Spatial Resolution of the Medipix-2 as Neutron Pixel Detector

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Work carried out within the Medipix Collaboration

Outline

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- Principle
- Spatial resolution
- Comparison of Medipix-2 with standard detectors for neutron radiography
- Sample images
- Conclusions

Principle

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Silicon pixel detector can not detect neutrons directly.

$\Rightarrow$ Conversion of thermal neutrons to detectable radiation in a converter layer deposited on the detector surface.

Converter materials:

^{6}Li: $^{6}Li + n \rightarrow \alpha\,(2.05\ MeV) + {}^{3}H\,(2.72\ MeV)$

^{10}B: $^{10}B + n \rightarrow \alpha\,(1.47\ MeV) + {}^{7}Li\,(0.84\ MeV) + \gamma\,(0.48MeV)$ (93.7%)

$^{10}B + n \rightarrow \alpha\,(1.78\ MeV) + {}^{7}Li\,(1.01\ MeV)$ (6.3%)

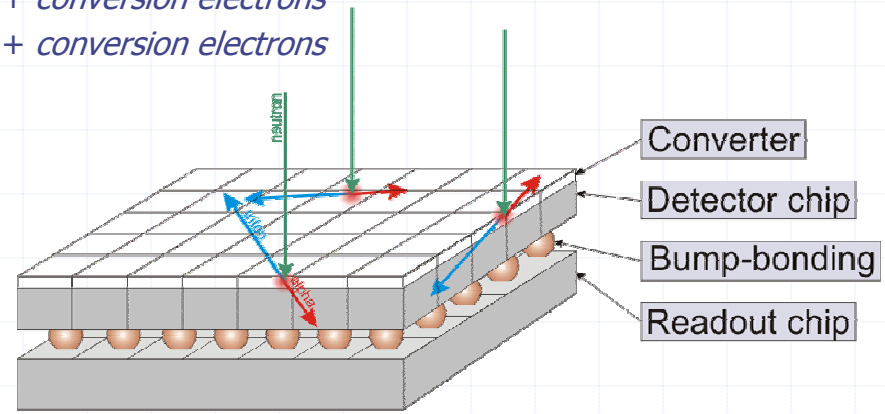
^{113}Cd: $^{113}Cd + n \rightarrow {}^{114}Cd + \gamma\,(0.56MeV)$ + *conversion electrons*

^{155}Gd: $^{155}Gd + n \rightarrow {}^{156}Gd + \gamma\,(0.09, 0.20, 0.30\ MeV)$ + *conversion electrons*

^{157}Gd: $^{155}Gd + n \rightarrow {}^{158}Gd + \gamma\,(0.08, 0.18, 0.28\ MeV)$ + *conversion electrons*

Detector:

300 μm thick silicon pixel detector (pixel size 55 μm) bump bonded to Medipix-2 readout chip.



Beam of Thermal Neutrons

- NEUTRA station of spallation neutron source SINQ in Paul Scherrer Institute, Villigen, Switzerland
  - Intensity about $3 \cdot 10^6$ neutrons/cm^{2}s at proton accelerator current of 1mA and proton energy of 590 MeV
  - Beam Cross section: 40 cm in diameter
- Horizontal channel of the LVR-15 nuclear research reactor at Nuclear Physics Institute of the Czech Academy of Sciences at Rez near Prague.
  - Intensity is about 10^7 neutrons/cm^{2}s (at reactor power of 8MW)
  - Beam Cross section: 4 mm (height) x 60 mm (width)
  - The divergence of the neutron beam is < 0.5°

^{6}LiF converter

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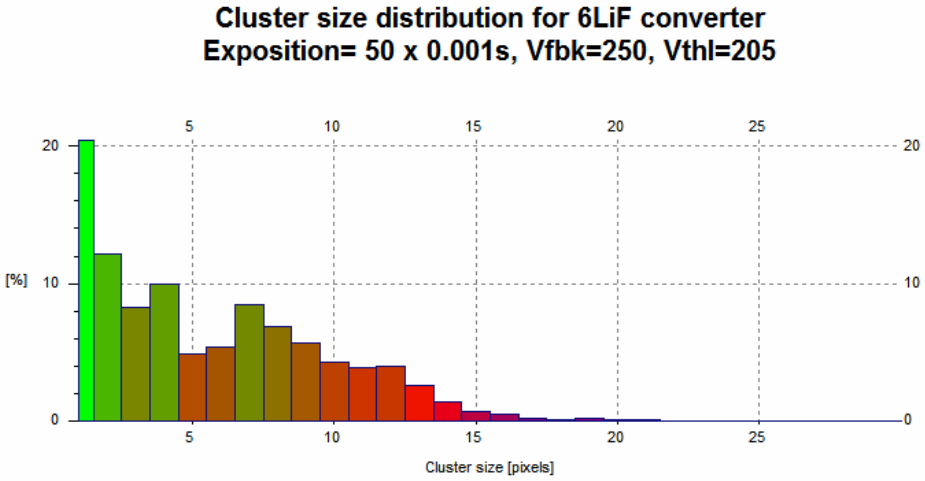
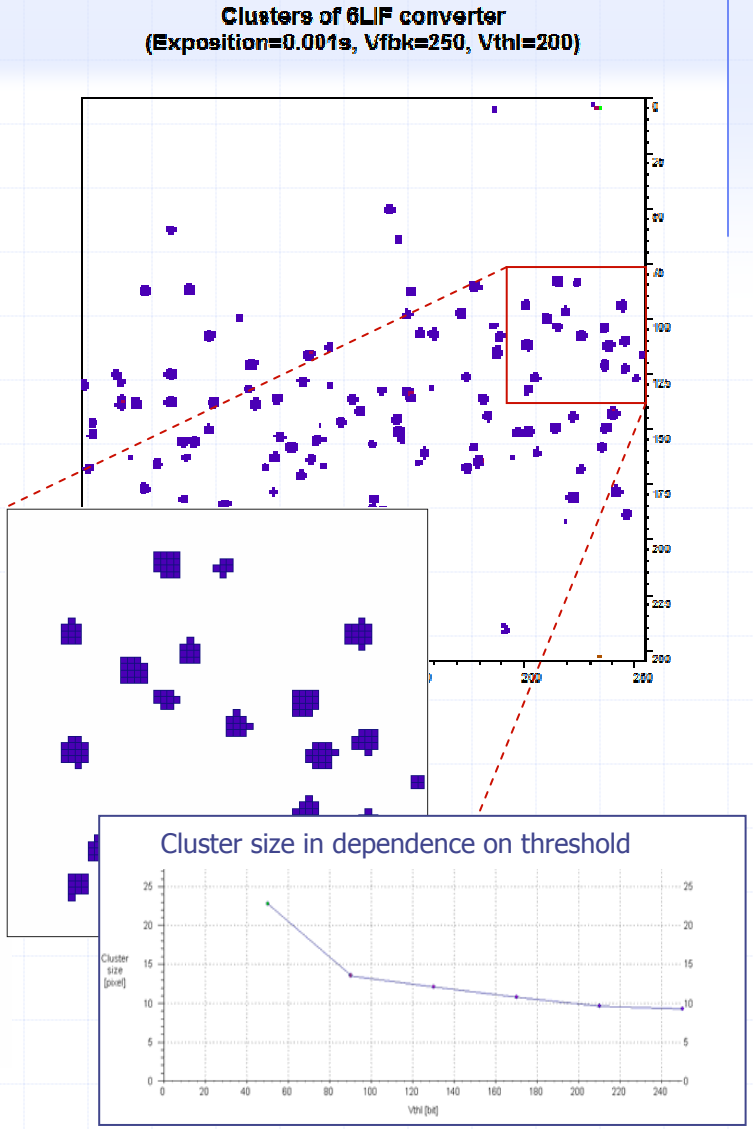
- High energy of alpha particles and tritons is deposited near detector surface => charge sharing is significant.
- Each hit creates signal in cluster of pixels.
- Cluster size limits spatial resolution in integrating regime.
- Cluster size can be decreased by high threshold at the expense of efficiency.
- Using event-by-event acquisition and finding centroids of clusters it is possible to reach subpixel spatial resolution (approximately half of pixel) – unusable with current readout system.





^{6}LiF converter
Spatial resolution – Edge response

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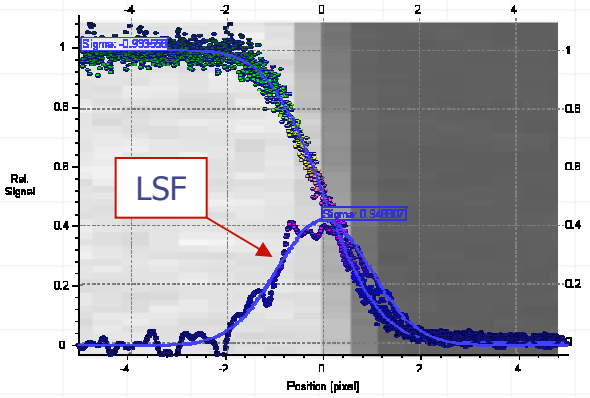
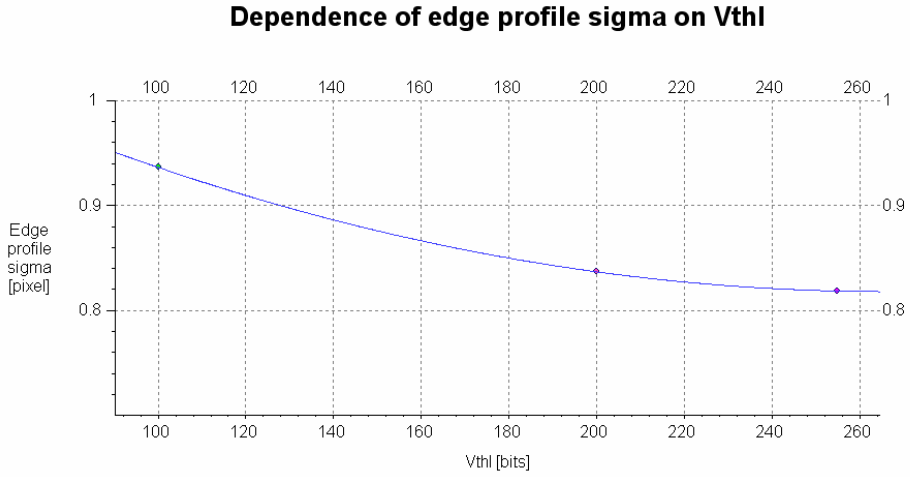
Tilted cadmium edge profile



Fit by ERF: σ=0.83 pixel
=> LSF FWHM=107 μm

Spatial resolution is limited by size of clusters and range of product particles in silicon (R_{Triton}=44μm, R_{α}=8.9μm)

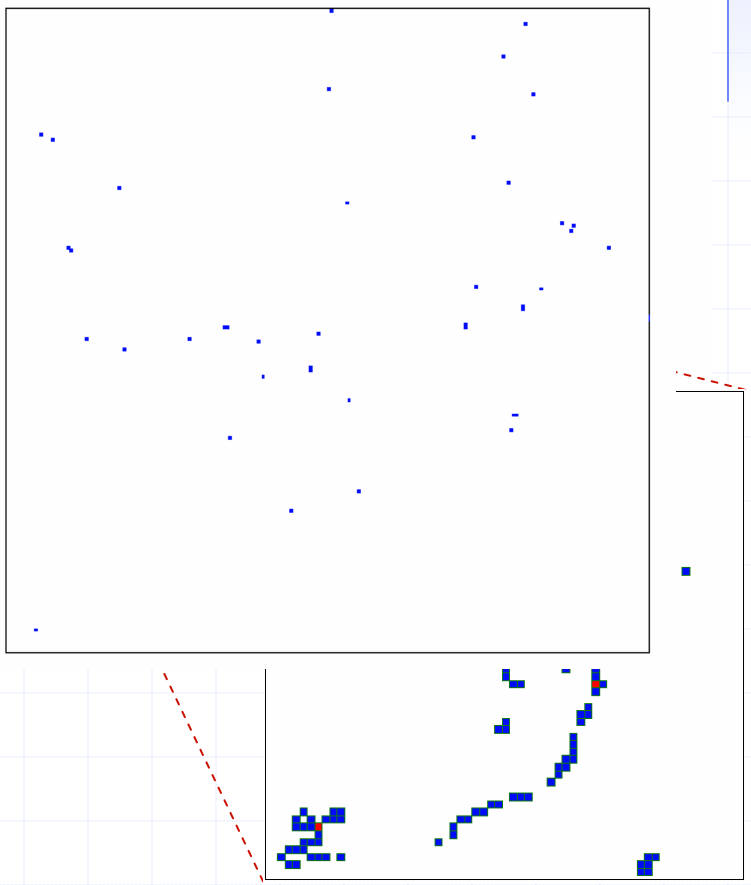
Edge blurring is caused by clusters => Spatial resolution is dependent on the threshold level



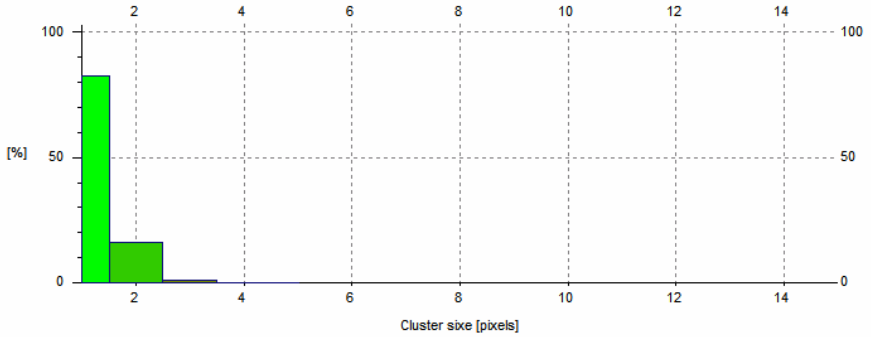
Amorphous ^{10}B converter

- Energy of heavy charged particles is lower then in case of ^{6}Li converter => smaller clusters are produced.
- Conversion electrons are emitted => electron tracks are present. Spatial resolution is deteriorated by electron tracks.
- Energy of conversion electrons is lower then energy of heavy particles => electron tracks can be suppressed by suitable threshold selection.

Clusters of 10B converter
(Exposition=0.001s, Vfbk=200, Vthl=200)



Cluster size distribution for 10B converter
Exposition= 50 x 0.001s, Vfbk=200, Vthl=200



^{10}B converter
Spatial resolution – Edge response

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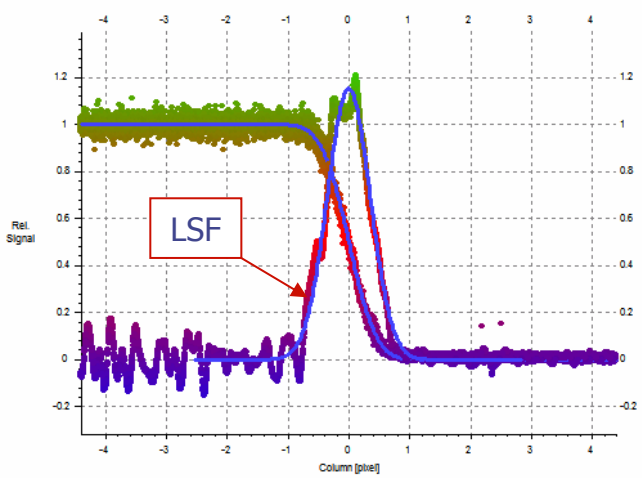
Tilted cadmium edge profile



Fit by ERF: σ=0.35 pixel
=> LSF FWHM=45 μm

Heavy charged particles emitted by ^{10}B converter after neutron capture have lower ranges then in case of ^{6}Li: R_{Li}=3μm/2.7μm, R_{α}=5.4μm/5.2μm.

$\Rightarrow$ Spatial resolution is better

But lower number of particles can penetrate to depleted volume of the detector so

$\Rightarrow$ Efficiency is lower (2 times)

^{113}Cd converter

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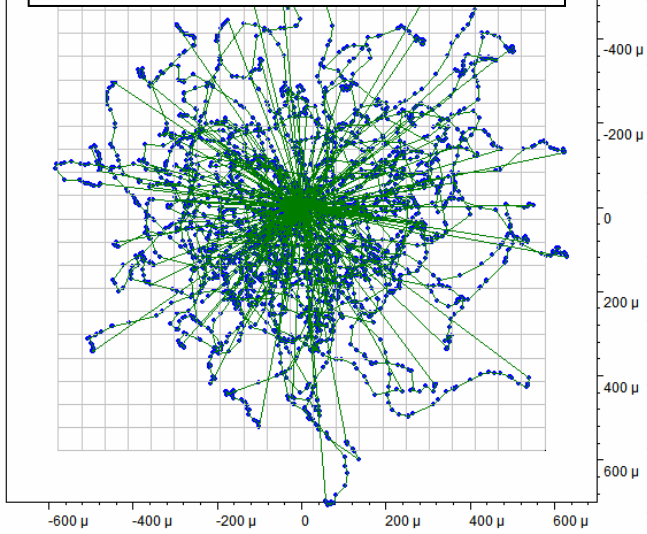
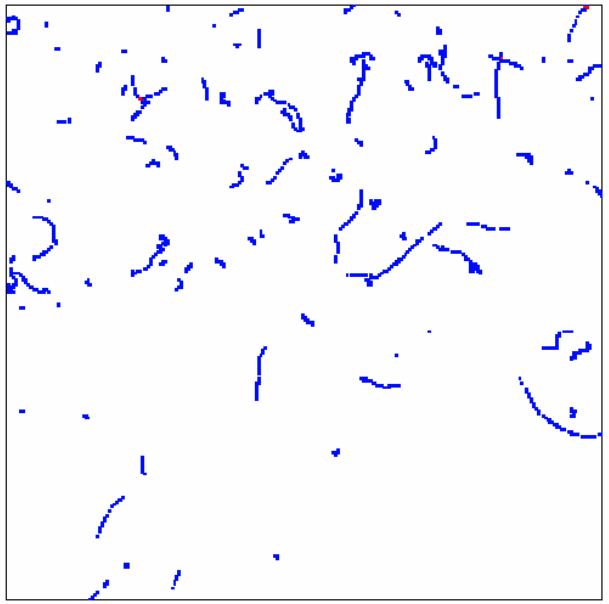
- Only conversion electrons are detectable by medipix
- Resolution highly deteriorated
- Using event-by-event acquisition and robust track analyzing algorithm it is probably possible to increase resolution.

Simulation of electron interactions in Si in MCNP



Tracks from 113Cd converter
Exposition=0.001s, Vfbk=250, Vthl=200



^{113}Cd converter
Spatial resolution – Edge response

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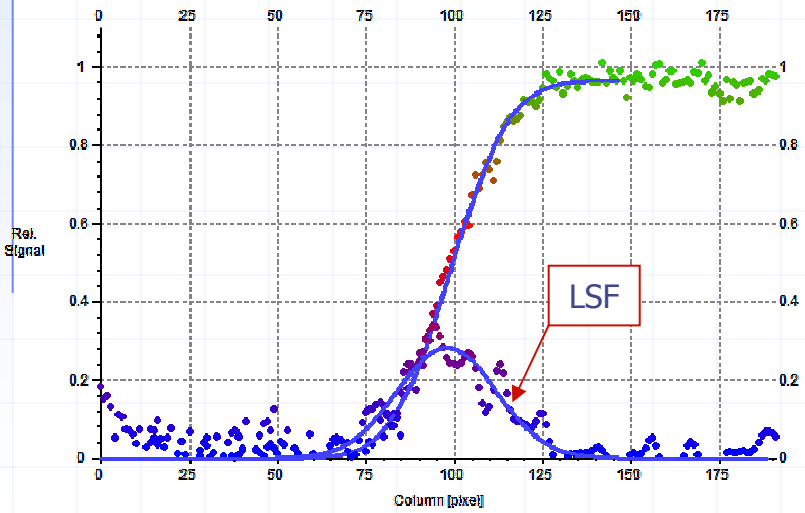
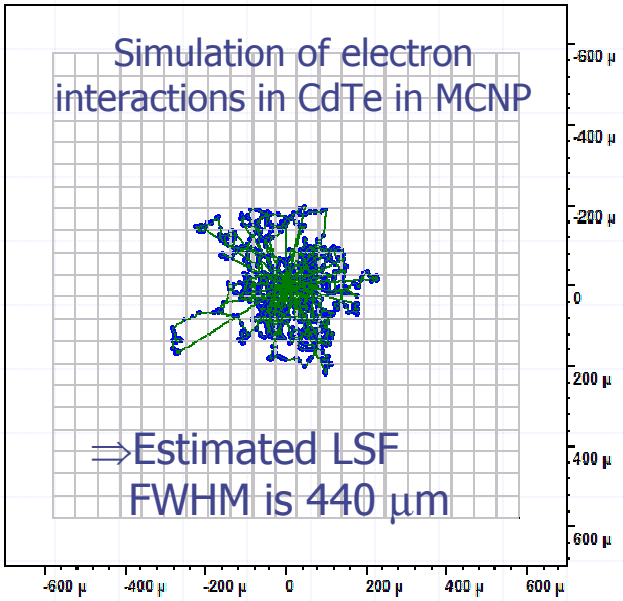
Tilted cadmium edge profile



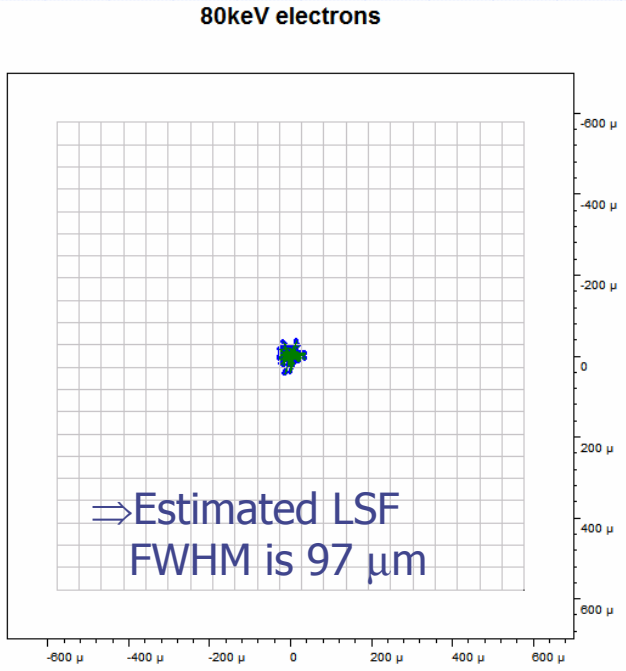
Fit by ERF: σ=13.1 pixel
=> LSF **FWHM=1.7 mm**

^{113}Cd as converter in combination with Si detector is not good choice for possition sensitive detection of neutrons. But thanks to the large cross section it can reach very good detection efficiency especially in case of **CdTe detectors**.



Gadolinium converter

- Medipix can detect conversion electrons and very small part of 90keV gammas
- Gadolinium was not available for us => only simulations done



The most probable is emission of 80keV electrons (~60%)

⇒Spatial resolution is estimated at 97 μm

⇒MTF will be degraded at low frequencies by more energetic electrons.

Comparison of Medipix-2 with other neutron imaging detectors

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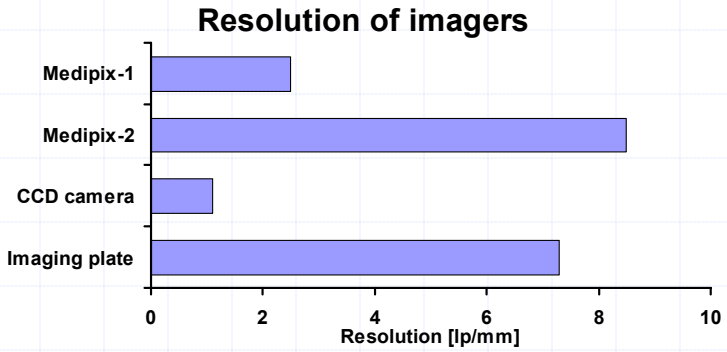
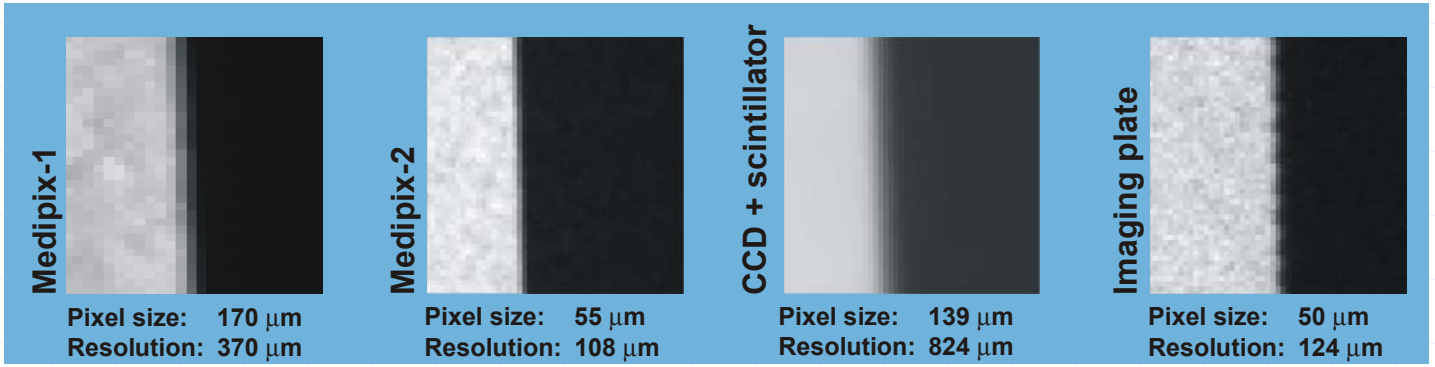
Tested:

- **CCD camera** with scintilator containing ^{6}Li (pixel size 0.139 mm)
- **Imaging plate** (excitation by neutrons, deexcitation by laser scanner followed by light emission, scanner pixel size 50μm)

Imager	Resolution (FWHM[1] of LSF[2]) [μm]	Resolution[3] [lp/mm]
Medipix-1 device	370	2.5
Medipix-2 device	108	8.5
CCD camera	824	1.1
Imaging plate	124	7.3





Sample objects – Blank cartridge

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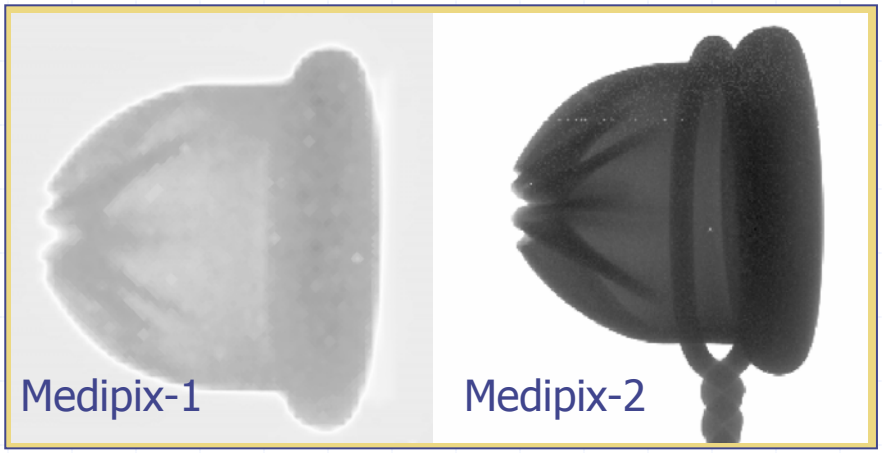
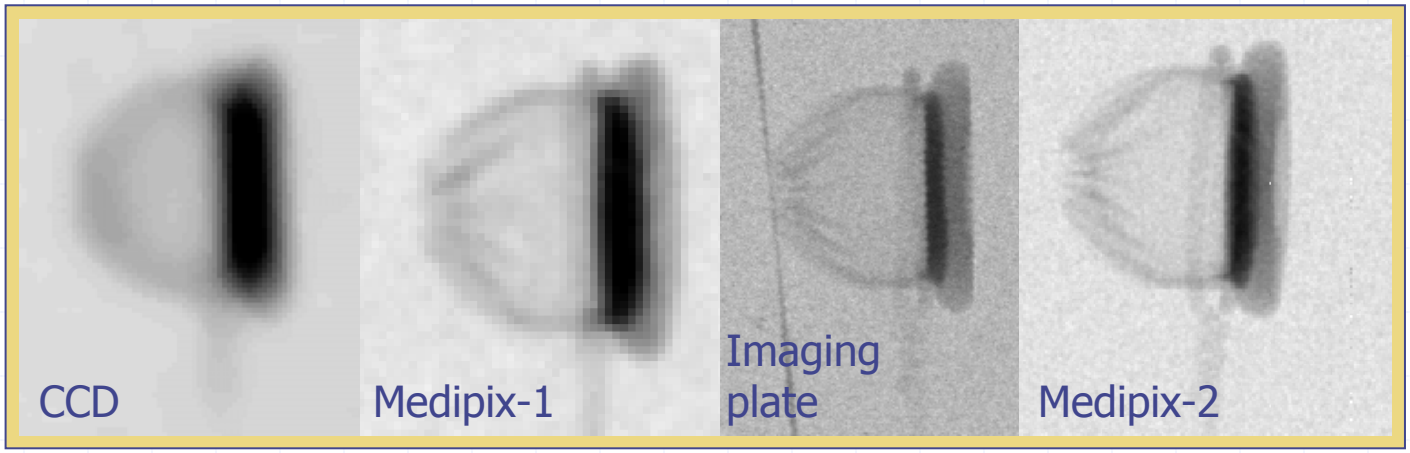
Roentgenography



Neutronography



Sample objects – Ground Beetle

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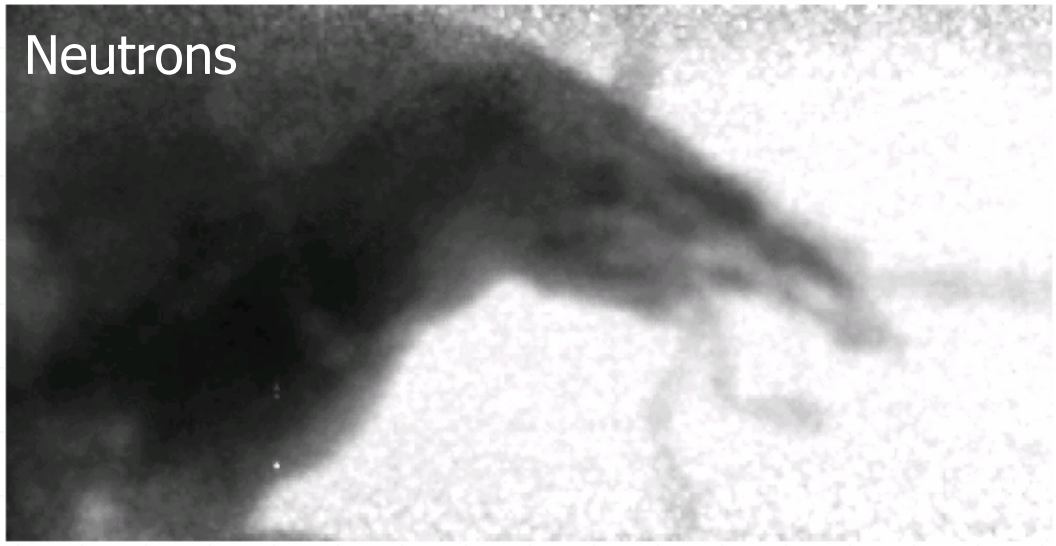
Neutrons shows soft tissue,
While X-rays armor



Sample objects – Fishing line

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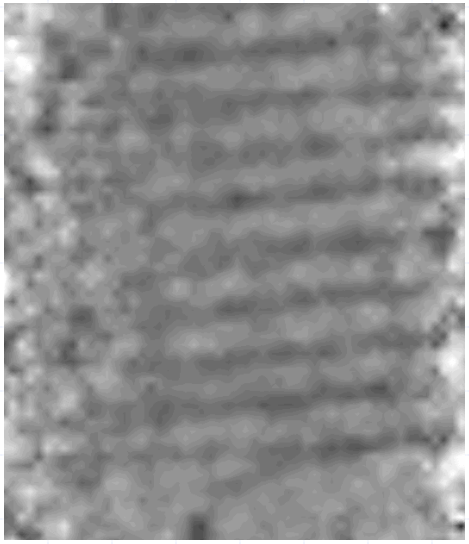
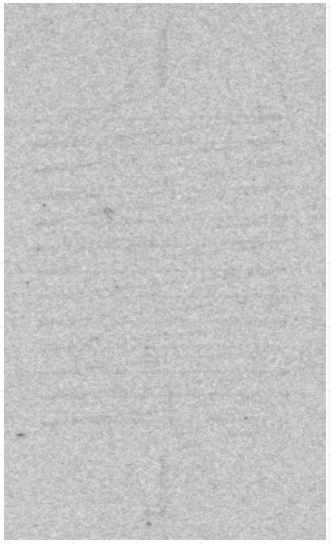
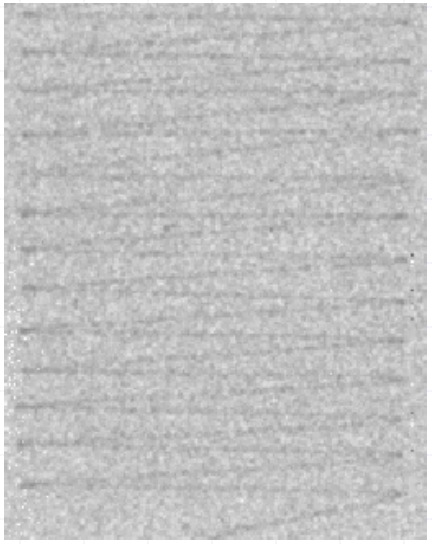
Fishing line of 100 μm diameter



Medipix-1



Imaging plate



Medipix-2

Conclusion

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- Several types of converter material were examined from point of view of spatial resolution. Best results gives ^{10}B and ^{6}Li.
- The performance of the imager was compared with several types of contemporary neutron imaging systems (Medipix-1, CCD camera, imaging plates). The results demonstrate superior properties of the Medipix-2 based neutron imager in terms of spatial resolution, linearity and dynamic range.
- After hardware interface adaptation, method of event-by-event readout with cluster centroids evaluation will lead to significant increase of spatial resolution.

Imager	Resolution (FWHM[1] of LSF[2]) [μm]	Resolution[3] [lp/mm]
Medipix-1 device	370	2.5
Medipix-2 device	108	8.5
CCD camera	824	1.1
Imaging plate	124	7.3

Medipix2 – "spectroscopic" pixel detector

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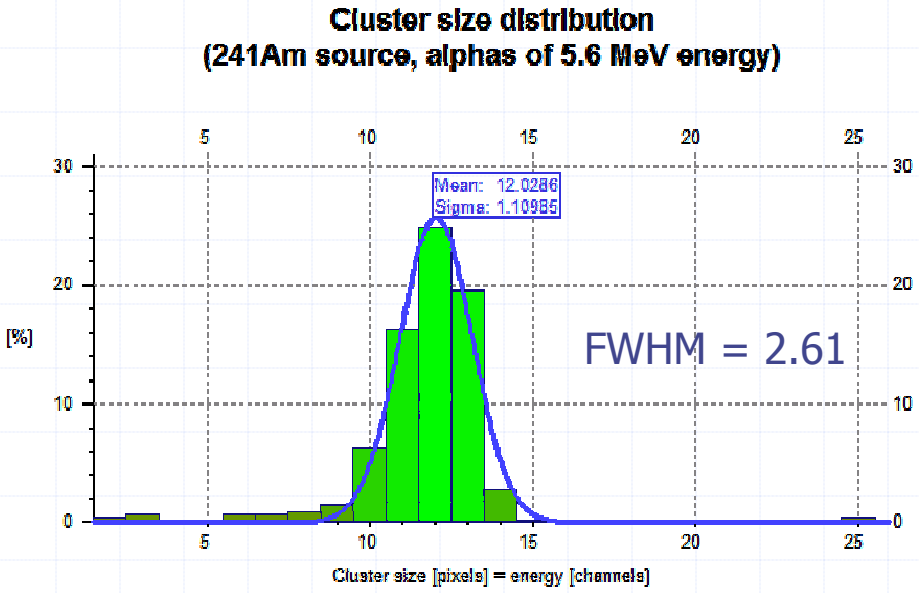
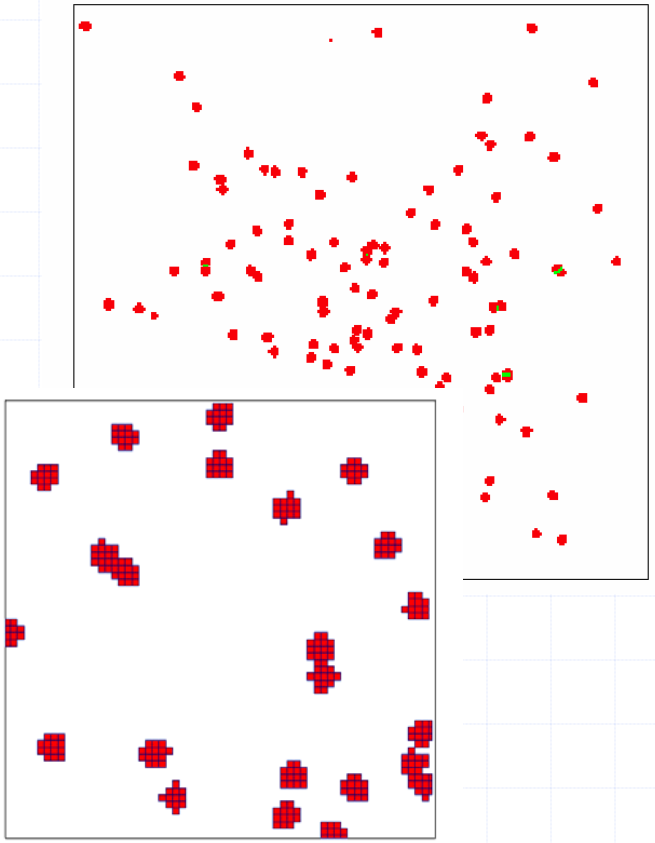
- Medipix-2 without converter layer
- Alpha particles: 5.6 MeV (^{241}Am)
- Short exposition time





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Any questions ?