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Prospects of high energy photon colliders

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Abstract

Photon colliders ($\gamma\gamma$, γe) have been considered a natural addition to e^+e^- linear-collider projects for more than 30 years [1, 2]. It was a common opinion that such linear collider with four types of colliding beams (plus e^-e^-) would be the best instrument for the study of particles physics at energies from 100 GeV to several TeV where a lot of new physics was expected, including the dark matter. Following the discovery of the Higgs boson at LHC (and nothing else), the physics community has been actively considering various approaches to building a Higgs factories for precision measurement of the Higgs properties, among them there are several proposals of photon colliders (PC). In this paper, following a brief discussion of general situation in particles physics and the place of the photon collider among candidates for future colliders, I give an overview of photon colliders based on linear colliders ILC and CLIC and of more recently proposed photon-collider Higgs factories (with no e^+e^- collision option) based on recirculation linacs in ring tunnels.

Keywords: Photon collider, linear collider, gamma collider, photon electron, Compton scattering

1. Introduction

In the middle of 2012, two detectors at the LHC announced the discovery of a new particle with the mass of about 126 GeV/c^2, with properties consistent with those predicted for the Standard Model Higgs boson. Physicists around the world had been waiting for many years for the first round of LHC discoveries in order to decide what the next HEP projects should be.

Since 1990-th the HEP community was unanimous that the next large HEP project should be a linear collider (LC) with the energy $2E_0$=500–1000 GeV. Up to now, the LHC has found only the Higgs boson—and nothing else below approximately one TeV/c^2: no supersymmetry, no dark matter particles, not a hint of anything else. It is not excluded that new physics will yet be found at LHC as higher statistics are accumulated and as LHC ramps up to its full design energy of 14 TeV. This means that the LC decision could be made no earlier than 2018. The physics motivation for an energy-frontier LC is no longer as strong as before because we know that the energy region below 1 TeV is not nearly as rich as had been expected. Are there any other strategies HEP could follow?

At the end on 2011, A. Blondel and F. Zimmermann [3] proposed e^+e^- ring collider in the LHC tunnel to study the Higgs boson with the energy $2E_0 = 240$ GeV, which is only somewhat larger than it was at LEP-2 (209 GeV). Soon thereafter, it became clear that it would be preferable to build a ring collider with a radius several times as large as LEP-2's because: a) for a fixed synchrotron radiation power, the luminosity is proportional to the ring's radius, b) in the future, one can place in the same tunnel a $\sim$ 100 GeV pp collider. The e^+e^- luminosity of such a ring collider could be several times larger that at the ILC. This clearly sounds like a serious long-term HEP strategy which is now seriously considered at CERN (FCC-ee [4, 5, 6]) and China (CEPC [7]).

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Such colliders in ∼ 100 km ring can cover the $t\bar{t}$ threshold energy $2E_0 = 350$ GeV. So, such scenario assumes building a low-energy facility for the detailed study of the Higgs boson while leaving the energy frontier to the LHC, the high-luminosity HL-LHC, and to some future, even more high-energy pp or muon collider.

Nevertheless, linear colliders are still not forgotten, though appearance of circular collider projects and absence of new physics signals other than the Higgs, certainly, weakens LC position. At present, there two linear collider projects: ILC ($2E_0$=250–1000 GeV) [8] and CLIC ($2E_0$=350–3000 GeV) [9]. The ILC team has published a Technical Design Report and waiting for approval in Japan, possibly after the LHC 2015-16 run at full energy. The CLIC team issued a Conceptual Design, with a Technical Design to be ready a few years later. The situation with linear colliders is really not clear. Correspondingly, photon colliders based on linear colliders have similar probability and additionally shifted by 15–20 years. There are also suggestions for a ring-type photon collider Higgs factory without e^+e^-) based on recirculating linacs [10, 11, 12], their prospects will be discussed below.

Another option is a muon-collider Higgs factory [13]. The technology is not ready yet, but the development of muon colliders is needed in any case for access to the highest energies. Various approaches to Higgs factories were discussed at HF2012 [14, 15].

Below we consider photon colliders, their physics motivations, possible schemes and some technical aspects.

2. Photon colliders, basic features and physics motivation

Photon colliders ($\gamma\gamma, \gamma e$) based on one-pass linear colliders (PLCs) have been in development since 1981 [1, 2]. A detailed description of the PLC can be found in Ref. [16]. After undergoing Compton scattering at a distance $b \sim 1$ mm from the IP (Fig. 1), the photons have an energy close to that of the initial electrons and follow the electrons' original direction toward the IP with a small additional angular spread of the order of $1/\gamma$. Using a modern laser with a flash energy of 5–10 joules, one can "convert" most of electrons to high-energy photons. The maximum energy of the scattered photons is

$$\omega_m = \frac{x}{x+1+\xi^2}E_0; \quad x = \frac{4E_0\omega_0}{m^2c^4} \simeq 19\left[\frac{E_0}{\text{TeV}}\right]\left[\frac{\mu\text{m}}{\lambda}\right],$$

where ξ^2 is the the parameter characterizing nonlinear effects in Compton scattering. Tighter focusing of a

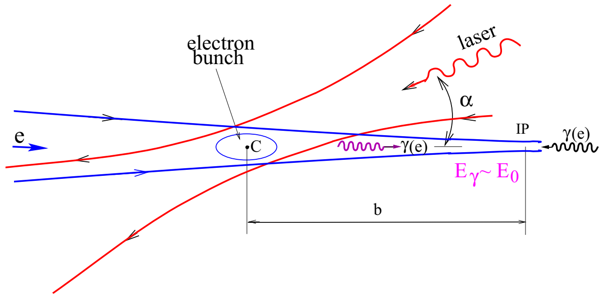

Figure 1: Scheme of $\gamma\gamma$, γe collider

laser is profitable for reduction of the flash energy, but leads to decrease of the maximum energy of scattered photons. It should be 0.15–0.3 is order to have the energy shift less than 5% for typical values x =2–5. The maximum value of x is about 5 due to e^+e^- pair creation in the conversion region. So, the maximum collision energy is about 80% for $\gamma\gamma$ and 90% for γe collisions. For example: $E_0 = 250$ GeV, $\omega_0 = 1.17$ eV ($\lambda = 1.06\ \mu m$) (for the most powerful solid-state lasers) ⇒ $x = 4.5$ and $\omega_m/E_0 = 0.82$.

If laser photons are 100% circularly polarized the backscattered photons at highest photon energy have also 100% circular polarization. A high degree of the photon 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. Using linear polarized laser photon one can obtain linear polarized backscattered photons, there polarization degree at ω_m varies between 0.6–0.3 for x =2–5, respectively.

The luminosity in the high-energy part of the spectrum $L_{\gamma\gamma} \sim 0.1L_{\text{geom}}$ [16], where L_{geom} in present ILC design with damping rings could be about 1.5 times larger than $L_{e^+e^-}$ due to tighter focusing in horizontal direction [17], so $L_{\gamma\gamma}$(in peak) is about 15% of $L_{e^+e^-}$. Due to absence of collision effects in $\gamma\gamma$ collisions for energies below one TeV the $\gamma\gamma$ luminosity is limited only by available beam emittances.

Let me enumerate briefly main arguments for photon colliders.

- the energy is lower than in e^+e^- collisions only by 10–20%;
- the number of interesting events is similar (this is valid both for charged pair and Higgs boson production);
- access to higher particle masses: single resonances H, A, etc., in $\gamma\gamma$ (while H+A in e^+e^-); heavy charged and light neutral (SUSY, etc.) in γe (while two charge in e^+e^-;