H and A Discrimination using Linear Polarization of Photons at the PLC

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First realistic estimate of the usefulness of the Photon Linear Collider with linearly polarized photons as analyzer of the CP-parity of Higgs bosons is presented. MSSM Higgs bosons H and A with 300 GeV mass, for the model parameters corresponding to the so called "LHC wedge" region, are considered. When switching from circular to linear photon polarization a significant increase in heavy quark production background, which is no longer suppressed by helicity conservation, and decrease of the Higgs boson production cross sections by a factor of two is expected. Nevertheless, after three years of Photon Linear Collider running heavy scalar and pseudoscalar Higgs bosons in MSSM can be distinguished at a 4.5 σ level.

1 Introduction

The physics potential of a Photon Linear Collider (PLC) is very rich and complementary to the physics program of the e^+e^- and hadron-hadron colliders. It is an ideal place to study the mechanism of the electroweak symmetry breaking (EWSB) and the properties of the Higgs sector, as it allows for a resonant production of the Higgs particles. In our previous studies we have performed realistic simulations of the Higgs boson production at PLC within the Standard Model [2, 3], Two Higgs Doublet Model (2HDM) [4], MSSM [5] and a generic model with the CP violating Higgs boson couplings [6]. In all cases we have assumed circular polarization of colliding photon beams, which is favourable from the point of view of production cross section and background suppression. However, it does not allow to disentangle between production of heavy MSSM Higgs bosons H and A [5]. It was suggested that for studies of the CP-parity of Higgs particles and search for a potential violation of the CP-invariance in the Higgs sector linear photon polarization should be used [7]. In the presented study [1] we have made the first realistic estimate of the Higgs measurement at PLC running with linearly polarized beams.

2 Luminosity spectra

In order to perform this analysis, parametrization of the PLC luminosity spectra CompAZ [8] has to be extended to linear photon polarization. As pointed out in [9], there are significant correlations between polarizations of colliding photons, resulting in sizable increase of the effective polarization. They are of special importance at high beam energies, where average beam polarizations are low. Only due to this phenomena measurements with linear polarization are possible at all in this energy region. CAIN [10] program was used to simulate

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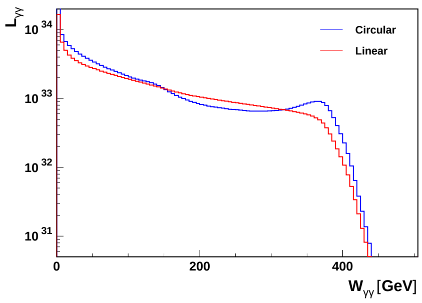

Figure 1: Expected luminosity spectra at the PLC for circular and linear photon beam polarizations, as obtained from CAIN simulation. Parameters of the TESLA Photon Collider were used with electron beam energy of 250 GeV and electron circular polarization of 85%.

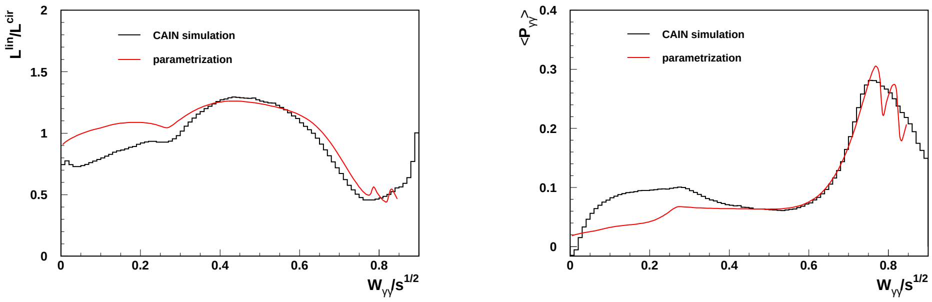

Figure 2: Comparison of the CAIN simulation results for linear photon beam polarization with new luminosity spectra parametrization based on CompAZ. Ratio of $\gamma\gamma$ luminosities for linear and circular polarization (left plot) and the average product of polarizations for colliding photons (right plot) are considered.

Compton backscattering process with linearly polarized laser photons at the PLC, taking into account all correlations. Based on this simulation we derive expected luminosity and polarization in $\gamma\gamma$ collisions. Figure 1 shows the comparison of the expected PLC luminosity spectra for circular and linear beam polarizations. For linear polarization luminosity spectra is no longer peaked at high energies and the luminosity in the region of high energy $W_{\gamma\gamma}$ decreases. Simulation results were used to constrain parameters describing polarization gain in $\gamma\gamma$ collisions. As shown in Figure 2 the obtained parametrization properly describes modification of the luminosity spectra due to change of beam polarization, especially in the high energy domain. Also the average product of photon polarizations, $\langle P_{\gamma\gamma}\rangle$, is well described. In the region of large $W_{\gamma\gamma}$, $\langle P_{\gamma\gamma}\rangle$ of up to about 30% can be obtained.

3 Cross section measurement

Parametrized luminosity spectra are used to simulate Higgs boson production with linearly polarized beams. We considered production of the MSSM Higgs bosons H and A for the parameter values corresponding to the "LHC wedge" region: M_A = 300 GeV, $\tan\beta = 7$, $M_2 = \mu$ = 200 GeV. For these parameter values, bosons H and A are almost degenerate

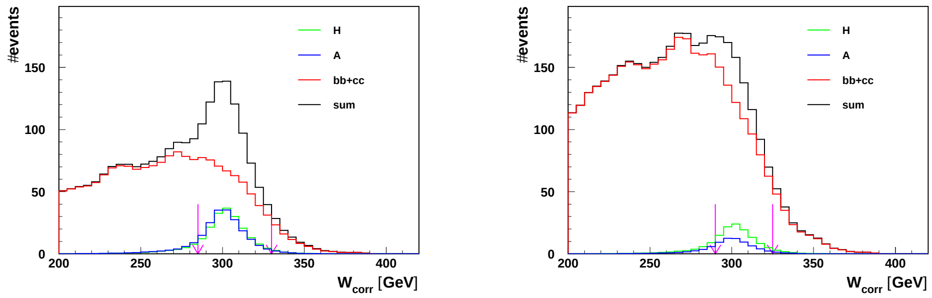

Figure 3: Reconstructed invariant mass distributions expected after one year of PLC running, for circular (left) and linear (right) photon beam polarizations.

in mass and can not be distinguished on the detector level. Analysis follows our previous study described in [5]. However, here only the background from heavy quark production ($\gamma\gamma \to Q\bar{Q}(g)$, $Q = b, c$) is taken into account. Figure 3 shows the reconstructed invariant mass distributions expected after one year of PLC running, for circular and linear beam polarizations. We observe that with linear polarization signal (H and A production) decreases by about factor of two. This is because of the luminosity drop at high $W_{\gamma\gamma}$, but also due to the reduced circular polarization of the photon beam (even with 100% linear laser polarization, some degree of the circular polarization is expected due to the polarization of the incident electron beam). Smaller degree of circular polarization results also in significant increase in heavy quark production background, which is no longer suppressed by the helicity conservation. After independent cut optimization, signal to background ratio for linear polarization is about factor of 3 smaller than for the circular polarization. Precision of the cross section measurement, for H and A production, changes from about 8% for circular beam polarization to about 18% for linear one, after one year of PLC running.

4 Discrimination between H and A

For linear photon polarization we observe a clear difference between production of scalar and pseudo-scalar Higgs bosons, as shown in Figure 3 (right). By selecting parallel or perpendicular orientation of linear polarizations of two beams, we enhance production of scalar or pseudo-scalar state, respectively. By combining measurements with different polarization orientations, cross sections for H and A production can be disentangled. After three years of PLC running (one year with each orientation of linear polarization and one year with circular polarisation) cross section determination precision of 22% can be obtained. Hypothesis of pure scalar or pure pseudo-scalar production (assuming that the total production cross section for unpolarized beam is the same as in the considered MSSM scenario) can be distinguished at 4.5 σ level, see Figure 4. Polarization of the photon beam obtained in the process of Compton backscattering is determined by polarizations of the incident laser and electron beams. Circular and linear polarization configurations considered so far correspond to the laser light with 100% circular or 100% linear polarization, and 85% circular polarization for electrons. However, one could also consider laser with mixed polarization. In fact, highest $\langle P_{\gamma\gamma} \rangle$ can be obtained by using 95% linear laser polarization with additional contribution of 30% circular laser polarization. However, the corresponding polarization configuration

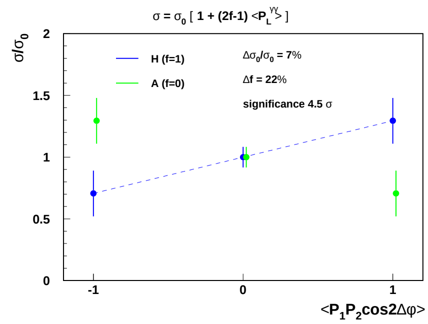

Figure 4: Expected precision of Higgs boson production cross section measurements after three years of PLC running with circular and two linear laser beam polarizations.

results also in sizable decrease of luminosity at high $W_{\gamma\gamma}$ so that the final measurement precision is significantly worse. Therefore we can conclude that the best separation between H and A states can be obtained with 100% linear laser polarization.

5 Conclusions

We presented the first realistic estimate of the Higgs boson CP-parity determination at the PLC with linear beam polarization. Heavy MSSM Higgs bosons H and A, for model parameters corresponding to the so called "LHC wedge", were considered. Significant increase in heavy quark production background, which is no longer suppressed by helicity conservation, and decrease of the Higgs boson production rate result in the cross section measurement precision much lower than for the circular beam polarization. Nevertheless, after three years of PLC running cross sections for H and A production can be separately measured with precision of about 20%. Hypotheses of pure scalar or pure pseudo-scalar nature of the Higgs boson (assuming the same value for the total production cross section) can be distinguished at 4.5 σ level.

References

[1] Slides:
`http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=441&sessionId=79&confId=1296`

[2] P. Nieżurawski, A. Żarnecki, M. Krawczyk, Acta Phys. Pol. **B 34**, 177 (2003);
P. Nieżurawski, arXiv:hep-ph/0507004, arXiv:hep-ph/0503295.

[3] P.Nieżurawski, A.F.Żarnecki, M.Krawczyk, JHEP 0211, 034 (2002).

[4] P. Nieżurawski, A.F. Żarnecki, M. Krawczyk, JHEP 0502, 041 (2005).

[5] P. Nieżurawski, A.F. Żarnecki, M. Krawczyk, arXiv:hep-ph/0507006;
P. Nieżurawski, A.F. Żarnecki, M. Krawczyk, Acta Phys. Pol. **B37**, 1187 (2006).

[6] P. Nieżurawski, A.F. Żarnecki, M. Krawczyk, Acta Phys. Pol. **B36**, 833 2005.

[7] K. Hagiwara, Nucl. Instrum. Meth. **A472**, 12 (2001).

[8] A.F. Żarnecki, Acta Phys. Polon. **B34** 2741 (2003).

[9] V. Telnov, *Nontrivial effects in linear polarization at photon colliders*, ECFA workshop, Montepellier, France (2003).

[10] K. Yokoya, KEK-Report-85-9.