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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

Measurements

Particle	Energy	Source	Sample	Detectors
Alpha	5.5 MeV	Radionuclide lab source	- Spider - Wing of fly	Timepix 300 µm Si sensor
Proton	3 MeV	Tandetron	- Al foils stairs - Metal grid	AdvaPix Timepix3 300 µm Si sensor
Proton	20, 30 MeV	Cyclotron	- Foils - PCB - Plastic mask	AdvaPix Timepix3 500 µm Si sensor

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

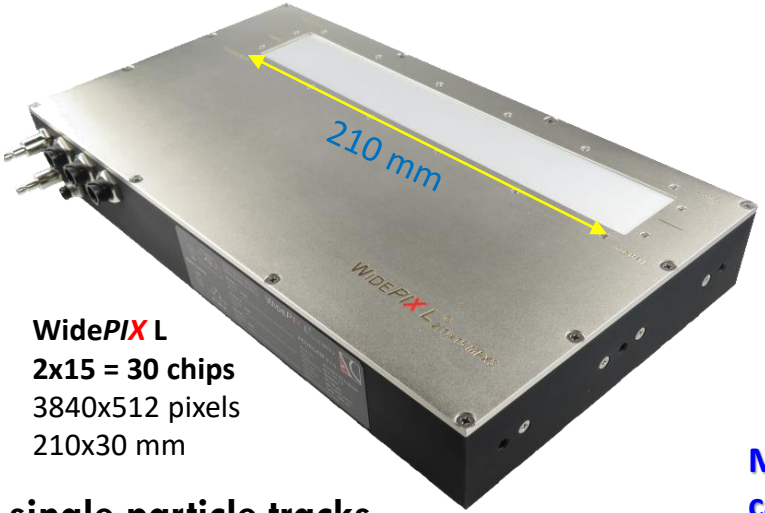
Fast pixel detectors

- Adva*PIX* Time*PIX3*
- *Si, CdTe, CZT sensors*

Fast camera
Single chip

256x256 pixels
14x14 mm

Large area imagers



Wide*PIX* L
2x15 = 30 chips
3840x512 pixels
210x30 mm

Features:

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

Mini*PIX* Time*PIX3*
Si or CZT sensors

Miniaturized camera TPX3

256x256 pixels
14x14 mm

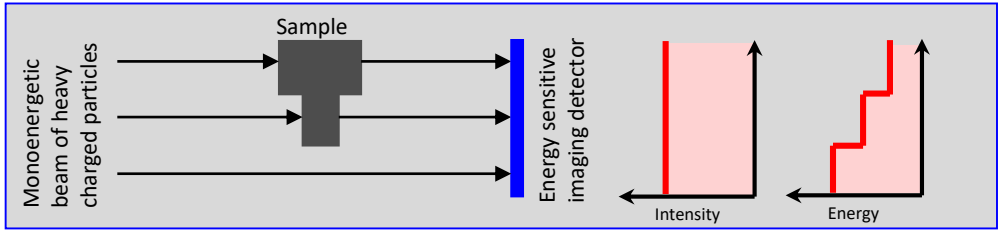
❑ **Pattern recognition analysis of single particle tracks**

- 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.

J. Jakubek, et al., Pixel Detectors for Imaging with Heavy Charged Particles, Nucl. Instr. and Meth. A 591 (2008) 155-158

Radiography of thin Mylar foils

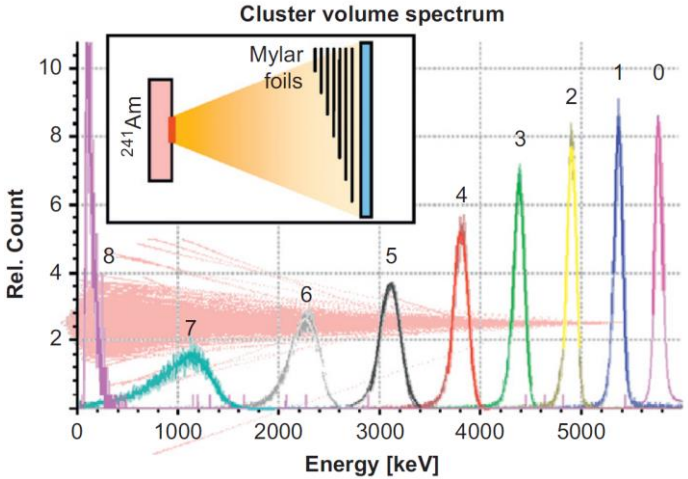


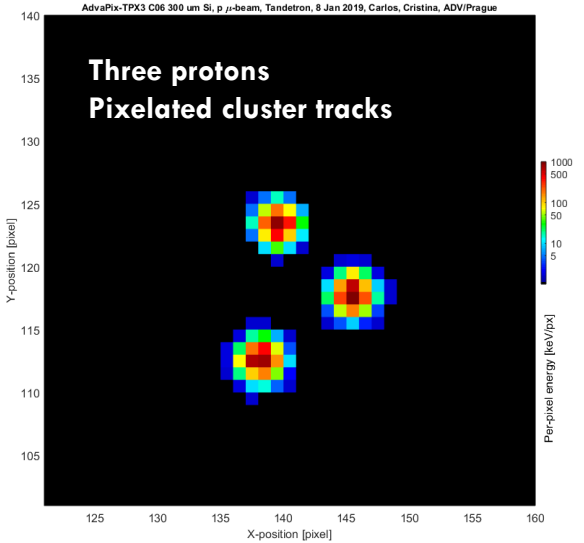
Table top setup, measurement in air, Timepix 300 um Si

Energy spectrum of alpha particles from ^{241}Am passing through a sample composed of 8 overlapping mylar foils of 4 μm(inset).

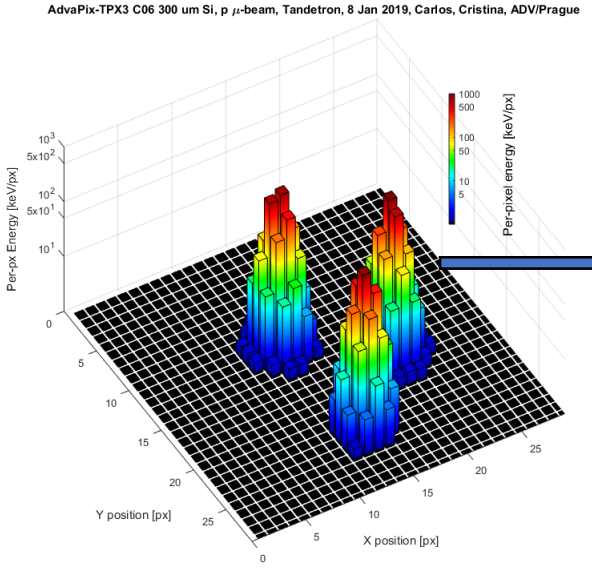
Ion Radiography with pixel detectors Timepix

Detection of heavy charged particles with Timepix → spectrometry, track visualization

3 MeV protons, Tandetron accelerator

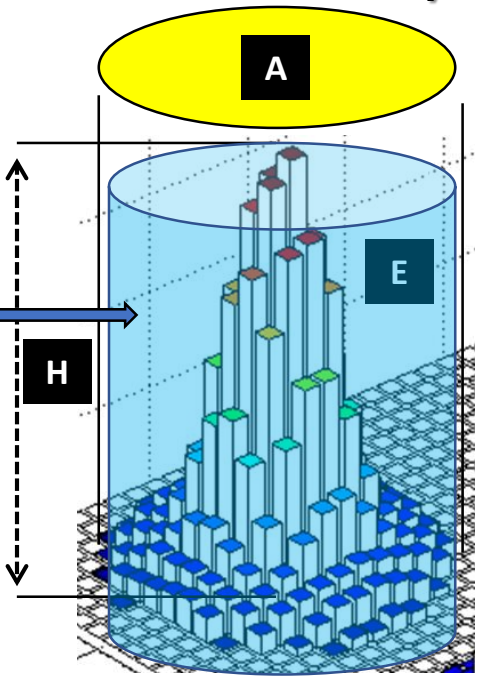


2D visualization



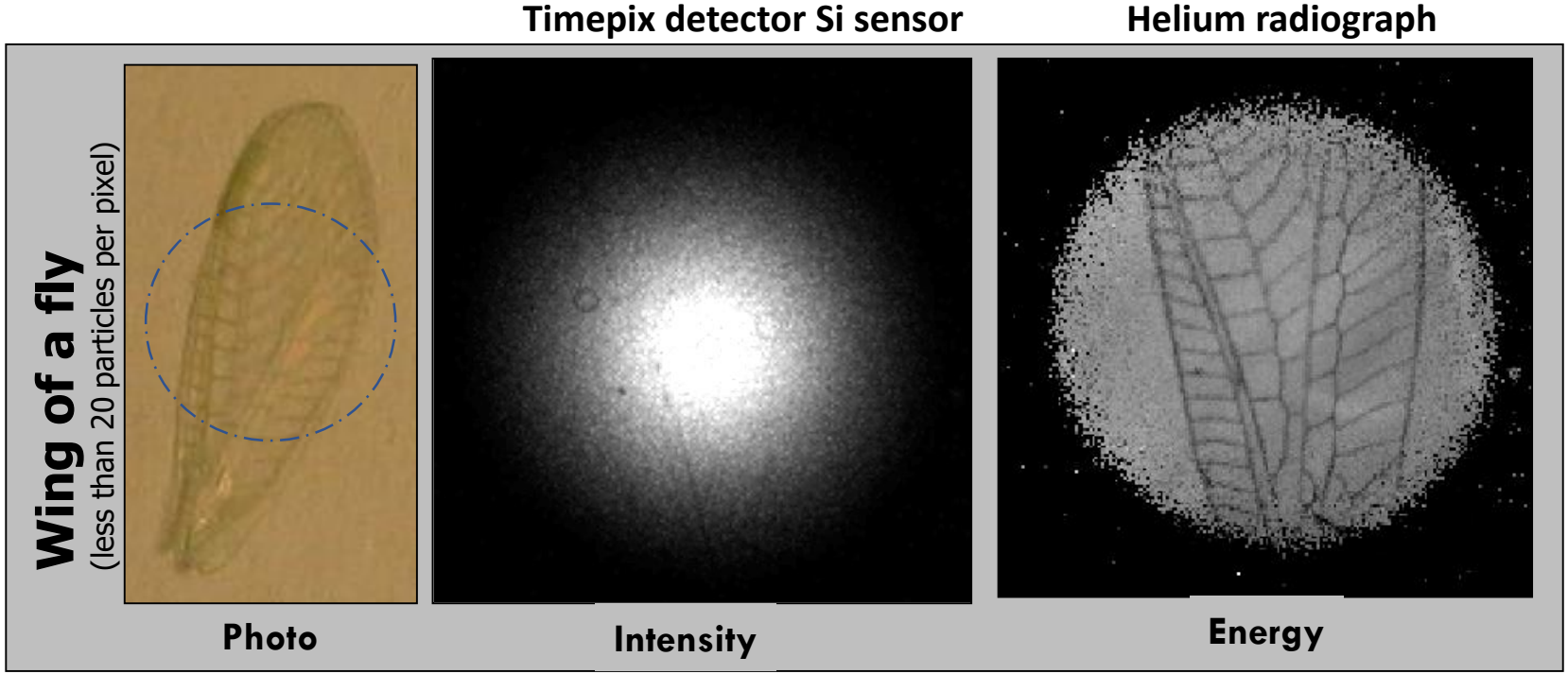
3D visualization

Pixel cluster analysis



Ion Radiography with Timepix detector

Table top setup and radionuclide lab source



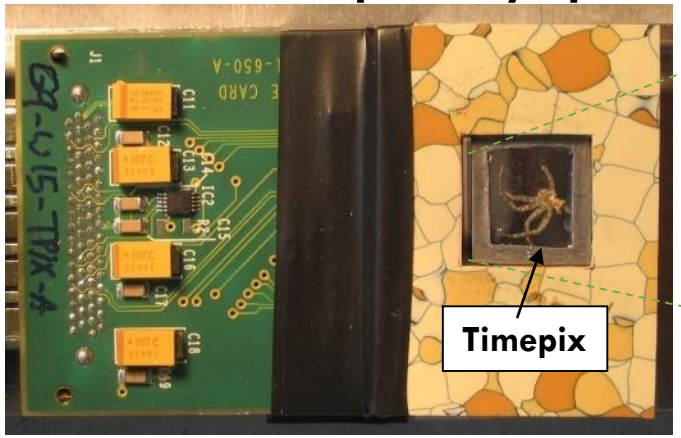
^{4}He, 5.5 MeV in air

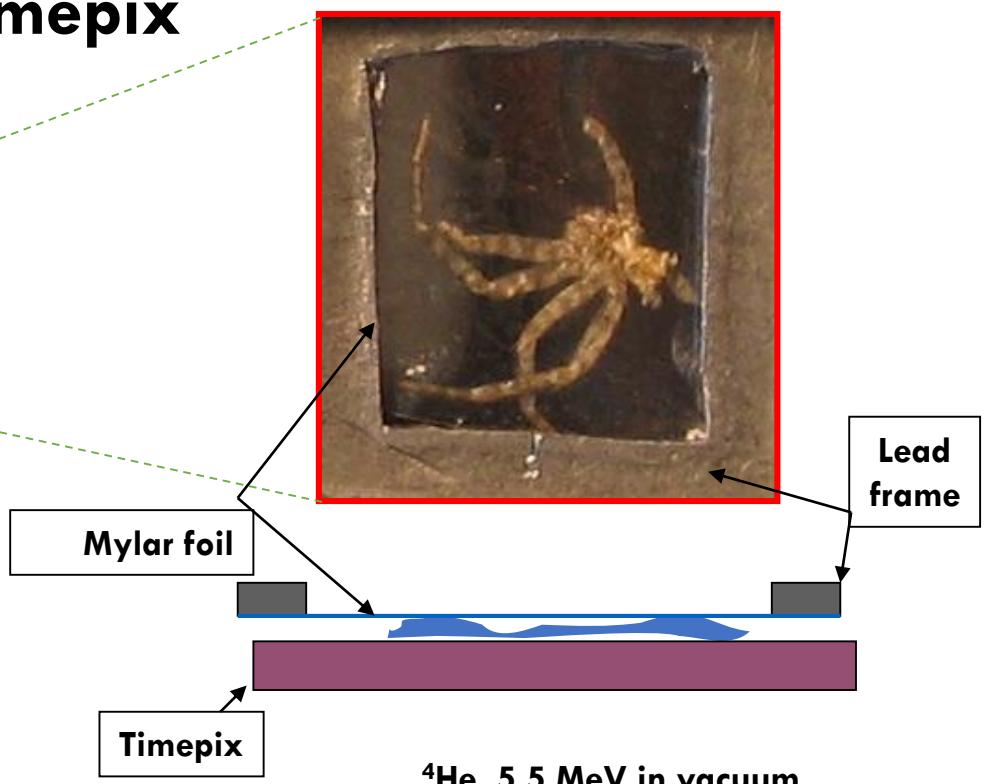
By cluster analysis it can be determined:

- **Centroid** to increase spatial resolution (sub-pixel → µm-scale resolution)

Ion Radiography with Timepix

Soft tissue sample: Dry spider



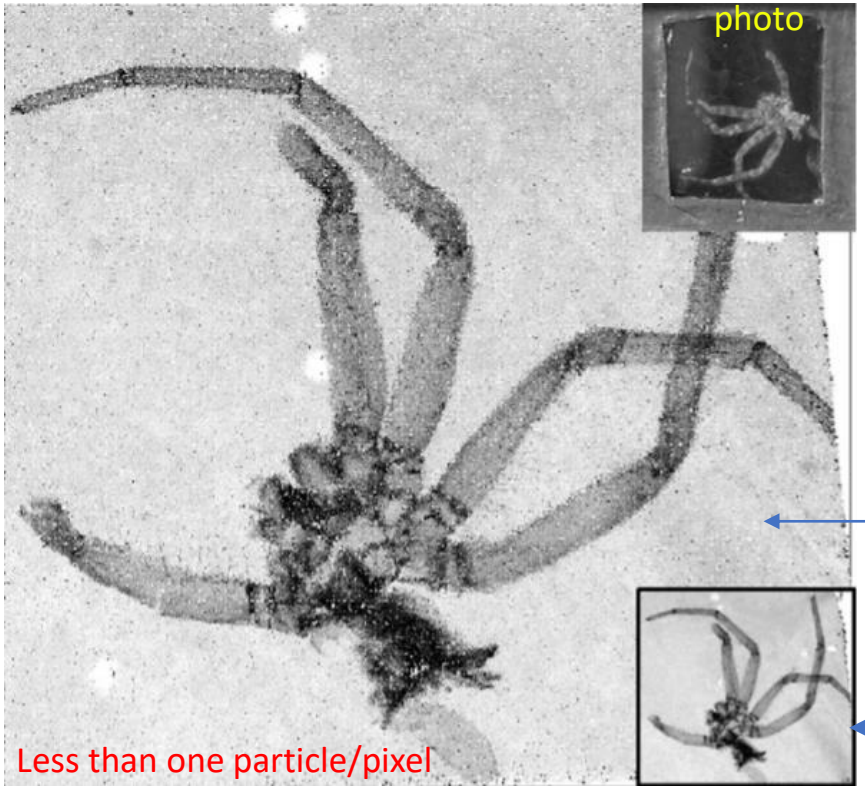


- Skin thickness ≈ µm
- Very weak alpha source ~ 12 particles per frame (1 second), standard ^{241}Am lab source
- 60 000 frames taken
- 750 000 clusters analyzed
- Not enough particles for "deep" sub-pixelization

Ion Radiography with Timepix

Soft tissue sample: Dry spider

J. Jakubek, et al., Pixel Detectors for Imaging with Heavy Charged Particles, Nucl. Instr. and Meth. A 591 (2008) 155-158



^{4}He, 5.5 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.

~0.7 particles per pixel

~ 12 particles per pixel, 65 kpixel image

Proton Radiography: Cluster area

Nuclear Physics Institute of the CAS
public research institution

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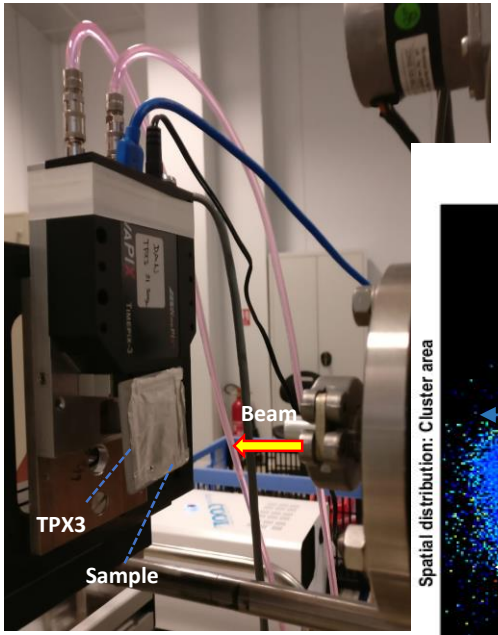
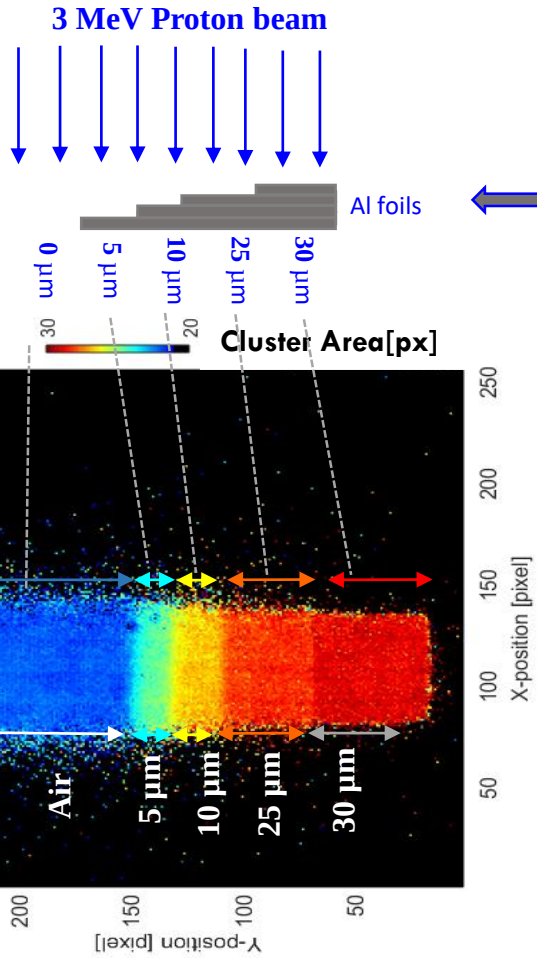
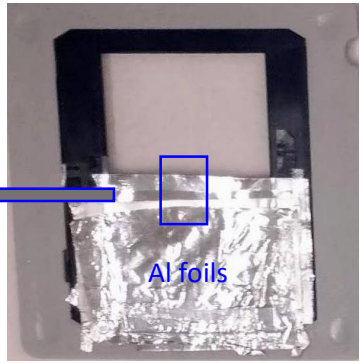
Proton beam, 3 MeV, Tandetron NPI Rez

AdvaPix Timepix3, 300 µm Si sensor

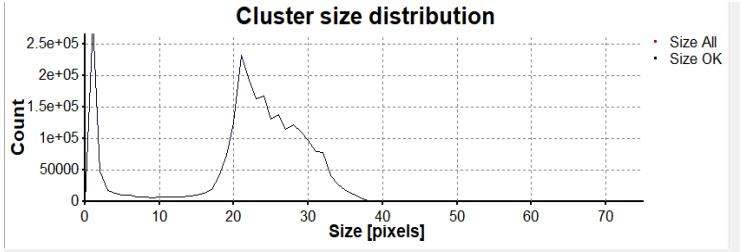




Scanned area:
3 mm x 11 mm



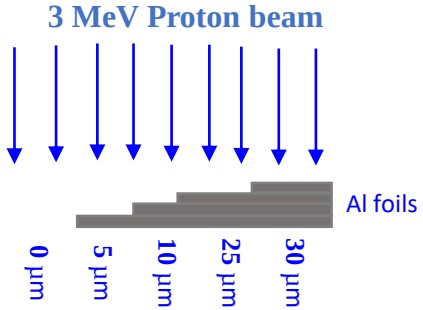
Cluster size distribution



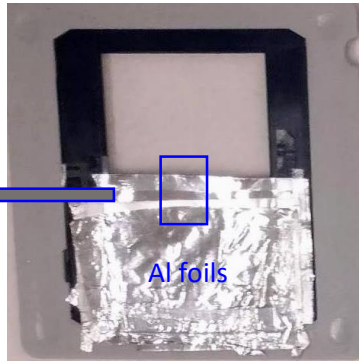
Proton Radiography: Cluster energy

Timepix 3, Si sensor 300 µm

Proton beam, 3 MeV, Tandetron

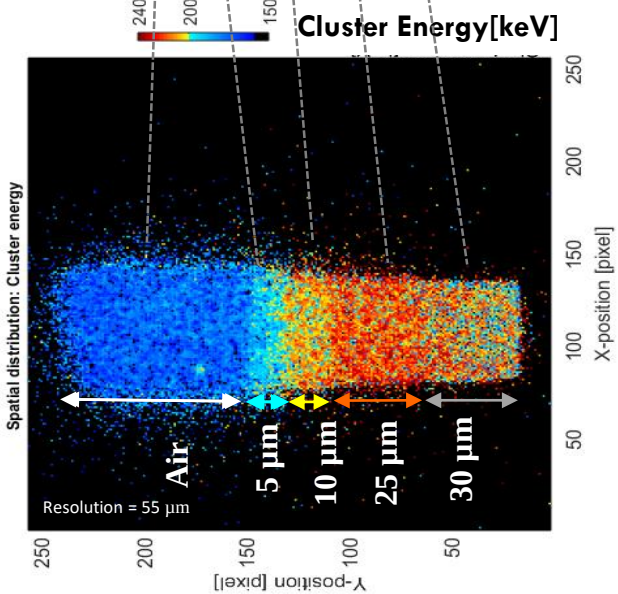


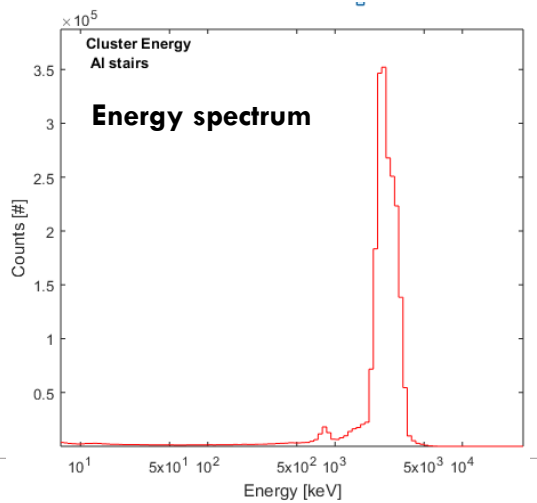
Sample: Al foil stairs

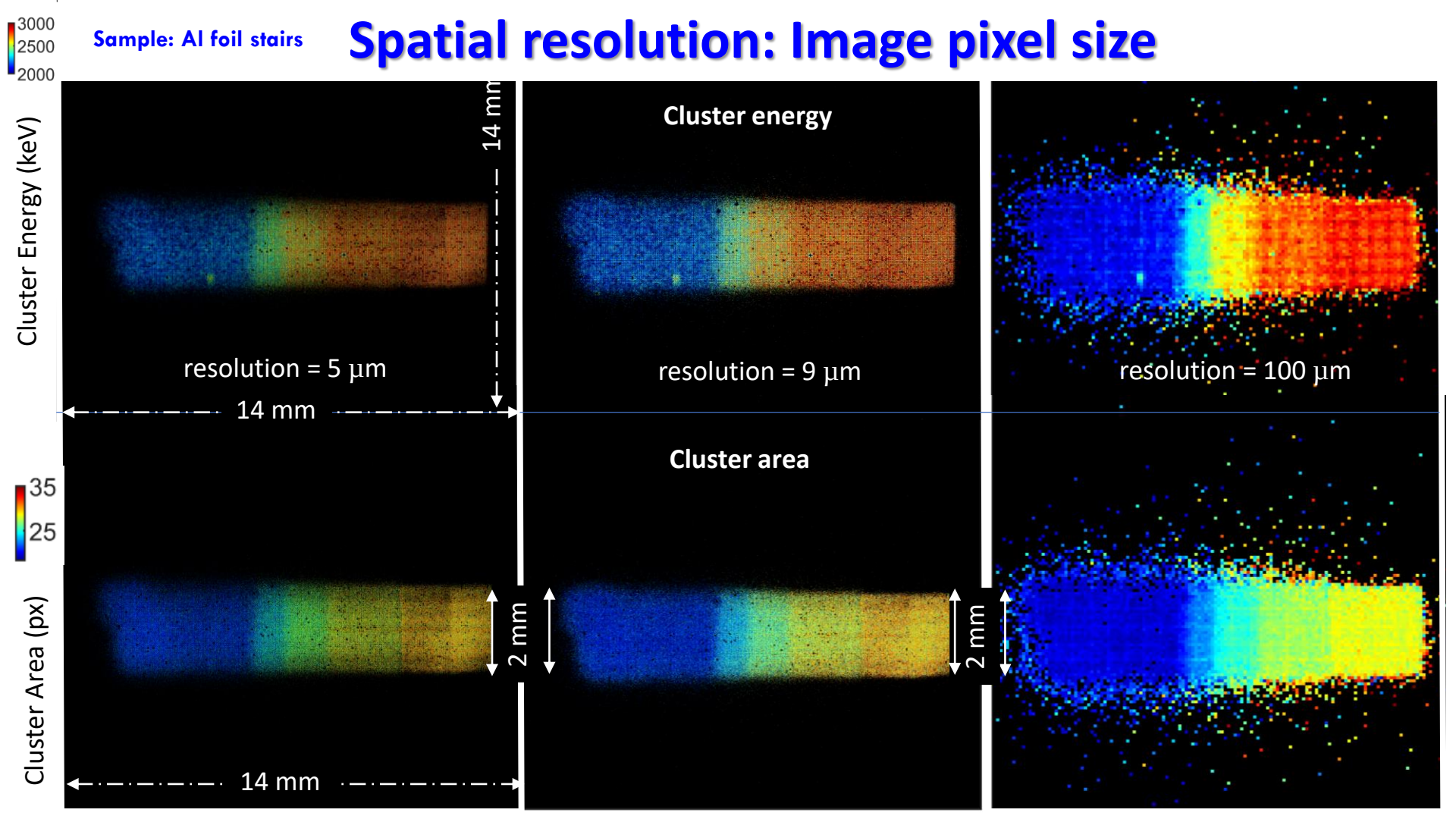


Scanned area:
3 mm x 11 mm

Spatial map of cluster Energy






Sample: Al foil stairs
Spatial resolution: Image pixel size
3000
2500
2000
Cluster Energy (keV)
14 mm
Cluster energy
resolution = 5 µm
14 mm
resolution = 9 µm
resolution = 100 µm
35
25
Cluster Area (px)
Cluster area
2 mm
2 mm
14 mm

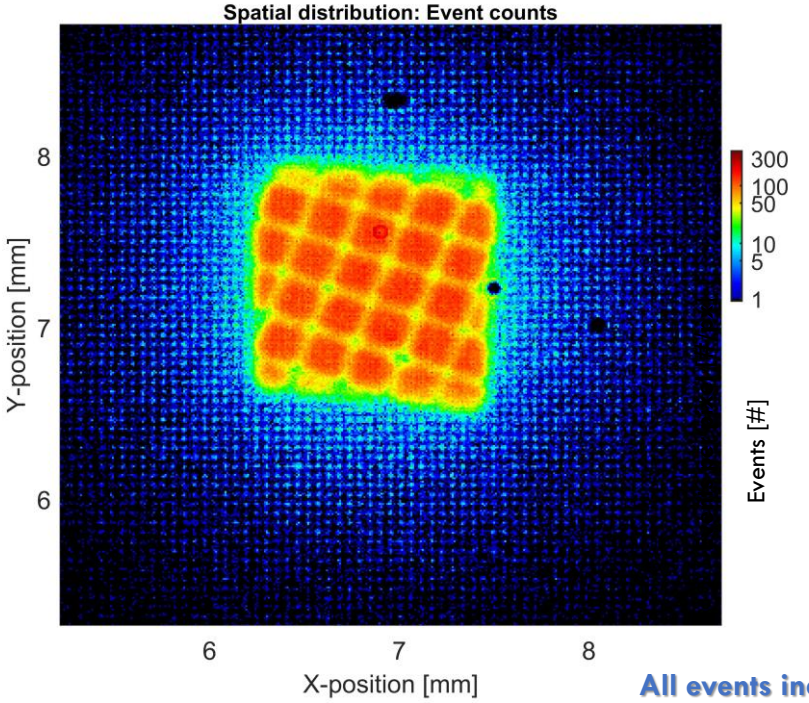
Applications: Proton Radiography

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

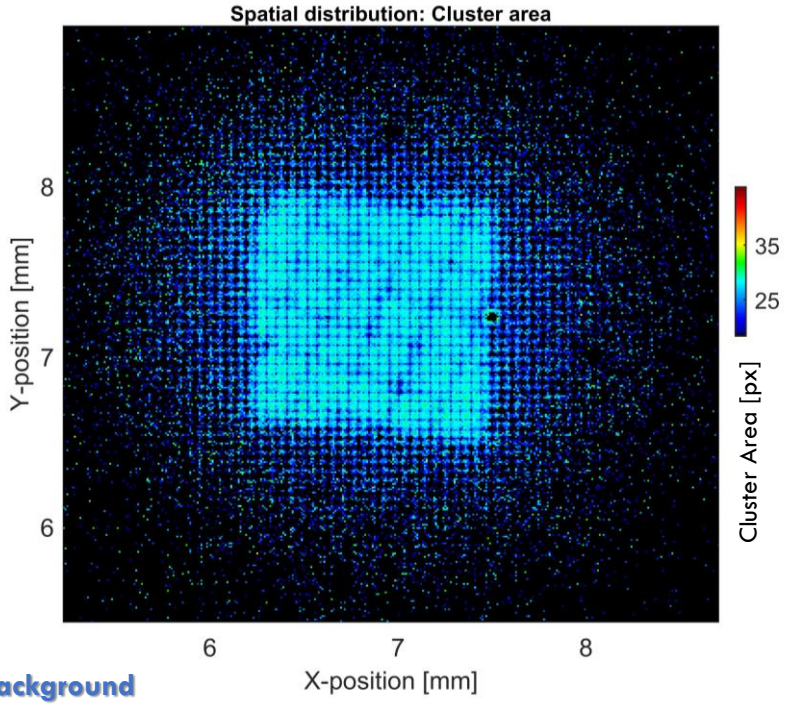
Sample: Metallic grid

Resolution = 10 μm

Event count



Cluster area



All events incl. background

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

- *J. Jakubek, et al., Pixel Detectors for Imaging with Heavy Charged Particles, Nucl. Instr. and Meth. A 591 (2008) 155-158*
- *T. Gehrke, et al., Proof of principle of helium-beam radiography using silicon pixel detectors for energy deposition measurement, identification, and tracking of single ions, Med. Phys. (2018)*

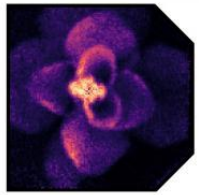
References & Questions at: **cristina.oancea@advacam.com**

Light ion / high energy Helium imaging with Timepix3 telescopes

Single detector setup Timepix, 300 µm Si sensor

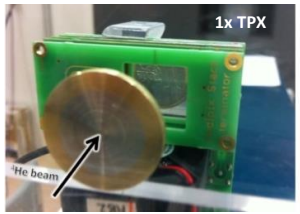
photo

He radiography

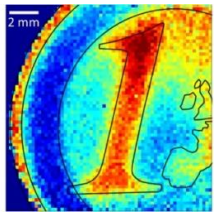


M. Martišíková, DKFZ, Heidelberg
https://medipix.web.cern.ch

photo

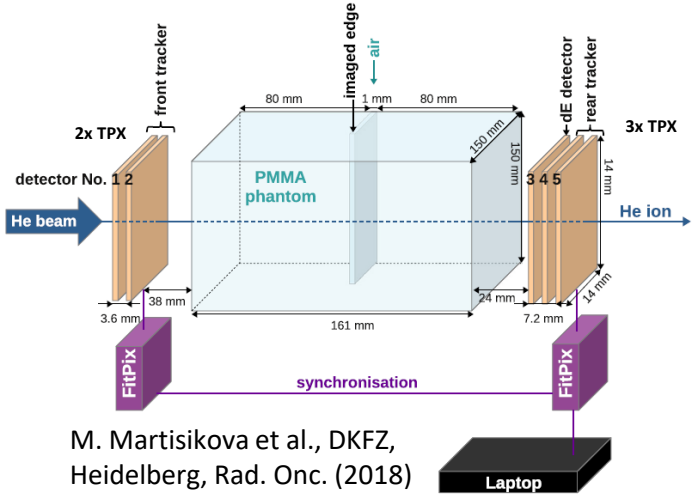


He radiography



M. Martisikova et al., DKFZ, Heidelberg
Physics World, March 2018

Multi-detector / telescope arrays



M. Martisikova et al., DKFZ, Heidelberg, Rad. Onc. (2018)

- *T. Gehrke, et al., Theoretical and experimental comparison of proton and helium-beam radiography using silicon pixel detectors, Physics in Medicine and Biology (2018)*
- *M. Martisikova, T. Gehrke, et al., Helium ion beam imaging for image guided ion radiotherapy, Rad. Oncology 13 (2018) 109*

Backup slides

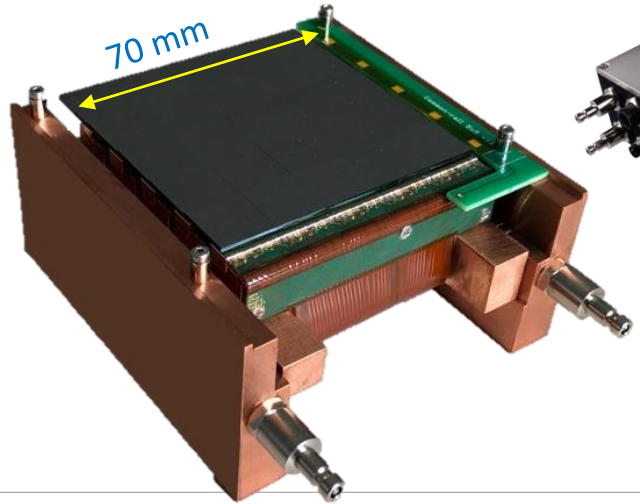
Large area WidePix detectors with CdTe and Si sensors
The large area CdTe imaging detector with continuous sensitivity

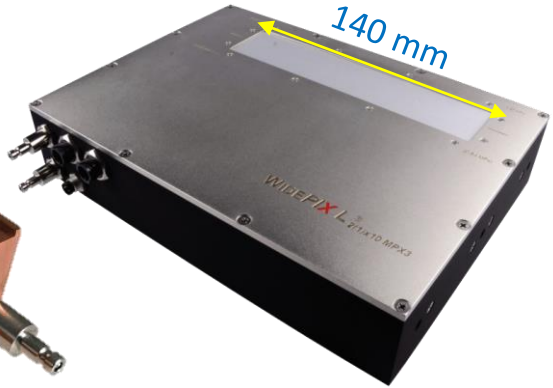
Features:

- 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**:
  - Gaps between modules smaller than quarter of the pixel
  - Edge pixels of 100 µm

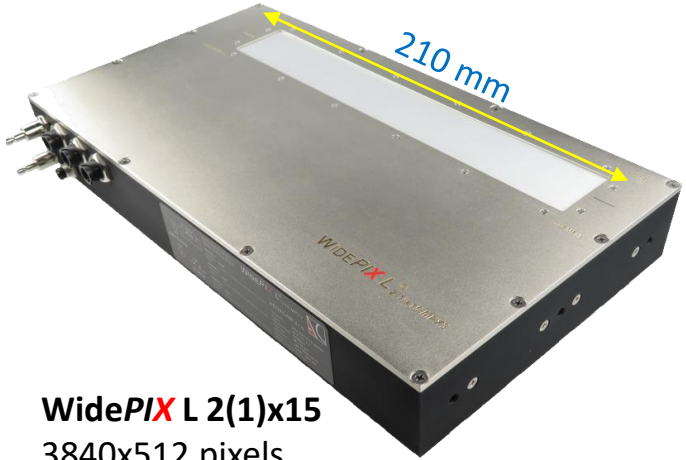
Supported sensor types:
(Bias voltage +/- 500 V)

- **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 Adva*PIX* Time*PIX*3

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

Si 500μm