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

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

- 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:
  $\max_T \mathscr{L}(M|T)$

Marginalization

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

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)**

Part 1

Applying profiling and marginalization to the old data set

Observables included in the old data set

Low kinematics constrain non-kinematically enhanced operators

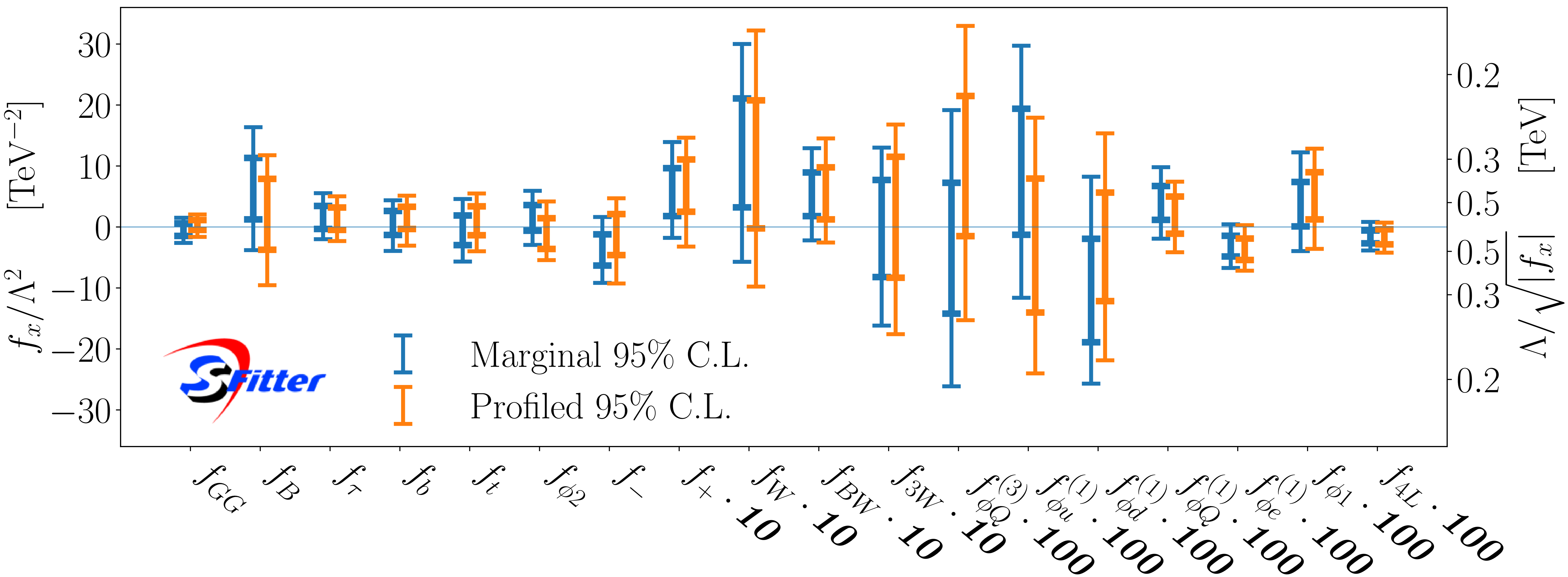
[Butter et al.: 1604.03105; Biekötter, Corbett, Plehn: 1812.07587]

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

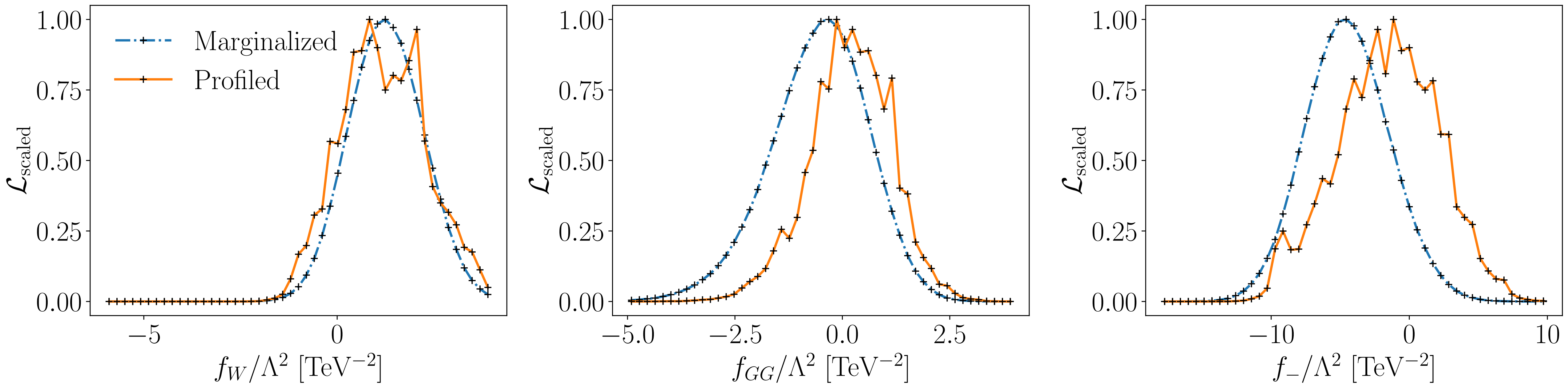
High kinematics constrain kinematically enhanced operators

- VH resonance search by ATLAS [1712.06518]

No big difference for the old data set

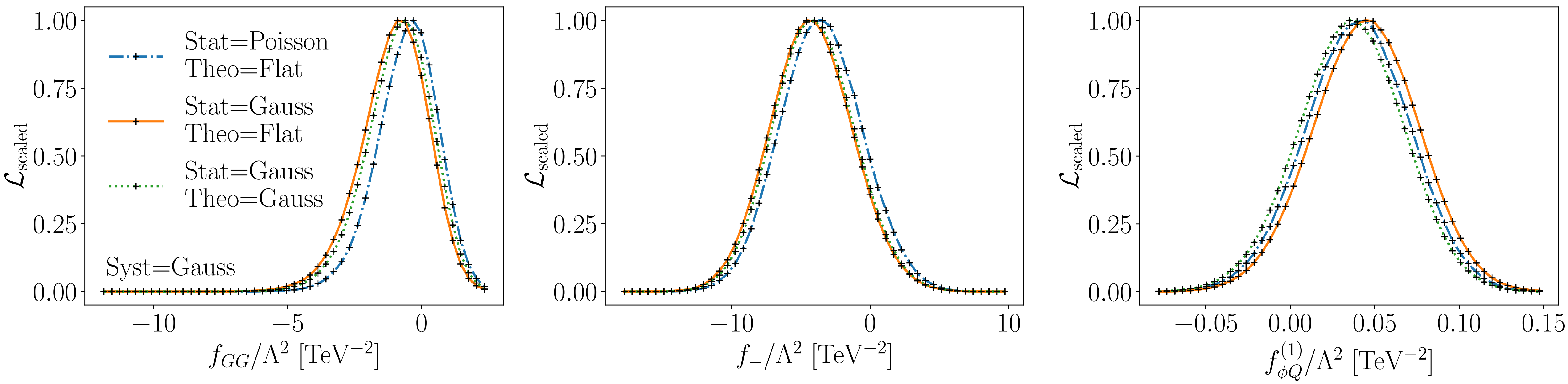


They are the same - aren't they?



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

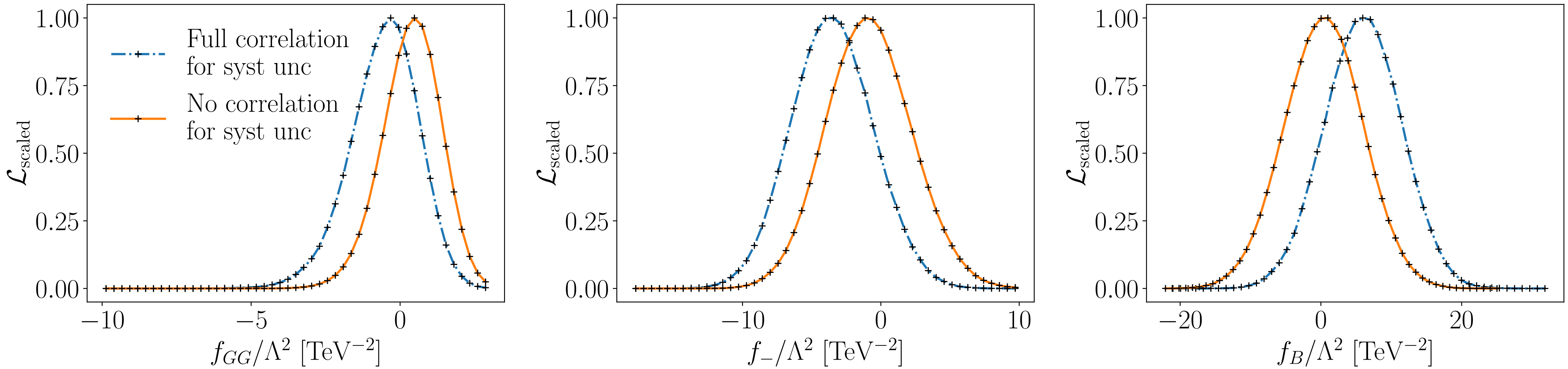
The impact of theory uncertainties



- 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

Part 2

Applying profiling and marginalization to the new data set

Observables included in the new data set

Low kinematics constrain non-kinematically enhanced operators

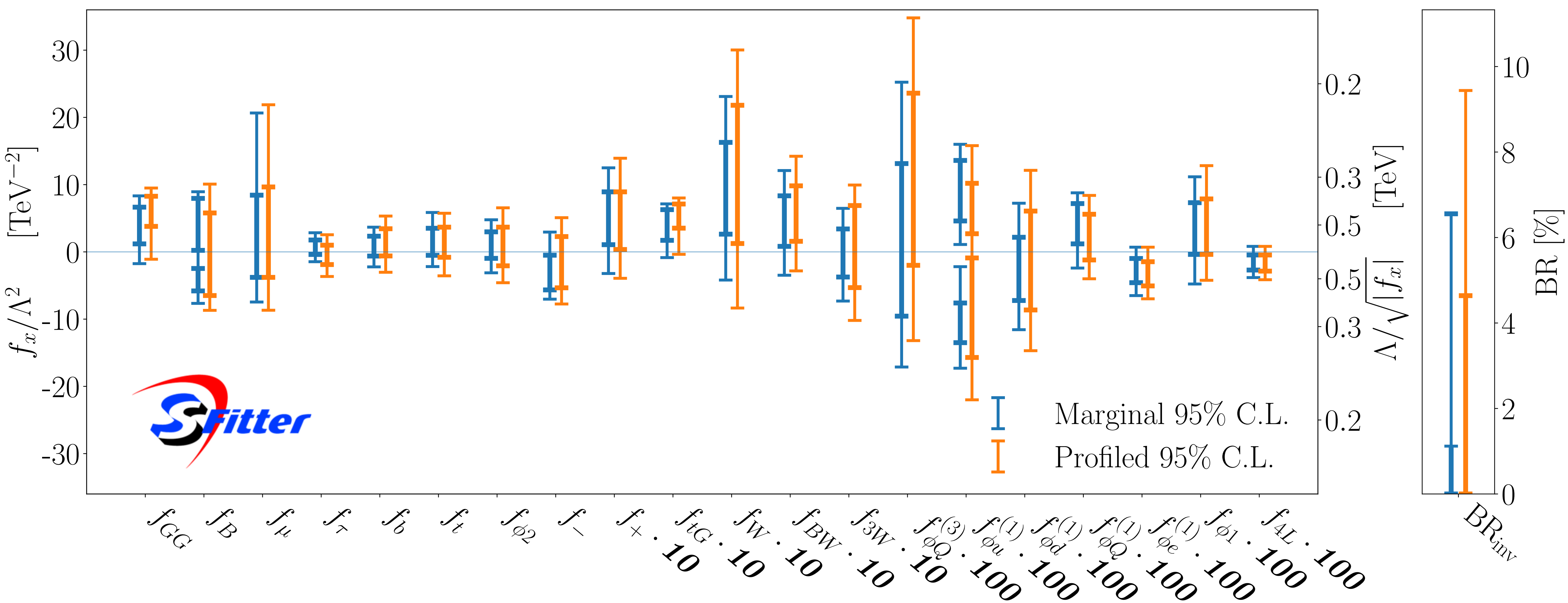
[Butter et al.: 1604.03105; Biekötter, Corbett, Plehn: 1812.07587]

- 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

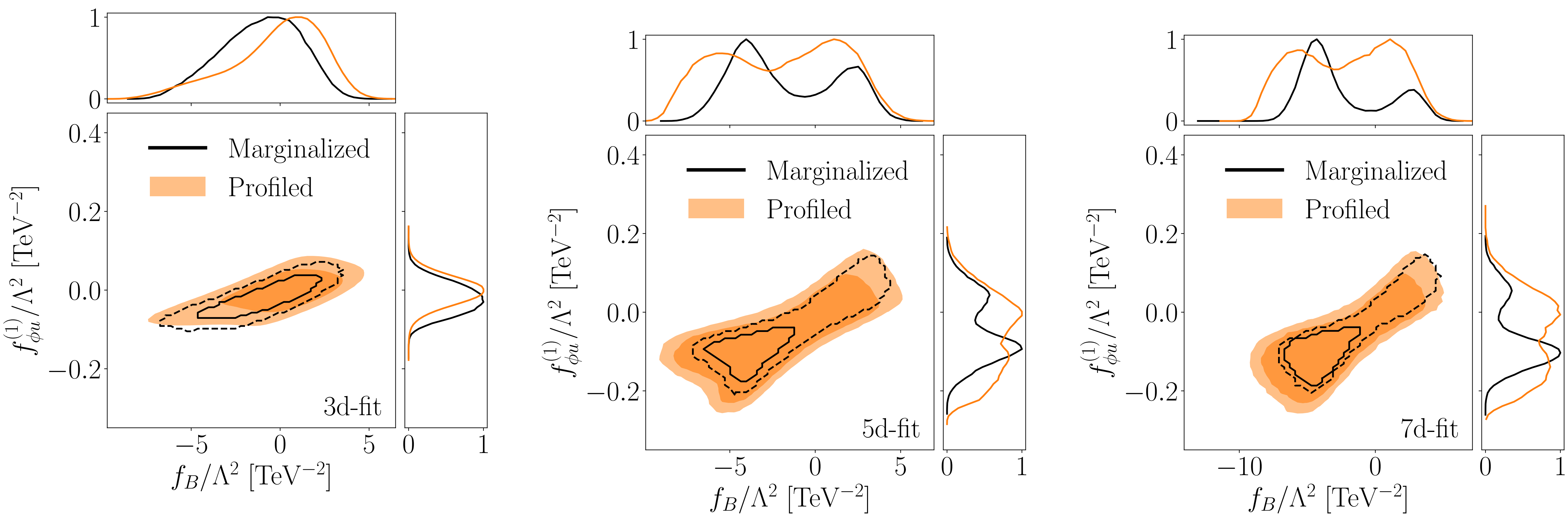
- VH resonance search by ATLAS: ATLAS-CONF-2021-026 and 2007.05293
- VV resonance search by ATLAS: 2004.14636
- ZH resonance search by CMS: 2102.08198
- Higgs p_T analysis by ATLAS: ATLAS-CONF-2019-029

Differences for the new data set



Unexpected volume effect

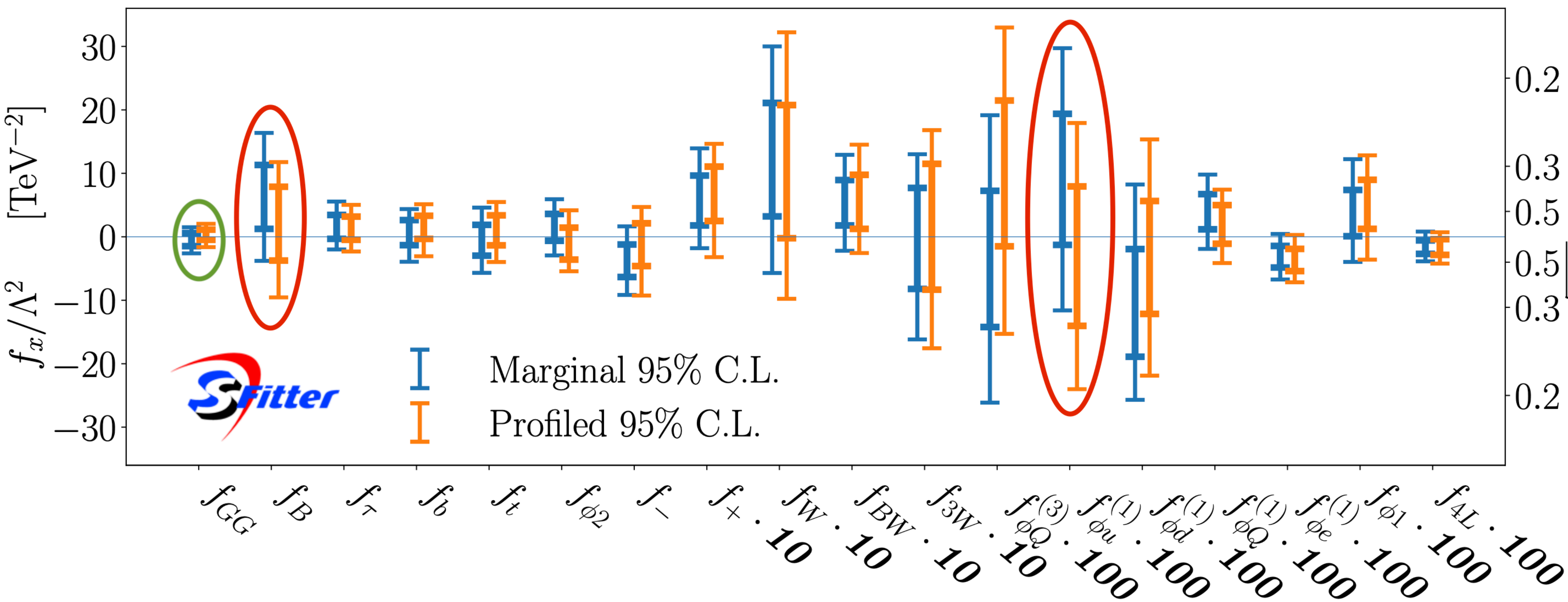
- Peak structure appears with higher dimensional fits
- Need enough dimensions to accommodate underfluctuations
- More coefficients ⇒ larger volume effect
  Strengthen limits on coefficients (marginal case only)

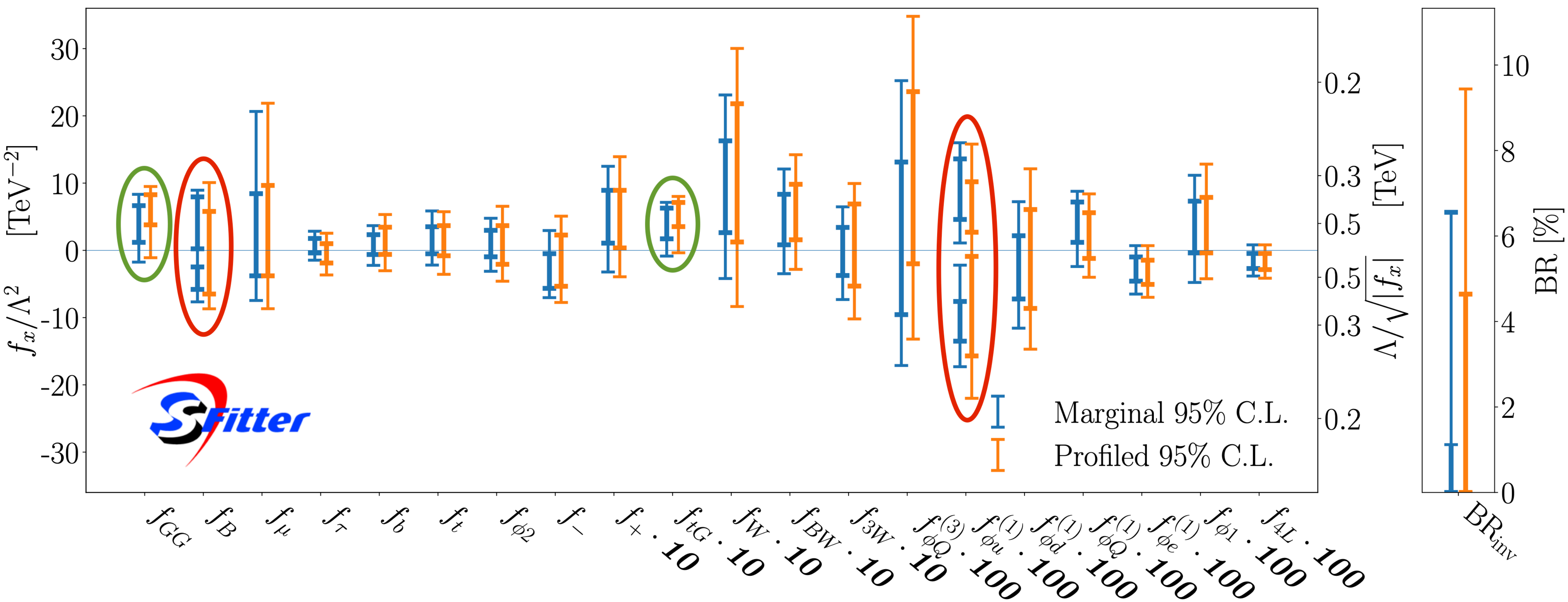


Part 3

Comparison of both data sets

Comparing both data sets





Part 4

Combining the Higgs and Top sector

(Preliminary, work done by Nikita Schmal)

Combining Higgs and Top

The Top dataset

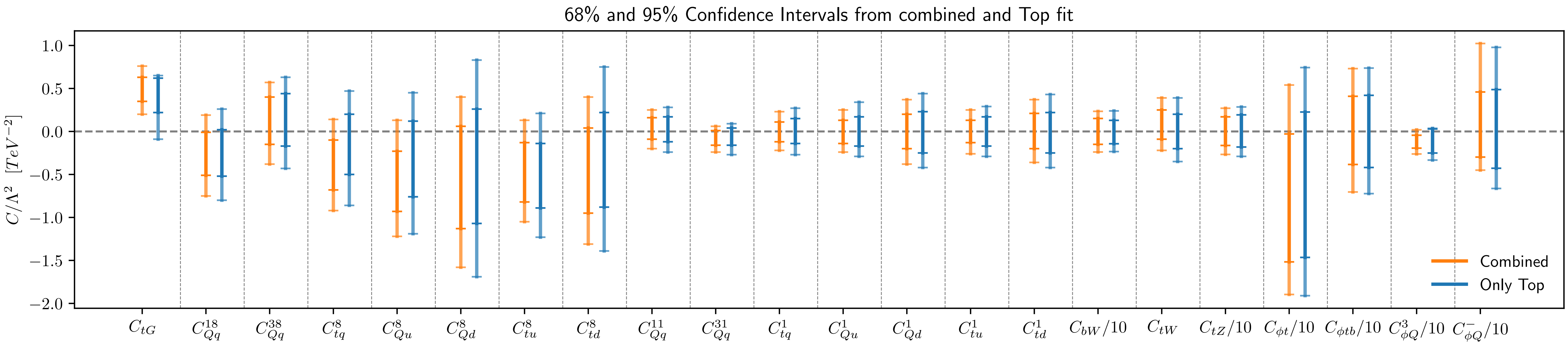
- 92 $t\bar{t}$ datapoints
- 2 $t\bar{t}Z$ datapoints
- 2 $t\bar{t}W$ datapoints
- 20 SingleTop datapoints

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)

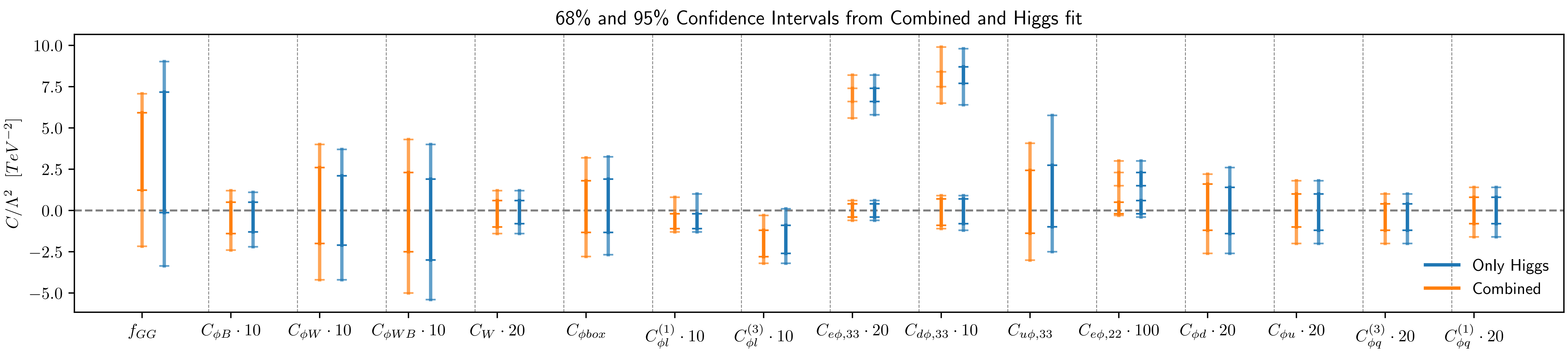
➡ **Omit 3 Wilson coefficients from the fit: $C_{\phi D}$, C_{ll} and $C_{\phi e}$**

Combining Higgs and Top (Top sector)



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

Combining Higgs and Top (Higgs sector)



- Only minor differences in constraining power for most WCs
- Slight shift in the peak of C_{GG}
- Using a profiled fit

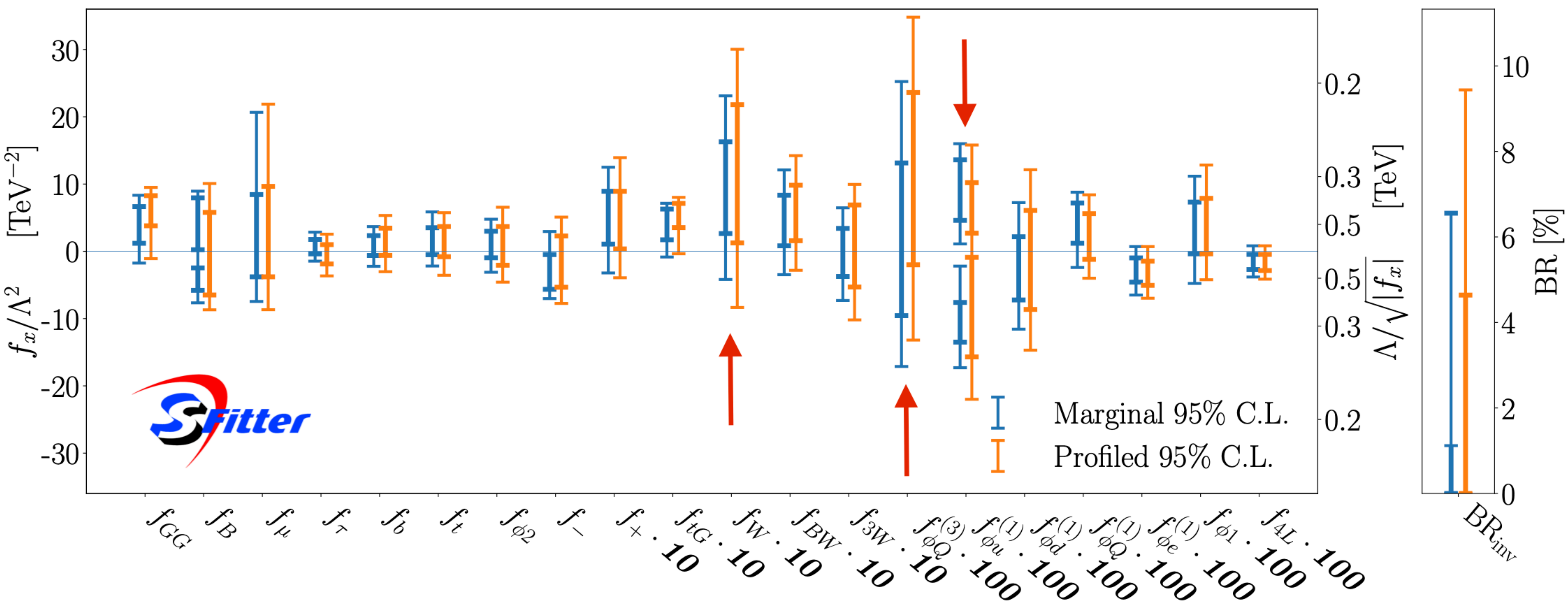
Conclusion and Outlook

- 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 work

Thanks for listening :)

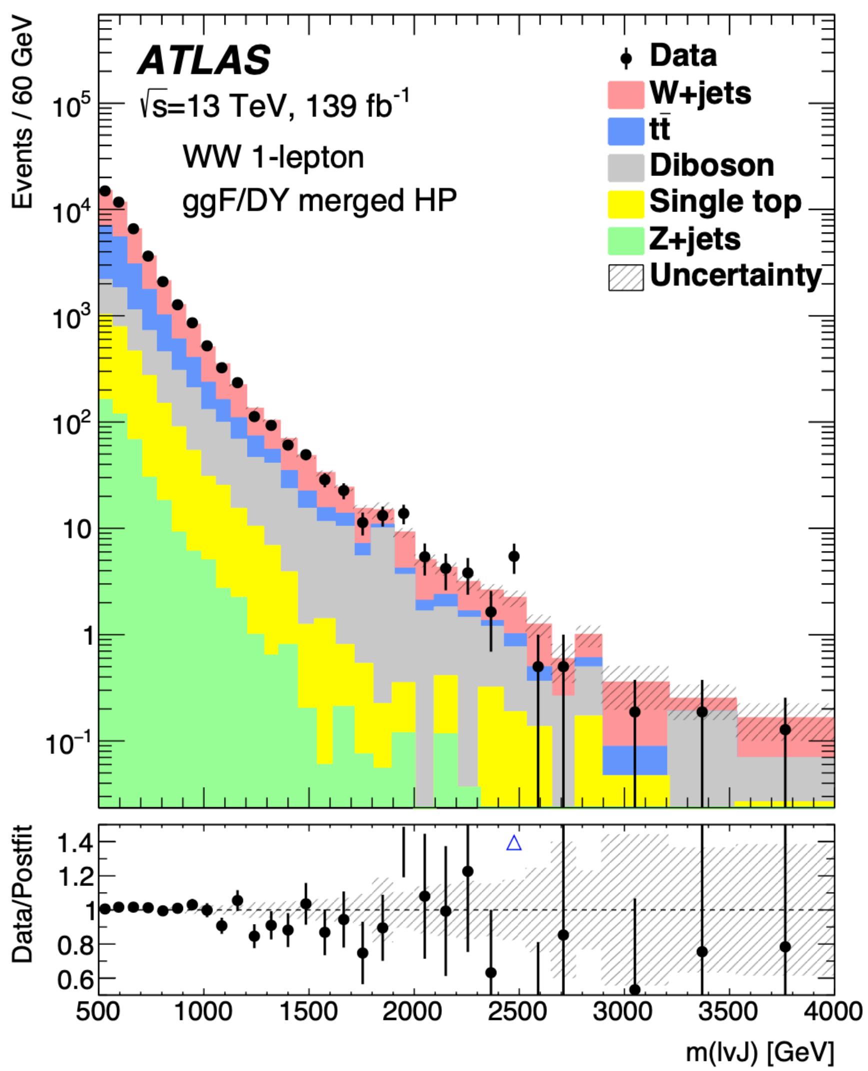
Backup slides

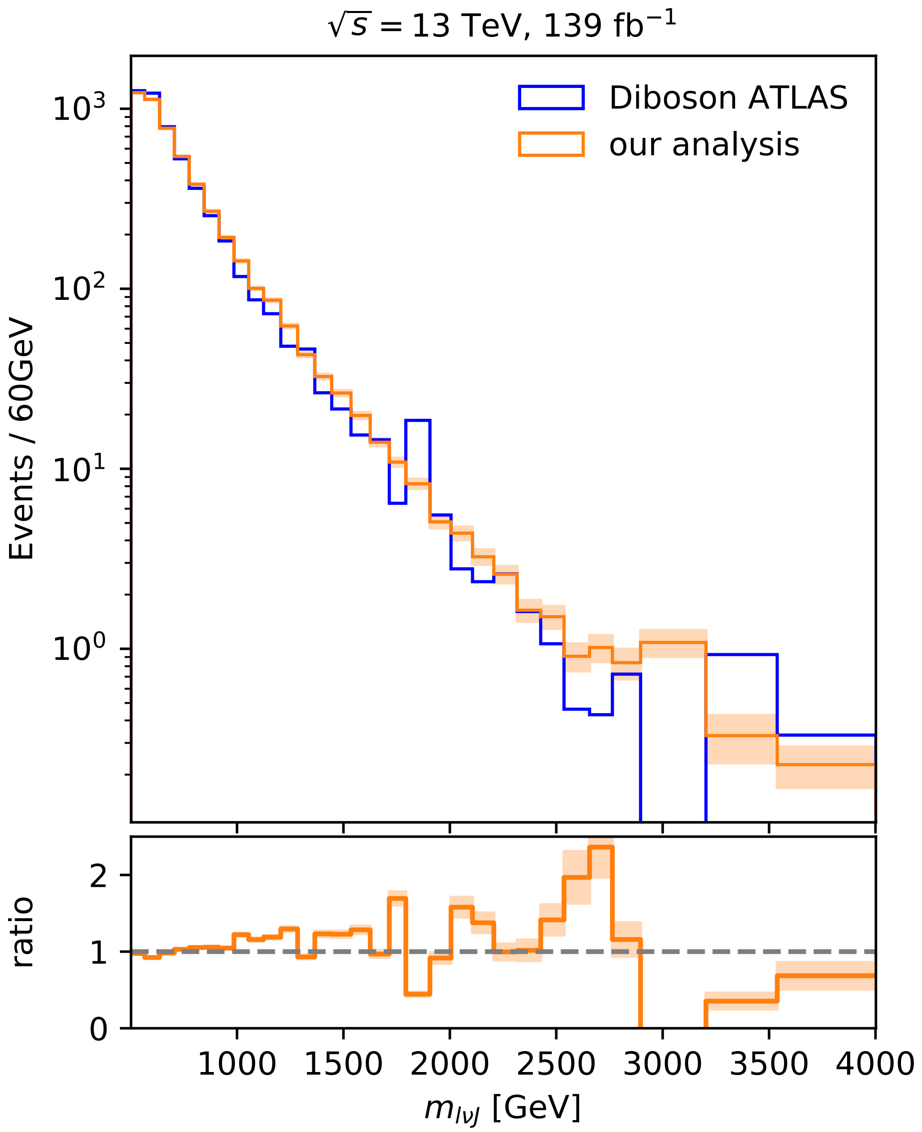
Differences in the new data set



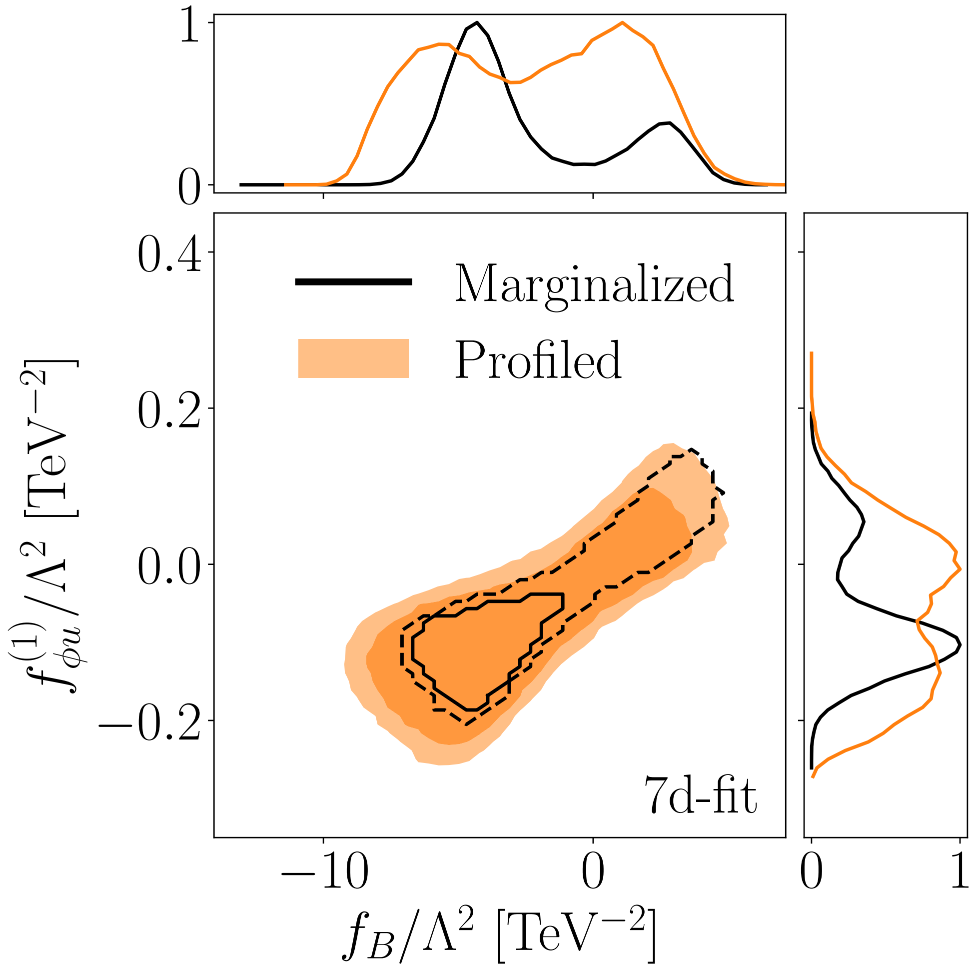
WW as one of a driving measurements

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



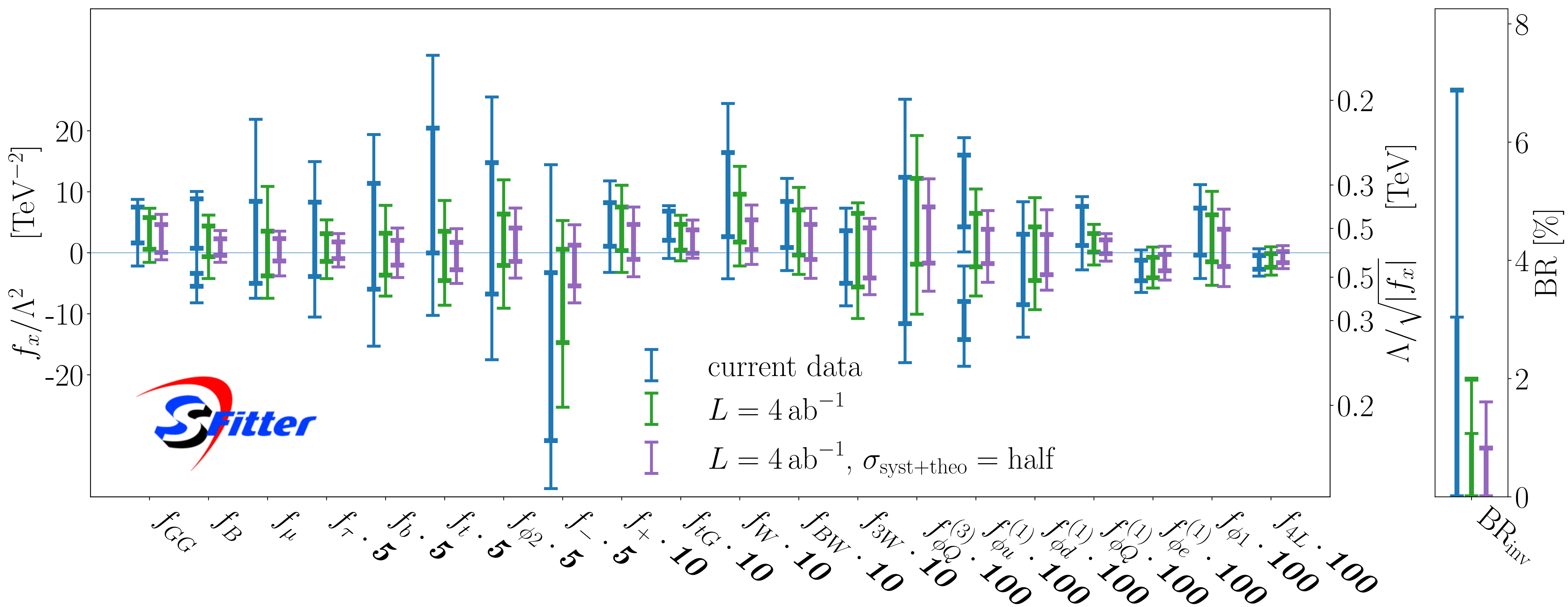


Problem with the two modes



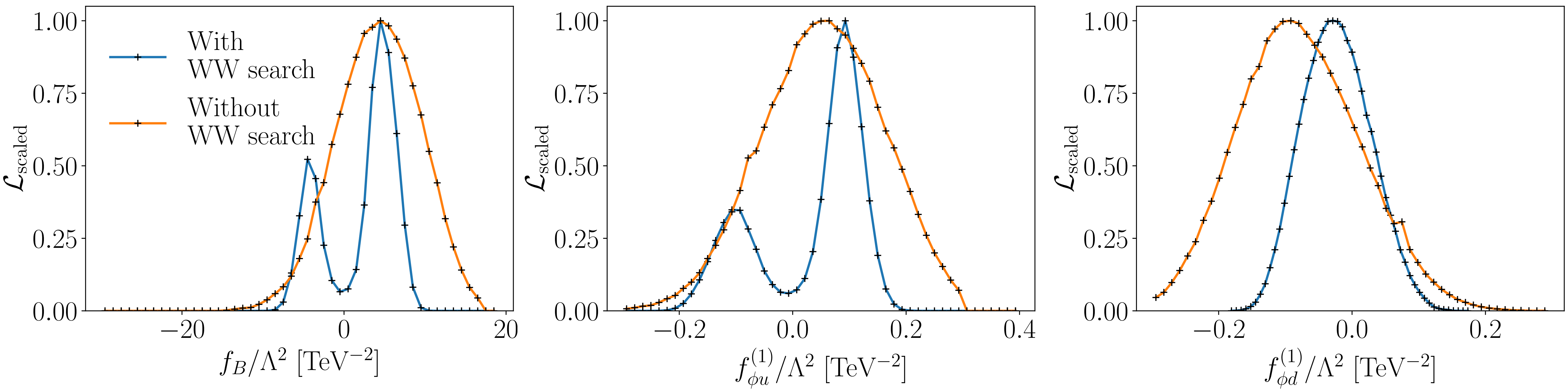
- Clear difference between both methods
- Because of the two mode structure
- Likelihood peaks are not on same level

High luminosity scaled LHC measurements

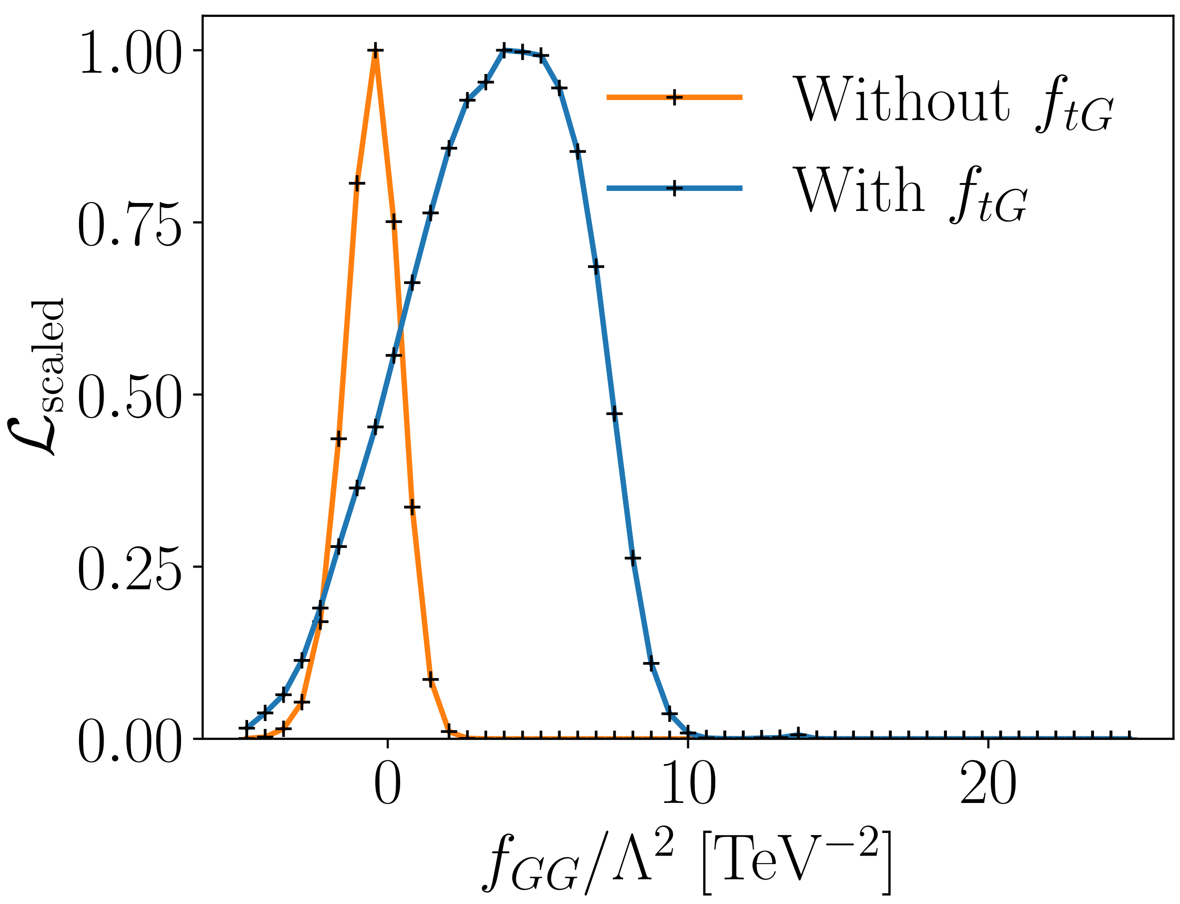


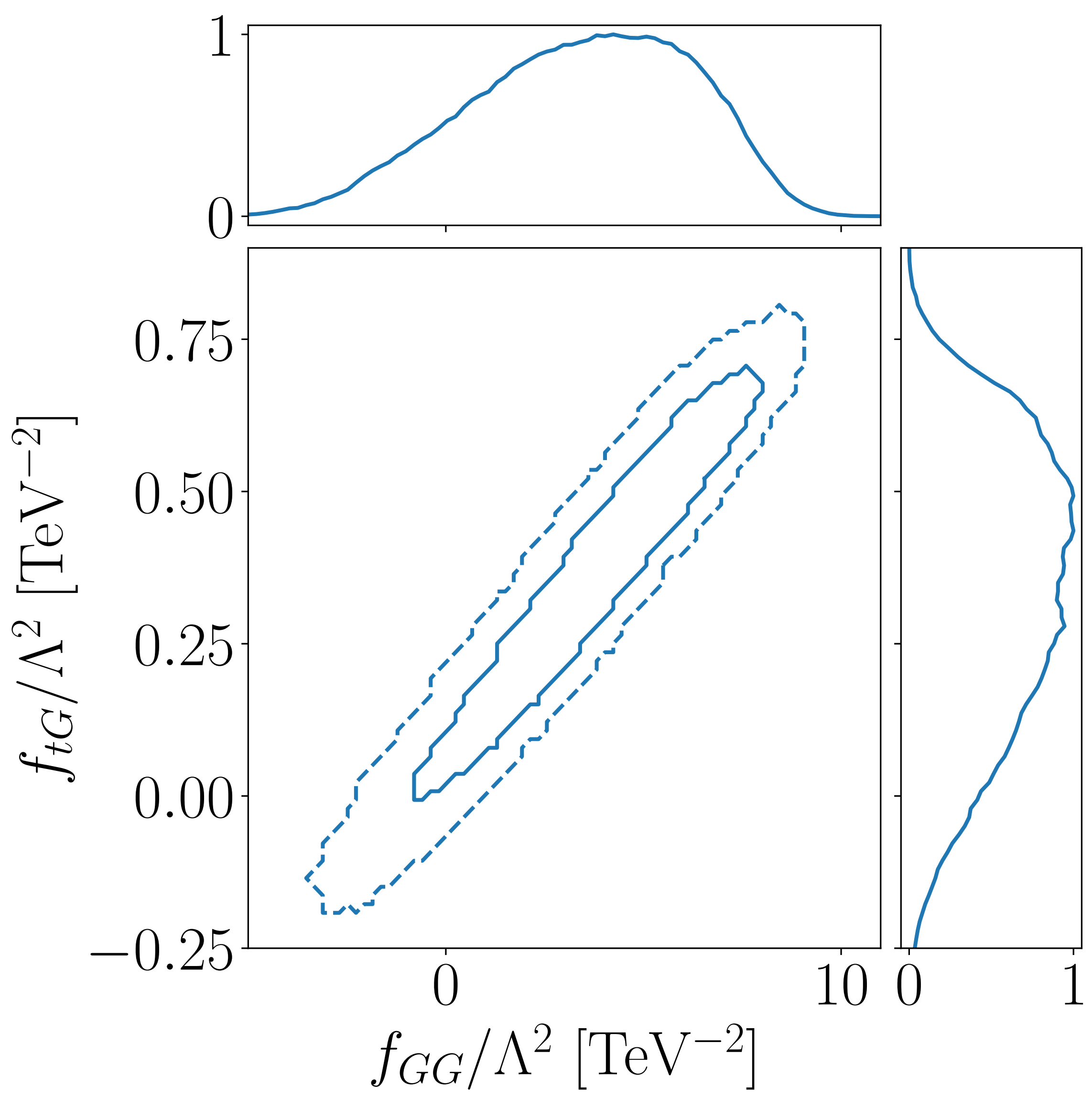
- using updated data set
- measurements set to background values (SM hypothesis)
- luminosity scaled to $4\,ab^{-1}$

Influence of WW measurement on two mode structure



Interplay of f_{GG} and f_{tG}





Combining Higgs and Top

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}	$i g_s (\bar{Q}_3 \sigma^{\mu\nu} T^A uR, 3)\tilde{\phi} G^A_{\mu\nu}$		

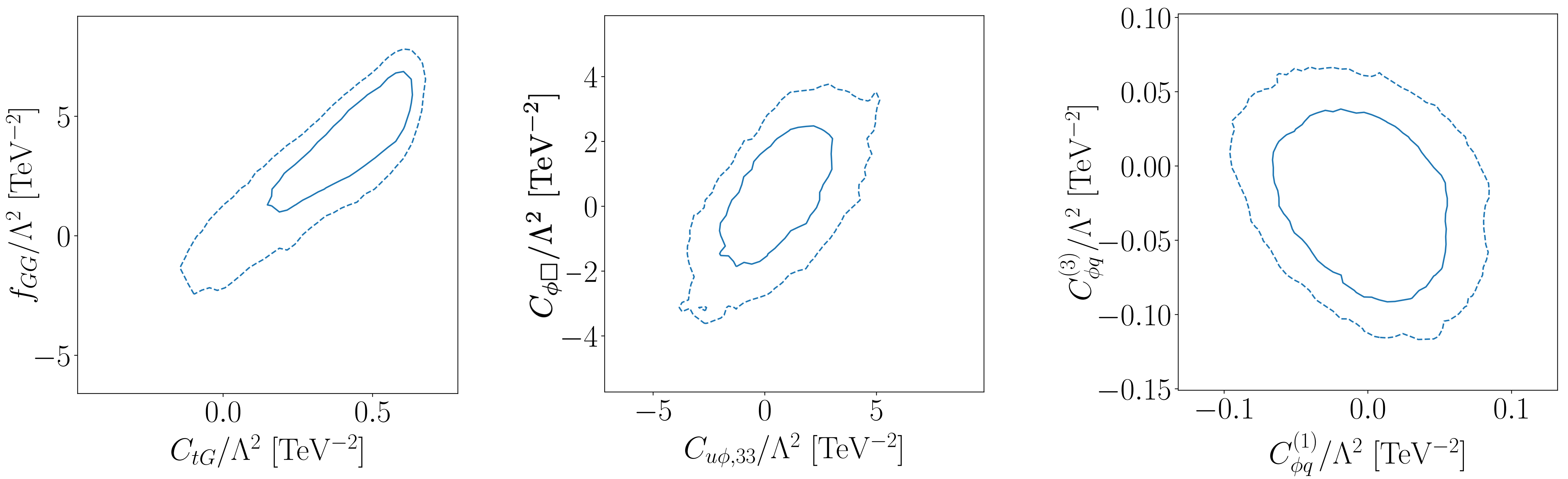
Higgs:

- $U(3)^5$ 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

Interplay of Higgs and Top



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