Eur. Phys. J. C 22, 743–747 (2002)
Digital Object Identifier (DOI) 10.1007/s100520100831

THE EUROPEAN PHYSICAL JOURNAL C

Identification of a horizontal gauge boson in hadronic collisions

Ali A. Bagneid

Department of Physics, Umm Al-Qura University, Makkah, Saudi Arabia

Received: 17 September 2001 /
Published online: 7 December 2001 –

Abstract. We compare distributions of leptons produced in hadronic collisions, by a horizontal neutral gauge boson, Z', suggested by the $Sp(6)_{\mathrm{L}} \otimes U(1)_Y$ model, to those produced by other theoretically motivated neutral gauge bosons occurring in left–right symmetric models and in superstring-inspired E_6 models. Forward–backward asymmetries in the gauge boson leptonic decay are found to be sensitive to specific forms of the couplings. The asymmetries are expected to be maximal for Z', distinguishing it from the other Z's.

The standard model (SM) [1] of electroweak interactions is in excellent agreement with existing data on low-energy neutral- and charged-current processes and on the mass of the W and Z bosons [2]. Moreover, the precision experiments from the CERN e^+e^- collider have spectacularly confirmed the model [3]. However, it is generally believed that the SM is just the low-energy limit of a more fundamental theory, containing new physics capable to address the many questions that the SM leaves unanswered.

In this work we consider the $Sp(6)_{\mathrm{L}} \otimes U(1)_Y$ model proposed some time ago [4]. This model predicts the existence of a set of intergenerational, horizontal gauge bosons, keeping the fermion spectrum intact. In the $Sp(6)_{\mathrm{L}} \otimes U(1)_Y$ model, the standard $SU(2)_{\mathrm{L}}$ is unified with the horizontal gauge group $G_H(= SU(3)_H)$ to an anomaly free, simple, Lie group. The six left-handed quarks (or leptons) belong to a **6** of $Sp(6)_{\mathrm{L}}$, while the right-handed fermions are all singlets. It is thus a straightforward generalization of $SU(2)_{\mathrm{L}}$ to $Sp(6)_{\mathrm{L}}$, with the three doublets of $SU(2)_{\mathrm{L}}$ coalescing into a sextet of $Sp(6)_{\mathrm{L}}$. $Sp(6)$ can be naturally broken into $[SU(2)]^3 = SU(2)_1 \otimes SU(2)_2 \otimes SU(2)_3$, where $SU(2)_i$ operates on the ith generation exclusively. Thus the standard $SU(2)_{\mathrm{L}}$ is to be identified with the diagonal $SU(2)$ subgroup of $[SU(2)]^3$. In terms of the $SU(2)_i$ gauge boson, $\boldsymbol{A}_i$, the $SU(2)_{\mathrm{L}}$ gauge bosons are given by $\boldsymbol{A} = \left(1/3^{1/2}\right)(\boldsymbol{A}_1 + \boldsymbol{A}_2 + \boldsymbol{A}_3)$. Of the other orthogonal combinations of $\boldsymbol{A}_i$, $\boldsymbol{A}' = \left(1/6^{1/2}\right)(\boldsymbol{A}_1 + \boldsymbol{A}_2 - 2\boldsymbol{A}_3)$, which exhibits universality only among the first two generations, can have a mass scale in the TeV range [5]. The additional gauge bosons $\boldsymbol{A}'$, denoted by Z' and ${W'}^{\pm}$, suggest new physics [6] beyond the standard model.

In this work we would like to compare characteristic signals in hadronic collisions, resulting from the neutral member Z', with those from other theoretically motivated, popular, neutral gauge bosons. In particular, we will consider here the neutral gauge boson, Z_{LR}, occurring in left–right symmetric models and Z_χ, Z_ψ and Z_η occurring in grand unified theories (GUTs) based on E_6 and $SO(10)$ groups (including superstring models) [7,8].

With one additional neutral gauge boson, the neutral-current Lagrangian is modified so as to contain an additional term,

$$-\mathcal{L}_{\mathrm{NC}} = eJ^\mu_{\mathrm{em}} A_\mu + g_1 J^\mu_1 Z^0_{1\mu} + g_2 J^\mu_2 Z^0_{2\mu}, \qquad (1)$$

where Z^0_1 is the $SU(2) \otimes U(1)$ boson and Z^0_2 is the additional boson in the weak eigenstate basis. The g_i are the gauge couplings with $g_1 = g/\cos\vartheta_{\mathrm{W}}$, where $g = e/\sin\vartheta_{\mathrm{W}}$. For the $Sp(6)_{\mathrm{L}} \otimes U(1)_Y$ model, $g_2 = ((1-x)/2)^{1/2} g_1 = g/2^{1/2}$, $x = \sin^2\vartheta_{\mathrm{W}}$. For the left–right models and GUT motivated cases considered here the couplings of the extra Z's are $g_2 = (5/3)^{1/2} \sin\vartheta_{\mathrm{W}} g_1$. The neutral currents $J_i, i = 1, 2$, are given by

$$J^\mu_i = \frac{1}{2} \sum_f \overline{\psi}_f \gamma^\mu (g^{(i)}_V(f) + g^{(i)}_A(f)\gamma_5)\psi_f. \qquad (2)$$

Here $g^{(i)}_{V,A}(f)$ are the vector and axial-vector couplings of fermion f to Z^0_i, respectively. They are related to the chiral couplings $\varepsilon^{(i)}_{\mathrm{L,R}}(f)$ by

$$g^{(i)}_{V,A}(f) = \varepsilon^{(i)}_{\mathrm{L}}(f) \pm \varepsilon^{(i)}_{\mathrm{R}}(f). \qquad (3)$$

After symmetry breaking the weak eigenstate bosons Z^0_i are related to the mass eigenstate bosons Z_i by

$$\begin{aligned} Z_1 &= Z^0_1 \cos\varphi + Z^0_2 \sin\varphi, \\ Z_2 &= -Z^0_1 \sin\varphi + Z^0_2 \cos\varphi, \end{aligned} \qquad (4)$$

where φ denotes the mixing angle between Z^0_1 and Z^0_2. The neutral-current Lagrangian now reads

$$-\mathcal{L}_{\mathrm{NC}} = g_1 \sum_{i=1}^{2} \left[\sum_f \overline{\psi}_f \gamma_\mu (V^{(i)}(f) + A^{(i)}(f)\gamma_5)\psi_f \right] Z^\mu_i, \qquad (5)$$

where

$$V^{(1)}(f), A^{(1)}(f) = \frac{1}{2}\left[g^{(1)}_{V,A}(f)\cos\varphi + \frac{g_2}{g_1}g^{(2)}_{V,A}(f)\sin\varphi\right], \quad (6)$$

$$V^{(2)}(f), A^{(2)}(f) = \frac{1}{2}\left[-g^{(1)}_{V,A}(f)\sin\varphi + \frac{g_2}{g_1}g^{(2)}_{V,A}(f)\cos\varphi\right]. \quad (7)$$

In our analysis, we make the simplifying assumption that Z_1^0–Z_2^0 mixing can be ignored, as it is constrained to be tiny for all the models considered in this work [9].

For the SM, $g_V^{(1)}(f) = (T_{3\mathrm{L}} - 2xQ)_f$ and $g_A^{(1)}(f) = (T_{3\mathrm{L}})_f$. Here $(T_{3\mathrm{L}})_f$ and Q_f are the third components of weak isospin and electric charge of fermion f, respectively. For the $Sp(6)_\mathrm{L} \otimes U(1)_Y$ model $g_V^{(2)}(f) = g_A^{(2)}(f) = (T_{3\mathrm{L}})_f$ for the first two generations and $g_V^{(2)}(f) = g_A^{(2)}(f) = -2(T_{3\mathrm{L}})_f$ for the third one. Thus, the fermion couplings in the $Sp(6)_\mathrm{L} \otimes U(1)_Y$ model are purely left handed. For the GUT cases considered here, the couplings are given in [7].

We will also consider the $SU(2)_\mathrm{L}\otimes SU(2)_\mathrm{R}\otimes U(1)$ (LR) model [8], for which the boson Z^0_{LR} couples to the current

$$J^\mu_{\mathrm{LR}} = \sqrt{3/5}\left(\alpha J^\mu_{3\mathrm{R}} - \frac{1}{2\alpha}J^\mu_{B-L}\right), \quad (8)$$

where $J_{3\mathrm{R}}$ is the third component of $SU(2)_\mathrm{R}$ and $B(L)$ is the baryon (lepton) number. Thus

$$\varepsilon_\mathrm{L}^{(\mathrm{LR})}(f) = \sqrt{\frac{3}{5}}\left(\frac{-1}{2\alpha}\right)(B-L), \quad (9)$$

$$\varepsilon_\mathrm{R}^{(\mathrm{LR})}(f) = \sqrt{\frac{3}{5}}\left[\alpha(T_{3\mathrm{R}})_f - \frac{1}{2\alpha}(B-L)\right]. \quad (10)$$

In (8)–(10)

$$\alpha = \left[\frac{1-\left(1+\dfrac{\varepsilon_\mathrm{L}^2}{\varepsilon_\mathrm{R}^2}\right)\sin^2\theta_\mathrm{W}}{\dfrac{\varepsilon_\mathrm{L}^2}{\varepsilon_\mathrm{R}^2}\sin^2\theta_\mathrm{W}}\right]^{1/2}, \quad (11)$$

where $\varepsilon_{\mathrm{L,R}}$ are the $SU(2)_{\mathrm{L,R}}$ gauge couplings. In the special case of left–right symmetry ($\varepsilon_\mathrm{L} = \varepsilon_\mathrm{R}$) considered here

$$\alpha = \left(\frac{1-2\sin^2\theta_\mathrm{W}}{\sin^2\theta_\mathrm{W}}\right) \simeq 1.53. \quad (12)$$

Several articles have dealt with phenomenological effects resulting from the presence of theoretically motivated, additional neutral gauge bosons [10]. However, to date, there is no experimental evidence from the Fermilab Tevatron for the existence of any additional neutral gauge bosons [11]. It is now commonly believed that if an additional neutral gauge boson exists, it should be observed through the Drell–Yan process at high-energy pp colliders if its mass is in the few TeV range or less. A Drell–Yan process for production of a vector boson of mass M by colliding hadrons A and B has the cross-section per unit rapidity

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y} = \frac{4\pi^2 x_A x_B}{3M^3}\sum_q G_q^+ \Gamma_{q\overline{q}}, \quad (13)$$

where we define

$$G_q^\pm = f_{q/A}(x_A)f_{\overline{q}/B}(x_B) \pm f_{\overline{q}/A}(x_A)f_{q/B}(x_B). \quad (14)$$

Here $f_{q/A}$ is the parton distribution function of quark q in hadron A, and $\Gamma_{q\overline{q}}$ is the partial width for the decay of the gauge boson into the quark pair $q\overline{q}$. The momentum fractions $x_{A,B}$ are related to the rapidity by

$$x_{A,B} = \left(\frac{M}{\sqrt{s}}\right)\mathrm{e}^{\pm y}, \quad (15)$$

where $s^{1/2}$ is the total c.m. energy. Consider the two-body process $q\overline{q} \to l\bar{l}$ in the quark–antiquark center of mass. Let the angle between l and q be θ^* in this frame. Then the angular distribution is a linear combination of $(1+\cos\theta^*)^2$ and $(1-\cos\theta^*)^2$ contributions:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} \propto (\varepsilon_\mathrm{L}(q)^2\varepsilon_\mathrm{L}(l)^2 + \varepsilon_\mathrm{R}(q)^2\varepsilon_\mathrm{R}(l)^2)(1+\cos\theta^*)^2 + (\varepsilon_\mathrm{L}(q)^2\varepsilon_\mathrm{R}(l)^2 + \varepsilon_\mathrm{R}(q)^2\varepsilon_\mathrm{L}(l)^2)(1-\cos\theta^*)^2, \quad (16)$$

where we use $\varepsilon_{\mathrm{L,R}}$ to denote $\varepsilon^{(2)}_{\mathrm{L,R}}$. For $A + B \longrightarrow Z_2 + \cdots \longrightarrow l^- + \cdots$, we have

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}(\cos\theta^*)} \propto \sum_q \{G_q^+(\varepsilon_\mathrm{L}(q)^2 + \varepsilon_\mathrm{R}(q)^2) \times (\varepsilon_\mathrm{L}(l)^2 + \varepsilon_\mathrm{R}(l)^2)(1+\cos^2\theta^*) + G_q^-(\varepsilon_\mathrm{L}(q)^2 - \varepsilon_\mathrm{R}(q)^2)(\varepsilon_\mathrm{L}(l)^2 - \varepsilon_\mathrm{R}(l)^2) \times (2\cos\theta^*)\}, \quad (17)$$

where we denote the forward direction by the one in which hadron A is traveling. Forward–backward asymmetries A_{FB} may be constructed by binning data with respect to rapidity. For any fixed y, we define

$$A_{\mathrm{FB}}(y) = \frac{F-B}{F+B}, \quad (18)$$

where

$$F \pm B = \left[\int_0^1 \pm \int_{-1}^0\right]\mathrm{d}(\cos\theta^*)\frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}(\cos\theta^*)}. \quad (19)$$

We then find

$$A_{\mathrm{FB}}(y) = \frac{3}{4}\frac{\varepsilon_\mathrm{R}(l)^2 - \varepsilon_\mathrm{L}(l)^2}{\varepsilon_\mathrm{R}(l)^2 + \varepsilon_\mathrm{L}(l)^2}\frac{\sum_q[\varepsilon_\mathrm{R}(q)^2 - \varepsilon_\mathrm{L}(q)^2]G_q^-}{\sum_q[\varepsilon_\mathrm{R}(q)^2 + \varepsilon_\mathrm{L}(q)^2]G_q^+}. \quad (20)$$

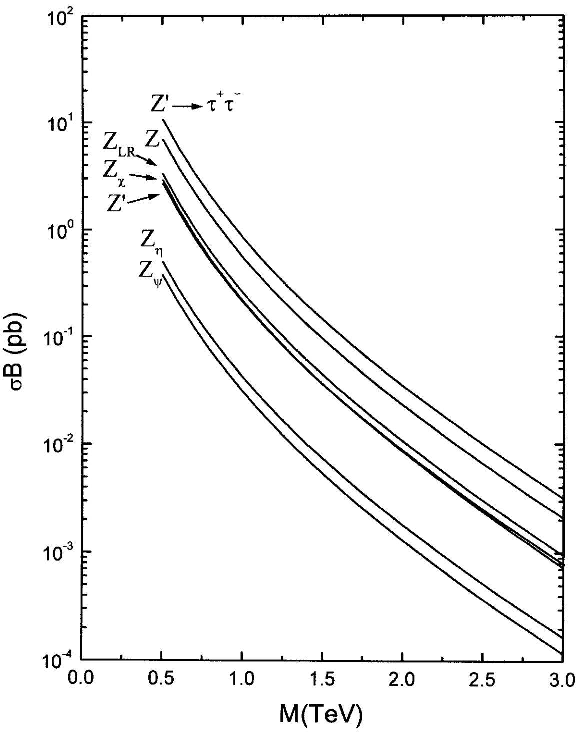

Fig. 1. Gauge boson production cross-section times branching fraction into $\mu^+\mu^-$ pair (σB), for Z', $Z_{\rm LR}$, Z_χ, Z_ψ, $Z\eta$ and Z, in pp collisions at $s^{1/2} = 14\,\text{TeV}$ as a function of the gauge boson mass M. Z here represents a gauge boson with the couplings of the standard Z, but with mass being a free parameter. Also shown is $\sigma B(Z' \to \tau^+\tau^-)$

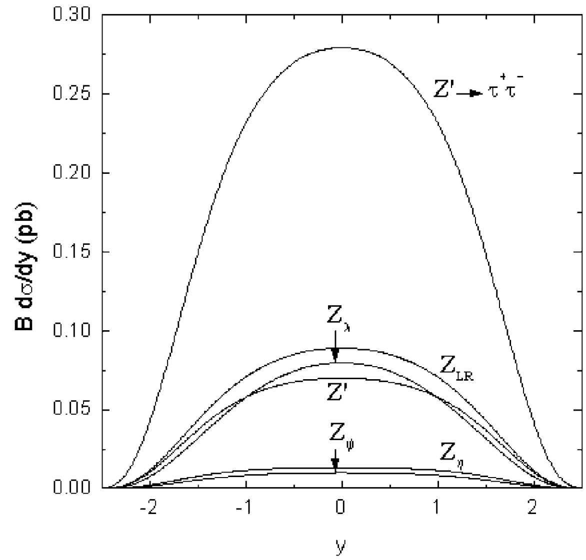

Fig. 2. Rapidity distributions ($B\mathrm{d}\sigma/\mathrm{d}y$) for muon pairs from Z', $Z_{\rm LR}$, Z_χ, Z_ψ and Z_η production by pp collisions at $s^{1/2} = 14\,\text{TeV}$, with $M = 1\,\text{TeV}$. Also shown is $B\mathrm{d}\sigma/\mathrm{d}y$ for tau pairs from Z'

The forward–backward asymmetry, $A_{\rm FB}(y)$, is even (odd) in y for $p\overline{p}$ (pp) machines. The integrated forward–backward asymmetry is defined by

$$A^{\rm FB} = \frac{\left[\int_0^{y_m} \pm \int_{-y_m}^{0}\right] \mathrm{d}y(F-B)}{\left[\int_0^{y_m} + \int_{-y_m}^{0}\right] \mathrm{d}y(F+B)}, \qquad (21)$$

with the +(-) sign relevant for $p\overline{p}$ (pp) collisions and $y_m = \ln(s^{1/2}/M)$.

In what follows we will be interested in studying distributions of leptons produced in Z_2 decay in hadronic collisions. In particular, we would like to examine and compare production cross-sections and characteristic asymmetries in pp collisions resulting from the additional neutral gauge bosons considered in this analysis.

Given the Tevatron null results on the discovery of new gauge bosons, it is necessary to consider higher collision energies in order to probe higher gauge boson masses. The proposed Large Hadron Collider (LHC) at CERN is expected to achieve a maximum collision energy of $s^{1/2} = 14\,\text{TeV}$, with a designed luminosity of $\mathcal{L} = 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$ [12]. The relevant quantity to consider here is σB: the gauge boson production cross-section times the branching fraction into dileptons. We calculated σB for the gauge bosons considered in this analysis at $s^{1/2} = 14\,\text{TeV}$ (LHC), assuming that $\varphi = 0$. In calculating cross-sections, we use the Martin–Roberts–Stirling–Thorne set MRST99 of parton distribution functions [13]. For comparison, we also consider a gauge boson, Z, with couplings identical to those of the standard Z, but with the mass being a free parameter. In calculating σB for $Z_{\rm LR}$, Z_χ, Z_ψ, and Z_η we use assumptions identical to those employed in [14]. The product σB is presented in Fig. 1 as a function of the gauge boson mass, M, for $M \geq 0.5\,\text{TeV}$. In fact, recent direct-search lower bounds on M, for any of the gauge bosons considered here, showed that $M \geq 0.5\,\text{TeV}$ [15]. Figure 1 shows that the $\mu^+\mu^-$ production rate for any of the considered gauge bosons is lower than the corresponding rate for Z. Also, the Z' muon pair production rate overlaps the corresponding rate for Z_χ. However, Fig. 1 shows that the $Z' \to \tau^+\tau^-$ production rate at LHC is higher than the corresponding rates of the other gauge bosons, allowing Z' to be distinguished. In fact, because of the generation-dependent couplings of fermions to Z', a four-fold enhancement is expected in its $\tau^+\tau^-$ production rate relative to its $\mu^+\mu^-$ production rate [16]. With the given luminosity, LHC is expected to achieve an integrated luminosity of $10^5\,\text{pb}^{-1}$ per 10^7 s year of running. Thus, for a typical value of $M_{Z'}$, $M_{Z'} = 1(2)\,\text{TeV}$, a run with the given integrated luminosity would yield approximately $2.1 \times 10^4 (8.4 \times 10^2)$ Z''s events decaying into a $\mu^+\mu^-$ pair and $8.67 \times 10^4 (3.47 \times 10^3)$ Z''s events decaying into a $\tau^+\tau^-$ pair a year. In Fig. 2 we compare rapidity distributions, $B\mathrm{d}\sigma/\mathrm{d}y$, for muon pairs from the gauge bosons, at the LHC, where we take $M = 1\,\text{TeV}$. The interference of the Z' and Z_χ cross-sections is made manifest in Fig. 2. For Z', the $Q = 2/3$ and $Q = -1/3$ quark components contribute equally to the cross-section. On the other hand, the cross-section for Z_χ is enhanced near $y = 0$ and suppressed at higher $|y|$. This is due to the relative sup-

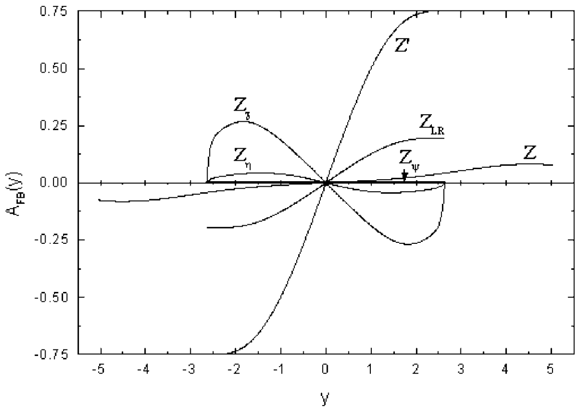

Fig. 3. Forward–backward asymmetries, $A_{\rm FB}(y)$, for $pp \to Z_2 + ... \to \mu^+\mu^-$ at $s^{1/2} = 14\,\mathrm{TeV}$, with $M = 1\,\mathrm{TeV}$. Also shown is $A_{\rm FB}(y)$ for the standard model gauge boson, Z

pression of the $Q = 2/3$ component which is more important at higher $|y|$ and less important near $y = 0$. Also shown in Fig. 2 is the expected $B(\mathrm{d}\sigma/\mathrm{d}y)$ for tau pairs from Z'.

The forward–backward asymmetry, $A_{\rm FB}(y)$, is very useful for identifying gauge bosons, because it is very sensitive to specific forms of the couplings. In Fig. 3 we present $A_{\rm FB}(y)$ for the models considered here as a function of y. We also consider the standard model gauge boson, Z, with mass $M = 91.1882\,\mathrm{GeV}$. No asymmetries are expected for Z_ψ because of its pure axial couplings. Small asymmetries are expected for Z because $\varepsilon_{\rm L}^2(e) \approx \varepsilon_{\rm R}^2(e)$. Larger asymmetries are expected for Z_χ and Z_η, still diluted somewhat because $\varepsilon_{\rm L}^2(u) = \varepsilon_{\rm R}^2(u)$. They fall off for large $|y|$ because the gauge boson is mainly produced by the u quark in this region, and $\varepsilon_{\rm L}^2(u) = \varepsilon_{\rm R}^2(u)$. For $Z_{\rm LR}$, since $\varepsilon_{\rm R}^2(q) \gg \varepsilon_{\rm L}^2(q)$, $A_{\rm FB}(y)$ is expected to approach $\approx \pm(3/4)(\varepsilon_{\rm L}^2(e) - \varepsilon_{\rm R}^2(e))/(\varepsilon_{\rm L}^2(e) + \varepsilon_{\rm R}^2(e))$ at $\pm y_m$, respectively. Maximal asymmetries are expected for Z' because of its pure left-handed couplings to fermions. Thus, for Z', with $\varepsilon_{\rm L}^2(u) = \varepsilon_{\rm L}^2(d) = \varepsilon_{\rm L}^2(e)$, $A_{\rm FB}(y)$ is expected to approach ± 0.75 at $\pm y_m$, respectively. The signs of the asymmetries in Z' production are identical to those in $Z_{\rm LR}$ and Z production and opposite to those in Z_χ and Z_η production, for the same value of y. In Fig. 4 we present the integrated forward–backward asymmetries $A^{\rm FB}$ for all models, as a function of the gauge boson mass which is taken as a free parameter. Figure 4 shows that $A^{\rm FB}$ is fairly uniformly distributed, over the considered range of M, for all models. The integrated forward–backward asymmetry is largest for Z', with $A^{\rm FB} \approx 0.4$ and smallest for Z_χ with $A_{\rm FB} \approx -0.15$.

In conclusion, the $Sp(6)_{\rm L} \otimes U(1)_Y$ extension of the standard model gauge group suggests an additional neutral horizontal gauge boson, Z'. We studied distributions of leptons produced by Z', as well as by other theoretically motivated neutral gauge bosons at the LHC. In particular, we considered the gauge bosons: $Z_{\rm LR}$, Z_χ, Z_ψ and Z_η occurring in left–right symmetric models and in models based on the E_6 and $S(10)$ groups. Z' is difficult to be distinguished through its $\mu^+\mu^-$ production rate because

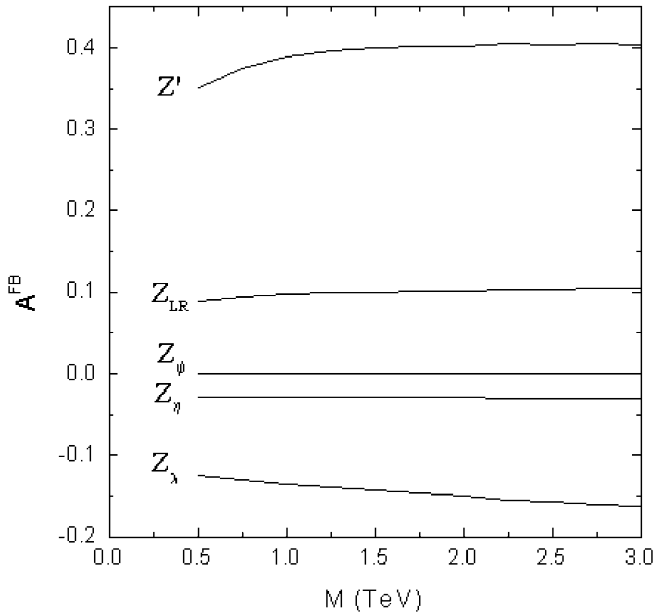

Fig. 4. Integrated forward–backward asymmetries $A^{\rm FB}$ for $pp \to Z_2 + ... \to \mu^+\mu^-$ at $s^{1/2} = 14\,\mathrm{TeV}$, with $M = 1\,\mathrm{TeV}$

of the overlapping with Z_χ. However, the $Z' \to \tau^+\tau^-$ production rate is higher than the corresponding rates of the other gauge bosons. The forward–backward asymmetry, $A_{\rm FB}(y)$, in the gauge boson leptonic decay is expected to provide crucial "fingerprints" of the gauge boson couplings. Because of its pure left-handed couplings to fermions, maximal asymmetries are expected for Z', distinguishing it from the other Z's. The integrated forward–backward asymmetry $A^{\rm FB}$ is largest for Z', with $A^{\rm FB} \approx 0.4$ and smallest for Z_χ with $A_{\rm FB} \approx -0.15$.

References

1. S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967); A. Salam, in Elementary Particle Theory: Relativistic Groups and Analyticity (Nobel Symposium No. 8), edited by N. Svartholm (Almqvist and Wiksell, Stokholm 1968), p. 367
2. See, for example, J.E. Kim et al., Rev. Mod. Phys. **53**, 211 (1981); Barbiellini, C. Santoni, Riv. Nuovo Cimento **9**, 1 (1986); Amaldi et al., Phys. Rev. D **36**, 1385 (1987); Costa et al., Nucl. Phys. B **297**, 244 (1988); P. Langacker, M. Luo, Phys. Rev. D **44**, 817 (1991); Particle data group, Eur. Phys. J. C **15**, 95 (2000)
3. The LEP collaborations and the LEP electroweak working group, Report No. CERN/PPE/94-187
4. T.K. Kuo, N. Nakagawa, Phys. Rev. D **30**, 2011 (1984); Nucl. Phys. B **250**, 641 (1985); A. Bagneid, T.K. Kuo, N. Nakagawa, Int. J. Mod. Phys. A **2**, 1351 (1987)
5. V. Barger et al., Int. J. Mod. Phys. A **2**, 1327 (1987)
6. See, for example, T.K. Kuo, N. Nakagawa, Phys. Rev. D **31**, 1161 (1985); **32**, 306 (1985); V. Barger et al. [3]; G.T. Park, T.K. Kuo, Phys. Rev. D **42**, 3879 (1990); **45**, 1720 (1992); Zeit. f. Phys. C **59**, 445 (1993); A. Bagneid, T.K. Kuo, G.T. Park, Phys. Rev. D **44**, 2188 (1991); G. Rizzo,

ibid. **42**, 3755 (1990); J.L. Hewett, T.G. Rizzo, ibid. **45**, 161 (1992); T.G. Rizzo, ibid. **46**, 3751 (1992); A. Bagneid, Phys. Rev. D **49**, 3755 (1994); T.K. Kuo, G.T. Park, Phys. Rev. D **50**, 3508 (1994); T.K. Kuo, G.T. Park, M. Zarlek, Nuovo Cimento A **107**, 757 (1994); A.A. Bagneid, Nuovo Cimento A **110**, 747 (1997); A.A. Bagneid, ibid. A **112**, 761 (1999)

7. See for example, P. Langacker, R.W. Robinett, J.L. Rosner, Phys. Rev. D **30**, 1470 (1984); D. London, J.L. Rosner, Phys. Rev. D **34**, 1530 (1986); J.L. Hewett, T.G. Rizzo, Phys. Rep. **194**, 194 (1989); P. Langacker, M. Luo, Rev. Mod. Phys. **64**, 87 (1992)
8. J.C. Pati, A. Salam, Phys. Rev. D **10**, 275 (1974)
9. R. Barate et al.,Eur. Phys. J. C **12**, 183 (2000); T. k. Kuo, G.T. Park, Phys. Rev. D **50**, 3508 (1994); G.T. Park, T.K. Kuo, Int. J. Mod. Phys. A **10**, 4387 (1995)
10. See, for example, P. Langacker, R.W. Robinett, J. Rosner, Phys. Rev. D **30**, 1470 (1984); L.S. Durkin, P. Langacker, Phys. Lett. B **166**, 436 (1986); Amaldi et al. [2]; Costa et al. [2]; A.A. Bagneid, T.K. Kuo, Phys. Rev. D **35**, R2275 (1987); Phys. Rev. D **38**, 2153 (1988); J.L. Hewett, T.G. Rizzo, Phys. Rep. **183**, 194 (1989); A. Bagneid, T.K. Kuo, G.T. Park, Phys. Rev. D **44**, 2188 (1991); F. del Aguila et al., Nucl. Phys. B **361**, 45 (1991); F. del Aguila et al., Nucl. Phys. B **372**, 3 (1992); P. Langacker, M. Luo, Phys. Rev. D **45**, 278 (1992); Rev. Mod. Phys. **64**, 87 (1992); G. Altarelli et al., Nucl. Phys. B **405**, 3 (1993); A.A. Bagneid, Phys. Rev. D **49**, 3755 (1994); F. Abe et al.,Phys. Rev. D **51**, R949 (1995); S. Godfrey, Mod. Phys. Lett. **12**, 1859 (1997); T.G. Rizzo, Phys. Rev. D **61**, 055005 (2000); S. Godfrey et al., Phys. Rev. D **61**, 113009 (2000); R. Barate et al.,Eur. Phys. J. C **12**, 183 (2000)
11. F. Abe et al.,Phys. Rev. Lett. **79**, 2192 (1997)
12. Particle data group, Eur. Phys. J. C **15**, 1 (2000)
13. A.D. Martin, R.G. Roberts, W.J. Stirling, R.S. Thorne, Eur. Phys. J. C **12**, 133 (2000)
14. P. Langacker, M. Luo, Phys. Rev. D **45**, 278 (1992)
15. F. Abe et al.,Phys. Rev. Lett. **79**, 2192 (1997); R. Barate et al.,Eur. Phys. J. C **12**, 183 (2000); A. Bagneid, to be published
16. A. Bagneid, [15]