♕ Checkmating Your Favourite ♕ BSM Model

http://checkmate.hepforge.org arXiv:1312.2591

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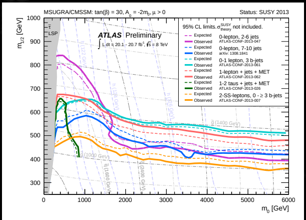
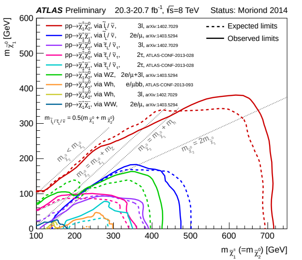
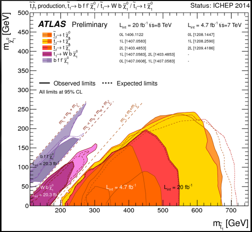
Motivation

SUSY might be around the corner

- ATLAS/CMS heavily constrain BSM physics
- However, not every model can be tested
- ATLAS/CMS published *model independent* limits on simplified topologies







How can I constrain my model?

- Use FastLim and SModels
  - These programs are very fast because these programs only need information about the spectrum
  - However, both codes are only reliable for *simple* topologies

How can I constrain my model?

- Use FastLim and SModels
  - These programs are very fast because these programs only need information about the spectrum
  - However, both codes are only reliable for *simple* topologies
- Recast limit from relevant ATLAS/CMS study
  - Generate truth level MC events (Herwig++, Pythia 8, Sherpa)
  - Run a fast detector simulation (Delphes, PGS)
  - Code up the ATLAS/CMS studies
  - It's very time consuming, in particular the validation of the implementation

♔ Our Idea

"The idea is to create a program:
You just enter a model ($\mathcal{L}$), press a button, and it accurately tells you whether the model is excluded or not."

"Sounds great! Let's do it!"

♔ ~~Our Idea~~ Our Reality

"We have created a program:
You just enter event files and cross sections of your model, press a button, and it tells you whether the model is excluded or not."

" Not a bad start!"

♕ Contents

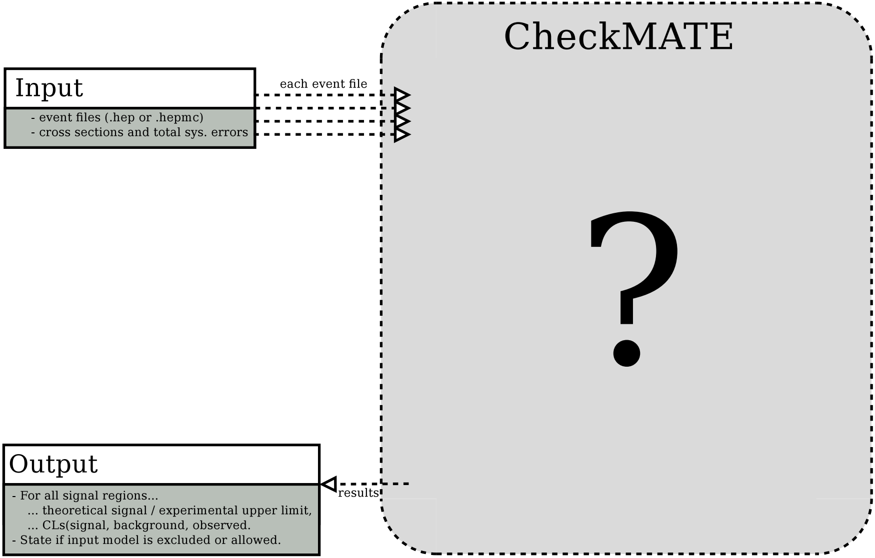
This talk will introduce a computer tool which
Checks **M**odels **A**t **T**erascale **E**nergies

CheckMATE

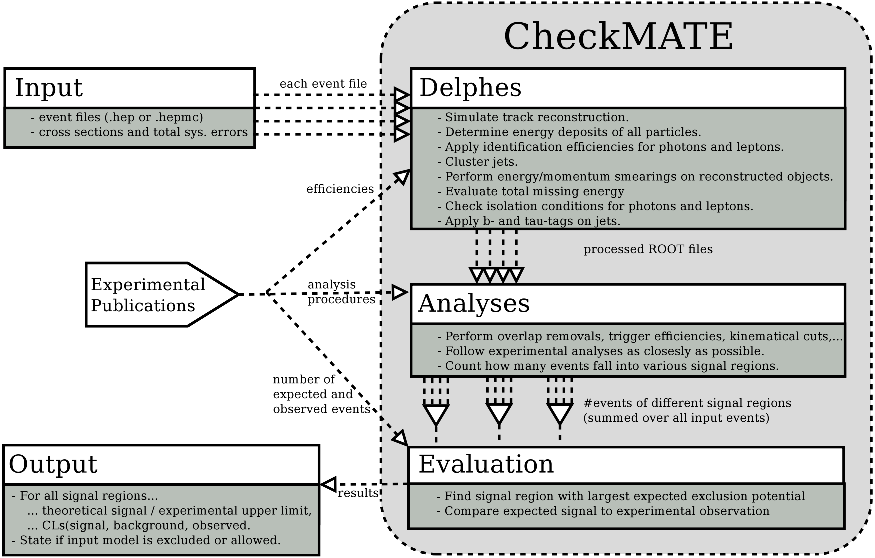
- ♘ Functionality (*How it works*)
- ♗ Demonstration (*How simple it is*)
- ♖ Validation (*Why you should use it*)
- ♙ Summary and Outlook (*What it will be*)

♕ General Structure ♕

♔ CheckMATE's Internal Structure



♔ CheckMATE's Internal Structure



♕ Detector Simulation ♕

♕ Detector Simulation

Delphes 3.0.10 — Standard Features

- Simulates track reconstruction
- Determines energy deposits of all particles
- Applies identification efficiencies for photons and leptons
- Clusters jets (using FastJet)
- 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

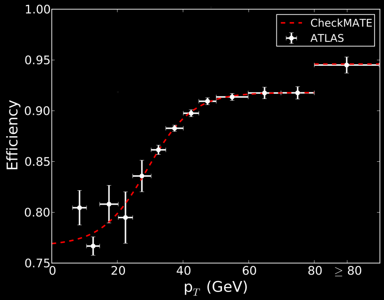
DELPHES
fast simulation

Delphes Improvements

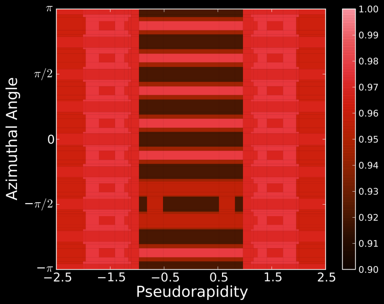
ATLAS tunings

- CheckMATE uses a C++ framework to process Delphes' results
- However, we improved the detector tunings of electrons and muons regarding efficiencies and momentum smearing

Examples



Electrons (Medium)



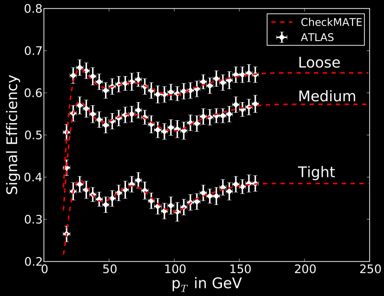
Muons (Combined)

♔ Delphes Improvements

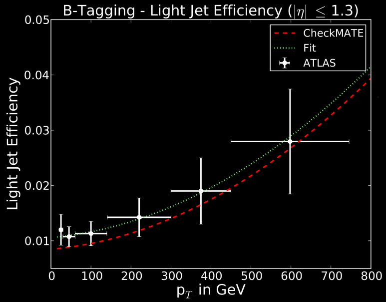
ATLAS tunings

- We did the same for B/Tau tagging of jets

Examples



Tau–Tag (3-prong)

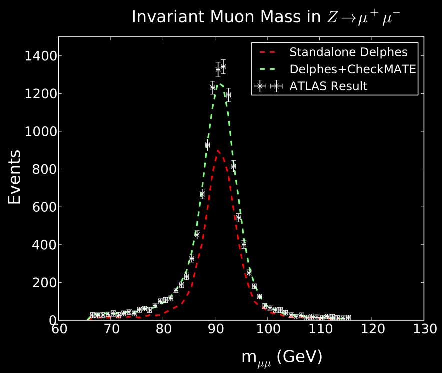


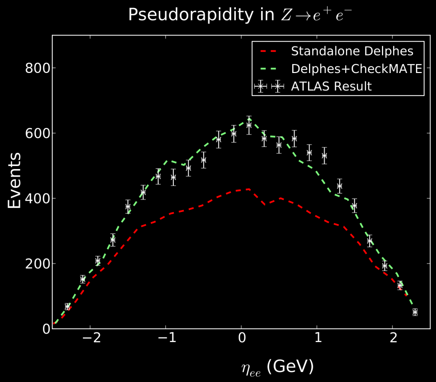
B–Tag

♚ Comparison

$Z \to \ell\ell$

- ♙ Performance checks tell us, if our functions are correct (more later)





♛ Performing Analyses ♛

♔ Current Analysis Selection

CheckMATE

- All analyses are written in the same structural form
- The number of events are calculated for each signal region of all analyses

♔ Current Analysis Selection

CheckMATE

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- ♕ The number of events are calculated for each signal region of all analyses

List of the Available Analyses (steadily growing)

internal name	#SR	description	$\sqrt{s}$	$\mathcal{L}$	incl. CR?
atlas_1308_2631	2	2 b-jets + $\not{E}_T$	8 TeV	20.1 fb^{-1}	✓
atlas_conf_2012_104	2	1 lepton + $\geq$ 4 jets + $\not{E}_T$	8 TeV	5.8 fb^{-1}	
atlas_conf_2012_147	4	Monojet + $\not{E}_T$	8 TeV	10.5 fb^{-1}	✓
atlas_conf_2013_024	3	0 leptons + 6 (2 b-)jets + $\not{E}_T$	8 TeV	20.5 fb^{-1}	✓
atlas_conf_2013_035	6	3 leptons + $\not{E}_T$	8 TeV	20.7 fb^{-1}	
atlas_conf_2013_047	9	0 leptons + 2-6 jets + $\not{E}_T$	8 TeV	20.3 fb^{-1}	✓
atlas_conf_2013_049	9	2 leptons + $\not{E}_T$	8 TeV	20.3 fb^{-1}	
atlas_conf_2013_061	9	0-1 leptons + $\geq$ 3 b-jets + $\not{E}_T$	8 TeV	20.1 fb^{-1}	✓
atlas_conf_2013_062	19	1-2 leptons + 3-6 jets + $\not{E}_T$	8 TeV	20.3 fb^{-1}	
atlas_conf_2013_089	12	2 leptons + jets + $\not{E}_T$	8 TeV	20.3 fb^{-1}	✓
cms_pas_exo_12_048	7	Monojet + $\not{E}_T$	8 TeV	19.5 fb^{-1}	
cms_1303_2985	59	α_T + b jet multiplicity	8 TeV	11.7 fb^{-1}	✓

♕ Setting Limits ♕

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}

User can choose

- Directly compare S to S^{95}_{max}
- If $r^c = \frac{S - 1.96 \times \Delta S}{S^{95}_{\text{max}}} > 1$: 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

Result

- Choose signal region with strongest *expected* exclusion
- Use its *observed* result to state "excluded" or "allowed"

♕ Demonstration ♕

♔ Example

ATLAS Reference

Signal Region	**A-loose**	**A-medium**	**B-medium**	**B-tight**
Total bkg	4700 ± 500	122 ± 18	33 ± 7	2.4 ± 1.4
Observed	5333	135	29	4
S^{95}_{obs}	1341.2	51.3	14.9	6.7
S^{95}_{exp}	$1135.0^{+332.7}_{-291.5}$	$42.7^{+15.5}_{-11.4}$	$17.0^{+6.6}_{-4.6}$	$5.8^{+2.9}_{-1.8}$

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atlas_conf_2013_047_r_limits

SR	S	dS_stat	dS_sys	dS_tot	S95_obs	S95_exp	r^c_obs	r^c_exp
AL	37.36	0.61	4.10	4.15	1341.20	1135.00	0.02	0.03
AM	5.34	0.22	0.55	0.59	51.30	42.70	0.08	0.10
BM	7.41	0.25	0.77	0.81	14.90	17.00	0.39	0.34
BT	0.86	0.07	0.10	0.12	6.70	5.80	0.09	0.11
CM	17.82	0.43	1.99	2.04	81.20	72.90	0.17	0.19
CT	2.40	0.12	0.28	0.31	2.40	3.30	0.75	0.54
D	12.14	0.34	1.29	1.33	15.50	13.60	0.61	0.70
EL	21.26	0.46	2.35	2.39	92.40	57.30	0.18	0.29
EM	16.14	0.40	1.79	1.83	28.60	21.40	0.44	0.59
ET	7.95	0.28	0.87	0.91	8.30	6.50	0.74	0.95

♔ Example

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Result

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

atlas_conf_2013_047_r_limits

SR	S	dS_stat	dS_sys	dS_tot	S95_obs	S95_exp	r^c_obs	r^c_exp
AL	37.36	0.61	4.10	4.15	1341.20	1135.00	0.02	0.03
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♕ Validation ♕

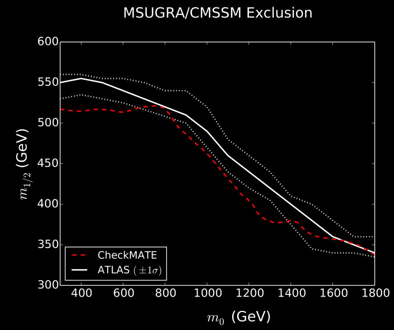
♔ Validation 1 — Cut Flows

atlas_conf_2013_047 (0 leptons + 2-6 jets + $\not{E}_T$, 8 TeV, 20.3 fb^{-1})

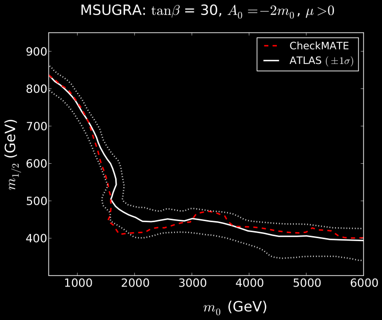
Process	$\tilde{q}\tilde{q}$ direct			
Point	$m(\tilde{q}) = 450$ GeV $m(\tilde{\chi}_1^0) = 400$ GeV		$m(\tilde{q}) = 662$ GeV $m(\tilde{\chi}_1^0) = 287$ GeV	
Signal Region	A-medium		C-medium	
Source	ATLAS	CheckMATE	ATLAS	CheckMATE
Generated events	20000	50000	5000	50000
In	100	100	100	100
Jet Cleaning *	99.7	-	99.6	-
0-lepton *	89.9	-	98.2	-
$E_T^{miss} > 160$ GeV *	15	-	80.7	-
$p_T(j_1) > 130$ GeV	12.9	12.9	80.0	79.3
$p_T(j_2) > 130$ GeV	9.0	8.4	75.6	75.3
$p_T(j_3) >$ 0-60 GeV	9.0	8.4	35.3	35.6
$p_T(j_4) >$ 0-60 GeV	9.0	8.4	11.5	11.3
$\Delta\phi(j_i > 40, E_T^{miss}) > 0.4$	7.0	6.8	10.1	9.9
$\Delta\phi(j_i > 40\text{ GeV}, E_T^{miss}) > 0 - 0.2$	7.0	6.8	9.3	9.2
$E_T^{miss}/\sqrt{H_T} > 0 - 15$	2.6	1.8	9.3	9.2
$E_T^{miss}/m_{eff}(N_j) > 0.15 - 0.4$	2.6	1.8	7.2	6.8
$m_{eff}(\text{incl.}) > 1 - 2.2$ TeV	0.1 ± 0.02	0.08 ± 0.01	3.0 ± 0.2	3.1 ± 0.1

♚ Validation 2 — Exclusion Lines

ATLAS, 1 ℓ + $\not{E}_T$



ATLAS, 0 ℓ + 2–6 jets + $\not{E}_T$

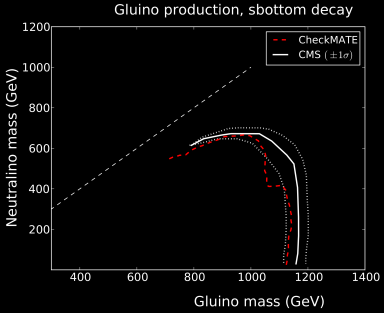


Overall Statement

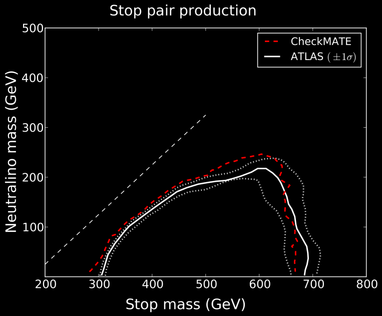
- Generally good agreement, sometimes more conservative

♔ Validation 2 — Exclusion Lines

CMS, α_T + multi-b



ATLAS, 0 ℓ + >6(2 b–) jets



Overall Statement

- Appearing discrepancies are mostly understood (left: different statistical method, right: b–tagging uncertainties)

Summary & Outlook

♔ Summary and Outlook

We **have** a program which . . .

- . . . tests any event + cross section combination against current LHC results
- . . . is simple to use (for the lazy physicist)
- . . . is transparent in its functionality (for the curious physicist)
- . . . is easy to extend (for the talented physicist)

We **work on** a program which . . .

- . . . has a larger selection of analyses (please ask!)
- . . . includes better detector tunings (also for CMS)
- . . . uses more fundamental input (.slha file, Lagrangian, . . .)

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