Physics at the new CERN neutron beam line

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Abstract
A new neutron beam line (n_TOF EAR-2) is being built at CERN within the n_TOF facility. Compared to the existing 185 meters long time-of-flight beam line, the new one (which will operate in parallel) will feature a shorter flight of 20 meters, providing a 27 times more intense neutron flux extending from thermal to 300 MeV. The scientific program is now being discussed and the first detailed proposals will be refereed by February 2014. This contribution is devoted to present and discuss the expected performance of the facility, briefly, and the details of some of the first measurements foreseen for 2014 and 2015.

1 Introduction
The European Organization for Nuclear Research (CERN) has hosted an extensive scientific program in nuclear physics. In particular, state of the art physics with white neutron beams has been carried out since 2001 at the CERN neutron time-of-flight n_TOF facility. The existing n_TOF neutron beam line, known as EAR-1 and featuring a beam line of 185 meters, provides a high instantaneous intensity pulsed neutron beam covering the energy range from thermal (25 meV) to 1 GeV. The experiments performed since 2001 are mostly aimed at measuring neutron induced cross sections of interest in nuclear technology, astrophysics, basic physics and medicine. A detailed description of the n_TOF-EAR1 facility and a comprehensive list of the experiments performed can be found in [1] and the references therein.

The increasing interest of the scientific community and the increasingly demanding measurements requests from the nuclear technology and stellar nucleosynthesis communities have triggered the upgrade of the n_TOF facility with a new neutron beam line, which is now know as n_TOF EAR-2. The main improvements with respect to the existing EAR-1, which will run in parallel to EAR-2, is that having a flight path of only 20 meters will result in a much higher neutron flux, thus allowing for measurements of lower cross sections and samples with smaller masses. A brief description is given below, but more details are given in Ref. [2].

This contribution describes the new neutron beam line and report on its construction. The expected performance and the first experiments that shall be performed along 2014 and 2015 are also summarized.

2 The new neutron beam line n_TOF EAR-2

2.1 Design and construction
The new experimental hall, at the end of a new 20 meters evacuated beam line that starts at the lead spallation target, is now under construction and is expected to be operational by Summer of 2014. The beam line will be equipped with two collimators, made of iron and polyethylene, a permanent magnet for deflecting relativistic charged particles, and a box for placing in and out neutron filters that will stop neutrons of specific energies. The second collimator, with a conical
shape of 20 mm minimal aperture, provides the desired shape to the neutron beam. The facility is sketched in Figure 1.

The experimental hall starts at 18.1 m from the spallation target as has a height of 6 meters. The ceiling holds the beam dump, which is made of concrete, iron and borated polyethylene, and has been designed in order to minimize the dose to the outside and the background from back-scattered neutrons.

The detectors and beam tubes in the experimental hall will be held and aligned from a reinforced aluminium structure. On the bottom two neutron monitors based on gas a silicon detectors will be installed and then the samples and detectors will be installed between 1.5 and 2 meters from the floor, i.e. the end of the second collimator.

![Fig. 1: Sketch of the new CERN facility n_TOF EAR-2, from the target to the measuring station and the beam dump. Details of the equipment along the beam line are also given.](image)

### 2.2 Expected performance

The geometry of the facility has been implemented in detail in FLUKA and a wide range of simulations have been performed for estimating and optimizing the characteristics of the neutron beam at n_TOF EAR-2 [2]. The main quantities of interest are the intensity of the neutron beam, its spatial profile, and the neutron energy resolution. The collimators were chosen to maximize the intensity on a surface of 1 cm diameter at 1.5 meters from the ground, minimizing the halo beyond that diameter.

As a result, the expected neutron fluence is, as shown in Figure 2, a factor of 27 higher than the one in the existing EAR-1 measuring station. In addition to the increase of neutron fluence, two important differences between EAR-1 and EAR-2 are that:
- The upper energy limit will be around 300 MeV instead of 1 GeV, because of the missing relativistic forward component. This could result, to be conformed, in a reduction of the so-called g-flash (See [1]).

- The neutrons arrive in 10 times less time than in EAR-1, thus the neutrons per second are 270 times higher than in EAR-1. This should help reducing significantly the background from sample activities when measuring radioactive isotopes.

![Graph showing comparison of neutron fluence in EAR1 and EAR2](image)

**Fig. 2:** Neutron fluence as function of neutron energy for the existing (EAR-1) and under construction (EAR-2) n_TOF measuring stations.

### 3 Measurements planned for n_TOF EAR-2 (2014-2015)

#### 3.1 Destruction of the cosmic γ-ray emitter $^{26}$Al by neutron induced reactions [3]

Observation of the cosmic g-ray emitter $^{26}$Al is proof that nucleosynthesis is ongoing in our galaxy. Detailed studies in satellite telescope missions revealed that $^{26}$Al is predominantly produced in massive stars. Recent sensitivity studies identified the neutron destruction reactions $^{26}$Al($n,p$) and $^{26}$Al($n,a$) as the main uncertainty to predict the galactic $^{26}$Al abundance.

![Sketch of the new ΔE-E telescope made of Si strip detectors](image)

**Fig. 3:** Sketch of the new ΔE-E telescope made of Si strip detectors for measuring the $^{26}$Al($n,p$) reaction.
There are only few experimental data on these reactions and they exhibit severe discrepancies. We propose to measure $^{26}\text{Al}(n,p)$ and $^{26}\text{Al}(n,a)$ cross sections at stellar neutron energies at EAR-2 of the n_TOF facility, using a highly enriched $^{26}\text{Al}$ sample. The charged particles emitted will be detected using a set of Silicon strip detectors arranged as $\Delta E - E$ telescopes.

3.2 \textit{g-ray energy spectra and multiplicities from }$^{235}\text{U(n,f)}$\textit{ using STEFF [4]}

An experiment is proposed to use the STEFF spectrometer at n_TOF to study fragment correlations following the neutron-induced fission of $^{235}\text{U}$. The STEFF array of 12 NaI detectors will allow measurements of the single energy, the multiplicity, and the summed energy distributions as a function of the mass and charge split, and deduced excitation energy in the fission event. These data will be used to study the origin of fission-fragment angular momenta, examining angular distribution effects as a function of incident neutron energy.

The principal application of this work is in meeting the NEA high-priority request for improved $g$ ray data from $^{235}\text{U(n,f)}$. To improve the detection rate and expand the range of detection angles, STEFF will be modified to include two new fission-fragment detectors each at 45 degrees to the beam direction.

3.3 \textit{Measurement of the neutron capture cross-sections of }$^{53}\text{Mn}$\textit{ [5]}

We propose to measure the neutron capture cross sections of $^{53}\text{Mn}$ at the Experimental Area 2 (EAR-2) of the n_TOF neutron time of flight facility at CERN. This will be the first ever determination of the $^{53}\text{Mn}$ excitation function. These data will influence the models of explosive stage of star evolution and will serve as input data to improve nuclear reaction codes.

The $^{53}\text{Mn}$ target will be manufactured in the frame of the ERAWAST project at PSI. A chemical separation of manganese out of irradiated steel samples will deliver a stock solution containing $5 \times 10^{19}$ atoms of $^{53}\text{Mn}$. Due to the high amount of $^{55}\text{Mn}$, the stock solution can not be used directly to prepare a target without a further treatment, but an additional depletion of $^{55}\text{Mn}$ must be performed in a subsequent mass separation using the ISOLDE off-line ion-source test setup. The final target will contain $5 \times 10^{17}$ atoms of $^{53}\text{Mn}$ and less than $1 \times 10^{16}$ atoms of $^{55}\text{Mn}$.

The aim of this experiment is the determination of the neutron capture cross sections of $^{53}\text{Mn}$ from thermal neutron energies to neutron energies of about 10 keV.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig_4.png}
\caption{The STEFF detector as it will be implemented at n_TOF EAR-2.}
\end{figure}
3.4 Neutron capture at the s-process branching point \(^{79}\text{Se}\) [6]

Selenium-79 is a branching point in the slow neutron capture process (s-process) with relevant implications in nucleosynthesis and in stellar models. Indeed, the products of the s-process nucleosynthesis after \(^{79}\text{Se}\) are the s-only \(^{80,82}\text{Kr}\), whose solar system abundances are accurately known from chemical analysis of pre-solar grains. This information, in conjunction with the experimental CS of \(^{79}\text{Se}(n,g)\) will allow one to extract reliable conditions for the neutron density, as well as the role of the main and weak s-process contributions to the nucleosynthesis in the A=80 mass region.

\(n_{\text{TOF EAR2}}\) represents a unique place to access this experimental information, owing to the very large instantaneous neutron flux and the possibility to use the TAC-technique in order to apply specific energy cuts, reduce contaminant events from the sample activity and separate the \((n,g)\) CS of interest from another isotopes present in the sample.

\[ \text{Capture cross sections of } ^{51}\text{Mn, showing that only two experimental data (at thermal) are available.} \]

\[ \text{Fig. 5: } \]

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\[ \text{Fig. 6: } s\text{-process path around the A=80 mass region.} \]
3.5 Test and development of a (n,p) detector for measuring $^{14}$N and $^{35}$Cl for BNCT [7]

We propose to study the Silicon Monitor (SiMon) and the Micromegas detector system for measuring (n,p) reactions at n_TOF. The final goal is to measure the 35Cl(n,p) and the 14N(n,p) cross-sections in a wide energy range at EAR-1 and EAR-2, respectively. These reactions are of interest in medical physics and nuclear astrophysics. SiMon is presently running at n_TOF for monitoring purposes.

This Letter of Intent can be considered as a continuation of our work related to the letter CERN-INTC-2010-023/INTC-I-092 and the subsequent proposal CERN-INTC-2012-006/INTC-P-322. In the mentioned Letter and Proposal we studied the fast ionization chamber based on Micromegas detectors, at that time running at n_TOF for monitoring purposes, with the intention to use it for measuring (n,α) cross sections. We successfully measured the 33S(n,α) cross section during the Campaign 2012 with such system. The physics motivations of the present LoI are deeply related to those of the 33S(n,α) experiment.

![Image of SiMon and Micromegas detector]

Fig. 7: The current silicon monitor for measuring (n,a) and (n,t) reactions.

3.6 Others

The current plans for future experiments include, among others, the following experiments:
- The role of $^{238}$Pu and $^{244}$Cm in the management of nuclear waste: (n,γ) cross sections
- Measurement of the capture (and fission) cross sections of the fissile $^{239,241}$Pu and $^{245}$Cm
- Measurements of (n,xn) reaction cross sections with HPGe detectors ($^{197}$Au, $^{181}$Ta, etc.)
- Measurements of (n,n) and (n,xn) reactions cross sections with CsI+Si telescopes
- Fission cross section of the $^{230}$Th, $^{231}$Pa and $^{232}$U reaction
- Measurement of the $^{25}$Mg(n,α)$^{22}$Ne cross section
- Neutron capture measurement of the s-process branching point $^{147}$Pm
- Measurement of $^7$Be(n,p)$^7$Li and $^7$Be(n,α)$^4$He cross sections, for the cosmological Li problem.

4 Summary and Outlook

A new neutron time-pf-flight measuring station, with a flight of only 20 meters, will be available at CERN n_TOF by Summer of 2014. With an increased neutron flux of a factor of 27 with respect to the existing 200 meters beam line, the new facility will allow performing interesting and challenging experiments on neutron-induced reactions. The ones already proposed to the CERN INTC committee have been summarized in this paper, but new ones are already being discussed.
References


