

Characterization of microMegas detectors at n_TOF experiment at CERN

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1 n_TOF experiment

The n_TOF facility at CERN aim of addressing the request of high accuracy nuclear data for advanced nuclear energy systems as well as for nuclear astrophysics and medical applications. The facility came into operational in 2001.

The Proton Synchrotron (PS) at CERN provide a proton beam which impinges on a lead target, producing by spallation process a large amount of neutrons. The nominal proton bunch intensity is 7×10^{12} , provided by a proton beam of 20 GeV with a maximum frequency of 0.8 Hz. Neutrons travel through two beam lines, where they encounter different elements to collimate the beam and reduce undesired particles. There are two experimental areas, Experimental Area 1 (EAR1) at 185 m in the incoming proton beam direction and Experimental Area 2 (EAR2) located at 20 m above the ground in the vertical direction. The first one is in operation since the beginning of the experiment and Experimental Area 2 was build in 2014.

The main elements and its positions are shown in the Table 1. First element, the spallation target, is cooled by water as a protection against thermal damage, eventually water can be boron enriched to reduce thermal neutron flux at n_TOF-EAR1. Next, the filter station is used to modify the neutron spectrum using various materials placed in beam path. Two collimation system are available to cover all the possible target needs. Further, the sweeping magnet deflects charged particles to clear the beam and the beam dump at the end is composed by different materials to stop the beam. Despite all these elements, gamma and relativistic particles are still reaching the experimental area which produces a large signal in the detector system that can be used as time reference.

Element	EAR1	EAR2
Filter box	135 m	11.4 m
1st collimator	137 m ($d = 11$ cm)	7.4 m ($d = 10$ cm)
sweeping magnet	145 m	10.4 m
2nd collimator	180 m (capture: $d = 1.8$ cm, fission ($d = 8$ cm))	15 m ($d = 2$ cm)
Experimental area	182-190 m	18-23 m
beam dump	200 m	24 m

Table 1: Different elements influencing beam.

1.1 Physics

The main physics goal is to measure neutron capture, fission and (n,charged particle) reaction cross-sections using the Time-of-Flight (TOF) technique. The TOF is used for initial neutron energy estimation combining kinetic energy formula $E = \frac{1}{2}mv^2$ and equation of motion $v = \frac{s}{t}$, where m is the neutron mass, v is the neutron speed, l neutron flight path and t flying time.

The cross-sections are used in various fields, e.g. nuclear astrophysics, medicine, reactors development and in research of nuclear waste. One of the main features of the n_TOF facility is the wide neutron energy range, allowing measuring cross-sections from thermal to 1 GeV. EAR1, with longer flight path, ensures a good energy resolution. While EAR2, with much shorter flight path, provides higher flux (by factor $\times 30$), allows measuring samples with short half-life (down to few weeks), with very low cross-section and small in quantity ($\ll 1$ mg).

1.2 Detectors

Different detections systems are used at n_TOF to measure neutron induced cross-section reactions such as (n, γ), (n,f), (n,cp)¹, for example:

¹f - fission fragment, cp - charged particle

- The Silicon Monitor Devices (SiMon and SiMon2), a solid state detector for (n,f) and (n,cp) measurement.
- C₆D₆ liquid scintillators for (n,γ).
- MicroMegas detector, a gaseous detector for (n,f) and (n,cp).
- Silicon Telescope, a silicon strip solid state detector providing 2D information for (n,f) and (n,cp) reaction.
- Organic scintillators, CeBr₃ and CeF₃ for capture measurement.
- ³He gaseous detector to measure neutron background,
- 4π BaF₂ scintillator – Total Absorption Calorimeter (TAC) to measure capture exclusively in EAR1.
- STEFF – STEFF is a complex of different detector systems (Bragg ionization chamber, full stop detector and MWPC to measure (n,f) and NaI scintillator to (n,γ) measurement) designed to study the fission reaction properties exclusively in EAR2.

2 MicroMegas micro–pattern gaseous detector

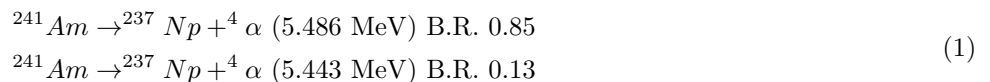
MicroMegas is a type of micro-pattern gaseous detector based on ionizing principle developed at CERN in collaboration with the CEA-Saclay for n.TOF as neutron monitor, due to its high radiation resistance and transparency to neutrons. The knowledge of the neutron flux is important to characterize the neutron beam.

The detector system consists of three main parts: drift electrode, micromesh and anode. First of all, neutrons need to be converted to charged particle, this is done by a neutron converter deposit on the surface of the drift electrode. Particles created in the target travel in the area between the drift electrode and the micromesh, where they ionize the gas creating electron–ion pairs. Electrons are drifted toward the micromesh, entering in the amplification region where the avalanche process takes place. Finally, the charge is collected either as ions or electrons by the mesh or the anode depending on the applied voltage. Micromesh is a metallic foil with holes 35 μm in diameter spaced by 100 μm, the foil is "transparent" for electrons and can hold voltage to provide isotropic electric field. The applied electric field for drift is around 1 kV/cm while the electric field between micromesh and anode is more than 10 kV/cm to provide sufficient amplification. The gas used in this type of detectors at n.TOF is 88% Ar + 10% CF₄ + 2% iC₄H₁₀ at atmospheric pressure.

2.1 Simulation with SRIM

To foresee a MicroMegas set-up for a given experiment a study on the energy loss in the gas system is needed, a Monte Carlo simulator (TRIM - Transport of Ions in Matter) contained in The Stopping and Range of Ions in Matter (SRIM) is used for this purpose. SRIM is a collection of software packages to simulate many features of the ion transport through matter.

MicroMegas characterization will be done with an α source, ²⁴¹Am, that decays by emitting alpha particles of two different energies:



The source is sealed in a 1.8 μm thick Palladium container mounted on a 18 μm thick Aluminium holder. Both of these additional materials are greatly modifying emitting energy spectrum, thus it needs to be considered in simulation. Sensitive volume in microMegas detector is composed of 88% Ar, 10% CF₄ and 2% isobutane.

2.1.1 Stopping length

One of the main parameters to be studied is the distance of the conversion or drift region. It is very desirable to fully stop the particles inside the active volume to ensure the good separation between particles. Assuming that α particle will be fully stopped in the volume thus the longest flying path is in perpendicular direction to the source as it travels the least thickness of Pd and Al which are greatly decreasing α energy, the simulation has been done for an emission angle of 0°. The stopping length for 5.486 MeV Am α particle for different entrance windows is shown in Figure 1 (left). As expected, the more material present along the α path, less energy remains when the particle enters the active volume. As can be seen the sufficient distance between drift electrode and mesh for our set-up is 0.5 cm.

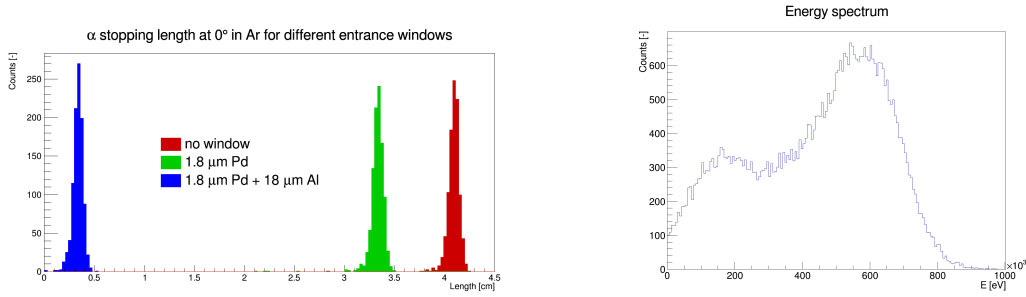


Figure 1: Left: The stopping length for 5.486 MeV Am α particle at 0° with different entrance windows. Right: Energy spectrum for 5.443 and 5.486 MeV Am α particle deposited in Ar layer, with Pd+Al entrance windows, simulated for angles $0-20^\circ$ weighted on α B.R. and lost particles from active volume.

2.1.2 Energy spectrum

With SRIM, a simulation of the energy loss in the gas volume has been done for combinations Pd+Al+Ar and Pd+Al. The first one provides information about average energy deposition in the layers and the number of particles that are fully stopped in the system. The second simulation provides the average energy loss in Pd+Al layer and number of particles stopped in that region. Combining these information one can estimate the average energy loss in Ar volume. The simulated energy spectrum for both α weighted on Branching ratio (B.R.), lost particles and modified by entrance window can be seen in Figure 1 (right).

2.2 MicroMegas characterization

The characterization of the microMegas detector requires the study/estimation of two properties: transparency and gain. Transparency represents the fraction of electrons reaching the multiplication area (crossing the mesh holes), i.e. how good the electric field is leading the electrons through the mesh grid. In order to get the transparency curve, the energy spectrum is measured for different drift voltages U_D , while the mesh voltage U_M and drift distance D_D are fixed. By other hand, the gain is an exponential function of the mesh voltage. The gain curve is obtained by measuring the energy spectra for different mesh voltages while fixing drift voltage. Characterization has been done for two microMegas detector systems: a 4-PAD monitor and a fission tagging microMegas. The 4-PAD monitor is a microMegas with divided drift cathode in 4 segments. The fission tagging has only one drift cathode and was previously used in physics measurement, thus is very important. Schematic of experimental set-up can be seen in Figure 2.

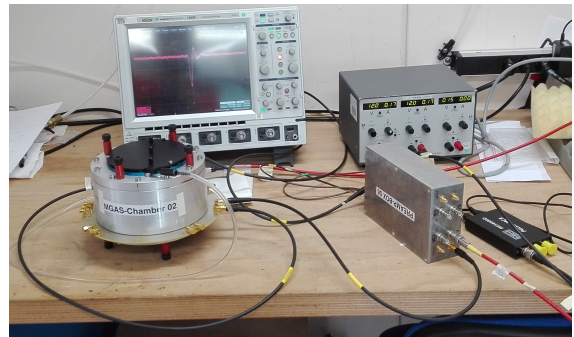
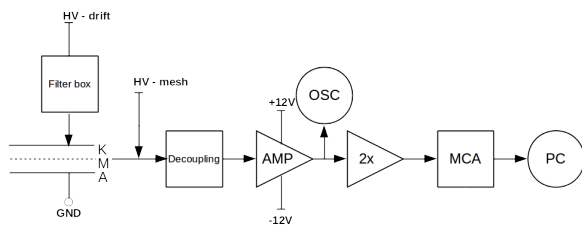


Figure 2: Left: Circuit schematic. A is anode, M mesh, K cathode, GND ground with 50ω termination, *Filterbox* to filter AC from power supply, *Decoupling* to filter DC offset, *AMP* pre-amplifier, *OSC* oscilloscope (LeCroy WaveRunner 104XI), $2x$ amplification by factor 2 (ORTEC TFA 474), *MCA* Multi channel analyser (AMPTEK MCA8000D) and *PC* computer. Right: Experimental set-up: from left: chamber (4-PAD microMegas), oscilloscope, low voltage DC supply, preamplifier and Multi channel analyser.

2.2.1 Characterization of the 4-PAD monitor

Transparency curve with fixed mesh voltage $U_D = -250$ V can be seen in Figure 3 (left). The best value is the one before reaching plateau, thus has been estimated as $U_D = -800$ V. For that drift voltage gain curve with drift gap $D_D = 7.4$ mm and mesh distance $D_M = 25$ μm has been measured and can be seen in Figure 3 (right).

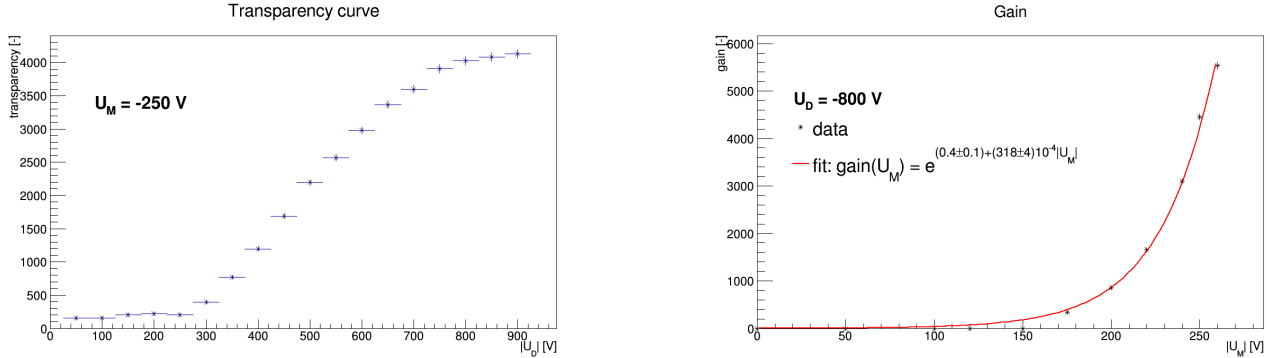


Figure 3: Left: Transparency curve for the 4-PAD microMegas with fixed mesh voltage $U_D = -250$ V, drift gap $D_D = 7.4$ mm and mesh distance $D_M = 25$ μm . the best value for drift voltage has been estimated as $U_D = -800$ V. Right: Gain for the 4-PAD microMegas chamber with fixed drift voltage $U_D = -800$ V.

2.2.2 Characterization of the fission tagging microMegas

This microMegas, includes pins to connect the necessary wires to applied the HV and take the signal and they are attached to a PCB ring. It turned out, that this ring absorbs air moisture, this reflects as measurable leakage current in nA range. The longer the chamber is off the air, flowed by working gas, the more it cleans and leakage current drops. Thus a several transparency and gain measurements has been done with days steps to see the effect of the leakage current on the detector. Both transparency and gain points in a graph is evaluated as mean value of Gaussian fit of the energy spectrum. Example of those fit is in the Figure 4.

The transparency curve for 3 values of mesh voltages is shown in Figure 5 and the evolution along days is presented in Figure 6 (left). Regarding the gain, it also changes with the current as can be seen in Figure 6 (right). The leakage current during first day was around 500 nA, during second day 250 nA and during sixth day around 80 nA for the $U_D = -500$ V and $U_M = -250$ V can be seen in the Figure 7.

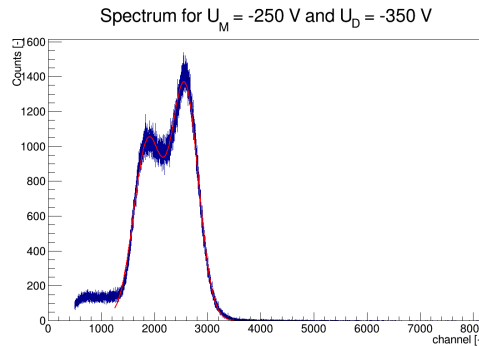


Figure 4: Example of fitted energy spectrum for the fission tagging microMegas for one drift voltage $U_D = -350$ V and mesh voltage $U_M = -250$ V.

3 Conclusion

The n-TOF facility at CERN provides high accuracy cross-section measurement of isotopes used in nuclear energy systems, nuclear astrophysics and medical applications. To provide this data a various detectors are used. One of these detectors is so called microMegas micro-pattern detector used for neutron beam flux measurement.

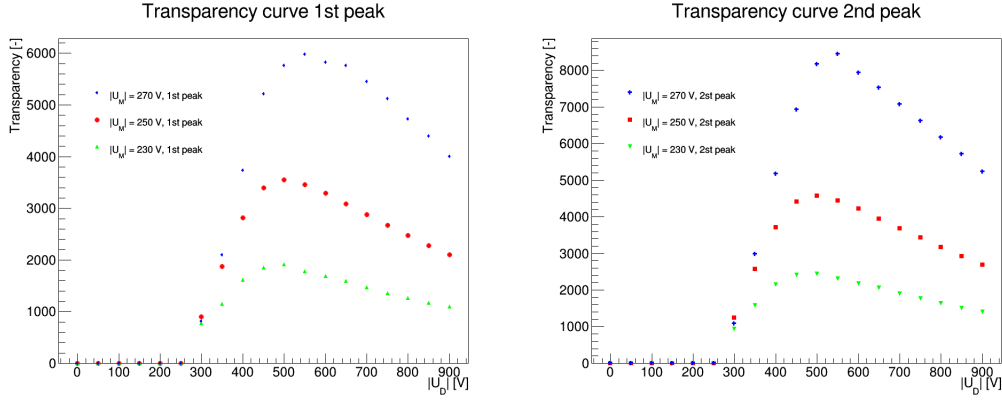


Figure 5: Transparency measurement for the fission tagging microMegas for different drift voltages with fixed mesh voltage $U_M = -230$ V, $U_M = -250$ V and $U_M = -270$ V and fixed drift gap $D_D = 7.4$ mm and mesh distance $D_M = 25$ μm .

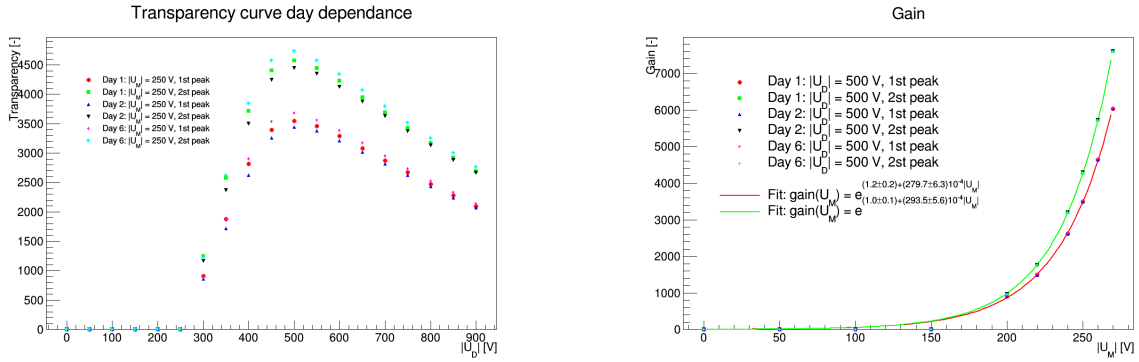


Figure 6: left: Transparency change during days for the fission tagging microMegas with fixed mesh voltage $U_M = -250$ V, drift gap $D_D = 7.4$ mm and mesh distance $D_M = 25$ μm . Right: Gain for the fission tagging microMegas with fixed drift voltage $U_D = -500$ V, maximum in the transparency.

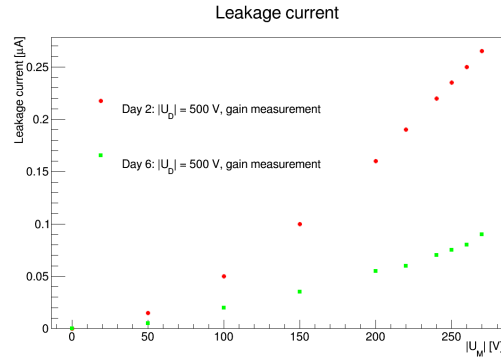


Figure 7: Leakage current during the gain measurements in day 2 and day 6.

The simulations on stopping length in a detector active volume and deposited energy spectrum has been done and can be seen in Figure 1. Measured real spectrum can be seen in Figure 4.

Afterwards two microMegas detectors has been characterised by evaluating transparency and gain curves. The result for the first detector – 4-PAD microMegas – can be seen in Figure 3 and the results for the second chamber – fission tagging microMegas – are shown in Figure 5 and 6.

Detector holding ring are affected by humidity absorption and this reflect on measurable leakage current in nA range. The leakage current is shown in Figure 7 and corresponding transparency curve and gain measurement in Figure 6.

As can be seen the leakage current does not affect the best voltage for transparency and the gain multiplication, on the other hand, it affects the measured spectra peak position and thus can harden the assignment of energies to MCA channels.