

# From Higgs to Top - A global SMEFT analysis

---

**Nina Elmer**

May, 2023

Institut für Theoretische Physik  
Universität Heidelberg

arXiv:2208.08454

Brivio, Bruggisser, Elmer, Geoffray, Luchmann, Plehn, Schmal



**UNIVERSITÄT  
HEIDELBERG**  
ZUKUNFT  
SEIT 1386

# Standard Model Effective Field Theory (SMEFT)



- Model independent approach for BSM physics

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

- Large number of possible operators
- ➔ **Restrict** to dimension six operators

# SFitter Framework

---



- Strong and comprehensive uncertainty treatment
- Including high kinematic distributions
- Fully correlated systematic uncertainties between measurements
- Operators included up to quadratic order
- Use profiling and marginalization constructing likelihoods



# Profiling vs. Marginalization

Two different ways to treat statistics



**Which one to choose?**

## Profiling

- Looking for the maximum of the parameter space
- Profiled likelihood:  
$$\max_T \mathcal{L}(M|T)$$

## Marginalization

- Integrating over parameter space
- Marginal probability:  
$$\int_T p(T|M) = \int_T \mathcal{L}(M|T) \frac{P(T)}{P(M)}$$

**The method to be chosen depends on the question asked**

# Today's Agenda

---



- 1. Profiling and marginalization for the Higgs sector**
  - 1.1. For the old data set
  - 1.2. For the new data set
- 2. Comparing both data sets (Higgs sector)**
- 3. Combination of Higgs and Top sector (Preliminary)**



## Applying profiling and marginalization to the old data set



# Observables included in the old data set

---

## **Low kinematics constrain non-kinematically enhanced operators**

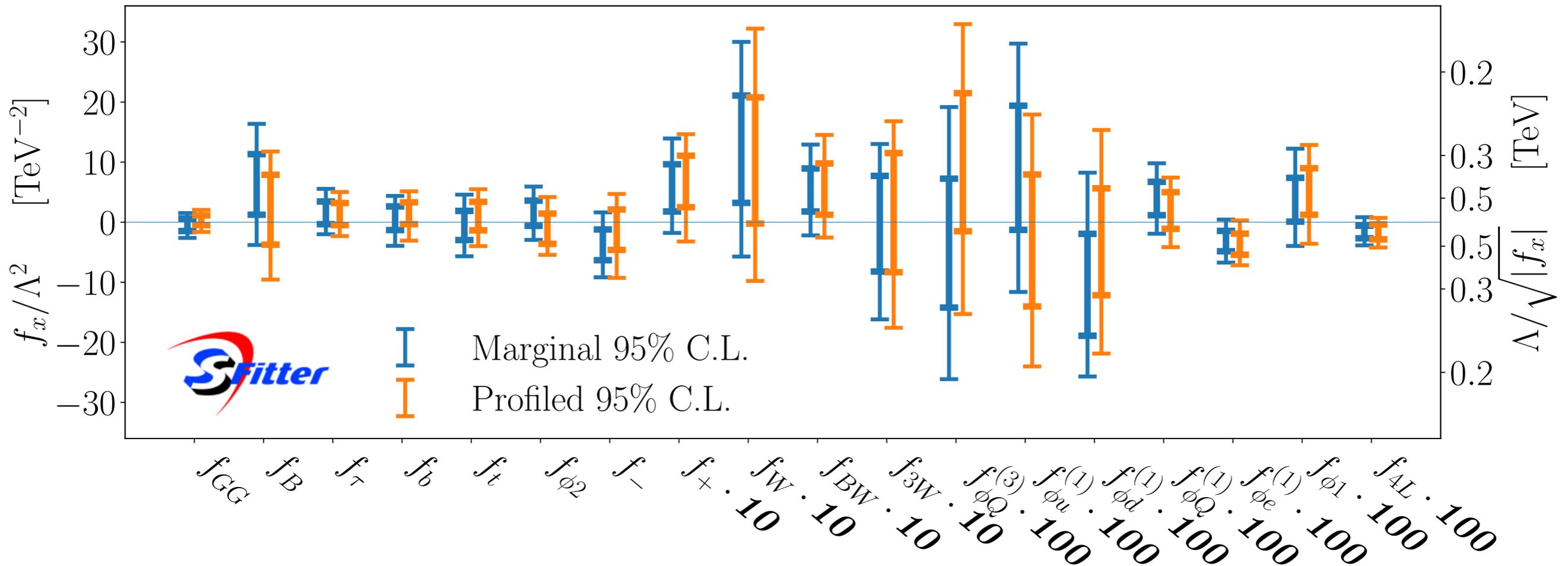
[Butter et al.: 1604.03105; Biekötter, Corbett, Plehn: 1812.07587]

- Higgs measurements at LHC (275)
- Di-boson measurements at LHC (43)
- Electroweak Precision Observables at LEP (14)

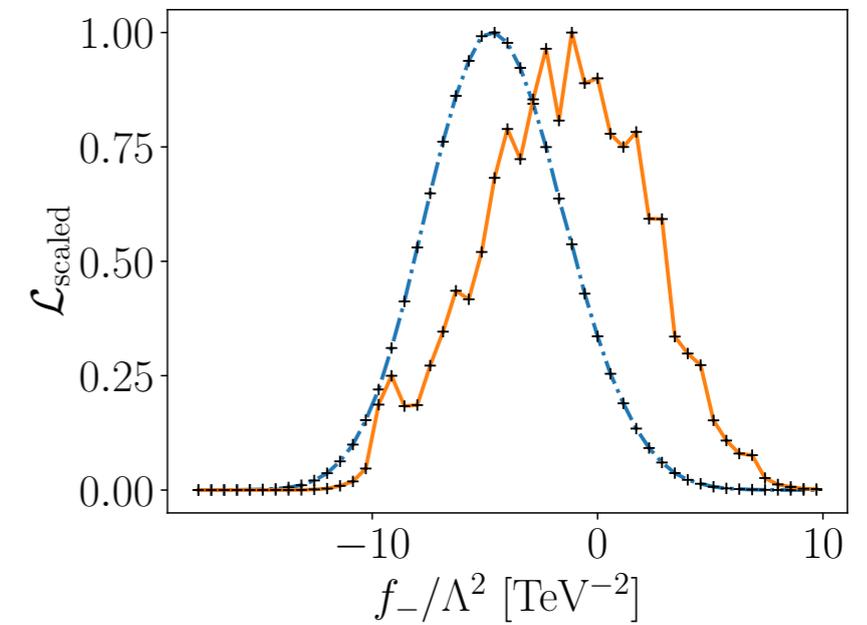
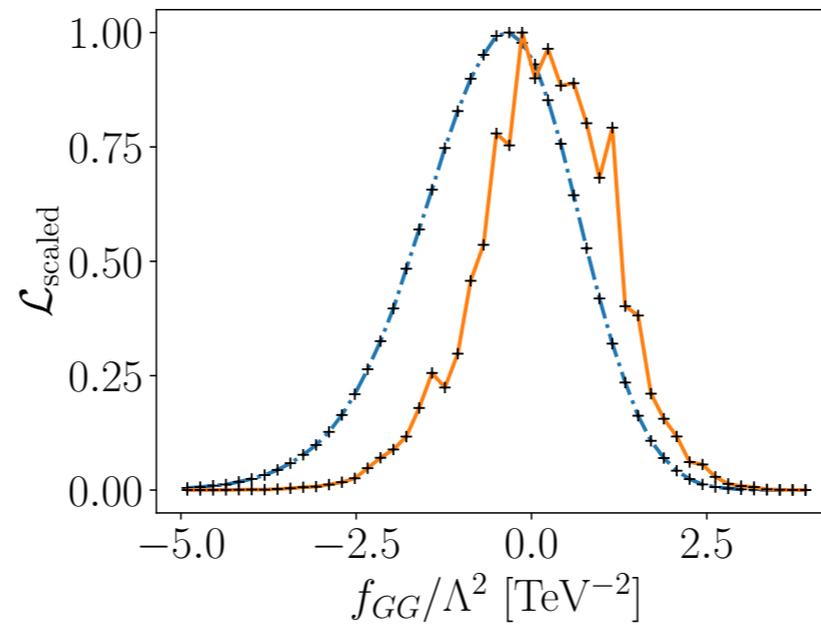
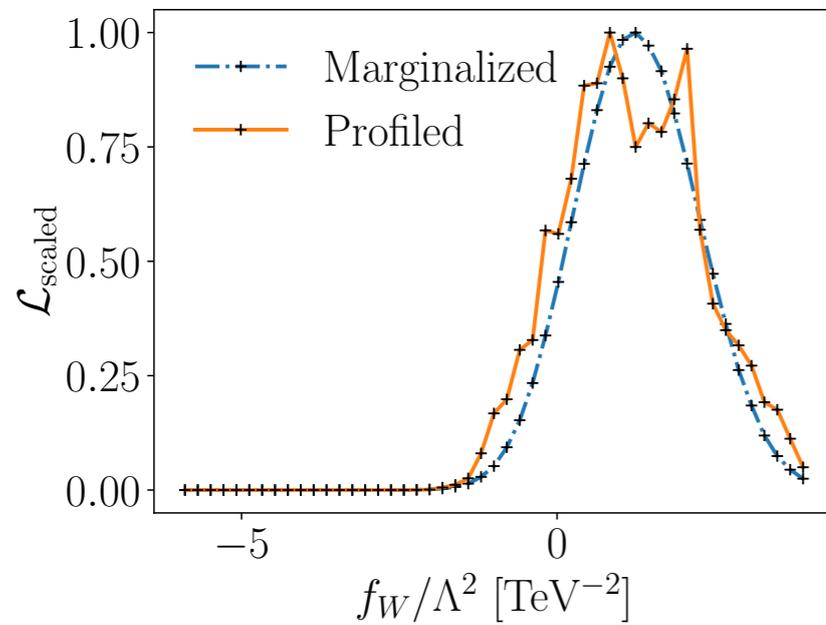
## **High kinematics constrain kinematically enhanced operators**

- VH resonance search by ATLAS [1712.06518]

# No big difference for the old data set



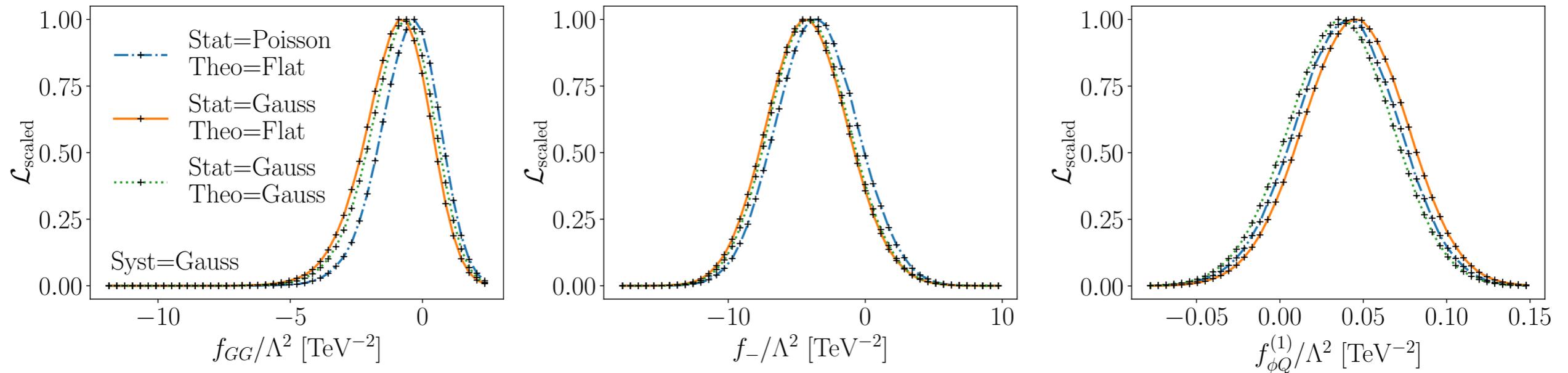
# They are the same - aren't they?



- Comparable results for both methods
- **Small shifts** in the peak



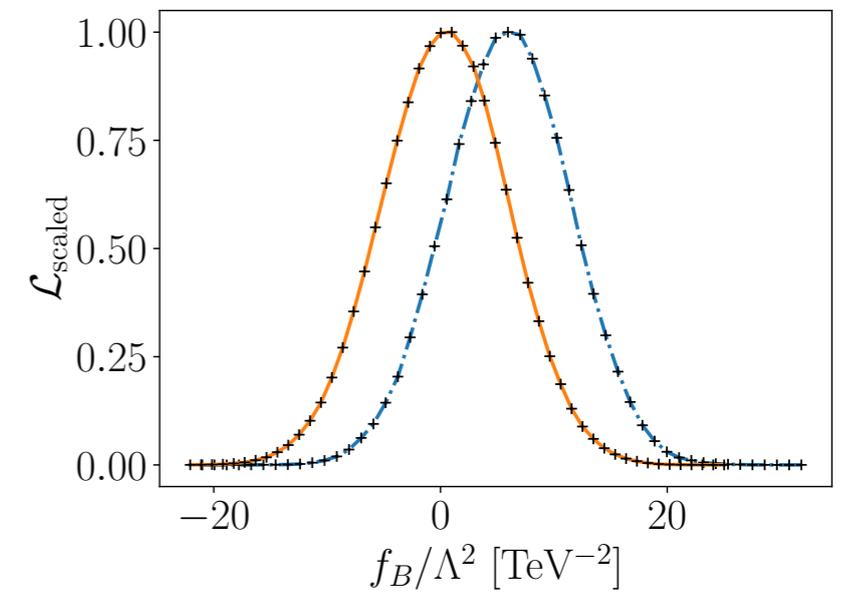
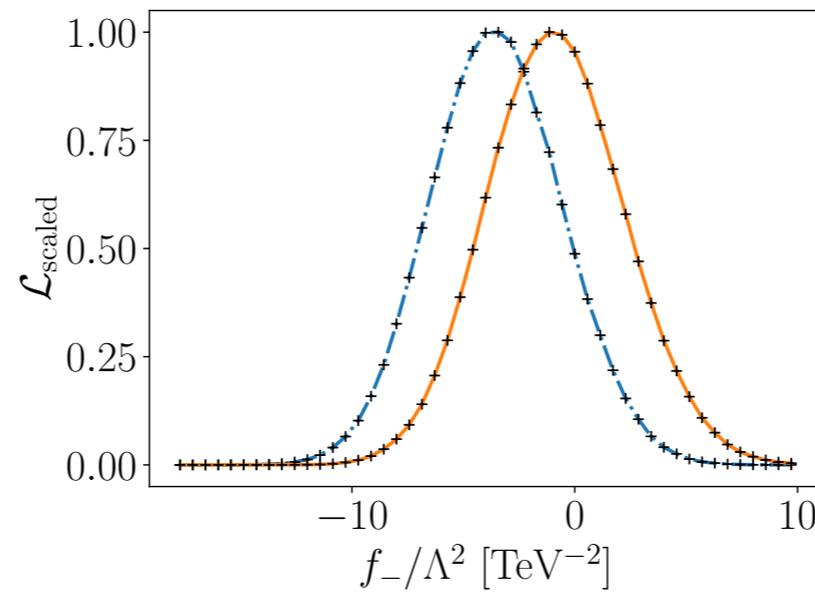
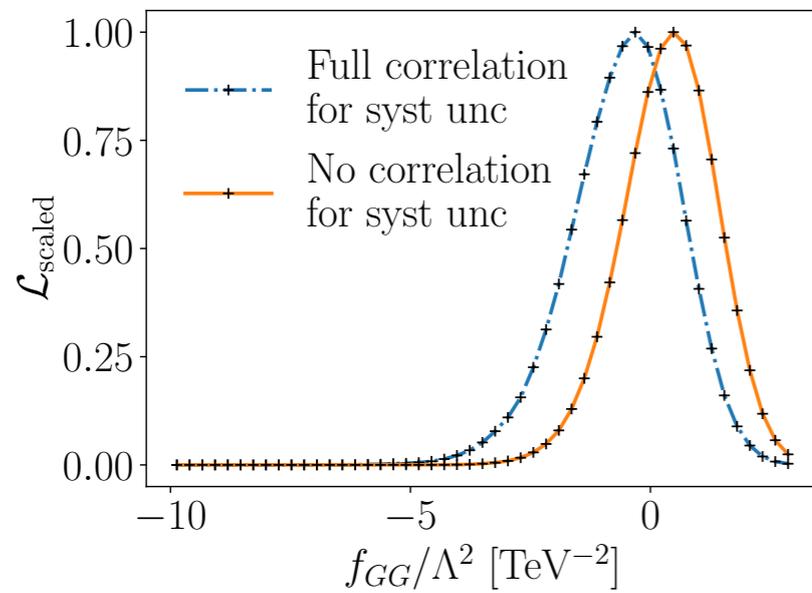
# The impact of theory uncertainties



- Consider different distributions for theory and statistical uncertainties
  - Systematic uncertainties are always Gaussian distributed
- ➔ **Little to no impact** on the overall distribution



# Impact of correlations



- Correlating systematic uncertainties
- Correlations have impact on the peak
- ➔ Responsible for **shifting the distribution**



## Applying profiling and marginalization to the new data set



# Observables included in the new data set

## Low kinematics constrain non-kinematically enhanced operators

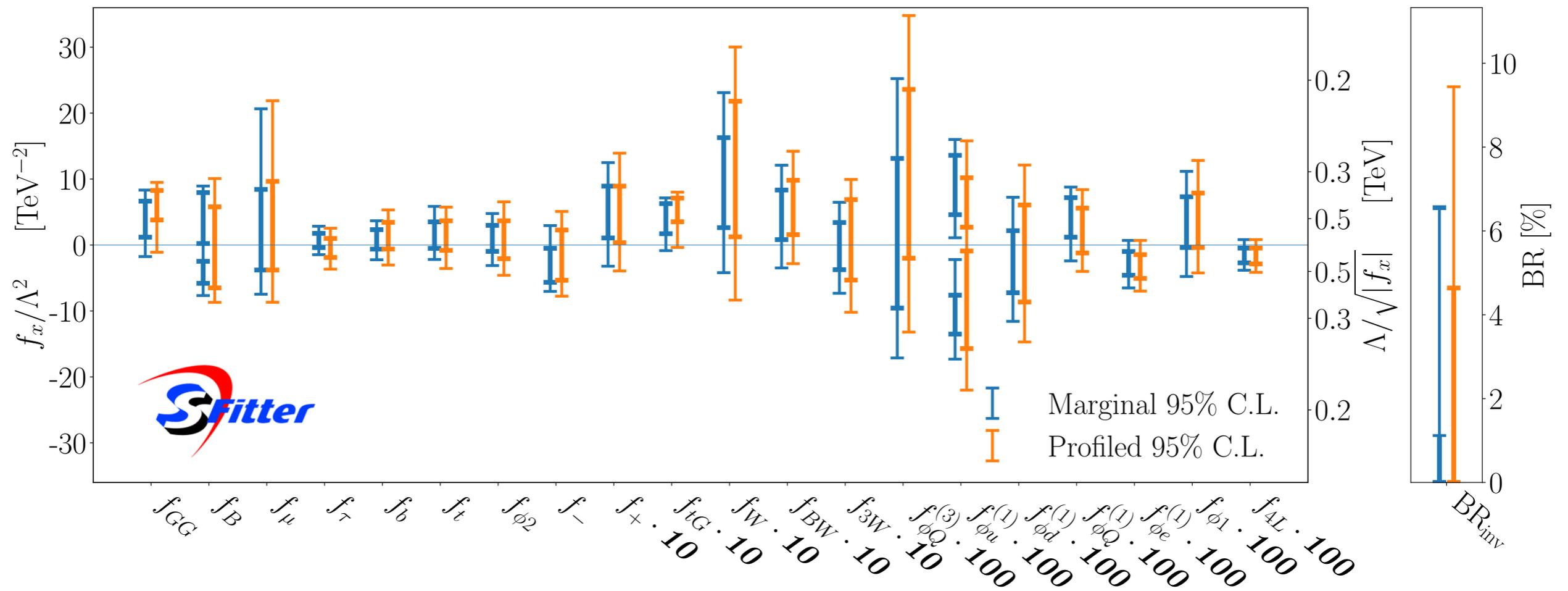
[Butter et al.: 1604.03105; Biekötter, Corbett, Plehn: 1812.07587]

- Higgs measurements at LHC (275) + new Higgs (36)
- Di-boson measurements at LHC (43)
- Electroweak Precision Observables at LEP (14)

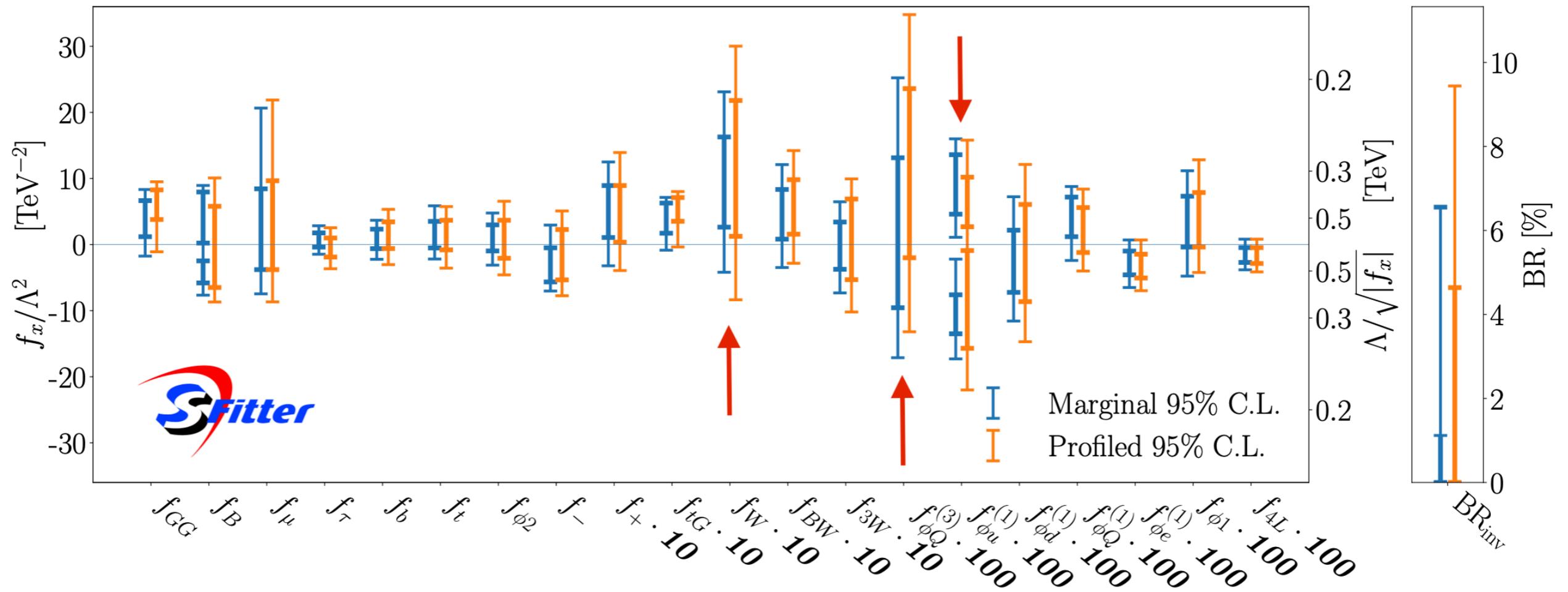
## High kinematics constrain kinematically enhanced operators

- VH resonance search by ATLAS: [ATLAS-CONF-2021-026](#) and [2007.05293](#)
- VV resonance search by ATLAS: [2004.14636](#)
- ZH resonance search by CMS: [2102.08198](#)
- Higgs  $p_T$  analysis by ATLAS: [ATLAS-CONF-2019-029](#)

# Differences in the new data set



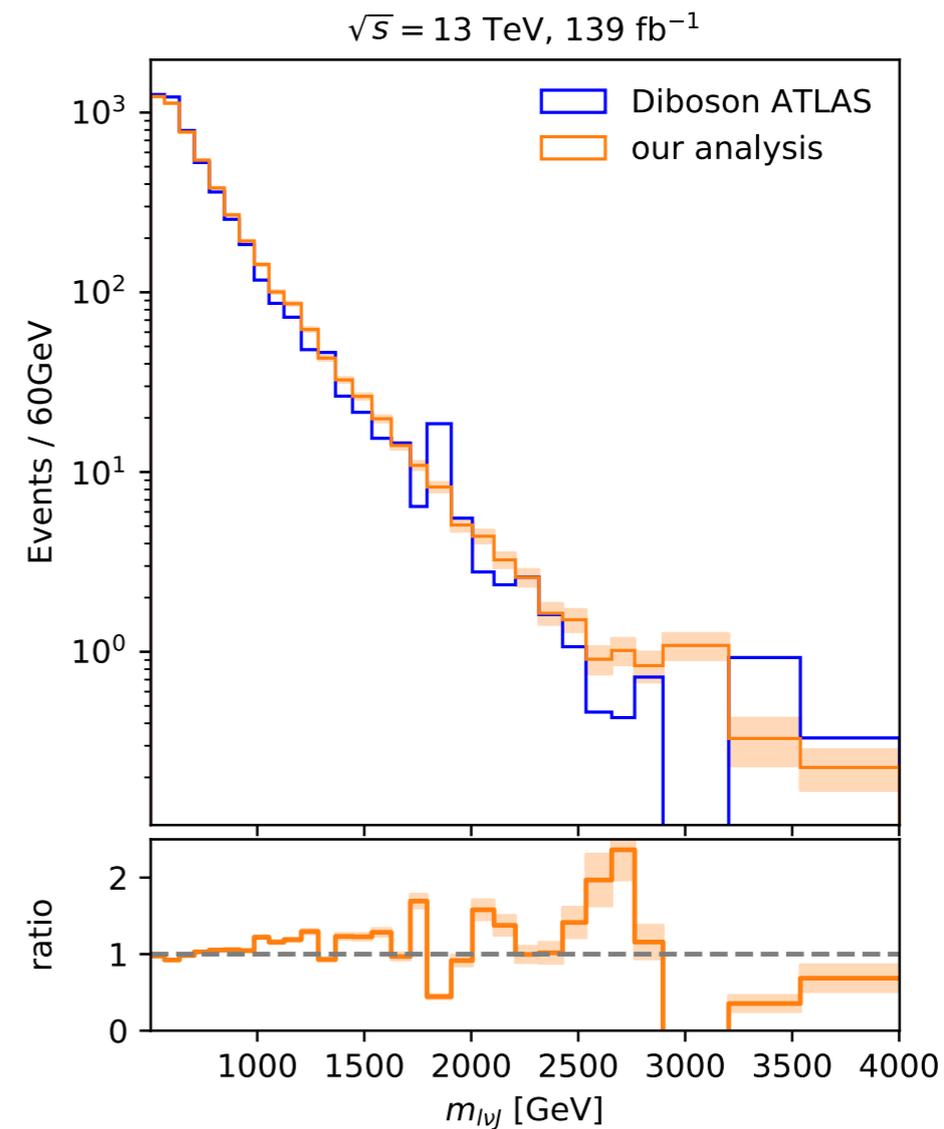
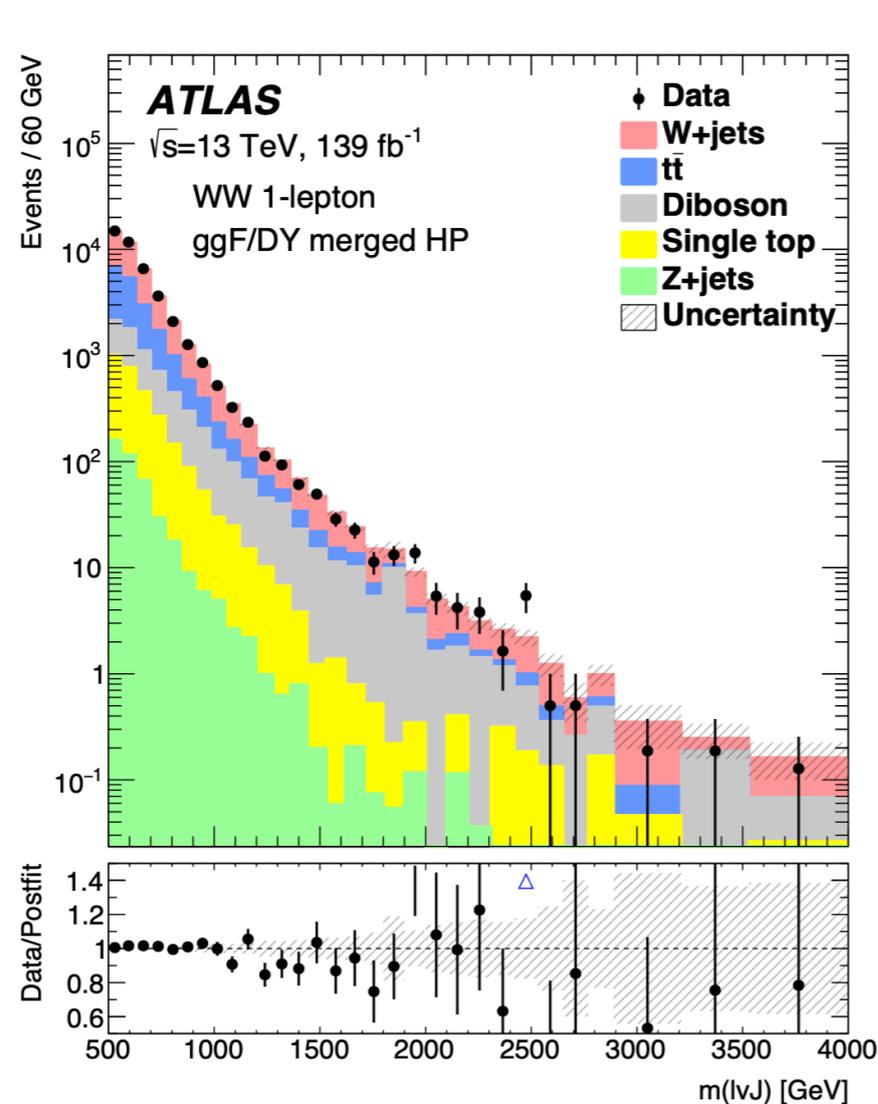
# Differences in the new data set





# WW as one of a driving measurements

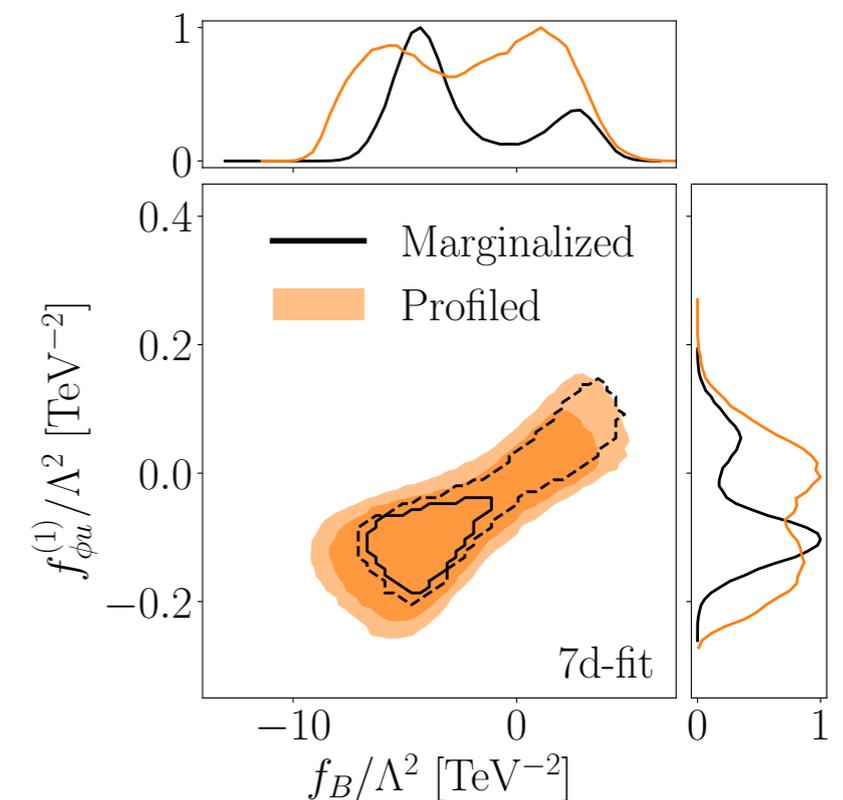
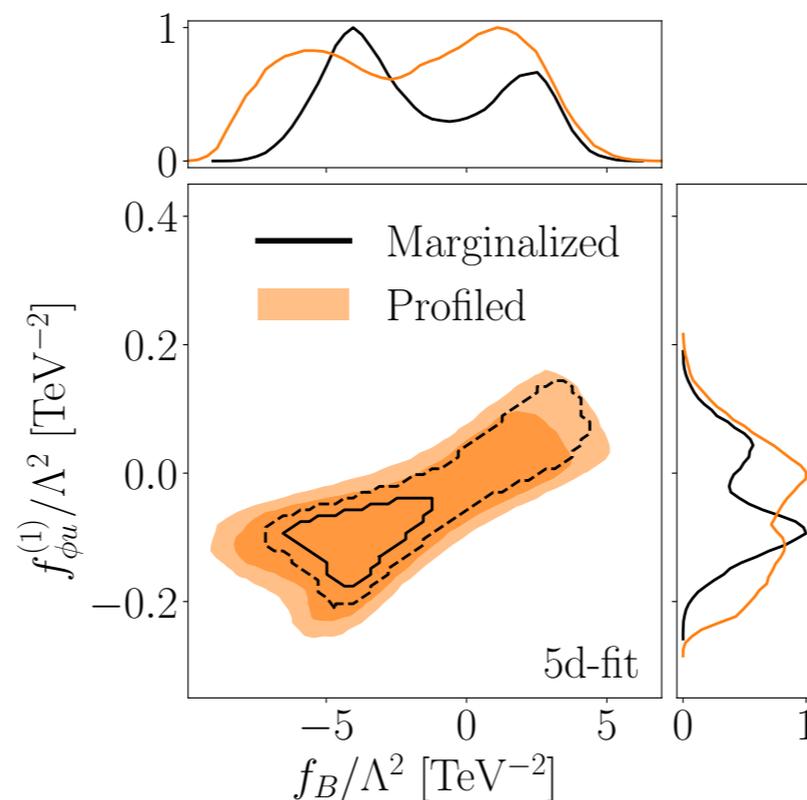
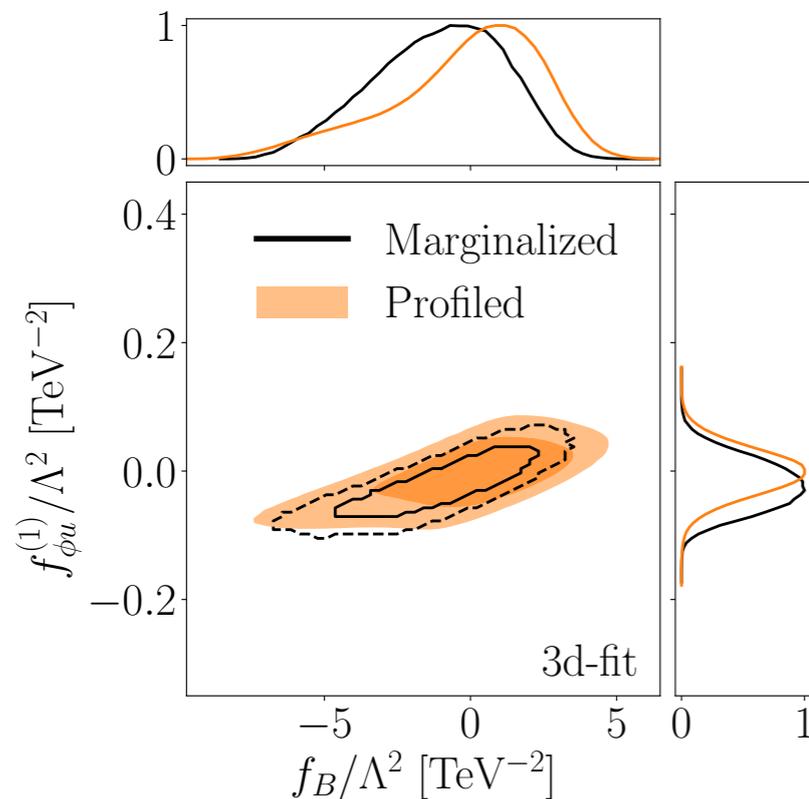
- Data set includes high kinematic distributions
- Driving measurement in linked coefficients
- Originally used for resonance searches



# Unexpected volume effect



- Peak structure appears with higher dimensional fits
- Need enough dimensions to accommodate underfluctuations
- More coefficients  $\Rightarrow$  larger volume effect  
Strengthen limits on coefficients (marginal case only)



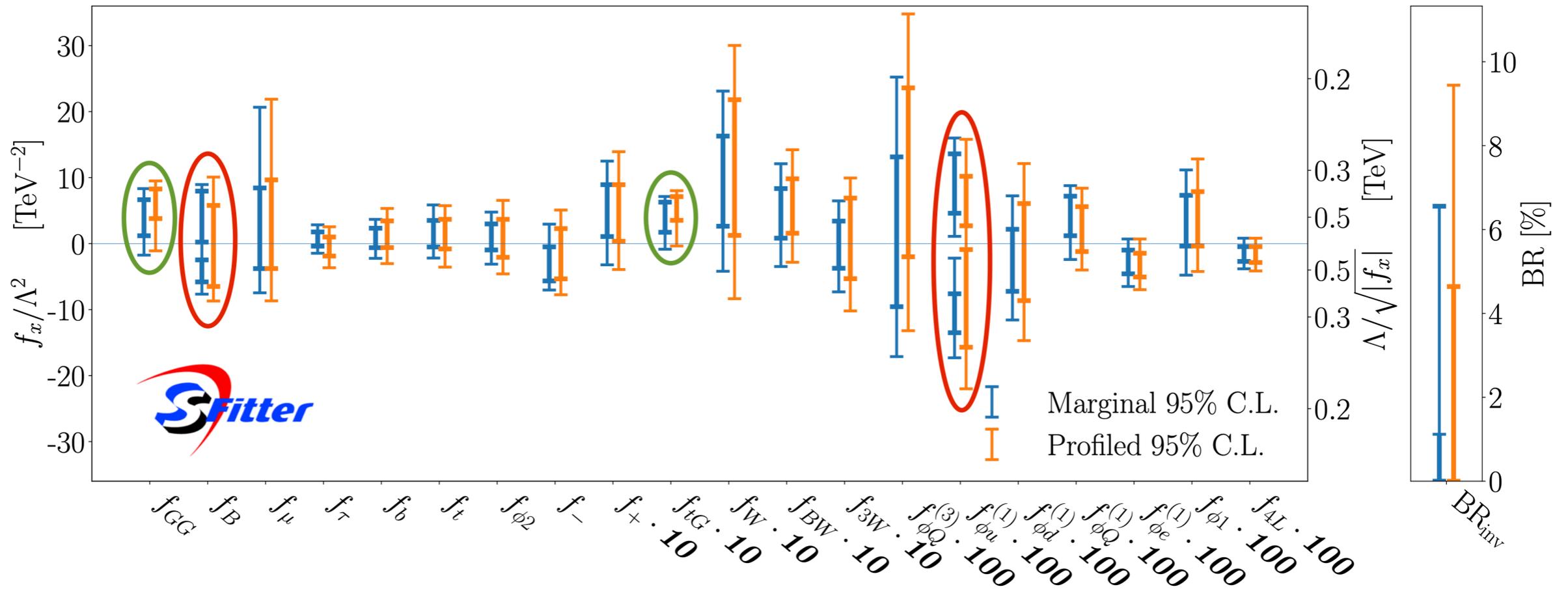
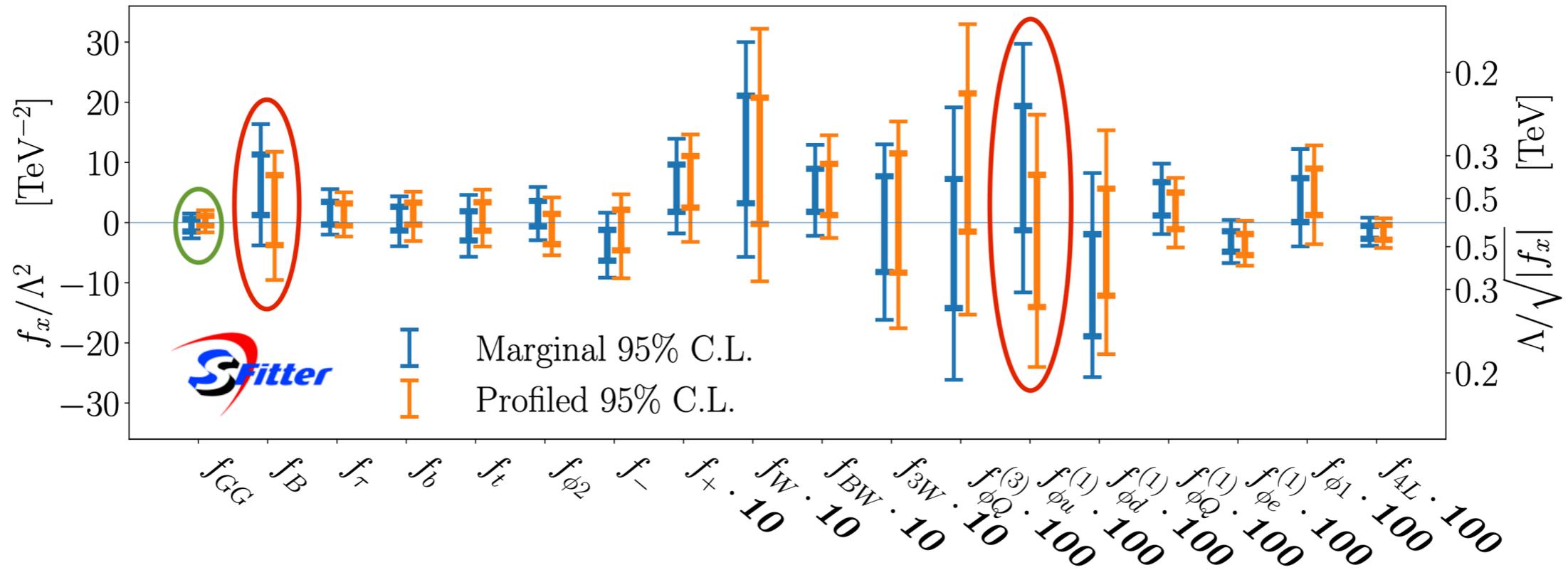
# Part 3

---

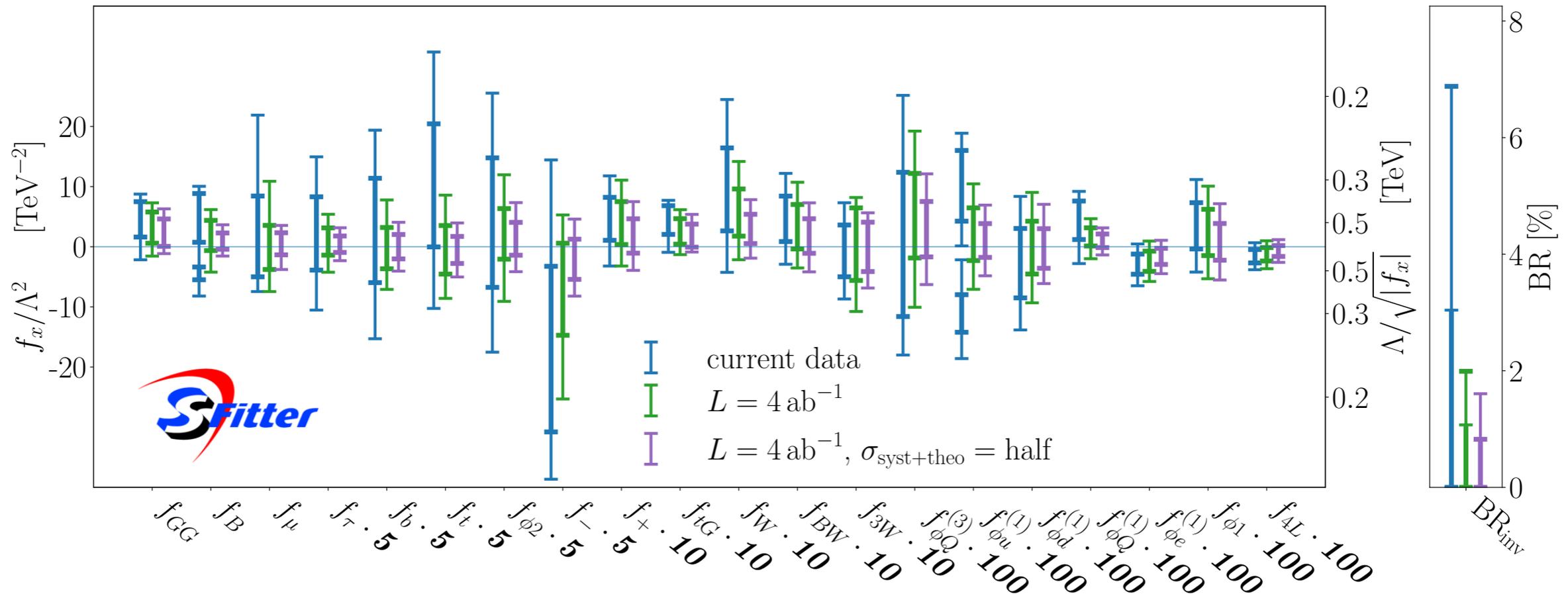


## Comparison of both data sets

# Comparing both data sets



# High luminosity scaled LHC measurements



- using updated data set
- measurements set to background values (SM hypothesis)
- luminosity scaled to  $4 \text{ ab}^{-1}$



## Combining the Higgs and Top sector

(Preliminary, work done by Nikita Schmal)

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

# 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

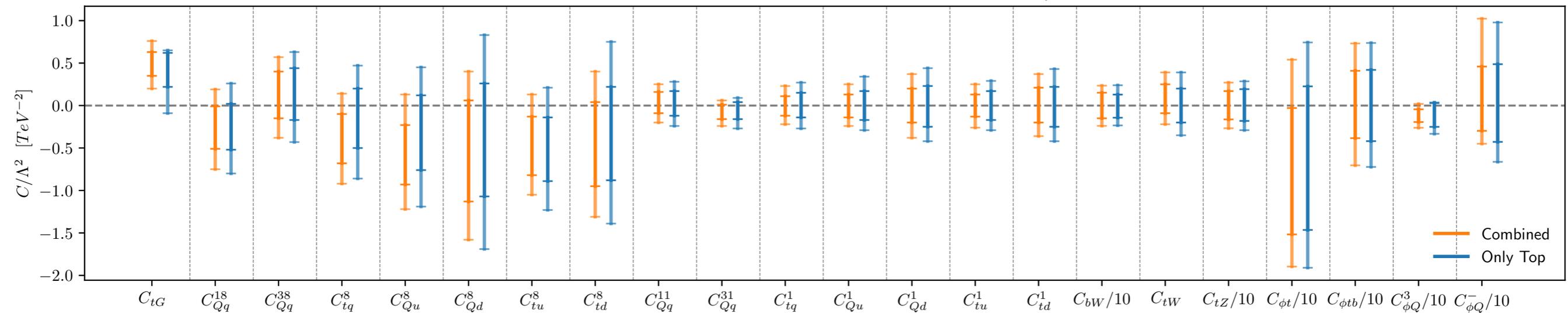
- 311 Higgs datapoints
- 43 Di-Boson datapoints
- 14 EWPOs (excluded for now)
- 4 high kinematic measurements (VH/ZH/WW resonance searches, Higgs  $p_T$  analysis)

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

# Combining Higgs and Top (Top sector)



68% and 95% Confidence Intervals from combined and Top fit

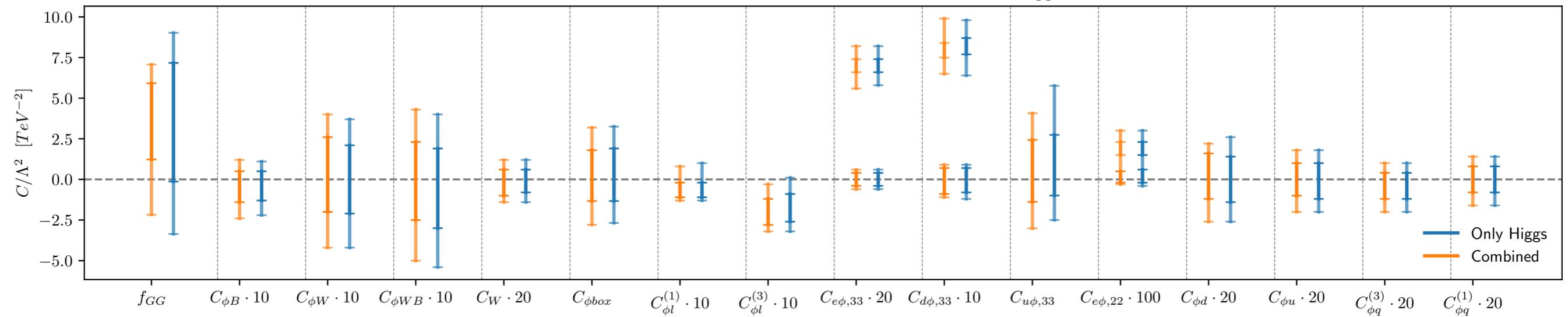


- Only **minor differences** in constraining power for most WCs
- **Slight shift** in the peak of  $C_{tG}$



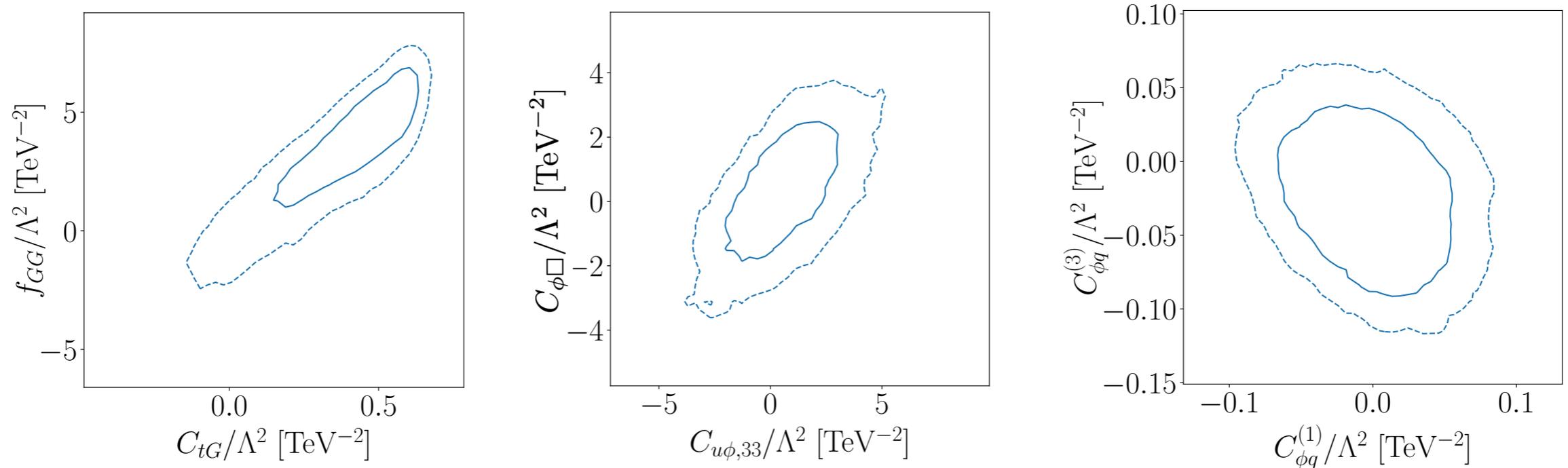
# Combining Higgs and Top (Higgs sector)

68% and 95% Confidence Intervals from Combined and Higgs fit



- Only **minor differences** in constraining power for most WCs
- **Slight shift** in the peak of  $f_{GG}$

# 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

---



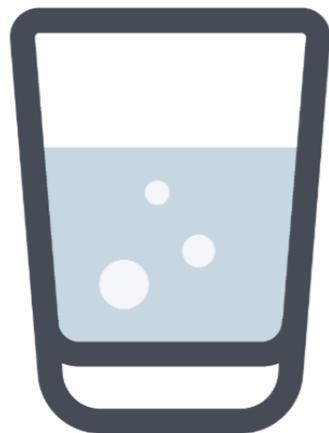
- Choose between profiling and marginalization
  - They are not the same, but you **might not see it at a first look**
  - Results might look similar for highly-Gaussian data sets
  - Results can look completely different for other data sets
- First results for combined Top and Higgs + Di-Boson fit
  - proper **implementation of EWPOs** in the works

# Backup slides



# Profiling vs. marginalization

Where is the water molecule most likely located?



Higher profiled likelihood:

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

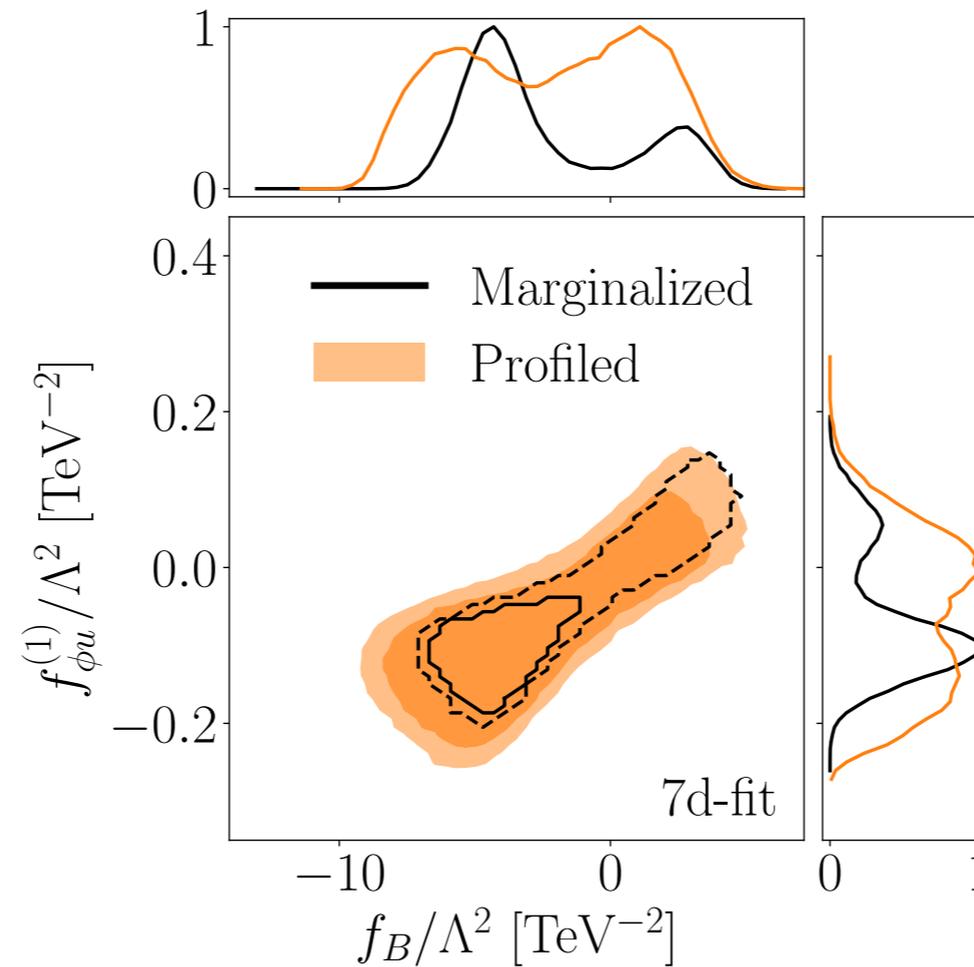
Which object is most likely to contain a water molecule?



Higher marginal probability:

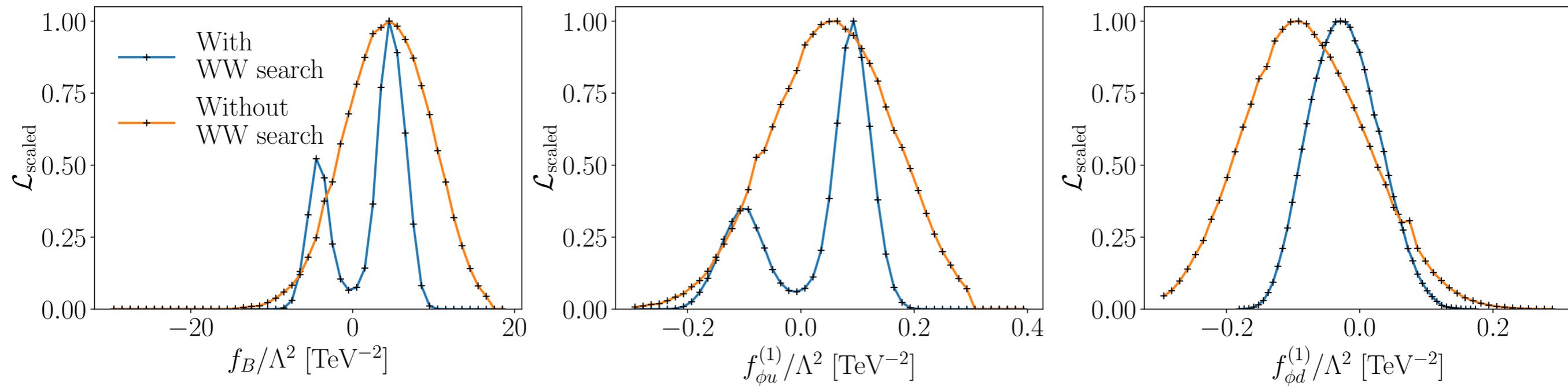
$$\int_T P(T | M) = \int_T \frac{L(M | T)P(T)}{P(M)}$$

# Problem with the two modes



- Clear difference between both methods
- Because of the **two mode structure**
- Likelihood peaks are not on same level

# Influence of WW measurement on two mode structure



# Interplay of $f_{GG}$ and $f_{tG}$

