Task
Degeneracies
Scanning
Simulation
Measurements
Matching

Towards New SFitter Analyses

Tilman Plehn for Heidelberg

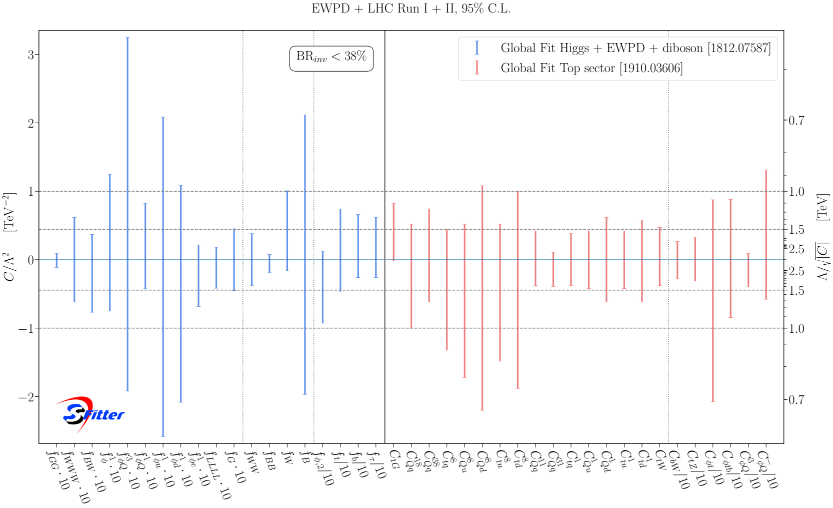
Transregio, Siegen, October 2020

Going more global

Why no combined Run II analysis? [A2a+B2b]

- including Higgs–gauge sector and top sector
- 1+18+22 operators closing in on D6@LHC

⇒ Technically not feasible



Allowed parameter space

D6 Lagrangian [SMEFT; review Brivio & Trott]

– set of Higgs operators [renormalizable]

$$\mathcal{O}_{GG} = \phi^\dagger \phi G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \cdots$$

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– actual basis after equation of motion, field re-definition, integration by parts

$$\mathcal{L}_{\text{D6}} = - \frac{\alpha_s v}{8\pi} \frac{f_g}{\Lambda^2} \mathcal{O}_{GG} + \frac{f_{BB}}{\Lambda^2} \mathcal{O}_{BB} + \frac{f_{WW}}{\Lambda^2} \mathcal{O}_{WW} + \frac{f_B}{\Lambda^2} \mathcal{O}_{B} + \frac{f_W}{\Lambda^2} \mathcal{O}_{W} + \frac{f_{\phi,2}}{\Lambda^2} \mathcal{O}_{\phi,2}$$

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– Higgs couplings to SM particles [derivatives = kinematics]

$$\begin{aligned} \mathcal{L}_{\text{D6}} = \; & g_g \; H G^a_{\mu\nu} G^{a\mu\nu} + g_\gamma \; H A_{\mu\nu} A^{\mu\nu} \\ & + g_Z^{(1)} \; Z_{\mu\nu} Z^\mu \partial^\nu H + g_Z^{(2)} \; H Z_{\mu\nu} Z^{\mu\nu} + g_Z^{(3)} \; H Z_\mu Z^\mu \\ & + g_W^{(1)} \; \left(W^+_{\mu\nu} W^{-\,\mu} \partial^\nu H + \text{h.c.} \right) + g_W^{(2)} \; H W^+_{\mu\nu} W^{-\,\mu\nu} + g_W^{(3)} \; H W^+_\mu W^{-\,\mu} + \cdots \end{aligned}$$

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– plus Yukawa structure $f_{\tau,b,t}$

– 7 Δ-like coupling modifications plus 4 new Lorentz structures

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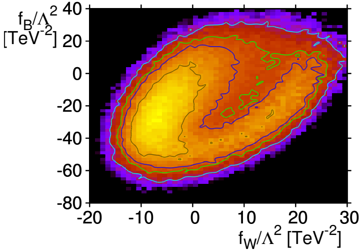
Parameter space challenges [Butter, Eboli, Gonzalez-Fraile, Gonzales-Garcia, TP, Rauch (2016)]

– rates



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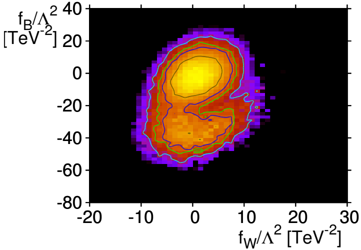

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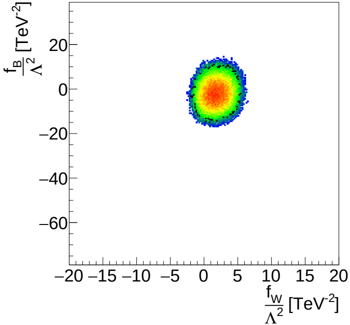
+ kinematics: $p_{T,V}$

+ TGV

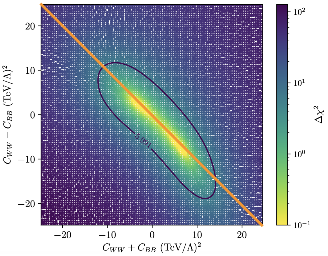
$\Rightarrow$ Plenty of measurements, few structures



Remaining degeneracies

Correlation of f_{BB} vs f_{WW} from $BW \to \gamma Z$ [Brivio, Geoffray]

– Run 2 without $H \to \gamma\gamma, \gamma Z$
orange: flat direction WBF, ZH, $H \to ZZ$...
all fine



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- add $H \to \gamma Z$
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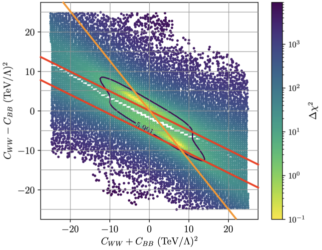
  slightly anomalous



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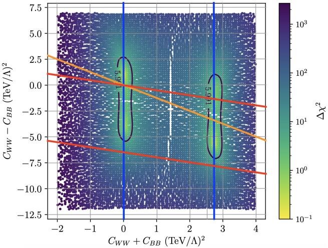
– add $H \to \gamma\gamma$
  blue: flat direction $H \to \gamma\gamma$
  on SM, but secondary minimum



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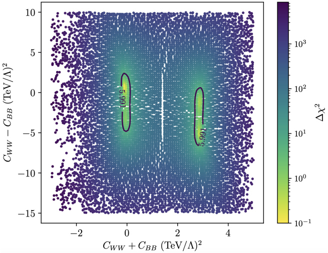
  on SM, but secondary minimum
- add electroweak precision
  well-separated secondary minimum



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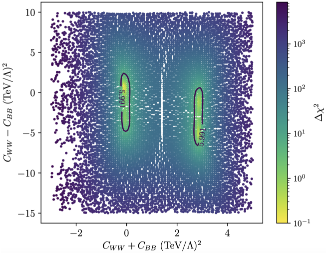
– cancellation within loop
  perfectly degenerate [remember CKM fits?]
  problem with EFT interpretation?

$\Rightarrow$ Clean description needed...



Scanning parameters

Some background [Bruggisser, Butter, Luchmann]

– probability (Bayesian) vs likelihood (frequentist)

$$P(A|B) := \frac{P(A \cap B)}{P(B)} \qquad \Rightarrow \qquad P(T|M) = P(M|T)\,\frac{P(T)}{P(M)}$$

– probability $P(T|M)$ the goal, likelihood $P(M|T)$ over M available
$P(T)$ unknown prior, $P(M)$ normalization factor

– shape of likelihoods
Poisson (tails), Gaussian (rates), centrally flat (theory)

– reducing parameter dimensions
probability: integrating over ‘nuisance parameter’
likelihood: projecting onto remaining axis, ‘profiling’
equivalent only for two Gaussians

– advantages
probability: prejudice well-defined, statistical interpretation clear
likelihood: assumptions minimal, frequentist post-processing

– Bayesian hopes
prior to describe SM+limits approach
central limit theorem to guess shapes

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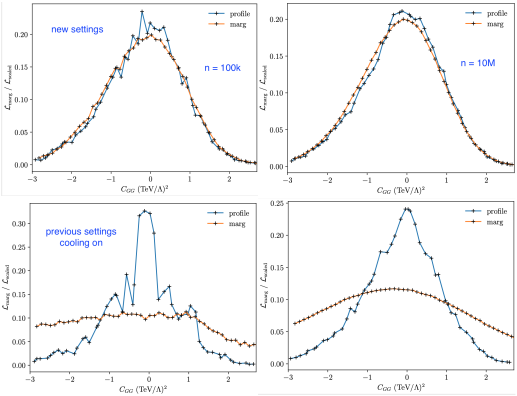
Likelihood scan around SM

– localized MC proposal
no MC cooling
optimized proposal width

$$\sigma^2_{\text{prop}} = \frac{2.38^2}{d}\,\sigma^2_{\text{target}}$$

$\Rightarrow$ Saving CPU time...



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Bayesian optimization

– for instance Dortmund: all Gaussian with correlations

– Poisson+flat: when does central limit theorem hit?

– magic inverse adding still working?

– scaling more like Vegas?

...

Madgraph simulations

Simulation improvements [Brivio]

– straightforward: full SMEFT simulation [SFitter-Higgs]
fit f_i-dependence per observable
numerical impact from large f_i

– limitations: NLO predictions [SFitter-top]
numerics noisy
hard to separate squared and interference

– morphing: combine phase space and parameter space
phase space noise $\rightarrow$ parameter space noise?

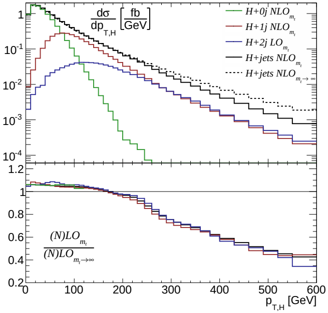
– re-weighting: use SM-like outcome
assume phase space sampling f_i-independent
re-weight phase space points
integrate re-weighted events

$\Rightarrow$ Huge potential gain in CPU time...

New measurements: boosted

SM top loop vs O_{GG} [Brivio, Geoffray]

– $H+j$: $\mathcal{M} \propto m_t^2 \log^2 p_T^2/m_t^2$ [Baur & Glover]
  same for $H+jj$ [Buschmann, Goncalves,...]



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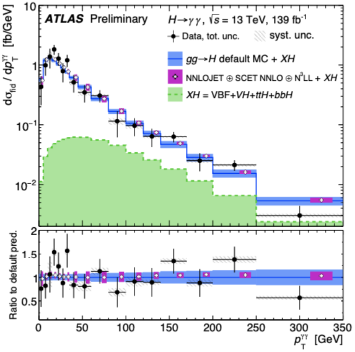
  same for $H + jj$ [Buschmann, Goncalves,...]
– first measurement, to be included
– check how it compares with GF$\otimes$*ttH*

ATLAS CONF Note
ATLAS-CONF-2019-029
15th July 2019

Measurements and interpretations of Higgs-boson fiducial cross sections in the diphoton decay channel using 139 fb^{-1} of pp collision data at $\sqrt{s} = 13$ TeV with the ATLAS detector



New measurements: exotics

More operators [Biekötter, Corbett, TP; also Alves etal]

– gauge-fermion operators [Zhang; Baglio, Dawson, Lewis]

$$\mathcal{O}^{(1)}_{\phi L} = \phi^\dagger \overleftrightarrow{D}_\mu \phi (\bar{L}_i \gamma^\mu L_i) \qquad \mathcal{O}^{(1)}_{\phi e} = \phi^\dagger \overleftrightarrow{D}_\mu \phi (\bar{e}_{R,i} \gamma^\mu e_{R,i}) \qquad \mathcal{O}^{(3)}_{\phi L} = \phi^\dagger \overleftrightarrow{D}^a_\mu \phi (\bar{L}_i \gamma^\mu \sigma_a L_i)$$

$$\mathcal{O}^{(1)}_{\phi Q} = \cdots \qquad \mathcal{O}^{(1)}_{\phi d} = \cdots \qquad \mathcal{O}^{(3)}_{\phi Q} = \cdots$$

$$\mathcal{O}^{(1)}_{\phi ud} = \tilde{\phi}^\dagger \overleftrightarrow{D}_\mu \phi (\bar{u}_{R,i} \gamma^\mu d_{R,i}) \qquad \mathcal{O}^{(1)}_{\phi u} = \cdots \qquad \mathcal{O}_{LLLL} = (\bar{L}_1 \gamma_\mu L_2)\,(\bar{L}_2 \gamma^\mu L_1)$$

– after equations of motions, etc

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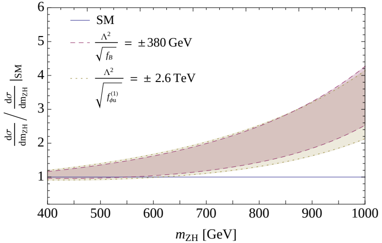
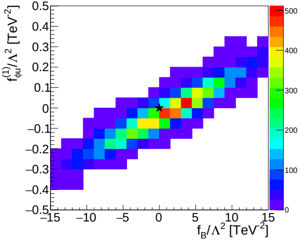
LHC kinematics

– m_{VH} di-fat-jet to 5 TeV





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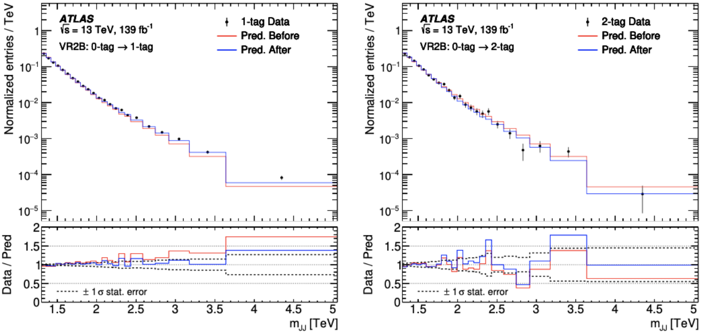

Matching explicit models

Motivation

- SMEFT at LHC poorly defined
- representing classes of models instead
- early 1-loop analysis: 1510.03443 [Brehmer, Freitas, Lopez-Val, TP]
- recently: 2007.01296 [Dawson, Homiller, Lane]

Aachen approach

- Use functional techniques to derive **U**niversal **O**ne-Loop **E**ffective **A**ction
  [Henning, Lu, Murayama, '15] [Drozd, Ellis, Quevillon, You, '16] [Ellis, Quevillon, You, Zhang '17] [Summ, Voigt '18] [Krämer, Summ, Voigt '19]
- Matching reduces to algebraic manipulations
- $\mathcal{L}_\text{EFT}$ is generated from $\mathcal{L}_\text{UV}$
- Matches all 1PI correlation functions
- $\mathcal{L}_\text{EFT}$ contains redundant operators

Matching explicit models

Tool development

- Can be used to integrate out heavy fields from any renormalizable, Lorentz invariant QFT containing vector fields, scalar fields and spin-$1/2$ fermions
- $\mathcal{L}_{\text{EFT}}$ is truncated at mass dimension six
- Implemented into **To**ol **f**or **U**niversal Matching at **One**-**Loop** (`TofuOnLoop`)
- Supplementary code `routeToWarsaw` translates redundant dimension six operators into the Warsaw basis
- Application to vector triplet model

No conclusions yet