SOURCES OF POLARIZED POSITRONS FOR COLLIDERS

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A number of projects of the electron-positron colliders are now under development such as ILC/CLIC, LHeC, TLEP and others. These colliders are intended for investigations the fundamental properties of matter in "post LHC era." These accelerator facilities imply use of the beams of polarized positrons. Comparative parameters of two major schemes of such sources – based on application of undulators and Compton scattering of laser beams for production of polarized gamma photons – are reported. Degree of polarization are estimated, ways to enhance the efficiency of sources are indicated as well. "Proof-of-principle" experiments are also proposed.

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INTRODUCTION

Research works in the high-energy physics are done on high-energy particle accelerators. From the point of view of theory, most interesting is the Terascale region – the energies of about one TeV. In this region expected is so called electroweak unification – the electromagnetic and the weak interactions merge into a single electroweak force.

The most advanced and merely the only high-energy accelerator in operation that overlap Terascale is the Large Hadron Collider (LHC), which consists of two storage rings with circulating proton beams. A Higgs boson like particle has been discovered LHC.

Nowadays accelerator physicists are involved in design of the post-LHC era accelerator facilities. Among these projects (of different degree of completeness) the following may be listed:

- ILC – the international linear collider [1];
- CLIC – the compact linear collider [2];
- LHeC – the large hadron-lepton collider [3];
- TLEP – the terascale electron-positron collider.

Layout of the most completed project – ILC – is presented in Fig. 1.

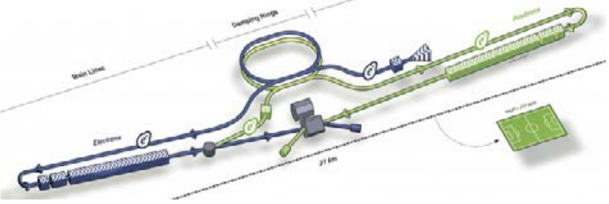

Fig. 1. Layout of International Linear Collider. The electron leg is depicted in blue color, the positron leg in green. The undulator depicted as the cylinder in the electron leg

All of the listed above projects are colliders used most "elementary" particles – leptons. Studies on processes with small cross sections, e.g. Higgs boson, require extremely dense beams with small energy spread that provide high luminosity. In addition, utterly important is possibility to employ the beams of polarized electrons and positrons to reduce uncertainty in results. The average current of polarized electrons/positrons should be as high as 50 µA for the linear colliders (ILC, CLIC), and up to 7 mA for LHeC.

The sources of polarized electrons that provide required beam current were built in a few labs. On the contrary, the sources of polarized positrons yet have not been designed.

Problems aroused in design of the sources of polarized positrons and contribution of NSC KIPT are described in this paper.

1. SOURCES OF POLARIZED POSITRONS

1.1. PHYSICAL PRINCIPLE

Positrons, like other antiparticles, do not exist in our part of the Universe. A process that can provide sufficiently big number of them is production of electron-positron pairs by high-energy photons (gammas with energy of order of 5 MeV and higher) in Coulomb field of nuclei. Therefore, generation of intense beams of polarized positrons require the intense beams of polarized gammas.

The polarized gammas impinge a metallic conversion target where produce the electron-positron pairs. Due to correlation between energy of positrons and their polarization it is possible to collect the emitted positrons of necessary degree of polarization.

1.2. SOURCES OF POLARIZED GAMMA QUANTA

Polarized gammas are generated due to interaction of (nonpolarized) ultrarelativistic electrons with electromagnetic field of the proper polarization. Since the longitudinally polarized positrons are suggested to employ, the electromagnetic field should be circularly polarized.

Nowadays the two types of sources of the circularly polarized gammas are under study, the undulator- and Compton-based. The undulator source is based on the helical magnetic undulator, the Compton one employs circularly polarized laser light stored in the resonator.

Both types realize Doppler blue shift: the frequency of electromagnetic wave emitted along direction of the electron trajectory is γ^2 times the frequency of driving field (γ is the Lorentz factor of relativistic electrons). Both the sources have its advantages and drawbacks owing to the driving field.

The undulator source requires the electrons with very high energy, above 100 GeV because the spatial period of undulator winding must be large enough to provide sufficient aperture for the electron beam.

The undulator source is baseline for ILC. This source uses the electrons with energy about 150 GeV accelerating in the electron leg of the collider. The maximum energy of the fundamental harmonics is about 10 MeV. The system is designed such every electron in the electron leg produces one positron in the positron leg.

With account for efficiency of conversion of the gammas into the positrons, their collection and 1.5 overhead, every electron must generate 300 gammas per pass through the undulator. Therefore, the undulator should be long, a few hundred meters, with the deflecting parameter about unity (0.9 for ILC). The high deflection parameter gives rise to higher harmonics in the spectrum that deteriorates the polarization degree.

Compton sources employ sufficiently shorter wavelength laser radiation (1…10 μm) than the undulator (spatial period 10 mm) therefore the energy of electrons may be much lower, 1…10 GeV. Because of relatively low power of modern lasers along with small cross section of Compton scattering, the Compton sources are not able to emit gamma beam of intensity enough to produce the positron bunches with necessary pulse current.

Due to this reason, the Compton source should be autonomous, operating with an independent intense electron beam. The source will generate long positron pulses subject to be accumulated and transformed into the short intense bunches.

The Compton source is the alternative for the ILC project and the baseline for others listed above.

For the electron source is suggested to employ a storage ring for energy about 1 GeV. This ring allows to keep circulating the current 1 A for sufficiently long time. The laser system based on YAG laser (the wavelength of 1 μm) can store laser pulses with the energy up to 100 mJ in the optical resonator, which are moving at the frequency of the bunches in the storage ring.

1.3. CONVERSION TARGET

The conversion target provides bearing of the electron-positron pairs followed by selection of the positrons with required polarization.

We – E. Bulyak, V. Lapko and N. Shulga – theoretically estimated the process of conversion and found the optimal conversion target thickness yielded maximum of positrons. The results were validated by numerical computation made by our colleagues from DESY (A. Schalicke, S. Riemann) [4]. The optimal target thickness is dependent upon the maximal energy of gammas in fundamental harmonic, the material of the target and required degree of polarization.

The working area envelope in the plane “conversion factor-degree of polarization” is presented in Fig. 2.

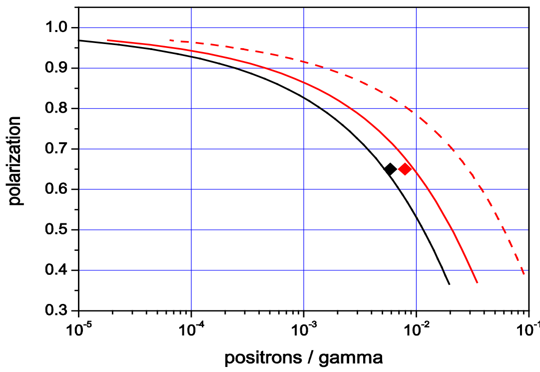

Fig. 2. The working area envelop. Black curve represents Ti material of target, the red one tungsten W. The dash line represents “Kharkov converter”, diamonds – the numerical simulation

Efficiency of the conversion target, as is well known, is increased with the atomic number of the material. Nevertheless, titanium – material with small atomic number – is intended to use in the ILC undulator source because its tolerance to high power load. It should be recalled that the target must withstand the gamma-ray beam of 140 kW power (from which 10 kW remains in the target body) impinging at 1 sq. mm area.

In the Compton sources radiation load is much more lower due to (a) the energy of gammas is two-fold higher that increases the pair production cross section, (b) the spot area at the front surface is ten-fold larger, and (c) the pulse of gammas is much longer.

We (E. Bulyak, V. Lapko, N. Shulga) proposed a sufficiently more effective rod target for Compton sources [4], also known as “Kharkov converter”. This converter allows obtaining sufficiently higher yield of positrons per gamma. The Kharkov converter weakens tough requirements on the electron beam current and/or the laser pulse energy, or increases polarization degree in the positron beam. Scheme of the converter is presented in Fig. 3 and its limits on the “efficiency-polarization plane” in Fig. 2 the dash curve.

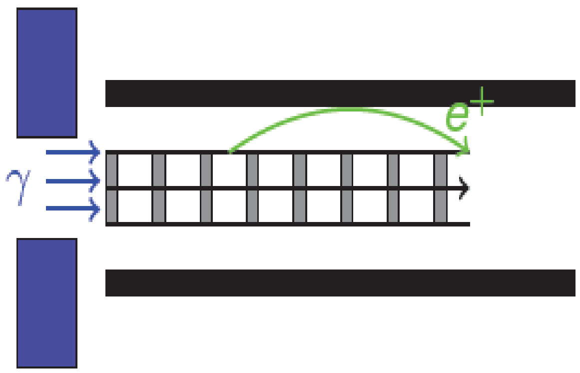

Fig. 3. The rod conversion target. The input collimator is depicted in blue color, the conversion discs in gray

2. RESULTS AND SUMMARY

Development of the intense source of polarized positrons is a complex and difficult problem, some components of this system not yet been experimentally realized.

It seems expedient to cite one of coordinators of PosiPol collaboration, Dr. Tsunehiko Omori of KEK (Japan): “The positron source is one of the most extensive homework for our phase of activity after accomplishment of the ILC technical design”.

It is necessary the electron beam of ILC for the undulator-based source experiments. The Compton scheme may be studied experimentally on existing storage rings such as the 1 GeV ATF damping ring of KEK (Japan). This source enables one to develop the system of positron collection, the measurement of polarization, the design of the conversion targets.

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ИСТОЧНИКИ ПОЛЯРИЗОВАННЫХ ПОЗИТРОНОВ ДЛЯ КОЛЛАЙДЕРОВ

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В настоящее время разрабатывается несколько проектов электрон-позитронных коллайдеров на высокие энергии, предназначенных для исследований фундаментальных свойств материи в «пост LHC эру», таких как ILC/CLIC, LHeC, TLEP и др. Эти установки предполагают использование поляризованных позитронов. Приведены сравнительные характеристики двух основных способов получения позитронных пучков: ондуляторного и комптоновского. Оценена степень поляризации пучка, а также намечены пути повышения эффективности источников. Рассматриваются возможности экспериментальной проверки эффективности схем формирования позитронных пучков.

ДЖЕРЕЛА ПОЛЯРИЗОВАНИХ ПОЗИТРОНІВ ДЛЯ КОЛАЙДЕРІВ

Є.В. Буляк

В цей час розроблюється декілька проектів електрон-позитронних колайдерів на високі енергії, які можуть бути використані для досліджень фундаментальних властивостей матерії в так звану «після LHC еру». Це такі проекти, як ILC/CLIC, LHeC, TLEP та інші. Ці прискорювальні установки будуть використовувати поляризовані позитрони. Наведено порівняльні характеристики двох основних способів отримання таких позитронних пучків: ондуляторного та комптонівського. Дається оцінка ступеня поляризації пучка, а також окреслено шляхи підвищення ефективності джерел. Розглядається можливість експериментальної перевірки ефективності схем формування позитронних пучків.