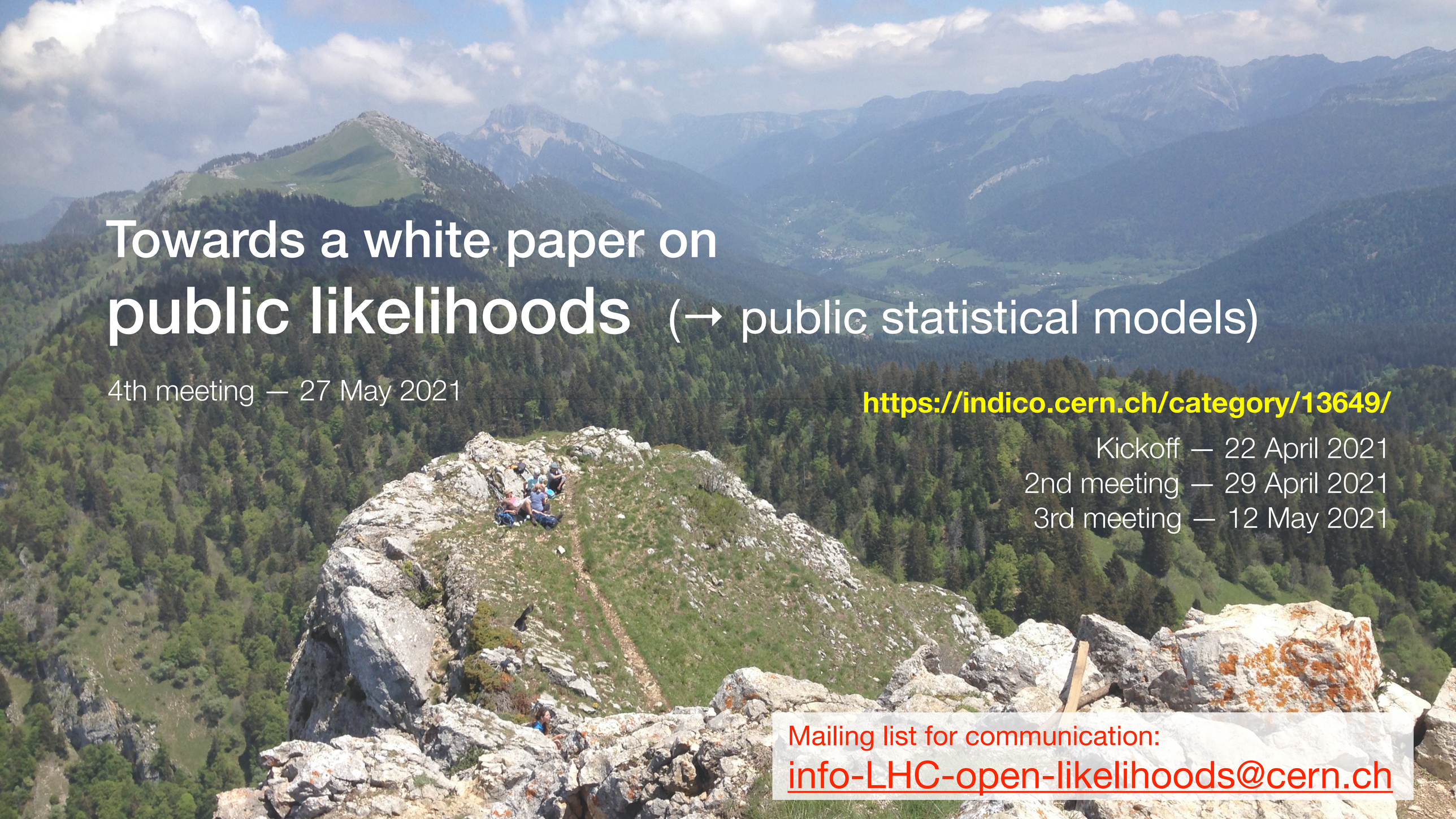


Towards a white paper on public likelihoods (→ public statistical models)

4th meeting — 27 May 2021

https://indico.cern.ch/category/13649/

Kickoff — 22 April 2021
2nd meeting — 29 April 2021
3rd meeting — 12 May 2021

Mailing list for communication:
info-LHC-open-likelihoods@cern.ch

A white paper on public likelihoods

suggestion from the Feb 2021 reinterpretation workshop

Objectives:

- to state as precisely as possible
  - the role of statistical models and likelihoods
  - why it's important to preserve -and publish- them
  - what issues need to be addressed, and
- to urge our field to reach consensus to make them openly available (in a standard from?).

Timeline: soon, next few months

Format: ~20 pages writeup

to be followed by a series of dedicated workshops

Why ?

- The statistical model of an experimental analysis provides the complete mathematical description of that analysis

  $p(o|\alpha)$ relating the observed quantities o to the parameters α

- Given the likelihood, all the standard statistical approaches are available for extracting information from it

- Essential information for any detailed interpretation of experimental results

  = determining the compatibility of the observations with theoretical predictions

Les Houches Recommandations (2012)

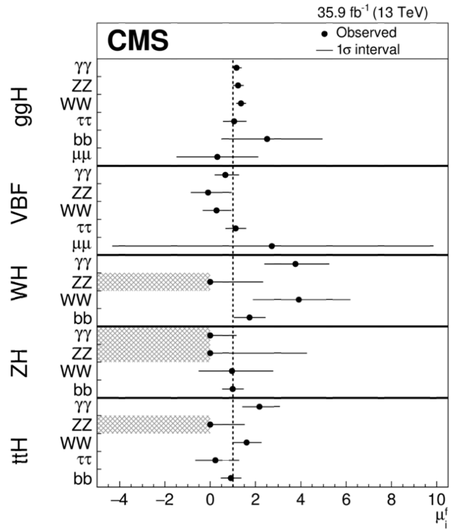
3b: When feasible, provide a mathematical description of the final likelihood function in which experimental data and parameters are clearly distinguished, either in the publication or the auxiliary information. Limits of validity should always be clearly specified.

3c: Additionally provide a digitized implementation of the likelihood that is consistent with the mathematical description.

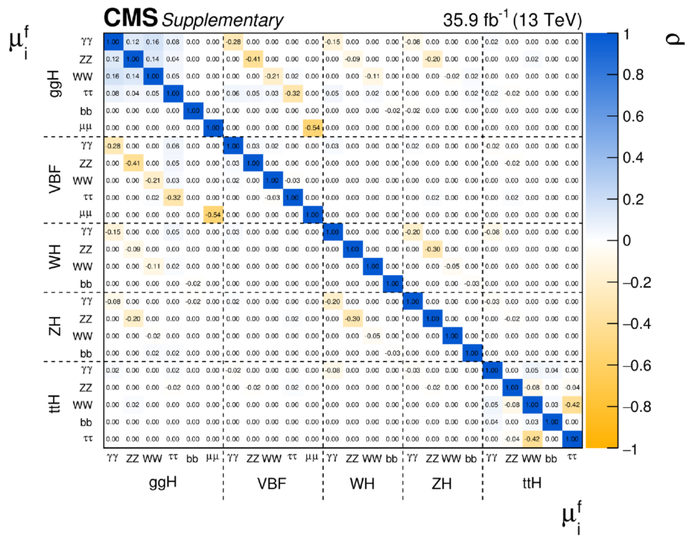
arXiv:1203.2489

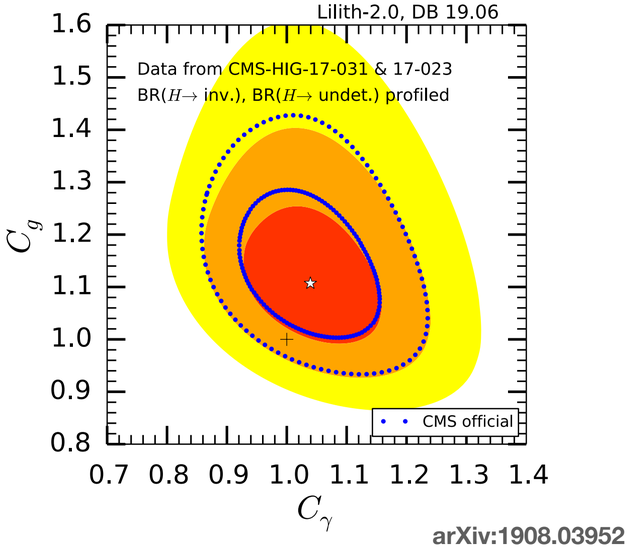
So far: O±δO plus correlations (sometimes)

- Simplified likelihood, Gaussian approximation
  - e.g., Higgs measurements, channel-by-channel correlation matrix



CMS-HIG-17-031





arXiv:1908.03952

«Correlation data […] has proven excellent for stabilising and ensuring better statistical definition in global fits as well as avoiding either overly conservative or over-enthusiastic interpretations.»

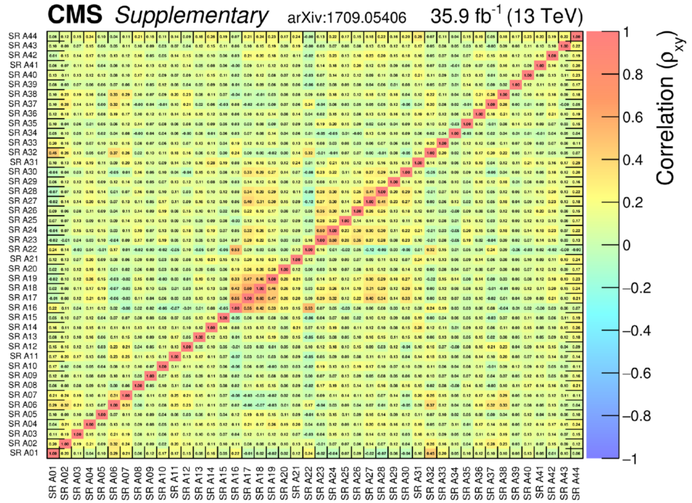
Reinterpretation Forum Report, 2003.07868

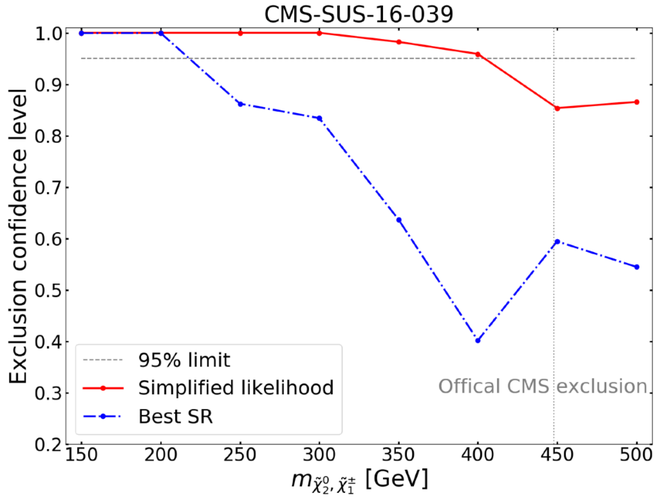
So far: O±δO plus correlations (sometimes)

- Simplified likelihood, Gaussian approximation
  - CMS SUSY group: covariance matrices for combination of signal regions

M_T (GeV)	p_T^{miss} (GeV)	$M_{\ell\ell} < 75$ GeV (exp.)	(obs.)	$75 \leq M_{\ell\ell} < 105$ GeV (exp.)	(obs.)	$M_{\ell\ell} \geq 105$ GeV (exp.)	(obs.)
0 – 100	50 – 100	185 ± 22	186	2180 ± 260	2278	121 ± 14	123
	100 – 150	35 ± 6	34	440 ± 70	429	32 ± 5	32
	150 – 200	9.3 ± 2.2	11	129 ± 28	123	11.6 ± 2.6	4
	200 – 250	3.3 ± 1.0	1	48 ± 10	37	2.9 ± 0.8	6
	250 – 400	4.0 ± 1.0	5	42 ± 9	38	3.7 ± 1.0	5
	400 – 550			8.5 ± 2.1	5		
	≥550			2.6 ± 0.8	2		
100 – 160	50 – 100	50 ± 8	60	390 ± 50	391	32 ± 5	17
	100 – 150	15 ± 4	19	72 ± 19	61	9.6 ± 2.4	9
	150 – 200	1.9 ± 0.6	1	10 ± 4	9	2.4 ± 0.7	0
	≥200	0.8 ± 0.4	3	4.9 ± 1.9	8	1.0 ± 0.4	2
≥160	50 – 100	13.0 ± 2.8	16	37 ± 9	35	9.4 ± 2.4	9
	100 – 150	11.9 ± 3.2	17	21 ± 8	17	6.6 ± 2.1	3
	150 – 200	3.1 ± 1.2	4	8.9 ± 3.1	7	3.1 ± 1.0	0
	200 – 250	2.1 ± 0.8	3	3.6 ± 1.3	5	2.5 ± 0.8	0
	250 – 400	0.9 ± 0.4	1	4.1 ± 1.6	3		
	≥400			1.0 ± 0.5	1		

CMS-SUS-16-039 (EWino search)





Contribution 15, LH 2019 BSM WG report
arXiv:2002.12220

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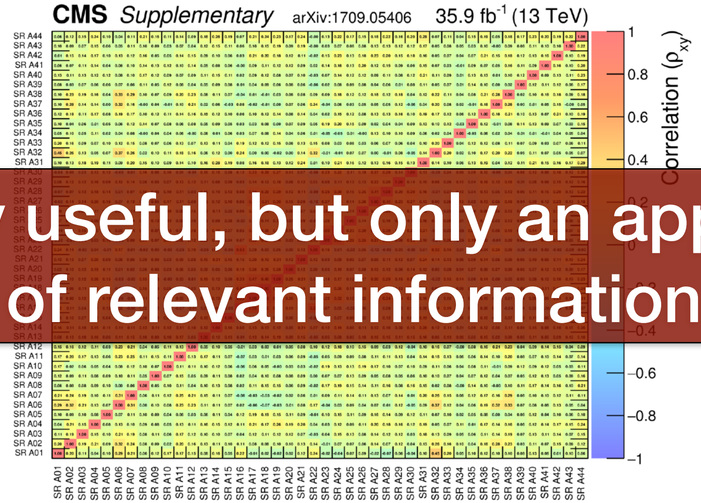

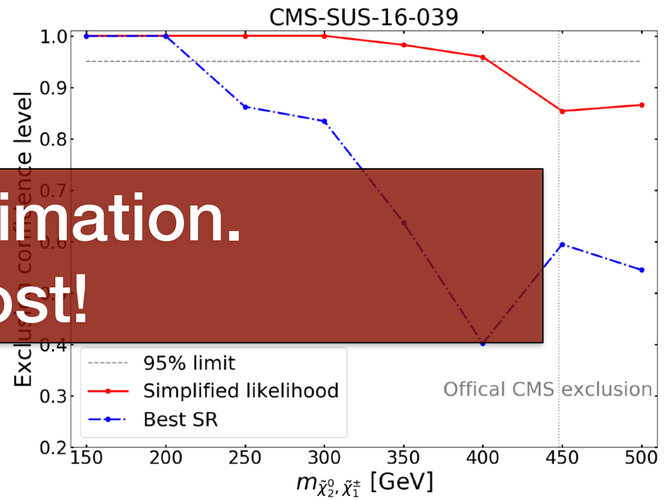

Extremely useful, but only an approximation.
Lots of relevant information is lost!

Contribution 15, LH 2019 BSM WG report
arXiv:2002.12220

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Reinterpretation Forum Report, 2003.07868

First full likelihoods from ATLAS

ATL-PHYS-PUB-2019-029

- Plain-text serialisation of HistFactory workspaces, JSON format
  - Provides background estimates, changes under systematic variations, and observed data counts at the same fidelity as used in the experiment.

	Description	Modification	Constraint Term c_χ	Input
constrained	Uncorrelated Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Pois}\left(r_b = \sigma_b^{-2} \middle\vert \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
	Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle\vert \Delta_{scb,\alpha=-1}, \Delta_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \vert\, \alpha, \sigma = 1)$	$\Delta_{scb,\alpha=\pm1}$
	Normalisation Unc.	$\kappa_{scb}(\alpha) = g_p\left(\alpha \middle\vert \kappa_{scb,\alpha=-1}, \kappa_{scb,\alpha=1}\right)$	$\text{Gaus}\,(a = 0 \vert\, \alpha, \sigma = 1)$	$\kappa_{scb,\alpha=\pm1}$
	MC Stat. Uncertainty	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \text{Gaus}\left(a_{\gamma_b} = 1 \middle\vert \gamma_b, \delta_b\right)$	$\delta_b^2 = \sum_s \delta_{sb}^2$
	Luminosity	$\kappa_{scb}(\lambda) = \lambda$	$\text{Gaus}\,(l = \lambda_0 \vert\, \lambda, \sigma_\lambda)$	$\lambda_0, \sigma_\lambda$
free	Normalisation	$\kappa_{scb}(\mu_b) = \mu_b$		
	Data-driven Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$		

Rate modifications defined in HistFactory for bin *b*, sample *s*, channel *c*.

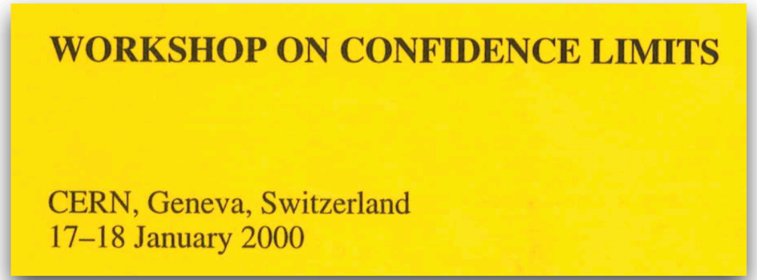
  - Usage: RooFit, **pyhf**
  - Target: long-term data/analysis preservation, reinterpretation purposes

Likelihood available

Search for chargino and neutralino pair RPV decays; 3L	SUSY	Submitted to PRD	20-NOV-20	13	139 fb^{-1}
Search for displaced leptons	SUSY	Submitted to PRL	13-NOV-20	13	139 fb^{-1}
Gluino pair; squark pair; gluino-squark; 0-lepton	SUSY	JHEP 02 (2021) 143	27-OCT-20	13	139 fb^{-1}
Chargino-neutralino pair; 3 leptons, weak-scale mass splittings	SUSY	Phys. Rev. D 101 (2020) 072001 C:R	18-DEC-19	13	139 fb^{-1}
Staus; taus	SUSY	Phys. Rev. D 101 (2020) 032009 C:R	15-NOV-19	13	139 fb^{-1}
Chargino-neutralino pair; Higgs boson in final state, 2 b-jets and 1 lepton	SUSY	Eur. Phys. J. C 80 (2020) 691 C:R	19-SEP-19	13	139 fb^{-1}
Stop pair, sbottom pair, gluino pair; two same-sign leptons or three leptons	SUSY	JHEP 06 (2020) 46 C:R	18-SEP-19	13	139 fb^{-1}
Sbottom; b-jets	SUSY	JHEP 12 (2019) 060 C:R	08-AUG-19	13	139 fb^{-1}

Publishing likelihoods

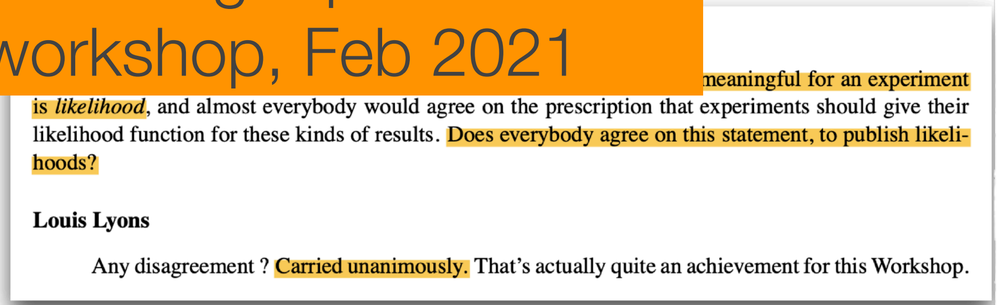
- **General agreement over importance of publishing likelihoods (LHs)**
  - Already back in 2000!


WORKSHOP ON CONFIDENCE LIMITS

CERN, Geneva, Switzerland
17–18 January 2000

- **Why is it important?**
  - Likelihood one of the most important data products of HEP analyses.
  - Nearly everything in an analysis affects the LH (trigger, detector, systematic uncertainties, event selection, …)
  - Most of the an
    - Theorists sti

Public Likelihoods were also a big topic
at last Reinterpretation Forum workshop, Feb 2021


meaningful for an experiment is *likelihood*, and almost everybody would agree on the prescription that experiments should give their likelihood function for these kinds of results. Does everybody agree on this statement, to publish likelihoods?

Louis Lyons

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

https://cds.cern.ch/record/452080

- **Actually publishing/preserving is tricky though …**
  - What do we want to preserve exactly? And how? In what format?
  - Do not really have a software-independent format of the LH to put on HEPdata …

➡ **Start with a single more tractable model first:** HistFactory

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- **Why is it important?**
  - Likelihood one of the most important data products of HEP analyses.
  - Nearly everything in an analysis affects the LH (trigger, detector, systematic uncertainties, event selection, …)
  - Most of the analysis products we publish on HEPdata are lossy projections of our LHs.
    - Theorists still have to do “guesses” to build realistic LH.

Massimo Corradi

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

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➡ **Start with a single more tractable model first:** HistFactory

We want this to become the standard!

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Different experiments/analyses use different modelling specifications,
but, whatever the choice, the full statistical model should be made public.

Would enormously benefit the short- and long-term reuse of experimental results.

White paper: structure of the document

1. Introduction and motivation
2. From probability models to likelihoods

   Brief review of the mathematical basics
   Setting the notation and terminology to be used throughout
3. Physics examples, use cases

   PDFs, EFT, Higgs, flavor, DM, global fits …. your contributions
4. Infrastructures and tools

   What is there, how it can be used, and what needs to be developed
5. Outstanding issues
6. Conclusions

Reinterpretation Forum Report 2020

"…. In fact, many of the data products discussed here, such as signal/background yields and correlations, are used by the various external reinterpretation packages to construct likelihoods. Whilst extremely useful, the likelihoods constructed from these products are however always only an approximation to the true underlying experimental likelihood. The reinterpretation workflow can be greatly facilitated and rendered much more precise if the original likelihood of the analysis is published in full. We strongly encourage the movement towards the publication of full experimental likelihoods wherever possible."

"ATLAS has recently started to do this using a JSON serialisation of the likelihood […] The provision of this full likelihood information is much appreciated and we hope that it will become a standard, as it **greatly improves the quality of any reinterpretation**."

Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2
arXiv:2003.07868, SciPost Phys. 9, 022 (2020)