Tau lepton charge asymmetry and new physics at the LHC

Sudhir Kumar Gupta and German Valencia*

Department of Physics, Iowa State University, Ames, IA 50011.

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Abstract

We consider the possibility of studying new physics that singles out the tau-lepton at the LHC. We concentrate on the tau-lepton charge asymmetry in $\tau^+\tau^-$ pair production as a tool to probe this physics beyond the standard model. We consider two generic scenarios for the new physics. We first study a non-universal Z' boson as an example of a new resonance that can single out tau-leptons. We find that it induces a charge asymmetry that is hard to distinguish from the SM. We then consider vector lepto-quarks coupling the first generation quarks with the third generation leptons as an example of non-resonant new physics. We find that this scenario results in a charge asymmetry that is sufficiently different from the SM to allow easy detection.

*Electronic address: skgupta@iastate.edu,valencia@iastate.edu

I. INTRODUCTION

The large hadron collider (LHC) has been running since earlier last year in an initial phase of rediscovering the Standard Model (SM). A variety of observables are necessary to completely measure the SM couplings and we concentrate here on the charge asymmetry, the hadron collider equivalent of the familiar forward-backward asymmetry. During the early stages of LHC running, the available event rates will possibly allow measurements of lepton charge asymmetries near the Z peak. These translate into measurements of the weak angle, $\sin^2\theta_W$, and can help in the SM rediscovery phase at LHC.

When the LHC is running at its design energy and luminosity, it will be possible to extend these measurements to regions of $m_{\ell\ell}$ not probed by LEP II, and in this way play an important role in the search for new physics. The Drell-Yan dilepton pair production process is important in this context due to its clean signature. In this paper we discuss the use of the lepton charge asymmetry as a tool to discover new physics, with emphasis on the τ-pair production channel for $M_{\tau\tau}$ above the reach of LEP II.

There exists a vast literature dedicated to the study of new physics associated with the top-quark, that is motivated by its large mass and possible unique role in electroweak symmetry breaking. It is natural to ask whether new physics that singles out the top-quark does not in fact single out the whole third generation of SM fermions. This is particularly the case in light of the existing anomaly in the forward-backward asymmetry of the b-quark [1].

With this in mind, we wish to explore the possibility of new physics that affects the tau-lepton but does not show up in studies of muons or electrons. To this effect we consider two different scenarios that single out the third generation leptons. The scenarios are not complete models, but instead they describe two simple possibilities. Our first example is a non-universal Z' which has been studied before in connection with the top-quark. Here we explore its consequences in tau-lepton physics at the LHC in the large $M_{\tau\tau}$ region. It is possible that such a Z' can be detected by simply looking for bumps in the $M_{\tau\tau}$ distribution, but we emphasize here the question of detecting its effect via the lepton charge asymmetry. Our second example consists of vector lepto-quarks which provide a benchmark for effects from non-resonant new physics. By associating the third family of leptons with the first family of quarks, the lepto-quarks in question single out the tau-lepton.

II. CHARGE ASYMMETRY

Forward-backward asymmetries have proved to be valuable tools for constraining the standard model (SM) and searching for new physics in e^+e^- colliders. A prominent example being the A^b_{FB} anomaly measured at LEP [2], which remains a hint for new physics [1]. More recently the Tevatron has reported an anomaly in the forward-backward asymmetry of the top-quark [3] which has also received considerable attention [4].

Forward-backward asymmetries can not be defined for the LHC, which is a symmetric pp collider. Nevertheless, it is possible to use in this case the closely related charge asymmetries [5, 6]. An example for the LHC phase of rediscovering the SM, is a proposal by the ATLAS collaboration to measure $\sin^2\theta_W$ using the electron forward-backward asymmetry at the Z peak [7].

The idea behind these asymmetries is simple. If we consider processes that are initiated by $q\bar{q}$ annihilation at the parton level, we can define the forward-backward asymmetry in the usual way in the parton center-of-mass frame (CM): the forward direction corresponding to the incoming quark direction. Since the quarks in the proton carry, on average, a larger fraction of the proton momentum than the anti-quarks, the direction of the quark momentum is correlated with the direction of the total momentum of the event in the lab frame (the boost direction).

Specifically, one can start from the parton CM asymmetry defined in the usual way,

$$\mathcal{A}^{\star}_{FB}(q\bar{q} \to \ell^-\ell^+) \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \tag{1}$$

where σ_F (σ_B) is the respective cross-section for producing a lepton ℓ^- that travels forward (backward) with respect to the initial quark direction. In the lab frame, a non-vanishing $\mathcal{A}^{\star}_{FB}$ will manifest itself as a rapidity asymmetry: the forward leptons in the parton center of mass will have a larger rapidity in the lab frame. At the LHC, the symmetry of the initial pp state introduces an additional complication because the quark direction is equally likely to correspond to either proton. The net result of an $\mathcal{A}^{\star}_{FB}$ in the lab frame at the LHC is a charge asymmetry in which the type of lepton that preferred the backward direction in the CM now concentrates in the central rapidity region.

Following this argument, it is common to define a charge asymmetry in terms of the fermion rapidity [5]. In our case,

$$\mathcal{A}(y) = \frac{N_{\ell^+}(y) - N_{\ell^-}(y)}{N_{\ell^+}(y) + N_{\ell^-}(y)} \tag{2}$$

where y is rapidity of the lepton $\ell^{\pm}$ and N is the number of events with a given rapidity y. It is also common to define an integrated asymmetry over a central region, limited by y_c:

$$\mathcal{A}_c(y_c) = \frac{N_{\ell^+}(-y_c \le y \le y_c) - N_{\ell^-}(-y_c \le y \le y_c)}{N_{\ell^+}(-y_c \le y \le y_c) + N_{\ell^-}(-y_c \le y \le y_c)}. \tag{3}$$

This integrated asymmetry can be optimized with a carefully chosen y_c [5]. Notice that the symmetry of the initial pp state at LHC causes the integrated asymmetry to vanish when the whole rapidity range is used. Finally, it may be convenient to integrate the charge asymmetry over different ranges of $m_{\ell\ell}$ as we discuss below.

III. MODEL DESCRIPTIONS AND NUMERICAL ANALYSIS

In this section we describe briefly the two models we use to illustrate the effectiveness of the charge asymmetry and we present the corresponding numerical results. These two models are chosen because we are mostly interested in applications to τ-lepton physics at LHC and both are examples of new physics that singles out the τ-lepton.

In all cases we use `MadGraph` [8] for event generation and `PYTHIA` [9] for the analysis. To this end we implement the vertices that originate in each of the two new physics models directly into `MadgGaph`. We use `CTEQ6L-1` parton distribution functions [10] with the two QCD scales, i.e. the renormalization scale, μ_R, and the factorization scale μ_F fixed at $\mu_R = \sqrt{\hat{s}} = \mu_F$. We also implement the basic acceptance cuts $p_{T_\tau} > 20$ GeV, $|\eta_\tau| < 2.5$, and $\Delta R_{\tau\tau} > 0.4$. Our results will show that the measurements we propose will not be possible in the early running of LHC. For this reason we will assume a τ physics program when LHC is running at $\sqrt{S} = 14$ TeV center-of-mass energy, and with an integrated luminosity of 10 fb^{-1} per year.

We carry our analysis at the τ-lepton level, without concerning ourselves with the subsequent τ decays. Both CMS and ATLAS expect to be able to detect τ-leptons with relatively large efficiencies, as large as 80% and 75% respectively [11, 12].

The SM itself produces a non-zero charge asymmetry so that a search for new physics involves measuring the deviation from the SM. Depending on the new physics, this deviation may be small and a precise measurement may be needed.

We begin with a discussion of the charge asymmetry in the SM. Within the SM, dileptons at the LHC are produced predominantly via s-channel exchange of a photon or a Z boson with a total cross-section (for our acceptance cuts) of ~ 941 pb at $\sqrt{S} = 14$ TeV. The corresponding SM $\tau^+\tau^-$ events exhibit an $M_{\tau\tau}$ distribution shown in Figure 1. This differential cross-section exhibits a clear Z peak and falls rapidly with $M_{\tau\tau}$. To distinguish possible new physics it is therefore useful to exclude the Z region and to look as far out in $M_{\tau\tau}$ as the event rate permits. We will find that the best region to look for new physics (at least in the two examples we consider) is $M_{\tau\tau} > 200$ GeV.

Our main observable is the integrated charge asymmetry over both rapidity, within a range determined by $|y| < y_c$, and $M_{\tau\tau} > M_{min}$. Previous studies related to the top-quark have shown that there is an optimal value for y_c in Eq. 3 [5] and we illustrate this point within the context of the SM in Figure 2. This figure indicates that values around $y_c \sim 0.5$ maximize the integrated charge asymmetry more or less independently from the M_{min} value used. The selection of M_{min} proceeds as discussed above: we want to exclude the Z peak region to minimize the effect of the SM as a background to the new physics without reducing the event rate too much. It turns out that the asymmetry increases with increasing M_{min} (at least up to the $M_{min} = 300$ GeV that we have tested) and this is illustrated in Figure 2. As M_{min} increases, this cut is more effective in rejecting events with a lower boost and

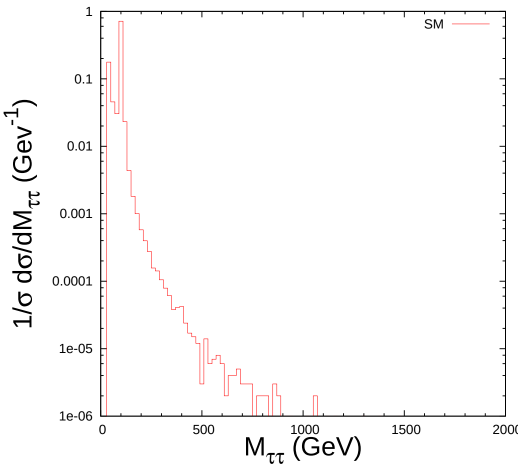

FIG. 1: Dilepton invariant mass distribution for the process $pp \to \tau^+\tau^-$ within standard model at the LHC for $\sqrt{S} = 14$ TeV.

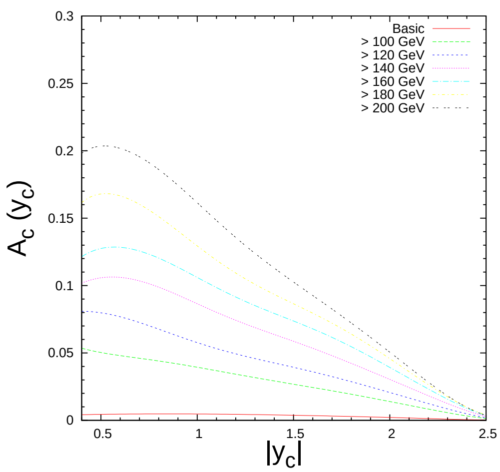

FIG. 2: Integrated charge asymmetry for the standard model with basic acceptance cuts as well as different minimum dilepton invariant mass cuts.

this results in an increased asymmetry. The choice of a specific value for M_{min} will thus result from a compromise between a somewhat larger asymmetry and reduced statistics as M_{min} increases. We explore this further when we discuss results within the illustrative models.

A. Non-Universal Z' model

One of the most frequently studied extensions of the Standard Model (SM) is an additional $U(1)'$ symmetry and its associated Z' boson [13]. Although the $U(1)'$ charges are family universal in most of the models discussed in the literature, this need not be the case. It is well known that a non-universal Z' induces tree-level flavor changing neutral currents (FCNC) which are severely constrained by experiment, most notably meson mixing [14].

In this paper we will not concern ourselves with the FCNC, but rather with the possibility of an enhanced coupling to the third generation as in the models of Ref. [15]. In particular we are interested in an enhanced coupling to τ-leptons that can be probed at LHC.

We write the general couplings of a non-universal Z' boson to the SM fermions as follows,

$$\mathcal{L}_{Z'} = \frac{g}{2\cos\theta_W} \left(\bar{f}\gamma^\mu \left(c_L^f P_L + c_R^f P_R\right) f\right) Z'^\mu. \tag{4}$$

A model with an enhanced coupling $c^\tau_{L,R}$ singles out the τ-lepton pair production process. Of course, at LHC, we also need to know how the Z' is produced and this forces us to specify its couplings to light quarks.

For definiteness we use the anomaly free model of Ref. [15]. In this model the new interaction is right-handed and its strength is determined by a new parameter, $\cot\theta_R$. In the limit in which $\cot\theta_R$ is large, the Z' couplings to the third generation fermions are much larger than the corresponding couplings to the fermions of the first two generations.

At LHC, the Z' is produced via light $q\bar{q}$ annihilation with couplings suppressed by $\tan\theta_R$ that simplify to

$$c_L^u = c_L^d = \frac{1}{3}\sin\theta_W \tan\theta_R,\ c_R^u = 4c_L^u,\ c_R^d = -2c_L^d, \tag{5}$$

in the limits of large $\cot\theta_R$, vanishing $Z - Z'$ mixing and negligible flavor changing neutral currents [15]. The Z' coupling to τ-leptons, in the same limits, is enhanced by $\cot\theta_R$ and is given by [15]

$$c_R^\tau = \sin\theta_W \cot\theta_R. \tag{6}$$

We consider these limits, instead of the more general case, for several reasons. First and foremost because we are interested in studying a generic new resonance that singles out τ-lepton pair production at LHC and not so much in the specific details of the model. The large $\cot\theta_R$ condition ensures that τ-lepton production is favored over say muon pair production. $Z - Z'$ mixing is severely constrained in this type of models and for simplicity we just set it to zero in our study. Finally, although non-universal Z' models generate very interesting phenomenology through the flavor changing couplings of the Z', these effects are not relevant to the issues discussed here and have been studied elsewhere [16].

Notice that the complete $q\bar{q} \to \tau^+\tau^-$ process is of electroweak strength, with the new contribution due to Z' exchange being independent of $\cot\theta_R$. Existing constraints of this model are twofold. From the LEP-II process $e^+e^- \to \tau^+\tau^-$ considering both the cross-section and the forward-backward asymmetry as a function of $M_{\tau\tau}$, Ref. [15] concludes that masses $M_{Z'} \lesssim 500$ GeV are excluded. Although the process is independent of $\cot\theta_R$, as argued above, this parameter cannot be much

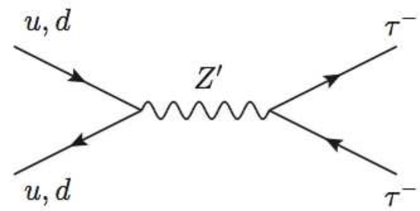

FIG. 3: Representative Feynman diagram for dilepton production through Z' exchange.

larger than about 15 to preserve perturbative unitarity of the model. In this study, the only numerical relevance of $\cot\theta_R$ is in determining the Z' width. The phenomenology of this model at LHC vis-a-vis its enhanced couplings to the top-quark has also been considered [17]. It was found that the simple Drell-Yan-type processes are completely overwhelmed by QCD background. Processes with three or four top (or bottom) quarks at the LHC could constrain the model for Z' masses up to 2 TeV, but several hundred fb^{-1} of integrated luminosity would be necessary.

With all this in mind, we consider two cases, corresponding to $M_{Z'} = 600$ GeV and $M_{Z'} = 1$ TeV. In both cases we will use a Z' width of 100 GeV which corresponds to a $\cot\theta_R \sim 10$; such that the effect expected in muon (or electron) pair production is completely negligible but the resonance is not too fat.

In this model, the additional contribution to the partonic process $q\bar{q} \to \ell^+\ell^-$ is due to an s-channel Z' exchange as shown in the Figure 3. Using the specific couplings in Eqs. 5, 6 we show in Table I the τ-pair cross-section as compared to its SM value.

Cuts	Z' Model		SM
	$M_{Z'} = 0.6$	$M_{Z'} = 1$	
Basic	949.3 ± 1.3	948.9 ± 1.3	941.0 ± 1.2
$M_{\tau\tau} > 0.2$ TeV	1.61 ± 0.002	1.49 ± 0.002	1.41 ± 0.002

TABLE I: Dilepton pair cross-sections (in pb) for the Z' model and the SM at the LHC with $\sqrt{S} = 14$ TeV. All the masses shown here are given in TeV.

In Figure 4 we present the resulting $M_{\tau\tau}$ distribution for two values of the Z' mass, 600 GeV and 1 TeV, as well as for the SM. As Table I shows, removing the low $M_{\tau\tau}$ region results in a significant loss of events. However, Figure 4 indicates that this is necessary to remove the SM background. With a resonance at 600 GeV, there is still a noticeable "bump" in the invariant mass distribution that could be used to discover such a resonance, and perhaps for a 1 TeV Z' as well. In this study we will not address this issue but concentrate on whether this model can yield a charge asymmetry that differs sufficiently from the SM. This is illustrated in Figure 5.

The first figure shows the charge asymmetry for $y < y_c = 0.5$ as a function of dilepton invariant mass. The second figure shows the corresponding asymmetry integrated over dilepton invariant mass, as a function of $M_{min} \gtrsim 200$ GeV.

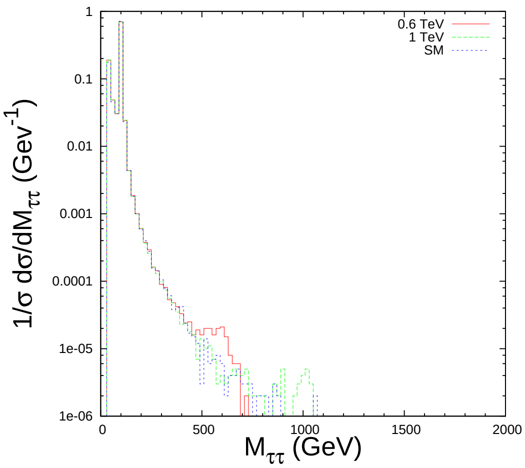

FIG. 4: Dilepton invariant mass distributions for the extra Z'-model at the LHC with $\sqrt{S} = 14$ TeV for $M_{Z'} = 0.6$ and 1 TeV.

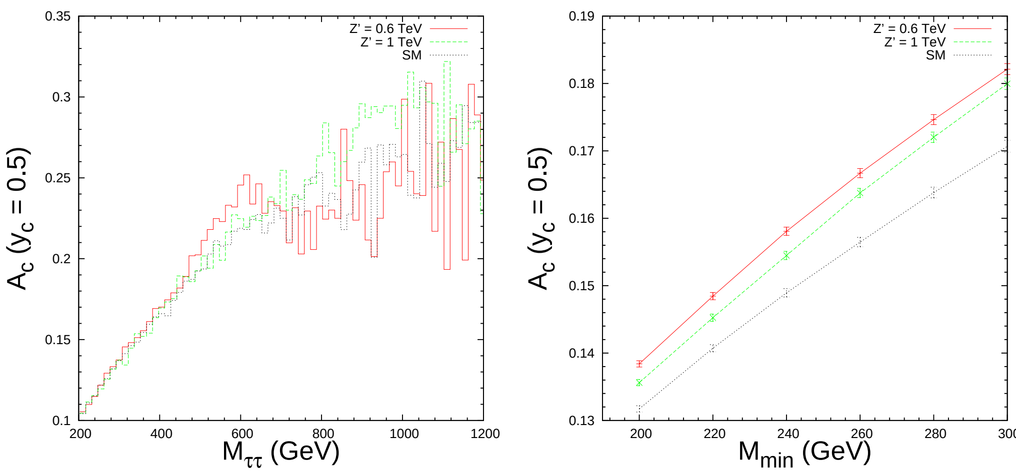

FIG. 5: Lepton charge asymmetry in the Z' model for $M_{\tau\tau} > 200$ GeV, $y_c = 0.5$ and $M_{Z'} = 0.6$ and 1 TeV vs (a) $M_{\tau\tau}$ and (b) integrated over $M_{\tau\tau} \geq M_{min}$.

To quantify these results further we study the statistical sensitivity of the LHC to these signals. In Table II we show the integrated τ-lepton charge asymmetry in percent for the two values of the Z' mass as well as for the SM. We show results for several values of M_{min} for $y_c = 0.5$ with their corresponding 1σ statistical error. These errors correspond to accumulated statistics for 10 fb^{-1} at $\sqrt{S} = 14$ TeV. We can see that the asymmetry increases (both for the SM and the Z' model) as we increase M_{min}, but the error also increases due to the correspondingly reduced statistics.

The interplay between these two effects is illustrated in Table III where, for each case, we show the number of years needed to accumulate sufficient statistics to distinguish the Z' model from the SM at the 1 or 3σ levels. For example, the best we can do for a 0.6 TeV Z' is to impose a cut $M_{min} = 240$ GeV. In this case we would need about 7 years of LHC data to distinguish between the asymmetry in

Cuts	Z' Model		SM
	$M_{Z'} = 0.6$	$M_{Z'} = 1$	
$M_{\tau\tau} > 0.20$	13.8 ± 0.6	13.6 ± 0.6	13.2 ± 0.6
$M_{\tau\tau} > 0.22$	14.8 ± 0.6	14.5 ± 0.7	14.1 ± 0.7
$M_{\tau\tau} > 0.24$	15.8 ± 0.7	15.4 ± 0.8	14.9 ± 0.8
$M_{\tau\tau} > 0.26$	16.7 ± 0.8	16.4 ± 0.9	15.6 ± 0.9
$M_{\tau\tau} > 0.28$	17.5 ± 0.9	17.2 ± 1.0	16.4 ± 1.0
$M_{\tau\tau} > 0.30$	18.2 ± 1.0	18.0 ± 1.1	17.1 ± 1.1

TABLE II: Integrated lepton charge asymmetry (in percent) , $\mathcal{A}_c(y_c)$, for the Z' model and the SM. The 1σ-errors correspond to statistics for one year of LHC data (at $\int \mathcal{L}dt = 10fb^{-1}$ per year). All the masses here are given in TeV.

this model and in the SM.

Cuts	Z' Model	
	$M_{Z'} = 0.6$	$M_{Z'} = 1$
$M_{\tau\tau} > 0.20$	0.8 , 7.2	2.3 , 21.1
$M_{\tau\tau} > 0.22$	0.8 , 7.3	2.4 , 21.3
$M_{\tau\tau} > 0.24$	0.8 , 6.9	2.1 , 18.7
$M_{\tau\tau} > 0.26$	0.8 , 7.1	1.6 , 14.0
$M_{\tau\tau} > 0.28$	0.9 , 8.0	1.5 , 13.9
$M_{\tau\tau} > 0.30$	1.0 , 8.9	1.5 , 13.5

TABLE III: LHC years needed to distinguish the charge asymmetry in the Z' model from the SM. The two numbers shown are for 1σ and 3σ significance. All the masses are given in TeV and we assume $\int \mathcal{L}dt = 10fb^{-1}$ per year.

B. Lepto-quark Models

As a second example of new physics that singles out τ-lepton pairs at LHC we consider lepto-quarks. This example will serve to illustrate the case where the new physics does not have a resonant peak in the channel of interest.

Generic couplings of vector lepto-quarks to standard model fermions can be written in the form [18]

$$\begin{aligned}
\mathcal{L}_{LQ} &= \mathcal{L}_{SM} \\
&+ \lambda^{(R)}_{V_0} \cdot \overline{d}\gamma^\mu P_R e \cdot V^{R\dagger}_{0\mu} + \lambda^{(R)}_{\tilde{V}_0} \cdot \overline{u}\gamma^\mu P_R e \cdot \tilde{V}^\dagger_{0\mu} \\
&+ \lambda^{(R)}_{V_{1/2}} \cdot \overline{d^c}\gamma^\mu P_L l \cdot V^{R\dagger}_{1/2\mu} + \lambda^{(R)}_{\tilde{V}_{1/2}} \cdot \overline{u^c}\gamma^\mu P_L l \cdot \tilde{V}^\dagger_{1/2\mu} \\
&+ \lambda^{(L)}_{V_0} \cdot \overline{q}\gamma^\mu P_L l \cdot V^{L\dagger}_{0\mu} + \lambda^{(L)}_{V_{1/2}} \cdot \overline{q^c}\gamma^\mu P_R e \cdot V^{L\dagger}_{1/2\mu} \\
&+ \lambda^{(L)}_{V_1} \cdot \overline{q}\gamma^\mu P_L V^\dagger_{1\mu} l + h.c..
\end{aligned} \tag{7}$$

In the equation above V_i^j are vector lepto-quarks with weak isospins $i = 0, 1/2, 1$ coupled to left-handed ($j = L$) or right-handed ($j = R$) quarks respectively.

Of course, scalar lepto-quarks are also possible [19] but we restrict ourselves to the vector case. In particular, we have in mind Pati-Salam [20] type lepto-quarks in which the coupling $\lambda^{(R)}_{V_0} = \lambda^{(L)}_{V_0} = g_s/\sqrt{2}$ at the unification scale. In order to single out the τ-lepton we envision a scenario described in Ref. [21] in which the third generation of leptons is associated with the first generation of quarks. This scenario results in $\tau^+\tau^-$ pairs produced by $d\bar{d}$ annihilation at LHC.

Although lepto-quarks with these particular quantum numbers are not generally discussed, typical direct bounds on vector lepto-quark masses are in the hundreds of GeV range [22]. It is well known, however that rare decays place stronger indirect constraints, for example [23]. For the specific flavor couplings we use here, Ref. [21] identified the process $B_s \to \mu e$ as the one yielding the tightest constraint. The most recent number obtained using this process corresponds to a lower bound on the lepto-quark mass near 50 TeV [24].

We will consider the following two scenarios as an illustration:

- LQ-1, a Pati-Salam lepto-quark as described above with coupling $\lambda^{(R)}_{V_0} = \lambda^{(L)}_{V_0} = g_s/\sqrt{2}$ between the first generation quarks and the third generation leptons.
- LQ-2, with coupling $\lambda^{(R)}_{\tilde{V}_0} = g_s/\sqrt{2}$ between the first generation quarks and the third generation leptons. This one is a variation of LQ-1 in which the $pp \to \tau^+\tau^-$ process is initiated by $u\bar{u}$ annihilation (instead of $d\bar{d}$ in LQ-1).

In both scenarios we will show numerical results for lepto-quark masses of 600 GeV and 1 TeV which are within the direct reach of LHC but significantly below the indirect limits.

The additional contributions to the dilepton cross-section are due to t-and u-channel exchange of lepto-quarks as illustrated in the Feynman diagrams shown in Fig. 6. In Table IV we compare the τ-pair cross-section that results in these models with the SM.

In Figure 7 we show the dilepton invariant mass distributions that result in both cases LQ-1 and LQ-2 for $M_{LQ} = 0.6, 1$ TeV respectively. As expected, these

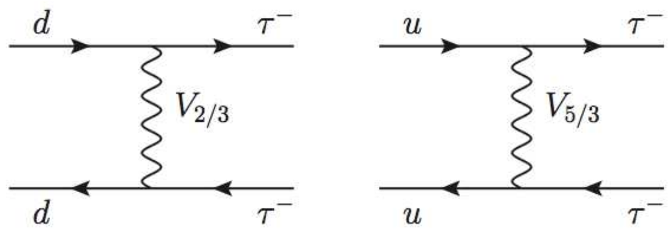

FIG. 6: Feynman diagram for dilepton production through lepto-quark exchange in lepto-quark Model 1 (Left) and 2 (Right).

Cuts	LQ-1		LQ-2		SM
	$M_{V_{2/3}} = 0.6$	$M_{V_{2/3}} = 1$	$M_{V_{5/3}} = 0.6$	$M_{V_{5/3}} = 1$	
Basic	938.1 ± 1.3	938.4±1.3	918.5±1.4	912.9±1.3	941.0±1.2
$M_{\tau\tau} > 0.2$ TeV	2.06 ± 0.002	1.43±0.002	4.70±0.002	2.21±0.002	1.41±0.002

TABLE IV: Dilepton pair cross-sections (in pb) for lepto-quark model 1, 2 (LQ-1, 2) and, the SM at the LHC with $\sqrt{S} = 14$ TeV. All the masses shown here are given in TeV.

distributions do not show any "bumps" as the lepto-quarks are not exchanged in the s-channel. However, they do show an enhancement over the SM, particularly for the larger values of $M_{\tau\tau}$.

The results for the charge asymmetry are shown in Figure 8 for scenario LQ-1 and in Figure 9 for scenario LQ-2. In both cases we show the charge asymmetry integrated over rapidity for $|y| < y_c = 0.5$ as a function of dilepton invariant mass as well as the asymmetry integrated over both rapidity and dilepton invariant mass.

In Table V we show the integrated τ-lepton charge asymmetry in percent for two different values of the lepto-quark mass in the two models discussed above as

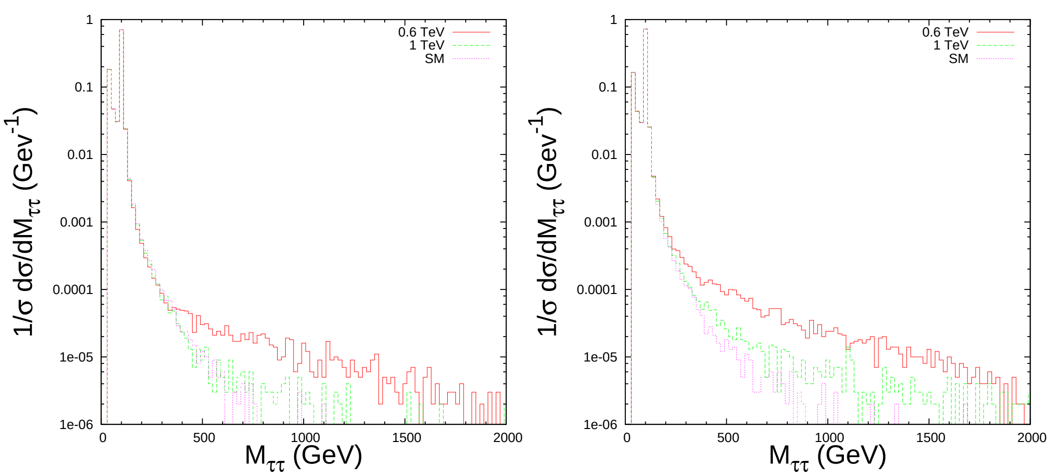

FIG. 7: Dilepton invariant mass distributions for the scenarios LQ-1 and LQ-2 at the LHC with $\sqrt{S} = 14$ TeV for $M_{LQ} = 0.6$ and 1 TeV.

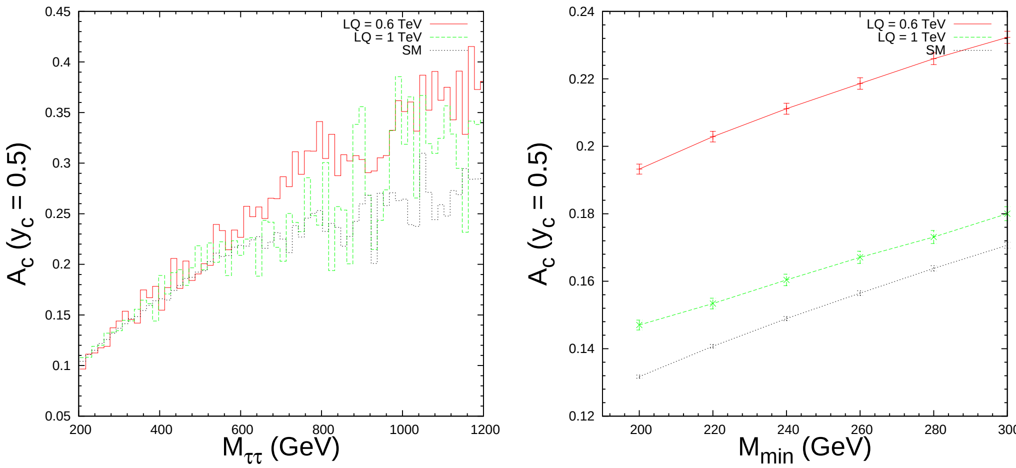

FIG. 8: Integrated charge asymmetry for the lepto-quark model 1 (LQ-1) for $M_{LQ} = 0.6, 1$ TeV vs (a) $M_{\tau\tau}$ and (b) integrated over $M_{\tau\tau} \geq M_{min}$.

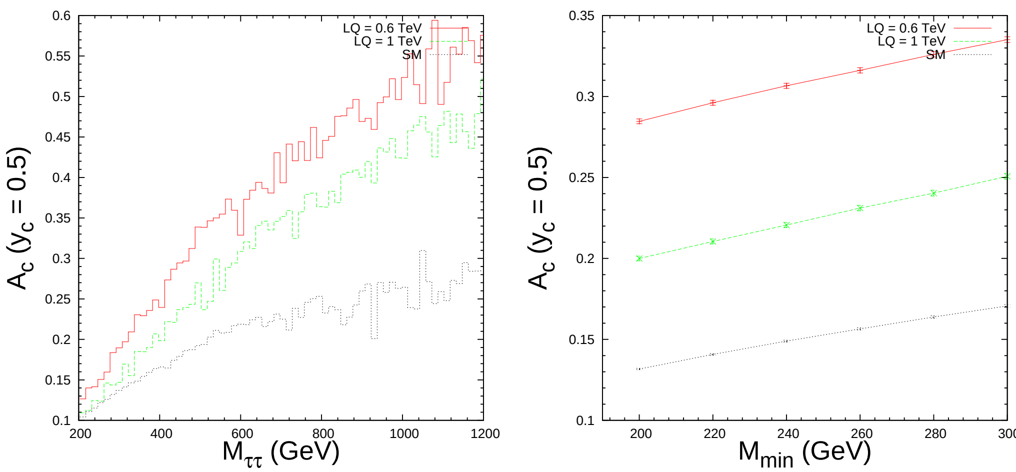

FIG. 9: Integrated charge asymmetry for the lepto-quark model 2 (LQ-2) for $M_{LQ} = 0.6, 1$ TeV vs (a) $M_{\tau\tau}$ and (b) integrated over $M_{\tau\tau} \geq M_{min}$.

well as for the SM. We show results for $y_c = 0.5$ and for different values of M_{min} with their corresponding 1σ statistical error for an integrated luminosity of 10 fb^{-1} at $\sqrt{S} = 14$ TeV.

In Table VI we show the number of LHC years necessary to accumulate sufficient statistics to distinguish between the τ-lepton charge asymmetry in the corresponding model and in the SM. The best results are obtained with the lower values of M_{min} and in some cases just a few days of LHC running would suffice to establish new physics.

Cuts	LQ-1		LQ-2		SM
	$M_{V_{2/3}} = 0.6$	$M_{V_{2/3}} = 1$	$M_{V_{5/3}} = 0.6$	$M_{V_{5/3}} = 1$	
$M_{\tau\tau} > 0.20$	19.3 ± 0.5	14.7±0.6	28.5±0.3	20.0±0.5	13.2±0.6
$M_{\tau\tau} > 0.22$	20.3 ± 0.5	15.3±0.7	29.6±0.3	21.0±0.5	14.1±0.7
$M_{\tau\tau} > 0.24$	21.1 ± 0.5	16.0±0.7	30.7±0.3	22.1±0.5	14.9±0.8
$M_{\tau\tau} > 0.26$	21.9 ± 0.6	16.7±0.8	31.6±0.4	23.1±0.6	15.6±0.9
$M_{\tau\tau} > 0.28$	22.6 ± 0.6	17.3±0.8	32.6±0.4	24.0±0.6	16.4±1.0
$M_{\tau\tau} > 0.30$	23.2 ± 0.6	18.0±0.9	33.5±0.4	25.1±0.6	17.1±1.1

TABLE V: Integrated lepton charge asymmetry (in percent) , $\mathcal{A}_c(y_c)$ for lepto-quark models 1, 2 (LQ-1, 2) and the SM with 1σ-errors for 1 year of LHC data (at $\int \mathcal{L}dt = 10fb^{-1}$ per year). All numbers are for $y_c = 0.5$, and all masses are given in TeV.

Cuts	LQ-1		LQ-2	
	$M_{V_{2/3}} = 0.6$	$M_{V_{2/3}} = 1$	$M_{V_{5/3}} = 0.6$	$M_{V_{5/3}} = 1$
$M_{\tau\tau} > 0.20$	0.01 , 0.08	0.15 , 1.37	− , 0.01	0.01 , 0.07
$M_{\tau\tau} > 0.22$	0.01 , 0.11	0.30 , 2.72	− , 0.02	0.01 , 0.09
$M_{\tau\tau} > 0.24$	0.02 , 0.15	0.49 , 4.38	− , 0.02	0.01 , 0.11
$M_{\tau\tau} > 0.26$	0.02 , 0.19	0.73 , 6.55	− , 0.03	0.01 , 0.13
$M_{\tau\tau} > 0.28$	0.03 , 0.24	1.20 , 10.83	0.01 , 0.04	0.02 , 0.16
$M_{\tau\tau} > 0.30$	0.03 , 0.31	1.48 , 13.35	0.01 , 0.04	0.02 , 0.18

TABLE VI: LHC years needed to distinguish the charge asymmetry in the lepto-quark models 1, 2 (LQ-1, 2) from the SM. The two numbers shown are for 1σ and 3σ significance. All the masses are given in TeV and we assume $\int \mathcal{L}dt = 10fb^{-1}$ per year.

IV. SUMMARY AND CONCLUSION

The forward-backward asymmetry has been a very useful tool to obtain information about the the SM couplings of fermions to the Z boson. At the LHC it will not be possible to reconstruct a forward-backward asymmetry, but some of the same information can be obtained from charge asymmetries. In this paper we have emphasized that the charge asymmetry can also play an important role in the search for new physics in τ-pair production at the LHC.

We have investigated some kinematic properties of this charge asymmetry concluding that a value of y_c near 0.5 is optimal in this case. The asymmetry can be constructed as a function of lepton pair invariant mass, $M_{\tau\tau}$, but a better probe of new physics is obtained by integrating the charge asymmetry over the available $M_{\tau\tau}$ range with a minimum cut, M_{min}. Originally this cut serves the purpose of removing the SM Z background. We found that the integrated asymmetry increases by increasing M_{min} far above the M_Z, although at the cost of lost statistics. We have explored the optimal value of M_{min} in the context of two examples.

We have illustrated two generic scenarios of new physics models that single out the τ-lepton and would not show up in $\mu^+\mu^-$ or e^+e^- pair production. We discuss a non-universal Z' as an example of a new resonance that prefers to decay into tau-leptons. This example generates a charge asymmetry that is too close to the SM for the LHC to distinguish without many years of accumulated statistics. We also considered certain lepto-quarks as an example of non-resonant new physics. They single out the tau-lepton by associating the third generation leptons with the first generation quarks. We find that this type of new physics can induce τ charge asymmetries that are very easy to distinguish from the SM.

In conclusion we find that an experimental study of the τ-lepton charge asymmetry at the LHC can provide valuable constraints in the search for new physics. This search will be most useful when the LHC is operating at 14 TeV and with high luminosity. During the early LHC running, the study of the lepton charge asymmetry would be limited to the Z resonance region and contribute to the rediscovery of the SM. The expected event rates during this phase, however, will not permit searches for new physics that are competitive with what is already known from LEP.

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