Sensitivity to Doubly Charged Higgs Bosons in the Process $e^-\gamma \to e^+\mu^-\mu^-$

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We study the sensitivity to doubly charged Higgs bosons, Δ^{--}, in the process $e^-\gamma \to e^+\mu^-\mu^-$ for centre of mass energies appropriate to future high energy e^+e^- collider proposals. For $M_\Delta < \sqrt{s_{e\gamma}}$ discovery is likely for even relatively small values of the Yukawa coupling to leptons. However, even far above threshold, evidence for the Δ can be seen due to contributions from virtual intermediate Δ's although, in this case, $\mu^-\mu^-$ final states can only be produced in sufficient numbers for discovery for relatively large values of the Yukawa couplings.

1. Introduction

Doubly charged Higgs bosons would have a distinct experimental signature. Such particles arise in many extensions of the Standard Model (SM) including as components of $SU(2)_L$ Higgs triplets. Models with triplet representations include the Left- handed Higgs triplet model of Gelmini and Roncadelli [1], where they provide Majorana masses for left-handed neutrinos while preserving $SU(2)_L$ gauge symmetry, and the Left-right symmetric model, which [2] requires an $SU(2)_R$ Higgs triplet for symmetry breaking with the corresponding left-handed triplet Higgs field added for the case of explicit $L \leftrightarrow R$ symmetry.

In this paper we study signals for doubly charged Higgs bosons arising from an $SU(2)_L$ triplet in the process $e^-\gamma \to e^+\mu^-\mu^-$. For more details, see reference [3]. We assume the photon is produced by backscattering a laser from the e^+ beam of an e^+e^- collider [4]. We consider e^+e^- centre of mass energies of $\sqrt{s} = 500$, 800, 1000, and 1500 GeV appropriate to the TESLA/NLC/JLC high energy colliders and $\sqrt{s} = 3$, 5, and 8 TeV for the CLIC proposal. In all cases we assume an integrated luminosity of $\mathcal{L} = 500$ fb^{-1}. Our calculation includes diagrams which would not contribute to on-shell production of Δ^{--}'s. Because the signature of same sign muon pairs in the final state is so distinctive and has no SM background, we find that the process can be sensitive to virtual Δ^{--}'s with masses in excess of the centre of mass energy, depending on the strength of the Yukawa coupling to leptons.

The $SU(2)_L$ triplet's Yukawa coupling to lepton doublets is given by

$$\mathcal{L}_{Yuk} = -ih_{ll'}\Psi^T_{lL} C\sigma_2 \Delta \Psi_{l'L} + h.c., \tag{1}$$

where C is the charge conjugation matrix and Ψ_{lL} denotes the left-handed lepton doublet with flavour l. Indirect constraints on Δ masses and couplings have been obtained from lepton number violating processes [5]. Rare decay measurements [6] yield very stringent restrictions on the non-diagonal couplings $h_{e\mu}$; consequently, we choose to neglect all non-diagonal couplings here. Stringent limits on flavour diagonal couplings come from the muonium anti-muonium conversion measurement [7] which requires that the ratio of the Yukawa coupling, h, and Higgs mass, M_Δ, satisfy $h/M_\Delta < 0.44$ TeV^{-1} at 90% C.L.. These bounds allow the existence of low-mass doubly charged Higgs with a small coupling constant.

Direct search strategies for the Δ^{--} have been explored for hadron colliders [8], with the mass reach at the LHC extending to ~ 850 GeV. Signatures have also been explored for various configurations of lepton colliders, including $e\gamma$ colliders. See Reference [3] for further references. The recent calculation of Gregores *et al* [9], most closely resembles the approach presented here but is restricted to resonance Δ production.

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2. Calculations and Results

In the process $e^-\gamma \to e^+\mu^-\mu^-$, the signal of like-sign muons is distinct and SM background free, offering excellent potential for doubly charged Higgs discovery. The process proceeds via the production of a positron along with a Δ^{--}, with the subsequent Δ decay into two muons as well as through additional non-resonant contributions. These play an important role in the reach that one can obtain for doubly charged Higgs masses.

The cross section is a convolution of the backscattered laser photon spectrum, $f_{\gamma/e}(x)$ [4], with the subprocess cross section, $\hat{\sigma}(e^-\gamma \to e^+\mu^-\mu^-)$. Because we are including contributions to the final state that proceed via off-shell Δ^{--}'s we must include the doubly-charged Higgs boson width. The Δ width, however, is dependent on the parameters of the model, which determine the size and relative importance of various decay modes. To account for the possible variation in width without restricting ourselves to specific scenarios we calculated the width using $\Gamma(\Delta^{--}) = \Gamma_b + \Gamma_f$ where Γ_b is the partial width to final state bosons and Γ_f is the partial width into final state fermions. We consider two scenarios for the bosonic width: a narrow width scenario with $\Gamma_b = 1.5$ GeV and a broad width scenario with $\Gamma_b = 10$ GeV. These choices represent a reasonable range for various values of the masses of the different Higgs bosons. The partial width to final state fermions is given by $\Gamma(\Delta^{--} \to \ell^-\ell^-) = \frac{1}{8\pi} h_{\ell\ell}^2 M_\Delta$. Since we assume $h_{ee} = h_{\mu\mu} = h_{\tau\tau} \equiv h$, we have $\Gamma_f = 3 \times \Gamma(\Delta^{--} \to \ell^-\ell^-)$. Many studies assume the Δ decay is entirely into leptons; for small values of the Yukawa coupling and relatively low M_Δ this leads to a width which is considerably more narrow than our assumptions for the partial width into bosons. Hence, we will also note some results for the case $\Gamma = \Gamma_f$.

We consider two possibilities for the Δ^{--} signal. We assume that either all three final state particles are observed and identified or that the positron is not observed, having been lost down the beam pipe. To take into account detector acceptance we restrict the angles of the observed particles relative to the beam, θ_μ, θ_{e^+}, to the ranges $|\cos\theta| \leq 0.9$. We restrict the particle energies E_μ, $E_{e^+} \geq 10$ GeV and assumed an identification efficiency for each of the detected final state particles of $\varepsilon = 0.9$.

Given that the signal for doubly charged Higgs bosons is so distinctive and SM background free, discovery would be signalled by even one event. Because the value of the cross section for the process we consider is rather sensitive to the Δ width, the potential for discovery of the Δ is likewise sensitive to this model dependent parameter. Varying Γ_b, we find that, relative to $\Gamma_b = 10$ GeV, the case of zero bosonic width has a sensitivity to the Yukawa coupling h which is greater by a factor of about 5 [3].

In Fig. 1 we show 95% probability (3 event) contours in the $h - M_\Delta$ parameter space. In each case, we assume the narrow width $\Gamma = 1.5 + \Gamma_f$ GeV case. Figure 1a corresponds to the center of mass energies $\sqrt{s} = 500$, 800, 1000, and 1500 GeV, for the case of three observed particles in the final state, whereas Fig. 1b shows the case where only the two muons are observed. Figs. 1c and 1d correspond to the energies being considered for the CLIC e^+e^- collider, namely, $\sqrt{s} = 3$, 5, and 8 TeV, for the three body and two body final states, respectively. In each case, for $\sqrt{s}$ above the Δ production threshold, the process is sensitive to the existence of the Δ^{--} with relatively small Yukawa couplings. However, when the M_Δ becomes too massive to be produced the values of the Yukawa couplings which would allow discovery grow larger slowly.

3. Summary

The observation of doubly charged Higgs bosons would represent physics beyond the SM and, as such, searches for this type of particle should be part of the experimental program of any new high energy facility. In this paper we studied the sensitivity of $e\gamma$ collisions to doubly charged Higgs bosons. We found that for $\sqrt{s_{e\gamma}} > M_\Delta$ doubly charged Higgs bosons could be discovered for even relatively small values of the Yukawa couplings; $h > 0.01$. For larger values of the Yukawa coupling the Δ should be produced in sufficient quantity to study its properties. For values of M_Δ greater than the production threshold, discovery is still possible due to the distinctive, background free final state in the process $e\gamma \to e^+\mu^-\mu^-$ which can proceed via virtual contributions from intermediate Δ's. Thus, even an e^+e^- linear collider with modest energy has the potential to extend Δ search limits significantly higher than can be achieved at the LHC.

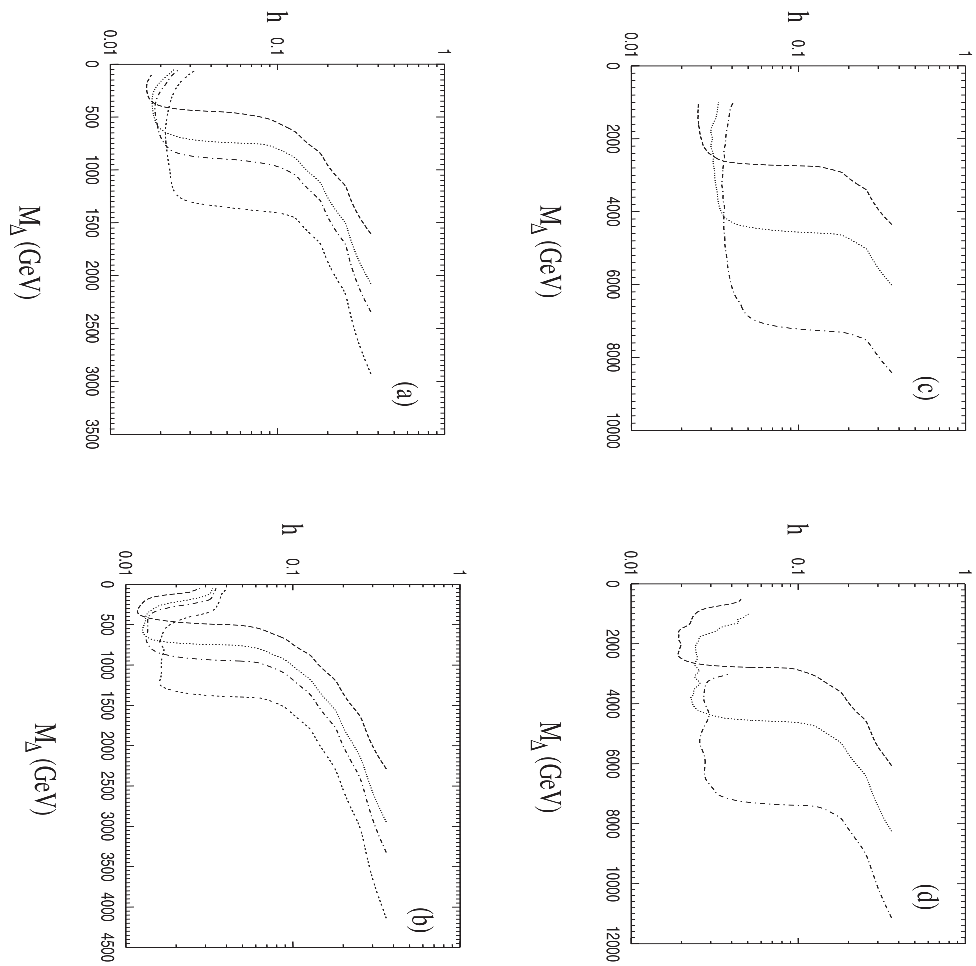

Figure 1: Discovery limits for the charged Higgs bosons as a function of Yukawa coupling and M_Δ.

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