Effects of Exotic Composite Particles in the TRISTAN, SLC, and LEP Energy Region

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Abstract

We investigate properties of exotic bosons in the subquark model. Starting with typical dynamical models, we derive their effective interactions, examine the restrictions from the presently known experimental results, and estimate possible effects on e^+e^- scattering. Some of the neutral exotics, which decouple from neutrinos at low energies, can be light, and offer the possibility of detecting sizable effects in the TRISTAN, SLC and LEP energy region.

This talk is based on the recent work [1] on exotic composite bosons in collaboration with T. Hattori and M. Yasuè. Proliferations of the color triplets and weak iso-doublets seem to suggest a further fundamental layer of matter, the subquark (or preon) [2] , [3] , [4]. In this picture, quarks q and leptons ℓ are composite such that

$$q \sim wc \quad or \quad whc, \qquad \ell \sim wc^{(\ell)} \quad or \quad whc^{(\ell)}, \tag{1}$$

where w, h, c, and $c^{(\ell)}$ are the subquarks carrying the weak isospin, the generation quantum number, the color, and the leptonic color, respectively. The weak bosons W^i_μ, Higgs scalars ϕ, and even photon A_μ and gluon G^a_μ could also be composite [3].

$$W^i_\mu \sim \bar{w}_L \gamma_\mu \tau^i w_L, \quad \phi \sim \bar{w}_L w_R, \quad G^a_\mu \sim \bar{c}\gamma_\mu \lambda^a c, \quad A_\mu \sim \bar{s}\gamma_\mu Q_s s, \tag{2}$$

where $s = (w, h, c, c^{(\ell)})$ and Q_s is the electric charge of the subquark s. In the following, we consider weak bosons as composite, but gluon and photon as elementary. The composite models predict various new phenomena at as high energies as the compositeness scale. New exotic and excited states would appear [5], the scattering cross sections would deviate from their standard model values due to their size effects [6] and subquarks would develop jets consisting of quarks, leptons and intermediate bosons [7]. From the argument on unnaturalness in the mass renormalization of the Higgs sector in the standard model, the scale of new physics can not be much beyond the TeV region [8]. If the compositeness is responsible for avoiding the unnaturalness, the above mentioned phenomena would be observed in this region. In particular, we expect that the neutral exotics can be observed at comparatively low energies. We consider, as examples, color-singlet gluon G^0_μ, leptonic gluon $G^{(\ell)}_\mu$, iso-singlet weak boson W^0_μ, and heavy photon $(\bar{s}\gamma_\mu Q_s s)^*$ such that

$$G^0_\mu \sim \bar{c}\gamma_\mu c, \quad G^{(\ell)}_\mu \sim \bar{c}^{(\ell)}\gamma_\mu c^{(\ell)}, \quad W^0_\mu \sim \bar{w}_L\gamma_\mu w_L, \quad A^*_\mu \sim (\bar{s}\gamma_\mu Q_s s)^*. \tag{3}$$

Then, we examine the possibilities to observe their effects in the energy regions of the experiments with the e^+e^- - colliders such as TRISTAN, SLC and LEP. The neutral exotics would exhibit their effects also in $p\bar{p}$ scattering, neutrino scattering, the anomalous magnetic moments of leptons and the Z - boson mass deviation via mixing. Among them, the neutrino scattering places the most severe restriction on their masses to be larger than a few hundred GeV [9]. Accordingly, they cannot affect e^+e^- scattering at 50 - 100 GeV so much, as long as they couple to neutrinos. The same restriction arises for the extra Z boson(s) in the grand unified models and superstring - inspired models [10]. However, some of the neutral exotics (e. g. the singlet gluon and the heavy photon) in the composite models may decouple from neutrinos at low energies and are free from the restriction.

Now we start with specifying dynamics.

(a) *Model of the Nambu-Jona-Lasinio-Bjorken type* [11] , [12]: The fundamental interactions to form the color-singlet gluon, leptonic gluon, iso-singlet weak boson, and heavy photon are given by

$$\mathcal{L}_{fund} = F(\bar{c}\gamma_\mu c)^2, \quad F(\bar{c}^{(\ell)}\gamma_\mu c^{(\ell)})^2, \quad F(\bar{w}_L\gamma_\mu w_L)^2, \quad F(\bar{s}\gamma_\mu Q_s s)^2, \tag{4}$$

respectively, where F is the coupling constant. The system with the interaction Lagrangian $\mathcal{L}_{fund}$ is equivalent to that with

$$\begin{aligned} \mathcal{L}_{aux} =& (\bar{c}\gamma_\mu c)\tilde{V}^\mu - \frac{1}{4F}(\tilde{V}_\mu)^2, \quad (\bar{c}^{(\ell)}\gamma_\mu c^{(\ell)})\tilde{V}^\mu - \frac{1}{4F}(\tilde{V}_\mu)^2, \\ & (\bar{w}_L\gamma_\mu w_L)\tilde{V}^\mu - \frac{1}{4F}(\tilde{V}_\mu)^2, \quad (\bar{s}\gamma_\mu Q_s s)\tilde{V}^\mu - \frac{1}{4F}(\tilde{V}_\mu)^2, \end{aligned} \tag{5}$$

respectively, where $\tilde{V}_\mu$ is an auxiliary field. The quantum loop effects give rise to the kinetic and interaction terms of $\tilde{V}_\mu$ and after appropriate rescaling, $\tilde{V}_\mu$ becomes the genuine composite field V_μ. The exotic boson V_μ is mixed with the photon A'_μ (primed because it is yet to be diagonalized to form the physical photon) and the neutral component W^3_μ of the weak boson through the effects of similar quantum loop diagrams.

(b) $SU(2)_L \times U(1) \times U(1)'$ *Gauge Model*: We assume that the scalar field $\phi_i \sim (\mathbf{2},-1,0)$ (or $(\mathbf{2},0,-1)$ in the model of the heavy photon) and $\xi \sim (\mathbf{1},1,\text{-}1)$ are condensed in a gauge invariant way as

$$< \phi^\dagger \phi > \sim \Lambda_\Phi^2, \qquad < \xi^\dagger \xi > \sim \Lambda_\xi^2, \tag{6}$$

where Λ_Φ and Λ_ξ are constants, which set the mass scale. The composite fields are assumed to be $SU(2)_L$ × $U(1)'$ - blind. A (broken) global $SU(2)$ symmetry with the fundamental doublet $w_L = (\phi, i\tau_2\phi^*)^\dagger$ is induced, and the vector bosons $\mathrm{Tr}(\tau_i w_L D_\mu w_L^\dagger)$ become the weak bosons (D_μ is the covariant derivative of the whole gauge group.). On the other hand, the vector boson $\xi^\dagger D_\mu \xi$ becomes the exotic boson. The colored subquark c and the leptonic one $c^{(\ell)}$ are fermionic and are assigned as follows: the left (right) handed component is a doublet (singlet) of the $SU(2)_L$. We denote the $U(1)$ and $U(1)'$ charges by y and y', respectively. Then, $y + y' = 1/3$, $4/3$, $-2/3$, -1, 0 and -2, for c_L, c_{1R}, c_{2R}, $c_L^{(\ell)}$, $c_{1R}^{(\ell)}$ and $c_{2R}^{(\ell)}$, respectively. The color singlet gluon is characterized by $y'(c) = 1/3$ and $y'(c^{(\ell)}) = 0$, the leptonic gluon, by $y'(c) = 0$ and $y'(c^{(\ell)}) = 1$, the iso-singlet weak boson, by $y'(c) = 1/3$ and $y'(c^{(\ell)}) = 1$, and the heavy photon, by $y(c) = 0$ and $y(c^{(\ell)}) = 0$. The composite quarks and leptons are assigned as follows: $q_L \sim w_L c_L \xi^a$, $q_R \sim c_R \xi^{a'}$, $\ell_L \sim w_L c_L^{(\ell)} \xi^b$, $\ell_R \sim c_R^{(\ell)} \xi^{b'}$, where a, a', b, and b' are fixed so that q and ℓ are $U(1)'$ neutral. One can further show that, as far as the scalar degrees of freedom are frozen, the model in the unbroken phase of $SU(2)_L$ × $U(1)_Y$ × $U(1)'$ (= G) with (6) is equivalent to the conventional model in the Higgs phase of G with $< \Phi > \sim \Lambda_\Phi$ and $< \xi > \sim \Lambda_\xi$ [13]. This equivalence has also been recognized by Bilchak and Schildknecht [14] and is expected to generally arise as a result of complementarity [15].

Both of the dynamical model lead to the following mixing and interaction Lagrangians,

$$\mathcal{L}_{mix} = -\frac{1}{2}\lambda A'_{\mu\nu} W^{3\mu\nu} - \frac{1}{2}\lambda' A'_{\mu\nu} V^{\mu\nu} - \frac{1}{2}\lambda'' W^3_{\mu\nu} V^{\mu\nu} + \Delta M^2 W_\mu V^\mu, \tag{7}$$

$$\mathcal{L}_{int} = e J^{em}_\mu A'^\mu + g J^3_\mu W^{3\mu} + g_V J^V_\mu V^\mu, \tag{8}$$

where $B_{\mu\nu} = \partial_\mu B_\nu$ - $\partial_\nu B_\mu$ for the vector field B_μ in general, e is the electromagnetic coupling constant, g is the weak coupling constant, g_V is the coupling constant of V_μ, J^{em}_μ is the electromagnetic current, and J^3_μ is the neutral component of the weak isospin current. The current mixing parameters λ, λ' and λ'', the mass mixing parameter ΔM in (7), and the form of the current J^V_μ in (8) depend on the species of the exotic boson, and given as follows.

i) *color singlet gluon:*

$$\lambda = e/g, \quad \lambda' = eQ_c/g, \quad \lambda'' = 0, \quad \Delta M^2 = 0, \quad J^V_\mu = J^q_\mu, \tag{9}$$

ii) *leptonic gluon:*

$$\lambda = e/g, \quad \lambda' = eQ_{c(\ell)}/g_V, \quad \lambda'' = 0, \quad \Delta M^2 = 0, \quad J_\mu^V = J_\mu^\ell, \tag{10}$$

iii) *iso-singlet weak boson:*

$$\lambda = e/g, \quad \lambda' = e(Q_{w1} + Q_{w2})/2g_V, \quad \lambda'' = 0, \quad \Delta M^2 = 0, \quad J_\mu^V = J_\mu^\ell + J_\mu^q, \tag{11}$$

iv) *heavy photon:*

$$\lambda = e/g, \quad \lambda' = e/g, \quad \lambda'' = 0, \quad \Delta M^2 = (g_V/g)M_W^2, \quad J_\mu^V = J_\mu^Y, \tag{12}$$

or equivalently

$$\lambda = e/g, \quad \lambda' = e/g_V, \quad \lambda'' = g_V/g, \quad \Delta M^2 = 0, \quad J_\mu^V = J_\mu^{em}, \tag{13}$$

where M_W is the mass of the W boson, J_μ^q, J_μ^ℓ, J_μ^Y, and J_μ^{em} are the quark number current, lepton number current, weak hypercharge current, and electromagnetic current, respectively, and Q_{w1}, Q_{w2}, Q_c, and $Q_{c(\ell)}$ are the electric charges of the subquarks w_1, w_2, c, and $c_{(\ell)}$, respectively. In the standard charge assignment, $Q_{w1} = -Q_{w2} = -Q_{c(\ell)} = 1/2$ and $Q_c = 1/6$. The unification condition $\lambda = e/g$ which is phenomenologically necessary, and conjectured in the models of the type in Ref. [16] is derived as a consequence of the subquark dynamics. The fact that λ' has the form e/g_V × (subquark charge) can be taken as a general consequence of the dynamics which respects the relation $\lambda = e/g$. It is remarkable that both of the dynamical models lead to the same results.

The mixing is diagonalized by the transformation

$$\begin{pmatrix} A'_\mu \\ W_\mu^3 \\ V_\mu \end{pmatrix} = \begin{pmatrix} 1 & -\lambda & -\lambda' \\ 0 & \frac{M_Z}{M_W}\cos\theta & -\frac{M_X}{M_W}\sin\theta \\ 0 & \frac{M_Z}{M_V}\sin\theta & \frac{M_X}{M_V}\cos\theta \end{pmatrix} \begin{pmatrix} A_\mu \\ Z_\mu \\ X_\mu \end{pmatrix}, \tag{14}$$

where the diagonalized states, A_μ, Z_μ and X_μ are interpreted as the physical photon, Z boson and extra vector boson, respectively. The masses should have the relation

$$[1 - (1 - \lambda^2)M_Z^2/M_W^2][1 - (1 - \lambda^2)M_X^2/M_W^2] = -(\lambda'' - \lambda\lambda')/\Delta, \tag{15}$$

where

$$\Delta = 1 - \lambda^2 - \lambda'^2 - \lambda''^2 + 2\lambda\lambda'\lambda''. \tag{16}$$

The λ's are written in terms of the coupling constants e, g and g_V (or g'_V) as in (9)-(13). Among them, e is precisely determined by experiment. We use the value such that $\alpha =$

$e^2/4\pi = 1/137.036(1 - \Delta r)$, where $\Delta r = 0.058$ is the radiative correction term with the top mass $m_t = 100$ GeV and the Higgs mass $M_H = 100$ GeV [17]. The coupling, g, is related to M_W by $g = (4\sqrt{2}G_F)^{1/2}M_W$, where the Fermi coupling constant G_F is precisely determined by β decay experiments. Thus, for a given set of $M_{W,Z,X}$, we can fix g_V by (15) and can calculate any physical quantities in terms of them.

Now, we consider the restrictions from presently known experimental results. We use the following numerical values. 1) ***weak boson masses:*** $M_W = (80.00 \pm 0.56)$ GeV [18] and $M_Z = (91.09 \pm 0.06)$ GeV [19] , [20] (as the averaged values). 2) ***neutrino scatterings:*** $\sin^2\theta_W = .2283 \pm .0048$ ($.2271 \pm .0143$) [21] from νp and $\bar{\nu}p$ (νe and $\bar{\nu}e$) scattering, where the $\sin^2\theta$ is determined by assuming the standard model. 3) ***Bhabha scattering:*** $\Lambda^c_- > 7.1$ TeV [22], where Λ^c_- is the compositeness scale for current × current interactions with the vector coupling. 4) $p\bar{p} \rightarrow$ "X" + ***anything,*** "X" $\rightarrow e^+e^-$: The bound on the coupling strength multiplied by the decay branching ratio B("X" $\rightarrow e^+e^-$) given in Fig. 5(b) of Ref. [23]. 5) $p\bar{p} \rightarrow$ "X" + ***anything,*** "X" $\rightarrow JJ$ (J denotes a jet): The bound on $\sigma(p\bar{p} \rightarrow$ "X" + anything)B("X" $\rightarrow JJ$) given in Fig. 3 of [24] for $M_X = 160 \sim 400$ GeV together with its linear extrapolation in the neighboring region, where σ and B denotes the cross section and the branching ratio, respectively. 6) The constraints from anomalous magnetic moments of the electron and muon are less restrictive than the above bounds. The values in 1) above allow M_W and M_Z inside the ellipse in Fig. 1 (up to 95% C. L.). The dot - dashed curve in Fig. 1 gives the kinematical limit such that only M_W and M_Z below (above) it are allowed for $M_X > M_Z$ ($M_X < M_Z$). The other experimental bounds place further constraints depending on the species and mass of the exotics. For example, consider the color singlet gluon with $M_X = 150$ GeV. The cross section, $\sigma(p\bar{p} \rightarrow$ "X" + anything)B("X" $\rightarrow e^+e^-$) calculated in our model for M_W and M_Z below the short - dashed curve in Fig. 1 does not satisfy the bound in 4) above. Similarly, the bound 5) forbids M_W and M_Z above the dotted curve while the bound 3) forbids the M_W and M_Z below the long -dashed curve. On the other hand, the bound 2) places no further restriction. Thus, the shaded region in Fig. 1. is finally left allowed. We repeat this procedure for each exotic boson at each M_X and map each region into the M_X - g_V (Fig. 2), M_X - R(60GeV) (Fig. 3(a,b)), M_X - $R(M_Z)$ (Fig.3(c,d)), and M_X - Γ_Z (Fig. 3(e,f)) planes, where $R(E)$ is $\sigma(e^+e^- \rightarrow \text{hadrons})$ at CM energy E divided by $\sigma(e^+e^- \rightarrow \mu^+\mu^-)_{QED} = 4\pi\alpha/3E^2$ and Γ_Z is the total decay width of the Z boson. The shaded regions are allowed.

Since the mixing parameter λ' is proportional to $1/g_V$, too small g_V causes too large mixing and is forbidden. The coupling, g_V, is bounded from the above if the exotic boson directly couples to the particles in the reaction channel, while it is bounded from the below if V_μ couples only through mixing. An advantage of the current mixing representation in (9)-(11) and (13) without mass mixing is that the extra neutral - current interaction at low energies is simply proportional to $(J_\mu^V)^2$. It is obvious from the form of J_μ^V that the singlet gluon and the heavy photon do decouple from neutrinos at low energies, but the leptonic gluon couples. In fact, the νp, $\overline{\nu}p$, νe and $\overline{\nu}e$ scatterings place the restriction on the mass of the leptonic gluon: $M_X > 390$ GeV (Fig.2(c)), and, when combined with the bound from $e^+e^- \rightarrow e^+e^-$, $M_X > 450$ GeV is required. The leptonic gluon can hardly affect R(60 GeV), R(M_Z) and Γ_Z. On the other hand, for the singlet gluon, the allowed region lies between the bounds from $e^+e^- \rightarrow e^+e^-$ and from $p\overline{p} \rightarrow JJ + \cdots$, which leaves the possibility of the smaller mass as $M_X > 126$ GeV, and, for heavy photon, the allowed region lies between the bounds from $e^+e^- \rightarrow e^+e^-$ and from $M_{W,Z}$, which imposes no essential lower bound on M_X. The values of R(60GeV), R(M_Z) and Γ_Z deviate from their standard model values. For example, R(60 GeV) of the singlet gluon is larger than the standard model prediction, which possibly explains the (slight) enhancement in R at TRISTAN [25]. The deviations in R(M_Z) and Γ_Z are still consistent with the recent results from SLC [19] and LEP [20] within errors. More precise measurements in the near future would be able to distinguish the present model from the standard model. We hope that these predictions are examined in the forthcoming experiments at TRISTAN, SLC and LEP.

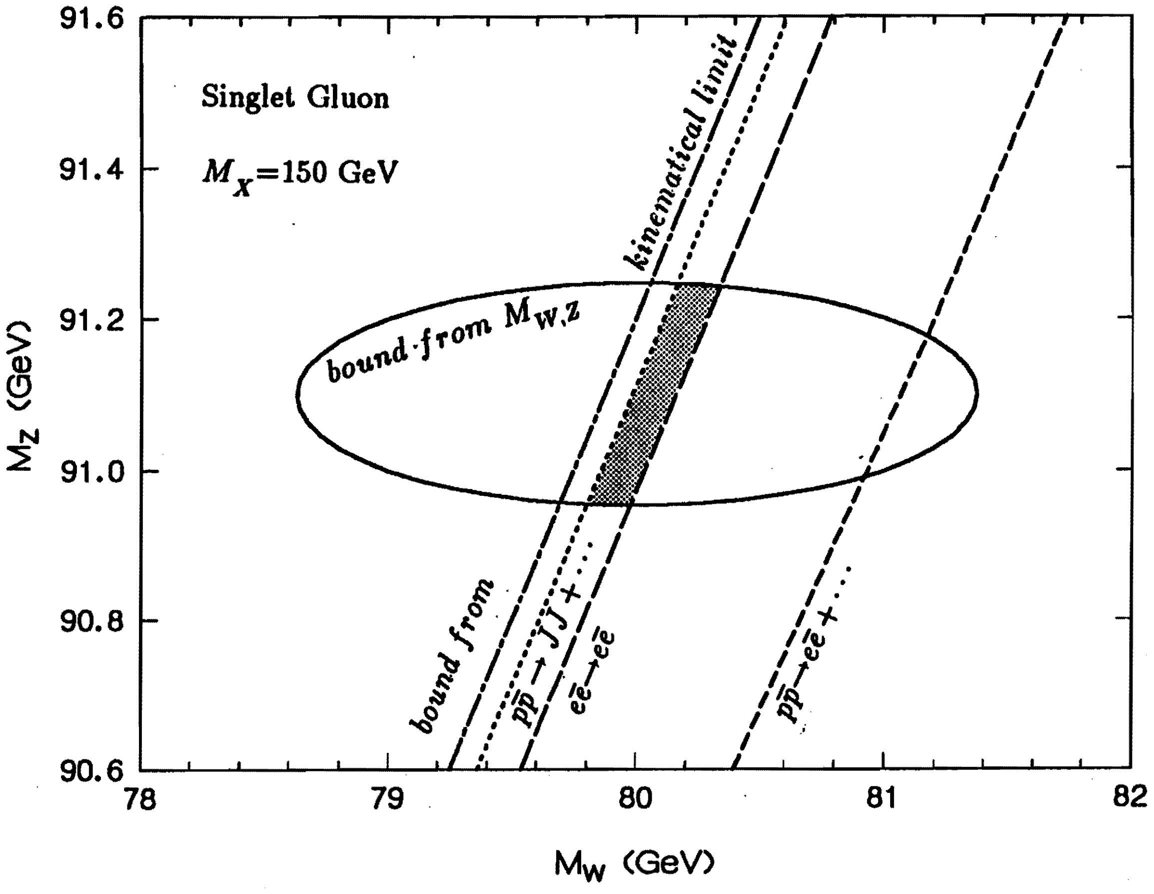

Fig. 1 The experimental bounds on M_W and M_Z for the color singlet gluon with M_X = 150GeV. The allowed region is indicated by the shaded area.

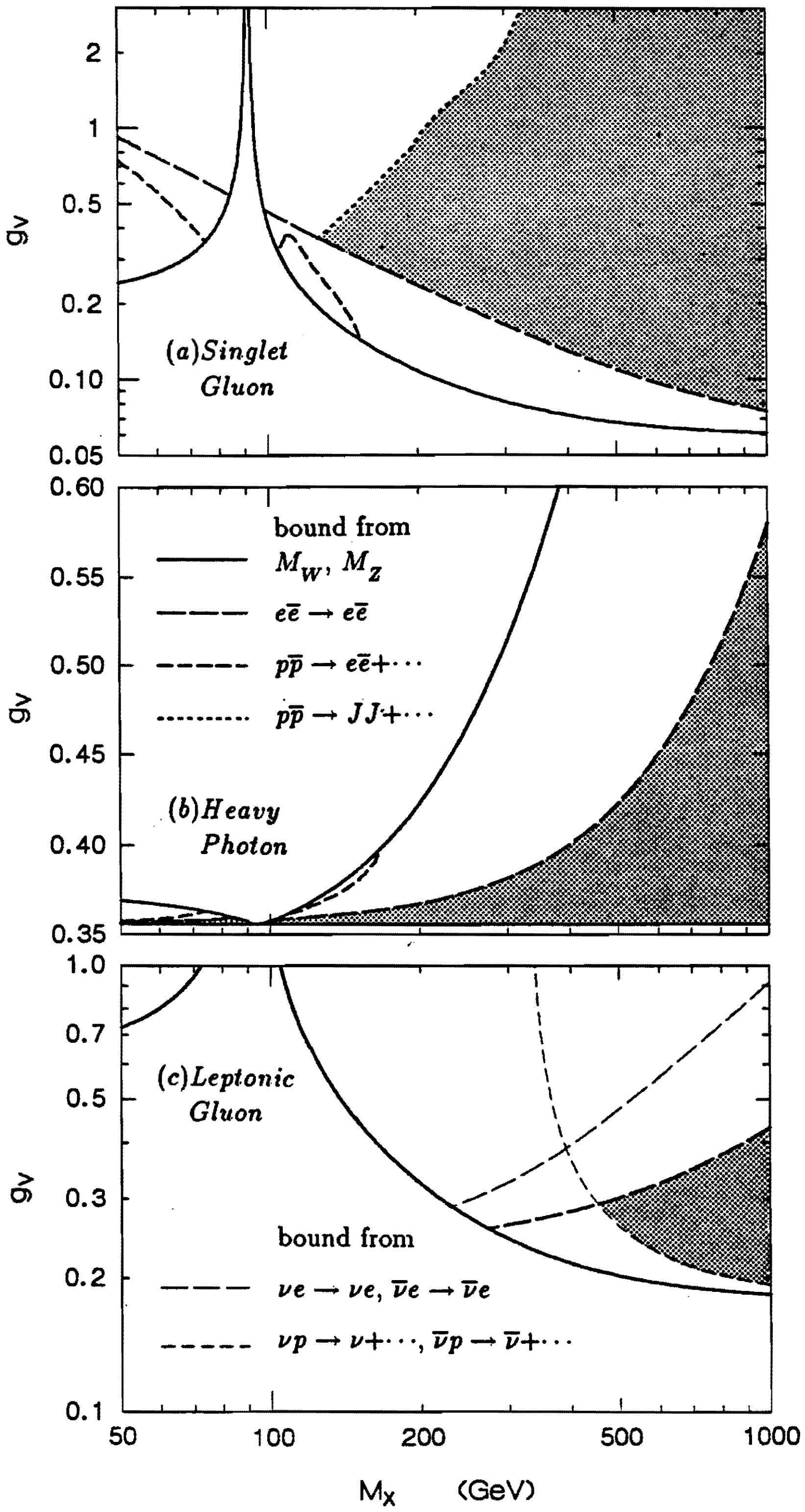

Fig. 2 The experimental bounds on g_V v.s. M_X for (a) color singlet gluon, (b) heavy photon and (c) leptonic gluon. The allowed regions are indicated by the shaded area. Each curve corresponds to the bound indicated in (b) and (c).

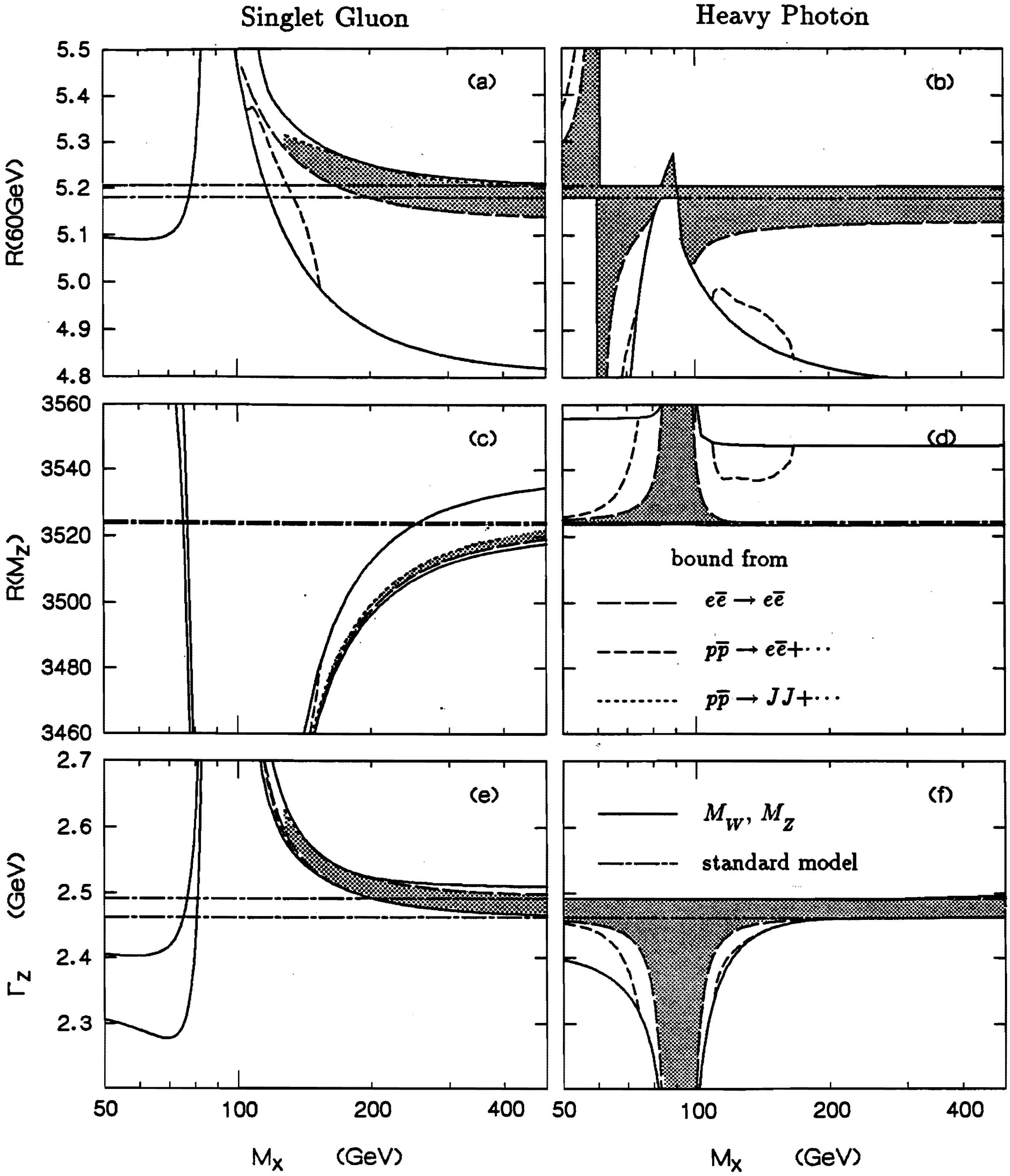

Fig. 3 The experimental bounds on (a,b) R(60GeV) v.s M_X, (c,d) R(M_Z) v.s. M_X and (e,f) Γ_Z v.s. M_X for the singlet photon (a,c,e) and for the heavy photon (b,d,f). The allowed regions are indicated by the shaded area. Each curve corresponds to the bound indicated in (d) and (e).

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