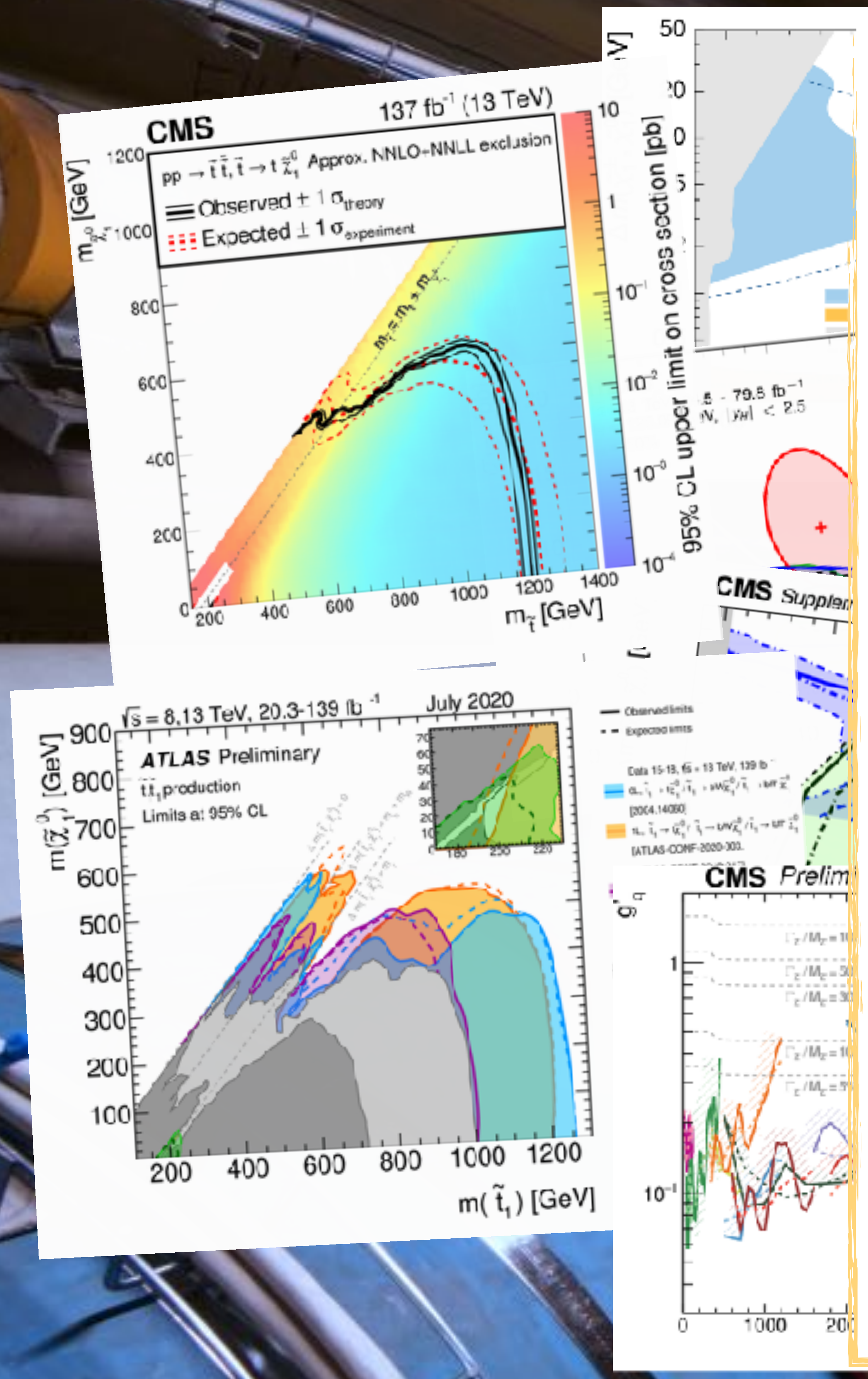
Sabine Kraml

Reinterpretation of LHC results for new physics

RTG 2994 PARTICLE PHYSICS AT COLLIDERS IN THE LHC PRECISION ERA
Inauguration Workshop, Univ. Würzburg, 17-18 March 2025

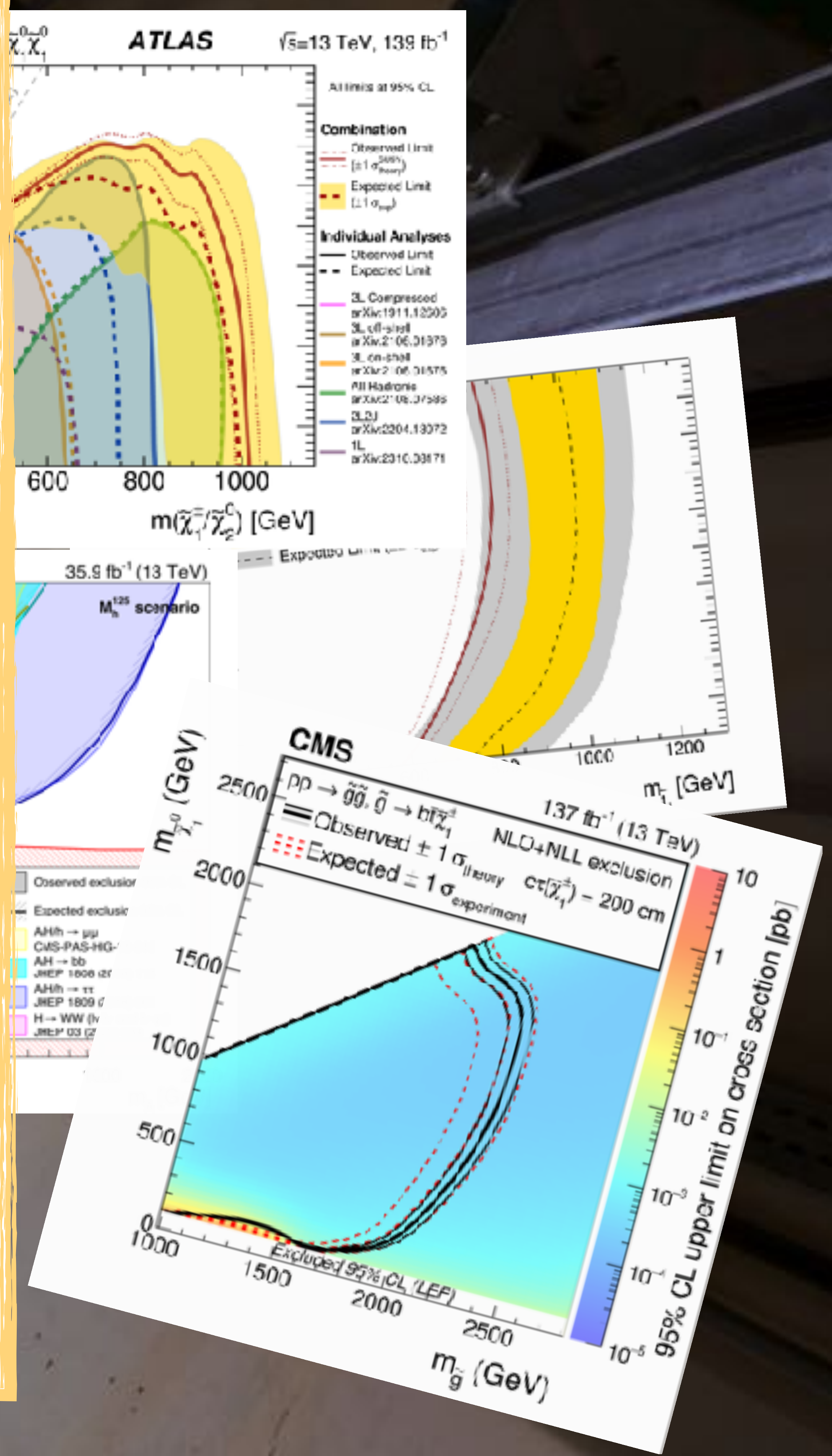
Why reinterpretation?



Experimental analyses at the LHC are sensitive to a far greater set of theories and parameter combinations than have so far been tested

(or even been thought of).

We want to obtain a **comprehensive view** of how the plethora of LHC results constrain new physics **in the context of different theoretical scenarios**.



Sensitive to a far greater set of theories …

- **Searches** for new physics at the LHC in a vast variety of channels; interpretations in specific target/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** (incl. such not yet thought of!)**.**

- In addition, **measurements** primarily aimed at understanding SM processes can have a high degree of model independence and implicitly contain information about potential contributions from new physics.

- Again, this requires the (re)interpretation of the experimental results in the context of new models.

- Requires close theory-experiment interaction and **public tools**.

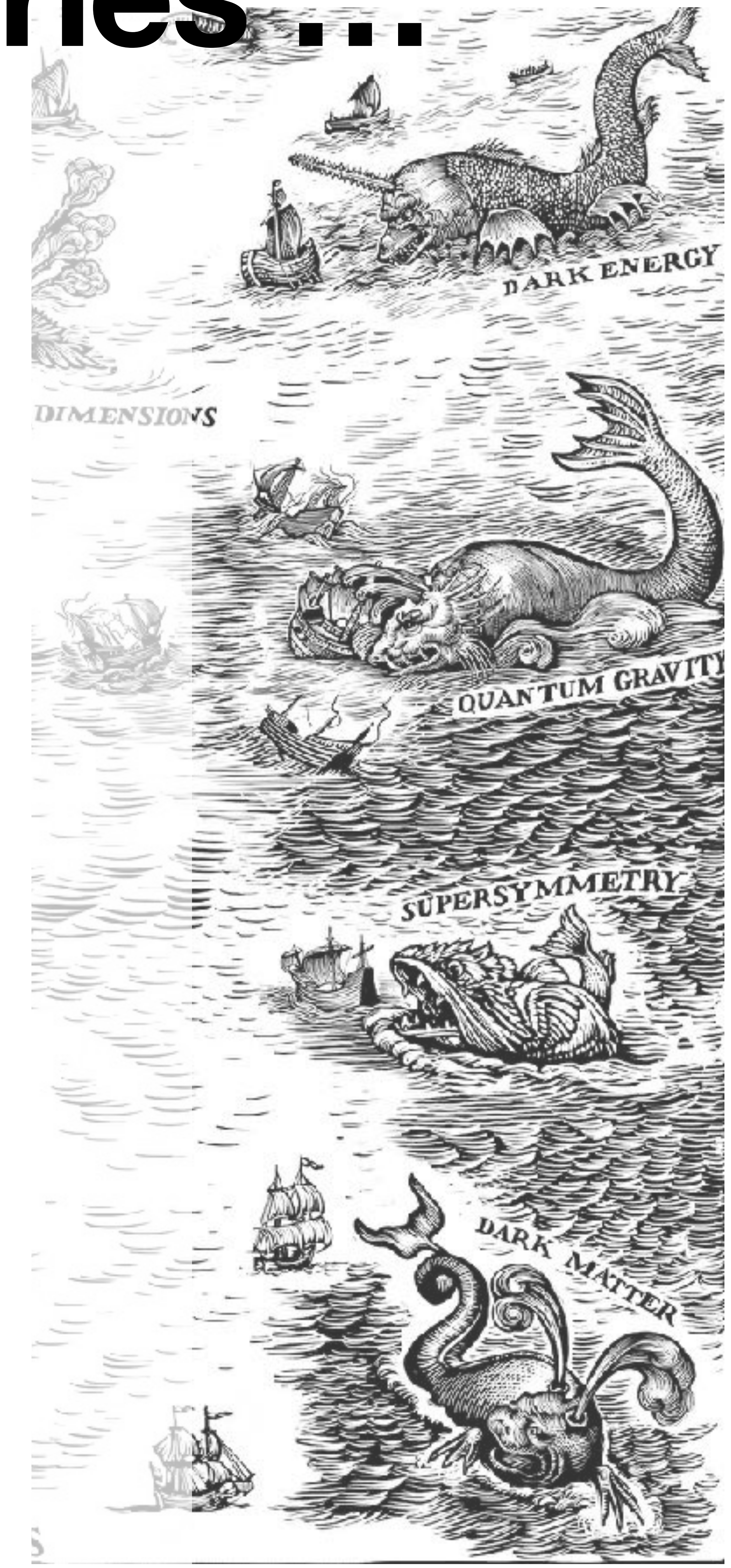


Illustration (c) C.Wormell from "A Map of the Invisible" by J.Butterworth

One of my favourite examples: IDM Inert Doublet Model

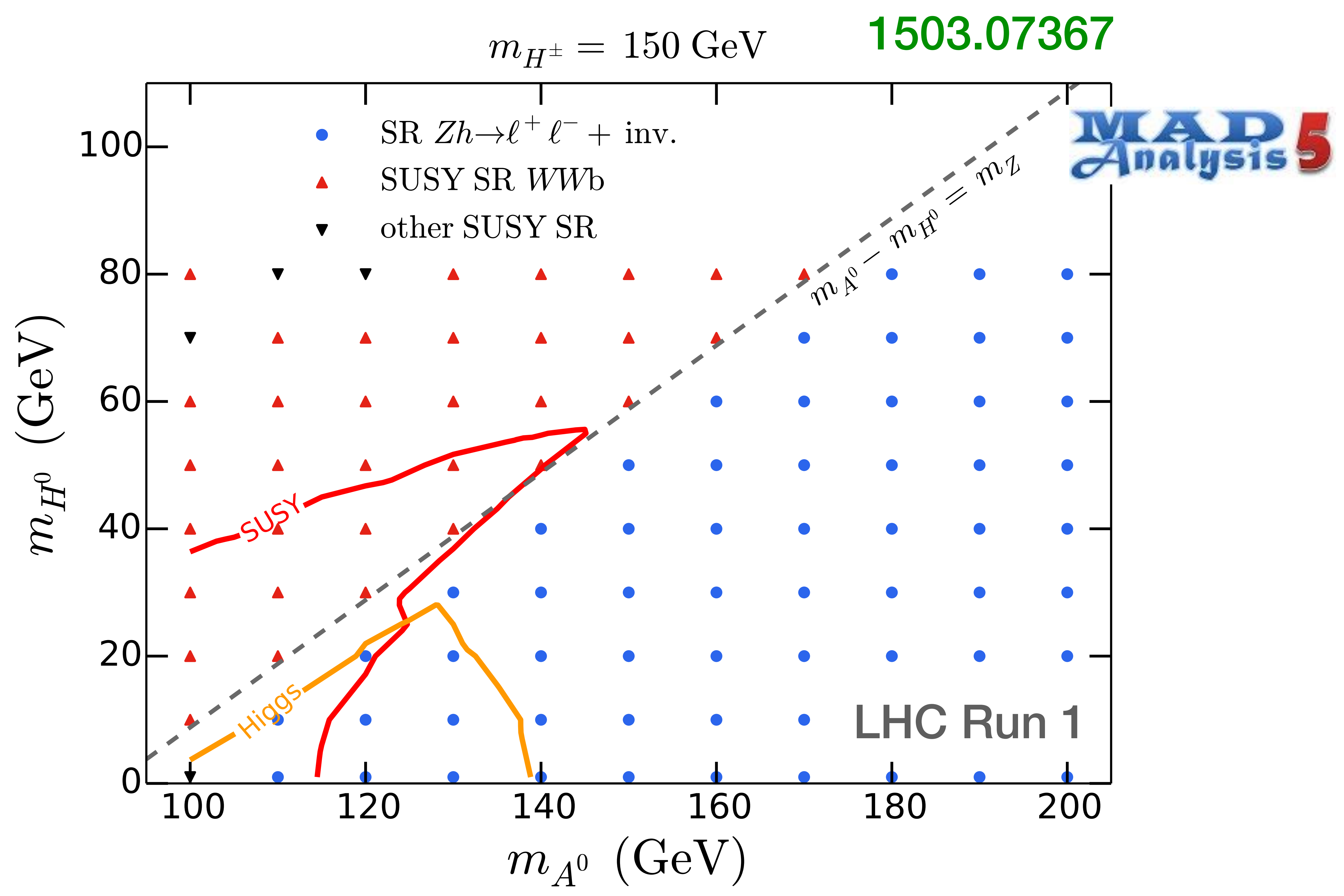
$$H = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v + h + iG^0\right) \end{pmatrix}$$ SM Higgs

$$\Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(H^0 + iA^0\right) \end{pmatrix}$$ odd under a new Z_2 symmetry

DM candidate (mH < mA)

Signature: OS di-leptons + MET

$$q\bar{q} \to Z \to A^0 H^0 \to Z^{(*)} H^0 H^0 \to \ell^+ \ell^- H^0 H^0,$$
$$q\bar{q} \to Z \to H^\pm H^\mp \to W^{\pm(*)} H^0 W^{\mp(*)} H^0$$
$$\to \nu \ell^+ H^0 \nu \ell^- H^0,$$
$$q\bar{q} \to Z \to Z h^{(*)} \to \ell^+ \ell^- H^0 H^0,$$
$$q\bar{q} \to Z \to Z H^0 H^0 \to \ell^+ \ell^- H^0 H^0.$$



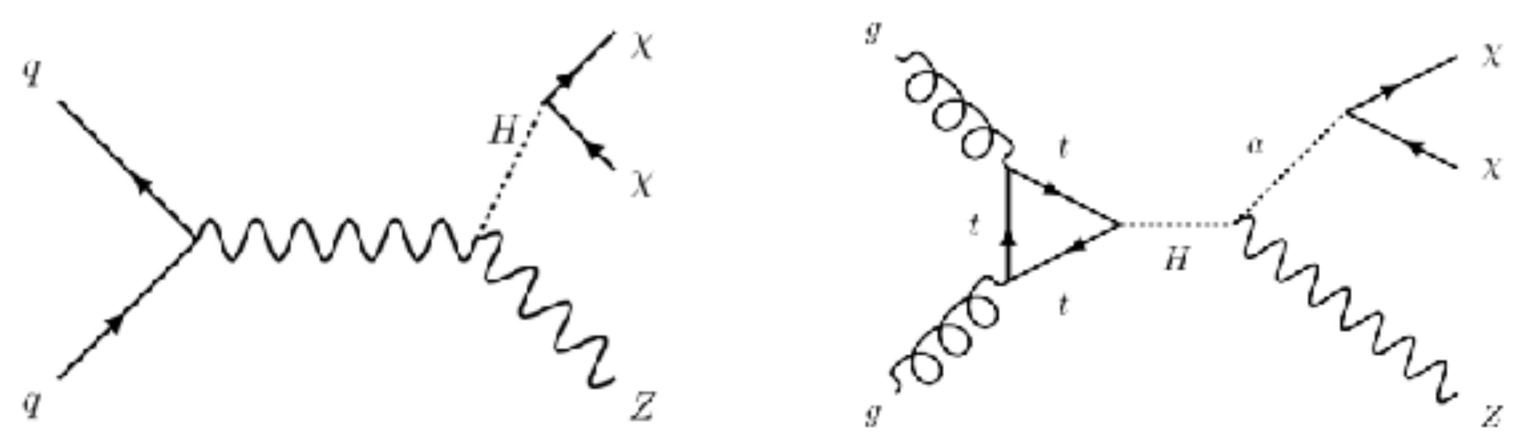
Constrained by leptons+MET SUSY and *Zh, h*→inv. searches

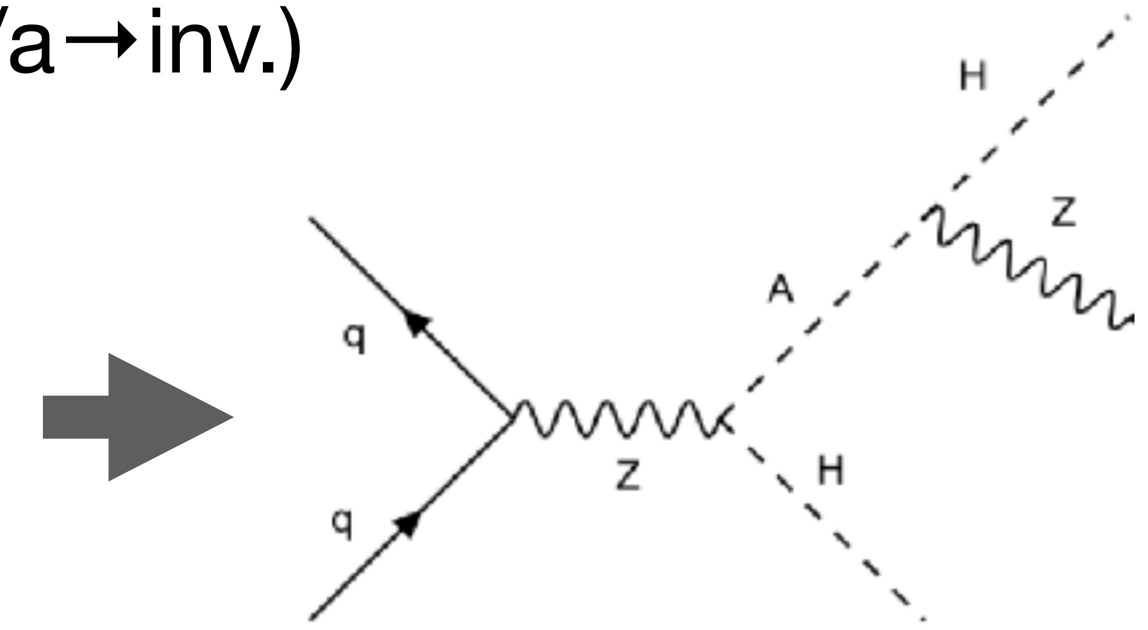
(+in compressed part of the parameter space also LLP searches)

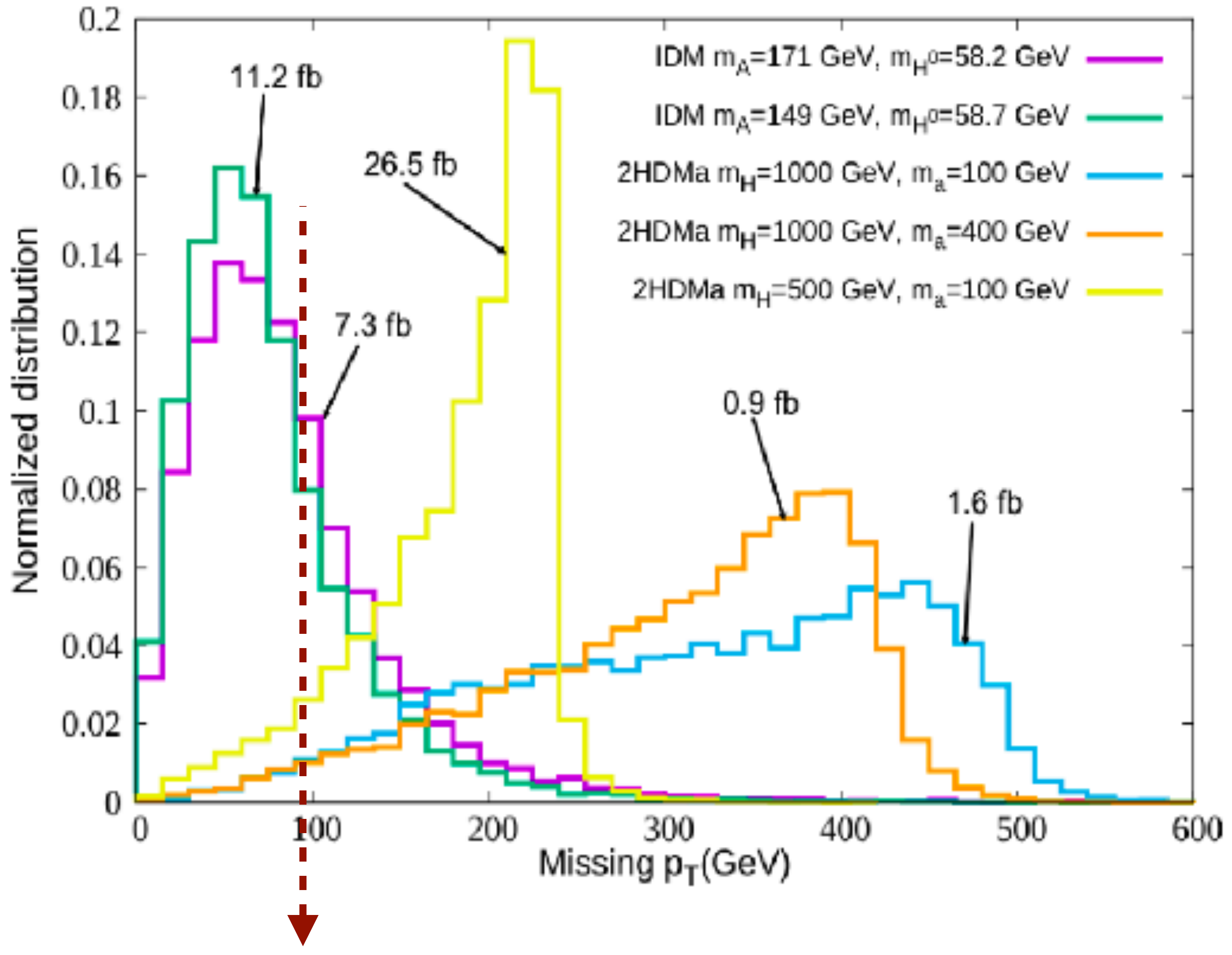
One of my favourite examples: IDM Inert Doublet Model

Revisited for Run 2 results [J. Lahiri, T. Robens, K. Rolbiecki]

ATLAS-HIGG-2018-26: Search for Z + (H/a→inv.)

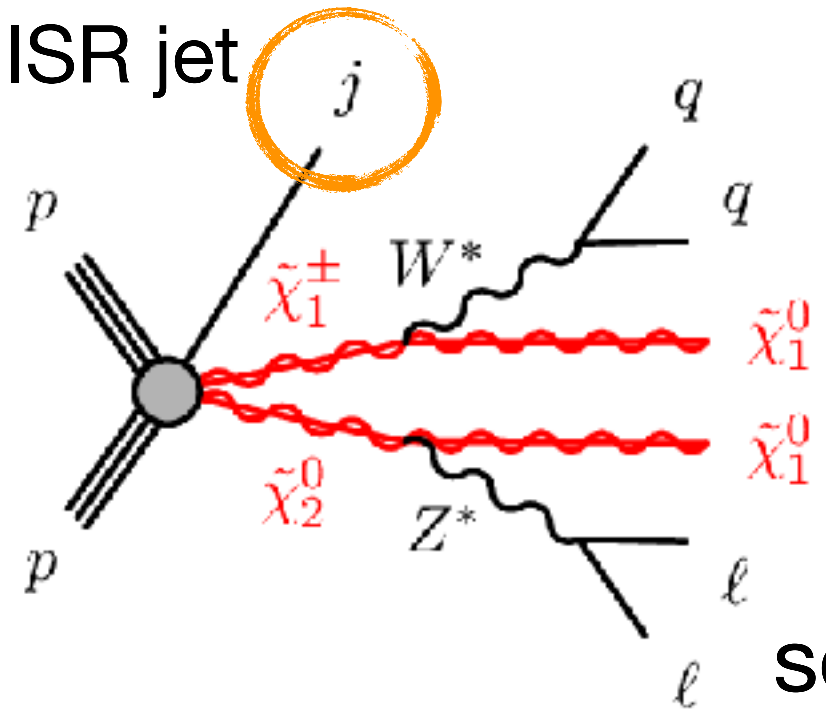


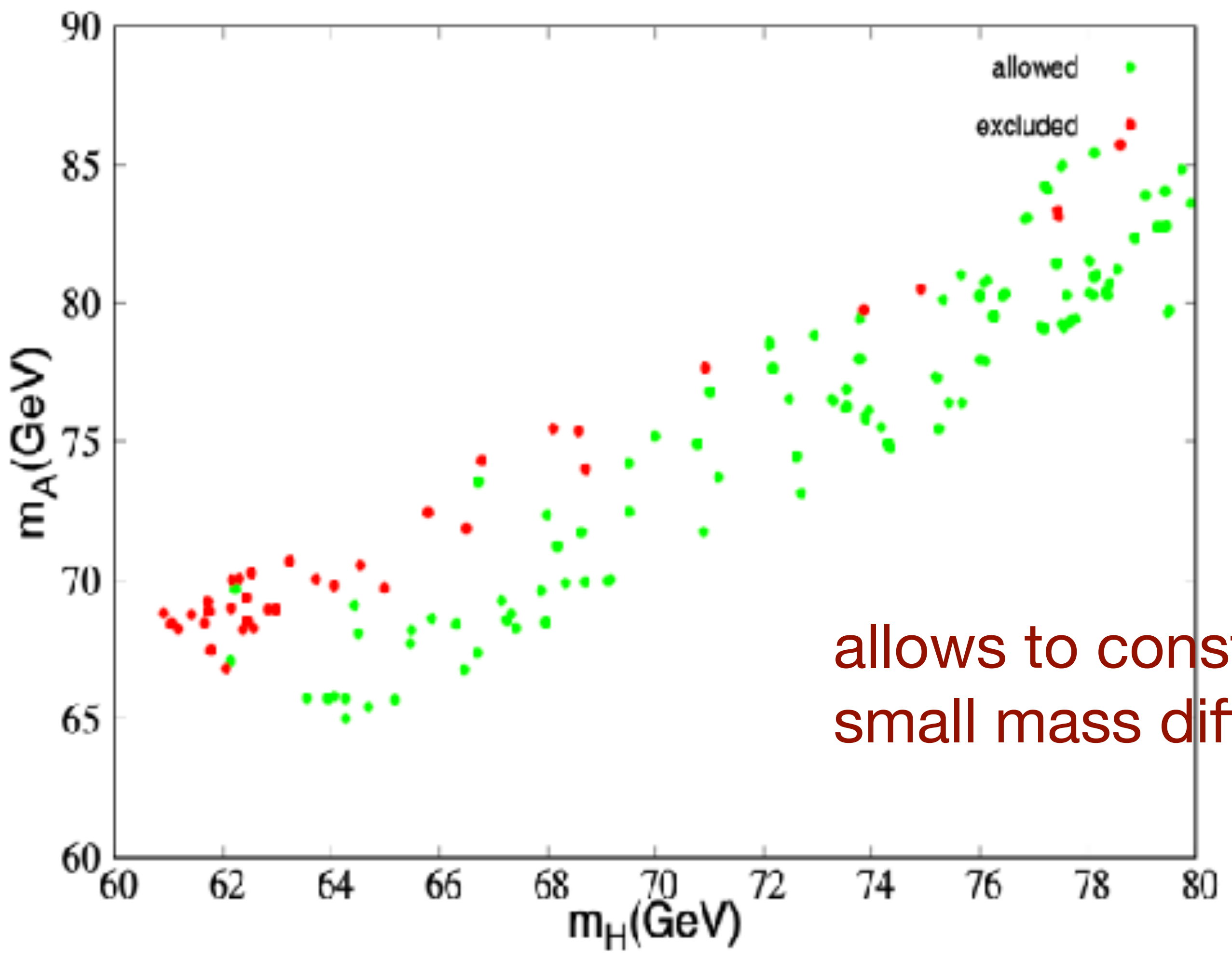




MET > 90 GeV cut kills the IDM signal !

ATLAS-SUSY-2018-16
EW SUSY with compressed mass spectra





allows to constrain region with small mass differences, Δm>5 GeV

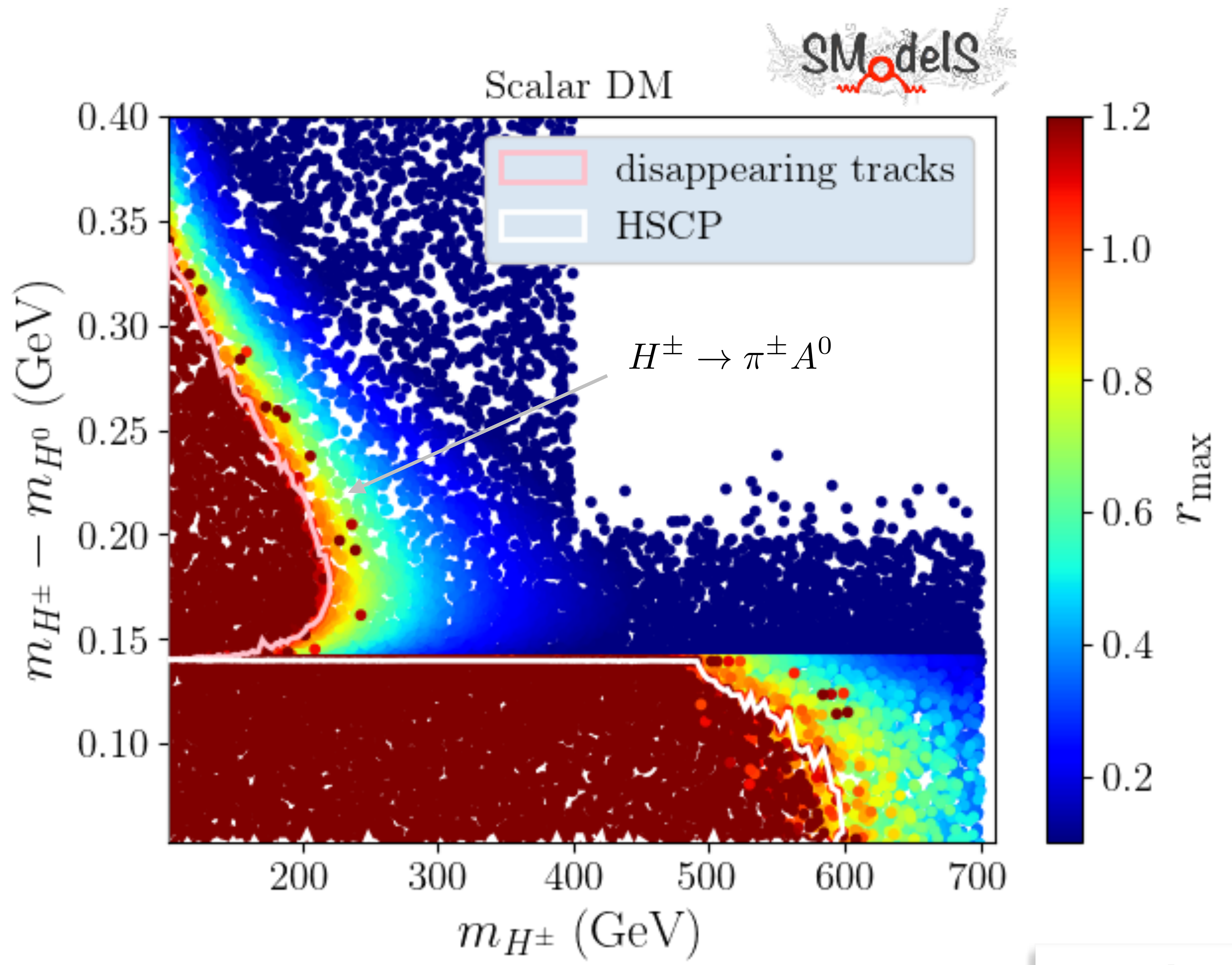
CHECKMATE

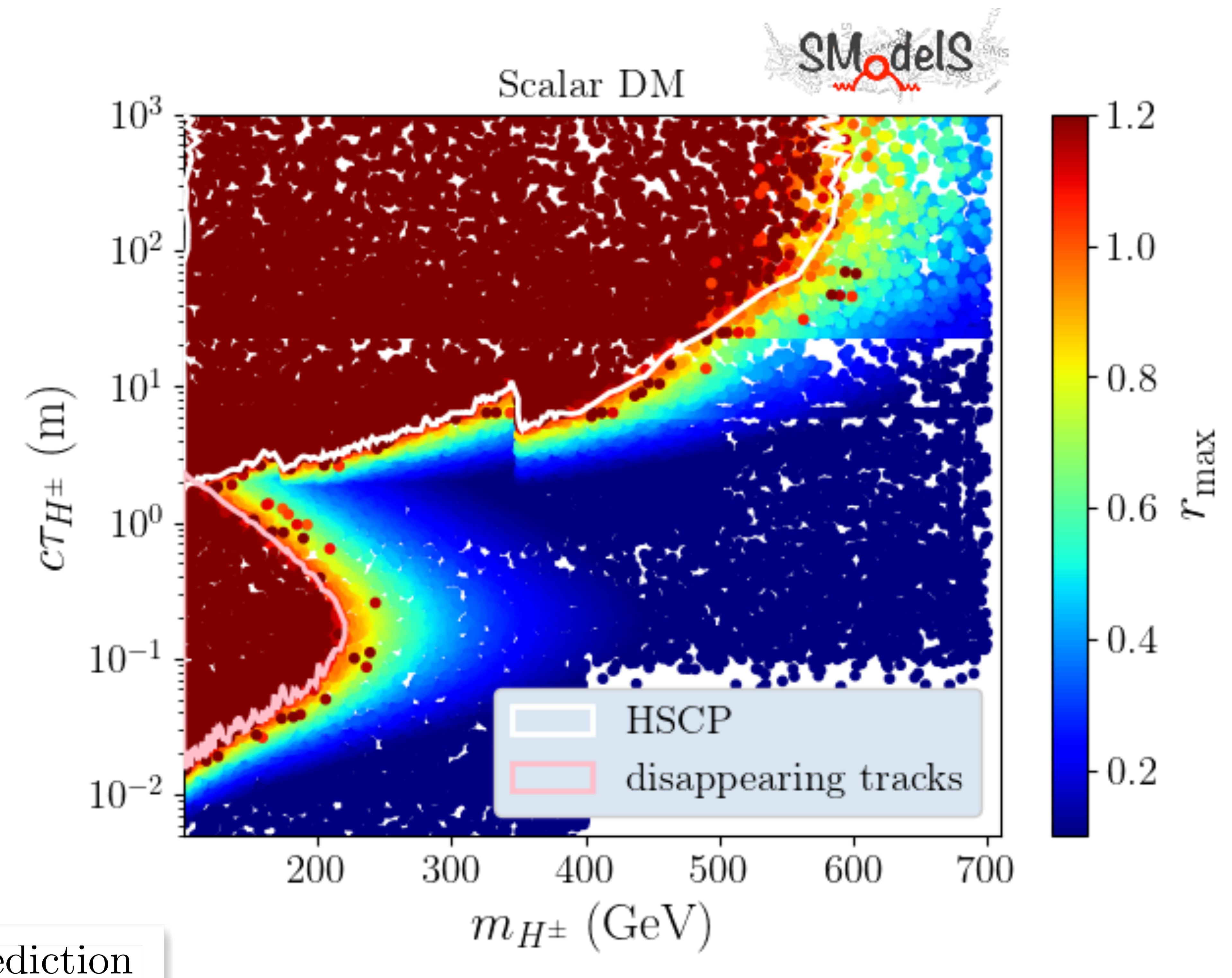
Jayita Lahiri, RiF workshop Feb. 2025

One of my favourite examples: IDM Inert Doublet Model

For very small mass differences, the charged scalar becomes long-lived

(dark matter co-annihilation region)





$$r = \frac{\text{theory prediction}}{\text{experimental limit}}$$

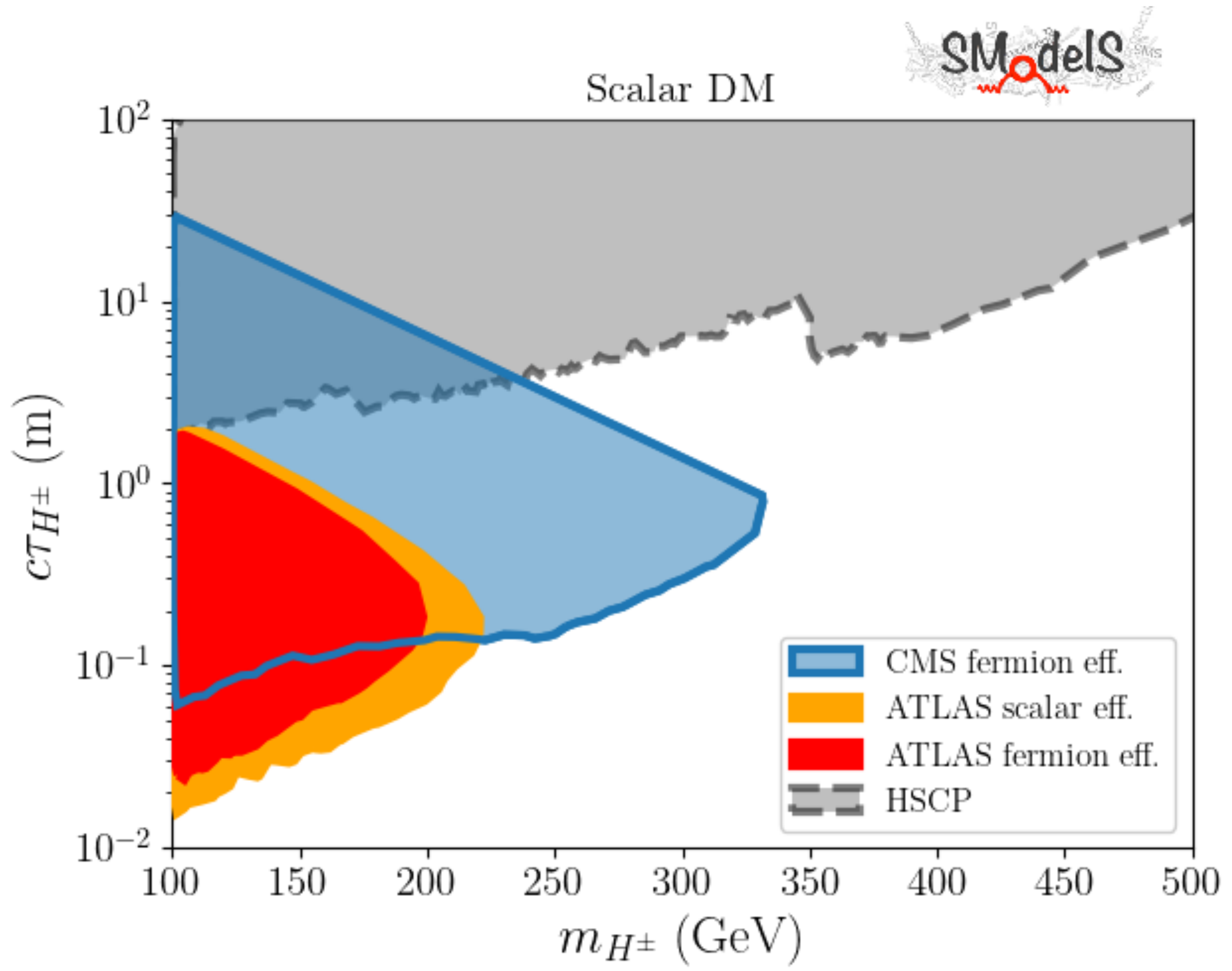
SModelS v2, arXiv:2112.00769

One of my favourite examples: IDM Inert Doublet Model

For very small mass differences, the charged scalar becomes long-lived → LLP

Disappearing track analyses: pursued as searches for long-lived charginos

- ATLAS-SUSY-2016-06, 36 / fb: efficiencies recasted by *Belyaev et al.* for both the fermion (chargino) and the scalar (charged Higgs) LLP cases. arXiv:2008.08581, Zenodo dataset
- CMS-EXO-19-010, 101 / fb: official CMS results; only the fermion (chargino) case is available.



(LLP decay length depends on the LLP boost and consequently on its spin!)

SModelS v2, arXiv:2112.00769

Lessons learned

#1:

even for such a simple model as the IDM, constraints from different analyses are relevant

#2:

no dedicated analyses exist for this model, so reinterpretation is the only way

Lessons learned

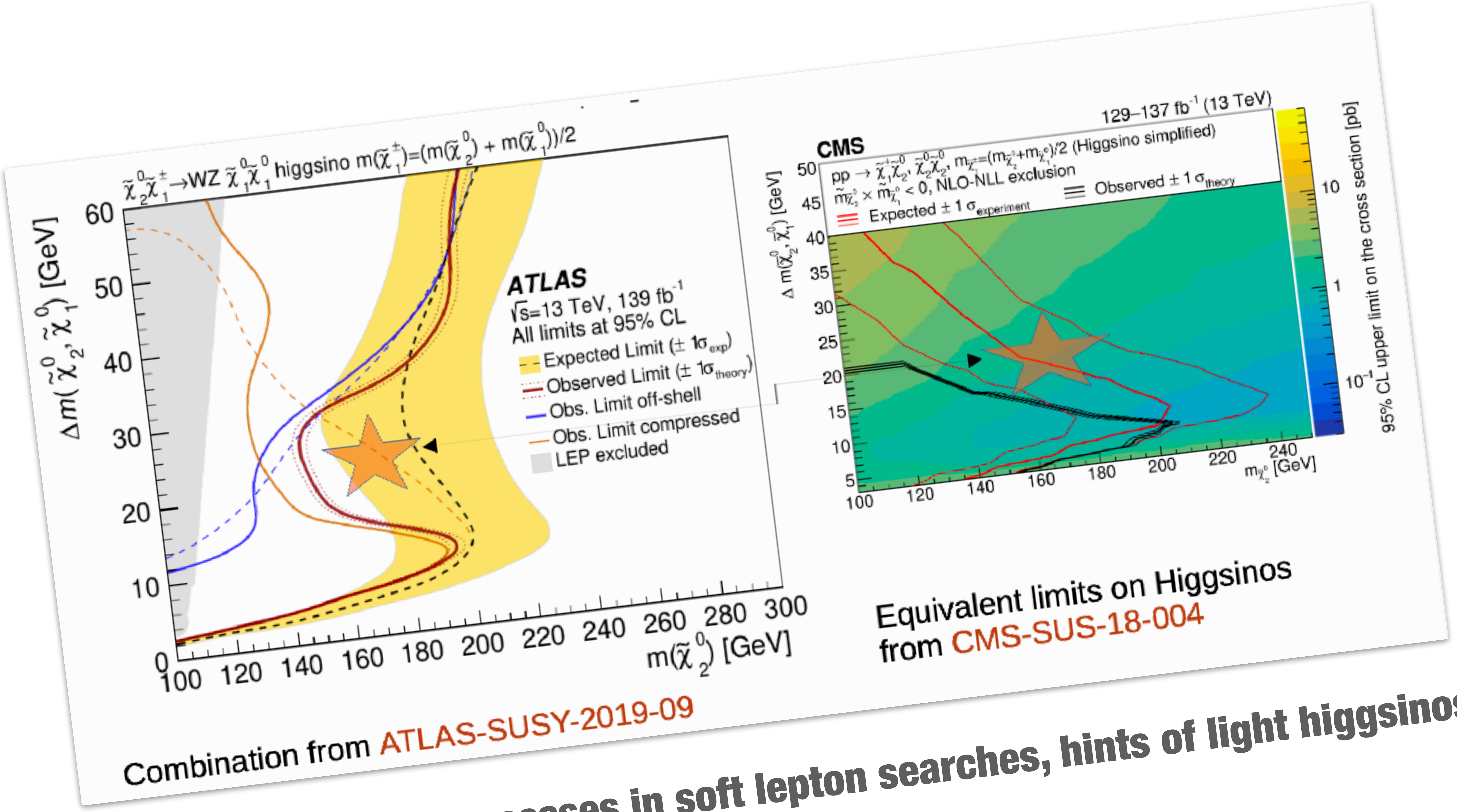
#3:

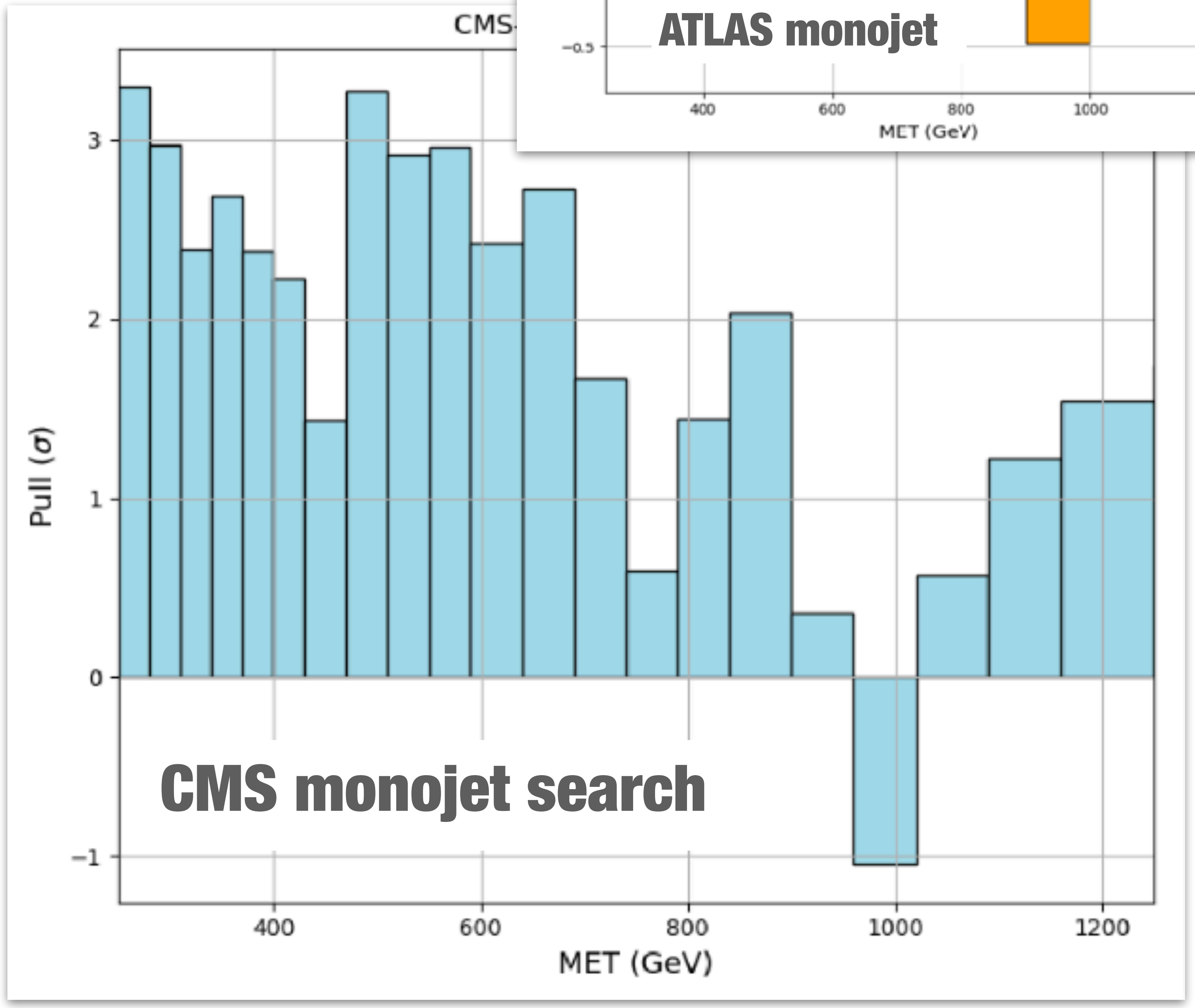
can elucidate gaps in experimental coverage and help define new benchmarks

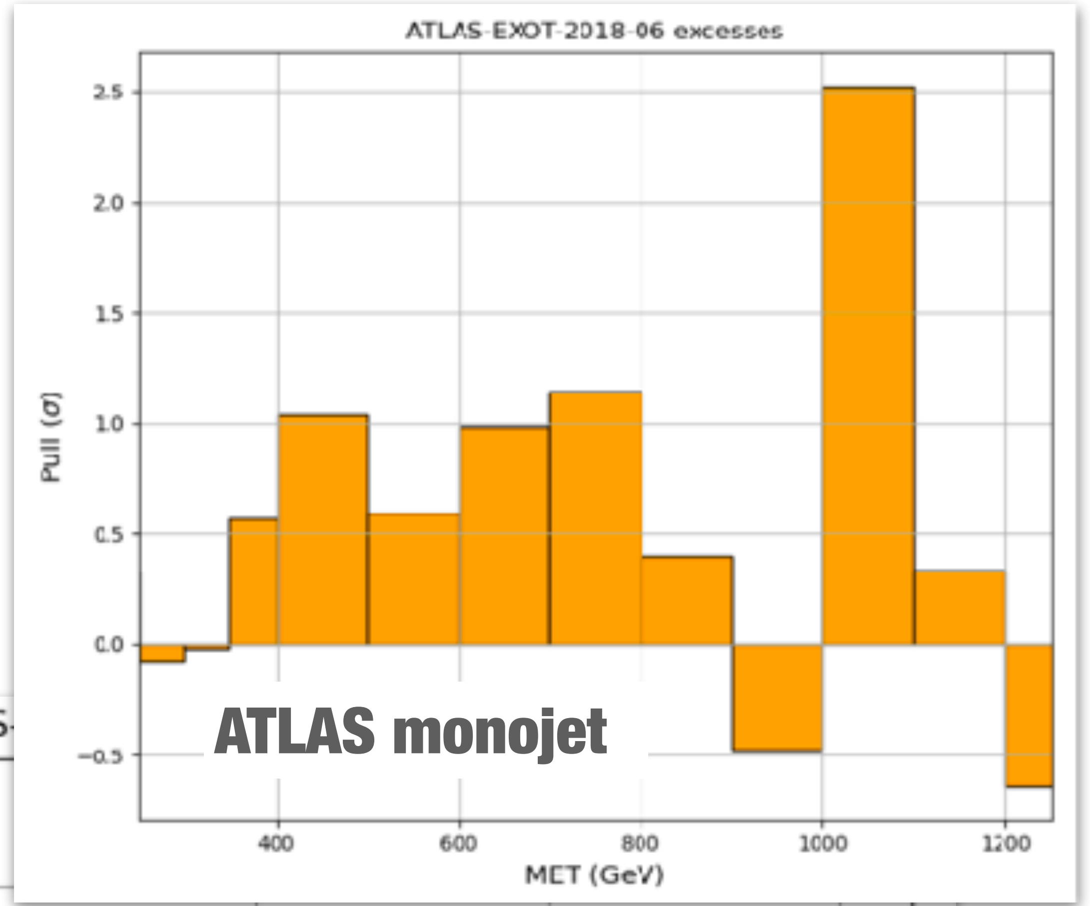
#4:

not straightforward; several tools involved

Interpretation of excesses







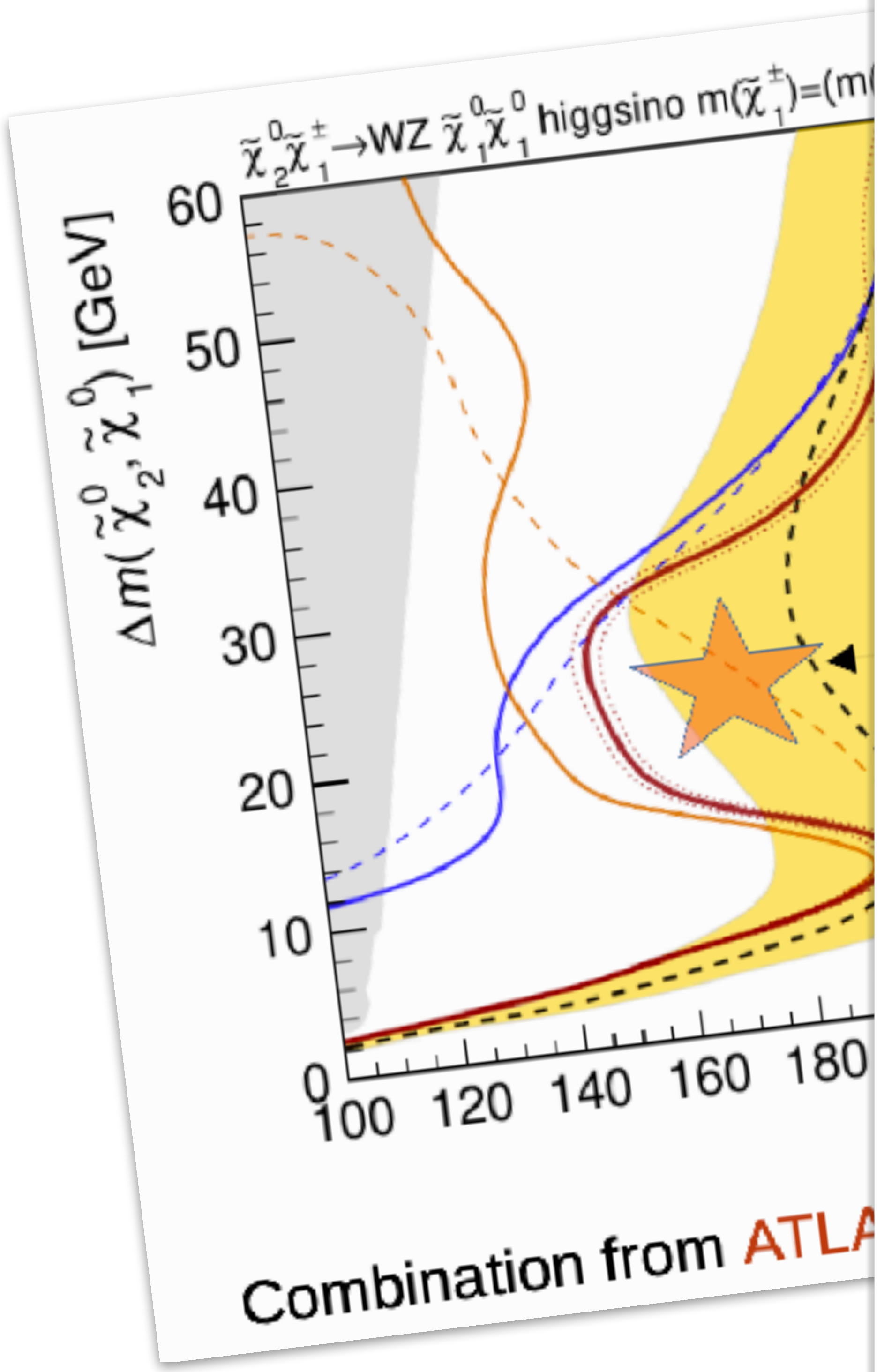
Small but intriguing excesses in soft lepton searches, hints of light higgsinos?

Consistent explanation in realistic models?

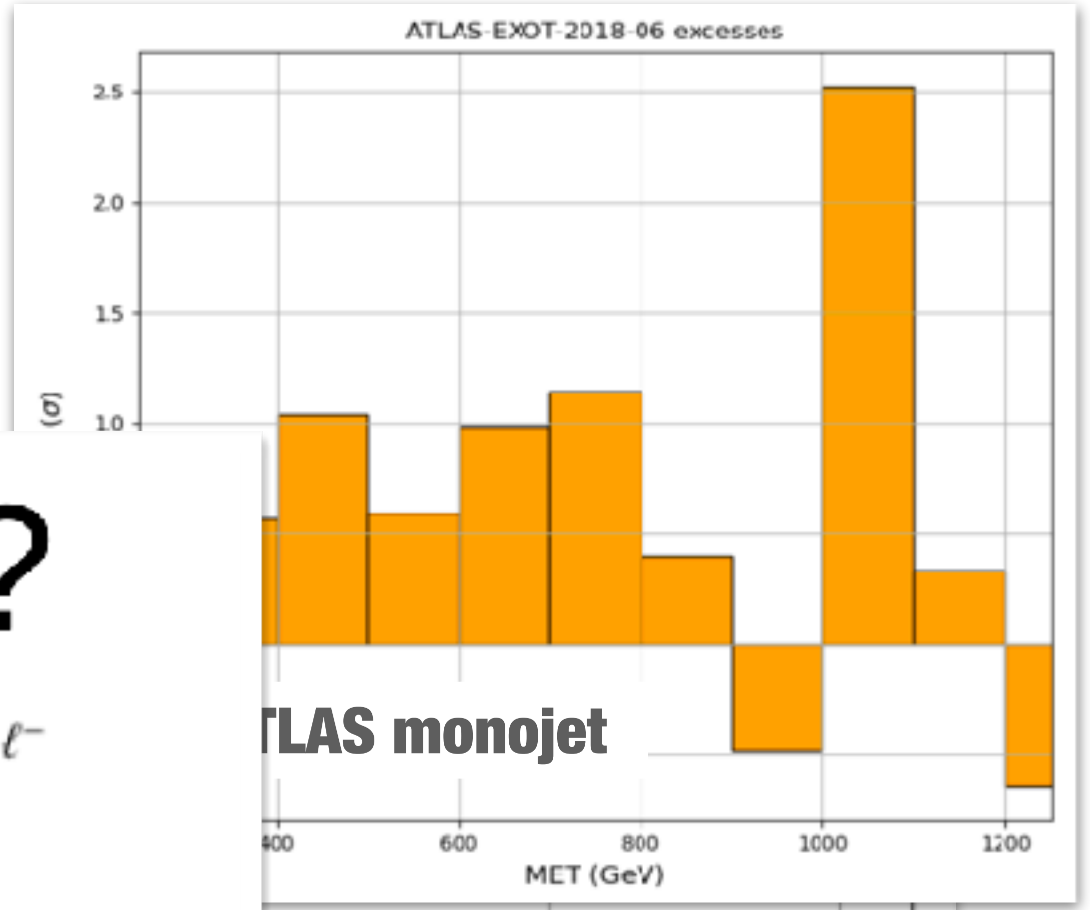
Interpretation of excesses

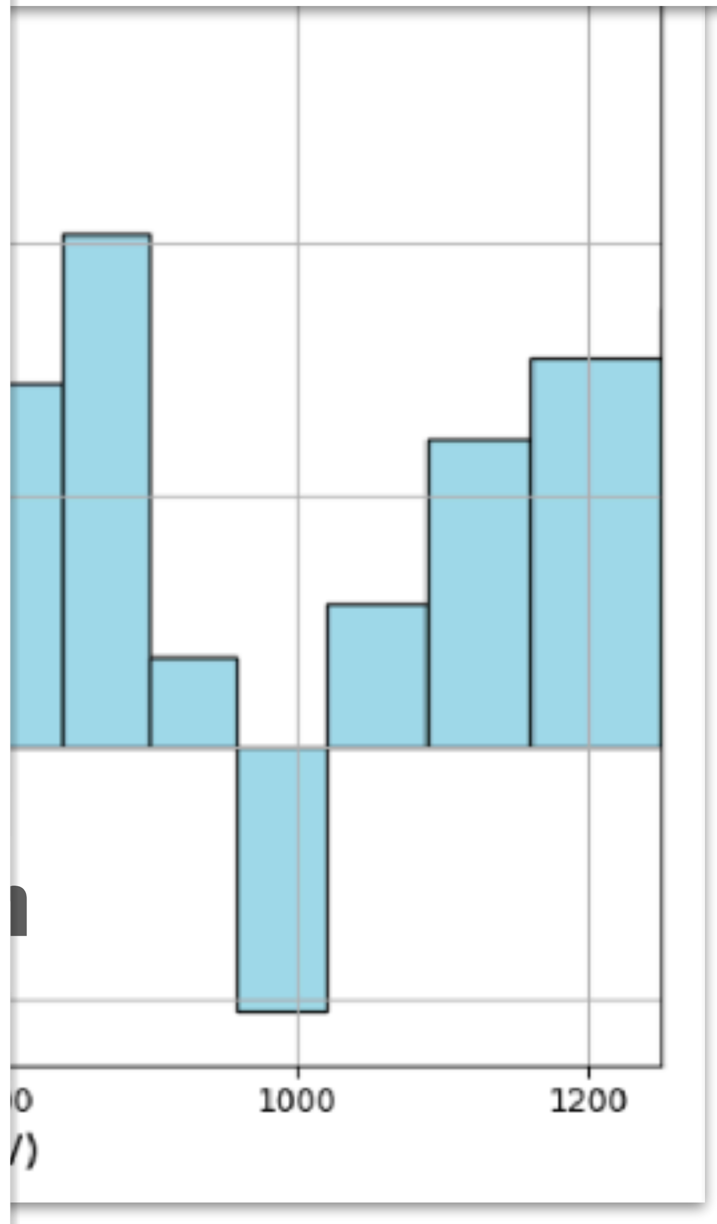
Mark Goodsell, RiF workshop Feb. 2025

Interpretation of excesses



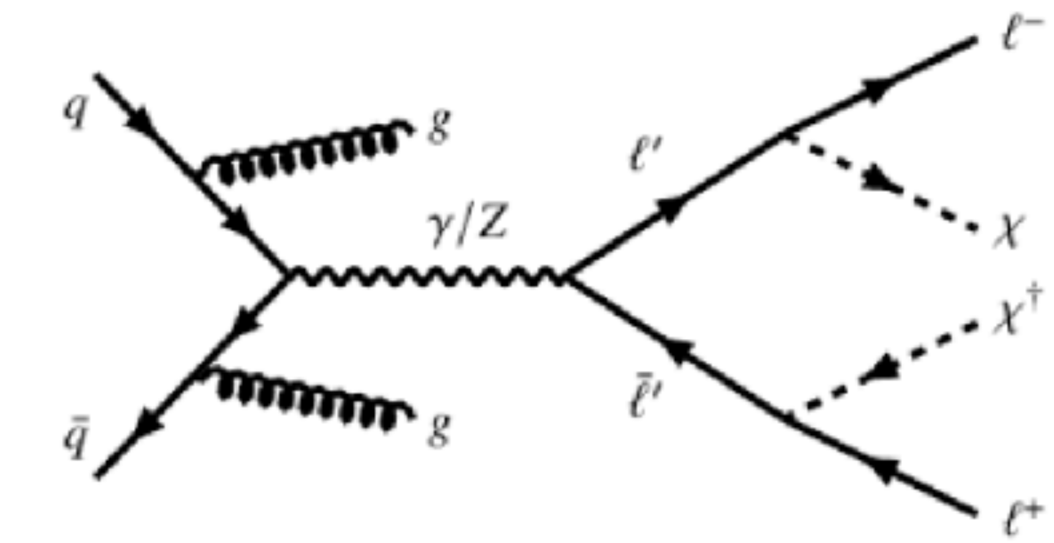
Small but intriguing

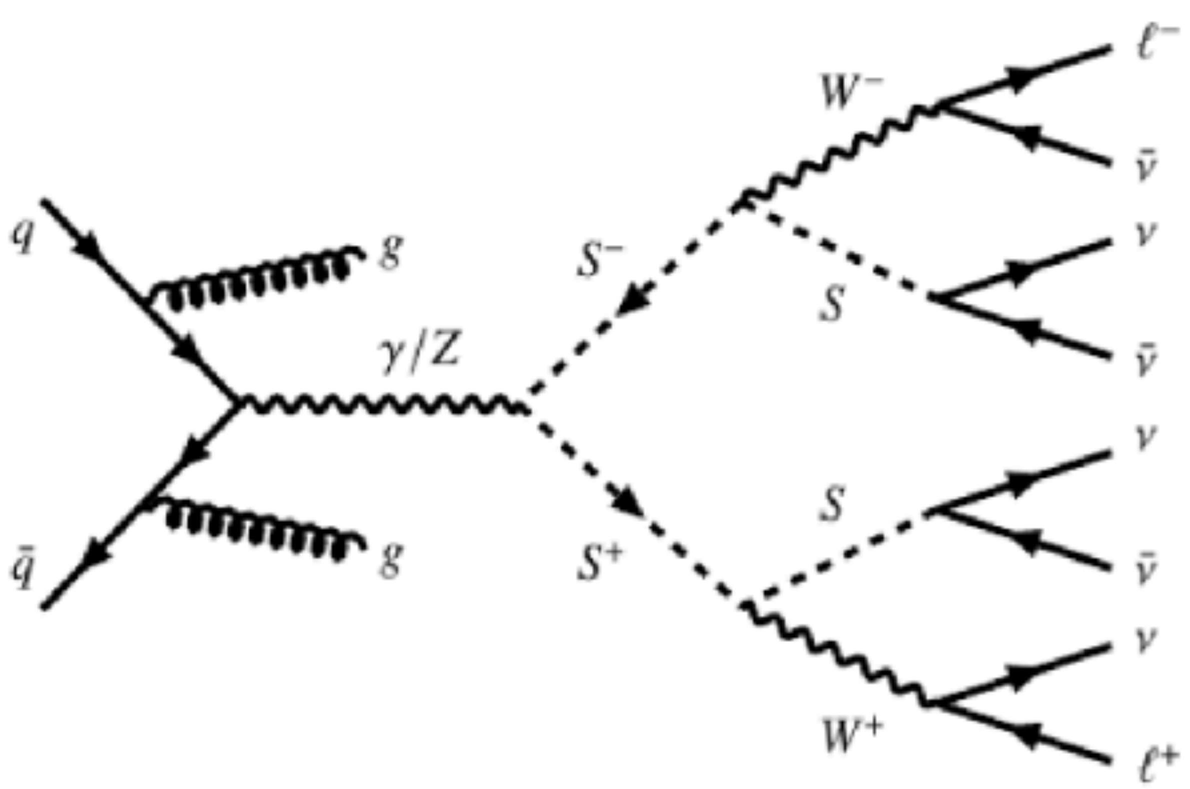




Non-SUSY models for the excesses?

- Scalar DM with vector-like leptons
- Type-II see-saw model
- These ***generically fit worse than the SUSY models***

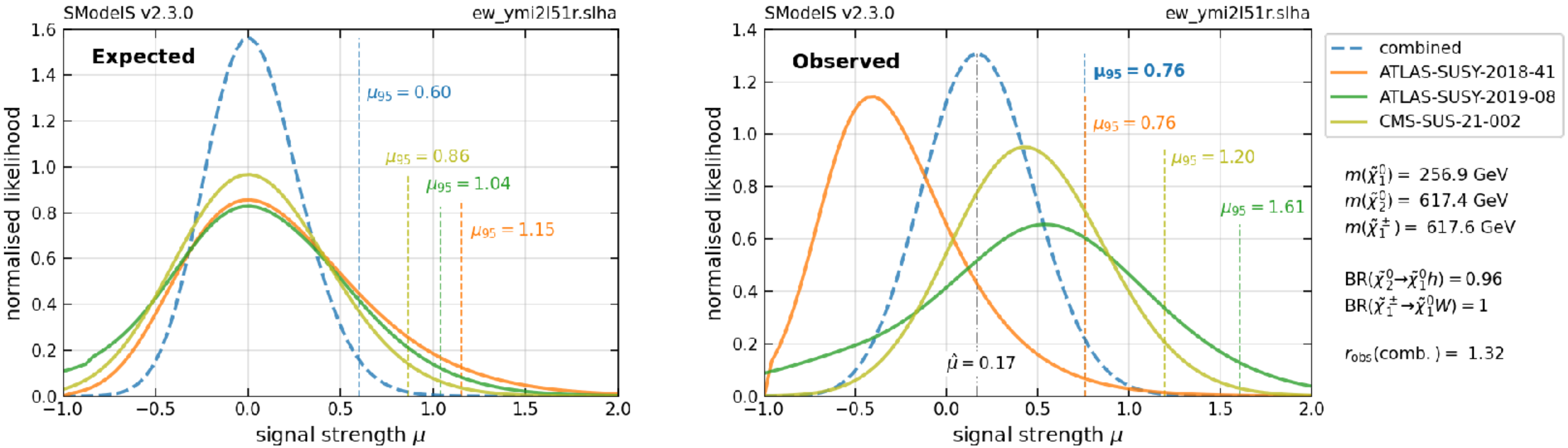




Mark Goodsell, RiF workshop Feb. 2025

(Global) likelihoods vs exclusion limits

95% CL limits only allow for binary decisions (excluded or not), but no rigorous statistical treatment. What we really need is likelihood information → global analyses, global fits, etc.



SUSY electroweak-ino example

from 2306.17676
(see also 2312.16635)

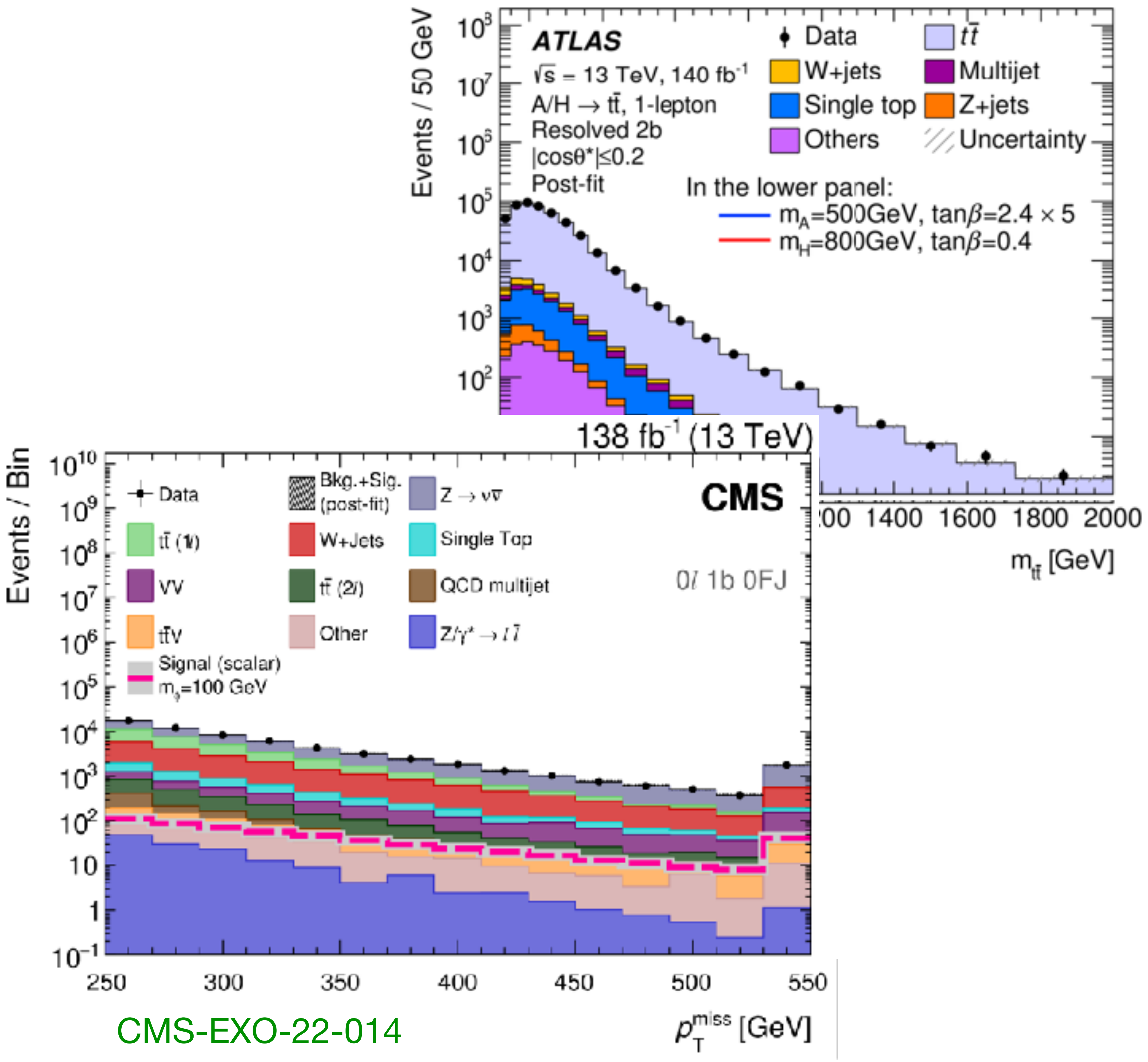
Experimental results vs. their interpretation

Empirical outcome, such as event counts or the measurement of some physical quantity

vs.

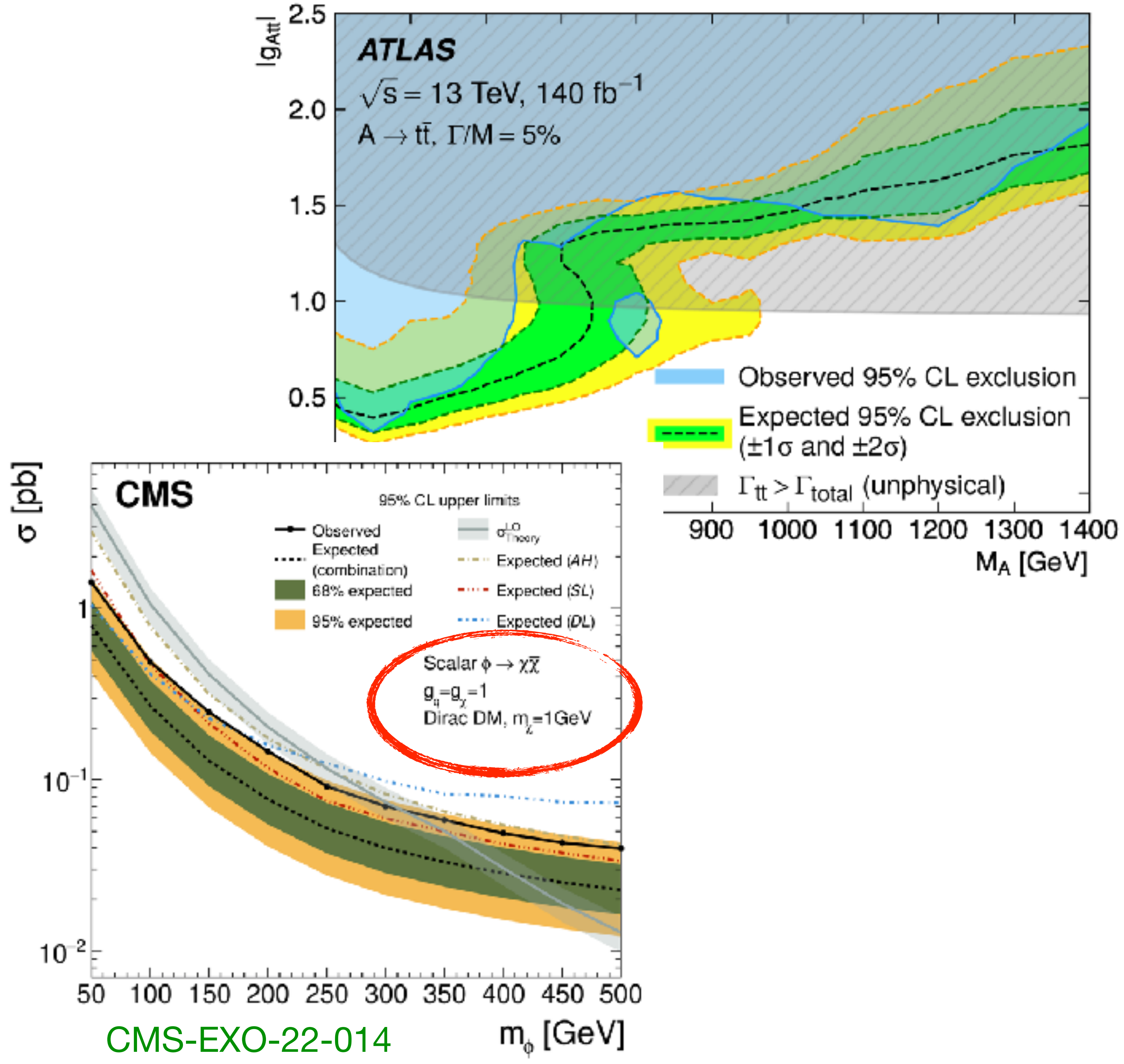
The act of comparing this empirical outcome to model predictions

ATLAS-EXOT-2020-25



CMS-EXO-22-014

ATLAS-EXOT-2020-25



CMS-EXO-22-014

Analysis / reinterpretation chain

Analysis / reinterpretation chain

Reproduce experimental analysis
in a Monte Carlo simulation ("recasting")

CHECKMATE MADAnalysis 5

RIVET Contur ADL ColliderBit

(+ ATLAS SimpleAnalysis)

- *Measurement analyses*: "SM" measurements (differential distributions), where detector effects have been unfolded to a fiducial phase-space; hundreds available in Rivet.
- *Search analyses*: concern tails of SM distributions and/or unusual objects; typically not unfolded, so detector effects need to be reproduced, too.
- Increasing use of *low-level detector quantities* and *machine learning techniques* to enhance sensitivity is a challenge for reproducibility.

(

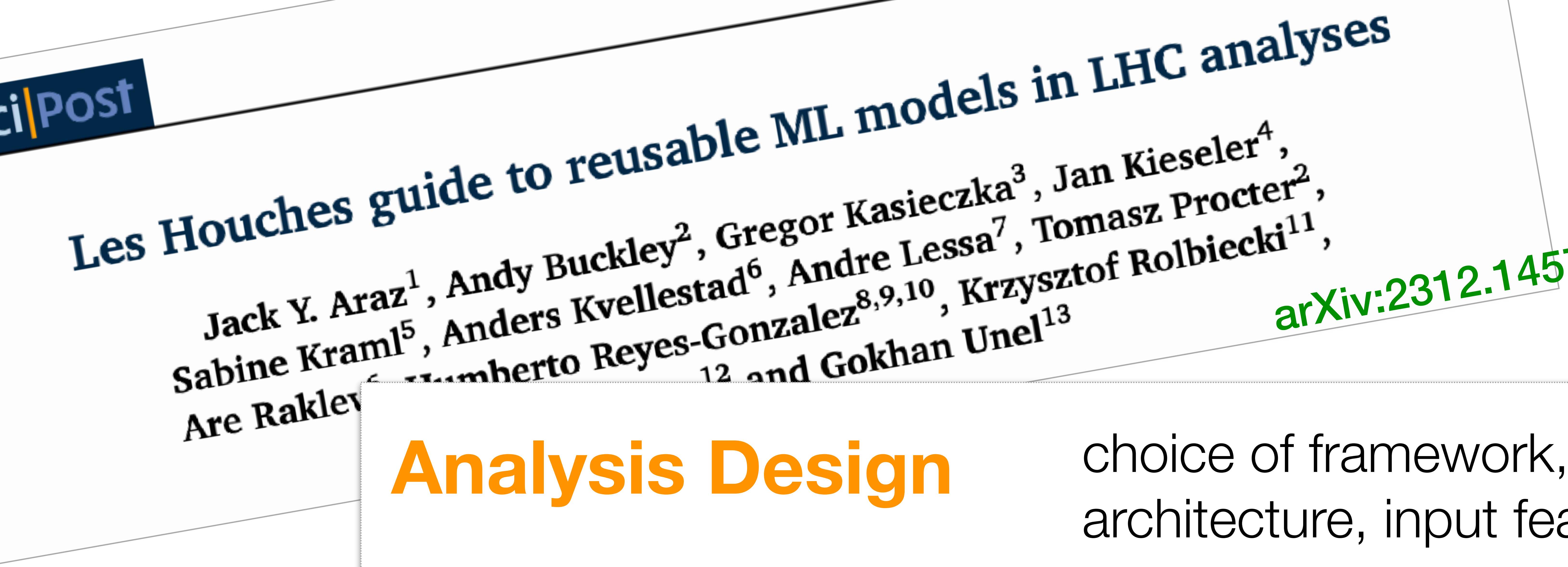
arXiv:2312.14575

ML-based analyses

Some ATLAS analyses have indeed started to provide their learned models in serialised form.

SUSY-2018-22	Search for squarks and gluinos: jets+MET BDT weights in XML format on HEPData + simpleAnalysis implementation
SUSY-2019-04	RPV SUSY search, leptons + many jets ONNX files for 5 NNs (4-8 jets SRs) on HEPData + simpleAnalysis implementation
SUSY-2018-30	SUSY search with MET and many b-jets simpleAnalysis implementation with ONNX-serialised NN model
EXOT-2019-23	Search for neutral LLPs with displaced hadronic jets (“CalRatio LLP search”) preserved NNs as ONNX, BDTs as executables with petrify-bdt; low level inputs; also 6d efficiency maps parametrising the BDT+NN selection + example code
HDBS-2019-23	Anomaly detection search for new resonances Y → X+H in hadronic final states VRNN python code + post-training weights (PyTorch .pth file)

→ CheckMATE, MadAnalysis5 and RIVET have developed interfaces.


Les Houches guide to reusable ML models in LHC analyses

Jack Y. Araz[1], Andy Buckley[2], Gregor Kasieczka[3], Jan Kieseler[4],
Sabine Kraml[5], Anders Kvellestad[6], Andre Lessa[7], Tomasz Procter[2],
Are Raklev ... Humberto Reyes-Gonzalez[8,9,10], Krzysztof Rolbiecki[11],
... [12] and Gokhan Unel[13]

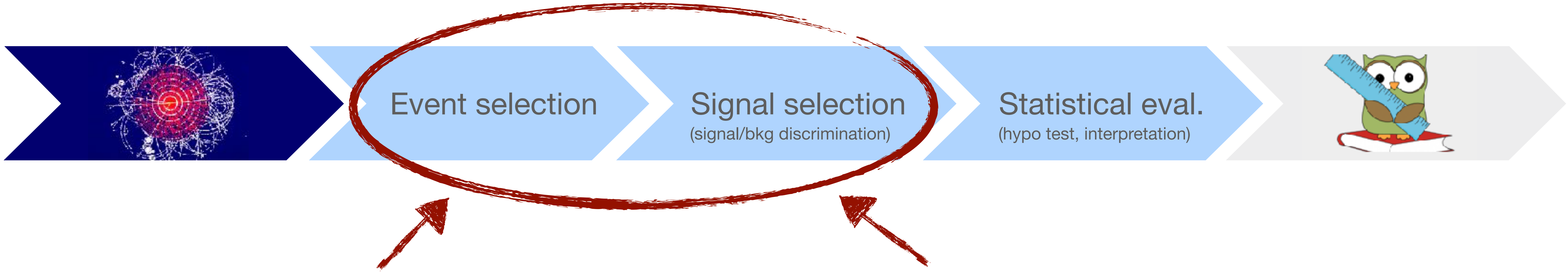
arXiv:2312.14575

Analysis Design	choice of framework, preservation format, architecture, input features
Documentation	clear definition of all input & output variables; code/framework version and dependencies
Validation	material enabling to verify performance (cut-flows, plots of in/out variables, runcards)
Surrogates	another ML model trained to approx. replicate the output of the original one (or simple parametrised efficiencies)

Keep reinterpretability in mind early on in analysis design!

)

Analysis / reinterpretation chain



Reproduce experimental analysis
in a Monte Carlo simulation (“recasting”)

CHECKMATE, MadAnalysis 5, RIVET Contur, ADL, ColliderBit

(+ ATLAS SimpleAnalysis)

Reuse simplified model results
(σ_{95}, signal A×ε)

SModelS, HiggsBounds

Valid if **signal acceptances** are to good approx. **the same** as in original experimental paper. (kinematic distributions don’t change too much)

Analysis / reinterpretation chain

Reuse experimental analysis
in a Monte Carlo simulation ("recasting")

(+ ATLAS SimpleAnalysis)

Analysis surrogates?

- *Idea: the probability of an event being selected should depend only on the physical properties of the final state (pT, position, flavor,…)*
- Parametrised efficiencies that relate selection probabilities to particle/truth level inputs

✓ ATLAS-EXOT-2022-04: Trained BDTs to give overall selection probability in ABCD plane, using truth-level (Lxy, Lz, η, p_T, E_T, Child ID);
pickle files + sample code

Pro's and Con's: simulation-based recasting

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.)

- **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 **mostly 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.

Pro’s and Con’s: simplified model approach

- 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

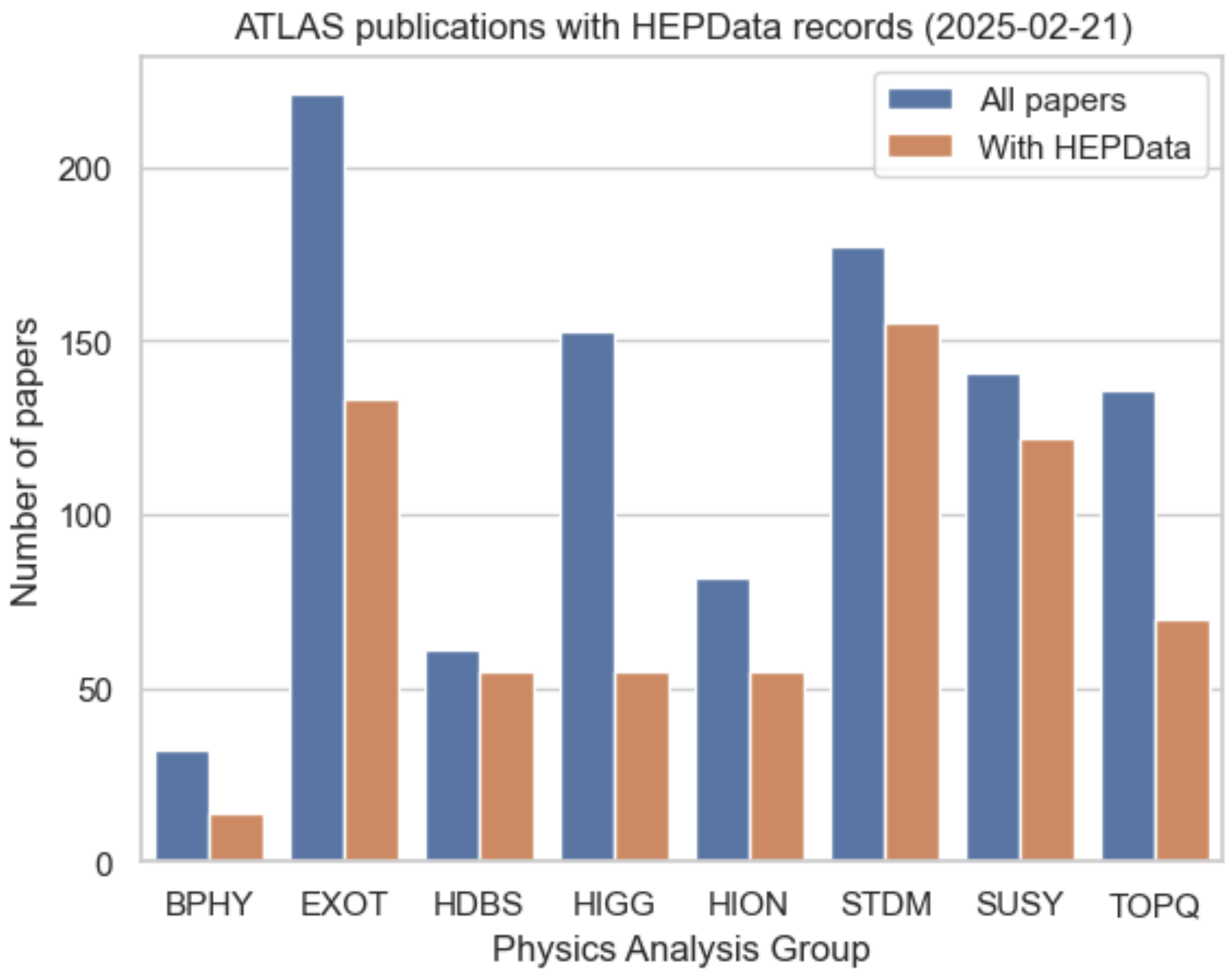
simplified model approach (SModelS)

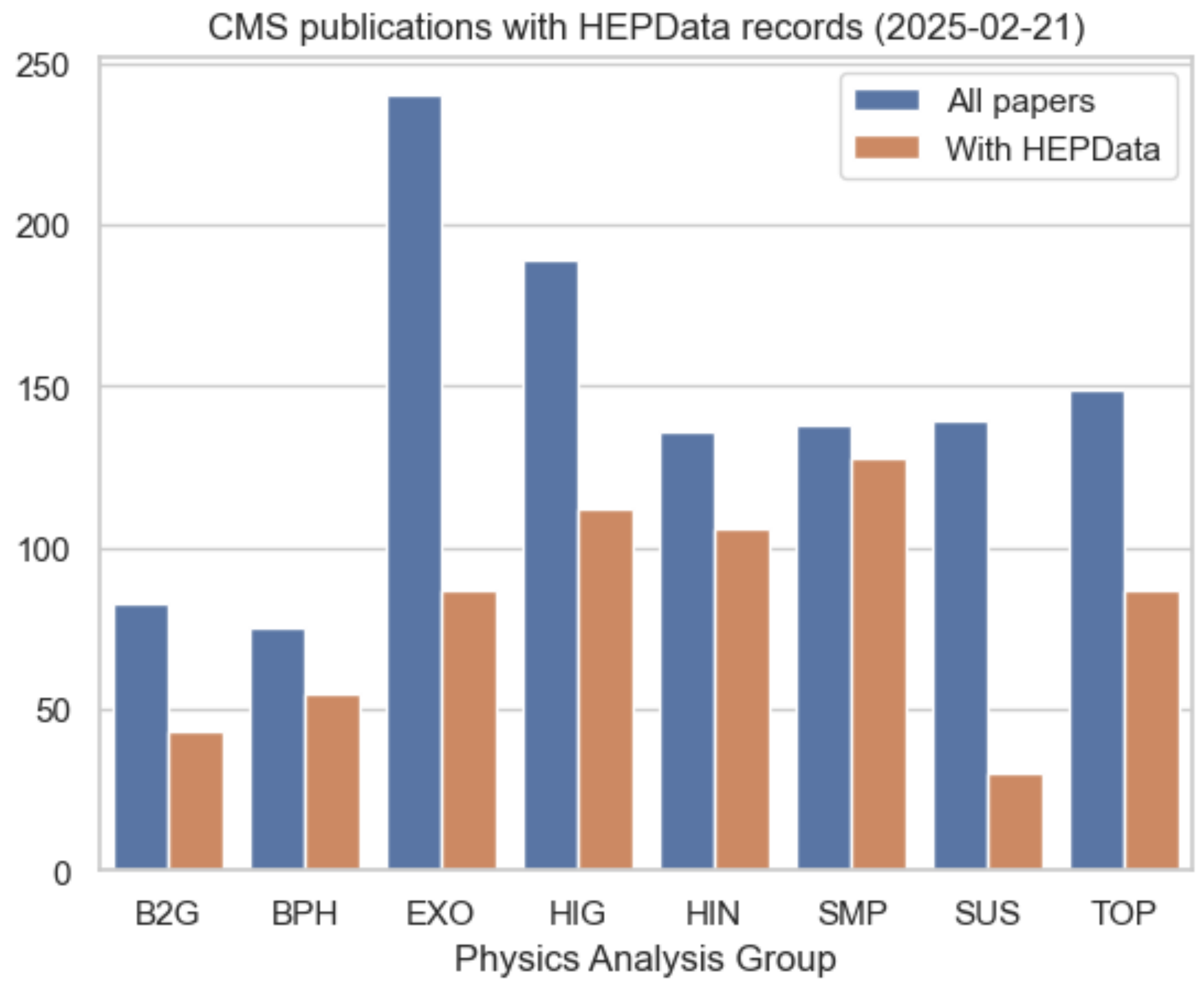
Create **SLHA file**
with mass spectrum and decay tables
⬇
add **production cross sections**
(SModelS xseccomputer or micrOMEGAs)
⬇
compute all **signal weights** :
$\sigma\times$BR$\times$BR…
⬇
sum **matching elements**
⬇
find and apply A$\times\varepsilon$ (or σ_{95}) values
from **experimental results**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

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

HEPData

- Digitised material is crucial but remains patchy!
- Possibility to search for tool implementations: “analysis:rivet” or “analysis:madanalysis”, etc.





[curtesy Graeme Watt]

Rivet Analysis **Measurements of inclusive and differential cross-sections of $t\bar{t}\gamma$ production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector**

The ATLAS collaboration Aad, Georges ; Aakvaag, Erlend ; Abbott, Braden Keim ; *et al.*

JHEP 10 (2024) 191, 2024.

Inspire Record 2768921

Version 4 **MadAnalysis** **HistFactory** **SModelS** **CheckMATE** **Search for electroweak production of charginos and sleptons decaying into final states with two leptons and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions using the ATLAS detector**

The ATLAS collaboration Aad, Georges ; Abbott, Brad ; Abbott, Dale Charles ; *et al.*

Eur.Phys.J.C 80 (2020) 123, 2020.

Inspire Record 1750597 DOI 10.17182/hepdata.89413

Rivet Analysis **MadAnalysis** **SModelS** **Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV**

The CMS collaboration Sirunyan, Albert M ; Tumasyan, Armen ; Adam, Wolfgang ; *et al.*

Phys.Rev.D 96 (2017) 032003, 2017.

Checkmate or MadAnalysis: 46 results
SModelS: 83 results

Analysis / reinterpretation chain

comparing empirical outcome
to model predictions

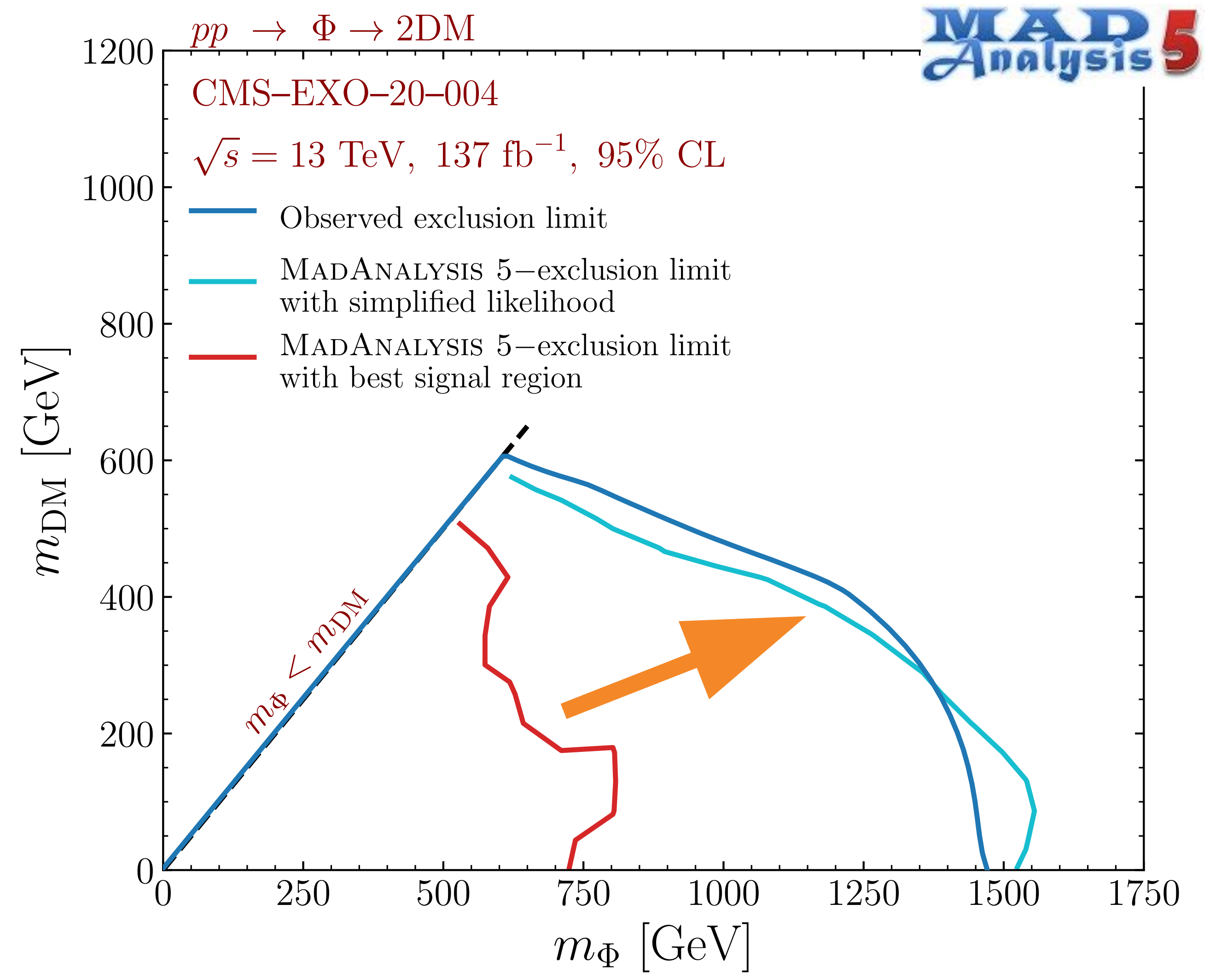
Analysis / reinterpretation chain

Given the signal yields together with the number of observed events, expected backgrounds and uncertainties (incl. correlations), one can compute a simplified likelihood

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

covariance matrix

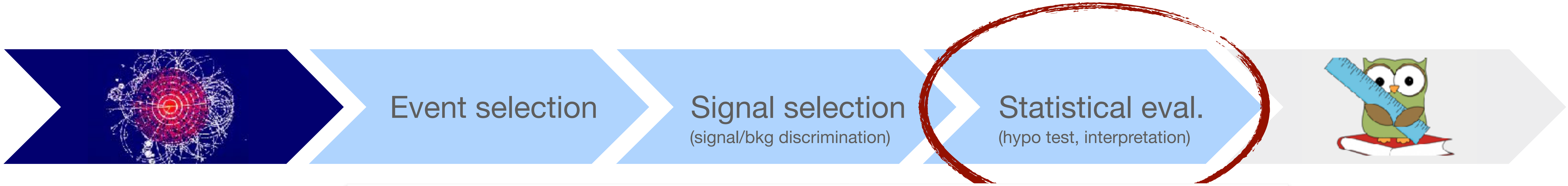
assuming a Poisson distribution for the data and Gaussian distributions for the nuisances.



NB for "measurement analyses" (Rivet/Contur) it is important that the SM predictions be available!

Same principle for STXS & EFT fits

Analysis / reinterpretation chain



Given the signal yields
expected background
compute a simplified l

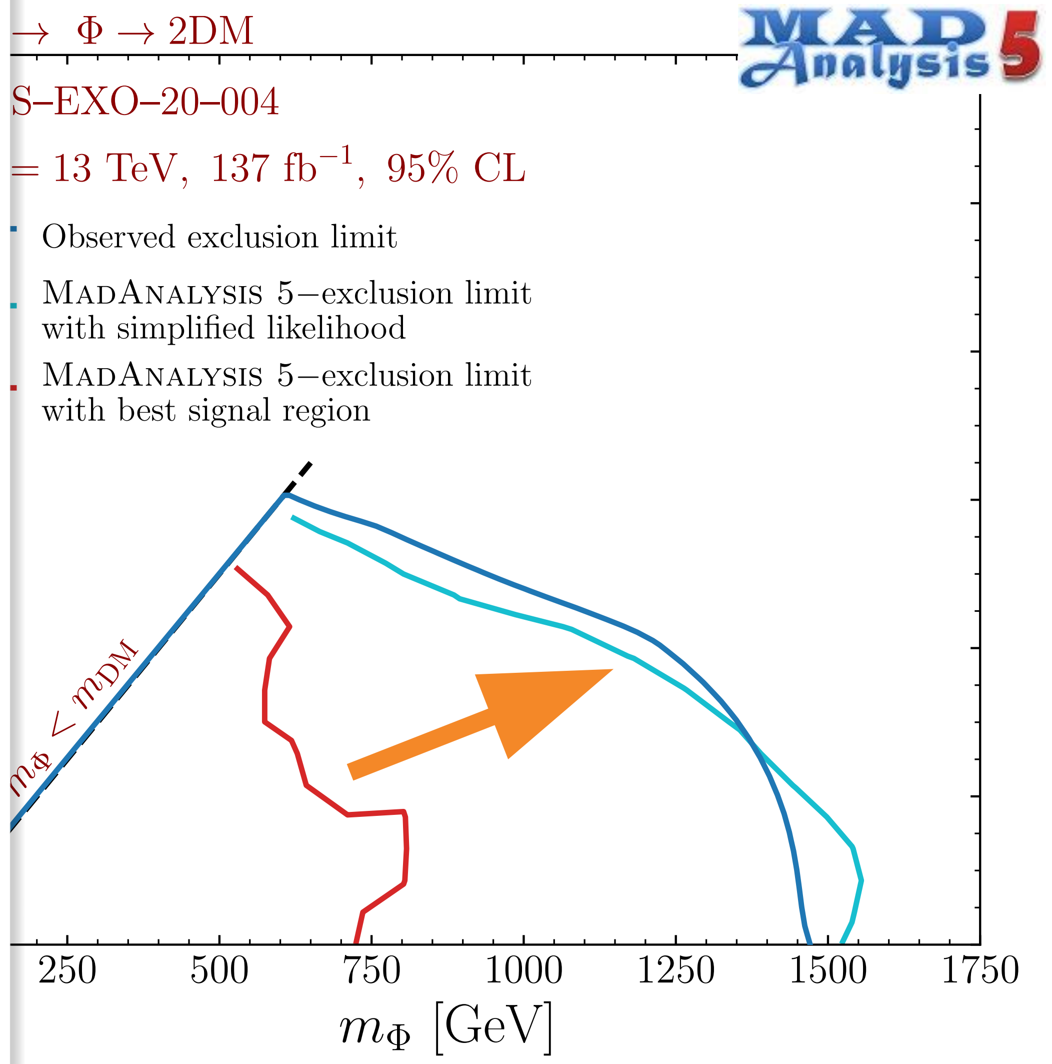
$$\mathcal{L}_S(\mu,\boldsymbol{\theta}) = \prod_{i=1}^{N} \frac{(\mu}{}$$

assuming a Poisson distribu

So far so good, but:

- bin-to-bin correlations not always available
- how good is the Gaussian approximation?
- what about signal leaking into control regions?
- can't determine inter-analysis correlations
- can't generate pseudo-data
- can't update constraint terms
- …..

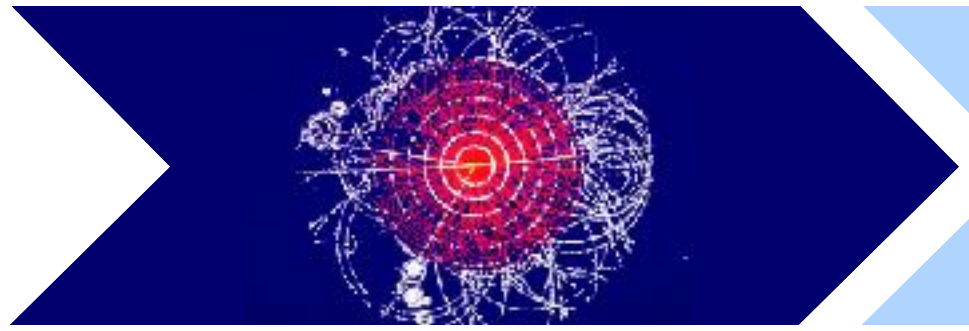
lots of information is lost w.r.t. full statistical model



NB for "measurement analyses" (Rivet/Contur) it is important that the SM predictions be available!

Same principle for STXS & EFT fits

Analysis / reinterpretation chain



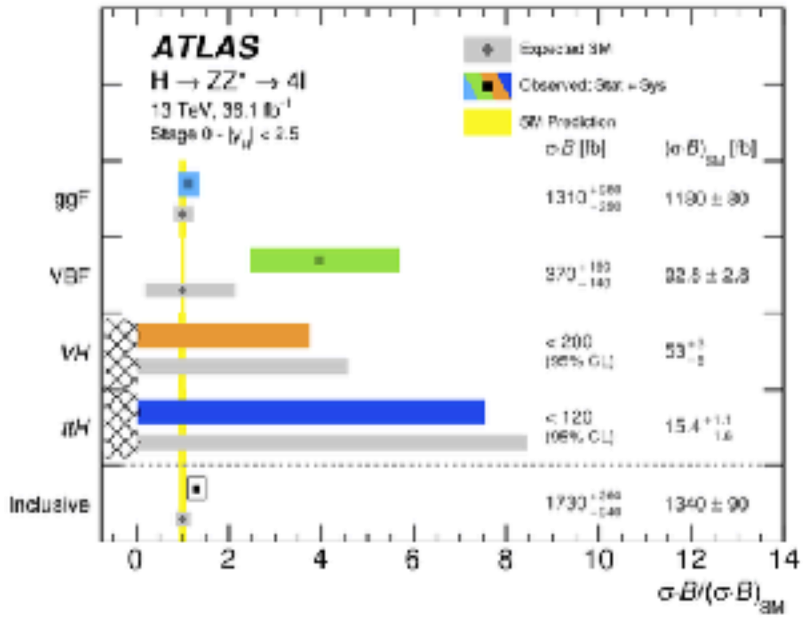
Event selection

Signal selection
(signal/bkg discrimination)

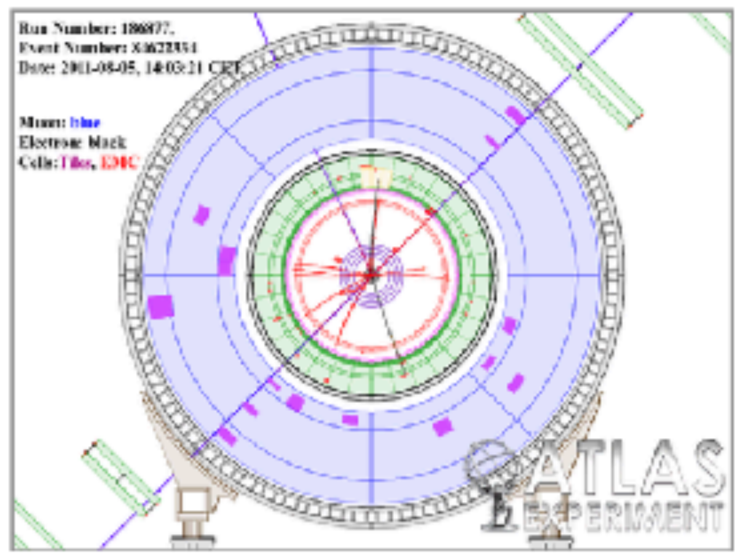
Statistical eval.
(hypo test, interpretation)

$$p(\text{theory}|\text{data}) = \frac{p(\text{data}|\text{theory})}{p(\text{data})}\, p(\text{theory})$$

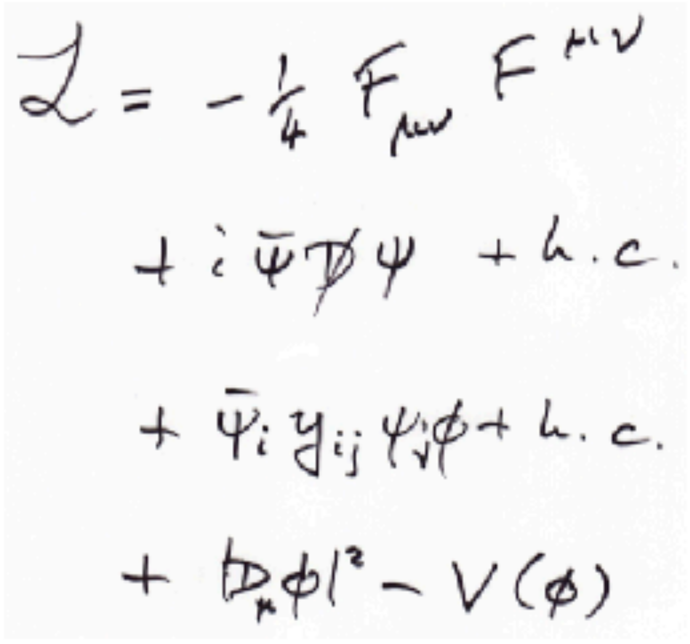
posterior, interpretation



experiment



prior



Statistical model: full probabilistic dependence of the *observable* data on the parameters of interest and nuisance parameters.

Full statistical models: ATLAS

ATL-PHYS-PUB-2019-029

ATLAS started in 2019 to publish plain-text serialisation of 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.

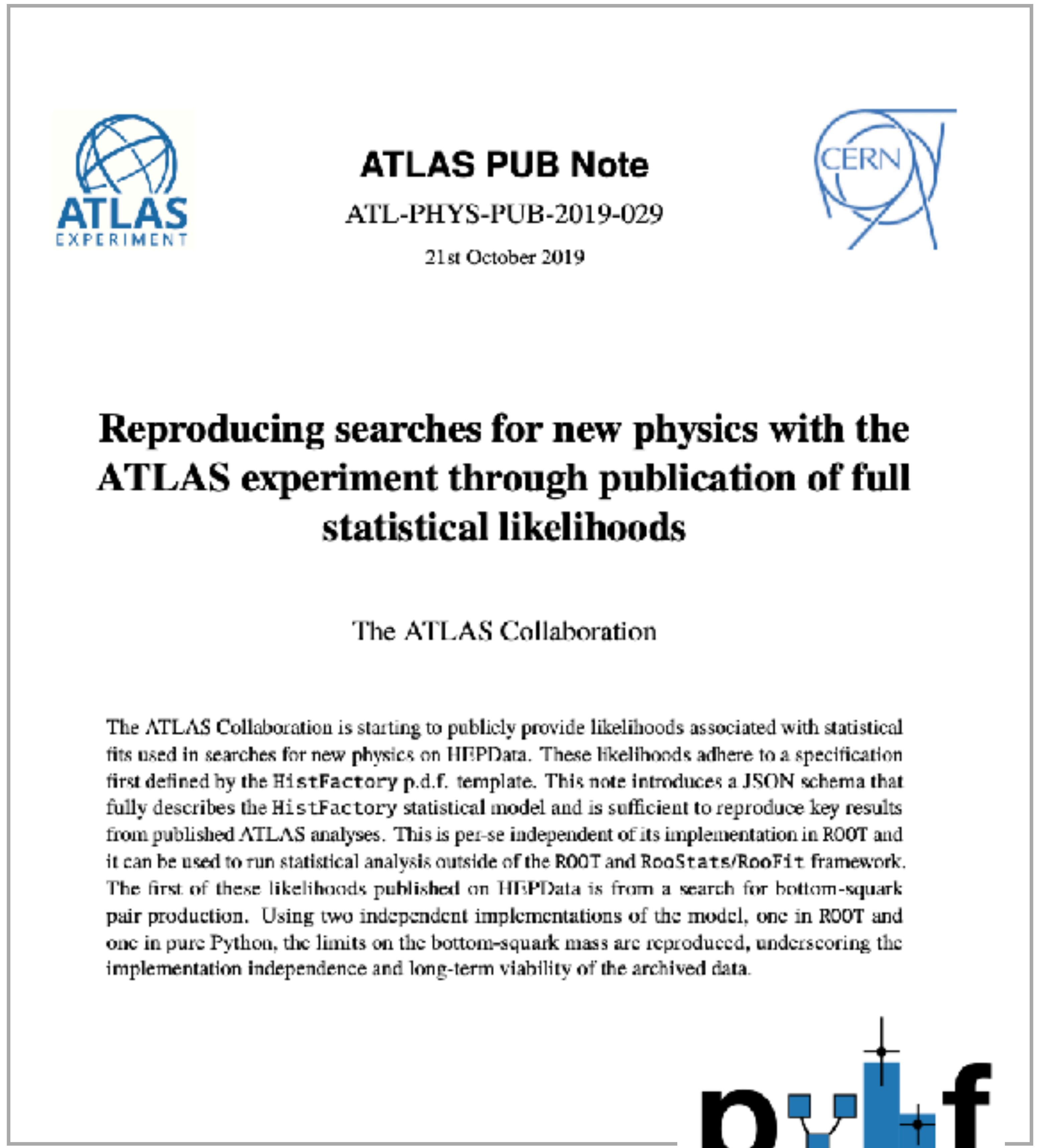
access to all nuisances

	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	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\| \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\| \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\,(a = 0 \| \alpha, \sigma = 1)$	$\kappa_{scb,\alpha=\pm1}$
	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



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.

Full statistical models: ATLAS

ATL-PHYS-PUB-2019-029

ATLAS started in 2019 to publish plain-text serialisation of 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.

access to all nuisances

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

- Next step: HS3 - HEP Statistics Serialisation Standard

HEPData

Resources

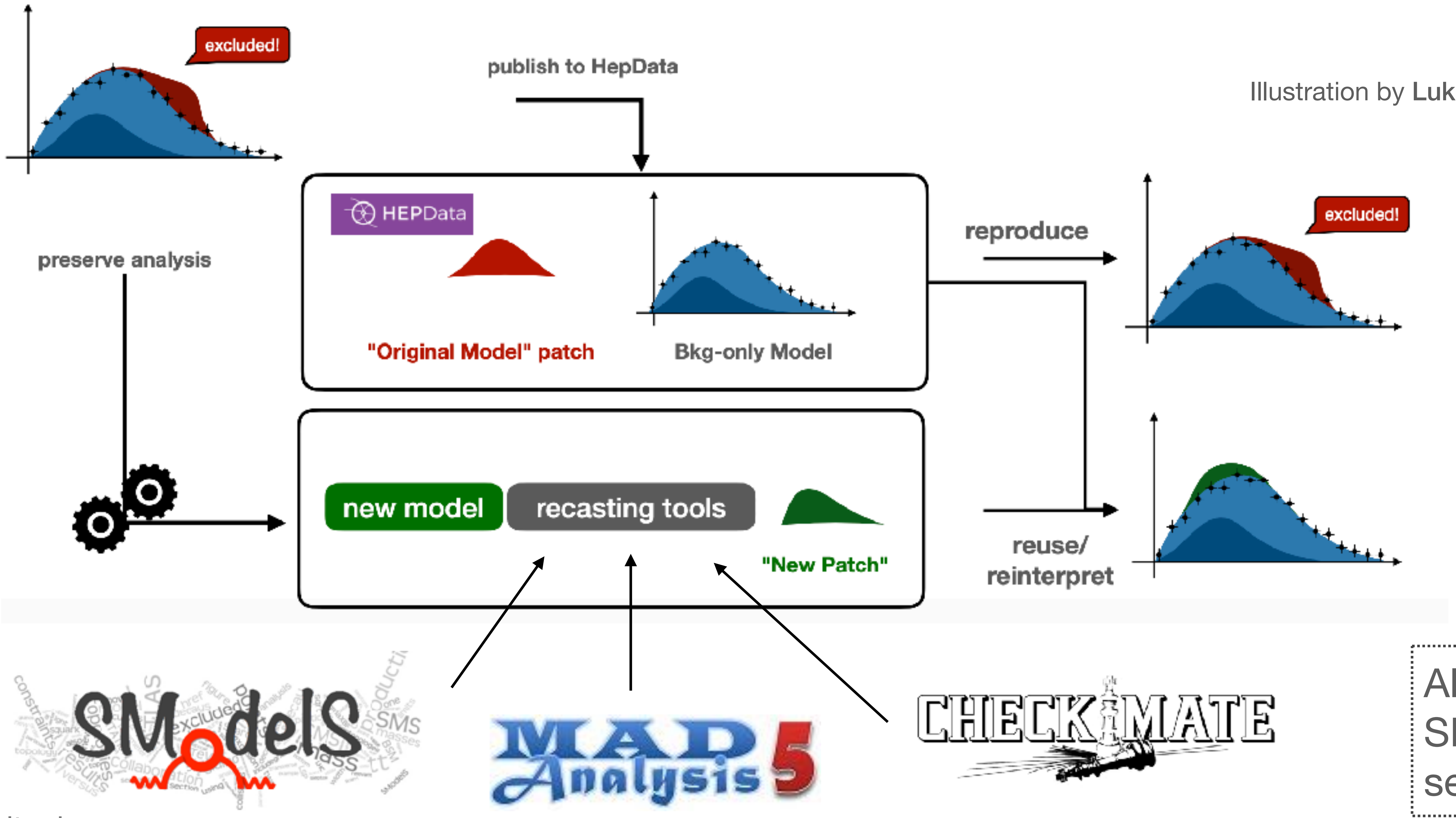
Likelihood available

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	[illegible]	13	139 fb^{-1}
Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	EXOT	JHEP 06 [illegible] 179	[illegible]	13	139 fb^{-1}
Search for squarks and gluinos in final states 1L, jets and MET	[illegible]	[illegible] J. C 81 [illegible]	05-JAN-21	13	139 fb^{-1}
Search for charginos and neutralinos in RPV models in final states with 3L (or more)	[illegible]	Phys. Rev. D [illegible]	[illegible]	13	139 fb^{-1}
Search for displaced leptons	[illegible]	[illegible] 051802	13-NOV-20	13	139 fb^{-1}
Search for [illegible] in [illegible] states with 0L, [illegible] MET	SUSY	JHEP 02 (2021) 143	27-OCT-20	13	139 fb^{-1}
Measurement of [illegible] tbar production cross-se[illegible] 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}

41 results as of today; 16 SUSY, 21 top

ATLAS full statistical models HistFactory JSON format

→ statistical evaluation through JSON patching



Alguero, SK, Waltenberger
arXiv:2009.01809

Alguero, Araz, Fuks, SK, arXiv:2206.14870

Also proved highly useful for SMEFT fits with **SFitter**, see N. Elmer et al, 2312.12502

Full statistical models: CMS

CMS-CAT-23-001

CMS recently published their Combine software and released the data cards describing the early measurements of the Higgs boson.

This includes the combination of all the Higgs boson searches that established the 2012 discovery of the Higgs boson.

- Combine is available as a container image
- Data cards to be published syste-matically for new CMS analyses
- pyhf ↔ combine conversion tool is being worked on; compliance w/HS3

Published April 15, 2024 | Version v1.0

Model Open

CMS Higgs boson observation statistical model

CMS Collaboration

Introduction

This resource contains the full statistical model from the Higgs Run-1 combination, which led to the Higgs boson discovery, in the format of `Combine` datacards. The instructions below include a few basic examples on how to extract the significance and signal strength measurements, for more details please consult the `Combine` documentation.

Datacards

Datacards for the combination (and per-decay channel sub-combinations) leading to the Higgs-boson discovery at CMS are in the `125.5` folder. The nuisance parameters corresponding to different sources of systematic uncertainties are described in the `*.html` files located in that folder.

For the full combination of decay channels, the relevant datacard is `125.5/comb.txt`. The individual datacards for each of the analyses in CMS targeting the main Higgs boson decay modes are also in the `125.5` folder.

Software instructions

General installation instructions for `Combine` can be found in the `Combine` documentation.

Reinterpretability and reuse of LHC results crucially depends on the material provided.

❃ Analysis data products ❃
❃ Analysis logic ❃
❃ Detector performance data ❃
❃ Statistical models ❃

LPCC
LHC Physics Centre at CERN

ABOUT | LHC WGS | LHC PUBLICATIONS | EVENTS | NEWSLETTER

LHC REI WG: BSM re-interpretation of LHC results

This subgroup of the BSM WG **builds on the** experience of the **long-established LHC re-interpretation forum (RIF)**, which will continue working under the umbrella of the BSM WG in continuity with its original scientific goals.

The REI WG provides a platform for **continued discussion of topics related to the BSM (re)interpretation of LHC data,** including the development of the necessary **public Recasting Tools and related infrastructure**.

Conveners:

- ATLAS: Martin Habedank
- CMS: Sezen Sekmen
- LHCb: Carlos Vazquez Sierra
- Theory: Sabine Kraml
- LPCC: Michelangelo Mangano

Contact us: lhc-reiwg-admin@cern.ch

https://lpcc.web.cern.ch/content/lhc-rei-wg

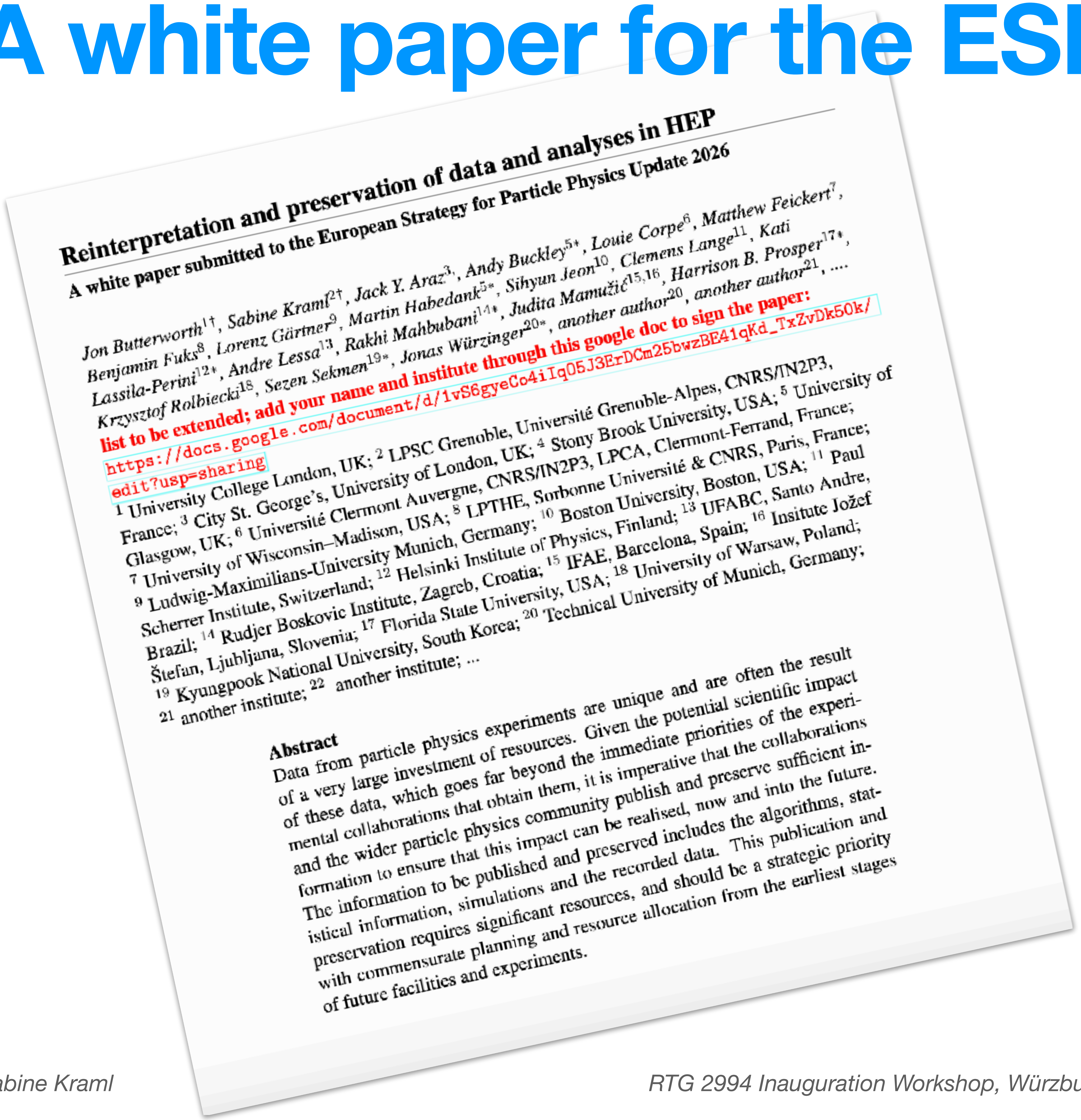
BSM WG
- Dark Matter
- Long-lived particles
- Prompt BSM signatures
- Reinterpretation

EFT WG
Electroweak WG
Forward Physics WG
Heavy Flavour WG
Heavy Ions WG
Machine Learning WG

A white paper for the ESPPU

European Strategy Update

European Strategy for Particle Physics – 2026 update


Reinterpretation and preservation of data and analyses in HEP

A white paper submitted to the European Strategy for Particle Physics Update 2026

Jon Butterworth[1†], Sabine Kraml[2†], Jack Y. Araz[3], Andy Buckley[5*], Louie Corpe[6], Matthew Feickert[7], Benjamin Fuks[8], Lorenz Gärtner[9], Martin Habedank[5*], Sihyun Jeon[10], Clemens Lange[11], Kati Lassila-Perini[12*], Andre Lessa[13], Rakhi Mahbubani[14*], Judita Mamužić[15,16], Harrison B. Prosper[17*], Krzysztof Rolbiecki[18], Sezen Sekmen[19*], Jonas Würzinger[20*], another author[20], another author[21], ...

list to be extended; add your name and institute through this google doc to sign the paper: https://docs.google.com/document/d/1vS6gyeCo4iIq05J3ErDCm25bwzBE41qKd_TxZvDk50k/edit?usp=sharing

[1] University College London, UK; [2] LPSC Grenoble, Université Grenoble-Alpes, CNRS/IN2P3, France; [3] City St. George's, University of London, UK; [4] Stony Brook University, USA; [5] University of Glasgow, UK; [6] Université Clermont Auvergne, CNRS/IN2P3, LPCA, Clermont-Ferrand, France; [7] University of Wisconsin–Madison, USA; [8] LPTHE, Sorbonne Université & CNRS, Paris, France; [9] Ludwig-Maximilians-University Munich, Germany; [10] Boston University, Boston, USA; [11] Paul Scherrer Institute, Switzerland; [12] Helsinki Institute of Physics, Finland; [13] UFABC, Santo Andre, Brazil; [14] Rudjer Boskovic Institute, Zagreb, Croatia; [15] IFAE, Barcelona, Spain; [16] Insitute Jožef Štefan, Ljubljana, Slovenia; [17] Florida State University, USA; [18] University of Warsaw, Poland; [19] Kyungpook National University, South Korea; [20] Technical University of Munich, Germany; [21] another institute; [22] another institute; ...

Abstract

Data from particle physics experiments are unique and are often the result of a very large investment of resources. Given the potential scientific impact of these data, which goes far beyond the immediate priorities of the experimental collaborations that obtain them, it is imperative that the collaborations and the wider particle physics community publish and preserve sufficient information to ensure that this impact can be realised, now and into the future. The information to be published and preserved includes the algorithms, statistical information, simulations and the recorded data. This publication preservation requires significant resources, and should be a strategic priority with commensurate planning and resource allocation from the earliest stages of future facilities and experiments.

Draft available for reading, commenting and endorsing

https://docs.google.com/document/d/1vS6gyeCo4iIqO5J3ErDCm25bwzBE41qKd_TxZvDk50k/edit?usp=sharing

Deadline next Wednesday (March 26)

Thanks for your attention