Top EFT fit

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LHC***top***WG open meeting

2022/06/15

Approaching EFT combination

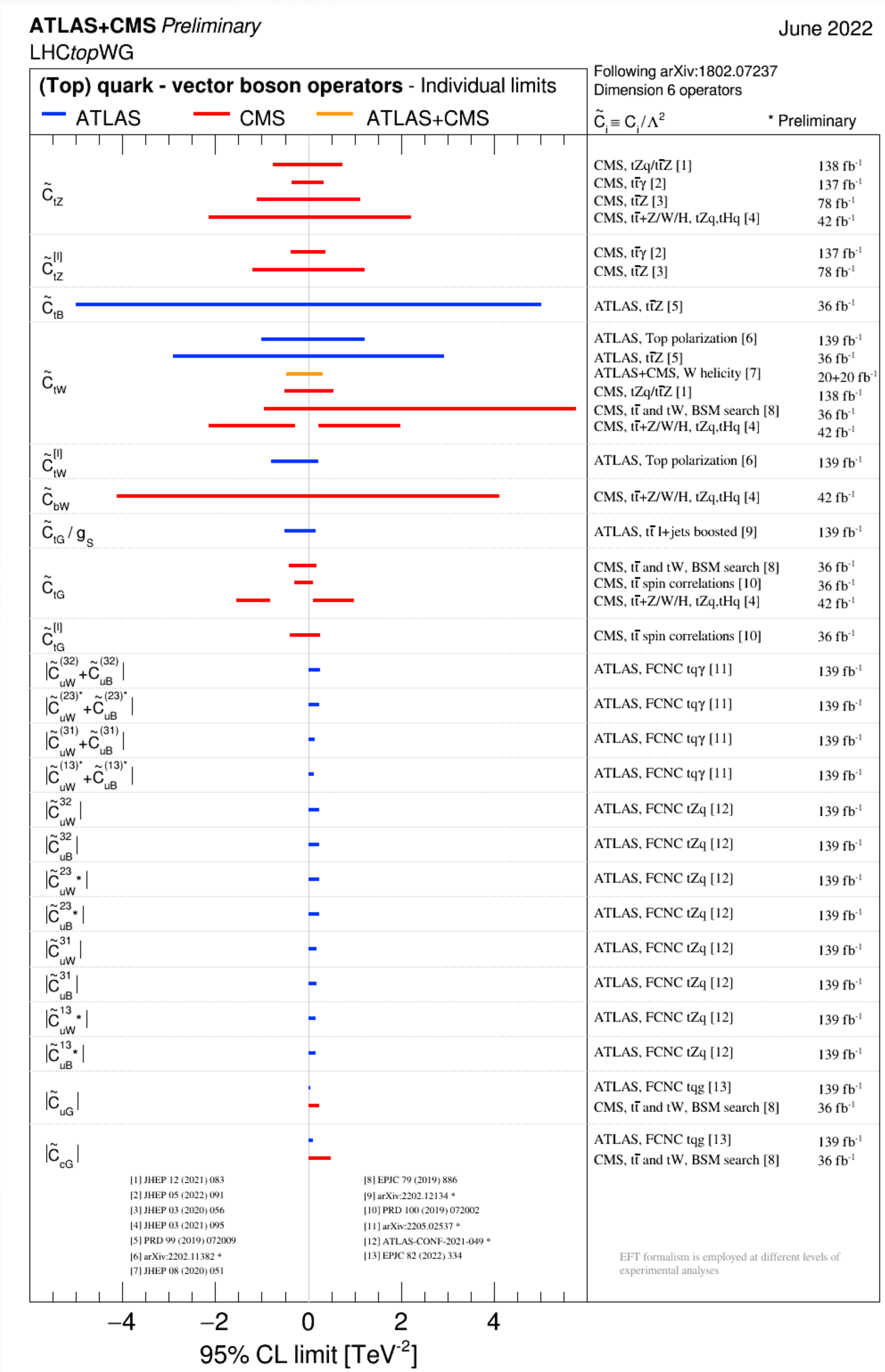
- An EFT analysis: **complex**!
- An EFT ATLAS+CMS combination: **complex^2**!
  → Need to **start early** in order not to cut corners later
  → Internal **discussions** and common **tools** development is a key
- How to combine?
  Faster: Combined reinterpretation of ATLAS and CMS results
  Better: Use ATLAS and CMS results in a common EFT fit
- Use **Run 2 data** → future baseline for Run 3
- Ultimately aim for a **likelihood-based combination**
  → in the meantime, various simplified approaches can be considered for existing results
- Benefit from **exploring both approaches** to agree on:
  - common conventions
  - systematics correlations
  - fitting method
  - publication format

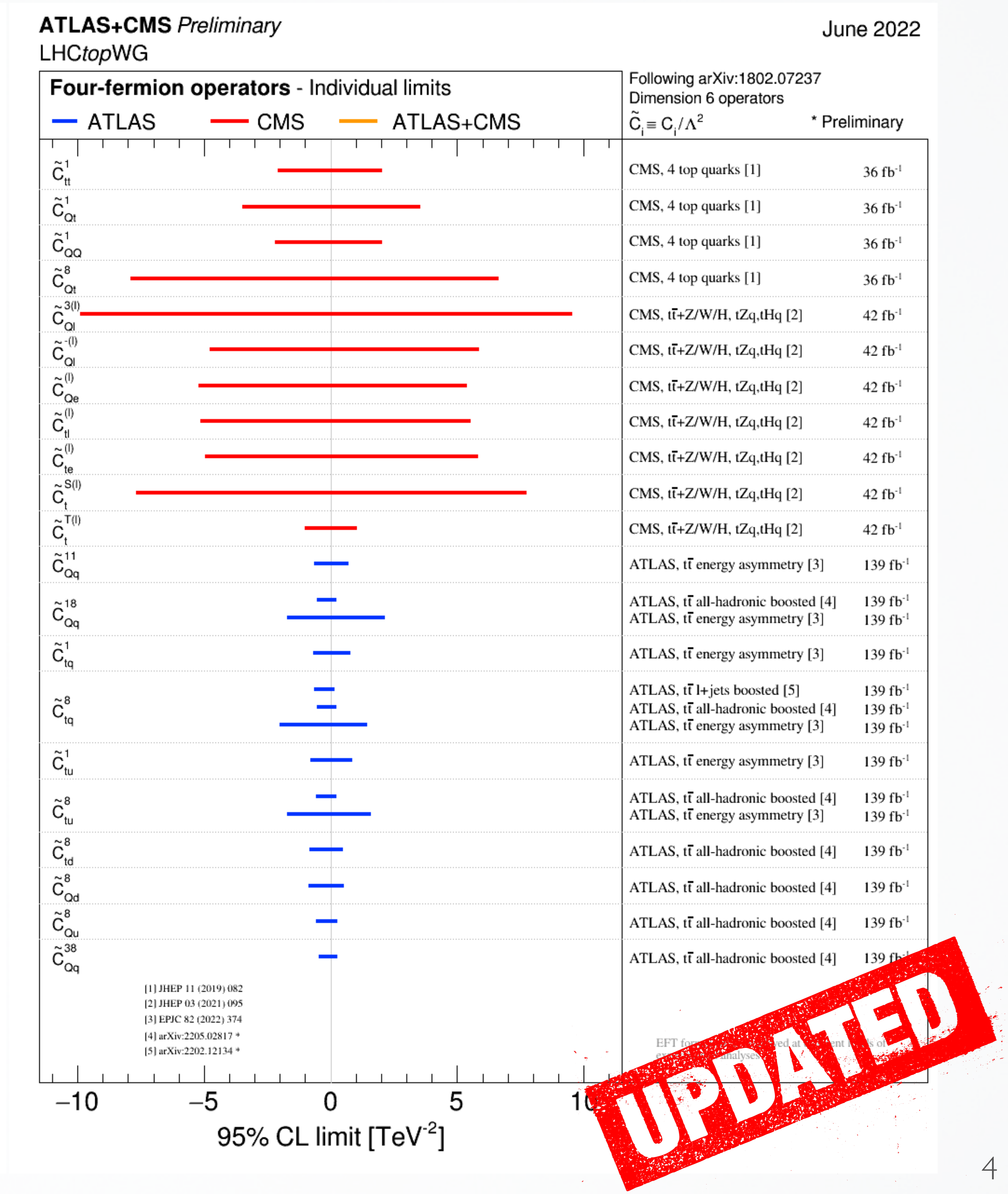
LHC*top*WG EFT combination

- Several discussions within LHCtopWG on how to perform an EFT combination (conventions, strategies, scope, etc.)
- Prepared a shortlist of candidates: focus on recent results (people are still active), look for overlap in EFT operators

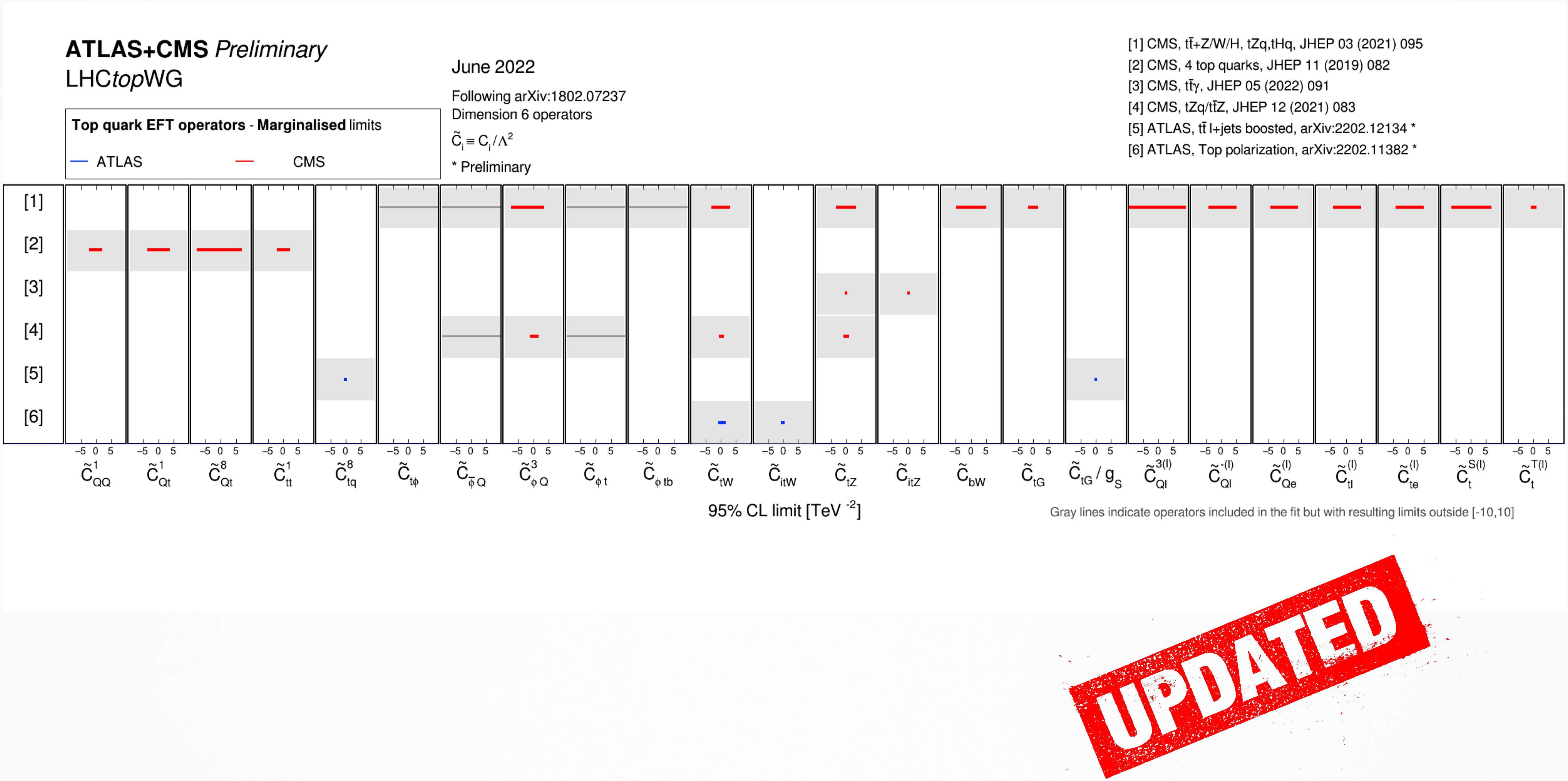
Process	ATLAS	CMS	Possible strategy
Spin correlations	EPJC 80 (2020) 754	PRD 100 (2019) 072002	Differential, EFTfitter
ttZ/W	PRD 99 (2019) 072009	JHEP 03 (2020) 056, JHEP 08 (2018) 011	EFT/SM generator-level reweighting, full likelihood
ttγ	JHEP 09 (2020) 049	CMS-PAS-TOP-21-004, arXiv:2107.01508	EFT/SM generator-level reweighting, full likelihood
tZq	JHEP 07 (2020) 124	arXiv:2107.13896, arXiv:2111.02860	Differential + inclusive, EFTfitter
FCNC t-gluon	EPJC 76 (2016) 55	JHEP 02 (2017) 028	Inclusive, EFTfitter
FCNC t-Higgs	JHEP 05 (2019) 123	arXiv:2111.02219, CMS-PAS-TOP-19-002	Inclusive, EFTfitter
t(t)X	ttZ/W	JHEP 03 (2021) 095	Detector level, full likelihood

LHC*top*WG EFT Summary plots

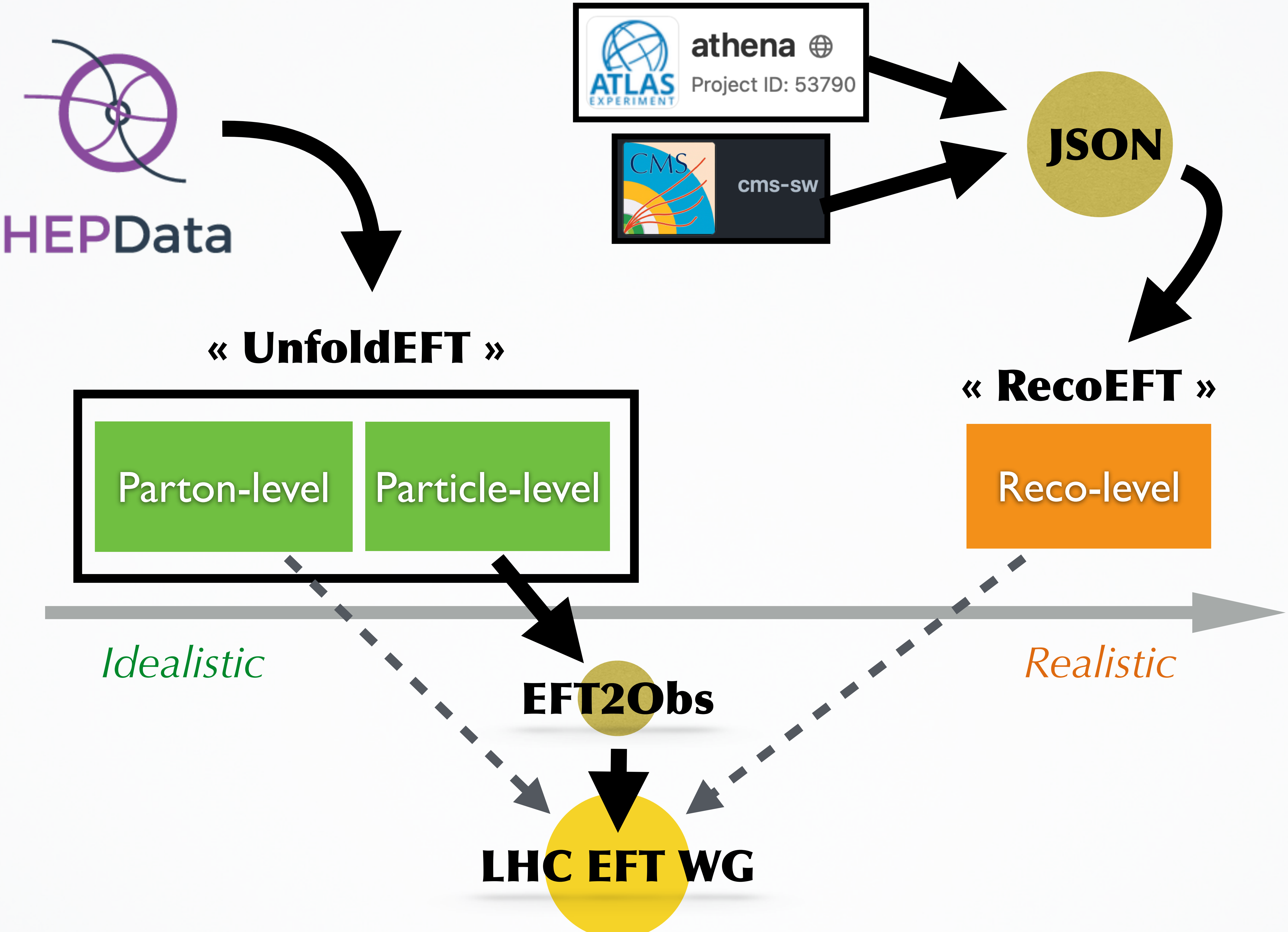




LHC*top*WG EFT Summary plots



Experimental EFT directions

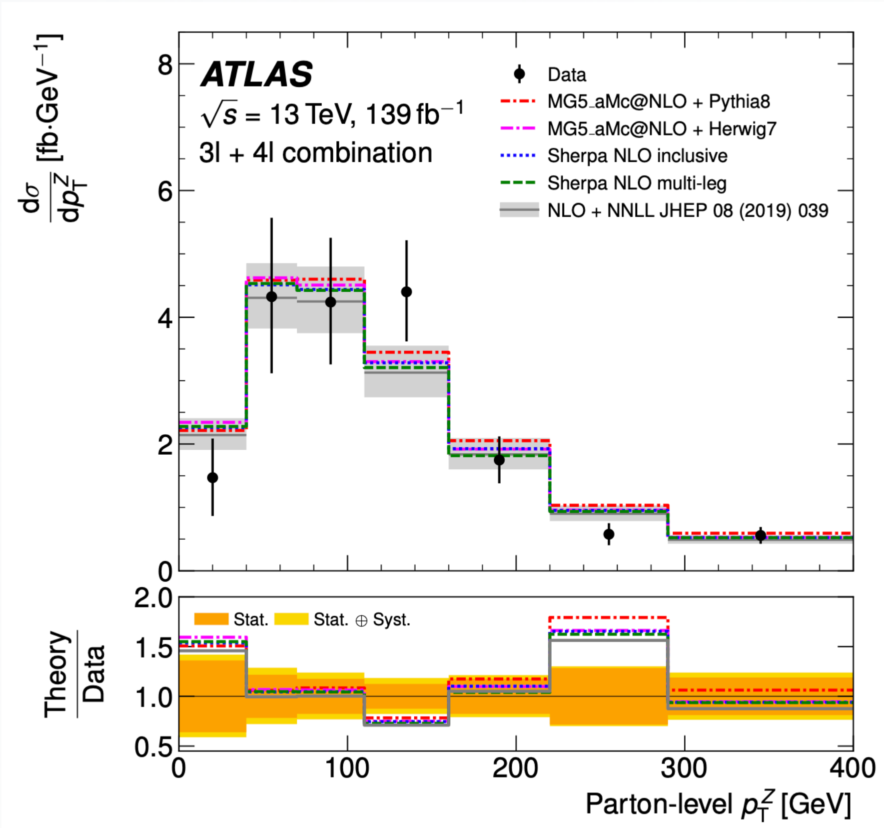


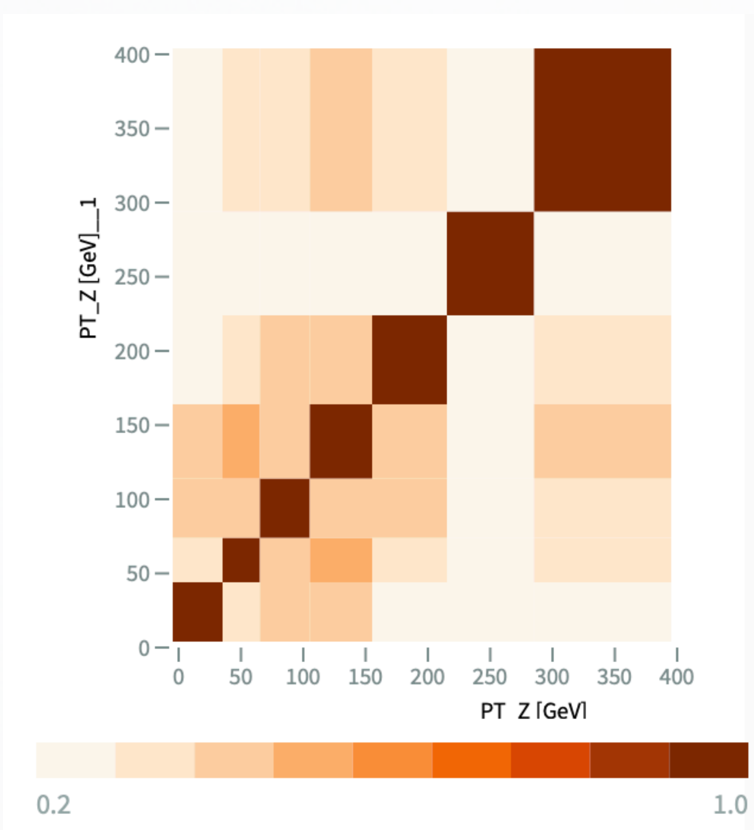
UnfoldEFT

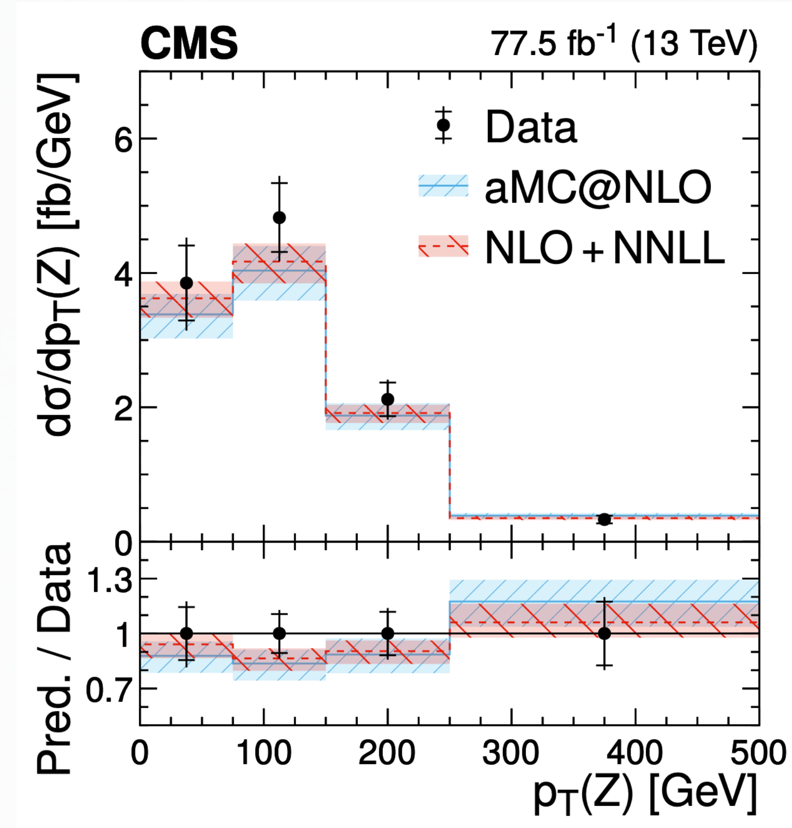
- **EFT reinterpretation** of experimental results using **Unfold**ed differential cross sections
- **Backgrounds subtracted** → information on EFT dependence of backgrounds is lost
- Typically, only total statistical and systematic uncertainties (split in signal and background) are available → **impossible** to properly correlate systematics
- Publishing unfolded cross sections in HEPData became a standard → **many suitable results** available for reinterpretation
- Exercise: start by combining ttZ unfolded results at **parton level (taken from HEPData)**; then extend to other processes

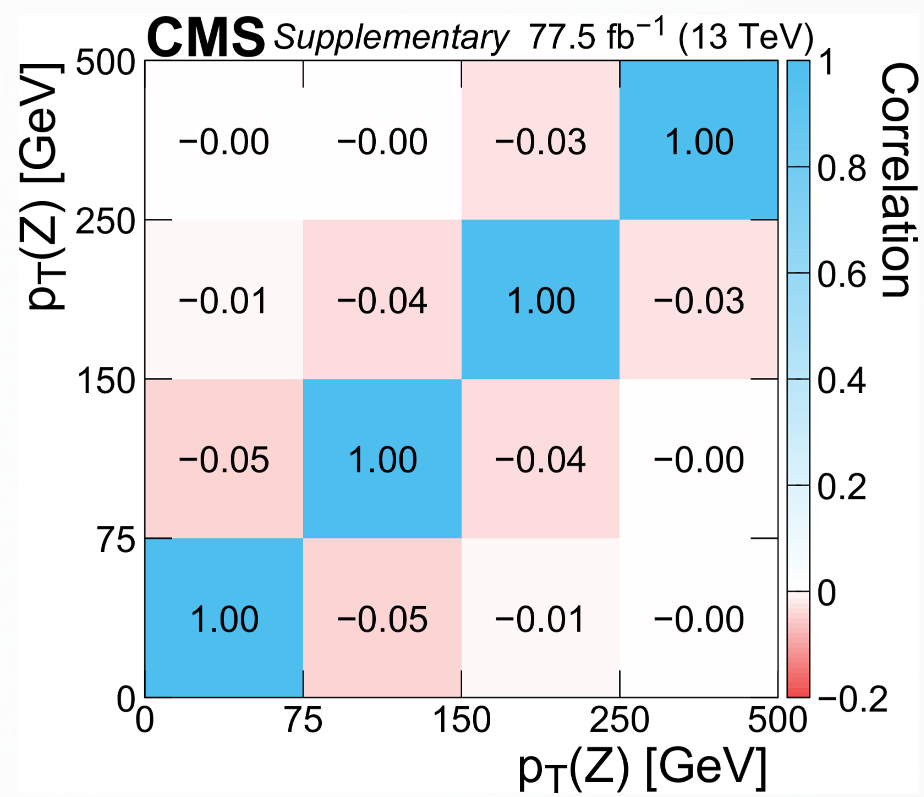
UnfoldEFT: Inputs

EPJC 81 (2021) 737





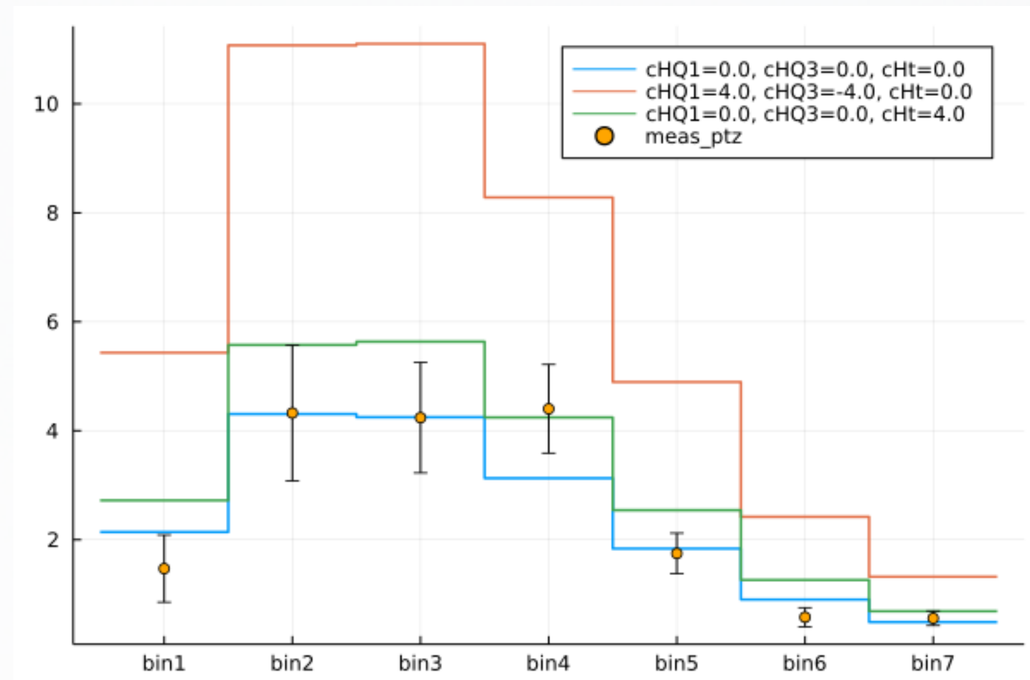


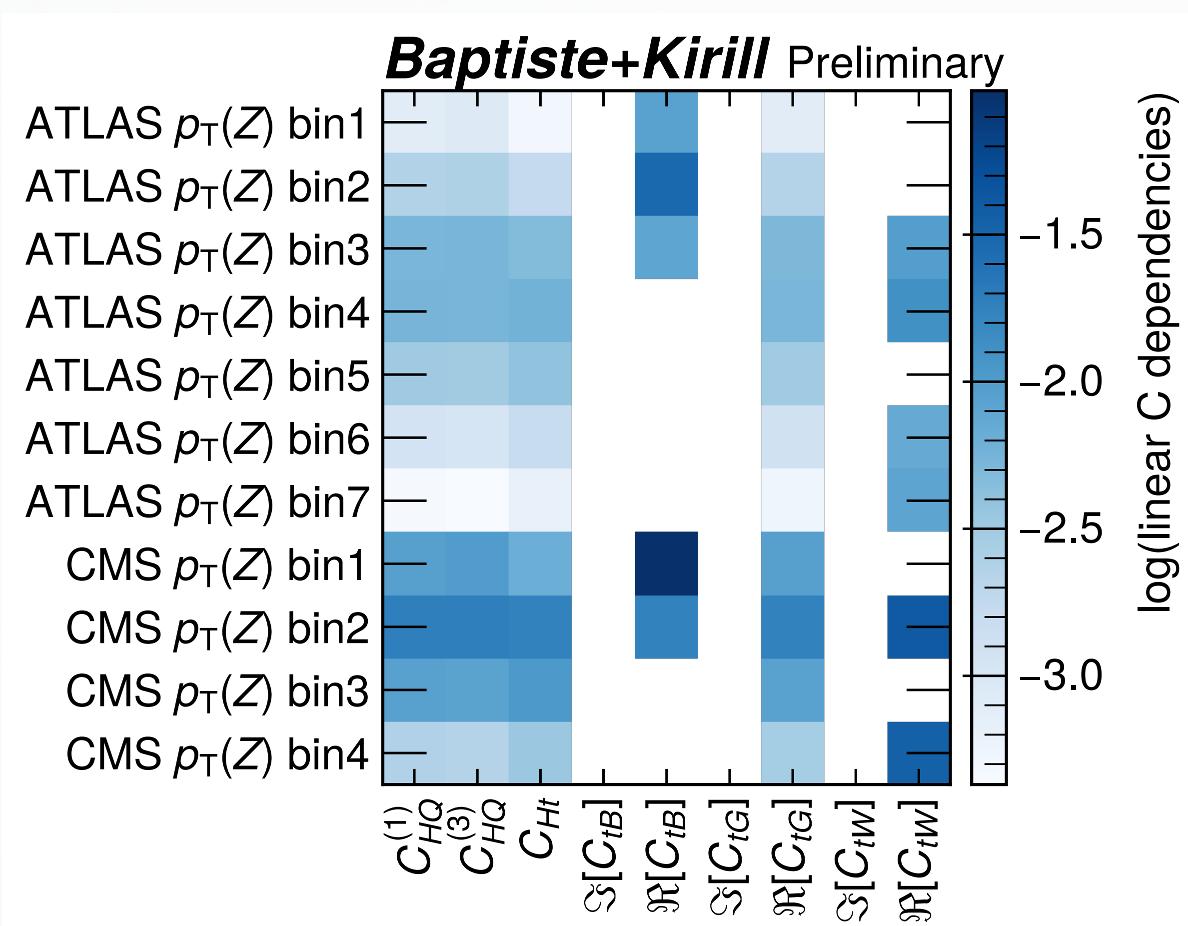


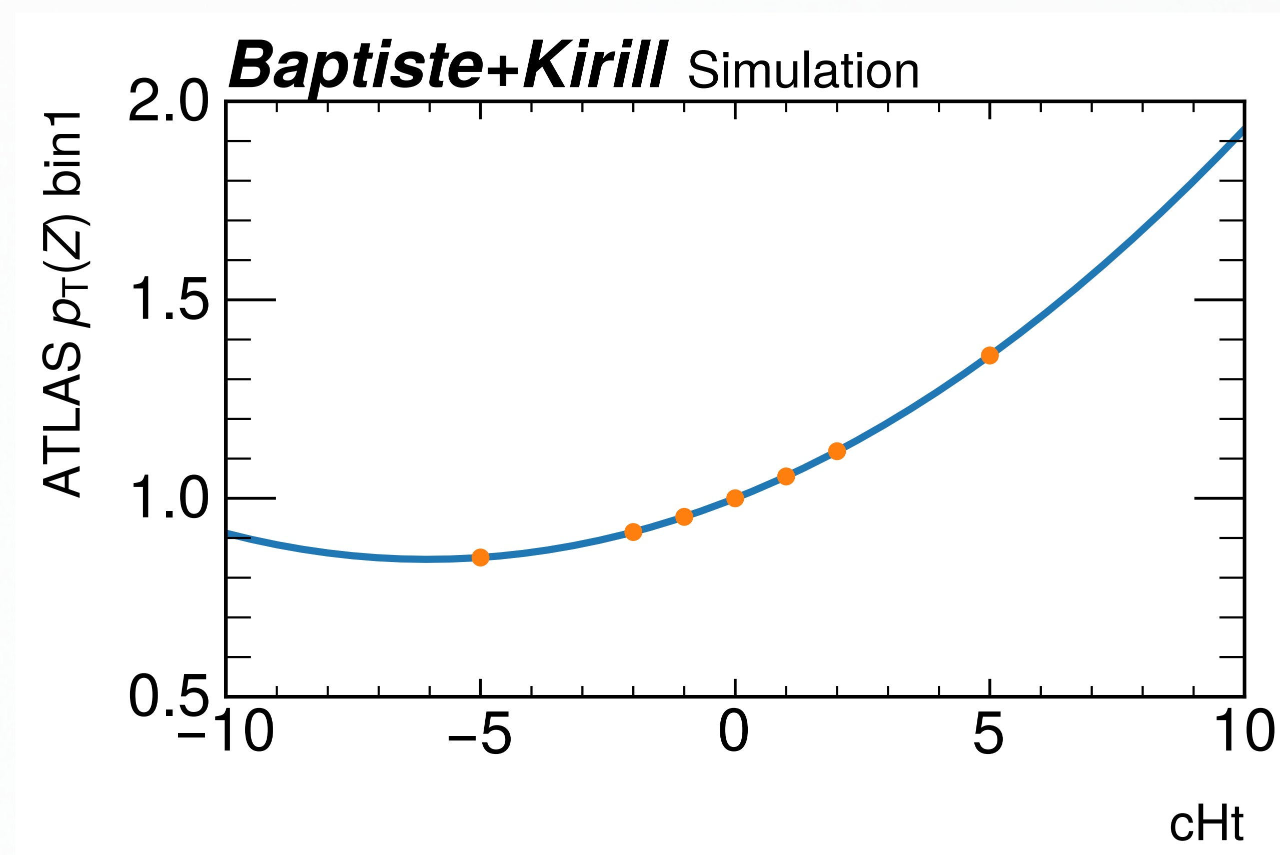
JHEP 03 (2020) 056

UnfoldEFT: Event generation

- Agreed on a **common set** of MG5 parameters and the EFT model (**SMEFTsim**, **topU3l**)
- Generated MC events with **EFT weights**
- **Include**: cHQ3, cHQ1, cHt, CtBRe, CtBIm, CtWRe, CtWIm, CtGRe, CtGIm
- Derived **EFT parametrization** as a function of kinematic variable (p_T of Z boson)

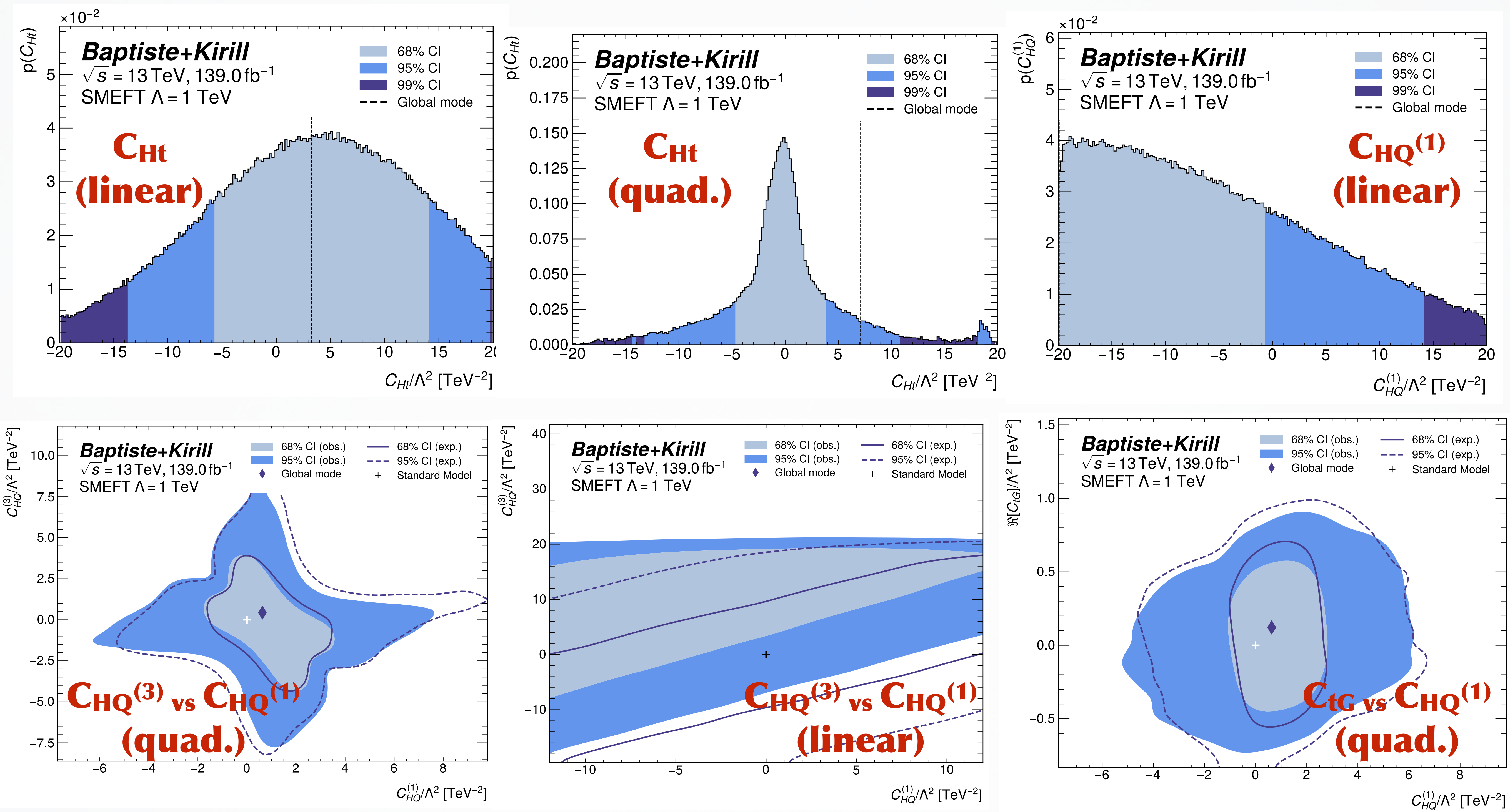






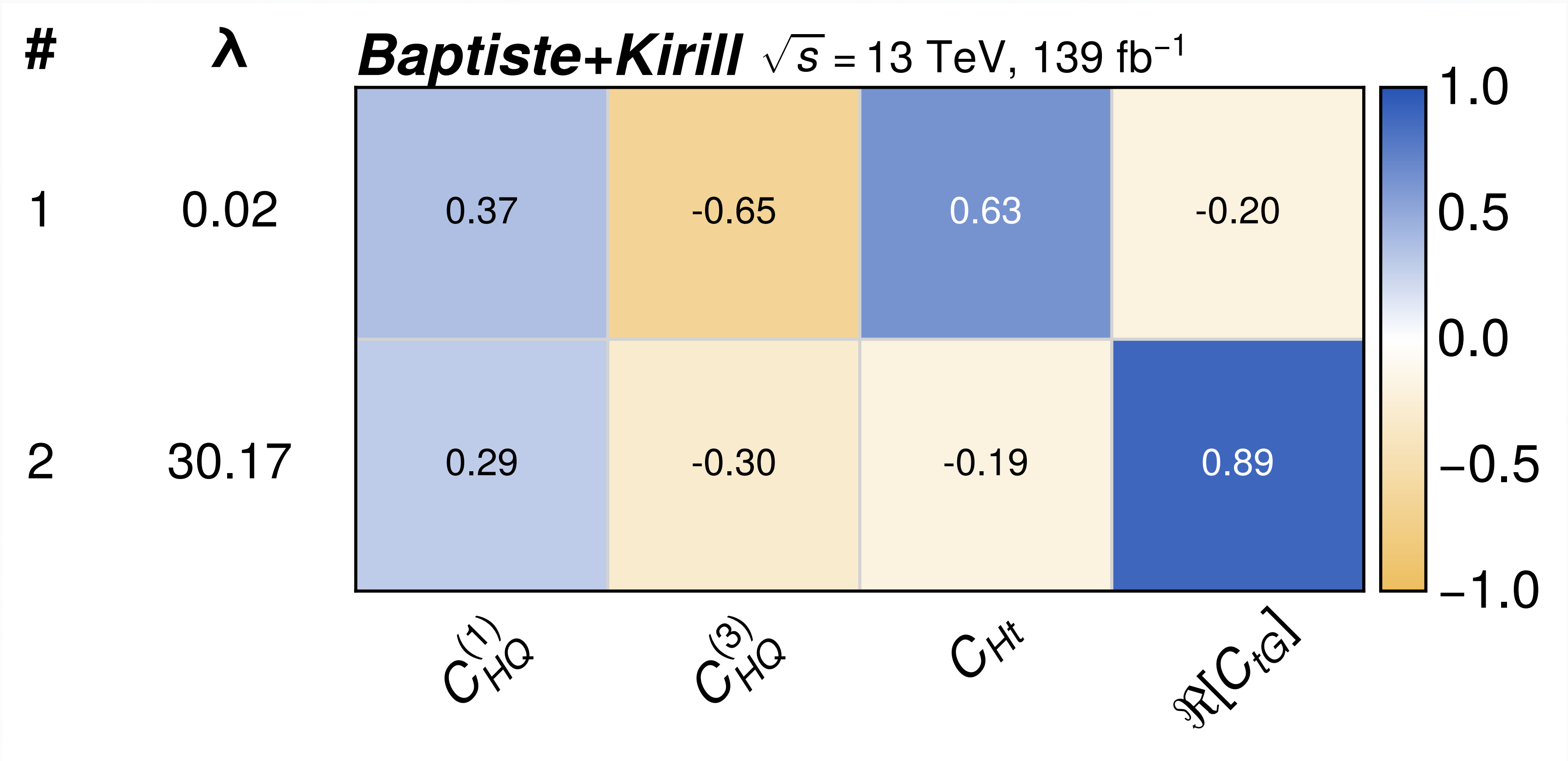
UnfoldEFT: Results

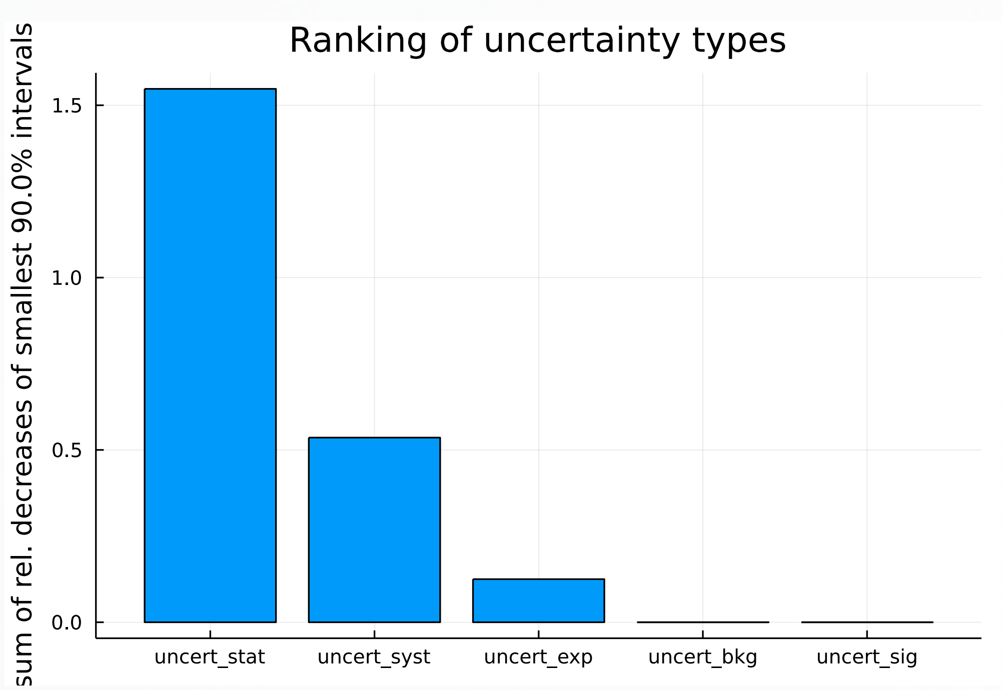
- Perform 1D and 2D fits to extract credible intervals

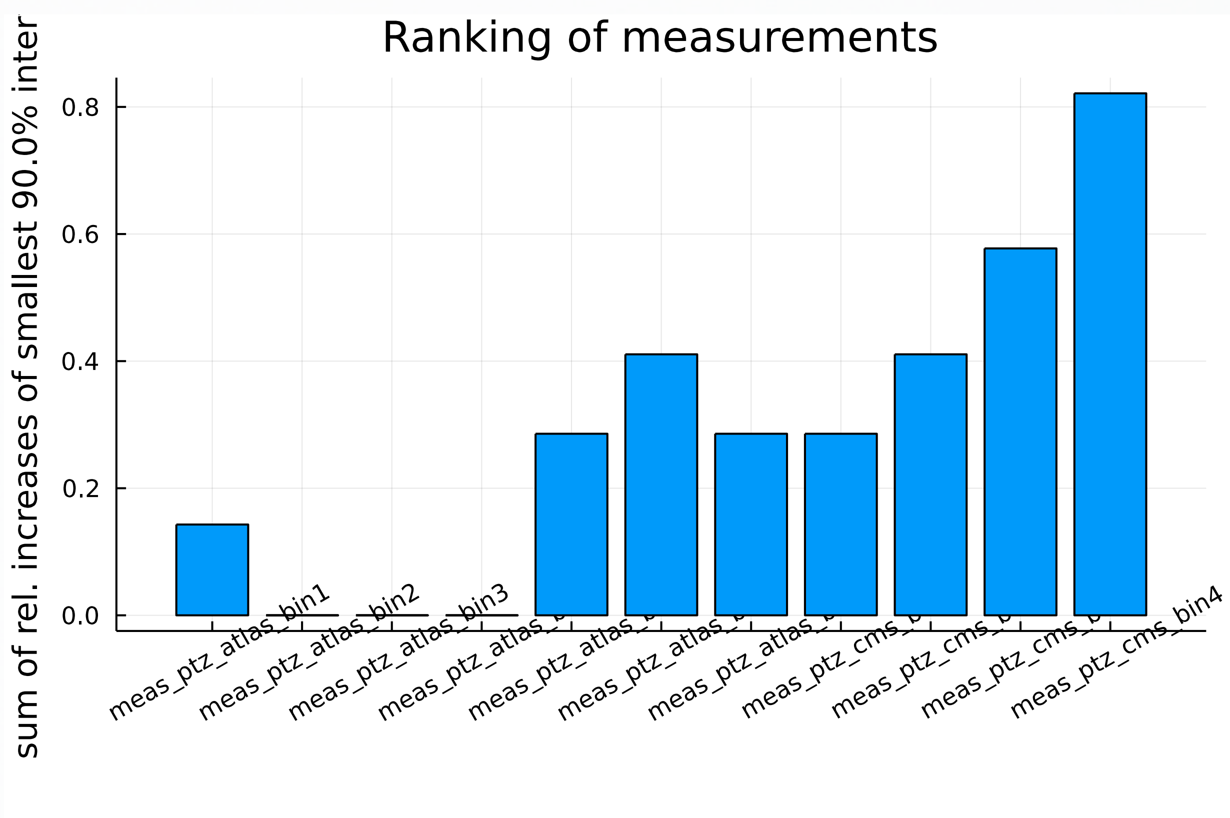


UnfoldEFT: Results

Fisher information matrix



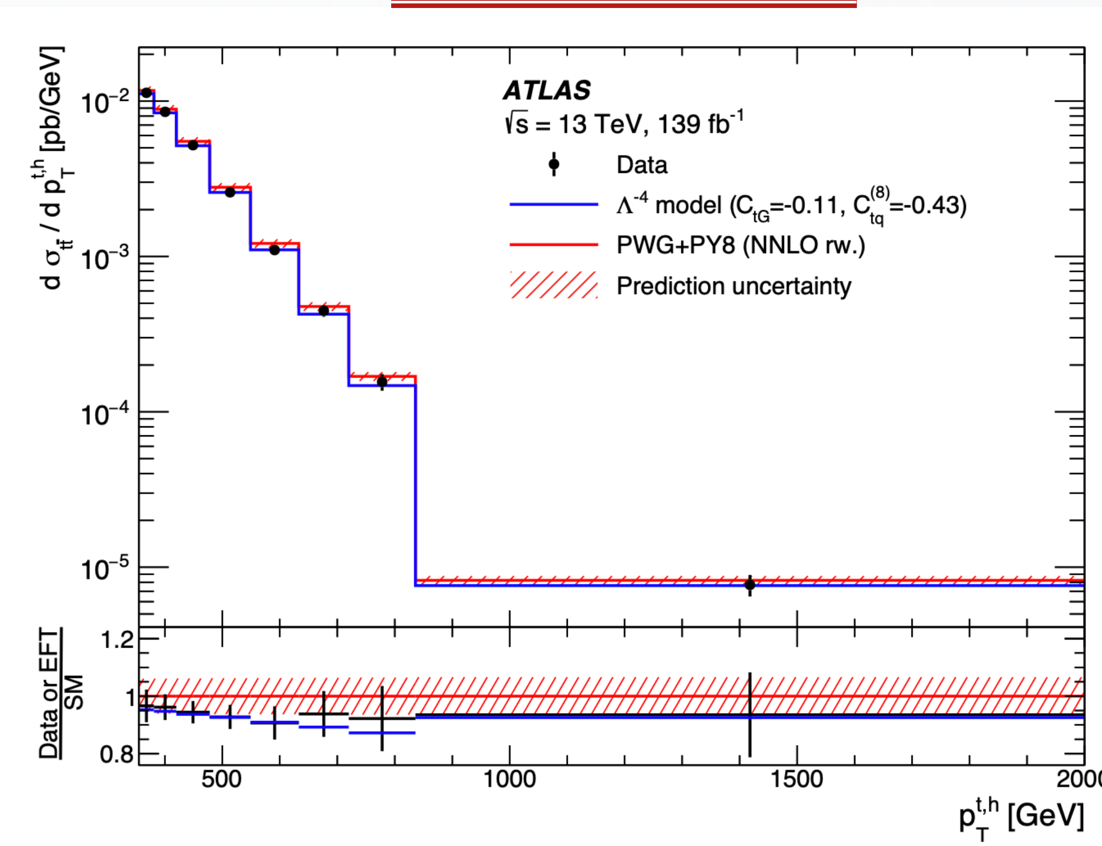


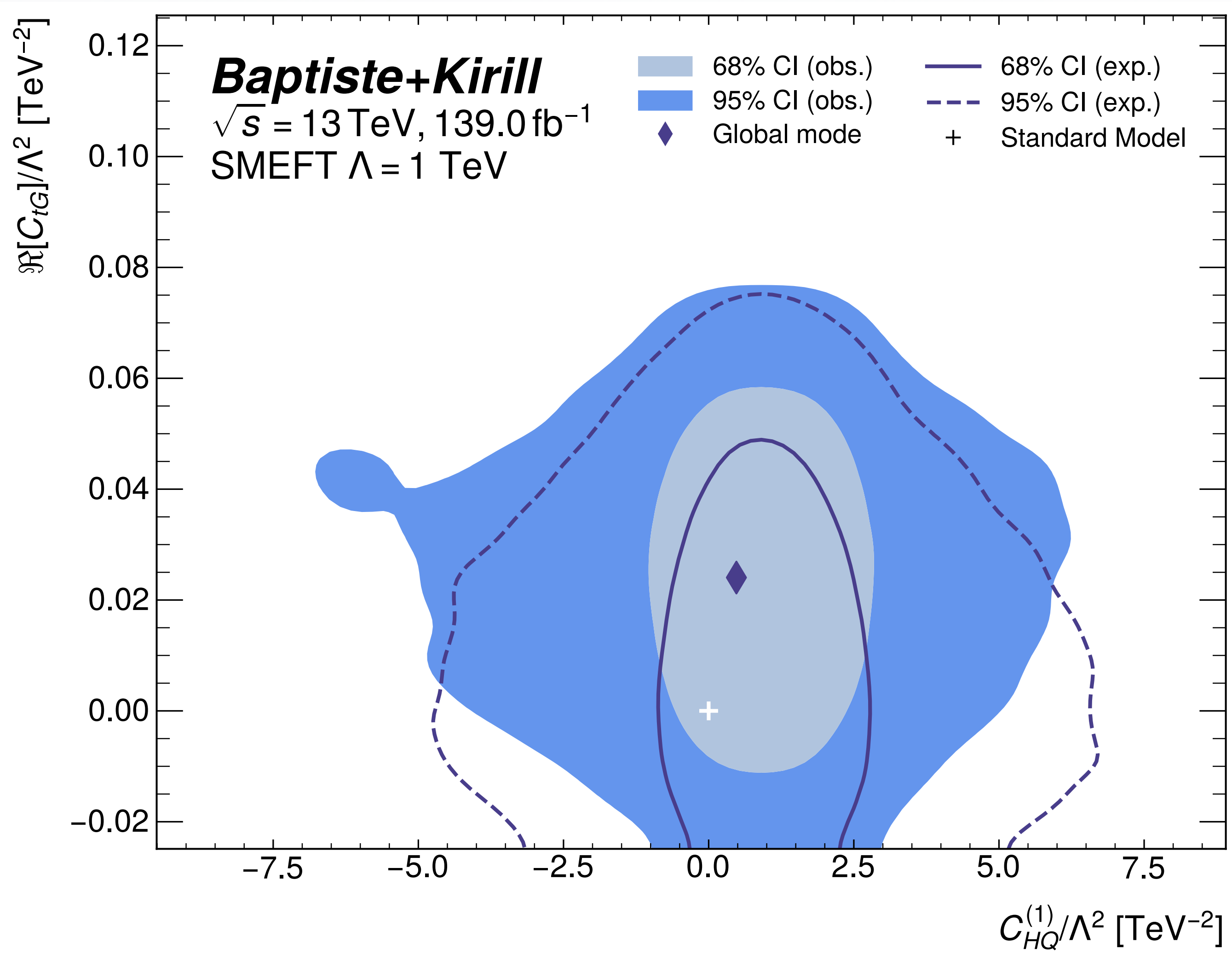


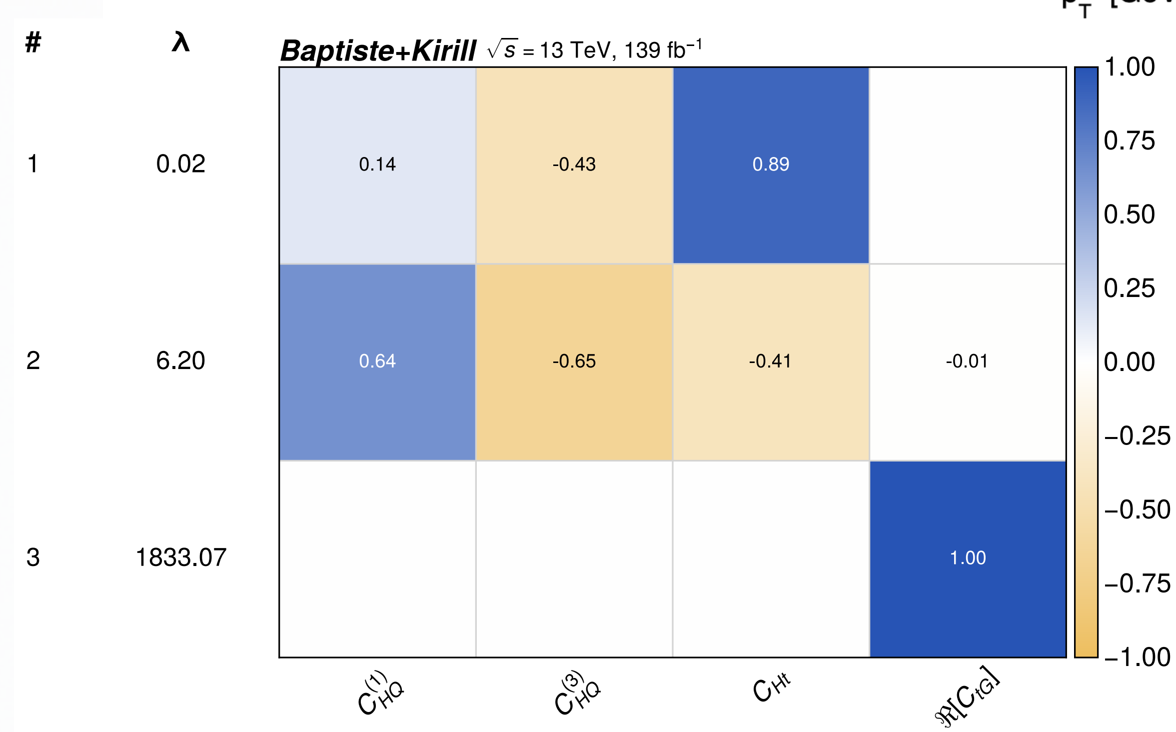
UnfoldEFT: Add more processes

- Include **boosted l+jets ttbar** results (ATLAS) in combination with ATLAS+CMS ttZ differential cross sections
- Improve **CtG** limits by 20x
- « **Factorize** » the CtG direction in global fit

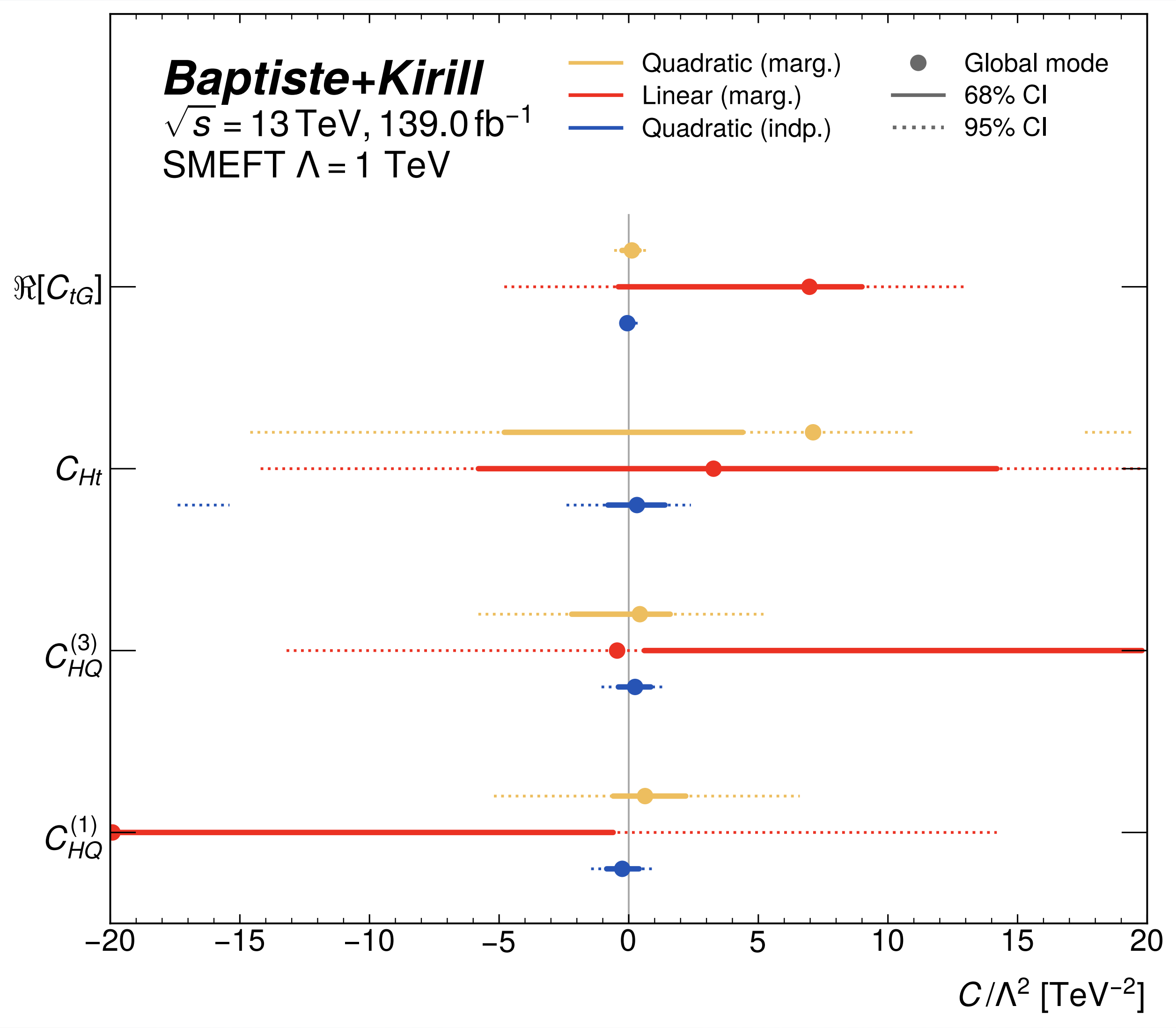
arXiv:2202.12134



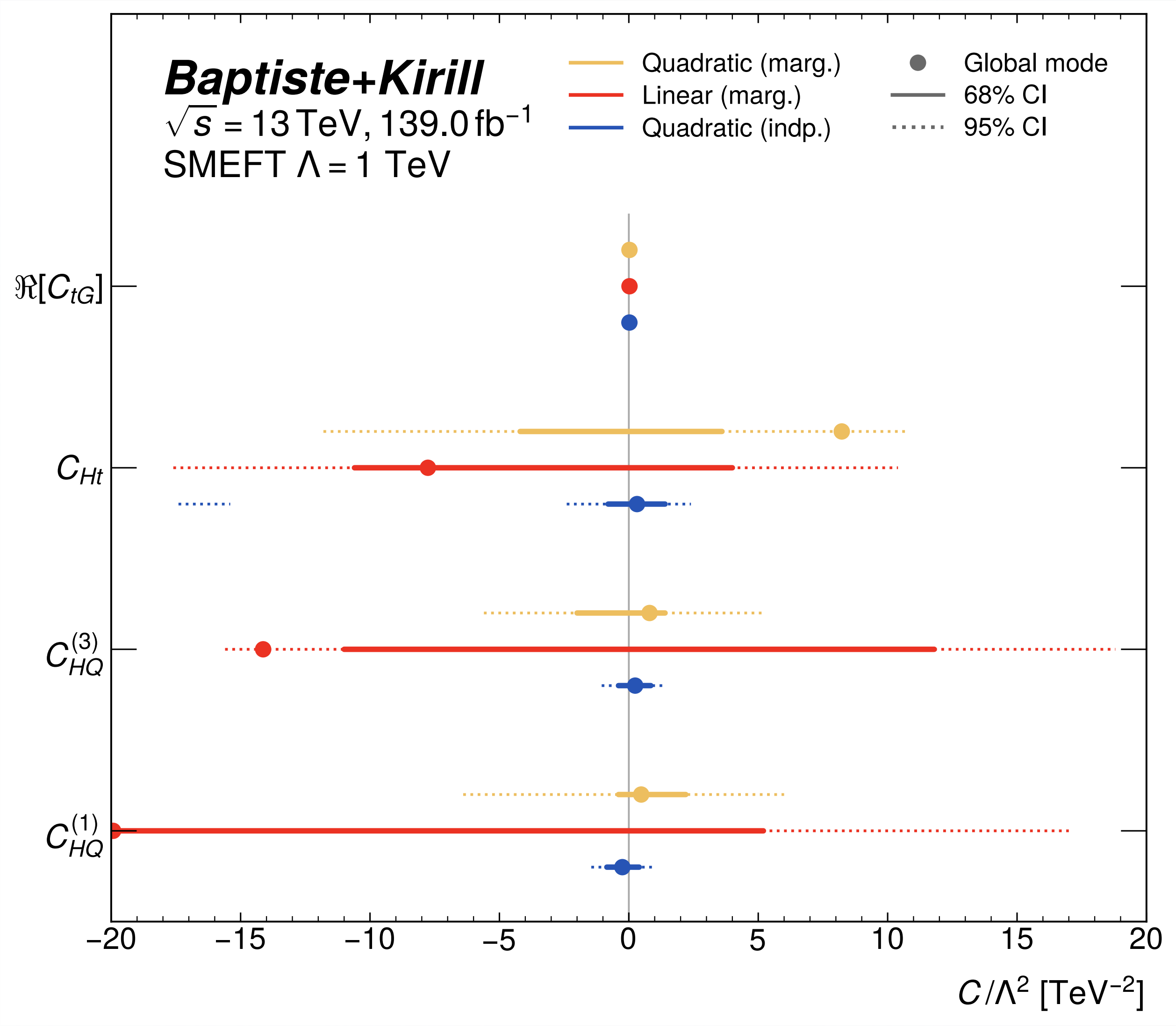




UnfoldEFT: Results



ATLAS+CMS ttZ

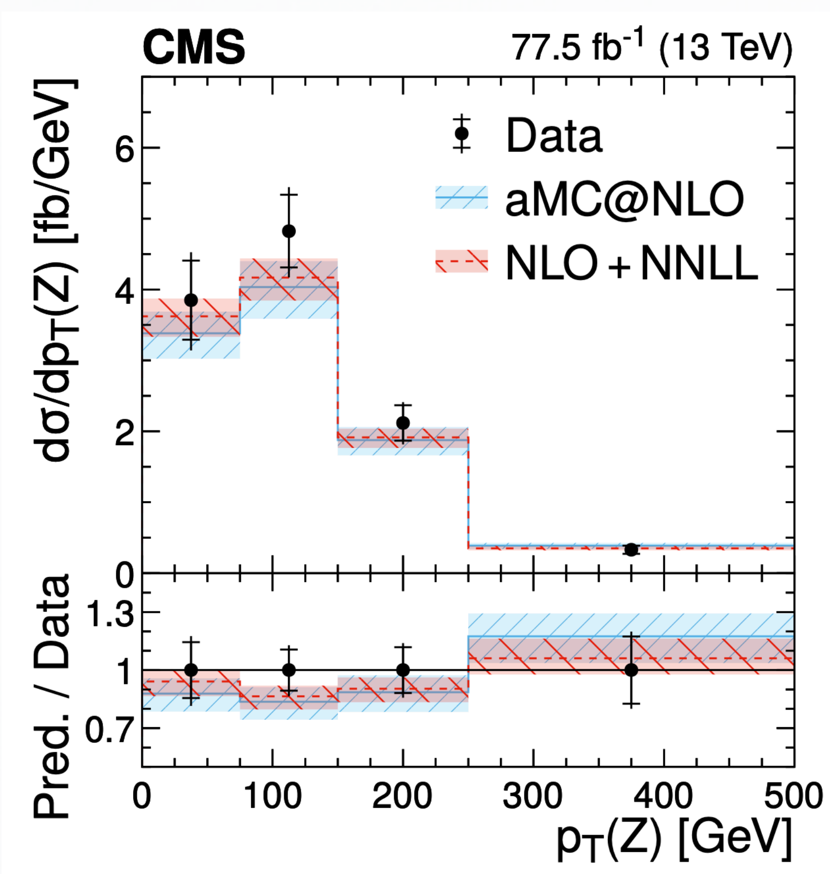


ATLAS+CMS ttZ
+ATLAS boosted ttbar

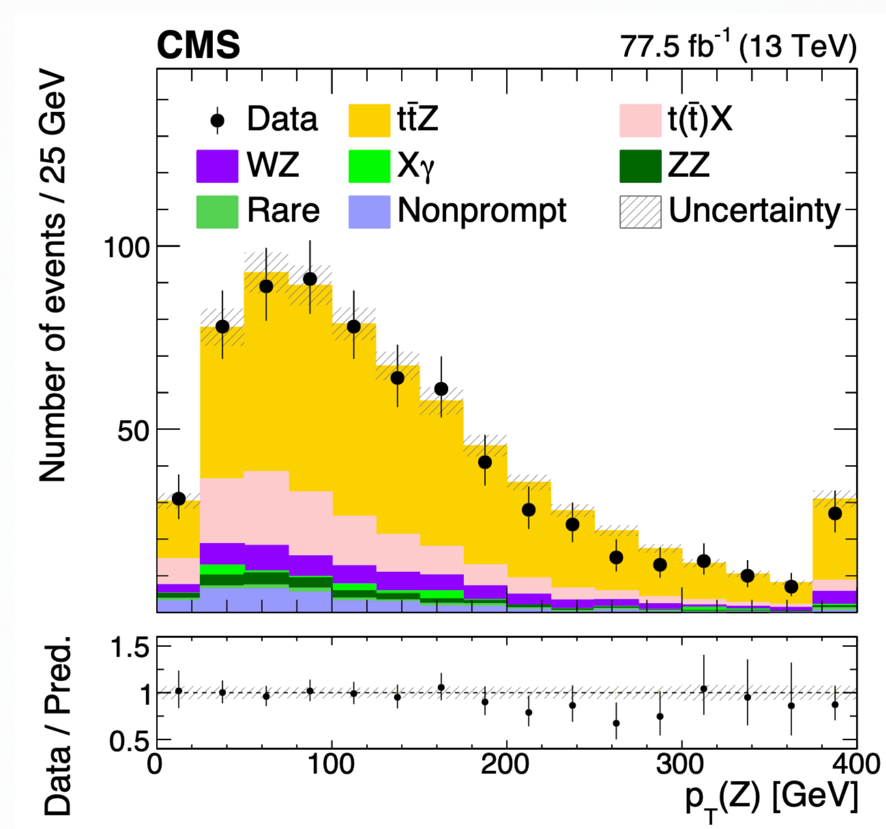
RecoEFT: Strategy

- Use **full Recostruction-level likelihoods** from both experiments
- The EFT **reinterpretation** becomes the direct EFT **measurement**
- **Full information** on signal and background processes with an extensive systematics breakdown → **preserve** experimental results
- **Reweight** generator-level SM predictions to EFT in a single observable - easier to agree on a common generation procedure; consider full MC simulation for (much) later time

UnfoldEFT

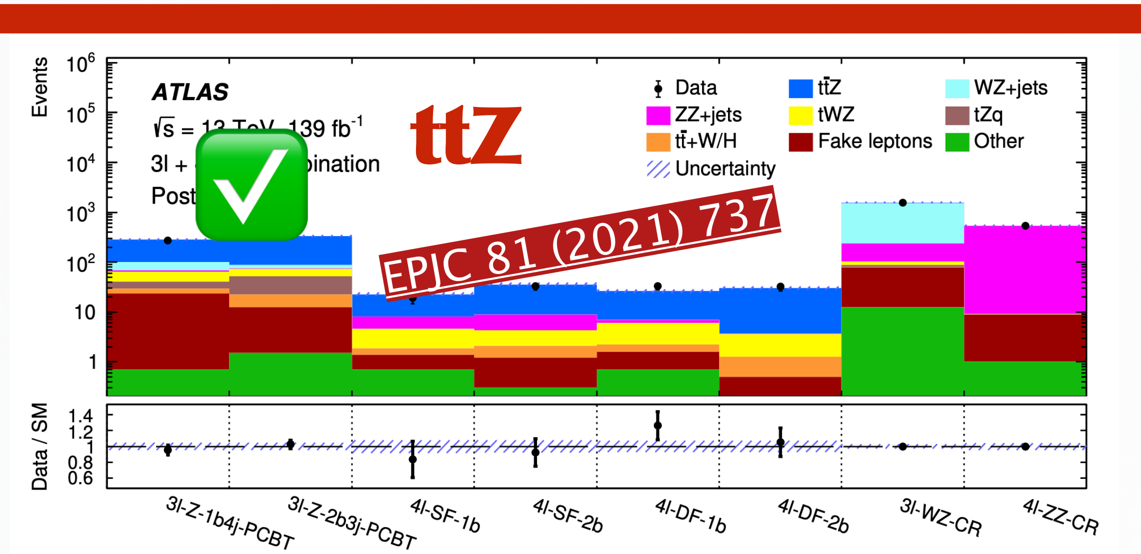


RecoEFT

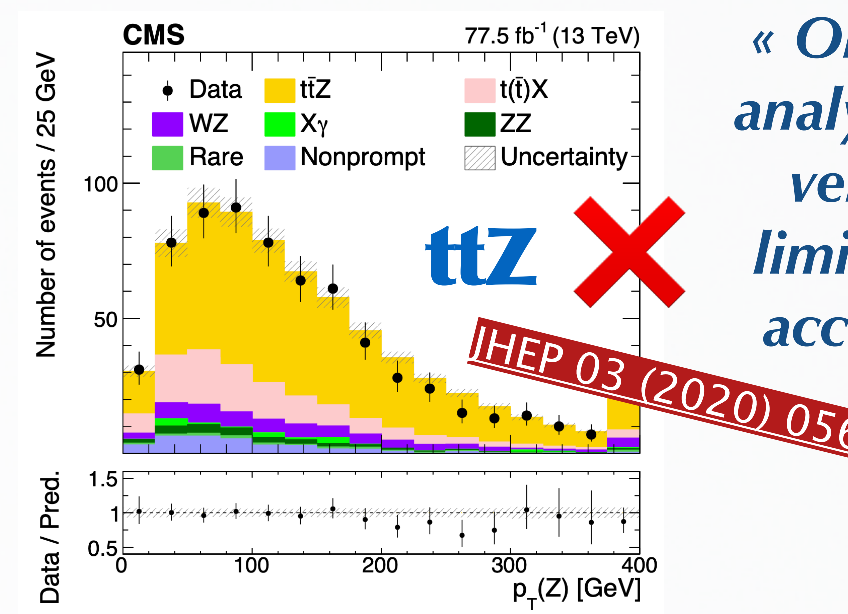


RecoEFT: Inputs

- Only a few detector-level likelihood are publicly available
- First published by ATLAS in the ttZ cross section measurement
- Need to agree on the data format, statistical model and tools

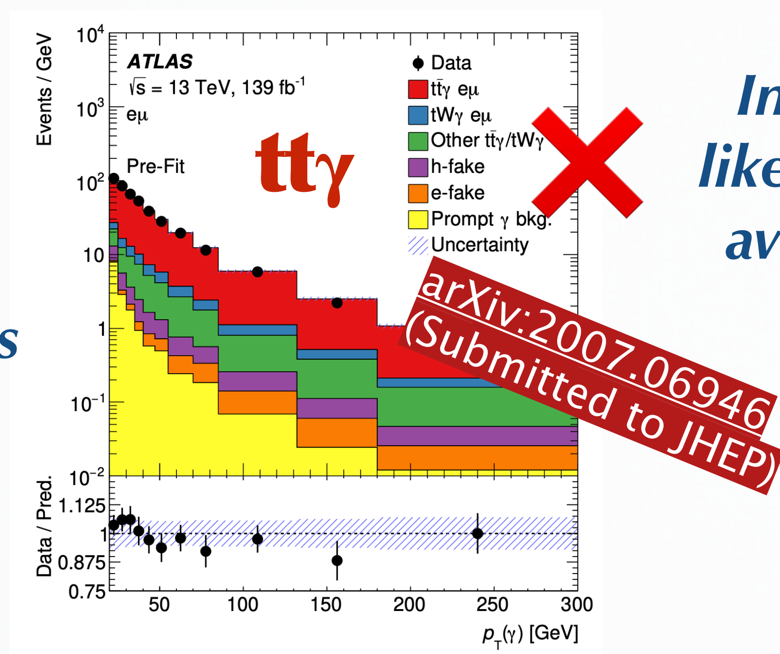


The main likelihood published - add more variables?

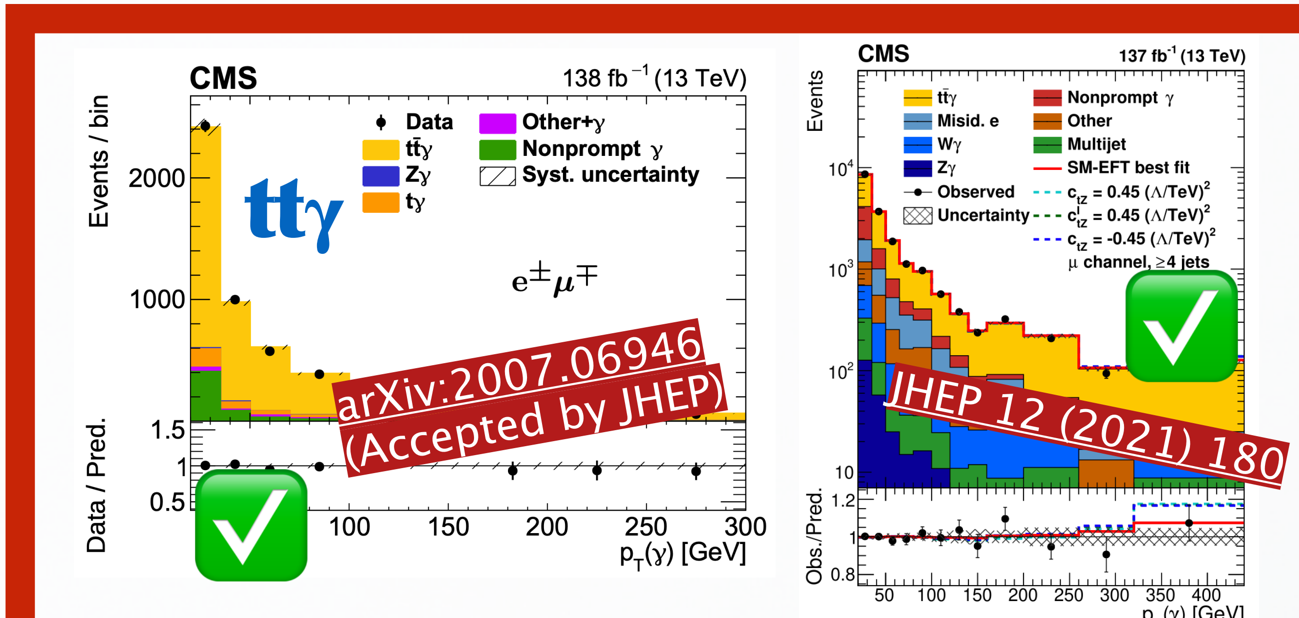


« Old » analysis: very limited access

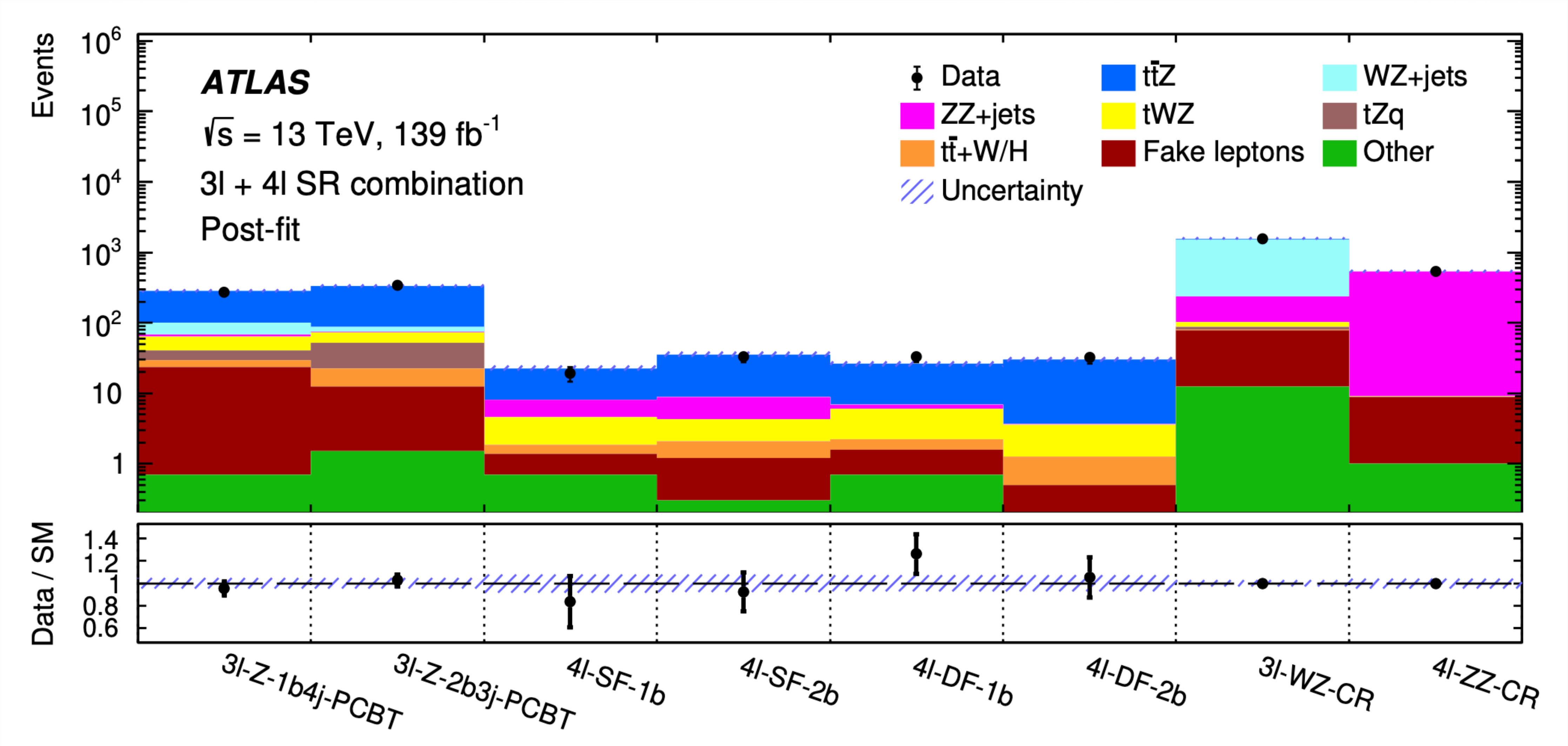
Recent analysis - likelihoods available soon?



Internal likelihoods available

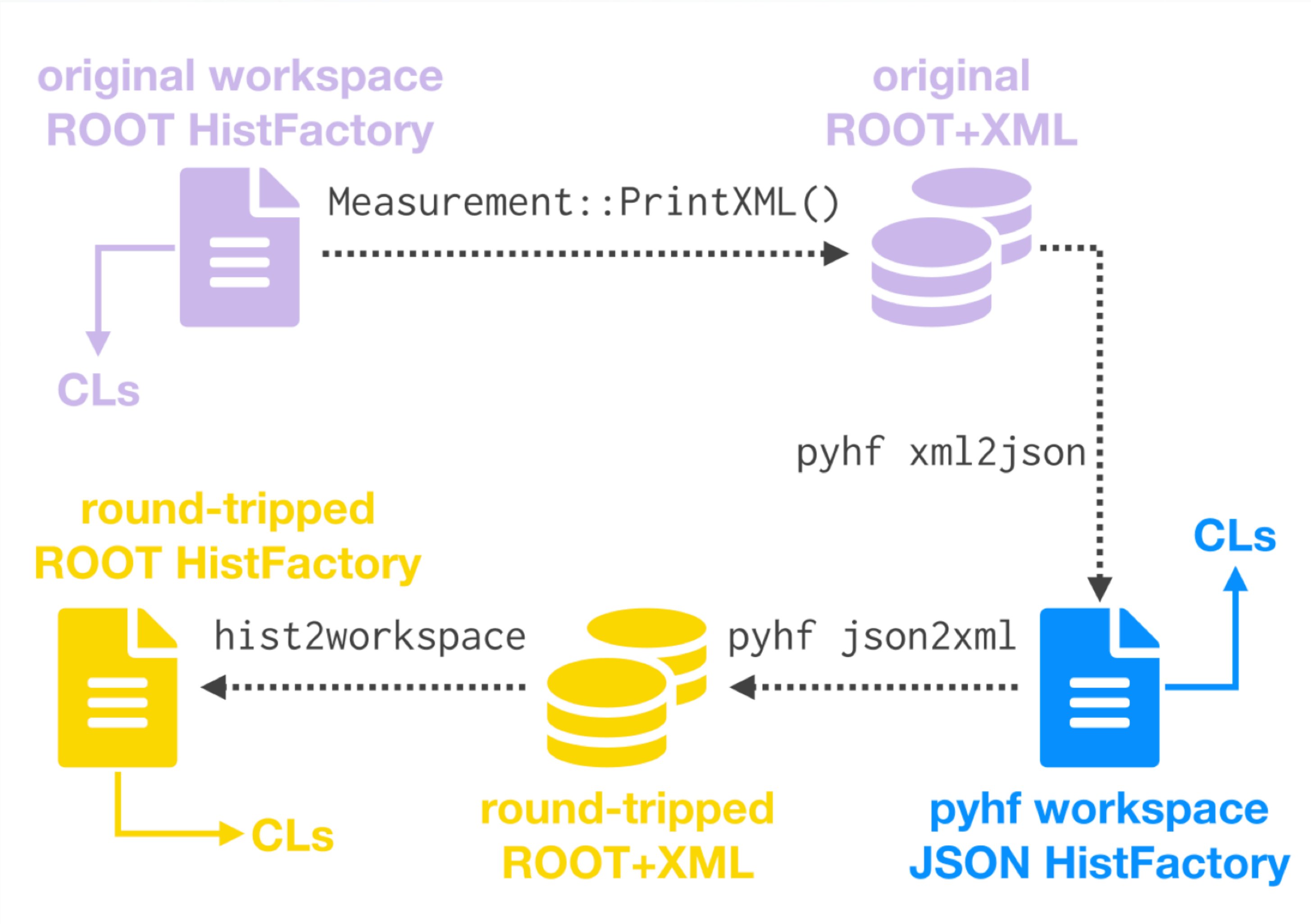


RecoEFT: ttZ (ATLAS)



- EPJC 81 (2021) 737, published detector-level likelihood (**pyhf**)
- No EFT results included
- Fit the number of reconstructed jets and b-tagged jets (bins = 8)
- Total number of bins = **8**
- Total number of nuisances = 223 (syst) + 8 (stat) = **231**

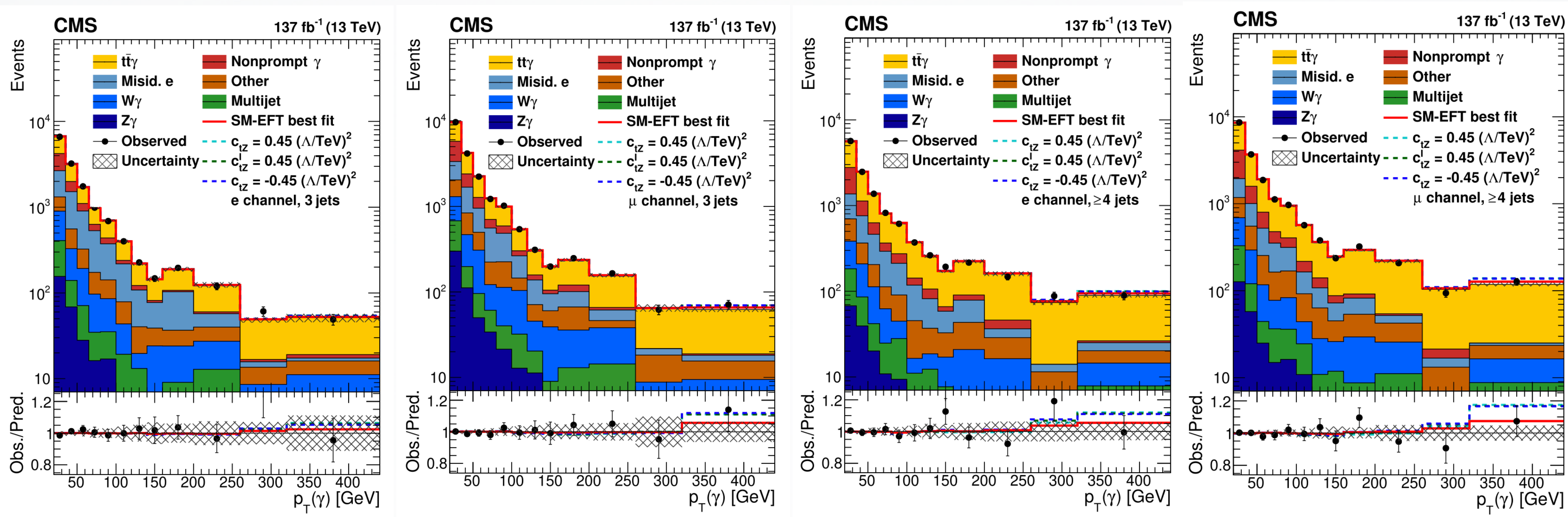
Preservation of likelihoods



- The methodology described in ATL-PHYS-PUB-2019-029
- Introduces a **JSON** schema for the **HistFactory** statistical model
- The mathematical model and fitting procedure implemented in **pyhf**
- ATLAS uses this approach to publish likelihoods in **HEPData**

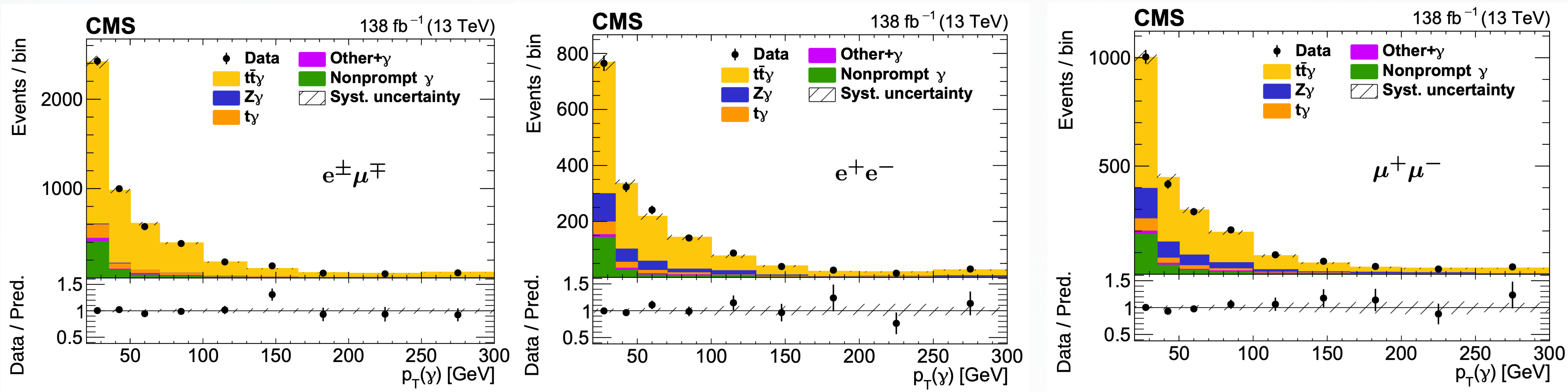
	Description	Modification	Constraint Term c_χ	Input
constrained	Uncorrelated Shape	$\kappa_{scb}(\gamma_b) = \gamma_b$	$\prod_b \mathrm{Pois}\left(r_b = \sigma_b^{-2} \middle| \rho_b = \sigma_b^{-2}\gamma_b\right)$	σ_b
	Correlated Shape	$\Delta_{scb}(\alpha) = f_p\left(\alpha \middle| \Delta_{scb,\alpha=-1},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

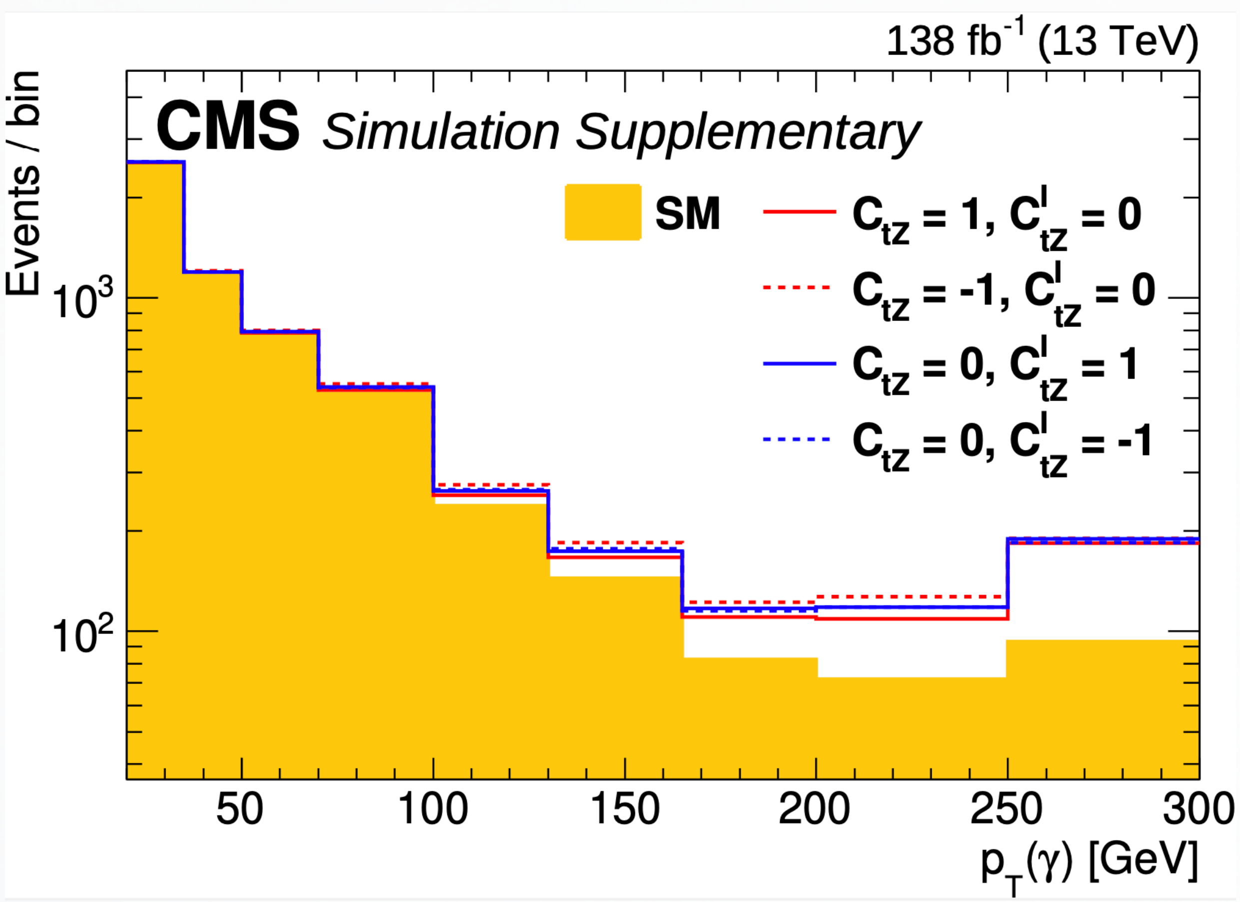
RecoEFT: tt̄γ, 1l (CMS)



- [JHEP 12 (2021) 180](), internal detector-level likelihood
- Includes reco-level EFT results (dim6top)
- Fit reconstructed photon p_T distributions (bins = 41)
- Per single-lepton channel (x2) and data-taking year (x3)
- Total number of bins = **246**
- Total number of nuisances = 105 (syst) + 246 (stat) = **351**

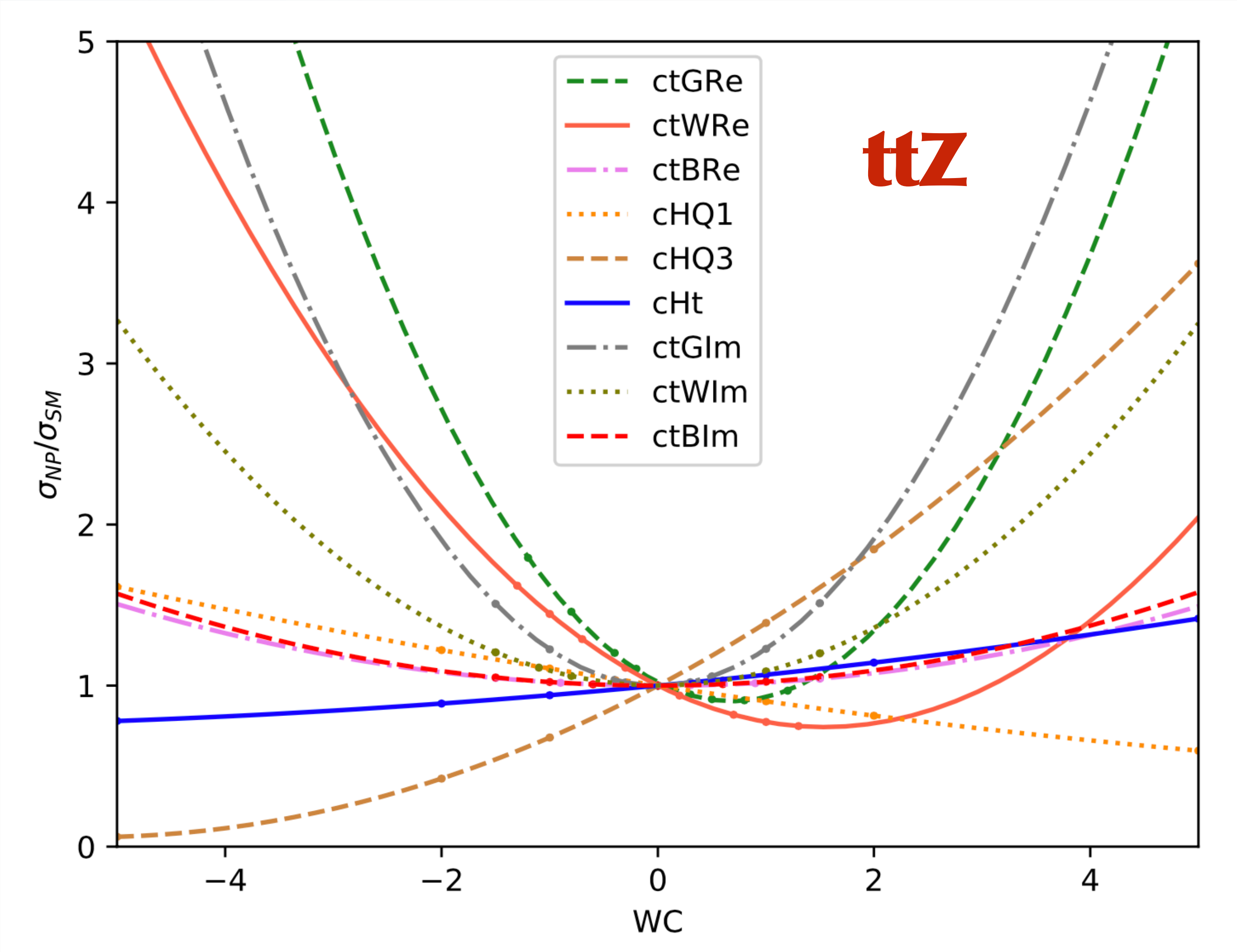
RecoEFT: ttγ, 2l (CMS)

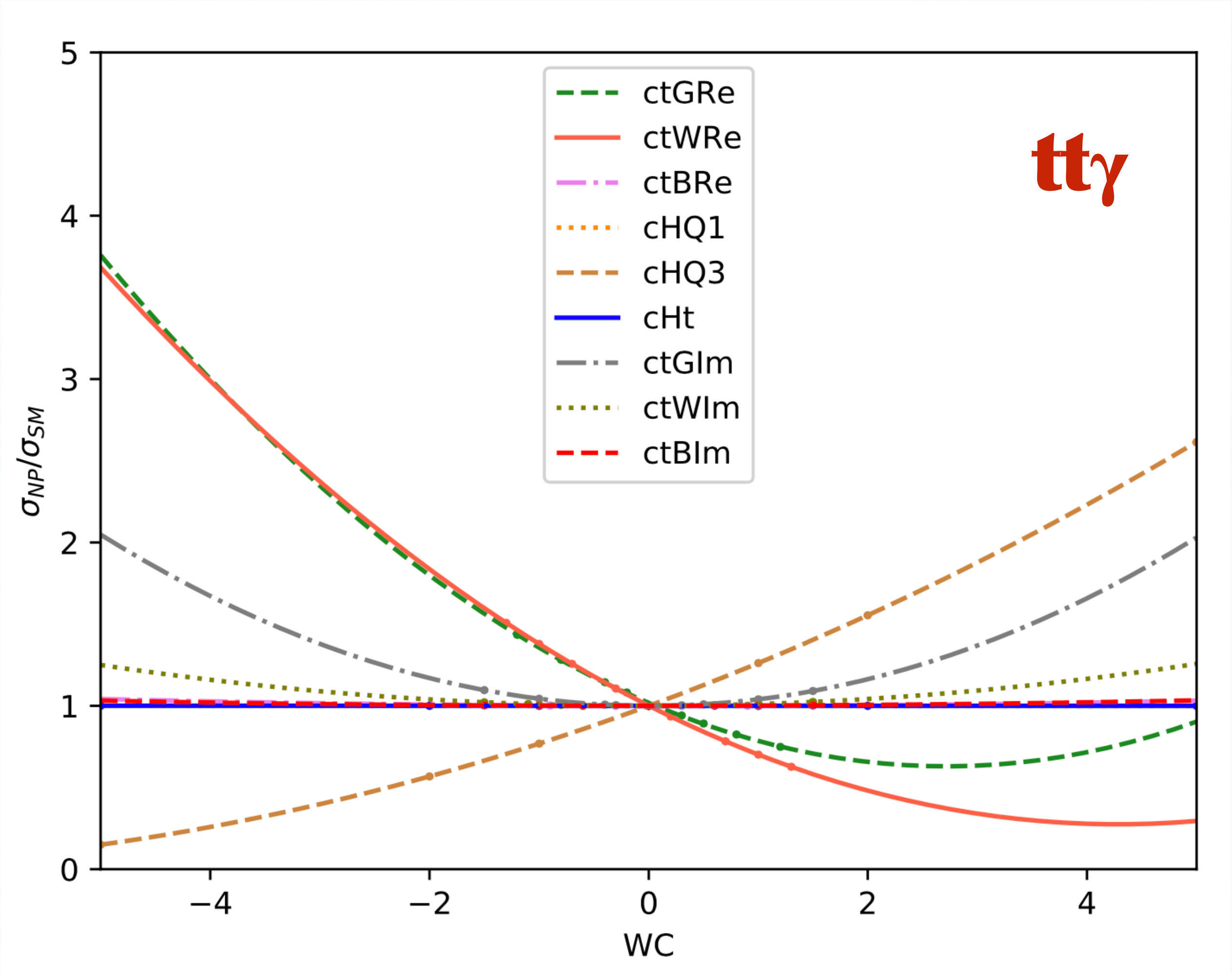




- arXiv:2201.07301 (Accepted by JHEP), internal detector-level likelihood
- Includes reco-level EFT results (dim6top)
- Fit reconstructed **photon p_T** distributions (bins = 9)
- Per dilepton channel (x3) and data-taking year (x3)
- Total number of bins = **81**
- Total number of nuisances = 80 (syst) + 81 (stat) = **161**

RecoEFT: Parametrization

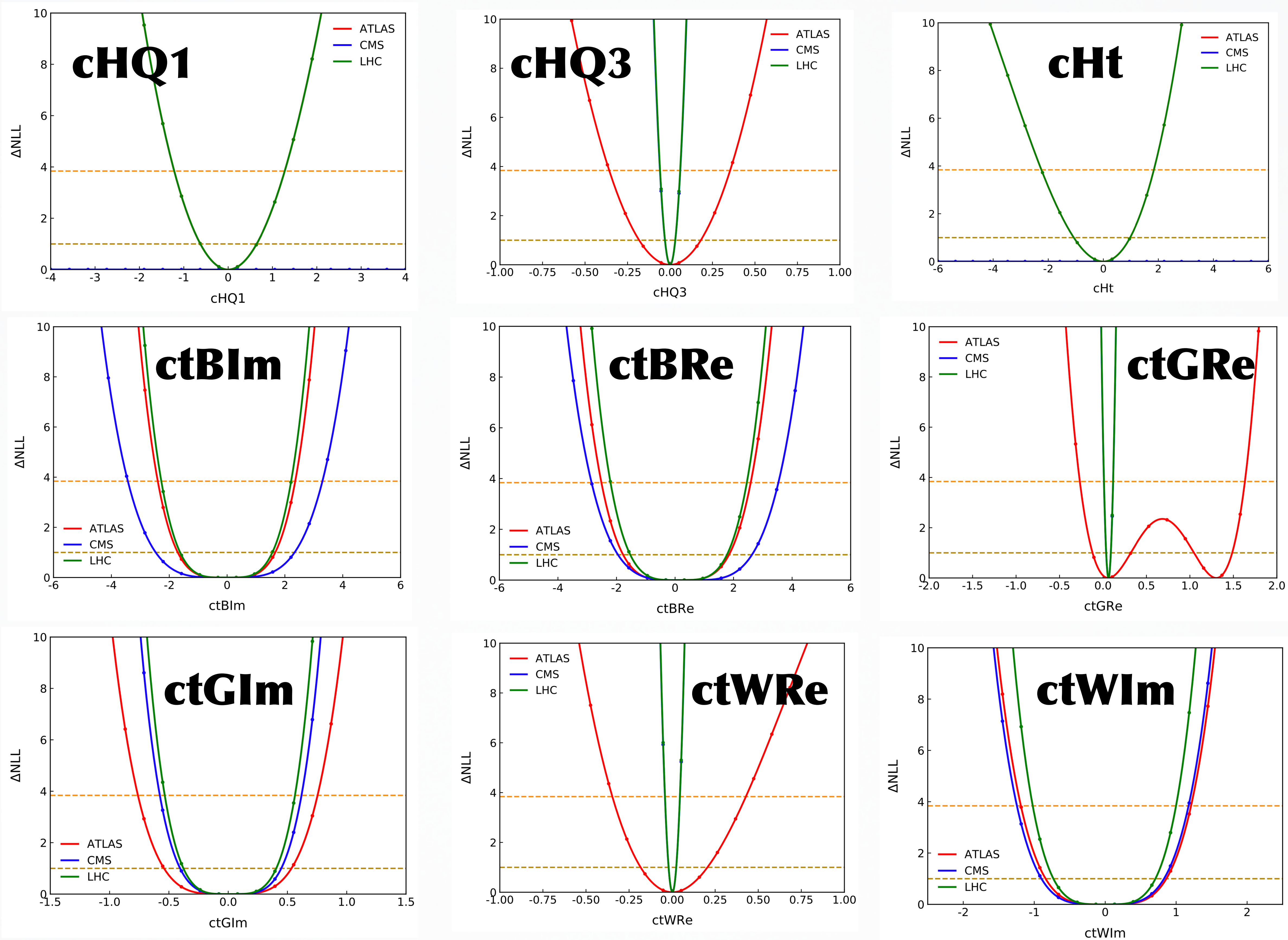




- Parametrize EFT effects based on the total cross section
- ATLAS likelihood is available in JSON
- Created a script to translate Combine datacard (CMS) to a common JSON format
- This translation procedure would need a dedicated validation
- First step: perform a global EFT fit of ttZ and tt**γ** results without uncertainties

RecoEFT: Results

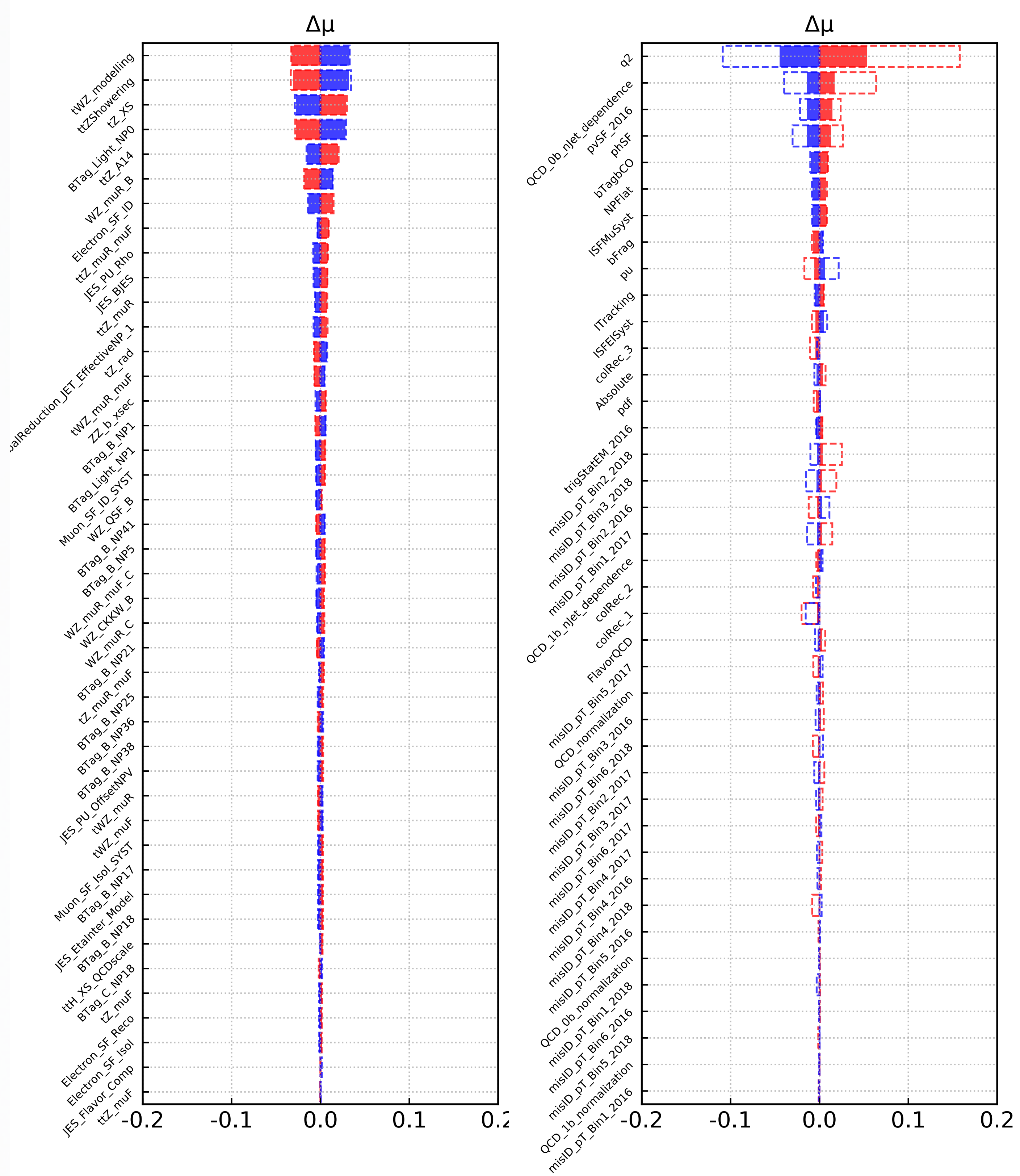
Asimov, w/o uncertainties



RecoEFT: Including uncertainties

- Statistical uncertainties (**335**)
- Statistical + systematic uncertainties (**743**)
- Very computationally intensive: include only **dominant systematic uncertainties** for now
- Proper **correlation of** experimental uncertainties is critical
- Hitting fit convergence & memory issues for **complex** models already at inclusion of statistical uncertainties
- In the process of **validating** implementation of shape uncertainties and the fitting model

ATLAS **CMS**



Individual Asimov fits

Summary

- **Active effort** in **LHC*top*WG** to perform an ATLAS-CMS EFT combination in the top quark sector
- Approaching EFT combinations using individual inputs from both experiments at **unfolded** and **reconstruction** levels
- **Complementary** ways of combining experimental results
- **First** (very preliminary) results obtained in both approaches
- Working on providing an UnfoldEFT input to **LHC EFT combination** (in EFT2Obs-compatible format)
- Exploring various options to further **optimize** the RecoEFT fits
- In the process of finalizing the Combine → pyhf **converter**
- **First** ATLAS-CMS EFT summary plots are also available