Charge Asymmetries in $e\gamma \to eW^+W^-$. Hunting for Strong Interaction in Higgs Sector

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The study of charge asymmetry of W bosons in the process $e\gamma \to eWW$ can be a tool for discovery of strong interaction in Higgs sector at energies that are lower than it is necessary for observation of resonances caused by this strong interaction.

1. INTRODUCTION

It is well known that at large values of Higgs boson self-coupling constant, the Higgs mechanism of Electroweak Symmetry Breaking in Standard Model (SM) can be realized without actual Higgs boson but with strong interaction in Higgs sector (SIHS) which will manifest itself as a strong interaction of longitudinal components of W and Z bosons. It is expected that this interaction will be similar to the interaction of π-mesons at $\sqrt{s} \lesssim 1.5$ GeV and will manifest itself in the form of W_LW_l, W_LZ_L and Z_LZ_L resonances. Main efforts to discover this opportunity are oriented for observation of such resonance states. It is a difficult task for the LHC due to high background and it cannot be realized at the energies reachable at the ILC in its initial stages.

The experience in low energy physics allows us to suggest the approach for discovery of SIHS at the second stage of ILC (with c.m.s. energy $0.8 \div 1$ TeV) in the case of realization of Photon Collider mode [1].

• **Some history**.

The study of charge asymmetry of pions in $e^+e^- \to e^+e^-\pi^+\pi^-$ allows to measure relative phase of $\gamma\gamma \to \pi\pi$ and $\gamma \to \pi\pi$ amplitude, caused by strong interaction [2]. This asymmetry appears due to interference of amplitudes describing production of $\pi\pi$ systems with opposite C–parities.

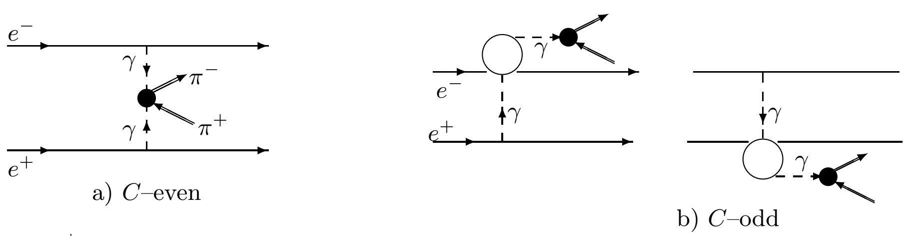

Figure 1: The $ee \to ee\pi^+\pi^-$ process amplitudes. Open circles — virtual Compton scattering. Black circles — amplitudes of subprocesses $\gamma\gamma \to \pi^+\pi^-$ (C–even dipion) and $\gamma \to \pi^+\pi^-$ (C–odd dipion), modified by strong interaction.

• Similarly, the opportunity to discover strong interaction in Higgs sector before observation of W_LW_L resonances via the study of the charge asymmetry of W in $e\gamma \to eWW$ was proposed in ref. [3]. This paper considers this asymmetry within SM in detail.

2. THE $e\gamma \to eWW$ PROCESS

The SM cross section of the process is about 10 pb in the discussed energy interval [4] which corresponds with about 10^6 expected events per year. Main contribution to the cross section is given by $e\gamma \to ee'\gamma^* \otimes \gamma\gamma^* \to WW$

process (like in fig. 1a). The charge asymmetry appears due to interference like in pion case. Therefore, its value grows with increase of electron transverse momentum. Fig. 2 demonstrates these facts for the unpolarized photons.

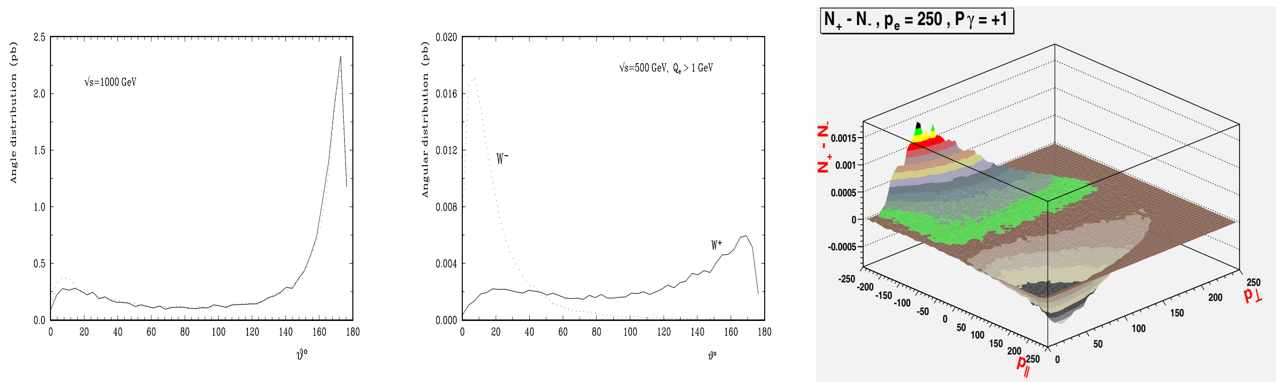

Figure 2: Two left graphs (old calculations): Angular distribution of W^+, W^- without cut in $p_\perp$ (left) and at $p_\perp^e > 1$ GeV (center); full – W^+, dotted – W^-, nonpolarized particles [7].
Right picture (recent calculations): Difference $N_{W+} - N_{W-}$ at $p_\perp^e > 10$ GeV, clockwise circularly polarized photons

2.1. Diagrams of the process

The diagrams of the process are subdivided into three types shown in Fig. 3.

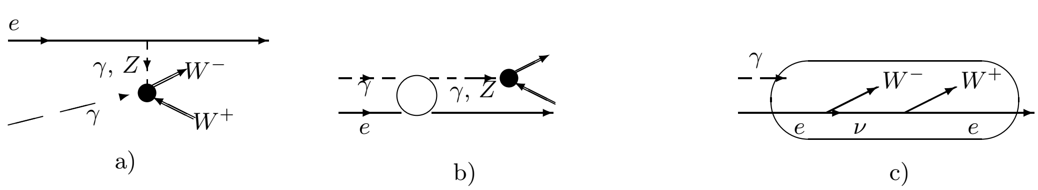

Figure 3: Types of amplitudes for $e\gamma \to eWW$ process.

• Diagrams of type a) contain subprocesses $\gamma\gamma \to W^+W^-$ and $\gamma Z \to W^+W^-$, modified by strong interaction in Higgs sector (*two–gauge contribution*).
• Diagrams of type b) contain subprocesses $\gamma \to W^+W^-$ and $Z \to W^+W^-$, modified by strong interaction in Higgs sector (*one–gauge contribution*). Open circle describes $e\gamma \to e\gamma$ or $e\gamma \to eZ$ subprocesses.
• Diagrams of type c) – with neutrino exchange – are built from the diagram shown inside the oval by connecting the photon line to each charged particle line. Strong interaction does not modify this contribution.

Diagrams 3a) and 3b) are similar to diagrams 1a) and 1b) for pions but have an essential difference. Because of Z contribution, corresponding final states have no definite C-parity. Therefore, charge asymmetry appears even within each this type, like charge asymmetry in e^+e^- collision near $Z-$ peak.

2.2. Asymmetries in SM

To see main features of the effect and its potential for the study of strong interaction in Higgs sector, we calculated some quantities describing charge asymmetry (charge asymmetric variables – CAV) for $e^-\gamma$ collision at $\sqrt{s} = 500$ GeV with polarized photons. We used CompHEP [5] and CalcHEP [6] packages for simulation.

We denoted

$$p^\pm \text{ – momenta of } W^\pm, \qquad p_e \text{ – momentum of scattered electron}, \quad W = \sqrt{(p^+ + p^-)^2}\,. \tag{1}$$

We studied W-dependence of the following averaged quantities

$$v_1 = \frac{\langle (p^+ - p^-) p_e \rangle}{\langle (p^+ + p^-) p_e \rangle}\,, \qquad v_2 = \frac{\langle (p_\parallel^+)^2 - (p_\parallel^-)^2 \rangle}{\langle (p_\parallel^+)^2 + (p_\parallel^-)^2 \rangle}\,, \qquad v_3 = \frac{\langle (p_\perp^+)^2 - (p_\perp^-)^2 \rangle}{\langle (p_\perp^+)^2 + (p_\perp^-)^2 \rangle}\,. \tag{2}$$

We applied the cut in transverse moment of scattered electron,

$$p_\perp^e \geq p_{\perp 0} \quad \text{with} \quad \begin{cases} a)\ p_{\perp 0} = 10\ GeV, \\ b)\ p_{\perp 0} = 30\ GeV. \end{cases} \tag{3}$$

With growth of $p_{\perp 0}$ the two–gauge contribution decreases strongly while the one–gauge contribution varies weakly. Therefore, the relative value of the asymmetry under interest grows. Besides, observation of scattered electron allows to check kinematics completely.

• **Influence of polarization**

First, we consider influence of photon polarization for the effect. Fig. 4 represents distribution in CAV v_1 for right-hand (upper curves) and left-hand (lower curves) polarized photons at cuts $p_{\perp 0} = 10$ GeV (left) and $p_{\perp 0} = 30$ GeV (right). We do not study the dependence on electron polarization. This dependence is expected to be

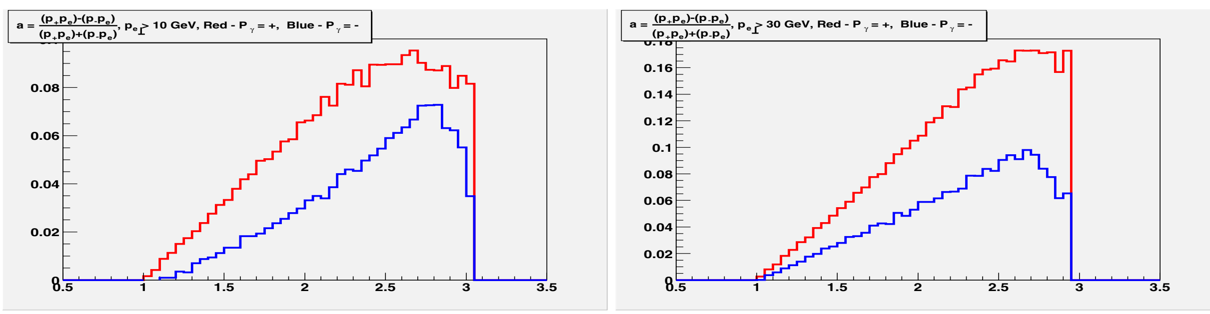

Figure 4: Dependence on polarization and cuts. Variable v_1.

weak in SM where main contribution to cross section is given by diagrams of Fig. 3a) with virtual photons having the lowest possible energy. These photons "forget" the polarization of incident electron. The strong interaction contribution becomes essential at highest effective masses of WW system with high energy of virtual photon or Z, the helicity of which reproduces almost completely the helicity of incident electron [8]. Therefore, study of this dependence will be necessary part of studies beyond SM.

• **Significance of different contributions.**

To observe the value of effect under interest, we compared the entire asymmetry and that without one-gauge contribution (Fig. 5). Strong interaction in Higgs sector modifies both one–gauge and two–gauge amplitudes. The observation of charge asymmetry caused by their interference will indicate this strong interaction. One can see that with the account of one–gauge contribution, the charge asymmetry even changes its sign.

Therefore, the influence of this potentially informative contribution to asymmetry is very high.

3. CONCLUSIONS AND PLANS

• Charge asymmetry of W is large enough easily observable effect.

• The value of the effect grows with increase of the cut in $p_{e\perp}$.

• Photon polarization influences strongly the value of charge asymmetry. The role of electron polarization remains to be studied.

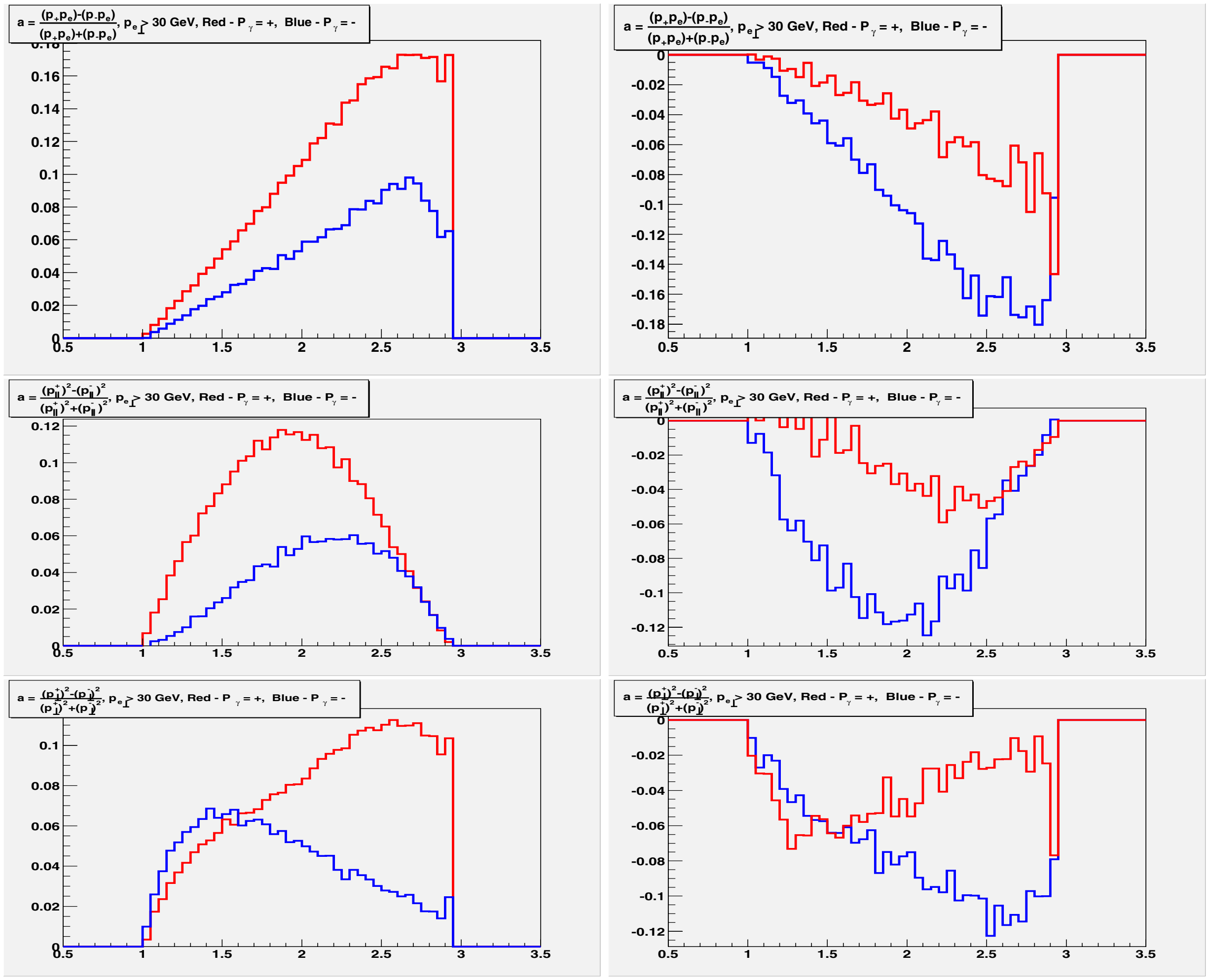

Figure 5: Asymmetries in variables v_1, v_2 and v_3 (from top to down). Right – total, left – without one gauge contributions. Upper curves for right–handed polarized photons, lower curves for left–handed polarized photons.

• Charge asymmetry is very sensitive to the interference of two–gauge and one–gauge contributions which modify under the strong interaction in Higgs sector. Reasonable approximation for this strong interaction is necessary to estimate the observable effects. It will be the next step in our studies.

Acknowledgments

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