

Photon Collider Technology Overview

V. I. Telnov

Institute of Nuclear Physics, Novosibirsk 630090, Russia

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In this conference paper, I review the present status and technical problems of the Photon collider, as well as various additional applications of Compton scattering.

1 Introduction

In this report, I provide an overview of the technical (and some political) aspects of the Photon Linear Collider (PLC). The physics program at the PLC is discussed in K. Mönig's talk at this conference [1].

The photon collider based on the conversion of electrons at a linear collider to high-energy photons through Compton scattering of laser photons has been discussed and developed since early 1980s [2, 3]. A photon collider would be a very natural and relatively cheap supplement to a high-energy e^+e^- linear collider. It would allow the study of New Physics in two additional types of collisions, $\gamma\gamma$ and γe with energies and luminosities close to those in e^+e^- collisions. A comprehensive description of the PLC is given in the TESLA TDR [4]; practically everything regarding the photon collider at TESLA is valid for the PLC at the ILC. Further progress on the PLC after 2001 has been summarized in my talks at PHOTON2005 [5, 6] and PHOTON2007 [7].

What's new since 2007? Unfortunately, the future of the ILC is still highly uncertain. A lot depends on the physics results from the LHC, but even the discovery of a new physics at the LHC would not guarantee the approval of the ILC (or CLIC?) construction due to its high cost ("high" as perceived by politicians). A possible way to overcome this barrier could be to build the linear collider in several stages. Recently, in October 2008, Prof. Hirotaka Sugawara suggested to the ILC Steering Committee the construction of a "Photon collider Higgs factory as a precursor to ILC," as the required energy for producing a 120 GeV Higgs is lower in $\gamma\gamma$ collisions than in e^+e^- , positrons are not needed, and therefore such a collider would be much cheaper. While laudable as an attempt to find a way out of the ILC stalemate, this suggestion has caused concern to many in the ILC community because it would have meant an additional delay of 5-6 years in the start of e^+e^- operations at the ILC. After consultations with PLC experts and additional study of the technical aspects and physics program for a low-energy startup scenario, the ILCSC rightfully concluded that it would more preferable to start with e^+e^- at $2E = 230$ GeV and investigate the Higgs in the $e^+e^- \rightarrow ZH$ process. This option's cost is not much higher than that of a 120 GeV PLC, but the physics case is stronger.

The other interesting activities in the last few years related to the photon collider and based on ideas originally proposed in the context of photon colliders are the developments of laser systems for various applications based on Compton scattering.

The outline of this paper is as follows. Basic properties of the PLC are considered in Sect. 2.

Technical aspects are overviewed in Sect. 3. The proposal of the PLC as the first stage of the ILC is discussed in Sect. 4. Various applications of Compton scattering are considered in Sect. 5.

2 Basics of the photon collider

Let us consider briefly the main characteristics of backward Compton scattering important for the photon collider.

Kinematics. In the conversion region, a laser photon of energy ω_0 collides with a high-energy electron of energy E_0 at a small collision angle α_0 (almost head-on). The energy of the scattered photon ω depends on the photon scattering angle ϑ with respect to the initial direction of the electron as follows [3]:

$$\omega = \frac{\omega_m}{1 + (\vartheta/\vartheta_0)^2}, \quad \omega_m = \frac{x}{x+1}E_0; \quad \vartheta_0 = \frac{mc^2}{E_0}\sqrt{x+1}; \quad x = \frac{4E\omega_0}{m^2c^4} \cos^2 \frac{\alpha_0}{2} \simeq 19 \left[\frac{E_0}{\text{TeV}} \right] \left[\frac{\mu\text{m}}{\lambda} \right], \quad (1)$$

where ω_m is the maximum energy of scattered photons. For example: $E_0 = 250$ GeV, $\omega_0 = 1.17$ eV ($\lambda = 1.06$ μm) (for the most powerful solid-state lasers) $\Rightarrow x = 4.5$ and $\omega_m/E_0 = 0.82$. Spectra of scattered photons are broad with enhancement at maximum energies. Formulae for the Compton cross section and graphs can be found elsewhere [3, 4].

Monochromatization. By collimating the photon beam, one can obtain monochromatic gamma (or X-ray) beams, which is important for various potential applications. At the photon collider, there are no collimators, but there is some monochromatization of collisions due to the fact that the higher-energy photons collide at smaller spot sizes and contribute more to the luminosity. In γe collisions, the resulting luminosity spectrum can, in principle, be very narrow (the electron beam collides with the most high-energy photons), while in $\gamma\gamma$ collisions the resulting luminosity spectra have the width at half-maximum of about 10-15% [8, 9].

Maximum energy of scattered photons. With increasing x , the energy of the backscattered photons increases and the energy spectrum becomes narrower. However, at large values of x photons may be lost due to creation of e^+e^- pairs in collisions with laser photons, which leads to a reduction of the $\gamma\gamma$ luminosity [3, 8, 9]. The threshold of this reaction is $x = 2(1 + \sqrt{2}) \approx 4.83$. The corresponding wavelength of laser photons is $\lambda = 4.2E_0$ [TeV] μm . Hence, the maximum energy of photons at the PLC is about $0.8E_0$.

Polarization If laser photons are 100% circularly polarized, the backscattered photons at the highest photon energy also have 100% circular polarization (even for unpolarized electrons and for any value of x). The energy spectrum of scattered photons depends on the average electron helicity λ_e and that of the laser photons P_c . The relative number of hard photons increases when one uses beams with a negative value of the product $\lambda_e P_c$. For large x , the polarization of electrons increases the number of photons in the high-energy peak almost by a factor of 2 (or 4 in the $\gamma\gamma$ luminosity). The energy spectrum of the scattered photons for various helicities of the electron and laser beams can be found elsewhere [3, 4]. A high degree of photon's circular polarization is essential for the study of many physics processes, for example, for suppression of QED background in the study of the Higgs boson [4]. The ratio L_0/L_2 (0,2 is the total helicity of colliding photons) is larger when electron beams have a higher degree of longitudinal polarization [4]. Modern electron guns give polarization up to $\sim 85\%$, which is OK. A high electron polarization is practically mandatory for the photon collider. With unpolarized electron beams, it would be practically impossible to study the Higgs(120) (or even to observe it).

Nonlinear effects in the conversion. In order to convert nearly all electrons to high-energy photons, the density of laser photons at the conversion point should be so high that the electron can interact with several laser photons simultaneously. This nonlinear effect is characterized by the parameter $\xi^2 = 2n_\gamma r_e^2 \lambda / \alpha$, where n_γ is the density of laser photons, $r_e = e^2 / mc^2$ and $\alpha = e^2 / \hbar c$ ([4] and references therein). The transverse motion of the electron in the electromagnetic wave leads to an effective increase of the electron mass: $m^2 \rightarrow m^2(1 + \xi^2)$, which decreases the maximum energy of the scattered photons: $\omega_m / E_0 = x / (1 + x + \xi^2)$. The Compton spectrum is shifted towards lower energies, higher harmonics appear, and the $\gamma\gamma$ luminosity spectra become broader. At $x = 4.8$, the value of ω_m / E_0 decreases by about 5% for $\xi^2 = 0.3$, which can be considered the limit.

Laser flash energy. For small conversion coefficients $k = N_\gamma / N_e \sim 1 - \exp(-A/A_0)$, where the flash energy A_0 is determined by the diffractive divergence of the laser beam and geometric size of the electron beam. For head-on collisions and very narrow electron beams $A_0 \sim 2\hbar c \sigma_z / \sigma_c$ [9], where σ_z is the r.m.s. length of the electron beam and σ_c is the Compton cross section. For $x = 4.8$ $A_0 \sim 3\sigma_z$ [mm] J, while for $x \ll 1$ the Compton cross section approaches the Thomson one and the coefficients $3 \Rightarrow 1$. For the ILC ($\sigma_z = 0.3$) mm this estimate gives $A_0 \sim 1$ J. However, when $k \sim 1$ the nonlinear effects become important. In order to keep ξ^2 small one should make the conversion length longer, which increases the required flash energy. In calculating the flash energy, one should also take into account the collision angle between the laser and electron beams (when the laser optics is outside of the electron beam), the effective transverse size of the electron beam due to the tilt in the crab-crossing scheme of collisions and the angular size of the first quad (if optical mirrors are situated outside the detector). A realistic calculation for ILC(500) gives $A_0 \sim 9J$ [12, 11, 6].

3 Technical problems of photon colliders

3.1 $\gamma\gamma, \gamma e$ luminosities

In e^+e^- collisions, the maximum achievable luminosity is determined by beamstrahlung and beam instabilities. At photon colliders, the only effect that restricts the $\gamma\gamma$ luminosity is the conversion of the high-energy photons into e^+e^- pairs in the field of the opposing beam – that is, the coherent pair creation [13, 8]. For γe collisions, the luminosity is determined by beamstrahlung, coherent pair creation, and the beam displacement during the collision [9, 4]. It is interesting to note that at the center-of-mass energies below 0.5–1 TeV and for electron beams that are not too short (the case of ILC), coherent pair creation is suppressed due to the broadening and displacement of the electron beams during the collision. For e^+e^- , the minimum horizontal beam size restricted by beamstrahlung is about 500 nm at the ILC, while the photon collider can work even with $\sigma_x \sim 10$ nm at $2E_0 = 500$ GeV, delivering a luminosity much higher than that in e^+e^- collisions [14, 15, 4]. In fact, the $\gamma\gamma$ luminosity is simply proportional to the *geometric* e^-e^- luminosity L_{geom} .

Unfortunately, the beam emittances in the damping-ring designs currently under consideration cannot achieve beam sizes that are smaller than $\sigma_x \sim 250$ nm and $\sigma_y \sim 5$ nm [6], though a reduction of σ_x by a factor of two seems possible. In principle, one can use electron beams directly from low-emittance photo-guns, avoiding the need for damping rings altogether, but at present they offer a product of the transverse emittances that is noticeably larger than can be obtained with damping rings: with polarized electron beams directly from photo-guns, the luminosity would be 100 times smaller!

Here is an approximate rule: the luminosity in the high-energy peak $L_{\gamma\gamma} \sim 0.1L_{\text{geom}}$ [4]. With “nominal” ILC beam parameters, the expected $\gamma\gamma$ luminosity in the high-energy peak of the luminosity spectrum $L_{\gamma\gamma}(z > 0.8z_m) \sim 3.5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \sim 0.17L_{e^+e^-}$ [11, 6].

Taking into account the fact that cross sections for many interesting processes are larger in $\gamma\gamma$ collisions than those in e^+e^- by an order of magnitude [4], the event rate in $\gamma\gamma$ collisions with the nominal ILC beams would be similar, or perhaps somewhat larger, than in e^+e^- collisions. However, it is a highly unsatisfying situation to have the $\gamma\gamma$ luminosity limited by the beam emittances, an order of magnitude below its physics limit determined by collision effects. It is an extremely interesting and important task to search for a realistic technical solution for obtaining beams with smaller emittances, and the first order of business should be trying to optimize the damping rings for the specific requirements of achieving the highest possible luminosity at the photon collider, as it was emphasized in [11, 6, 16]. Up to now the ILC damping-ring design has been guided only by the baseline e^+e^- collisions.

The typical $\gamma\gamma$, γe luminosity spectra for the TESLA-ILC(500) parameters are shown in Fig. 1 [4]. One can see that $\gamma\gamma$ and γe luminosities are comparable and these processes can be studied simultaneously. However, it is much better to study γe collisions when only one of the electron beams is converted to photons. In this case, one can measure the γe luminosity much more precisely [19]. The problem of measuring the γe luminosity spectra when both beams are converted to photons is due to the uncertainty which direction the photon came from. For most

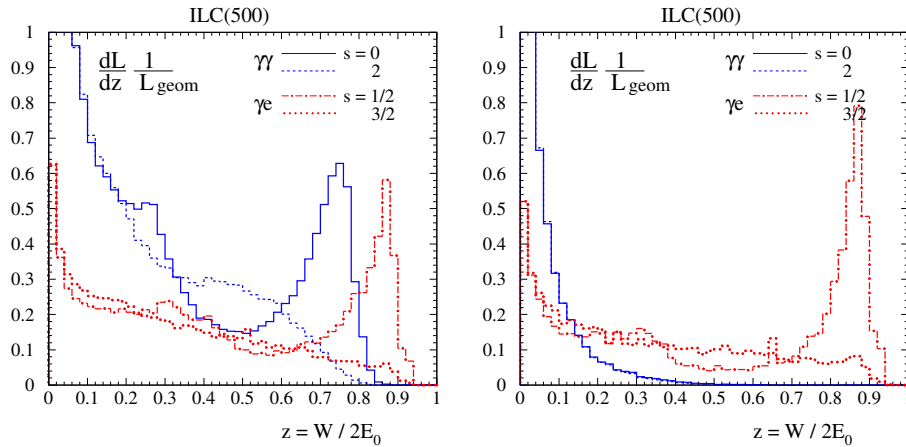


Figure 1: $\gamma\gamma$, γe luminosity spectra, left: both beams are converted to photons; right: only one beam is converted to photons.

measurements, the luminosity as high as possible is desired. However, sometimes very clean $\gamma\gamma$ collisions with good monochromaticity and a reduced luminosity (in order to avoid overlapping events) are needed. At large CP-IP distances and a non-zero crossing angle, the detector field serves as a deflecting magnet and allows more-or-less clean and quite monochromatic $\gamma\gamma$, γe collisions to be obtained with a reduced luminosity, which will be useful to QCD studies, [20, 21].

Luminosity stabilization. Beam collisions (luminosity) at linear colliders can be adjusted by a feedback system that measures the beam-beam deflection using beam position monitors and corrects beam positions by fast kickers. This method is considered for e^+e^- collisions and is assumed for $\gamma\gamma$ as well [4, 6], though there are some differences between the e^+e^- and $\gamma\gamma$ cases. This problem and a stabilization algorithm were considered in detail in Ref. [6].

Luminosity measurement. The measurement of the luminosity at the photon collider is not an easy task. The spectra are broad, and one should measure the luminosity and polarization as a function of energies E_1, E_2 of the colliding particles [19]. The luminosity spectrum and polarization can be measured using various QED processes. These are $\gamma\gamma \rightarrow l^+l^-$ ($l = e, \mu$) [4, 19], $\gamma\gamma \rightarrow l^+l^-\gamma$ [19, 22] for $\gamma\gamma$ collisions and $\gamma e \rightarrow \gamma e$ and $\gamma e \rightarrow e^-e^+e^-$ for γe collisions [19]. Some other SM processes could be useful as well.

Absolute beam energy measurement. At the photon collider, the edge energy of the photon spectra and the electron beam energy E_0 are not strictly connected due to nonlinear effects in Compton scattering. The absolute energy calibration of the detector can be done using the process $\gamma e \rightarrow eZ$ (during normal runs in γe mode or mixed $\gamma\gamma$ and γe mode) [23].

3.2 Removal of used beams

The general scheme of the photon collider is shown in Fig. 2. The optimum $b \sim \gamma\sigma_y$, which is ~ 1.5 mm for $\sigma_y = 3$ nm and $2E_0 = 500$ GeV. This space is too small to fit any kind of a magnet for deflection of used electron beams. In this case, there is a mixture of $\gamma\gamma$, γe and e^-e^- collisions. After crossing the conversion region, the electrons have a very broad energy spectrum, $E = (0.02-1)E_0$ and large disruption angles due to deflection of low-energy electrons in the field of the opposing beam. The removal of such a beam from the detector is therefore far from trivial.

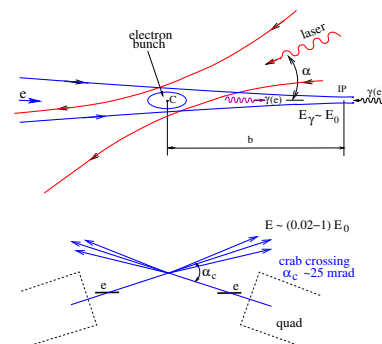


Figure 2: Scheme of $\gamma\gamma$, γe collider.

The “crab crossing” scheme of beam collisions solves the problem of beam removal at photon colliders [8, 9], Fig. 2 (bottom). In the crab-crossing scheme [25], the beams are collided at a crossing angle α_c . In order to preserve the luminosity, the beams are tilted by a special RF cavity by the angle $\alpha_c/2$. If the crossing angle is larger than the disruption angles, the beams just travel straight outside the quadrupoles.

The disrupted beams after the IP have an angular spread of about ± 12 mrad [4, 11, 6]. The disruption angle for low-energy particles is proportional to $\sqrt{N/\sigma_z E}$ [8, 9] and depends very weakly on the transverse beam sizes. The required crossing angle is determined by the disruption angle, the outer radius of the final quadrupole (about 5 cm [11, 6]), and the distance between the first quad and the IP (about 4 m), which gives $\alpha_c = 12 + 5/400 \approx 25$ mrad.

In the present ILC design [10] only one IP is planned, with a crossing angle of 14 mrad and two detectors in the pull-push configuration. On the other hand, at the photon collider the crossing angle should be at least 25 mrad. At first sight, it would therefore seem quite reasonable to design the ILC with 25 mrad crossing angle both for the e^+e^- and the photon collider. However, it was decided to make different collision angles due to very different requirements to the extraction lines and beam dumps. In the e^+e^- case, after collision the beams remain quite monochromatic, and so there is a possibility to measure their properties (the energy spectrum and polarization). At the photon collider, the situation is different: 1) the disrupted beams at a photon collider consist of an equal mixture of electrons and photons; 2) beams have a large angular spread and need exit pipes of a large diameter; 3) the photon beam after the Compton scattering is very narrow, it cannot be dumped directly at any solid or liquid material. There

exist an idea and simulations of a beam dump for the photon collider [24, 11, 6]. Conceptually, it is a long tube, the first 100 m of which is vacuum, followed by a 150 m long gas converter ending in a water-filled beam dump. In addition, there are fast sweeping magnet for electrons. Due to a large beam width, no detailed diagnostics are possible except, perhaps, for beam profile measurements.

So, it makes sense to have different crossing angles, separate extraction lines and beam dumps for e^+e^- and $\gamma\gamma$. For the transition from e^+e^- to $\gamma\gamma$, one has to move the detector and about 700 m of the up-stream beamline [26].

3.3 The laser and optics

The photon collider at ILC(500) requires a laser system with the following parameters [11, 6]: flash energy $A \sim 10$ J, $\sigma_t \sim 1.5$ ps, $\lambda \sim 1 \mu\text{m} (\leq 5E_0 [\text{TeV}] \mu\text{m}$ in a general case), and the ILC pulse structure: 3000 bunches within a 1 ms train and 5 Hz repetition rate for the trains, the total collision rate being 15 kHz.

In addition to the average repetition rate, the time structure is of great importance. The average power required of each of the two lasers for the photon collider at the ILC is $10 \text{ J} \times 15000 \text{ Hz} \sim 150 \text{ kW}$; however, the power within the 1 msec train is $10 \text{ J} \times 3000/0.001 \sim 30 \text{ MW}$! The cost of diodes is about $\mathcal{O}(1\$/\text{W})$, the pumping efficiency about 25%, so the cost of just the pumping diodes would be $\mathcal{O}(\$100\text{M})$.

Fortunately, at the PLC and other Compton scattering applications the same laser bunch can be used multiple times. The most attractive approach is a stacking optical cavity that is pumped by a laser via a semi-transparent mirror [14, 17, 15, 18, 4, 12]. The ILC pulse structure (3000 bunches in the train with inter-pulse distance 100 m) is sufficient to create a ring cavity around the detector. One can create inside such a cavity a light pulse with an intensity that is by a factor of Q (the quality factor of the cavity) greater than the incoming laser power. The value of Q achievable at such powers is several hundreds and (even $Q > 1000$ is not excluded). This means reduction of the required laser power by the large factor Q .

The external optical cavity (pulse stacking cavity) idea has proven to be a highly useful technique for HEP and other application (see the last Section). Recently at LAL, F. Zomer's group has received in a Fabry-Perot cavity an enhancement factor of 10000! [27] They found that a simple concentric Fabry-Perot cavity is very unstable and sensitive to displacements. Much more stable is the 2D (planar) concave 4-mirror system, but it also has a problem: astigmatic and only linearly (or elliptically) polarized eigenmodes due to different reflection for the s and p waves. A possible solution: 3D 4-mirror cavity that has reduced astigmatism and stable circularly polarized eigenmodes. The LAL group working in collaboration with Japanese colleagues (see T. Takahashi's talk in these proceedings) is in the process of developing such a 3D 4-mirror cavity, plans to install it at the KEK ATF2 facility and obtain 1 MW average power in the cavity. For the photon collider, very stable both circular and linear polarizations are needed. We see that this is not a simple task.

Recently, J. Gronberg and B. Stuart from LLNL have proposed a plan on possible stages in the development and construction of the laser system for the PLC [28]. They demonstrate that all the necessary technologies already exist. Pulse injection and intermediate amplification devices are off-the-shelf technologies; the main amplifier is not commercially available but at LLNL all required technologies exist (the Mercury laser is an existence proof). Gronberg and Stuart specified six stages, where the first one is the pre-conceptual design and the last one is the construction of a full-scale cavity and demonstration of its operation. The rough estimate

of the cost of the laser system is \$20 M (“once it is known technology”). These are very nice plans! (dreams?) Unfortunately, at present there are no resources for such a program, partially due to the very uncertain plans on the ILC.

In summary: at present, practically all laser technologies and components required for a photon collider are in existence; nevertheless, the construction of such a state-of-the-art laser system will not be an easy task. The next step will be the development (on paper) of a detailed laser scheme, its optimization, analyses of tolerances, methods of stabilization, figuring out what already exists and is known and what should be experimentally verified. Current development of passive stacking cavities for various applications based on Compton scattering is very helpful for the PLC.

4 Photon collider Higgs factory as a precursor to ILC

We have routinely assumed that a linear collider would start with e^+e^- , while $\gamma\gamma, \gamma e$ collisions would arrive several years later. However, on many occasions many people have suggested to build the photon collider before e^+e^- (or even without e^+e^-) because it is simpler (no e^+ , may be no damping rings) and a somewhat lower beam energy is needed to produce an intermediate-mass Higgs boson. Several such suggestions (not all) are 1) V. Balakin et al. (1993)[29], based on the VLEPP and D. Asner et al. (2001) [30], based on CLIC-1 with $E_0 = 70$ GeV.

Recently, in October 2008, H. Sugawara gave a talk at the ILCSC meeting entitled “Photon-photon collider Higgs factory as a precursor to ILC”. His main motivation was the following: the ILC(500) is too expensive, so let us build first a collider for the smallest reasonable energy. If the physics goal is H(120), then it could be produced in $\gamma\gamma \rightarrow H$ at $2E_0 \sim 160$ GeV, while $e^+e^- \rightarrow ZH$ needs higher energy. Besides, $\gamma\gamma$ does not need positrons. Before Sugawara’s presentation at the ILCSC meeting, one of the ILCSC members sent me the slides of the proposal and asked for an opinion on this subject. My reply to the ILCSC and to Sugawara-san was the following (shortly):

- the cost of such a PLC will be not much cheaper because it needs damping rings with small emittance and polarized electrons. Polarization is absolutely necessary for the Higgs study. A polarized electron gun with small emittance does not exist, therefore damping rings are unavoidable;
- the laser system for the PLC is not simple, its developments have not started yet;
- the H(120) can be studied much better in $e^+e^- \rightarrow ZH$ at $2E_0 = 230$ GeV;
- the ILC community will never agree with a proposal that shifts the start of e^+e^- experiments by about 5 years;
- the PLC gives a unique possibility to study new physics at the LC in two additional modes at a small additional cost, gives access to higher masses, but it would be better to plan the PLC as the second stage of the ILC (as it was usually assumed).

After the meeting, the ILCSC requested the LOI Physics panel to look in more detail into the physics case, and the GDE to look at machine designs for this kind of a staged approach to ILC construction and operation. In January 2009, T. Barklow, J. Gronberg, M. Peskin and A. Seryi (BGPS) prepared a draft of the report, which was discussed at the expanded Physics panel with invited PLC experts and was not supported.

In February 2009, the BGPS report was reviewed at an ILCSC meeting and the conclusion was the following: “A 180 GeV gamma-gamma precursor would cost about half that of the

500 GeV ILC, but would produce much less physics. A better alternative for early Higgs studies would be a ~ 230 GeV e^+e^- collider for studying the Higgs through ZH production; this would be about 30% more costly than the $\gamma\gamma$ collider. ILCSC decided not to pursue the gamma-gamma collider (as the ILC precursor) further at this time.”

The PLC as the first stage of ILC was also discussed at TILC09 in April 2009: T. Barklow’s plenary talk [31] and the discussion at Joint Physics session with my introductory talk [32]. All people have agreed that PLC is certainly necessary, but it would be better to start with e^+e^- (230). Since e^+e^- (230) is needed in any case, a PLC precursor results in no cost reduction at all. See also J. Gronberg’s talk at PHOTON-2009 [33]. This is all about the PLC as a precursor to the ILC.

Nevertheless, proposals to build some type of a ”cheap” low-energy PLC continue to resurface. It could have made sense if the production rates for some particles were higher than those at e^+e^- factories. However, simple estimates show that e^+e^- B-factories (and especially a future Super B factory) have much higher productivity for any particles of interest. So, the PLC should wait for its logical turn at the ILC (or CLIC, or other LC).

5 Applications based on Compton scattering

In 1981, when the PLC was proposed, the maximum $e \rightarrow \gamma$ conversion efficiency in Compton scattering of a laser light was at the level $k = N_\gamma/N_e \sim 10^{-7}$. For the PLC, $k \sim 1$ was needed. Our first journal paper was published only from the third attempt because the editors and reviewers considered the idea to be unrealistic. After invention of the chirped-pulse technique in 1985 [34], the required flash energy of several joules and ps duration became a reality. The remaining problem was the repetition rate. An optical pulse stacking cavity provides a nice solution to this problem. This technique was known for a long time (the Fabry–Perot resonator) but its wide application in HEP and other Inverse Compton Scattering (ICS) applications was triggered by PLC developments.

Collision of a relativistic electron bunch with an intense laser pulse generates photon beams with the following characteristics: source is bright (directional, ultra-fast); scattered light is monochromatic (after collimation); tunable wavelength, like FEL; much less expensive than XFEL; broad energy reach: keV, MeV, GeV TeV; polarization (useful for e^+ generation).

Let us enumerate some of the applications:

- Medical applications:
 - Dichromatic imaging: illuminate above and below contrast K-edge, digital image subtraction. Established at synchrotrons (access limited, expensive \$100s);
 - Computer tomography with monochromatic X-rays. In mammography conventional X-ray imaging is difficult, soft-tissue contrast is poor. Monochromatic X-rays enable new techniques: phase contrast imaging 3D with low dose;
- Fast X-ray materials characterization: composition of materials, inspection of trucks and containers;
- Nuclear materials detection (in trucks and containers) by monochromatic γ beam;
- Defect profiling with e^+ s. MeV photons produce positrons which gather at defects, detection of two 510 keV annihilation photons shows the source position (PET-tomography). Directly probe material defects.
- Nuclear waste assay. Resonance scattering of 1-5 MeV γ -quanta is a unique fingerprint of nuclides, radioactive and stable nuclides can be detected;

- Beam diagnostics and polarimetry at electron accelerators;
- Obtaining polarized e^+ for e^+e^- linear colliders [35]. Similar to the undulator source of polarized γ based on ~ 150 GeV main linac beams but needs much lower electron energies and is independent of the main collider. There is a very active collaboration named POSIPOL, which has already conducted four workshops on this topic;
- Laser cooling of electrons [36] can considerably reduce emittances of beams and increase the luminosity of photon colliders, provide a fast beam cooling in damping rings [37] for X-ray production and for e^+ production [35];
- The Photon Collider.

Already many ICS facilities are under construction in the world [38]. These activities (all enumerated above and some others) are called by people as the "Compton World Wide Web of Laser Compton." Let us hope that the Photon Collider will be eventually constructed somewhere in the world as well!

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