

Preservation and reuse of BSM searches: ATLAS review

—(Re)interpretation of the LHC results for new physics 2022

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2022-12-12

RiF 2022

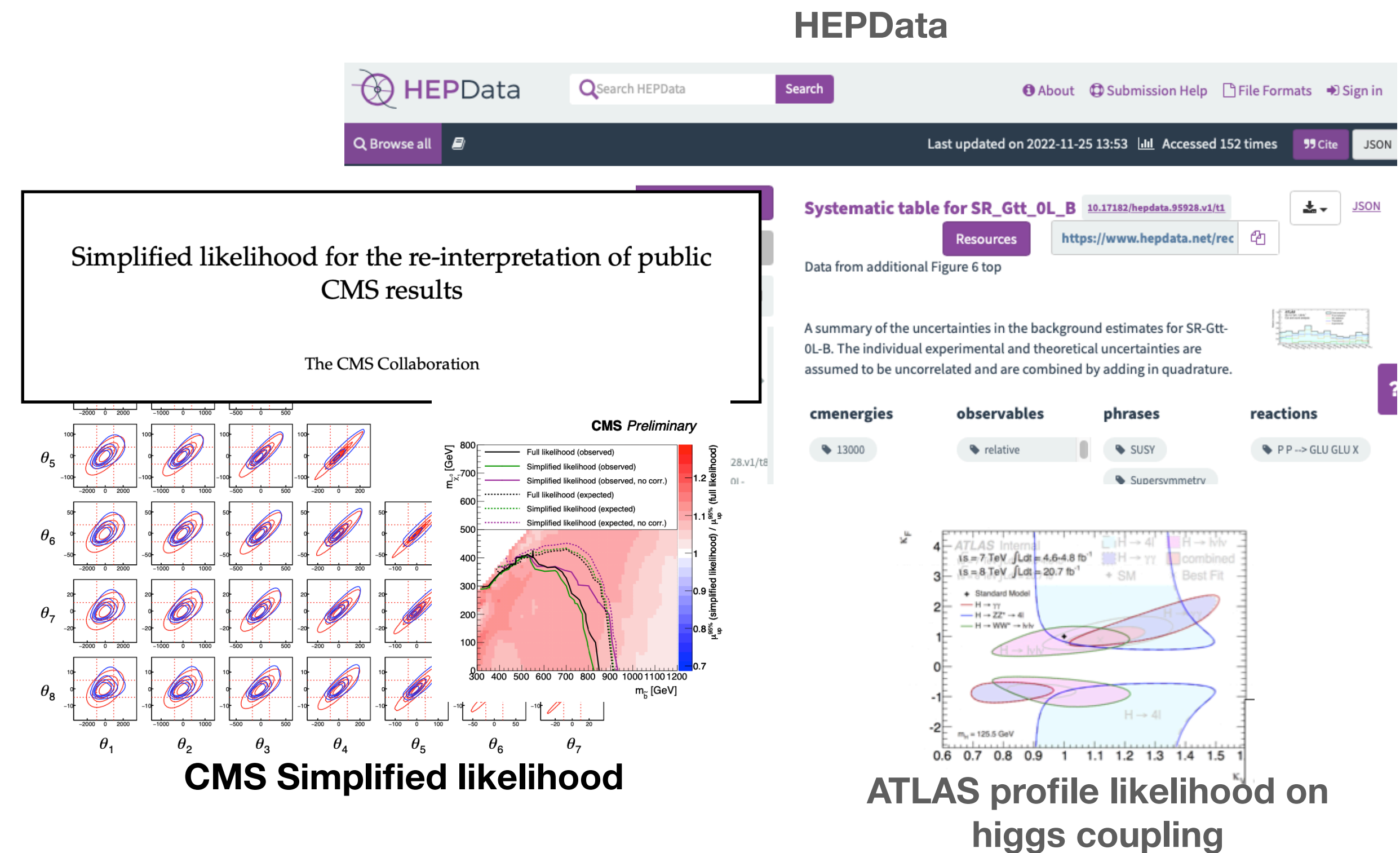
HELMHOLTZ



A timeline on Reinterpretation

– Development of Tools and the Progression of Collaboration Standard

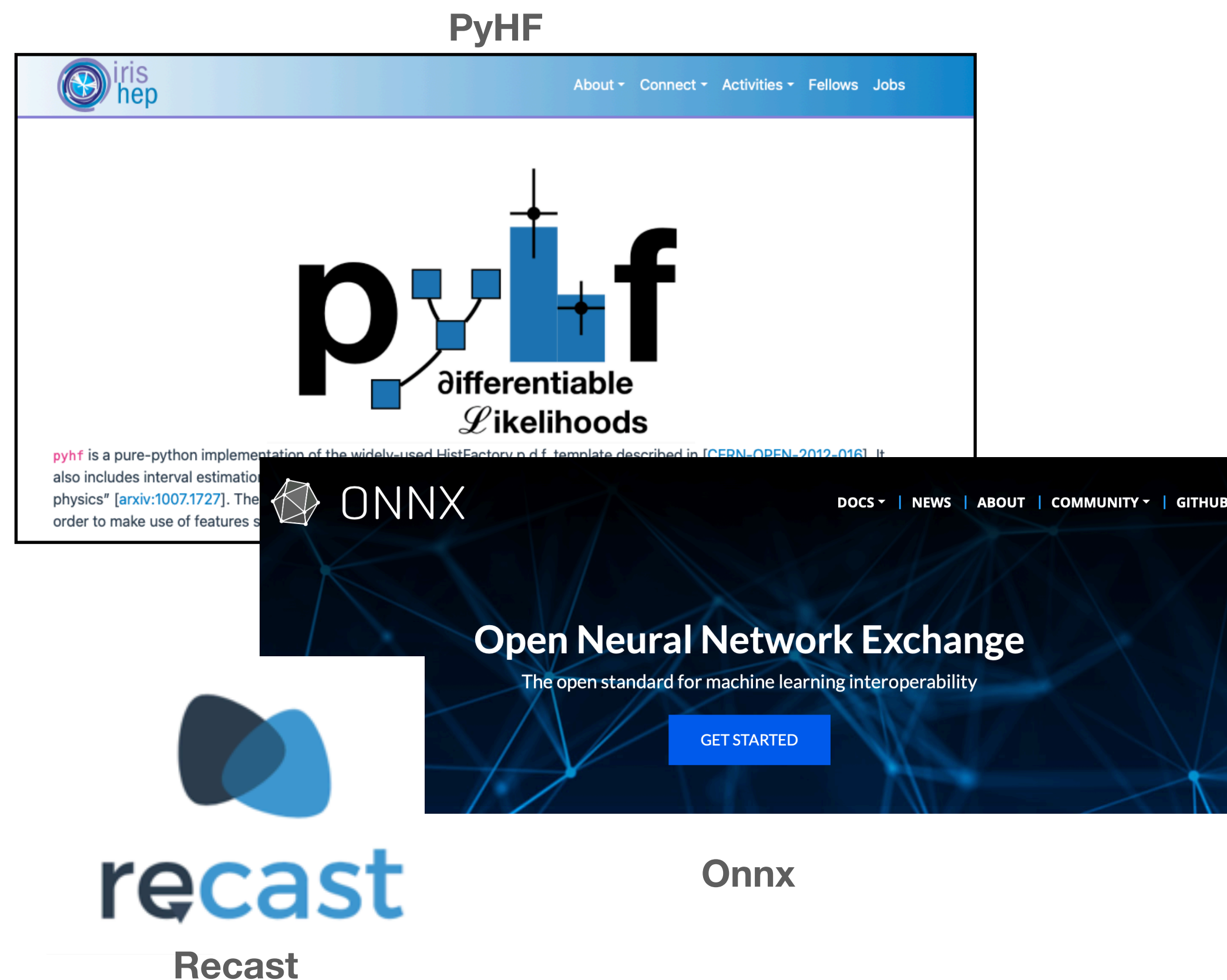
- 2000: 1st PHYSTAT
- 2010: introduction of Workspaces
- 2010: First proposition of Recast
- **2012: ATLAS profile likelihoods scans released for Higgs coupling**
- 2017: CMS Simplified Likelihoods
- **2018: Release of analysis preservation and systematic reinterpretation with Recast within ATLAS**



*ATLAS development highlighted in blue

A timeline on Reinterpretation

– Development of Tools and the Progression of Collaboration Standard



*ATLAS development highlighted in blue

- 2019: [First full likelihood release in ATLAS for SUSY searches](#)
 - Using json schema of Histfactory class of likelihood
- 2019: [ATLAS publication of full statistical likelihoods PUB note released \(JSON HF\)](#)
- 2020: [First full likelihood release regularly in ATLAS for SUSY searches](#)
- 2022: “[Simple Analysis: Generator-level Analysis Framework](#)” pub note released—Framework going public!
- 2022: Snowmass: “Reinterpretation and Long-Term Preservation of Data and Code”

Tools used by ATLAS for reinterpretation

—Introducing the players

Precision Level	Preserved Item	Tools/Service used by ATLAS	
0	Data product	HEPData	++Increased level of Information/ Precision
1	Likelihood	Simple likelihood JSON HistFactory	
2	Truth Level Pipeline	SimpleAnalysis/Rivet	
10	Full Reco Pipeline	Recast	
10+	Preservation of ML Model/optimization	ONNX	
Increase precision enable better reinterpretation from original analysis!			

Level 0: HEPData

– Storing of experimental data product from analyses for reinterpretation

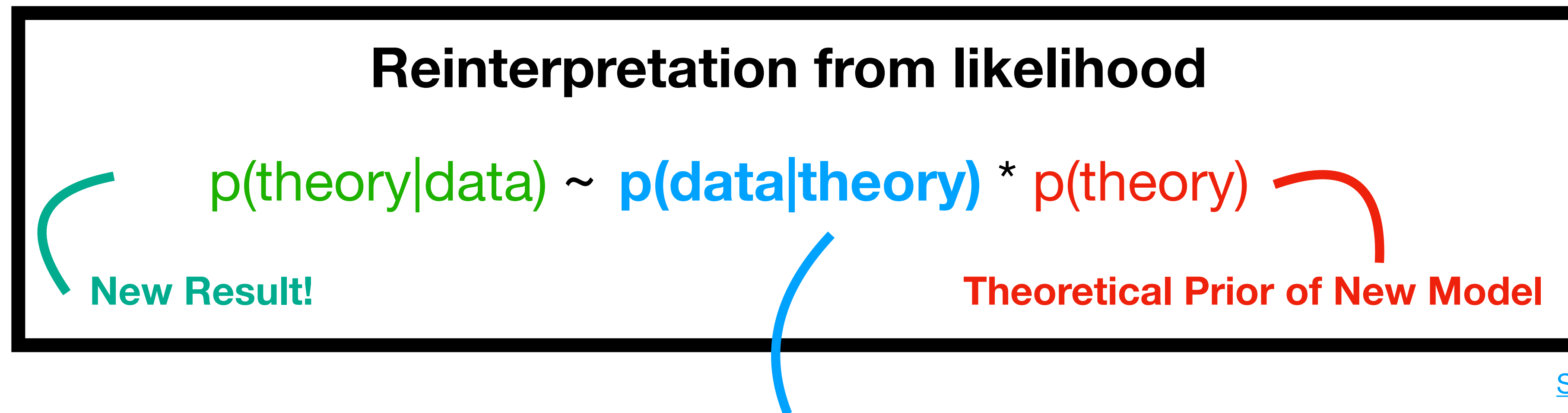
- Previously: Table-based webpage (40 year-old):
- [New digital library](#) : Paper
 - Database: Include Efficiency Map, yields, uncertainties, outflow tables
 - Reinterpretation tools: Rivet and SimpleAnalysis code, preservation of ML
 - Webservice
- Made an ATLAS requirement for publication
- Centralized tool across other HEP experiments



Level 1: Statistical Model (Simple Likelihood)

—Saving the most of our experiment results in one variable

- Previously, often HEPData information is used to construct approximate likelihood
- **Likelihood: Great bang for the buck:** encapsulate information about Limits, data/MC plots, yield take, and systematics. ->Best object that can be provided!
- ATLAS started providing them on HEPData since 2019 (SUSY)



[Simple Likelihood Pubnote](#)

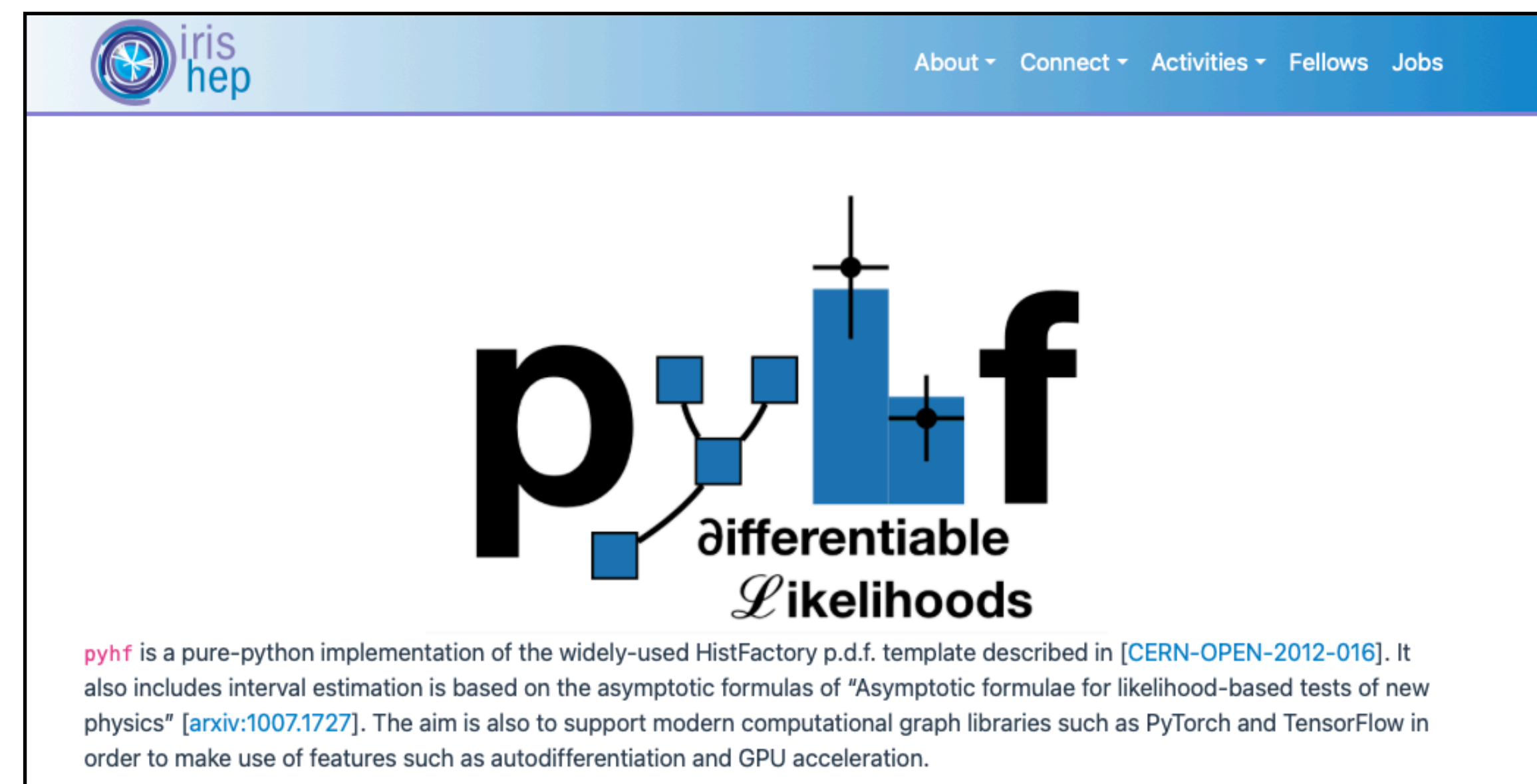
Existing Exp. Likelihood (What We Provide)

Level 1: HistFactory JSON

See ["Publishing statistical models discussion" on Tuesday](#)

—pyhf as a pure-Python implementation of HistFactory with JSon

- [PyHF](#): HistFactory in full python
- Increasingly used by ATLAS analyses ([24 analyses](#) published-up-to-date)
- Results in easy to read json format: [Database](#)
- Reinterpretation:
 - 1. Publishes statistical model (Likelihood) in json file format
 - 2. New version of [SModel](#) and [MadAnalysis5](#) allow for automatic reinterpretation from pyHF json file



Source Code

Level 2: SimpleAnalysis

— Truth level pipeline preservation

- Preserves the analysis code pipeline
- Allow for reinterpretation up to the truth level
 - Detector effect can be added: public simulation like Delphes or internally by ATLAS fast simulation
- Experimentalist friendly input format (HepMC, DAOD, ROOT n-tuple, DELPHES)
- Large list of [ATLAS SUSY analyses](#) available:
- For **public use**: can be used external to ATLAS

See [tutorial by Giordon Stark](#) Wednesday

Analysis Name	ATLAS Public Result page
ZeroLeptonJigsaw2016	ANA-SUSY-2016-07
SbottomMultiB2018	ANA-SUSY-2018-31
DMbb2016	ANA-SUSY-2016-18
DMttZeroLepton2016	ANA-SUSY-2016-18
MultiJets2018	ANA-SUSY-2018-17
EwkThreeLeptonResonance2018	ANA-SUSY-2018-36
EwkThreeLeptonERJR2018	ANA-SUSY-2018-06
PairedDijets2016	ANA-SUSY-2016-09
EwkTwoLeptonTwoJet2016	ANA-SUSY-2016-24
DirectStau2018	ANA-SUSY-2018-04
OneLeptonMultiJets2016	ANA-SUSY-2016-11
DisappearingTrack2016	ANA-SUSY-2016-06
StopZ2016	ANA-SUSY-2016-20
EwkTwoLeptonRJ2016	ANA-SUSY-2017-03

SimpleAnalysis: [Webpage](#)



[SimpleAnalysis PubNote](#)

Available list of Analyses

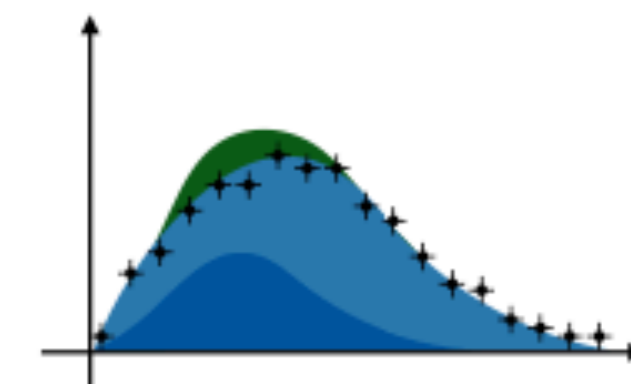
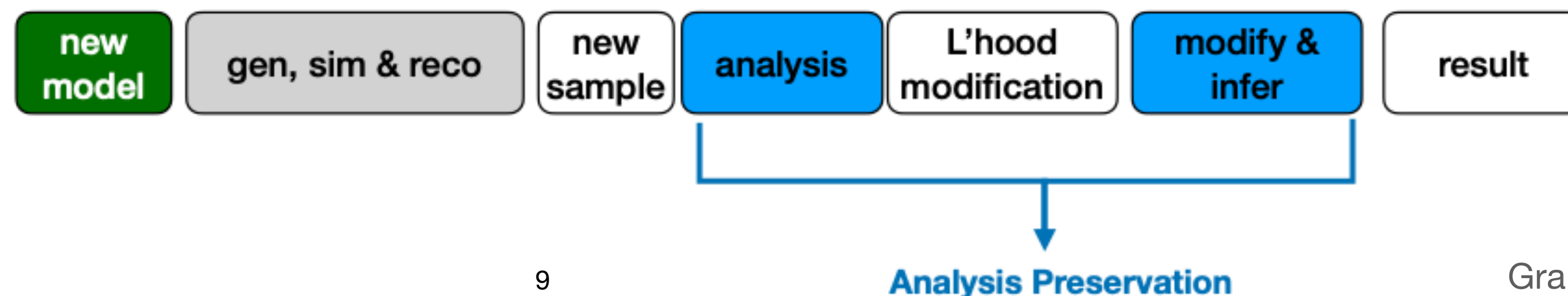
Level 10: Recast

—Full Analysis pipeline preservation

- Preservation of original analysis pipeline for re-interpretation
- Contain full detector simulation information + original code/workflow
- Reinterpretation with full workflow + simulation effect
- Made a requirement for publication in Exotics, HDBS and SUSY
- Implementation Internal to ATLAS: some reinterpretation results published with the tool
- [Software](#) fully open source!
- Future: Allow for an interface to submit reinterpretation request online



preservation of the original analysis pipeline
for collaboration-approvable results

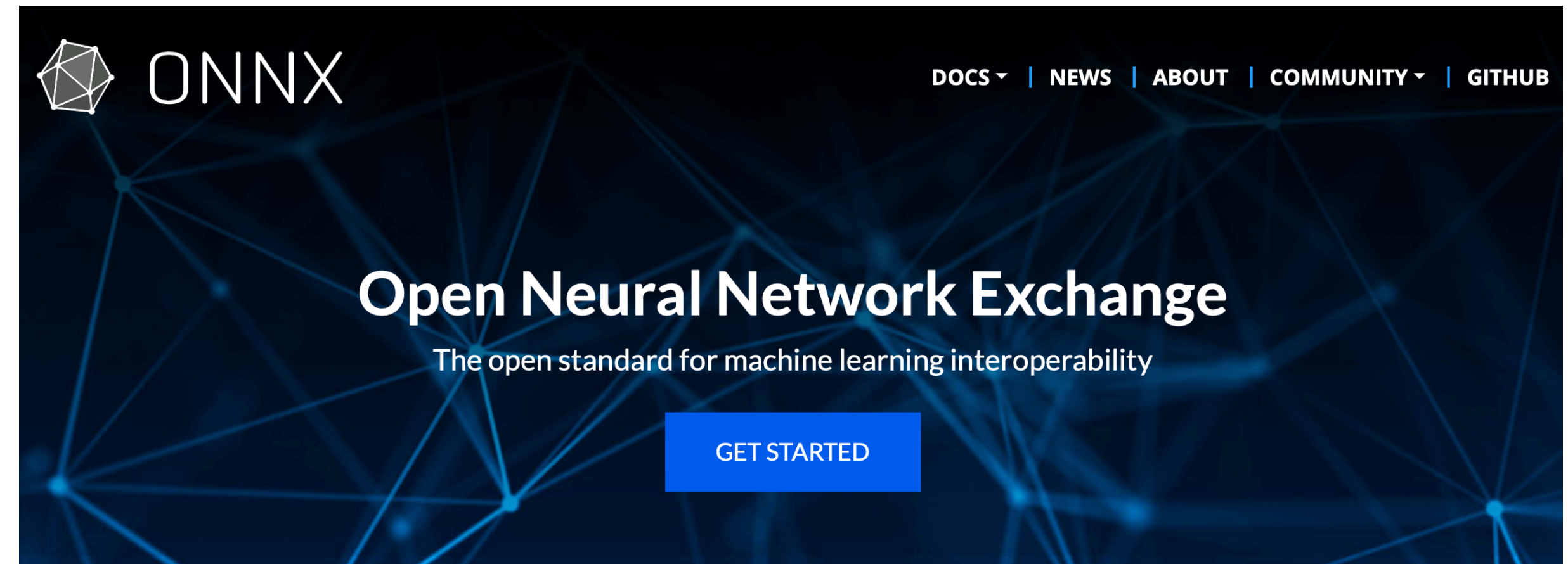


Level 10+: ONNX/NN

See [talk by Dan Guest](#) later today

—Beyond usual pipeline preservation: Reuse of ML training results

- ML development significantly improve analyses sensitivity. Theorists would like to make use of the BDTs/NN.
- ONNX(Open Neural Network Exchange)
- BDT preservation -> convert to standalone c++ in SimpleAnalysis
- Non-BDT NN -> Preservation by Serializing through Onnx
- Can be preserved with SimpleAnalysis to be reused
- 2 analyses already have ML encapsulated in the workflow



3 b-jets+

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

[ANA-SUSY-2018-30](#)

[SA with Onnx](#)

One Lepton MultiJets

Search for R-parity-violating supersymmetry in a final state containing leptons and many jets with the ATLAS experiment using $\sqrt{s} = 13 \text{ TeV}$ proton–proton collision data

The ATLAS Collaboration

[ANA-SUSY-2019-04](#)

[SA with Onnx](#)

Two existing analyses already contain Onnx



Source Code

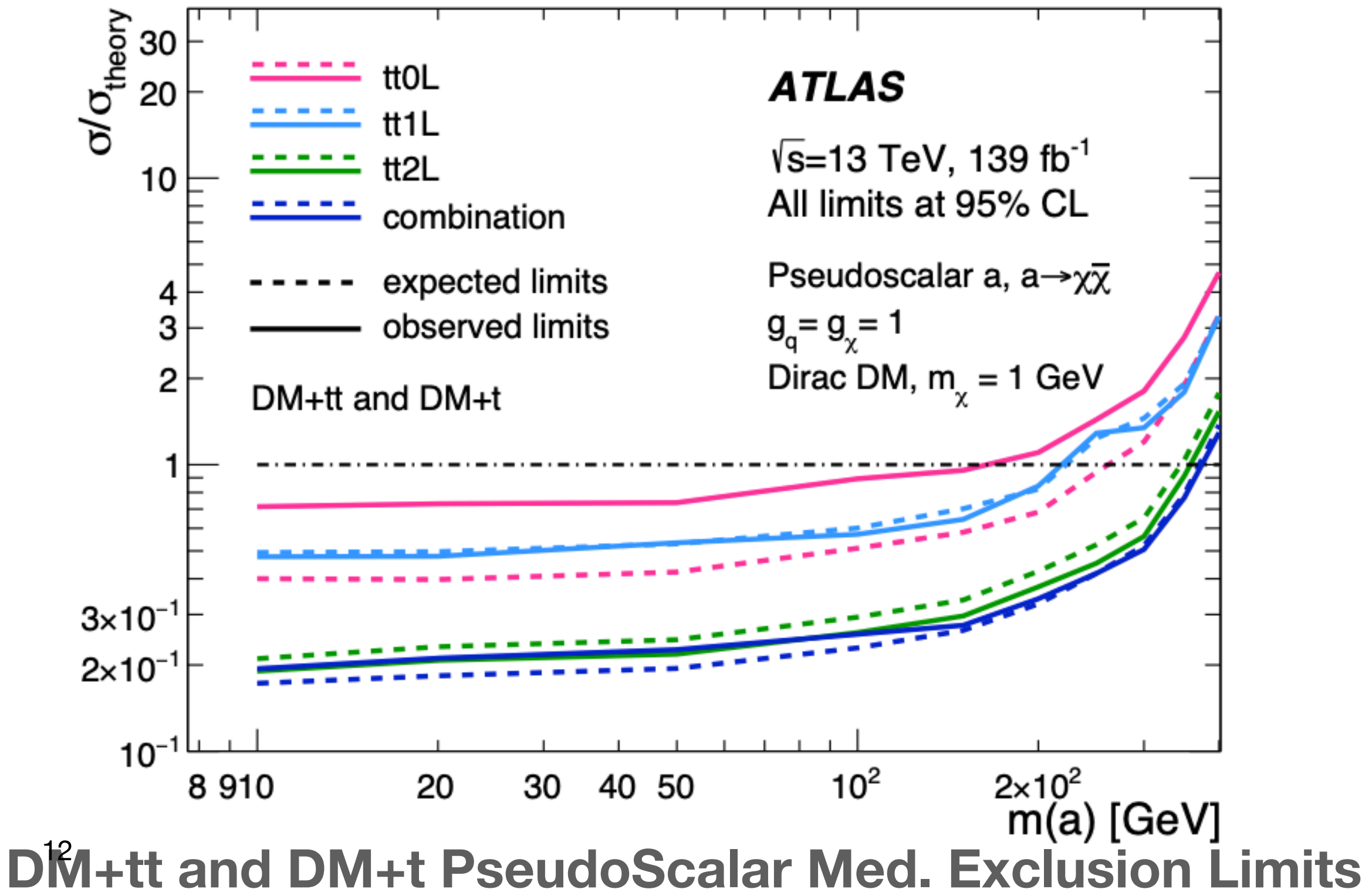
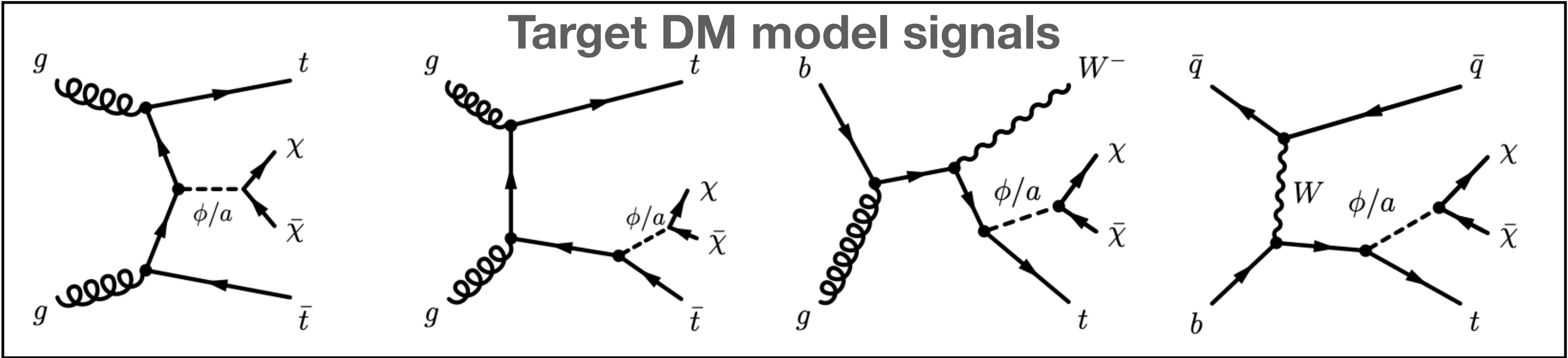
ATLAS Re-interpretation Effort Highlights

Spin-0 dark matter mediators and invisible Higgs decays

- Arxiv: [2211.05426](#)
- From SUSY [tt0L](#) , [tt1L](#) [tt2L](#)
- Spin-0 DM/ $ttH \rightarrow \text{inv}$ results
- Utilized RECAST and Statistical Combination with PyHF

Analysis	Best fit $\mathcal{B}_{H \rightarrow \text{inv}}$	Observed upper limit	Expected upper limit
tt0L	$0.48^{+0.27}_{-0.27}$	0.95	$0.52^{+0.23}_{-0.16}$
tt1L	$-0.04^{+0.35}_{-0.29}$	0.74	$0.80^{+0.40}_{-0.26}$
tt2L	$-0.08^{+0.20}_{-0.19}$	0.36	$0.40^{+0.18}_{-0.12}$
$t\bar{t}H$ comb.	$0.08^{+0.15}_{-0.15}$	0.38	$0.30^{+0.13}_{-0.09}$

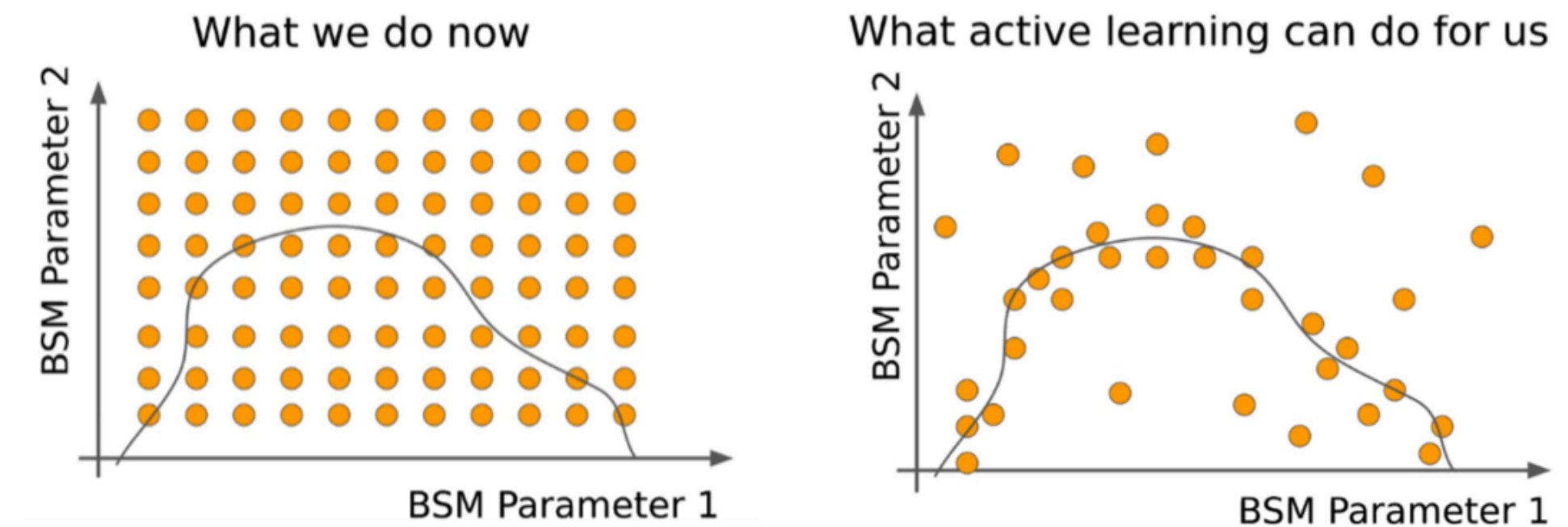
ttH ($H \rightarrow \text{inv}$) Reinterpretation



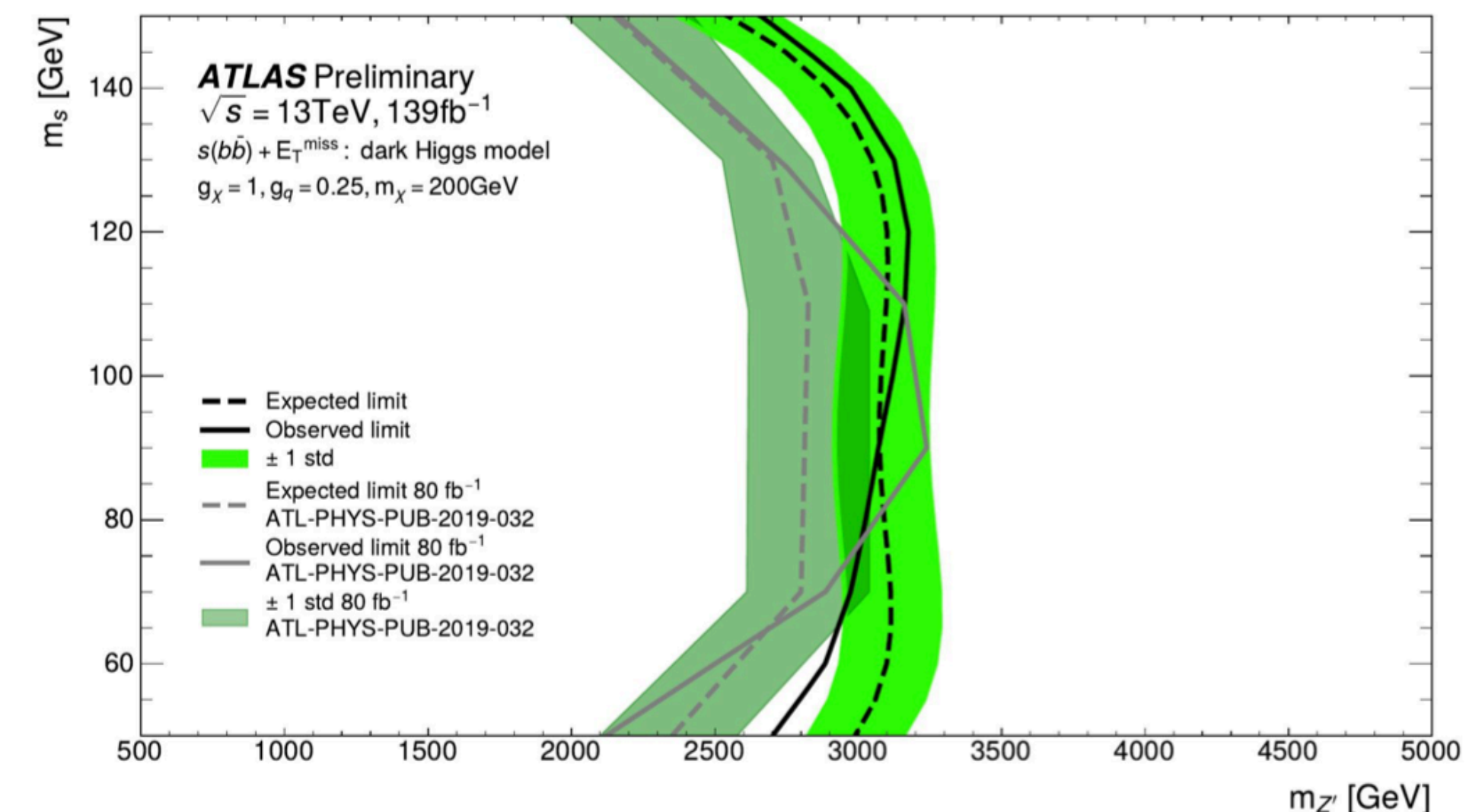
Active learning through Mono-H(bb) Recast

See [talk by Irina Morales](#) Thursday

- Reinterpretation from Mono-H(bb) to Dark Higgs Model (4 params: $\{\mathbf{x}\} = \{ (m_{Z'}, m_{DM}, m_s, g_{DM}) \}$)
- Active learning reinterpretation Gaussian Process to determine exclusion contours
 - Training: 10 hyperparameters determined from RECAST data
 - Inference: Gaussian Process prediction of limits and their uncertainties
- > High Efficiency, Full accuracy Limit setting with active learning of samples using RECAST
- HDBS Effort in Dark Z search plans to use the same method



Graphics from Irina Espejo, Patrick Rieck and Zubair Bhatti



Improved the Dark Higgs Limit, using recast and active learning

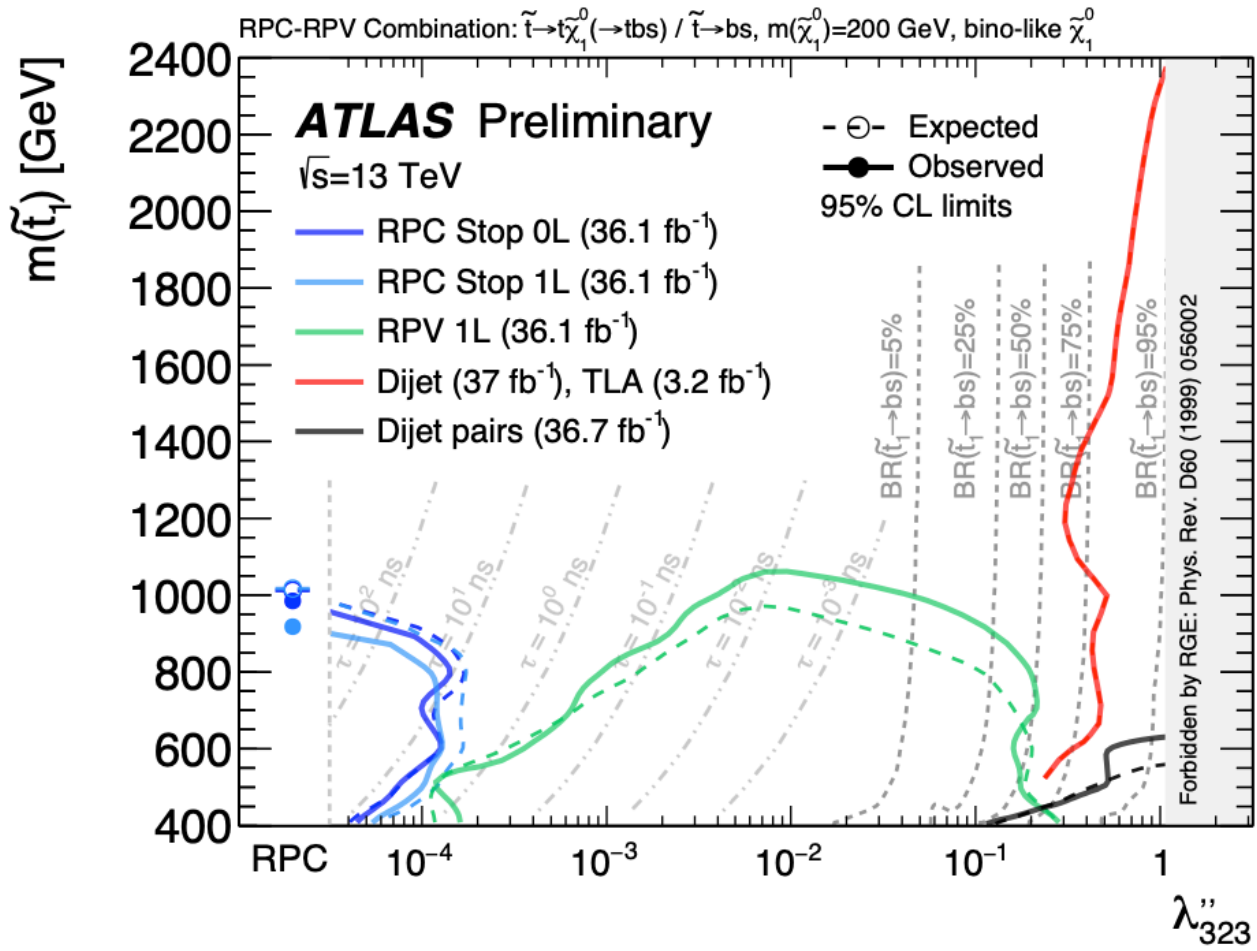
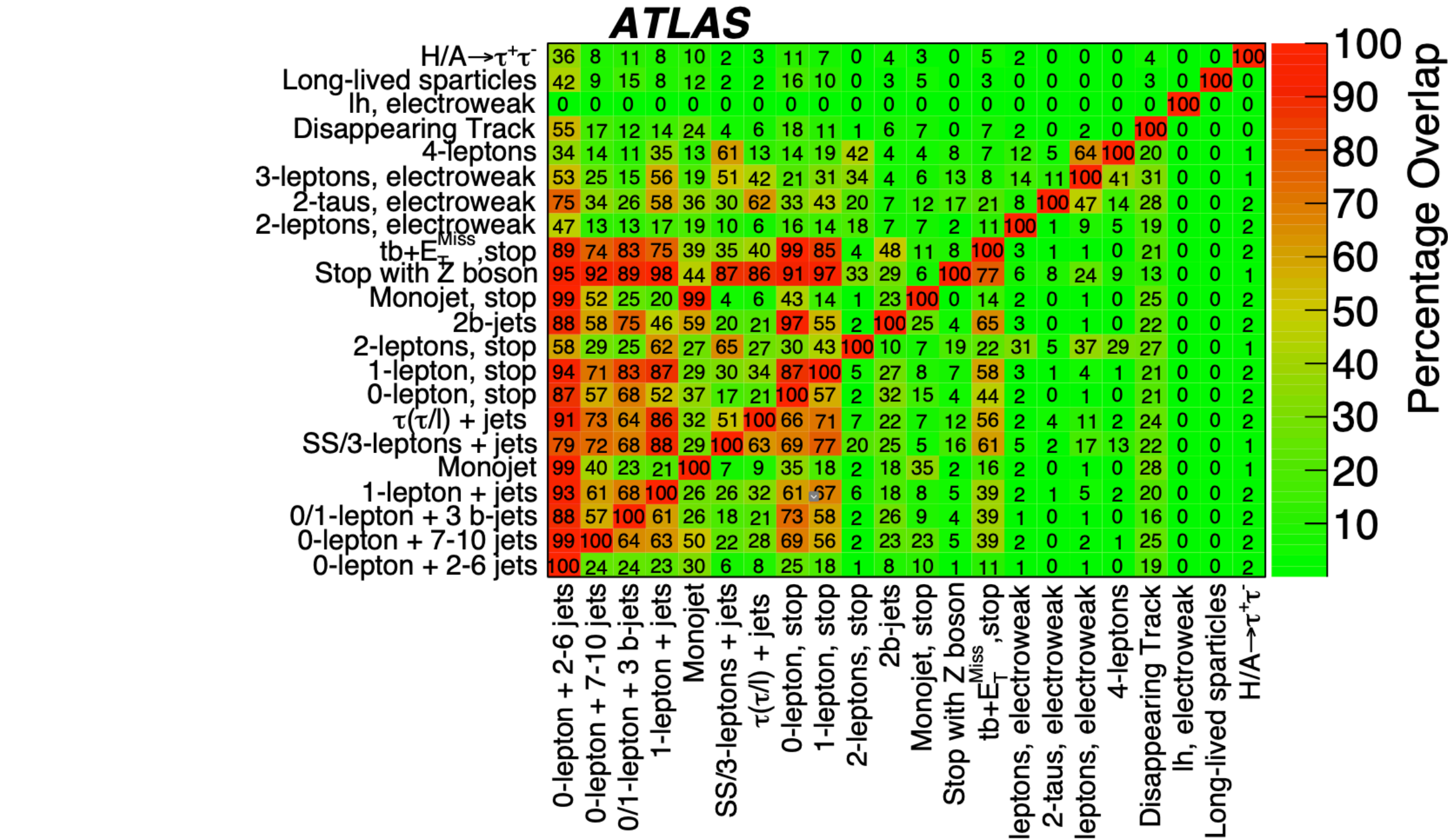
PMSSM and RPC-RPV Summary

- **RPC-RPV:**

- Recast of signals with a variable RPV coupling.
- Leading to changes in phenomenology: MET > LLP > no MET

- **PMSSM:** SUSY summary middle ground (19 params) between MSSM(>100+ free param) and Simplified Model (Used by individual Analysis with focus on a production process)

- Reinterpretation tools for an improved workflow!
- Run1 summary paper: Reran every analysis with original workflow
- Run 2 summary in preparation: Workflow Utilizes reinterpretation tools mentioned
 - Full/simplified Likelihood
 - SimpleAnalysis
 - RECAST
- Run 3: use result from Run2 to steer the ship towards uncovered phase space. RECAST=streamlined workflow!



PMSSM-Exclusion percentage
 (Previous results: Arxiv:
[1508.06608](https://arxiv.org/abs/1508.06608))

RPC-RPV reinterpretation Contour
 (Previous results: [ATLAS-CONF-2018-003](https://arxiv.org/abs/1508.06608))

A growing number of analyses!

—With the new re-interpretation workflow

- $\gamma\gamma \rightarrow \tau\tau$ and τ g-2 interpretation (Accepted by RPL)
- Dark Matter and Dark Energy Summary 13 TeV 2016
- VLQ pair search combination 13 TeV 2016
- VV/VH and $l\bar{l}/\nu\bar{\nu}$ search combination 13 TeV 2016
- Reinterpretation of EW Run 1 analyses in 5-D pMSSM
- VV heavy resonance search combination
- Search HBSM H/A constraints
- Reinterpretation of many $t\bar{t}$ searches
- **Search for the pair production of a new particle**
- Studies on H(125) effective couplings

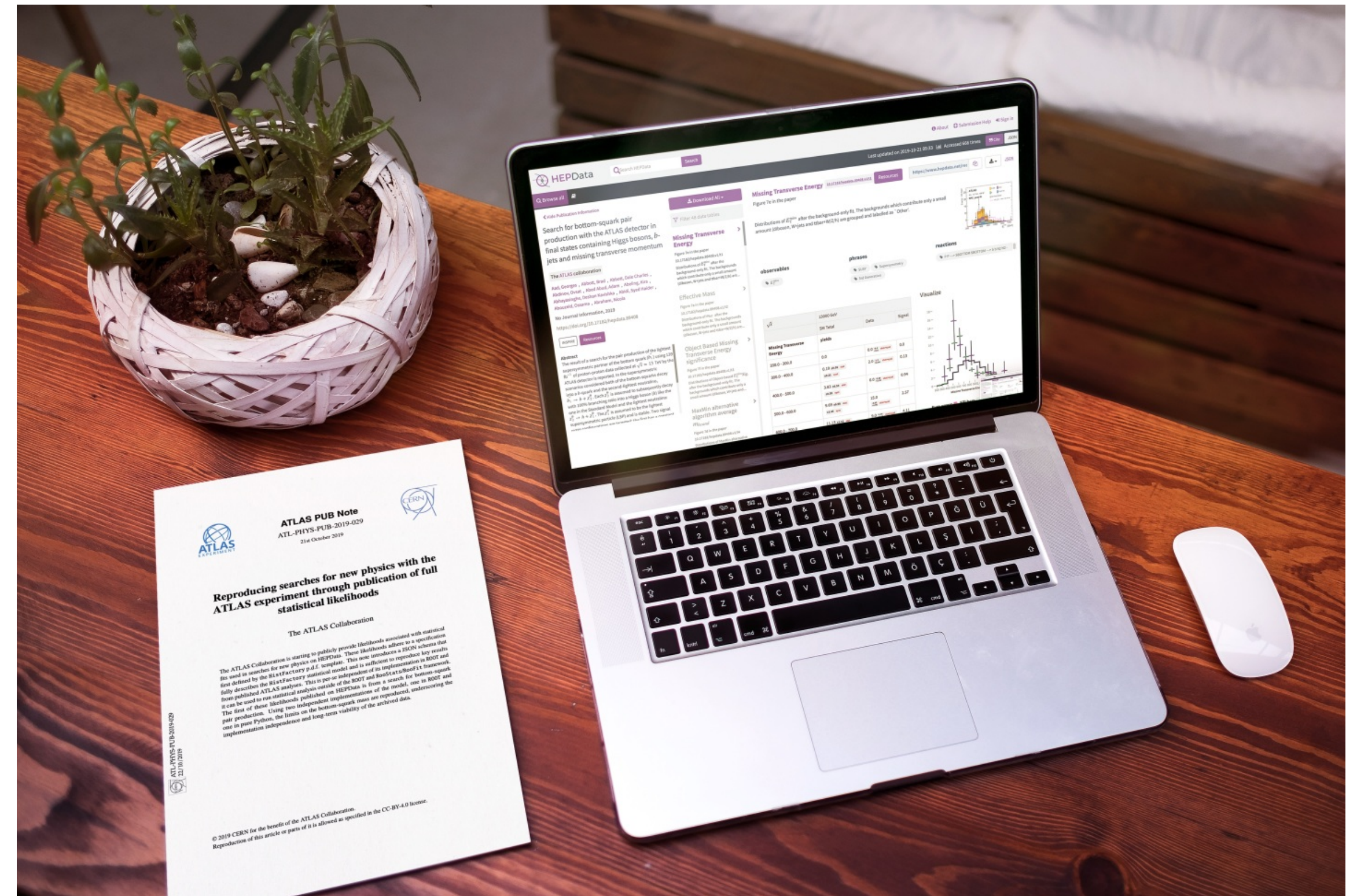
....And more!

Short Title	Group	Document number	Date	\sqrt{s} (TeV)	Links
<input type="text" value="search..."/>	<input type="text" value="search..."/>	<input type="text" value="search..."/>	<input type="text" value="search..."/>		
Active Learning Mono-H(bb) Recast	EXOT	ATL-PHYS-PUB-2022-045	2022-11-07	13	Documents Internal
HEFT interpretations of HH bbtatau+bbyy searches	HDBS	ATL-PHYS-PUB-2022-019	2022-03-18	13	Documents Internal
CalRatio jet reinterpretation	EXOT	ATL-PHYS-PUB-2020-007	2020-03-27	13	Documents Internal
SUSY Likelihoods for Reinterpretation	SUSY	ATL-PHYS-PUB-2019-029	2019-08-02	13	Documents Internal
Displaced jet response	SUSY	ATL-PHYS-PUB-2019-025	2019-07-15	13	Documents Internal
R-Hadron Event Generation and Simulation	SUSY	ATL-PHYS-PUB-2019-019	2019-05-21	13	Documents Internal
Higgsino pair; disappearing track reinterpretation	SUSY	ATL-PHYS-PUB-2017-019	2017-12-09	13	Documents Internal
Search BSM combination 2HDM prospects HL-LHC	HIGG	ATL-PHYS-PUB-2013-015	2013-10-08	14	Documents Internal

Summary

—Reinterpretation effort in ATLAS

- Tools and Collaboration Standard has driven the development of reinterpretation on ATLAS. Up to 91 analyses now contain the RECAST workflow. Requirement for new publication.
- Growing numbers of reinterpretation publications being done within the collaboration with existing tools
- Newly released information tools available for external reinterpretation (SimpleAnalysis made fully public)

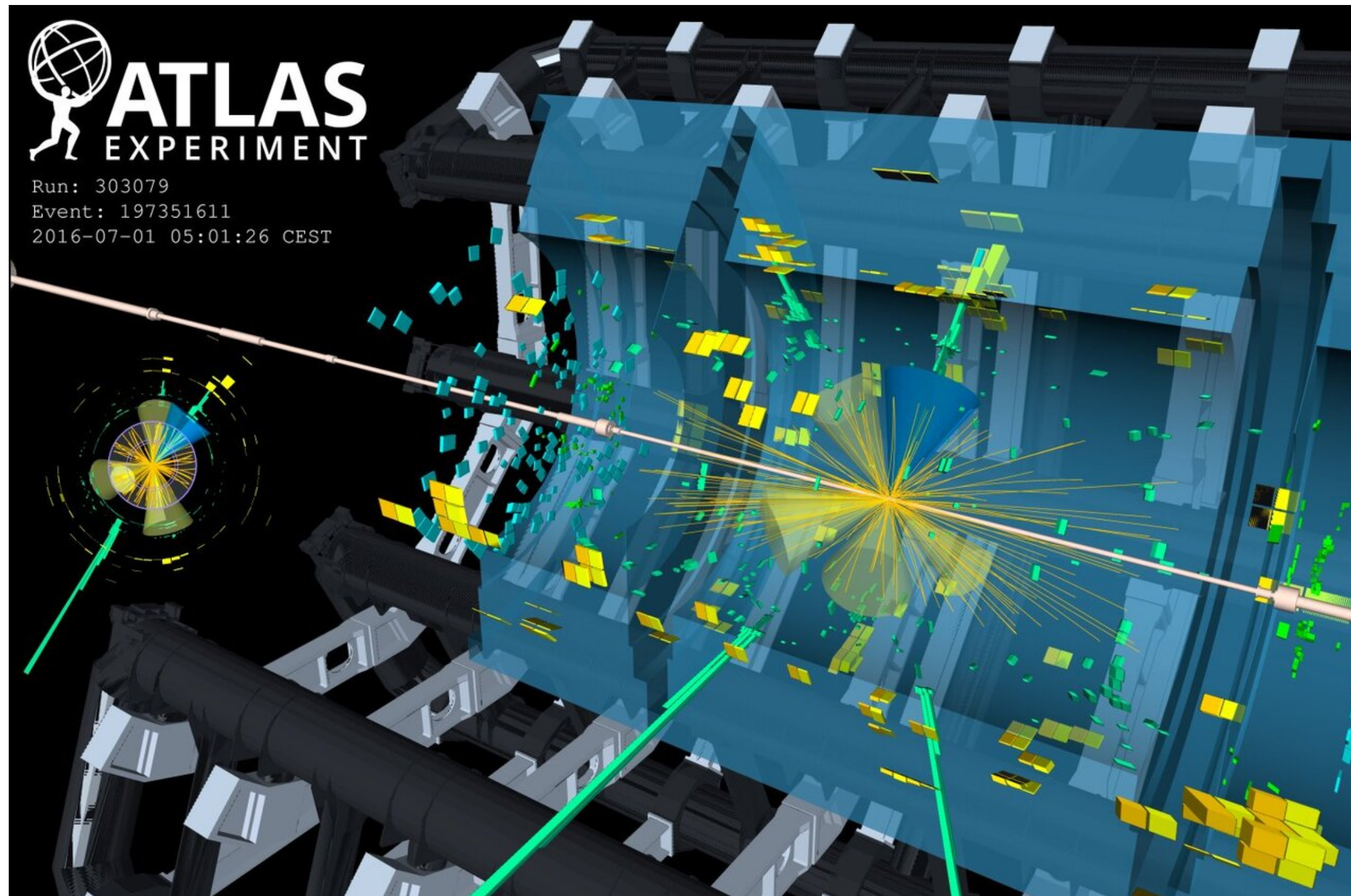


The Future

—To Run 3 and Beyond



Image from K Cranmer



Reuse not just our data, but also analysis studies and more!

- Key insights in re-interpretation is being carried over to Higgs physics, not just BSM topics
- Towards the direction of more open data/ open tools for reinterpretation/preservation (Recast for public request)
- Novel physics papers ideas: Recasting SUSY models into little Higgs/Extra dimension Kaluza Klein Models
- Tools: Further automation in data preservation(HEPData), optimization workflow in analysis/ ML models.

Acknowledgement

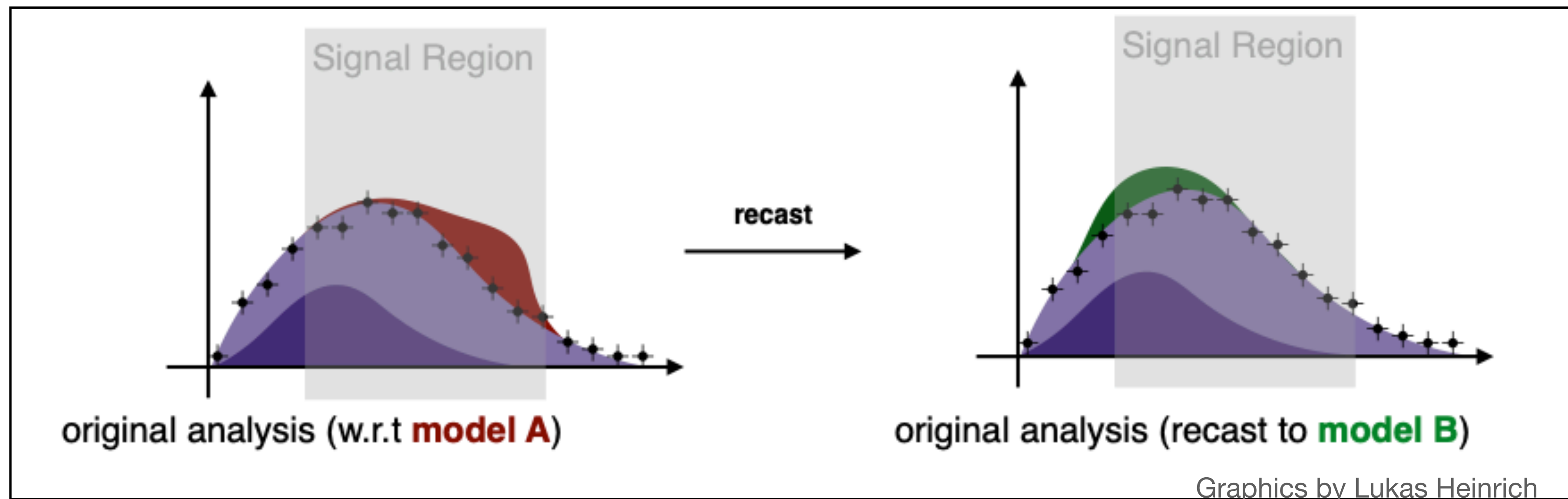
- Thank you Giordon Stark, Matthew Feikert

Back up

What is re-interpretation?

—And its importance in the BSM context

- Reinterpretation: The reusing of experimental results for alternative physics hypothesis
- **Advantages:** 1. Reuse of data/workflow/optimization 2. Less labor intensive 3. Time saving



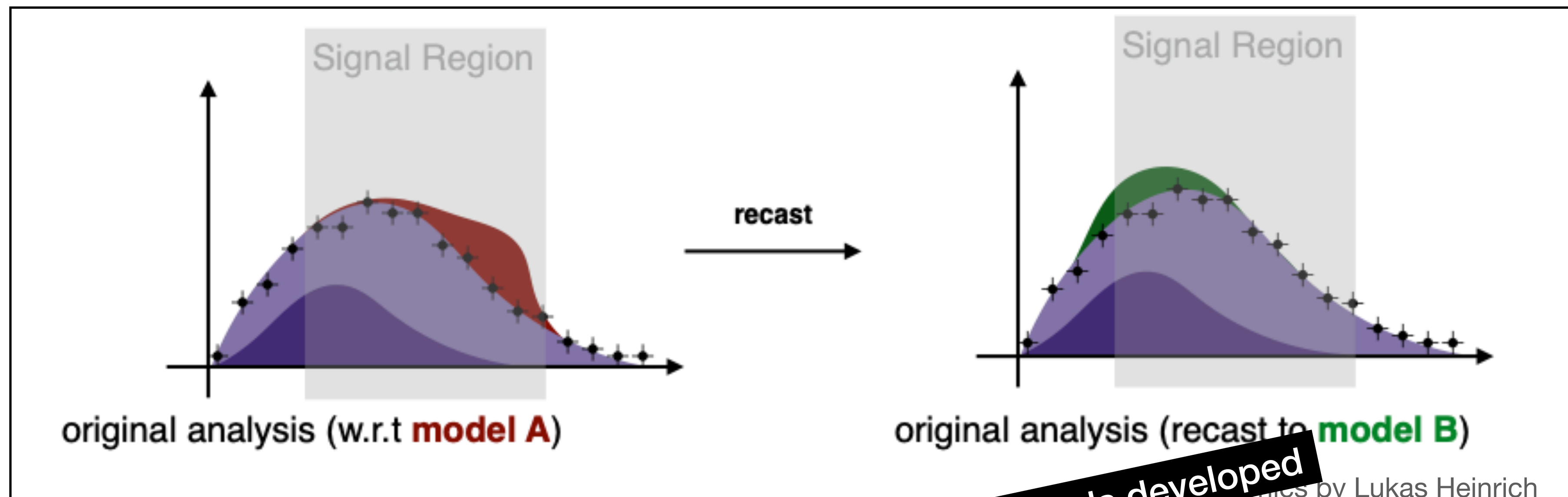
• Two types of Reinterpretation

- > 1. Re-interpretation (Single data -> Many theory)
Abundance of theoretical ideas vs experimental results available
- > 2. Combination (Many data -> Single theory)
"Combination of results (E.G. Higgs combination)"

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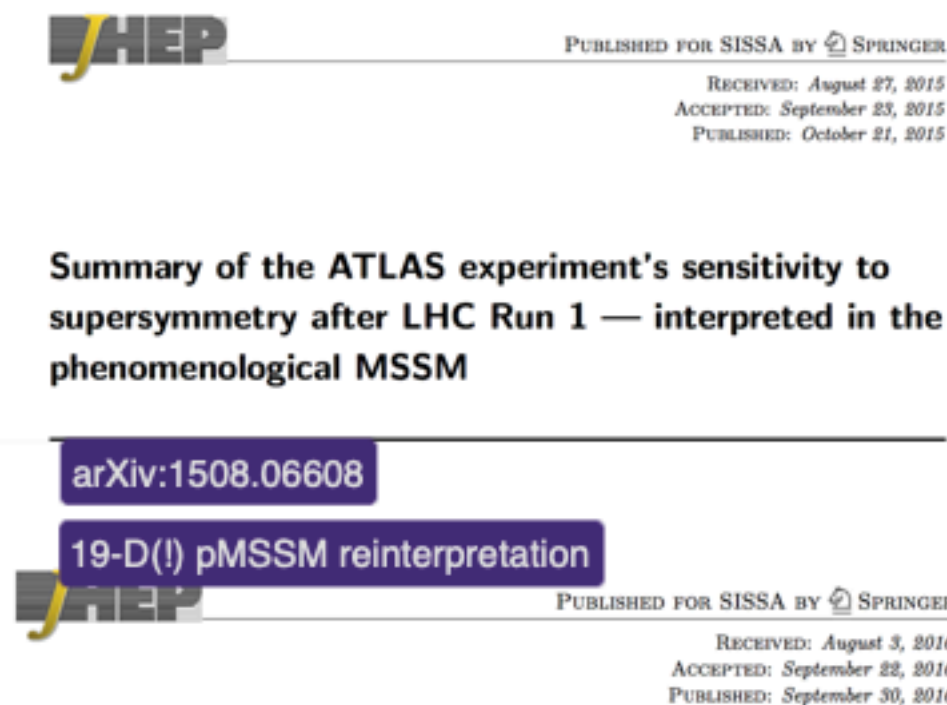
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"Combination of results (E.G. Higgs combination)"

Both performed on ATLAS using various tools developed

Available reinterpretation tools

Within Experiment



Dark matter interpretations of ATLAS searches for the electroweak production of supersymmetric particles in $\sqrt{s} = 8$ TeV proton-proton collisions

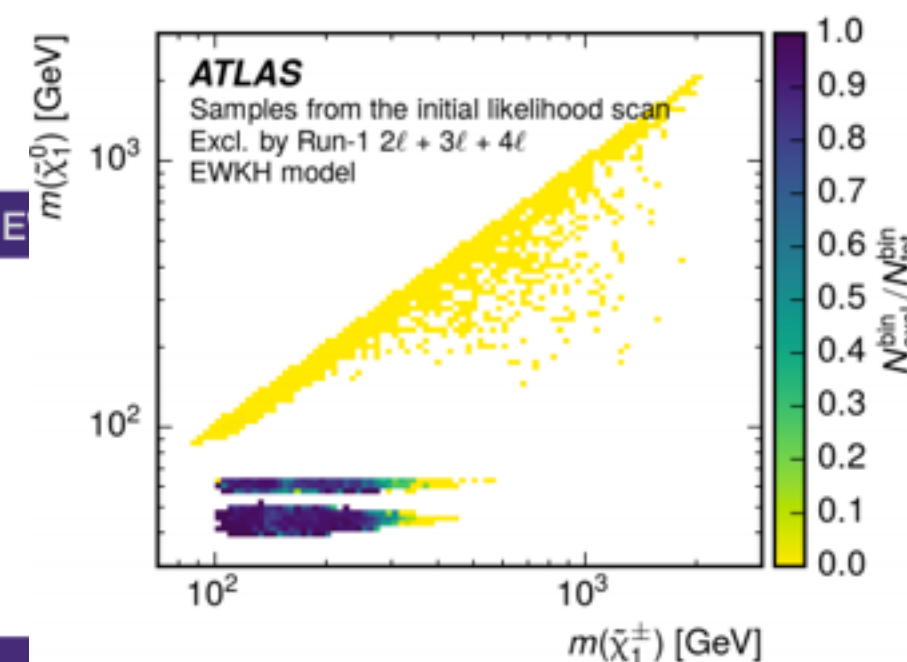
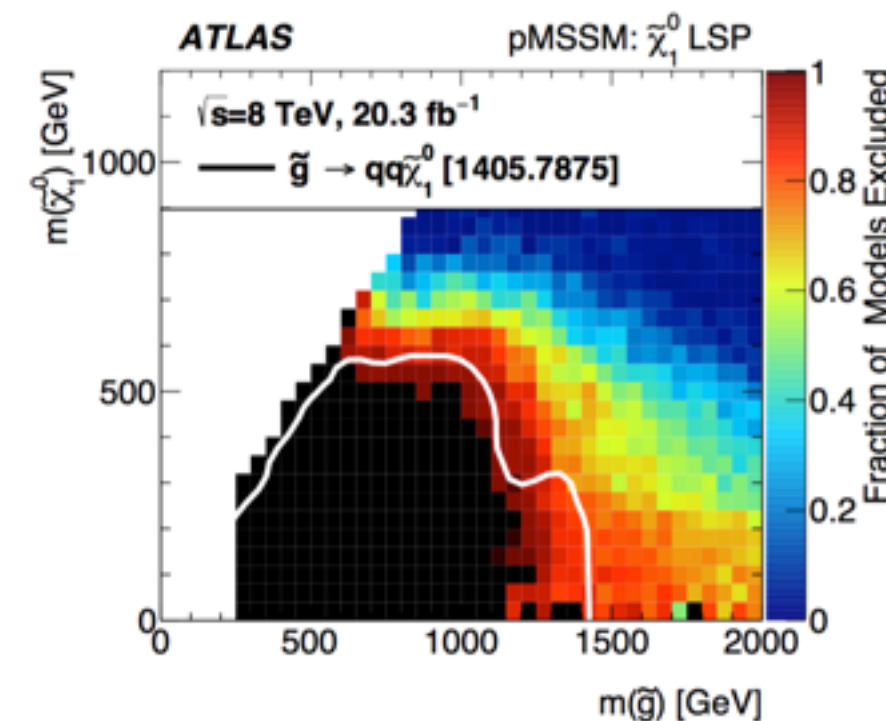
5-D scan of E

A re-interpretation of $\sqrt{s} = 8$ TeV ATLAS results on electroweak supersymmetry production to explore general gauge mediated models

The ATLAS Collaboration

3-D recast for General Gauge Med

ATLAS-CONF-2016-033



Outside of Experiment

Unfolded Reinterpretation(Without detector effect) Tools:

MAD Analysis 5

MadAnalysis

Rivet

Other Homegrown
HepMC based
Analysis

Folded Reinterpretation(With Detector Effect) Tools:

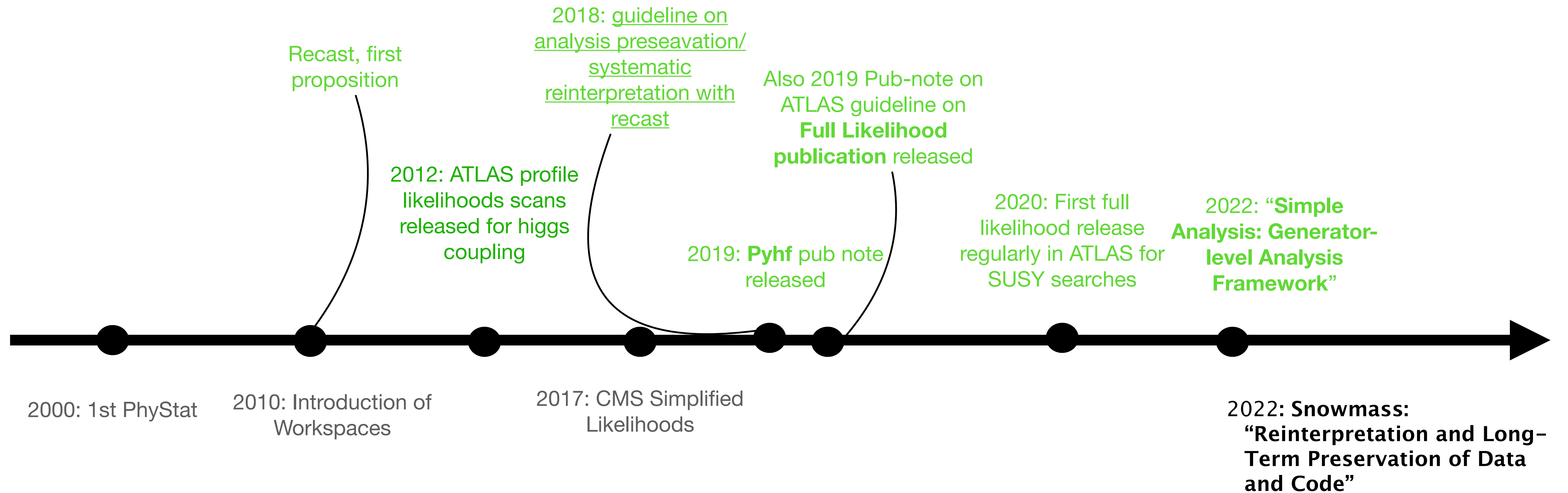
CHECKMATE

Homegrown Toy Detector Approximation

Delphes based Analysis

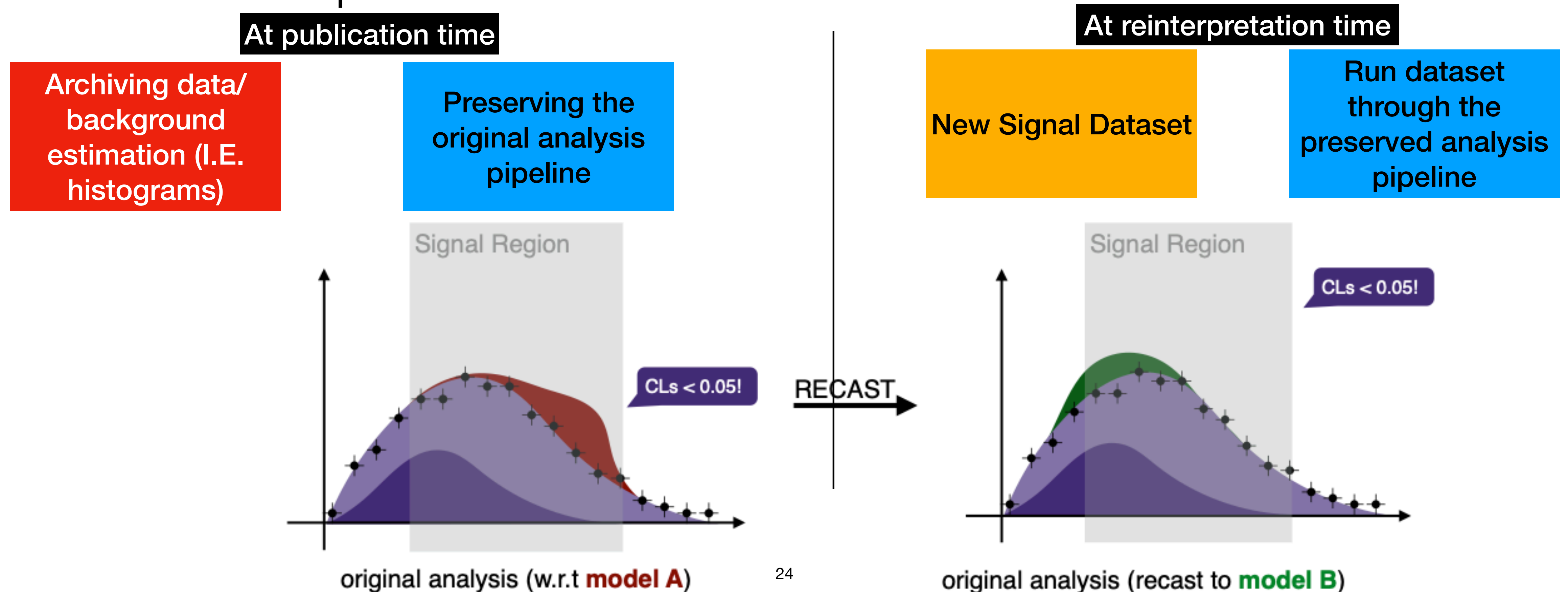
Re-interpretation effort on ATLAS

—A timeline



Recast for reinterpretation on ATLAS

- Recast has been adopted as the ATLAS standard for reinterpretation
- Yaml based implementation

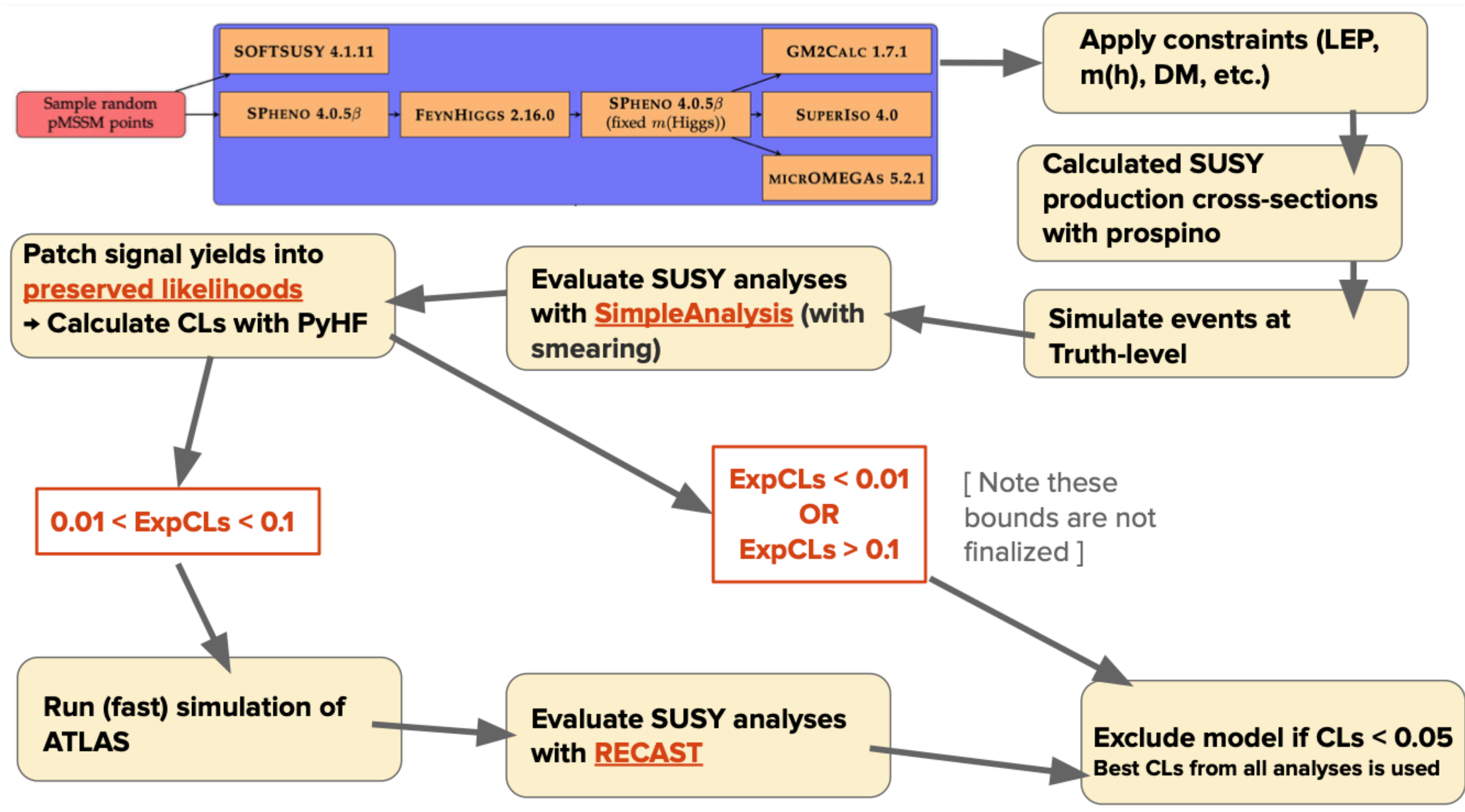


Rivet

— Truth level analysis

- Transfer function based:
From Generator level to
Reconstruction Level
- Relies on analysis-provided
acceptance/efficiencies

PMSSM



LeptoQuark Reinterpretation

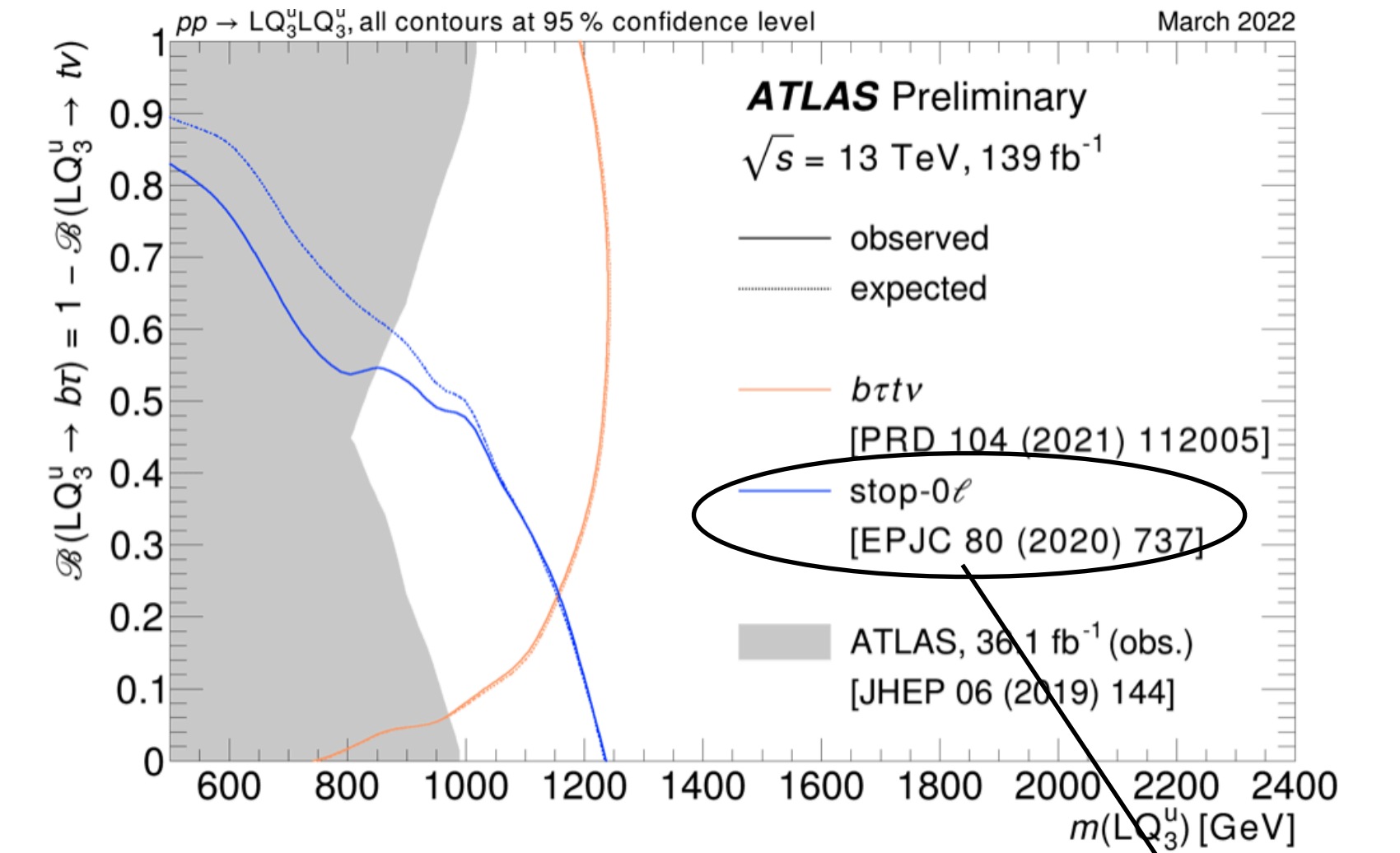
Contours from the following five dedicated analyses are included in the plots:

- $b\tau t\nu / t\tau b\nu$: “Search for new phenomena in pp collisions in final states with tau leptons, b -jets, and missing transverse momentum with the ATLAS detector” [17].
- $t\tau t\tau$: “Search for pair production of third-generation scalar leptoquarks decaying into a top quark and a τ -lepton in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector” [18].
- $b\ell b\ell$: “Search for pairs of scalar leptoquarks decaying into quarks and electrons or muons in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector” [19].
- $t\ell t\ell$: “Search for pair production of scalar leptoquarks decaying into first- or second-generation leptons and top quarks in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector” [20].
- $b\ell t\nu / t\ell b\nu$: “Search for pair-produced scalar and vector leptoquarks decaying into third-generation quarks and first- or second-generation leptons in pp collisions with the ATLAS detector” [21].

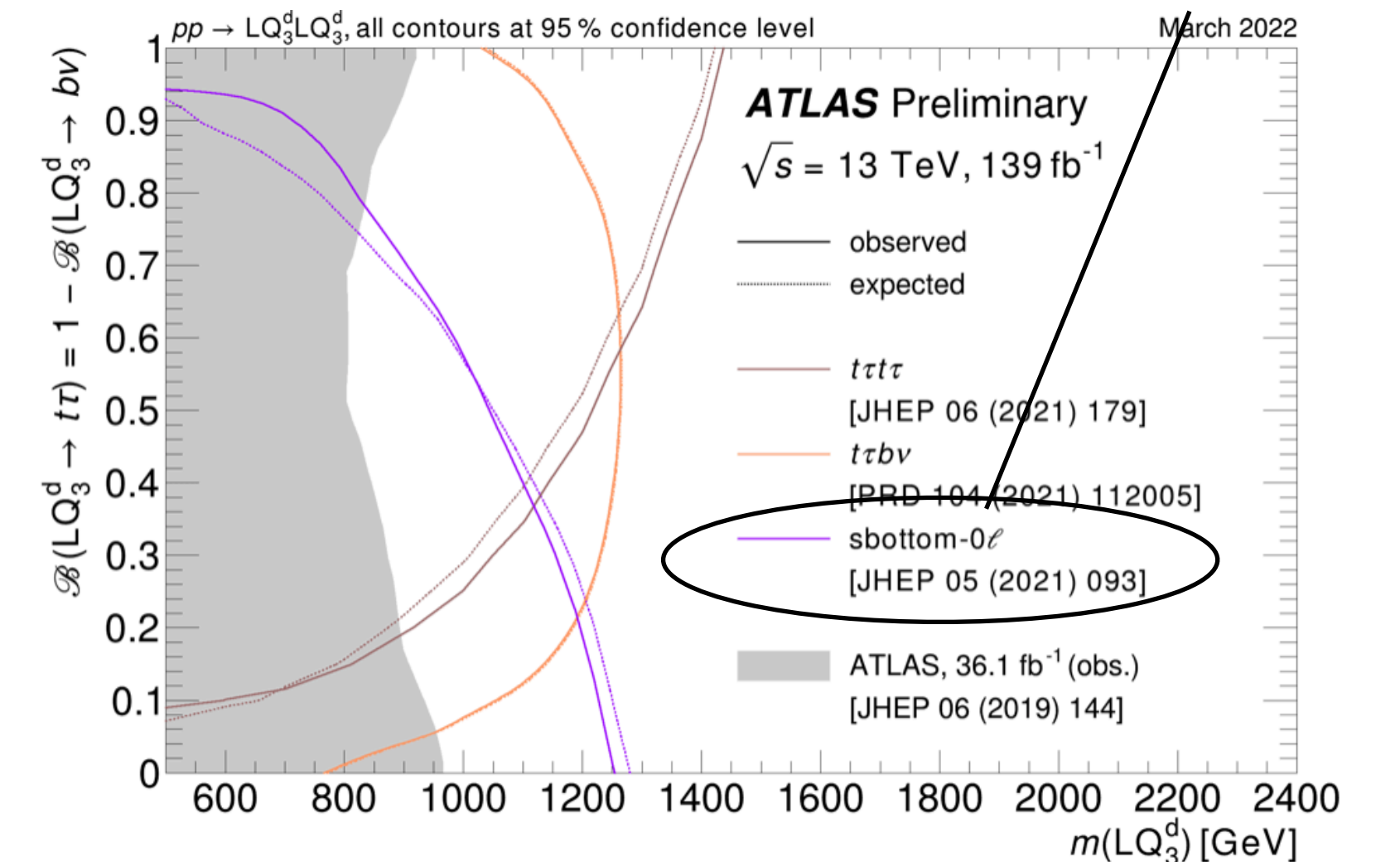
Contours from the following reinterpretations of searches for pair production of supersymmetric particles are included in the plots:

- stop-0 ℓ : “Search for a scalar partner of the top quark in the all-hadronic $t\bar{t}$ plus missing transverse momentum final state at $\sqrt{s} = 13$ TeV with the ATLAS detector” [22].
- sbottom-0 ℓ : “Search for new phenomena in final states with b -jets and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector” [23].

•

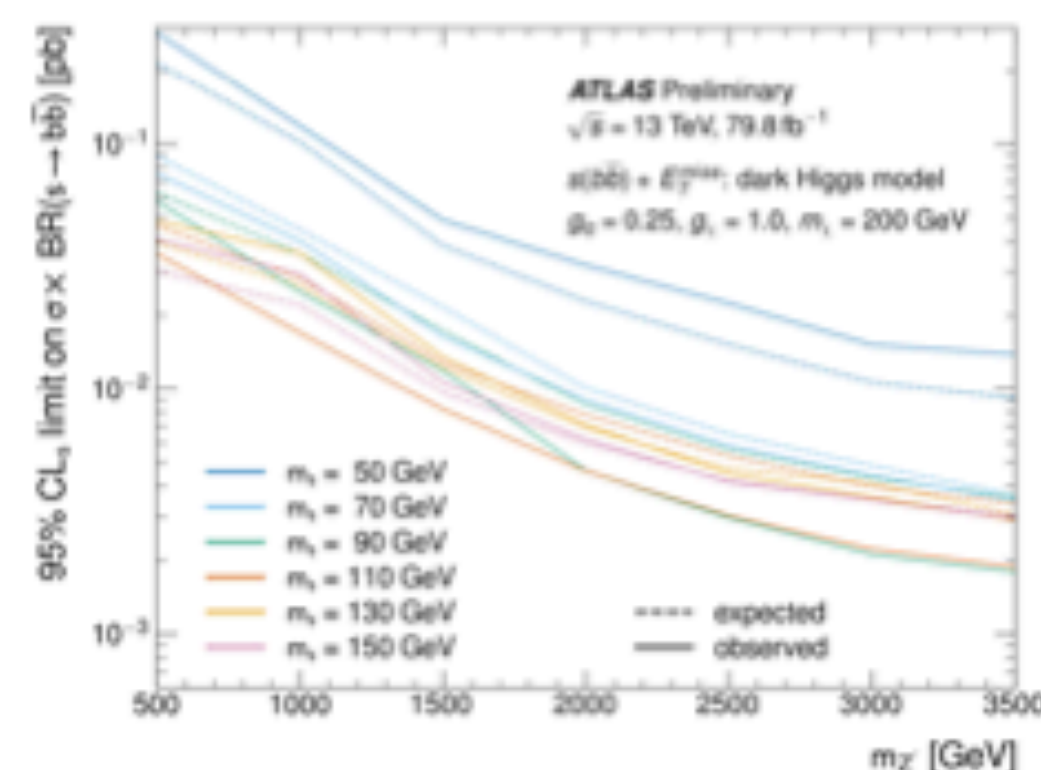


From RECAST

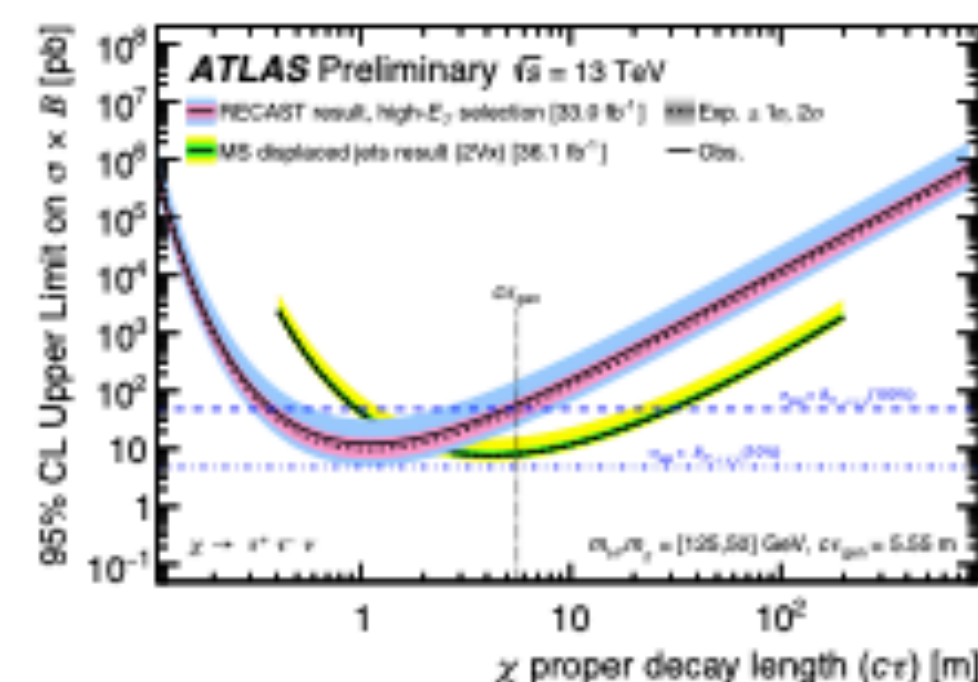


ATLAS RECAST Run 2 wins

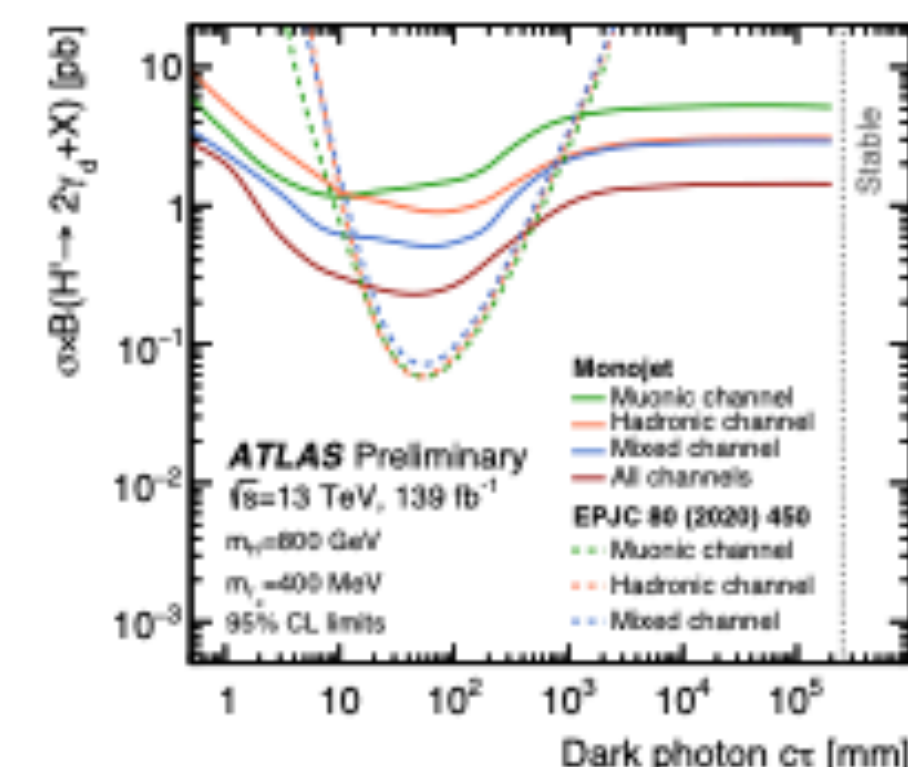
- ▶ SUSY, Exotics, and HDBS have successfully demonstrated RECAST as part of analysis pipeline: total of **91 analyses with RECAST workflow repos**
 - ▶ Need to increase number of *validated* workflows
- ▶ RECAST as an enabling technology (c.f. **Ben Hodkinson's SUSY Workshop talk on pMSSM scan**)
- ▶ Recasting of analyses resulted in ATLAS PUB notes from Exotics that extended the scope of the original publications!



ATL-PHYS-PUB-2019-032



ATL-PHYS-PUB-2020-007



ATL-PHYS-PUB-2021-020

Other effort:

- Analysis Preservation:
 - SUSY, Exotics and HDBS have made RECAST a publication requirement:
 - Up to 91 analyses now contain the RECAST workflow
- Reinterpretation effort Publication plans:
 - PMSSM summary
 - RPC-RPV paper
 - Active reinterpretation of Mono-H(bb)
 - Summary Plots from ATLAS Searches for Pair-Produced Leptoquarks
 - Constraints on spin-0 dark matter mediators and invisible Higgs decays