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The Neutron Time of Flight Facilty at CERN

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The neutron Time of Flight (n_TOF) facility at CERN is a high flux neutron source obtained by the spallation of 20 GeV/*c* protons onto a solid lead target. The proton beam beam is delivered by the Proton Synchrotron (PS) at CERN capable of providing up to four sharp bunches (6 *ns*) with an intensity of 7 10^ 12 protons per bunch within a 14.4s supercycle. The outstanding characteristics of this facility: high neutron flux of 10^ 6 n/cm^2/7 10^12 p. at 182.5 m, wide spectral function from 1 *eV* up to 250 *MeV*, low repetition rates and an excellent energy resolution of 2 x 10^-4 open new possibilites for high precision neutron induced cross section measurements, using samples of modest mass. The facility was commisioned in Nov. 2000 and Apr. 2001, with performances similar to those predicted by Monte Carlo simulations.

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The neutron Time of Flight (n_TOF) facility at CERN is a high flux neutron source obtained by the spallation of $20\,\mathrm{GeV}/c$ protons onto a solid lead target. The proton beam is delivered by the Proton Synchrotron (PS)[1] capable of providing up to four sharp bunches ($6\,ns$) with an intensity of $7\,10^{12}$ protons per bunch, within a $14.4\,\mathrm{s}$ supercycle. The outstanding characteristics of this facility: high neutron flux of $10^6\,\mathrm{n/cm^2/7\,10^{12}\,p.}$ at $182.5\,\mathrm{m}$, wide spectral function from $1\,eV$ up to $250\,MeV$, low repetition rates and an excellent energy resolution of 2×10^{-4} open new possibilities for high precision neutron induced cross section measurements, using samples of modest mass. The facility was commissioned in Nov. 2000 and Apr. 2001, with performances similar to those predicted by Monte Carlo simulations.

KEYWORDS: n_TOF, CERN, commissioning, cross section measurements

I. Introduction

The n_TOF facility at CERN is a high flux spallation neutron source followed by a $182.5\,m$ time of flight basis. The aim of the n_TOF project is the measurement of cross sections needed for the design of innovative ADS applications like incineration of nuclear waste,[2,3] energy production,[4,5] radio-isotope production for medical applications[6] and basic science subjects in particular astrophysics.[7] As a result of the studies reported in a first paper[8] and an addendum,[9] the neutron time of flight facility has been proposed at the CERN PS[7] delivering a maximum intensity of 3×10^{13} protons within a $14.4\,s$ supercycle at a momentum of $20\,GeV/c$. The facility allows to study systematically and with excellent resolution, neutron induced cross sections in the interval from $1\,eV$ to $250\,MeV$, of almost any element using targets of very modest mass, necessary for the unstable or otherwise expensive materials.

II. The n_TOF Facility

Following an overall optimization between neutron flux Φ and resolution $\Delta\lambda$ ($\lambda =$ effective neutron path), the spallation target was chosen to be a lead block of $80 \times 80 \times 40\,cm^3$, followed by a water moderator of $5\,cm$ thickness.[10] In the final design[11] the neutron emission takes place at an angle of 10^o with respect to the proton beam direction and the target is made of pure lead blocks already used in the TARC experiment.[12] A thin single metallic window (aluminum alloy) of 1.6 mm thickness is the interface between the moderator and the vacuum in the n_TOF tube.[11]

The horizontal time of flight tube (Fig. 1) starts directly after the window and ends where the sloped floor of the TT2A tunnel (1.18% gradient) touches the tube, thus allowing a length up to $200\,m$. The pressure in the vacuum tube is less than $1\,mbar$. The tube is made up of four different sectors, the first one ($\varnothing = 80\,cm$), closest to the target, is made of aluminum alloy whereas the others ($\varnothing = 80$, 60 and $40\,cm$) are made of stainless steel.[11]

Two collimators were installed to reduce the radius of the neutron beam, necessary for the capture measurements. The first one, $2\,m$ in length (beam shaping collimator) is located at $136.7\,m$ and is made of $1\,m$ of iron and $1\,m$ of concrete; its inner diameter is $\varnothing = 11.5\,cm$. The second collimator (source screening collimator) with $\varnothing = 1.8\,cm$ inner diameter, is placed at $178\,m$ with $50\,cm$ of 5% borated polyethylene, $125\,cm$ of iron and $75\,cm$ of 5% borated polyethylene. For the fission measurements, a second collimator with a larger inner diameter $\varnothing \approx 8\,cm$ will be used, in order to exploit the full neutron flux of the installation.

In spite of the 10^o angle between the time of flight tube and the proton beam, some charged particles will remain and contaminate the neutron flux. Therefore, a $2\,m$ long dipole magnet, located at $145\,m$, is used to sweep away these unwanted secondary charged particles.

1. The Neutron Flux and the Energy Resolution

The simulation of the detailed geometry of the lead target has been performed to estimate the neutron flux at $182.5\,m$. Two Monte-Carlo codes have been used successively: FLUKA[14] and the EA-MC Monte-Carlo code.[15] FLUKA generates the spallation neutrons and transports them from high energies down to $19.6\,MeV$. The neutrons from FLUKA simulations with kinetic energy lower than

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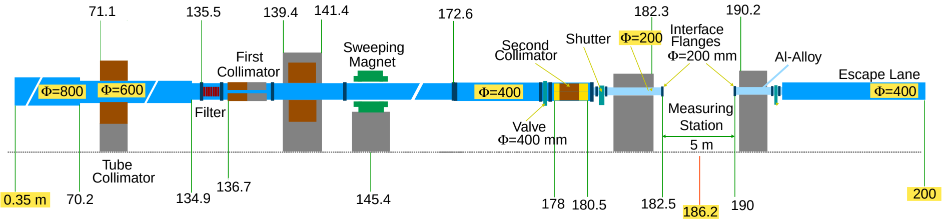

Fig. 1 TOF tube sections up to the end of the TT2A tunnel (200 m).

19.6 MeV are further transported by the EA-MC code using the same geometry as in the previous simulation. In both cases, the position, velocity, time and energy of each neutron entering the neutron tube are recorded. The upper curve in Fig. 2 shows the neutron flux expected at 182.5 m with no collimators, given in isolethargic units as $dn/dlnE/cm^2/7\,10^{12}\,p$. A gravitational cut-off will occur due to the geometry of the beam pipe for neutrons with kinetic energies less than $0.02\,eV$. The neutron background at the measuring station is $5-6$ orders of magnitude smaller than the neutron flux.

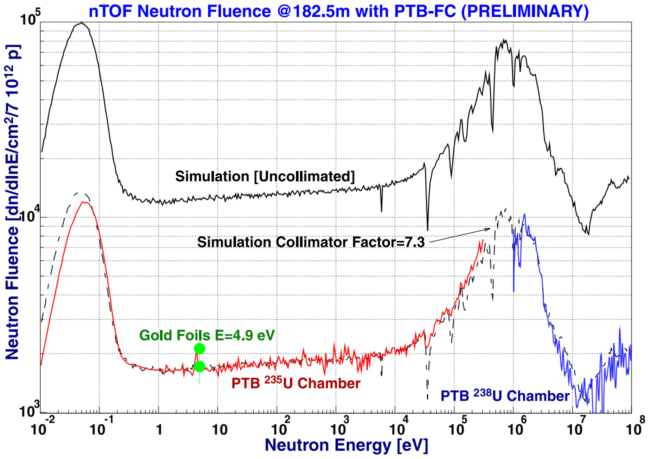

Fig. 2 *Upper curve:* Simulation of the uncollimated neutron flux at 182.5 m in isolethargic units. *Lower curve:* average neutron flux with the collimator setup for capture measurements, measured during the commissioning phase with ^{235}U, ^{238}U fission chambers and Gold activation foils. Due to the small diameter of the second collimator $\varnothing = 1.8\,cm$ for the capture setup, the average neutron flux compared to the uncollimated one is reduced by a factor of ~ 7 depending on the distance.

The energy resolution has been estimated using the relation $\Delta E/E = 2\lambda/(\lambda + L)$ between the energy E and the effective neutron path λ inside the lead followed by the 5 cm thick water moderator. This effective neutron path λ can be evaluated as $\lambda = v \times t$, where v is the neutron speed when entering the neutron tube and t the time elapsed since its creation (Fig. 3). The effective neutron path in the lead target is a few centimeters for the lowest energies; the variance $\Delta\lambda$ has been evaluated taking in either the r.m.s of the λ distributions, or the standard deviation from gaussian fit of the peaks.

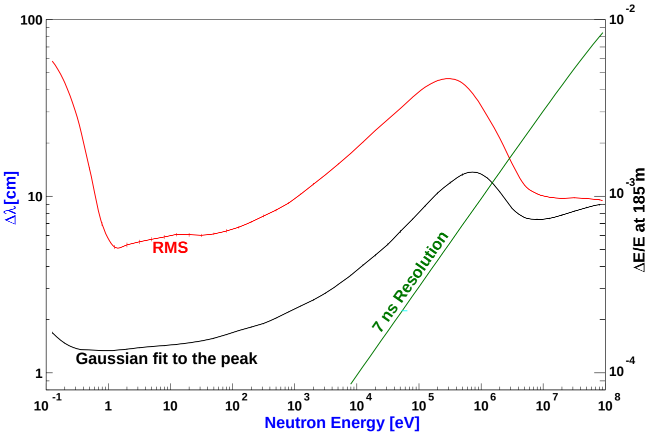

Fig. 3 Monte Carlo simulation of the energy resolution at 185 m. The 7 ns resolution due to the proton beam becomes important for neutron energies above a few MeV.

2. Charged Particles and Photons

The 20 GeV/c proton beam interacting with the lead target is a source of many other charged and neutral particles.$^{13)}$ As already mentioned, the elimination of the charged particles is achieved by the sweeping magnet located at 145 m. The momentum distribution of the charged particles as resulting from simulations is shown in Fig. 4, together with that of neutrons.

Along the spallation and moderation process of neutrons on the lead target, photons are produced. These photons can be well separated into two groups: a "fast" component resulting from the spallation process with times $t < 1\,\mu s$, and a "slow" component arriving at times $t > 1\,\mu s$ up to a few $100\,\mu s$, mainly due to thermal neutron capture with the elements present in the moderator and the lead target. The "fast" component, which is often called γ-flash provides a mean of accurately measuring the t_o of each pulse. The γ-flux of the "slow" component at the measuring station comes along with the neutrons having energies of a few keV, but is more than an order of magnitude lower than the neutron flux. From the energy spectrum of these photons, 40% of the contribution is due to the neutron capture on hydrogen (2.2 MeV γ-rays). Another 5% contribution comes from photons with energies around 7 MeV resulting from the capture on lead, on the alu-

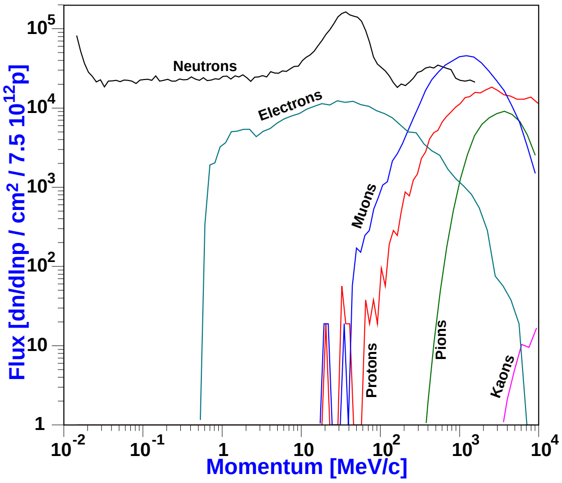

Fig. 4 Fluxes of the charged secondary particles and neutrons produced by the spallation process as a function of their momentum.

minum alloy container and on the iron target support. Figure 5 shows photon distributions versus their energy.

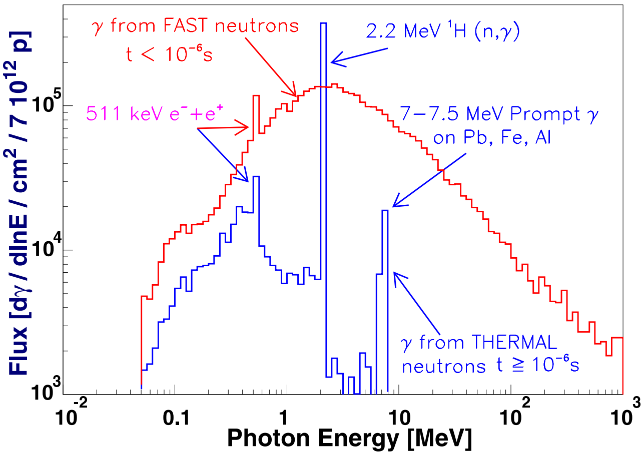

Fig. 5 Prompt photon flux at the measuring station versus energy, from the fast and thermal neutrons.

III. Commissioning Phase

In order to determine the physical parameters of the installation and compare them with the calculated ones, two campaigns of measurements have been carried out during the commissioning.[16] A first phase took place in November 2000 and a second in April 2001. While the main interest was concentrated on the physical parameters of the installation, the target behaviour and various safety related aspects were also monitored.

In the first commissioning phase, a BC702 detector from BICRON, with an active diameter of $38\,mm$, was used for neutron energies below about $200\,keV$. This detector contains a mixture of ^{6}LiF and ZnS(Ag) powders, fixed in a transparent plastic matrix attached to a photomultiplier tube. For high energy neutrons a BC404 plastic detector was used. Two bunches of optical fibre were attached on two adjacent sides of the plastic to conduct the light to two photomultipliers. The plastic is fast enough to avoid long term blinding by the prompt gamma flash and to allow time of flight measurements for fast neutrons. Measurements were done with these detectors at $173\,m$ downstream from the target, first without and then with the first collimator. The final measurements were done after the second collimator at $182.5\,m$. The beam profile has been determined both after the first and second collimator, using a scanning device for remotely moving and positioning the detectors.

In the second commissioning period two parallel plate ionisation chambers with fissile deposits, one with ^{235}U and another with ^{238}U, were used. These detectors are intercomparison instruments and were provided by PTB Braunschweig.[17] The fissile deposit size was much larger than the beam size ($\varnothing\ =\ 76\,mm$ compared to less than $30\,mm$ for the beam). The fission chambers have been used many times in the past and careful simulations have evaluated their efficiency. The detection efficiency is practically constant and equal to 95% up to neutron energies of $10\,MeV$.

In both commissioning phases also pairs of gold foils were irradiated (capture resonance at $4.9\,eV$), followed by their gamma decay measurement cf. Fig. 2. The data acquisition system[18] recorded each event in a flash ADC and a multi-hit TDC together with the beam information.

The lower curve of Fig. 2 shows the average neutron flux at the distance of $182.5\,m$ for the current set-up of collimators as it was measured with the above detectors (Gold foils, ^{235}U, ^{238}U fission chambers) during the last commissioning phase. There is a good agreement between the various detectors and the simulated flux.

The incident proton beam delivered by the PS has been monitored in intensity by current transformers accurate to 1% for nominal intensities of 7×10^{12} protons per burst and to 5% at 10^{11} protons. In the second commissioning phase also the shape of the proton beam has been continuously monitored via CCD cameras and digitised. All the information was continuously recorded per pulse. Furthermore, additional measurements related to safety aspects were performed, namely the temperature of the target, of the cooling water as well as the activity of the resin filters.

A careful monitoring of the target temperature as a function of the incident proton beam intensity has been performed. The maximum steady state temperature of $80^o\,C$ was registered for a regime of 5 pulses of 7×10^{12} protons within a super-cycle of $16.8\,s$.

To illustrate the quality of the data, Fig.6 shows a zoom on the ^{235}U fission chamber reaction rate, after correcting for the Ta and Pt contributions used as support for the fissile deposit and electrode materials. For comparison, the continuous line shows the expected number of fissions per energy as resulting from the fission cross section of ^{235}U taken from the ENDF-B/VI[19] database convoluted with the isolethargic flux.

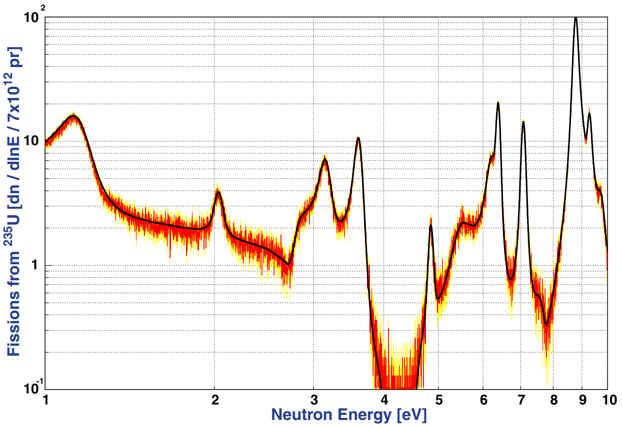

Fig. 6 Number of fission (corrected for Ta and Pt contributions) in the ^{235}U fission chamber between 1 and 10 eV together with the expectation.

IV. n_TOF Proposals

Currently there are 4 approved experiments for the n_TOF facility submitted by the n_TOF Collaboration:
NTOF1 European Collaboration for High-Resolution Measurements of Neutron Cross Sections between $1\,eV$ and $250\,MeV$;
NTOF2 Determination of the Neutron Fluence, the Beam Characteristics and the Backgrounds at the CERN-PS TOF Facility;
NTOF3 The Importance of ^{22}Ne(a,n)^{25}Mg as s-Process Neutron Source and the s-Process Thermometer ^{151}Sm;
NTOF4 The Re/Os Clock Revisited.
More information about the above experiments can be found in Ref.20)

V. Conclusions

The n_TOF facility at the CERN-PS offers unique features for precise and systematic study of neutron cross sections in a wide energy domain, from $1\,eV$ up to $250\,MeV$. The nominal integrated flux intensity of $\approx 1.5\times10^5\ n/cm^2/s$ at $182.5\,m$, with the current setup of collimators, is achieved by using four bunches of 7×10^{12} protons within a PS supercycle of $14.4\,s$. The integrated flux produced by a single bunch is $5.6\times10^5\ n/cm^2$. Since the maximum repetition rate in the PS complex is $1/1.2\,s^{-1}$, the problem of time overlap at the measuring station due to successive neutron pulses is completely avoided even for thermal energies. Finally, the excellent energy resolution of 2×10^{-4} at $1\,keV$ (2×10^{-3} at $1\,MeV$) allows the separation of closely spaced resonances for many nuclides.

The preliminary results from the commissioning measurements show a good agreement between the data and expectations. More measurements and calculations, mainly concerning the background, are now performed before the facility is ready to make precise physics measurements.

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