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POSITRON PHOTOPRODUCTION AT LI2FE

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Abstract

LI2FE (Laboratorio Integrato Interdisciplinare con Fotoni ed Elettroni) 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 in 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 positron source, to complete the beam facility, through the photoproduction is investigated through preliminary computations with the FLUKA code. The biasing effect has been investigated.

Good positrons fluence (some percent of the primary photon) will be available by an optimization of the impinging photon energy and the target geometry.

Electrons and lower amount of neutrons are produced too.

The time structure of the produced beams is the same as the one of the primary photon beam, i.e. ps pulses with 1-10Hz repetition rate.

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

1 INTRODUCTION

LI2FE (Laboratorio Integrato Interdisciplinare con Fotoni ed Elettroni), 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.

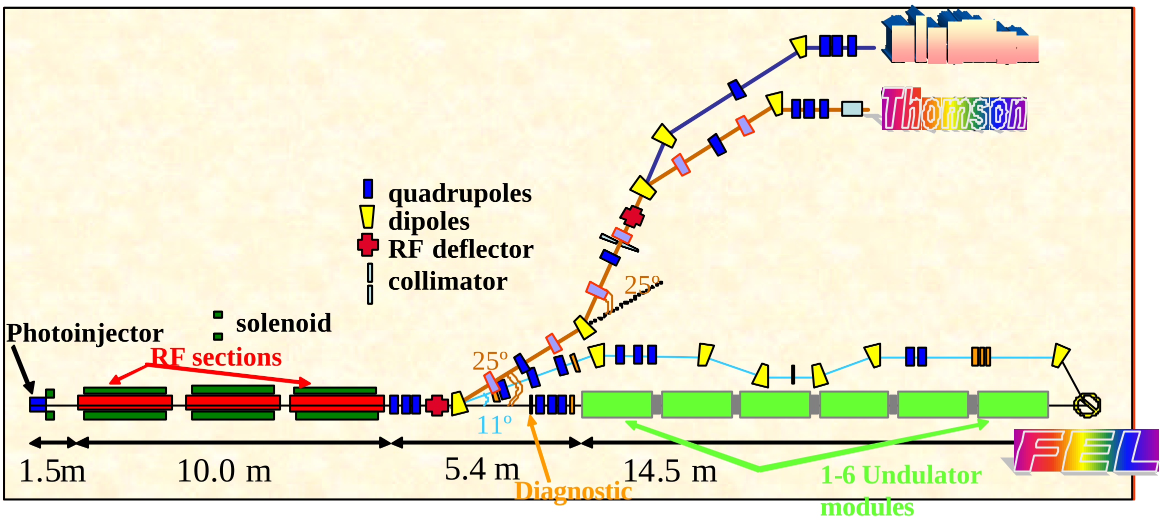

Fig.1 The SPARC/LI2FE Facility

In Tab.1 the characteristics of the electron and photon beam are summarized.

Tab.1 SPARC-PLASMON-X facility 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 (about 20.7 keV) 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 make 4MeV gamma photons available.

Interaction of the photon beam with appropriate target can produce positrons.

Next development of the laboratory towards the SPARX project (Ref.3) will provide higher energy electron beam, and consequently higher photon beam energy.

In this paper the efficiency of positron production is investigated for different target materials at 10 MeV photon energy with the FLUKA (Ref. 4,5) code.

Then the target dimensions (1,2,5 mm thickness) and photon energy (4,10,20 MeV) effects are evaluated for Tungsten.

The scattered electron beam is composed of some ps long bunches with a repetition rate 1-10Hz (see tab.1), this will be the same time structure of the Thomson produced photon beams and of the produced positrons and other secondary beams.

2 PAIR PRODUCTION CROSS SECTION

The cross section for pair production is (Ref.6,7) $\sigma_{pp} = \alpha r_e^2 Z^2 P(\varepsilon, Z)$ with

α : fine structure constant $= 1/137$
r_e : classical electron radius $= 2.818\,10^{-15}$ m
Z : Atomic number of the target

The function P(ε,Z) depends on the target material and the photon energy through the parameter $\varepsilon = h\nu/m_e c^2$, the photon energy in electron rest mass unit with:

h : Planck constant
ν : photon frequency
m_e : electron mass
c : velocity of light in vacuum

Pair production can occur in the nuclear electric field or in the atomic electron electric field. Depending on the energy of the incident photon a screening effect of the electric field of the nucleus, by the K shell electrons must be taken into account.

$$P(e,Z)=\begin{cases}\frac{28}{9}\ln(2e)-\frac{218}{27} & \text{for } 1<<e<<1/(aZ^{1/3}) \text{ Nuclear Field, Low photon energy, no screening}\\ \frac{28}{9}\ln\frac{183}{Z^{\frac{1}{3}}}-\frac{2}{27} & \text{for} e>>1/(aZ^{1/3}) \quad \text{Nuclear fileld, High photon energy, complete screening}\\ \frac{28}{9}\ln(2e)-\frac{218}{27}-1.027 & \text{Nuclear field, outside the above limits but } e>4\\ \frac{1}{Z}\left(\frac{28}{9}\ln(2e)-11.3\right) & \text{Electron field and } e>4\end{cases}$$

For the energy considered (4<E_γ<10 MeV the limit of ε are 7.83< ε< 39.14 while the limit $1/(\alpha Z^{1/3})$ spans from 45.67 (for light element like Cobalt) to 30.35 for Uranium.

So the cross section expression that best fits our problem is the first and the third one.

3 FLUKA GEOMETRY AND PARAMETERS

The primary beam is a monochromatic photon beam with 0.5 cm radius, moving along the z axis towards the positive direction, starting at 5 cm from the target (at point 0,0,-5.0). The target is located at (0,0,0).

The beam divergence is within 1.5 mrad. The target is a cylinder with diameter of 4 mm. The beam is coaxial to the target.

Different target height, primary beam energy and target materials have been investigated.

The transport cut-offs for electrons and photons are set at 10 keV
(EMFCUT -1E-05 1E-05 0.0 @LASTMAT 1.0PROD-CUT)
the photonuclear reactions are on
(PHOTONUC 1. @LASTMAT).

4 SIMULATION RESULTS

The first results obtained refer to the biasing test.

Just to show the geometry of the problem in Figs. 2a, 2b and 2c the plots of the fluence of photons, electrons and positrons ~~and neutrons~~ for 10 MeV photons on 1 mm Tungsten, are shown. The y coordinate extends from -30 cm to 30 cm.

Upstream the target there is vacuum while aside the target and downstream it there is air.

The primary photon beam starts at z=-5.0 cm

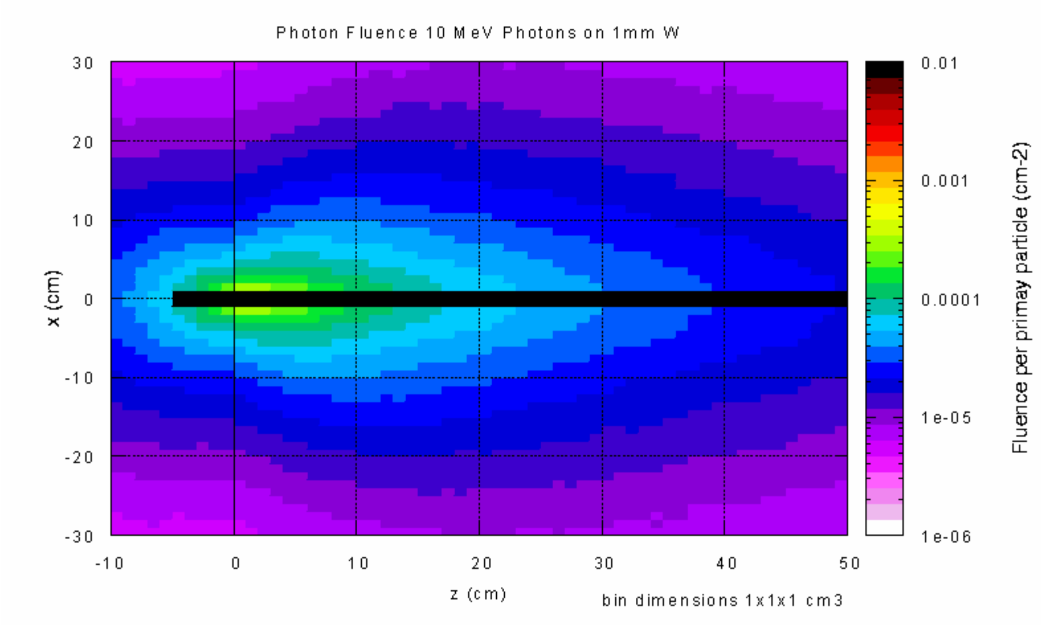

Fig.2a Photon fluence for 10 MeV photon on 1 mm Tungsten. The primary beam starts at (0,0,-5.0), and moves towards the positive z.

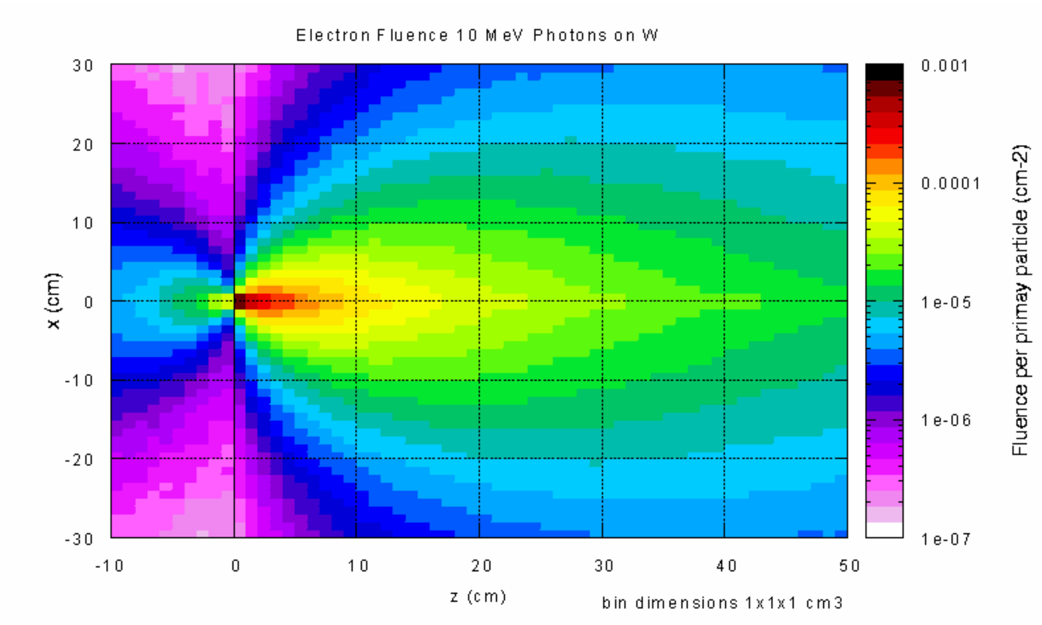

Fig.2b Electron fluence for 10 MeV photon on 1 mm Tungsten. The primary beam starts at (0,0,-5.0), and moves towards the positive z.

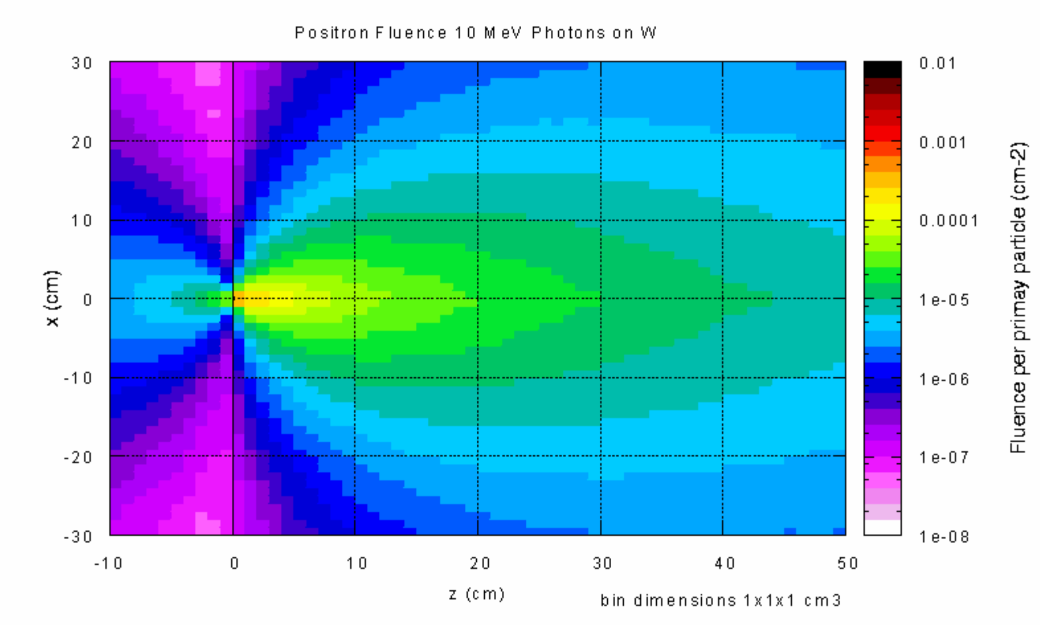

Fig.2c Positron fluence for 10 MeV photon on 1 mm Tungsten. The primary beam starts at (0,0,-5.0), and moves towards the positive z.

4.1 Target Material

The efficiency of positron production has been investigated for different materials.

The results are obtained with 10 different runs of 10^6 particles each. In Fig.3 the number of positrons produced per primary photon in the forward direction for different target materials is shown and compared with a calculation using the cross sections reported above. Cross section "4", the one related to the positron production in the electron field, is neglected because it is 4 orders of magnitude lower than the others.

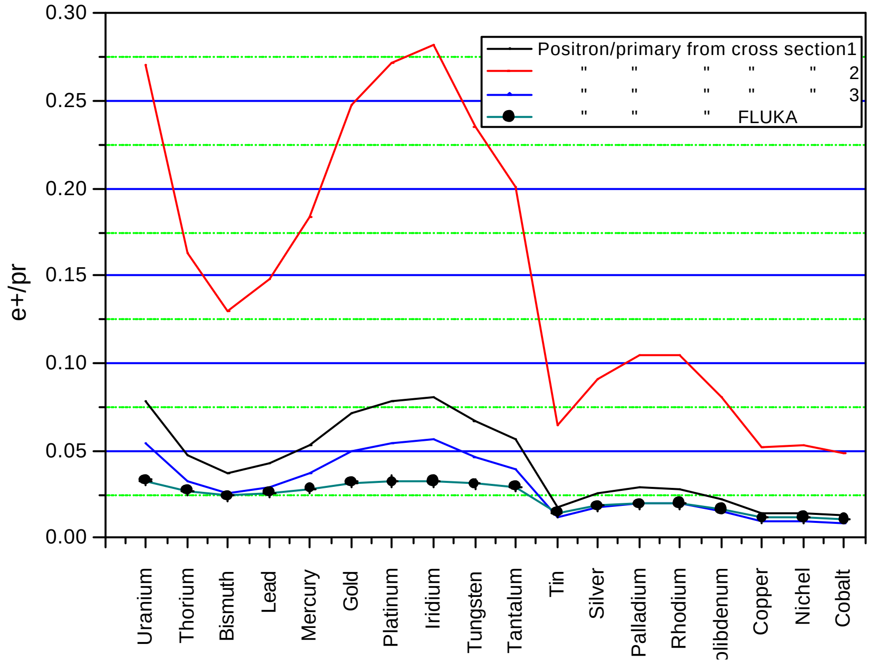

Fig.3. Number of positrons/primary photon in the forward direction for different 1mm thick target materials by 10 MeV photons.
Lines : expected as from the theoretical cross sections
Line+symbol : FLUKA results

As expected the cross section expression that better fits the problem is the 1 and 3.

In Fig 4 all the secondary particles, positrons, electrons and neutrons, in the forward direction production is shown, for the various materials.

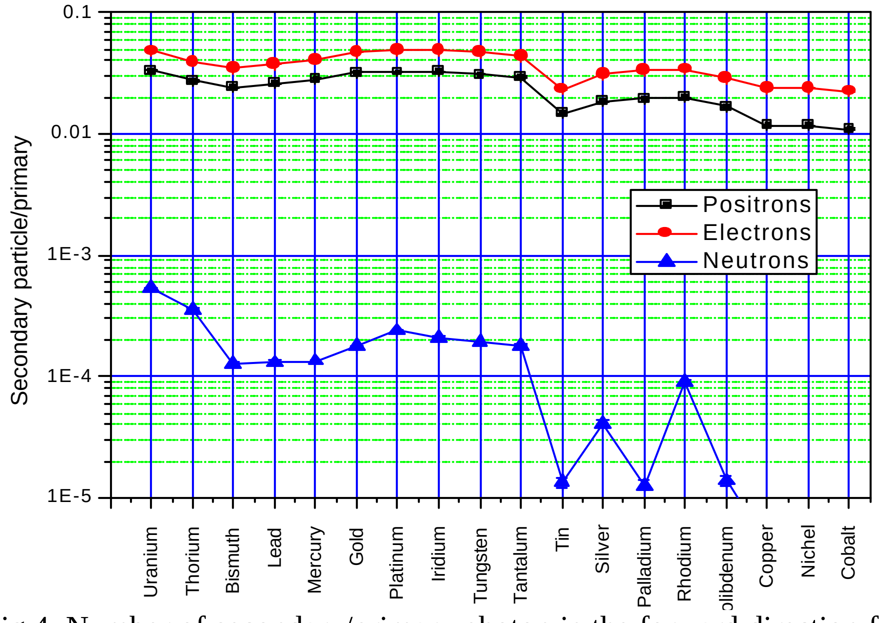

Fig.4. Number of secondary/primary photon in the forward direction for different 1mm thick target materials by 10 MeV photons.

4.2 Target Geometry

The production of positrons and of the other secondary particles has been investigated for different Tungsten target thickness, (1,2, and 5 mm).

In Figs.5,6,7 the positrons, electrons and neutrons produced in the forward direction per primary photon for the different target thickness and primary photon energy examined are shown respectively.

The neutron refers only to 10 and 20 MeV photon energy, because no neutron production occurs at 4 MeV.

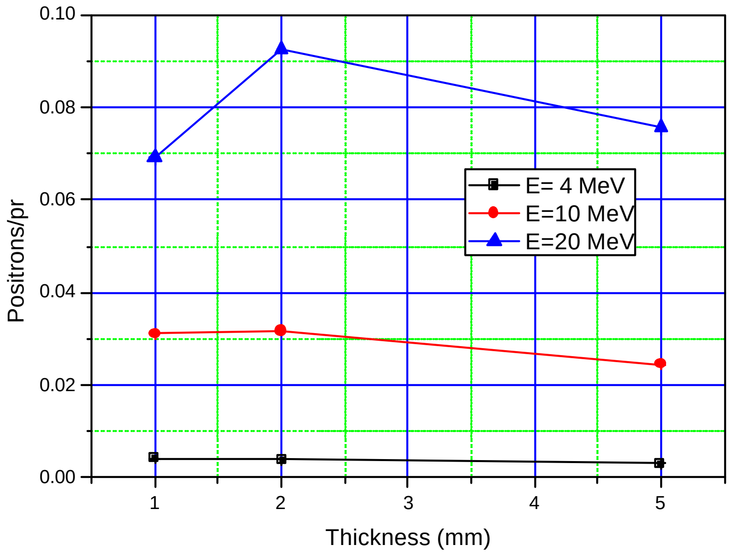

Fig.5. Number of positrons/primary photon in the forward direction for different Tungsten thickness and photon energy.

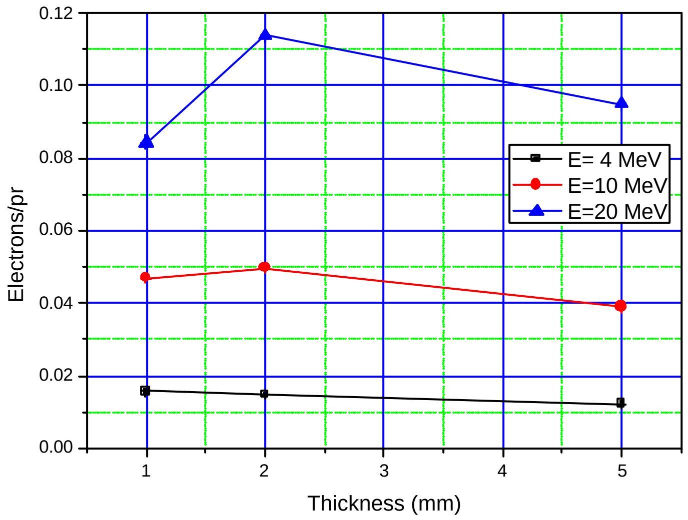

Fig.6. Number of electrons/primary photon in the forward direction for different Tungsten thickness and photon energy.

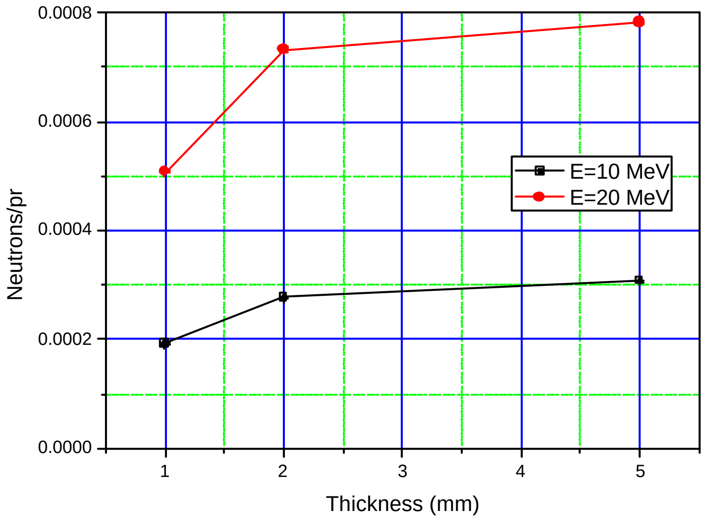

Fig.7. Number of neutrons/primary photon in the forward direction for different Tungsten thickness and photon energy.

The plot shows that a higher production occurs at higher energy (because the cross section increases as the logarithm of the energy). In addition the best thickness for positrons (and electrons) is 2 mm, being the effect more evident for E=20 MeV. This behaviour is probably due to a trade-off between the number of the target nuclei and the self absorption.

At 4 MeV the geometry of the target seems unessential for positrons.

4.3 Positron Spectra

In Figs. 8 and 9 the double differential "spectra" of the forward produced positrons and electrons respectively, are shown for 10 MeV primary energy and 1mm Tungsten target.

We refer to these plots as spectra even if they are not spectra in the actual meaning. As a matter of fact the ordinate of the distribution is 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 particles of a given energy interval produced per unit area per primary incident photon in the angular aperture.

The series refer to the different angular aperture, so the first series refers to positrons emitted in an angle between 0 and 25.8 degree, the second one refers to angle between 25.8 and 36.9. This division comes from having divided the 2π solid angle in 10 parts.

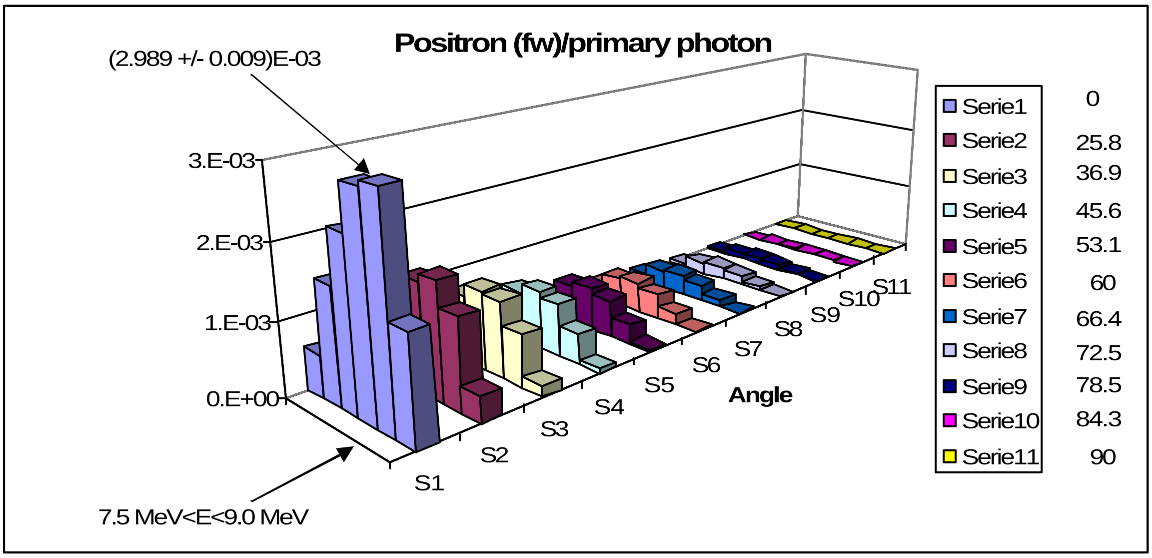

Fig.8. Positron “spectrum” (see text for details) in the forward direction for 10 MeV photon on 1 mm Tungsten.

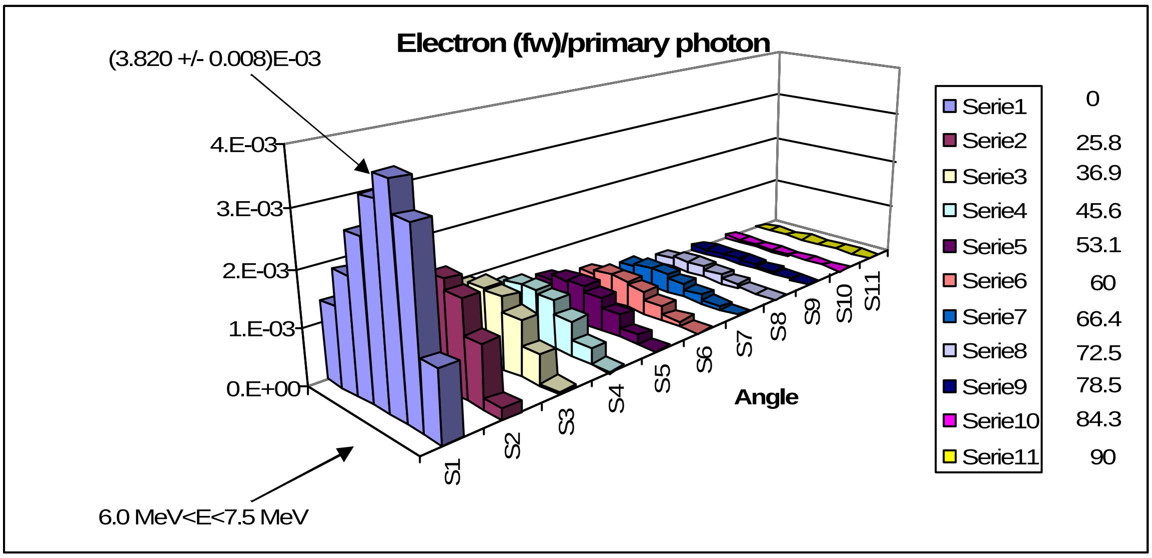

Fig.9. Electron “spectrum” (see text for details) in the forward direction for 10 MeV photon on 1 mm Tungsten.

In Figs. 10 and 11 the same spectra as in the previous figures but for 20 MeV primary energy are shown.

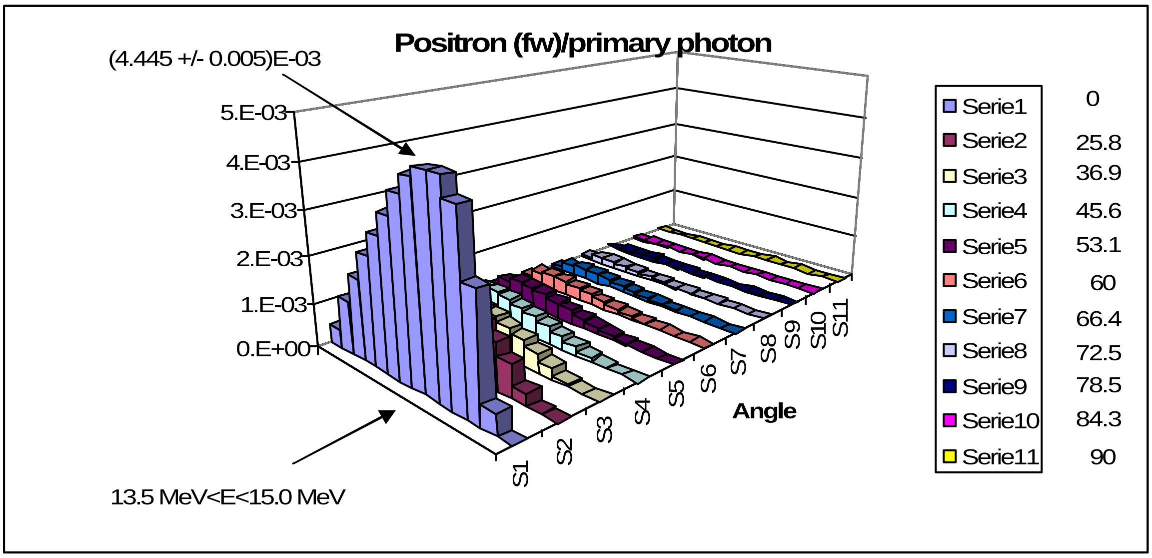

Fig.10. Positron “spectrum” (see text for details) in the forward direction for 20 MeV photon on 1 mm Tungsten.

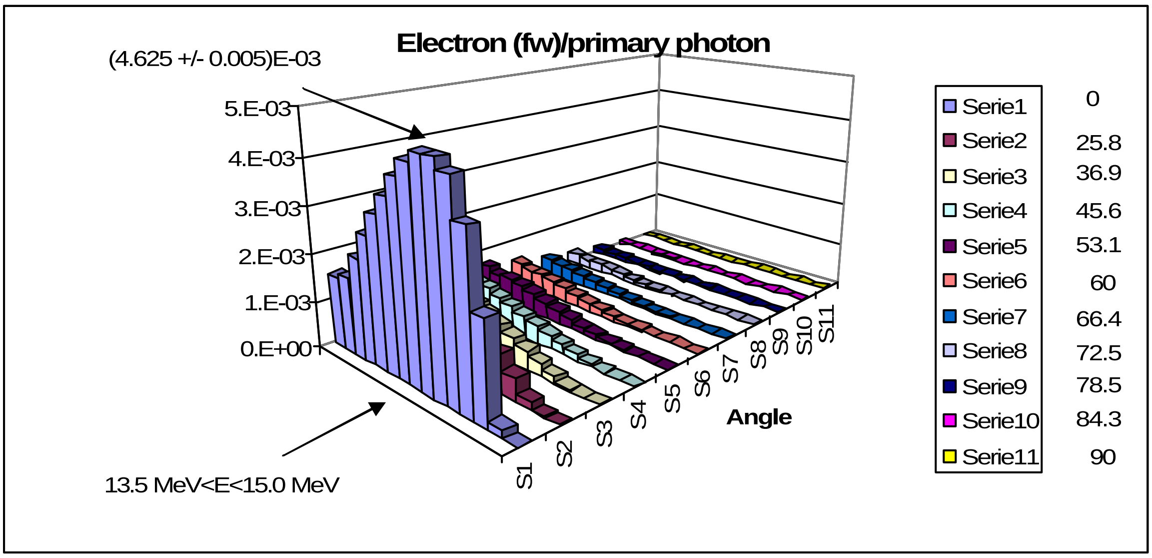

Fig.11. Electron “spectrum” (see text for details) in the forward direction for 20 MeV photon on 1 mm Tungsten.

It can be seen that positron and electrons are emitted from the target have a forward peaked angular distribution while the energy is not very peaked.

The neutrons (about 3 order of magnitude less than electrons and positrons) have a spread angular distribution.

5 CONCLUSIONS

The simulations show that positron production is possible at SPARC-PLASMON-X laboratory with efficiency (positron produced/primary photo) of some percent.

The best target material is Uranium, being the highest Z element; anyway Tungsten (more easily manageable) gives about the same results.

About 38% of the total positron production is in the forward direction.

Secondary neutrons are emitted too; in case of experimental use of the produced positrons shielding may be necessary. Detailed geometry of the target is necessary in case of specific experimental design.

All the secondary beams have the same time structure of the electron beam from the linac (1ps, with 10 Hz repetition rate).

Upgrade of the SPARC-PLASMON-X laboratory to higher photon energy can provide higher energy positrons and other secondary beams (Ref.8) productions.

6 REFERENCES

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