Validation of implementation of compressed stop search in monojet channel in MadAnalysis 5 framework (CMS-SUS-14-001)

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1 Introduction

The CMS collaboration has performed searches for pairs of third generation supersymmetric quarks decaying in various fully hadronic final states using pp collision data at $\sqrt{s} = 8$ TeV [1]. The dataset used for analyses corresponds to an integrated luminosity of 19.7 fb^{-1}. Three complemetary analyses presented in the paper target stop pair production ($\widetilde{t}\,\widetilde{t}$) and sbottom pair production ($\widetilde{b}\,\widetilde{b}$) using the following final state signature:

1. pp→$\widetilde{t}\,\widetilde{t}$; $\widetilde{t} \to t\,\widetilde{\chi}_1^0$ using a reconstructed on-shell top quark candidate
2. pp→$\widetilde{b}\,\widetilde{b}$; $\widetilde{b} \to b\,\widetilde{\chi}_1^0$ using two b-jets in final state
3. pp→$\widetilde{t}\,\widetilde{t}$; $\widetilde{t} \to c\,\widetilde{\chi}_1^0$ using a monojet signature (Fig. 1)

Each of these searches requires a large imbalance in the momentum transverse to the beam direction ($p_{\mathrm{T}}^{\mathrm{miss}}$) in the final state.

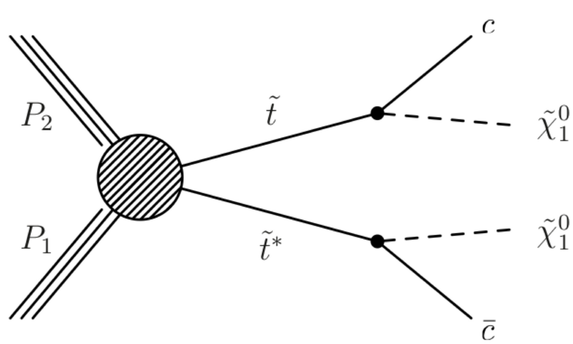

Figure 1: Feynman diagram representing pp→$\widetilde{t}\,\widetilde{t}$, and each $\widetilde{t} \to c\,\widetilde{\chi}_1^0$

In this report, we present an implementation of the analysis based on monojet signature to search for production of stop pairs assuming mass difference between $\widetilde{t}$ and $\widetilde{\chi}_1^0$ smaller than the mass of W boson. Since the decay products of $\widetilde{t}$ are produced with low transverse momenta (p_{T}), the analysis relies on presence of a high p_{T} jet because of a hard initial state radiation, resulting in the monojet signature. A brief summary of the selection criteria used in the analysis is given below:

- Pre-selection of events:
  - $p_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV
  - At least one jet with transverse momentum $p_{\mathrm{T}}^{\mathrm{jet1}} > 110$ GeV and $|\eta^{\mathrm{jet1}}| < 2.4$
  - $N_{\mathrm{Jets}} < 3$, where N_{Jets} is number of jets with $p_{\mathrm{T}} > 60$ GeV and $|\eta| < 4.5$
  - $\Delta\phi(\vec{p}_T^{\,\mathrm{jet1}}, \vec{p}_T^{\,\mathrm{jet2}}) < 2.5$
  - $\mathrm{N}_{e/\mu}$ = 0, where $\mathrm{N}_{e/\mu}$ is number of isolated electrons or muons (with relative isolation value below 0.2 within a cone with ΔR = 0.4 as used in reference [1]) with $\mathrm{p}_T > 10$ GeV and $|\eta| < 2.4$ (also excluding $1.44 < |\eta| < 1.56$ for electrons)
  - N_τ = 0, where N_τ is number of τ jets (hadronically decaying τs) with $\mathrm{p}_T > 20$ GeV and $|\eta| < 2.3$
- Search regions (SRs) are defined using tighter selections on $p_{\mathrm{T}}^{\mathrm{miss}}$ and $p_{\mathrm{T}}^{\mathrm{jet1}}$:
  - Each search region is required to have $p_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV
  - Seven search regions are defined using the thresholds on $p_{\mathrm{T}}^{\mathrm{jet1}}$ as $p_{\mathrm{T}}^{\mathrm{jet1}} > 250$ GeV, $p_{\mathrm{T}}^{\mathrm{jet1}} > 300$ GeV, $p_{\mathrm{T}}^{\mathrm{jet1}} > 350$ GeV, $p_{\mathrm{T}}^{\mathrm{jet1}} > 400$ GeV, $p_{\mathrm{T}}^{\mathrm{jet1}} > 450$ GeV, $p_{\mathrm{T}}^{\mathrm{jet1}} > 500$ GeV, and $p_{\mathrm{T}}^{\mathrm{jet1}} > 550$ GeV

The pp$\rightarrow\widetilde{t}\,\widetilde{t}$ are generated using `MADGRAPH V2.3.0`. A 100% decay branching ratio is assumed for the decay $\widetilde{t} \rightarrow c\,\widetilde{\chi}_1^0$. As noted in the reference [1], processes up to one additional parton in the matrix element are included in the event generation. These events are written in `LHE` format which are then processed through `PYTHIA 6 (pythia-pgs from MG5 interface)` for parton showering and hadronization.

The simulation of detector level and selection of event are implemented in `MadAnalysis 5` framework [2]. For the implementation presented here, we have used `MadAnalysis5_v1.1.11_patch1b` version. Reconstruction of higher level objects such as jets, e,μ,τ leptons, $p_{\mathrm{T}}^{\mathrm{miss}}$ etc. is performed using a customized version of `Delphes` (`DelphesMA5tune`) available with `MadAnalysis 5` package. The package also includes a default CMS datacard to account for detector efficiencies and resolution effects corresponding to the CMS experiment.

2 Validation of selection cutflow

We use two benchmark signal models in ($\mathrm{m}_{\widetilde{t}}$, $\mathrm{m}_{\widetilde{\chi}_1^0}$) = (250,240) and (200,120) to cross-check our implementation of cutflow in `MadAnalysis 5` framework and compare the efficiencies available in [1] and [3]. The results are summarized in Table 1. The various selections used are given in the first column, and the signal efficiency after every selection is provided in the column labelled as "Official CMS". Since the `Delphes` uses a fast parametrization of the detector effects, the event cleaning cannot be implemented. The event cleaning is not expected to affect the event yields in the final search regions.

To cross-check our implementation of analysis in `MadAnalysis 5` framework, we generated the two benchmark signal models in $(m_{\tilde{t}}, m_{\tilde{\chi}_1^0})$ = (250,240) and (200,120) using MADGRAPH + PYTHIA, and processed these through `DelphesMA5tune` to account for the detector effects. The efficiencies obtained using the cutflow implemented in `MadAnalysis 5` framework are provided in the column labelled as "Private LHE events" of Table 1. The event selection efficiencies at various stages of cutflow match the CMS results [3] within a few percent for both the model points. Comparisons of distributions of $p_{\mathrm{T}}^{\mathrm{jet1}}$, $p_{\mathrm{T}}^{\mathrm{jet2}}$, η^{jet1}, η^{jet2}, ϕ^{jet1}, ϕ^{jet2}, $p_{\mathrm{T}}^{\mathrm{miss}}$ and $\Delta\phi(\vec{p}_T^{\,\mathrm{jet1}}, \vec{p}_T^{\,\mathrm{jet2}})$ with the CMS results [4] are provided in the Figure 2 after applying the selections corresponding to the first search region i.e. $p_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV and $p_{\mathrm{T}}^{\mathrm{jet1}} > 250$ GeV in addition to the preselection cuts. The various distributions are closely reproduced by the present implementation.

We also validate our event generation machinery using the LHE events provided by the CMS collaboration for the the same benchmark model points [3]. We process these events through `DelphesMA5tune`, and the selection efficiencies are summarized in the column labelled as "CMS LHE events". The efficiencies otained using CMS LHE events are similar to those obtained using our private generation of the events in most of the search regions.

Table 1: Validation of efficiencies at various stages of event selection provided by the CMS collaboration (column "Official CMS") and using privately generated events (column "Private LHE events"). The selection efficiencies starting with the LHE events provided by the CMS collaboration are provided in the column "CMS LHE events".

Selection	$(m_{\tilde{t}}, m_{\tilde{\chi}_1^0})$ = (250,240)			$(m_{\tilde{t}}, m_{\tilde{\chi}_1^0})$ = (200,120)		
	Official CMS results	Private LHE generation	CMS LHE events	Official CMS results	Private LHE generation	CMS LHE events
Event Cleaning	97.54	100	100	99.21	100	100
$p_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV	7.17	8.20	7.58	4.29	5.23	4.99
Noisy Events	6.68	NA	NA	4.01	NA	NA
$p_{\mathrm{T}}^{\mathrm{jet1}} > 110$ GeV	6.35	7.69	7.08	3.71	4.75	4.55
$N_{\mathrm{Jets}} < 3$	5.56	6.34	5.88	2.30	2.59	2.49
$\Delta\phi(\vec{p}_T^{\,\mathrm{jet1}}, \vec{p}_T^{\,\mathrm{jet2}})$	5.36	6.07	5.67	1.96	2.26	2.16
Lepton veto ($\mathrm{N}_{e/\mu} = 0$)	5.36	6.07	5.67	1.96	2.26	2.16
τ-jet veto ($\mathrm{N}_{\tau} = 0$)	5.30	6.06	5.65	1.93	2.25	2.15
For all the search regions below, $p_{\mathrm{T}}^{\mathrm{miss}} > 250$ GeV						
$p_{\mathrm{T}}^{\mathrm{jet1}} > 250$ GeV	2.04	2.29	2.16	0.42	0.45	0.45
$p_{\mathrm{T}}^{\mathrm{jet1}} > 300$ GeV	1.32	1.51	1.41	0.25	0.26	0.27
$p_{\mathrm{T}}^{\mathrm{jet1}} > 350$ GeV	0.81	0.92	0.86	0.13	0.13	0.14
$p_{\mathrm{T}}^{\mathrm{jet1}} > 400$ GeV	0.50	0.56	0.52	0.072	0.067	0.076
$p_{\mathrm{T}}^{\mathrm{jet1}} > 450$ GeV	0.32	0.35	0.32	0.041	0.036	0.039
$p_{\mathrm{T}}^{\mathrm{jet1}} > 500$ GeV	0.19	0.21	0.20	0.023	0.020	0.023
$p_{\mathrm{T}}^{\mathrm{jet1}} > 550$ GeV	0.12	0.13	0.12	0.013	0.009	0.014

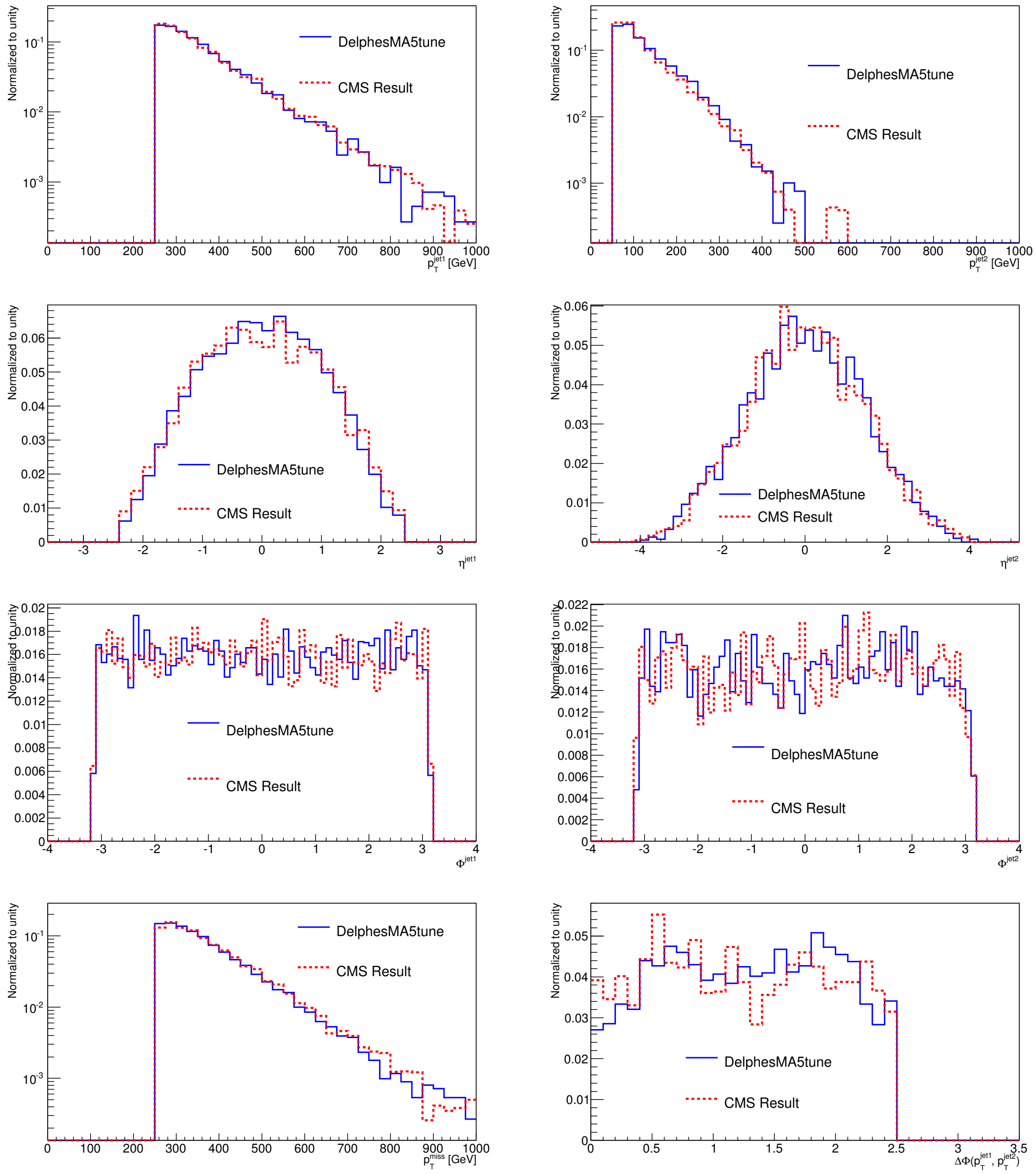

Figure 2: Comparisons of distributions of $p_{\mathrm{T}}^{\mathrm{jet1}}$, $p_{\mathrm{T}}^{\mathrm{jet2}}$, η^{jet1}, η^{jet2}, ϕ^{jet1}, ϕ^{jet2}, $p_{\mathrm{T}}^{\mathrm{miss}}$ and $\Delta\phi(\vec{p}_T^{\,\mathrm{jet1}}, \vec{p}_T^{\,\mathrm{jet2}})$ obtained in `MadAnalysis 5` implementation with those provided by the CMS collaboration.

3 Exclusion

We generated events using MADGRAPH+PYTHIA, and reconstructed these events in MA5 framework for several model points in the plane of masses of $\tilde{t}$ and $\tilde{\chi}_1^0$ in the neighborhood of the exclusion curve published by the CMS in the Ref. [1]. A simplified version of upper limit on signal cross-section is obtained using the *exclusion_CLs.py* provided along with the MA5 package. The script uses a simplified version of CLs and is described in [2]. A comparison of observed upper limit on cross-sections for various model points obtained from our implementation with the CMS official results is provided in figure 3.

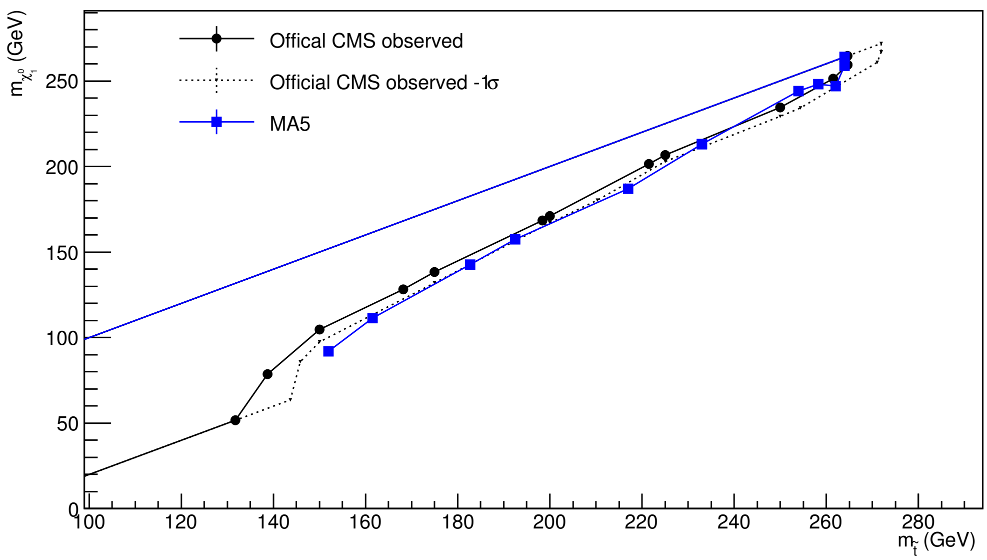

Figure 3: Observed exclusion curves in $(m_{\tilde{t}}, m_{\tilde{\chi}_1^0})$ plane using efficiencies obtained with MA5 framework (blue squares), and those published by the CMS collaboration (black circles) [1].

4 Acknowledgement

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[4] https://spiral.imperial.ac.uk/handle/10044/1/25749