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A POSSIBLE NEUTRON SOURCE AT "LIFE"

Francesco Broggi, Luca Serafini

INFN-Sezione di Milano, Via Celoria 16, 20133 Milano, Italy

Abstract

LIFE (Laboratorio Interdisciplinare Fotoni ed Elettoni) is a facility in construction at the INFN Laboratori Nazionali di Frascati (LNF). The backbone of the facility will be the 20-150 MeV in 2-5 ps electron beam from SPARC and the FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments) laser, an 800 nm, 6 J energy laser with 300 TW peak pulse in 20 fs and a repetition rate of 10 Hz.

The laser is under commissioning while the electron beam is already available for the SPARC FEL experiment. Next year two additional beam lines will provide the electron beam to the PLASMON-X (where plasma acceleration experiment will be carried out, through the interaction of the electron beam with the FLAME laser) and a Thomson backscattering experiment.

The possibility of having a neutron source, to complete the beam facility, through the photodissociation of deuterons in heavy water (cost about 400 €/l) is investigate through preliminary computations with the FLUKA code

Good neutron fluencies will be available by an optimization of the impinging gamma energy and the target geometry.

The peculiarity of this type of source is not on the high neutron fluxes (higher fluxes are available at nuclear reactors) but on its time structure. As a matter of fact it is related to the ps structure of the laser-electron beam.

Work performed in the frame of the FLUKA collaboration and SPARC activity

1 INTRODUCTION

LIFE (Laboratorio Interdisciplinare Fotoni ed Elettoni), will be a multidisciplinary laboratory at LNF Frascati, where electron and photon beams from the SPARC (Ref.1) accelerator and FEL experiment will be available.

Another photon source will be FLAME laser (Ref.2), and the X photons from Thomson scattering experiment, as shown in Fig.1.

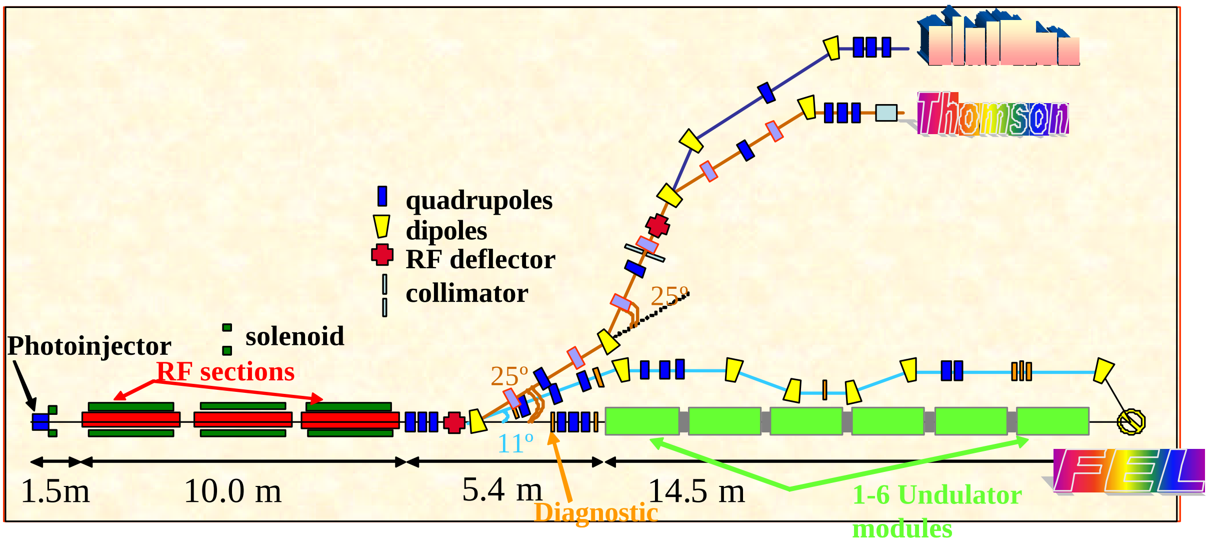


Fig.1 The SPARC/LIFE Facility

In the following table the characteristics of the electron and photon beam are summarized.

Tab.1 SPARC and FLAME parameters

ELECTRON BEAM (SPARC)	
Electron Beam Energy (MeV)	30-150
Bunch Charge (nC)	1
Rep rate (Hz)	1-10
Rms norm. transverse emitt. @ Linac exit (mm.mrad)	< 2
Rms longitudinal emittance (deg.keV)	1000
Rms total correlated energy spread (%)	0.2
Rms beam spot size @ Linac exit (mm)	0.4
Rms bunch length @ Linac exit (mm)	1
LASER BEAM (FLAME)	
Wavelength (nm)	800
Pulse Energy (J)	6
Pulse duration (FWHM) (fs)	< 30
Repetition rate (Hz)	10

The Thomson scattered wavelength is given by

$$\lambda_x = \lambda_L \frac{1}{4\gamma^2\left(\frac{1-\cos\theta}{2}\right)}$$

so wavelength of 0.06 nm will be available for electron energy of 30 MeV (gamma =58.7) in a head on ($\theta=\pi$) collision.

Possible future upgrade of the SPARC electron beam to 300 MeV combined with the second harmonic of the laser beam will made 4MeV gamma photons available.

The photodissociation of the deuterons by gamma photons can provide neutrons in the ps time scale (related to the pulse length of the electron and laser beam time interaction). Such neutrons can be delivered to users for multidisciplinary applications.

2 NEUTRON SOURCE BY DEUTERON PHOTODISSOCIATION

The binding energy of the deuteron ^2H is: $E_b = 2.2246\,MeV$ so an interaction of a gamma photon with energy higher than E_b will liberate neutrons.

The process has been simulated with the FLUKA code (Ref.3,4), considering a monoenergetic gamma beam impinging on a heavy water (D_2O) target.

Different photon energies and target geometries have been investigated.

The cost of the heavy water is about 400 €/l so a cylindrical target with a diameter of 1 cm and a length of 10 cm will cost about 13 €, while a larger target with 10cm radius and 10 cm length will cost about 1250 €.

2.1 Geometry and parameters

Different target geometries have been considered, both in the transverse dimension and in length.

The impinging gamma beam has a Gaussian transverse profile with 0.5 mm FWHM (the 3σ beam radius is about 0.6 mm).

The target consists of a cylinder and the beam impinges along the axis.

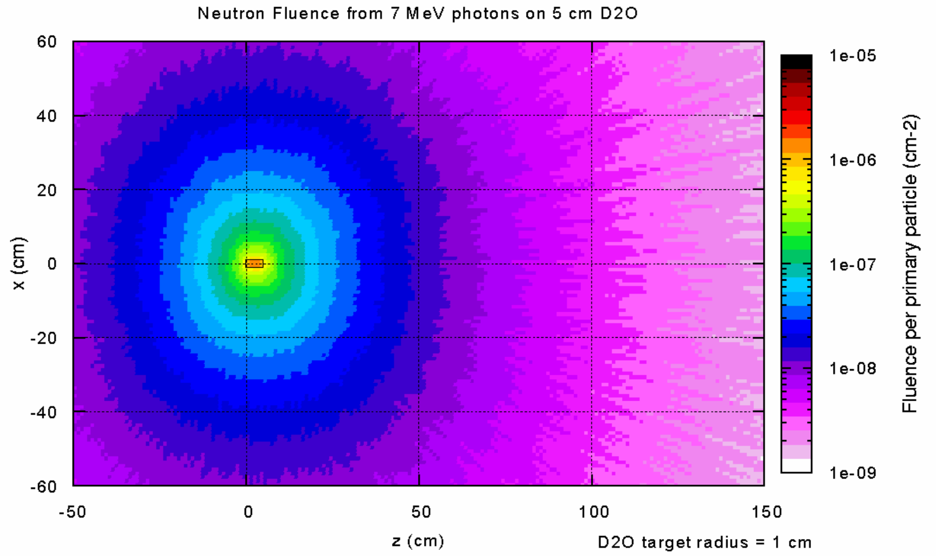
Different target length, 5,10 and 25 cm have been investigated.

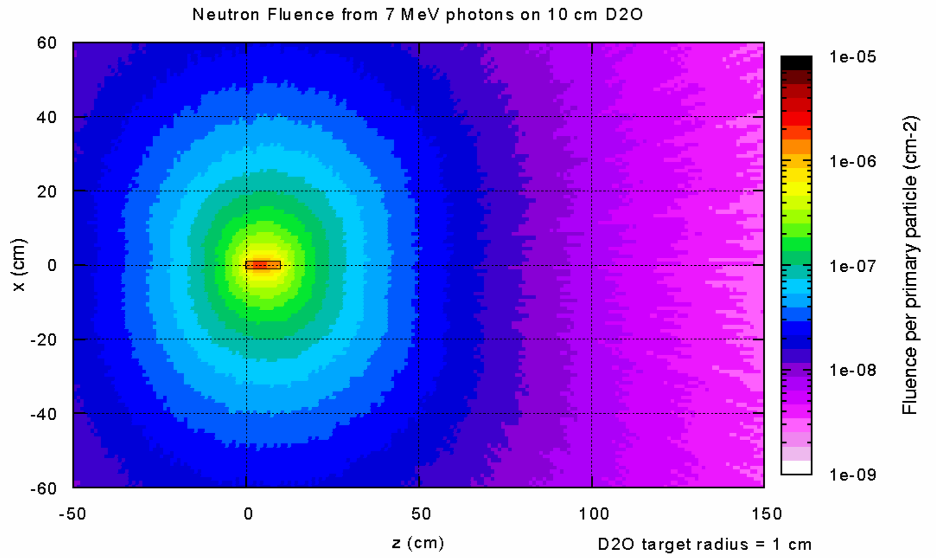
Incident gamma beam of 2.5 MeV (just above the threshold energy), 4,5,7 and 10 MeV have been examined.

The data are obtained with 10 different runs with 10^6 particles each.

3 SIMULATION RESULTS

In Fig. 2 the neutron fluence (the number of the track length of neutrons per unit volume per primary particle) are shown for a 7 MeV photon beam on a D_2O target with a radius of 1 cm and length of 5cm (top), 10 cm (middle) and 25 cm respectively (bottom).





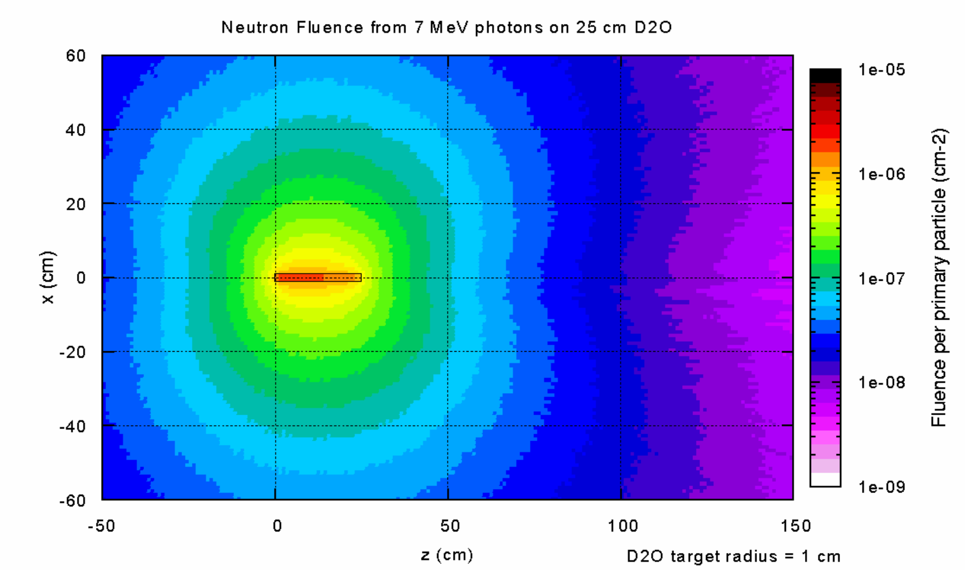


Fig.2. Neutron fluence as from 7 MeV gamma on 5 cm heavy water target (top), 10 cm (middle) 25 cm (bottom) the target radius is 1 cm
The bin dimensions are 1x1x1 cm^3.

3.1 Neutron spectra and dependence on the photon energy

Different photon energy has been investigated; the neutrons produced have a wide spectrum with a peak at about

$$E_n \approx \frac{E_g - E_b}{2} = \frac{E_g[MeV] - 2.2246}{2} \qquad (1)$$

In Fig. 3, 4 and 5 the distributions of the neutrons produced per incident gamma are shown for the forward direction, sidely and backward respectively, for different gamma energies. Only the case of 10 cm long and large (10 cm radius) target is shown. The plots are obtained by integrating the double differential distribution over the solid angle and multiplying the spectrum energy for the corresponding energy interval, in order to have an "easy" number of neutrons per gammas. The plots show a good agreement with (1).

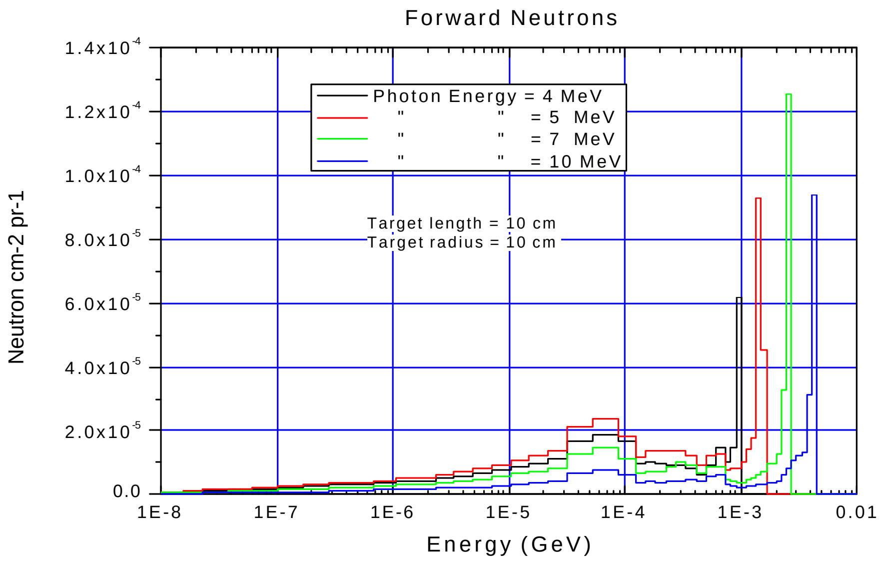


Fig.3. Neutrons produced per primary incident photon in the forward direction from a 10 cm long and 10 cm radius D_2O target by gammas of different energies.

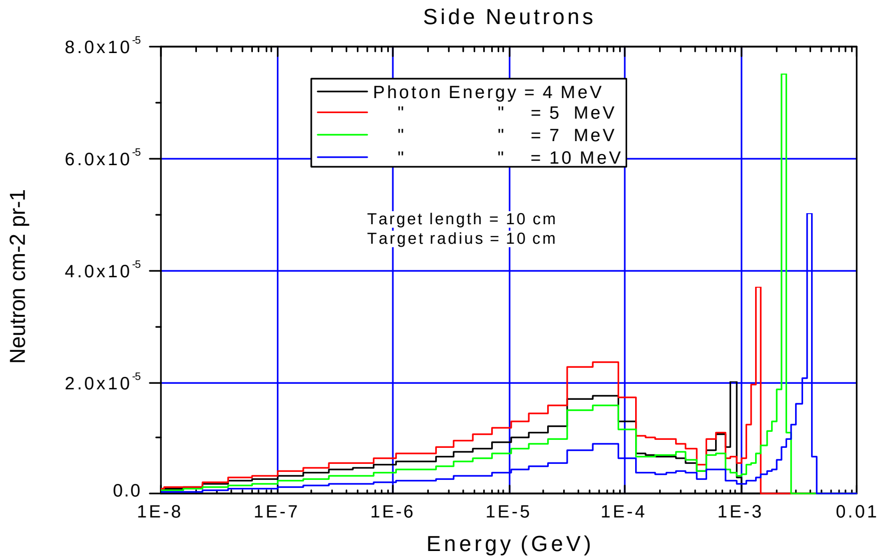


Fig.4. Neutrons sidely produced per primary incident photon from a 10 cm long and 10 cm radius D_2O target by gammas of different energies.

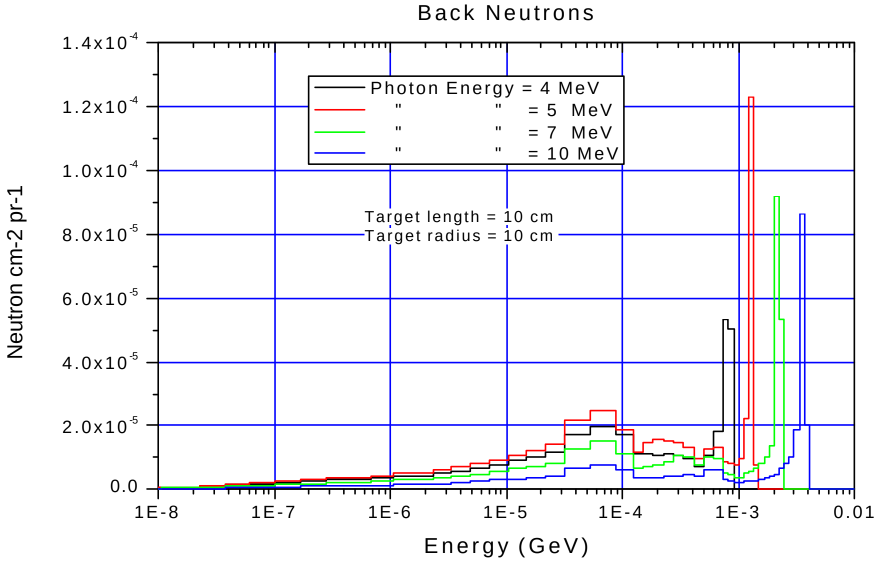


Fig.5. Neutrons produced backward per primary incident photon from a 10 cm long and 10 cm radius.

From Figs. 3 and 4, the optimum photon energy for the forward and side neutron production is about 7 MeV, while for the backward neutron production (Fig. 5) the best energy is 5 MeV.

This is probably due to the self-absorption of the target. i.e. the neutrons produced just above the production threshold (2.2 MeV) has very low kinetic energy and will be absorbed by the target material if travelling inside it, while they can escape form the back face, conversely the neutron with higher energy can escape.

3.2 Dependence on the target geometry

The effect of different target radii and length has been investigated for photon energy of 7 MeV, as stated in the previous section. Different photon energy has been investigated.

3.2a Different lengths

The effect of different length has been investigated for a target radius of 1 cm for photon energy of 7 MeV.

In Figs, 6,7 and 8, as for the Figs, 4,5, and 6, the integrated (over the solid angle) neutron production in the direction forward, side and back is shown.

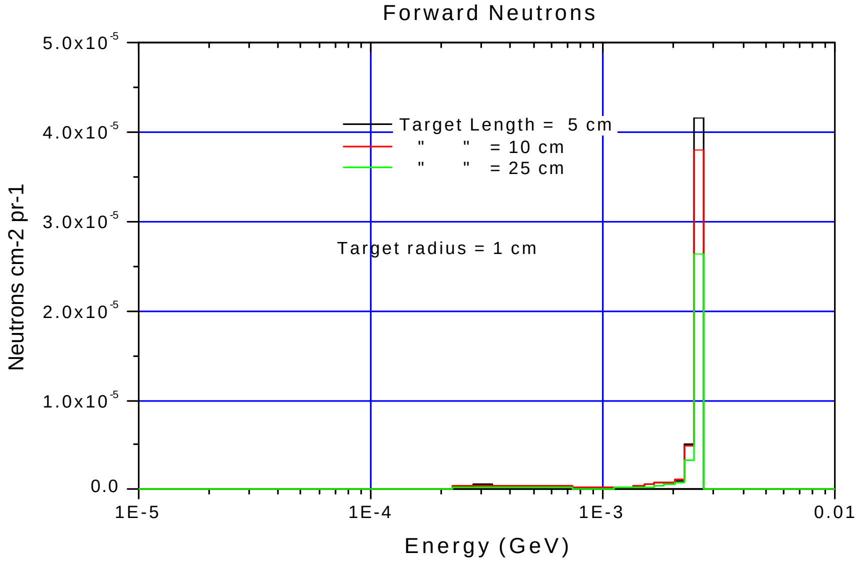


Fig.6. Neutrons produced per primary 7 MeV incident photon in the forward direction for different target length and 1 cm radius.

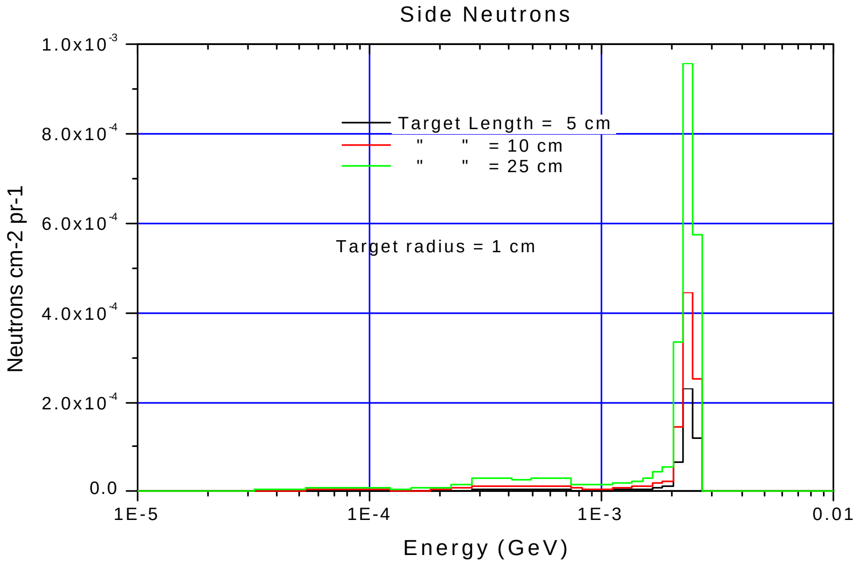


Fig.7. Neutrons sidely produced per primary 7 MeV incident photon for different target length and 1 cm radius.

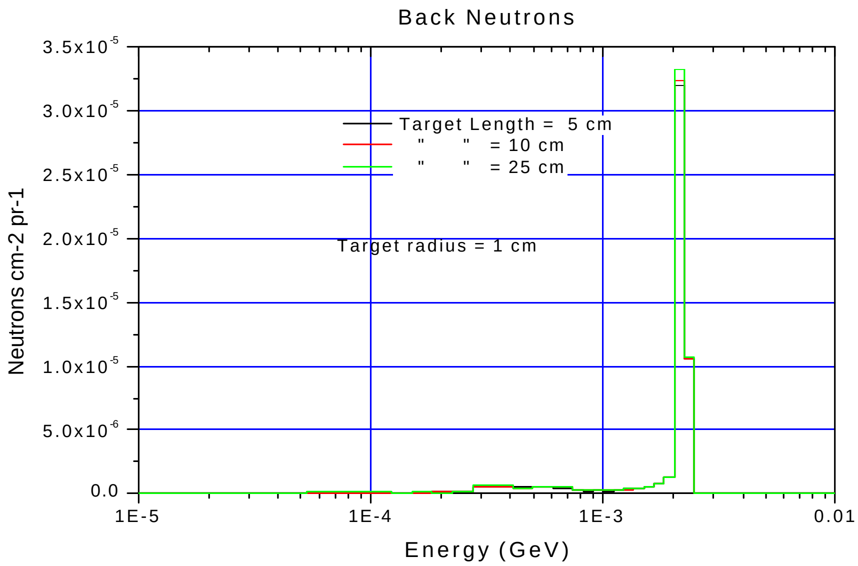


Fig.8. Neutrons produced backward per primary incident 7 MeV incident photon for different target length and 1 cm radius.

As it can be seen from the plots above a shorter target has a higher forward production, because of the reduced self-absorption; longer target provides more neutrons aside, because of the higher nuclei target amount; the backward production is not affected by the target length, as expected.

3.2b Different radii

The effect of the target radius has been investigated by considering 7 MeV photons on a target 10 cm long with radii of 1 and 10 cm.

In Figs, 9,10 and 11 the integrated spectra (as the previous figures) show the radius effect.

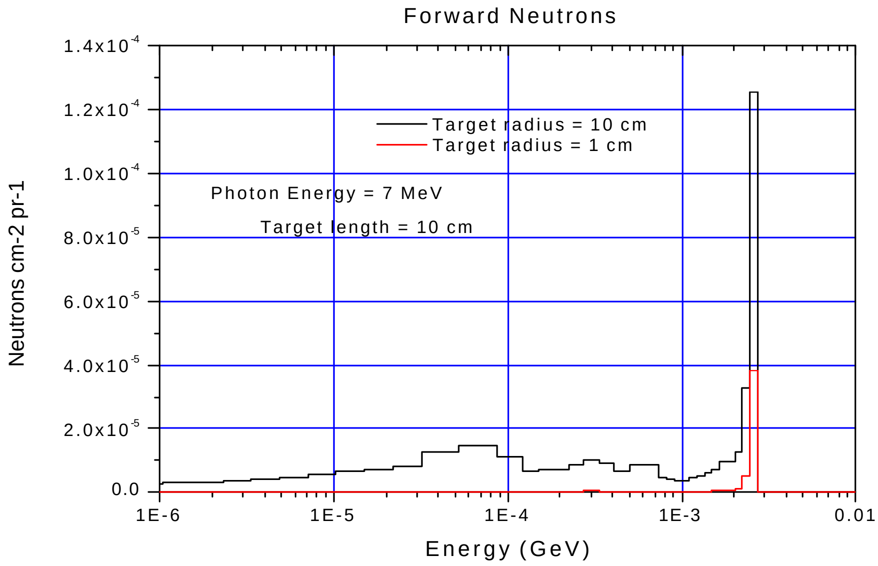


Fig.9. Neutrons forward produced per primary incident 7 MeV incident photon for different radii and length of 10 cm.

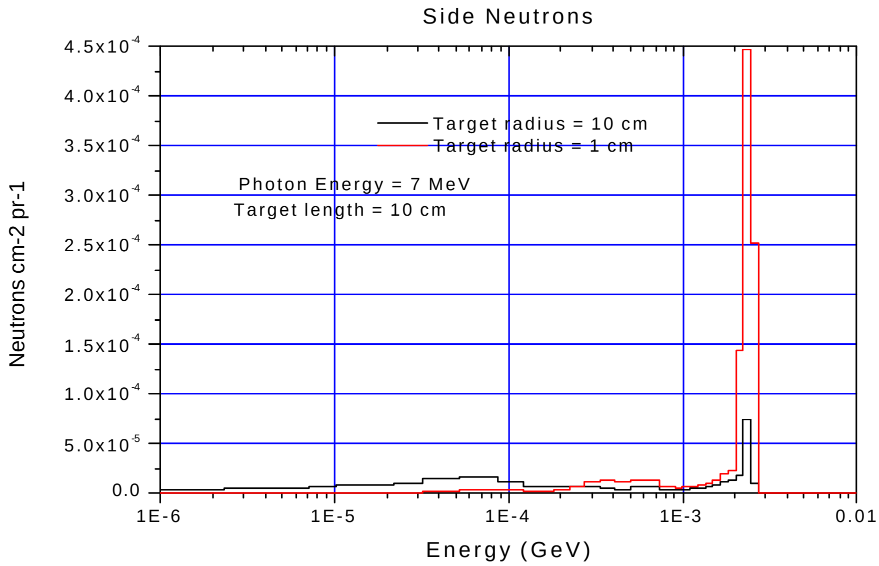


Fig.10. Neutrons sidely produced per primary incident 7 MeV incident photon for different radii and length of 10 cm.

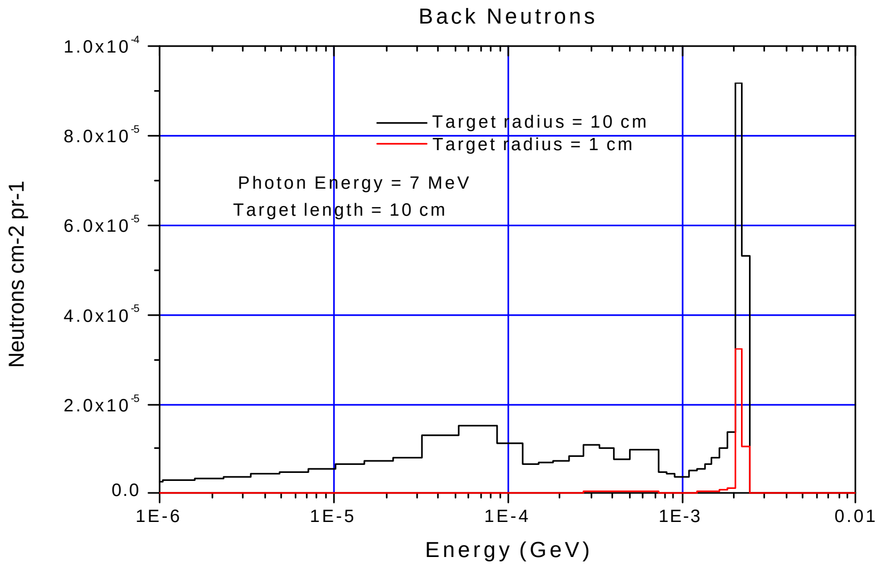


Fig.11 Neutrons produced backward per primary incident 7 MeV incident photon for different radii and length of 10 cm.

As we can see there is a higher neutron production in the forward and in the backward direction for the larger target.

The side production, conversely, decreases with the increasing of the target radius.

The decreasing for the side production can be explained again by the self-absorption.

The forward and backward increase can be due to the fact that not only the geometrical cross section of the beam to the target is responsible for the interaction, as a matter of fact the photon beam spot has a radius of 0.6 mm.

So the increasing of the photoproduction with the target radius can be explained by considering that the photoproduction is not the only interaction that occurs, but some other scattering of the photon are present.

Once the photon is scattered, maybe outside the cross section of the primary beam spot, it can give photoproduction. In this way larger dimensions of the target increase the probability of this secondary interaction.

To verify this hypothesis a run with a very big target radius (50 cm) and length of 10 cm has been carried on.

In this case there are no neutrons laterally produced, while there is an increase in the forward directions, about 5% at the maximum energy, more at lower energy as shown in Fig.12.

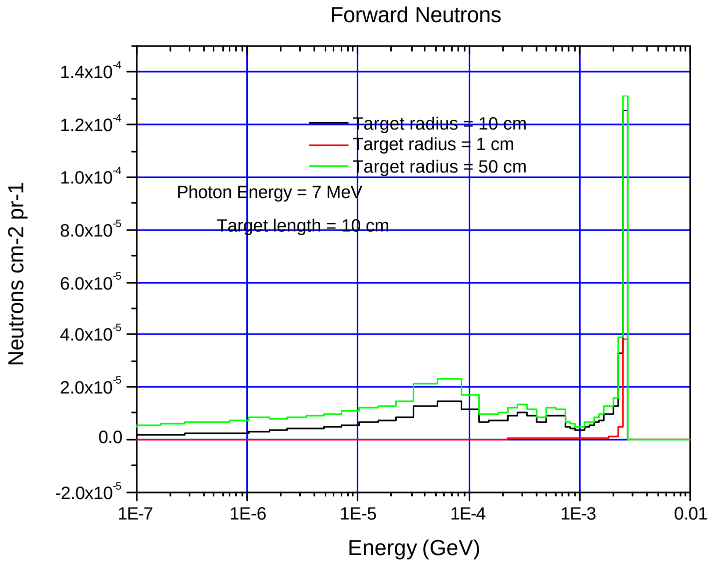


Fig.12 Neutrons forward produced per primary incident 7 MeV incident photon for different radii and length of 10 cm.

3.3 Double differential spectra

The spectra shown in the previous figures (from 3 to 12) are only energy spectra, integrated over the solid angle under which the neutrons are produced.

More precisely, we want to underline that they are not really "spectra" as usually referred, being the ordinate of the distribution already multiplied for the corresponding energy interval, giving in this way, according to our opinion, a more useful way to read the plots, representing the number of neutrons produced per unit area per primary incident photon.

Let's examine now the double differential distribution, i.e. the distribution of the produced neutrons, versus the energy and the angle.

In Fig. 13, 14 and 15 the forward, the side and backward spectrum of the neutron produced by a target of 1 cm radius 10 cm length when hit by a 7 MeV photon beam are shown respectively.

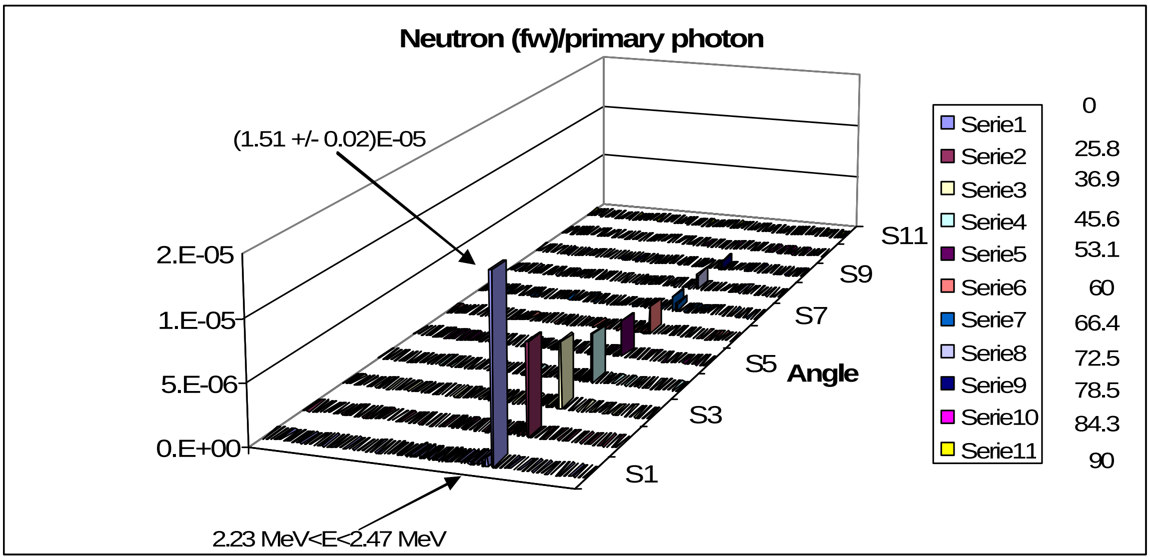


Fig.13 Neutron double differential distribution forward produced per primary incident 7 MeV incident photon for 1cm radius and length of 10 cm.

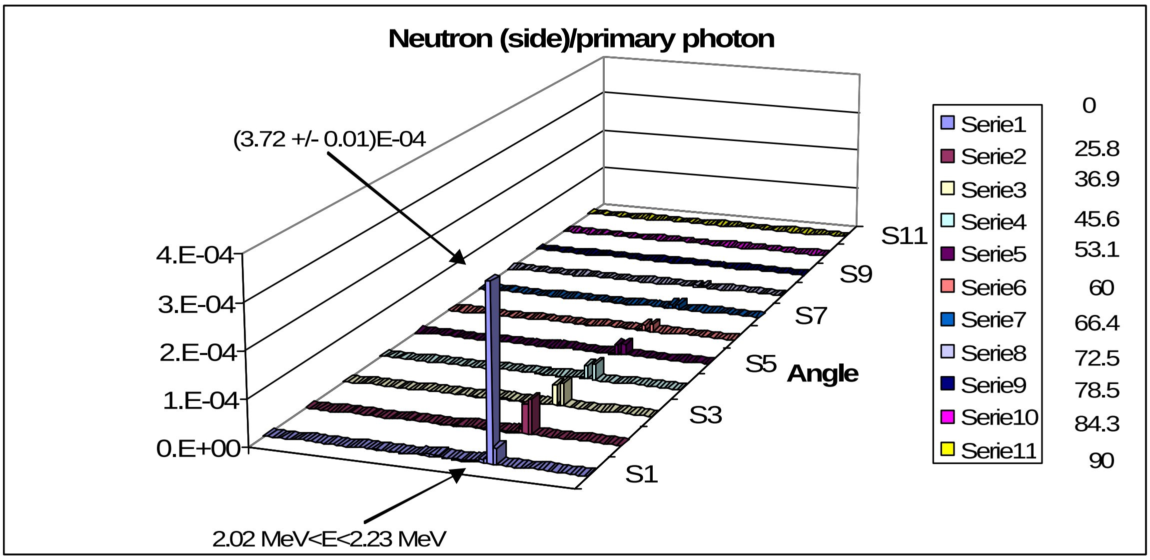


Fig.14 Neutron double differential distribution side produced per primary incident 7 MeV photon for 1 cm radius and length of 10 cm.

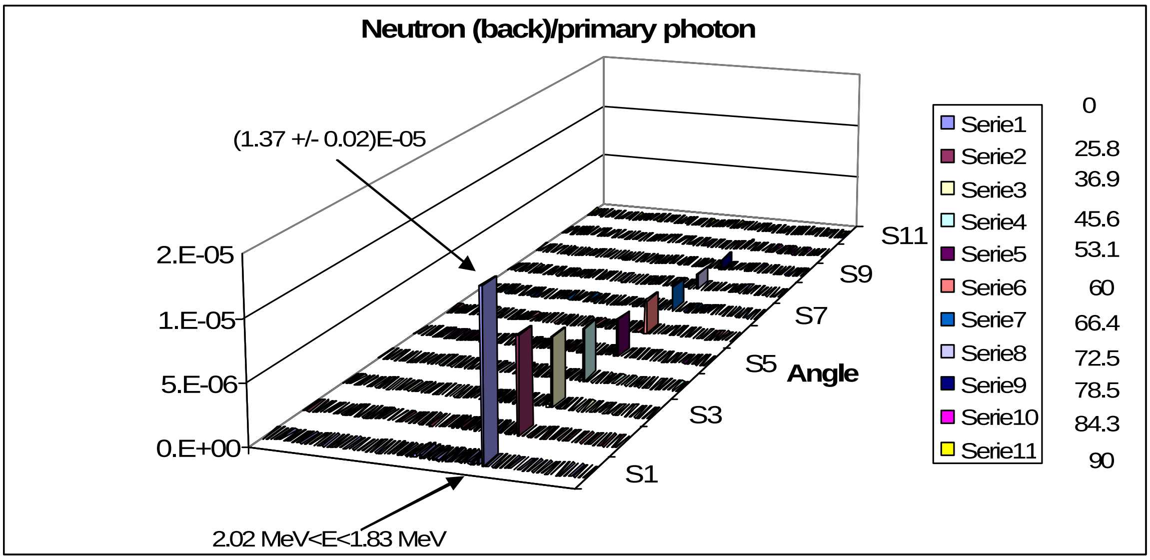


Fig.15 Neutron double differential distribution backward produced per primary incident 7 MeV photon for 1cm radius and length of 10 cm.

As we can see from the spectra shown in the previous section the neutrons are mostly produced in a cone of amplitude of 25.8° (because the 2π solid angle has been sampled in 10 parts); this means that for the forward and backward production they are mostly produced in a cone around the cylinder axis.

For the side production the direction of higher production is the cone around the normal to the lateral surface of the cylinder, being azimuthally isotropic, for the symmetry of the problem and being absent any polarization.

3.4 Summary

In the following table the total number of neutron produced in the different direction for the various examined cases are summarized.

Tab.2 Summary of the total neutron production

γ Energy (MeV)	Target Geometry (cm) Length	Radius	Neutron produced ($n\ cm^{-2}\ pr^{-1}$) ± err% Forward	Side	Backward
4	10	10	3.12E-04 ± 0.3	2.55E-04 ± 0.3	3.49E-04 ± 0.2
5	10	10	4.88E-04 ± 0.2	3.85E-04 ± 0.3	4.82E-04 ± 0.2
7	5	1	5.46E-05 ± 0.7	5.00E-04 ± 0.2	5.06E-05 ± 0.7
		10	2.75E-04 ± 0.3	7.43E-05 ± 0.5	2.56E-04 ± 0.3
	10	1	5.08E-05 ± 0.7	1.04E-03 ± 0.1	5.11E-05 ± 0.7
		10	4.07E-04 ± 0.2	3.59E-04 ± 0.2	3.93E-04 ± 0.2
	25	1	3.49E-05 ± 0.8	2.32E-03 ± 0.1	5.24E-05 ± 0.6
		10	4.02E-04 ± 0.2	1.65E-03 ± 0.2	4.77E-04 ± 0.2
10	10	10	3.04E-04 ± 0.3	2.64E-04 ± 0.3	2.78E-04 ± 0.3

From the data above the maximum integrated neutron production in the forward direction occurs for a gamma energy of 5 MeV (but from the spectra shown in Fig. 3 the highest monochromatic neutron amount is for 7 MeV); for the side production the optimum conditions are for 7 MeV gamma energy, 25 cm target length and 1 cm target radius, because of the self absorption and nuclei target amount; in the backward direction the best situation is for energy of 5 MeV.

If we consider the expected PLASMON-X photon production (10^{12} - 10^{14} photons per shot) it follows that a neutron fluence of the order of 10^8 - 10^9 are expected, at a repetition rate of 1 Hz, a factor ten more is achievable by working at 10 Hz (operation already foreseen as shown in Tab.1). Further increases to 100 Hz are under investigation.

The peculiarity of the produced neutron beam is in its energy spectrum tunability (according to (1)) and time structure, correlated with the Thomson scattered photons.

4 CONCLUSIONS

The simulations show that it is possible to have a neutron source at the LIFE laboratory with an upgrading of the initial electron and laser beam parameters.

The energy of the neutron produced can be varied by varying the energy of the incident gamma beam, and most of the neutrons are realized in the direction normal to the surfaces of the target.

Neutron fluencies of 10^8-10^{11} are expected at the normal repetition rate of the SPARC-FLAME facility, further repetition rate increase to 100 Hz are under investigation.

The neutrons have a peak in the energy spectrum so can be considered as monochromatic, in addition the energy can be varied by changing the primary photon energy.

Another peculiarity of these neutron beams is in their time structure (not continuous) being related to the photon beam.

5 REFERENCES

(1) http:/ /www.lnf.infn.it /acceleratori / sparc /

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(3) A.Fasso`, A.Ferrari, J.Ranft, and P.R.Sala, "FLUKA: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

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