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Nishita Desai, Manuel Drees, Herbi Dreiner, Jong Soo Kim, Krzysztof Rolbiecki,
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CERN, June 15, 2015

CheckMATE: Confronting your Favourite New Physics Model with LHC Data

Drees, Dreiner, Kim, DS, Tattersall
arXiv:1312.2591, Comput.Phys.Commun. 187 (2014) 227-265

A framework to create customised LHC analyses within CheckMATE

Kim, DS, Tattersall, Rolbiecki
arXiv:1503.01123, Comput.Phys.Commun. 196 (2015) 535-562

CheckMATE 2: (not) harder (but) better, faster, stronger

Desai, Drees, Dreiner, Kim, Rolbiecki, DS, Tattersall
arXiv:16xx.xxxxx

The Idea

*"The idea is to create a program:
You just enter a model, press a button, and it tells you whether the model is excluded or not."*

"Sounds great! Let's do it!"

♔ Contents

1. How to use CheckMATE 1 ...
   - ... to test against results from LHC 8/13
   - ... to add new results
   - ... to estimate future results from LHC 13/14
2. How to soon use CheckMATE 2 ...
   - ... with embedded event generation
   - ... wih greatly improved performance
3. Outlook

In Short

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- Step 2: Write a very small parameter file `param.dat`,

```
## General Options
[Mandatory Parameters]
Name: My_CheckMATE_Run
Analyses: atlas_conf_2013_047

## Process Information
[gluinopairproduction]
XSect: 3.53 FB
XSectErr: 0.01 PB
Events: /scratch/MSSM_gg.hep
```

In Short

- Step 1: Produce **simulated LHC event files** from Herwig, Pythia, CalcHEP, MadGraph, ...
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- Step 3: Run `./CheckMATE param.dat` and wait ...

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## General Options
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Name: My_CheckMATE_Run
Analyses: atlas_conf_2013_047

## Process Information
[gluinopairproduction]
XSect: 3.53 FB
XSectErr: 0.01 PB
Events: /scratch/MSSM_gg.hep
```

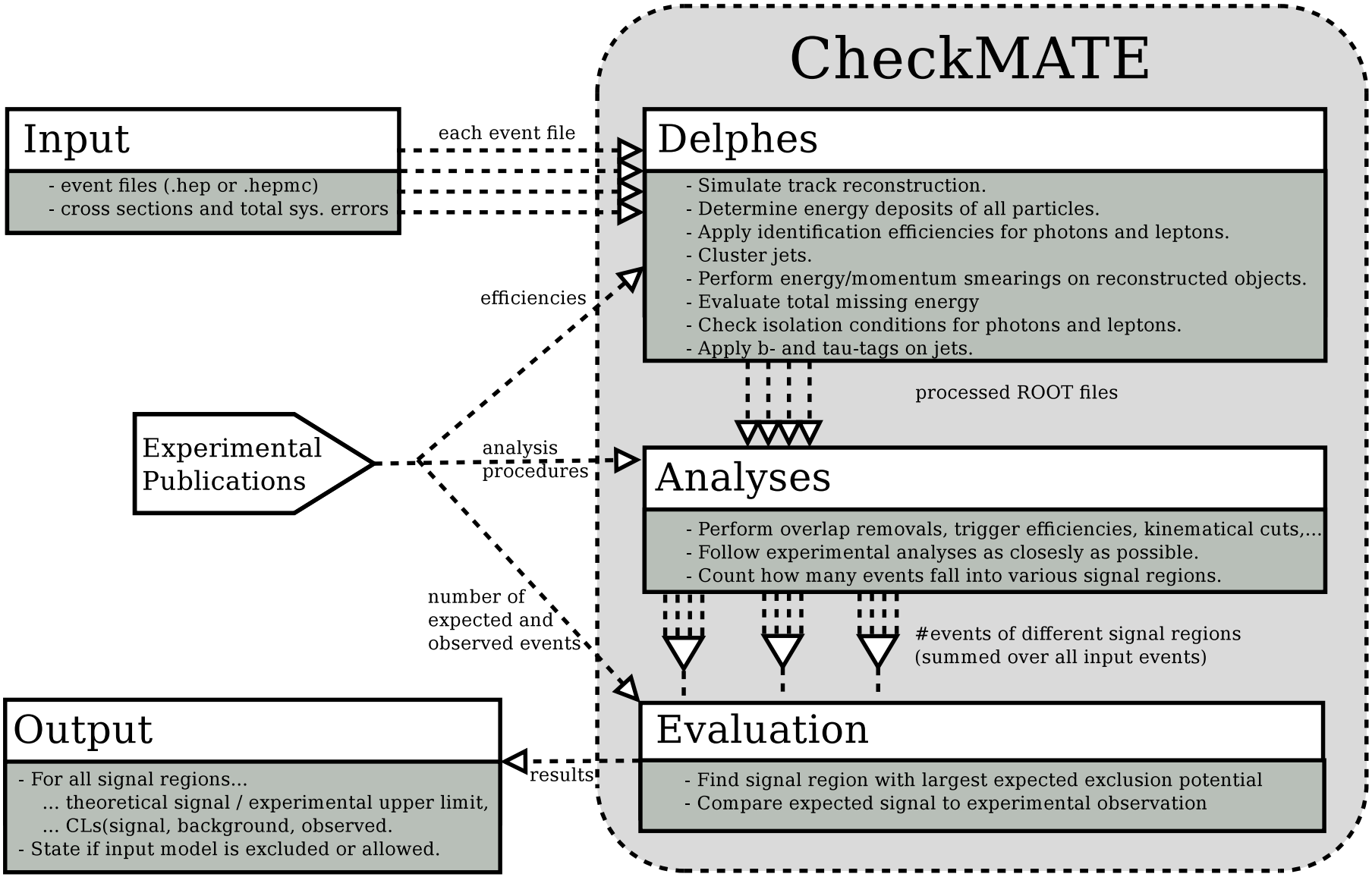
```
Result: Allowed
Result for r: r_max = 0.74
SR: atlas_conf_2013_047 - ET
```

or

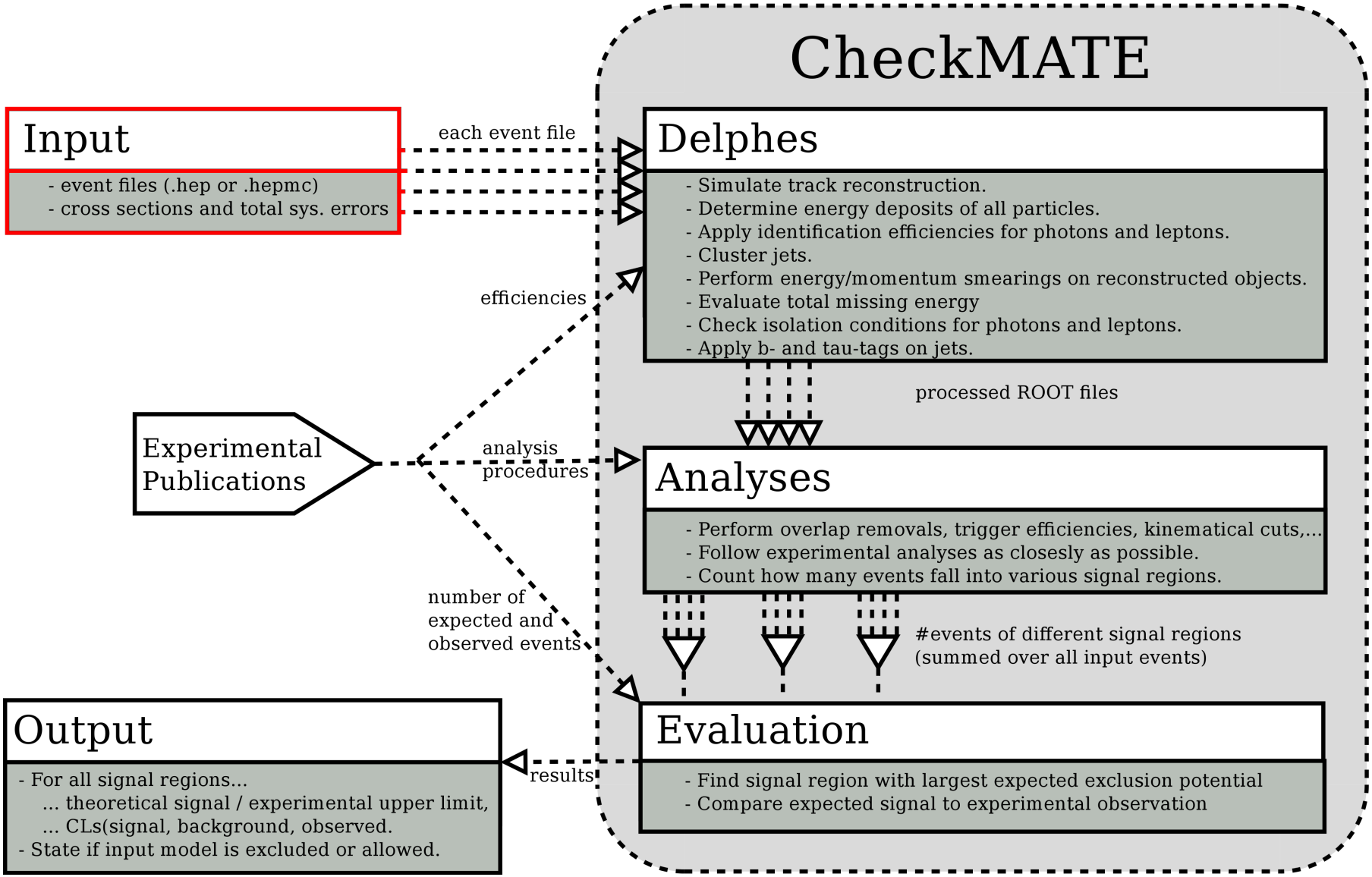
```
Result: Excluded
Result for r: r_max = 1.33
SR: atlas_conf_2013_047 - A
```

You quickly know if your model has been excluded by current LHC results without writing a single line of analysis code

Overview: Data Flow



Input


CheckMATE
Input
- event files (.hep or .hepmc)
- cross sections and total sys. errors
each event file
Delphes
- Simulate track reconstruction.
- Determine energy deposits of all particles.
- Apply identification efficiencies for photons and leptons.
- Cluster jets.
- Perform energy/momentum smearings on reconstructed objects.
- Evaluate total missing energy
- Check isolation conditions for photons and leptons.
- Apply b- and tau-tags on jets.
efficiencies
processed ROOT files
Experimental Publications
analysis procedures
Analyses
- Perform overlap removals, trigger efficiencies, kinematical cuts,...
- Follow experimental analyses as closesly as possible.
- Count how many events fall into various signal regions.
number of expected and observed events
#events of different signal regions (summed over all input events)
Output
- For all signal regions...
... theoretical signal / experimental upper limit,
... CLs(signal, background, observed.
- State if input model is excluded or allowed.
results
Evaluation
- Find signal region with largest expected exclusion potential
- Compare expected signal to experimental observation

Input: Minimal Case

checkmate_input_parameter.dat

```
[Mandatory Parameters]
Name: My_CMSSM_Run
Analyses: atlas_conf_2013_047

[gluinogluino]
XSect: 3.53 FB
XSectErr: 10 %
Events: /scratch/cmssms_data/events/gg/tag1_pythia_events.hep
```

Required

- Name
- At least one analysis
- At least one `[process]` with at least one item in `Events` (.hep or .hepmc) and one total cross section and a total estimate on the *systematic* error

♔ Input: Extended Case 1

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checkmate_input_parameter.dat

```
[Mandatory Parameters]
Name: My_CMSSM_Run
Analyses: atlas, cms_sus_13_016

[gluinogluino]
XSect: 3.53 FB
XSectErr: 10 %
Events: /scratch/mycmssmscn/events/gg/tag1_pythia_events.hep
```

Optional

- More analyses

Input: Extended Case 2

checkmate_input_parameter.dat

```
[gluinogluino]
XSect: 3.53 FB
XSectErr: 10 %
Events: /scratch/mycmssmscn/events/gg/tag1_pythia_events.hep,
        /scratch/mycmssmscn/events/gg/tag2_pythia_events.hep

[squarksquark]
XSect: 4.64 FB
XSectErr: 0.25 FB
Events: /scratch/mycmssmscn/events/ss/tag1_pythia_events.hep
```

Optional

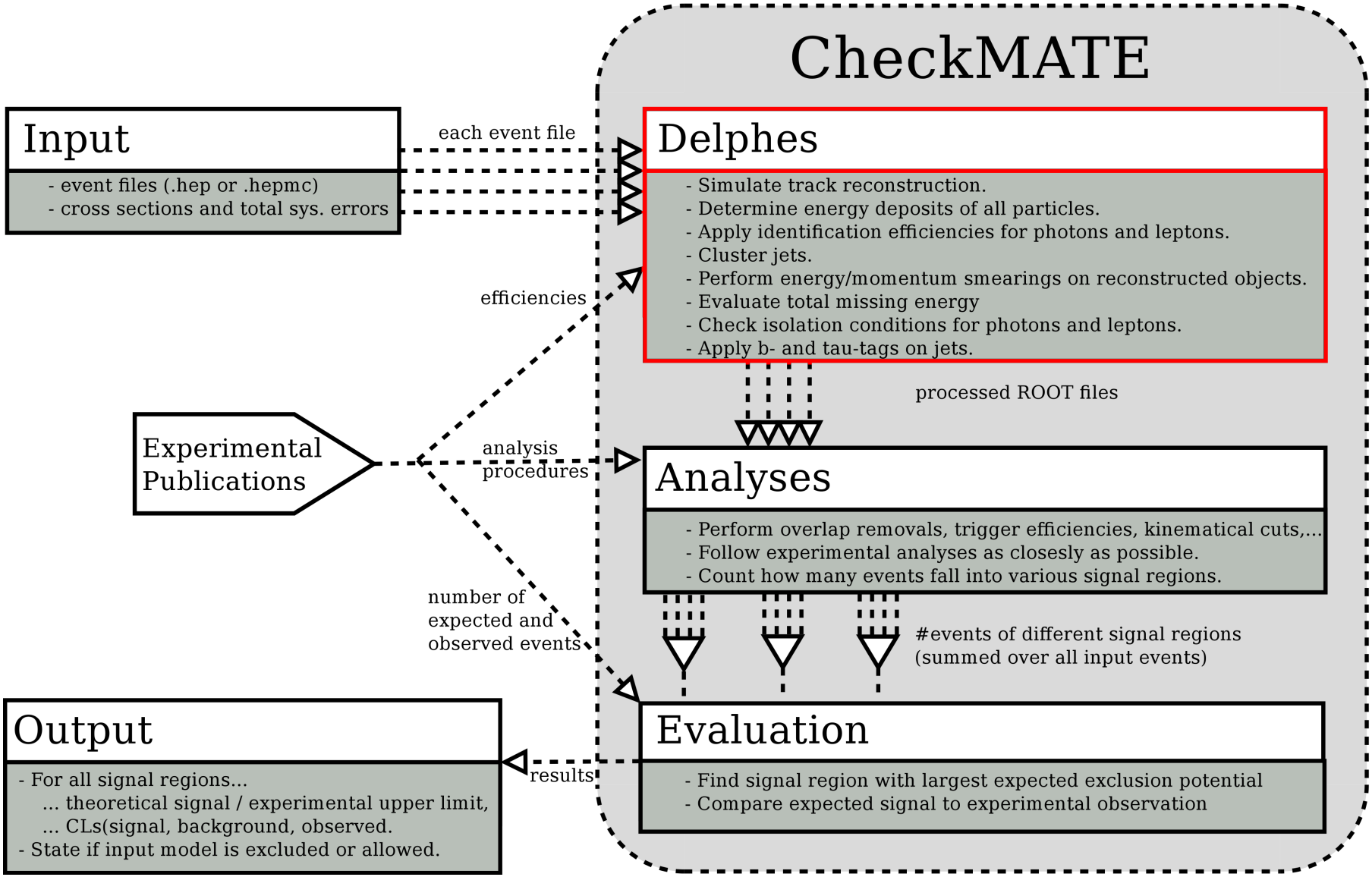
- Many event files for one process

  (are processed one by one, normalised *in total* to the given cross section)

- Events for different processes with individual $\sigma \pm \Delta\sigma$

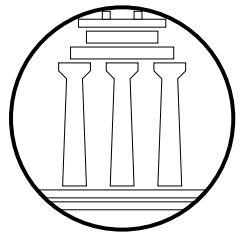
  (are processed one by one, normalised events *independently added* in the end)

Step 1: Delphes



Delphes 3.0.10 Standard

- Simulates tracking and energy deposition
- Applies identification 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

Extra Features / Improvements

- Added identification and isolation flags
- Tuned to better represent ATLAS detector

Detector Tunings — Examples

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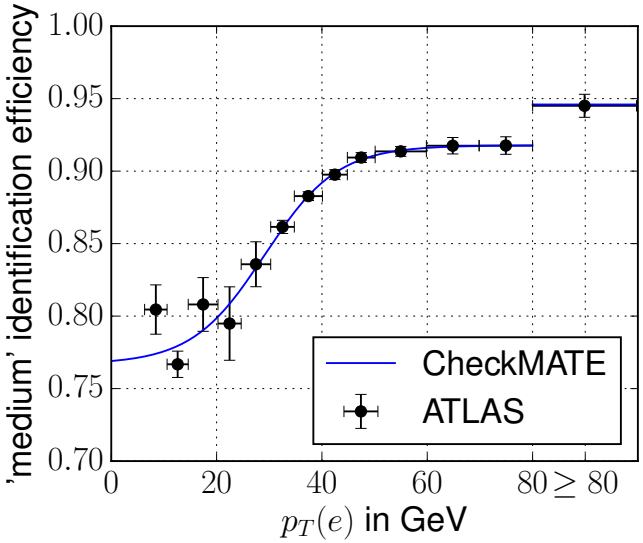
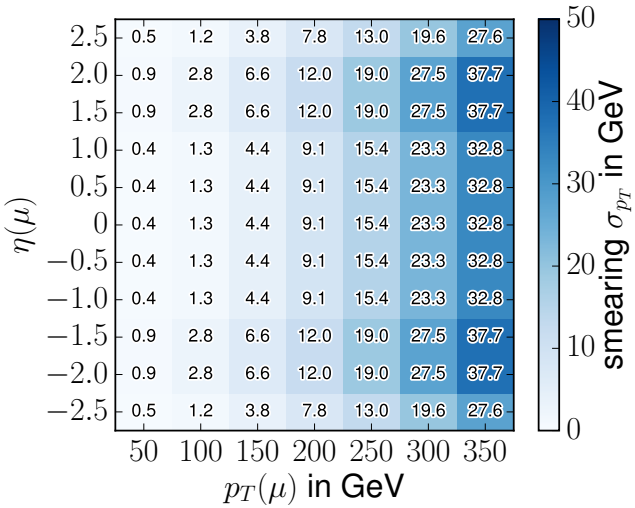
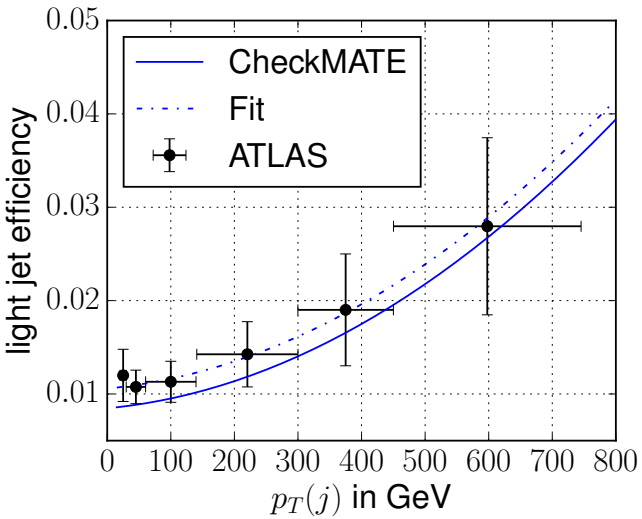
e reconstruction eff.

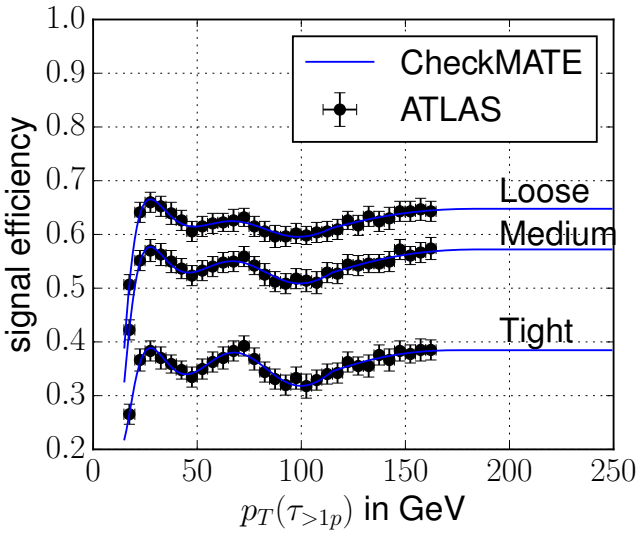


μ momentum smearing



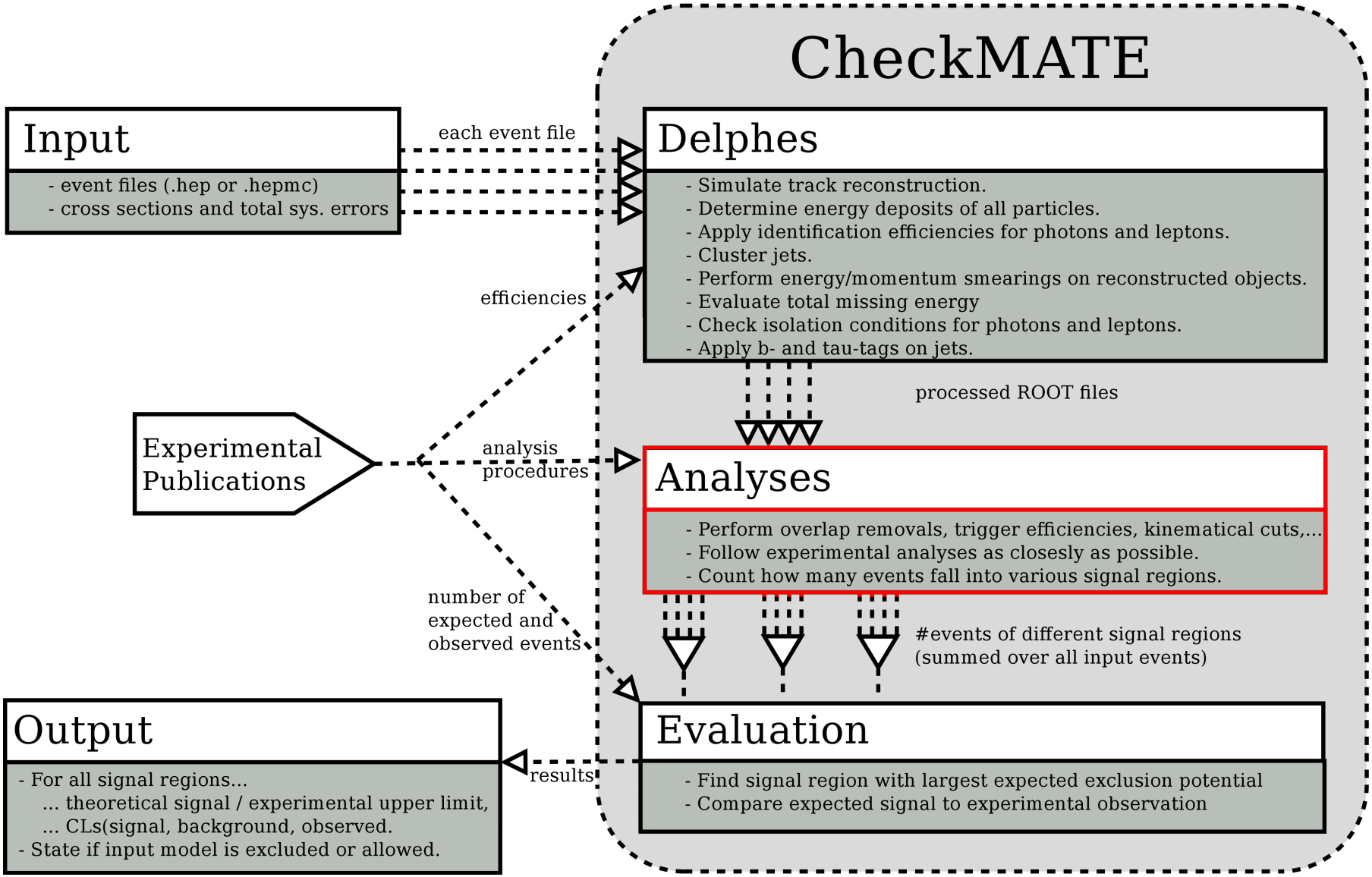


b-jet eff.



τ-jet eff.

Step 2: Analyses



Analyses

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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

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Output

- For each input file, store general information and
- for each SR, store Σ (weights) and Σ(weights^2) for the input events that passed the respective signal region cuts

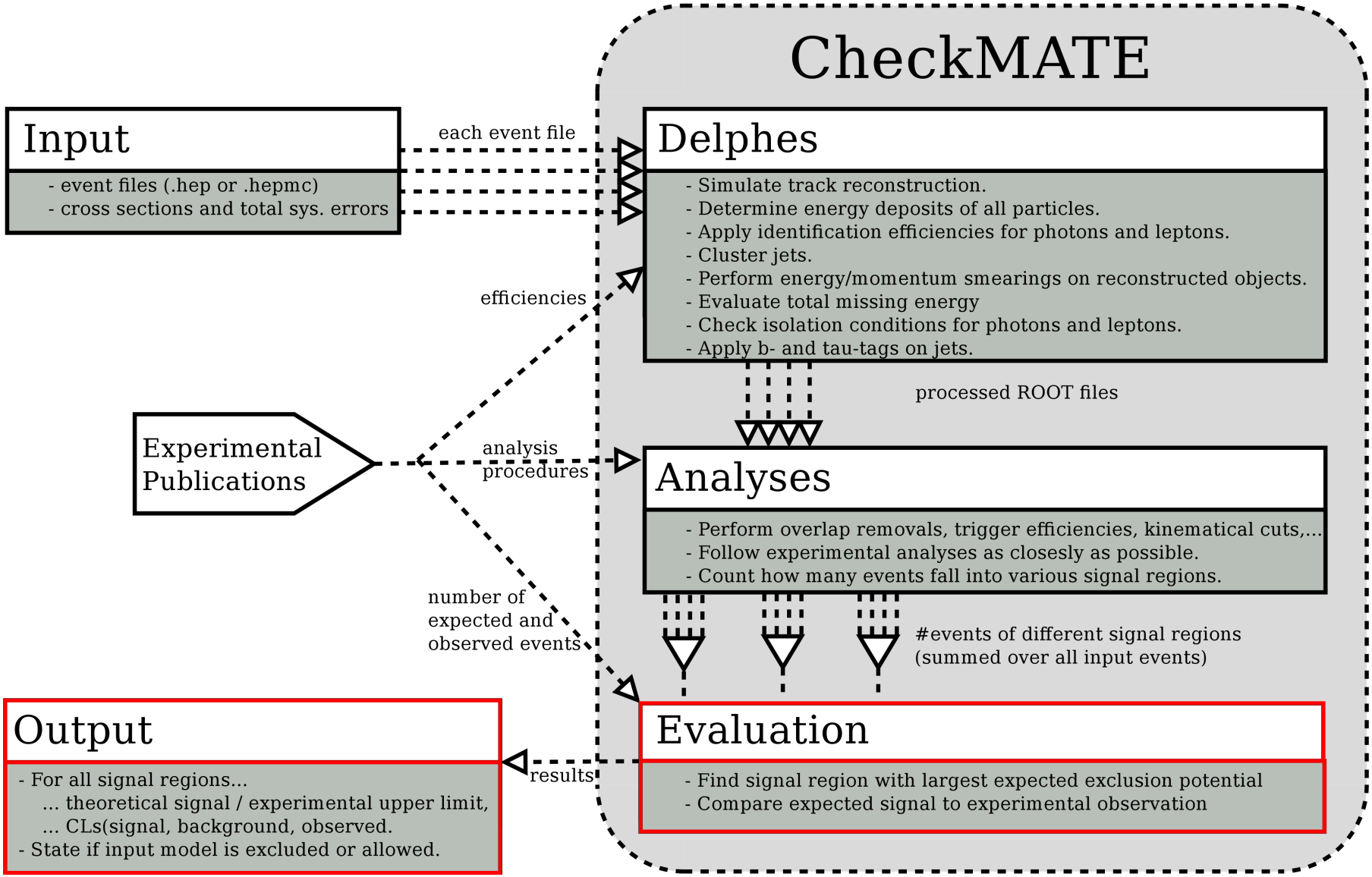
Example Output


```
# 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
ET   149     149      0.0298   2.62096
```

Step 3: 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_{max}^{95}

♔ Evaluation

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User can choose

- Directly compare S to S^{95}_{max}
- If $r^c = \frac{S-2\Delta S}{S^{95}_{\text{max}}} > 1$: 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

♔ Evaluation

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- 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 ($O = B$)
- Use its *observed* result to state final "excluded" or "allowed"

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}	$1135.0^{+332.7}_{-291.5}$	$42.7^{+15.5}_{-11.4}$	$17.0^{+6.6}_{-4.6}$	$5.8^{+2.9}_{-1.8}$

Example

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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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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}	$1135.0^{+332.7}_{-291.5}$	$42.7^{+15.5}_{-11.4}$	$17.0^{+6.6}_{-4.6}$	$5.8^{+2.9}_{-1.8}$

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
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 Input: Natural NMSSM

Idea

- Light $\tilde{g}, \tilde{t}, \tilde{b}, \tilde{\chi}^{\pm}, \tilde{\chi}^{0}$ and many poss. decays [arXiv:1510.04871]

```
[Mandatory Parameters]
Name: NMSSM_lambdaL_1000_800_500_250
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/11428609[184].pbs.baf.lan/herwig/gluinopair.hepmc

[stop1pair]
XSect: 0.794E-02 PB
XSectErr: 0.00149 PB
Events: /scratch/11428609[184].pbs.baf.lan/herwig/stop1pair.hepmc

[stop2pair]
XSect: 0.122E-02 PB
XSectErr: 0.00024 PB
Events: /scratch/11428609[184].pbs.baf.lan/herwig/stop2pair.hepmc

[sbottom1pair]
XSect: 0.620E-02 PB
XSectErr: 0.00119 PB
Events: /scratch/11428609[184].pbs.baf.lan/herwig/sbottom1pair.hepmc

[sbottom2pair]
XSect: 0.419E-02 PB
XSectErr: 0.00089 PB
Events: /scratch/11428609[184].pbs.baf.lan/herwig/sbottom2pair.hepmc
```

♔ Example Output: Nat. NMSSM

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```
~: ./CheckMATE NMSSM_setupfile.txt
```

♔ Example Output: Nat. NMSSM

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```
~: ./CheckMATE NMSSM_setupfile.txt


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

[... roughly 2 minutes per 5k events later ... ]

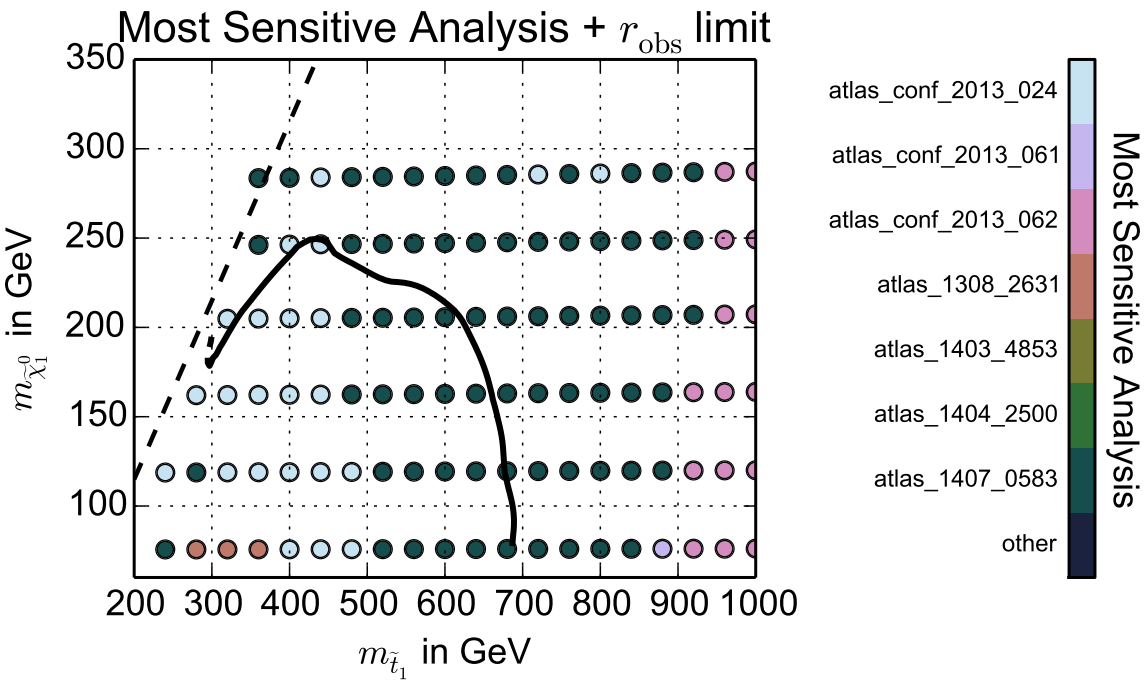
************************************
*******      EVALUATION      *******
************************************

Test: Calculation of r = signal/(95%CL limit on signal)
Result: Excluded
Result for r: r_max = 3.45937
SR: atlas_conf_2013_061 - SR1L6JB
```

Example Output: Nat. NMSSM

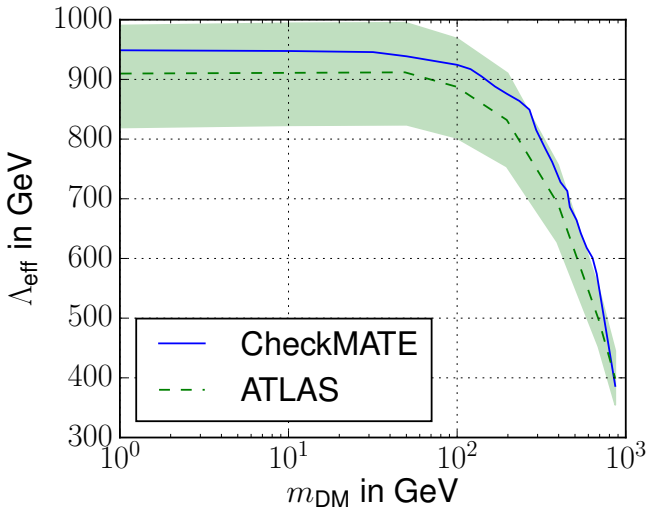
Scan Parameter Region

- Gen. events for each param. point (*Trivial, once the setup is ready*)
- Run CheckMATE on these events (*Trivial, just change event-URL*)
- Draw line between `Excluded` and `Allowed` (*Trivial with Matplotlib*)

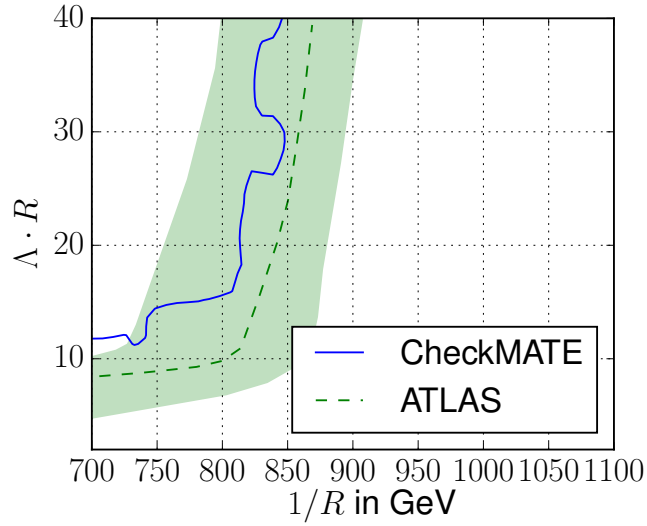


Performance Test via Models

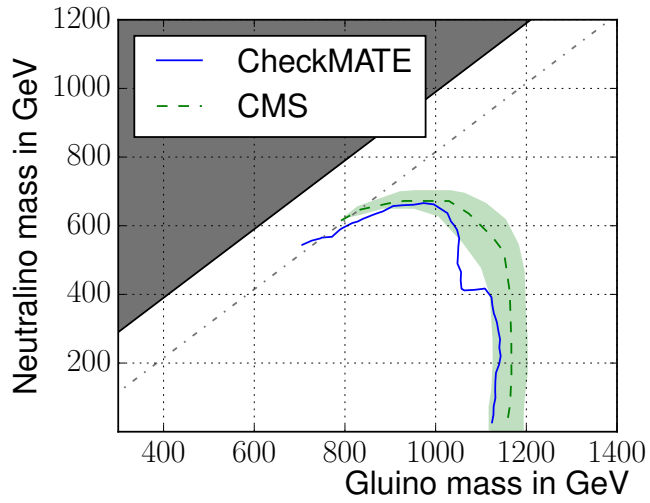
Effective DM via `atlas_1502_01518`



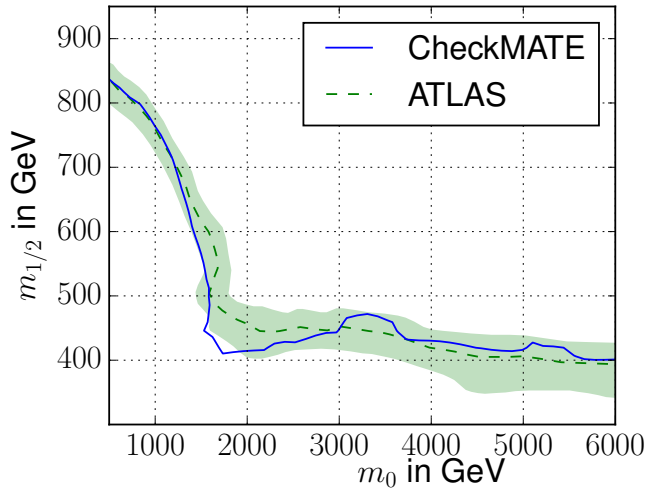
UED via `atlas_conf_2013_089`



Simple SUSY via `cms_1303_2985`

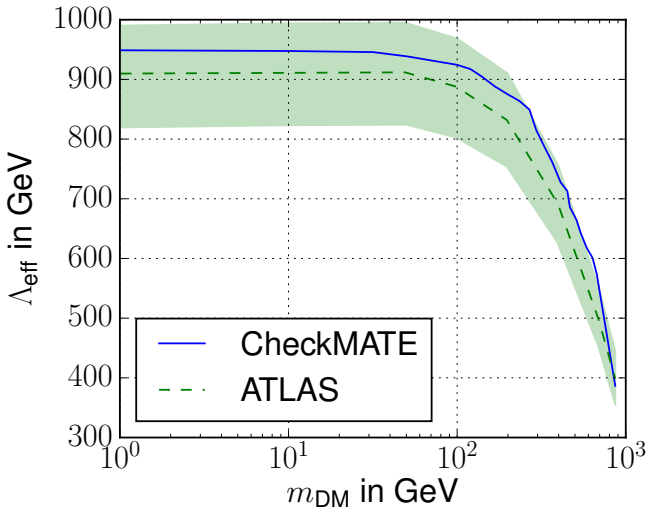


MSUGRA via `atlas_conf_2013_047`

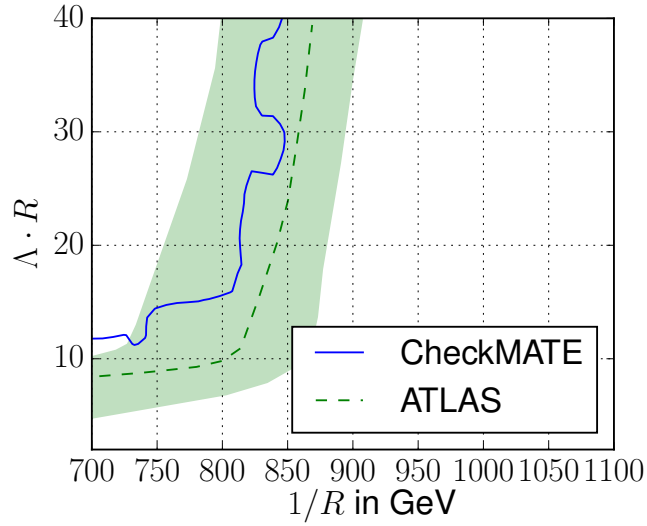


Performance Test via Models

Effective DM via `atlas_1502_01518`



UED via `atlas_conf_2013_089`



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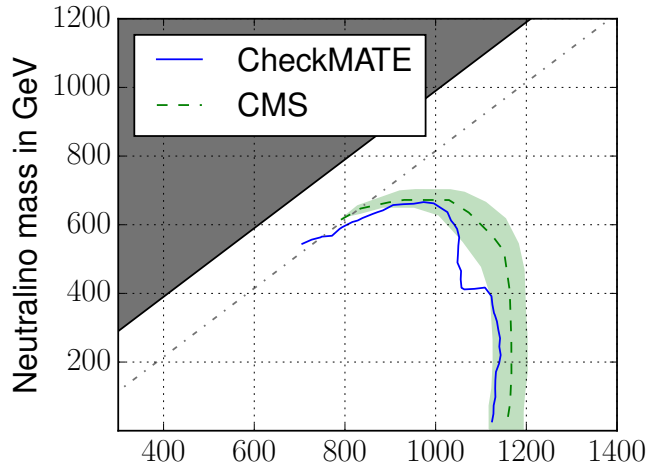
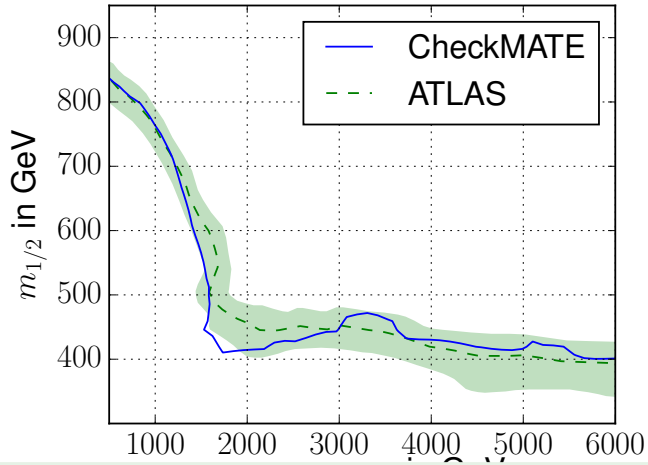


MSUGRA via `atlas_conf_2013_047`



CheckMATE is a model-independent tool!

Performance Test via Cutflows

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`atlas_1405_7875` and $\tilde{g} \to qq'\tilde{\chi}^{\pm}, \tilde{\chi}^{\pm} \to W^{\pm}\tilde{\chi}^{0}$

Cut	Signal Region `D` ATLAS	Signal Region `D` `Ch.M.`	Signal Region `ET` ATLAS	Signal Region `ET` `Ch.M.`
Generated Monte Carlo events	20,000	50,000	20,000	50,000
In %	100 %	100 %	100 %	100 %
Jet cleaning *	99.8 %	-	99.8 %	-
0 lepton *	63.7 %	-	63.5 %	-
$\not{E}_T \geq 160\,\text{GeV}$	50.0 %	-	55.6 %	-
$p_T(j_1) > 130\,\text{GeV}$	49.3 %	47.7 %	55.6 %	54.4 %
$p_T(j_2) > 130\,\text{GeV}$	49.2 %	47.6 %	55.6 %	54.4 %
$p_T(j_3) > 60\,\text{GeV}$	48.6 %	47.1 %	55.4 %	54.2 %
$p_T(j_4) > 60\,\text{GeV}$	44.5 %	43.8 %	53.4 %	52.8 %
$p_T(j_5) > 60\,\text{GeV}$	34.4 %	34.8 %	46.3 %	46.6 %
$p_T(j_5) > 60\,\text{GeV}$ (only ET)	34.4 %	34.8 %	31.7 %	33.0 %
$\Delta\phi(j_{1,2,3}, \not{E}_T) > 0.4$	29.2 %	29.5 %	26.5 %	27.5 %
$\Delta\phi(j_k, \not{E}_T) > 0.2\ \forall k$ with $p_T(j_k) > 40\,\text{GeV}$	24.6 %	24.7 %	21.3 %	22.4 %
$\not{E}_T / m_{\text{eff}}$(all jets) > 0.2(`D`), 0.25(`ET`)	21.6 %	21.2 %	12.0 %	11.2 %
m_{eff}(all jets) > 1.6 TeV(`D`), 1.5 TeV(`ET`)	2.0 %	1.9 %	7.9 %	8.2 %
Monte Carlo Error	±0.1 %	±0.1 %	±0.2 %	±0.1 %

Most important source of validation

- Need as many and as detailed of of these as possible!

α / Fully Validated Analyses

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Name	Search designed for	$\sqrt{s}$	L	N_{SR}
atlas_1308_1841	new phenomena in final states with large jet multiplicities and $\not{E}_T$	8	20.3	19
atlas_1308_2631	third-generation squark pair production with $\not{E}_T$ and two b-jets	8	20.1	6
atlas_1402_7029	charginos and neutralinos in events with 3 leptons and $\not{E}_T$	8	20.3	24
atlas_1403_4853	top-squark pair production in final states with two leptons	8	20.3	12
atlas_1404_2500	SUSY with jets and two same-sign leptons or three leptons	8	20.3	5
atlas_1403_5222	top squark pair production in events with a Z boson, b-jets and $\not{E}_T$	8	20.3	5
atlas_1405_7875	squarks and gluinos in final states with jets and $\not{E}_T$	8	20.3	15
atlas_1407_0583	stop pair production in final states with one isolated lepton, jets, and $\not{E}_T$	8	20.3	27
atlas_1407_0608	pair-produced third-generation squarks decaying via charm quarks or in compressed supersymmetric scenarios	8	20.3	3
atlas_1502_01518	new phenomena in final states with an energetic jet and large $\not{E}_T$	8	20.3	9
atlas_1503_03290	Supersymmetry in events containing a same-flavour opposite-sign dilepton pair, jets, and large $\not{E}_T$	8	20.3	1
atlas_1506_08616	pair production of third-generation squarks	8	20.3	11
atlas_conf_2012_104	Supersymmetry in final states with jets, $\not{E}_T$ and one isolated lepton	8	5.8	2
atlas_conf_2012_147	new phenomena in monojet plus $\not{E}_T$ final states	8	10	4
atlas_conf_2013_024	production of the top squark in the all-hadronic $t\bar{t}$ and $\not{E}_T$ final state	8	20.5	3
atlas_conf_2013_049	direct-slepton and direct-chargino production in final states with two opposite-sign leptons, $\not{E}_T$ and no jets	8	20.3	9
atlas_conf_2013_061	strong production of supersymmetric particles in final states with $\not{E}_T$ and at least three b-jets	8	20.1	9
atlas_conf_2013_089	strongly produced supersymmetric particles in decays with two leptons	8	20.3	12
atlas_conf_2015_004	invisibly decaying Higgs boson produced via vector boson fusion	8	20.3	1
cms_1303_2985	supersymmetry in hadronic final states with missing transverse energy using the variables α_T and b-quark multiplicity	8	11.7	59
cms_1408_3583	dark matter, extra dimensions, and unparticles in monojet events	8	19.7	7
cms_1502_06031	BSM physics in events with two Leptons, jets, and $\not{E}_T$	8	19.4	6
cms_1504_03198	production of dark matter in association with top-quark pairs in the single-lepton final state	8	19.7	1
cms_sus_13_016	new physics in events with same-sign dileptons and jets	8	19.5	1

β / Partially Validated Analyses

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Name	Search designed for	$\sqrt{s}$	L	N_{SR}
atlas_1210_2979	WW production	7	4.6	1
atlas_1403_5294	charginos, neutralinos and sleptons with 2 leptons and $\not{E}_T$	8	20.3	13
atlas_1407_0600	strong production of SUSY particles with $\not{E}_T$ and at least 3 b-jets	8	20.1	9
atlas_1411_1559	new phenomena in events with a photon and $\not{E}_T$	8	20.3	1
atlas_conf_2013_021	WZ production	8	20.3	4
atlas_conf_2013_031	spin properties of h in $h \to WW^{(*)} \to e\nu\mu\nu$	8	20.7	2
atlas_conf_2013_036	Supersymmetry in events with four or more leptons	8	20.7	5
atlas_conf_2013_062	squarks and gluinos in events with isolated leptons, jets and $\not{E}_T$	8	20.1	19
atlas_conf_2014_014	$\tilde{t}\tilde{t}^*$ decaying to a b, a τ and weakly interacting particles	8	20.3	1
atlas_conf_2014_033	WW production	8	20.3	3
atlas_conf_2014_056	spin correlation in top–antitop$t\bar{t}$ events and search for $\tilde{t}\tilde{t}^*$	8	20.3	1
cms_1301_4698_WW	WW production	8	3.5	1
cms_1306_1126_WW	WW production	7	4.92	1
cms_1405_7570	electroweak production of charginos, neutralinos and sleptons decaying to leptons and W, Z, and Higgs bosons	8	19.5	57
cms_smp_12_006	WZ production into 3ℓ	8	19.6	4
cms_sus_12_019	physics beyond the standard model in events with two opposite-sign same-flavor leptons, jets, and missing transverse energy	8	19.4	4
atlas_conf_2015_062	squarks and gluinos in final states with jets and $\not{E}_T$	13	3.2	7
atlas_conf_2015_067	$\tilde{g}\tilde{g}$ decaying via stop and sbottom in events with b-jets and $\not{E}_T$	13	3.3	8
atlas_conf_2015_076	gluinos in events with an isolated lepton, jets and$\not{E}_T$	13	3.3	6
atlas_1602_09058	SUSY with jets and 2 same-sign leptons or 3 leptons	13	3.2	4
atl-phys-pub-2014-010-sbottom	SUSY at the high lumi LHC with zero leptons, two b-jets and $\not{E}_T$	14	300	6
atlas-phys-pub-2013-011-stop	SUSY at the high lumi LHC with zero or one lepton	14	300	4
atlas_2014_010_hl_3l	SUSY at the high lumi LHC with 3 ℓ + $\not{E}_T$	14	3000	9
atlas_phys_2014_010_300	SUSY at the high lumi LHC with jets + $\not{E}_T$	14	300	10
atlas_phys_2014_010_sq_hl	SUSY at the high lumi LHC with jets and $\not{E}_T$	14	3000	10

Name	Search designed for	$\sqrt{s}$	L	N_{SR}
atlas_1210_2979	WW production	7	4.6	1
atlas_1403_5294	charginos, neutralinos and sleptons with 2 leptons and $\not{E}_T$	8	20.3	13
atlas_1407_0600	strong production of SUSY particles with $\not{E}_T$ and at least 3 b-jets	8	20.1	9
atlas_1411_1559	new phenomena in events with a photon and $\not{E}_T$	8	20.3	1
atlas_conf_2013_021	WZ production	8	20.3	4
atlas_conf_2013_031	spin properties of h in $h \to WW^{(*)} \to e\nu\mu\nu$	8	20.7	2
atlas_conf_2013_036	Supersymmetry in events with four or more leptons	8	20.7	5
atlas_conf_2013_062	squarks and gluinos in events with isolated leptons, jets and $\not{E}_T$	8	20.1	19
cms_sus_12_019	physics beyond the standard model in events with two opposite-sign same-flavor leptons, jets, and missing transverse energy	8	19.4	4
atlas_conf_2015_062	squarks and gluinos in final states with jets and $\not{E}_T$	13	3.2	7
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atl-phys-pub-2014 -010-sbottom	SUSY at the high lumi LHC with zero leptons, two b-jets and $\not{E}_T$	14	300	6
atlas-phys-pub-2013 -011-stop	SUSY at the high lumi LHC with zero or one lepton	14	300	4
atlas_2014_010_hl_3l	SUSY at the high lumi LHC with 3 ℓ + $\not{E}_T$	14	3000	9
atlas_phys_2014_010_300	SUSY at the high lumi LHC with jets + $\not{E}_T$	14	300	10
atlas_phys_2014 _010_sq_hl	SUSY at the high lumi LHC with jets and $\not{E}_T$	14	3000	10

What do I need to add a new analysis on my own?

β / Partially Validated Analyses

Name	Search designed for	$\sqrt{s}$	L	N_{SR}
atlas_1210_2979	WW production	7	4.6	1
atlas_1403_5294	charginos, neutralinos and sleptons with 2 leptons and $\not{E}_T$	8	20.3	13
atlas_1407_0600	strong production of SUSY particles with $\not{E}_T$ and at least 3 b-jets	8	20.1	9
atlas_1411_1559	new phenomena in events with a photon and $\not{E}_T$	8	20.3	1
atlas_conf_2013_021	WZ production	8	20.3	4
atlas_conf_2013_031	spin properties of h in $h \to WW^{(*)} \to e\nu\mu\nu$	8	20.7	2
atlas_conf_2013_036	Supersymmetry in events with four or more leptons	8	20.7	5
atlas_conf_2013_062	squarks and gluinos in events with isolated leptons, jets and $\not{E}_T$	8	20.1	19

What do I need to add a new analysis on my own?

- Ability to answer questions
- Some understanding of C++

cms_sus_12_019	physics beyond the standard model in events with two opposite-sign same-flavor leptons, jets, and missing transverse energy	8	19.4	4
atlas_conf_2015_062	squarks and gluinos in final states with jets and $\not{E}_T$	13	3.2	7
atlas_conf_2015_067	$\tilde{g}\tilde{g}$ decaying via stop and sbottom in events with b-jets and $\not{E}_T$	13	3.3	8
atlas_conf_2015_076	gluinos in events with an isolated lepton, jets and$\not{E}_T$	13	3.3	6
atlas_1602_09058	SUSY with jets and 2 same-sign leptons or 3 leptons	13	3.2	4
atl-phys-pub-2014 -010-sbottom	SUSY at the high lumi LHC with zero leptons, two b-jets and $\not{E}_T$	14	300	6
atlas-phys-pub-2013 -011-stop	SUSY at the high lumi LHC with zero or one lepton	14	300	4
atlas_2014_010_hl_3l	SUSY at the high lumi LHC with 3 ℓ + $\not{E}_T$	14	3000	9
atlas_phys_2014_010_300	SUSY at the high lumi LHC with jets + $\not{E}_T$	14	300	10
atlas_phys_2014 _010_sq_hl	SUSY at the high lumi LHC with jets and $\not{E}_T$	14	3000	10

Running the Analysis Manager

- Run `make AnalysisManager; /bin/AnalysisManager`

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

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

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

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.
```

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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
[...]
```

```
 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
```

Add a published analysis

- Provide results straight away
- Typical mode for 8 and 13 TeV

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

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
```

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
```

Adding an analysis

```
- Variable values saved in /hdd/sandbox/managertest/data/atlas_conf_2013_047X_var.j
- Created source file    /hdd/sandbox/managertest/tools/analysis/src/atlas_conf_2013_047X.cc
- Created header file    /hdd/sandbox/managertest/tools/analysis/include/atlas_conf_2013_047X.h
- Updated Makefile
- Updated main source    main.cc
- Reference file created
- List of analyses updated
Analysis atlas_conf_2013_047X has been added successfully!
Run 'make' from the main CheckMATE folder to compile it!
```

Some example lines

```
void Atlas_conf_2013_047::analyze() {
  missingET->addMuons(muonsCombined);
  electronsLoose = filterPhaseSpace(electronsLoose, 10., -2.47, 2.47
  muonsCombined = filterPhaseSpace(muonsCombined, 10., -2.4, 2.4);
  jets = filterPhaseSpace(jets, 20., -2.8, 2.8);
  [...]
  jets = overlapRemoval(jets, electronsLoose, 0.2);
  electronsLoose = overlapRemoval(electronsLoose, jets, 0.4);
  if(!electronsLoose.empty())
      return;
  [...]
  double HT = 0.;
  for(int j = 0; j < jets.size(); j++)
      HT += jets[j]->PT;
  double mEffInc = missingET->P4().Et() + HT;
  [...]
  mEffA = missingET->P4().Et() + jets[0]->PT + jets[1]->PT;
  if (missingET->P4().Et()/mEffA > 0.2) {
    countCutflowEvent("AL1");
    if (mEffInc > 1000.)
        countSignalEvent("AL");
  }
  [...]
```

What to do for CheckMATE 2?

What to do for CheckMATE 2?

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We want to start early in the chain

Goal $\longleftrightarrow$ Reality

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

What to do for CheckMATE 2?

We want to start early in the chain

So far the user has to provide the event files

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

What to do for CheckMATE 2?

We want to start early in the chain

Why not embed event generation within CheckMATE?

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

What to do for CheckMATE 2?

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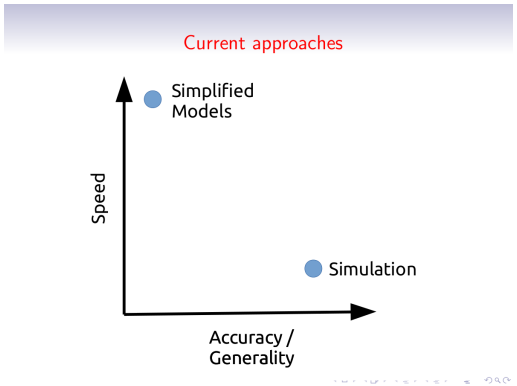
Why not embed event generation within CheckMATE?

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

We want to be fast



Goal $\longleftrightarrow$ Reality

```
[... roughly 2 minutes per
5k events later ... ]
```

What to do for CheckMATE 2?

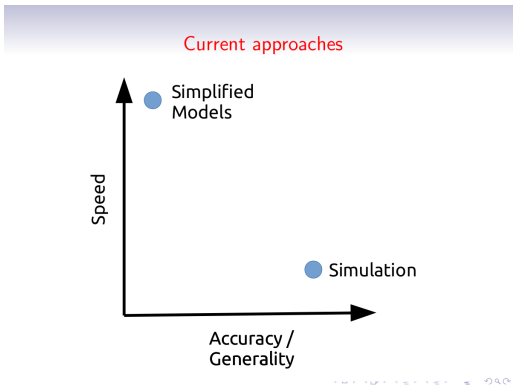
We want to start early in the chain

Why not embed event generation within CheckMATE?

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

We want to be fast



Simulations are slow

```
[... roughly 2 minutes per
5k events later ... ]
```

What to do for CheckMATE 2?

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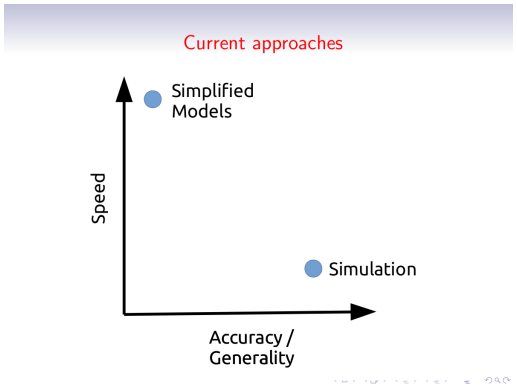
We want to start early in the chain

Why not embed event generation within CheckMATE?

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

We want to be fast



Try to speed up whatever possible

```
[... roughly 2 minutes per
5k events later ... ]
```

What to do for CheckMATE 2?

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We want to start early in the chain

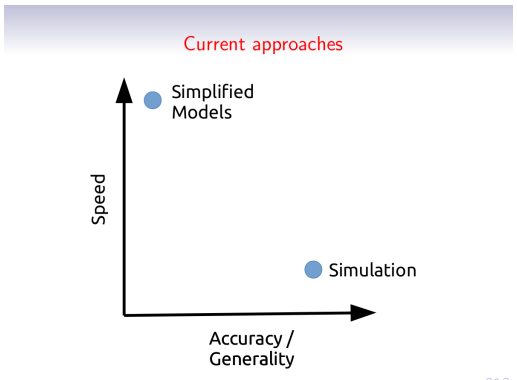
Why not embed event generation within CheckMATE?

```
Name: NMSSM_600_200
Analyses: atlas

[gluinopair]
XSect: 0.239E-01 PB
XSectErr: 0.00575 PB
Events: /scratch/gluinopair.hepmc
```

FRITZ = Flexible Rapid Interactive Tool Zipper

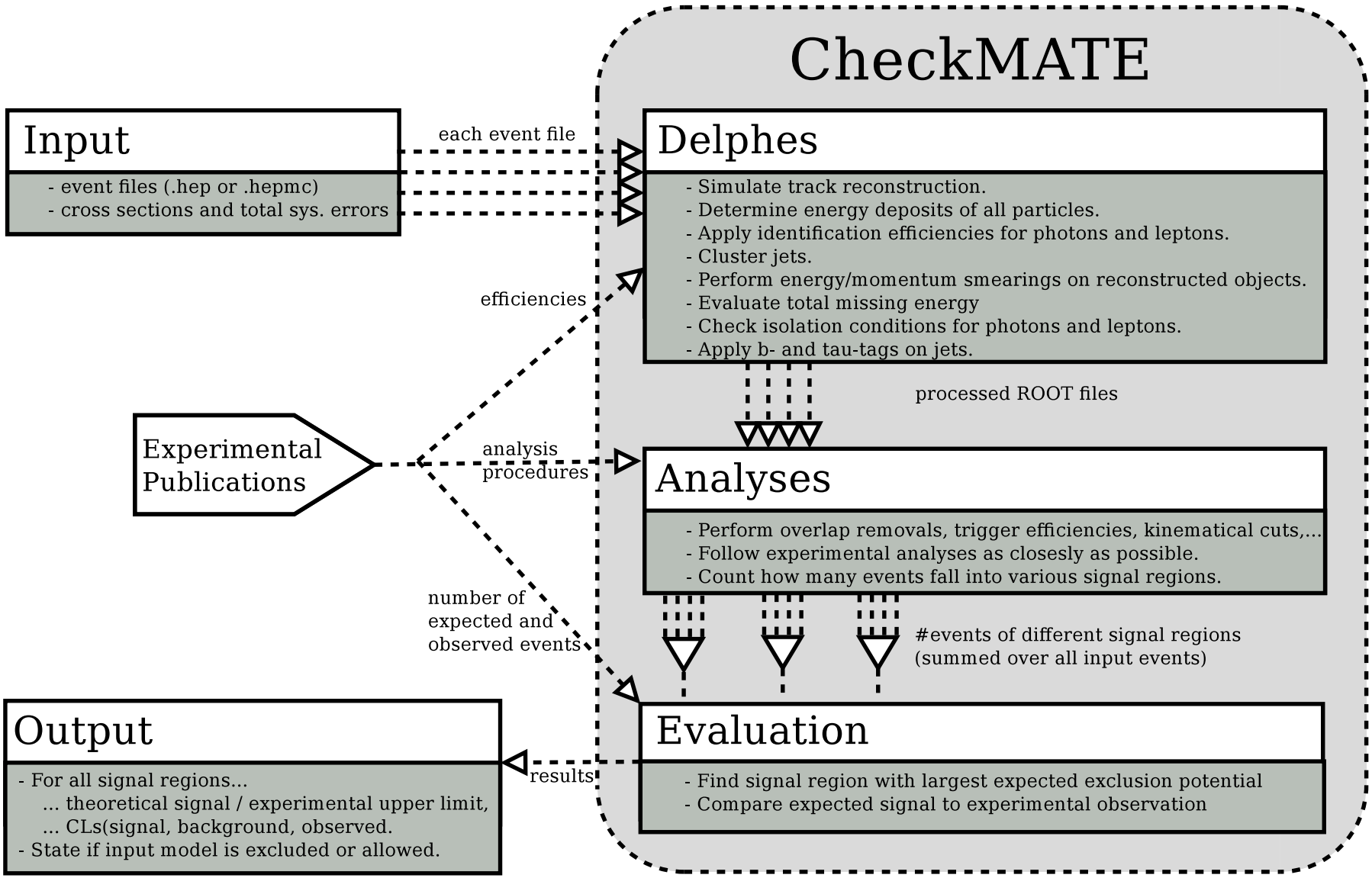
We want to be fast



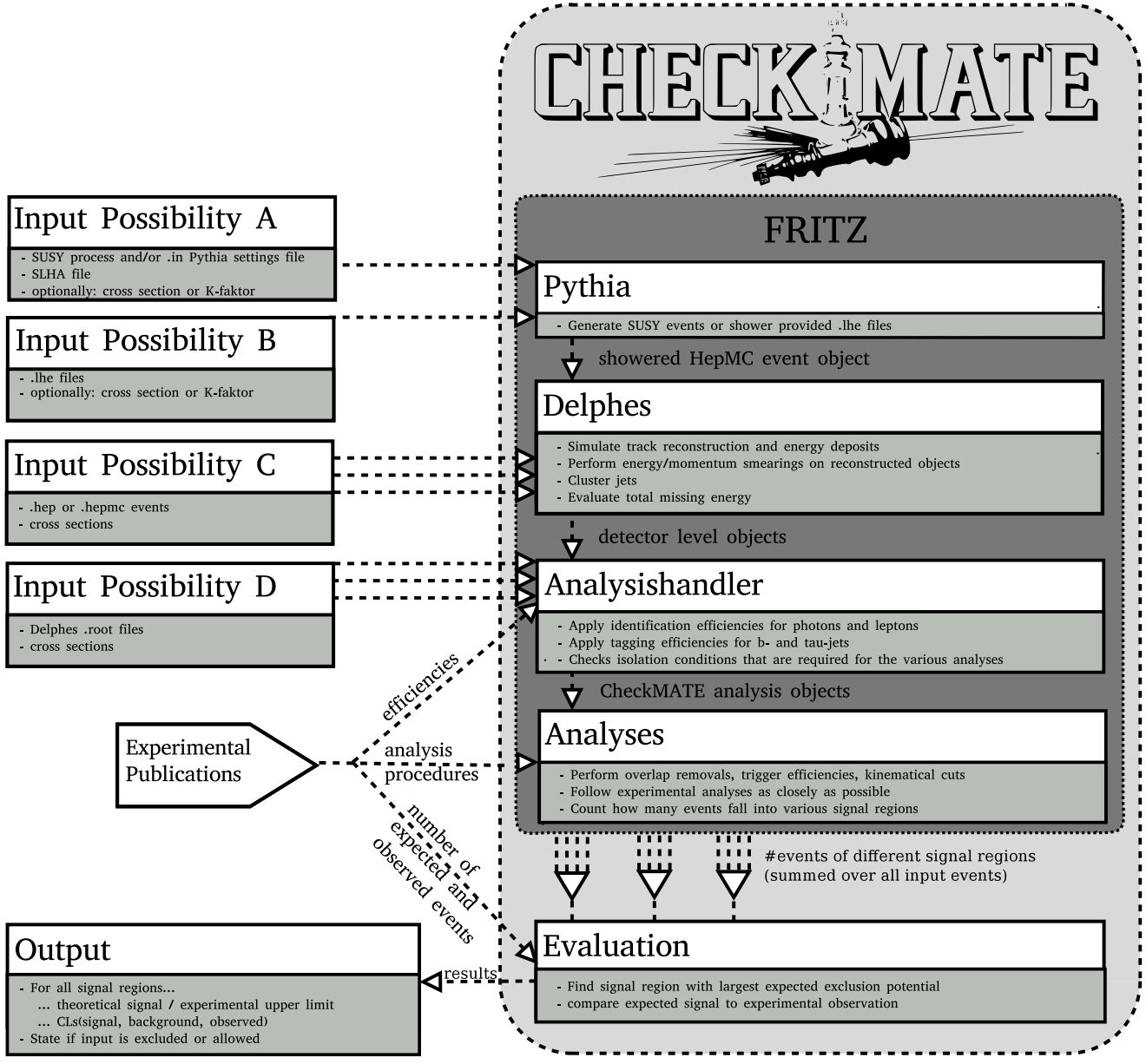
Try to speed up whatever possible

```
[... roughly 2 minutes per
5k events later ... ]
```

Old CheckMATE 1



...New CheckMATE 2 *somewhat ready*



Working Pythia8 Functionalities

Example 1: Use Pythia on SLHA in specific SUSY production modes

```
Name: MSSM_GluinoPair
Analyses: cms & 8TeV
SLHAFile: myspectrum.slha

[gluinopair]
Pythia8Process: p p > go go~
```

Working Pythia8 Functionalities

Example 1: Use Pythia on SLHA in specific SUSY production modes

```
Name: MSSM_GluinoPair
Analyses: cms & 8TeV
SLHAFile: myspectrum.slha

[gluinopair]
Pythia8Process: p p > go go~
```

Example 2: Provide .in file with arbitrary Pythia settings

```
Name: MSSM_SquarkPair
Analyses: atlas & 8TeV

[squ_squ]
Pythia8Card: /scratch/files/pythiasqusqu.in
```

```
PDF:pSet = 8 !(CTEQ6L1)
Beams:idA = 2212
Beams:idB = 2212
Beams:eCM = 8000.
SLHA:file = /scratch/files/point.slha
SUSY:qq2squarksquark = on
SUSY:idVecA = 1000001,1000002,[...]2000003,2000004
```

Working Pythia8 Functionalities

Bethe Center for Theoretical Physics

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Example 1: Use Pythia on SLHA in specific SUSY production modes

```
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Analyses: cms & 8TeV
SLHAFile: myspectrum.slha

[gluinopair]
Pythia8Process: p p > go go~
```

Example 2: Provide .in file with arbitrary Pythia settings

```
Name: MSSM_SquarkPair
Analyses: atlas & 8TeV

[squ_squ]
Pythia8Card: /scratch/files/pythiasqusqu.in
```

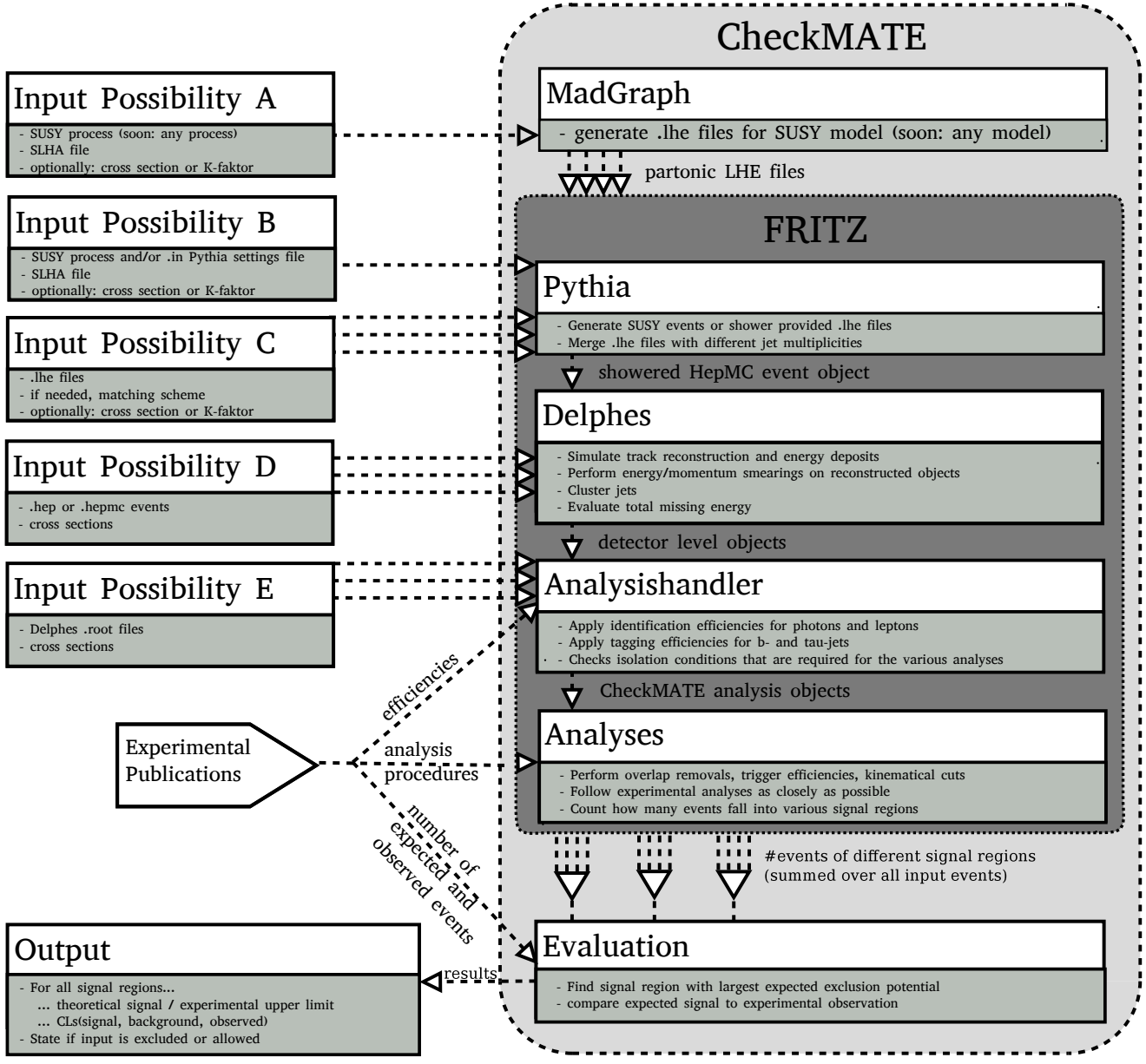
```
PDF:pSet = 8 !(CTEQ6L1)
Beams:idA = 2212
Beams:idB = 2212
Beams:eCM = 8000.
SLHA:file = /scratch/files/point.slha
SUSY:qq2squarksquark = on
SUSY:idVecA = 1000001,1000002,[...]2000003,2000004
```

Example 3: Use Pythia to shower .lhes of an arbitrary model

```
Name: NewModelTest
Analyses: atlas & 8TeV, cms & 8 TeV

[Supermodel]
Events: test_events/mysupermodel_point1.lhe
```

CheckMATE 2.X *In Development*



Example 4: Shower and Merge Multiple LHE

```
Name: Zplusjets
Analyses: atlas_1403_5222

[Zjets]
Merging: ckkwl
Scale: 30
MaxJets: 2
Events: test_events/zRes_0jet_1k.lhe, test_events/zRes_1jet_1k.lhe, test_events/zRes_2jet_1k.lhe
```

Example 4: Shower and Merge Multiple LHE

```
Name: Zplusjets
Analyses: atlas_1403_5222

[Zjets]
Merging: ckkwl
Scale: 30
MaxJets: 2
Events: test_events/zRes_0jet_1k.lhe, test_events/zRes_1jet_1k.lhe, test_events/zRes_2jet_1k.lhe
```

Example 5: Link to MG5_aMC@NLO

```
Name: MSSM_SquarkPair
Analyses: atlas & 8TeV
MG5Model: InertDoublet

[a_h]
MG5Process: p p > a h
MaxEvents: 10000
```

Example 4: Shower and Merge Multiple LHE

```
Name: Zplusjets
Analyses: atlas_1403_5222

[Zjets]
Merging: ckkwl
Scale: 30
MaxJets: 2
Events: test_events/zRes_0jet_1k.lhe, test_events/zRes_1jet_1k.lhe, test_events/zRes_2jet_1k.lhe
```

Example 5: Link to MG5_aMC@NLO

```
Name: MSSM_SquarkPair
Analyses: atlas & 8TeV
MG5Model: InertDoublet

[a_h]
MG5Process: p p > a h
MaxEvents: 10000
```

- CheckMATE still simple to use via `./CheckMATE input.txt`
- With mode 5 we come very close to the dedicated goal to *enter a model, press a button, and it tells you whether the model is excluded or not."*

Other Features of 2.0

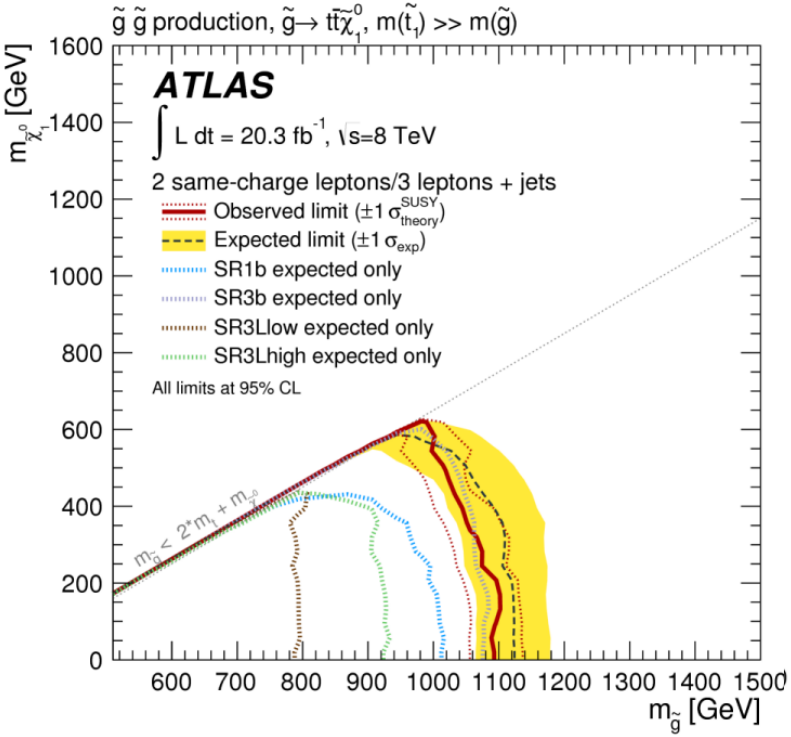
Faster Event Procession

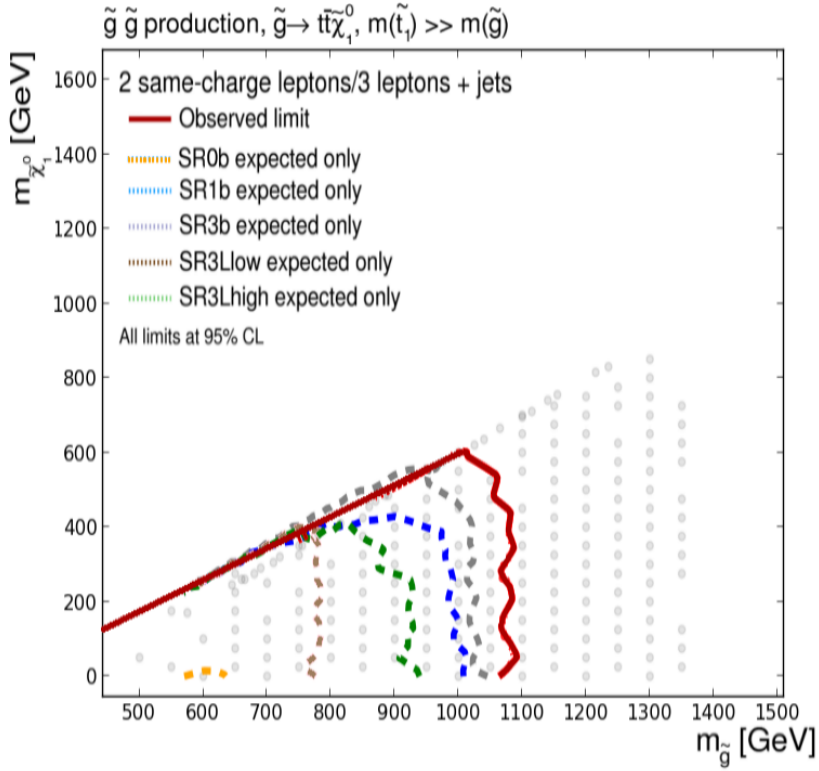
- sizable speed boost (Now: $\approx$ 30s for creating 1000 events and testing one analysis, 1 min for testing all analyses)
- Much better cluster performance

```
Fritz: Initialising handlers from file $CMDIR/results/ThesisExample/fritz/squ_squ.ini
PythiaHandler 'pythia': Initializing Pythia8 with $CMDIR/bin/thesisexample/pythiasqusqu.in
PythiaHandler 'pythia': Output redirected to $CMDIR/results/ThesisExample/pythia/pythia_squ_squ.log
PythiaHandler 'pythia': Pythia8 initialized successfully!
DelphesHandler 'atlas8tev': Initialising Delphes via linking to PythiaHandler 'pythia'
[...]
DelphesHandler 'cms8tev': Delphes successfully initialised!
AnalysisHandler 'atlas8tev': Initialising AnalysisHandler
AnalysisHandler 'atlas8tev': Loading Analysis atlas_1308_1841
AnalysisHandler 'atlas8tev': Successfully loaded analysis atlas_1308_1841
[...]
AnalysisHandler 'cms8tev': AnalysisHandler successfully linked to DelphesHandler 'cms8tev'
Fritz: Fritz successfully loaded command line parameters!
Fritz: >> Successfully initialized and linked all handlers! <<
Fritz: Starting event loop!
Fritz: Progress: 10 %
[...]
Fritz: Progress: 100 %
Fritz: >> Finalising after 1000 events. <<
PythiaHandler 'pythia': Pythia8 returned cross section of 2.43366 fb
AnalysisHandler 'atlas8tev': Analyses successfully finished!
DelphesHandler 'cms8tev': Delphes successfully finished!
PythiaHandler 'pythia': Pythia8 successfully finished!
Fritz: >> Done <<
```

Statistical Combination of Signal Regions

- Working: Combination of orthogonal SR assuming uncorrelated errors



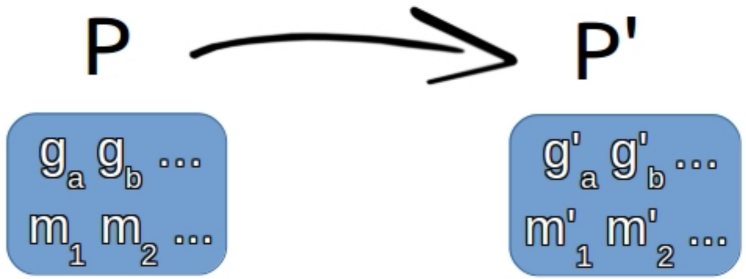


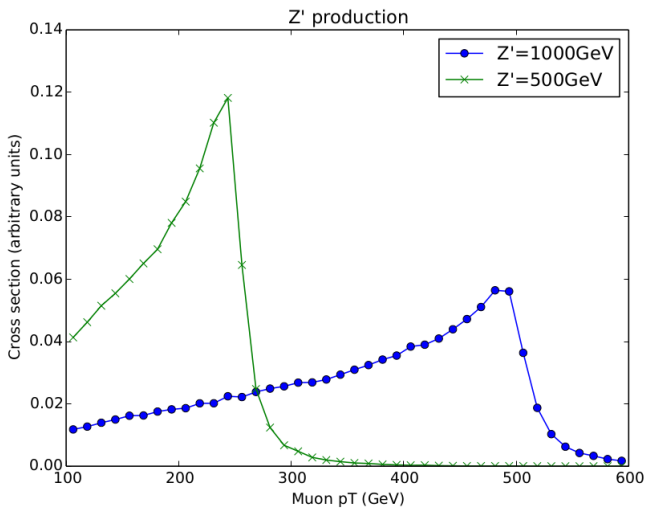
- *Under Development:* Guesstimating correlations of background errors

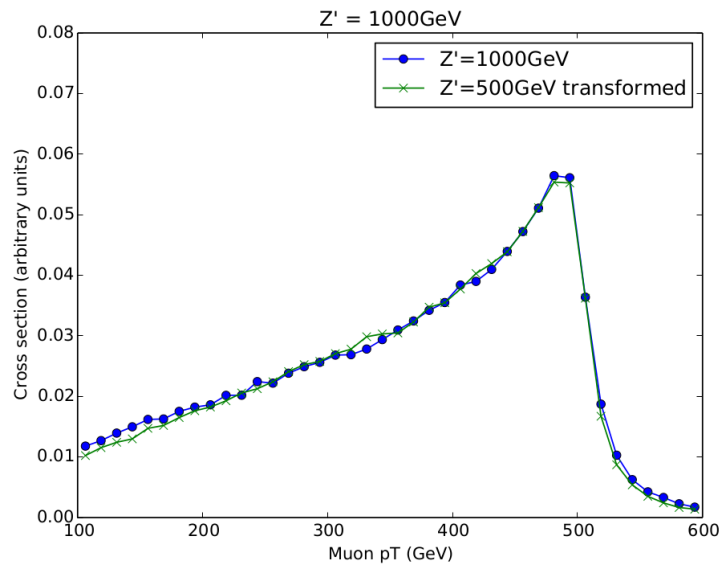
Other Features of 2.0

Faster scanning of parameter space

- *Under Development:* Guesstimating related kinematics of nearby parameter points without re-simulating events







Conclusions

Go ahead and have a look!

`http://checkmate.hepforge.org/`

Appendix