LHC recasting tools and approaches

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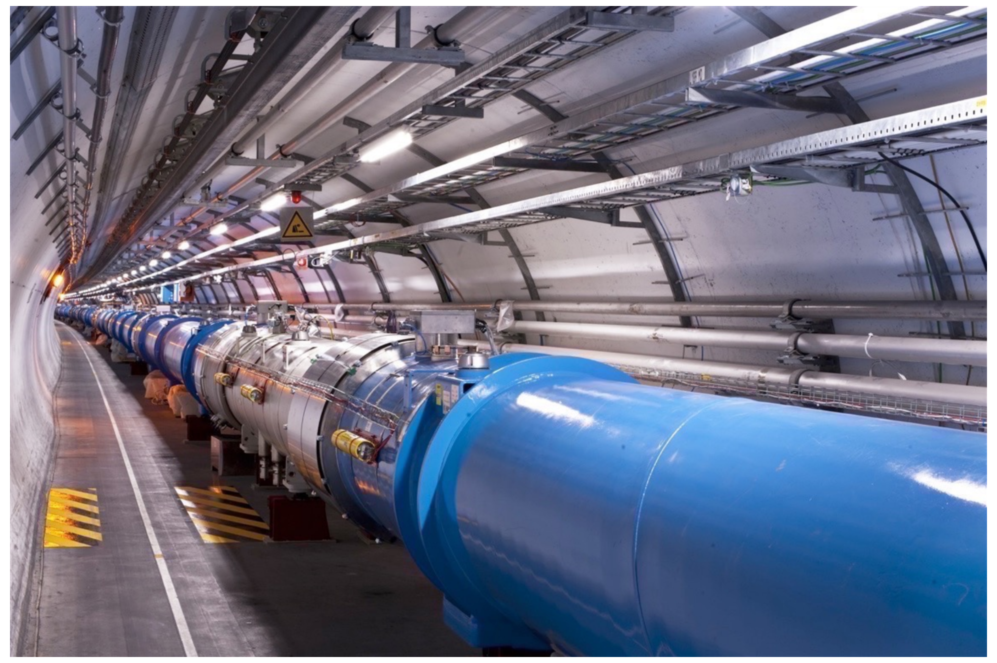
Computational Tools for High Energy Physics and Cosmology (Tools2021) 22-26 Nov 2021 IP2I, Lyon

Motivation

- **Experiments** at the LHC are searching for new phenomena **beyond the SM (BSM)** in many different channels
- **Results** are interpreted by the experimental collaborations in terms of simplified models, and/or specific theoretical scenarios

  n.b. mostly on an analysis-by-analysis basis
- However, a particular analysis may **also constrain other models** than considered in the experimental publication
- A full (complex) theoretical model is often constrained by **more than one analysis**



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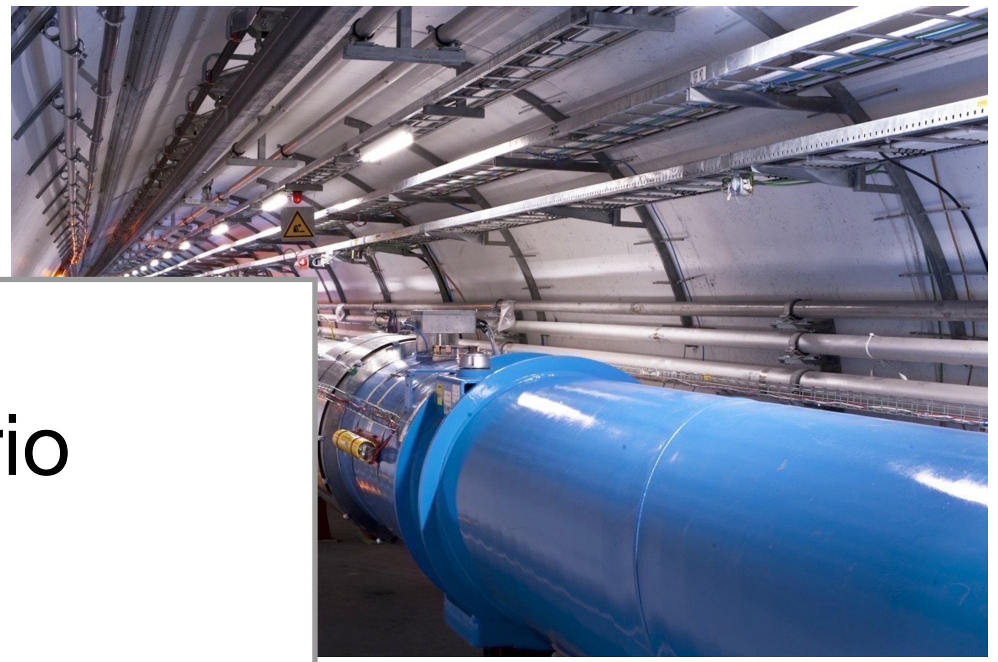
We want to be able to test any model or scenario against the plethora of LHC results :

- 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** ☜



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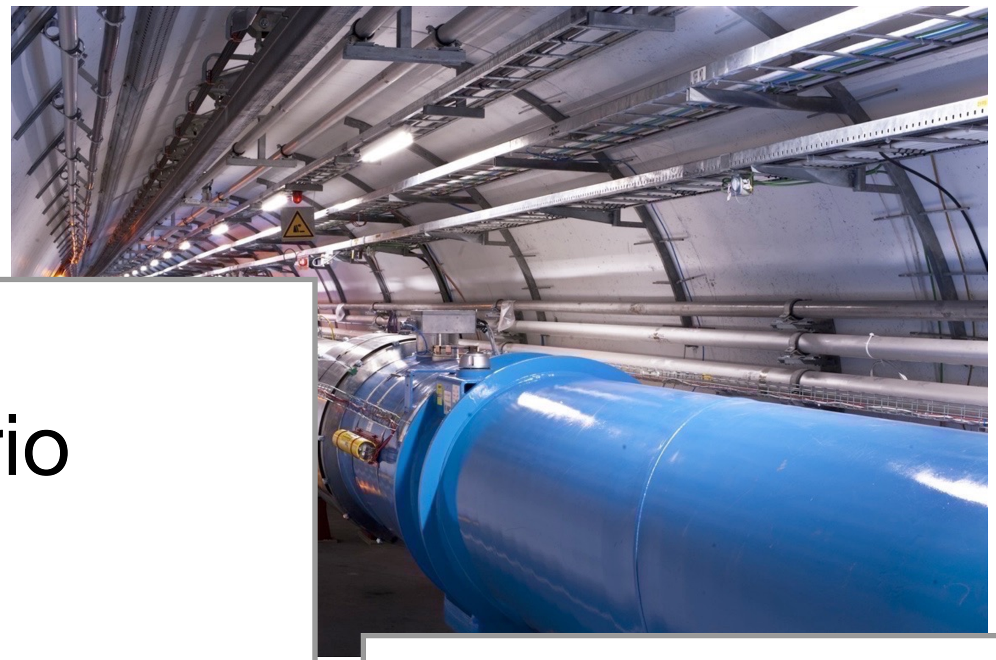

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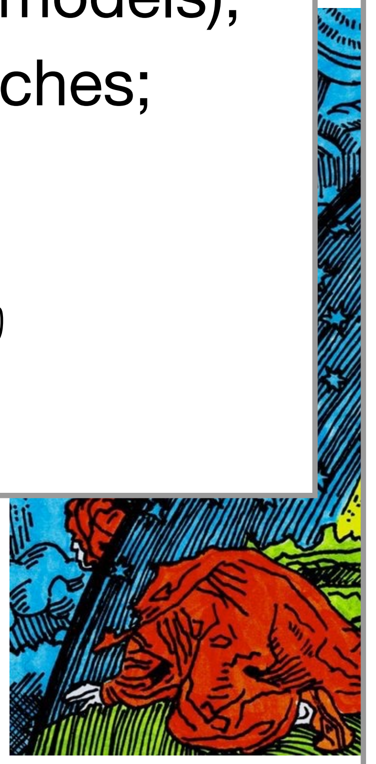


Science 2061

- Many members of the generation who may wish to re-analyze the LHC Run 3 data in 2061 have yet to be born.
- That generation may wish to re-analyze these data simultaneously with old LSST and LIGO data using BSM models that they invent from which (with the help of their AI assistants) they are able to compute testable predictions for LHC, LSST, and LIGO data.
- Now ask yourself: What are we doing wrong, or what are we forgetting, that risks thwarting such heroic efforts forty year hence?

H. Prosper at Reinterpretation Forum workshop, Feb. 2021

Aim of this talk

- Compare different approaches
- Give an overview of existing public tools
  (incl. those not represented in dedicated talks later today)
- Point out recent developments and future directions

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

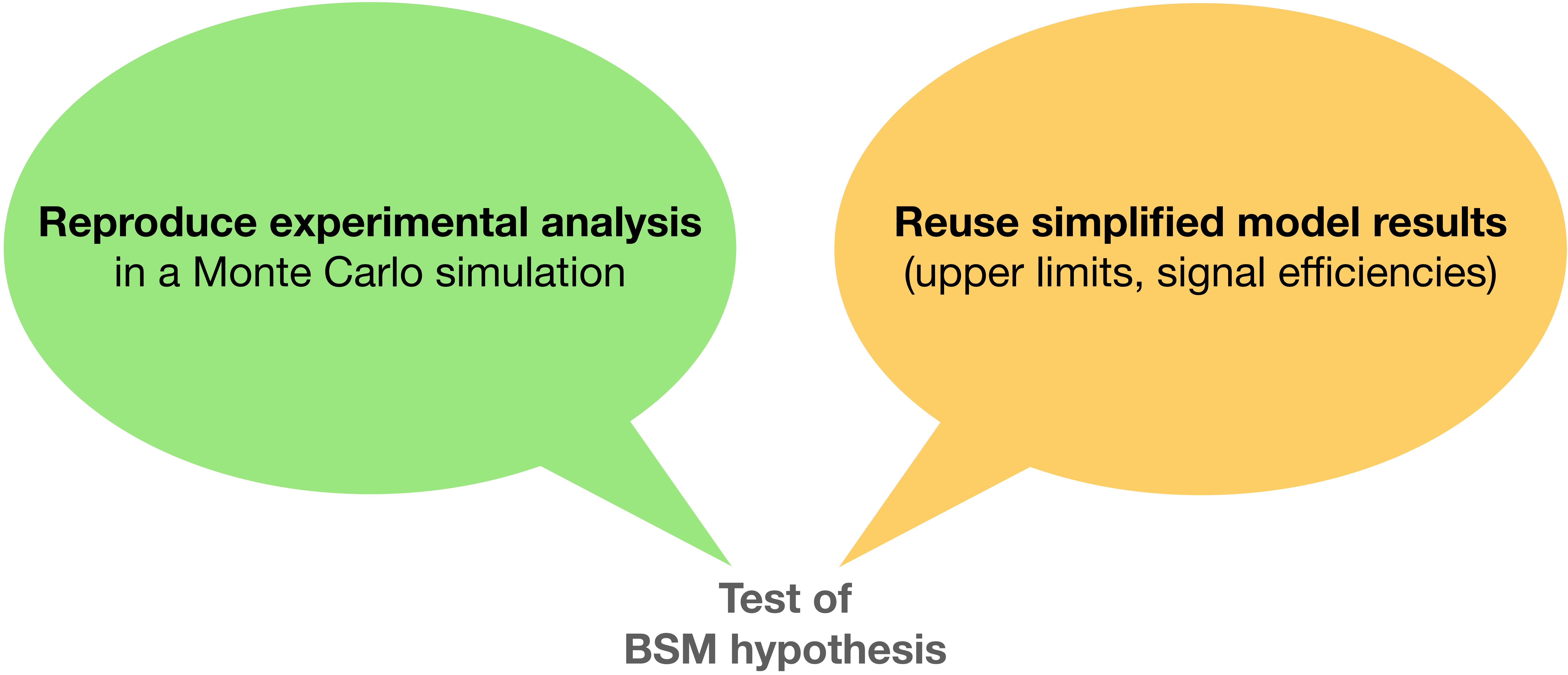
SciPost SciPost Phys. 9, 022 (2020)

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

The LHC BSM Reinterpretation Forum

arXiv:2003.07868

Two approaches



Tools for simulation-based recasting

Package	Experimental inputs	Event input	Detector simulation	Inference/Output
GAMBIT (ColliderBit)	Cut-flows, analysis logic, object-level efficiency functions, observed event numbers in signal regions, background covariance matrices	particle	BuckFast (smearing & efficiencies)	Detector-level distributions, signal region efficiencies, simplified likelihood for calculating exclusion limits/contours
CheckMATE	Cut-flows, analysis logic, object-level efficiency functions, observed event numbers in signal regions	particle, parton	Delphes	Detector-level distributions, signal region efficiencies, ratio of predicted to excluded cross-section
MadAnalysis 5	Cut-flows, analysis logic, object-level efficiency functions, observed event numbers in signal regions, background covariance matrices, JSON likelihoods	particle	Delphes; customisable smearing	Detector-level distributions, signal region efficiencies, $1 - \mathrm{CL}_s$ values
Rivet	Cut-flows, analysis logic, detector smearing & efficiency functions	particle	Customisable smearing	Truth/detector-level distributions
Contur	Unfolded (particle-level) differential cross-sections via Rivet	particle	N/A	Exclusion contours in BSM model space
ADL interpreters: adl2tnm, CutLang	analysis logic, external functions of complex variables, object or event level efficiencies	particle	External (Delphes, CMS and ATLAS simulations)	cutflows, event-by-event weights per region, histograms
Recast	Experiment-specific formats	parton	Experiment-owned (fast) simulation	*p*-values, upper limits, likelihood values

Tools using a simplified model approach

Package	Experimental inputs	Model input	Inference/Output
SModelS	Simplified-model cross-section upper limits and efficiency maps from SUSY searches, background covariance matrices	SLHA or LHE (any BSM model with Z_2-like symmetry)	Ratio of predicted to excluded cross-section, exclusion CL (if efficiency maps are available)
HiggsBounds	Model independent (exp. and obs.) 95% CL upper limits and exclusion likelihoods from BSM Higgs searches	masses, widths, cross-sections and BRs (or effective couplings) of all Higgs bosons	Ratio of predicted to excluded cross-section, allowed/excluded at 95% CL, χ^2 for specific searches
ZPEED	Observed event numbers in signal regions, background predictions, detector resolution and efficiencies	Model parameters	Likelihood values
DarkCast	Simplified-model production mechanism, cross-section upper limits or ratio map of observed to expected cross-sections for dark photon searches	couplings of new gauge bosons to the SM fermions	95% CL exclusion limits on couplings
DarkEFT	95% CL exclusion limits on dark sector searches and rare meson decay BRs	effective couplings for 4-fermion operators	95% CL exclusion limits on the effective coupling

Reinterpretation Forum report, sec. 3,
arXiv:2003.07868, SciPost Phys. 9, 022 (2020)

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CheckMATE	Cut-flows, analysis logic, object-level efficiency ↳ **Z. S. Wang, this morning**	particle, parton	Delphes	Detector-level distributions, signal region efficiencies, ratio of predicted to excluded cross-section
MadAnalysis 5	Cut-flows, analysis logic, object-level efficiency ↳ **Jack Araz, this morning** background covariance matrices, JSON likelihoods	particle	Delphes; customisable smearing	Detector-level distributions, signal region efficiencies, $1-\mathrm{CL}_s$ values
Rivet	Cut-flows, analysis logic, ↳ **Louie Corpe, this morning**	particle	Customisable smearing	Truth/detector-level distributions
Contur	Unfolded (particle-level) differential cross-sections via Rivet	particle	N/A	Exclusion contours in BSM model space
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Workflow

simulation-based recasting

Simulation of **hard scattering process(es)**
(e.g. MadGraph)
⬇
showering and hadronization,
incl. matching & merging
(e.g. Pythia)
⬇
emulation of **detector effects**:*
object reconstruction, efficiencies, …
(e.g. DELPHES)
⬇
application of **signal selection cuts**
(actual recast code)
⬇
statistical evaluation
(background numbers usually from exp. pub.)

* except for detector-unfolded results (Rivet/Contur)

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simplified model approach (SModelS)

Create **SLHA file**
with mass spectrum and decay tables
⬇
add **production cross sections**
(SModelS xseccomputer or micrOMEGAs)
⬇
compute all **signal weights** :
$\sigma \times BR \times BR \ldots$
⬇
sum **matching elements**
⬇
find and apply $A \times \varepsilon$ (or σ_{95}) values
from **experimental results**
⬇
statistical evaluation‡
(background numbers usually from exp. pub.)

‡ in case exp. result is σ_{95}: only allowed/excluded

Pro’s and con’s

Pro's and con's

- Assumes that **signal acceptances** are to good approximation **the same** as in original experimental result.

  Valid for **simple rescaling** of production and decay rates ($\sigma \times BR$); other cases need to be **verified**, e.g. spin or production mode dependence.

- Applicable beyond cut & count analyses
  (ML techniques)

- Advantages are simplicity and **speed!**
  → **very fast** b/c no MC simulation needed
  → well suited for large scans and model surveys

- **Large database** of experimental results

- ATLAS and CMS, Run1 and Run2, **prompt and long-lived results** all **treated simultaneously**

- Easy **classification of** unconstrained cross section, **missing topologies**

- **Often conservative:** coverage depends on variety of available simplified-model results

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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]	$\geq 2\,c$-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			✓	

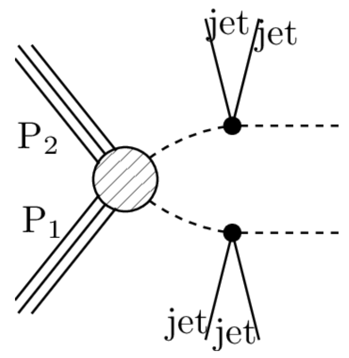
UL = cross section upper limit maps; EM = efficiency maps

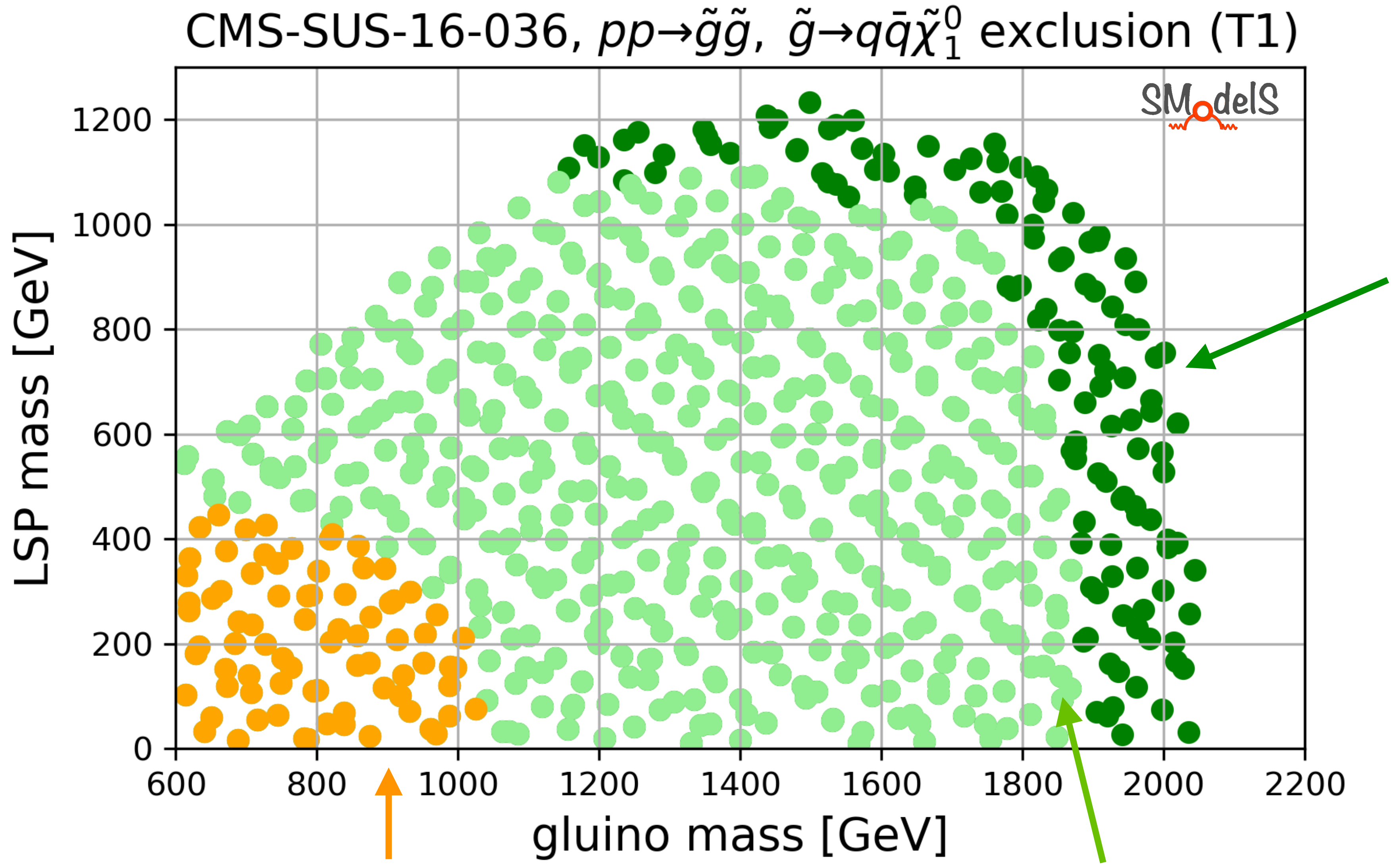
Full likelihoods

See talk by Gael Alguero

Coverage of total BSM cross section limited by variety and kind of simplified model results

- most simplified model results are for symmetric topologies and
- many only available as upper limits





Dirac gluino: Xsection x2

If only 10% $\tilde{g}$ decay directly to qq+LSP

Majorana gluino
decoupled squarks

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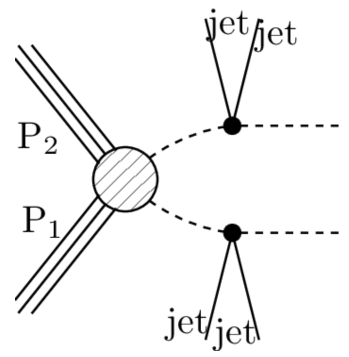

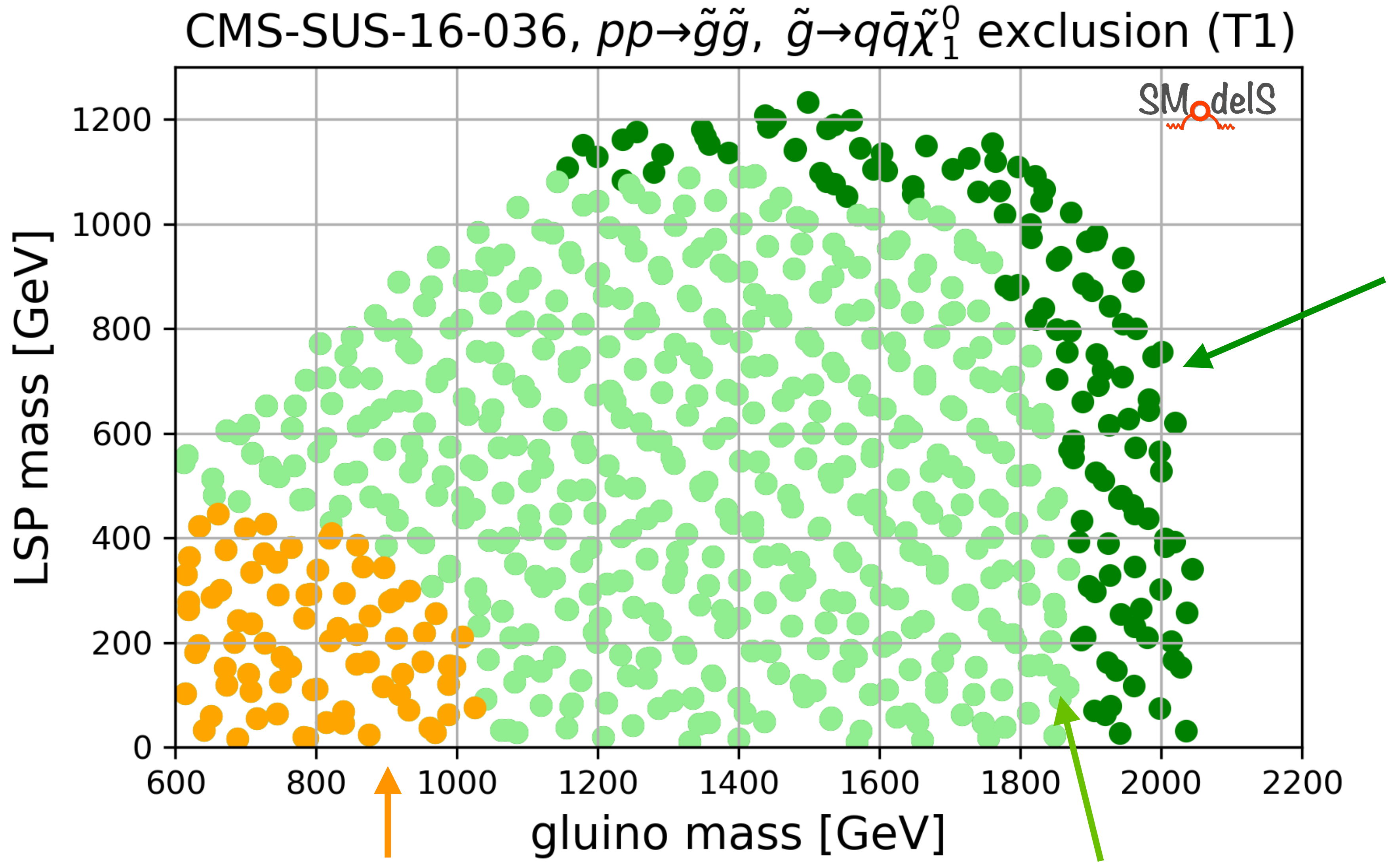

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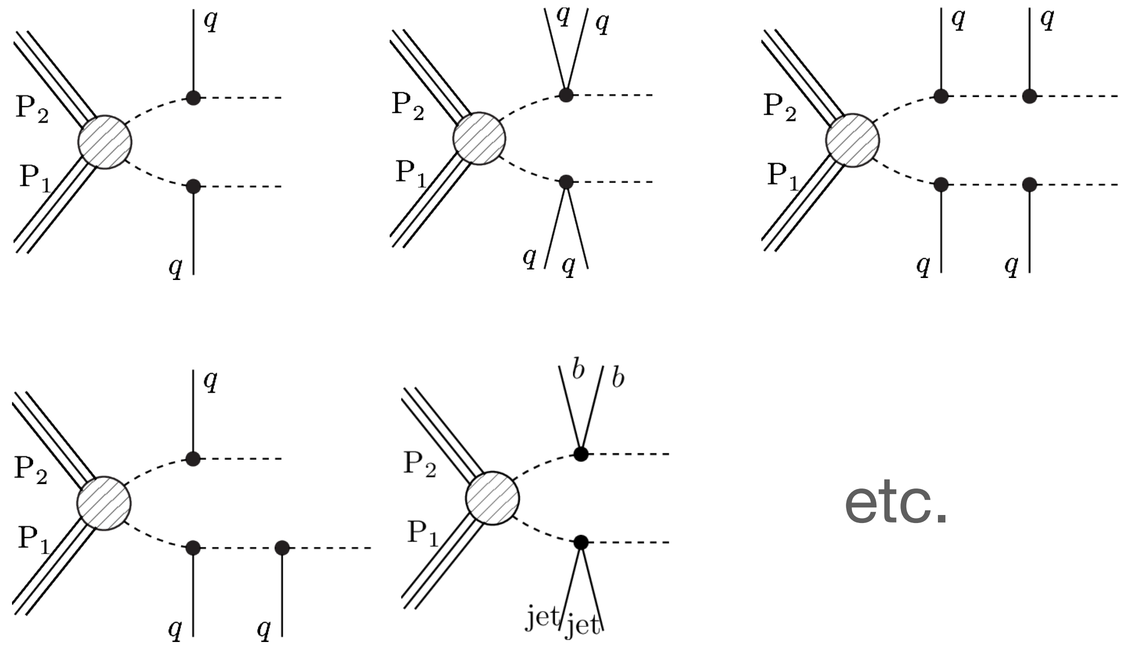
Need efficiency maps for a variety of simplified models to be able to sum different contributions to the same signal region



etc.

→ Limit on Σ(A×ε)×σ×BR

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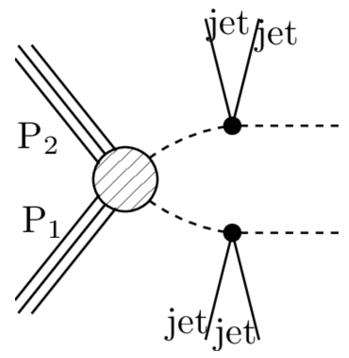

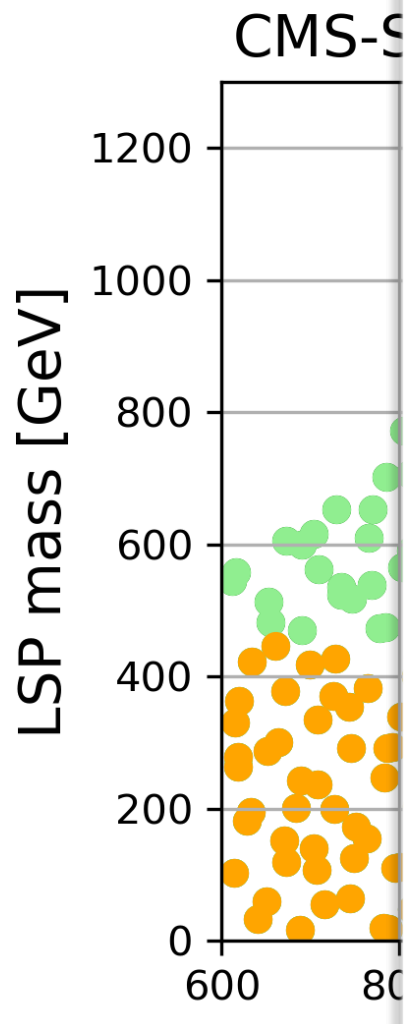

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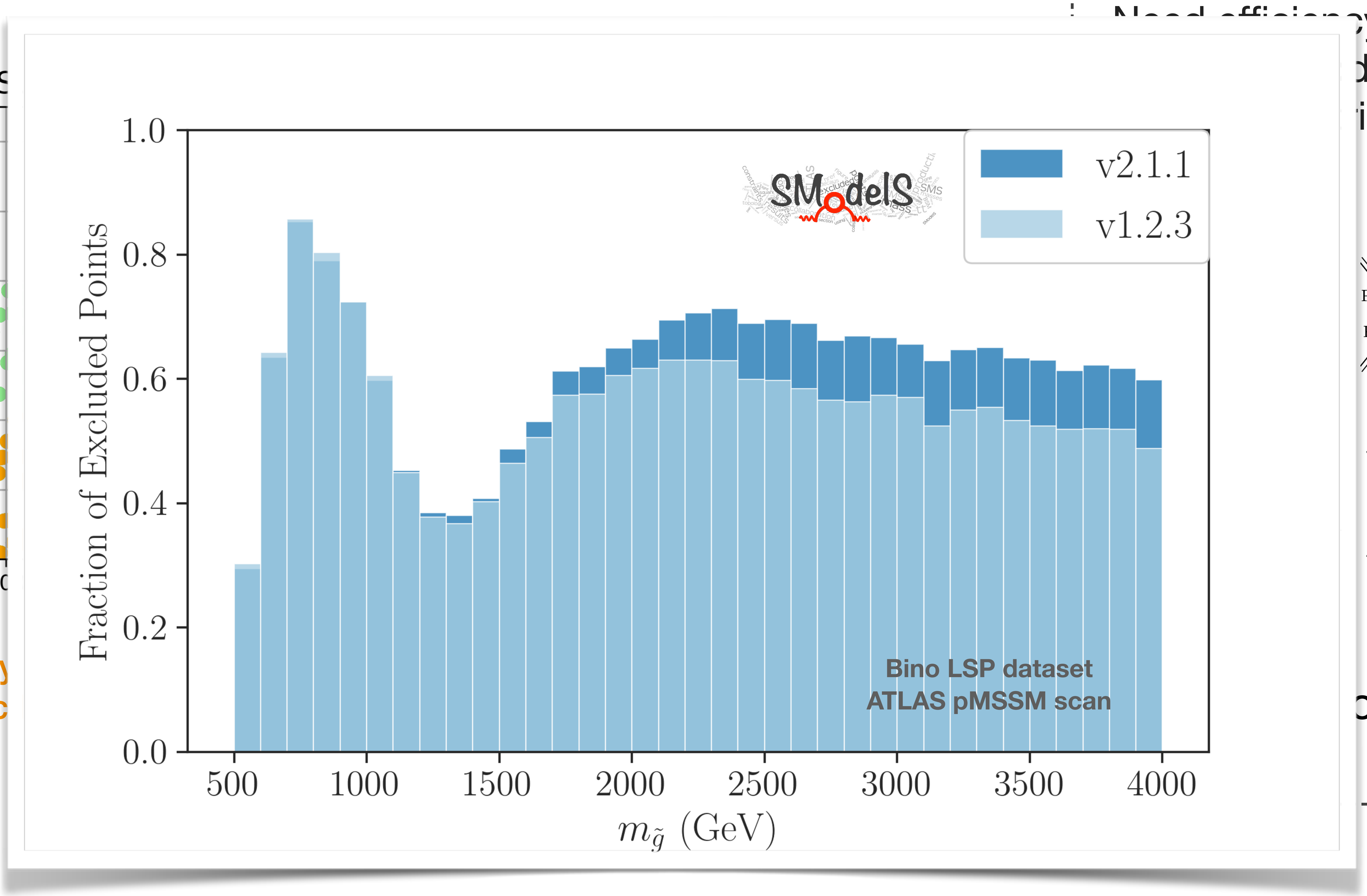

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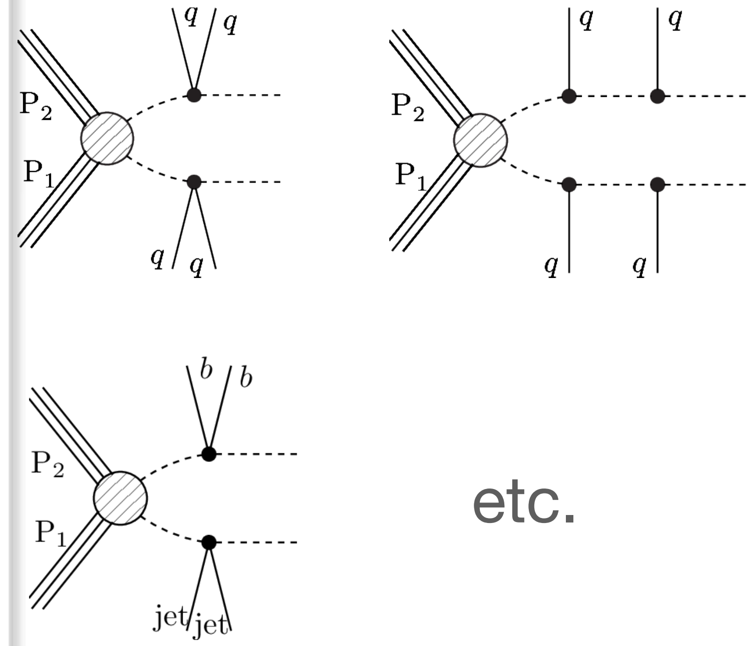

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on Σ(A×ε)×σ×BR

Pro’s and con’s

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Simulation of **hard scattering process(es)**
(e.g. MadGraph)

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Showering and hadronization,
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emulation of **detector effects**:
object reconstruction, efficiencies, …
(e.g. DELPHES)

⬇

application of **signal selection cuts**
(actual recast code)

⬇

statistical evaluation
(background numbers usually from exp. pub.)

- **More generic** and often **more precise** than simplified model results; in principle applicable to any new signal
  caveat: control regions typically not included in react codes!
- Need to take care to **simulate all relevant processes**
  (not always obvious e.g. in scans of complex parameters spaces where dominant processes can change)
- **Very CPU expensive**
- So far **only cut-and-count** analyses are recasted
- **ATLAS / CMS** as well as Run1 (8 Tev) / Run 2 (13 TeV) analyses need to be **run separately**
- So far, **prompt and long-lived signatures need to be treated separately**
  → careful separation needed in models featuring both
  → response of prompt analyses to LLPs unclear / wrong
- Implementation and validation of new analyses is time-consuming and sometimes quite difficult

  → **Detailed information needed from experiment**

  analysis logic, object definitions, cuts, efficiencies, cut-flows, etc.

Reinterpretation: Auxiliary Material Presentation (RAMP) seminars

RAMP is a **new series** of short meetings throughout the year, where **young experimentalists present the material for their analyses** in a ~15-20 min talk, followed by a **discussion with potential (re)users**. The aim is to create **more direct experiment-theory interaction**, and to give **more visibility and recognition** to the effort of preparing and providing extensive material for reinterpretation.

As speakers, we invite primarily ECRs (students and young postdocs) who

- **have provided extensive material** for a recent analysis (HEPData entries, pseudo code, likelihoods, a Rivet routine, etc), wish to raise awareness of it, and **foster its re-use**;
- are preparing a publication (e.g., based on a conference note or PAS) and want to discuss how to best follow the recommendations of arXiv:2003.07868.

HEPData

The presentations are recorded and made available for interested people, e.g. in other time zones, who cannot attend live. Of course the RAMP meetings are also open to report on the actual reuse of the material presented earlier on.

Contact: info-LHC-interpretation-organisers@cern.ch

So far 7 RAMP meetings since April 2021 (1-2 per month) https://indico.cern.ch/category/14155/

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)

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

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)

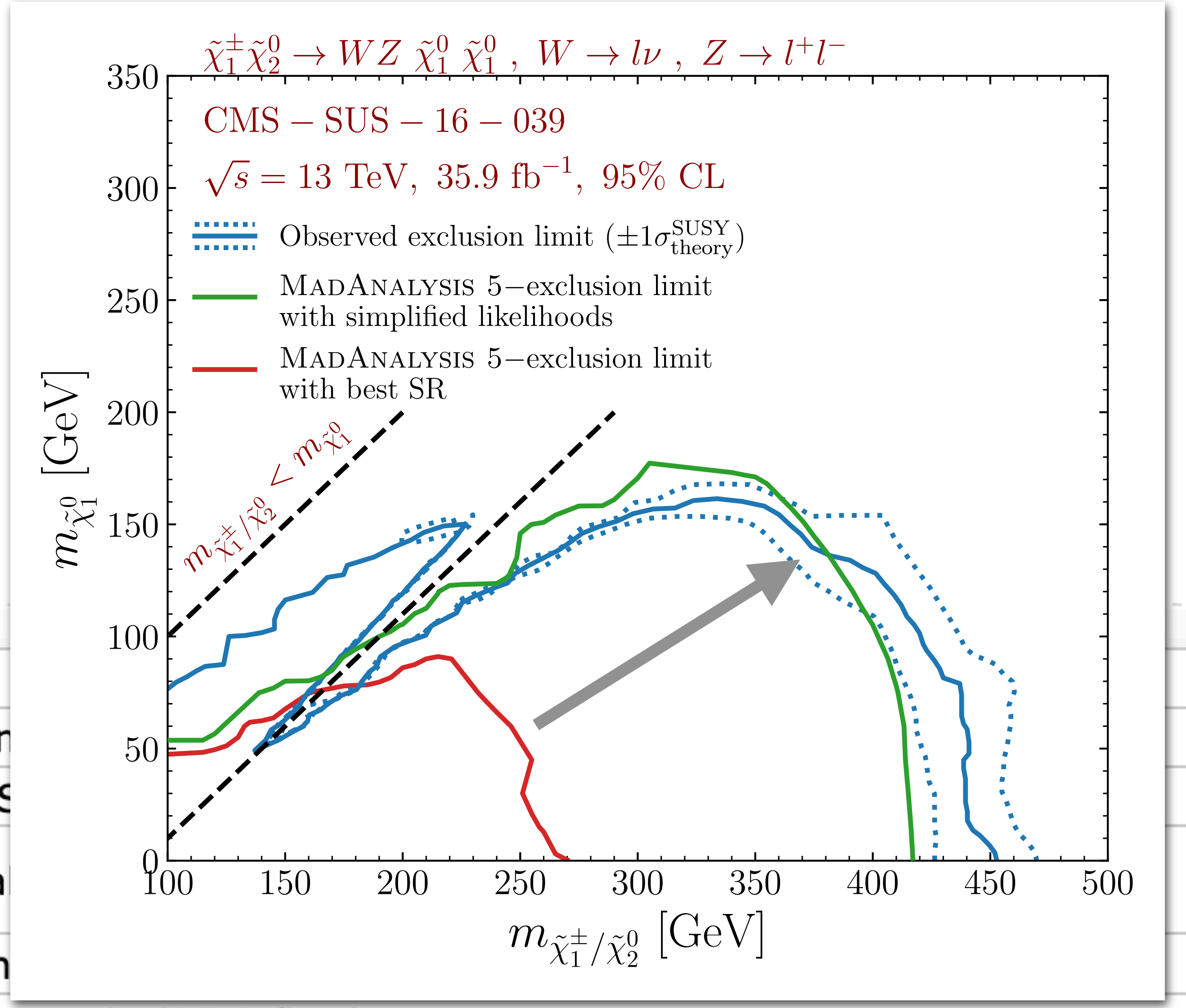
What is implemented where …

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)

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

Signal region combination

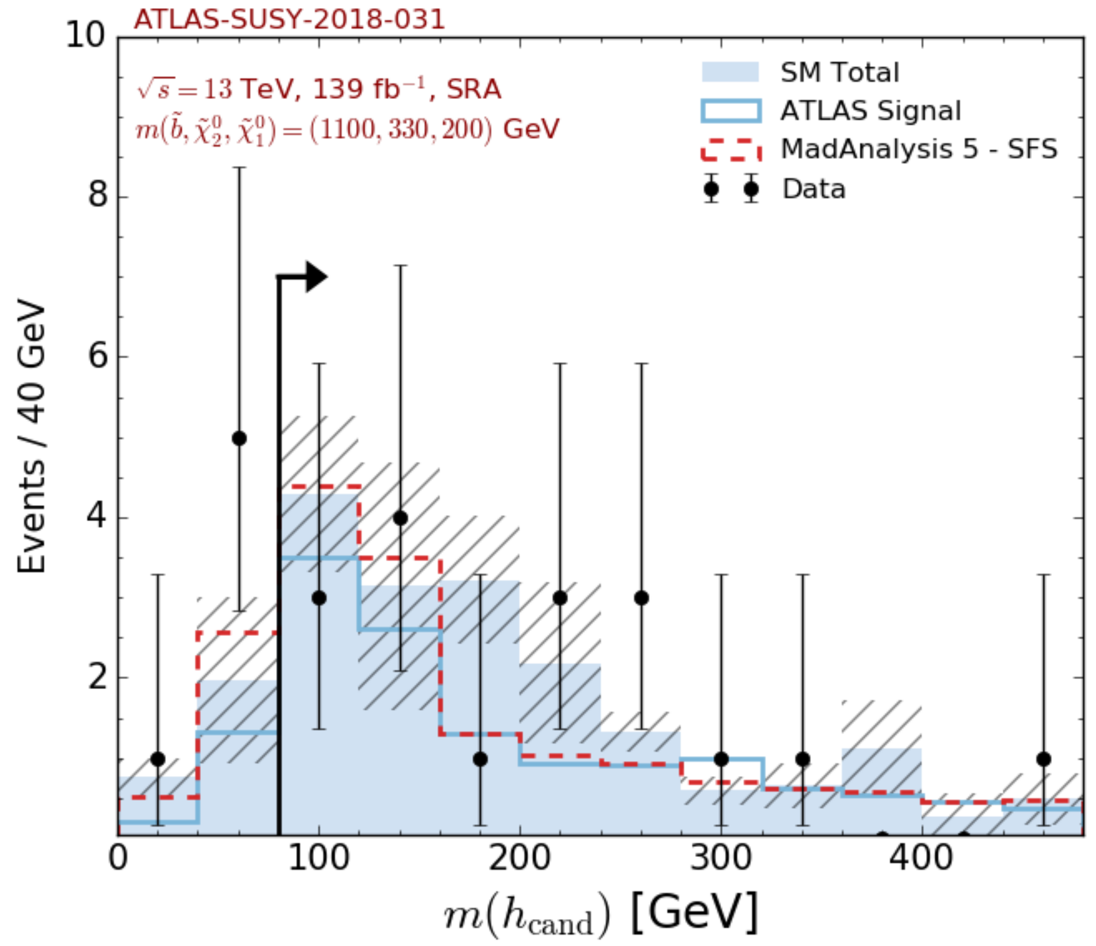


CMS analyses, 13 TeV

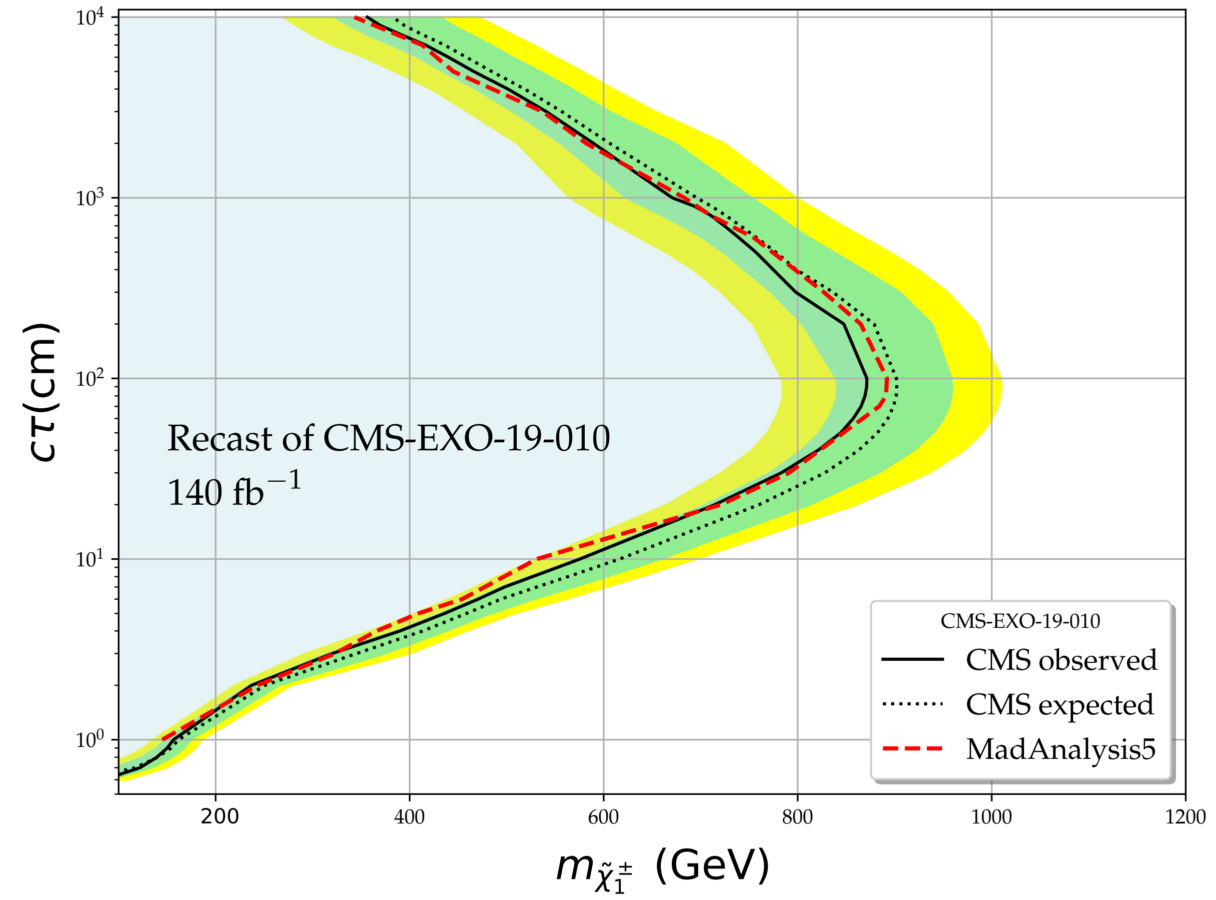
Analysis	Short Description
CMS-SUS-16-033	Supersymmetry in the r
CMS-SUS-16-039	Electroweakinos in the S
CMS-SUS-16-048	Compressed electrowea
CMS-SUS-16-052	SUSY in the 1l + jets ch
CMS-SUS-17-001	Stops in the OS dilepton mode (35.9 fb-1)
CMS-SUS-19-006	SUSY in the HT/missing HT channel (137 fb-1)
CMS-B2G-17-014	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)

Other recent developments

- A Simplified Fast Detector Simulator (aka SFS) [Araz, Fuks & Polykratis, EPJC'21]
  - Simulation through transfer functions (efficiencies, tagging, *etc.*)
  - Detector definition through the PYTHON interface
    - Automatic generation of the analysis workspace
    - Object-oriented features accessible within the expert mode



- LLPs [Araz, Fuks, Goodsell & Utsch, to appear]
  - Access to displacement variables (d_0, d_z, closest approach, *etc.*)
  - Object propagation in a magnetic field added to the SFS
  - Few analyses added to the database (using the SFS)
    - CMS-EXO-16-022: displaced leptons; update of the 2017 recast
    - ATLAS-SUSY-2017-04: displaced vertices of charged leptons
    - CMS-EXO-16-010: disappearing tracks



See talk by Jack Araz

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

See talk by Z.S. Wang

Upcoming

info Nishita Desai

CHECKMATE Version 3

- New searches with t/b's and taus using full 139/fb data

  Done — currently being validated:

  - arXiv:2010.01015 (bjets + MET),
  - arXiv:1911.06660 (taus + MET),
  - arXiv:2011.09308 (single top + MET).

  Stop searches (arXiv:2102.01444, arXiv:2012.03799)

- Using Simplified Likelihoods for combinations of different searches

- Updating compatibility with recent releases of HepMC/Pythia

What is implemented where …

LLP Recasting Repository

This repository holds example codes for recasting long-lived particle (LLP) searches. The code authors and repository maintainers are not responsible for how the code is used and the user should use discretion when applying it to new models.

Adding your recasting code

This is an open repository and if you have developed a code for recasting a LLP analysis, we encourage you to include it here. Please contact llp-recasting@googlegroups.com and we will provide you with the necessary information for including your code.

https://github.com/llprecasting/

master · 3 branches · 0 tags · Go to file · Add file · Code

andlessa Merge pull request #5 from mdgoodsell/master … dd9930b on Jun 16 · 56 commits

DisappearingTracks	Mark Goodsell: Added CMS-EXO-19-010	5 months ago
DisplacedVertices	Added validation with MLM matching	3 years ago
HSCPs	Small change in HSCP	15 months ago
.gitignore	Added gitignore	16 months ago
README.md	Fixes in README	15 months ago

What is implemented where …

info Anders Kvellestad

ColliderBit

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

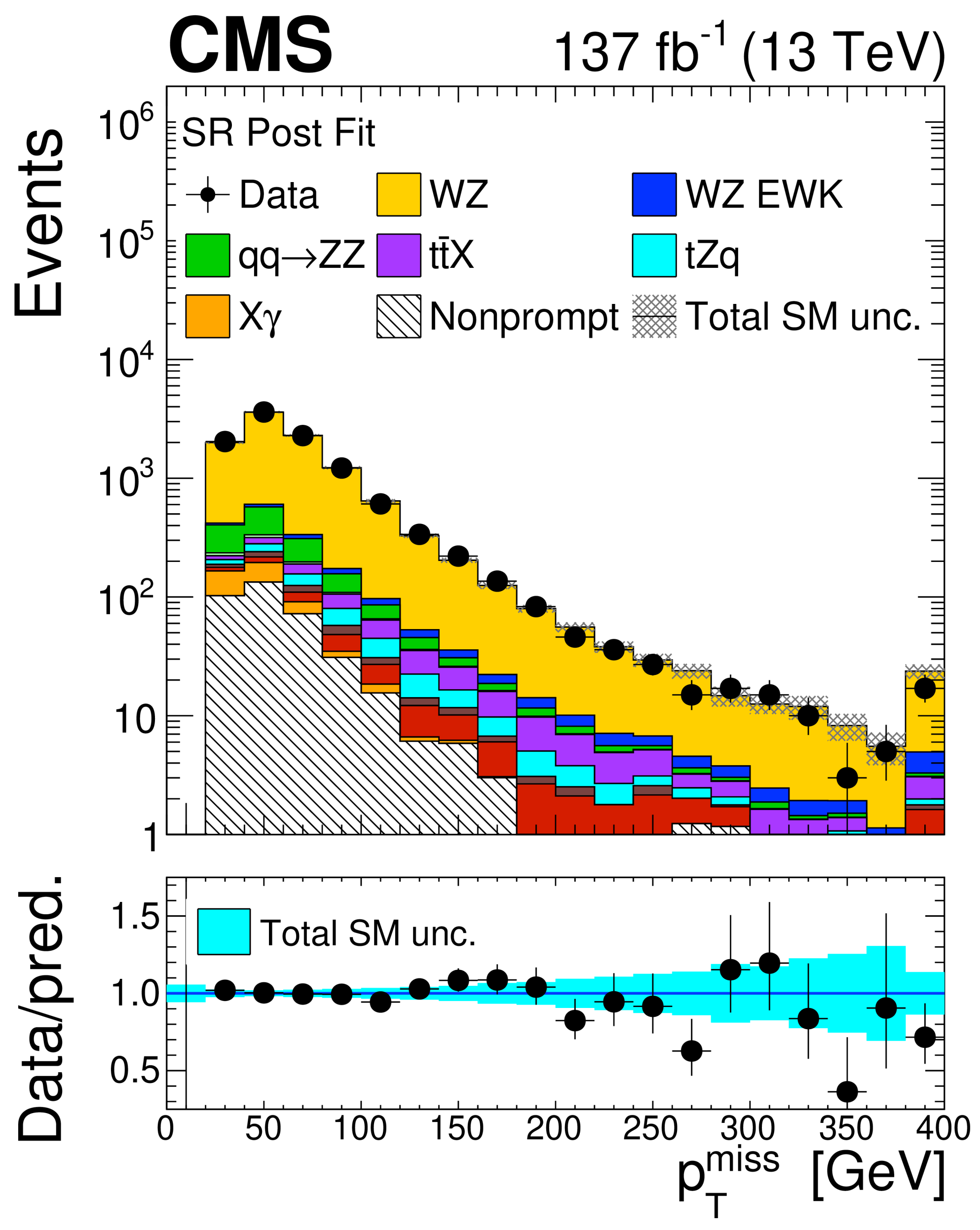
- 9 analyses for full Run 2 luminosity in recent GAMBIT releases
- The main new development is integration with GUM (**Gambit Universal Models**) framework*
- Ongoing efforts:
  - ColliderBit interface to Contur/Rivet
  - Enable use of ATLAS full likelihoods (CMS simplified likelihoods already in use)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

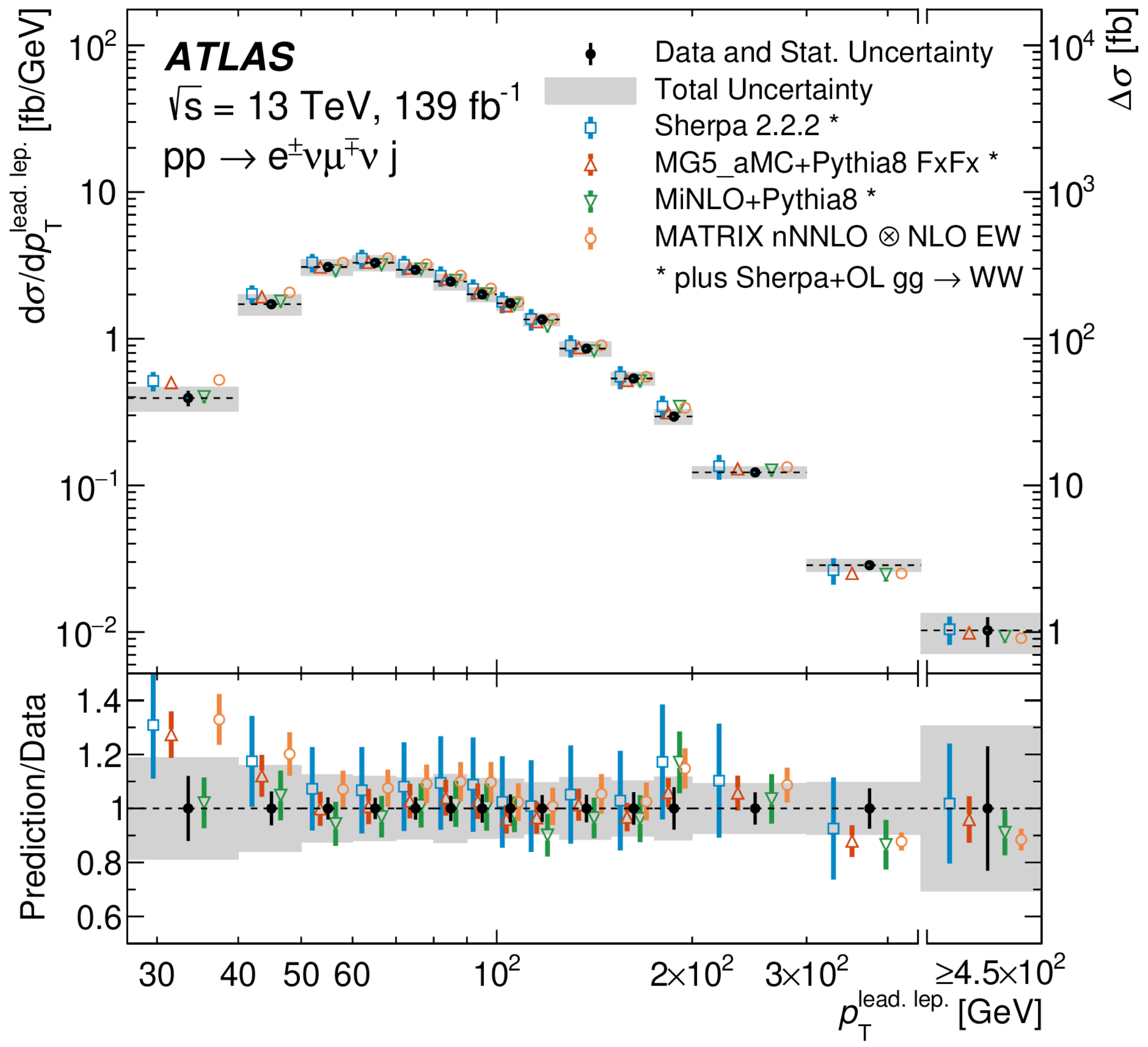
** See talk by Anders Kvellestad*

Rivet/Contur

- Searches for new physics are usually performed in the tails of SM distributions
- SM *measurements* can give important complementary constrains, as BSM effects must not alter (or "leak") into them too much
  - ➡ **particle-level differential measurements** made in fiducial regions of phase-space; high degree of model-independence
  - ➡ 100s of them available in Rivet
- Contur toolkit: "Constraints On New Theories Using Rivet"
- Many technical developments, including use of correlations whenever available

See talk & tutorial by Louie Corpe





missing:

- ❑ searchable database: which analysis is implemented in which framework(s)
- ❑ code-sharing/translation btw frameworks

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.

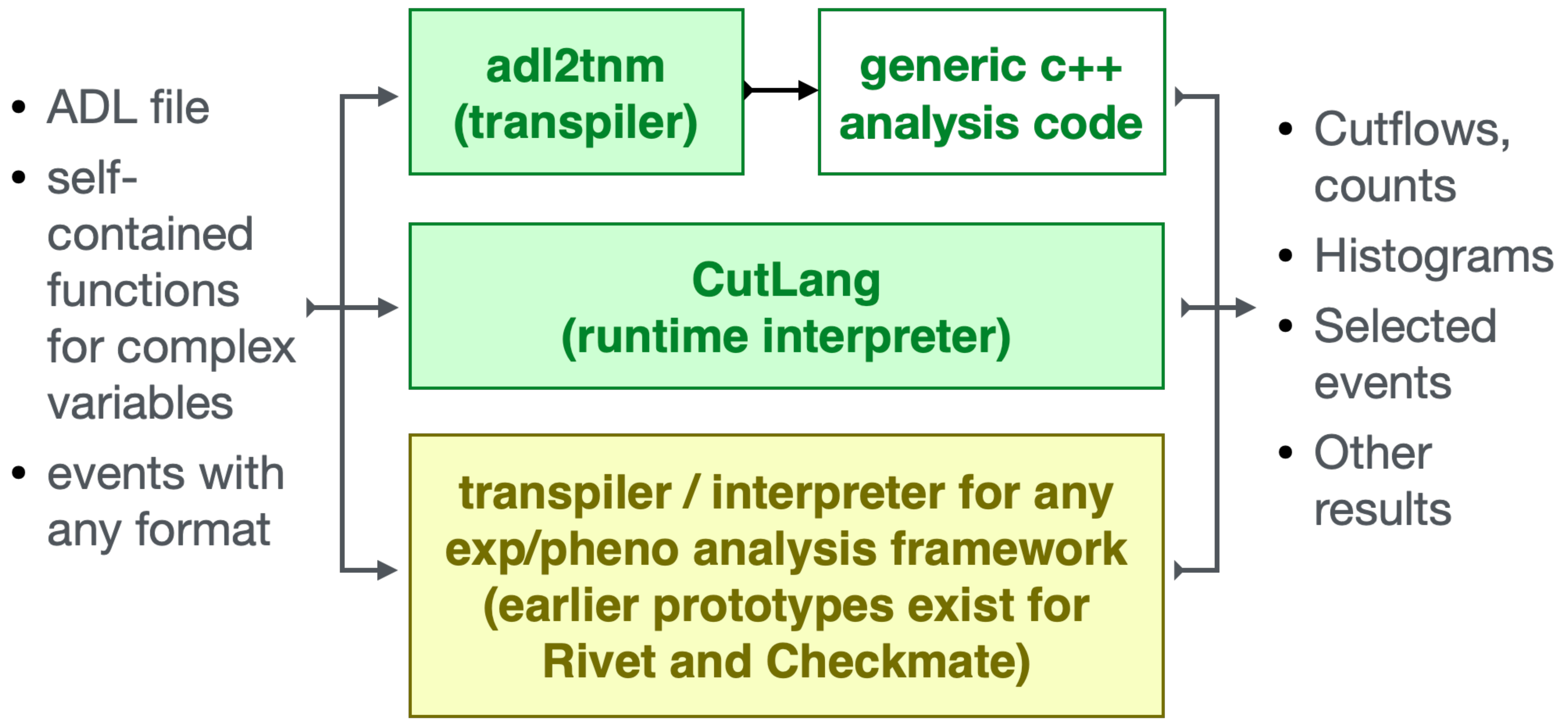
ADL is a language, independent of software frameworks:

(—> 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

Experimental / phenomenology analysis model with ADLs



Curtesy Sezen Sekmen

https://github.com/ADL4HEP/ADLLHCanalyses

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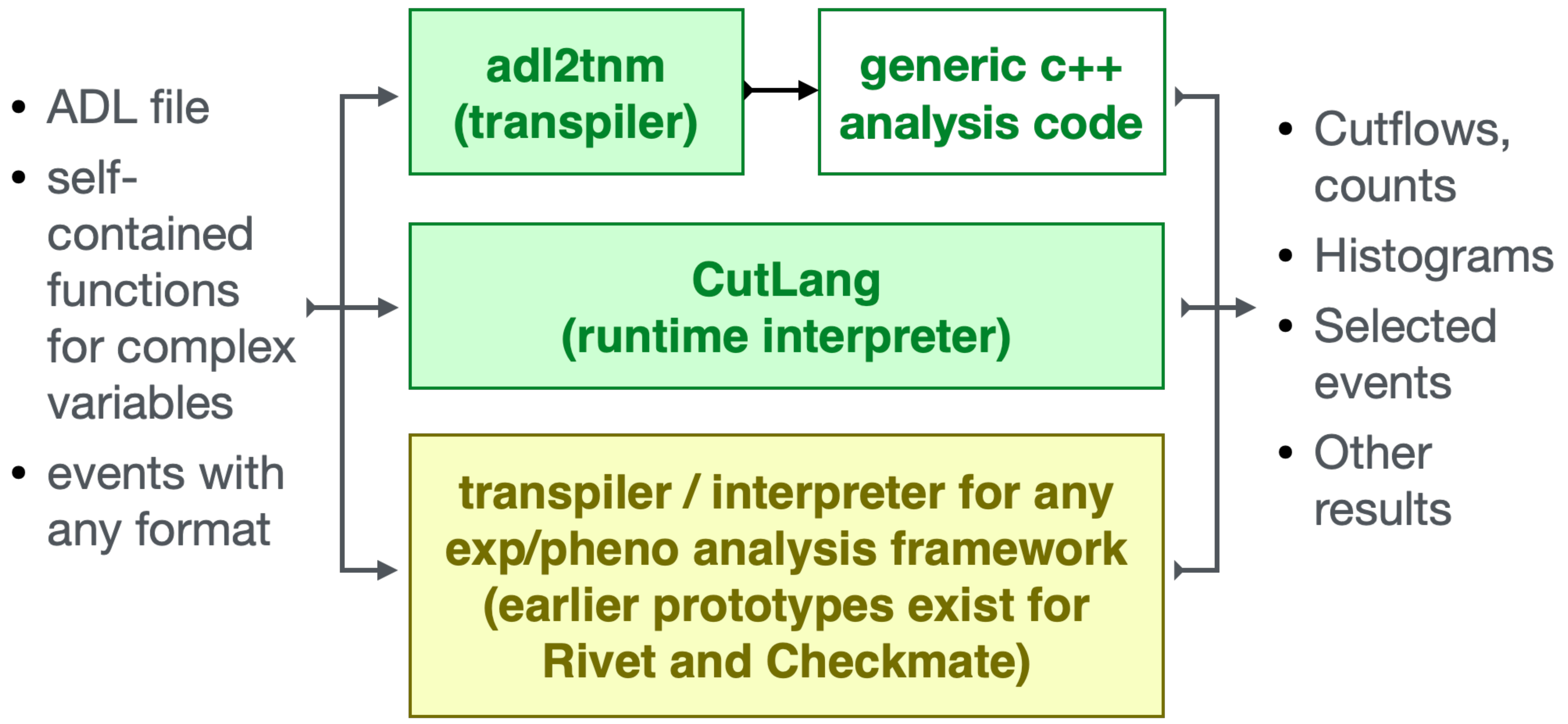
being validated via interface to SModelS

- 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

Experimental / phenomenology analysis model with ADLs



Curtesy Sezen Sekmen

Protomodel builder

PROTOMODEL BUILDER

Waltenberger, Lessa, SK, arXiv:2012:12246

- 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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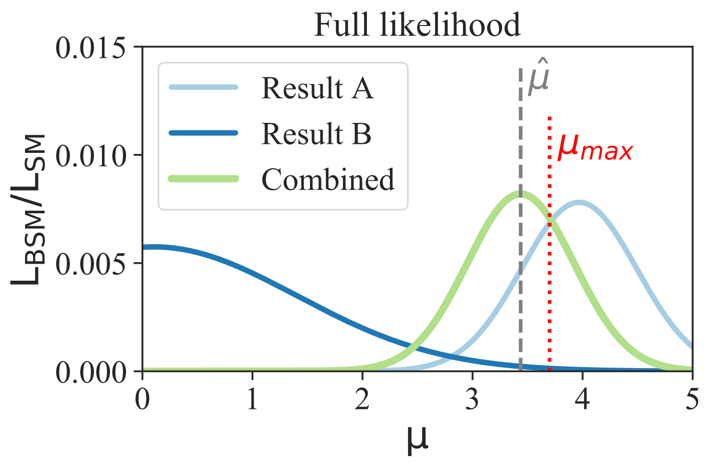
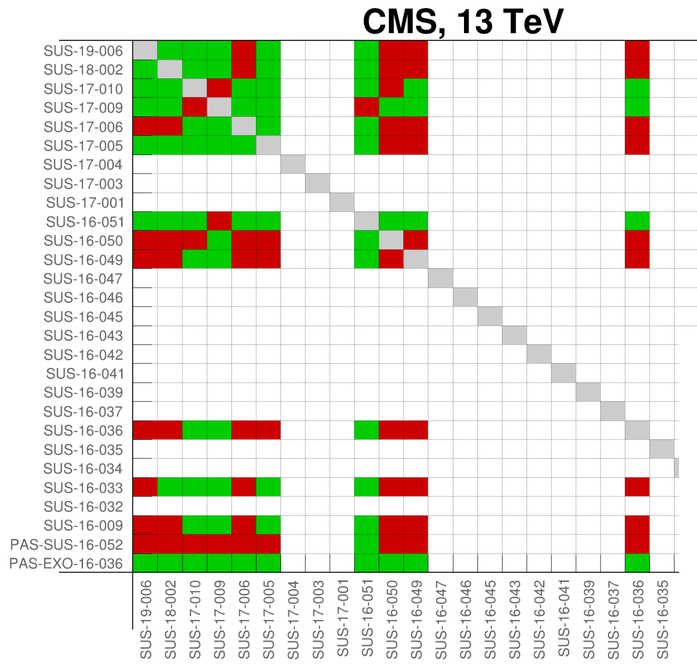
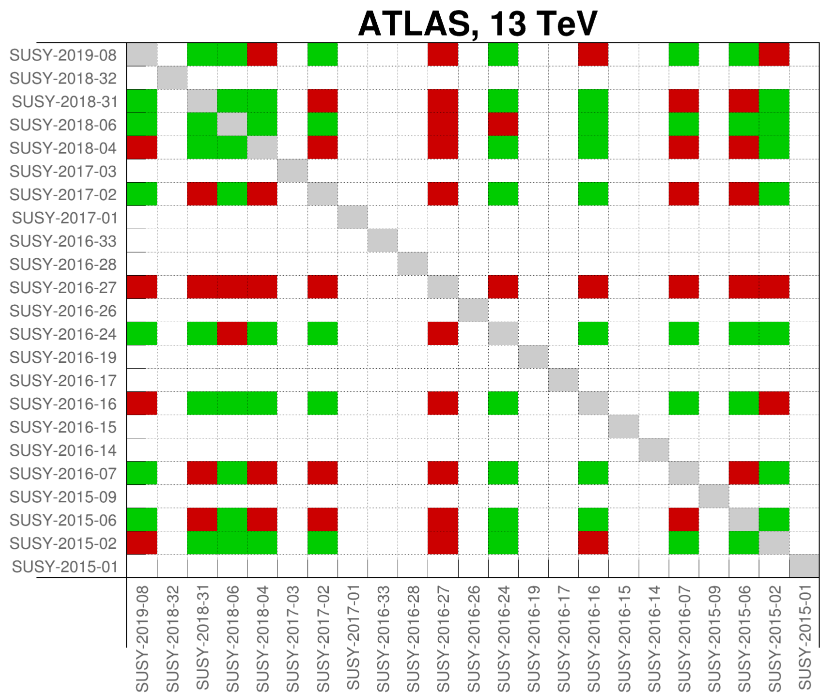
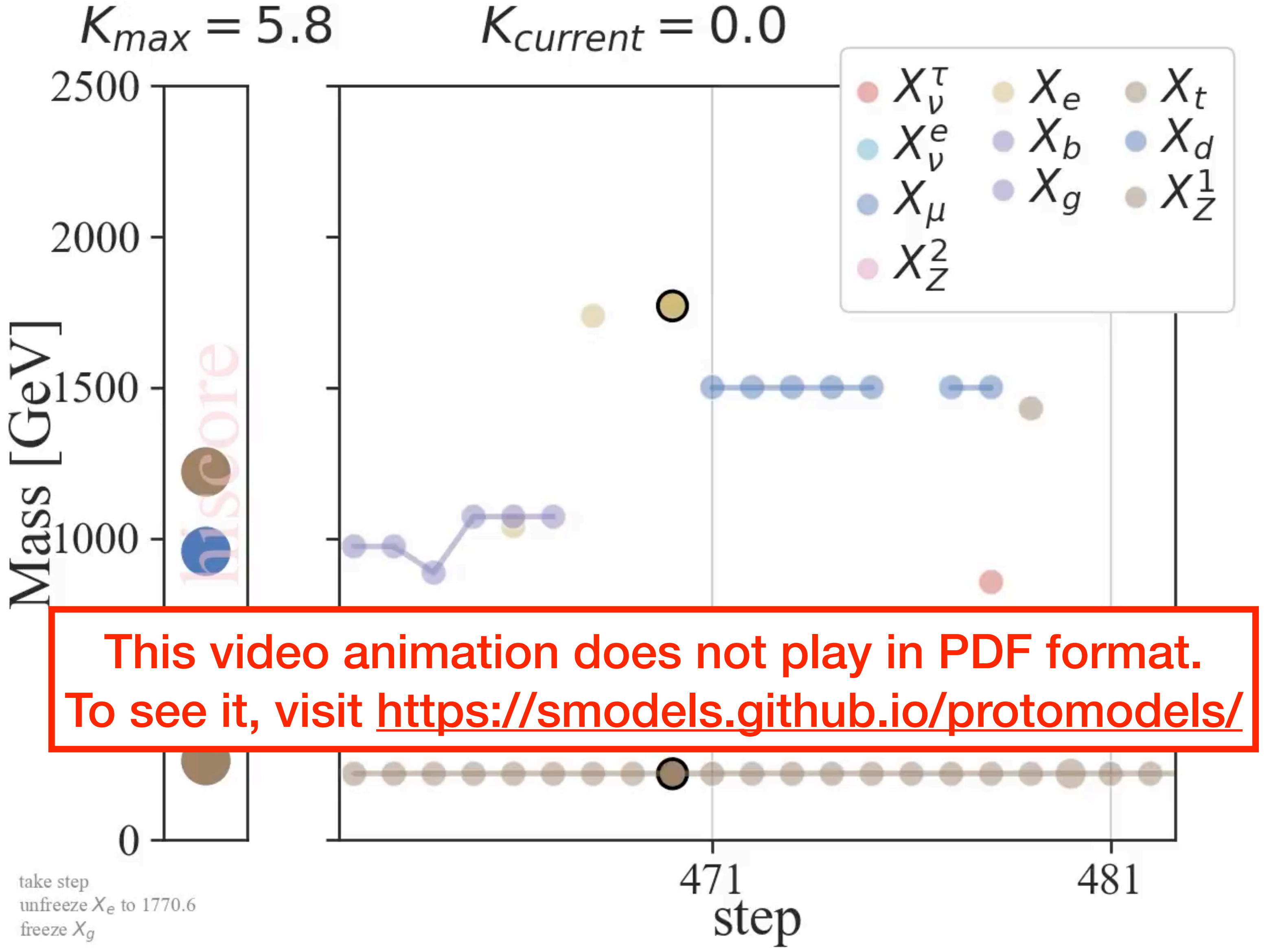




trivial cross-analysis correlations





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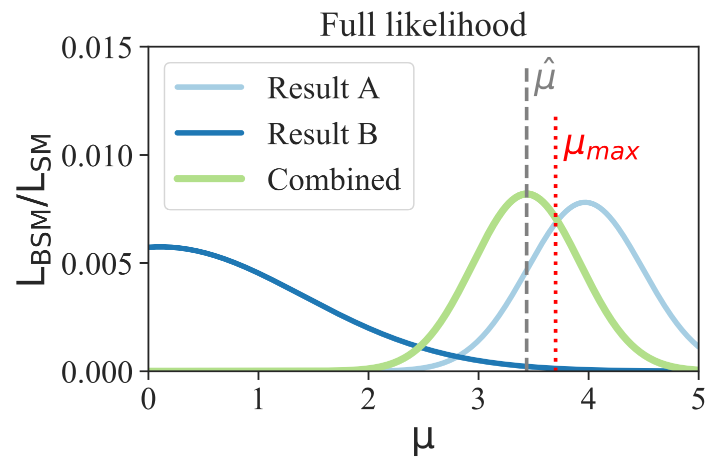

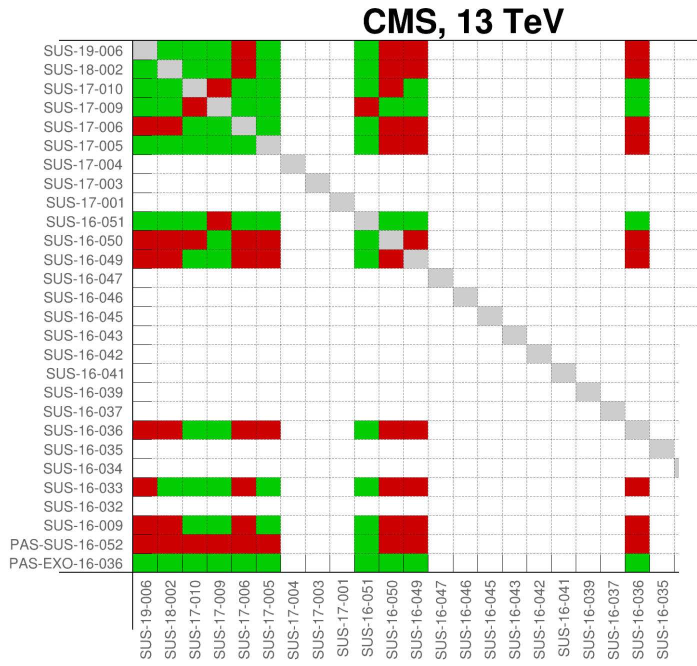

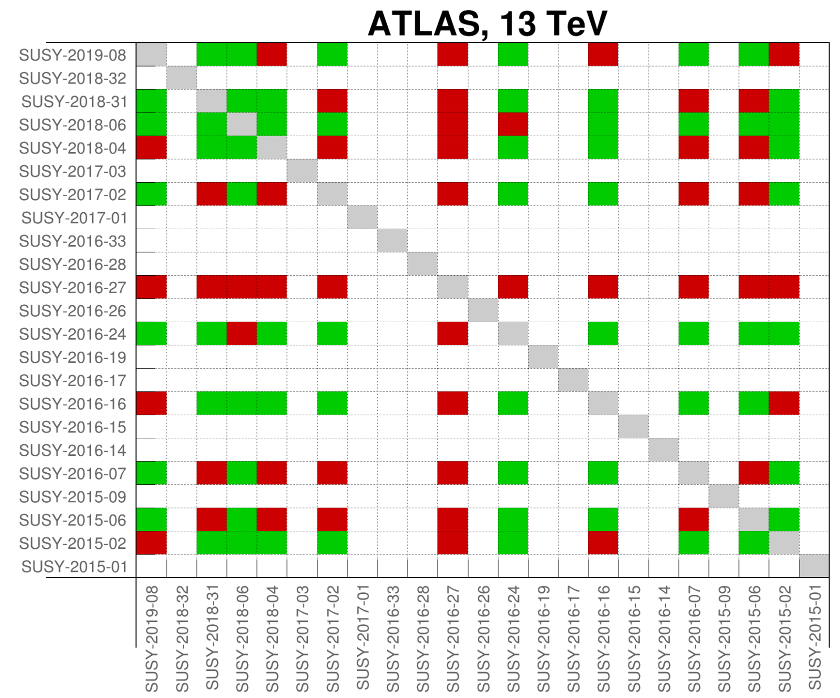

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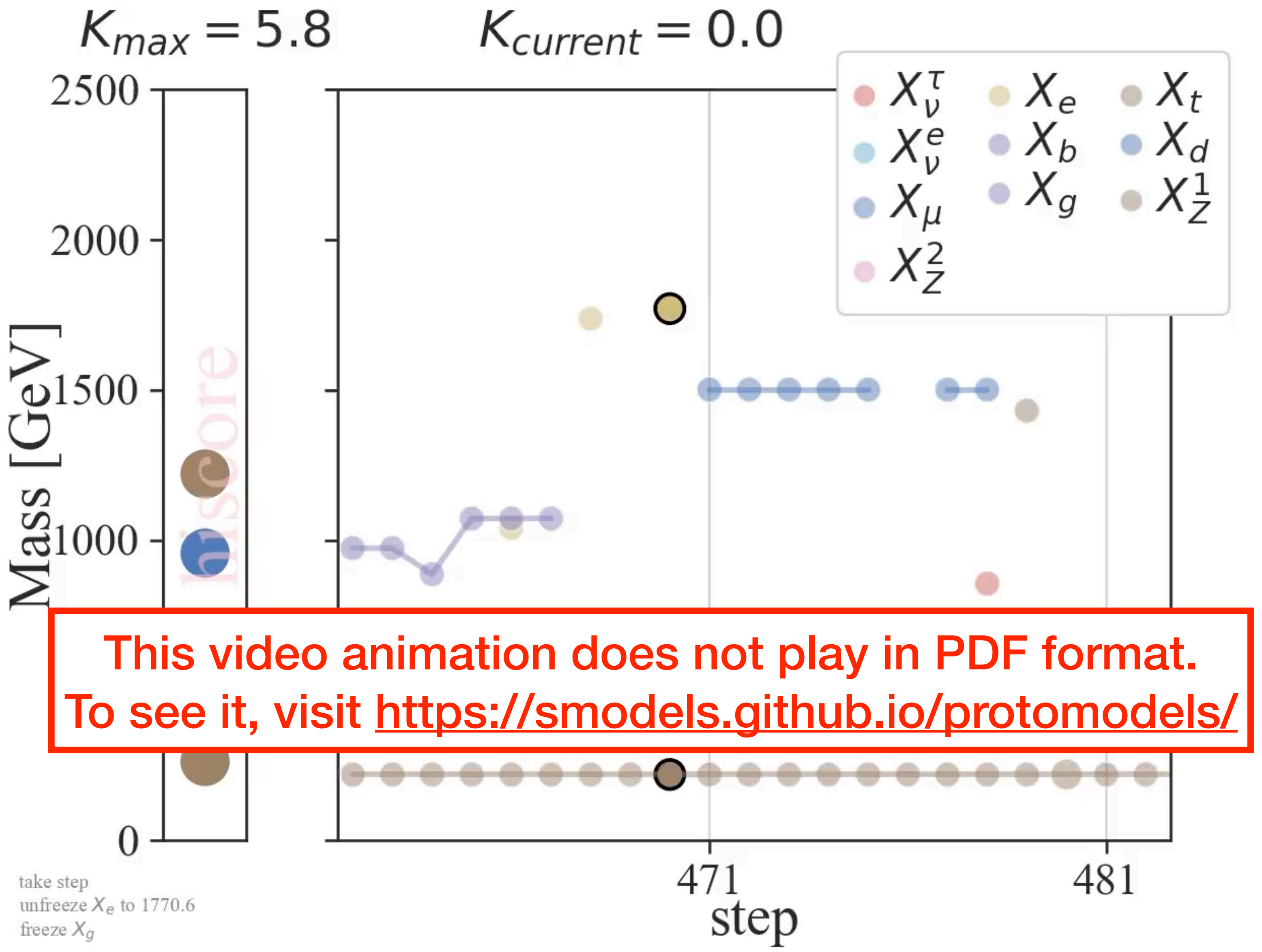

Waltenberger, Lessa, SK, arXiv:2012:12246

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 Andy Buckley, Benjamin Fuks, Humberto Reyes-González, W Waltenberger, Sophie Williamson, Jamie Yellen

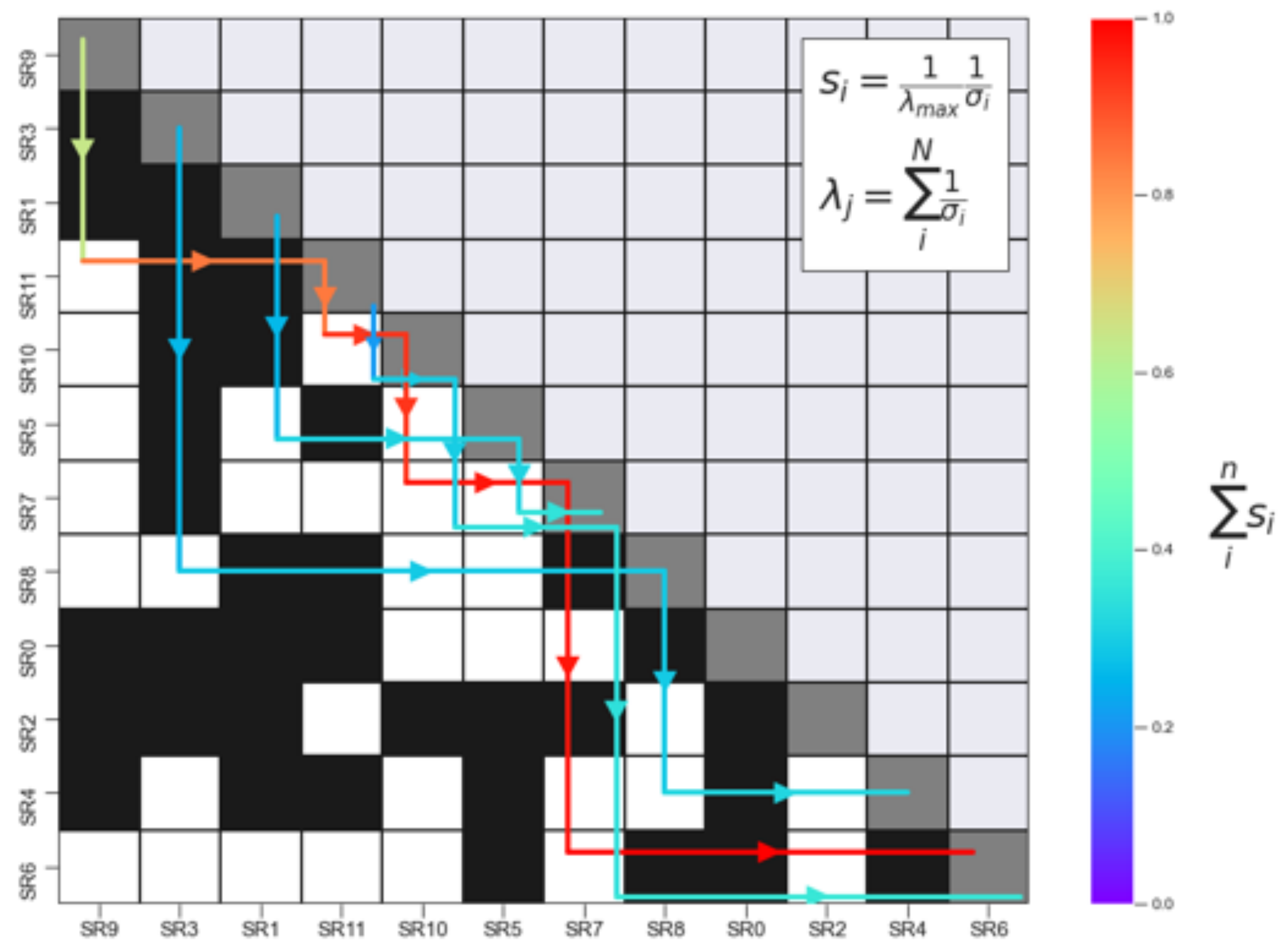

Illustration by Jamie Yellen

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	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Pois}\left(r_b = \sigma_b^{-2} \middle\| \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
	Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\| \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\| \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\kappa_{scb,\alpha=\pm1}$
	MC Stat. Uncertainty	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Gaus}\left(a_{\gamma_b} = 1 \middle\| \gamma_b, \delta_b\right)$	$\delta_b^2 = \sum_s \delta_{sb}^2$
	Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\text{Gaus}\,(l = \lambda_0 \| \lambda, \sigma_\lambda)$	$\lambda_0, \sigma_\lambda$
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

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	Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\text{Gaus}\,(l = \lambda_0 \mid \lambda, \sigma_\lambda)$	$\lambda_0, \sigma_\lambda$
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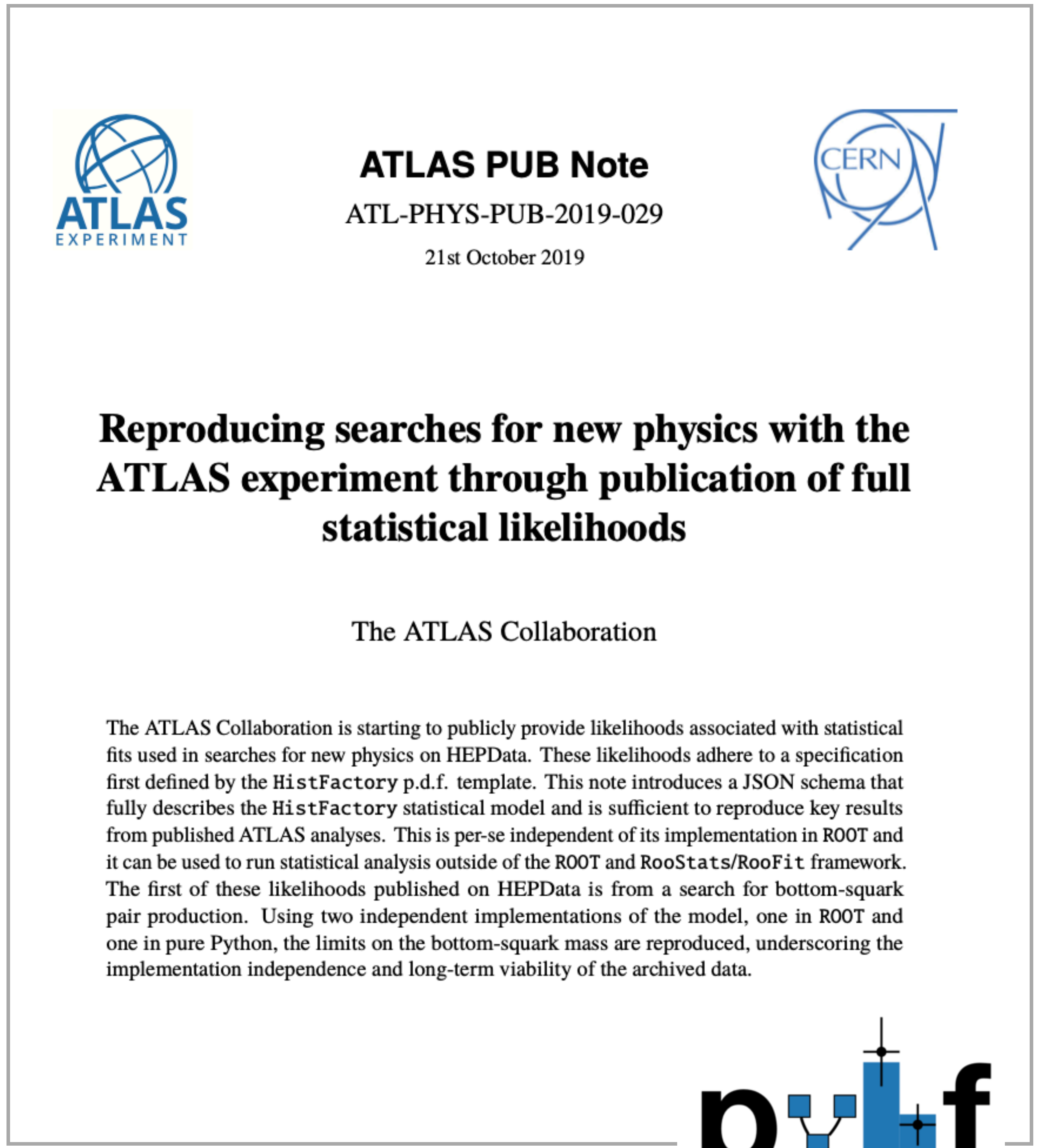

ATLAS PUB Note
ATL-PHYS-PUB-2019-029
21st October 2019

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.

ATLAS full statistical models

ATL-PHYS-PUB-2019-029

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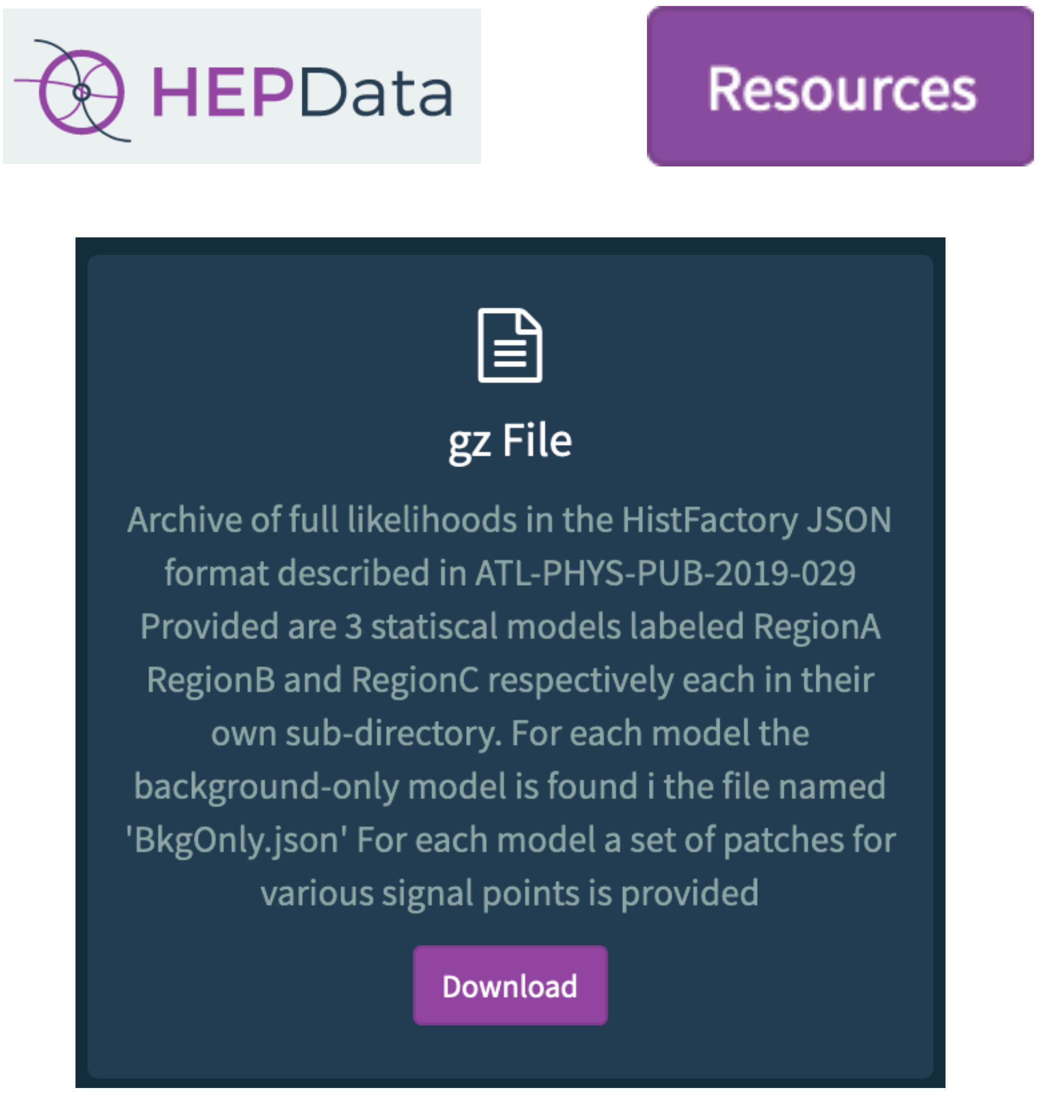
- Provides background estimates, changes under systematic variations, and observed data counts at the same fidelity as used in the experiment.

	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	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\vert \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \vert\, \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\vert \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \vert\, \alpha, \sigma = 1)$	$\kappa_{scb,\alpha=\pm1}$
	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 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	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \mathrm{Pois}\left(r_b = \sigma_b^{-2} \middle\| \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
	Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\| \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm 1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\| \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\kappa_{scb,\alpha=\pm 1}$
	MC Stat. Uncertainty	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \mathrm{Gaus}\left(a_{\gamma_b} = 1 \middle\| \gamma_b, \delta_b\right)$	$\delta_b^2 = \sum_s \delta_{sb}^2$
	Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\mathrm{Gaus}\,(l = \lambda_0 \| \lambda, \sigma_\lambda)$	$\lambda_0, \sigma_\lambda$
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

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}

Usage in reinterpretation tools

reinterpretation becomes JSON patching

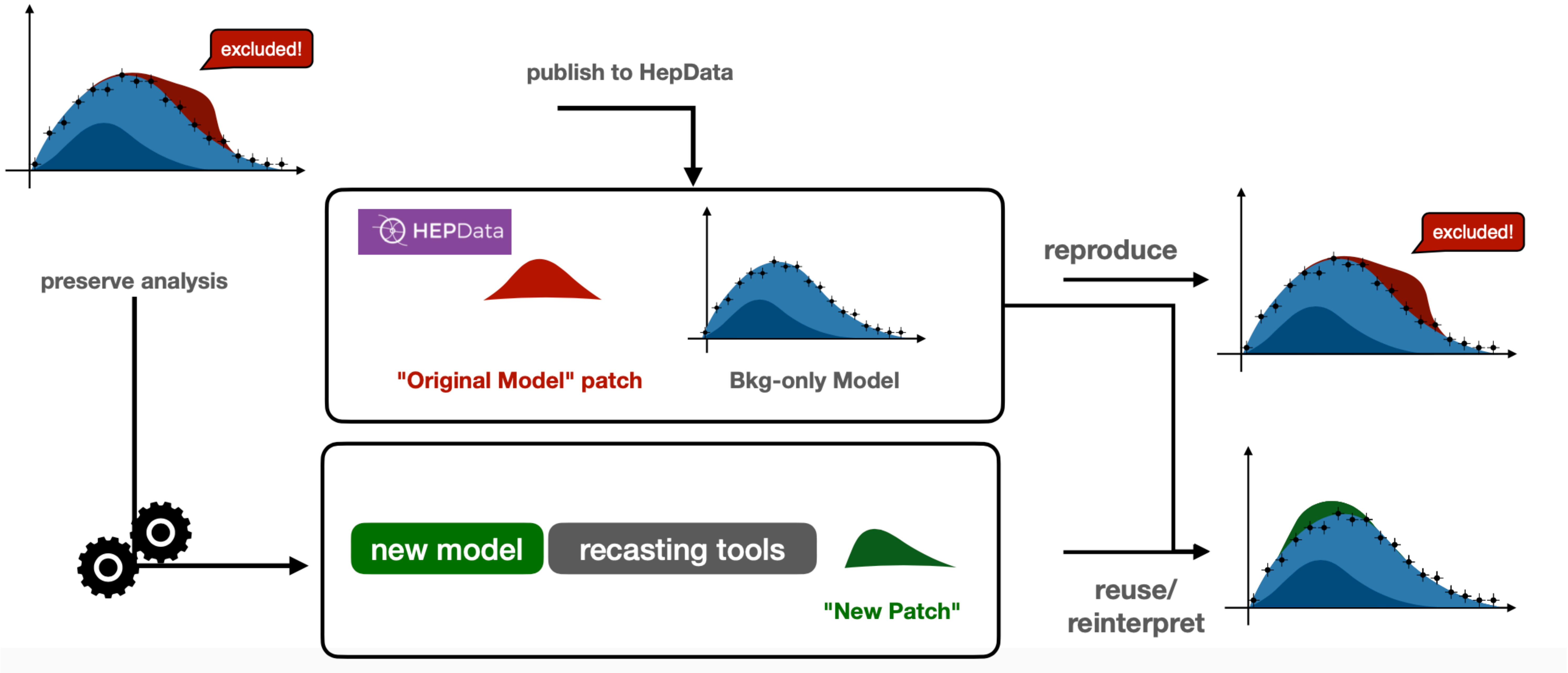


Illustration from talk by Lukas Heinrich
Hands-on workshop 8 Nov 2021

Usage in reinterpretation tools

reinterpretation becomes JSON patching

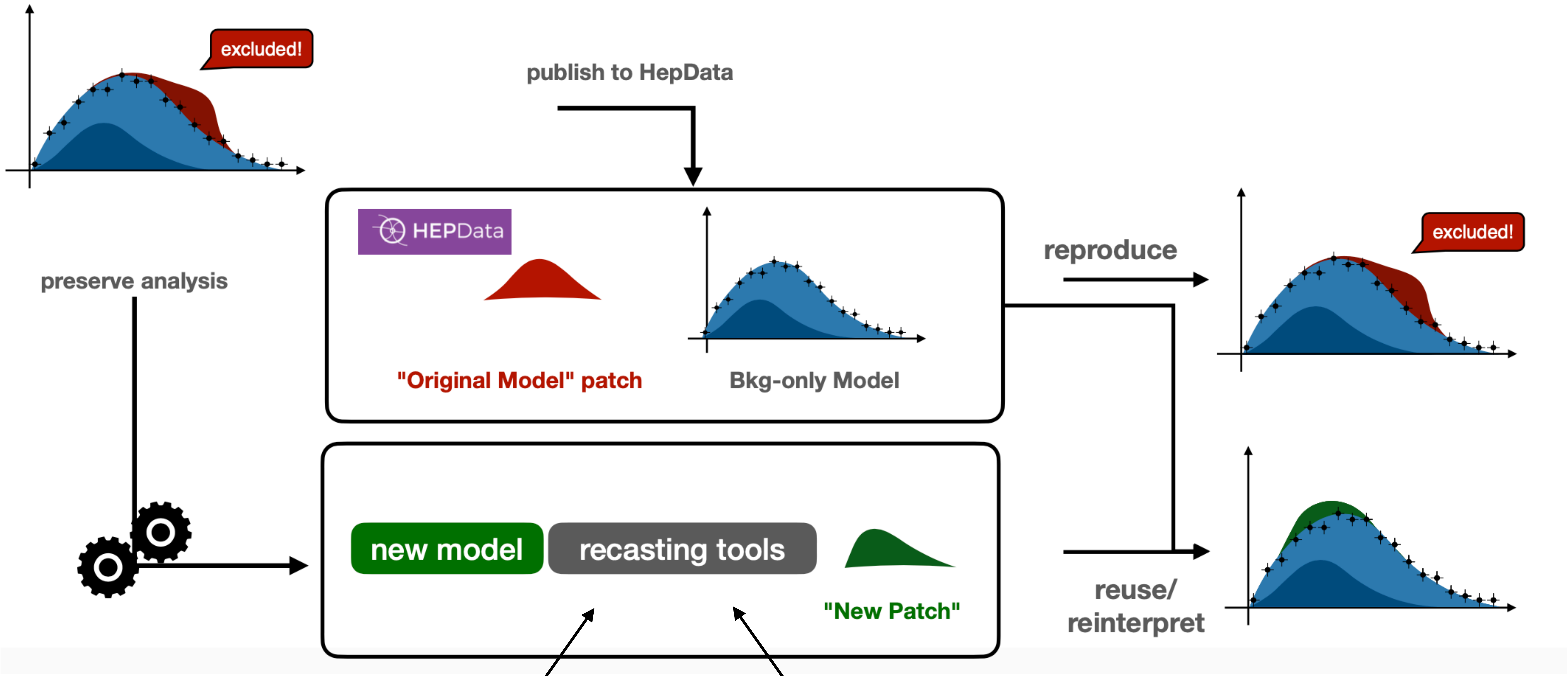


Illustration from talk by Lukas Heinrich
Hands-on workshop 8 Nov 2021

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

Interfaced to pyhf since SModelS v1.2.4 (now v2.1)
G. Alguero, SK, W. Waltenberger, arXiv:2009.01809

Others (Checkmate, GAMBIT) are working on interfaces

DarkCast —a public code for recasting dark photon search results

- Current bounds and future projections can be reinterpreted for arbitrary models with a new massive gauge field

$$\mathcal{L} \subset g_X \sum_f x_f \bar{f} \gamma^\mu f X_\mu + \sum_\chi \mathcal{L}_{X\chi\bar{\chi}}$$

- Based on **rescaling ratios of production and decay rates**, while also accounting for detector efficiencies due to the lifetime of the vector boson.

- Includes a comprehensive set of data from **ATLAS, CMS and LHCb** dark photon searches
  - via data scouting methods and
  - Higgs-produced dark photon decays into prompt and displaced lepton-jet final states

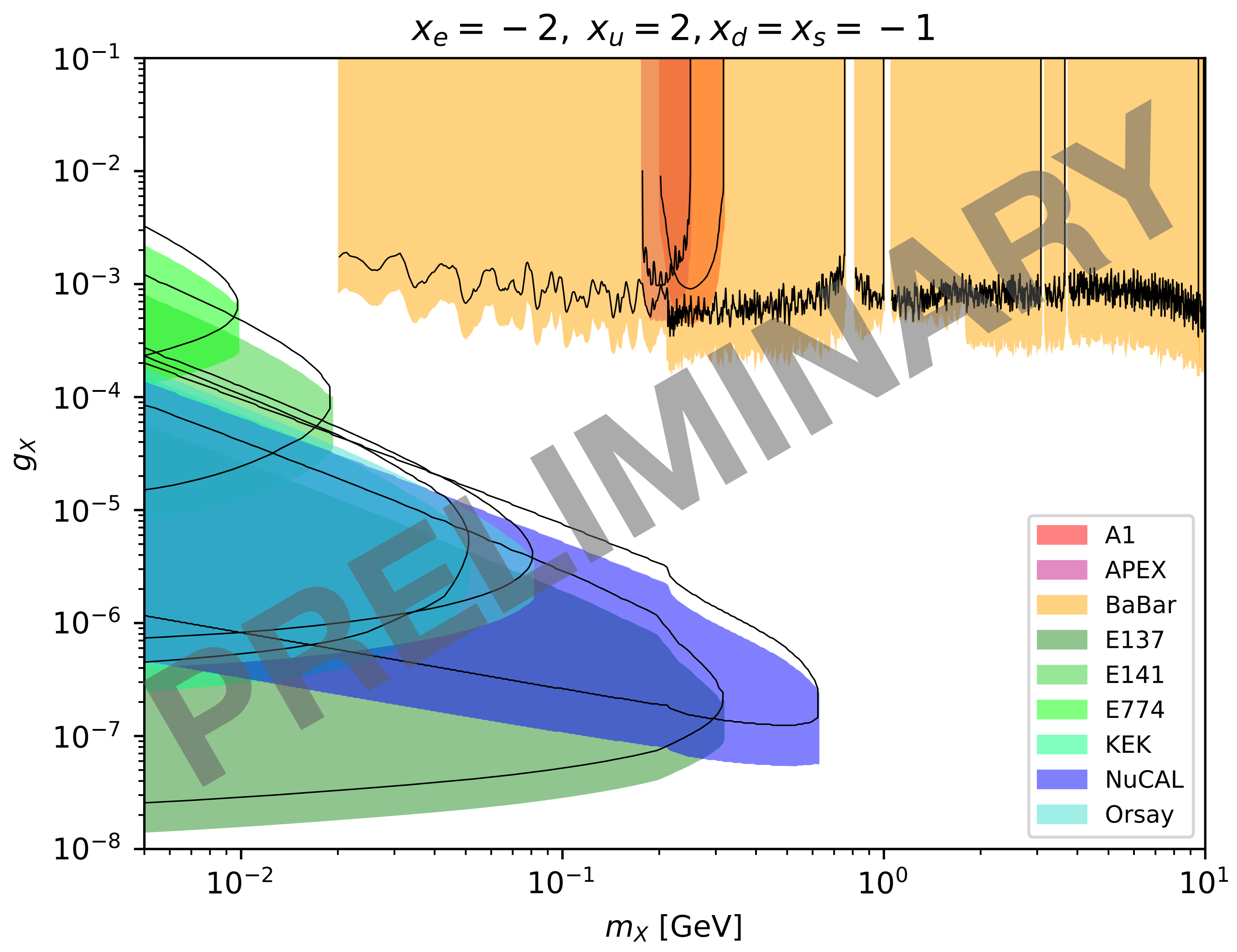
  and a number of low energy (e.g. BaBar, Belle II) and beam-dump (e.g. NA62 and NA64) experiments.

https://gitlab.com/philten/darkcast

<u>Recent developments</u> (info P. Ilten)

- decoupled decay and production
- mass dependent couplings
- new models, including various lepton number scenarios added
- a number of new limits have been added

Extension to axial-vector case



Work by Chaja Baruch and Yotam Soreq

Conclusions

Tools development for the reinterpretation of LHC results for BSM studies is an active field

* Full-steam implementation of **full Run 2 luminosity** results
* Inclusion of searches for **long-lived particles**
* Combination of signal regions with simplified and **full likelihoods**
* Active exchanges with experimentalists e.g. via RAMP seminars

Future:

* More global approaches to where BSM may be hiding

➡ combination of analyses