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The Neutron Time of Flight Facility at CERN

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Abstract

The n_TOF facility at CERN is a high flux spallation neutron source, followed by a 200 m time of flight basis. The 20 GeV/c high intensity proton beam delivered by the CERN PS produces spallation neutrons in the interval from 1 eV to 250 MeV. The intense flux and the excellent resolution of this neutron beam allow one to study systematically neutron cross-sections with very modest mass samples. The unique features of this new facility are described herewith following a detailed description of the experimental installation.

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1. Introduction

The n_TOF is a high flux spallation neutron source followed by a 200 m time of flight basis. The aim of the n_TOF facility at CERN is the measurement of cross-sections needed for the design of innovative ADS applications like incineration of nuclear waste [1], energy production [2], radioisotope production for medical applications [3] and many other basic science subjects in particular astrophysics [4]. As a result of the studies reported in a first paper [5] and an addendum [6], the neutron time of flight facility has been proposed at the CERN PS [4] delivering a maximum intensity of 2.8×10^{13} protons within a 14.4 s supercyle at a momentum of 20 GeV/c. This allows one to study systematically and with excellent resolution, neutron cross-sections of almost any element, using targets of very modest mass, necessary for unstable or otherwise expensive materials, in the interval from 1 eV to 250 MeV. The unique features of this new spallation neutron source at the CERN PS are given next, after an overview of the n_TOF multipurpose experimental installation.

2. The PS proton beam

During the initial phase of the project, called "1st year test phase", the proton beam features will be the following. One bunch of 7×10^{12} protons will be extracted at 20 GeV/c within a PS supercycle of 14.4 s. In a "final phase", 4 bunches with a total intensity of 2.8×10^{13} protons will be extracted within the 14.4 s and spaced in time every 3.6 s [7].

Two modes of operation are foreseen, a dedicated mode and a parasitic mode. In the dedicated mode, one or more 1.2 s cycles at 20 GeV/c will be available for the n_TOF experiment and a r.m.s. bunch length of 6 ns will be achieved. In the parasitic mode, the bunch will have the same length but its maximum intensity will be about 4×10^{12} protons. In Table 1 the beam parameters used for the computation of the beam envelope are reported, together with the beam size at the target location.

Transverse parameters		Longitudinal parameters	Beam size at target	
ε_H (1σ) [mm mrad]	$1.88\ \pi$	$\Delta p/p$ $\pm3\times10^{-3}$	σ_H [mm]	7.8
ε_V (1σ) [mm mrad]	$1.41\ \pi$		σ_V [mm]	5.6

Table 1: Beam parameters used for computation of beam envelope.

3. The spallation target

Following an overall optimisation, the spallation target was chosen to be a lead block of length h, diameter P, followed by a water moderator of thickness W. The neutron emission takes place at an angle of 10^o, with respect to the proton beam direction [5]. As result of a general trade-off between neutron flux and $\Delta\lambda$ resolution, the selected parameters are h = 40 cm, P = 80 cm, and W = 5 cm [6]. In the final design [8], the target is made with pure lead blocks already used in the TARC [9]. Its actual shape is $80 \times 80 \times 60$ cm^3, except for the spallation area where a volume of $30 \times 55 \times 20$ cm^3 is removed to have the nominal design dimension h = 40 cm [8].

Detailed calculations have shown that the power dissipation of the incident beam in the target gives rise to an increased temperature and therefore requires cooling. In extreme conditions up to 4 bunches per supercyle at 20 GeV/c could be delivered separated by a minimum of 1.2 s with a total yield of 2.8×10^{13} protons. The average beam current will be about 0.31 µA, and the beam energy in a supercycle will reach about 85.6 kJ. According to simulations with the Fluka Monte-Carlo code [10], the power deposit in the target is about 51% of the beam power, some 3.03 kW in such conditions. The maximum theoretical temperature increase during one bunch will be about 34.5°. The average temperature distribution in the lead target with the cooling system active (6 l/s) has been evaluated in the 4 bunches running conditions. The maximum asymptotic temperature in the central block corresponding to the above power deposit is 135 °C. The cooling of the lead target will be made by circulating a 3 cm thick layer of demineralized water at 30 °C around the target except for the TOF face, where the water layer will be 5 cm for moderation.

One of the main concerns for this TOF facility, using a high intensity proton beam and producing a high flux of neutrons, charge particles and photons, is clearly the radio protection and radiation safety aspects. Detailed simulations have been performed to estimate the activity of the lead target after 1 and 9 months running time with 1 to 4 bunches per supercycle. In an extreme case, this activity is estimated around 3200 Ci. The dose rate in contact for the TOF side of the block after 1 month's beam time with 4 bunches per 14.4 s should be about 25 Sv/h maximum after one day and of cooling time [8].

The target, on its stainless steel support, will be lowered through the 1.3 m diameter shaft inside the water tank. During the operation of the TOF facility, this shaft will be completely closed by concrete blocks and on top, in the ISR gallery, an additional iron shielding is necessary to keep the radiation below 1 µSv/h, dose rate allowed for free access areas at CERN.

Concerning the lead target design criteria, materials have been chosen to minimize the neutron flux perturbation. A thin single metallic window (Aluminium alloy) will be the interface between the moderator and the vacuum in the TOF tube [8], [11]. This window mounted onto the water tank will be 1.6 mm in thickness and 800 mm in diameter.

4. The TOF tunnel

The time of flight tube will start directly behind the window and will end where the sloped floor of the TT2A tunnel (1.18% gradient) touches the tube, thus allowing a length of 200 m. This tube is at an angle of 10° with respect to the proton beam direction in order to minimize the collection of unwanted secondary particles. The pressure in the vacuum tube will be about 1 mbar. The TOF tube is made up of four different sectors, the first one, closest to the target, is made of aluminium alloy whereas the others are made of stainless steel [8]. The characteristics of the four sectors are given in Table 2.

Sector number	Length (m)	Int. diameter (mm)	Thickness (mm)
1	4.135	800.00	8.00
2	65.750	796.96	7.92
3	68.350	596.90	6.35
4	61.372	396.88	4.76

Table 2: Characteristics of the various sectors of the time of flight tube. The lengths of the different sectors include some bellows.

Two collimators will be installed to reduce the radius of the neutron beam. The first one, 2 metres in length (beam shaping collimator) will be located at 136.7 m and will be made of 1 m of iron and 1 m of concrete; its inner diameter will be 11 cm. The second collimator (source screening collimator), 1.8 cm inner diameter, will be placed at 178 m with 50 cm of 5 % borated polyethylene, 125 cm of iron and 75 cm of 5 % borated polyethylene (Figure 1). This collimation set-up is optimized for the capture cross-section measurements and will be modified to fully exploit the useful neutron beam cross-section area (~ 78 cm^2) for fission cross-section measurements.

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 beam, as shown in section 6. A 2 m long dipole magnet will be used to sweep away these unwanted secondary particles. With a magnetic rigidity of 1.5 Tm, all charged particles with a momenta up to p_{max} = 10 GeV/c will be removed. This 410 mm gap high "sweeping" magnet will be located at 145 m.

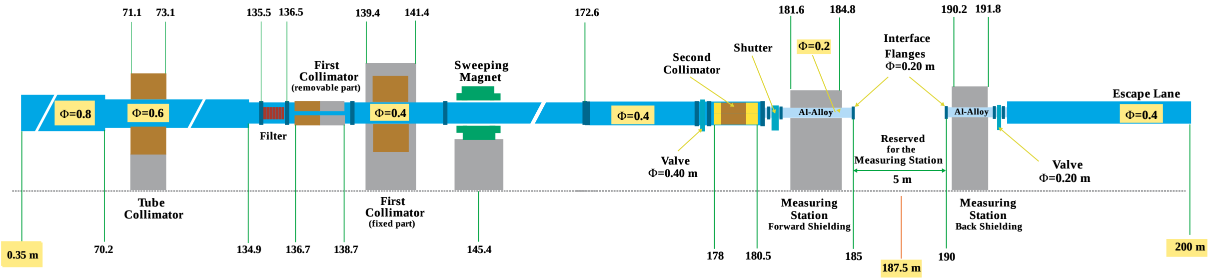


Figure 1: TOF tube sections up to the end of the TT2A tunnel (200 m).

5. 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 200 m. Two Monte-Carlo codes have been used successively FLUKA [10] and the EA-MC Monte-Carlo code [12]. 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 19.6 MeV are further transported by the EA-MC code using the same geometry as in previous simulation.

In both cases, the position, speed, time and energy of each neutron entering the neutron tube are recorded. The neutron flux expected at 200 m is shown in figure 2.

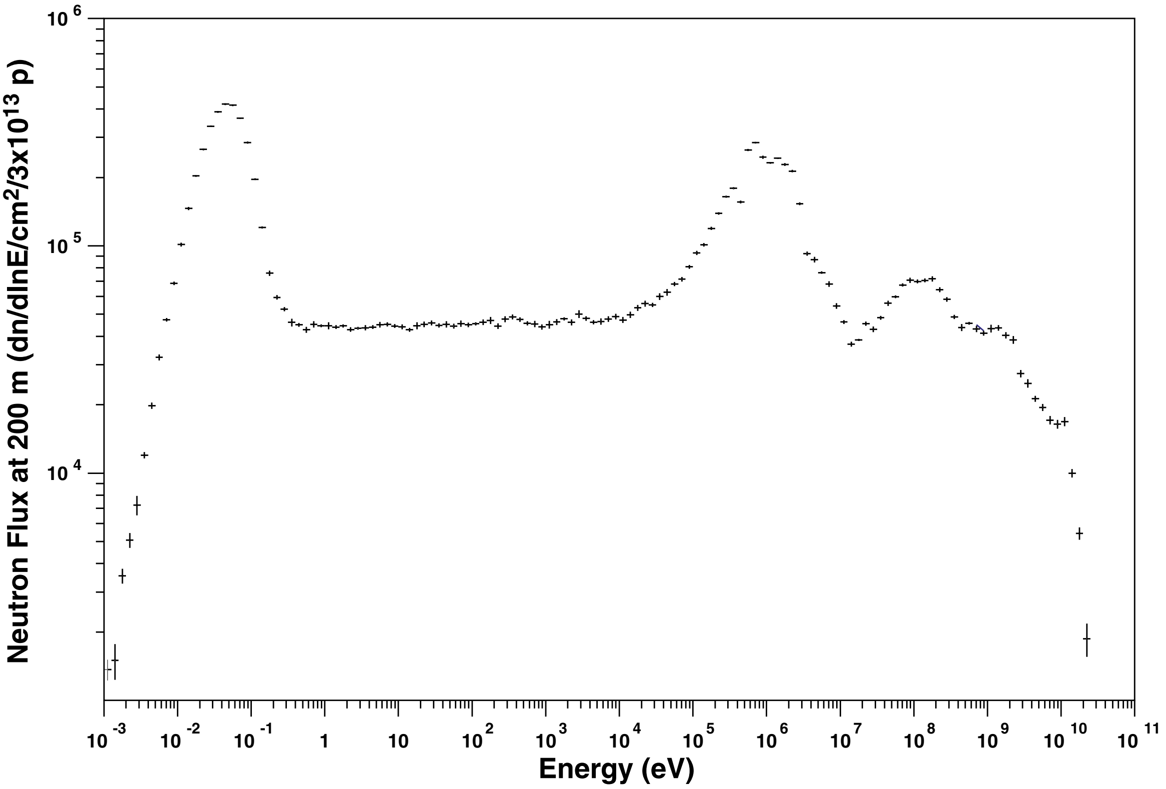


Figure 2: Neutron flux spectrum at 200 m

A gravitational cut-off will occur due to the geometry of the beam pipe for the neutrons with kinetic energies less than 0.02 eV. The energy resolution has been estimated using the relation between ΔE/E and the effective neutron path λ [5] inside the lead followed by the 5 cm thick water moderator.

$$\frac{\Delta E}{E} = \frac{2\Delta\lambda}{\lambda + L}$$

This effective neutron path λ can be evaluated using the previous stored neutron data as we consider λ = v×t where v is the speed of the neutron when entering the neutron tube and t the time elapsed since its creation and from its velocity (Figure 3a).

The effective neutron path in the lead target is about a few centimetres for the lowest energies; the variance Δλ has been evaluated separately taking the r.m.s of the λ distributions and in taking the standard deviation from gaussian fit of the peaks.

The total neutron background inside the tunnel will be different according to the diameter of the last collimator (Figure 4). The diameter of this collimator will be 2 cm for the neutron capture cross-section measurements, and 15 cm for the fission cross-section measurements. In the first case, at the measuring station (187 m from the lead target) the background is 7 orders of magnitude smaller than the neutron flux; in the second configuration, this ratio will be about 10^{-5}.

The background inside the TOF tunnel is increased at 70 m, by the first concrete wall set after the first TOF tube reduction, then by the first collimator at 140 m and then by the last collimator at 178 m.

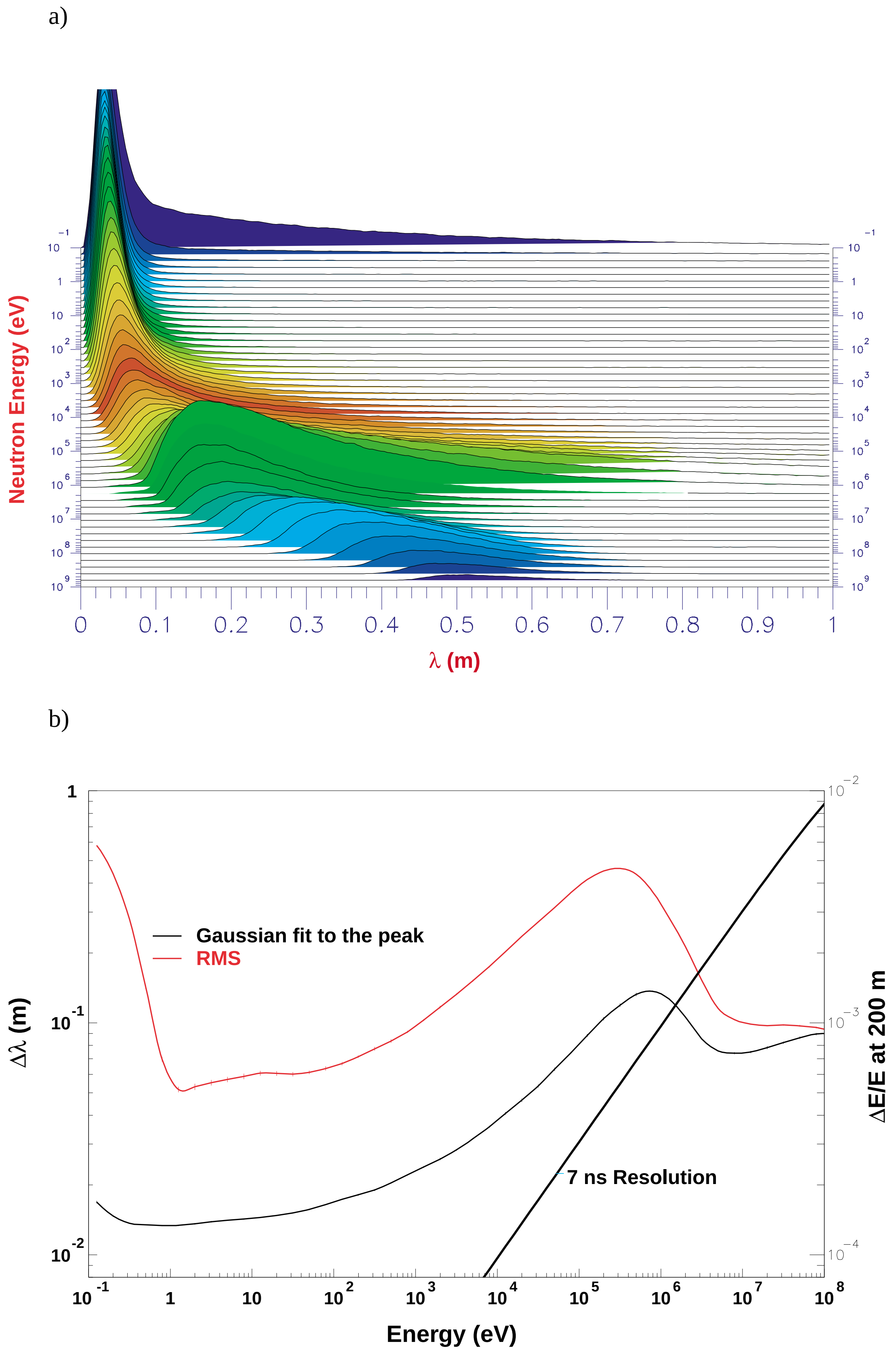
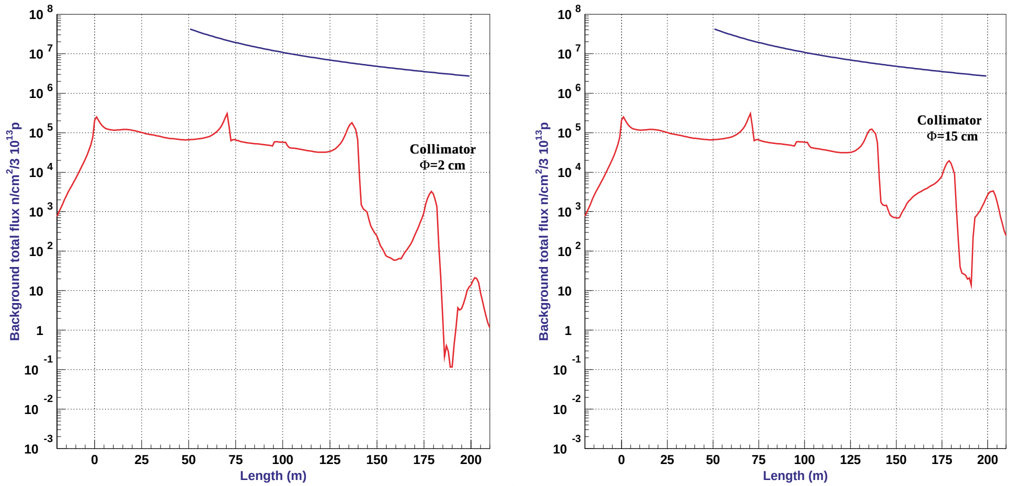


Figure 3: *a)* Monte Carlo simulation of the equivalent neutron path inside the lead spallation target followed by a 5 cm hydrogen rich moderator; evaluated at the energy of observation. *b)* energy resolution spectrum at 200 m.



a) b)

Figure 4: Total neutron background flux in the tunnel versus the flight distance (lower curve) and the flux inside the neutron beam tube (upper curve) with a collimator of *a)* 2 cm in diameter (capture measurements), *b)* 15 cm in diameter (fission measurements).

The radial neutron profile at the measuring distance of 187 m is shown in Figure 5; this profile is obtained with the 15 cm diameter and 2 m long second collimator. This profile shows a plateau of 10 cm in diameter (a surface of 78 cm^2) where the neutron flux is about 3×10^6 $n/cm^2/3 \times 10^{13}$ protons. The neutron halo extends by 5 cm.

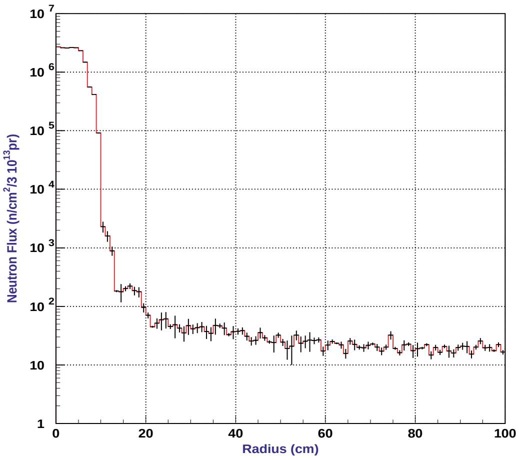


Figure 5: Radial neutron profile at the measuring station (187 m).

6. Charged particles contamination

The 20 GeV/c proton beam interacting with the lead target is also a source of many other charged and neutral particles [13]. We already mentioned the elimination of the charged particles with momenta lower than 10 GeV/c by the sweeping magnet. The momentum distribution of the charged particles resulting from simulations is shown in Figure 6, together with that of the neutrons.

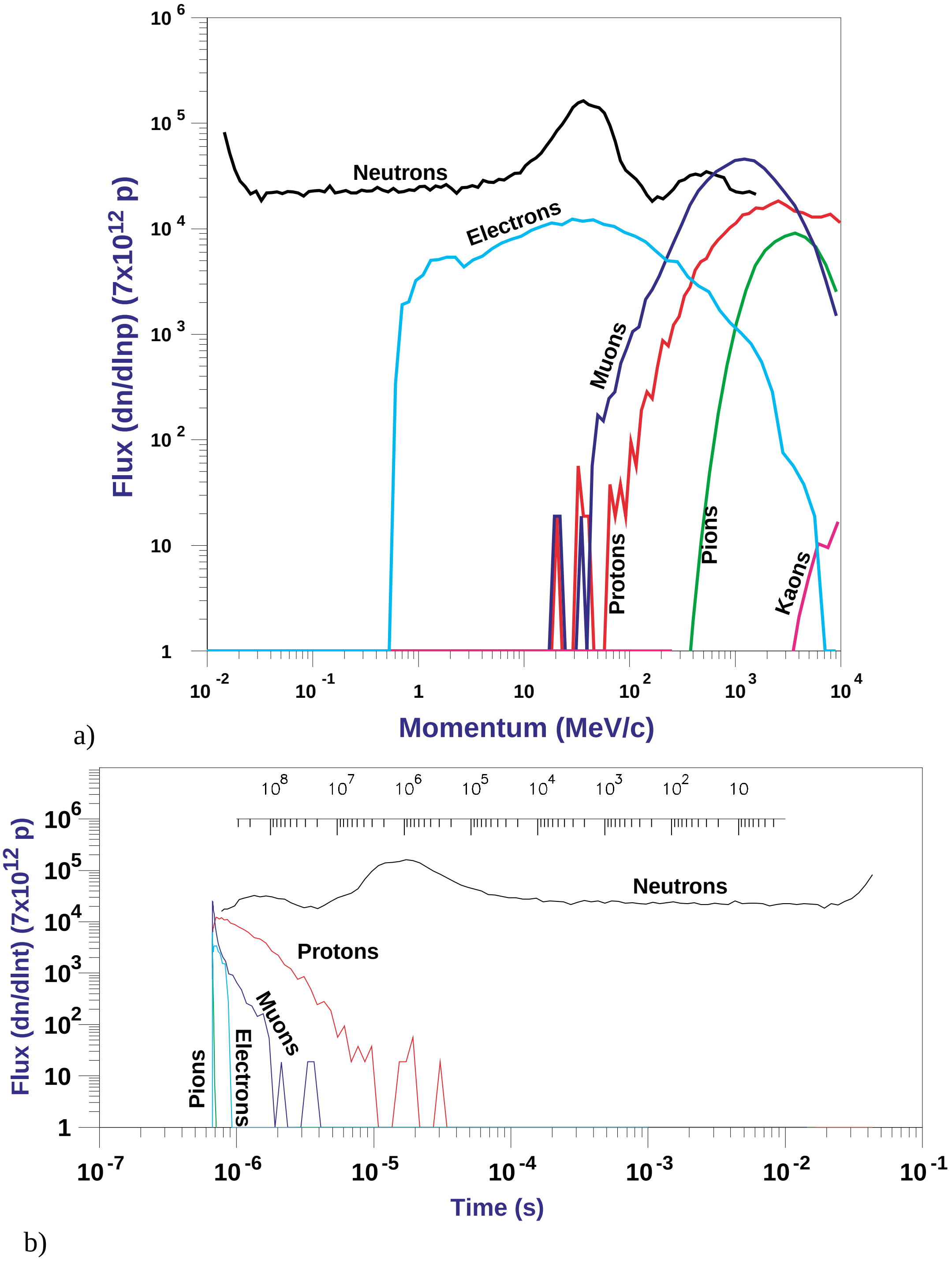


Figure 6: Fluxes of the charged secondary particles and neutrons produced by the spallation process as a function *a)* of their momentum, *b)* of their arrival time at 200 m, without the sweeping magnet.

7. Photons

The photons emerging from the lead can be clearly separated into two groups. The distribution includes a “fast” component resulting from the spallation process with times t < 1 µs. A second group of photons arrives in times > 1 µs and are mainly due to thermal neutron capture in the elements present in the moderator and the lead target. 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, the aluminum alloy container, and the iron target support. The photon distributions versus their energy then versus time are shown in Figure 7.

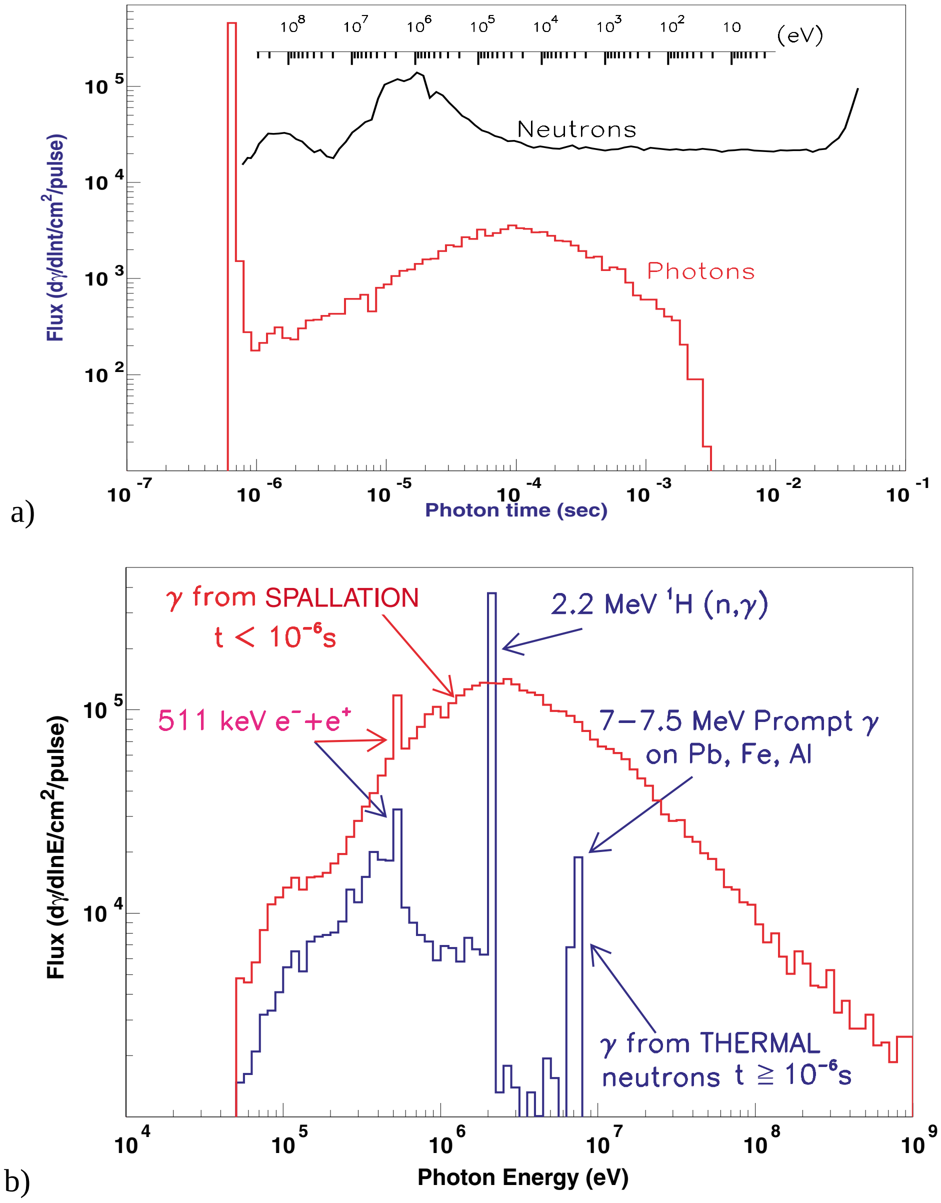


Figure 7: a) Distribution of photons as a function of their arrival time at 200 m. *b)* Photon distributions at 200 m, from the fast and the thermal neutrons.

8. Conclusion

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 1eV up to 250 MeV. The nominal integrated flux intensity of 1.5×10^5 n/cm^2/s at 200 m 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 5.6×10^5 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. During the first 15 ms (time of flight of 1 eV neutrons) the neutron flux reaches 3.7×10^{7} n/cm^{2}/s. 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 commissioning of the n_TOF facility [14] will be done during the summer of 2000; the experimental program [4] will follow till the PS shutdown.

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