Tau Lepton Charge Asymmetry: A tool to proble New Physics Models at the LHC

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Introduction

This is an LHC analog of the Forward-backward asymmetry of the Tevatron and is defined in terms of the lepton rapidity as follows

$$\mathcal{A}(y) = \frac{N_{l^+}(y) - N_{l^-}(y)}{N_{l^+}(y) + N_{l^-}(y)}$$

where N denotes the number of events with a given rapidity y.

Features

1. Parton Centre-of-Mass frame does not need to be reconstructed which is not possible for all the time.

2. Symmetry of initial pp state at the LHC cause the integrated asymmetry to vanish when integrated over the whole rapidity range.

3. It is also possible to define an integrated charge asymmetry over a central region, limited by Yc as follows

$$\mathcal{A}_c(y_c) = \frac{N_{l^+}(-y_c \le y \le y_c) - N_{l^-}(-y_c \le y \le y_c)}{N_{l^+}(-y_c \le y \le y_c) + N_{l^-}(-y_c \le y \le y_c)}$$

4. A careful (process dependent) choice of Yc can be useful to optimize the Ac, which can be improved further by making selections over different ranges of Mll. (See Fig. 1 &2)

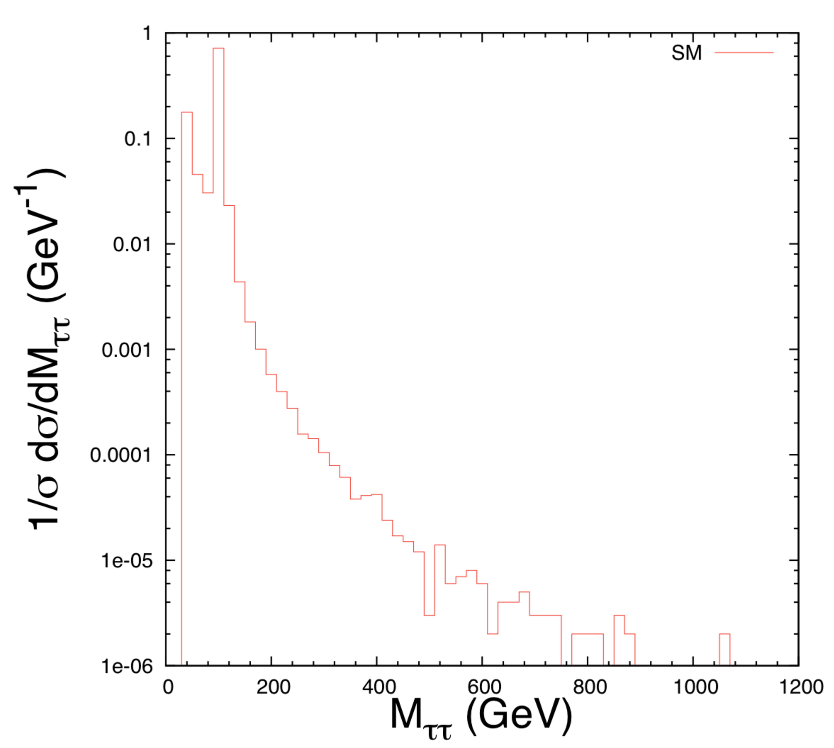


FIG. 1: Dilepton invariant mass distribution for the process pp → τ+τ− within the Standard Model at the LHC for √S = 14 TeV.

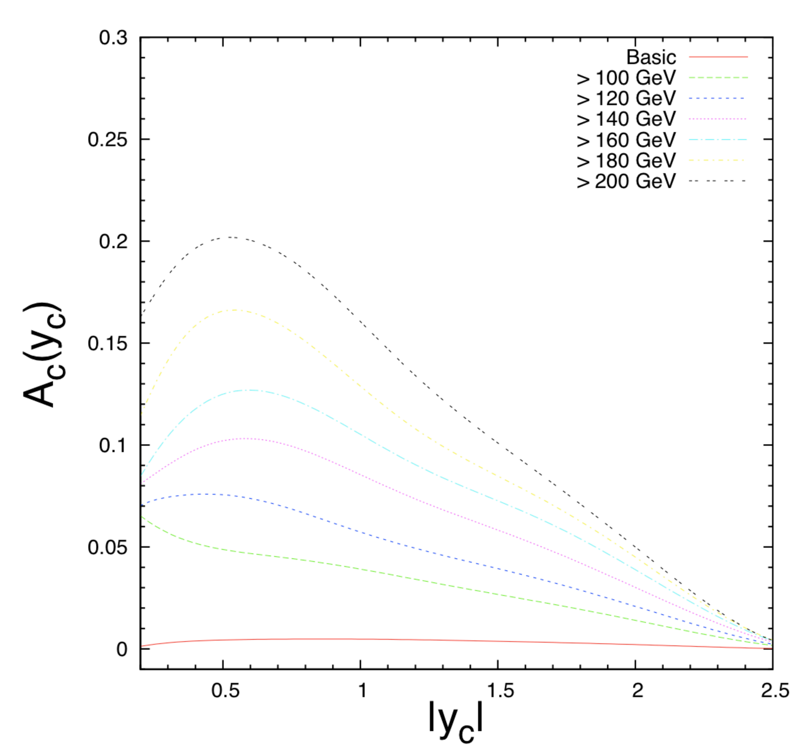


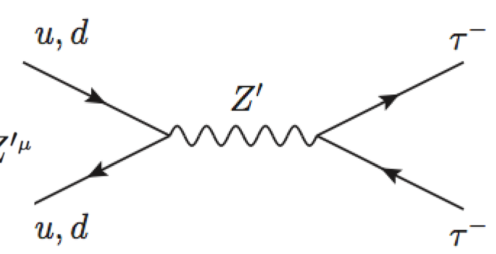
FIG. 2: Integrated charge asymmetry for the standard model with basic acceptance cuts as well as different minimum dilepton invariant mass cuts.

Case 1: The Z' Model

The s-channel New Physics Example

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

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



For illustration purposes we considered pure right-handed Z' couplings to the third generation with an overall strength of $c_R^u \times c_R^\tau = 1/3$

Cuts	Z' Model		SM
	$M_{Z'} = 0.6$	$M_{Z'} = 1$	
Basic	948.9 ± 1.3	948.6±1.3	941.0±1.2
$M_{\tau\tau} > 0.2$ TeV	1.58 ± 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.

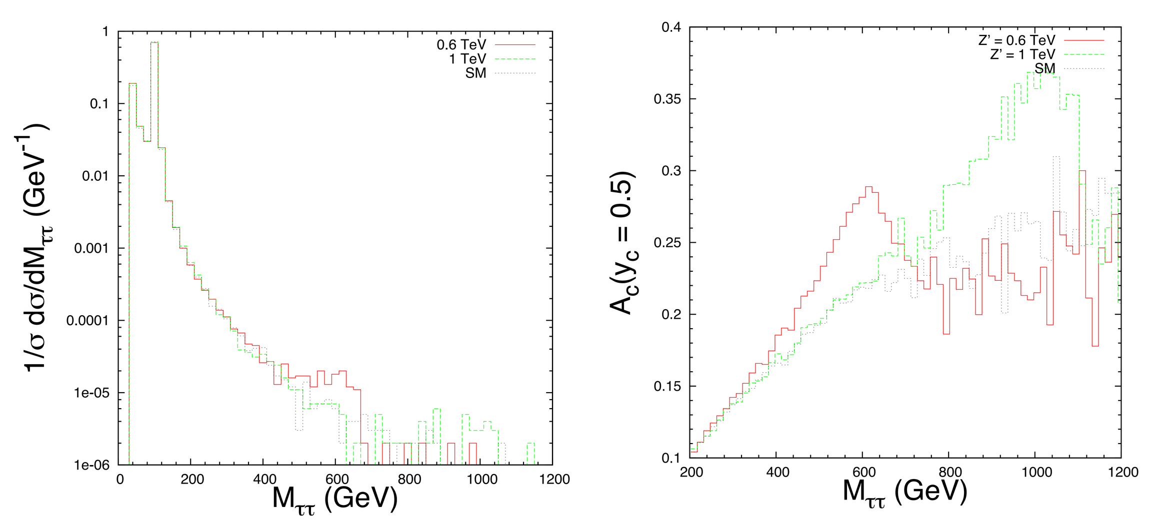


FIG.: Dilepton invariant mass distributions (Left), and, differential charge asymmetries (Right) for the Z' model at the LHC with √S = 14TeV.

Cuts	Z' Model		SM
	$M_{Z'} = 0.6$	$M_{Z'} = 1$	
$M_{\tau\tau} > 0.20$ TeV	20.1 ± 0.6	19.6±0.6	13.2±0.6
$M_{\tau\tau} > 0.22$ TeV	21.1 ± 0.7	20.6±0.7	14.1±0.7
$M_{\tau\tau} > 0.24$ TeV	22.1 ± 0.8	21.5±0.8	14.9±0.8
$M_{\tau\tau} > 0.26$ TeV	23.0 ± 0.8	22.5±0.9	15.6±0.9
$M_{\tau\tau} > 0.28$ TeV	23.8 ± 1.0	23.3±1.0	16.4±1.0
$M_{\tau\tau} > 0.30$ TeV	24.6 ± 1.0	24.1±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 $\int \mathcal{L}dt = 10$ fb^{-1} per year). All the masses here are given in TeV. In this Table the Z' model's only non-zero couplings are c_R^τ, and c_R^u such that $c_R^\tau \cdot c_R^u = 1/3$.

Case 2: The Leptoquark Model

The t-channel New Physics Example

Generic couplings of vector lepto-quarks to standard model fermions can be written as follows,

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

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. The cases with weak isospin $i = 0, 1/2$ admit two possible values of hypercharge (leading to different electric charges), which are denoted by V and $\tilde{V}$.

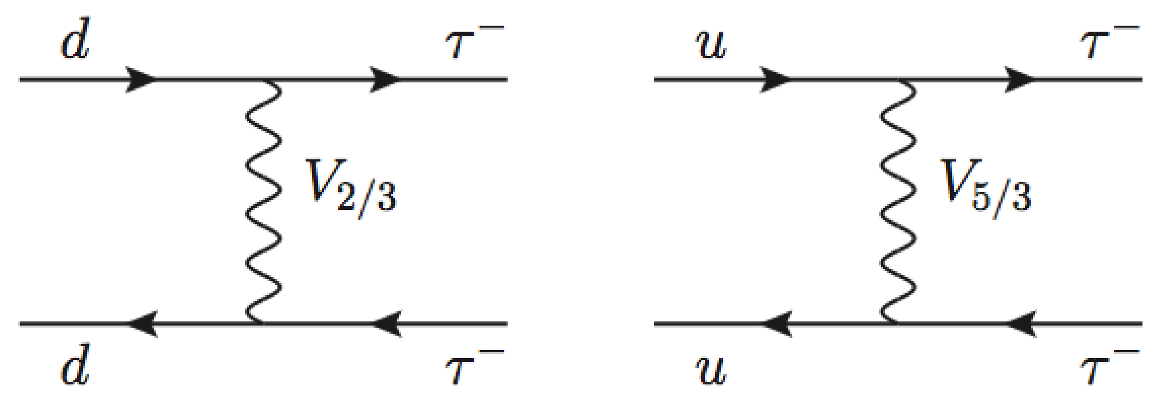


FIG. :Two Leptoquark Scenarios: LQ-1 (Left), LQ-2 (Right).

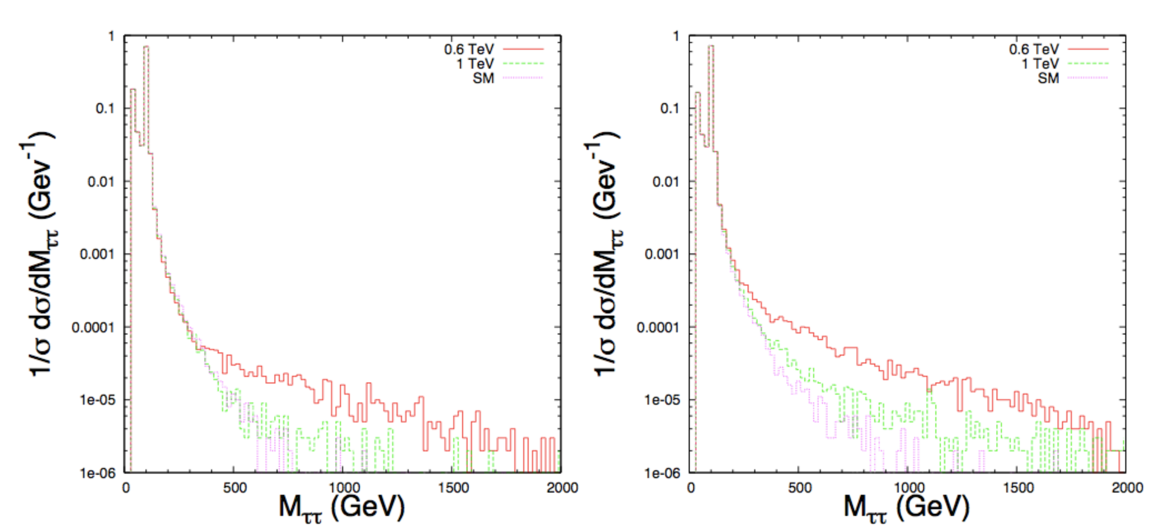


FIG.: Dilepton invariant mass distributions for the scenarios LQ-1 and LQ-2 at the LHC with √S = 14TeV.

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

TABLE IV: 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 $\int \mathcal{L}dt = 10$ fb^{-1} per year). All numbers are for $y_c = 0.5$, and all masses are given in TeV.

Summary & Conclusions

We have investigated some kinematic properties of this charge asymmetry concluding that a value of yc near 0.5 is optimal in this case.

With two different examples of s- and t-channel new physics we have shown that although the asymmetry can be constructed as a function of lepton pair invariant mass, Mττ, but a better probe of new physics is obtained by integrating the charge asymmetry over the available Mττ range with a minimum cut.

The integrated asymmetry increases by increasing the minimum cut over the Mττ.

This also stays as a good tool to probe the new physics contributions even when both taus decay leptonically. (See for example, the following table for the LQ-2 scanario)

(ℓ, ℓ')	$LQ-2$ Model		SM
	$M_{V_{5/3}} = 0.6$	$M_{V5/3} = 1$	
(μ^+, μ^-)	9.1 ± 0.5	9.0±0.6	8.9±0.6
(e^+, e^-)	9.2 ± 0.5	9.1±0.6	9.1±0.6
(e^+, μ^-)	36.2 ± 1.6	25.6±2.0	12.1±2.3
(μ^+, e^-)	36.5 ± 1.6	25.8±2.0	11.7±2.3

(ℓ, ℓ')	$LQ-2$ Model		SM
	$M_{V_{5/3}} = 0.6$	$M_{V5/3} = 1$	
(μ^+, μ^-)	37.5 ± 1.7	26.7±2.2	11.5±2.4
(e^+, e^-)	37.7 ± 1.7	26.6±2.2	12.4±2.4
(e^+, μ^-)	37.4 ± 1.7	26.6±2.2	12.2±2.4
(μ^+, e^-)	37.7 ± 1.7	26.8±2.2	11.8±2.4

TABLE V: Integrated lepton charge asymmetry $\mathcal{A}_{\ell\ell'}$ (in percent) for the $LQ-2$ model and the SM with $M_{min}^{\ell\ell'} = 130$ GeV (a) without (Left table) and (b) with the requirement of a minimum missing E_T (Right table). The 1σ-errors correspond to statistics for one year of LHC data (at $\int \mathcal{L}dt = 10$ fb^{-1} per year). All the masses are given in TeV.

In conclusion, we find that an experimental study of the τ-lepton charge asymmetry at the LHC can provide valuable information in the search for new physics. Clearly a detector level study by the experimental collaborations will be necessary to accurately quantify the possibilities of this proposal, and we encourage both ATLAS and CMS to conduct such studies.

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References: S. K. Gupta and G. Valencia, Phys. Rev. D **84, 036009 (2011) [arxiv: 1102. 0741 [hep-ph]].**

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