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Technology for a photon collider experiment at a future TeV-scale linear collider has been under development for many years. The laser and optics technology has reached the point where a GeV-scale photon collider experiment is now feasible. We report on the photon-photon luminosities that would be achievable at a photon collider experiment based on a refurbished Stanford Linear Collider.

1. Introduction

The basic idea for producing a photon-photon collider through Compton backscattering was proposed more than 20 years ago [1], and implementations for both warm and superconducting accelerators have been under development [2,3]. Several years ago the idea to revive the world's only e^+e^- linear collider, the Stanford Linear Collider (SLC), as a linear collider R&D testbed was proposed [4]. A plan to upgrade the interaction point with hardware to support photon-photon collisions was included as part of that proposal. While lasers capable of the high average power need for a TeV-scale linear collider are still under development, currently demonstrated lasers could support an experiment at the SLC, given its 120 Hz repetition rate. The achievable luminosity for a feasible set of machine and laser parameters is presented in this paper.

2. Luminosity

The photon-photon luminosity is a function of the geometrical e^+e^- luminosity of the SLC ($\mathcal{L}_{\rm geom}$) and the number of photons per incoming electron ($k_{\rm photon}$) generated during the Compton backscattering, as shown in Equation 1.

$$\mathcal{L}_{\gamma\gamma} \propto \mathcal{L}_{geom} \times k^2_{\rm photon} \quad (1)$$

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The value of $k_{\rm photon}$, and thus the total luminosity, can be made arbitrarily large by increasing the laser flash energy. However, the Compton scattering depletes the electron energy, so each subsequent Compton scatter produces lower energy photons. Therefore, for any particular energy a point of diminishing return is reached.

2.1. SLC

The SLC achieved a peak luminosity of 3×10^{30} $cm^{-1}s^{-1}$ before it was shut down. It has been estimated separately [5] that the accelerator could be restarted and various components upgraded to achieve a peak luminosity of 2×10^{31} $cm^{-1}s^{-1}$. In this paper we assume beam parameters from the machine upgrades detailed in the LINX proposal [4] with the full SLC repetition rate and bunch charge, as shown in Table 1. This corresponds to a luminosity of 3×10^{31} $cm^{-1}s^{-1}$.

Table 1
SLC machine parameters used in this study.

rep rate	120 Hz
bunch charge	4.0×10^{10} e
beam energy	30 GeV
$\beta_{\rm x,y}$	(8.0 , 0.1) mm
$\gamma\epsilon_{x,y}$	(1.6 , 0.16) $\times10^{-5}$ m
σ_z	100 microns

2.2. Compton photons

The interaction of the electron beam with the laser is modeled using the CAIN [6] program. The laser parameters are given in Table 2 and produce 4.5 photons per incoming electron.

Table 2
Laser and focusing optics parameters.

wavelength	1.053 microns
flash energy	2.0 Joules
Pulse width	1.8 ps FWHM
Raleigh range$_{(x,y)}$	(100 , 100) microns
CP-IP distance	2 mm

The wavelength and pulse duration are set by the laser technology used in the MERCURY laser [7], which is a high average power laser technology being developed for the TeV-scale warm machine. The Raleigh range defines the depth of focus of the optics and is matched to the electron bunch length. The CP-IP distance is the separation of the Compton scattering point from the interaction point.

The distribution of photon energies is shown in Figure 1. Linear Compton scattering does not produce photons above 10 GeV. The tail above 10 GeV comes from non-linear Compton scattering due to the significant laser intensity at the focus. The enhancement at low energy is from Compton scatters where the electron is not at full energy due to previous scatters.

2.3. Luminosity Calculation

The CAIN program tracks the photons and electrons from the conversion point (CP) to the interaction point (IP), taking into account all energy-angle correlations. At the IP the beam-beam effects of the charged particles are simulated and additional “beamstrahlung” photons are generated. The luminosities calculated by CAIN are shown in Figure 2. Since it is assumed that the laser is linearly polarized the photon-photon luminosity divides evenly between spin-0 and spin-2 states.

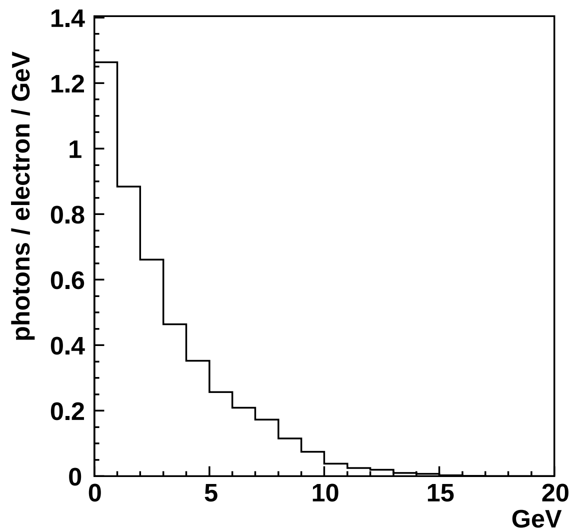

Figure 1. Energy distribution of photons produced in the Compton scattering.

3. Accessible Physics

A rigorous analysis of the physics reach of such a facility will require a full Monte Carlo analysis, but a number of promising avenues can be identified from the luminosity distribution.

3.1. Total Photon-Photon Cross Section

This experiment will provide an environment where photon-photon events are the dominant source of events and all crossing will be able to be written to tape without any trigger requirements. This should lead to a clean environment for the study of the total cross section from 0 to 30 GeV.

3.2. Beyond Standard Model

Studying the Higgs boson in photon-photon collisions is one of the main physics justifications for a photon collider experiment at high energies. While the Standard Model Higgs has been ruled out at energies accessible at the SLC, there are SUSY models [9] in which a Higgs in the SLC energy range is still allowed. A search for these particles could be performed at this facility.

The quantum numbers of the photon-photon

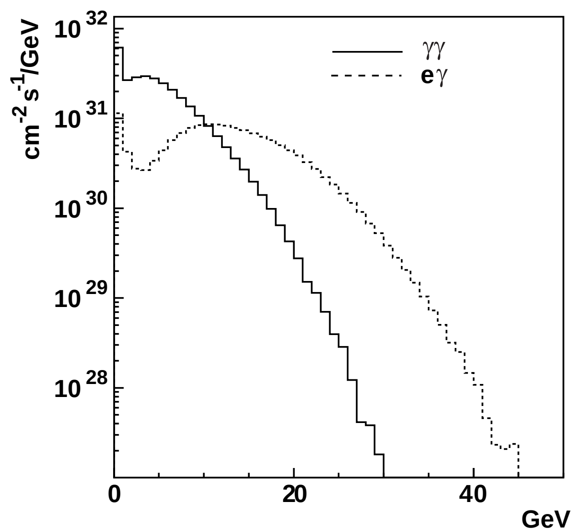

Figure 2. The distribution of both the photon-photon (solid) and electron-photon (dashed) luminosities.

collision make it a perfect place to produce pairs of charged scalar particles. Searching for low mass SUSY squarks would be one area in which this facility could outperform others.

3.3. Bound states of $c\bar{c}$ and $b\bar{b}$

The spin-0 and spin-2 heavy quark bound states will be produced with a cross section given by Equation 2.

$$\sigma(s) = \frac{8\pi\Gamma(\gamma\gamma)\Gamma_{\rm tot}}{(s-m^2)^2 + \Gamma_{\rm tot}^2 m^2} \quad (2)$$

The number of mesons produced in 10^7 seconds is shown in Table 3 and can be determined using the calculated photon-photon luminosity and measured values [8] of m and $\Gamma(\gamma\gamma)$ for observed $c\bar{c}$ bound states. The number of η_b mesons produced can be scaled from the η_c result, taking into account quark charge (1/16), mass suppression of $\Gamma(\gamma\gamma)$ (2.979/9.3), and decreased luminosity.

Table 3
Number of mesons produced for one Snowmass Year of running.

Meson:	Events:
$\eta_c(1S)$	1.79×10^6
$\chi_{c0}(1P)$	4.97×10^5
$\chi_{c2}(1P)$	9.23×10^4
$\eta_b(1S)$	1.36×10^3

4. Hardware

Much of the hardware designed for the TeV-scale experiment can be directly adapted to the SLC and the reduced number of electron bunches decreases the required laser power by two orders of magnitude.

4.1. Interaction Region Optics

The interaction region optics that have been designed for the NLC can be scaled down in size by a factor of two in order to fit into the SLC with no other modifications required.

4.2. Laser

Making a conservative estimate of 20% power loss between the laser and the focal point and including a factor of 2 for two conversion points we can calculate the average laser power required to be:

$$\frac{2\text{J}\times 2\text{CPs}\times 120\text{Hz}}{0.8\ \text{efficiency}} = 600\text{W} \quad (3)$$

The MERCURY laser [7] is designed to have an average power of 1kW and its prototype has already been operated with pulses of 20J × 10Hz = 200W. Therefore, there exists a laser that is already demonstrated to be within a factor of three of the required average power. If necessary, a set of three of these prototypes could be combined to yield the required power.

4.3. SLC modifications

Aside from the upgrades to increase the SLC's geometric luminosity, there are several modifications that must be made in order to handle the spent beams. The incoming electron beam is essentially monochromatic at 30 GeV. Each electron loses energy during the Compton scattering leading to a final distribution of energies as shown in Figure 3. About half of the incoming beam energy is transfered to the Compton photons. The large value of the electron energy spread makes traditional steering optics difficult and, of course, the Compton photons cannot be steered at all. One solution for the spent beams would be to include a crossing angle such that the spent electrons could travel in a straight line to the beam dump. This would require a new beam dump and extraction line tunnel.

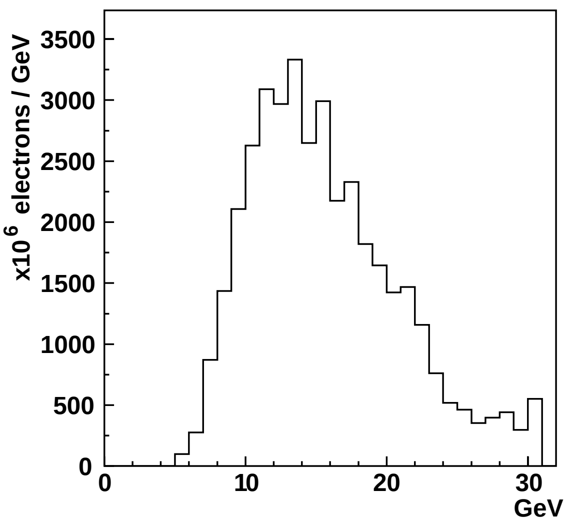

Figure 3. Energy distribution of the electron beam after Compton scattering.

5. Conclusion

The existence of the SLC provides an opportunity to create the first photon-photon collider based on Compton scattering. The facility would provide experience in the operation of photon colliders and, with a reasonably sized laser, sufficient luminosity to enable physics analyses would be produced. The attainable luminosities would provide large data samples of $\eta_{c,b}$ and $\chi_{c,b}$ mesons and would allow for searches for new physics.

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