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“HIGGS” FACTORY AT THE GREEK-TURKISH BORDER: A REGIONAL PROJECT

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YUNAN-TÜRK SINIRINDA HIGGS FABRİKASI: BÖLGESEL BİR PROJE

Abstract:

We would like to propose the construction of the photon collider based "Higgs factory" in the coming years at the Greek-Turkish border, starting from its test facility with a high energy photon beam. The photon beams are to be obtained via the inverse Compton scattering of fiber laser photons of high energy electron beams. Photon electron collisions at high energies would be a bonus of this machine. This proposal (http://indico.cern.ch/event/175067/contributions/284345/) was among the contributions to the Open Symposium of the ESPG’12 (Open Symposium - European Strategy Preparatory Group, 2012, Krakow, Poland).

Özet:

Önümüzdeki yıllardaTürk-Yunan sınırında foton çarpıştırıcısı temelli bir "Higgs fabrikası"nın kurulumunu, yüksek enerjili bir foton demeti içeren deneme tesisi ile başlamak üzere, önermek istiyoruz. Foton demetleri, fiber lazer fotonlarının yüksek enerjili elektron demetlerinden ters Kompton saçılımıyla elde edilecektir. Bu öneri (http://indico.cern.ch/event/175067/contributions/284345/) ESPG'12 Açık Sempozyumuna (Open Symposium - European Strategy Preparatory Group, 2012, Krakow, Poland) sunulan katılımlar arasında yer almıştır.

Key words: Higgs factory, Photon collider, laser technology, electron linac

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Anahtar kelimeler: Higgs fabrikası, Foton çarpıştırıcısı, lazer teknolojisi, elektron linak

1. Introduction

After the discovery of the new boson at the LHC (ATLAS collaboration, Physics Letters B 716 (2012) 30–61), the natural next step is to produce it in a dedicated factory for detailed studies. There are three possibilities for building such a factory:

1) e^+e^- collider at a center of mass of about 260 GeV to produce ZH final states (F. Zimmermann, 2016, October 24-27),

2) a photon-photon collider at the resonance of 126 GeV (corresponding to E_{ee}=160 GeV),

3) a muon collider at the resonance of 126 GeV.

From these three options the last one requires a serious research and development effort, among other topics on the muon cooling, making it the least feasible at the present time, considering the current know-how. Therefore, one really needs to compare the first two options. The cross section of the Z associated Higgs production at the e^+e^- collider at $\sqrt{s}$ = 260 GeV with unpolarized beams is 0.2 pb, about the same as the direct Higgs production at a polarized gamma-gamma collider. Such a photon collider could be obtained from electron beams of 80 GeV via Inverse Compton Scattering. The achievable luminosities are also comparable: L $=10^{33}$ cm^{-2} s^{-1} or better has been previously envisaged (D. Asner et al, 2003, C28:27-44). However, the photon collider option has the advantage of the determination of the spin and CP properties of the new boson, by adjusting the polarization of the electron and laser beams. The idea of a photon collider was first suggested in 1982 (Ginzburg, Kotkin, Serbo and Telnov, 2001), and later updated for various electron machines that were planned: for example see (Telnov, 2001) and the references therein.

Therefore, we would like to revive the idea of construction of a photon collider based "Higgs factory" in the coming years. We propose South-East Europe, Caucasus and Middle-East countries as the possible hosts for such a laboratory. Establishment of such a facility in this area would help the development of both accelerator and high energy physics in the region. At the same time this project would promote peace in this region through international scientific collaboration.

Inspiring from the very successful CERN experience, we propose the Greek-Turkish border in Thrace as the laboratory location.

2. Electrons and Positrons vs Gammas

An electron positron collider to study the ZH final states could be made with either circular or linear machines. The first one has the obvious advantage of reusing the positrons at the expense of a large radius of curvature to reduce the energy loss by synchrotron radiation. For the second case, a fast source has to be established to produce positrons copiously to have the desired luminosity.

The cross section for the ZH final state has been calculated by using two independent tools: CompHEP (Boos et al, 2004) and Pandora (Pandora by M. Peskin) . The results are shown in Fig. 1 left side, with both unpolarized and polarized electron beams. Following the earlier examples in the field, an optimistic scenario is considered: the electron (positron) polarization is assumed to be 80% (60%). In this case, the maximum cross section is 0.20 pb for the unpolarized and it is 0.31 pb for the polarized beams.

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A similar plot for proposed $\gamma\gamma$ collider can be found in Fig. 1 right side. The maximum cross section that can be achieved is about 0.23 pb with polarized electron beams and assuming 100% laser polarization. Similar to previous case, the electron polarization is taken to be 80%. One should note that, for such a machine, one doesn't need to produce positrons. Previous work has shown that in a $\gamma\gamma$ collider, the achievable luminosities are better than 1/10 of the luminosity that can be obtained from an e^-e^- machine, meaning somewhere between 10 to 100 fb^{-1}. Such a collider would therefore yield, 2300 to 23000 Higgs bosons per year.

A $\gamma\gamma$ machine would also have the intrinsic capability to produce γe^- collisions with a considerable physics potential on its own. For example, it provides an opportunity to measure the triple gauge boson coupling WWγ, without involving the ambiguities from quartic or ZWW couplings (Mönig and Sekaric, 2005).

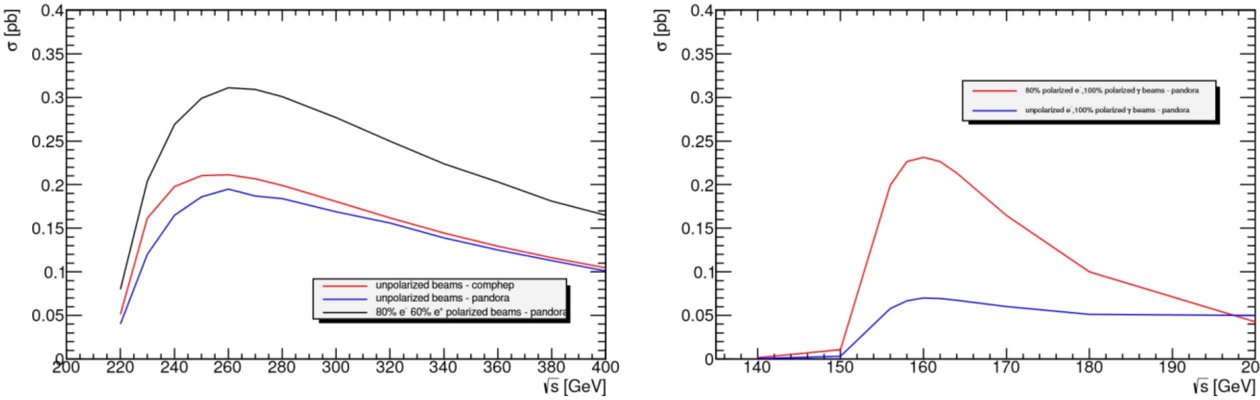

Figure 1. Left: Higgs production cross section in an e$^+$e$^-$ collider as a function of $\sqrt{s}$_ for the ZH final state. Right: Higgs production cross section in a $\gamma\gamma$ collider as a function of $\sqrt{s}$ (of the e–e– machine) to produce H bosons in the final state. Two different numerical tools are used to consider both polarized and unpolarized beams.

3. Photon Collider Specifics

3.1 Accelerator Considerations

A dedicated electron linac with two arcs bending in opposite directions or two independent electron linacs facing each other seem to be the two possible options for obtaining the 80 GeV electron beams. The relative merits of both approaches have been previously considered within the context of CLIC1 with the conclusion that the first option was simpler and cheaper to build, whereas the second one was preferable from a performance point of view (Schulte and Zimmermann, 2001, CLIC Note 496). The utilization of CLIC technology would permit an accelerating gradient of about 100 MV/m, thus an electron machine of about 1.5 km would reach the target energy of 80 GeV. For comparison, the ILC design with superconducting cavities yields a gradient of about 35 MV/m thus roughly tripling the length of the accelerator. The CLIC option has the potential of being cheaper since apart from being shorter, it uses normal conducting accelerating structures.

CLIC accelerating gradient is feasible today? They didn't progress much.

High energy photon beam will be obtained via Compton backscattering of a laser beam off the electron beam at Conversion Point (CP) which is prior to interaction point of $\gamma\gamma$ collisions. The distance between the CP and the interaction region could be as small as 5 cm.

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3.2. Laser Technologies

The technological basis of generation of highly intense ultrafast pulses is rapidly developing on multiple fronts and a future laser-based source for gamma particles is likely to be well-served by these advances. The requirements for high flux translate into large average powers, as well as high peak powers and short pulses to maximize the interaction cross section for (inverse) Compton scattering, which appears to be most feasible approach to laser-based gamma ray generation.

The wavelength needed to obtain a γ beam of 64 GeV can be easily found as λ = 0.38 μm according to the well known formula: $E_\gamma^{max} = E_e \frac{x}{x+1}\,,\;\; x \approx 19 \times E_e[TeV]/\lambda[\mu m]$ as given in (Mönig and Sekaric, 2005). As such a wavelength is hard to obtain for extremely high average power and pulse energy combinations required, a tradeoff can be envisaged to slightly increase the electron beam energy to E_e = 85 GeV, which would require a longer laser wavelength to match the change in the x factor and in the maximum photon energy calculation. With λ = 0.53 μm, x becomes 3.2 yielding the required $E_\gamma^{max} = 64$ GeV. The main parameters of the proposed photon collider are summarized in Table 1.

There are three potential technology lines that may be pursued to achieve the desired laser parameters: (1) traditional solid state laser technology, (2) thin-disk lasers, and (3) fiber lasers. In all three cases, conversion to 0.5 μm wavelength region is accomplished via second harmonic generation (SHG).

1) Solid state lasers: Well-established ultrafast solid state lasers (most notably Ti:sapphire, Nd:glass, etc) have generated even J-level energies with picosecond and femtosecond pulse durations being routine. Nevertheless, it will be challenging to scale up these lasers to kW-level average powers. One notable exception is cryogenically cooled Yb:YAG, with which 2.3 kW CW operation has been demonstrated (Brasseur et al., 2009). In the pulsed regime, 40 mJ pulses at 1 kHz and 15 ps has been generated (Hong et al., 2010) . However, the narrow bandwidth of the gain medium limits pulse durations to above few ps or longer.

2) Thin disk lasers: There has been significant advances in this area, with already >1 kW-level average powers and high energies being demonstrated (Beil, et al., 2010). Thin-disk lasers hold good potential for scaling up power levels even further. However, these systems are quite complex at high powers and pulse scaling has been relatively little studied for short pulses.

3) Fiber lasers: A non-conventional approach would be to capitalize on the developments in fiber lasers, which have excellent performance at high average powers, with as much as 10 kW demonstrated from a nearly diffraction limited CW source (Stiles, 2009). Even with sub-picosecond pulses, 830 W has been generated from rod-type fiber lasers (Eidam et al, 2010). While fiber lasers have practical advantages, such as robustness, lower cost, etc, their outstanding drawback is limited potential for scaling up the pulse energy due to peak limitations induced by nonlinear effects. However, this limitation can be circumvented through the use coherent beam combining. Given the relative simplicity and very little added cost of developed multiple fiber amplifier branches of total power equal to that of a single amplifier, and recent advances in coherent beam combining, this is an attractive prospect (Augst, Ranka, Fan and Sanchez, 2007). One could imagine combining up to 100 such sources into a single, massive powerful beam. An additional prospect is the equally rapid development of burst-mode fiber lasers, which generate a group of closely spaced high-energy pulses (Kalaycıoğlu, Eken and Ilday, 2011; Kalaycıoğlu et al, 2012).

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Here, we would like to express particular interest in meeting the challenging laser technology requirements through the development of fiber laser technology given their potential to surpass the other alternatives in a ∼5-year time frame, although it is evident that competing technologies should also be carefully considered and evaluated. With the fiber approach, pulse energy can potentially be scaled up to 1-mJ for all-fiber-integrated amplifiers and few-mJ through the use of specialty rod-type amplifiers, assuming, in both cases, use of phase compensation techniques.

Massively beam combining burst-mode ultrahigh-power fiber amplifiers: Considering rapid developments of coherent beam combining of 100-1000 W level CW fiber lasers, it is reasonable to expect that this technology will mature in the 4-5 year time scale, allowing combining potentially more than 100 beams. Although this brings up increased complexity, the potential for all-fiber-integrated amplifiers greatly simplify the laser design. Therefore, it seems reasonable to propose development of a unique laser system, comprising of 100 amplifier channels, each providing, e.g., 1 mJ/pulse, with 100 mJ/burst at 1 kHz and 100 W average power at 1.06 μm. Thus, the combined system, after SHG, could offer 50 mJ/pulse with 5 J/burst at 1 kHz and 5 kW average power at 530 nm. Pulse durations in the range of 1 ps could be targeted.

Table 1. The parameters of the proposed $\gamma\gamma$ collider

Parameter	Value
E_{e-} (GeV)	85 (80)
E_γ (GeV)	64
$L_{\gamma\gamma}$ (10^{33} cm^{-2} s^{-1})	1 .. 10
Laser wavelength (μm)	0.53 (0.38)
repetition frequency (Hz)	same as electron beam

3.3. Other Physics Potential

Apart from the already mentioned studies on the "Higgs" properties which would give the discriminating power between various models (such as MSSM Higgs vs SM Higgs) and the W-W-γ coupling studies, a 160-GeV photon collider would have possibility for other interesting physics cases as well. For example, the photon structure function could be investigated with the γe collisions, especially the gluon distribution of the photon. The possibility to change the polarization of the beams would also allow to determine the spin dependent structure function of the photon (Telnov, 2001). Another interesting case is the study of the W boson in detail. It could be single produced in the√ γe collisions and pair produced in the $\gamma\gamma$ collisions, where the latter at $\sqrt{s} = 160$ GeV would yield very few events (about 24 per year in the best case) but would also permit the investigation of the WW$\gamma\gamma$ quartic vertex. However, increasing the electron beam energy by 10 GeV would increase the yearly event yield 10 fold.

3.4. Location Considerations

We propose the establishment of a regional laboratory in Thrace to promote the accelerator and high energy physics potential of South-East Europe, Caucasus and Middle-East. Fig. 2 contains a map of the region with a marker showing the possible laboratory site. If the two linac option of

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the machine is adopted, Greece and Turkey could host one linac each and the detector(s) could be right at the border. The schematic view of such a machine is presented in Fig. 3. If a single linac with two arcs is selected the linac could be along the borderline, with facilities on each side of the border.

Thrace region has a low cost of real estate, manpower and living. Therefore the overall project would require lower investments compared to a similar installation at CERN or at any other Western European location. Additionally ,the local industries would benefit from this project and the region would greatly develop, leading to an increased gross regional productivity.

Figure 2. Geographical location of the suggested laboratory. The Greek-Turkish border is marked on the left side and zoomed in on the right side.

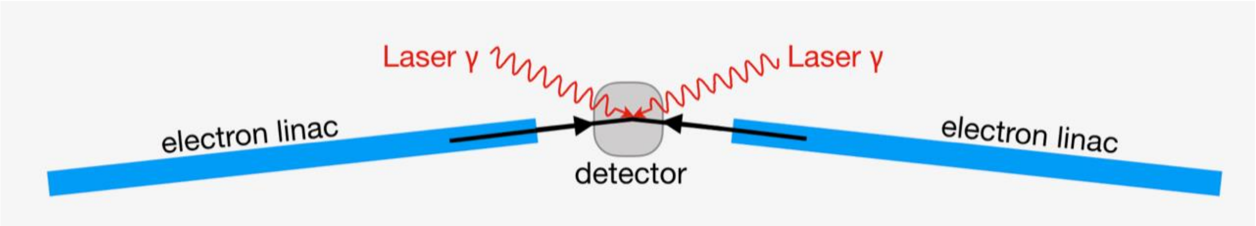

Figure 3. Schematic view of the two linac layout for the $\gamma\gamma$ collider

4. Conclusions

We believe the world would benefit from a photon collider for a multitude of reasons: foremost, a detailed study of the boson that has recently been discovered at LHC is needed. The branching fractions, the CP properties would be investigated in details. Additionally, the γe collisions would be available, opening the potential for other physics studies such as triple gauge boson couplings.

We believe the South-East Europe, Caucasus and Middle-East region could benefit from an international laboratory for a multitude of reasons: foremost, the establishment of such a facility in this area would promote peace in this region through international scientific collaboration. Inspiring from the very successful CERN experience, a double or triple country border could be the the ideal laboratory location. Additionally, it would also help the development of both accelerator and high energy physics as well as the laser technology in this part of the world.

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In conclusion, we propose the construction of a photon collider based "Higgs factory" as an international collaboration in Thrace, where Greece and Turkey (and even Bulgaria) border each other. The very first milestone towards such an effort is a good understanding of the Conversion Point. The establishment of a regional laboratory (with the prospect of enlargement), with the precise initial target of obtaining a high energy photon beam is the very first step towards the final goal.

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