Performance of the Medipix and Timepix devices for the recognition of electron-gamma radiation fields

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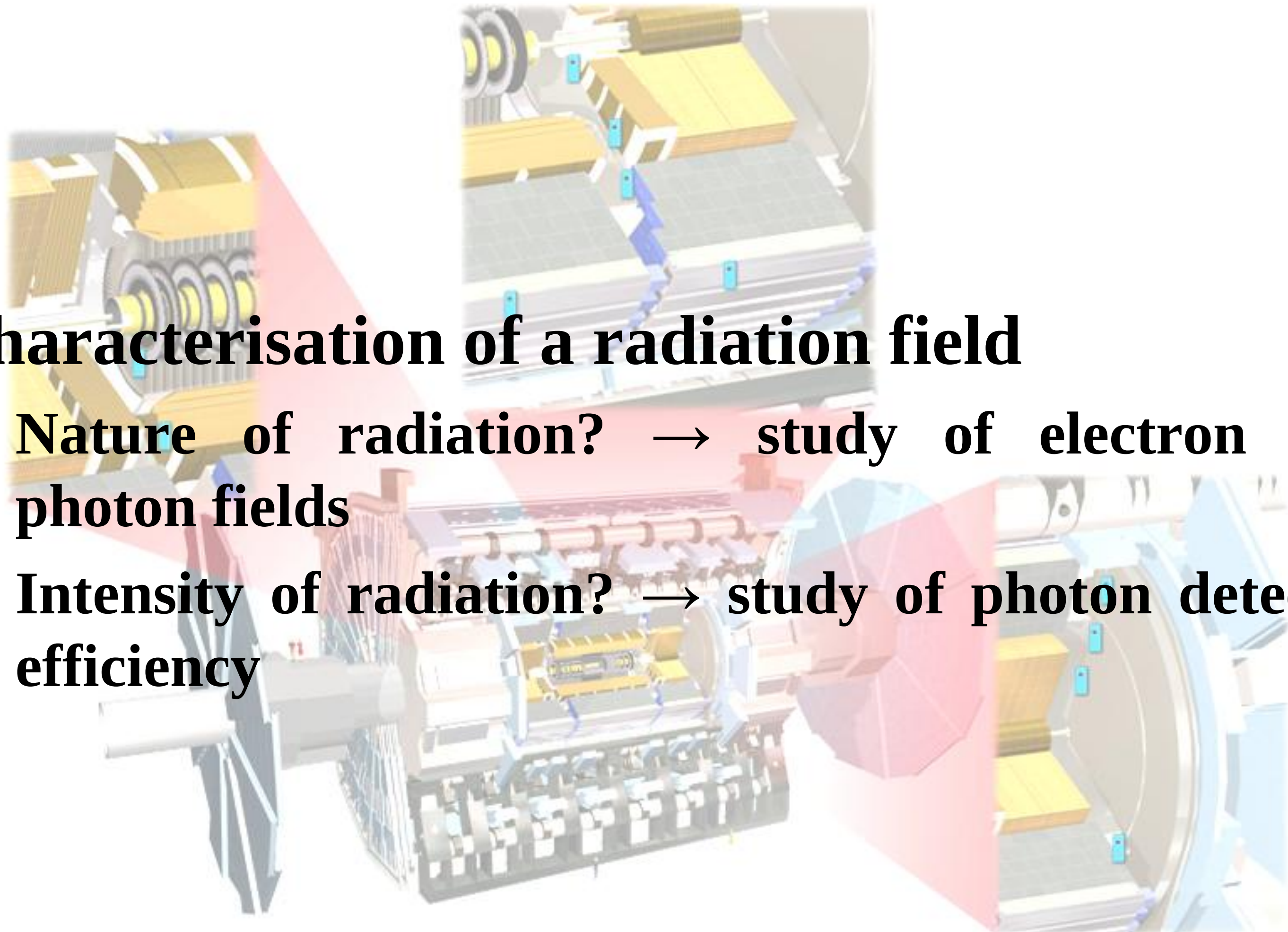
Carried out within the CERN MediPix Collaboration

- Silicon pixelated detectors designed for imaging
- Also used in fundamental physics research



- Characterisation of a radiation field
  - Nature of radiation? → study of electron and photon fields
  - Intensity of radiation? → study of photon detector efficiency

I/ Presentation of the detectors

- Structure
- Charge sharing effect
- Pattern recognition

II/ Mistagging: photon or electron?

- Experimental setup and method
- Results for Ru source

III/ Photon detector efficiency

- Experimental setup
- Results
- Geant4 simulation

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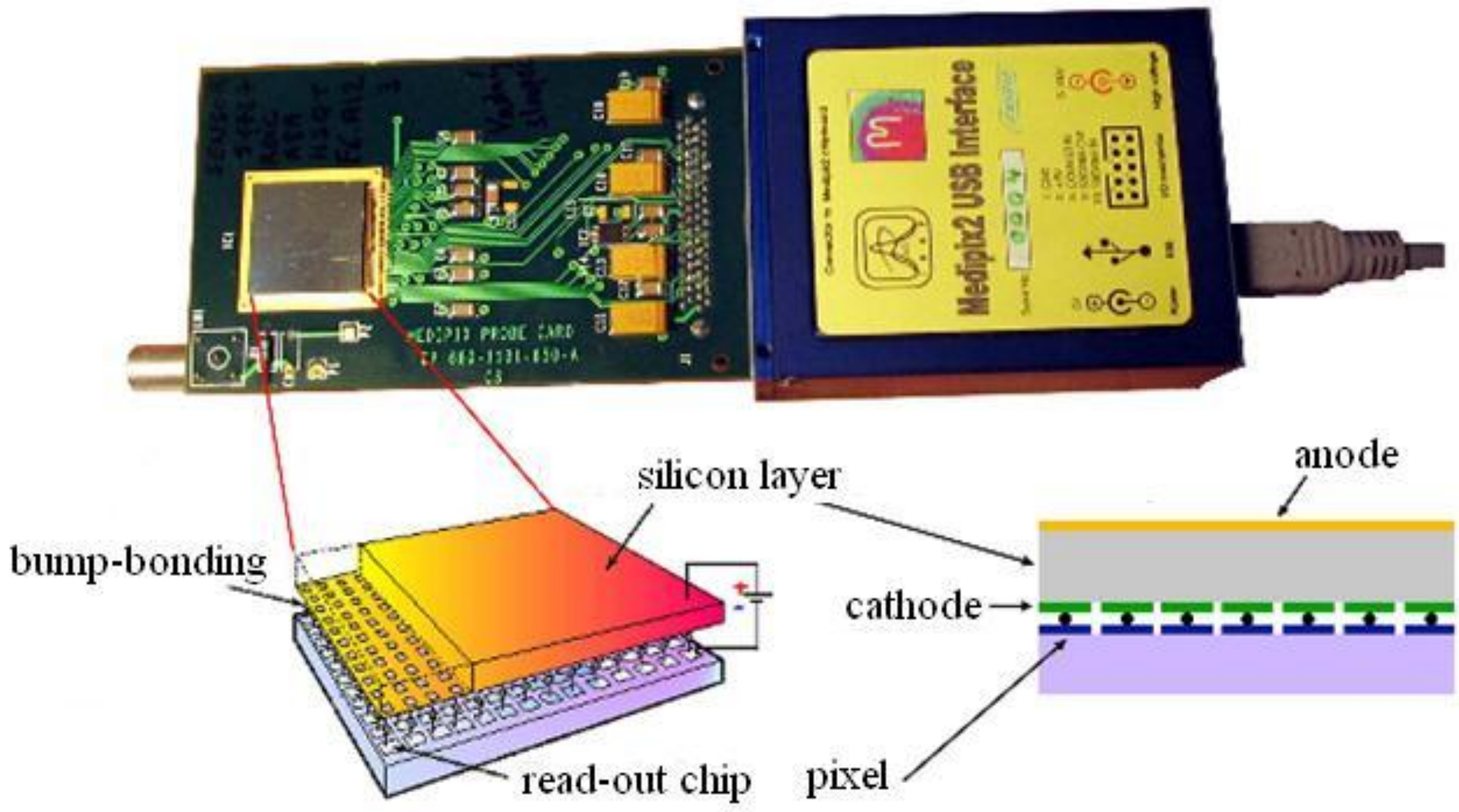
MPX or Medipix2-USB Device :

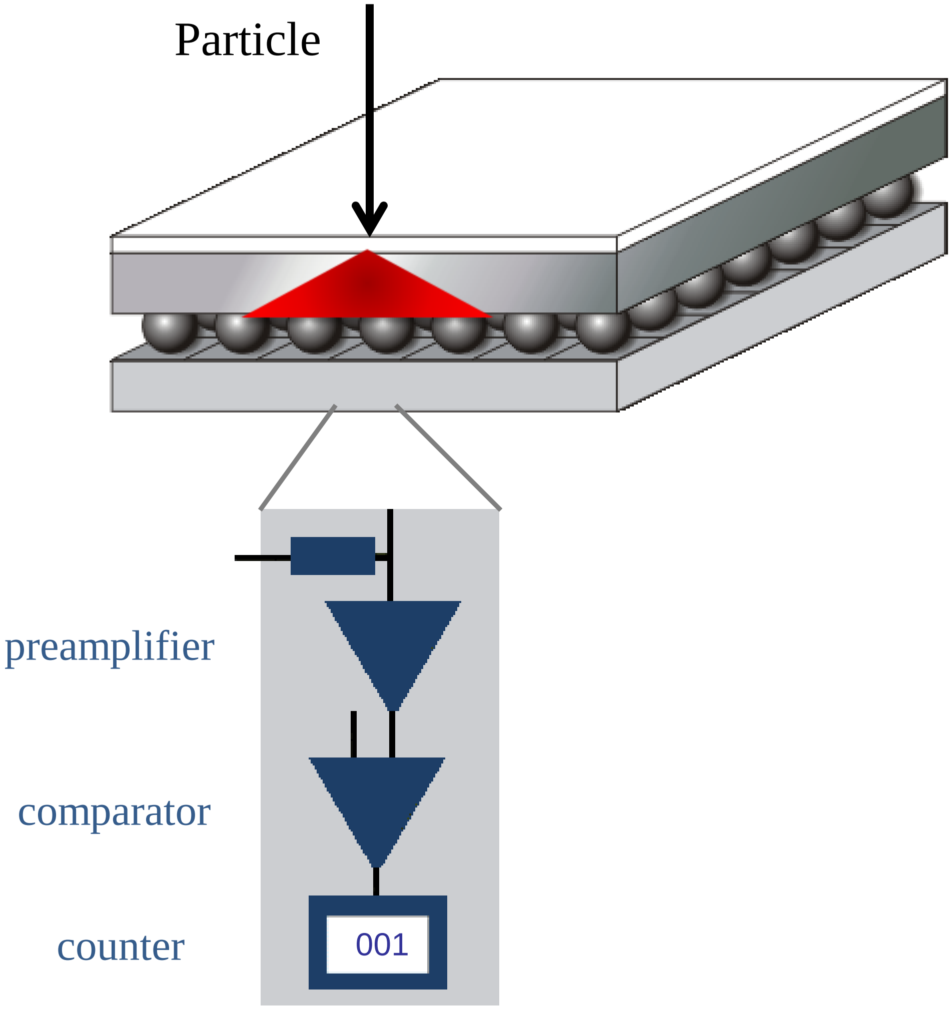


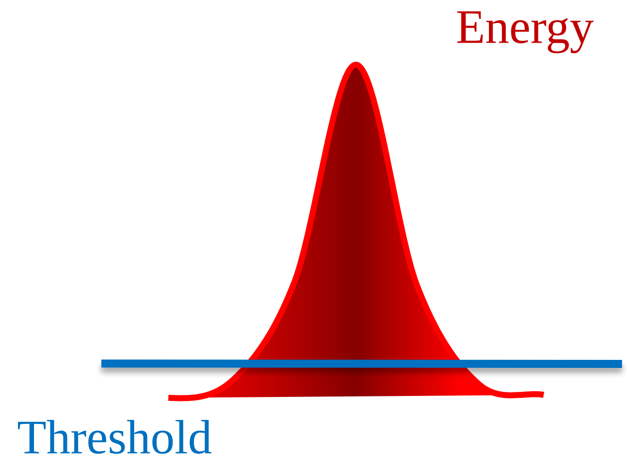
- 300 µm thick silicon pixel detector

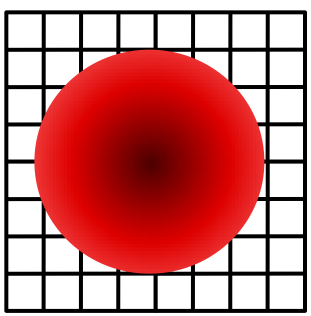
- 256 x 256 pixels each of 55 x 55 μm^2 area

- bump-bonded to Medipix2 readout chip containing in each pixel cell : preamplifier, comparator and counter.

Charge sharing effect

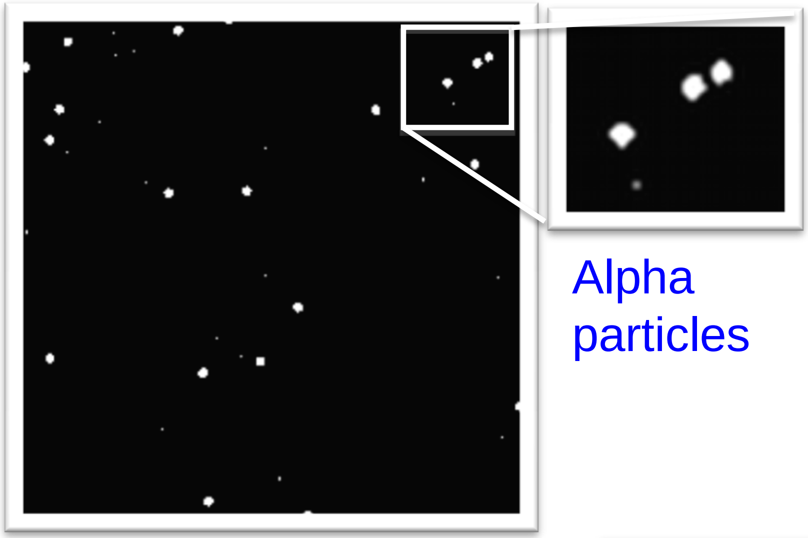






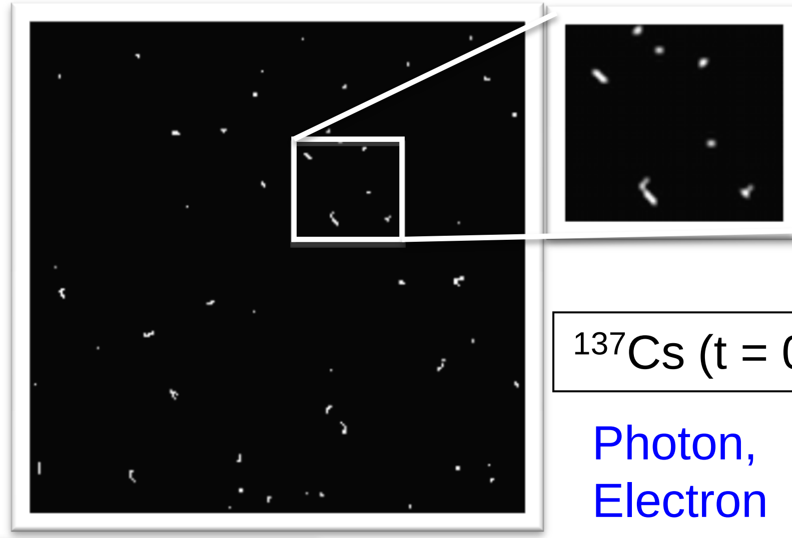
Cluster size

Medipix2 response to different ionizing particles



Alpha particles

^{241}Am (t = 2 sec)



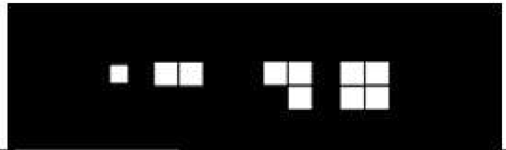
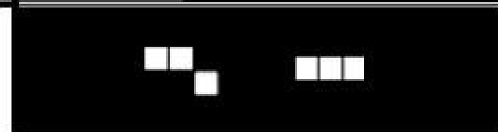
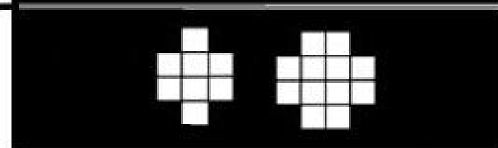
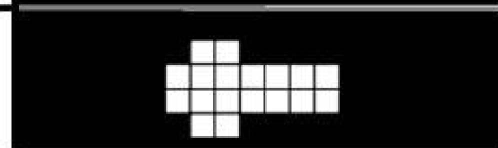
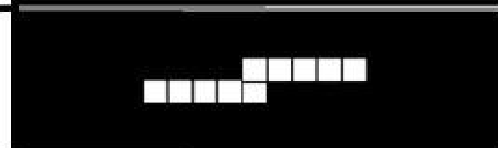
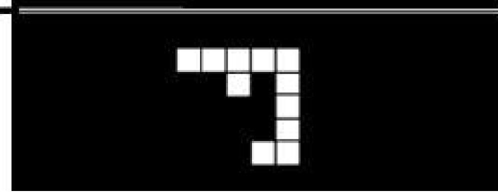
^{137}Cs (t = 0.2 sec)

Photon, Electron

Electron

^{106}Ru (t = 0.15 sec)

Pattern recognition

Single, double, triple and quad hits		Photons and electrons
Long Gamma		Photons and electrons
Heavy blobs		Heavy ionizing particles
Heavy tracks		Heavy ionizing particles → Incidence is not perpendicular to the detector's surface (Bragg curve)
Straight tracks		MIP
Curly tracks		Energetic electrons

Valid under certain experimental conditions

Timepix device

- Same structure as Medipix but equipped with a clock
- Measurement of the time over threshold in each pixel (TOT)
- Evaluation of energy deposit after calibration

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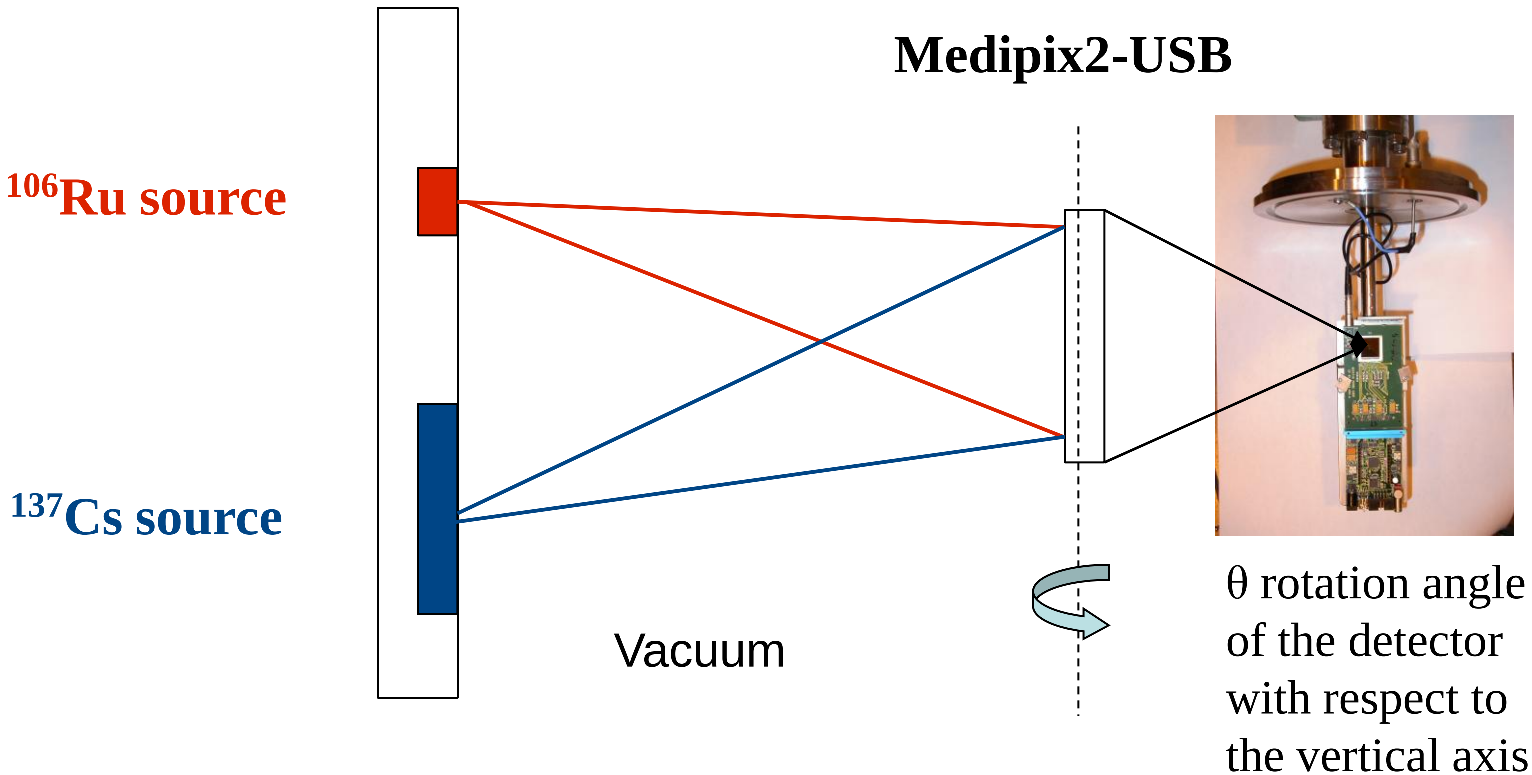
Why?

- Photons detected via 3 interactions
  - Photoelectric effect
  - Compton effect
  - Pair creation

- Hard to differentiate electrons produced by photons from electrons of the field.

- Aim → To evaluate a mistagging rate

Experimental setup



Activity reconstruction

- First case: all the tracks are considered

$$A_1 = \frac{R_{all}}{F_\theta \times (f_{\gamma,X} + f_{e-})}$$

- Second case : tracks associated to electrons

$$A_2 = \frac{R_{e-}}{F_\theta \times f_{e-}}$$

- Third case : tracks associated to photons

$$A_3 = \frac{R_{\gamma,X}}{F_\theta \times f_{\gamma,X}}$$

$$f_{\gamma,X} = \sum_{i=\gamma,X} \%_i \times efficiency_i \qquad f_{e-} = \sum_{i=e-} \%_i$$

F_θ Fraction of solid angle

Results for the ^{106}Ru source

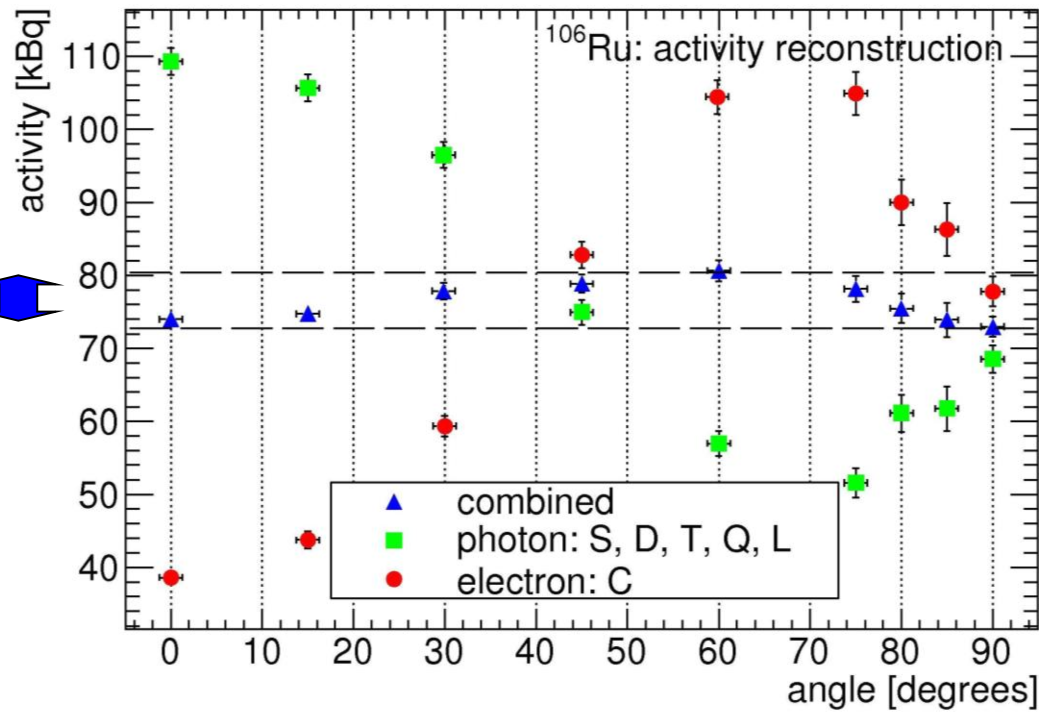
Simplified spectrum:

- Gamma:

512 keV 20.4% ;

622 keV 9.9%.

Known activity 5%



- Electron: 2 beta decays

Mean beta- energy:

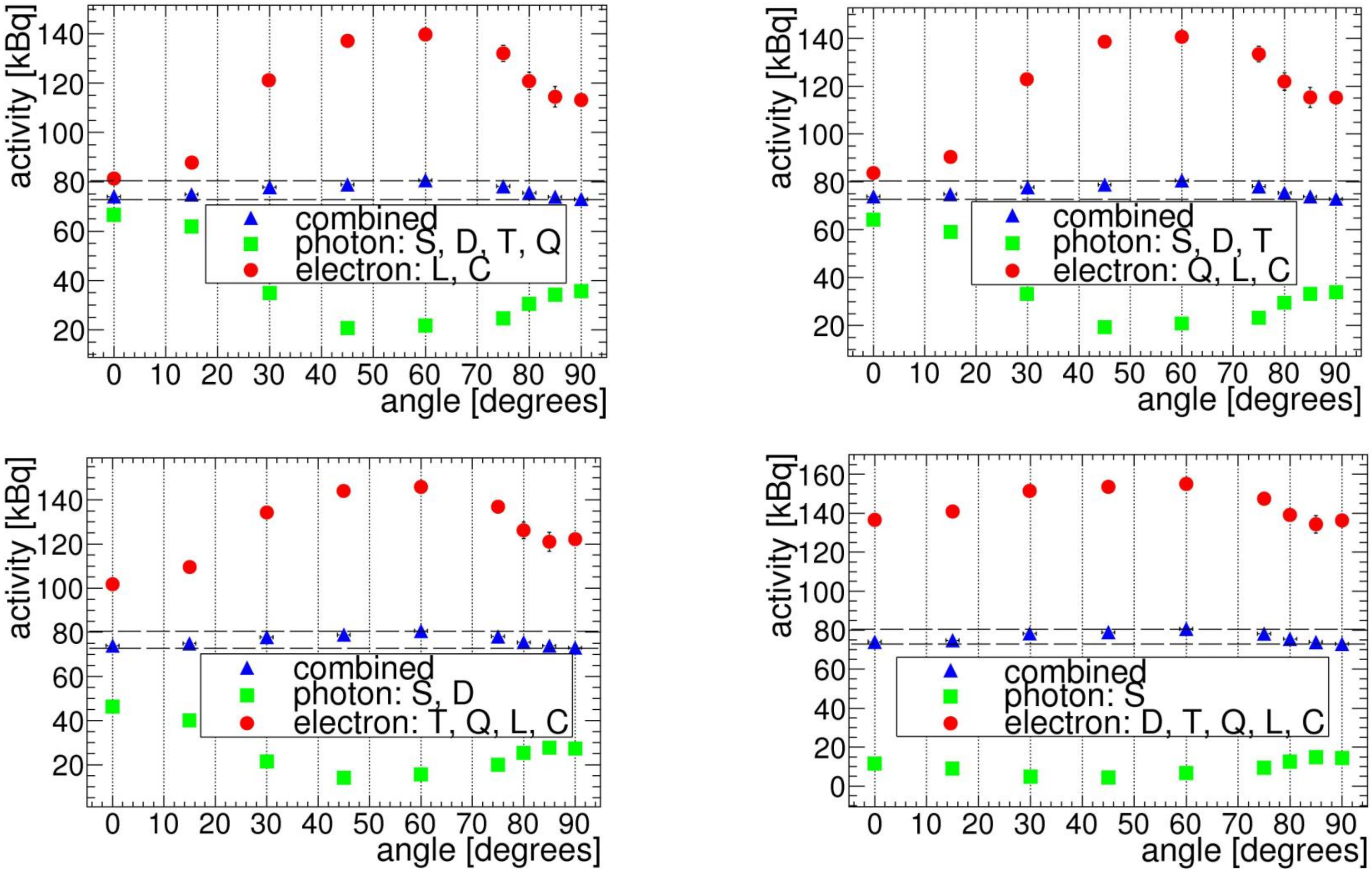
1410 keV and 10.03 keV

- Configuration legend

Photon: S: Single hits, D: Double hits, T: Triple hits, Q: Quad hits, L: Long gamma

Electron: C: Curly

Evolution of the configuration



Summary on mistagging

Mis-association stongly depends on:

- Energy of the particles (other experiment)
- Incidence of the particles
- Configuration setup

→ mistagging rate can be evaluated but is hard to extrapolate to another mixed field

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Why?

- Until now, detection efficiency calculated by considering the interaction probability in the silicon layer
- But photons interact with surrounding materials and produced electrons can be detected, increasing the detector efficiency.
- Aim → to quantify these changes

Experimental setup

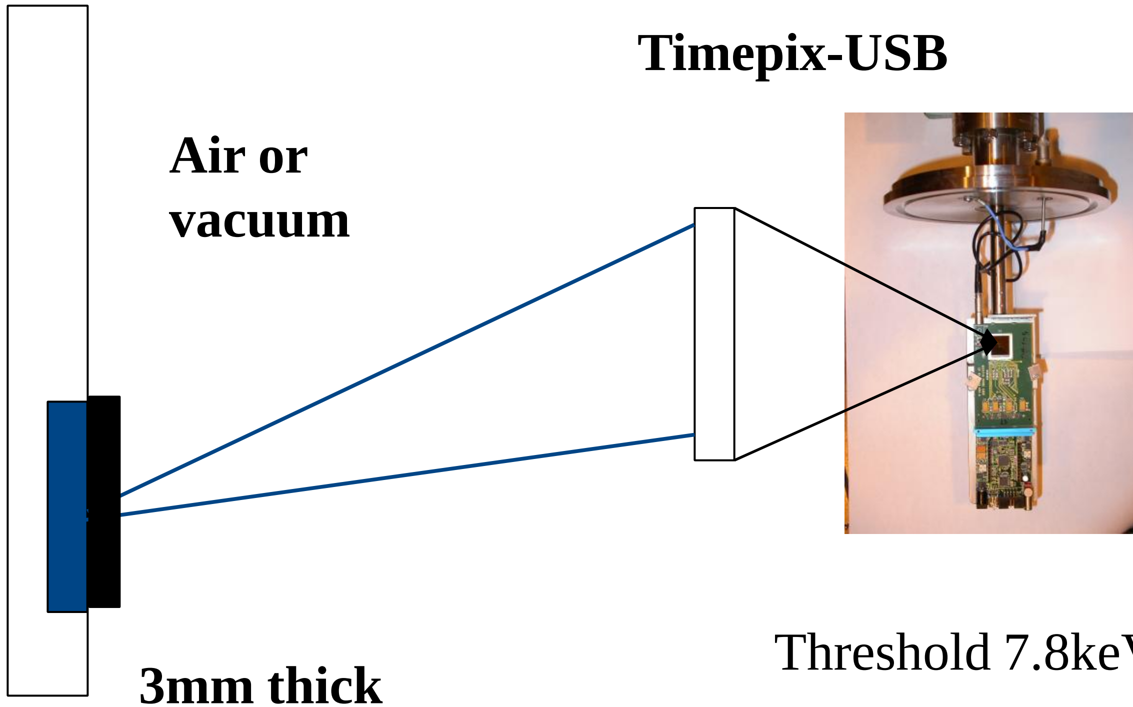
Simplified gamma spectrum:

32 keV 5.8% ;

36 keV 1.3% ;

662 keV 85.1%.

^{137}Cs source



3mm thick Al layer (to get rid of e-)

Threshold 7.8keV

Rate of particles interacting with the detector

- Theoretical rate

$$rate = A \times F_\theta \times \sum_{i=\gamma,X} \%_i \times \eta_i$$

For air and vacuum:

$$R_{theo} = 1.64 \pm 0.10 \cdot s^{-1}$$

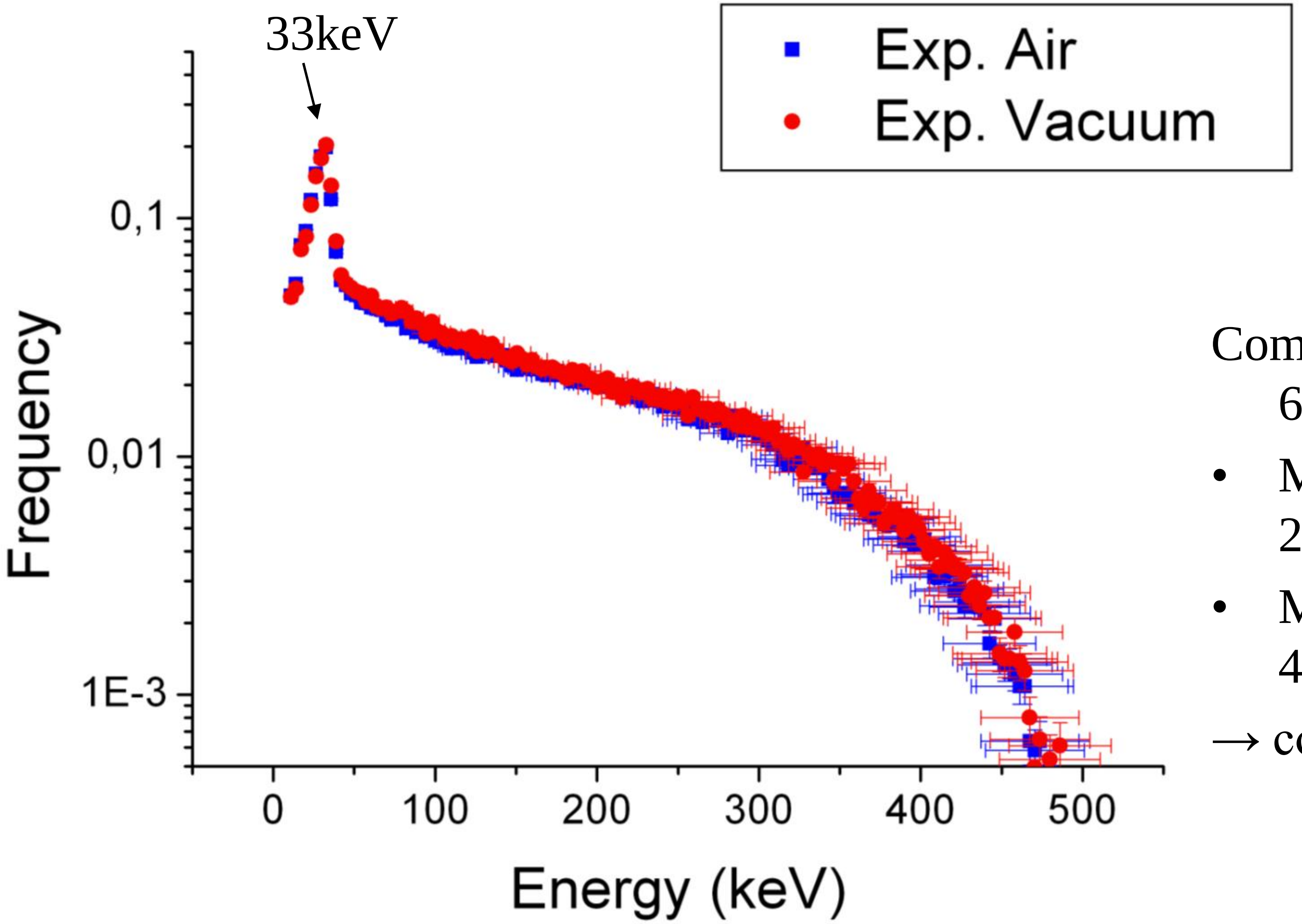
- Experimental rates:

$$R_{\exp,Air} = 3.75 \pm 0.06 \cdot s^{-1}$$

$$R_{\exp,vacuum} = 3.89 \pm 0.07 \cdot s^{-1}$$

$$\frac{R_{\exp,Air}}{R_{theo}} = 2.29 \pm 0.18 \qquad \frac{R_{\exp,Vacuum}}{R_{theo}} = 2.37 \pm 0.19$$

Experimental spectrum with timepix



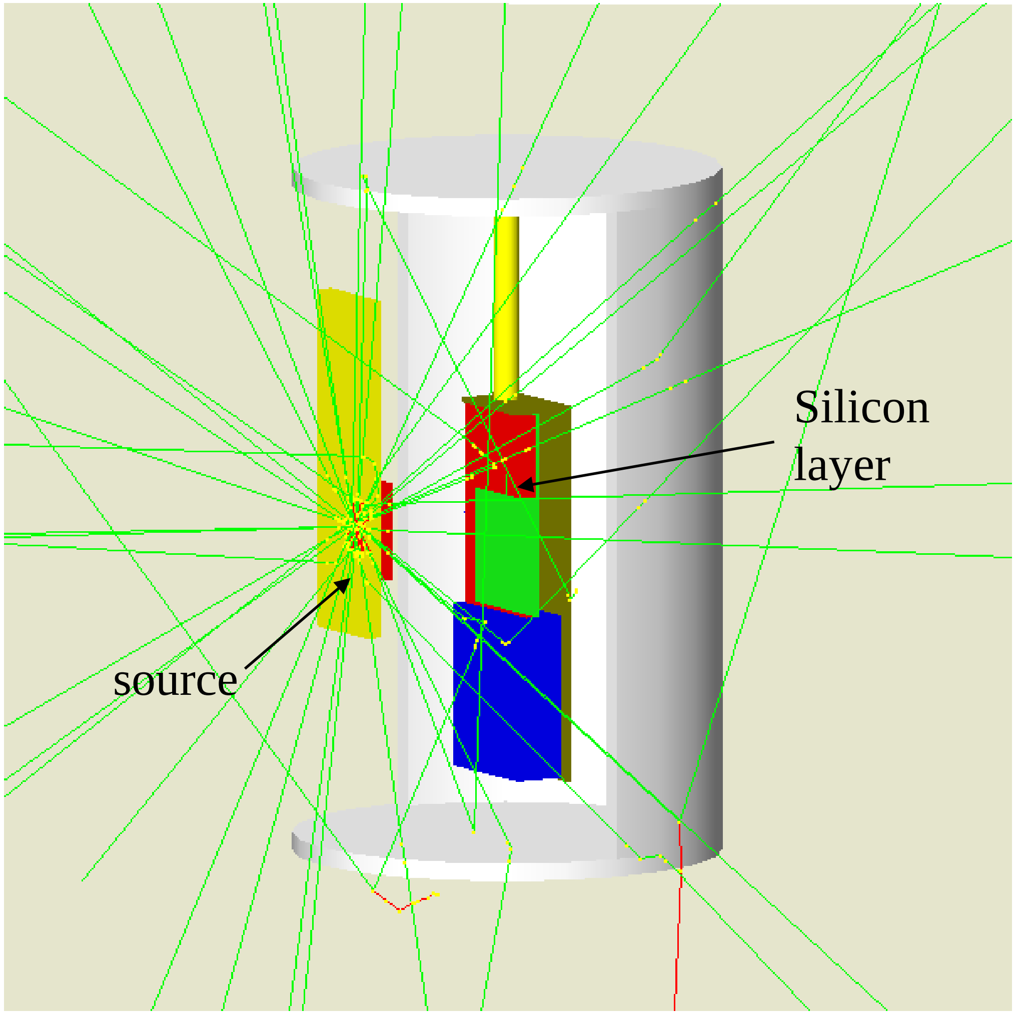
Compton electron from 662keV photons:

- Mean energy: 253keV
- Maximal energy: 478 keV

→ compatible

Simulation

- Geant4 environment
- Programmation of the experimental elements
- Reproduction of Medipix behaviour → same type of files generated.



Green rays: photon

Red rays: electron

Comparison of the rates

- experimental

$$R_{\exp,Air} = 3.75 \pm 0.06 \cdot s^{-1}$$

$$R_{\exp,vacuum} = 3.89 \pm 0.07 \cdot s^{-1}$$

$$\frac{R_{\exp,Air}}{R_{\exp,Vacuum}} = 0.964 \pm 0.033$$

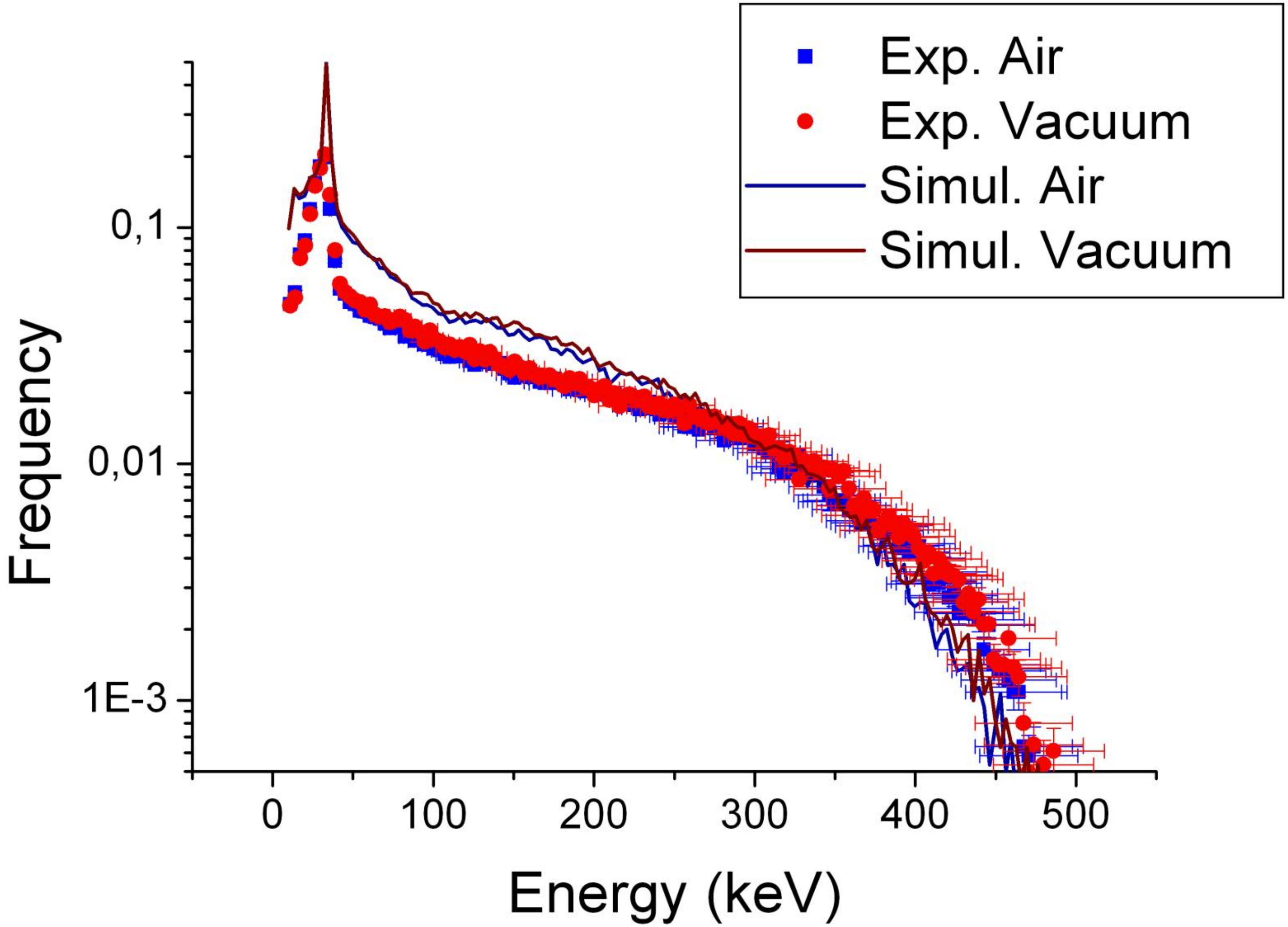
- simulated

$$R_{simul,Air} = 4.97 \pm 0.07 \cdot s^{-1}$$

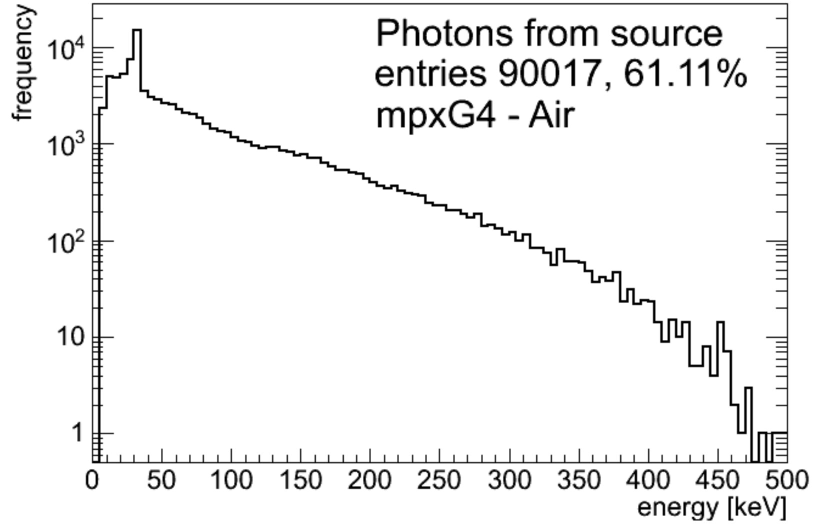
$$R_{simul,vacuum} = 5.12 \pm 0.08 \cdot s^{-1}$$

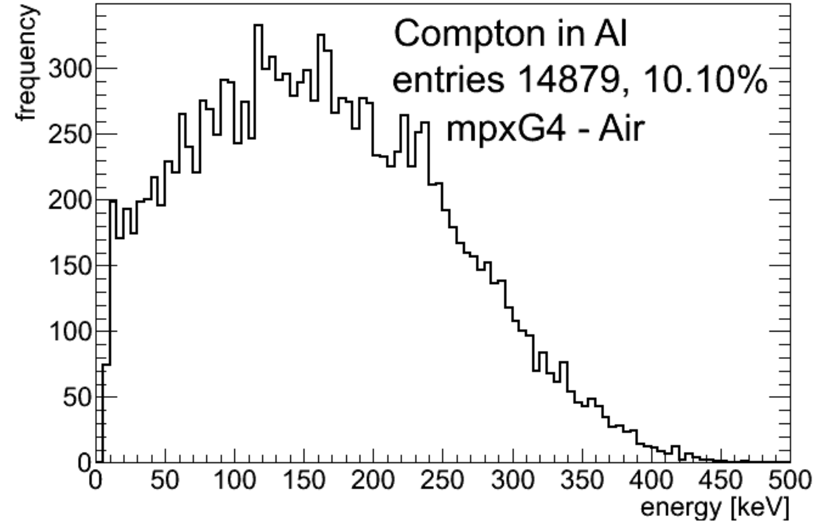
$$\frac{R_{simul,Air}}{R_{simul,Vacuum}} = 0.970 \pm 0.029$$

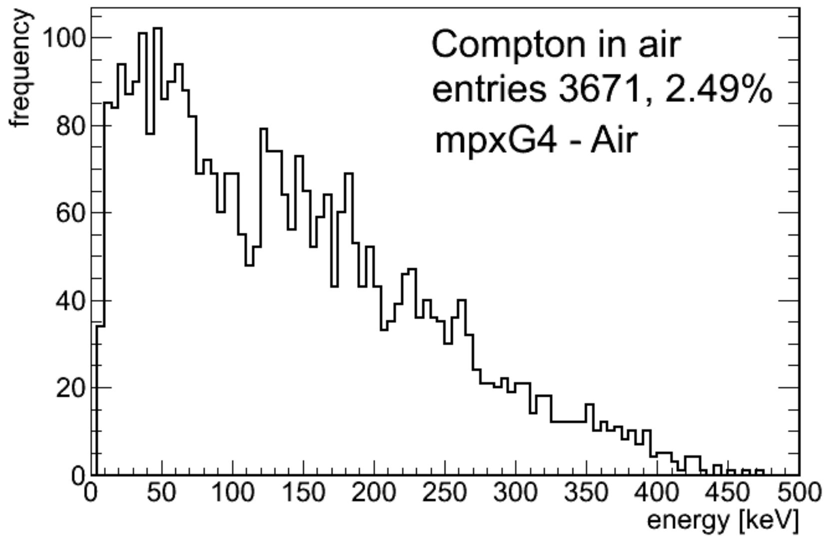
Simulation results and comparison

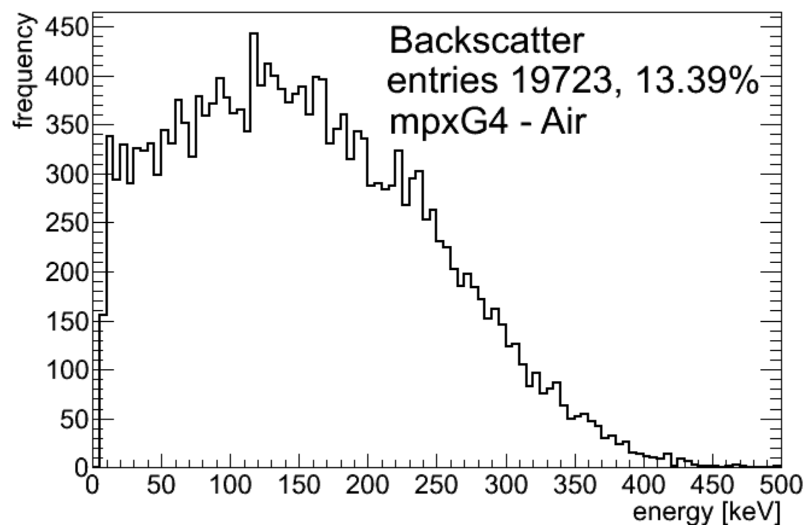


Origine of detected particles - Air

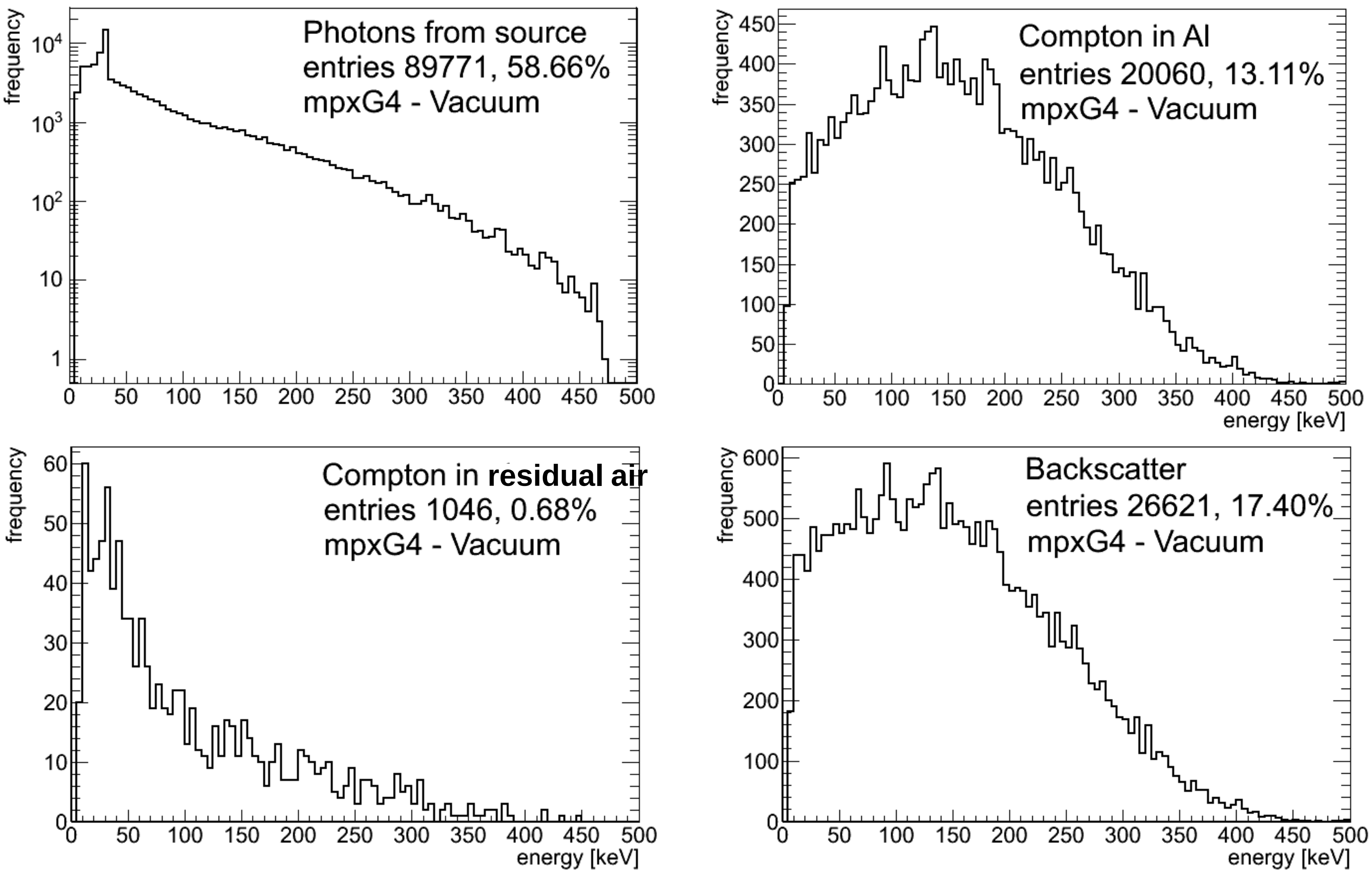








Origine of detected particles - Vacuum



Summary on photon detection

- indirect detection → correction factor to theoretical detector efficiency.
- Other experimental setups and other photon energies → other correction factors

- Promising results of the simulation

- Improvements to do:

Better definition of the experimental elements in the simulation (first results)

More precise spectrum

Conclusion

- Photons or electrons?
- Mistagging rate depends on several parameters that makes extrapolation difficult.

- Photon detection efficiency greatly improved by surrounding materials. Correction factors can be evaluated.
- Geant4 simulation for Medipix gives promising results

Thank you!

Evaluation of mistagging rate

Negative mistagging

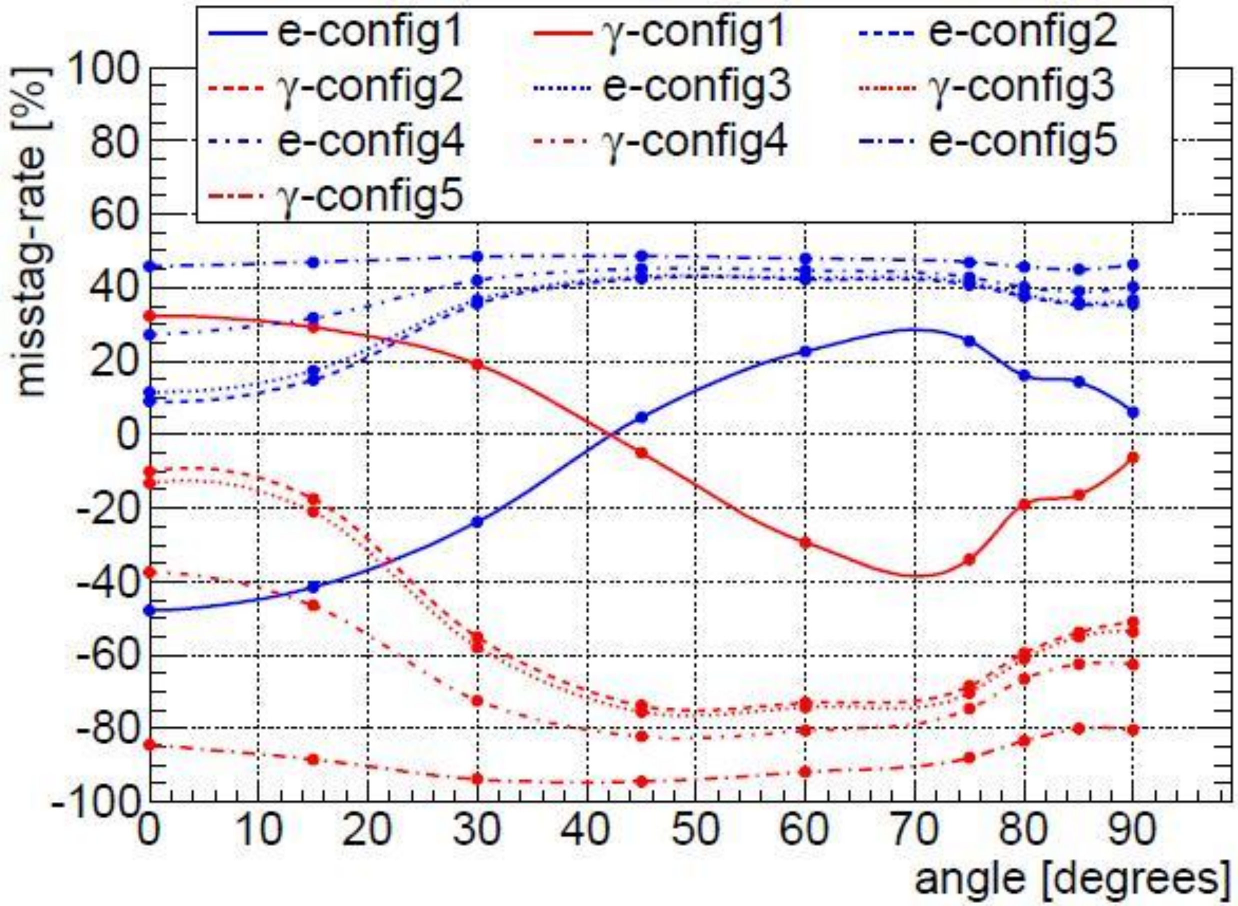
$$mistagging_i = -\left(1 - \frac{A_i}{A_1}\right) \quad \text{if} \quad \frac{A_i}{A_1} < 1$$

Positive mistagging

$$mistagging_i = \left(1 - \frac{A_1}{A_i}\right) \quad \text{if} \quad \frac{A_i}{A_1} > 1$$

i is for photon or electron

Mistagging rate for Ru



results for the ^{137}Cs source

Simplified spectrum:

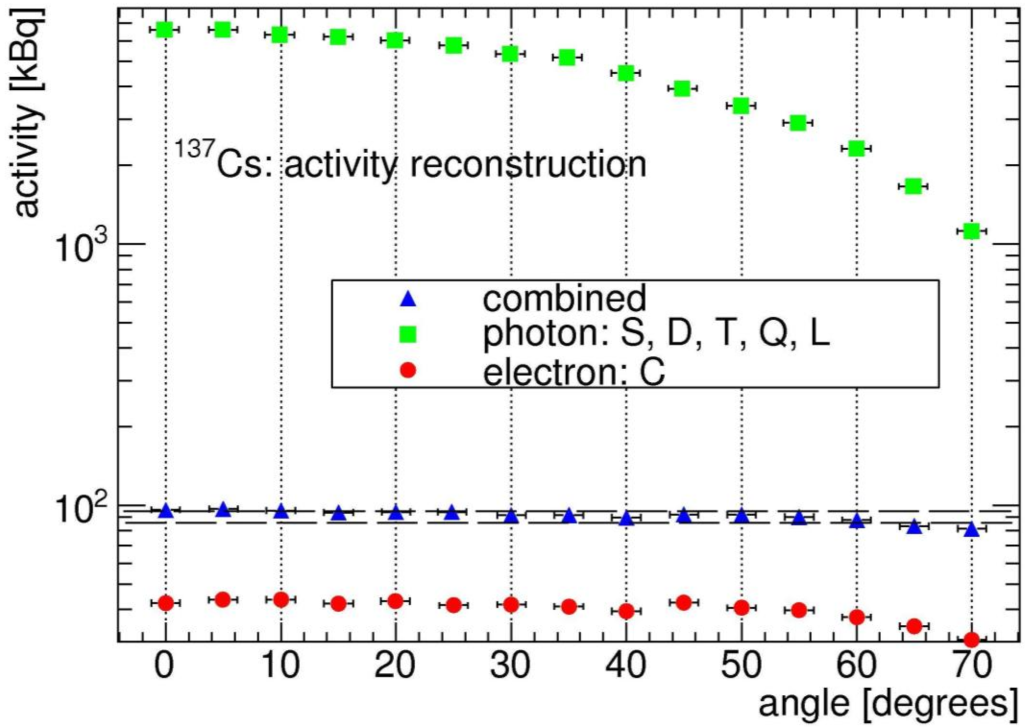
- Gamma:

32 keV 5.8% ; 36 keV 1.3% ; 662 keV 85.1%.

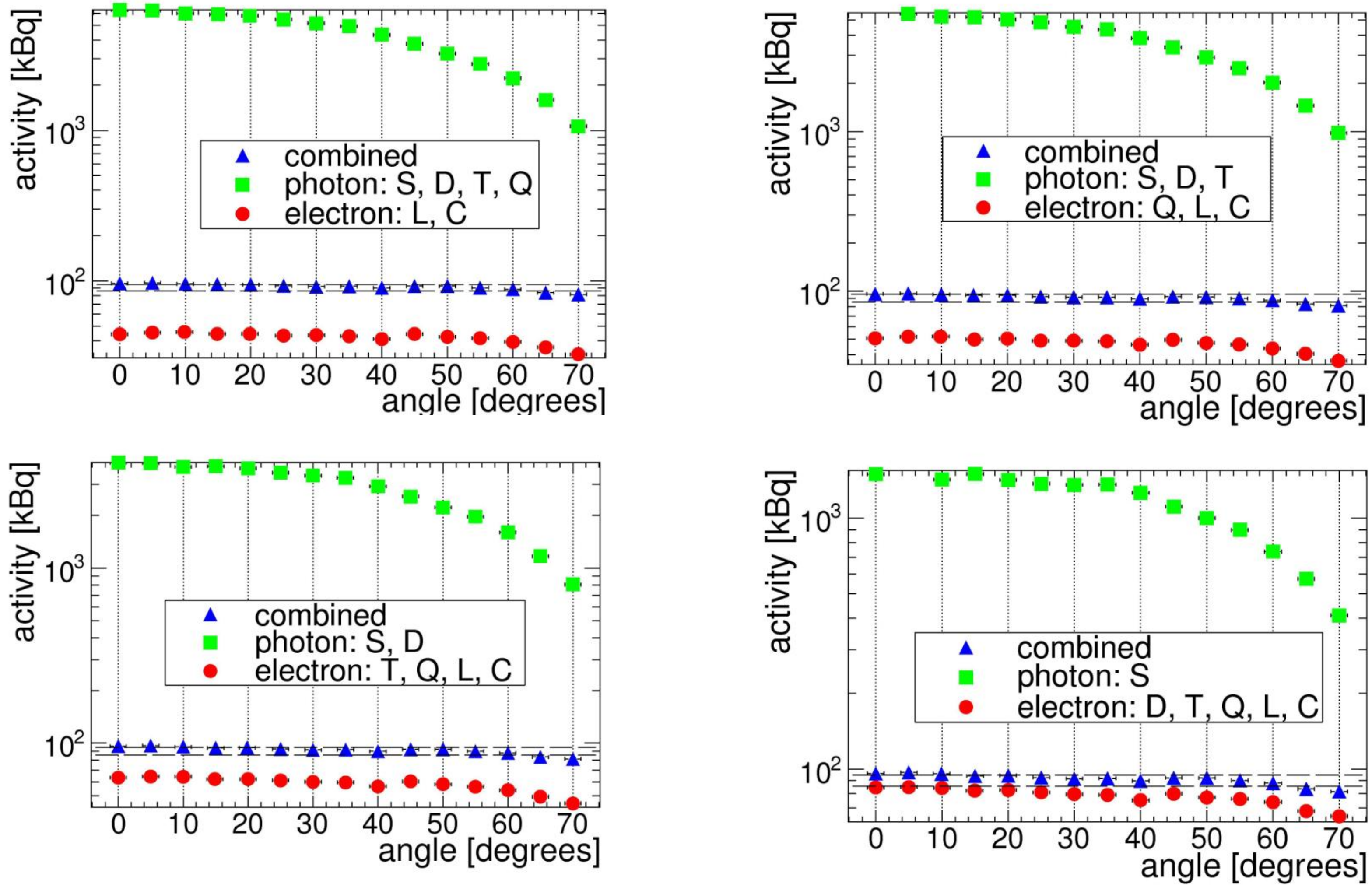
- Electron:

Mean beta- energy: 187.1 keV

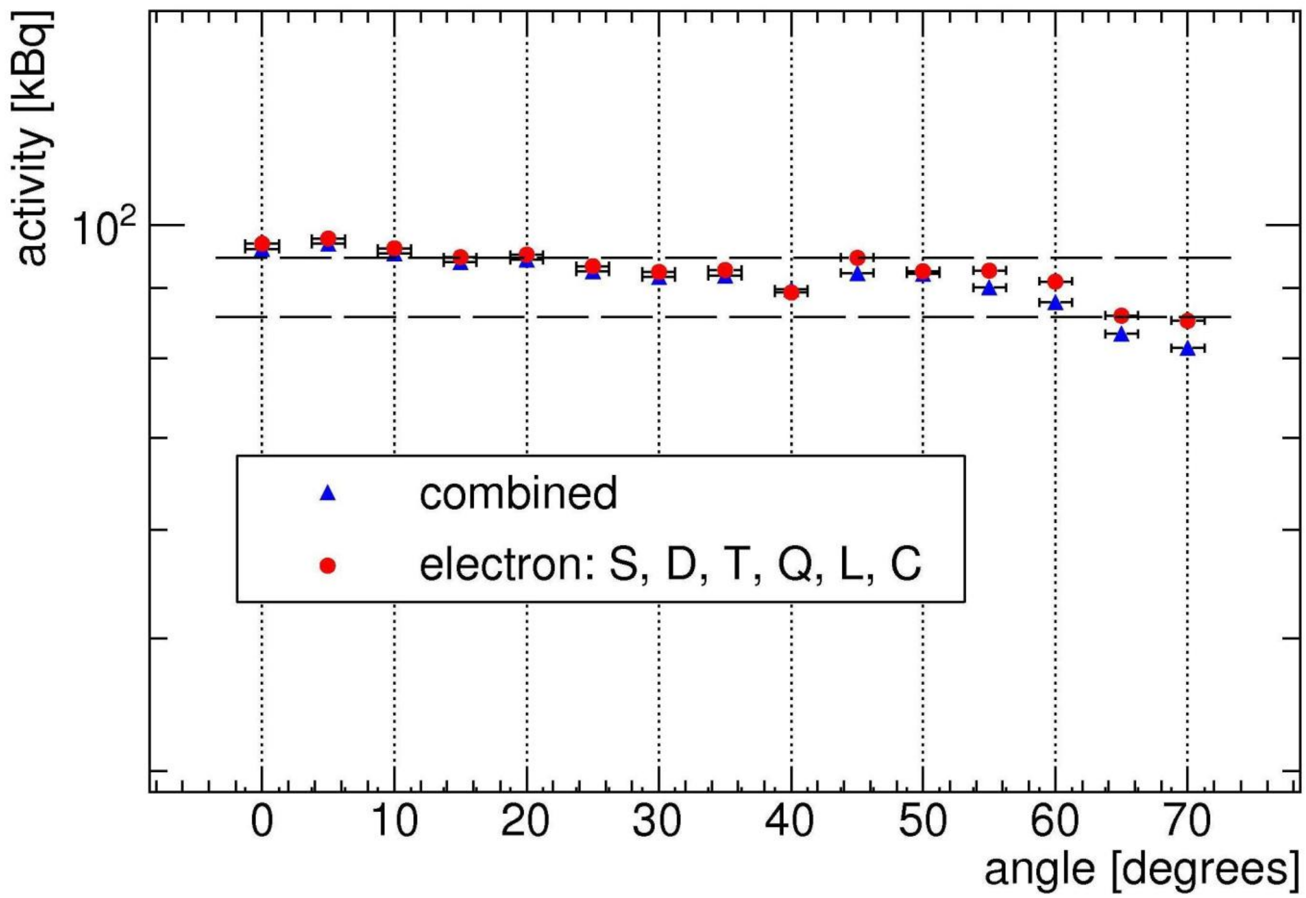
625 keV 7.8%; 656 keV 1.4%

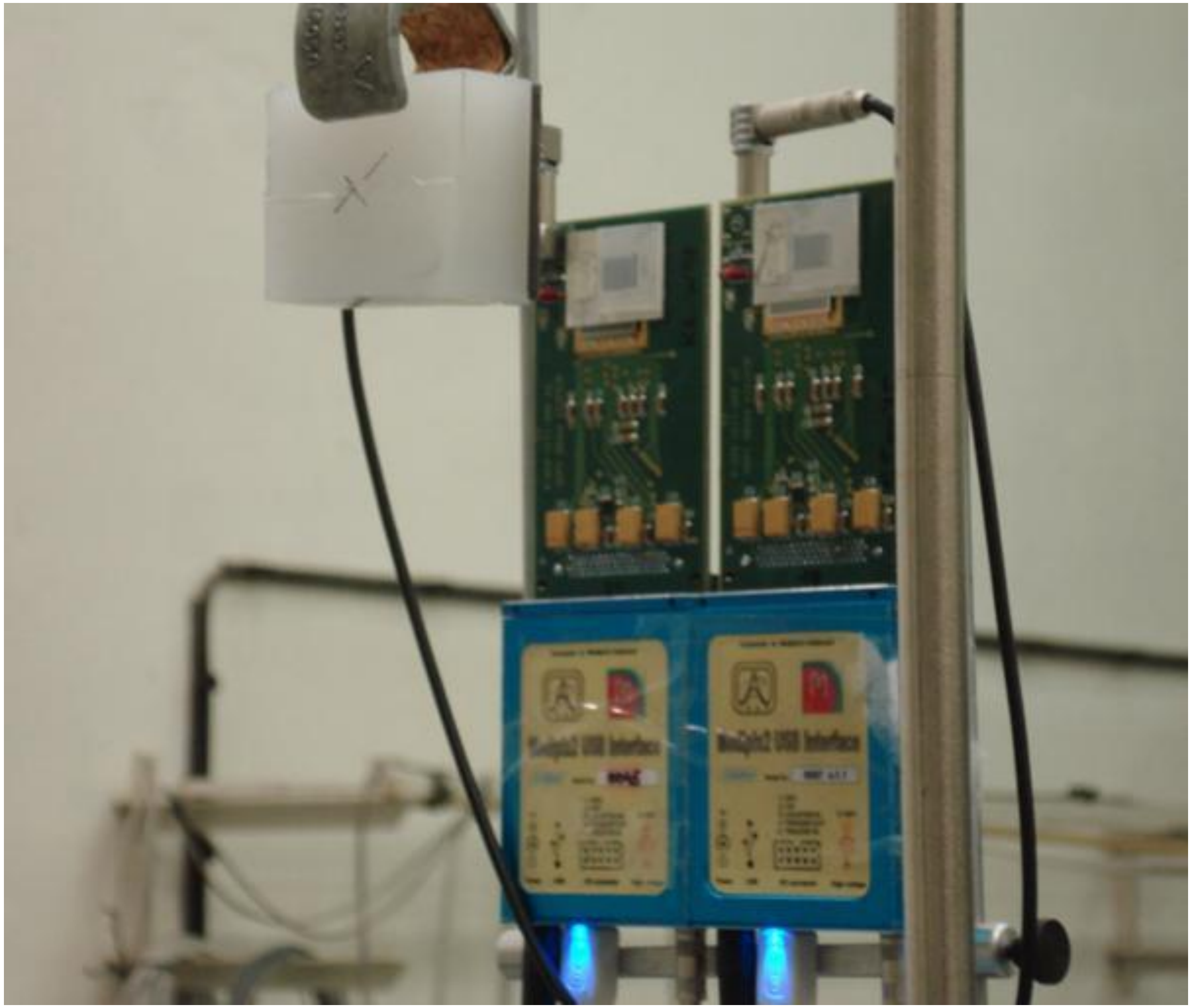


Evolution of the configuration



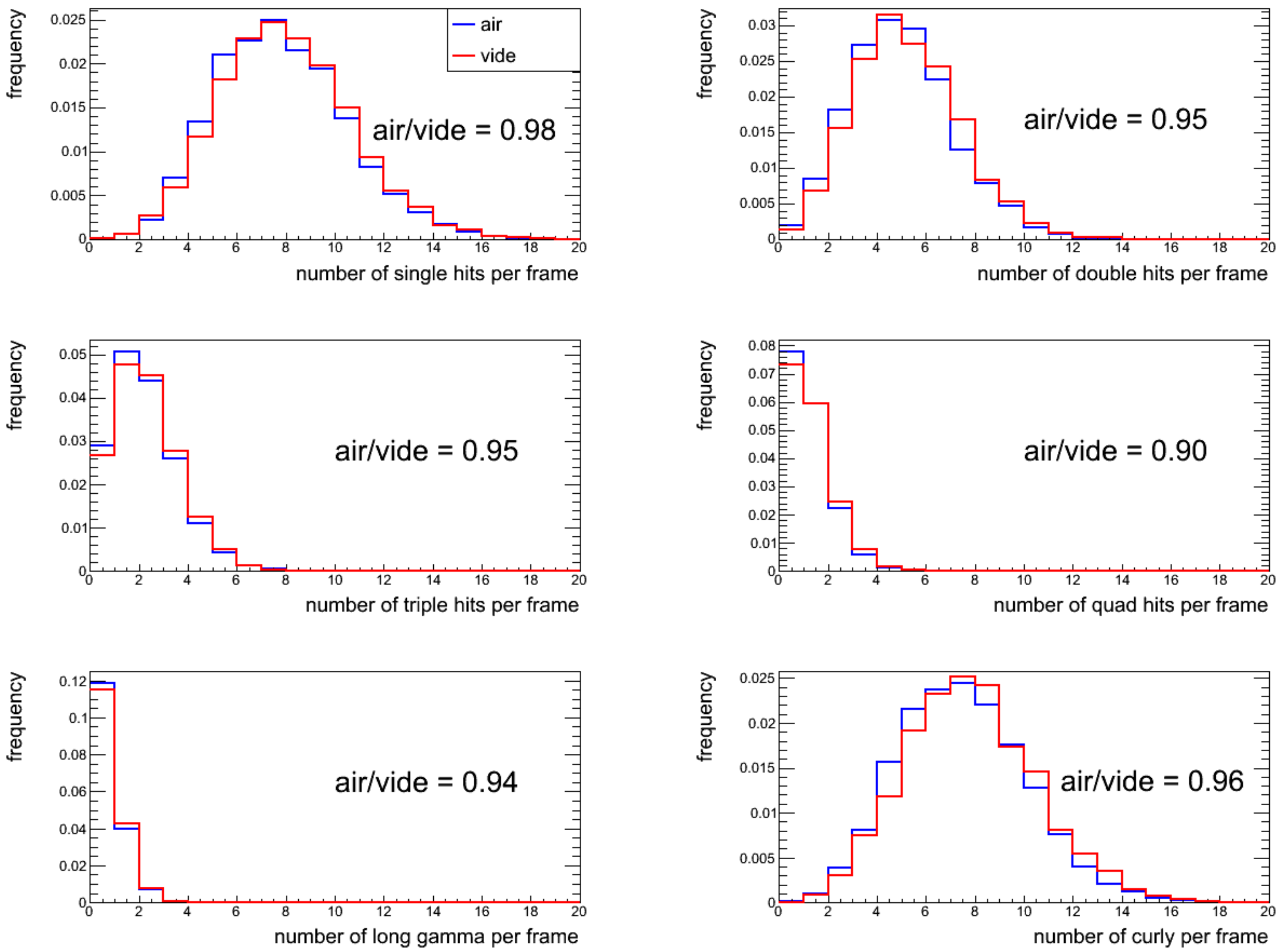
If we considere all the tracks as electrons…





Prague results

Medipix	measured flow s^{-1}	theoretical flow s^{-1}	ratio
^{252}Cf source, 914 keV photons			
$MPX18$	263.52 ± 0.93	50.24 ± 1.30	5.24 ± 0.15
$MPX20$	166.14 ± 0.91	32.51 ± 0.84	5.11 ± 0.16
$^{241}AmBe$ source, 4.438 MeV photons			
$MPX18$	32.81 ± 0.07	3.57 ± 0.09	9.19 ± 0.25
$MPX20$	20.03 ± 0.05	2.31 ± 0.06	8.67 ± 0.24


air
vide
air/vide = 0.98
number of single hits per frame
air/vide = 0.95
number of double hits per frame
air/vide = 0.95
number of triple hits per frame
air/vide = 0.90
number of quad hits per frame
air/vide = 0.94
number of long gamma per frame
air/vide = 0.96
number of curly per frame
frequency