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.
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
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

This 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

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

Energy ~ **44 keV/pix**

Depth resolution: **28.5 µm (RMS)**

Depth resolution: **31.5 µm (RMS)**

*Compton scattering*

*Measured track*

*Drift speed*

*Muon*

*Charge collection time as function of bias voltage*
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

**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

$\Rightarrow$ We can reconstruct Compton cone:

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

$$E_0 = E_1 + E_2$$
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

\[ E_0 = E_1 + E_2 \]

\[ \cos \theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)} \]
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Isotope

Timepix3 CdTe detector
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E0

Isotope

Emitted gamma ray

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Compton scattering => two hits detected

$$E_0 = E_1 + E_2$$

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Isotope

E

E_0

E_1

E_2

Compton scattering

E_0 = E_1 + E_2

Isotope

Compton scattering

$$E_0 = E_1 + E_2$$
Scattering angle calculated:

\[
\cos \theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}
\]
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Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Isotope

Projection plane

Timepix3 CdTe detector

Image

$E_1$

$E_2$

$\theta$
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Timepix3 CdTe detector

Isotope

Image

1
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Image

1

Isotope

Second gamma ray

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Timepix3 CdTe detector

Isotope

Image

2
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Image

2

Timepix3 CdTe detector

Isotope
Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe
$E_0 = E_1 + E_2$

$\cos \theta = 1 - m_e c^2 \frac{E_1}{E_2(E_1 + E_2)}$
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Timepix3 CdTe detector

Projection plane

Isotope

Image

\[ E_0 \]

\[ E_1 \]

\[ E_2 \]

\[ \theta \]
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Isotope

Projection plane

Image

$E_0$

$E_1$

$E_2$

$\theta$
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Isotope

Projection plane

E_0
E_1
E_2

Image

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Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Isotope

Projection plane

Timepix3 CdTe detector

Image

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Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Timepix3 CdTe detector

Isotope

Projection plane

E₀

E₁

E₂

Image

8

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Isotope

Projection plane

Image

$E_0$, $E_1$, $E_2$
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Single Layer Compton Camera with MiniPIX TPX3 + 2mm CdTe

Timepix3 CdTe detector

Isotope

Projection plane

Image

$E_0$

$E_1$

$E_2$

$\theta$
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Projection plane

Isotope

Image

Filter

$E_0$, $E_1$, $E_2$
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Timepix3 CdTe detector

Isotope localized

Projection plane

Image

Filter
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)
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

- Iodine-131 364 keV

Reconstruction of position of three $^{131}$I gamma sources (364 keV)
Third Test – $^{137}$Cesium gamma source
- Weak source – 100 kBq
- Distance from detector 10 cm
- Source localized

Energy Spectrum of $^{137}$Cs

Cesium-137 662 keV

Coincidence Energy Spectrum of $^{137}$Cs
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)
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

- Spectrum of I-131
  - I-131 364 keV
  - I-131
  - Background

- Spectrum of Na-22
  - Na-22 511 keV

- Spectrum of Cs-137
  - Cs-137 662 keV
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

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

200 – 250 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

250 – 300 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

300 – 350 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

350 – 400 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

400 – 450 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

450 – 500 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

500 – 550 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

550 – 600 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
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

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

700 – 750 keV

Spectrum of 3 Sources (131I, 22Na, 137Cs)
Single Layer Compton Camera with MiniPIX TPX3 – Multiple Gamma Sources

250 – 300 keV

350 – 400 keV

500 – 550 keV

650 – 700 keV

$^{131}I$ 284 keV (7%)

$^{131}I$ 364 keV

$^{22}Na$ 511 keV

$^{137}Cs$ 662 keV

Spectrum of 3 Sources ($^{131}I$, $^{22}Na$, $^{137}Cs$)

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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?