On a Possibility of Intense Positron Source for TESLA Based on HERA-e

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Abstract

In this article we perform a general study of possible positron source for linear collider TESLA based on the HERA electron ring. 30 GeV electrons passing 10T wiggler can produce intense synchrotron radiation with characteristic energy of photons of about 6 MeV. High energy photons are converted to few-MeV positrons in a suitable target. The ability of such a source to fit for the TESLA requirements is discussed.

1 Introduction

Linear collider TESLA [1] intends to operate with some 1100 bunches in electron and positron beam each populated with about $3.7 \cdot 10^{10}$ particles. Thus, the linac cycle of 5Hz yields the production requirement of $2 \cdot 10^{14}$ particles per second. While one expects no severe problems with the electron production, several types of the positron source options are now under consideration (see e.g. [2, 3]) which have to fit in requirements of the TESLA linac and damping ring [4]. In particular, one scheme assumes conversion of electrons from a powerful electron linac into positrons in a target [5], and the second concept is based on target conversion of high-energy gamma quanta produced by a high-energy electron beam in short-period helical undulator [6]. Few more sophisticated positron production schemes were discussed at *Sources'94* Workshop [7].

This paper presents a brief consideration of another possible positron production option with use of existing high current HERA electron storage ring - see general layout in Fig.1. The electrons pass some 10T magnetic wiggler (presumably, superconducting) and produce powerful synchrotron radiation (SR) with the characteristic energy of photons of

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about 6 MeV. These photons are converted into positrons in a target and captured by special optics for further acceleration and injection into the TESLA damping ring.

As the mean electron current in the storage ring is much higher than in electron linacs to be used for positron production, then the ring-based scheme may have an advantage in obtaining the required positron production rate.

In the further chapters of this article we consider main characteristics of the synchrotron radiation, study the process of the positron production in the conversion target, derive requirements on positron capture efficiency, and briefly discuss impact on the electron beam and injection into the damping ring.

2 Storage Ring-Based Positron Source

The idea of positron production with use of SR from a storage ring is not new. For example, ring-based sources of slow positrons for technological applications were proposed in Refs.[8, 9]. Few MeV positrons are much more suitable for the Linear Collider sources. Below we discuss several aspects of production of such particles.

2.1 SR from Superconducting Wiggler

Let us estimate the rate of photon production in a wiggler with a high magnetic field. We assume the undulator parameter of the device $K = \theta_{max}\gamma$ to be much bigger than 1, therefore, the known formula of the photon flux density can be applied [10, 11]:

$$\frac{dN_\gamma}{dt\,d\theta}\,[\frac{photons}{s\,mrad}] \approx 3.96\cdot 10^{16}\,E[GeV]\,I[A]\,S(\varepsilon/\varepsilon_c)\frac{\Delta\epsilon}{\epsilon}, \qquad (1)$$

where I is the electron beam current, ε is the photon energy, $S(\varepsilon/\varepsilon_c)$ is the spectral function [11] defined as

$$S(x) = \frac{9\sqrt{3}x}{8\pi}\int_x^\infty K_{5/3}(y)dy, \quad \int_0^\infty S(x)dx = 1 \qquad (2)$$

- the function is plotted in Fig.2.

The characteristic photon energy is

$$\varepsilon_c = 2.218[keV]\,\frac{E^3[GeV]}{R[m]}, \qquad (3)$$

the curvature radius R of electron trajectory in magnetic field B is equal to

$$R[m] = \frac{3.33E[GeV]}{B[T]}. \qquad (4)$$

For B = 10T and energy of HERA-e E = 30 GeV, the radius is equal to R = 10m and characteristic photon energy ε_c = 6 MeV that is much bigger than the $e^- - e^+$ pair production threshold $\varepsilon_{th} = 2m_0c^2 \approx 1.022\,MeV$, or $x_{th} = (\varepsilon_{th}/\varepsilon_c) \approx 0.16$.

Accordingly to Fig.3, the integral of $\int_{x_{th}}^{\infty} S(\varepsilon/\varepsilon_c) \simeq 1$, thus, for the storage ring with $I = 50$ mA the total flux of photons which can produce electron-positron pairs is equal to

$$\frac{dN_\gamma}{dt\, d\theta} \left[\frac{photons}{s \cdot mrad}\right] \approx 6 \cdot 10^{16}. \tag{5}$$

The corresponding power of the SR is about 57 $kW/mrad$.

If we assume the that the total electron current of 50 mA is distributed uniformly between 10 bunches, then each bunch produces some $1.3 \cdot 10^{11}$ $\gamma/mrad$ per single passage through the magnet with the HERA revolution frequency of 47 kHz.

2.2 Positron Production

The process of positron production and interaction with the target material involves several physical phenomena (pair creation, ionization losses, scattering, etc.). Some analytical estimations of the conversion efficiency can be found elsewhere (see, e.g [8, 2, 9] and references there). Our further consideration is based on computer simulations [12].

All the results below are obtained for tungsten target (3.5 mm radiation length) under the following parameters: the distance from the 8T magnet to the target is 10 m, the width of the target is w =10 mm (therefore, horizontal angular size of the target is $\theta = 1\, mrad$), its height is 0.3mm, the thickness of the target is 10 mm. In a good accordance with Eq.(1), the code estimates the photon flux on the target of $5 \cdot 10^{16}$ photons per second in the photon energy range from 1.022 MeV to 20 MeV (see Fig.4). Fig.5 shows histogram kinetic energy – the angle of leaving the target $E_{kin} - -\Theta$ for the emitted positrons. The conversion efficiency is of the order of $N_{e^+}/N_{gamma} \simeq 0.11$. For SR from 10T magnet this value arises up to $\simeq$0.13.

Fig.6 and Fig.7 present energy and angular distribution of the positrons correspondingly. One can see that the mean particles energy is about 2 MeV while the FWHM of the energy distribution is some 3 MeV. Positrons leave the target in orthogonal plane to the orbit of HERA-e with broad spread of angles $\simeq \pi/2$ rad.

2.3 Capture Efficiency and Injection Scheme

The efficiency of the capture optics and acceptance of further acceleration are key issues for the source. Major problems to solve are to capture as many particles as possible and, at the same time, to avoid unacceptable pulse lengthening (initially the rms length of the HERA-e bunch is about 1 cm) when the pulse can not be accelerated as a whole. For the considered source, a two stage system could be proposed which consists of initial part with low frequency RF (e.g., 500 MHz) acceleration up to 20-30 MeV with large transverse and longitudinal acceptance, weak longitudinal magnetic field in the section, as high as possible pulsed magnetic field at the target position and/or other measure to focus positrons leaving the target. Then the bunch has to be compressed in α-magnet or other magnetic structure for further acceleration to some 3 GeV in the high gradient S-band accelerating structure.

We will characterize the capture efficiency by a factor of $\eta = N^{e^+}_{accelerated}/N^{e^+}_{produced}$. Assuming the angular width of the target equal to θ, each of 10 HERA-e bunches passing the wiggler with N_P periods gives outcome of:

$$N_{e^+} = 1.3 \cdot 10^{11} \cdot 0.13 \cdot \eta \cdot N_P \cdot \theta = 1.7 \cdot 10^{10} \cdot \eta N_P \theta. \tag{6}$$

The TESLA damping ring requires bunch population of $3.7 \cdot 10^{10}$ which can be obtained with multi- or single-turn injection. At present time, the multiturn injection into the ring does not look very attractive because due to limited linac shot cycle of 200 ms the damping time have to be reduced down to some 5–10 ms (compare with the design value of 37 ms [4]) that needs several times longer damping wiggler and more powerful RF system.

Thus, the better choice is single-turn bunch-by-bunch injection. Comparison of the design bunch population with (6) yields the requirement:

$$\eta \cdot N_P \cdot \theta \approx 2.2. \tag{7}$$

Taking as an optimistic estimate the value $\eta = 0.25$, we get for the single pole wiggler $\theta \approx 8.7$ mrad. As an example, the target could be 2 cm wide and set at the distance of 2.3 m from the wiggler. Corresponding wiggler pole length has to be more than $\theta R = 8.7$ cm. The total radiated SR power is equal to 0.5 MW which requires rotating or liquid target as it is assumed in other e^+ sources for LC [2].

If (7) is satisfied, then filling of the TESLA DR with use of 10 bunches in HERA-e will take 110 revolutions, or about 2.3 ms. It is much less than 200 ms of the TESLA linac repetition time and allows to use the bypass with the wiggler in the pulsed regime while all other time the HERA-e ring can work for high energy physics experiments.

2.4 Effects on the Electron Beam

The vertical tune shift and distortion of the amplitude function due to installation of the wiggler are estimated to be $\Delta\nu_y \simeq 0.001$ and $(\Delta\beta_y)/\beta_y \leq 1$ % that could be compensated by tuning the strength of nearby quadrupoles.

While some 10 MeV energy loss of 30-GeV electrons in the 9-cm long 10T wiggler is much less than the total losses of 70 MeV/turn in HERA-e, than the effects on the electrons' damping times, energy spread and emittances does not look drastic, although not negligible. Certainly, these effects are weak if the bypass will operates in the pulsed mode.

Other important issues such as changes of dynamic aperture due to the wiggler installation and the electron beam stability in the presence of the SR absorbers, collimators and other discontinuities of vacuum chamber have to be checked numerically as soon as more detailed design of the source will appear.

3 Discussion and Conclusions

The proposed scheme of positron production – through conversion of energetic photons of synchrotron radiation from 30 GeV electrons of HERA in the target material – looks very promising and fits into the TESLA requirements, although further detailed studies of the positron production efficiency, the target, the capture optics and acceleration systems optimization are necessary. The efficiency of the positron capture looks the most important parameter to investigate.

An obvious disadvantage of the source is that it needs operation of the HERA-electron ring (although with a small duty factor).

As the 5 mA single bunch current looks to be an upper limit for HERA-e [13], we would note a possibility of further increase of positron production with use of several-poles wiggler or a wiggler with higher field. An experience with construction and exploitation of "state-of-the-art" high field magnets (see e.g. [14]) has shown a good field quality in them.

We would like also note that with the use of elliptical wiggler the proposed scheme allows to obtain polarized photons and therefore, polarized positrons. This topic also needs thorough numerical studies.

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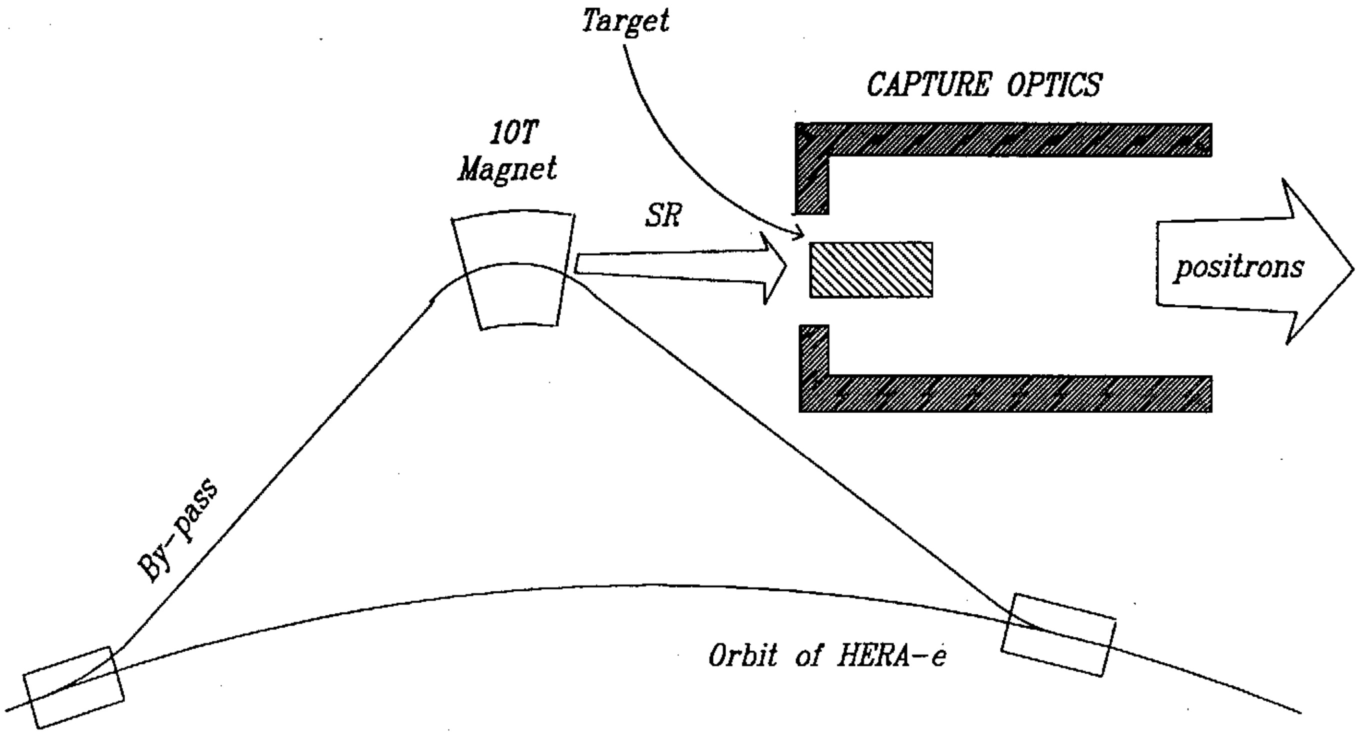

Fig.1: General layout of the positron source.

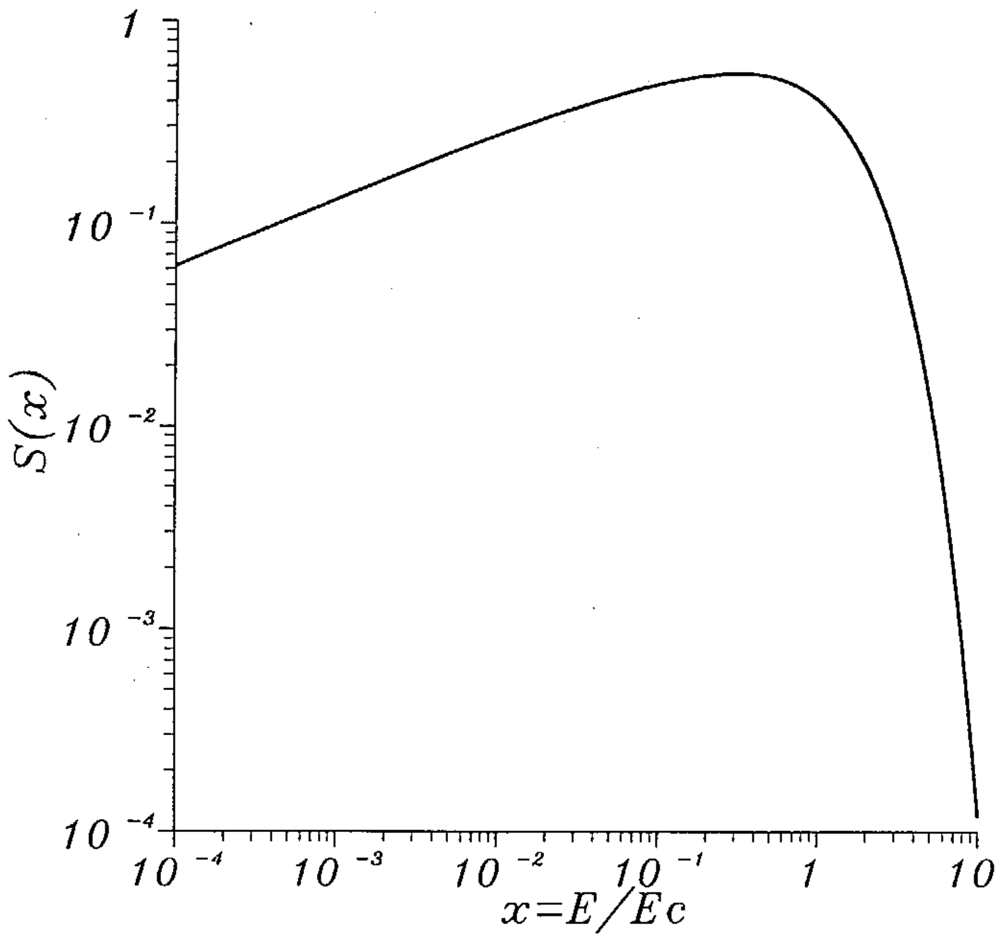

Fig.2: Spectral function $S(x)$ versus $x = \varepsilon/\varepsilon_c$

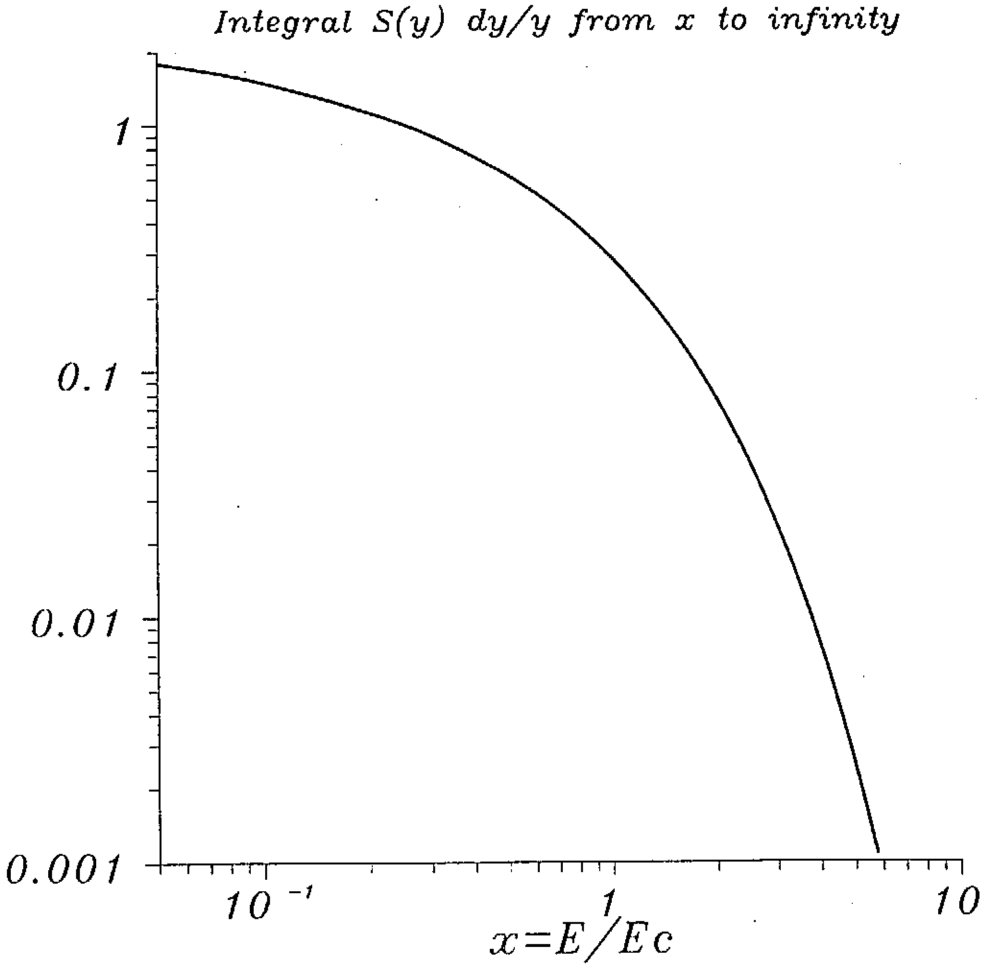

Fig.3: Integral $\int\limits_x^\infty dy S(y)/y$.

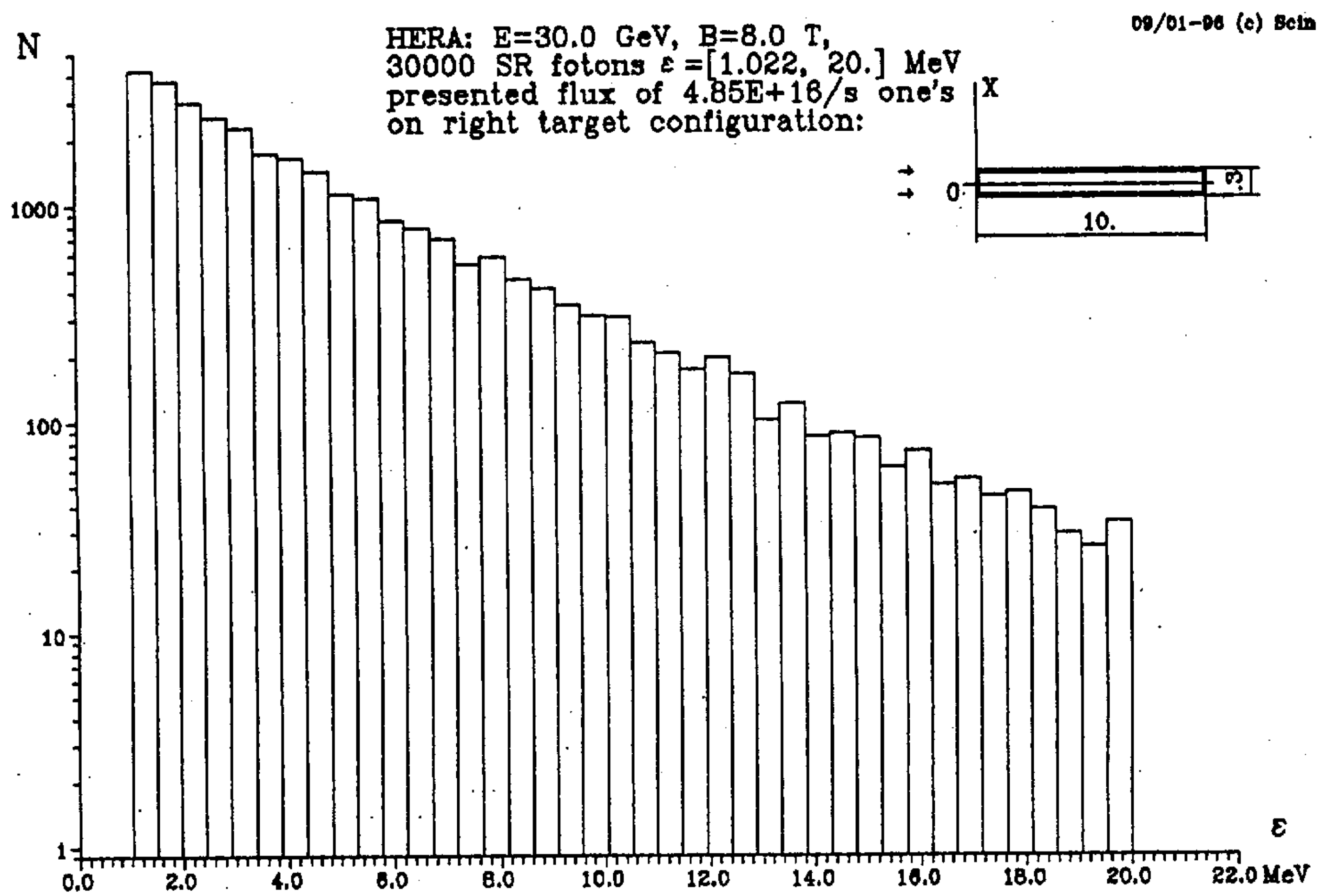

Fig.4: Histogram of SR photon flux distribution over photon energy ε for 8T wiggler, $I = 50$ mA, vertical center slit 0.3 mm, distance to the target 10 m, within horizontal angle of 1 mrad.

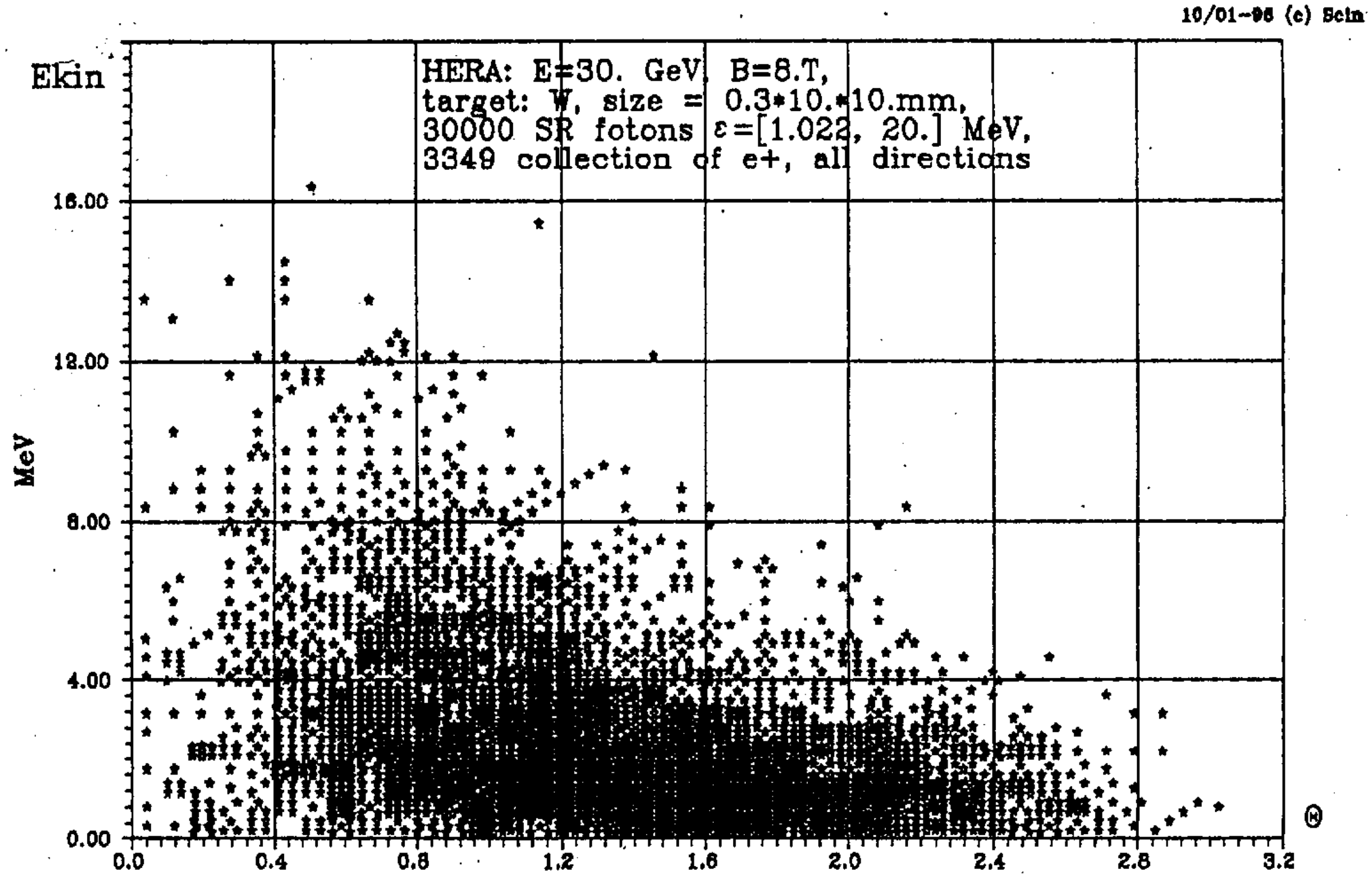

Fig.5: Histogram of $\Theta - E_{kin}$ for positrons from SR photons, tungsten target size $0.3 \times 10 \times 10$ mm, photon energies 1.022–20 MeV, all positrons are emitted from the target.

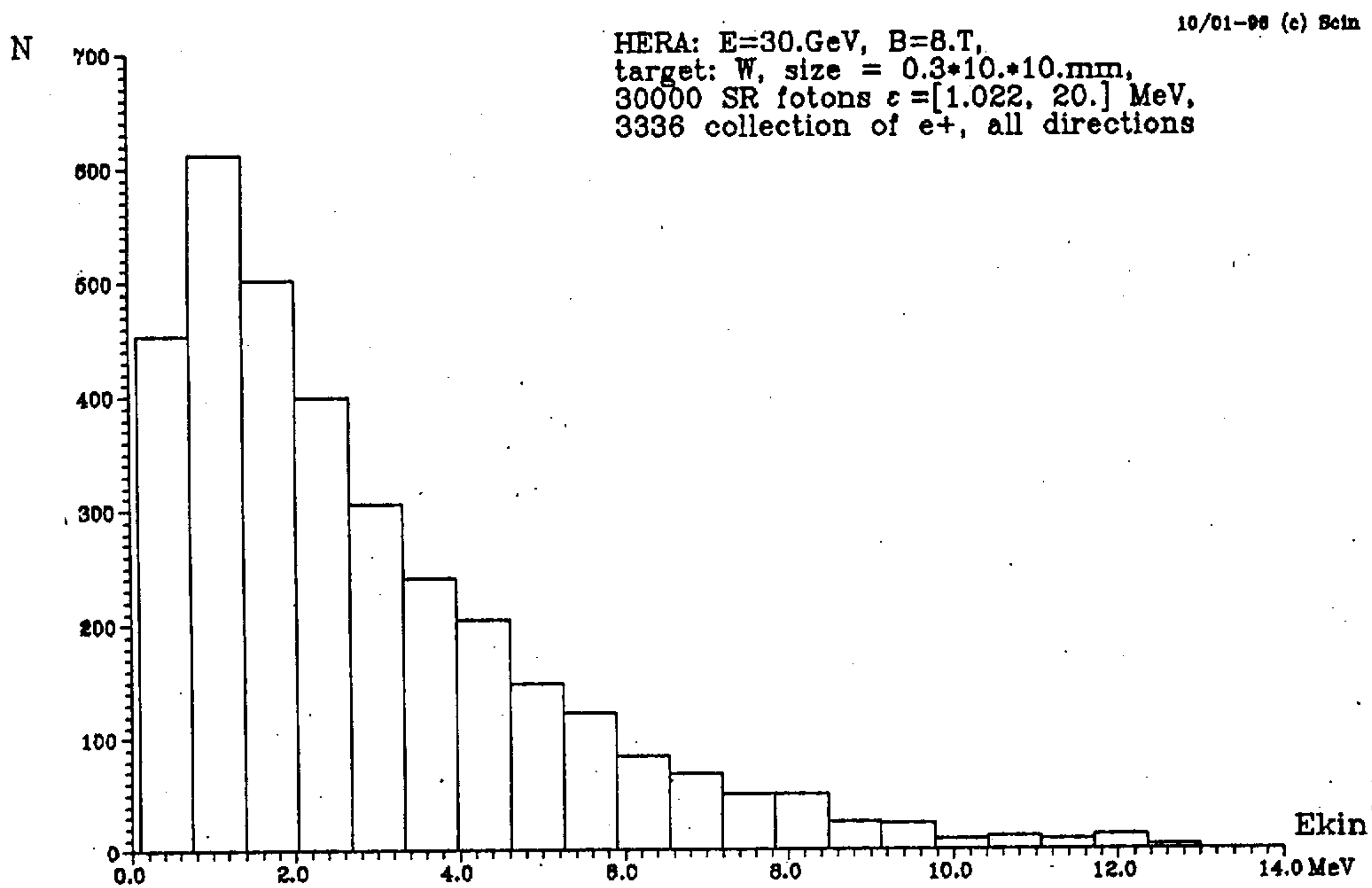

Fig.6: Distribution over E_{kin} for positrons from SR photons, tungsten target size $0.3 \times 10 \times 10$ mm, photon energies 1.022–20 MeV, all positrons are emitted from the target.

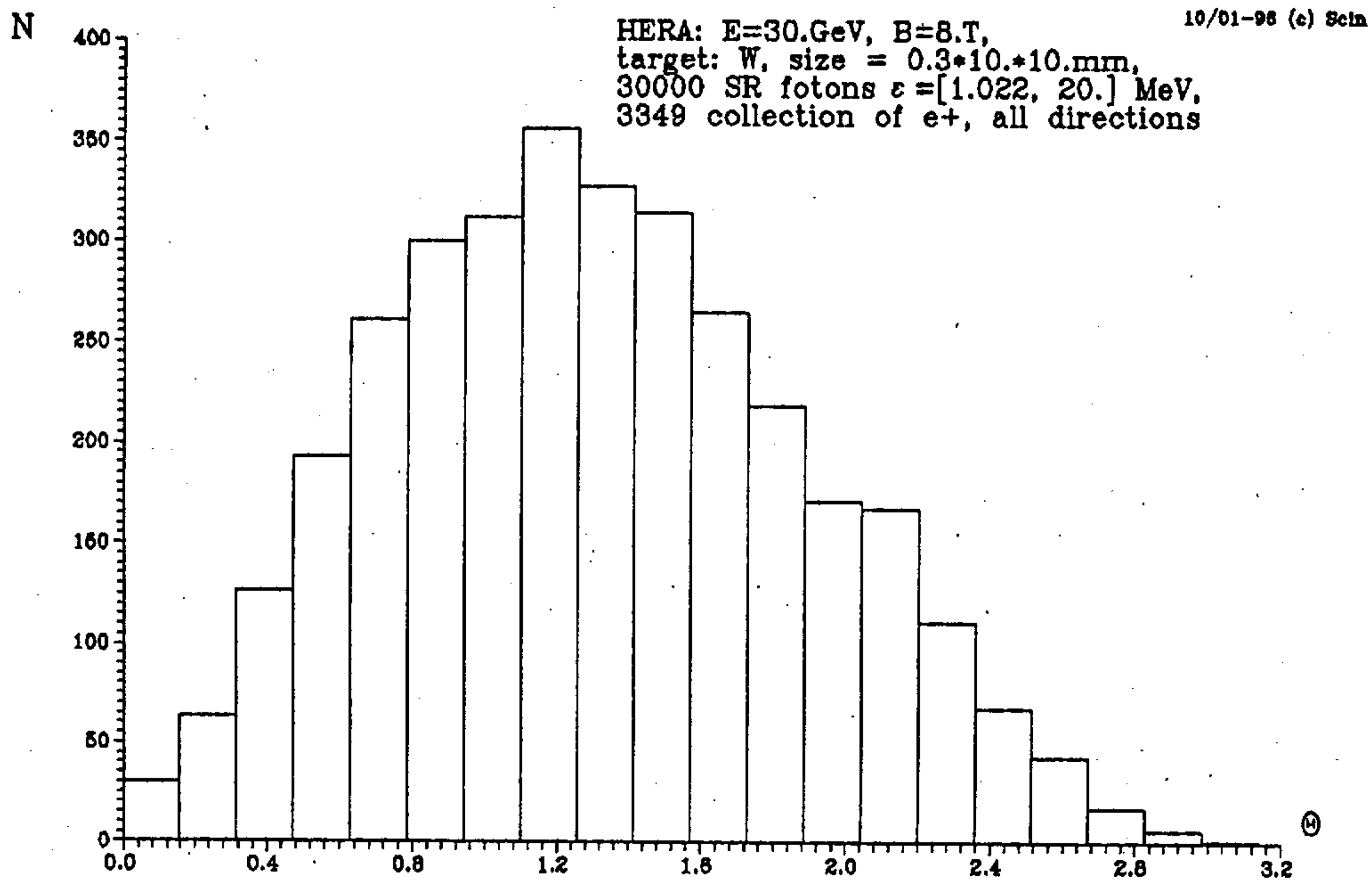

Fig.7: Distribution over Θ for positrons from SR photons, tungsten target size $0.3 \times 10 \times 10$ mm, photon energies 1.022–20 MeV, all positrons are emitted from target.