

# CheckMATE

Check Models At Terascale Energies

MC School 2015, IFT Madrid

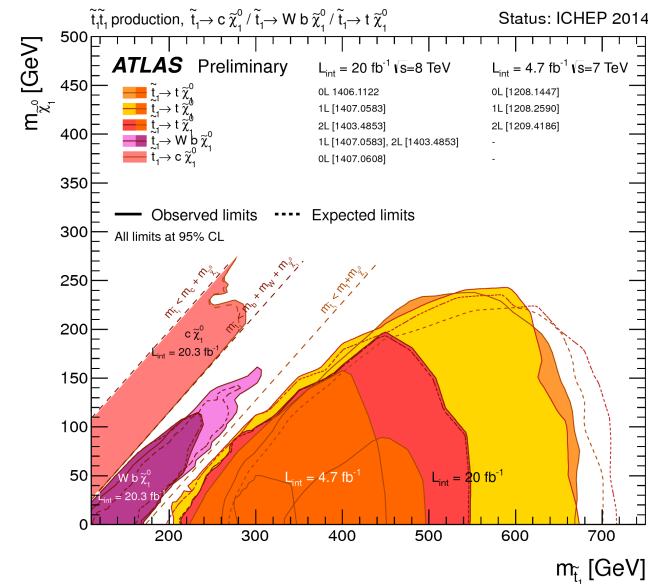
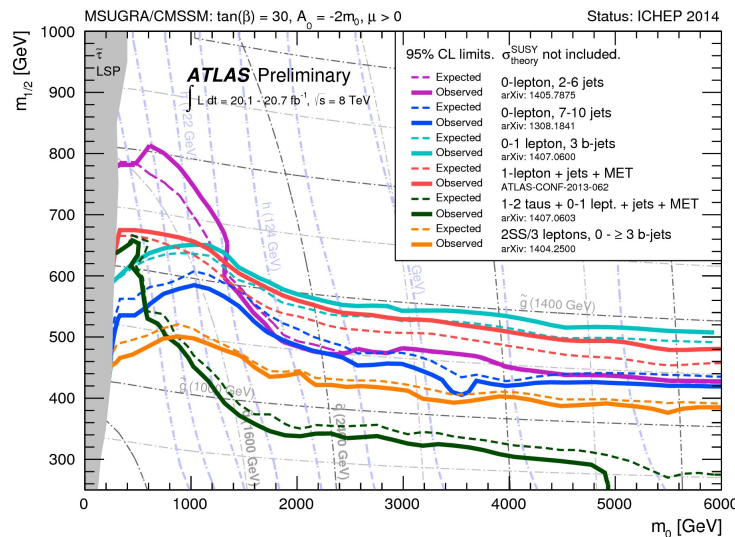
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IFT UAM/CSIC Madrid

<https://checkmate.hepforge.org>

# After LHC Run 1

- no significant excess above SM expectation in any final state configuration
- null results can be interpreted in term of strong limits on BSM physics scenarios
- e.g., first two generation squarks are now heavily constrained and even limits on third generations squarks become pretty strict.

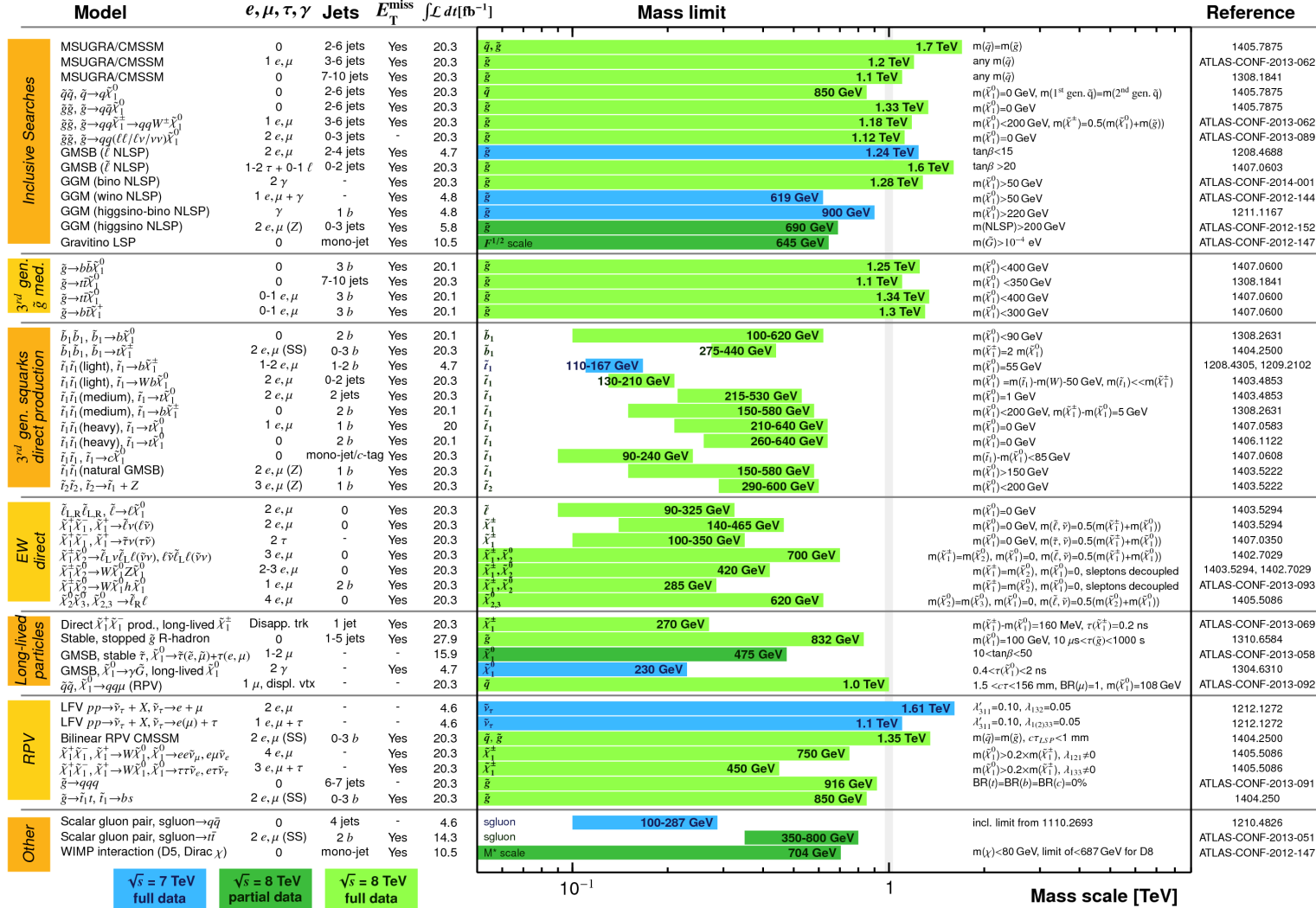


# ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

$\sqrt{s} = 7, 8 \text{ TeV}$



\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 $\sigma$  theoretical signal cross section uncertainty.

In particular, ATLAS/CMS have derived strict limits on simplified models or on constrained models

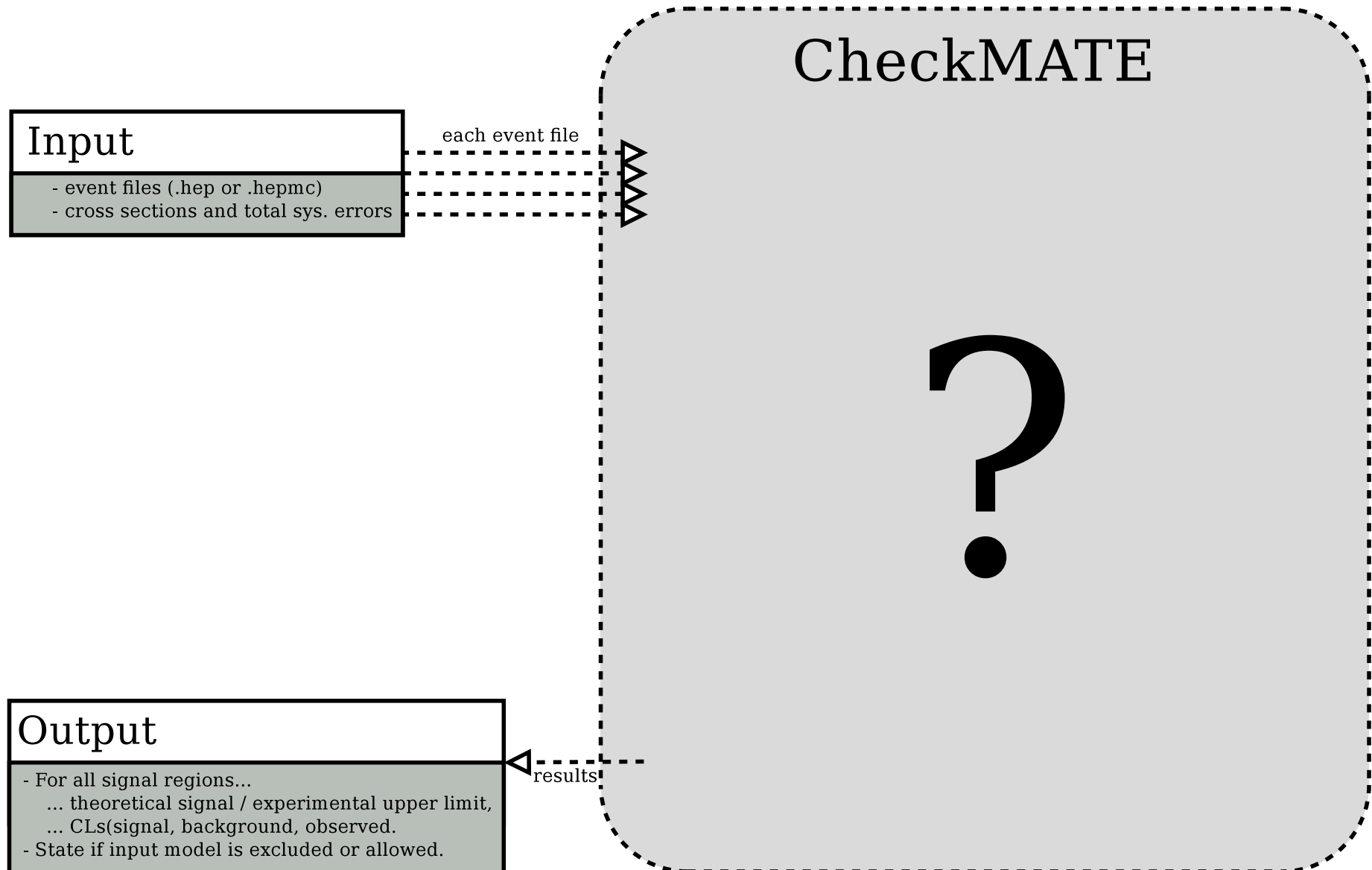
# Drawbacks...

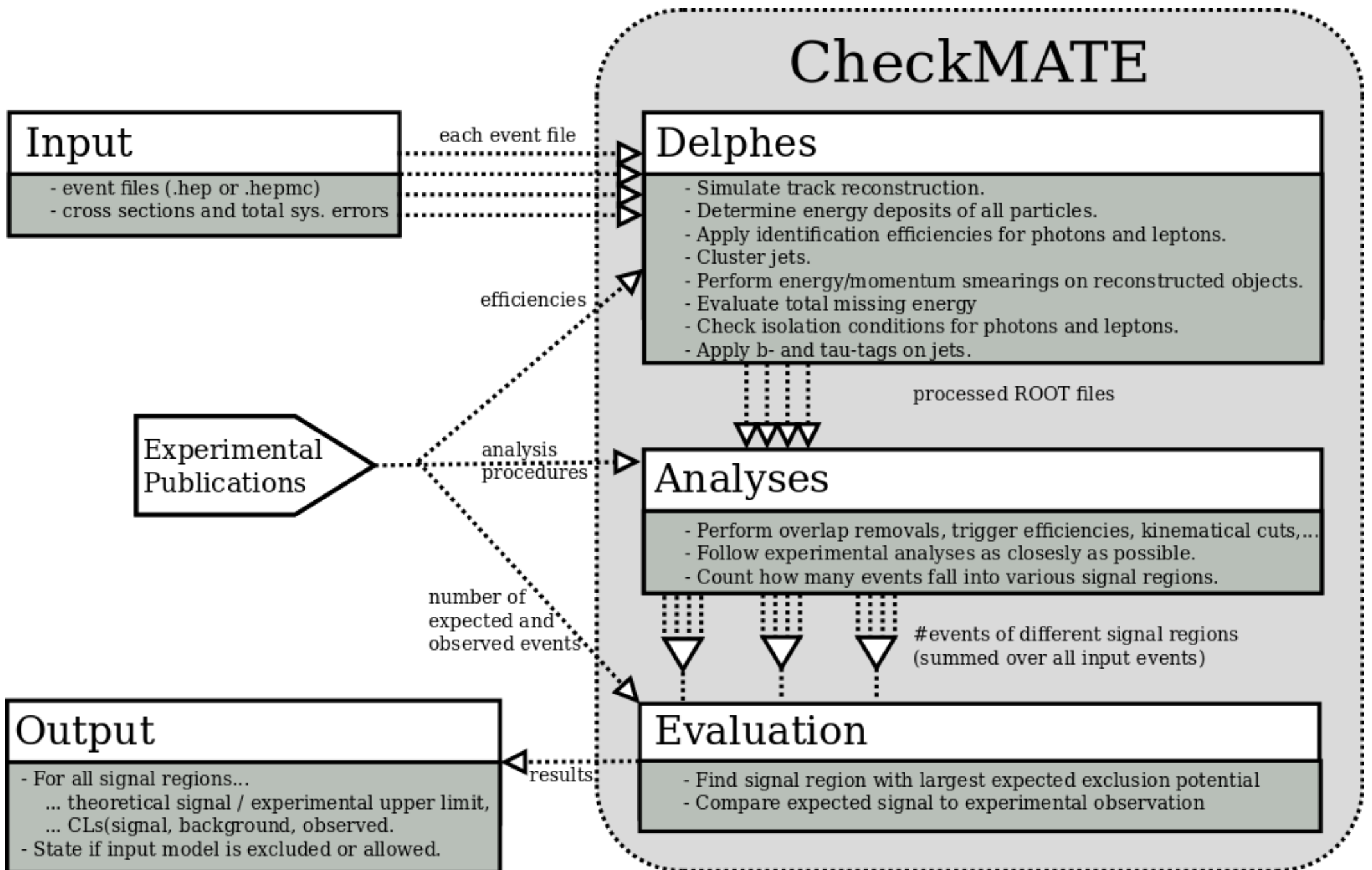
- However, many simplified models are *unrealistic*
- Limits would be heavily modified if one changes the assumptions on the sparticle spectrum and couplings
- E.g., softer jets/leptons, reduced MET, BR < 1
- Constrained models have a small number of parameters but they are not the most general realisation of a model
- How can we constrain all kinds of models by experimental data?

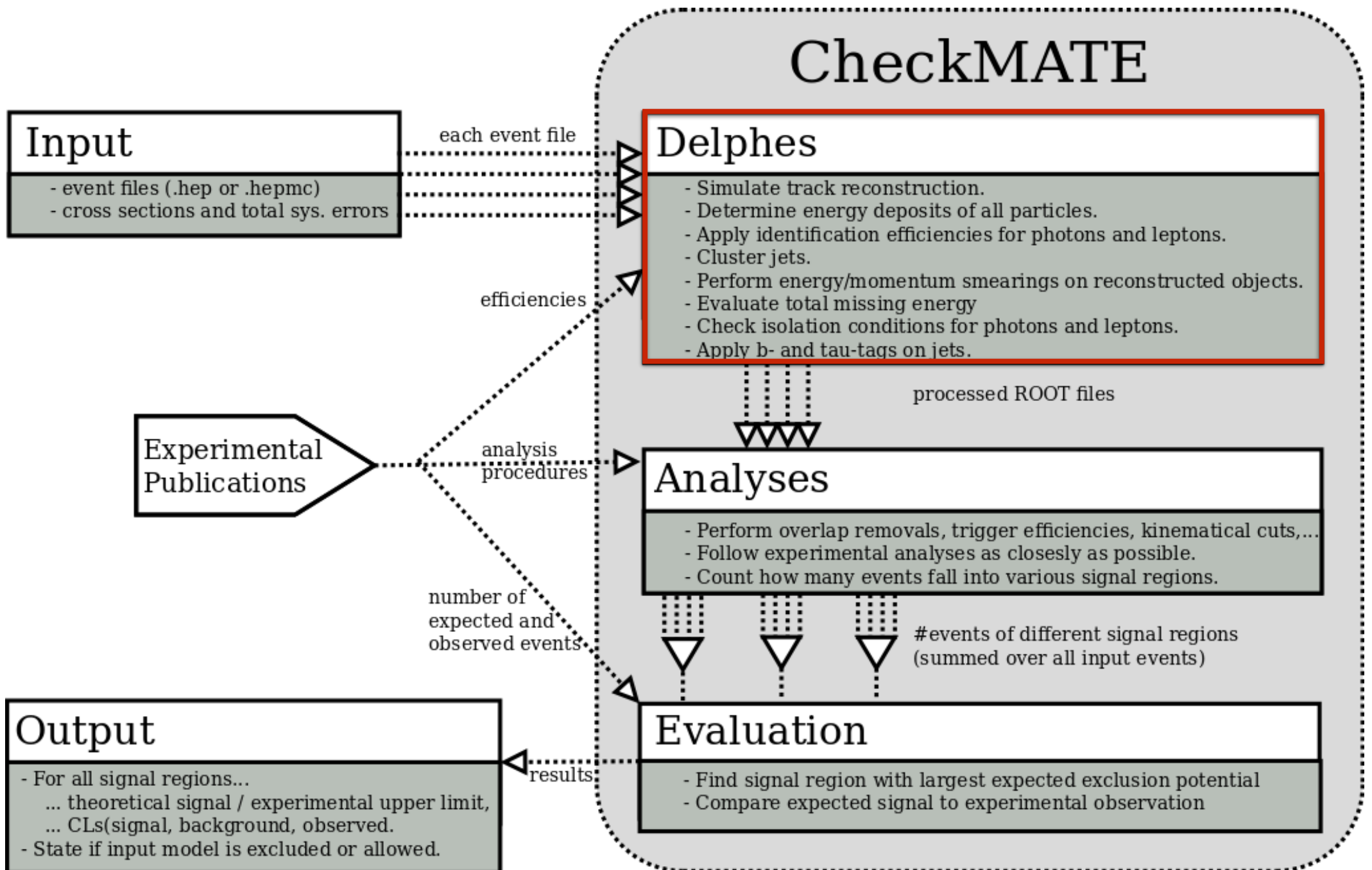
# Recast experimental limits

- Generate MC events with Madgraph, Whizard, Pythia, Herwig, Sherpa,...
- Simulate the detector response with Delphes/PGS
- Code up the relevant experimental study
- Validate the whole implementation
- This is very time consuming

# Our idea





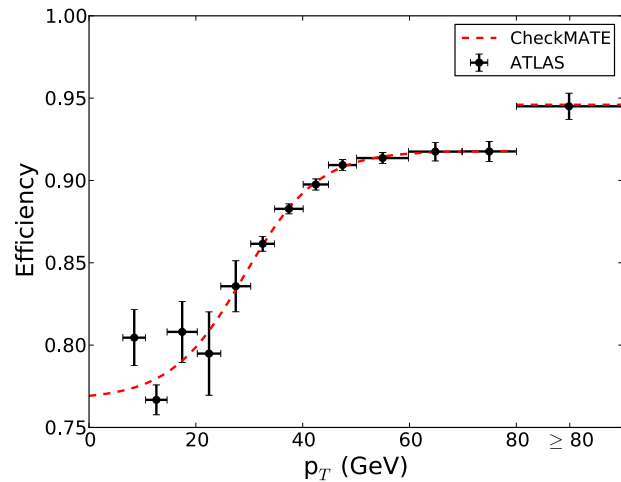




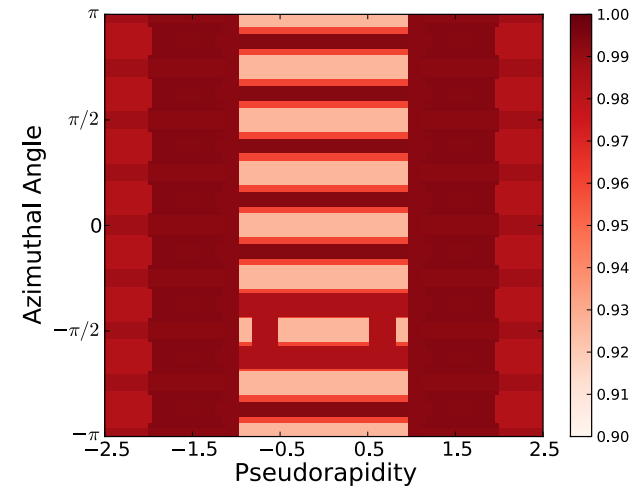
# Detector simulation

- We heavily rely on the fast detector simulation Delphes 3
- However, we have modified the default Delphes version
  - Many studies require multiple “types” of the same final state
  - The need of several isolation criteria for the same object
  - Retune of the detector response for many final state objects

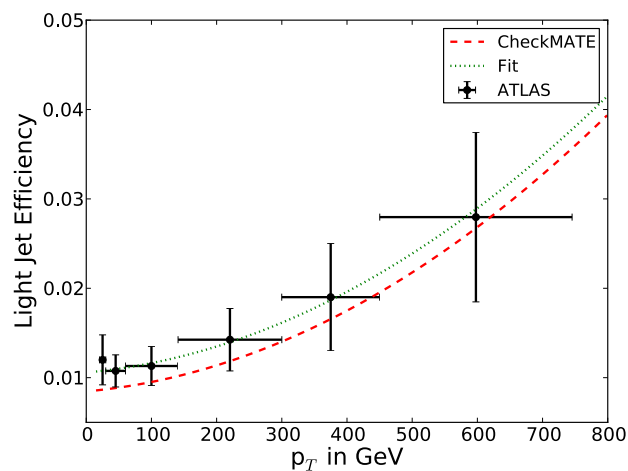
# Retune of Delphes



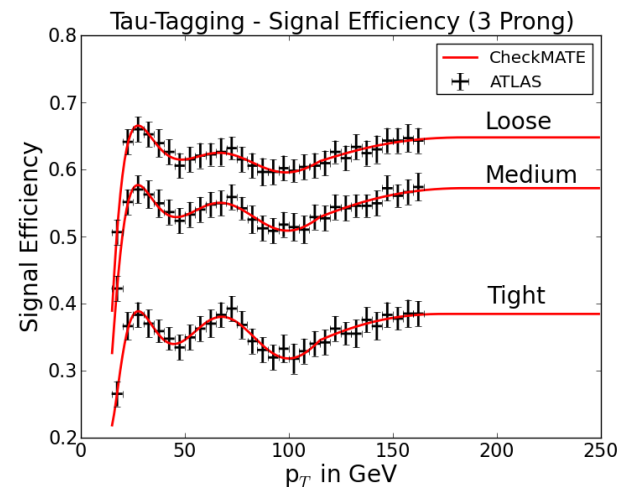
Id efficiency for "medium" electrons



Efficiency for muon objects

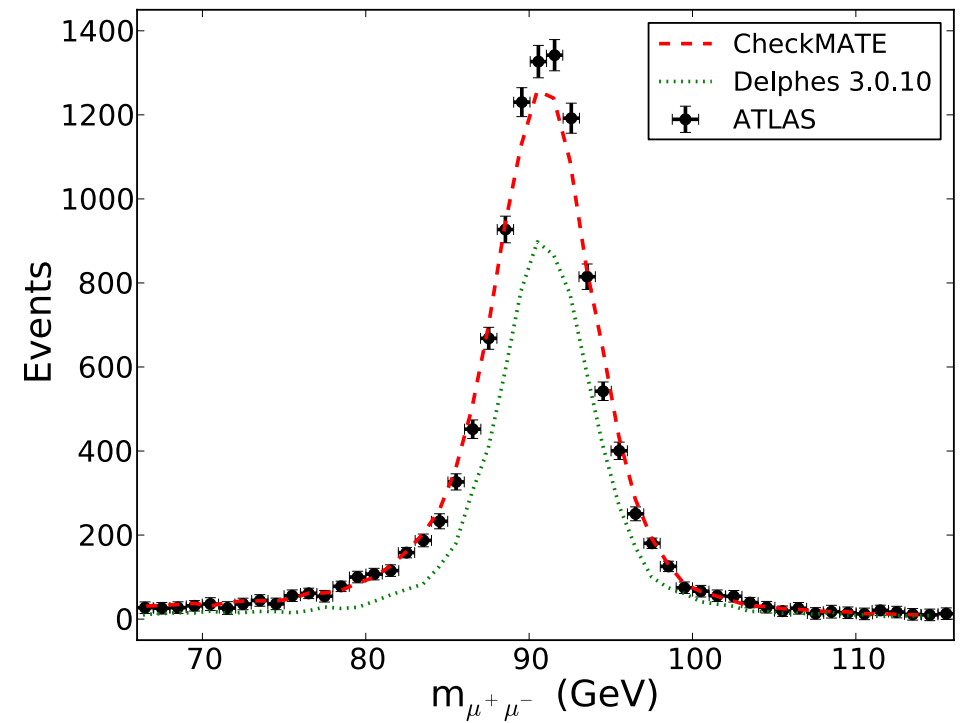
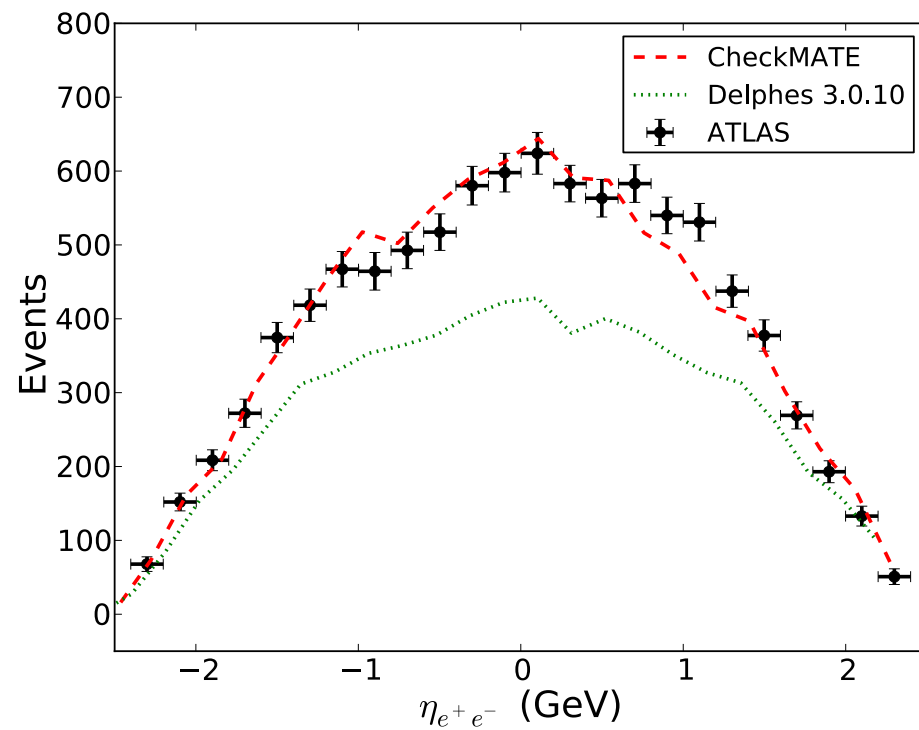


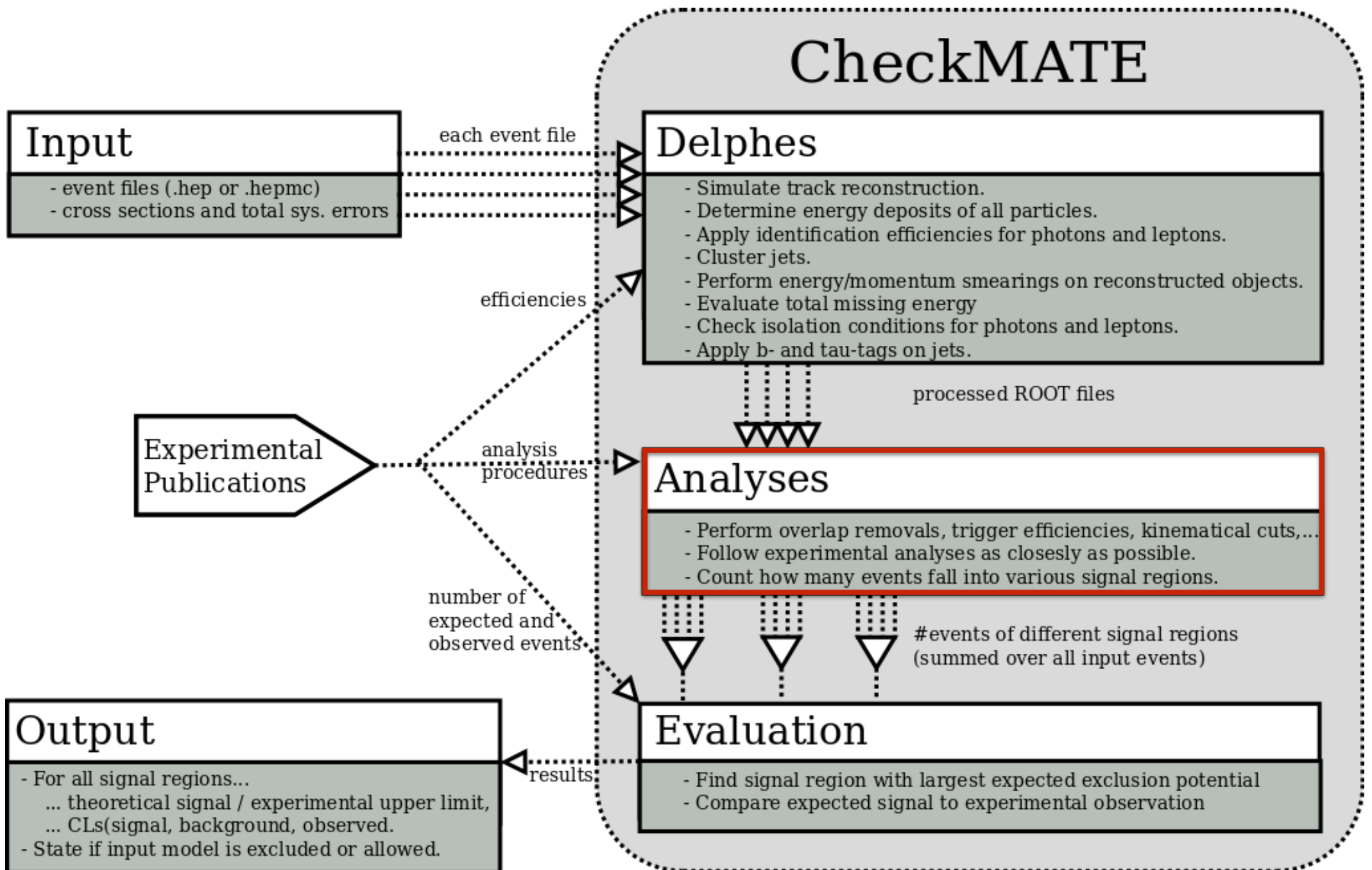
B tagging efficiency of jets containing light quarks



Signal efficiencies for 3 prong taus

# Validation plots





# Analyses

- CheckMATE uses a C++/Python framework to process Delphes' results
- All analyses are written in the same structural form
- We have implemented methods for object removal, a number of kinematical functions and tools for plotting
- CheckMATE is also interfaced with Root and has access to its methods, e.g. TLorentzVector and the histogramm tools
- A typical analysis consists of
  - choosing final state objects
  - trigger efficiencies/vetoing events
  - define signal/control regions
  - count number of events in each SR

# Example analysis

```
#include "example.h"

void Example::initialize() {
    setAnalysisName("example");
    setInformation("""@#Example Analysis\n""");
    setLuminosity(10*units::INVFB);
    ignore("towers");
    ignore("tracks");
    bookSignalRegions("jets;jets_plus_e;jets_plus_m");
    bookCutflowRegions("singlelep;twojets");
}

void Example::analyze() {
    electronsMedium = filterPhaseSpace(electronsMedium, 20, -2.5, 2.5, true);
    std::vector<Electron*> isoElecs = filterIsolation(electronsMedium);

    muonsCombined = filterPhaseSpace(muonsCombined, 25, -2.0, 2.0);
    std::vector<Muon*> isoMuons = filterIsolation(muonsCombined);
    missingET->addMuons(isoMuons);
    jets = filterPhaseSpace(jets, 50);
    jets = overlapRemoval(jets, electronsMedium, 0.2);

    if (isoElecs.size() + isoMuons.size() == 1)
        return;
    countCutflowEvent("singlelep");

    if (jets.size() < 2)
        return;
    countCutflowEvent("twojets");

    double E_tot = 0;
    for(int j = 0; j < jets.size(); j++)
        E_tot += jets[j]->PT;

    if (E_tot >= 150) {
        countSignalEvent("jets");
        if ((isoElecs.size() == 1) && (fabs(isoElecs[0]->P4().DeltaPhi(missingET->P4())) < 0.3))
            countSignalEvent("jets_plus_e");
        else if ((isoMuons.size() == 1) && (fabs(isoElecs[0]->P4().DeltaPhi(missingET->P4())) < 0.15))
            countSignalEvent("jets_plus_m");
    }
}

void Example::finalize() {
}
```

## Cuts

at least one lepton

at least two jets

$\text{Sum(Scalar ET)} > 150 \text{ GeV}$

$\text{DeltaPhi(lepton, MET)} < 0.3$

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    std::vector<Muon*> isoMuons = filterIsolation(muonsCombined);  
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```

```
    if (isoElecs.size() + isoMuons.size() == 1)  
        return;  
    countCutflowEvent("singlelep");
```

```
    if (jets.size() < 2)  
        return;  
    countCutflowEvent("twojets");
```

```
    double E_tot = 0;  
    for(int j = 0; j < jets.size(); j++)  
        E_tot += jets[j]->PT;
```

```
    if (E_tot >= 150) {  
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        else if ((isoMuons.size() == 1) && (fabs(isoElecs[0]->P4().DeltaPhi(missingET->P4())) < 0.15))  
            countSignalEvent("jets_plus_m");  
    }  
}
```

```
void Example::finalize() {  
}
```

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$\Delta\Phi(\text{lepton}, \text{MET}) < 0.3$

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    electronsMedium = filterPhaseSpace(electronsMedium, 20, -2.5, 2.5, true);  
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    muonsCombined = filterPhaseSpace(muonsCombined, 25, -2.0, 2.0);  
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    jets = filterPhaseSpace(jets, 50);  
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    if (isoElecs.size() + isoMuons.size() == 1)  
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```
    double E_tot = 0;  
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        E_tot += jets[j]->PT;
```

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    if (E_tot >= 150) {  
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            countSignalEvent("jets_plus_e");  
        else if ((isoMuons.size() == 1) && (fabs(isoElecs[0]->P4().DeltaPhi(missingET->P4())) < 0.15))  
            countSignalEvent("jets_plus_m");  
    }
```

```
void Example::finalize() {  
}
```

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at least one lepton

at least two jets

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$\Delta\Phi(\text{lepton}, \text{MET}) < 0.3$

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```

```
    if (isoElecs.size() + isoMuons.size() == 1)  
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    if (jets.size() < 2)  
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    double E_tot = 0;  
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            countSignalEvent("jets_plus_e");  
        else if ((isoMuons.size() == 1) && (fabs(isoElecs[0]->P4().DeltaPhi(missingET->P4())) < 0.15))  
            countSignalEvent("jets_plus_m");  
    }  
}
```

```
void Example::finalize() {  
}
```

## Cuts

at least one lepton

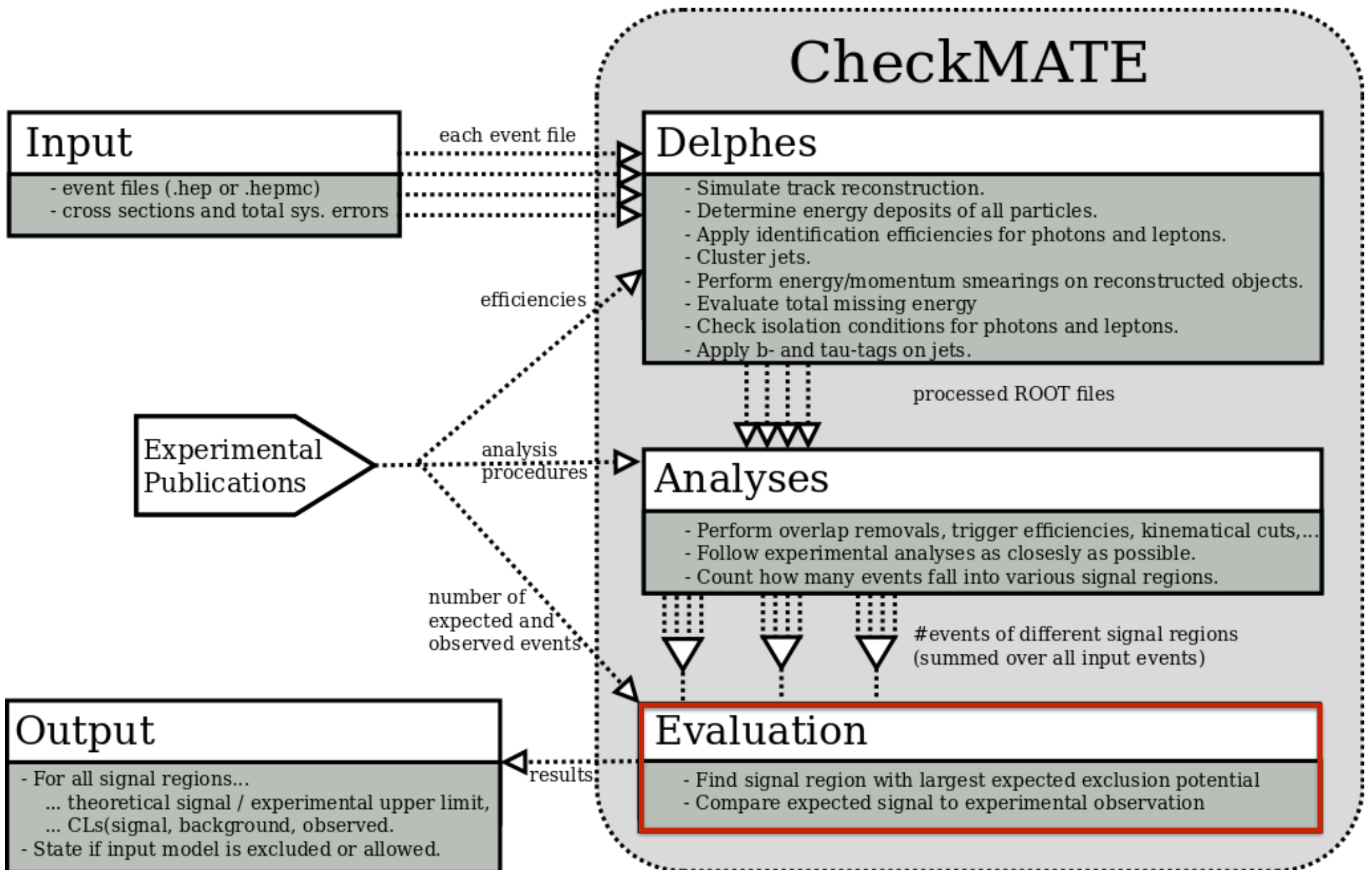
at least two jets

Sum(Scalar ET) > 150 GeV

DeltaPhi(lepton, MET) < 0.3

# List of analyses

#####					
# #Name	NSR	Description	Lumi	CR?	#
# atlas_1210_2979	1	ATLAS, WW measurement with 2 leptons (7TeV)	4.6	no	#
# atlas_1308_2631	6	ATLAS, 0 leptons + 2 b-jets + etmiss	20.1	yes	#
# atlas_1402_7029	20	ATLAS, 3 leptons + etmiss (chargino+neutralino)	20.3	no	#
# atlas_1403_4853	12	ATLAS, 2 leptons + etmiss (direct stop)	20.3	no	#
# atlas_1403_5294	13	ATLAS, 2 leptons + etmiss, (SUSY electroweak)	20.3	yes	#
# atlas_1403_5294_CR	4	ATLAS, 2 leptons + etmiss CR, (SUSY electroweak)	20.3	yes	#
# atlas_1404_2500	5	ATLAS, Same sign dilepton or 3l	20.3	no	#
# atlas_1407_0583	27	ATLAS, 1 lepton + (b-)jets + etmiss (stop)	20.3	no	#
# atlas_1407_0600	9	ATLAS, 3 b-jets + 0-1 lepton + etmiss	20.1	no	#
# atlas_1407_0608	3	ATLAS, Monojet or charm jet (stop)	20.3	no	#
# atlas_1502_01518	9	ATLAS, Monojet plus missing energy	20.3	no	#
# atlas_conf_2012_104	2	ATLAS, 1 lepton + >= 4 jets + etmiss	5.8	yes	#
# atlas_conf_2012_147	4	ATLAS, Monojet + etmiss	10.0	yes	#
# atlas_conf_2013_021	4	ATLAS, WZ standard model (3 leptons + etmiss)	13.0	no	#
# atlas_conf_2013_024	3	ATLAS, 0 leptons + 6 (2 b-)jets + etmiss	20.5	yes	#
# atlas_conf_2013_031	2	ATLAS: Higgs spin measurement (WW)	20.7	no	#
# atlas_conf_2013_036	5	ATLAS: 4 leptons + etmiss	20.7	no	#
# atlas_conf_2013_047	10	ATLAS, 0 leptons + 2-6 jets + etmiss	20.3	yes	#
# atlas_conf_2013_049	9	ATLAS, 2 leptons + etmiss	20.3	yes	#
# atlas_conf_2013_061	9	ATLAS, 0-1 leptons + >= 3 b-jets + etmiss	20.1	yes	#
# atlas_conf_2013_062	19	ATLAS: 1-2 leptons + 3-6 jets + etmiss	20.1	yes	#
# atlas_conf_2013_089	12	ATLAS, 2 leptons (razor)	20.3	yes	#
# atlas_conf_2014_014	1	ATLAS, 2 leptons + b-jets (stop)	20.3	yes	#
# atlas_conf_2014_033	3	ATLAS, WW standard model measurement	20.3	yes	#
# atlas_conf_2014_056	1	ATLAS, ttbar spin correlation measurement	20.3	yes	#
# cms_1303_2985	59	CMS, alpha_T + b-jets	11.7	yes	#
# cms_1301_4698_WW	1	CMS, WW standard model measurement	3.5	no	#
# cms_1306_1126_WW	1	CMS, WW standard model measurement (7TeV)	4.9	no	#
# cms_1405_7570	57	CMS, Various chargino and neutralino	19.5	no	#
# cms_smp_12_006	4	CMS, WZ standard model (3 leptons + etmiss)	19.6	no	#
# cms_sus_12_019	4	CMS, 2 leptons, >= 2 jets + etmiss (dilep edge)	19.4	no	#
# cms_sus_13_016	1	CMS, OS lep 3+ b-tags	19.5	no	#
# # Superseded analyses #					
# #atlas_conf_2013_035	6	ATLAS, Superseded by atlas_1402_7029	20.7	no	#
# #atlas_conf_2013_037	6	ATLAS, Superseded by atlas_1407_0583	20.7	no	#
# #atlas_conf_2013_048	4	ATLAS, Superseded by atlas_1403_4853	20.0	no	#
# # User added analyses #					
# #					
# atlas_1411_1559	1	Search for new phenomena in events with a photon and missing transverse momentum in pp collisions	20.3	no	#
#####					



# Setting limits

- Many searches provides  $O$ ,  $B$ , uncertainty on  $B$ , upper limits on signal  $S_{95}$
- Directly compare  $S$  to 95% upper limit on signal  $S_{95}$
- Calculate the ratio  $r=S/S_{95}$ . If  $r>1$ : Excluded!
- Choose signal region with strongest expected exclusion
- Use its observed result to state “excluded” or “allowed”
- Alternatively, calculate  $CL$ . If  $CL < 0.05$ : Excluded!

# Demonstration

## Input

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

[Optional Parameters]

## Process Information (Each new process 'X' must start with [X])
[gluinogluino]
XSect: 3.53*FB
XSectErr: 1e-5*PB
Events: testfile.hep
```

# Demonstration

## Input

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[Mandatory Parameters]
Name: My_New_Run
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[gluinogluino]
XSect: 3.53*FB
XSectErr: 1e-5*PB
Events: testfile.hep
```

## Output

SR	S	dS_stat	dS_sys	dS_tot	S95_obs	S95_exp	r <sup>c</sup> _obs	r <sup>c</sup> _exp
AL	37.41	0.43	4.10	4.12	1341.20	1135.00	0.02	0.03
AM	5.37	0.15	0.56	0.58	51.30	42.70	0.08	0.10
BM	7.33	0.18	0.76	0.78	14.90	17.00	0.39	0.34
BT	0.84	0.05	0.10	0.11	6.70	5.80	0.09	0.11
CM	18.22	0.30	2.04	2.07	81.20	72.90	0.17	0.19
CT	2.32	0.08	0.27	0.28	2.40	3.30	0.74	0.54
D	12.15	0.24	1.29	1.32	15.50	13.60	0.62	0.70
EL	21.56	0.33	2.38	2.41	92.40	57.30	0.18	0.29
EM	16.08	0.29	1.79	1.81	28.60	21.40	0.44	0.59
ET	8.10	0.20	0.89	0.91	8.30	6.50	0.76	0.97

# Demonstration

## Input

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

[Optional Parameters]

## Process Information (Each new process 'X' must start with [X])
[gluinogluino]
XSect: 3.53*FB
XSectErr: 1e-5*PB
Events: testfile.hep
```

## Output

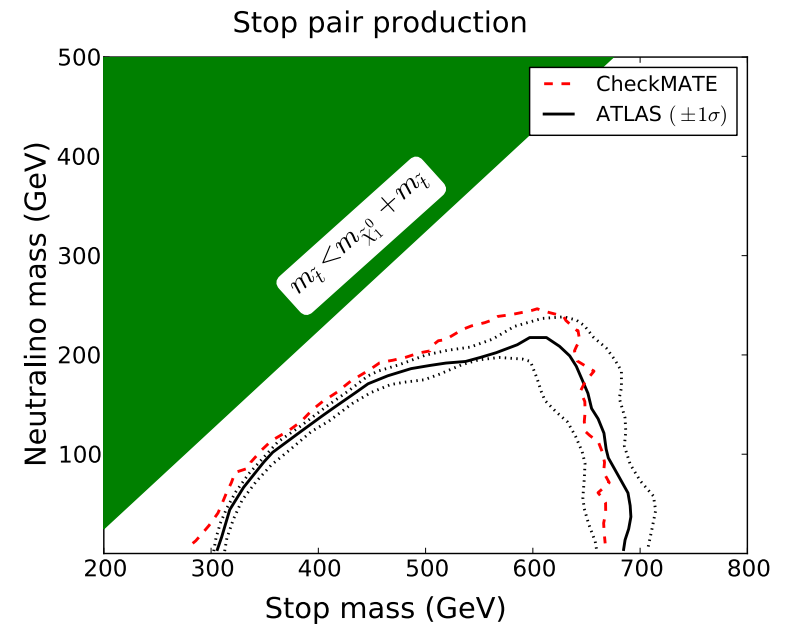
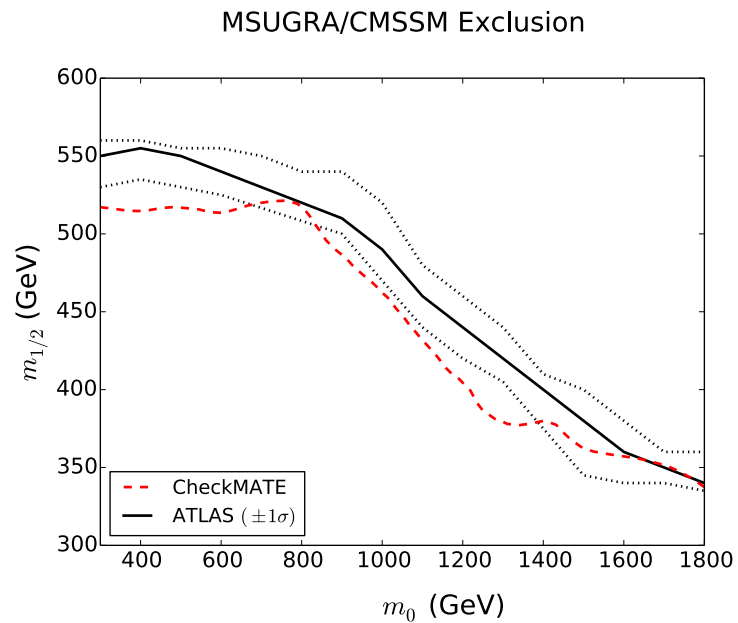
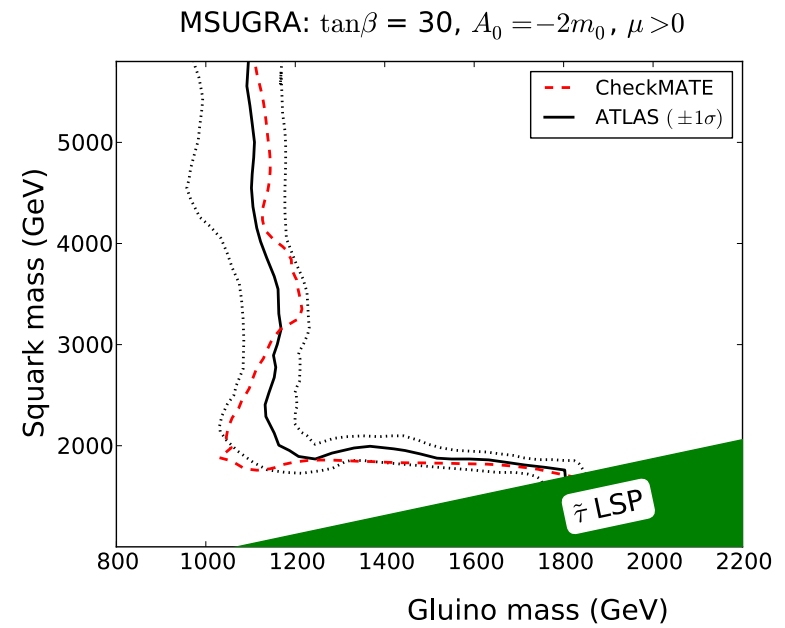
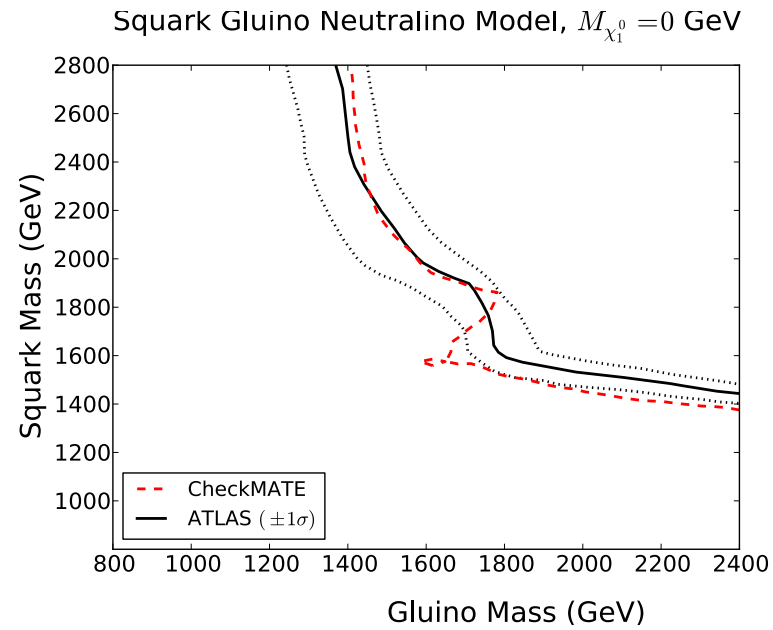
SR	S	dS_stat	dS_sys	dS_tot	S95_obs	S95_exp	r <sup>c</sup> _obs	r <sup>c</sup> _exp
AL	37.41	0.43	4.10	4.12	1341.20	1135.00	0.02	0.03
AM	5.37	0.15	0.56	0.58	51.30	42.70	0.08	0.10
BM	7.33	0.18	0.76	0.78	14.90	17.00	0.39	0.34
BT	0.84	0.05	0.10	0.11	6.70	5.80	0.09	0.11
CM	18.22	0.30	2.04	2.07	81.20	72.90	0.17	0.19
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EL	21.56	0.33	2.38	2.41	92.40	57.30	0.18	0.29
EM	16.08	0.29	1.79	1.81	28.60	21.40	0.44	0.59
ET	8.10	0.20	0.89	0.91	8.30	6.50	0.76	0.97

## Result

analysis	bestSR	r_obs <sup>c</sup>	r_exp <sup>c</sup>	CLs_obs	dCLs_obs	CLs_exp	dCLs_exp	[...]
atlas_conf_2013_047	ET	0.76	0.97	0.0609	0.0027	0.0077	0.0013	[...]



# Validation



# Validation

ATLAS-CONF-2013-047 CutFlow

ATLAS

ATLAS-CONF-2013-047

0 lepton +  $\geq 2$ -6 jets +  $E_T^{miss}$

Energy: 8 TeV

Luminosity: 20.3 fb<sup>-1</sup>

Process	$\tilde{q}\tilde{g}$ direct				$\tilde{g}\tilde{g}$ direct	
Point	$m(\tilde{g}) = 1425$ GeV $m(\tilde{\chi}_1^0) = 525$ GeV B-medium		$m(\tilde{g}) = 1612$ GeV $m(\tilde{\chi}_1^0) = 37$ GeV B-tight		$m(\tilde{g}) = 1162$ GeV $m(\tilde{\chi}_1^0) = 337$ GeV D	
Signal Region Source	ATLAS	CheckMATE	ATLAS	CheckMATE	ATLAS	CheckMATE
Generated events	5000	50000	5000	50000	5000	50000
In	100	100	100	100	100	100
Jet Cleaning *	99.7	-	99.6	-	99.8	-
0-lepton *	98.0	-	98.8	-	98.5	-
$E_T^{miss} > 160$ GeV *	93.3	-	95.9	-	88.9	-
$p_T(j_1) > 130$ GeV	93.3	93.9	95.8	96.0	88.8	88.1
$p_T(j_2) > 130$ GeV	92.4	92.7	95.2	95.1	88.8	88.1
$p_T(j_3) > 0$ -60 GeV	68.5	67.0	75.7	73.5	87.1	86.8
$p_T(j_4) > 0$ -60 GeV	68.5	67.0	75.7	73.5	74.1	74.4
$p_T(j_5) > 0$ -60 GeV	68.5	67.0	75.7	73.5	40.9	36.0
$\Delta\phi(j_i > 40, E_T^{miss}) > 0.4$	60.4	58.7	66.2	64.2	34.2	30.1
$\Delta\phi(j_i > 40 \text{ GeV}, E_T^{miss}) > 0 - 0.2$	60.4	58.7	66.2	64.2	28.6	25.9
$E_T^{miss}/m_{eff}(N_j) > 0.15 - 0.4$	44.8	41.8	31.8	28.1	22.1	18.9
$m_{eff}(incl.) > 1 - 2.2$ TeV	$27.5 \pm 0.7$	$25.8 \pm 0.2$	$22.8 \pm 0.7$	$20.5 \pm 0.2$	$13.4 \pm 0.5$	$13.0 \pm 0.2$

Table 2: Final error is monte carlo statistics from both ATLAS and CheckMATE. \* Variable trigger efficiencies mean that the results are only comparable after both an  $E_T^{miss}$  and jet  $p_T$  cut have been applied.

# Analysis Manager

- The Analysis Manager allows for easy implementation of new studies
- It asks as input the number of expected background, observed background events and the error and calculates the S95 C.L. limit for each SR
- All needed final states with their properties (e.g. isolation criteria of leptons, working point for b-tagging, jets size...) can be defined
- The AnalysisManager provides a skeleton code for easy implementation of a new search

## 1. General Information to build analysis

Analysis Name:

MC4BSM

Your Name (to declare the analysis author):

Jong Soo Kim

Your Email:

jong.kim@csic.es

Analysis Description (short, one line):

Example

Description (long, multiple lines, finish with empty line:

Example

Luminosity (in fb<sup>-1</sup>):

20.3

Do you plan to implement control regions to that analysis? [(y)es, (n)o]

n

## 2. Information on Signal Regions

List all signal regions (one per line, finish with an empty line):

SR1

Is the SM expectation B known? [(y)es, (n)o]?

y

Information: We are now going to ask you which numbers you want to provide for each signal region.

The following items are possible:

obs: Observed number of events

bkg: Expected number of background events

bkg\_err: Expected total error on bkg

bkg\_errp: Expected total upper error (in case of asymmetric errors)

bkg\_errm: Expected total lower error (in case of asymmetric errors)

bkg\_err\_stat: Expected statistical error on bkg

bkg\_err\_sys: Expected systematical error on bkg (in case of symmetric errors)

bkg\_errp\_sys: Expected systematical upper error (in case of asymmetric errors)

bkg\_errm\_sys: Expected systematical lower error (in case of asymmetric errors)

Note that not all of these numbers have to be given (e.g. you don't have to give the total error if you give the individual stat and sys contributions)

However, there are some requirements, about which you will be warned if you don't meet them (e.g. giving xyz\_errp without xyz\_errm)

The standard, minimum set of information consists of obs, bkg and bkg\_err

List all categories you want to supply (one per line)

obs

bkg

bkg\_err

The set of information you entered is valid.

You now have to add the numbers for each of the given signal regions.

Note that while you enter more numbers, the corresponding model independent 95% confidence limits for the items you have already entered are calculated in the background.

SR1

obs:

20

bkg:

15

bkg\_err:

5

S95obs and S95exp values are calculated internally (progress: 0 / 2)

## 1. General Information to build analysis

Analysis Name:

MC4BSM

Your Name (to declare the analysis author):

Jong Soo Kim

Your Email:

jong.kim@csic.es

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SR1

obs:

20

bkg:

15

bkg\_err:

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S95obs and S95exp values are calculated internally (progress: 0 / 2)

### 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 (default ATLAS values: tracks=0.4, calo=0.1)? [in GeV]

1.0

What is the dR used for isolation?

0.3

Is there an absolute or a relative upper limit for the surrounding pt? [(a)bsolute, (r)elative]

r

What is the maximum pt ratio used for isolation?

0.16

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

#### 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]

20.

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]

n

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

n

All necessary information has been entered. Before the AnalysisManager can create all required files, the internal S95obs and S95exp calculations have to finish. The calculation should take between 10 and 100s per point.

... done!

Please check the below results for sanity. If anything looks suspicious, please contact the CheckMATE authors.

obs	bkg	bkgerr	S95obs	S95exp
20	15	5	17	14

(Press any key to continue)

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obs	bkg	bkgerr	S95obs	S95exp
20	15	5	17	14

(Press any key to continue)

# Outlook

- CheckMATE 2 will be public soon
- A Pythia/Madgraph module is added to CheckMATE
- The user can select a process
- MC events can be directly interfaced with Delphes
- Delphes events are interfaced to CheckMATE (no root file is generated)
- CheckMATE can be used with the most recent Delphes version soon
- a common interface between CheckMATE and MadAnalysis is being developed



# Conclusion

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