Performances of a Medium-Size Boron-coated GEM detector for thermal neutrons at the ISIS Neutron and Muon Source

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the Unimib and ISTP-CNR group

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Outline

- Introduction “ The spallation Sources”
- GEM detectors and neutron detection
- The I-MS-BGEM detector
- Characterisation at ISIS
- Conclusions

Introduction

- Increase of the number of the neutron spallation sources.
- 3He Shortage

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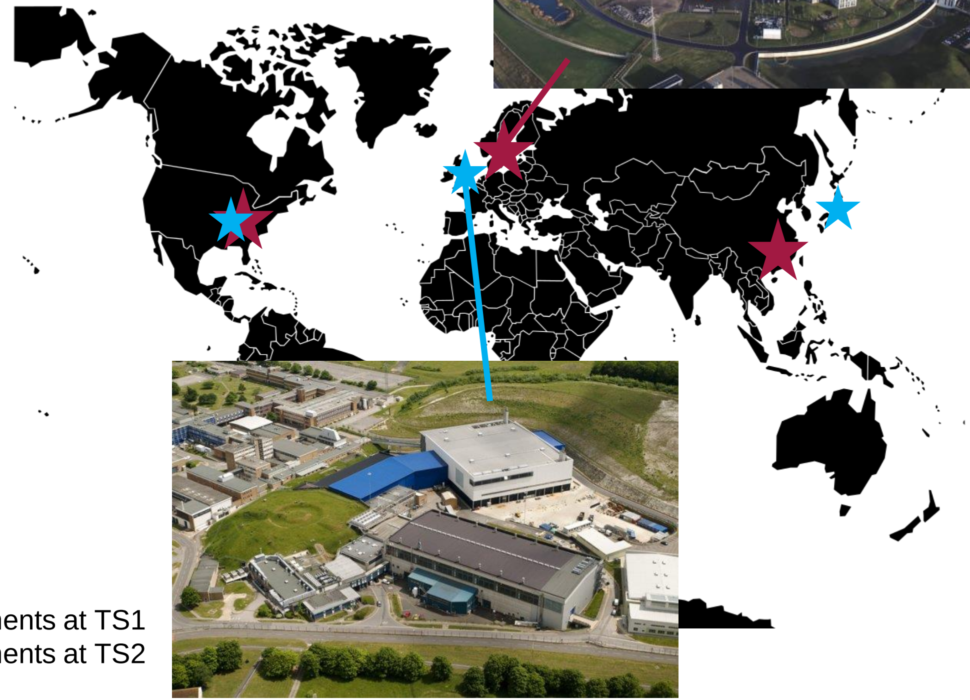
Request of new devices capable to combine high detection efficiency and low costs

New spallation source

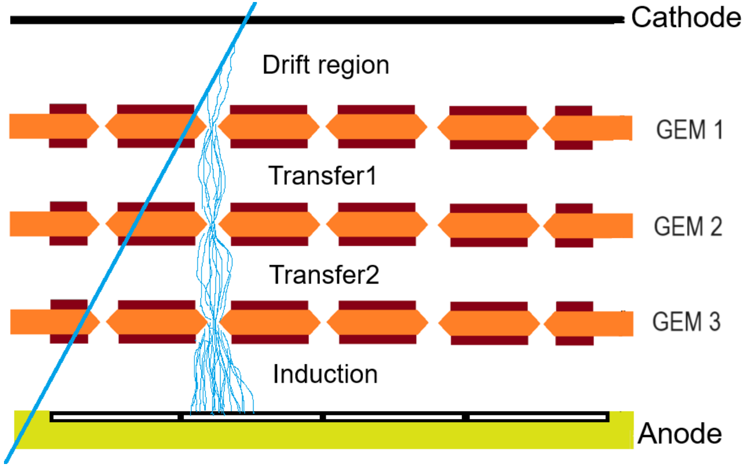
Operative spallation source

ESS (Lund)
Start in 2024
22 instruments to be built



ISIS (UK)
19 instruments at TS1
12 instruments at TS2

GEM detectors



GEM detectors features:

- Very high rate capability (MHz/mm^2)
- Good space resolution (order of μm)
- Time resolution of ns.
- Possibility to be realized in large areas and in different shapes.
- Radiation hardness.
- Low sensitivity to gamma rays.

GEM detectors need a neutron converter.

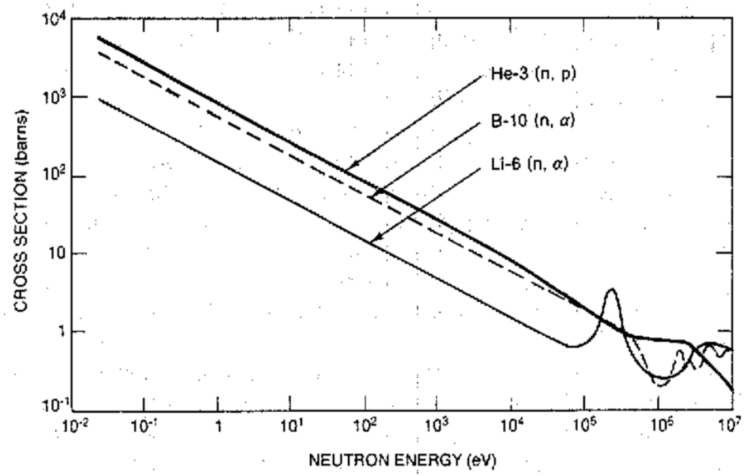
Neutron detection

Mostly based on three nuclear reaction:

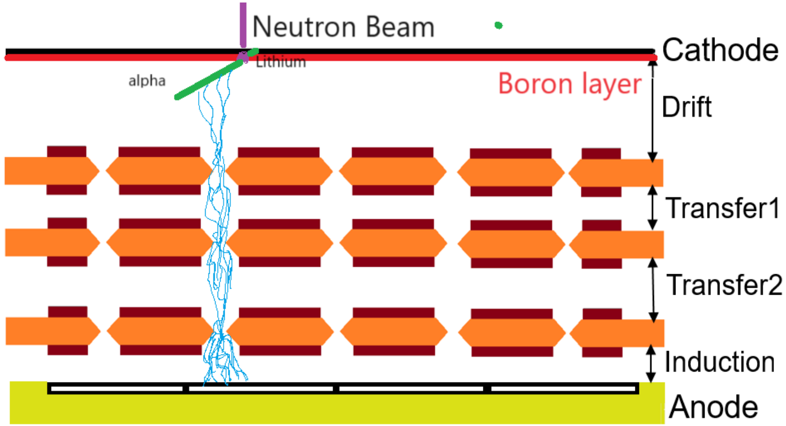
$$n + {}^{3}He \rightarrow {}^{3}H + p \qquad Q_{val} = 0{,}764\ MeV, \sigma = 5330\ b$$

$$n + {}^{6}Li \rightarrow {}^{3}H + \alpha \qquad Q_{val} = 4{,}78\ MeV, \sigma = 940\ b$$

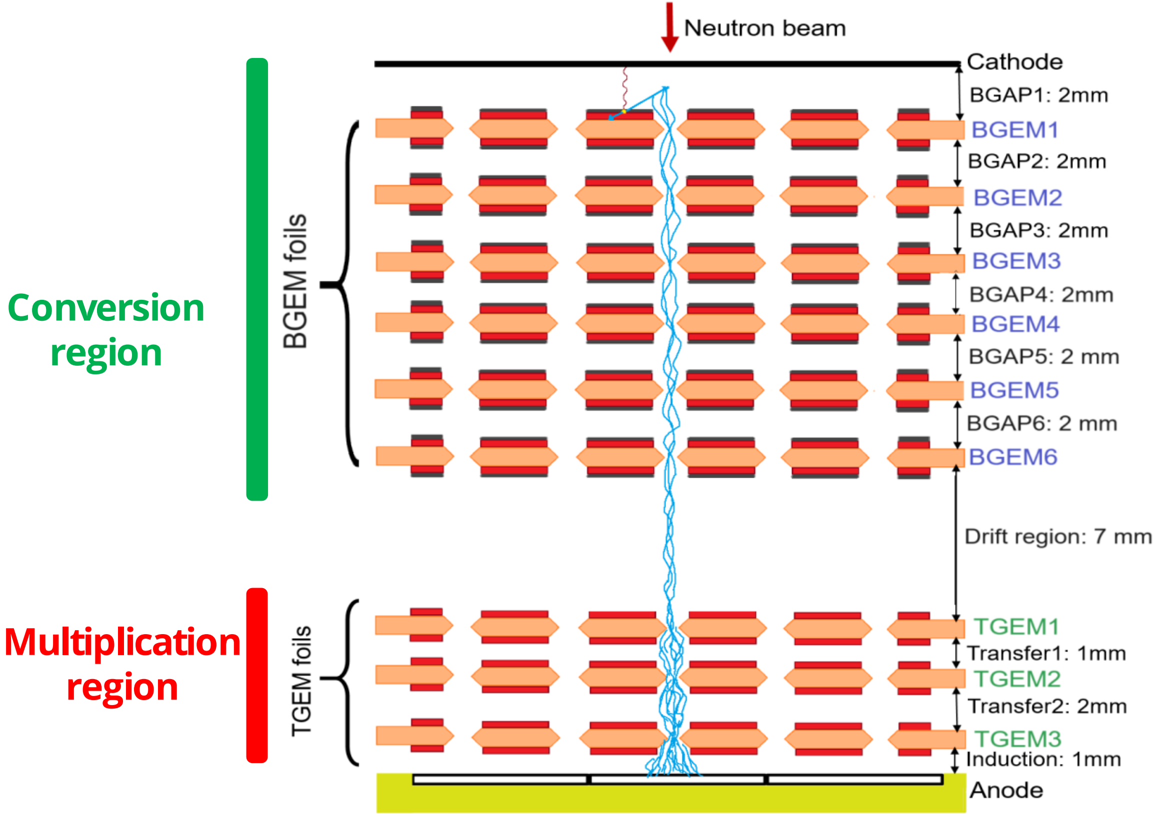
$$n + {}^{10}B \rightarrow \begin{cases} \alpha + {}^{7}Li \\ \alpha + {}^{7}Li^{*} \end{cases} \qquad Q_{val} = 2{,}792\ MeV\ (g.s) \quad \sigma = 3840\ b$$



Knoll "Radiation detection and measurements"



The I-MS-BGEM detector



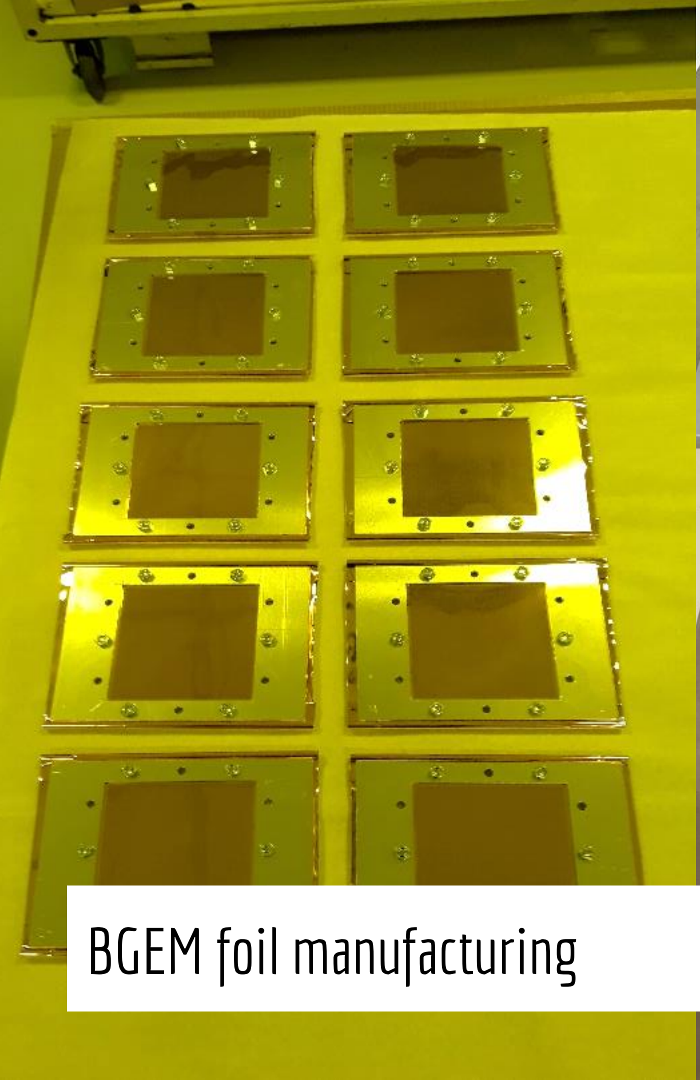
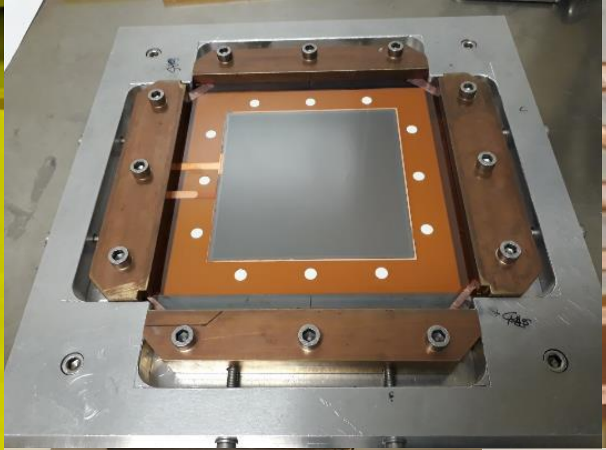
The detector is composed of two stacks:

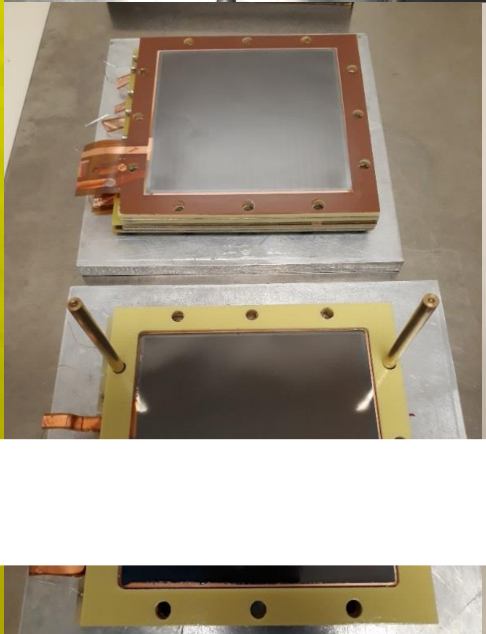
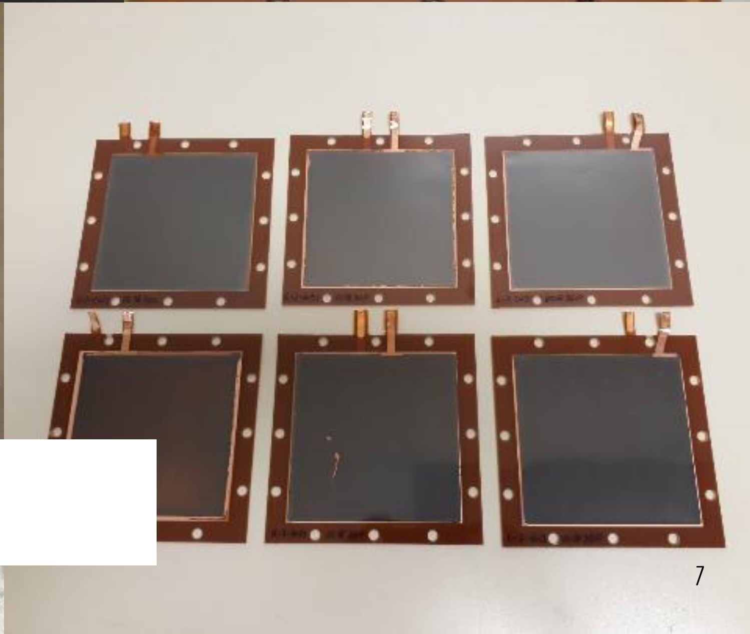
- The **conversion** stack
- The **multiplication** stack

The conversion stack must have a **unitary gain**, in order to:

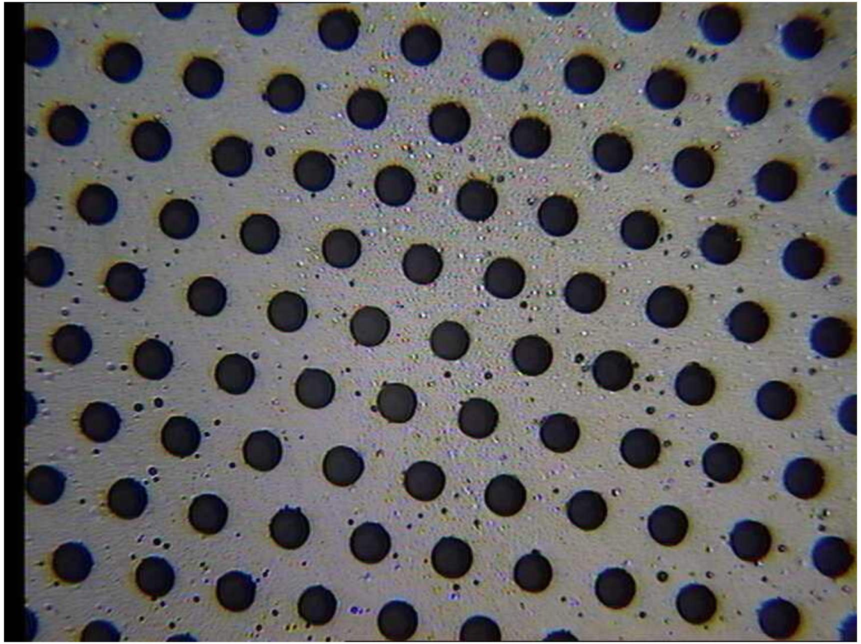
- Have the same response inside the region.
- Avoid discharges.

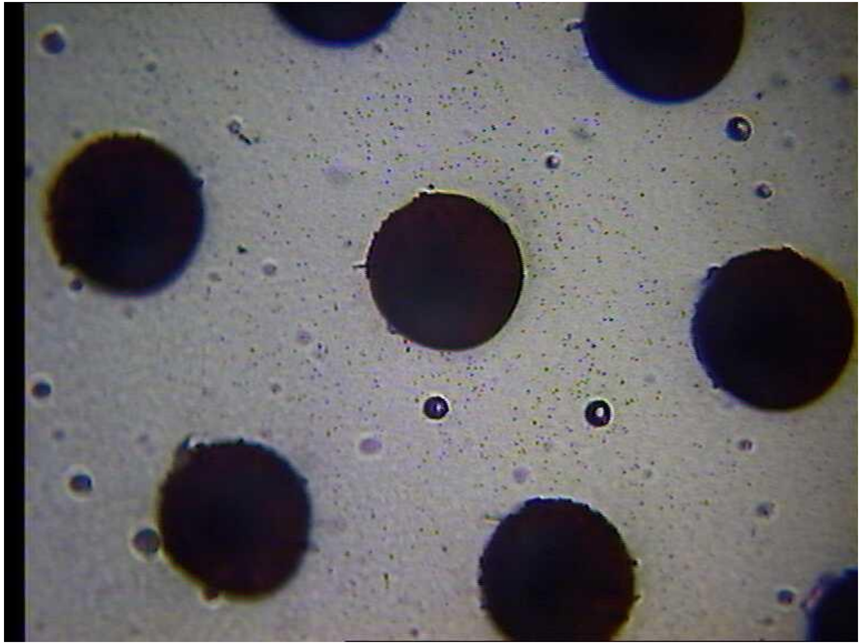
The electron multiplication must happen only inside the multiplication region.

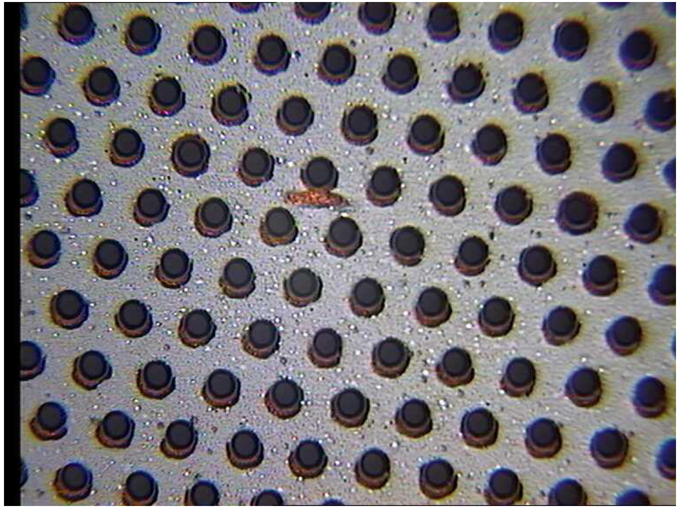
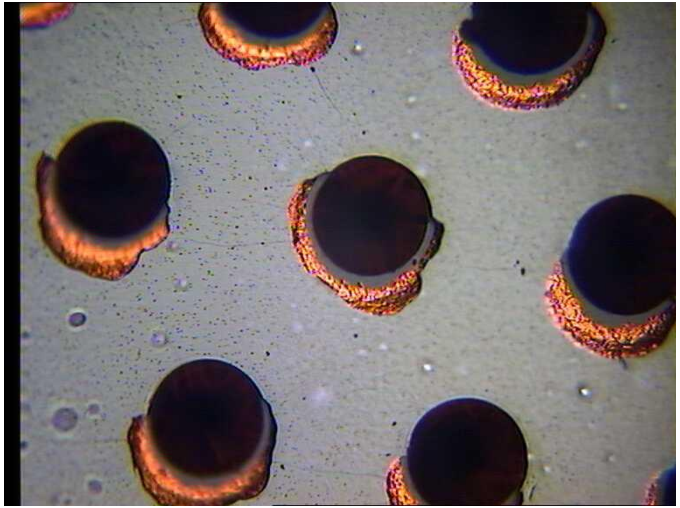
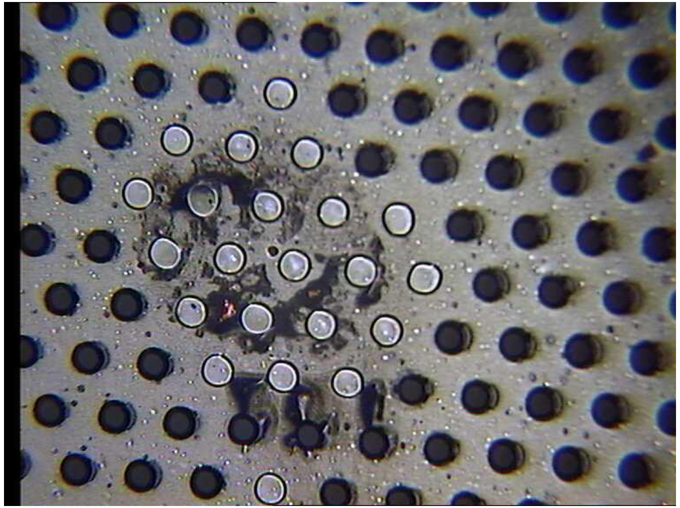



BGEM foil manufacturing

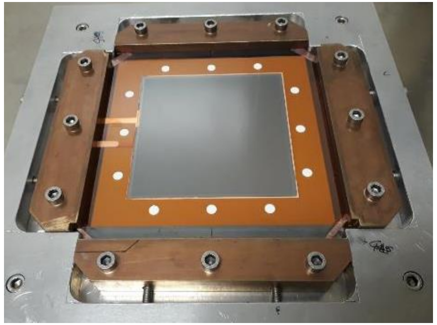




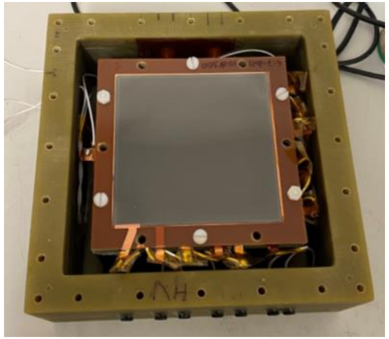
BGEM foil manufacturing

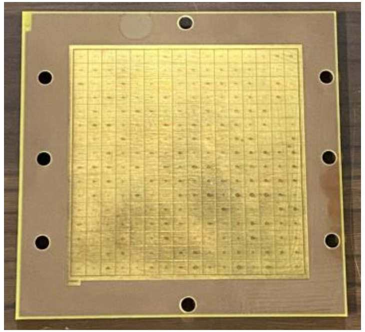

Detector Realisation



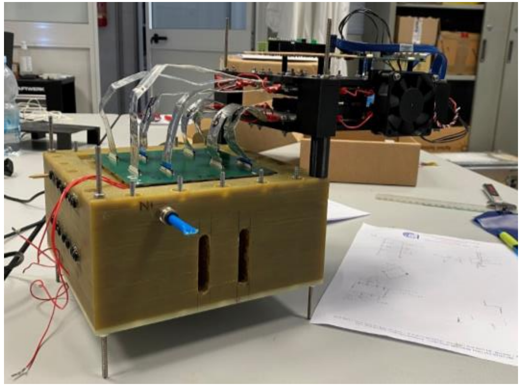
BGEM foil stretching



BGEM foils stack placed inside the faberglass box



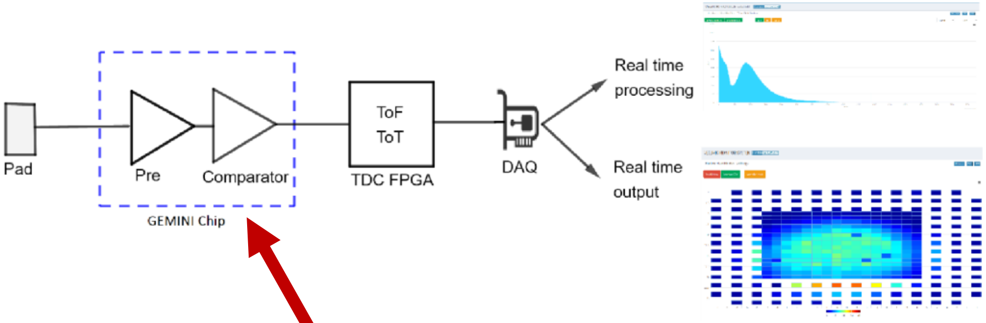
Padded anode

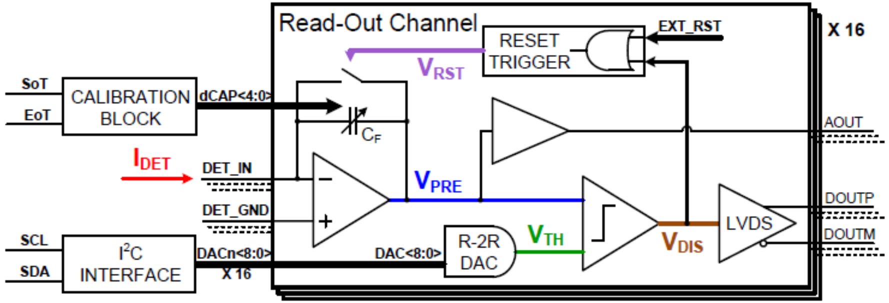


The detector with the GEMINI readout

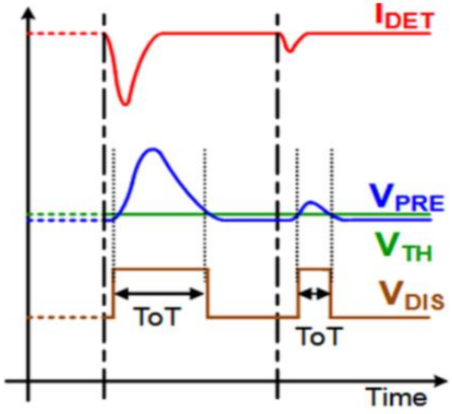
The Electronic readout

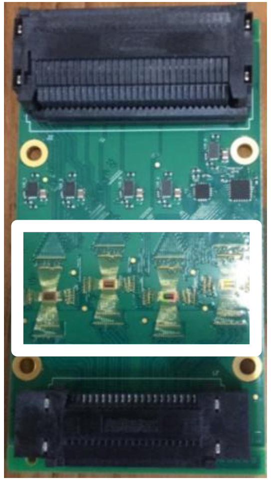
The GEM INtegrated Interface (GEMINI) readout system





Features	
CMOS technology	180 nm
N° of channels	16
Max pixel capacitance	40 pF
Max count rate 1 channel at the min detectable charge	5 Mcps
Min detectable charge	2.5 fC

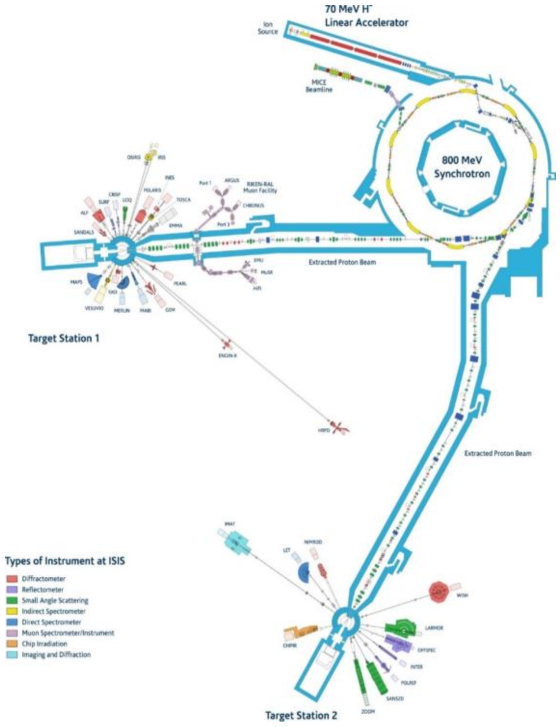


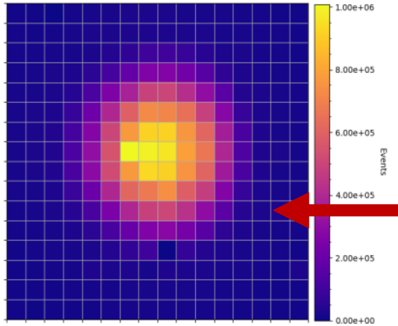


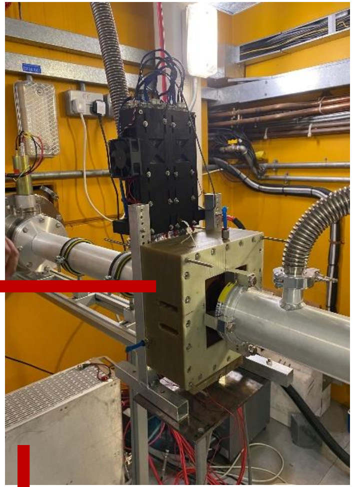
The four GEMINI ASIC

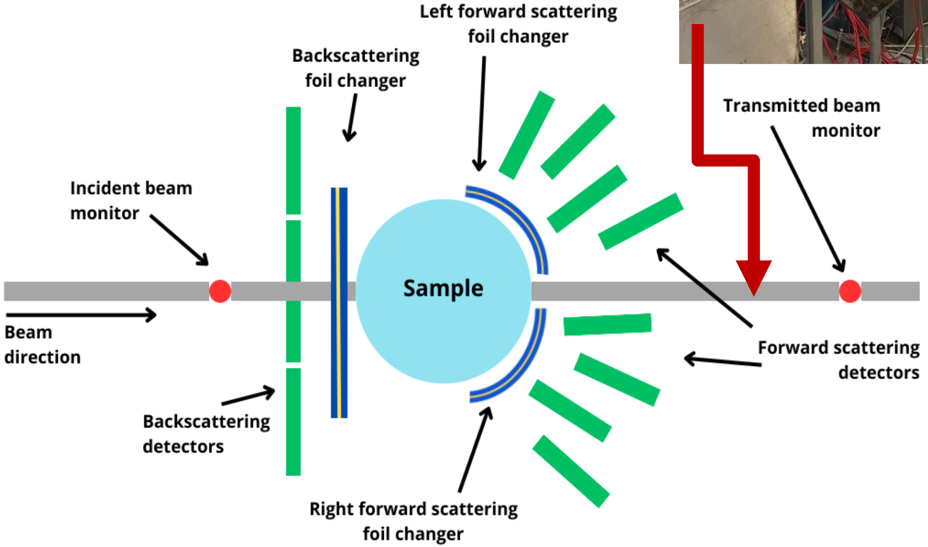
Characterisation at ISIS

ISIS Neutron and Muon Source (UK)



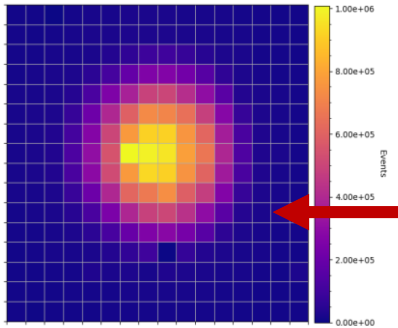


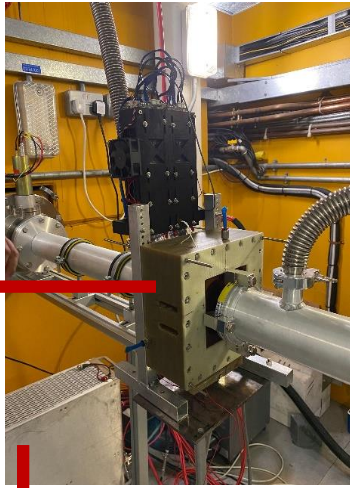


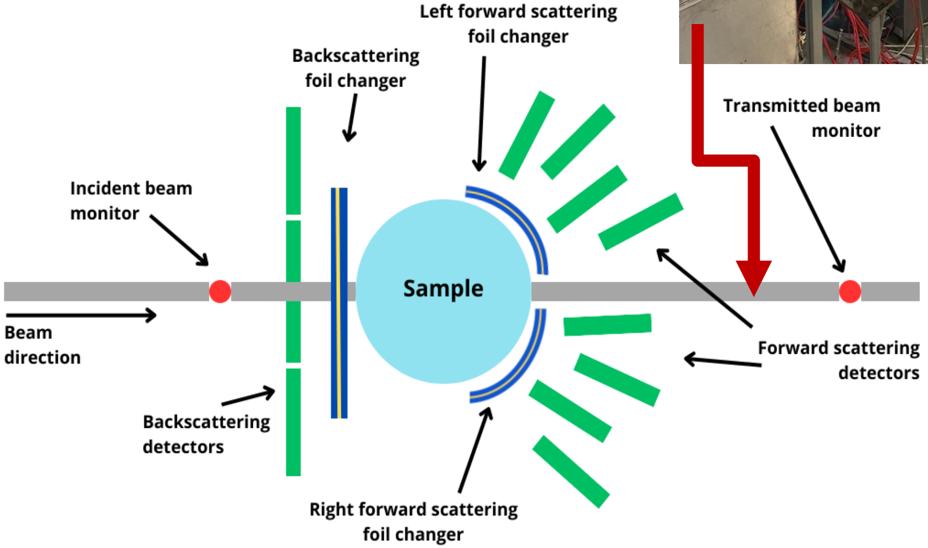


Characterisation at ISIS

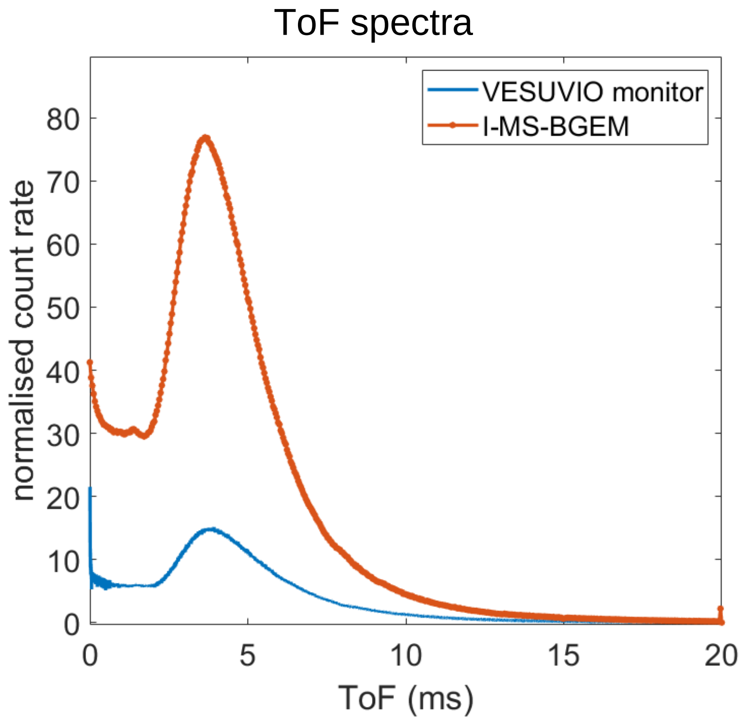
- Use of the **VESUVIO spectrometer**
- Thermal and epithermal neutron beam from 0,02 up to 150 eV.
- n flux of $\approx 10^7 \frac{n}{s*cm^2}$
- Use of **Time of Flight (ToF) technique.**
- 6MBGEM detector placed at 12,6 m from target and at 40 cm from the VESUVIO transmitted beam monitor.
- The VESUVIO transmitted beam monitor is a 6Li-based scintillator (**GS20** detector).

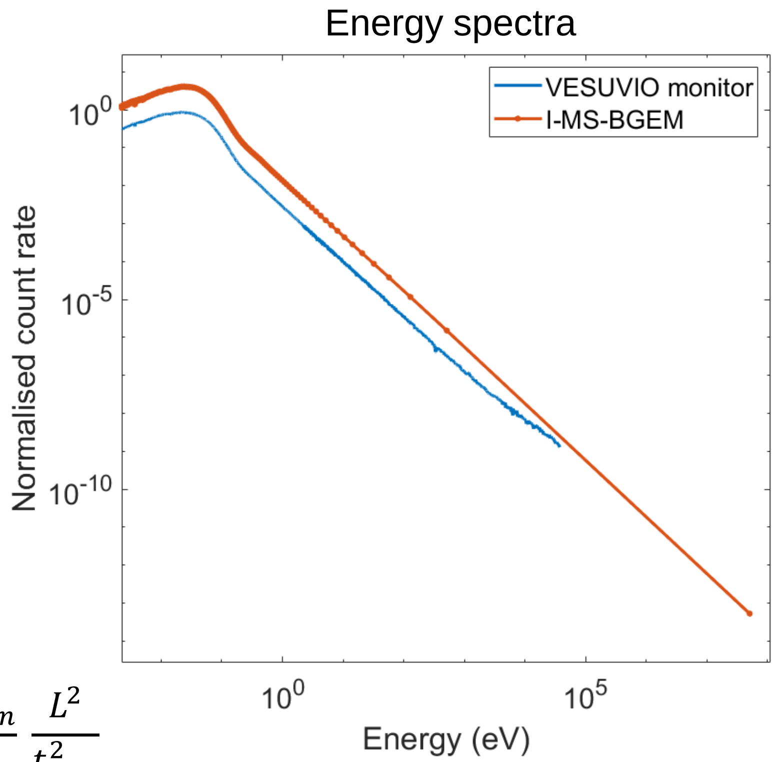






I-MS-BGEM detector

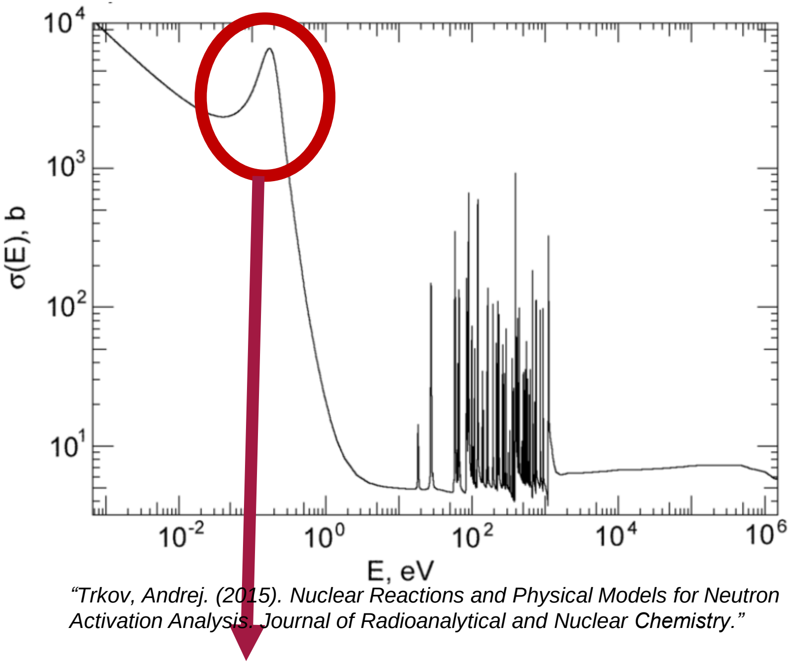




$$E_n = \frac{m_n}{2} \frac{L^2}{t_{ToF}^2}$$

I-MS-BGEM detector

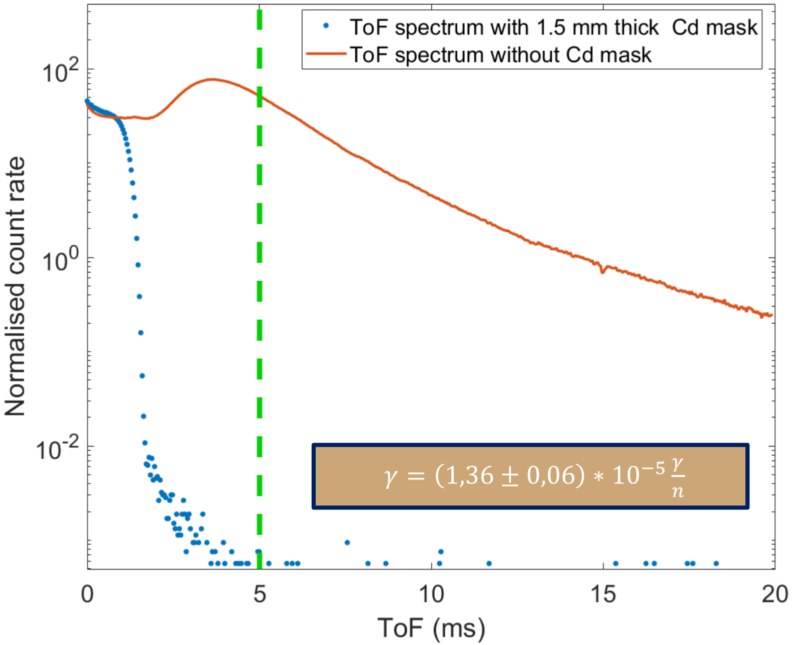
Cadmium total neutron cross section



“Trkov, Andrej. (2015). Nuclear Reactions and Physical Models for Neutron Activation Analysis. Journal of Radioanalytical and Nuclear Chemistry.”

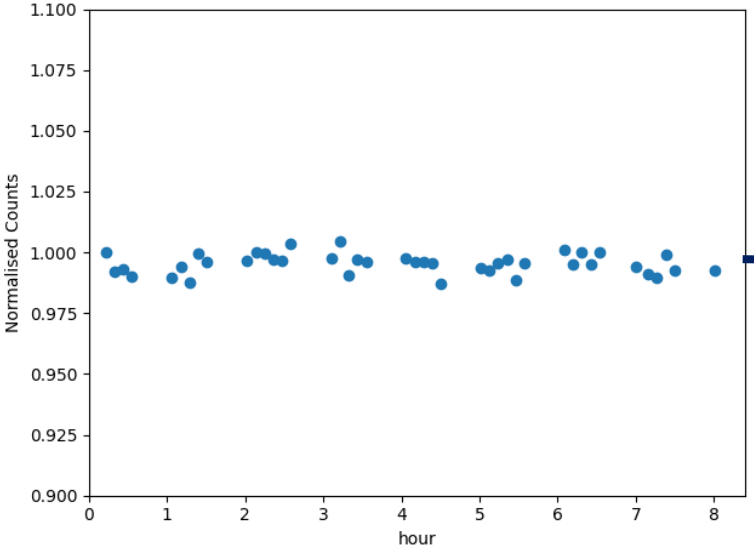
Cadmium Black Resonance at 0,5 eV.

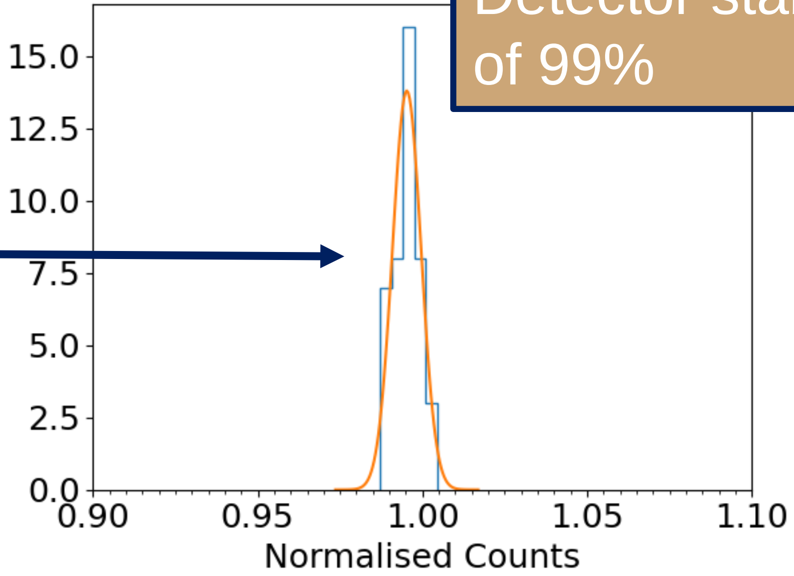
ToF spectra



$$\gamma = \frac{Area\ inside\ resonance\ with\ Cd\ mask}{Area\ outside\ resonance\ without\ Cd\ mask}$$

I-MS-BGEM detector

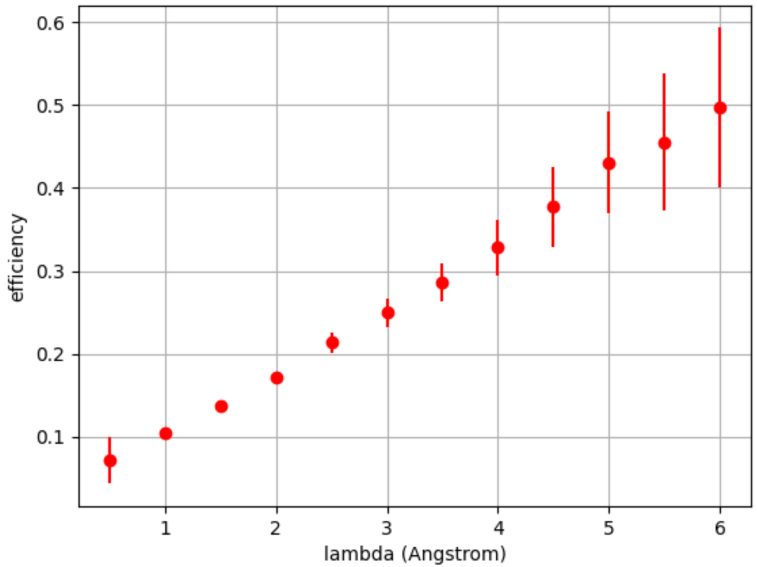




Detector stability of 99%

- Measurements conducted with the use of a Cd mask with a hole of 6 mm of diameter.
- Measurement time of 2 minutes and 10 minutes between each run.
- The measurements have been normalised for a reference run.

I-MS-BGEM detector



$$E_n = \frac{m_n}{2}\frac{L^2}{t_{ToF}^2}$$
$$E_n = \frac{hc}{\lambda}$$
$$\Rightarrow \lambda = \frac{h * t_{ToF}}{m_n * L}$$

- Measurements conducted with the use of a Cd mask with a hole of 6 mm of diameter.
- The measurements obtained with the 6MBGEM and the GS20 detector have been performed with the same experimental conditions.
- The efficiency has been estimated with:

$$\varepsilon_{6MBGEM} = \frac{counts_{6MBGEM}}{counts_{GS20}} * \varepsilon_{GS20}$$

$$\varepsilon_{GS20} = 0{,}6\% \text{ at } 82 \text{ meV}$$

At 1,8 Å (25 meV) the I-MS-MBGEM efficiency is 16%

Conclusions

- The I-MS-BEGM detector has shown a good response at thermal and epithermal neutrons:
  - Counting rate stability during a long period of measurements of 99%.
  - Gamma insensitive factor in the order of 10^{-5} Y/n.
  - Detection efficiency of 16% at 1.8 Å.
- The next step will be the use of the BGEM foils coupled with a strip anode for imaging measurements.

Thank You for your attention

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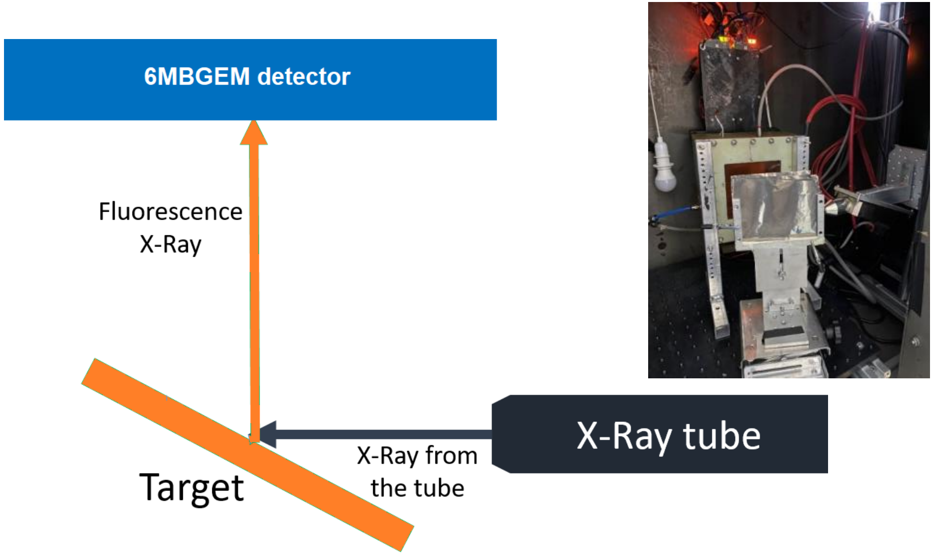
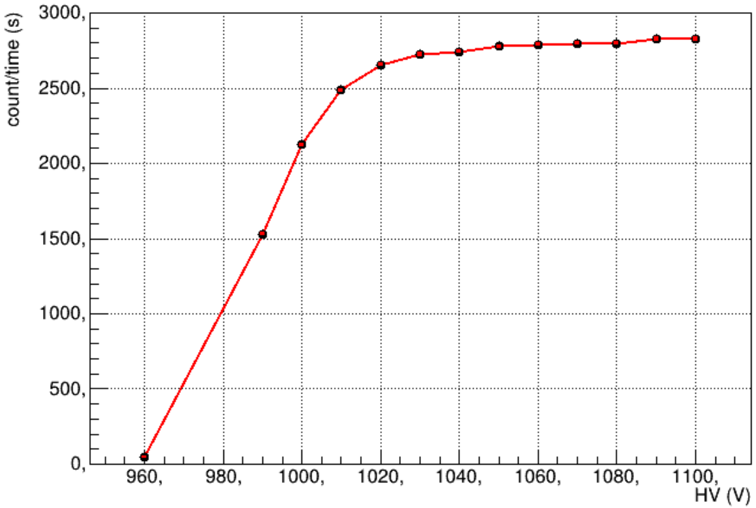
The 6MBGEM: characterisation with X-rays

- Preliminary test to determine the detector working point → to reach the unitary gain.
- Study of the electron transport through the foils.
- Amptek-MiniX2 X-Ray Tube (V=15 kV and I=150 µA).
- Measurements performed at the ISTP-CNR laboratories.
- Copper target.
- ArCO2(70%-30%) fluxed at 5l/h at 1 bar.

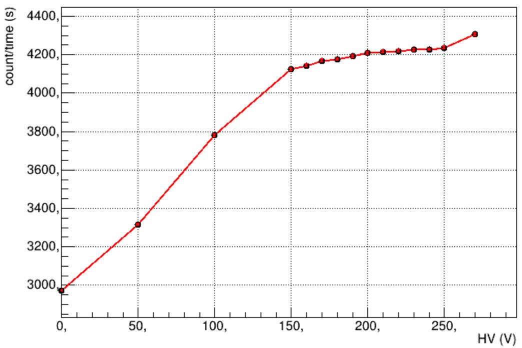


TGEM HV scan

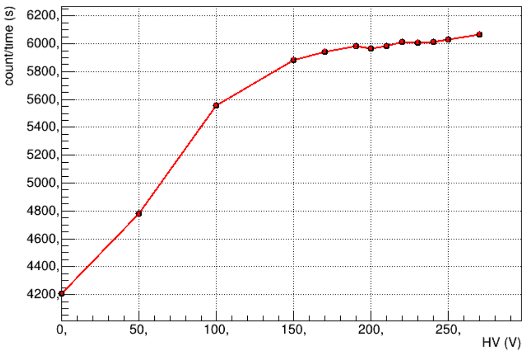


TGEM fields: $D=T_1=T_2=Ind=1$ kV/cm

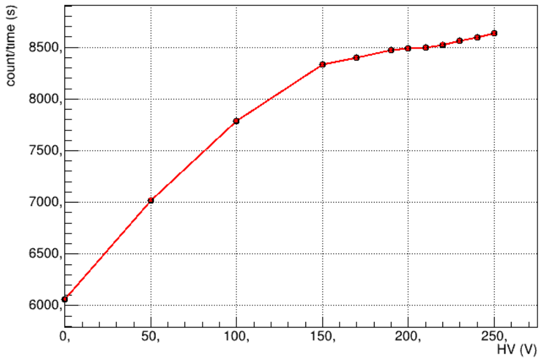
The 6MBGEM: characterisation with X-rays



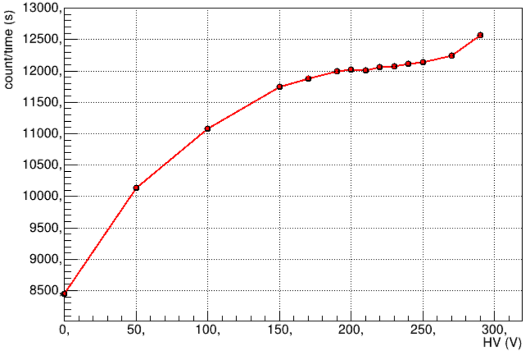
1) BGEM 6



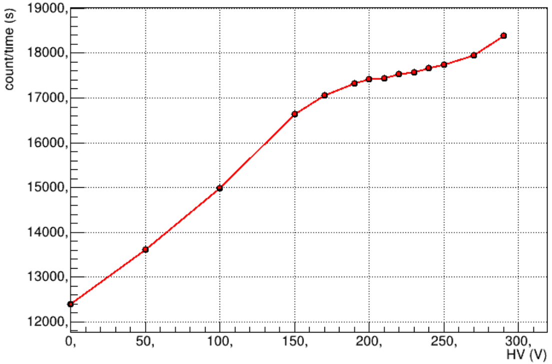
2) BGEM 5



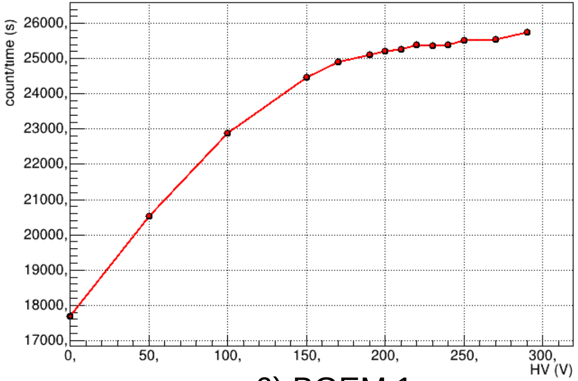
3) BGEM 4



4) BGEM 3



5) BGEM 2



6) BGEM 1

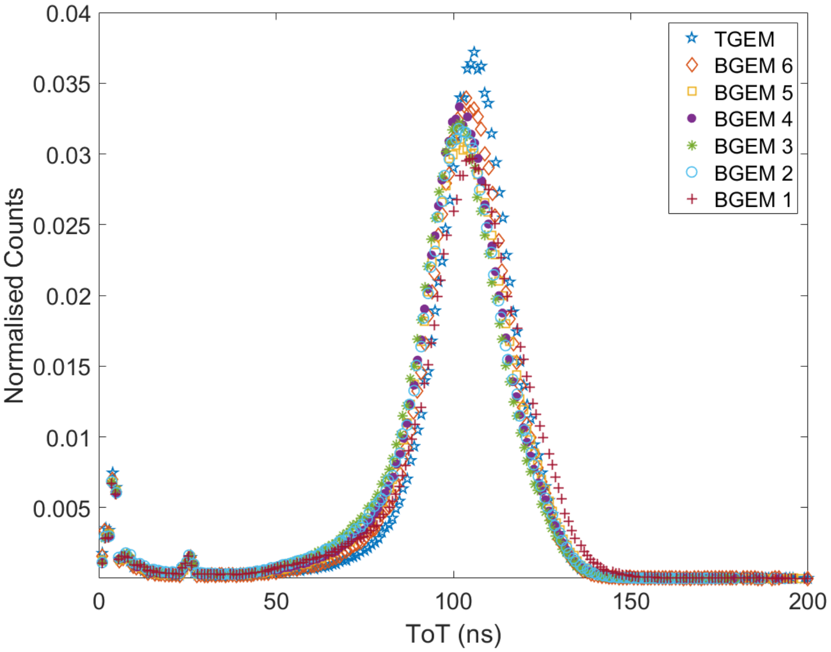
The 6MBGEM: characterisation with X-rays

Plot	HV BGEM6 (V)	HV BGEM5 (V)	HV BGEM4 (V)	HV BGEM3 (V)	HV BGEM2 (V)	HV BGEM1 (V)
1	220	0	0	0	0	0
2	220	220	0	0	0	0
3	220	220	230	0	0	0
4	220	220	230	230	0	0
5	220	220	230	230	230	0
6	220	220	230	230	230	230

$BGEM_i$ fields: 1kV/cm

The 6MBGEM: characterisation with X-rays

ToT spectra of the Copper target



Unitary Gain: $\frac{Peak_{BGEM_i}}{Peak_{Drift}} \approx 1$

The 6MBGEM: characterisation with neutrons

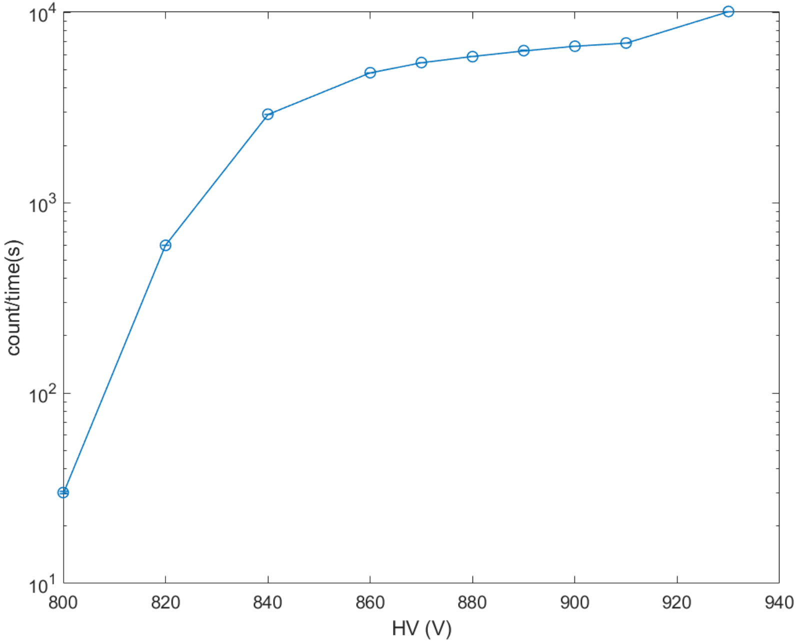
Preliminary test at the Laboratorio Energia Nucleare Applicata (L.E.N.A.), Pavia

- TRIGA Mark II reactor
- Detector installed at the channel B at 30 cm from the beam shutter
- Use of Cd mask with a hole of 6 mm of diameter.
- Thermal neutron beam with a neutron flux of $\approx 10^6 \frac{n}{s*cm^2}$

Channel B

The 6MBGEM: characterisation with neutrons

TGEM HV scan

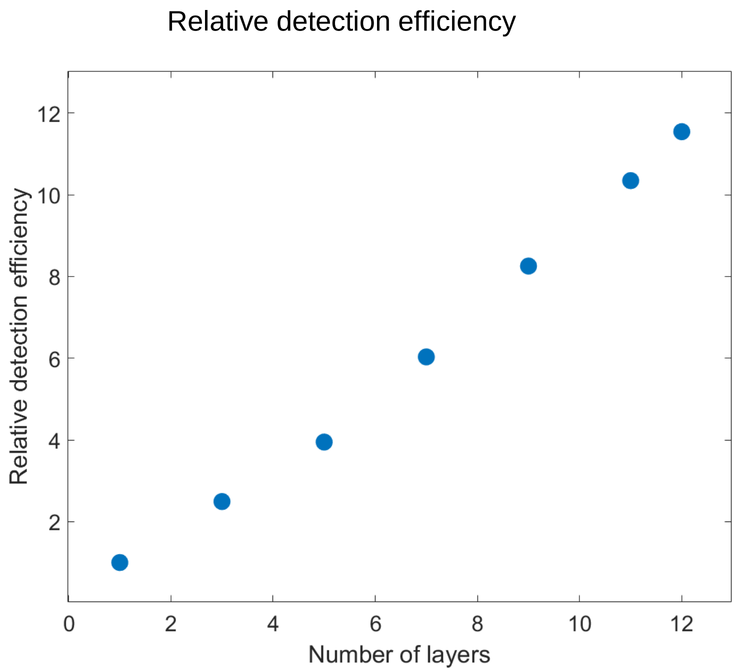


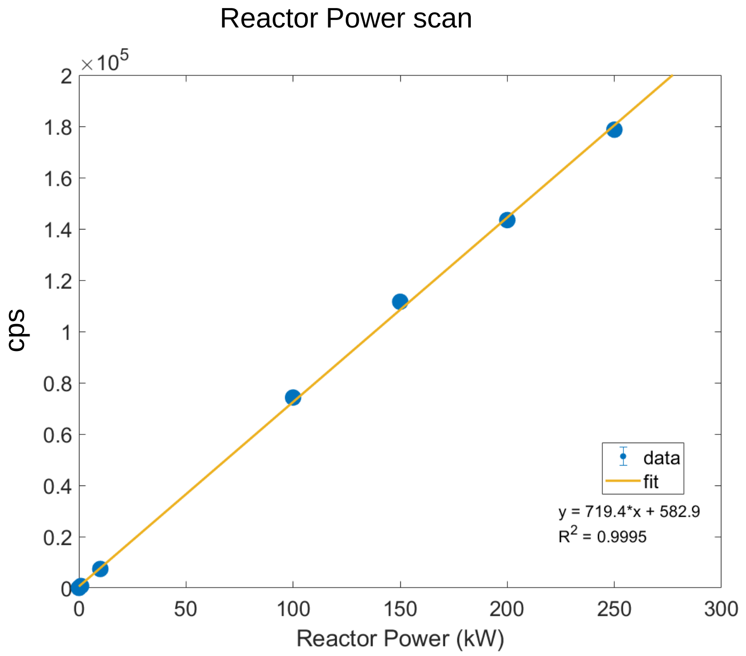
TGEM fields: D=T_1=T_2=Ind=1 kV/cm

HV BGEM 6	HV BGEM 5	HV BGEM 4	HV BGEM 3	HV BGEM 2	HV BGEM 1
300 V	0 V	0 V	0 V	0 V	0 V
300 V	230 V	0 V	0 V	0 V	0 V
300 V	230 V	230 V	0 V	0 V	0 V
300 V	230 V	230 V	230 V	0 V	0 V
300 V	230 V	230 V	230 V	230 V	0 V
300 V	230 V	230 V	230 V	230 V	230 V

$BGEM_i$ fields: 1kV/cm

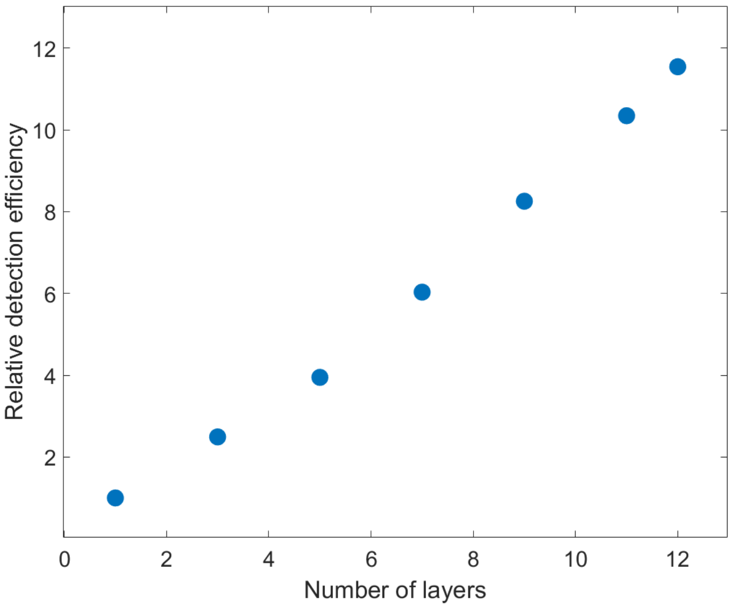
The 6MBGEM: characterisation with neutrons





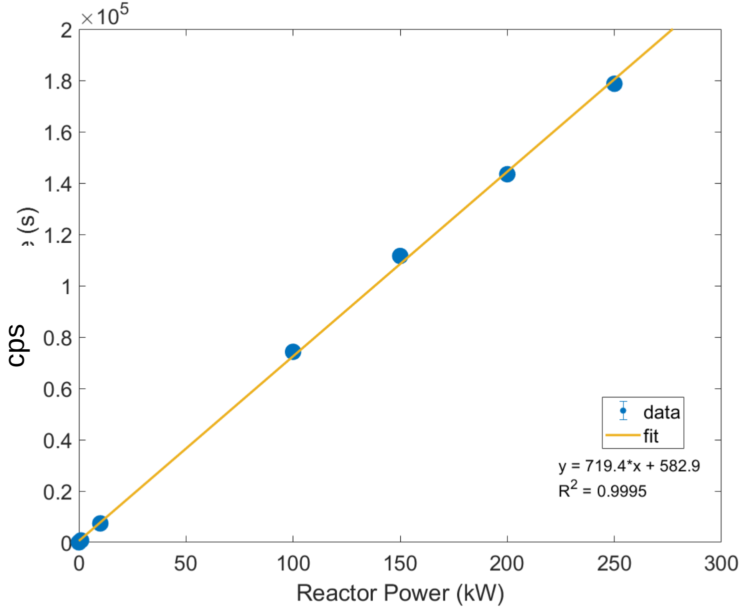
The 6MBGEM: characterisation with neutrons

Relative detection efficiency



The detector response still linear with the increase of the boron layers

Reactor Power scan



The detector response still linear with the increase of the neutron flux.