FAST NEUTRON SPECTROSCOPY WITH MIMAC-FASTn:
A mobile and directional fast neutron spectrometer
10 keV up to more than 200 MeV

Nadine Sauzet, Daniel Santos, Olivier Guillaudin

Laboratoire de Physique Subatomique et de Cosmologie
(Université Grenoble-Alpes -CNRS/IN2P3)
CONTEXT OF MIMAC-FASTn : a valorisation project

Root of the project : MIMAC

Instrumentation dedicated to directional dark matter detection

Valorisation in a fast neutron spectrometer

1 Collaboration with IRSN/LMDN

Laboratory of Neutron Metrology and Dosimetry

Since 2010

2 Fundings by :

Enigmass Labex, « Prematuration » of CNRS, SATT/LINKSIUM (« maturation »)

Since September 2014
Specificity of MIMAC-FASTn

**NOT JUST NEUTRON COUNTING !**

**A 3D DETECTION**

**NO MODERATION**
no $^3\text{He}$ or $^6\text{Li}$

**ADJUSTABLE RANGE :**

[ 10 keV ; 200 MeV ]
From $\theta$, $E_{\text{ion}}$, and the IQF, we get the neutron energy $E_n$.
Valorisation of MIMAC-FASTn

MIMAC (Modane)

MIMAC-FASTn
$^4$He nuclear recoil / electron discrimination

A $^4$He nuclear recoil track
2.9 MeV kinetic

Measurements at CERF facility
(CERN high energy Reference Field)

A muon track
90 keV
Specificity for high neutron energies, above 5 MeV

Angular distributions of $^4\text{He}$ recoils, resulting from elastic diffusions with neutrons:

*Read-out strategy patented for high energy neutron spectroscopy*

Measurement configuration above 5 MeV: perpendicular to the detector axis
Direction of $^4$He recoil tracks: head-tail signature

**Detector perpendicular to the beam direction**

1. Cathode direction
2. Anode direction

**Analysis from the charge deposit profile on the grid:**

The track direction is essential for the definition of the interaction point.

**IRSN /AMANDE (Cadarache)**

$^3$H(p(3357 keV),n)

Monoenergetic neutrons of 2.5 MeV
Energy calibration of the Flash-ADC

Detection of $\alpha$ and $^7$Li, resulting from thermal neutron capture on a $B_4C$ layer

**Alpha track**

![Graph showing energy calibration of the Flash-ADC with peaks at 840 keV, 1.16 MeV, and 1.78 MeV.]

![Anode projection showing track start and layers.]

$B_4C$ layer
Selection of $^4$He nuclear recoils: $D(d(1.8\,\text{MeV}),n)$

Discrimination from protons, $^{12}\text{C}$, $^{16}\text{O}$, and $(n,\alpha)$ reactions

$700\,\text{mbar He/CO}_2 (5\%)$

IRSN /AMANDE (Cadarache)
Monoenergetic measurement with neutrons of 3.1 MeV and 15 MeV on GENEPI (LPSC)

D(d(220 keV),n) Parallel configuration

Residual scattered neutrons

150 keV/bin

700 mbar He/CO₂ (5%)

Paper to be submitted

T(d(220 keV),n) Perpendicular configuration

1.5 MeV/bin
Monoenergetic measurements: detection of target pollution

\[ D(d(1.8 \text{ MeV}, n)) : \text{neutrons of 5 MeV} \]

\[ D(d(3.2 \text{ MeV}, n)) : \text{neutrons of 6.5 MeV} \]

NPL / (UK)

\[ ^{12}\text{C}(d, n) \]

\[ ^{16}\text{O}(d, n) \]

700 mbar He/CO\(_2\) (5%)

IRSN / AMANDE (Cadarache)

\[ ^{12}\text{C}(d, n) \]

Counts

Neutron energy (keV)

Paper to be submitted
Polyenergetic measurement with $^{9}$Be(d($1.45$ MeV),n)

Angular distribution

**Spectrum measured at 0 deg**

[Graph showing neutron energy distribution at 0 degrees]

**Spectrum measured at 60 deg**

[Graph showing neutron energy distribution at 60 degrees]

M.E. Capoulat, N. Sauzet et al.  
« Neutron spectrometry of the $^{9}$Be(d($1.45$ MeV),n)$^{10}$B reaction for accelerator-based BNCT »  

INFN LNL  
(Legnaro - Italy)  
700 mbar  
He/CO$_2$ (5%)
Exploration up to 200 MeV: measurement at CERF

Perpendicular configuration

Below 25 MeV:

![Graph showing neutron flux vs. neutron energy for the below 25 MeV region with bins of 250 keV.](image)

- 1.2 bars He/CO₂ (5%)
- Preliminary results

Above 10 MeV:

![Graph showing neutron flux vs. neutron energy for the above 10 MeV region with bins of 5 MeV.](image)
Exploration up to 200 MeV: measurement at CERF

Discrimination of muons and pions

1. GEANT4 simulation

CERF facility (neutrons, muons, pions)

2. Measurement with Mimac-FastN

CERF facility: $^{63}\text{Cu}(p(120 \text{ GeV}),n)$

- Protons
- Pions
- $^4\text{He}$ recoils
- $^{16}\text{O}$ and $^{12}\text{C}$ recoils
A large energy adjustable range

$E_n = 27\text{ keV}$

$E_n = 127\text{ keV}$

$E_n = 1.2\text{ MeV}$

D. Maire et al.
« Neutron energy reconstruction and fluence determination at 27 keV with the LNE-IRSN-MIMAC $\mu$-TPC recoil detector »
IEEE Transactions on Nuclear Science, 63(3) : 1934-1941, June 2016

D. Maire et al.
« First measurement of a 127 KeV neutron field with a $\mu$-TPC spectrometer »

Paper to be submitted
Conclusion

A NEW NEUTRON SPECTROMETER WITH A LARGE ADJUSTABLE RANGE

A MOBILE DEVICE, WITH A COMPETITIVE ENERGY RESOLUTION

OPENING TO NEW MEASUREMENTS AND APPLICATION FIELDS
BACK-UP SLIDES
In high neutron flux, in a window of 25 microseconds

**Multiple $^4$He recoil tracks:**

- **Anode projection**
- **Track ZX**
- **Track ZY**

**Flash profile derivative**

**Flash ADC – anode synchronization**
Ionization quenching factor measure of $^4$He

An IQF measure relative to protons

IPNL beam line coupled to a drift space of 25 cm and a 512 µm Micromegas through a 1 µm hole interface

*Mixture of $^4$He/CO$_2$ 700 mbar*
PIONS INTERACTIONS WITH MIMAC-FASTn

GEANT4 simulation

Energy deposited in ionization by $1.10^7$ pions of 200 MeV, through protons and alpha particles:

Energy deposited in ionization by $1.10^7$ pions of 200 MeV, through electrons:
PROTONS ORIGIN AT CERF

Cross-section of $^{27}$Al(n,p) :

Most probable inelastic reaction induced by neutrons of 70 MeV on $^{27}$Al : $^{27}$Al(n,pn$\gamma$)

Pavlik et al. «$^{27}$Al(n,xy) reactions for neutron energies from 3 to 400 MeV », PhysRevC vol.57 , 1998
PROTONS ORIGIN: inelastic reactions of 70 MeV neutrons on 27Al

GEANT4 simulation

Protons induced by inelastic reactions of 70 MeV neutrons on Mimac-FastN aluminium structure (thickness of 3 mm):

Protons that deposit all their energy in the gaseous active volume
GEANT4 simulation
Energy deposited in ionization by \(1.10^7\) muons of 100 MeV:

Measurement with Mimac-FastN

A 90 keV muon track

- Very few muons detected, because they lose at maximum 100 keV in the gaseous volume
- Ionization energy threshold = 60 keV
PION DISCRIMINATION WITH MIMAC-FASTn AT CERF

A 162 keV pion track and charge profile:

Pion ionization energy spectrum:

10% of the events detected with tracks
A 356 keV proton track and charge profile:

Proton ionization energy spectrum:

Proton track length = f(Eion):

25% of the events detected with tracks are protons.
Flash profile:

Risetime 2 = f(risetime 1):

The track direction is essential for the definition of the interaction point.