X-events and their Interpretation

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Abstract

We point out that when doubly-charged bileptons are pair produced at the LHC, kinematics dictate that they are both almost at rest in the lab frame and therefore their decays lead to final state muons in a characteristic X-shape with only very tiny track curvature because of the high muon energies. Such X-events have essentially no standard model background and provide a smoking gun for the 331 model.

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1 Introduction

In the aftermath of the discovery of the BEH scalar boson with $M_H \simeq 125$ GeV, there is an urgent phenomenological question of what further can be expected to be discovered at the LHC?

The cases for both weak-scale supersymmetry and large extra dimensions have been seriously weakened by the LHC data already in hand, because there is no sign of either superpartners or Kaluza-Klein modes.

Nevertheless, nobody expects the Standard Model (SM) to be the final theory. The SM possesses 28 free parameters, only 6 of which has been convincingly derived by theory. The 12 fermion masses remain unexplained. Leaving temporarily aside the 4 CP-violating phases, the six real mixing angles in the CKM and PMNS matrices do now have a semi-quantitative theoretical explanation by appending to the SM a discrete nonabelian flavor symmetry. The final six SM parameters are all mysterious.

In the present article we adopt the strategy of ignoring the problem of the twenty-two unexplained SM parameters. Instead we consider the simplest extension of the SM which has the benefit of explaining why there are three sequential quark-lepton generations.

This is the 331 model invented in 1992 [1,2] which now appears more unique than expected [3,4]. Aside from trivial redefinitions of the embedding of the electric charge there is only one known example of such a set-up which can explain the three-fold replication of the first generation. The model has far fewer free parameters than occur for either supersymmetry or extra spatial dimensions. This renders the LHC predictions more quantitative.

An overriding feature of the 331 model is that the symmetry breaking from 331 to the 321 of the SM must be at a scale below about 4 TeV. This was first pointed out uniquely in [1]. The theoretical reason involves the group embedding of the SM $SU(2)_L$ into the 331’s $SU(3)_L$ and arises phenomenologically because of the proximity of the electroweak mixing angle $\Theta_W$ to the crucial value above which the embedding of $SU(2)_L$ into $SU(3)_L$ requires an unphysical imaginary gauge coupling constant.

More specifically, at the Z-pole the latest value of $\Theta_W$ is [5]

$$\sin^2 \Theta_W(M_Z) = 0.23126$$

and under the SM renormalization group equations $\sin^2 \Theta_W(\mu)$ increases only slowly with increasing the scale $\mu$ such that the special value

$$\sin^2 \Theta_W(\mu) \equiv \left(\frac{1}{4}\right)$$

is achieved for $\mu \simeq 4$ GeV. To avoid imaginary couplings, this provides an upper limit for the 331 $\rightarrow$ 321 symmetry breaking scale.
The new physics particles

The 331 model [1,2] predicts far fewer new physics particles than does the competing supersymmetric model, the MSSM. The additional 331 particles we focus on here, because they are the simplest to recognize experimentally, are the extra 331 gauge bosons. These are five in number, comprising a neutral \( Z' \)-boson and four bileptons \(^3\). They are similar to the \( Z' \)-bosons in many other models beyond the SM so it does not itself provide the most useful 331 smoking gun.

The 331 bileptons, especially those with double electric charge \( Y^{++} \) and \( Y^{--} \), do provide such a 331 smoking gun. After studying many different results of proton-proton collisions at \( \sqrt{s} = 14 \) TeV, within the context of the 331 model, including the production and decay of the bileptons as well as the exotic quarks with electric charges \( +\frac{5}{3} \) and \( -\frac{4}{3} \), we wish to point out, as a candidate for the most striking 331 smoking gun, the existence of X-events.

What are X-events? To illustrate the unusual kinematics let us assume the bilepton mass is \( M_Y = 1.5 \) TeV. The bileptons are siblings of the familiar \( W^\pm \) of the weak interactions and just as for \( W^\pm \) it is reasonable to assume a gauge boson mass somewhat below the corresponding spontaneous symmetry breaking scale.

There are also important lower bounds on the bilepton mass. There exist two such bounds, both arising from table-top experiments and both by coincidence having been exquisitely measured at the Paul Scherrer Institute (PSI).

The first lower mass limit arises from muonium-antimuonium conversion where the exchange of the doubly-charged bilepton can give the requisite \( \Delta L = \pm 2 \) violation of lepton number. The experimental result [7] provides a lower limit depending on the 331 gauge coupling \( g_{3l} \) and corresponds to \( M_Y > 850 \) GeV.

A second lower bound on \( M_Y \) originates from high precision measurements of muon decay. The point is that bilepton exchange contributes a \( (V + A) \) component to the familiar \( (V - A) \) structure for muon decay predicted by the SM. This \( (V + A) \) component is best measured by the Michel parameter and measurements existing for muon decay provide [8] a lower mass limit \( M_Y > 1 \) TeV, slightly stronger than the lower limit from muonium conversion.

Now let us consider proton-proton collisions at 14 TeV and, in particular, the inclusive process \( p + p \rightarrow Y^{++} + Y^{--} + \text{anything} \), with \( M(Y^{\pm\pm}) \approx 1.5 \) TeV. The kinematics strongly favor production of the two on-shell bileptons extremely close to at rest in the center-of-mass frame. They then both decay into back-to-back muons, which explains the name X-event to characterize its appearance.

\(^3\)In 1992 these gauge bosons were named dileptons [1] despite a different usage of the same word by experimentalists; in 1996 the name was therefore changed to bileptons [6].
The four muons share a huge Lorentz factor \( \gamma = (0.75 \times 10^6)/106 \simeq 7,000 \) corresponding to a velocity divided by the speed of light equal to one up to a part in \( 10^8 \). This ultrarelativistic speed raises a practical difficulty in detecting the track curvature due to the magnetic field in either the ATLAS or the CMS detectors. If this curvature could be measured, however, it would provide a useful check because the same-sign nature of the bilepton decays could be confirmed.

3 Discussion

The X-event we have discussed in this letter provides a simple smoking gun for the 331 model. It is the simplest example of which we are aware. There are, of course, many other characteristic 331 signatures, some of which were discussed in [9].

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