Charged particle imaging with Timepix and Timepix3 Pixel Detectors

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Particle imaging with Timepix and Timepix3 detectors
Preliminary radiography experiments, methodology

Outline

- Pixel detectors
- Ion Radiography, imaging principle
- Proton micro-beam experiments
  - Al stairs-like target
  - Grid target
- Low-energy proton beam radiography
- Outlook

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Ion Radiography with energy sensitive pixel detectors

Motivation

• Ion imaging can improve particle therapy, reduce uncertainties, …

• Hybrid semiconductor pixel detectors Timepix, Timepix3
  • High spatial granularity (pixel pitch 55 µm) + particle track analysis → sub-pixel/µm scale resolution
  • Quantum imaging sensitivity → Low doses needed
  • Per-pixel spectrometry → High-contrast imaging
  • Multi-parameter image generation for single particles
    • Energy deposition
    • Dose
    • Particle Tracking, LET, direction for energetic charged particles
      • Imaging of soft-tissue and low-contrast objects
      • Lower doses, small/thin objects
Hybrid Semiconductor Pixel Detectors

**Timepix3 ASIC**

**Fast pixel detectors**
- AdvaPIX TimePIX3
- Si, CdTe, CZT sensors

**Features**:
- Pixel size of 55 µm
- 1.6 Mega pixels
- Sensitive area
- (can be larger if needed)
- Gap-less tilling

**Large area imagers**

- **Fast camera**
  - Single chip
  - 256x256 pixels
  - 14x14 mm
- **WidePIX L**
  - 2x15 = 30 chips
  - 3840x512 pixels
  - 210x30 mm
- **MiniPIX TimePIX3**
  - Si or CZT sensors
  - 256x256 pixels
  - 14x14 mm

**Pattern recognition analysis of single particle tracks**
- Particle direction tracking in 3D
- Wide Field of View (2π), no collimators
- Fast data acquisition (ns)
- Records simultaneously Time of arrival (TOA) and Energy deposited (TOT) by individual tracks
- Energy of all charged particles starting from few keV up to highly energetic particles.
Ion Radiography with pixel detectors Timepix

Per-pixel energy sensitivity

**Imaging principle**

- Instead of registering the intensity of the transmitted beam, we measure changes in the energy of single particles → imaging contrast from energy loss changes sensitive to sample density.

- A single particle is sufficient in each imaging spatial bin.

- Mono-energetic charged particle beams → imaging + inspection of thin samples (thin layers, foils).

- Precision of thickness measurement can reach sub-pixel / μm-scale.

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**Radiography of thin Mylar foils**

- Energy spectrum measurement in air, Timepix 300 um Si

- Table top setup, measurement in air, Timepix 300 um Si

- Energy spectrum of alpha particles from \(^{241}\text{Am}\) passing through a sample composed of 8 overlapping mylar foils of 4 μm (inset).
Ion Radiography with pixel detectors Timepix

Detection of heavy charged particles with Timepix $\rightarrow$ spectrometry, track visualization

3 MeV protons, Tandetron accelerator

2D visualization

3D visualization

Pixel cluster analysis
Ion Radiography with Timepix detector
Table top setup and radionuclide lab source

By cluster analysis it can be determined:
- **Centroid** to increase spatial resolution (sub-pixel → µm-scale resolution)

Wing of a fly (less than 20 particles per pixel)

*Photo*, *Intensity*, *Energy*

$^4$He, 5.5 MeV in air
Ion Radiography with Timepix

Soft tissue sample: Dry spider

- Skin thickness ≈ µm
- Very weak alpha source ~ 12 particles per frame (1 second), standard $^{241}$Am lab source
- 60 000 frames taken
- 750 000 clusters analyzed
- Not enough particles for “deep” sub-pixelization

$^4\text{He}, 5.5 \text{ MeV in vacuum}$
Ion Radiography with Timepix
Soft tissue sample: Dry spider

\[ _4^\text{He}, 5.5 \text{ MeV measured in vacuum} \]

Spider radiograph obtained by measurement of energy losses of 5.5 MeV alpha particles.

The image looks dotted because only 720,000 alpha particles were used for 1 megapixel image.

\[ \sim 0.7 \text{ particles per pixel} \]

\[ \sim 12 \text{ particles per pixel, 65 kpixel image} \]
Proton Radiography: Cluster area

Proton beam, 3 MeV, Tandetron NPI Rez
AdvaPix Timepix3, 300 µm Si sensor

Scanned area: 3 mm x 11 mm

Cluster size distribution
Proton Radiography: Cluster energy

Timepix 3, Si sensor 300 µm
Proton beam, 3 MeV, Tandetron

Sample: Al foil stairs
Scanned area: 3 mm x 11 mm

Spatial map of cluster Energy

Cluster Energy [keV]

Energy spectrum

Resolution = 55 µm

Proton beam, 3 MeV, Tandetron

Al foils

Sample: Al foil stairs
Scanned area: 3 mm x 11 mm

Spatial map of cluster Energy
Sample: Al foil stairs

Spatial resolution: Image pixel size

- Cluster energy
  - resolution = 5 µm
  - 14 mm

- Cluster area
  - resolution = 9 µm
  - 2 mm
  - 14 mm

- resolution = 100 µm

Cluster energy and area with different resolutions.
Applications: Proton Radiography

Sample: Metallic grid

Event count

Resolution = 10 μm

Cluster area

Spatial distribution: Event counts

Spatial distribution: Cluster area

All events incl. background

Proton beam, 3 MeV, Tandetron
Timepix 3, Si sensor 300 μm
Particle imaging with Timepix and Timepix3 detectors

Summary, Outlook, References

- Simplified instrumentation, single detector setup
- Multi-parameter imaging-contrast radiographies
  - Event-by-event analysis (cluster area, energy, flux)
- Need for well-defined energy of primary beam
- Spatial resolution ≈ few μm, possible sub μm (800 nm)
- Directional and time response can be exploited, improve image quality


References & Questions at: cristina.oancea@advacam.com
Light ion / high energy Helium imaging with Timepix3 telescopes

Single detector setup Timepix, 300 μm Si sensor

- M. Martišíková, DKFZ, Heidelberg
  https://medipix.web.cern.ch
- M. Martisikova et al., DKFZ, Heidelberg
  Physics World, March 2018


Backup slides
Large area WidePix detectors with CdTe and Si sensors
The large area CdTe imaging detector with continuous sensitivity

Features:
• Pixel size of 55 µm
• 1280 x 1280 pixels = 1.6 Mega pixels
• Sensitive area of 70 x 70 mm² (can be larger if needed)
• Gap-less tilling:
  o Gaps between modules smaller than quarter of the pixel
  o Edge pixels of 100 µm

Supported sensor types:
(Bias voltage +/- 500 V)
• CdTe 1 mm
• CdTe 2 mm
• Si 300 µm

WidePix L 2(1)x10
2560x512 pixels
140x30 mm

WidePix L 2(1)x15
3840x512 pixels
210x30 mm

Suited for: CT scans
Particle Tracking with AdvaPIX TimePIX3
Directional per pixel E measurements vs particle type and angle

40 MeV $^3$He- (top row) and 31 MeV protons (bottom row) from the NPI-CAS Cyclotron, Prague

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