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THEORETICAL SPECULATIONS ON THE TRISTAN RESULTS AT $\sqrt{s} < 60$ GeV

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ABSTRACT

We show that, if the value of the ratio $R' = \sigma_{\text{had}}/\sigma_{\mu}$ measurable by the TRISTAN experiment at $\sqrt{s} \lesssim 60$ GeV were substantially higher than the SM prediction, a very natural explanation of this apparent inconsistency would be provided by the existence of a new gauge boson Z' . Precise extra measurements at $\sqrt{s} < 70$ GeV would be crucial for this interpretation.

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In a very recent paper [1], it has been shown that the ratio $R = \sigma(\text{had})/\sigma(\text{QED})$ measured at TRISTAN for $\sqrt{s} < 60$ GeV seems to be inconsistent with the corresponding prediction of the Minimal Standard Model (MSM) for $M_Z \approx 92$ GeV. The aim of this letter is to show that, if this were the case, a very natural explanation of the (apparent) discrepancy would exist which would require the presence of a very special kind of New Physics beyond the MSM. Moreover, the same theoretical mechanism of New Physics would make crucial predictions that might be tested by extra measurements at nearby higher energies, since the involved deviations from the MSM results would achieve a maximum at $\sqrt{s} \approx 70$ GeV.

The starting point of our paper is the observation that, for Z masses of, say, ~ 92 GeV, the ratio R measured at TRISTAN seems to be larger than the corresponding predictions of the MSM, the difference increasing with energy for $\sqrt{s} \gtrsim 50$ GeV. This discrepancy, if confirmed by future measurements, would thus require some extra mechanism able to increase the involved ratio.

In another recent paper [2], it was shown that a class of models of New Physics exists which would be able to increase, for e^+e^- energies $100 \text{ GeV} < \sqrt{s} < 200 \text{ GeV}$, the experimental quantity

$$R' = \frac{\sigma(e^+e^- \rightarrow \text{had.})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} \quad (1)$$

(where the denominator contains the full $e^+e^- \rightarrow \mu^+\mu^-$ cross-section, i.e., not only the purely QED quantity) with respect to the SM predictions. The relevant models of New Physics are such that a new Z' of very general gauge origin is predicted. Thus it appears very natural to generalize the analysis of Ref. [2] to the TRISTAN situation, and see whether similar effects could be produced at the involved energies.

With this aim, we have considered the illustrative case of the most general E_6 -generated Z' [3]. We have not included in this short paper the most general left-right symmetry model [4], since one of the considered cases of the E_6 Z' 's would coincide with a "reasonable" left-right symmetry representative situation [5]. Using the same conventions as Amaldi et al. [6], we define the physical Z, Z' states as functions of the mathematical Z_0 , Z'_0 ones:

$$Z = \cos \theta_M Z_0 + \sin \theta_M Z'_0 \quad (2)$$

$$Z' = -\sin \theta_M Z_0 + \cos \theta_M Z_0' \quad (3)$$

where

$$Z_0' = \cos \beta Z_\gamma' + \sin \beta Z_\psi' \quad (4)$$

Two relevant experimental quantities for our search would be

$$R_\mu = \frac{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}{\sigma_{QED}} \quad (5)$$

$$\sigma_{QED} = \sigma(e^+e^- \xrightarrow{\gamma} \mu^+\mu^-)$$

$$R = \frac{\sigma(e^+e^- \rightarrow \text{had.})}{\sigma_{QED}} \quad (6)$$

Here, rather than R we shall use the ratio

$$R' = \frac{R}{R_\mu} = \frac{\sigma(e^+e^- \rightarrow \text{had.})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} \quad (7)$$

for which we expect, from previous analyses [2], possible and particularly strong Z' effects.

We have therefore computed the theoretical expression of R' [Eq. (7)], both in the MSM and in a model with a new Z' [Eqs. (3) and (4)], in the Born approximation. In fact, we are only interested in deviations from the MSM predictions, and when computing these deviations, radiative corrections would cancel exactly. Thus, the new effects with respect to the MSM will come from the $\gamma Z'$, ZZ' interference at tree level. This will introduce the parameters θ_M , $\cos \beta$ of Eqs. (2) - (4) and the quantity

$$\varepsilon = \frac{M_Z^2}{M_{Z'}^2} \quad (8)$$

In principle, the mixing angle can vary, for every $\cos \beta$ value, within a certain range fixed by the available experimental constraints [6]. This would introduce an extra complication in our analysis. However, we have verified that all our results would not change appreciably (i.e., they would vary by factors smaller than a rela-

tive few per cent) if we allowed θ_M to assume the highest allowed values for every $\cos \beta$ value, for $\sqrt{s} \lesssim 80$ GeV. This was somehow expected from previous analyses performed beyond the Z resonance [2]. This fact allows us to neglect θ_M systematically from now on. Moreover, for the purposes of a first qualitative analysis, we have been limited to the consideration of three particularly representative cases, i.e., the χ ($\cos \beta = 1$), ψ ($\cos \beta = 0$) and η ($\cos \beta = \sqrt{3/8}$, $\sin \beta = -\sqrt{5/8}$) models. Note that all the conclusions valid for the χ model would also apply to a left-right symmetric model with $g_R^2 \approx \frac{1}{2}g_L^2$ [5].

We show first the results for the muon ratio [Eq. (5)]. Figure 1a contains the relative shift

$$\delta_\mu = \frac{R_\mu - R_\mu^{SM}}{R_\mu^{SM}} = \frac{\sigma_\mu(\gamma, Z, Z') - \sigma_\mu(\gamma, Z_0)}{\sigma_\mu(\gamma, Z_0)} \quad (11)$$

evaluated at tree level for $\sqrt{s} < 80$ GeV in the three considered models, at the smallest value of $M_{Z'}$, that each model allows [6]. To fix the scale of the effect, we shall assume a realistic experimental error of at least a few per cent. With this prescription we shall only be interested in effects that are of at least, say, 5%. As Fig. 2a shows, the only case for which a sizeable effect persists is represented by the η model. Thus we shall concentrate our δ_μ analysis on this model from now on.

Figure 2b shows the effect on δ_μ of a Z'_η of variable mass. One sees that this might be seen for $M_{Z'_\eta}$, not larger than approximately 130 GeV, a value already practically ruled out by previous analyses [7].

When we repeat our analysis for the ratio R' [Eq. (7)], we note that the Z' effect is again negligible for the χ , ψ models. However, for the η model it is now definitely more pronounced. This pleasant fact is shown in Fig. 2a, which contains the shift

$$\delta_h = \frac{R' - R'^{SM}}{R'^{SM}} \Big|_{\text{Born}} \quad (10)$$

(again, we used the smallest allowed masses of the three models). Technically speaking, the enhancement in the η model is due to a combination of opposite effects that increase the hadronic cross-section and decrease the leptonic one. In fact, in the case of the leptonic cross-section, the γ - Z' contribution would be

negative and much larger than the (positive) $Z-Z'$ one for the η model; in the ϕ case, only the (small) positive $Z-Z'$ would survive, since the $\gamma-Z'$ term would vanish in this instance; as far as χ is concerned, both (small) terms would contribute but in a destructive way (these facts were known from previous work [8]). In the hadronic case, both the $\gamma-Z'$ and the $Z-Z'$ terms are sizeable and positive in the η model, while in the other cases they would again interfere destructively.

Figure 2b shows the effect on δ_H of a Z'_η for variable masses. As one can see, the positive shift attains a maximum for energy values $\sqrt{s} \approx 70$ GeV; in the region $60 \text{ GeV} \leq \sqrt{s} \leq 70 \text{ GeV}$ and for $M_{Z'_\eta}$ up to ~ 160 GeV, it remains larger than a relative 5%, which is probably a rather pessimistic request. In fact, if a more optimistic experimental error on the variable R' were assumed, say of 2-3%, values of $M_{Z'_\eta}$ up to ~ 200 GeV might be revealed. Note that this value would be competitive with the most optimistic bounds derivable by future measurements at the Tevatron collider [9]. This confirms that, even in the energy range $\sqrt{s} \lesssim 70$ GeV, the ratio R' would be a unique and ideal tool to reveal the presence of such a theoretically motivated new gauge boson or, in case of negative search, to set new and rather stronger limits on its mass.

In conclusion, we have shown that a precise measurement of the ratio R' [Eq. (7)] at the highest energy achievable at TRISTAN would in any case contain relevant information on a fascinating kind of New Physics, which future measurements at $\bar{p}p$, pp colliders would soon be able to confirm.

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FIGURE CAPTIONS

- Fig. 1a : Energy behaviour of the function δ_λ for $\theta_M = 0$, $M_{Z'} = 154$ GeV (ϕ model, solid curve), $M_{Z'} = 111$ GeV (η model, dotted-dashed curve), $M_{Z'} = 273$ GeV (χ model, dotted curve).
- Fig. 1b : Energy behaviour of the function δ_λ for the η model and $\theta_M = 0$. The curves 1-5 correspond to values of $M_{Z'} = 110, 130, 150, 170$ and 200 GeV respectively.
- Fig. 2a : The same as Fig. 1a, but for δ_H .
- Fig. 2b : The same as Fig. 1b, but for δ_H .

Fig. 1a

Fig. 1b

Fig. 2a

Fig. 2b