Nikita Schmal
ITP, Universität Heidelberg

Collaborators:

Nina Elmer, Emma Geoffray, Michel Luchmann, Tilman Plehn

USING LIKELIHOOD ANALYSES IN THE TOP AND HIGGS SECTOR

TOWARDS A COMBINED GLOBAL SMEFT FIT

STANDARD MODEL EFFECTIVE FIELD THEORY

Well established model independent approach for BSM physics

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{C_j}{\Lambda^4}\mathcal{O}_j^{(8)} + \dots$$

STANDARD MODEL EFFECTIVE FIELD THEORY

Well established model independent approach for BSM physics

$$\boxed{\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i^{(6)}} + \sum_j \frac{C_j}{\Lambda^4}\mathcal{O}_j^{(8)} + \dots$$

Huge number of possible operators ⟶ Restrict to dimension 6 operators

THE SFITTER FRAMEWORK

- Strong and comprehensive treatment of uncertainties
- Fully correlated systematic uncertainties between measurements
- Luminosity correlated between measurements and experiments
- Operators included up to quadratic terms in the observables
- NEW: Both profiling and marginalization to construct likelihoods
- Make use of MCMC methods to map these likelihoods

PREVIOUS ANALYSES

O new physics, where art thou? A global search in the top sector

Ilaria Brivio,[1] Sebastian Bruggisser,[1] Fabio Maltoni,[2,3] Rhea Moutafis,[1,4] Tilman Plehn,[1] Eleni Vryonidou,[5] Susanne Westhoff,[1] and Cen Zhang[6]

[1] *Institut für Theoretische Physik, Universität Heidelberg, Germany*
[2] *CP3, Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[3] *Dipartimento di Fisica e Astronomia, Università di Bologna, INFN, Sezione di Bologna, Italy*
[4] *LAL, IN2P3, CNRS, Orsay, France*
[5] *Theoretical Physics Department, CERN, Geneva, Switzerland*
[6] *Institute for High Energy Physics and School of Physical Sciences, University of Chinese Academy of Sciences, Beijing, China*

arXiv:1910.03606 [hep-ph]

To Profile or To Marginalize – A SMEFT Case Study

Ilaria Brivio[1,2], Sebastian Bruggisser[1,3], Nina Elmer[1], Emma Geoffray[1], Michel Luchmann[1], and Tilman Plehn[1]

1 Institut für Theoretische Physik, Universität Heidelberg, Germany
2 Physik Institut, University of Zurich, Switzerland
3 Department of Physics and Astronomy, Uppsala University, Sweden

August 19, 2022

arXiv:2208.08454 [hep-ph]

OUTLINE OF THIS TALK

1. Profiling and marginalization in the Top fit
2. Likelihoods published by ATLAS
   - Nuisance Parameters and uncertainties
   - Correlations between nuisance parameters
3. Combination of the Higgs and Top fit (Preliminary)

PART 1

PROFILING AND MARGINALIZATION IN THE TOP SECTOR

THE TOP AND THE WARSAW BASIS

- Impose $U(2)_q \times U(2)_u \times U(2)_d$ flavor symmetry
- Same dataset as before i.e.
  - 92 $t\bar{t}$ datapoints
  - 2 $t\bar{t}Z$ datapoints
  - 2 $t\bar{t}W$ datapoints
  - 20 SingleTop datapoints

Operator	Definition	Operator	Definition
$O_{Qq}^{3,8}$	$(\bar{Q}\gamma_\mu T^A\tau^I Q)(\bar{q}_i\gamma^\mu T^A\tau^I q_i)$	$O_{Qq}^{3,1}$	$(\bar{Q}\gamma_\mu\tau^I Q)(\bar{q}_i\gamma^\mu\tau^I q_i)$
$O_{Qq}^{1,8}$	$(\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i\gamma^\mu T^A q_i)$	$O_{Qq}^{1,1}$	$(\bar{Q}\gamma_\mu Q)(\bar{q}_i\gamma^\mu q_i)$
O_{tu}^{8}	$(\bar{t}\gamma_\mu T^A t)(\bar{u}_i\gamma^\mu T^A u_i)$	O_{tu}^{1}	$(\bar{t}\gamma_\mu t)(\bar{u}_i\gamma^\mu u_i)$
O_{td}^{8}	$(\bar{t}\gamma_\mu T^A t)(\bar{d}_i\gamma^\mu T^A d_i)$	O_{td}^{1}	$(\bar{t}\gamma_\mu t)(\bar{d}_i\gamma^\mu d_i)$
O_{Qu}^{8}	$(\bar{Q}\gamma^\mu T^A Q)(\bar{u}_i\gamma_\mu T^A u_i)$	O_{Qu}^{1}	$(\bar{Q}\gamma^\mu Q)(\bar{u}_i\gamma_\mu u_i)$
O_{Qd}^{8}	$(\bar{Q}\gamma^\mu T^A Q)(\bar{d}_i\gamma_\mu T^A d_i)$	O_{Qd}^{1}	$(\bar{Q}\gamma^\mu Q)(\bar{d}_i\gamma_\mu d_i)$
O_{tq}^{8}	$(\bar{q}_i\gamma^\mu T^A q_i)(\bar{t}\gamma_\mu T^A t)$	O_{tq}^{1}	$(\bar{q}_i\gamma^\mu q_i)(\bar{t}\gamma_\mu t)$
$O_{\phi Q}^{3}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{Q}\gamma^\mu\tau^I Q)$	$O_{\phi Q}^{1}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{Q}\gamma^\mu Q)$
$O_{\phi t}$	$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{t}\gamma^\mu t)$	$O_{\phi tb}$	$(\tilde{\phi}^\dagger iD_\mu\phi)(\bar{t}\gamma^\mu b)$
O_{tB}	$(\bar{Q}\sigma^{\mu\nu}t)\tilde{\phi}B_{\mu\nu}$	O_{tW}	$(\bar{Q}\sigma^{\mu\nu}t)\tau^I\tilde{\phi}W_{\mu\nu}^I$
O_{bW}	$(\bar{Q}\sigma^{\mu\nu}b)\tau^I\phi W_{\mu\nu}^I$	O_{tG}	$(\bar{Q}\sigma_{\mu\nu}T^A t)\tilde{\phi}G_{\mu\nu}^A$

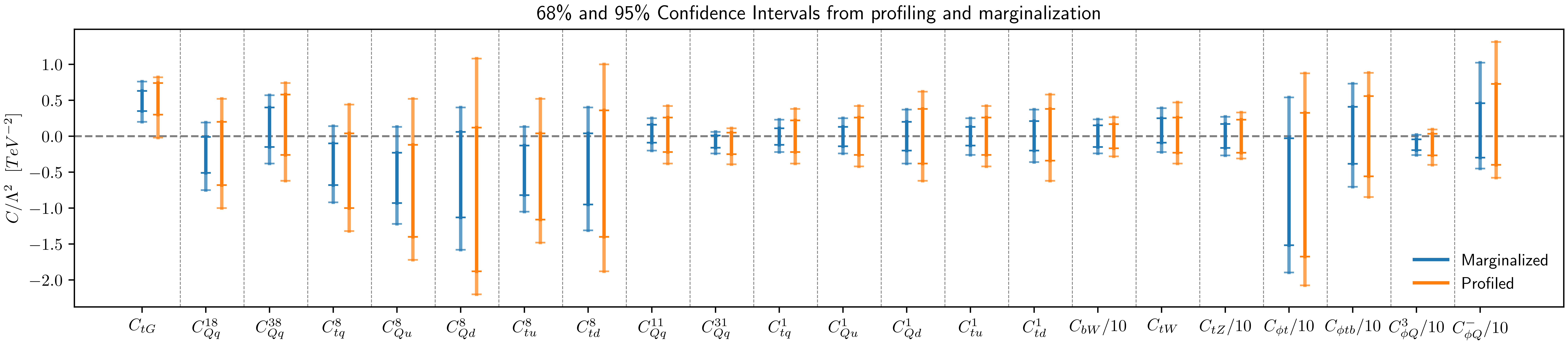
PROFILING VS MARGINALISATION

- Construct same exclusive likelihood for both treatments

$$\mathcal{L}_{\text{excl}}(\theta) \approx \text{Pois}(d|s + b + \Sigma\theta_{\text{theo},j} + \Sigma\theta_{\text{syst},i})\, p(b) \prod_j \mathcal{F}_{0,\sigma_j}(\theta_{\text{theo},j}) \prod_i \mathcal{N}_{0,\sigma_i}(\theta_{\text{syst},i})$$

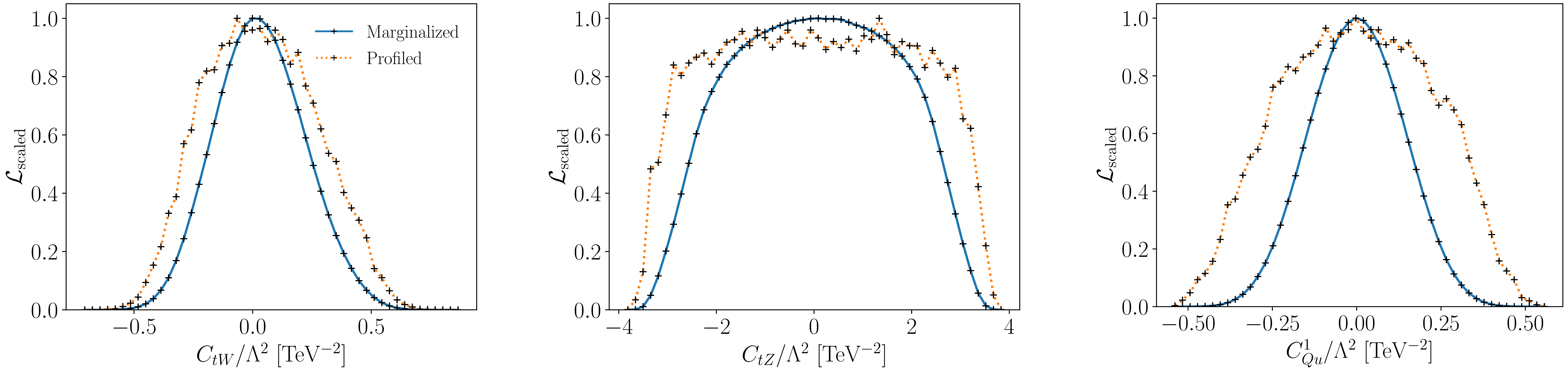
- To profile $\mathcal{L}_{prof} = \max_\theta \mathcal{L}_{excl}(\theta)$ or to marginalize $\mathcal{L}_{marg} = \int d\theta \mathcal{L}_{excl}(\theta)$
  - Difference in treatment of uncertainties

PROFILING VS MARGINALIZATION (SUMMARY)



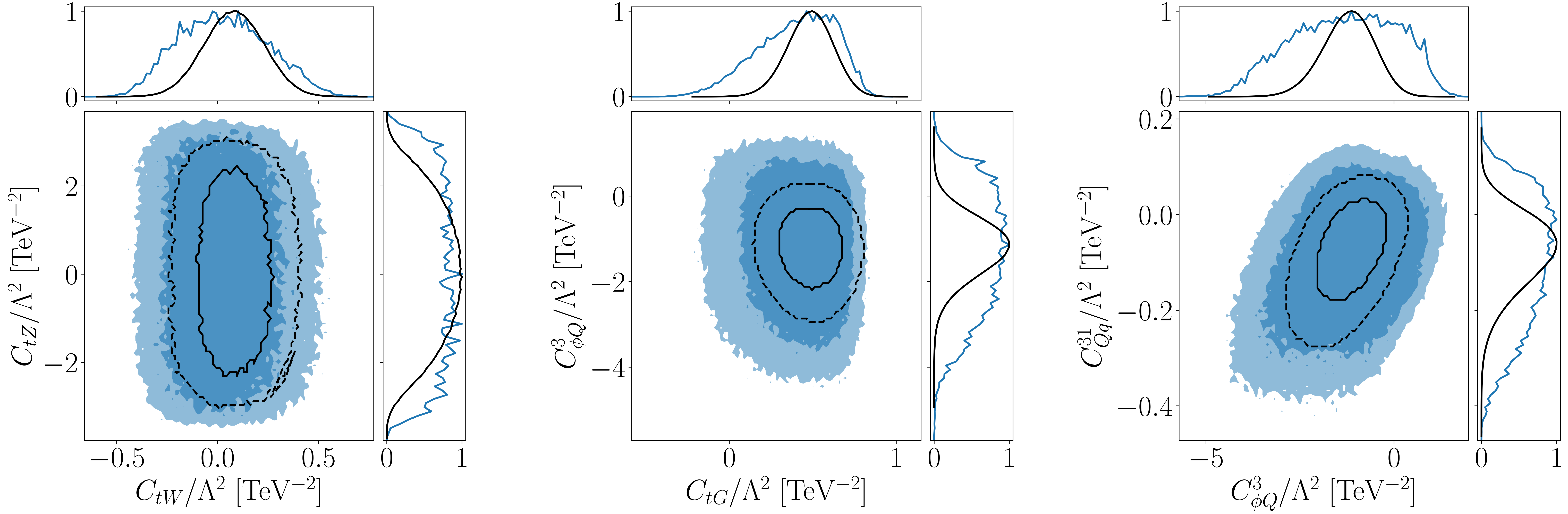
- Multiple coefficients show better constraints

PROFILING VS MARGINALIZATION (LIKELIHOODS)



- Marginalized results show well defined maxima opposed to profiled ones
- Can be understood as a result of large theory uncertainties

PROFILING VS MARGINALIZATION (CORRELATIONS)



PART 2

PUBLISHED LIKELIHOODS

PUBLISHED LIKELIHOODS

From https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Search for squarks and gluinos in final states 1L, jets and MET	SUSY	Eur. Phys. J. C 81 (2021) 600 (Erratum)	2021-01-05	13	139 fb^{-1}	Documents | 2101.01629 Inspire | HepData Internal
Search for charginos and neutralinos in RPV models in final states with 3L (or more)	SUSY	Phys. Rev. D 103, (2021) 112003	2020-11-20	13	139 fb^{-1}	Documents | 2011.10543 Inspire | HepData Briefing | Internal
Search for displaced leptons	SUSY	Phys. Rev. Lett. 127 (2021) 051802	2020-11-13	13	139 fb^{-1}	Documents | 2011.07812 Inspire | HepData Briefing | Internal
Search for squarks and gluinos in final states with 0L, jets and MET	SUSY	JHEP 02 (2021) 143	2020-10-27	13	139 fb^{-1}	Documents | 2010.14293 Inspire | HepData Internal
Evidence for four-top-quarks production in the two same-sign lepton and three lepton channels	TOPQ	Eur. Phys. J. C 80 (2020) 1085	2020-07-29	13	139 fb^{-1}	Documents | 2007.14858 Inspire | HepData Briefing | Internal
Measurement of the ttbar production cross-section in the lepton+jets channel at 13 TeV	TOPQ	Phys. Lett. B 810 (2020) 135797	2020-06-24	13	139 fb^{-1}	Documents | 2006.13076 Inspire | HepData Internal
Stop pair, long-lived; displaced vertex and displaced muon	SUSY	Phys. Rev. D 102 (2020) 032006	2020-03-26	13	136 fb^{-1}	Documents | 2003.11956 Inspire | HepData Internal
Chargino-neutralino pair; 3 leptons, weak-scale mass splittings	SUSY	Phys. Rev. D 101 (2020) 072001	2019-12-18	13	139 fb^{-1}	Documents | 1912.08479 Inspire | HepData Internal

PUBLISHED LIKELIHOODS BY ATLAS TOP WORKING GROUP

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

Phys. Lett. B 810 (2020) 135797
DOI: 10.1016/j.physletb.2020.135797
CERN-EP-2020-096
10th November 2020

Measurement of the $t\bar{t}$ production cross-section in the lepton+jets channel at $\sqrt{s}$ = 13 TeV with the ATLAS experiment

The ATLAS Collaboration

arXiv:2006.13076 [hep-ex]

Eur. Phys. J. C (2021) 81:737
https://doi.org/10.1140/epjc/s10052-021-09439-4
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Experimental Physics

Measurements of the inclusive and differential production cross sections of a top-quark–antiquark pair in association with a Z boson at $\sqrt{s}$ = 13 TeV with the ATLAS detector

ATLAS Collaboration*
CERN, 1211 Geneva 23, Switzerland

Received: 24 March 2021 / Accepted: 10 July 2021 / Published online: 16 August 2021

arXiv:2103.12603 [hep-ex]

- Complete likelihoods publicly available on HEPData

WHAT DID WE HAVE BEFORE?

- Different uncertainties extracted directly from paper
- Put into different categories $\theta_{theo}, \theta_{syst}$ defined in SFitter

$$\mathcal{L}_{\text{excl}}(\theta) \approx \text{Pois}(d|s + b + \Sigma\theta_{\text{theo},j} + \Sigma\theta_{\text{syst},i})\, p(b) \prod_j \mathcal{F}_{0,\sigma_j}(\theta_{\text{theo},j}) \prod_i \mathcal{N}_{0,\sigma_i}(\theta_{\text{syst},i})$$

- Same for both profiling and marginalization

Uncertainty	$\Delta\sigma_{t\bar{t}Z}/\sigma_{t\bar{t}Z}$ [%]
$t\bar{t}Z$ parton shower	3.1
tWZ modelling	2.9
b-tagging	2.9
WZ/ZZ + jets modelling	2.8
tZq modelling	2.6
Lepton	2.3
Luminosity	2.2
Jets + $E_{\text{T}}^{\text{miss}}$	2.1
Fake leptons	2.1
$t\bar{t}Z$ ISR	1.6
$t\bar{t}Z$ μ_{f} and μ_{r} scales	0.9
Other backgrounds	0.7
Pile-up	0.7
$t\bar{t}Z$ PDF	0.2
Total systematic	8.4
Data statistics	5.2
Total	10

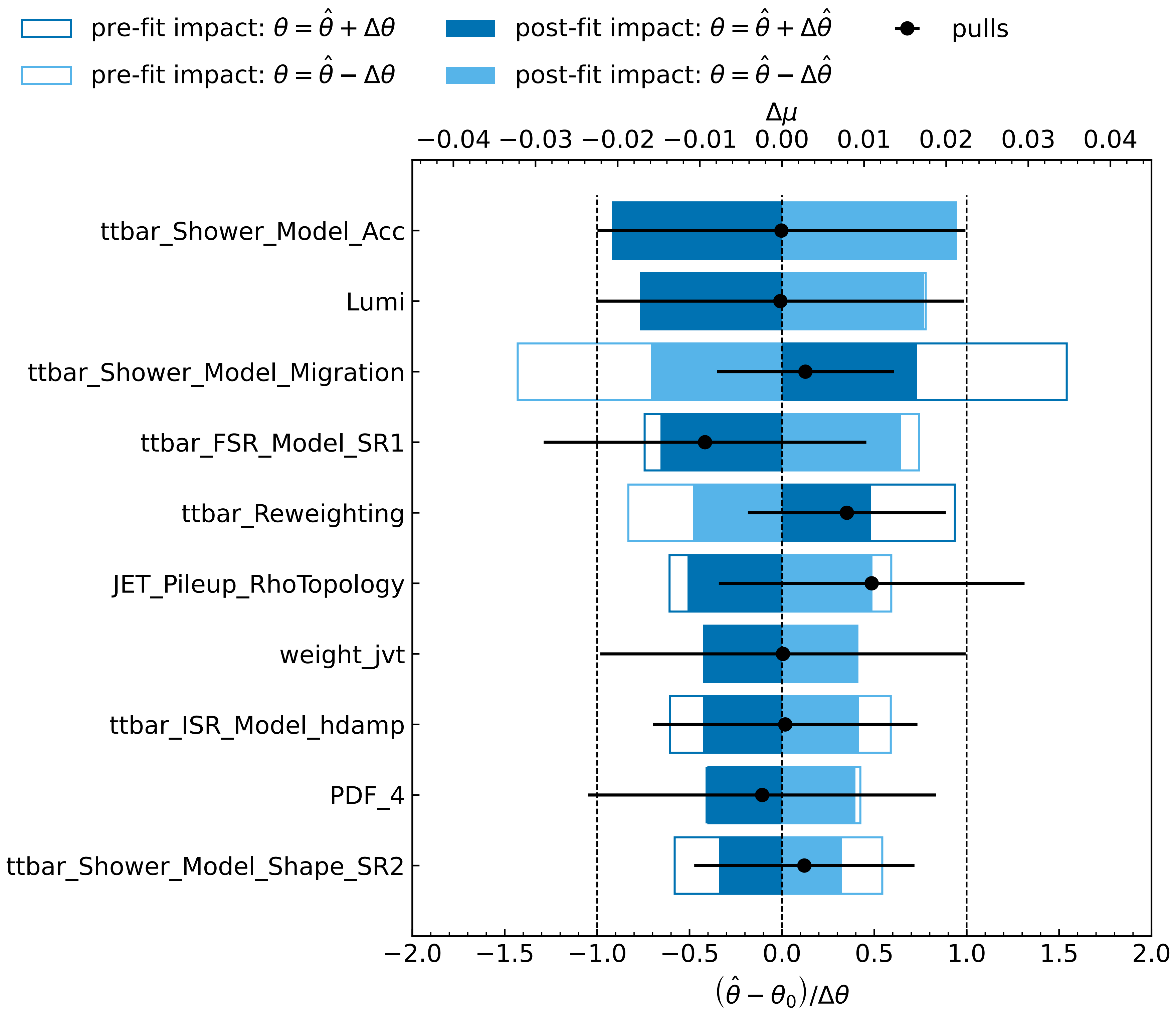
arXiv:2103.12603 [hep-ex]

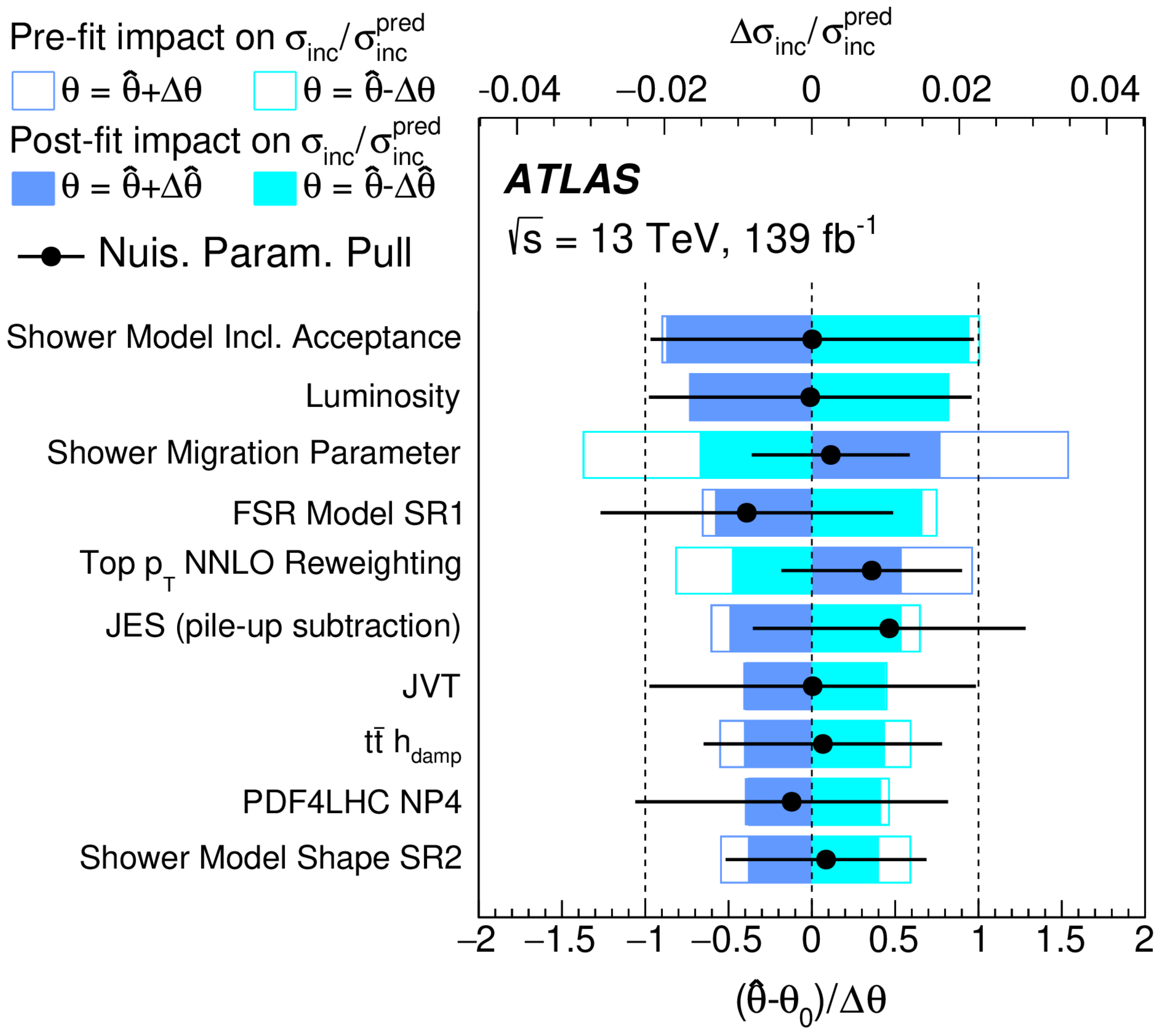
WHAT DO WE HAVE NOW?

- Published likelihoods in the HistFactory format [CERN-OPEN-2012-016]
- Gives information on large number of nuisance parameters in simple JSON file
- Multiple python packages for their analysis exist
  (Pyhf[1] for statistical analyses, Cabinetry[2] for visualisation)

[1][https://doi.org/10.5281/zenodo.7807148], [2][https://doi.org/10.5281/zenodo.7791483]

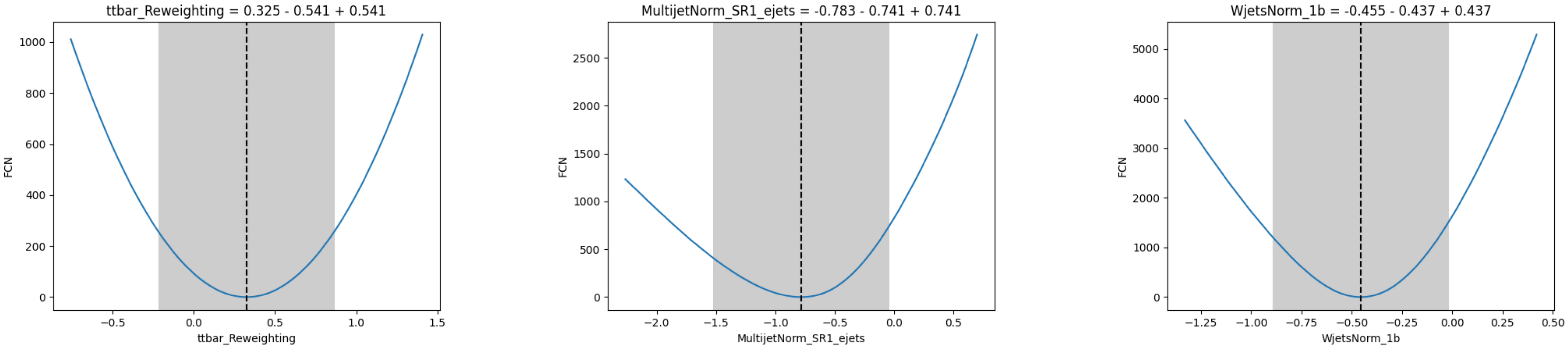
WHAT DO WE HAVE NOW?





Taken from [arXiv:2006.13076](https://arxiv.org/abs/2006.13076) [hep-ex]

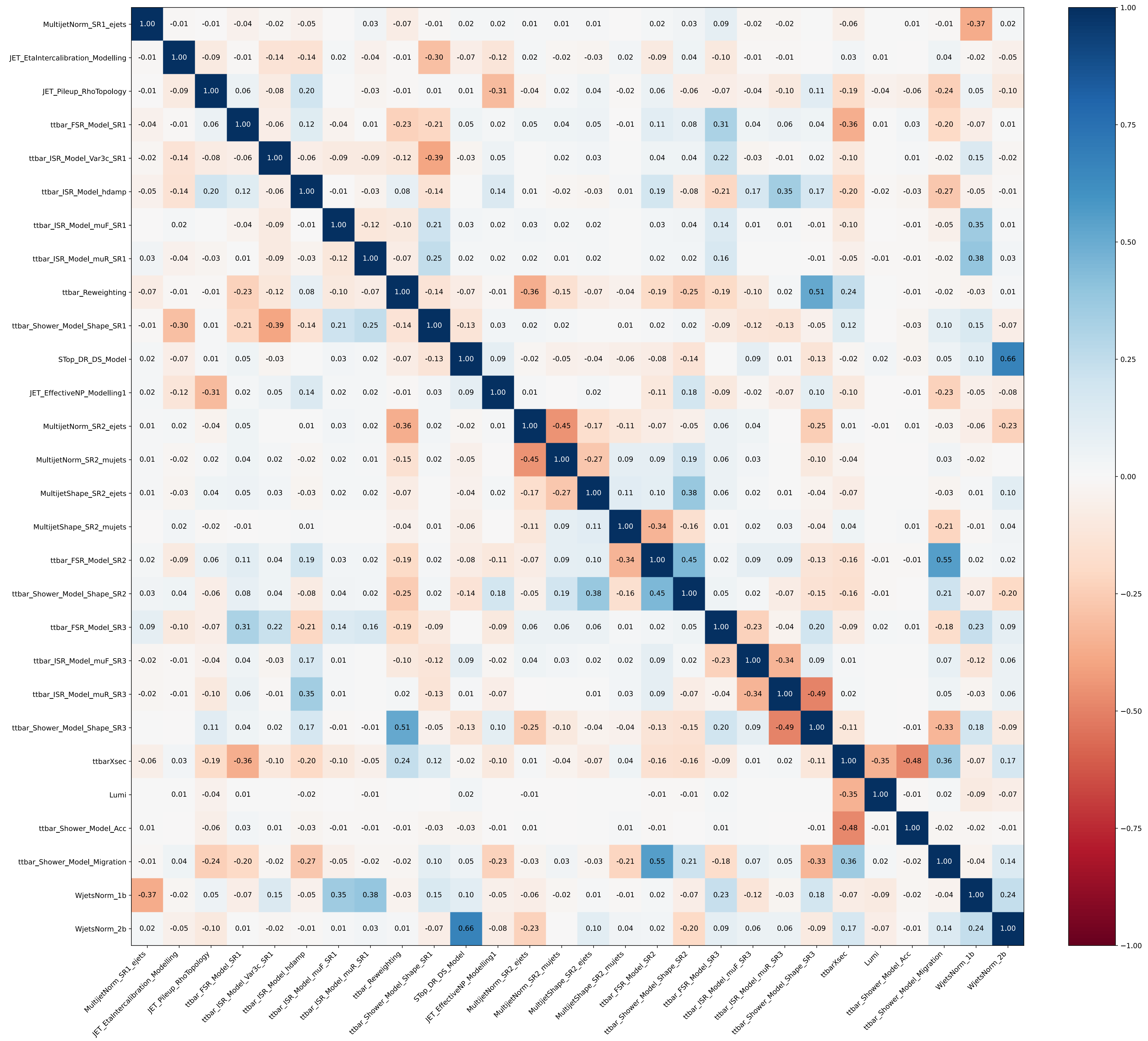
WHAT DO WE HAVE NOW?



- Possible to analyze individual nuisance parameters
- Justifies gaussian approximations, possibly consider asymmetries

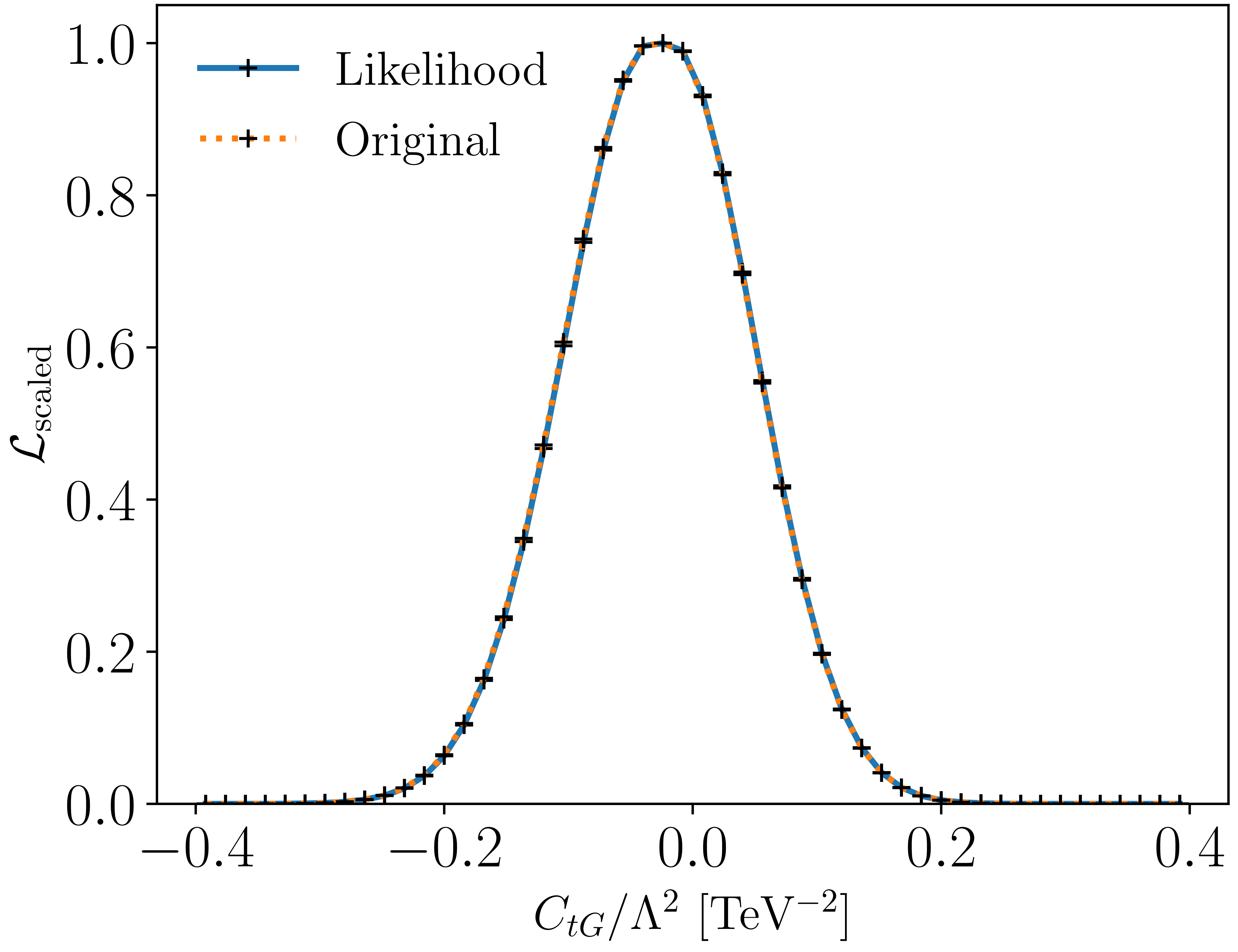
WHAT DO WE HAVE NOW?

- Hundreds of Nuisance Parameters
- Individual impact and uncertainties can be easily determined via profiled fit
- Implementing individual NPs is unreasonable
- Reduce to uncertainty groups used in SFitter

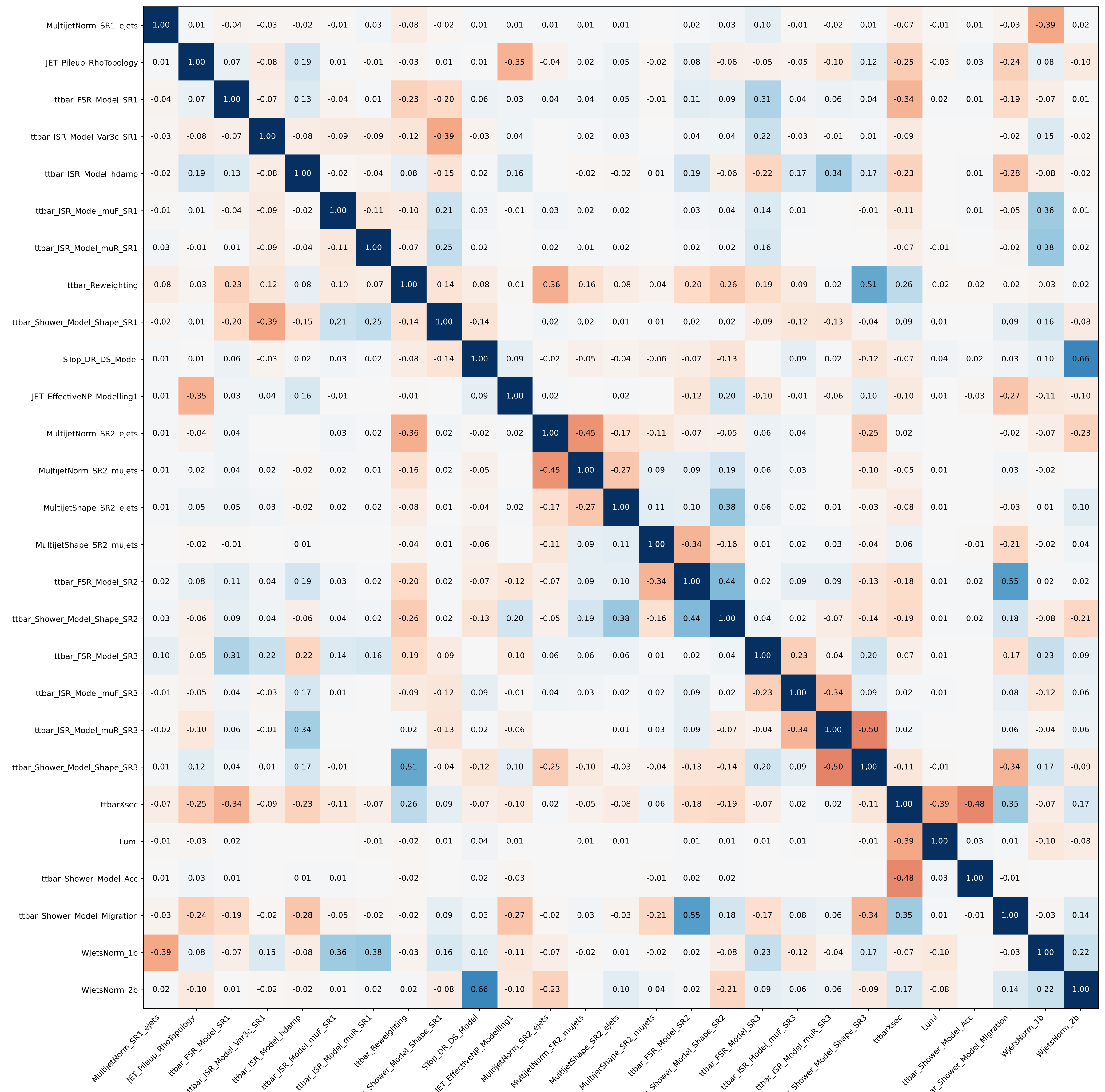


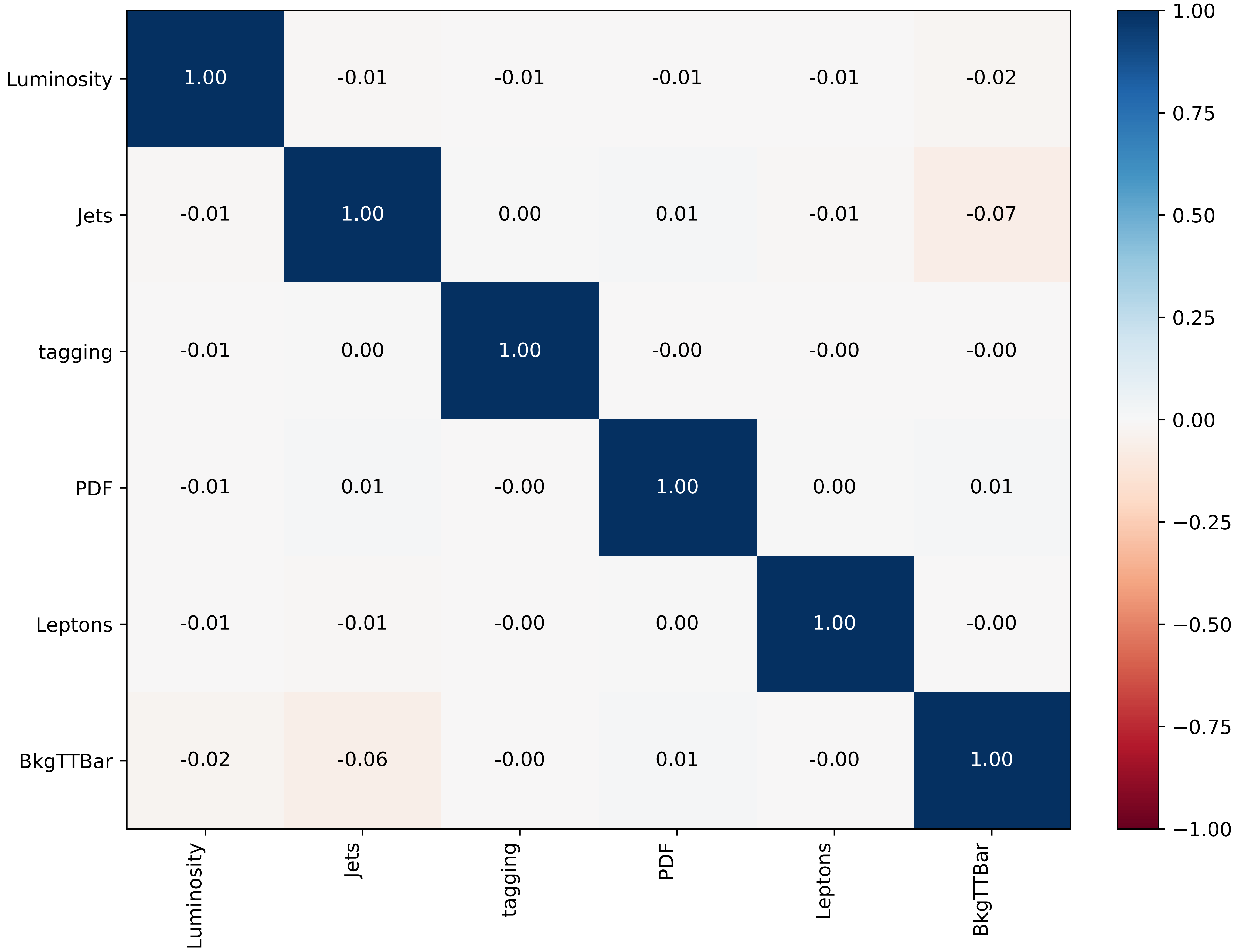
IMPLEMENTING LIKELIHOODS

- Determine uncertainties of NP groups from profiled fit
- Restrict dataset to only $\sigma_{t\bar{t}}$ measurements
- Check validity via low dimensional fit
  - Excellent agreement between both



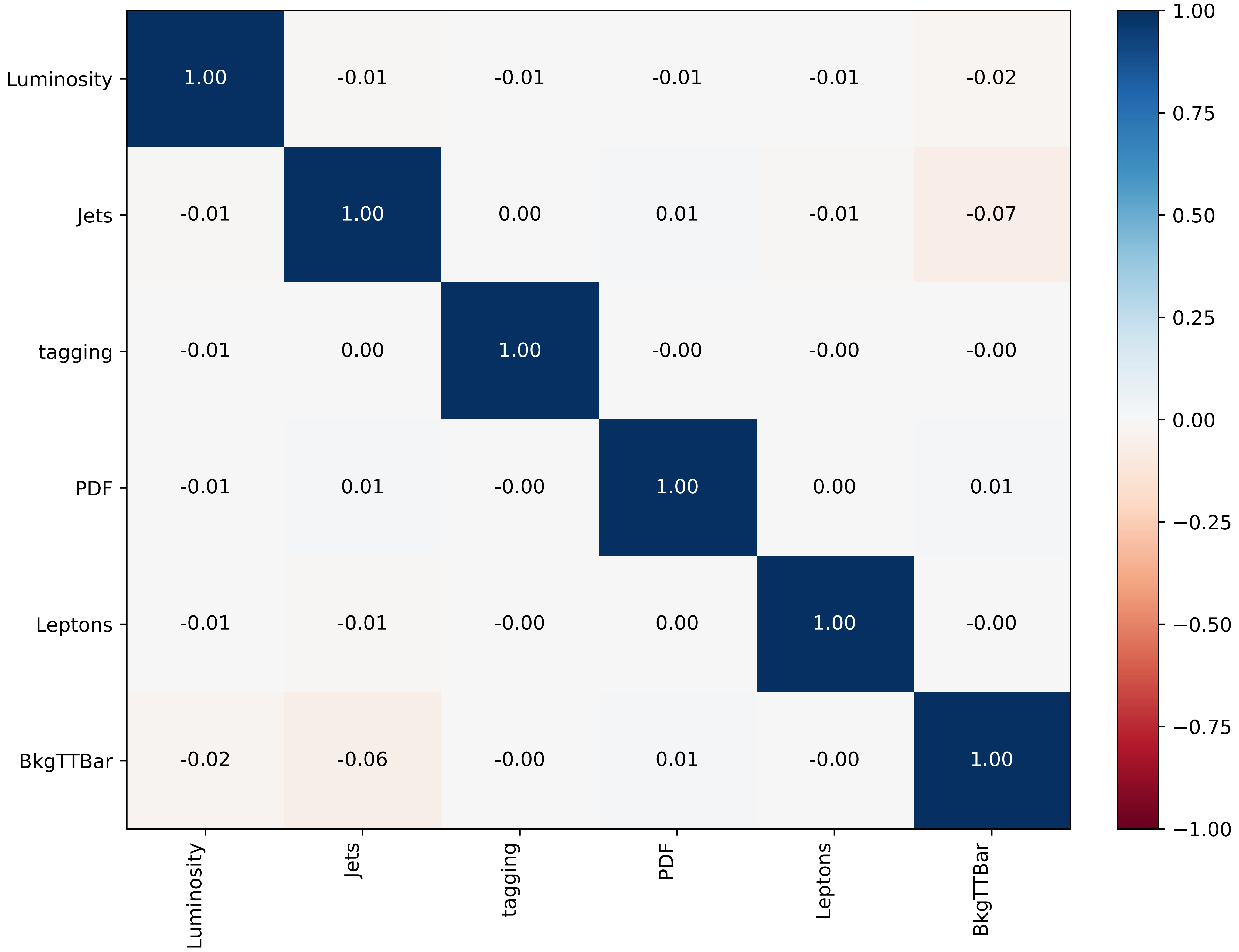
CONSIDERING CORRELATIONS





CONSIDERING CORRELATIONS

- Categories currently implemented are hardly correlated
  - Previous datasets implemented in such a way that correlations within a measurement are negligible



PART 3

COMBINATION OF HIGGS AND TOP

(PRELIMINARY)

COMBINING HIGGS AND TOP

- Higgs:
  - $U(3)^5$ flavor symmetry for Higgs
  - Based on the HISZ basis
- Top:
  - $U(2)_q \times U(2)_u \times U(2)_d$ flavor symmetry
  - Warsaw basis

Operator	Definition	Operator	Definition
O_{GG}	$\phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu}$	O_{WW}	$\phi^\dagger W_{\mu\nu} W^{\mu\nu} \phi$
O_{BB}	$\phi^\dagger B_{\mu\nu} B^{\mu\nu} \phi$	O_{BW}	$\phi^\dagger B_{\mu\nu} W^{\mu\nu} \phi$
O_B	$(D_\mu \phi)^\dagger B_{\mu\nu} (D_\nu \phi)$	O_W	$(D_\mu \phi)^\dagger W_{\mu\nu} (D_\nu \phi)$
O_{3W}	$\mathrm{Tr}(W_{\mu\nu} W^{\nu\rho} W^\mu_\rho)$		
$O_{\phi 1}$	$(D_\mu \phi)^\dagger \phi \phi^\dagger (D^\mu \phi)$	$O_{\phi 2}$	$\frac{1}{2} \partial^\mu (\phi^\dagger \phi) \partial_\mu (\phi^\dagger \phi)$
$O_{e\phi,22}$	$(\phi^\dagger \phi) \bar{l}_2 \phi e_2$	$O_{e\phi,33}$	$(\phi^\dagger \phi) \bar{l}_3 \phi e_3$
$O_{d\phi,33}$	$(\phi^\dagger \phi) \bar{q}_3 \phi d_3$	$O_{u\phi,33}$	$(\phi^\dagger \phi) \bar{q}_3 \tilde{\phi} u_3$
O_{4L}	$(\bar{l}_1 \gamma_\mu l_2)(\bar{l}_2 \gamma^\mu l_1)$	$O^{(1)}_{\phi e}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{e}_i \gamma^\mu e_j) \delta^{ij}$
$O^{(1)}_{\phi d}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{d}_i \gamma^\mu d_j) \delta^{ij}$	$O^{(1)}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{u}_i \gamma^\mu u_j) \delta^{ij}$
$O^{(1)}_{\phi Q}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{q}_i \gamma^\mu q_j) \delta^{ij}$	$O^{(3)}_{\phi Q}$	$(\phi^\dagger i \overleftrightarrow{D}^A_\mu \phi)(\bar{q}_i \gamma^\mu t^A q_j) \delta^{ij}$
C_{tG}	$i g_s (\bar{Q}_3 \sigma^{\mu\nu} T^A uR, 3) \tilde{\phi} G^A_{\mu\nu}$		

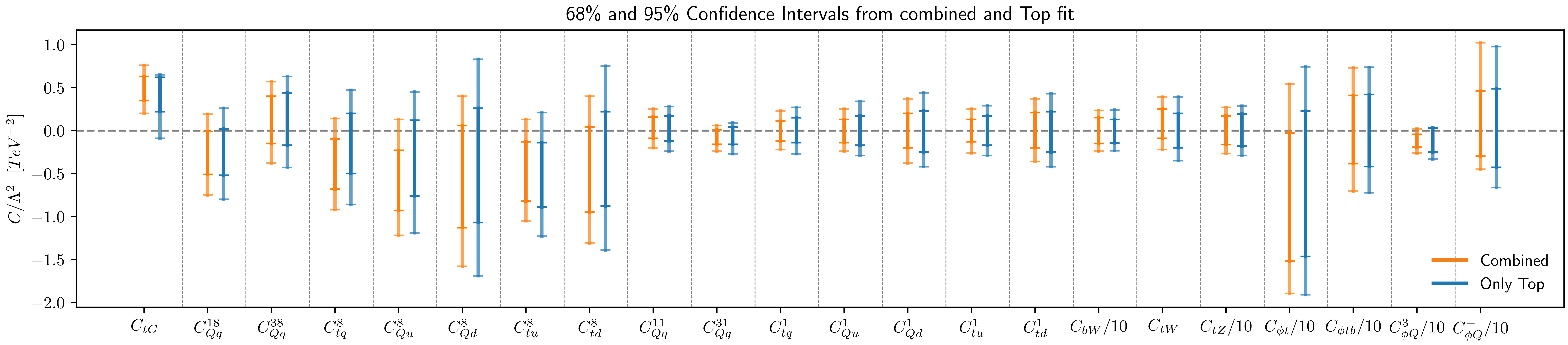
COMBINING HIGGS AND TOP

- The Top dataset
  - 92 $t\bar{t}$ datapoints
  - 2 $t\bar{t}Z$ datapoints
  - 2 $t\bar{t}W$ datapoints
  - 20 SingleTop datapoints

- The 'Higgs' dataset
  - 311 Higgs datapoints
  - 43 Di-Boson datapoints
  - 14 EWPOs (excluded for now)
  - 4 high kinematic measurements (VH/ZH/VV resonance searches, Higgs p_T analysis)

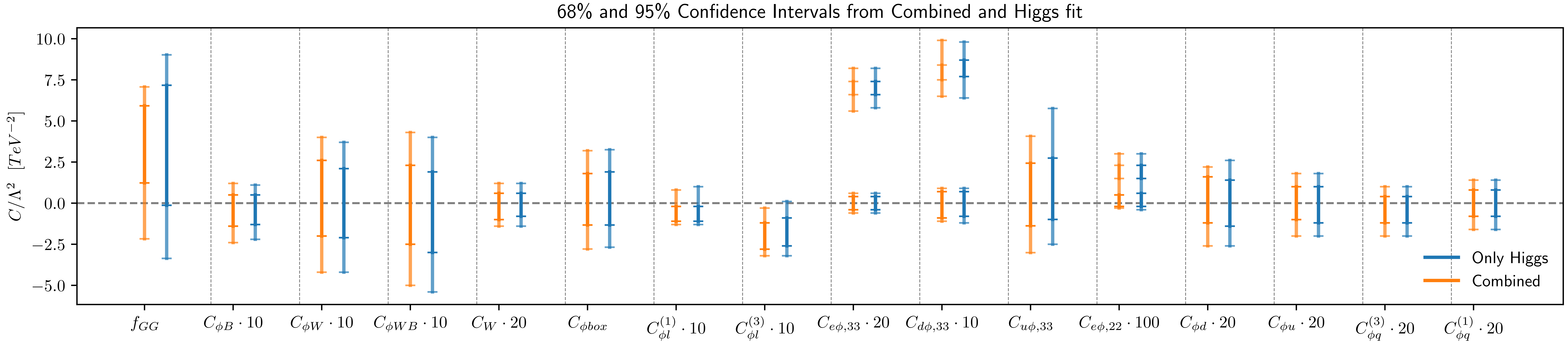
–> Omit 3 Wilson coefficients from the fit: $C_{\phi D}$, C_{ll} and $C_{\phi e}$

COMBINING HIGGS AND TOP (TOP SECTOR)



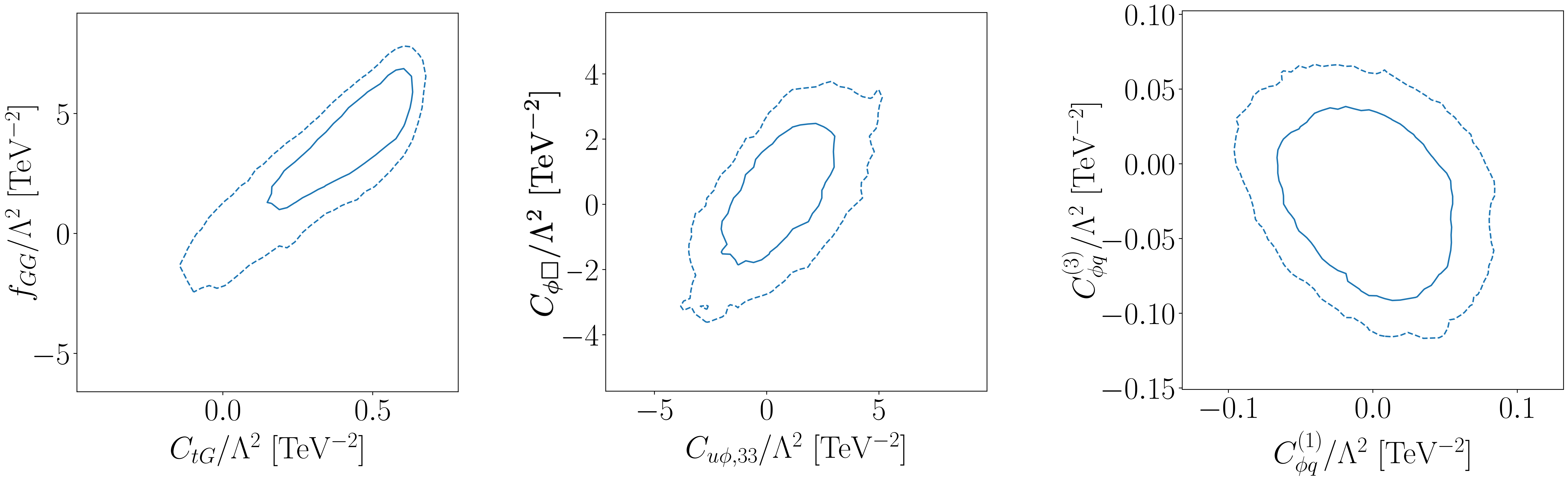
- Only minor differences in constraining power for most WCs
- Slight shift in the peak of C_{tG}

COMBINING HIGGS AND TOP (HIGGS SECTOR)



- Once again very similar results for both fits
- Larger difference for f_{GG}

INTERPLAY OF HIGGS AND TOP



- Strong correlation between C_{tG} and f_{GG}
- Small interplay between the different sectors, most correlations within individual ones

CONCLUSION AND OUTLOOK

Marginalization gives second different way of interpreting data
→ for Top one sees differences as a result of large theoretical uncertainties

Published likelihoods gives more flexible treatment of uncertainties
→ Publication of more likelihoods make more interesting analyses possible

First results for the combined Top and Higgs + Di-Boson fit
→ proper implementation of EWPOs in the works

CONCLUSION AND OUTLOOK

Marginalization gives second different way of interpreting data
→ for Top one sees differences as a result of large theoretical uncertainties

Published likelihoods gives more flexible treatment of uncertainties
→ Publication of more likelihoods make more interesting analyses possible

First results for the combined Top and Higgs + Di-Boson fit
→ proper implementation of EWPOs in the works

Thanks for listening :)

BACKUP SLIDES

PROFILING VS MARGINALIZATION

Where is the water molecule most likely located?

Higher profiled likelihood:

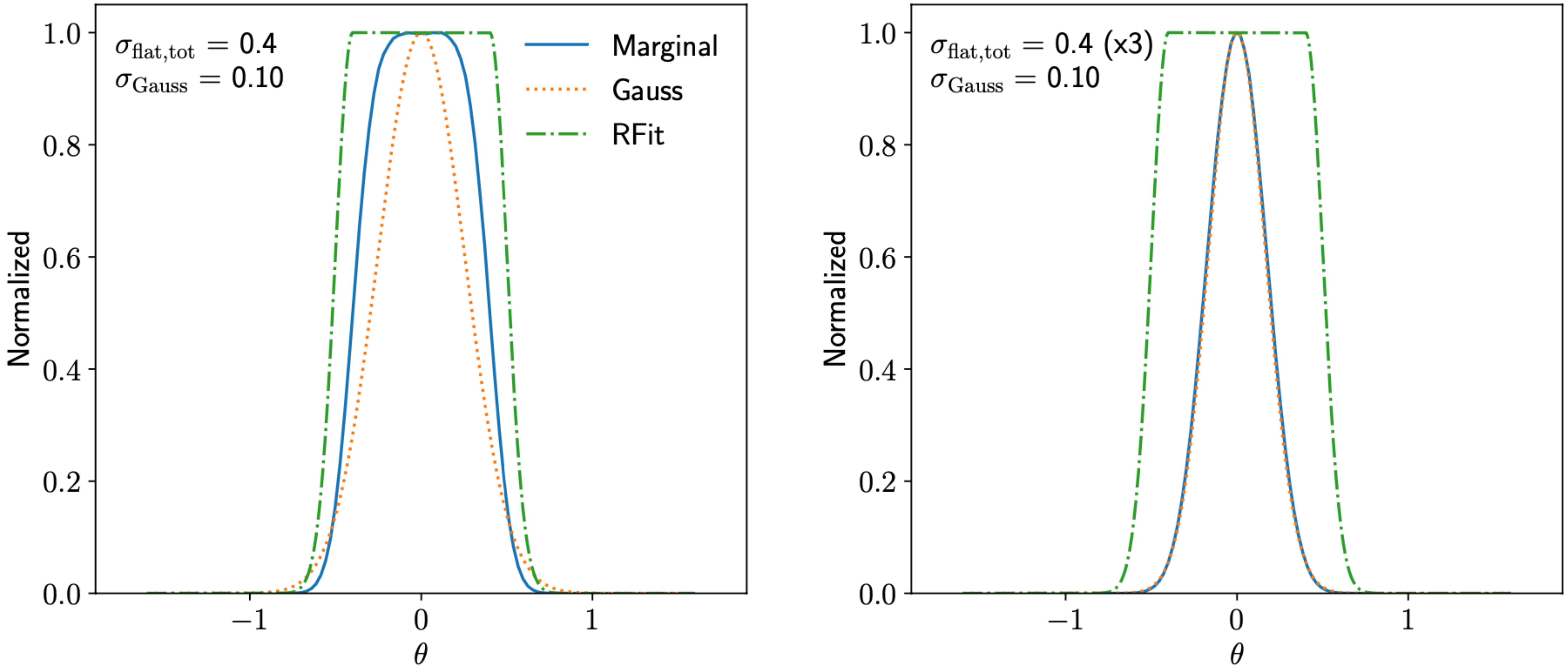
$$\max_T L(M\,|\,T)$$

Which object is most likely to contain a water molecule?

Higher marginal probability:

$$\int_T P(T|M) = \int_T \frac{L(M\,|\,T)P(T)}{P(M)}$$

PROFILING VS MARGINALISATION (FLAT THEORY UNCERTAINTIES)



arXiv:2208.08454 [hep-ph]

THE TOP DATASET

experiment	$\sqrt{S}$ (TeV)	$\mathcal{L}$ (fb^{-1})	channel	observable & K-factor		#bins	R	M	D	A
$pp \to t\bar{t}$										
CMS [52]	8	19.7	$e\mu$	$\sigma_{t\bar{t}}$	[53]		✓	✓	.	.
ATLAS [54]	8	20.02	lj	$\sigma_{t\bar{t}}$	[53]		✓	✓	.	.
CMS [55]	13	2.3	lj	$\sigma_{t\bar{t}}$	[53]		✓	✓	.	.
CMS [56]	13	3.2	ll	$\sigma_{t\bar{t}}$	[53]		✓	✓	.	.
ATLAS [57]	13	3.2	$e\mu$	$\sigma_{t\bar{t}}$	[53]		✓	✓	.	.
ATLAS [58]	8	20.3	lj	$\sigma^{-1}(d\sigma/dm_{t\bar{t}})$	[59–61]	7	.	✓	✓	.
CMS [62]	8	19.7	lj	$\sigma^{-1}(d\sigma/dp_{T,t})$	[59–61]	7	.	.	✓	.
			ll	$\sigma^{-1}(d\sigma/dp_{T,1})$		5	.	.	✓	.
CMS [63]	8	19.7	$e\mu$	$\sigma^{-1}(d^2\sigma/dm_{t\bar{t}}dy_{t\bar{t}})$	[64]	16	.	.	.	.
CMS [65]	8	19.7	lj high p_T	$d\sigma/dp_{T,t}$		5	.	.	.	.
CMS [66]	13	2.3	lj	$\sigma^{-1}(d\sigma/dm_{t\bar{t}})$		8	.	✓	✓	.
CMS [67]	13	35.8	lj	$\sigma^{-1}(d\sigma/dp_T(t_h))$	[59–61]	12	.	.	✓	.
CMS [68]	13	2.1	ll	$\sigma^{-1}(d\sigma/dp_{T,t})$	[59–61]	6	.	.	✓	.
CMS [69]	13	35.9	ll	$\sigma^{-1}(d\sigma/d\Delta y_{t\bar{t}})$	[59–61]	8	.	.	.	✓
ATLAS [70]	13	36.1	aj high p_T	$\sigma^{-1}(d\sigma/dm_{t\bar{t}})$		8	.	.	.	.
CMS [71]	8	19.7	lj	A_C	[72]		.	.	.	✓
CMS [73]	8	19.7	ll	A_C	[72]		.	.	.	✓
ATLAS [74]	8	20.3	lj	A_C	[72]		.	.	.	✓
ATLAS [75]	8	20.3	ll	A_C	[72]		.	.	.	✓
ATLAS [76]	13	139	lj	A_C	[72]		.	.	.	✓
$pp \to t\bar{t}Z$										
CMS [77]	13	77.5	multi lept.	$\sigma_{t\bar{t}Z}$	[78]		.	.	.	.
ATLAS [79]	13	3.2	multi lept.	$\sigma_{t\bar{t}Z}$	[78]		.	.	.	.
$pp \to t\bar{t}W$										
CMS [80]	13	35.9	multi lept.	$\sigma_{t\bar{t}W}$	[78]		.	.	.	.
ATLAS [79]	13	3.2	multi lept.	$\sigma_{t\bar{t}W}$	[78]		.	.	.	.

experiment	$\sqrt{S}$ (TeV)	$\mathcal{L}$ (fb^{-1})	channel	observable & K-factor	
$t-$channel					
CMS [81]	7	1.17 (μ), 1.56 (e)	$e+\mu$	$\sigma_{tq+\bar{t}q}$	
ATLAS [82]	7	4.59	$e+\mu$	$\sigma_{tq+\bar{t}q}$	
ATLAS [83]	8	20.2	$e+\mu$	$\sigma_{tq}, \sigma_{\bar{t}q}$	
CMS [84]	8	19.7	$e+\mu$	$\sigma_{tq}, \sigma_{\bar{t}q}$	
ATLAS [85]	13	3.2	$e+\mu$	$\sigma_{tq}, \sigma_{\bar{t}q}$	[86]
CMS [87]	13	2.3	μ	$\sigma_{tq}, \sigma_{\bar{t}q}$	[86]
$s-$channel					
CMS [88]	7	5.1	μ	$\sigma_{t\bar{b}+\bar{t}b}$	
	8	19.7	$e+\mu$	$\sigma_{t\bar{b}+\bar{t}b}$	
ATLAS [89]	8	20.3	$e+\mu$	$\sigma_{t\bar{b}+\bar{t}b}$	
tW channel					
ATLAS [90]	7	2.05	$2lj$	$\sigma_{tW+\bar{t}W}$	
CMS [91]	7	4.9	$2lj$	$\sigma_{tW+\bar{t}W}$	
ATLAS [92]	8	20.3	$2lj$	$\sigma_{tW+\bar{t}W}$	
CMS [93]	8	12.2	$2lj$	$\sigma_{tW+\bar{t}W}$	
ATLAS [94]	13	3.2	$2lj$	$\sigma_{tW+\bar{t}W}$	
CMS [95]	13	35.9	$e\mu j$	$\sigma_{tW+\bar{t}W}$	
tZ channel					
ATLAS [96]	13	36.1	$3l2j$	σ_{tZq}	
W helicities in top decays					
ATLAS [97]	7	1.04		F_0, F_L	
CMS [98]	13	5.0		F_0, F_L	
ATLAS [99]	8	20.2		F_0, F_L	
CMS [100]	8	19.8		F_0, F_L	

arXiv:1910.03606 [hep-ph]

ROTATION BETWEEN BASES

$$-\frac{\alpha_s}{8\pi} f_{GG} = C_{\phi G}$$
$$f_{3W} = \frac{4}{g^3} C_W$$
$$f_{\phi 1} = C_{\phi D} + 4\bar{C}^{(1)}_{\phi l}$$
$$f_{\phi 2} = -2C_{\phi\Box} - 2\bar{C}^{(1)}_{\phi l} + 6\bar{C}^{(3)}_{\phi l}$$
$$f_{\phi} = C_{\phi} - 4\lambda \bar{C}^{(3)}_{\phi l}$$

$$f_B = \frac{8}{g'^2} \bar{C}^{(1)}_{\phi l}$$
$$f_W = -\frac{8}{g^2} \bar{C}^{(3)}_{\phi l}$$
$$f_{BB} = -\frac{4}{g'^2} \left[C_{\phi B} - \bar{C}^{(1)}_{\phi l}\right]$$
$$f_{WW} = -\frac{4}{g^2} \left[C_{\phi W} + \bar{C}^{(3)}_{\phi l}\right]$$
$$f_{BW} = 4\left[-\frac{C_{\phi WB}}{gg'} - \frac{\bar{C}^{(3)}_{\phi l}}{g^2} + \frac{\bar{C}^{(1)}_{\phi l}}{g'^2}\right]$$

$$\frac{m_\tau}{v} f_\tau = C_{e\phi,33} - 2(Y_e)_{33} \bar{C}^{(3)}_{\phi l}$$
$$\frac{m_t}{v} f_t = C_{u\phi,33} - 2(Y_u)_{33} \bar{C}^{(3)}_{\phi l}$$
$$\frac{m_b}{v} f_b = C_{d\phi,33} - 2(Y_d)_{33} \bar{C}^{(3)}_{\phi l}$$
$$\frac{m_\mu}{v} f_\mu = C_{e\phi,22} - 2(Y_e)_{22} \bar{C}^{(3)}_{\phi l}$$
$$f_{4L} = \bar{C}'_{ll}$$
$$f_{tG} = -\frac{i}{g_s} C_{uG,33} \, .$$

$$f^{(1)}_{\phi e} = \bar{C}_{\phi e} - 2\bar{C}^{(1)}_{\phi l}$$
$$f^{(1)}_{\phi u} = \bar{C}_{\phi u} + \frac{4}{3} \bar{C}^{(1)}_{\phi l}$$
$$f^{(1)}_{\phi d} = \bar{C}_{\phi d} - \frac{2}{3} \bar{C}^{(1)}_{\phi l}$$
$$f^{(1)}_{\phi Q} = \bar{C}^{(1)}_{\phi q} + \frac{1}{3} \bar{C}^{(1)}_{\phi l}$$
$$f^{(3)}_{\phi Q} = 4\left[\bar{C}^{(3)}_{\phi q} - \bar{C}^{(3)}_{\phi l}\right]$$