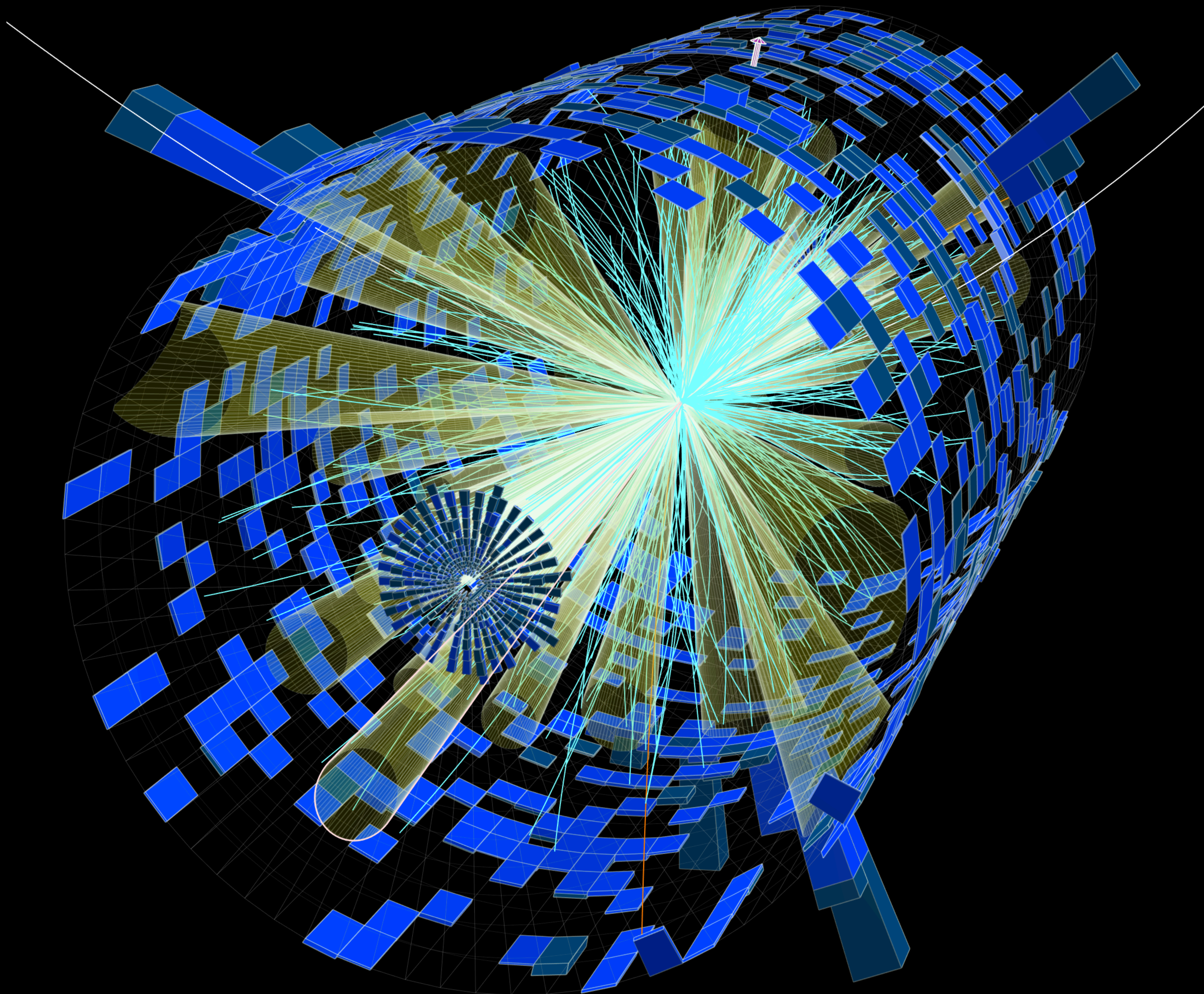
NYU Center for Data Science

Center for Cosmology and Particle Physics

TOWARDS A WHITE-PAPER ON PUBLIC LIKELIHOODS



@KyleCranmer
New York University
Department of Physics
Center for Data Science
CILVR Lab

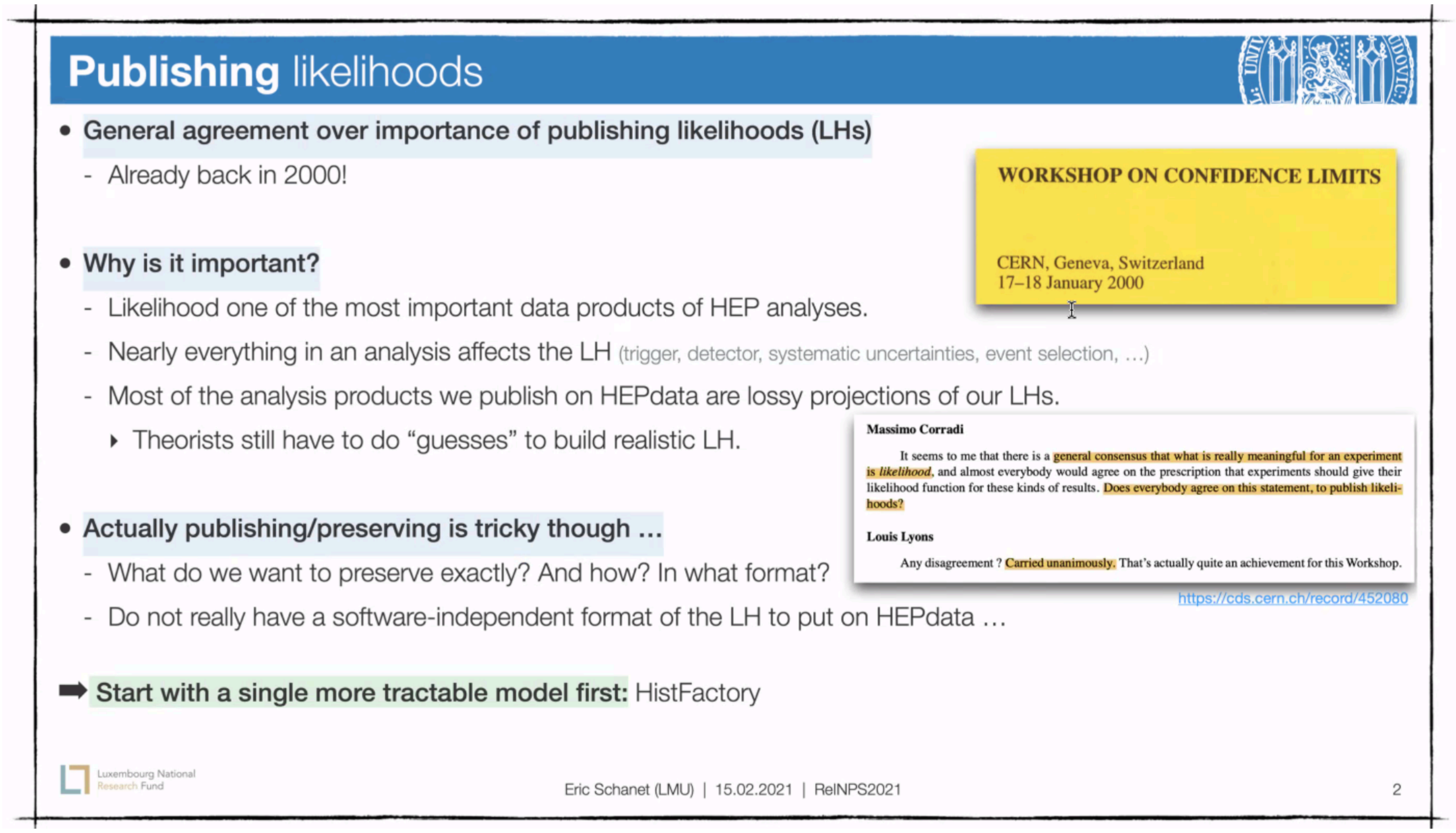
Introduction

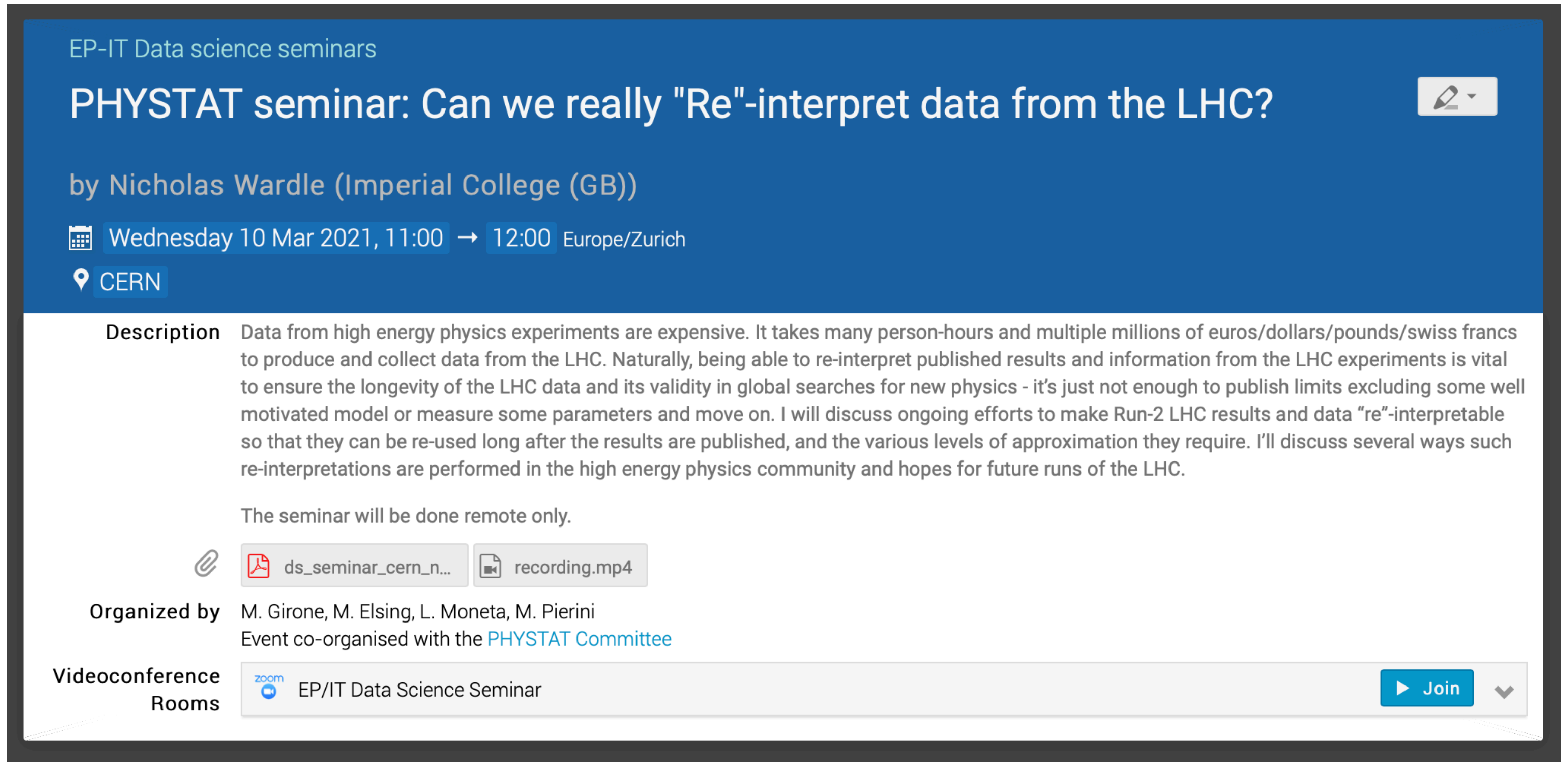
I have **a lot** of thoughts on this topic, so aiming at high-level points

- Please see PhyStat seminar for more details that may be helpful for the white paper https://indico.cern.ch/event/962997/

See also Nicholas Wardle's PhyStat Seminar:

- https://indico.cern.ch/event/1012319/





Introduction

Topics:

- Technical issues around likelihoods
- Surrounding (cyber)infrastructure: repositories, citation, RECAST, …
- Incentives, encouragement, evidence to support those in community working to make this happen
- Goals of white paper, audience

Introduction

We are at a "tipping point" There is more positive momentum than I've ever seen

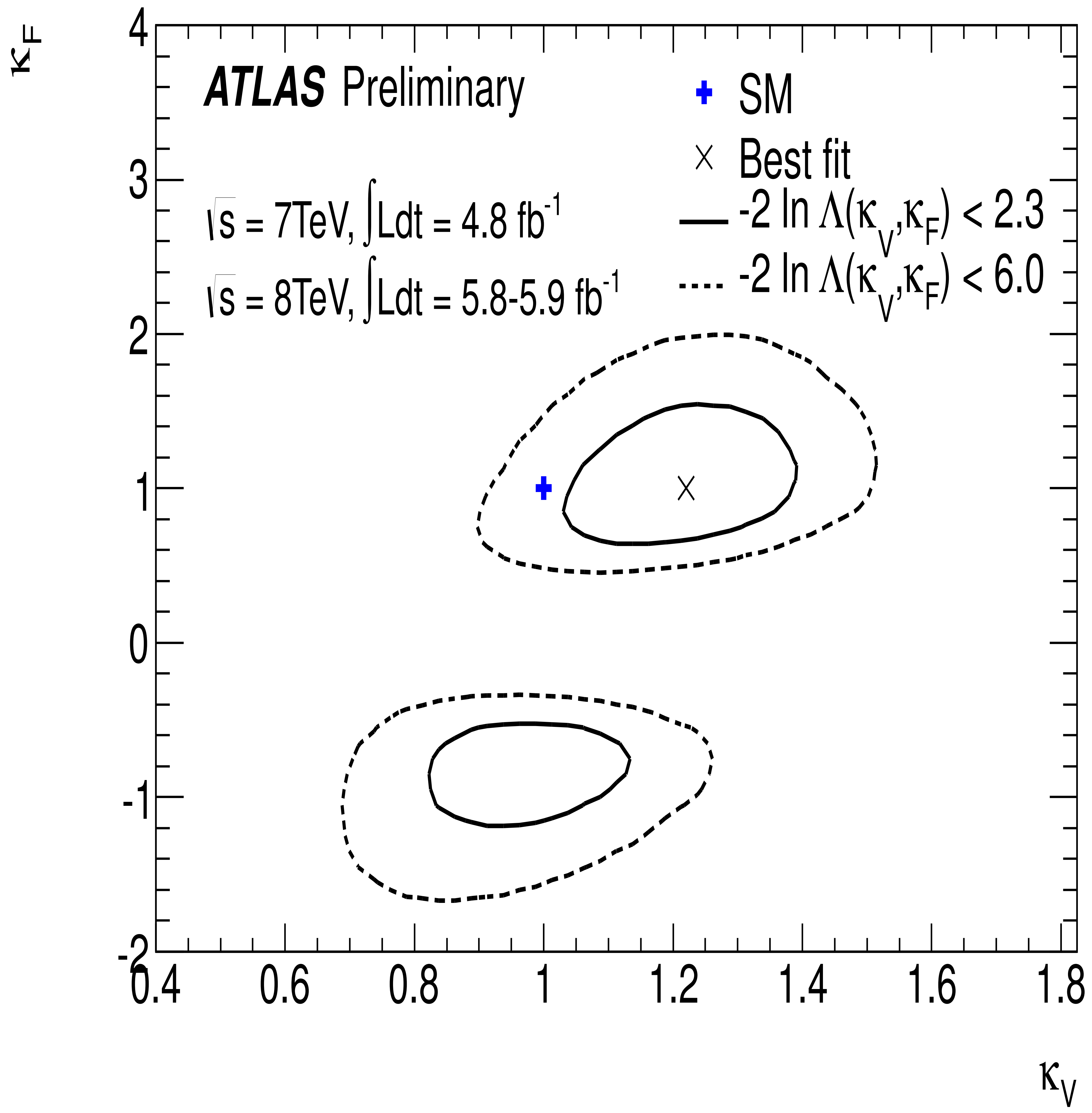
- Suggest we take a positive tone of encouragement
- We should also all educate ourselves about all the efforts that are going on:
  - Citations to DOIs for software and data products
  - Training efforts

My sense is that within different groups (Higgs, SM, SUSY/Exotics, top, flavor) and different experiments (ATLAS, CMS, LHCb, …) there are different attitudes

- e.g. ATLAS SUSY/Exotics embracing full likelihoods, opening discussion more broadly
- but surprisingly Higgs EFT and STXS community don't seem to be very aware of developments or relevance to their problems

REPRODUCIBILITY PROBLEM

Not possible for others to reproduce results from paper.



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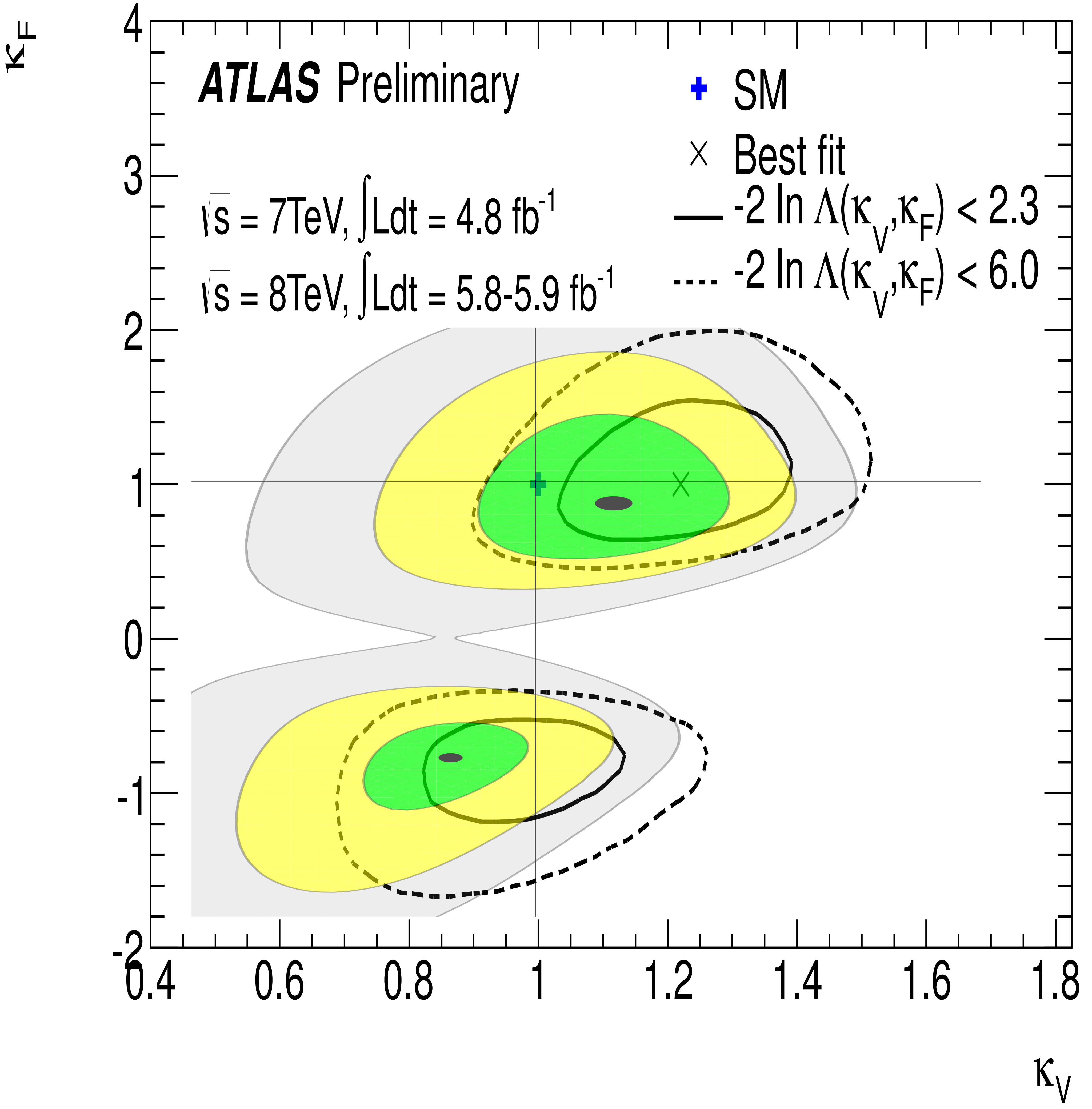
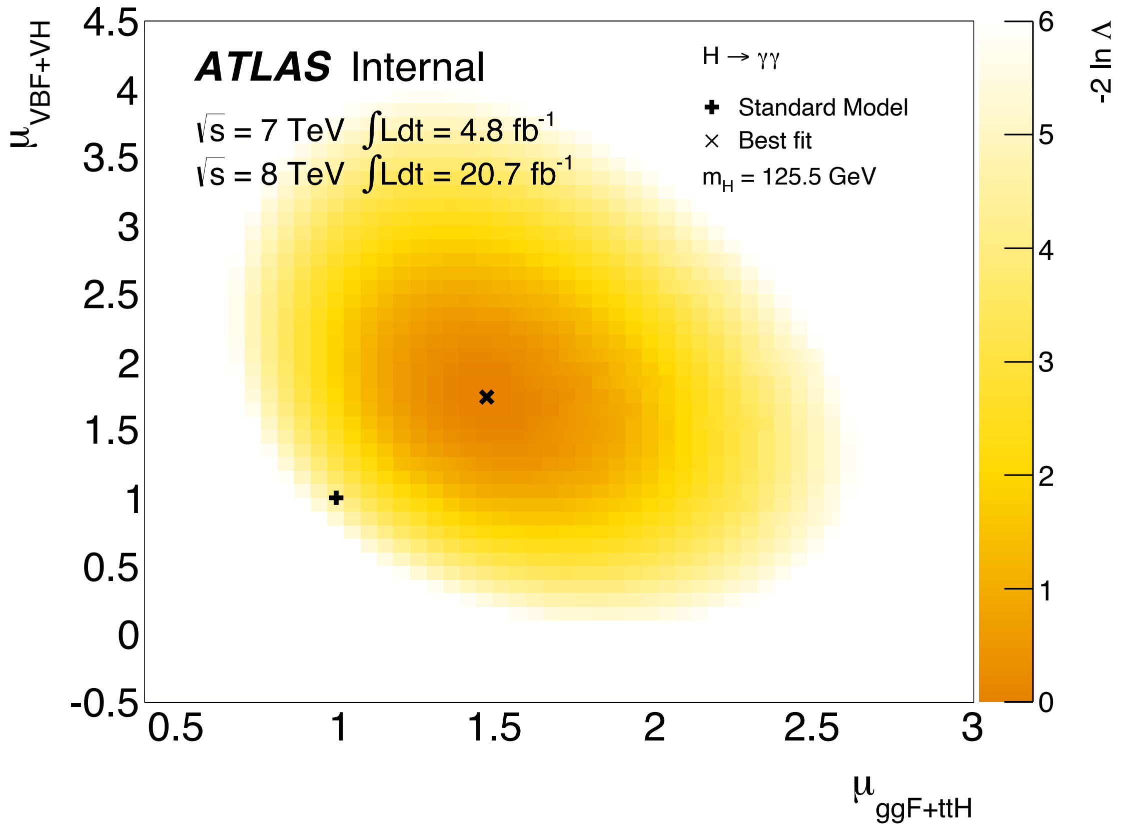


LIKELIHOOD SCANS

First step: publish likelihood scans for communicating LHC Higgs results.

http://doi.org/10.7484/INSPIREHEP.DATA.A78C.HK44



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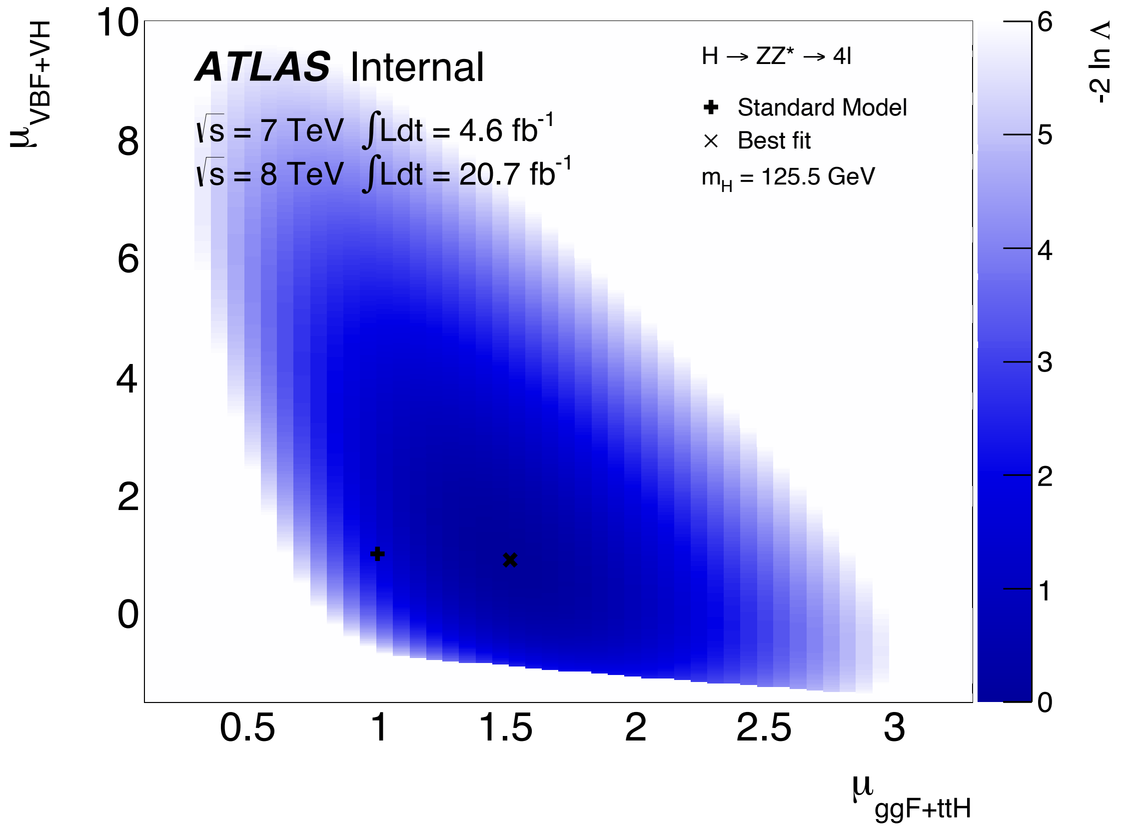
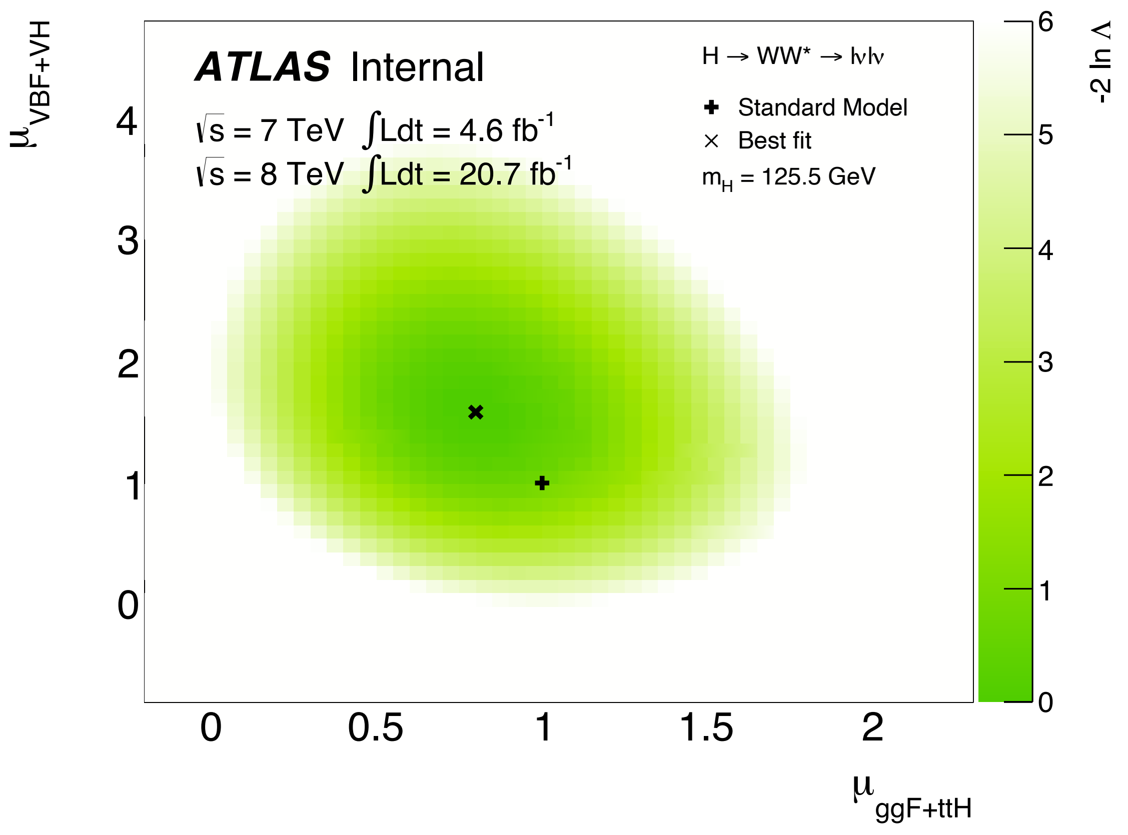


http://doi.org/10.7484/INSPIREHEP.DATA.26B4.TY5F



Information | References (121) | Citations (128) | Files | Plots | HepData

Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

ATLAS Collaboration (Georges Aad (Freiburg U.) *et al.*) *Show all 2923 authors*

Jul 4, 2013 - 32 pages

Phys.Lett. B726 (2013) 88-119

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23

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Information | Citations (7) | Files

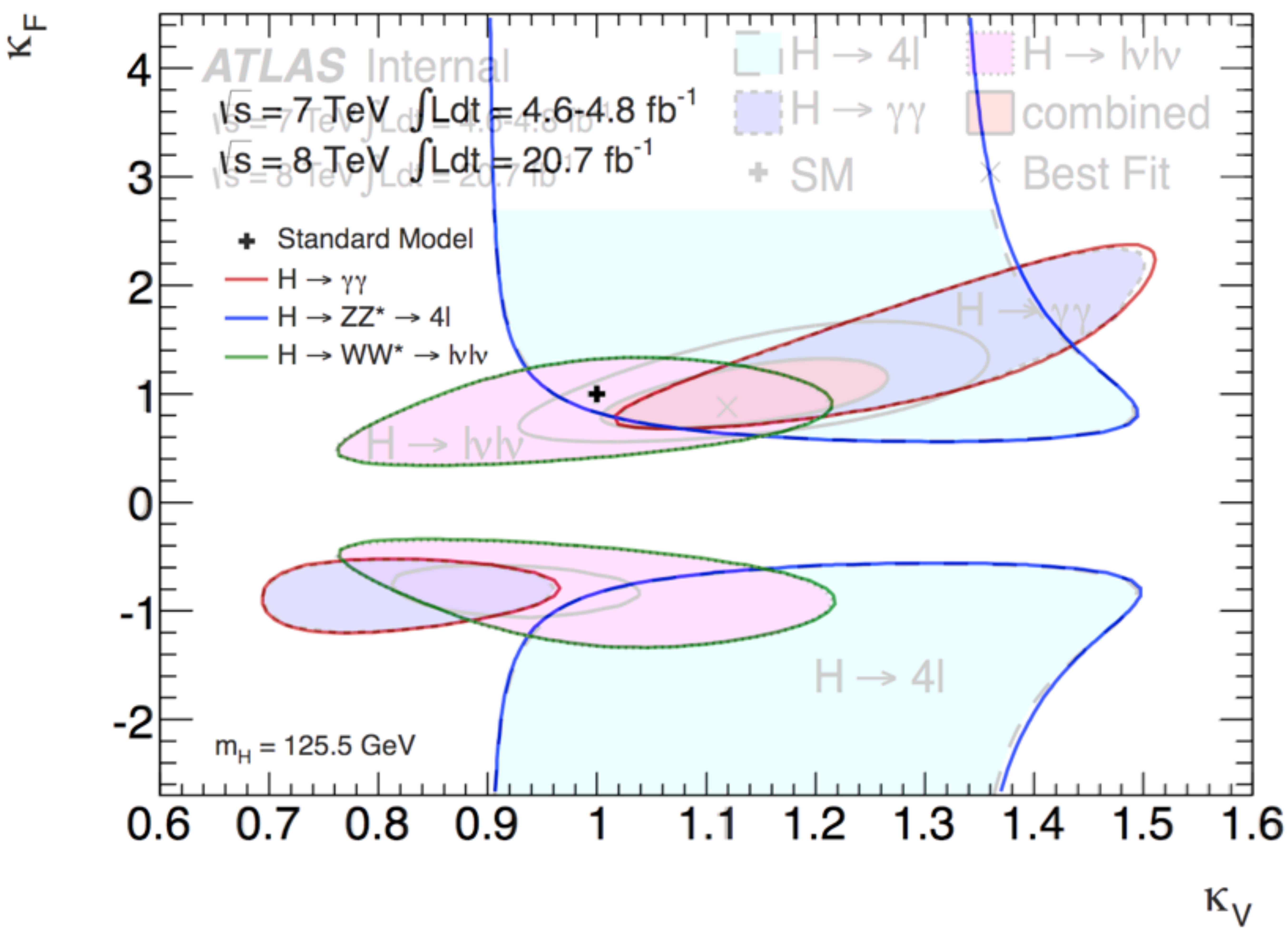
Data from Figure 7 from: Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC

ATLAS Collaboration (Aad, Georges (Freiburg U.) [...]) *Show all 2923 authors*

Cite as: ATLAS Collaboration (2013) HepData, http://doi.org/10.7484/INSPIREHEP.DATA.A78C.HK44

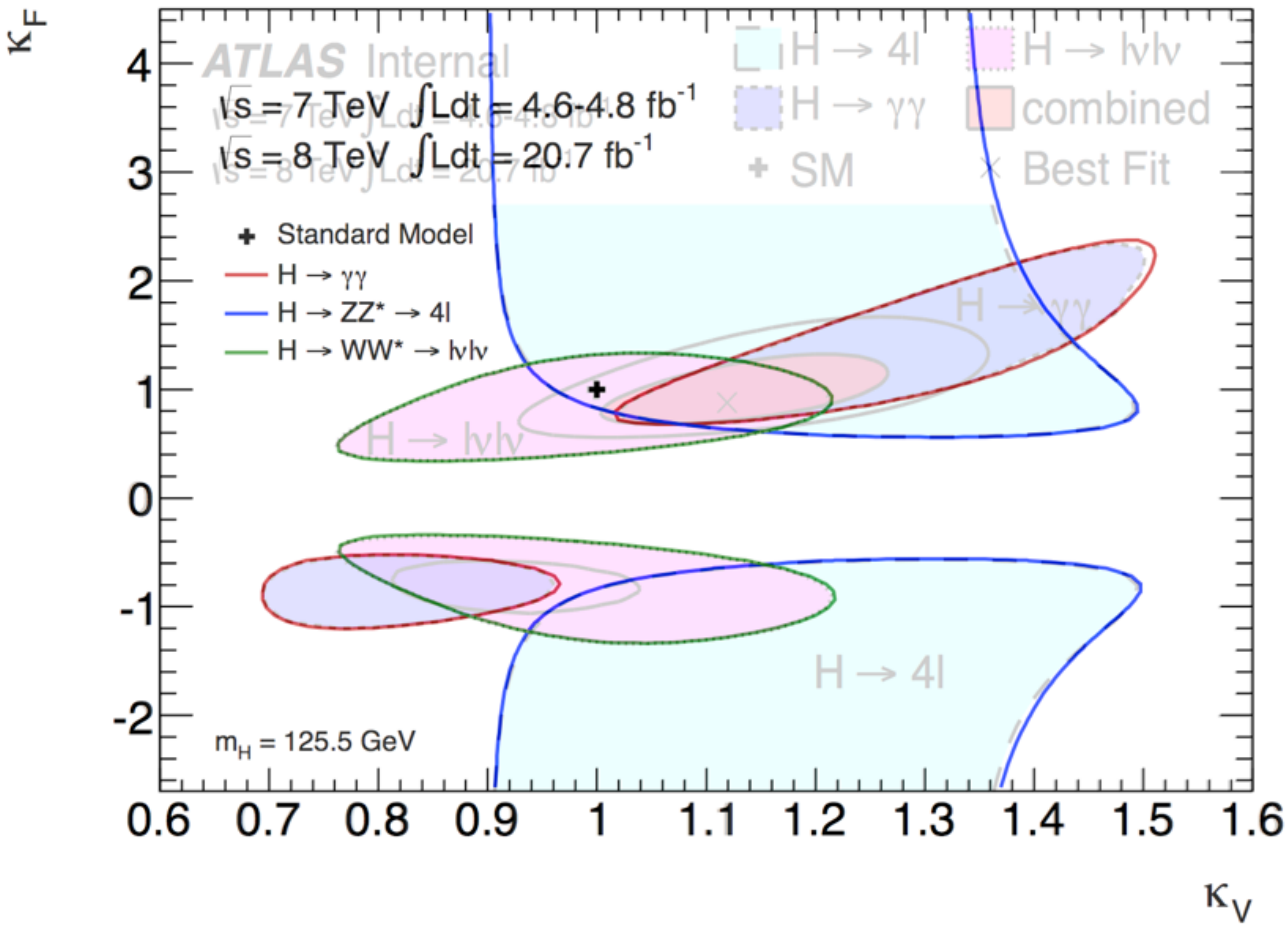
LIKELIHOODS SCANS

Reproducing derived results from original paper!



LIKELIHOODS SCANS

Reproducing derived results from original paper!



But still simplified likelihood scans, not the full statistical model

Terminology

Given a **probability model** $p(X | \theta)$ and a data x_0

- The **likelihood function** is a function of the parameter θ, and the value is given by $L(\theta) = p(X = x_0 | \theta)$
- But $L(\theta)$ doesn't describe the distribution in X
- Technically the likelihood function doesn't have enough enough information to generate synthetic data (toy Monte Carlo), which is needed for most frequentist statistical procedures

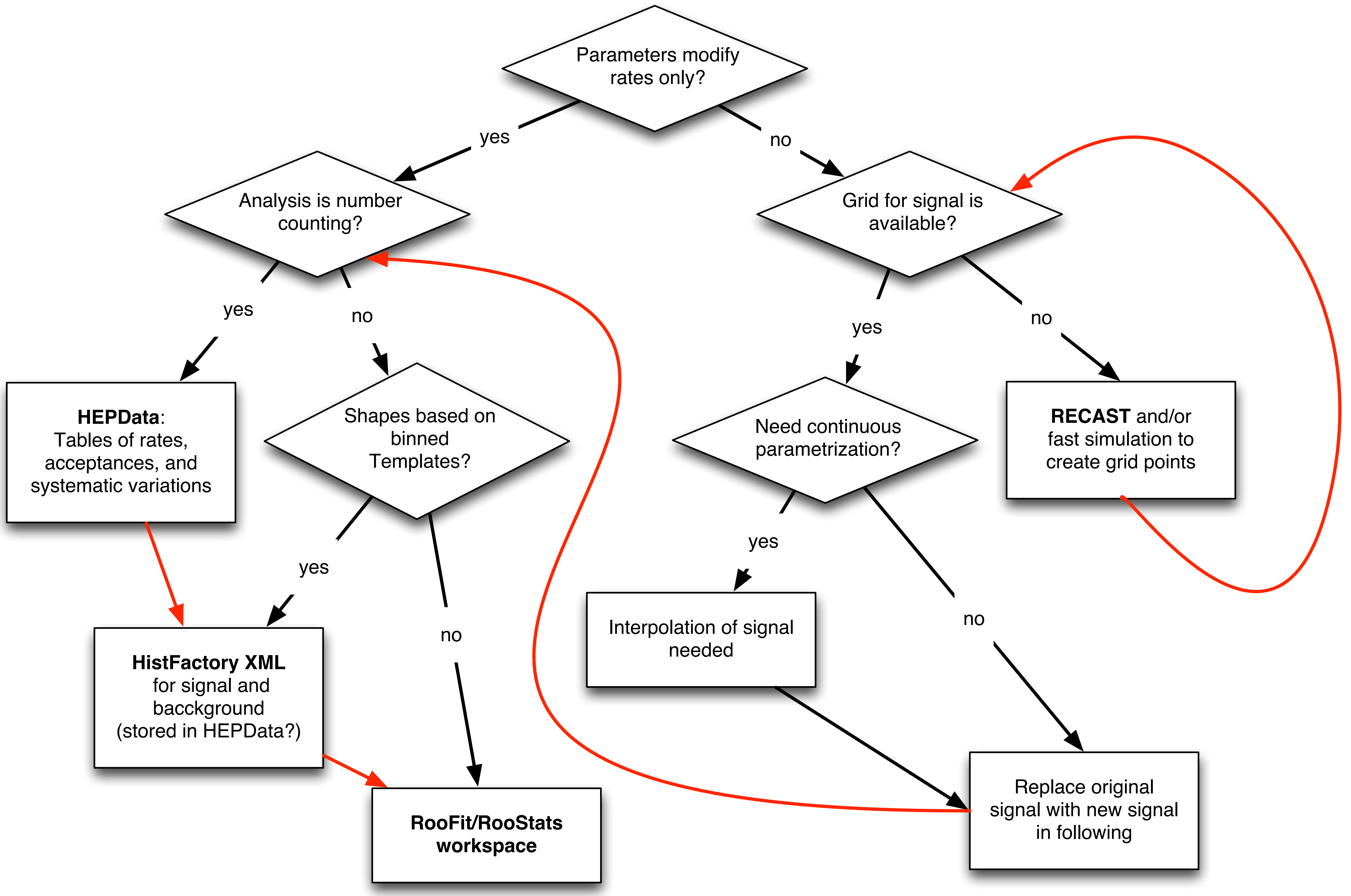
Colloquially, the term likelihood function is used in HEP often when we mean the full probability model $p(X | \theta)$

- We should be clear in paper, but no need to belabor the point here

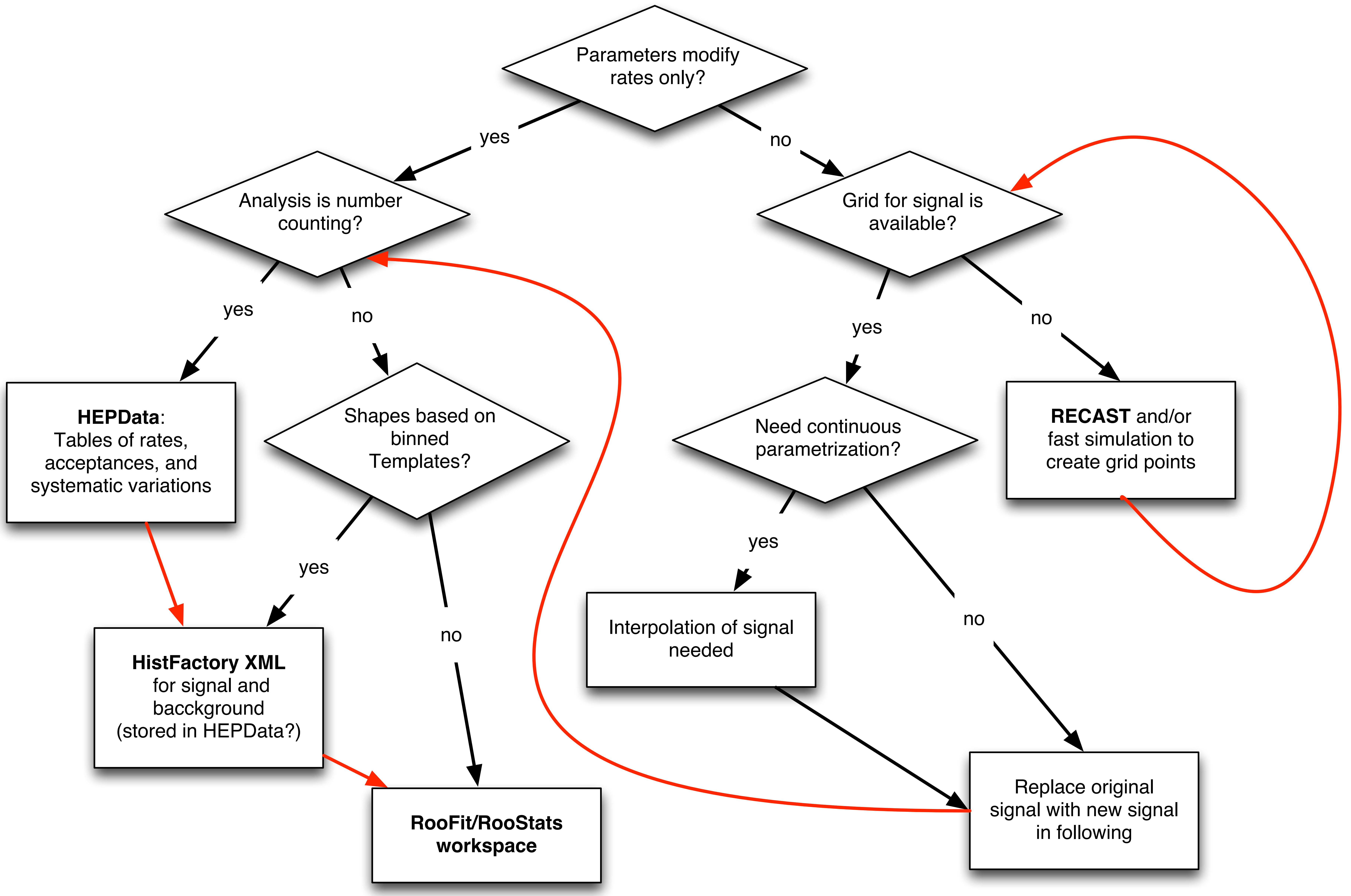
Note: an intermediate provide a function $f(x, \theta) \propto p(x | \theta)$ (e.g. a NN likelihood ratio)

- it is a function of the data x, but you can't (easily) sample from it (e.g. to generate toy MC)

Roadmap (2012)



Roadmap (2012)



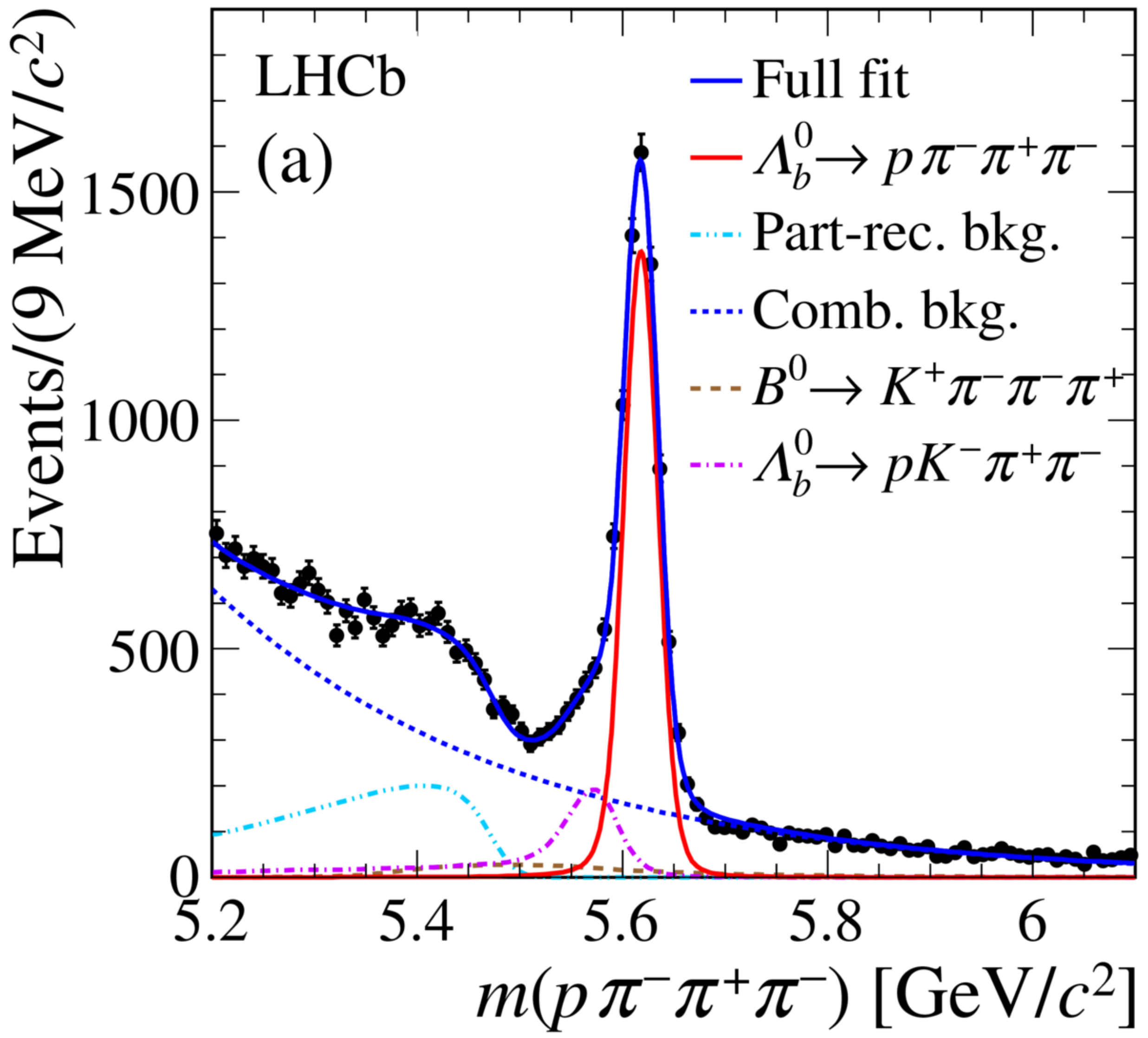
Likelihood Publishing + RECAST =

Binned vs. unbinned

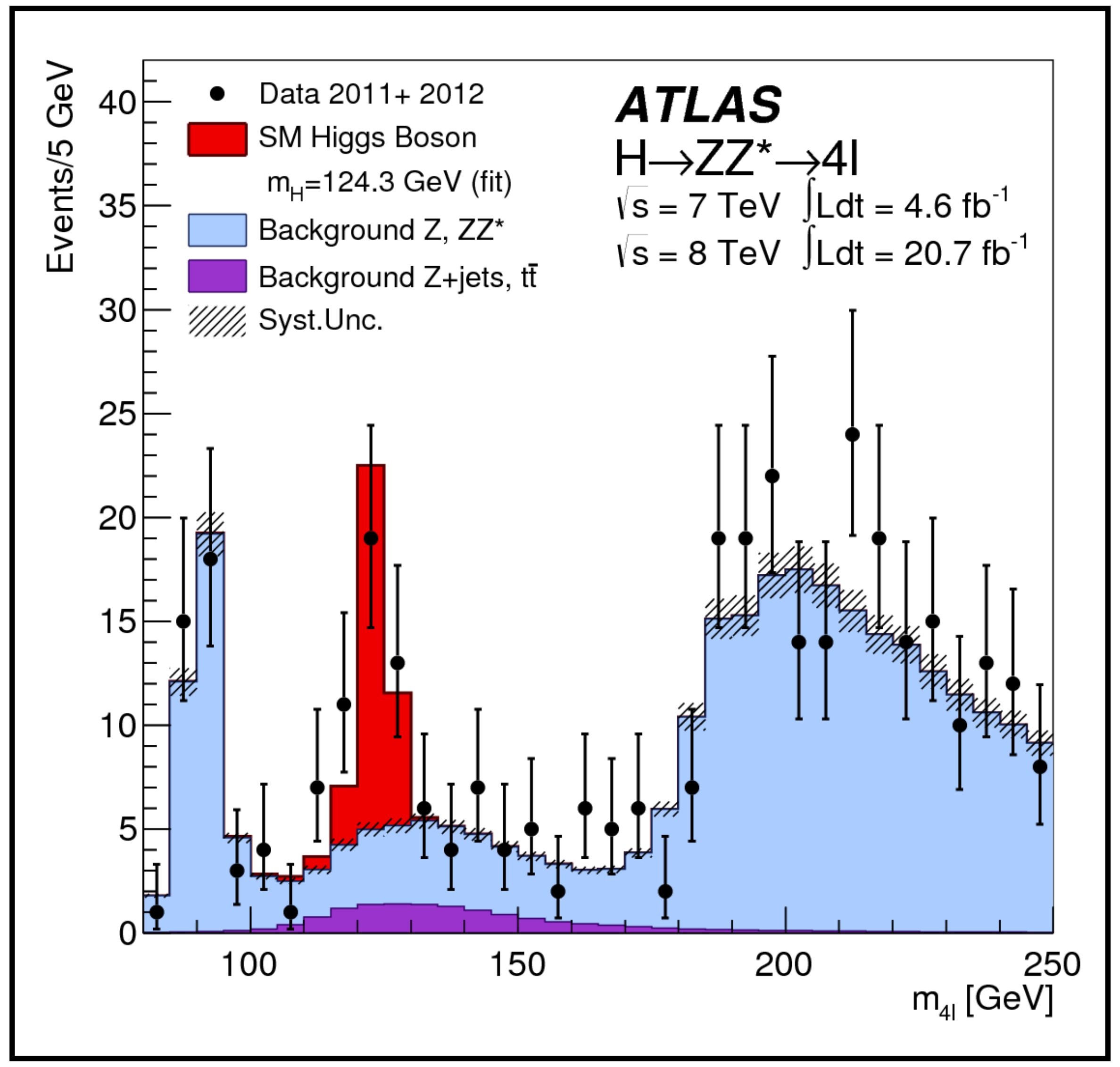
The RooWorkspace was designed to be able to store any type of statistical model
→ source of many complications

broadly we have two classes of analyses: **binned** and **unbinned**

unbinned



binned

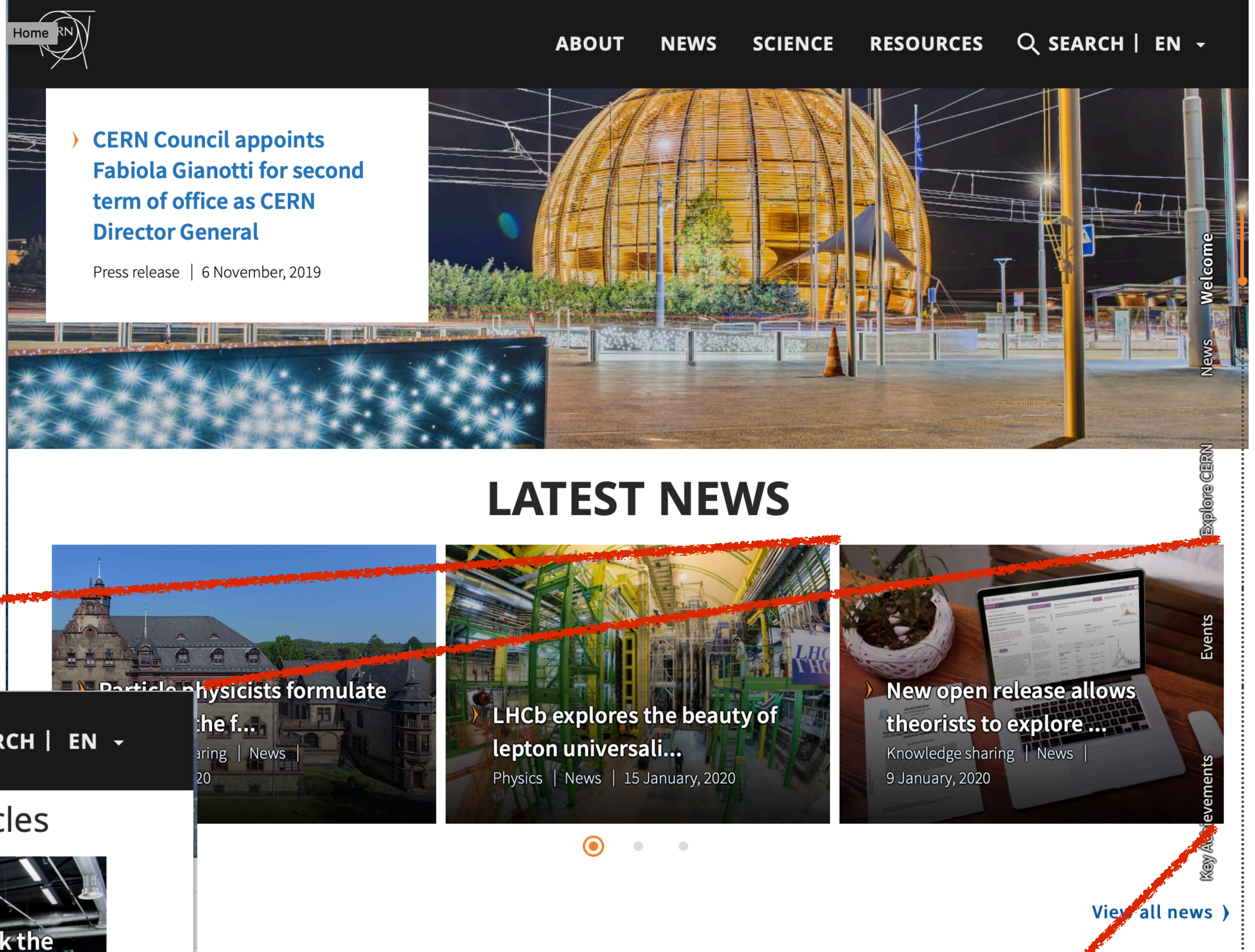


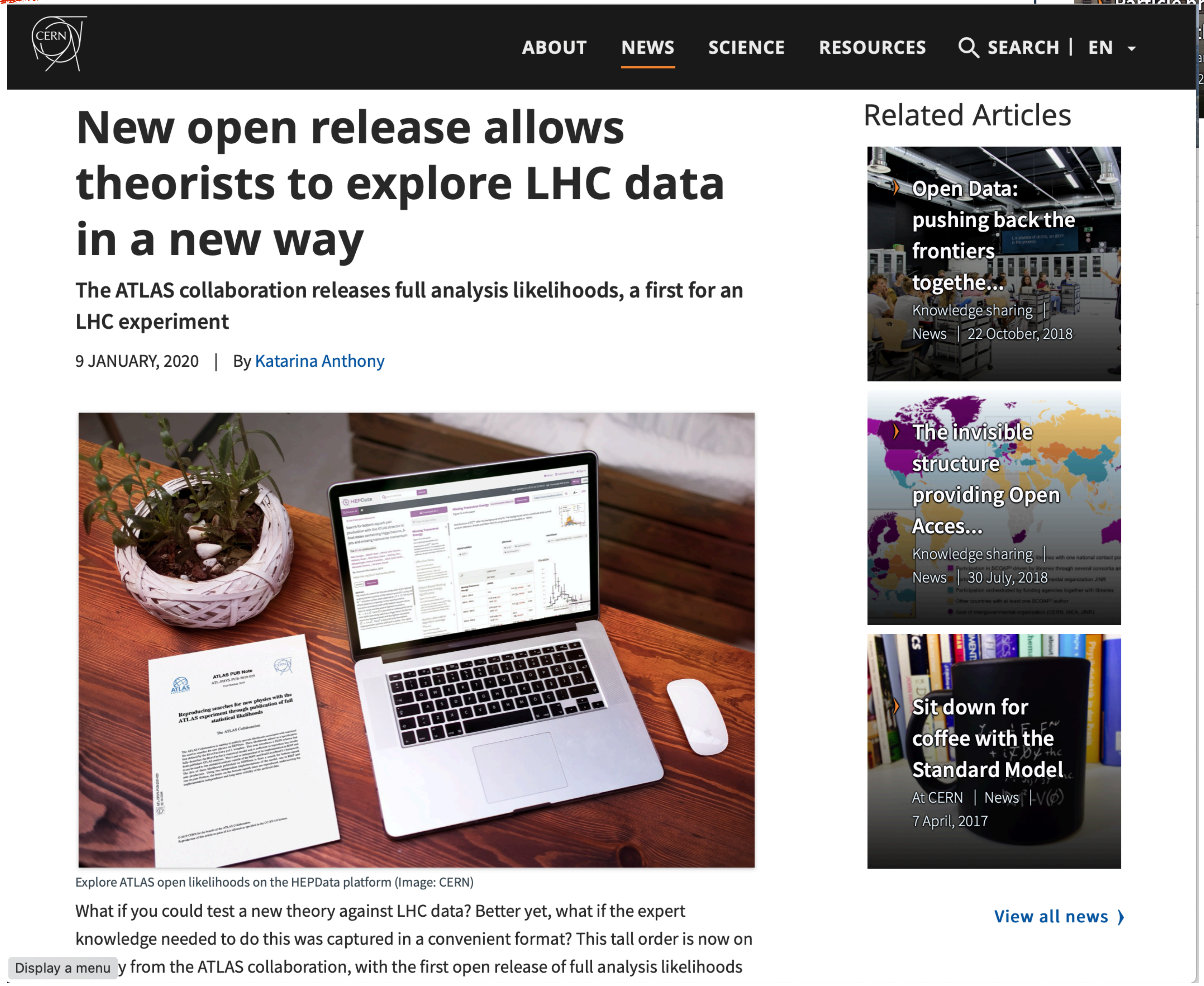
[Slide from Lukas Heinrich]

Recent progress

Recently ATLAS has started publishing full likelihoods to HEPData for SUSY and exotics searches

- Perfect for STXS-type measurements





New open release allows theorists to explore LHC data in a new way

The ATLAS collaboration releases full analysis likelihoods, a first for an LHC experiment

9 JANUARY, 2020 | By Katarina Anthony

Explore ATLAS open likelihoods on the HEPData platform (Image: CERN)

What if you could test a new theory against LHC data? Better yet, what if the expert knowledge needed to do this was captured in a convenient format? This tall order is now on

Display a menu y from the ATLAS collaboration, with the first open release of full analysis likelihoods

Related Articles

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https://scikit-hep.org/pyhf/

pyhf
differentiable Likelihoods

More published pyhf probability models

More on the way

Cite these!

Published Likelihoods

Updating list of HEPData entries for publications using `HistFactory` JSON likelihoods:

- Search for trilepton resonances from chargino and neutralino pair production in s√=13 TeV pp collisions with the ATLAS detector. 2020. doi:10.17182/hepdata.99806.
- Search for displaced leptons in s√=13 TeV pp collisions with the ATLAS detector. 2020. 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. doi:10.17182/hepdata.91214.
- Search for direct production of electroweakinos in final states with one lepton, missing transverse momentum and a Higgs boson decaying into two b-jets in (pp) collisions at s√=13 TeV with the ATLAS detector. 2020. doi:10.17182/hepdata.90607.
- Search for chargino-neutralino production with mass splittings near the electroweak scale in three-lepton final states in s√ = 13 TeV pp collisions with the ATLAS detector. 2019. doi:10.17182/hepdata.91127.
- Search for direct stau production in events with two hadronic τ-leptons in s√=13 TeV pp collisions with the ATLAS detector. 2019. doi:10.17182/hepdata.92006.
- Search for bottom-squark pair production with the ATLAS detector in final states containing Higgs bosons, b-jets and missing transverse momentum. 2019. doi:10.17182/hepdata.89408.

HEPData

Repository for publication-related High-Energy Physics data

pyhf ∂ifferentiable ℒikelihoods

From yesterday

Different analysis strategies

- Highly optimised analyses targeting specific properties / operators
  - → "best possible" sensitivity
  - → very model specific
- Fiducial and differential cross section measurements
  - → minimise model dependence
  - → relatively restricted sensitivity (hard to combine different channels)
  - → re-interpretable outside experiment
- Differential measurements in experimentally sensitive observables per production mode (STXS)
  - → model dependence from production mode definition
  - → easy combination of different Higgs decay channels → sensitivity to large number of EFT operators
  - → re-interpretable outside experiment

Saskia Falke | Inputs to EFT fits | 29/10/2020 | 3 /

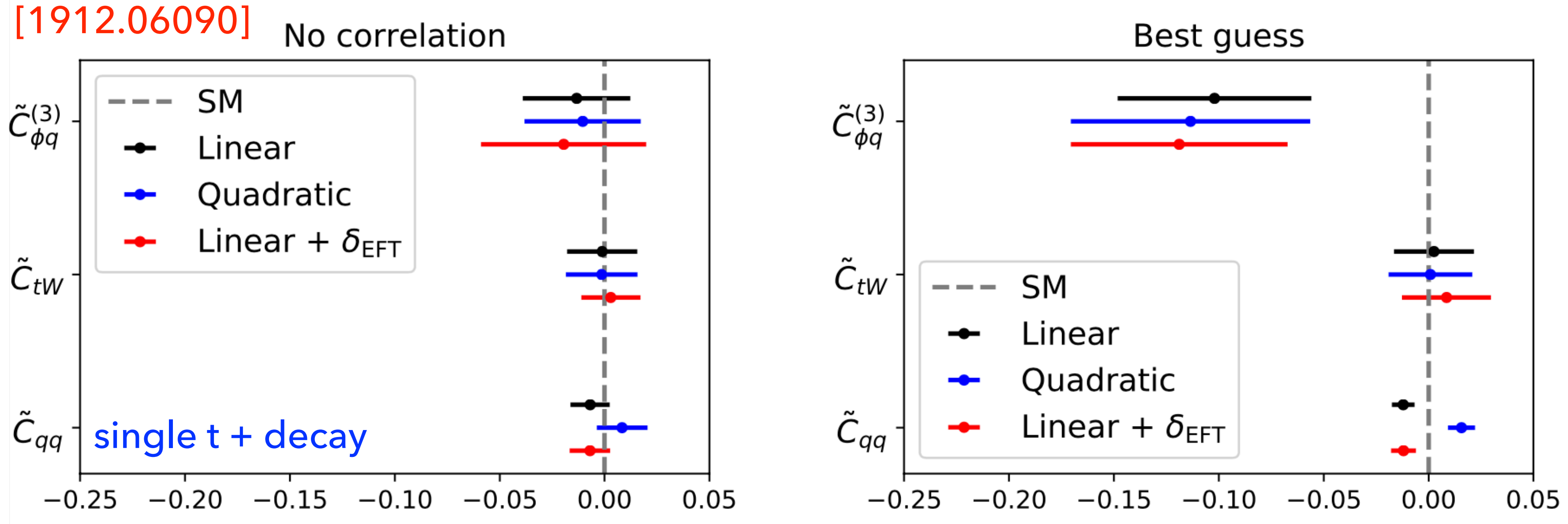
← Note the pros and cons

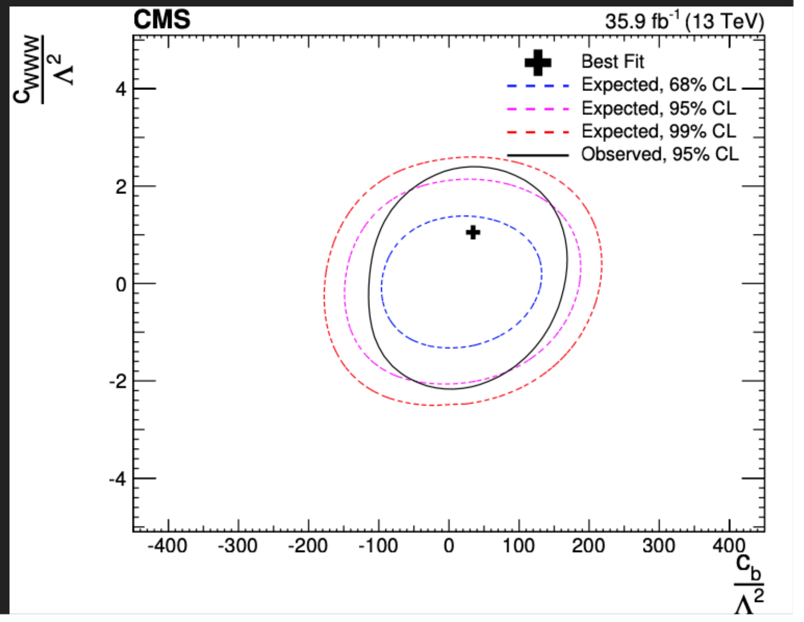
- This list of what is needed looks a lot like the discussions in reinterpretation of BSM searches ↓

WHAT IS NEEDED | OSCAR ÉBOLI | 12

- Information on experimental cut flows, efficiencies
- Information on backgrounds
- Information on results and corresponding correlations (becoming standard)
- Information on the likelihood
- Desirable to have results at particle level, and distributions (STXS or fiducial distr.)

[1912.06090]





- Makes me think of this ↓ from 2012

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

S. Kraml[1], B.C. Allanach[2], M. Mangano[3], H.B. Prosper[4], S. Sekmen[3,4] (editors), C. Balazs[5], A. Barr[6], P. Bechtle[7], G. Belanger[8], A. Belyaev[9,10], K. Benslama[11], M. Campanelli[12], K. Cranmer[13], A. De Roeck[3], M.J. Dolan[14], T. Eifert[15], J.R. Ellis[16,3], M. Felcini[17], B. Fuks[18], D. Guadagnoli[8,19], J.F. Gunion[20], S. Heinemeyer[17], J. Hewett[15], A. Ismail[15], M. Kadastik[21], M. Krämer[22], J. Lykken[23] F. Mahmoudi[3,24], S.P. Martin[25,26,27], T. Rizzo[15], T. Robens[28], M. Tytgat[29], A. Weiler[30]

Gold Standard: Full Likelihoods

Different analysis strategies

- Highly optimised analyses targeting specific properties / operators
  - → "best possible" sensitivity
  - → very model specific
- Fiducial and differential cross section measurements
  - → minimise model dependence
  - → relatively restricted sensitivity (hard to combine different channels)
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- Differential measurements in experimentally sensitive observables per production mode (STXS)
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  - → re-interpretable outside experiment

Saskia Falke | Inputs to EFT fits | 29/10/2020 | 3 / 22

For EFT measurements, I think combined fits based on the full likelihood models in the "folded" data space are the most principled approach

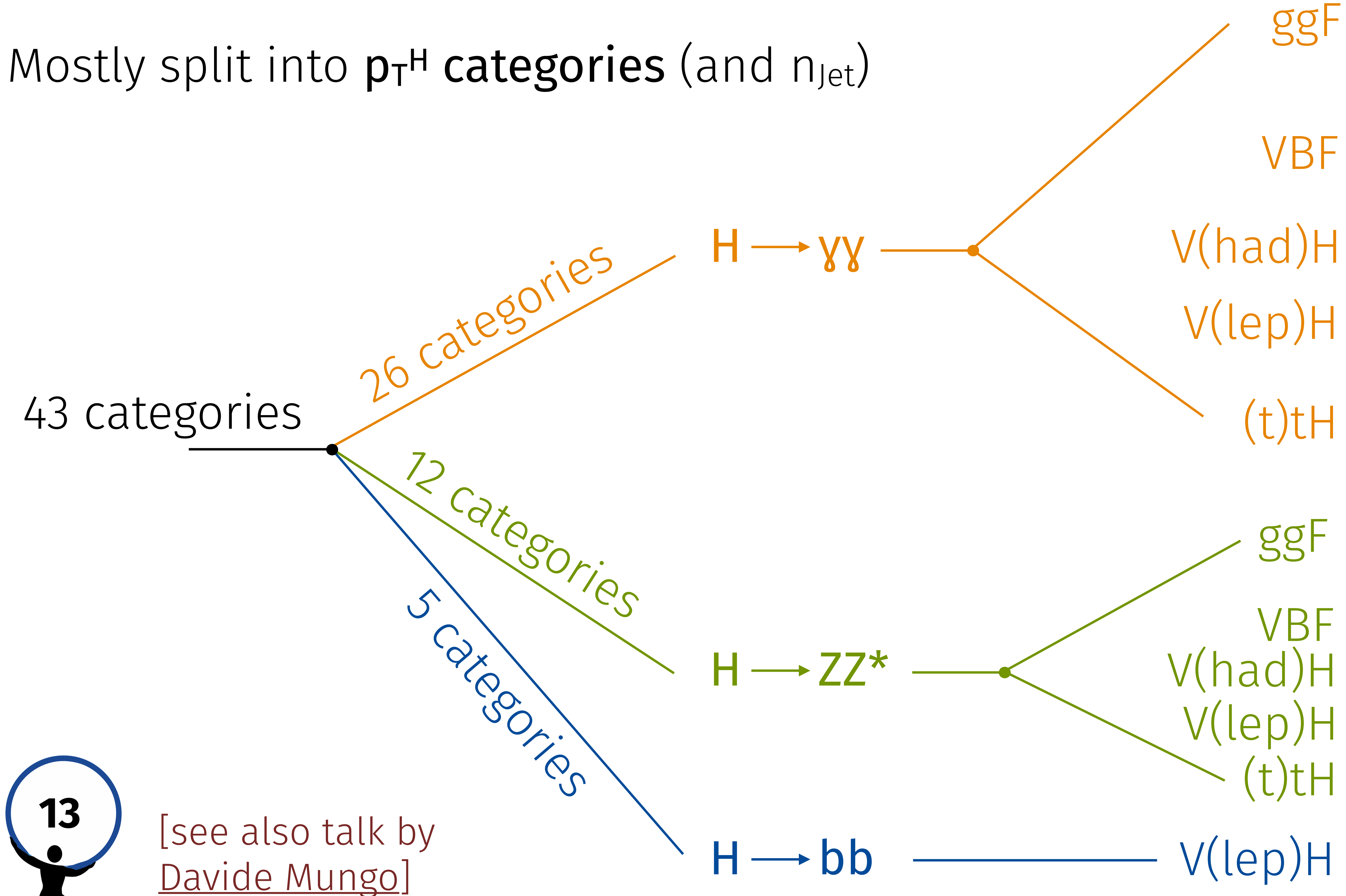
- Likelihood can be based on STXS or dedicated analysis
- This should be the gold standard for the flagship EFT results

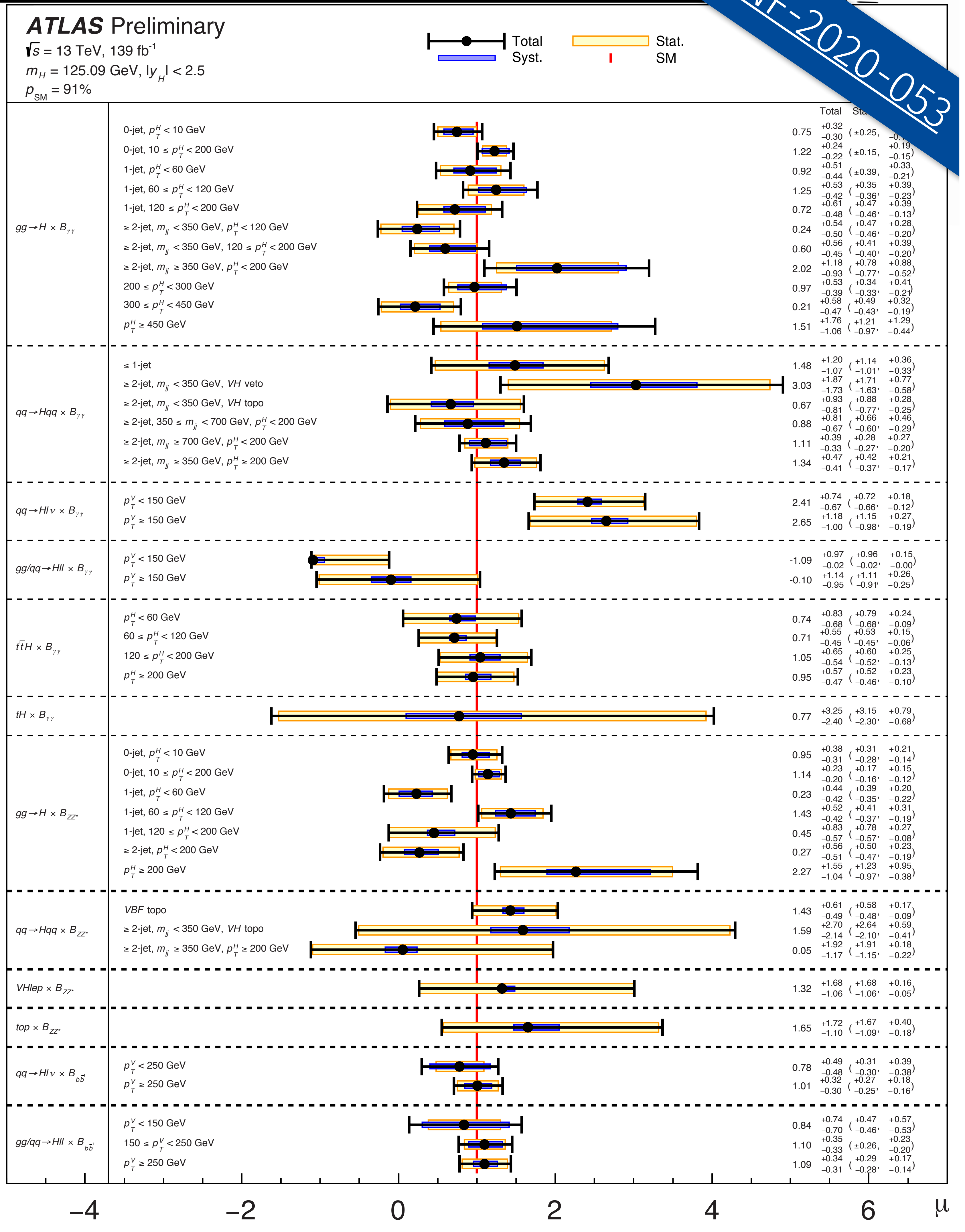
The STXS combination measurement

ATLAS-CONF-2020-053

Aim: EFT interpretation of the 139 fb^{-1} combination of $H \rightarrow ZZ^* \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow bb$ merged stage-1.2 STXS measurement

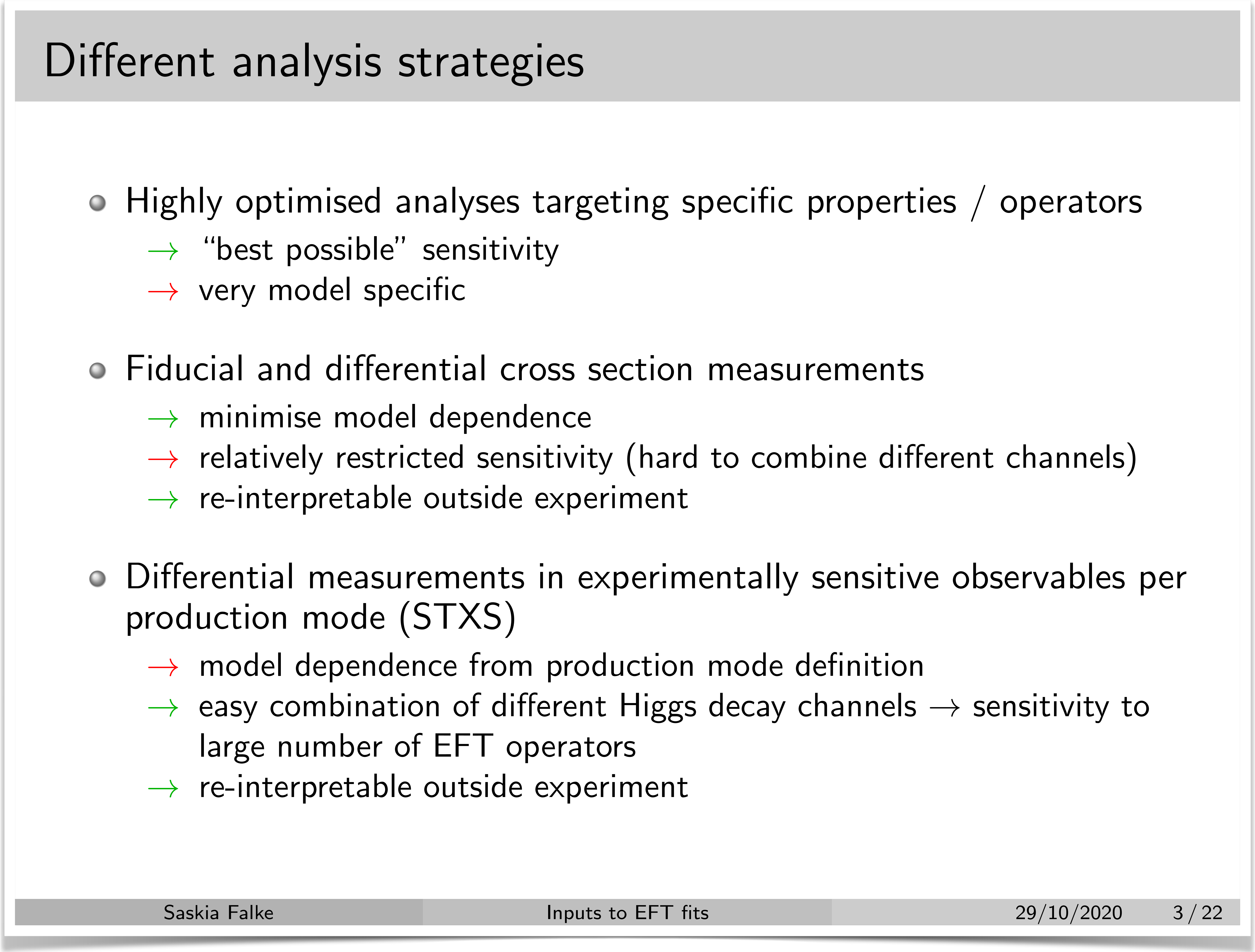
Mostly split into p_T^H **categories** (and n_{Jet})





[see also talk by Davide Mungo]

RECAST + STXS overcomes model dependence



The model dependence in STXS mainly connected to how results are conveyed.

- The phase space regions are just phase space regions, they don't assume any model
- Paired with RECAST one could reinterpret any model using the STXS phase space regions

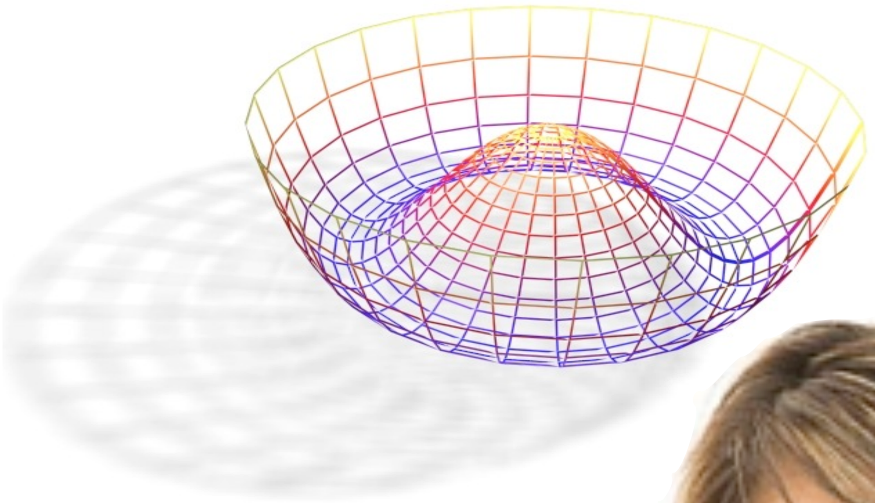
Likelihoods don’t address reinterpretation for signals with different final states or kinematics (eg. Exotic Higgs)

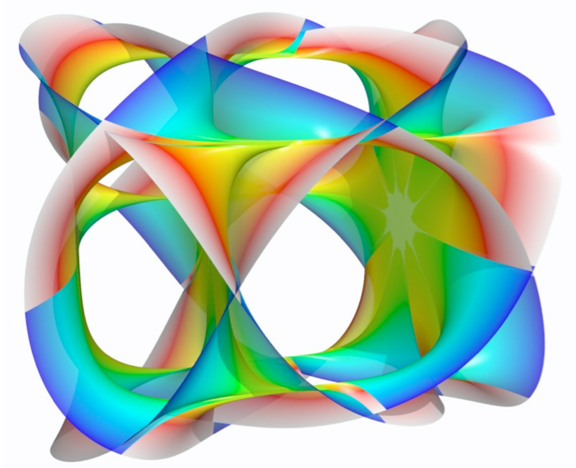
THEORY recast SERVICE

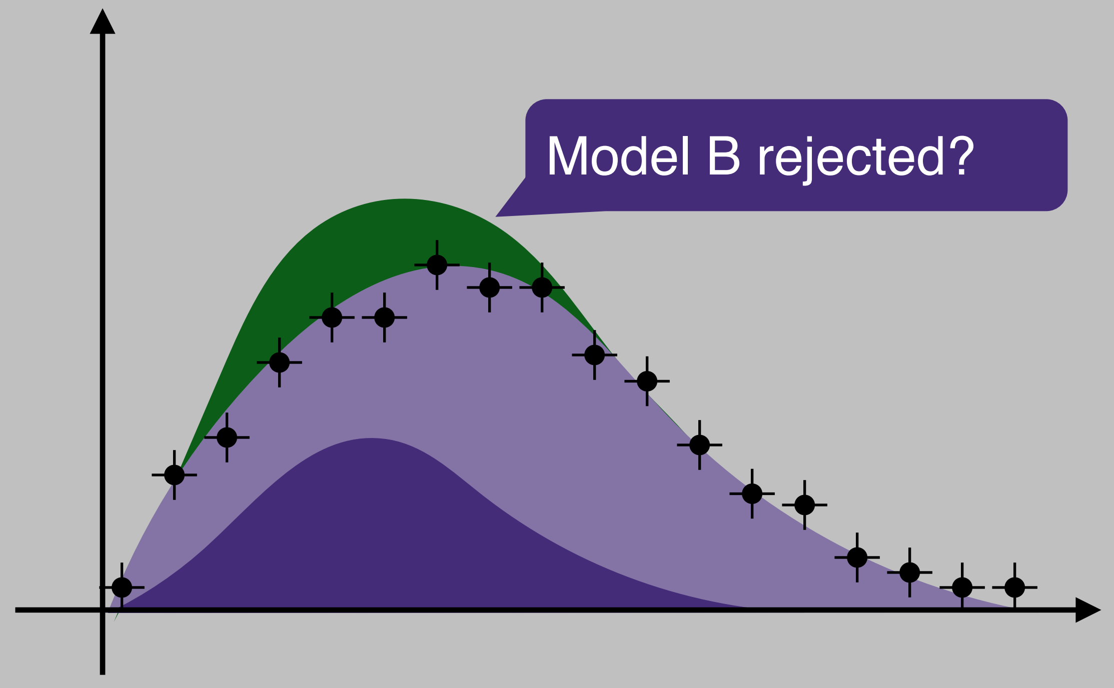
$$
\begin{aligned}
\mathcal{L}_{SM} = \; & \underbrace{\frac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^{a}_{\mu\nu}G^{\mu\nu}_{a}}_{\text{kinetic energies and self-interactions of the gauge bosons}} \\
& + \underbrace{\bar{L}\gamma^{\mu}(i\partial_{\mu} - \frac{1}{2}g\tau\cdot\mathbf{W}_{\mu} - \frac{1}{2}g'YB_{\mu})L + \bar{R}\gamma^{\mu}(i\partial_{\mu} - \frac{1}{2}g'YB_{\mu})R}_{\text{kinetic energies and electroweak interactions of fermions}} \\
& + \underbrace{\frac{1}{2}\left|(i\partial_{\mu} - \frac{1}{2}g\tau\cdot\mathbf{W}_{\mu} - \frac{1}{2}g'YB_{\mu})\,\phi\right|^{2} - V(\phi)}_{W^{\pm},Z,\gamma,\text{and Higgs masses and couplings}} \\
& + \underbrace{g''(\bar{q}\gamma^{\mu}T_{a}q)\,G^{a}_{\mu}}_{\text{interactions between quarks and gluons}} + \underbrace{(G_{1}\bar{L}\phi R + G_{2}\bar{L}\phi_{c}R + h.c.)}_{\text{fermion masses and couplings to Higgs}}
\end{aligned}
$$

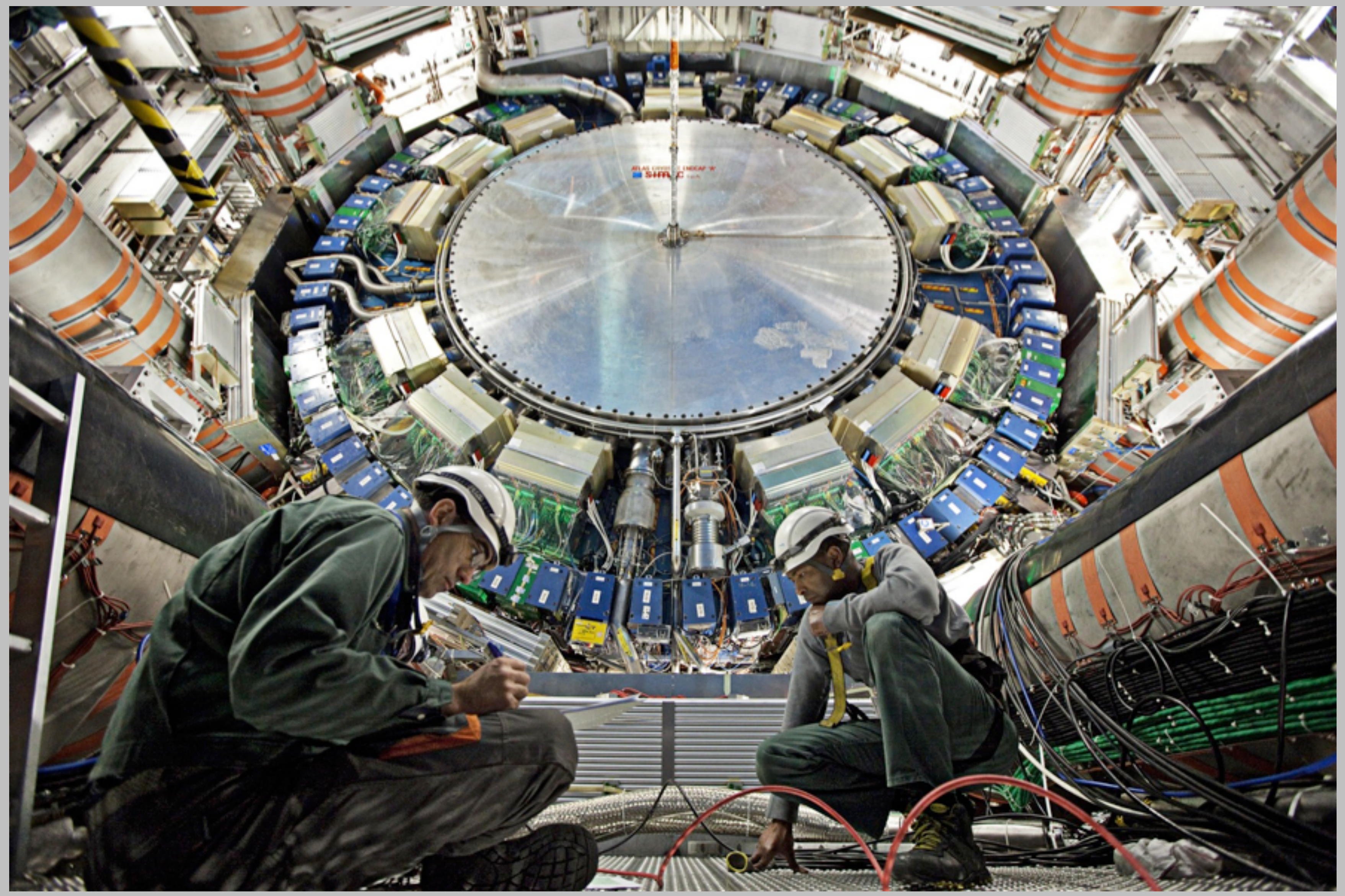
Q

A









Analysis Preservation

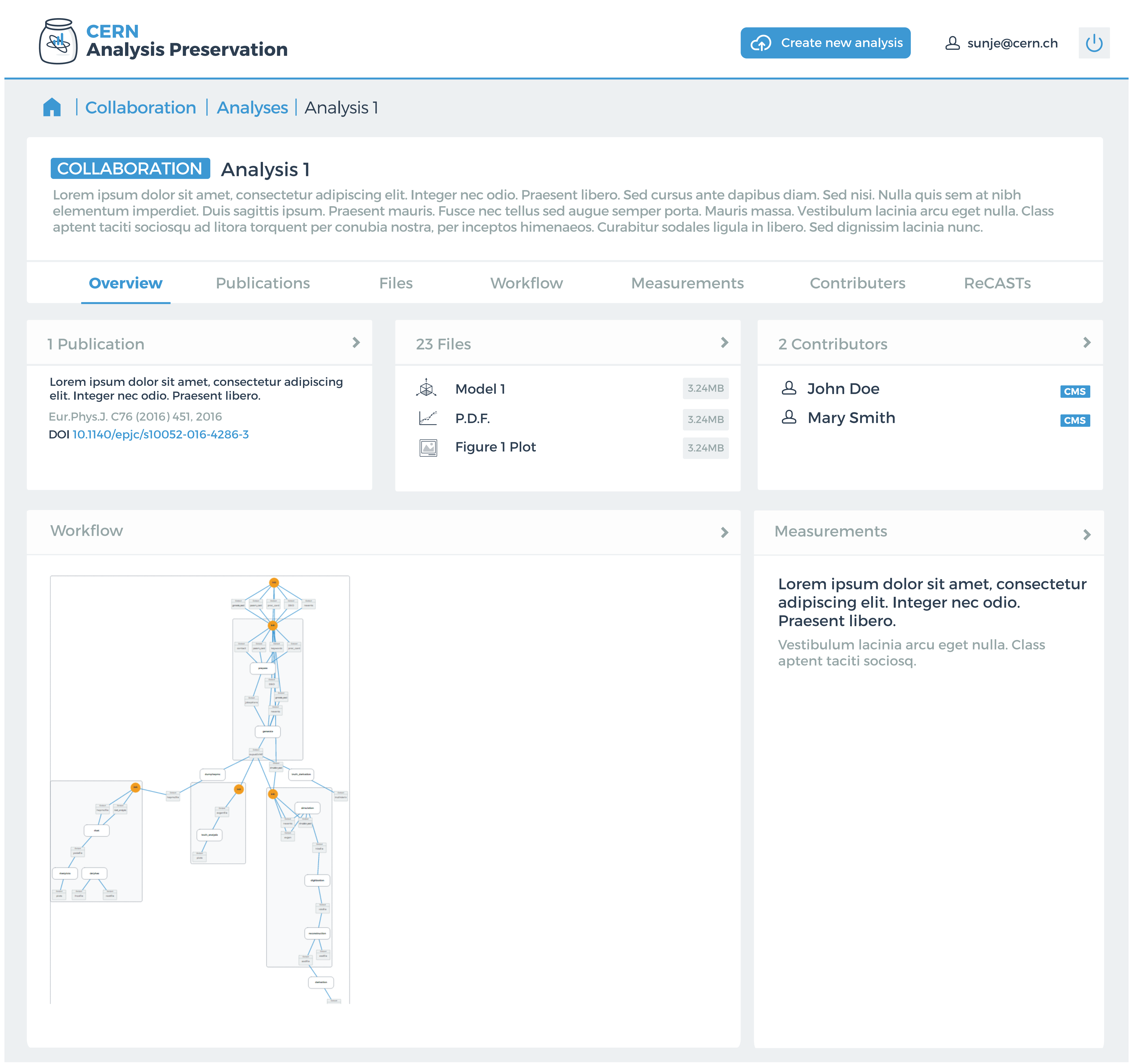
Recently we've made enormous progress in preserving the full analysis chain.

- Makes it possible to run a new new signal through the full analysis chain

reana

Reproducible research data analysis platform

Flexible	Scalable	Reusable	Free
Run many computational workflow engines.	Support for remote compute clouds.	Containerise once, reuse elsewhere. Cloud-native.	Free Software. MIT licence. Made with ❤ at CERN.



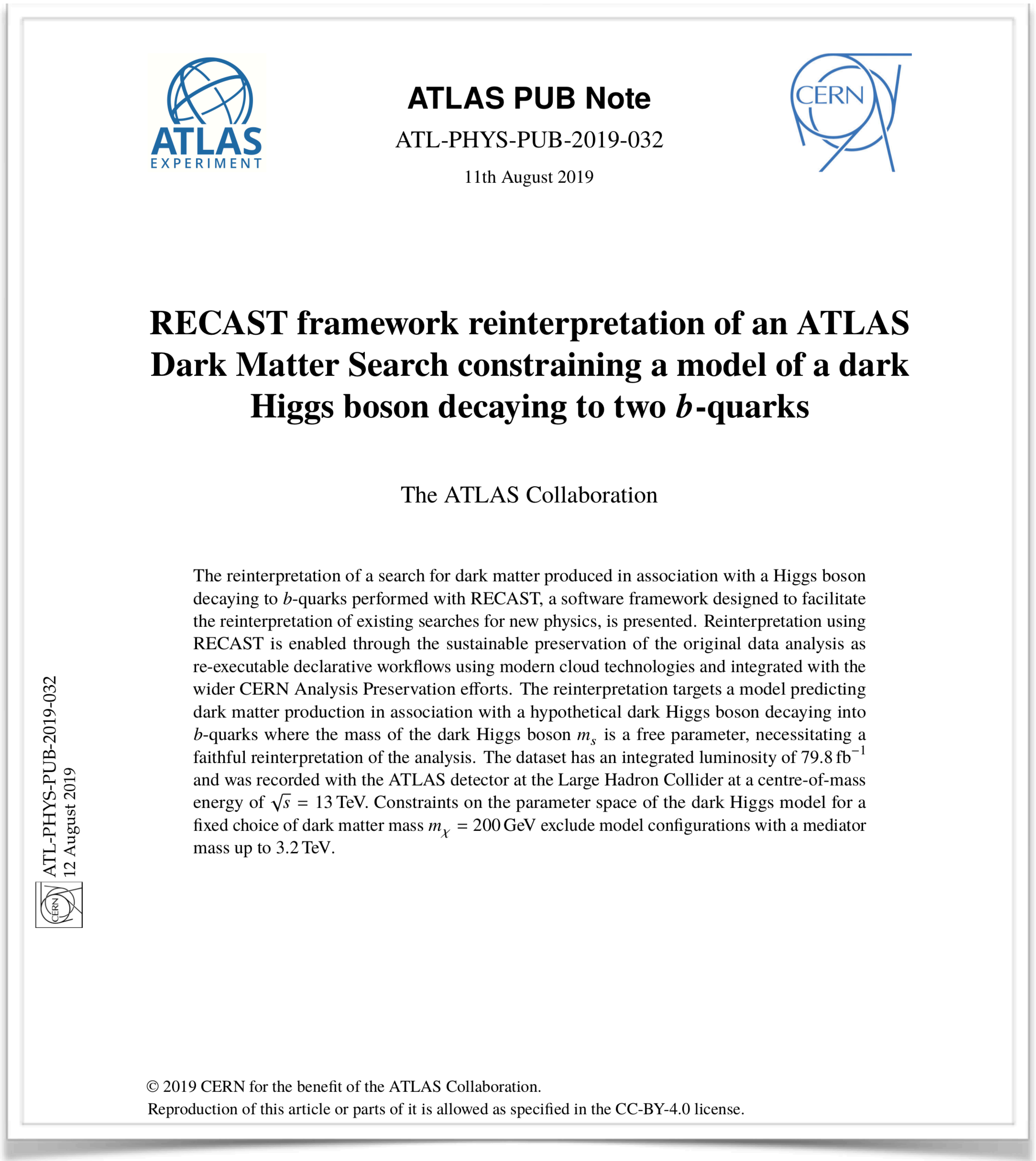
CERN Analysis Preservation

https://doi.org/10.1038/s41567-018-0342-2

RECAST in action

ATLAS has started using RECAST to reinterpret SUSY and exotics searches

- Also relevant for exotic BSM Higgs scenarios



ATLAS PUB Note

ATL-PHYS-PUB-2019-032

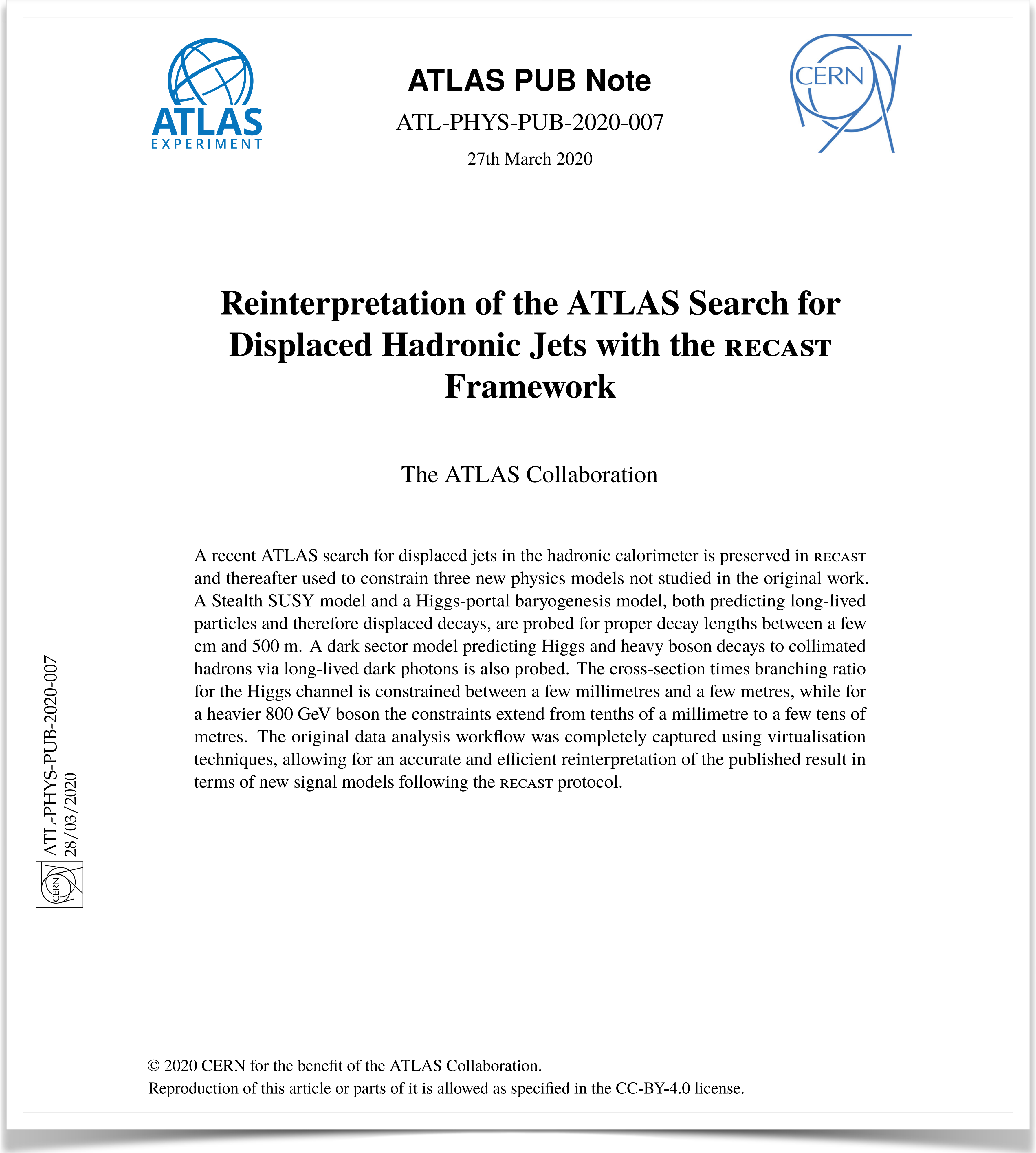
11th August 2019

RECAST framework reinterpretation of an ATLAS Dark Matter Search constraining a model of a dark Higgs boson decaying to two *b*-quarks

The ATLAS Collaboration

The reinterpretation of a search for dark matter produced in association with a Higgs boson decaying to *b*-quarks performed with RECAST, a software framework designed to facilitate the reinterpretation of existing searches for new physics, is presented. Reinterpretation using RECAST is enabled through the sustainable preservation of the original data analysis as re-executable declarative workflows using modern cloud technologies and integrated with the wider CERN Analysis Preservation efforts. The reinterpretation targets a model predicting dark matter production in association with a hypothetical dark Higgs boson decaying into *b*-quarks where the mass of the dark Higgs boson m_s is a free parameter, necessitating a faithful reinterpretation of the analysis. The dataset has an integrated luminosity of 79.8 fb^{-1} and was recorded with the ATLAS detector at the Large Hadron Collider at a centre-of-mass energy of $\sqrt{s}$ = 13 TeV. Constraints on the parameter space of the dark Higgs model for a fixed choice of dark matter mass m_χ = 200 GeV exclude model configurations with a mediator mass up to 3.2 TeV.

ATL-PHYS-PUB-2019-032
12 August 2019



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 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 cm and 500 m. A dark sector model predicting Higgs and heavy boson decays to collimated hadrons via long-lived dark photons is also probed. The cross-section times branching ratio for the Higgs channel is constrained between a few millimetres and a few metres, while for a heavier 800 GeV boson the constraints extend from tenths of a millimetre to a few tens of metres. The original data analysis workflow was completely captured using virtualisation techniques, allowing for an accurate and efficient reinterpretation of the published result in terms of new signal models following the RECAST protocol.

ATL-PHYS-PUB-2020-007
28/03/2020

Shifting from reproducibility to reuse

nature physics

PERSPECTIVE

https://doi.org/10.1038/s41567-018-0342-2

Corrected: Publisher Correction

OPEN

Open is not enough

Xiaoli Chen[1,2], Sünje Dallmeier-Tiessen[1]*, Robin Dasler[1,11], Sebastian Feger[1,3], Pamfilos Fokianos[1], Jose Benito Gonzalez[1], Harri Hirvonsalo[1,4,12], Dinos Kousidis[1], Artemis Lavasa[1], Salvatore Mele[1], Diego Rodriguez Rodriguez[1], Tibor Šimko[1]*, Tim Smith[1], Ana Trisovic[1,5]*, Anna Trzcinska[1], Ioannis Tsanaktsidis[1], Markus Zimmermann[1], Kyle Cranmer[6], Lukas Heinrich[6], Gordon Watts[7], Michael Hildreth[8], Lara Lloret Iglesias[9], Kati Lassila-Perini[4] and Sebastian Neubert[10]

The solutions adopted by the high-energy physics community to foster reproducible research are examples of best practices that could be embraced more widely. This first experience suggests that reproducibility requires going beyond openness.

- Reuse provides a forward-looking narrative, while reproducibility often perceived as backward-looking
- Reproducibility is a byproduct!
- Analysis Preservation distinct from reproducibility
  - Helps with onboarding
  - Empowers reuse, remixing, reproducibility
  - Improves efficiency & equity

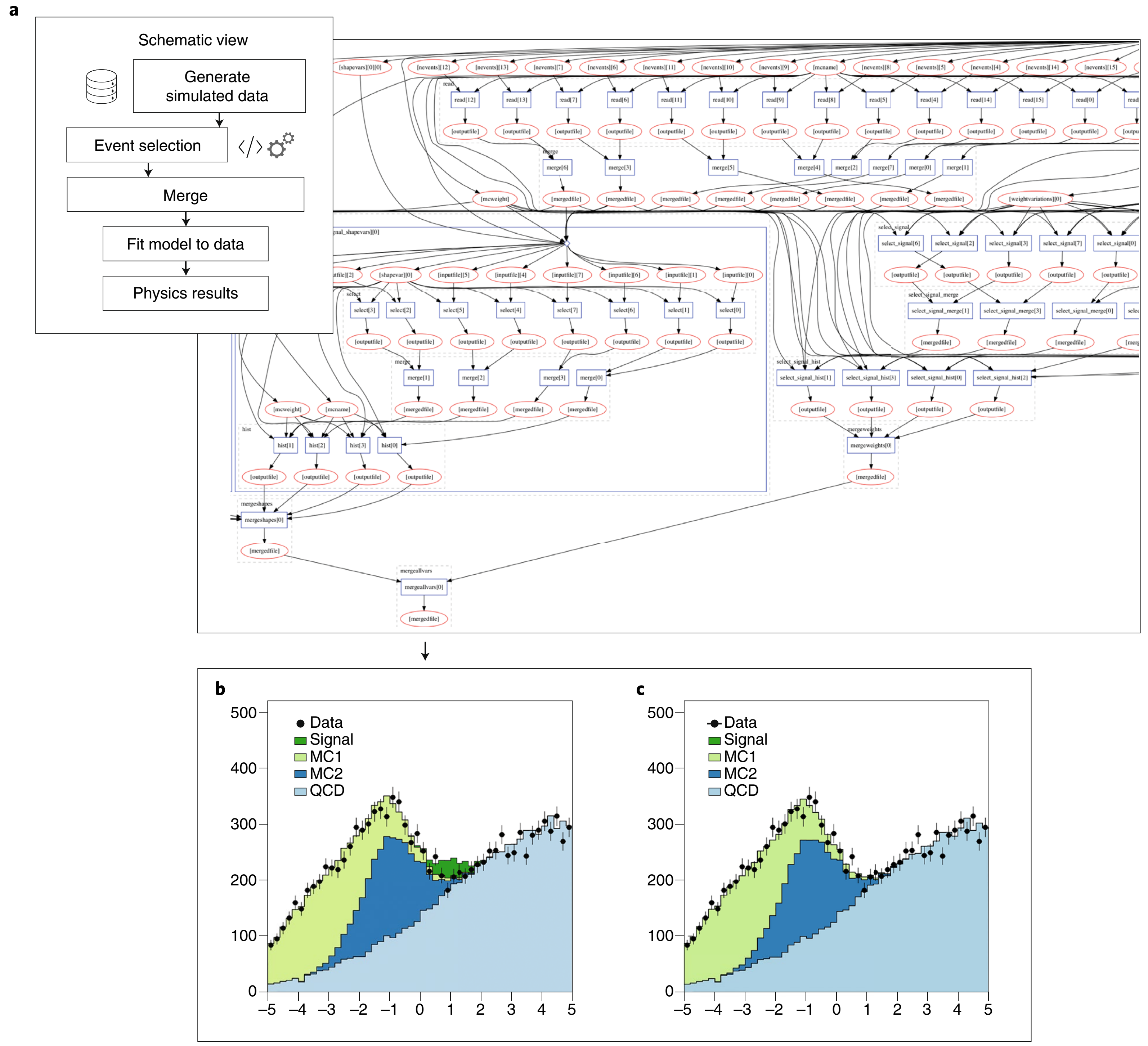
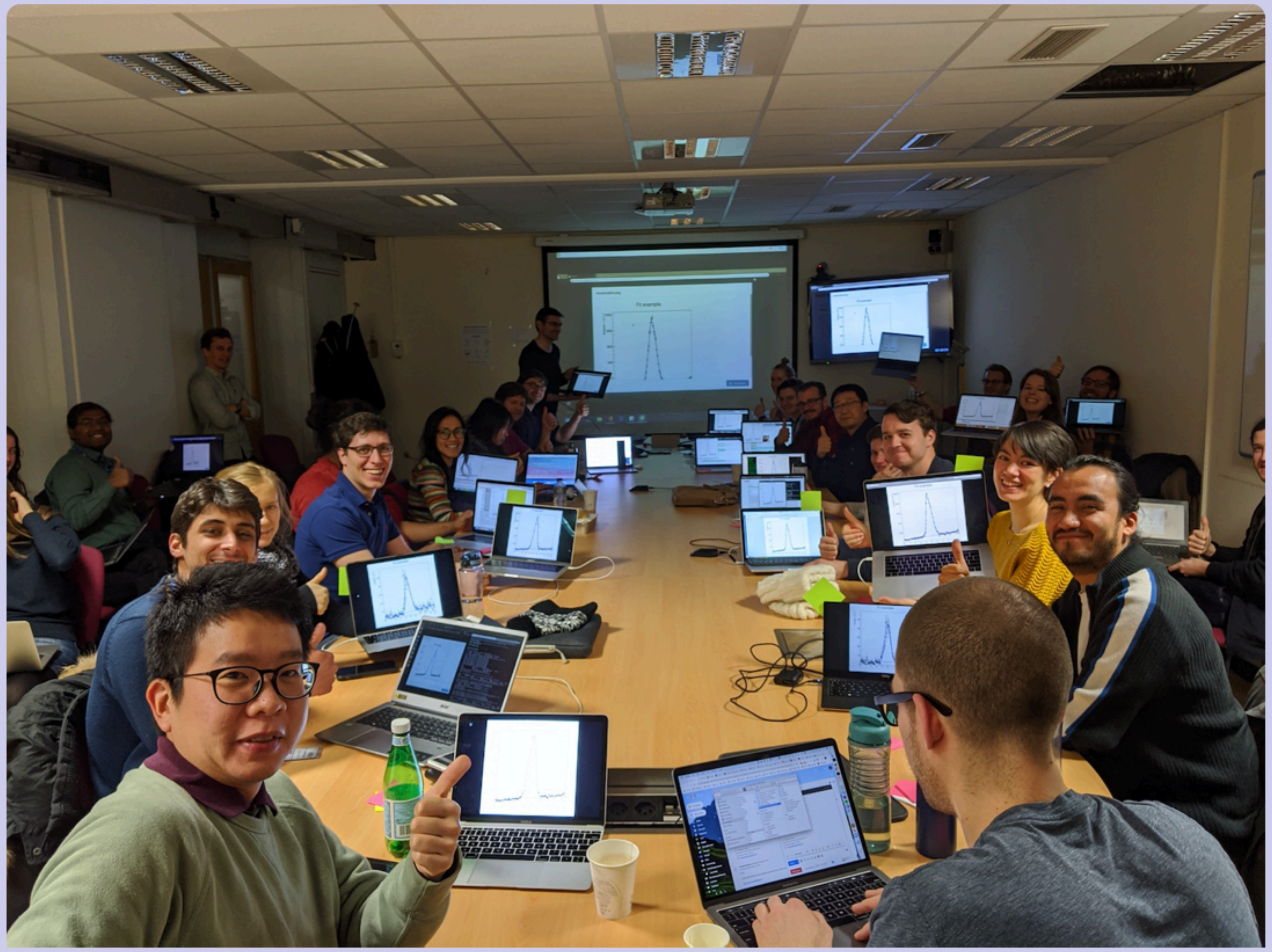


Fig. 2 | **Example of a complex computational workflow on REANA mimicking a beyond the standard model (BSM) analysis .** This figure shows an example where the experimental data is compared to the predictions of the standard model with an additional hypothesized signal component. The example permits one to study the complex computational workflows used in typical particle physics analyses. **a**–**c**, The computational workflow (**a**) may consist of several tens of thousands of computational steps that are massively parallelizable and run in a cascading 'map-reduce' style of computations on distributed compute clusters. The workflow definition is modelled using the Yadage workflow specification and produces an upper limit on the signal strength of the BSM process. A typical search for BSM physics consists of simulating a hypothetical signal process (**c**), as well as the background processes predicted by the standard model with properties consistent with the hypothetical signal (marked dark green in (**b**)). The background often consists of simulated background estimates (dark blue and light green histograms) and data-driven background estimates (light blue histogram). A statistical model involving both signal (dark green histogram) and background components is built and fit to the observed experimental data (black markers). **b**, Results of the model in its pre-fit configuration at nominal signal strength. We can see the excess of the signal over data, meaning that the nominal setting does not describe the data well. The post-fit distribution would scale down the signal in order to fit the data. This REANA example is publicly available at ref. [35]. For icon credits, see Fig. 1.

https://doi.org/10.1038/s41567-018-0342-2

Encouraging response by the community



Participants in Analysis Preservation Bootcamp showing off their ability to reproduce an LHC analysis. Photo Credit: Samuel Meehan

Instructors Danika MacDonnel and Giordon Stark working with participants. Photo Credit: Samuel Meehan.