EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Commissioning of n_TOF EAR2

September 25, 2013

The n_TOF Collaboration

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Abstract

The construction of the second beam line and experiment area (EAR2) of the n_TOF facility is currently ongoing and scheduled to be completed by July 2014. An extensive series of measurements is planned in order to determine the beam characteristics like the neutron flux, the spatial beam profile and the resolution function, as well as the response of several detectors considered for use in future measurements at EAR2. A rigorous study of backgrounds will be undertaken in various conditions.

Requested protons: 9.8×10^{18} protons on target

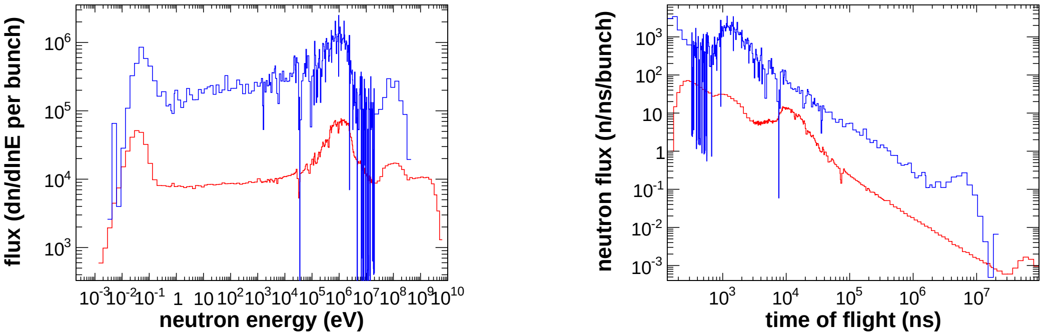

Figure 1: The neutron intensity for EAR1 (red) and EAR2 (blue) in isolethargic units as a function of neutron energy (left panel) and in neutrons per ns as a function of neutron time-of-flight (right panel).

Introduction

Since the early days of the CERN's neutron time-of-flight facility n_TOF the idea of a second short flight path, complementing the existing 185 m flight path (EAR1), has been suggested and several feasibility studies have been performed [1]. The idea has ripened and a proposal of a second experimental area (EAR2) with a vertical flight path length of about 20 m, was eventually proposed by the collaboration to the INTC [2] and finally approved by CERN in 2012. More details on the design can be found in these documents [1, 2]. The construction of EAR2 has started in May 2013 and the first beam is expected by mid 2014.

For the commissioning of the new neutron beam line a programme of measurements has been set up and will be specified in more detail in the following sections.

An essential part of the commissioning is to measure the beam characteristics in terms of neutron flux, the spatial beam profile and the resolution function. In addition, a precise knowledge of the background conditions is crucial for the planning of future measurements. We plan to determine the background in EAR2 under several conditions of in-beam and surrounding material and for different collimators, by using neutron and gamma-ray detectors. Both a mapping of the background throughout the volume of the experimental hall, as well as a careful examination of the background for in- and off-beam detectors are foreseen. Furthermore, the determination of the response to the gamma-flash and high instantaneous count rates of various detectors is planned. An important item of the commissioning will be to reproduce capture and fission cross sections of some well-known isotopes in order to validate the full data reduction procedure involving high count rates and background subtraction.

A number of institutes of the collaboration are currently developing new detector systems which are especially designed for EAR2.

1 Expected reaction rates

The simulated expected neutron flux per standard proton bunch is shown in figure 1 both for EAR1 and EAR2 as a function of neutron energy and of time-of-flight. The full energy spectrum for EAR2 is mapped onto a 10 times smaller time-of-flight window than for EAR1, as can be seen from the figure. One consequence is that the cumulated radioactive background during measurements is a factor 10 less, in addition to a factor 25 higher neutron flux than for EAR1. This means also that the full thermal neutron energy range is in covered by the flash ADC memory, allowing precise thermal measurements by time-of-flight down to subthermal energies.

While EAR2 allows to measure small amounts of material, such measurements are commonly completed by the measurement of several standard reactions [3] in order to determine the incident neutron flux (^{6}Li(n,α), ^{10}B(n,α), ^{235}U(n,f)) or to normalize the capture (^{197}Au(n,γ)) and fission (^{235}U(n,f), ^{238}U(n,f)) measurements. The much higher count rates in EAR2 as compared to EAR1 put a limit on the mass of these standard isotopes that can be used so that the count rates in the detectors still can be handled.

For a number of isotopes with thicknesses typically used at EAR1 [4], the reaction yield was calculated using standard evaluated data files. The yield was then multiplied by the incident number of neutrons at the sample position, both for EAR1 and EAR2, expressed per ns time-of-flight and per standard bunch of $7 \cdot 10^{12}$ protons, resulting in the reaction rate. For the count rate in the detector the efficiency needs to be taken into account. For most in-beam charged particle detectors (fission, alpha) an efficiency in the range 0.5-0.9 is usual, while for the gamma-ray detectors the efficiency is in the order of 0.1 or less.

In figure 2 the number of induced reactions per ns are shown for several often-used nuclear reactions. The difference in reaction rate of approximately a factor 250 in EAR1 and EAR2 for the same quantity of material is clearly visible. In order to have reasonable count rates, the thicknesses of for example ^{6}Li and ^{10}B, used for the neutron flux measurements, needs to be reduced in EAR2.

2 Determination of the neutron flux

The in-beam neutron flux will be measured with several detectors mounted in parallel in the neutron beam. While for most measurements only the energy dependence of the neutron flux is needed, it is also needed to obtain the absolute level of the neutron flux to validate the simulations and make reliable count rate estimations. PPAC and MicroMegas detectors, equipped with deposits of ^{235}U, ^{238}U, ^{10}B or ^{6}Li, will be used for this purpose. Also a new SiMon detector, similar to the SiMon detector routinely in use at EAR1, is currently being developed by INFN. To obtain an absolute calibration, we will use as in the past a calibrated ^{235}U fission chamber from PTB together with the PPACs and MicroMegas detectors. A dedicated PPACs detector is being developed by IN2P3 and USC and a new MicroMegas detector by CEA. In addition the neutron flux will be measured independently by the activation of gold foils.

Due to the lower amount of material that can be used for flux measurements, we base the number of protons on the estimations for EAR1, aiming at a 2% statistical uncer-

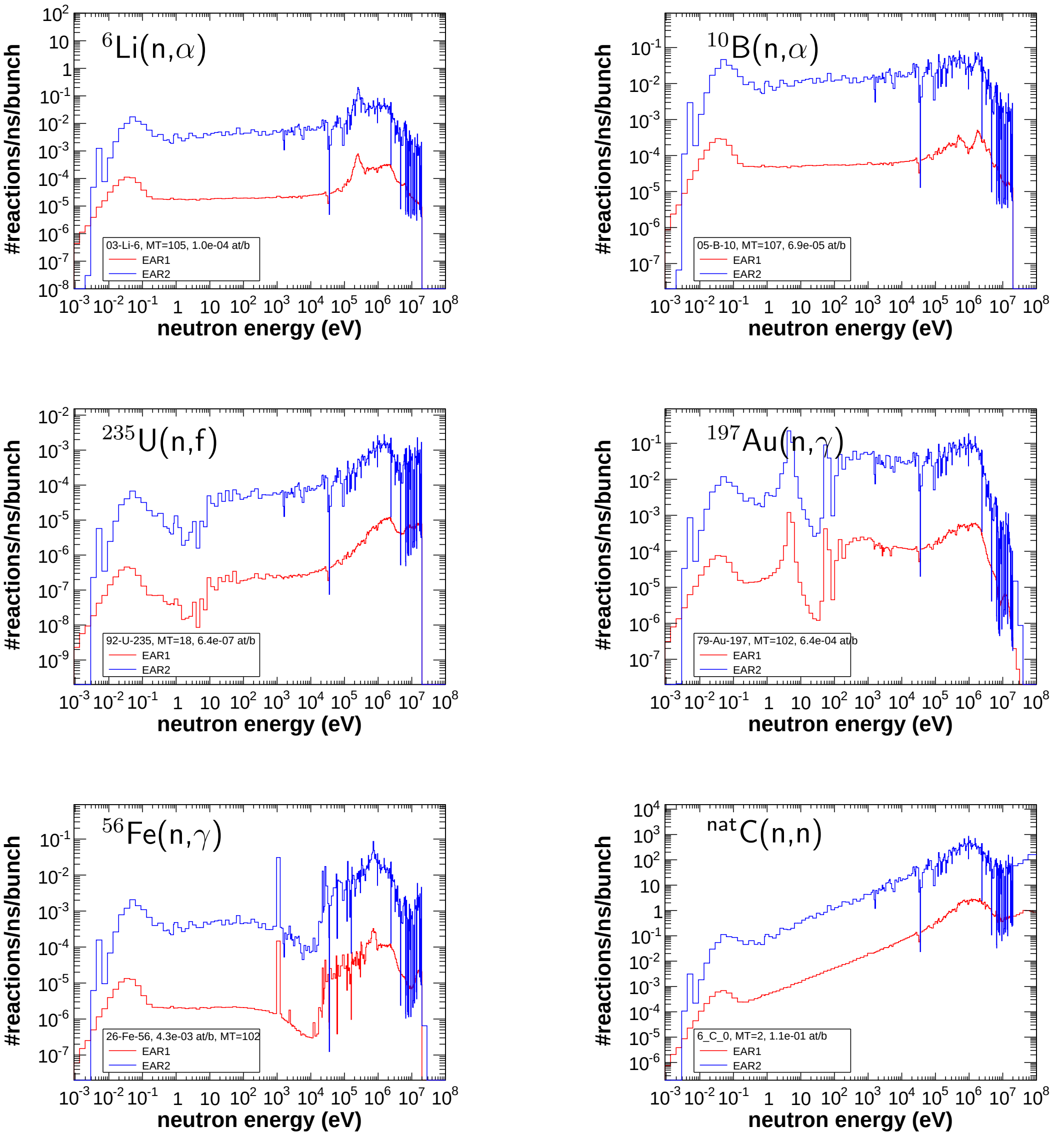

Figure 2: Reaction rate estimations, both for EAR1 and EAR2, for ^{6}Li(n,α), ^{10}B(n,α), ^{235}U(n,f), ^{197}Au(n,γ),^{56}Fe(n,γ), and $^{\mathrm{nat}}$C(n,n) for sample thicknesses, specified in at/b, which are typically used in EAR1 for optimized conditions in terms of saturation, count-rate, α-range, and multiple scattering.

tainty for 100 bins per decade. Additional measurements using neutron filters allow to assess the background at specific neutron energies. The total number of protons for these measurements is $24 \cdot 10^{17}$ protons.

3 Determination of the neutron beam profile

The neutron beam profile and its energy dependence is essential for the analysis of capture data. The neutron flux is measured over an area much larger than a typical capture sample and the capture yield is normalized in an absolute way at a single neutron energy.

The beam profile can be measured by positioning CR39 neutron dosimeters and by using the halo of Au activation foils. The PPACs detectors can measure the beam profile in a single measurement. Two new detectors are currently being developed. The first is a transparent MicroMegas detector developed by CEA and IN2P3 with a segmented mesh and anode acting as a XY detector. When this detector is fully operational it can be placed permanently in the beam. The second detector is a thin ^{6}Li layer sandwiched between two silicon strip detectors, developed by INFN. Dedicated beam-time is needed for this detector. Also in this case low sample masses are needed to have count rates similar to EAR1. With two configurations the number of protons needed is $12 \cdot 10^{17}$ protons.

4 Determination of the resolution function

The resolution function (RF) alters the shape of resonances. It is usually parametrized as an asymmetric distribution of distance and depends on the neutron energy. The RF is closely connected to the time-energy calibration of the neutron time-of-flight. The resolution function is obtained by simulations which are validated by measurements of well-known isotopes. In order to cover both the low-energy and high-energy region, we intend to measure the resolution using neutron capture on ^{54}Fe, ^{56}Fe, and ^{238}U. The needed statistics are fully determined by the counts in the weaker high-energy resonances. The off-beam detector can handle the count rate of the ^{56}Fe. The number of reactions in the weak 180 keV resonance of ^{56}Fe is 0.8 per standard proton bunch. Assuming a detector efficiency of 0.1, and a goal of 3000 detected counts in the weak resonance leads to $3 \cdot 10^{17}$ protons per isotope.

The effective flight path length is related to the resolution function and will be determined using the above mentioned isotopes, completed with short runs on different isotopes with well known resonances like ^{197}Au, ^{93}Ir, and ^{32}S.

5 Determination of backgrounds

The background in EAR2 will be measured with both neutron and gamma-ray detectors as a function of neutron time-of-flight, in two different ways: on a spatial measurement grid throughout the volume of EAR2 using various detectors, and in measurement positions for selected in- and off-beam detectors.

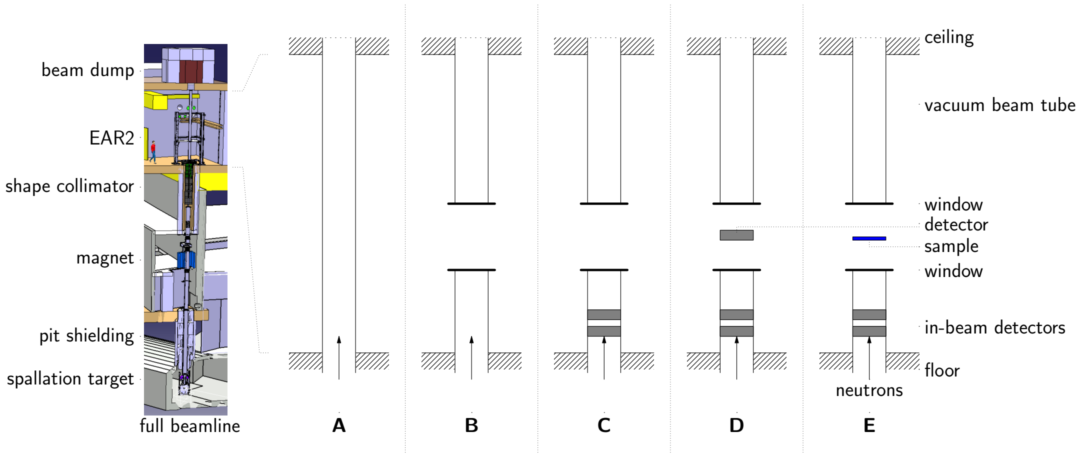

Figure 3: The full second vertical beam line (left panel) and a zoom of the experimental hall with different schematic configurations labelled (A) to (E) to be used for background measurements. Also the shape collimator will be varied. The figures are not to scale. Off-beam detectors are not shown. See text for details.

For a thorough understanding of the background, which is essential for the design of future experiments, a number of situations with a progressively increasing amount of in-beam material will be explored, since in-beam material can be a major source of background.
In figure 3 a number of beam-line configurations are shown, starting with only a vacuum beam tube from the spallation target up to the beam dump (A) and therefore without any in-beam material off which neutrons could be scattered. A normal measurement configuration needs a discontinuity of the vacuum by a space of air (B), with permanent in-beam neutron flux detectors (C), in such a way that an in-beam detector for example fission (D), or a sample for capture measurements (E) can be positioned. Notably for capture measurements different samples will be used for a careful examination of the backgrounds induced in measurement conditions. Several thicknesses of carbon will be used to generate scattered neutrons, a lead sample to induce scattered in-beam photons, as well as a 0.1 mm gold sample, usually used for the normalization of capture measurements. An empty-frame sample will be used as well.
In addition the influence of the presence of a fission chamber on the background in the capture detectors will be measured. Other background contributions from the detector support structure, the sample exchanger, the neutron filters, and the sweeping magnet (on/off) will also be investigated. The procedure will be repeated with a different shape collimator with a larger aperture, which can be used for in-beam detector measurements like fission.
Off-beam neutron and gamma-ray detectors will measure the backgrounds at several positions. A number of detectors is available and several of them can be used at the same time at different positions on the measurement grid during the background mapping procedure. To study the background in measurement conditions close to the sample, only a few detectors can be used simultaneously.
For the background mapping with neutron detectors a ^{3}He-array, CR39 neutron dosimeters, TLDs, PPACs, MicroMegas, ^{6}Li-glass, Timepix, and BC501 detectors are available.

Several gamma-ray detectors will be used as well. An (x, y, z) grid of about 25 points will be set up to cover the volume of EAR2.

For the detectors in measurement positions PPACs, MicroMegas and SiMon detectors will be used as in-beam neutron detectors and C_6D_6 scintillator detectors as off-beam gamma-ray detectors. In addition to the already available Bicron C_6D_6 detectors, INFN has developed C_6D_6 detectors with a low-mass carbon housing as a follow-up of similar detectors from FZK.

In the measurement configuration with gamma-ray detectors and especially C_6D_6 detectors near the sample position, the background will be measured with different thicknesses of C, Pb, and Au and empty frame, including measurements on very thin samples.

In addition, DGS/RP detectors, such as a differential chamber for air activation and a PMI for the ambient dose equivalent, will be used regularly to monitor radiation levels.

In total we estimate that $35 \cdot 10^{17}$ protons are needed to adequately accomplish the background measurement programme.

6 Determination of the response of detectors

The response of the detectors is needed for two purposes. One is the response to the desired reaction channel under measurement conditions. The other is the response to the gamma flash which determines up to which neutron energy detector signals can be exploited. The response of many detectors will already be tested during the background survey. Other detectors will be tested as well, like the $LaBr_3$/$LaCl_3$/$CeBr_3$, and BaF_2 crystals for gamma-ray detectors. This is essential for the development of a $LaBr_3$-based array under study by CIEMAT. A MicroMegas-based (n,α) detector proposed by USE will also be tested under beam conditions using the ^{33}S(n,α) reaction. Other detectors, including NaI crystals, part of a CsI/Si array and HPGe detectors, may be used for future experiments at n_TOF EAR2, also for reactions other than capture and fission, like (n,n'), (n,xn) and (n,cp). We intend to measure their response during the commissioning in order to evaluate the feasibility of future experiments. In addition we will possibly perform tests with gated photomultipliers and preamplifiers, as well as measure the detector response to the gamma flash with different HV settings. For these tests we would like to reserve a number of $8 \cdot 10^{17}$ protons.

7 Summary of requested protons

The following table summarizes the number of protons needed for the commissioning. About 10% additional protons are scheduled as "unforeseen" accounting for possible additional measurements to be identified during data taking. Due to the numerous technical interventions in EAR2 during the measurement programme, which for safety reasons are only possible during working hours, it is likely that the commissioning phase will last in the order of 5 months, assuming on average $0.6 \cdot 10^{17}$ protons/day.

Table 1: Summary of requested protons for the commissioning of EAR2.

measurement	#protons ($\times 10^{17}$ protons)
neutron flux	24
beam profile	12
resolution	9
backgrounds	35
detector tests	8
unforeseen	10
total #protons	**98**

References

[1] The n_TOF Collaboration. "n_TOF Experimental Area 2 (EAR2) preliminary feasibility study". *CERN-INTC-2011-032 / INTC-O-013* (2011).

[2] The n_TOF Collaboration. "Proposal for n_TOF Experimental Area 2 (EAR-2)". *CERN-INTC-2012-029 / INTC-O-015* (2012).

[3] A.D. Carlson et al. "International Evaluation of Neutron Cross Section Standards". *Nuclear Data Sheets* 110.12 (2009), pp. 3215 –3324.

[4] The n_TOF Collaboration. "n_TOF new target commissioning and beam characterization". *CERN-INTC-2008-035 / INTC-P-249* (2008).