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POLARIZATION STUDY FOR NLC POSITRON SOURCE USING EGS4

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ABSTRACT

SLAC is exploring a polarized positron source to study new physics for the NLC project. The positron source envisioned in this paper consists of a polarized electron source, a 50-MeV electron accelerator, a thin target (≤ 0.2 radiation length) for positron production, and a capture system for high-energy, small angular divergence positrons. The EGS4 code was used to study the yield, energy spectra, emission-angle distribution, and the mean polarization of the positrons emanating from W-Re and Ti targets hit by longitudinally polarized electron and photon beams. To account for polarization within the EGS4 code a method devised by Flöttmann was used, which takes into account polarization transfer for pair production, bremsstrahlung, and Compton interactions. A mean polarization of 0.85 for positrons with energies greater than 25 MeV was obtained. Most of the high-energy positrons were emitted within a forward angle of 20 degrees. The yield of positrons above 25 MeV per incident photon was 0.034, which was about 70 times higher than that obtained with an electron beam.

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INTRODUCTION

SLAC is exploring a polarized positron source to study new physics for the Next Linear Collider (NLC) project. The positron source envisioned [1] consists of a polarized electron source, a 50-MeV electron accelerator, a thin target for positron production, and a capture system for high-energy, small angular divergence positrons.

In the beginning of the study, the positron yield and its spectral and angular distributions for W-Re targets (0.5 to 5 mm thick) struck by 30-MeV electrons were first calculated with EGS4 [2] and FLUKA99 [3]. To check the validity of our polarization calculations, the polarization of positrons from a tungsten target hit by backward-Compton scattered photons calculated by Omori [4] were also compared with our calculated values. In the main work, the EGS4 code was used to study the yield, energy spectra, emission-angle distribution, and the polarization of the positrons emanating from thin targets hit by longitudinally polarized, 50 MeV electron and photon beams.

METHODS

A generalized cylinder-slab EGS4 user code, called ucRTZ.mortran, has been designed to run with the EGS4 Code System that was officially released by the National Research Council of Canada in Canada in January 1997. This version of EGS4 contains all of the latest features, such as the PRESTA-I algorithm for low-energy electron transport and proper sampling of angles following bremsstrahlung and pair-production processes. With the ucRTZ.mortran user code, geometry implementation was facilitated by means of an input file (e.g., ucRTZ.data) that allows the user to specify, among other things, cylindrical shells (concentric with the Z-axis), planes (normal to the Z-axis), and azimuthal planes (parallel to the Z-axis, and rotated at an angle relative to X-axis). The azimuthal-plane feature was not required in the present study.

All materials were prepared with AE=0.521 MeV, UE=100.511 MeV, AP=0.001 MeV, and UP=100 MeV. The material of W-Re has 75% tungsten and 25% rhenium (by weight fraction), a density of 19.65 g cm^{-3}. Unless otherwise specified, the ECUT and PCUT for all regions were set at 1.511 and 1 MeV, respectively.

Flottmann [5] introduced mean polarization calculations into the AUSGAB subroutine of the EGS4 user code. His method, acceptable in high-energy region, considered polarization transfer process only in the bremsstrahlung, pair production and Compton reactions. The depolarization processes in other reactions, e.g., Bhabha and Rayleigh scattering, were not considered. Thus, the polarization calculated using this scheme should represent a higher estimation of the actual polarization. Since we are interested in only high-energy positrons (> a few MeV), the Flottmann's approach is suitable. In this work Flottmann's routines were incorporated into our EGS4 user code.

Only the longitudinal polarization, the fourth Stokes parameter ξ_3 [5], has a long-term stability in an electromagnetic shower development. In the NLC source polarization study, longitudinal polarization is the parameter studied. Positrons from the W-Re and titanium targets (0.2-radiation-length thick) hit by an electron beam (50-MeV kinetic energy and a longitudinal polarization ξ_3=1) were scored as a function of yield, energy-angle distribution, and the polarization. The case of a 50-MeV, polarized photon beam incident on the W-Re target was also studied for comparison.

RESULTS

Spectra and Yield Comparison

Energy spectra of positrons, emanating from the downbeam side of W-Re targets having thicknesses of 0.5, 1, 2 and 5 mm, are given in Figures 1a through 1d for an incident electron with the kinetic energy of 30 MeV (ECUT=0.611 MeV and PCUT=0.1 MeV). The solid histograms are EGS4 calculations (100,000 cases) and the points are the FLUKA99 results (500,000 cases). A special EGS4 run (15,000,000 cases) was also made using cutoffs of 19.9 MeV, and the results are shown as dotted histograms. The agreement is quite good.

In Figure 2 we presents the positron yield (within energy range of 0.1 – 30 MeV) as a function of polar angle emitted from the back plane of the W-Re target at four thicknesses. In Table 1 we compared the positron yields (integrated over all angles) calculated by EGS4 and FLUKA99.

Comparison of Polarization Calculations

Omori of KEK has proposed a polarized positron source design [4] based on electron-positron pair creation from backward-Compton scattered laser photons (maximum energy 60 MeV) hitting a 1.5-mm-thick tungsten target. Omori calculated the positron production and polarization using the EGS4/GRACE codes. To check the validity of our approach, we performed a corresponding calculation. Table 2 shows that the positron yields between Omori's and our results are in good agreement, while the positron polarization values calculated in this work are higher than those of Omori.

Polarization for NLC Positron Source

The NLC decided to explore in detail the positron yield and polarization from thin W-Re and titanium targets hit by monoenergetic, longitudinally polarized electron and photon beam at 50 MeV. The target thickness was 0.2-radiation-length, i.e., 0.06866 cm for W-Re and 0.7124 cm for Ti.

The EGS4-calculated positron spectra from the electron beam hitting the W-Re and Ti target are shown in Figure 3. The yield of high-energy positrons (defined here as above 25 MeV) per incident electron is 0.00048 for the W-Re target and 0.00035 for the Ti target. The corresponding longitudinal polarization of positron as a function of positron energy (relative to beam energy), shown in Figure 4, indicated that the higher the positron energy, the higher the polarization. The mean polarization for positrons above 25 MeV is 0.84 for W-Re and 0.86 for Ti targets.

For the same beam-target condition, Potylitsin [6] calculated analytically a high-energy positron yield of 0.002, about 5 times higher than our EGS4 value. Potylitsin also estimated a mean polarization of 0.6, which is 30% smaller than ours; this could be due to Potylitsin's assumption of linear relationship between photon polarization and photon energy in the bremsstrahlung process (see Figure 3 of [6]). Table 3 summarizes the above comparison between our results and Potylitsin's.

The positron spectrum from a polarized 50-MeV photon beam hitting the W-Re target is shown in Figure 5. The yield of positrons above 25 MeV per incident photon is 0.034, about 70 times higher than that of the electron beam. A comparison of positron polarization from the W-Re target hit by the electron and photon beams is shown in Figure 6. The mean polarization for positrons above 25 MeV is 0.88 for the photon beam, slightly higher than that of the electron beam. On the other hand, for low-energy positrons, the mean polarization from the photon beam is lower than that from the electron beam, although the yield is ~10 time higher. The comparison between electron and photon beams is also shown in Table 3.

The 3-D energy-angle distribution of positrons from the 0.2-radiation-length W-Re target hit by the 50-MeV electron beam, shown in Figure 7, indicates that high-energy positrons are more forward peaked. Figure 8 shows that almost all positrons above 25 MeV are emitted within a small angle of 20 degrees. It was also found that the angular profile of the emitted positrons is not a strong function of beam type or target material.

CONCLUSIONS

High mean longitudinal polarization (>0.8) of positrons above 25 MeV was calculated using EGS4 for a W-Re or Ti target (0.2-radiation-length thick) struck by a electron or photon beam (longitudinally polarized, 50 MeV). Most high-energy positrons were emitted within a forward angle of 20 degrees. The yield of positrons above 25 MeV per incident photon is 0.034, ~70 times higher than that of the electron beam.

ACKNOWLEDGEMENTS

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6. A. P. Potylitsin, "Production of polarized positrons through interaction of longitudinally polarized electrons with thin targets", NIM A398, p.395-398, 1997.

Table 1. Comparison of positron yields from W-Re targets hit by 30-MeV electron beam, calculated between EGS4 and FLUKA99.

W-Re Target Thickness (mm)	0.1 MeV ≤ E ≤ 30 MeV		20 MeV ≤ E ≤ 30 MeV	
	EGS4	FLUKA99	EGS4	FLUKA99
0.5	0.0035	0.0035	0.000056 (11%)	0.000088 (25%)
1.0	0.0099	0.010	0.00013 (7%)	0.00013 (17%)
2.0	0.023	0.024	0.00017 (6%)	0.00019 (3%)
5.0	0.026	0.029	0.00013 (7%)	0.00014 (3%)

Note: W-Re has 75% (by weight) tungsten and 25% rhenium and a density of 19.65 g cm^{-3}.

Table 2. Comparison of positron yield and mean longitudinal polarization from calculations between Omori and this work.

Positron Energy	Positron Yield		Mean Polarization	
	Omori	This Work	Omori	This Work
$E_{e+} > 17$ MeV	0.045	0.047	0.6	0.87
$E_{e+} > 27$ MeV	0.022	0.024	0.8	0.93

Note: Positrons from backward-Compton scattered laser photons (maximum energy 60 MeV) hitting a 1.5-mm-thick tungsten target.

Table 3. Comparison of positron yield and mean longitudinal polarization for positrons > 25 MeV calculated between EGS4 and Potylitsin.

Beam	Target	Positron Yield		Mean Polarization	
		EGS4	Potylitsin	EGS4	Potylitsin
Electron	W-Re	0.00048	0.002	0.84	0.6
	Ti	0.00035		0.86	
Photon	W-Re	0.034	NA	0.88	NA

Note: 0.2-radiation-length target hit by monoenergetic 50-MeV, polarized beam.

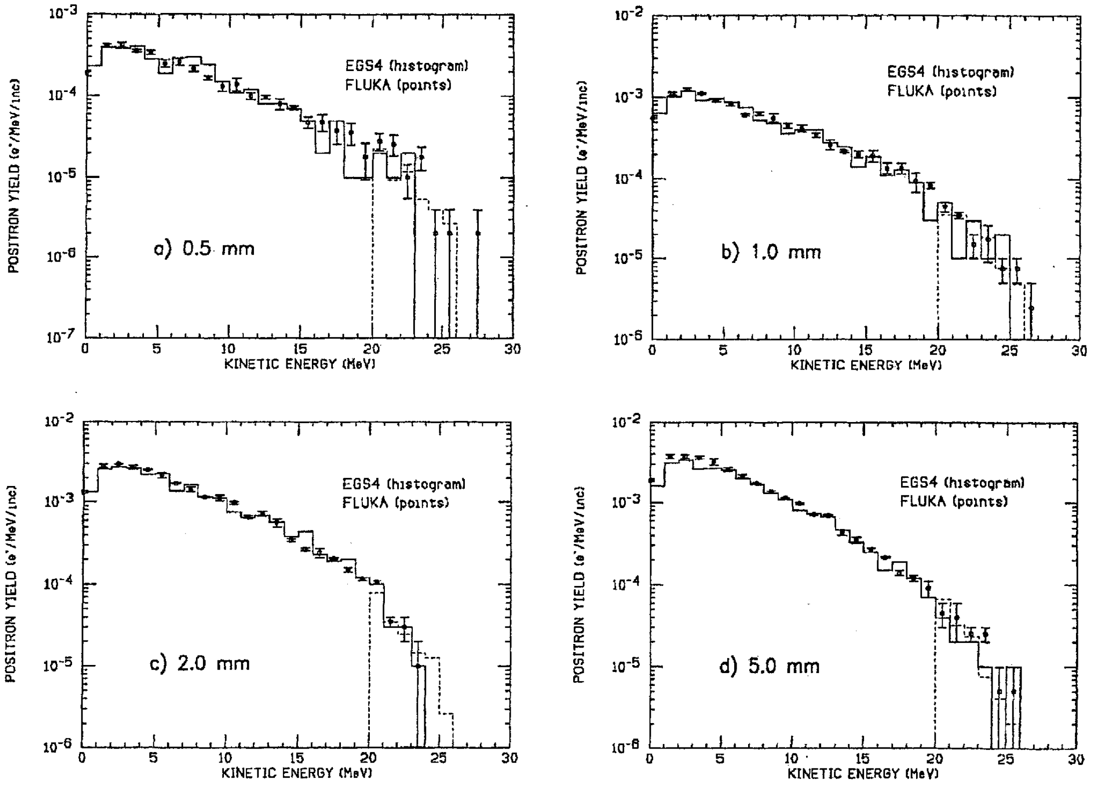

Figure 1. Comparison of energy spectra of positrons, calculated by EGS4 and FLUKA99, emanating from the downbeam side of W-Re targets having thicknesses of 0.5, 1, 2 and 5 mm for an incident electron with the kinetic energy of 30 MeV.

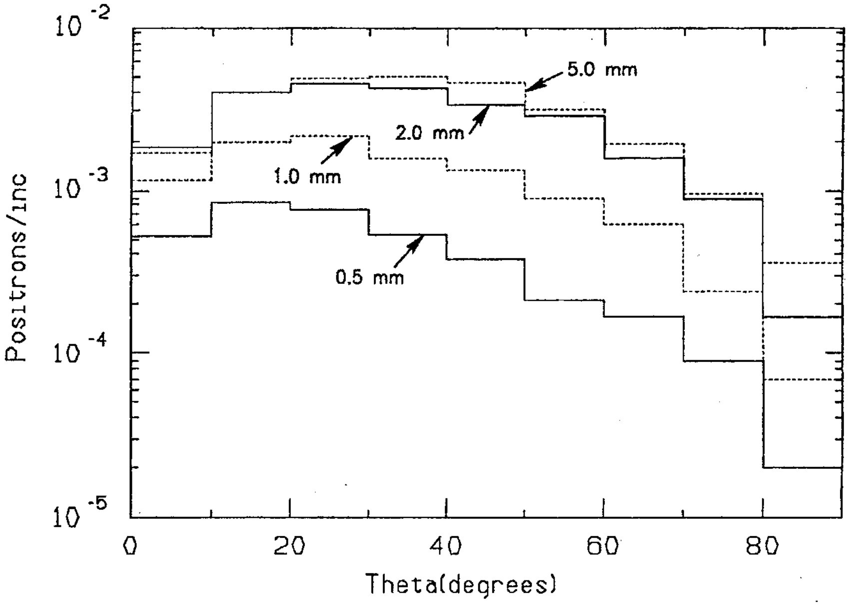

Figure 2. EGS4-calculated positron yield (within energy range of 0.1 – 30 MeV) as a function of polar angle emitted from the back plane of W-Re targets at four thicknesses hit by 30-MeV electron beam.

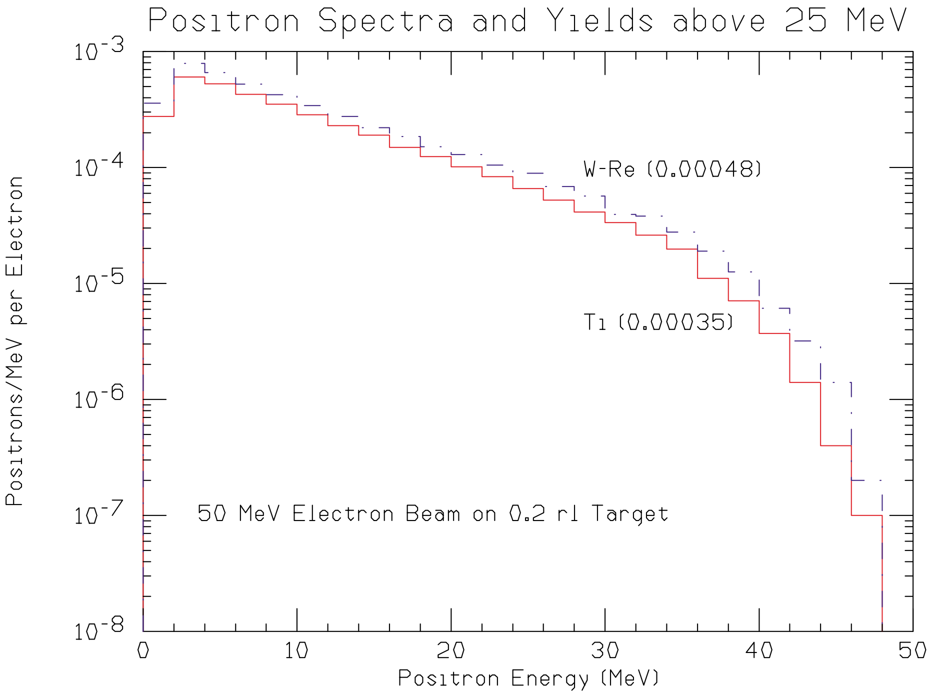

Figure 3. Energy spectra of positrons emanating from a W-Re or Ti target (0.2 radiation length thick) struck by a longitudinally polarized, 50 MeV electron beam. Numbers inside parentheses are the yields for positrons above 25 MeV per beam particle.

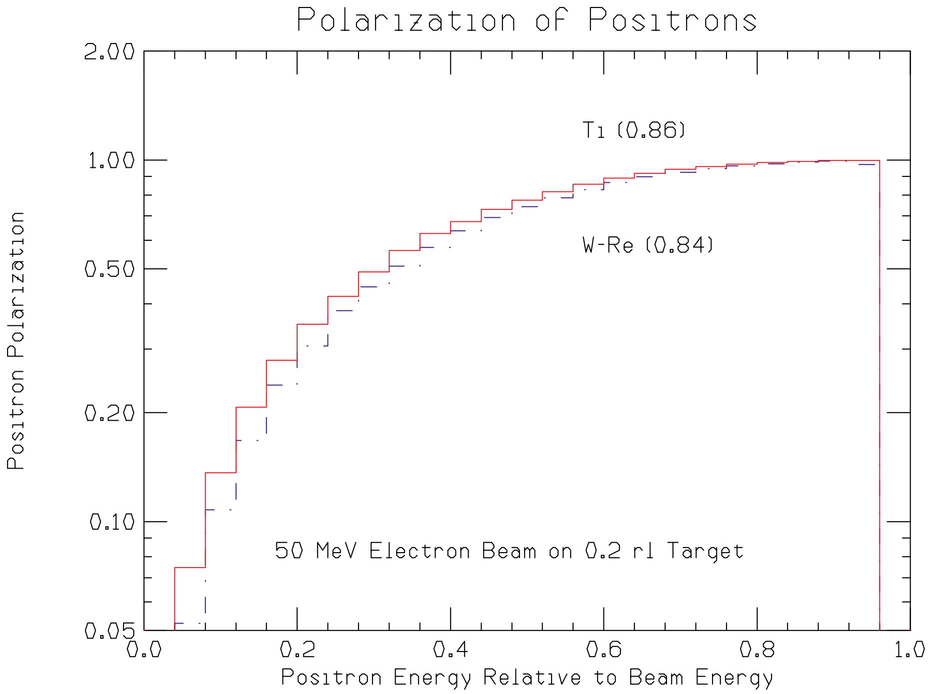

Figure 4. Longitudinal polarization of positron as a function of positron energy, relative to beam energy, from the W-Re and Ti targets hit by a longitudinally polarized electron beam. Numbers inside parentheses are the mean polarization for positrons above 25 MeV.

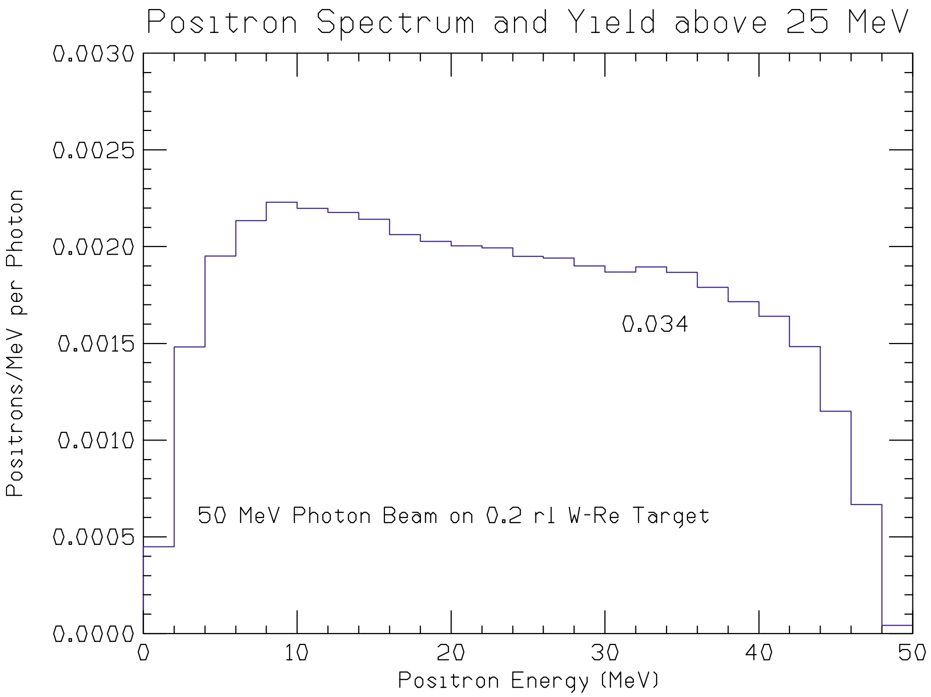

Figure 5. Positron spectrum from the W-Re target hit by a longitudinally polarized, 50-MeV photon beam. Number is the yield for positrons above 25 MeV per beam particle.

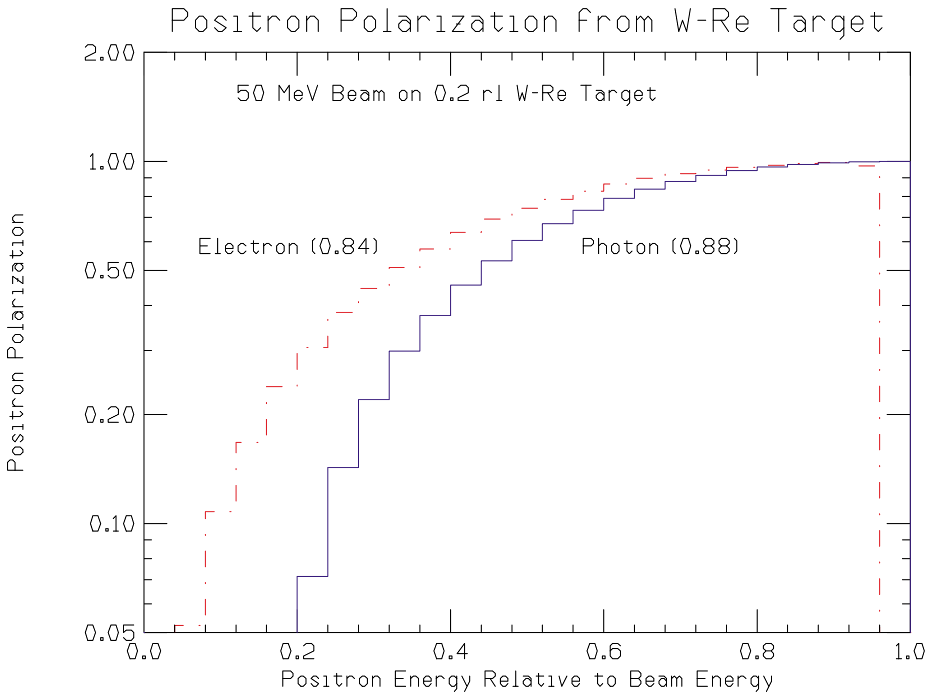

Figure 6. A comparison of longitudinal polarization of positrons from the W-Re target hit by polarized electron and photon beams. Numbers inside parentheses are the mean polarization for positrons above 25 MeV.

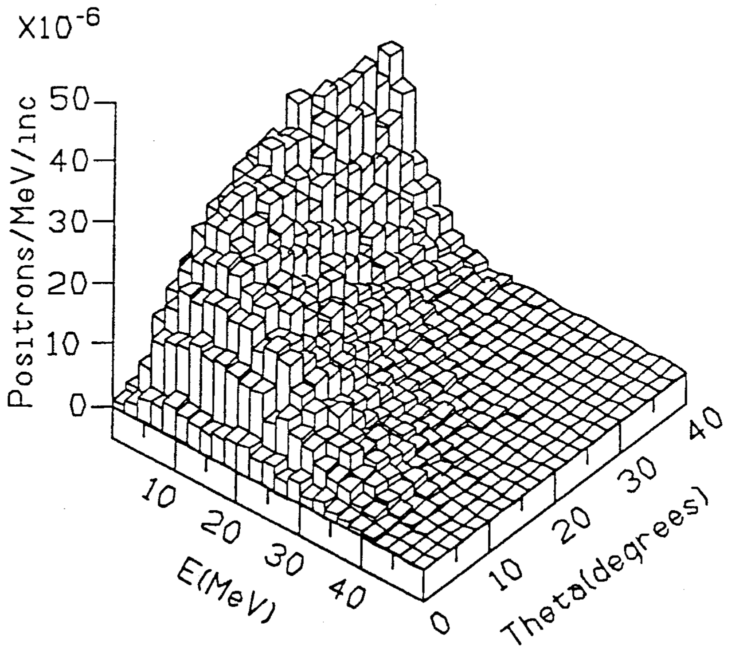

Figure 7. Energy-angle distribution of positrons from the 0.2-radiation-length W-Re target hit by the 50-MeV electron beam.

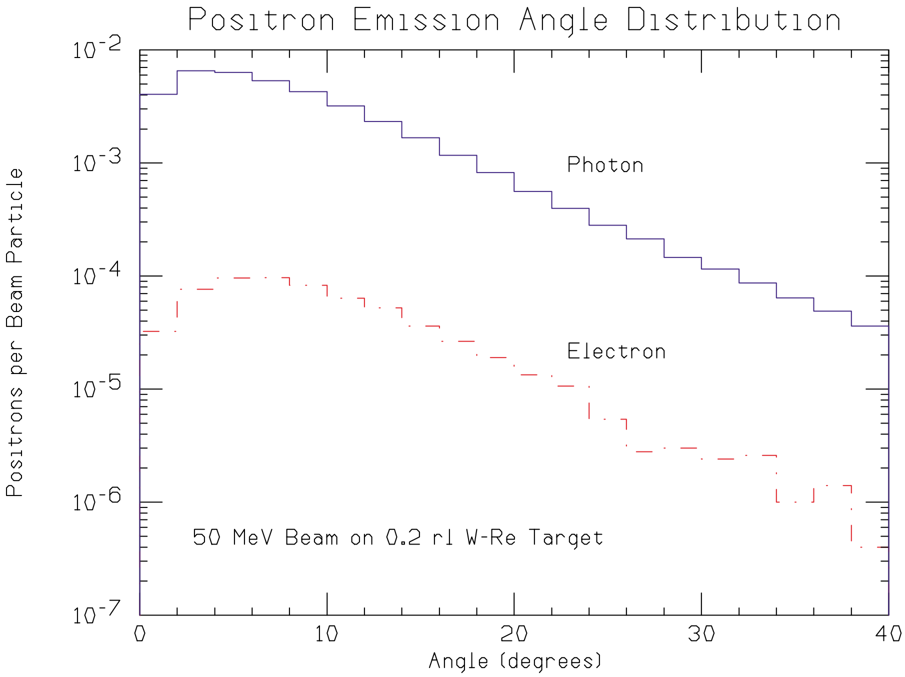

Figure 8. Distribution of emission angle of positrons from the W-Re target struck by electron and photon beams.