New Developments in Recasting

Sabine Kraml
LPSC Grenoble

The 10th Annual
Large Hadron Collider Physics Conference
May 16-21, 2022

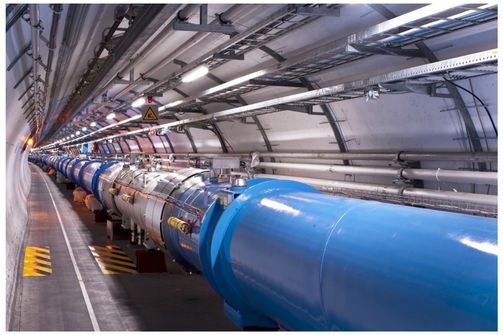
2022 LHCP TAIPEI ONLINE

Motivation

We want to be able to test any model or scenario against the plethora of LHC results :

- understand full theoretical implications (e.g. naturalness, DM models);
- give feedback to the experiments about loopholes in the searches;
- elucidate underlying theory in case of a discovery.

☞ **Public tools for reinterpretation** ☜



LHC Reinterpretation Forum
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults

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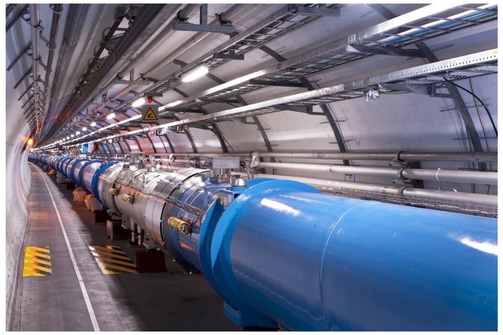

MADAnalysis 5 · SModelS · RIVET Contur · CheckMATE · ADL · GAMBIT ColliderBit · LLP Recasting · ....

LHC Reinterpretation Forum

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults

SciPost Phys. 9, 022 (2020)

arXiv:2003.07868

Reinterpretation of LHC results for new physics: status and recommendations after run 2

The LHC BSM Reinterpretation Forum

Contents

58 pages, 141 signatories

(Re)interpreting the results of new physics searches at the LHC

15–19 Feb 2021
CERN
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Registration
- Call for Abstracts
- Participant List
- Videoconference
- Programme Commitee

The LHC collaborations are pursuing searches for new physics in a vast variety of channels. While the collaborations typically provide themselves interpretations of their results, for instance in terms of simplified models, the full understanding of the implications of these searches requires the interpretation of the experimental results in the context of all kinds of theoretical models. This is a very active field, with close theory-experiment interaction and with several public tools being developed.

A Forum on the interpretation of the LHC results for BSM studies was thus initiated to discuss topics related to the BSM (re)interpretation of LHC data, including the development of the necessary public recasting tools and related infrastructure, and to and to provide a platform for a continued interaction between theorists and with the experiments.

This is the **sixth workshop** of this Forum and will be held purely online. Previous meetings took place

1. workshop: 15-17 June 2016 (kick-off meeting) at CERN
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SciPost Phys. 12, 037 (2022)

arXiv:2109.04981

Publishing statistical models: Getting the most out of particle physics experiments

Kyle Cranmer[1†⋆], Sabine Kraml[2‡⋆], Harrison B. Prosper [3○⋆], Philip Bechtle[4], Florian U. Bernlochner[4], Itay M. Bloch[5], Enzo Canonero[6], Marcin Chrzaszcz[7], Andrea Coccaro[8], Jan Conrad[9], Glen Cowan[10], Matthew Feickert[11], Nahuel F. Iachellini[12,13], Andrew Fowlie[14], Lukas Heinrich[15], Alexander Held[1], Thomas Kuhr[13,16], Anders Kvellestad[17], Maeve Madigan[18], Farvah Mahmoudi[15,19], Knut D. Morå[20], Mark S. Neubauer[11], Maurizio Pierini[15], Juan Rojo[8], Sezen Sekmen[22], Luca Silvestrini[23], Veronica Sanz[24,25], Giordon Stark[26], Riccardo Torre[8], Robert Thorne[27], Wolfgang Waltenberger[28], Nicholas Wardle[29] and Jonas Wittbrodt[30]

Abstract

The statistical models used to derive the results of experimental analyses are of incredible scientific value and are essential information for analysis preservation and reuse. In this paper, we make the scientific case for systematically publishing the full statistical models and discuss the technical developments that make this practical. By means of a variety of physics cases — including parton distribution functions, Higgs boson measurements, effective field theory interpretations, direct searches for new physics, heavy flavor physics, direct dark matter detection, world averages, and beyond the Standard Model global fits — we illustrate how detailed information on the statistical modelling can enhance the short- and long-term impact of experimental results.

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Abstract

Publication of statistical models: hands-on workshop

8–12 Nov 2021
CERN (online only)
Europe/Zurich timezone

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- Overview
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- Timetable
- My Conference
- My Contributions
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- Resources

The statistical models used to derive the results of experimental analyses are of incredible scientific value and are essential information for analysis preservation and reuse. In arXiv:2109.04981, we made the scientific case for systematically publishing the full statistical models; we discussed the technical developments that make this practical, and illustrated by a variety of physics cases how detailed information on the statistical modelling can enhance the short- and long-term impact of experimental results

This workshop is intended as the first in a series to discuss in more detail practical issues for publishing statistical models and likelihoods, and work towards concrete solutions.

In this context **note also** the PHYSTAT workshop on systematics (Nov 1-3 + Nov 10) and in particular the **talk by Kyle Cranmer on "A call to action: Honoring PHYSTAT's 20 year old agreement" at 6 pm CET on Nov 1st** there, which will also in part set the stage for our workshop here.

Overall, apart from the first two days the workshop addresses a rather specialized audience, i.e. people want to who work on technical solutions for publishing and/or (re)using statistical models and likelihoods.

Highlights from tools - in a nutshell

- Inclusion of **many new analyses**; focus on
  - searches / measurements for full Run 2 luminosity
  - long-lived particles

Active exchanges with experimentalists, e.g. via RAMP seminars

- **Contur**: extended toolkit (param scanning w/ active learning), SM predictions as input 2202.05882 2111.15406
- **Checkmate**: SR combination w/ **covariance matrices**
- **MadAnalysis**: SR combination w/ covariance matrices and **interface to pyhf**
- **SModelS v2** with extended topology description (better treatment of **LLPs**) and extended likelihoods calculation → **analysis combination**! 2112.00769
- **TACO** (testing analysis correlations) effort nearing publication
- **GAMBIT 2.0**: "universal model machine" (**GUM**) for auto-generating GAMBIT code for global fits of arbitrary BSM models ; interface to Rivet+Contur ; interface to pyhf upcoming 2107.00030
- **Protomodel builder**: statistical learning of **dispersed signals** of new physics 2012.12246

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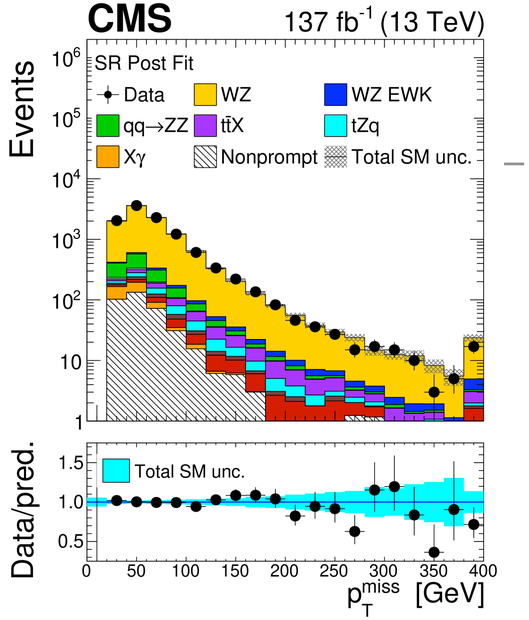
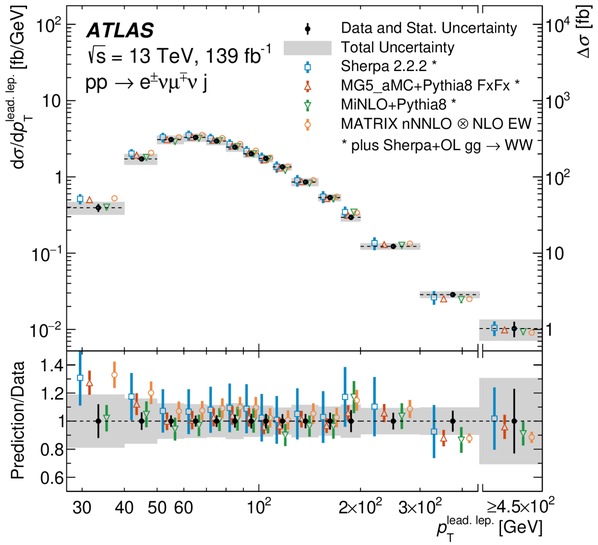
- better statistical treatment (likelihoods instead of limits, combinations)
- global approaches to where BSM may be hiding; increasingly data-driven

Rivet/Contur

- 100s of **particle-level differential measurements,** made in fiducial regions of phase-space available in **Rivet.** (“SM measurements”)
- Can give important complementary constrains to “searches”, with a **high degree of model-independence**
- **CONTUR** toolkit: “**Constraints On New Theories Using Rivet**”
- Many new technical developments, different ways of data-theory comparison, parameter scanning, use of correlations whenever available, etc.
  - v2 manual → accessibility to wider HEP community [2102.04377]
  - Signal-SM interference; proof-of-concept for including higher orders [2111.15406]
  - CONTUR ORACLE: Random Forest trained to identify boundaries in parameter spaces that separate excluded from non-excluded regions [2202.05882]





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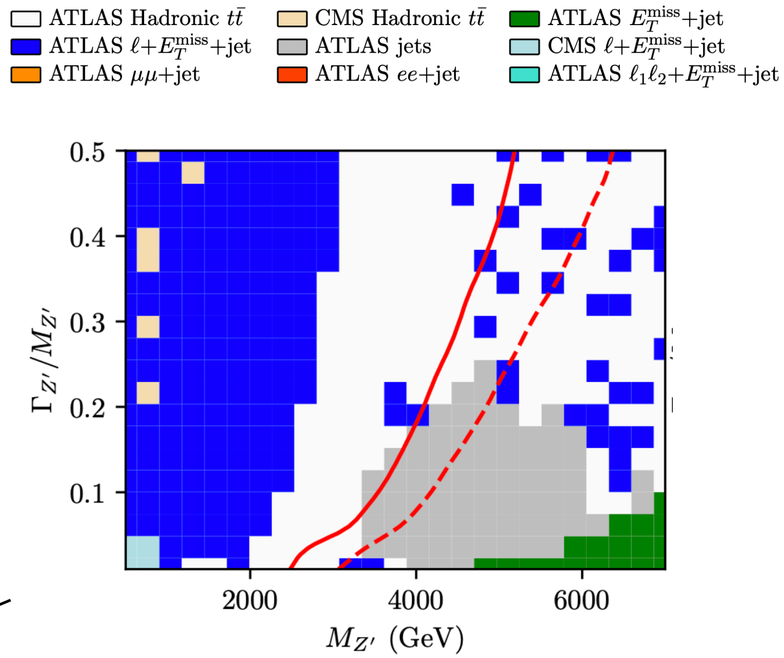


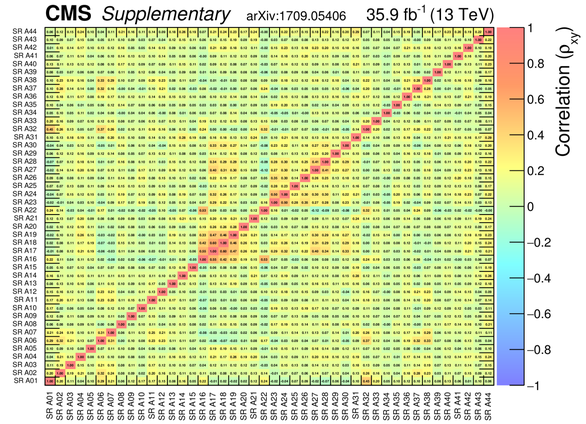
Constraints on leptophobic top-colour model, using NNLO SM prediction as background

Needs Rivet routines from exp. collaborations; data + SM predictions on HEPData

Searches: combination of signal regions (SRs)

- Reinterpretation tools attempt to evaluate the signal counts for a BSM hypothesis in each signal region (SR) of an analysis. Together with the number of observed events, expected backgrounds and uncertainties thereon, this is used to compute a likelihood

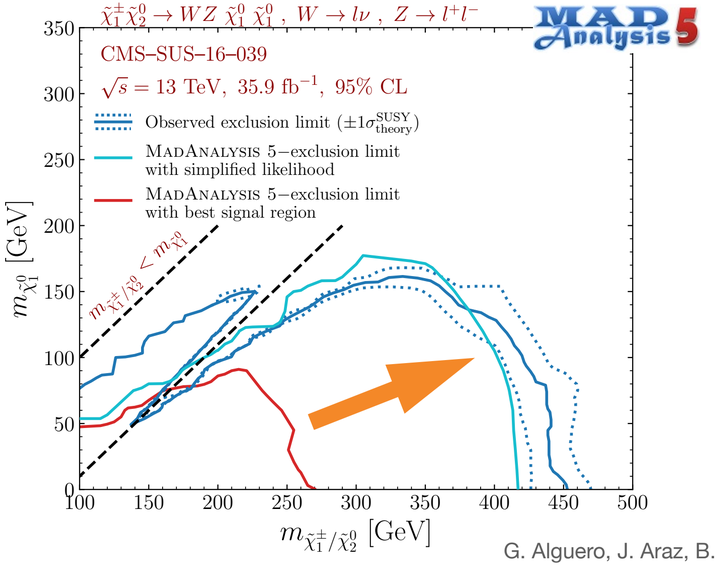
- **CMS** analyses sometimes provide a covariance matrix, which allow for the combination of disjoint SRs in a **simplified likelihood approach**



$$\mathcal{L}_S(\mu,\boldsymbol{\theta}) = \prod_{i=1}^{N} \frac{(\mu\cdot s_i + b_i + \theta_i)^{n_i} e^{-(\mu\cdot s_i + b_i + \theta_i)}}{n_i!} \cdot \exp\left(-\frac{1}{2}\boldsymbol{\theta}^T \mathbf{V}^{-1}\boldsymbol{\theta}\right)$$

covariance matrix

[**CMS NOTE-2017/001**]



G. Alguero, J. Araz, B. Fuks, SK

- Implemented in SModelS and GAMBIT since a while ✅✅
- Now also in MadAnalysis ✅
- Checkmate coming soon

Much(!) better than best-SR, but caveat are non-Gaussian effects when systematic unc. dominate

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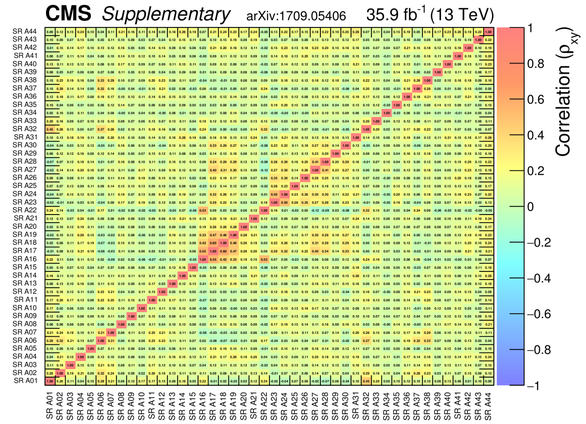
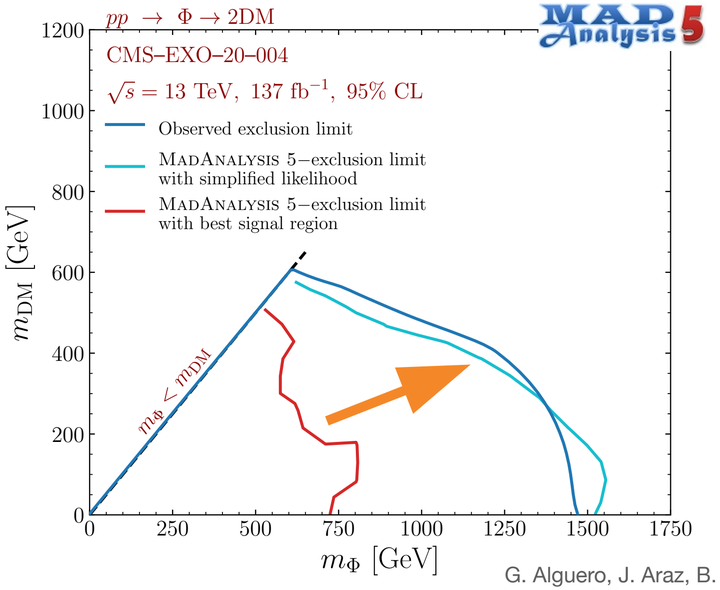
[CMS NOTE-2017/001]





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ATLAS full statistical models

ATL-PHYS-PUB-2019-029

ATLAS started to publish plain-text serialisation of full HistFactory workspaces in JSON format

- Provides background estimates, changes under systematic variations, and observed data counts at the same fidelity as used in the experiment.

	Description	Modification	Constraint Term c_χ	Input
constrained	Uncorrelated Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Pois}\left(r_b = \sigma_b^{-2} \middle\vert \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
	Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\vert \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \vert\, \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm1}$
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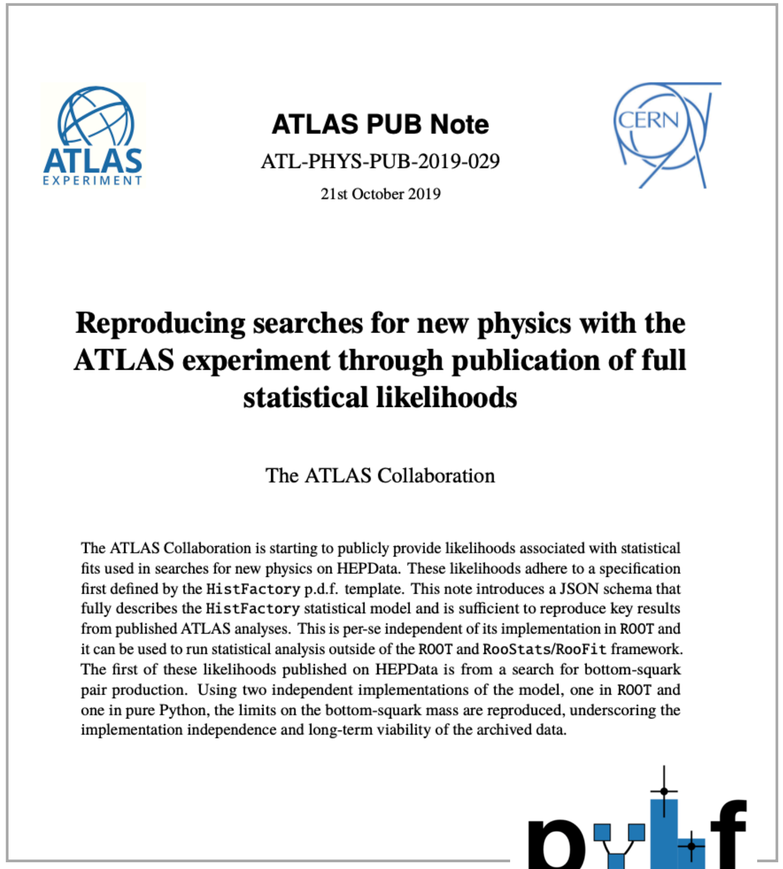
	MC Stat. Uncertainty	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Gaus}\left(a_{\gamma_b} = 1 \middle\vert \gamma_b, \delta_b\right)$	$\delta_b^2 = \sum_s \delta_{sb}^2$
	Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\text{Gaus}\,(l = \lambda_0 \vert\, \lambda, \sigma_\lambda)$	$\lambda_0, \sigma_\lambda$
free	Normalisation	$\kappa_{scb}(\mu_b) = \mu_b$		
	Data-driven Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$		

Rate modifications defined in HistFactory for bin *b*, sample *s*, channel *c*.

- Usage: RooFit, **pyhf**
- Target: long-term data/analysis preservation, reinterpretation purposes



ATLAS EXPERIMENT

ATLAS PUB Note

ATL-PHYS-PUB-2019-029

21st October 2019

CERN

Reproducing searches for new physics with the ATLAS experiment through publication of full statistical likelihoods

The ATLAS Collaboration

The ATLAS Collaboration is starting to publicly provide likelihoods associated with statistical fits used in searches for new physics on HEPData. These likelihoods adhere to a specification first defined by the `HistFactory` p.d.f. template. This note introduces a JSON schema that fully describes the `HistFactory` statistical model and is sufficient to reproduce key results from published ATLAS analyses. This is per-se independent of its implementation in `ROOT` and it can be used to run statistical analysis outside of the `ROOT` and `RooStats/RooFit` framework. The first of these likelihoods published on HEPData is from a search for bottom-squark pair production. Using two independent implementations of the model, one in `ROOT` and one in pure Python, the limits on the bottom-squark mass are reproduced, underscoring the implementation independence and long-term viability of the archived data.

pyhf differentiable likelihoods

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HEPData

Resources

Total: 21 Likelihood available

Search for charginos and neutralinos in all-hadronic final states	SUSY	Accepted by PRD	17-AUG-21	13	139 fb^{-1}
4-top xsec measurement	TOPQ	Accepted by JHEP	22-JUN-21	13	139 fb^{-1}
Search for gluinos, stops and electroweakinos in RPV models in final states with 1L and many jets	SUSY	Accepted by EPJC	17-JUN-21	13	139 fb^{-1}
Search for charginos and neutralinos in final states with 3L and MET	SUSY	Accepted by EPJC	03-JUN-21	13	139 fb^{-1}
Measurement of ttZ cross sections in Run 2	TOPQ	Eur. Phys. J. C 81 (2021) 737	23-MAR-21	13	139 fb^{-1}
Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	EXOT	JHEP 06 (2021) 179	27-JAN-21	13	139 fb^{-1}
Search for squarks and gluinos in final states 1L, jets and MET	SUSY	Eur. Phys. J. C 81 (2021) 600	05-JAN-21	13	139 fb^{-1}
Search for charginos and neutralinos in RPV models in final states with 3L (or more)	SUSY	Phys. Rev. D 103, (2021) 112003	20-NOV-20	13	139 fb^{-1}
Search for displaced leptons	SUSY	Phys. Rev. Lett. 127 (2021) 051802	13-NOV-20	13	139 fb^{-1}
Search for squarks and gluinos in final states with 0L, jets and MET	SUSY	JHEP 02 (2021) 143	27-OCT-20	13	139 fb^{-1}
Measurement of the ttbar production cross-section in the lepton+jets channel at 13 TeV	TOPQ	Phys. Lett. B 810 (2020) 135797	24-JUN-20	13	139 fb^{-1}
Stop pair, long-lived; displaced vertex and displaced muon	SUSY	Phys. Rev. D 102 (2020) 032006	26-MAR-20	13	136 fb^{-1}
Chargino-neutralino pair; 3 leptons, weak-scale mass splittings	SUSY	Phys. Rev. D 101 (2020) 072001	18-DEC-19	13	139 fb^{-1}
Chargino-neutralino pair, slepton pair; soft leptons	SUSY	Phys. Rev. D 101 (2020) 052005	28-NOV-19	13	139 fb^{-1}
Staus; taus	SUSY	Phys. Rev. D 101 (2020) 032009	15-NOV-19	13	139 fb^{-1}
Chargino-neutralino pair; Higgs boson in final state, 2 b-jets and 1 lepton	SUSY	Eur. Phys. J. C 80 (2020) 691	19-SEP-19	13	139 fb^{-1}
Stop pair, sbottom pair, gluino pair; two same-sign leptons or three leptons	SUSY	JHEP 06 (2020) 46	18-SEP-19	13	139 fb^{-1}
Sbottom; b-jets	SUSY	JHEP 12 (2019) 060	08-AUG-19	13	139 fb^{-1}

ATLAS full statistical models

reinterpretation becomes JSON patching

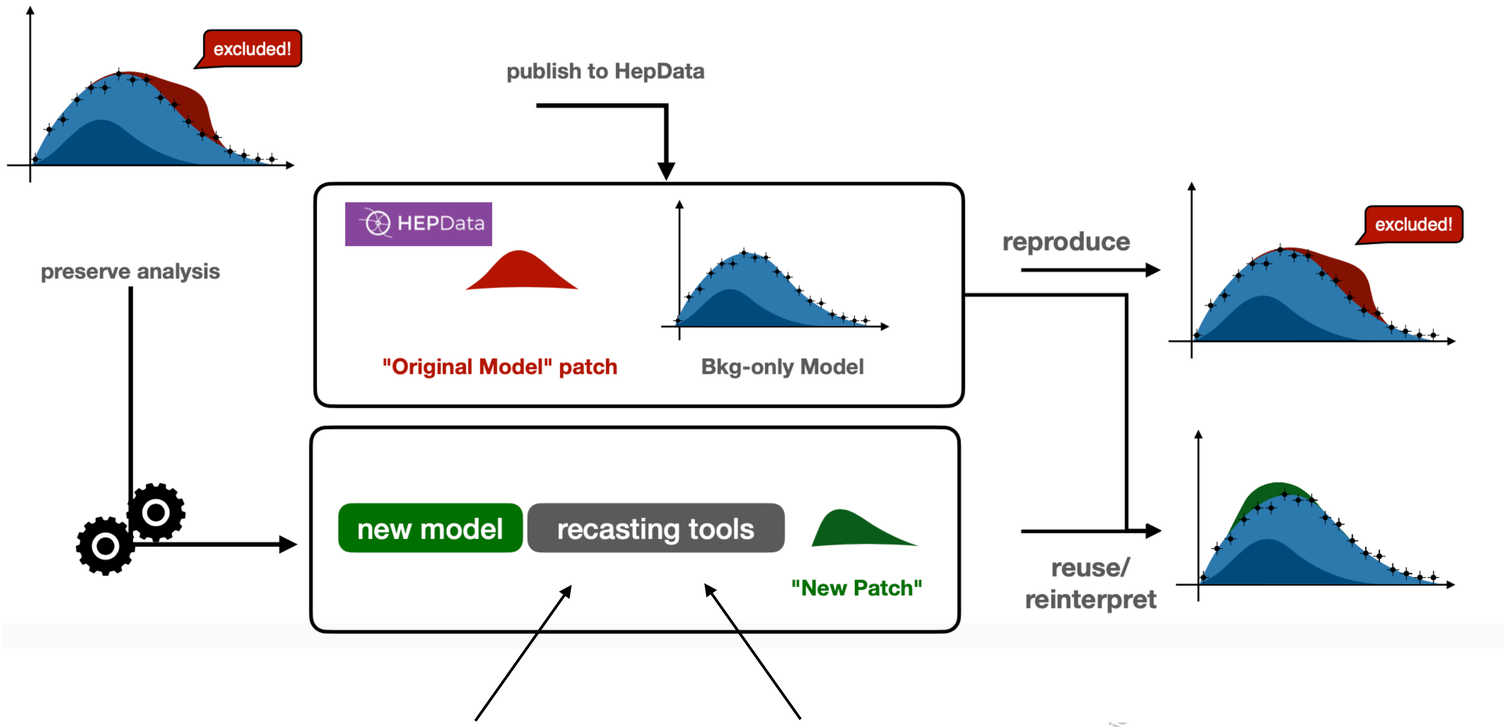


Illustration from talk by Lukas Heinrich
Hands-on workshop 8 Nov 2021

MadAnalysis 5

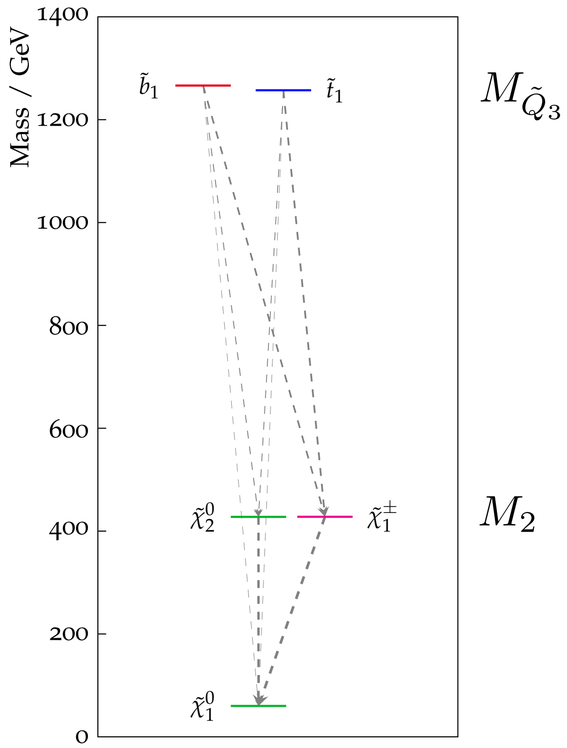
G. Alguero, J. Araz, B. Fuks, SK,
Functionality available v1.9 onward, paper in preparation

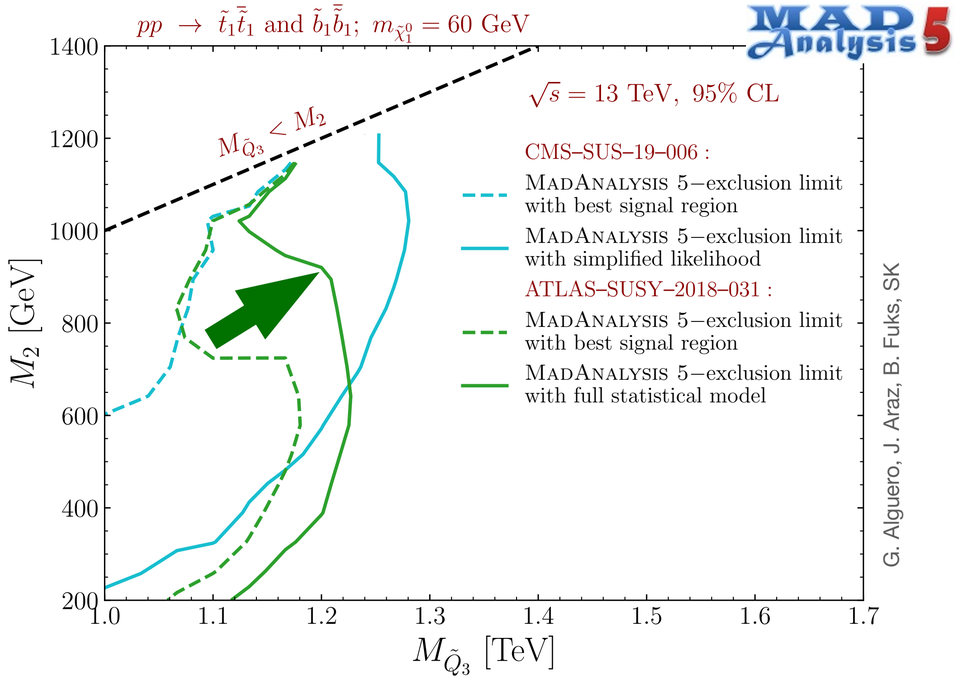
SModelS

Interfaced to pyhf since SModelS v1.2.4 (now v2.2)
G. Alguero, SK, W. Waltenberger, arXiv:2009.01809

Others (Checkmate, GAMBIT) are working on interfaces

Physics impact in MSSM scenarios





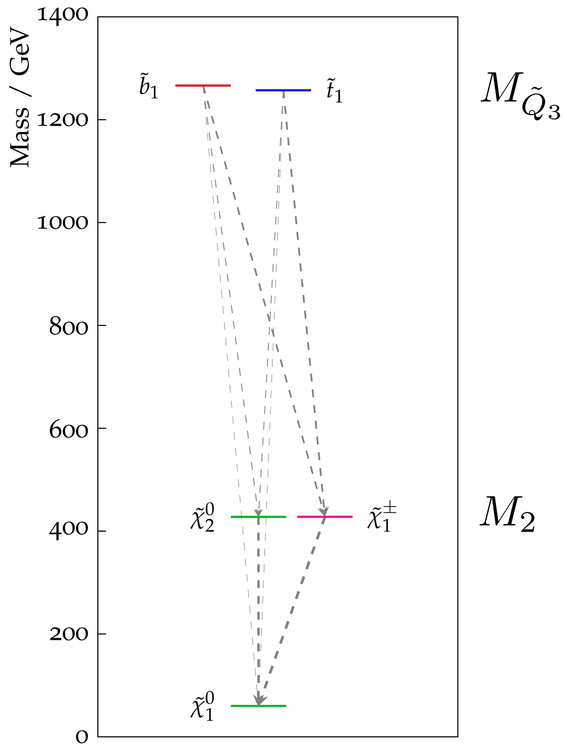
ATLAS multi-b + MET (sbottom), 8 SRs

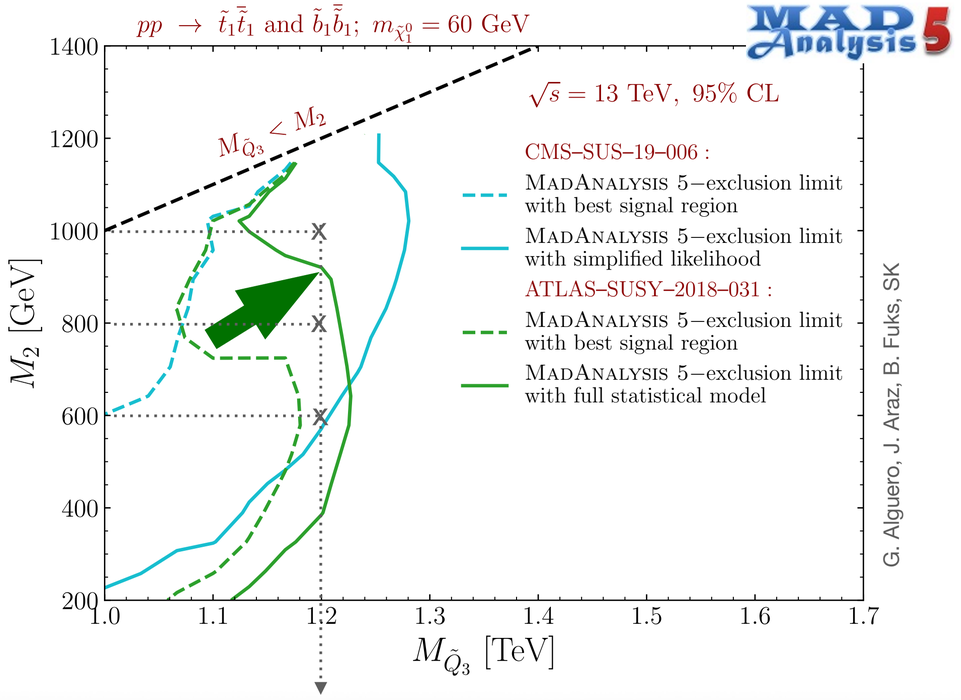
CMS jets + MET (gluino/squark), 174 SRs

		$M_2 = 600$ GeV			$M_2 = 800$ GeV			$M_2 = 1$ TeV		
analysis	method	$\tilde{b}_1\tilde{b}_1^*$	$\tilde{t}_1\tilde{t}_1^*$	total	$\tilde{b}_1\tilde{b}_1^*$	$\tilde{t}_1\tilde{t}_1^*$	total	$\tilde{b}_1\tilde{b}_1^*$	$\tilde{t}_1\tilde{t}_1^*$	total
ATLAS	best-SR	0.71	0.66	0.94	0.70	0.59	0.91	0.29	0.21	0.57
	combined	0.83	0.80	**0.98**	0.84	0.74	**0.97**	0.80	0.56	**0.92**
CMS	best-SR	0.31	0.37	0.62	0.38	0.45	0.73	0.29	0.38	0.70
	combined	0.79	0.71	**0.96**	0.89	0.83	**0.99**	0.93	0.82	**0.99**

1-CLs values $M_{\tilde{Q}_3} = 1.2$ TeV

Physics impact in MSSM scenarios





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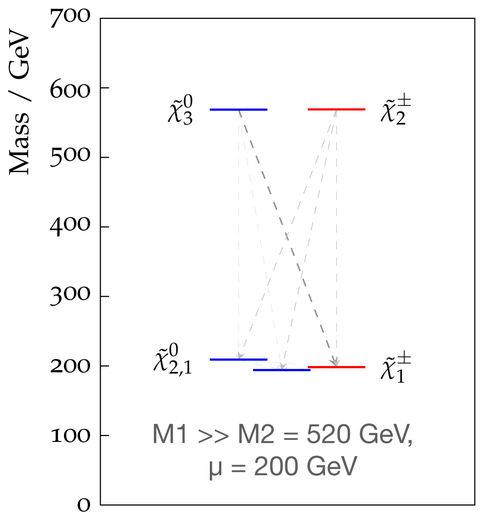
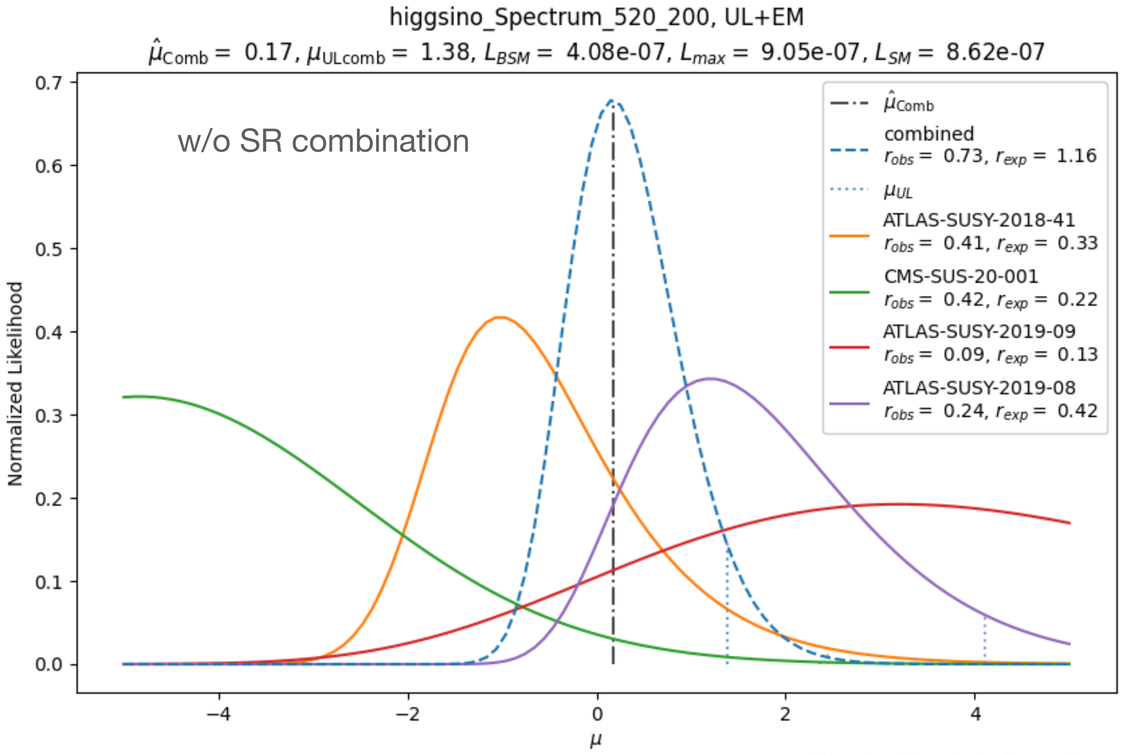


Would appreciate efficiency maps for CMS-SUS-20-001 and 21-002 !!



Plot by Timothée Pascal

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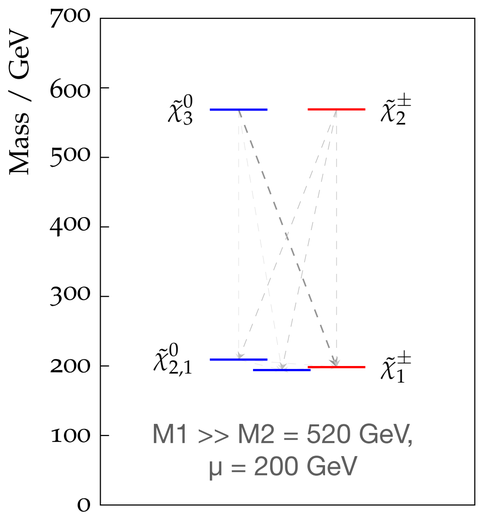

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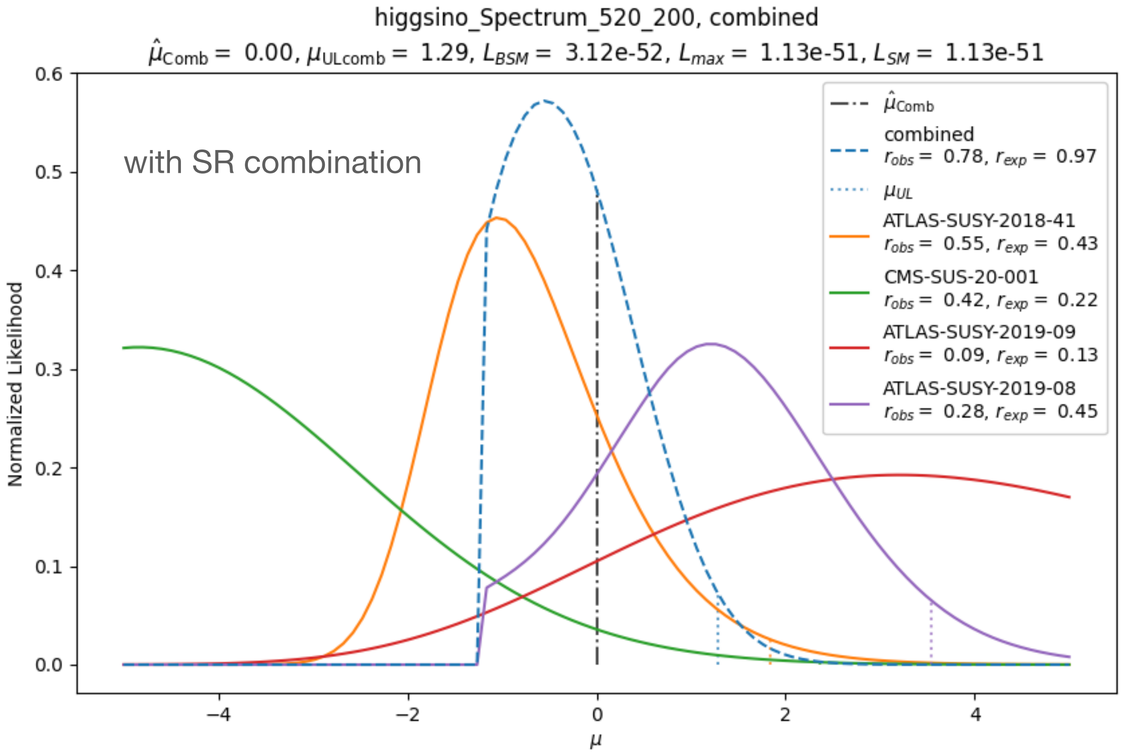
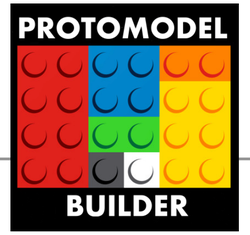


Plot by Timothée Pascal

Protomodel builder



Waltenberger, Lessa, SK, arXiv:2012:12246

- The LHC currently has no clear sign of new physics; nonetheless there may be dispersed signals* hiding in the slew of data

  * effects of new particles which are spread out over several search regions or final states

- Novel statistical learning algorithm to
  - identify potential dispersed signals in the LHC data
  - fit candidate "proto-models" to them while remaining consistent with all other LHC results in the SModelS database

- Based on simplified model results
  → exploits SModelS functionality and database

- Construct a global likelihood as product of likelihoods of approximately uncorrelated analyses

- Maximise test statistic *K* in an MCMC-like walk through proto-model space, randomly adding and removing particles and changing their properties

- The aim is to obtain a global view of (mutually consistent) small excesses in the data; can also determine global p-value for the SM

Proto-models are defined by their:

- ***Particle content****
- ***Masses***
- ***Decay modes***
- ***Signal strengths***

NB this gives a parameter space of varying dimensionality !

* BSM particles are assumed odd under a Z_2-type symmetry, so they are pair produced and cascade decay to the lightest state

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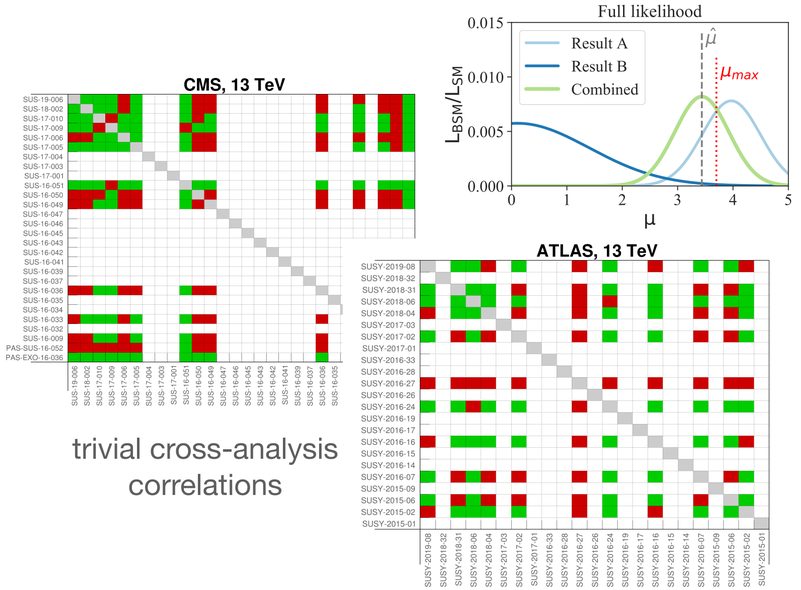

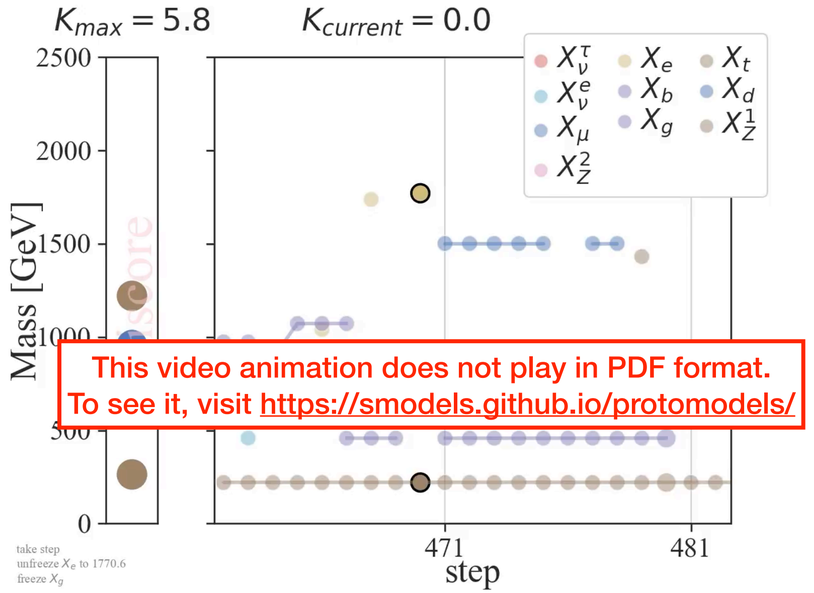

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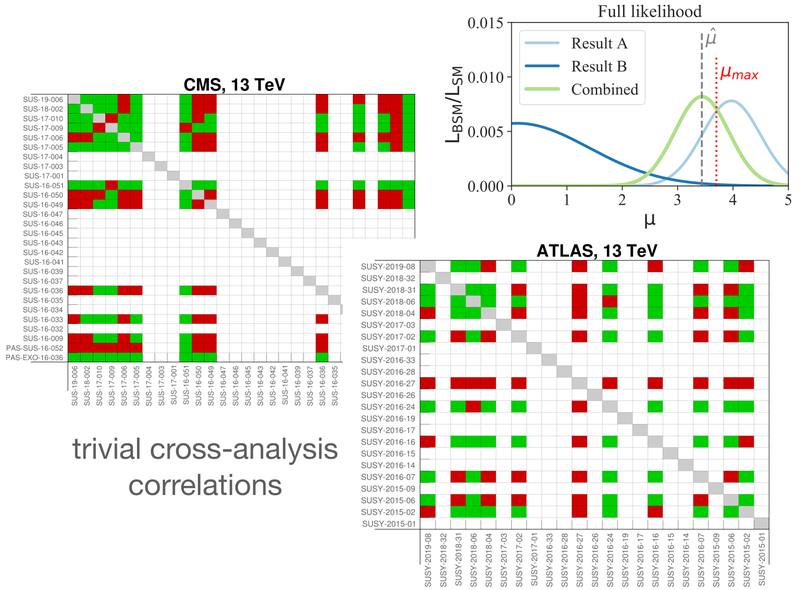

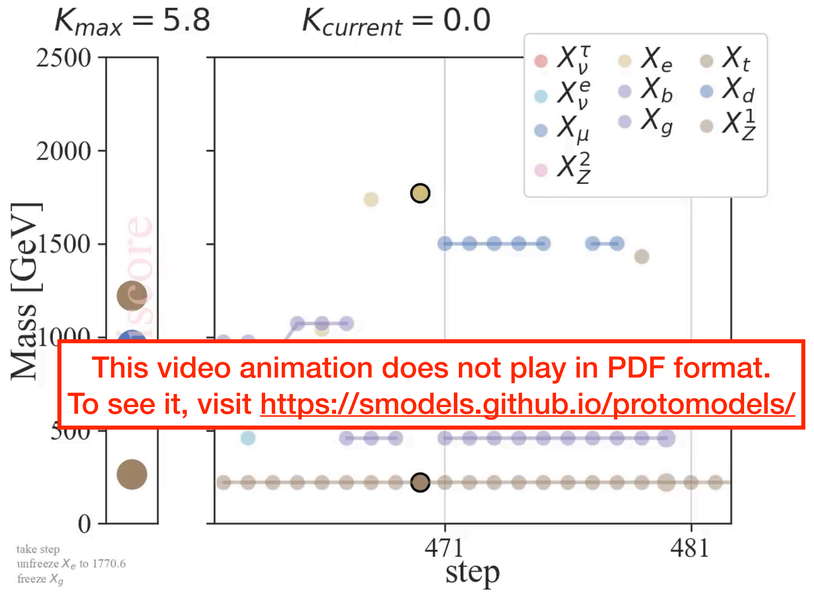

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TACO: Testing Analysis Correlations

- Growing need of combining results from different analyses for more global studies
  - systematically study “overlaps” between signal regions
  - automatically find orthogonal sets and
  - develop smart combination algorithm
- Best possible effort in case of simplified likelihoods
- Might go further with full likelihoods (and standardized naming conventions for nuisances)
- Small team w/ members of MA5, SModelS, Rivet, GAMBIT builds on Les Houches effort Jack Araz, Andy Buckley, Benjamin Fuks, Humberto Reyes-González, Wolfgang Waltenberger, Sophie Williamson, Jamie Yellen

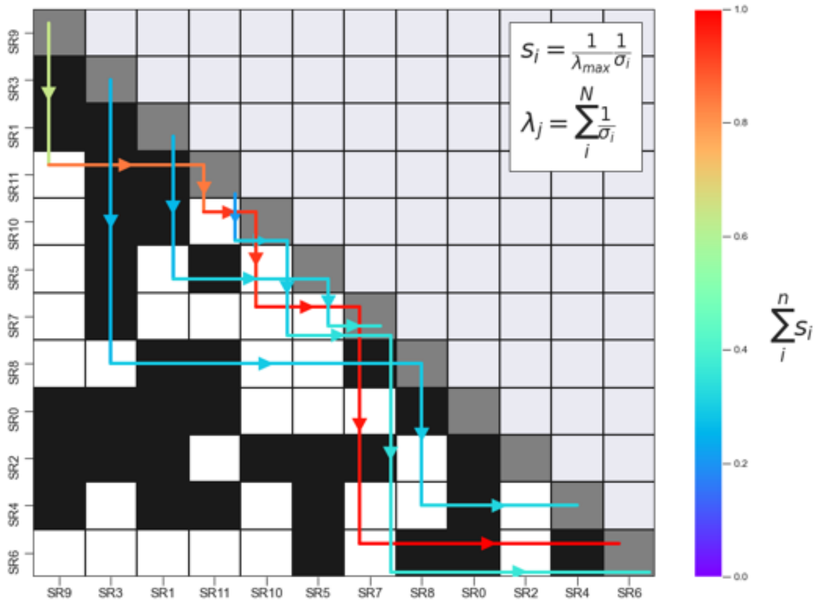

Illustration by Jamie Yellen

“Pathfinder” algorithm based on a depth-first search

Conclusions

- Lots of exciting new developments in tools for reinterpretation
  presented some highlights, personal bias, many aspects not covered in this talk

  - The field is moving toward exploiting full statistical models, analysis combinations, and generally toward data-driven global approaches
    replaces the “traditional” per-model, per-analysis or per-final-state testing

    - Reinterpretation tools are becoming more inter-connected
      → code sharing, inter-operability, …
      e.g. SModelS and MadAnalysis are already sharing their statistics code; ADL/cutLang validation with SModelS; pathfinder for optimal analysis combinations could be used by everyone; etc.

NB What can be achieved crucially depends on public material from the exp. collaborations

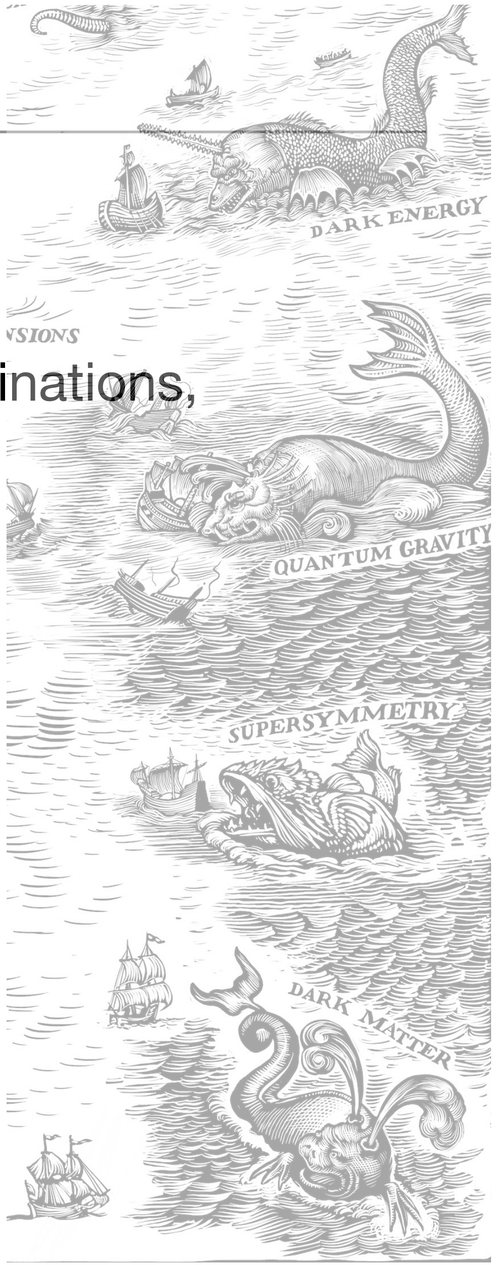

Illustration (c) C.Wormell from "A Map of the Invisible" by J.Butterworth

BACKUP

Combination of analyses in SModelS - comments

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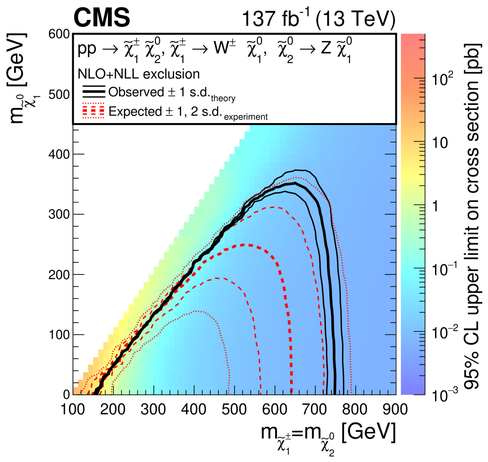
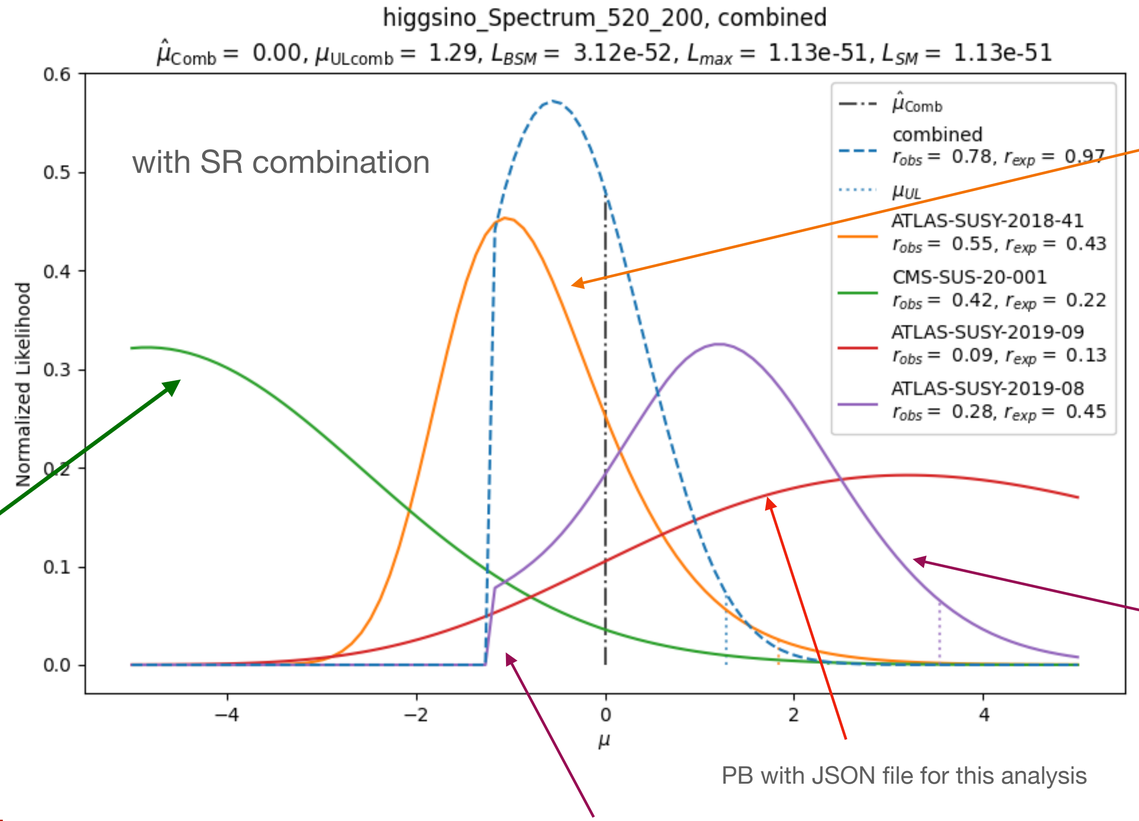


CMS 2 SFOS lept. EW-ino limit stronger than expected; n(obs) < n(exp) in 2 SRs

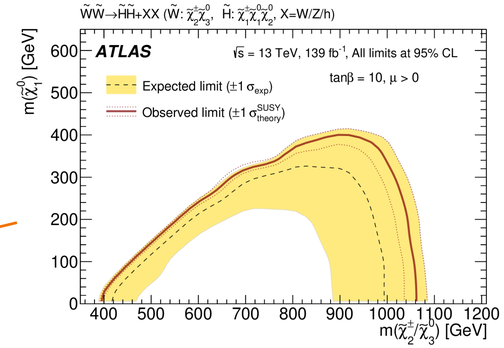
But only obs+exp ULs available, crude approximation of llhd

Need efficiency maps for CMS analyses, SUS-20-001, SUS-21-002, etc.

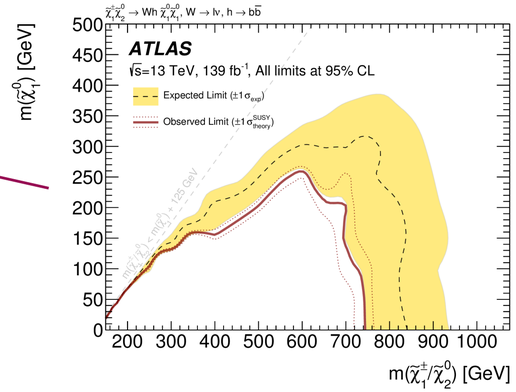


PB with JSON file for this analysis

pb: pyhf llhds often truncated ??



ATLAS fully hadronic EW-ino search dominates llhd; obs limit slightly stronger than exp.



ATLAS WH(→bb)+MET, small excess;

Beware of pre-fit vs post-fit expected limits!

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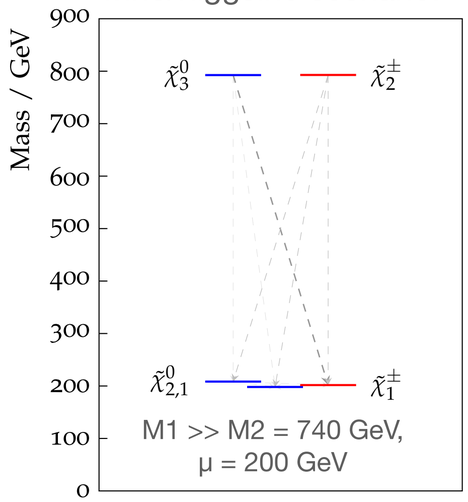

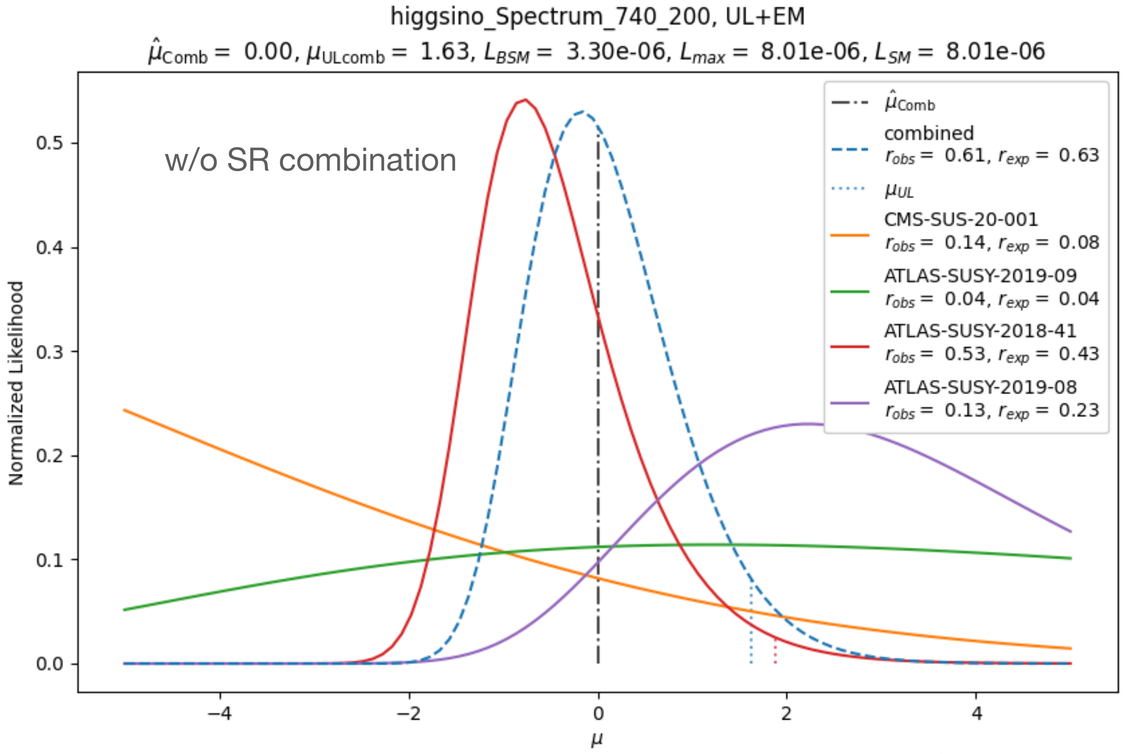

Plot by Timothée Pascal

Would appreciate efficiency maps for CMS-SUS-20-001 and 21-002 !!

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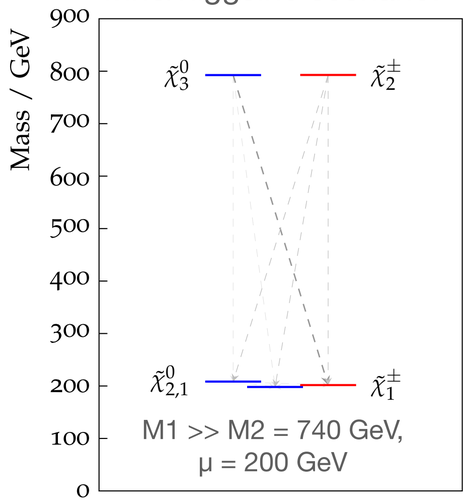

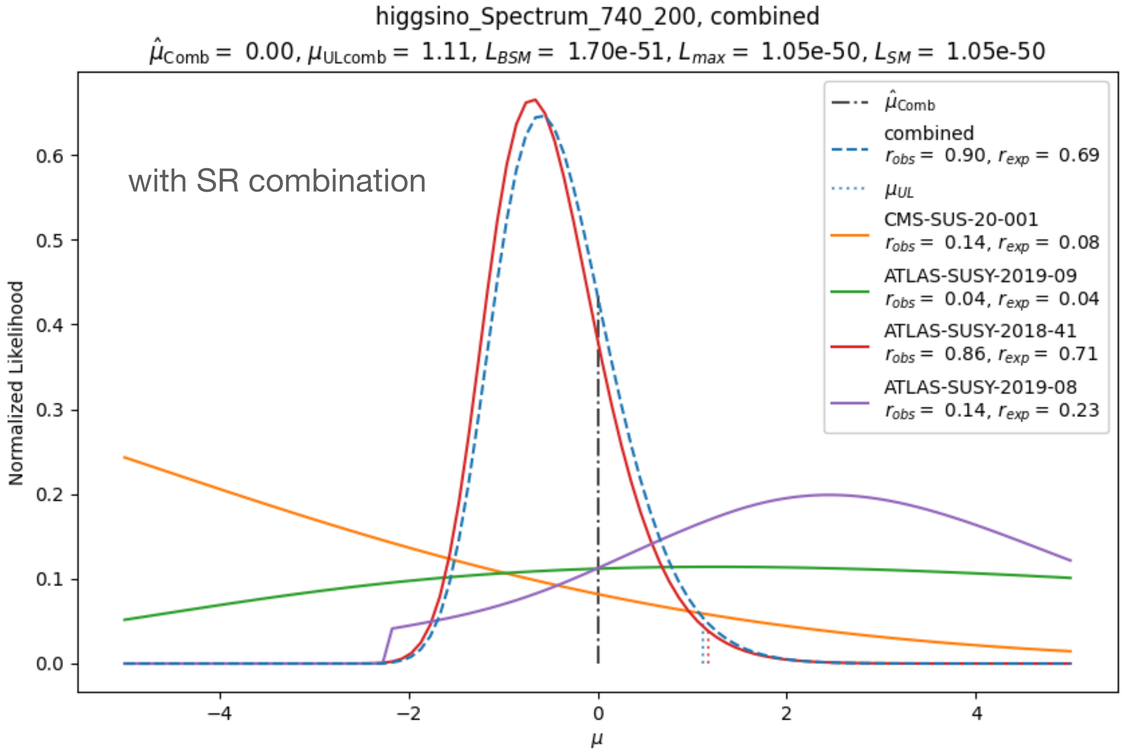

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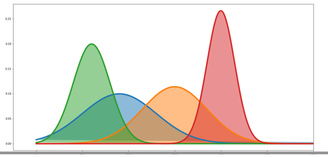
Plot by Timothée Pascal

Likelihoods for individual analyses



Key to the statistical learning procedure is the construction of a likelihood for the hypothesised signal (the proto-model)

$$\mathrm{L}_{\mathrm{BSM}}(\mu|D) = \mathrm{L}\left(D|\mu + b + \theta\right) p(\theta)$$

μ … signal
b … background
$p(\theta)$ … pdf of nuisances

- For **efficiency-map (EM)** results, we can compute a *simplified likelihood* for each signal region, assuming a Poisson distribution for the data and a Gaussian with variance of δ^2 for the nuisances, $p(\theta)$:

$$\mathrm{L}_{\mathrm{BSM}}(\mu|D) = \frac{(\mu + b + \theta)^{n_{\mathrm{obs}}} e^{-(\mu+b+\theta)}}{n_{\mathrm{obs}}!} \exp\left(-\frac{\theta^2}{2\delta^2}\right)$$

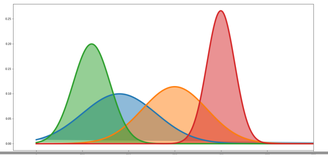
$\delta^2 = \delta_s^2 + \delta_b^2$
signal+background uncertainties

  - CMS sometimes provides a covariance matrix, which allows the combination of signal regions.
  - ATLAS has started to provide *full likelihoods* (JSON format), making the above approximation unnecessary.

- For **upper limit (UL) maps**, if observed+expected ULs are available: L_{BSM} ~ truncated Gaussian (nb: crude approx!!)

  ⚠ If only the observed UL is available → constraint in the form of a step function at the observed 95% CL limit.
  Not useful for constructing L_{BSM} per se; only used to determine the maximal allowed signal strength μ_{max} (in the critic).

Likelihoods for individual analyses -2-



Truncated Gaussian approximation (for UL results, if observed+expected ULs are available)

normalization constant

Cross section of the protomodel

chosen such that the 95% CL observed limit on the cross section is reproduced

$$\mathrm{L}(\mu|D) = \frac{c}{\sqrt{2\pi}\,\boldsymbol{\sigma}_{\mathrm{obs}}}\,\sigma_{\mathrm{ref}}\, e^{-(\mu\sigma_{\mathrm{ref}}-\sigma_{\mathrm{max}})^2/2\boldsymbol{\sigma}^2_{\mathrm{obs}}},\ \text{for}\ \mu \geq 0$$

$$\boldsymbol{\sigma}_{\mathrm{obs}} \approx \boldsymbol{\sigma}_{\mathrm{exp}} = \frac{\sigma^{\mathrm{UL}}_{\mathrm{exp}}}{1.96}$$

approximated with the standard deviation of the *expected* Gaussian likelihood

In most cases only a crude approximation to real L_{BSM}, can't expect this to be reliable for sizeable excesses, i.e. when observed and expected UL are very different. Therefore we "cap" deviations by setting $\sigma^{\mathrm{UL}}_{\mathrm{obs}} \leq \sigma^{\mathrm{UL}}_{\mathrm{exp}} + 2\boldsymbol{\sigma}_{\mathrm{exp}}$.

What is implemented where …

ATLAS analyses, 13 TeV

Analysis	Short Description
ATLAS-SUSY-2015-06	Multijet + missing transverse momentum (3.2 fb-1)
ATLAS-SUSY-2016-07	Multijet + missing transverse momentum (36.1 fb-1)
ATLAS-SUSY-2018-04	Staus in the ditau + met channel (139 fb-1)
ATLAS-SUSY-2018-06	Electroweakinos with Jigsaw variables (139 fb-1)
ATLAS-SUSY-2018-17	At least 8 jets + met (139 fb-1)
ATLAS-SUSY-2018-31	Sbottoms in the multibottom (including Higgs decays) + met channel (139 fb-1)
ATLAS-SUSY-2018-32	Electroweakinos/sleptons in the 2l + met channel (139 fb-1)
ATLAS-SUSY-2019-08	H (into b bbar) + 1 lepton + missing transverse momentum (139 fb-1)
ATLAS-EXOT-2015-03	Monojet (3.2 fb-1)
ATLAS-EXOT-2016-25	Mono-Higgs (36.1 fb-1)
ATLAS-EXOT-2016-27	Monojet (36.2 fb-1)
ATLAS-EXOT-2016-32	Monophoton (36.1 fb-1)
ATLAS-EXOT-2018-30	W' into lepton+neutrino (139 fb-1)
ATLAS-CONF-2016-086	b-pair + missing transverse momentum (13.3 fb-1)
ATLAS-CONF-2019-040	Jets + missing transverse momentum (139 fb-1)
ATLAS-CONF-2020-002	At least 8 jets + missing transverse momentum (139 fb-1)

CMS analyses, 13 TeV

Analysis	Short Description
CMS-SUS-16-033	Supersymmetry in the multijet plus missing energy channel (35.9 fb-1)
CMS-SUS-16-039	Electroweakinos in the SS2L, 3L and 4L channels (35.9 fb-1)
CMS-SUS-16-048	Compressed electroweakinos with soft leptons (35.9 fb-1)
CMS-SUS-16-052	SUSY in the 1l + jets channel (36 fb-1)
CMS-SUS-17-001	Stops in the OS dilepton mode (35.9 fb-1)
CMS-SUS-19-006	SUSY in the HT/missing HT channel (137 fb-1)
CMS-B2G-17-014	Vector-like quarks with charge 5/3 with same-sign dileptons (35.9/fb)
CMS-EXO-16-010	Mono-Z-boson (2.3 fb-1)
CMS-EXO-16-012	Mono-Higgs (2.3 fb-1)
CMS-EXO-16-022	Long-lived leptons (2.6 fb-1)
CMS-EXO-17-015	Leptoquarks + dark matter in the 1mu+1jet+met channel (77.4 fb-1)
CMS-EXO-17-030	Pairs of trijet resonances (35.9 fb-1)
CMS-EXO-19-002	Type-III seesaw and top-philic scalars with multileptons (137/fb)
CMS-EXO-20-004	Dark matter in the multi-jet+met channel (137 fb-1)
CMS-HIG-18-011	Exotic Higgs decay in the 2 muons + 2 b-jet channel via 2 pseudoscalars (35.9 fb-1)
CMS-TOP-17-009	SM four-top analysis (35.9 fb-1)
CMS-TOP-18-003	SM four-top analysis (137 fb-1)

SUSY, Exotics, Top, Higgs analyses
from ATLAS & CMS (16+16)
9 ATLAS, 4 CMS analyses for full Run 2 luminosity

☞ full llhd JSON file (ATLAS) or covariance matrix (CMS)

What is implemented where …

#Name	NSR	Description	Lumi
atlas_1609_01599	9	ttV cross section measurement at 13 TeV	3.2
atlas_1704_03848	5	monophoton dark matter search	36.1
atlas_conf_2016_013	10	4 top quarks (VLQ search)	3.2
atlas_conf_2017_060	20	monojet search	36.1
atlas_conf_2016_066	2	photons, jets and met	13.3
atlas_1712_08119	39	electroweakinos search with soft leptons	36.1
atlas_1712_02332	24	squarks and gluinos, 0 lepton, 2-6 jets	36.1
atlas_1709_04183	14	stop pair production, 0 leptons	36.1
atlas_1802_03158	7	GMSB with photons	36.1
atlas_1708_07875	2	electroweakino search with taus and MET	36.1
atlas_1706_03731	19	same-sign or 3 leptons RPC and RPV SUSY	36.1
atlas_1908_08215	16	charginos/sleptons, 2 leptons + MET	139
atlas_1909_08457	5	squarks and gluinos with same-sign leptons	139
atlas_conf_2019_040	70	squarks and gluinos in MET_jet final states	139
atlas_conf_2019_020	2	chargino-neutralinos, EW-scale mass splittings	139
atlas_1803_02762	20	electroweakinos, 2-3 leptons	36.1
atlas_conf_2018_041	10	gluinos decaying via 3rd gen; multi b-jets and MET	79.8
atlas_2101_01629	32	squarks/gluinos, 1 lepton, jets, MET	139
atlas_conf_2020_048	26	dark matter with monojets	139
atlas_2004_14060	9	stops, leptoquarks, 0 lepton	139
atlas_1908_03122	10	0 leptons, 3 or more b-jets, sbottoms	139
atlas_1911_12606	87	sleptons and electroweakinos with soft leptons	139
atlas_1807_07447	633	general new phenomena	3.2
atlas_2103_11684	2	SUSY in events with four or more leptons (gravitino SR)	139
atlas_2004_10894	12	EWino search in Higgs (diphoton) and met	139
atlas_2106_09609	21	RPV SUSY in final states with leptons and many jets	139
atlas_1911_06660	2	direct stau production	139
cms_sus_16_025	14	electroweakino and stop compressed spectra	12.9
cms_sus_16_039	158	electrowekinos in multilepton final state	35.9
cms_sus_16_048	20	two soft opposite sign leptons	35.9

- Total 45 analyses at 13 TeV
- **13 ATLAS searches for 139/fb**
- 7 future 14 TeV high lumi (ATLAS, using published projections)
- Model independent ATLAS search with 633 signal regions (counting objects)
  NB dedicated searches always do better.
- **Long-lived particle searches**
  - **Displaced vertex + MET** : ATLAS 1710.04901
  - **Displaced vertex + μ** : ATLAS 2003.11956
  - **Heavy Charged track** : ATLAS 1902.01636
  - **Displaced Leptons** : CMS 1409.4789 PAS-EXO-16-022
  - **Disappearing track** : ATLAS 1712.02118

What is implemented where …

info Anders Kvellestad

New searches in ColliderBit (in GAMBIT 2.1)

139 /fb searches:

- arxiv:2010.14293 : ATLAS jets + MET, 139 /fb
- arxiv:2102.01444 : ATLAS 2 OS leptons + jets + MET (stop search), 139 /fb
- arxiv:2006.05880 : ATLAS H/Z + jets + MET (stop search), 139 /fb
- arxiv:1909.08457 : ATLAS 2/3 leptons + jets + MET, 139 /fb
- arxiv:1908.08215 : ATLAS 2 OS leptons + MET (chargino/slepton search), 139 /fb
- arxiv:2103.11684 : ATLAS 4 leptons + MET, 139 /fb
- arxiv:2102.10874 : ATLAS monojet + MET, 139 /fb
- arxiv:1908.04722 : CMS jets + MET, 137 /fb
- arxiv:2001.10086 : CMS 2/3 leptons + jets + MET, 137 /fb

80 /fb searches (no corresponding 139 /fb version have been published)

- ATLAS-CONF-2018-019 : ATLAS Z + photon + MET, 80 /fb

36 /fb searches (no corresponding 139 /fb searches have been published)

- arxiv:1711.08008 : CMS 1 photon + MET, 36 /fb
- arxiv:1812.04066 : CMS 1 photon + 1 lepton + MET, 36 /fb
- arxiv:1903.07070 : CMS 2 photons + MET, 36 /fb

…. plus older analyses in previous versions

- 9 analyses for full Run 2 luminosity in recent GAMBIT releases
- The main new development is integration with GUM (**Gambit Universal Models**) framework*
- Ongoing efforts:
  - ColliderBit interface to Contur/Rivet
  - Enable use of ATLAS full likelihoods (CMS simplified likelihoods already in use)
  - Release of ColliderBit Solo

62 ATLAS and CMS Run 2 analyses in SModelS 2.1.0 database

LLP searches

ID	Short Description	$\mathcal{L}$ [fb^{-1}]	UL$_{obs}$	UL$_{exp}$	EM	comb.
ATLAS-SUSY-2015-01 [62]	2 b-jets	3.2	✓			
ATLAS-SUSY-2015-02 [63]	1ℓ stop	3.2	✓		✓	
ATLAS-SUSY-2015-06 [64]	0ℓ + 2–6 jets	3.2			✓	
ATLAS-SUSY-2015-09 [65]	jets + 2 SS or $\geq 3\ell$	3.2	✓			
ATLAS-SUSY-2016-06 [66]	disappearing tracks	36.1			✓	
ATLAS-SUSY-2016-07 [67]	0ℓ + jets	36.1	✓		✓	
ATLAS-SUSY-2016-08 [68]	displaced vertices	32.8	✓			
ATLAS-SUSY-2016-14 [69]	2 SS or 3 ℓ's + jets	36.1	✓			
ATLAS-SUSY-2016-15 [70]	0ℓ stop	36.1	✓			
ATLAS-SUSY-2016-16 [71]	1ℓ stop	36.1	✓		✓	
ATLAS-SUSY-2016-17 [72]	2 OS leptons	36.1	✓			
ATLAS-SUSY-2016-19 [73]	2 b-jets + τ's	36.1	✓			
ATLAS-SUSY-2016-24 [74]	2–3 ℓ's, EWino	36.1	✓		✓	
ATLAS-SUSY-2016-26 [75]	≥ 2 c-jets	36.1	✓			
ATLAS-SUSY-2016-27 [76]	jets + γ	36.1	✓		✓	
ATLAS-SUSY-2016-28 [77]	2 b-jets	36.1	✓			
ATLAS-SUSY-2016-32 [44]	HSCP	31.6	✓	✓	✓	
ATLAS-SUSY-2016-33 [78]	2 OSSF ℓ's	36.1	✓			
ATLAS-SUSY-2017-01 [79]	$WH(bb)$, EWino	36.1	✓			
ATLAS-SUSY-2017-02 [80]	0ℓ + jets	36.1	✓	✓		
ATLAS-SUSY-2017-03 [21]	multi-ℓ EWino	36.1	✓		✓	
ATLAS-SUSY-2018-04 [81]	2 hadronic taus	139.0	✓		✓	JSON
ATLAS-SUSY-2018-06 [22]	3 leptons, EWino	139.0	✓	✓	✓	
ATLAS-SUSY-2018-10 [17]	1ℓ + jets	139.0	✓		✓	
ATLAS-SUSY-2018-12 [19]	0ℓ + jets	139.0	✓	✓	✓	
ATLAS-SUSY-2018-14 [15]	displaced leptons	139.0			✓	JSON
ATLAS-SUSY-2018-22 [18]	multi-jets	139.0	✓		✓	
ATLAS-SUSY-2018-23 [20]	$WH(\gamma\gamma)$, EWino	139.0	✓	✓		
ATLAS-SUSY-2018-31 [82]	$2b + 2H(bb)$	139.0	✓		✓	JSON
ATLAS-SUSY-2018-32 [59]	2 OS leptons	139.0	✓			
ATLAS-SUSY-2019-08 [60]	1ℓ + $H(bb)$, EWino	139.0	✓		✓	JSON

ID	Short Description	$\mathcal{L}$ [fb^{-1}]	UL$_{obs}$	UL$_{exp}$	EM	comb.
CMS-PAS-EXO-16-036 [83]	HSCP	12.9	✓			
CMS-PAS-SUS-16-052 [84]	ISR jet + soft ℓ	35.9	✓		✓	Cov.
CMS-SUS-16-009 [85]	0ℓ + jets, top tag	2.3	✓	✓		
CMS-SUS-16-032 [86]	2 b- or 2 c-jets	35.9	✓			
CMS-SUS-16-033 [87]	0ℓ + jets	35.9	✓	✓	✓	
CMS-SUS-16-034 [88]	2 OSSF leptons	35.9	✓			
CMS-SUS-16-035 [89]	2 SS leptons	35.9	✓			
CMS-SUS-16-036 [90]	0ℓ + jets	35.9	✓	✓		
CMS-SUS-16-037 [91]	1ℓ + jets with MJ	35.9	✓			
CMS-SUS-16-039 [92]	multi-ℓ, EWino	35.9	✓			
CMS-SUS-16-041 [93]	multi-ℓ + jets	35.9	✓			
CMS-SUS-16-042 [94]	1ℓ + jets	35.9	✓			
CMS-SUS-16-043 [95]	$WH(bb)$, EWino	35.9	✓			
CMS-SUS-16-045 [96]	2 b + 2 $H(\gamma\gamma)$	35.9	✓			
CMS-SUS-16-046 [97]	high-p_T γ	35.9	✓			
CMS-SUS-16-047 [98]	γ + jets, high H_T	35.9	✓			
CMS-SUS-16-049 [99]	0ℓ stop	35.9	✓	✓		
CMS-SUS-16-050 [100]	0ℓ + top tag	35.9	✓	✓		
CMS-SUS-16-051 [101]	1ℓ stop	35.9	✓	✓		
CMS-SUS-17-001 [102]	2ℓ stop	35.9	✓			
CMS-SUS-17-003 [103]	2 taus	35.9	✓			
CMS-SUS-17-004 [58]	EWino combination	35.9	✓			
CMS-SUS-17-005 [104]	1ℓ + jets, top tag	35.9	✓	✓		
CMS-SUS-17-006 [105]	jets + boosted $H(bb)$	35.9	✓	✓		
CMS-SUS-17-009 [106]	SFOS leptons	35.9	✓	✓		
CMS-SUS-17-010 [107]	2ℓ stop	35.9	✓	✓		
CMS-SUS-18-002 [108]	γ + (b-)jets, top tag	35.9	✓	✓		
CMS-SUS-19-006 [109]	0ℓ + jets, MHT	137.0	✓	✓		
CMS-SUS-19-009 [110]	1ℓ + jets, MHT	137.0	✓			
CMS-EXO-19-001 [111]	non-prompt jets	137.0			✓	
CMS-EXO-19-010 [10]	disappearing tracks	101.0			✓	

UL = cross section upper limit maps; EM = efficiency maps

Full likelihoods

DB v2.2.0: + new results from 4 ATLAS and 11 CMS analyses

https://github.com/ADL4HEP/ADLLHCanalyses

ADL : Analysis Description Language for LHC physics

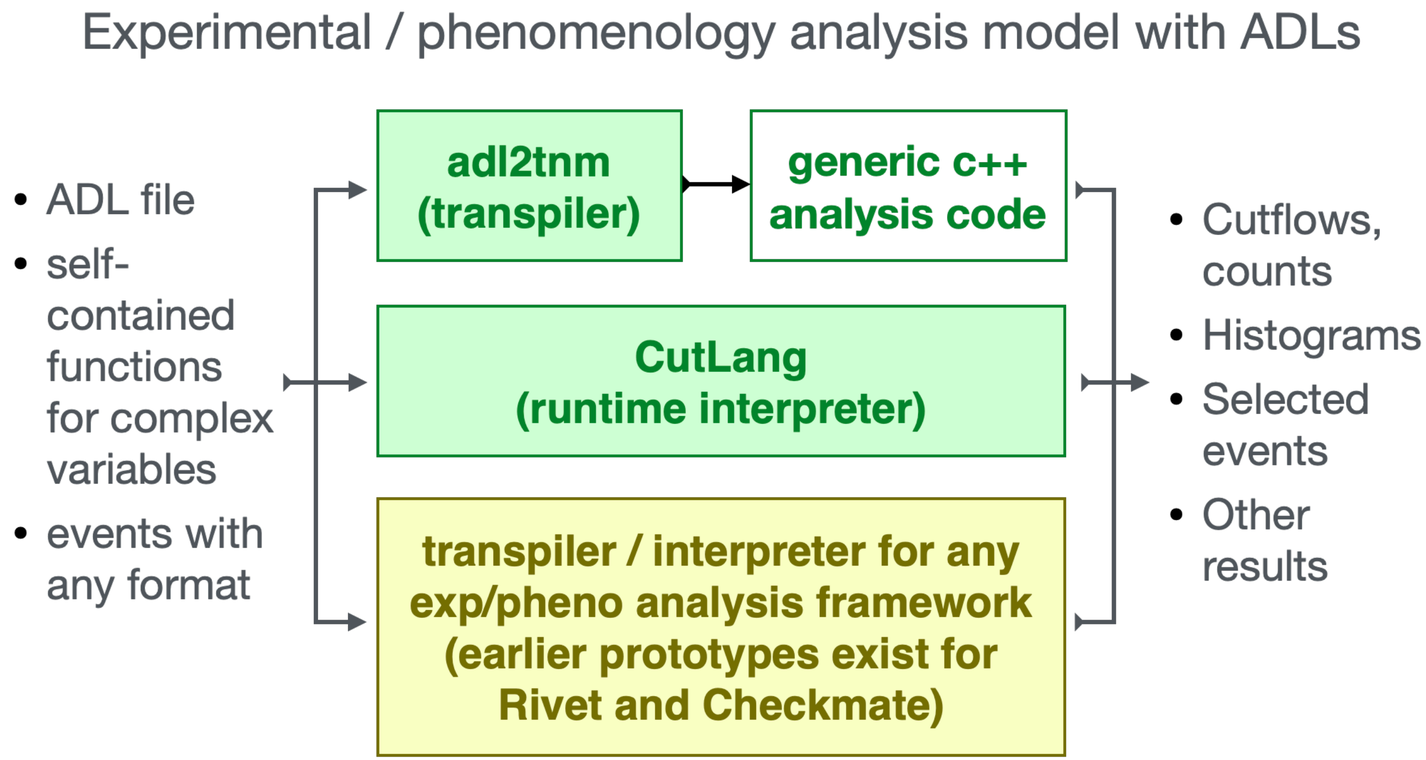
Analysis Description Language (ADL) is a domain specific, declarative language for describing event selections; analyses are written in plain text files separating object, variable and event selection definitions in blocks following a keyword-value structure, where keywords specify analysis concepts and operations.

ADL is a language, independent of software frameworks:

(—> Any framework recognizing ADL can run analyses written in ADL).

- Communicate analyses easily between groups, exp, pheno, students, public.
- Currently **two interpreters** can **parse and run ADL** analyses:

  adl2tnm and CutLang
- Works with various event formats including Delphes, CMS nanoaod, several open data formats, etc.
- Very interesting for long-term preservation



Curtesy Sezen Sekmen

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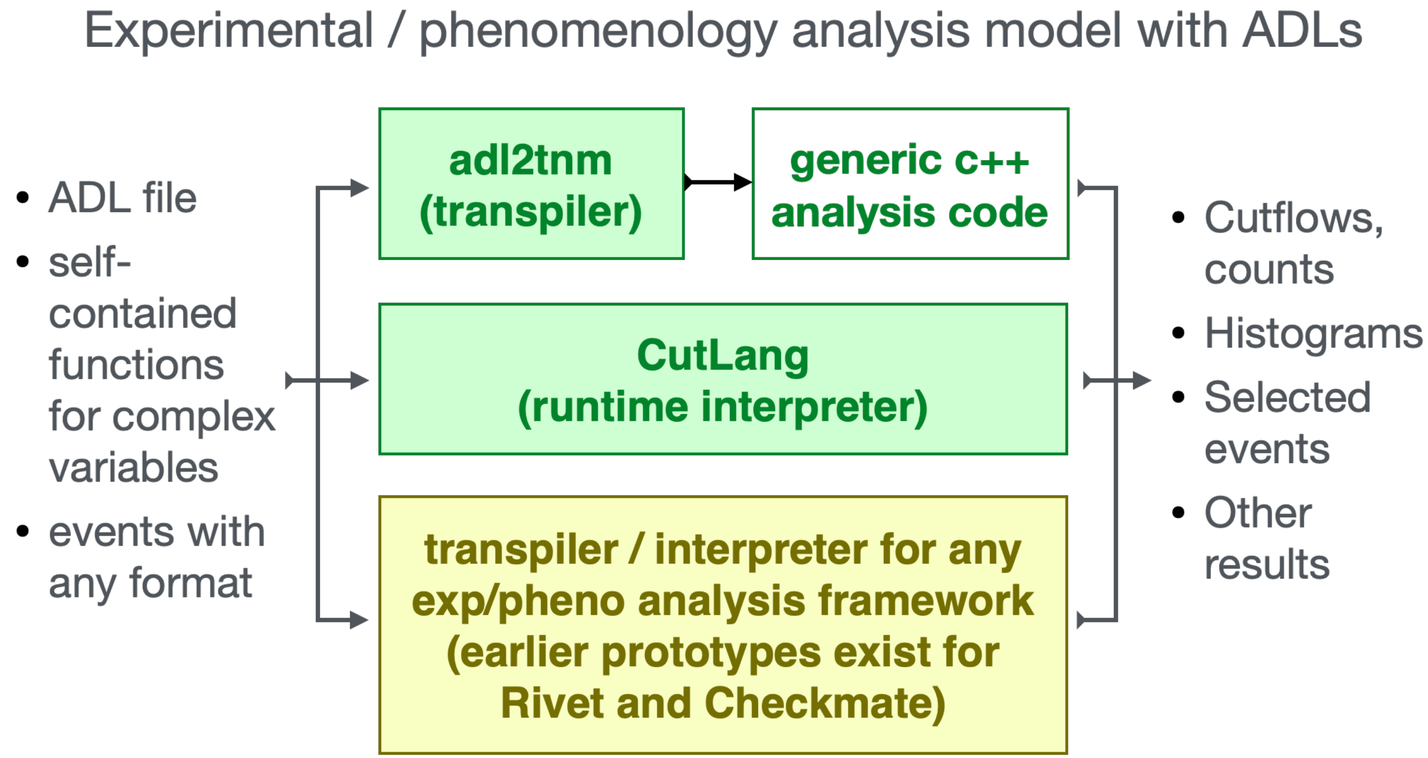
being validated via interface to SModelS

- ATLAS-EXOT-2016-32
- CMS-OD-12350-Htautau
- CMS-SUS-16-017
- CMS-SUS-16-032
- CMS-SUS-16-033
- CMS-SUS-16-035
- CMS-SUS-16-037
- CMS-SUS-16-041
- CMS-SUS-16-042
- CMS-SUS-16-043
- CMS-SUS-16-046
- CMS-SUS-16-047
- CMS-SUS-16-048
- CMS-SUS-16-049
- CMS-SUS-19-005
- CMS-SUS-19-006



Curtesy Sezen Sekmen