Validation of the MadAnalysis 5 implementation of CMS-SUS-13-011

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This note contains detailed validation material for the MadAnalysis 5 implementation [1] of the CMS search [2] for stops in the single-lepton mode at the 8 TeV run of the LHC. Note that this analysis requires MINUIT libraries. Therefore, the line

```
LIBFLAGS += -lMinuit
```

should be added to the Makefile of the Build/ directory before compilation.

The validation was based on `LHE` files provided by the CMS collaboration. Showering and hadronization of the events was done with `PYTHIA 6.4`, and simulation of detector effects was done within `MadAnalysis 1.1.11`, using `delphesMA5tune` with a dedicated detector card [3].

References

[1] http://inspirehep.net/record/1301484/

[2] https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS13011

[3] http://madanalysis.irmp.ucl.ac.be/attachment/wiki/PhysicsAnalysisDatabase/delphesMA5tune_card_CMS_SUSY.tcl

1 Cutflows

$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) cutflow for SR $\tilde{t} \to t\tilde{\chi}_1^0$, high ΔM, $E_T^{\rm miss} > 300$ GeV				
cut	# events (scaled to σ and $\mathcal{L}$)	relative change	# events (official)	relative change (official)
Initial number of events	272.2	272.2		
trigger	113.3	-58.4%		
≥ 1 candidate lepton	59.8	-47.2%		
≥ 4 central jets	29.6	-50.5%		
$E_T^{\rm miss} > 50$ GeV	29.0	-2.0%	31.6	31.6
$E_T^{\rm miss} > 100$ GeV	27.3	-5.9%	29.7	-6.0%
≥ 1 b-tagged jet	23.8	-12.8%	25.2	-15.2%
veto isol lepton and track	19.8	-16.8%	21.0	-16.7%
No hadronic tau	19.4	-2.0%	20.6	-1.9%
$\Delta\phi(E_T^{\rm miss}, j_1$ or j$_2) > 0.8$	16.7	-13.9%	17.8	-13.6%
Hadronic $\chi^2 < 5$	9.8	-41.3%	11.9	-33.1%
$M_T > 120$ GeV	7.9	-19.4%	9.6	-19.3%
$E_T^{\rm miss} > 300$ GeV	5.2	-34.2%		
$M_{T2}^W > 200$ GeV	3.9	-25.0%	4.2	-56.3%

Table 1: Cutflow for the $\tilde{t} \to t\tilde{\chi}_1^0$ benchmark point with $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (650, 50)$ GeV in the high ΔM, $E_T^{\rm miss} > 300$ GeV signal region.

$\tilde{t} \to t\tilde{\chi}_1^0$ (250/50) cutflow for SR $\tilde{t} \to t\tilde{\chi}_1^0, \mathrm{low}\,\Delta\mathrm{M}, \mathrm{E_T^{miss}} > 150$ GeV				
cut	# events (scaled to σ and $\mathcal{L}$)	relative change	# events (official)	relative change (official)
Initial number of events	108731.2	108731.2		
trigger	33258.0	−69.4%		
$\geq$ 1 candidate lepton	22947.8	−31.0%		
$\geq$ 4 central jets	9443.4	−58.8%		
$E_T^{\mathrm{miss}} > 50$ GeV	7365.0	−22.0%	8033.0	8033.0
$E_T^{\mathrm{miss}} > 100$ GeV	3787.2	−48.6%	4059.2	−49.5%
$\geq$ 1 b-tagged jet	3166.0	−16.4%	3380.1	−16.7%
veto isol lepton and track	2601.4	−17.8%	2770.0	−18.0%
No hadronic tau	2557.2	−1.7%	2683.1	−3.1%
$\Delta\phi(E_T^{\mathrm{miss}}, j_1 \text{ or } \mathrm{j}_2) > 0.8$	2021.3	−21.0%	2019.1	−24.7%
Hadronic $\chi^2 < 5$	1092.0	−46.0%	1375.9	−31.9%
$M_T > 120$ GeV	261.3	−76.1%	355.1	−74.2%
$E_T^{\mathrm{miss}} > 150$ GeV	107.9	−58.7%	124.0	−65.1%

Table 2: Cutflow for the $\tilde{t} \to t\tilde{\chi}_1^0$ benchmark point with $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (250, 50)$ GeV in the low ΔM, $E_T^{\mathrm{miss}} > 150$ GeV signal region.

2 Final number of events

benchmark point	CMS result	MA 5 result
$\tilde{t} \to t\tilde{\chi}_1^0$, low ΔM, $E_T^{\rm miss} > 150$ GeV		
(250/50)	108 ± 3.7	100.1
$\tilde{t} \to t\tilde{\chi}_1^0$, high ΔM, $E_T^{\rm miss} > 300$ GeV		
(650/50)	3.7 ± 0.1	3.6

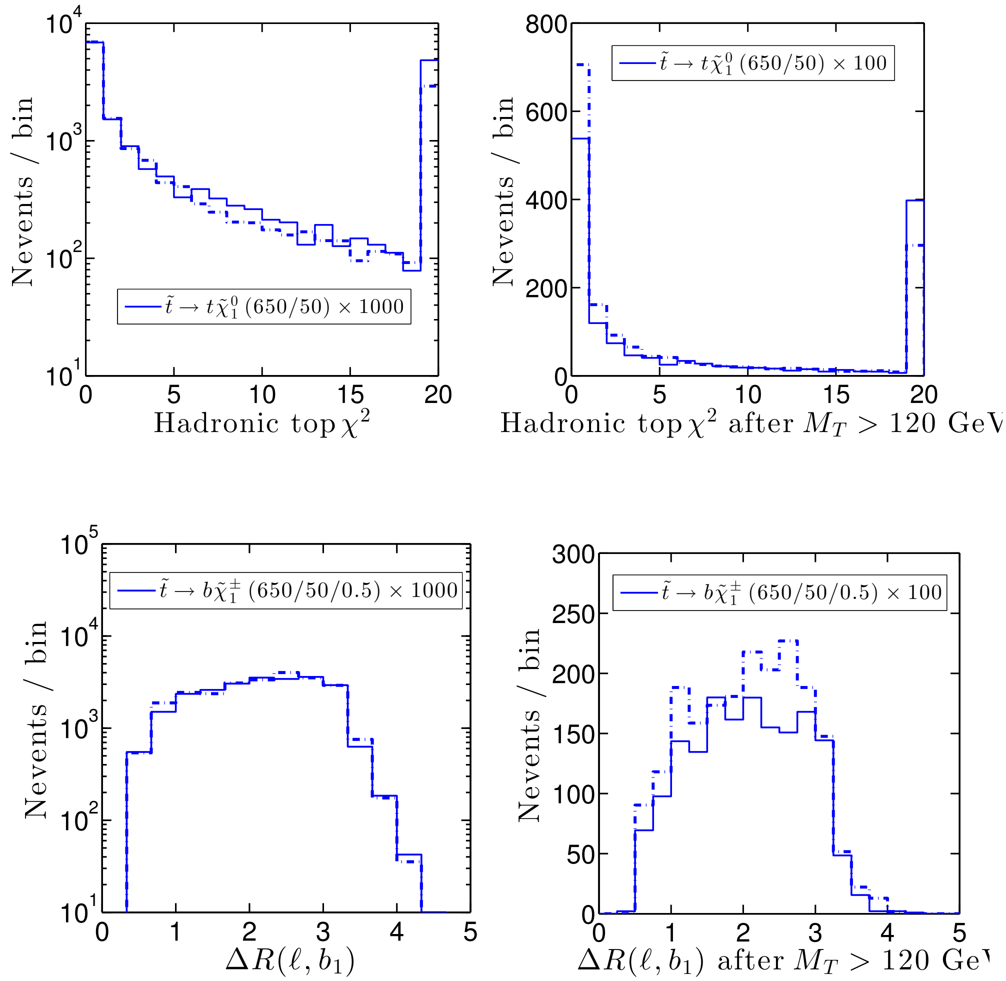
Table 3: Final number of events for $\tilde{t} \to t\tilde{\chi}_1^0$ in the two relevant signal regions. For each benchmark point, the first number indicates the stop mass, the second the LSP mass.

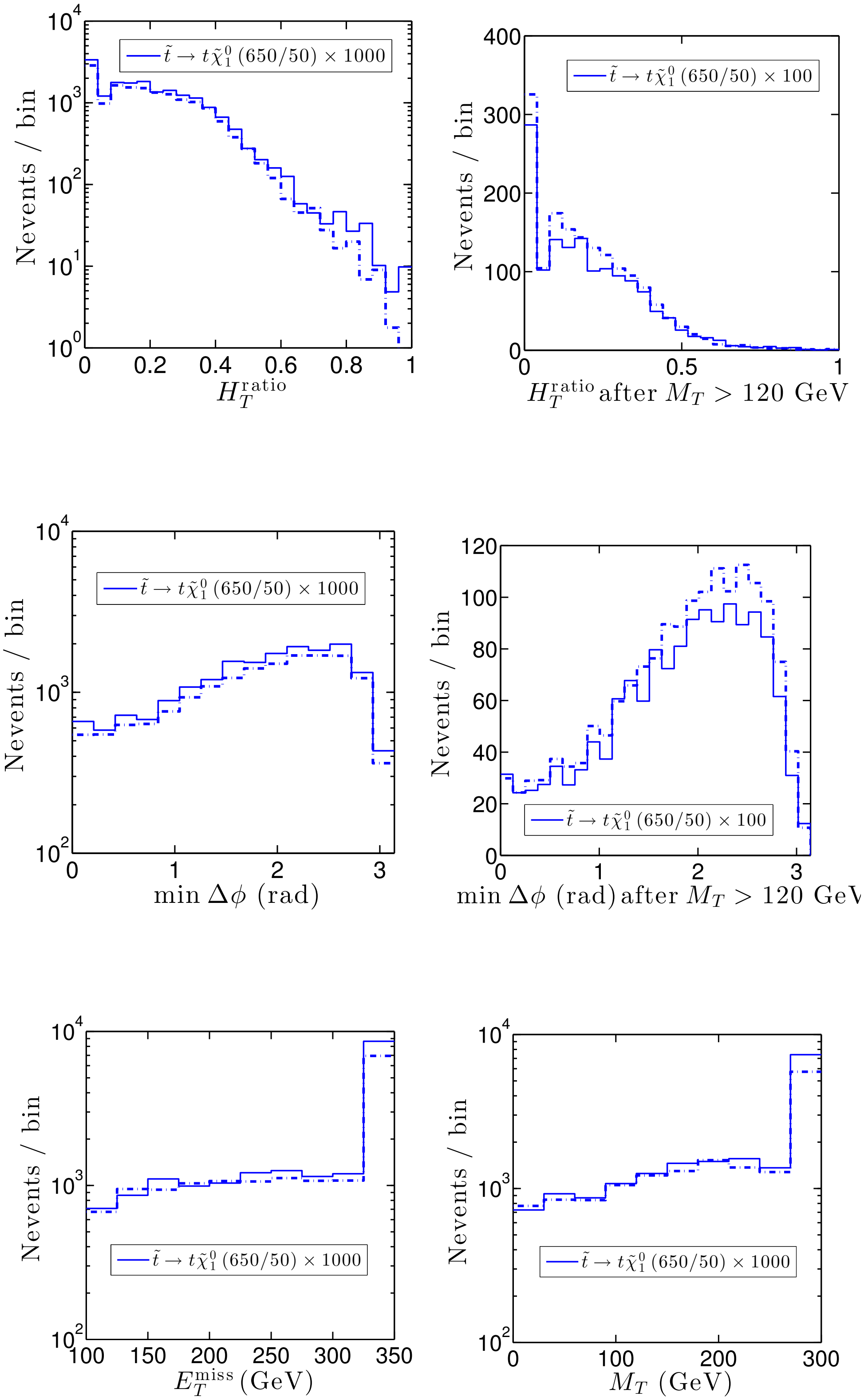
benchmark point	CMS result	MA 5 result
$\tilde{t} \to b\tilde{\chi}_1^\pm$, low ΔM, $E_T^{\rm miss} > 150$ GeV		
(250/50/0.5)	157 ± 9.9	141.2
(250/50/0.75)	399 ± 18	366.8
$\tilde{t} \to b\tilde{\chi}_1^\pm$, high ΔM, $E_T^{\rm miss} > 150$ GeV		
(450/50/0.25)	23 ± 2.3	23.4
$\tilde{t} \to b\tilde{\chi}_1^\pm$, high ΔM, $E_T^{\rm miss} > 250$ GeV		
(600/100/0.5)	6.1 ± 0.5	5.4
(650/50/0.5)	6.7 ± 0.4	5.8
(650/50/0.75)	6.3 ± 0.4	5.7

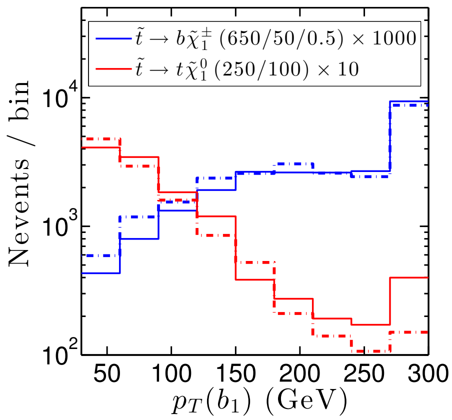
Table 4: Final number of events for $\tilde{t} \to b\tilde{\chi}_1^\pm$ in the three signal regions. The benchmark points are given in the format $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}, x)$ with x setting the chargino mass according to $m_{\tilde{\chi}_1^+} = x \cdot m_{\tilde{t}_1} + (1-x) m_{\tilde{\chi}_1^0}$.

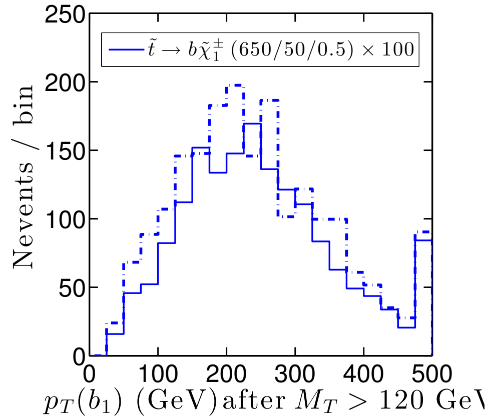
3 Histograms

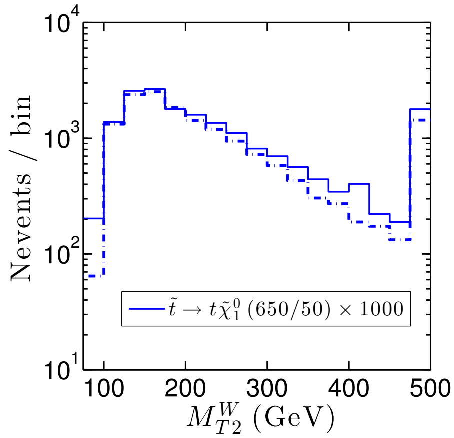
In the histograms below, the solid lines correspond to the results from the MadAnalysis 5 implementation, while the dashed lines are the official CMS results. All histograms are filled after preselection cuts. When $M_T > 120$ GeV is mentioned, this cut is applied in addition to the preselection cuts. The notation for the benchmark points is as in Tables 3 and 4.

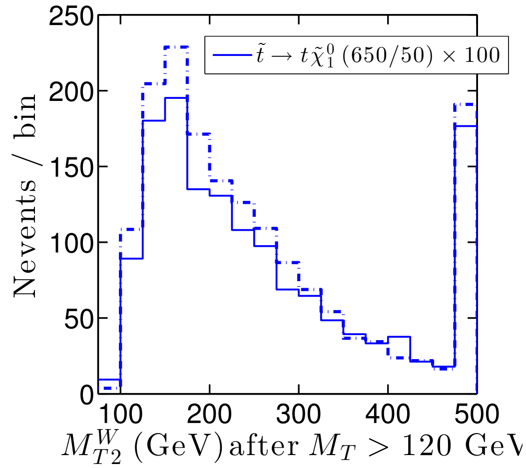


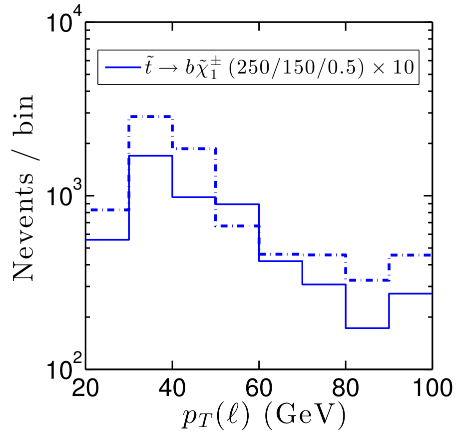

Nevents / bin
$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 1000
$H_T^{\rm ratio}$
$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 100
$H_T^{\rm ratio}$ after $M_T > 120$ GeV
min $\Delta\phi$ (rad)
min $\Delta\phi$ (rad) after $M_T > 120$ GeV
$E_T^{\rm miss}$ (GeV)
M_T (GeV)


$\tilde{t} \to b\tilde{\chi}_1^\pm$ (650/50/0.5) × 1000
$\tilde{t} \to t\tilde{\chi}_1^0$ (250/100) × 10
Nevents / bin
$p_T(b_1)$ (GeV)


$\tilde{t} \to b\tilde{\chi}_1^\pm$ (650/50/0.5) × 100
Nevents / bin
$p_T(b_1)$ (GeV) after $M_T > 120$ GeV


$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 1000
Nevents / bin
M_{T2}^W (GeV)


$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 100
Nevents / bin
M_{T2}^W (GeV) after $M_T > 120$ GeV


$\tilde{t} \to b\tilde{\chi}_1^\pm$ (250/150/0.5) × 10
Nevents / bin
$p_T(\ell)$ (GeV)

4 Limit-setting procedure

Limits are derived using `exclusion_CLs.py`. The 95% CL upper limits on the model cross section obtained from the code are compared to the CMS value [2] for the eleven benchmark points considered above, as well as the best expected signal region for each benchmark point. "T2tt" and "T2bw" benchmark points correspond to the $\tilde{t} \to t\tilde{\chi}_1^0$ and $\tilde{t} \to b\tilde{\chi}_1^\pm$ simplified models, respectively. Regarding signal regions, "TT" and "TB" correspond to signal regions targeting the $\tilde{t} \to t\tilde{\chi}_1^0$ and $\tilde{t} \to b\tilde{\chi}_1^\pm$ simplified models, respectively, while "LM" and "HM" correspond to low ΔM and high ΔM, and the final number correspond to the $E_T^{\rm miss}$ cut.

benchmark point	xs95 MA5	xs95 CMS	bestSR MA5	bestSR CMS
T2tt_250_50	3.41 pb	3.44 pb	TB_LM150	TT_LM150
T2tt_250_75	5.83 pb	9.52 pb	TB_LM250	TT_LM150
T2tt_250_100	3.28 pb	3.78 pb	TB_LM200	TT_LM150
T2tt_650_50	0.0151 pb	0.0152 pb	TB_HM250	TT_HM300
T2bw0.25_450_50	0.148 pb	0.141 pb	TB_HM150	TB_HM150
T2bw0.25_600_100	0.0268 pb	0.0203 pb	TB_HM250	TB_HM250
T2bw0.5_250_50	4.96 pb	3.48 pb	TB_LM100	TB_LM150
T2bw0.5_250_150	6.42 pb	6.32 pb	TB_LM200	TB_LM250
T2bw0.5_650_50	0.0144 pb	0.0103 pb	TB_HM250	TB_HM250
T2bw0.75_250_50	1.53 pb	1.37 pb	TB_LM200	TB_LM150
T2bw0.75_650_50	0.0143 pb	0.0110 pb	TB_HM250	TB_HM250

Surprisingly, all $\tilde{t} \to t\tilde{\chi}_1^0$ benchmark points have as best expected signal region a signal region optimized for $\tilde{t} \to b\tilde{\chi}_1^\pm$, instead of a signal region optimized for $\tilde{t} \to t\tilde{\chi}_1^0$ as given by CMS. Re-computing exclusions for the T2tt benchmark points considering only the eight $\tilde{t} \to t\tilde{\chi}_1^0$ signal regions yields:

benchmark point	xs95 MA5	xs95 CMS	bestSR MA5	bestSR CMS
T2tt_250_50	4.92 pb	3.44 pb	TT_LM150	TT_LM150
T2tt_250_75	12.5 pb	9.52 pb	TT_LM150	TT_LM150
T2tt_250_100	4.97 pb	3.78 pb	TT_LM200	TT_LM150
T2tt_650_50	0.0171 pb	0.0152 pb	TT_HM300	TT_HM300

5 Analysis steps

For completeness we also list the sequence of steps done in the analysis:

1. cut ISR boost factor (switched off for validation with cutflow)
2. object definitions:
   - `Tracks`: $p_T > 10$ GeV, $|\eta| < 2.1$
   - `SignalElectrons`: $p_T > 30$ GeV and $|\eta| < 1.4442$

- `SignalMuons`: $p_T > 25$ GeV and $|\eta| < 2.1$
- `OtherLeptons`: electron with 5 GeV $< p_T <$ 30 GeV and $|\eta| < 1.4442$ or muon with 5 GeV $< p_T <$ 25 GeV and $|\eta| < 2.1$
- `Jets`: $p_T > 30$ GeV and $|\eta| < 2.4$ (anti-k_T, $\Delta R = 0.5$)
- `Taus`: jets with $p_T > 20$ GeV, $|\eta| < 2.4$ and tagged as hadronic taus

3. cut trigger: efficiencies from Twiki page (for validation with cutflow: 100% efficiency is there is at least one object in `SignalElectrons` $\cup$ `SignalMuons`)

4. isolation of the `SignalElectrons` and `SignalMuons` leptons: if Σp_T in a cone of $\Delta R = 0.3$, excluding the lepton itself, is $> \min(5\text{ GeV}, 0.15 \times p_{T,\ell})$, the given lepton is moved to `OtherLeptons`

5. apply identification efficiencies: we will want ≥ 1 lepton from `SignalElectrons` $\cup$ `SignalMuons`. We calculate the probability to have 0 lepton ($p_{0\ell}$) in `SignalElectrons` $\cup$ `SignalMuons`, which corresponds to the product of $(1 - \varepsilon_i)$, where ε_i is the individual identification efficiency (given the nature of the lepton and its p_T). Then we reweight the event by $(1 - p_{0\ell})$. The ε_i used are:

   - electron: if $p_T < 30$ GeV, $\varepsilon_i = 0.78$; else if $p_T < 40$ GeV, $\varepsilon_i = 0.84$; else $\varepsilon_i = 0.87$
   - muons: if $p_T < 200$ GeV, $\varepsilon_i = 0.95$; else if $p_T < 300$ GeV, $\varepsilon_i = 0.90$; else $\varepsilon_i = 0.80$

6. cut ≥ 1 candidate lepton: size(`SignalElectrons` $\cup$ `SignalMuons`) > 0

7. discard jets (remove from `Jets`) within $\Delta R = 0.4$ of a lepton from `SignalElectrons` $\cup$ `SignalMuons`

8. cut ≥ 4 central jets: size(`Jets`) > 4

9. cut $E_T^{\text{miss}} > 50$ GeV

10. cut $E_T^{\text{miss}} > 100$ GeV

11. cut ≥ 1 b-tagged jet

12. count number of leptons ($n_{\text{isol}-\ell}$) from `SignalElectrons`, `SignalMuons` and `OtherLeptons` for which Σp_T in a cone of $\Delta R = 0.3$, excluding the lepton itself, is $< \min(0.20 \times p_{T,\ell})$

13. cut (do not appear separately in this cutflow): $n_{\text{isol}-\ell} = 1$

14. define `SignalLepton` as this one isolated lepton

15. for the tracks (from `Tracks`) with a charge of opposite-sign to the signal lepton, check if they are isolated (Σp_T in a cone of $\Delta R = 0.3$, excluding the track itself, is $< 0.10 \times p_{T,\text{track}}$)

16. cut veto isol lepton and track: number of the above defined isolated OS tracks = 0 and apply a weight of 0.885 to account for the difference in isolation between Particle Flow methods and our tracks-only method (0.885 has been obtained from the two cutflow charts below)

17. cut No hadronic tau: 0 element in `Taus`

18. the following cuts are defined without ambiguity from their names in the cutflow (the hadronic χ^2 and M_{T2}^W are calculated from the snippets of code provided by CMS on the Twiki page of the analysis). Note that the order in which cuts are applied is different in the cutflow and in the histograms.