

pyhf Intro

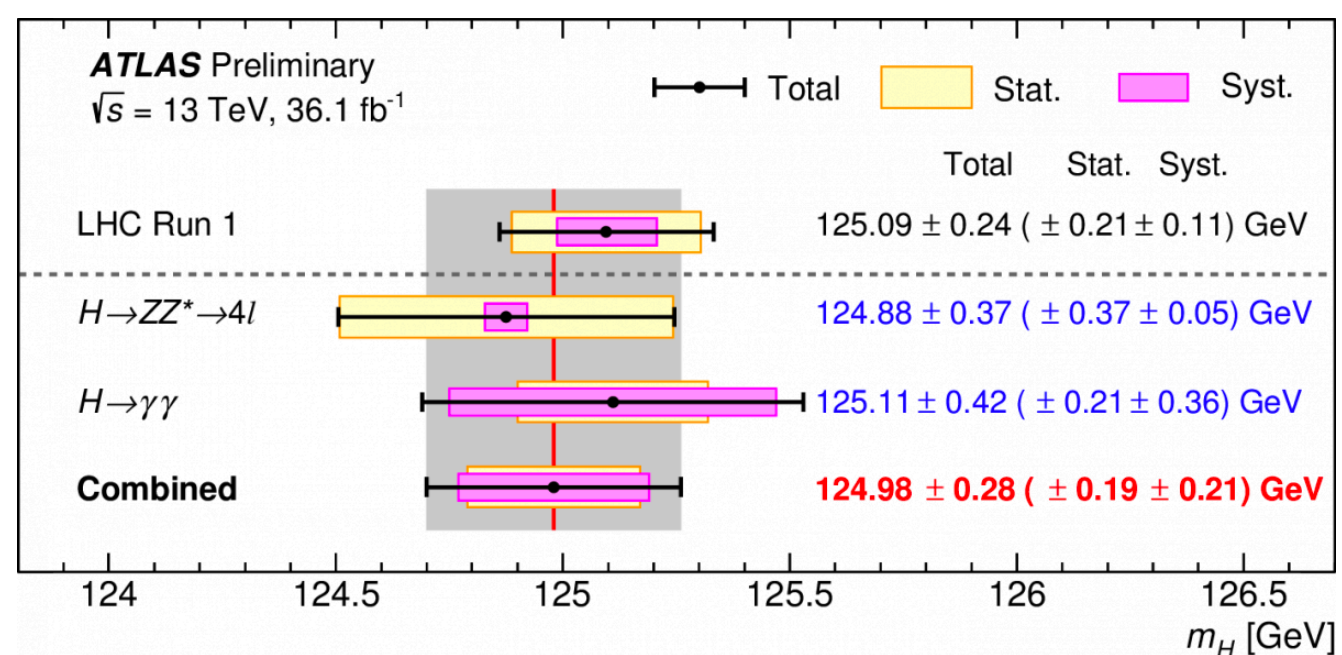
public likelihoods & all that

Lukas Heinrich, CERN

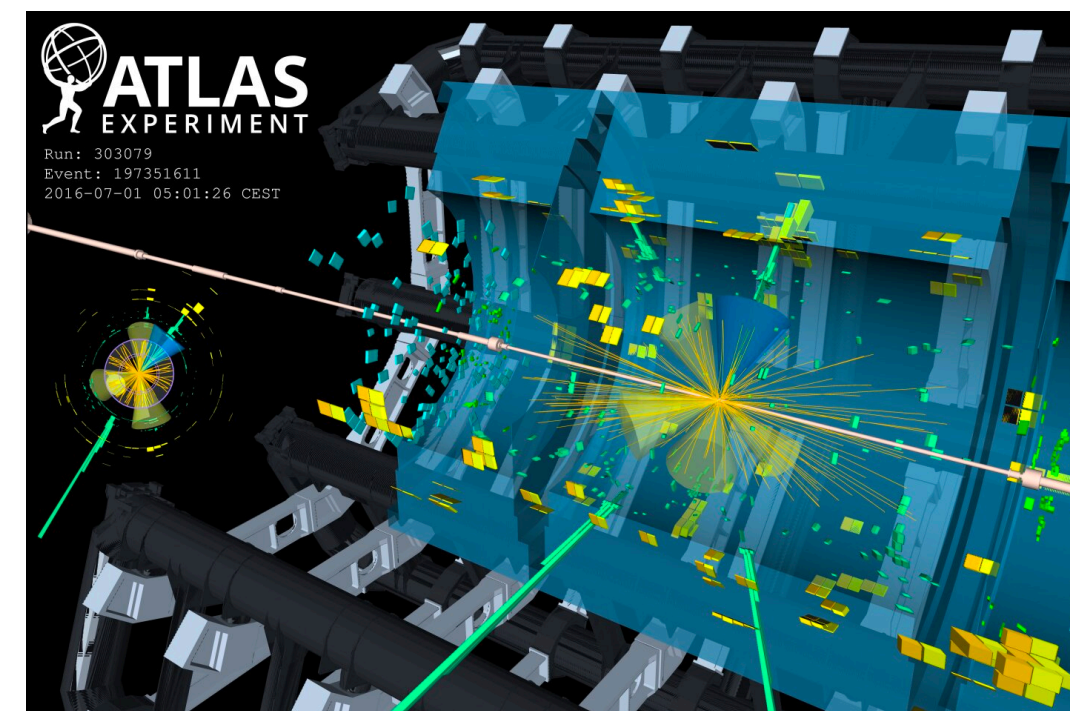
Big Picture Goals

Our job: extract as much information from experimental data as possible

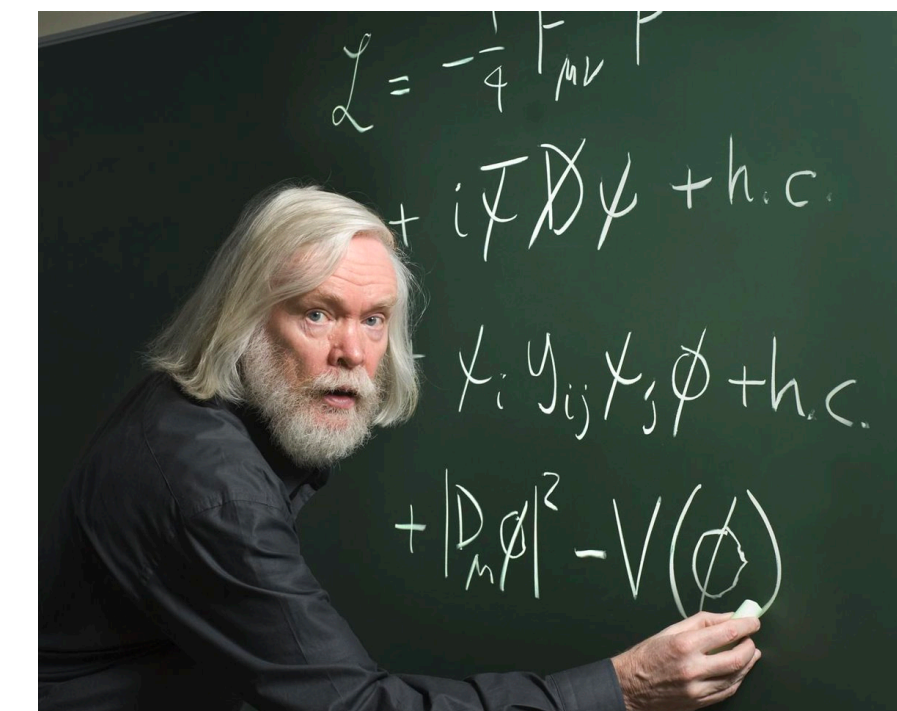
$$p(\text{theory}|\text{data}) = \frac{p(\text{data}|\text{theory})}{p(\text{data})} p(\text{theory})$$



results / insight



experimentalists



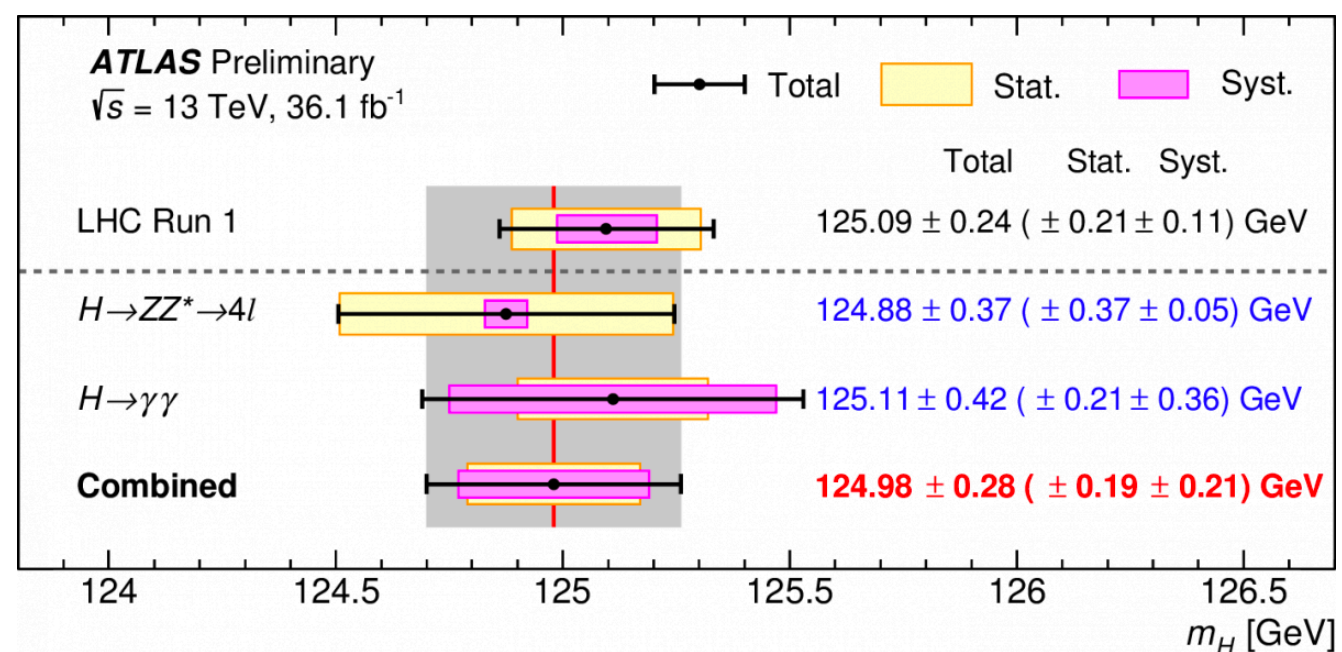
theorists

Big Picture Goals

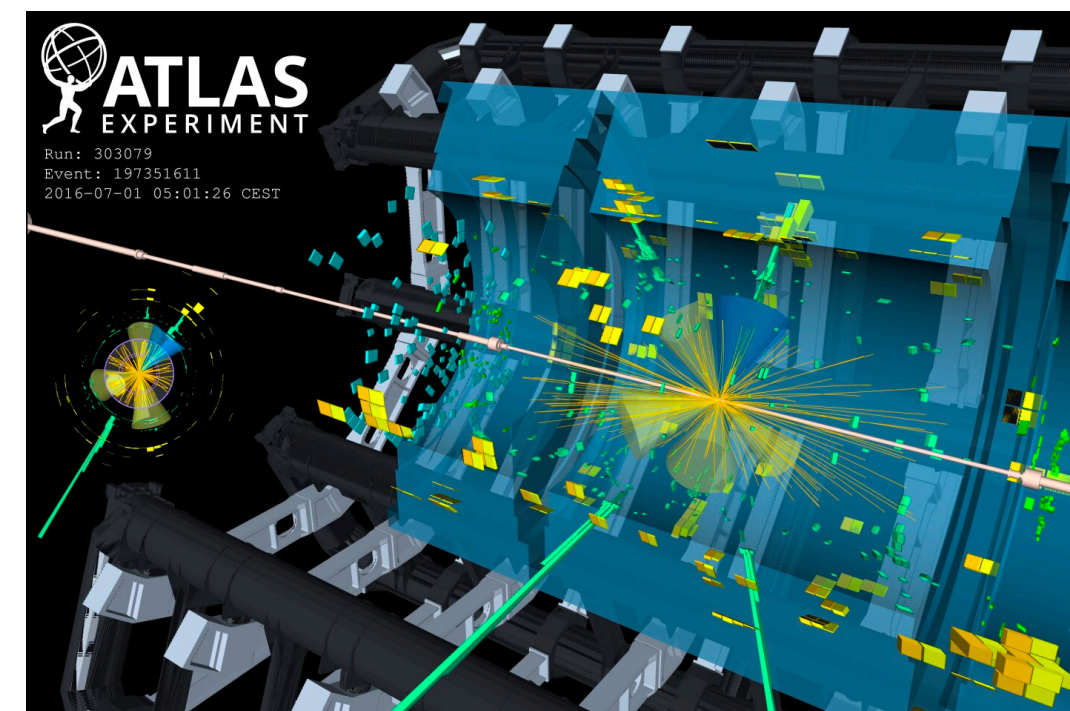
Our job: extract as much information from experimental data as possible

$$p(\text{theory}|\text{data}) = \frac{\overset{\text{The Likelihood}}{p(\text{data}|\text{theory})}}{\underset{\text{Evidence}}{p(\text{data})}} \underset{\text{Prior}}{p(\text{theory})}$$

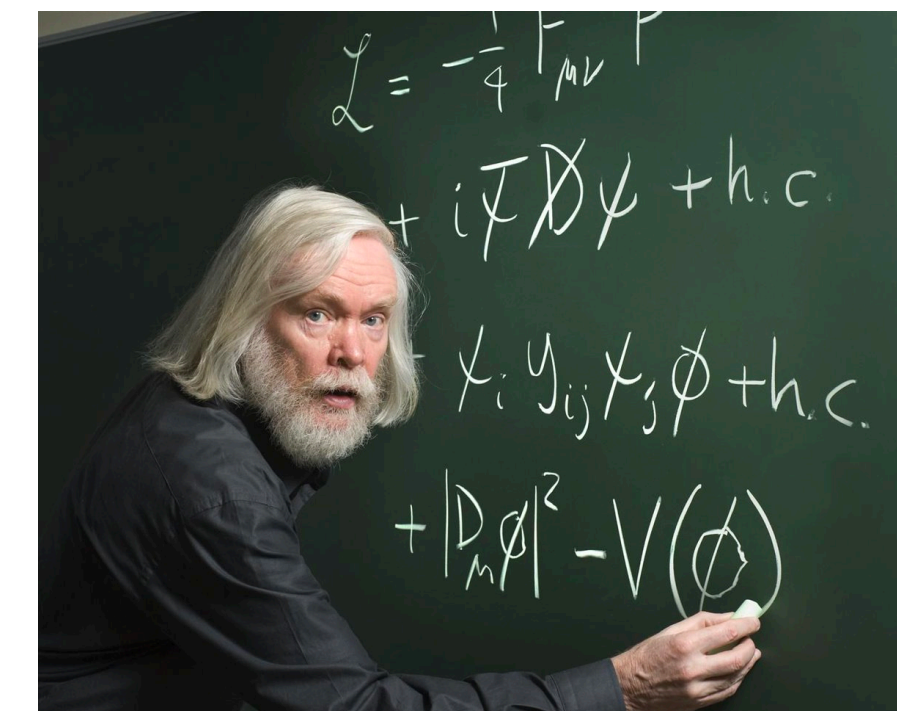
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results / insight



experimentalists



theorists

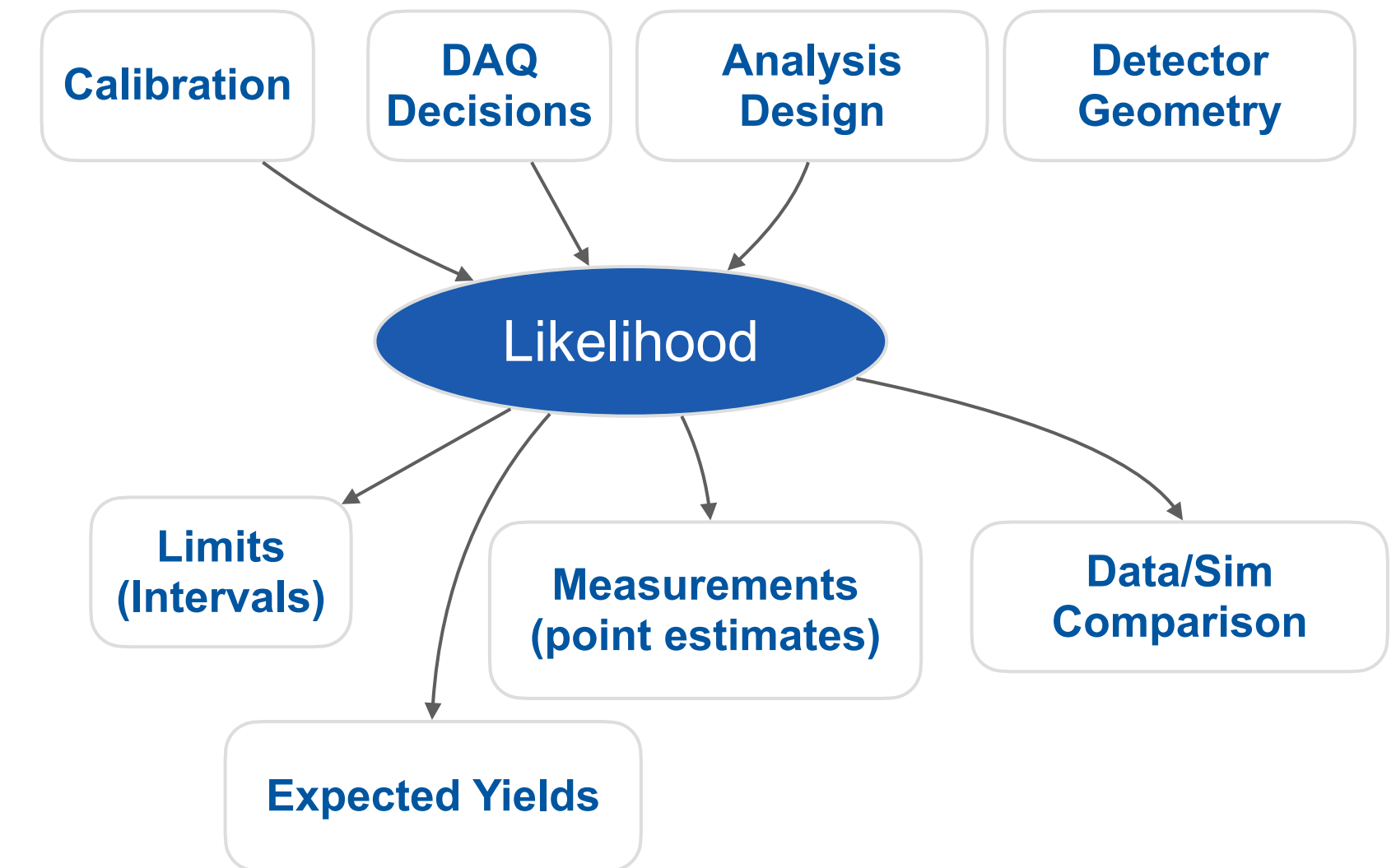
Big Picture Goals

Why focus on the likelihood?

It's the best data product we have: all other results usually **derive from it**

Unique as a high information-density product

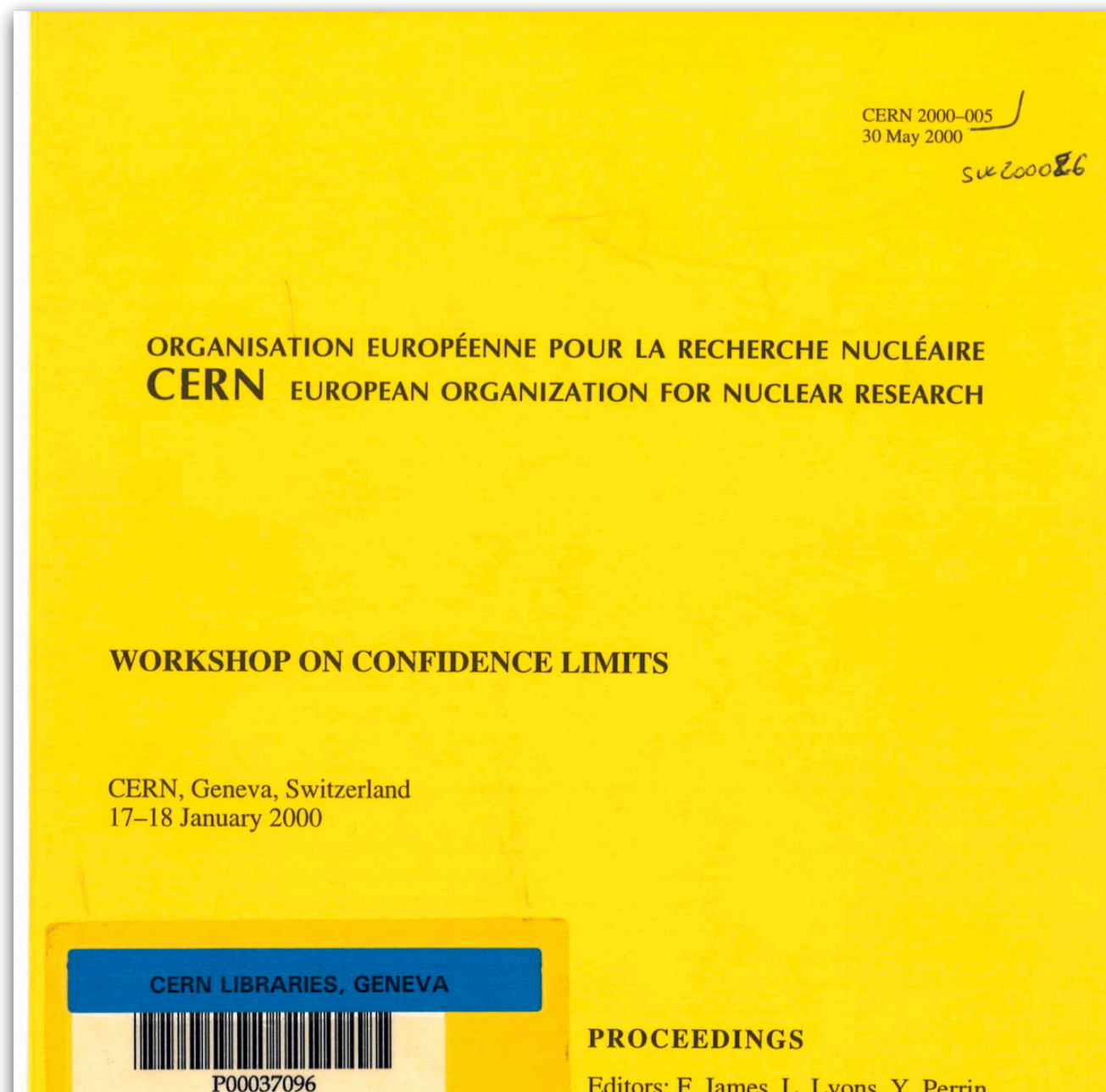
- almost every important decision is reflected in the likelihood
(if it doesn't affect the likelihood, what are you doing?)



Likelihoods are a good bottleneck through which all information flows

- can recompute all important results without having to know details of analysis
- based on this it's clear: this should be shared!

And we (ATLAS) now do share the likelihood



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

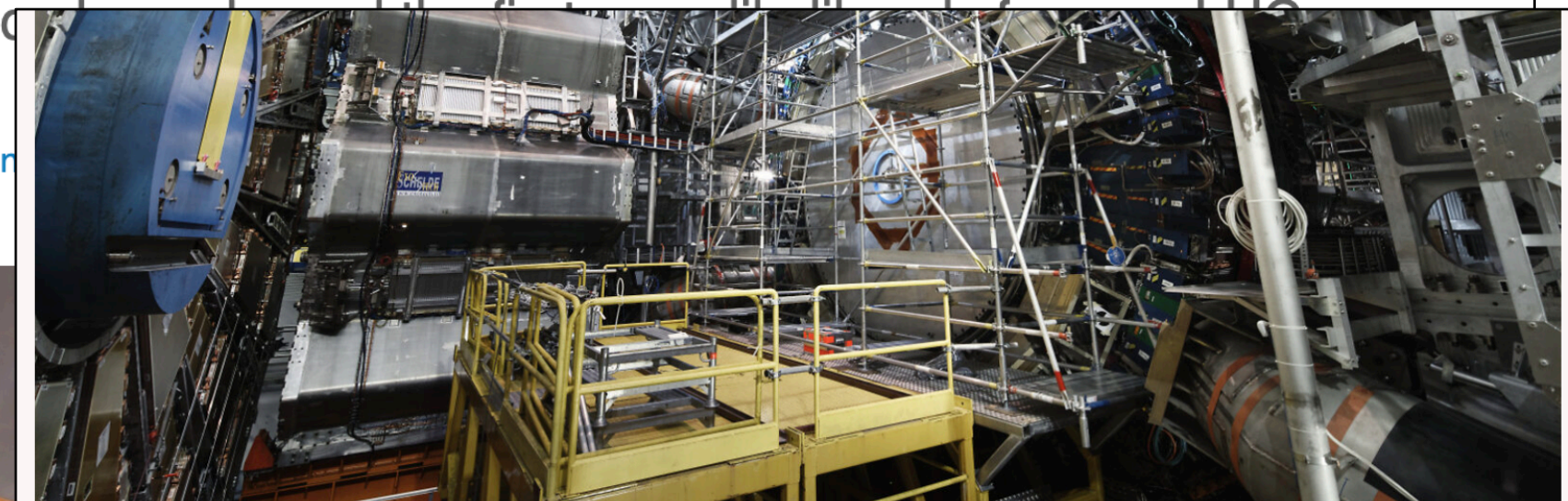
Any disagreement? Carried unanimously. That's actually quite an achievement for this Workshop.

2000

New open release streamlines interactions with theoretical physicists

The ATLAS Collaboration experiment.

12th December 2019 | By Katarina



Courtesy of CERN

ATLAS releases 'full orchestra' of analysis instruments

01/14/21 | By Stephanie Melchor

The ATLAS collaboration has begun to publish likelihood functions, information that will allow researchers to better understand and use their experiment's data in future analyses.

Meyrin, Switzerland, sits serenely near the Swiss-French border, surrounded by green fields and the beautiful Rhône river. But a hundred meters beneath the surface, protons traveling at nearly the speed of light collide and create spectacular displays of subatomic fireworks inside the experimental detectors of the Large Hadron Collider at CERN, the European particle physics laboratory.

One detector, called ATLAS, is five stories tall and has the largest volume of any particle detector in the world. It captures the trajectory of particles from collisions that happen a billion times a second and measures their energy and momentum. Those collisions produce incredible amounts of data for researchers to scour, searching for

2020

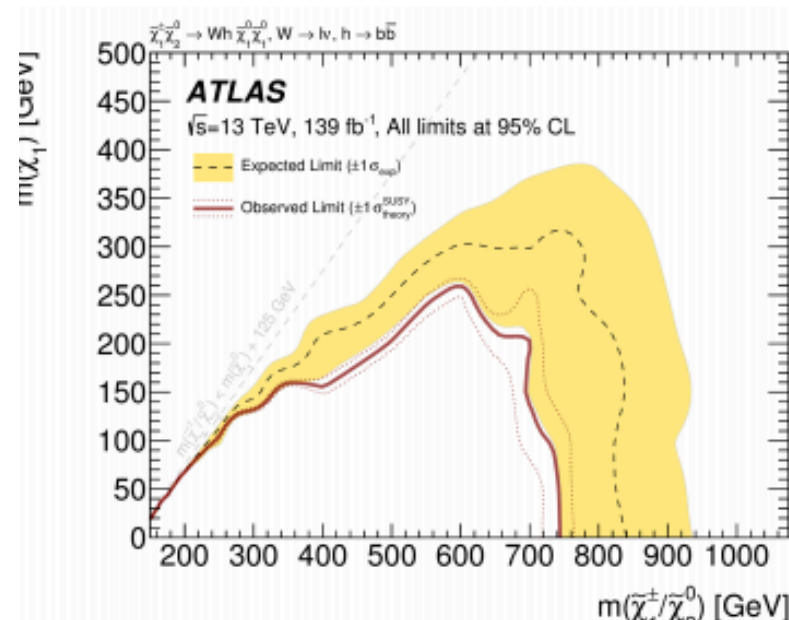
It's all on HepData and citable

Published Statistical Models

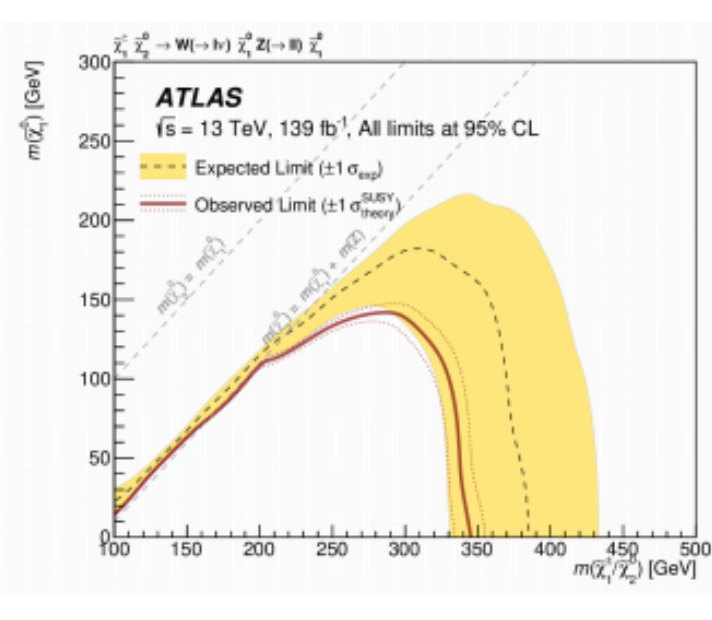
Updating list of HEPData entries for publications using [HistFactory](#) JSON statistical models:

- Search for bottom-squark pair production with the ATLAS detector in final states containing Higgs bosons, $b\bar{b}$ -jets 2019. URL: <https://doi.org/10.17182/hepdata.89408>, doi:10.17182/hepdata.89408.
- Search for chargino-neutralino production with mass splittings near the electroweak scale in three-lepton final states with the ATLAS detector. 2019. URL: <https://doi.org/10.17182/hepdata.91127>, doi:10.17182/hepdata.91127.
- Search for direct stau production in events with two hadronic τ -leptons in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector. 2020. URL: <https://doi.org/10.17182/hepdata.92006>, doi:10.17182/hepdata.92006.
- Search for direct production of electroweakinos in final states with one lepton, missing transverse momentum and jets in (pp) collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector. 2020. URL: <https://doi.org/10.17182/hepdata.90607.v2>, doi:10.17182/hepdata.90607.v2.
- Search for displaced leptons in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector. 2020. URL: <https://doi.org/10.17182/hepdata.98796>, doi:10.17182/hepdata.98796.
- Search for squarks and gluinos in final states with same-sign leptons and jets using 139 fb^{-1} of data collected with the ATLAS detector. 2020. URL: <https://doi.org/10.17182/hepdata.91214.v3>, doi:10.17182/hepdata.91214.v3.
- Search for trilepton resonances from chargino and neutralino pair production in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector. 2020. URL: <https://doi.org/10.17182/hepdata.99806>, doi:10.17182/hepdata.99806.
- Search for squarks and gluinos in final states with jets and missing transverse momentum using 139 fb^{-1} of $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector. 2021. URL: <https://doi.org/10.17182/hepdata.95664>, doi:10.17182/hepdata.95664.

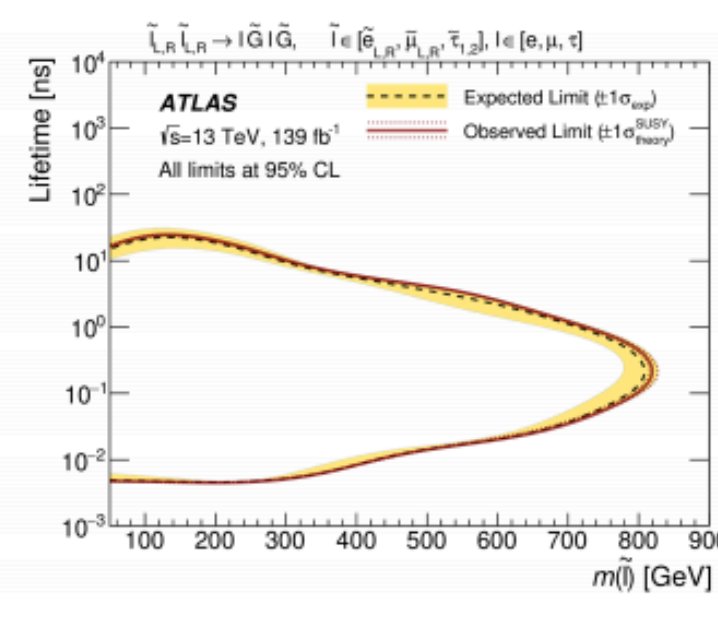
DOI 10.17182/hepdata.90607.v3



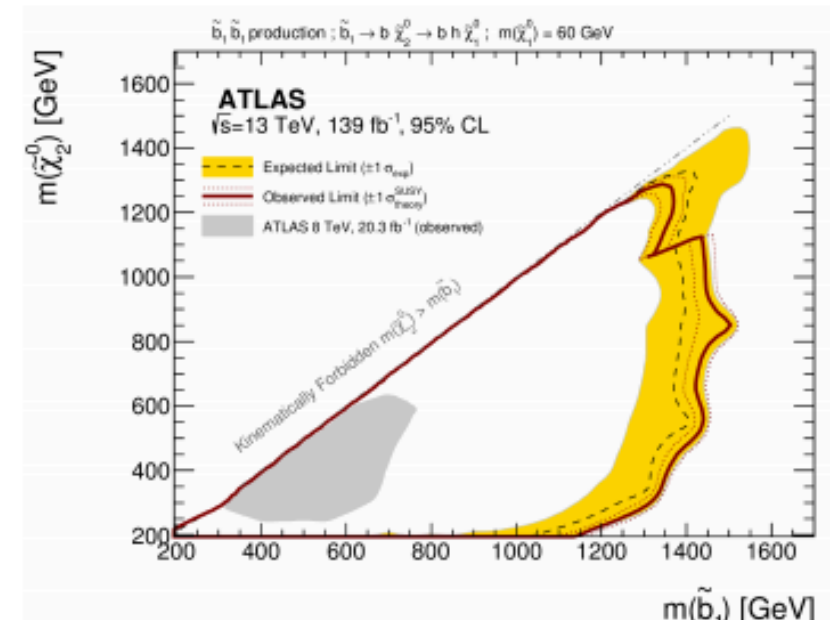
DOI 10.17182/hepdata.91127.v2



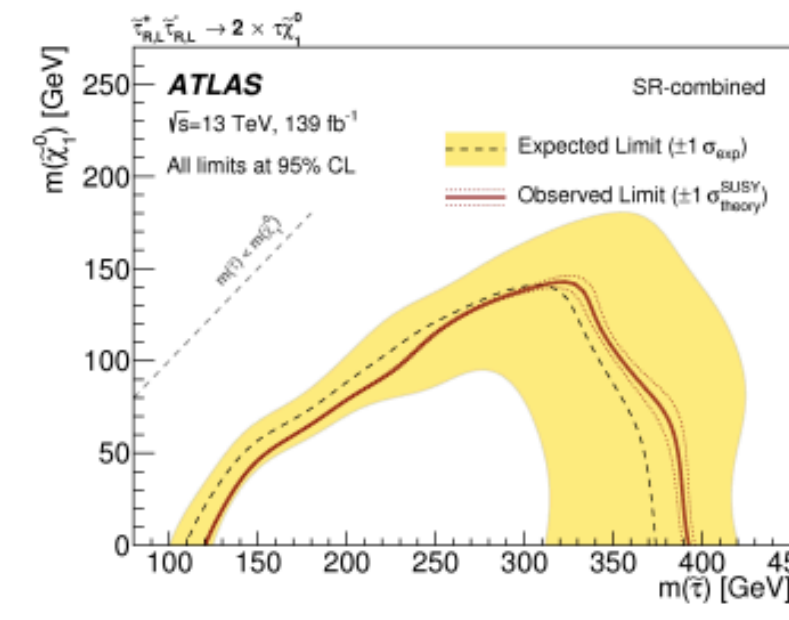
DOI 10.17182/hepdata.98796.v2



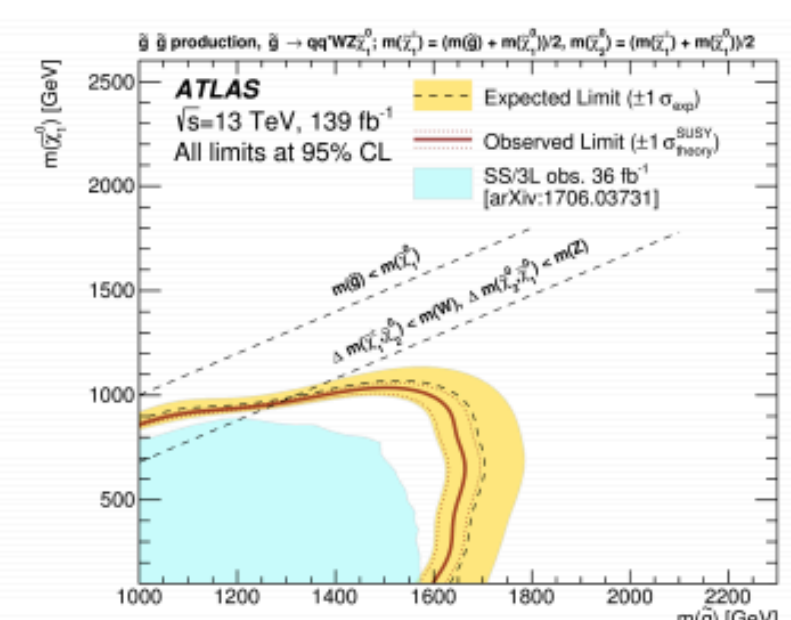
DOI 10.17182/hepdata.89408.v2



DOI 10.17182/hepdata.92006.v2



DOI 10.17182/hepdata.91214.v3



Can reproduce results very quickly with a few lines of Python

```

import json
import cabinetry
import pyhf
from cabinetry.model_utils import prediction
from pyhf.contrib.utils import download

# download the ATLAS bottom-squarks analysis probability models from HEPData
download("https://www.hepdata.net/record/resource/1935437?view=true", "bottom-squarks")

# construct a workspace from a background-only model and a signal hypothesis
bkg_only_workspace = pyhf.Workspace(json.load(open("bottom-squarks/RegionC/BkgOnly.json")))
patchset = pyhf.PatchSet(json.load(open("bottom-squarks/RegionC/patchset.json")))
workspace = patchset.apply(bkg_only_workspace, "sbottom_600_280_150")

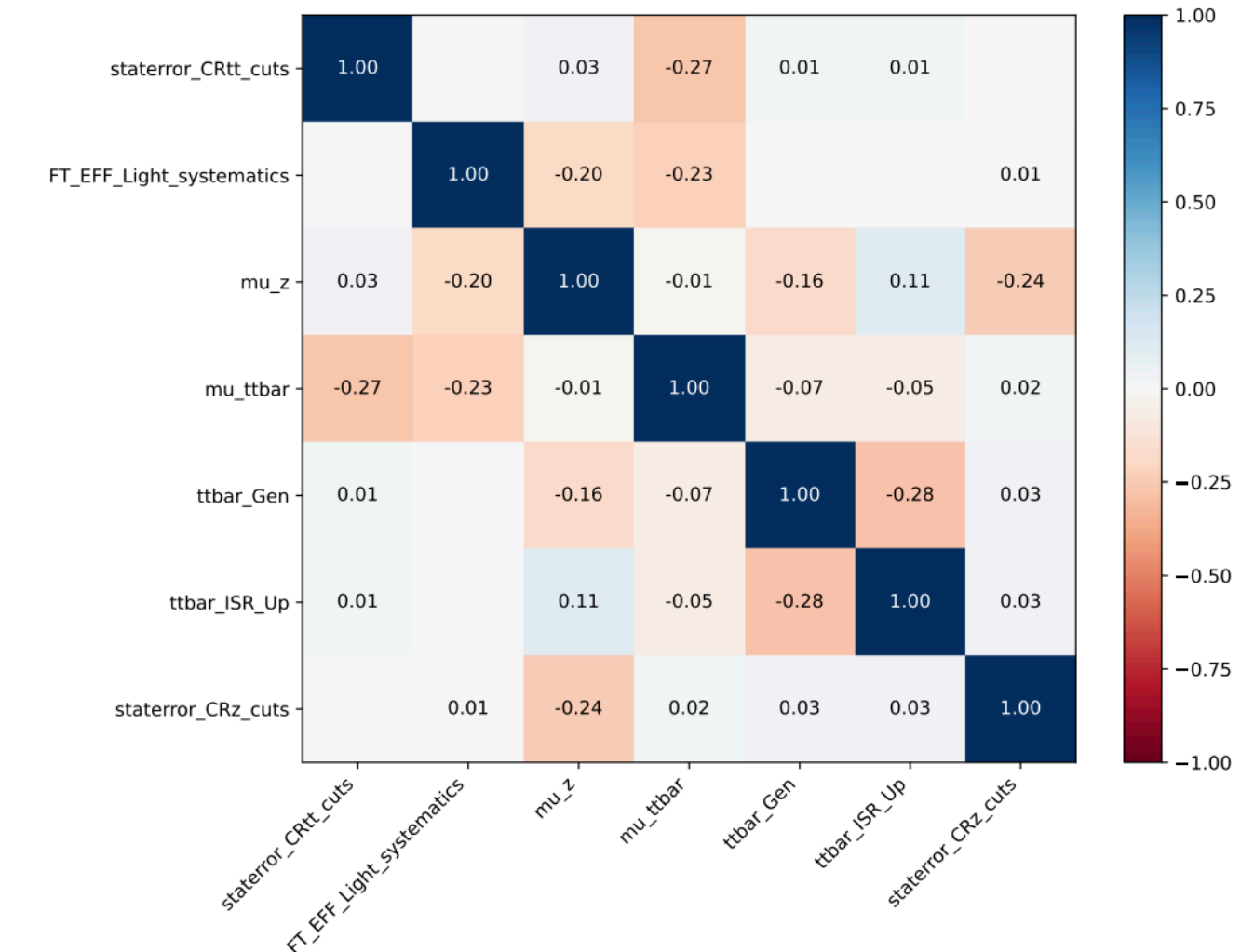
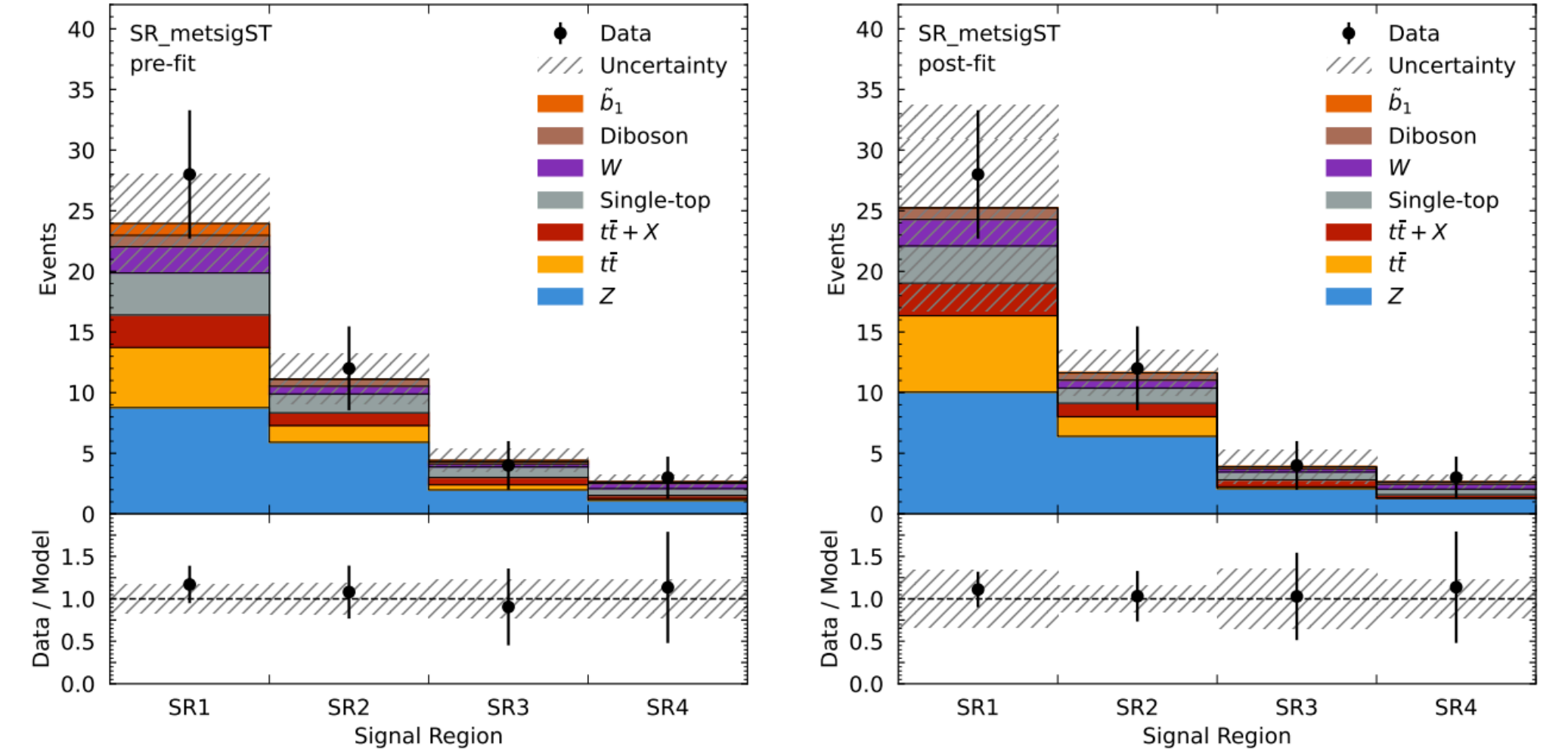
# construct the probability model and observations
model, data = cabinetry.model_utils.model_and_data(workspace)

# produce visualizations of the pre-fit model and observed data
prefit_model = prediction(model)
cabinetry.visualize.data_mc(prefit_model, data)

# fit the model to the observed data
fit_results = cabinetry.fit.fit(model, data)

# produce visualizations of the post-fit model and observed data
postfit_model = prediction(model, fit_results=fit_results)
cabinetry.visualize.data_mc(postfit_model, data)

```



Quite a bit of excitement in the community

Twitterati

Will Kinney @WKCosmo · Sep 14
So much this. Publishing full likelihood codes is already commonplace in cosmology. It's difficult to overestimate the impact this has had.

Kyle Cranmer @KyleCranmer · Sep 13

Dr Fiona H. Panther @FiPanther · Sep 14
This is a great call to action. A thought: if your parameter estimation, or any result for that matter, cannot be reliably reproduced and all the inputs to it are fully public (and my view is they should be after proprietary periods end) it is a problem.

Kyle Cranmer @KyleCranmer · Sep 13
A call to action for the particle physics community. For 20 years we have agreed that we should publish likelihoods. We can do it technically, and

Workshops

Publication of statistical models: hands-on workshop

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

- Overview
- Scientific Programme
- Timetable
- My Conference

The statistical models used to derive the results of experimental analyses value and are essential information for analysis preservation and reuse. In the scientific case for systematically publishing the full statistical models developments that make this practical, and illustrated by a variety of physics information on the statistical modelling can enhance the short- and long-term results.

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

Kyle Cranmer¹, Philip Bechtel⁴, Florian Chruszcz⁷, Andrea C. Nahuel Ferreiro Iachellini, Thomas Kuhr^{13,16}, Aron Knut Dundas Morã²⁰, Sekmen²², Luca Silvestri, Robert Thorne²⁷, Wolfgang

A SModelS interface for pyhf likelihoods

Gaël Alguero^a, Sabine Kraml^a, Wolfgang Waltenberger^{b,c}

^aLaboratoire de Physique Subatomique et de Cosmologie, Université Grenoble-Alpes, CNRS/IN2P3, 53 Avenue des Martyrs, F-38026 Grenoble, France

^bInstitut für Hochenergiephysik, Österreichische Akademie der Wissenschaften,

Papers

Postdoc position in research data infrastructure technologies

LMU Munich · Europe

hep-ex PostDoc

🕒 **Deadline on Nov 30, 2021**

Jobs(!)

Job description:

The Experimental Particle Physics Groups at the Ludwig-Maximilians-Universität München (LMU) invite applications for a postdoctoral research position for four years, starting early 2022.

The LMU is involved in the construction, software development, computing, and data analysis of the ATLAS and Belle II experiments. As partners in the [PUNCH4NFDI consortium](#) both groups collaborate on advancing research data infrastructures.

The successful candidate is expected to promote the joint analysis of datasets by developing technologies and procedures for the sharing of statistical models and to connect with the community to exploit synergies. The work will be embedded in task area 3, work package 4 and task area 6, work package 4 of the PUNCH4NFDI consortium.

This talk

- Explain a bit statistical Models we do publish
some details on HistFactory, pyhf, etc...

Note: this is only what's possible now, lots of new developments & ideas during public likelihoods workshop for Combine, unbinned analyses, etc..

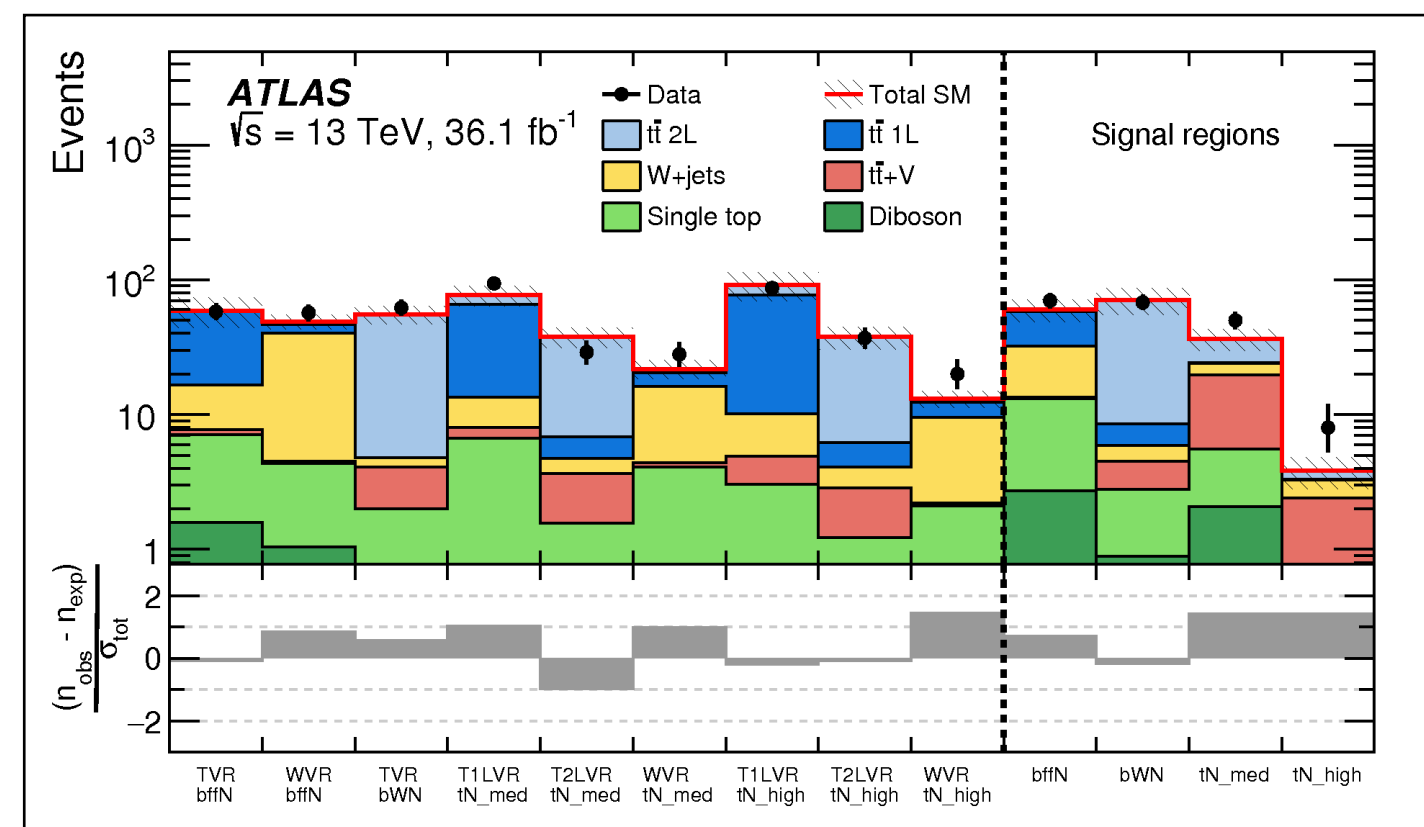
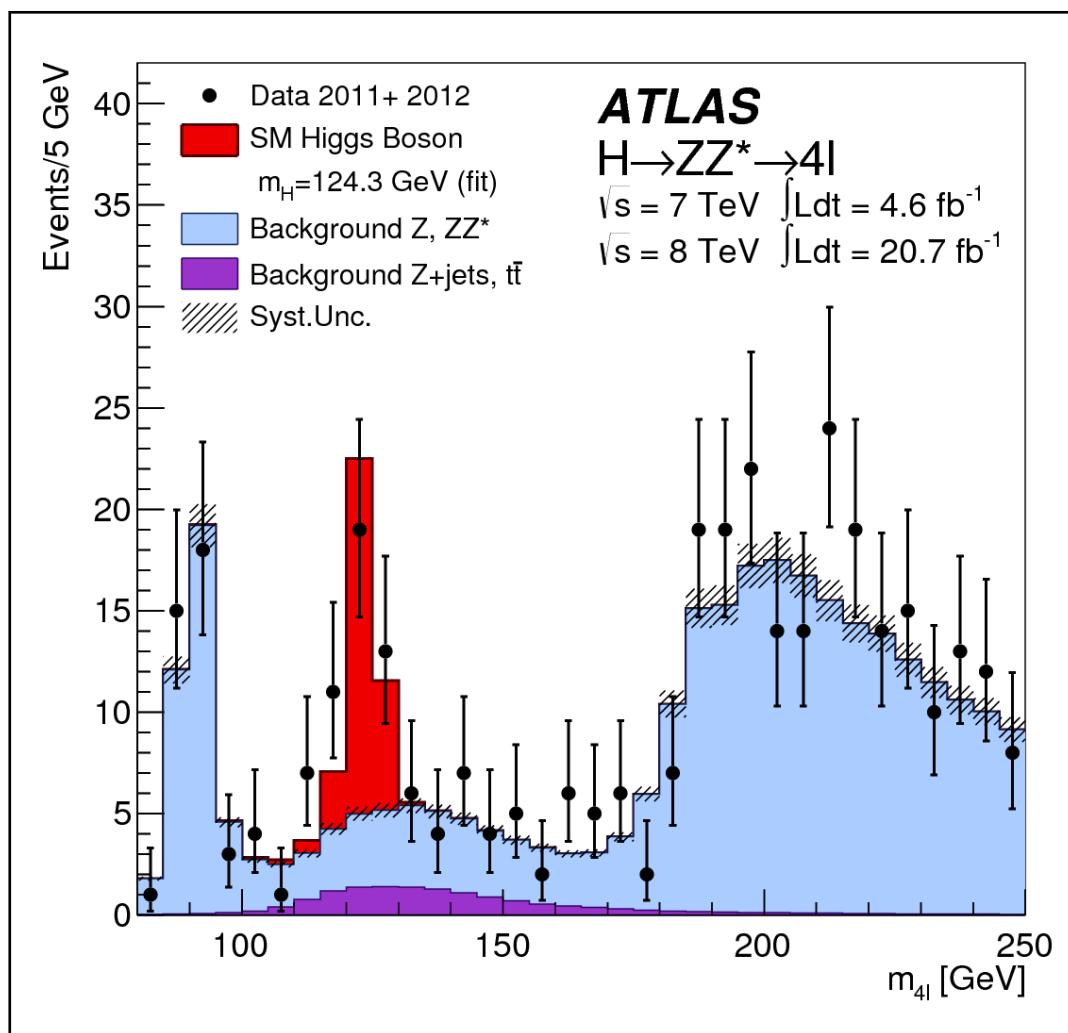
- How they can be used
 - RECAST - particularly interesting for LLP searches
 - statistical combination of multiple searches

Lightning Intro to HistFactory

HistFactory

- simultaneous **binned fits** to multiple disjoint phase space regions ("channels")
- provides **standard building blocks** for modelling simulation-based and data-driven systematics (e.g. ABCD type methods in LLP)

Very widely used in ATLAS, with additionally use in Belle-II, LHCb, Pheno ...



Charged Lepton Flavor Violation at the EIC
 arXiv: 2102.06176
EIC
 Vincenzo Cirigliano, Kaori Fuyuto, Christopher Lee, Emanuele Mereghetti, and Bin Yan
 Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.
 E-mail: cirigliano@lanl.gov, fuyuto@lanl.gov, lee@lanl.gov, emereghetti@lanl.gov, yan@lanl.gov
 acceptance, obtained from the yields of the two validation regions given in Ref. [63]. We then used signal and background events in a likelihood analysis using `pyhf` [66], obtaining³
 $BR(t \rightarrow qe\tau) \leq 2.2 \cdot 10^{-4}$. (6.10)

Sensitivity of Future Hadron Colliders to Leptoquark Pair Production in the Di-Muon Di-Jets Channel
 arXiv: 1911.04455
FCC
 B. C. Allanach¹, Tyler Corbett², Maeve Madigan^{3,1}
¹DAMTP, Univ. of Cambridge, Cambridge, U.K.
²The Niels Bohr Institute, Copenhagen, Denmark
³INFN, Padova, Italy
 fixed μ . The upper limit at 95% CL on μ is then given by the value of μ at which $CL_s = 0.05$. We compute the CL_s values using `pyhf` [64], a Python implementation of the `pyhf` package [64].

Search for $B^+ \rightarrow K^+ \mu^+ \nu$ decays using an inclusive tagging method at Belle II
 arXiv: 2104.12624
Belle-II
 F. Abudinén,^{1,2} I. Adachi,^{2,1,3} K. Adamczyk,^{6,6} P. Ahlbum,⁴ N. Anzures,^{1,2} D. M. Asner,² H. Atmacan,^{1,6} T. Aushev,⁵ P. Baillon,^{1,6} Sw. Banerjee,^{1,6} S. Banerjee,^{7,7} J. Barak,^{1,6} E. Bernieri,^{1,6} F. U. Bernlochner,⁸ M. Bertemes,^{1,6} E. Bertoni,^{1,6} T. Bilka,^{1,6} D. Blythe,^{1,6} A. Boock,^{1,6} M. Brada,^{1,6} P. Brau,^{1,6} S. Brusaferri,^{1,6} M. Campajola,^{1,6} L. Cao,^{1,6} G. Casarosa,^{1,6} et al.
 The statistical analysis to determine the signal yields is performed with the `pyhf` package [42, 43], which constructs a binned likelihood following the HistFactory [44] formalism. The templates for the yields of the signal and the seven background processes are derived from sim-

Lepton Flavor Violation and Dilepton Tails at the LHC
 arXiv: 2002.05684
LHC BSM
 Andrei Angelescu,^{1,*} Darius A. Faroughy,^{2,1} and Oleg Samsonov^{3,4,1}
¹Department of Physics, University of Illinois at Chicago, Chicago, IL 60607, USA
²Department of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA
³Department of Physics, University of Michigan, Ann Arbor, MI 48106, USA
⁴Department of Physics, University of California, San Diego, La Jolla, CA 92037, USA
 respective tight signal region selection is applied. The systematic uncertainty on the background is estimated as described in the previous sections, and ranges from about 20% at low invariant masses to about 50% at high invariant masses. The limits are then performed as counting experiment with the `pyhf` package [51]. The results are shown in Fig. 21 for [41]. For High Luminosity (HL) projections, we repeated the

How to discover QCD Instantons at the LHC¹
 arXiv: 2012.09120
LHC QCD
 Simone Amoroso^a, Deepak Kar^b, and Maarten van Leeuwen^c
^aDESY, Hamburg, Germany
^bDepartment of Physics, University of Illinois at Chicago, Chicago, IL 60607, USA
^cDepartment of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA
 respective tight signal region selection is applied. The systematic uncertainty on the background is estimated as described in the previous sections, and ranges from about 20% at low invariant masses to about 50% at high invariant masses. The limits are then performed as counting experiment with the `pyhf` package [51]. The results are shown in Fig. 21 for [41]. For High Luminosity (HL) projections, we repeated the

Hunting wino and higgsino dark matter at the muon collider with disappearing tracks
 arXiv:2102.11292
μ-Collider
 Rodolfo Capdevilla,^{a,b} and Federico Bazzucchi^a
^aDepartment of Physics, University of Illinois at Chicago, Chicago, IL 60607, USA
^bDepartment of Physics, University of Wisconsin-Madison, Madison, WI 53706, USA
 prediction in SR_{μ} has been reduced to 10%. The discovery significance is evaluated from the expected discovery p -value, while limits are set at 95% CL using the CLs method [91] with the `pyhf` software package [92, 93]. Additional lines show the sensitivity of the conservative scenario inflating the background estimates by an order of magnitude. The sensitivity is

Search for chargino-neutralino pair production in final states with three leptons and missing transverse momentum in $\sqrt{s} = 13 \text{ TeV}$ pp collisions with the ATLAS detector
 arXiv:2106.01676
ATLAS
 The statistical analysis to determine the signal yields is performed with the `pyhf` package [42, 43], which constructs a binned likelihood following the HistFactory [44] formalism. The templates for the yields of the signal and the seven background processes are derived from sim-

Lightning Intro to HistFactory

An Example from LLP community

PHYSICAL REVIEW D **99**, 052005 (2019)

Search for long-lived particles produced in pp collisions that decay into displaced hadronic jets in the ATLAS detector

M. Aaboud *et al.**
(ATLAS Collaboration)

(Received 21 November 2018; published 15 May 2019)

A search for the decay of neutral, weakly interacting, long-lived particles produced in pp collisions at the LHC is presented. The analysis in this paper uses collision data at $\sqrt{s} = 13$ TeV recorded in 2015–2016. The search employs vertices of long-lived particles decaying into jets in the muon spectrometer and a novel technique that requires only one vertex in association with a displaced jet that improves the sensitivity for longer lifetimes. The observed numbers of events, the expected background and limits for several benchmark signals are determined.

DOI: 10.1103/PhysRevD.99.052005

I. INTRODUCTION

The discovery of the Higgs boson at the LHC completed the Standard Model (SM) of elementary particles and focused attention on the many central features of our universe that the SM does not address: dark matter, neutrino mass, matter-antimatter asymmetry (baryogenesis), and the hierarchy problem (naturalness). Many beyond the Standard Model (BSM) theoretical constructs proposed in the past few years that address these phenomena predict the existence of long-lived particles (LLPs) with macro-

scopic lifetimes produced in collisions at $\sqrt{s} = 13$ TeV and LHCb collisions more recently by the ATLAS [35]. To date, no neutral LLPs.

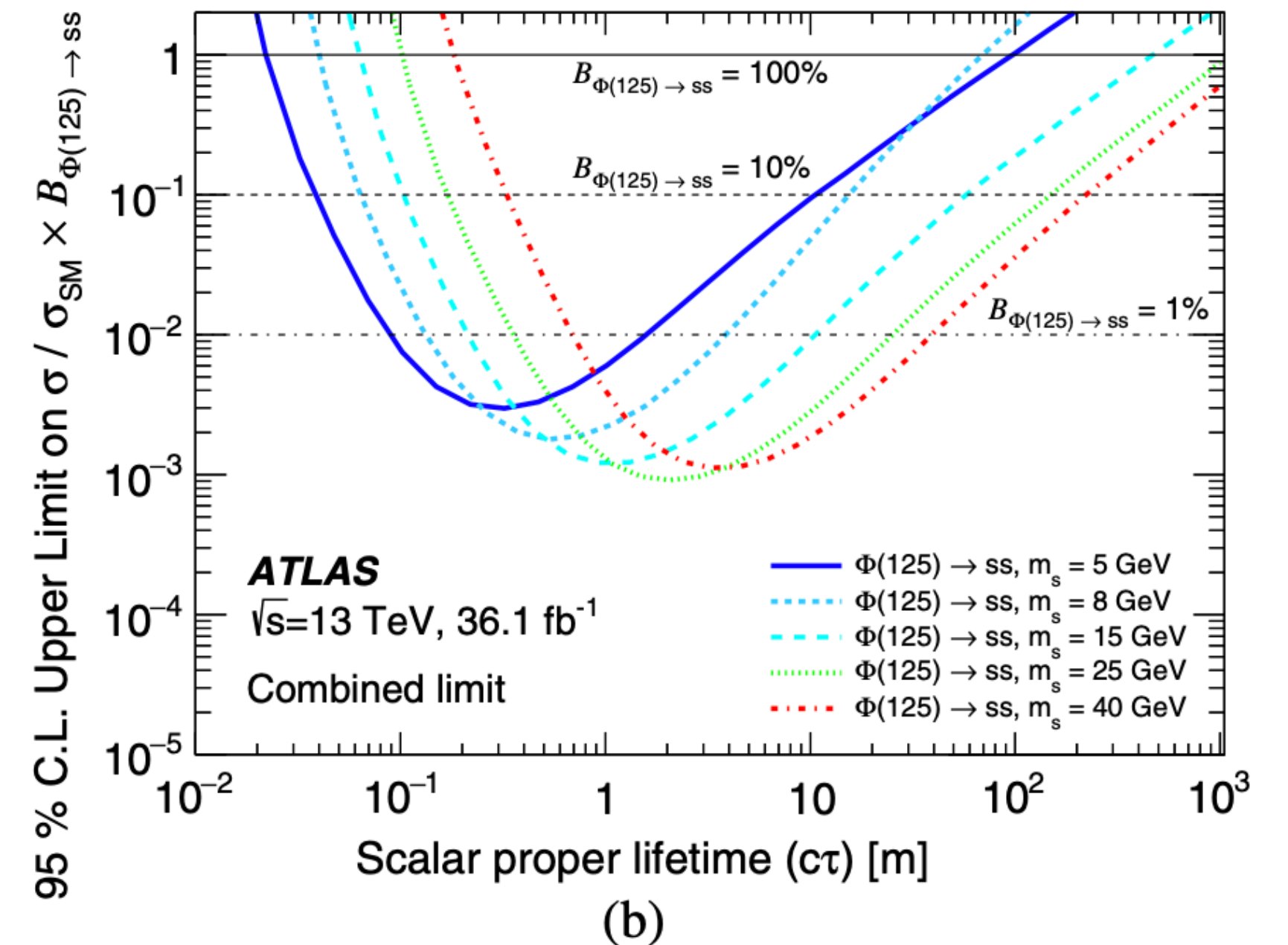
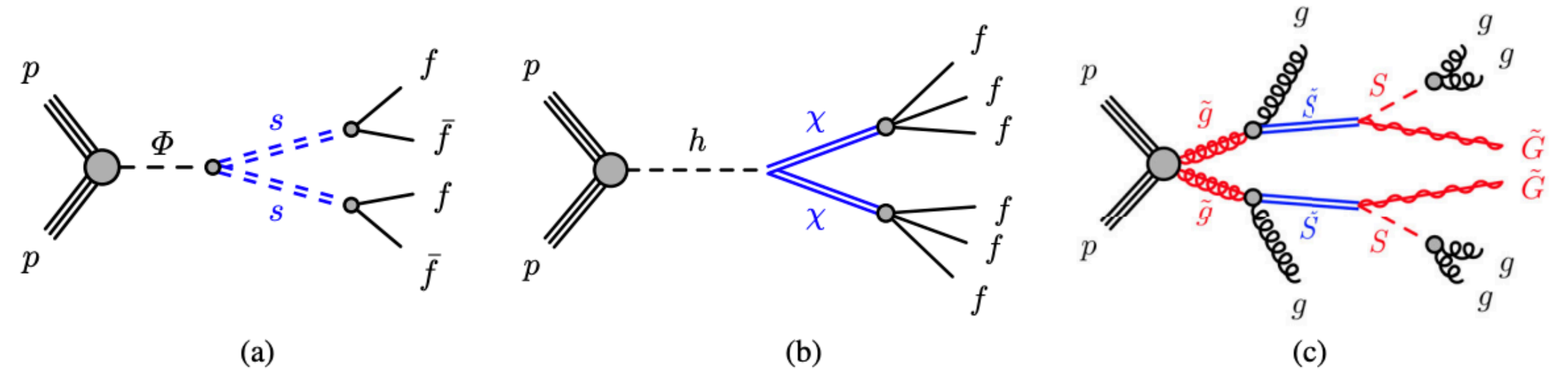
This paper describes the search for long-lived particles produced in proton-proton collisions at $\sqrt{s} = 13$ TeV during 2015–2016 at the LHC during 2015–2016.

XI. RESULTS

For the 2MSVx strategy, 0.027 ± 0.011 background events are expected. After unblinding, no events passing the full signal selection were found.

For the 1MSVx+AO strategies, the number of observed events in the four regions of the ABCD plane and the background prediction in region A for events passing the SR selection are summarized in Table XI. No significant excess above the predicted number of background events is found.

Upper limits on the production cross section times branching fraction were derived using the CL_s prescription [78], implemented with the ROOSTAT [79] and HISTFACTORY [80] packages using a profile likelihood function [81]. For the 2MSVx and 1MSVx+Jets strategies the likelihood includes a Poisson probability term describing the total number of observed events. For the 1MSVx + E_T^{miss} strategy the likelihood described in Sec. IX B 2 was used. For scalar boson benchmark samples with $m_\Phi \neq 125$ GeV, upper limits were set on $\sigma \times B$, where B represents the branching fraction for $\Phi \rightarrow ss$ assuming 100% branching fraction into fermion pairs. For scalar boson benchmark samples with $m_\Phi = 125$ GeV, upper limits were set on $\sigma/\sigma_{\text{SM}} \times B$, where σ_{SM} is the SM Higgs boson production cross section, 48.58 pb [82]. For the stealth SUSY benchmarks, upper limits were set on $\sigma/\sigma_{\text{SUSY}} \times B$, where σ_{SUSY} is the SUSY production cross



Lightning Intro to HistFactory

HistFactory

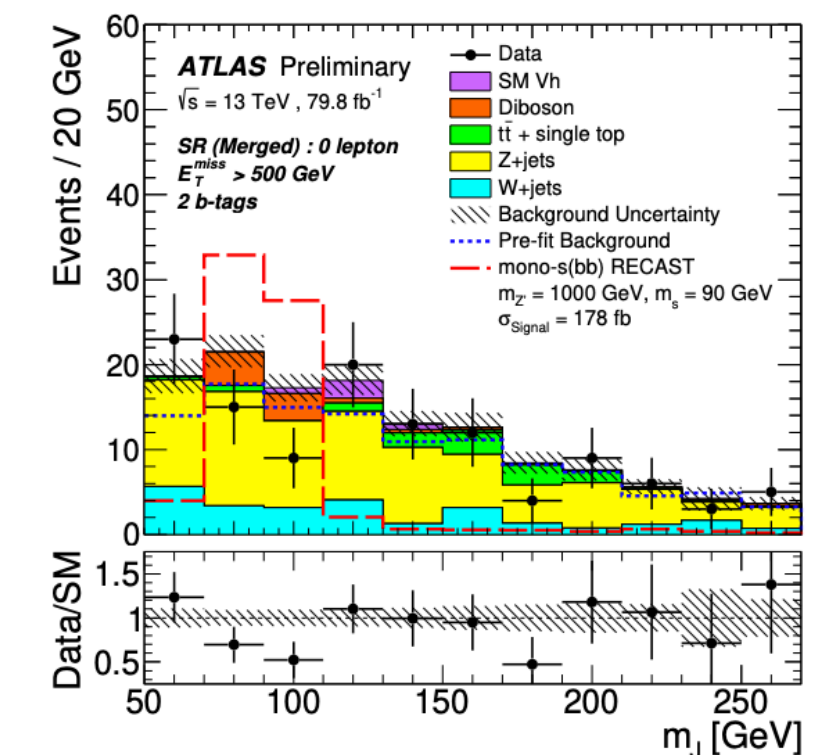
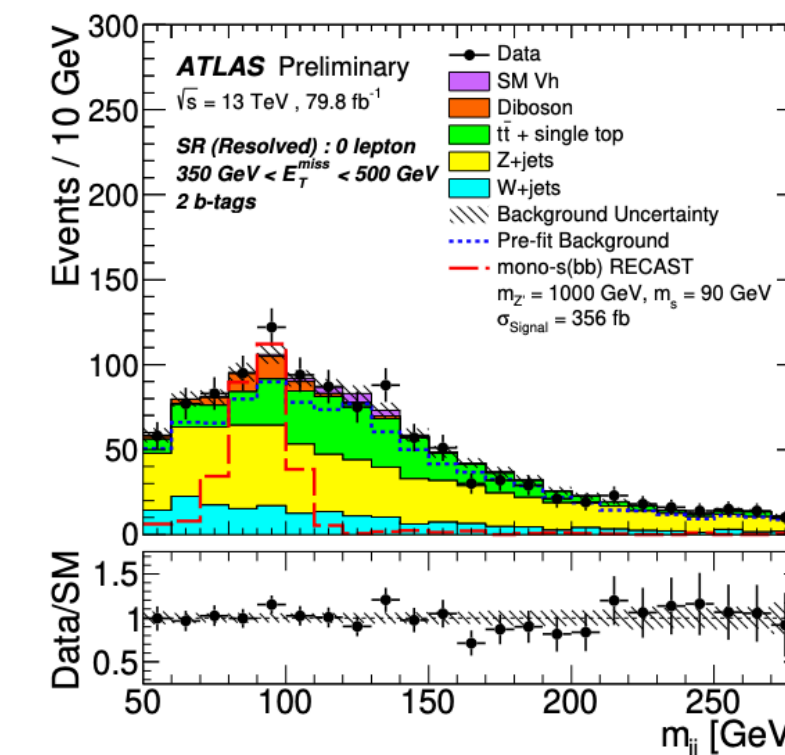
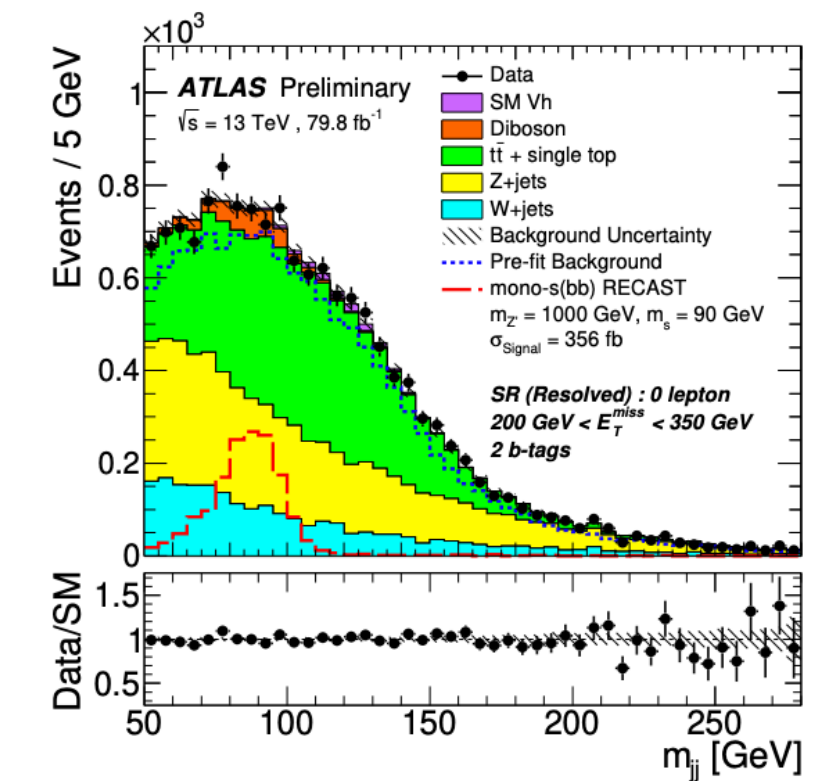
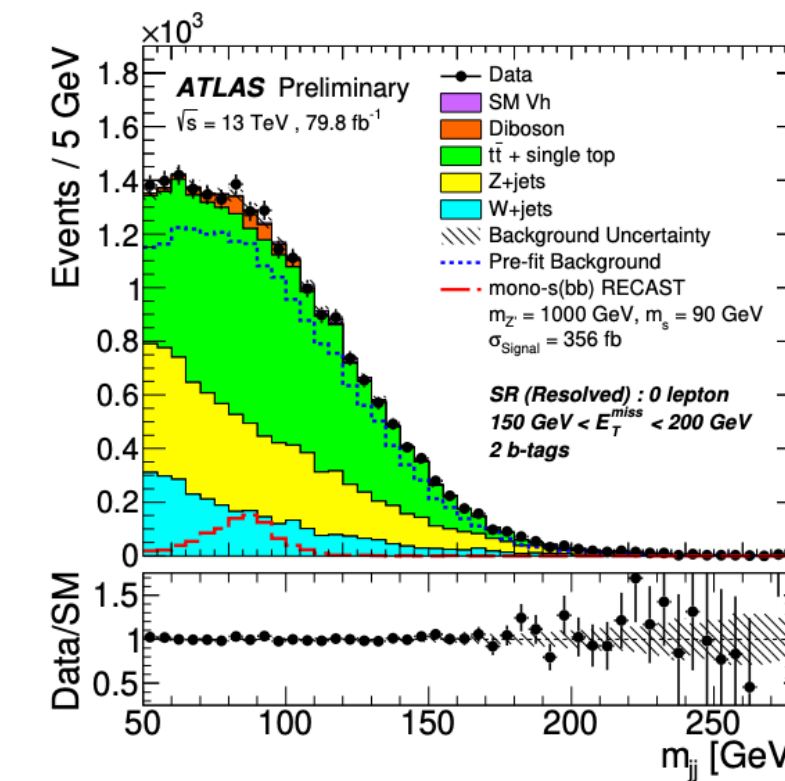
- simultaneous binned fits to multiple disjoint phase space regions ("channels")
- provides standard building blocks for systematics

$$f(n, a | \eta, \chi) = \underbrace{\prod_{c \in \text{channels}} \prod_{b \in \text{bins}_c} \text{Pois}(n_{cb} | \nu_{cb}(\eta, \chi))}_{\text{Simultaneous measurement of multiple channels}} \underbrace{\prod_{\chi \in \mathcal{X}} c_{\chi}(a_{\chi} | \chi)}_{\text{constraint terms for "auxiliary measurements"}}$$

out main analysis (joint of multiple channels)
constraint terms for systematics

$$\nu_{cb}(\phi) = \sum_{s \in \text{samples}} \nu_{scb}(\eta, \chi) = \sum_{s \in \text{samples}} \left(\prod_{i \in \vec{\kappa}} \kappa_{i,scb}(\eta, \chi) \right) \left(\nu_{scb}^0(\eta, \chi) + \sum_{j \in \vec{\Delta}} \Delta_{j,scb}(\eta, \chi) \right)$$

nominal expected yield
systematics affecting yields



Lightning Intro to HistFactory

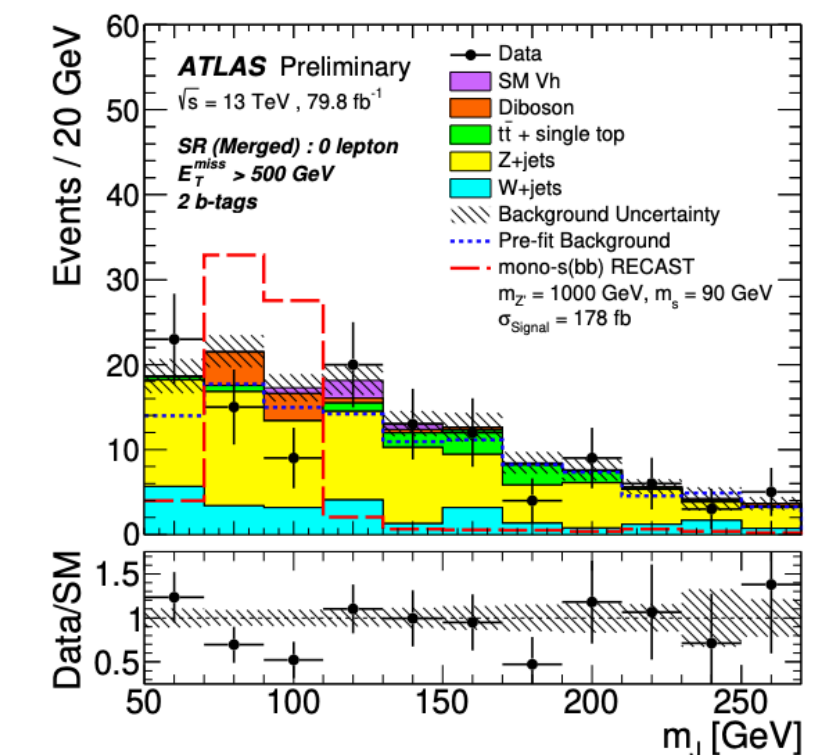
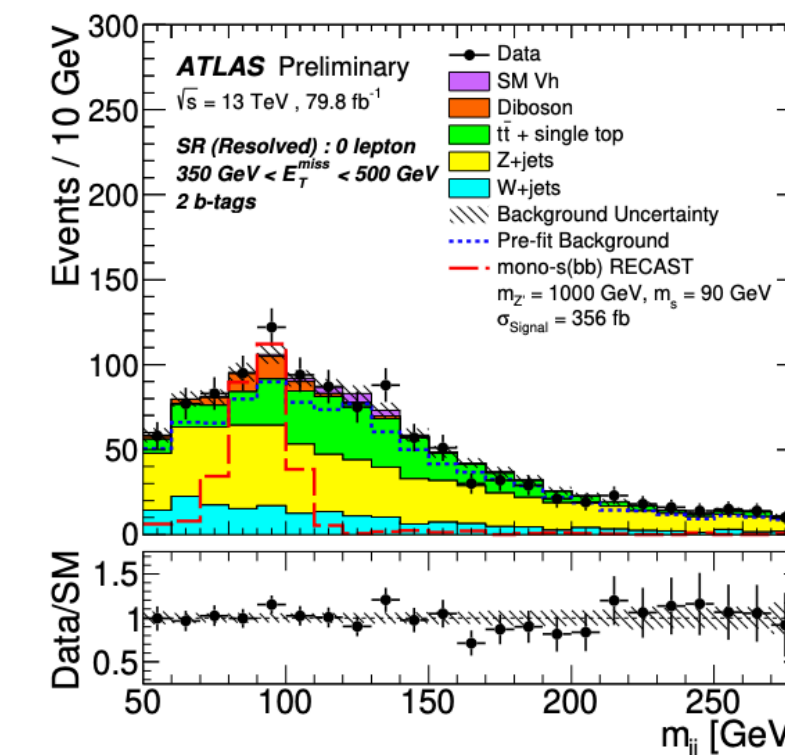
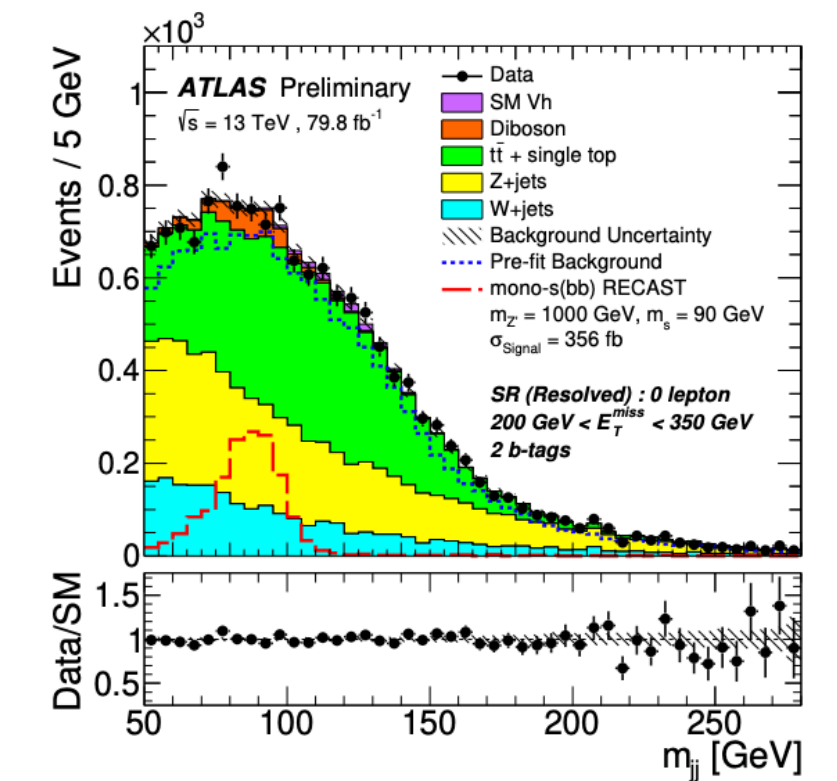
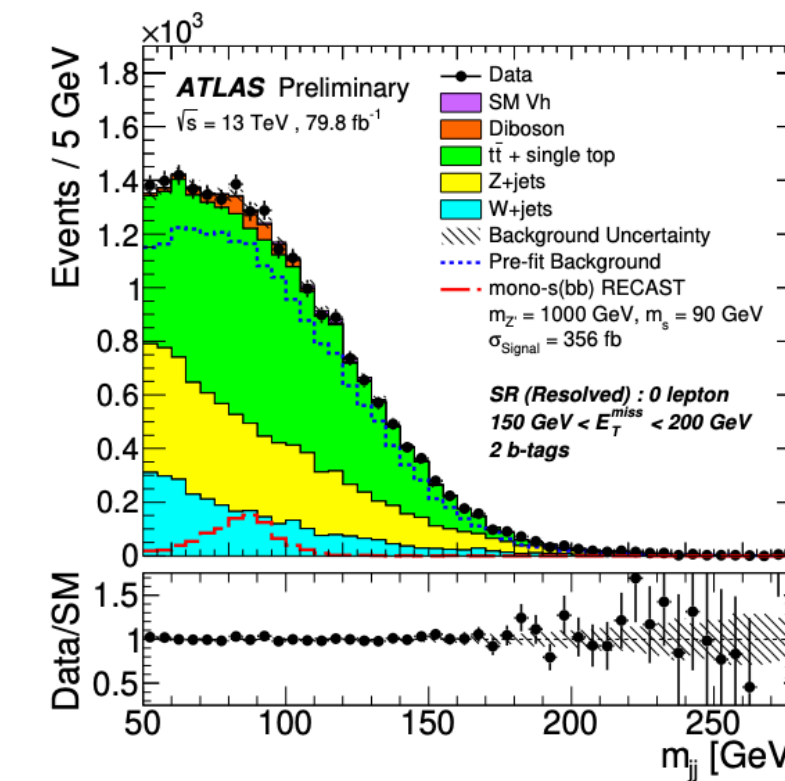
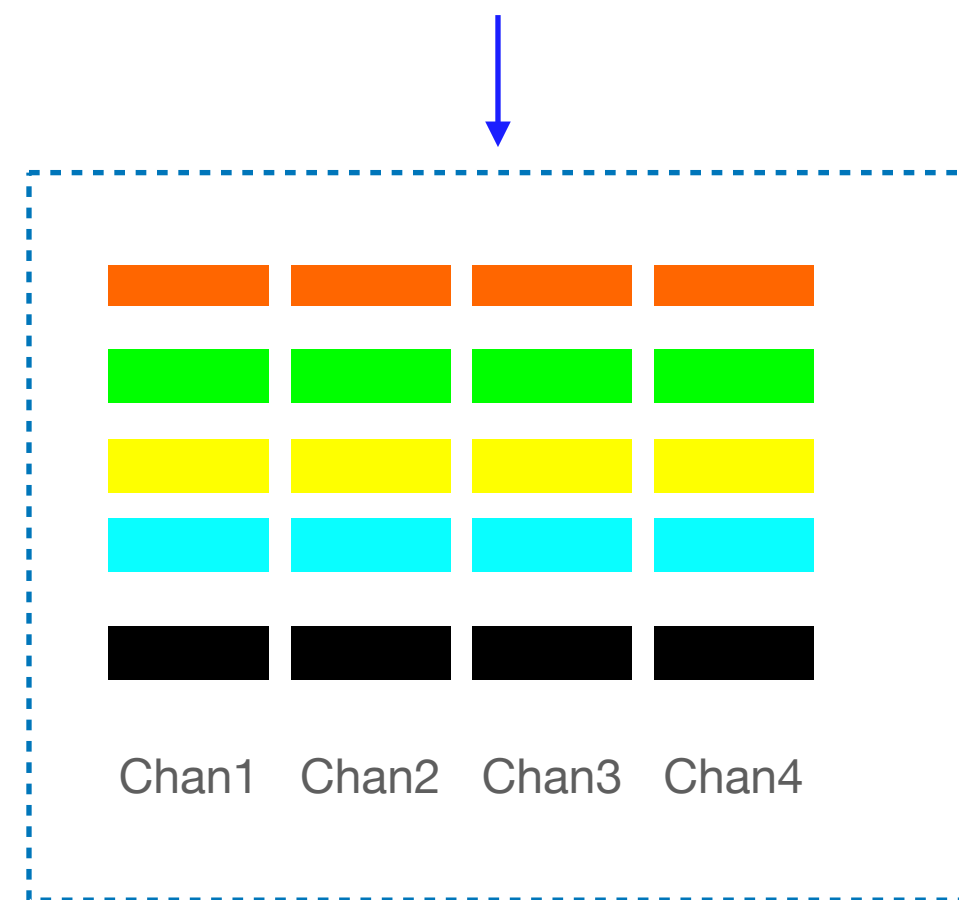
For a given HistFactory model you thus need to keep track of

- observed yields in all bins of all channels
- nominal expected yields (all bins, channels, samples)
- systematic effects on expectation

$$f(\mathbf{n}, \mathbf{a} | \boldsymbol{\eta}, \boldsymbol{\chi}) = \prod_{c \in \text{channels}} \prod_{b \in \text{bins}_c} \text{Pois}(n_{cb} | \nu_{cb}(\boldsymbol{\eta}, \boldsymbol{\chi})) \prod_{\chi \in \mathcal{X}} c_{\chi}(a_{\chi} | \boldsymbol{\chi})$$

out main analysis
(joint of multiple channels)

constraint terms
for systematics



Lightning Intro to HistFactory

For a given HistFactory model you thus need to keep track of

- observed yields in all bins of all channels
- nominal expected yields (all bins, channels, samples)
- systematic effects on expectation

We do this in a straight forward JSON Format

This is what's on HepData



```
{
  "channels": [
    {
      "name": "singlechannel",
      "samples": [
        {
          "name": "sig",
          "data": [12.0, 11.0],
          "modifiers": [
            { "name": "mu", "data": null, "type": "normfactor" }
          ]
        },
        {
          "name": "bkg",
          "data": [50.0, 52.0],
          "modifiers": [
            { "name": "uncorr_bkguncrt", "data": [3.0, 7.0], "type": "shapesys" }
          ]
        }
      ]
    }
  ],
  "data": {
    "singlechannel": [51.0, 48.0]
  },
  "toplvl": {
    "measurements": [
      {
        "config": { "poi": "mu" },
        "name": "singlechannel"
      }
    ]
  }
}
```

nominal expected

systematic effects

observed data

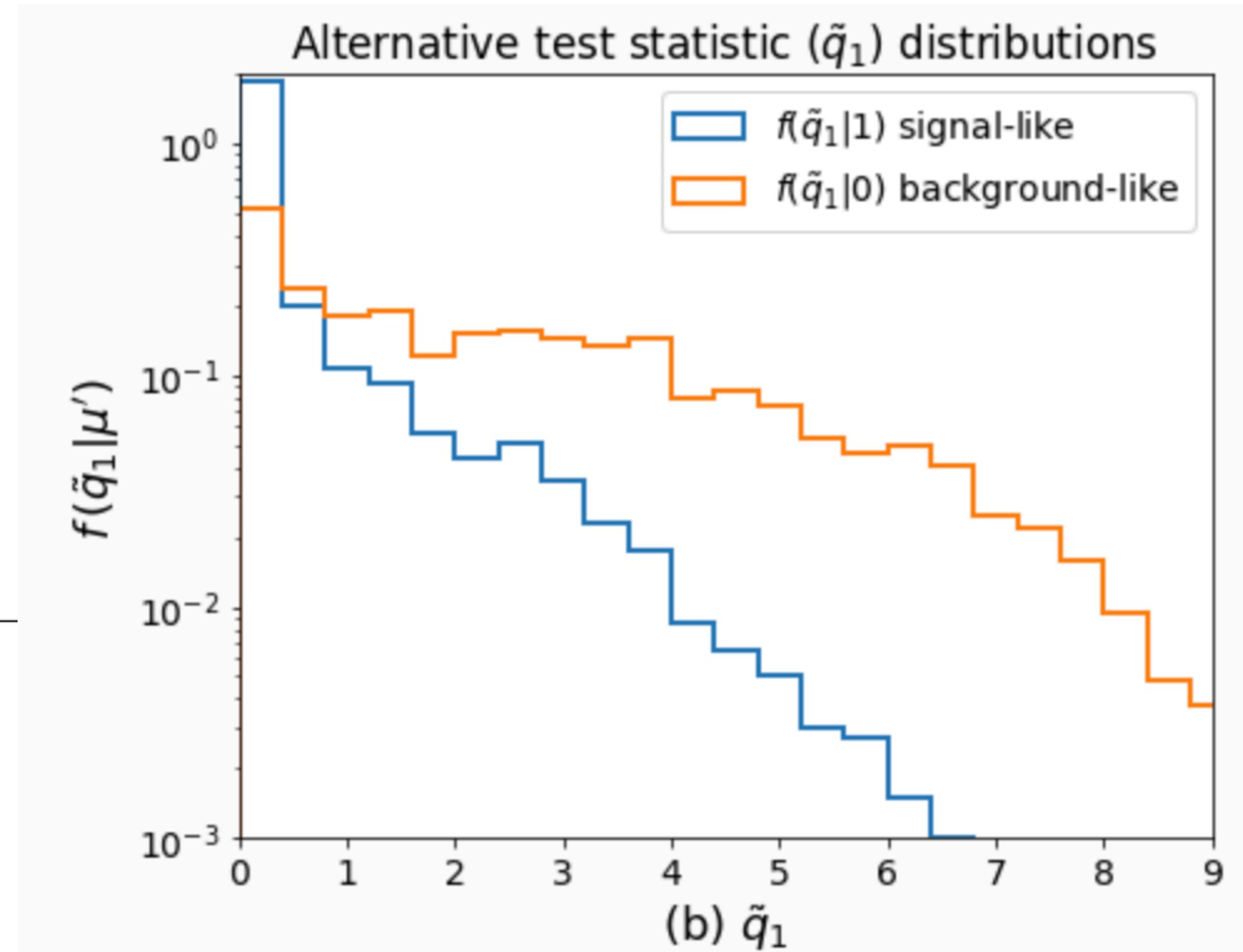
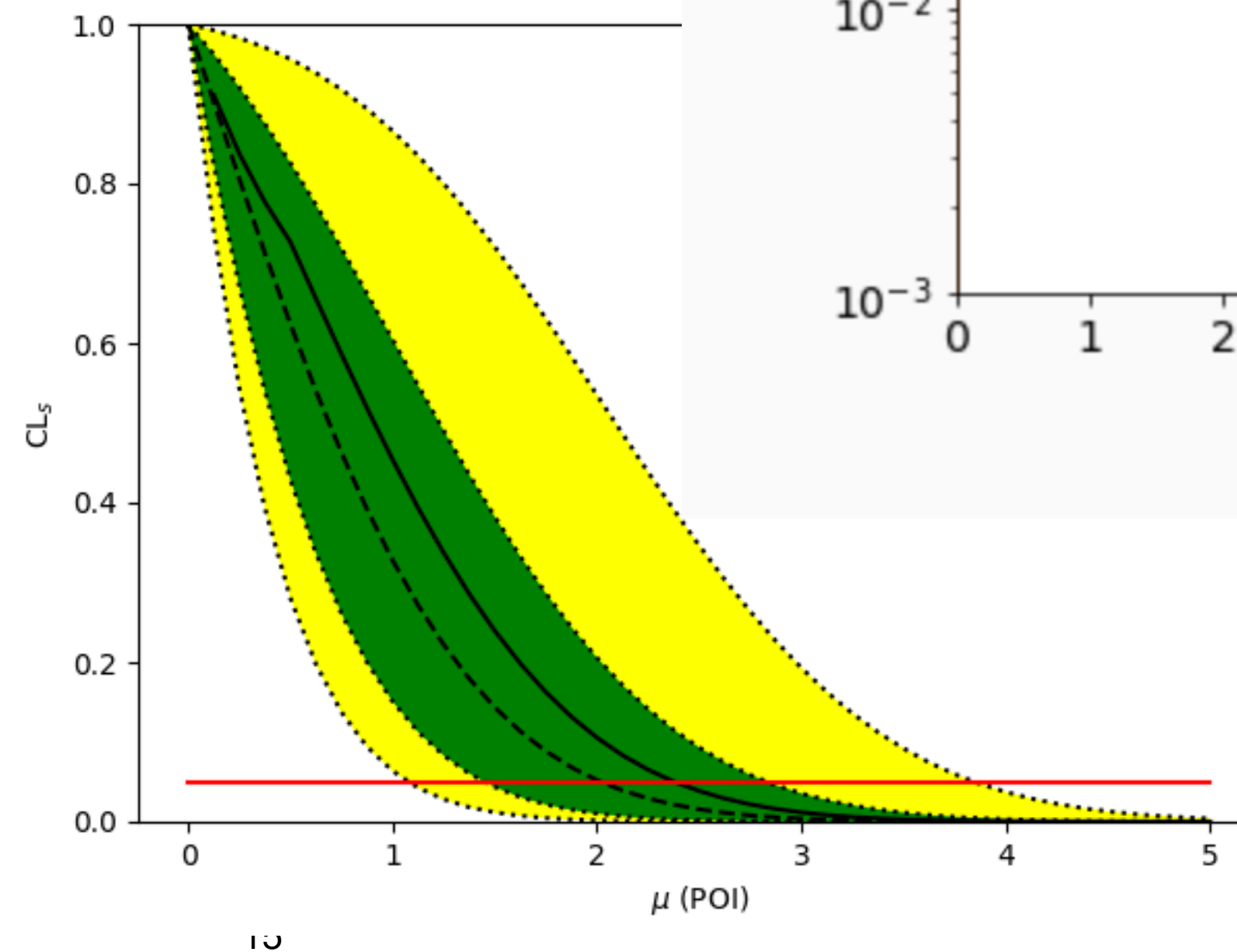
Once you have a JSON, getting limits is easy

pyhf has both asymptotic and toy-MC based inference APIs

- for low-count LLP toys can become important



```
$> pip install pyhf
$> pyhf cls workspace.json
{
  "CLs_exp": [
    0.008897411763217407,
    0.03524468002619176,
    0.1243148689002353,
    0.3514186235832989,
    0.6941411699405086
  ],
  "CLs_obs": 0.03607409335946063
}
```

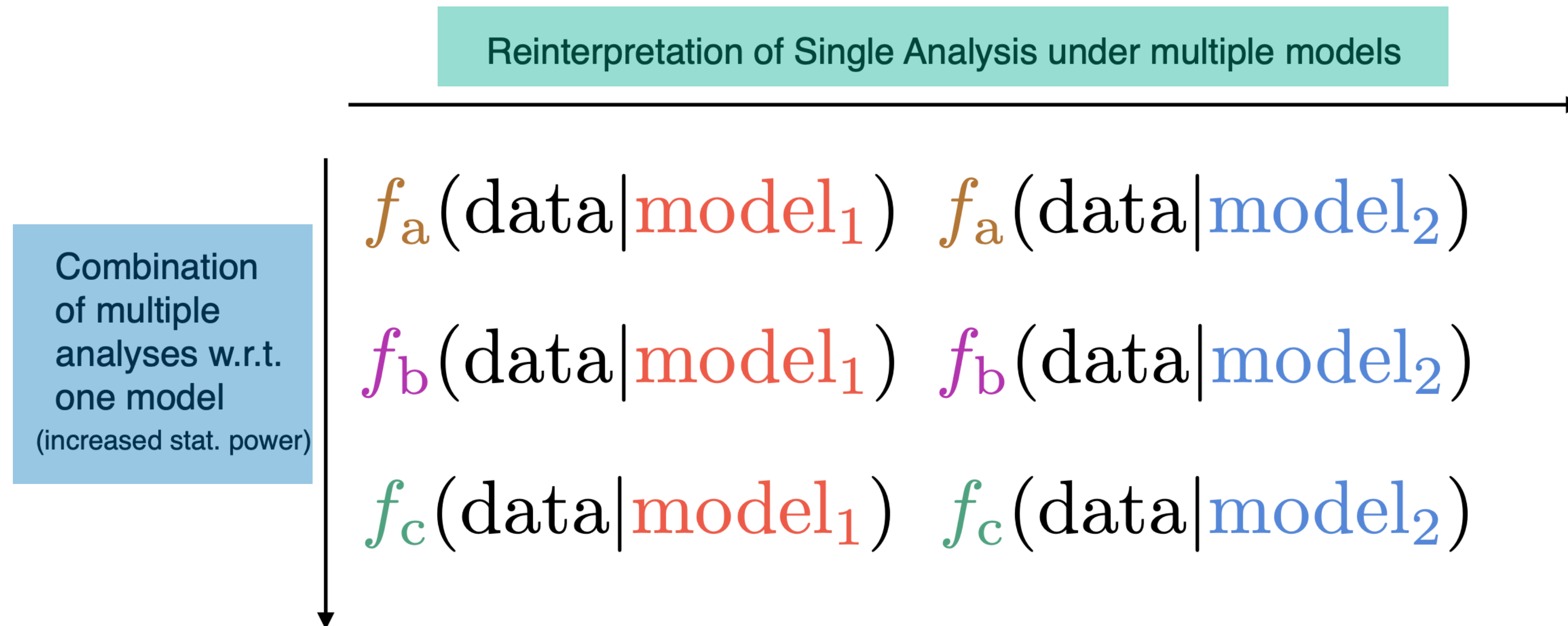


Beyond reproducing

It's great to be able reproduce results, but doesn't give us new science

- Much more exciting: reuse! This is what public L'hoods & other tools are about.

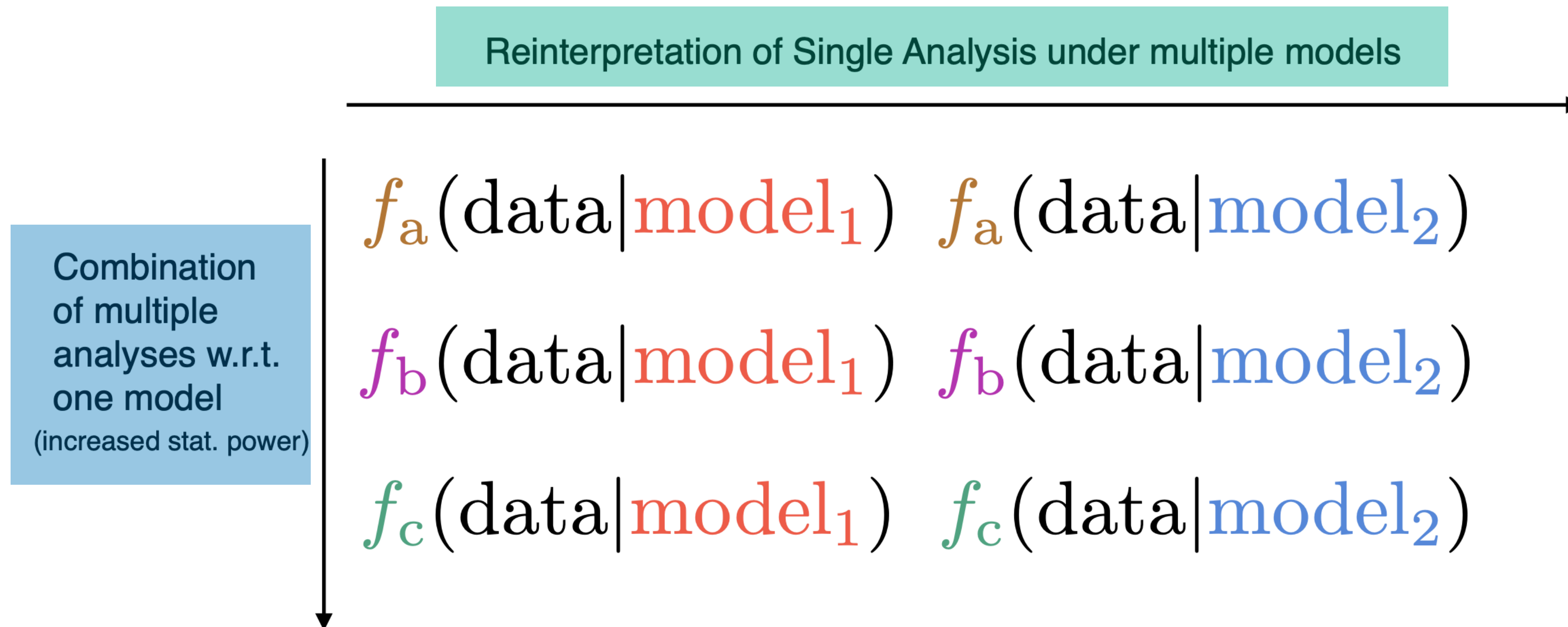
Two broad ways to reuse existing analyses: **RECAST** & **Combination**



Beyond reproducing

RECAST: modifying one likelihood into a new likelihood ("patching")

Combination: taking N likelihoods and building a new likelihood ("stitching")



RECAST

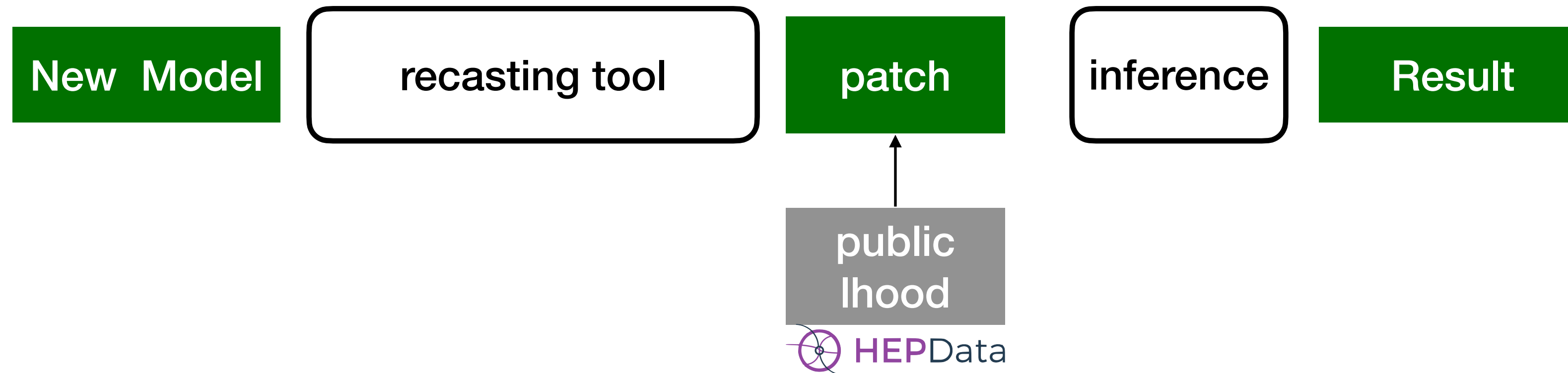
RECAST reuses almost all of the statistical model

- same data, same backgrounds, different new signals



Three Step Procedure:

- 1) compute new signal
- 2) make new L'hood
- 3) redo stat. analysis



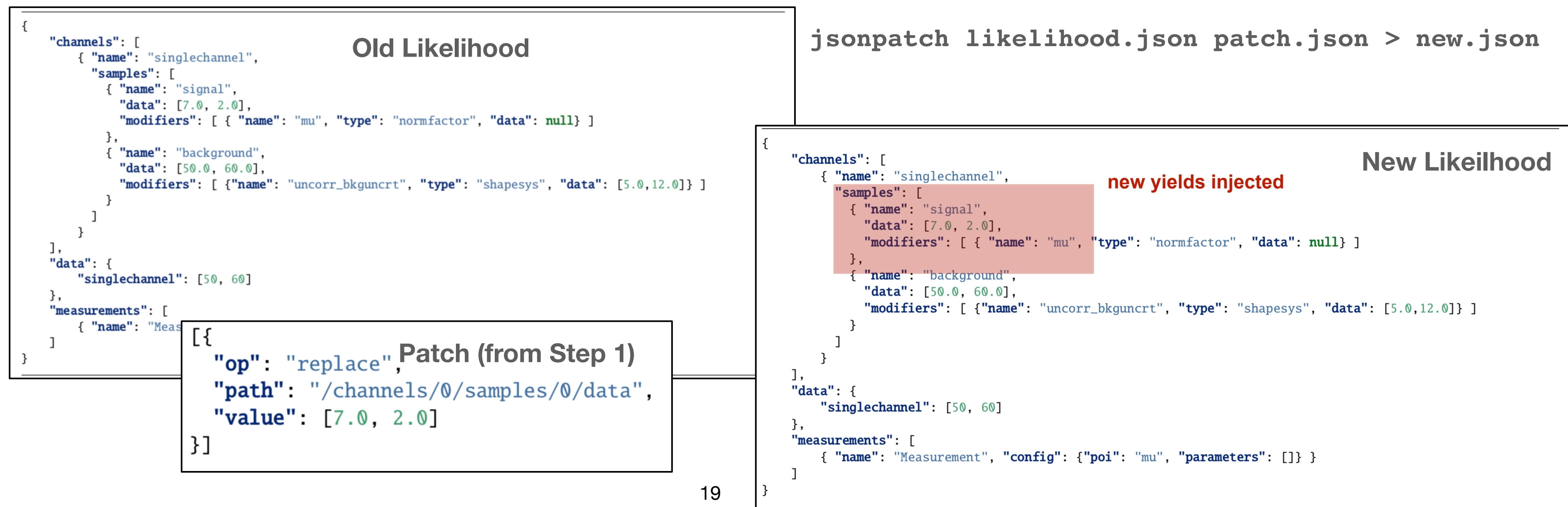
recasting = patch-generation machinery for public likelihoods

For 1) use your favorite recasting tool that gives you est. yields in analysis regions

- Note (important also for LLP), you need yields for SR and CR regions!


For 2) pyhf introduced the idea of a "JSON Patch"

- a special format for the new yields you get from recasting tool
- modifies existing likelihood to incorporate the new model
 - like a code patch "remove original signal", "add new signal"




Example from LLP

Great Example of RECAST from ATLAS w/ CalRatio Analysis

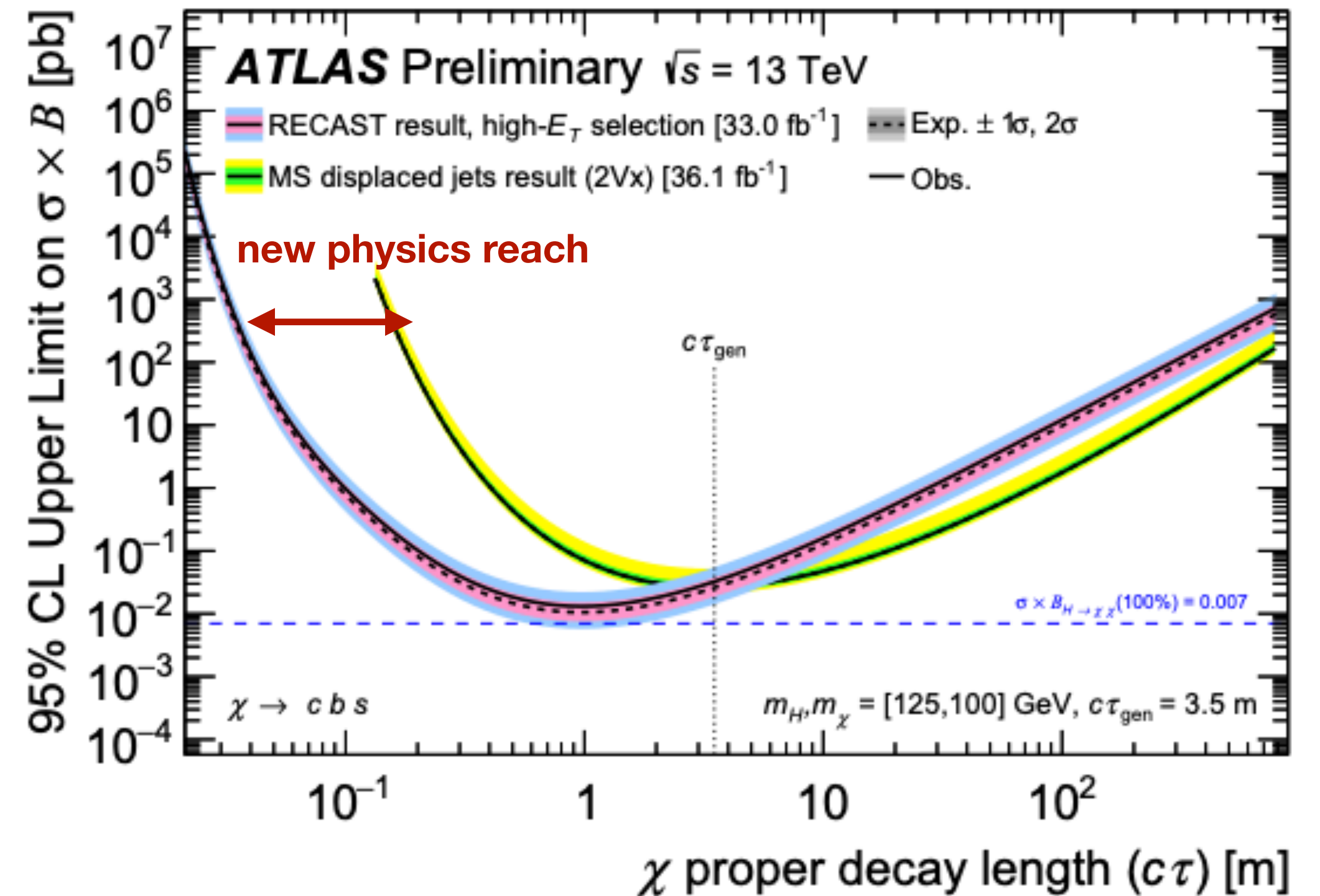
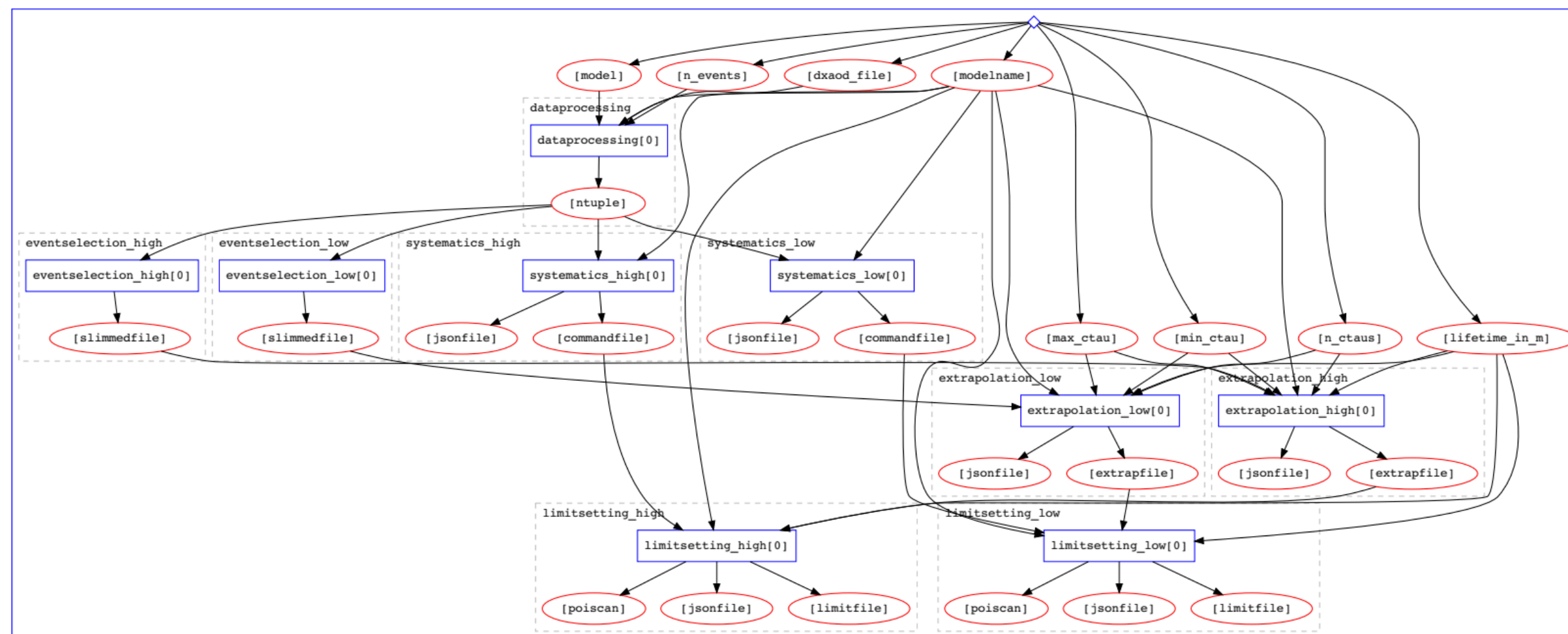


ATLAS PUB Note
ATL-PHYS-PUB-2020-007
27th March 2020



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

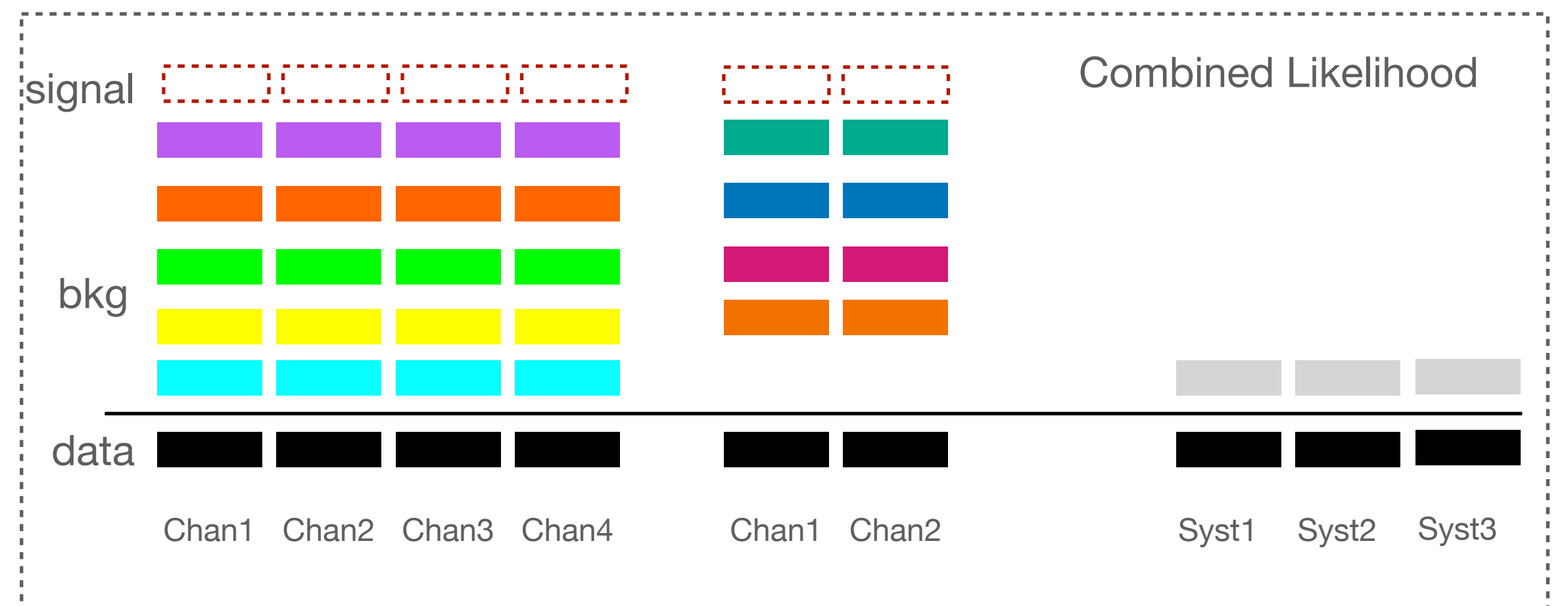
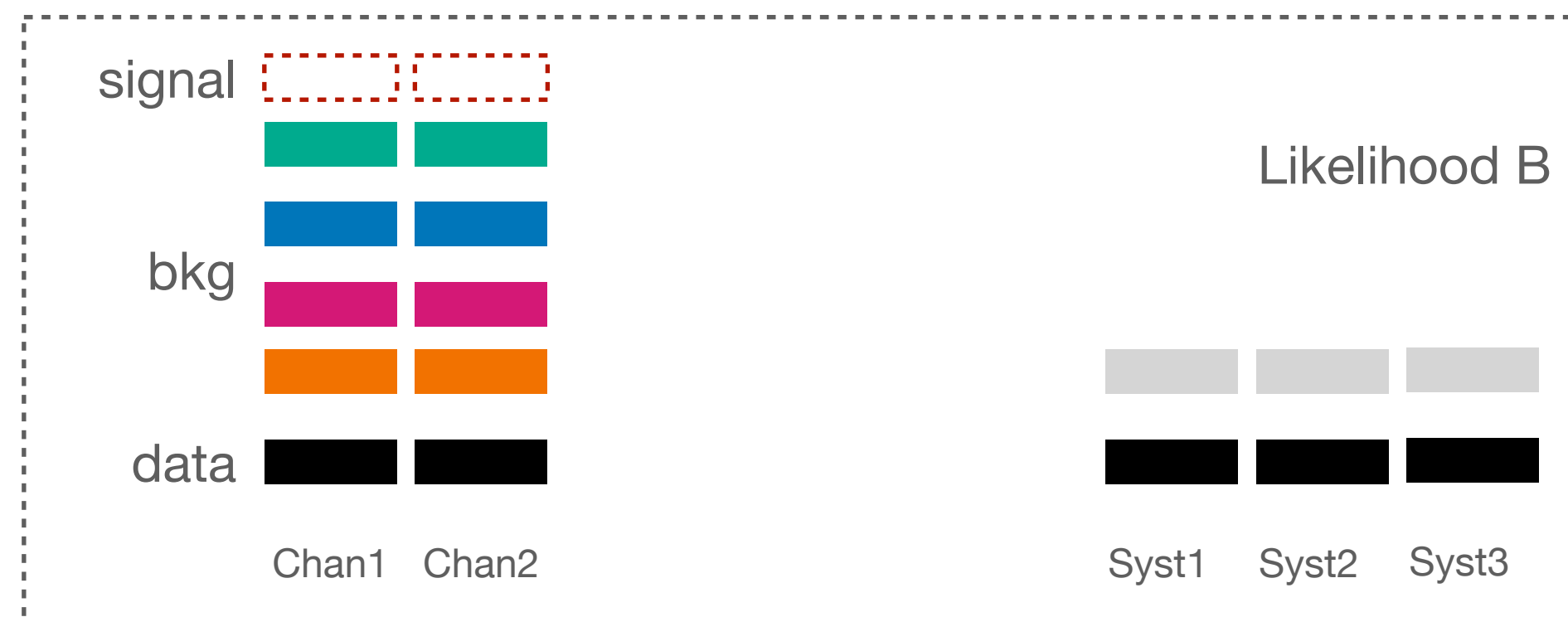
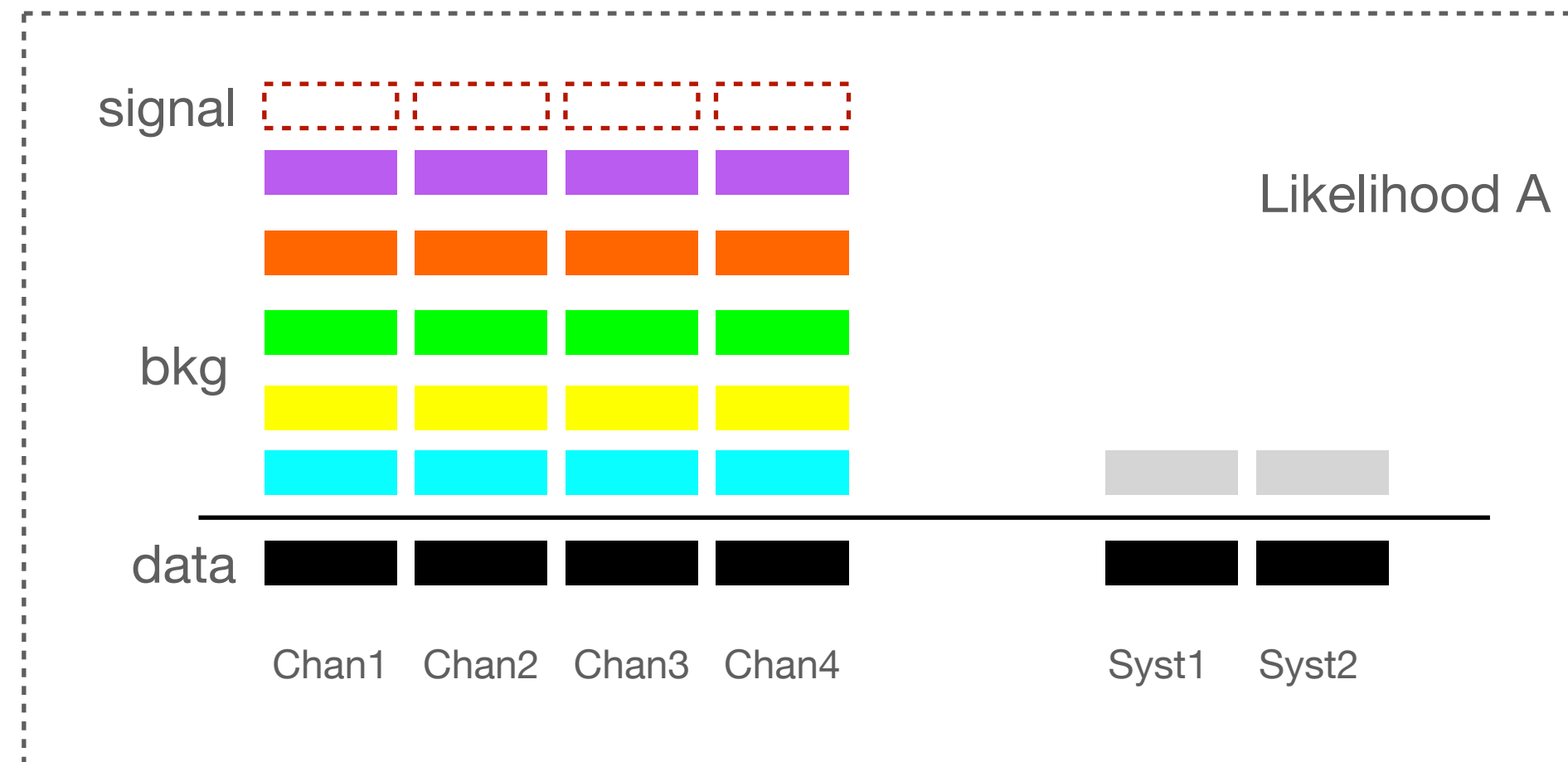
full collaboration-level RECAST important due to low-level detector inputs & lots of ML



Combinations

For combinations you need to ensure three things

- phase-space regions must be disjoint and uniquely named
- ensure consistency of nuisance parameter naming across input likelihoods
- avoidance of double counting of external constraint terms



add channels together

deduplicate constraints

Combinations

For combinations you need to ensure three things

- phase-space regions must be disjoint and uniquely named
- ensure consistency of nuisance parameter naming across input likelihoods
- avoidance of double counting of external constraint terms

pyhf provides *some* tooling, but it's not as fully-featured

- expect some manual JSON hacking for combination work
- if people want to collaborate on JSON-combiner tooling let us know

```
lukasheinrich mpb2019lheinric ~ $ pyhf combine --help
Usage: pyhf combine [OPTIONS] [WORKSPACE_ONE] [WORKSPACE_TWO]

Combine two workspaces into a single workspace.


See :func:`pyhf.workspace.Workspace.combine` for more information.


Options:
  -j, --join [none|outer|left outer|right outer]
                                The join operation to apply when combining
                                the two workspaces.
  --output-file TEXT             The location of the output json file. If not
                                specified, prints to screen.
  --merge-channels / --no-merge-channels
                                Whether or not to deeply merge channels. Can
                                only be done with left/right outer joins.
  -h, --help                     Show this message and exit.
```

Example from ATLAS SUSY:

all done with exactly the same JSONs as they are released

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

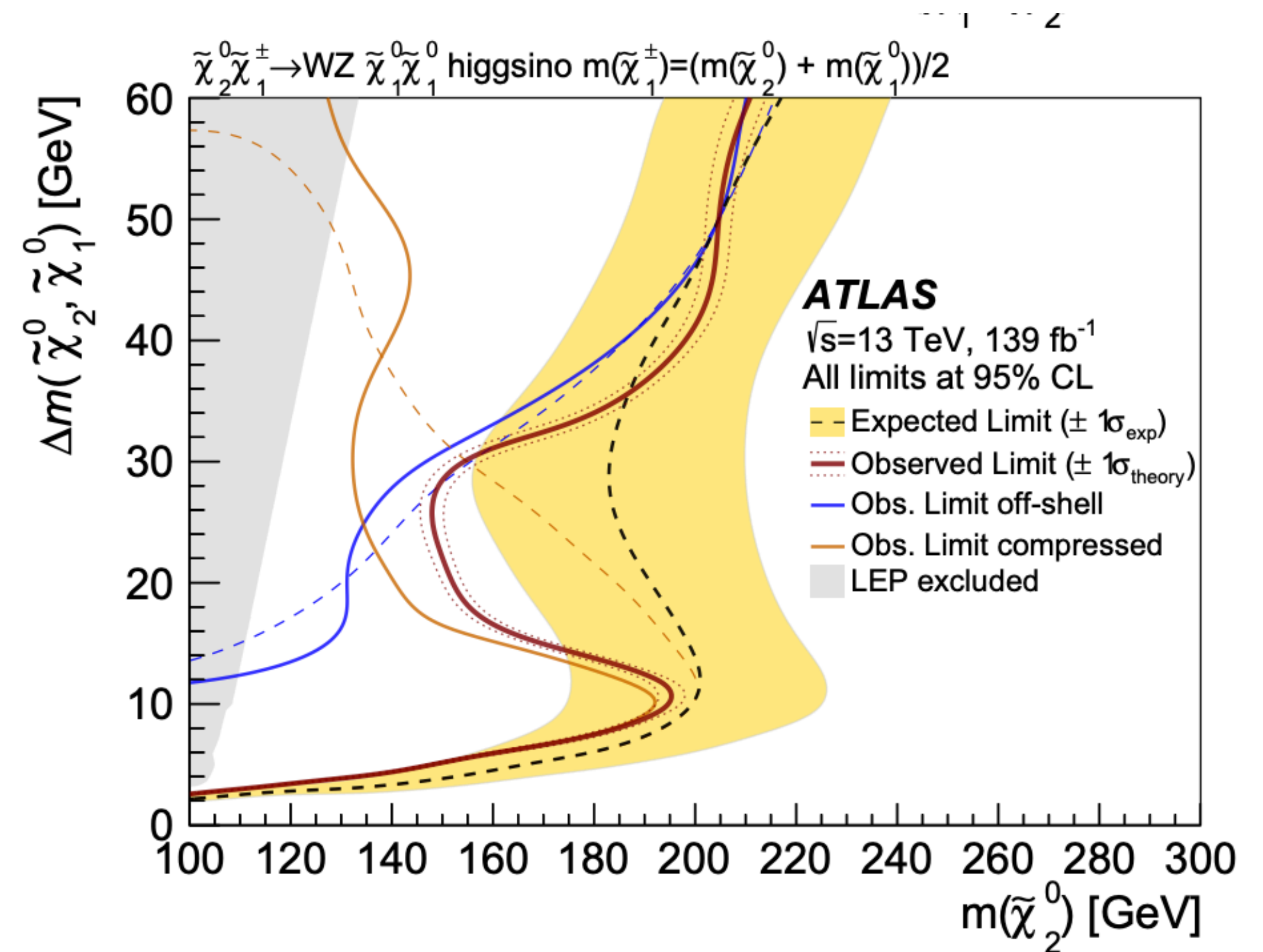
 Submitted to: EPJC

 CERN-EP-2021-059
4th June 2021

Search for chargino–neutralino pair production in final states with three leptons and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

The ATLAS Collaboration

A search for chargino–neutralino pair production in three-lepton final states with missing transverse momentum is presented. The study is based on a dataset of $\sqrt{s} = 13$ TeV pp collisions recorded with the ATLAS detector at the LHC, corresponding to an integrated luminosity of 139 fb^{-1} . No significant excess relative to the Standard Model predictions is found in data. The results are interpreted in simplified models of supersymmetry, and statistically combined with results from a previous ATLAS search for compressed spectra in two-lepton final states. Various scenarios for the production and decay of charginos ($\tilde{\chi}_1^\pm$) and neutralinos ($\tilde{\chi}_2^0$) are considered. For pure higgsino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ pair-production scenarios, exclusion limits at 95% confidence level are set on $\tilde{\chi}_2^0$ masses up to 210 GeV. Limits are also set for pure wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ pair production, on $\tilde{\chi}_2^0$ masses up to 640 GeV for decays via on-shell W and Z bosons, up to 300 GeV for decays via off-shell W and Z bosons, and up to 190 GeV for decays via W and Standard Model Higgs bosons.



Summary

- publishing Likelihood is becoming a new normal
- this enables new science through stat. combination & reinterpretation
- particularly powerful for LLP searches
- get in touch if you need help

Searches for long-lived particles at the LHC: Workshop of the LHC LLP Community

24–26 Apr 2017
CERN
Europe/Zurich timezone

RECAST

Lukas Heinrich
LLP Prep Meeting

NEW YORK UNIVERSITY

Technical Solution:

Preserve Software using industry standard Linux Containers (Docker)

- industry backed (Google, Amazon, ...) solution for reproducible software environments. Like a VM, but boots in milliseconds.
- complete freedom for analysis team on software choices. Makes no assumption on how experiments run analysis code.
- can capture conveniently by analysis team:

```
lxplus> docker run ... #start snapshot session
container> svn co ...
container> make ...
lxplus> docker commit ... #save snapshot of workdir
```

Host

- Base OS system libs
- HEP software ASG releases, LCG releases etc
- User Code

Docker Image. Think: executable filesystem snapshot

docker

NEW YORK UNIVERSITY

17

2017!

Kyle Cranmer
@KyleCranmer

I'm so happy to see this out! 🙌 @ATLASexperiment
"Long-lived particle searches are particularly interesting in terms of their discovery potential & the difficulty of reinterpreting them in the context of new physics models"
A perfect example for the RECAST framework! @iris_hep

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

The ATLAS Collaboration

A recent ATLAS search for displaced jets in the hadronic calorimeter is preserved in RECAST and thereafter used to constrain three new physics models not studied in the original work. A Stealth SUSY model and a Higgs-portal baryogenesis model, both predicting long-lived particles and therefore displaced decays, are probed for proper decay lengths between a few

Figure 4: A more detailed view of the workflow used in the analysis preservation. Individual steps (blue boxes) have inputs (red ellipses) which are either set initially by the user, or result from previous steps. The arrows indicate the direction of information flow between the steps. The initialization step is indicated as 'init' while 'high' and 'low' refer to the high- and low- E_T selections respectively.

preserved in this way. The data analysis workflow required to estimate the efficiency for, and sensitivity to, any new signal was completely captured using virtualisation techniques. This allowed an accurate and efficient reinterpretation of the published result following the RECAST protocol in terms of three signal models featured in other dedicated LLP searches. In all three cases, the existing limits were extended to short lifetimes and decay lengths.

The reinterpretation of the CalRatio jet search was performed in the context of a Higgs-portal model which offers an explanation of baryogenesis, a stealth SUSY model and a dark sector model predicting SM and exotic Higgs decays to collimated light SM fermions via dark photons. The Higgs-portal baryogenesis model was constrained to a branching ratio for $H \rightarrow \chi\chi$ below 10% at decay lengths approximately one half of those in the existing results [28]. For the stealth SUSY model, constraints on the singlino production branching ratio were also extended to decay lengths approximately 0.5 times shorter than those obtained previously [28]. Finally, for the dark photon model, the limits for the SM Higgs channel are the first obtained by ATLAS in the context of hadronic decays of the dark photon in this model, with the cross-section times branching ratio constrained between a few millimetres and a few tens of centimetres, depending on the multiplicity of dark photons. Alongside the existing limits for muonic dark photon decays [41], these constraints provide comprehensive coverage for this model. Concurrently, the limits for the exotic Higgs boson ($m_H = 800$ GeV) channel with hadronic dark photon decays were extended to shorter decay lengths than those in existing results [41]. This sensitivity to new models may be further extended in future by preserving combinations of the CalRatio displaced jets search with complementary

Figure 14: Diagrams of the Higgs portal model with dark photon final states. The dark fermions f_{d_i} each decay to SP and a dark photon γ_d in the diagram on the left, and a HLSP and a dark scalar s_d that in turn decays to γ_d in the diagram on the right. The γ_d decay into SM fermions, denoted by ℓ^+ and ℓ^- .

12:15 AM · Mar 31, 2020 · Twitter Web App

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LLP community has been a constant companion in getting here. Thanks!