GEM-based detector for neutrons: a first prototype

2020-10-06 – RD51 collaboration meeting

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High Energy Physics and Instrumentation Center at USP

Introduction

https://www.industrial.ai/measurement-sensing/radiation-measurement/homeland-security-radiation-detectors.

Example He^3 filled proportional counters for use in homeland security radiation portals, made by Reuter-Stokes.

^{3}He is the most common gas used for neutron detection

Introduction

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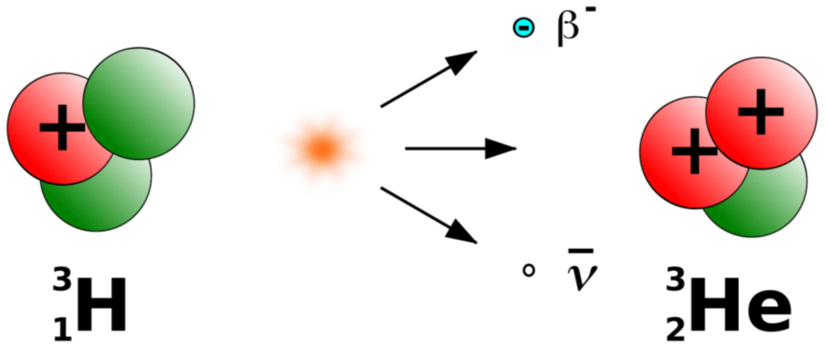
Example He^3 filled proportional counters for use in homeland security radiation portals, made by Reuter-Stokes.

^3He is the most common gas used for neutron detection

→ High neutron capture cross section.

→ Low γ-rays sensitivity.

→ Easy to build, stable under several conditions: do not degrade for a long time.



https://www.pinclipart.com/

^{3}He is obtained from tritium decay

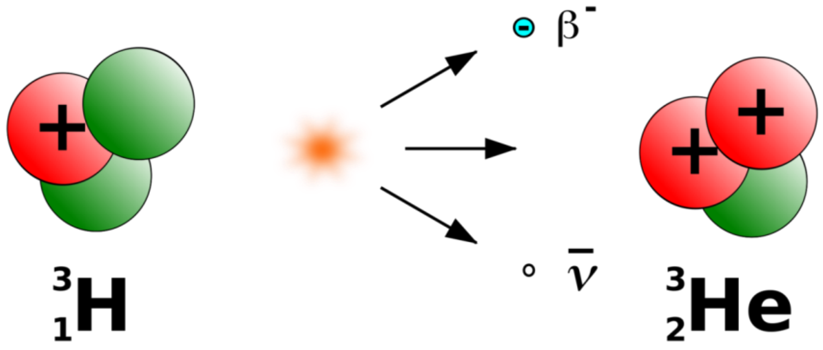
$$^3_1\mathrm{H} \rightarrow {}^3_2\mathrm{He} + \mathrm{e}^- + \tilde{\nu}$$

$$T_{1/2} = 12.3289(22)\mathrm{years}$$ [1]

→ Main suppliers: US and Russia (nuclear weapon programs) [2].

[1] L. Lucas, "Comprehensive review and critical evaluation of the half-life of tritium" 10.6028/jres.105.043

[2] R. Kouzes et. al., "Progress in alternative neutron detection to address the helium-3 shortage," 10.1016/j.nima.2014.10.046



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$$ T_{1/2} = 12.3289(22)\text{years} $$ [1]

→ Main suppliers: US and Russia (nuclear weapon programs) [2].

→ Higher demand and smaller supply.

→ We have no more ^{3}He available. (^{3}He shortage)

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Introduction

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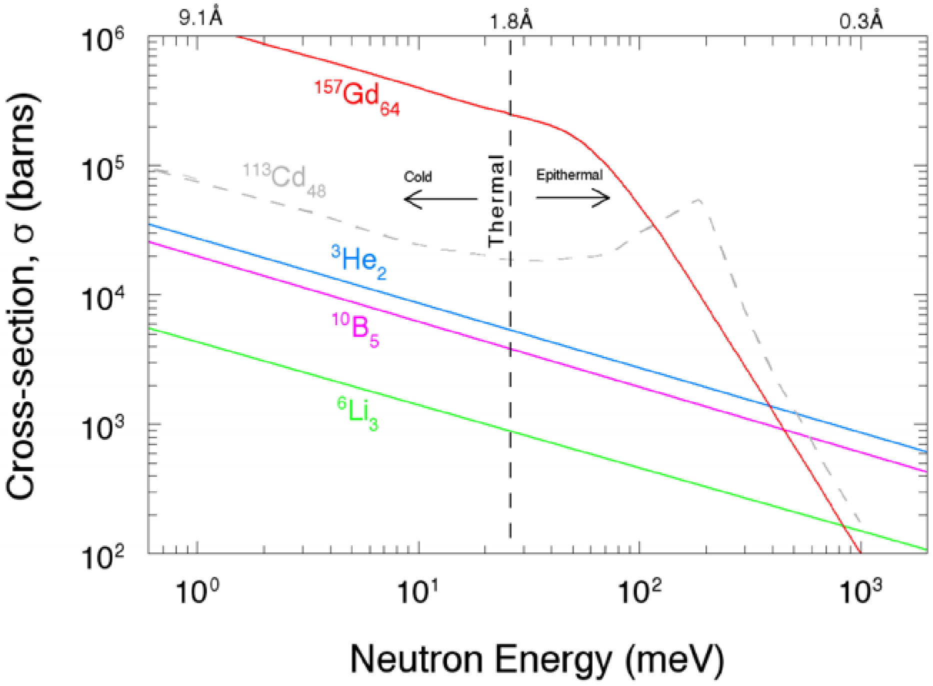


Alternatives to ^{3}He. V. Radeka, DOE BES Neutron&Photon Detector Workshop, Aug 1-3, 2012.

^{3}He common alternatives

Cross sections at 25.2 meV:

^{113}Cd → 20600 b
^{157}Gd → 254000 b
^{3}He → 5327 b
^{10}B → 3837 b
^{6}Li → 940 b

Possible to explore different reactions:

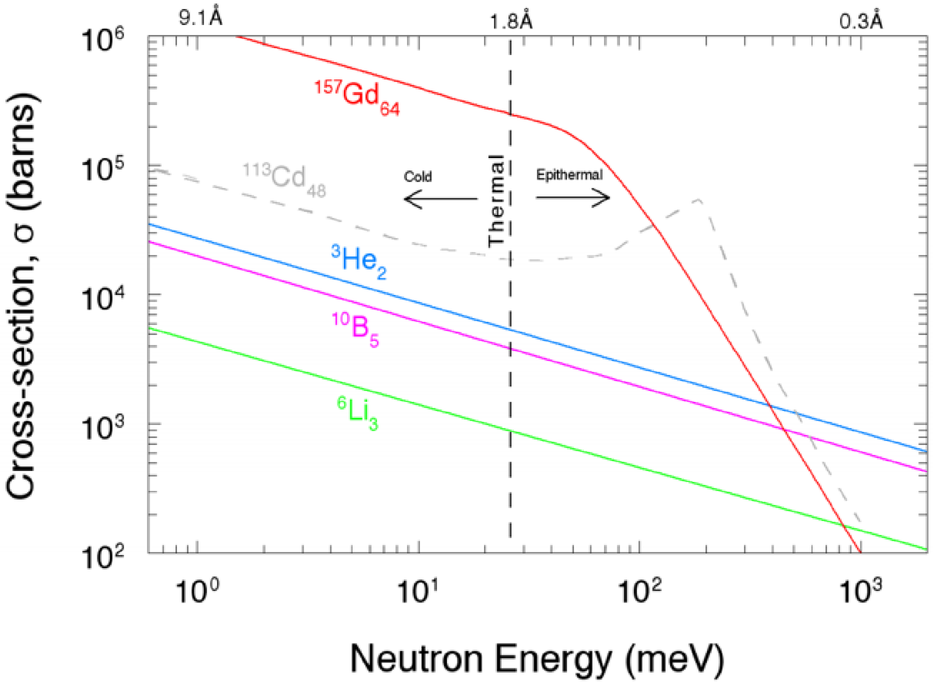
n + ^{157}Gd → ^{158}Gd + γ + e^{-} + (30-180) keV

n + ^{113}Cd → ^{114}Cd + γ (several energies)

n + ^{6}Li → ^{4}He + ^{3}H + 764 keV

n + ^{10}B → ^{7}Li + ^{4}He + γ + 2.31 MeV (93.6%)
→ ^{7}Li + ^{4}He + 2.79 MeV (6.4%)

Introduction



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→ ^{7}Li + ^{4}He + 2.79 MeV (6.4%)

GEM structure

The Gas Electron Multiplier (GEM) became a well known and successful micropattern used nowadays in gaseous proportional detectors.

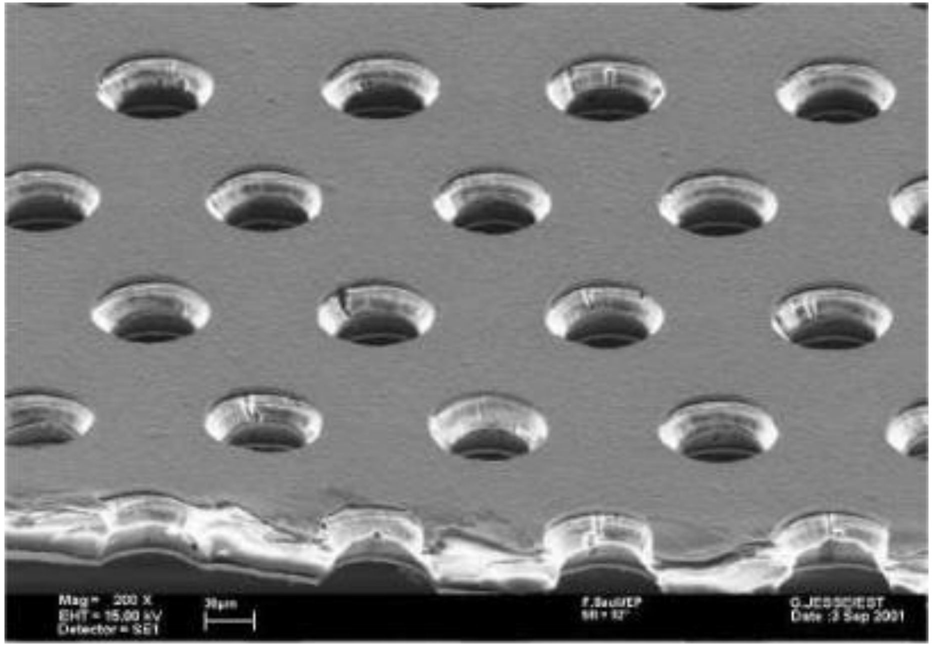
They have some advantages compared to multiwire proportional detectors:

→ Smaller ion backflow.

→ Robustness and good cost-benefit ratio.

→ Support high event rates
(up to 10^5 counts.mm^{-2}.s^{-1})

→ Better energy and position resolutions



GEM structure seen through an electron microscope. Image from CERN GDD group.

GEM-based prototype

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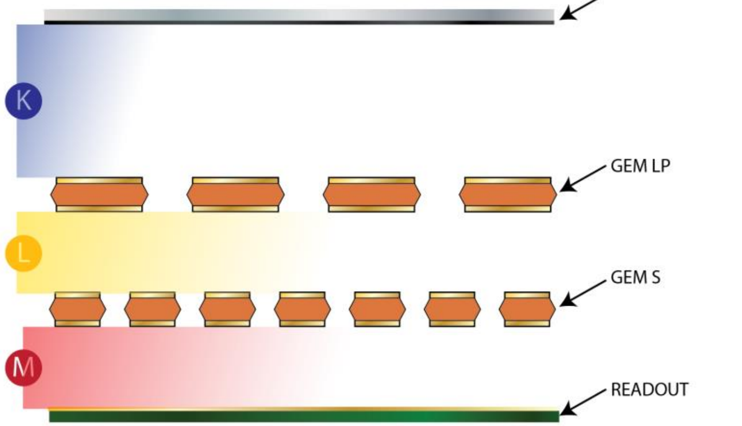
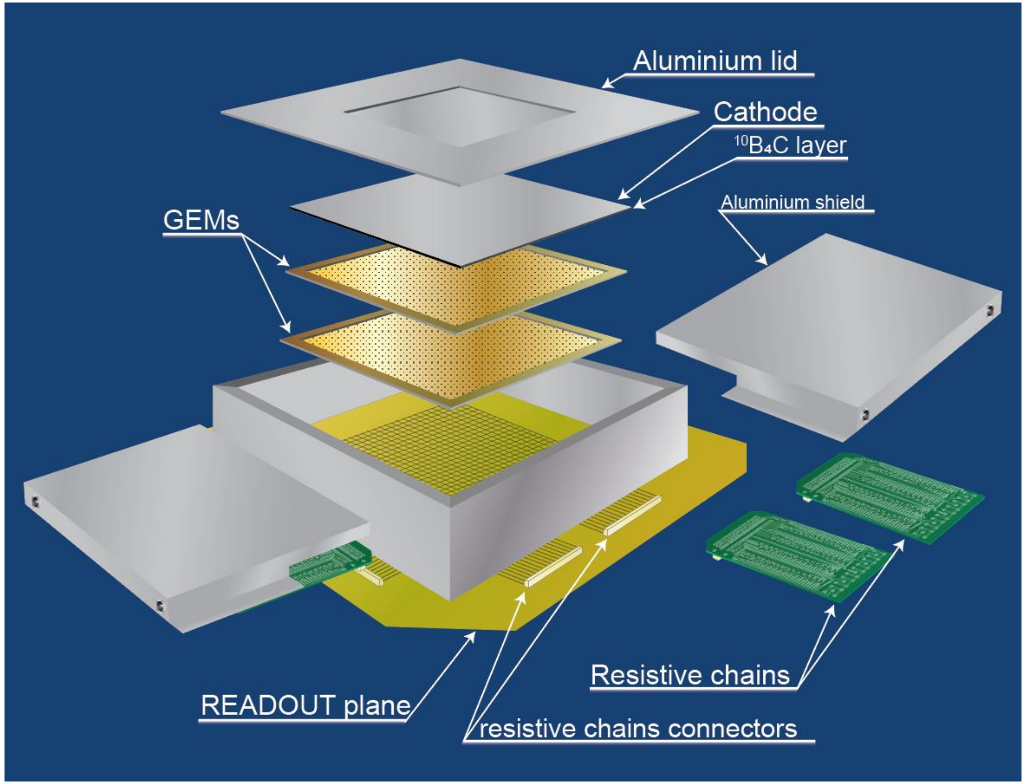
Double-GEM gaseous detector

- Double-GEM (LP and S) prototype, operating under $ArCO_2$ (90/10) open flux.
- Aluminum cathode (0.5 mm thickness) with 2.2 μm $^{10}B_4C$ deposition kindly provided by European Spallation Source (ESS).



Prototype transversal cut. The widths of K, L, and M regions are 2 mm, 1 mm, and 1 mm, respectively.

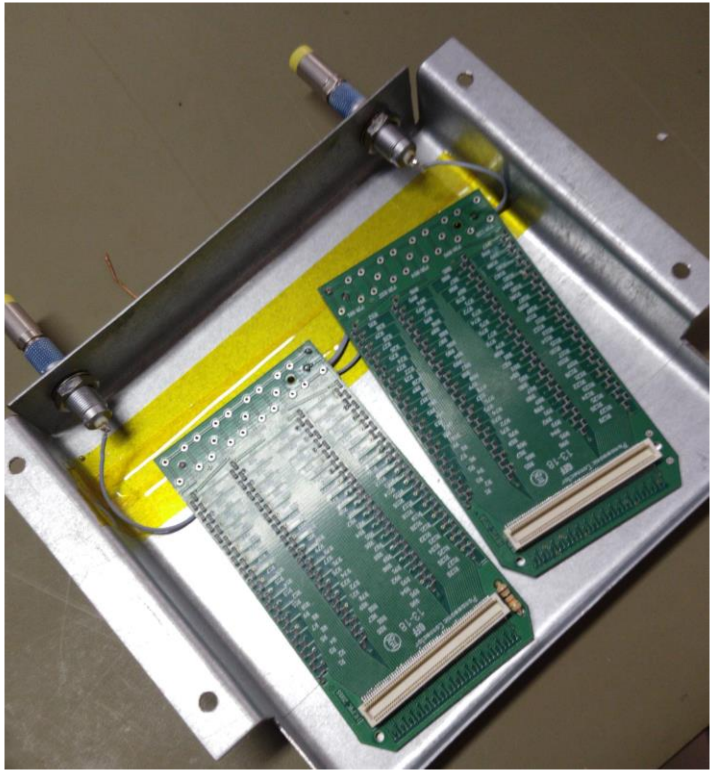


Prototype scheme.

GEM-based prototype

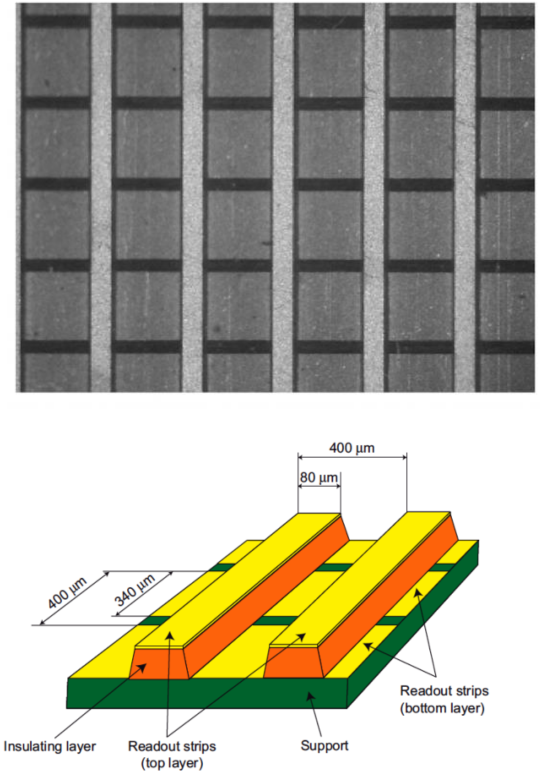
Sensitive position readout

256x256 strips readout.

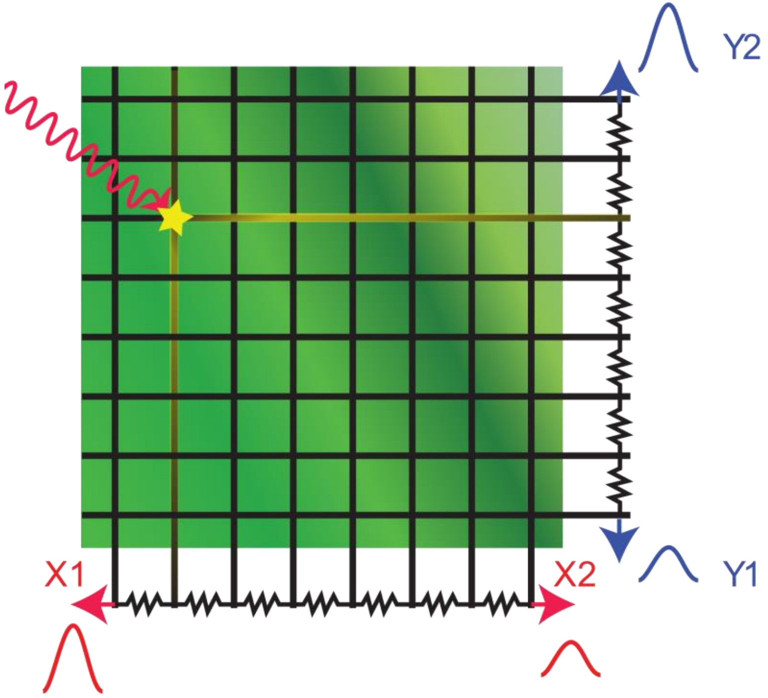


Resistive chains

F. Sauli. In Gaseous Radiation Detectors: Fundamentals and Applications.
doi:10.1017/CBO9781107337701.015



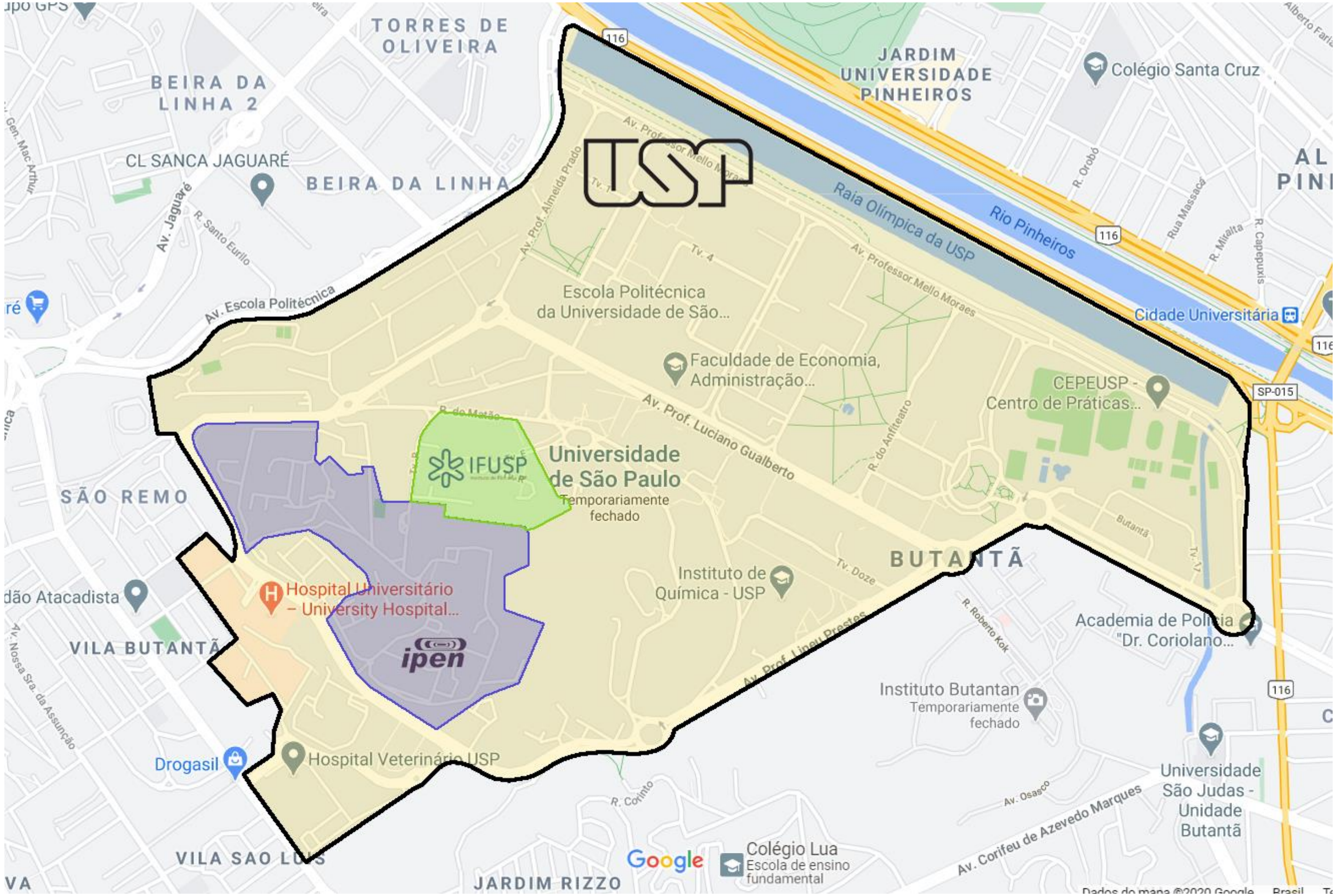
Stripes dimensions.



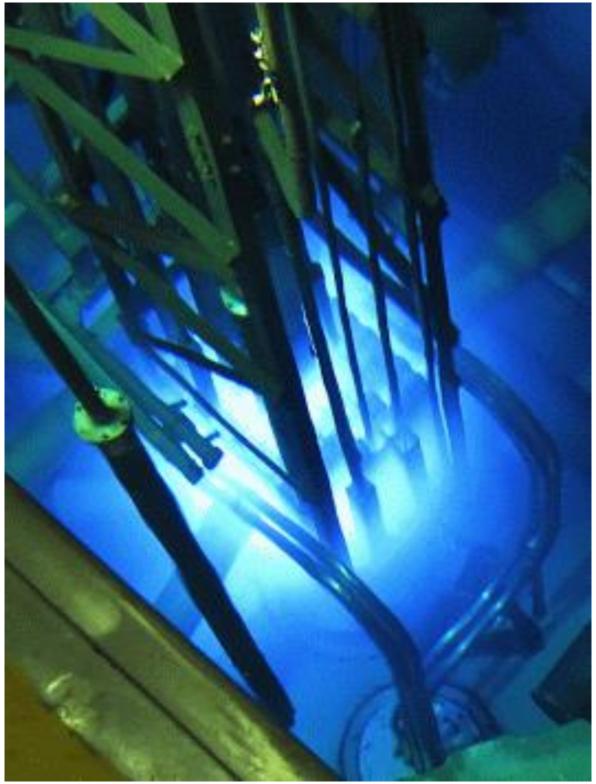
Readout working principle.

GEM-based prototype

Nuclear and Energy Research Institute (IPEN)



We use the IEA-R1 research nuclear reactor (4.5 MW) at IPEN.



https://bit.ly/34jJOAS

GEM-based prototype

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Double-GEM gaseous detector

Preparing the prototype to test! (4.5 MW) Nuclear reactor facility at the Nuclear and Energy Research Institute (IPEN) .

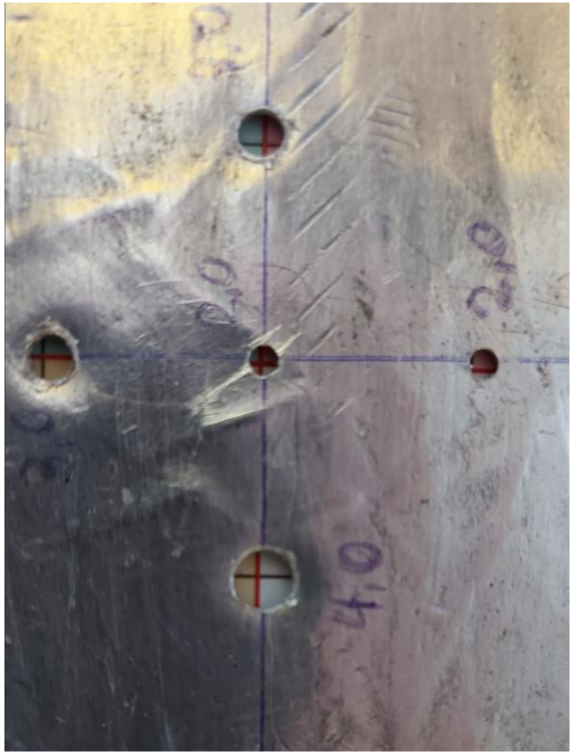
- → 1.4 Å (41.80 meV) neutron beam from diffractometer.
- → 6,22(19)x10^4 n/cm^{2}s^{-1} neutron flux

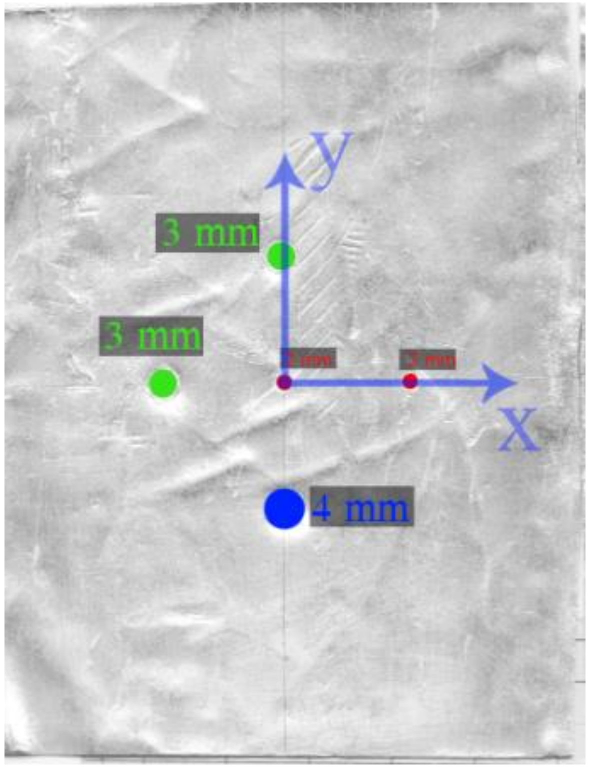
AURORA diffractometer exit.

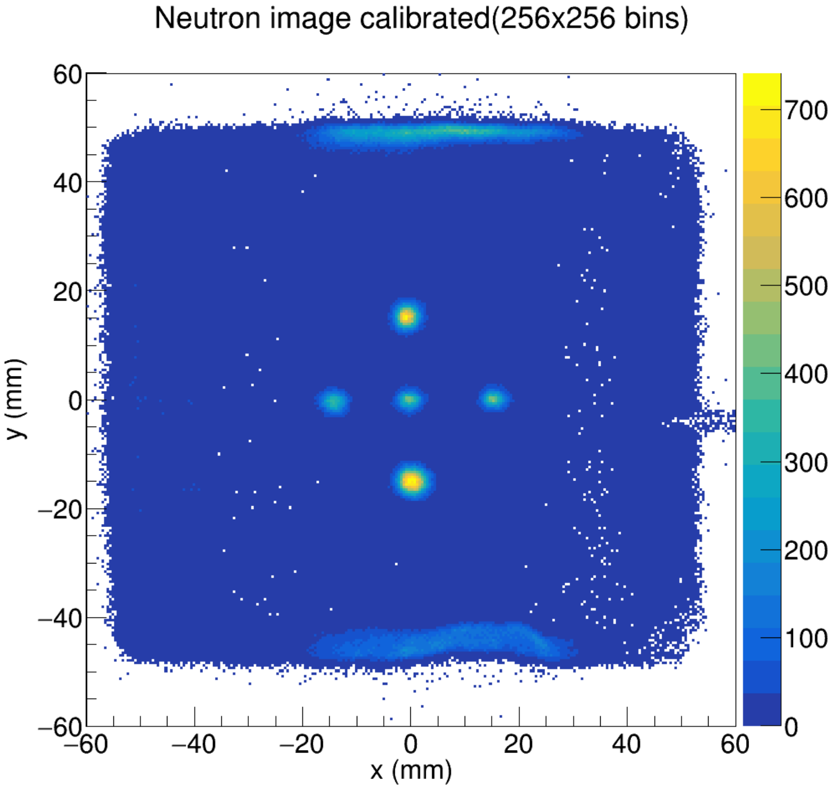
C. Parente et. al. 10.1016/j.nima.2010.06.203

GEM-based prototype

Test Cd masks (self-made)

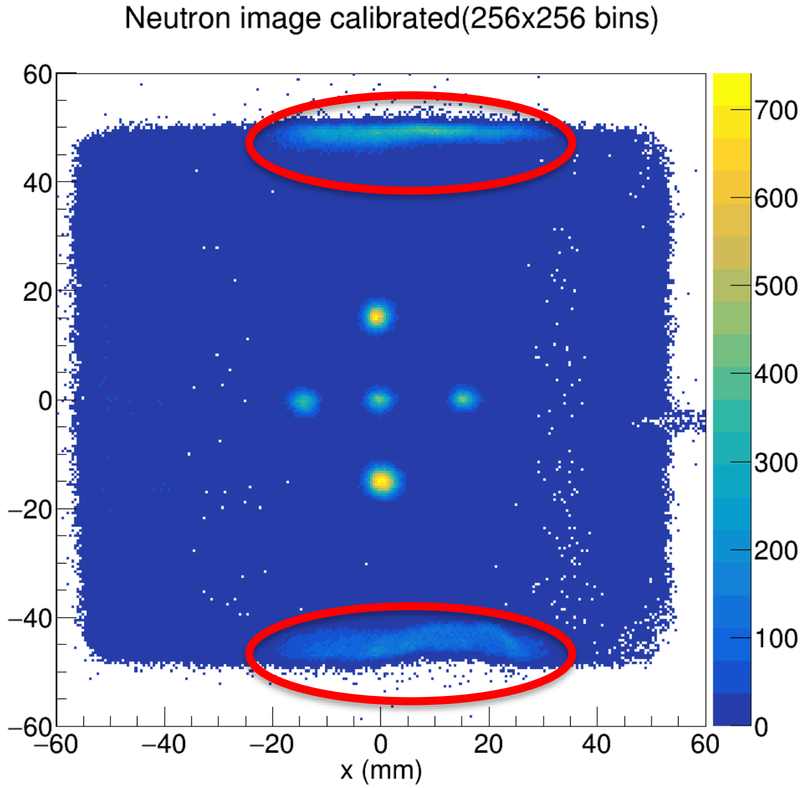






Left side: mask over detector, note the scale used to align it. Center: scan calibrated Cadmium mask. Right side: obtained image (833311 events).

Test Cd masks (self-made)



Left side: Mask over detector; the mask is smaller than the beam. Right side: obtained image (833311 events).

GEM-based prototype

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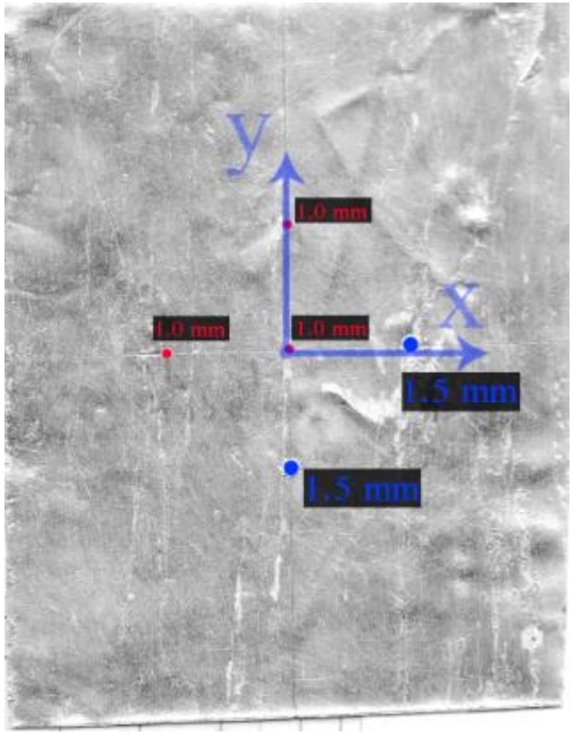
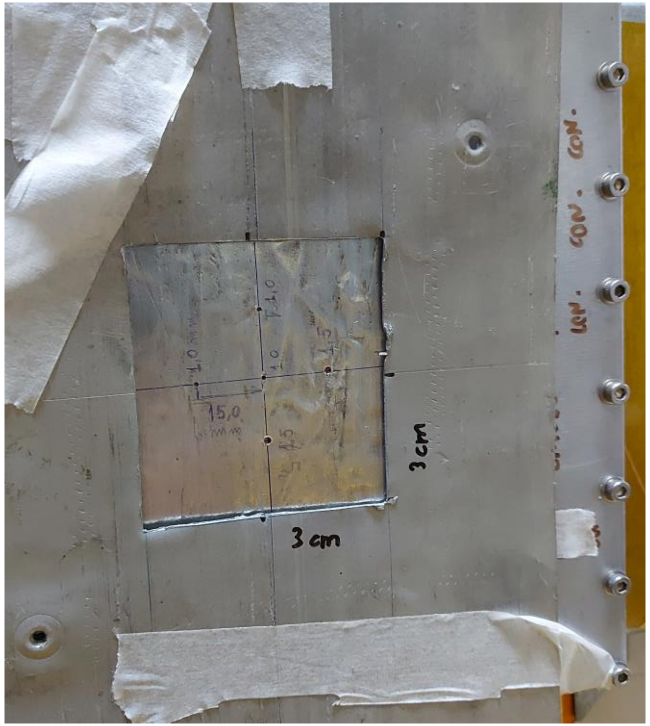
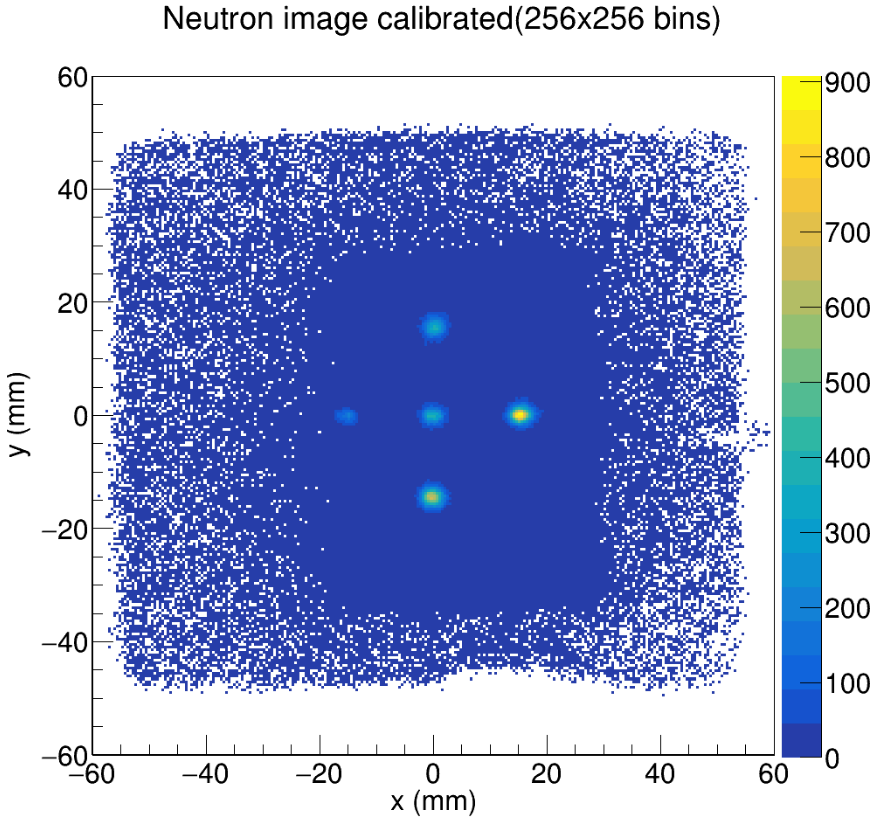
Test Cd masks (self-made)



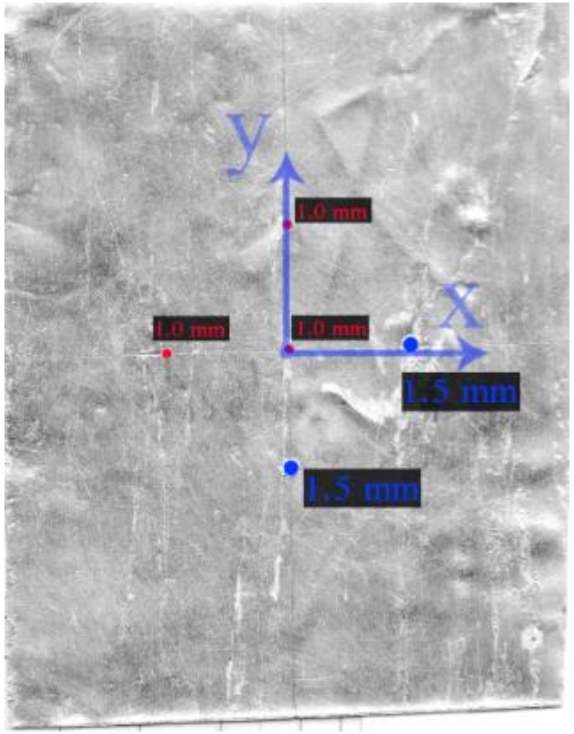


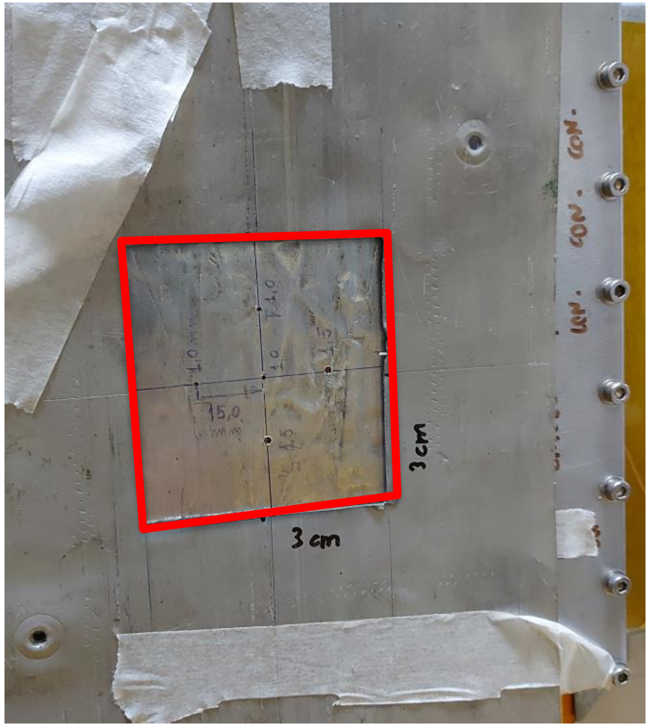


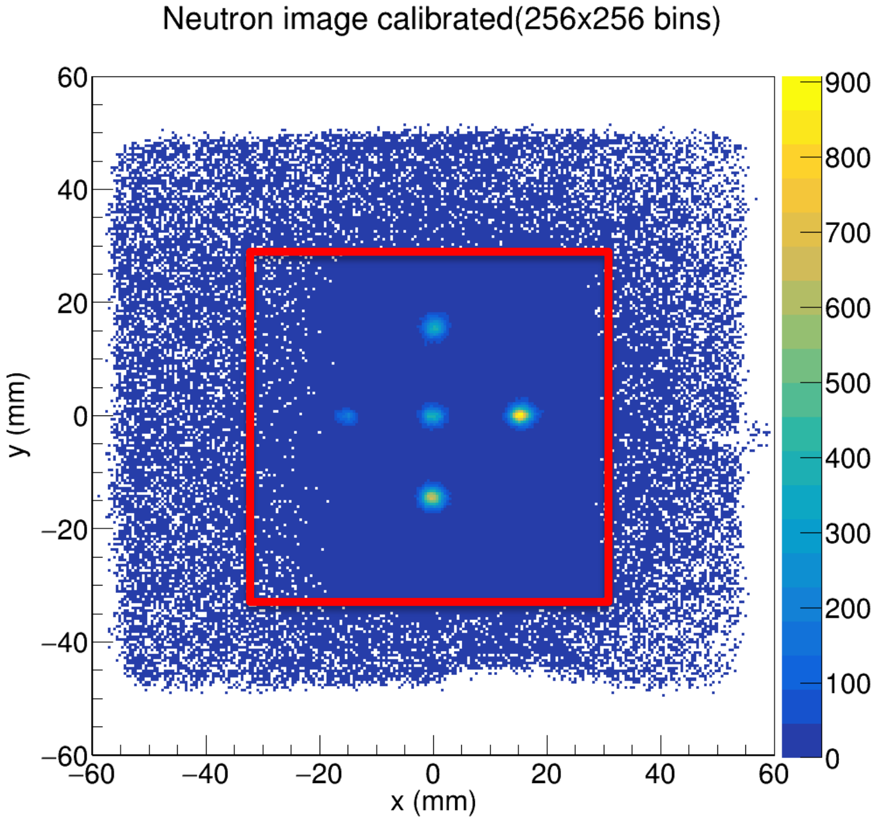
Left side: scan calibrated Cadmium mask. Center: mask over detector. Right side: obtained image (329062 events).

GEM-based prototype

Test Cd masks (self-made)



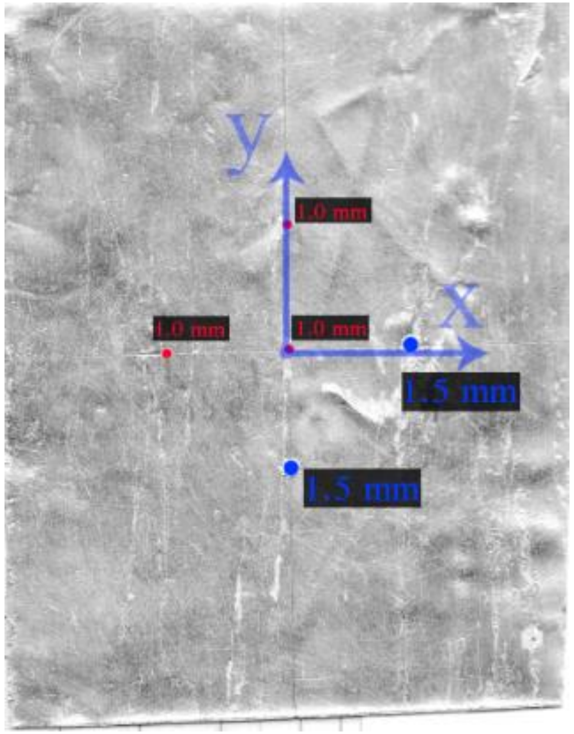


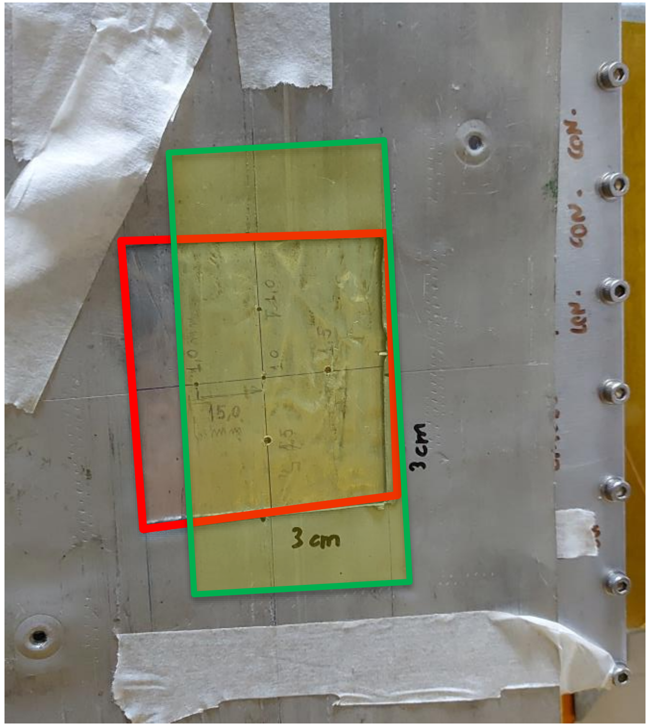


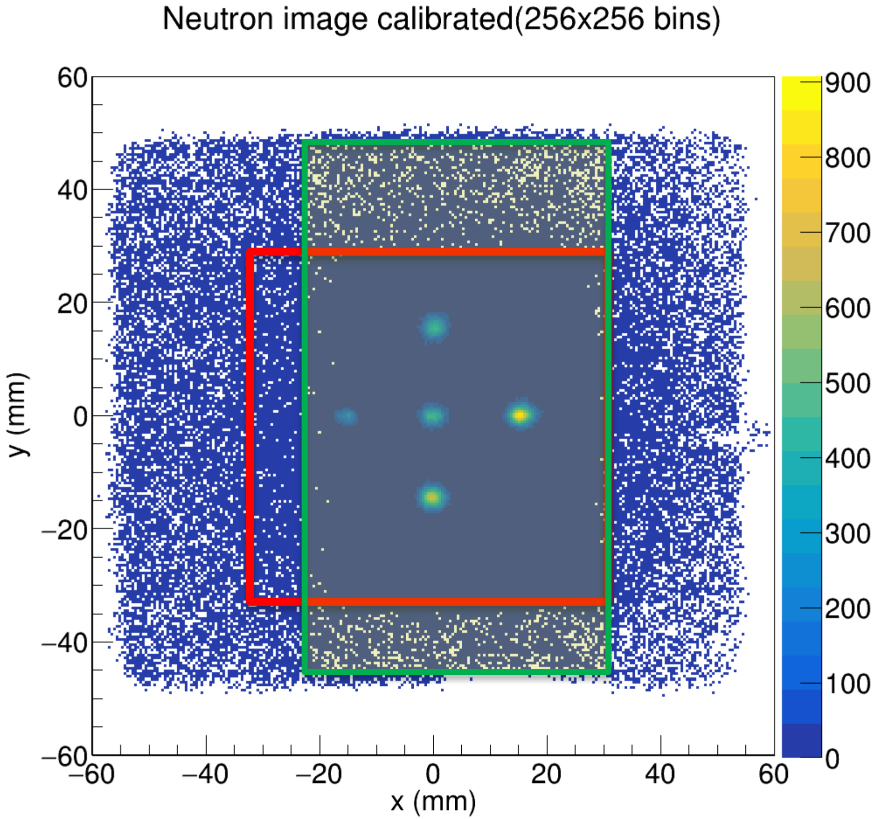
Left side: scan calibrated Cadmium mask. Center: mask over detector. Right side: obtained image (329062 events).
The red region represents the window in the outer mask.

GEM-based prototype

Test Cd masks (self-made)



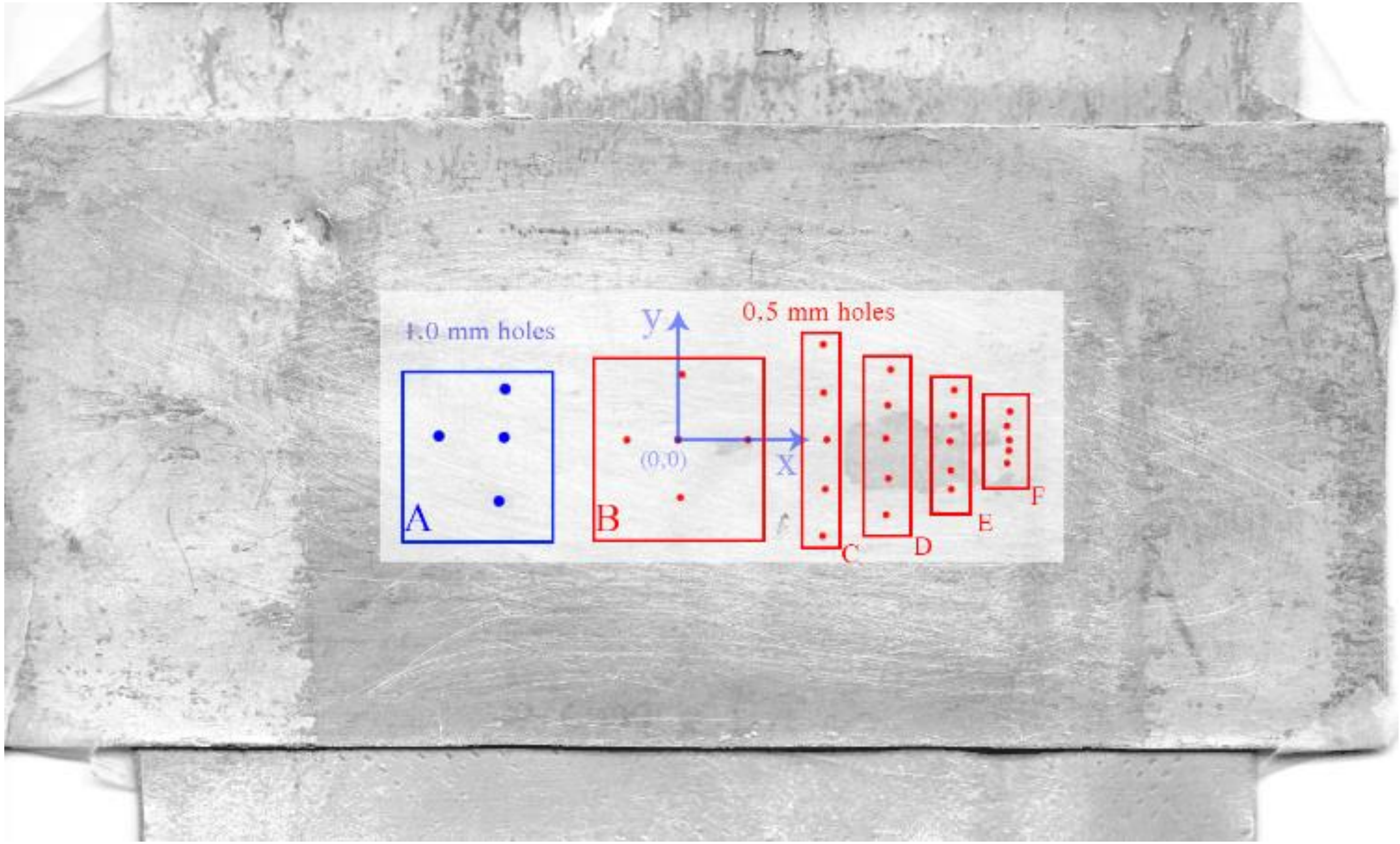




Left side: scan calibrated Cadmium mask. Center: mask over detector. Right side: obtained image (329062 events).
The red region represents the window in the outer mask. The yellow region represents the beam.

GEM-based prototype

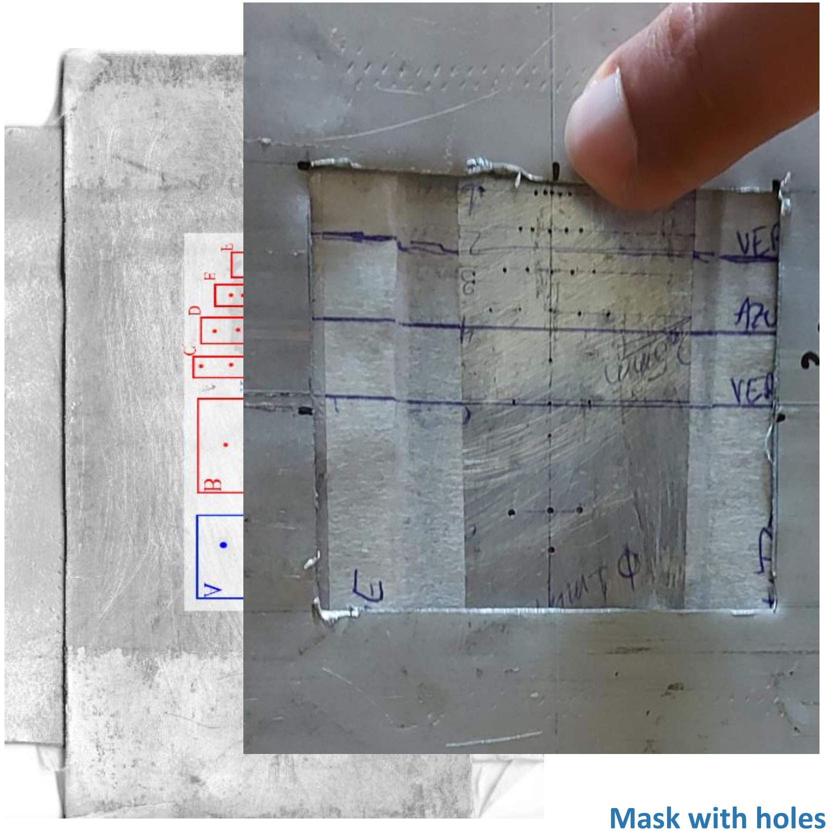
Test Cd masks (self-made)

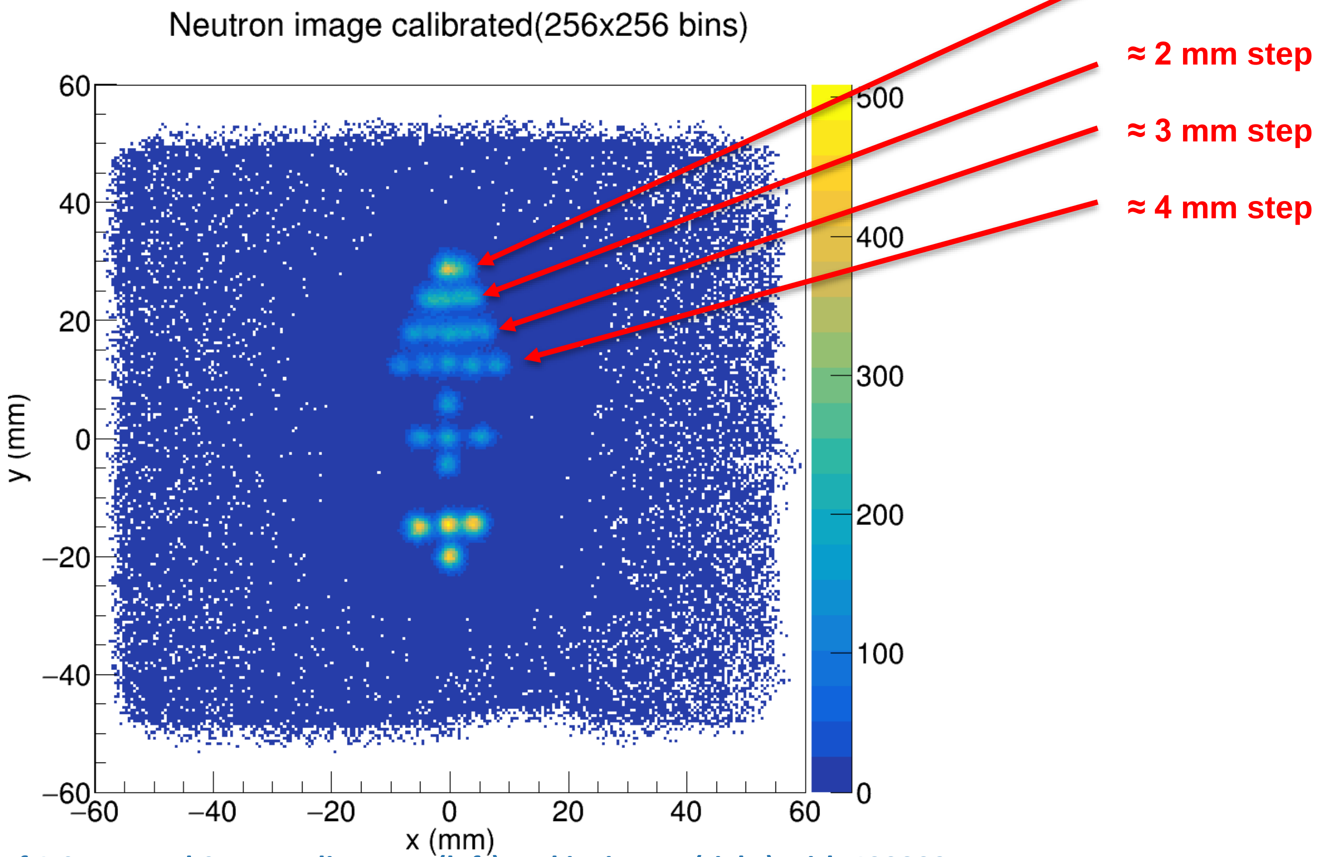


Mask with holes of 1.0 mm and 0.5 mm diameter.

GEM-based prototype

Test Cd masks (self-made)

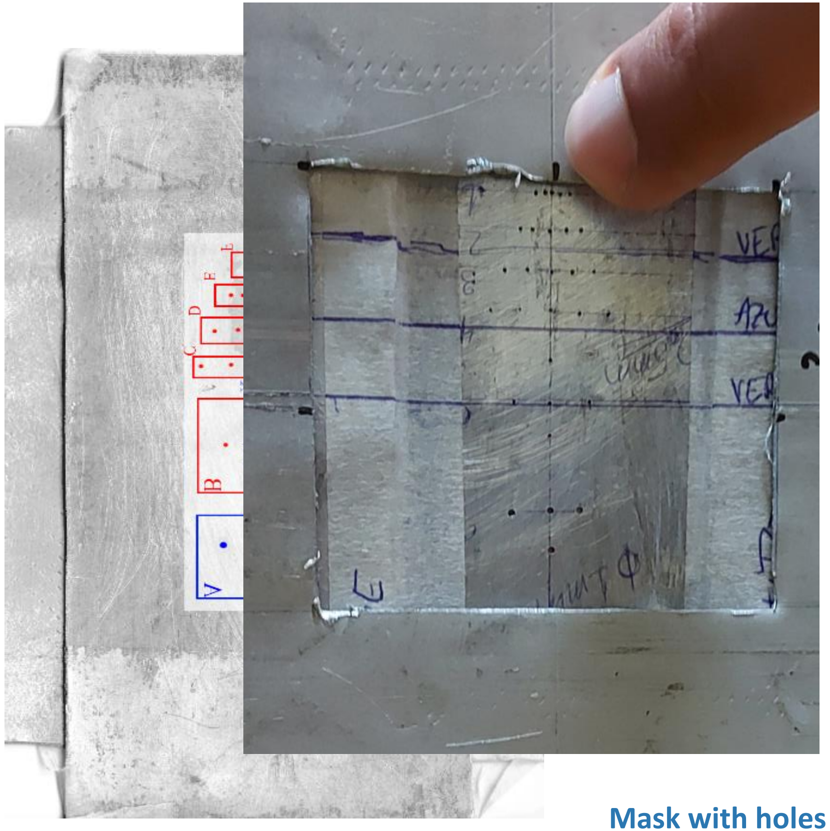


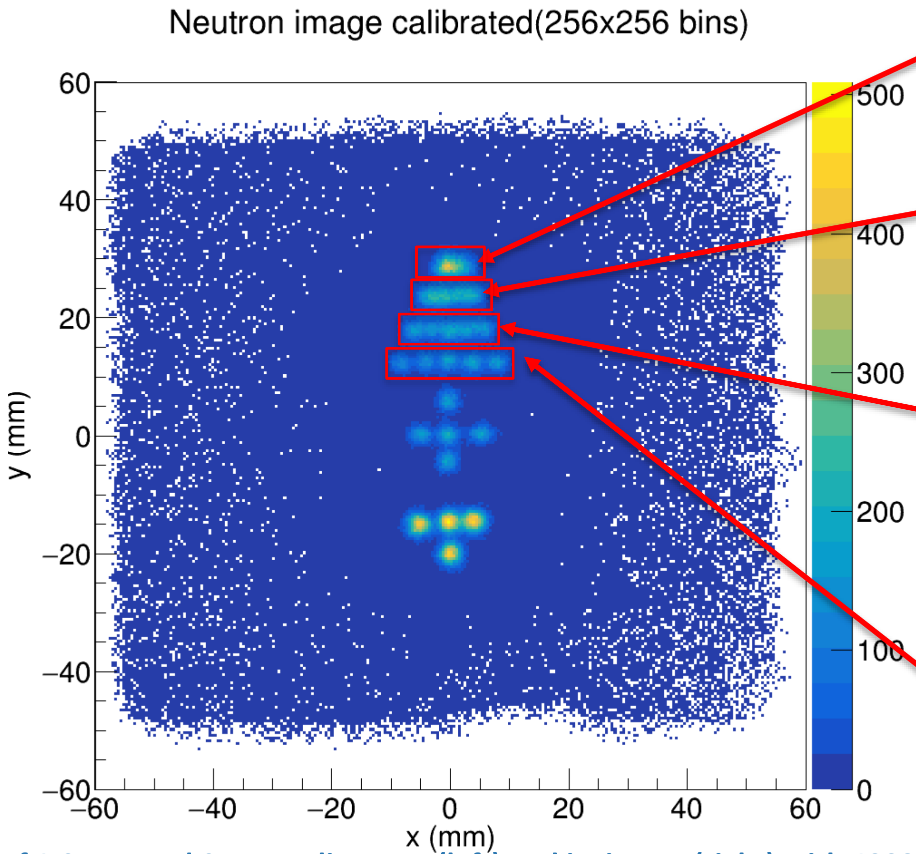


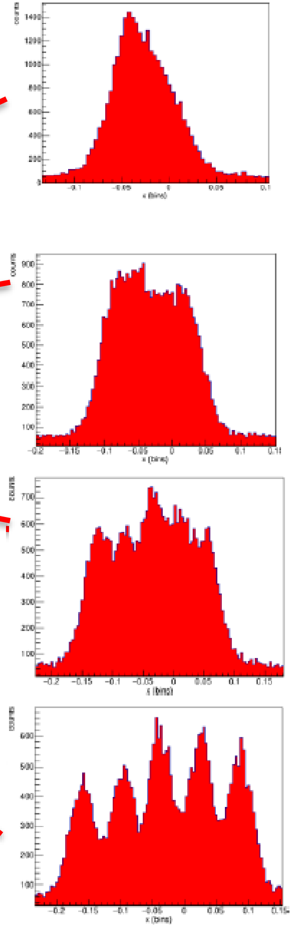
Mask with holes of 1.0 mm and 0.5 mm diameter (left) and its image (right) with 422323 events.

GEM-based prototype

Test Cd masks (self-made)

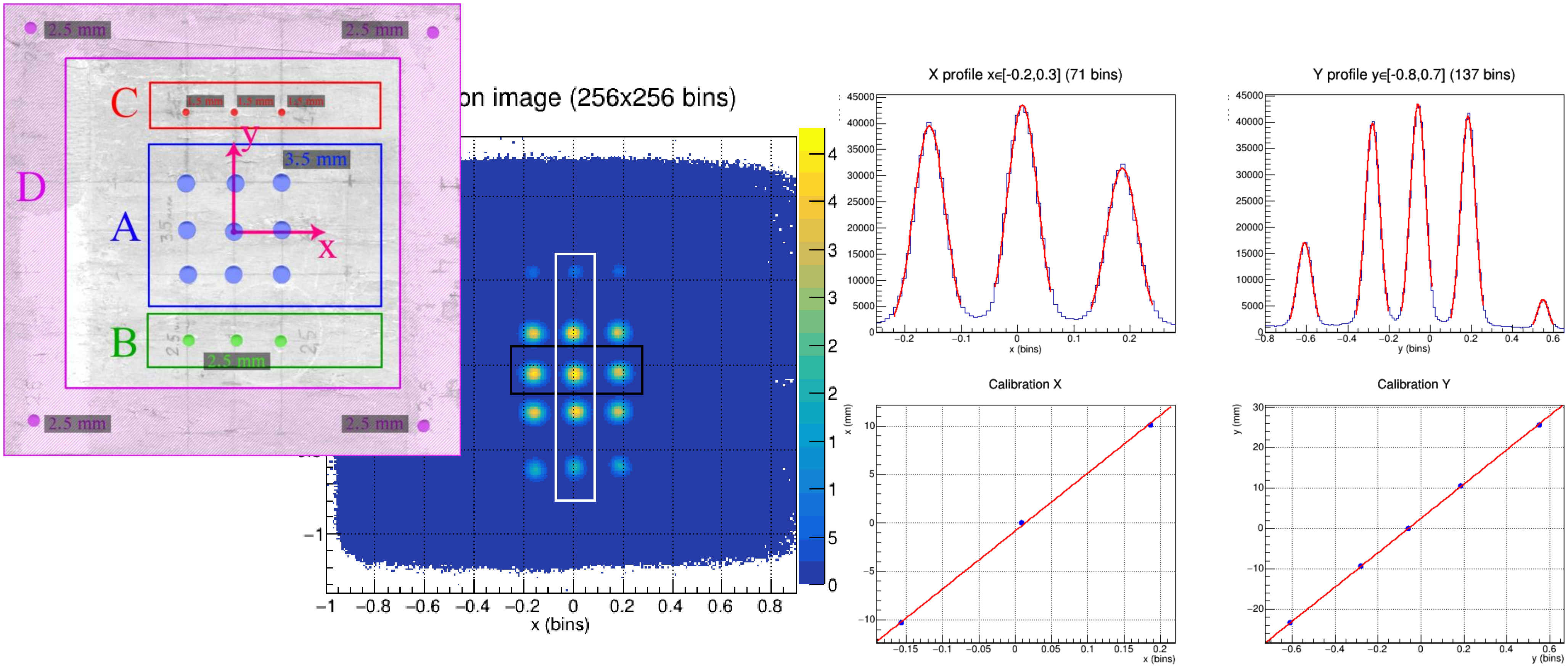






Mask with holes of 1.0 mm and 0.5 mm diameter (left) and its image (right) with 422323 events.

Calibration process



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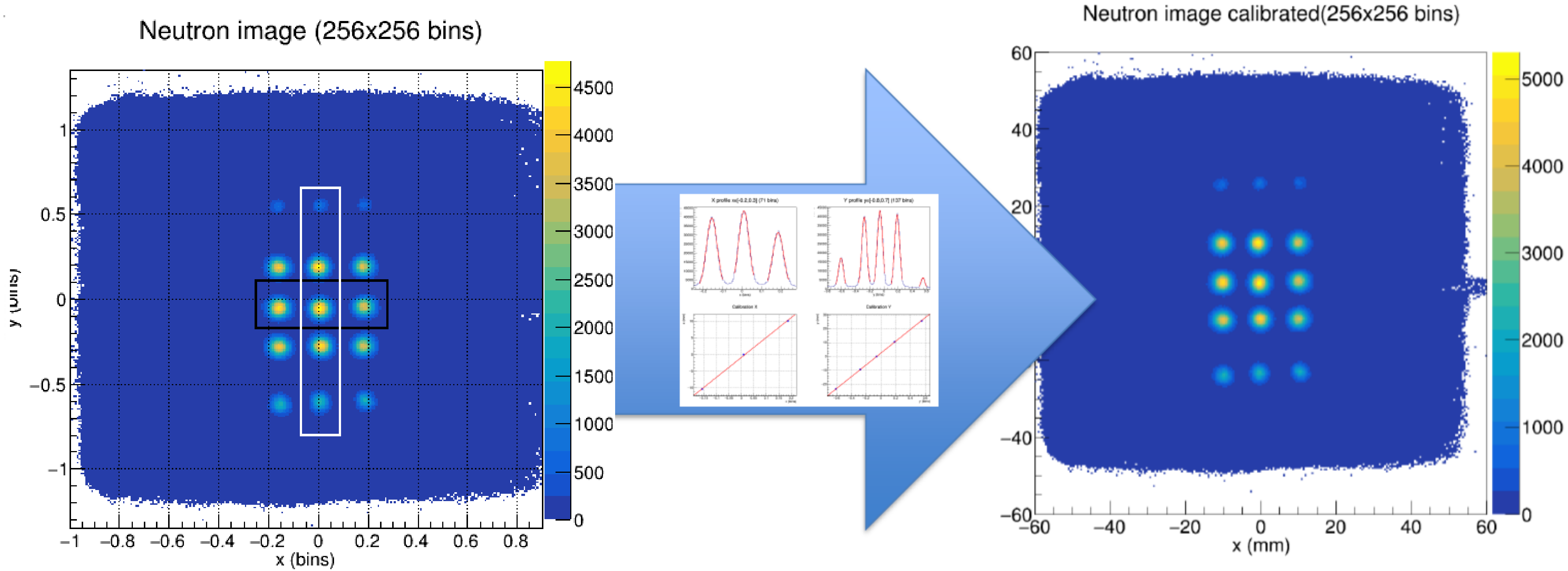
Calibration process



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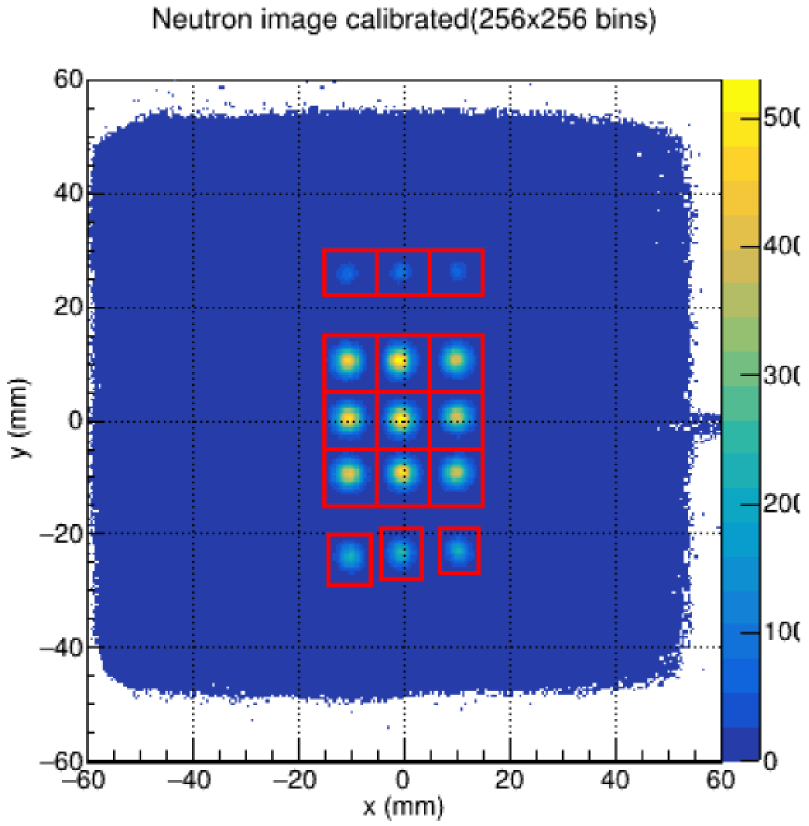
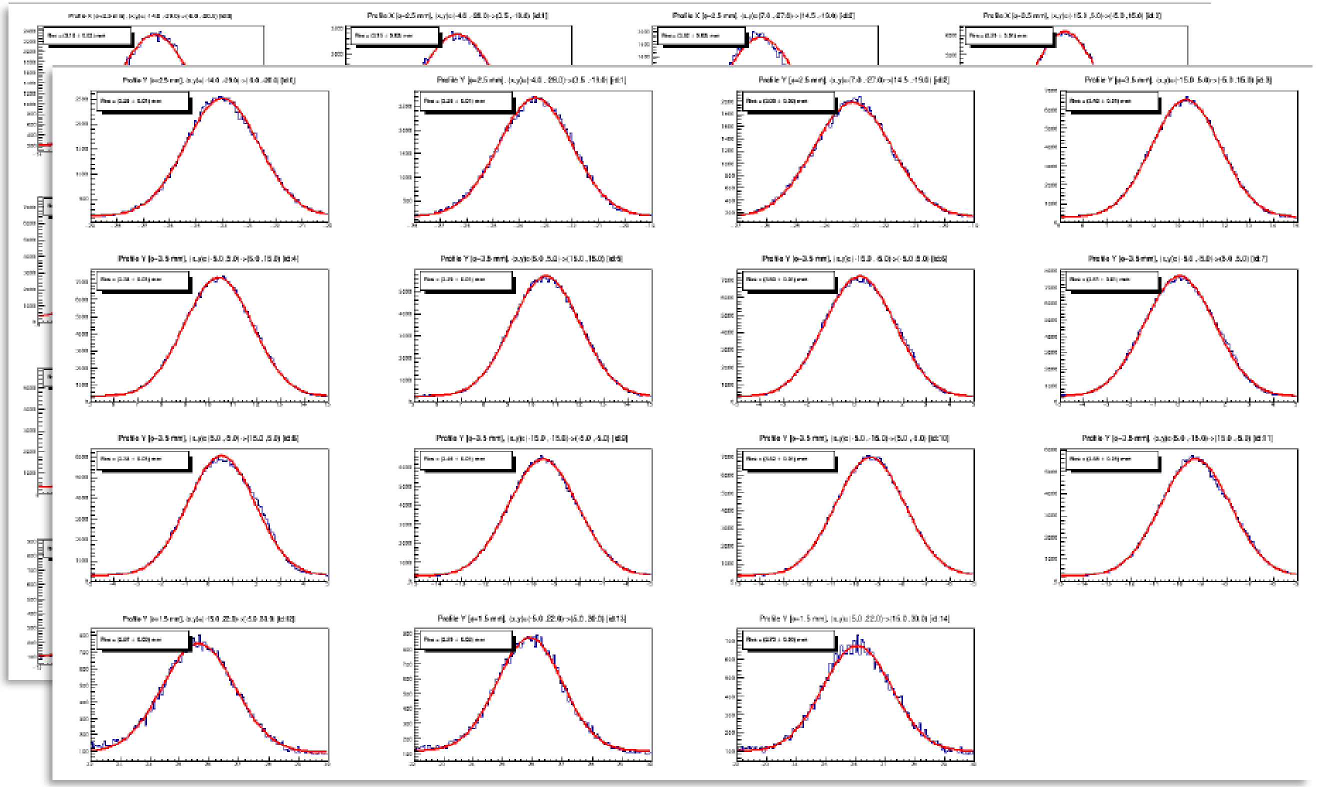
Fitting profiles





GEM-based prototype

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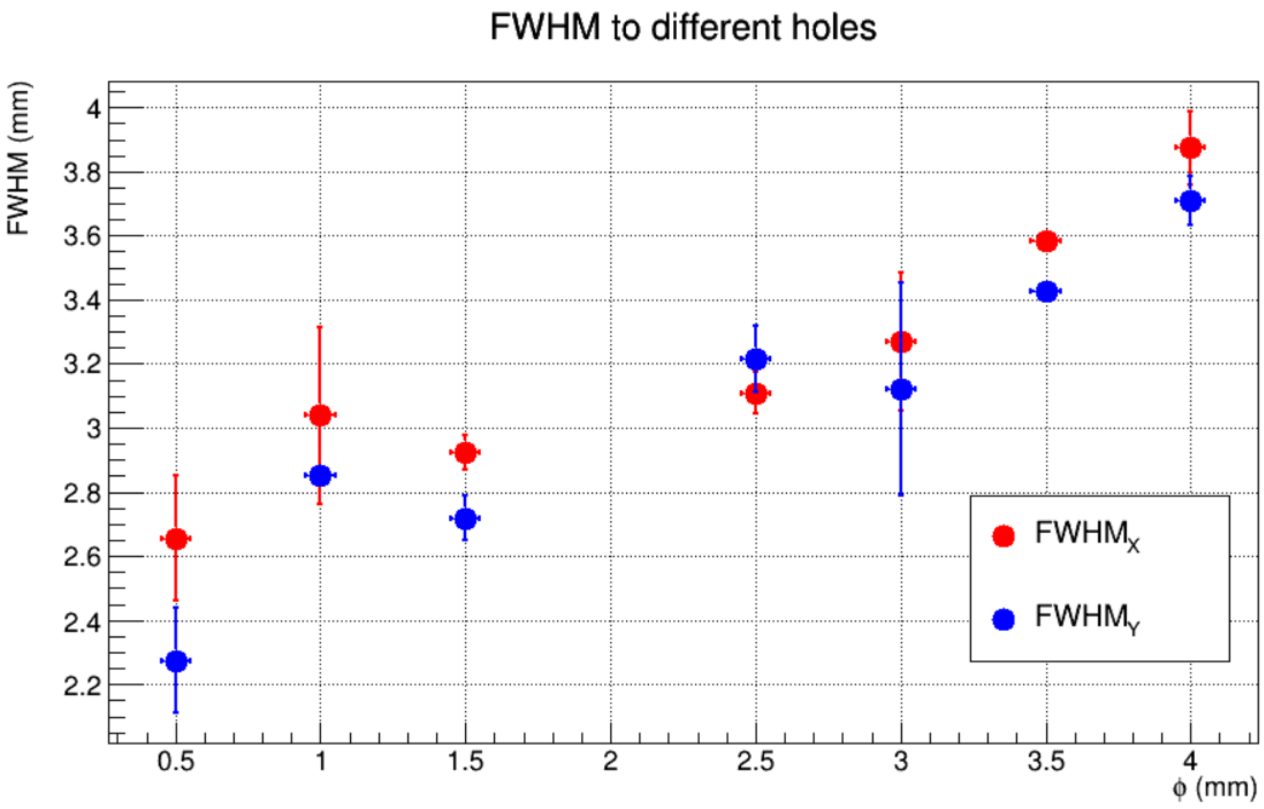
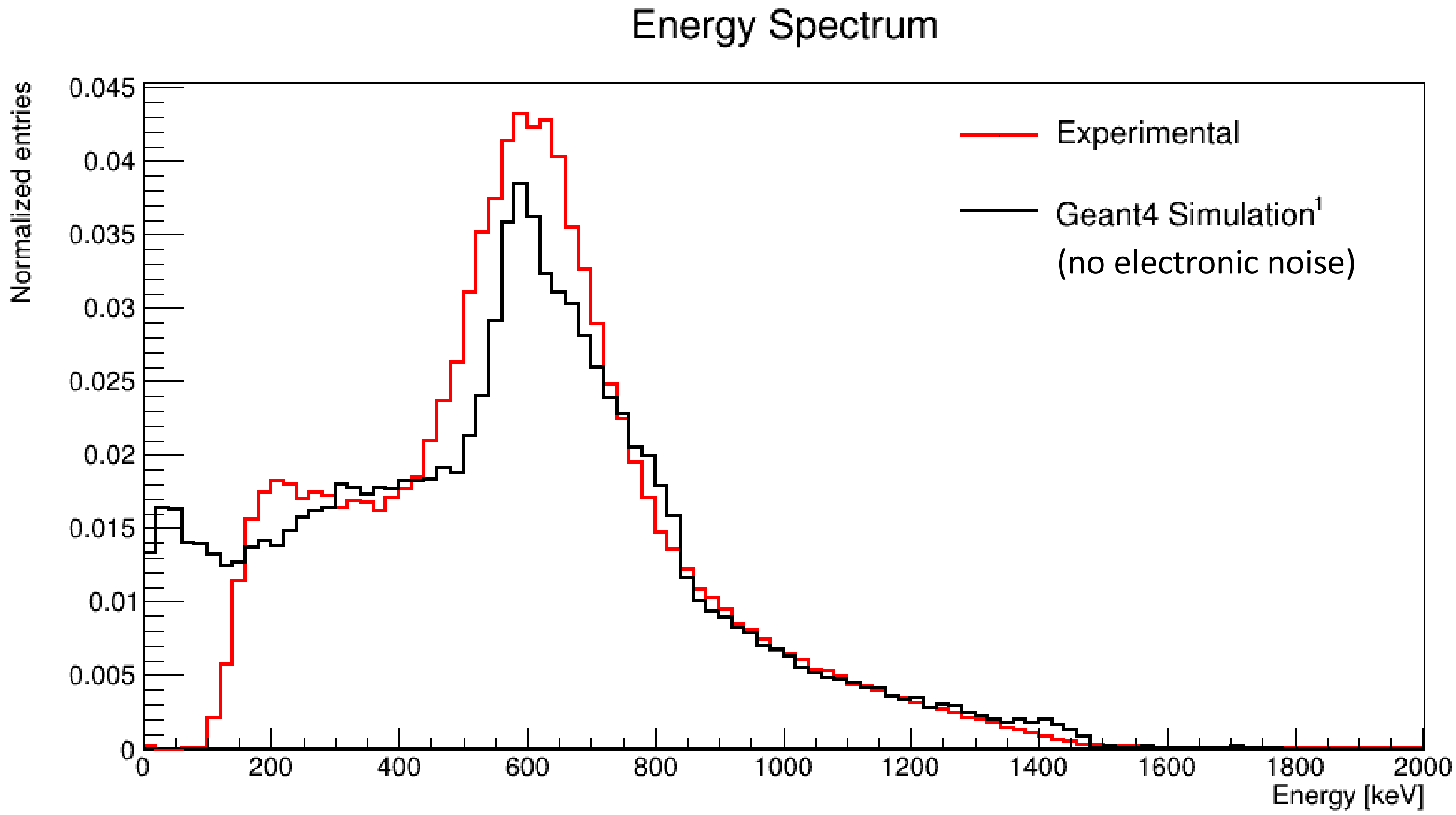
Why study holes of different diameters?



GEM-based prototype

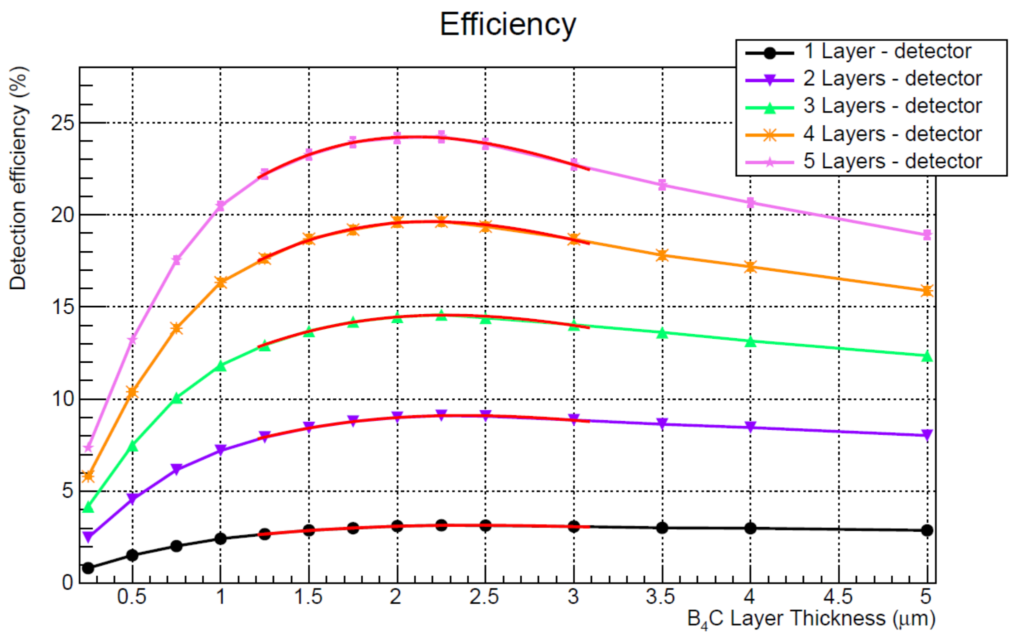
Energy Spectrum



Simulation provided by Renan Felix (also from our group at USP).

GEM-based prototype

Detection efficiency



2.25 µm $^{10}B_4C$ on cathode:

Simulated efficiency: 3.16(4)%

Neutron flux ($^{197}Au(n, \gamma)^{198}$ reaction):

$6{,}22(19) \times 10^4$ n/cm²s^{-1}

\+

Aquisition time

\+

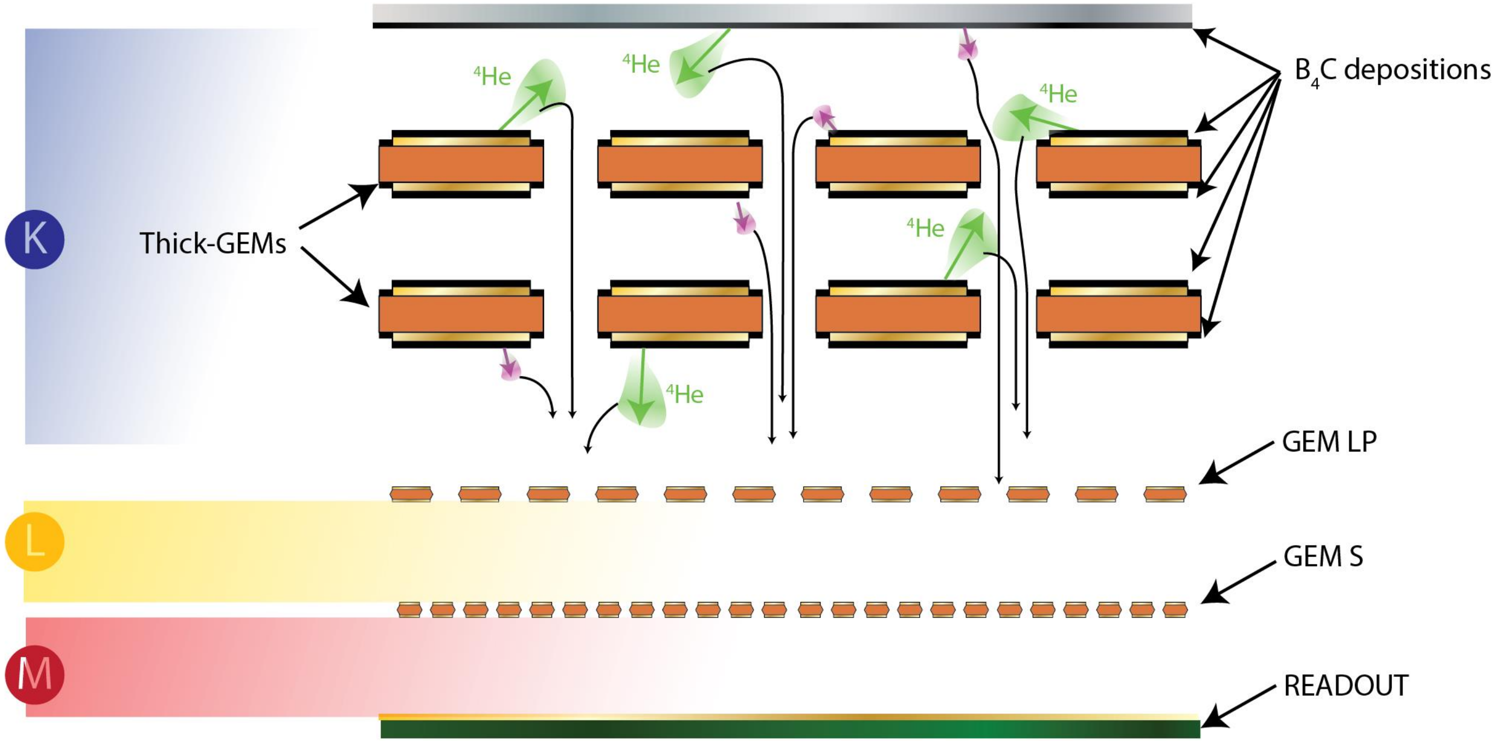
Calibrated mask area

Experimental efficiency: 2.97(25)%

Simulation provided by M. Monalisa Melo Paulino (also from our group at USP).

GEM-based prototype: next steps

Thick-GEM hybrid prototype with higher efficiency



Hybrid detector scheme. The thick-GEMs are represented

→ Thick-GEMs as neutron converters, operating at gain ≈ 1.

- → Easy assembly and deposition.
- → Better cost-benefit ratio.
- → Higher efficiency.
- → More robust.

HEPIC IFUSP

Thank you!

Acknowledging

Financial support by

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

and ESS ERIC for $^{10}B_4C$ deposition on our samples

References

[1] L. Lucas, “Comprehensive review and critical evaluation of the half-life of tritium,” Journal of Research of the National Institute of Standards and Technology, vol. 105, 07 2000.

[2] R. Kouzes, A. Lintereur, and E. Siciliano, “Progress in alternative neutron detection to address the helium-3 shortage,” Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment, vol. 784, pp. 172–175, 06, 2015.

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M. Baginova, P. Vojtyla, and P. Povinec, “Investigation of neutron interactions with ge detectors,” Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 897, 04 2018.