9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPML047

DIVERSIFIED APPLICATION OF ILC

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Abstract

ILC will be a unique and very powerful accelerator complex, once it is built. It has not only the high power energetic electron beam but also powerful positron and photon beams. In addition to these beams, large cryogenic plants are furnished together with various utility facilities in a site. Some suggestions on the supposition of availability of ILC are given from various fields. Some of these discussions are reported briefly.

INTRODUCTION

ILC has not only the high power energetic electron beam but also powerful positron and photon beams. It will be a unique and very powerful accelerator complex. ILC facility that includes the infrastructure will be a precious resource for humanity. In order to explore possibilities of this unique facility, we held a meeting to discuss diversified applications on ILC and/or its facilities. Among various fields discussed such as X-rays, gamma rays, muons, positrons, neutrons, RI applications and so on, four topical items will be introduced in this paper. They are short wavelength X-ray FEL, exotic research on photons, muon research and future neutron source by direct production of slow neutrons. These are presented in following sections.

SHORT WAVELENGTH X-RAY FEL

In the history of the ILC development in Japan, close collaboration has been continuing in these three decades with the motivation of production of coherent and brilliant photons by (super) high quality electron/positron beams produced by ILC. Based on the recent progress in the synchrotron radiation research, there should be two possible methods of the effective production of very brilliant and coherent (in some cases) photon beams.

The science and technology established at SPring-8/SACLA (SPring-8 Angstrom Compact Free Electron Laser) for the development of insertion devices and FELs lead to a possibility of a high power X-ray FEL and/or a gamma-ray FEL [1]. It is noted that SASE type FEL is able to provide high power of 10TW and high flux of 10^{12}photons/pulse/0.1%band-width in an angstrom wave length region, if we can modify the parameters of ILC accelerator appropriately after its completion (Fig. 1). In a gamma ray region at 1.666MeV, a gamma-ray FEL, the power of which exceeds 100GW, is also realistic [1].

Even in a development phase, high performance of the ILC accelerator is useful to produce brilliant X- and gamma-rays. It is noted that the very-short-period undulator with 4-mm period length [2] is able to produce brilliant X-rays in the energy region of 15-40keV with a fundamental harmonic by 3GeV electron beams from the ILC in the development phase [3] (see Fig. 2). When the energy of the ILC is reinforced up to 20GeV, gamma-rays of 1-3MeV are obtained by the very-short-period undulator.

EXOTIC PHOTON RESEARCH

Quantum electrodynamics (QED) predicted the interaction between a photon and a photon such as photon-photon scattering, and photon splitting. However, their measurements have been extremely difficult and thus the photon-photon interaction has been an unresolved question. Recently, photon-photon scattering has been measured for the first time in heavy ion collisions in LHC [4], where a pair of 5 TeV energy gamma-rays by virtual photon-photon scattering in heavy ion collision were measured, but the number of the total events is only 13. We cannot expect to measure precisely the photon-photon scattering with the heavy ion collision. Koga and Hayakawa have proposed a new method to measure

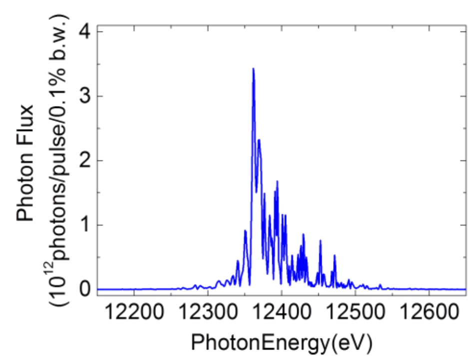

Figure 1: Spectrum example of SASE-FEL at ILC.

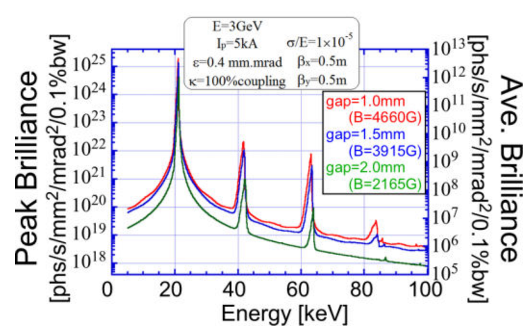

Figure 2: Example of the X-ray spectrum from very-short-period undulator (λu=4mm, L=1m) at ILC.

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Delbrück scattering with linearly polarized gamma-rays. Delbrück scattering is elastic scattering of a photon following a pair creation of electron and position and their annihilation after the interaction with the Coulomb field by an atomic nucleus (see Fig. 3). Because Delbrück scattering has cross sections larger than other photon-photon interactions, it has been experimentally studied for long time. In previous studies, high flux gamma-rays from radioactivity produced in a nuclear reactor have been mainly used. However, the fact that this method cannot distinguish Delbrück scattering from other gamma-ray elastic scattering was pointed out theoretically. Koga and Hayakawa [5] theoretically found that the amplitude of Delbrück scattering can be selectively measured without contribution of other elastic scattering in a specific condition. Thus, high intense linearly polarized gamma-rays will address an unresolved problem, the photon-photon interaction in QED.

Photon vortices with helical wave front carrying orbital angular momentum are interesting both for fundamental research and for applications [6]. Recently, gamma/X-ray vortices in the MeV energy region using non-linear inverse Compton scattering with highly intense circular polarized laser [7,8] or higher-harmonics radiation from helical undulator [9,10] have been proposed or developed. One of the most important features for photon vortices is that it has a non-zero value for the projection of the orbital angular momentum of the incident photon for the photon propagation axis. The total angular momentum is larger than or equal to the projection of the angular momentum. When a photon vortex interacts with a particle or an atomic nucleus, the total angular momentum of the incident photon vortex is conserved the interacted photon-particle (nucleus) system. This suggests that photon vortices leading to this interaction are different from those with plane wave photons. For example, it suggests that the excitation of giant dipole resonances on even-even nuclei with gamma-ray vortices carrying high angular momentum is forbidden because of the conservation law of angular momentum. A helical undulator with an electron beam with an energy higher than 10 GeV can generate the photon vortices with energy of MeV, leading to a new frontier in nuclear and particle physics.

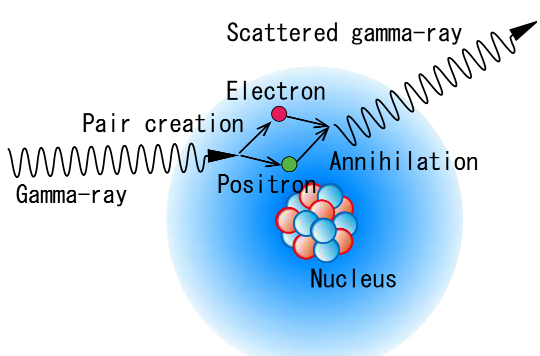

Figure 3: Schematic view of Delbrück scattering.

MUON RESEARCH

As one of the most illuminating ideas for the application of ILC was also discussed that a muon collider might be realized by using ILC infrastructure. The basic idea was pointed out by M. Antonelli, et al. [11]

Muon is the second generation of charged lepton, which has 200 times larger mass than electron, therefore the energy loss by synchrotron radiation is suppressed 40,000 times smaller than electron. This feature opens the possibility to realize a multi-TeV lepton collider. Such an idea was discussed a long time with the basis that a proton accelerator would be the driver to produce intense muon beam, however, this scheme requires a muon cooling system to achieve reasonable luminosity. This technique has been developed many years by adopting so called ionization cooling. Nevertheless, in spite of great efforts, the scheme is still at a preliminary stage.

An alternative idea to produce intense and small emittance muon (both positive and negative) beams is to inject a positron beam on to a thin fixed target, where the positron energy is set at around 45 GeV in laboratory frame. The energy is adjusted to the threshold of the pair creation of a muon pair by positron and electron in the target. Figure 4 shows the total cross section of muon pair production. In this scheme, transverse momentum distributions are limited and the production ratios of positive and negative muon are the same. The energy of produced muons is around 22 GeV, therefore, their life time is more than 400 μs. These features give us great advantages to realize the muon collider with reasonable luminosity.

Now we are starting to discuss the possibility to realize this scheme based on ILC accelerator.

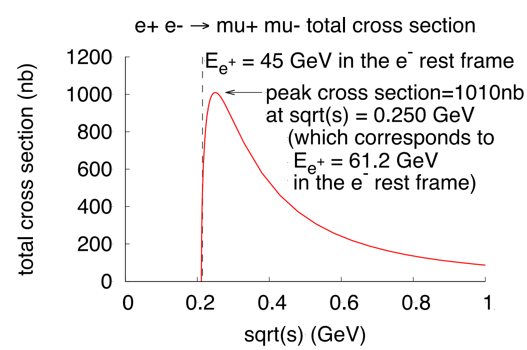

Figure 4: Total cross section of muon pair production in a fixed target.

FUTURE NEUTRON SOURCE

Since neutrons are sensitive for all four interactions: strong, weak, electromagnetic and gravity, they are widely used for particle, nuclear and condensed matter physics, such as neuron electric dipole moment search to find the origin of CP violation or measurements of the neutron lifetime. Bragg edge neutron imaging and soft error evaluation in electronic circuit devices using high-energy neutrons are receiving increased attention for industrial use. Neutrons have been available at nuclear reactors or spallation neutron sources. In addition to compact neutron

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sources driven by small accelerators, those by lasers that have high peak intensity are recently developed. One has to choose one of these sources according to his purpose.

Known methods to extract neutrons from nuclei are listed as follows:

1) Nuclear reactions of ^{7}Li, ^{9}Be with a few MeV protons or deuterons.
2) Chain reactions of ^{235}U fissions.
3) Nuclear fusions of deuterons and tritons
4) Spallation reactions of W, Hg with a few hundred MeV protons.
5) Nuclear photodisintegration by γ-rays.

Initial neutron energies from these reactions are generally on the order of MeV. Moderation processes to reduce the neutron energies degrade the quality as neutron beams. Direct extraction of low energy neutrons will avoid this situation.

Neutron production with the nuclear photodisintegration process by γ-rays listed above in 5) is discussed as a candidate for a new generation source when ILC becomes available. There are mainly two processes to produce neutrons by photodisintegration reaction. One is the reaction with light nuclei like ^{9}Be or deuteron (see Fig. 5 [12]). Although their reaction cross sections are small (~ a few mbarn), the required energies of the γ-rays are relatively small (~2 MeV) and less radioactive residuals are produced. It is worth to mention that this process produces monochromatic keV neutrons. The other is use of the giant dipole resonances of heavy nuclei. While the cross sections are relatively larger (a few hundred mbarn), the mean free paths in the target materials are short and more radioactive residuals are produced. The neutron production rate per a γ-ray was calculated as 0.6% for ^{9}Be with γ-rays of 1.69 MeV and ~3% for ^{208}Pb with 13 MeV. In both reactions, consuming energy of γ-rays to produce a neutron was 300-400 MeV/neutron, which was 6-8 times larger than the spallation reactions. Thus, heat resistance of the target is expected to limit the neutron production.

The produced neutrons by the photodisintegration by γ-rays have short time pulse structure the same as ns electron bunches. The photodisintegration reactions of light nuclei produce neutrons with energy of a few tens of keV within a short pulse. It is a unique new type of neutron source, and possibly available for new applications like precise total cross section measurements or keV neutron imaging. The keV neutron beam may be possible to apply Boron Neutron Capture Therapy.

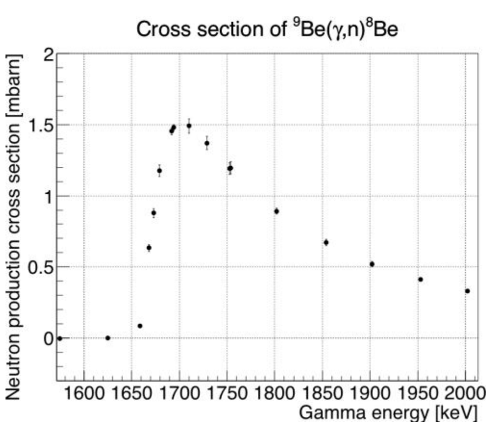

Figure 5: Photo-neutron production cross section of ^{9}Be [12]. The peak cross section is 1.5 mbarn at 1690 keV. Threshold energy is 1665 keV. This reaction produces monochromatic neutrons if γ-rays are monochromatic.

CONCLUSION

We discussed wide possibilities of ILC once it was build. Since this kind of big facility will be supported by a town wide community, it should last decades of years as has the success of CERN. The authors hope this project will go well and grow for long time to produce fruitful results.

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