GEM-based thermal neutron detector preparing for a ^{10}B-coated multi-ThickGEM cascade

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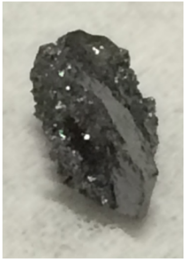
RD51 Mini Week — December, 2017

15th December, 2017

Outline

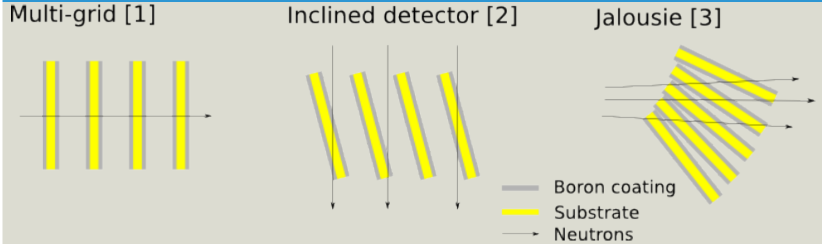
Motivation - Boron-10



$$n + {}^{10}B \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48\,MeV\gamma + 2.3\,MeV\,(93\,\%)$$
$$\rightarrow {}^{7}Li + {}^{4}He + 2.8\,MeV\,(7\,\%)$$

- Solid state at NPT,
- Challenging to deposit on surfaces,
- Limited efficiency when too thick, due to self absorption of reaction products.

Some ^{10}B-based solutions:

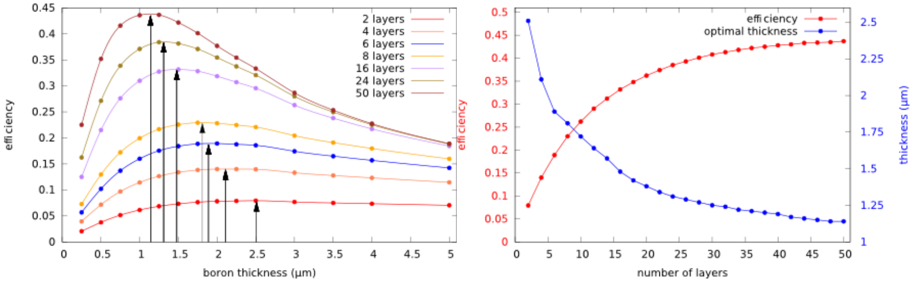


Boron coated microstructured cathodes in stacked MPWC [4]

Boron coated straw tubes [5].

[1] J.C. Buffet et al., IEEE NSS 15 Conf. Rec., p. 171, 2012.
[2] J. Buffet et al., NIM A, 554, 1-3, p. 392, 2005.
[3] C.J.Schmidt, M. Klein, CDT: www.n-cdt.com/
[4] I.Stefanescu et al., Jinst, 8 P12003, 2013.
[5] Proportional Technologies Inc., www.proportionaltech.com

Simulations



Competing processes

As thickness of ^{10}B increases:

- higher probability for neutron absorption, but
- higher probability of α and ^{7}Li loosing their whole energy before leaving the ^{10}B layer.

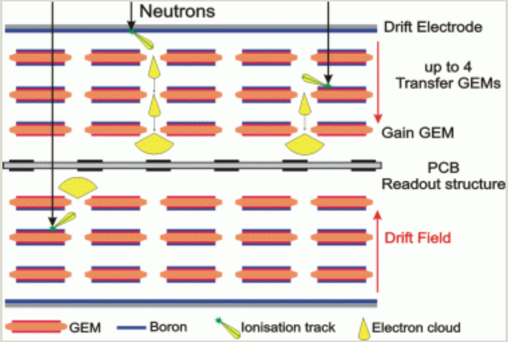
- Optimal thickness decreases when more layers are used,
- But: deposition must be more precise in each layer.

GEANT 4 with emstandard_opt3 and QGSP_BERT_HP, no energy threshold (all α and ^{7}Li considered), neutron energy: 25 meV (1.8 Å)

The GEM in neutron detection

$n\left(^{10}B,^{7}Li\right)^{4}He$

The CASCADE concept (M. Klein and J. Schmidt, NIM A, 628, p. 9, 20)



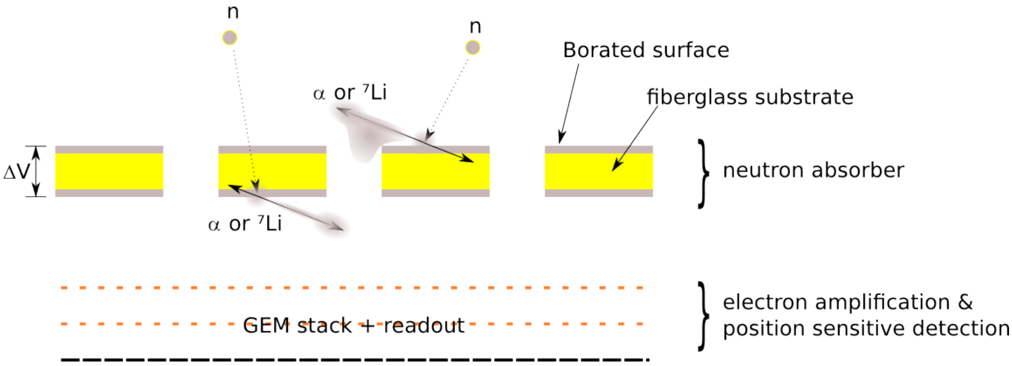
- Deposition of ^{10}B layers on the copper surfaces,
- Transport of the electrons generated by α and/or lithium to a multiplication stage.
- Since electrons can be transported through the holes, many boron-coated foils can be stacked.

The Thick-GEM in neutron detection

Simple, more cost effective structures could be used.

With Thick-GEMs:

- Production of the detector could even take place in Brazil.



Prototypes already produced

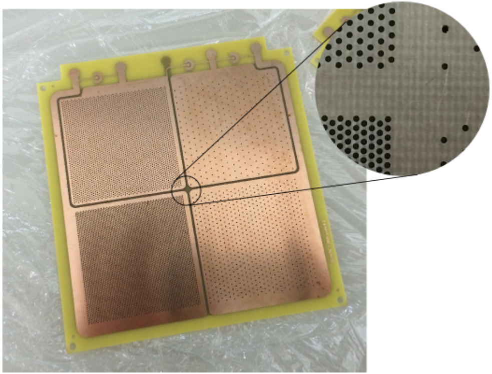
Sensitive area: $10 \times 10\,cm^2$, 0.5 mm de diameter holes

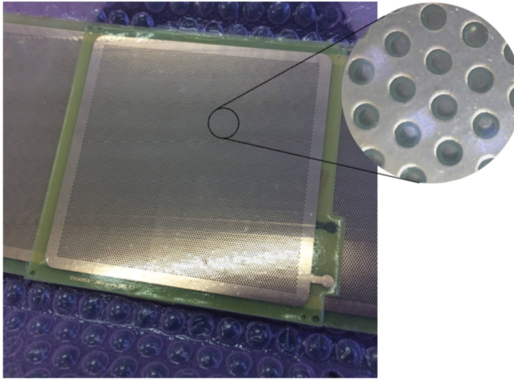
Prototype 1

- 4 sectors with 0.75, 1, 2 and 3 mm pitch
- Holes drilled directly through the copper layer.

Prototype 2

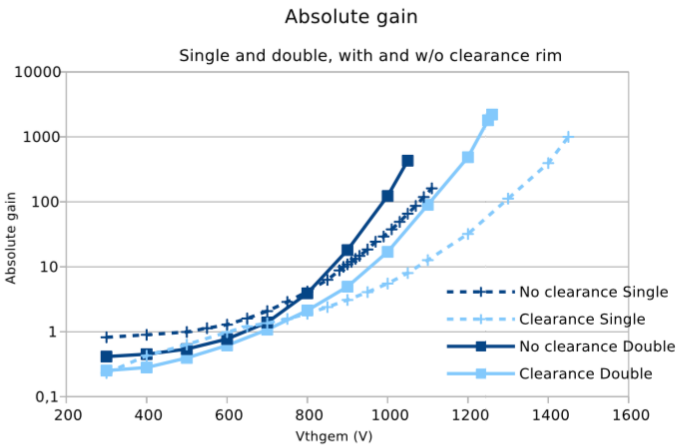
- 1 sector with 1 mm pitch,
- hole diameter: 0.4 mm, diameter in copper: 0.6 mm (clearance rim around the hole).





THGEM — performance

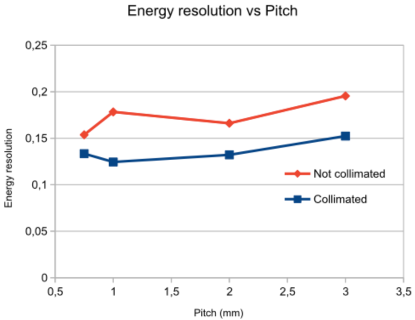
Charge gain:

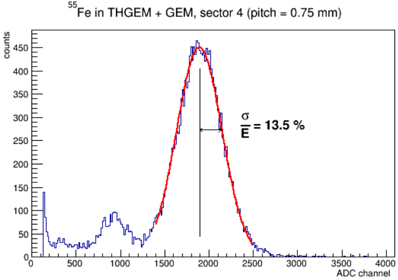


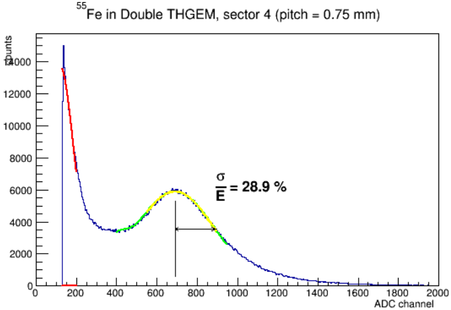
- The clearance rim requires higher voltages accross the holes for the saim gain, but
- Maximum gain achieved is about 8 times higher.

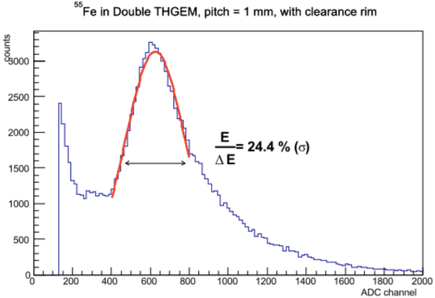
THGEM — performance

Energy resolution:



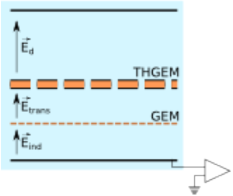


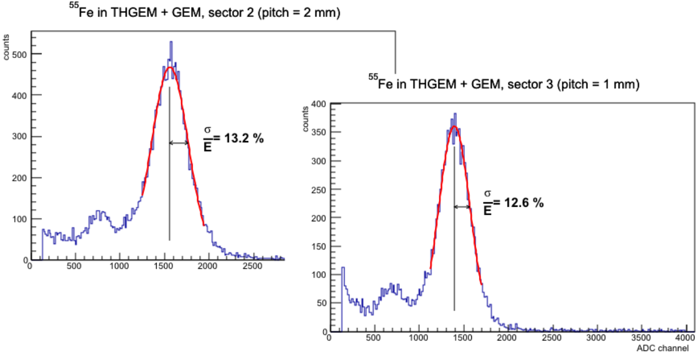




Characterization - Energy resolution

Hybrid mode (THGEM + GEM)



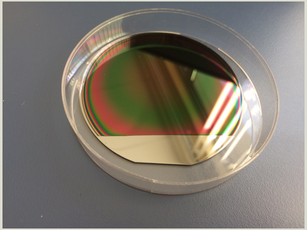


- Operating in hybrid mode (together with GEMS) resolution is kept,
- Results suitable for neutron detection.

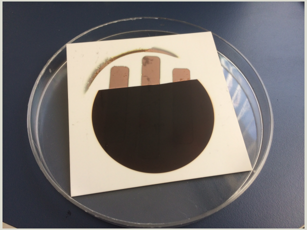
The challenge of boron depositions

Laboratory of Integrable Systems (Poli/USP in collaboration with LACIFID/USP))

In crystaline silicon



In alumina (Al_2O_3) — new materials!



Sample analysis in Laboratory for Ion Beam Analysis of Materials — LAMFI/USP).

- Several test depositions already made, using different substrates,
- Many good ideas for new materials for Thick-GEM substrates (minimizing neutron scattering)
- Project on going for building a Thick-GEM in alumina:
    - laser drilled holes
    - magnetron sputtering deposition of conductive layers and neutron converter

Challenges:

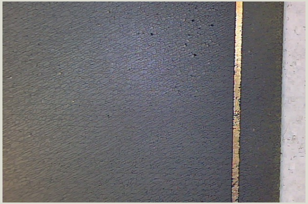
- Limitted boron thickness achieved
- Limitations in deposition area.

The challenge of boron depositions

ESS — European Spallation Source, Depositions Lab

- Using $^{10}B_4C$ films
- Adherence to copper is very tricky
- Optimization of deposition parameters ongoing.

$^{10}B_4C$ deposition on FR4
(fiberglass subtrate of PCBs)

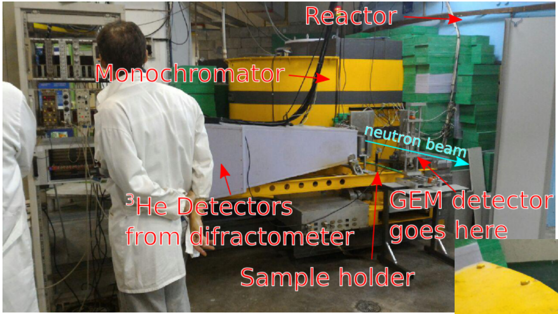


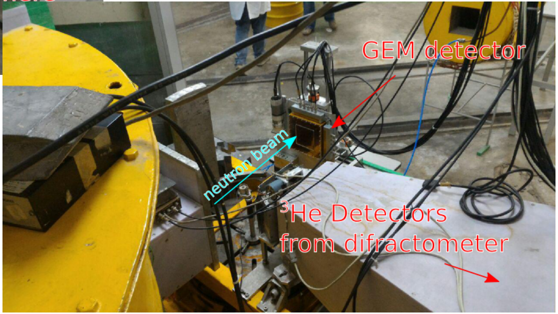
Could even be drilled
in a Thick-GEM pattern

- $^{10}B_4C$ is not conductive (Thick-GEM needs conductive layers to work) but:
- deposition on FR4 is already a neutron converter and was used to build a prototype.

Setup at neutron beam line

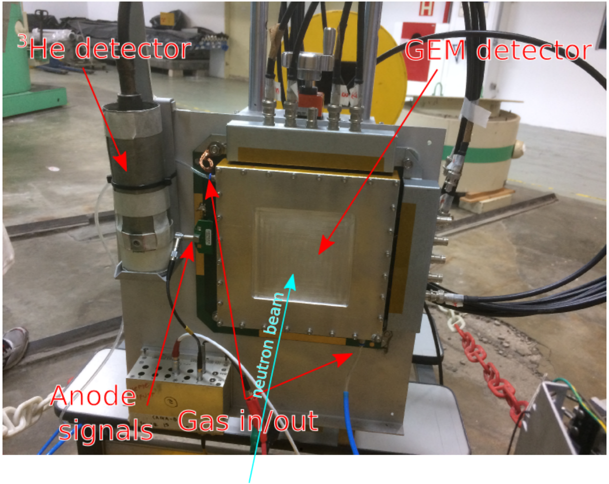
- Setup mounted in IEA-R1, line BH-6
- 1.4 Å neutrons from AURORA's monocromator (NIMA 622 (2010) 678)
- From diffractometer AURORA, only the monochromator is used.



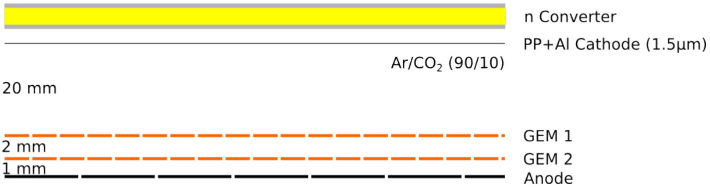


Setup at IEA-R1

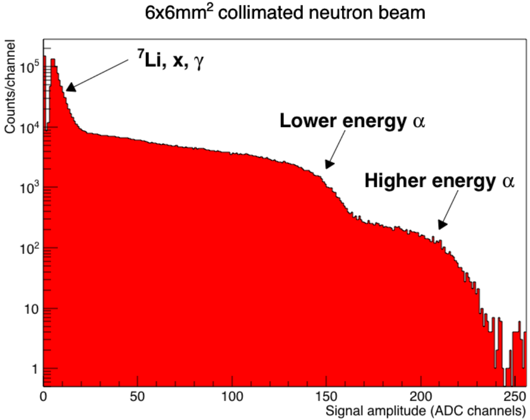
- Setup mounted in IEA-R1, line BH-6
- 1.4 Å neutrons from AURORA's monocromator (NIMA 622 (2010) 678)
- Neutrons hitting the detector through 6 mm and 12 mm square slits.



Setup at IEA-R1



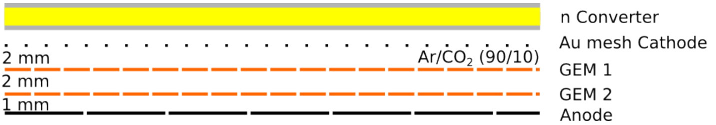
- Very large signals,
- High energy and low energy alphas clearly distinguishable,
- Li hidden within the large gamma background:

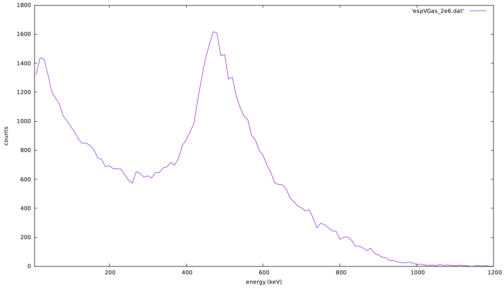


Setup at IEA-R1

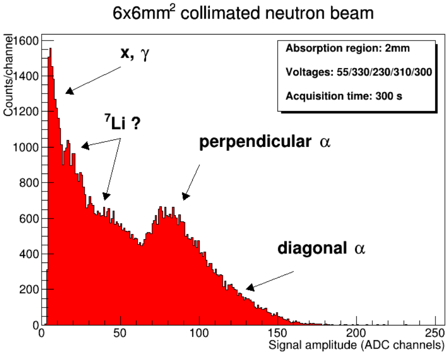
No need to absorb the whole particle energy:

- Absorption region reduced to 2 mm (α peak @ ∼500 keV)
- PP replaced by mesh





GEANT4 Simulation

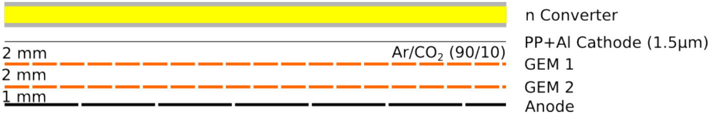


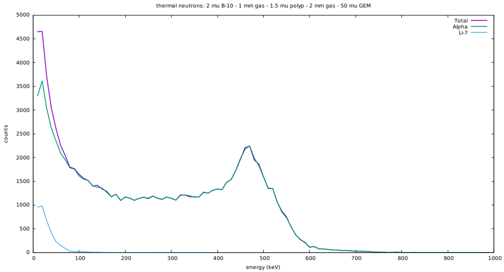
Instability problems, eventually caused by film particles falling inside GEM holes.

Setup at IEA-R1

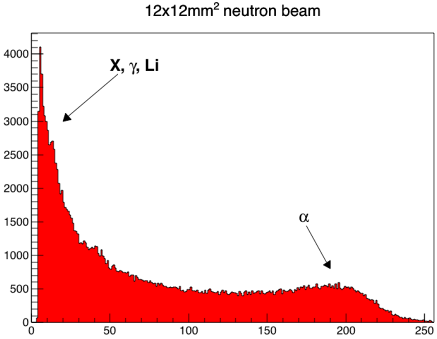
Replaced again the mesh by the aluminized PP foil.

- Assumed loss of Li ions and eventually a much more complex spectrum...
- Detector was stable again.

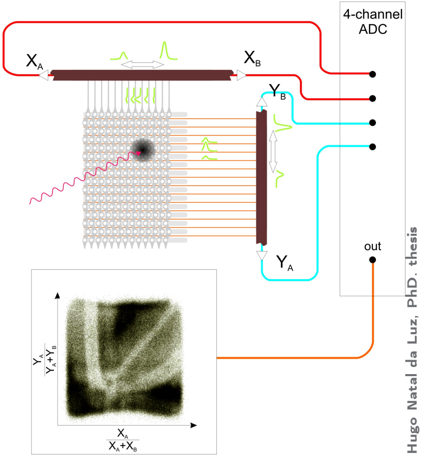




GEANT4 Simulation.



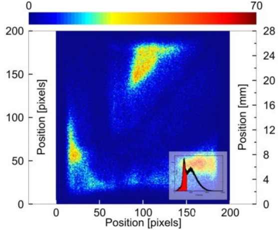
Imaging with GEMs (and Thick-GEMs)

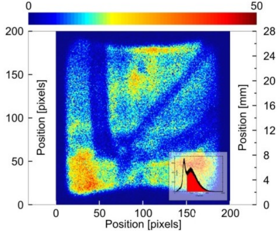


Electron collection by resistive charge division

For each particle detected *x*, *y* e *E* are determined.

Low energies

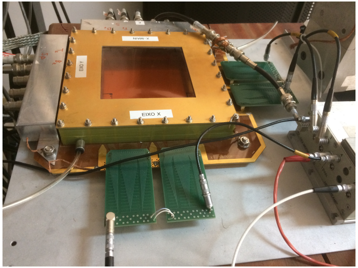




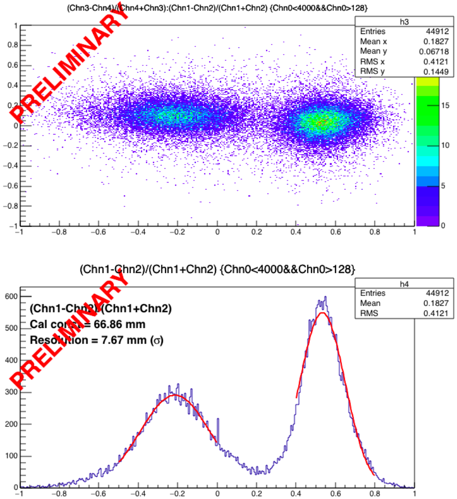
High energies

Signal-to-noise ratio for neutrons is typically 100 times higher than for X-rays!

Position sensitive detectors in HEPIC@USP



Collimated X-ray tube in two different positions, 5 cm appart.



Conclusions and near future

Conclusions

- Although $^{10}B_4C$ depositions posed a great challenge, the team from ESS delivered neutron converters with the required thickness.
- Multiplication stage composed of double GEM stack is simple and effective,
- Position sensitive detectors under development with preliminary results, Beam monitor coming soon.
- High efficiency thermal neutron detection: Thick-GEMs manufactured in local industry in São Paulo with good performance.

Future

- $^{10}B_4C$ deposition in Al to work as cathode/converter will merge the FR4 converter and the PP foil,
- Optimization of parameters for robust coating of Thick-GEMs with $^{10}B_4C$ ongoing,
- New materials, under study for alternatives less prone to scattering of neutrons.

The End

Thank you for your attention

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