LHC recasting in a nutshell

Fuks Benjamin

LPTHE / UPMC

1st MADANALYSIS 5 workshop on LHC recasting
@ High 1, Gangwon Province, Korea

August 20 - 28, 2017
Outline

1. Introduction
2. The Simplified Model Spectra approach
3. The ‘FastSim-based’ approach
4. Challenges for reimplementing an LHC analysis
5. Preservation of the reimplementation works
6. Some physics results
7. Summary
Introduction
The quest for physics beyond the Standard Model has started!

- How to get hints of new physics?
  - Confront data to the Standard Model expectation in search channels
  - Observe unexplained deviations at a good confidence level

- Ingredient 1: predictions for the Standard Model background
- Ingredient 2: predictions for the new physics signals

More on the new physics nature

- Fitting deviations by new physics signals
  - Designing new analyses to probe new ideas
  - Reinterpretation of data in possibly different theoretical frameworks
  - Leading order MC tools do a proper job
New physics simulations so far

Streamlining the links between models and simulations

- Implementation of any theory in MC tools is straightforward (LO and NLO)

Let's reverse the chain…
Reinterpreting LHC physics analyses

✧ Exploit the full potential of the LHC (for new physics)
  ✧ Priority #1 of the European strategy for particle physics
  ✧ Designing new analyses to probe new ideas
  ✧ Recasting LHC analyses to study models not considered

✧ LHC data has been collected with significant human and financial efforts
  ✧ Important for on-going analyses (within popular theoretical contexts of today)
  ✧ Important for future opportunities (within future scientific contexts)
  ✧ Data preservation in high-energy physics is mandatory
    [ Kogler, South & Steder (JPCS'12) ]
  ✧ Studies are on-going and go beyond raw data (ICFA DPHEP Study Group)

✧ Related tools need to be supported by the entire community
  ✧ Both theorists and experimentalists
  ✧ Allowing for the reinterpretation of the LHC analysis results

[ Kraml et al. (EPJC'12) ]
The LHC has been built as a discovery machine

- There are many ATLAS and CMS searches for new physics
- Interpretation within popular frameworks and simplified models (SMS)

We need to reinterpret the results for all kinds of models
The SMS approach for reinterpretations

✦ The SMS-based reinterpretation framework
  ✤ All signatures of a theory are decomposed according to those of the SMS searches
  ✤ Fiducial cross sections are calculated on the basis of public efficiency maps
  ✤ Comparisons to published upper bounds are made

✦ Main features
  ✤ Extremely fast
  ✤ Moderately accurate and general
    ★ Kinematical configurations often not close to the SMS ones
    ★ Multistep or asymmetric decays
**Existing tools:** FASTLIM, SMODELS, XQCAT

- [Papucci, Sakurai, Weiler & Zeune (EPJC’14)]
- [Kraml et al. (EPJC’14)]
- [Barducci et al. (CPC’15)]

**Examples**

- **Limitations (using SMODELS):** SUSY versus UED

- **MSSM reinterpretations with FASTLIM**

- **Limitations:**
  - $q^{(1)} \in \{u^{(1)}, d^{(1)}, c^{(1)}, s^{(1)}\}$
  - UED-like $q^{(1)}$ production
  - $m_{\tilde{g}^{(1)}} = 2m_{q^{(1)}}$
  - $m_{\tilde{g}^{(1)}} = 4m_{q^{(1)}}$
  - SUSY-T2 (T2 $A_t$)
  - Correct $A_t$
The ‘fastsim’-based approach
Beyond the SMS approach

✦ There are plethora of new physics realizations that deserve to be studied
  ❖ Experimentalists cannot study all the options
  ❖ The simplified model approach is often not sufficient (e.g., different topologies)
  ❖ Our choice: rely on a public detector simulator mimicking ATLAS and CMS
  ❖ Need for a (public) framework where LHC analyses can be easily implemented

✦ Another recasting strategy (as used in MADANALYSIS 5)

✦ 2 options for detector effects
  ★ \textit{DELPHES}/PGS-like (resolutions, efficiencies, etc.)
  ★ \textit{RIVET}-like (transfer functions)
Detector modeling with DELPHES 3

✦ Detector simulation with DELPHES 3

★ Starts from hadron-level MC information
★ Derive calorimetric and track information; object reconstruction is then necessary
  ★ Close to what actually happens in a real experiment
★ DELPHES is modular ➢ extra modules and tuning can be added / included
  ★ Information on lepton isolation or track information; skimming of the output files, etc.

Medium electron efficiency in CHECKMATE

Corresponding implementation in MADANALYSIS 5

![Graph showing medium electron efficiency in CHECKMATE](image)

```plaintext
module Efficiency ElectronEfficiency {
set InputArray ElectronEnergySmearing/electrons
set OutputArray electrons

# efficiency formula for electrons
# medium efficiency from a fit to ATLAS medium electron efficiencies
set EfficiencyFormula {
  (pt < 90.) * ((1.65892e-11)*pt^6 + \\
   -5.71108e-09)*pt^5 + \\
   8.08921e-07)*pt^4 + \\
   -5.88213e-05)*pt^3 + \\
   0.00219812)*pt^2 + \\
   -0.0345875)*pt + 0.968282) + \\
  (pt >= 90.) * 0.945514]
}
```
Current existing programs

✦ Two public programs using DELPHES: CHECKMATE and MADANALYSIS 5
   [ Drees et al. (CPC’14; 2016); Conte, BF & Serret (CPC’12); Conte, Dumont, BF & Wymant (EPJC’14) ]

✦ One private program based on RIVET: ATOM
   [ Kim, Papucci, Sakurai & Weiler ]

✦ RIVET can now be used for new physics
   [ Buckley et al. (CPC’13) ]

✦ CONTUR uses Standard Model searches
   [ Butterworth et al. ]

✦ Examples

Constraining the inert Higgs doublet model with SUSY searches and MADANALYSIS 5
Confronting a BSM signal to LHC analyses is straightforward

✦ Starting point: a showered/hadronized event file
✦ Installation of the detector simulators: ‘install DELPHES’
✦ Installation of the analysis libraries: ‘install PAD’ (more analyses with the MA5tune)

In practice:

Snippet of the recasting card (only on/off switches to be set by the user)

✦ O(20) 8 TeV ATLAS and CMS analyses; O(5) 13 TeV ATLAS+CMS analyses

<table>
<thead>
<tr>
<th></th>
<th>v1.2</th>
<th>on</th>
<th>delphes_card_ATLAS_1604_07773.tcl</th>
<th># ATLAS - 13 TeV - multijet (2-6 jets) + met</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS_1604_07773</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_ATLAS_1604_07773.tcl</td>
<td># ATLAS - 13 TeV - monojet</td>
</tr>
<tr>
<td>ATLAS_EXOT_2014_06</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_ATLAS_SUS_2013_05_pad.tcl</td>
<td># ATLAS - 8 TeV - monophoton</td>
</tr>
<tr>
<td>cms_exo_12_047</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_CMS_B2G_12_012.tcl</td>
<td># CMS - 8 TeV - monophoton</td>
</tr>
<tr>
<td>cms_exo_12_048</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_CMS_B2G_12_012.tcl</td>
<td># CMS - 8 TeV - monojet</td>
</tr>
<tr>
<td>cms_B2G_14_084</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_CMS_B2G_14_084.tcl</td>
<td># CMS - 8 TeV - Dark matter production with a t\bar{t} pair</td>
</tr>
<tr>
<td>cms_B2G_12_022</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_CMS_B2G_14_084.tcl</td>
<td># CMS - 8 TeV - Monotop search</td>
</tr>
<tr>
<td>CMS_B2G_12_012</td>
<td>v1.2</td>
<td>on</td>
<td>delphes_card_CMS_B2G_12_012.tcl</td>
<td># CMS - 8 TeV - T5/3 partners in the SSDL channel</td>
</tr>
</tbody>
</table>
Recasting made easy with MADANALYSIS 5 (2)

Snippet of the output file (example: low statistics ➞ lots of ‘-1’ in the example)

- CLs if a signal cross section is provided
- Cross sections excluded at the 95% CL

<table>
<thead>
<tr>
<th>ATLAS_1604_07773</th>
<th>EM1</th>
<th>25.8538538</th>
<th>27.4980471</th>
<th>I</th>
<th>0.0100000</th>
<th>0.0099499</th>
<th>0.0000000</th>
<th>0.0099499</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM2</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM3</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM4</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM5</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM6</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>EM7</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM1</td>
<td>58.3118133</td>
<td>52.7020233</td>
<td>I</td>
<td>0.0100000</td>
<td>0.0099499</td>
<td>0.0000000</td>
<td>0.0099499</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM2</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM3</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM4</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM5</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ATLAS_1604_07773</td>
<td>IM6</td>
<td>-1</td>
<td>-1</td>
<td>I</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>
Reimplementation challenges
Reimplementing an analysis: the challenges

Recasting strategy (as in MADANALYSIS 5)

How easy is it to implement (and validate) an LHC analysis?
Implementing a new analysis in a recasting tool

- Picking up an experimental publication
  - Reading
  - Understanding
  - Relatively easy

- Writing the analysis code in the tool internal language
  - Relatively easy

- Getting the information missing from the publication for a proper validation
  - Efficiencies (trigger, electrons, muons, b-tagging, JES, etc.)
    - Including $p_T$ and/or $\eta$ dependence
    - Accurate information
  - Detailed cutflows for some well-defined benchmark scenarios
    - Exact definition of the benchmarks (spectra)
    - Event generation information (cards, tunes, etc.)
  - Expected number of events in each region and cross sections
  - Digitized histograms (e.g., on HEPDATA)
  - Essential
  - Often difficult!

- Comparing theory tools and real life
**Ex. 1: CMS-SUS-13-11 (stops with one lepton)**

- Missing information for the validation
  - Efficiencies
  - Cutflows and Monte Carlo information for given benchmarks

- All missing information was provided
  - [Additional Material to aid the Phenomenology Community with Reinterpretations of these Results](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS13011#Additional_Material_to_aid_the_P)
  - Update of the analysis wiki page
  - Shared LHE files and PYTHIA cards

- Validation

<table>
<thead>
<tr>
<th>Cut</th>
<th>MadAnalysis 5</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least one lepton, four jets and 100 GeV of missing transverse energy</td>
<td>31.4</td>
<td>29.7</td>
</tr>
<tr>
<td>At least one $b$-tagged jet</td>
<td>27.1</td>
<td>25.2</td>
</tr>
<tr>
<td>No extra loosely-isolated lepton or track</td>
<td>22.5</td>
<td>21.0</td>
</tr>
<tr>
<td>No hadronic tau</td>
<td>22.0</td>
<td>20.6</td>
</tr>
<tr>
<td>Angular separation between the missing momentum and the two hardest jets</td>
<td>18.9</td>
<td>17.8</td>
</tr>
<tr>
<td>Hadronic top quark reconstruction</td>
<td>12.7</td>
<td>11.9</td>
</tr>
<tr>
<td>The transverse mass $M_T$ (defined in the text) is larger than 120 GeV</td>
<td>10.4</td>
<td>9.6</td>
</tr>
<tr>
<td>At least 300 GeV of missing transverse energy and $M_{T^W} &gt; 200$ GeV</td>
<td>5.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>
Ex. 2: ATLAS-EXO-2014-04 (monophoton)

- Missing information
  - Crack in the detector: no photons in the \([1.37-1.52]\) \(\eta\)-range
  - Tight photon requirements
    - Discussions with ATLAS needed
- Event generation for the test benchmarks
  - Monte Carlo information (cards, tunes, etc.)
    - Kindly provided by ATLAS

**Very good results**
(ratio of efficiencies)

![Graph showing MA5/ATLAS: \(A \epsilon\) [%]](image_url)
### Validation:

<table>
<thead>
<tr>
<th>Selection step</th>
<th>CMS</th>
<th>(\epsilon_{CMS}^i)</th>
<th>MA5</th>
<th>(\epsilon_{MA5}^i)</th>
<th>(\delta_{rel}^i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nominal</td>
<td>84653.7</td>
<td>84653.7</td>
<td>84653.7</td>
<td>5.2%</td>
</tr>
<tr>
<td>1</td>
<td>One hard jet</td>
<td>50817.2</td>
<td>0.6</td>
<td>53431.28</td>
<td>0.721</td>
</tr>
<tr>
<td>2</td>
<td>At most two jets</td>
<td>36061</td>
<td>0.7096</td>
<td>38547.75</td>
<td>1.000</td>
</tr>
<tr>
<td>3</td>
<td>Requirements if two jets</td>
<td>31878.1</td>
<td>0.884</td>
<td>34436.35</td>
<td>0.893</td>
</tr>
<tr>
<td>4</td>
<td>Muon veto</td>
<td>31878.1</td>
<td>1</td>
<td>34436.35</td>
<td>1.000</td>
</tr>
<tr>
<td>5</td>
<td>Electron veto</td>
<td>31865.1</td>
<td>1</td>
<td>34436.35</td>
<td>1.000</td>
</tr>
<tr>
<td>6</td>
<td>Tau veto</td>
<td>31695.1</td>
<td>0.995</td>
<td>34397.54</td>
<td>0.998</td>
</tr>
<tr>
<td>(E_T &gt; 250) GeV</td>
<td></td>
<td>8687.22</td>
<td>0.274</td>
<td>7563.04</td>
<td>0.219</td>
</tr>
<tr>
<td>(E_T &gt; 300) GeV</td>
<td></td>
<td>5400.51</td>
<td>0.621</td>
<td>4477.67</td>
<td>0.592</td>
</tr>
<tr>
<td>(E_T &gt; 350) GeV</td>
<td></td>
<td>3394.09</td>
<td>0.628</td>
<td>2813.70</td>
<td>0.628</td>
</tr>
<tr>
<td>(E_T &gt; 400) GeV</td>
<td></td>
<td>2224.15</td>
<td>0.6553</td>
<td>1753.71</td>
<td>0.623</td>
</tr>
<tr>
<td>(E_T &gt; 450) GeV</td>
<td></td>
<td>1456.02</td>
<td>0.654</td>
<td>1110.92</td>
<td>0.633</td>
</tr>
<tr>
<td>(E_T &gt; 500) GeV</td>
<td></td>
<td>989.806</td>
<td>0.679</td>
<td>722.83</td>
<td>0.650</td>
</tr>
<tr>
<td>(E_T &gt; 550) GeV</td>
<td></td>
<td>671.442</td>
<td>0.678</td>
<td>487.54</td>
<td>0.674</td>
</tr>
</tbody>
</table>

- **Validated at the 20% level**
- **Issue with the low-MET modelling in DELPHES**
- **Discussions with CMS needed**
- **Validated at the 20% level**
Ex.4 : When things are borderline...

✦ ATLAS-EXOT-2014-04 (monophotons)
  ❖ Effects non-reproducible with DELPHES (cleaning cuts, triggers, good vertexing)

✦ ATLAS-SUS-2013-09 (stops in the dilepton channel)
  ❖ Information on effects non-reproducible with DELPHES lost (student quitted)

⚠ Efficiencies computed by hand
  Maybe model-dependent

<table>
<thead>
<tr>
<th>Cut</th>
<th>ATLAS</th>
<th>Rel. decr.</th>
<th>MA5 (u1 u1~)</th>
<th>Rel. decr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>9989</td>
<td></td>
<td>9989</td>
<td></td>
</tr>
<tr>
<td>a. Trigger</td>
<td>8582</td>
<td></td>
<td>2637</td>
<td>-39.8</td>
</tr>
<tr>
<td>b. Good Vertex</td>
<td>8574</td>
<td></td>
<td>2052</td>
<td>-22.2</td>
</tr>
<tr>
<td>c. Cleaning cuts</td>
<td>8213</td>
<td></td>
<td>1856</td>
<td>-9.6</td>
</tr>
<tr>
<td>0. $E_T^{miss} &gt; 150$ GeV</td>
<td>4131</td>
<td>2645</td>
<td>2637</td>
<td>1887</td>
</tr>
<tr>
<td>1. 1 loose $\gamma$, $p_T &gt; 125$ GeV, $</td>
<td>\eta</td>
<td>&lt; 2.37$</td>
<td>2645</td>
<td>-36.0</td>
</tr>
<tr>
<td>2. Tight leading $\gamma$ with $</td>
<td>\eta</td>
<td>&lt; 1.37$</td>
<td>2068</td>
<td>-21.8</td>
</tr>
<tr>
<td>3. Isolated leading $\gamma$</td>
<td>1898</td>
<td>-8.2</td>
<td>1856</td>
<td>-9.6</td>
</tr>
<tr>
<td>4. $\Delta \phi(\gamma^{leading}, E_T^{miss}) &gt; 0.4$</td>
<td>1887</td>
<td>-0.6</td>
<td>1840</td>
<td>-0.8</td>
</tr>
<tr>
<td>5. $N_{jet} \leq 1$ and $\Delta \phi(jet, E_T^{miss}) &gt; 0.4$</td>
<td>1219</td>
<td>-35.4</td>
<td>1234</td>
<td>-33.0</td>
</tr>
<tr>
<td>6. Lepton veto</td>
<td>1188</td>
<td>-2.5</td>
<td>1233</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

Very good results (for a SUSY benchmark)

[ Barducci ('15) ]
Ex.5: And the darkness came...

- Missing or incomplete validation information
  - CMS-SUS-12-028 ($\alpha_T$)
    - No cutflows; no answers from CMS to requests
  - CMS-SUS-13-007 (1 lepton+b-jets+met)
    - Semi-official validation material (that cannot be used for a public validation)
    - No cutflows
    - Messy definition of the benchmark points

- Dead end!

- Missing or incomplete analysis information
  - ATLAS-EXOT-2013-10 (monolepton)
    - The average trigger efficiency is 80%-90% in the muon channel
    - 80% of the muons are reconstructed with most of the loss coming from...
    - No precise information on signal event generation
    - No signal distributions on HEPDATA

- Too vague!

Unfortunately: many more examples!
A wishlist for experimentalists - analysis

✨ Analysis description

✧ Clear description of the selections, including their sequence
  ★ Tabulated form appreciable

✧ Efficiencies for objects (electrons, muons, jets, taus, b-tagging, etc.)
  ★ Including $p_T$ and $\eta$ dependence

✧ Efficiencies for triggers, event cleaning, etc.
  ★ Effects that cannot be modeled in our fast simulation

✧ Digitized figures (ROOT format, text format, etc.)

✧ Special variables (e.g., the CMS razor, asymmetric $M_{T2}$)
  ★ Snippets of code highly appreciated
A wishlist to experimentalists - validation

- **Validation material ➔ quality of the reinterpretation**
  - Public information on benchmark scenarios
    - Spectra and decay tables (under an SLHA-form)
    - Several scenarios are appreciable
  - Public information on the Monte Carlo tools configuration
    - Cards, tunes, merging information, etc.
  - Detailed cutflows for the benchmarks, with the correct cut ordering
    - Including each step of the (pre)selection
    - For several benchmarks
    - The more steps available, the better (preselection, cleaning, etc.)
      (pin down the differences of our machinery with CMS-ATLAS simulations)
  - Kinematical distributions at different steps of the selection
    - Extra cross-checks
Preservation
Recasting strategy (as in MADANALYSIS 5)

1. Signal events (STDHEP or HEPMC format)
2. Tuned detector simulation
3. Recast selection
4. Limit computation
5. Numbers of data and background events
6. How to store recasted analyses? Part of the LHC legacy

Part of the LHC legacy

Recasting strategy (as in MADANALYSIS 5)
Implementation of LHC analyses can be uploaded on INSPIRE

DOI are assigned: can be cited, searched for, etc.

MadAnalysis5 implementation of the CMS search for dark matter production with top quark pairs in the single lepton channel (CMS-B2G-14-004)

DOI and citations

Fuks, Benjamin; Martini, Antony

Description: This is the MadAnalysis5 implementation of the CMS search for dark matter in a channel where a pair of dark matter particles is produced in association with a top-antitop system. This search targets events featuring a single lepton originating from the top decays and a large amount of missing transverse energy.

Information how to use this code and a detailed validation summary are available at http://madanalysis.irmp.ucl.ac.be/wiki/PhysicsAnalysisDatabase. The CMS analysis is documented at https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G14004.


Automatic installation of all implemented analyses from MadAnalysis5

Record added 2016-05-09, last modified 2016-05-09
A database with MADANALYSIS 5 implementations of LHC analyses exists

**http://madanalysis.irmp.ucl.ac.be/wiki/PublicAnalysisDatabase**

Snippet of the webpage

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Short Description</th>
<th>Implemented by</th>
<th>Code</th>
<th>Validation note</th>
<th>Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS-EXOT-2015-03</td>
<td>monojet + missing transverse energy</td>
<td>D. Sengupta</td>
<td>Inspire</td>
<td>PDF</td>
<td>v1.3/Delphes3</td>
</tr>
</tbody>
</table>

Can be automatically installed within MADANALYSIS 5
Physics
NLO effects on a CLs: top-philic dark matter

✦ A simplified model for top-philic dark matter
  ✦ A dark sector with a fermionic dark matter candidate \( X \)
  ✦ A (scalar) mediator \( Y_0 \) linking the dark sector and the top

\[
\mathcal{L}_{t,X}^{Y_0} = - \left( g_t \frac{y_t}{\sqrt{2}} \bar{t}t + g_X \bar{X}X \right) Y_0
\]

✦ Could be probed with \( tt+\text{MET} \) events (CMS-B2G-14-004)

♪ For central scales: mild (but visible) NLO effects on the exclusions

How is the picture changing when including scale variations?
There are theoretical uncertainties on a CLs number

<table>
<thead>
<tr>
<th>(m_Y, m_X)</th>
<th>σ_{LO} [pb]</th>
<th>CL_{LO} [%]</th>
<th>σ_{NLO} [pb]</th>
<th>CL_{NLO} [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (150, 25) GeV</td>
<td>0.658⁺34.9⁻24.0</td>
<td>98.7⁺0.8⁻13.0</td>
<td>0.773⁺6.1⁻10.1</td>
<td>95.0⁺2.7⁻0.4</td>
</tr>
<tr>
<td>II (40, 30) GeV</td>
<td>0.776⁺34.2⁻24.1</td>
<td>74.7⁺19.7⁻17.7</td>
<td>0.926⁺5.7⁻10.4</td>
<td>84.2⁺0.4⁻14.4</td>
</tr>
<tr>
<td>III (240, 100) GeV</td>
<td>0.187⁺37.1⁻24.4</td>
<td>91.6⁺6.4⁻18.1</td>
<td>0.216⁺6.7⁻11.4</td>
<td>86.5⁺8.6⁻5.5</td>
</tr>
</tbody>
</table>

- An excluded point (95% CL) may not be excluded when accounting for errors
- The CLs number can increase / decrease at NLO
- The error band is reduced
Summary

✦ The LHC legacy
✦ It is crucial to be able to reinterpret the LHC results in any theoretical context
✦ This is a very active field of the last few years: several tools are available
✦ Reproducibility is the ability of an entire experiment to be reproduced, (possibly by an independent theoretical study)

✦ Two approaches
✦ The simplified model spectrum approach (based on efficiencies and cross sections)
✦ The fastsim strategy (simulating the detector in some ways)

✦ Recasting in MADANALYSIS 5
✦ MADANALYSIS 5 has been actively developed along the ‘fastsim strategy’ lines
   ★ User-friendly way to confront any MC-simulated BSM signal to LHC results