Photon Collider Technology Overview

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The photon collider option requires the generation of large amounts of laser power to drive the Compton scattering. The selection of the superconducting RF for the baseline of the ILC makes a recirculating solution attractive. A baseline for a recirculating cavity for the photon collider has been developed by a team [1, 2] at DESY/Zeuthen and the Max Born Institute. Similar cavities at much lower scale are being developed for laser wire and Compton polarimeter applications. The current status of the laser technology and a proposal for future development are reviewed. The impact of the $\gamma\gamma$ experiment on the accelerator and detector is also discussed.

1. OVERVIEW

The photon collider has the potential to expand the range of physics accessible to the ILC. The basic concept of generating photon collisions is well understood [3, 4]. What remains to be done falls into three broad areas.

- **Laser -** The ideas for the laser architecture must be developed and demonstrated
- **Accelerator -** The accelerator can be used "as is", if e^-e^- collisions are supported and there is a 20 mR crossing angle. The extraction line must be redesigned to handle the highly disrupted beams.
- **Detector -** The endcaps must be modified to provide a line-of-sight for the laser light to enter and leave the IP and a radiation hard silicon detector is required.

2. LASER

Each electron bunch must intersect a powerful laser pulse in order to generate the high energy gamma rays. For a diffraction limited laser spot the pulse energy must be several Joules and have a duration of 1 picosecond. To provide 2820 pulses/train x 5 Hz x 2 beams would be prohibitive if each pulse were used once and then thrown away. However, each laser pulse is essentially unused during each collision leading to the possibility of reusing each pulse multiple times. If technically feasible, this would lower the cost of the photon collider option to be small compared to an ILC detector. The cost of a high-average power laser is dominated by the diodes which pump energy into the amplifying medium. The cost of these diodes is expected to drop in the future but would need to fall by a factor of 10 for a single pass system to be economic.

2.1. Laser Cavities

Pulse stacking laser cavities are expected to have a number of uses for the basic operation of the ILC. A cavity with a narrow focus has application as a laser wire for beam diagnostics. It would also be useful for a Compton polarimeter. Creating a cavity for these applications would demonstrate a solution for most of the issues involved with the photon collider laser cavity except for issues involved with high average power.

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2.2. Current Cavity Efforts

Work on a laser cavity for a laser wire application [5] is ongoing at the KEK laboratory. Pulse stacking has been demonstrated in a recirculating cavity and the project is moving toward a demonstration of a similar cavity with narrow focus. The experience gained with this is a useful first step toward demonstration of a cavity with the requirements for the photon collider. Work is also proceeding at LAL-ORSAY on a Fabry-Perot cavity for a Compton polarimeter [6] and should have first results in the coming year.

2.3. Future R&D

A design for a laser cavity for the photon collider has been specified [1, 2]. The next step should be to have laser experts review and simulate the design so that we can get a better understanding of the tolerances and likely performance of the design. This would allow us to specify a series of prototyping steps and cost out a development program. The first steps of such a program are quite likely to be synergystic with the work that is already on-going to develop stacking cavities for the laser wire and Compton polarimeter applications. The photon collider laser developers should participate fully with these initial efforts to develop their expertise and to demonstrate basic issues with the stacking cavities.

3. ACCELERATOR REQUIREMENTS

The basic ILC accelerator can support the $\gamma\gamma$ experiment with some modifications and constraints that come from the necessity of handling the highly disrupted beam after the interaction point. There are also some modifications of the accelerator that could increase the delivered luminosity but they are optional and not required for a successful experiment. Electron-electron collisions, already part of the ILC baseline, are desired since they suppress physics backgrounds and allow polarization control of both beams.

3.1. Disrupted beam

The Compton scattering creates a large energy spread in the electron beam. During the beam-beam interaction this leads to a large spread in angle of the outgoing beam. For nominal beam and laser parameters the outgoing beam pipe must have an aperture of ± 10 milliradians in order to allow the disrupted beam to be extracted. Given the physical size of the final focus magnet this sets a lower limit on the crossing angle of the two beams. The fringe field from the magnet must also be minimized in the extraction line to prevent low energy particles from being lost and creating a radiation and heat problem. Designs of a final focus quadrupole with a compensating coil to minimize the field in the extraction line have recently been produced by BNL [7]. Using these designs a minimum crossing angle of 21 milliradians is achieved.

The feedback system for bringing the beams into collision relies on downstream beam position monitors to measure the beam-beam deflection. The effect of these disrupted beams on the feedback system should be fully simulated to show that there are no issues in bringing the beams into collision.

The maximum angle of the disrupted beam is a function of the beam and laser parameters. The parameters should be set to optimize the luminosity in the peak of the $\gamma\gamma$ distribution once a crossing angle and exit line aperture are set.

3.2. Extraction line and beam dump

The energy spread of the disrupted beam makes it impossible to steer the beam without large beam losses. This will make it prohibitively difficult to have any post interaction point diagnostics. Therefore the extraction line will essentially be a straight vacuum pipe respecting the ± 10 milliradian stay-clear of the beam from the IP to the front face of the beam dump. Much of the beam power will be in the form of high energy photons from the Compton scattering which will be in a cone matching the input angular spread of the electron beam. This would deposit a large amount of energy into a small volume of the beam dump leading to vaporization of the water. One solution for this would be to convert the photons to e^+e^- pairs in a gas volume [8] before the beam dump.

3.3. Accelerator improvements for $\gamma\gamma$

The basic ILC accelerator can drive the $\gamma\gamma$ interaction region but the beam parameters are chosen to maximize the e^+e^- luminosity. The e^+e^- luminosity is affected by beam-beam disruption effects that are not present in $\gamma\gamma$ collisions. One modification to increase the $\gamma\gamma$ luminosity would be to change the final focus optics to decrease the β_x, reducing the spot size at the IP. This can be accomplished by varying the magnet strengths in the final focus without significant changes to the physical layout. Another possibility is to improve the damping ring through a laser cooling technique to reduce the emmittance of the beam. This would reduce the beam spot size but would require significant changes to the damping ring design and a closer look at whether the emmittance could be preserved through the linac.

4. DETECTOR MODIFICATIONS

The detector required for the photon collider is essentially identical to the e^+e^- experiments with some modifications around the beamline. The laser cavity requires a line-of-sight from the interaction point to the turning mirrors outside the detector. This requires two holes above and below the accelerator beamlines. The endcaps for the calorimeter will need to be designed so that an experiment can accomodate either e^+e^- or a $\gamma\gamma$ experiment. A replacable plug for the endcap could achieve this. The silicon vertex detector may see a higher radiation load from the beam dump since the accelerator exit aperture must be increased to accommodate the disrupted beam. Therefore the $\gamma\gamma$ experiment may require a dedicated, radiation hardened, vertex detector.

5. CONCLUSIONS

The photon collider has the capacity to extend the physics reach of a future TeV scale linear collider. At this stage in the project planning, certain design choices in the accelerator layout must be made to insure the possibility of future $\gamma\gamma$ running. If the accelerator does not support a 20 mRad crossing angle then the option of future $\gamma\gamma$ running will be foreclosed. Additionally, now is the time to begin a program to develop and demonstrate the laser cavity so that the technology will be mature and demonstrated by the time $\gamma\gamma$ running is desired.

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