Exploring Minimal Composite Higgs Models from a Bayesian Perspective

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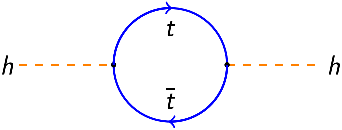
Higgs mass naturalness problem

- If the Standard Model is accurate up to a high energy scale Λ_{UV}, the Higgs mass will contain large contributions:

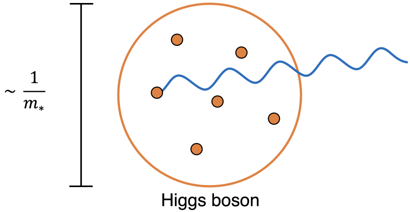


$$m_h^2 = m_{\mathrm{bare}}^2 - \frac{3y_t^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2 + \cdots$$

- If $\Lambda_{\mathrm{UV}} \gg m_h$, bare mass parameter must be extremely fine-tuned to result in observed mass $m_h \approx 125$ GeV

Solution: a composite Higgs boson

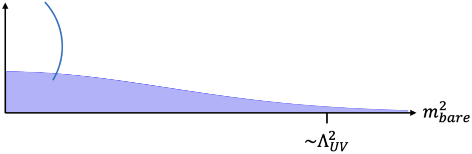
- Suppose the Higgs is a bound state of a new strongly interacting sector at a scale $m_* \sim$ few TeV
- Virtual particles of momenta $\gtrsim m_*$ will see the constituent particles, not the Higgs itself



- Loop integrals then have to be cut off at $\Lambda_{UV} \sim m_*$, alleviating need for large cancellations

Naturalness from a Bayesian perspective

Prior $\pi(p)$: our initial guess for how the parameter should be distributed



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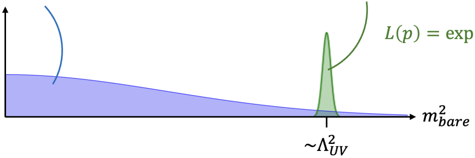
Likelihood L(p): how well this parameter value predicts observables, e.g.

$$L(p) = \exp\left(-\frac{(m(p) - m_h)^2}{2\sigma^2}\right)$$



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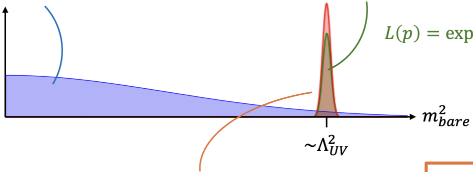

Posterior $P(p)$: how we should update our guess after learning the likelihood. By Bayes' Theorem,

$$P(p) = \frac{L(p)\pi(p)}{Z}$$

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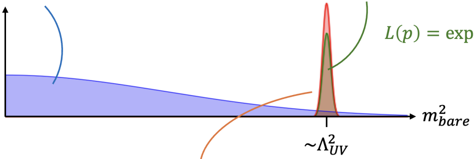

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- Fine-tuning is quantified by the **Kullback-Leibler divergence**

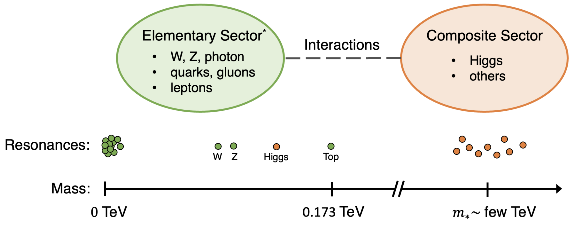
$$D_{KL} = \int dp\, P(p) \ln\left(P(p)/\pi(p)\right)$$

- **Bayesian evidence** measures the fitness of the model, balancing how well it fits experiments with naturalness

$$\mathcal{Z} \equiv \int dp\, L(p)\pi(p) \quad \Longrightarrow \quad \ln(\mathcal{Z}) = \langle \ln(L) \rangle_P - D_{KL}$$

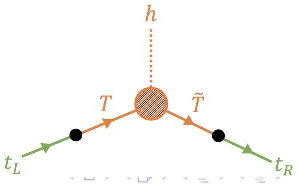
Composite Higgs models

- Expect a zoo of new composite particles



- The Higgs is lighter than the other composite particles because it is a **pseudo Nambu-Goldstone boson**

- Standard Model particles get their mass by mixing with the composite sector



Minimal composite Higgs models

- The minimal symmetry breaking structure is $SO(5) \to SO(4)$
- Many possible choices of $SO(5)$ representations for the fermions $(\mathbf{1}, \mathbf{5}, \mathbf{10}, \mathbf{14}, \ldots)$
- Interesting phenomenology, e.g. modified Higgs couplings and heavy quark partners with exotic charge

Exploring minimal composite Higgs models

- Fit models to a wide range of experimental constraints:
  - Standard Model masses, electroweak precision observables, Z boson decay ratios, Higgs signal strengths, LHC heavy quark partner bounds
  - Likelihood taken to be Gaussian in the observables

- We couple fermions from only the third generation to the composite sector for simplicity

- Even these minimal models have huge parameter spaces:

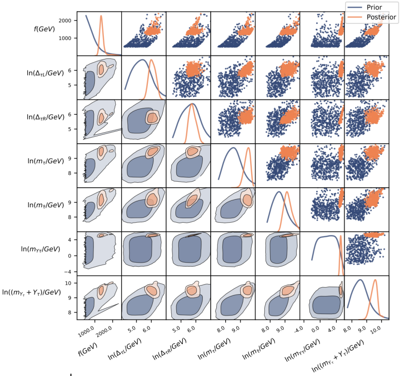
$$\mathcal{L} \supset \Delta_L t_L T_R + \Delta_R t_R \tilde{T}_L - m\bar{T}T - \tilde{m}\bar{\tilde{T}}\tilde{T} - m_Y \bar{T}_L \tilde{T}_R + \cdots$$

- **Nested sampling** allowed us to explore parameter spaces efficiently and estimate Bayesian evidence

Results

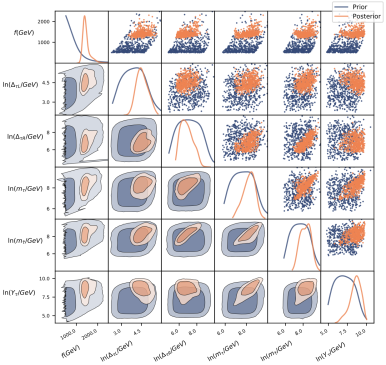
Model 1

(t_L, b_L): **5** t_R: **5** b_R: **5** (ν_L, τ_L): **5** τ_R: **5**



Model 2

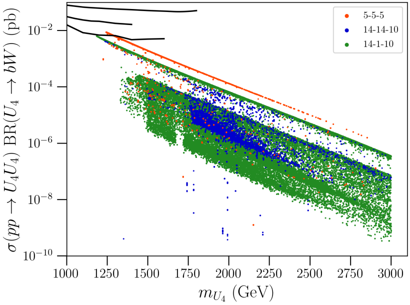
(t_L, b_L): **5** t_R: **5** b_R: **5** (ν_L, τ_L): **14** τ_R: **10**

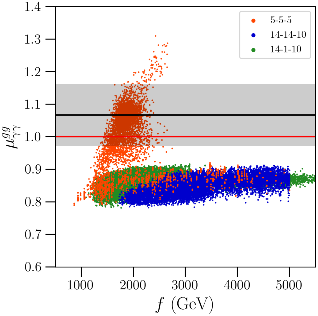


$\ln(Z)$	-45.60 ± 0.06	-36.30 ± 0.05
$\langle \ln(L) \rangle_P$	-17.27	-14.63
D_{KL}	28.33	21.67

Experimental signatures

- As a by-product of the fits, we can analyse phenomenology of the models in their viable regions





Summary

- We performed the first global fits of several minimal composite Higgs models with differing fermion representations
- All the models can fit experimental constraints reasonably well
- They generically predict SM partners too heavy to be seen at the LHC, but more precise measurements of Higgs decays might be able to distinguish the models
- The Bayesian approach allowed for model comparisons based on both experimental fitness and naturalness