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ABSTRACT

We have so far been carrying out systematic investigations to create polarized e^+ on the basis of two new methods. Here I describe technical aspects on productions of polarized e^+ beams and measurements of the polarization. I also present new ideas to realize polarized positron beams for future e^+e^- linear colliders. Some examples are given for possible physics performed advantageously by using polarized e^+ beams.

1. Introduction

From the point of view of high energy physics, polarized e^+ beams should be effectively utilized in next generation e^+e^- colliders. Within the framework of the Standard Model, e^+ and e^- always interact in their combination of $e_R^+e_L^-$ and $e_L^+e_R^-$ except in the case of two photon interactions. However in studying new physics beyond the Standard Model, the polarization of e^+ beams would play essential roles because some models allow interactions in "wrong" combinations $e_R^+e_R^-$ and $e_L^+e_L^-$.

Since there might be long time and drastic progress of accelerator technology will be expected before polarized e^+ beams are actually realized in future linear colliders(LC), we therefore attempt to create polarized e^+ on the basis of possible two ideas, one of which will be later decided to adopt for LC.

In this paper, I report the present status of technical development of creating polarized e^+ and propose ideas to realize polarized e^+ beams in the future linear colliders[1]. I demonstrate some physics which we will be able to carry out advantageously using the polarized e^+ beams.

2. Creation of Polarized Positrons

2.1. β^+ Decay Method

The first method, i.e. a β^+ deay method, is besed on the fact that e^+ emitted through β^+ decays are longitudinally polarized with the helicity v/c, v and c being the velocities of e^+ and light respectively. A radioisotope ^{27}Si with the half-life of 4.1 sec and the maximum β^+ energy of 3.85 MeV is produded in on-line manner by a compact cyclotron[2] through the nuclear reaction $^{27}Al(p,n)^{27}Si$. A saturated radioactivity in the Al target of 1.8 mm thickness is estimated as 0.2 mCi for the proton enrgy of 18 MeV and the current of 1 μA. The fraction of β^+ with wide energy spread is thermarized in a moderator of 25 μm thick polycrystal W foil, so that e^+'s are re-emitted with the energy of about 2 eV corresponding to the negative work-function of W. The calculated intensity of the slow e^+ is 4.3×10^5 /sec for the re-emission efficiency of the moderator 10^{-4}. The slow e^+ thus produced is transported to the polarimeter set 27 m downstream using a 100 G magnetic field supplied by solenoid coils. Fig.1 shows a schematic view of the slow positron production system.

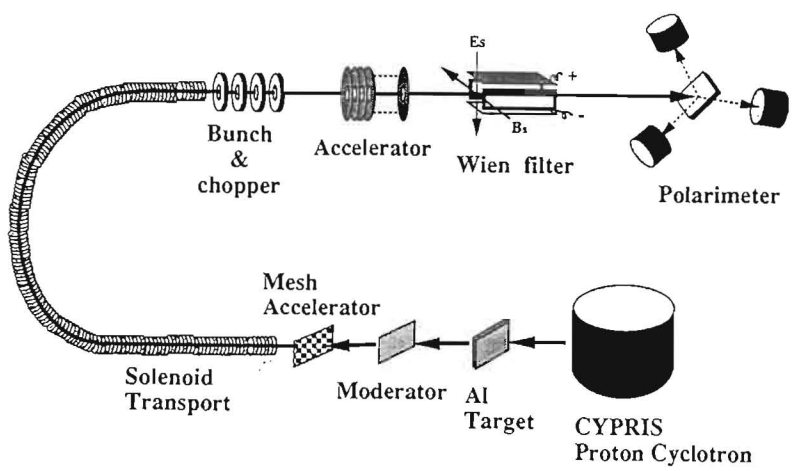

Fig. 1 Schematic view of the experimental apparatus.

In order to simulate the trajectory and polarization of the slow e^+ in static electric and magnetic fields, we have been developing the Monte Carlo program POEM (POlarized beam simulator in Electric and Magnetic fields) based on GEANT[3]. First we calculate E and B in various components equipped along the beam transport system using the program POISCR[4] and then simulate the trajectory and the magnitude of the spin precession by means of POEM. The depolarization due to multiple coulomb scattering in materials, i.e. Al and W is also simulated under the asumption that the magnetic field is

absent in the materials. We can thus estimate the depolarization as 12% for the Al target and 4% for the W moderator.

In the external magnetic field B, the singlet state of a positronium (para-Ps) and the sub-states (m=0) of the triplet state (ortho-Ps) are perturbed to form two mixed states, i. e. the ortho-like-Ps and para-like-Ps, while other triplet sub-states with $m=\pm 1$ are not perturbed. For sufficiently long times beyond the singlet decay and the prompt peak of free annihilation, the time spectrum of positronium decays in the magnetic field B can practically be written as

$$\frac{dN(t)}{dt} = N_0\left[\tfrac{1}{2}\lambda_T e^{-\lambda_T t} + \tfrac{1}{4}(1-\varepsilon P\cos\phi)\lambda_T^{'} e^{-\lambda_T^{'} t}\right]$$

Here, N_0 is the total number of observed Ps, $1/\lambda_T$ and $1/\lambda_T^{'}$ are the life-times of the ortho-Ps (140 nsec) and the ortho-like-Ps, respectively and $\varepsilon=x/(1+x^2)$ for $x=0.0276B$. The quantity P represents the polarization, and ϕ the angle between the spin direction and B. Thus the $P_z=P\cos\phi$ can be determined from the shape of the time spectrum for the known strength of the magnetic field.

A schematic view of the polarimeter is shown in Fig.2. The e^+ beam accelerated to any energy up to 20 keV enters through a hole in one of the pole pieces of the magnet and strikes the surface of a microchannel plate (MCP) target whose output signal is utilized as a start pulse for the life-time measurement. The ortho-like Ps created on the surface of MCP annihilates into γ-rays which are detected with six modules of NaI(Tl) scintillation counters surrounding the MCP target.

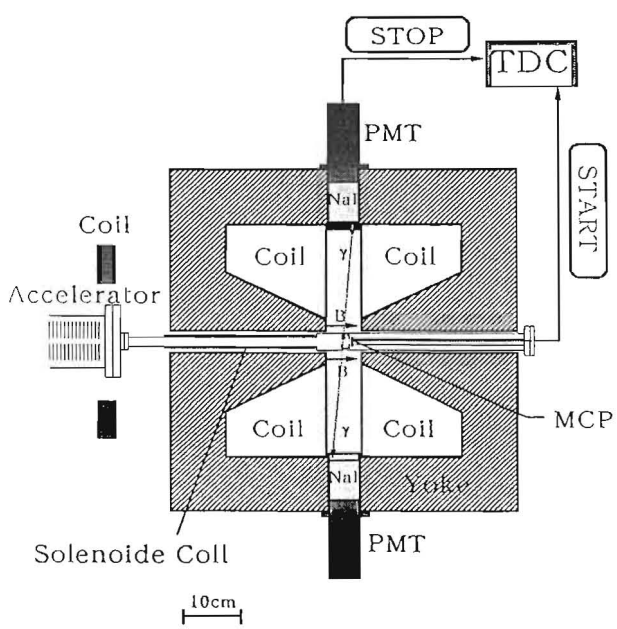

Fig. 2 Schematic design of the polarimeter.

Since the magnitude of B can be changed from 0.1 to 8 kG, the gradient of the magnetic field should be designed to minimize the depolarization of incident e^+ by introducing tapered shapes of the pole pieces. We also supress inhomogeneity of B near the MCP target less than 1%. Simulating the trajectry and the spin direction in the polarimeter, POEM reveals that e^+ can reach the target with reasonablly low depolarization resulting in the average polarization of P_z=40 %.

2.2. *Laser Compton-Scattering Method*

The second method i. e. a laser Compton-sacattering method, is to use e^+e^- pair creation of polarized γ-beams, which is made by backward Compton scattering of circularly polarized laser-lights on the 1.54 GeV e^- beams (see Fig.3). From the viewpoint of application to linear colliders, this method has an advantage that the γ-beam thus produced can have the same time structure as that of the initial laser-beam. In comparison with other methods proposed for VLEPP[5] and DLC/TESLA[6], our method is relatively compact although there might be lots of technical problems to be overcome for the application to linear colliders.

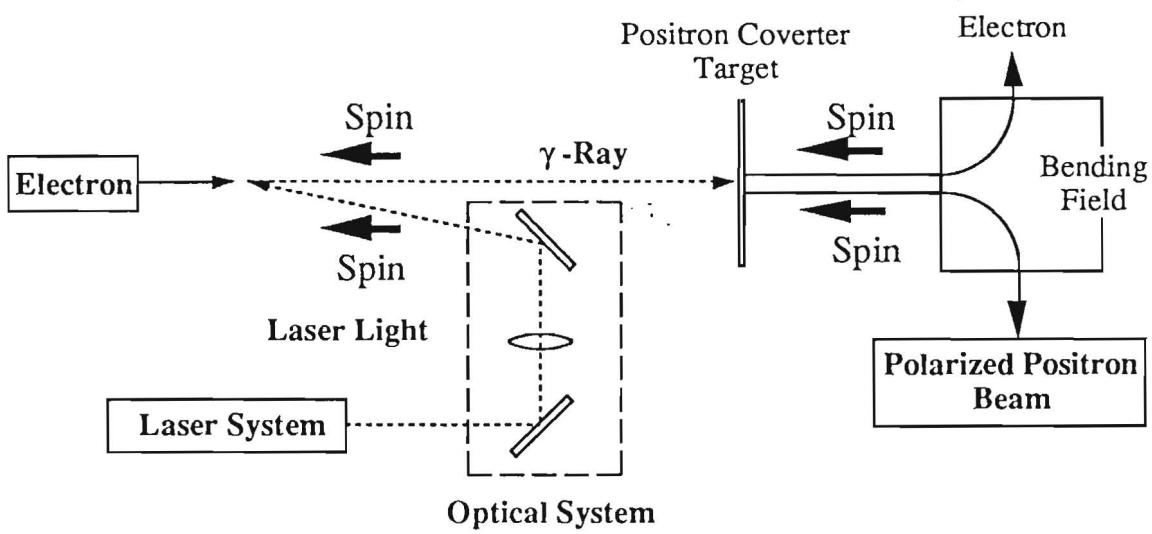

Fig. 3 Schematic design of a polarized e^+ source using backward

We use a Nd: YAG laser, Continuum, NY81C-10 with the power of 550 mJ in 6ns pulse at a wave length of 532 nm for 2 times harmonic doubler wave. The e^- beams of about 2×10^{10} per bunch in our experiment is supplied from the Accelerator Test Facility (ATF) at KEK. Figure 4 shows the differential cross section for the Compton scattering of circularly polarized lasers against unpolarized e^- and the polarization of scattered photons;

the energy distribution of scattered photons with a helicity = +1 or -1 are separately shown. In this figure, one can see that γ-rays produced at the high-end of the energy spectrum are highly polarized. It is clarify as shown in Fig. 5 that the pair created e^+ weighted by energy distributions of incident γ-rays has also high polarization in the high energy region. The average polarization is expected to be 80% when e^+'s with the energy greater than 35 MeV are chosen.These calculations were performed numerically based on the helicity amplitude in the laboratory flame with Born approximation using HELAS[7] and BASES[8].

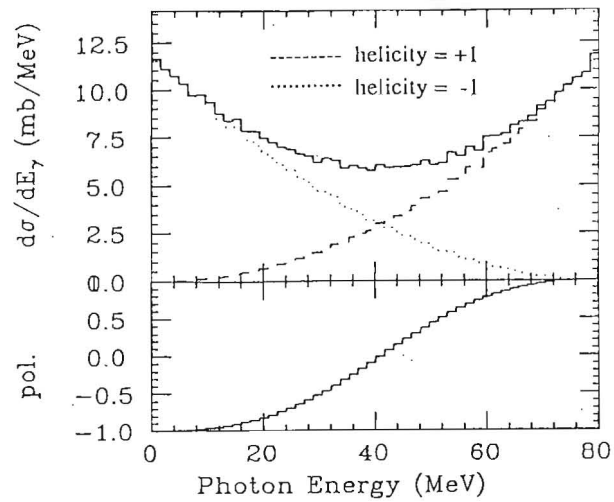

Fig. 4 Differential cross section of Compton scattering (upper figure) for the incident photon with the helicity -1 and scattered photon polarization (lower figure) as a function of final photon energy. The dashed line (the dotted line) represents the helicity +1 (the helicity -1) for the photons.

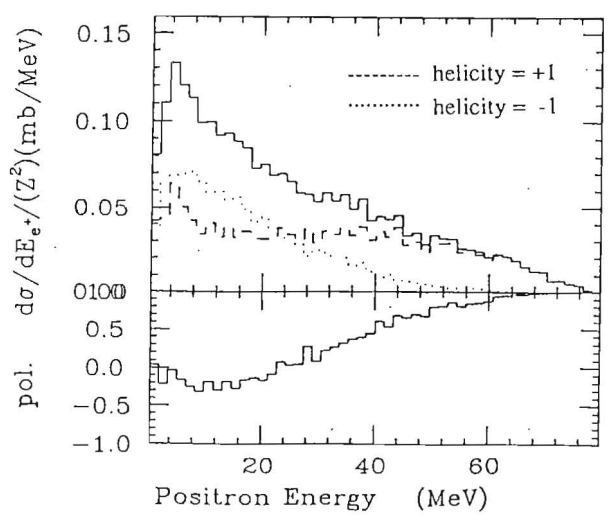

Fig. 5 Differential cross section of pair-creation (upper figure) and created e^+ polarization (lower figure) as a function of final e^+ energy weighted by energy distribution of Compton scattered photons.

In the experiment designed for ATF, we will be able to produce about 1.4×10^4 e^+ per bunch, when we take into account, numbers of e^-'s per bunch and various properties of the laser, i. e. power, spot size, beam profile and optics. We have now observed the Compton scattered γ-rays. In the next year, we will produce polarized e^+'s and continue to measure the polarization by Bhabha scattering.

3. Polarized Positron Beams for Linear Colleders

In ordet to achieve polarized e^+ beams at the JLC designed at KEK, we have to overcome two crucial problems of realizing the high intensity and the complex bunching structure of the JLC beam consisting of 150 trains, each of which contains 100 bunches in the time interval of 5.6 ns.

For the first method using the β^+ decay, naive extension of our method makes it possible to produce 2×10^{15} e^+/sec using a thicker (6mm) Al target and a high current (100 mA) proton beams with an energy of 40 MeV which might be provided by a proton Linac. It is reported that a moderator with the conversion efficiency of about 20% will possibly be available using a silicon (or diamond) crystal sandwiched by electrodes which supply high electric field to extract thermalized e^+. Therefore, if we can collect e^+'s emitted in a large solid angle and create the complex pulse structure with about 25% efficiency, the intensity of 10^{14} e^+/sec required for JLC can be achieved. The JLC bunch structure will be realized as described in ref. 1 by means of two stage potential gaps.

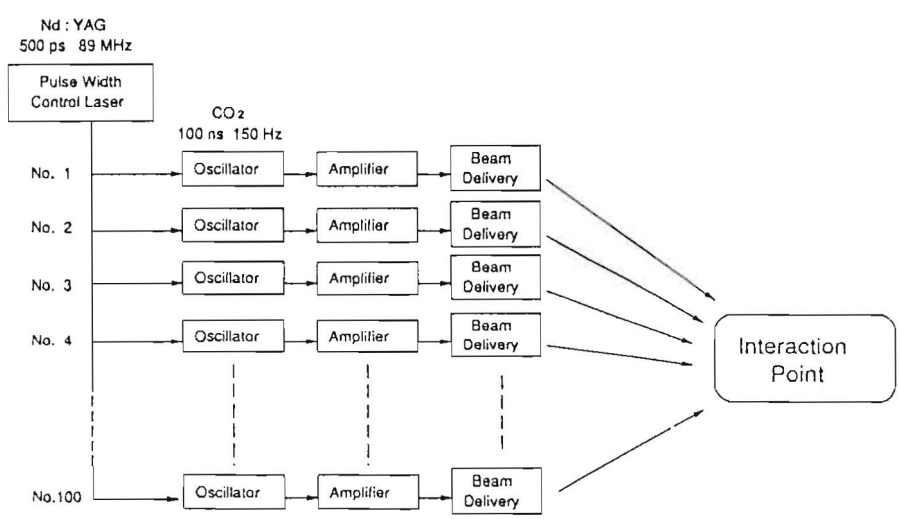

Fig. 6 Schematic view of the laser system for JLC.

For the second method, a basic idea on the system architecture is given in Fig.6. The 100 parallel lines of pulesed CO_2 laser oscillator-amplifiers are provided and each line is operated at 150 Hz. The time inteval between successive two lines is controlled as 5.6 nsec through semiconductors switched by two modules of Nd: YAG lasers of 500 psec.and 89 MHz specificatin. The proposed laser system is well within reach by existing technologies of high power laser architecture, although we will have to challenge and solve lots of technical problems such as management of the large system, damage threshold of the output window, optics and so on. The technical details was described in ref. 9.

4. Physics with Polarized e+ Beam at Linear Colliders

When LC is utilized to study physics of the Standar Model, one of the impotant business is the accurate determination of the Weinberg angle $\sin\theta^2$ through the left-right cross-section asymmetry A_{LR} of the process $e^+e^- \to \bar{f}f$ measured on the Z-pole[7]. Since the observed asymmetry A_{obs} is described as

$$A_{obs} = -A_{LR}P$$

where P represents the polarization of e^- beams, the error of the polarization is derectly related to the accuracy of determining A_{LR} or $\sin\theta^2$. If e^+ beams in addition to e^- beams are polarized, we can increase the magnitude of the polarization as $P_{eff} = (P_- - P_+)/(1 - P_-P_+)$, P_- and P_+ being the polarizatin of e^- and e^+ respectively and thus achieve significant improvement for the determination of $\sin\theta^2$. Another examle is to test the super-symmetric extension of the Standard Model allowing reactions such as, $e_R^+e_R^- \to \tilde{e}_R^-\tilde{\chi}^+\bar{\nu}_e$ and $e_L^+e_L^- \to \tilde{e}_R^+\tilde{\chi}^-\nu_e$ where $\tilde{e}^\pm$ and $\tilde{\chi}^\pm$ stand for a scaler electron and a chargino, respectively. Hence, by choosing the helicities as $e_R^+e_R^-$ or $e_L^+e_L^-$, we can study efficiently these interactions with suppression of the backgrounds from the Standard Model interactions, e.g. $e_R^+e_L^- \to W^+W^-$, $e_L^+e_R^- \to W^+W^-$. Furthermore, if the mass of $\tilde{e}^\pm$ are smaller than that of $\tilde{\chi}^\pm$, the interactions mentioned above have a lower threshold than $e_L^+e_R^- \to \tilde{\chi}^+\tilde{\chi}^-$ to produce $\tilde{\chi}^\pm$. Although only a few example is pointed out here, we will expect lots of important advatages of the double beam polarization in the future linear collider.

5. Acknowledgement

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