Artificial Model Building

(searching for dispersed signals in the LHC search results)

Wolfgang Waltenberger (ÖAW and Uni Vienna), August 2019

Disclaimer

What I wish to present here, is a proof of principle, no more.

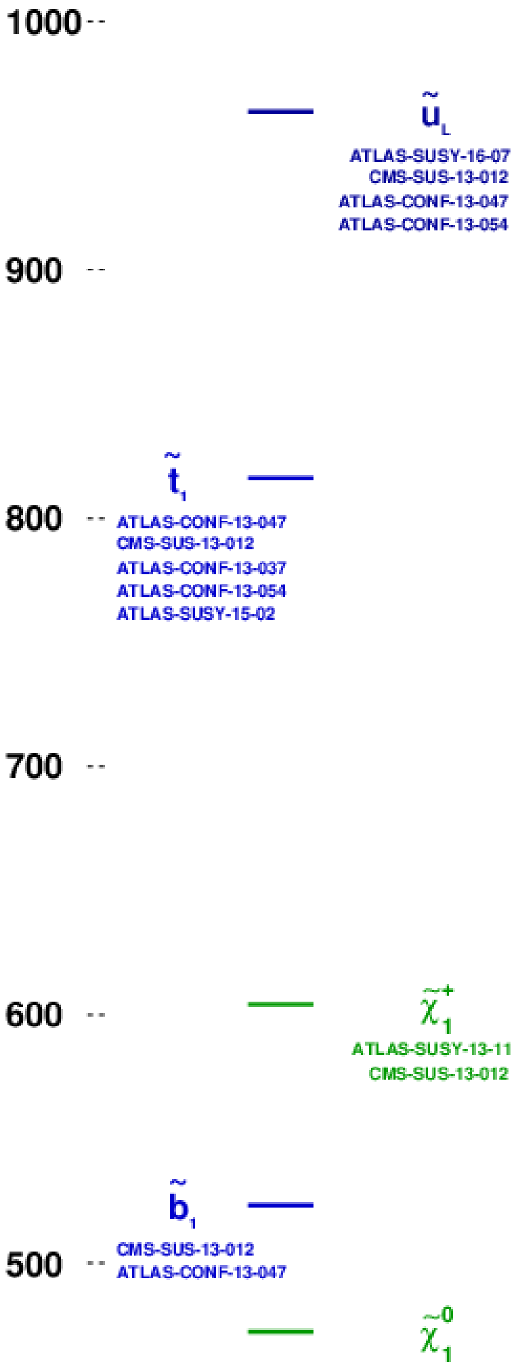
(But hey, I will show running code, that mostly doesn’t crash!)

The bigger philosophy behind this goes as follows:

We have all these hundreds of wonderful LHC results (simplified models results, to be more concrete). Not to mention non-LHC data.

Let’s maximally combine results and data-mine and machine-learn the sh*t out of them!

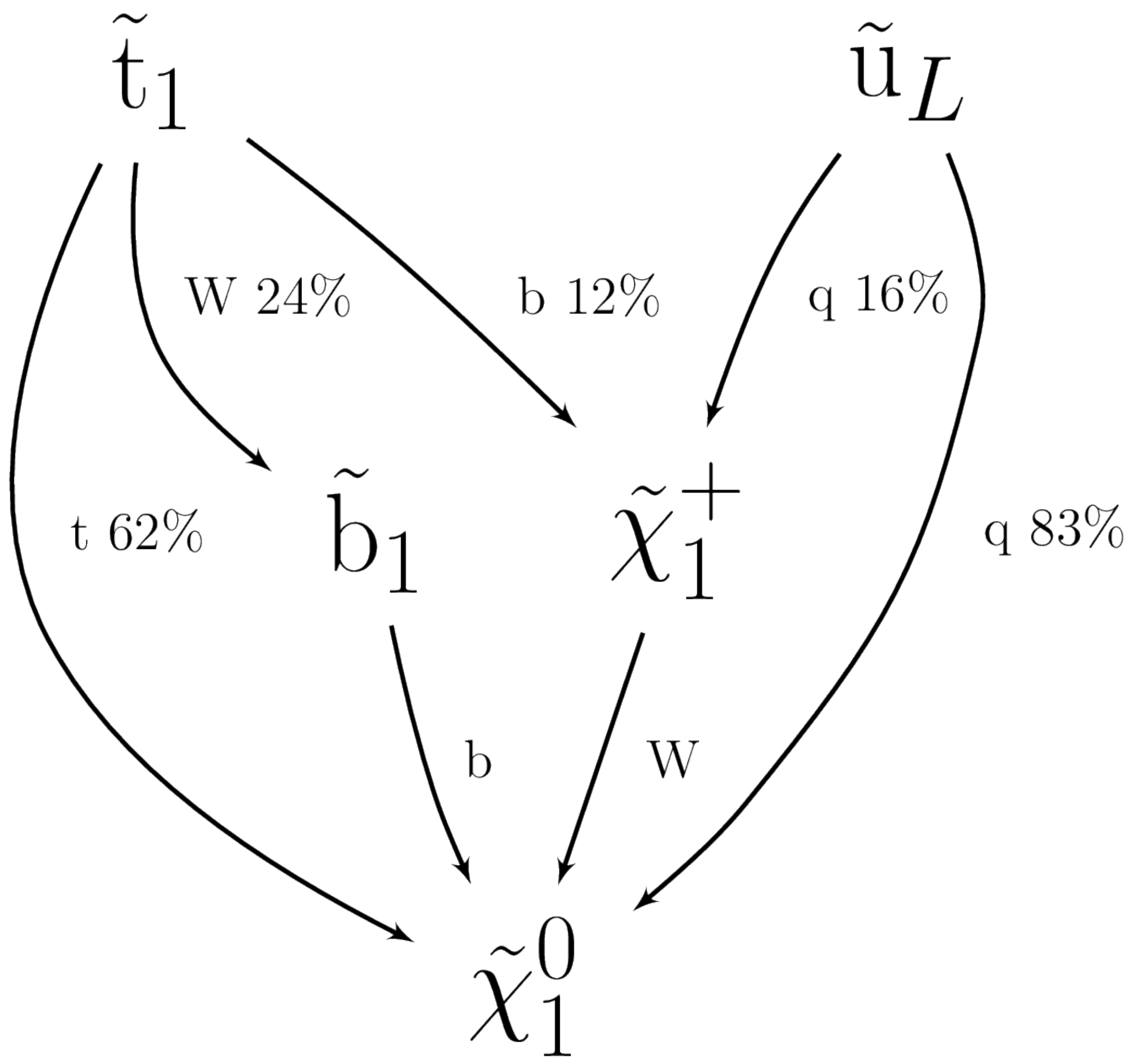
This – I shall claim – is an interesting BSM model



Signal strength multipliers: $\tilde{u}_L = 0.88, \tilde{b}_1 = 1.22, \tilde{t}_1 = 0.74, \tilde{\chi}_1^+ = 1.03$

Contributions by particles: $\tilde{u}_L = 0.76, \tilde{t}_1 = 0.72, \tilde{\chi}_1^+ = 0.08, \tilde{b}_1 = 0.15$

Z=3.25



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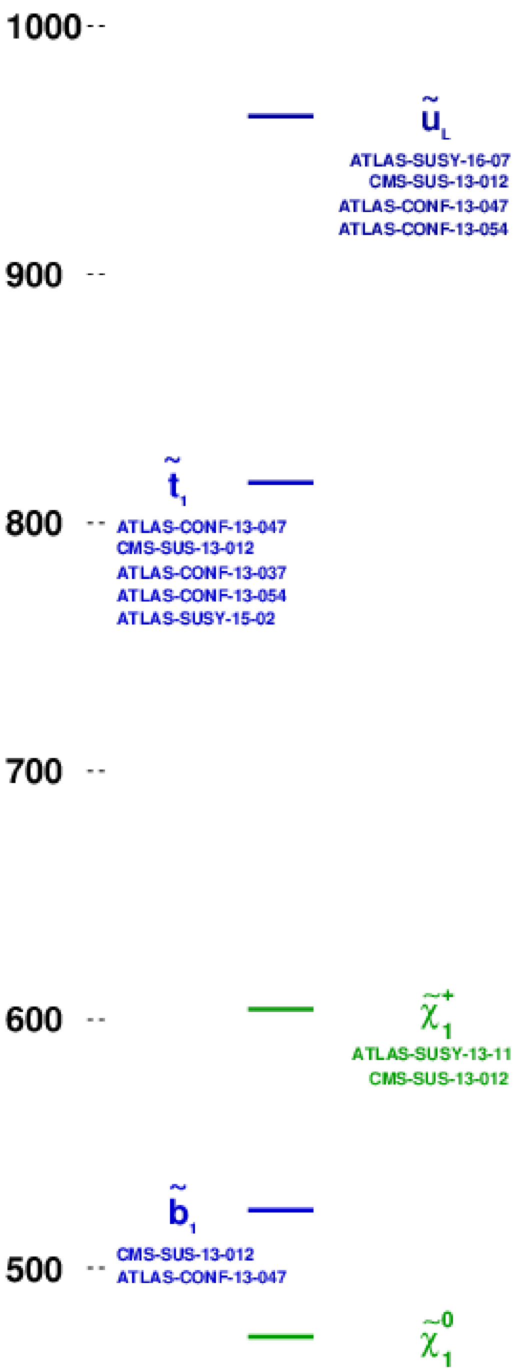

- Dark matter candidate +/- compatible with the WIMP miracle
- Spectrum +/- compatible with natural SUSY (stop < 1 TeV, can accomodate a gluino < 2.5 TeV)

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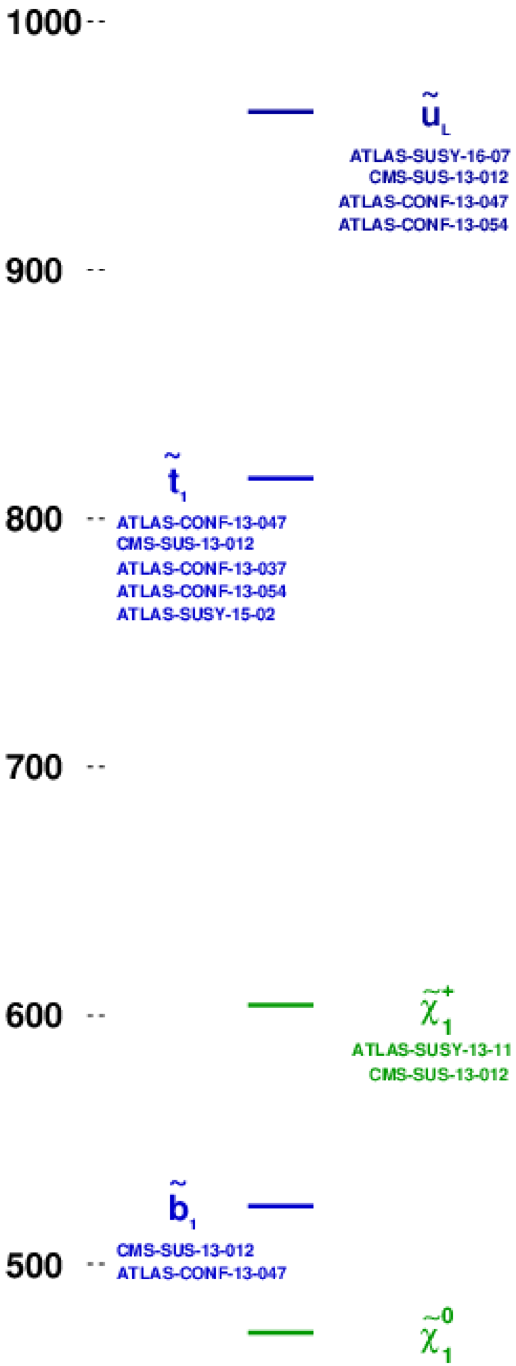

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- Spectrum +/- compatible with natural SUSY
(stop < 1 TeV, can accomodate a gluino < 2.5 TeV)

- 42 SMS results of the SModelS database apply.
None can exclude the model.
With r:= σ(theory)/σ(upper limit),
the highest r values are

  CMS-SUS-16-032:T2bb r=0.56, rexp=N/A
  CMS-SUS-16-036:T2bb r=0.49, rexp=0.29
  CMS-SUS-16-033:T2bb r=0.35, rexp=0.34

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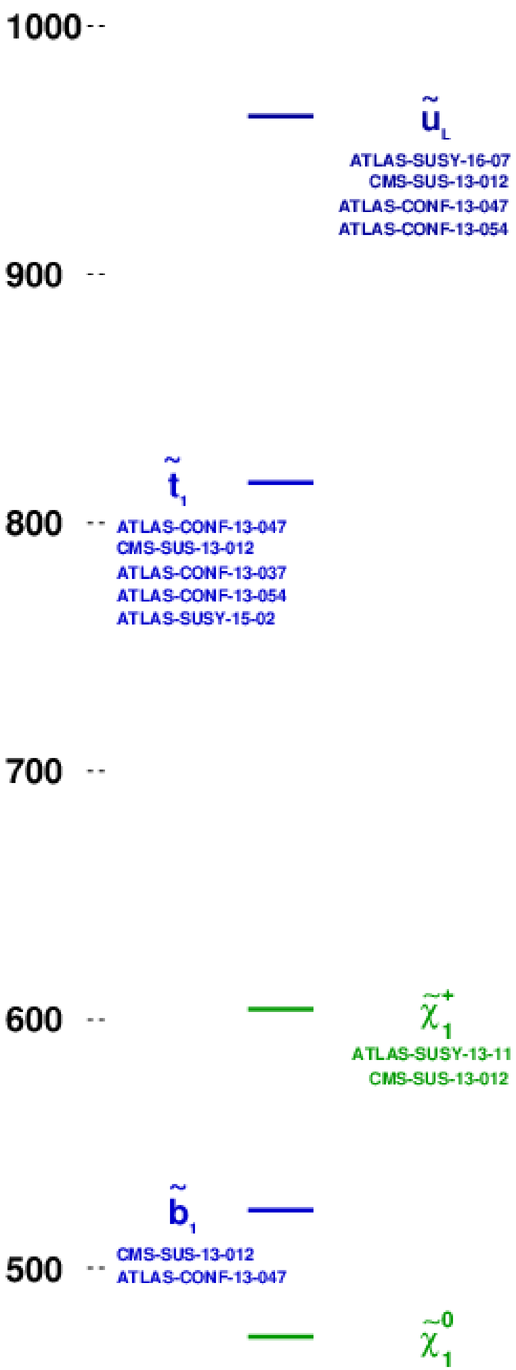

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- Consider that we combine the respective topologies and analyses listed on the left, and treat it as a single BSM model with an overall signal strength μ as the only free parameter. Testing for compatibility with the Standard Model results in a test statistic Z (significance) of 3.25.

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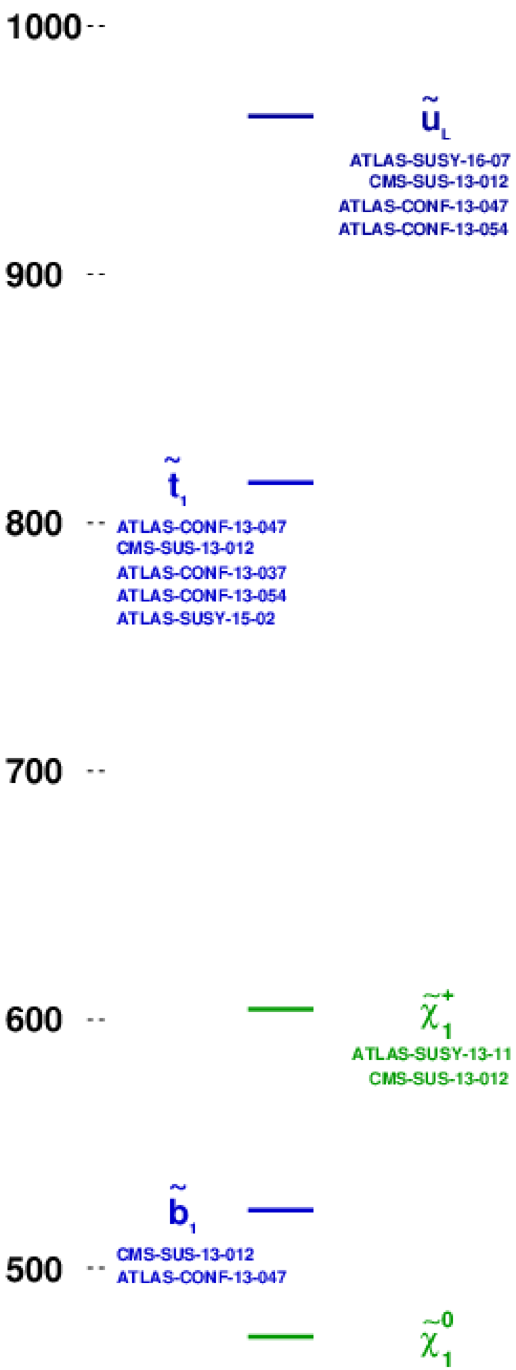


Where does the significance Z come from?

`- ATLAS-SUSY-2015-02:SR1 (EM, T2tt)
nobs: 12, nbg: 5.5 +/- 0.72
`- ATLAS-SUSY-2016-07:2j_Meff_1200 (EM, T2)
nobs: 611.0, nbg: 526.0 +/- 31.0
`- ATLAS-CONF-2013-037:SRtN3 (EM, T2tt)
nobs: 7, nbg: 5.0 +/- 2.0
`- ATLAS-CONF-2013-047:A Medium (EM, T2*)
nobs: 135, nbg: 122.0 +/- 18.0
`- ATLAS-CONF-2013-054:8j50 flavor 0 b-jets (EM, T2*)
nobs: 40, nbg: 35.0 +/- 4.0
`- ATLAS-SUSY-2013-11:WWc-DF (EM, TChiWW)
nobs: 11, nbg: 9.0 +/- 2.2
`- CMS-SUS-13-012:3NJet6_1000HT1250_600MHTinf (EM, many)
nobs: 32, nbg: 22.8 +/- 5.2

(In that run we didn't produce "likelihoods from limits" → only efficiency-map based results)

How was this model constructed?

How was this model constructed?

Two new components on top of SModelS:

- An analysis combiner algorithm that finds the optimal “legal” combination of analysis results.

- In this talk, “optimal” means “maximizing the significance Z while evading all exclusions”. Other criteria can however be employed (finding BSM models that are interesting in a different way).
- Different choices of what are “legal” combinations are possible. In this talk I am using “aggressive” combination: signal regions must be clearly distinct. Control regions are ignored.

- A “model builder” that randomly constructs BSM models in a Metropolis-Hastings-like fashion.

- The walker starts from the Standard Model
- It may randomly introduce and “kill” BSM particles.
- It may randomly change masses of particles.
- It may randomly change branching ratios.
- The cross section is computed as if it were a SUSY model. However, the walker may randomly change particle-specific signal strength modifiers that are applied to the computed cross sections.
- A neural network the learns to predict the “score” of the combiner, and then uses the gradient of the score instead of a random step may speed things up.

SModelS database

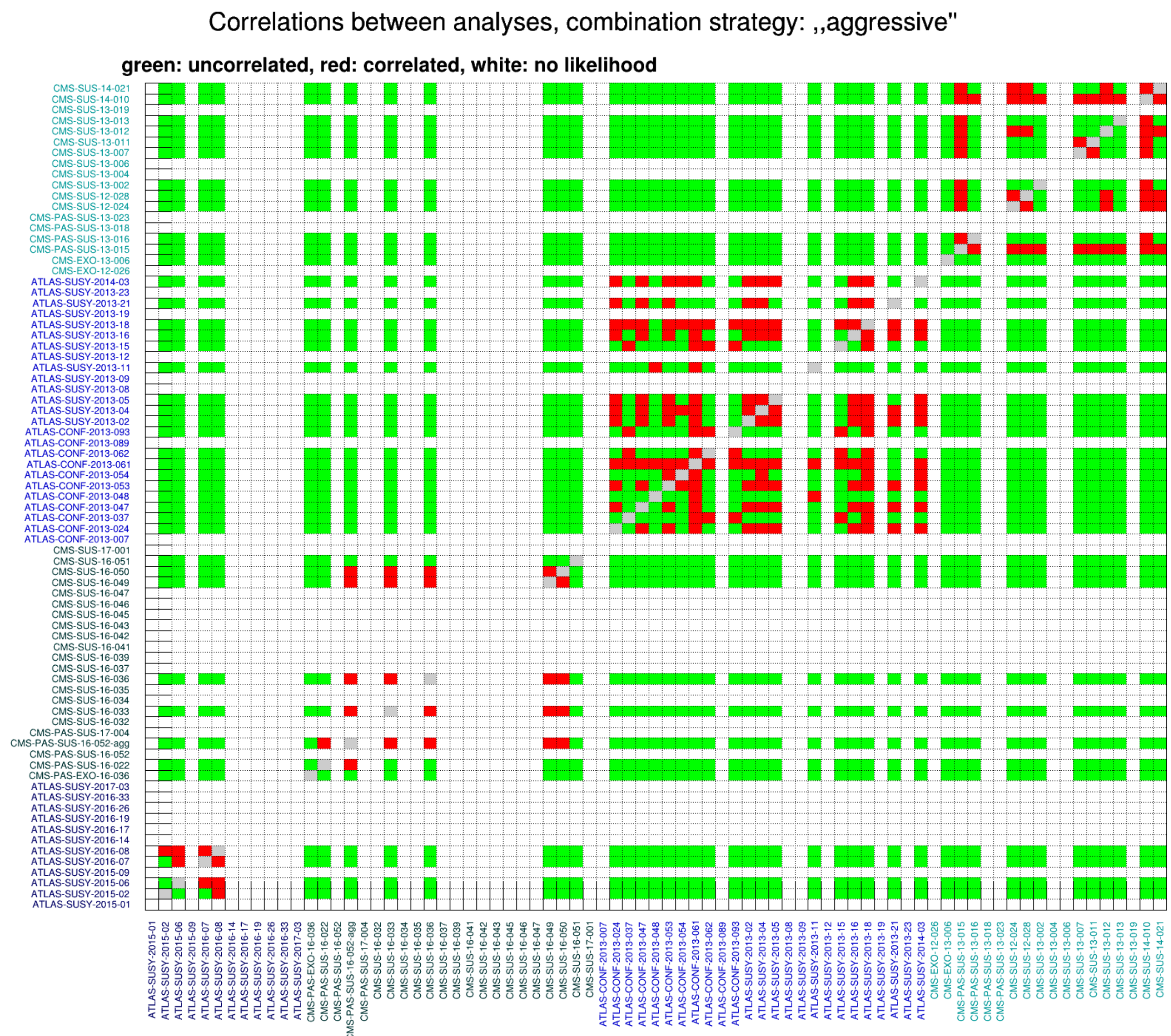
#	ID	pretty name	Topologies	Type	$\mathcal{L}$ [fb^{-1}]
1	ATLAS-SUSY-2015-01	2 b-jets + $\not{E}_T$	1: T2bb	ul	3.2
2	ATLAS-SUSY-2015-02	single l stop	1: T2tt	ul	3.2
	ATLAS-SUSY-2015-02	single l stop	1: T2tt	eff	3.2
3	ATLAS-SUSY-2015-06	0 l's + 2-6 jets + $\not{E}_T$	2: T1, T2	eff	3.2
4	ATLAS-SUSY-2015-09	jets + 2 SS l's or >=3 l's	1: T1tttt	ul	3.2
5	ATLAS-SUSY-2016-14	2 SS or 3 l's + jets + $\not{E}_T$	3: T1tt[off]tt, T1tttt[off]...	ul	36.1
6	ATLAS-SUSY-2016-17	2 opposite sign l's + $\not{E}_T$	2: T2bbWW[off], T2tt[off]...	ul	36.1
7	ATLAS-SUSY-2016-19	stops to staus	1: T4bnutaubnutau...	ul	36.1
8	ATLAS-SUSY-2016-26	>=2 c jets + $\not{E}_T$	1: T2cc	ul	36.1
9	ATLAS-SUSY-2016-33	2 OSSF l's + $\not{E}_T$	2: T5ZZ, T6ZZ	ul	36.1
10	ATLAS-SUSY-2017-03	multi-l EWK searches	1: TChiWZ	ul	36.1
11	ATLAS-CONF-2012-105	2 SS l's + >= 4 jets + $\not{E}_T$	1: T1tttt	ul	5.8
12	ATLAS-CONF-2012-166	1 l + 4(1 b-)jets + $\not{E}_T$	1: T2tt	ul	13.0
13	ATLAS-CONF-2013-001	0 l's + 2 b-jets + $\not{E}_T$	1: T6bbWW[off]	ul	12.8
14	ATLAS-CONF-2013-007	2 SS l's + 0-3 b-jets + $\not{E}_T$	4: T1btbt, T1tttt...	ul	20.7
15	ATLAS-CONF-2013-024	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	ul	20.5
	ATLAS-CONF-2013-024	0 l + 6 (2 b-)jets + $\not{E}_T$	21: T1bbbb, T1bbbt...	eff	20.5
16	ATLAS-CONF-2013-025	>= 5 (>=1 b-)jets + 2, 3 SFOS l's + $\not{E}_T$	1: T6ZZtt	ul	20.7
17	ATLAS-CONF-2013-035	3 l's (e,mu) + $\not{E}_T$	2: TChiChipmSlepL...	ul	20.7
18	ATLAS-CONF-2013-037	1 l + >= 4(1 b-)jets + $\not{E}_T$	1: T2tt	ul	20.7
	ATLAS-CONF-2013-037	1 l + >= 4(1 b-)jets + $\not{E}_T$	18: T1bbbb, T1bbbt...	eff	20.7
19	ATLAS-CONF-2013-047	0 l's + 2-6 jets + $\not{E}_T$	3: T1, T5WW[off]...	ul	20.3
	ATLAS-CONF-2013-047	0 l's + 2-6 jets + $\not{E}_T$	24: T1, T1bbbb, T1bbbt...	eff	20.3
20	ATLAS-CONF-2013-048	2 l's + (b-)jets + $\not{E}_T$	2: T2bbWW, T6bbWW[off]...	ul	20.3
	ATLAS-CONF-2013-048	2 l's + (b)jets + $\not{E}_T$	11: T1bbtt, T1btbt...	eff	20.3
21	ATLAS-CONF-2013-049	2 l's (e,mu) + $\not{E}_T$	1: TSlepSlep	ul	20.3
22	ATLAS-CONF-2013-053	0 l's + 2 b-jets + $\not{E}_T$	1: T2bb	ul	20.1
	ATLAS-CONF-2013-053	0 l's + 2 b-jets + $\not{E}_T$	17: T1bbbb, T1bbbt...	eff	20.1
23	ATLAS-CONF-2013-054	0 l's + >= 7-10 jets + $\not{E}_T$	24: T1, T1bbbb, T1bbbt...	eff	20.3
24	ATLAS-CONF-2013-061	jets + >= 3 b-jets + $\not{E}_T$	3: T1bbbb, T1btbt...	ul	20.1
	ATLAS-CONF-2013-061	jets + >= 3 b-jets + $\not{E}_T$	21: T1bbbb, T1bbbt...	eff	20.1
25	ATLAS-CONF-2013-062	1 l + jets + $\not{E}_T$	21: T1, T1bbbb, T1bbbt...	eff	20.3
26	ATLAS-CONF-2013-065	2 l's + (b-)jets + $\not{E}_T$	2: T2tt, T6bbWW	ul	20.3
27	ATLAS-CONF-2013-089	2 l's (e,mu) + $\not{E}_T$	1: T6WW	ul	20.3
28	ATLAS-CONF-2013-093	1 l + 2 b-jets + $\not{E}_T$	1: TChiWH	ul	20.3
	ATLAS-CONF-2013-093	1 l + 2 b-jets + $\not{E}_T$	6: T1bbbt, T2bt, T2tt...	eff	20.3
29	ATLAS-SUSY-2013-02	0 l's + 2-6 jets + $\not{E}_T$	5: T1, T2, T5WW[off]...	ul	20.3
	ATLAS-SUSY-2013-02	jets and met	4: T1, T2, T3GQ, T5...	eff	20.3
30	ATLAS-SUSY-2013-04	0 l's + >= 7-10 jets + $\not{E}_T$	1: T1tttt	ul	20.3
	ATLAS-SUSY-2013-04	0 l's + >= 7-10 jets + $\not{E}_T$	8: T1bbbb, T1btbt...	eff	20.3
31	ATLAS-SUSY-2013-05	0 l's + 2 b-jets + $\not{E}_T$	2: T2bb, T6bbWW[off]...	ul	20.1
	ATLAS-SUSY-2013-05	0 l's + 2 b-jets + $\not{E}_T$	1: T2bb	eff	20.1
32	ATLAS-SUSY-2013-08	Z + b-jets + $\not{E}_T$	1: T6ZZtt	ul	20.3
33	ATLAS-SUSY-2013-09	2 SS l's + $\not{E}_T$	1: T1tttt	ul	20.3
34	ATLAS-SUSY-2013-11	2 l's (e,mu) + $\not{E}_T$	4: TChiWW, TChiWZ...	ul	20.3
	ATLAS-SUSY-2013-11	2 l's (e,mu) + $\not{E}_T$	3: TChiWW[off], TChipChimSlepSnu...	eff	20.3
35	ATLAS-SUSY-2013-12	3 l's (e,mu,tau) + $\not{E}_T$	4: TChiChipmSlepL...	ul	20.3
36	ATLAS-SUSY-2013-15	1 l + 4 (1 b-)jets + $\not{E}_T$	1: T2tt	ul	20.3
	ATLAS-SUSY-2013-15	1 l + 4 (1 b-)jets + $\not{E}_T$	1: T2tt	eff	20.3
37	ATLAS-SUSY-2013-16	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	ul	20.1
	ATLAS-SUSY-2013-16	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	eff	20.1
38	ATLAS-SUSY-2013-18	0-1 l's + >= 3 b-jets + $\not{E}_T$	2: T1bbbb, T1tttt...	ul	20.1
	ATLAS-SUSY-2013-18	0-1 l's + >= 3 b-jets + $\not{E}_T$	2: T1bbbb, T1tttt...	eff	20.1
39	ATLAS-SUSY-2013-19	2 OS l's + (b-)jets + $\not{E}_T$	2: T2bbWW, T2tt	ul	20.3
40	ATLAS-SUSY-2013-21	monojet or c-jet + $\not{E}_T$	3: T2bb, T2bbWW[off]...	eff	20.3
41	ATLAS-SUSY-2013-23	1 l + 2 b-jets (or 2 γs) + $\not{E}_T$	1: TChiWH	ul	20.3
42	ATLAS-SUSY-2014-03	>= 2(c-)jets + $\not{E}_T$	1: TScharm	eff	20.3

#	ID	pretty name	Topologies	Type	$\mathcal{L}$ [fb^{-1}]	$\sqrt{s}$
1	CMS-PAS-EXO-16-036	hscp search	3: THSCPM1b, TRHadGM1...	ul	12.9	13
	CMS-PAS-EXO-16-036	hscp search	8: THSCPM1b, THSCPM2b...	eff	12.9	13
2	CMS-PAS-SUS-15-002	>= 4jets + $\not{E}_T$, HT, HTmiss	2: T1, T1bbbb	ul	2.2	13
3	CMS-PAS-SUS-16-014	jets + $\not{E}_T$, HT	6: T1, T1bbbb, T1tttt[off]...	ul	12.9	13
4	CMS-PAS-SUS-16-015	jets + $\not{E}_T$, MT2	6: T1, T1bbbb, T1tttt[off]...	ul	12.9	13
5	CMS-PAS-SUS-16-016	>= 1 jet + $\not{E}_T$, α_T	4: T1bbbb, T1tttt[off]...	ul	12.9	13
6	CMS-PAS-SUS-16-019	jets + 1 l	1: T1tttt[off]	ul	12.9	13
7	CMS-PAS-SUS-16-022	>= 3 l's + $\not{E}_T$	1: T1tttt[off]	ul	12.9	13
8	CMS-PAS-SUS-16-052	soft l, <= 2 jets	2: T2bbWW[off], T6bbWW[off]...	ul	35.9	13
9	CMS-PAS-SUS-16-052-agg	soft l, <= 2 jets	2: T2bbWW[off], T6bbWW[off]...	eff	35.9	13
10	CMS-PAS-SUS-17-004	multi-l EWK searches	2: TChiWH, TChiWZ[off]...	ul	35.9	13
11	CMS-SUS-15-002	multijets + $\not{E}_T$, HT	3: T1, T1bbbb, T1tttt[off]...	ul	2.2	13
12	CMS-SUS-15-008	SS dil	1: T1tttt[off]	ul	2.3	13
13	CMS-SUS-16-032	Sbottom and compressed stop	2: T2bb, T2cc	ul	35.9	13
14	CMS-SUS-16-033	0L + jets + $\not{E}_T$	6: T1, T1bbbb, T1tttt[off]...	ul	35.9	13
15	CMS-SUS-16-034	2 OSSF l's	2: T5ZZ, TChiWZ	ul	35.9	13
16	CMS-SUS-16-035	2 SS l's	7: T1tttt[off], T5WW[off]...	ul	35.9	13
17	CMS-SUS-16-036	0L + jets + $\not{E}_T$	8: T1, T1bbbb, T1tttt[off]...	ul	35.9	13
18	CMS-SUS-16-037	1L + jets + $\not{E}_T$ with MJ	3: T1tttt[off], T5tt[off]tt...	ul	35.9	13
19	CMS-SUS-16-039	multi-l EWK searches	5: TChiChipmSlepL...	ul	35.9	13
20	CMS-SUS-16-041	multi-ls + jets + $\not{E}_T$	6: T1tttt[off], T6HHtt...	ul	35.9	13
21	CMS-SUS-16-042	1L + jets + $\not{E}_T$	2: T1tttt[off], T5WW[off]...	ul	35.9	13
22	CMS-SUS-16-043	EWK WH	1: TChiWH	ul	35.9	13
23	CMS-SUS-16-045	Sbottom to bHbH and H $\rightarrow \gamma\gamma$	2: T6bbHH, TChiWH...	ul	35.9	13
24	CMS-SUS-16-046	γ + $\not{E}_T$	2: T5gg, T6gg	ul	35.9	13
25	CMS-SUS-16-047	γ + HT	2: T5gg, T6gg	ul	35.9	13
26	CMS-SUS-16-049	All hadronic stop	4: T2cc, T2ttC, T2tt[off]...	ul	35.9	13
27	CMS-SUS-16-050	0L + top tag	4: T1tttt[off], T2tt[off]...	ul	35.9	13
28	CMS-SUS-16-051	1L stop	2: T2tt[off], T6bbWW...	ul	35.9	13
29	CMS-SUS-17-001	Stop search in dil + jets + $\not{E}_T$	2: T2tt[off], T6bbWW...	ul	35.9	13
30	CMS-EXO-12-026	hscp search	3: THSCPM1b, TRHadGM1...	ul	18.8	8
31	CMS-EXO-13-006	hscp search	8: THSCPM1b, THSCPM2b...	eff	18.8	8
32	CMS-PAS-SUS-12-022	multi-l + $\not{E}_T$	6: TChiChipmSlepL...	ul	9.2	8
33	CMS-PAS-SUS-12-026	>= 3 l's (+jets) + $\not{E}_T$	1: T1tttt	ul	9.2	8
34	CMS-PAS-SUS-13-015	>= 5(1b-)jets + $\not{E}_T$	1: T2tt[off]	eff	19.4	8
35	CMS-PAS-SUS-13-016	2 OS l's + >= 4 (2 b-)jets + $\not{E}_T$	1: T1tttt[off]	ul	19.7	8
	CMS-PAS-SUS-13-016	2 OS l's + >= 4 (2b-)jets + $\not{E}_T$	1: T1tttt[off]	eff	19.7	8
36	CMS-PAS-SUS-13-018	1-2 b-jets + $\not{E}_T$, M_CT	1: T2bb	ul	19.4	8
37	CMS-PAS-SUS-13-023	hadronic stop	2: T2tt[off], T6bbWW[off]...	ul	18.9	8
38	CMS-PAS-SUS-14-011	razor with b-jets	3: T1bbbb, T1tttt[off]...	ul	19.3	8
39	CMS-SUS-12-024	0 l's + >= 3 (1b-)jets + $\not{E}_T$	1: T1tttt[off]	ul	19.4	8
	CMS-SUS-12-024	0 l's + >= 3 (1b-)jets + $\not{E}_T$	2: T1bbbb, T1tttt[off]...	eff	19.4	8
40	CMS-SUS-12-028	jets + $\not{E}_T$, α_T	5: T1, T1bbbb, T1tttt...	ul	11.7	8
41	CMS-SUS-13-002	>= 3 l's (+jets) + $\not{E}_T$	1: T1tttt	ul	19.5	8
42	CMS-SUS-13-004	>= 1 b-jet + $\not{E}_T$, Razor	3: T1bbbb, T1tttt[off]...	ul	19.3	8
43	CMS-SUS-13-006	EW prod. to l's, W, Z, and H	5: TChiChipmSlepL...	ul	19.5	8
44	CMS-SUS-13-007	1 l + >= 2 b-jets + $\not{E}_T$	2: T1tttt[off], T5tttt...	ul	19.3	8
	CMS-SUS-13-007	1 l + >= 2 b-jets + $\not{E}_T$	1: T1tttt[off]	eff	19.3	8
45	CMS-SUS-13-011	1 l + >= 4 (1b-)jets + $\not{E}_T$	2: T2tt[off], T6bbWW[off]...	ul	19.5	8
	CMS-SUS-13-011	1 l + >= 4 (1b-)jets + $\not{E}_T$	1: T2tt[off]	eff	19.5	8
46	CMS-SUS-13-012	n_{jets} + HTmiss	3: T1, T1tttt[off]...	ul	19.5	8
	CMS-SUS-13-012	n_{jets} + HTmiss	19: T1, T1bbbb, T1btbt...	eff	19.5	8
47	CMS-SUS-13-013	2 SS l's + (b-)jets + $\not{E}_T$	2: T1tttt[off], T6ttWW[off]...	ul	19.5	8
	CMS-SUS-13-013	2 SS l's + (b-)jets + $\not{E}_T$	1: T1tttt[off]	eff	19.5	8
48	CMS-SUS-13-019	>= 2 jets + $\not{E}_T$, MT2	6: T1, T1bbbb, T1tttt[off]...	ul	19.5	8
49	CMS-SUS-14-010	b-jets + 4 Ws	1: T1tttt[off]	ul	19.5	8
50	CMS-SUS-14-021	soft l's, low n_{jets}, high $\not{E}_T$	1: T2bbWW[off]	ul	19.7	8

The current database consists of almost 50 CMS and almost 50 ATLAS results.

https://smodels.github.io/docs/ListOfAnalyses

Combination of analyses



Joint likelihoods for combining analyses

many pairs of analyses can be treated as approximately uncorrelated in the "aggressive combination" scheme
(the green blocks, think e.g. of a 8 TeV ATLAS result and a 13 TeV CMS result)

Started a Les Houches project to systematically study correlations between analyses: https://phystev.cnrs.fr/wiki/2019:groups:tools:correlations

Combination of analyses

The Z score

- finds optimal combinations of analyses, combinability given by matrix in slide before
- if a result can be added to a combination, it *has to be* added.
- will implement different criteria for what is considered “optimal”. In this talk, optimal means, it finds the combination that maximally falsifies the standard model hypothesis in a likelihood ratio test.

$$T = -2 \ln \frac{\mathrm{H}_{\mathrm{SM}}}{\sup\{\mathrm{H}_{\mathrm{BSM}}(\mu) : \mu \in \mathbb{R}^+\}}, Z = \sqrt{T}$$

So we optimize for the test statistic of the hypothesis test, where the standard model is the null hypothesis and the BSM model is the alternative hypothesis with an overall signal strength multiplier as the only free parameter. That way Neyman-Pearson Lemma holds, at least in principle, as μ=0 gives the Standard Model. Since I search for models that maximize T, I do not compute a p value, as it would be misleading. **One should refrain from giving the test statistic a probabilistic meaning. In the next iteration I will want to replace it with a Bayes factor.**

- All models have to evade all exclusions of all results in the SModelS database (though I relaxed the requirement a bit since strictly speaking we are “allowed” to violate one out of twenty 95% exclusions).

Houston, we have a problem!

CMS analyses with no digital SMS results

CMS-PAS-SUS-18-006
CMS-PAS-SUS-19-005
CMS-PAS-SUS-18-005
CMS-PAS-SUS-18-005
CMS-SUS-17-011
CMS-SUS-17-006
CMS-SUS-16-017
CMS-SUS-16-048
CMS-SUS-16-008
CMS-SUS-16-003
CMS-SUS-15-012
CMS-SUS-15-004
CMS-SUS-15-011
CMS-SUS-15-005
CMS-SUS-15-006
CMS-SUS-15-003
CMS-SUS-17-003
CMS-SUS-17-012
CMS-PAS-SUS-17-002

(The fix would be utterly simple. Just put the root files online, as was done in the past)

CMS analyses with no (simple) way to construct an approximate likehood

CMS-PAS-SUS-17-004
CMS-SUS-16-032
CMS-SUS-16-034
CMS-SUS-16-035
CMS-SUS-16-037
CMS-SUS-16-039
CMS-SUS-16-041
CMS-SUS-16-042
CMS-SUS-16-043
CMS-SUS-16-045
CMS-SUS-16-046
CMS-SUS-16-047
CMS-SUS-17-001
CMS-EXO-12-026
CMS-PAS-SUS-13-018
CMS-PAS-SUS-13-023
CMS-SUS-13-004
CMS-SUS-13-006
CMS-SUS-13-019

(once we have expected upper limits, we are in the business. give us efficiency maps and we can go to the moon)

Second new SModelS ingredient: model builder

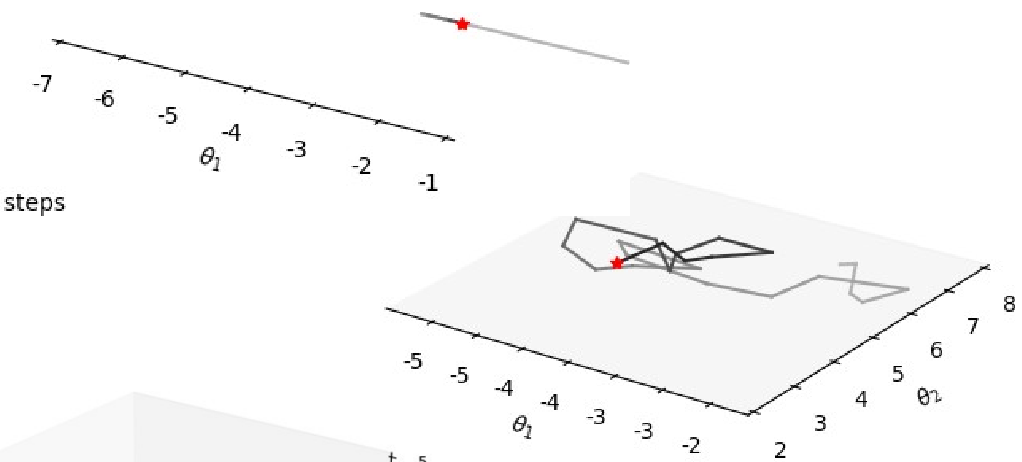
- currently a Metropolis-Hastings-type random walk in the space of all models that can be described with semantically correct SLHA files (actually currently only a subset).

- in the future will want to try a neural network that learns “Z”. Should be faster, as long was we want only central values, and not complete distributions.

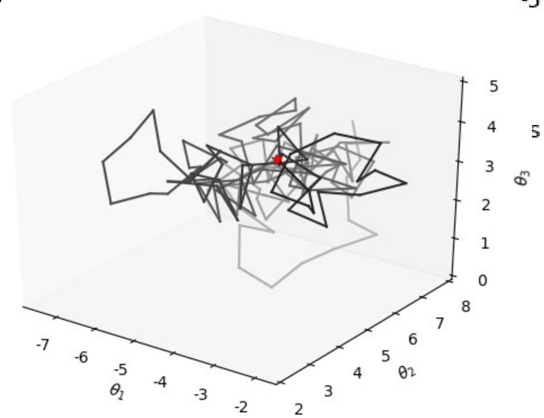
- We begin with the standard model, all BSM particles being “frozen out” (put to high masses). We then take random steps in model space.
  Possible random steps:
    - freezing a particle out
    - unfreezing a particle
    - changing a particle’s mass
    - changing a particle’s branchings
    - changing a particle’s signal strength modifier
      (we use the NLO SUSY cross sections for defaults)

- All models need to obey all (relaxed) SModelS exclusions. So both antagonists (the “excluder” and the “excess finder”) experience the same biasses from the incomplete SModelS database.

- We can punish the algorithm for introducing new particles.



after 5 steps



ICMC walk, after 200 steps

http://www.hephy.at/user/wwaltenberger/models/mcmc.webm

Ach, come on – it’s just a game!

Loosely speaking, we can think of it as a game, in the game-theoretical sense. Played between the algorithm that tries to exclude the model (“excluder”, “experimentalist”), and the algorithm that tries to build a model that maximally violates the Standard Model hypothesis (“builder”, “theorist”).

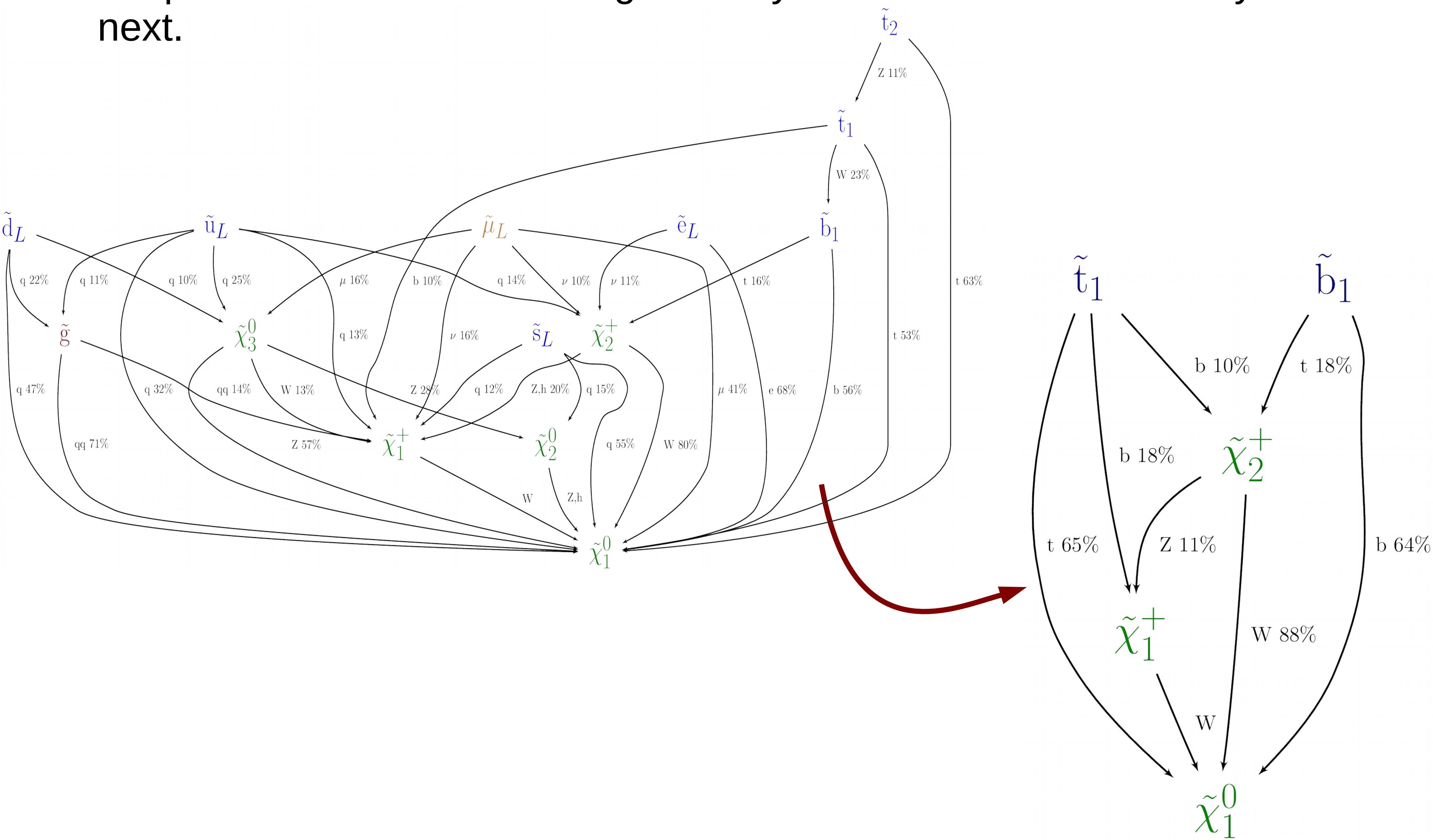
$$\hat{M} \equiv \underset{M:\text{models}}{\operatorname{argmax}} Z(M) \Big|_{\max\limits_{i:\text{results}} (r_i(M)) \lesssim 1.5}$$

r_i: predicted signal strength / experimental upper limit, for the result (combination) “i”

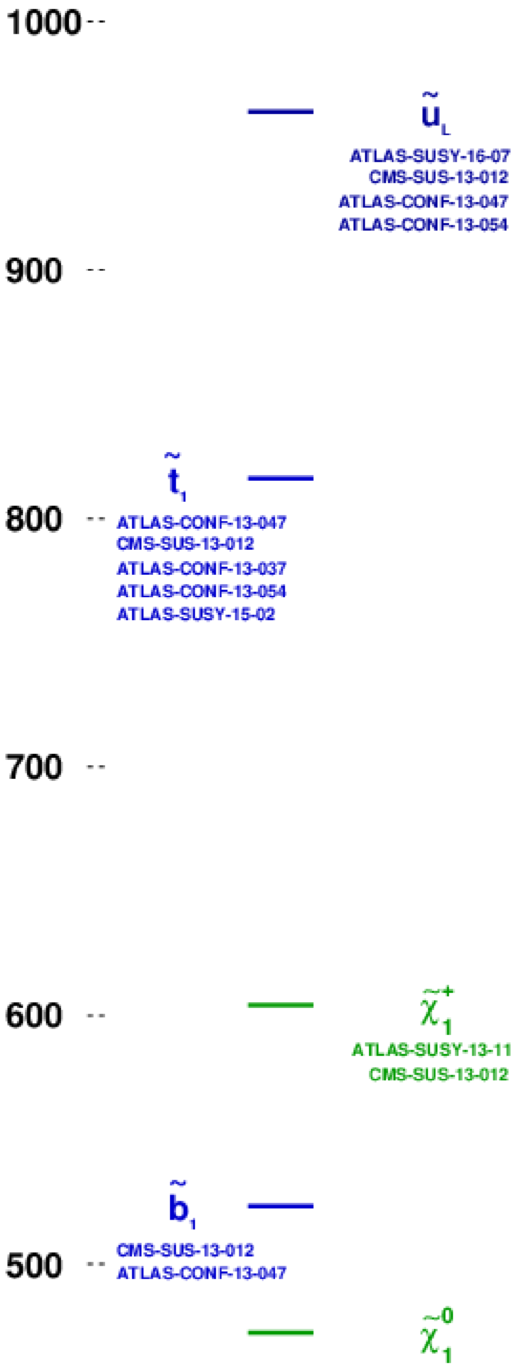
(Ok, ok, I guess one could also think of it as “optimization with constraints”.
But that sounds so much less cool.)

Trimming

After having found models of interest, we trim them. First we try to take out particles and see if that significantly reduces the score. Decays are next.



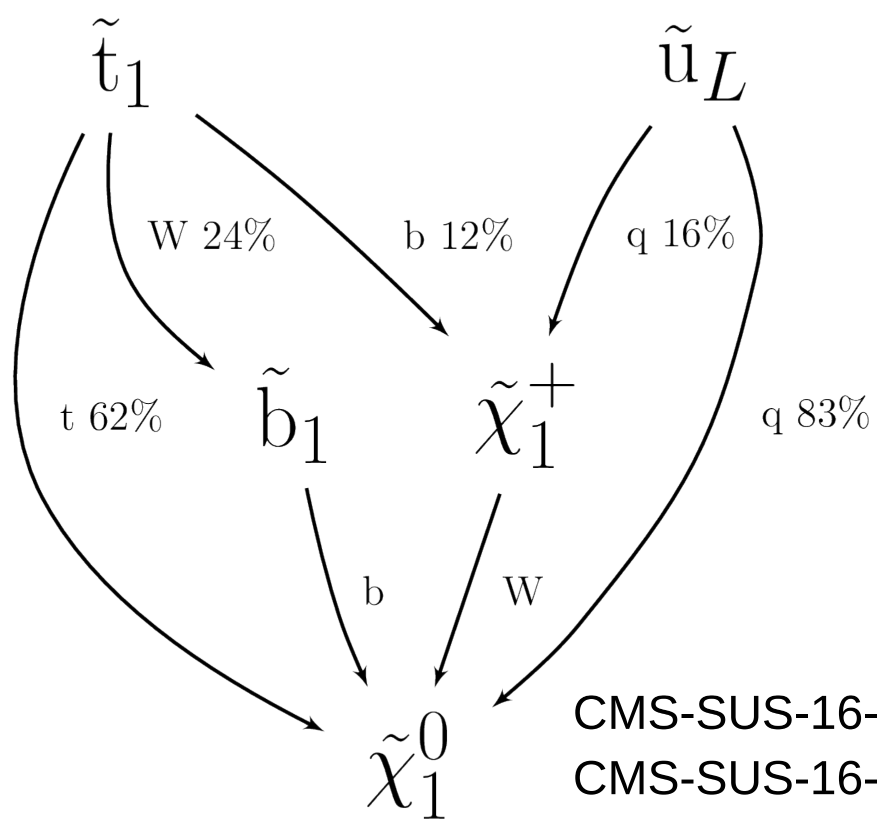
To repeat: this is what the algorithm found after O(100) steps



Signal strength multipliers: $\tilde{u}_L = 0.88, \tilde{b}_1 = 1.22, \tilde{t}_1 = 0.74, \tilde{\chi}^+_1 = 1.03$

Contributions by particles: $\tilde{u}_L = 0.76, \tilde{t}_1 = 0.72, \tilde{\chi}^+_1 = 0.08, \tilde{b}_1 = 0.15$

Z=3.25



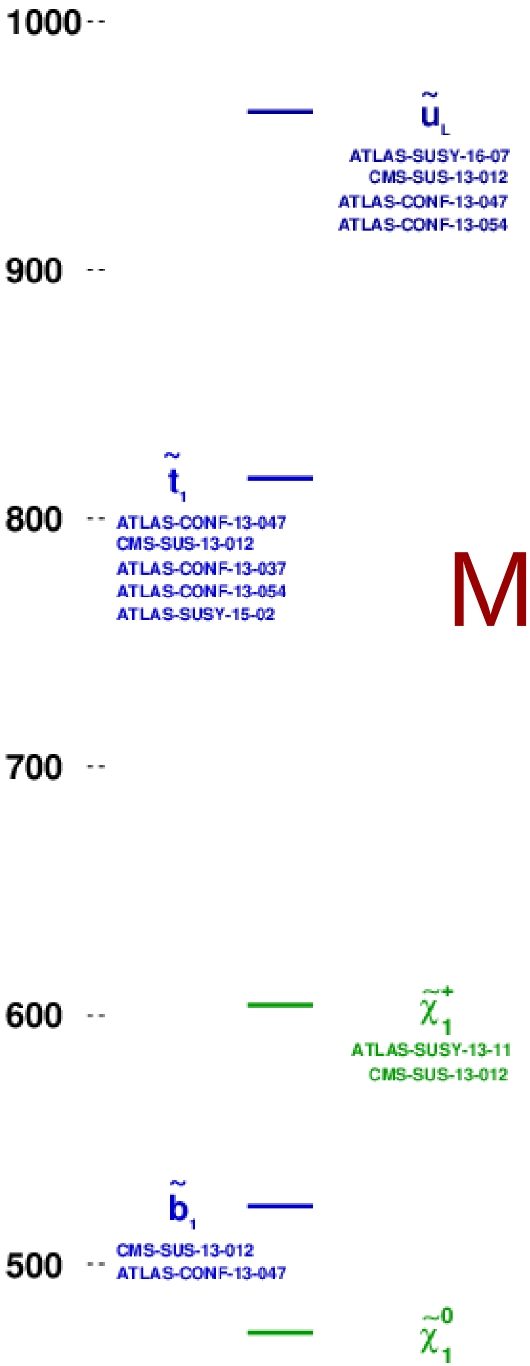
CMS-SUS-16-032:T2bb r=0.56, r_{exp}=N/A

CMS-SUS-16-036:T2bb r=0.49, r_{exp}=0.29

CMS-SUS-16-033:T2bb r=0.35, r_{exp}=0.34

(And no, I have no idea if the model was still interesting, were we to fully recast all analyses)

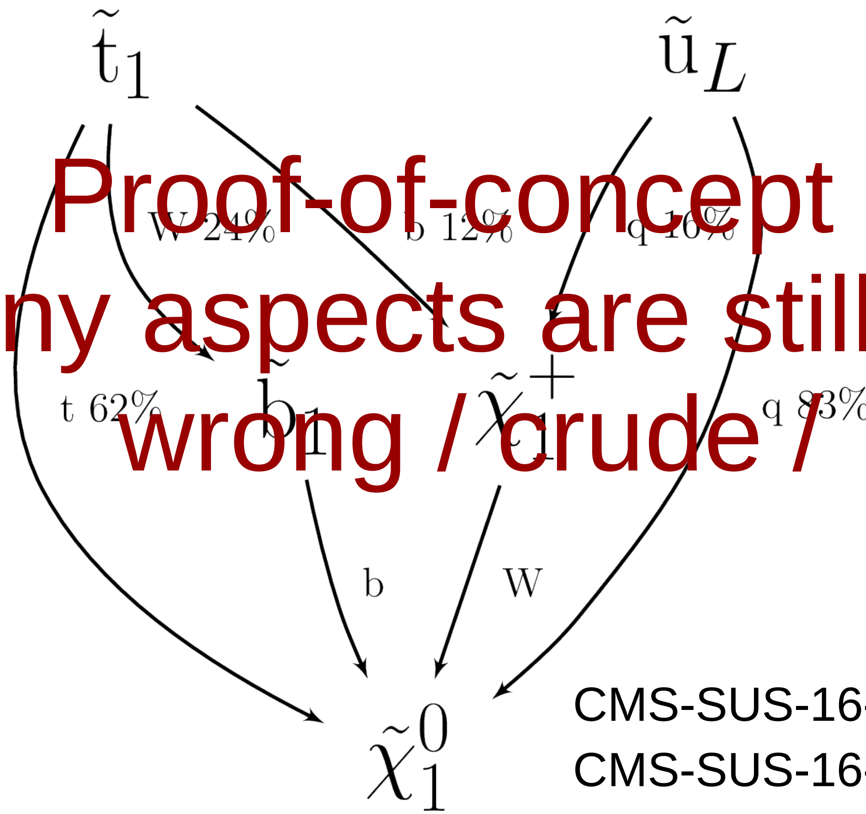
To repeat: this is what the algorithm found after O(100) steps



Signal strength multipliers: $\tilde{u}_L = 0.88, \tilde{b}_1 = 1.22, \tilde{t}_1 = 0.74, \tilde{\chi}_1^+ = 1.03$

Contributions by particles: $\tilde{u}_L = 0.76, \tilde{t}_1 = 0.72, \tilde{\chi}_1^+ = 0.08, \tilde{b}_1 = 0.15$

Z=3.25



Proof-of-concept only

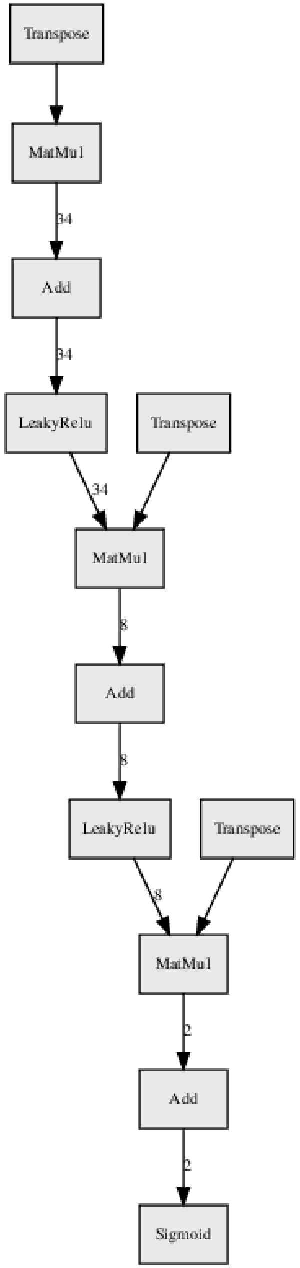
Many aspects are still buggy / wrong / crude / ….

CMS-SUS-16-032:T2bb r=0.56, r_{exp}=N/A

CMS-SUS-16-036:T2bb r=0.49, r_{exp}=0.29

CMS-SUS-16-033:T2bb r=0.35, r_{exp}=0.34

(And no, I have no idea if the model was still interesting, were we to fully recast all analyses)



To Do

- Try learning different criteria, e.g. most "spectacular" signatures that miraculously evade all SMS constraints.
- Train a neural network that predicts the objective function (e.g. the significance Z for the builder, r_{max} for the excluder) → differentiable function, should make for much faster convergence (as long as we only want central values)
- Add the most recent results (CMS, what shall we do?)
- Allow also for displaced signatures (widths as free parameters? computed widths?) [SModelS 2.0.0]
- Constraints from measurements may be added via likelihoods on Wilson coefficients.
- Compute the distribution of the test statistic T under the Standard Model assumption.
- SModelS actually gives much more detailed feedback than just a single test statistic. Make use of it.
- Long term vision: to have a full, real sample of a posterior in model space.
- Can we / should we move from SLHA files to arbitrary Lagrangians (described eg as UFO or Sarah files)?

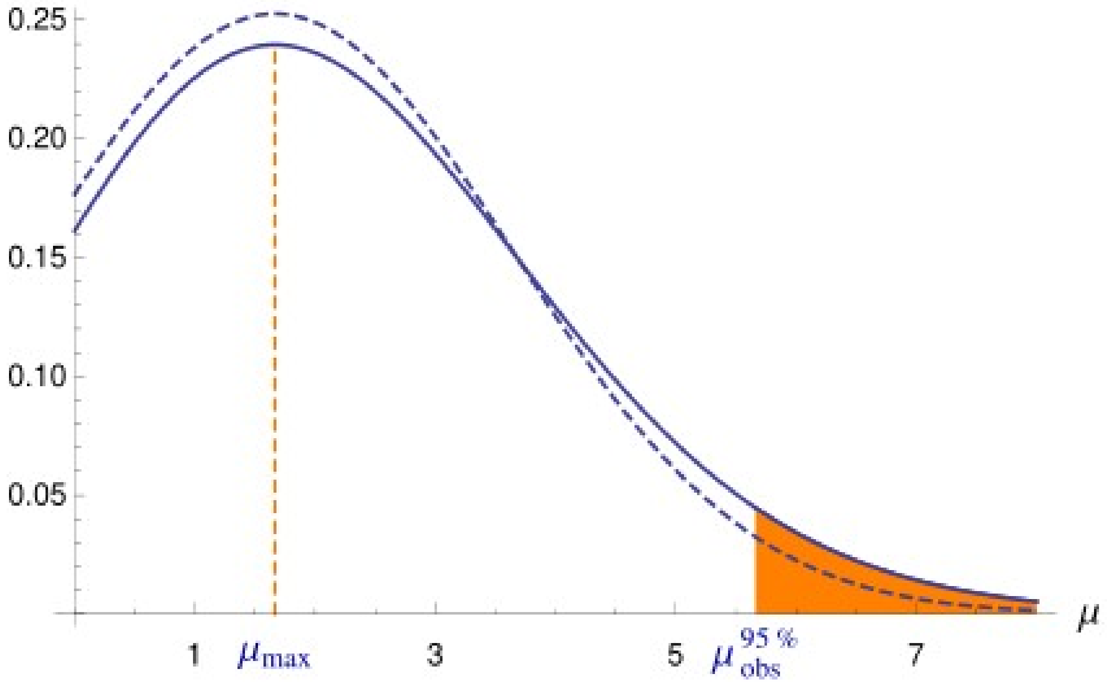
Epilogue

The model shown was obtained before we had our experimental “likelihoods from limits” code in place. After adding these likelihoods, a few CMS results (CMS-SUS-16-051, CMS-SUS-16-033) pretty much ruined the Z score. Here is the best model obtained so far after having added these likelihoods:

Backup

Likelihoods from limits

When we have observed **and** expected upper limits, we compute an approximate truncated Gaussian likelihood from it (procedure taken from arXiv:1202.3415)



ArXiv:1202.3415

Communication of Likelihoods

CMS has introduced the simplified likelihoods (thanks a lot!),

CMS-NOTE-2017-001

The authors of that paper have addressed a conceptual problem

when dealing with “deeply Poissonian regions (very small expected counts) in version 2 of the formalism,

“The Simplified likelihood framework”

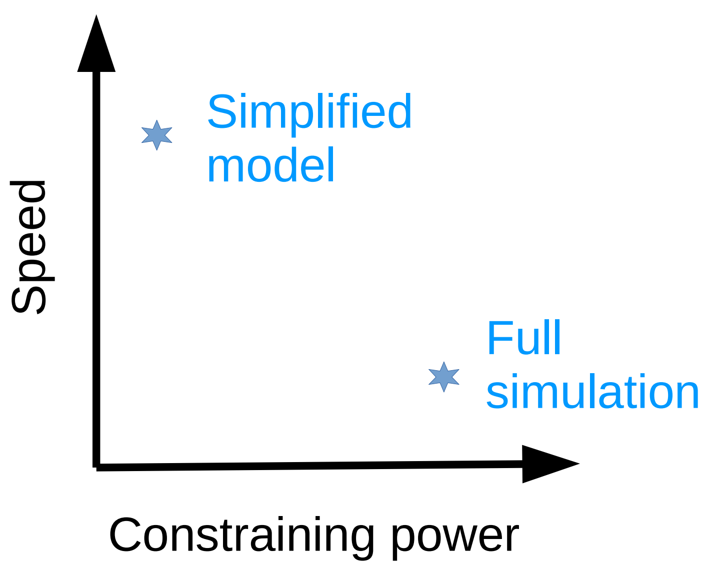
ATLAS has only recently published their alternative to CMS’es simplified likelihoods,

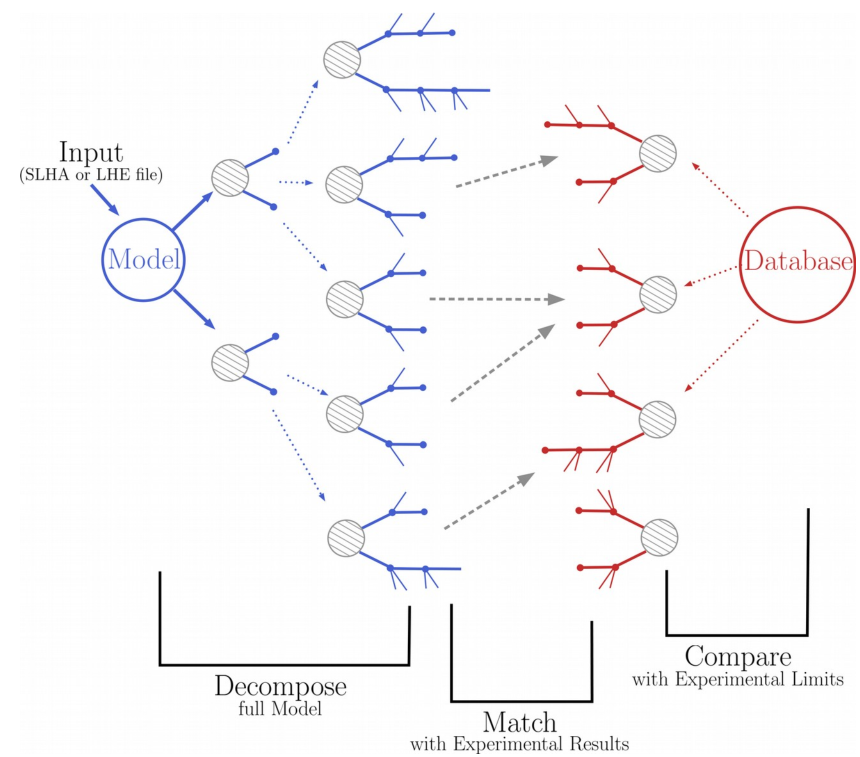
ATL-PHYS-PUB-2019-029

SModelS has implemented CMS’es simplified likelihoods, will implement ATLAS’es histogram-factory based approach in the future.

Recap: the Idea behind SModelS

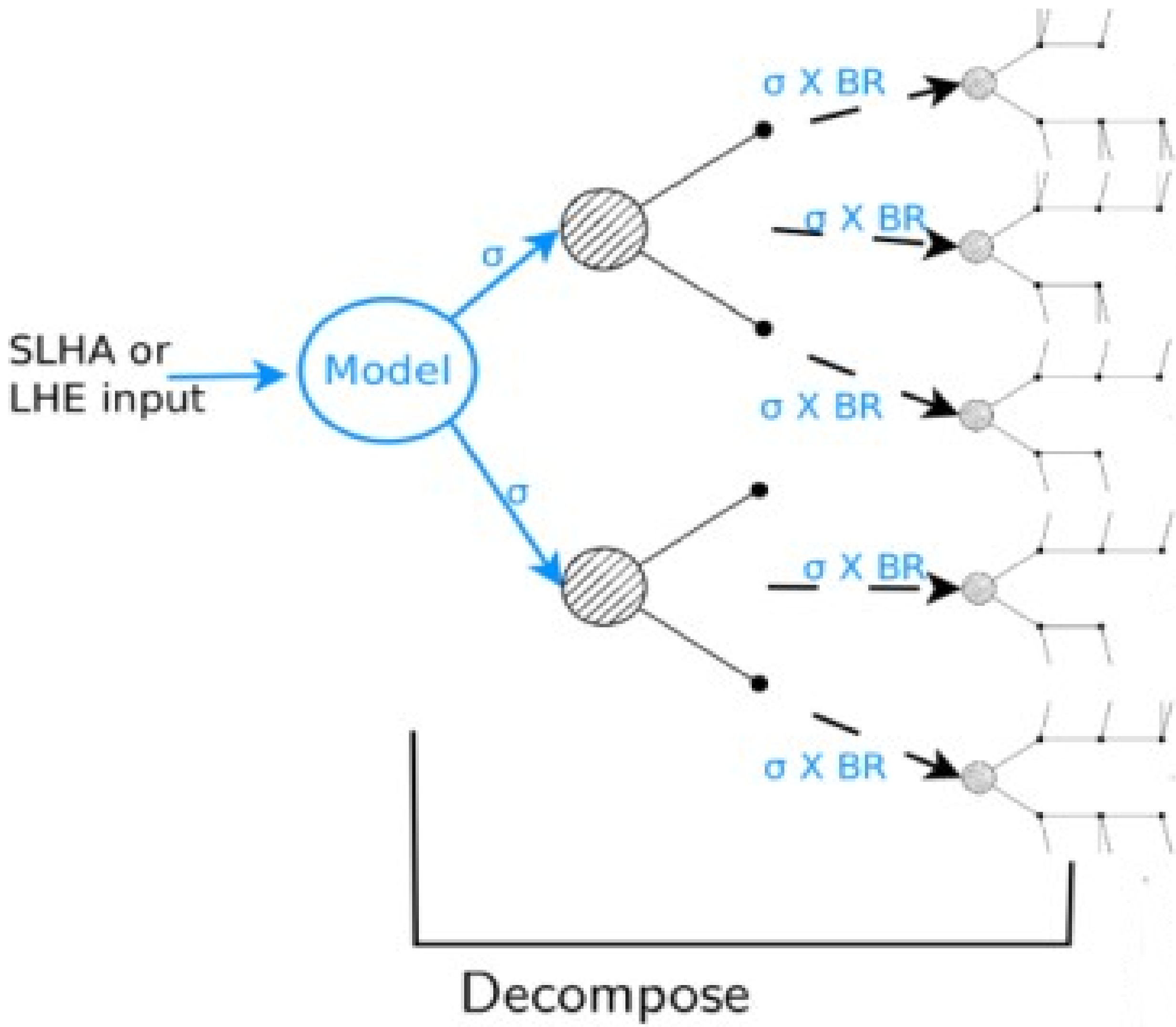
SModelS confronts theories beyond the Standard Model (BSM) with LHC search results by decomposing full models into their simplified models topologies, and comparing the cross section predictions of these individual topologies with a database of SMS results.





Recap: How SModelS works

1) Decomposition of a fundamental model



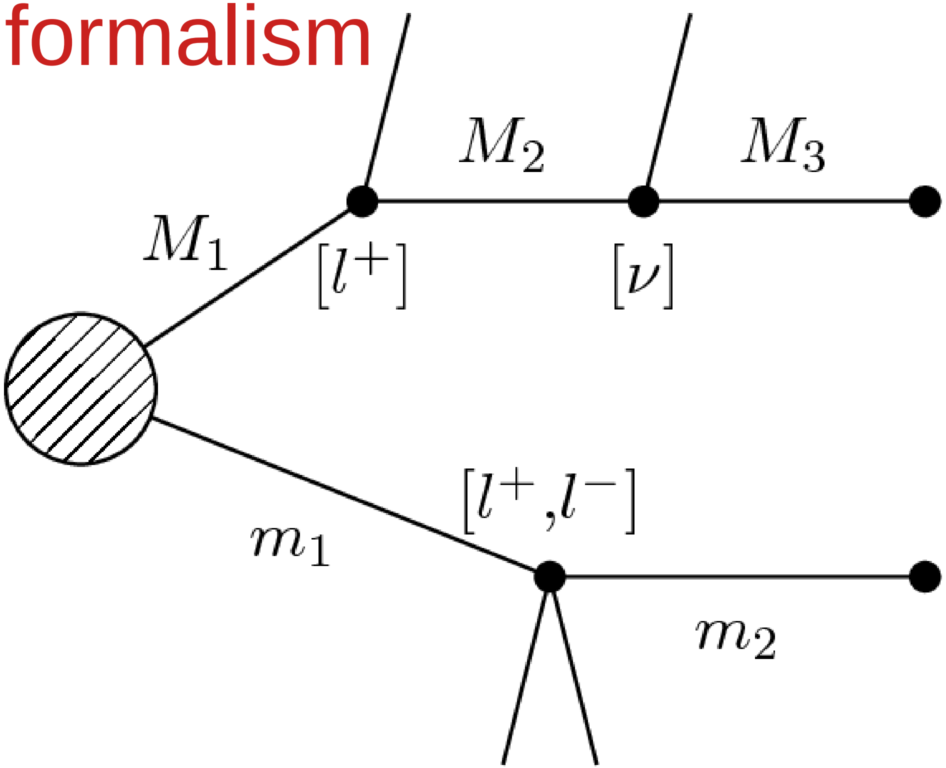
Input: SLHA file (mass spectrum, BRs) or LHE file (parton level)

Currently the model must have a **Z**$_2$ symmetry

The decomposition produces a set of simplified model topologies (dubbed “elements”)

Recap: How SModelS works

2) Description of the topology in the SModelS formalism



$$= [[l^+],[\nu]]$$

$$= [\ [[l^+],[\nu]]\ ,\ [[l^+,l^-]]\ ]$$
$$([[M_1,M_2,M_3],[m_1,m_2]])$$

$$= [[l^+,l^-]]$$

Each topology is described by:

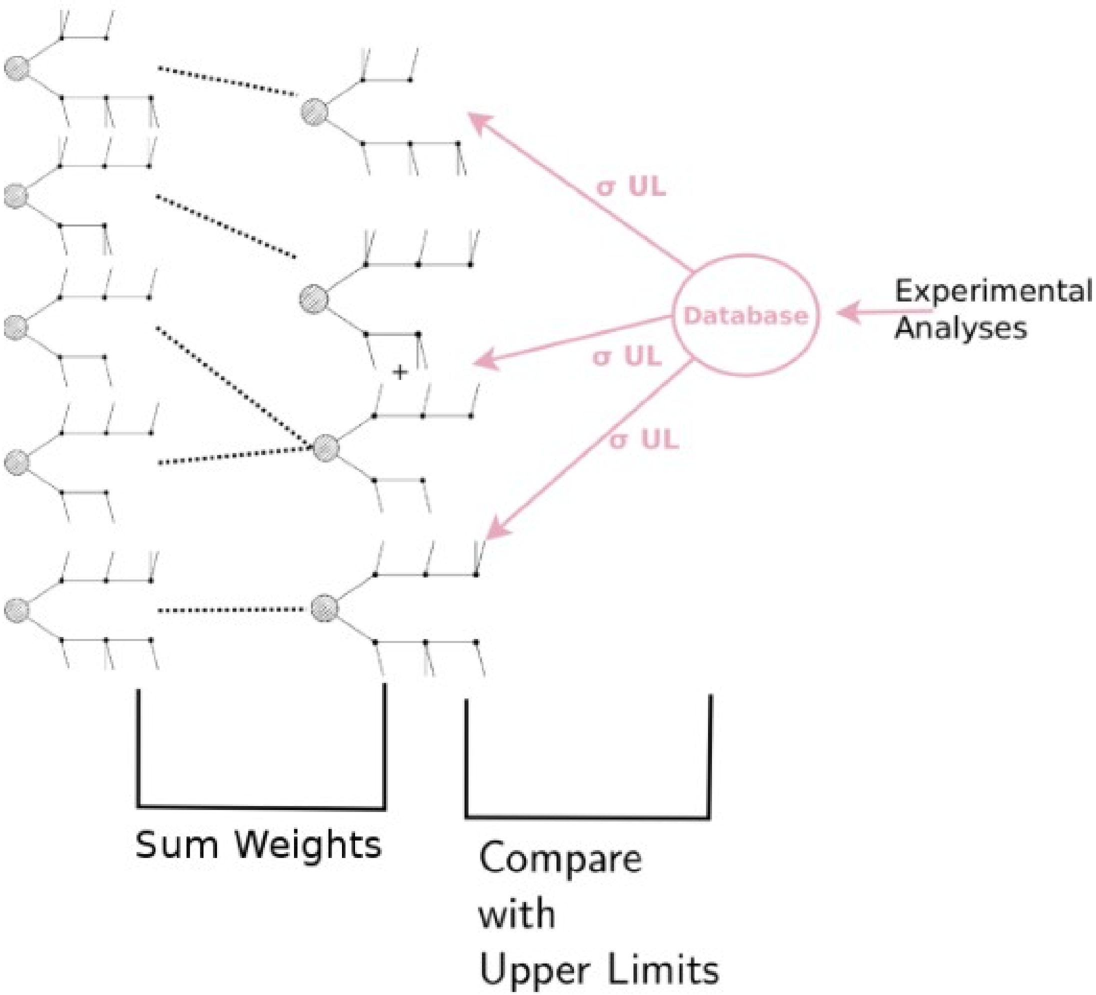
- Topology shape + final states
- BSM masses
- σ x BR

We (currently) ignore spin, color, etc of the BSM particles

It is model independent, there is no reference to the original model

Recap: How SModelS works

3) Comparison of predicted signal strengths with experimental result:



- **Upper Limit Results:**
  Predicted signal strength = σ x BR
  Experimental result: σ_{UL}

- **Efficiency Map Results:**
  Predicted signal strength = ∑ σ x BR x ε
  Experimental result: $\sigma_{UL}=N_{UL}/ L$ from $N_{observed}$, expected(BG), error(BG)

- r = predicted / σ_{UL}

- Model is excluded if most constraining analysis has r > 1