ATOM/Fastlim

Recasting LHC constraints on new physics models

Kazuki Sakurai

(King's College London)

ATOM collaboration: Ian-Woo Kim, Michele Papucci, KS, Andreas Weiler

Fastlim collaboration: Michele Papucci, KS, Andreas Weiler, Lisa Zeune

24/11/2014 Seminar @ Sussex in Brighton

Contents

Introduction

- The LHC has finished the 8TeV run and ATLAS and CMS have conducted a number of BSM searches.
- No significant excess has ben found. => constrain CMSSM, SUSY simplified models.
- The limit on the other models (non-CMSSM, non-SUSY, …) are also very important but less studied.
- The size of the BSM model space is huge and the resource in the experiments is limited. => It is desirable for phenomenologists to be able to compute the LHC constraints by themselves.

Testing a Model

ATLAS-CONF-2011-086

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
N_{BSM}^{UL}	5.77	4.95	5.77

Testing a Model

Signal Regions

ATLAS-CONF-2011-086

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\mathrm{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
N_{BSM}^{UL}	5.77	4.95	5.77

Testing a Model

Signal Regions

ATLAS-CONF-2011-086

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
N_{BSM}^{UL}	5.77	4.95	5.77

statistically consistent

Testing a Model

N_{BSM} = ..., 2, ..., 10, ... ?

contribution from BSM should be added

statistically consistent

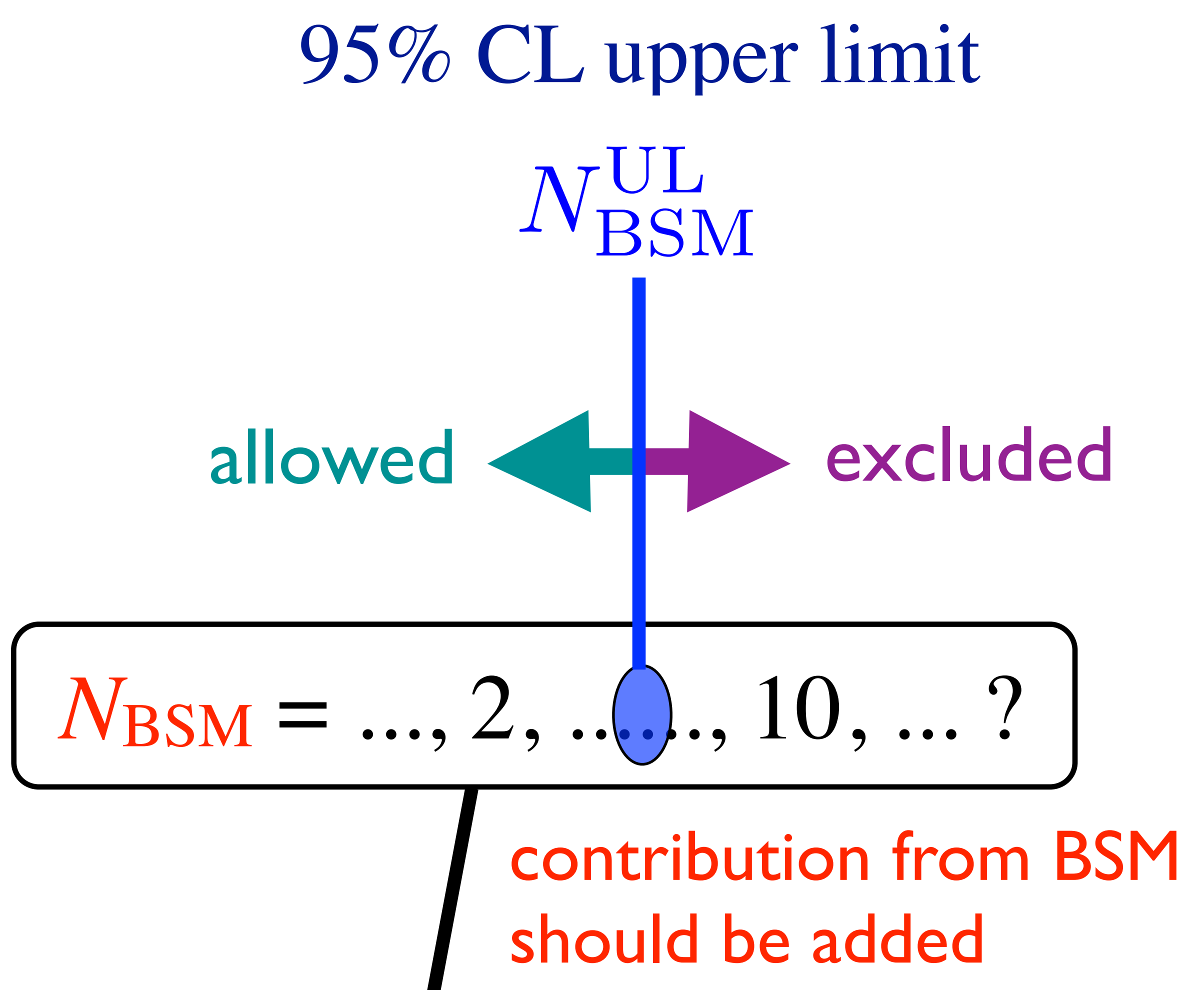
Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
$N_{\text{BSM}}^{\text{UL}}$	5.77	4.95	5.77

Testing a Model

for signal region a,

$$N^{(a)}_{\rm BSM}/N^{(a)}_{\rm UL} \begin{cases} > 1 & \text{: excluded} \\ \leq 1 & \text{: allowed} \end{cases}$$

$$CL^{(a)}_s = p^{(a)}_{\rm excl}(N^{(a)}_{\rm obs}, N^{(a)}_{\rm SM}, N^{(a)}_{\rm BSM}, \sigma^{(a)}_{\rm sys})$$



statistically consistent

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
$N^{\rm UL}_{\rm BSM}$	5.77	4.95	5.77

Testing a Model

for signal region a,

$$N_{\rm BSM}^{(a)} / N_{\rm UL}^{(a)} \begin{cases} > 1 & \text{: excluded} \\ \leq 1 & \text{: allowed} \end{cases}$$

$$CL_s^{(a)} = p_{\rm excl}^{(a)}(N_{\rm obs}^{(a)}, N_{\rm SM}^{(a)}, N_{\rm BSM}^{(a)}, \sigma_{\rm sys}^{(a)})$$

several different tests per analysis

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
SM prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7
$N_{\rm BSM}^{\rm UL}$	5.77	4.95	5.77

How to calculate N_{BSM}?

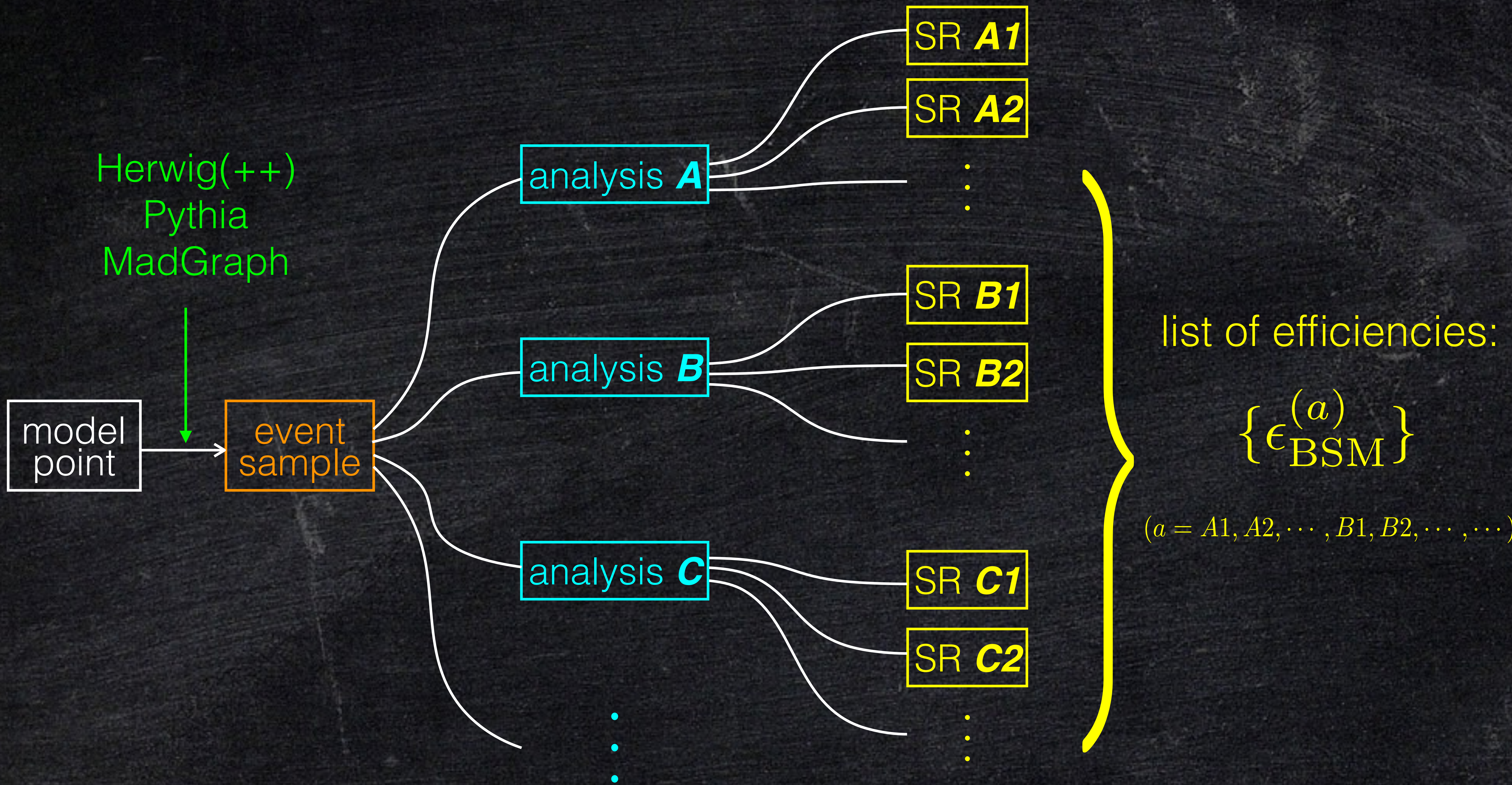
analytically calculable (factorisation)

known

$$N^{(a)}_{\mathrm{BSM}} = \epsilon^{(a)}_{\mathrm{BSM}} \cdot \sigma_{\mathrm{BSM}} \cdot \mathcal{L}$$

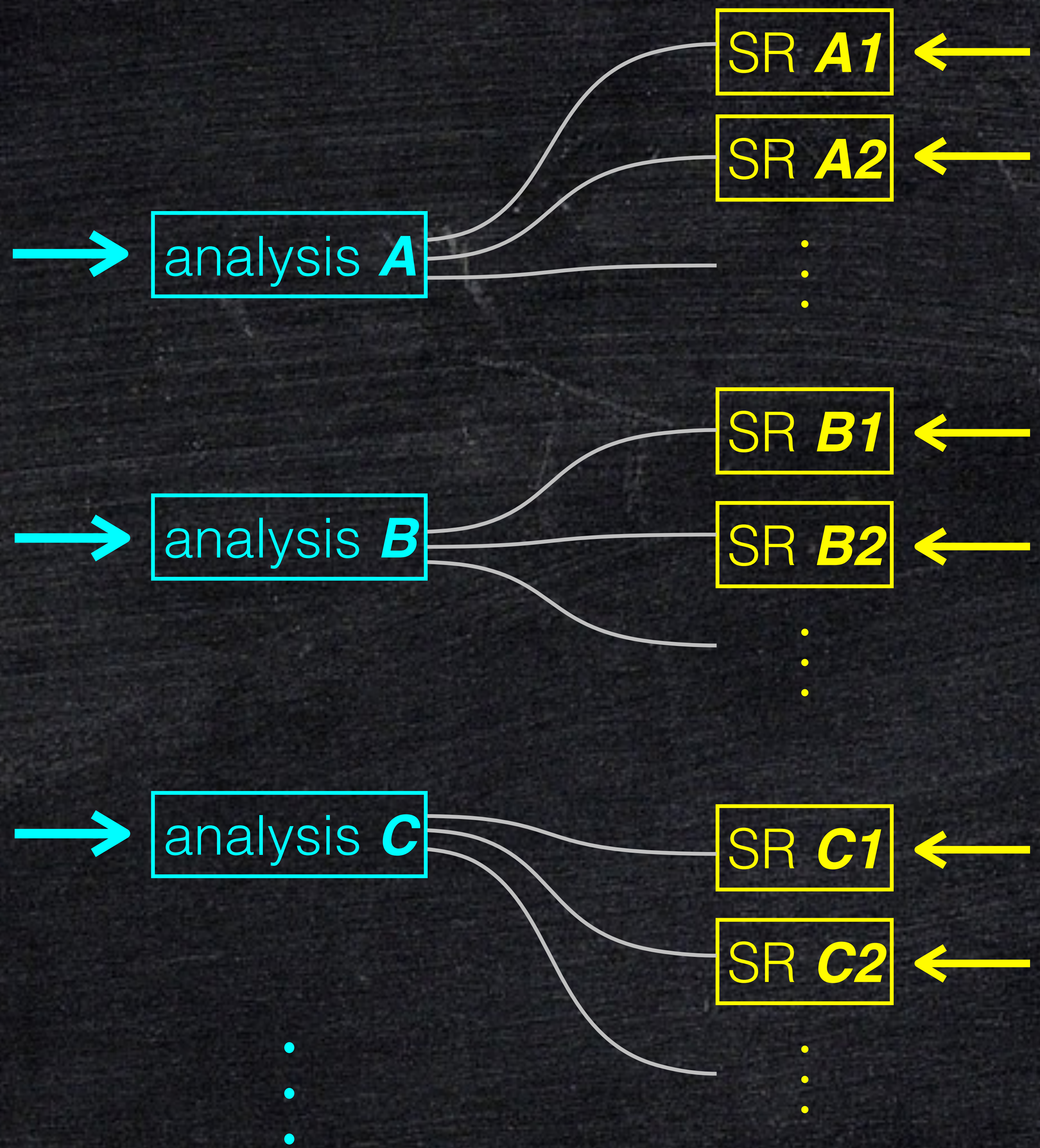
$$\epsilon^{(a)}_{\mathrm{BSM}} = \lim_{N_{\mathrm{MC}} \to \infty} \frac{N\left(\begin{array}{c}\text{Events fall into}\\ \text{signal region } a\end{array}\right)}{N_{\mathrm{MC}}}$$

- Parton shower
- Hadronization
- Detector resolution
- …


Herwig(++)
Pythia
MadGraph
model point
event sample
analysis A
analysis B
analysis C
SR A1
SR A2
SR B1
SR B2
SR C1
SR C2
list of efficiencies:
$\{\epsilon_{\rm BSM}^{(a)}\}$
$(a = A1, A2, \cdots, B1, B2, \cdots, \cdots)$

reconstructed objects (jets, electrons, ...) need to be tuned for each analysis

needs to write a detector card and run detector simulation for every analysis



Validation is required for every analysis

generate an event sample at the benchmark point used in the analysis paper and compare the efficiency with the one reported in the paper for every signal region

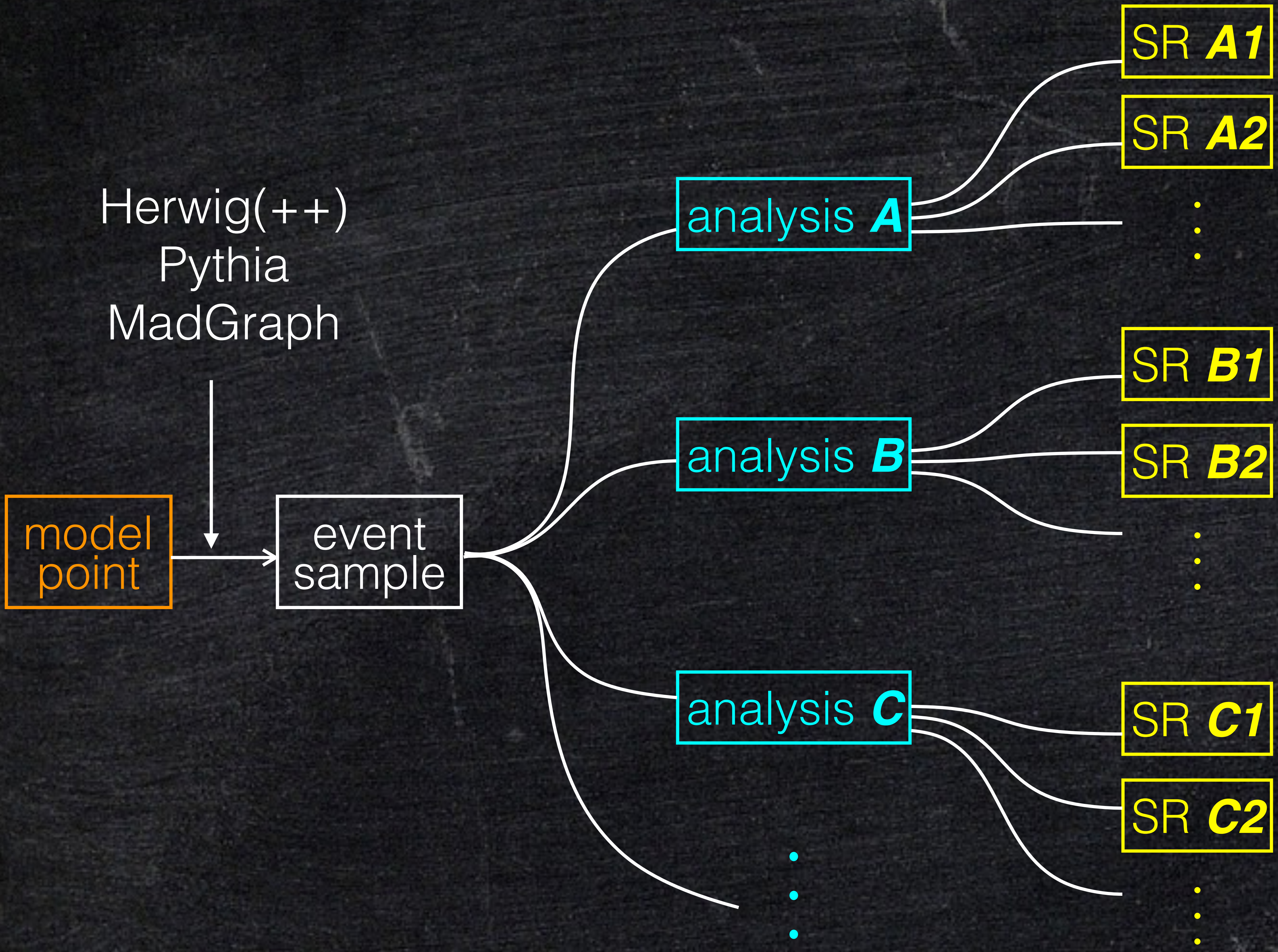
A lot of work!

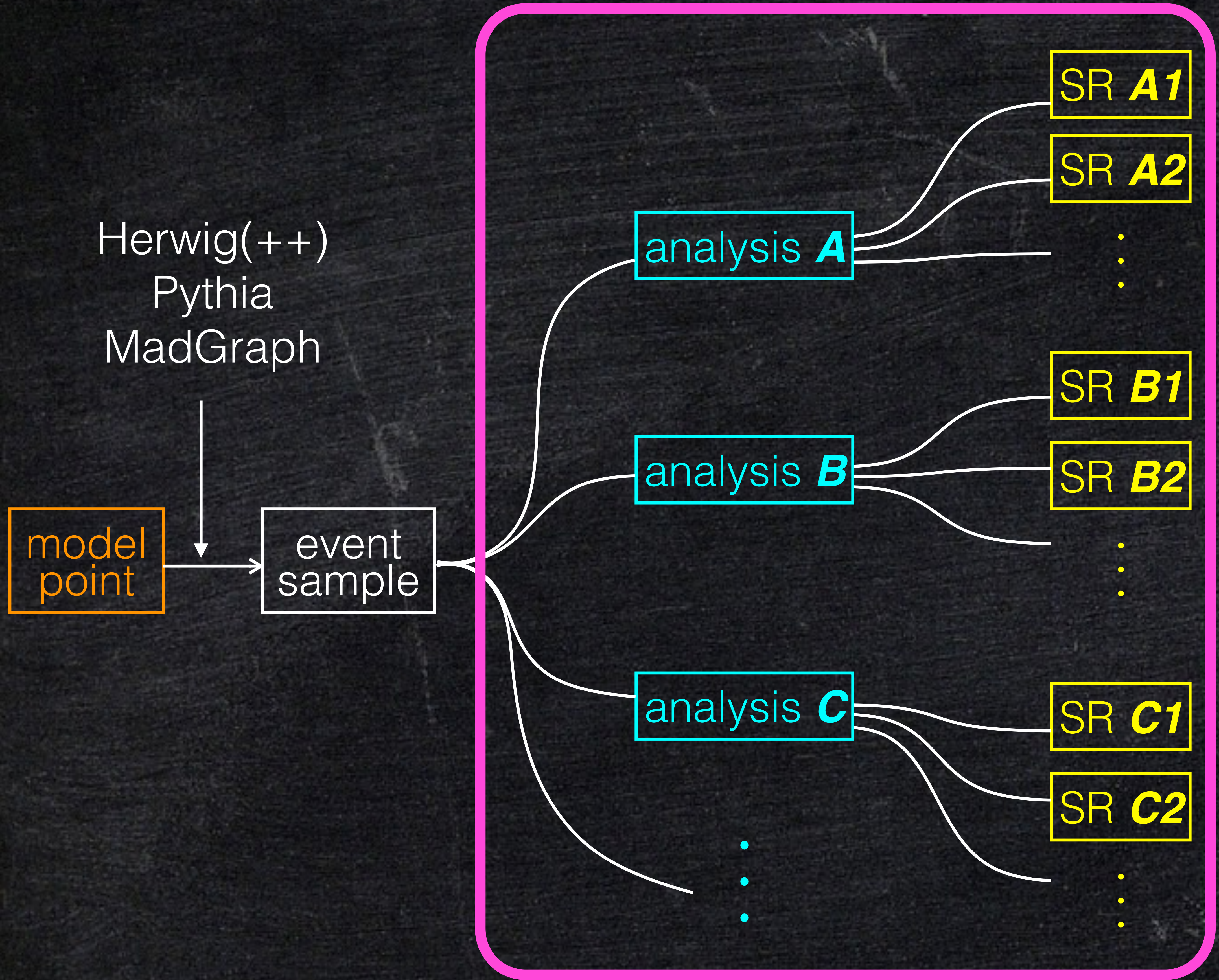
Y. Kats and D. Shih, JHEP **1108**, 049 (2011) [arXiv:1106.0030 [hep-ph]], M. Lisanti, P. Schuster, M. Strassler and N. Toro, JHEP **1211**, 081 (2012) [arXiv:1107.5055 [hep-ph]], R. Essig, E. Izaguirre, J. Kaplan and J. G. Wacker, JHEP **1201**, 074 (2012) [arXiv:1110.6443 [hep-ph]], C. Brust, A. Katz, S. Lawrence and R. Sundrum, JHEP **1203**, 103 (2012) [arXiv:1110.6670 [hep-ph]], T. J. LeCompte and S. P. Martin, Phys. Rev. D **85**, 035023 (2012) [arXiv:1111.6897 [hep-ph]], B. He, T. Li and Q. Shafi, JHEP **1205**, 148 (2012) [arXiv:1112.4461 [hep-ph]], Y. Kats, P. Meade, M. Reece and D. Shih, JHEP **1202**, 115 (2012) [arXiv:1110.6444 [hep-ph]], K. Sakurai and K. Takayama, JHEP **1112** (2011) 063 [arXiv:1106.3794 [hep-ph]], B. C. Allanach, T. J. Khoo and K. Sakurai, JHEP **1111** (2011) 132 [arXiv:1110.1119 [hep-ph]], M. Badziak and K. Sakurai, JHEP **1202** (2012) 125 [arXiv:1112.4796 [hep-ph]], B. C. Allanach and B. Gripaios, JHEP **1205**, 062 (2012) [arXiv:1202.6616 [hep-ph]], J. Fan, M. Reece and J. T. Ruderman, JHEP **1207**, 196 (2012) [arXiv:1201.4875 [hep-ph]], G. D. Kribs and A. Martin, Phys. Rev. D **85**, 115014 (2012) [arXiv:1203.4821 [hep-ph]], D. Curtin, P. Jaiswal and P. Meade, Phys. Rev. D **87**, no. 3, 031701 (2013) [arXiv:1206.6888 [hep-ph]], J. A. Evans and Y. Kats, JHEP **1304**, 028 (2013) [arXiv:1209.0764 [hep-ph]], P. Bechtle, T. Bringmann, K. Desch, H. Dreiner, M. Hamer, C. Hensel, M. Kramer and N. Nguyen *et al.*, JHEP **1206**, 098 (2012) [arXiv:1204.4199 [hep-ph]], K. Rolbiecki and K. Sakurai, JHEP **1210** (2012) 071 [arXiv:1206.6767 [hep-ph]], M. Asano, K. Rolbiecki and K. Sakurai, JHEP **1301** (2013) 128 [JHEP **1301** (2013) 128] [arXiv:1209.5778 [hep-ph]], M. Redi, V. Sanz, M. de Vries and A. Weiler, JHEP **1308**, 008 (2013) [arXiv:1305.3818, arXiv:1305.388 [hep-ph]], K. Kowalska and E. M. Sessolo, Phys. Rev. D **88**, 075001 (2013) [arXiv:1307.5790 [hep-ph]], J. A. Evans, Y. Kats, D. Shih and M. J. Strassler, arXiv:1310.5758 [hep-ph].

[...]

Many people have been performing similar studies….

duplicating effort


Herwig(++)
Pythia
MadGraph
model point
event sample
analysis A
analysis B
analysis C
SR A1
SR A2
SR B1
SR B2
SR C1
SR C2



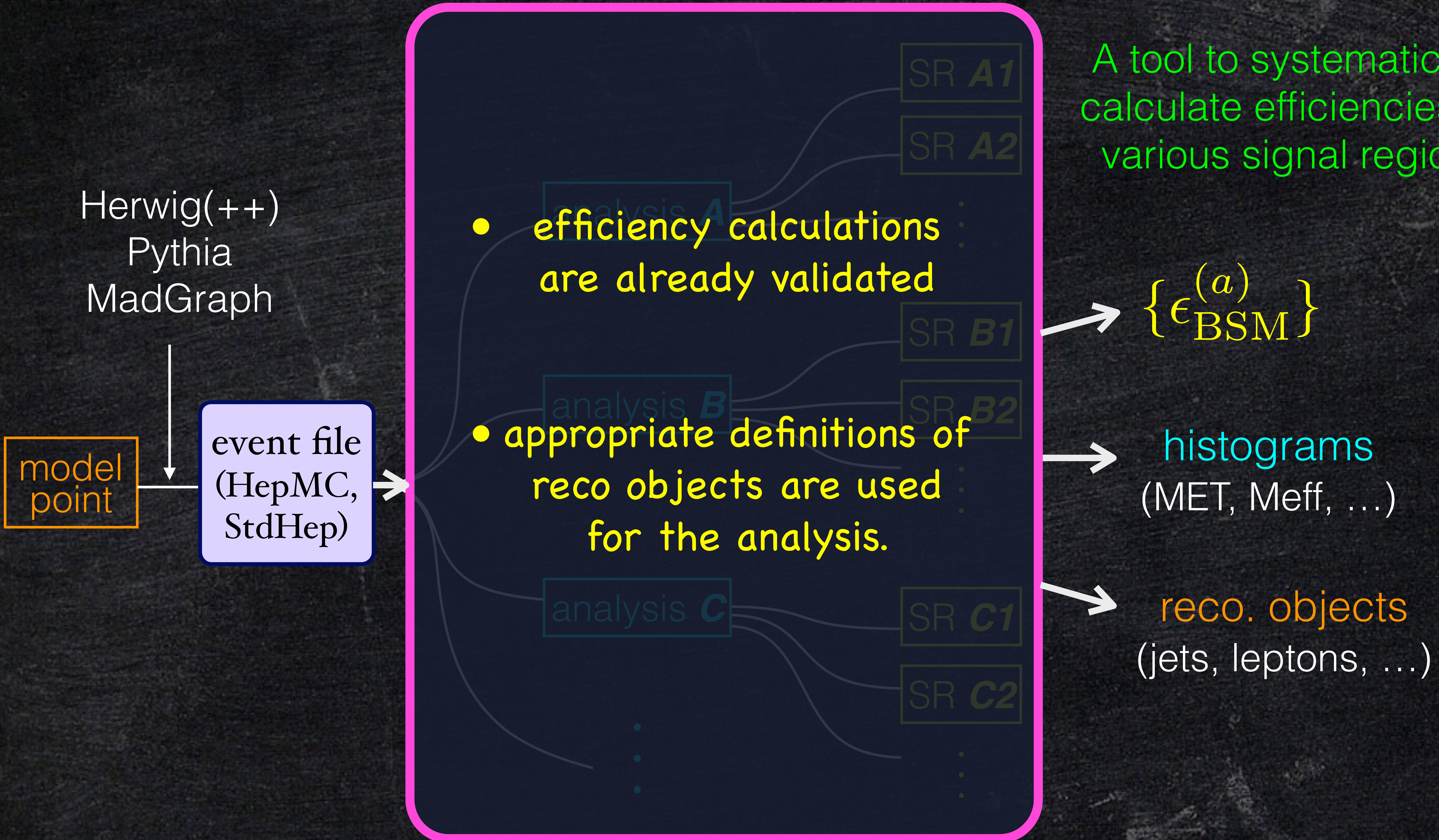
A tool to systematically calculate efficiencies for various signal regions

ATOM

(Automated Testing Of Models)

I-W.Kim, M.Papucci, KS, A.Weiler

A tool to systematically calculate efficiencies for various signal regions



Analyses in ATOM

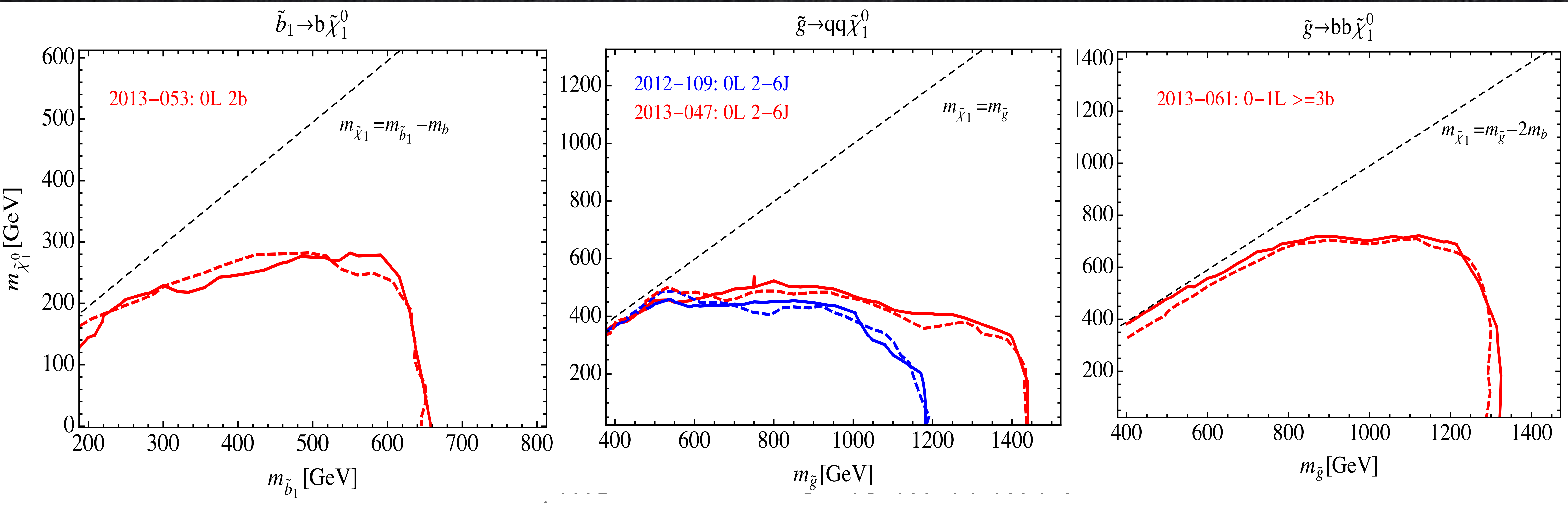
Name	Short description	E_{CM}	$\mathcal{L}_{int}$	# SRs	Ref.
ATLAS_CONF_2013_024	0 lepton + (2 b-)jets + MET [Heavy stop]	8	20.5	3	[32]
ATLAS_CONF_2013_035	3 leptons + MET [EW production]	8	20.7	6	[33]
ATLAS_CONF_2013_037	1 lepton + 4(1 b-)jets + MET [Medium/heavy stop]	8	20.7	5	[34]
ATLAS_CONF_2013_047	0 leptons + 2-6 jets + MET [squarks & gluinos]	8	20.3	10	[35]
ATLAS_CONF_2013_048	2 leptons (+ jets) + MET [Medium stop]	8	20.3	4	[36]
ATLAS_CONF_2013_049	2 leptons + MET [EW production]	8	20.3	9	[37]
ATLAS_CONF_2013_053	0 leptons + 2 b-jets + MET [Sbottom/stop]	8	20.1	6	[38]
ATLAS_CONF_2013_054	0 leptons + $\geq$ 7-10 jets + MET [squarks & gluinos]	8	20.3	19	[39]
ATLAS_CONF_2013_061	0-1 leptons + $\geq$ 3 b-jets + MET [3rd gen. squarks]	8	20.1	9	[40]
ATLAS_CONF_2013_062	1-2 leptons + 3-6 jets + MET [squarks & gluinos]	8	20.3	13	[41]
ATLAS_CONF_2013_093	1 lepton + bb(H) + Etmiss [EW production]	8	20.3	2	[42]

⋮

- Many ATLAS (a few CMS) analyses are implemented. Most of the 2013-2014 ATLAS MET searches are implemented.

Validation

- The analyses are validated using the official cut flow tables and exclusion contours.



Validation

- The analyses are validated using the official cut flow tables and exclusion contours.

#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$	$(\epsilon_{Atom}-\epsilon_{ATLAS})$/Stat
1	[01] No cut	100.	100.	±			
2	[02] Lepton (=1 signal)	22.82	22.732	±	0.477	0.996	−0.184
3	[03] 4jets (80,60,40,25)	12.33	11.291	±	0.336	0.916	−3.092
4	[04] >=1b in 4 leading jets	10.53	9.481	±	0.308	0.9	3.407
5	[05] MET > 100	8.64	7.721	±	0.278	0.894	3.308
6	[06] MET/sqrt(HT) > 5	8.45	7.521	±	0.274	0.89	3.388
7	[07] delPhi(J2,MET) > 0.8	7.52	7.351	±	0.271	0.977	0.624
8	[SRtN2] MET > 200	4.31	4.15	±	0.204	0.963	0.783
9	[SRtN2] MET/sqrt(HT) > 13	2.33	2.36	±	0.[illegible]54	1.013	.197
10	[SRtN2] mT > 140	1.91	2.02	±	0.[illegible]42	1.058	0.775
11	[SRtN3] MET > 275	1.87	1.76	±	0.1[illegible]3	0.941	−0.828
12	[SRtN3] MET/sqrt(HT) > 11	1.82	1.73	±	0.13[illegible]	0.951	−0.683
13	[SRtN3] mT > 200	1.06	1.06	±	0.103	1.	0.001

#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$	$(\epsilon_{Atom}-\epsilon_{ATLAS})$/Stat
1	same flavour	100.	100.	±			
2	SF: Opposite Sign	97.8	98.6	±	4.28	1.01	0.18
3	SF:						
4	SF:						
5	SF:						
6	SF:						
7	SF:						
8	SF:						
9	SF:						
10	SF:						
11	SF:						

#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$	$(\epsilon_{Atom}-\epsilon_{ATLAS})$/Stat
1	MET > 50	100.	100.	±			
2	>= 2 central jets	76.28	71.27	±	0.98	0.93	−5.12
3	2 leading je						
4	4th leading						
5	baseline lep						
6	mjj > 50						
7	mT > 40						
8	mCT > 160						
9	MET > 100						
10	exactly 2 le						
11	SRA: 100 <						
12	SRB: mT >						

#	Cut Name	ϵ_{ATLAS}	ϵ_{Atom}	±	Stat	$\epsilon_{Atom}/\epsilon_{ATLAS}$	$(\epsilon_{Atom}-\epsilon_{ATLAS})$/Stat
1	[01] No cut	100.	100.	±			
2	[02] Lepton (=1 signal)	22.82	22.732	±	0.477	0.996	−0.184
3	[03] 4jets (80,60,40,25)	12.33	11.291	±	0.336	0.916	−3.092
4	[04] >=						
5	[05] ME						
6	[06] ME						
7	[07] del						
8	[SRtN2						
9	[SRtN2						
10	[SRtN2						
11	[SRtN3						
12	[SRtN3						
13	[SRtN3						
14	[SRbC1						
15	[SRbC1						
16	[SRbC1						
17	[SRbC1−3] MET >						
18	[SRbC1−3] MET/s						
19	[SRbC1−3] meff >						
20	[SRbC1−3] meff >						
21	SRtN2	0.84					
22	SRtN3	0.38					
23	SRbC1	3.11					
24	SRbC2	0.59					
25	SRbC3	0.16					

Coding in Atom

ATLAS-CONF-2013-093

Contents

1 Introduction

Supersymmetry (SUSY) [1–9] provides an extension that solves the hierarchy problem [10–13] by introdu

ATLAS_CONF_2013_093.cc

```
void initLocal() {

      ✦ JET DEFINITION
      ✦ TIGHT ELECTRON DEFINITION
      ✦ LOOSE ELECTRON DEFINITION
                    ⋮
}
/// Perform the per-event analysis
bool analyzeLocal(const Event& event, const double weight) {
                    ⋮
    if( jets.size() >= 4 ){
        _effh.PassEvent("Njet >= 4");
    }else{ vetoEvent; }

    if( jets[0].momentum().pT() > 100 ){
        _effh.PassEvent("pT(j1) > 100");
    }else{ vetoEvent; }
                    ⋮
}
```

✦ JET DEFINITION

```
RangeSelector jetrange =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 20., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -4.5, 4.5);
//                                                              radius
JetFinalState jets_Base = jetBase(base, muDetRange, FastJets::ANTIKT,   0.4, hadRange, jetrange);
jets_Base.setFSSmearing  ( dp.jetSim( "Smear_TopoJet_ATLAS" ) );
jets_Base.setFSEfficiency( dp.jetEff( "Jet_ATLAS" ) );
```

```
void initLocal() {

      ✦ JET DEFINITION
      ✦ TIGHT ELECTRON DEFINITION
      ✦ LOOSE ELECTRON DEFINITION
                  ⋮
}
/// Perform the per-event analysis
bool analyzeLocal(const Event& event, const double weight) {
                  ⋮
    if( jets.size() >= 4 ){
        _effh.PassEvent("Njet >= 4");
    }else{ vetoEvent; }

    if( jets[0].momentum().pT() > 100 ){
        _effh.PassEvent("pT(j1) > 100");
    }else{ vetoEvent; }
                  ⋮
}
```

✦ JET DEFINITION

$p_T > 20\,\mathrm{GeV},\ |\eta| < 4.5$

anti-kT, ΔR=0.4 (by Fastjet)

```
RangeSelector jetrange =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 20., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -4.5, 4.5);
//                                                              radius
JetFinalState jets_Base = jetBase(base, muDetRange, FastJets::ANTIKT,     0.4, hadRange, jetrange);
jets_Base.setFSSmearing  ( dp.jetSim( "Smear_TopoJet_ATLAS" ) );
jets_Base.setFSEfficiency( dp.jetEff( "Jet_ATLAS" ) );
```

```
void initLocal() {

        ✦ JET DEFINITION
        ✦ TIGHT ELECTRON DEFINITION
        ✦ LOOSE ELECTRON DEFINITION
                    ⋮
}
/// Perform the per-event analysis
bool analyzeLocal(const Event& event, const double weight) {
                    ⋮
    if( jets.size() >= 4 ){
        _effh.PassEvent("Njet >= 4");
    }else{ vetoEvent; }

    if( jets[0].momentum().pT() > 100 ){
        _effh.PassEvent("pT(j1) > 100");
    }else{ vetoEvent; }
                    ⋮
}
```

✦ TIGHT ELECTRONS

$p_T > 25\,\mathrm{GeV}, \;\; |\eta| < 2.47$

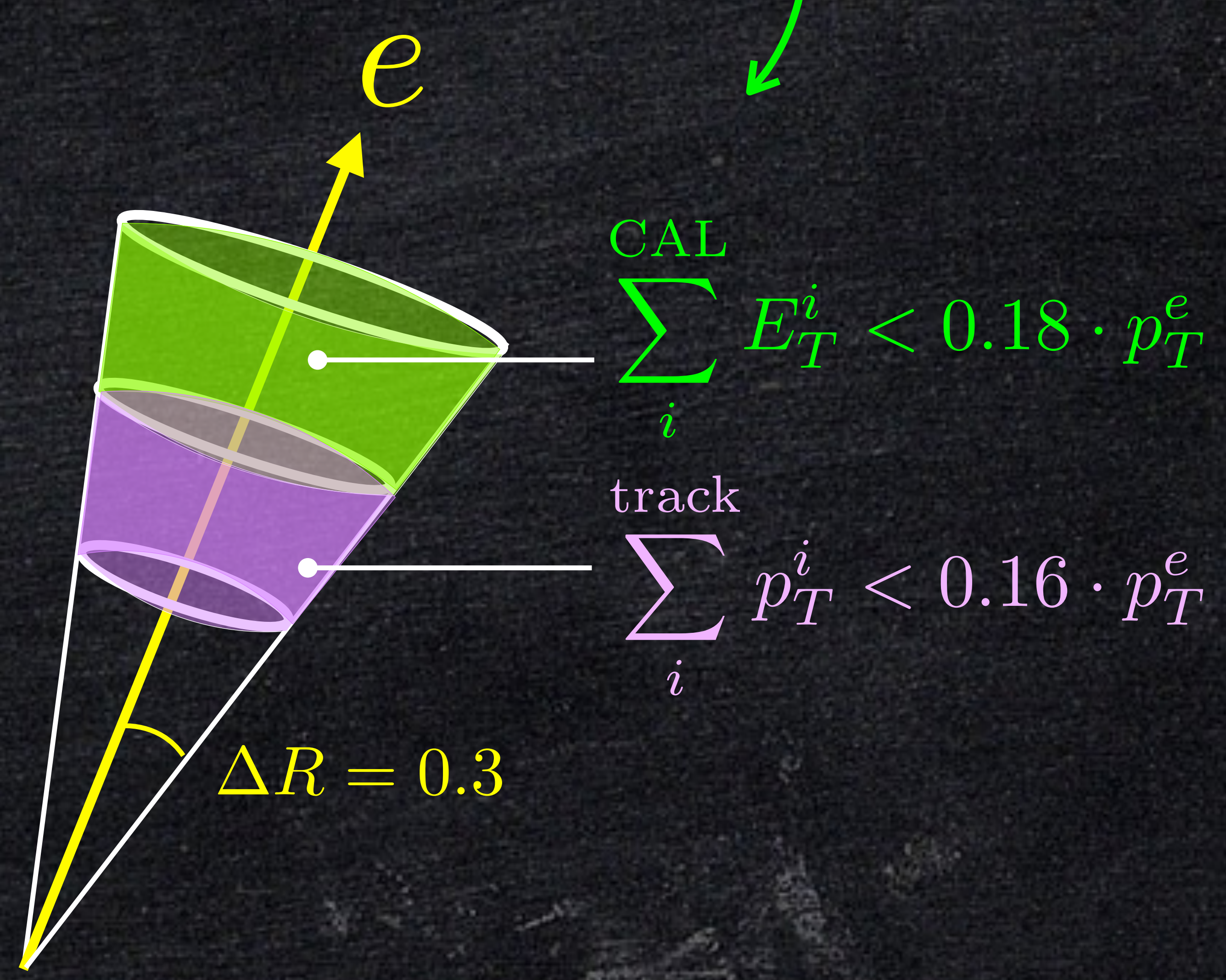
```
// prepare for tight electrons
RangeSelector ele_range =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 25., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -2.47, 2.47);
IsoElectron ele_smear(ele_range);
ele_smear.setIso(TRACK_ISO_PT, 0.3,  0.01, 0.16, 0.0, CALO_ALL);
ele_smear.setIso(CALO_ISO_ET,  0.3,  0.01, 0.18, 0.0, CALO_ALL);
ele_smear.setVariableThreshold(0.0);
ele_smear.setFSSmearing  ( dp.electronSim( "Smear_Electron_ATLAS" ) );
ele_smear.setFSEfficiency( dp.electronEff( "Electron_Tight_ATLAS" ) );
```

✦ TIGHT ELECTRONS

$p_T > 25\,\mathrm{GeV}, \quad |\eta| < 2.47$

```
// prepare for tight electrons
RangeSelector ele_range =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 25., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -2.47, 2.47);
IsoElectron ele_smear(ele_range);
ele_smear.setIso(TRACK_ISO_PT, 0.3,  0.01, 0.16, 0.0, CALO_ALL);
ele_smear.setIso(CALO_ISO_ET,  0.3,  0.01, 0.18, 0.0, CALO_ALL);
ele_smear.setVariableThreshold(0.0);
ele_smear.setFSSmearing  ( dp.electronSim( "Smear_Electron_ATLAS" ) );
ele_smear.setFSEfficiency( dp.electronEff( "Electron_Tight_ATLAS" ) );
```

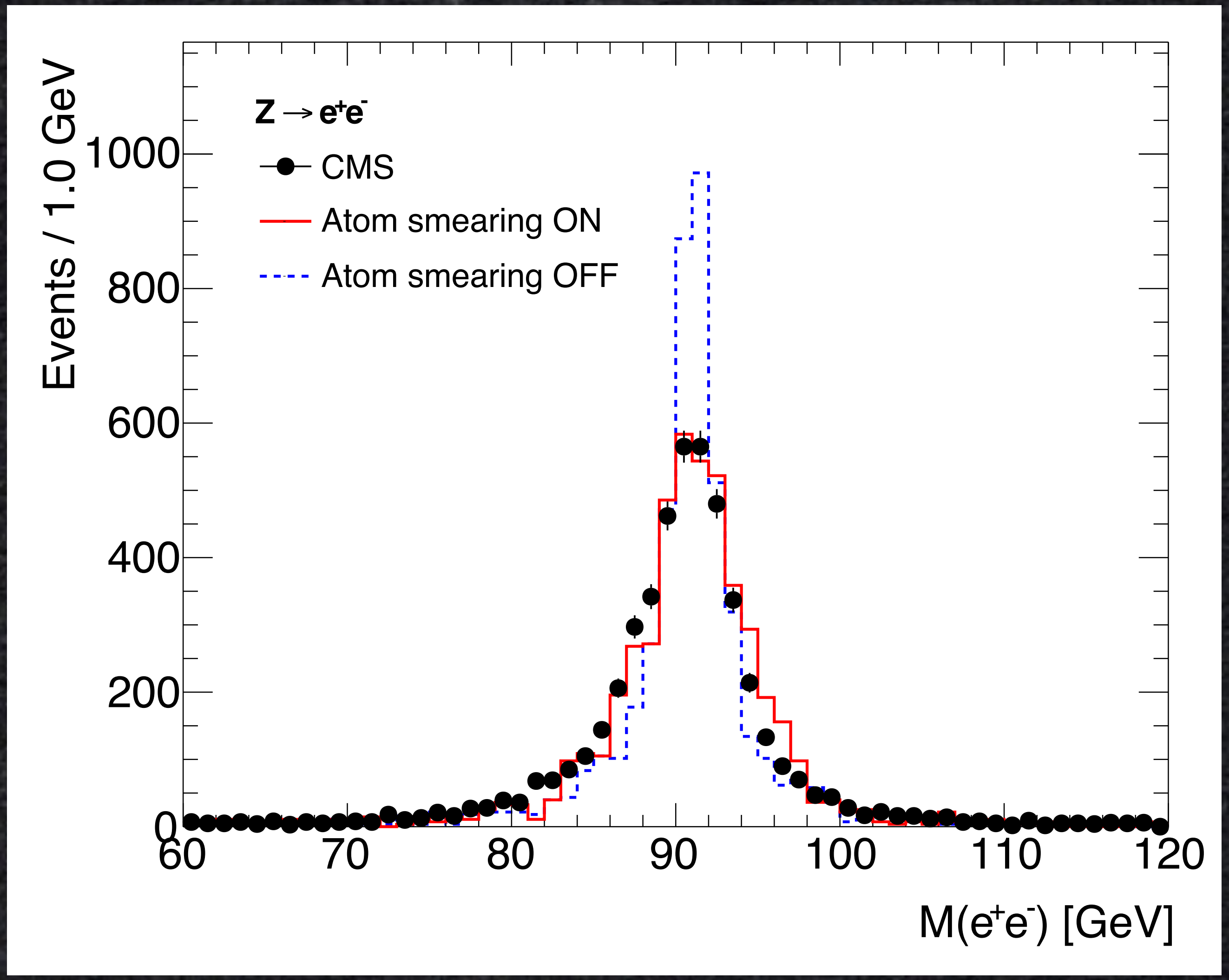
track calorimeter isolation

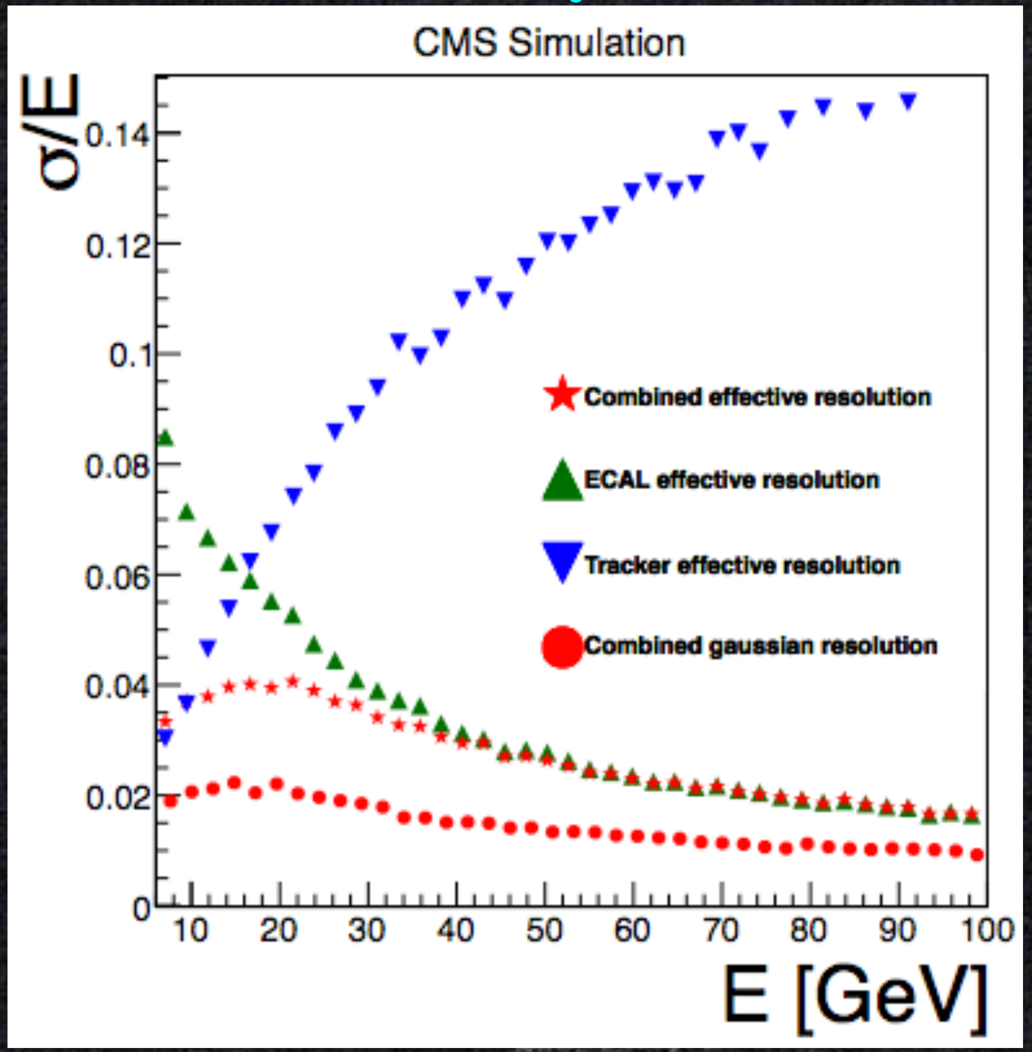


✦ TIGHT ELECTRONS

$p_T > 25\,\mathrm{GeV},\ \ |\eta| < 2.47$

```
// prepare for tight electrons
RangeSelector ele_range =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 25., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -2.47, 2.47);
IsoElectron ele_smear(ele_range);
ele_smear.setIso(TRACK_ISO_PT, 0.3,  0.01, 0.16, 0.0, CALO_ALL);
ele_smear.setIso(CALO_ISO_ET,  0.3,  0.01, 0.18, 0.0, CALO_ALL);
ele_smear.setVariableThreshold(0.0);
ele_smear.setFSSmearing  ( dp.electronSim( "Smear_Electron_ATLAS" ) );
ele_smear.setFSEfficiency( dp.electronEff( "Electron_Tight_ATLAS" ) );
```



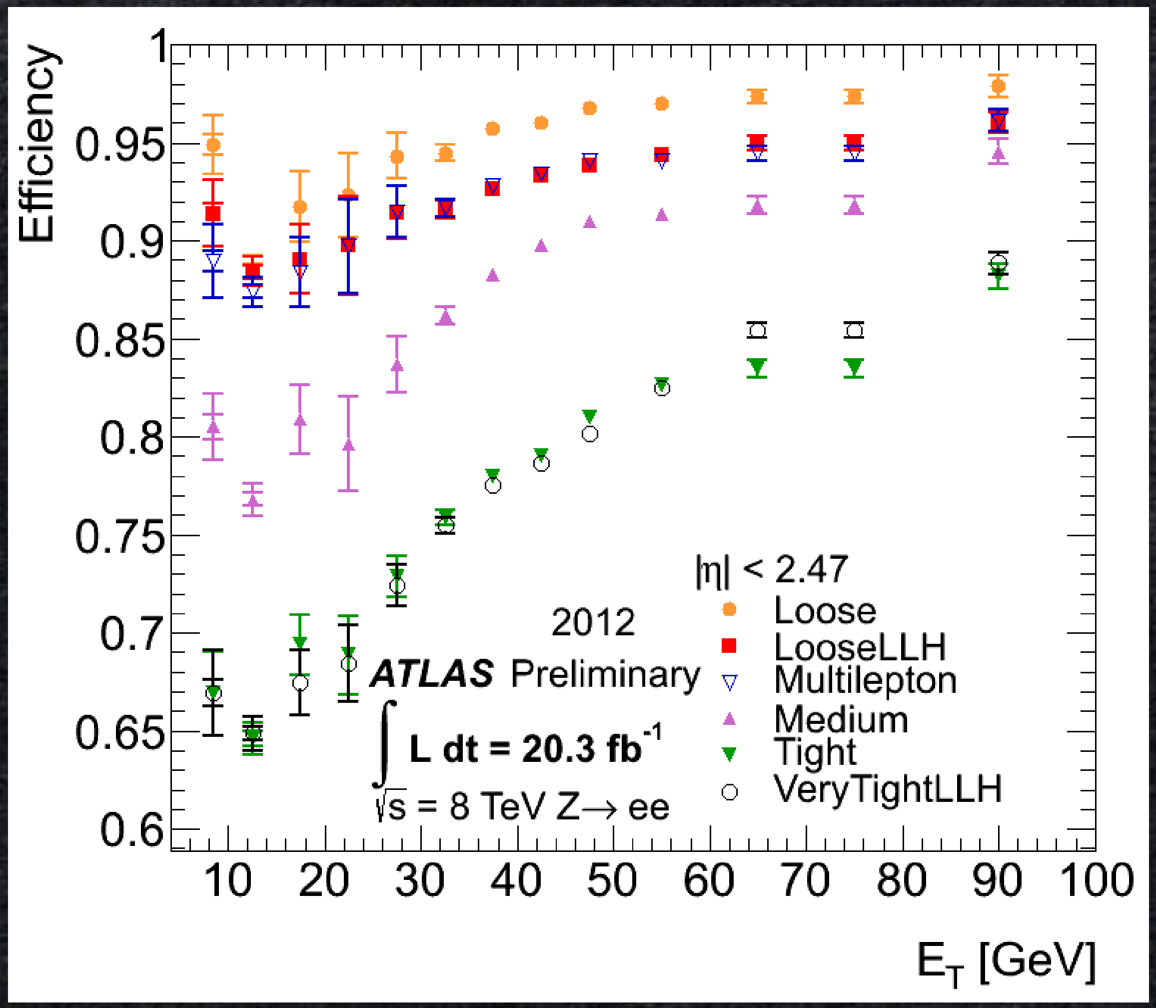


✦ TIGHT ELECTRONS

$p_T > 25\,\mathrm{GeV},\ \ |\eta| < 2.47$

```
// prepare for tight electrons
RangeSelector ele_range =
    RangeSelector(RangeSelector::TRANSVERSE_MOMENTUM, 25., 8000.) &
    RangeSelector(RangeSelector::PSEUDO_RAPIDITY, -2.47, 2.47);
IsoElectron ele_smear(ele_range);
ele_smear.setIso(TRACK_ISO_PT, 0.3,  0.01, 0.16, 0.0, CALO_ALL);
ele_smear.setIso(CALO_ISO_ET,  0.3,  0.01, 0.18, 0.0, CALO_ALL);
ele_smear.setVariableThreshold(0.0);
ele_smear.setFSSmearing  ( dp.electronSim( "Smear_Electron_ATLAS" ) );
ele_smear.setFSEfficiency( dp.electronEff( "Electron_Tight_ATLAS" ) );
```

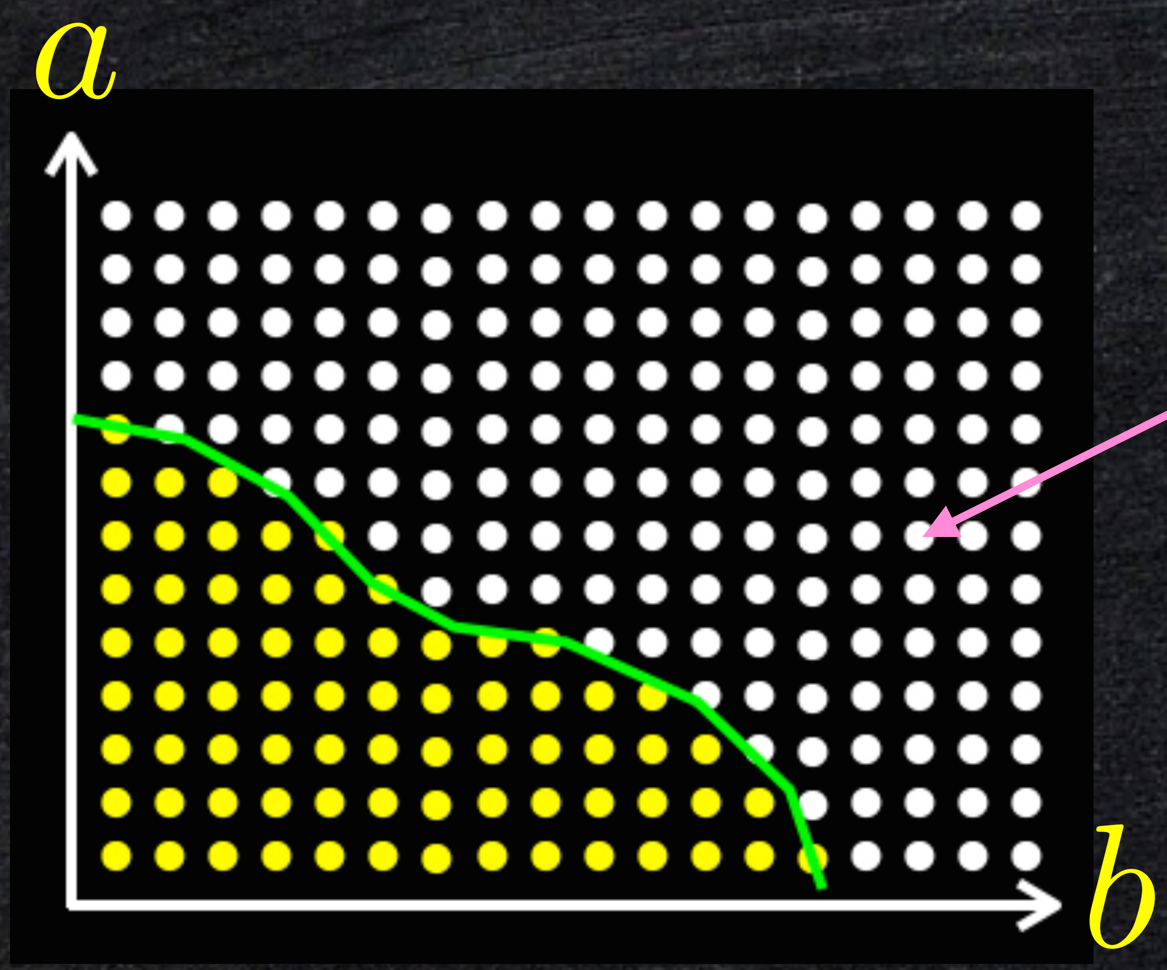
reconstruction efficiencies



Fastlim

Fastlim motivation

- In the standard procedure, testing model points is time consuming. This is problematic when performing parameter scans.



It is desirable to have a fast, efficient model testing method.

Factorisation

- Factorisation and parametrisation often provide a way of making things more efficient and quick.

Factorisation

- Factorisation and parametrisation often provide a way of making things more efficient and quick.

Example: fast detector simulation

Full simulation —factorisation→ **Object ID** x **Smearing** x **Cuts**

Factorisation

- Factorisation and parametrisation often provide a way of making things more efficient and quick.

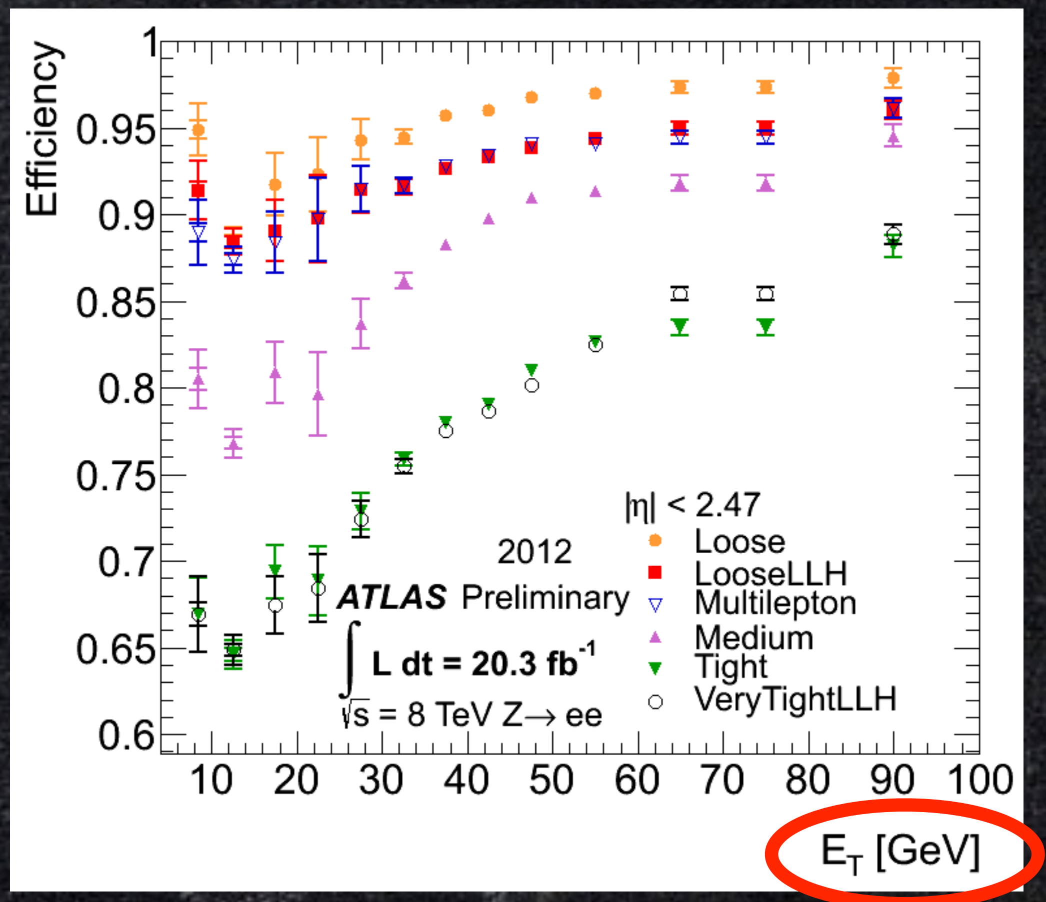
Example: fast detector simulation

Full simulation —factorisation→ **Object ID** x **Smearing** x **Cuts**

Electron ID

- shower shape
- track quality
- HCAL/ECAL ratio
- …

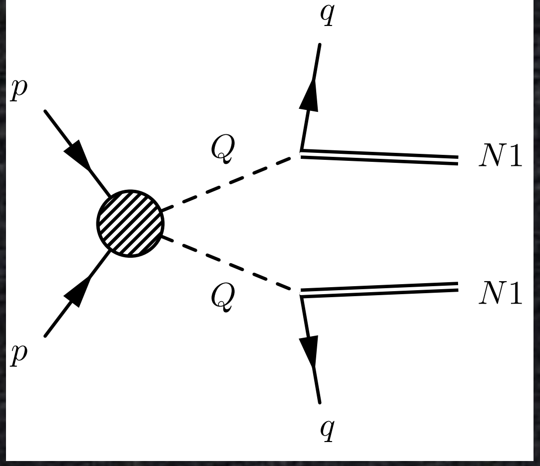
parametrisation →

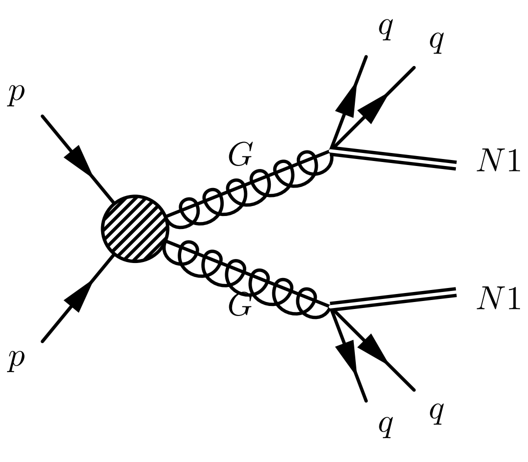


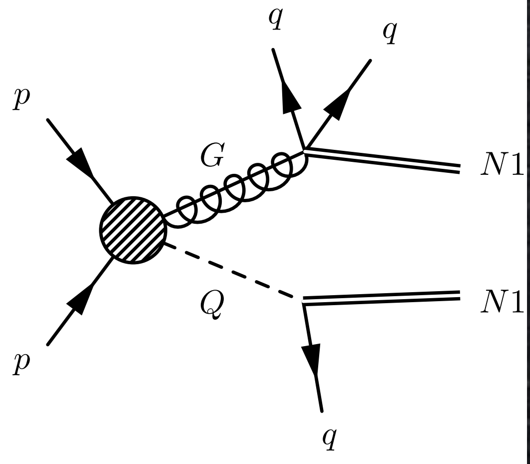
Event factorisation

$Q = \tilde{q}$
$G = \tilde{g}$
$N1 = \tilde{\chi}_1^0$

$$N^{(a)}_{\rm BSM} = \begin{cases} N^{(a)}_{\rm QqN1:QqN1} \\ + \\ N^{(a)}_{\rm GqqN1:GqqN1} \\ + \\ N^{(a)}_{\rm GqqN1:QqN1} \\ \vdots \end{cases}$$







Event factorisation

Q $= \tilde{q}$
G $= \tilde{g}$
N1 $= \tilde{\chi}_1^0$

dominantly depends on BSM particle masses

$$N_{\rm BSM}^{(a)} = \begin{cases} N_{\rm QqN1:QqN1}^{(a)} = \epsilon_{\rm QqN1:QqN1}^{(a)}(m_{\rm Q}, m_{\rm N1}) \cdot \sigma_{\rm QQ} \cdot BR \cdot \mathcal{L} \\ + \\ N_{\rm GqqN1:GqqN1}^{(a)} = \epsilon_{\rm GqqN1:GqqN1}^{(a)}(m_{\rm G}, m_{\rm N1}) \cdot \sigma_{\rm GG} \cdot BR \cdot \mathcal{L} \\ + \\ N_{\rm GqqN1:QqN1}^{(a)} = \epsilon_{\rm GqqN1:QqN1}^{(a)}(m_{\rm G}, m_{\rm Q}, m_{\rm N1}) \cdot \sigma_{\rm GQ} \cdot BR \cdot \mathcal{L} \\ \vdots \end{cases}$$

parametrisation

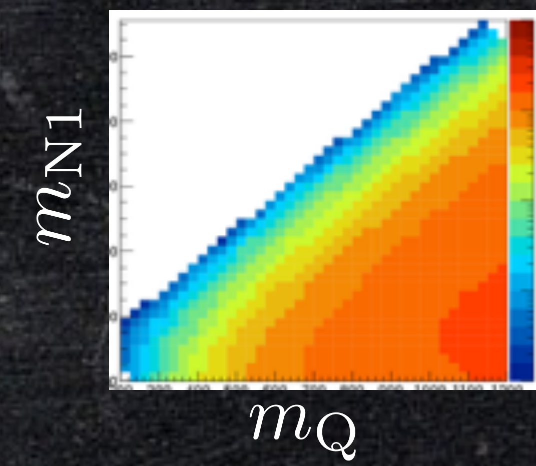
Event factorisation

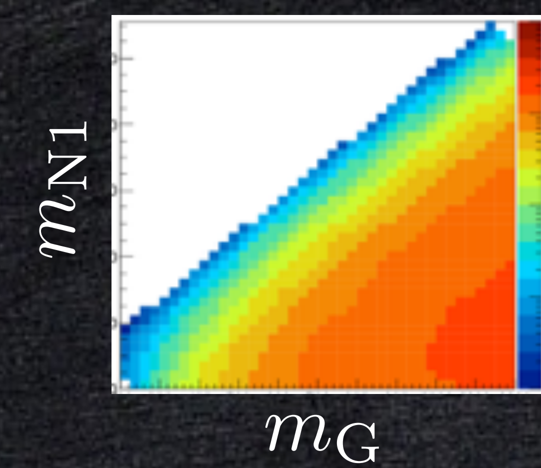
$Q = \tilde{q}$

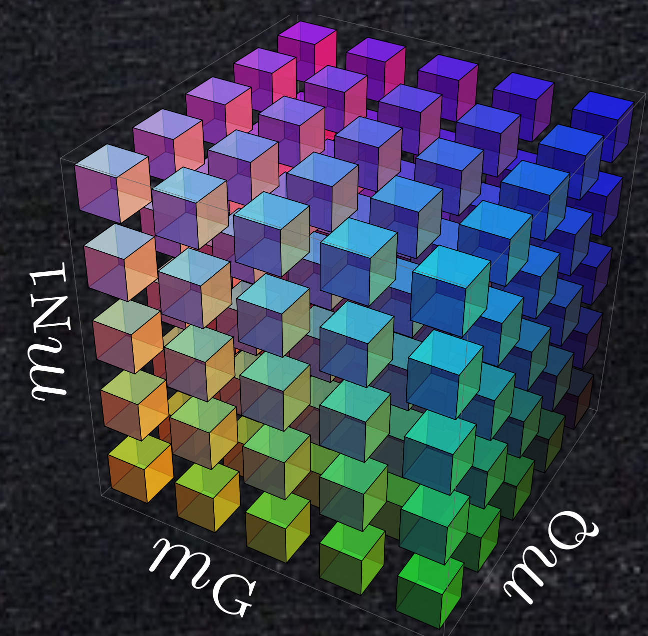
$G = \tilde{g}$

$N1 = \tilde{\chi}_1^0$

$$N^{(a)}_{\mathrm{BSM}} = \begin{cases} N^{(a)}_{\mathrm{QqN1:QqN1}} = \sigma_{\mathrm{QQ}} \cdot BR \cdot \mathcal{L} \\ + \\ N^{(a)}_{\mathrm{GqqN1:GqqN1}} = \sigma_{\mathrm{GG}} \cdot BR \cdot \mathcal{L} \\ + \\ N^{(a)}_{\mathrm{GqqN1:QqN1}} = \sigma_{\mathrm{GQ}} \cdot BR \cdot \mathcal{L} \\ \vdots \end{cases}$$







Approximation

$$N_{\rm BSM} \simeq \sum_i^{\rm topologies} N_i$$

topology =
on-shell production
and decay

- Neglecting interference: $\Rightarrow$ Good approx for weakly coupled BSM

Approximation

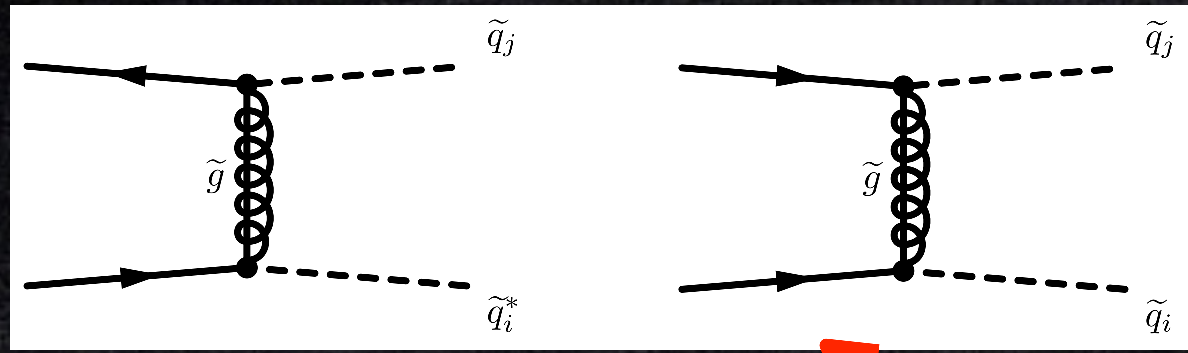
$$N_{\rm BSM} \simeq \sum_i^{\rm topologies} N_i$$

topology = on-shell production and decay

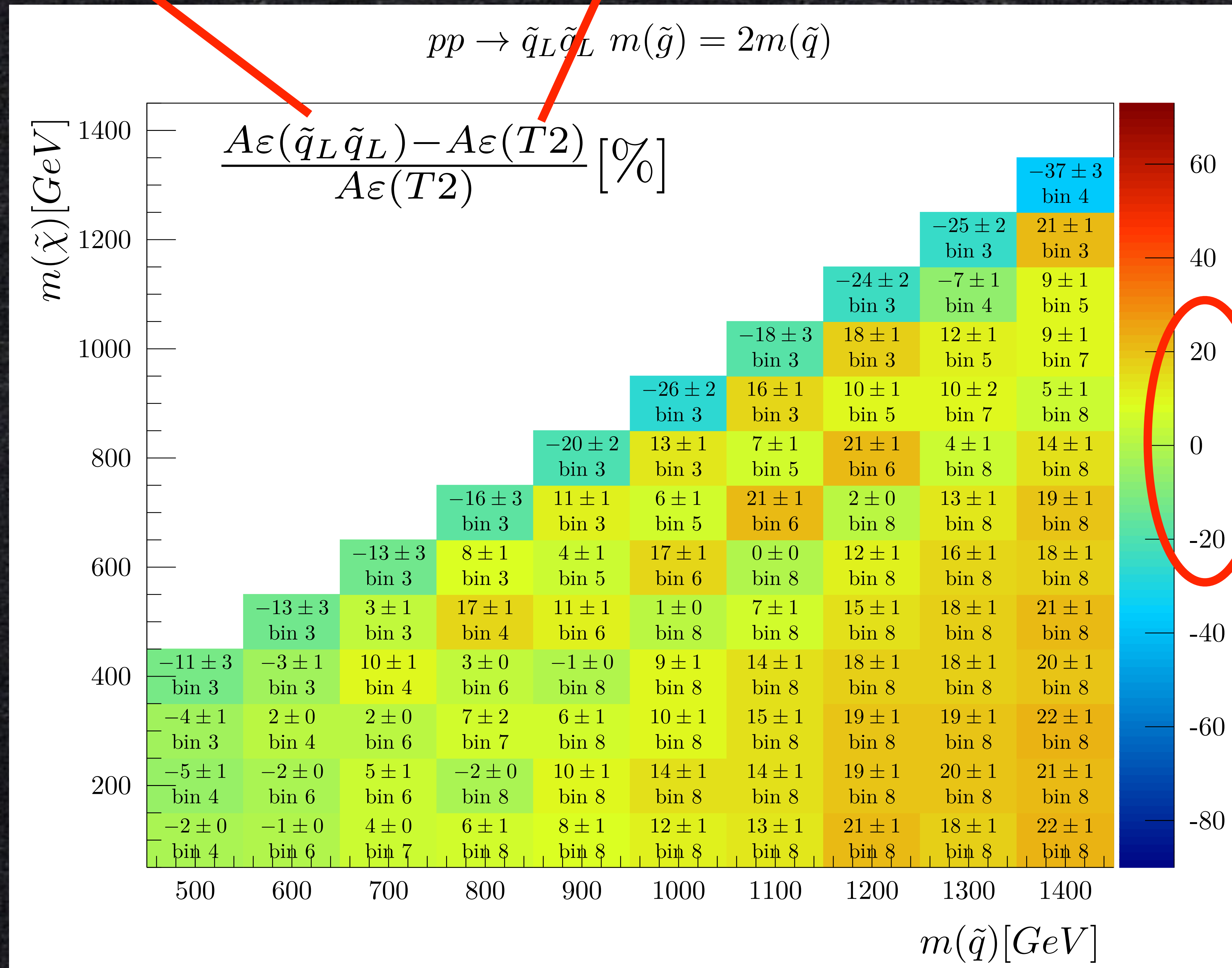
- Neglecting interference: $\Rightarrow$ Good approx for weakly coupled BSM

$$\epsilon_i \simeq \epsilon_i(\{m_{\rm BSM}\})$$

- Neglecting
  - width: $\Rightarrow$ Good approx for weakly coupled BSM
  - production mechanism
  - coupling (chirality) structure



$m_{\tilde{g}} = 10^5$ GeV (decoupled)



CMS α_T analysis
(CMS-SUS-12-028)

L.Edelhauser,
J.Heisig, M.Kramer,
L.Oymanns,
J.Sonneveld
1410.0965

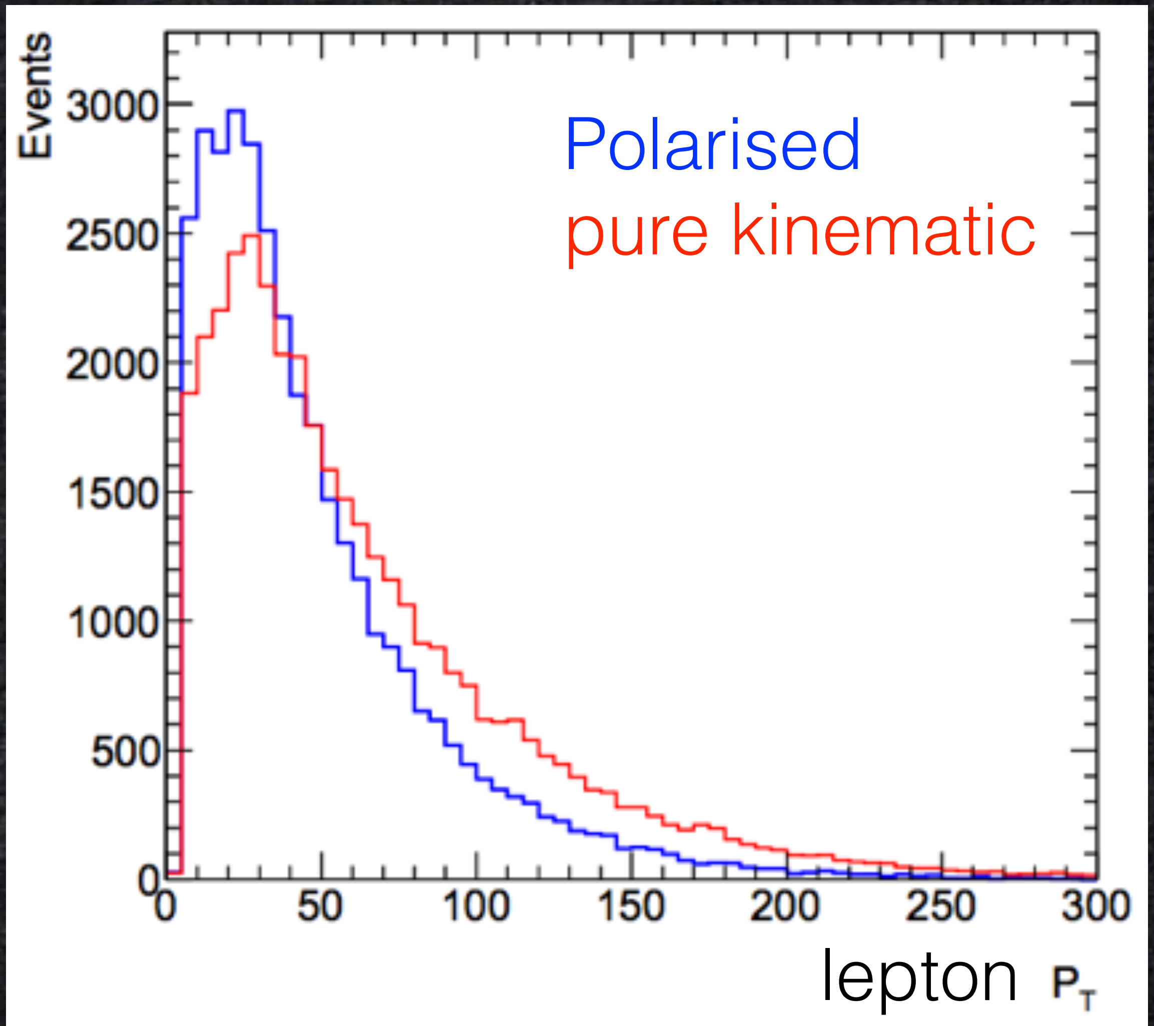
ATLAS-CONF-2013-024 (stop → t, neut1)

How large is the effect of the stop chirality in BSM searches?

Selection	$\tilde{t}_R\tilde{t}_R^*$	$\tilde{t}_L\tilde{t}_L^*$
No selection	507.3	507.3
Trigger	468.0	467.8
Primary Vertex	467.8	467.4
Event cleaning	459.0	459.6
Muon veto	381.2	382.5
Electron veto	284.4	292.3
$E_T^{miss} > 130$ GeV	263.1	270.1
Jet multiplicity and p_T	97.7	92.2
$E_T^{miss,track} > 30$ GeV	96.3	90.5
$\Delta\phi(E_T^{miss}, E_T^{miss,track}) < \pi/3$	90.3	84.3
$\Delta\phi(\mathrm{jet}, E_T^{miss}) > \pi/5$	77.1	72.0
Tau veto	67.4	61.9
≥ 2 b-tagged jets	29.5	31.5
$m_T(b\text{-jet}, E_T^{miss}) > 175$ GeV	20.2	23.6
80 GeV $< m_{jjj}^0 <$ 270 GeV	17.8	20.4
80 GeV $< m_{jjj}^1 <$ 270 GeV	10.9	11.9
$E_T^{miss} > 150$ GeV	10.8	11.8
$E_T^{miss} > 200$ GeV	10.3	11.2
$E_T^{miss} > 250$ GeV	9.2	10.0
$E_T^{miss} > 300$ GeV	7.8	8.3
$E_T^{miss} > 350$ GeV	6.1	6.6

How large is the effect of the stop chirality in BSM searches?

- Polarised stop vs. pure kinematic decay: $\tilde{t} \to b\tilde{\chi}_1^{\pm} \to b\ell\nu\tilde{\chi}_1^0$



K.Wang, L.Wang, T.Xu, L.Zhang, 2013

$M_{\tilde{t}}$	Category	$p_T > 20$ GeV	$p_T > 25$ GeV	$p_T > 30$ GeV
1.3 TeV	Polarized	52%	46%	40%
	Kinematic	64%	59%	54%
1.5 TeV	Polarized	54%	48%	44%
	Kinematic	65%	61%	57%

How large is the effect of the stop chirality in BSM searches?

- The effect can be factorable by the R and L contributions.

weight (analytical)

$$\epsilon(\theta_{eff}) = \epsilon_{\tilde{t}_R} \cdot \cos\theta_{eff} + \epsilon_{\tilde{t}_L} \cdot \sin\theta_{eff}$$

efficiency maps for R and L

Other limitation

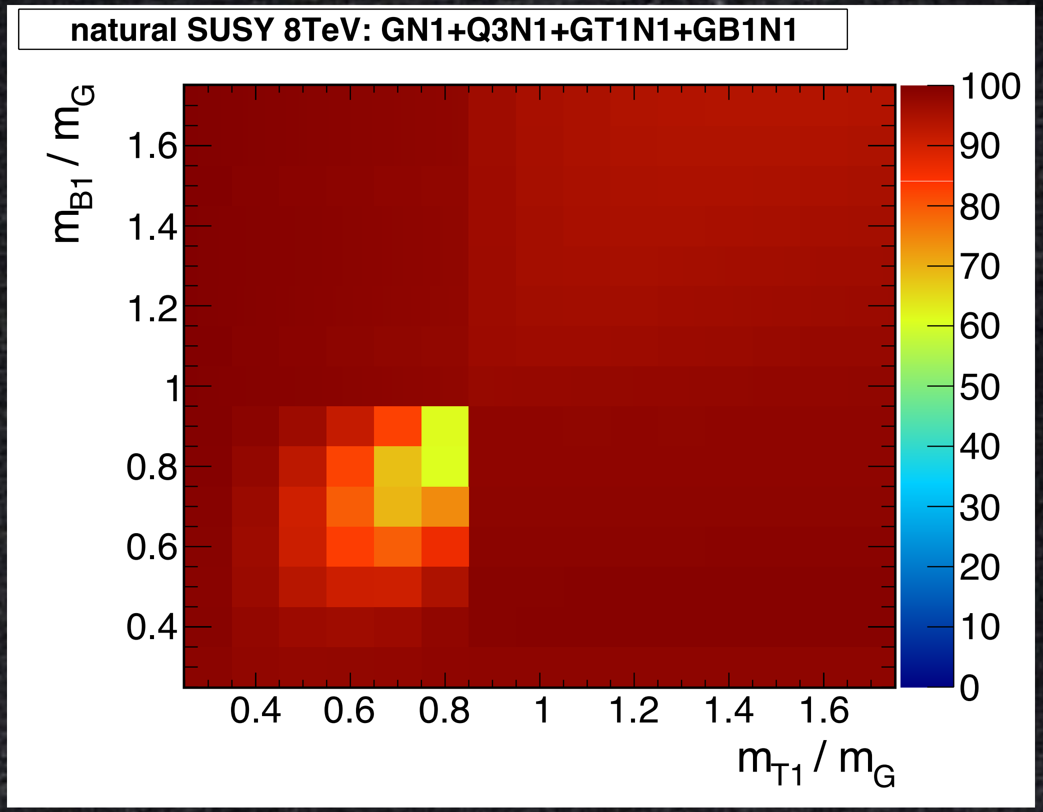
$$
\begin{aligned}
\sigma_{\rm vis}^{(a)} \;=\;& \\
& \epsilon^{(a)}_{\tilde g\to qq\tilde\chi_1^0:\tilde g\to qq\tilde\chi_1^0}(m_{\tilde g}, m_{\tilde\chi_1^0}) \cdot \sigma_{\tilde g\tilde g}(m_{\tilde g}, m_{\tilde q}) \cdot (BR_{\tilde g\to qq\tilde\chi_1^0})^2 + \\
& \epsilon^{(a)}_{\tilde q\to q\tilde\chi_1^0:\tilde q\to q\tilde\chi_1^0}(m_{\tilde q}, m_{\tilde\chi_1^0}) \cdot \sigma_{\tilde q\tilde q}(m_{\tilde g}, m_{\tilde q}) \cdot (BR_{\tilde q\to q\tilde\chi_1^0})^2 + \\
& \epsilon^{(a)}_{\tilde g\to qq\tilde\chi_1^0:\tilde q\to q\tilde\chi_1^0}(m_{\tilde g}, m_{\tilde q}, m_{\tilde\chi_1^0}) \cdot \sigma_{\tilde g\tilde q}(m_{\tilde g}, m_{\tilde q}) \cdot BR_{\tilde g\to qq\tilde\chi_1^0} \cdot BR_{\tilde q\to q\tilde\chi_1^0} + \\
& \dots .
\end{aligned}
$$

- difficult to cover all the topologies
- for the topology with long decay chain, the efficiency depends on 4 or more BSM masses => difficult to generate the efficiency maps
- However, the limit is always conservative.

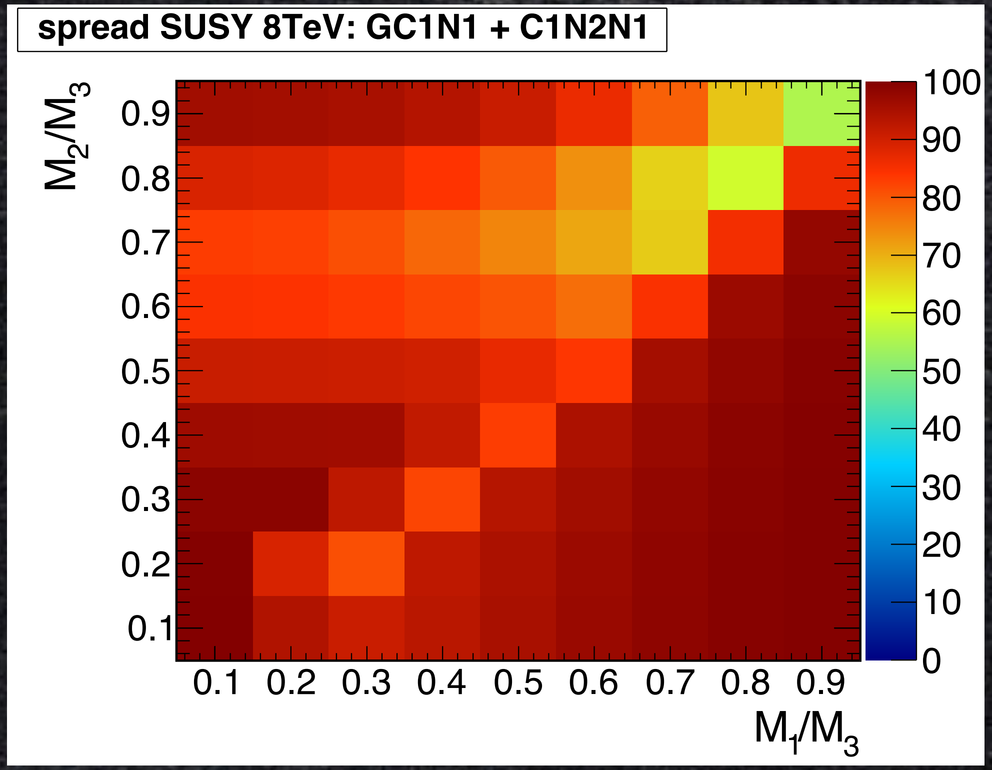
- Popular models can have good coverage with some 3- or 4-D efficiency maps.

$$\text{coverage} = \frac{\sigma^{\text{implimented}}}{\sigma_{\text{tot}}}$$

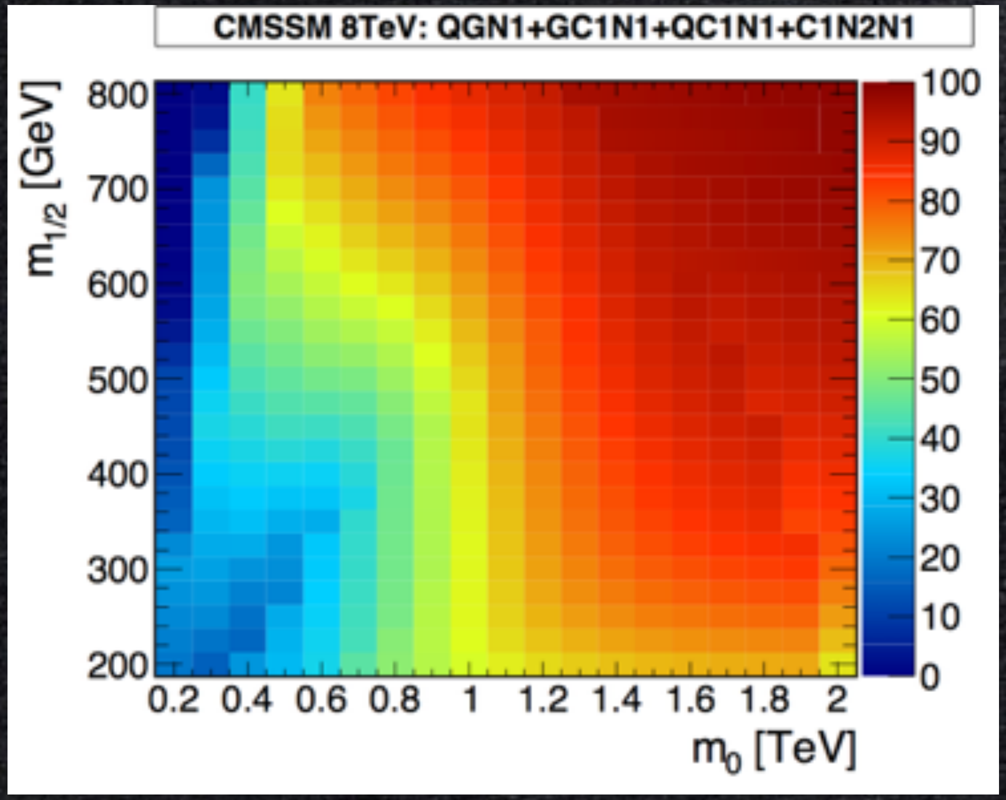
Natural SUSY



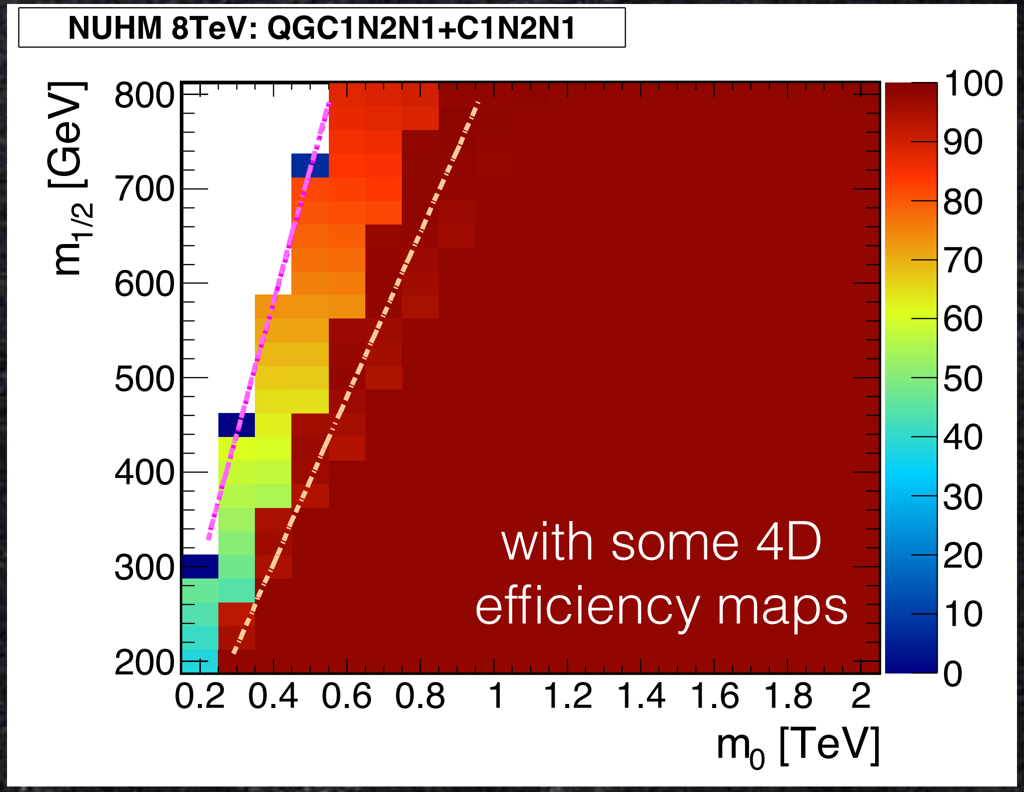
Split SUSY



CMSSM



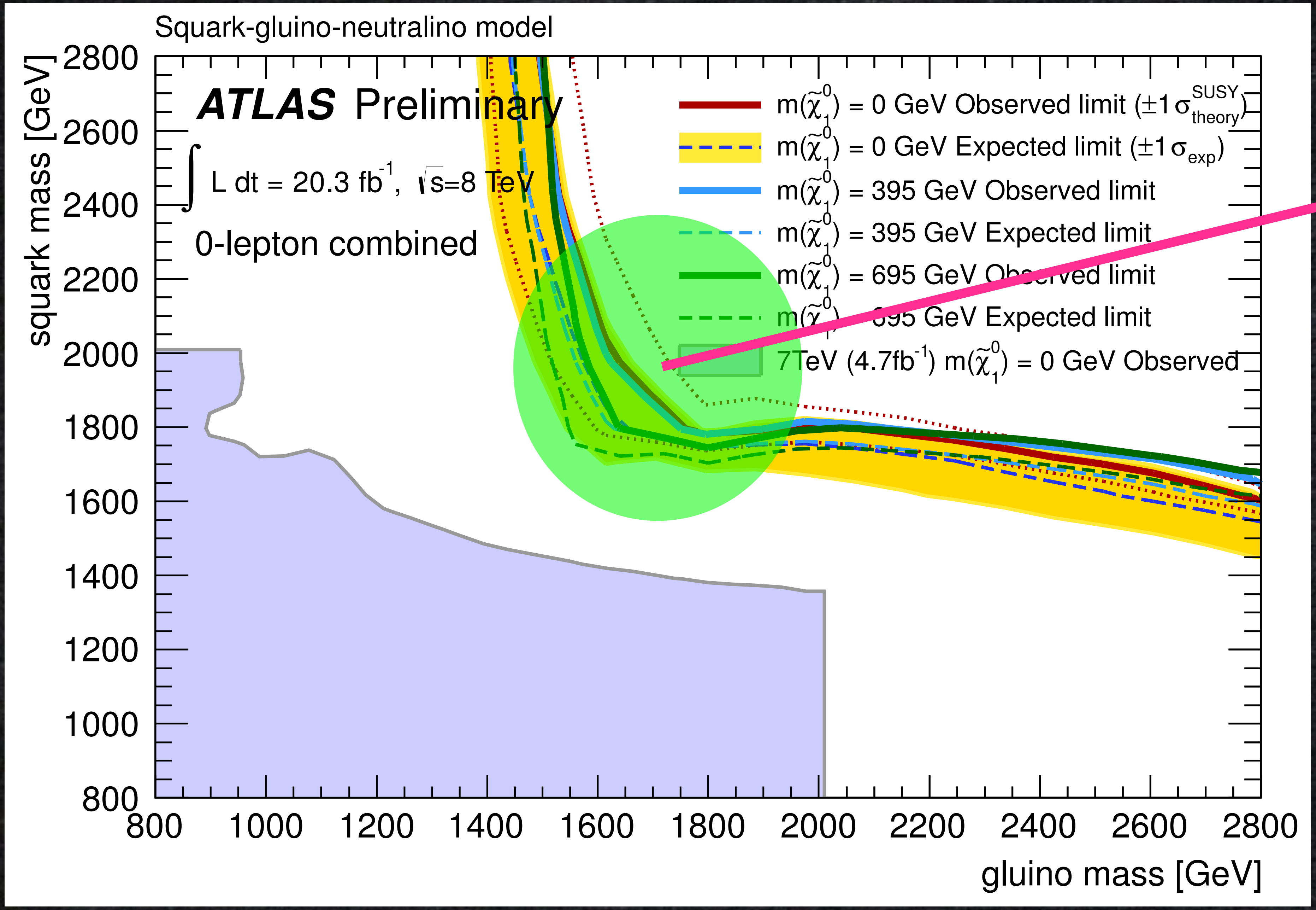
NUHM



Topologies vs Simplified Models

[Gluino-Squark-Neutralino model]

$$\mathcal{L} = \mathcal{L}_{kin} + \tilde{g}^A \tilde{q} T^A \bar{q} + \tilde{q}\bar{q}\tilde{\chi}^0_1 + \frac{1}{\Lambda^2}\tilde{g}^A q T^A \bar{q}\tilde{\chi}^0_1 + m_{\tilde{g}}\tilde{g}\tilde{g} + m^2_{\tilde{q}}\tilde{q}\tilde{q} + m_{\tilde{\chi}}\tilde{\chi}^0_1\tilde{\chi}^0_1$$



production		decay
$pp \to \tilde{q}\tilde{q}$	$\otimes$	$\tilde{g} \to \tilde{q}\bar{q}$
$pp \to \tilde{g}\tilde{g}$		$\tilde{g} \to q\bar{q}\tilde{\chi}^0_1$
$pp \to \tilde{g}\tilde{q}$		$\tilde{q} \to q\tilde{g}$
		$\tilde{q} \to q\tilde{\chi}^0_1$

⇒ mixture of various topologies

The rate of topologies is easily violated with (e.g.)

$$\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$$

and the limit cannot be used.

http://fastlim.web.cern.ch/fastlim/

Fastlim

Papucci, KS, Weiler, Zeune 1402.0492

cross section tables

m_Q	m_G	σ
300	300	87.94
300	350	34.98
...		

efficiency tables

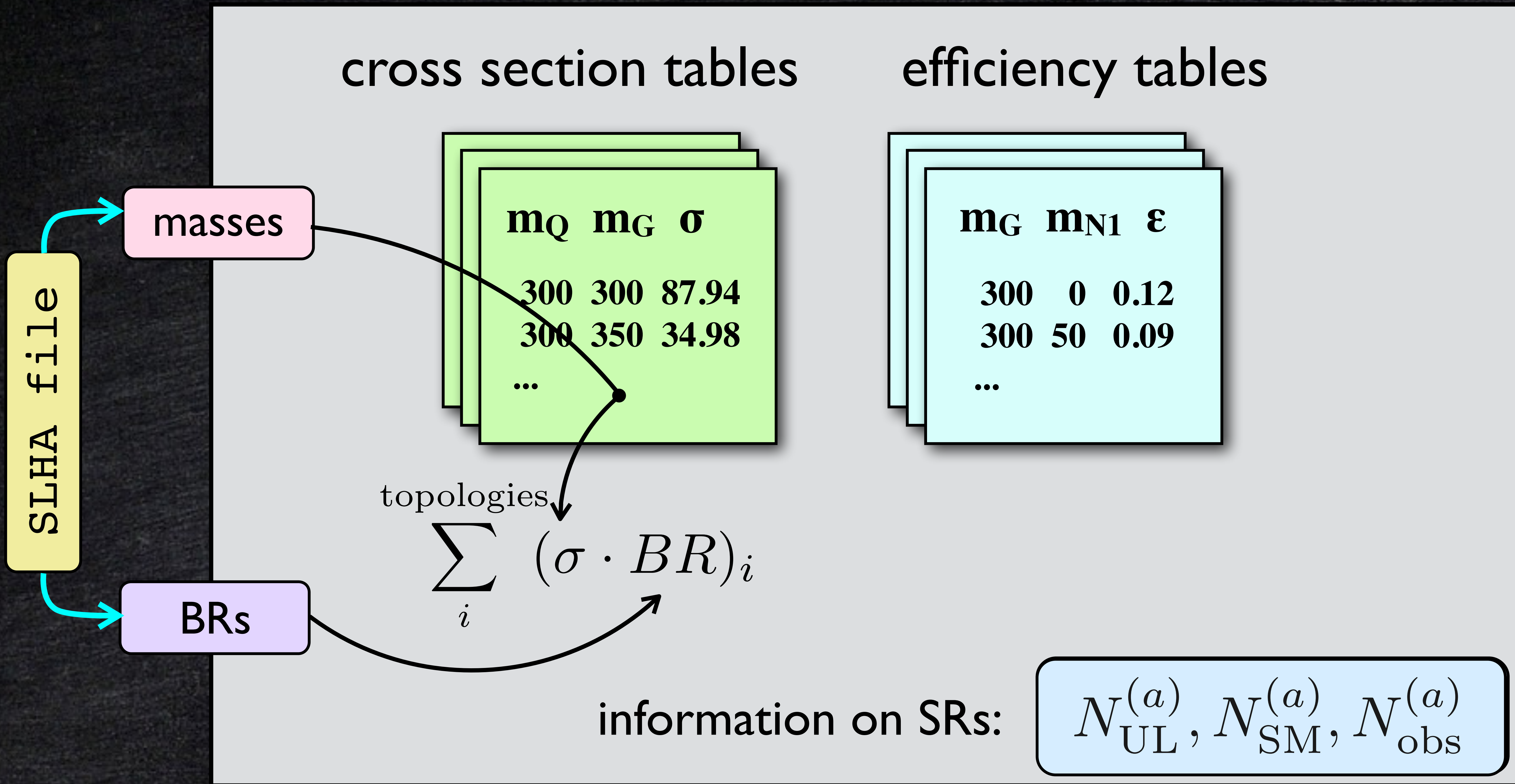
m_G	m_{N1}	ε
300	0	0.12
300	50	0.09
...		

information on SRs: $N_{\rm UL}^{(a)}, N_{\rm SM}^{(a)}, N_{\rm obs}^{(a)}$

http://fastlim.web.cern.ch/fastlim/

Fastlim

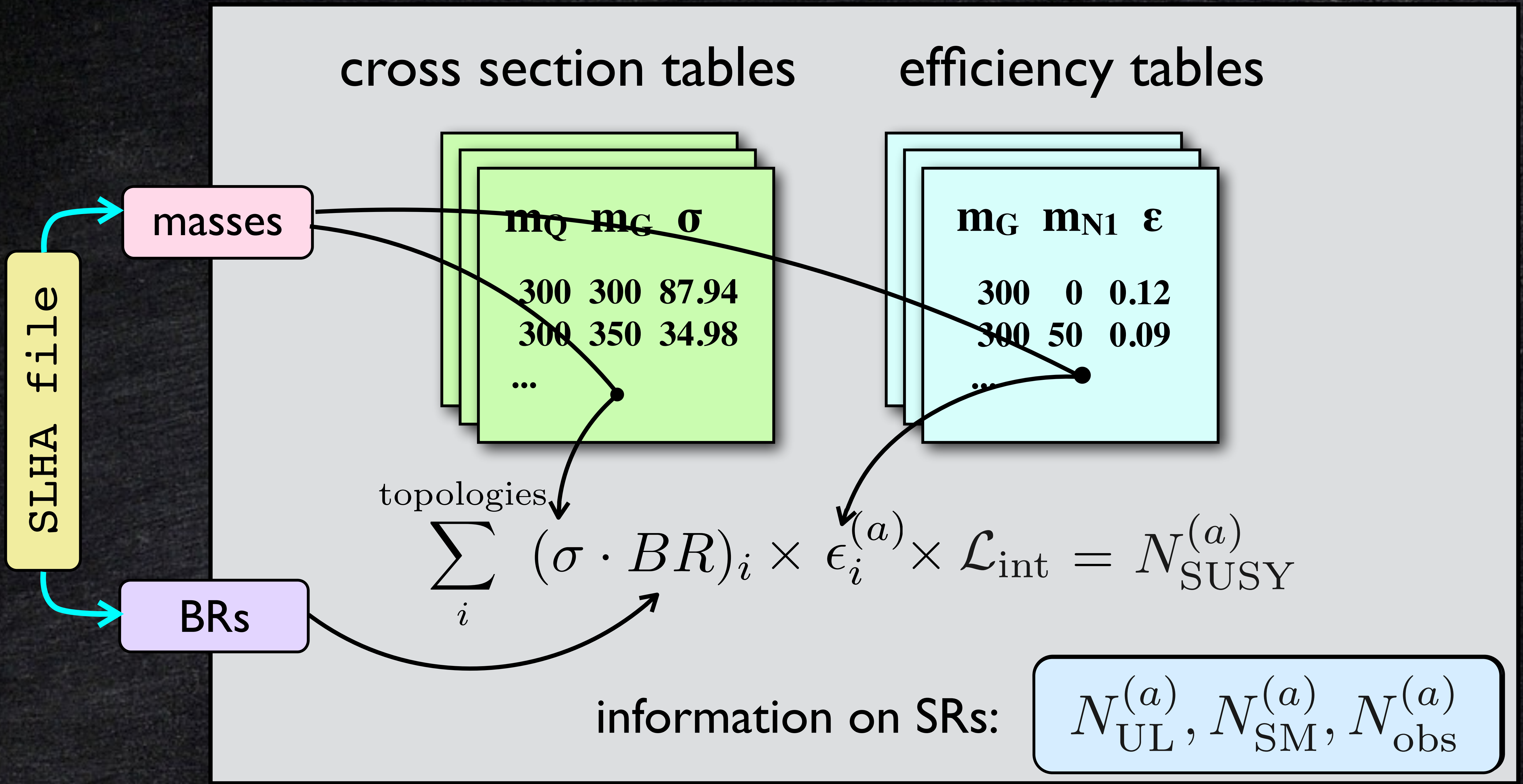
Papucci, KS, Weiler, Zeune 1402.0492



http://fastlim.web.cern.ch/fastlim/

Fastlim

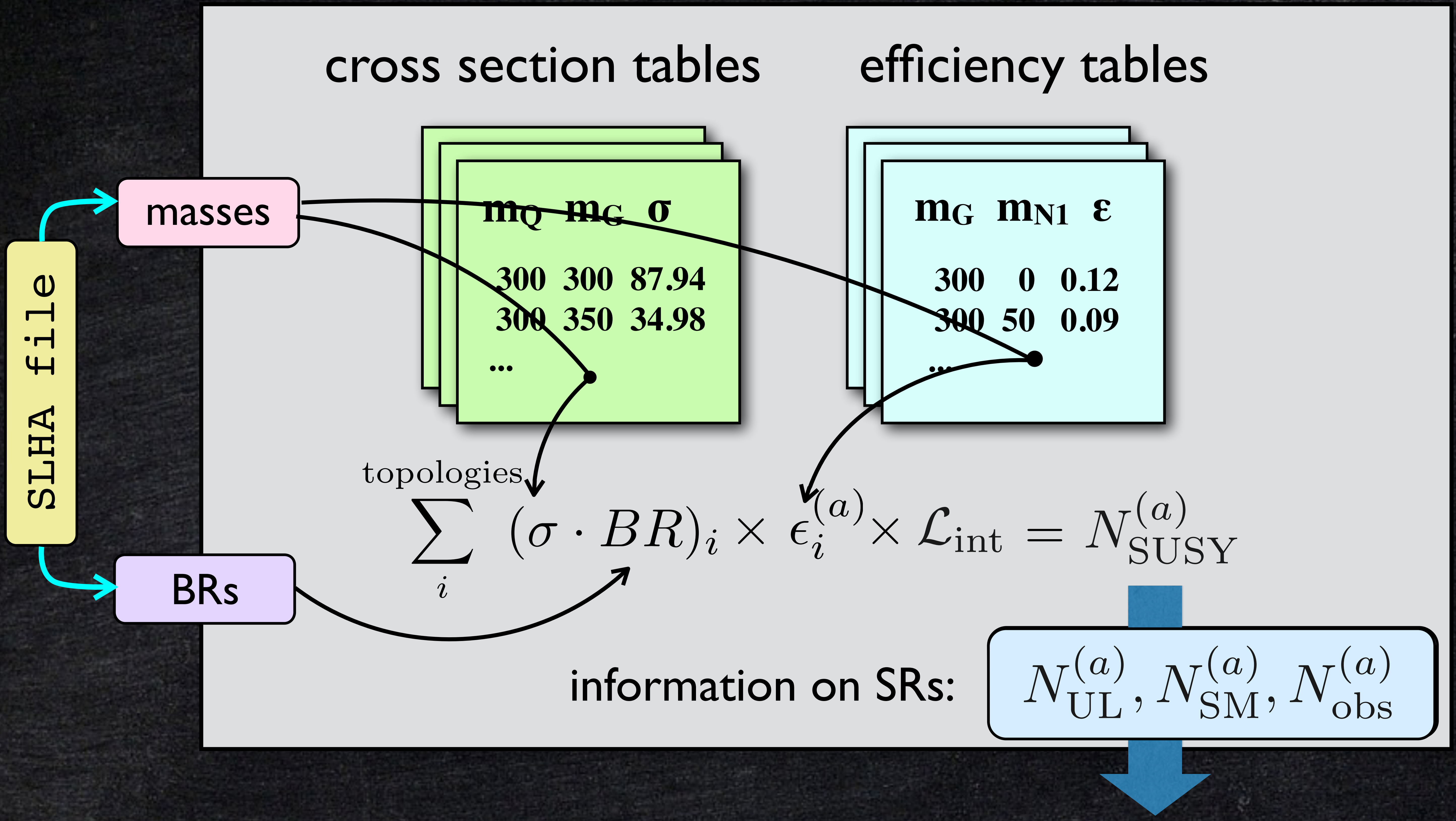
Papucci, KS, Weiler, Zeune 1402.0492



http://fastlim.web.cern.ch/fastlim/

Fastlim

Papucci, KS, Weiler, Zeune 1402.0492

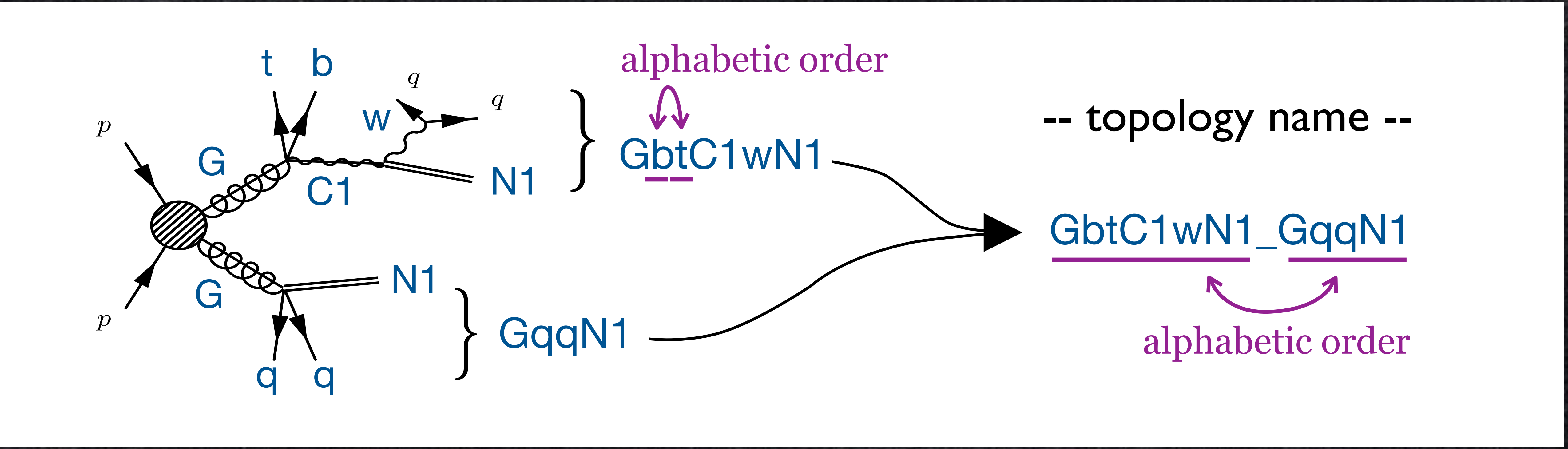


No MC sim. required

output: $N_{\rm SUSY}^{(a)}/N_{\rm UL}^{(a)},\ CL_s^{(a)}$

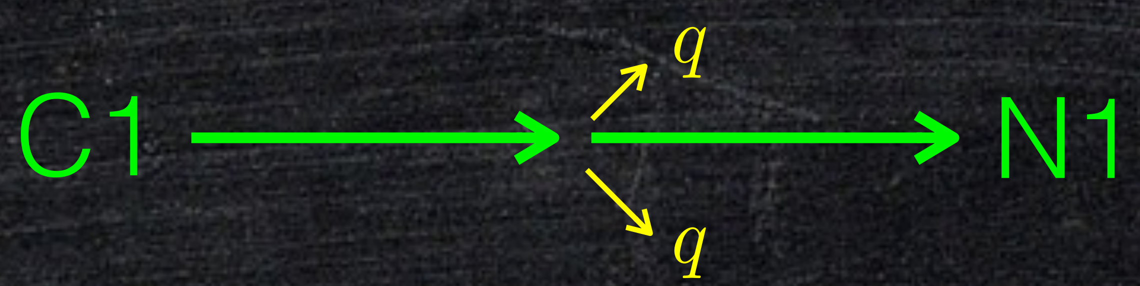
Naming topologies

SM	g	gam, z, w, h	q	t	b	e, m, ta	n
BSM	G	N1,…,N4, C1,C2	Q	T1, T2	B1, B2	E, M, TAU	NU, NUT



Truncation of soft decays

$$m_{\mathrm{C1}} \simeq m_{\mathrm{N1}}$$



very soft and do not affect efficiencies

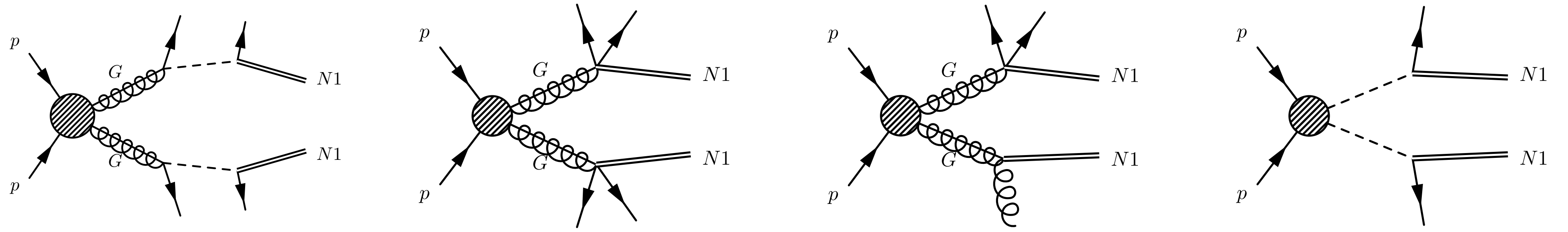
G→btC1→qqN1 ⇒ GbtN1

- note: this introduces topologies as if EM charge is not conserved.

useful for wino and higgsino scenarios

Fastlim 1.0

topologies in Fastlim 1.0



GbB1bN1_GbB1bN1
GbB1bN1_GbB1tN1
GbB1tN1_GbB1tN1
GtT1bN1_GtT1bN1
GtT1bN1_GtT1tN1
GtT1tN1_GtT1tN1
(GbB2bN1_GbB2bN1)
(GbB2bN1_GbB2tN1)
(GbB2tN1_GbB2tN1)
(GtT2bN1_GtT2bN1)
(GtT2bN1_GtT2tN1)
(GtT2tN1_GtT2tN1)
[GbB1bN1_GbB2bN1]
[GbB1bN1_GbB2tN1]
[GbB1tN1_GbB2bN1]
[GbB1tN1_GbB2tN1]
[GtT1bN1_GtT2bN1]
[GtT1bN1_GtT2tN1]
[GtT1tN1_GtT2bN1]
[GtT1tN1_GtT2tN1]

GbbN1_GbbN1
GbbN1_GbtN1
GbbN1_GttN1
GbbN1_GqqN1
GbtN1_GbtN1
GbtN1_GttN1
GbtN1_GqqN1
GttN1_GttN1
GttN1_GqqN1
GqqN1_GqqN1

GbbN1_GgN1
GbtN1_GgN1
GgN1_GgN1
GgN1_GttN1
GgN1_GqqN1

T1bN1_T1bN1
T1bN1_T1tN1
T1tN1_T1tN1
(B1bN1_B1bN1)
(B1bN1_B1tN1)
(B1tN1_B1tN1)
(B2bN1_B2bN1)
(B2bN1_B2tN1)
(B2tN1_B2tN1)
(T2bN1_T2bN1)
(T2bN1_T2tN1)
(T2tN1_T2tN1)

not all topologies are implemented

↓

the result may be underestimated but at least conservative

Fastlim 1.0

available analyses

Name	Short description	E_{CM}	$\mathcal{L}_{int}$	# SRs
ATLAS_CONF_2013_024	0 lepton + (2 b-)jets + MET [Heavy stop]	8	20.5	3
ATLAS_CONF_2013_035	3 leptons + MET [EW production]	8	20.7	6
ATLAS_CONF_2013_037	1 lepton + 4(1 b-)jets + MET [Medium/heavy stop]	8	20.7	5
ATLAS_CONF_2013_047	0 leptons + 2-6 jets + MET [squarks & gluinos]	8	20.3	10
ATLAS_CONF_2013_048	2 leptons (+ jets) + MET [Medium stop]	8	20.3	4
ATLAS_CONF_2013_049	2 leptons + MET [EW production]	8	20.3	9
ATLAS_CONF_2013_053	0 leptons + 2 b-jets + MET [Sbottom/stop]	8	20.1	6
ATLAS_CONF_2013_054	0 leptons + $\geq$ 7-10 jets + MET [squarks & gluinos]	8	20.3	19
ATLAS_CONF_2013_061	0-1 leptons + $\geq$ 3 b-jets + MET [3rd gen. squarks]	8	20.1	9
ATLAS_CONF_2013_062	1-2 leptons + 3-6 jets + MET [squarks & gluinos]	8	20.3	13
ATLAS_CONF_2013_093	1 lepton + bb(H) + Etmiss [EW production]	8	20.3	2

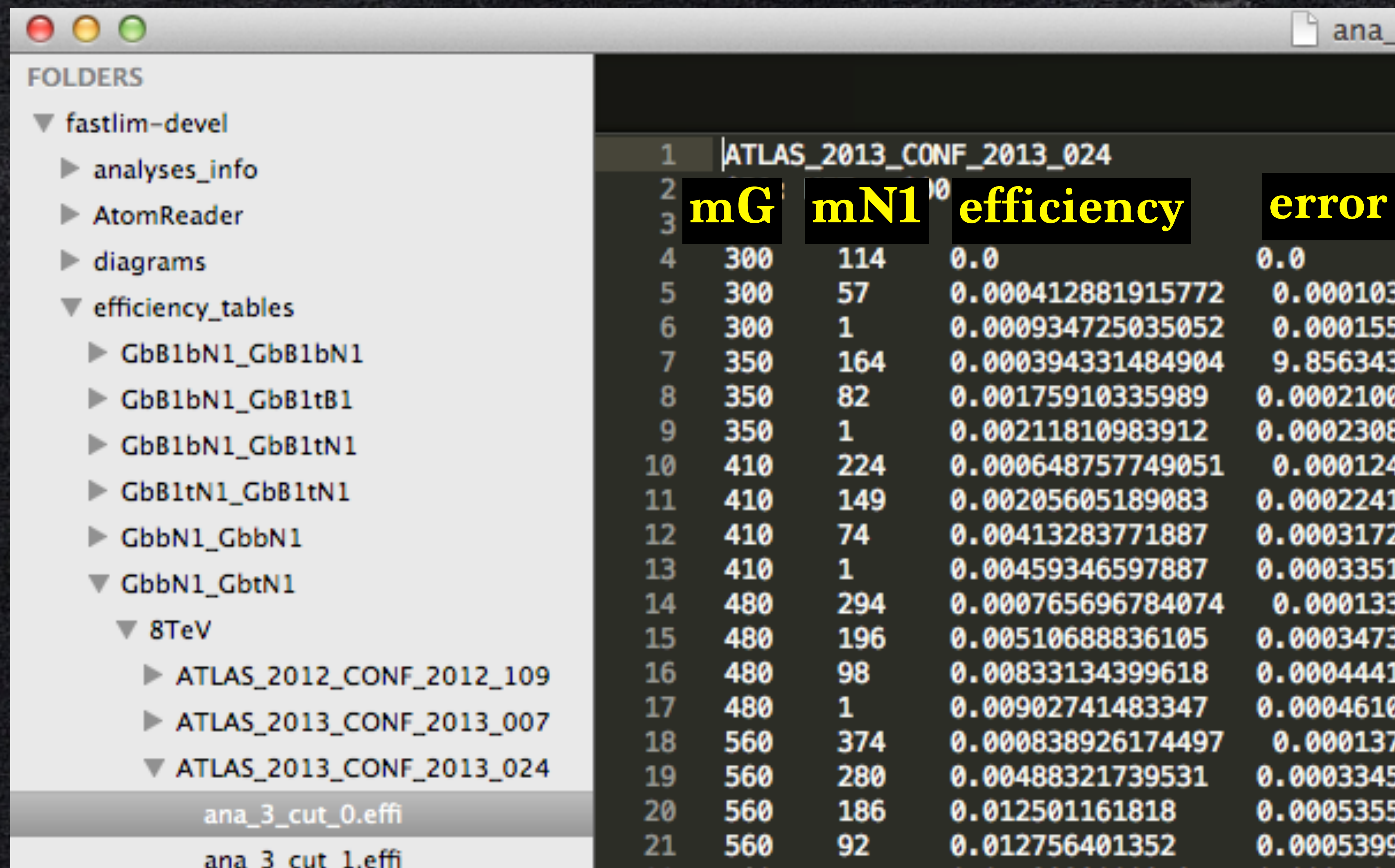
- Most 2013 ATLAS analyses are implemented (CMS analyses will be implemented soon).
- Event generation was done using MadGraph 5. The sample include up to extra 1 parton emission at ME level, matched to parton shower using MLM scheme.
- ATOM is used for efficiency estimation.

Efficiency tables

- efficiency tables are standard text file.
- should be given for each signal region and each topology
- any 3rd party's efficiency tables can be easily incorporated.

global coordinating effort to generate efficiency maps and share

https://indico.cern.ch/event/272303/



Effi

- efficiency tables are standa
- should be given for each si
- any 3rd party's efficiency ta

global coordinating effort to generate efficiency maps and share

https://indico.cern.ch/event/272303/

can include efficiency maps on HepData very easily.

Please provide more maps!

The Durham HepData Project

REACTION DATABASE • DATA REVIEWS • PDF PLOTTER

Reaction Database Full Record Display

View short record or as: input, plain text, AIDA, PyROOT, YODA, ROOT, mpl, ScaVis or MarcXML

AAD 2012 — Search for squarks and gluinos with the ATLAS detector in final states with jets and missing transverse momentum using 4.7 fb^-1 of sqrt(s) = 7 TeV proton-proton collision data

Experiment: CERN-LHC-ATLAS (ATLAS)
Preprinted as **CERN-PH-EP-2012-195**
Archived as: ARXIV:1208.0949
Record in: INSPIRE
Rivet Analysis: ATLAS_2012_I1125961

CERN-LHC. Data from proton-proton interactions at a centre-of-mass energy of 7 TeV with a final state consisting of jets and missing transverse momentum and no high-pT electron or muons are interpreted in a number of SUSY model, listed in the table below.

The table below provides links to the following information for each of the SUSY models

Nevt/Xsec	Number of Monte Carlo events generated The Total SUSY production cross section
AccEffUnc:	Signal Acceptance (truth level) Efficiency (reconstruction level) Uncertainty on signal efficiencies due to detector effects and ISR
CLs	Observed and expected 95% CLs of signal models
SLHA	SLHA files from the analyses
xsUL	Combined and inidividual signal level upper limits on the effective cross sections
Exclusion	The exclusion plot contours as presented in the figures

Model	Nevt/Xsec	AccEffUnc	CLs	SLHA	xsUL	Exclusion
CMSSM/MSUGRA, tan beta=10, A_0=0, mu0	select	select	select	select		select
compressed SUSY (baseline)	select	select	select	select		select
compressed SUSY, (heavy EW gauginos)	select	select	select	select		select
compSUSY_HSQ	select	select	select	select		select
MSSM squark-gluino-neutralino model, mLSP=0	select	select	select	select	select	select
MSSM squark-gluino-neutralino model, mLSP=195 GeV	select	select	select	select	select	select
MSSM squark-gluino-neutralino model, mLSP=395 GeV	select	select	select	select	select	select
gluino-gluino simplified model, direct decays	select	select	select	select	select	select
squark-antisquark simplified model, direct decays	select	select	select	select	select	select
gluino-gluino simplified model, intermediate chargino, vs mLSP	select	select	select	select	select	select
gluino-gluino simplified model, intermediate chargino, vs mChargino	select	select	select	select	select	select
squark-antisquark simplified model, intermediate chargino, vs mLSP	select	select	select	select	select	select
squark-antisquark simplified model, intermediate chargino, vs mChargino	select	select	select	select	select	select

Application

Natural SUSY

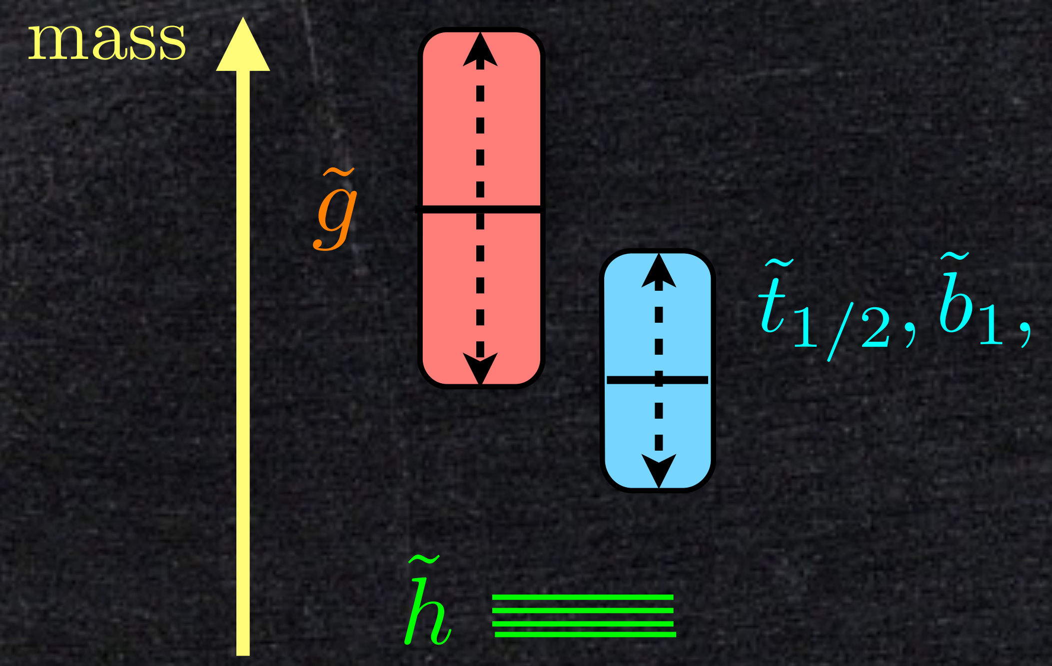
- Natural SUSY contains a minimum particle content that makes the EWSB natural.

$$-\frac{m_Z^2}{2} \simeq |\mu|^2 + m_{H_u}^2(\Lambda) + \Delta m_{H_u}^2$$

μ is higgsino mass: higgsino is lightest

stop 1 loop correction to $\Delta m_{H_u}{}^2$: stop is very light

gluino 2-loop correction to $\Delta m_{H_u}{}^2$: gluino is light



- Only a few particles are accessible at the LHC

⇒ nice playground for Fastlim 1.0

M_{Q3} vs μ

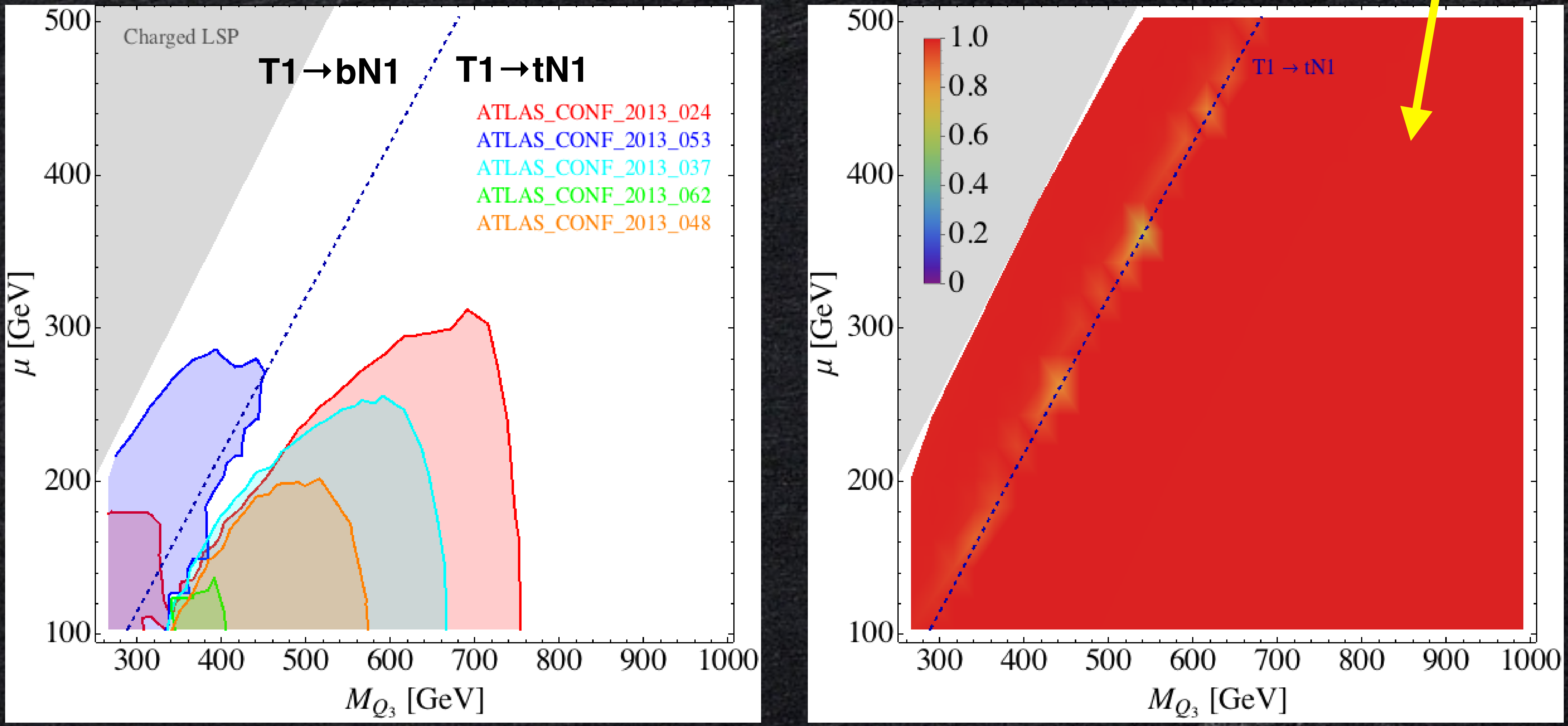
$$\mathcal{L} \supset y_t \cdot t_R \widetilde{Q}_3 \widetilde{H}_u + y_b \cdot b_R \widetilde{Q}_3 \widetilde{H}_d$$

$$\text{coverage} = \frac{\sigma^{\text{implimented}}}{\sigma_{\text{tot}}}$$

$$\begin{cases} \mathrm{T1} \to t\,\mathrm{N1} \\ \mathrm{B1} \to t\,\mathrm{C1}\ (\mathrm{C1} \to \mathrm{N1}) \end{cases}$$

$\tan\beta = 10$

good coverage



M_{Q3} vs μ

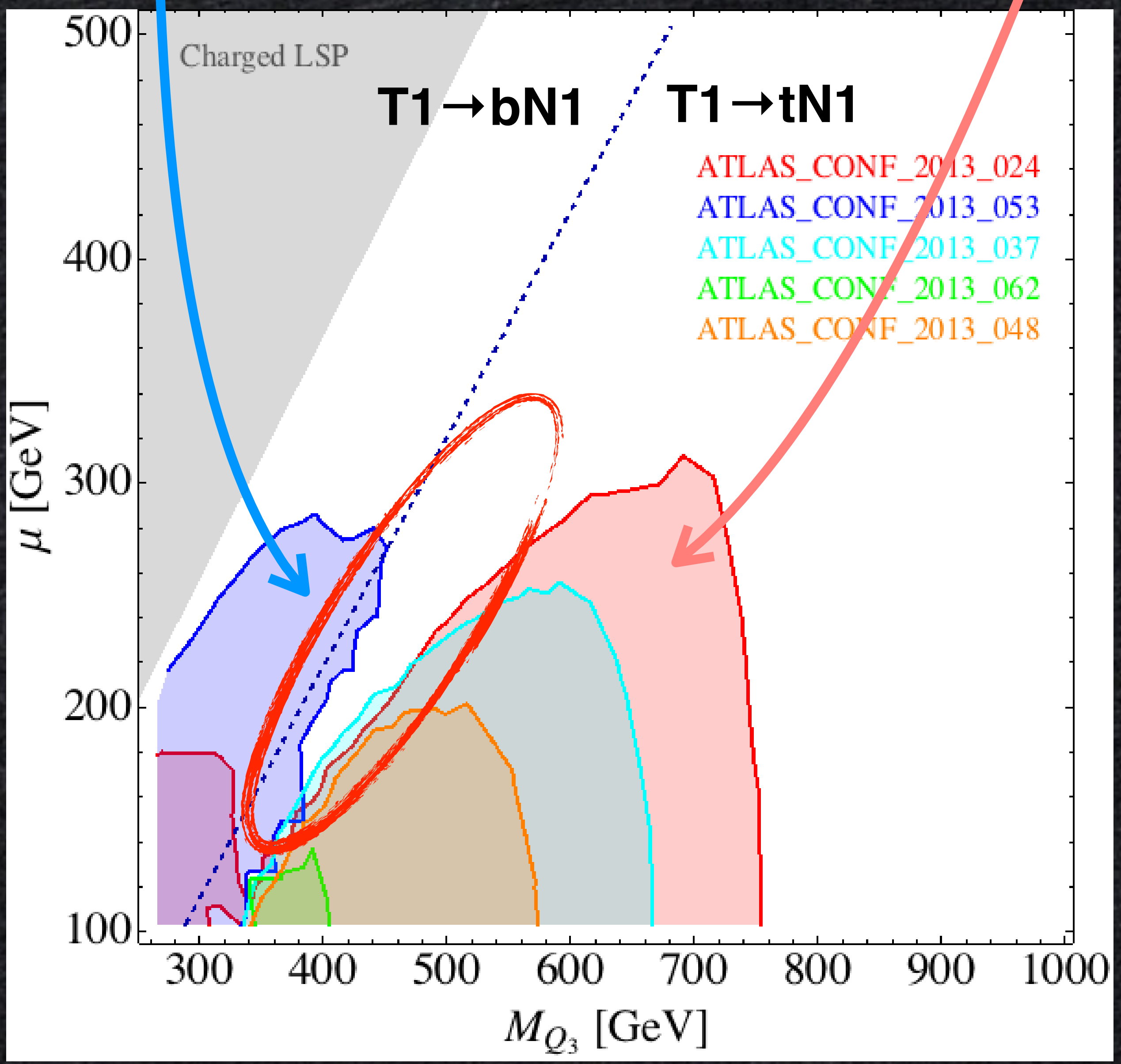
$$\text{coverage} = \frac{\sigma^{\text{implimented}}}{\sigma_{\text{tot}}}$$

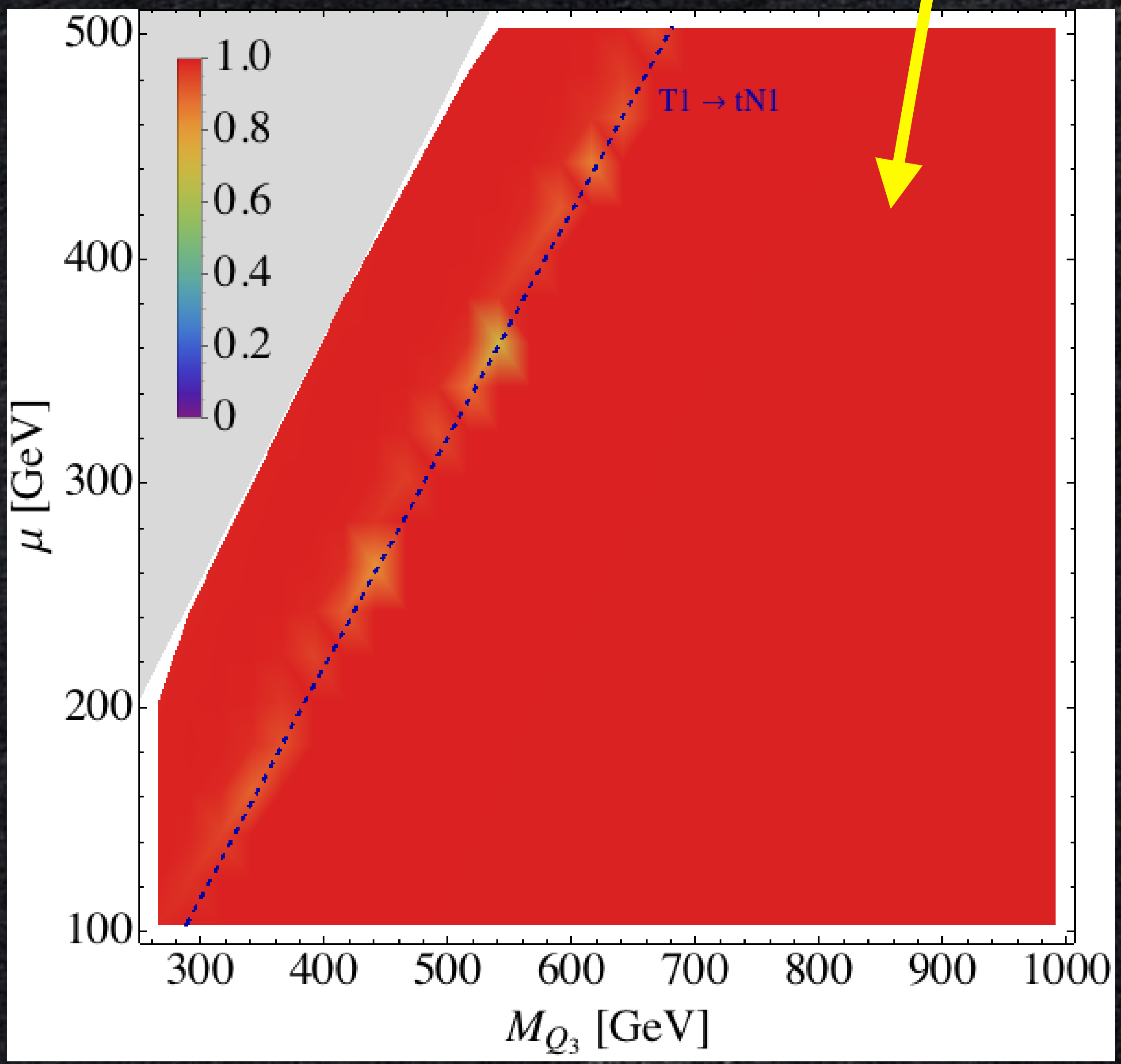
for B1→bN1 topology

designed for T1→tN1 topology

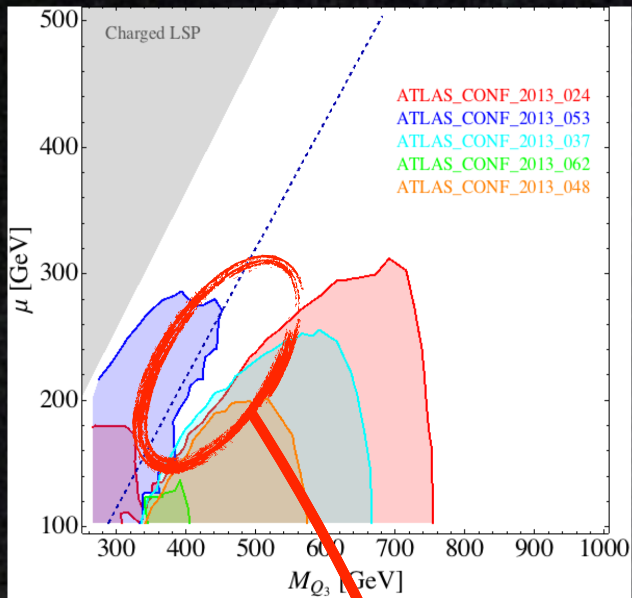
good coverage

$\tan\beta = 10$





M_{Q3} vs tanβ

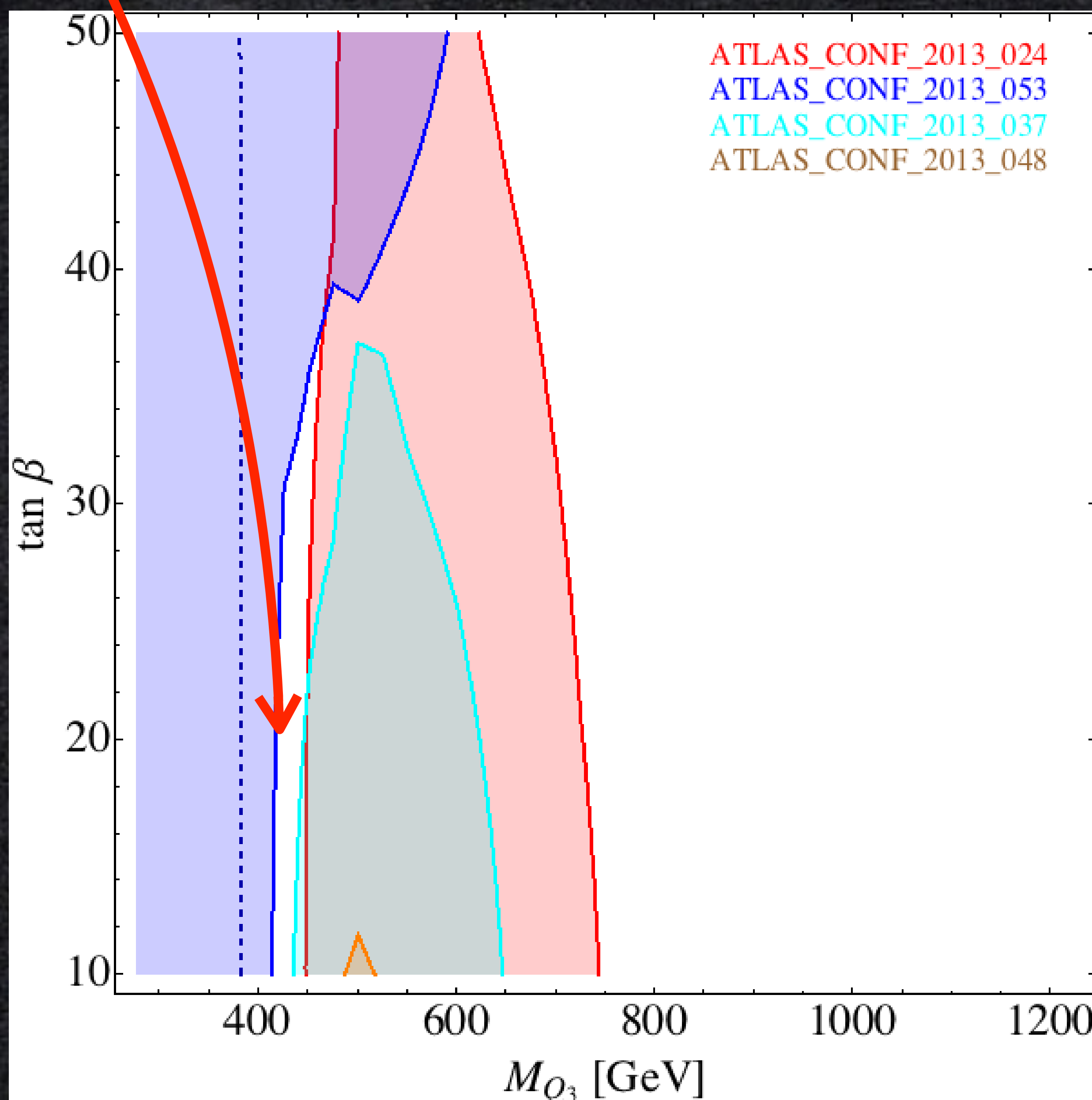


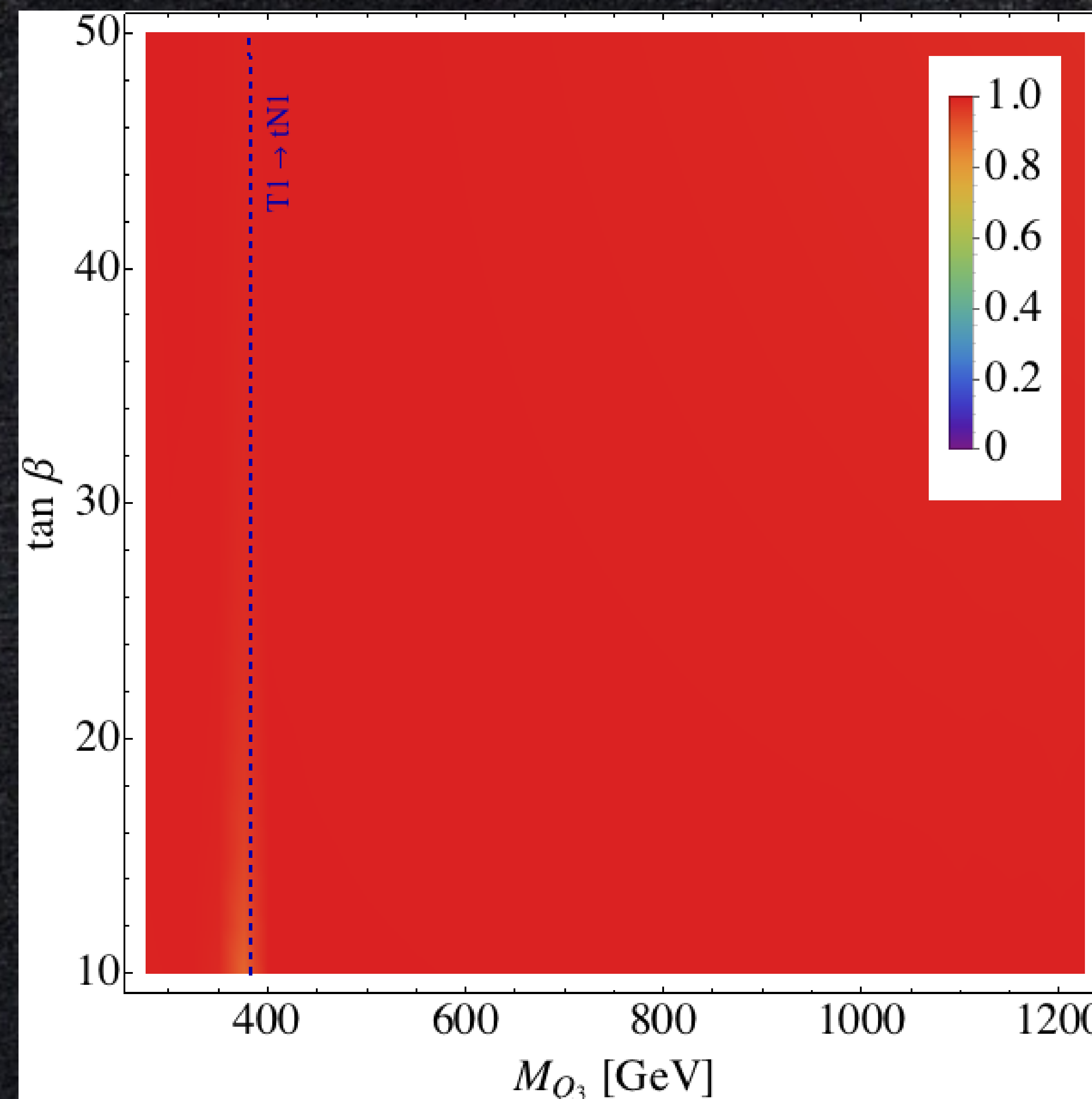
$$\mathcal{L} \supset y_t \cdot t_R \widetilde{Q}_3 \widetilde{H}_u + y_b \cdot b_R \widetilde{Q}_3 \widetilde{H}_d$$

tanβ enhancement

$$\begin{cases} \mathrm{T1} \to b\,\mathrm{C1}\ (\mathrm{C1} \to \mathrm{N1}) \\ \mathrm{B1} \to b\,\mathrm{N1} \end{cases}$$

$\mu = 200\mathrm{GeV}$





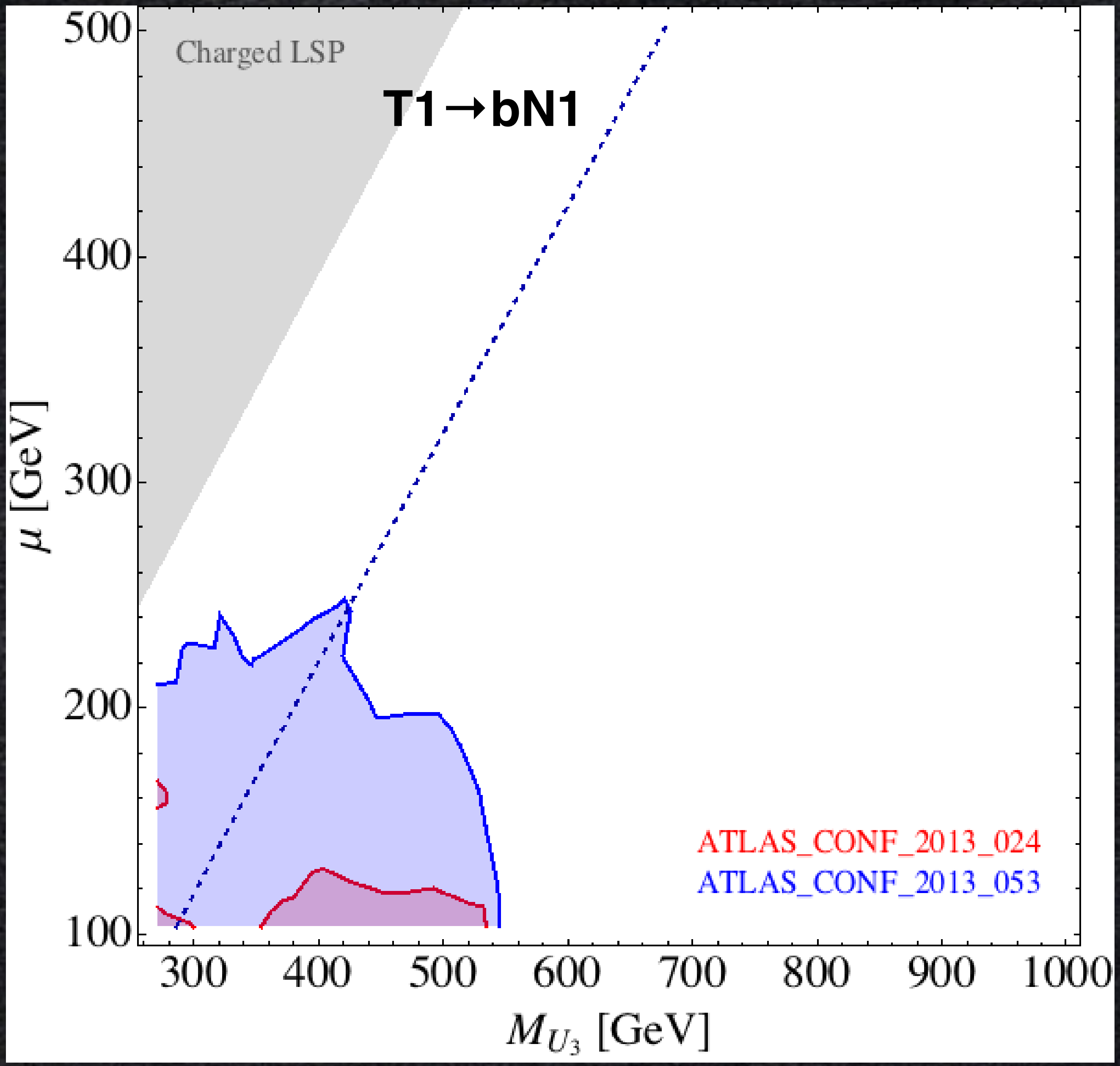
M_{U3} vs μ

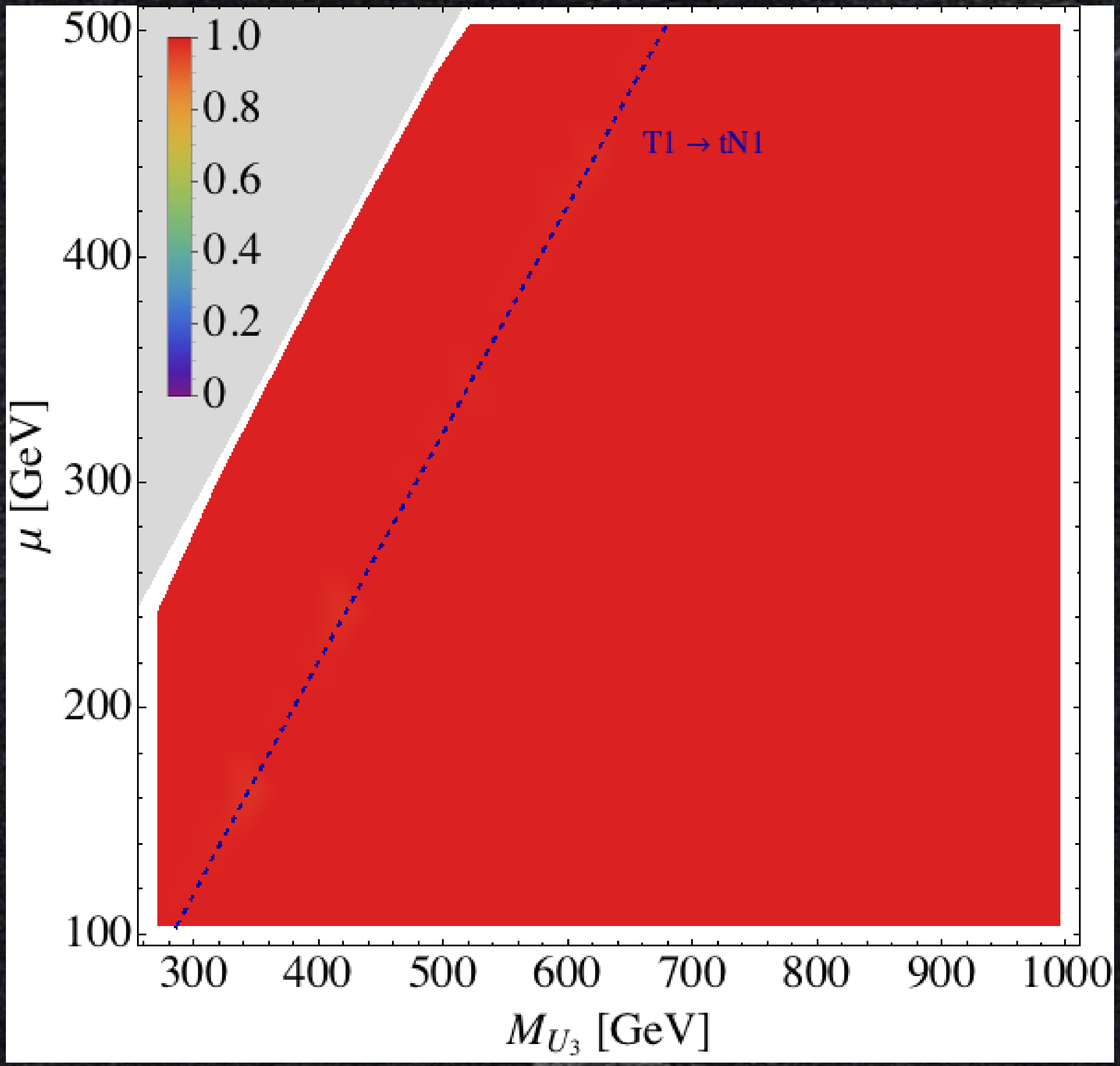
$$\mathcal{L} \supset y_t \cdot \widetilde{t}_R Q_3 \widetilde{H}_u$$

BR(T1bN1_T1tN1) > BR(T1bN1_T1bN1) > BR(T1tN1_T1tN1)

asymmetric topology

$\tan\beta = 10$





M_G vs M_{Q3}

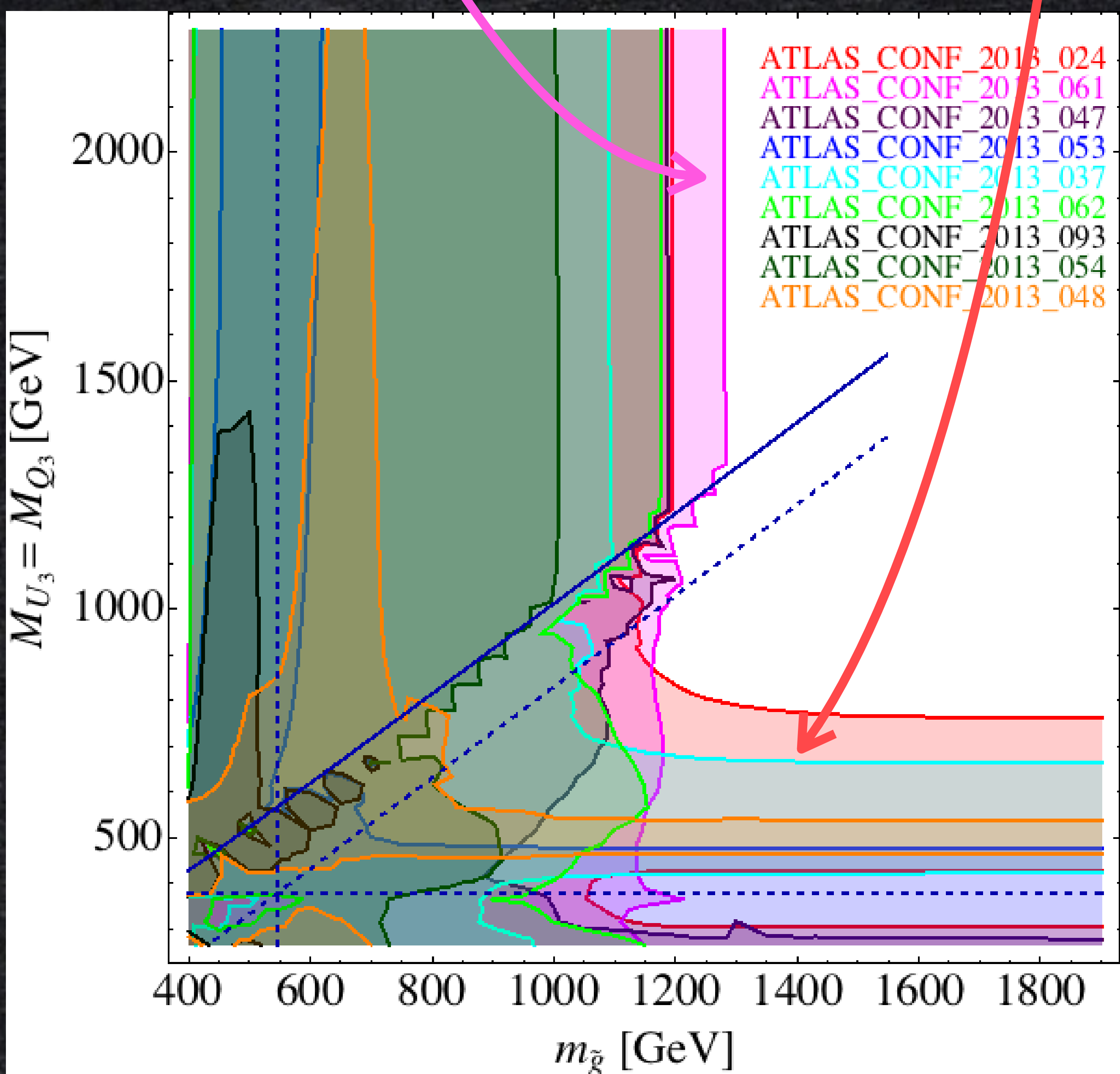
designed for G→ffN1

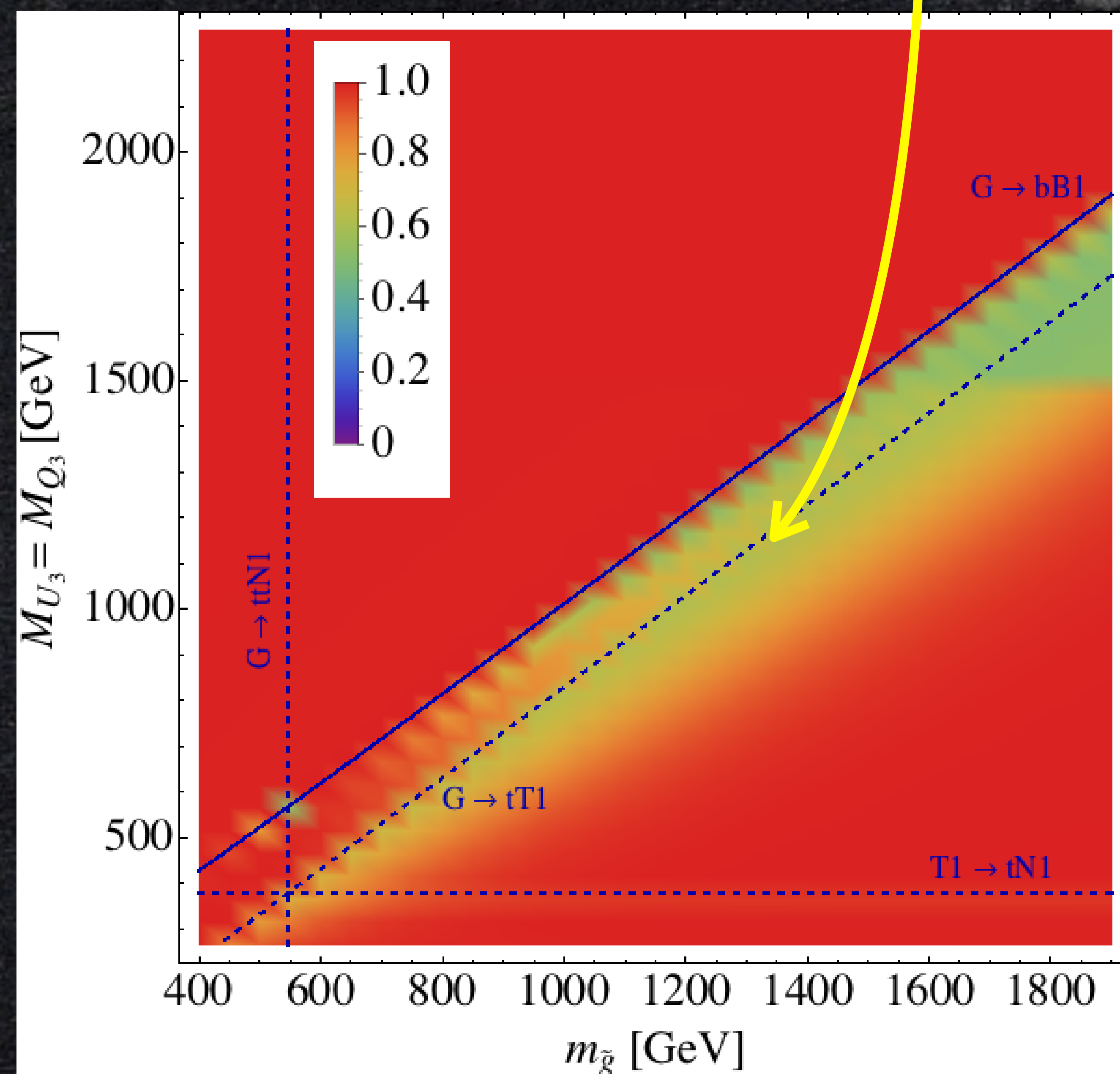
for T1→tN1

T1→qqB1 via W* &

GtT1tN1_GbB1bN1 (4D)

$\mu = 200\mathrm{GeV}$



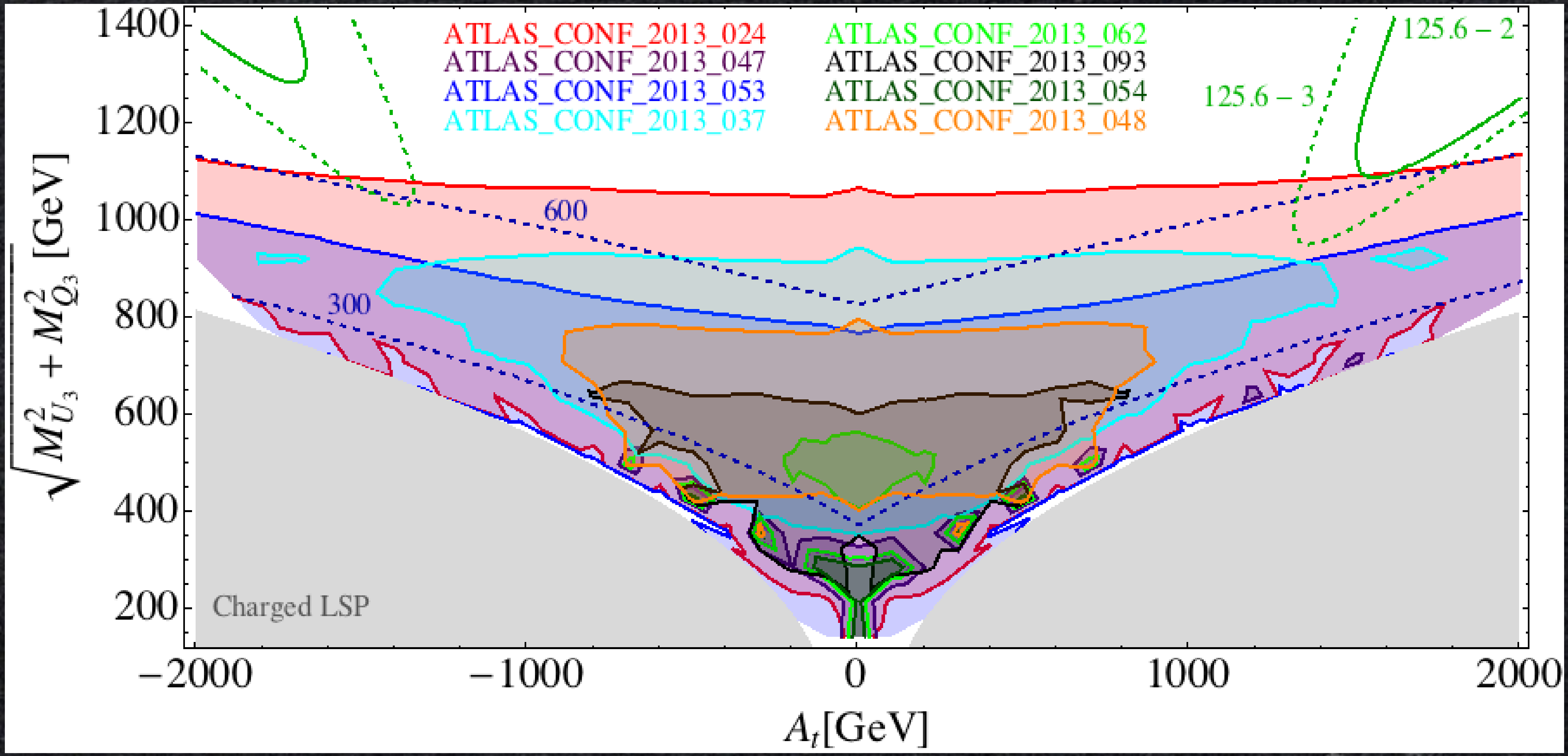


A_t vs $M_{Q,U3}$

- distance from the origin is sensitive to the fine-tuning

$$\Delta m_{H_u}^2 \simeq -\frac{3y_t^2}{8\pi^2}(M_{U_3}^2 + M_{Q_3}^2 + A_t^2)\ln\left(\frac{\Lambda}{m_{\tilde{t}}}\right)$$

$\mu = 100\text{GeV},\ M_{Q_3} = M_{U_3}$

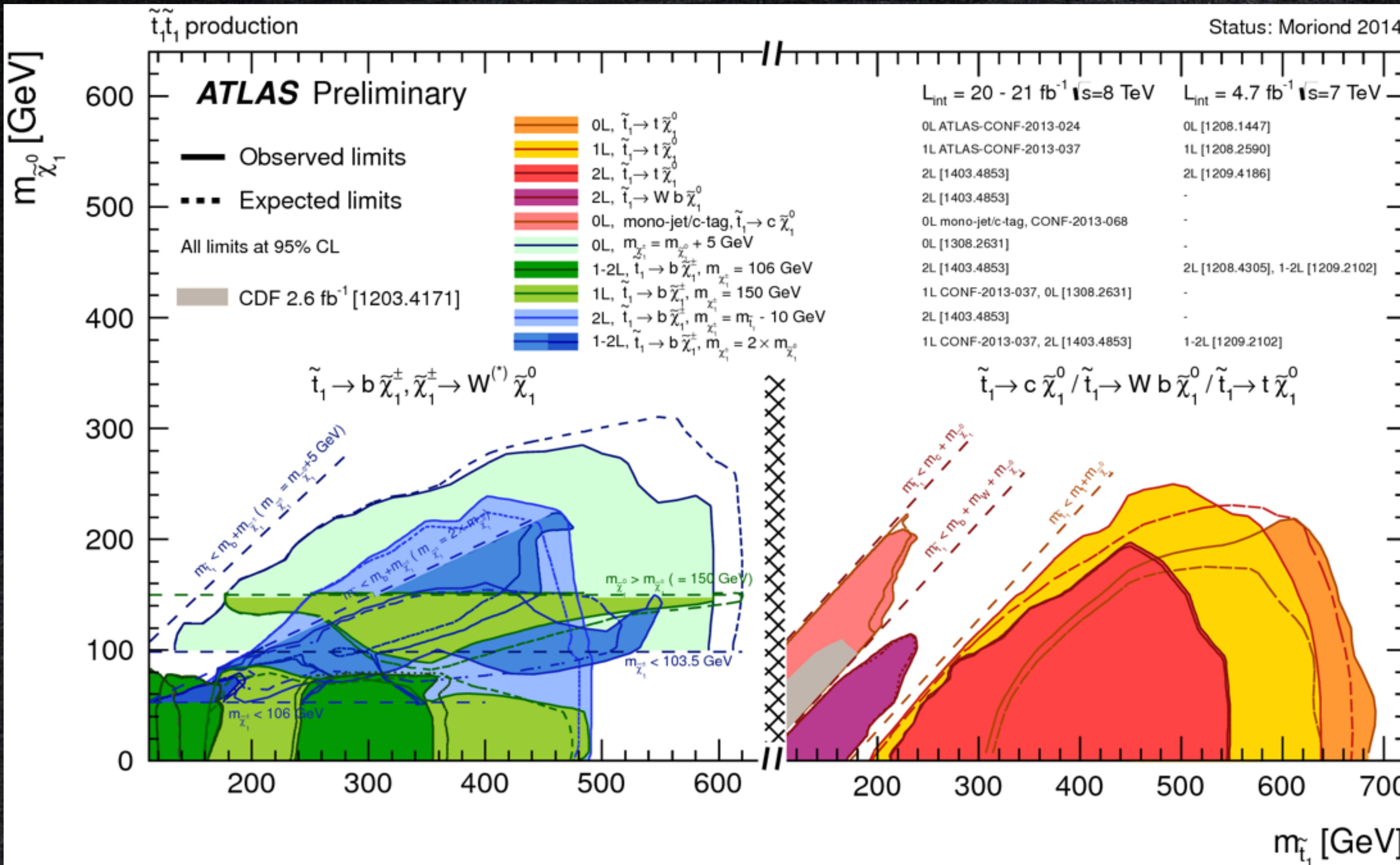


Summary

- It is possible for phenomenologists to test BSM models against the LHC results.
- ATOM follows the standard approach: taking event files as inputs and outputs the efficiency and compute the CLs. (The event generation have to be done separately.)
- Fastlim can skip the event generation. It contains a number of efficiency maps for every topology and SRs. The input is SLHA file and output the CLs directly.

	input	output	application	limit	speed
ATOM:	**event file**	**efficiency**	**any**	**full**	**normal**
Fastlim:	**model file**	N_{BSM}/N_{UL}	**SUSY-like**	**conservative**	**fast**

Backup



$\tilde{t}_1\tilde{t}_1$ production
Status: Moriond 2014
ATLAS Preliminary
Observed limits
Expected limits
All limits at 95% CL
CDF 2.6 fb^{-1} [1203.4171]
L_{int} = 20 - 21 fb^{-1} $\sqrt{s}$=8 TeV
L_{int} = 4.7 fb^{-1} $\sqrt{s}$=7 TeV
0L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ | 0L ATLAS-CONF-2013-024 | 0L [1208.1447]
1L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ | 1L ATLAS-CONF-2013-037 | 1L [1208.2590]
2L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ | 2L [1403.4853] | 2L [1209.4186]
2L, $\tilde{t}_1 \rightarrow W b\tilde{\chi}_1^0$ | 2L [1403.4853] | -
0L, mono-jet/c-tag, $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ | 0L mono-jet/c-tag, CONF-2013-068 | -
0L, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_1^0}$ + 5 GeV | 0L [1308.2631] | -
1-2L, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm}$ = 106 GeV | 2L [1403.4853] | 2L [1208.4305], 1-2L [1209.2102]
1L, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm}$ = 150 GeV | 1L CONF-2013-037, 0L [1308.2631] | -
2L, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{t}_1}$ - 10 GeV | 2L [1403.4853] | -
1-2L, $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, $m_{\tilde{\chi}_1^\pm} = 2 \times m_{\tilde{\chi}_1^0}$ | 1L CONF-2013-037, 2L [1403.4853] | 1-2L [1209.2102]
$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow W^{(*)}\tilde{\chi}_1^0$
$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{t}_1 \rightarrow W b\tilde{\chi}_1^0 / \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
$m_{\tilde{\chi}_1^\pm} > m_{\tilde{\chi}_1^0}$ (= 150 GeV)
$m_{\tilde{\chi}_1^\pm}$ < 103.5 GeV
$m_{\tilde{\chi}_1^\pm}$ < 106 GeV
$m_{\tilde{t}_1} < m_c + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_b + m_W + m_{\tilde{\chi}_1^0}$
$m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]
0
100
200
300
400
500
600
700

SModelS

Sabine Kraml, *et.al*, 2013

- SModelS is a tool to automatically check the simplified model constraints on a given BSM model.