NEUTRON SOURCE AT THE DAΦNE BEAM TEST FACILITY

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Abstract

A neutron source, based on photo-neutron production by electrons impinging on target, has been designed and constructed at the DAΦNE Beam Test Facility (BTF). This upgrade makes the DAΦNE BTF an almost unique accelerator facility able to provide electrons, positrons, tagged photons and neutrons. We describe the neutron source feasibility study, the final experimental set-up and the preliminary investigation on different solutions to optimize the extraction lines to maximize the neutron/photon ratio. Monte Carlo simulations (by FLUKA and MCNPX codes) have been performed to estimate the neutron fluence and spectrum at different positions around the source. Preliminary comparison between MC predictions and first measurements are presented and discussed.

THE DAΦNE BEAM TEST FACILITY

BTF is part of the DAΦNE accelerator complex: it is composed by a transfer line, driven by a pulsed magnet, that allows to divert electrons or positrons, normally released to the DAΦNE damping ring, from the end of the high intensity LINAC (see Table 1) towards a 100 m^2 experimental hall, where detector calibrations and tests can be carried out. The facility, initially optimized to produce single electrons and positrons in the 25-750 MeV energy range, can now provide beam in a wider range of intensity, up to 10^{10} electrons/pulse [1]. Typical applications are high-energy detector calibration, low energy calorimetry, detector efficiency study, electronic equipment aging measurements, beam diagnostics device tests, etc.

Table 1. DAΦNE LINAC Parameters

Particle	Electron	Positron
Energy	750 MeV	510 MeV
Max. Current	500 mA/pulse	100 mA /pulse
Transverse emittance	≤ 1 mm mrad at 510 MeV	≤ 10 mm mrad at 510 MeV
Energy spread	1% at 510 MeV	2.5 % at 510 MeV
Pulse duration	1 or 10 ns	
Repetition rate	1-50 Hz	

Since the start of operations with users, in 2003, many upgrades [2] and diagnostic improvements [3] have been performed in order to cover all the possible requests from the scientific community and to be able to qualify as much as possible the beam characteristics (see Table 2). The facility is operative an average of 200-250 days per year, day and night time, with users coming from Italy (about 50%) and all over the Europe.

Table 2. DAΦNE BTF Electron, positron, gamma, neutron beam characteristics.

Operation mode	Electrons positrons	Gammas	Neutrons
Energy range [MeV]	25-500 25 – 750 (*)	100-500 100-750(*)	10^{-9}-200
Repetition rate [Hz]	20 – 49 49 (*)		
Pulse duration [ns]	10 1 or 10 (*)		
Multiplicity	1 up to 10^5 1 up to 10^{10}		4.9 10^{-5} n/cm2/electron
Duty cycle [%]	~ 80% ~ 96 % (*)		~ 40% ~ 96% (*)
Spot size (σ_xxσ_y) [mm]	~ 2×2 ~ 5.5x5.5	>20	-
Divergence [mrad]	~ 1 - 1.7	> 15	-
Energy resolution	< 1%	7%	-

(*) Dedicated time: from single electron mode to high multiplicity (full LINAC beam). These values can be obtained only when the BTF is operated without the DAΦNE main ring topping up. In this condition, the full intensity LINAC, needed for example for neutron production, can be transported and delivered into the BTF experimental hall. This kind of operation must be carefully scheduled with BTF staff.

NEUTRON PRODUCTION AT BTF

The main idea to produce neutrons at BTF (n@BTF project) consists in dumping high-energy electrons on a suitable target located in the BTF experimental hall as shown in fig 1. The interacting electrons generate inside the target a cascade shower of bremsstrahlung photons with an energy spectrum ending at maximum electron beam energy. The photons can be absorbed by the nuclei of the target, which are excited. These nuclei go back in their fundamental state boiling off neutrons, mainly according the well known mechanism of the Giant Resonance, even if also neutron of higher energy are expected due to the Quasi Deuteron mechanism [4].

Experimental Set-up

In order to maximize the neutron yield per primary electron the target has been chosen between high Z elements. Thermal physical properties, and Monte Carlo optimization, pushed us to choose a cylinder made of W with radius 35 mm and length 60 mm.

Figure 1: Experimental Layout.

The target is hosted inside a suitable shielding structure, as shown in fig 2. The shield cover almost all the solid angle around the target, leaving only three free paths: the middle square window for the primary electron inlet, and two cylindrical holes for the neutron extraction.

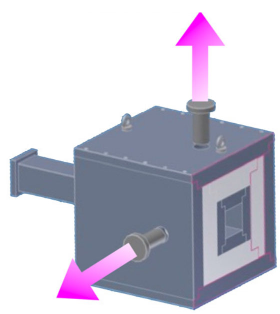

Figure 2: Extraction Lines and Shield's Dump.

The assembly around the target was designed for optimizing the neutron extraction with respect to the high background of gamma rays. Photons, and in particular those of higher energy, are essentially collimated forward around the beam direction and indeed their intensity decreases of more of two orders of magnitude going from the primary beam direction to the orthogonal one, while the neutron flux intensity value is almost unchanged. These considerations lead us to realize the neutron extraction lines in a plane orthogonal with respect to the primary beam direction (see fig. 2).

The shield is a box made of different layers: 2 layers of lead (respectively the inner and outer one, each one 7.5 cm thick) and a layer of polyethylene in the middle (10 cm thick).

The shield foresees also a thicker (20 cm) external lead layer, along the beam direction, in front of the inlet window, in order to adequately dump primary and secondary particle beam. The W target is centered in the shield by means of two Aluminum rings.

MONTE CARLO PREDICITONS

In order to estimate the expected neutron rates and spectra along the extraction lines and all around the shield, we used FLUKA [5] and MCNPX code [6], while simulations with other Monte Carlo codes (Geant4) are still in progress: one of the main objective of n@BTF project is, in fact, to investigate if there are qualitative and quantitative differences in the simulation results of the major simulation packages due to different photo-nuclear physics implementation as well as different cross-section data libraries.

We have chosen to use, as starting point, the FLUKA code because, in addition to the fact that since a long time, it implements the photo-nuclear physics on the whole energy range and offers a rich data-base of the total photo-neutron cross sections for 190 nuclides, derived from experimental data or from existing evaluations.

We validated the Monte Carlo predictions of the source term (neutron/primary) with respect to semi-empirical correlations by Swanson [4] for several cases (thick cylinders of different materials), always finding an agreement better than 10% [7].

Simulation Details

Up to now two independent simulation campaigns were performed using the version 2006.3 of FLUKA and MCNPX 2.6f.

In FLUKA simulations, the photo-nuclear physics was activated over all the energy range for all the relevant heavy elements included in the model: natural W and Pb, respectively. In order to improve the statistics, without affecting the physics, and to optimize computational CPU time, we used a biasing technique, increasing the interaction probability of photons by a factor 100 (photon inelastic interaction length, λ set equal to 0.01). Neutron fluences [n/cm2/pr] and spectra have been estimated in different positions around the neutron source (see fig. 3).

By FLUKA simulations we finally estimated to produce neutrons with continuous energy spectrum, from 1E-9 MeV up to about 200 MeV, but more than 80% of all neutrons has energy in between 10 keV and 20 MeV. The estimated distribution is a Maxwellian with average around 0.7 MeV.

Concerning MCNPX, the calculations relied on the ENDF/B-VII photonuclear data library. The S(a,b) data were used for the treatment of the thermal scattering in polyethylene. Both F4 and F5 tallies were used to determine the neutron fluence energy distribution in the points of interest, obtaining coincident results within the simulation uncertainties (±4% for F4 and ±0.2% for F5)

NEUTRON MEASUREMENT

Two independent neutron detection systems have been used in the first measurement campaign: Bonner Sphere [8] and Bubble Dosimeters [9].

The main objective of these measurements is to show the actual feasibility of the photo-neutron source at BTF and to check the expected energy spectrum and rates.

PRELIMINARY RESULTS

Spectrum measurements were performed with a Bonner Sphere Spectrometer equipped with Dysprosium activation foils (Dy-BSS), whose response matrix was previously tested in reference neutron fields, obtaining a ±2% overall uncertainty. Seven polyethylene spheres (conventionally labeled using the diameter expressed in inches, 2", 3", 5", 7", 8", 10", 12") were sequentially exposed in a test point located at 150 cm from the target centre along the a direction of one of the extraction line (at 90° with respect to the incident electron beam). The activation of the foils was measured in a portable beta counter and the specific activity of each foil was corrected by taking into account the discrete activation function (10 ns pulses delivered at 1 Hz) and the decay during exposure and counting The final counts were normalized to the number of 510 MeV electrons actually delivered to the target. The corrected and normalized specific activities of the foils were then unfolded using the FRUIT unfolding code [10] to obtain the neutron spectrum.

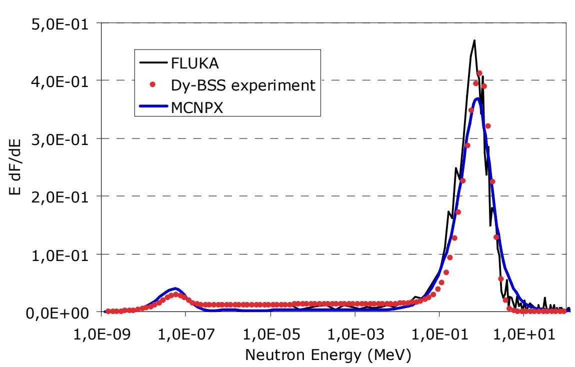

Figure 3: Experimental and computational neutron spectra in the point of test at 150 cm from the target at 90° wr to the impinging electron beam line.

The total neutron fluence per primary particle obtained from the experiment is 8.04E-7 cm^{-2} ±3%. The fluence above 10 keV is 6.53E-7 cm^{-2}, which is fully in agreement with the Swanson empirical formula (6.85E-7 cm^{-2}).

Furthermore, fluence estimated at the exit of the shield hole by FLUKA and the respective values measured by Bubble Dosimeter differ by less than 20%.

In fig. 3 the lethargic (EdF/dE) spectrum, normalized to the total neutron fluence, estimated by Monte Carlo codes (continuous lines) is shown together with the normalized lethargic spectrum (red dots), obtained with Bonner Spheres. There is a substantial good agreement between experiment and simulations in the shape of the spectrum, and several statistical tests are ongoing in order to quantify it, properly.

So we can conclude that a preliminary analysis of data shows a good agreement between the Monte Carlo predictions and the measured data: as expected from simulations, neutrons are measured over 10 decades in energy (from 0.001 eV up to about 160 MeV), even if more than 80% is found around the Giant resonance, around 1 MeV.

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