Development of GEM detector as a compact neutron spectrometer for fusion plasmas

Monitoring of 2021 activities

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Development of the design requirements of the NS-GEM demonstrator and the measuring set-up at NG-14 MeV generator.

1. Theory and modelling: NS-GEM synthetic diagnostic: Assumptions and design requirements for ITER neutron spectrometers.
2. NS-GEM Demonstrator: Initial stage of MCNP NS-GEM system modelling and the technical design of NS-GEM demonstrator
3. Neutron generator NG-14 MeV: MCNP modelling of the radiation field in the NG-14 MeV hall and the technical design of the measuring set-up.

Modification

Year	Beneficiary	Person	PM (Planned)	PM (possible in 2021)
2021	IPPLM	Marek Scholz (IFJ PAN)	3	2
2021	IPPLM	Axel Jardin (07-IFJ PAN)	2	0
2021	IPPLM	Wladyslaw Dabrowski (06-AGH)	1.5	0
2021	IPPLM	Bartłomiej Łach(AGH)	3	0
2021	IPPLM	Arkadiusz Kurowski (07-IFJ PAN)	2	0
2021	IPPLM	Urszula Woznicka (IFJ PAN)	2	2
2021	IPPLM	Jakub Bielecki (07-IFJ PAN)	2	0
2021	IPPLM	Urszula Wiacek (IFJ PAN)	3	0
2021	IPPLM	Krzysztof Drozdowicz (IFJ PAN)	2	2
2021	IPPLM	Anna Wojcik-Gargula (IFJ PAN)	2	0
2021	CEA	Didier Mazon (CEA)	2	2

Introduction

Neutrons are the most accessible particles of all the fusion products and they provide direct information on the fusion power

Role of neutrons in fusion

Neutrons emitted from a deuterium/tritium thermonuclear plasma are the main signature of the nuclear fusion and plasma parameters.

Neutron diagnostic system for fusion

Time resolved neutron yield monitor

Activation system

Neutron profile camera

Neutron spectrometers

- provides ion temperature
- information on the neutron fractions from thermal and non-thermal fusion reactions (fuel ratio).

Introduction

Requirements:

Neutron spectrometer:

Measuring the fusion power, ion temperature and/or non-thermal to thermal ratio using neutron spectroscopy relies on precise measurements on neutron spectrum with high resolution

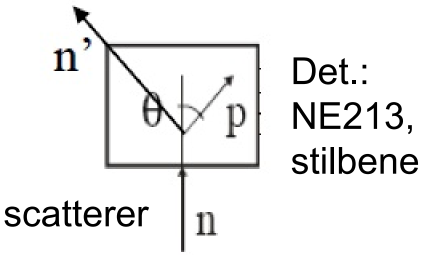
For DT plasma scenarios this sets strict requirements on the spectrometer performance. The main parameters are:

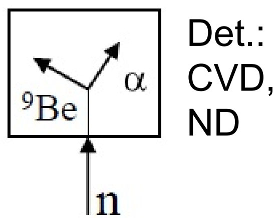
- A relatively compact size and low weight; the entire spectrometer should fit within roughly 1 m^3.
- An intrinsic energy resolution (prior to any unfolding techniques) of about 8% or better combined with an efficiency of 10^{-5} or better.
- A count rate capability of at least several 100 kHz.
- A stable response function that is precisely known down to at least the per mille level and that shows very little degradation during high count-rate operations.
- The signal-to-noise ratio in the spectrum should be at least 1000.

Introduction

In-beam

PMT, stability



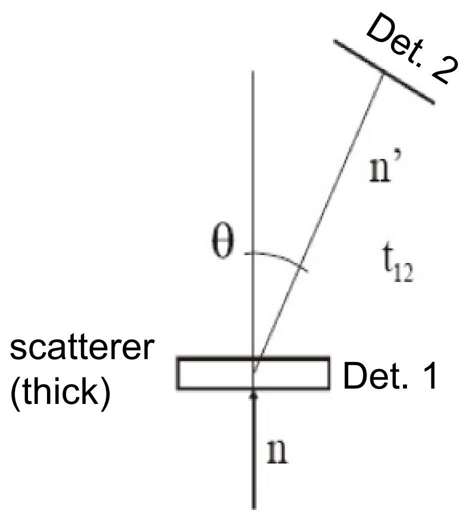


about 8%.

(+) pro:
conceptually simple
(-) con:
exposed to full n flux,
function mixed

ToF

PMT, size



4.5 to 7.4 % FWHM.

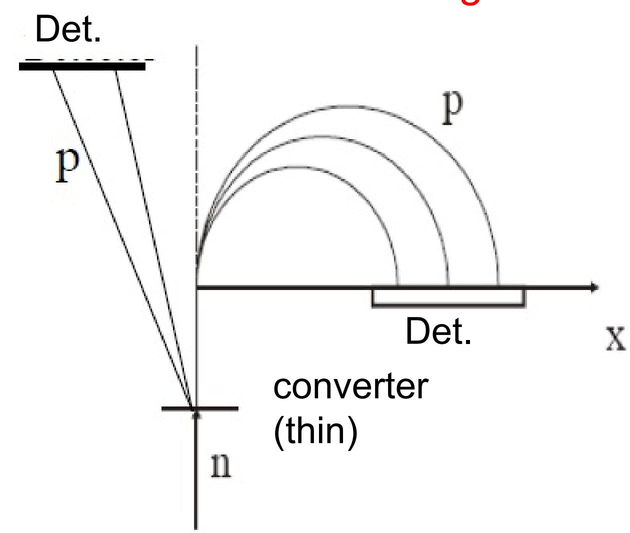
(+) pro:
high efficiency suited
for 2.45 MeV
(-) con:
random coincidences
exposed scatterer

TPR

vacuum

MPR

vacuum, magnet, size, weight



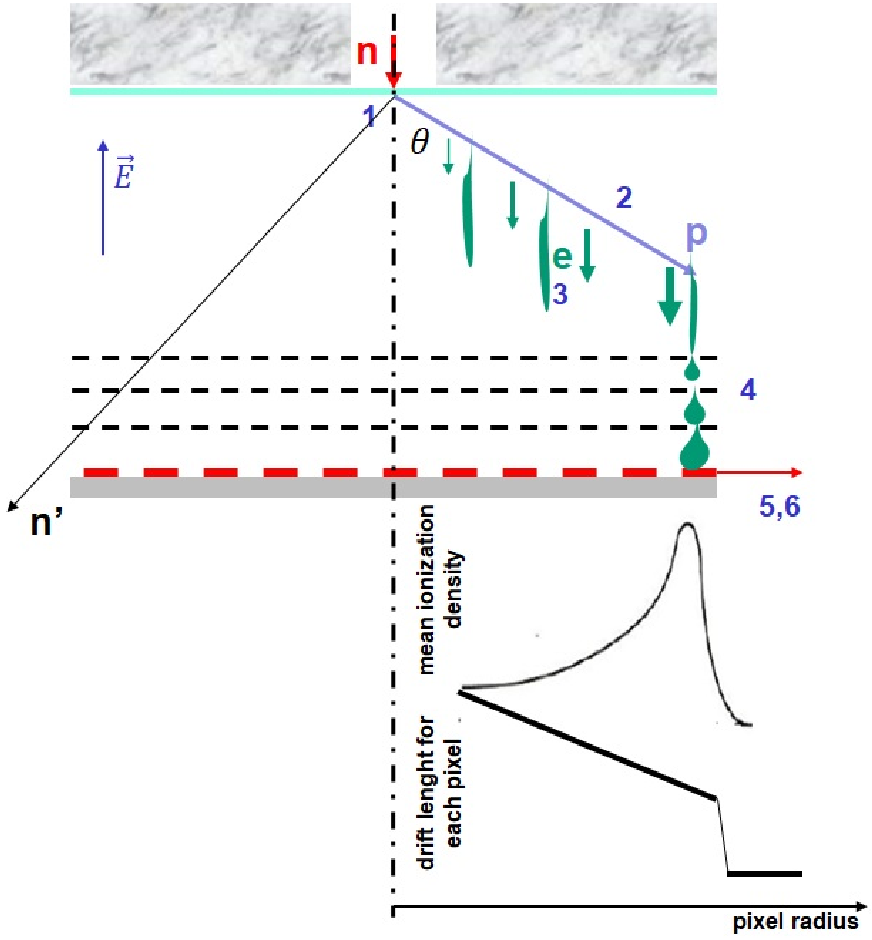
TPR: about 8%.

MPR: 3.4 to 4.2 %

(+) pro: sensitivity
(background rejection)
(-) con: low efficiency,
complexity

Neutron spectrometeric techniques

Spectrometer concept



n - the collimated neutron beam, p – recoil proton; n' – scattered neutron

$$E_n = \frac{E_p}{cos^2\theta}$$

Basic idea of the GEM detector as a neutron spectrometer.

1) the convertor for converting neutron to proton,
2) the proton recoil trace,
3) electron cloud transport in the drift regions,
4) electron avalanches through GEM holes,
5) collection of the electron cloud on the anode pixel and
6) GEM signal post-processing to calculate charge, time and position to reconstruct trace of the proton recoil.

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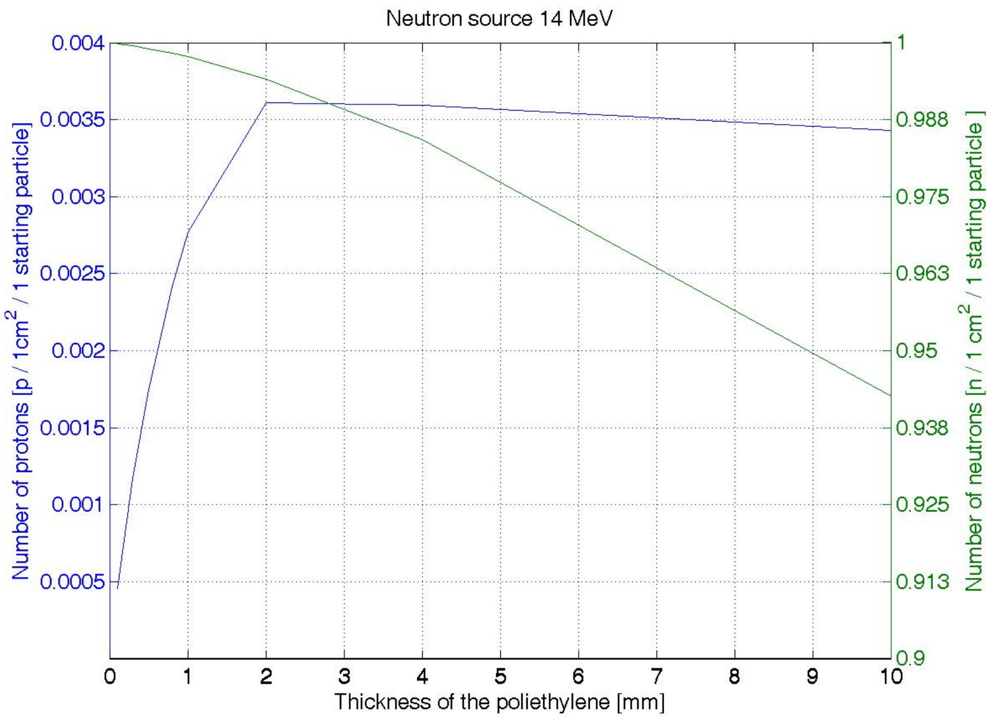
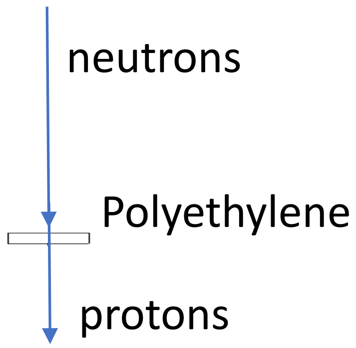
NS-GEM detector feasibility study

Expected inputs from simulations

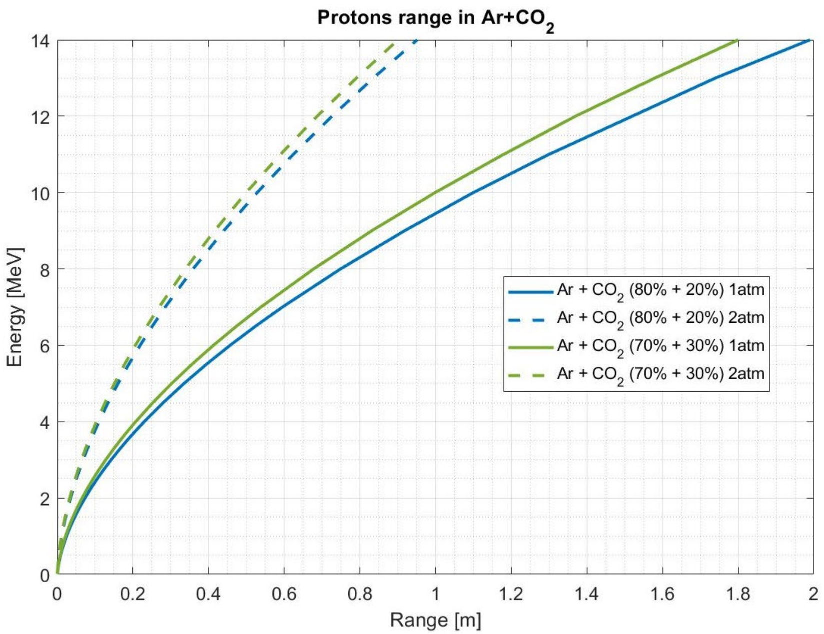
- Expected range of track lengths
- Charge distribution along the track
- Rate of events (protons)

MC calculations: Number of the protons vs thickness of the polyethylene



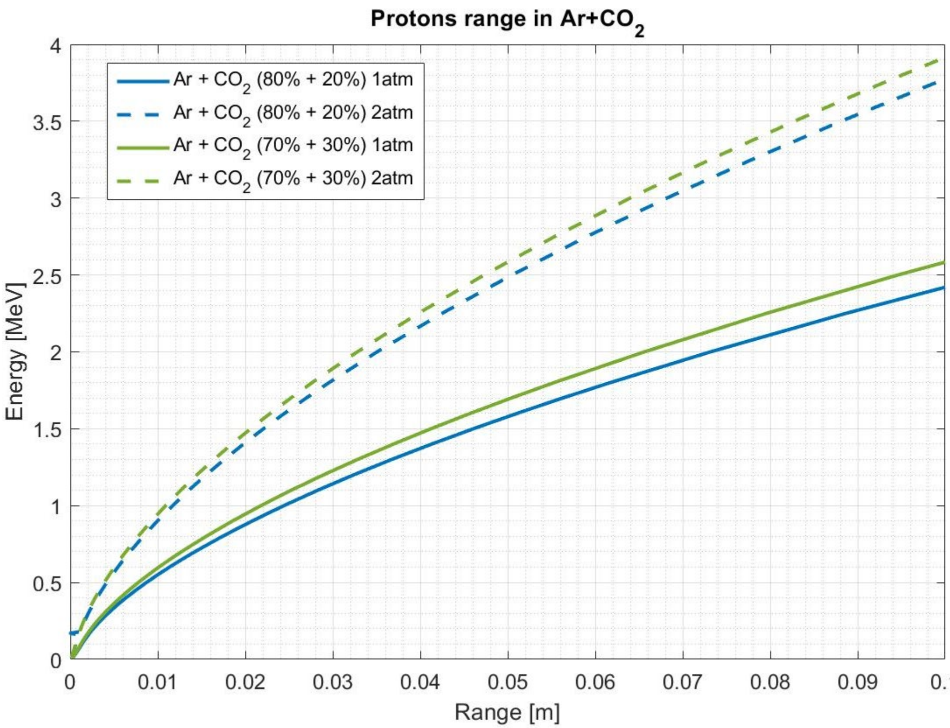


NS-GEM detector feasibility study



SRIMM calculations

Proton Energy vs Range

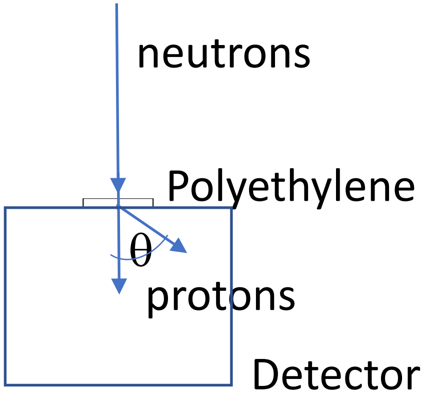


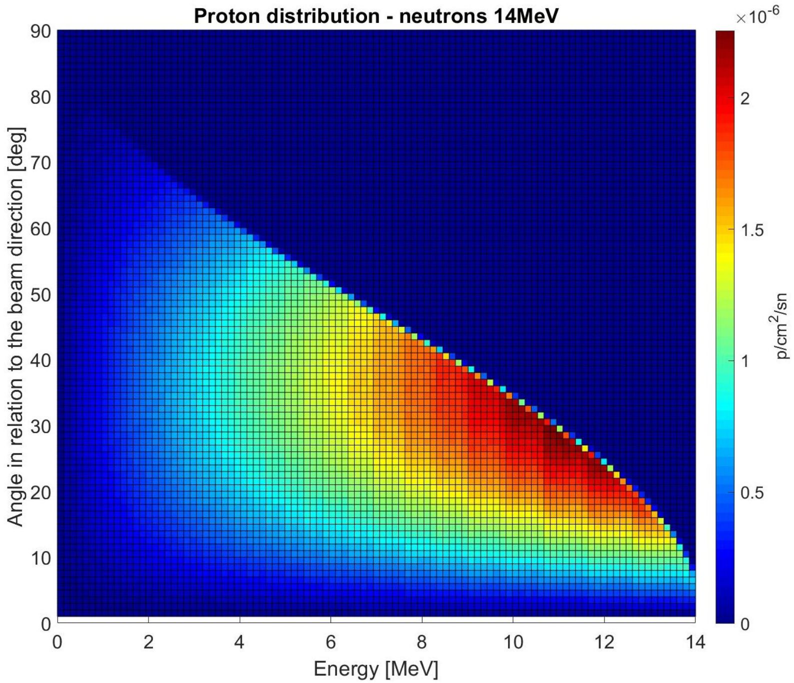
$$En = \frac{Ep}{cos^2\theta} \Rightarrow En = 14\ MeV,\ Ep = 2.5\ MeV \Rightarrow \theta = 65°$$

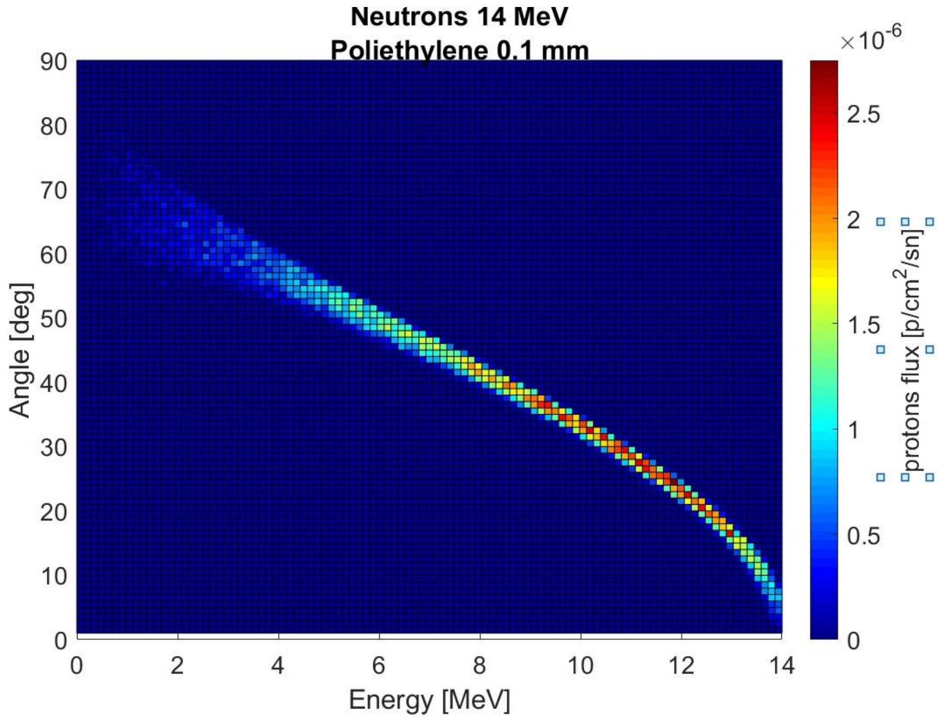
For distance 10 cm – max. 2.5 MeV protons

NS-GEM detector feasibility study

Neutrons: 14 MeV on Surface 1x1 cm2
Polyethylene: 1 cm x 1 cm x **0.3 cm**

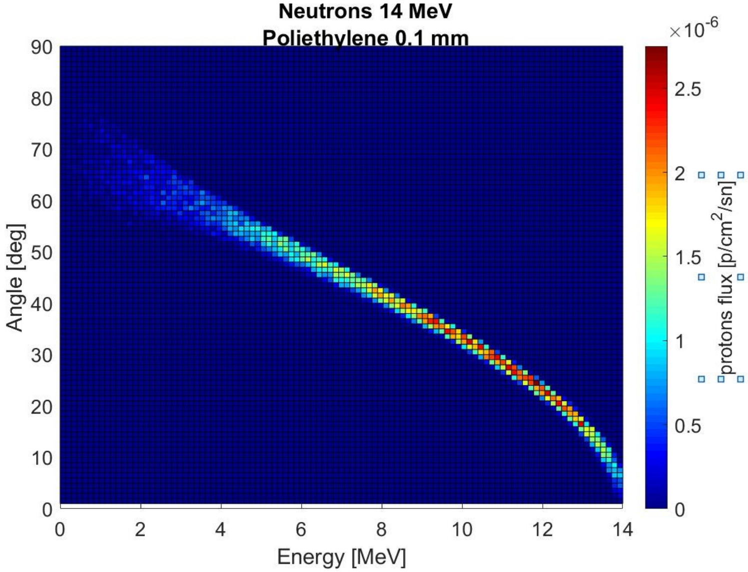


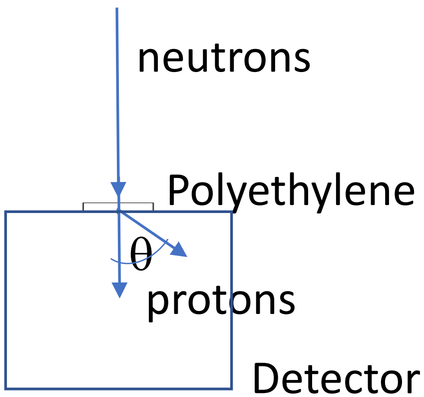


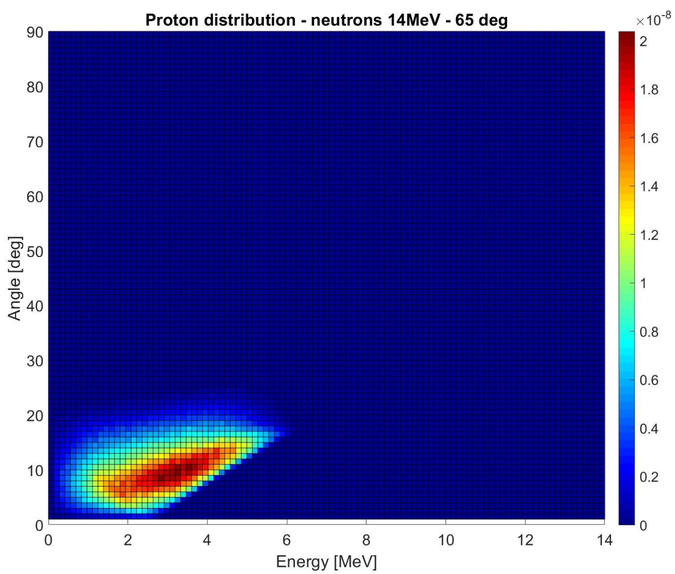


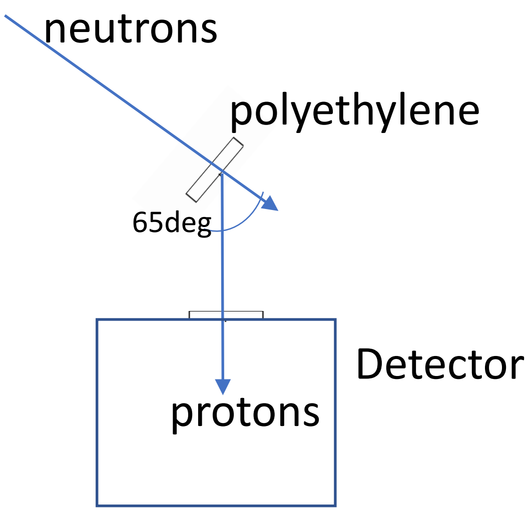
NS-GEM detector feasibility study

Polyethylene 0.1 mm

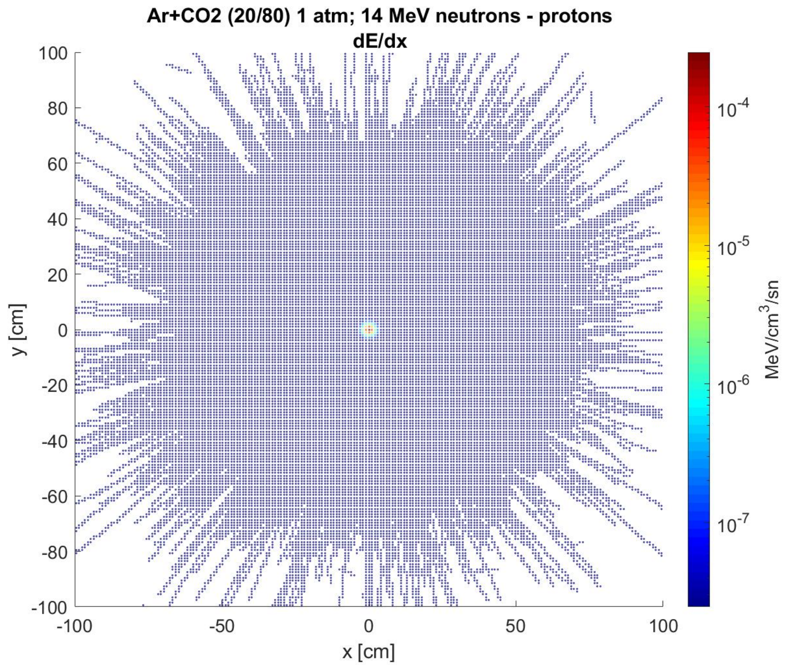


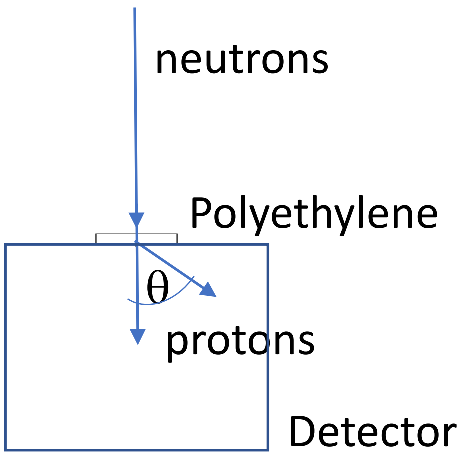


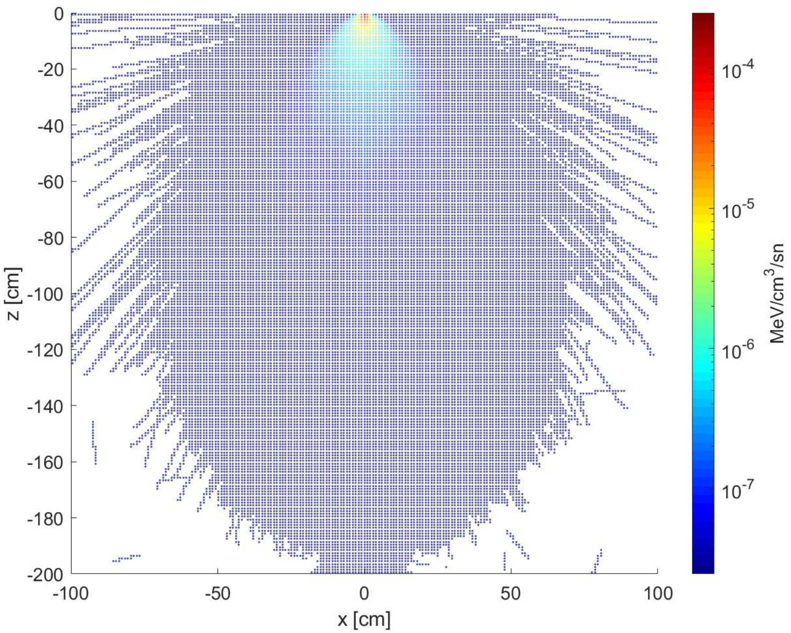




NS-GEM detector feasibility study



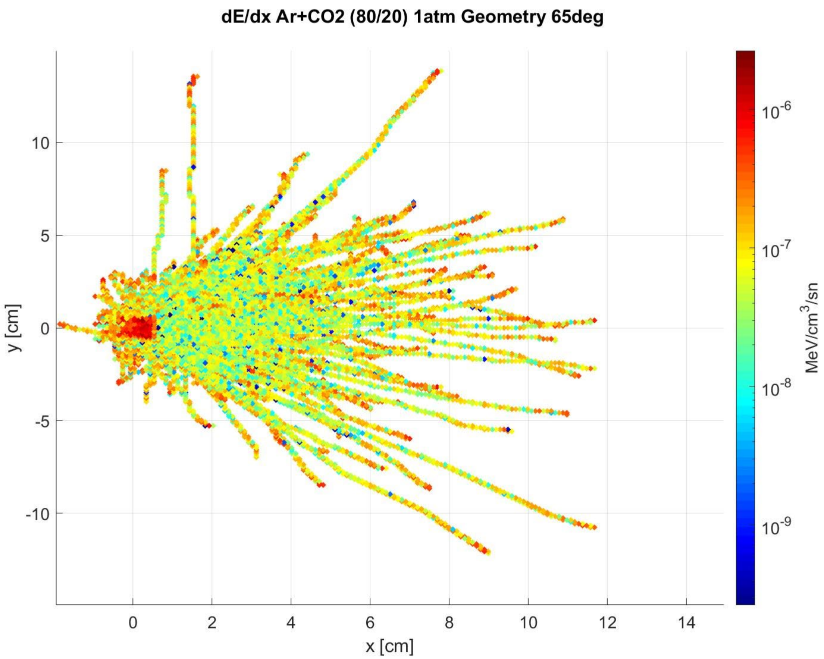


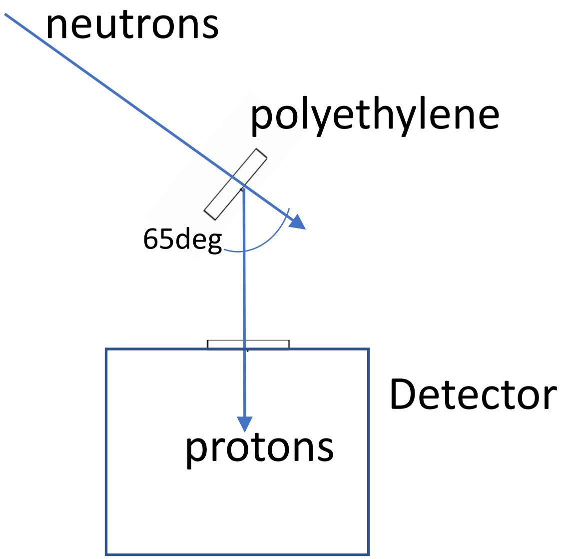


Polyethylene 0.1 mm

Voxels: 1 cm x 1 cm x 1 cm

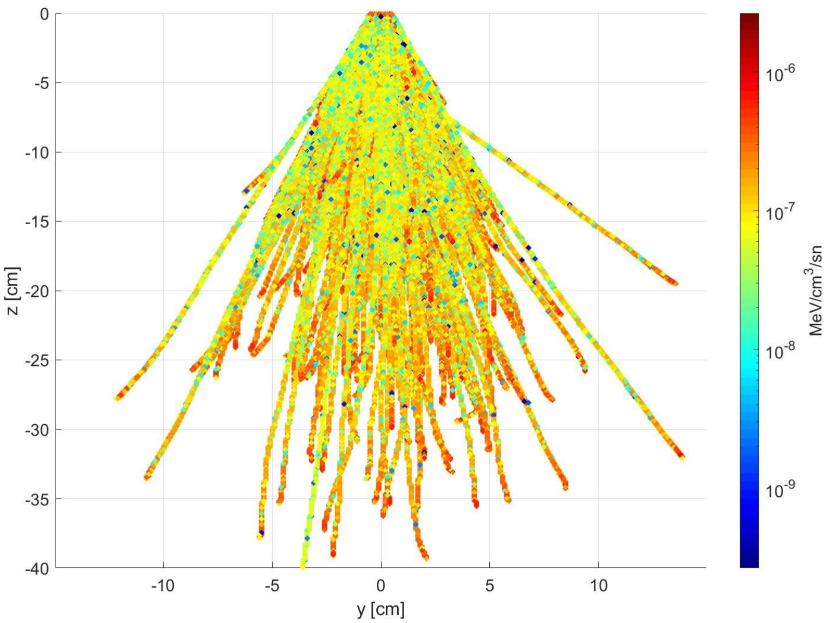
NS-GEM detector feasibility study





Polyethylene 0.1 mm

Voxels: 0.1 cm x 0.1 cm x 0.1 cm



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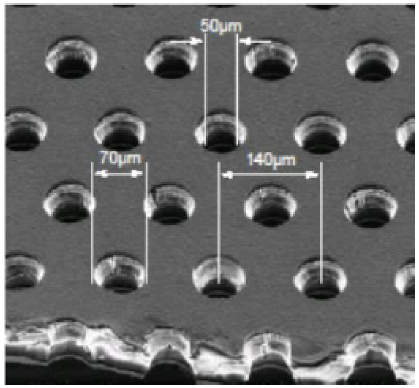
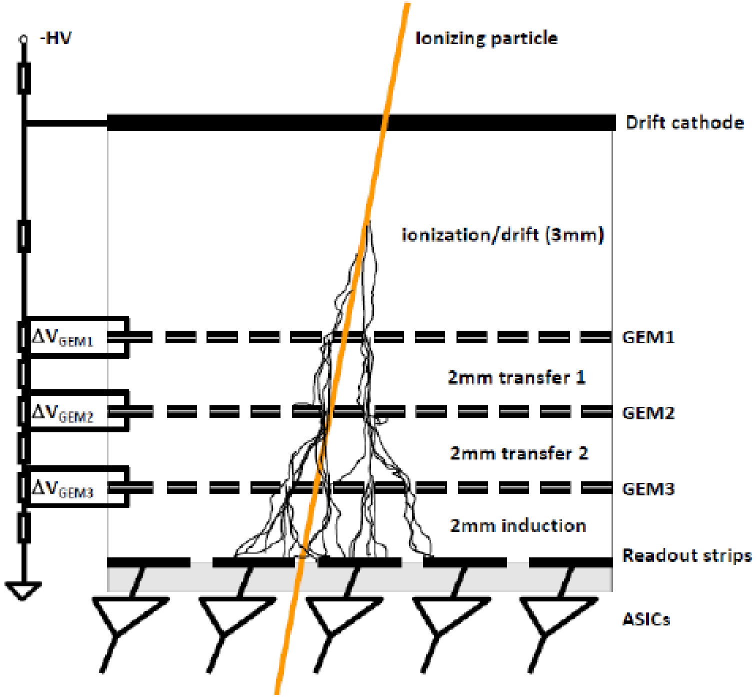
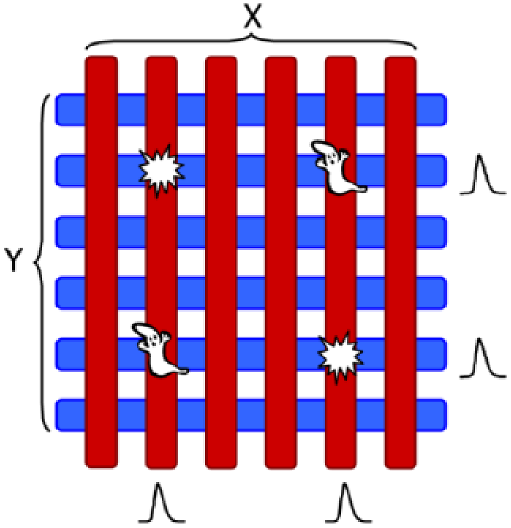
GEM detector performance

Strip-like readout





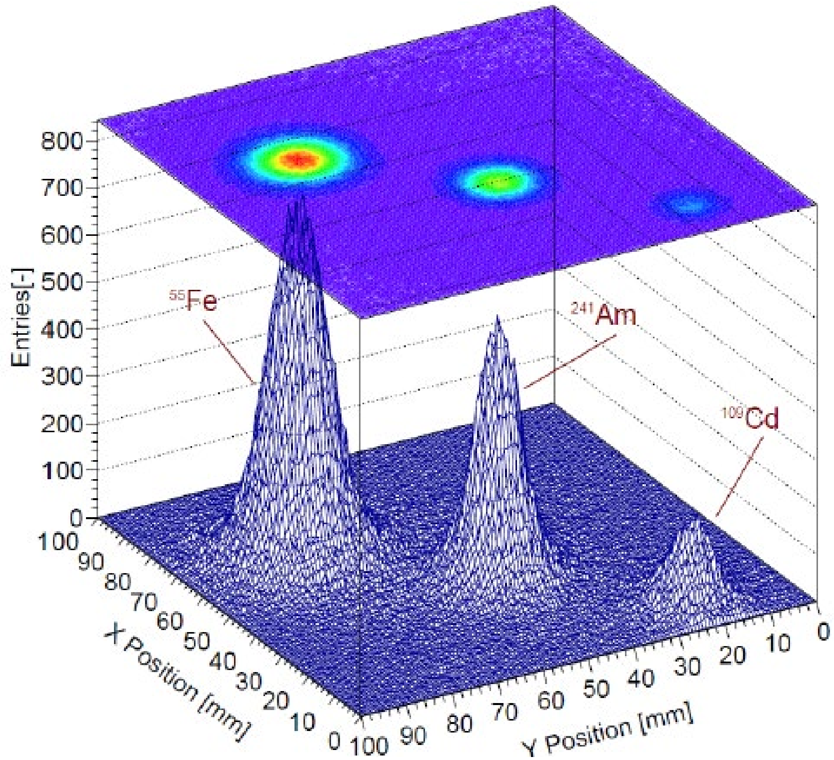


Position is determined based on coincidences of X and Y timing signals – works well for point charges (like from X-rays), will have some limitations for distributed charges (tracks) in the drift region)

GEM detector performance

Count rate measurements

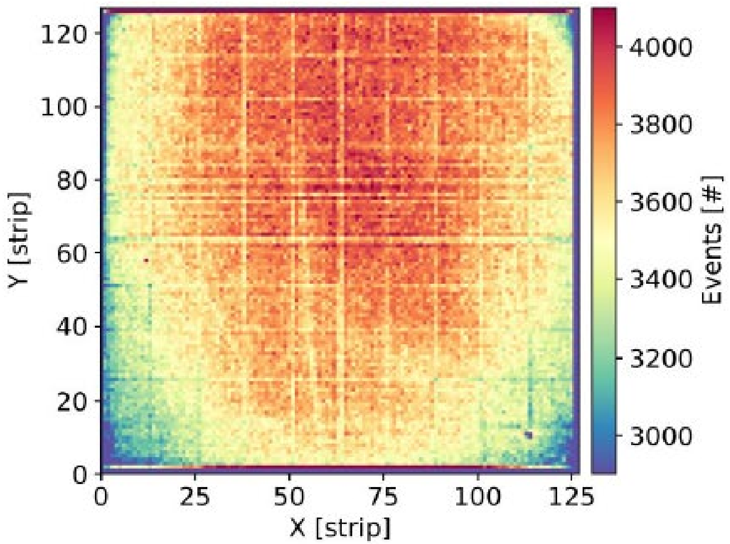
Simultaneous measurement with Fe-55, Am-241, and Cd-109 X-ray

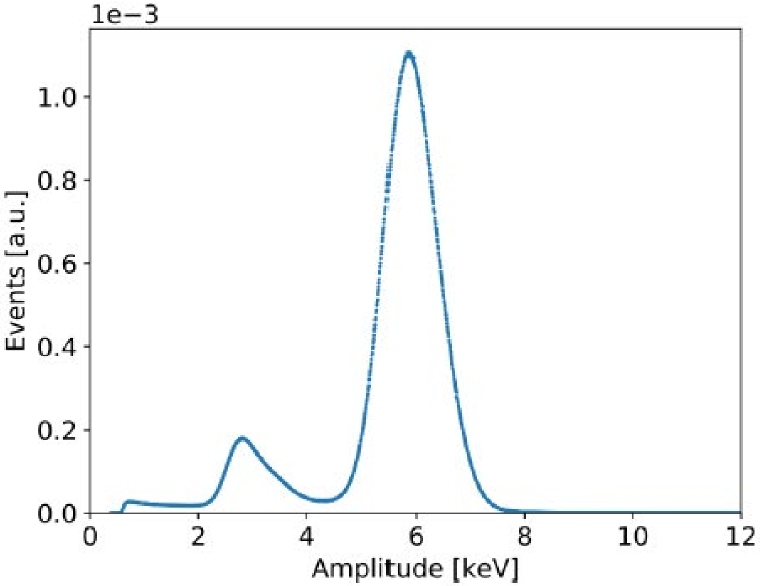


Reconstructed events count rate ~ 1.5 Me/s Hits count rate ~ 5.6 Mh/s (~9 kh/s/mm2)

GEM detector performance

Energy resolution



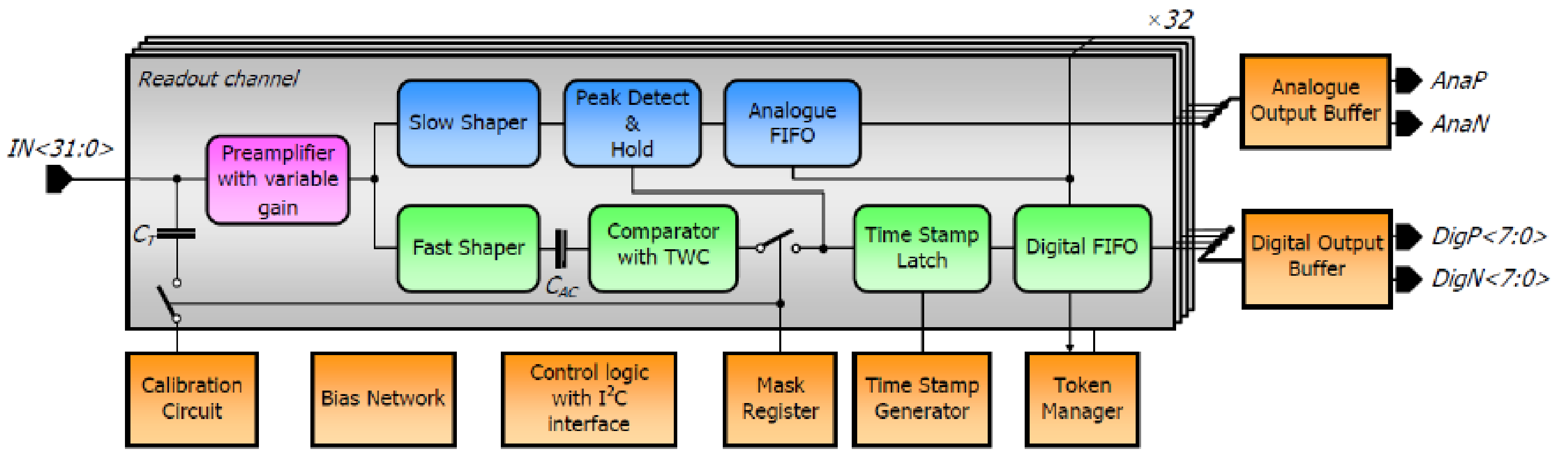


Energy resolution Fe-55 (FWHM) - 19.8% @ 3860V Ar/CO2 (70/30)

GEM detector performance

We have three different ASICs optimized for different requirements.

GEMROC2 architecture



- each channel is split into: slow (energy) and fast (timing) sub-channels
- switchable gain (2 modes) and signal polarity selection
- signal range: 300 fC (low gain mode), 150 fC (high gain mode)
- derandomization of data and zero suppression in the token-based readout
- hit rate per strip: ~ 1 M/s
- ENC < 0.2 fC (detection limit below 1 keV)
- self triggering mode – readout initiated by the input signal
- internal testability functions
- 32 channels per ASIC
- 0.35µm CMOS process

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Neutron generator NG-14 MeV

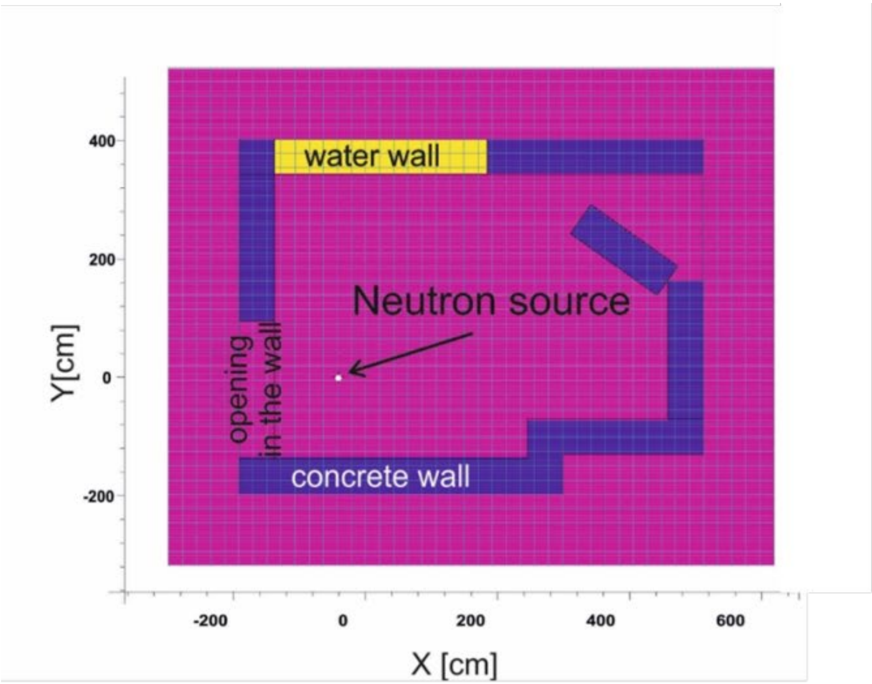
A fast neutron generator is considered as the neutron source for tests of **a demonstrator of the spectrometer** in question. Here, some important features has to be ensured.

1) A collimated narrow neutron beam has to be used in order to have a well defined neutron traveling direction to have the well defined θ scattering angle.

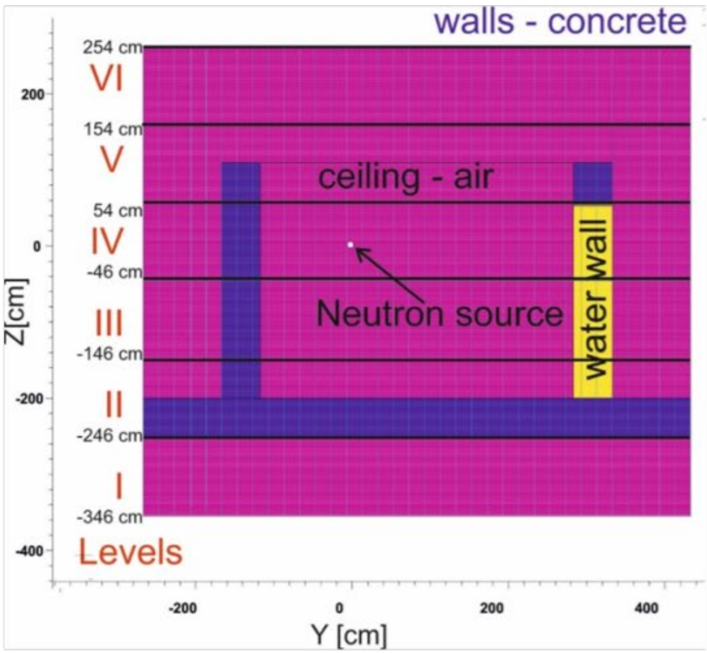
2) The primary neutron energy has to be precisely known.

A proper collimator, dedicated to those purposes, is to be designed.

Neutronic model of the experimental bunker at IGN-14.



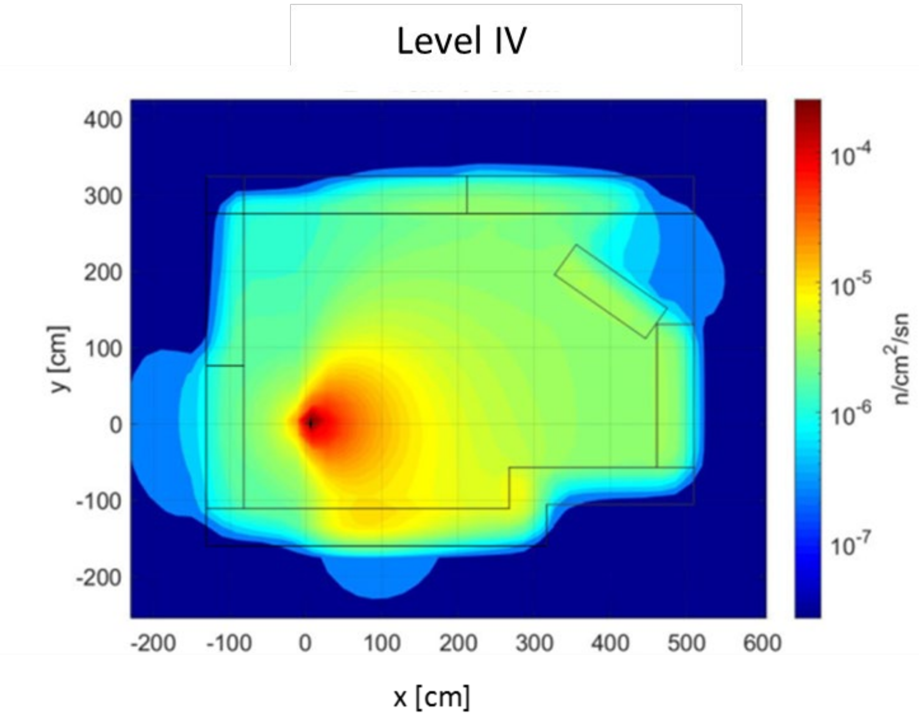
Horizontal (xy) cross section

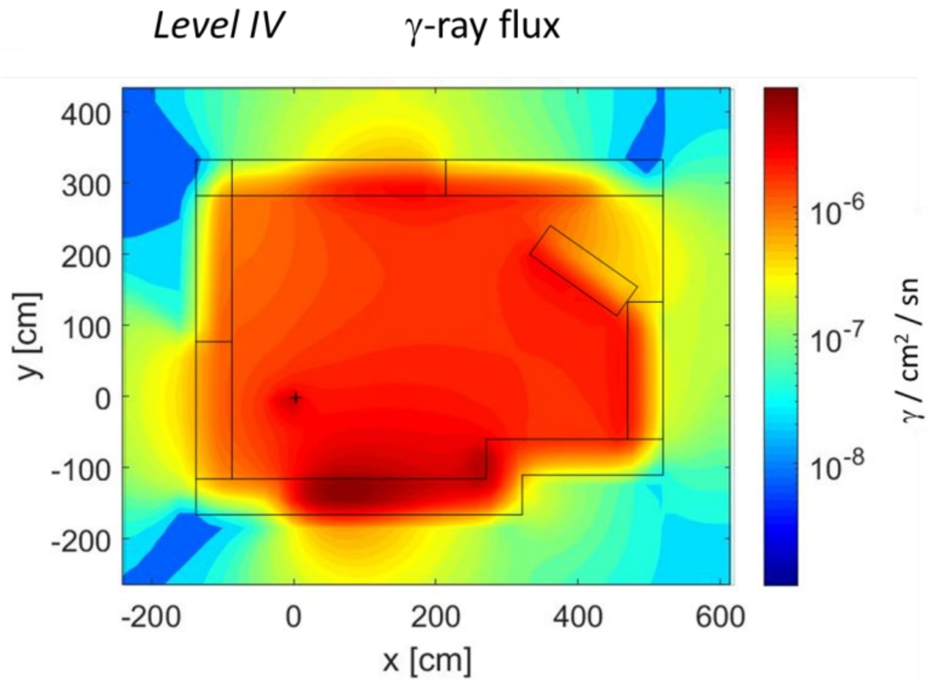


Vertical (yz) cross section

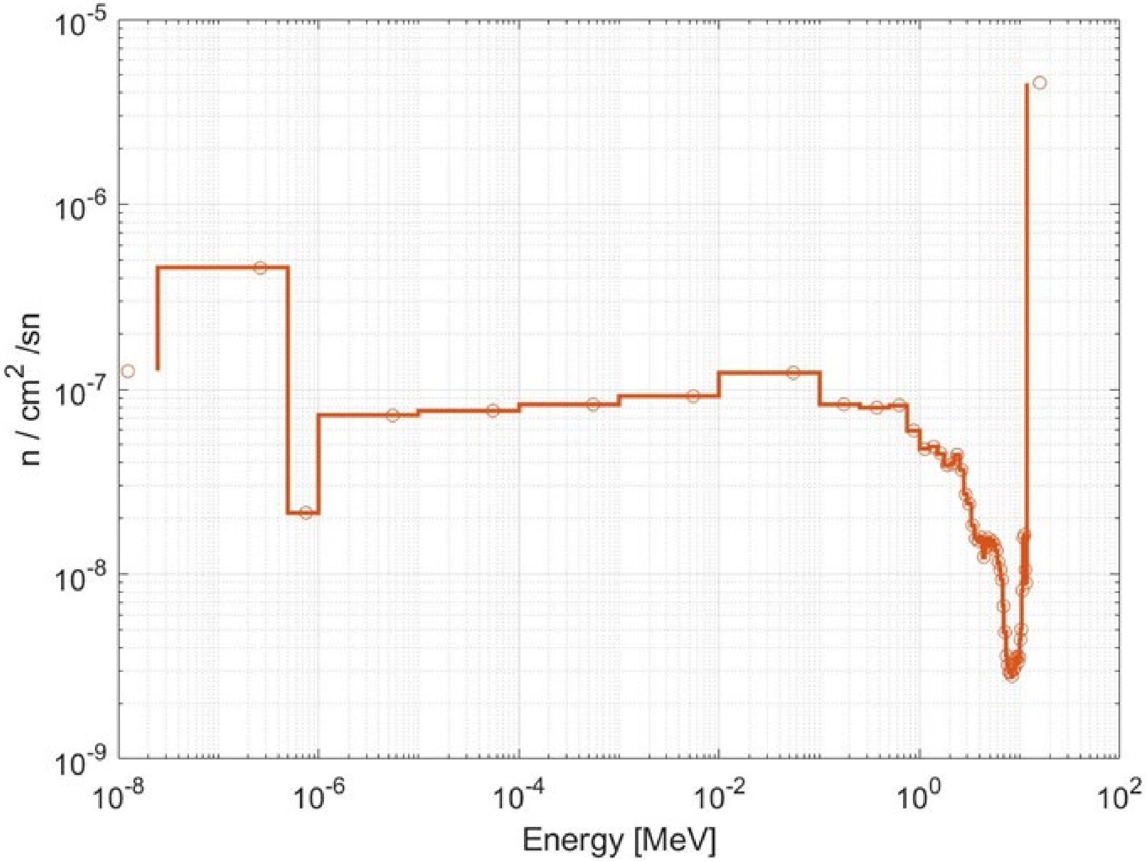
Total neutron flux distribution in Level IV of the experimental bunker

Accompanying γ-ray flux in Level IV of the experimental bunker



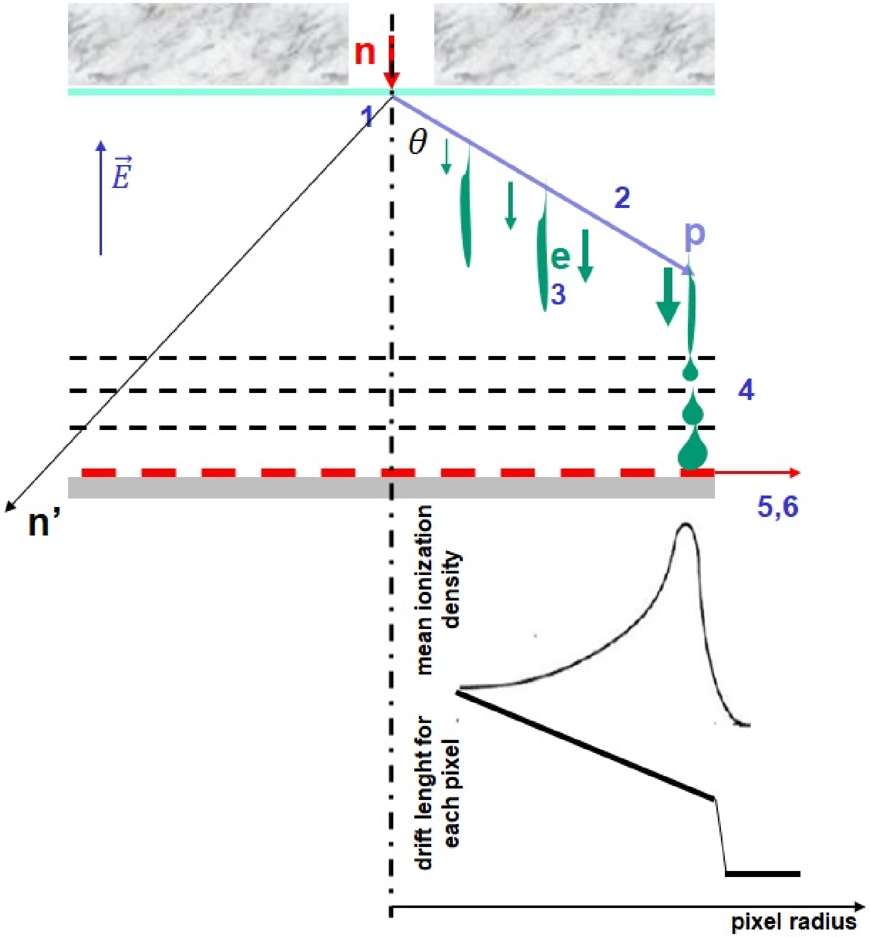


Energy distribution of the neutron flux in the experimental bunker.



Although an amount of 14 MeV neutrons is 1–1.5 order higher than of others, it would be desired to prepare a neutron collimator which will direct more 14 MeV neutrons to an appointed destination and will eliminate neutrons of lower energies and will form a narrow neutron beam.

Detector requirements to be defined



n - the collimated neutron beam, p – recoil proton; n' – scattered neutron

$$E_n = \frac{E_p}{cos^2\theta}$$

- Time resolution ?
- Energy resolution ?
- Dynamic range (min , max charge to be measured) ?
- Position resolution ?
- Count rate ?

We have three different ASICs optimized for different requirements.

Summary

Expected inputs from simulations

- Expected range of track lengths
- Charge distribution along the track
- Rate of events (protons)

<u>Next steps:</u>

- To chose the type of converter
- To chose the thickness of the converter
- To check another geometry neutron „beam" vs GEM
- to prepare a neutron collimator which will direct more 14 MeV and experimental set-up