# TOWARDS A COMMON FRAMEWORK FOR RECASTING NEW PHYSICS ANALYSES WITH MADANALYSIS 5

Guillaume CHALONS

*LPSC Grenoble*

**In collaboration with S. Bein, E. Conte, B. Dumont, B. Fuks, S. Kraml S. Kulkarni, D. Sengupta, L. Mitzka, C. Wymant and others**

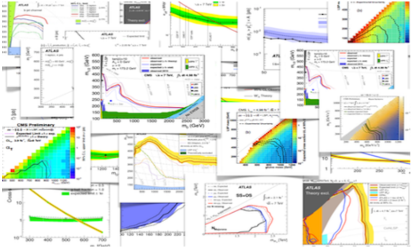
# MOTIVATIONS

The LHC is the high energy frontier machine to explore the TeV scale and provide answers to many key questions in particle physics.

Many Many New Physics searches

Particular slices of the parameter space of a few models

Pheno studies seek to constrain as many models using as many analyses as possible
$\longrightarrow$ Reinterpreting the data



The complexity of the analyses together with the complexity of the NP models requires active collaboration of experimentalists and theorists to fully exploit the LHC potential

To tackle this issues several tools have been developped (public or not) ATOM, FASTLIM, CHECKMATE, XQCAT, SMODELS, MADANALYSIS 5

Or resort to the RECAST initiative

# THE STATUS

The Simplified Models cover many topologies but have limitations (signal efficiencies depend on the event kinematics, not details of BSM model)

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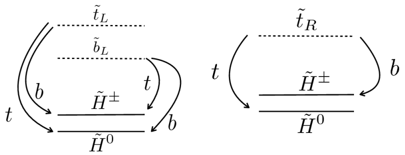
## A LITTLE EXAMPLE:

- Natural SUSY scenarios do not predict $BR(\tilde{t}_1, \tilde{b}_1 \rightarrow X) = 100\%$



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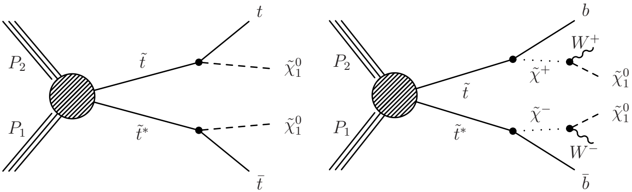


- CMS-SUS-13-011 ($\ell + \not{E}_T$) targets each topology in each SR
- In a typical Natural SUSY scenario the decay chains of $\tilde{t}_1$ can be mixed and would lead to the same final state ($1\ell + 2b + 2j + \not{E}_T$)
- What would be the sensitivity of this analysis to this mixed topology ?

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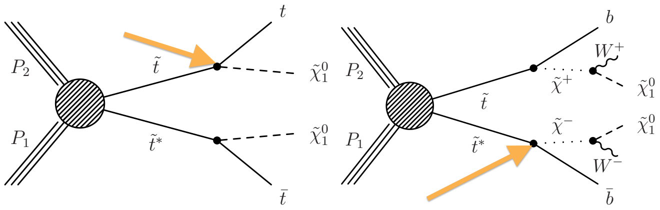


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# THE STATUS

The Simplified Models cover many topologies but have limitations (signal efficiencies depend on the event kinematics, not details of BSM model)

Going beyond the SMS approach requires a fast detector simulation

For a given topology one needs to :

- Scan over parameter space including event generation
- Implement some of the related existing experimental analyses
- Validate the implementations
- Then apply to different frameworks

The task is huge!

- Need to iterate for each topology
- A lot of manpower needed
- Some analyses may have been already implemented by other groups but validation of the implementation not always public.

Instead of reinventing the wheel and to avoid redundancy we may want to share the effort

# SHORTCOMINGS

Legimate question:

- Can an analysis implemented and validated by a group A be used by a group B ?
  - Each tool has its own programming language
  - Each tool has its own internal set of conventions

Not all the analyses can be implemented (ex: MVA)

The information needed is not always available (more on this later)

Need for an important collaborative effort between exp. and theo.

A unique, easy-to-use and flexible well-documented framework desirable

# WHY MADANALYSIS 5 (see E.Conte's talk)

- Expert mode extended to recast existing LHC analyses
  - C++/ROOT language within the SAMPLEANALYZER framework
  - Supports multiple sub-analyses, a developer-friendly way of handling cuts and histograms

- Results are stored in a so-called SAF file
  - Text based (similar to XML)
  - Easily reprocessable

```
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</SAFHEADER>

<HISTO>
<DESCRIPTION>
"MCT SRA"
# NBINS        XMIN          XMAX
20             0             500
# ASSOCIATED REGIONSELECTIONS
 SRA, HIGHDELTAM, MET > 150                              # REGION NR. 1
</DESCRIPTION>
<STATISTICS>
326 0 # NEVENTS
326 0 # SUM OF EVENT-WEIGHTS OVER EVENTS
326 0 # NENTRIES
326 0 # SUM OF EVENT-WEIGHTS OVER ENTRIES
326 0 # SUM WEIGHTS^2
39046.3 0 # SUM VALUE*WEIGHT
5.28533E+06 0 # SUM VALUE^2*WEIGHT
</STATISTICS>
```

- Modified version of DELPHES 3 (see E. Conte's talk)
  - New isolations methods

- Current developments
  - Import/Export Analyses as analysis codes or shared librairies
  - A SAF reader to generate histograms and cut-flows charts (also as a shared library)
  - A module to provide a comparison with the $N_{95}$ upper limit or a simplified CLs via

$$\mathcal{L} = \text{poiss}(n_i^{obs.} | n_i^s + n_i^b) \cdot \text{gauss}(n_i^b | n_i^{b,exp}, \Delta n_i^b)$$

# AIM OF THE PROJECT

Our aim : reimplement several ATLAS and CMS analyses and create a public analysis database (PAD) within a common platform for collecting objects definitions, cuts, etc...

To draw limits and/or interpret a deviation from the SM expectation one needs

- # expected bckgd events & # of observed events from physics paper
- # of expected signal events after cuts for a given NP model

MADANALYSIS5 is designed to take care of the last item : takes a simulated event sample, pass it to detector simulation and then analysis code

To validate the analysis we have to rely on our own detector simulation

Try to reproduce the official cutflows and distributions given in the analysis paper

Very tedious (given the available information)

# CURRENT STATUS OF IMPLEMENTATION/VALIDATION

- First milestone : implementing 6 analyses (3 ATLAS + 3 CMS) related to searches for $3^{rd}$ generation squarks and gluinos.

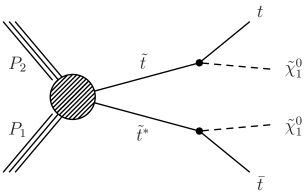
- CMS searches:
  - CMS-SUS-13-011 ($\tilde{t}$ search, 1 $\ell$-analysis)
  - CMS-SUS-13-016 ($\tilde{g}$ search, 2 OS $\ell$, large $\not{E}_T$ & High Jet-multiplicity)
  - CMS-SUS-13-012 ($\tilde{q}, \tilde{g}$ search, multijet + large $\not{E}_T$)

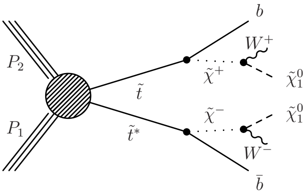
- ATLAS searches:
  - ATLAS-SUSY-13-05 ($\tilde{t}, \tilde{b}$ search, 2 $b$-jets + $\not{E}_T$)
  - ATLAS-SUSY-13-19 ($\tilde{t}$ search, 2 OS $\ell$ analysis)
  - ATLAS-CONF-2013-061 ($\tilde{g}, \tilde{t}, \tilde{b}$ search, 0-1 $\ell$ + $\geq$ 3 $b$-jets + $\not{E}_T$)

- CMS analyses are generally difficult to understand but well documented for validation and we get a lot of direct help (more material)
- ATLAS analyses are easier to understand but not as well documented for validation.

# CMS-SUS-13-011: DESCRIPTION

- CMS search for $\tilde{t}$ in the $\ell + \not{E}_T$ final state $pp$ collisions at 8 TeV with full $\mathcal{L}$.
- Targets $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ & $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$




- Two sets of SRS defined, sensitive to each topology
- Each set further divided into "Low $\Delta M$" & "High $\Delta M$" and then sub-divided according to $\neq \not{E}_T$ thresholds.
- Two specific variables to reduce the dilepton $t\bar{t}$ bckg.
  - a $\chi^2$ resulting from the full reconstruction of the had. top (straightforward: available on the `Twiki` page)
  - a variant of $M_{T2}$, $M_{T2}^W$ implemented following *JHEP* **1207** (2012) 110.

- Analysis very well documented (lots of distribution of variables available)
- Detailed trigger efficiencies and ID-only efficiencies for $e^{\pm}$ and $\mu^{\pm}$ missing but provided kindly by CMS upon request

- Approved tables and plots ( *click on plot to get larger version* )
  - (pseudo) Feynman diagrams
  - Results: yields vs. background prediction, kinematical distributions of (near-)final event sample
  - Interpretation: SUSY summary plots
  - Interpretation: limits on SUSY parameters
  - Kinematical quantities used in the event selection
  - Signal Region definitions
  - Sample BDT outputs at the preselection stage
  - Control region studies
  - Systematic uncertainties on the background prediction
  - Additional MT and BDT output distributions
  - Monte Carlo modeling of initial state radiation
  - Signal Regions used for limit extraction
  - Acceptance maps, not in paper
- Additional plots, not in paper
- Code
- Electronic material
- Additional Material to aid the Phenomenology Community with Reinterpretations of these Results

# CMS-SUS-13-011: IMPLEMENTATION

- Analysis very well documented (lots of distribution of variables available)
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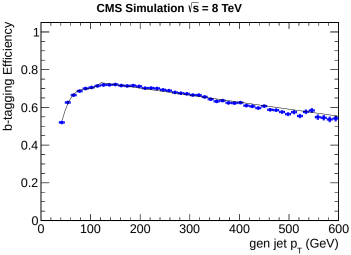


| Parameter | Value |
|---|---|
| $A$ | $(1.55 \pm 0.05) \times 10^{-6}$ |
| $B$ | $(-4.26 \pm 0.12) \times 10^{-4}$ |
| $C$ | $0.0391 \pm 0.0008$ |
| $D$ | $-0.496 \pm 0.020$ |
| $E$ | $(-3.26 \pm 0.01) \times 10^{-4}$ |
| $F$ | $0.7681 \pm 0.0016$ |

$Fit = Ax^3 + Bx^2 + Cx + D$ for $p_T < 120$ GeV, linear $Ex + F$ above

- $b$-tagging efficiency in function of $p_T$ missing but taken from *JHEP* **1401** (2014) 163
- Analysis isolation criteria difficult: relies on so-called PF particles $p_T$ in a cone of given size $\Delta R$.
- Only tracks from the inner detector used for isolation

# CMS-SUS-13-011: CUTFLOWS

- Use of the 11 benchmark points in the physics paper (7 "T2bW" & 4 "T2tt")
- LHE files (partonic event samples) provided by CMS (extremely useful)
- Passed through PYTHIA6 & modified DELPHES 3 (no MC generation)

| benchmark point | CMS result | MA 5 result |
|---|---|---|
| $\tilde{t} \to b\tilde{\chi}_1^{\pm}$, low $\Delta M$, $E_T^{\rm miss} > 150$ GeV | | |
| (250/50/0.5) | 157 ± 9.9 | 193.7 |
| (250/50/0.75) | 399 ± 18 | 533.1 |
| $\tilde{t} \to b\tilde{\chi}_1^{\pm}$, high $\Delta M$, $E_T^{\rm miss} > 150$ GeV | | |
| (450/50/0.25) | 23 ± 2.3 | 27.5 |
| $\tilde{t} \to b\tilde{\chi}_1^{\pm}$, high $\Delta M$, $E_T^{\rm miss} > 250$ GeV | | |
| (600/100/0.5) | 6.1 ± 0.5 | 6.0 |
| (650/50/0.5) | 6.7 ± 0.4 | 6.6 |
| (650/50/0.75) | 6.3 ± 0.4 | 6.2 |

| benchmark point | CMS result | MA 5 result |
|---|---|---|
| $\tilde{t} \to t\tilde{\chi}_1^{0}$, low $\Delta M$, $E_T^{\rm miss} > 150$ GeV | | |
| (250/50) | 108 ± 3.7 | 131.7 |
| $\tilde{t} \to t\tilde{\chi}_1^{0}$, high $\Delta M$, $E_T^{\rm miss} > 300$ GeV | | |
| (650/50) | 3.7 ± 0.1 | 4.5 |

- $m_{\tilde{\chi}_1^+} = x \cdot m_{\tilde{t}_1} + (1-x) m_{\tilde{\chi}_1^0}$.

Very good agreement for $m_{\tilde{t}_1} > 600$ GeV, discrepancies of 20-30% for lighter $\tilde{t}_1$ low $\Delta M$

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| cut | $m_{\tilde{t}_1} = 650$ GeV CMS | $m_{\tilde{t}_1} = 650$ GeV MA 5 | $m_{\tilde{t}_1} = 250$ GeV CMS | $m_{\tilde{t}_1} = 250$ GeV MA 5 |
|---|---|---|---|---|
| $1\ell + \geq$ 4jets+ $\not{E}_T > 50$ | $31.6 \pm 0.3$ | 33.3 | $8033.0 \pm 38.7$ | 8871.4 |
| $+ \not{E}_T > 100$ GeV | $29.7 \pm 0.3$ | 31.4 | $4059.2 \pm 27.5$ | 4634.5 |
| $+ n_b \geq 1$ | $25.2 \pm 0.2$ | 27.1 | $3380.1 \pm 25.1$ | 3930.5 |
| + iso-track veto | $21.0 \pm 0.2$ | 22.5 | $2770.0 \pm 22.7$ | 3229.9 |
| + tau veto | $20.6 \pm 0.2$ | 22.0 | $2683.1 \pm 22.4$ | 3153.5 |
| $+ \Delta\phi_{\rm min} > 0.8$ | $17.8 \pm 0.2$ | 18.9 | $2019.1 \pm 19.4$ | 2509.4 |
| + hadronic $\chi^2 < 5$ | $11.9 \pm 0.2$ | 12.7 | $1375.9 \pm 16.0$ | 1553.1 |
| $+ M_T > 120$ GeV | $9.6 \pm 0.1$ | 10.4 | $355.1 \pm 8.1$ | 406.8 |
| high $\Delta M$, $\not{E}_T > 300$ GeV | $4.2 \pm 0.1$ | 5.1 | — | — |
| low $\Delta M$, $\not{E}_T > 150$ GeV | — | — | $124.0 \pm 4.8$ | 152.3 |

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- For validation cutflows are valuable information
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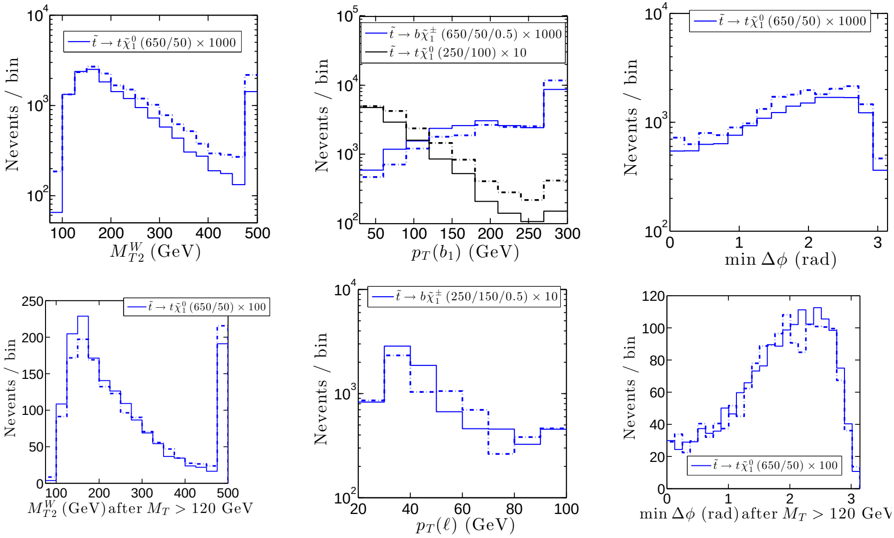
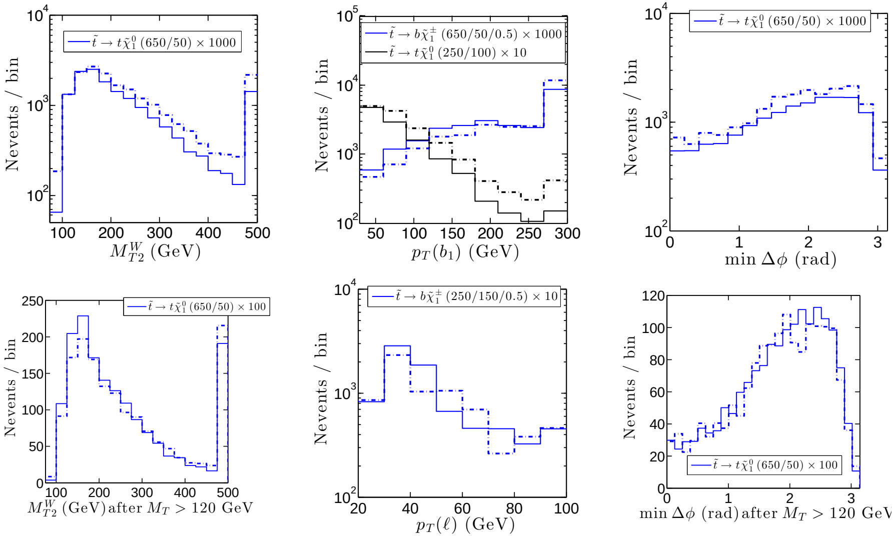
- For validation cutflows are valuable information
- Track step-by-step the analysis
- As isolation difficult → we applied a weighting factor to correct our track-only isolation method
- CMS results reproduced within 20%

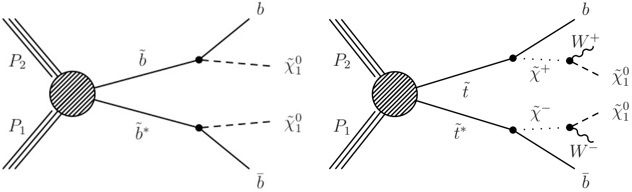

$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 1000
Nevents / bin
$M_{T2}^W$ (GeV)
$\tilde{t} \to b\tilde{\chi}_1^\pm$ (650/50/0.5) × 1000
$\tilde{t} \to t\tilde{\chi}_1^0$ (250/100) × 10
$p_T(b_1)$ (GeV)
$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 1000
min $\Delta\phi$ (rad)
$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 100
$M_{T2}^W$ (GeV) after $M_T > 120$ GeV
$\tilde{t} \to b\tilde{\chi}_1^\pm$ (250/150/0.5) × 10
$p_T(\ell)$ (GeV)
$\tilde{t} \to t\tilde{\chi}_1^0$ (650/50) × 100
min $\Delta\phi$ (rad) after $M_T > 120$ GeV




Reasonable agreement for a fastsim

# ATLAS-SUSY-2013-05: DESCRIPTION

- Search for 3[rd] gen. squarks in the $0\ell + 2b + \not{E}_T$ final state $pp$ collisions at 8 TeV
- Targets $\tilde{b}_1 \to b\tilde{\chi}_1^0$ & $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$

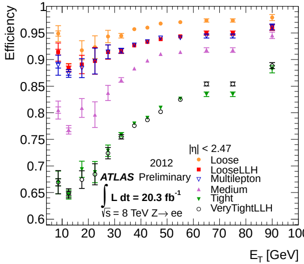


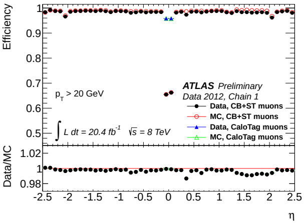

- Two SR defined
  - SRA: large mass splitting $\Delta m = m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$
  - SRB: small $\Delta m$
- SRB selects a high-$p_T$ coming from ISR to increase sensitivity for small $\Delta m$.
- Specific kin variable used: contransverse mass $M_{CT}$ (with ISR boost factor included)

- Similarly to $M_{T2}$, $M_{CT}$ designed to measure masses of pair-produced particles decaying invisibly

- Analysis very well documented for physics (CLs, $\mathcal{A} \times \varepsilon$ plots)
- Analysis less documented for reimplementation/validation purposes (only final distributions, no CF)
- $M_{CT}$ variable implemented using code available from `http://mctlib.hepforge.org/`

- At the detector simulation level we updated the ATLAS card for the $e^{\pm}$ and $\mu^{\pm}$ efficiency



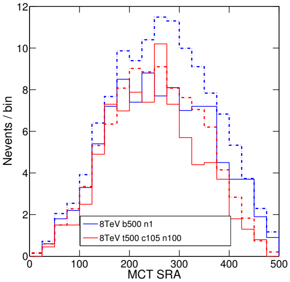



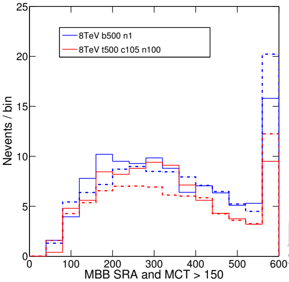

- light-jets, c-jets, $\tau$, $b$-jets rejection factor taken from physics paper

- Only very recently a cutflow table was made available

- No LHE input files were provided by the ATLAS collab.
- Simulate the signal sample through MadGraph5_v1.4.8+PYTHIA6 then passed to DELPHES modified version using generic official SLHA files

- For SRA two benchmark point are given for validation
  - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (500, 1)$ GeV
  - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (500, 105, 100)$ GeV



# ATLAS-SUSY-2013-05: VALIDATION

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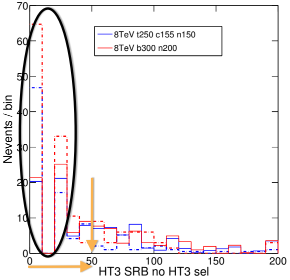
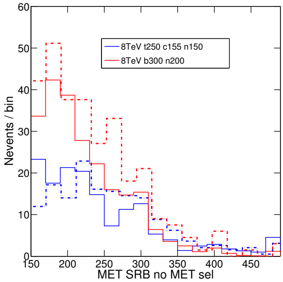
- No LHE input files were provided by the ATLAS collab.
- Simulate the signal sample through MadGraph5_v1.4.8+PYTHIA6 then passed to DELPHES modified version using generic official SLHA files

- For SRB two benchmark point are given for validation
  - $(m_{\tilde{b}_1}, m_{\tilde{\chi}_1^0}) = (300, 200)$ GeV
  - $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (250, 155, 150)$ GeV



- ATLAS-SUSY-2013-19 cutflow on `Twiki Page`: $\tilde{t}_1$ search in $2\ell + (b)j + \not{E}_T$

| | |
|---|---|
| Total events | 100000 |
| Cleaning cuts | 99093.3 |
| Trigger | 25923.2 |
| **same flavour** | |
| Two 10 GeV SF leptons | 3679.1 |
| Isolation | 2844.6 |
| $m_{\ell\ell} > 20$ GeV | 2775.8 |
| opposite sign | 2744.7 |
| Trigger lepton $p_{\mathrm{T}}$ requirements | 2613.5 |
| 2 $b$-jets | 1074.1 |
| $m_{\mathrm{T2}}^{\text{b-jet}} > 160$ GeV | 151.9 |
| $m_{\mathrm{T2}} < 90$ GeV | 147.6 |
| leading lepton $p_{\mathrm{T}}$ <60 GeV | 75.3 |
| **different flavour** | |
| Two 10 GeV DF leptons | 6125.8 |
| Isolation | 4857.8 |
| $m_{\ell\ell} > 20$ GeV | 4726.3 |
| opposite sign | 4670.6 |
| Trigger lepton $p_{\mathrm{T}}$ requirements | 2470.4 |
| 2 $b$-jets | 893.5 |
| $m_{\mathrm{T2}}^{\text{b-jet}} > 160$ GeV | 137.7 |
| $m_{\mathrm{T2}} < 90$ GeV | 135.0 |
| leading lepton $p_{\mathrm{T}} < 60$ GeV | 58.2 |

# TWO EXAMPLES OF GOOD COMMUNICATION

- ATLAS-SUSY-2013-19 cutflow on `Twiki Page`: $\tilde{t}_1$ search in $2\ell + (b)j + \not{E}_T$

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| Two 10 GeV DF leptons | 6125.8 |
| Isolation | 4857.8 |
| $m_{\ell\ell} > 20$ GeV | 4726.3 |
| opposite sign | 4670.6 |
| Trigger lepton $p_{\mathrm{T}}$ requirements | 2470.4 |
| 2 $b$-jets | 893.5 |
| $m_{\mathrm{T2}}^{\text{b-jet}} > 160$ GeV | 137.7 |
| $m_{\mathrm{T2}} < 90$ GeV | 135.0 |
| leading lepton $p_{\mathrm{T}} < 60$ GeV | 58.2 |

$\Longrightarrow$

| | |
|---|---|
| Total events | 100000 |
| Cleaning cuts | 99093 |
| Trigger | 49660 |
| **same flavour** | |
| Two 10 GeV SF leptons | 3668.1 |
| Isolation | 2844.6 |
| opposite sign | 2805.2 |
| $m_{\ell\ell} > 20$ GeV | 2744.7 |
| Trigger lepton $p_{\mathrm{T}}$ requirements | 2613.5 |
| 2 $b$-jets | 1074.1 |
| $m_{\mathrm{T2}}^{\text{b-jet}} > 160$ GeV | 151.9 |
| $m_{\mathrm{T2}} < 90$ GeV | 147.6 |
| leading lepton $p_{\mathrm{T}}$ <60 GeV | 75.3 |
| **different flavour** | |
| Two 10 GeV DF leptons | 3460.3 |
| Isolation | 2699.1 |
| opposite sign | 2660.3 |
| $m_{\ell\ell} > 20$ GeV | 2591.9 |
| Trigger lepton $p_{\mathrm{T}}$ requirements | 2470.4 |
| 2 $b$-jets | 893.5 |
| $m_{\mathrm{T2}}^{\text{b-jet}} > 160$ GeV | 137.7 |
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- CMS-SUS-13-012 private cutflow exchange on `Twiki Page`

Table 1: Cut flow of an benchmark point with gluino mass of 1.1 TeV and LSP mass of 125 GeV. All events are simulated with CMS detector simulation. The number of events is normalized to 19.5 $\text{fb}^{-1}$. Units of cuts on HT and MHT are in GeV.

| Selection | T1qqqq |
|---|---|
| MET cleaning | $53.5 \pm 0.4$ |
| no lepton | $53.4 \pm 0.4$ |
| no lepton+$N_{\text{Jets}} > 2$ | $52.9 \pm 0.4$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$ | $52.8 \pm 0.4$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$+MHT$> 200$ | $44.6 \pm 0.3$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$+MHT$> 200$+min$\Delta\Phi$ | $36.7 \pm 0.3$ |

# TWO EXAMPLES OF GOOD COMMUNICATION

- CMS-SUS-13-012 private cutflow exchange on `Twiki Page`

Table 1: Cut flow of an benchmark point with gluino mass of 1.1 TeV and LSP mass of 125 GeV. All events are simulated with CMS detector simulation. The number of events is normalized to 19.5 $\text{fb}^{-1}$. Units of cuts on HT and MHT are in GeV. The cross section for this process is $\sigma = 0.0102$pb.

| Selection | T1qqqq |
|---|---|
| MET cleaning | $190.6 \pm 1.1$ |
| no lepton | $190.3 \pm 1.1$ |
| no lepton+$N_{\text{Jets}} > 2$ | $188.1 \pm 1.1$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$ | $187.6 \pm 1.1$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$+MHT$> 200$ | $158.7 \pm 1.0$ |
| no lepton+$N_{\text{Jets}} > 2$+HT$> 500$+MHT$> 200$+min$\Delta\Phi$ | $130.8 \pm 0.9$ |

# CONCLUSIONS

- A publicly available analysis database would strengthen LHC legacy
  - Re-use of old analysis
  - in case of NP discovery at 14 TeV $\longrightarrow$ was it already hiding in 7-8 TeV ?
- This is of utmost importance since there is a lot of turnover (PhD, Post-Doc's) in the HEP community
  - some analyses/data of 7 TeV run already lost

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- First steps towards a common analysis database
- Within MA5 3 ATLAS and 3 CMS analyses implemented
- Efficient communication between Theo. & Exp crucial
- Common effort to define new strategies to cover "theory" parameter space

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- More pragmatically:
  - Level of information at least as high as CMS-SUS-13-011 systematically for each analysis desirable
  - `LHE` files available or at least input files for MC (`SLHA`+ configuration)
  - preselection informations crucial (trigger/ID/b-tagging efficiencies)
  - Follow more systematically Les Houches Recommandation for presenting public results arXiv:1203.2489

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