On New Gauge Boson Signals According to the Littlest Higgs Model in Future e^+e^- Colliders

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There is a recent proposal of identifying the Higgs particle of the Standard Model as a pseudo Nambu-Goldstone boson. This new broken symmetry introduces new particles and new interactions. Among these new interactions a central role to get an experimental signal of a new physics is played by the new neutral gauge bosons, A_H and Z_H. We study the associated production of general new neutral gauge boson Z' and a hard photon in the process $e^+ + e^- \longrightarrow \mu^+ + \mu^- + \gamma$. For $M_{A_H} < \sqrt{s}$ we show that the hard photon energy distribution in $e^+ + e^- \longrightarrow \gamma + f + \bar{f}$ can present a model dependence and establish the theoretical origin of a new possible heavy neutral gauge boson.

Keywords: Littlest Higgs; New Gauge Bosons

I. THE LITTLEST HIGGS MODEL

Recently, new models have been proposed as possible solutions to the hierarchy problem of the Standard Model (SM). The Little Higgs models [1] implement the idea that the Higgs boson is a pseudo-Goldstone boson. They are constructed by embedding the Standard Model inside a larger group with an enlarged symmetry. The minimal model was called the Littlest Higgs Model (LHM). The LHM consists of an $SU(5)$ non-linear sigma model which is spontaneously broken to its subgroup $SO(5)$ by vacuum expectation value (VEV) of order f. The gauged group $(SU(2)\otimes U(1))^2$ is broken at the same time to its diagonal electroweak SM subgroup $SU(2)\otimes U(1)$. The new heavy states in this model consists of heavy gauge bosons (W_H, Z_H, A_H), a triplet Higgs Φ and a vector like top quark which cancels the quadratic divergences coming from the SM top quark. By construction, all of the new states acquire masses of order f and typically in the TeV range. The approximate mass relations for the heavy gauge bosons can be written as [2]:

$$M^2_{W_H} \simeq M^2_{Z_H} \geq \frac{M_W^2 4f^2}{v^2} \qquad M^2_{A_H} \geq M^2_w \tan^2\theta_w \frac{4f^2}{5v^2} \qquad (1)$$

where θ_w is the Weinberg angle, v is the electroweak scale and the mass parameter $M_W \equiv gv/2$ approaches the SM W-boson mass when $f \rightarrow \infty$. The neutral gauge boson A_H is typically light and should be the first signal of the LHM. A first property of this model is the presence of a second, heavier, new neutral gauge boson, named Z_H ($M_{Z_H} \approx 4M_{A_H}$). The total decay width Γ_{Z_H} is mainly dependent of the free parameters M_{Z_H} and c ($\cos\theta$), while the total decay width Γ_{A_H} is sensitive to the free parameters M_{A_H} and c' ($\cos\theta'$). The parameter space for the two mixing angles, c and c', is $0 \leq c \leq 0.5$ and $0.62 \leq c' \leq 0.73$, consistent with the precision electroweak constraints.

II. THE HARD PHOTON

The most direct channel to study the A_H, Z_H properties is $e^+ + e^- \longrightarrow f + \bar{f}$, at the ressonant energy $\sqrt{s} = M_{Z_H}, M_{A_H}$. As these masses are unknown, the new high-energy accelerators will have to vary $\sqrt{s}$. As this procedure is a very complex operation it is important to have physical alternatives at fixed $\sqrt{s}$.

In this work we explore the interesting properties of the fundamental interaction mechanism of the associated production of new neutral gauge bosons and a hard photon in the process $e^+ + e^- \longrightarrow \mu^+ + \mu^- + \gamma$. (For more details see [3]). The Feynman diagrams for this channel are shown in Fig. 1. A

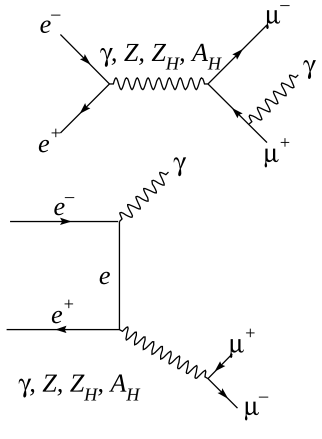

FIG. 1: Feynman diagrams for the process $e^+ + e^- \longrightarrow \mu^+ + \mu^- + \gamma$.

very simple consequence of the conservation of energy and momentum is that the final high energy photon has a fixed

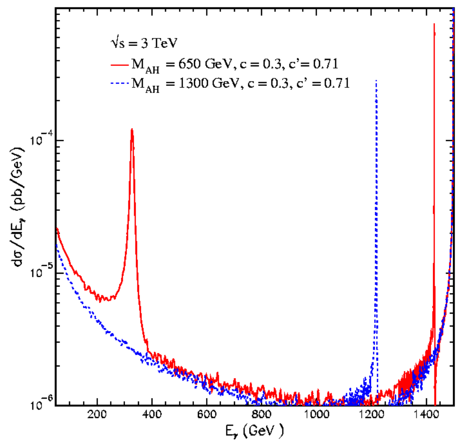

FIG. 2: Photon energy distribution in $e^+ + e^- \longrightarrow \gamma + \mu^- + \mu^+$ showing the two peaks associated to Z_H and A_H with $\sqrt{s} = 3$ TeV for LHM ($c = 0.3$ and $c' = 0.71$).

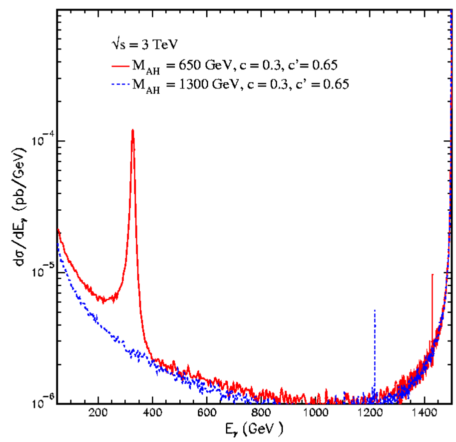

FIG. 3: Photon energy distribution in $e^+ + e^- \longrightarrow \gamma + \mu^- + \mu^+$ showing the two peaks associated to Z_H and A_H with $\sqrt{s} = 3$ TeV for LHM ($c = 0.3$ and $c' = 0.65$).

energy given by [4].

$$E_\gamma \mp \Delta_\gamma = \frac{s - (M_{Z'} \pm \Delta_{Z'})^2}{2\sqrt{s}} \qquad (2)$$

where Δ_γ and $\Delta_{Z'}$ are the uncertainties in the photon energy and in $M_{Z'}$.

The study of the hard photon energy distribution will give most information as the direct new bosons decays, but in a simple and direct way. Since the new boson masses are not known, colliders are considered at the highest energy and so we are considering $\sqrt{s} = 3$ TeV. If indications of new bosons are found with masses lower than $\sqrt{s}$, a new run with a c.m. energy near the mass value is not necessary in order to study the new bosons properties in details.

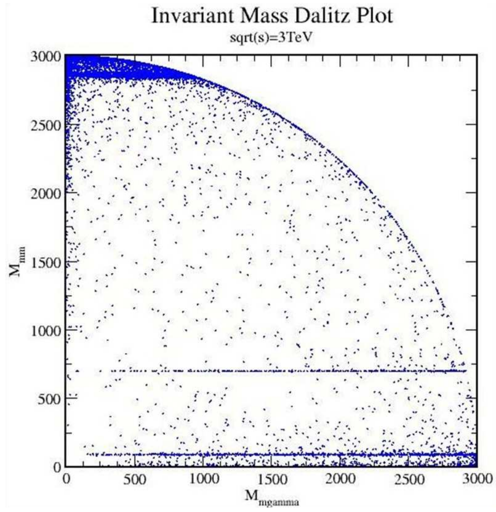

FIG. 4: Dalitz Plot.

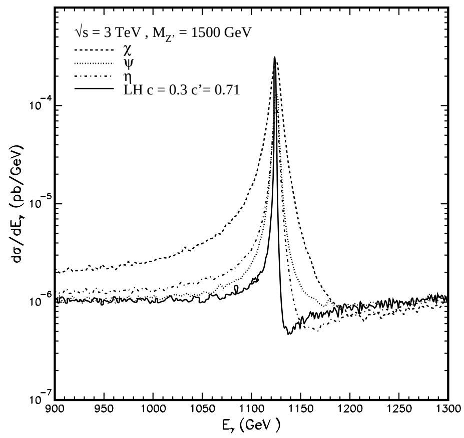

FIG. 5: Photon energy distribution in $e^+ + e^- \longrightarrow \gamma + \mu^- + \mu^+$ with $\sqrt{s} = 3$ TeV for χ, η, ψ and for LHM ($c = 0.3$ and $c' = 0.71$).

III. RESULTS

In order to obtain the hard photon energy distribution, we imposed a set of realistic cuts: all final states particles were required to emerge with a polar $\cos\theta$, measured with respect to the direction of the electron beam, in the range $|\cos\theta| \leq 0.995$. The hard photon energy was required to be greater than 5 GeV. The resulting photon energy distributions are shown in Figs. 2 and 3 in the channel $\mu^+\mu^-\gamma$ for two different c' values ($c' = 0.65$ and $c' = 0.71$). For $M_{A_H} = 650$ GeV, we can see two peaks, the first one associated to Z_H, and the second to A_H. For $M_{A_H} = 1300$ GeV, only the peak associated to A_H appears. We remark the strong mixing angle dependence on the magnitude of the photon peak. We show in Fig. 4 the invariant mass Dalitz plot. The three horizontal lines correspond to the three different neutral gauge boson (Z, A_H, Z_H) masses. Depending on the heavy boson masses one can see two horizontal lines (Z and A_H) or even only the SM Z mass. In Fig. 5 we can see the hard-photon energy distribution associated with the A_H compared to the canonical η, χ, ψ super-string inspired E_6 models. The η, χ, ψ models have a much larger value for the total neutral gauge boson width and this fact makes the hard photon energy much broader.

IV. CONCLUSIONS

We have shown that the hard photon energy distribution can establish the theoretical origin of a new possible heavy neutral gauge boson independent of how all new boson decays. This alternative signature for Z' production at the new electron-positron colliders could allow us to study its properties, at a fixed collider energy $\sqrt{s} > M_{Z'}$. Moreover, if the neutral gauge boson is identified, due to the width of the hard photon energy distribution, as the A_H of the LHM, this would imply the existence of another neutral gauge boson, the Z_H, with mass approximately four times the A_H mass.

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