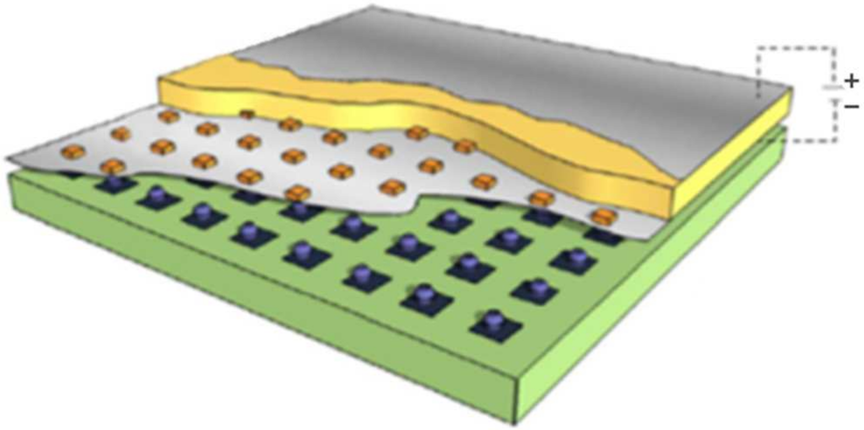

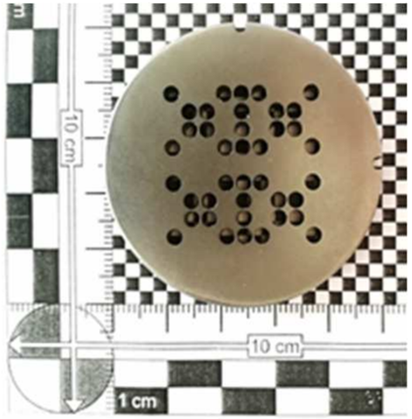

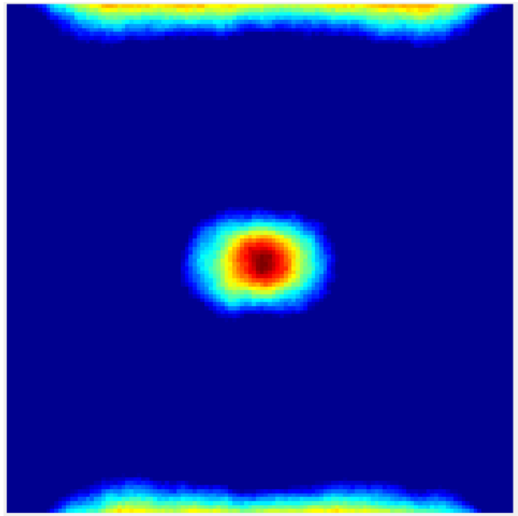

DEVELOPMENT OF PIXELATED DIAMOND FOR A PORTABLE NEUTRON IMAGER

LYNDE Clément | 6th ADAMAS Workshop | 27th November 2017

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(3) INSTITUT PLURIDISCIPLINAIRE HUBERT CURIEN/IN2P3/CNRS, STRASBOURG, FRANCE
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(5) CEA, DEN, 13115 SAINT-PAUL-LEZ-DURANCE, FRANCE

SUMMARY

1. CONTEXT
2. CODED-APERTURE IMAGING
3. WHY TIMEPIX ?
4. WHY DIAMOND ?
5. SIMULATED NEUTRON IMAGER
6. CONCLUSIONS

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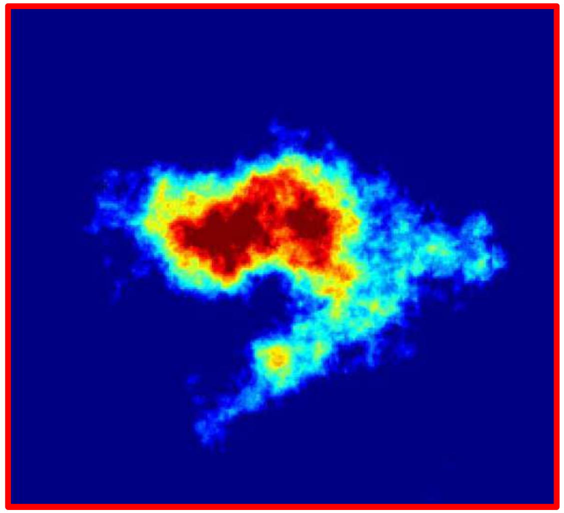
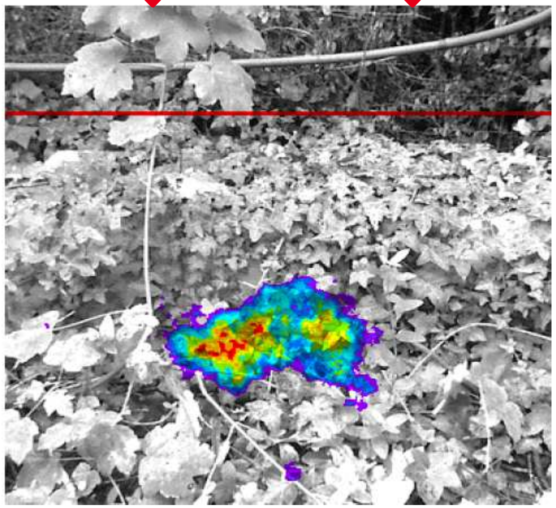
RADIATION IMAGING PRINCIPLE

Visible image



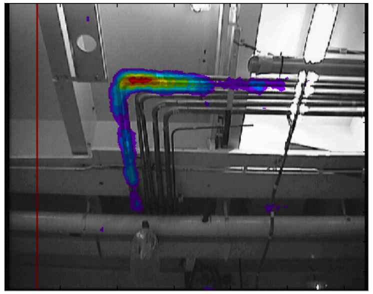
Radiation image

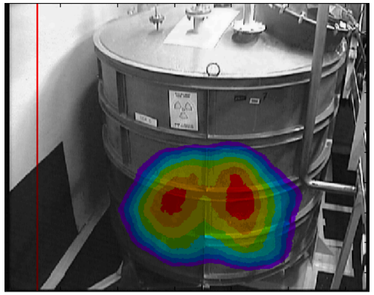
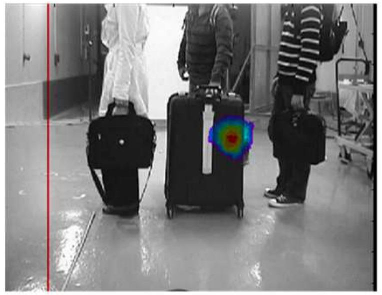


Superimposition of the two images

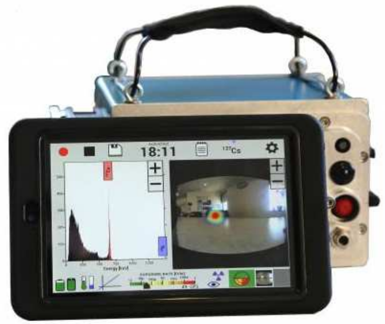
STAKE OF RADIOACTIVE HOT SPOT LOCALIZATION

- **Nuclear industry and Homeland Security applications**
  - Decommissioning, waste management and radiation protection
  - Non-proliferation of nuclear material



- **Gamma imaging systems are currently available at a industrial level: iPIX, ASTROCAM 7000HS, H-Polaris**

CHALLENGE FOR NEUTRON IMAGING

- **Use of the neutron signature :**
  - Make up for some limitations of gamma imaging (presence of gamma shield)

- **Neutron imaging still under investigation :**
  - Efficiency or portability improvements are still required for direct applications in nuclear industry

- **Some limitations formed strong technological challenges :**
  - Compactness
  - Exposure time

➢ **My PhD project**

Development of a portable neutron imager

SUMMARY

1. CONTEXT
2. CODED-APERTURE IMAGING
3. WHY TIMEPIX ?
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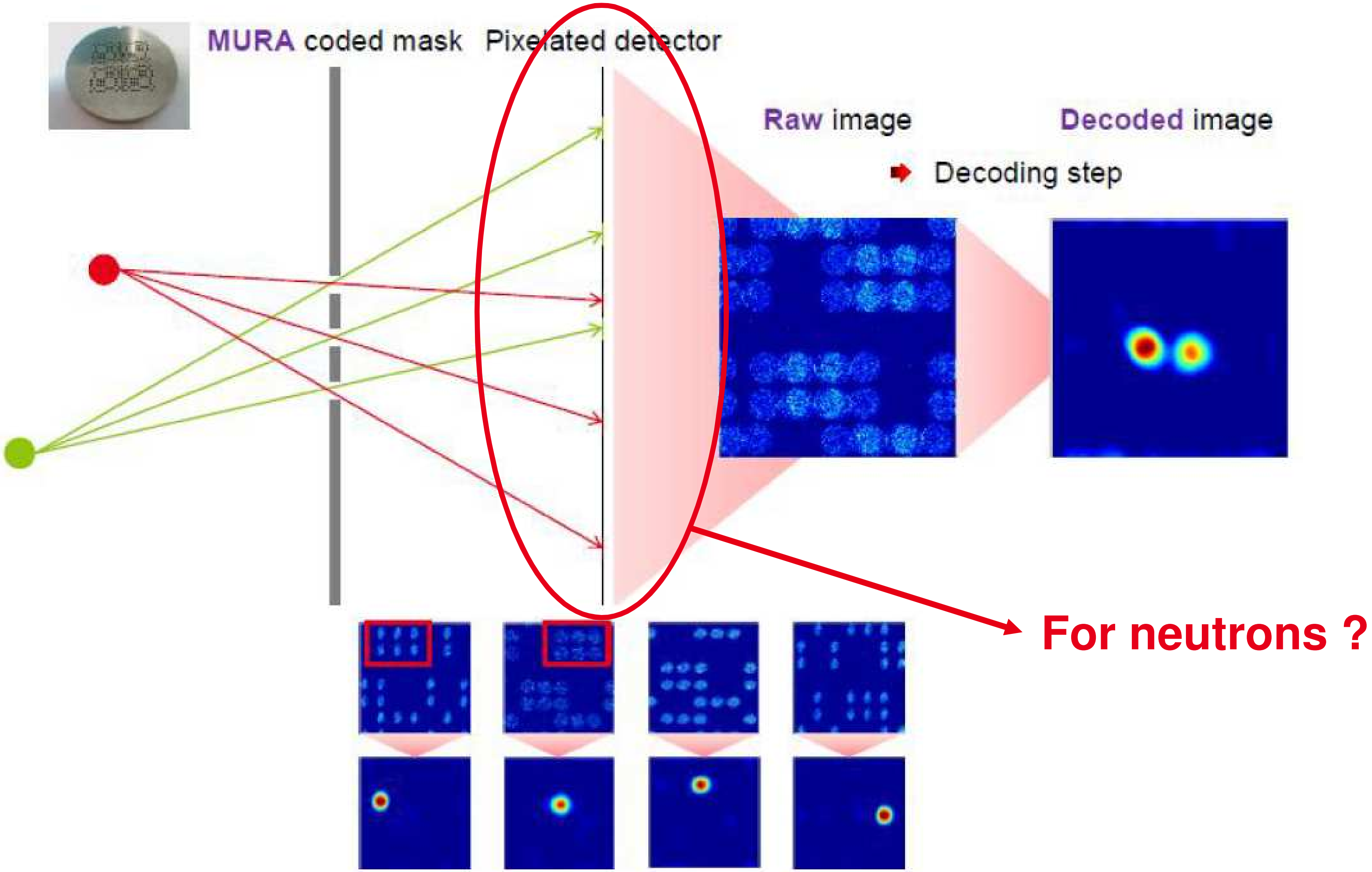
SELECTED LOCALIZATION APPROACH

Principle of coded-aperture imaging

Encoding of the fast neutron emission thanks to coded mask



ONE OF THE SELECTED NEUTRON DETECTOR

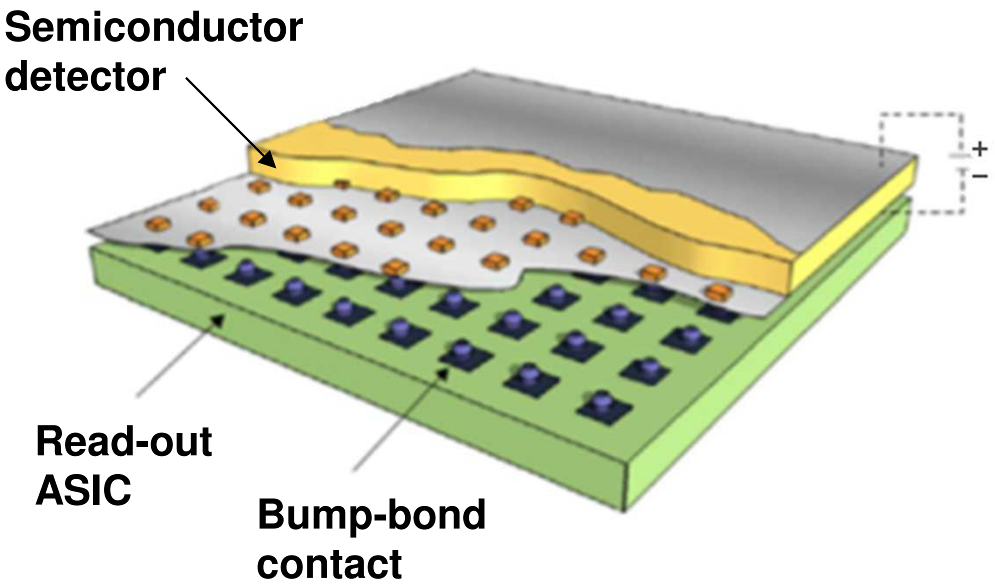
Timepix

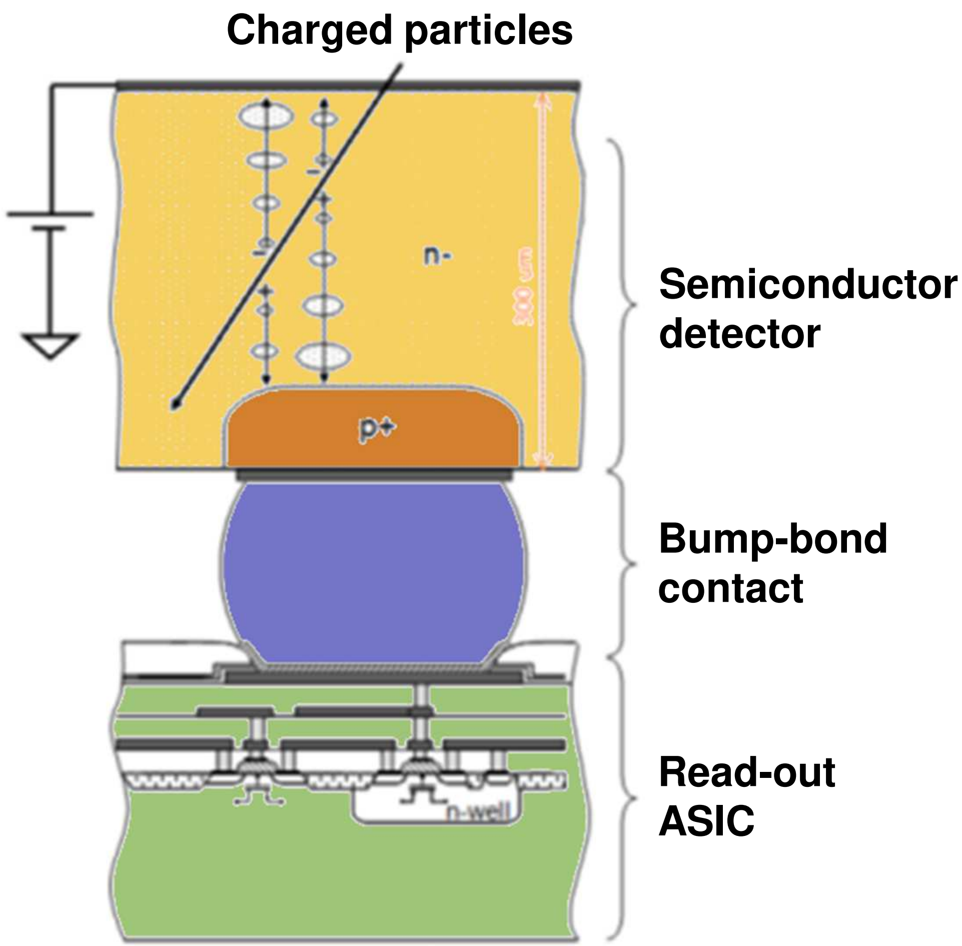
Diamond

Neutron pixelated detector

SUMMARY

DESCRIPTION OF TIMEPIX





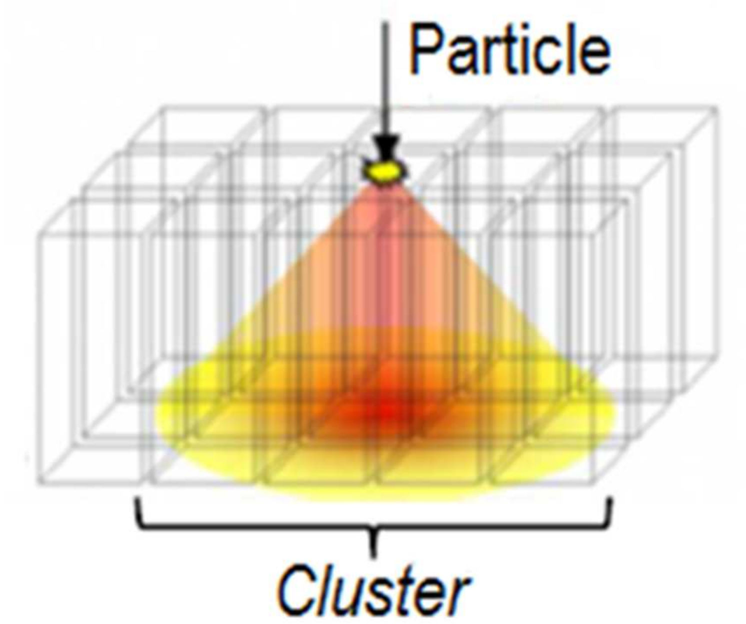
Modified schemas based on C. Granja *et al.*, Planetary and Space Science, Volume 125, June 2016, Pages 114-129

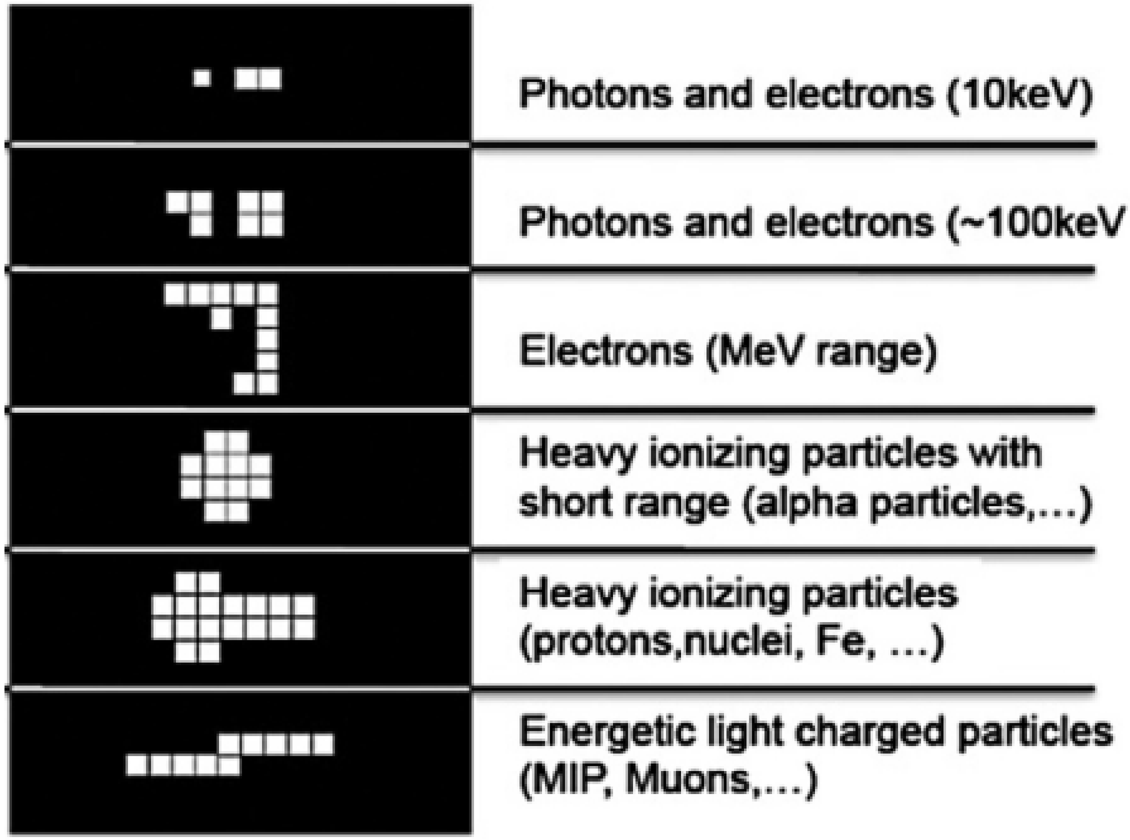
- Semiconductor detector
- 256 × 256 pixels

- ➢ Signal induced by charged particles
- ➢ Localization of the interaction

CHARGED PARTICLES IDENTIFICATION WITH TIMEPIX

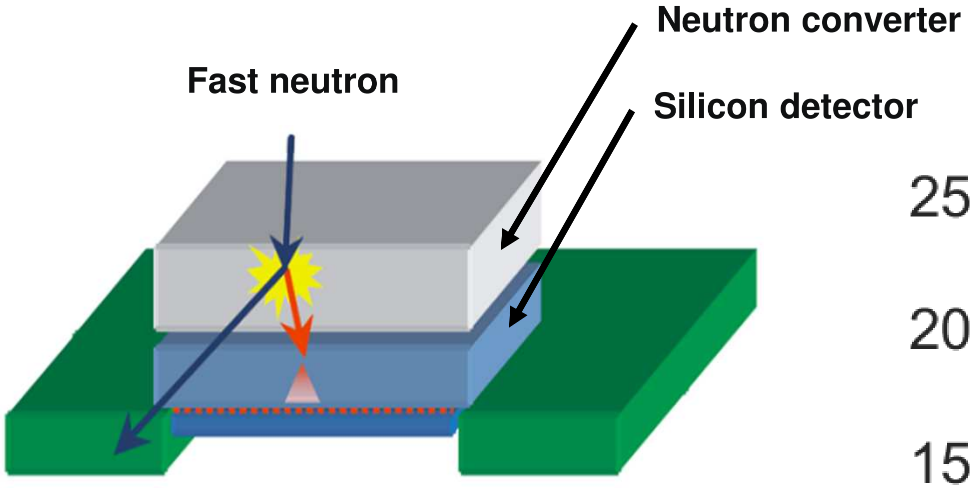
Based on pattern of clusters and deposited energy





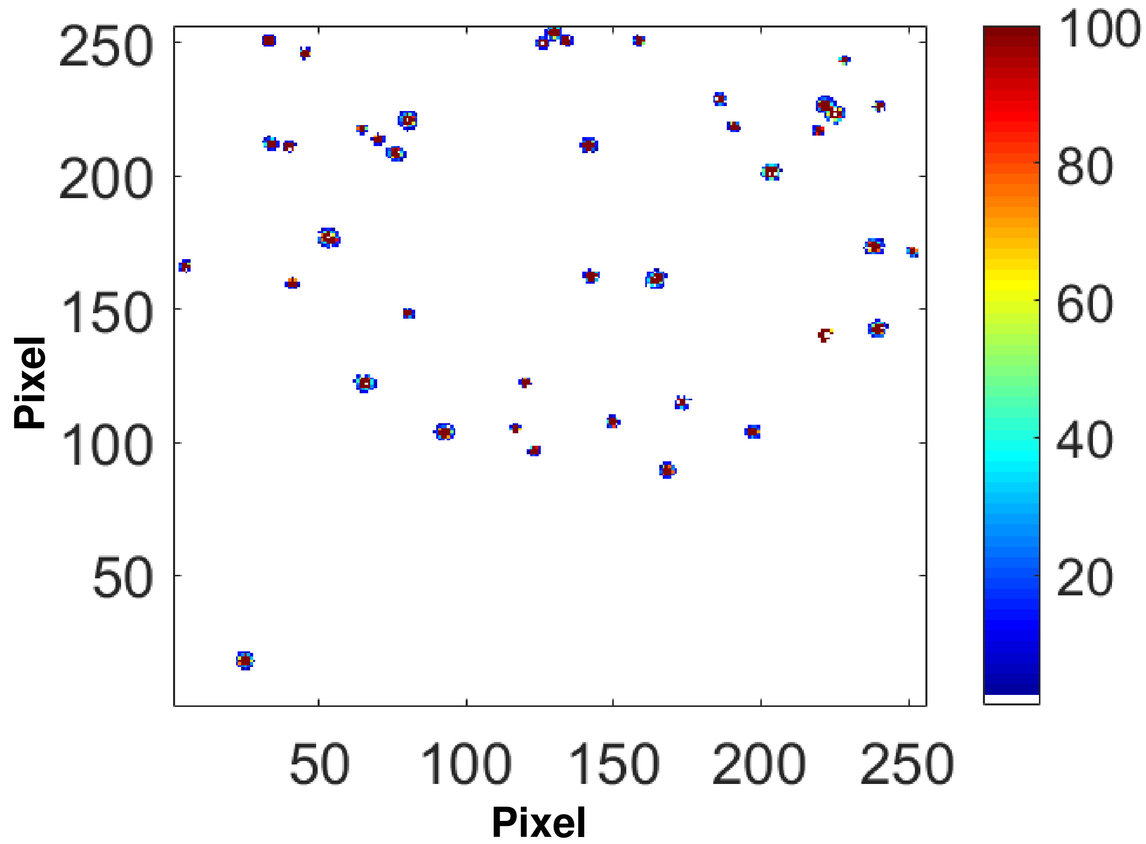
C. Granja and S. Pospisil, Advances in Space Research, Volume 54, Issue 2, 15 July 2014, Pages 241–251

CHARGED PARTICLES IDENTIFICATION WITH TIMEPIX



Detection principle [(1)]

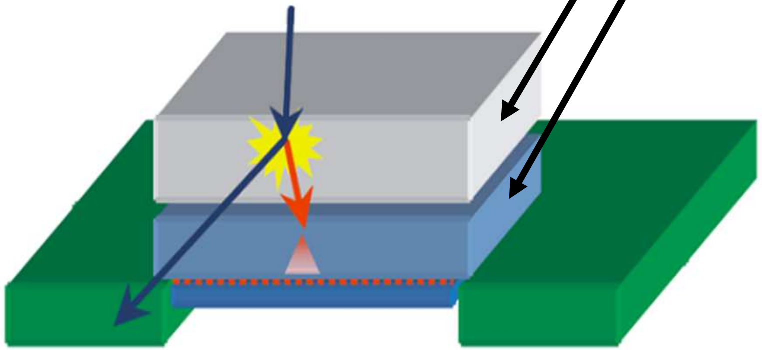
Paraffin (n, p^+)



Detection and track visualization of clusters induced by protons

(1) Modified schema based on P. Masek et al, Journal of Instrumentation, Volume 8 C01021, January 2013

CHARGED PARTICLES IDENTIFICATION WITH TIMEPIX



Detection principle [(1)]

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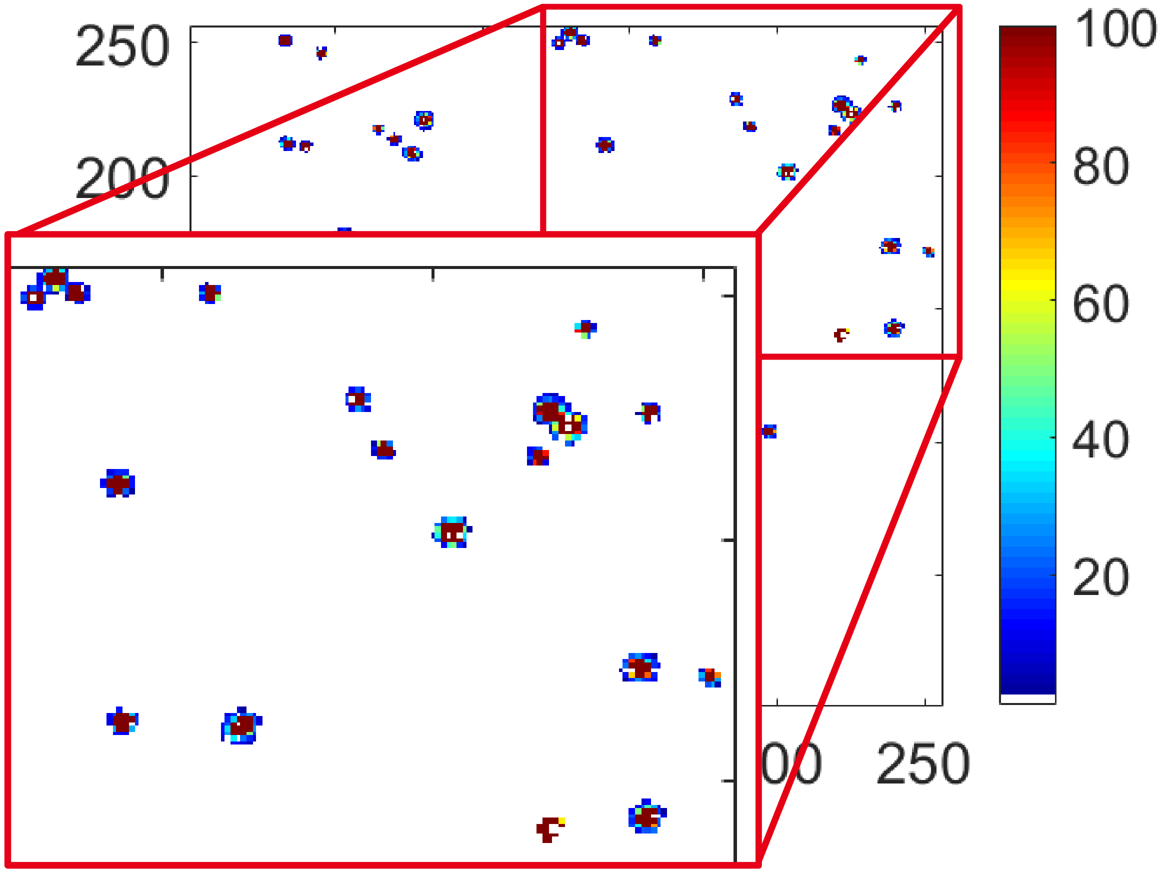


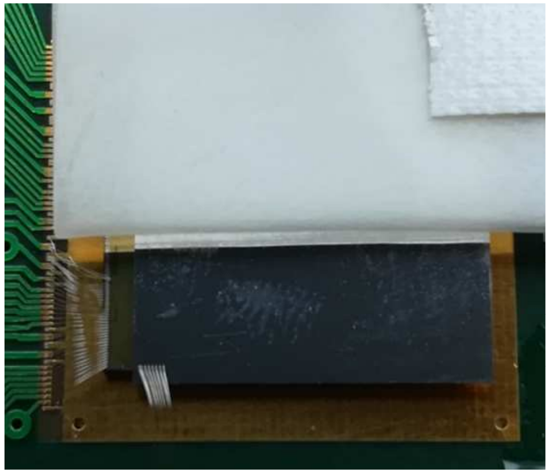
Detection and track visualization of clusters induced by protons

(1) Modified schema based on P. Masek et al, Journal of Instrumentation, Volume 8 C01021, January 2013

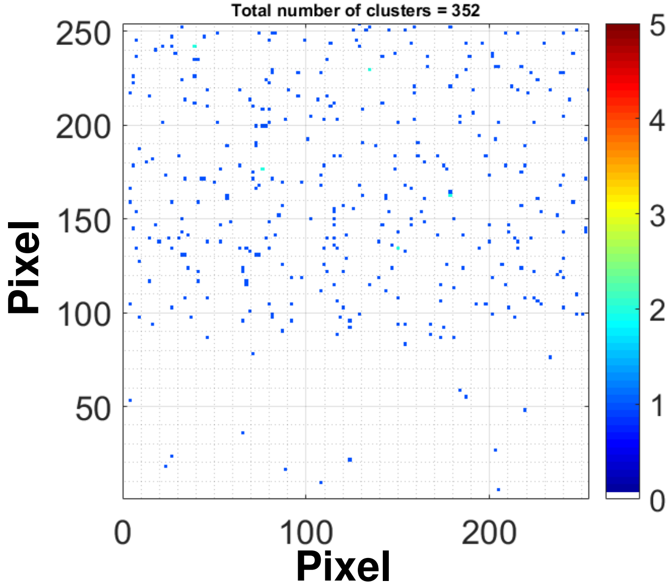
CHARGED PARTICLES IDENTIFICATION WITH TIMEPIX

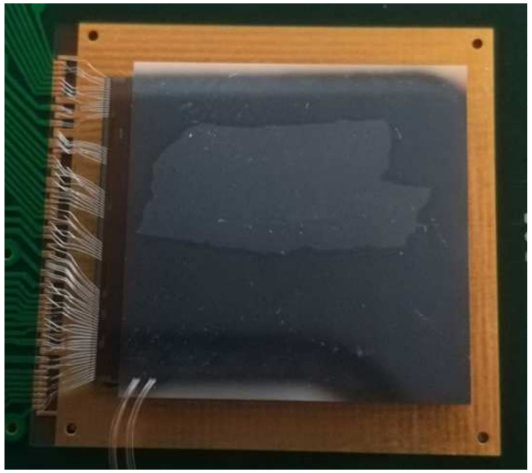
Setup

^{252}**Cf source**

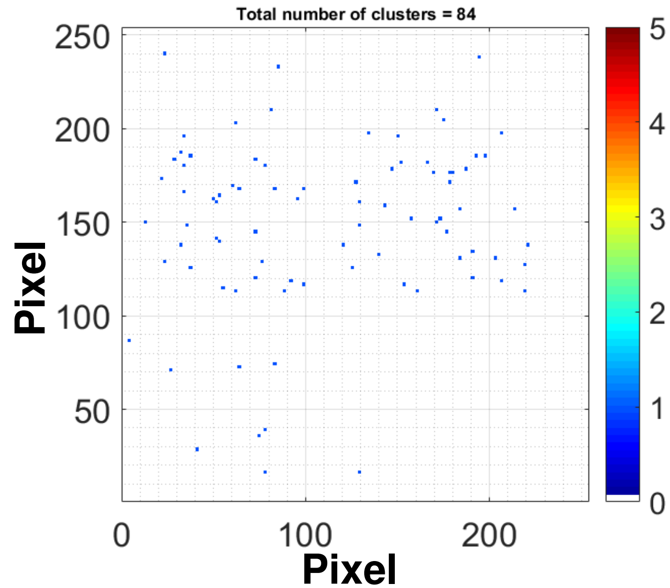


Paraffin film





Lithium fluoride deposited by chemical vapor

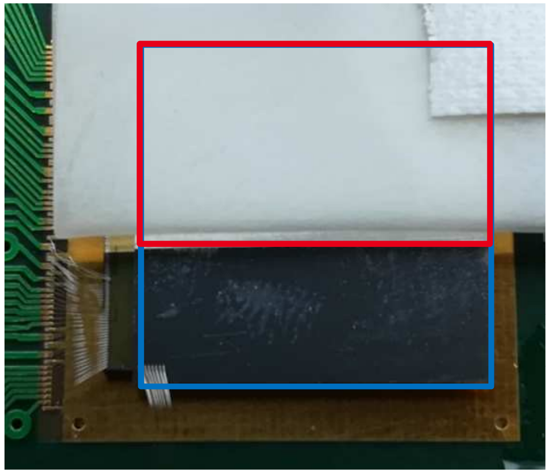


→ Possibility to identify charged particles with Timepix

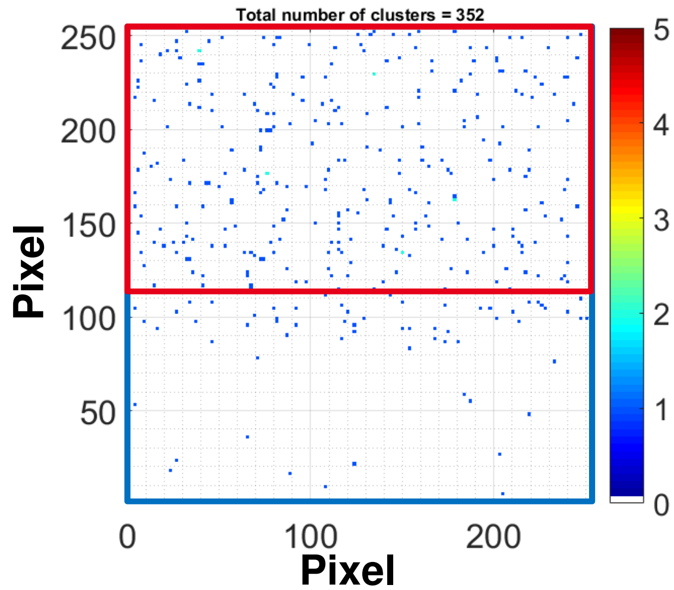
CHARGED PARTICLES IDENTIFICATION WITH TIMEPIX

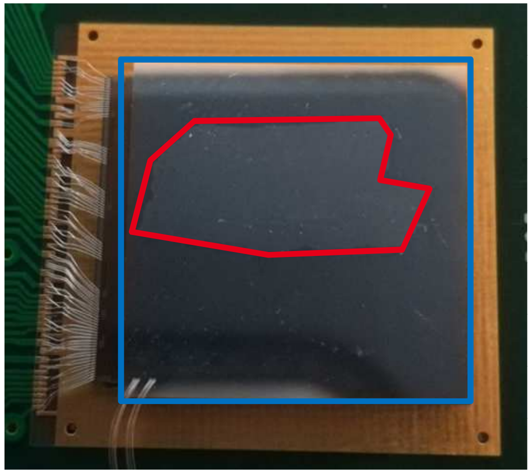
Setup

^{252}Cf source

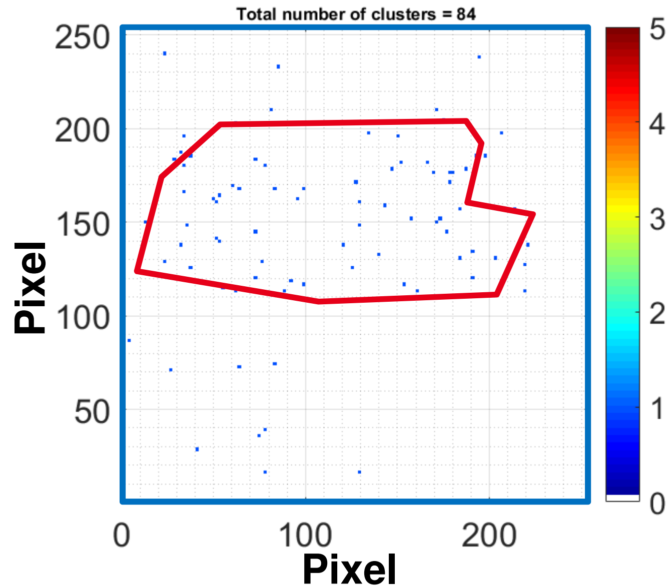


Paraffin film





Lithium fluoride deposited by chemical vapor



→ Possibility to identify charged particles with Timepix

SUMMARY

1. CONTEXT
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3. WHY TIMEPIX ?
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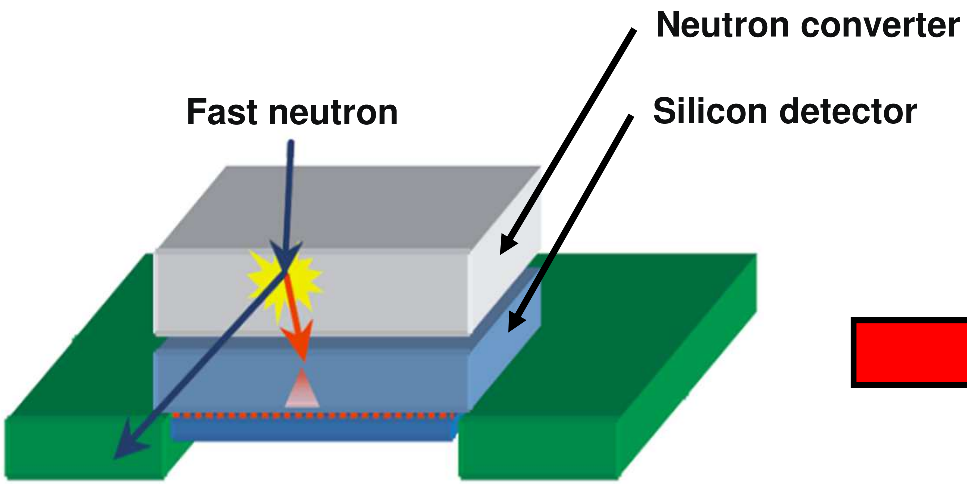
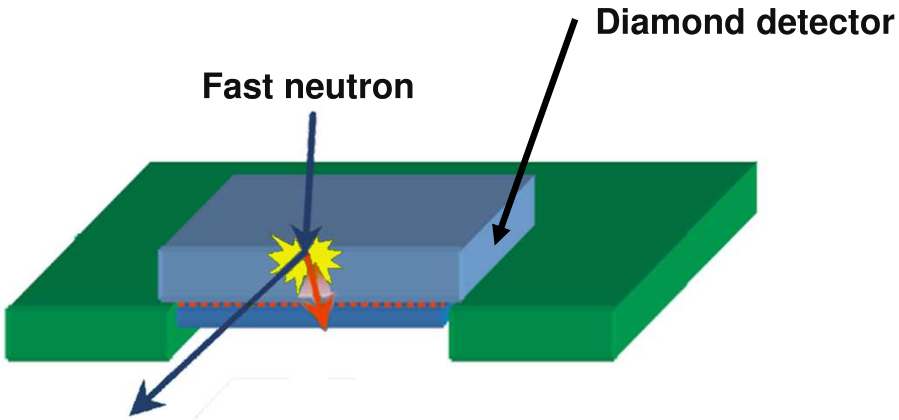
DIAMOND AS THE DETECTION SUBSTRATE FOR TIMEPIX

- Sensitivity for fast neutrons
- Low sensitivity for gammas
- Semiconductor properties

- ➢ Higher energy collection
- ➢ Higher spatial resolution



Detection with conversion(1)

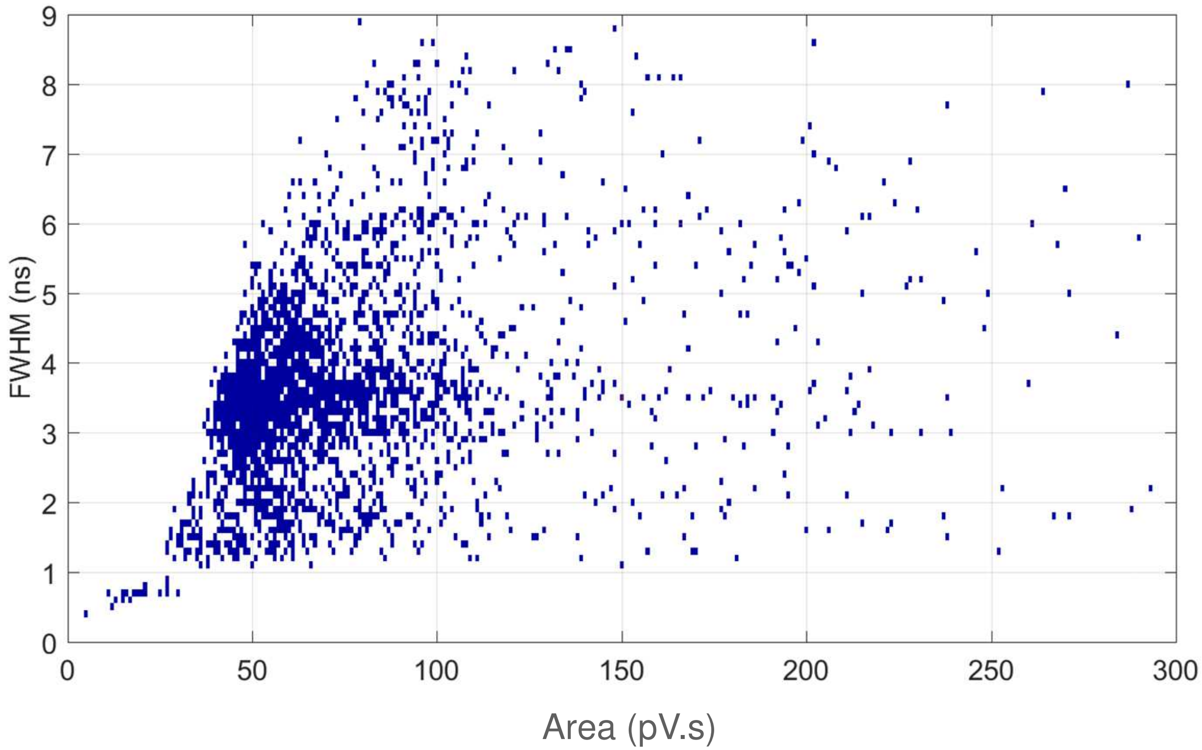


Direct detection(1)

(1) Modified schema based on P. Masek et al, Journal of Instrumentation, Volume 8 C01021, January 2013

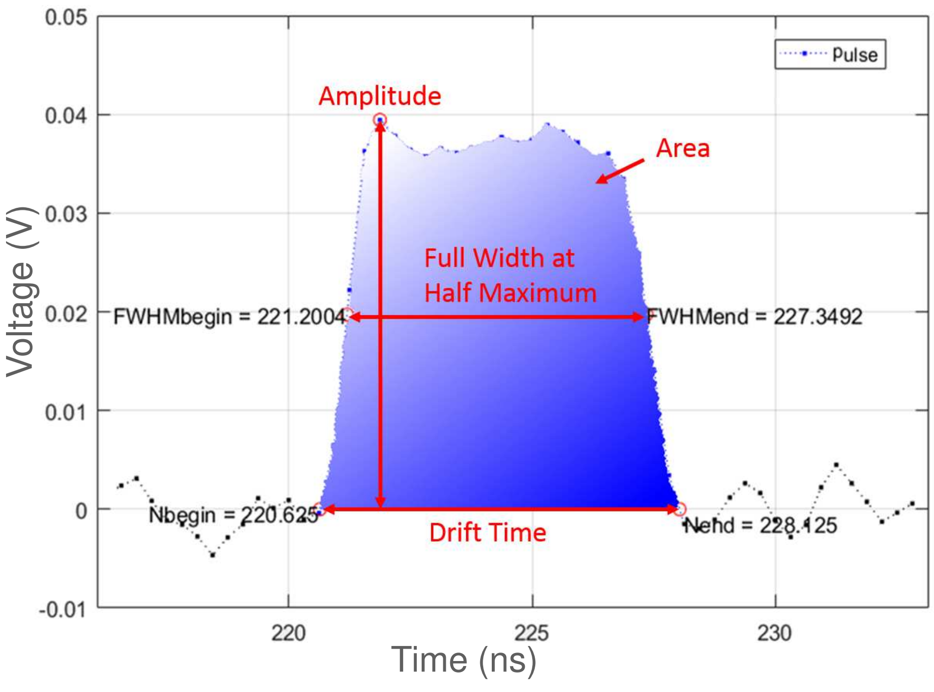
CHARGED PARTICLES IDENTIFICATION WITH DIAMOND

scCVD diamond

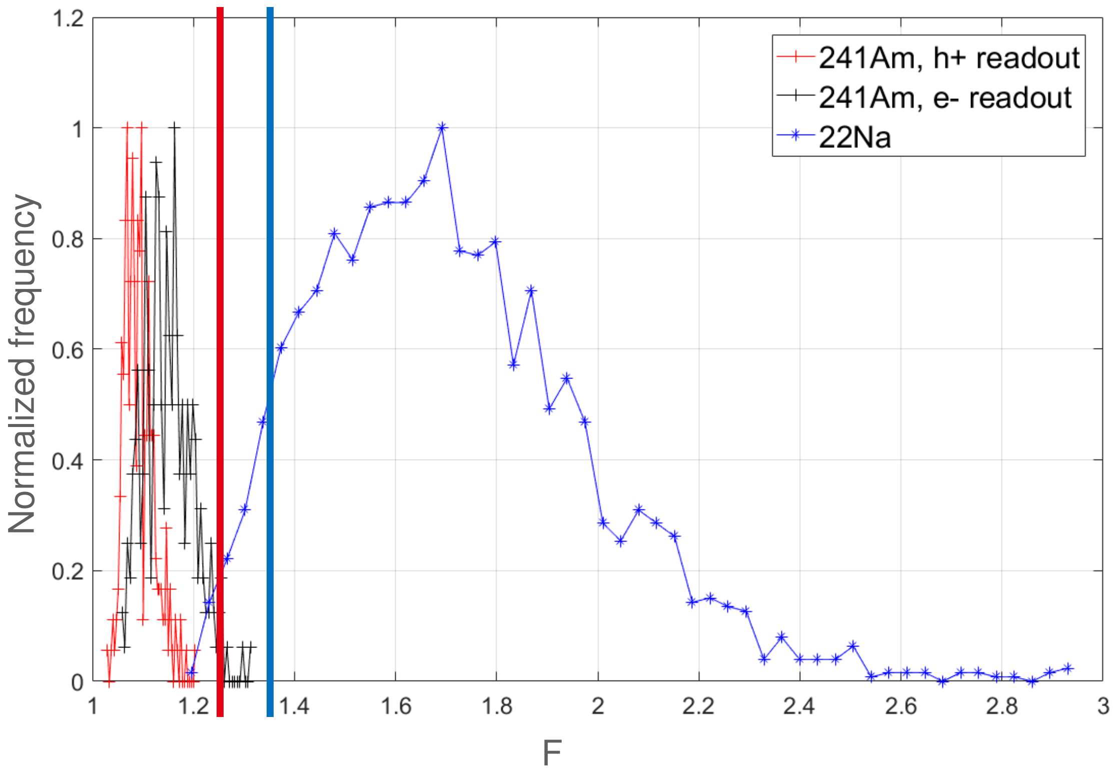


^{252}Cf
+
AmBe

Based on pulse shape analysis



Pulse analysis



$$F = \frac{Amplitude \times DriftTime}{Area}$$

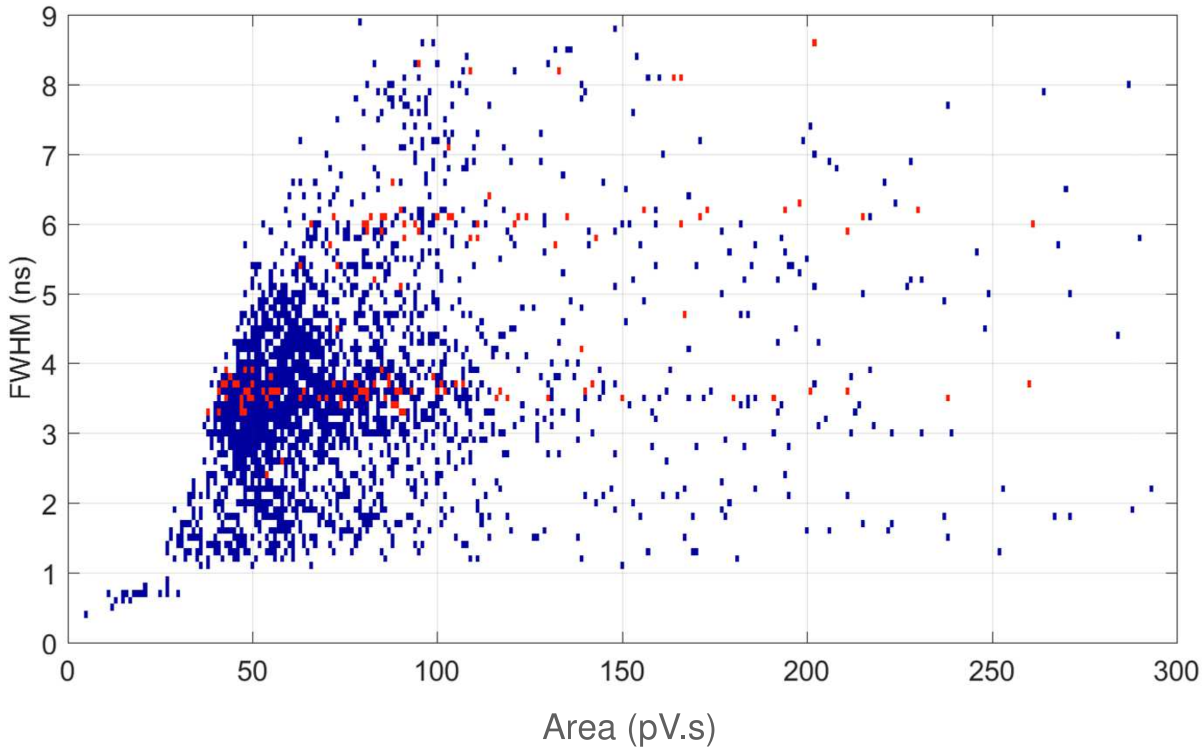
→Alpha (neutron): F < 1,25

→Electron (gamma): F > 1,35

Analysis based on C. Weiss, 5th ADAMAS Workshop, 2016

CHARGED PARTICLES IDENTIFICATION WITH DIAMOND

scCVD diamond



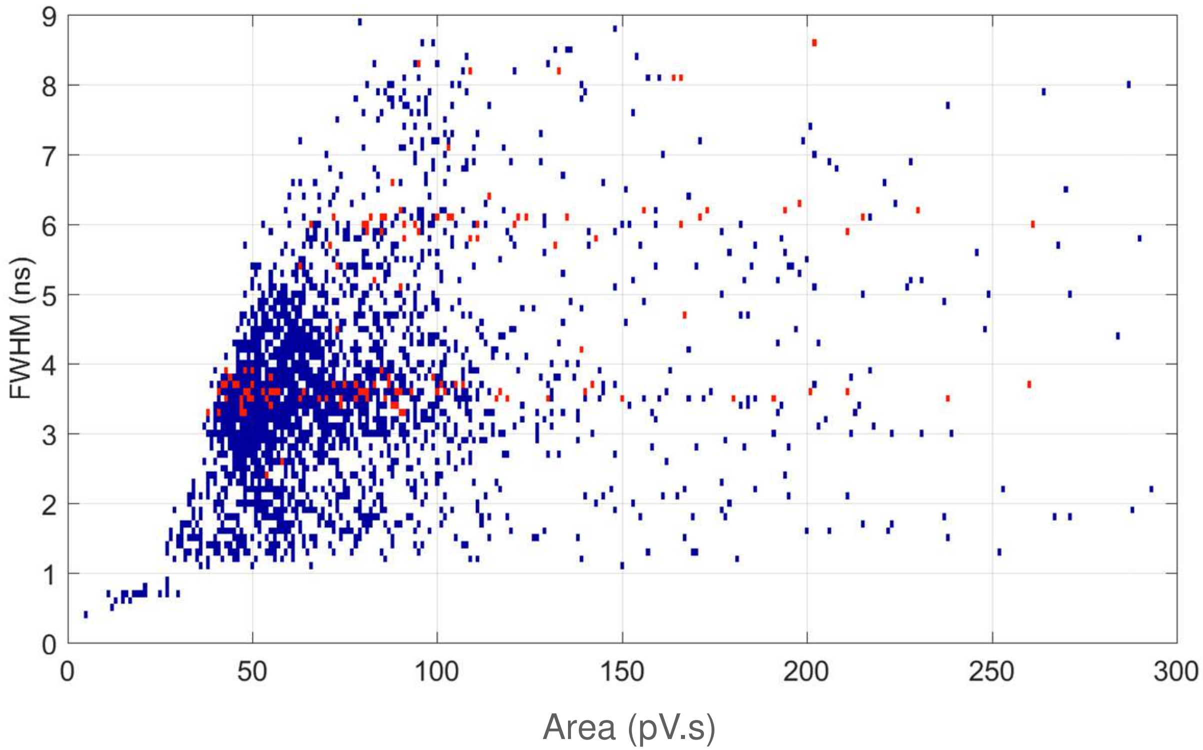
^{252}Cf + AmBe

Neutron/gamma

→Alpha (neutron): F < 1,25
→Electron (gamma): F > 1,35

CHARGED PARTICLES IDENTIFICATION WITH DIAMOND

scCVD diamond



^{252}Cf + AmBe

Neutron/gamma

FWHM (neutron pulse)	Ballistic center	Holes drifting	Electrons drifting
Mean (ns)	3,46	5,89	8,05
Standard deviation (ns)	0,17	0,19	0,16
Deviation from the expected value (ns)	0,02	0,09	0,26

≤ 3%

→ Possibility to detect and identify neutrons with diamond

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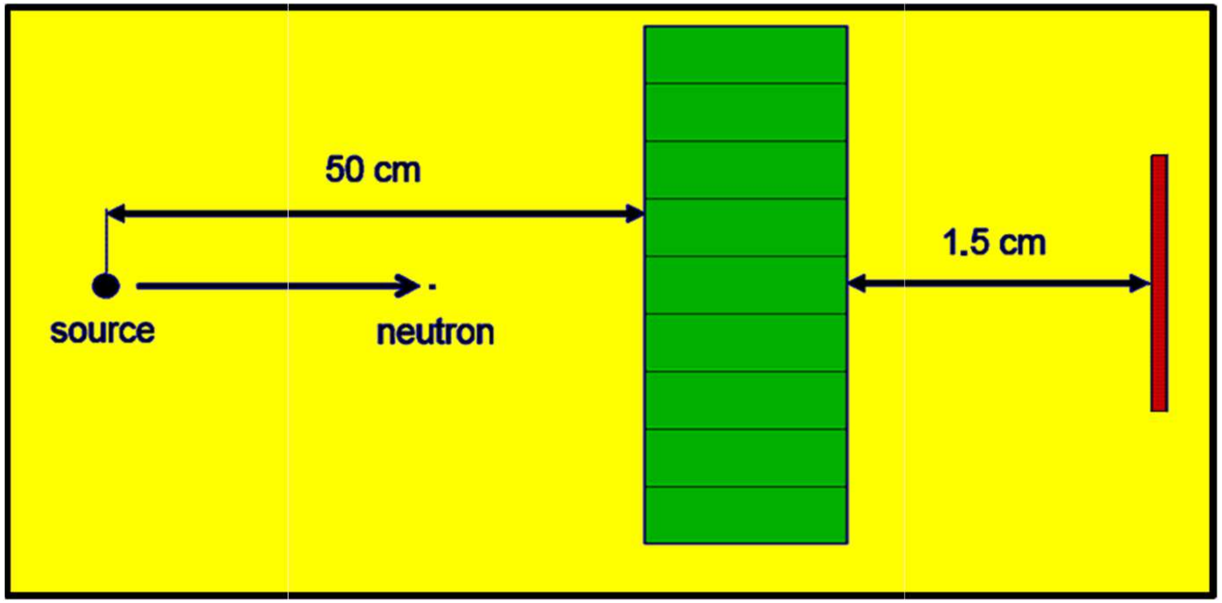
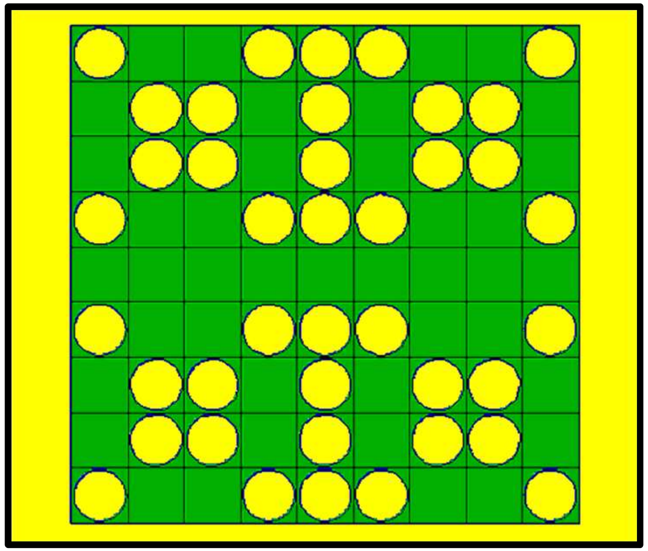
MODELING





Rank 5 MURA coded aperture

Monte-Carlo simulations

Neutron source

^{252}Cf

Coded aperture

Chemical composition: Polyethylene

Thickness: 3 cm

Diamond

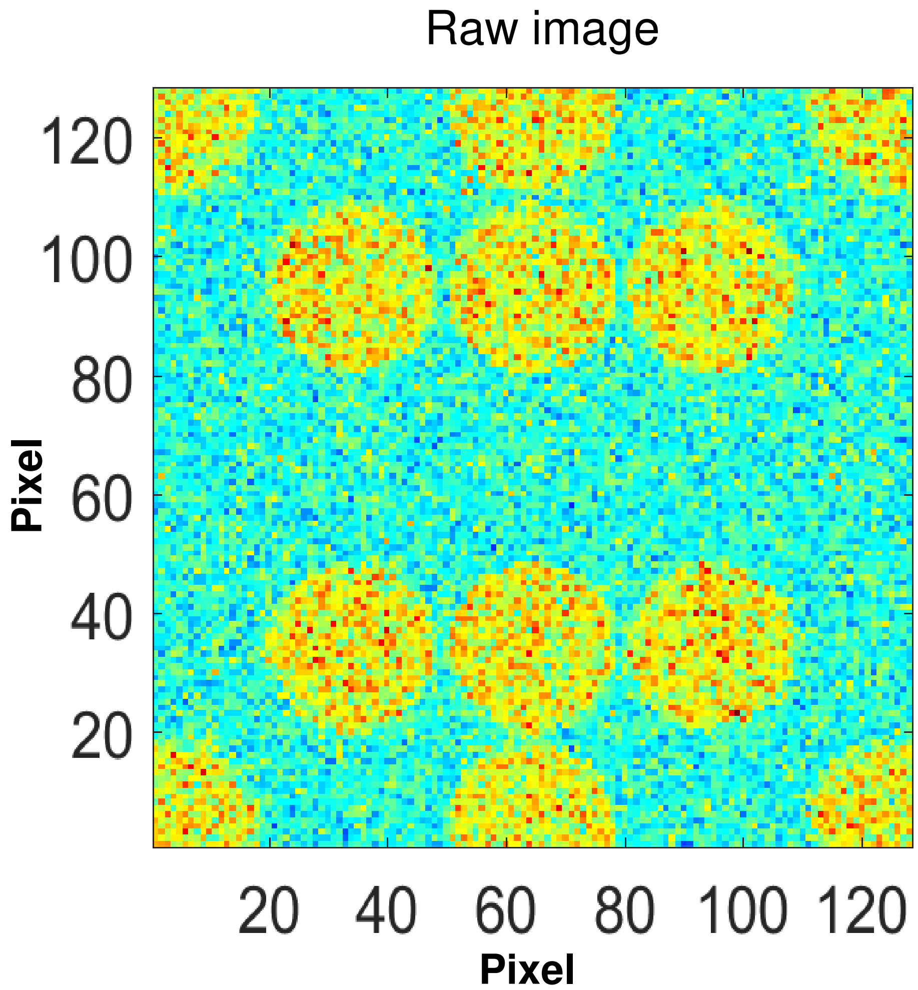
Pixel matrix: 128 × 128 (16384) pixels

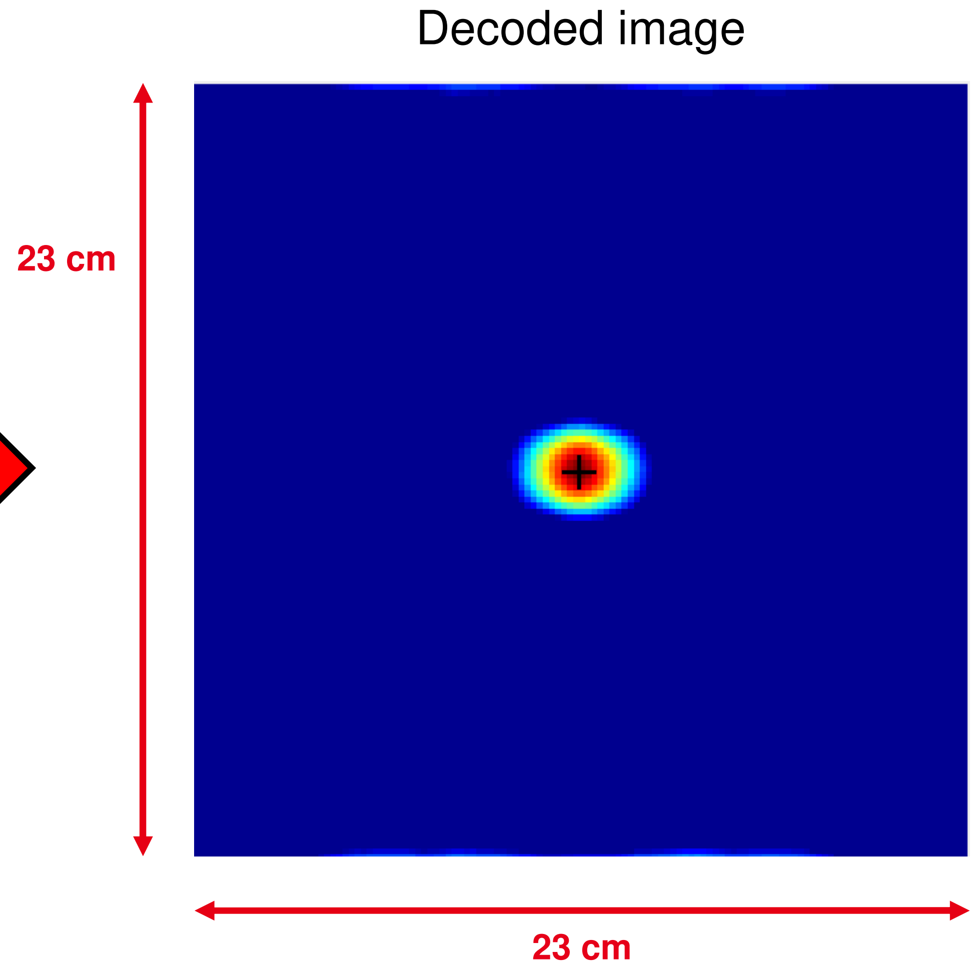
Surface of diamond: 1.408 cm × 1.408 cm

Thickness of diamond: 300 µm

SIMULATED IMAGE

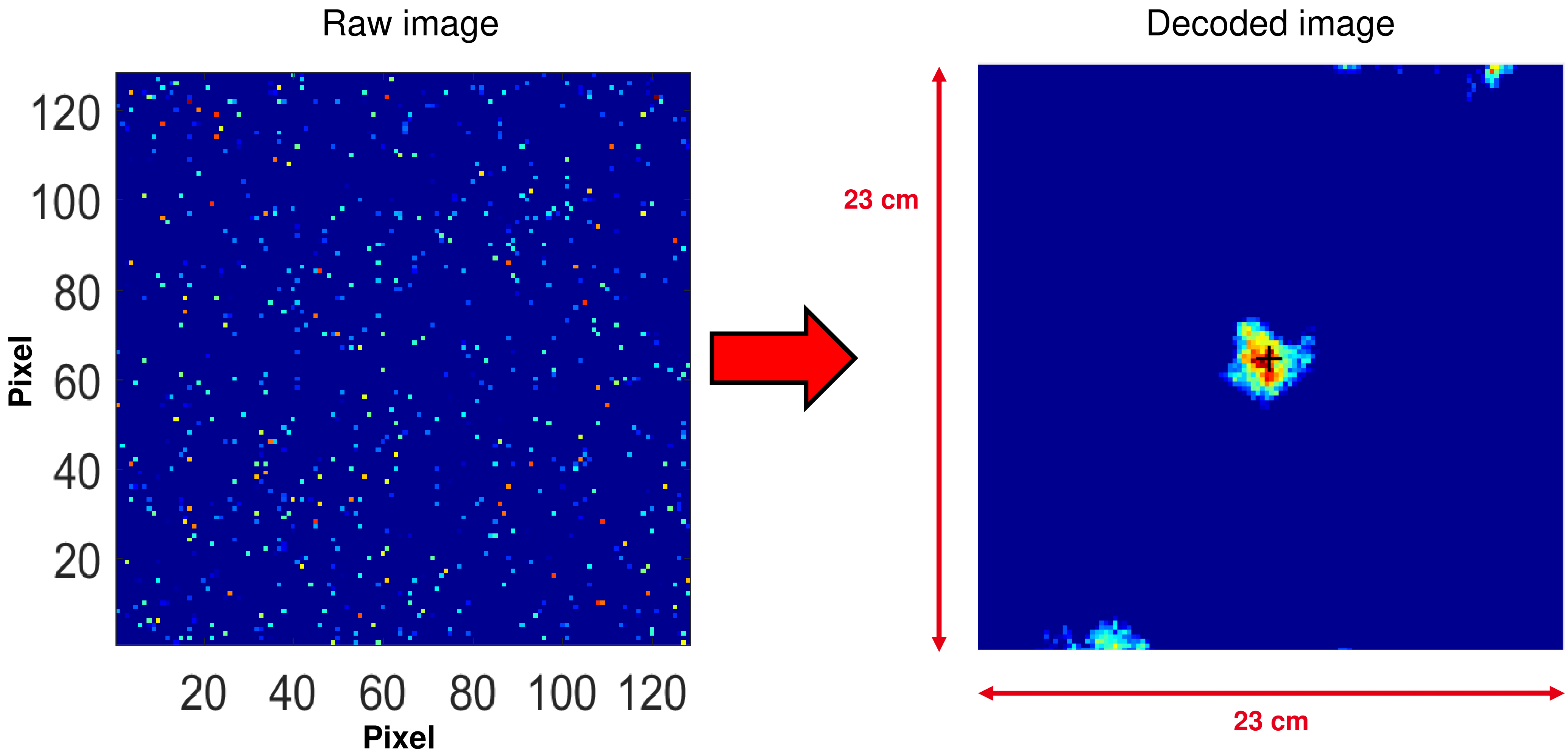
Equivalent to a 3 hours acquisition with a ^{252}Cf source with a emission of 76×10^{6} neutron/s (~32 µg)





SIMULATED IMAGE

Equivalent to a 11 seconds acquisition with a ^{252}Cf source with a emission of 76×10^{6} neutron/s (~32 µg)

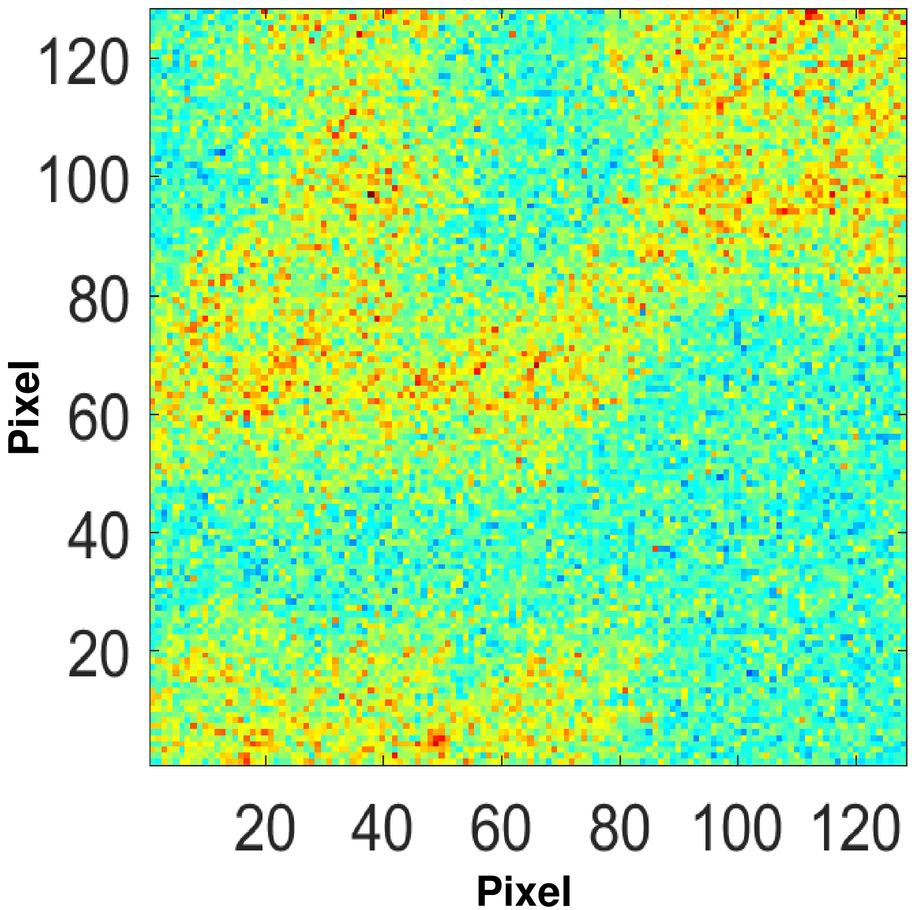


SIMULATED IMAGE

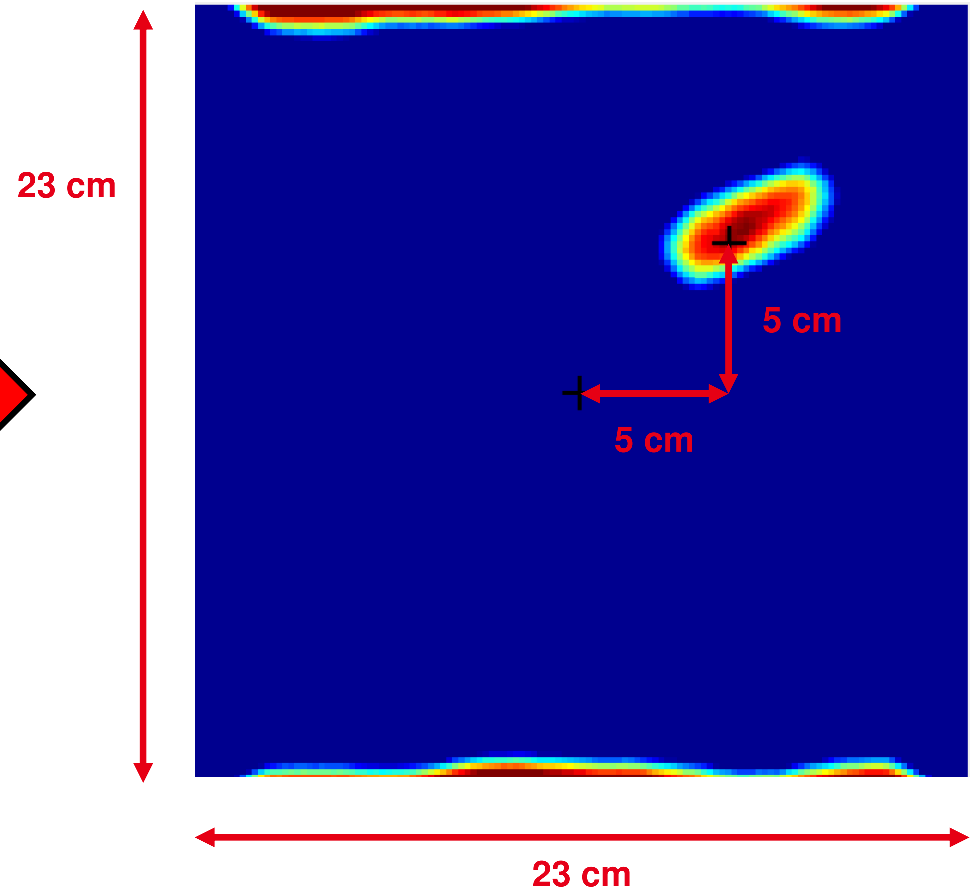
Same conditions but the source is **off centered** by

$$\vec{v} = (5,5)\ \text{cm}$$

Raw image



Decoded image



CONCLUSIONS ON SIMULATION

- Possibility to localize a neutron source with a pixelated diamond
- Possibility to localize a neutron source even with relatively low statistic
- Possibility to localize an off centered source

➢ **First design** for the neutron imager with a diamond substrate

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Conclusions

- Verification of Timepix capacity to identify particles
- Verification of diamond capacity to detect neutrons
- First design for the neutron imager

Perspectives

1. **Bond a pixelated diamond to a Timepix readout chip**
2. **Locate and identify neutron interactions**
3. **Prototype a portable neutron imager**

THANKS FOR YOUR ATTENTION

Commissariat à l’énergie atomique et aux énergies alternatives
Institut List | Centre CEA SACLAY | BAT. 516
91191 Gif-sur-Yvette Cedex - FRANCE
www-list.cea.fr

THREE RESEARCH PATHS

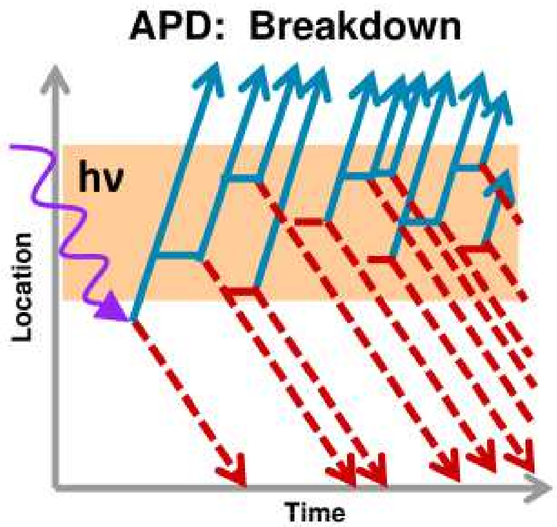
- **Path 1: Timepix detector and converter**

- **Path 2: Timepix and diamond substrate**

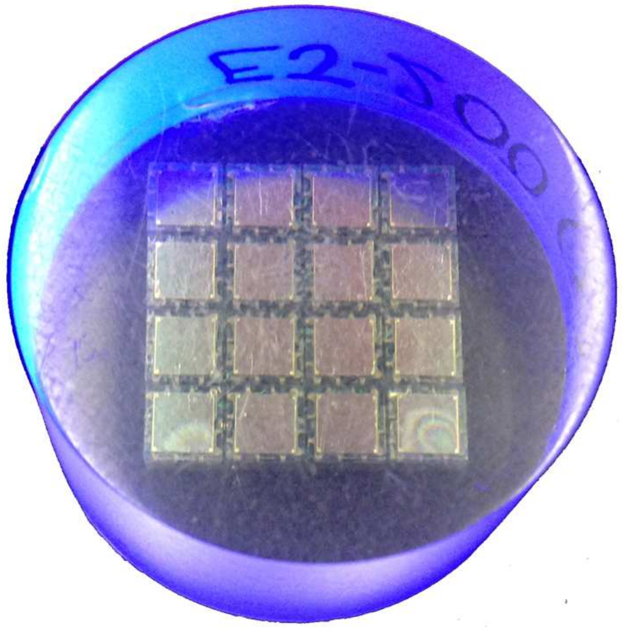
- **Path 3: Scintillator and SiPM matrix**

PATH 3

- **Scintillator and SiPM matrix**
  - Organic scintillator (liquid or plastic) with gamma/neutron discrimination properties
  - Matrix of Silicon PhotoMultipliers (SiPM)



Principle of Geiger-Mode Avalanche PhotoDiode (GM-APD)



Plastic scintillator and SiPM matrix