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Possible Bilepton Resonances in Like-Sign Pairs

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Abstract

We consider pair production of bileptons $Y^{++}Y^{--}$ at the LHC for the presently accumulated integrated luminosity of 150/fb. It is shown that the entire mass range $800 \text{ GeV} \leq M(Y) \leq 2000 \text{ GeV}$ can be successfully searched. A bilepton resonance will have an exceptionally large ratio of signal to background because the standard model prediction is so infinitesimal. A $5\sigma$ discovery is quite feasible.
1 Introduction

High energy particle physics is in a crisis because of the lack of new physics discovered at the LHC since the Higgs boson in 2012. This impasse impacts also on early universe studies in cosmology and thus effects astrophysics and astronomy; and progress in particle theory has traditionally been intertwined with that in condensed matter physics.

Because the LHC data have provided no encouragement for the most popular extensions beyond the standard model (BSM), we are led to consider less popular alternatives. One attractive and conservative possibility is to adhere to the way in which the standard model was discovered, viz to seek a renormalizable gauge theory in flat four-dimensional commuting spacetime.

One wants the BSM to subsume the standard model and be identical to it at low energies except for tiny corrections. One also wants it to answer some mystery about the standard model, e.g. why there are three quark-lepton families. Both of these requirements are fulfilled by the Bilepton Model invented by Frampton [1], and by Pisano and Pleitez [2]. There have been two changes in nomenclature since 1992: first, the original name “dilepton” was changed [3] in 1996 to “bilepton” because of a pre-existing usage for opposite-sign lepton pairs by experimentalists; second, the original name 331-Model has more recently been changed to Bilepton Model to mean only that subclass of 331-Models which predict the doubly-charged gauge bosons that are the subject of the present article.

The reason for the resurgence of interest in the Bilepton Model which has been cited more in the last decade than previously is probably related to the lack of encouragement from LHC data for the more popular BSM models. There has recently been detailed analysis of its properties [4–9], especially its predictions with respect to flavour. As stated in [5,6], one nice feature of these models is the small number of free parameters.

In the papers [10,11] we have discussed the signatures of bilepton production at the LHC. At present, the LHC has accumulated an integrated luminosity of about 150/fb, compared to the expected final integrated luminosity of 3000/fb. The LHC will be shut down for all of 2019 and 2020 so, for the moment, we must make do with the 150/fb. In [10], we studied the pair production of bileptons with two jets detected in the final state; in [11], this was extended to the case of zero jets detected in the final state. In both cases, the bilepton signal was clearly visible over the Standard Model background.
2 Resonance bumps

In the present article, we discuss the detection of the bilepton as a resonance in like-sign lepton pairs. At first sight, with only 150/fb and the requirement of pair production of the heavy bileptons this might appear to be an overly optimistic quest. To anticipate our result of making an approximate, but plausible, estimate of the cross-sections, the pleasant surprise is that the already-acquired data stored in the LHC “cloud” are more than sufficient to explore the complete range of possible bilepton masses.

What is the complete range of bilepton masses? The lower bound comes from low-energy experiments performed over 20 years ago at PSI who examined over one trillion muon decays to look for contamination by right-handed \((V + A)\) interactions of the type which would be generated by bilepton exchange. The result was summarised by a lower limit on the Michel parameter and translated into \(M(Y) > 800\) GeV. A second experiment, also at PSI, studied over ten billion examples of muonium and searched for muonium-antimuonium conversion which can be mediated by bilepton exchange. By coincidence, this second experiment provided the same lower limit \(M(Y) > 800\) GeV. The upper limit on \(M(Y)\) arises from the fact that, as first pointed out in \([1]\), there exists an upper limit on the possible scale of spontaneous symmetry breaking of the 331 gauge group into the 321 gauge group of the standard model. That limit arises from the avoidance of imaginary couplings which occur if \(\sin^2 \theta_{EW} \geq \frac{1}{4}\), where \(\theta_{EW}\) is the electroweak mixing angle. This is an interesting property of the Bilepton Model because it requires the new physics to be accessible to the LHC. The maximum 331 breaking scale is 4000 GeV. One then argues that the dynamics are analogous to the electroweak model and the \(Y\) is analogous to the \(W\). Hence the expected bilepton mass is \(4000 \times (80/248) \simeq 1300\) GeV. By this argument, it is improbable that \(M(Y) > 2000\) GeV. Thus, our five benchmark points will be the equal spaced masses \(M(Y) = 800, 1100, 1400, 1700, 2000\) GeV.

Our method of estimating the numbers of events at ATLAS is to use old ATLAS data \([12]\) which were analysed to search for a SSM(=Sequential Standard Model) \(Z'\) which was not discovered. There is some similarity between production of \(Y\) and \(Z'\). The biggest difference is that \(Y\) must be pair produced so we approximate by using \(\sigma_{SSM}^{Z'}(M(Z') = 2M(Y))\). We need to estimate the branching ratio (BR) for \((Y \rightarrow e^+e^+, \mu^+\mu^+, \tau^+\tau^+)\). Because there exist non-leptonic decays \(B \rightarrow Q\bar{q}, q\bar{Q}\) where \(Q\) is an exotic quark, the BRs depend on the mass \(M(Q)\) of the exotic quarks.
3 Exotic quark mass

In the Bilepton Model there are three exotic quarks $Q^i$ with $i=1,2,3$, one for each family. $Q^1$ and $Q^2$ have electric charge $-\frac{2}{3}$ while $Q^3$ has $+\frac{2}{3}$. For simplicity, we shall assume all three have the same mass $M(Q^1) = M(Q^2) = M(Q^3) = M(Q)$.

The value of $M(Q)$ is regretfully not known from experiment and it is important in predicting our event rates.

In what we shall call (A), $M(Q) = 0$, and the branching ratios for $Y$ decay resemble those for a sequential $Z'$, meaning that $BR = 0.03$. In this limit the S=signal and B=background events are predicted as shown in Table 1.

| M(Y) GeV | $\sigma_{SSM}^Z(M_{Z'} = 2M(Y))$ (fb) | $(BR)^2$ | S=signal events | B=background events |
|----------|-------------------------------------|----------|-----------------|--------------------|
| 800      | 100                                 | 0.0009   | 13.5            | < 0.01             |
| 1100     | 20                                  | 0.0009   | 2.7             | < 0.01             |
| 1400     | 6                                   | 0.0009   | 0.81            | < 0.01             |
| 1700     | 1                                   | 0.0009   | 0.135           | < 0.01             |
| 2000     | 0.6                                 | 0.0009   | 0.081           | < 0.01             |

Here, the predicted S are not encouraging, especially for the highest M(Y).

As another illustration we consider (B) $M(Q) > 2000$ GeV so that the non-leptonic $Y$ decay is kinematically excluded and $BR = 0.33$ with the results shown in Table 2.

Here, the predictions for S are much more hopeful. The question is what is the case in the real world?

4 Most reliable predictions

In the previous subsection we investigated two extremes where (A)$M(Q) = 0, BR = 0.03$ and (B)$M(Q) = 2000$ GeV, BR=0.33 respectively. These are
Table 2: Numbers of signal and background events at resonance in like-sign lepton pairs, calculated as explained in the text (B) for integrated luminosity 150/\text{fm}.

| $M(Y) \text{ GeV}$ | $\sigma_{SSM}^2(M_{Z'} = 2M(Y))$ (fb) | $(BR)^2$ | Signal events | Background events. |
|-------------------|--------------------------------------|----------|---------------|-------------------|
| 800               | 100                                  | 0.109    | 1635          | < 0.01            |
| 1100              | 20                                   | 0.109    | 327           | < 0.01            |
| 1400              | 6                                    | 0.109    | 29            | < 0.01            |
| 1700              | 1                                    | 0.109    | 16            | < 0.01            |
| 2000              | 0.6                                  | 0.109    | 6             | < 0.01            |

two limits and the real world lies between (A) and (B). We shall designate our most reliable estimates by (C) in which $M(Q) = 800 \text{ GeV}$. In this case, we have $BR = 0.33$ when $M(Y) = 800 \text{ GeV}$ because the non-leptonic decay is kinematically disallowed. For the higher values of $M(Y)$, $BR$ decreases as dictated by 2-body phase space, according to Table 3.

Table 3: Branching ratio for bilepton $Y^{++}$ decay into like-sign leptons, with $BR(Y^{++} \rightarrow \tau^+\tau^+) = BR(Y^{++} \rightarrow \mu^+\mu^+) = BR(Y^{++} \rightarrow e^+e^+)$. Assumes exotic quark mass $M(Q) = 800 \text{ GeV}$ for all three families.

| $M(Y) \text{ GeV}$ | BR=branching ratio into like-sign lepton pair (per flavour) |
|-------------------|-----------------------------------------------------------|
| 800               | 0.33                                                       |
| 1100              | 0.31                                                       |
| 1400              | 0.28                                                       |
| 1700              | 0.25                                                       |
| 2000              | 0.21                                                       |

In case (C) we re-calculate the numbers of $S$=signal events and $B$=background events, using the values of $BR$ from Table 3. The results which are our most reliable predictions for the LHC are displayed in Table 4.
Table 4: Numbers of signal and background events at resonance in like-sign lepton pairs, calculated as explained in the text (C) for integrated luminosity 150/fm. This Table gives our most reliable predictions.

| M(Y) GeV | $\sigma_{SSM}^{Z'}(M_{Z'} = 2M(Y))$ (fb) | $(BR)^2$ | Signal events | Background events |
|----------|---------------------------------|----------|--------------|------------------|
| 800      | 100                             | 0.109    | 1635         | < 0.01          |
| 1100     | 20                              | 0.096    | 288          | < 0.01          |
| 1400     | 6                               | 0.078    | 70           | < 0.01          |
| 1700     | 1                               | 0.062    | 9            | < 0.01          |
| 2000     | 0.6                             | 0.044    | 4            | < 0.01          |

Because of the insignificant standard model background, for any of these $Y^{\pm \pm}$ masses, detection of events at resonance signals discovery of a new particle.

5 Summary

By analysis of the already existing LHC data, corresponding to an integrated luminosity 150/fb, the doubly-charged bileptonic gauge bosons predicted by the Bilepton Model can potentially be discovered for the entire mass range from 800 GeV to 2000 GeV.

Our results for our most reliable predictions are summarised in Table 4, Because background is tiny, a 5$\sigma$ signal is quite feasible.

Such a discovery can revolutionise particle physics by providing direction for research beyond the fifty-year-old standard model and giving useful knowledge about the evolution of the early universe.

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