

Reinterpretation Forum

LHC Higgs Working Group Meeting

Lukas Heinrich, TUM

MDSI

TUM



Big Picture

CERN

Given the unique nature of the LHC, we should try to extract as much science out of the data as we can.

Fundamental Issue: many more questions we could ask than we have capacity in experiments to answer.

Need strategies to overcome this tension.

ALICE

LHCb

ATLAS

The LHC Reinterpretation Forum

Community of ~ 100 physicists across theory & experiment working on tools to make this as easy as possible

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 Run 2 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.** 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.

Web	https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCresults
Mailing List	info-LHC-interpretation@cern.ch
Meetings	https://indico.cern.ch/category/14156/

Recommendations

To provide guidance to experiments & theorists the Forum developed recommendations on what types of information experiments should publish.

Close collaboration with experiments to develop new norms.

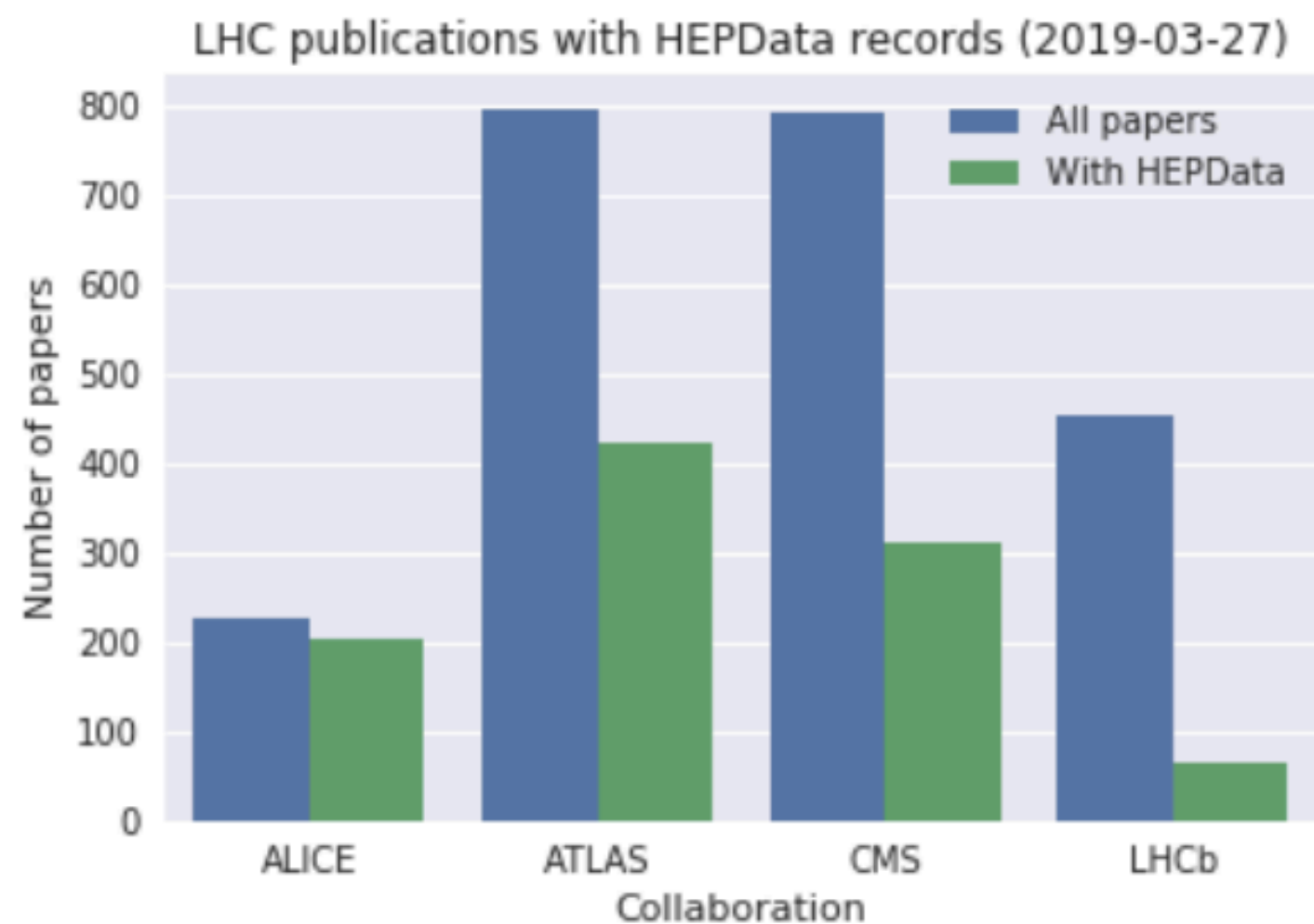
The image shows the cover page of a SciPost paper. At the top left is the SciPost logo, and at the top right is the journal information 'SciPost Phys. 9, 022 (2020)'. The title is 'Reinterpretation of LHC results for new physics: status and recommendations after run 2' by 'The LHC BSM Reinterpretation Forum'. Below the title is an abstract: 'We report on the status of efforts to improve the reinterpretation of searches and measurements at the LHC in terms of models for new physics, in the context of the LHC Reinterpretation Forum. We detail current experimental offerings in direct searches for new particles, measurements, technical implementations and Open Data, and provide a set of recommendations for further improving the presentation of LHC results in order to better enable reinterpretation in the future. We also provide a brief description of existing software reinterpretation frameworks and recent global analyses of new physics that make use of the current data.' At the bottom, there is a Creative Commons license notice, the date 'Received 02-04-2020', 'Accepted 06-08-2020', 'Published 21-08-2020', and the DOI 'doi:10.21468/SciPostPhys.9.2.022'.

Contents	
1 Introduction	5
2 Information provided by experiments	6
2.1 Direct BSM searches	7
2.1.1 Background estimates	8
2.1.2 Correlations	9
2.1.3 Smearing functions and efficiencies	9
2.1.4 Full likelihoods	11
2.1.5 Simplified model results	11
2.1.6 Statistical method	13
2.1.7 Further metadata	14
2.1.8 Pseudocode, code snippets	15
2.1.9 Direct analysis code preservation	16
2.1.10 Open questions	16
2.2 Measurements	17
2.2.1 Primary data	18
2.2.2 Background estimates	18
2.2.3 Correlations	19
2.2.4 Likelihoods	19
2.2.5 Desirable reproduction metadata	19
2.2.6 Theoretical predictions	20
2.2.7 Higgs signal strengths and STXS	20
2.2.8 Summary of key recommendations	21
2.3 Open Data	22
3 Comparison of reinterpretation methods	23
3.1 Public tools for interpretation of BSM searches	24
3.2 Interpretation of measurements	28
4 Global fits to LHC data	30
5 Summary	31
A Technical recommendations on how to publish correlations	33
References	34

HepData - a central data Hub.

Since many decades the primary platform for exchanging information has been HepData: From a database to a full-fledged web service (with APIs, tools, etc)

Strong culture within experiments to provide a lot of high quality data



HEPData
Repository for publication-related High-Energy Physics data

Search on 9842 publications and 121115 data tables.

Search for a paper, author, experiment, reaction

e.g. reaction $P P \rightarrow L Q L Q X$, title has "photon collisions", collaboration is LHCf or D0.

Data from the LHC

- ATLAS View Data
- ALICE View Data
- CMS View Data

HEPData

Search HEPData

Showing 10 of 625 results

Date

Collaboration

- ATLAS 625
- CMS 1

Subject_areas

- hep-ex 625
- nucl-ex 40
- Instrumentation 4

Phrases

- Proton-Proton Scattering 75

HistFactory Search for supersymmetry in final states with missing transverse momentum and three or more b -jets in 139 fb^{-1} of proton-proton collisions at $\sqrt{s} = 13 \text{ TeV}$ with the ATLAS detector

The ATLAS collaboration

CERN-EP-2022-213, 2022.

Inspire Record 2182381 DOI 10.17182/hepdata.95928

A search for supersymmetry involving the pair production of gluinos decaying via off-shell third-generation squarks into the lightest neutralino ($\tilde{\chi}^0$) is reported. It exploits LHC proton-proton collision data at a centre-of-mass energy $\sqrt{s} = 13 \text{ TeV}$ with an integrated luminosity of 139 fb^{-1}

138 data tables

Systematic summary of the uncertainties in the background estimates for SR-Gtt-0L-B. The individual experimental and theoretical table for uncertainties are assumed to be uncorrelated and are combined by adding in quadrature.

SR_Gtt_0L_B

Systematic summary of the uncertainties in the background estimates for SR-Gtt-0L-M1. The individual experimental and theoretical table for uncertainties are assumed to be uncorrelated and are combined by adding in quadrature.

SR_Gtt_0L_M1

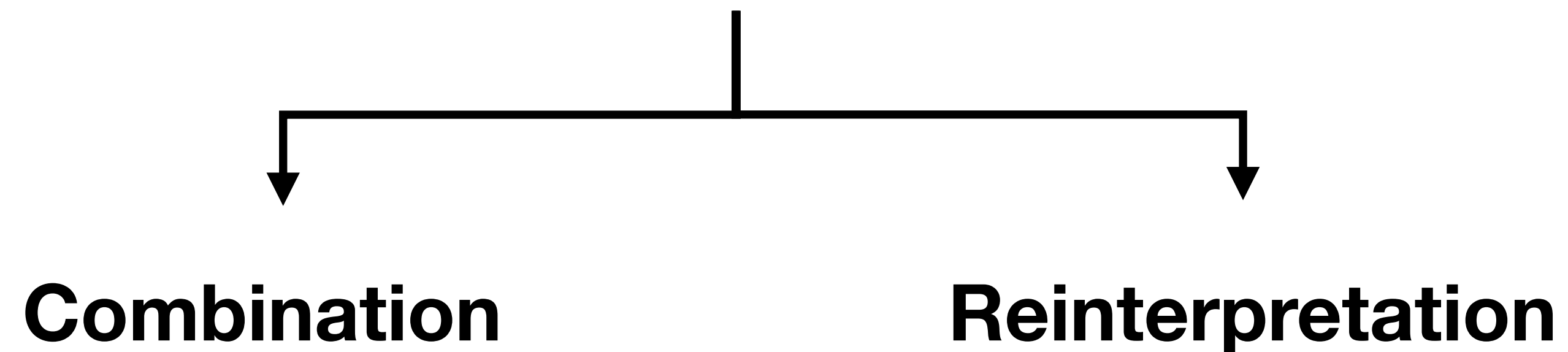
Systematic summary of the uncertainties in the background estimates for SR-Gtt-0L-M2. The individual experimental and theoretical table for uncertainties are assumed to be uncorrelated and are combined by adding in quadrature.

SR_Gtt_0L_M2

Extracting the most Science by Reuse

Instead of developing an entirely new analyses:

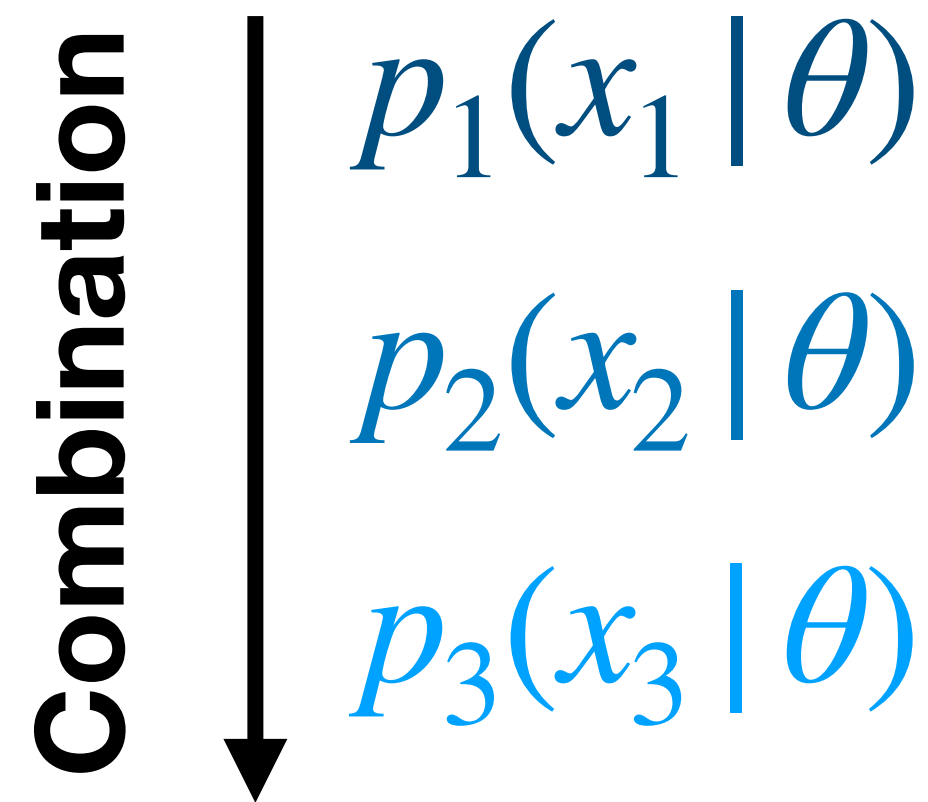
extract more scientific results by reusing existing analyses



- Much less labor- and compute intensive
- Reuses **experiment-approved elements** of the analysis chain

Reuse with Combination

Combination (many data - single theory): accumulate sensitivity from multiple independent measurements in the context of the **same theory model**.



Good if you have identified a target theory (i.e. Standard Model) and many orthogonal measurements $H \rightarrow \gamma\gamma$, $H \rightarrow b\bar{b}$, ...

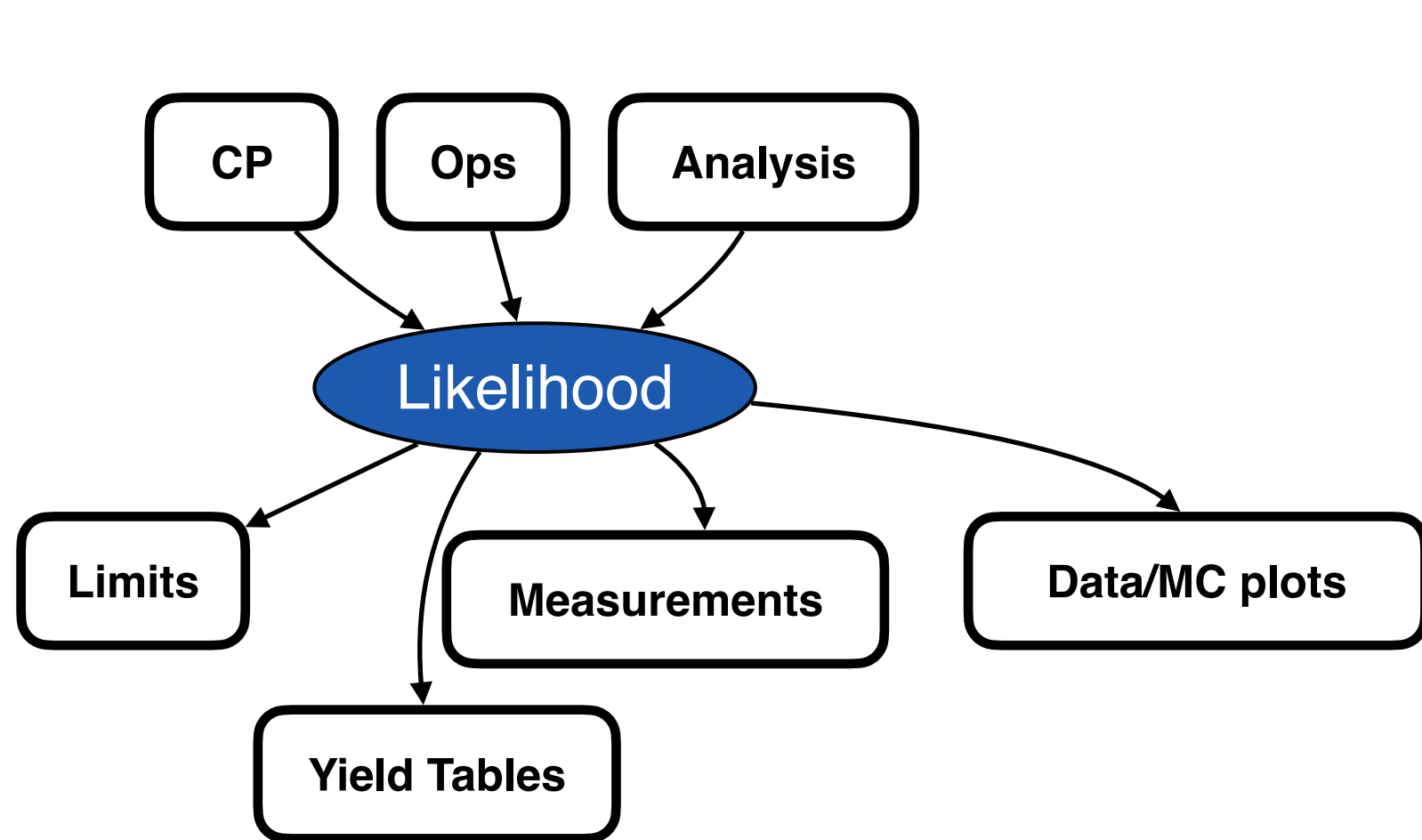
Best example: **Higgs Combination**

Requires availability of highly detailed likelihood information for analyses

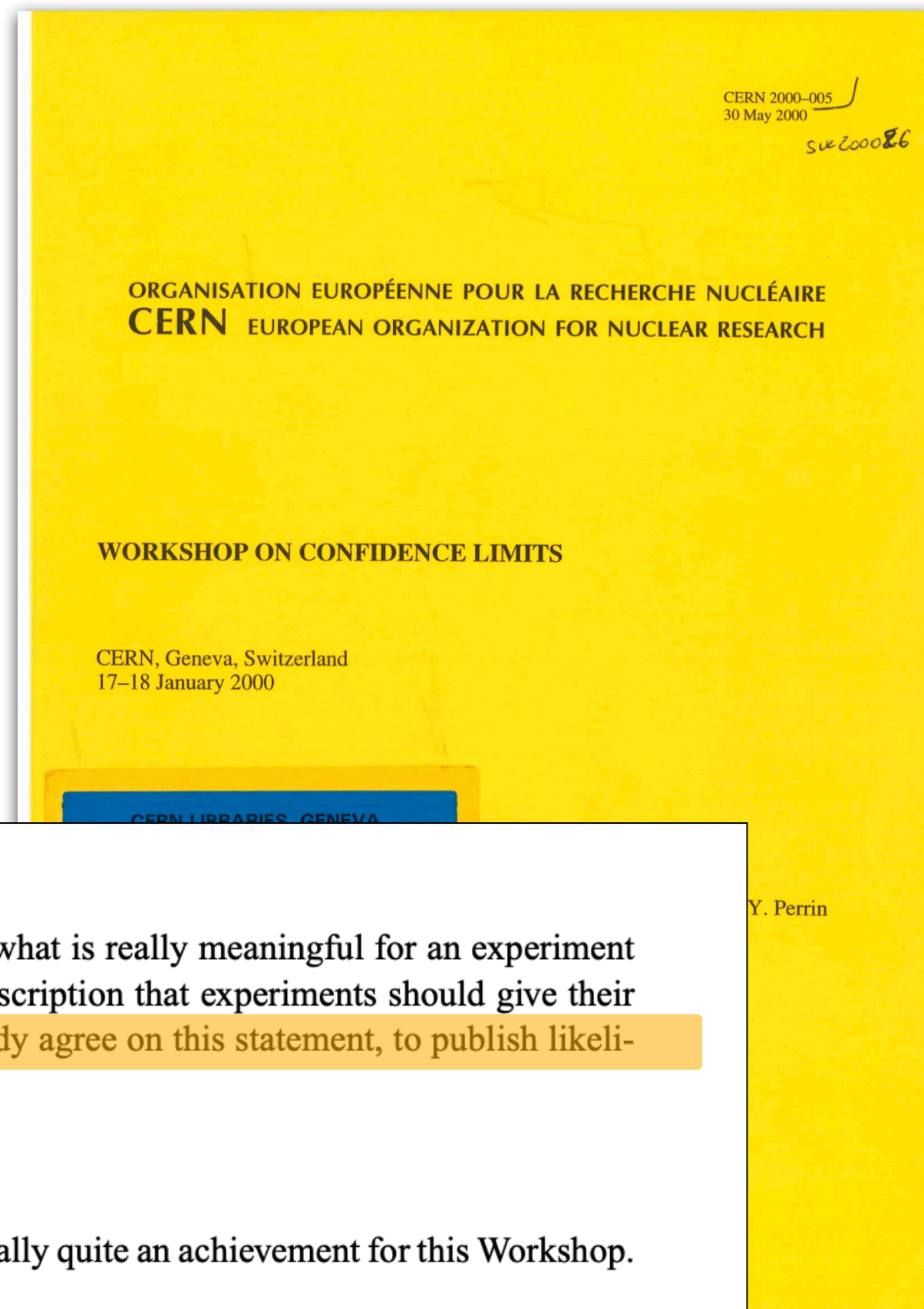
$$p_{\text{comb}} = \prod_i p_i(x_i | \theta)$$

A recent highlight - public Likelihoods

For a long time, combination-grade likelihoods have been kept internal, but recent push to make more public - Higgs Likelihoods are a prime target!



2000



2021

SciPost Physics Submission

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

Kyle Cranmer^{1*}, Sabine Kraml^{2†}, Harrison B. Prosper^{3§} (editors), Philip Bechtel⁴, Florian U. Bernlochner⁴, Itay M. Bloch⁵, Enzo Canonero⁶, Marcin Chrzasczcz⁷, Andrea Coccaro⁸, Jan Conrad⁹, Glen Cowan¹⁰, Matthew Feickert¹¹, Nahuel Ferreiro Iachellini^{12,13}, Andrew Fowlie¹⁴, Lukas Heinrich¹⁵, Alexander Held¹, Thomas Kuhr^{13,16}, Anders Kvellestad¹⁷, Maeve Madigan¹⁸, Farvah Mahmoudi^{15,19}, Knut Dundas Morá²⁰, Mark S. Neubauer¹¹, Maurizio Pierini¹⁵, Juan Rojo⁸, Sezen Sekmen²², Luca Silvestrini²³, Veronica Sanz^{24,25}, Giordon Stark²⁶, Riccardo Torre³, Robert Thorne²⁷, Wolfgang Waltenberger²⁸, Nicholas Wardle²⁹, Jonas Wittbrodt³⁰

¹ New York University, USA ² IPhS Grenoble, France ³ Florida State University, USA ⁴ University of Bonn, Germany ⁵ School of Physics and Astronomy, Tel-Aviv University, Israel ⁶ University of Genova, Italy ⁷ Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland ⁸ INFN, Sezione di Genova, Italy ⁹ Oskar Klein Centre, Stockholm University, Sweden ¹⁰ Royal Holloway, University of London, UK ¹¹ University of Illinois at Urbana-Champaign, USA ¹² Max Planck Institute for Physics, Munich, Germany ¹³ Exzellenzcluster ORIGINS, Garching, Germany ¹⁴ Nanjing Normal University, Nanjing, PRC ¹⁵ CERN, Switzerland ¹⁶ Ludwig-Maximilians-Universität München, Germany ¹⁷ University of Oslo, Norway ¹⁸ DAMTP, University of Cambridge, UK ¹⁹ Lyon University, France ²⁰ Columbia University 10027, USA ²¹ VU Amsterdam and Nikhef, The Netherlands ²² Kyungpook National University, Daegu, Korea ²³ INFN, Sezione di Roma, Italy ²⁴ University of Sussex, UK ²⁵ IFIC, Universidad de Valencia-CSIC, Spain ²⁶ SCIPP, UC Santa Cruz, CA, USA ²⁷ University College London, UK ²⁸ HEPHY and University of Vienna, Austria ²⁹ Imperial College London, UK ³⁰ Lund University, Sweden

* kyle.cranmer@nyu.edu, † sabine.kraml@lpsc.in2p3.fr, § harry@hep.fsu.edu (mailing list: open-likelihoods@cern.ch)

September 9, 2021

Abstract

The statistical models used to derive the results of experimental analyses are of incredible scientific value and are essential information for analysis preservation and reuse. In this paper, we make the scientific case for systematically publishing the full statistical models and discuss the technical developments that make this

arXiv:2109.04981v1 [hep-ph] 10 Sep 2021

Massimo Corradi

It seems to me that there is a general consensus that what is really meaningful for an experiment is *likelihood*, and almost everybody would agree on the prescription that experiments should give their likelihood function for these kinds of results. **Does everybody agree on this statement, to publish likelihoods?**

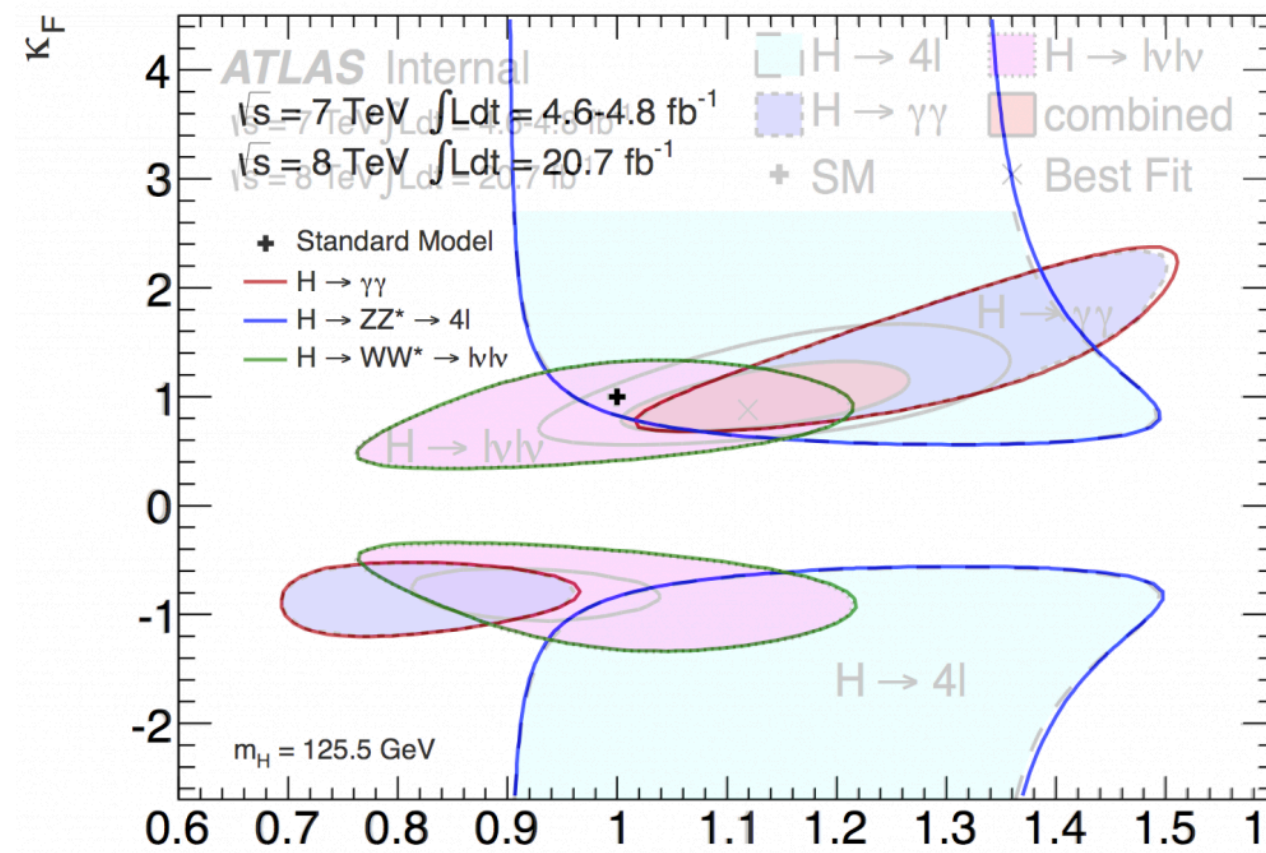
Louis Lyons

Any disagreement? **Carried unanimously.** That's actually quite an achievement for this Workshop.

A recent highlight - public Likelihoods

2012:

Profile Likelihood Scans released for Higgs Couplings



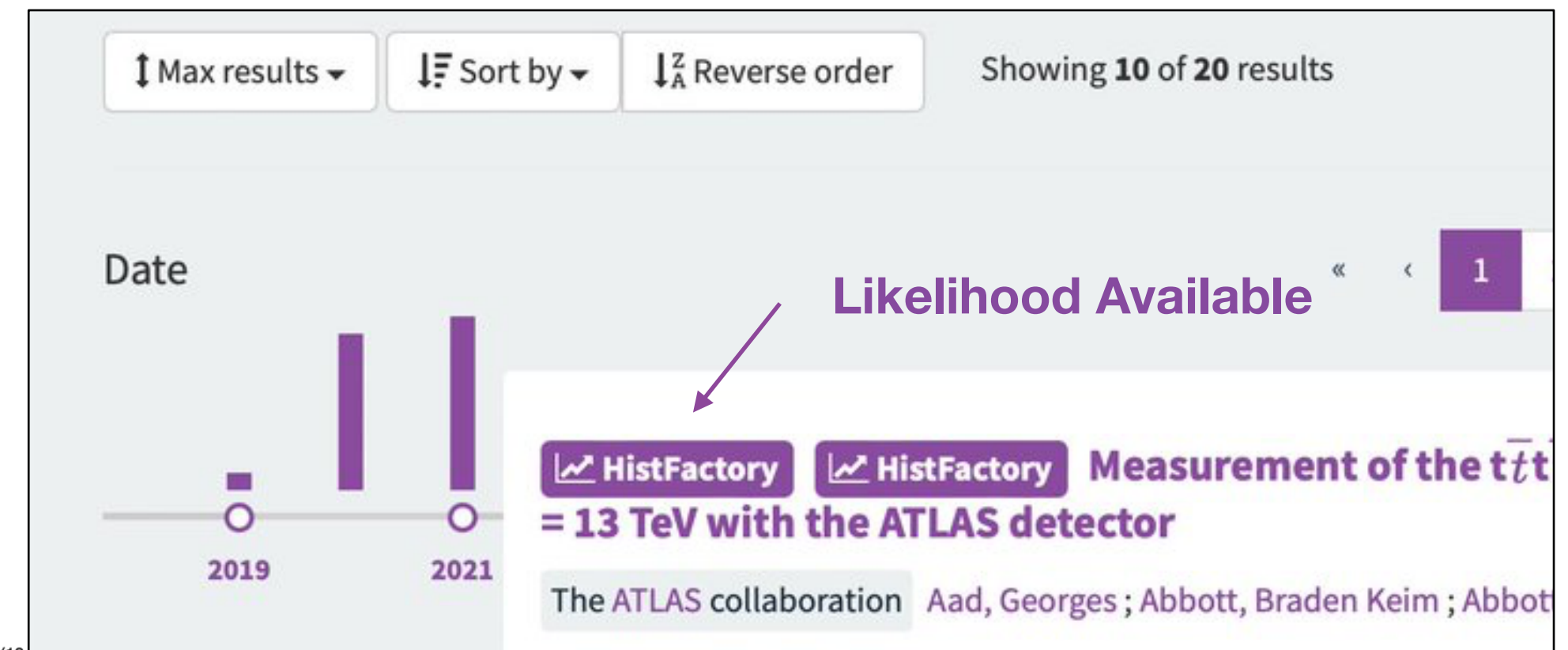
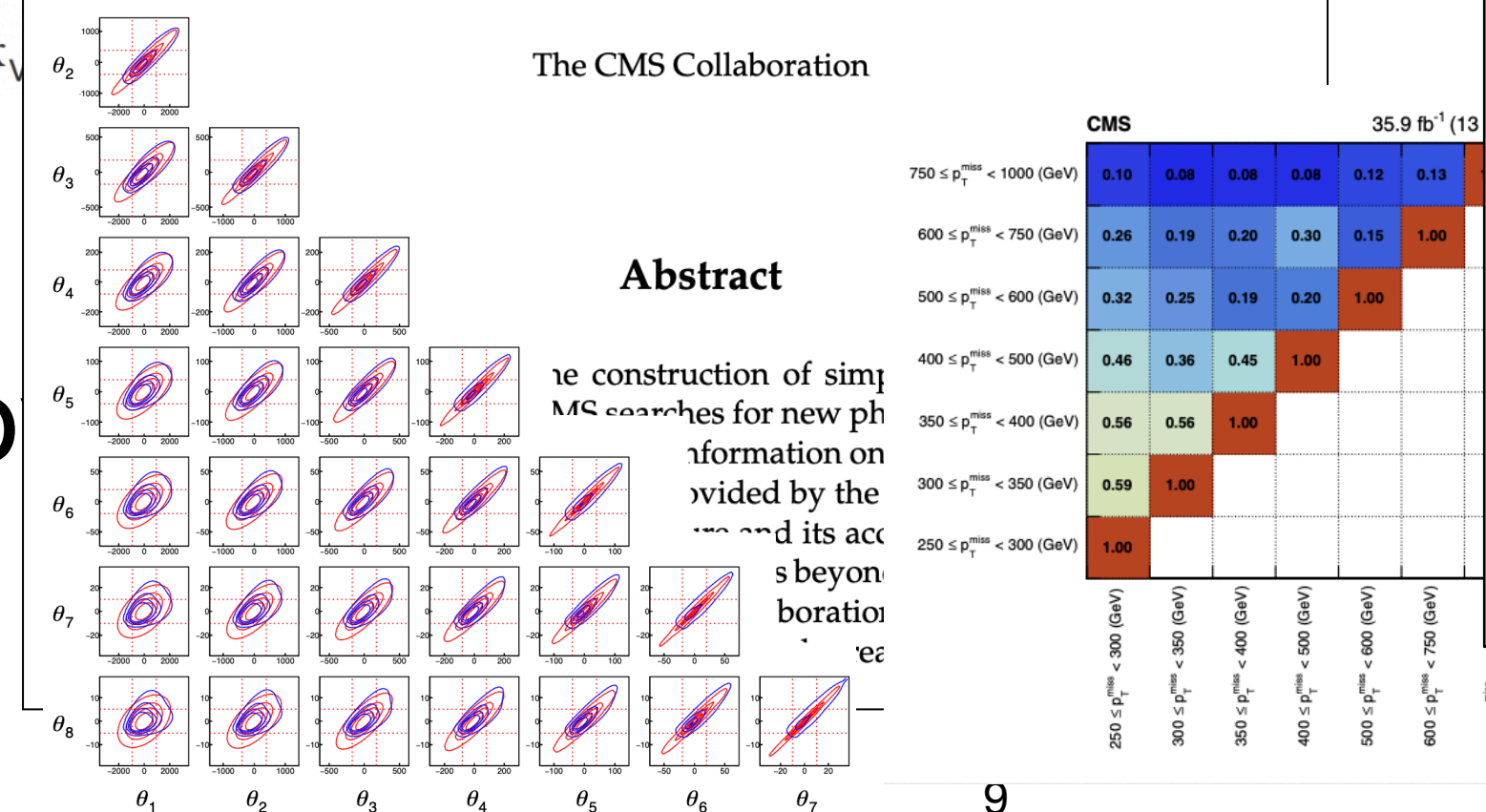
2020:

Full Likelihoods released regularly by ATLAS for SUSY Searches

2017:

Simplified Likelihoods for CMS with nuisance parameters

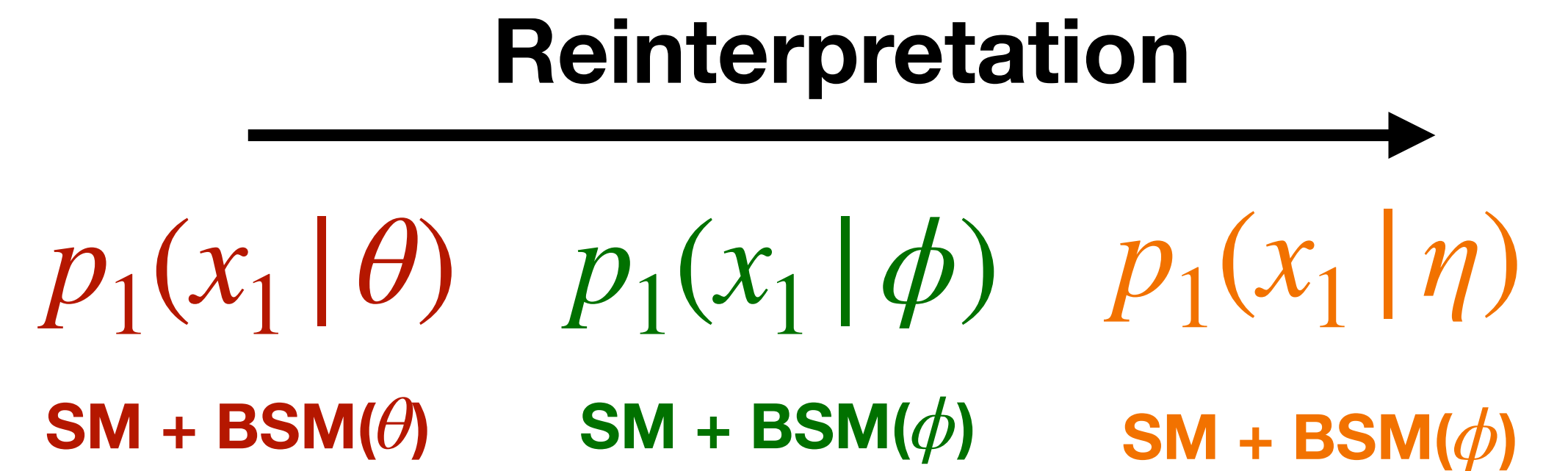
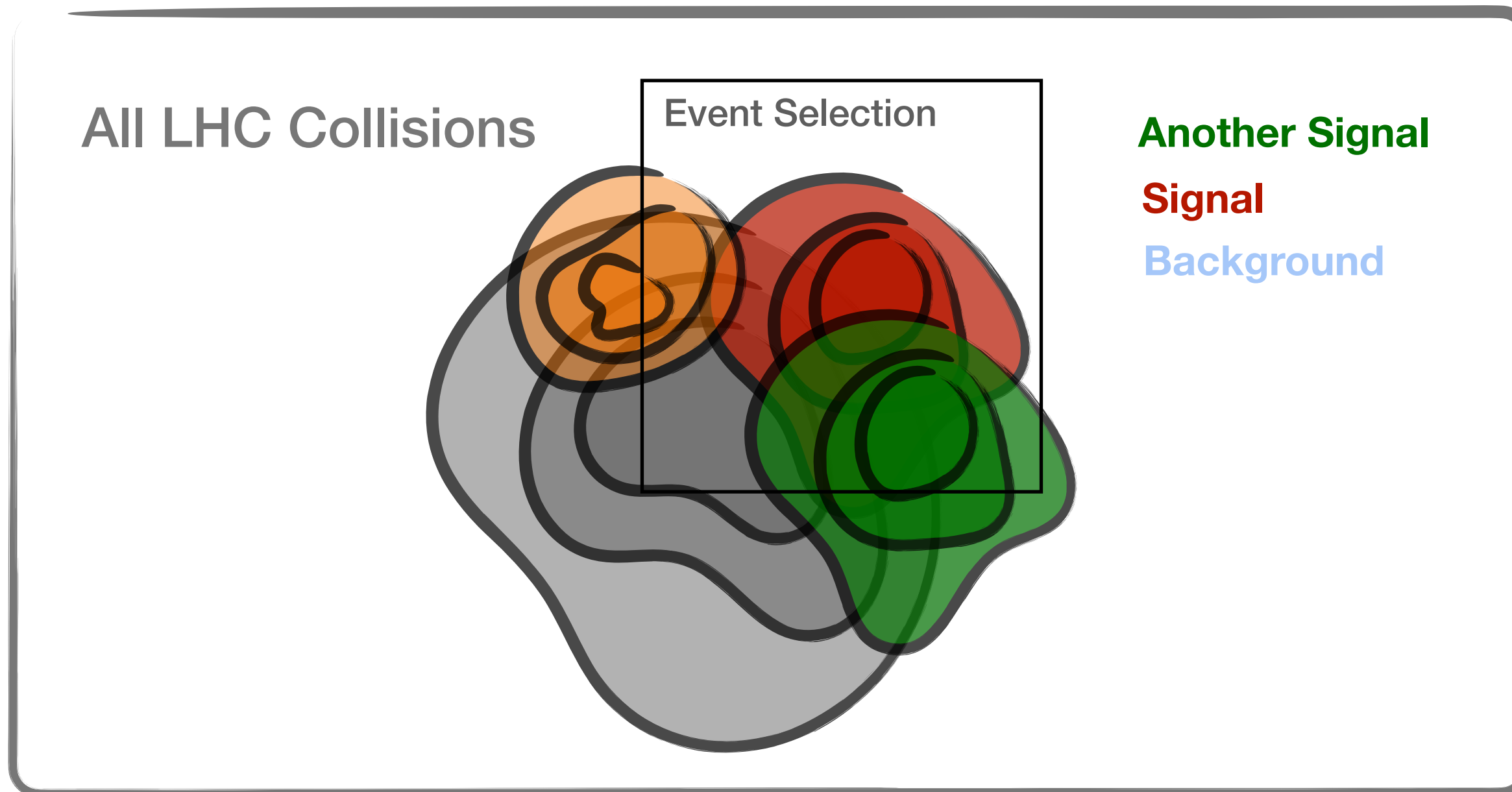
Simplified likelihood for the re-interpretation of public CMS results



```
$> curl -sL https://doi.org/10.17182/hepdata.89408.v1/r2|tar -xf -
$> pyhf cls RegionA/BkgOnly.json --patch RegionA/patch.sbottom_1300_205_60.
{
  "CLs_exp": [
    0.09022509053507759,
    0.1937839194960632,
    0.38432344933992,
    0.6557757334303531,
    0.8910420971601081
  ],
  "CLs_obs": 0.24443627759085326
}
```

Reuse with Reinterpretation

Reinterpretation (single data - many theories):



Often the phase space analyzed by a given measurement is sensitive to many theories at once. Even if not optimal can give strong limits

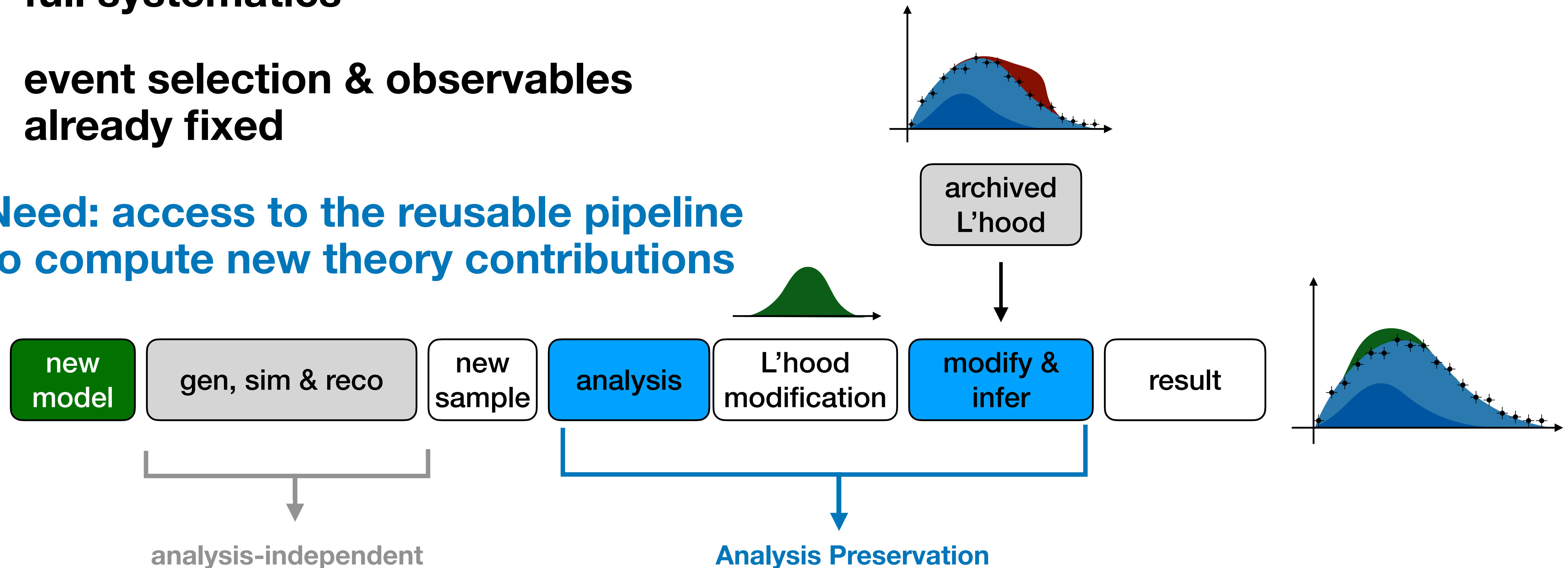
Requires richer information about analysis (on top of likelihood data)

Reuse with Reinterpretation

Reinterpretation is attractive because most of the work is already done.

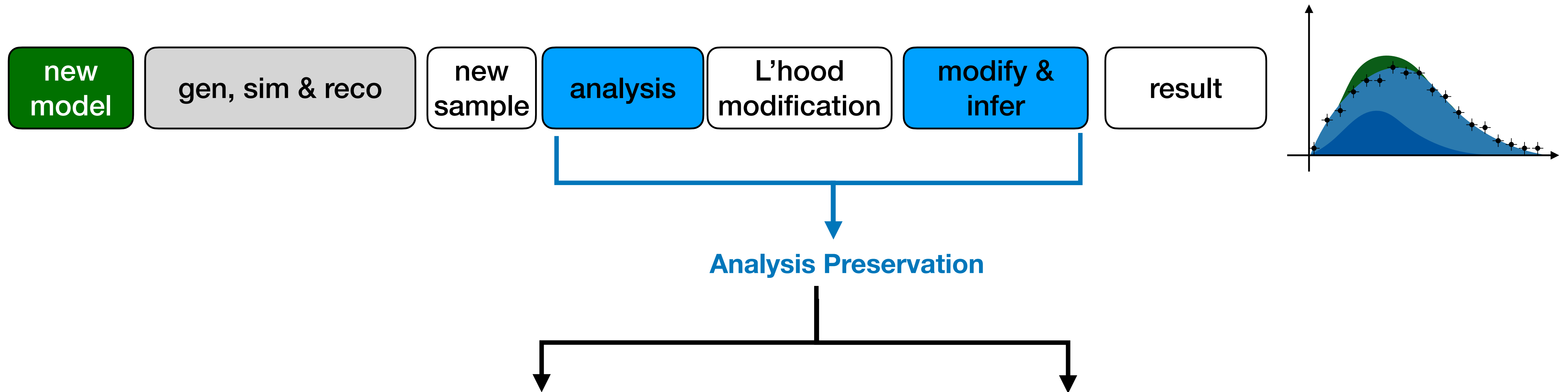
- backgrounds are estimated with full systematics
- event selection & observables already fixed

Need: access to the reusable pipeline to compute new theory contributions



Reinterpretation Toolchains

Within the reinterpretation forum we recommend to complementary ways:



*approximate & fast public pipelines
for use by non-collaboration members*

**preservation of the original analysis pipeline
for collaboration-approvable results**

Reinterpretation Toolchains

Within the reinterpretation forum we recommend to complementary ways:



Rivet




MadAnalysis




(most toolmakers active in Reinterpretation Forum)

*approximate & fast public pipelines
for use by non-collaboration members*



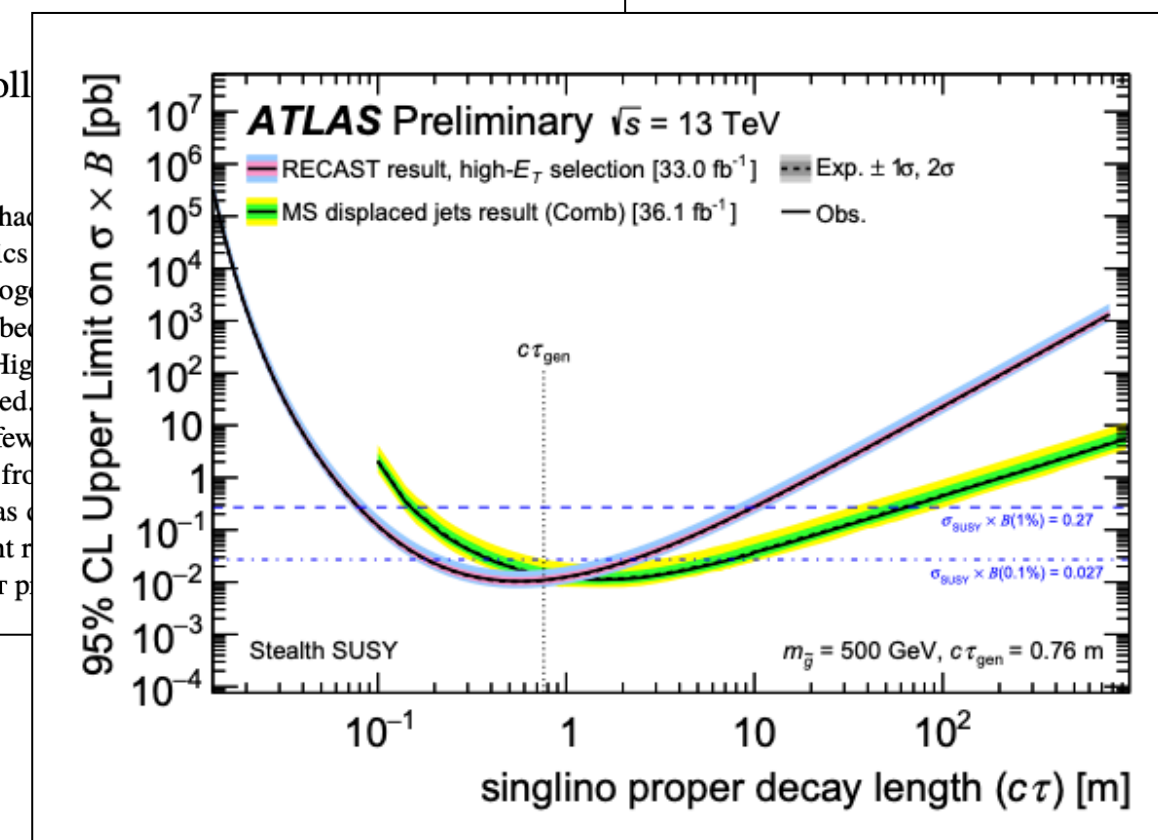
ATLAS PUB Note
ATL-PHYS-PUB-2020-007
27th March 2020



Reinterpretation of the ATLAS Search for Displaced Hadronic Jets with the RECAST Framework

The ATLAS Coll

A recent ATLAS search for displaced jets in the hadronic channel and thereafter used to constrain three new physics models: a Stealth SUSY model and a Higgs-portal baryon number violating model. A dark sector model predicting Higgs boson decays into displaced hadrons via long-lived dark photons is also probed. The original data analysis workflow was reinterpreted using the RECAST framework, allowing for an accurate and efficient reinterpretation of new signal models following the RECAST pipeline.



**preservation of the original analysis pipeline
for collaboration-approvable results**

Reinterpretation Toolchains

For toolmakers the experiments provide a broad range of resources to cross-check their approximate implementations

- cutflows
- efficiency maps
- yield tables
- model descriptions
- public copies of trained ML models
- internal truth-level codes (new!)

The screenshot shows the HEPData website interface. A search result is visible in the background, including the title 'Search for new phenomena in the final state with the ATLAS experiment using \sqrt{s} proton-proton collisions', the ATLAS collaboration, and authors 'Aaboud, Morad, Aad, Georges, Abidinov, Ovsat, Abeloos, Baptiste, Haider, AbouZeid, Ossama, Abramowicz, Halina, Abreu, He'. The publication is cited as 'JHEP 09 (2017) 088, 2017' with a DOI link. A modal window titled 'Additional Publication Resources' is overlaid on the page. It features a 'filter' dropdown menu with 'Common Resources' selected, showing a count of 5. Below the filter is a table listing 'Table 1' through 'Table 15', each with a '2' in the second column. The modal also displays three resource cards: two 'SUSY Les Houches Accord File' cards and one 'C++ File' card. Each card includes a description of the resource and a 'Download' button with a corresponding DOI link.

Resource Name	Description	DOI	Action
SUSY Les Houches Accord File	SLHA file for a model of gluino pair production where the gluino decays to a top quark and a top squark, with the top squark decaying to an s-quark and a b-quark via a non-zero λ_{323} RPV coupling. $m_{\text{gluino}} = 1600$ GeV, $m_{\text{stop}} = 1000$ GeV	10.17182/hepdata.77491.v3/r3	Download
SUSY Les Houches Accord File	SLHA file for a model of gluino pair production where the gluino decays to two light quarks ($q=u,d,s,c$) and the neutralino, which then decays to two light quarks and a charged lepton or a neutrino. $m_{\text{gluino}} = 1800$ GeV, $m_{\text{neutralino}} = 900$ GeV	10.17182/hepdata.77491.v3/r4	Download
C++ File	Code snippet with the implementation of the analysis selection at truth-level, as used to produce the acceptance numbers	10.17182/hepdata.77491.v3/r5	Download

Events

In order to develop consensus & adoption of tools, there are regular events on reinterpretation topics

- **RAMP Seminars:** showcase of specific analyses and their reinterpretations
- **Yearly Workshops (next one in 2 weeks):** have a look!

(Re)interpretation of the LHC results for new physics

12–15 Dec 2022
CERN
Europe/Paris timezone

- Overview
- Timetable
- Registration
- Call for Abstracts
- Participant List
- Videoconference
- Practical information
 - Accommodation
 - Internet/wifi access

+++ We have hit the limit of room capacity for in-person participation on Tue/Wed (smaller meeting rooms than on Mon/Thu). Registration for the workshop is still possible, in particular for online attendance, but we cannot guarantee place in the room for late birds wishing to attend in person +++

This is the 7th 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, pheno, and the experimental sides, and to prepare for the Run 3 results of the LHC. In this context, major topics of this workshop will be:

- i) the publication and reuse of statistical models,
- ii) the reinterpretation of analyses that employ machine learning, and
- iii) global analyses and global fits.

Continuing the conversation from the last workshop session, we would like to include general best practices for reinterpretation/reuse of experimental results beyond the LHC, and particularly welcome contributions regarding results from precision or astrophysical experiments.

Summary & Outlook

The Reinterpretation Forum is a central place to discuss how to extract as much science from the analyses we prepare at the LHC

In recent years lots of new momentum due to some key events (e.g. likelihood publishing)

A lot of the insights can be (and is) carried over to Higgs analyses, not just a BSM topic.