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

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Motivation

- Dominant SM contribution to $2SS\ell$ (with $\ell = e, \mu$) with jets ($n_j \geqslant 2$): $t\bar{t}W$. Most measurements in ATLAS & CMS give slightly higher x-section than theoretical prediction.

$$\sigma = 890 \pm 90 \text{ fb} \quad \text{vs.} \quad \sigma^{th} = 722^{+70}_{-78} \text{ fb}$$

  - Still large (statistical) uncertainties.
  - Major background in other rare processes like $t\bar{t}H$ and $t\bar{t}t\bar{t}$.

- $t\bar{t}W$ has charge-asymmetric production (of $t\bar{t}W^+$ and $t\bar{t}W^-$) and it is an opportunity to measure it.
  - Measuring leptonic asymmetry at the LHC is very challenging due to the symmetry of the proton-proton collisions.
  - Both inclusive as differential cross-sections give us information on the charge asymmetry!

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Measuring differential charge asymmetries in $2SS\ell+$ jets can show us New Physics!

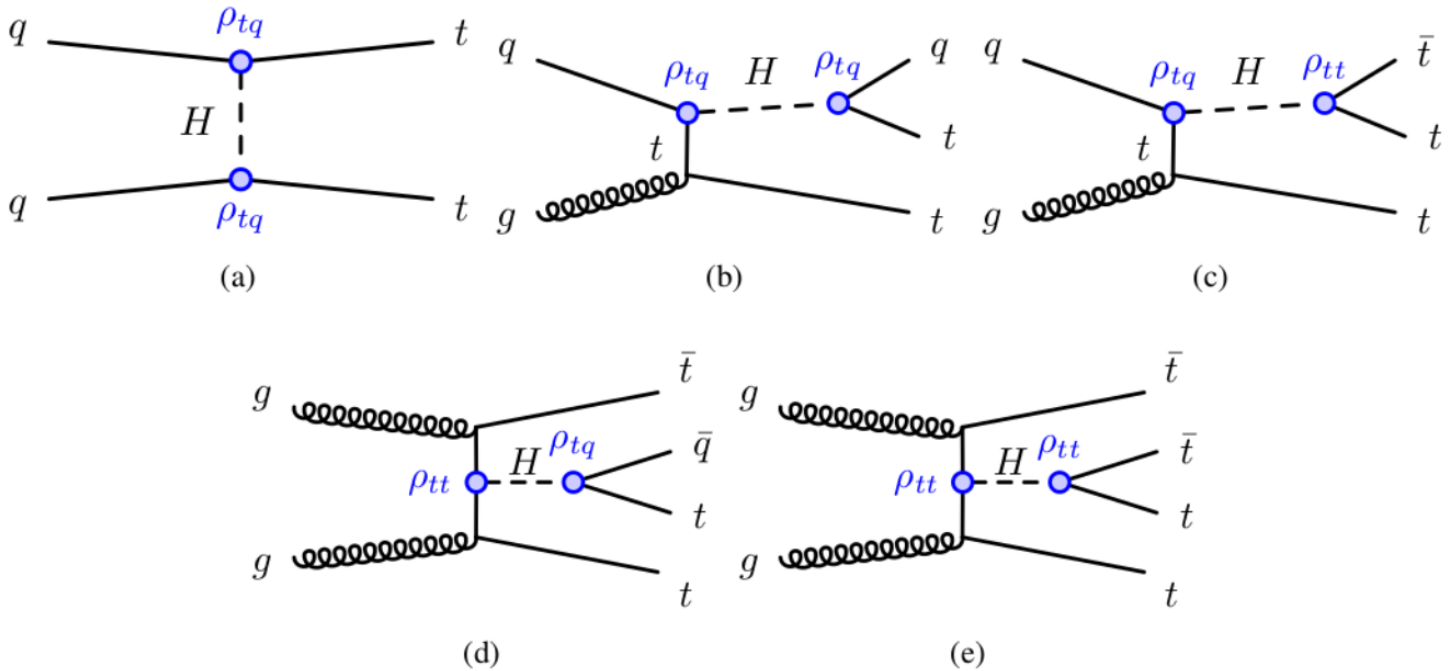
Main Goal

Study the impact of 3 different NP models in the $2SS\ell + n_j \geqslant 2$, with $t\bar{t}W$ as the main background, measuring differential charge asymmetries with respect to different kinematic variables. The NP signals are:

- A heavy scalar/pseudoscalar (H/A) arising from a flavour violating 2HDM.
- A simplified RPV MSSM model with electrowikino production (higgsino/wino-like).
- An effective theory with 4-quark operators of dimension 6.

Flavour violating 2HDM

- A heavy neutral (pseudo) scalar (A) H lighter than the (scalar) pseudoscalar and charge states, or a new singlet (A) H.
- At effective level, we only consider couplings to up-type fermions: $\mathcal{L} = \frac{y_{i,j}}{\sqrt{2}} H u_i u_j$ (i, j generation indices)

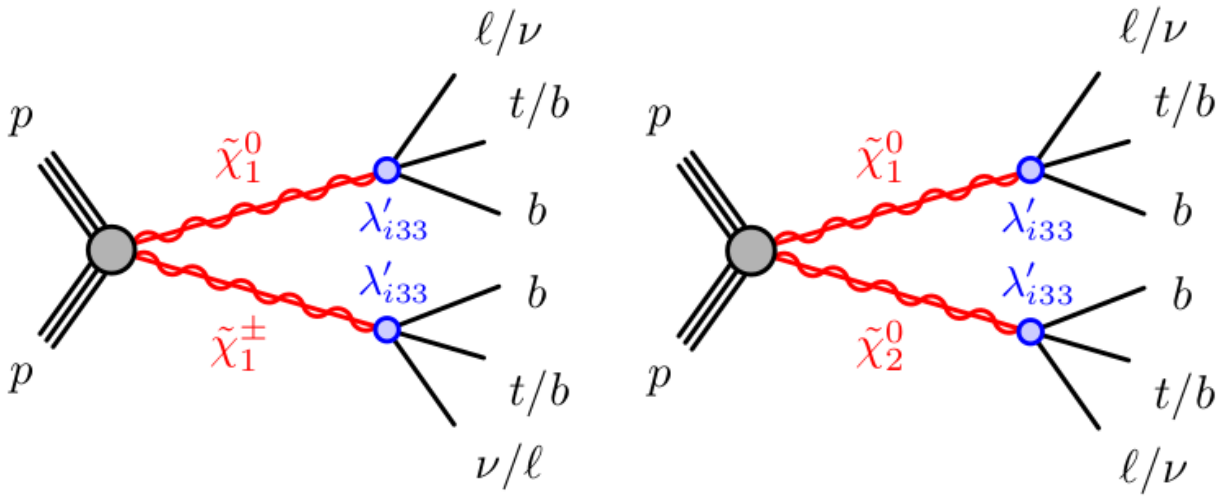


Diagrams with (pseudo) scalar that contribute to the final state.

RPV MSSM

- MSSM with non-conserved R-parity $\longrightarrow$ SUSY particles do not have to be produced in pairs, are not stable, and decay into SM particles.
- Simplified model with 2 scenarios: neutralinos and charginos being higgsino/wino-like.
- We take $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ as degenerate, and the rest of susy particles at the TeV order.
- We consider only $\lambda'_{233} = \lambda'_{333}$ (motivated by B-anomalies) which give

$$\tilde{\chi}_1^{\pm} \to bb\ell, bt\nu \qquad \tilde{\chi}_1^0/\tilde{\chi}_2^0 \to bt\ell, bb\nu$$

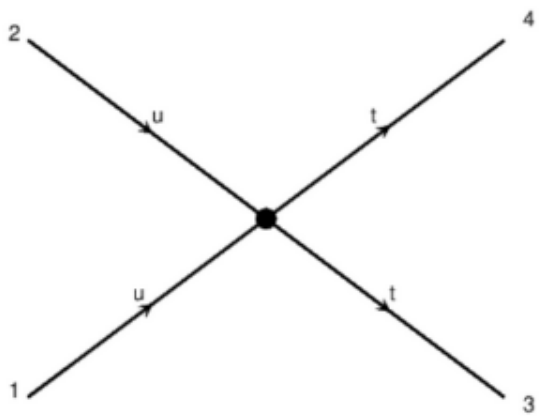


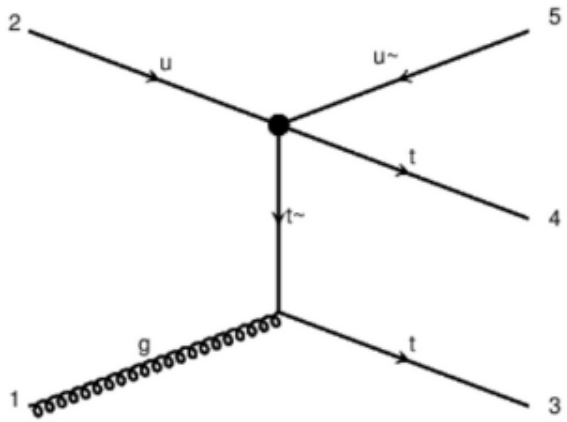
Feynman diagrams for RPV SUSY.

4q-FCNC

- We consider dimension 6 operators modeling the effects of integrated heavy particles.
- The final states that contribute to the asymmetry are tt, $tt\bar{u}$ and their conjugates.
- For simplicity, we only select 2 color singlet operators from the Buchmuller-Wyler base (with $Q_{L_1} = (u_L, d_L)$ and $Q_{L_3} = (t_L, b_L)$):

$$\mathcal{Q}_u^{(1)} = (\bar{t}_R \gamma_\mu u_R)^2 \qquad \mathcal{Q}_{qu}^{(1)} = (\bar{Q}_{L_3} u_R)(\bar{u}_R Q_{L_1})$$





Representative Feynman diagrams of $t\bar{t}$ and $t\bar{t}j$ production in effective theory.

Final state

$2SS\ell$ ($\ell = e, \mu$) with jets, and inclusive (exclusive) selection of b-tagged jets. Selection cuts extracted from ATLAS-CONF-2019-045:

- Two very tight ($\eta < 2/2.5$ for e/μ) same-sign leptons with $p_T > 20$ GeV.
- No τ_{had} candidates.
- $m(\ell^{\pm}, \ell^{\pm}) > 12$ GeV
- $n_j > 2$
- Inclusive $n_b > 1$ (exclusive $n_b = 1$, exclusive $n_b = 2$ and inclusive $n_b \geqslant 3$).

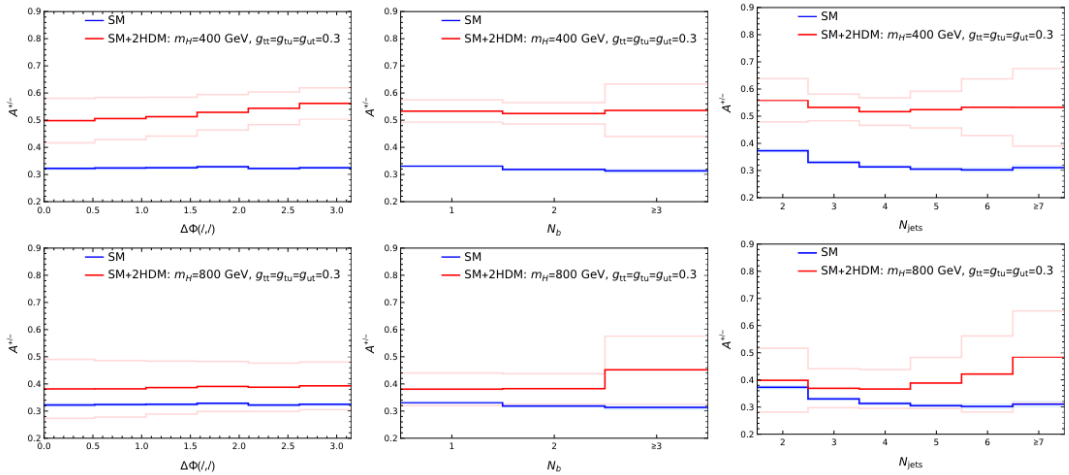
Set up

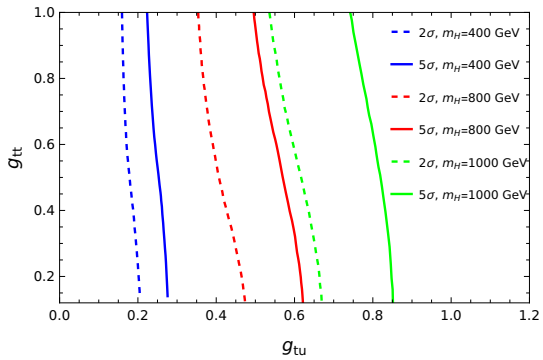
- We generate background ($t\bar{t}W$) and signal events with `MadGraph`, `Pythia8` (with Monash Tune) and `Delphes` at $\sqrt{s} = 13$ TeV and an integrated luminosity of 139 fb^{-1}.
- We reproduce Events/bin vs. N_j from ATLAS-CONF-2019-045 for $t\bar{t}W$ as event generation validation.
- We also simulate other SM backgrounds for uncertainties estimation: $t\bar{t}H$,$t\bar{t}\ell\ell$ and $W\ell\ell$
- Considering $\sigma_{\pm}$ as the positive/negative $2SS\ell$, we define the charge asymmetry

$$A^{+/-} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- We estimate $A_i^{+/-}$ in bins of N_j (and N_b, H_{T_j}, $H_{T_{lep}}$, $m_{inv}(\ell,\ell)$, $\Delta\eta(\ell,\ell)$, $\Delta\Phi(\ell,\ell)$, Eff_{mass}).
- We assume statistical uncertainties are dominant.

Results: Flavour-violating 2HDM

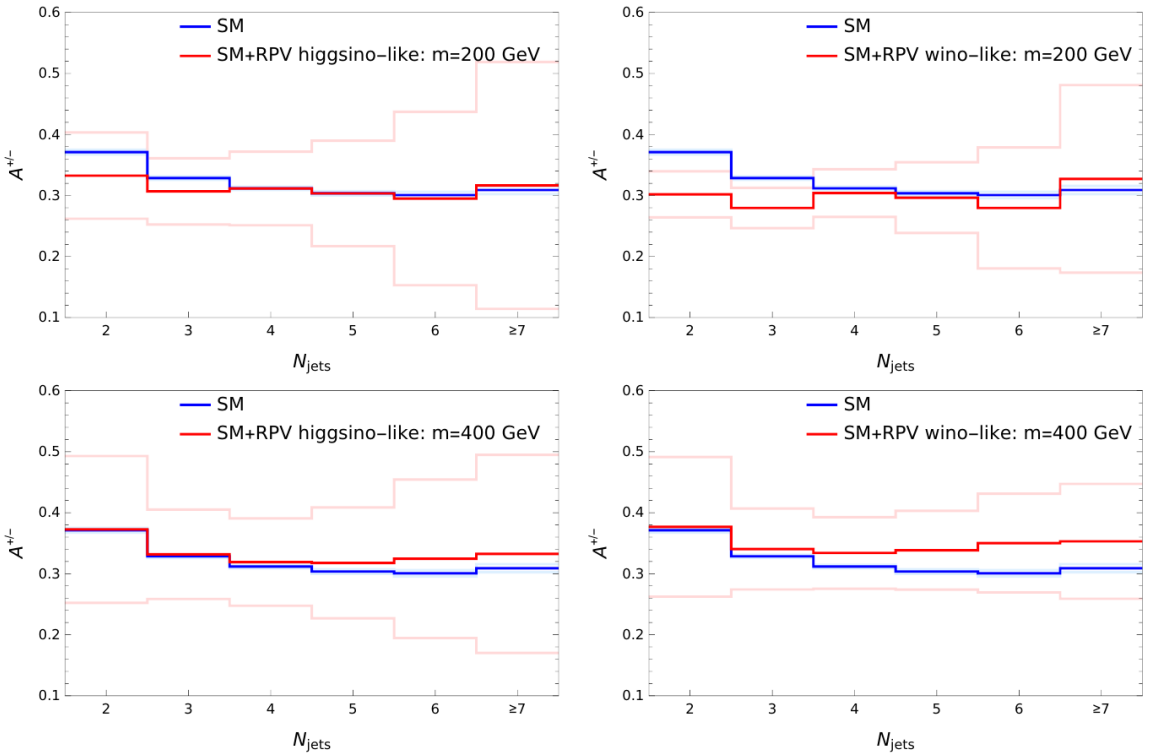




Left: Examples of $A^{+/-}$ vs. $\Delta\Phi(\ell,\ell)$, N_b and N_j. *Right:* Gaussian significance vs. $g_{tu} - g_{tt}$ estimated with $A^{+/-}$ vs. N_{jets}.

- Charge asymmetries are able to probe flavour-violating 2HDM for all the considered masses ($m_{H/A} \in [400, 1000]$ GeV).
- If $g_{tu} > 0$, always more charge asymmetric than the SM, both for extra H/A.
- Binning in different kinematic variables for the differential asymmetries gives more information to distinguish/discard models.

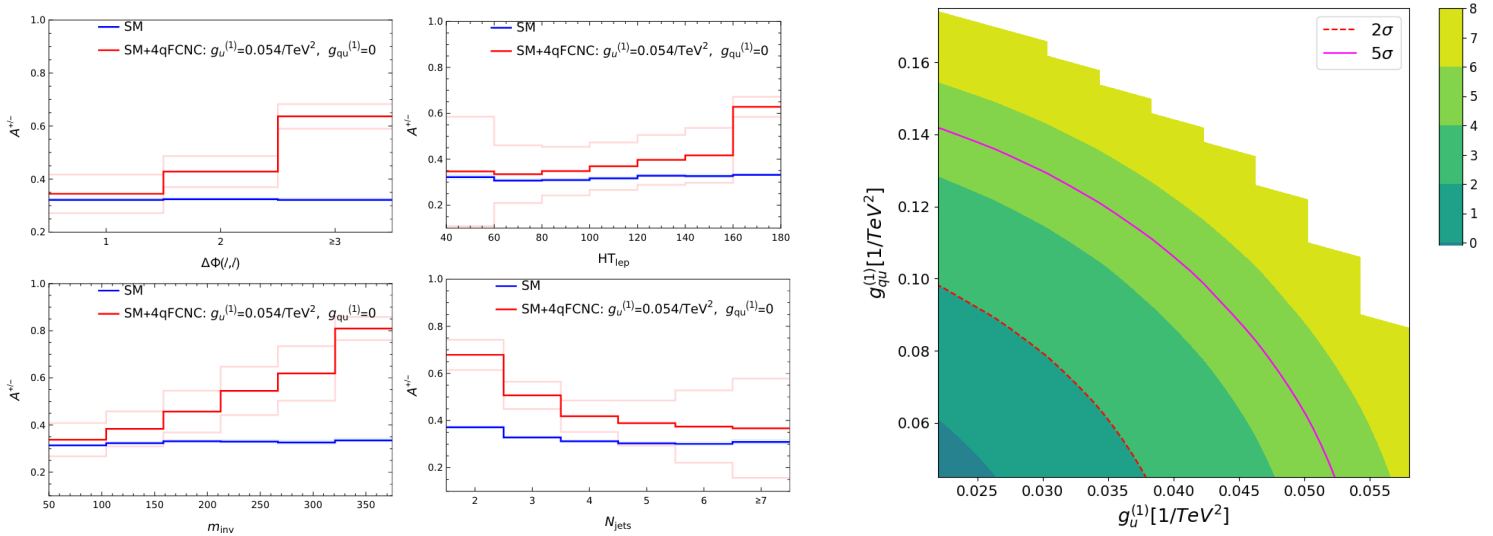
Results: RPV MSSM



Examples of $A^{+/-}$ vs. N_j.

- Charge asymmetries are not sensitive to the RPV MSSM model.
- Significance does not improve binning in other kinematic observables, or with exclusive selection in n_b.
- Dependence on the mass of the electrowikinos in the asymmetry. For $m \in [600, 800]$ GeV no separation at all from the SM.

Results: 4q-FCNC



Left: Examples of $A^{+/-}$ vs. $\Delta\Phi(\ell,\ell)$, $H_{T\,lep}$, $m_{inv}(\ell,\ell)$ and N_j. *Right:* Gaussian significance vs. $g_u^{(1)} - g_{qu}^{(1)}$ estimated with $A^{+/-}$ vs. N_{jets}.

- The charge asymmetries for all kinematic variables are sensitive to the model with similar χ^2.
- More sensitive to $\mathcal{Q}_u^{(1)} = (\bar{t}_R \gamma_\mu u_R)^2$ than to $\mathcal{Q}_{qu}^{(1)} = (\bar{Q}_{L_3} u_R)(\bar{u}_R Q_{L_1})$.
- In all cases, the model is always more charge-asymmetric than the SM.

Conclusions

- Differential charge asymmetries in the $2SS\ell$ with jets final state are sensitive to probe NP such as the proposed flavour violating 2HDM and effective 4-quark operator scenario.
- No sensitivity to the RPV MSSM at $\sqrt{s} = 13$ TeV and 139 fb^{-1}, for degenerate electrowikinos higgsinos/wino-like with $m \in [200, 800]$ GeV.
- The inclusive $n_b > 1$ selection is the more sensitive in all scenarios.
- Significance analysis focuses on asymmetries vs. N_j, but all the other kinematic observables are also sensitive to NP and help to distinguish between models.

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Stay tuned for more results!

Thank you!