Energy calibration of the threshold of Medipix for ATLAS

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presenting for the

Institut of Experimental and Applied Physics
of the Czech Technical University in Prague

People involved in this project

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  - Vlastimil Král
  - Michal Platkevič
  - Vladimír Tichý
- Charles University
  - Michal Suk
  - …
- Université de Montréal
  - Claude Leroy
  - Céline Lebel

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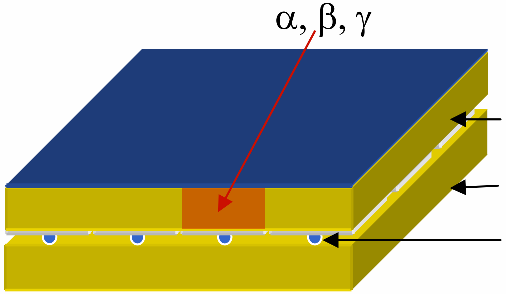
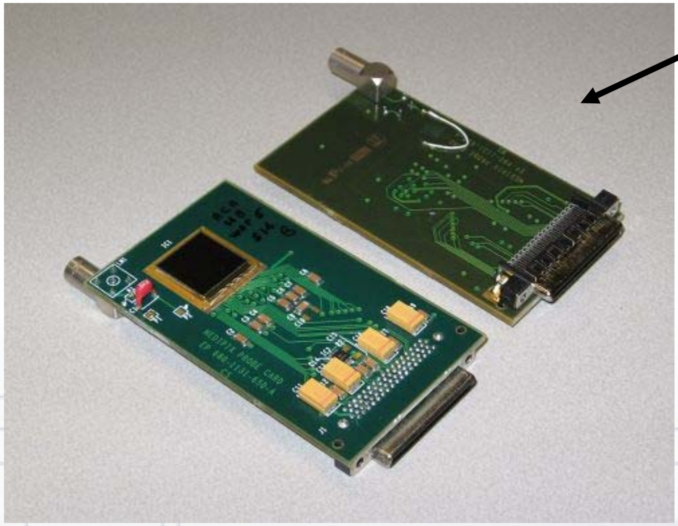
Outline

- Medipix
- Medipix in ATLAS: challenges foreseen
- Energy calibration of the low threshold
  - Equalization
  - Photons: Decreasing Flux
  - Alphas
  - Electrons
  - Neutrons
- Summary and Outlook

Medipix2 device - a single X-ray photon counting pixel detector

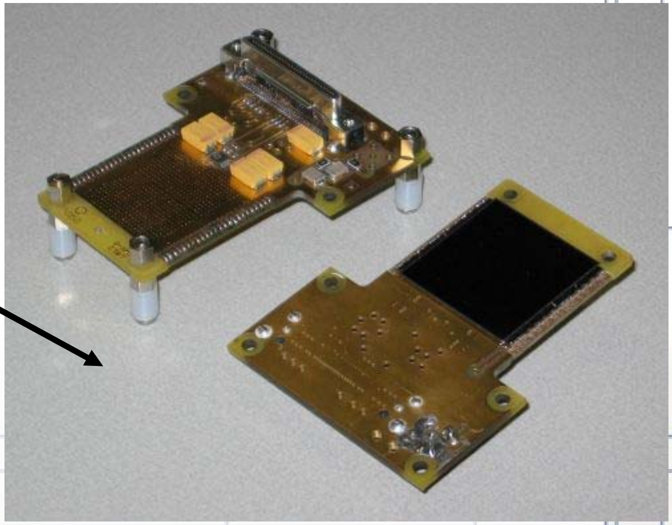
- Planar pixellated detector (Si, GaAs, CdTe, thickness: 300/700/1000mm)
- Bump-bonded to Medipix readout chip containing in each pixel cell:
  - amplifier,
  - double discriminator
  - and counter





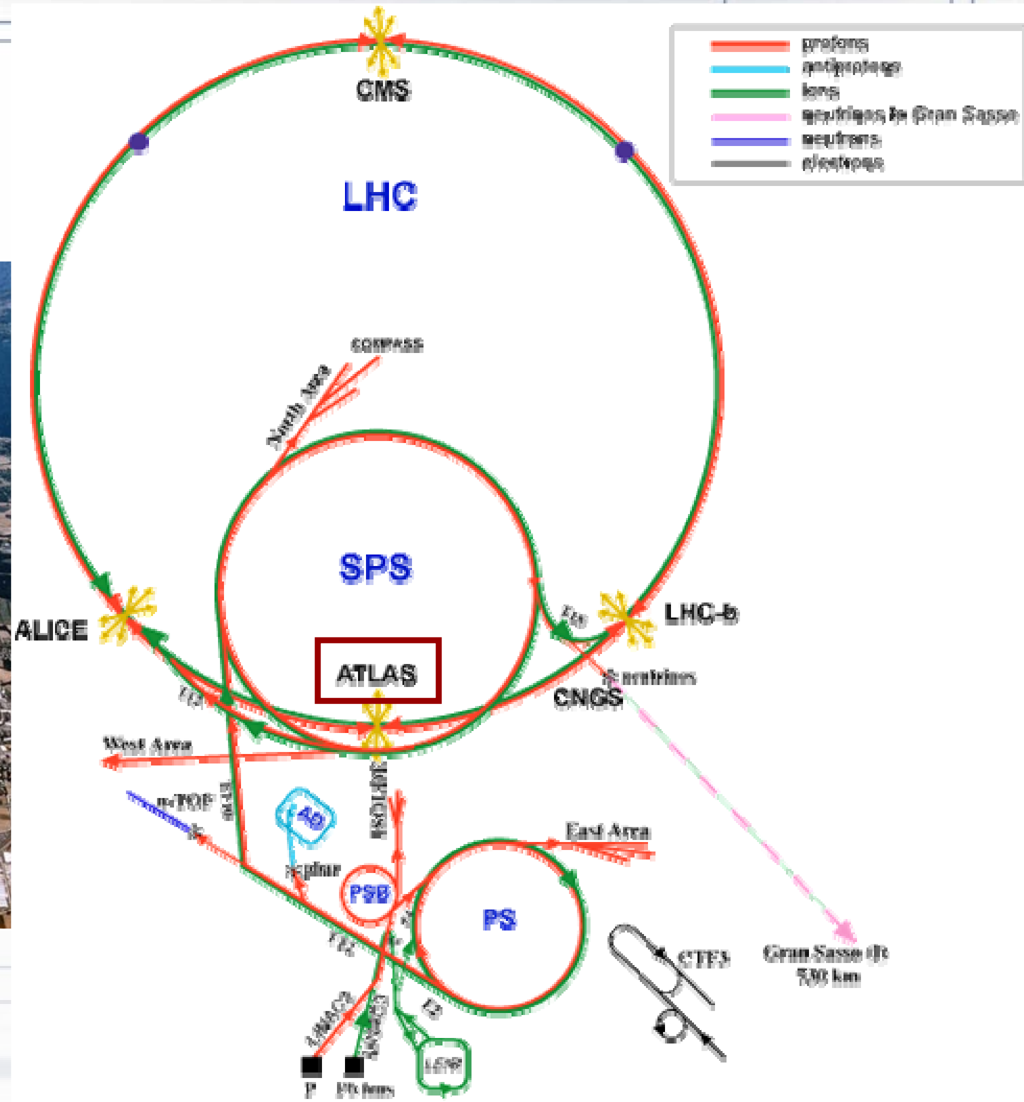
Medipix2
Pixels: 256 x 256
Pixel size: 55 x 55 μm^2
Area: 1.5 x 1.5 cm^2

Medipix2 Quad
Pixels: 512 x 512
Pixel size: 55 x 55 μm^2
Area: 3 x 3 cm^2

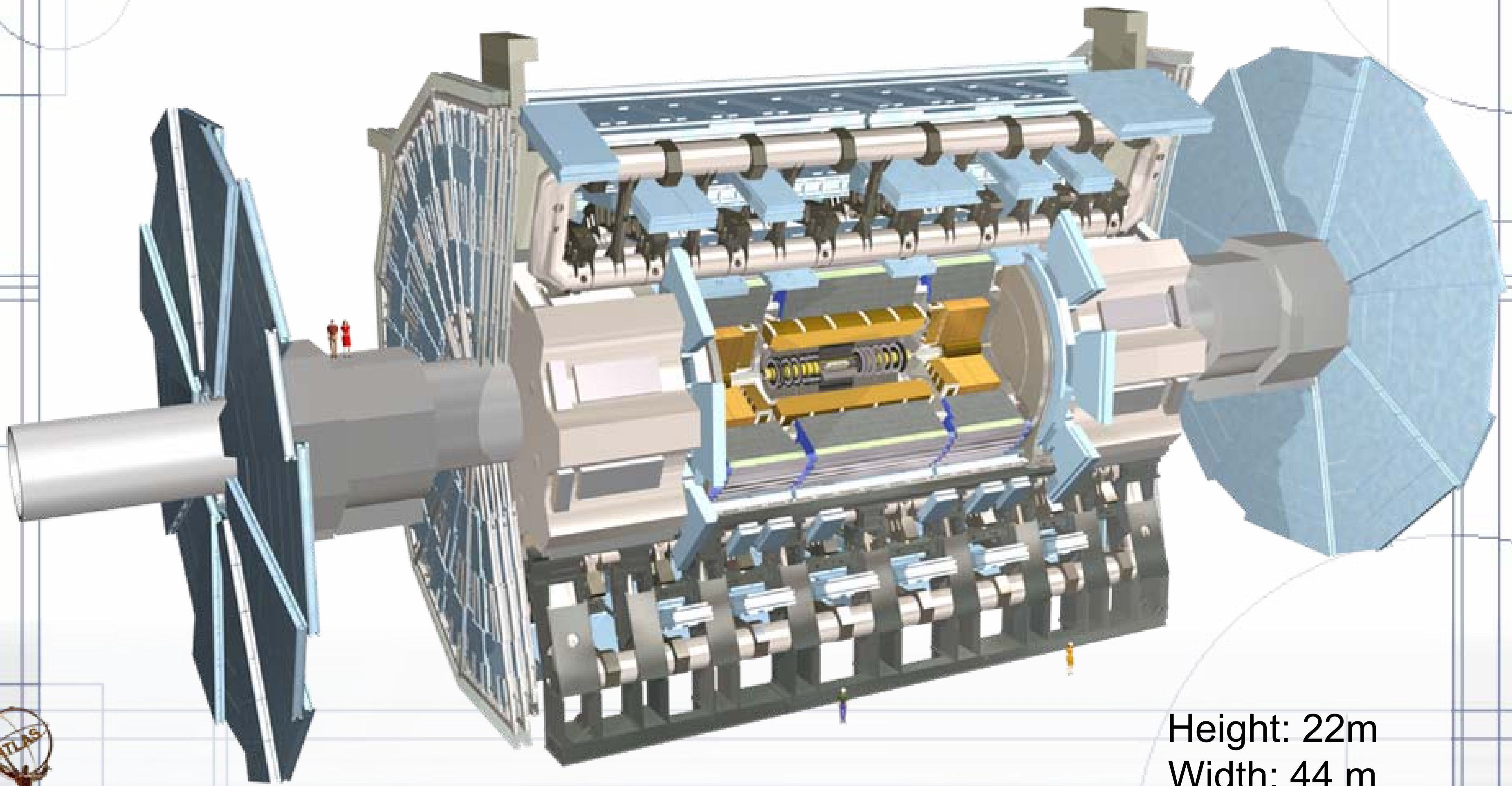


ATLAS

LHC


CMS
LHC
COMPASS
North Area
SPS
ALICE
ATLAS
LHC-b
CNGS
West Area
n-TOF
AD
ISOLDE
East Area
PSB
PS
CTF3
Gran Sasso (I)
730 km
LEIR
p
Pb ions

ATLAS

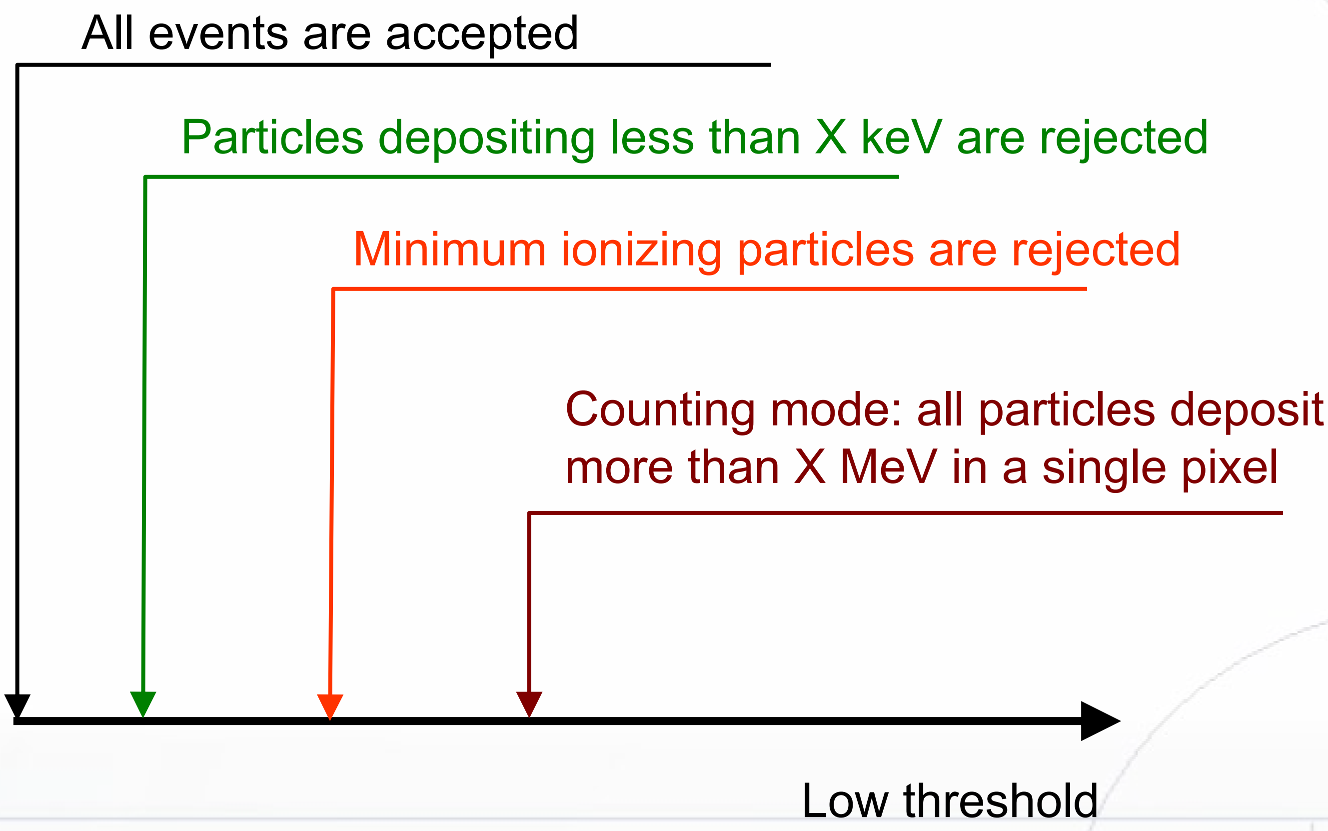


Height: 22m
Width: 44 m
Weight: 7000 tons

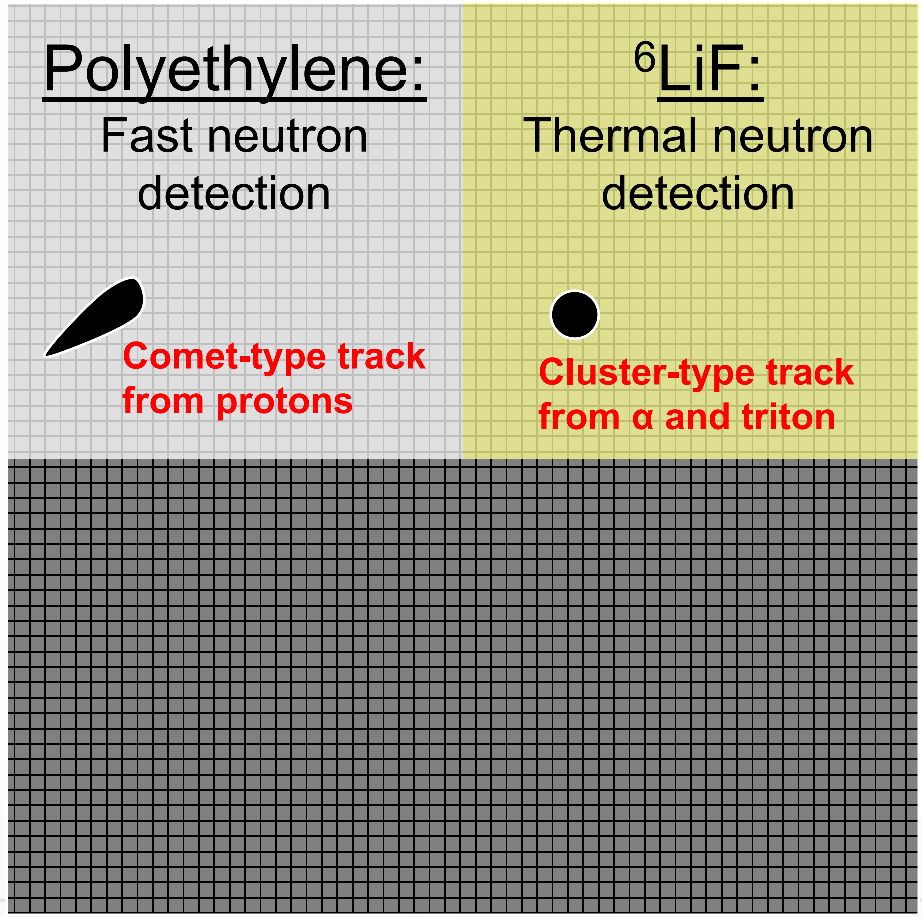
Medipix in ATLAS: the challenge

- ATLAS environment has high radiation fluxes
- Problem: is the device radiation hard?
  - We don't know.
- The data acquisition must be optimized to obtain the maximum information in the shortest time.
- What kind of information are we looking for?
  - Composition and spectroscopic characteristics of the radiation field inside ATLAS
    - Number of particles, energy and type

Approach for ATLAS: Layers



Approach for ATLAS: multiple area



Adaptation of the Medipix2 device for position sensitive detection of neutrons

Silicon pixel detector can not detect neutrons directly. Conversion of neutrons to detectable radiation in a converter layer (via nuclear reactions or recoiled protons) deposited on the detector surface is needed.

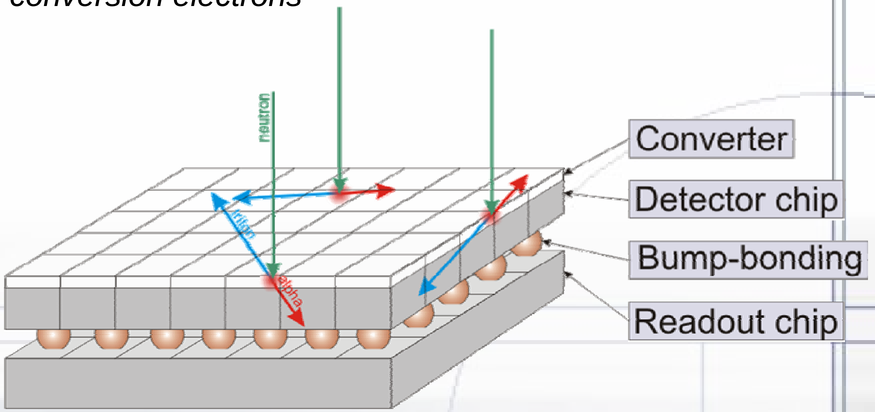
Converter materials for thermal neutrons:

^{6}Li:	^{6}Li + n → a (2.05 MeV) + ^{3}H (2.72 MeV)	
^{10}B:	^{10}B + n → a (1.47 MeV) + ^{7}Li (0.84 MeV) + g (0.48MeV)	(93.7%)
	^{10}B + n → a (1.78 MeV) + ^{7}Li (1.01 MeV)	(6.3%)
^{113}Cd:	^{113}Cd + n → ^{114}Cd + g (0.56MeV) + *conversion electrons*	
^{155}Gd:	^{155}Gd + n → ^{156}Gd + g (0.09, 0.20, 0.30 MeV) + *conversion electrons*	
^{157}Gd:	^{157}Gd + n → ^{158}Gd + g (0.08, 0.18, 0.28 MeV) + *conversion electrons*	

Converter for fast neutrons: polyethylene foil

Detector:

150 – 700 mm thick silicon pixel detector (pixel size 55 mm) bump bonded to Medipix-2 readout chip.

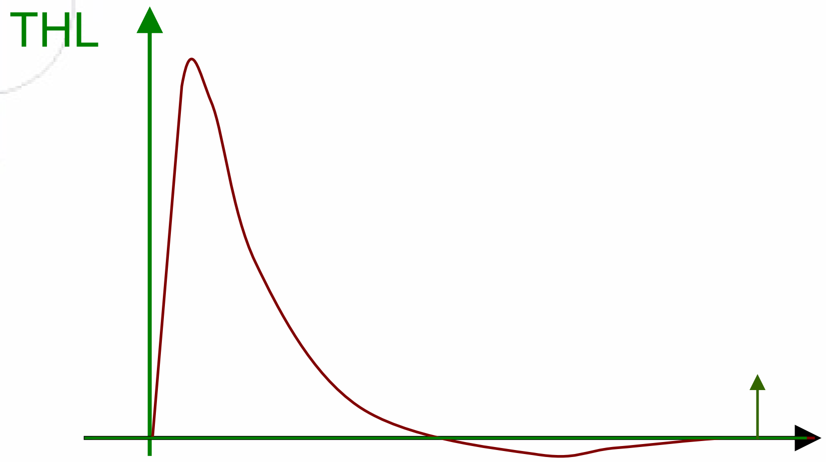


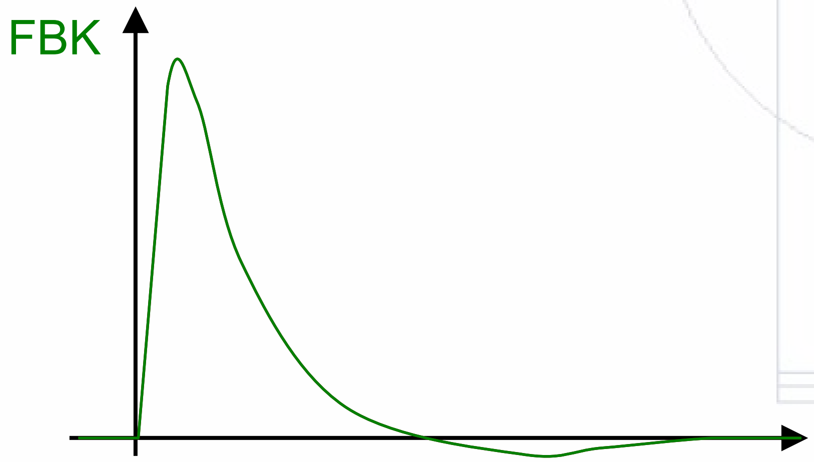
Equalization and parameters

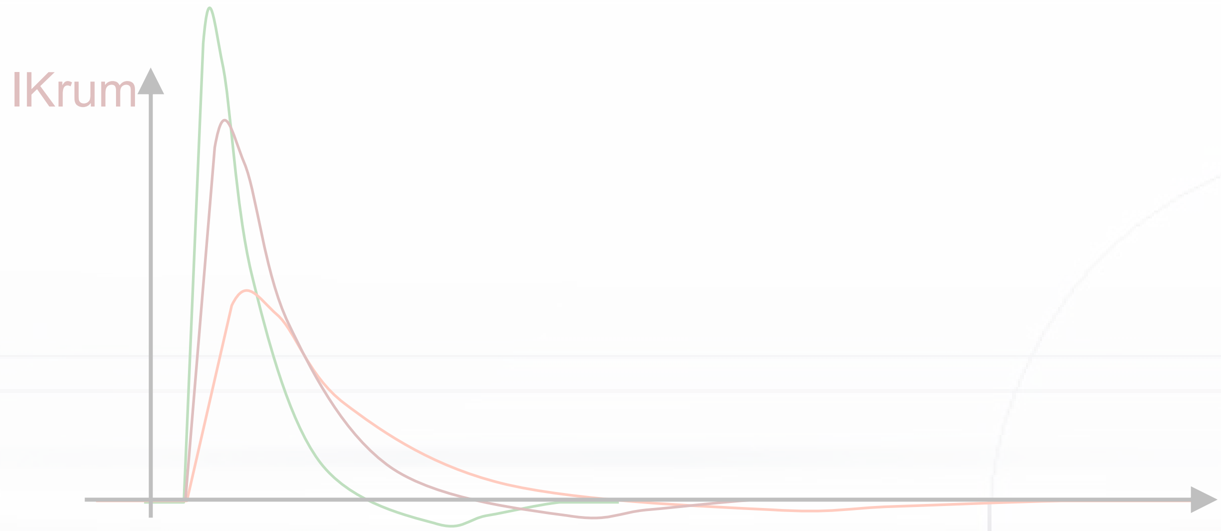
Equalization

- Medipix is composed of 65536 pixel channels. All are not created equal!
  - Pixelman allows for the equalization of the low threshold (THL)
    - This is a small but necessary adjustment
- Two methods:
  - Use noise edge
    - Useful to remove the noisiest pixels
  - Use noise center
    - Centers the noise → This puts the necessary offsets so that all pixels read the same energy

Parameters to adjust







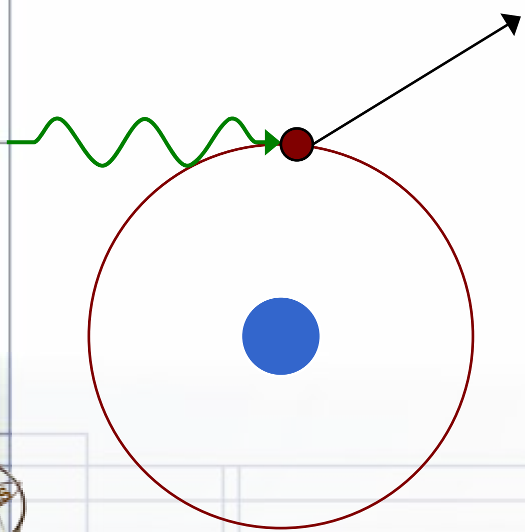
Particle detection

Photons

- Photons can be detected in silicon only by transferring their energy to charged particles.

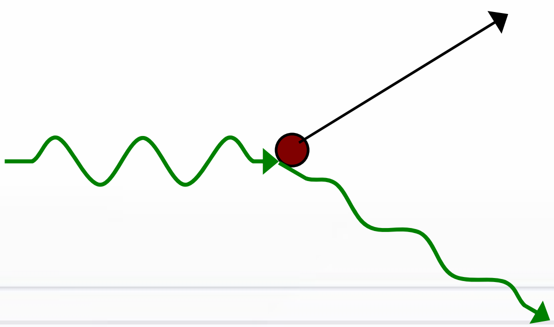
Photoelectric effect

All energy transferred to the material



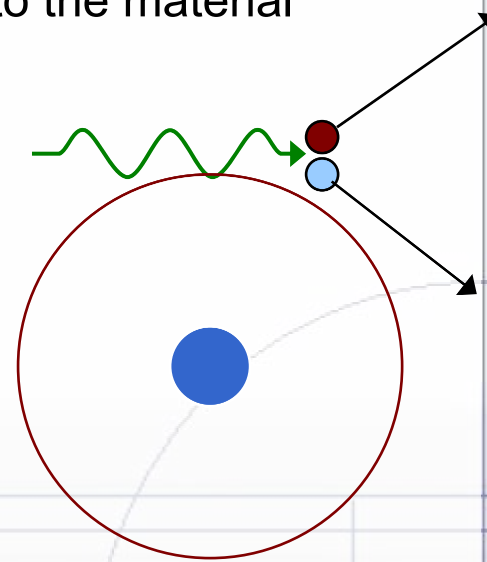
Compton diffusion

Energy partially transferred to the material

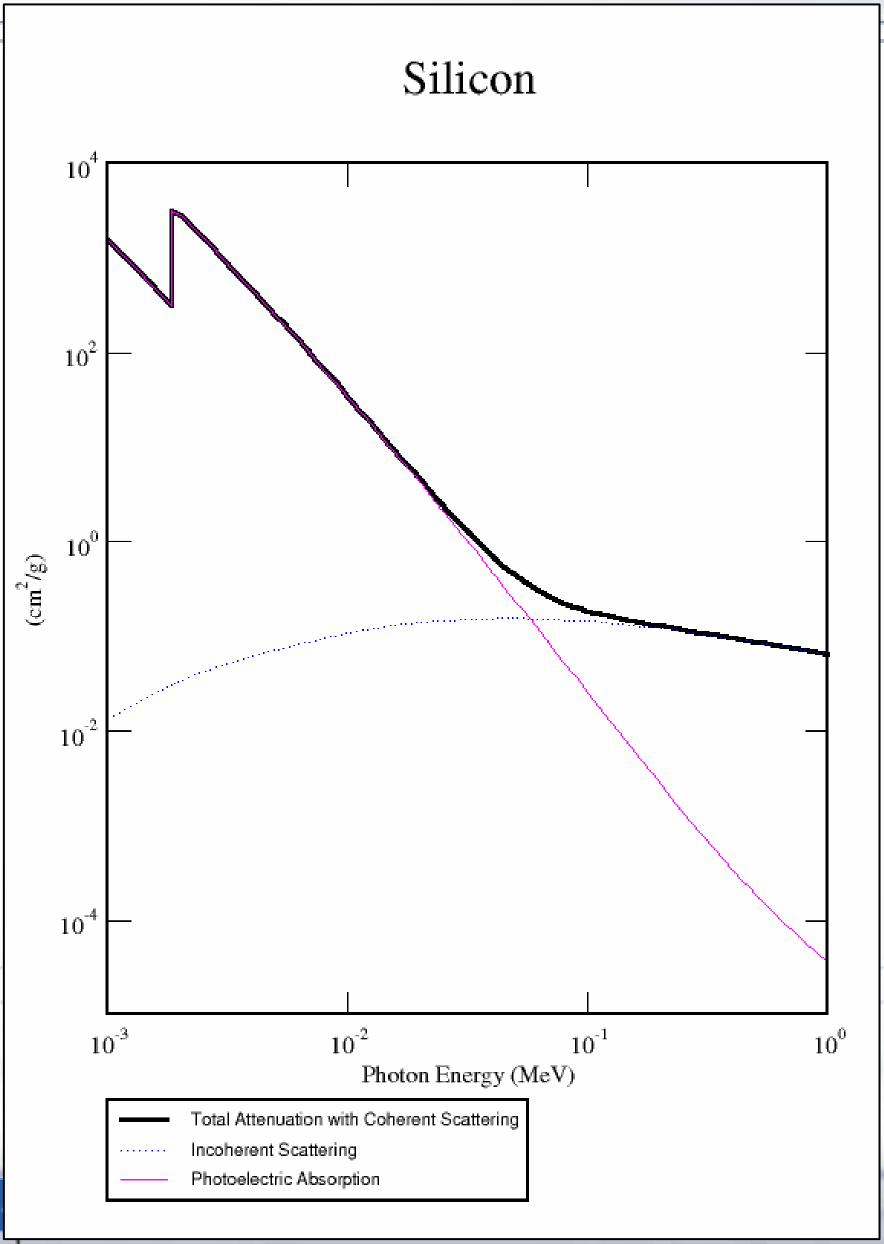


Pair production

All energy transferred to the material

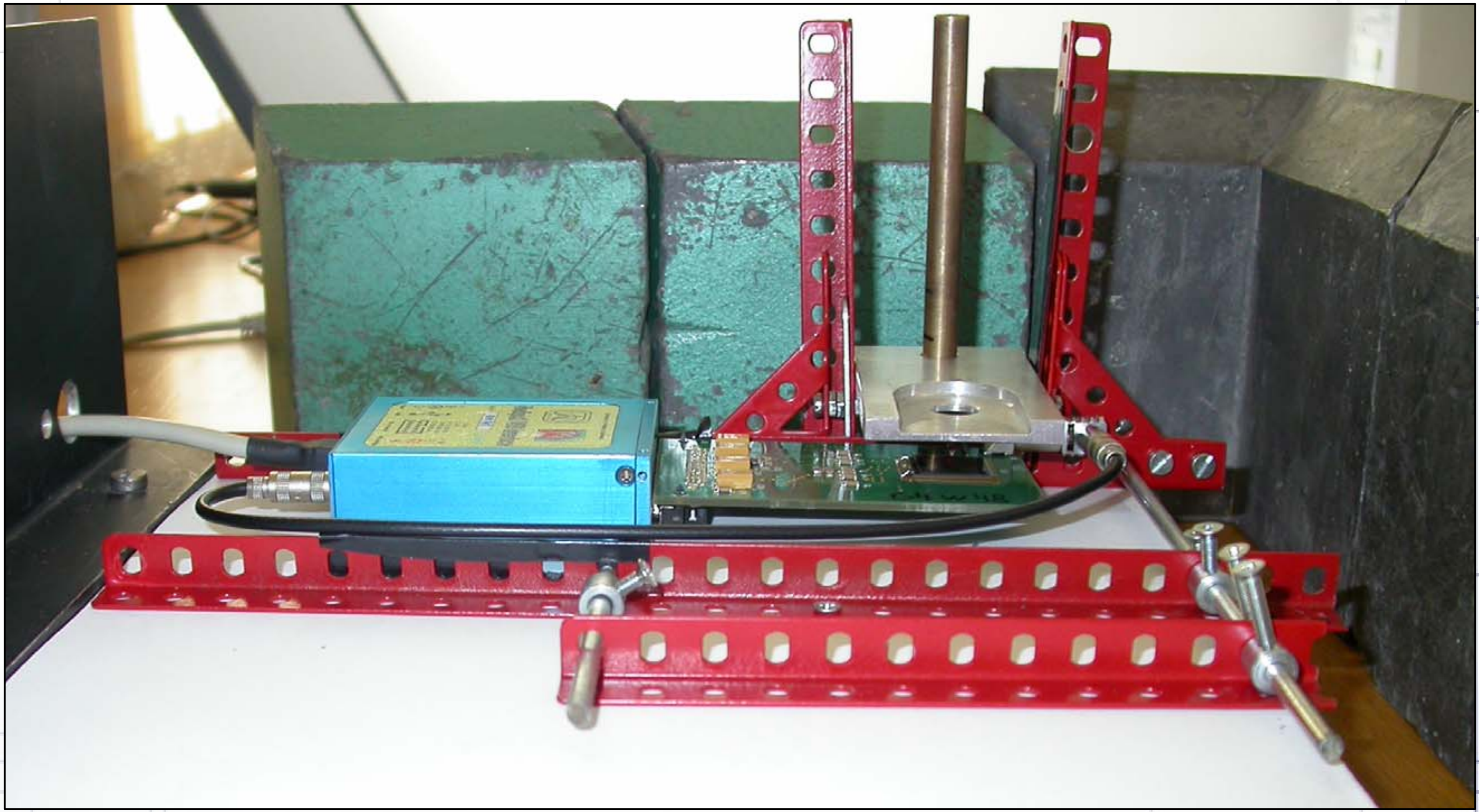


Photons



http://www.physics.nist.gov/PhysRefData/Xcom/Text/XCOM.html

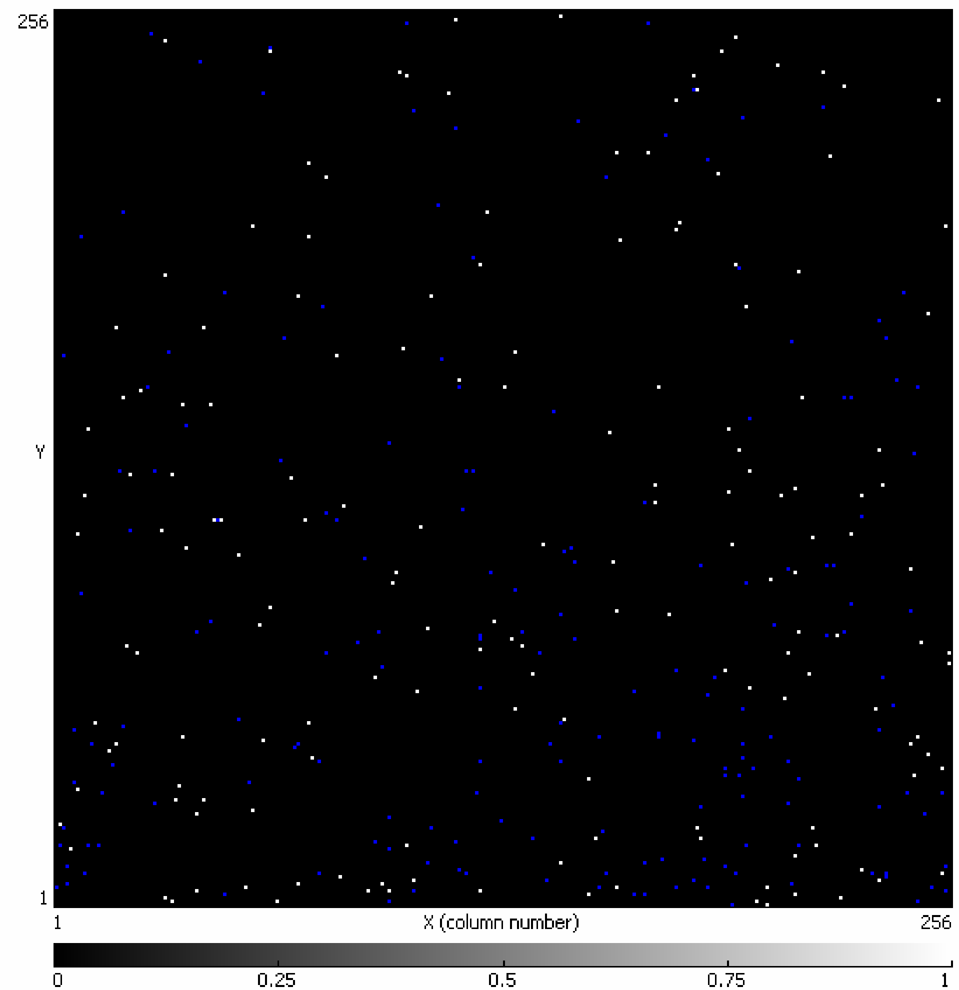
Setup for sources



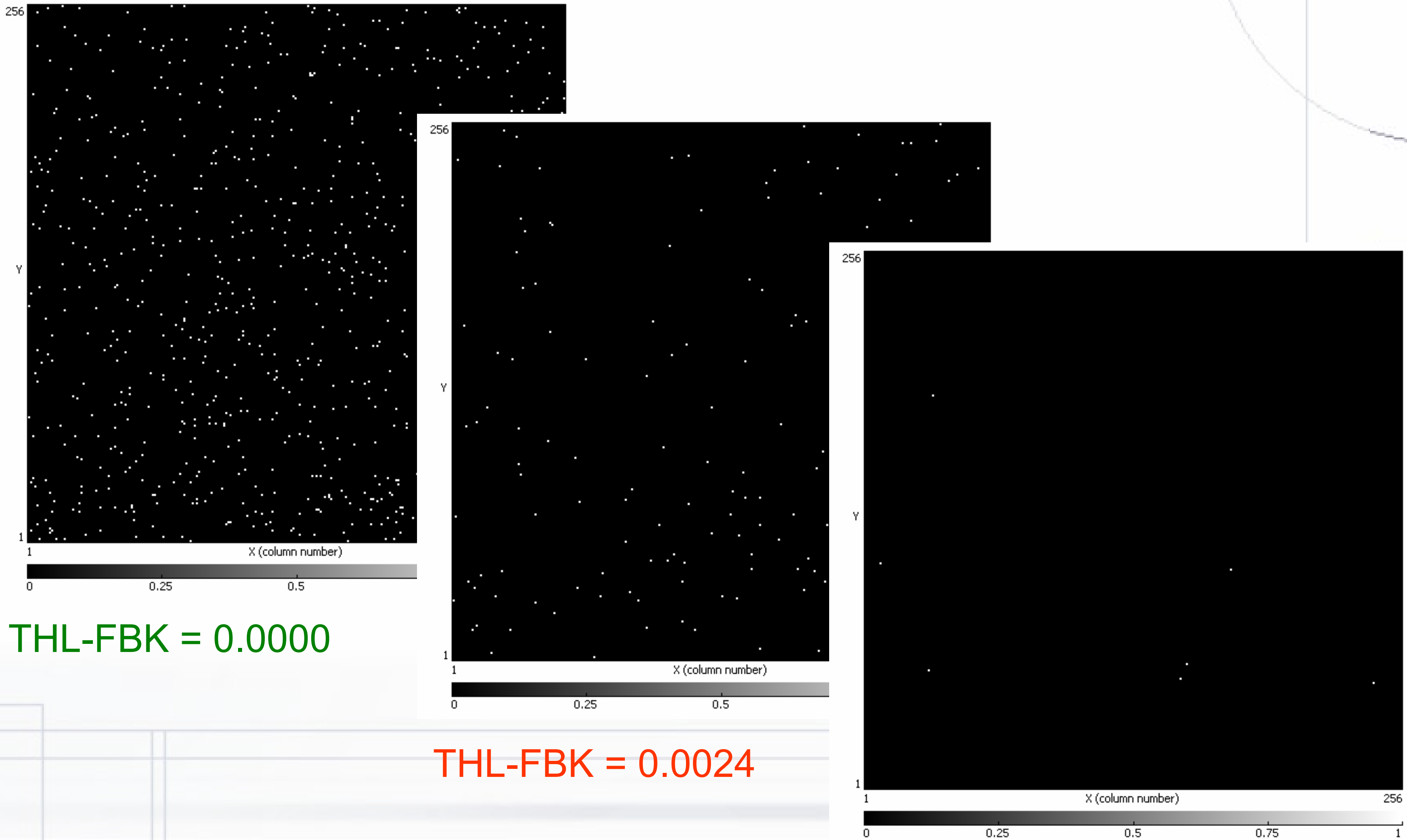
Photons – ^{55}Fe

- Production of X-rays with hv = 6 keV
  - Primary interaction in
    - Energy of the photoel
      E = hv – BE
      for silicon, 1.8 keV is t
      (predominant at that p

    Energy deposited by the
    Range of such electrons
- Deposition is always



Photons – 6 keV X-Rays (1 sec)

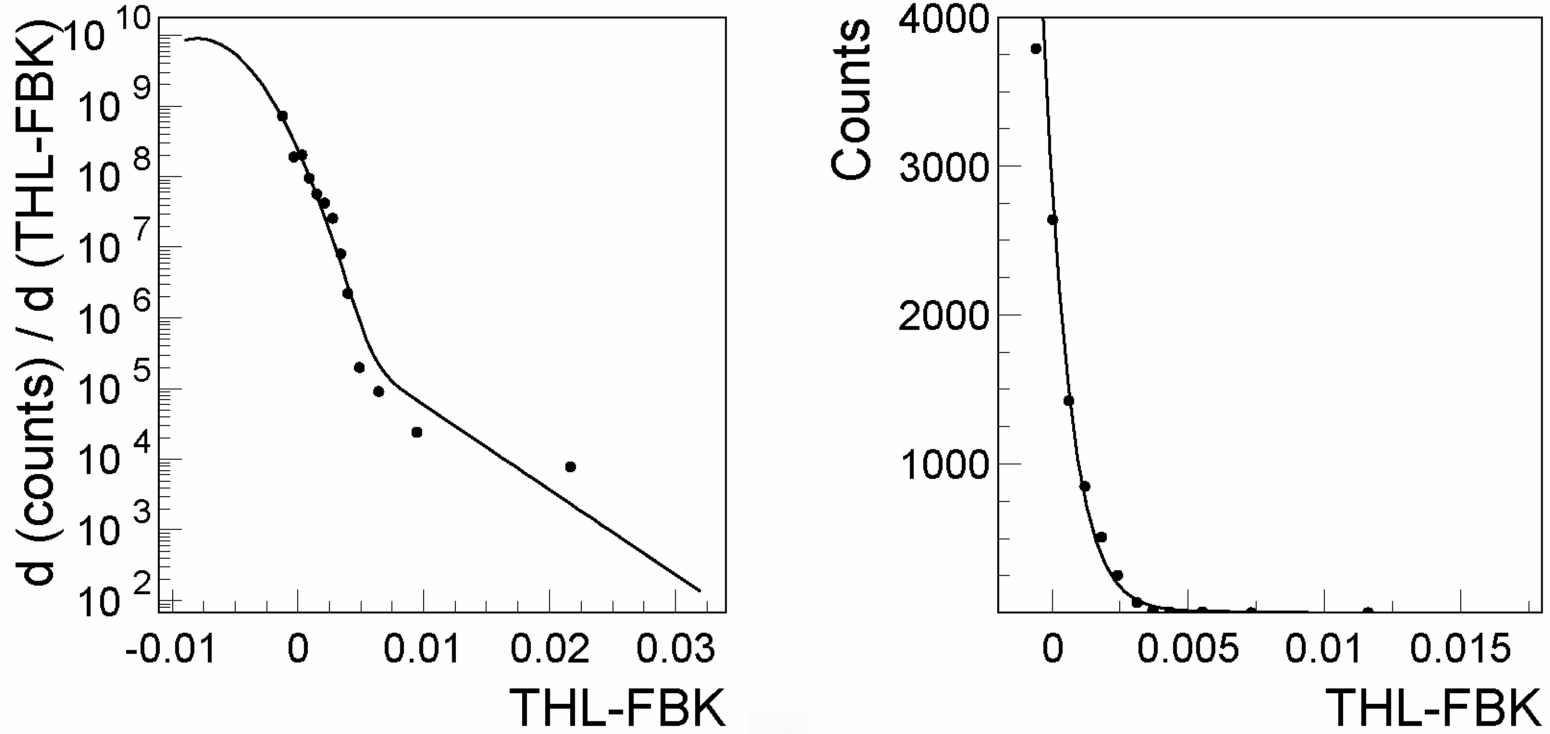


THL-FBK = 0.0000

THL-FBK = 0.0024

THL-FBK = 0.0049

Photons – 6 keV X-Rays

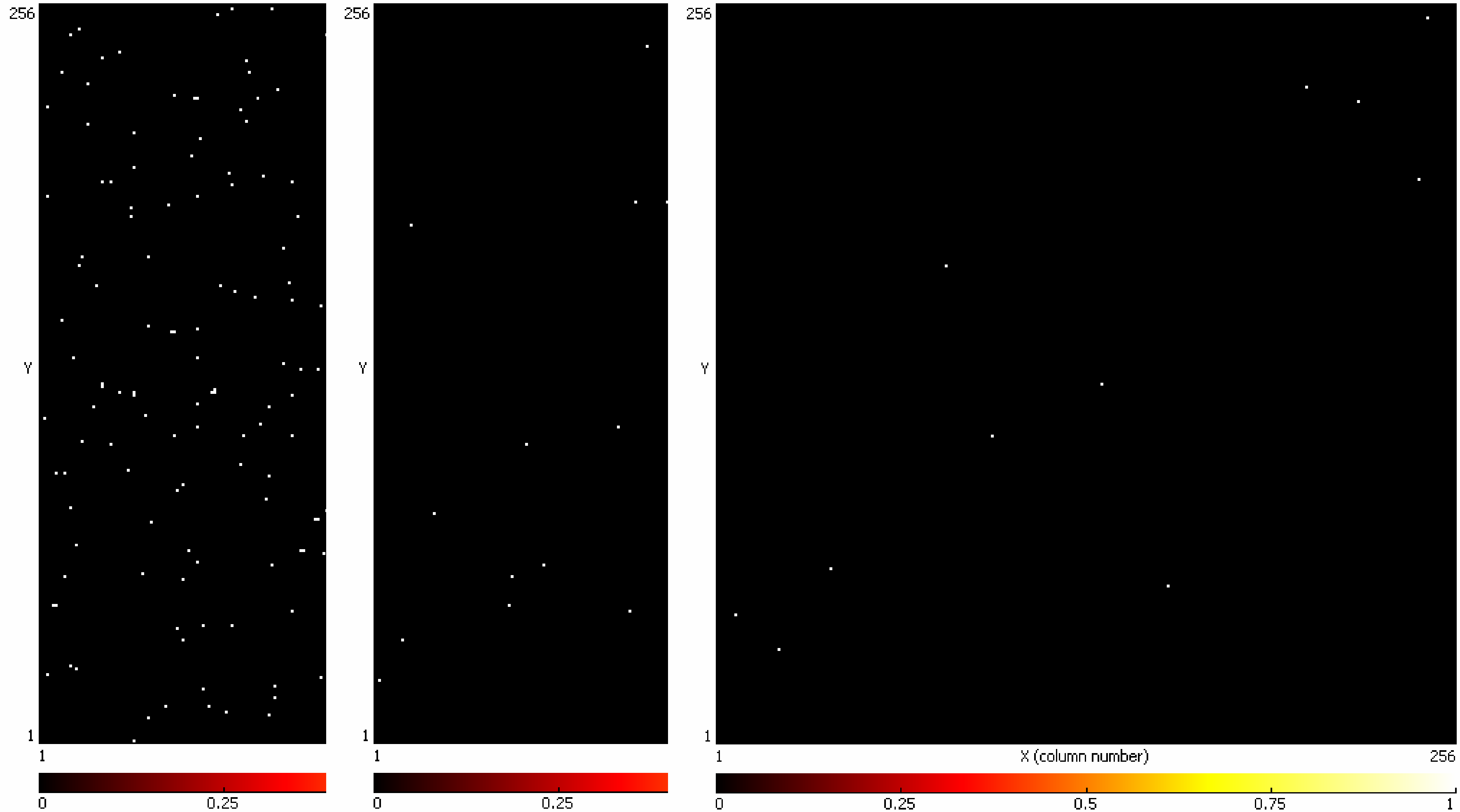


Photons – ^{241}Am

- Decays to ^{237}Np, emitting alphas and gammas.
  - Main gamma lines:
    59.5 keV at 35.9 % and 26.3 keV at 2.4 %
- At 59.5 keV:
  - Photoelectric effect with the K-shell
- Energy of the electron: 57.7 keV
- Range using CSDA approximation: ~30 μm

(Source:http://www.physics.nist.gov/PhysRefData/Star/ESTAR.html)

Photons – 60 keV



THL-FBK = 0.0000 THL-FBK = 0.0049 THL-FBK = 0.1074

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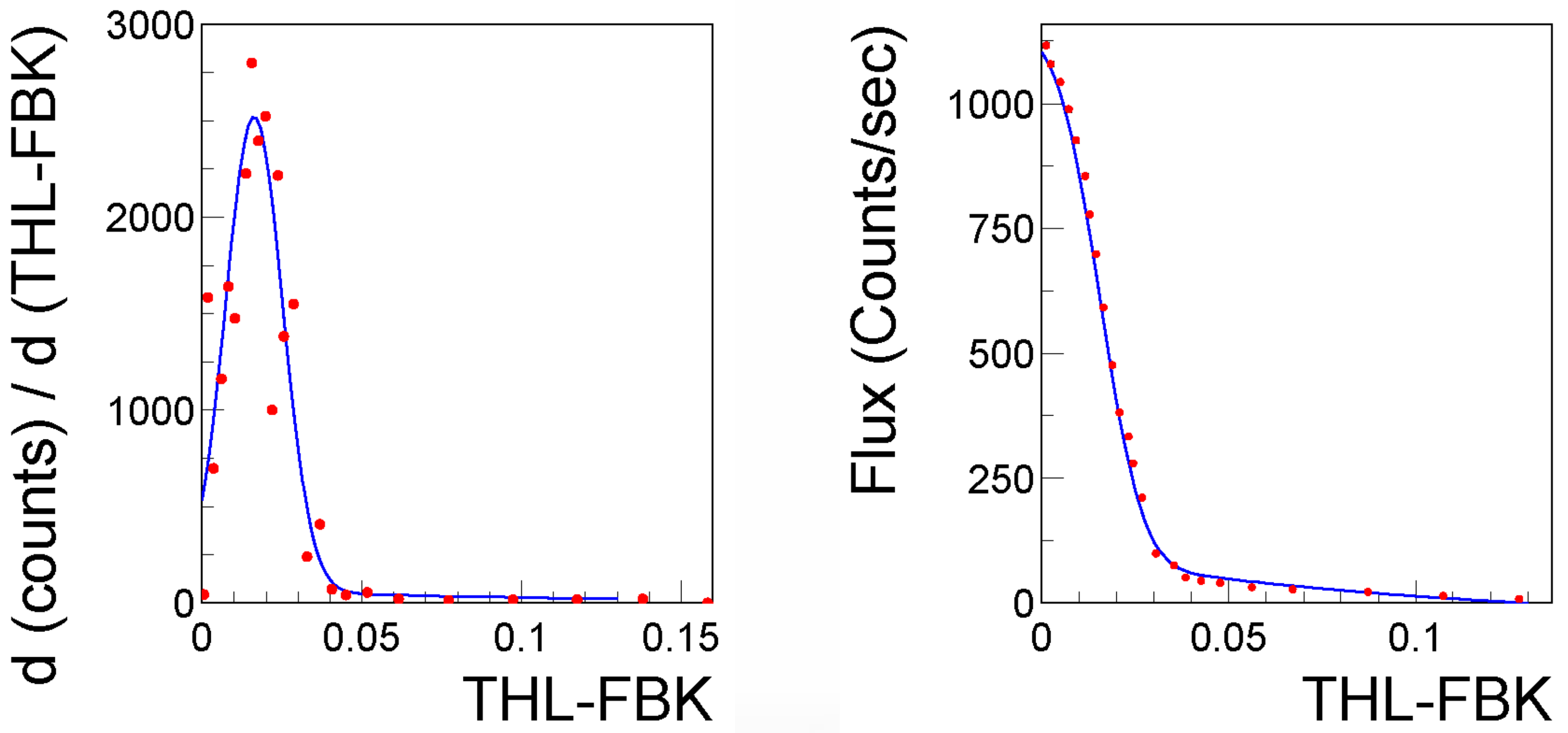
Photons – 60 keV gammas



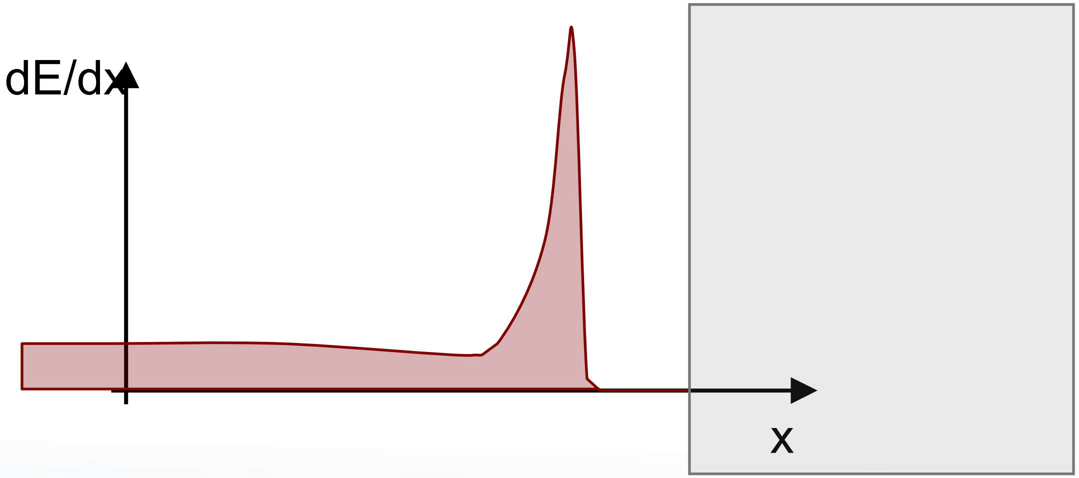
THL-FBK = 0.0163 → E = 58 keV !

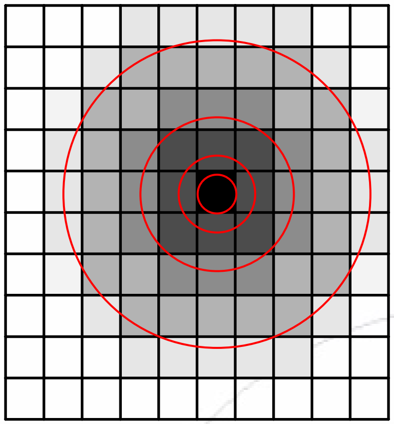
Alphas

Alphas

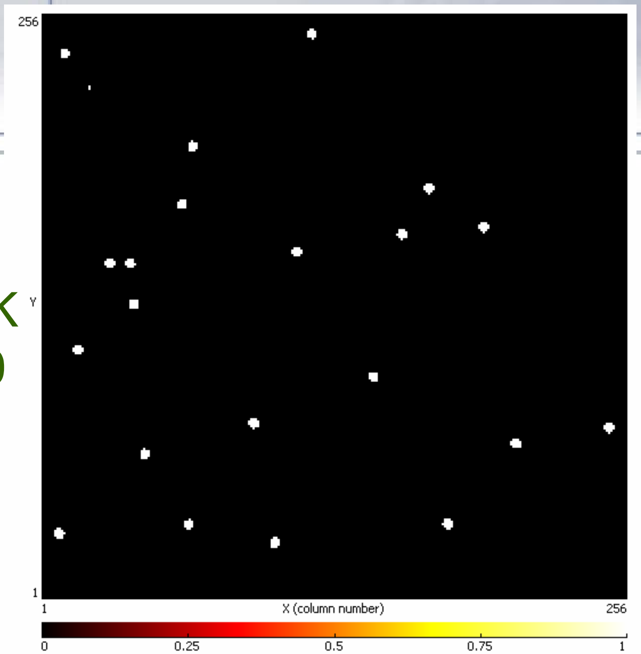
- Bethe-Bloch

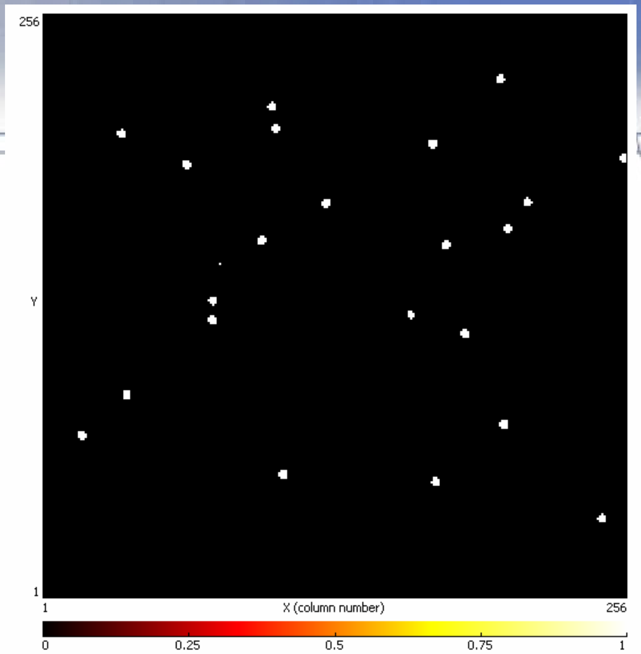
$$-\frac{1}{\rho}\frac{dE}{dx} = 4\pi r_e^2 m_e c^2 z^2 \frac{N_{Avogadro} Z}{A}\frac{1}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right) - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}\right]$$





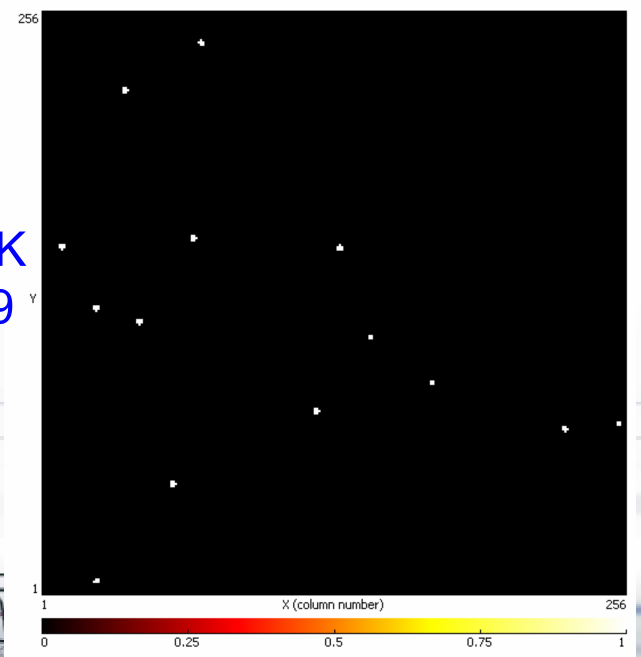
THL-FBK
= 0.0000

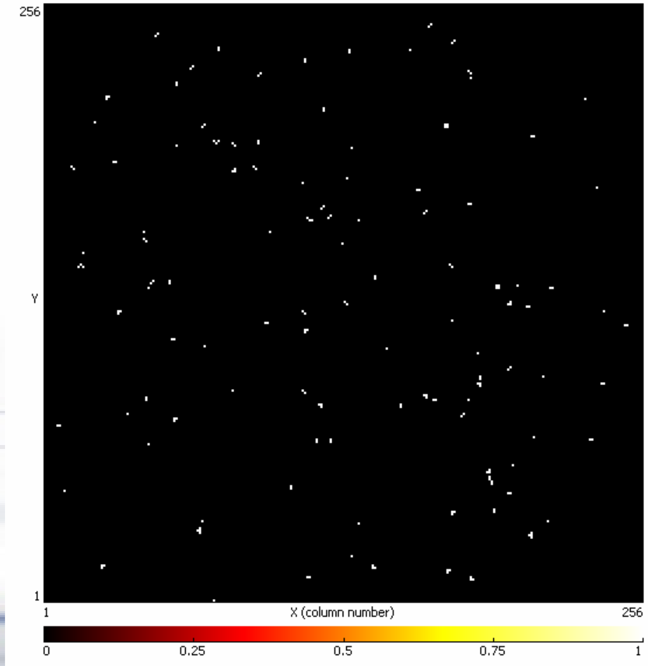




THL-FBK
= 0.0116

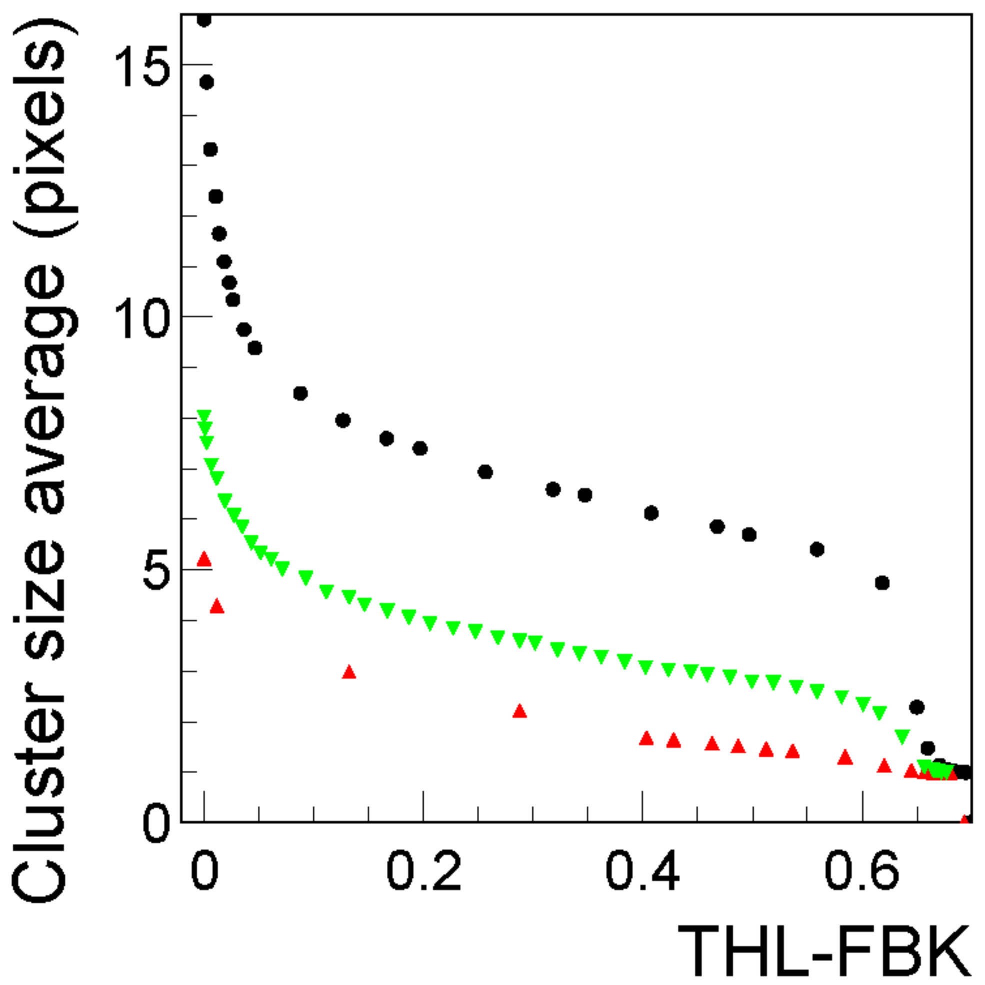
THL-FBK
= 0.3479





THL-FBK
= 0.6604

Changing Alpha Energy



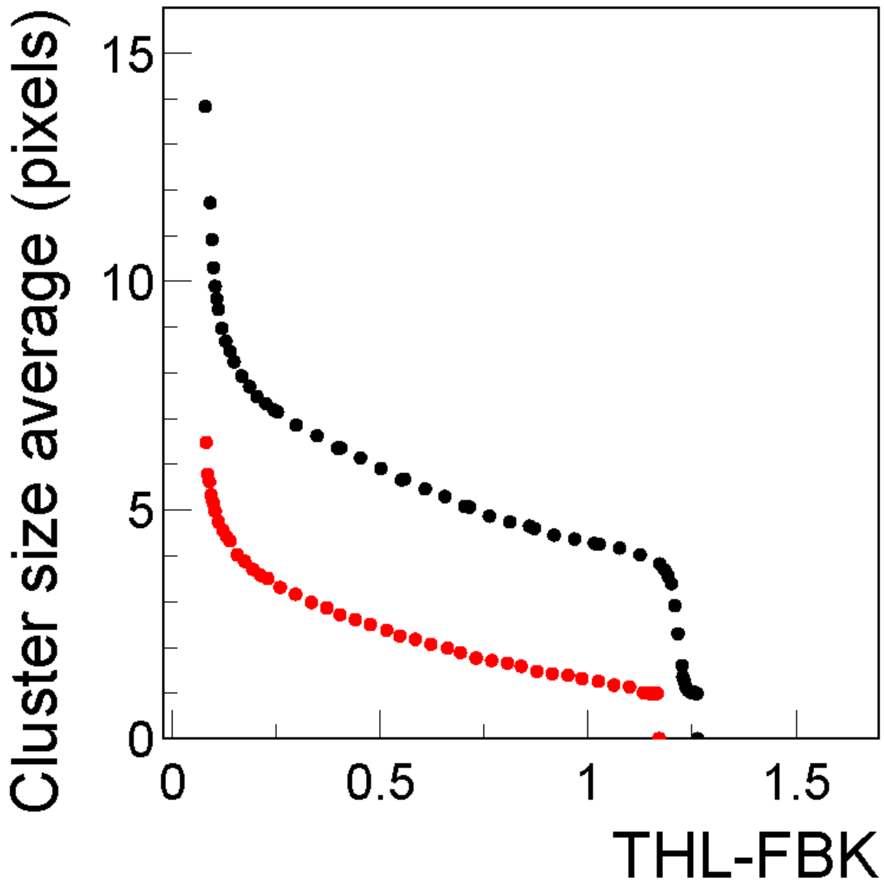
E_α = 4.20 MeV

E_α = 1.41 MeV

E_α = 0.69 MeV

The threshold is too low.
These energies cannot calibrate the threshold with this FBK.

Raising FBK

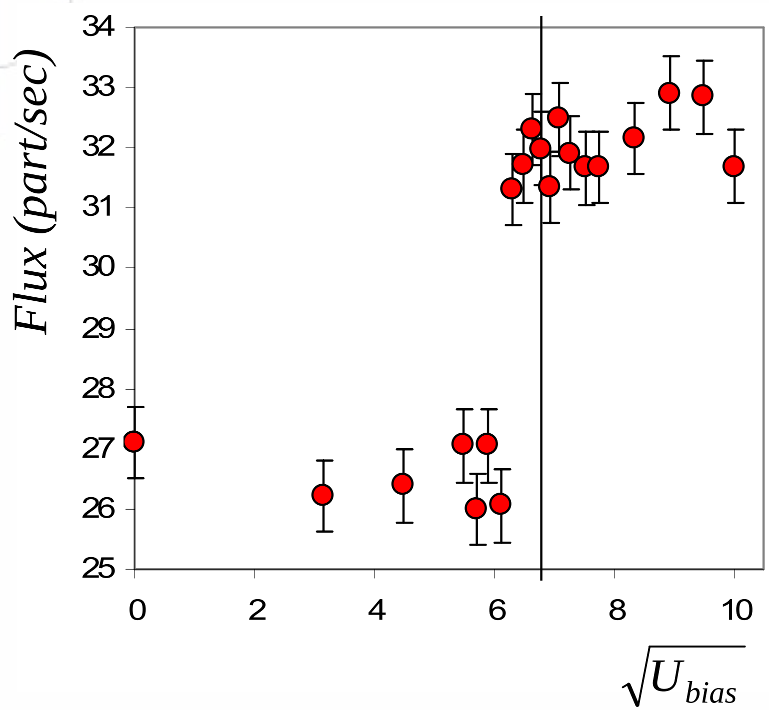


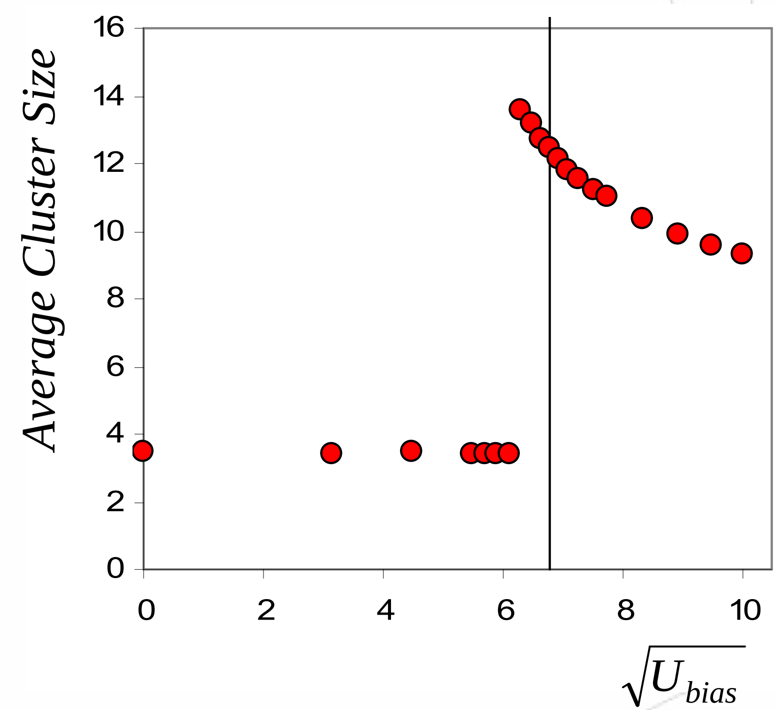
E_α = 4.20 MeV

E_α = 0.74 MeV

Tentatively:
THL-FBK = 1.1719 → 735 keV

About full depletion voltage …

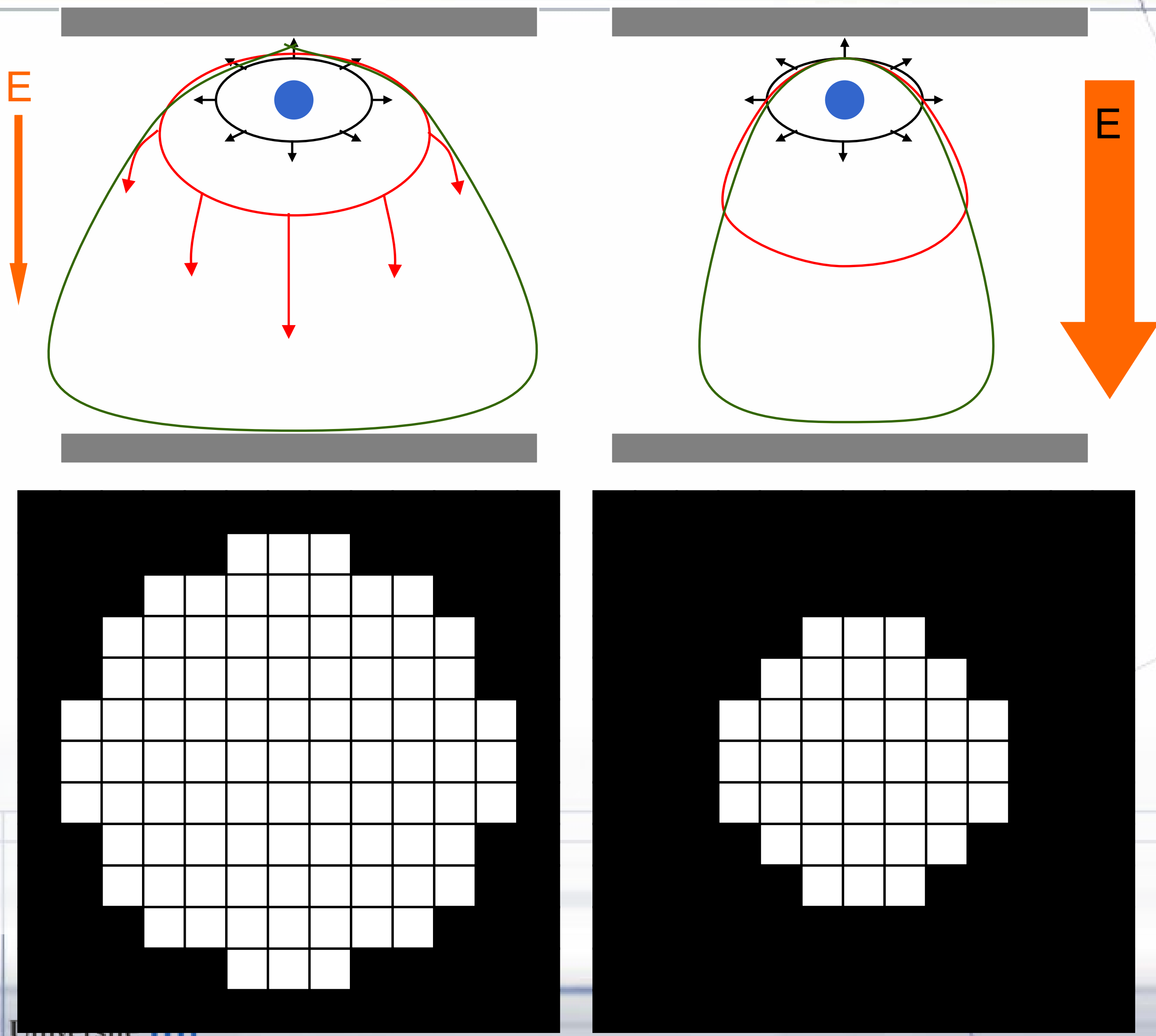




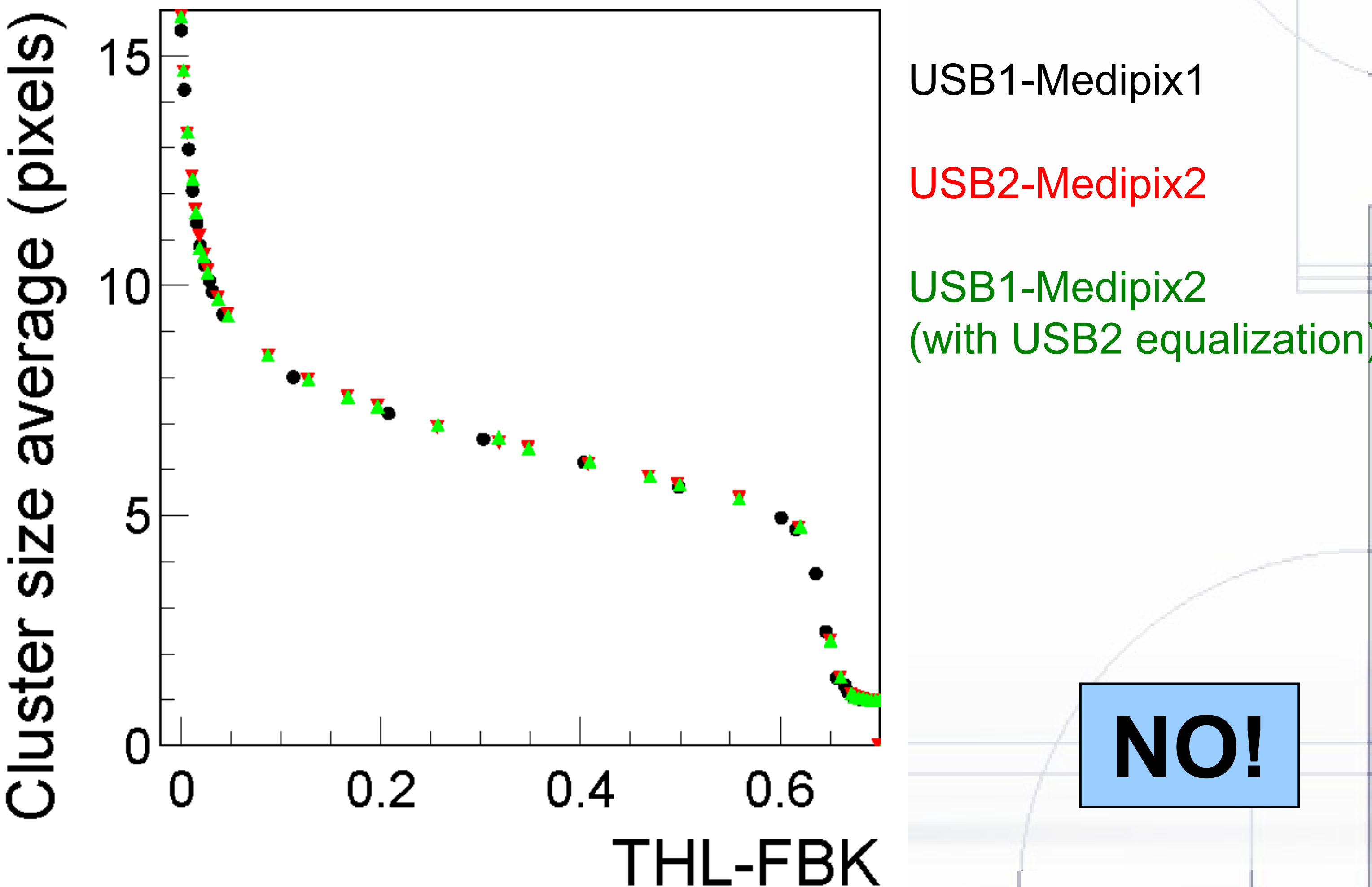
4.478 MeV deposit → Range of ~21 µm

Collection starts at 40 V → **V_{fd} = 46 ± 1 V**

Cluster Size as function of U_{bias}



Does the threshold depend on the USB or the Medipix used?



NO!

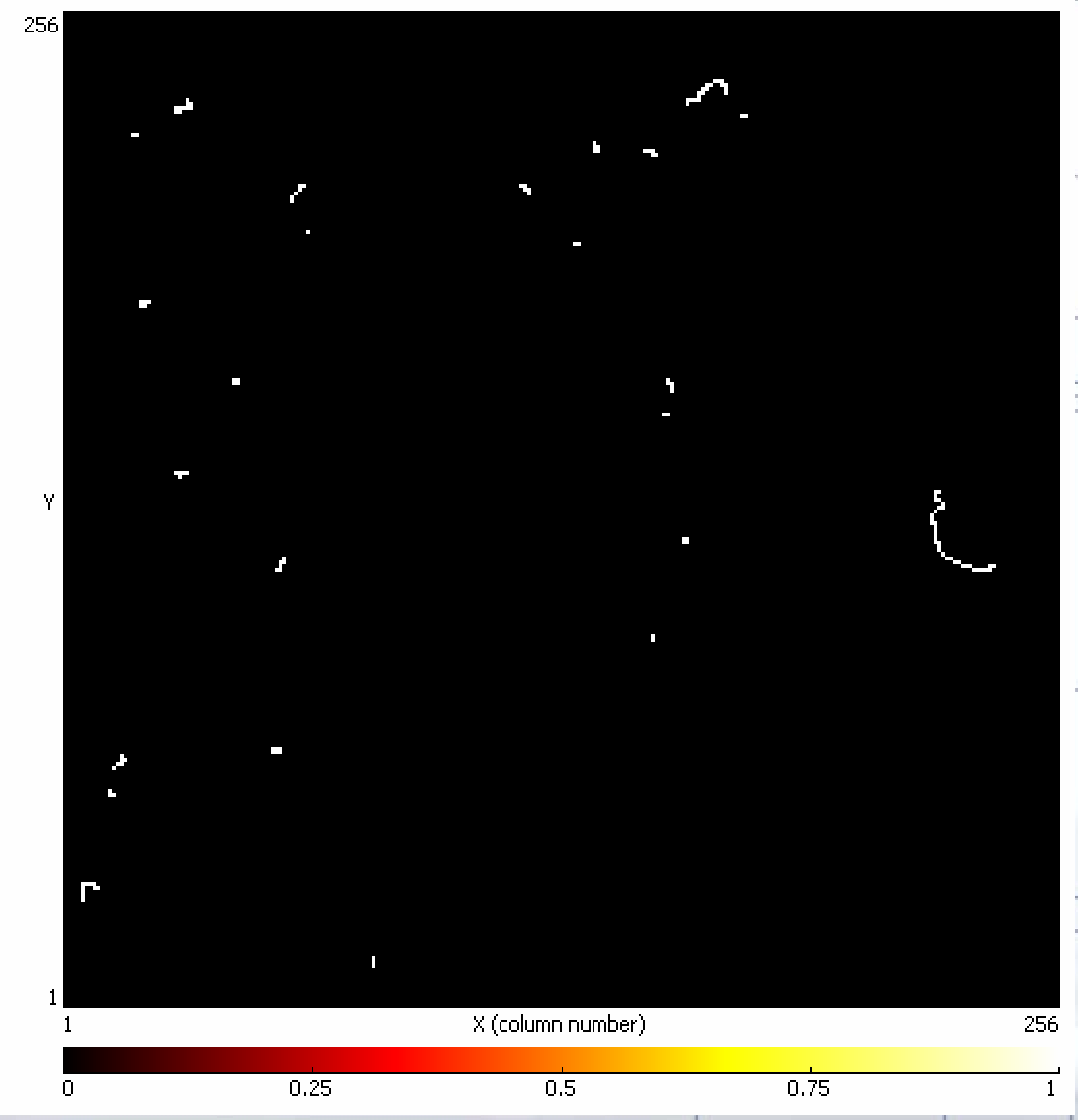
Electrons

THL-FBK = 0.0000

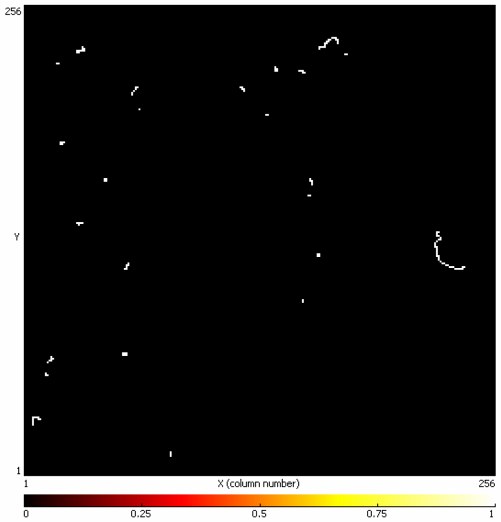
Electrons

Source ^{90}Sr-Y

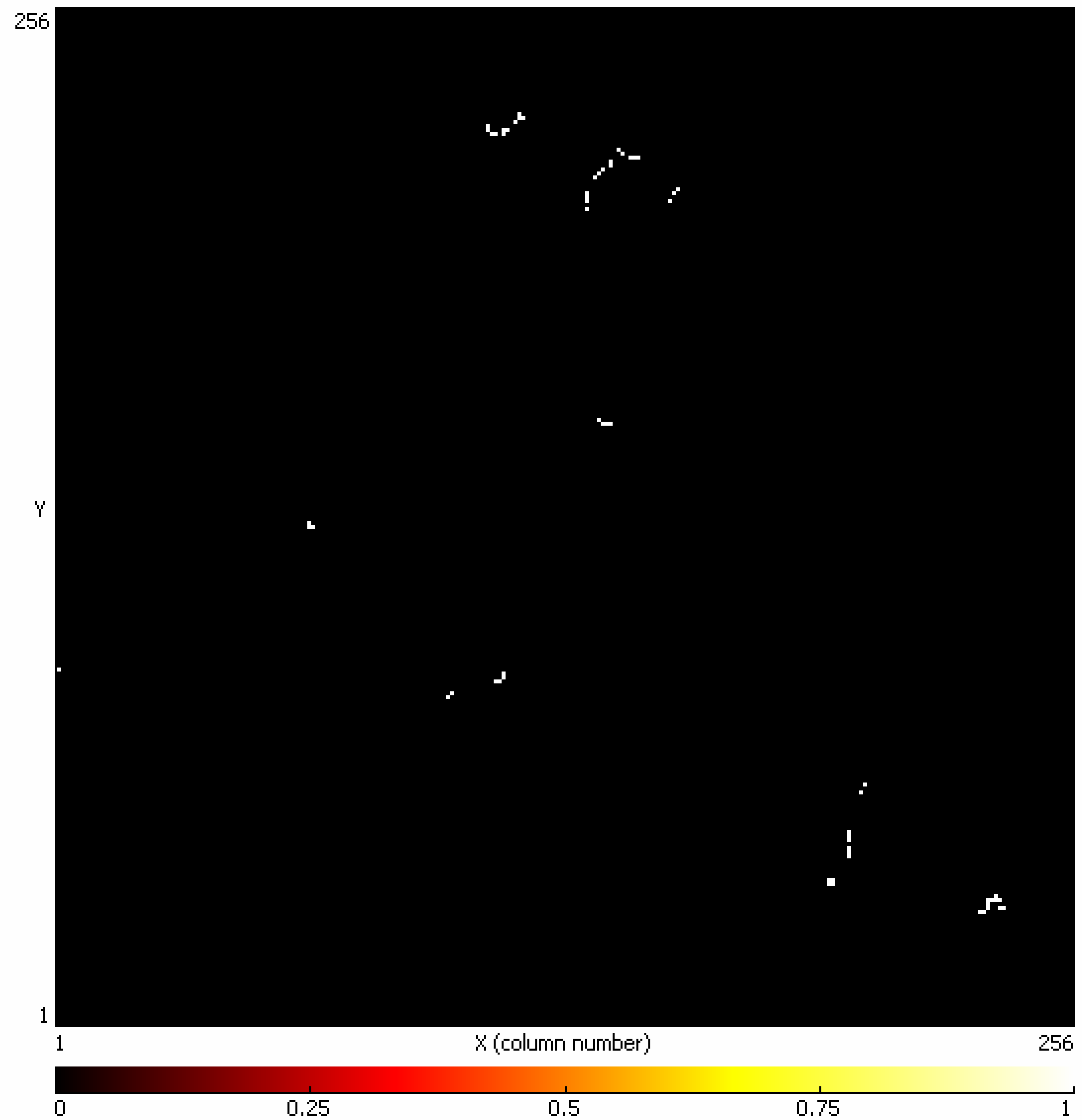
Average electron energy:
935 keV → mip



THL-FBK = 0.0275



THL-FBK=0.0000



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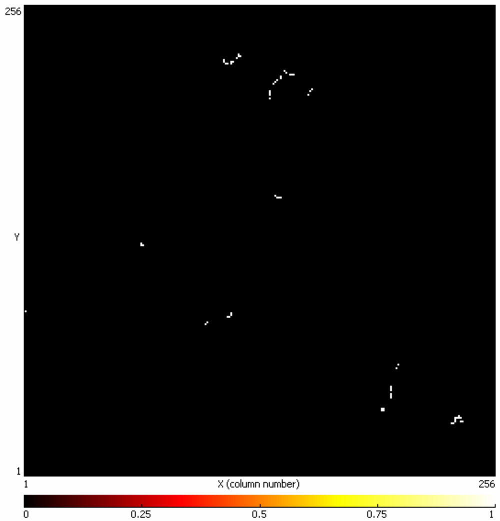
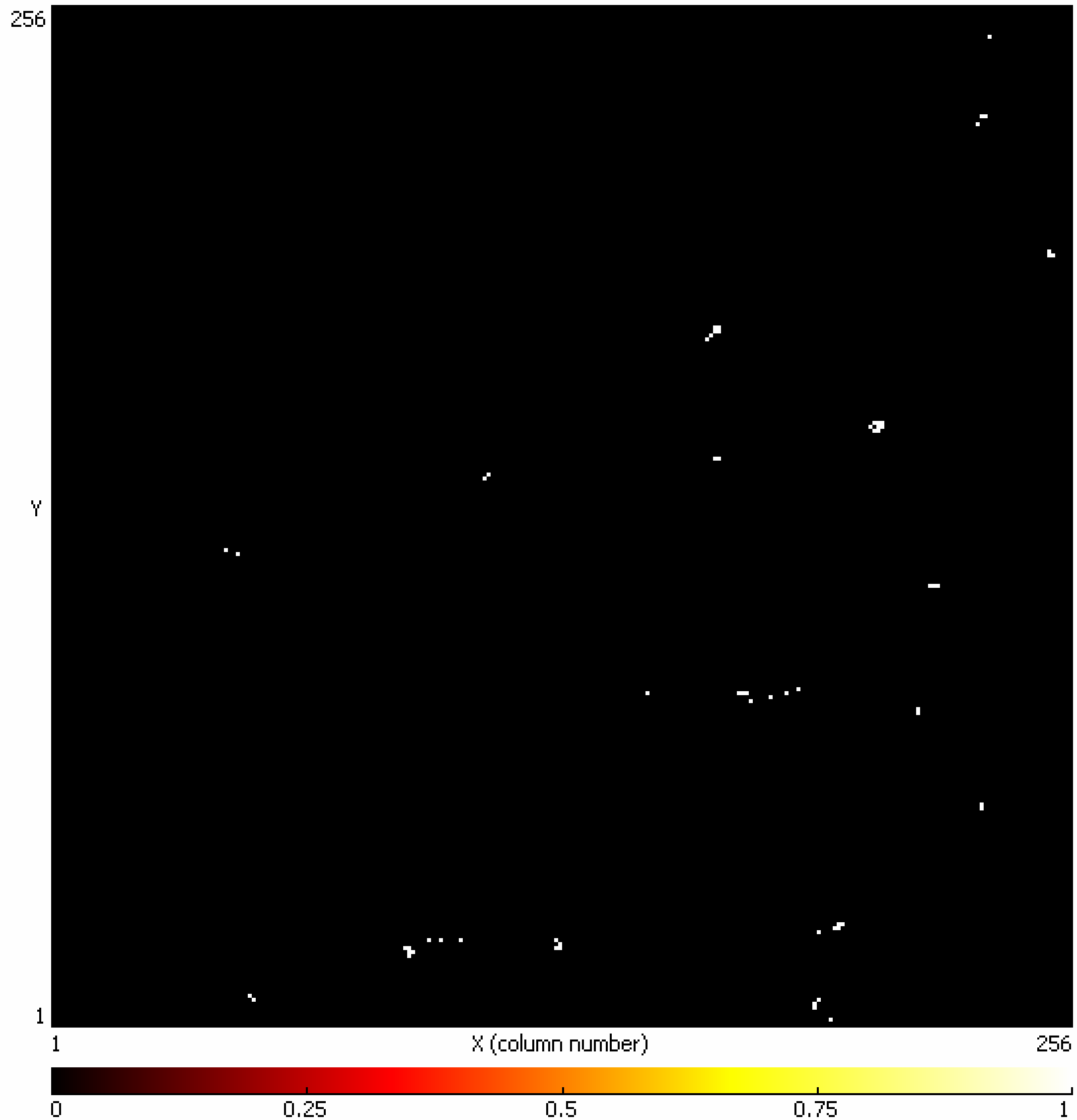
THL-FBK = 0.0519

Electrons



THL-FBK=0.0275



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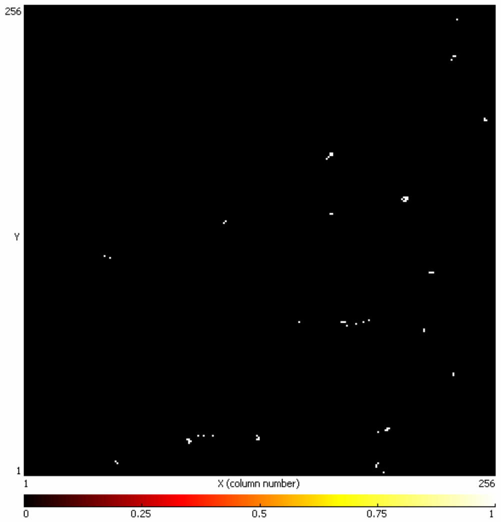
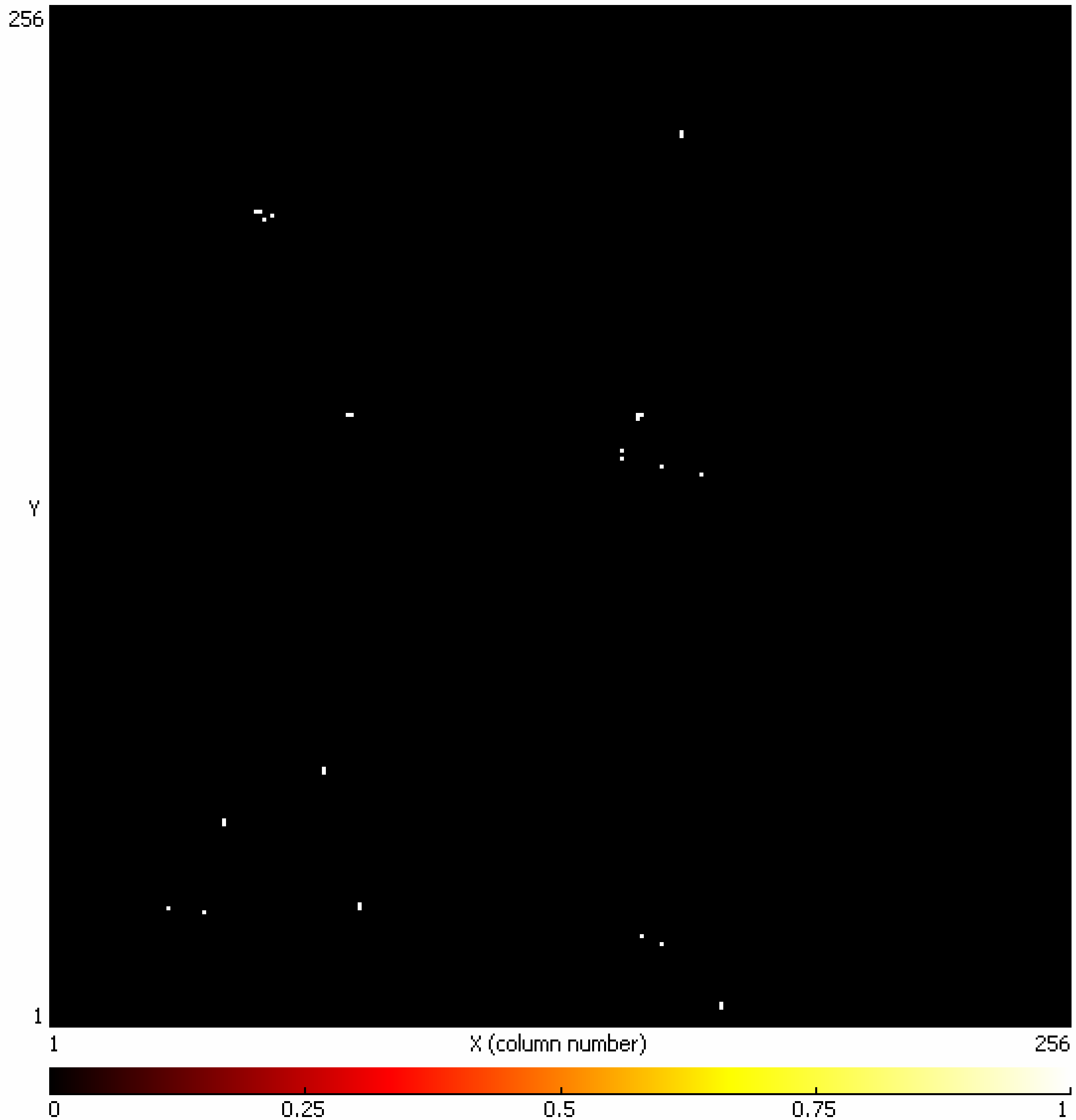
THL-FBK = 0.0842

Electrons



THL-FBK=0.0519



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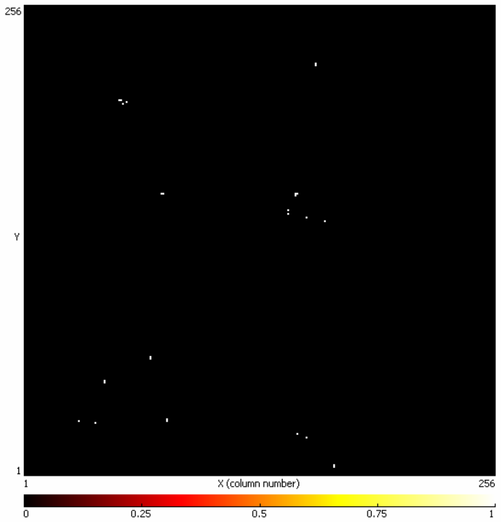
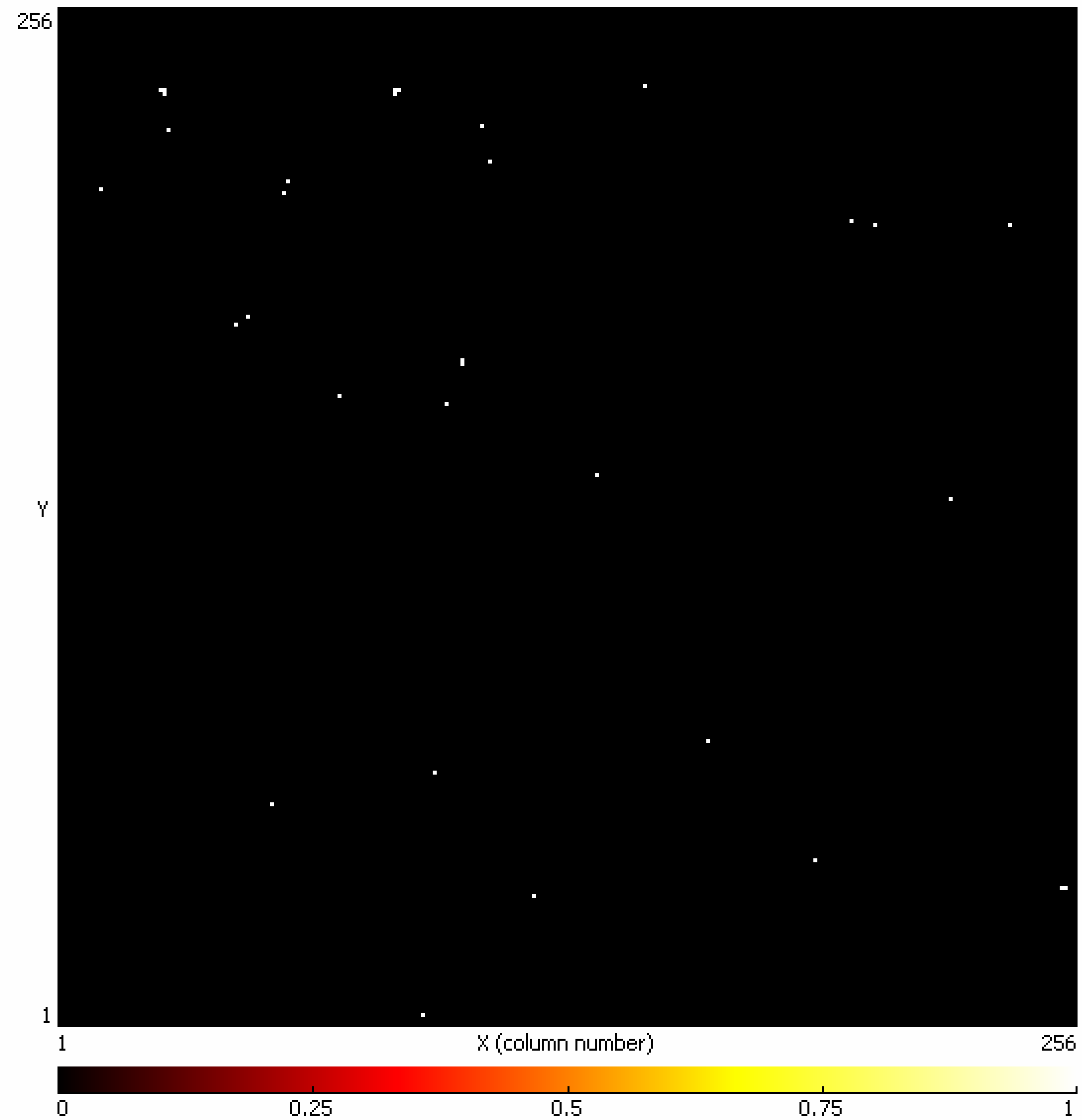
THL-FBK = 0.1324

Electrons



THL-FBK=0.0842



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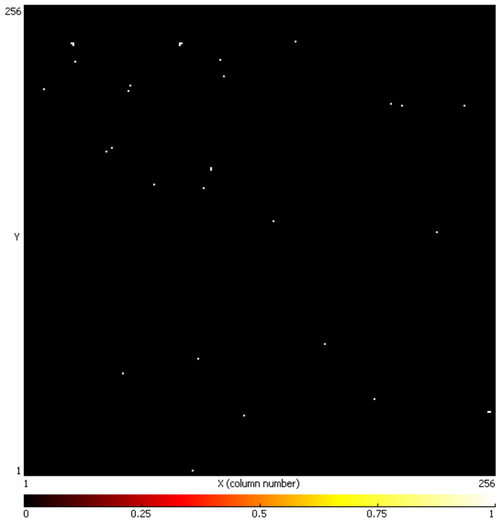
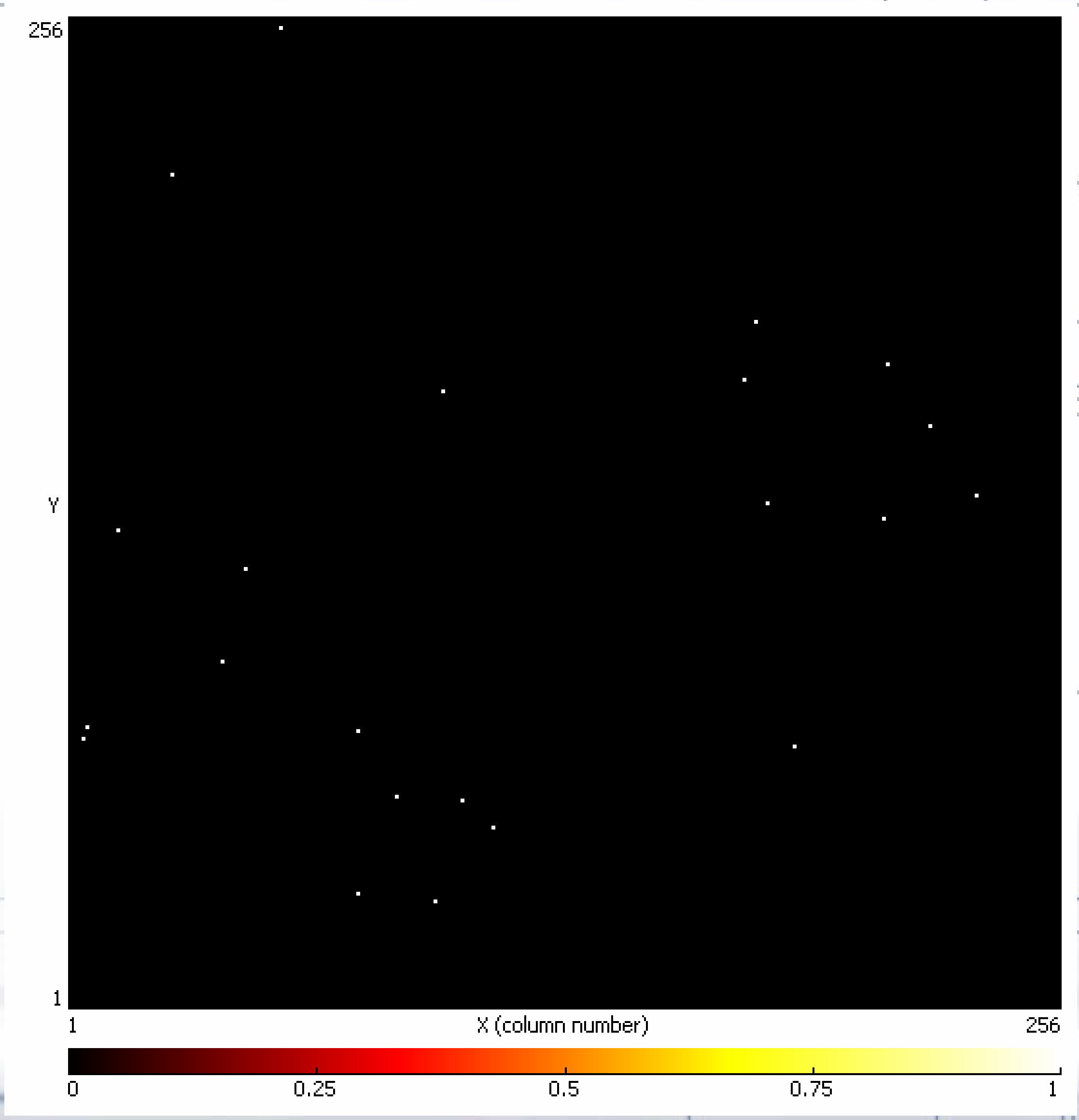
THL-FBK = 0.2875

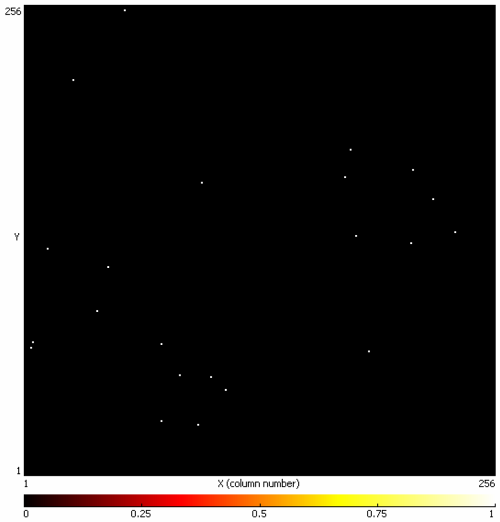
Electrons



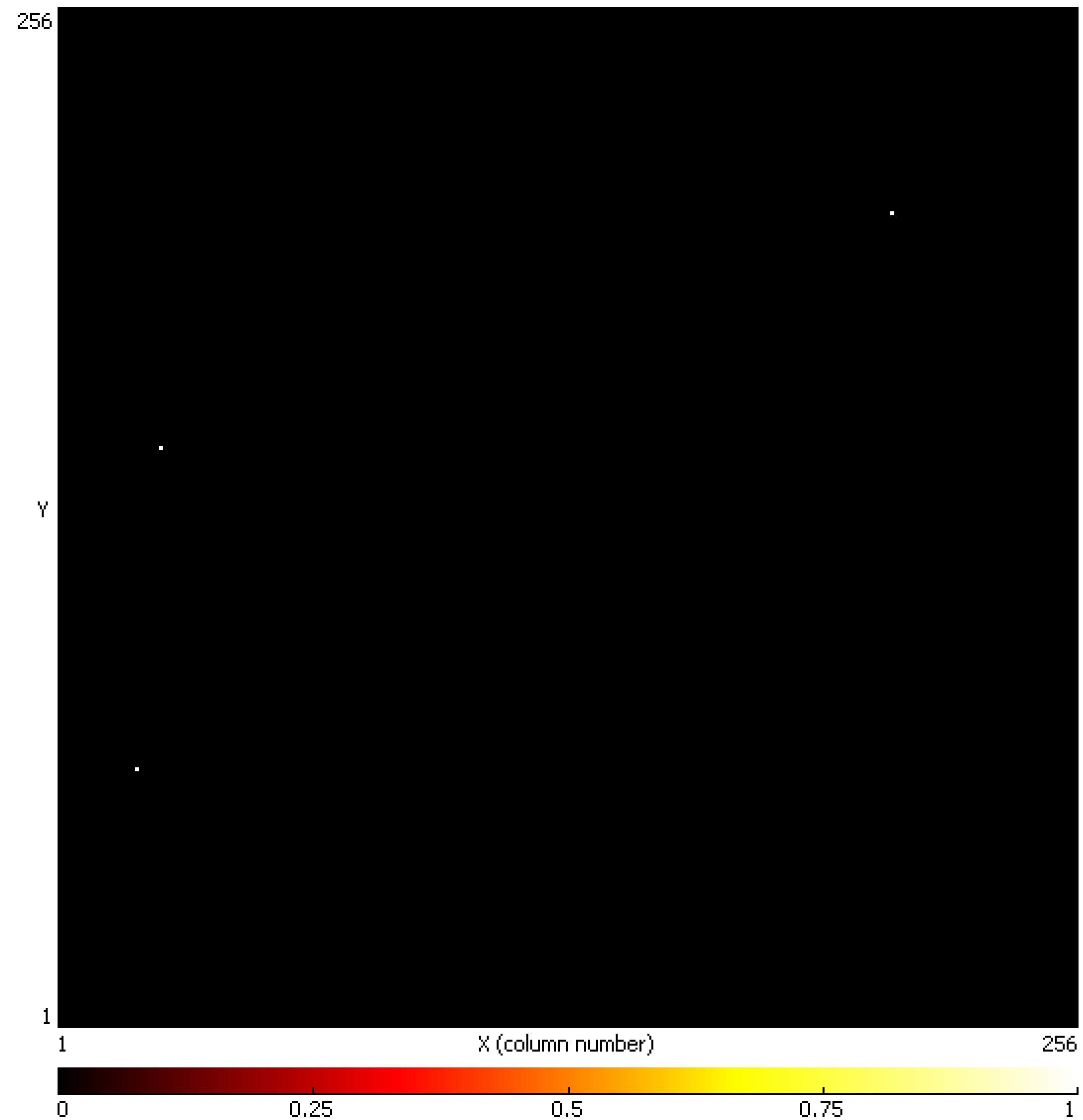
THL-FBK=0.1324



THL-FBK = 0.5194



THL-FBK=0.2875



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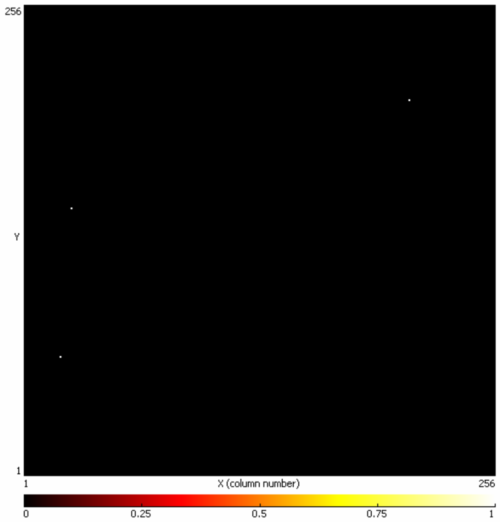
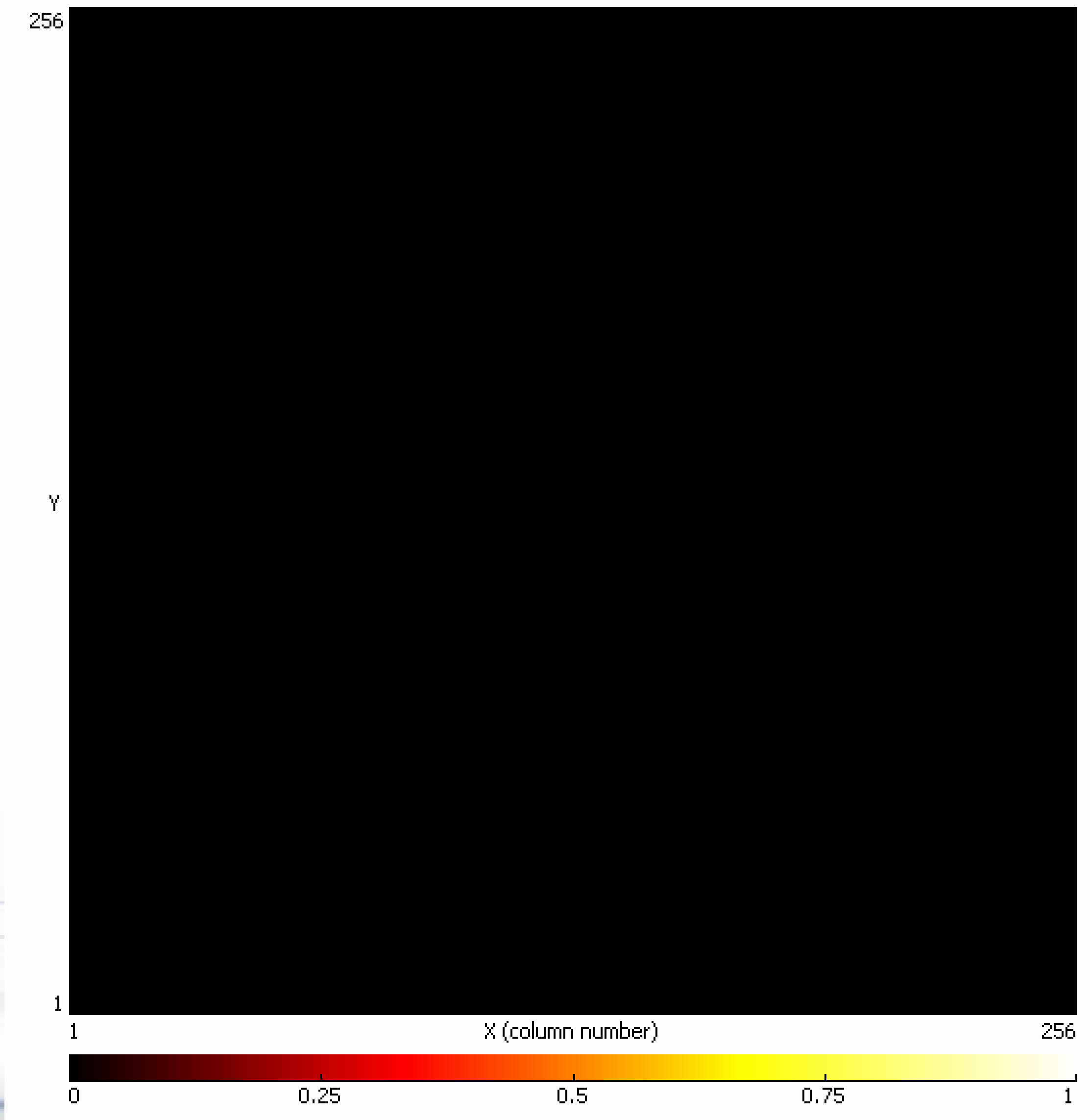
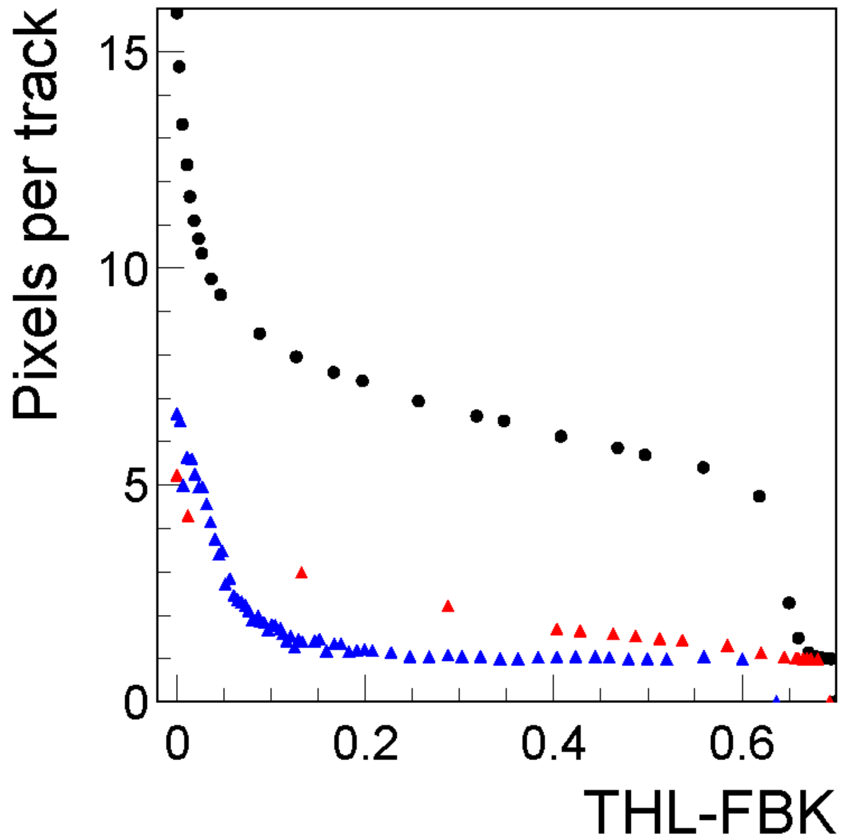
THL-FBK = 0.6000



THL-FBK=0.5194



Some – very preliminary – results

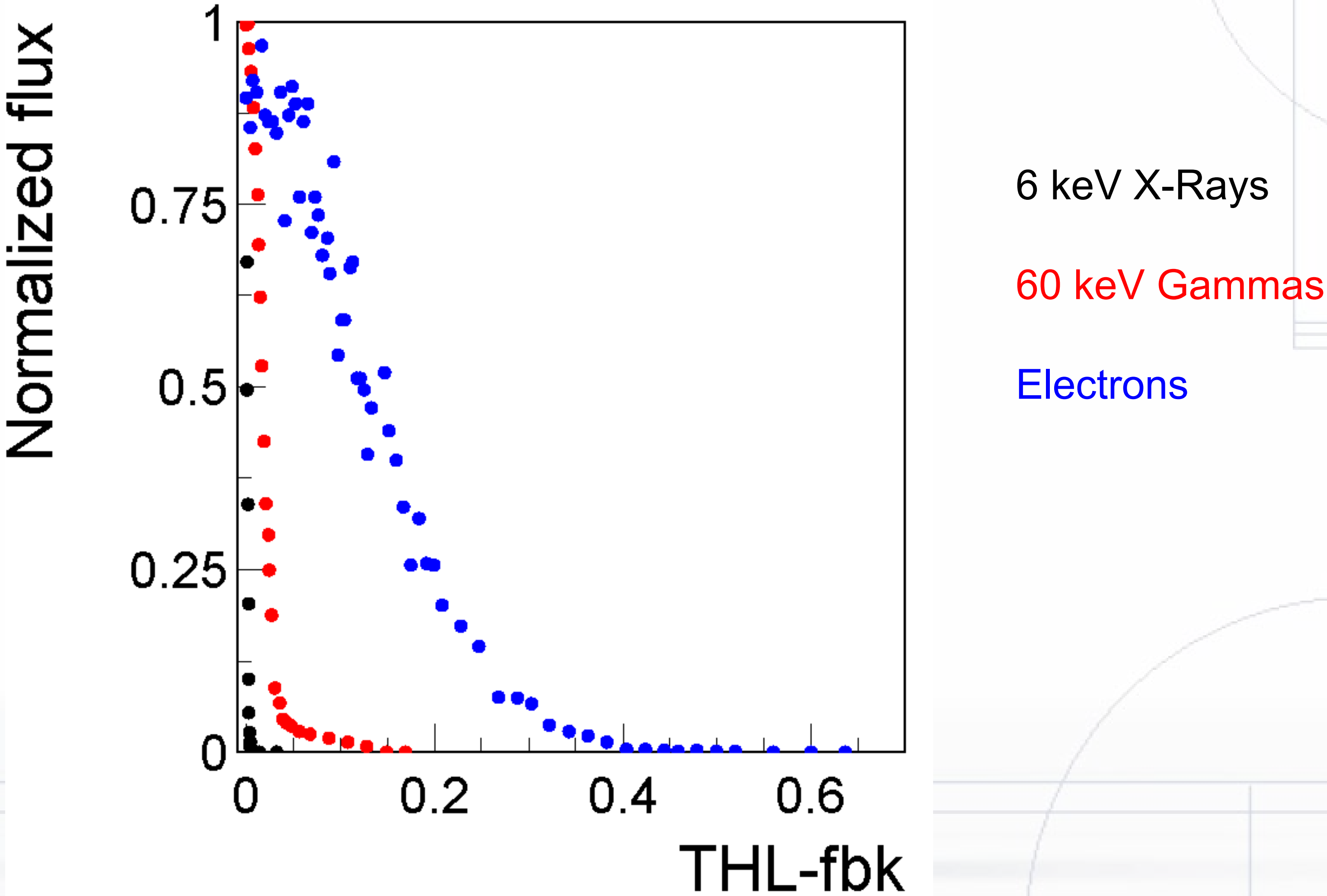


E_α = 4.20 MeV

E_α = 0.69 MeV

Electrons

Some – very preliminary – results

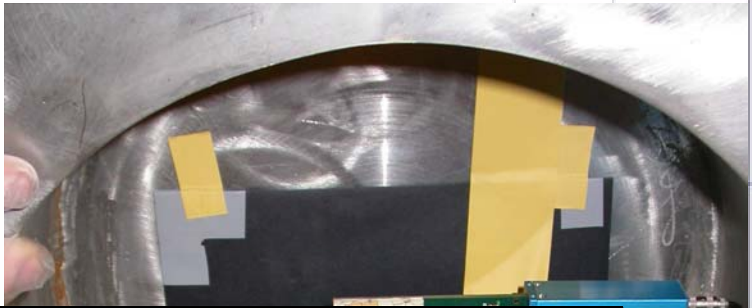


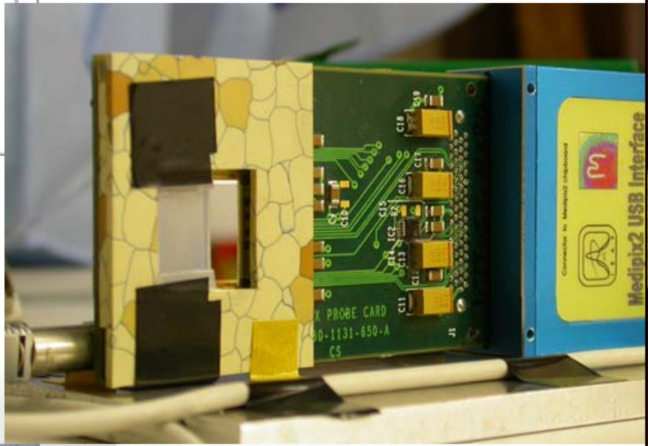
Neutrons

Neutrons

detection through reaction with Polyethylene

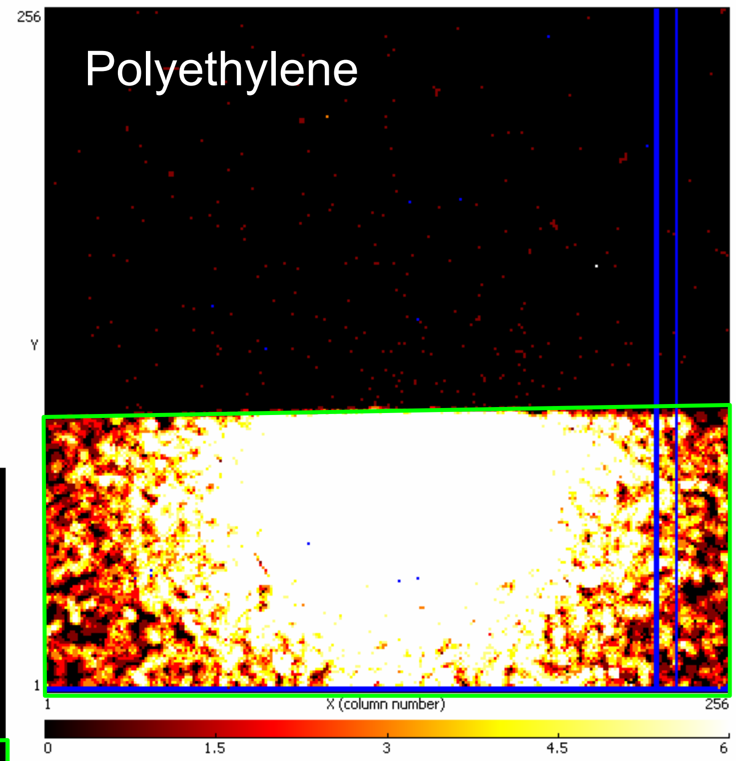
- Using the reaction
  $n + {}^{1}H \rightarrow p + n$
- Fast neutrons from reactor

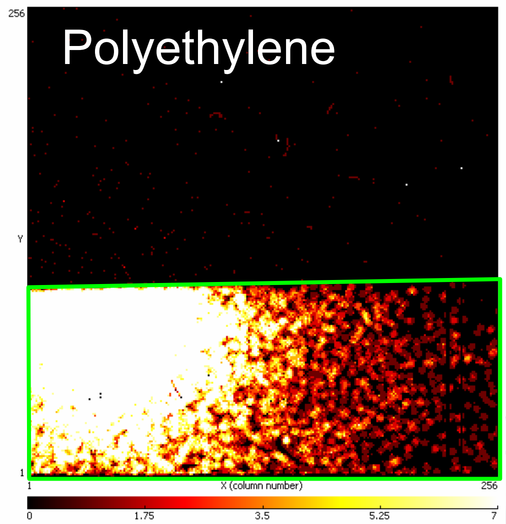


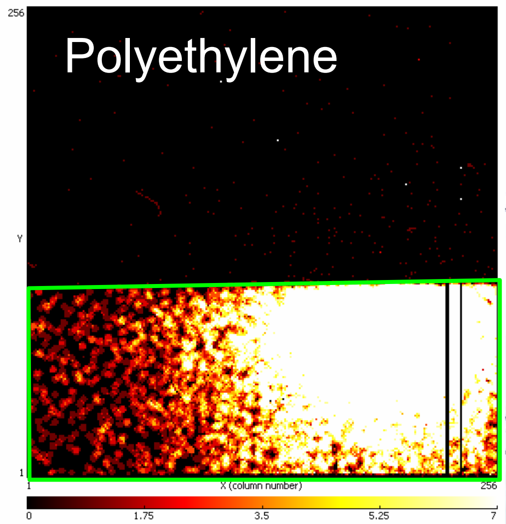


Thank you, Radek Skoda, for making this measurement possible!

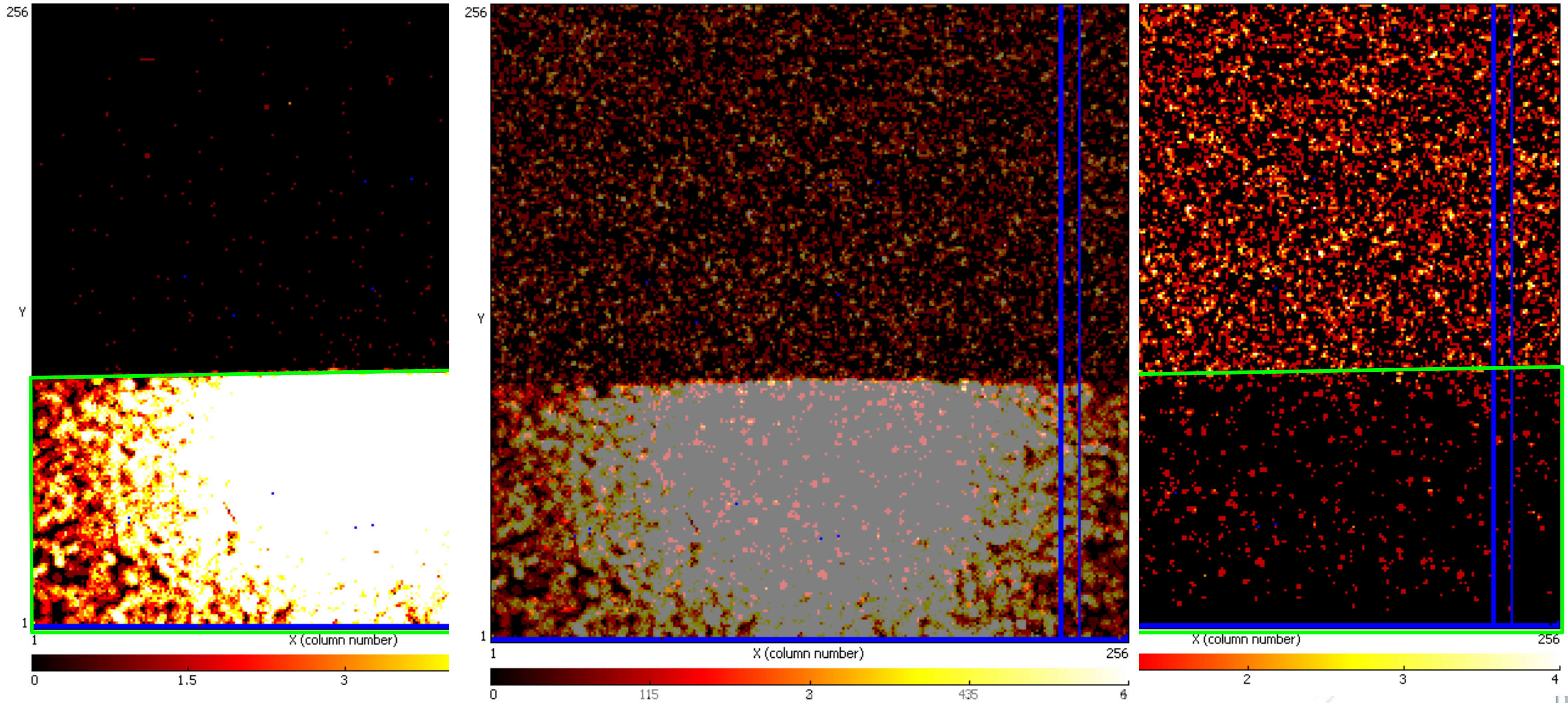
Position of the polyethylene layer



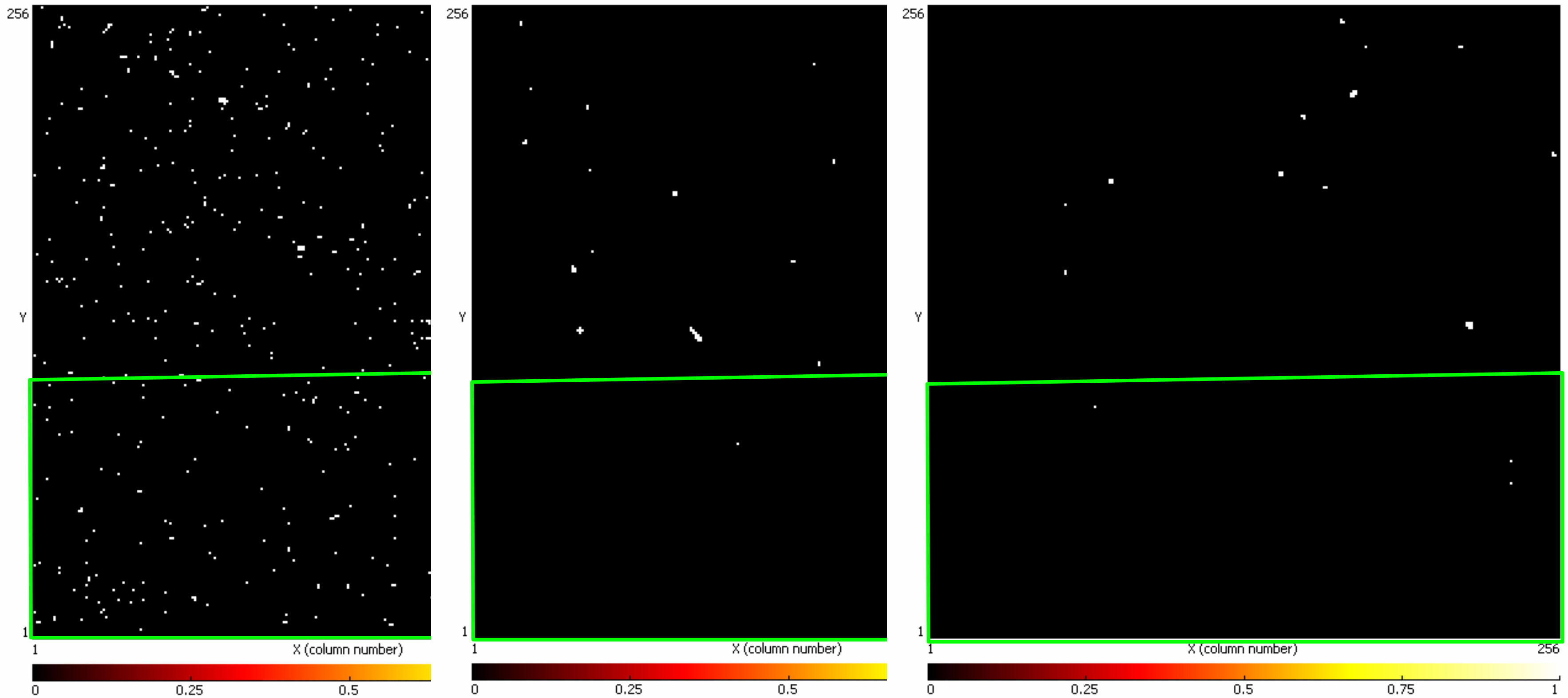




Results obtained at the reactor Sparrow



Importance of threshold

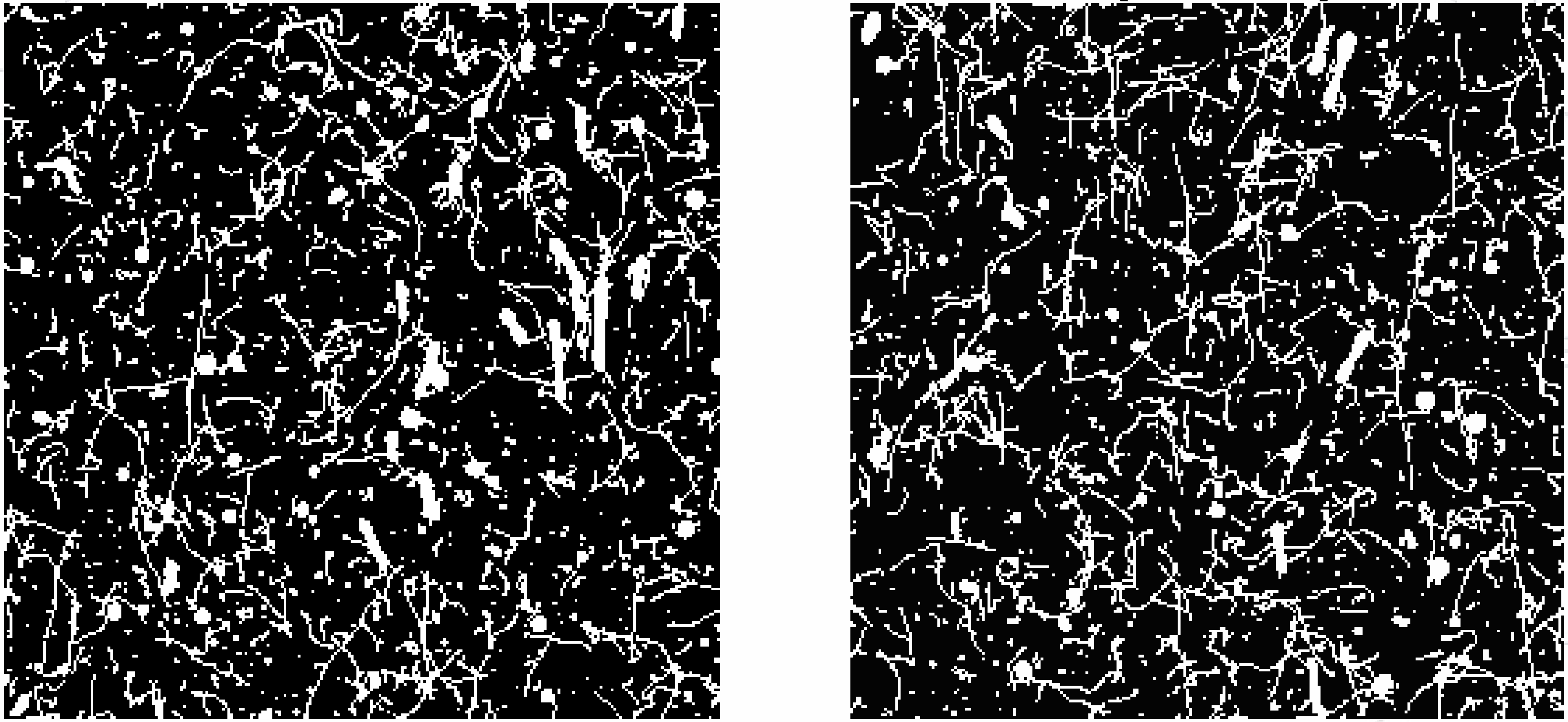


THL-FBK = 0.1459
FBK = 128

THL-FBK = 0.6268
FBK = 200

THL-FBK = 0.8929
FBK = 200

Examples of response of MEDIPIX-USB device to fast monochromatic neutrons: 17MeV neutrons, flux about 10^4 n/(s.cm^2)



- The direction of the neutrons with respect to the image was upstream (from bottom to top). The huge background is due to gamma rays which accompany neutrons. Half of the sensor (the right-hand side) was covered with a CH2 foil about 1.3 mm thickness.
- One can clearly recognize long and rather thick tracks of recoiled protons (up to 2 mm, vertically oriented) and big tracks and clusters generated via 28Si(n,α)25Mg, 28Si(n,p)28Al nuclear reactions in the body of the silicon detector. These events are displayed on the dense background caused by tracks and traces of electrons from interactions of gamma rays. One can even recognize that proton tracks shapes follows a Bragg law.

Conclusions

- ONE energy (58 keV) has been definitively attributed to a threshold value
- A threshold has been identified to isolate the contribution of heavy charged particle from electrons
- All USB and Medipix give the same variation as a function of effective threshold
- Photons, Heavy charged particles and Electrons give specific tracks which can be identified.
- Adding a Polyethylene layer allows the detection of fast neutrons

Outlook

- More energy lines must be attributed to specific values of THL-FBK
  - Different X-Rays!
- More on neutrons
- Analysis of heavy charged particle tracks: influence of plasma effect in silicon

Děkuji vám!

Thank you!