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Probing new physics with charge asymmetries in 2 same sign leptons plus jets final states

Ernesto Arganda,[a,b] **Leandro Da Rold,**[c] **Aurelio Juste,**[d,e] **Anibal D. Medina**[b] **and Rosa María Sandá Seoane**[a,*]

[a] *Instituto de Física Teórica UAM-CSIC,*
C/ Nicolás Cabrera 13-15, Campus de Cantoblanco, 28049, Madrid, Spain

[b] *IFLP, CONICET - Dpto. de Física, Universidad Nacional de La Plata,*
C.C. 67, 1900 La Plata, Argentina

[c] *Centro Atómico Bariloche, Instituto Balseiro and CONICET,*
Av. Bustillo 9500, 8400, S. C. de Bariloche, Argentina

[d] *Institut de Física d'Altes Energies (IFAE), Edifici Cn, Facultat de Ciencies,*
Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

[e] *Institució Catalana de Recerca i Estudis Avançats (ICREA), E-08010 Barcelona, Spain*

E-mail: ernesto.arganda@csic.es, daroldl@ib.edu.ar, juste@ifae.es, anibal.medina@fisica.unlp.edu.ar, r.sanda@csic.es

We study the impact of three different BSM models in the charge asymmetry defined for the 2SSl (with $l = e, \mu$) with jets ($N_{\text{jets}} \geq 2$) final state at the LHC, at $\sqrt{s} = 13$ TeV, where the main SM contribution is the $t\bar{t}W$ production. We consider the impact of a heavy neutral scalar/pseudoscalar arising from a general two Higgs doublet model (g2HDM); a simplified R-parity-violating minimal supersymmetric model (RPV MSSM) with electrowikino production (higgsino or wino-like); and an effective theory with dimension 6 four-quark operators. We propose measuring the charge asymmetries differentially with respect to different kinematic observables, and inclusively/exclusively with the number of b-tagged jets in the final state ($N_b \geq \{1, 2, 3\}$). We show that the 2HDM and the four quark operator scenarios may be sensitive to the detection of new physics, even for an integrated luminosity of 139 fb^{-1}.

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*Speaker

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1. Introduction

One of the most promising signatures at the LHC is the two same-sign leptons (2SSl, with $l = e, \mu$) plus jets final state. After the requirement of at least one b-tagged jet, the SM background is dominated by $t\bar{t}W$ production, with additional contributions from $t\bar{t}Z/\gamma^*$, $t\bar{t}H$, tqZ/γ^*, and diboson production. Among the challenges these physics analyses had to face, there was the apparent mismodeling of the $t\bar{t}W$ background, whose cross-section was found to be underestimated by factors ~1.3–1.7 with respect to the state-of-art theoretical cross-section at the time (NLO+NLL), and the concern whether the $t\bar{t}W$ kinematics was adequately modeled by the Monte Carlo simulation. In response to this situation, several recent developments are helping consolidate the theoretical understanding of the $t\bar{t}W$ background, culminating with the calculation of its cross-section at NNLO [1, 2]. On the experimental side, the ATLAS and CMS Collaborations have recently performed precise measurements of the total $t\bar{t}W$ cross-section [3, 4], which still come out a bit high compared to the NNLO prediction, confirming a trend that was already observed in previous measurements with a smaller dataset. In addition, for the first time, the ATLAS Collaboration has performed a detailed set of $t\bar{t}W$ differential cross-section measurements [3], which can be used to validate the kinematic modeling by Monte Carlo (MC) generators, although the measurements are still limited by the data statistics.

One of the unique observables that can be exploited in the 2SSl final state in pp collisions is the charge asymmetry, $A^{+/-}$, defined as the difference between the numbers of events with two positively charged leptons and with two negatively-charged leptons, divided by their sum. Most backgrounds contributing to the 2SSl final state are charge symmetric and thus have zero charge asymmetry. In contrast, $t\bar{t}W$ production has a strong charge asymmetry, with about twice more events with two positively charged leptons than with two negatively charged leptons. Interestingly, this charge asymmetry is very well known theoretically, since it mainly depends on the u- and d-quark parton distribution functions, and thus is quite robust against higher-order QCD effects. In addition, it can also be measured experimentally with small systematic uncertainties, which largely cancel in the ratio. This raises the interesting possibility of exploiting differential measurements of the charge asymmetry in $t\bar{t}W$ production as a robust observable to probe for BSM effects. The first such measurements have been recently performed by the ATLAS Collaboration [3]. In this work, we show part of the results in [5], where we explore this idea and evaluate the potential of such measurements to probe some illustrative new physics signals that could contaminate the $t\bar{t}W$ measurement.

2. Setup

We study the impact of three different BSM models in the 2SSl plus jets final state, with $t\bar{t}W$ as the main background, measuring differential charge asymmetries with respect to different kinematic variables. The new physics signals are:

- A heavy scalar/pseudoscalar (H/A) arising from a flavour violating g2HDM, with only non-zero effective couplings $\rho_{ut} = \rho_{tu}$ and ρ_{tt}.
- A simplified RPV MSSM model with electrowikino production (higgsino/wino-like), with $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_2^0}$, and the rest of SUSY particles decoupled at the TeV scale.

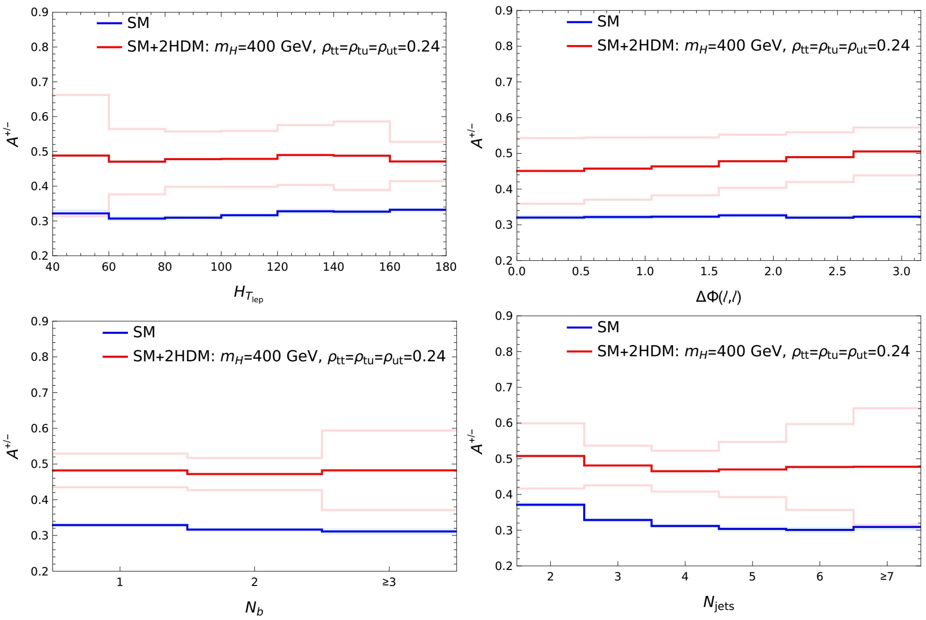

Figure 1: Examples of charge asymmetry distributions at $\sqrt{s}$ = 13 TeV and 139 fb^{-1} for a BP with $\sigma = 1.5 \times \sigma_{t\bar{t}W}$. Shaded lines represent the corresponding uncertainties.

- An effective theory with 4-quark operators of dimension 6 and flavour changing neutral currents (4qFCNC), where we only consider 2 color-singlet operators, and their corresponding couplings $C_u^{(1)}$ and $C_{qu}^{(1)}$.

The analysis is performed at 13TeV for an integrated luminosity of 139 fb^{-1}, offering also prospects for the HL-LHC (3000 fb^{-1}). We select benchmark points (BPs) whose total cross-section is 1.5 times the theoretical prediction of $t\bar{t}W$ production, according to the current experimental bounds. We require $N_{\text{jets}} \geq 2$ and $N_b \geq 1$. We estimate $A^{+/-}$ in bins of different kinematic observables, like N_{jets}, assuming that statistical uncertainties are dominant (including the contribution from other SM backgrounds). Further details on the BSM models, the data simulation, the event selection criteria, and the estimation of observables and uncertainties can be found in [5].

3. Results

In Fig. 1 can be found some illustrative charge asymmetry distributions within the g2HDM. Whenever $\rho_{tu} > 0$, the final state is always more charge asymmetric than the SM, for decoupled H (or A). From Fig. 2 it can be seen that charge asymmetries can probe flavour-violating g2HDM for all the considered masses ($\text{m}_{H/A} \in [200, 1000]$ GeV). Furthermore, it is possible to test discovery for $\text{m}_{H/A} \in [800, 1000]$ GeV, and binning in different kinematic variables gives more information to distinguish/discard models. When increasing the total integrated luminosity to 3000 fb^{-1}, it is also possible to test discovery for lower masses such as $\text{m}_H = 400$ GeV, as can be seen in Fig. 3.

The 4qFCNC model is always more charge asymmetric than the SM, as can be seen for example in Fig. 4, and we also checked that binning in the different kinematic observables offers the same

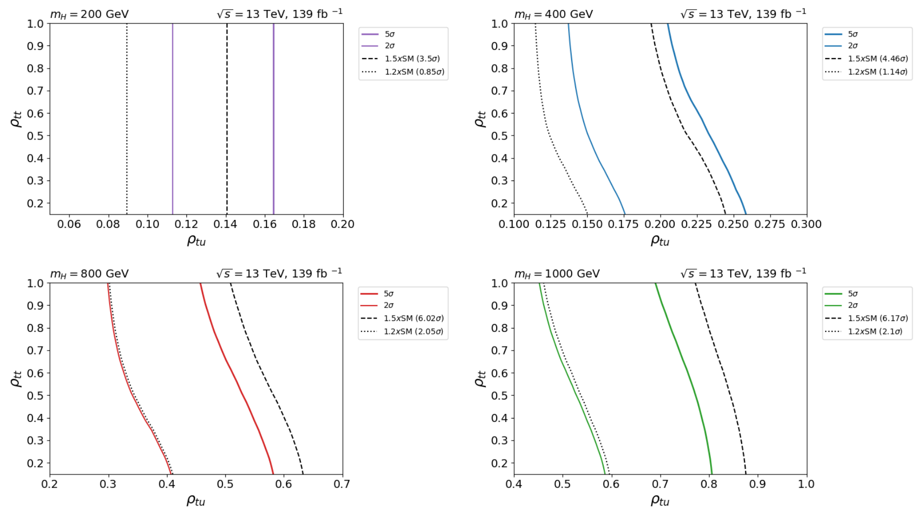

Figure 2: Normal Gaussian significance for $m_H = \{200,\ 400,\ 800,\ 1000\}$ GeV in the (ρ_{tu}, ρ_{tt}) plane, estimated from $A^{+/-}$ vs. N_j.

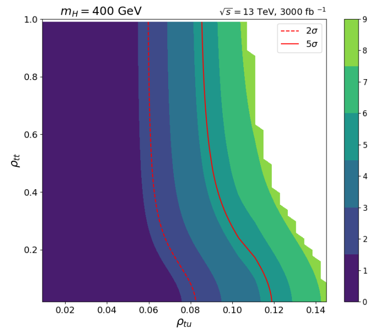

Figure 3: Normal Gaussian significance vs. $\rho_{tu} - \rho_{tt}$ estimated with $A^{+/-}$ vs. N_{jets} for $m_H = 400$ GeV, at $\sqrt{s} = 13$ TeV and 3000 fb^{-1}.

sensitivity in terms of χ^2. The normal Gaussian significance obtained from $A^{+/-}$ vs. N_{jets} can be found in the left panel of Fig. 5, where we can conclude that the asymmetry is more sensitive to $C_u^{(1)}$ than to $C_{qu}^{(1)}$. The sensitivity to the Wilson coefficients increases by a factor of ~ 2.5 for the high-luminosity prospects, as can be seen in the right panel of Fig. 5, mainly due to the reduction of the statistical uncertainties.

Charge asymmetries are not able to probe the RPV MSSM model at $\sqrt{s} = 13$ TeV and 139 fb^{-1} since the slight differences from the SM are buried under the statistical uncertainties. However, the scenario changes when increasing the luminosity to 3000 fb^{-1}, as can be seen in Fig. 6. For this wino-like example with m= 400 GeV, a combined statistical analysis of different exclusive b-jet selections can offer a better sensitivity than the default inclusive 1 b-jet selection, reaching a combined significance of $\sim 5.2\sigma$. The latter points towards the need for a full study at 14 TeV,

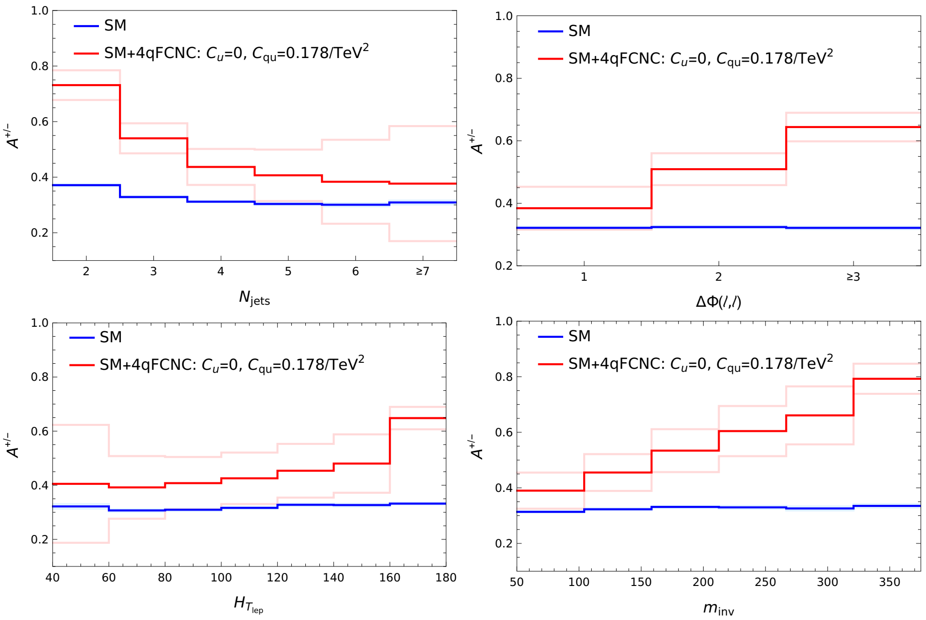

Figure 4: Charge asymmetry distributions at $\sqrt{s}$ = 13 TeV and 139 fb^{-1} for a BP with $\sigma = 1.5 \times \sigma_{t\bar{t}W}$.

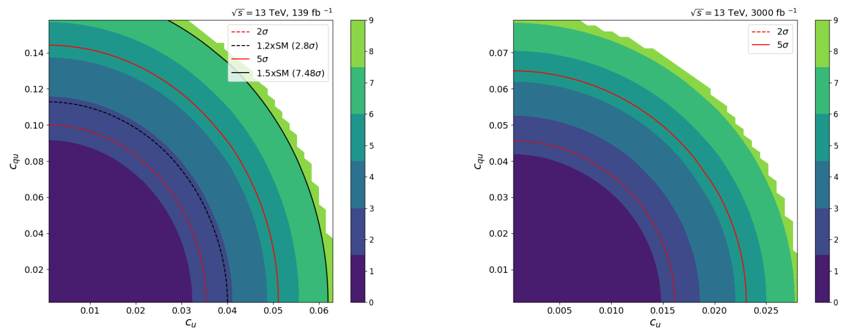

Figure 5: Normal Gaussian significance vs. $C_u^{(1)} - C_{qu}^{(1)}$ estimated with $A^{+/-}$ vs. $N_{\rm jets}$. at $\sqrt{s}$ = 13 TeV and 139 fb^{-1} (left) or 3000 fb^{-1} (right).

where alternative b-jet selections would become crucial.

4. Conclusions

The results presented in this proceeding, part of a work submitted in [5], show that differential charge asymmetries in the 2SSl with jets final state are sensitive to probe new physics at the LHC@13TeV and 139 fb^{-1}, such as the proposed flavour violating g2HDM and effective 4-quark operator scenario. The inclusive 1-b jet selection is the most sensitive in all scenarios, and even though the significance analysis focuses on asymmetries vs. $N_{\rm jets}$, all the considered kinematic observables are also sensitive to new physics and help to distinguish between models. No sensitivity

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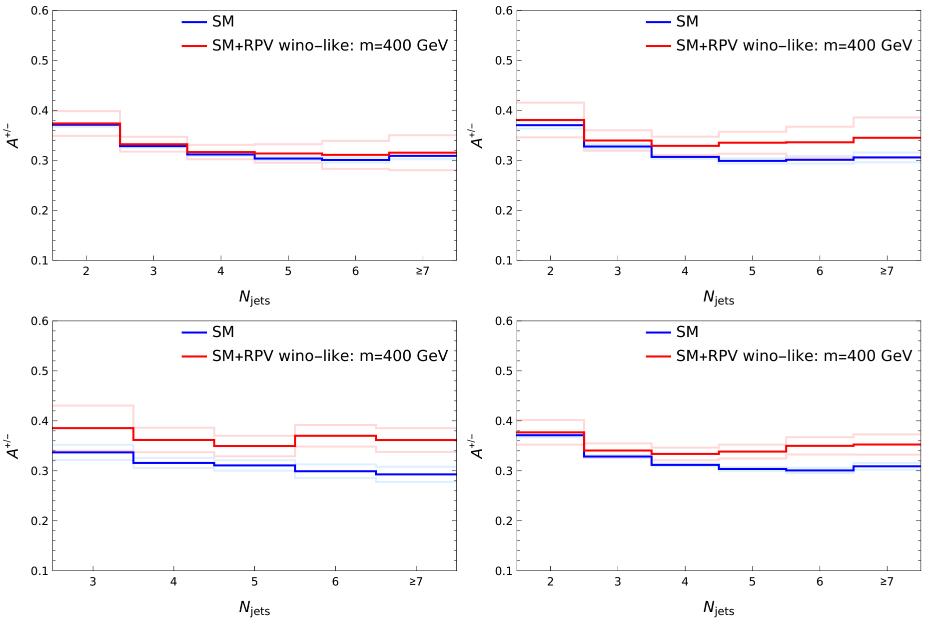

Figure 6: $A^{+/-}$ vs. N_{jets} at $\sqrt{s}$ = 13 TeV and 3000 fb^{-1} for different b-jet selections: N_b = 1 (*top-left*), N_b = 2 (*top-right*), $N_b \geq 3$ (*bottom-left*) and $N_b \geq 1$ (*bottom-right*).

is reached for the proposed RPV MSSM scenario for degenerate electrowikinos higgsinos/wino-like with m $\in$ [200, 800] GeV, but when increasing the luminosity to 3000 fb^{-1}, for some benchmark points it would be possible to obtain evidence and discovery significances. The former indicates that a full study at 14 TeV is necessary for this model, where alternative b-jet selections would play a fundamental role. Regarding the high-luminosity prospects for the other two models, the increase in the significance given by the reduction of the statistical uncertainties allows not only to probe all the proposed b-jet selections, but also to test new benchmark points in the g2HDM, and to increase the sensitivity to the Wilson Coefficients by a factor of $\sim$ 2.5 even with the inclusive 1 b-jet selection in the 4qFCNC scenario.

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