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HUNTING NEW VECTOR BOSONS IN HIGH PRECISION MEASUREMENTS

WITHOUT POLARIZATION

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A B S T R A C T

We illustrate a strategy to identify the effect of a possible extra neutral vector boson of several different theoretical origins (extended gauge groups, composite models, models with a strongly interacting Higgs sector), assuming that only precision experiments without polarized e^+e^- beams were available. We show that it might be relatively easy to discover evidence of genuine New Physics (i.e., effects not depending on the value of the top mass, or on the existence of new families...) if a certain set of observables, including the final τ polarization in unpolarized e^+e^- annihilation, were measured. The region of possible confusion between different theoretical models would be, though, sensibly larger than in the case in which e^+e^- polarization were available.

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A realistic strategy to identify in a clean way signals of a new neutral vector boson from high precision experiments has been proposed very recently [1,2]. The main idea of the method is to combine certain observables that are only sensitive to genuine New Physics effects and are not affected by theoretical uncertainties or by residual unknown parameters of the Minimal Standard Model (top mass, new families...). This approach, that generalizes an original proposal of Cvetic and Lynn [3], would be particularly effective if longitudinally polarized e^+e^- beams at energies close to the Z resonance mass were available at SLC [4] and LEP 100 [5]. If this were the case, it would in fact be possible to define the following four observables:

$$\tilde{A}_b \equiv A^{(b)} - \frac{1}{15} A \quad (1)$$

$$\tilde{A}_c \equiv A^{(c)} - \frac{9}{25} A \quad (2)$$

$$\tilde{f} \equiv f - \frac{1}{3} A \quad (3)$$

$$\tilde{\xi} \equiv \xi - \frac{1}{2} A \quad (4)$$

where

$$A^{(b),(c)} \equiv \frac{1}{P} \frac{(N_{F,P}^{b,c} - N_{F,-P}^{b,c}) - (N_{B,P}^{b,c} - N_{B,-P}^{b,c})}{(N_{F,P}^{b,c} + N_{F,-P}^{b,c}) + (N_{B,P}^{b,c} - N_{B,-P}^{b,c})} \quad (5)$$

$$f \equiv \frac{g}{\alpha_{QED}} \frac{\Gamma_{Z \rightarrow e^+e^-}}{M_Z} \quad (6)$$

$$\xi \equiv \frac{M_W^2}{M_Z^2 \sin^2 \theta_Z} \quad (7)$$

and

$$A \equiv \frac{\sigma(e^+e^-_L \rightarrow \text{had.}) - \sigma(e^+e^-_R \rightarrow \text{had.})}{\sigma(e^+e^-_L \rightarrow \text{had.}) + \sigma(e^+e^-_R \rightarrow \text{had.})} \quad (8)$$

In Eq. (5), P is the degree of polarization of the initial beam $P = (P_{e+} - P_{e-}) / (1 - P_{e+} + P_{e-})$, and $N_{N,B}^{(f)}$ is the number of $f\bar{f}$ quarks in the forward (backward) hemisphere. Equation (7) contains the W/Z mass ratio, to be measured at ACOL [6]. The quantity $\tilde{c}_z$ is defined as:

$$\tilde{c}_z^2 \equiv 1 - \tilde{s}_z^2 = \frac{1}{2} \left[1 + \sqrt{1 - \frac{4\mu^2}{M_z^2}} \right] \quad (9)$$

where $\mu^2 \approx (37.28 \text{ GeV})^2$ and M_z is the physical Z mass. In Eq. (8) all hadronic states have to be included. The three longitudinal polarization asymmetries $A_{(b),(c)}$ are supposed to be measured at $s \equiv (p_{e+} + p_{e-})^2 \approx M_z^2$.

The definition of the four variables, Eqs. (1)-(4), is chosen in such a way that they fulfil the request of being only sensitive to genuine New Physics effects. In particular, the systematical subtraction of the longitudinal asymmetry A guarantees that unknown effects from the minimal standard model (MSM) due to possible heavy particles (top, new families...) are systematically washed out. At the same time, all those parameters of possible New Physics that would only contribute to a formal redefinition of the custodial $SU(2)$ symmetry breaking [7] indicator $\rho_L \equiv 1 + \delta\rho_L$ [3] are eliminated as well [2]. Thus, the only possible deviations of Eqs. (1)-(4) from their predicted values in the MSM would come from a (generally reduced) number of New Physics parameters. Given the computed theoretical uncertainty [8,9] and the expected experimental uncertainty [6,10] on every quantity, it becomes therefore possible to introduce realistic observables (with realistic errors) that would act as genuine New Physics "filters". In particular, one can define the variables [2]:

$$x \equiv \tilde{A}_b - [\tilde{A}_b]^{MSM}, \quad \Delta x \approx \pm 0.025 \quad (10)$$

$$y \equiv \tilde{A}_c - [\tilde{A}_c]^{MSM}, \quad \Delta y \approx \pm 0.025 \quad (11)$$

$$z \equiv \tilde{f} - [\tilde{f}]^{MSM}, \quad \Delta z \approx \pm 0.020 \quad (12)$$

$$w \equiv \tilde{\{ \}} - [\tilde{\{ \}}]^{MSM}, \quad \Delta w \approx \pm 0.005 \quad (13)$$

where $\Delta_{x,y} \dots$ represent the overall uncertainties on $x, y \dots$, and, for each model of New Physics, one can write the corresponding expression of the (x, y, z, w) set. If the number of involved New Physics parameters is not larger than three, one might hope, in principle, to be able to identify each different model by a different

characterizing region in the (x,y,z,w) space. This would provide a realistic and unambiguous way of identifying possible signals of genuine New Physics origin.

In Ref. [2], this program of identification was carried through for a class of particularly representative models, i.e., for models sharing the common feature of predicting an extra neutral vector boson and therefore, a priori, expected to produce similar effects on a single observable quantity. These included theories where the extra vector boson is produced by an assumed extended gauge group (E_6 [11] or $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ [12] in particular) or by "alternative models" [13] with composite vector bosons (isoscalar Y, Y_L) or by a model [14] with a strongly interacting sector (Z_V). The result of this search is summarized in Figs. 1 and 2. One sees that the space of the Z-factory variables (x,y,z) provides a clear differentiation of the class of E_6 models from the Y, Y_L and Z_V cases. Then, the (x,y,w) space provides the differentiation between the E_6 class and the left-right symmetric models. Thus, the identification would be "almost" complete, for those values of the parameters not falling into the "dead" region defined by the uncertainties of Eqs. (10)-(13). To make a quantitative example, this program would differentiate a Z' of E_6 superstring (η) origin from all the other considered models for values of the mixing angle

$$|\theta_\eta| \gtrsim 0.03. \quad (14)$$

This "no confusion" threshold should be compared to the smallest value of θ_η that would produce a visible (but not identifiable) effect, which would be seen in the w variable for

$$|\theta_\eta| \gtrsim 0.01. \quad (15)$$

In the range $0.01 < |\theta_\eta| < 0.03$, effects coming from such a Z' might therefore be seen, but it would not be possible to discriminate them from similar effects coming from some of the other considered models. This represents, qualitatively, one of the typical conclusions in Ref. [2].

A key ingredient of the machinery is, clearly, the availability of longitudinal polarization at SLC and LEP 100, which would provide three of the five measurables required to generate the four "clean" variables, Eqs. (10)-(13). Since, during the first year(s) of running, polarization will certainly not be available, one might wonder whether the previously illustrated strategy should be, in the meanwhile, considered as a purely academic exercise. The purpose of this letter is to show that, even without polarization, it would be possible to construct a "fac-simile" of the previous approach, and to illustrate briefly its possible several positive features, together with its unavoidable relative limitations.

The main point that makes it possible to construct our strategy is represented by the (known) fact that there exists one observable which provides, in principle, the same theoretical information as the longitudinal asymmetry A of Eq. (8). This observable is the polarization of the final τ , produced by (unpolarized) e^+e^- annihilation on top of the Z resonance, i.e., the quantity [6]:

$$A_\tau \equiv \frac{\sigma(\tau_L) - \sigma(\tau_R)}{\sigma(\tau_L) + \sigma(\tau_R)} \Big|_{s \simeq M_Z^2} \quad (16)$$

If one assumes $e-\tau$ universality, A_τ measures in fact, in first (Born) approximation, the same quantity measured by A , i.e.,

$$A_\tau = \frac{2 v_e a_e}{v_e^2 + a_e^2} + \delta A_\tau. \quad (17)$$

The quantity δA_τ contains all the corrections to the Born term, both from the MSM to one loop and from possible New Physics treated at tree level [2]. The corrections within the MSM can be computed [15]. The important feature is that, from the point of view of those contributions that are quadratic in the top mass (and in that of new families) A_τ and A have exactly the same structure, the latter being solely dictated by the Born term of Eq. (17). Therefore it will still be possible to define two clean observables:

$$\hat{y} \equiv y - \frac{1}{3} A_\tau. \quad (18)$$

$$\hat{\xi} \equiv \xi - \frac{1}{2} A_\tau. \quad (19)$$

that will be the analogues of Eqs. (3) and (4), the only difference being that the uncertainty on A_τ will be generally larger than that on A . We shall assume (rather pessimistically) an experimental uncertainty [16]

$$\Delta^{(exp)} A_\tau \simeq \pm 0.020 \simeq \Delta^{(exp.+th.)} A_\tau \quad (20)$$

and the last equality is due to the fact that the theoretical uncertainty in A_τ will be of the same size as that of A , i.e., [8]

$$\Delta^{(th.)} A_\tau \simeq \Delta^{(th.)} A \simeq \pm 0.003 \quad (21)$$

Note that, in our approach, it is not terribly important to estimate to a high accuracy the uncertainty on A_τ in Eq. (18), since the leading uncertainty will still be produced by the partial Z width observable y . On the contrary, in Eq. (19), ΔA_τ will now give the leading effect. We believe that assuming an

uncertainty larger than that of Eqs. (20) would be, though, unduly pessimistic. Under these realistic assumptions, we can now define the two unpolarized genuine New Physics filters:

$$\hat{z} = \hat{f} - [\hat{f}]^{MSM} ; \Delta \hat{z} \simeq \pm 0.020 \quad (22)$$

$$\hat{w} = \hat{\xi} - [\hat{\xi}]^{MSM} ; \Delta \hat{w} \simeq \pm 0.040 \quad (23)$$

We stress the fact that the only difference, with respect to the polarized case, is that the overall uncertainty on $\hat{w}$ has been now doubled. Still, the latter uncertainty has remained sufficiently small not to discourage, a priori, systematic searches of New Physics effects. Actually, we have considered in this paper the combined effect on $\hat{z}$, $\hat{w}$ of a class of particularly representative models already considered in Ref. [2]. More precisely, we have selected the three models η , χ , ϕ of E_6 origin [11] (corresponding to an E_6 symmetry breaking pattern down to $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_Y$, of Witten kind, of purely $SU(5)$ and of purely $SO(10)$ kind) and the so-called "standard" left-right symmetric models [12] $Q = I_{3L} + I_{3R} + (B-L)/2$ to represent the class of extended gauge groups. We have also considered two kinds of composite models [13] with an isoscalar vector boson, whose couplings to fermions are proportional to the full fermion hypercharge (Y) or to the left-handed fermion hypercharge (Y_L), and a model [14] with a strongly interacting sector (Z_V) obtainable from a non-linear realization of symmetry breaking. All these models contribute to z , w in a specific way; the relevant definitions and equations can be found elsewhere [2] and, for simplicity, we shall not give their complete expressions here.

Figure 3 shows the results of our analysis in the plane of the unpolarized filters $\hat{z}$, $\hat{w}$. As one sees, each of the considered models occupies a certain region of the plane, whose thickness is dictated by the overall uncertainties Eqs. (22) and (23), that also generate a black "dead" region where no effect would be visible. All these regions have a common intersection surrounding the origin of the plane. When the distance from the origin increases, it becomes possible to discriminate some of the considered models, but not all of them. More precisely, one finds the following main results.

- I) - The left-right symmetric models are practically disentangled from all the other competitors, apart from the Y_L model for negative $\hat{z}$. This is a consequence of the fact that $\hat{w}^{(LR)} < 0$ [2].

II) - The ϕ model is completely "embedded" in the Y_L model^{*)}. The latter could be discriminated from the remaining ones for sufficiently positive $\hat{w}$. To be more precise, one sees that:

III) - The χ model would be disentangled for values of the mixing angle:

$$|\theta_\chi| \gtrsim 0.04 \quad (24)$$

to be compared to the existing [17] limit $\theta_\chi \lesssim 0.06$.

IV) - The Z_v model would be disentangled for values of the parameter

$$X_v \equiv \left(\frac{e}{g''} \right)^2 \gtrsim 4 \cdot 10^{-3} \quad (25)$$

to be compared to the qualitative expectation [14] that x_v might be as large as $\sim 10^{-2}$.

V) - The η model could be disentangled from the (L-R, Y_L , ϕ , χ , Z_v) models for $\theta_\eta \gtrsim 0.06$ (experimentally [17] $\theta_\eta \lesssim 0.20$). However, the η ζ model and the Y model would coincide in the $(\hat{z}, \hat{w})$ plane.

Table I contains a summary of our results for the particular case of η disentangling. More generally, as we said, there remain two situations of "pathological" confusion, i.e., that between the ϕ and Y_L and that between the η and Y models. To remove the latter ones, some extra suitable variable(s) would be needed.

A rather simple and attractive possibility would be to generate "artificially" new variables having theoretical properties similar to those of $A^{(b),(c)}$ in Eqs. (1) and (2). From the property, strictly valid on top of Z resonance (in Born approximation)

$$[A^{(b),(c)}]^{(Born)} \equiv [A_{FB(U)}^{(b),(c)} / A]^{(Born)} \quad (26)$$

where $A_{FB(U)}^{(b),(c)}$ is the usual unpolarized forward-backward asymmetry for production of $(b, \bar{b})$, $(c, \bar{c})$ couples, and from the previous discussion about A_τ , one guesses that a simple possibility would be to define the new observables:

*) We have used the simplifying ansatz $\theta_{\eta, \chi, \phi} > 0$, supported by the already existing experimental information [17].

$$\hat{A}_b \equiv \frac{A_{FB(U)}^{(b)}}{A_2} - \frac{1}{15} A_2 \quad (27)$$

$$\hat{A}_c \equiv \frac{A_{FB(U)}^{(c)}}{A_2} - \frac{9}{25} A_2 \quad (28)$$

whose Born approximation coincides with that of Eqs. (1) and (2).

The evaluation of the theoretical uncertainty for these new unpolarized filters could be in principle performed. As a first working (and optimistic) hypothesis, we shall assume that it can be neglected with respect to the experimental one. The latter can be estimated [10], which leads to the possibility of defining the extra unpolarized filters:

$$\hat{x} \equiv \hat{A}_b - [\hat{A}_b]^{MSM}; \quad \Delta \hat{x} \simeq \pm 0.070 \quad (29)$$

$$\hat{y} \equiv \hat{A}_c - [\hat{A}_c]^{MSM}; \quad \Delta \hat{y} \simeq \pm 0.050. \quad (30)$$

Note that the estimated uncertainties for $\hat{x}$ and $\hat{y}$ are (at least) three and two times larger than in the polarized case, Eqs. (10) and (11).

The possibility of using $\hat{x}$, $\hat{y}$ to disentangle the ϕ and/or η models from the (Y, Y_L) ones stems from the fact that for composite models, $\hat{x}$ and $\hat{y}$ would be rigorously zero [2], while for (ϕ, η) they would be proportional to the mixing angle. Writing the precise expressions leads us to the following conclusions:

- i) the uncertainty in $\hat{x}$ is too large to allow any effect from ϕ and/or η models to be visible;
- ii) the variable $\hat{y}$, with an uncertainty given by Eq. (29), would only allow a disentangling of the η model from the Y model for values of θ_η such that

$$|\theta_\eta| \gtrsim 0.08. \quad (31)$$

Note that the minimum value of θ_η that might be visible (from w) would be in this case

$$|\theta_\eta| \gtrsim 0.02 \quad (32)$$

thus in the unpolarized case, a Z' of η origin might be seen for $|\theta_\eta| \gtrsim 0.02$. However, in the range $0.02 \lesssim \theta_\eta \lesssim 0.08$ there would be at least some competitor

model from which it could not be discriminated. These quantitative results should be compared with the corresponding Eqs. (14) and (15) valid for the polarized case.

The conclusion of this letter is that, even without polarization, clear indications of the existence of some kind of New Physics might be obtained in a relatively easy way, combining the measurements of the W/Z mass ratio and of the partial width $Z \rightarrow e^+e^-$ with that of the final τ polarization (assuming, of course, a knowledge of the Z mass to the expected [6] ≈ 30 MeV accuracy). Although the specific identification of the theoretical model will be sensibly less clear than in the corresponding case with polarization, we believe that our strategy could well lead to a discrete "preliminary screening" of possible New Physics in a very near future.

NO VISIBLE EFFECT	N.C.	NO CONFUSION	NO CONFUSION
	Ψ LR	Ψ, χ, LR, Y_L	Ψ, χ, LR, Y_L, Z_V
	C.	CONFUSION	CONFUSION
	χ Y, Y_L Z_V	Y, Z_V	Y

0 2 3 6 $\theta_\eta (10^{-2})$

TABLE - Regions of confusion (C) and of no confusion (N.C.) between the superstring inspired η model and the other considered models, when the mixing angle θ_η varies from 0.02 to 0.20. For smaller $|\theta_\eta|$ values, no effect would be seen.

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FIGURE CAPTIONS

- Fig. 1 The characteristic wafers of the Y , Y_L , Z_v models, compared with (part of) the E_6 allowed region. Only the component of the Y_L figure with positive x and y has been drawn.
- Fig. 2 E_6 and left-right wafers in the $(x, y' = -y, w' = 5w)$ space. Only the component of the left-right wafer in the negative w' space has been drawn. The point-dashed lines define the intersection region of the two solids.
- Fig. 3 Characteristic strips of the E_6 models η , χ , ϕ , of the Y , Y_L , Z_v models and of the left-right models in the $\hat{z}$, $\hat{w}$ plane. In the different dark regions, no confusion exists between the models. In the white regions, generally, some confusion between different models arises.

- Fig. 1 -

- Fig. 2 -

- Fig. 3 -