Suche nach Elektroweakinos mit dem ATLAS Detektor

Ludwig-Maximilians-Universität München
Fakultät für Physik

Dissertation

Eric Schanet

March 2021

Supervisor: PD Dr. Jeanette Lorenz

Part I

Fundamental concepts

Part II

The 1-lepton analysis

Part III

Reinterpretation

Chapter 9

Analysis preservation

Today's particle physics experiments operate are designed to collect physics data over a span over several decades. They thus operate at scales that makes it impossible for the experiments to be repeated in the foreseeable future. The data taken at these experiments and physics results derived are thus extremely valuable and major problems arise from a scientific reproducibility point of view. In this chapter, the reproducibility problems directly connected to an individual analysis are discussed, and approaches taken in view of analysis preservation are presented.

9.1 The case for reinterpretations

9.1.1 Motivation

Designing and executing searches for beyond the Standard Model (BSM) physics requires a large amount of human and computational resources. As laid out in the previous part of this work, an analysis generally aims to define a phase space region where a given signal model can be efficiently discriminated against Standard Model of Particle Physics (SM) background. Although the careful design of such regions already requires significant amount of resources, it constitutes only a fraction of the work necessary for concluding the search. Contributions from SM processes need to be estimated, usually requiring expensive Monte Carlo (MC) simulation and the development of background estimation strategies. Systematic uncertainties arising from numerous sources need to be considered and estimated. Furthermore, simulated signal events also need to be generated, reconstructed and processed through the event selection. Recorded data also needs to be reconstructed and processed through the event selection. Only after all three processing pipelines are concluded can the likelihood be built and statistical inference can be performed, produced the results like e.g. limits on model parameters can be obtained. Figure 9.1 illustrates the main data pipelines in an analysis, including their most important processing steps.

Due to the substantial amount of resources necessary for each analysis, it is not feasible to develop dedicated searches optimised for every possible signal model. Instead, analyses are typically interpreted in a finite set of BSM models. Still, it is very likely that any given analysis is sensitive to a variety of different BSM models not considered in the original publication. There is a real possibility that Supersymmetry (SUSY) is accessible at the energies of the Large

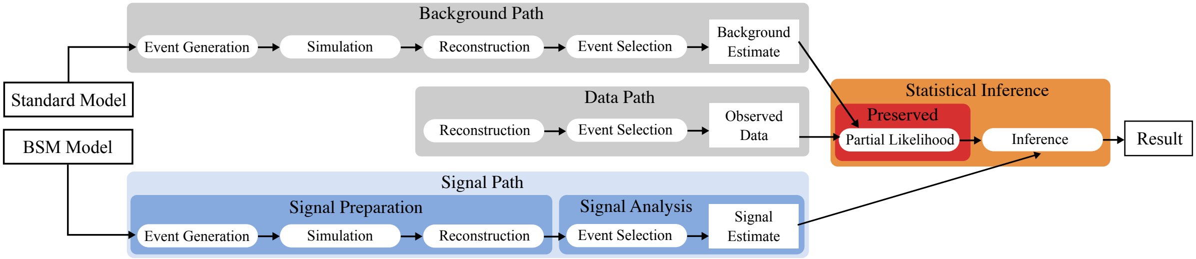

Figure 9.1: Full analysis workflow including the three main processing pipelines for deriving background and signal estimates as well as observed data rates. The outputs of the three processing pipelines are combined into a likelihood forming the basis for statistical inference. In a Recast setup, the background and data paths are archived (e.g. by preserving the partial likelihood created from the background estimates and the observed data), and the signal path is fully preserved such that it can be re-run at any time. Figure recreated from Ref. [246].

Hadron Collider (LHC) but is still hiding in unexpected places or the complex topologies arising from complete SUSY models.

Consequently, it is not surprising that there is significant interest in the high energy physics community in reinterpreting BSM searches in different signal models. Reinterpretations of published BSM searches routinely happen both within as well as outside of the ATLAS collaboration. For theorists, the analyses performed by the collaboration represent the only available windows into the dataset recorded. Reinterpretations of reproducible analyses are thus the only possibility to determine the implications of LHC data for a variety of models [245]. Likewise, within the experimental collaborations, reinterpretations can additionally serve as powerful guides for designing the search program. Reinterpretations of ATLAS SUSY searches in more complete SUSY models like the phenomenological Minimal Supersymmetric Standard Model (pMSSM)(as was done after Run 1 of the LHC, see Ref. [76]) not only allow to state a combined sensitivity of ATLAS to more realistic SUSY models, but also enables the collaboration to identify potential blind spots and parameter regions still uncovered by existing analyses. Reinterpretations of existing analyses are thus highly desirable and vital for designing future searches with a maximal scientific relevance.

9.1.2 Necessary ingredients

As the event selection of an analysis is fixed, the background estimates and observed data in the targeted regions of interest do not change and can be archived in a suitable format. Reinterpreting a search in the light of a new signal model consequently only requires the signal pipeline in fig. 9.1 to be run again, in order to derive the signal estimates that serve as input for the statistical inference. As the data and background processing pipelines shown in fig. 9.1 only enter the statistical inference as estimated event rates, the volume of data that needs to be archived is significantly smaller than the original input data. As will be discussed in section 9.2, it has recently become technically possible to directly preserve the partial analysis likelihood built from the background estimates and observed data and including all details of the statistical model used for inference. Once the signal estimates are known, a new full analysis likelihood can be built, and the viability of the new signal model can be tested.

Different approaches exist for deriving signal estimates. Manifestly the most precise approach involves running the original analysis using a different BSM model. As this requires to preserve the entirety of the original software and workflows used in the analysis, this is arguably the most involved approach. A framework designed to facilitate such an effort, called RECAST, has originally been proposed in Ref. [247] and aims to provide reintepretations as a service. Through a web interface, physicists would request a reinterpretation of a search, providing an alternative model, triggering a computational workflow executing the original analysis and delivering the recasted results. Section 9.3 discusses an attempt at fully preserving the search for electroweakinos presented in this work in the context of RECAST.

In many cases, the full precision of the original analysis pipeline is either not needed, or not accessible. As the full detector simulation requires access to the collaborations's detector description and is the most computationally expensive step in the signal pipeline, even when using fast simulations like ATLFAST-II, it is often approximated using simplified detector geometries and granularities. The most commonly used package for fast detector simulation outside of the collaboration is DELPHES [248]. Other packages like e.g. RIVET [249, 250] approximate the detector response using dedicated 4-vector smearing techniques, assuming that the detector response roughly factorises into the responses of single particles. Internally, ATLAS also uses a dedicated framework for 4-vector smearing techniques, used in scenarios where other fast simulation techniques are still too expensive. Section 11.1 discusses these dedicated smearing functions further.

Similarly to the detector simulation, the analysis-specific event selection is also routinely approximated using different approaches. A number of public tools aiming to reimplement approximations of the event selections of various BSM searches are available. Prominent examples include CHECKMATE [251, 252] and MADANALYSIS [253]. ATLAS has internally maintained a similar catalogue of its SUSY analyses and has published event selection snippets in C++ on HEPDATA [254]. Recently, this package maintained by ATLAS, called SIMPLEANALYSIS [255], has been made publicly available, allowing the C++ snippets published to be run outside the collaboration.

Instead of trying to estimate the signal rates of a new signal model using MC simulation and (reimplemented) analysis event selections, some reinterpretation efforts like e.g. SMODELS [256, 257] use *efficiency maps* encoding the selection efficiency of the analysis as a function of some of the analysis observables (typically the sparticle masses). Such efficiency maps are routinely published by the ATLAS SUSY searches on HEPDATA, and allows for efficient reinterpretations as long as the signal efficiencies mostly depend on the signal kinematics and are largely independent from the specific details of the signal model [256]. For the analysis presented in the previous part of this work, the efficiency maps and further analysis data products are available at Ref. [258].

9.2 Public full likelihood

The likelihood is arguably one of the most information-dense and thus valuable data products of an analysis. Without precise knowledge of the exact likelihood of the original analysis, approximations need to be made for the statistical inference e.g. in terms of correlations between event rate estimates as well as the treatment of uncertainties. Recently, ATLAS has started to publish full analysis likelihoods built using the HistFactory Probability Density Function (pdf) template introduced in chapter 3 [147]. This extraordinary step towards more open and reproducible science has been praised by the theory community [259] as it allows for considerably more trustful reinterpretations. This effort has been facilitated by the development of `pyhf` in conjunction with the introduction of a `JSON` specification fully describing the HistFactory template. As a pure-text format, the `JSON` likelihoods are human- and machine-readable, highly compressible and can easily be put under version control, all of which are properties that make them ideal for long-term preservation.

The full likelihood (in `JSON` format) of the search for electroweakinos presented in the previous part of this work has been published [260] and is not only heavily used in the following chapters, but also in various analysis reinterpretation and combination efforts currently ongoing in ATLAS. Several efforts outside of the ATLAS collaboration have already included the analysis likelihood into their reinterpretations, e.g. SModelS [261] and MadAnalysis [262, 263] both reporting significant precision improvements through the use of the full likelihood (as opposed to approximating the statistical model). Furthermore, the full likelihood of the search presented herein has recently been used to demonstrate the concept of scalable distributed statistical inference on high-performance computers (HPCs) [264]. Through the `funcX` package [265], `pyhf` is used as a highly scalable *function as a service* to fit the entire signal grid of 125 signal points with a wall time of 156 s using 85 available worker nodes†.

9.3 Analysis preservation using containerised workflows

For an analysis to be fully re-usable under the Recast paradigm, the signal pipeline of the original analysis (see fig. 9.1) needs to be preserved such that it can be re-executed on new inputs. As typically only the processing steps after the event reconstruction are analysis-specific, it is sufficient to preserve this part of the signal pipeline. Processing steps preceding the calibration and selection of physics objects only involve the central ATLAS production system and result in *derived analysis object data* formats that are used by analyses. These processing steps are preserved using centrally provided infrastructure.

In the following, the term *analysis pipeline* will refer to the analysis-specific data processing steps that are not handled by the central ATLAS production system, typically starting with selection of events in the *derived analysis object data* format that have passed the reconstruction step in fig. 9.1. Preserving the analysis pipeline not only needs preservation of the full software environment for the different data processing steps, but also knowledge about the correct usage of the software through parameterised job templates together with a workflow graph connecting the different steps.

9.3.1 Software preservation

As much of the software is only tested, validated and deployed on a narrow set of architectures and platforms, the full software environment defining an analysis pipeline not only includes the original analysis-specific code used for object definitions, calibrations, event selection and

† Theses benchmarks use `pyhf`'s NumPy backend and SciPy optimiser, which does have a slower log-likelihood minimisation time than e.g. PyTorch coupled with SciPy, as will be shown in **??**.

statistical inference, but also the operating system used and a number of low-level system libraries that the applications depend upon. This can be achieved through the use of *Docker containers* [266, 267] that—except for the operating system kernel—are able to package the full software environment, including a layered file system, the operating system as well as the actual application and all of its dependencies in a portable data format. As opposed to full virtualisation, Docker containers do not rely on hardware virtualisation but share the operating system kernel with host. Docker containers thus only interact with the host through system calls to the Linux kernel [246] via a highly stable interface. This makes Docker containers a well-suited solution for deploying isolated applications on a heterogeneous infrastructure.

Due to the software structure of the analysis presented in this work, a containerisation requires a total of three container images spanning the following processing steps:

- Event selection and physics object calibration: this step reads events in the *derived analysis object data* format and produces flat ROOT files.
- Generation of expected signal rates: the histogram-building features of HistFitter are exploited to generate the necessary signal histograms in the relevant selections including all systematic variations. The histograms are subsequently converted into a JSON patch file that can be used to patch the partial likelihood.
- Statistical inference: although the original analysis used HistFitter for the statistical inference, the Recast implementation uses the `pyhf`-implementation of the HistFactory models in order to benefit from the possibility of using a partial `JSON` likelihood to preserve background and data rates. The HistFitter and `pyhf` implementations of the statistical inference have been shown to produce exactly the same results up to machine precision.

The first Docker image is based on a *base image* providing a fixed ATLAS software release including all dependencies, expanded with the relevant analysis software. The second docker image uses the ROOT installation version originally used in the analysis, provided as part of a suitable ATLAS software release. The last image is based on a `pyhf` base image containing the `pyhf` release version used when validating the two HistFactory implementations against each other in the context of the analysis.

9.3.2 Processing steps preservation

Preserving the software environment is not sufficient, as detailed instructions on how to use it have to be given to the user. This is achieved through parameterised job templates that specify the precise commands and arguments required to re-execute the analysis code for specific processing steps. As re-executing the analysis pipeline using different signal models involves varying input parameters, all job template parameters are exposed to the user. Within Recast, the job templates are formulated using the YAML format.

User-specifiable arguments and inputs to the event selection and physics object calibration step include the actual reconstructed MC events in *derived analysis object data* format, obtained through the central ATLAS production system, as well as corresponding files necessary for the pile-up correction in MC. In addition, the signal process cross section as well as MC generator-level efficiencies need to be given for correct normalisation the estimated signal rates to the integrated luminosity of the full Run 2 dataset.

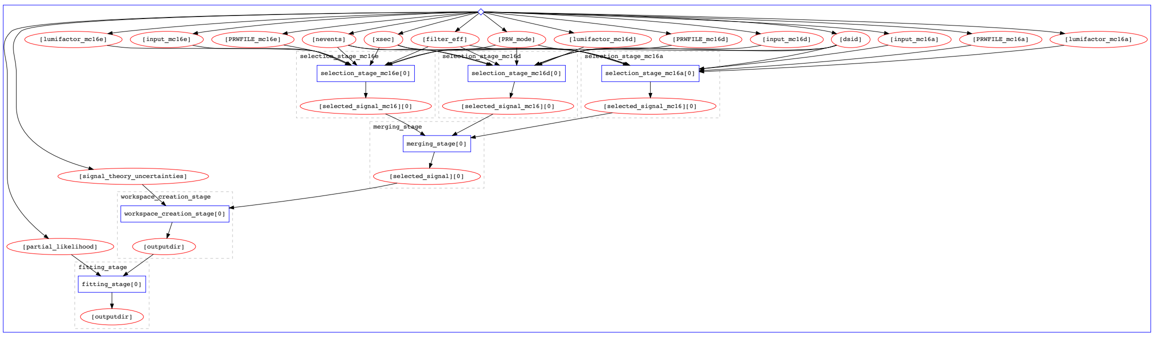

Figure 9.2: Workflow

9.3.3 Workflow preservation

Recast, originally proposed in Ref. [247] and recently used within ATLAS in e.g. Ref. [246]

Part IV

Summary and Outlook

Part V

Appendix

Abbreviations

BSM beyond the Standard Model. 127–129

HPC high-performance computer. 130

LHC Large Hadron Collider. 127, 128

MC Monte Carlo. 127, 129, 131

pdf Probability Density Function. 130

pMSSM phenomenological Minimal Supersymmetric Standard Model. 128

SM Standard Model of Particle Physics. 127

SUSY Supersymmetry. 127–129

Bibliography

[1] I. C. Brock and T. Schorner-Sadenius, *Physics at the terascale*. Wiley, Weinheim, 2011. https://cds.cern.ch/record/1354959.

[2] M. E. Peskin and D. V. Schroeder, *An Introduction to quantum field theory*. Addison-Wesley, Reading, USA, 1995. http://www.slac.stanford.edu/~mpeskin/QFT.html.

[3] S. P. Martin, "A Supersymmetry primer," arXiv:hep-ph/9709356 [hep-ph]. [Adv. Ser. Direct. High Energy Phys.18,1(1998)].

[4] M. Bustamante, L. Cieri, and J. Ellis, "Beyond the Standard Model for Montaneros," in *5th CERN - Latin American School of High-Energy Physics*. 11, 2009. arXiv:0911.4409 [hep-ph].

[5] L. Brown, *The Birth of particle physics*. Cambridge University Press, Cambridge Cambridgeshire New York, 1986.

[6] P. J. Mohr, D. B. Newell, and B. N. Taylor, "CODATA Recommended Values of the Fundamental Physical Constants: 2014," *Rev. Mod. Phys.* **88** no. 3, (2016) 035009, arXiv:1507.07956 [physics.atom-ph].

[7] P. D. Group, "Review of Particle Physics," *Progress of Theoretical and Experimental Physics* **2020** no. 8, (08, 2020) , https://academic.oup.com/ptep/article-pdf/2020/8/083C01/34673722/ptaa104.pdf. https://doi.org/10.1093/ptep/ptaa104. 083C01.

[8] **Super-Kamiokande** Collaboration, Y. Fukuda *et al.*, "Evidence for oscillation of atmospheric neutrinos," *Phys. Rev. Lett.* **81** (1998) 1562–1567, arXiv:hep-ex/9807003 [hep-ex].

[9] Z. Maki, M. Nakagawa, and S. Sakata, "Remarks on the unified model of elementary particles," *Prog. Theor. Phys.* **28** (1962) 870–880. [,34(1962)].

[10] N. Cabibbo, "Unitary symmetry and leptonic decays," *Phys. Rev. Lett.* **10** (Jun, 1963) 531–533. https://link.aps.org/doi/10.1103/PhysRevLett.10.531.

[11] M. Kobayashi and T. Maskawa, "CP Violation in the Renormalizable Theory of Weak Interaction," *Prog. Theor. Phys.* **49** (1973) 652–657.

[12] E. Noether and M. A. Tavel, "Invariant variation problems," arXiv:physics/0503066.

[13] J. C. Ward, "An identity in quantum electrodynamics," *Phys. Rev.* **78** (Apr, 1950) 182–182. https://link.aps.org/doi/10.1103/PhysRev.78.182.

[14] Y. Takahashi, "On the generalized ward identity," *Il Nuovo Cimento (1955-1965)* **6** no. 2, (Aug, 1957) 371–375. https://doi.org/10.1007/BF02832514.

[15] G. 'tHooft, "Renormalization of massless yang-mills fields," *Nuclear Physics B* **33** no. 1, (1971) 173 – 199. http://www.sciencedirect.com/science/article/pii/0550321371903956.

[16] J. Taylor, "Ward identities and charge renormalization of the yang-mills field," *Nuclear Physics B* **33** no. 2, (1971) 436 – 444. http://www.sciencedirect.com/science/article/pii/0550321371902975.

[17] A. A. Slavnov, "Ward identities in gauge theories," *Theoretical and Mathematical Physics* **10** no. 2, (Feb, 1972) 99–104. https://doi.org/10.1007/BF01090719.

[18] C. N. Yang and R. L. Mills, "Conservation of isotopic spin and isotopic gauge invariance," *Phys. Rev.* **96** (Oct, 1954) 191–195. https://link.aps.org/doi/10.1103/PhysRev.96.191.

[19] K. G. Wilson, "Confinement of quarks," *Phys. Rev. D* **10** (Oct, 1974) 2445–2459. https://link.aps.org/doi/10.1103/PhysRevD.10.2445.

[20] T. DeGrand and C. DeTar, *Lattice Methods for Quantum Chromodynamics*. World Scientific, Singapore, 2006. https://cds.cern.ch/record/1055545.

[21] S. L. Glashow, "Partial-symmetries of weak interactions," *Nuclear Physics* **22** no. 4, (1961) 579 – 588. http://www.sciencedirect.com/science/article/pii/0029558261904692.

[22] S. Weinberg, "A model of leptons," *Phys. Rev. Lett.* **19** (Nov, 1967) 1264–1266. https://link.aps.org/doi/10.1103/PhysRevLett.19.1264.

[23] A. Salam and J. C. Ward, "Weak and electromagnetic interactions," *Il Nuovo Cimento (1955-1965)* **11** no. 4, (Feb, 1959) 568–577. https://doi.org/10.1007/BF02726525.

[24] C. S. Wu, E. Ambler, R. W. Hayward, D. D. Hoppes, and R. P. Hudson, "Experimental test of parity conservation in beta decay," *Phys. Rev.* **105** (Feb, 1957) 1413–1415. https://link.aps.org/doi/10.1103/PhysRev.105.1413.

[25] M. Gell-Mann, "The interpretation of the new particles as displaced charge multiplets," *Il Nuovo Cimento (1955-1965)* **4** no. 2, (Apr, 1956) 848–866. https://doi.org/10.1007/BF02748000.

[26] K. Nishijima, "Charge Independence Theory of V Particles*," *Progress of Theoretical Physics* **13** no. 3, (03, 1955) 285–304, `https://academic.oup.com/ptp/article-pdf/13/3/285/5425869/13-3-285.pdf`. https://doi.org/10.1143/PTP.13.285.

[27] T. Nakano and K. Nishijima, "Charge Independence for V-particles*," *Progress of Theoretical Physics* **10** no. 5, (11, 1953) 581–582, `https://academic.oup.com/ptp/article-pdf/10/5/581/5364926/10-5-581.pdf`. https://doi.org/10.1143/PTP.10.581.

[28] F. Englert and R. Brout, "Broken symmetry and the mass of gauge vector mesons," *Phys. Rev. Lett.* **13** (Aug, 1964) 321–323. https://link.aps.org/doi/10.1103/PhysRevLett.13.321.

[29] P. W. Higgs, "Broken symmetries and the masses of gauge bosons," *Phys. Rev. Lett.* **13** (Oct, 1964) 508–509. https://link.aps.org/doi/10.1103/PhysRevLett.13.508.

[30] P. W. Higgs, "Spontaneous symmetry breakdown without massless bosons," *Phys. Rev.* **145** (May, 1966) 1156–1163. https://link.aps.org/doi/10.1103/PhysRev.145.1156.

[31] Y. Nambu, "Quasiparticles and Gauge Invariance in the Theory of Superconductivity," *Phys. Rev.* **117** (1960) 648–663. [,132(1960)].

[32] J. Goldstone, "Field Theories with Superconductor Solutions," *Nuovo Cim.* **19** (1961) 154–164.

[33] V. Brdar, A. J. Helmboldt, S. Iwamoto, and K. Schmitz, "Type-I Seesaw as the Common Origin of Neutrino Mass, Baryon Asymmetry, and the Electroweak Scale," *Phys. Rev. D* **100** (2019) 075029, `arXiv:1905.12634 [hep-ph]`.

[34] G. 't Hooft and M. Veltman, "Regularization and renormalization of gauge fields," *Nuclear Physics B* **44** no. 1, (1972) 189 – 213. http://www.sciencedirect.com/science/article/pii/0550321372902799.

[35] F. Zwicky, "Die Rotverschiebung von extragalaktischen Nebeln," *Helv. Phys. Acta* **6** (1933) 110–127. https://cds.cern.ch/record/437297.

[36] V. C. Rubin and W. K. Ford, Jr., "Rotation of the Andromeda Nebula from a Spectroscopic Survey of Emission Regions," *Astrophys. J.* **159** (1970) 379–403.

[37] G. Bertone, D. Hooper, and J. Silk, "Particle dark matter: Evidence, candidates and constraints," *Phys. Rept.* **405** (2005) 279–390, `arXiv:hep-ph/0404175`.

[38] D. Clowe, M. Bradac, A. H. Gonzalez, M. Markevitch, S. W. Randall, C. Jones, and D. Zaritsky, "A direct empirical proof of the existence of dark matter," *Astrophys. J.* **648** (2006) L109–L113, `arXiv:astro-ph/0608407 [astro-ph]`.

[39] A. Taylor, S. Dye, T. J. Broadhurst, N. Benitez, and E. van Kampen, "Gravitational lens magnification and the mass of abell 1689," *Astrophys. J.* **501** (1998) 539, `arXiv:astro-ph/9801158`.

[40] C. Bennett *et al.*, "Four year COBE DMR cosmic microwave background observations: Maps and basic results," *Astrophys. J. Lett.* **464** (1996) L1–L4, `arXiv:astro-ph/9601067`.

[41] G. F. Smoot *et al.*, "Structure in the COBE Differential Microwave Radiometer First-Year Maps," *ApJS* **396** (September, 1992) L1.

[42] **WMAP** Collaboration, "Nine-year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Final Maps and Results," *ApJS* **208** no. 2, (October, 2013) 20, `arXiv:1212.5225 [astro-ph.CO]`.

[43] **WMAP** Collaboration, "Nine-year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Cosmological Parameter Results," *ApJS* **208** no. 2, (October, 2013) 19, `arXiv:1212.5226 [astro-ph.CO]`.

[44] **Planck** Collaboration, "Planck 2018 results. I. Overview and the cosmological legacy of Planck," *Astron. Astrophys.* **641** (2020) A1, `arXiv:1807.06205 [astro-ph.CO]`.

[45] A. Liddle, *An introduction to modern cosmology; 3rd ed.* Wiley, Chichester, Mar, 2015. https://cds.cern.ch/record/1976476.

[46] **Planck** Collaboration, "Planck 2018 results. VI. Cosmological parameters," *Astron. Astrophys.* **641** (2020) A6, `arXiv:1807.06209 [astro-ph.CO]`.

[47] H. Georgi and S. L. Glashow, "Unity of all elementary-particle forces," *Phys. Rev. Lett.* **32** (Feb, 1974) 438–441. https://link.aps.org/doi/10.1103/PhysRevLett.32.438.

[48] I. Aitchison, *Supersymmetry in Particle Physics. An Elementary Introduction*. Cambridge University Press, Cambridge, 2007.

[49] **Muon g-2** Collaboration, G. Bennett *et al.*, "Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL," *Phys. Rev. D* **73** (2006) 072003, `arXiv:hep-ex/0602035`.

[50] H. Baer and X. Tata, *Weak Scale Supersymmetry: From Superfields to Scattering Events*. Cambridge University Press, 2006.

[51] A. Czarnecki and W. J. Marciano, "The Muon anomalous magnetic moment: A Harbinger for 'new physics'," *Phys. Rev. D* **64** (2001) 013014, `arXiv:hep-ph/0102122`.

[52] J. L. Feng and K. T. Matchev, "Supersymmetry and the anomalous magnetic moment of the muon," *Phys. Rev. Lett.* **86** (2001) 3480–3483, `arXiv:hep-ph/0102146`.

[53] S. Coleman and J. Mandula, "All possible symmetries of the s matrix," *Phys. Rev.* **159** (Jul, 1967) 1251–1256. https://link.aps.org/doi/10.1103/PhysRev.159.1251.

[54] R. Haag, J. T. Lopuszanski, and M. Sohnius, "All Possible Generators of Supersymmetries of the s Matrix," *Nucl. Phys.* **B88** (1975) 257. [,257(1974)].

[55] J. Wess and B. Zumino, "Supergauge transformations in four dimensions," *Nuclear Physics B* **70** no. 1, (1974) 39 – 50. http://www.sciencedirect.com/science/article/pii/0550321374903551.

[56] H. Georgi and S. L. Glashow, "Gauge theories without anomalies," *Phys. Rev. D* **6** (Jul, 1972) 429–431. https://link.aps.org/doi/10.1103/PhysRevD.6.429.

[57] S. Dimopoulos and D. W. Sutter, "The Supersymmetric flavor problem," *Nucl. Phys. B* **452** (1995) 496–512, `arXiv:hep-ph/9504415`.

[58] **MEG** Collaboration, T. Mori, "Final Results of the MEG Experiment," *Nuovo Cim. C* **39** no. 4, (2017) 325, `arXiv:1606.08168 [hep-ex]`.

[59] H. P. Nilles, "Supersymmetry, Supergravity and Particle Physics," *Phys. Rept.* **110** (1984) 1–162.

[60] A. Lahanas and D. Nanopoulos, "The road to no-scale supergravity," *Physics Reports* **145** no. 1, (1987) 1 – 139. http://www.sciencedirect.com/science/article/pii/0370157387900342.

[61] J. L. Feng, A. Rajaraman, and F. Takayama, "Superweakly interacting massive particles," *Phys. Rev. Lett.* **91** (2003) 011302, `arXiv:hep-ph/0302215`.

[62] **Super-Kamiokande** Collaboration, K. Abe *et al.*, "Search for proton decay via $p \to e^+\pi^0$ and $p \to \mu^+\pi^0$ in 0.31 megaton-years exposure of the Super-Kamiokande water Cherenkov detector," *Phys. Rev.* **D95** no. 1, (2017) 012004, `arXiv:1610.03597 [hep-ex]`.

[63] J. R. Ellis, "Beyond the standard model for hill walkers," in *1998 European School of High-Energy Physics*, pp. 133–196. 8, 1998. `arXiv:hep-ph/9812235`.

[64] J. R. Ellis, J. Hagelin, D. V. Nanopoulos, K. A. Olive, and M. Srednicki, "Supersymmetric Relics from the Big Bang," *Nucl. Phys. B* **238** (1984) 453–476.

[65] D. O. Caldwell, R. M. Eisberg, D. M. Grumm, M. S. Witherell, B. Sadoulet, F. S. Goulding, and A. R. Smith, "Laboratory limits on galactic cold dark matter," *Phys. Rev. Lett.* **61** (Aug, 1988) 510–513. https://link.aps.org/doi/10.1103/PhysRevLett.61.510.

[66] M. Mori, M. M. Nojiri, K. S. Hirata, K. Kihara, Y. Oyama, A. Suzuki, K. Takahashi, M. Yamada, H. Takei, M. Koga, K. Miyano, H. Miyata, Y. Fukuda, T. Hayakawa, K. Inoue, T. Ishida, T. Kajita, Y. Koshio, M. Nakahata, K. Nakamura, A. Sakai, N. Sato, M. Shiozawa, J. Suzuki, Y. Suzuki, Y. Totsuka, M. Koshiba, K. Nishijima, T. Kajimura, T. Suda, A. T. Suzuki, T. Hara, Y. Nagashima, M. Takita, H. Yokoyama, A. Yoshimoto, K. Kaneyuki, Y. Takeuchi, T. Tanimori, S. Tasaka, and K. Nishikawa, "Search for neutralino dark matter heavier than the w boson at kamiokande," *Phys. Rev. D* **48** (Dec, 1993) 5505–5518. https://link.aps.org/doi/10.1103/PhysRevD.48.5505.

[67] **CDMS** Collaboration, D. S. Akerib *et al.*, "Exclusion limits on the WIMP-nucleon cross section from the first run of the Cryogenic Dark Matter Search in the Soudan Underground Laboratory," *Phys. Rev. D* **72** (2005) 052009, `arXiv:astro-ph/0507190`.

[68] A. Djouadi, J.-L. Kneur, and G. Moultaka, "SuSpect: A Fortran code for the supersymmetric and Higgs particle spectrum in the MSSM," *Comput. Phys. Commun.* **176** (2007) 426–455, `arXiv:hep-ph/0211331`.

[69] C. F. Berger, J. S. Gainer, J. L. Hewett, and T. G. Rizzo, "Supersymmetry without prejudice," *Journal of High Energy Physics* **2009** no. 02, (Feb, 2009) 023–023. http://dx.doi.org/10.1088/1126-6708/2009/02/023.

[70] J. Alwall, P. Schuster, and N. Toro, "Simplified Models for a First Characterization of New Physics at the LHC," *Phys. Rev.* **D79** (2009) 075020, `arXiv:0810.3921 [hep-ph]`.

[71] **LHC New Physics Working Group** Collaboration, D. Alves, "Simplified Models for LHC New Physics Searches," *J. Phys.* **G39** (2012) 105005, `arXiv:1105.2838 [hep-ph]`.

[72] D. S. Alves, E. Izaguirre, and J. G. Wacker, "Where the Sidewalk Ends: Jets and Missing Energy Search Strategies for the 7 TeV LHC," *JHEP* **10** (2011) 012, `arXiv:1102.5338 [hep-ph]`.

[73] F. Ambrogi, S. Kraml, S. Kulkarni, U. Laa, A. Lessa, and W. Waltenberger, "On the coverage of the pMSSM by simplified model results," *Eur. Phys. J. C* **78** no. 3, (2018) 215, `arXiv:1707.09036 [hep-ph]`.

[74] O. Buchmueller and J. Marrouche, "Universal mass limits on gluino and third-generation squarks in the context of Natural-like SUSY spectra," *Int. J. Mod. Phys. A* **29** no. 06, (2014) 1450032, `arXiv:1304.2185 [hep-ph]`.

[75] **ATLAS** Collaboration, M. Aaboud *et al.*, "Dark matter interpretations of ATLAS searches for the electroweak production of supersymmetric particles in $\sqrt{s} = 8$ TeV proton-proton collisions," *JHEP* **09** (2016) 175, `arXiv:1608.00872 [hep-ex]`.

[76] **ATLAS** Collaboration, "Summary of the ATLAS experiment's sensitivity to supersymmetry after LHC Run 1 — interpreted in the phenomenological MSSM," *JHEP* **10** (2015) 134, `arXiv:1508.06608 [hep-ex]`.

[77] **ATLAS** Collaboration, "Mass reach of the atlas searches for supersymmetry." https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2020-020/fig_23.png, 2020.

[78] **CMS** Collaboration, "Summary plot moriond 2017." https://twiki.cern.ch/twiki/pub/CMSPublic/SUSYSummary2017/Moriond2017_BarPlot.pdf, 2017.

[79] L. S. W. Group, "Notes lepsusywg/02-04.1 and lepsusywg/01-03.1." http://lepsusy.web.cern.ch/lepsusy/, 2004. Accessed: 2021-02-11.

[80] **ATLAS** Collaboration, G. Aad *et al.*, "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC," *Phys. Lett. B* **716** (2012) 1–29, `arXiv:1207.7214 [hep-ex]`.

[81] **CMS** Collaboration, S. Chatrchyan *et al.*, "Observation of a New Boson at a Mass of 125 GeV with the CMS Experiment at the LHC," *Phys. Lett. B* **716** (2012) 30–61, `arXiv:1207.7235 [hep-ex]`.

[82] CERN, "About cern." https://home.cern/about. Accessed: 2021-01-21.

[83] CERN, "CERN Annual report 2019," tech. rep., CERN, Geneva, 2020. https://cds.cern.ch/record/2723123.

[84] O. S. Bruning, P. Collier, P. Lebrun, S. Myers, R. Ostojic, J. Poole, and P. Proudlock, *LHC Design Report*. CERN Yellow Reports: Monographs. CERN, Geneva, 2004. https://cds.cern.ch/record/782076.

[85] M. Blewett and N. Vogt-Nilsen, "Proceedings of the 8th international conference on high-energy accelerators, cern 1971. conference held at geneva, 20–24 september 1971.," tech. rep., 1971, 1971.

[86] L. R. Evans and P. Bryant, "LHC Machine," *JINST* **3** (2008) S08001. 164 p. http://cds.cern.ch/record/1129806. This report is an abridged version of the LHC Design Report (CERN-2004-003).

[87] R. Scrivens, M. Kronberger, D. Küchler, J. Lettry, C. Mastrostefano, O. Midttun, M. O'Neil, H. Pereira, and C. Schmitzer, "Overview of the status and developments on primary ion sources at CERN*,". https://cds.cern.ch/record/1382102.

[88] M. Vretenar, J. Vollaire, R. Scrivens, C. Rossi, F. Roncarolo, S. Ramberger, U. Raich, B. Puccio, D. Nisbet, R. Mompo, S. Mathot, C. Martin, L. A. Lopez-Hernandez, A. Lombardi, J. Lettry, J. B. Lallement, I. Kozsar, J. Hansen, F. Gerigk, A. Funken, J. F. Fuchs, N. Dos Santos, M. Calviani, M. Buzio, O. Brunner, Y. Body, P. Baudrenghien, J. Bauche, and T. Zickler, *Linac4 design report*, vol. 6 of *CERN Yellow Reports: Monographs*. CERN, Geneva, 2020. https://cds.cern.ch/record/2736208.

[89] E. Mobs, "The CERN accelerator complex - 2019. Complexe des accélérateurs du CERN - 2019,". https://cds.cern.ch/record/2684277. General Photo.

[90] **ATLAS** Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider," *JINST* **3** (2008) S08003.

[91] **CMS** Collaboration, S. Chatrchyan *et al.*, "The CMS Experiment at the CERN LHC," *JINST* **3** (2008) S08004.

[92] **ALICE** Collaboration, K. Aamodt *et al.*, "The ALICE experiment at the CERN LHC," *JINST* **3** (2008) S08002.

[93] **LHCb** Collaboration, J. Alves, A.Augusto *et al.*, "The LHCb Detector at the LHC," *JINST* **3** (2008) S08005.

[94] **TOTEM** Collaboration, G. Anelli *et al.*, "The TOTEM experiment at the CERN Large Hadron Collider," *JINST* **3** (2008) S08007.

[95] **LHCf** Collaboration, O. Adriani *et al.*, "Technical design report of the LHCf experiment: Measurement of photons and neutral pions in the very forward region of LHC,".

[96] **MoEDAL** Collaboration, J. Pinfold *et al.*, "Technical Design Report of the MoEDAL Experiment,".

[97] **ATLAS** Collaboration, "ATLAS Public Results - Luminosity Public Results Run 2,". https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2. Accessed: 2021-01-17.

[98] **ATLAS** Collaboration, Z. Marshall, "Simulation of Pile-up in the ATLAS Experiment," *J. Phys. Conf. Ser.* **513** (2014) 022024.

[99] "First beam in the LHC - accelerating science,". https://home.cern/news/news/accelerators/record-luminosity-well-done-lhc. Accessed: 2021-01-10.

[100] **ATLAS Collaboration** Collaboration, "Luminosity determination in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC," Tech. Rep. ATLAS-CONF-2019-021, CERN, Geneva, Jun, 2019. https://cds.cern.ch/record/2677054.

[101] **ATLAS** Collaboration, M. Aaboud *et al.*, "Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC," *Eur. Phys. J. C* **76** no. 12, (2016) 653, `arXiv:1608.03953 [hep-ex]`.

[102] G. Avoni, M. Bruschi, G. Cabras, D. Caforio, N. Dehghanian, A. Floderus, B. Giacobbe, F. Giannuzzi, F. Giorgi, P. Grafström, V. Hedberg, F. L. Manghi, S. Meneghini, J. Pinfold, E. Richards, C. Sbarra, N. S. Cesari, A. Sbrizzi, R. Soluk, G. Ucchielli, S. Valentinetti, O. Viazlo, M. Villa, C. Vittori, R. Vuillermet, and A. Zoccoli, "The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS," *Journal of Instrumentation* **13** no. 07, (Jul, 2018) P07017–P07017. https://doi.org/10.1088/1748-0221/13/07/p07017.

[103] S. van der Meer, "Calibration of the effective beam height in the ISR," Tech. Rep. CERN-ISR-PO-68-31. ISR-PO-68-31, CERN, Geneva, 1968. https://cds.cern.ch/record/296752.

[104] P. Grafström and W. Kozanecki, "Luminosity determination at proton colliders," *Progress in Particle and Nuclear Physics* **81** (2015) 97 – 148. http://www.sciencedirect.com/science/article/pii/S0146641014000878.

[105] "New schedule for CERN's accelerators and experiments,". https://home.cern/news/press-release/cern/first-beam-lhc-accelerating-science. Accessed: 2021-01-10.

[106] **ATLAS** Collaboration, G. Aad *et al.*, “Luminosity Determination in *pp* Collisions at $\sqrt{s} = 7$ TeV Using the ATLAS Detector at the LHC,” *Eur. Phys. J. C* **71** (2011) 1630, arXiv:1101.2185 [hep-ex].

[107] **ATLAS Collaboration** Collaboration, G. Aad *et al.*, “Improved luminosity determination in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector at the LHC. Improved luminosity determination in pp collisions at sqrt(s) = 7 TeV using the ATLAS detector at the LHC,” *Eur. Phys. J. C* **73** no. CERN-PH-EP-2013-026. CERN-PH-EP-2013-026, (Feb, 2013) 2518. 27 p. https://cds.cern.ch/record/1517411. Comments: 26 pages plus author list (39 pages total), 17 figures, 9 tables, submitted to EPJC, All figures are available at <a href=.

[108] “Record luminosity: well done LHC,”. https://home.cern/news/news/accelerators/new-schedule-cerns-accelerators-and-experiments. Accessed: 2021-01-10.

[109] A. G., B. A. I., B. O., F. P., L. M., R. L., and T. L., *High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1*. CERN Yellow Reports: Monographs. CERN, Geneva, 2017. https://cds.cern.ch/record/2284929.

[110] J. Pequenao, “Computer generated image of the whole ATLAS detector.” Mar, 2008.

[111] **ATLAS** Collaboration, “ATLAS: Detector and physics performance technical design report. Volume 1,”.

[112] J. Pequenao, “Computer generated image of the ATLAS inner detector.” Mar, 2008.

[113] **ATLAS Collaboration** Collaboration, K. Potamianos, “The upgraded Pixel detector and the commissioning of the Inner Detector tracking of the ATLAS experiment for Run-2 at the Large Hadron Collider,” Tech. Rep. ATL-PHYS-PROC-2016-104, CERN, Geneva, Aug, 2016. https://cds.cern.ch/record/2209070. 15 pages, EPS-HEP 2015 Proceedings.

[114] **ATLAS IBL** Collaboration, B. Abbott *et al.*, “Production and Integration of the ATLAS Insertable B-Layer,” *JINST* **13** no. 05, (2018) T05008, arXiv:1803.00844 [physics.ins-det].

[115] **ATLAS** Collaboration, “ATLAS Insertable B-Layer Technical Design Report,” Tech. Rep. CERN-LHCC-2010-013. ATLAS-TDR-19, Sep, 2010. http://cds.cern.ch/record/1291633.

[116] **ATLAS** Collaboration, G. Aad *et al.*, “ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13$ TeV,” *Eur. Phys. J. C* **79** no. 11, (2019) 970, arXiv:1907.05120 [hep-ex].

[117] ATLAS Collaboration, “Particle Identification Performance of the ATLAS Transition Radiation Tracker.” ATLAS-CONF-2011-128, 2011. https://cds.cern.ch/record/1383793.

[118] J. Pequenao, “Computer Generated image of the ATLAS calorimeter.” Mar, 2008.

[119] J. Pequenao, “Computer generated image of the ATLAS Muons subsystem.” Mar, 2008.

[120] S. Lee, M. Livan, and R. Wigmans, “Dual-Readout Calorimetry,” *Rev. Mod. Phys.* **90** no. arXiv:1712.05494. 2, (Dec, 2017) 025002. 40 p. https://cds.cern.ch/record/2637852. 44 pages, 53 figures, accepted for publication in Review of Modern Physics.

[121] M. Leite, “Performance of the ATLAS Zero Degree Calorimeter,” Tech. Rep. ATL-FWD-PROC-2013-001, CERN, Geneva, Nov, 2013. https://cds.cern.ch/record/1628749.

[122] S. Abdel Khalek *et al.*, “The ALFA Roman Pot Detectors of ATLAS,” *JINST* **11** no. 11, (2016) P11013, `arXiv:1609.00249 [physics.ins-det]`.

[123] U. Amaldi, G. Cocconi, A. Diddens, R. Dobinson, J. Dorenbosch, W. Duinker, D. Gustavson, J. Meyer, K. Potter, A. Wetherell, A. Baroncelli, and C. Bosio, “The real part of the forward proton proton scattering amplitude measured at the cern intersecting storage rings,” *Physics Letters B* **66** no. 4, (1977) 390 – 394. http://www.sciencedirect.com/science/article/pii/0370269377900223.

[124] L. Adamczyk, E. Banaś, A. Brandt, M. Bruschi, S. Grinstein, J. Lange, M. Rijssenbeek, P. Sicho, R. Staszewski, T. Sykora, M. Trzebiński, J. Chwastowski, and K. Korcyl, “Technical Design Report for the ATLAS Forward Proton Detector,” Tech. Rep. CERN-LHCC-2015-009. ATLAS-TDR-024, May, 2015. https://cds.cern.ch/record/2017378.

[125] **ATLAS** Collaboration, A. R. Martínez, “The Run-2 ATLAS Trigger System,” *J. Phys. Conf. Ser.* **762** no. 1, (2016) 012003.

[126] **ATLAS Collaboration** Collaboration, *ATLAS level-1 trigger: Technical Design Report*. Technical Design Report ATLAS. CERN, Geneva, 1998. https://cds.cern.ch/record/381429.

[127] **ATLAS** Collaboration, G. Aad *et al.*, “Operation of the ATLAS trigger system in Run 2,” *JINST* **15** no. 10, (2020) P10004, `arXiv:2007.12539 [physics.ins-det]`.

[128] **ATLAS Collaboration** Collaboration, P. Jenni, M. Nessi, M. Nordberg, and K. Smith, *ATLAS high-level trigger, data-acquisition and controls: Technical Design Report*. Technical Design Report ATLAS. CERN, Geneva, 2003. https://cds.cern.ch/record/616089.

[129] **ATLAS** Collaboration, G. Aad *et al.*, “The ATLAS Simulation Infrastructure,” *Eur. Phys. J. C* **70** (2010) 823–874, `arXiv:1005.4568 [physics.ins-det]`.

[130] T. Gleisberg, S. Hoeche, F. Krauss, M. Schonherr, S. Schumann, F. Siegert, and J. Winter, “Event generation with SHERPA 1.1,” *JHEP* **02** (2009) 007, `arXiv:0811.4622 [hep-ph]`.

[131] A. Buckley *et al.*, “General-purpose event generators for LHC physics,” *Phys. Rept.* **504** (2011) 145–233, `arXiv:1101.2599 [hep-ph]`.

[132] V. N. Gribov and L. N. Lipatov, “Deep inelastic e p scattering in perturbation theory,” *Sov. J. Nucl. Phys.* **15** (1972) 438–450.

[133] J. Blumlein, T. Doyle, F. Hautmann, M. Klein, and A. Vogt, “Structure functions in deep inelastic scattering at HERA,” in *Workshop on Future Physics at HERA (To be followed by meetings 7-9 Feb and 30-31 May 1996 at DESY)*. 9, 1996. `arXiv:hep-ph/9609425`.

[134] A. Buckley, J. Ferrando, S. Lloyd, K. Nordström, B. Page, M. Rüfenacht, M. Schönherr, and G. Watt, “LHAPDF6: parton density access in the LHC precision era,” *Eur. Phys. J. C* **75** (2015) 132, `arXiv:1412.7420 [hep-ph]`.

[135] M. Bengtsson and T. Sjostrand, "Coherent Parton Showers Versus Matrix Elements: Implications of PETRA - PEP Data," *Phys. Lett. B* **185** (1987) 435.

[136] S. Catani, F. Krauss, R. Kuhn, and B. R. Webber, "QCD matrix elements + parton showers," *JHEP* **11** (2001) 063, arXiv:hep-ph/0109231.

[137] L. Lonnblad, "Correcting the color dipole cascade model with fixed order matrix elements," *JHEP* **05** (2002) 046, arXiv:hep-ph/0112284.

[138] B. Andersson, G. Gustafson, G. Ingelman, and T. Sjostrand, "Parton Fragmentation and String Dynamics," *Phys. Rept.* **97** (1983) 31–145.

[139] B. Andersson, *The Lund Model*. Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology. Cambridge University Press, 1998.

[140] D. Amati and G. Veneziano, "Preconfinement as a Property of Perturbative QCD," *Phys. Lett. B* **83** (1979) 87–92.

[141] D. Yennie, S. Frautschi, and H. Suura, "The infrared divergence phenomena and high-energy processes," *Annals of Physics* **13** no. 3, (1961) 379–452. https://www.sciencedirect.com/science/article/pii/0003491661901518.

[142] M. Dobbs and J. B. Hansen, "The HepMC C++ Monte Carlo event record for High Energy Physics," *Comput. Phys. Commun.* **134** (2001) 41–46.

[143] **GEANT4** Collaboration, S. Agostinelli *et al.*, "GEANT4: A Simulation toolkit," *Nucl. Instrum. Meth.* **A506** (2003) 250–303.

[144] **ATLAS Collaboration** Collaboration, "The new Fast Calorimeter Simulation in ATLAS," Tech. Rep. ATL-SOFT-PUB-2018-002, CERN, Geneva, Jul, 2018. https://cds.cern.ch/record/2630434.

[145] K. Cranmer, "Practical Statistics for the LHC," in *2011 European School of High-Energy Physics*, pp. 267–308. 2014. arXiv:1503.07622 [physics.data-an].

[146] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, "Asymptotic formulae for likelihood-based tests of new physics," *Eur. Phys. J.* **C71** (2011) 1554, arXiv:1007.1727 [physics.data-an]. [Erratum: Eur. Phys. J.C73,2501(2013)].

[147] ATLAS Collaboration, "Reproduction searches for new physics with the ATLAS experiment through publication of full statistical likelihoods." ATL-PHYS-PUB-2019-029, 2019. https://cds.cern.ch/record/2684863.

[148] **ROOT Collaboration** Collaboration, K. Cranmer, G. Lewis, L. Moneta, A. Shibata, and W. Verkerke, "HistFactory: A tool for creating statistical models for use with RooFit and RooStats," Tech. Rep. CERN-OPEN-2012-016, New York U., New York, Jan, 2012. https://cds.cern.ch/record/1456844.

[149] W. Verkerke and D. P. Kirkby, "The RooFit toolkit for data modeling," *eConf* **C0303241** (2003) MOLT007, arXiv:physics/0306116 [physics]. [,186(2003)].

[150] L. Moneta, K. Belasco, K. S. Cranmer, S. Kreiss, A. Lazzaro, D. Piparo, G. Schott, W. Verkerke, and M. Wolf, "The RooStats Project," *PoS* **ACAT2010** (2010) 057, arXiv:1009.1003 [physics.data-an].

[151] F. James and M. Roos, "MINUIT: a system for function minimization and analysis of the parameter errors and corrections," *Comput. Phys. Commun.* **10** no. CERN-DD-75-20, (Jul, 1975) 343–367. 38 p. https://cds.cern.ch/record/310399.

[152] R. Brun and F. Rademakers, "ROOT: An object oriented data analysis framework," *Nucl. Instrum. Meth.* **A389** (1997) 81–86.

[153] I. Antcheva *et al.*, "Root — a c++ framework for petabyte data storage, statistical analysis and visualization," *Computer Physics Communications* **182** no. 6, (2011) 1384 – 1385. http://www.sciencedirect.com/science/article/pii/S0010465511000701.

[154] M. Baak, G. J. Besjes, D. Côte, A. Koutsman, J. Lorenz, and D. Short, "HistFitter software framework for statistical data analysis," *Eur. Phys. J.* **C75** (2015) 153, arXiv:1410.1280 [hep-ex].

[155] L. Heinrich, M. Feickert, G. Stark, and K. Cranmer, "pyhf: pure-python implementation of histfactory statistical models," *Journal of Open Source Software* **6** no. 58, (2021) 2823. https://doi.org/10.21105/joss.02823.

[156] L. Heinrich, M. Feickert, and G. Stark, "pyhf: v0.6.0." https://github.com/scikit-hep/pyhf.

[157] A. Paszke, S. Gross, F. Massa, A. Lerer, J. Bradbury, G. Chanan, T. Killeen, Z. Lin, N. Gimelshein, L. Antiga, A. Desmaison, A. Kopf, E. Yang, Z. DeVito, M. Raison, A. Tejani, S. Chilamkurthy, B. Steiner, L. Fang, J. Bai, and S. Chintala, "Pytorch: An imperative style, high-performance deep learning library," in *Advances in Neural Information Processing Systems 32*, H. Wallach, H. Larochelle, A. Beygelzimer, F. d'Alché-Buc, E. Fox, and R. Garnett, eds., pp. 8024–8035. Curran Associates, Inc., 2019. http://papers.neurips.cc/paper/9015-pytorch-an-imperative-style-high-performance-deep-learning-library.pdf.

[158] M. Abadi, A. Agarwal, P. Barham, E. Brevdo, Z. Chen, C. Citro, G. S. Corrado, A. Davis, J. Dean, M. Devin, S. Ghemawat, I. Goodfellow, A. Harp, G. Irving, M. Isard, Y. Jia, R. Jozefowicz, L. Kaiser, M. Kudlur, J. Levenberg, D. Mané, R. Monga, S. Moore, D. Murray, C. Olah, M. Schuster, J. Shlens, B. Steiner, I. Sutskever, K. Talwar, P. Tucker, V. Vanhoucke, V. Vasudevan, F. Viégas, O. Vinyals, P. Warden, M. Wattenberg, M. Wicke, Y. Yu, and X. Zheng, "TensorFlow: Large-scale machine learning on heterogeneous systems," 2015. https://www.tensorflow.org/. Software available from tensorflow.org.

[159] J. Bradbury, R. Frostig, P. Hawkins, M. J. Johnson, C. Leary, D. Maclaurin, and S. Wanderman-Milne, "JAX: composable transformations of Python+NumPy programs," 2018. http://github.com/google/jax.

[160] A. Wald, "Tests of statistical hypotheses concerning several parameters when the number of observations is large," *Transactions of the American Mathematical Society* **54** no. 3, (1943) 426–482. https://doi.org/10.1090/S0002-9947-1943-0012401-3.

[161] S. S. Wilks, "The large-sample distribution of the likelihood ratio for testing composite hypotheses," *Ann. Math. Statist.* **9** no. 1, (03, 1938) 60–62. https://doi.org/10.1214/aoms/1177732360.

[162] G. Cowan, "Statistics for Searches at the LHC," in *69th Scottish Universities Summer School in Physics: LHC Physics*, pp. 321–355. 7, 2013. arXiv:1307.2487 [hep-ex].

[163] A. L. Read, "Presentation of search results: the CL_S technique," *J. Phys. G* **28** (2002) 2693.

[164] R. D. Cousins, J. T. Linnemann, and J. Tucker, "Evaluation of three methods for calculating statistical significance when incorporating a systematic uncertainty into a test of the background-only hypothesis for a Poisson process," *Nucl. Instrum. Meth. A* **595** no. 2, (2008) 480, `arXiv:physics/0702156 [physics.data-an]`.

[165] K. CRANMER, "Statistical challenges for searches for new physics at the lhc," *Statistical Problems in Particle Physics, Astrophysics and Cosmology* (May, 2006) . http://dx.doi.org/10.1142/9781860948985_0026.

[166] ATLAS Collaboration, "Search for direct pair production of a chargino and a neutralino decaying to the 125 GeV Higgs boson in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector," *Eur. Phys. J. C* **75** (2015) 208, `arXiv:1501.07110 [hep-ex]`.

[167] ATLAS Collaboration, "Search for chargino and neutralino production in final states with a Higgs boson and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector," *Phys. Rev. D* **100** (2019) 012006, `arXiv:1812.09432 [hep-ex]`.

[168] CMS Collaboration, "Search for electroweak production of charginos and neutralinos in WH events in proton–proton collisions at $\sqrt{s} = 13$ TeV," *JHEP* **11** (2017) 029, `arXiv:1706.09933 [hep-ex]`.

[169] ATLAS Collaboration, "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 $\sqrt{s} = 13$ TeV with the ATLAS detector," *Eur. Phys. J. C* **80** (2020) 691, `arXiv:1909.09226 [hep-ex]`.

[170] ATLAS Collaboration, "Improvements in $t\bar{t}$ modelling using NLO+PS Monte Carlo generators for Run 2." ATL-PHYS-PUB-2018-009, 2018. https://cds.cern.ch/record/2630327.

[171] ATLAS Collaboration, "Modelling of the $t\bar{t}H$ and $t\bar{t}V(V = W, Z)$ processes for $\sqrt{s} = 13$ TeV ATLAS analyses." ATL-PHYS-PUB-2016-005, 2016. https://cds.cern.ch/record/2120826.

[172] ATLAS Collaboration, "ATLAS simulation of boson plus jets processes in Run 2." ATL-PHYS-PUB-2017-006, 2017. https://cds.cern.ch/record/2261937.

[173] ATLAS Collaboration, "Multi-Boson Simulation for 13 TeV ATLAS Analyses." ATL-PHYS-PUB-2017-005, 2017. https://cds.cern.ch/record/2261933.

[174] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations," *JHEP* **07** (2014) 079, `arXiv:1405.0301 [hep-ph]`.

[175] R. Frederix and S. Frixione, "Merging meets matching in MC@NLO," *JHEP* **12** (2012) 061, `arXiv:1209.6215 [hep-ph]`.

[176] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, "An Introduction to PYTHIA 8.2," *Comput. Phys. Commun.* **191** (2015) 159–177, `arXiv:1410.3012 [hep-ph]`.

[177] L. Lönnblad and S. Prestel, "Matching tree-level matrix elements with interleaved showers," *JHEP* **03** (2012) 019, arXiv:1109.4829 [hep-ph].

[178] R. D. Ball *et al.*, "Parton distributions with LHC data," *Nucl. Phys. B* **867** (2013) 244, arXiv:1207.1303 [hep-ph].

[179] ATLAS Collaboration, "ATLAS Pythia 8 tunes to 7 TeV data." ATL-PHYS-PUB-2014-021, 2014. https://cds.cern.ch/record/1966419.

[180] D. J. Lange, "The EvtGen particle decay simulation package," *Nucl. Instrum. Meth. A* **462** (2001) 152.

[181] ATLAS Collaboration, "The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie–Landshoff diffractive model." ATL-PHYS-PUB-2016-017, 2016. https://cds.cern.ch/record/2206965.

[182] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, "Precision predictions for electroweak superpartner production at hadron colliders with RESUMMINO," *Eur. Phys. J. C* **73** (2013) 2480, arXiv:1304.0790 [hep-ph].

[183] J. Fiaschi and M. Klasen, "Neutralino-chargino pair production at NLO+NLL with resummation-improved parton density functions for LHC Run II," *Phys. Rev. D* **98** no. 5, (2018) 055014, arXiv:1805.11322 [hep-ph].

[184] B. Fuks, M. Klasen, D. R. Lamprea, and M. Rothering, "Gaugino production in proton-proton collisions at a center-of-mass energy of 8 TeV," *JHEP* **10** (2012) 081, arXiv:1207.2159 [hep-ph].

[185] S. Alioli, P. Nason, C. Oleari, and E. Re, "A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX," *JHEP* **06** (2010) 043, arXiv:1002.2581 [hep-ph].

[186] S. Frixione, P. Nason, and G. Ridolfi, "A Positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction," *JHEP* **09** (2007) 126, arXiv:0707.3088 [hep-ph].

[187] P. Nason, "A New method for combining NLO QCD with shower Monte Carlo algorithms," *JHEP* **11** (2004) 040, arXiv:hep-ph/0409146.

[188] E. Bothmann *et al.*, "Event generation with Sherpa 2.2," *SciPost Phys.* **7** no. 3, (2019) 034, arXiv:1905.09127 [hep-ph].

[189] S. Höche, F. Krauss, S. Schumann, and F. Siegert, "QCD matrix elements and truncated showers," *JHEP* **05** (2009) 053, arXiv:0903.1219 [hep-ph].

[190] S. Höche, F. Krauss, M. Schönherr, and F. Siegert, "QCD matrix elements + parton showers. The NLO case," *JHEP* **04** (2013) 027, arXiv:1207.5030 [hep-ph].

[191] **NNPDF** Collaboration, R. D. Ball *et al.*, "Parton distributions for the LHC run II," *JHEP* **04** (2015) 040, arXiv:1410.8849 [hep-ph].

[192] ATLAS Collaboration, "Example ATLAS tunes of PYTHIA8, PYTHIA6 and POWHEG to an observable sensitive to Z boson transverse momentum." ATL-PHYS-PUB-2013-017, 2013. https://cds.cern.ch/record/1629317.

[193] M. Czakon and A. Mitov, "Top++: A program for the calculation of the top-pair cross-section at hadron colliders," *Comput. Phys. Commun.* **185** (2014) 2930, arXiv:1112.5675 [hep-ph].

[194] M. Cacciari, M. Czakon, M. Mangano, A. Mitov, and P. Nason, "Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation," *Phys. Lett. B* **710** (2012) 612–622, arXiv:1111.5869 [hep-ph].

[195] P. Kant, O. M. Kind, T. Kintscher, T. Lohse, T. Martini, S. Mölbitz, P. Rieck, and P. Uwer, "HatHor for single top-quark production: Updated predictions and uncertainty estimates for single top-quark production in hadronic collisions," *Comput. Phys. Commun.* **191** (2015) 74–89, arXiv:1406.4403 [hep-ph].

[196] N. Kidonakis, "Two-loop soft anomalous dimensions for single top quark associated production with a W^- or H^-," *Phys. Rev. D* **82** (2010) 054018, arXiv:1005.4451 [hep-ph].

[197] J. M. Campbell and R. K. Ellis, "$t\bar{t}W^{+-}$ production and decay at NLO," *JHEP* **07** (2012) 052, arXiv:1204.5678 [hep-ph].

[198] A. Lazopoulos, T. McElmurry, K. Melnikov, and F. Petriello, "Next-to-leading order QCD corrections to $t\bar{t}Z$ production at the LHC," *Phys. Lett. B* **666** (2008) 62–65, arXiv:0804.2220 [hep-ph].

[199] R. Gavin, Y. Li, F. Petriello, and S. Quackenbush, "FEWZ 2.0: A code for hadronic Z production at next-to-next-to-leading order," arXiv:1011.3540 [hep-ph].

[200] **LHC Higgs Cross Section Working Group** Collaboration, D. de Florian *et al.*, "Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector," arXiv:1610.07922 [hep-ph].

[201] ATLAS Collaboration, "Performance of the ATLAS track reconstruction algorithms in dense environments in LHC Run 2," *Eur. Phys. J. C* **77** (2017) 673, arXiv:1704.07983 [hep-ex].

[202] R. Frühwirth, "Application of Kalman filtering to track and vertex fitting," *Nucl. Instrum. Methods Phys. Res., A* **262** no. HEPHY-PUB-503, (Jun, 1987) 444. 19 p. https://cds.cern.ch/record/178627.

[203] T. Cornelissen, M. Elsing, I. Gavrilenko, W. Liebig, E. Moyse, and A. Salzburger, "The new ATLAS track reconstruction (NEWT)," *J. Phys.: Conf. Ser.* **119** (2008) 032014. https://cds.cern.ch/record/1176900.

[204] ATLAS Collaboration, "Vertex Reconstruction Performance of the ATLAS Detector at $\sqrt{s} = 13$ TeV." ATL-PHYS-PUB-2015-026, 2015. https://cds.cern.ch/record/2037717.

[205] ATLAS Collaboration, "Reconstruction of primary vertices at the ATLAS experiment in Run 1 proton–proton collisions at the LHC," *Eur. Phys. J. C* **77** (2017) 332, arXiv:1611.10235 [hep-ex].

[206] ATLAS Collaboration, "Topological cell clustering in the ATLAS calorimeters and its performance in LHC Run 1," *Eur. Phys. J. C* **77** (2017) 490, arXiv:1603.02934 [hep-ex].

[207] ATLAS Collaboration, "Electron and photon performance measurements with the ATLAS detector using the 2015–2017 LHC proton–proton collision data," *JINST* **14** (2019) P12006, arXiv:1908.00005 [hep-ex].

[208] ATLAS Collaboration, "Measurement of the photon identification efficiencies with the ATLAS detector using LHC Run 2 data collected in 2015 and 2016," *Eur. Phys. J. C* **79** (2019) 205, arXiv:1810.05087 [hep-ex].

[209] ATLAS Collaboration, "Electron and photon energy calibration with the ATLAS detector using 2015–2016 LHC proton–proton collision data," *JINST* **14** (2019) P03017, arXiv:1812.03848 [hep-ex].

[210] ATLAS Collaboration, "Electron reconstruction and identification in the ATLAS experiment using the 2015 and 2016 LHC proton–proton collision data at $\sqrt{s} = 13\,\mathrm{TeV}$," *Eur. Phys. J. C* **79** (2019) 639, arXiv:1902.04655 [hep-ex].

[211] ATLAS Collaboration, "Muon reconstruction performance of the ATLAS detector in proton–proton collision data at $\sqrt{s} = 13\,\mathrm{TeV}$," *Eur. Phys. J. C* **76** (2016) 292, arXiv:1603.05598 [hep-ex].

[212] **ATLAS** Collaboration, "Muon reconstruction and identification efficiency in ATLAS using the full Run 2 *pp* collision data set at $\sqrt{s} = 13$ TeV," arXiv:2012.00578 [hep-ex].

[213] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_t jet clustering algorithm," *JHEP* **04** (2008) 063, arXiv:0802.1189 [hep-ph].

[214] M. Cacciari, G. P. Salam, and G. Soyez, "FastJet user manual," *Eur. Phys. J. C* **72** (2012) 1896, arXiv:1111.6097 [hep-ph].

[215] M. Cacciari, "FastJet: A Code for fast k_t clustering, and more," in *Deep inelastic scattering. Proceedings, 14th International Workshop, DIS 2006, Tsukuba, Japan, April 20-24, 2006*, pp. 487–490. 2006. arXiv:hep-ph/0607071 [hep-ph]. [,125(2006)].

[216] **ATLAS** Collaboration, G. Aad *et al.*, "Jet energy scale and resolution measured in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector," arXiv:2007.02645 [hep-ex].

[217] M. Cacciari and G. P. Salam, "Pileup subtraction using jet areas," *Phys. Lett. B* **659** (2008) 119–126, arXiv:0707.1378 [hep-ph].

[218] ATLAS Collaboration, "Jet energy measurement with the ATLAS detector in proton–proton collisions at $\sqrt{s} = 7\,\mathrm{TeV}$," *Eur. Phys. J. C* **73** (2013) 2304, arXiv:1112.6426 [hep-ex].

[219] ATLAS Collaboration, "Determination of jet calibration and energy resolution in proton–proton collisions at $\sqrt{s} = 8\,\mathrm{TeV}$ using the ATLAS detector," arXiv:1910.04482 [hep-ex].

[220] ATLAS Collaboration, "Performance of pile-up mitigation techniques for jets in *pp* collisions at $\sqrt{s} = 8\,\mathrm{TeV}$ using the ATLAS detector," *Eur. Phys. J. C* **76** (2016) 581, arXiv:1510.03823 [hep-ex].

[221] ATLAS Collaboration, "Optimisation and performance studies of the ATLAS b-tagging algorithms for the 2017-18 LHC run." ATL-PHYS-PUB-2017-013, 2017. https://cds.cern.ch/record/2273281.

[222] ATLAS Collaboration, "ATLAS b-jet identification performance and efficiency measurement with $t\bar{t}$ events in pp collisions at $\sqrt{s} = 13\,\text{TeV}$," *Eur. Phys. J. C* **79** (2019) 970, arXiv:1907.05120 [hep-ex].

[223] ATLAS Collaboration, "Measurements of b-jet tagging efficiency with the ATLAS detector using $t\bar{t}$ events at $\sqrt{s} = 13\,\text{TeV}$," *JHEP* **08** (2018) 089, arXiv:1805.01845 [hep-ex].

[224] ATLAS Collaboration, "Performance of missing transverse momentum reconstruction with the ATLAS detector using proton–proton collisions at $\sqrt{s} = 13\,\text{TeV}$," *Eur. Phys. J. C* **78** (2018) 903, arXiv:1802.08168 [hep-ex].

[225] **ATLAS Collaboration** Collaboration, "$E_{\text{T}}^{\text{miss}}$ performance in the ATLAS detector using 2015-2016 LHC p-p collisions," Tech. Rep. ATLAS-CONF-2018-023, CERN, Geneva, Jun, 2018. http://cds.cern.ch/record/2625233.

[226] D. Adams *et al.*, "Recommendations of the Physics Objects and Analysis Harmonisation Study Groups 2014," Tech. Rep. ATL-PHYS-INT-2014-018, CERN, Geneva, Jul, 2014. https://cds.cern.ch/record/1743654.

[227] M. Cacciari, G. P. Salam, and G. Soyez, "The Catchment Area of Jets," *JHEP* **04** (2008) 005, arXiv:0802.1188 [hep-ph].

[228] **UA1** Collaboration, G. Arnison *et al.*, "Experimental Observation of Isolated Large Transverse Energy Electrons with Associated Missing Energy at $\sqrt{s} = 540$ GeV," *Phys. Lett. B* **122** (1983) 103–116.

[229] **Aachen-Annecy-Birmingham-CERN-Helsinki-London(QMC)-Paris(CdF)-Riverside-Rome-Rutherford-Saclay(CEN)-Vienna** Collaboration, G. Arnison *et al.*, "Further evidence for charged intermediate vector bosons at the SPS collider," *Phys. Lett. B* **129** no. CERN-EP-83-111, (Jun, 1985) 273–282. 17 p. https://cds.cern.ch/record/163856.

[230] D. R. Tovey, "On measuring the masses of pair-produced semi-invisibly decaying particles at hadron colliders," *JHEP* **04** (2008) 034, arXiv:0802.2879 [hep-ph].

[231] G. Polesello and D. R. Tovey, "Supersymmetric particle mass measurement with the boost-corrected contransverse mass," *JHEP* **03** (2010) 030, arXiv:0910.0174 [hep-ph].

[232] **ATLAS** Collaboration, G. Aad *et al.*, "Performance of the missing transverse momentum triggers for the ATLAS detector during Run-2 data taking," *JHEP* **08** (2020) 080, arXiv:2005.09554 [hep-ex].

[233] **ATLAS** Collaboration, G. Aad *et al.*, "Performance of algorithms that reconstruct missing transverse momentum in $\sqrt{s} = 8$ TeV proton-proton collisions in the ATLAS detector," *Eur. Phys. J. C* **77** no. 4, (2017) 241, arXiv:1609.09324 [hep-ex].

[234] ATLAS Collaboration, "ATLAS data quality operations and performance for 2015–2018 data-taking," *JINST* **15** (2020) P04003, arXiv:1911.04632 [physics.ins-det].

[235] ATLAS Collaboration, "Selection of jets produced in 13 TeV proton–proton collisions with the ATLAS detector." ATLAS-CONF-2015-029, 2015. https://cds.cern.ch/record/2037702.

[236] N. Hartmann, "ahoi." https://gitlab.com/nikoladze/ahoi, 2018.

[237] **ATLAS** Collaboration, "Object-based missing transverse momentum significance in the ATLAS detector," Tech. Rep. ATLAS-CONF-2018-038, CERN, Geneva, Jul, 2018. https://cds.cern.ch/record/2630948.

[238] A. Roodman, "Blind analysis in particle physics," *eConf* **C030908** (2003) TUIT001, arXiv:physics/0312102.

[239] ATLAS Collaboration, "A method for the construction of strongly reduced representations of ATLAS experimental uncertainties and the application thereof to the jet energy scale." ATL-PHYS-PUB-2015-014, 2015. https://cds.cern.ch/record/2037436.

[240] J. Bellm *et al.*, "Herwig 7.0/Herwig++ 3.0 release note," *Eur. Phys. J.* **C76** no. 4, (2016) 196, arXiv:1512.01178 [hep-ph].

[241] ATLAS Collaboration, "Simulation of top-quark production for the ATLAS experiment at $\sqrt{s} = 13$ TeV." ATL-PHYS-PUB-2016-004, 2016. https://cds.cern.ch/record/2120417.

[242] S. Frixione, E. Laenen, P. Motylinski, C. White, and B. R. Webber, "Single-top hadroproduction in association with a W boson," *JHEP* **07** (2008) 029, arXiv:0805.3067 [hep-ph].

[243] **ATLAS Collaboration** Collaboration, "SUSY July 2020 Summary Plot Update," Tech. Rep. ATL-PHYS-PUB-2020-020, CERN, Geneva, Jul, 2020. http://cds.cern.ch/record/2725258.

[244] G. Apollinari, I. Béjar Alonso, O. Brüning, M. Lamont, and L. Rossi, *High-Luminosity Large Hadron Collider (HL-LHC): Preliminary Design Report*. CERN Yellow Reports: Monographs. CERN, Geneva, 2015. https://cds.cern.ch/record/2116337.

[245] **LHC Reinterpretation Forum** Collaboration, W. Abdallah *et al.*, "Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2," *SciPost Phys.* **9** no. 2, (2020) 022, arXiv:2003.07868 [hep-ph].

[246] ATLAS Collaboration, "RECAST framework reinterpretation of an ATLAS Dark Matter Search constraining a model of a dark Higgs boson decaying to two b-quarks." ATL-PHYS-PUB-2019-032, 2019. https://cds.cern.ch/record/2686290.

[247] K. Cranmer and I. Yavin, "RECAST: Extending the Impact of Existing Analyses," *JHEP* **04** (2011) 038, arXiv:1010.2506 [hep-ex].

[248] S. Ovyn, X. Rouby, and V. Lemaitre, "DELPHES, a framework for fast simulation of a generic collider experiment," arXiv:0903.2225 [hep-ph].

[249] A. Buckley, J. Butterworth, D. Grellscheid, H. Hoeth, L. Lonnblad, J. Monk, H. Schulz, and F. Siegert, "Rivet user manual," *Comput. Phys. Commun.* **184** (2013) 2803–2819, arXiv:1003.0694 [hep-ph].

[250] A. Buckley, D. Kar, and K. Nordström, "Fast simulation of detector effects in Rivet," *SciPost Phys.* **8** (2020) 025, arXiv:1910.01637 [hep-ph].

[251] D. Dercks, N. Desai, J. S. Kim, K. Rolbiecki, J. Tattersall, and T. Weber, "CheckMATE 2: From the model to the limit," *Comput. Phys. Commun.* **221** (2017) 383–418, arXiv:1611.09856 [hep-ph].

[252] M. Drees, H. Dreiner, D. Schmeier, J. Tattersall, and J. S. Kim, "CheckMATE: Confronting your Favourite New Physics Model with LHC Data," *Comput. Phys. Commun.* **187** (2015) 227–265, arXiv:1312.2591 [hep-ph].

[253] E. Conte, B. Fuks, and G. Serret, "MadAnalysis 5, A User-Friendly Framework for Collider Phenomenology," *Comput. Phys. Commun.* **184** (2013) 222–256, arXiv:1206.1599 [hep-ph].

[254] E. Maguire, L. Heinrich, and G. Watt, "HEPData: a repository for high energy physics data," *J. Phys. Conf. Ser.* **898** no. 10, (2017) 102006, arXiv:1704.05473 [hep-ex].

[255] **ATLAS** Collaboration, "Simpleanalysis." https://gitlab.cern.ch/atlas-sa/simple-analysis, 2021.

[256] S. Kraml, S. Kulkarni, U. Laa, A. Lessa, W. Magerl, D. Proschofsky-Spindler, and W. Waltenberger, "SModelS: a tool for interpreting simplified-model results from the LHC and its application to supersymmetry," *Eur. Phys. J. C* **74** (2014) 2868, arXiv:1312.4175 [hep-ph].

[257] F. Ambrogi, S. Kraml, S. Kulkarni, U. Laa, A. Lessa, V. Magerl, J. Sonneveld, M. Traub, and W. Waltenberger, "SModelS v1.1 user manual: Improving simplified model constraints with efficiency maps," *Comput. Phys. Commun.* **227** (2018) 72–98, arXiv:1701.06586 [hep-ph].

[258] **ATLAS** Collaboration, "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 $\sqrt{s} = 13$ tev with the atlas detector," 2021. https://www.hepdata.net/record/ins1755298?version=4.

[259] **LHC Reinterpretation Forum** Collaboration, W. Abdallah *et al.*, "Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2," *SciPost Phys.* **9** no. 2, (2020) 022, arXiv:2003.07868 [hep-ph].

[260] **ATLAS** Collaboration, "1lbb-likelihoods-hepdata.tar.gz," 2020. https://www.hepdata.net/record/resource/1408476?view=true.

[261] G. Alguero, S. Kraml, and W. Waltenberger, "A SModelS interface for pyhf likelihoods," arXiv:2009.01809 [hep-ph].

[262] M. D. Goodsell, "Implementation of the ATLAS-SUSY-2019-08 analysis in the MadAnalysis 5 framework (electroweakinos with a Higgs decay into a $b\bar{b}$ pair, one lepton and missing transverse energy; 139 fb^{-1})," *Mod. Phys. Lett. A* **36** no. 01, (2021) 2141006.

[263] J. Y. Araz *et al.*, "Proceedings of the second MadAnalysis 5 workshop on LHC recasting in Korea," *Mod. Phys. Lett. A* **36** no. 01, (2021) 2102001, arXiv:2101.02245 [hep-ph].

[264] M. Feickert, L. Heinrich, G. Stark, and B. Galewsky, "Distributed statistical inference with pyhf enabled through funcX," in *25th International Conference on Computing in High-Energy and Nuclear Physics*. 3, 2021. arXiv:2103.02182 [cs.DC].

[265] R. Chard, Y. Babuji, Z. Li, T. Skluzacek, A. Woodard, B. Blaiszik, I. Foster, and K. Chard, "funcx: A federated function serving fabric for science," ACM, Jun, 2020. http://dx.doi.org/10.1145/3369583.3392683.

[266] D. Merkel, "Docker: Lightweight linux containers for consistent development and deployment," *Linux J.* **2014** no. 239, (Mar., 2014) .

[267] S. Binet and B. Couturier, "docker & HEP: Containerization of applications for development, distribution and preservation," *J. Phys.: Conf. Ser.* **664** no. 2, (2015) 022007. 8 p. https://cds.cern.ch/record/2134524.