Invisible Gauge Bosons

Bogdan Dobrescu (*Fermilab*)

Could there exist massless gauge bosons other than the photon?

$U(1)_{B-L}$ **is the only global symmetry of the standard model that can be gauged and unbroken.**

Z_{B-L} **coupling to ordinary matter:** $N_n\, g_z$
($N_n =$ **number of neutrons)**

To avoid deviations from Newton's law:

$$g_z \ll \frac{m_n}{M_{\rm Pl}} \sim 10^{-19}$$

Tests of the equivalence principle: $g_z < 10^{-24}$

weaker limit if $B - L$ **force is screened by** ν**'s** *(Okun, et al)*

But **even when** $z_q = z_u = z_d = z_l = z_e = 0$

there can still be interactions of the standard model fields with the new massless gauge boson:

higher-dimensional operators!

γ' **couplings to leptons:**

$$\frac{1}{M^2} P_{\mu\nu} \ \left(\bar{l}_L \sigma^{\mu\nu} F_e H e_R + \mathrm{h.c.}\right)$$

F_e**: 3×3 matrix in flavor space,**

dimensionless parameters

γ' **couplings to quarks: similar dimension-6 operators**

In the mass eigenstate basis $F_e \rightarrow F'_e = U^e_L F_e U^{e\dagger}_R$

U^e_L and U^e_R are the unitary matrices that diagonalize the masses of the electrically-charged leptons.

• Interactions of the mass-eigenstate leptons with P^μ

(chirality-flip operators $\sim v_h \approx 174$ GeV) :

$$\frac{v_h}{M^2} P_{\mu\nu}\, \overline{e'} \sigma^{\mu\nu} \left(\mathrm{Re} F'_e + i\, \mathrm{Im} F'_e \gamma_5\right) e'$$

$\rightarrow$ magnetic-like and electric-like dipole moments

$\mathrm{Re}(F_e')^{ij}$, $\mathrm{Im}(F_e')^{ij}$ could have any value $\lesssim 4\pi$, but:

chirality-flip operators $\rightarrow$ probably $\left|F_e^{ij}\right| \lesssim \left|\lambda_e^{ij}\right|$

$$\Longrightarrow \quad \left|F_e'^{ij}\right| \lesssim \frac{m_\tau}{v_h} \approx 10^{-2}$$

$\left|F_e'^{11}\right|$ may naturally be below $m_e/v_h \approx 3 \times 10^{-6}$

Kinetic mixing of $U(1)_Y \times U(1)_z$ gauge bosons:

$c_0 B^{\mu\nu} P_{\mu\nu}$ dimension-four operator!

Holdom 1985:

Kinetic terms can be diagonalized and canonically normalized by a $SL(2,R)$ transformation.

Global $SO(2)$ symmetry: linear combination of $U(1)$ fields that couples to hypercharge is the real B^μ.

Orthogonal combination ("paraphoton" $= \gamma'$) does not have any renormalizable couplings to standard model fields.

Conclusion:
kinetic mixing has no effect on the standard model fields other than a renormalization of the hypercharge gauge coupling.

Bosonic interactions of the paraphoton:

$$\frac{1}{M^2} H^\dagger H \left(c_1 B_{\mu\nu} + \tilde{c}_1 \widetilde{B}_{\mu\nu} + c_2 P_{\mu\nu} + \tilde{c}_2 \widetilde{P}_{\mu\nu} \right) P^{\mu\nu}$$

- **renormalize the $U(1)$ gauge couplings**
- **include vertices with two $U(1)$ gauge bosons and Higgs bosons.**

These are all operators of $d \leq 6$ involving both γ' and SM fields

Primordial Nucleosynthesis

Constraints on any new particles with mass below several MeV.

Interaction rate of γ' with SM fields: $\Gamma_s \approx \frac{c^2 m_e^2 T^3}{M^4}$

$c \equiv F_e'^{11} \frac{v_h}{m_e}$

Expansion rate of the universe: $H \approx \frac{T^2}{M_{\rm Pl}} \left(\frac{2\pi^3}{45} g_*(T) \right)^{1/2}$

At the freeze-out temperature, T_D: $\Gamma_s = H$

$$\Longrightarrow \quad \frac{M}{\sqrt{c}} \approx 1.5 \text{ TeV} \times [g_*(T_D)]^{-1/8} \left(\frac{T_D}{1 \text{ GeV}} \right)^{1/4}$$

Number of degrees of freedom contributed by γ' during nucleosynthesis, for $T_D > T_{\rm BBN} \approx 1$ MeV:

$$\Delta g_*(T_{\rm BBN}) = 2\left[\frac{g_*(T_{\rm BBN})}{g_*(T_D)}\right]^{4/3}$$

$$\Delta g_*^{\rm max} = \frac{7}{8}\Delta N^{\rm max} \quad \longrightarrow \quad g_*(T_D) > \frac{20.0}{(\Delta N_\nu^{\rm max})^{3/4}}$$

At the 2σ level, $\Delta N_\nu^{\rm max} \approx 0.6 \;\; \longrightarrow \;\; g_*(T_D) > 30$

$T_D > T_{\rm QCD} \approx 150 - 180$ MeV

(for $T_D \gtrsim T_{\rm QCD}$: $g_* = 247/4$)

$$\frac{M}{\sqrt{c}} \gtrsim 0.5 \text{ TeV}$$

Star cooling

Effective coupling of γ' to electrons: $$g_{\gamma' e} = \frac{c}{M^2} m_e^2$$

Red giant stars:

$$g_{\gamma' e} < 2.5 \times 10^{-13} \quad \Rightarrow \quad \frac{M}{\sqrt{c}} \gtrsim 1.2 \text{ TeV}$$

For supernovae: ν emission rate $\gg$ γ' emission rate

$\Rightarrow$ no useful bound on electron-γ' coupling

(strong bound on quark-γ' couplings)

Flavor-changing neutral currents

Chirality-flip transition:

$$\Gamma\left(\mu \to e\gamma'\right) = c_{e\mu}^2 \frac{m_\mu^5}{8\pi M^4}$$

Standard model:

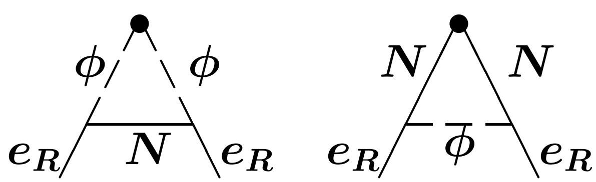
$$\Gamma\left(\mu \to e\nu\bar{\nu}\right) = \frac{m_\mu^5 G_F^2}{192\pi^3} \approx 3.2 \times 10^{-10}\,\mathrm{eV}$$

$$\mathrm{Br}\left(\mu \to e\gamma'\right) < 3 \times 10^{-4} \qquad \Rightarrow \qquad \frac{M}{\sqrt{c_{e\mu}}} \gtrsim 8\ \mathrm{TeV}$$

	l_L	e_R	N_L	N_R	H	ϕ
$SU(2)_W$	2	1	1	1	2	1
$U(1)_Y$	-1	-2	0	0	$+1$	-2
$U(1)_D$	0	0	$+1$	$+1$	0	-1

Yukawa interaction: $\lambda_\phi^j \, \overline{e}_R^j N_L \, \phi + \mathrm{h.c.}$

Contribution to the $iP_{\mu\nu}\overline{e}_R \gamma^\mu \partial^\nu e_R$ operator ($\sim P_{\mu\nu}\bar{l}_L \sigma^{\mu\nu} e_R H$):



$$\Rightarrow \quad C_e^{ij} = \frac{\lambda_\phi^i \lambda_\phi^{*j} g_p}{192\pi^2}$$

Conclusions

New massless gauge boson may couple to quarks and leptons via dimension-6 operators suppressed by the TeV scale!

The lightest particle charged under the new $U(1)$ is a good dark matter candidate.

Look for paraphotons at the Tevatron (coupling to top-quark), LHC, LC, ...