Checkmating New Physics at the LHC

Krzysztof Rolbiecki
University of Warsaw

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D. Dercks, N. Desai, M. Drees, H. Dreiner, J. S. Kim, KR, J. Tattersall, T. Weber
with contributions from
S. Belkner, A. Biekoetter, T. Keller, F. Ponzca, J. Schutte-Engel

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Check **M**odels **A**t **T**erascale **E**nergies

http://checkmate.hepforge.org

1. What is CheckMATE?
2. Testing models against current LHC results
3. Testing new ideas for future LHC results

Minimal Running Example

- Step 1: Decide on a SUSY parameter point `benchmark1.slha`
- Step 2: Set up parameters `param.dat`

```
[Parameters]
SLHAFile: /scratch/benchmark1.slha

[squ_asq]
Pythia8Process: p p > sq sq~
MaxEvents: 1000
```

Minimal Running Example

- Step 1: Decide on a SUSY parameter point `benchmark1.slha`
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- Step 3: Run `./CheckMATE`

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- Wait.

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```
[Parameters]
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[squ_asq]
Pythia8Process: p p > sq sq~
MaxEvents: 1000
```
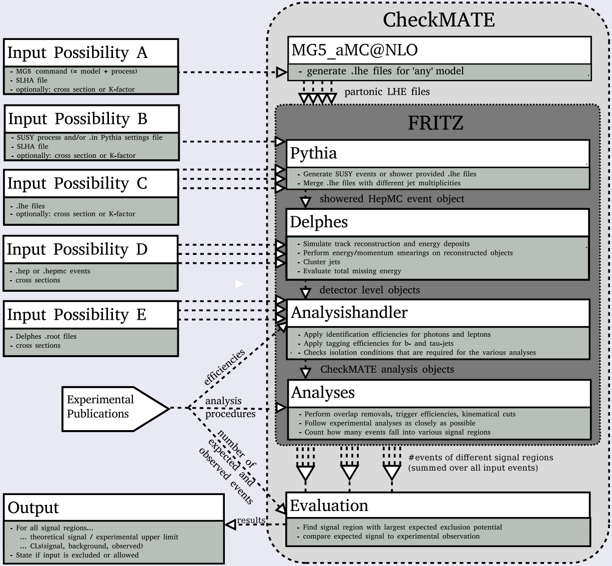

```
Result:  Allowed
Result for r: r_max = 0.74
SR: atlas_conf_2013_047 - ET
```

or

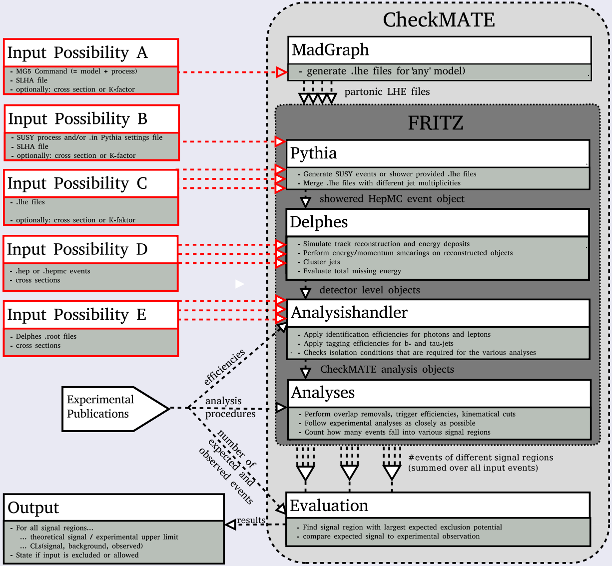
```
Result: Excluded
Result for r: r_max = 1.33
SR: atlas_conf_2013_047 - A
```

You quickly know if your model has been excluded or not by current LHC results

Overview: Data Flow



Input


CheckMATE
Input Possibility A
- MG5 Command (= model + process)
- SLHA file
- optionally: cross section or K-factor
Input Possibility B
- SUSY process and/or .in Pythia settings file
- SLHA file
- optionally: cross section or K-factor
Input Possibility C
- .lhe files
- optionally: cross section or K-faktor
Input Possibility D
- .hep or .hepmc events
- cross sections
Input Possibility E
- Delphes .root files
- cross sections
MadGraph
- generate .lhe files for 'any' model)
partonic LHE files
FRITZ
Pythia
- Generate SUSY events or shower provided .lhe files
- Merge .lhe files with different jet multiplicities
showered HepMC event object
Delphes
- Simulate track reconstruction and energy deposits
- Perform energy/momentum smearings on reconstructed objects
- Cluster jets
- Evaluate total missing energy
detector level objects
Analysishandler
- Apply identification efficiencies for photons and leptons
- Apply tagging efficiencies for b- and tau-jets
- Checks isolation conditions that are required for the various analyses
CheckMATE analysis objects
Analyses
- Perform overlap removals, trigger efficiencies, kinematical cuts
- Follow experimental analyses as closely as possible
- Count how many events fall into various signal regions
Experimental Publications
efficiencies
analysis procedures
number of expected and observed events
#events of different signal regions (summed over all input events)
Evaluation
- Find signal region with largest expected exclusion potential
- compare expected signal to experimental observation
results
Output
- For all signal regions...
... theoretical signal / experimental upper limit
... CLs(signal, background, observed)
- State if input is excluded or allowed

Different Input Methods

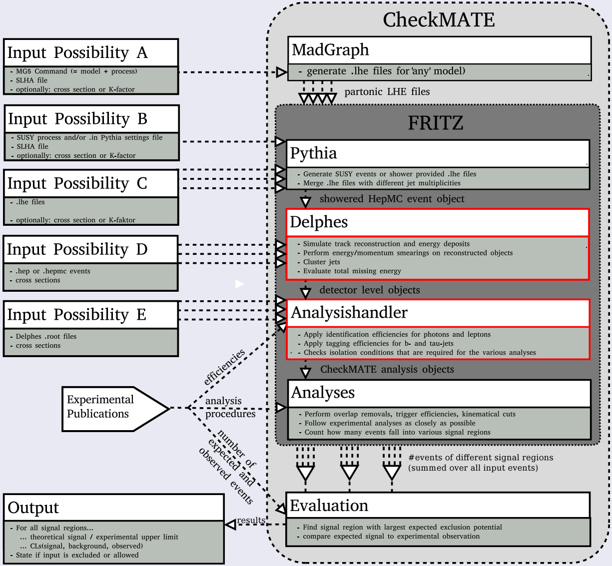
checkmate_input_parameter.dat

```
[Parameters]
SLHAFile: /scratch/point.slha

[squ_asq]
Pythia8Process: p p > sq sq~

[squ_squ]
MGCommand: import model mssm
    define sq = ~ul ~ur ~dl ~dr ~sl ~
    generate p p > sq sq

[glu_glu]
Events: /scratch/glu_glu.lhe

[glu_sq]
Events: /scratch/glu_squ_1.hepmc,
        /scratch/glu_squ_2.hepmc
XSect: 0.75 fb
```

Possibilities

1. Internal `Pythia8` for parton event generation and parton showering (*Limited to certain BSM models*)
2. Internal `MG5_aMC@NLO` for parton event generation, `Pythia8` for parton showering (*Works for 'any' BSM model*)
3. External parton event generation, internal `Pythia8` for parton showering
4. External parton showered events

Detector simulation



Detector Simulation

Delphes 3.3.3

- Simulates tracking and energy deposition
- Applies efficiencies for photons and leptons
- Clusters jets
- Performs energy/momentum smearings of all reconstructed objects
- Evaluates total missing energy
- Checks isolation conditions for photons and leptons
- Applies b-/ tau-tag on jets

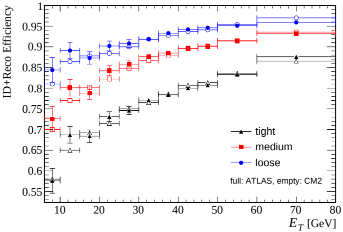
DELPHES
fast simulation

CheckMATE improvements

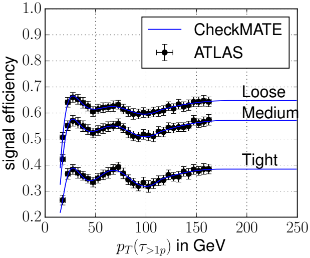
- Added identification and isolation flags
- Tuned to reproduce LHC detectors:
    - ATLAS mostly finished for 13 TeV Run
    - CMS work in progress

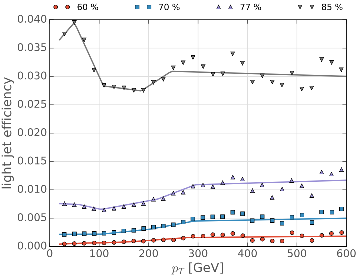
Detector Tunings — Examples

e reconstruction eff.

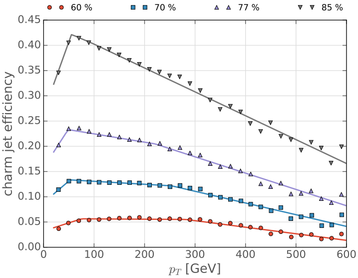


τ-jet eff.



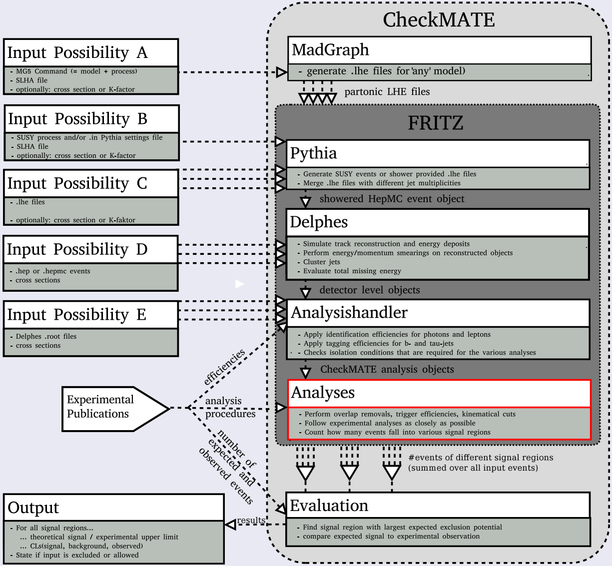


light jet eff.



c-jet eff

Step 2: Analyses



Analyses

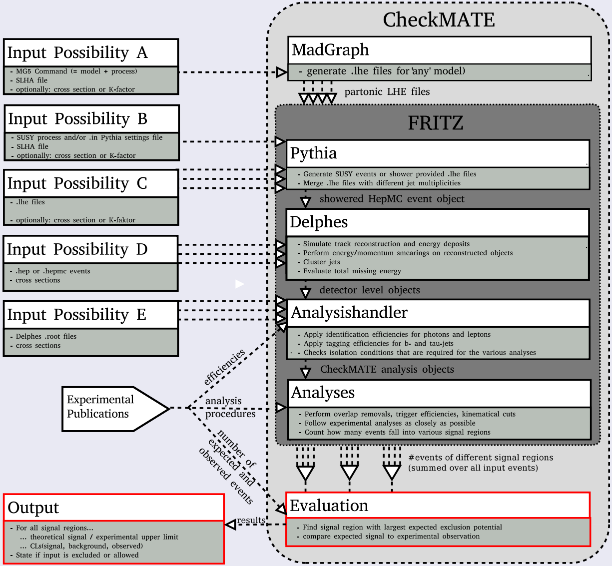
A CheckMATE analysis does the following

- Choose the objects of interest (leptons, jets,...)
- Filter objects (efficiency and isolation flags, kinematical cuts, overlap removals, ...)
- Check event vetoes (Too many/few objects, trigger efficiencies, ...)
- Check various signal region criteria (total $\not{E}_T$, # and energy of objects, ...)
- Count number of input events that fall into each signal region
- Make plots, save additional data etc.

Example Output

```
# ATLAS-CONF-2013-047
# 0 leptons, 2-6 jets, etmiss
# sqrt(s) = 8 TeV
# int(L) = 20.3 fb^-1

Inputfile:          /hdd/results/cMSSM/delphes/000_delphes.root
XSect:              4.35 fb
 Error:             1.22086 fb
MCEvents:           5000
 SumOfWeights:      5000
 SumOfWeights2:     5000
 NormEvents:        87.9518

SR  Sum_W  Sum_W2  Acc     N_Norm
AL  1315   1315    0.263   23.1313
AM  71     71      0.0142  1.24892
BM  98     98      0.0196  1.72385
BT  2      2       0.0004  0.0351807
CM  505    505     0.101   8.88313
CT  9      9       0.0018  0.158313
D   184    184     0.0368  3.23663
EL  613    613     0.1226  10.7829
EM  398    398     0.0796  7.00096
```

Step 3: Evaluation



Evaluation

Input and Setup

- We have number of expected signal $S \pm \Delta S$ in each signal region
- `CheckMATE` has a reference card with experimental results:
  - observed events O
  - expected background plus uncertainty $B \pm \Delta B$
  - (in most cases) translated 95% upper limit on signal S^{95}_{max}

Evaluation

Input and Setup

- We have number of expected signal $S \pm \Delta S$ in each signal region
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  - observed events O
  - expected background plus uncertainty $B \pm \Delta B$
  - (in most cases) translated 95% upper limit on signal S^{95}_{max}

User can choose

- Directly compare S to S^{95}_{max}
- If $r^{\text{c}} = \frac{S - 2\Delta S}{S^{95}_{\text{max}}} > 1$: Excluded!
- Quick and easy for limit setting

- Evaluate $\text{CL}_s(O, B, \Delta B, S, \Delta S)$
- If $\text{CL}_s < 0.05$: Excluded!
- Slower, but limits can be set to different confidence levels

Selected Analyses at 13 TeV (out of $\sim$ 70 available)

Name	Search designed for	L	N_{SR}
atlas_conf_2016_050	stops in events with an isolated lepton, jets and $\not{E}_T$	13.3	5
atlas_conf_2016_054	1 lepton + (b) jets + $\not{E}_T$	14.8	10
atlas_conf_2016_076	SUSY with 2 leptons + jets + $\not{E}_T$	13.3	6
atlas_conf_2016_096	2-3 leptons + $\not{E}_T$ (electroweak)	13.3	6
atlas_conf_2017_060	monojet search	36.1	20
atlas_conf_2017_039	2-3 leptons + $\not{E}_T$	36.1	37
atlas_conf_2017_019	search for stops with Higgs or Z	36.1	6
atlas_conf_2017_040	mono-Z: Z + $\not{E}_T$	36.1	2
atlas_1710_11412	dark matter with bottom or top quarks	36.1	1
atlas_1712_02332	squarks and gluinos, 0 lepton, 2-6 jets, $\not{E}_T$	36.1	24
atlas_1704_03848	monophoton dark matter search	36.1	5
atlas_1712_08119	electroweakinos search with soft leptons	36.1	39
atlas_1709_04183	stop pair production, 0 leptons	36.1	14
atlas_1802_03158	search for GMSB with photons	36.1	7
atlas_1708_07875	electroweakino search with taus and $\not{E}_T$	36.1	2
atlas_1706_03731	same-sign or 3 leptons RPC and RPV SUSY	36.1	19
cms_sus_16_025	electroweakino and stop compressed spectra	12.9	14
cms_sus_16_039	electrowekinos in multilepton final state	35.9	158
cms_sus_16_048	soft opposite sign leptons	35.9	20

Selected Analyses at 13 TeV (out of $\sim$ 70 available)

Name	Search designed for	L	N_{SR}
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atlas_conf_2016_054	1 lepton + (b) jets + $\not{E}_T$	14.8	10

What if an analysis is not listed or doesn't exist yet?

- Use `AnalysisManager` to create a new one
- Answer questions to setup framework
- Code in C++ actual selections

Name	Search designed for	L	N_{SR}
atlas_1709_04183	stop pair production, 0 leptons	36.1	14
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cms_sus_16_048	soft opposite sign leptons	35.9	20

The Analysis Manager

Running the Analysis Manager

- Run `make AnalysisManager; /bin/AnalysisManager`

```
  ____ _               _    __  __    _  _____ _____
 / ___| |__   ___  ___| | _|  \/  |  / \|_   _| ____|
| |   | '_ \ / _ \/ __| |/ / |\/| | / _ \ | | |  _|
| |___| | | |  __/ (__|   <| |  | |/ ___ \| | | |___
 \____|_| |_|\___|\___|_|\_\_|  |_/_/   \_\_| |_____|

                   /\  _  _ |   _. _   |\/| _  _  _  _  _ _
                  /--\| )(_||\/_)|_)   |  |(_|| )(_|(_)(-|
                             /                      _/

What would you like to do?
  -(l)ist all analyses,
  -(a)dd a new analysis to CheckMATE,
  -(r)emove an analysis from CheckMATE
```

The Analysis Manager

Adding an analysis

```
    a
This will collect all necessary information to create a full analysis and
Takes care for the creation and implementation of the source files into the code.
Please answer the following questions.
Attention: Your input is NOT saved before you finish this questionnaire.
1. General Information to build analysis
Analysis Name:
       ATLAS_1234_5678
Description (short, one line):
       ATLAS: many leptons, few jets
Description (long, multiple lines, finish with ';;' on a new line):
       ATLAS
       many leptons, few jets
       sqrt(s) = 9 TeV
       int(L) = 42 fb^-1
       ;;
Luminosity (in fb^-1):
       42
Do you plan to implement control regions to that analysis? [(y)es, (n)o)
       n
```

Adding an analysis

```
2. Information on Signal Regions
List all signal regions (one per line, finish with ';;' on a new line):
 1l
 2l
[...]
Is the SM expectation B known? [(y)es, (n)o]?
```

```
 y
You now have to add the
numbers for each of the
given signal regions.
1l
obs:
 100
bkg:
 90
bkg_err:
 15
2l
obs:
 200
bkg:
 180
bkg_err:
 30
[...]
```

```
 n
Signal regions are registered but without any
numbers associated to them.
IMPORTANT: The analysis will be created and can
then be used like any other analysis.
CheckMATE will skip the model exclusion
tests as long as the expectation is not
known. You can e.g. use CheckMATE on background
samples to estimate B and dB. As soon as
you know these numbers, run the
AnalysisManager again and use the (e)dit
feature to add them.
```

Adding an analysis

```
2. Information on Signal Regions
List all signal regions (one per line, finish with ';;' on a new line):
 11
 21
[...]
Is the SM expectation B known? [(y)es, (n)o]?
```

```
  y
You now have to add the
numbers for each of the
```

```
 n
Signal regions are registered but without any
numbers associated to them.
IMPORTANT: The analysis will be created and can
```

Add a published analysis

- Provide results straight away
- Typical mode for 8 and 13 TeV
- Compare with existing distributions

```
[...]
```

Add a new analysis

- run on SM backgrounds first
- add these results to CM
- Typical mode to project to 13 and 14 TeV and to invent new cutflows or observbles

The Analysis Manager

Adding an analysis

```
3. Settings for Detector Simulation
3.1: Miscellaneous
To which experiment does the analysis correspond? (A)TLAS, (C)MS
 A
3.2: Electron Isolation
Do you need any particular isolation criterion? [(y)es, (n)o]
 y
Isolation 1:
Which objects should be considered for isolation? [(t)racks, (c)alo objects?
 t
What is the minimum pt of a surrounding object to be used for isolation? [in GeV]
 5
What is the dR used for isolation?
 0.4
Is there an absolute or a relative upper limit for the surrounding pt? [(a)bsolute, (r)elative]
 a
What is the maximum surrounding pt used for isolation [in GeV]?
 20

Do you need more isolation criteria? [(y)es, (n)o]
 n
3.3: Muon Isolation
Do you need any particular isolation criterion? [(y)es, (n)o]
 n
3.4: Photon Isolation
Do you need any particular isolation criterion? [(y)es, (n)o]
 n
```

The Analysis Manager

Adding an analysis

```
3.5: Jets
Which dR cone radius do you want to use for the FastJet algorithm?
 0.4
What is the minimum pt of a jet? [in GeV]
 10
Do you need a separate, extra type of jet? [(y)es, (n)o]
 n
Do you want to use b-tagging? [(y)es, (n)o]
 y

b-Tagging 1:
What is the signal efficiency to tag a b-jet? [in %]
 70
Do you need more b tags? [(y)es, (n)o]
 y

b-Tagging 2:
What is the signal efficiency to tag a b-jet? [in %]
 40
Do you need more b tags? [(y)es, (n)o]
 n

Do you want to use tau-tagging? [(y)es, (n)o]
 n
```

Some example lines

```
void Atlas_1609_01599::analyze() {
  missingET->addMuons(muonsCombined);
  electronsMedium = filterPhaseSpace(electronsMedium, 7., -2.47, 2.47, tru
  muonsCombined = filterPhaseSpace(muonsCombined, 7., -2.4, 2.4);
  jets = filterPhaseSpace(jets, 25., -2.5, 2.5);
  [...]
  if ( muonsCombined.size() > 1 && muonsCombined[0]->Charge*muonsCombined[
    if ( nbjets > 1 ) countCutflowEvent("muSS_04_bjets>0");
    else return;
    if ( muSS && electronsMedium.size() == 0 && muonsCombined.size() == 2)
    else return;
    if (muSS && muonsCombined[1]->PT > 25.) countCutflowEvent("muSS_06_pT>
    else return;
    if (muSS && MET > 40.) countCutflowEvent("muSS_07_met>40");
    else return;
    if (muSS && ht > 240. ) {
      countCutflowEvent("muSS_08_ht>240");
      countSignalEvent("2muSS");
    }
  }
```

Conclusions

- CheckMATE is a very simple to use LHC-phenomenology tool
- It is fully model independent
- Enables testing against many BSM searches and SM measurements
- It can be used to check against existing results **or** to do prospective studies
- Can be used to compare higher order calculations to differential distributions measured at the LHC

http://checkmate.hepforge.org/

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Installation (additionally also NNLLfast):

http://checkmate.hepforge.org/tutorial/ver2/start.php

https://www.uni-muenster.de/Physik.TP/~akule_01/nnllfast/

Tutorial:

http://checkmate.hepforge.org/online_tutorial/2018_MC4BSM/