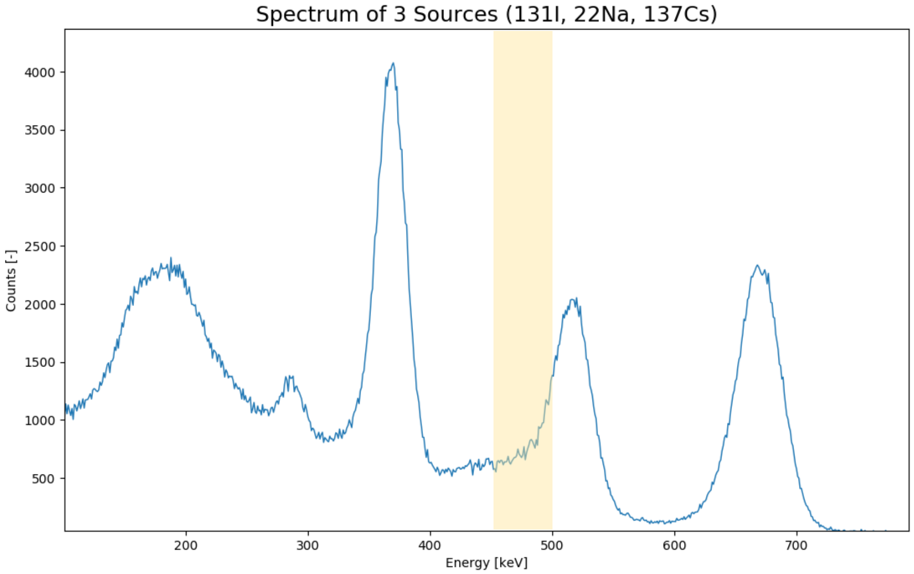




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

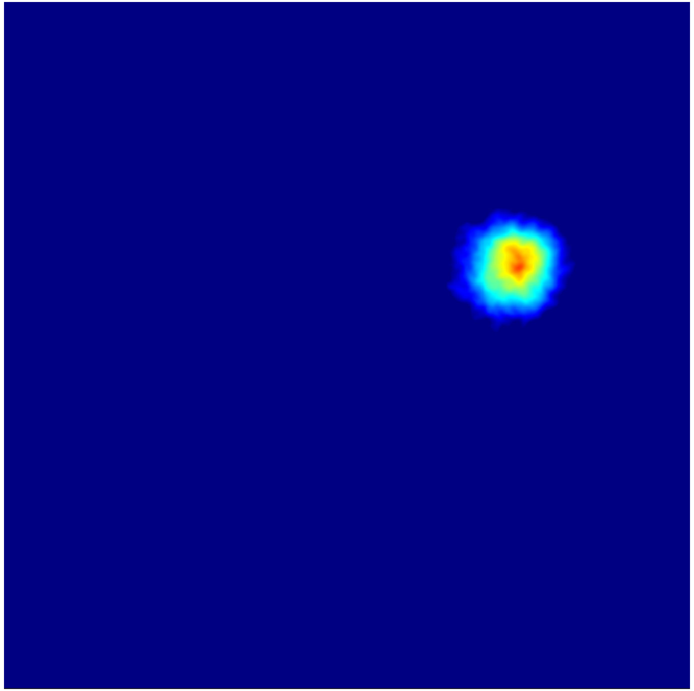
450 – 500 keV

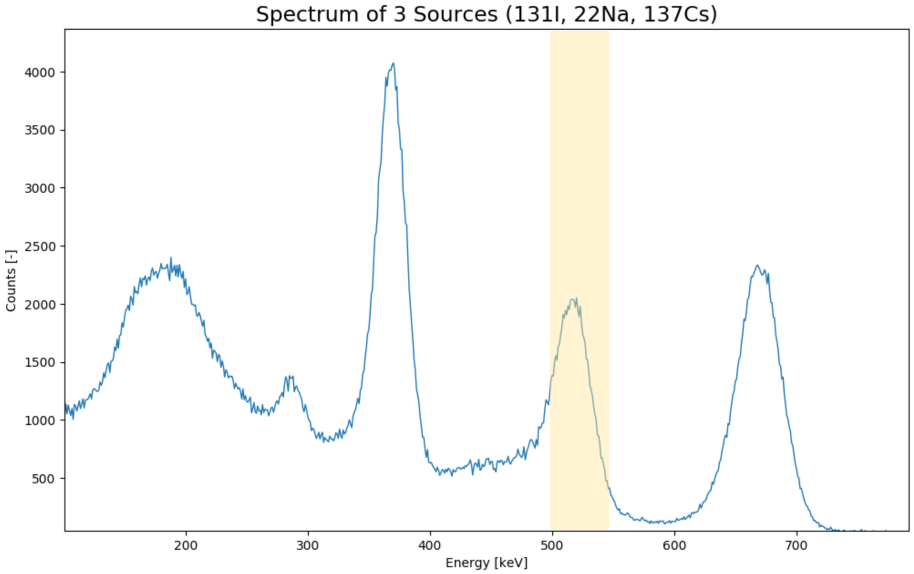




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

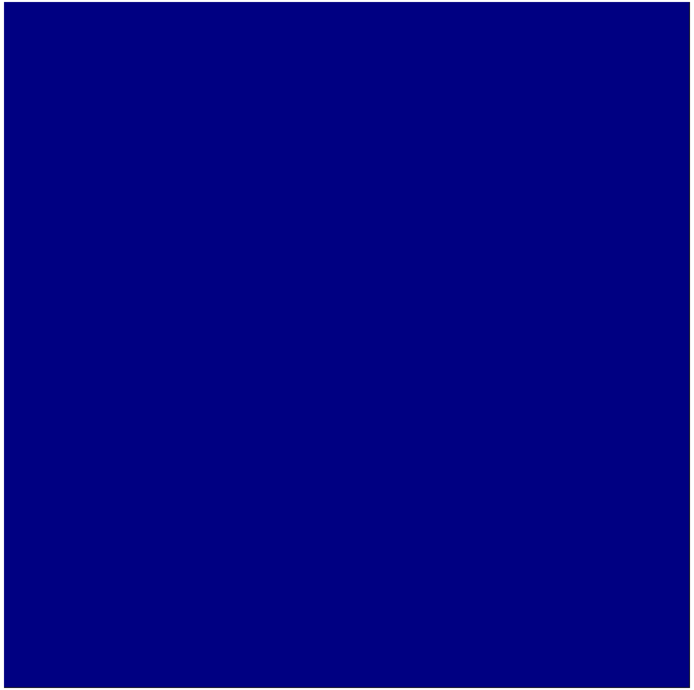
500 – 550 keV

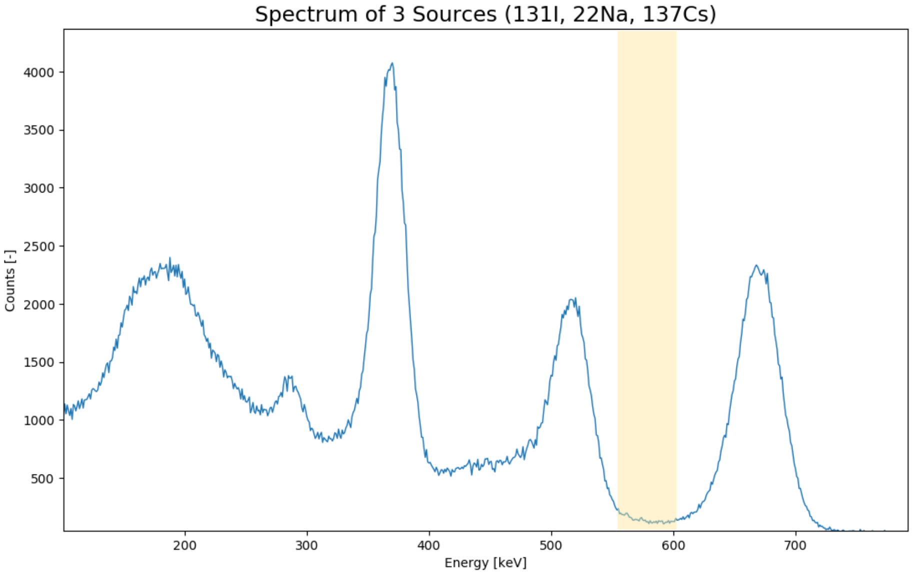




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

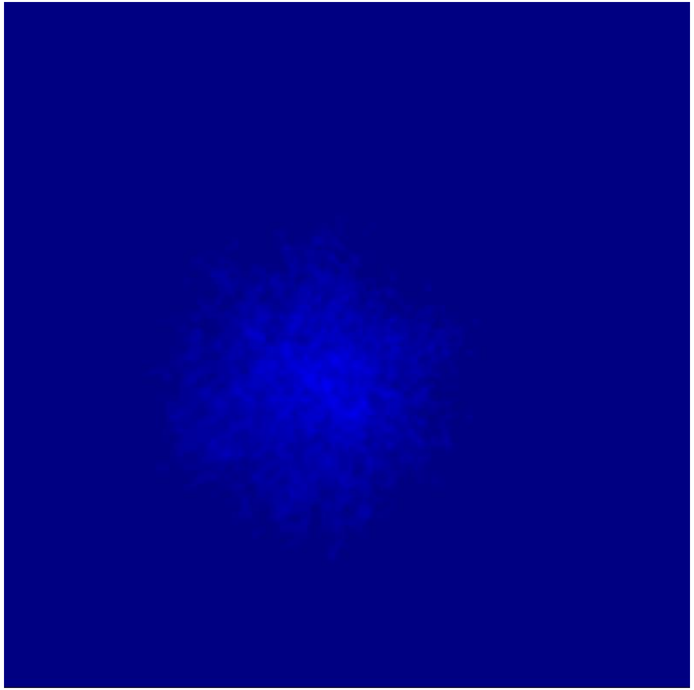
550 – 600 keV

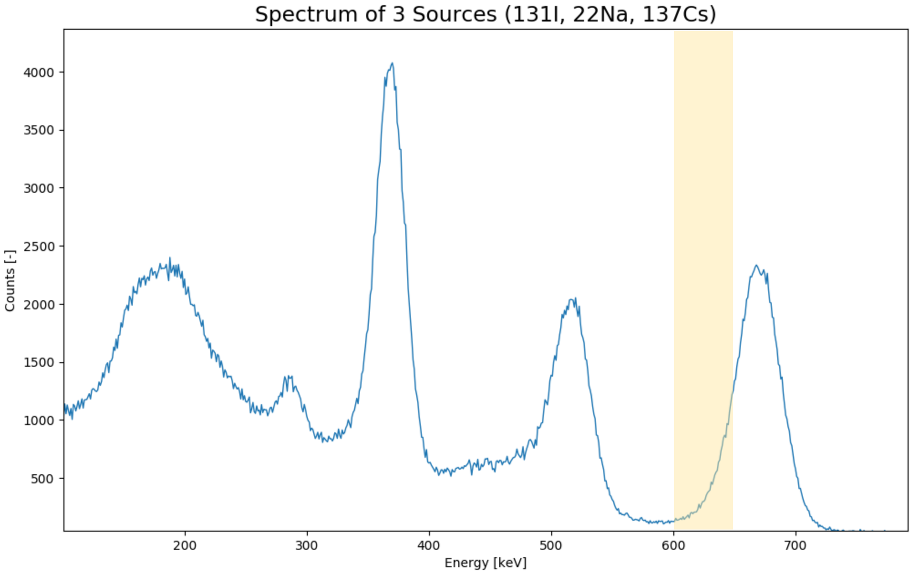




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

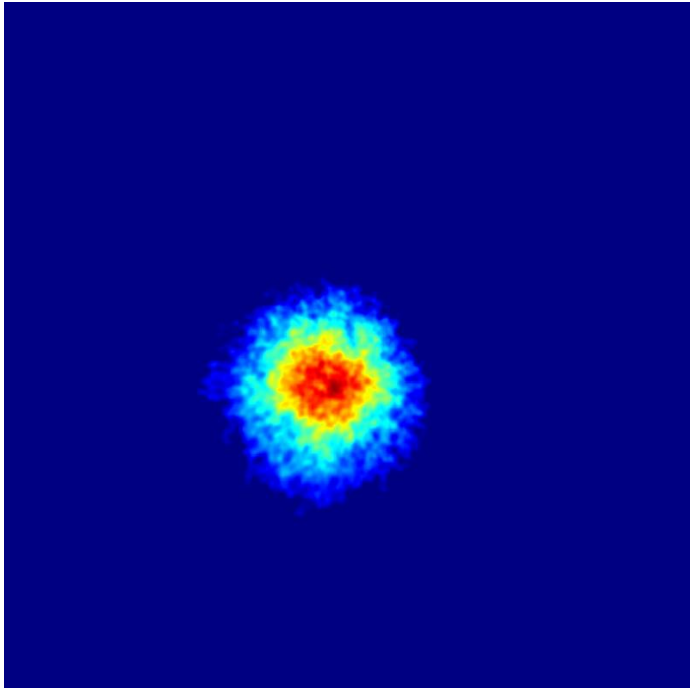
600 – 650 keV

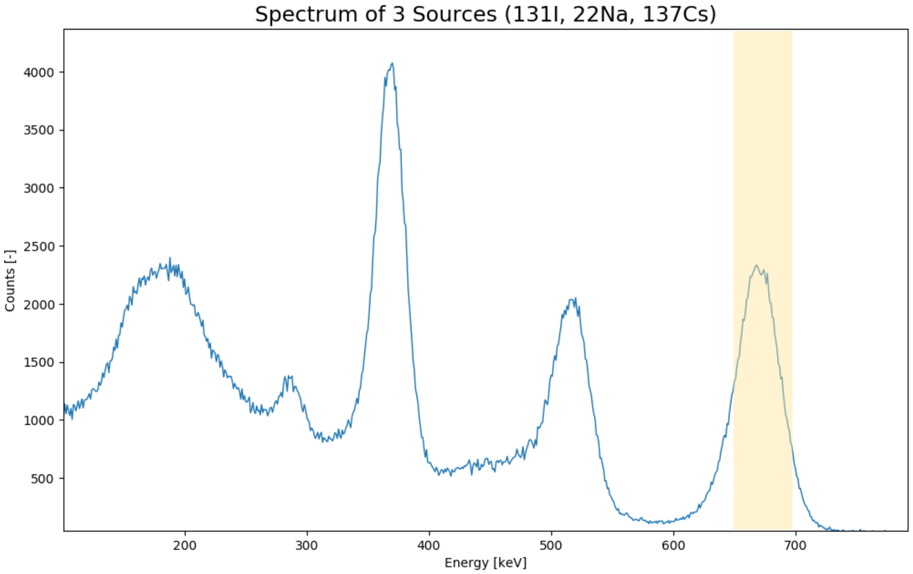




Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

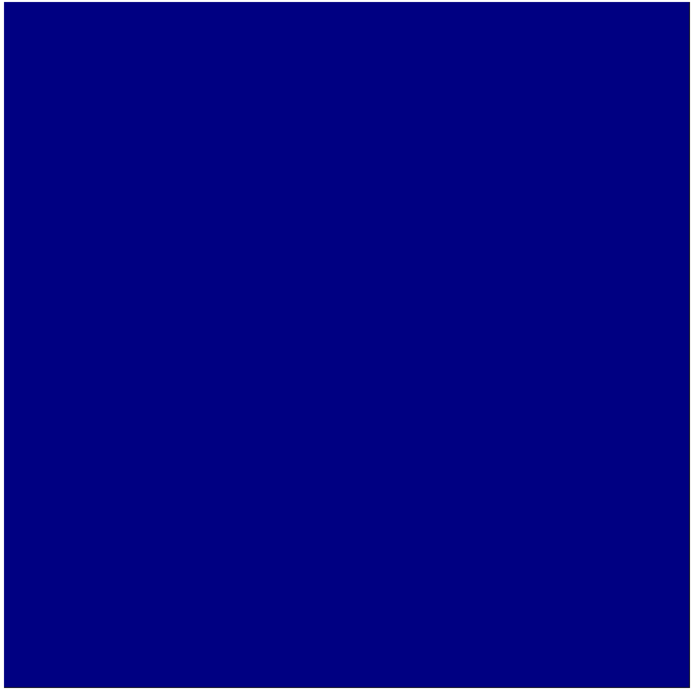
650 – 700 keV

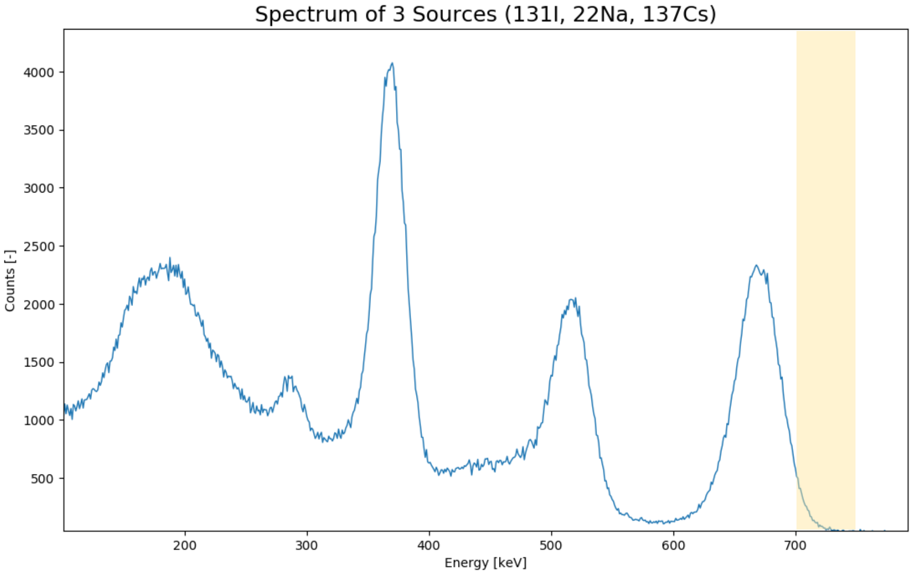




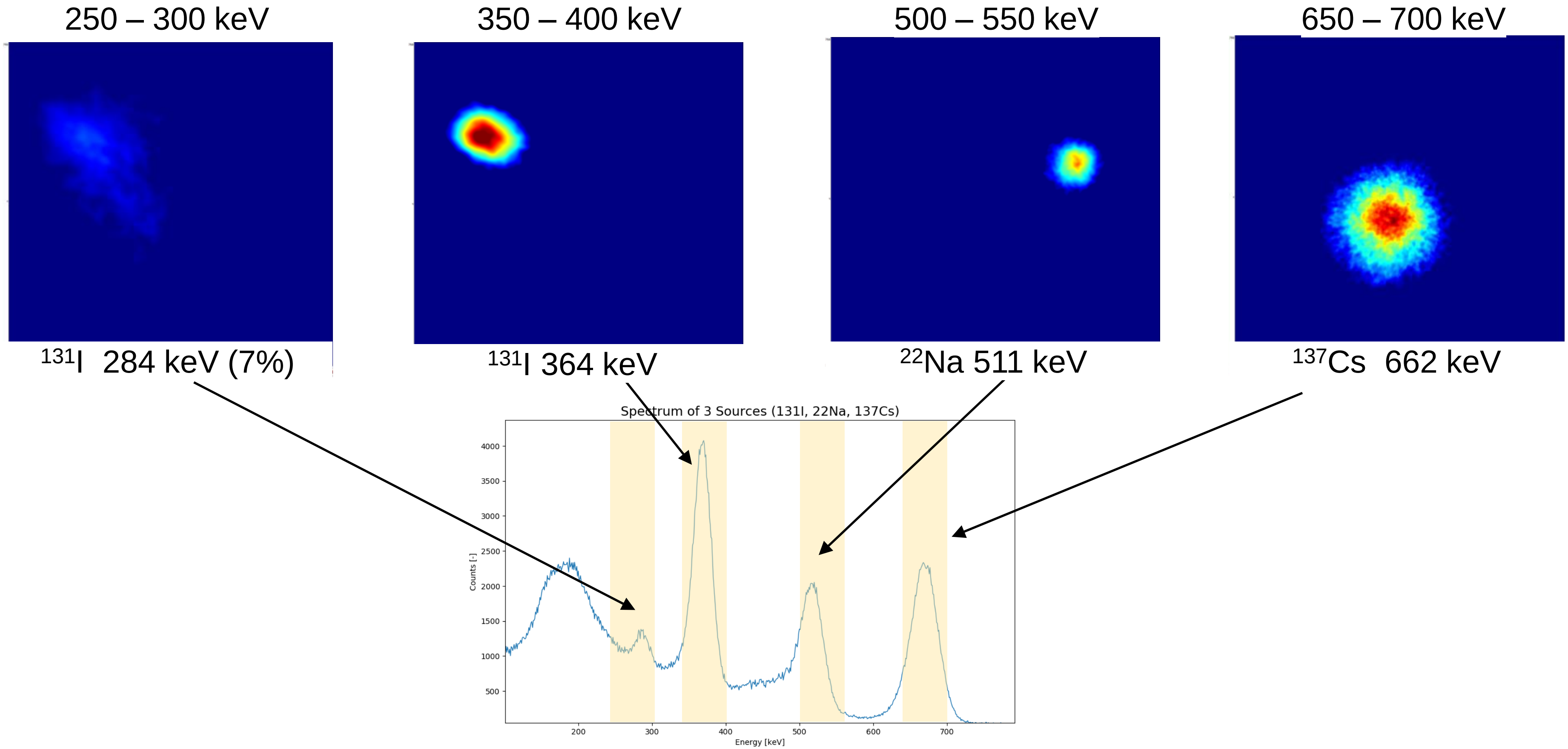
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

700 – 750 keV





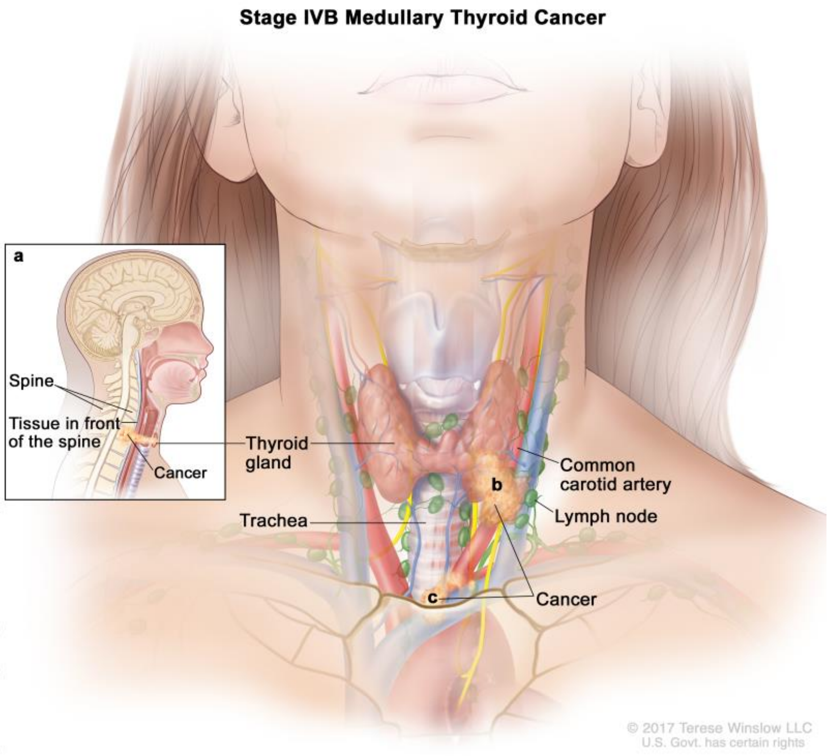
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources



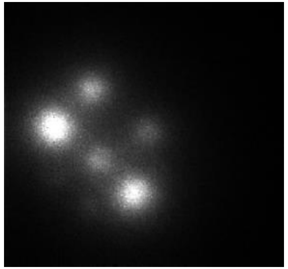
Gamma camera applications: Thyroid diagnostics

Thyroid cancer diagnostics and treatment monitoring:

- The second most frequent cancer for women (after breast cancer)
- Current imaging methods offer resolution of about 12 mm in 2D
- **Our technology allows**
  - **5 times better resolution and 3D** (2.5 mm)
  - **4 times lower dose**



- Principle:
  - Single layer Compton camera



Gamma camera applications: Source localization

- Localization of isotopes in an environment
  - Nuclear powerplant
  - Radioactive waste

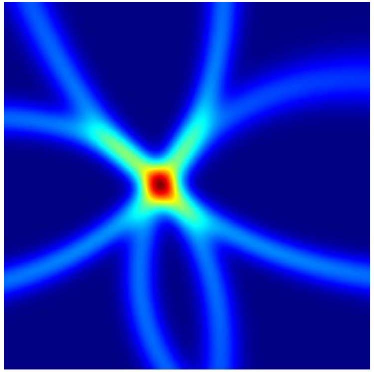
- Combined with MiniPIX TPX3
  - Small device
  - Very light
  - Handheld

- Localization of sources
  - Mounted on a helicopter
  - Drones

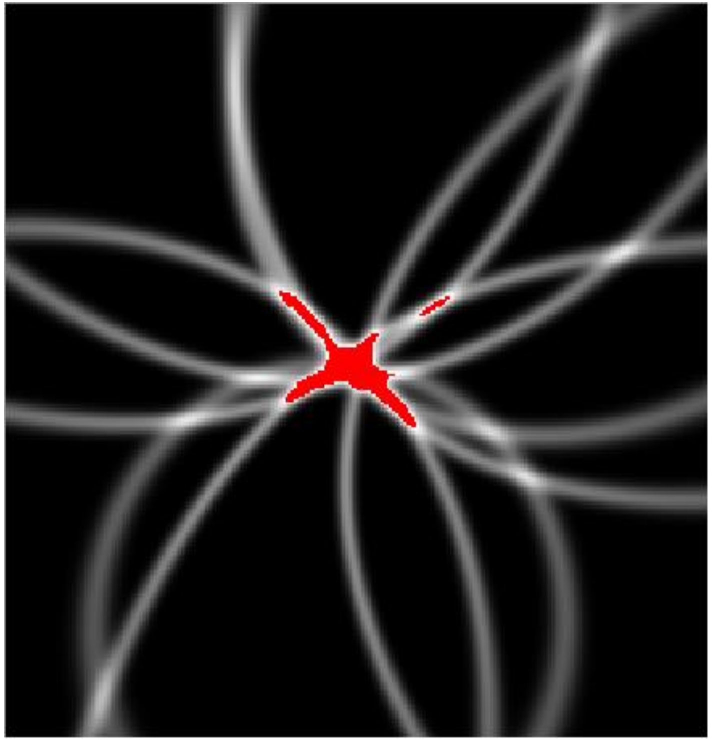
Conclusions

- MiniPIX TPX3 – a new miniaturized Timepix3 readout device
- Takes advantages of Timepix3 chip, slower than faster devices like AdvaPIX TPX3, but low power and small size
- Can be integrated in other systems
- Allows many different applications

- Single layer Timepix3 Compton camera possible with Timepix3 and MiniPIX
- Can localized isotopes in an environment
- Recognize different sources (different energies)
- Allows many new applications (SPECT, thyroid diagnostics …)



Thank you for your attention



Questions?