CheckMATE

Checkmating your favorite BSM model

MC4BSM 2015 at Fermilab

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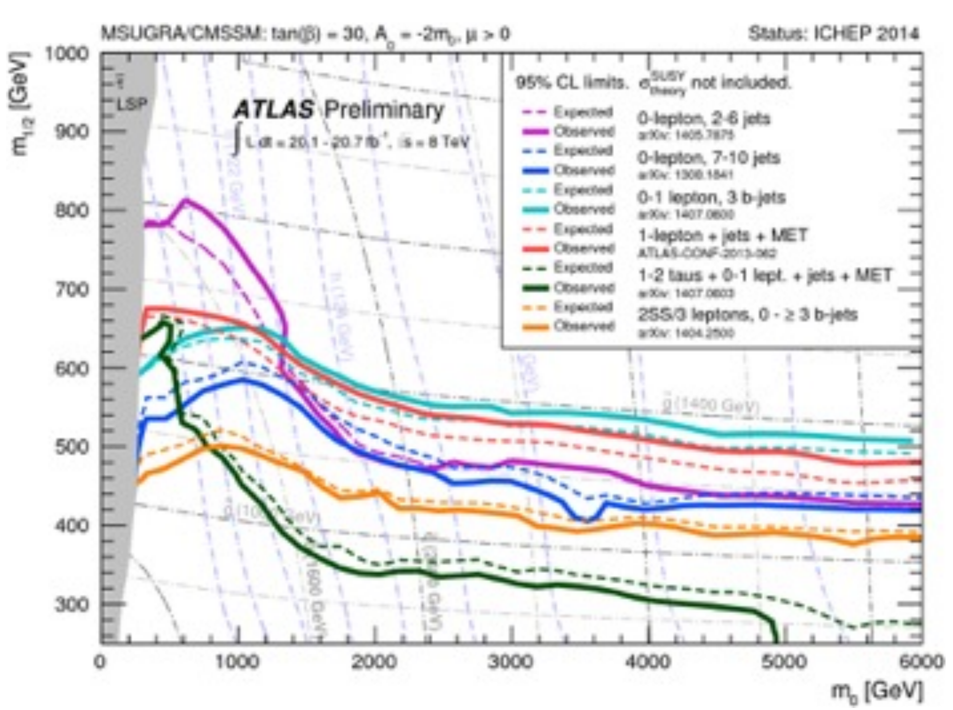
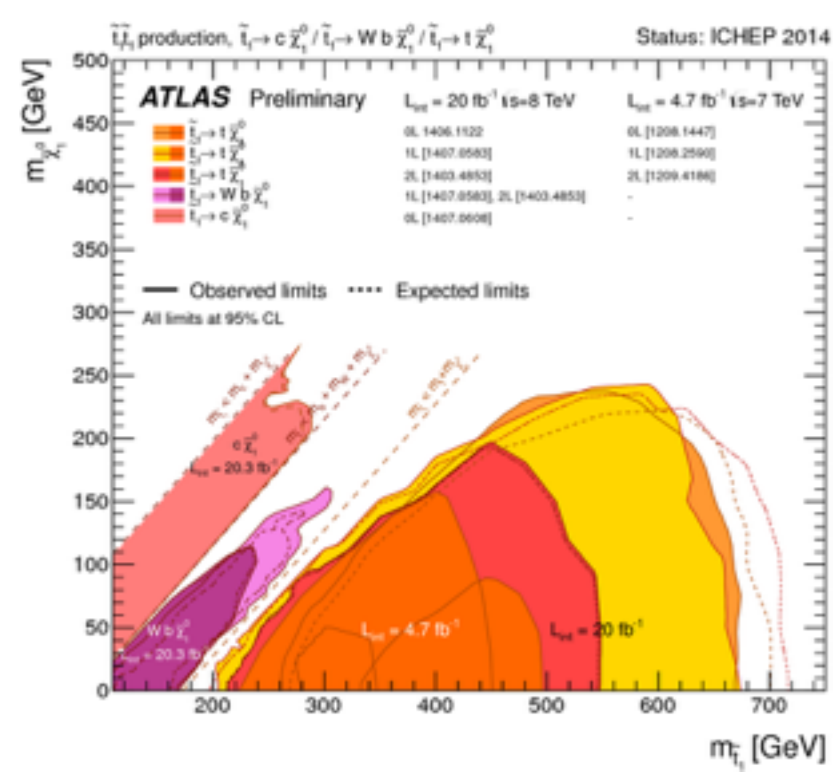
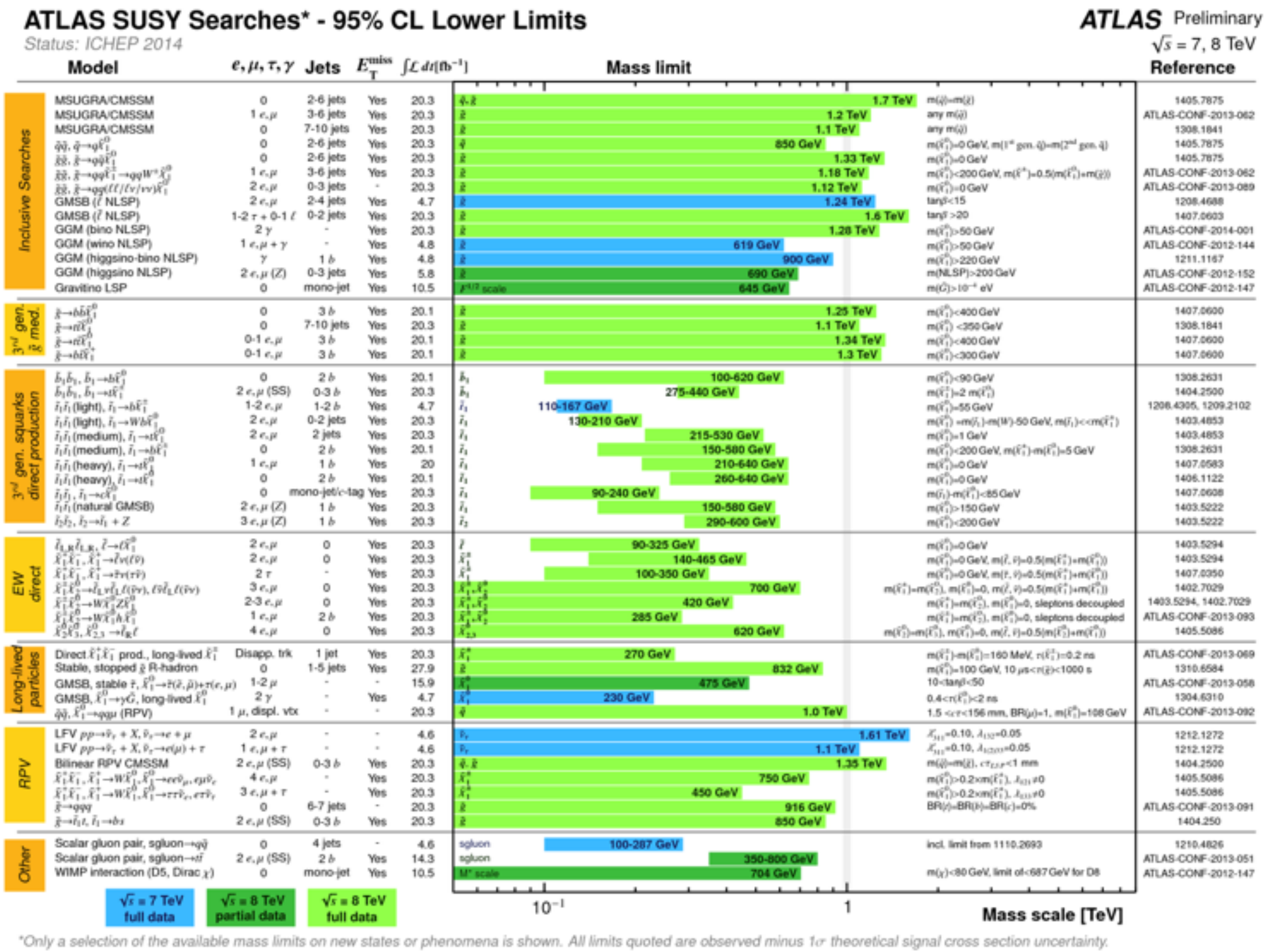
http:checkmate.hepforge.org

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.







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 I

- SModels (arXiv:1312.4175) decomposes the spectrum into simplified topologies and compare their rates with experimental limits

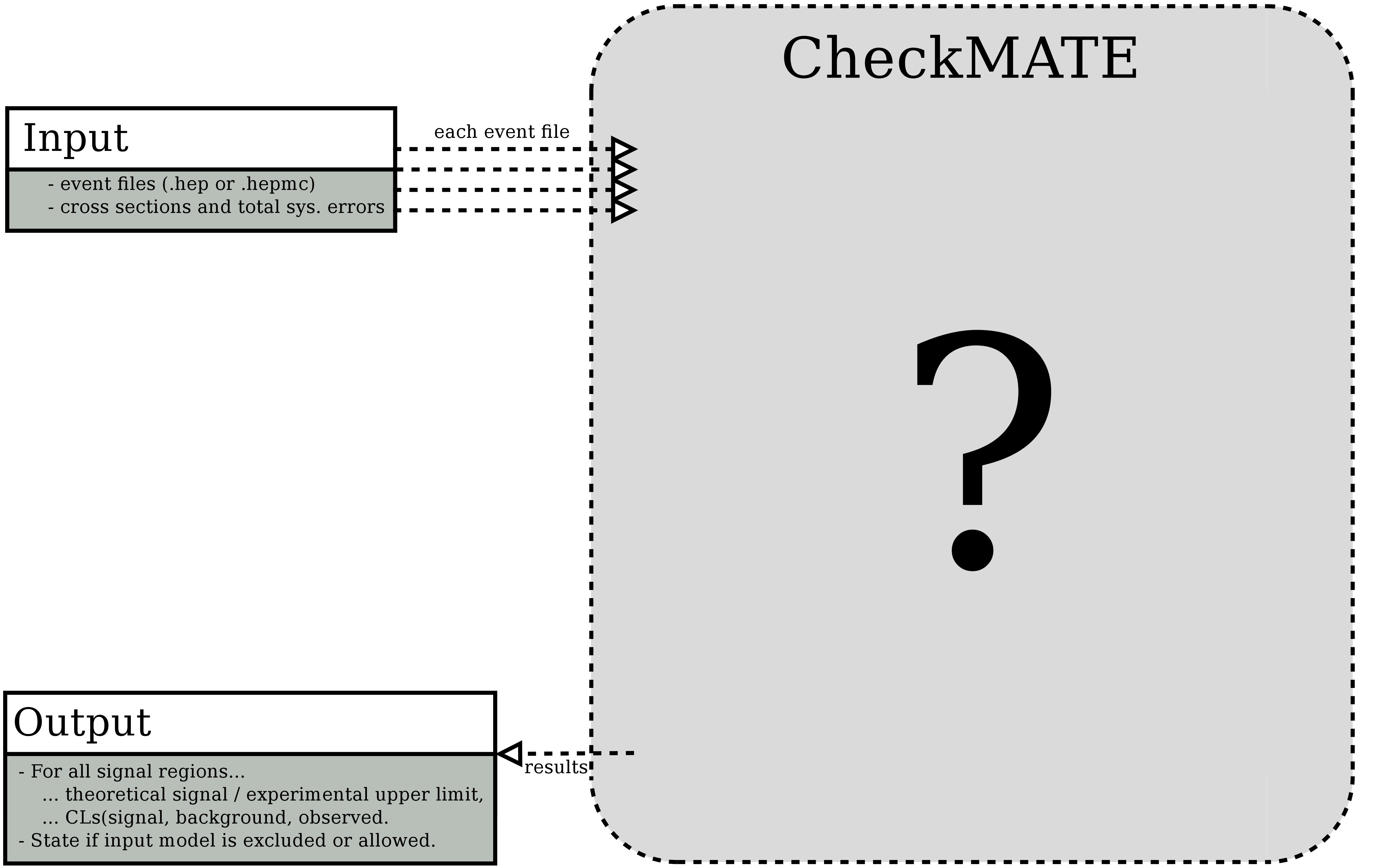
- FastLim (arXiv:1402.0492) calculates limits based on simplified models by providing pre-calculated efficiency tables for each simplified topology

- Both are very fast but the topology must be very simple

Recast experimental limits II

- Generate MC events with 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



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- event files (.hep or .hepmc)
- cross sections and total sys. errors
each event file
CheckMATE
?
Output
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... theoretical signal / experimental upper limit,
... CLs(signal, background, observed.
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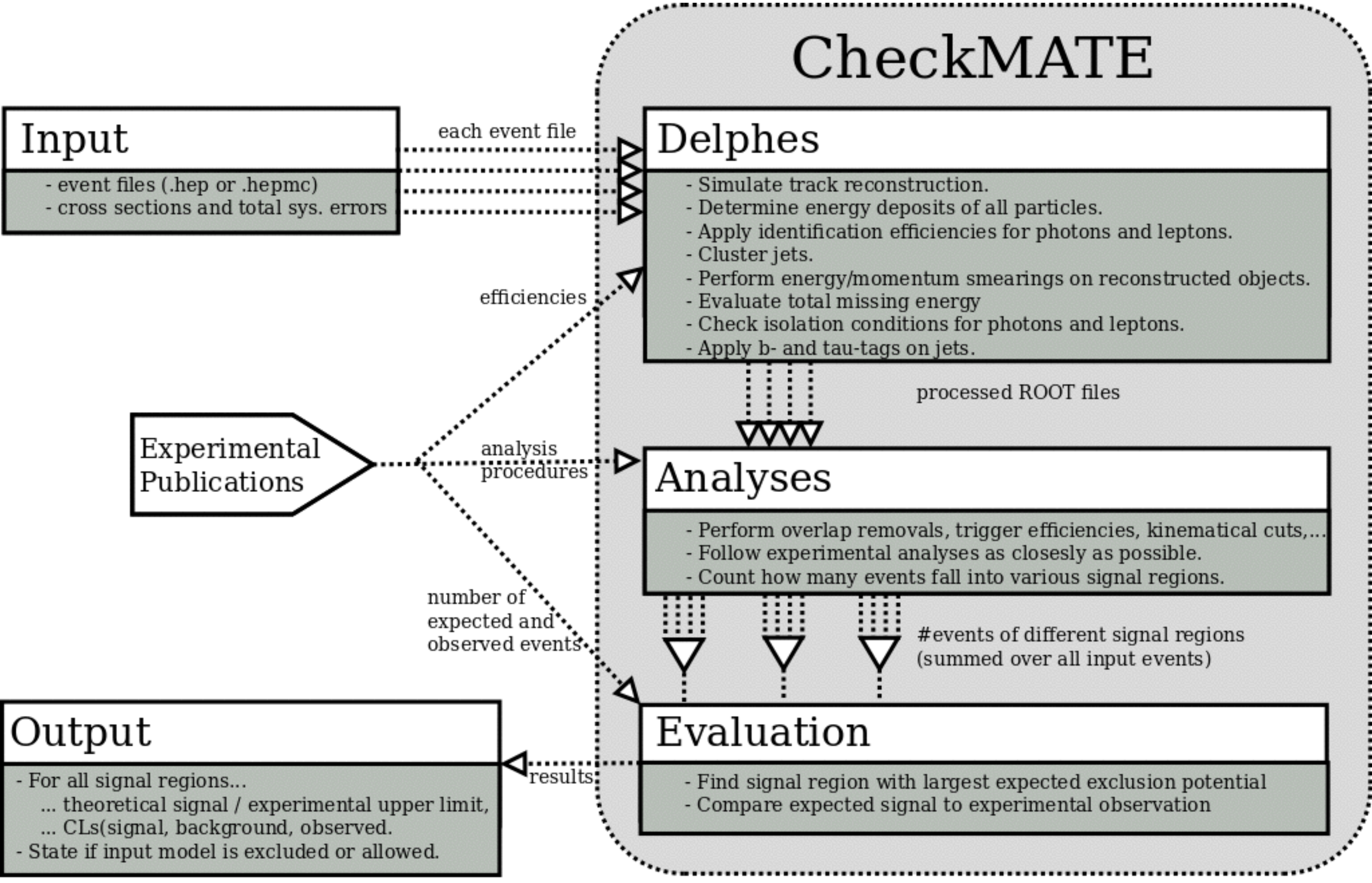
results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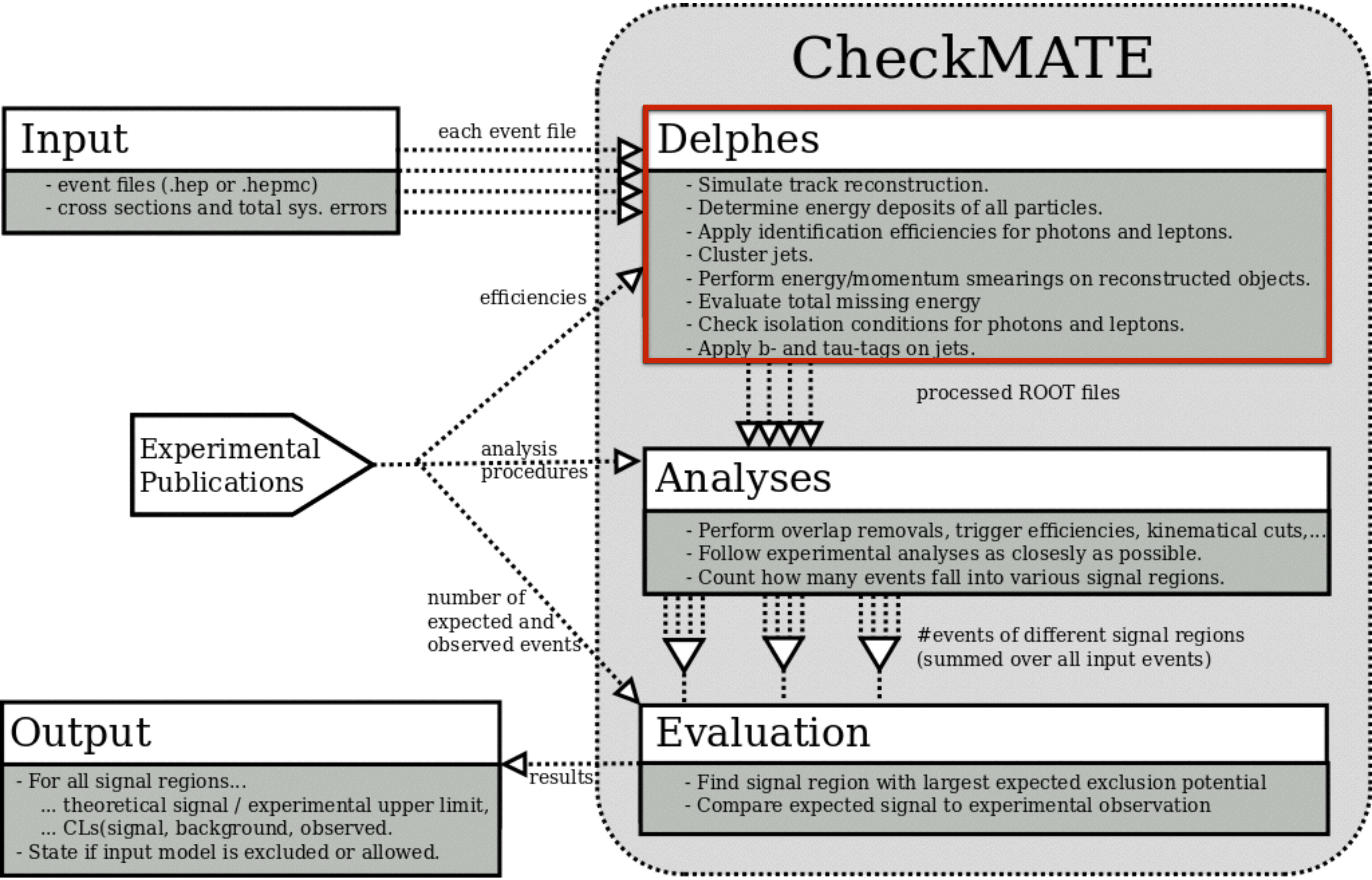
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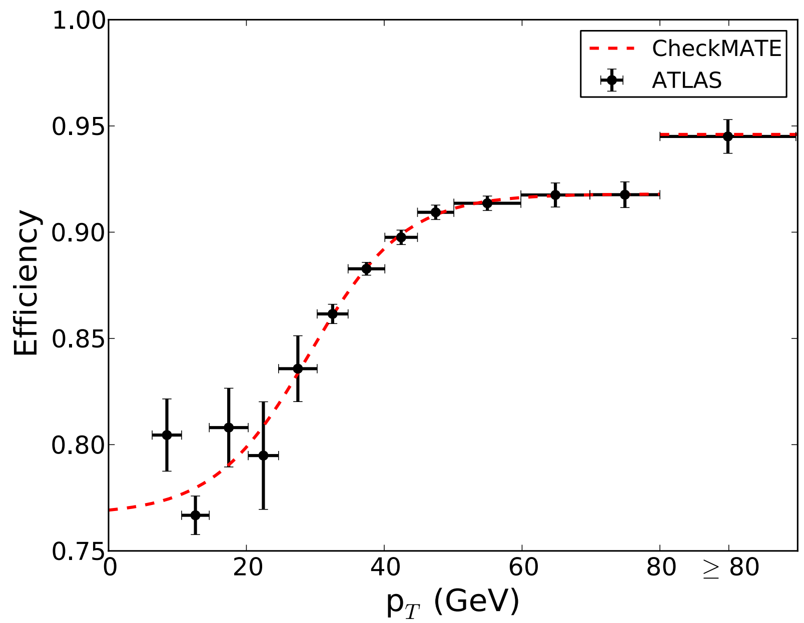
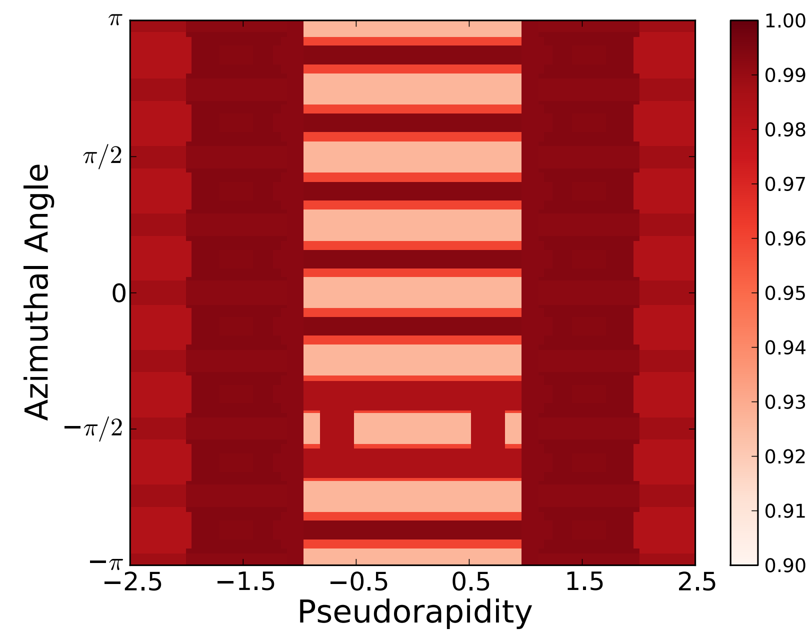
Detector simulation

- 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

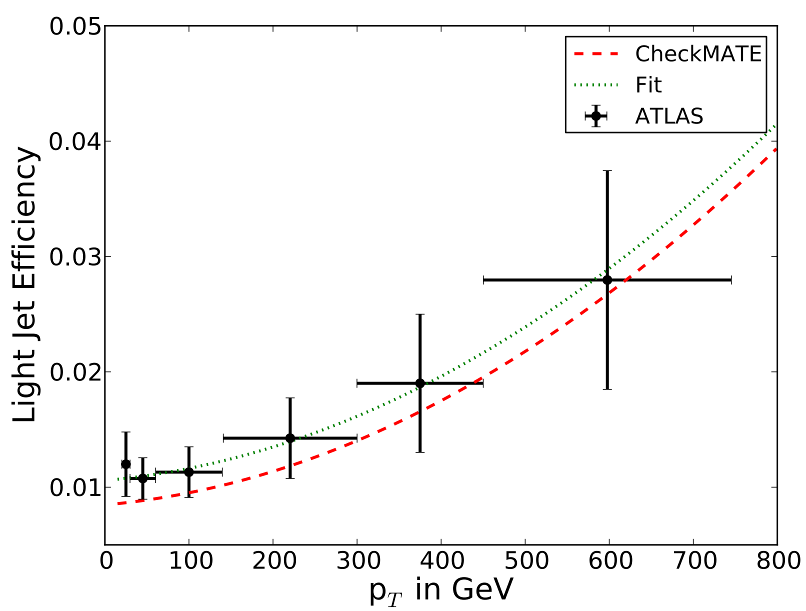
Retune of Delphes



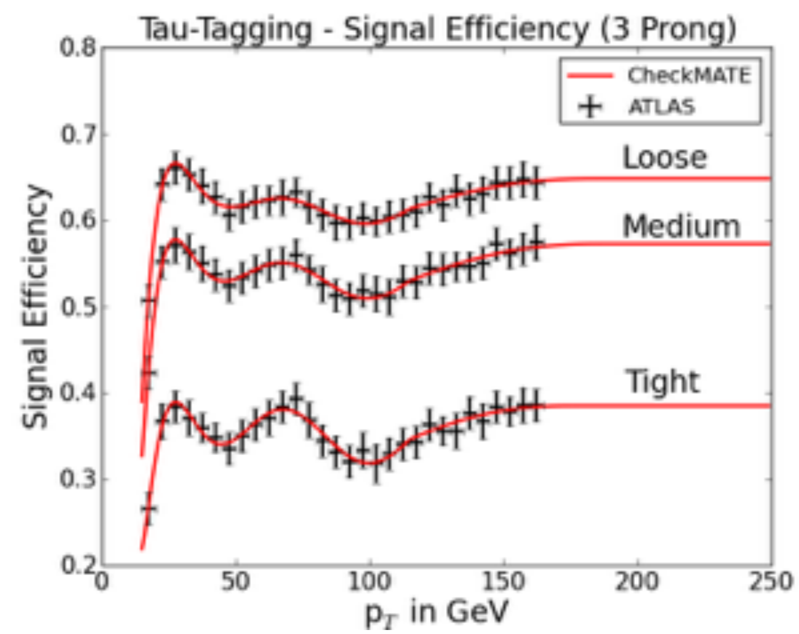
Id efficiency for “medium” electrons



Efficiency for muon objects

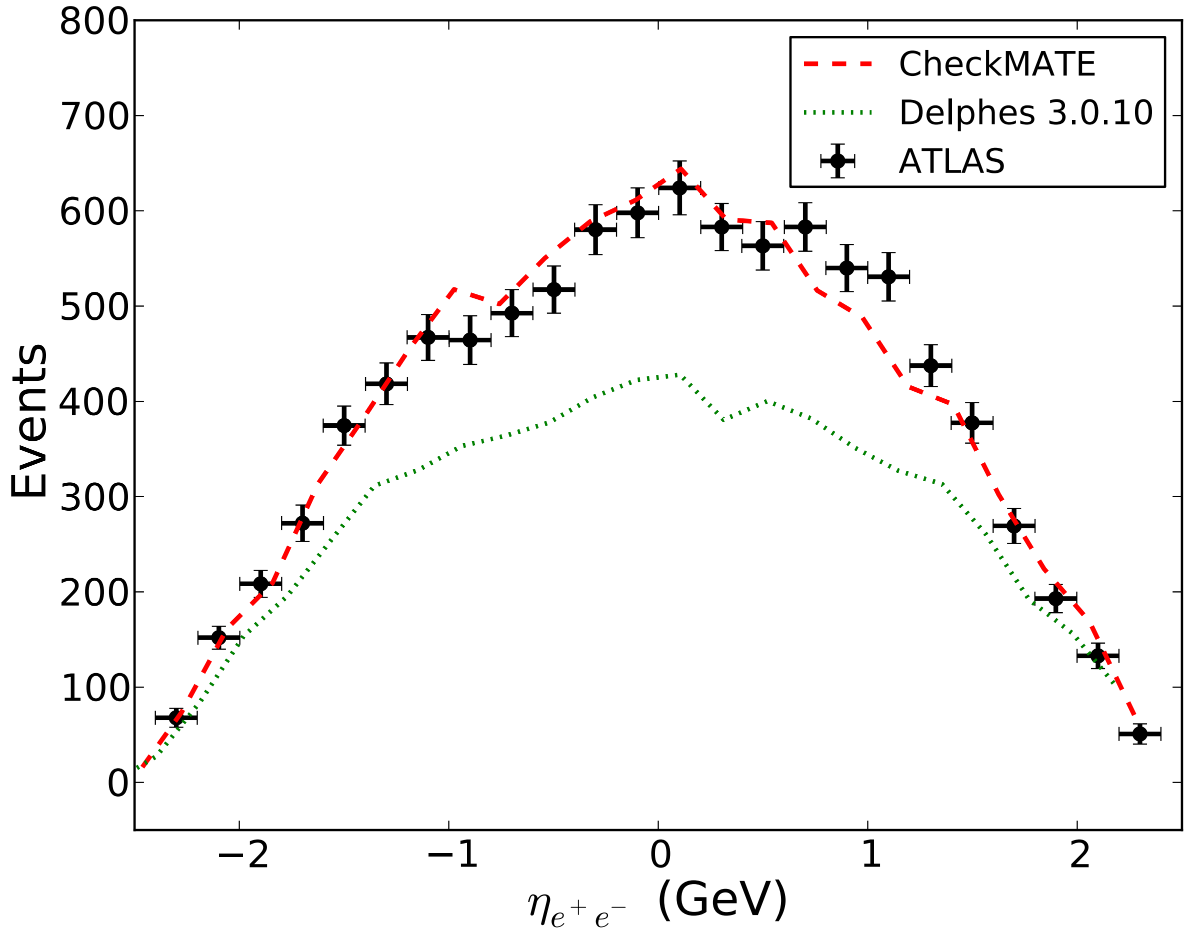


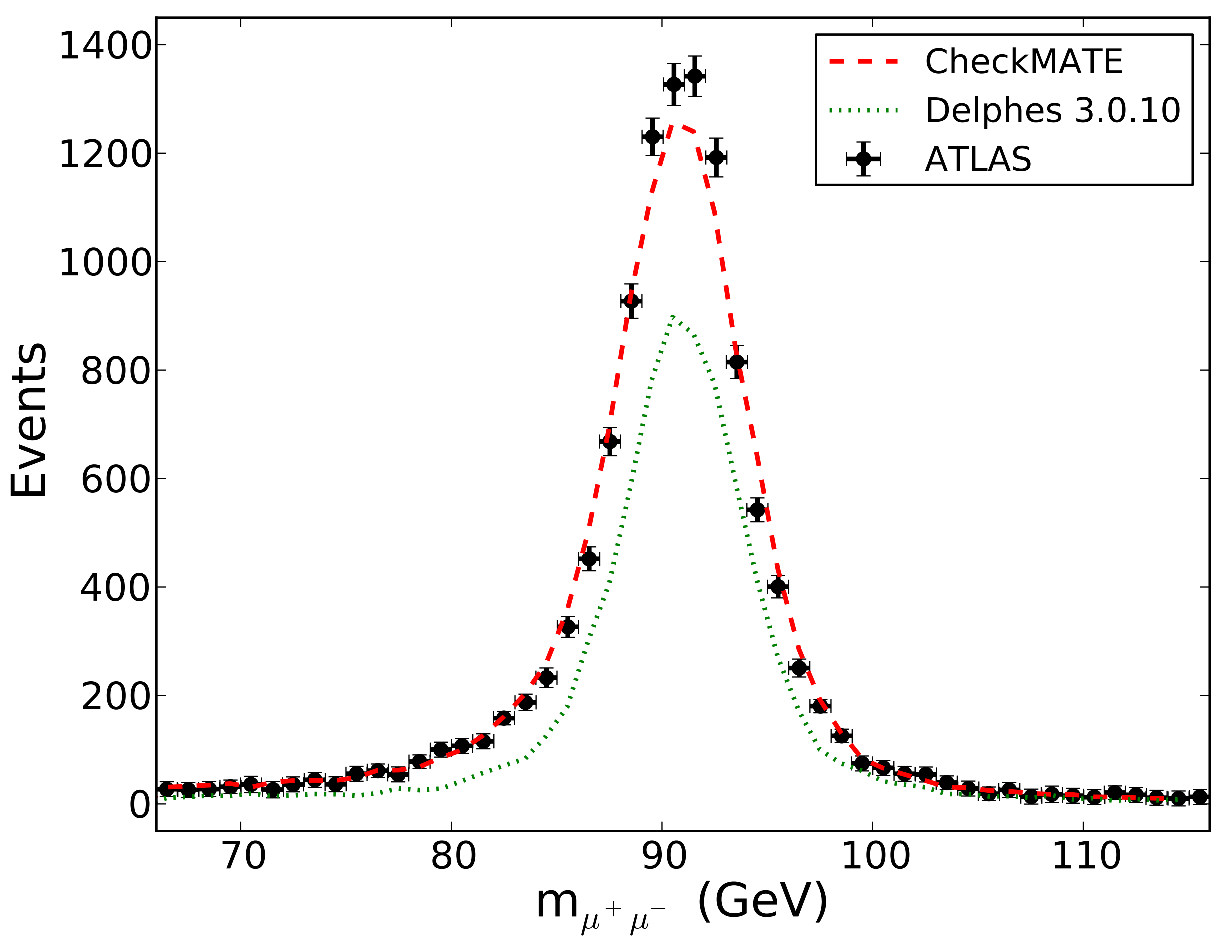
B tagging efficiency of jets containing light quarks

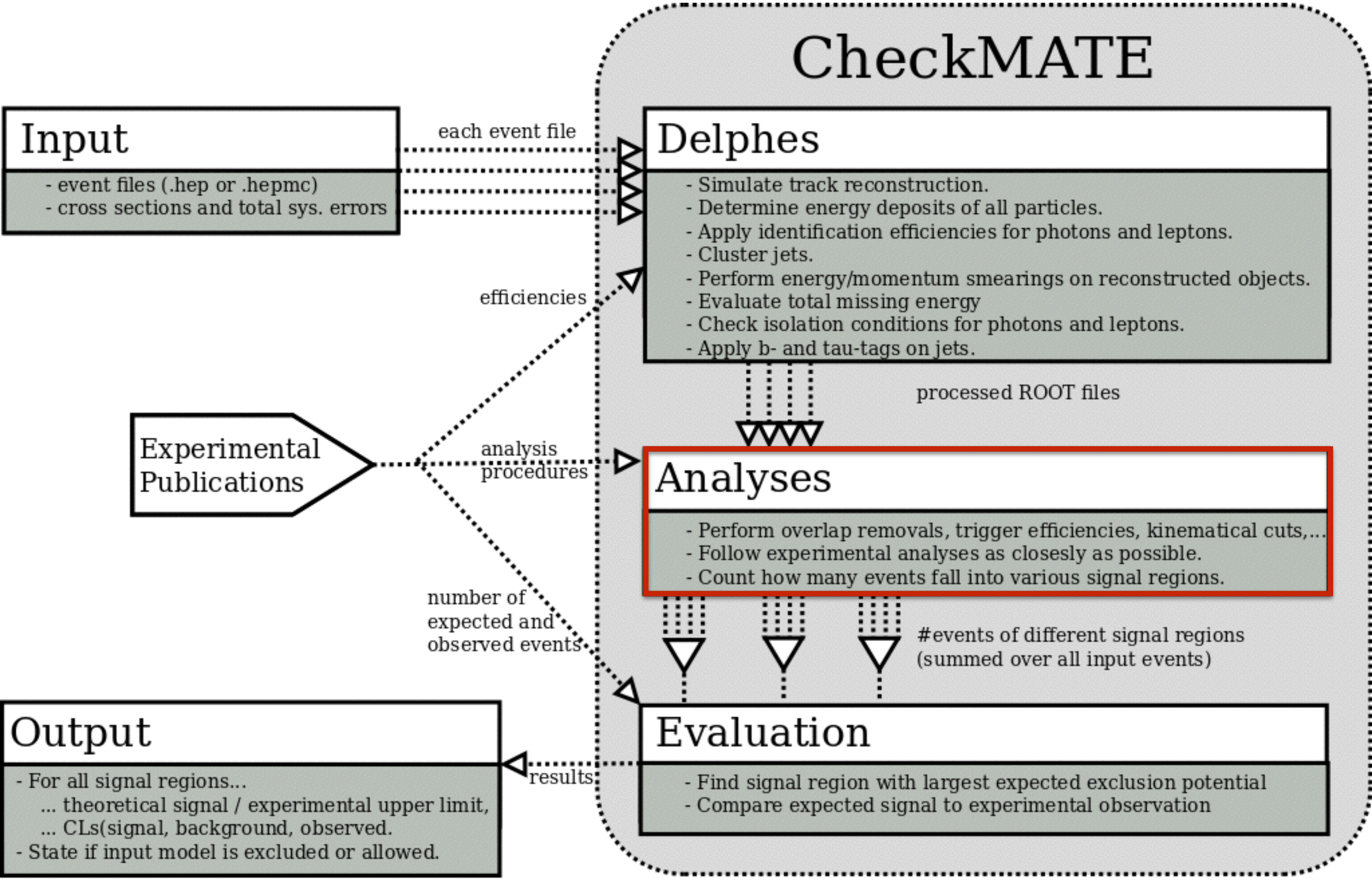


Signal efficiencies for 3 prong taus

Validation plots



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Analyses

- CheckMATE uses a C++ 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

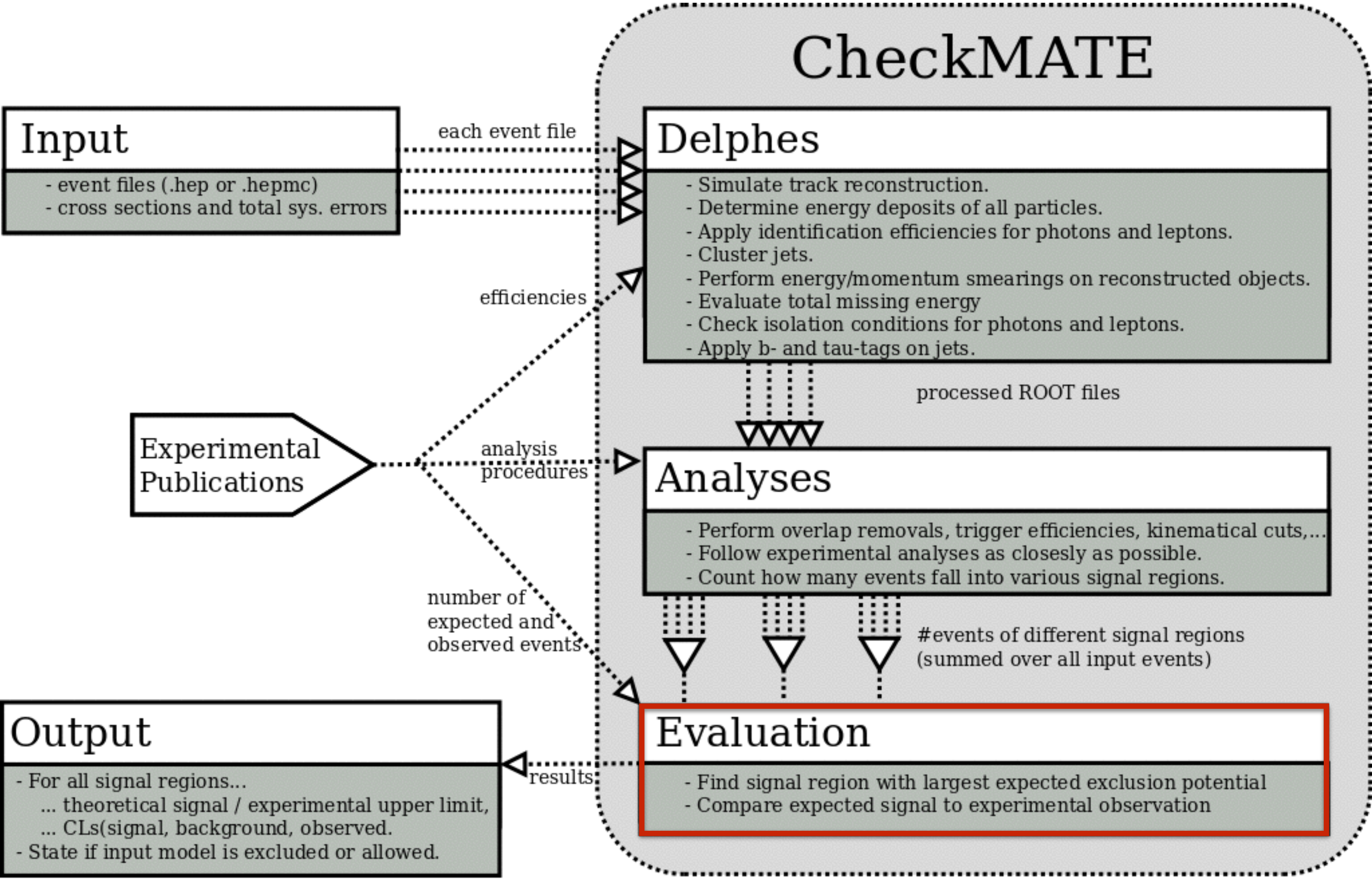
at least two jets

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    #
##############################################################################################################################################
```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Setting limits

- Many searches provides O, B, uncertainty on B, upper limits on signal S95
- Directly compare S to 95% upper limit on signal S95
- Calculate the ratio r=S/S95. 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
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Output

SR	S	dS_stat	dS_sys	dS_tot	S95_obs	S95_exp	r^c_obs	r^c_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

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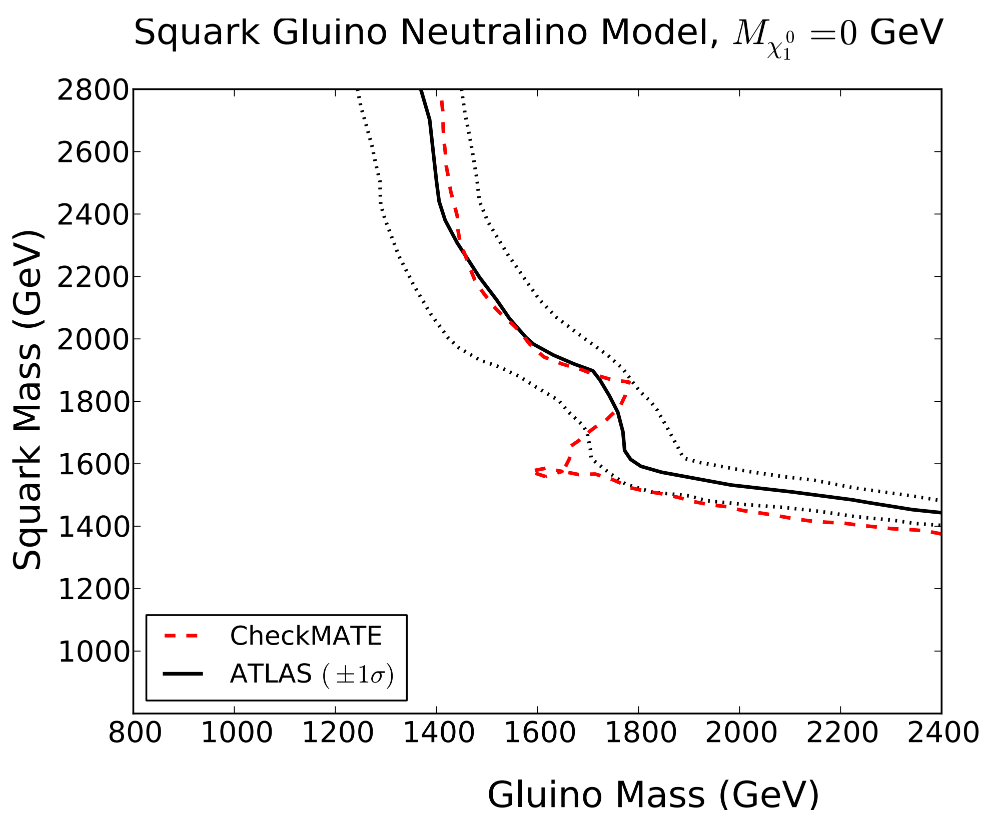
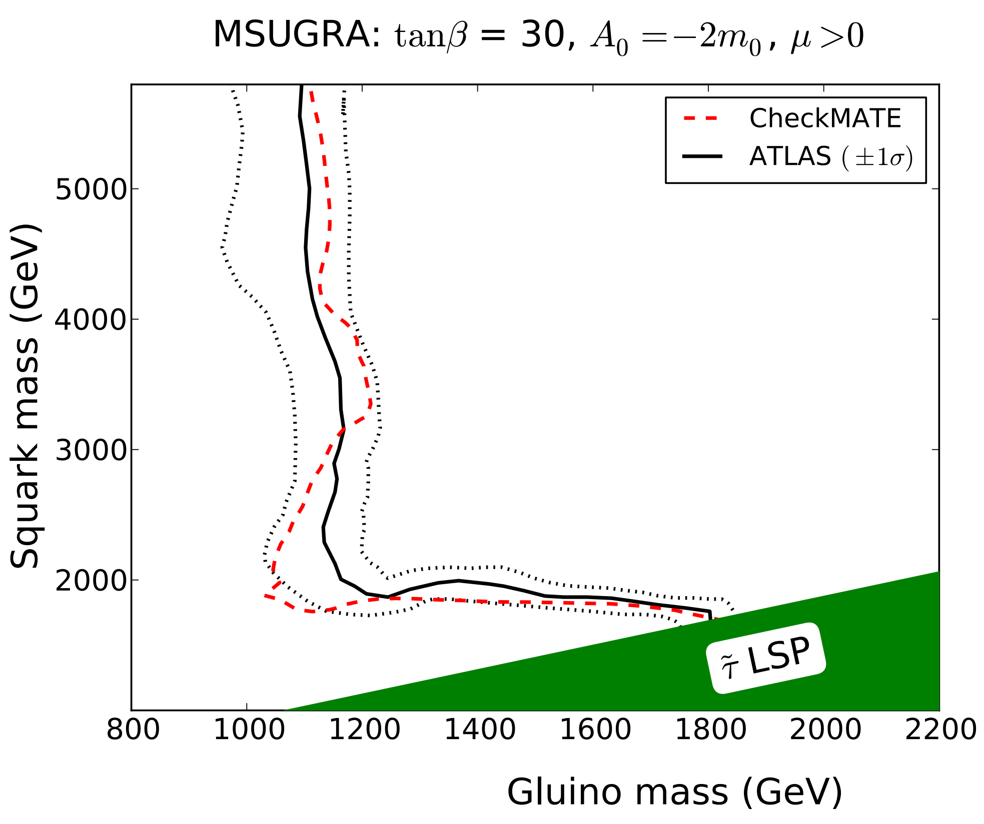
ET	8.10	0.20	0.89	0.91	8.30	6.50	0.76	0.97

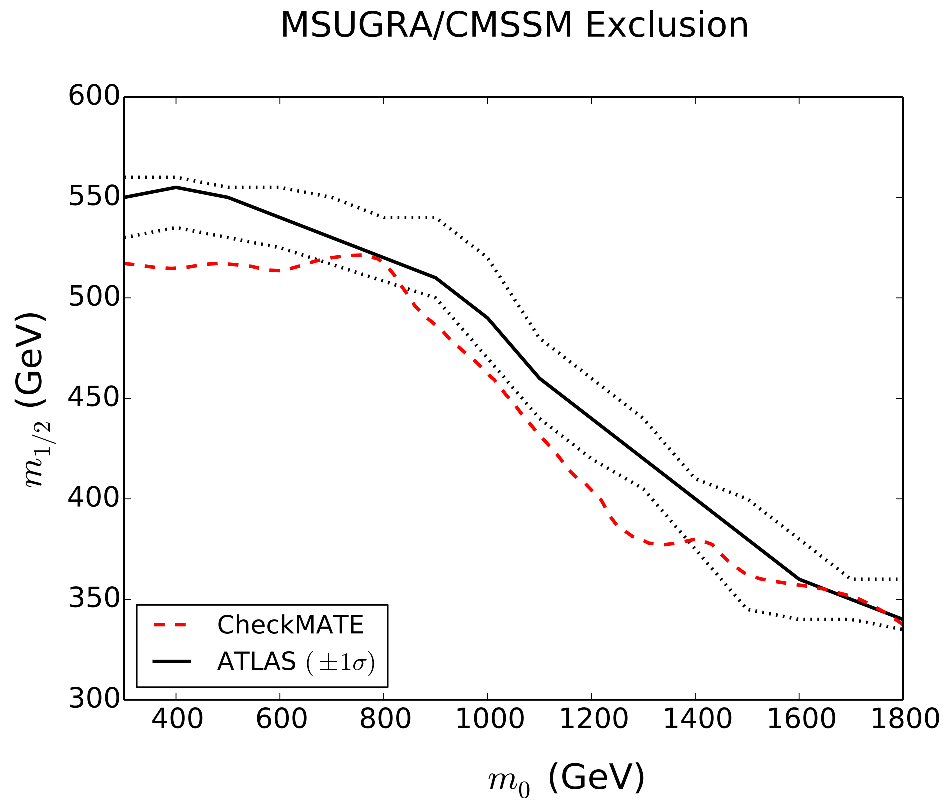
Result

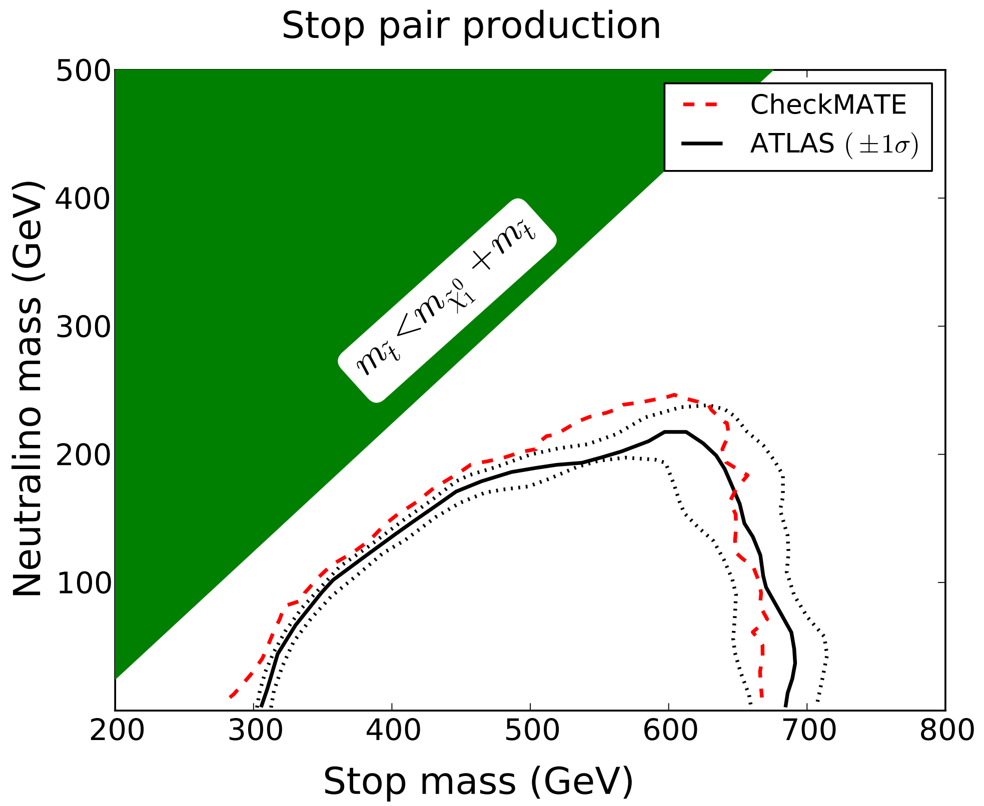
analysis	bestSR	r_obs^c	r_exp^c	CLs_obs	dCLs_obs	CLs_exp	dCLs_exp	[...]
atlas_conf_2013_047	ET	0.76	0.97	0.0609	0.0027	0.0077	0.0013	[...]

Validation


Squark Gluino Neutralino Model, $M_{\chi_1^0} = 0$ GeV
Squark Mass (GeV)
Gluino Mass (GeV)
CheckMATE
ATLAS $(\pm 1\sigma)$


MSUGRA: $\tan\beta$ = 30, $A_0 = -2m_0$, $\mu > 0$
Squark mass (GeV)
Gluino mass (GeV)
CheckMATE
ATLAS $(\pm 1\sigma)$
$\tilde{\tau}$ LSP


MSUGRA/CMSSM Exclusion
$m_{1/2}$ (GeV)
m_0 (GeV)
CheckMATE
ATLAS $(\pm 1\sigma)$


Stop pair production
Neutralino mass (GeV)
Stop mass (GeV)
CheckMATE
ATLAS $(\pm 1\sigma)$
$m_{\tilde{t}} < m_{\tilde{\chi}_1^0} + m_t$

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^{-1}

Process	$\tilde{q}\tilde{g}$ direct				$\tilde{g}\tilde{g}$ direct	
Point	$m(\tilde{g}) = 1425$ GeV $m(\tilde{\chi}_1^0) = 525$ GeV		$m(\tilde{g}) = 1612$ GeV $m(\tilde{\chi}_1^0) = 37$ GeV		$m(\tilde{g}) = 1162$ GeV $m(\tilde{\chi}_1^0) = 337$ GeV	
Signal Region	B-medium		B-tight		D	
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
$m_{eff}(\text{incl.}) > 1 - 2.2$ TeV	27.5 ± 0.7	25.8 ± 0.2	22.8 ± 0.7	20.5 ± 0.2	13.4 ± 0.5	13.0 ± 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^-1):
            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)
```

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```
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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```

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)

http:checkmate.hepforge.org