

Effective Higgs Physics at the LHC

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Universität Heidelberg

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Theory in data-driven era

Same old theory motivation

- dark matter still not understood [WIMP still best choice]
- hierarchy problem (probably) a problem
- but: **data in driving seat** [remember 750]

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Theory tool box

- **Lagrangian language** obvious after Higgs discovery
- 1 full new physics model [built to solve problems, extrapolating to high scales, think SUSY]
- 2 simplified models [Feynman diagrams for experimental features, theoretically poor at best]
- 3 effective Lagrangians [symmetries and particles fixed, non-renormalizable operators, SMEFT]

⇒ matter of experimental needs, convenience and taste

	effective Lagrangian	simplified models	full models
agnostic	(×)		
data-driven		(×)	(×)
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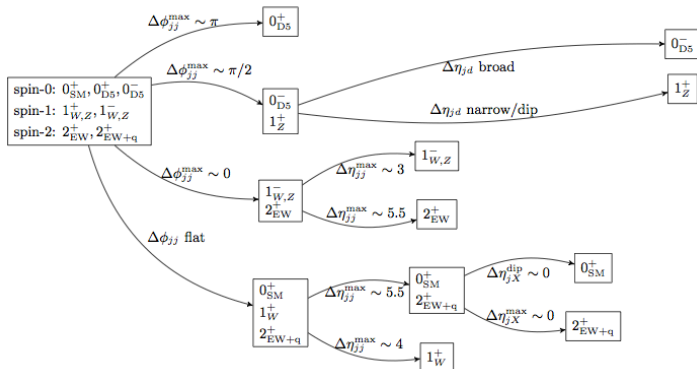
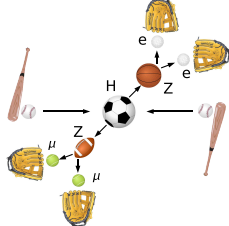
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Higgs questions

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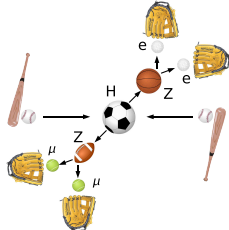
- psychologically: looked for Higgs, so found a Higgs
- CP-even spin-0 scalar expected, which operators?
spin-1 vector unlikely
spin-2 graviton unexpected
- **ask LHCb** [Cabibbo–Maksymowicz–Dell'Aquila–Nelson angles, not part of talk]



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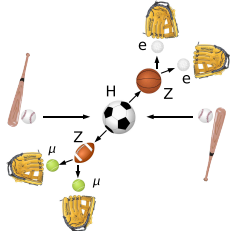
2. What is the Lagrangian? [SMEFT: Trott et al]

- naive-but-useful: set of 'couplings' given Lagrangian
- bottom-up: effective theory [simplified models?]
- top-down: modified Higgs sectors

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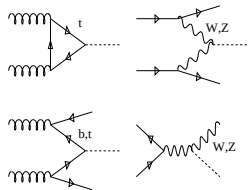
3. What does all this tell us? [not part of this talk]

- strongly interacting models?
- weakly interacting extensions?
- TeV-scale physics, hierarchy problem, vacuum stability, Higgs inflation, etc

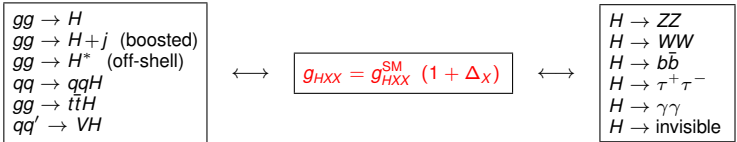
Couplings

Standard Model operators [historic slide]

- assume: narrow CP-even scalar
- Standard Model operators
- **couplings proportional to masses?**
- fundamental physics in terms of Lagrangian



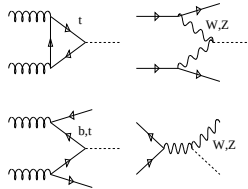
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$$+ \Delta_g F_G \frac{H}{v} G_{\mu\nu} G^{\mu\nu} + \Delta_\gamma F_A \frac{H}{v} A_{\mu\nu} A^{\mu\nu} + \text{invisible} + \text{unobservable}$$



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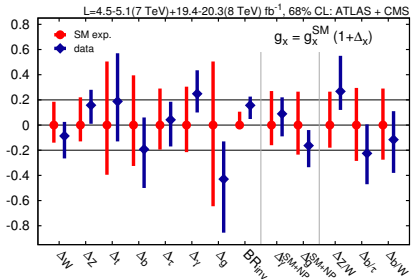
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Great Run I results, but issues... [Corbett, Eboli, Goncalves, Gonzalez-Fraile, TP, Rauch]

- 1 electroweak renormalizability broken
- 2 total rates only
- 3 hard to relate to gauge, flavor sectors



D6 Higgs operators

D6 Lagrangian at face value [HISZ, polish, Trott etal, Goncales-Garcia etal]

– set of Higgs operators [renormalizable, #1 solved]

$$\mathcal{O}_{GG} = \phi^\dagger \phi G_{\mu\nu}^a G^{a\mu\nu} \quad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \quad \mathcal{O}_{BB} = \dots$$

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- actual basis after equation of motion, etc

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

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- plus Yukawa structure $f_{\tau,b,t}$
- 7 Δ -like coupling modifications

4 new Lorentz structures

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- linking couplings and operators

$$\begin{aligned}
 g_g &= \frac{f_{GG} v}{\Lambda^2} \equiv -\frac{\alpha_s}{8\pi} \frac{f_g v}{\Lambda^2} & g_\gamma &= -\frac{g^2 v s_w^2}{2\Lambda^2} \frac{f_{BB} + f_{WW}}{2} \\
 g_Z^{(1)} &= \frac{g^2 v}{2\Lambda^2} \frac{c_w^2 f_W + s_w^2 f_B}{2c_w^2} & g_W^{(1)} &= \frac{g^2 v}{2\Lambda^2} \frac{f_W}{2} \\
 g_Z^{(2)} &= -\frac{g^2 v}{2\Lambda^2} \frac{s_w^4 f_{BB} + c_w^4 f_{WW}}{2c_w^2} & g_W^{(2)} &= -\frac{g^2 v}{2\Lambda^2} f_{WW} \\
 g_Z^{(3)} &= \frac{g^2 v}{4c_w^2} \left(1 - \frac{v^2}{2\Lambda^2} f_{\phi,2} \right) & g_W^{(3)} &= \frac{g^2 v}{4} \left(1 - \frac{v^2}{2\Lambda^2} f_{\phi,2} \right) \\
 g_f &= -\frac{m_f}{v} \left(1 - \frac{v^2}{2\Lambda^2} f_{\phi,2} \right) + \frac{v^2}{\sqrt{2}\Lambda^2} f_f
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D6 Higgs operators

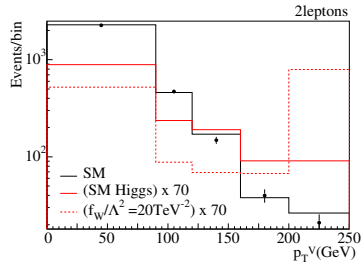
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Run 1 legacy

– kinematics: $p_{T,V}, \Delta\phi_{jj}$ [#2 solved]



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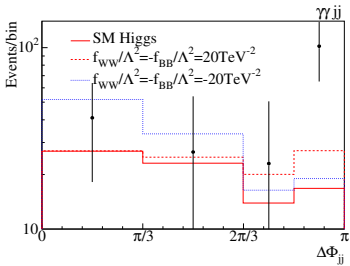
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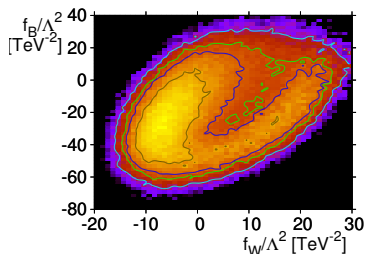
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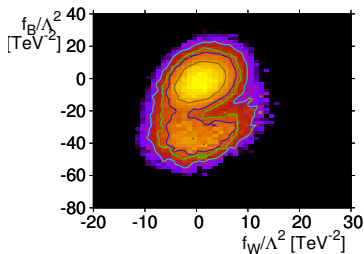
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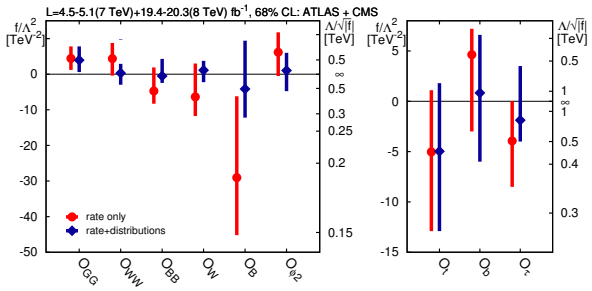
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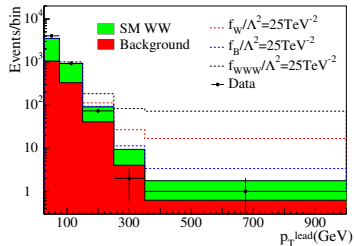
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- one more Higgs-gauge operator [#3 solved]

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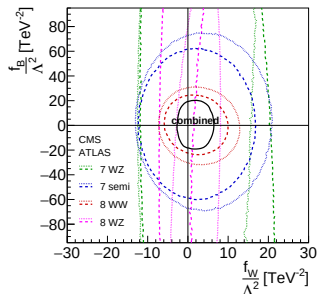
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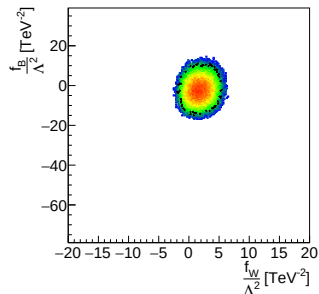
D6 Higgs-gauge operators

Triple gauge couplings

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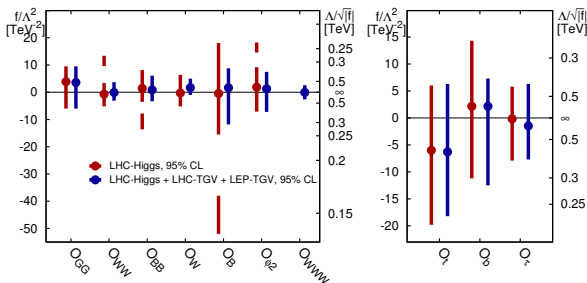
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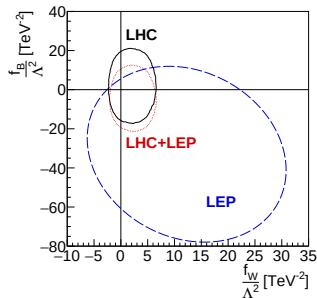
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LHC vs LEP

- triple gauge vertices g_1, κ, λ vs operators
- LEP limits from precision
LHC limits from energy
- semileptonic analyses missing for 8 TeV

⇒ LHC beating LEP, but what does it mean?



Self consistency

Ideal LEP and flavor worlds [ask Michael]

- unique EFT Lagrangian: linear realization matching unbroken phase
- chain of well separated energy scales $E \ll \Lambda_1 \ll \dots \ll \Lambda_N$

⇒ systematic expansion in E/Λ and α [example: ew precision data]

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Rotten LHC world [Brehmer, Freitas, Lopez-Val, TP]

- range of (partonic) energy scales [H +jets production]
- electroweak symmetry breaking at $v \sim E_{\text{LHC}}$
- low precision, reach from energy

$$\left| \frac{\sigma \times \text{BR}}{(\sigma \times \text{BR})_{\text{SM}}} - 1 \right| = \frac{g^2 m_h^2}{\Lambda^2} \approx 10\% \quad \xleftrightarrow{g=1} \quad \Lambda \approx 400 \text{ GeV}$$

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Task for LHC theory

- **develop a working D6 framework**
or find a better approach, test it, include in Monte Carlos...
- keep theorist's self respect
- look beyond

Matching matters

Example: oblique parameters from Higgs portal vs D6 [Freitas, Lopez-Val, TP; Brivio & Trott]

- operators

$$\mathcal{L}_{\text{EFT}} \supset \frac{c_H}{2\Lambda^2} \partial^\mu (\phi^\dagger \phi) \partial_\mu (\phi^\dagger \phi) + \frac{c_T}{2\Lambda^2} (\phi^\dagger \overleftrightarrow{D}^\mu \phi) (\phi^\dagger \overleftrightarrow{D}_\mu \phi) + \frac{igc_W}{2\Lambda^2} (\phi^\dagger \sigma^k \overleftrightarrow{D}^\mu \phi) D^\nu W_{\mu\nu}^k$$

- predictions of Higgs portal model [$m_H \approx 2\lambda_2 v_s^2$, $s_\alpha^2 \approx \lambda_3^2 v^2 / (2\lambda_2 m_H^2)$]

$$S \approx \frac{\lambda_3^2}{24\pi\lambda_2} \frac{v^2}{m_H^2} \log \frac{m_H^2}{m_h^2} \quad T \approx \frac{-3\lambda_3^2 v^2}{32\pi s_W^2 \lambda_2 m_W^2} \left(\frac{m_Z^2}{m_H^2} - \frac{m_W^2}{m_H^2} \right) \log \frac{m_H^2}{m_h^2}$$

- leading log with tree-insertion of loop operators $\mathcal{O}_{T,B,W}$ [$\Lambda^2 = 2\lambda_2 v_s^2$]

$$\frac{c_T}{\Lambda^2} = -\frac{3\alpha_{\text{ew}} s_W^2 \lambda_3^2}{32\pi c_W^2 \lambda_2 \Lambda^2} \log \frac{\Lambda^2}{\mu^2} \quad \frac{c_{B,W}}{\Lambda^2} = \frac{\lambda_3^2}{192\pi^2 \lambda_2 \Lambda^2} \log \frac{\Lambda^2}{\mu^2}$$

- including weak-scale loops including $\mathcal{O}_H$

$$\frac{c_H}{\Lambda^2} = \frac{\lambda_3^2}{2\lambda_2 \Lambda^2}.$$

- **v-improvement**: $\Lambda = m_H$ and full model in terms of c_α [resumming VEV insertions]

$$\frac{c_H}{\Lambda^2} = \frac{2(1 - c_\alpha)}{v^2} \quad \frac{c_T}{\Lambda^2} = -\frac{3\alpha_{\text{ew}} s_W^2 (1 - c_\alpha)}{8\pi c_W^2 v^2} \log \frac{m_H^2}{\mu^2} \quad \frac{c_{B,W}}{\Lambda^2} = \frac{1 - c_\alpha}{48\pi^2 v^2} \log \frac{m_H^2}{\mu^2}$$

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- **broken-phase matching**: systematically all terms v/Λ

$$\frac{c_T}{\Lambda^2} = -\frac{\alpha_{ew} s_W^2 (1 - c_\alpha)}{8\pi c_W^2 v^2} \left(-\frac{5}{2} + 3 \log \frac{m_H^2}{\mu^2} \right) \quad \frac{c_{B,W}}{\Lambda^2} = \frac{1 - c_\alpha}{144\pi^2 v^2} \left(-\frac{5}{2} + 3 \log \frac{m_H^2}{\mu^2} \right)$$

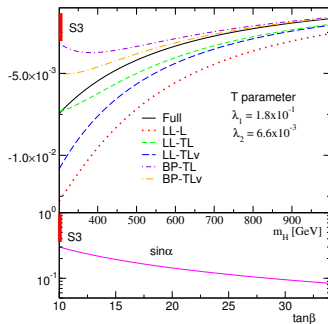
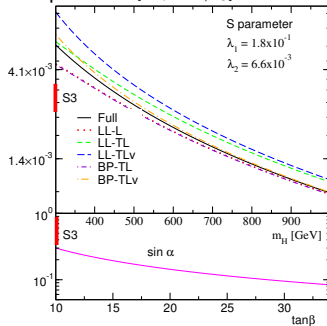
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– numerical comparison [tan $\beta = v/v_S$]



– similar analysis for loop-induced $H \rightarrow \gamma\gamma$ [Trott et al]

⇒ D6 Lagrangian systematically improved

EFT strategy at LHC

What does the D6 analysis at LHC mean? [Brehmer, Freitas, Lopez-Val, TP]

- phenomenology: does D6 capture features of model classes at LHC?
- theory: how do D6 vs EFT vs full model differences appear?

- 1 push (simplified) models to visible deviations at LHC
Higgs portal, 2HDM, stops, vector triplet [weakly interacting]
- 2 construct and match D6-Lagrangian to model
coupling modifications v^2/Λ^2 vs new kinematics ∂/Λ ?
 v -improved and broken phase matching
- 3 LHC simulations: D6-Lagrangian vs full model
production: WBF, VH , HH
decays: $H \rightarrow \gamma\gamma, 4\ell$

⇒ check for differences

kinematic distributions like $p_{T,j}$ or m_{VH} ?
resonance peaks of new states?

⇒ consider uncertainties as **matching uncertainties**

Model by model...

Higgs singlet/doublet extensions [\[Higgs portal\]](#)

- mixing with SM-like Higgs, not too interesting

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Triplet gauge extension [Brehmer, Biekötter, Krämer, TP]

- additional vector triplet field V_μ
- Lagrangian modulo UV completion

$$\begin{aligned} \mathcal{L} \supset & -\frac{1}{4} \tilde{V}_{\mu\nu}^a \tilde{V}^{\mu\nu a} + \frac{M_V^2}{2} \tilde{V}_\mu^a \tilde{V}^{\mu a} + i \frac{g_V}{2} c_H \tilde{V}_\mu^a \left[\phi^\dagger \sigma^a \overleftrightarrow{D}^\mu \phi \right] + \frac{g_w^2}{2g_V} \tilde{V}_\mu^a \sum_{\text{fermions}} c_F \bar{F}_L \gamma^\mu \sigma^a F_L \\ & + \frac{g_V}{2} c_{VVV} \epsilon_{abc} \tilde{V}_\mu^a \tilde{V}_\nu^b D^{[\mu} \tilde{V}^{\nu]c} + g_V^2 c_{VVHH} \tilde{V}_\mu^a \tilde{V}^{\mu a} (\phi^\dagger \phi) - \frac{g_w}{2} c_{VWW} \epsilon_{abc} W^{\mu\nu} \tilde{V}_\mu^b \tilde{V}_\nu^c \end{aligned}$$

- new states, mixing with $W^\pm$ and Z
weak gauge coupling to W, Z mass eigenstates

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Triplet model						EFT			
M_V	g_V	c_H	c_F	c_{VVHH}	m_ξ	$\bar{c}_W$	$\bar{c}_H$	$\bar{c}_6$	$\bar{c}_f$
591	3.0	-0.47	-5.0	2.0	1200	-0.044	0.000	0.000	0.000
946	3.0	-0.47	-5.0	1.0	1200	-0.017	0.000	0.000	0.000
941	3.0	-0.28	3.0	1.0	1200	0.006	0.075	0.100	0.025
1246	3.0	-0.50	3.0	-0.2	1200	0.006	0.103	0.138	0.034
846	1.0	-0.56	-1.32	0.08	849	-0.007	-0.020	-0.027	-0.007

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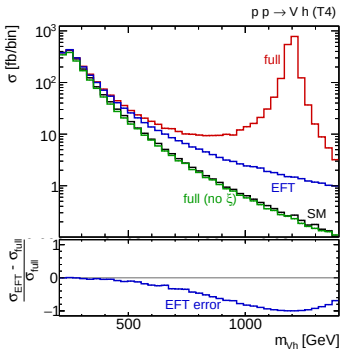
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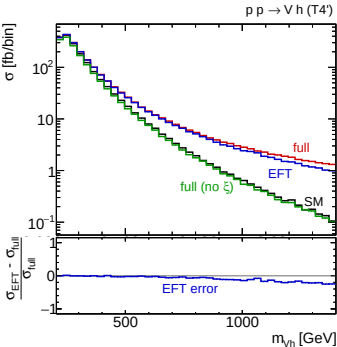
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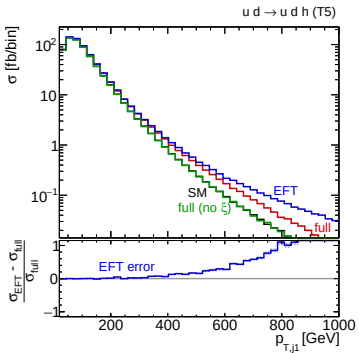
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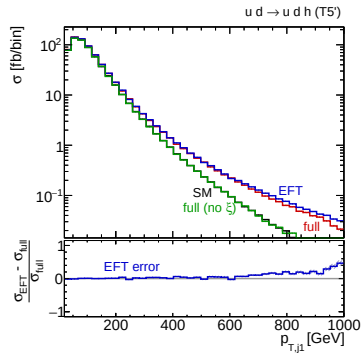
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Higgs@LHC

Tilman Plehn

Couplings

Higgs EFT

More EFTs

DUH!

D6 QCD operators

Ubiquitous QCD operator [TP, Krauss, Kuttimalai]

- anomalous gluon coupling

$$c_G \mathcal{O}_G = \frac{g_s c_G}{\Lambda^2} f_{abc} G_{a\nu}^\rho G_{b\lambda}^\nu G_{c\rho}^\lambda \quad \text{with} \quad G_a^{\rho\nu} = \partial^\rho G_a^\nu - \partial^\nu G_a^\rho - ig_s f_{abc} G^{b\rho} G^{c\nu}$$

- affecting multi-jet production [CMS black hole search]

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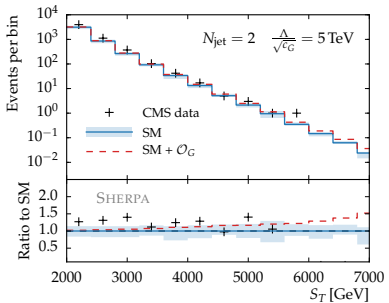
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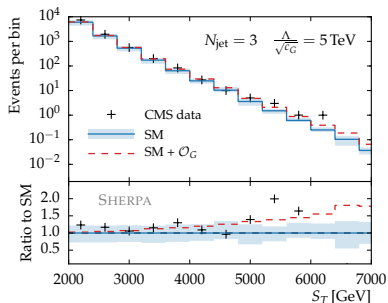
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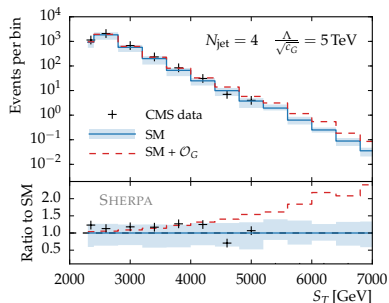
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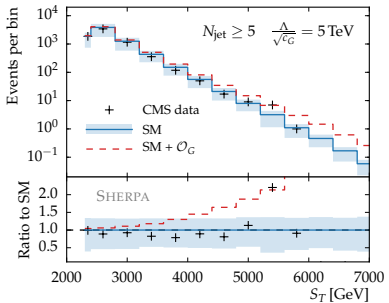
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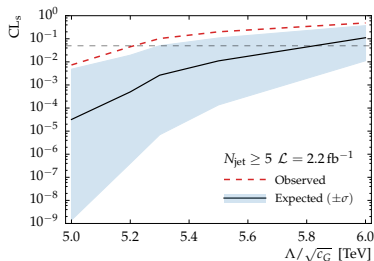
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- 4-fermion operators from ATLAS $\Lambda/\sqrt{c} > 4.8 \dots 6.8 \text{ TeV}$

⇒ gluon operator $\Lambda/\sqrt{c} > 5.2 \text{ TeV} \sim S_{\text{max}}$



D6 top operators

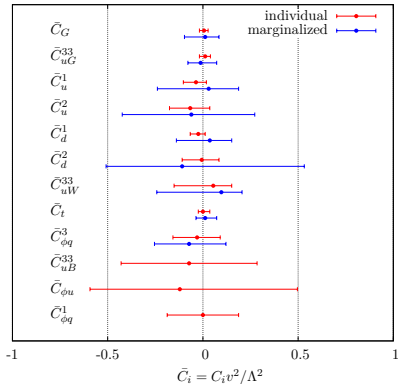
EFT for tops@LHC [TopFitter: Buckley, Englert, Ferrando, Miller, Moore, Russell, White]

- single, pair-wise, and associated top production [plus decays]
- including anomalous A_{FB} from Tevatron
- 4-quark, Yang-Mills, electroweak operators

$$\mathcal{O}_{qq} = \bar{q}\gamma_{\mu}q\bar{t}\gamma^{\mu}t \quad \mathcal{O}_G = f_{ABC}G_{\mu}^{A\nu}G_{\nu}^{B\lambda}G_{\lambda}^{C\mu} \quad \mathcal{O}_{\phi G} = \phi^{\dagger}\phi G_{\mu\nu}^a G^{a\mu\nu} \dots$$

- profile likelihoods and individual limits

⇒ **generic D6 reach ~ 500 GeV** [C = 1]



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- including anomalous A_{FB} from Tevatron
- 4-quark, Yang-Mills, electroweak operators

$$\mathcal{O}_{qq} = \bar{q}\gamma_\mu q \bar{t}\gamma^\mu t \quad \mathcal{O}_G = f_{ABC} G_\mu^{A\nu} G_\nu^{B\lambda} G_\lambda^{C\mu} \quad \mathcal{O}_{\phi G} = \phi^\dagger \phi G_{\mu\nu}^a G^{a\mu\nu} \dots$$

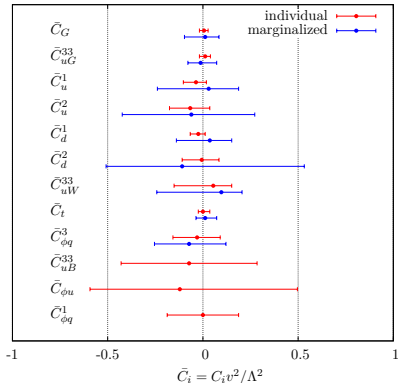
- profile likelihoods and individual limits

⇒ **generic D6 reach ~ 500 GeV** [C = 1]

For theorists: in terms of models

- axigluon: $M_A > 1.4$ TeV [$t\bar{t}$ resonance]
- SM-like W' : $M_{W'} > 1.2$ TeV [t -channel,...]

⇒ **models less sensitive to correlations**



D6 dark matter operators

Combining direct, indirect, collider results for WIMPs [Tait etal]

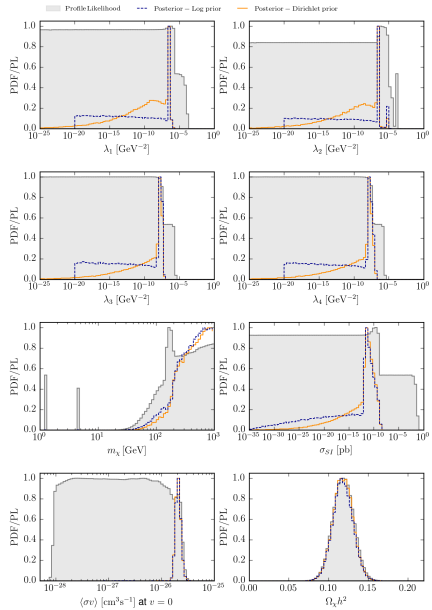
- choose dark matter candidate [Majorana/Dirac fermion, scalar, dark photon]
- consider D6 scattering process $\chi\chi \rightarrow \text{SM SM}$
- relic density from annihilation [$m_\chi / T \sim 30$]
- indirect detection even later
- direct detection non-relativistic [$E \sim 10 \text{ MeV}$]
- LHC tricky: single scale $m_\chi \ll m_{\text{mediator}}$?
- example: scalar dark matter

Label	Coefficient	Operator	σ_{SI}	$\langle \sigma_{\text{ann}} v \rangle$
Real scalar				
R1	$\lambda_1 \sim 1/(2M^2)$	$m_q \chi^2 \bar{q} q$	✓	s-wave
R2	$\lambda_2 \sim 1/(2M^2)$	$im_q \chi^2 \bar{q} \gamma^5 q$		s-wave
R3	$\lambda_3 \sim \alpha_S/(4M^2)$	$\chi^2 G_{\mu\nu} G^{\mu\nu}$	✓	s-wave
R4	$\lambda_4 \sim \alpha_S/(4M^2)$	$i \chi^2 G_{\mu\nu} \tilde{G}^{\mu\nu}$		s-wave
Complex scalar				
C1	$\lambda_1 \sim 1/(M^2)$	$m_q \chi^\dagger \chi \bar{q} q$	✓	s-wave
C2	$\lambda_2 \sim 1/(M^2)$	$im_q \chi^\dagger \chi \bar{q} \gamma^5 q$		s-wave
C3	$\lambda_3 \sim 1/(M^2)$	$\chi^\dagger \partial_\mu \chi \bar{q} \gamma^\mu q$	✓	p-wave
C4	$\lambda_4 \sim 1/(M^2)$	$\chi^\dagger \partial_\mu \chi \bar{q} \gamma^\mu \gamma^5 q$		p-wave
C5	$\lambda_5 \sim \alpha_S/(8M^2)$	$\chi^\dagger \chi G_{\mu\nu} G^{\mu\nu}$	✓	s-wave
C6	$\lambda_6 \sim \alpha_S/(8M^2)$	$i \chi^\dagger \chi G_{\mu\nu} \tilde{G}^{\mu\nu}$		s-wave

D6 dark matter operators

Relic density plus Hooperon [Liem, Bertone, Calore, Ruiz de Austri, Tait, Trotta, Weniger]

- default input: relic density
 - scalar dark matter
- | Label | Coefficient | Operator | $\sigma_{SI} / \langle \sigma_{ann} v \rangle$ |
|-------------|----------------------------------|--|--|
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| R3 | $\lambda_3 \sim \alpha_S/(4M^2)$ | $\chi^2 G_{\mu\nu}^2 G^{\mu\nu}$ | ✓ s-wave |
| R4 | $\lambda_4 \sim \alpha_S/(4M^2)$ | $i \chi^2 G_{\mu\nu} \tilde{G}^{\mu\nu}$ | s-wave |
- profile likelihood
 - flat prior on $\log \lambda_i$ [prior $1/\lambda_i$]
 - Dirichlet prior preferring similar-sized Wilson coefficients



D6 dark matter operators

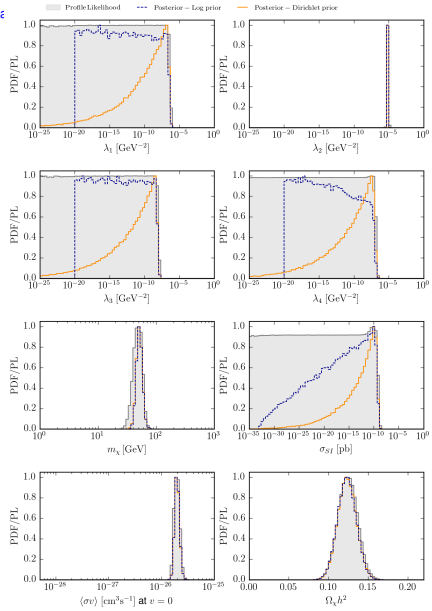
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- profile likelihood
- flat prior on log λ_i [prior $1/\lambda_i$]
- Dirichlet prior preferring similar-sized Wilson coefficients
- Fermi: GCE plus dwarf galaxies

⇒ working in practice...



Matching hurts

Combination of measurements [Bauer, Butter, Desai, Gonzalez-Fraile, TP]

- relic density, annihilation in early universe [non-relativistic]
- indirect detection, annihilation today [very non-relativistic]
- direct detection [non-relativistic]
- collider searches [away from poles]

⇒ **EFT not from first principles**

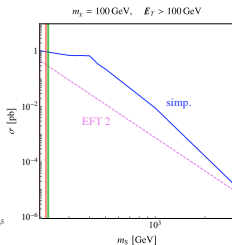
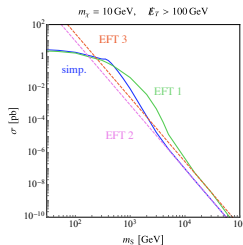
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Representing models?

- more or less simplified for LHC
- relic density only actual data
mass scale $m_{\text{med}}^2/(g^2 m_\chi) \sim 8 \text{ TeV}$
- tree-level colored t -channel mediator [squark-neutralino in MSSM]
relic density requiring light mediator, direct production at LHC



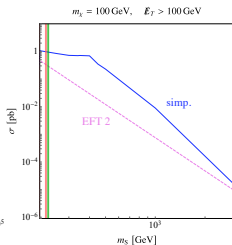
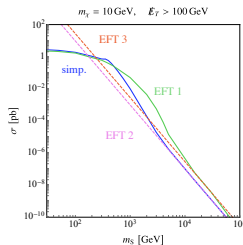
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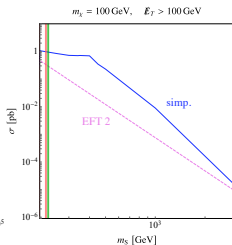
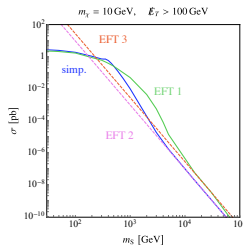
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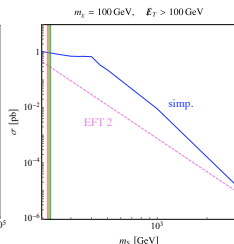
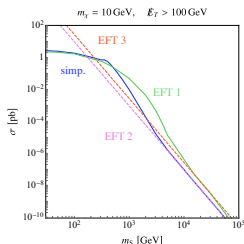
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Matching hurts

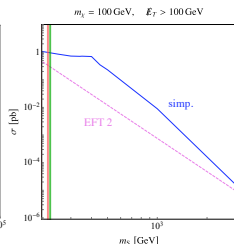
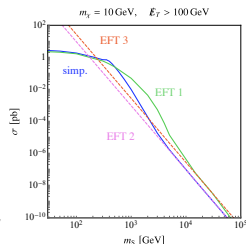
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⇒ relic density needing further consideration...



Questions

Where we stand with LHC theory

Is it really the Standard Model Higgs? [no]

Is there WIMP dark matter? [yes]

Is there TeV-scale physics beyond the Standard Model? [yes]

Are EFT analyses un-inspired? [totally]

Can we use first-principle EFT at LHC? [no]

Are there nice theory aspects to work on? [plenty]

Will I stop doing EFT once we find new states? [definitely]

⇒ **Welcome to a data-driven era!** [it sucks]

Lectures on LHC Physics and dark matter updated under www.thphys.uni-heidelberg.de/~plehn/

Much of this work was funded by the BMBF Theorie-Verbund which is ideal for relevant LHC work



Bundesministerium
für Bildung
und Forschung

Exercise: higher-dimensional operators

Higgs sector including dimension-6 operators

$$\mathcal{L}_{D6} = \sum_{i=1}^2 \frac{f_i}{\Lambda^2} \mathcal{O}_i \quad \text{with} \quad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial_\mu (\phi^\dagger \phi) \partial^\mu (\phi^\dagger \phi), \quad \mathcal{O}_{\phi,3} = -\frac{1}{3} (\phi^\dagger \phi)^3$$

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first operator, wave function renormalization

$$\mathcal{O}_{\phi,2} = \frac{1}{2} \partial_\mu (\phi^\dagger \phi) \partial^\mu (\phi^\dagger \phi) = \frac{1}{2} (\tilde{H} + v)^2 \partial_\mu \tilde{H} \partial^\mu \tilde{H}$$

proper normalization of combined kinetic term [LSZ]

$$\mathcal{L}_{\text{kin}} = \frac{1}{2} \partial_\mu \tilde{H} \partial^\mu \tilde{H} \left(1 + \frac{f_{\phi,2} v^2}{\Lambda^2} \right) \stackrel{!}{=} \frac{1}{2} \partial_\mu H \partial^\mu H \quad \Leftrightarrow \quad H = \tilde{H} \sqrt{1 + \frac{f_{\phi,2} v^2}{\Lambda^2}}$$

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second operator, minimum condition giving v

$$v^2 = -\frac{\mu^2}{\lambda} - \frac{f_{\phi,3} \mu^4}{4\lambda^3 \Lambda^2}$$

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both operators contributing to Higgs mass

$$\begin{aligned} \mathcal{L}_{\text{mass}} &= -\frac{\mu^2}{2} \tilde{H}^2 - \frac{3}{2} \lambda v^2 \tilde{H}^2 - \frac{f_{\phi,3}}{\Lambda^2} \frac{15}{24} v^4 \tilde{H}^2 \stackrel{!}{=} -\frac{m_H^2}{2} H^2 \\ \Leftrightarrow \quad m_H^2 &= 2\lambda v^2 \left(1 - \frac{f_{\phi,2} v^2}{\Lambda^2} + \frac{f_{\phi,3} v^2}{2\Lambda^2 \lambda} \right) \end{aligned}$$

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Higgs self couplings momentum dependent

$$\begin{aligned} \mathcal{L}_{\text{self}} = & -\frac{m_H^2}{2v} \left[\left(1 - \frac{f_{\phi,2} v^2}{2\Lambda^2} + \frac{2f_{\phi,3} v^4}{3\Lambda^2 m_H^2} \right) H^3 - \frac{2f_{\phi,2} v^2}{\Lambda^2 m_H^2} H \partial_\mu H \partial^\mu H \right] \\ & -\frac{m_H^2}{8v^2} \left[\left(1 - \frac{f_{\phi,2} v^2}{\Lambda^2} + \frac{4f_{\phi,3} v^4}{\Lambda^2 m_H^2} \right) H^4 - \frac{4f_{\phi,2} v^2}{\Lambda^2 m_H^2} H^2 \partial_\mu H \partial^\mu H \right] \end{aligned}$$

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alternatively, strong multi-Higgs interactions

$$H = \left(1 + \frac{f_{\phi,2} v^2}{2\Lambda^2} \right) \tilde{H} + \frac{f_{\phi,2} v}{2\Lambda^2} \tilde{H}^2 + \frac{f_{\phi,2}}{6\Lambda^2} \tilde{H}^3 + \mathcal{O}(\tilde{H}^4)$$

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⇒ operators and distributions linked to poor UV behavior