A POLARIZED POSITRON SOURCE FOR LINEAR COLLIDERS

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Abstract

We propose a design of polarized e^+ source for linear colliders. The design is based on e^-e^+ pair creation from backward-Compton scattered laser photons. Future linear colliders of TeV-energy region require large number of e^+'s in multi-bunch time structure. In this article, we show a possible design to meet this requirement.

1 INTRODUCTION

A polarized beam is an useful tool to study particle physics in e^-e^+ colliders. It can enhance certain type of interactions, can suppress certain background interactions, can resolve weak mixing of particle components, etc.

Polarized e^-'s can be photoemitted from a semiconductor cathode. Recent developments of semiconductor photocathode having high polarization[1, 2, 3] makes polarized e^- beams more powerful in physics study. Especially, an accurate measurement of $\sin^2\theta_W$ by using the polarized e^- beam in SLC gives an impressive example [4]. A polarized e^- beam, also, will be very useful in future linear colliders of TeV-energy region. For example, if we choose right-hand[1] polarization of e^-'s, it can suppress W^-W^+ pair production which is the most serious background in many studies.

If we prepare a polarized e^+ beam as well as polarized e^- beam in a linear collider, we call it double beam polarization, the power of polarized beams are enhanced significantly[5]. First, W^-W^+ pair production can be suppressed farther more, if we choose the polarities of an e^- beam in right-hand and an e^+ beam in left-hand. Second, this combination of beam polarities increase rate of e^-e^+ interactions through intermediate vector bosons. Since in many cases new particles will be produced through vector bosons, double beam polarization will increase number of new particles produced. By both the first and the second points, we expect significant improvement of S/N ratio in new particle searches. Third, double beam polarization reduces systematic error coming from polarization measurement of each beam[6]. Fourth, if we choose both e^- and e^+ beams in right-hand, most of the standard-model processes are suppressed significantly[2]. Then interactions, for example, such as $e^+e^- \to \tilde{e}^-\tilde{\chi}^+\bar{\nu}_e$, $\tilde{e}^-\tilde{e}^+q\bar{q}$, $e^-W^+\bar{\nu}_e$, can be observed without being subject to backgrounds[3]. Finally, we mention usage of transverse polarization[7]. To realize an effect of transverse polarization, both beams must be polarized. Since a transversely polarized state is a linear combination of longitudinally polarized states, the effect of new physics can be observed through the interference between initial states which have different combinations of longitudinal polarizations of e^- and e^+.

Although polarization of an e^+ beam is very useful, progress of it's development was rather slow. Since a e^+ is an anti-particle and thus there is no e^+ in material, we should *create* them. This makes development of a polarized e^+ source difficult. There are typically two methods to create polarized e^+'s. One is to use β^+ decay of radioisotopes; naturally existed isotopes[8] or short life isotopes produced by an accelerator[9]. However, e^+ beams thus generated are essentially DC, and hence are not appropriate for linear colliders. The other method is to use e^-e^+ pair creation from circularly polarized γ-rays. To create circularly polarized γ-rays, Balakin and Michailichenko proposed to use a high energy e^- beam running through a long helical undulater[10]. This proposal, however, needs very large facility to meet requirements of linear colliders, for example energy of an e^- beam being $\sim 100\,GeV$ and length of an undulater being $\sim 100\,m$. In this article, we propose a relatively compact facility to create polarized e^+'s for linear colliders by using backward Compton scattered laser photons[11].

2 PROPOSED DESIGN

Figure 1 shows principle configuration of proposed e^+ source. Laser light is backward scattered by an e^- beam. We choose CO_2 laser with photon energy of $0.117eV$ as a light source. Energy of the e^- beam is chosen to be $5.8GeV$.

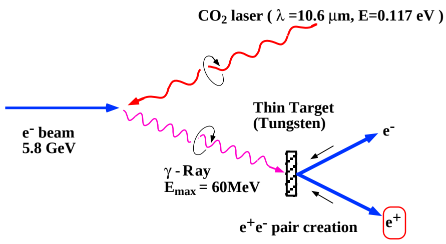

Figure 1: Basic scheme of the polarized positron source.

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[1] In this article, when the direction of a particle spin and the direction of momentum is parallel, we call it right-handed. We use this definition both for e^-'s (particles) and for e^+'s (anti-particles), as well as for photons.

[2] Two-photon interaction still has large cross section.

[3] In the both left polarization, the similar situation also is expected.

This configuration has many advantages as follows. The total cross section of Compton scattering is large; $658mb$. The maximum energy of scattered γ-ray is $60MeV$. In this energy region the cross section of e^-e^+ pair creation on Tungsten (**W**) target is also large, i.e. order of $\sim 10000\,mb$. The maximum energy of created e^+'s is $60MeV$. This energy is suitable (not too high) to capture e^+'s by the combination of solenoid magnetic field and RF acceleration. A CO_2 laser has high power and high efficiency. Since photon energy of a CO_2 laser is small, number of photons in a pulse of certain energy is large. This makes probability of laser-e^- collision large. Since required energy to the e^- beam is not too high, an accelerator to provide the e^- beam can be not too large. This contributes whole facility to be moderate size. Since energy of scattered γ-rays is much smaller than energy of the e^- beam, one e^- can generate several γ's successively. This helps to make number of scattered γ's large.

Differential cross section of Compton scattering as a function of final photon energy is shown in Fig.2, where the laser light is assumed to be right-handed circularly polarized. In Fig.2 circles (filled squares) show contribution of left-handed (right-handed) final photons. Crosses show sum of them. As shown in Fig.2, if incident laser light is right-handed circularly polarized, Compton-scattered photons are left-handed polarized in high energy part of the spectrum.

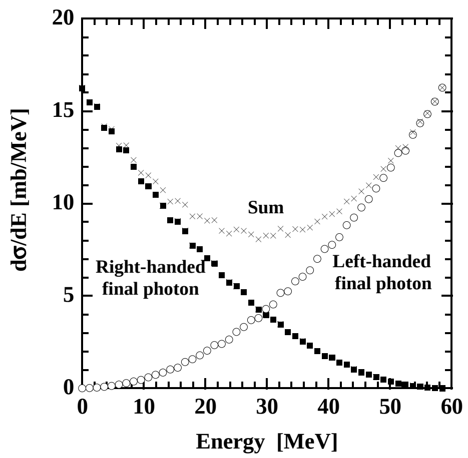

Figure 2: Differential cross section of Compton scattering. Calculated by using GRACE[12]

Then Compton scattered photons (γ-rays) hit a thin **W**-target, and some of them are converted into e^-e^+ pairs. Created e^+'s (e^-'s) on the target are also polarized longitudinally in high energy part of the spectrum. Figure 3 shows production rate of e^+s, as a function of energy, per one incident photon on 1.5 mm-thick **W**-target. The total production rate is calculated to be 9.6%. Here incident photons are assumed to have energy and polarization distributions shown in the Fig.2. In Fig.3, circles (filled squares) show production of left-handed (right-handed) e^+'s. Crosses show sum of them. Figure 3 shows, if we collect e^+'s having relatively high energy, we can generate polarized e^+ beam. When we collect e^+'s which energy are higher than 17 (27) MeV, the resultant polarization is 60% (80%) and the production rate becomes 4.5 (2.2) %.

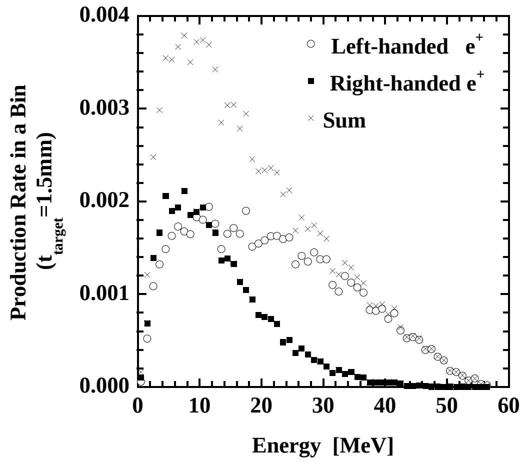

Figure 3: Production rate of positrons per one photon. Calculated by using GRACE[12] and EGS[13]

Although the principle of our scheme is very simple, the application to proposed linear colliders of TeV-energy region is rather difficult, because these linear colliders require huge number of e^+'s in a very short pulse. In this article, we choose JLC[15] as an example of TeV-energy linear colliders. Figure 4 shows requirements to the JLC e^+ source. JLC beam has complicated time structure. The repetition of RF pulse of the linear accelerator is 150 Hz. Each RF pulse (each train) has 85 bunches with $1.4nsec$ interval. Each bunch contains 0.7×10^{10} e^+'s. This large number is problem as well as time structure.

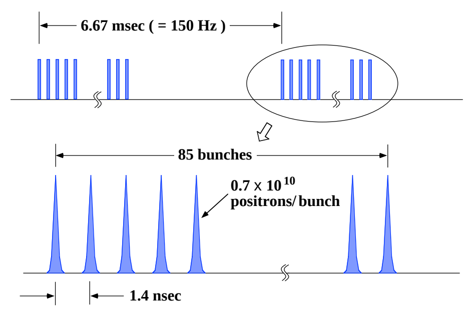

Figure 4: Requirements of JLC beam.

To meet those requirements, we propose the design as shown in Fig.5. We employ a high current multi-bunch e^- linac which has the same time structure as that of JLC. Each bunch has 1×10^{11} e^-'s. An RF-gun is adopted as a e^- source of this linac, to produce low emittance beam. The normalized emittance of the beam is assumed to be 1×10^{-5} rad-m. The focus system has $\beta^* = 0.5m$. The combination of low emittance and this focus system makes small spot size of the e^- beam at the focal point as well as at the point $\pm 1m$ away from the focal point. The spot size (σ_x and σ_y) at the focal point (at the point $\pm 1m$ away from the focal point) is 21 (46) μm. This long well-focused region helps efficient production of γ-rays.

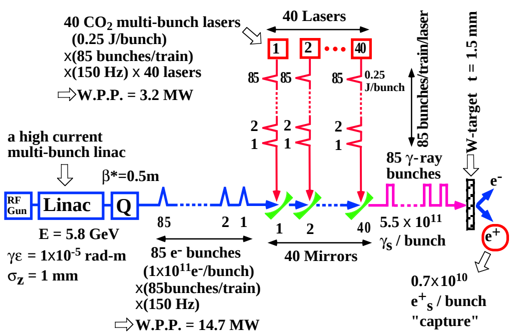

Figure 5: Schematic design of the positron source.

As a light source, we employ 40 CO_2 lasers. Each laser generates multi-bunch pulse whose time structure is the same as that of the JLC accelerator. Each laser bunch has energy of $0.25J$.

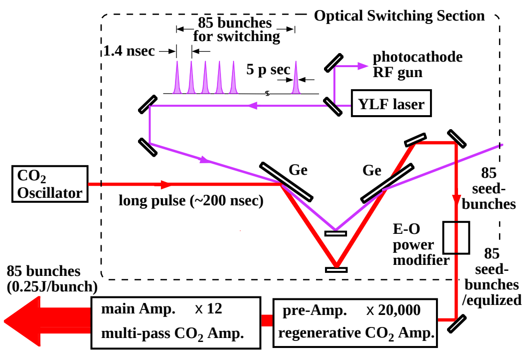

Figure 6: Schematic design of the laser system.

Figure 6 shows how to generate multi-bunch laser pulse. A long, $\sim 200\ nsec$, pulse which energy is $\sim 0.1\ J$ is generated by a CO_2 oscillator (150Hz). Then the long pulse is sliced into 85 seed-bunches, by reflection and transmission **Ge**-plate switching[16]. Reflectivity/transparency of **Ge**-plates are controlled by a multi-bunch pico-second YLF laser. After slicing, energy of 85 seed-bunches are not equal. Then a E-O power modifier is adopted to equalize energy of all seed-bunches. Then 85 seed-bunches are amplified by a pre-amplifier and a main amplifier. Finally we obtain 85 bunches; each bunch contains $0.25J$ in it. A time width of each bunch is $\sim 10\ psec$. 40 sets of a pre-amplifier and a main amplifier are employed to prepare 40 laser beams (in Fig.6, only one set is drawn).

Then 40 concave mirrors are employed to make head-on collisions of an e^- beam and laser beams, as shown in Fig.5. The 40 mirrors are located within $\pm 1m$ of the focal point of the e^- beam. The space between adjacent mirrors is $\sim 50\,mm$. The i-th bunch of an e^- beam collides with 40 of i-th bunches provided by 40 lasers. Each mirror has a small hole at it's center, so that the e^- beam and produced γ-rays pass through the array of 40 mirrors. Each laser beam is focused by each mirror. The r.m.s. spot size of the laser beam is $15.5\mu m$. The peak power of a laser bunch at the focal point is $2.2 \times 10^{19} W/m^2$. In this peak power, the effect of non-linear QED is still small, and then the effect decrease the polarization degree of scattered γ-rays by $\sim 10\,\%$ (estimated by using CAIN[14]). In average, one e^- collides with 5.5 laser photons, so that finally $5.5 \times 10^{11} \gamma\text{-}rays/bunch$ are produced. If we employ 1.5 mm-thick **W**-plate as a converter, we will get $5.3 \times 10^{10} e^+/bunch$. Therefore, if we capture 14% of them mainly from higher part of the energy spectrum (for example higher than $17MeV$), we can produce a polarized positron beam whose intensity is $0.7 \times 10^{10} e^+/bunch$. The study of a capture system to meet above requirements is now in progress. Preliminary simulation shows the capture efficiency of $\sim 7\,\%$ being half as small as the required one. However, since there are many points which can be improved, we expect that we will obtain the design of the capture system having required performance.

Finally, we estimate the power consumption. If we assume total power efficiency of the e^- linac (40 CO_2 lasers) is 8 (4) %, the required wall-plug-power is $\sim 14.7\ (3.2) MW$. Then $\sim 18\ MW$ is required in total. This is about 10% of whole JLC facility. Since a polarized e^+ beam will be so useful, we think the required power is reasonable.

3 ACKNOWLEDGMENTS

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