Lessons from recasting

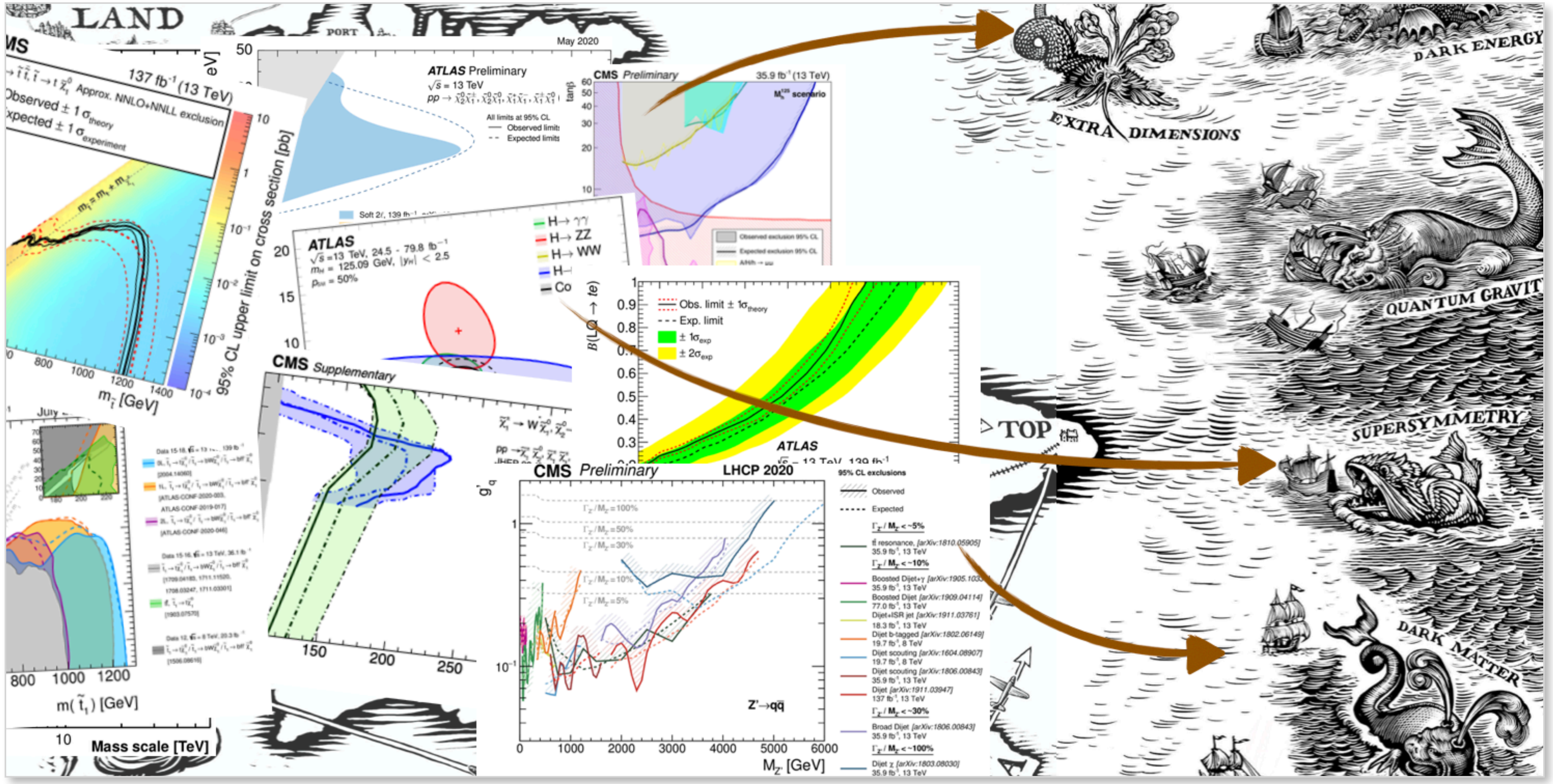
Sabine Kraml

Extended Scalar Sectors From All Angles

CERN, 24 Oct 2024

Motivation

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).



CERNCOURIER
SCIENTIFIC PRACTICE | MEETING REPORT
28 April 2021

We want to obtain a **comprehensive view** of how the plethora of LHC results constrain new physics **in the context of different theoretical scenarios** (incl. non-minimal/non-standard ones!)

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

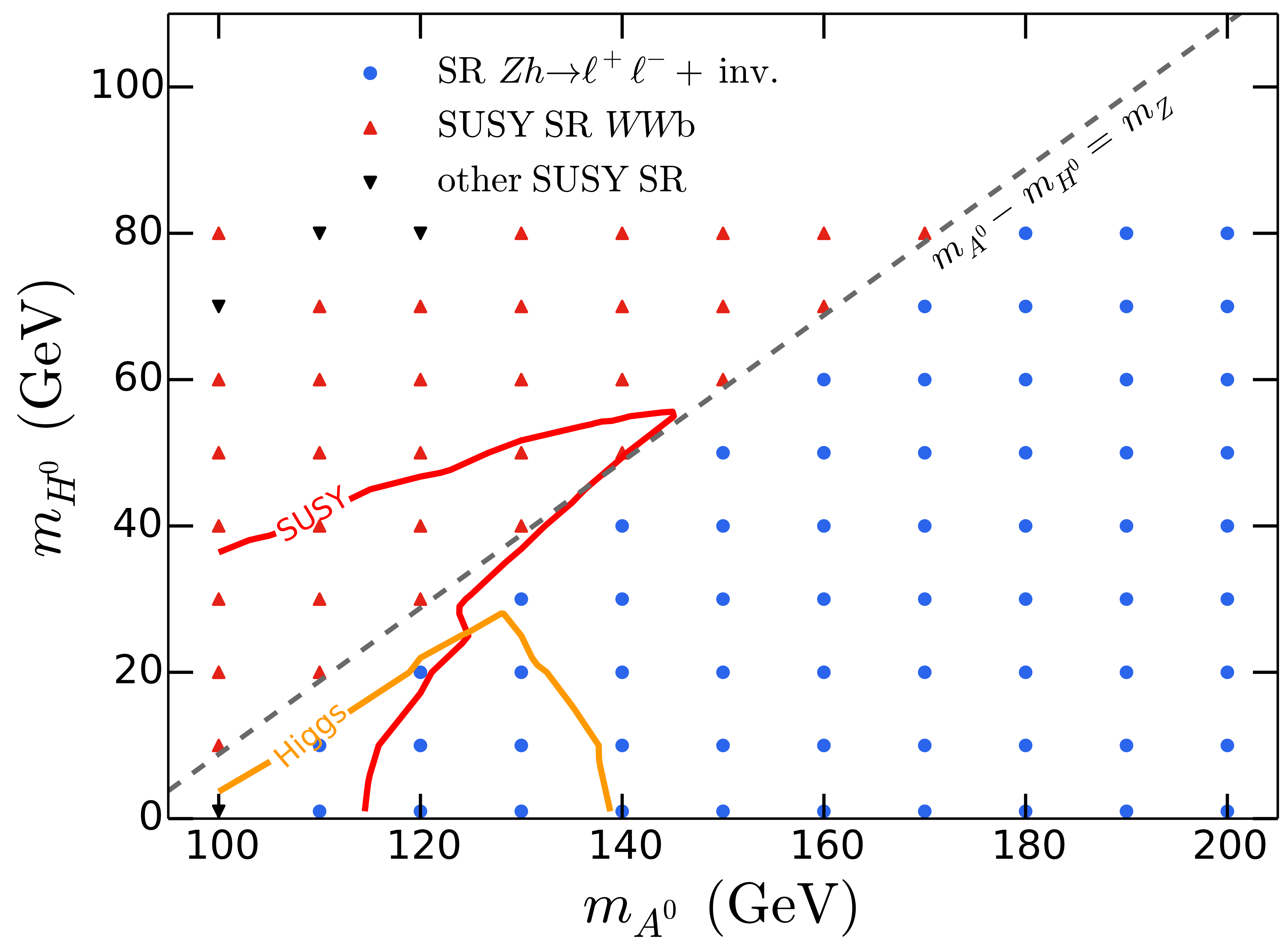
$$\Phi = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(H^0 + iA^0\right) \end{pmatrix}$$ odd under a new Z_2 symmetry

DM candidate (mH < mA)

Signature: OS di-leptons + MET

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

1503.07367



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

Another example: 4 tops

Probing sgluons with four tops @ LHC

New top-philic particles

- Non-minimal SUSY: top-philic sgluon [(pseudo-)scalar colour-octet]

S=0	S=1/2	S=1
S_8	$\tilde{g}$	G_μ

proportional to m_t

$$\mathcal{L}_{S_8} = \frac{1}{2} D_\mu S_8^A D^\mu S_8^A - \frac{1}{2} m_{S_8}^2 S_8^A S_8^A + \bar{t}\left[y_{8S} + i\, y_{8P}\gamma^5\right] T^A S_8^A\, t$$

Heavy new states

- EFT operators (beyond the SMEFT)

$$\mathcal{O}_S^8 = \bar{t}T^A t\; \bar{t}T^A t$$ SU(2)$_L$ breaking

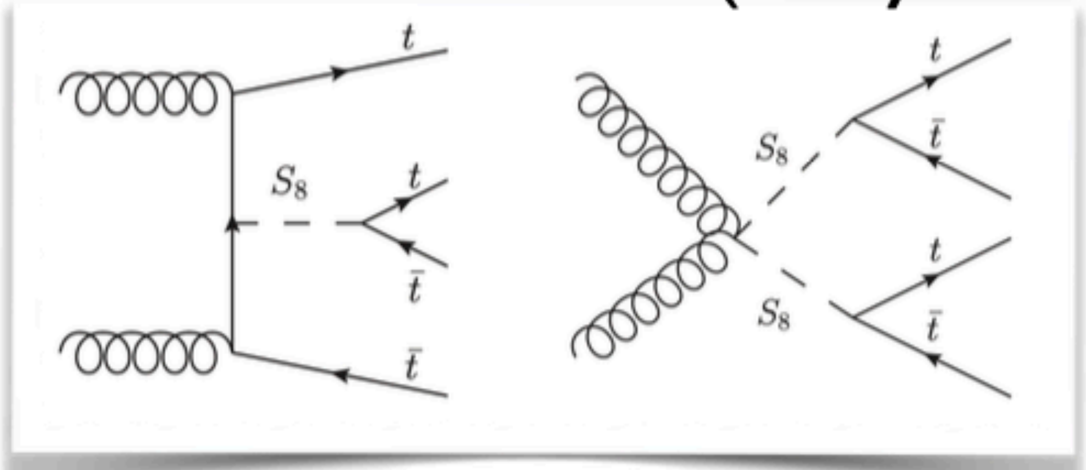
$$\mathcal{O}_{LR}^1 = \bar{t}_L\gamma^\mu t_L\; \bar{t}_R\gamma_\mu t_R$$

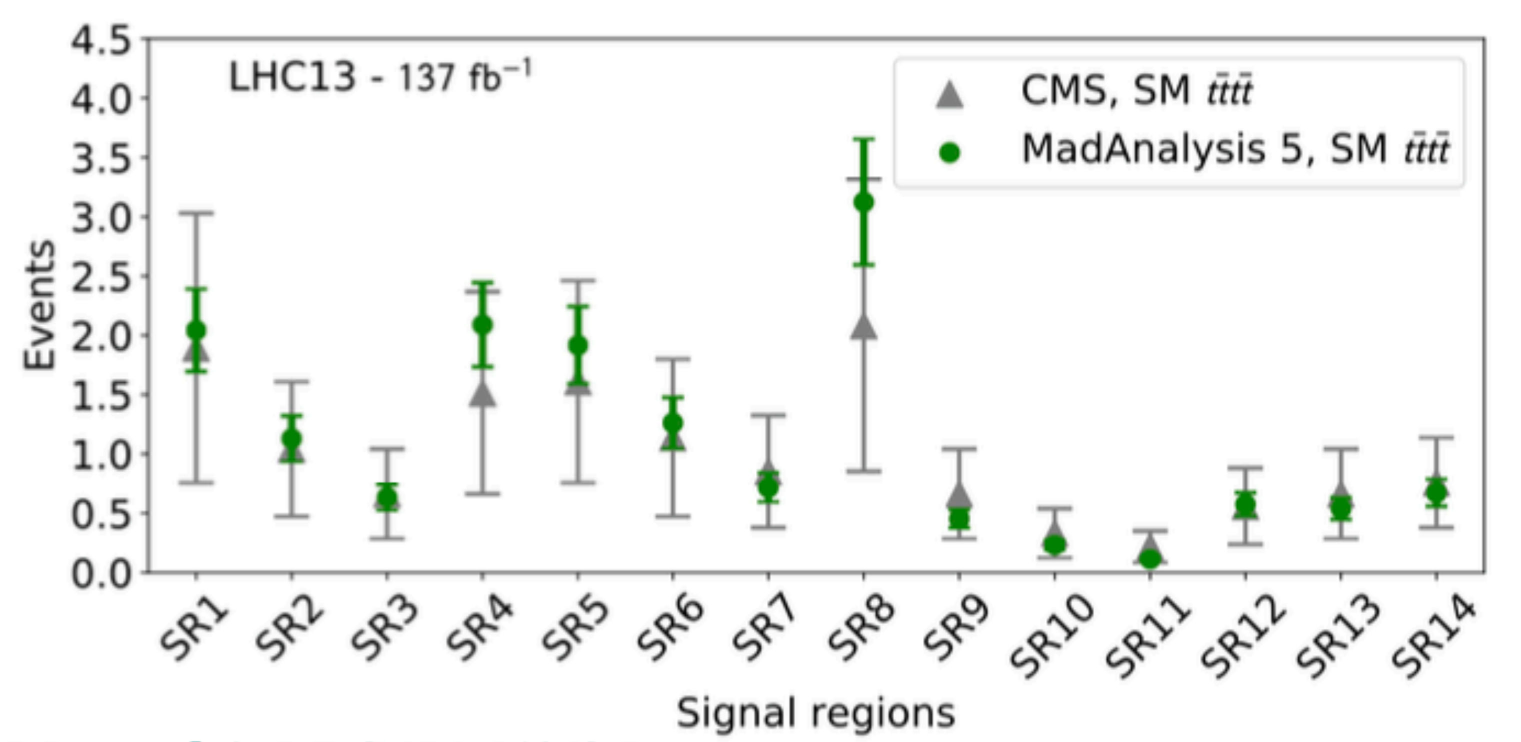
$$\mathcal{O}_{LR}^8 = \bar{t}_L T^A\gamma^\mu t_L\; \bar{t}_R T^A\gamma_\mu t_R$$

Heavy Mediator	$\mathcal{O}_S^8$	$\mathcal{O}_{LR}^1$	$\mathcal{O}_{LR}^8$
S_8	$\frac{y_{8S}^2}{2m_{S_8}^2}$	/	/
$\tilde{S}_8$	$-\frac{y_{8P}^2}{2m_{\tilde{S}_8}^2}$	$-\frac{4y_{8P}^2}{9m_{\tilde{S}_8}^2}$	$\frac{y_{8P}^2}{3m_{\tilde{S}_8}^2}$

BSM impact on four-top production

- Resonant effects (light states)
  - → Associated and pair production contributions
  - → Different kinematics ↔ two handles
- Non-resonant effects (heavy states)





[Darmé & BF (MPLA'21)]

CMS-TOP-18-003

- Run 2 measurement of σ_{tttt}
- 14 SRs: *cf.* (*b*-)jet/lepton multiplicities
- H_T spectra measured
  - → BSM-improvement: high-H_T bin

[Darmé, BF & Goodsell (PLB'18)]

- MadAnalysis 5 implementation

from Benjamin Fuks @ SUSY'24

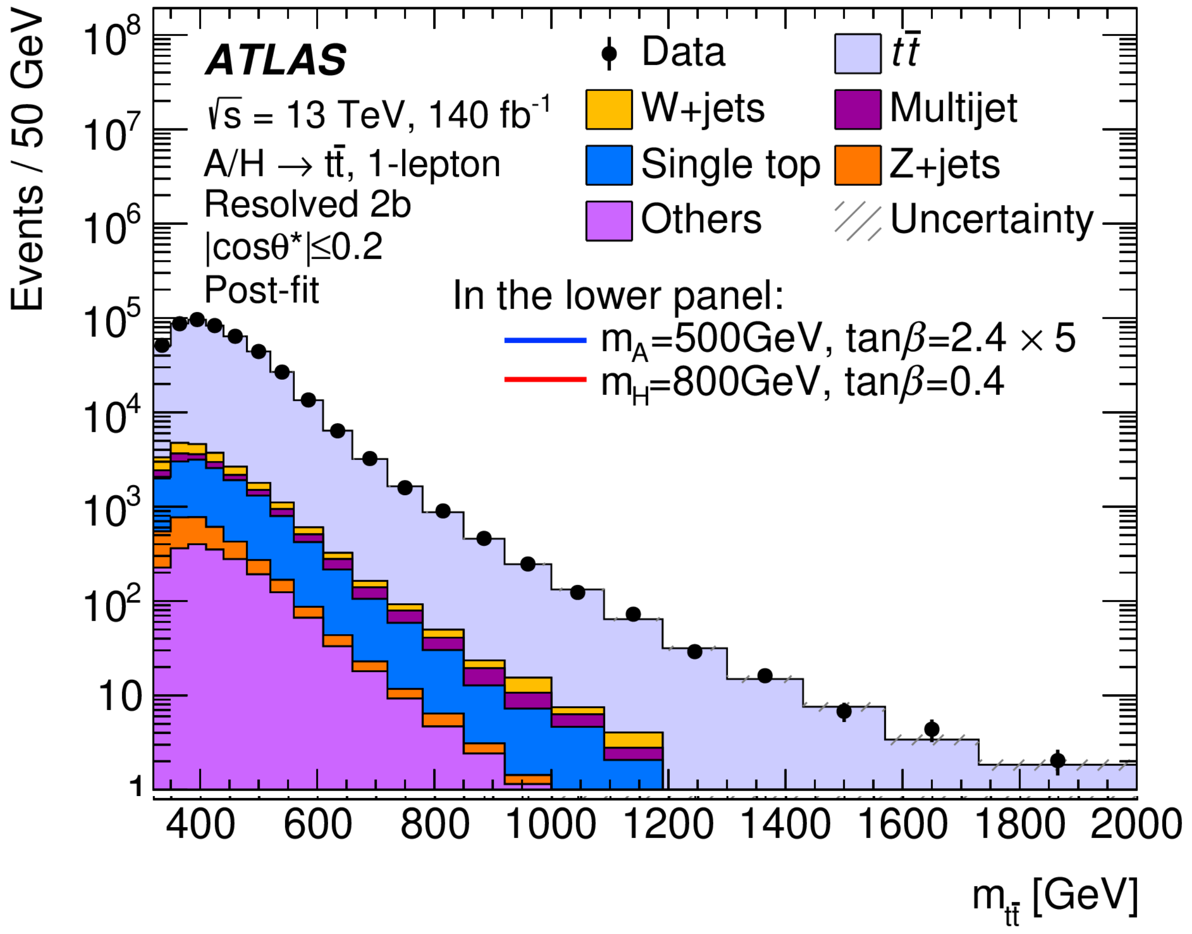
Experimental results vs. their interpretation

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

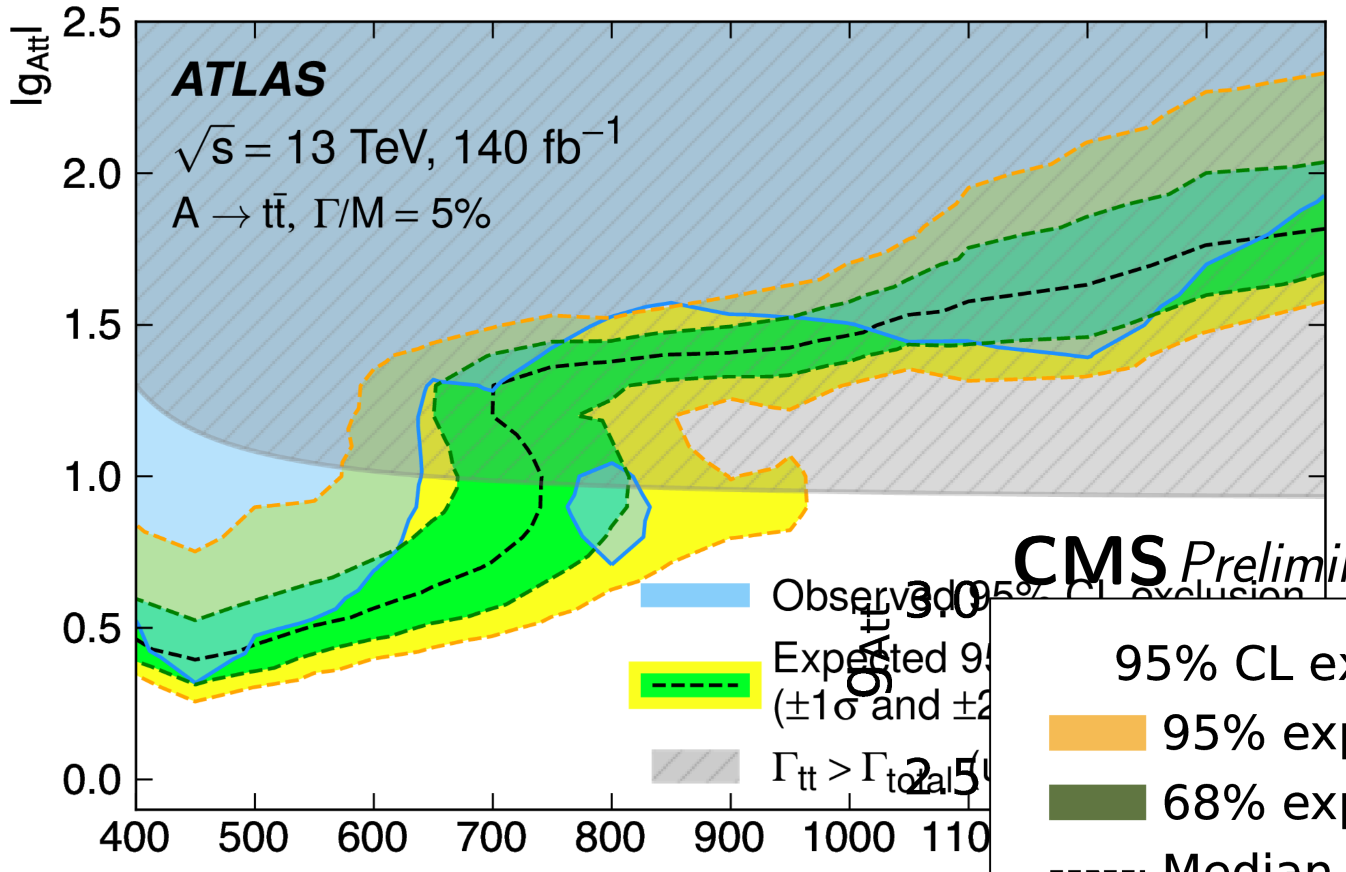
vs.

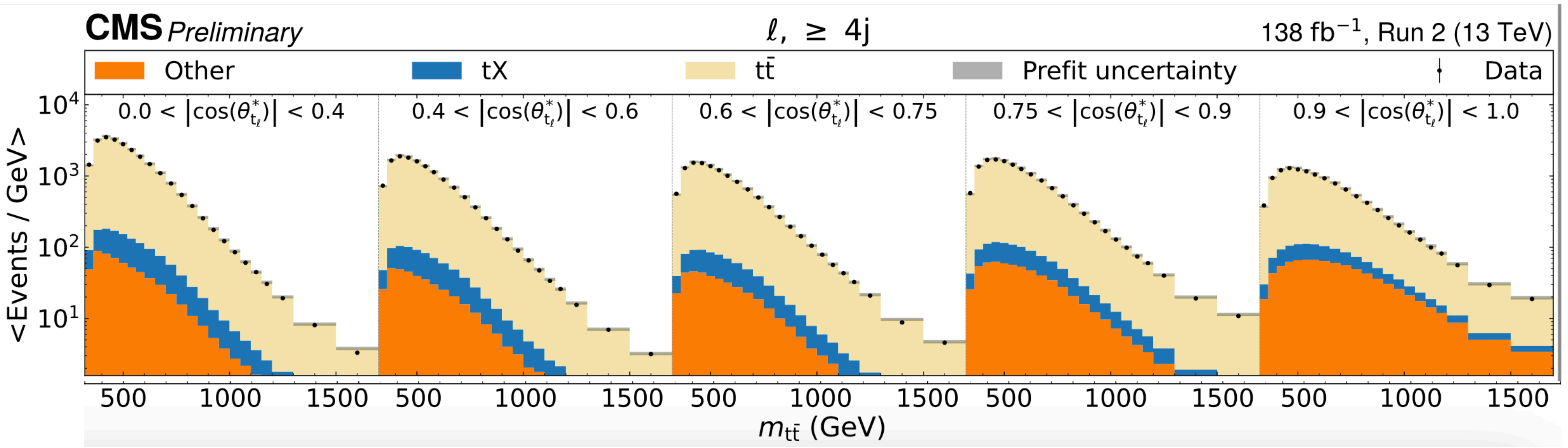
The act of comparing this empirical outcome to model predictions

ATLAS-EXOT-2020-25

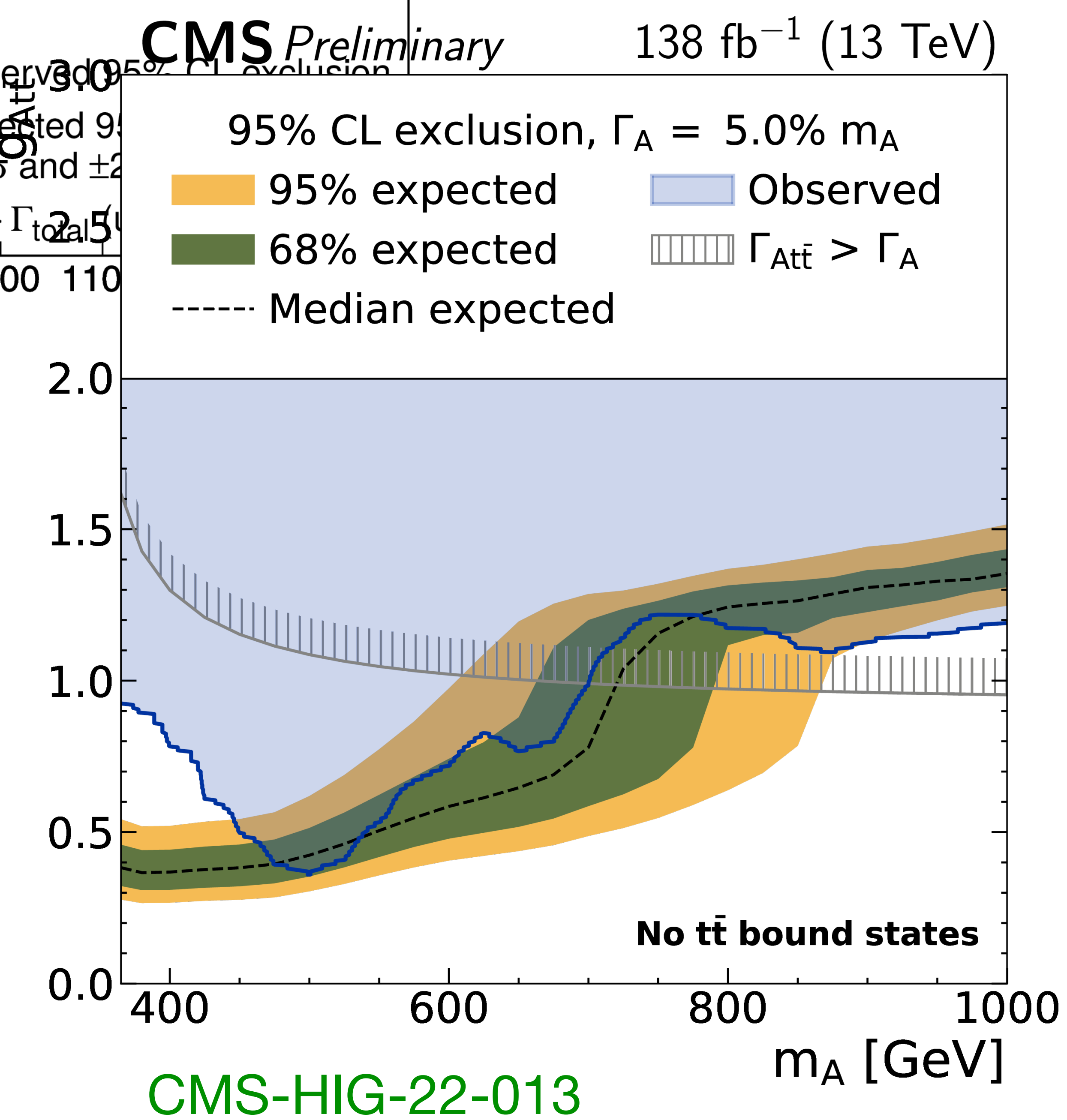


ATLAS-EXOT-2020-25





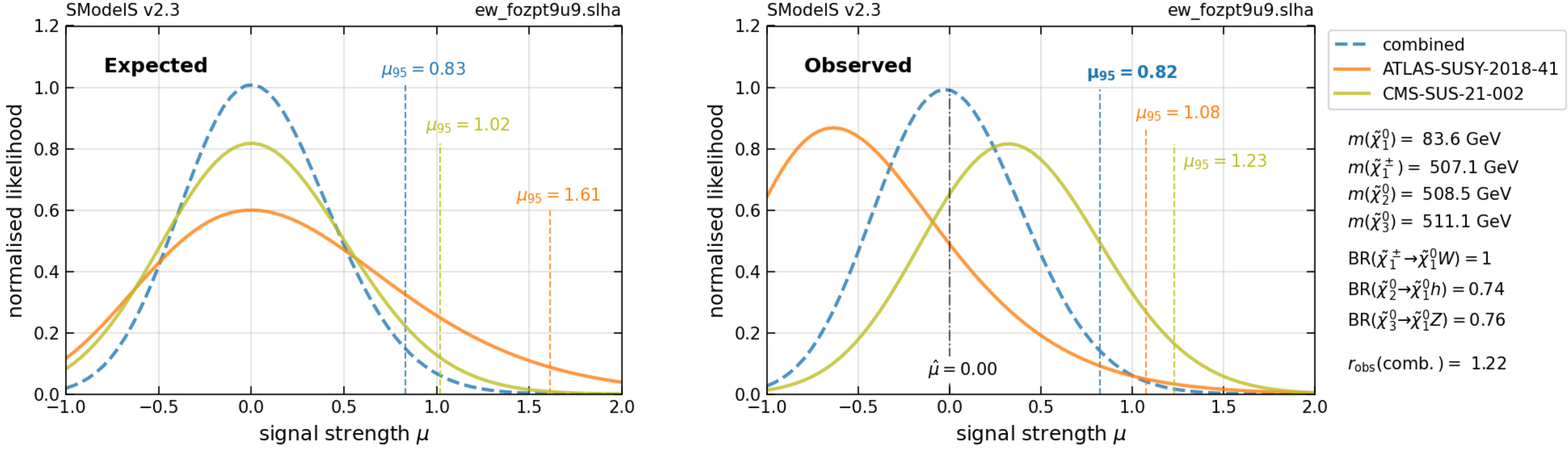
CMS-HIG-22-013



CMS-HIG-22-013

(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.



from 2306.17676
(see also 2312.16635)

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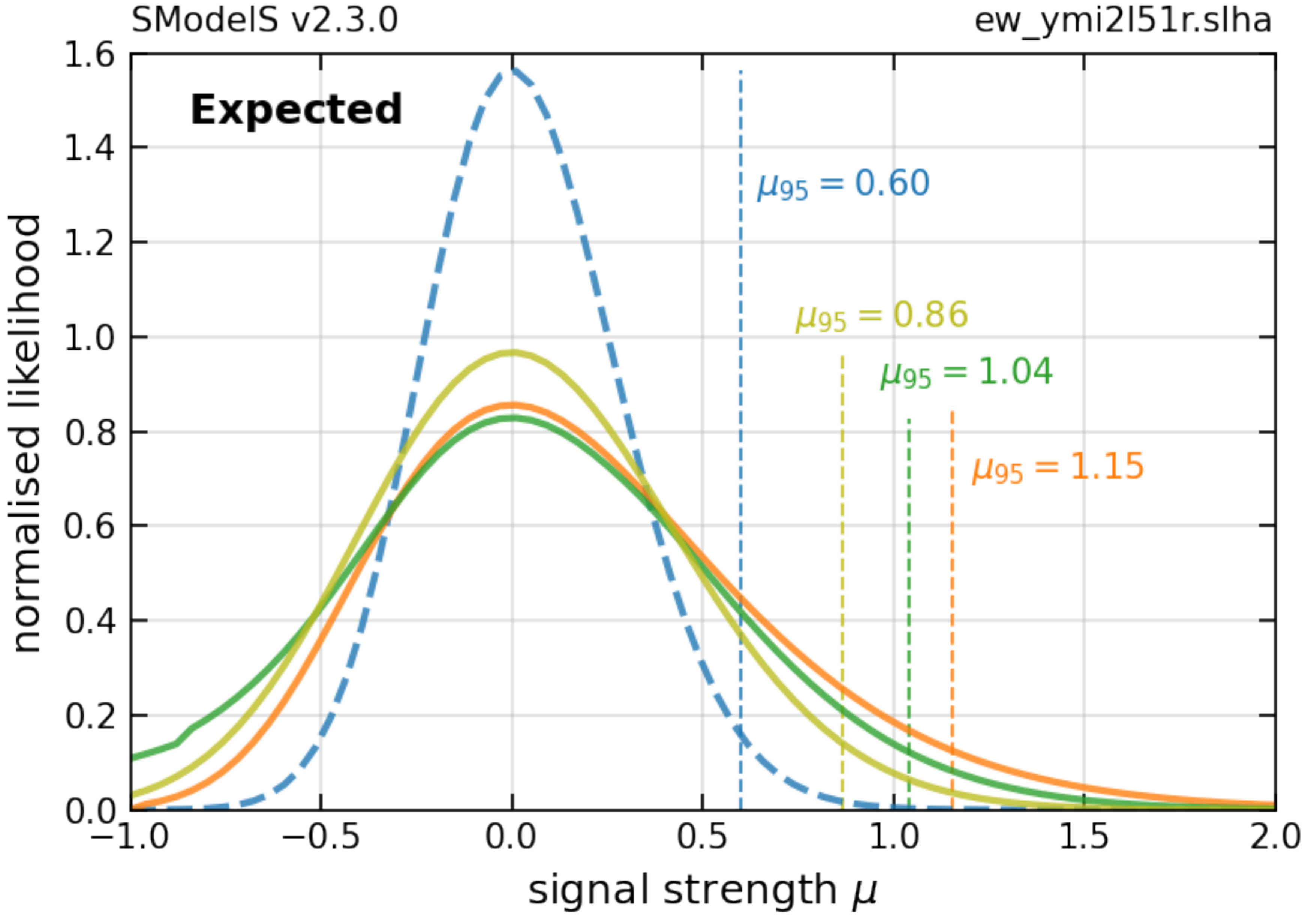
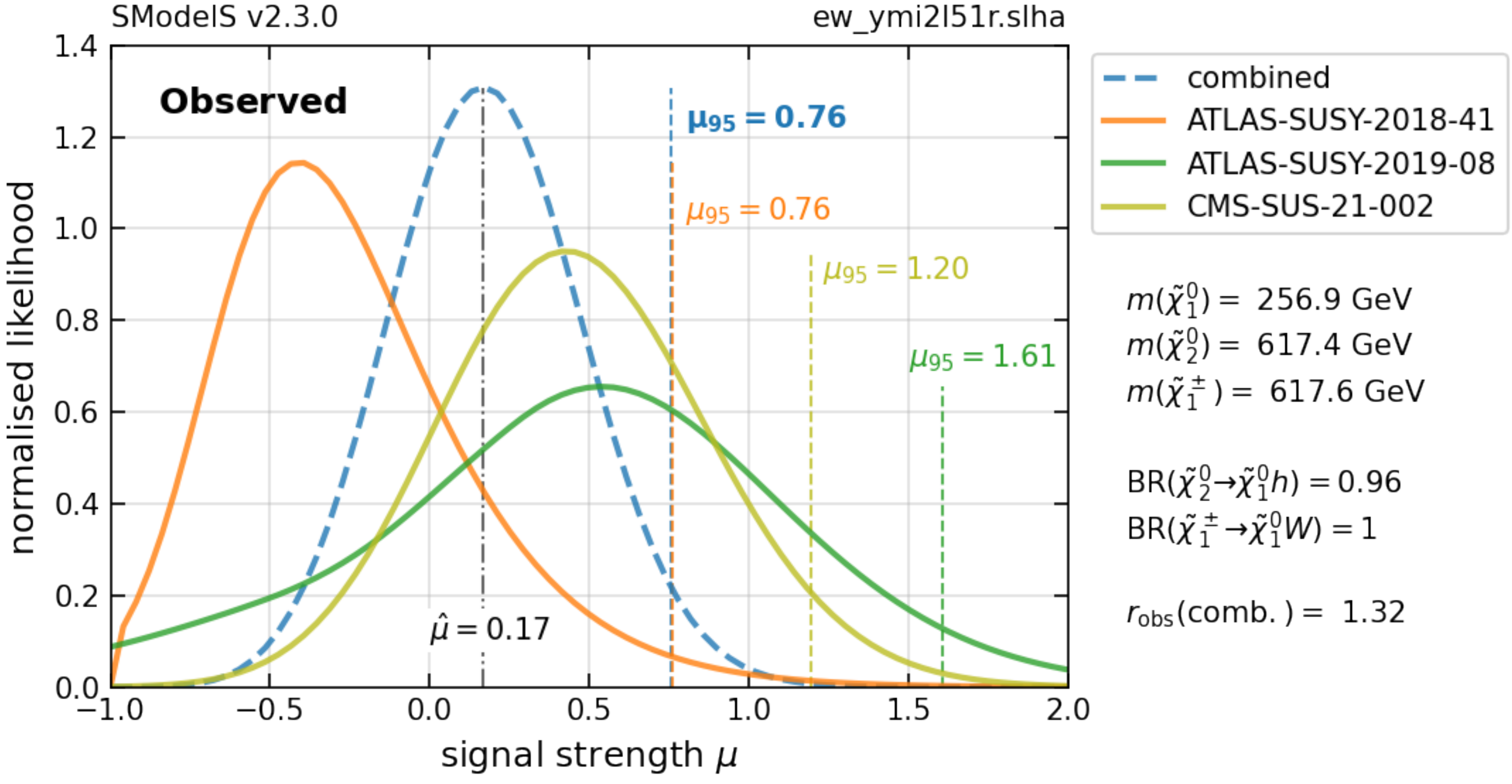




from 2306.17676
(see also 2312.16635)

G. Belanger et al., 2405.18332

Georgi-Machacek model with a scalar singlet

- Scalar sector consisting of SM doublet Φ, two triplets $\xi = (\xi^{++}, \xi^0, \xi^-)^T$ and $\chi = (\chi^{++}, \chi^+, \chi^0)^T$, and a real scalar *S*, which serves as a DM candidate
- Physical states: $H_5^{++}, H_5^{+}, H_5^0, H_3^+, H_3^0, H, h, S$

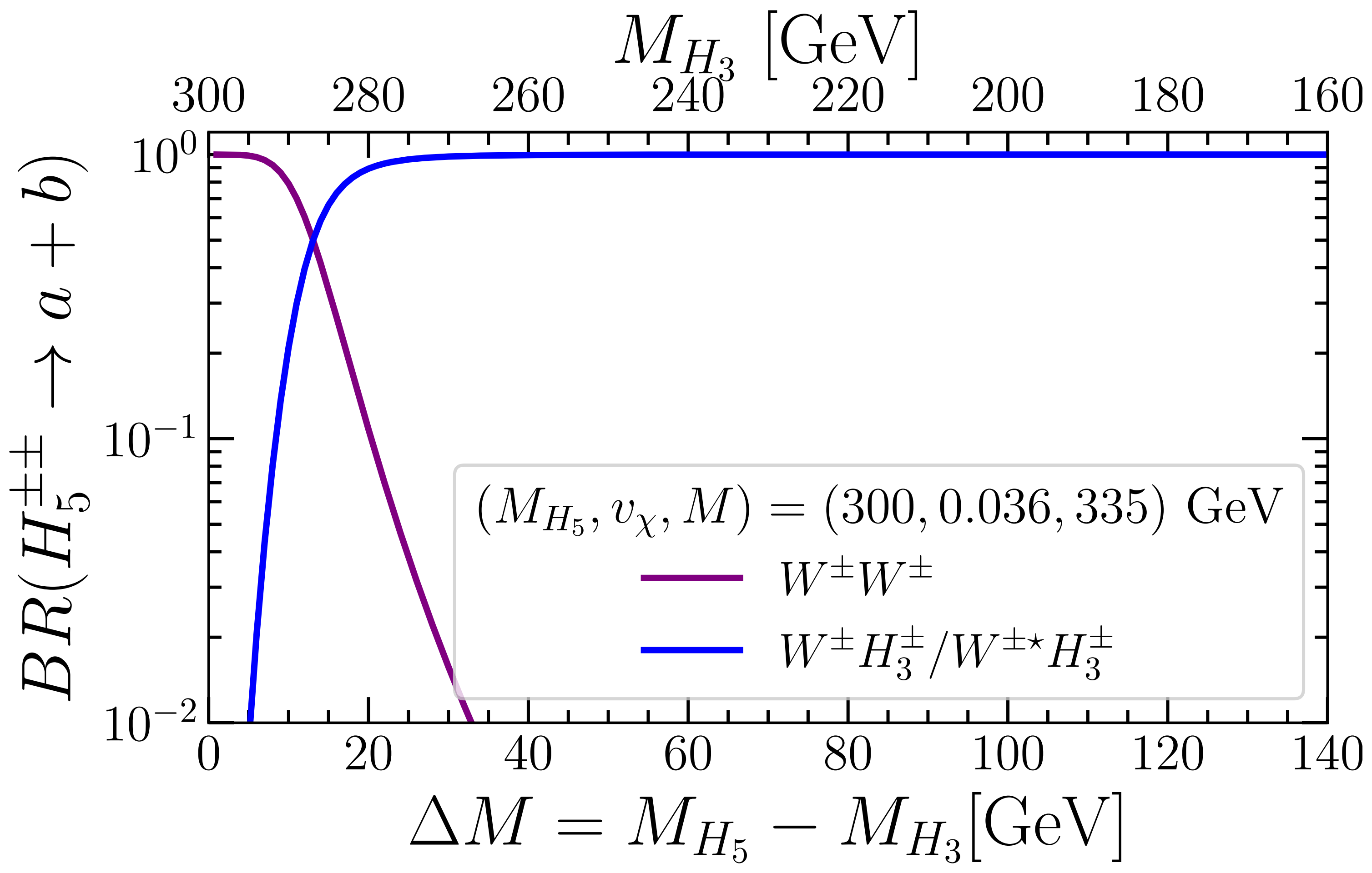
$$H_5^{++} = \chi^{++}\,, \quad H_5^+ = \frac{1}{\sqrt{2}}\left(\chi^+ - \xi^+\right)\,, \quad H_5^0 = \sqrt{\frac{2}{3}}\,\xi^{0,r} - \sqrt{\frac{1}{3}}\,\chi^{0,r}\,,$$

$$H_3^+ = -s_H\,\phi^+ + \frac{1}{\sqrt{2}}c_H\left(\xi^+ + \chi^+\right)\,, \quad H_3^0 = -s_H\,\phi^{0,i} + c_H\,\chi^{0,i}\,,$$

$$h = c_\alpha \phi^{0,r} - s_\alpha H_1^{0'}\,, \qquad H_1^{0'} = \sqrt{\frac{1}{3}}\,\xi^{0,r} + \sqrt{\frac{2}{3}}\,\chi^{0,r}\,.$$
$$H = s_\alpha \phi^{0,r} + c_\alpha H_1^{0'}\,,$$

$$c_H \equiv \cos\theta_H = \frac{v_\phi}{v}\,, \quad s_H \equiv \sin\theta_H = \frac{2\sqrt{2}v_\chi}{v}\,.$$

$$\langle \xi^0 \rangle = \langle \chi^0 \rangle = v_\chi.$$



$$H^{\pm\pm} \to W^\pm W^\pm$$

ATLAS-HDBS-2019-06

ATLAS-HIGG-2016-09

CMS-SMP-17-004

G. Belanger et al., 2405.18332

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$$H_5^{++} = \chi^{++}, \quad H_5^+ = \frac{1}{\sqrt{2}}(\chi^+ - \xi^+), \quad H_5^0 = \sqrt{\frac{2}{3}}\xi^{0,r} - \sqrt{\frac{1}{3}}\chi^{0,r},$$

$$H_3^+ = -s_H\,\phi^+ + \frac{1}{\sqrt{2}}c_H\,(\xi^+ + \chi^+), \quad H_3^0 = -s_H\,\phi^{0,i} + c_H\,\chi^{0,i},$$

$$h = c_\alpha \phi^{0,r} - s_\alpha H_1^{0\prime}, \qquad H = s_\alpha \phi^{0,r} + c_\alpha H_1^{0\prime}, \qquad H_1^{0\prime} = \sqrt{\frac{1}{3}}\xi^{0,r} + \sqrt{\frac{2}{3}}\chi^{0,r}.$$

$$c_H \equiv \cos\theta_H = \frac{v_\phi}{v}, \quad s_H \equiv \sin\theta_H = \frac{2\sqrt{2}v_\chi}{v}.$$

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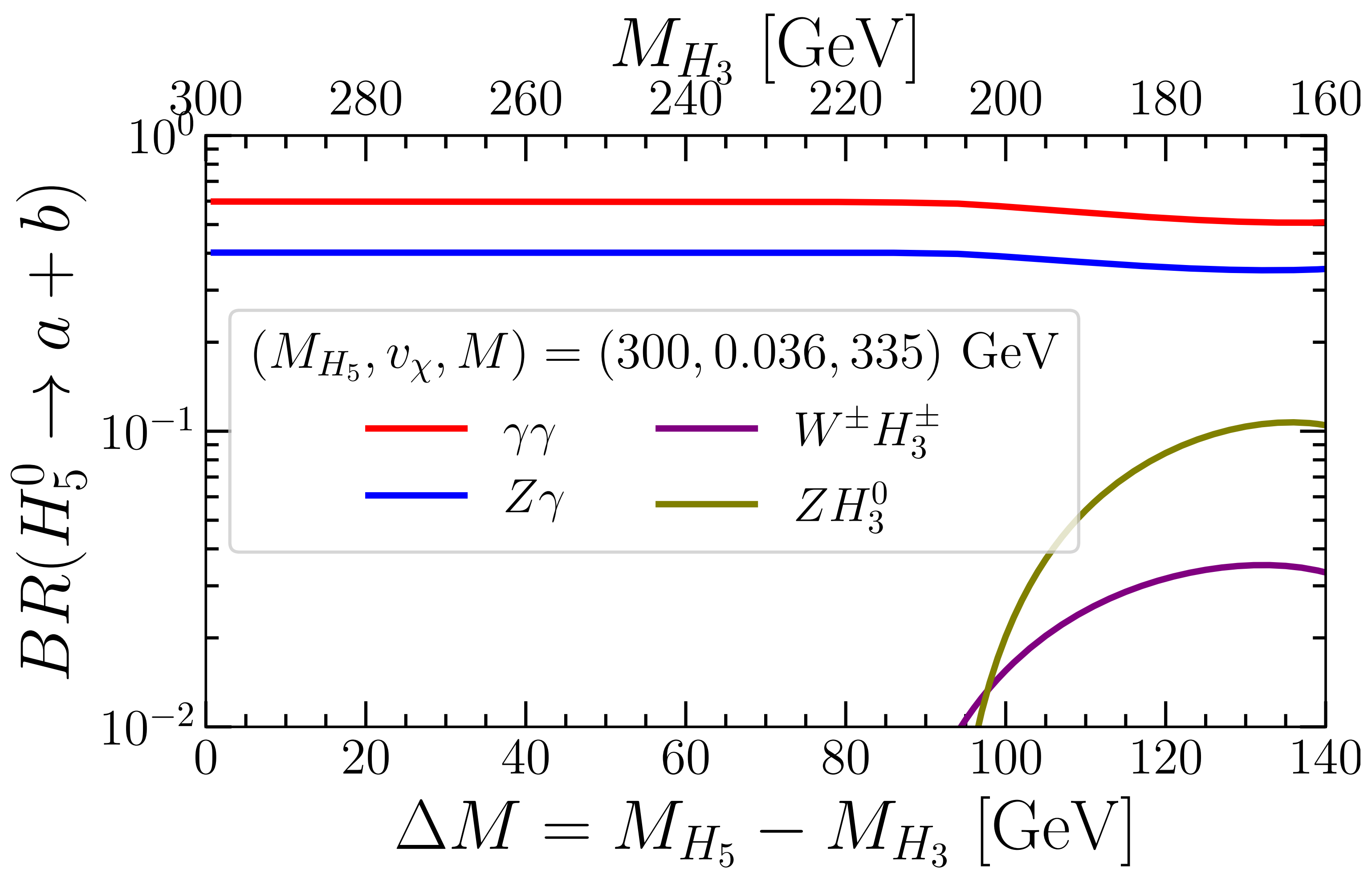
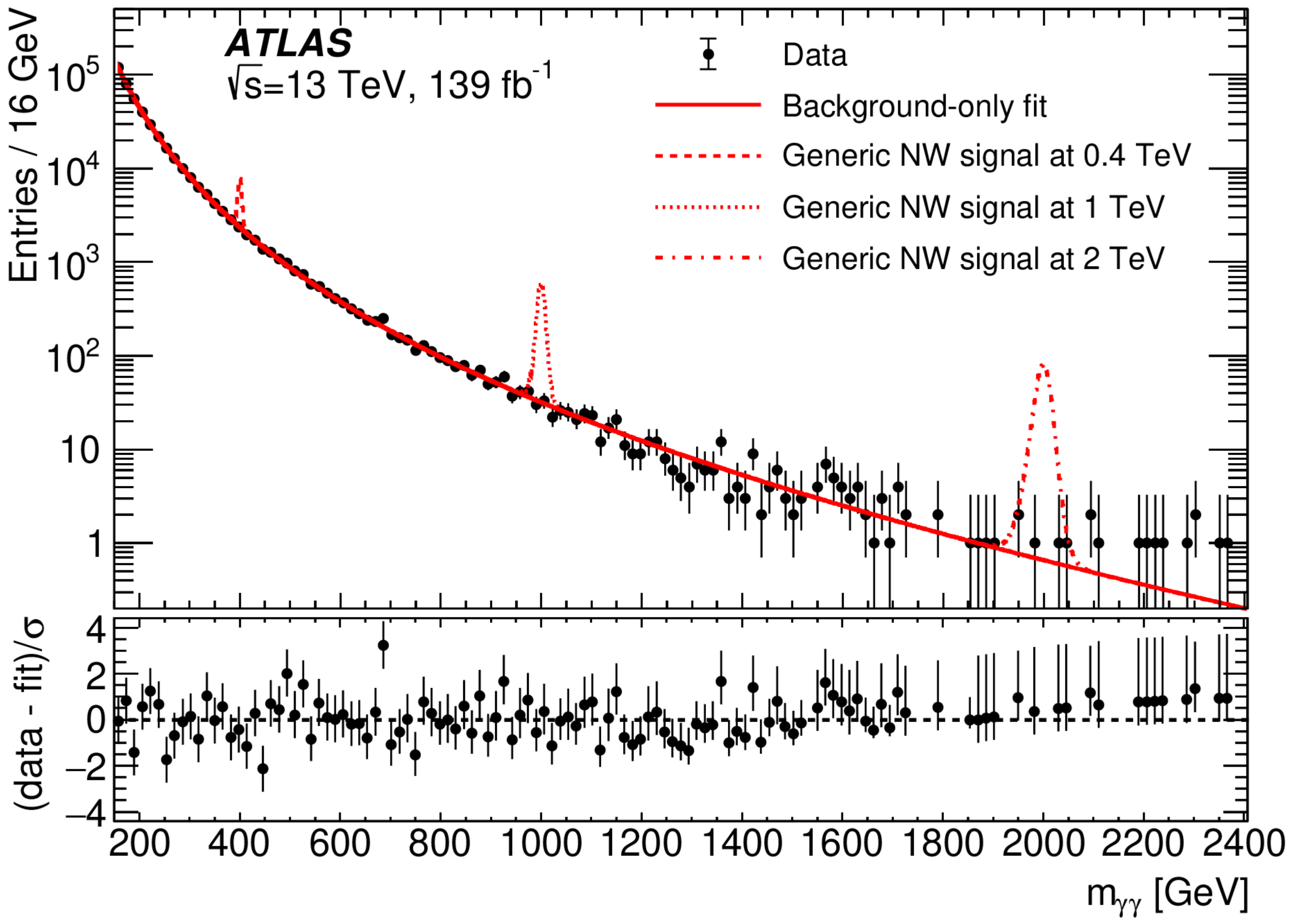
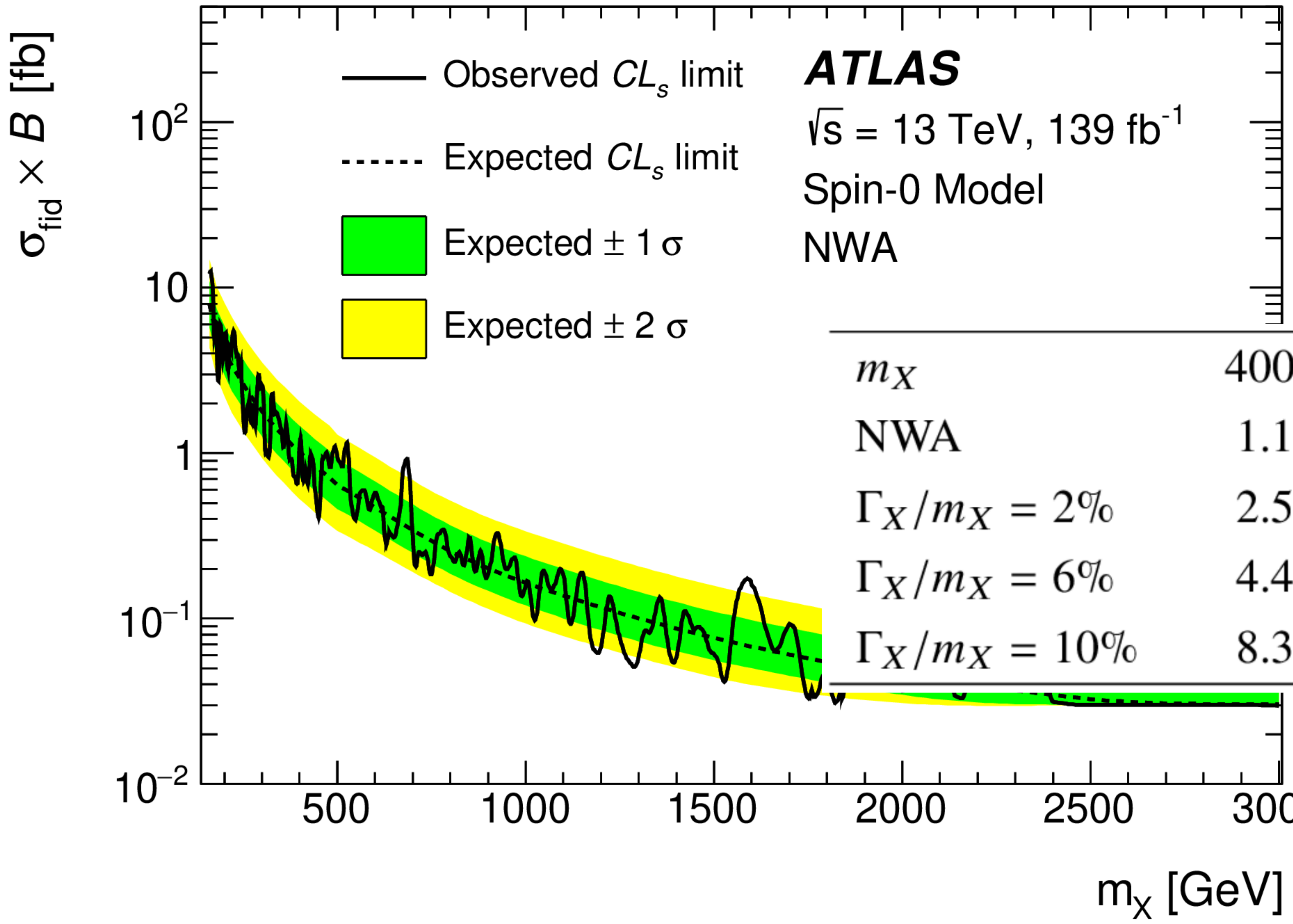


$H_{\rm BSM} \to \gamma\gamma$ ATLAS-HIGG-2018-27

Georgi-Machacek model with a scalar singlet:
constraints from ATLAS-HIGG-2018-27 ($H_{\rm BSM} \to \gamma\gamma$)

The fiducial volume for the spin-0 interpretation is defined by requiring two photons at generator level with $|\eta| < 2.37$, and $E_{\rm T}/m_{\gamma\gamma} > 0.3$ and $E_{\rm T}/m_{\gamma\gamma} > 0.25$ for the leading and subleading photons, respectively. The particle isolation, defined as the scalar sum of $p_{\rm T}$ of all the stable particles (except neutrinos) found within a $\Delta R = 0.4$ cone around the photon direction, is required to be less than $0.05E_{\rm T} + 6$ GeV.



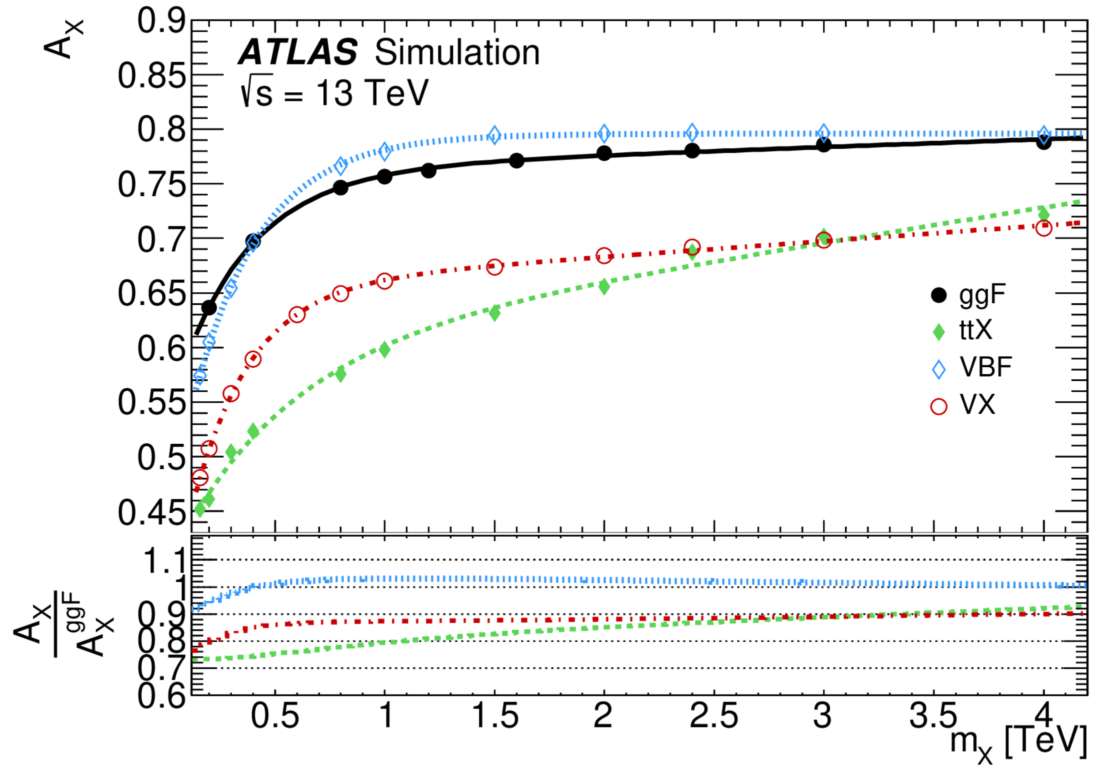


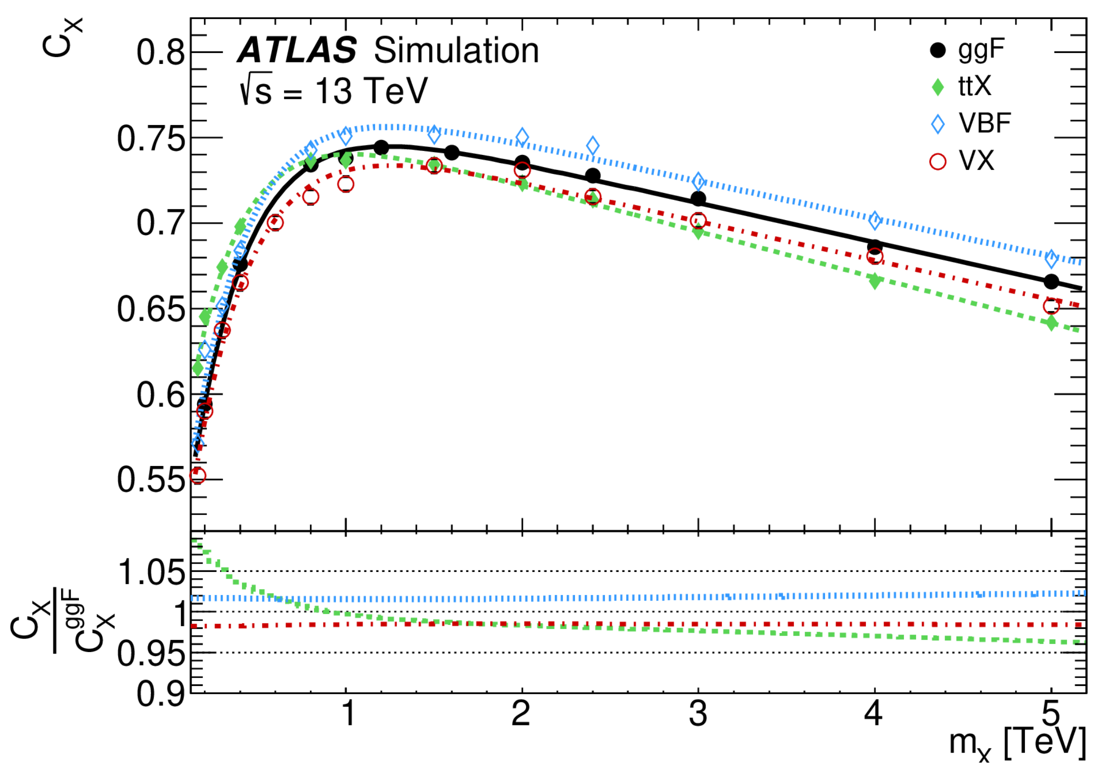
m_X	400 GeV	2800 GeV
NWA	1.1 fb	0.03 fb
Γ_X/m_X = 2%	2.5 fb	0.03 fb
Γ_X/m_X = 6%	4.4 fb	0.03 fb
Γ_X/m_X = 10%	8.3 fb	0.04 fb

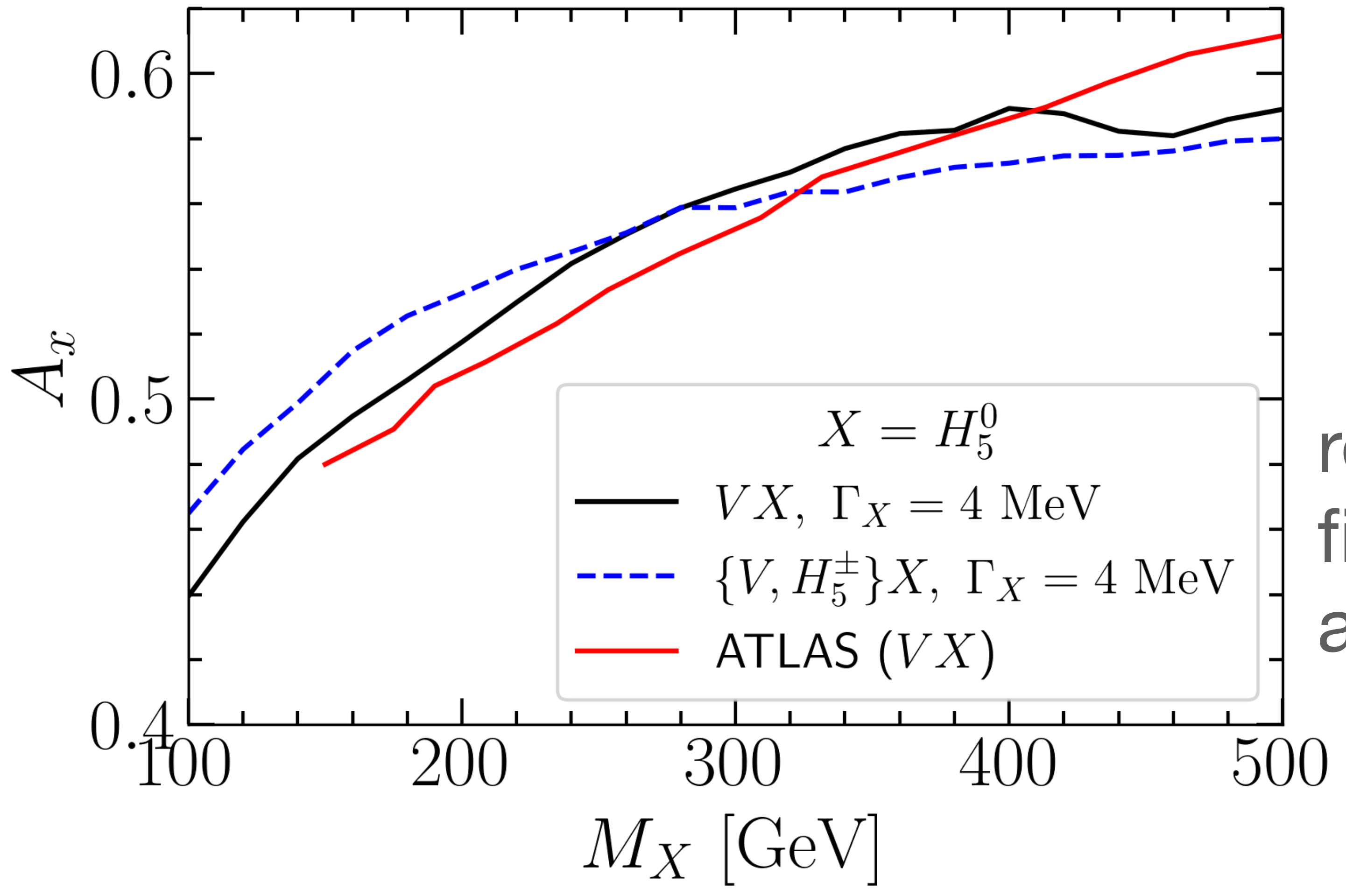
2405.18332

Georgi-Machacek model with a scalar singlet: constraints from ATLAS-HIGG-2018-27 ($H_{\mathrm{BSM}} \to \gamma\gamma$)

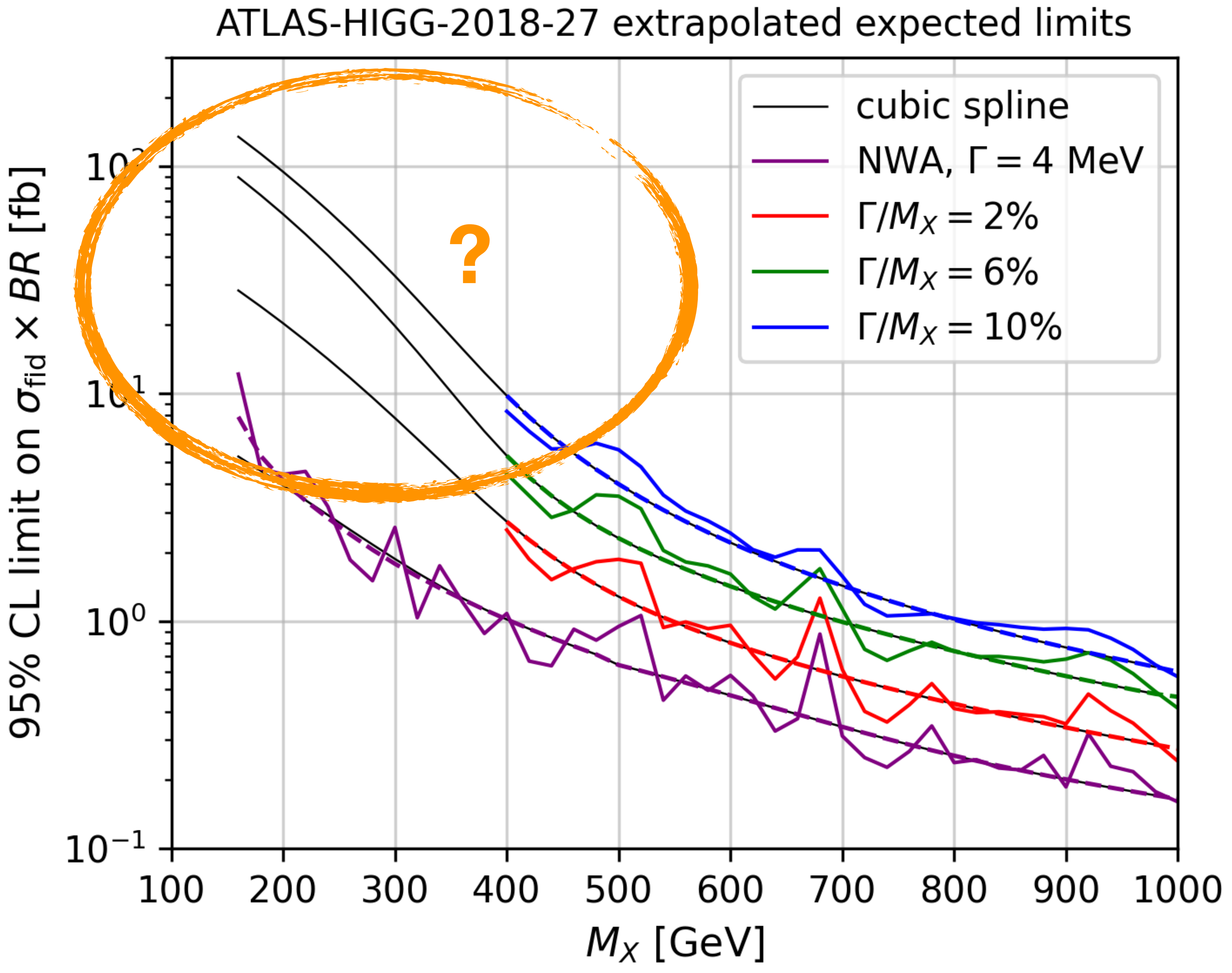
Auxiliary material: fiducial acceptance and truth-to-reco level correction







recast fiducial acceptance



Limits beyond the NWA only for masses > 400 GeV

BSM Reinterpretation Forum (RiF)

TWiki > LHCPhysics Web > LHCPhysics > InterpretingLHCresults (2024-09-11, SabineKraml)

Forum on the Interpretation of the LHC Results for BSM studies

The quest for new physics beyond the Standard Model is arguably the driving topic for the physics Runs of the LHC. Indeed, 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.** In addition, measurements primarily aimed at understanding Standard Model 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. All this is a very active field, with close theory-experiment interaction and with several public tools being developed.

With this forum, we want to provide a platform for continued discussion of topics related to the BSM (re)interpretation of LHC data, including the development of the necessary **public RecastingTools and related infrastructure.** The forum was initiated in 2016 and has been active since.

WG with > 100 participants; recurrent workshops; white papers formulating recommendations, ….

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

Good practice:

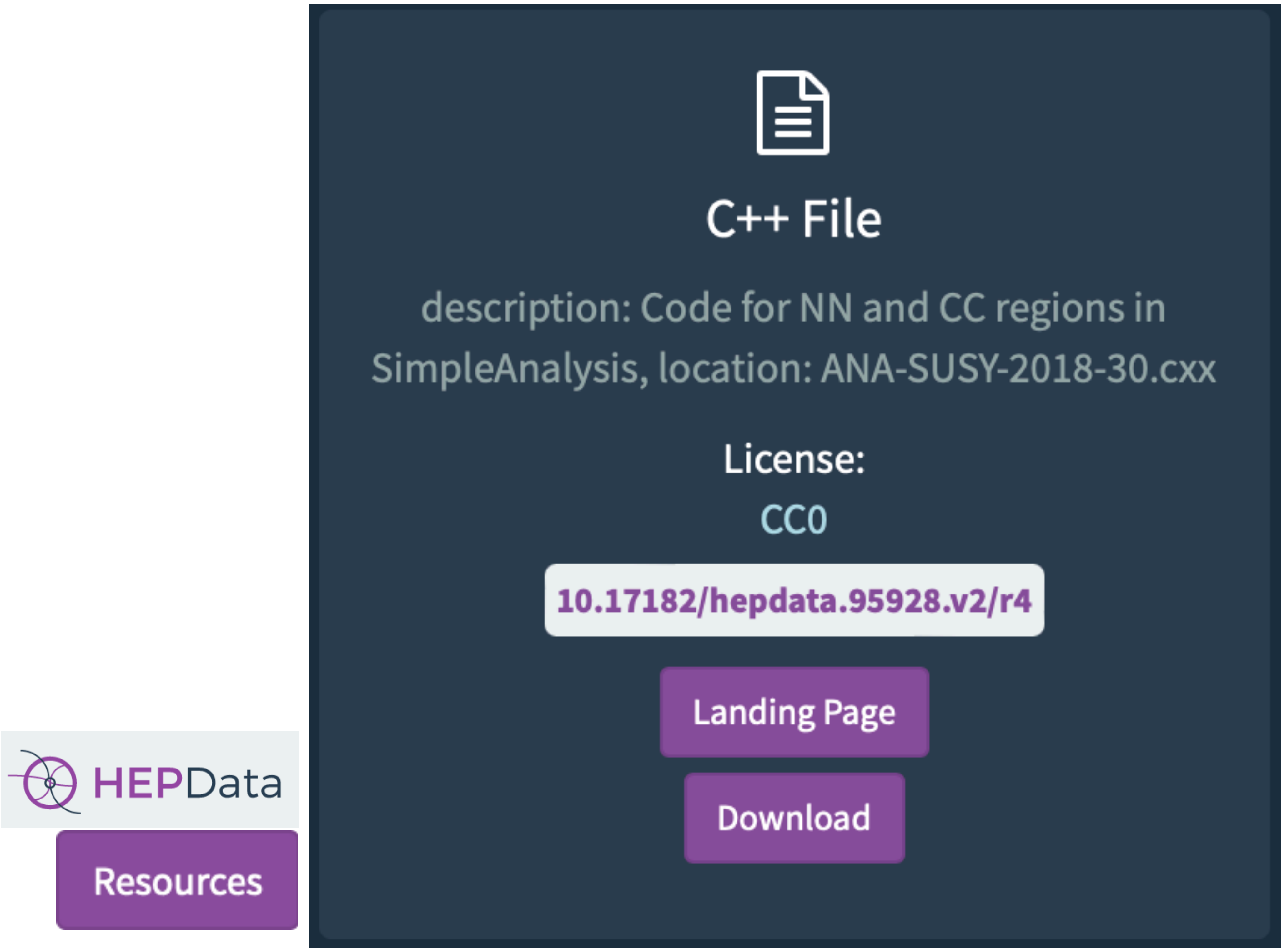
What ATLAS/CMS analyses nowadays should (and increasingly do) provide

Object definitions and signal selection

- Clear and unambiguous object definitions
- Precise reco efficiencies (parametrised…)

  ML-based taggers are still a problem (top, tau)
- Clear and unambiguous analysis logic (signal selection `cuts’, tabulated/code)
- Cutflows !!!
- Other validation material:
  - input models (UFO…)
  - run cards
  - SLHA files of benchmarks
  - event samples?

(pseudo)code helps !

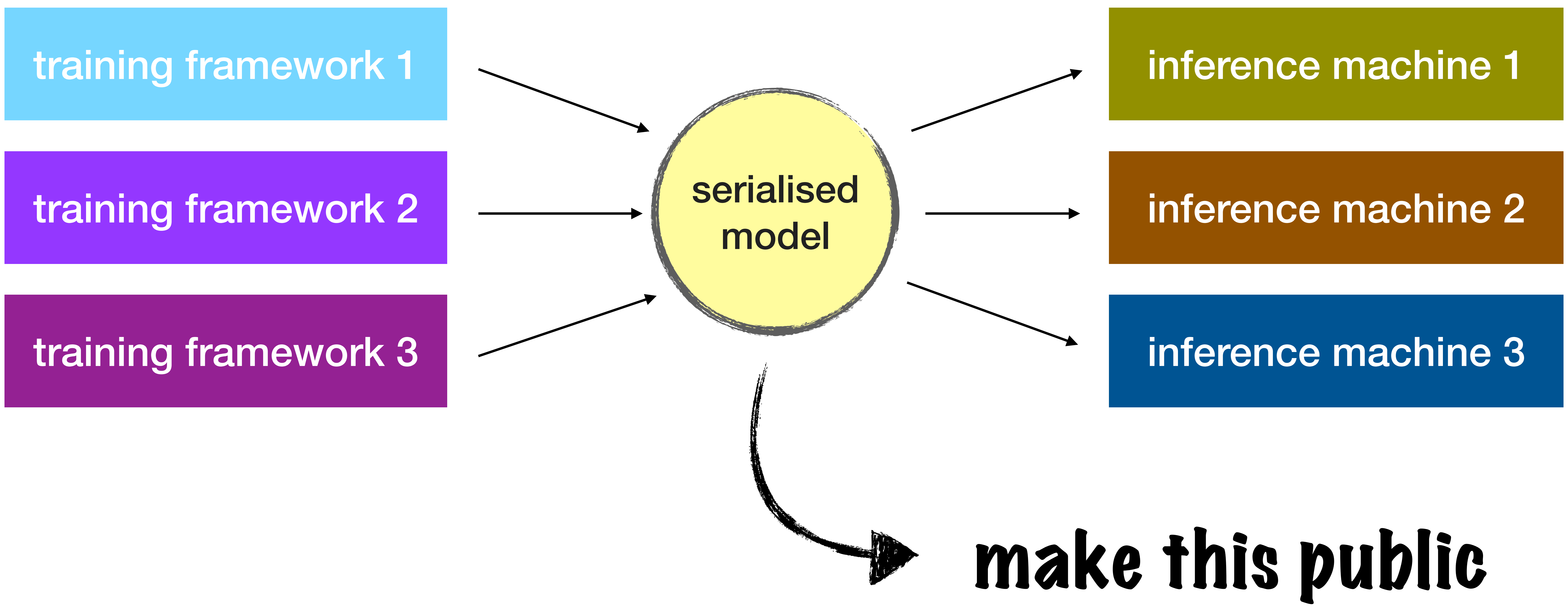


ATLAS SimpleAnalysis: ATL-PHYS-PUB-2022-017

ML-based analyses — a dead end for recasting ?

Not necessarily; solutions exist

training and inferencing interoperability:
save ML model in a stable exchange format



together with a clear description of inputs and output

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.

arXiv:2312.14575

Guidelines for reusable ML models

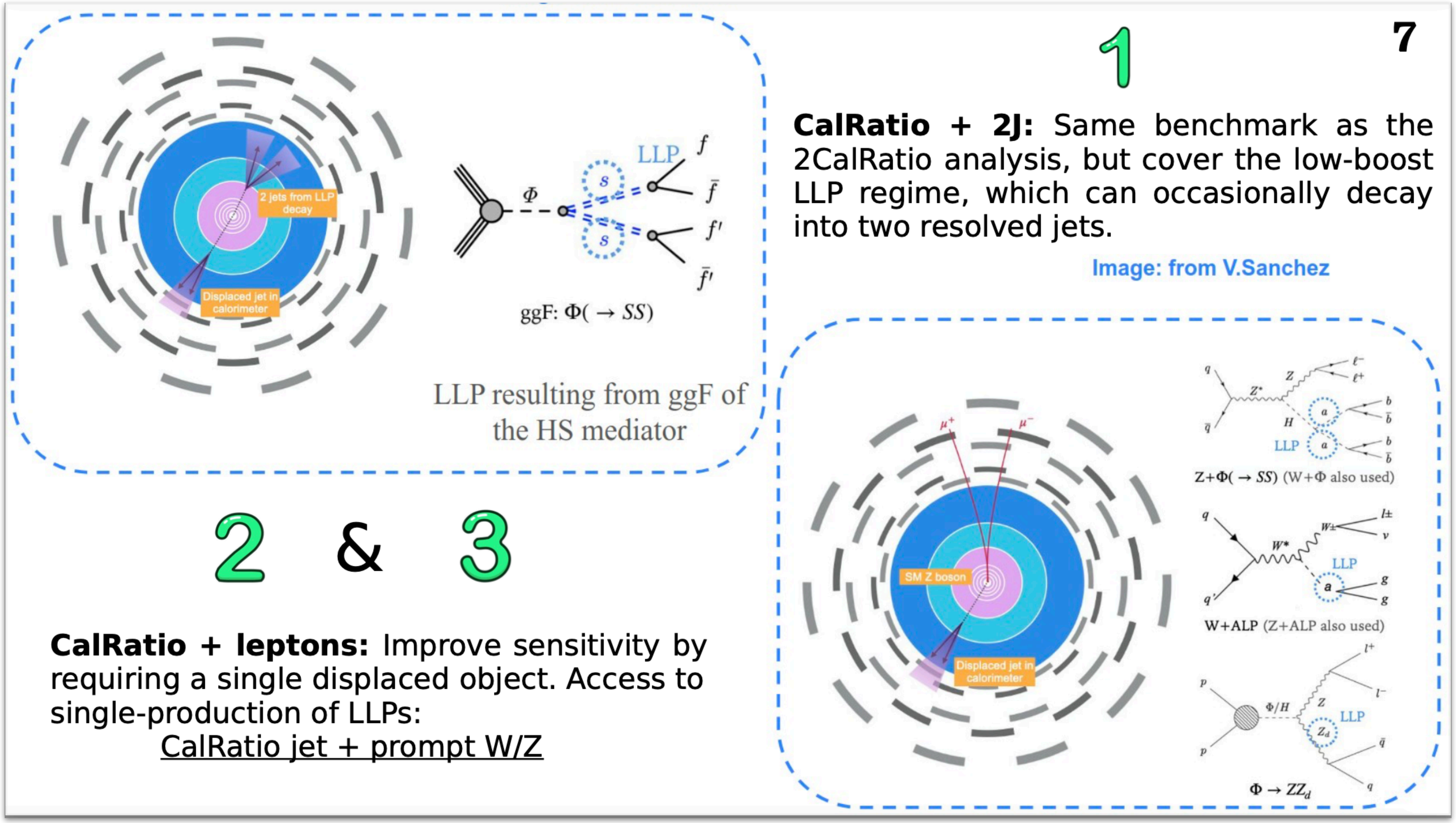
Analysis Design	choice of framework, preservation format, architecture, input features
Documentation	clear definition of all input & output variables; code/framework version and dependencies
Validation	material enabling to verify performance (cut-flows, plots of in/out variables, runcards)
Surrogates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

ML-based analyses: Surrogates

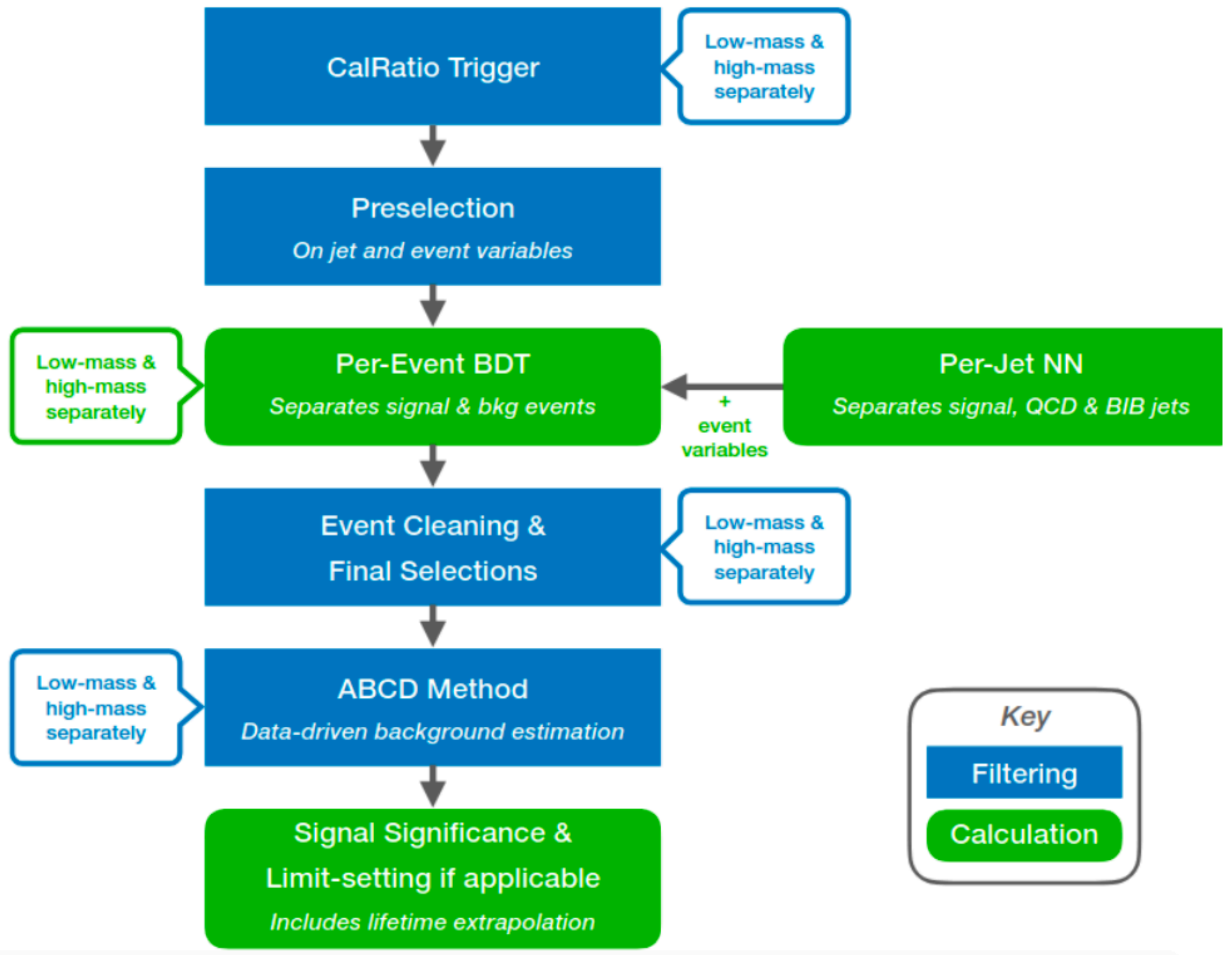
EXOT-2019-23

EXOT-2022-04

ATLAS CalRatio LLP search (displaced jets + leptons or extra jets)



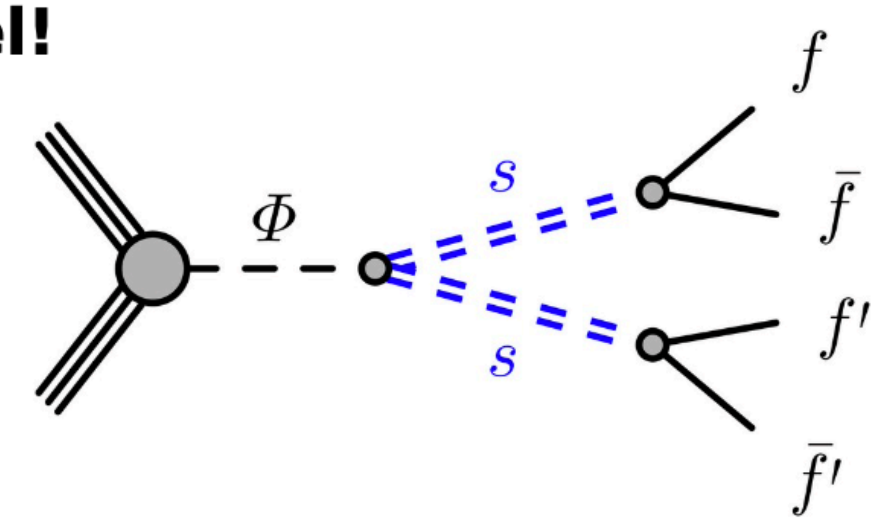
from RAMP seminar by
Abdelhamid Haddad
16 Oct 2024



ML-based analyses: Surrogates

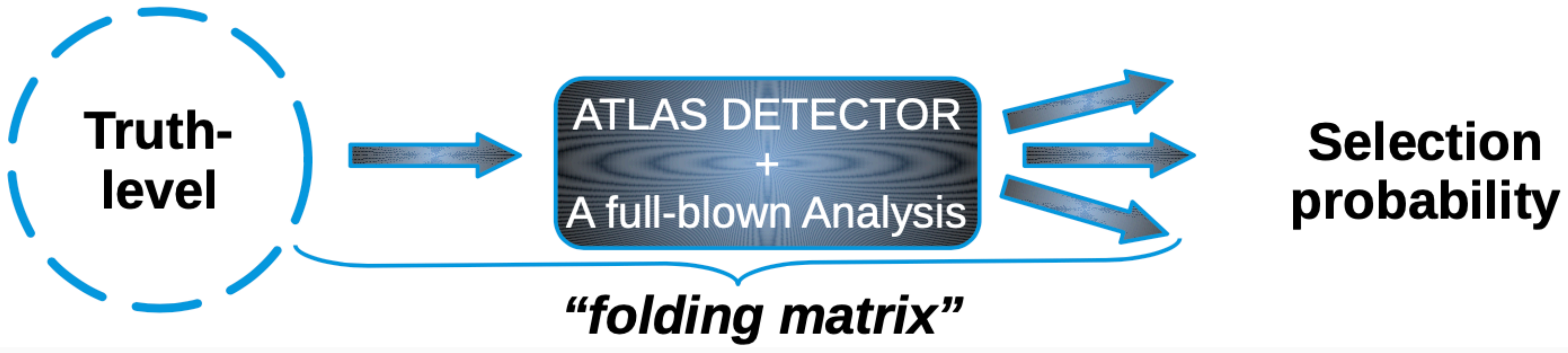
ATLAS CalRatio LLP search (displaced jets + leptons or extra jets)

Idea: The probability of **an event being selected** in an analysis should ultimately only **depend on the physical properties** (Position, Flavor, and pT) **of the decays** and **not the internal details of the model!**



Tentative solution:

1. Create a **probability map for selection events in Region A** based on LLP decay kinematics.
2. **Obtain sample efficiency** by summing the probabilities for selected events and divide by the sum of events.



A. Haddad

EXOT-2019-23

6d efficiency maps parametrising the BDT+NN selection + example code

RAMP seminar by Louie Corpe
16 Jan 2023

EXOT-2022-04

Trained BDT to give overall selection probability in ABCD plane, using truth-level (L_{xy}, L_z, η, p_T, E_T, Child ID); pickle files + sample code

RAMP seminar by Abdelhamid Haddad
16 Oct 2024

Similar approach in CMS displaced di-muon search

Available material

To go with the paper, we provide:

Auxiliary material, on the paper webpage

- **Trigger and overall selection efficiencies** as a function of $c\tau_{\mathrm{LLP}}$, $m_{\mu\mu}$ for the signals considered in the paper.
- **Comparisons** of the final 95% CL constraints with other results.
- **Reinterpretation recipe** (instructions similar and transferrable to the Run 2 paper).
- **Reinterpretation: signal efficiency maps** as a function of generator-level quantities.

HEPData

- **Digitised and tabulated paper and auxiliary material plots**, including reinterpretation material (+ recipe).

⇒ **Three-dimensional efficiency maps** in ($\min(p_{\mathrm{T}})$, $\min(d_0)$, L_{xy}).

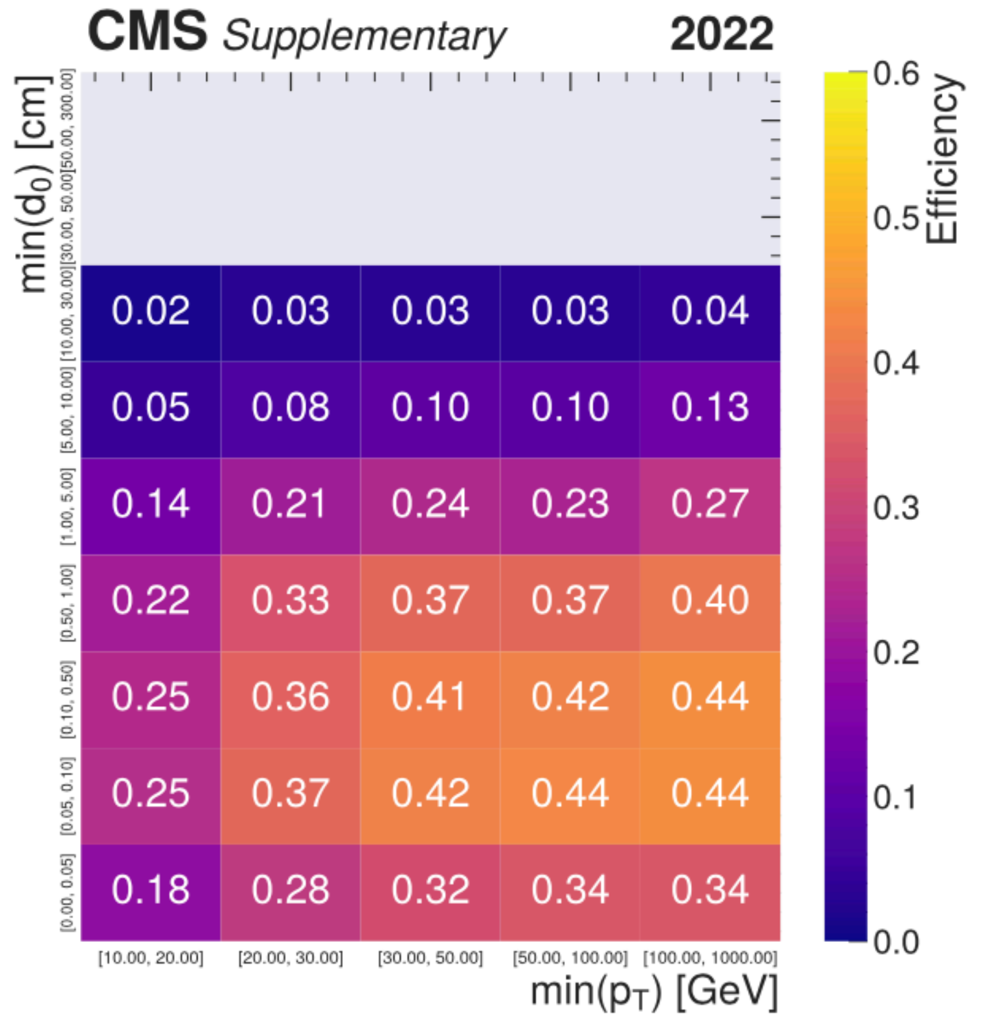
$$\text{Efficiency in each bin} = \frac{N(\text{simulated signal dimuons in the bin passing trigger and selection})}{N(\text{simulated signal dimuons in the bin within geometric acceptance})}$$

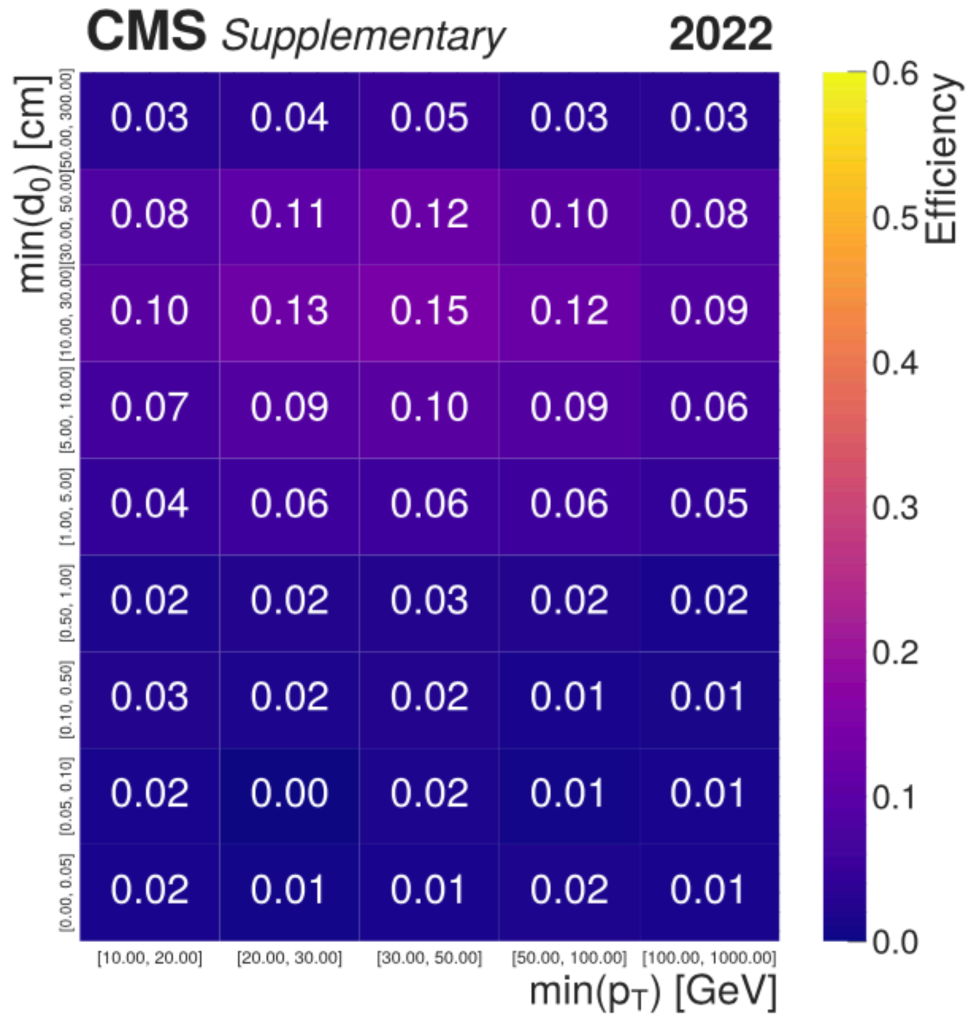
, with geometric acceptance: $\min(d_0) < 300$ cm, $L_{xy} < 500$ cm, $L_z < 800$ cm for the dimuon and $|\eta| < 2.0$ for each muon.

* Efficiencies are corrected by data-to-sim. scale factors, described in the paper.

Example:

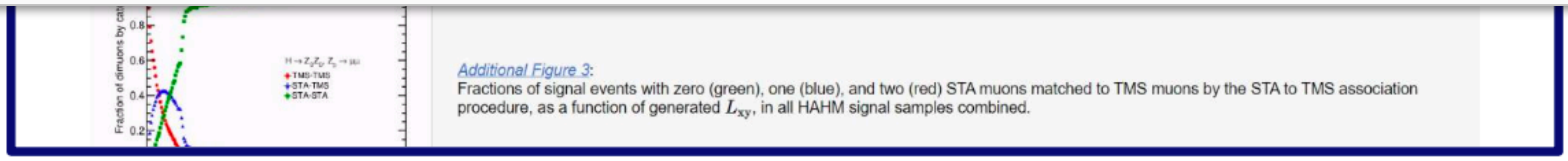
non-collinear;
TMS-TMS;
$L_{xy} < 20$ cm





Example:

non-collinear;
STA-STA;
20 cm < L_{xy} < 70 cm



Webpage: CMS-EXO-23-014 webpage
HEPData: HEPData record

from RAMP seminar by
Muhammad Ansar Iqbal
16 Oct 2024

Good practice:

What ATLAS/CMS analyses nowadays should (and increasingly do) provide

Statistical models

The **complete probability model for the analysis** includes dependence on the data x,y, the parameters of interest μ and nuisance parameters θ, access to the individual terms and the ability to generate pseudo-data ("toy Monte Carlo").

$$p(n,x,y|\mu,\theta) = \prod_{i=1}^{N_c} \left[\mathrm{Pois}(n_i \mid \nu_i(\mu,\theta)) \prod_{j=1}^{n_i} p_i(x_{ij}|\mu,\theta) \right] p(y|\theta) \rightarrow L(\mu,\theta)$$

Likelihood: The value of the statistical model for a given fixed dataset as a function of the parameters

pdf of auxiliary data *y*

Access to the individual components v_{ik} and p_{ik} is needed for certain types of reinterpretations, e.g.

- changing the distributions $p_{ik}(x_{ij}|\mu,\theta)$ because a different physical process with a different phase space distribution is being considered;
- updates of existing interpretations using more precise theoretical calculations or improved experimental calibrations, or both.

$$p_i(x_{ij}|\mu,\theta) = \sum_k \frac{\nu_{ik}(\mu,\theta)}{\nu_i(\mu,\theta)} p_{ik}(x_{ij}|\mu,\theta)\,,$$

$$\nu_i(\mu,\theta) = \sum_k \nu_{ik}(\mu,\theta)$$

The probability to measure xij in channel i event j

Essential information for analysis preservation and reuse

Full statistical models: ATLAS

ATL-PHYS-PUB-2019-029

ATLAS started in 2019 to publish plain-text serialisation of HistFactory workspaces in JSON format

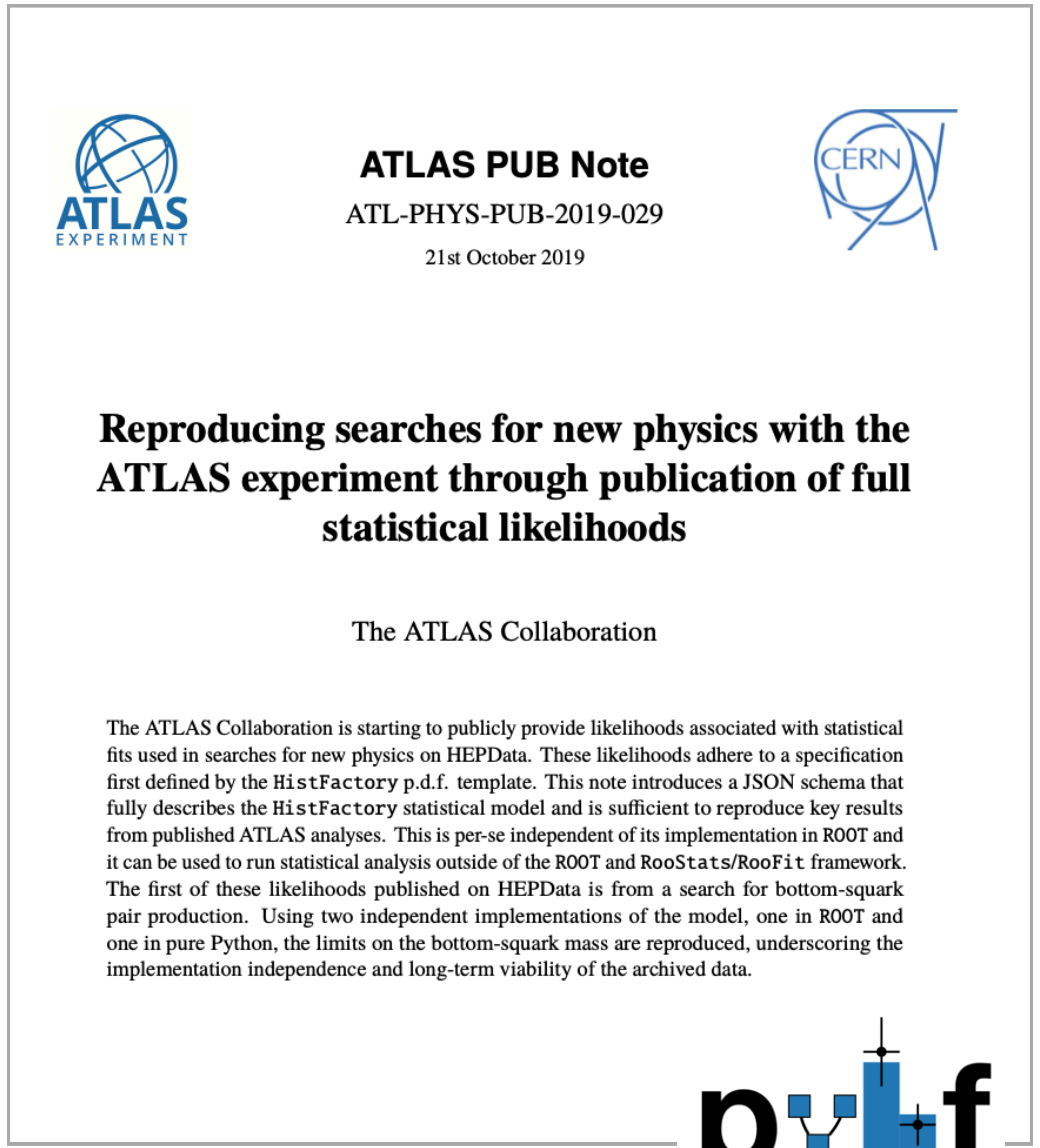
- Provides background estimates, changes under systematic variations, and observed data counts at the same fidelity as used in the experiment.

	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.

pyhf ∂ifferentiable ℒikelihoods

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.

	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	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\| \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\left(a = 0 \| \alpha, \sigma = 1\right)$	$\Delta_{scb,\alpha=\pm 1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\| \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\mathrm{Gaus}\left(a = 0 \| \alpha, \sigma = 1\right)$	$\kappa_{scb,\alpha=\pm 1}$
	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	$\kappa_{scb}(\lambda) = \lambda$	$\mathrm{Gaus}\left(l = \lambda_0 \| \lambda, \sigma_\lambda\right)$	$\lambda_0, \sigma_\lambda$
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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	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

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	[illegible]	139 fb^{-1}
Measurement of ttZ cross sections in Run 2	TOPQ	Eur. Phys. J. C 81 (2021) 737	23-MAR[illegible]	[illegible]	139 fb^{-1}
Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton	EXOT	JHEP 06 (2021) 179	[illegible]	13	139 fb^{-1}
Search for squarks and gluinos in final states 1L, jets and MET	SUSY	Eur. Phy[illegible] (2021)[illegible]	05-JAN-21	13	139 fb^{-1}
Search for charginos and neutralinos in RPV models in final states with 3L (or more)	SU[illegible]	[illegible]ys. 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 sta[illegible] jets and MET	SUSY	JHEP 02 (2021) 143	27-OCT-20	13	139 fb^{-1}
Measurement of the ttbar pro[illegible]ss-section in the lepton+jets channel at [illegible]	TOPQ	Phys. Lett. B 810 (2020) 135797	24-JUN-20	13	139 fb^{-1}
Stop p[illegible] displaced vertex and displaced muon	SUSY	Phys. Rev. D 102 (2020) 032006	26-MAR-20	13	136 fb^{-1}
Chargino-[illegible]tralino 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}

35 results as of yesterday

ATLAS full statistical models HistFactory JSON format

∂ifferentiable ℒikelihoods

→ statistical evaluation through JSON patching

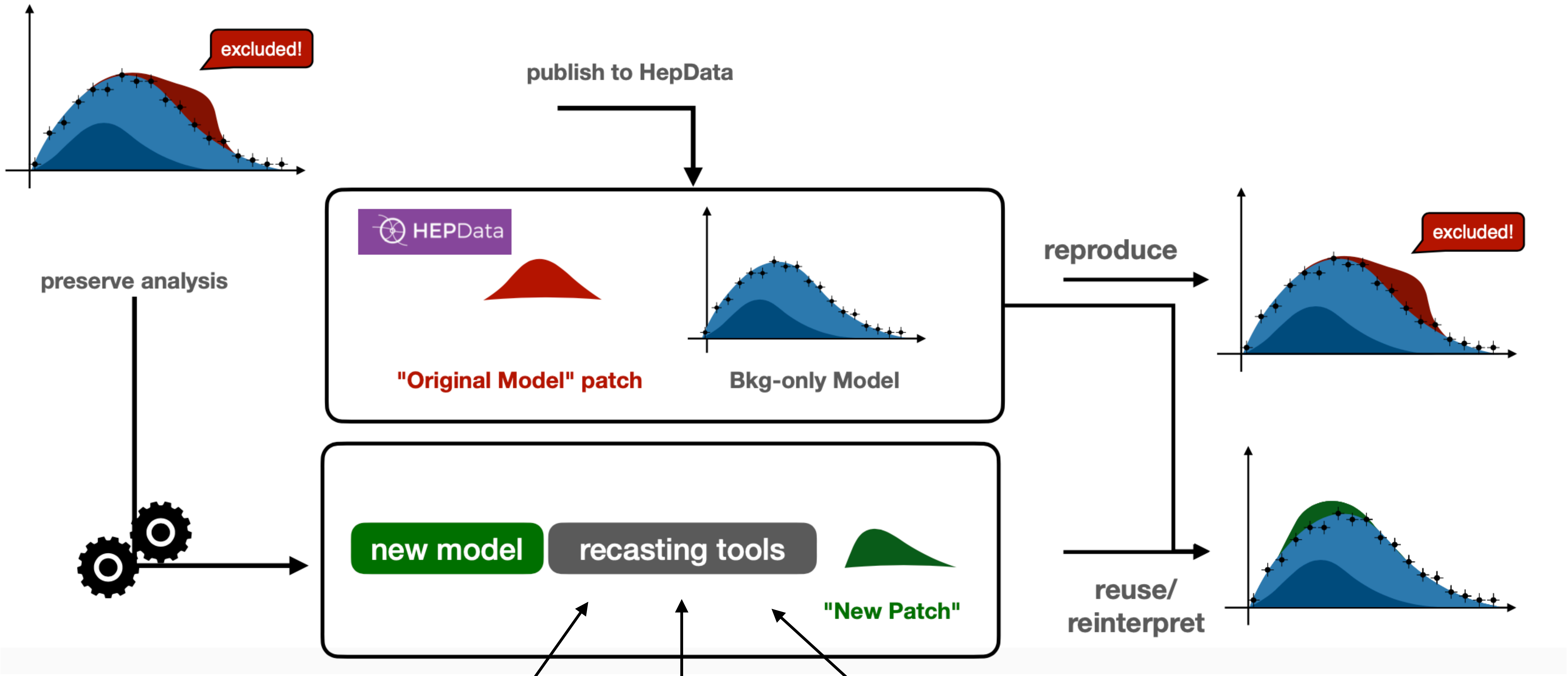


Illustration by **Lukas Heinrich**
Hands-on workshop 8 Nov 2021

Alguero, SK, Waltenberger
arXiv:2009.01809

Alguero, Araz, Fuks, SK, arXiv:2206.14870

The `Simplify` python tool can be used to create simplified statistical models from full ones by merging all background contributions and combining all nuisance parameters into a single one; may yield equivalent results at much lower CPU cost — needs testing case-by-case!

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 for more, new analyses to come (hopefully)
- pyhf <-> combine conversion tool is being worked on

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.

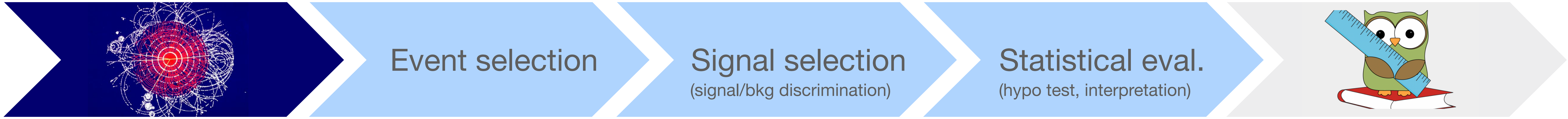
For the full combination of decay channels, the relevant datacard is `125.5/comb.txt`. The individual datacards for each of the analyses in CMS targeting the main Higgs boson decay modes are also in the `125.5` folder.

Software instructions

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

Good practice:

How do we get more of this ?



Interact

Use and cite what exists already,
give feedback to the exp. collaborations

Searches for New Physics: Les Houches Recommendations for the Presentation of LHC Results

S. Kraml[1], B.C. Allanach
C. Balazs[5], A. Barr[6], F
M. Campanelli[12], K. Cran
M. Felcini[17], B. Fuks[1
J. Hewett[15], A. Ismail[15],
S.P. Martin[25,26,27], T. Riz

arXiv:1203.2489

Sci|Post SciPost Phys. 9, 022 (2020)

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

The LHC BSM Reinterpretation Forum

Abstract

We report on the
surements at the
Reinterpretation F
new particles, me
set of recommenc
to better enable r

arXiv:2003.07868

Sci|Post SciPost Phys. 12, 037 (2022)

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], Ita

In this paper, we make the scienti
models and discuss the technical
a variety of physics cases — inclu
surements, effective field theory
flavor physics, direct dark matte

arXiv:2109.04981

arXiv:2312.14575

Sci|Post SciPost Phys. Comm. Rep. ? (20??)

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[6], Humberto Reyes-Gonzalez[8,9,10], Krzysztof Rolbiecki[11],
Sezen Sekmen[12] and Gokhan Unel[13]

arXiv:2203.10057

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Data and Analysis Preservation, Recasting, and Reinterpretation

TF07 (Collider Phenomenology in the Theory Frontier)
COMPF7 (Reinterpretation and long-term preservation of data and code)

Stephen Bailey[1], Christian Bierlich[2], Andy Buckley[3], Jon Butterworth[4],

RAMP seminars

RAMP (Reinterpretation Auxiliary Material Presentation) is a series of short, online seminars, where young experimentalists (ECRs) present the material for their analyses in a ~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.

The presentations are recorded and made available for interested people, e.g. in other time zones, who cannot attend live.

https://indico.cern.ch/category/14155/

next RiF workshop

(Re)interpretation of the LHC results for new physics

25–28 Feb 2025
CERN
Europe/Zurich timezone

Enter your search term

- Overview
- Timetable
- Registration
- Call for Abstracts
- Participant List
- Code of Conduct
- Practical information

This is the 9th general workshop of the "Forum on the interpretation of the LHC results for BSM studies", or LHC Reinterpretation Forum (RIF) for short. Its aim is to review new developments on the tools, phenomenology, and the experimental sides, regarding the questions of data and analysis preservation and reuse.

Emphasis at this workshop will be given to current and future developments regarding analysis preservation and reuse, and recommendations of best practises, in particular with regards to the upcoming European Strategy for Particle Physics Update. Moreover, an extensive session will be devoted to recent reinterpretation studies. Cross-talks with various LHC working groups will be appreciated.

https://indico.cern.ch/event/1466101/

Conclusions

TH-EXP community effort

It is important to enable reinterpretation and reuse of LHC analyses …

e.g., updating constraints, testing new hypotheses, performing combinations and/or fits, etc.

→ new research based on existing data and analyses

longer shelf life & more scientific impact

BACKUP

Snowmass 2021

➜ ESPPU 2025

US Community Study on the Future of Particle Physics

To achieve their full scientific impact, HEP experiments need to integrate **extensive data and analysis preservation efforts** into their publication processes, alongside the communication of results **in reusable form** and preservation of data products, and making event-level data publicly available.

Without this, the influence of the hundreds of published analyses from the LHC, HL-LHC, EIC, and other future experiments will be **limited mainly to the physics ideas in vogue** at the time the collaboration collected their data. The public investment in experimental programs underscores the importance of going beyond the original paper publication and ensuring that analyses continue providing scientific value in perpetuity.

Executive summary from “Data and Analysis Preservation, Recasting and Reinterpretation”
arXiv:2203.10057

Snowmass white paper on data and analysis preservation and reinterpretation

S. Bailey et al., arXiv:2203.10057

Analysis Preservation Recommendations

3.1: Ensure use of interoperable systems to maximise the preservability and reusability of experiment simulation and analysis software chains. This includes the use of version control, archival systems, containerisation, common software interfaces and data formats, and commitments from experimental collaborations and their host laboratories to maintain documentation and provide long-term support.

3.2: Ensure that all operational and in-preparation experiments have a planned and resourced programme for capture and long-term reproduction of their complete computational processing chain, including validation regression-tests.

3.3: Ensure
commu
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for community consumption.

Ensure that **release of analysis preservation logic via public frameworks for the community to use** is **integrated with experiment publication and data-release processes**, to maximise analysis impact.

3.4: Support continuing development and uptake of new technologies for increasingly framework-independent analysis specifications, such as via declarative domain-specific analysis description languages.

Snowmass white paper on data and analysis preservation and reinterpretation

S. Bailey et al., arXiv:2203.10057

Reinterpretation and Recasting Recommendations

5.1: Encourage that reinterpretability and reuse be kept in mind early on in the
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Encourage that **reinterpretability and reuse be kept in mind early on in the analysis design**. This concerns, for instance, the **choice of input parameters in ML models**, the full specification of the fiducial phase space of a measurement in terms of the final state, including any vetos applied, and generally the **choice of non-overlapping regions and standard naming of shared nuisances to facilitate the combination of analyses**.

5.2: De
ucts, such as statistical models, with reinterpretation use-cases in mind.

5.3: Improve the coordination among the different public reinterpretation frameworks with the goal of a centralised database of recast codes, common input/output formats, and a unified statistical treatment.

5.4: Encourage the FAIR-ification of codes and data products from (theory) reinterpretation studies outside the experimental collaborations at the same level of sophistication as asked for experimental analyses and results. Suitable repositories are, e.g., GitHub and Zenodo; appropriate versioning is essential.

Solutions for neural nets (e.g.)

Lightweight Trained Neural Network

- Designed to take tensorflow/sk-learn trained NNs and run them in C++
- Originally developed for ATLAS trigger; used internally in the collaboration
- Minimal dependencies: Eigen and Boost only; 20 operators.
- Human-readable JSON files

lwtnn

Open Neural Network Exchange

- Designed to allow NNs trained in one context to be run in a completely different one
- Industry standard, developed by Facebook and Microsoft
- Supports tensorflow, pytorch, sk-learn and more; almost 200 operators
- Binary ONNX files

ONNX

and more … see e.g. talk by Dan Guest at Reinterpretation Forum 2022

Analysis Design Guidelines

- ☑ Use an **open-source framework** (tensorflow, pytorch, etc.)
  - Proprietary packages, such as NeuroBayes or Matlab-based packages, can make reuse difficult
- ☑ Ensure the network or tree can be saved in a **useful preservation format** for inference (e.g. ONNX or lwtnn).
  - Just leaving a `.h5` file or `.pkl` file is unlikely to be stable
- ☑ Be considerate with **choice of inputs** (can they be reproduced?)
  - Tomasz: “If a tagger depends entirely on detector level inputs, that’s fine (but please provide detailed efficiencies – including misstags – or surrogates), but 10 truth-level quantities + pseudo-continuous b-score is frustrating.”
- ☑ **Avoid over-complexity** in the network design - heavily customised layers or activation functions, e.g. TensorFlow lambdas, may not be well preserved (test!)

Documentation Guidelines

- ☑ Like for variables in any other analysis, we need **full definitions of all variables** that go into and come out of the ML model.

- ☑ Definitions include:
  - **Units** (GeV vs MeV, …)
  - **Normalisations**
  - **Phi conventions**: $[0, 2\pi]$ vs $[-\pi, \pi]$
  - **Input and output ordering**
  - …

- ☑ A validated **analysis code** (rivet, simpleAnalysis) automatically supplies much of this information.

- ☑ A short **explanatory note** uploaded alongside the ML model (e.g., in the form of a `README` file) is always a good idea; include all relevant **version info**!

nb. ONNX interpreter must match ONXX version

Validation Guidelines

- ☑ Where cuts depend on the ML model output, like for every other cut-based analysis, setp-by-step **cutflows** are a vital validation tool.
  - cut-flow information both before and after any ML-based selections
- ☑ **Plots of input and output variables** for validation samples (especially for most important features) are also useful.
- ☑ Full details of the **physics models** used to generate the information above are essential for any serious validation, e.g. **SLHA files and generator run cards**, or directly event samples
- ☑ Some understanding of feature importance is not only physically interesting, but can be essential in debugging.

Efficiencies and Surrogate Models

If an ML-model requires very experiment-specific inputs which cannot be reproduced outside the collaboration (low-level detector quantities, hits, tracks, …)

☑ If possible, provide **parametrised efficiencies** in terms of physics quantities accessible in simulation outside the collaboration

☑ **Train *another* network** approx. replicating the output of the original one

- can use truth-, parton- or reco-level inputs
- mimic output score of original model case by case
- need to determine level of accuracy of the surrogate

May or may not have access to the “true” answer (e.g. does the jet really contain a top quark?).

Same analysis design, documentation and validation guidelines as above apply