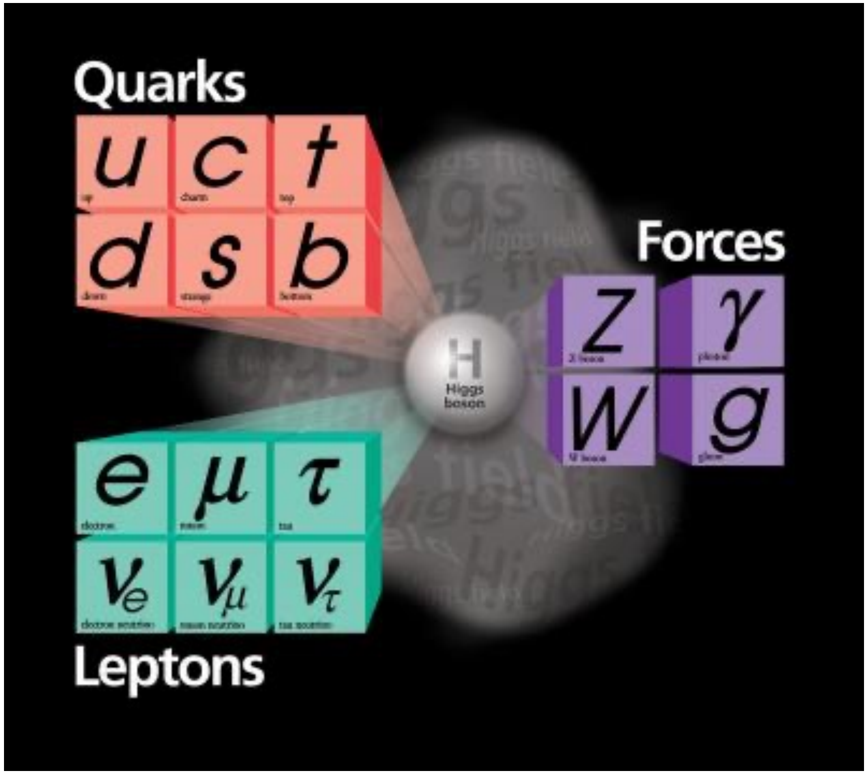
Research on the Theory of the TeV energy scale (Terascale)

Howard Haber
SCIPP Theory
March 12, 2024

For further details, check out my webpage:
http://scipp.ucsc.edu/~haber/

The Standard Model (SM) of Particle Physics



The elementary particles consists of three generations of spin-1/2 quarks and leptons, the gauge bosons of SU(3)xSU(2)xU(1), and the Higgs boson.

Technically, massive neutrinos require an extension of the Standard Model, but most likely the relevant scale of the new physics lies way beyond the terascale.

On July 4, 2012, the discovery of a new boson is announced which may be the long sought after Higgs boson.

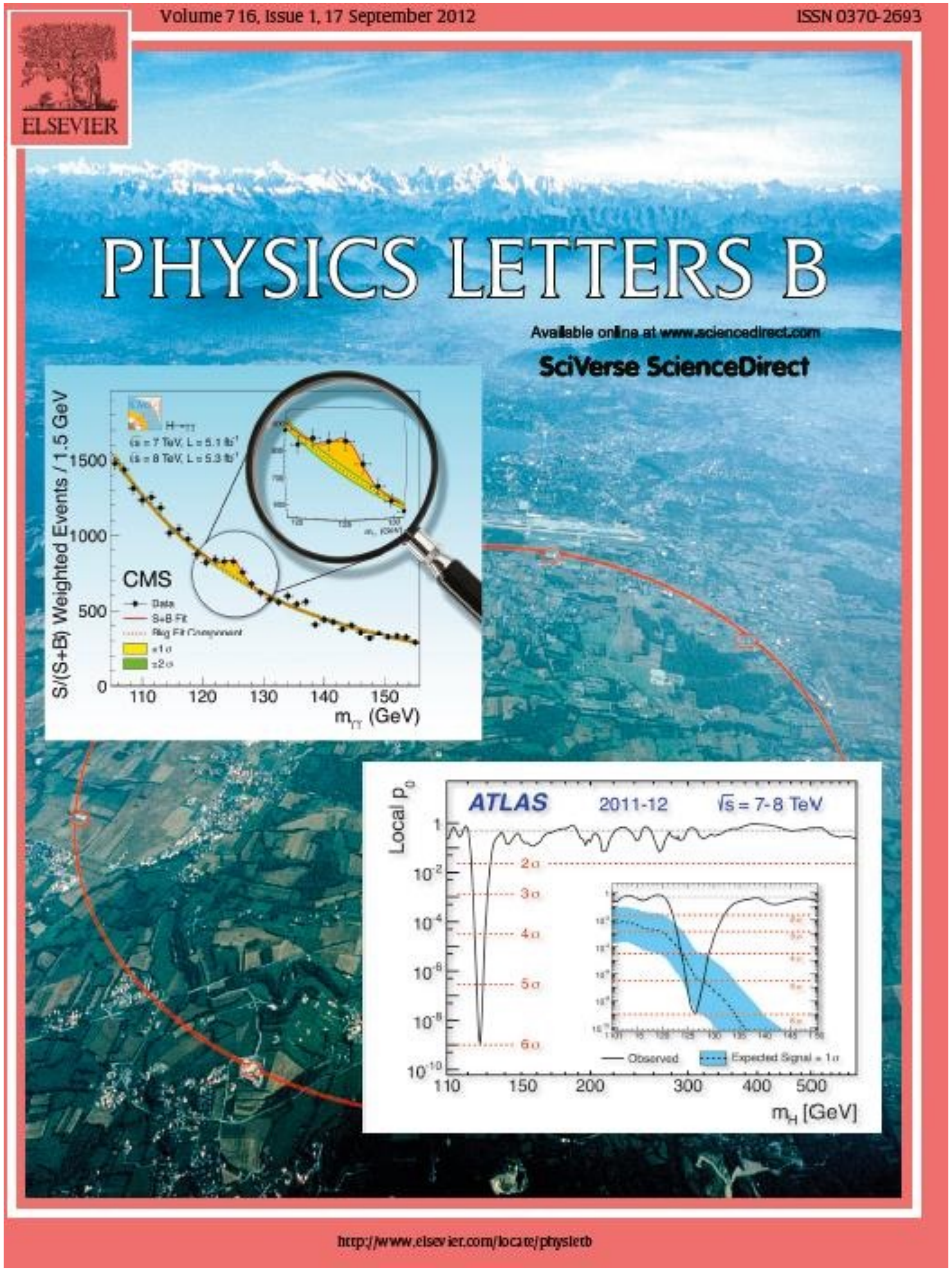
The discovery papers are published two months later In Physics Letters B.

ATLAS Collaboration:

Physics Letters B716 (2012) 1—29

CMS Collaboration:

Physics Letters B716 (2012) 30—61



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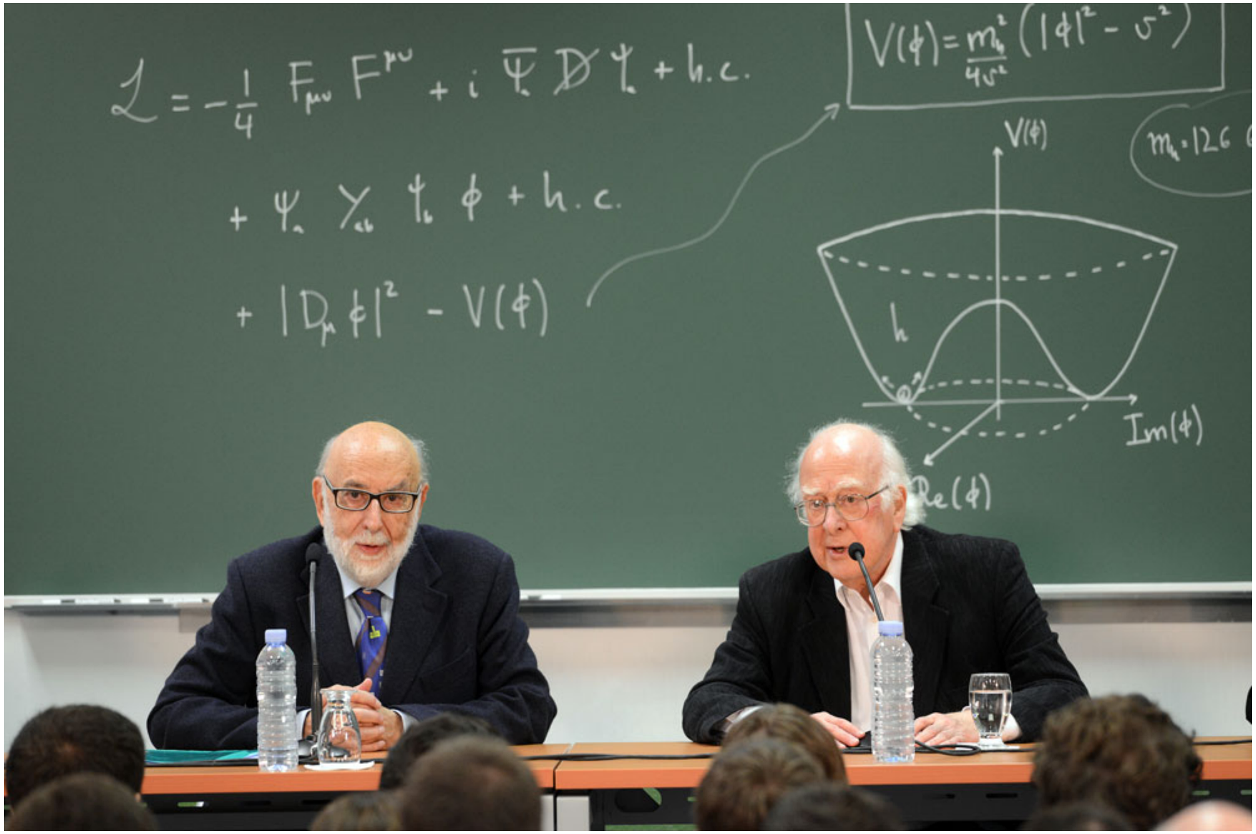
Winners of the 2013 Nobel Prize in Physics



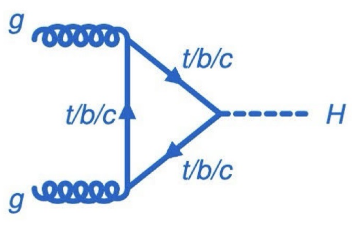
François Englert

and

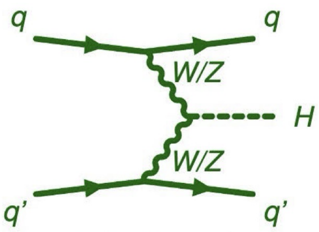
Peter Higgs

Higgs boson production and decay mechanisms

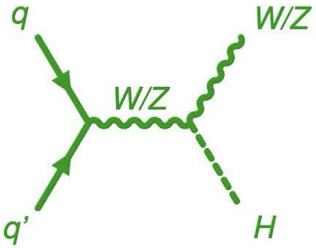
Higgs boson production



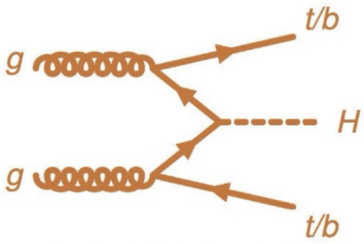
ggF (87%)



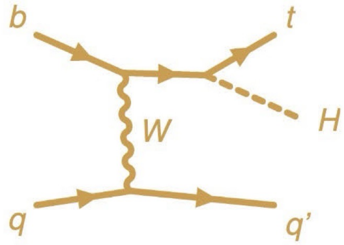
VBF (7%)



VH (4%)

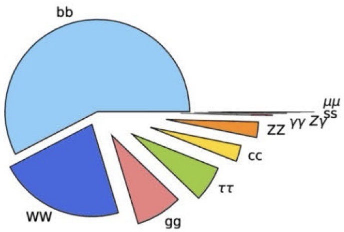


ttH/bbH (2%)

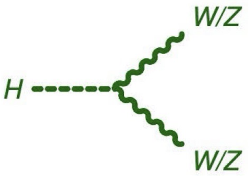


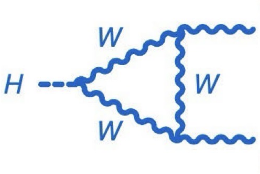
tH (0.1%)

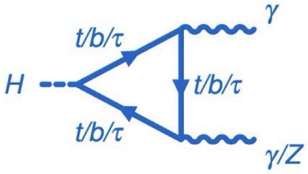
Higgs boson decay channels

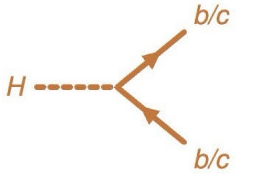


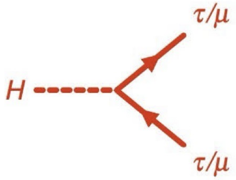
Higgs boson decay BR



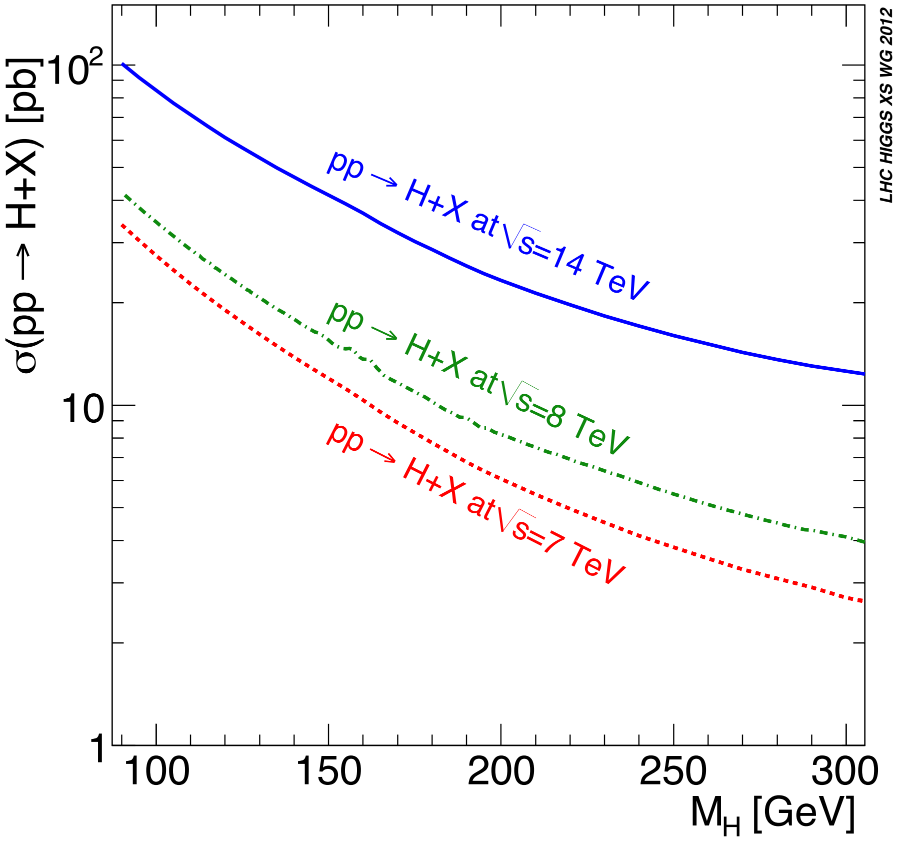


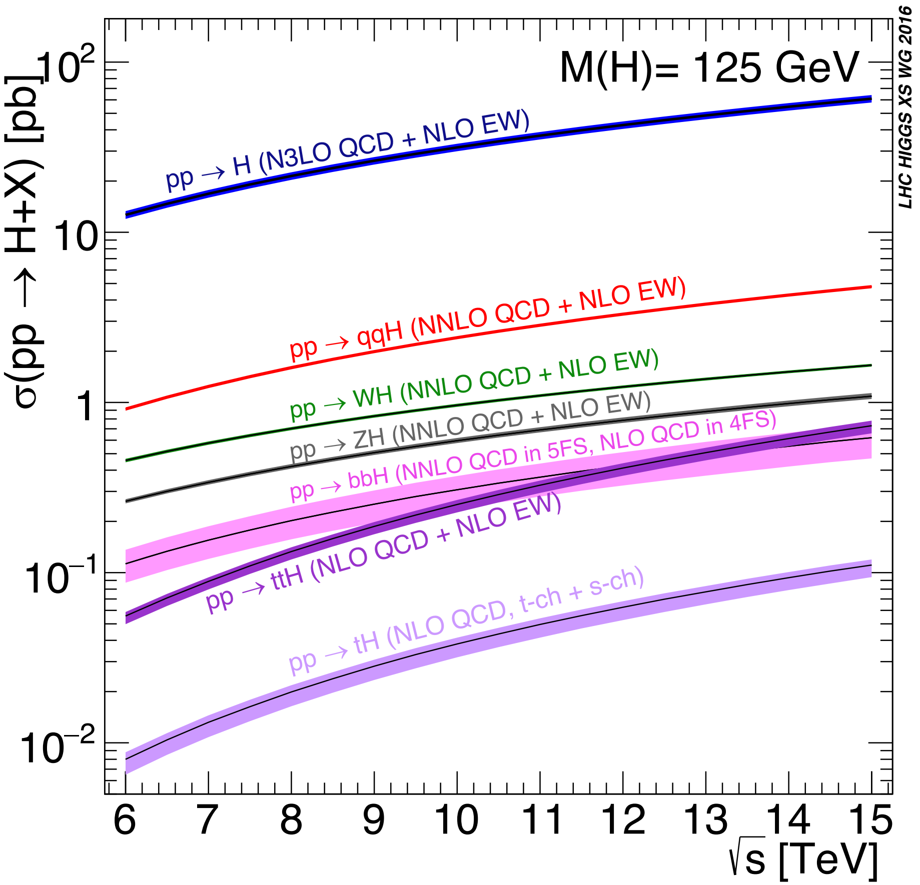






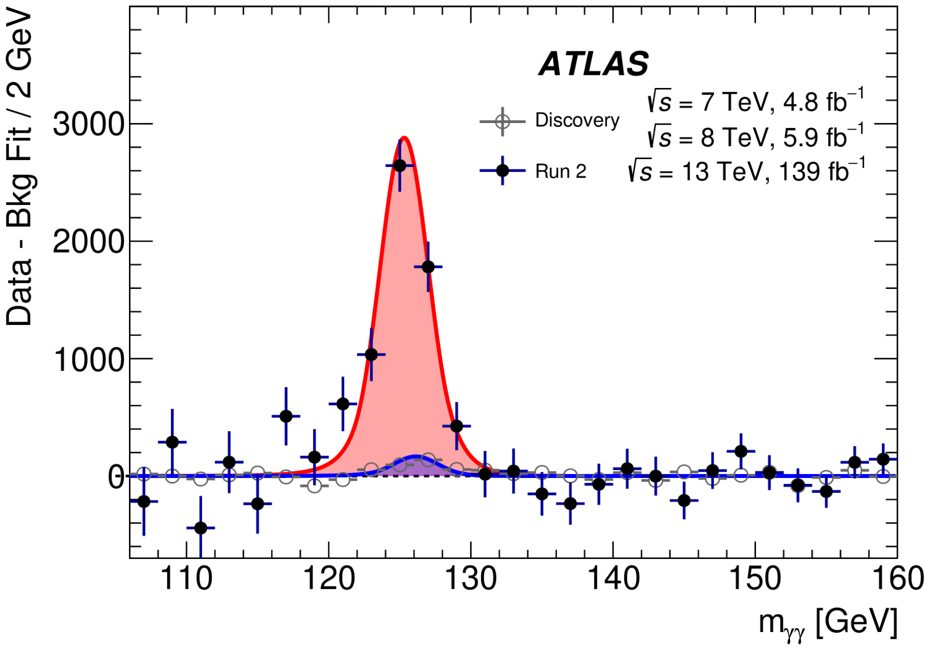
Higgs boson production cross sections at a pp collider



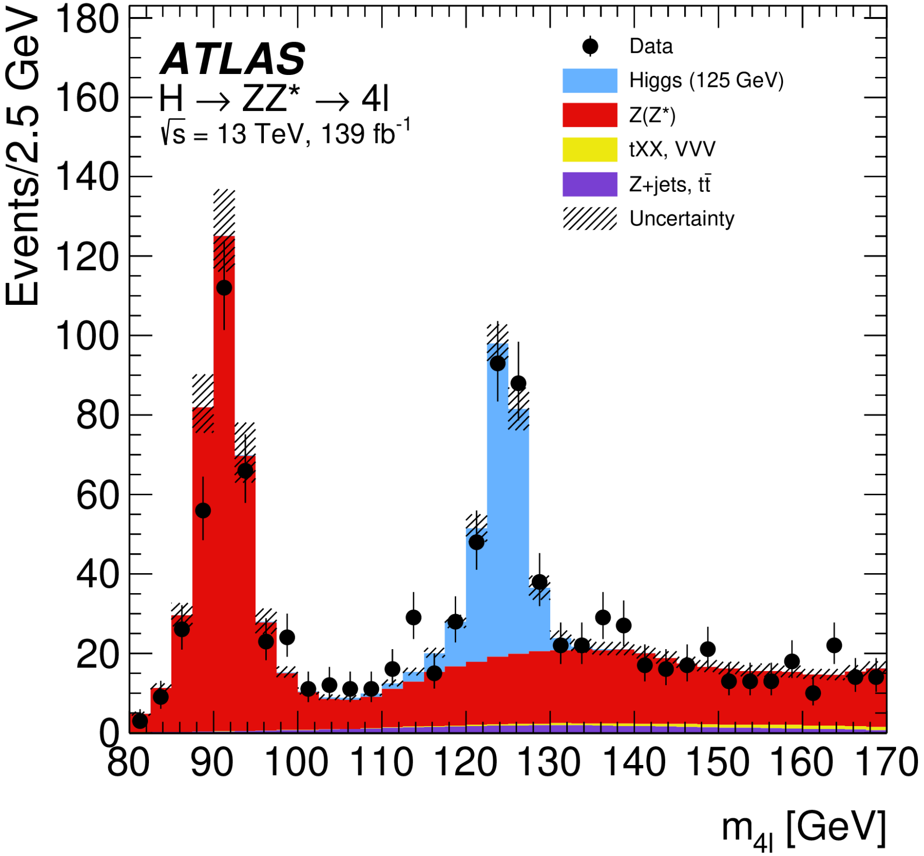


With nearly 140 fb^{-1} of data delivered by the LHC in Run 2 to both ATLAS and CMS in 2015—2018 at a center of mass energy of 13 TeV, roughly 7.5 million Higgs bosons per experiment were produced, assuming the Higgs mass is 125 GeV.

ATLAS Run 2 observations of the Higgs boson

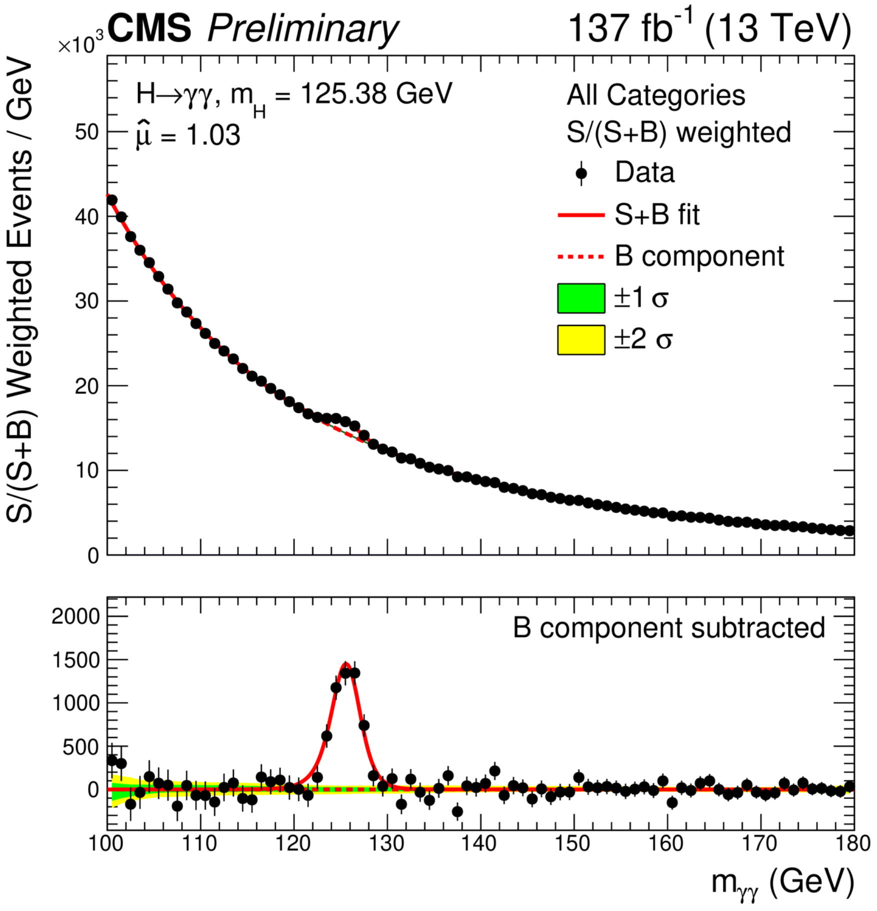


Taken from *Nature 607, 52 (2022)*

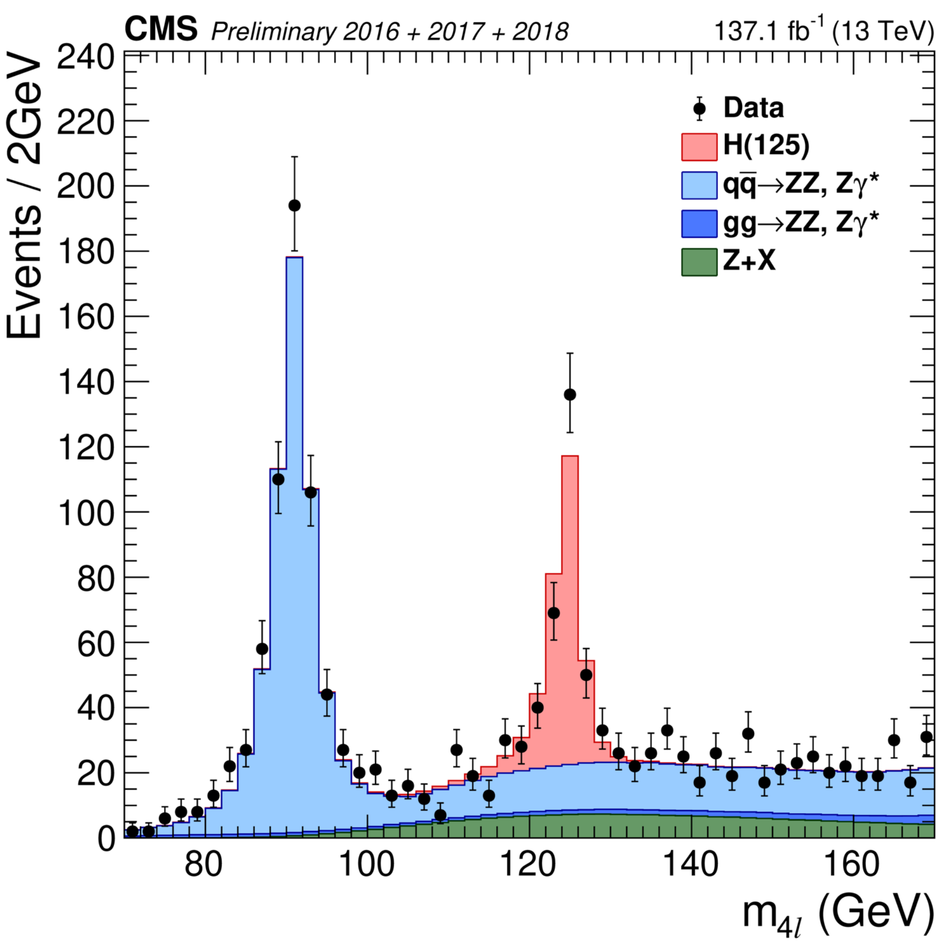


Taken from *Eur. Phys. J. C 80 (2020) 941*

CMS Run 2 observations of the Higgs boson

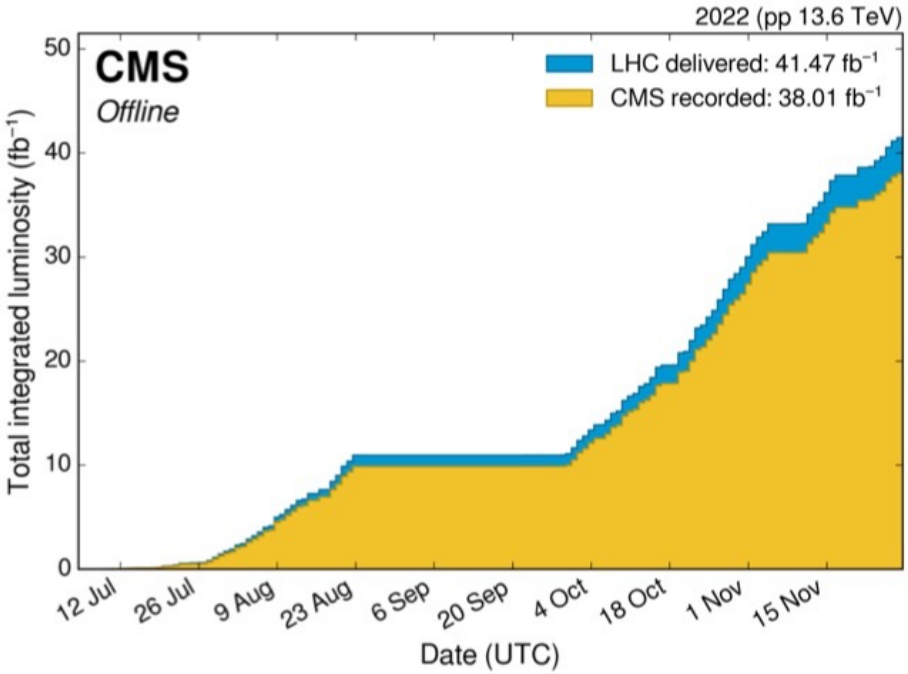


Taken from CMS-PAS-HIG-19-015

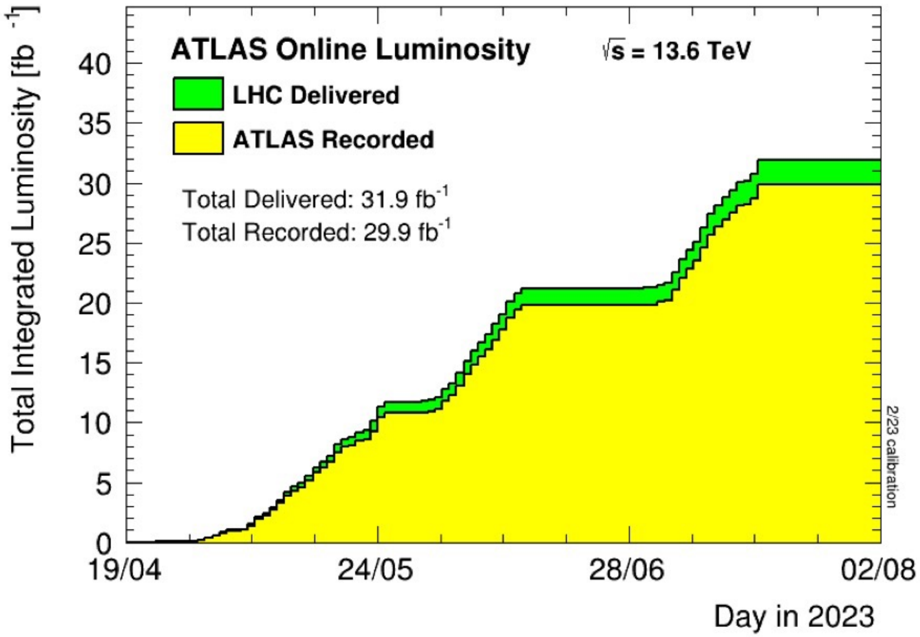


Taken from CMS-PAS-HIG-19-001

LHC Run 3 started in 2022 and will finish up in 2025. So far, no Higgs data from Run 3 have been presented. The 2024 run began this week. By the end of 2025, the anticipated integrated luminosity of Run 3 is about 250 fb^{-1} at a CM energy of 13.6 TeV.



- **2023 pp collisions**: Recorded 29.9 fb^{-1}, delivered 31.9 fb^{-1}



Higgs boson decay channels observed at the LHC

Higgs boson decay mode	**Branching ratio (for $m_h = 125\ \mathrm{GeV}$)**
$h^0 \rightarrow \mathbf{b}\mathbf{b}$	0.582
$h^0 \rightarrow \boldsymbol{\tau}^+ \boldsymbol{\tau}^-$	6.27×10^{-2}
$h^0 \rightarrow \boldsymbol{\ell}^+ \boldsymbol{\ell}^- \boldsymbol{\nu\nu}$ ($\boldsymbol{\ell} = \boldsymbol{e}$ or $\boldsymbol{\mu}$)	1.06×10^{-2}
$h^0 \rightarrow \boldsymbol{\gamma\gamma}$	2.27×10^{-3}
$h^0 \rightarrow \boldsymbol{\ell}^+ \boldsymbol{\ell}^- \boldsymbol{\ell}^+ \boldsymbol{\ell}^-$ ($\boldsymbol{\ell} = \boldsymbol{e}$ or $\boldsymbol{\mu}$)	1.24×10^{-4}

Taken from https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR#Branching_Ratios

Remarks:

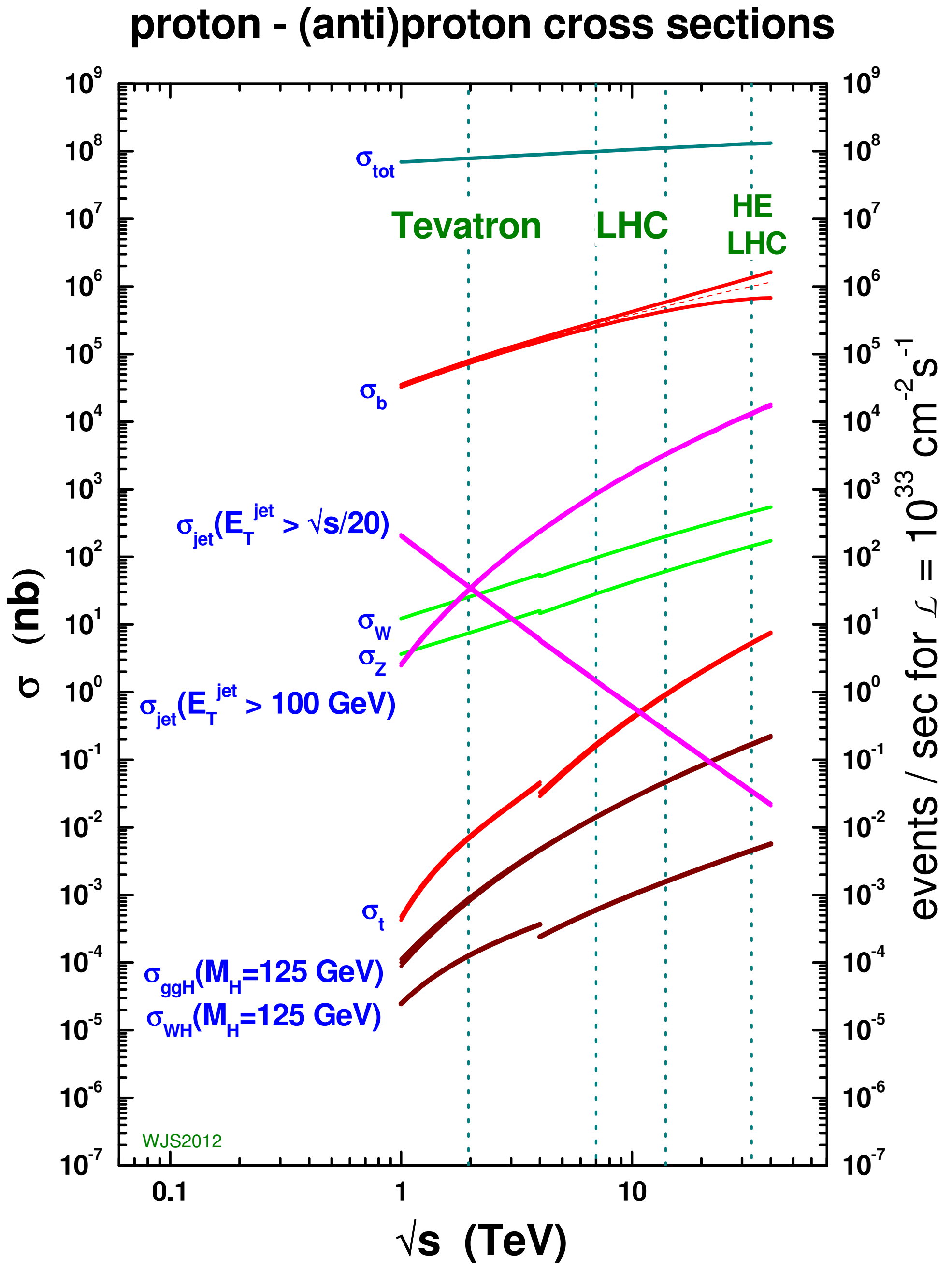
1. $h^0 \rightarrow WW^*$ is observed primarily via the $\boldsymbol{\ell}^+ \boldsymbol{\nu} \boldsymbol{\ell}^- \boldsymbol{\nu}$ ($\boldsymbol{\ell} = \boldsymbol{e}$ or $\boldsymbol{\mu}$) final state.
2. $h^0 \rightarrow ZZ^*$ is observed primarily via the $\boldsymbol{\ell}^+ \boldsymbol{\ell}^- \boldsymbol{\ell}^+ \boldsymbol{\ell}^-$ ($\boldsymbol{\ell} = \boldsymbol{e}$ or $\boldsymbol{\mu}$) final state.

In the decays to the diboson final state, kinematics dictates that one of the vector bosons is off-shell (i.e., “virtual”) and is thus indicated by a superscript star.

Question: why not search inclusively for Higgs bosons that decay into a pair of b-quarks?

Answer: The Standard Model background is overwhelming. There are more than 10^7 times as many b-quark pairs produced in proton-proton collisions as compared to b-quark pairs that arise from a decaying Higgs boson.

Nevertheless, the observation of H → bb in the VH channel was confirmed by ATLAS and CMS in 2018!



Summary of ATLAS Higgs boson data from Run 2 at the LHC

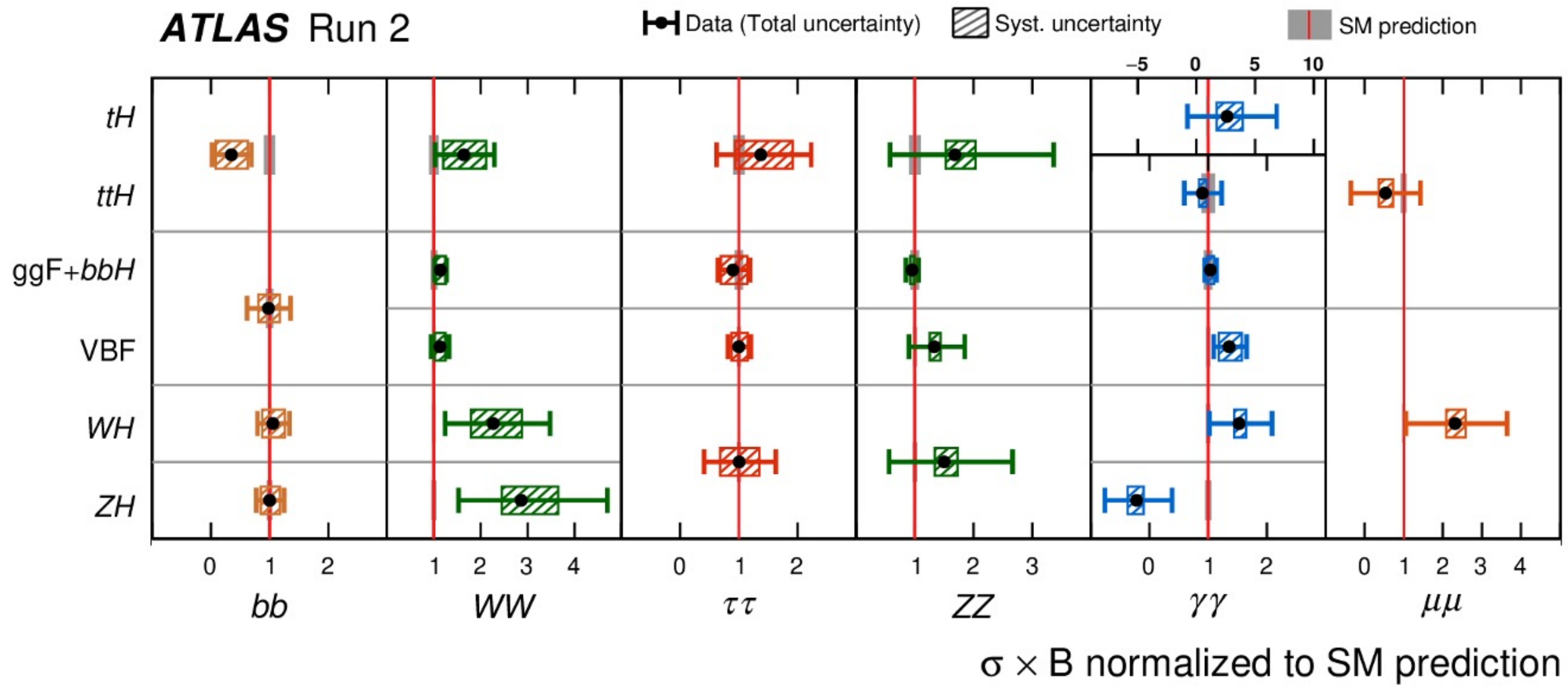
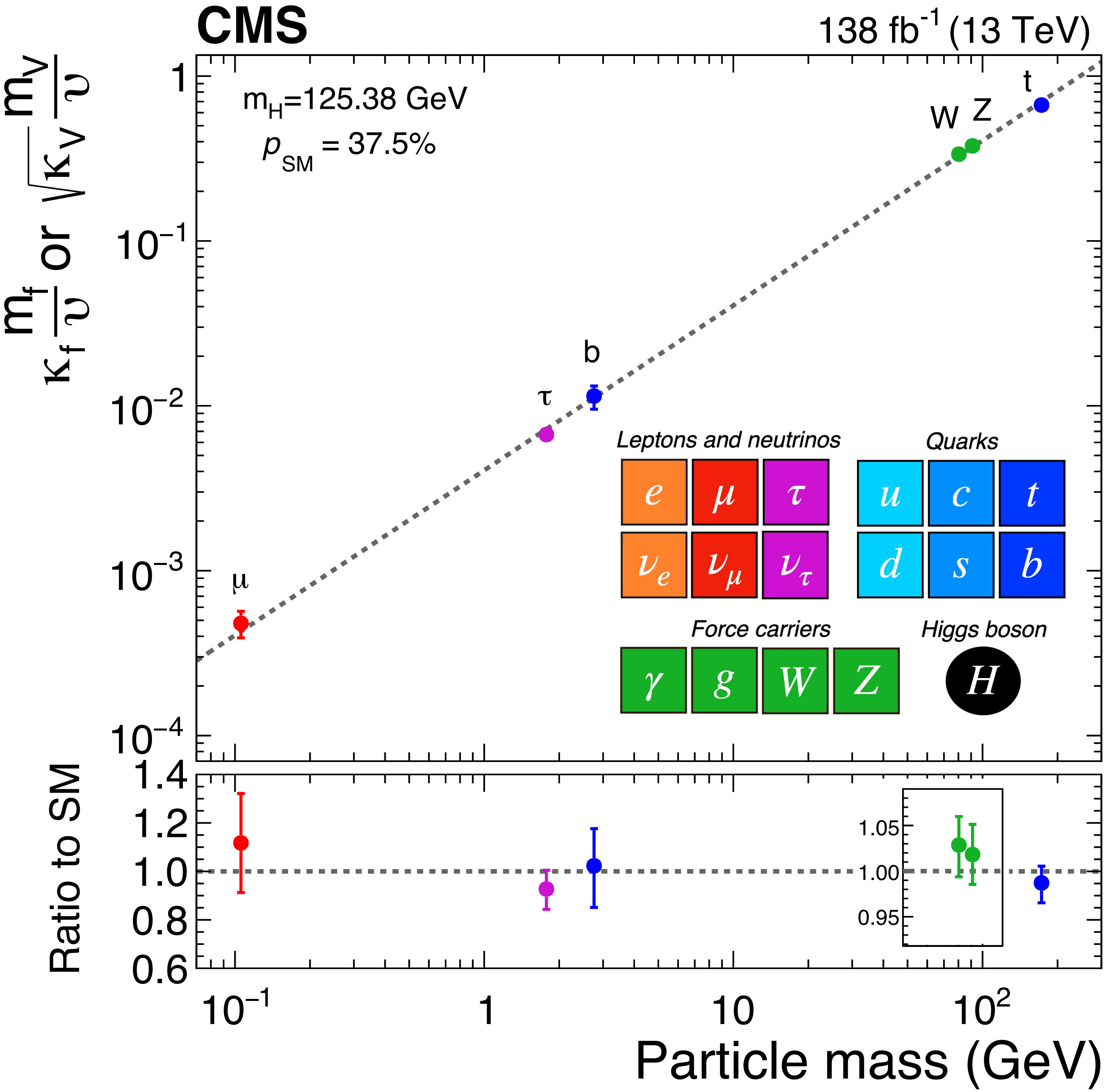


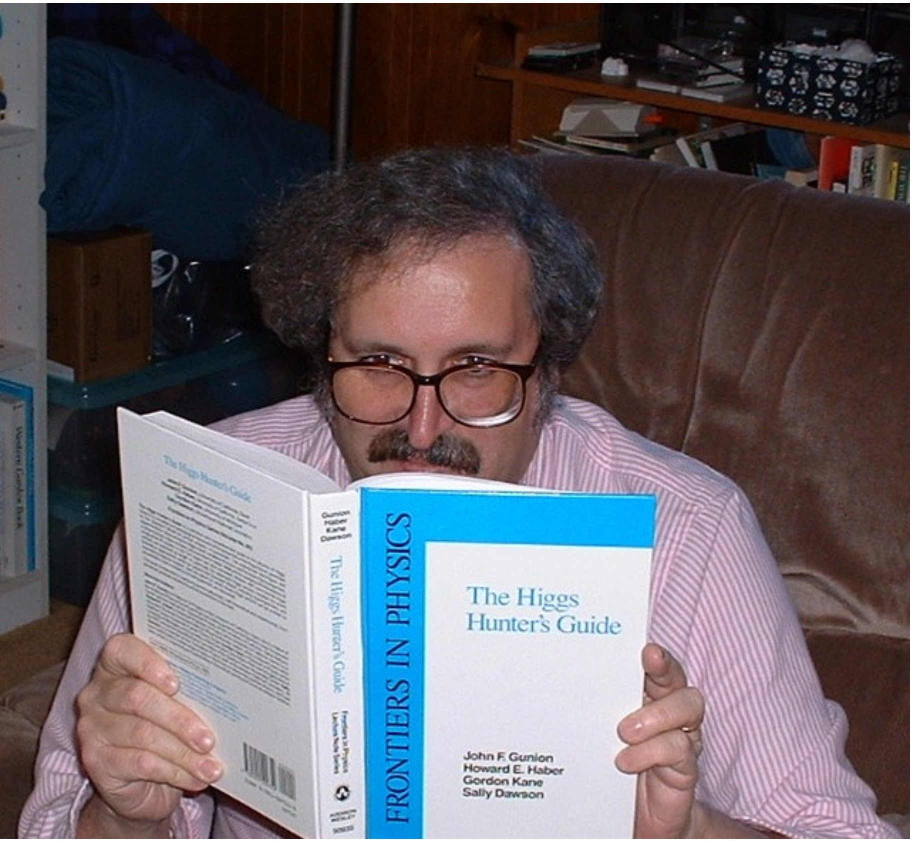
Fig. 3 | Ratio of observed rate to predicted standard model event rate for different combinations of Higgs boson production and decay processes. The horizontal bar on each point denotes the 68% confidence interval. The narrow grey bands indicate the theory uncertainties in the standard model (SM) cross-section multiplied by the branching fraction predictions. The *p* value for compatibility of the measurement and the SM prediction is 72%. $\sigma_i B_f$ is normalized to the SM prediction. Data are from ATLAS Run 2.

Nature | Vol 607 | 7 July 2022 | **55**

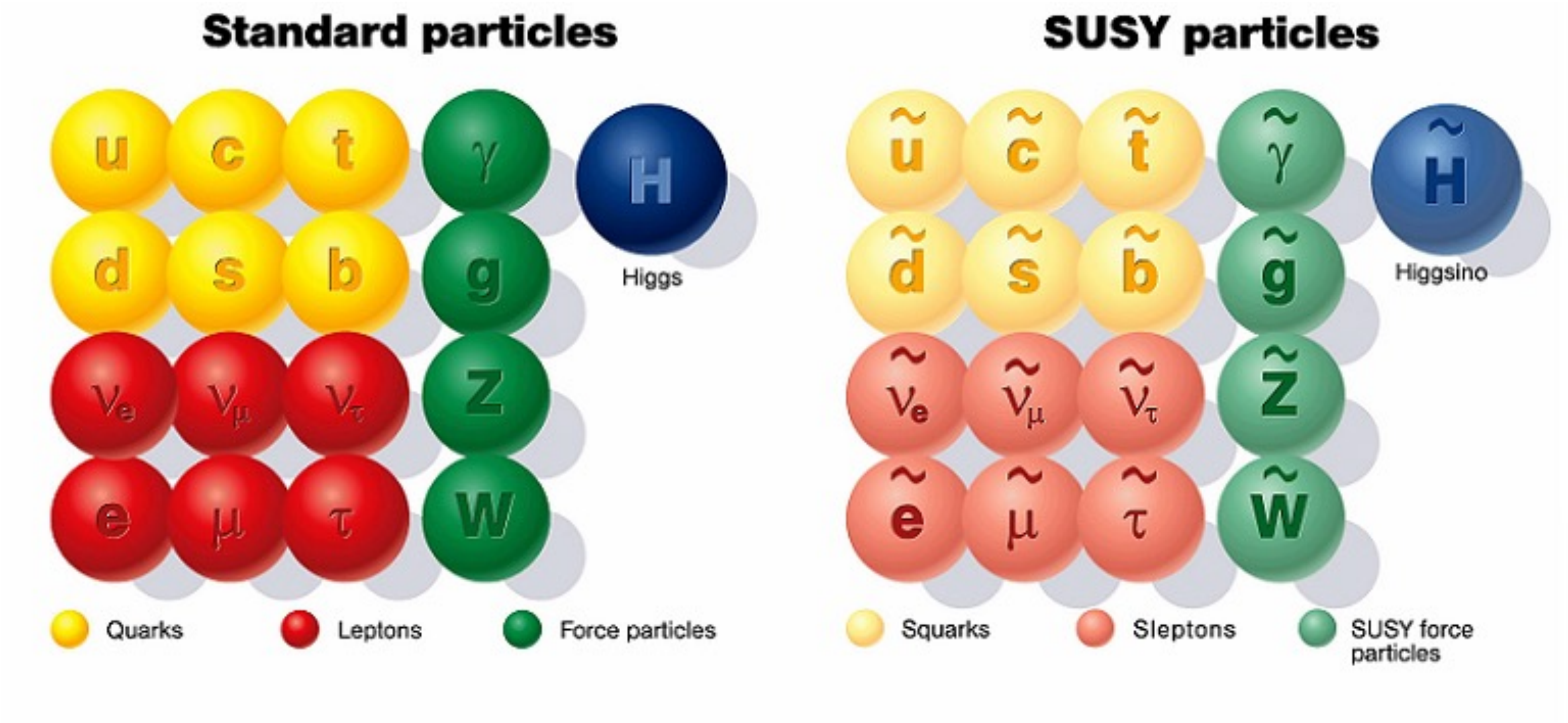


Reduced Higgs coupling modifiers compared to their corresponding prediction from the Standard Model (SM). The error bars represent 68% CL intervals for the measured parameters. In the lower panel, the ratios of the measured coupling modifiers values to their SM predictions are shown. [Taken from: Nature 607 (2022) 60]

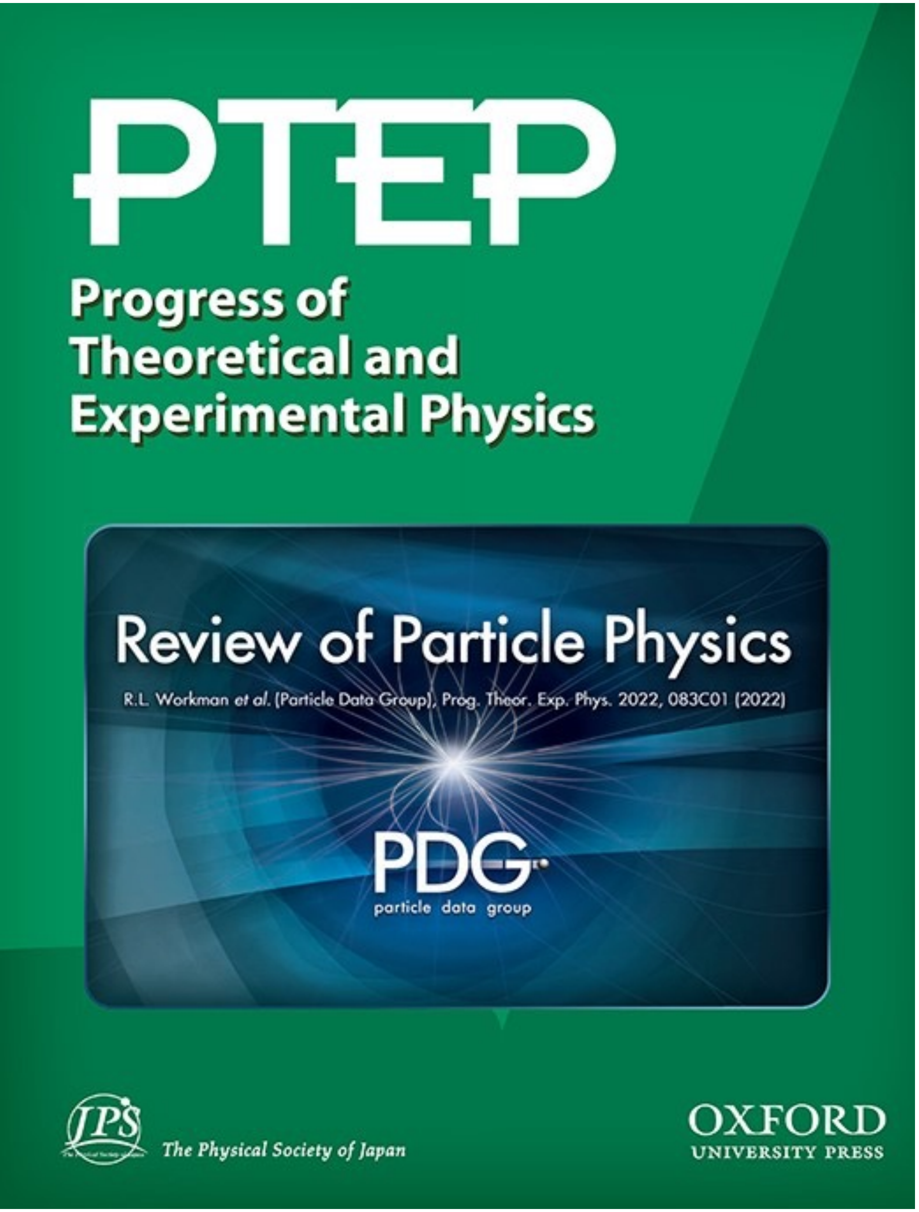
Research program 1: theory and phenomenology of Higgs bosons



Research program 2: theory and phenomenology of TeV-scale supersymmetry (SUSY)



As members of the Particle Data Group, B.C. Allanach and I are co-authors of the biennial Supersymmetry Theory review.



PTEP

Progress of Theoretical and Experimental Physics

Review of Particle Physics

R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

PDG particle data group

JPS The Physical Society of Japan

OXFORD UNIVERSITY PRESS

88. Supersymmetry, Part I (Theory)

Revised August 2023 by B.C. Allanach (DAMTP, Cambridge U.) and H.E. Haber (UC Santa Cruz).

88.1 Introduction

Supersymmetry (SUSY) is a generalization of the space-time symmetries of quantum field theory that transforms fermions into bosons and vice versa [1]. The existence of such a non-trivial extension of the Poincaré symmetry of ordinary quantum field theory was initially surprising, and its form is highly constrained by theoretical principles [2]. SUSY also provides a framework for the unification of particle physics and gravity [3–5] at the Planck energy scale, $M_P \sim 10^{19}$ GeV, where the gravitational interac-

less, with some restrictions on the dimension-three terms
dated in Ref. [10]. The impact of the soft terms becomes
at energy scales much larger than the size of the SUSY-
masses. Thus, a theory of weak-scale supersymmetry,
effective scale of supersymmetry breaking is tied to the
electroweak symmetry breaking, provides a natural fram
the origin and the stability of the gauge hierarchy [6–9].

At present, there is no unambiguous experimental evi
the breakdown of the SM at or below the TeV scale.
pectations for new TeV-scale physics beyond the SM
primarily on three theoretical arguments. First, in a th
an elementary scalar field of mass m and interaction st
(*e.g.*, a quartic scalar self-coupling, the square of a gauge
or the square of a Yukawa coupling), the stability with
quantum corrections requires the existence of an ener
roughly of order $(16\pi^2/\lambda)^{1/2}m$, beyond which new phy
enter [12]. A significantly larger energy cutoff would r
unnatural fine-tuning of parameters that govern the effe
energy theory. Applying this argument to the SM lea
expectation of new physics at the TeV scale [9].

Second, the unification of the three SM gauge coupl
very high energy close to the Planck scale is possible if ne
beyond the SM (which modifies the running of the gauge
above the electroweak scale) is present. The minimal s
metric extension of the SM, where superpartner masses
a few TeV, provides an example of successful gauge cou
fication [13].

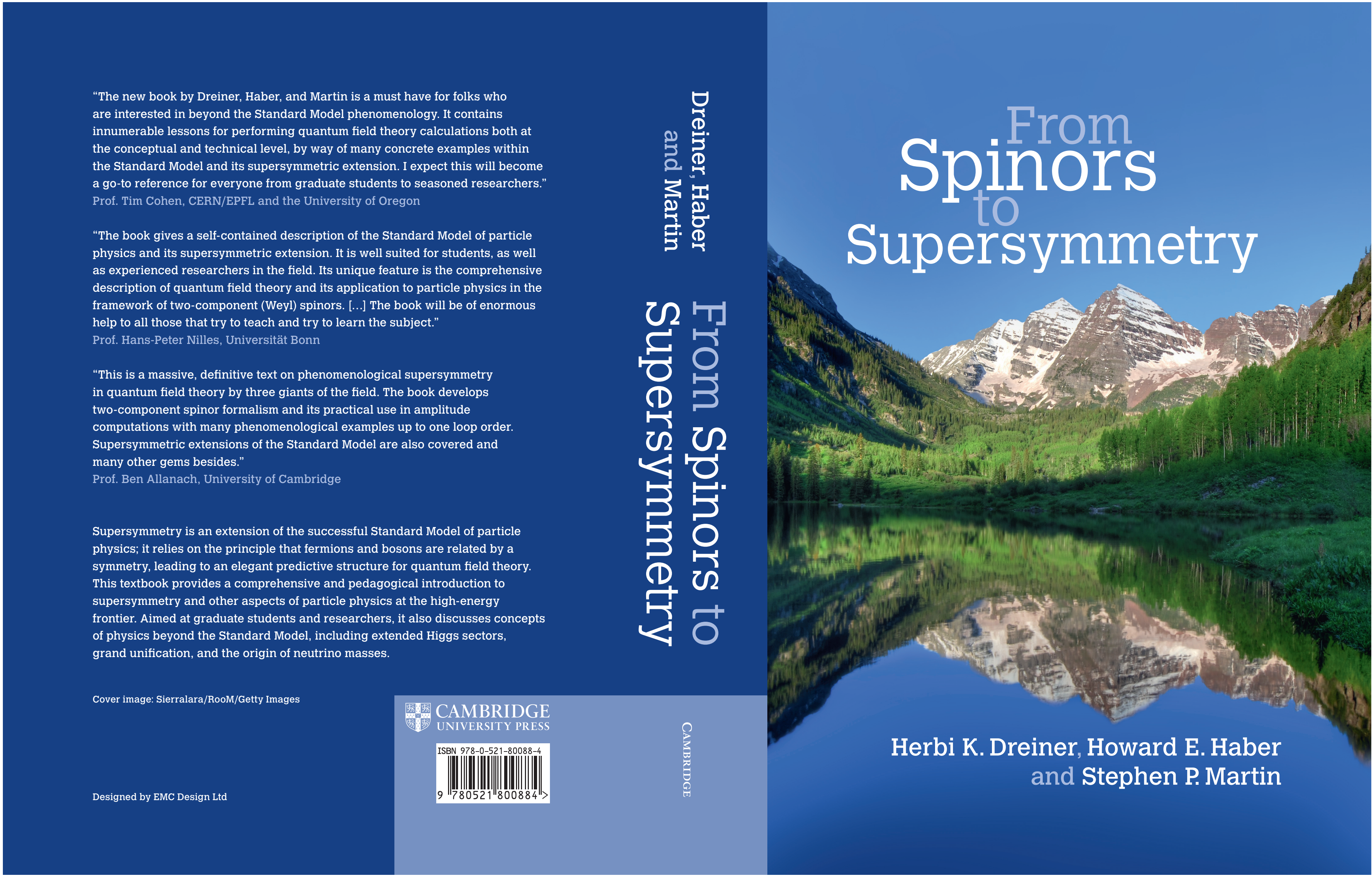
Third, the existence of dark matter that makes up
mately one quarter of the energy density of the univers
be explained within the SM of particle physics [14]. Re
a stable weakly-interacting massive particle (WIMP) wh
and interaction rate are governed by new physics associ
the TeV-scale can be consistent with the observed densit
matter (this is the so-called WIMP miracle, which is re
Ref. [15]). The lightest supersymmetric particle (LSP),
is a promising (although not the unique) candidate for
matter [16–20]. Further aspects of dark matter can be
Sec. 27.

88.2 Structure of the MSSM

The minimal supersymmetric extension of the SM (MS
sists of the fields of the two-Higgs-doublet extension of th
the corresponding superpartner fields [21–25]. A partic
superpartner together form a supermultiplet. The corre
field content of the supermultiplets of the MSSM and th
quantum numbers are shown in Table 88.1. The electr
$Q = T_3 + \frac{1}{2}Y$ is determined in terms of the third com
the weak isospin (T_3) and the U(1) weak hypercharge (

The gauge supermultiplets consist of the gluons and th
fermionic superpartners and the SU(2)×U(1) gauge bo
their gaugino fermionic superpartners. The matter su

Published by Cambridge University Press on June 7, 2023



"The new book by Dreiner, Haber, and Martin is a must have for folks who are interested in beyond the Standard Model phenomenology. It contains innumerable lessons for performing quantum field theory calculations both at the conceptual and technical level, by way of many concrete examples within the Standard Model and its supersymmetric extension. I expect this will become a go-to reference for everyone from graduate students to seasoned researchers."
Prof. Tim Cohen, CERN/EPFL and the University of Oregon

"The book gives a self-contained description of the Standard Model of particle physics and its supersymmetric extension. It is well suited for students, as well as experienced researchers in the field. Its unique feature is the comprehensive description of quantum field theory and its application to particle physics in the framework of two-component (Weyl) spinors. [...] The book will be of enormous help to all those that try to teach and try to learn the subject."
Prof. Hans-Peter Nilles, Universität Bonn

"This is a massive, definitive text on phenomenological supersymmetry in quantum field theory by three giants of the field. The book develops two-component spinor formalism and its practical use in amplitude computations with many phenomenological examples up to one loop order. Supersymmetric extensions of the Standard Model are also covered and many other gems besides."
Prof. Ben Allanach, University of Cambridge

Supersymmetry is an extension of the successful Standard Model of particle physics; it relies on the principle that fermions and bosons are related by a symmetry, leading to an elegant predictive structure for quantum field theory. This textbook provides a comprehensive and pedagogical introduction to supersymmetry and other aspects of particle physics at the high-energy frontier. Aimed at graduate students and researchers, it also discusses concepts of physics beyond the Standard Model, including extended Higgs sectors, grand unification, and the origin of neutrino masses.

Cover image: Sierralara/RooM/Getty Images

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Dreiner, Haber
and Martin

From Spinors to
Supersymmetry

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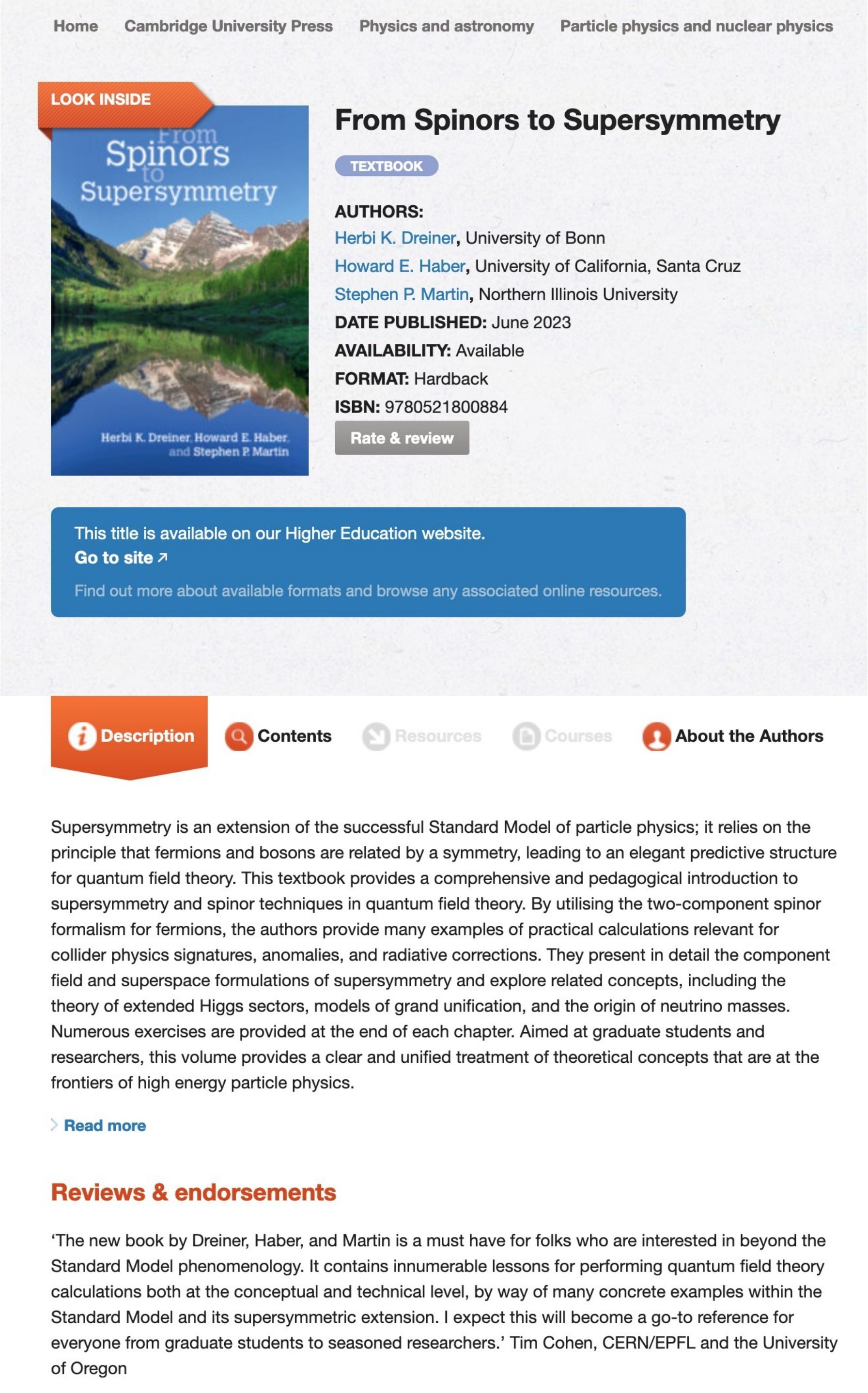
From
Spinors
to
Supersymmetry

Herbi K. Dreiner, Howard E. Haber
and Stephen P. Martin



Home   Cambridge University Press   Physics and astronomy   Particle physics and nuclear physics

From Spinors to Supersymmetry

TEXTBOOK

AUTHORS:
Herbi K. Dreiner, University of Bonn
Howard E. Haber, University of California, Santa Cruz
Stephen P. Martin, Northern Illinois University

DATE PUBLISHED: June 2023
AVAILABILITY: Available
FORMAT: Hardback
ISBN: 9780521800884

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Supersymmetry is an extension of the successful Standard Model of particle physics; it relies on the principle that fermions and bosons are related by a symmetry, leading to an elegant predictive structure for quantum field theory. This textbook provides a comprehensive and pedagogical introduction to supersymmetry and spinor techniques in quantum field theory. By utilising the two-component spinor formalism for fermions, the authors provide many examples of practical calculations relevant for collider physics signatures, anomalies, and radiative corrections. They present in detail the component field and superspace formulations of supersymmetry and explore related concepts, including the theory of extended Higgs sectors, models of grand unification, and the origin of neutrino masses. Numerous exercises are provided at the end of each chapter. Aimed at graduate students and researchers, this volume provides a clear and unified treatment of theoretical concepts that are at the frontiers of high energy particle physics.

› Read more

Reviews & endorsements

‘The new book by Dreiner, Haber, and Martin is a must have for folks who are interested in beyond the Standard Model phenomenology. It contains innumerable lessons for performing quantum field theory calculations both at the conceptual and technical level, by way of many concrete examples within the Standard Model and its supersymmetric extension. I expect this will become a go-to reference for everyone from graduate students to seasoned researchers.’ Tim Cohen, CERN/EPFL and the University of Oregon


Cruz
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From
Spinors
to
Supersymmetry
Herbi K. Dreiner, Howard E. Haber
and Stephen P. Martin

Research program 3: explorations of the Terascale at the LHC and at future colliders

- Studies of non-minimal Higgs sectors
- Precision measurements of new physics observables
- Distinguishing among different theoretical interpretations of new physics signals
- Using a future lepton collider as a precision Higgs factory
- Terascale footprints of lepton-number-violation
- New sources for CP-violation (Higgs and/or SUSY mediated)

Selected Publications (2022—2024)

Classes of complete dark photon models constrained by Z-Physics
M. Bento, H.E. Haber, and J.P. Silva, Phys. Lett. B 850, 138501 (2024).

Tree-level Unitarity in $SU(2)_L \times U(1)_Y \times U(1)_{Y'}$ Models
M. Bento, H.E. Haber, and J.P. Silva, JHEP 10 (2023) 083.

Accommodating Hints of New Heavy Scalars in the Framework of the Flavor-Aligned Two-Higgs-Doublet Model
J.M. Connell, H.E. Haber, and P. Ferreira, Phys.Rev. D 108, 055031 (2023).

Higgs Boson Physics -- The View Ahead
H.E. Haber, Letters in High Energy Physics, LHEP-451 (2023).

P-even, CP-violating Signals in Scalar-Mediated Processes
H.E. Haber, V. Keus, and R. Santos, Phys.Rev. D **106** (2022) 095038.

Exceptional regions of the 2HDM parameter space
H.E. Haber and J.P. Silva, Phys.Rev. D 103, 115012 (2021), Erratum-ibid. D105, 119902 (2022).

Major thrusts in phenomenological particle physics today

➢ What lies beyond the Standard Model and why haven't we seen it yet?

- New physics beyond the Standard Model (BSM) may be associated with a new heavy mass scale of order a few TeV or larger. If accessible at the LHC, not enough events have been produced yet (more luminosity needed). If the LHC is not energetic enough, one would need a higher energy collider facility.

- New BSM physics may be very weakly coupled to the Standard Model (SM). It could consist of completely new sectors of particles (e.g., the dark sector). The origin of dark matter could reside here. Many possibilities exist, so it is difficult to guess where the breakthrough will occur.

- If new BSM physics is completely neutral with respect to the SM, then it can only communicate with the SM via "portals" that consist of products of SM fields that have no net SM (color, weak or EM) charge.
  Examples: the Higgs portal $H^\dagger H$; the neutrino portal $H^\dagger LN$ (N could be a new sterile neutrino); or photon mixing $F_{\mu\nu}X^{\mu\nu}$ (where X is the dark photon).

Should we expect an extended Higgs sector beyond the SM?

- The fermion and gauge boson sectors of the SM are not of minimal form ("who ordered that?"). So, why should the spin-0 (scalar) sector be minimal?

- Adding new scalar states can alleviate the metastability of the vacuum, allowing the Higgs-sector-extended SM to be valid all the way up to the Planck scale.

- Extended Higgs sectors can provide a dark matter candidate.

- Extended Higgs sectors can provide new sources of CP violation (which may be useful in baryogenesis).

- Models of physics beyond the SM often require additional scalar Higgs states. E.g., two Higgs doublets are required in the minimal supersymmetric extension of the SM (MSSM).

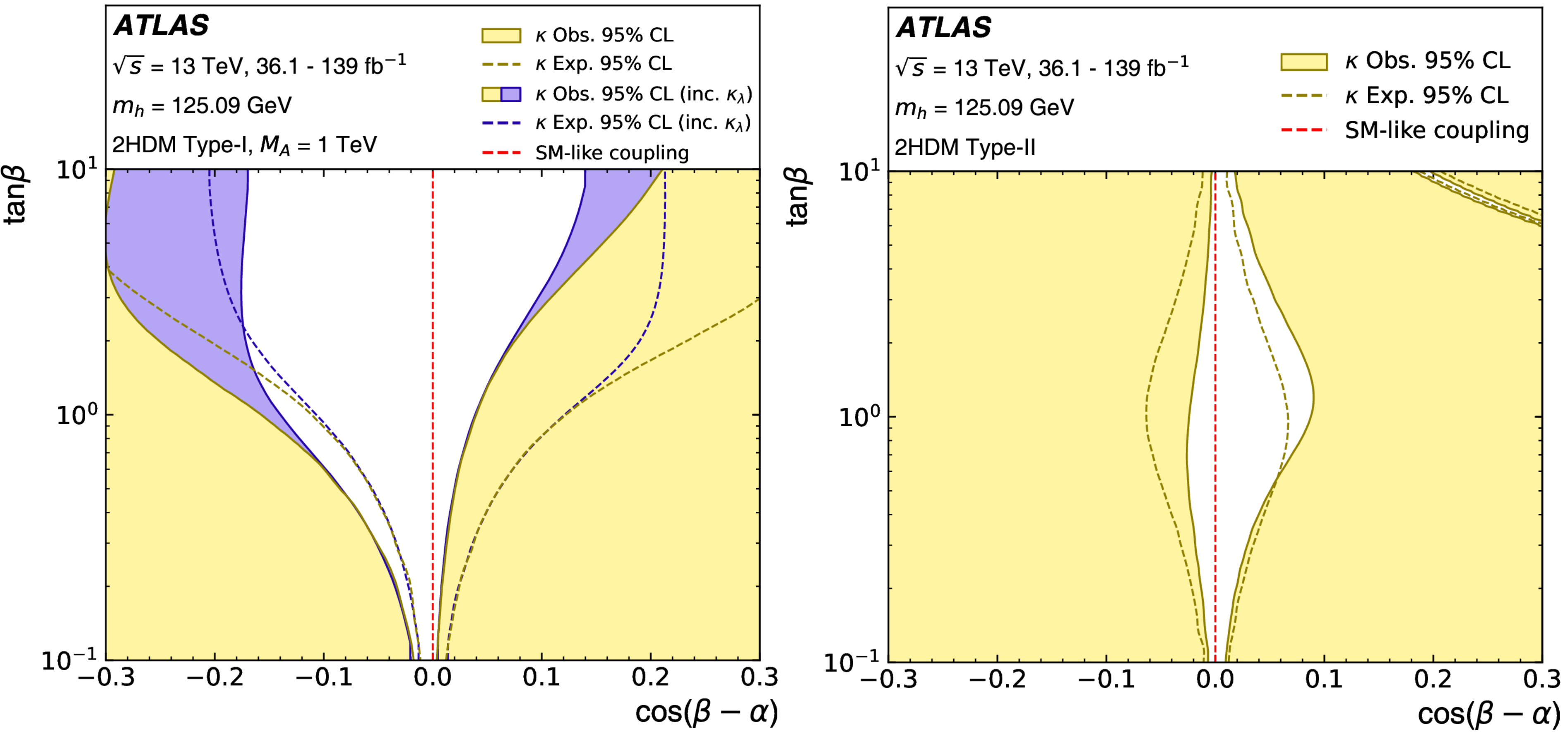
Why is the observed Higgs boson SM-like?

- There is no extended Higgs sector.

- All other scalars (apart from the SM-like Higgs boson) are very heavy
  - This is the decoupling limit.

- A neutral scalar field with the tree-level properties of the SM Higgs boson is an approximate mass eigenstate (due to suppressed mixing with other neutral scalar fields of the extended Higgs sector).
  - This is the Higgs field alignment limit.
  - The other physical scalars of the model may or may not be significantly heavier than the SM Higgs boson. That is, the decoupling limit is a special case of the Higgs field alignment limit.

Experimental constraints on the two Higgs doublet model (2HDM)



Regions excluded at 95% CL in the κ-framework-based approach by the measured rates of Higgs boson production and decays in the 2HDM with Type-I and Type-II Yukawa couplings, respectively. The dark yellow dashed lines show the borders of the corresponding expected exclusion regions for the SM hypothesis. Exact Higgs alignment corresponds to cos(β - α) = 0. Taken from the ATLAS Collaboration, **arXiv:2402.05742**.

My current Ph.D. students and their projects

- 2HDM high energy flavor alignment (with S. Gori and E. Shahly). Eric advanced to Ph.D. candidacy in September, 2020. Expected Ph.D. in December 2024.

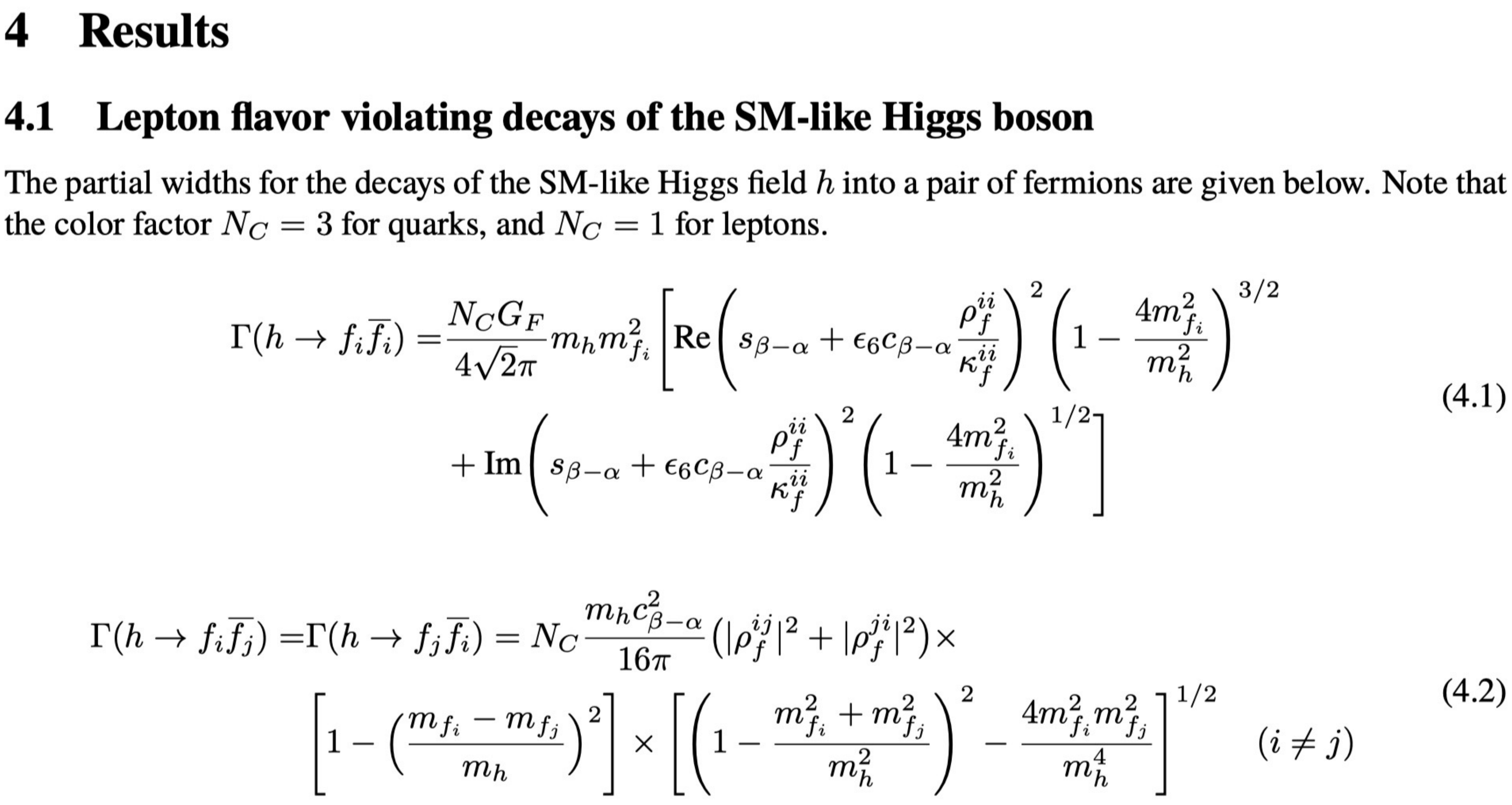
  - Neutral Higgs-mediated flavor violation in the lepton sector.
  - One-loop renormalization of the 2HDM in the Higgs basis.

- Phenomenological aspects of more general 2HDMs (with J.M. Connell). Zippy advanced to Ph.D. candidacy in March, 2021. Expected Ph.D. in June 2024.

  - Explored some (local) 2—3$\boldsymbol{\sigma}$ deviations in LHC searches for new Higgs bosons, with implications for the flavor-aligned 2HDM.

  - Examining the structure of lepton flavor-changing neutral currents mediated by neutral Higgs bosons in extended Higgs models.

From a forthcoming paper in collaboration with Stefania Gori and Eric Shahly. Off-diagonal couplings of the neutral Higgs boson to $\tau\mu$ can be generated if flavor alignment is imposed at a very high energy scale $\boldsymbol{\Lambda}$, due to renormalization group evolution from $\boldsymbol{\Lambda}$ down to the energy scale of electroweak physics (100 GeV).



4 Results

4.1 Lepton flavor violating decays of the SM-like Higgs boson

The partial widths for the decays of the SM-like Higgs field h into a pair of fermions are given below. Note that the color factor $N_C = 3$ for quarks, and $N_C = 1$ for leptons.

$$\begin{aligned}\Gamma(h \to f_i \bar{f}_i) =& \frac{N_C G_F}{4\sqrt{2}\pi} m_h m_{f_i}^2 \left[\mathrm{Re}\left(s_{\beta-\alpha} + \epsilon_6 c_{\beta-\alpha} \frac{\rho_f^{ii}}{\kappa_f^{ii}} \right)^2 \left(1 - \frac{4m_{f_i}^2}{m_h^2} \right)^{3/2} \right. \\ & \left. + \,\mathrm{Im}\left(s_{\beta-\alpha} + \epsilon_6 c_{\beta-\alpha} \frac{\rho_f^{ii}}{\kappa_f^{ii}} \right)^2 \left(1 - \frac{4m_{f_i}^2}{m_h^2} \right)^{1/2} \right]\end{aligned} \tag{4.1}$$

$$\begin{aligned}\Gamma(h \to f_i \bar{f}_j) =& \Gamma(h \to f_j \bar{f}_i) = N_C \frac{m_h c_{\beta-\alpha}^2}{16\pi} \left(|\rho_f^{ij}|^2 + |\rho_f^{ji}|^2 \right) \times \\ & \left[1 - \left(\frac{m_{f_i} - m_{f_j}}{m_h} \right)^2 \right] \times \left[\left(1 - \frac{m_{f_i}^2 + m_{f_j}^2}{m_h^2} \right)^2 - \frac{4 m_{f_i}^2 m_{f_j}^2}{m_h^4} \right]^{1/2} \quad (i \neq j)\end{aligned} \tag{4.2}$$

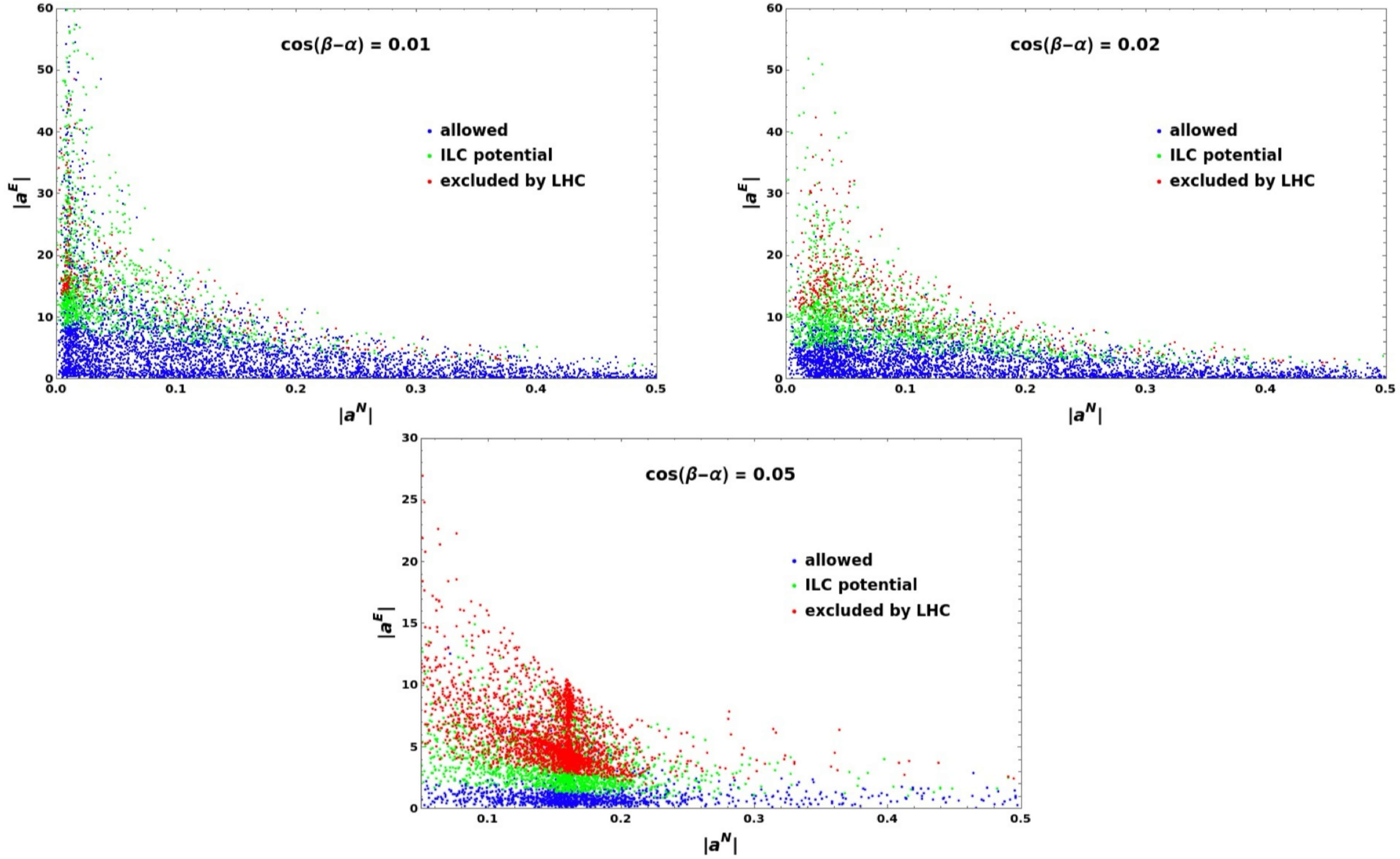


Figure 3: BR($h \to \mu\tau$) results for the case of $\cos(\beta - \alpha) = 0.01$ (left), 0.02 (right) and 0.05 (bottom) for fixed quark parameters $a^U = 0.1$ and $a^D = 1$. Green points indicate choices of the alignment parameters that lead to $h \to \mu\tau$ branching ratios that exceed the projected ILC upper bound of 2.3×10^{-4}, but are not yet excluded by LHC bounds. Red points are already excluded by LHC bounds and blue points remain unexcluded by both current experimental bounds and ILC projections.

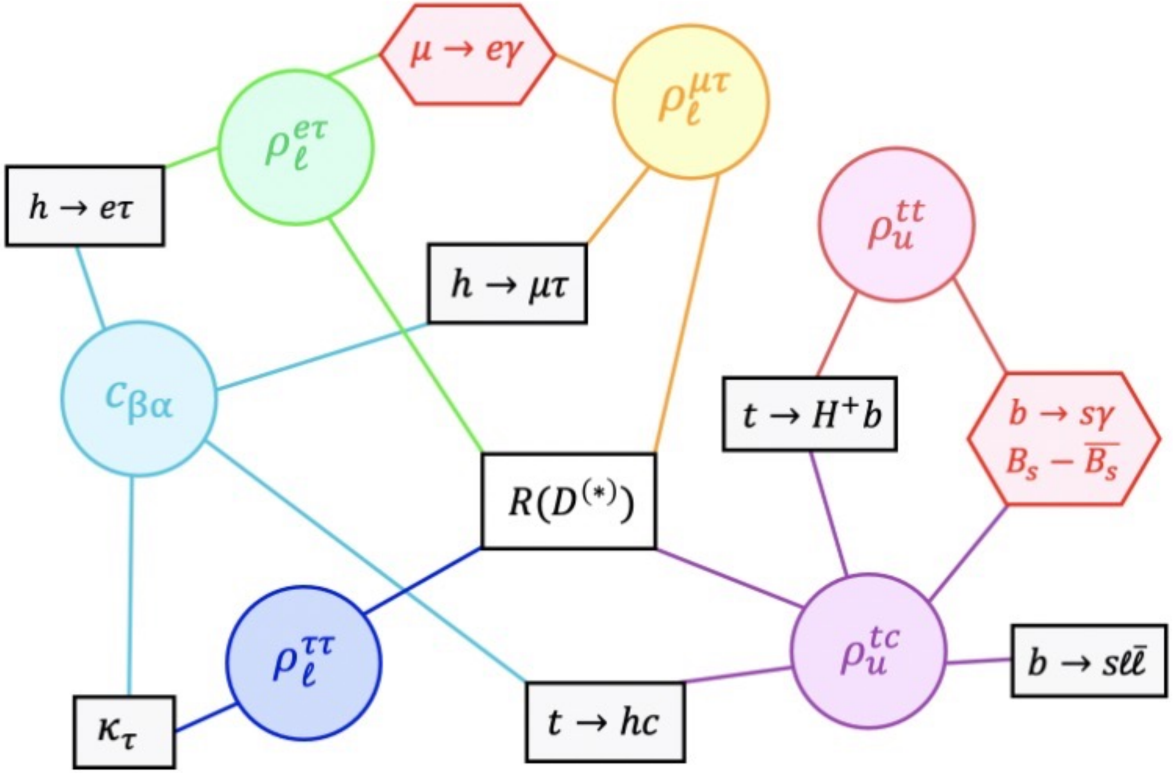


FIG. 3. Diagram showing the correlations between the free parameters (circles) of our model (except the Higgs masses) and the observables. Observables providing strong constraints are shown as red hexagons while the ones pointing towards a NP effect are shown as black rectangles.

Taken from A. Crivellin and S. Iguro, Arxiv: 2311.03430 [hep-ph]

From a forthcoming paper with Joseph Connell. Nondiagonal lepton—Higgs couplings are constrained by many observables. For example, consider $\tau \longrightarrow \mu\,\gamma$.

$$A(\tau \to \mu\gamma) \simeq \frac{1}{16\pi^2}\left(\sqrt{2}\sum_{\phi}\frac{g_{\phi\mu\tau}g_{\phi\tau\tau}}{m_\phi^2}\left(\ln\frac{m_\phi^2}{m_\tau^2}-\frac{3}{2}\right)+2\sum_{\phi,f} g_{\phi\mu\tau}g_{\phi ff}\frac{N_cQ_f^2\alpha}{\pi}\frac{1}{m_\tau m_f}f_\phi(\frac{m_f^2}{m_\phi^2})\right.$$

$$\left.-\sum_{\phi=h,H} g_{\phi\mu\tau}C_{\phi WW}\frac{g\alpha}{2\pi m_\tau m_W}\left[3f_\phi(\frac{m_W^2}{m_\phi^2})+\frac{23}{4}g(\frac{m_W^2}{m_\phi^2})+\frac{3}{4}h(\frac{m_W^2}{m_\phi^2})+m_\phi^2\frac{f_\phi(\frac{m_W^2}{m_\phi^2})-g(\frac{m_W^2}{m_\phi^2})}{2m_W^2}\right]\right)$$

We define three integrals for real positive values of z $[1,2]$:

$$g(z) = \tfrac{1}{2}z\int_0^1 \frac{dx}{x(1-x)-z}\ln\left[\frac{x(1-x)}{z}\right],$$

$$f(z) = \tfrac{1}{2}z\int_0^1 \frac{1-2x(1-x)}{x(1-x)-z}\ln\left[\frac{x(1-x)}{z}\right]dx\,,$$

$$h(z) = -\tfrac{1}{2}z\int_0^1 \frac{dx}{x(1-x)-z}\left\{1-\frac{z}{x(1-x)-z}\ln\left[\frac{x(1-x)}{z}\right]\right\}.$$

Then, one can derive the following expressions for $f(z)$ and $h(z)$ in terms of $g(z)$:

$$f(z) = z(2+\ln z)+(1-2z)g(z)\,,$$

$$h(z) = \frac{z\left[2g(z)+\ln z\right]}{1-4z}\,.$$

An explicit expression for $g(z)$ is given by:

$$g(z)=\begin{cases}\dfrac{z}{\sqrt{1-4z}}\left\{\mathrm{Li}_2(x_+)-\mathrm{Li}_2(x_-)-\tfrac{1}{2}\ln z\ln\left(\dfrac{x_+}{x_-}\right)\right\}, & \text{for } 0<z\leq\tfrac{1}{4}\,,\\[2ex] \dfrac{2z}{\sqrt{4z-1}}\,\mathrm{Cl}_2\left(2\sin^{-1}\dfrac{1}{2\sqrt{z}}\right), & \text{for } z>\tfrac{1}{4}\,,\end{cases} \tag{62}$$

where $x_\pm\equiv\frac{1}{2}\big[1\pm\sqrt{1-4z}\,\big]$ and $0\leq\sin^{-1}[1/(2\sqrt{z})]\leq\frac{1}{2}\pi$ (for $z\geq\frac{1}{4}$). In Fig. 1, we have employed Mathematica (Version 14.0) to produce plots of the functions $g(z)$, $f(z)$ and $-h(z)$ for $0.01\leq z\leq 100$. This figure reproduces the results first shown in Fig. 3 of Ref. [2].

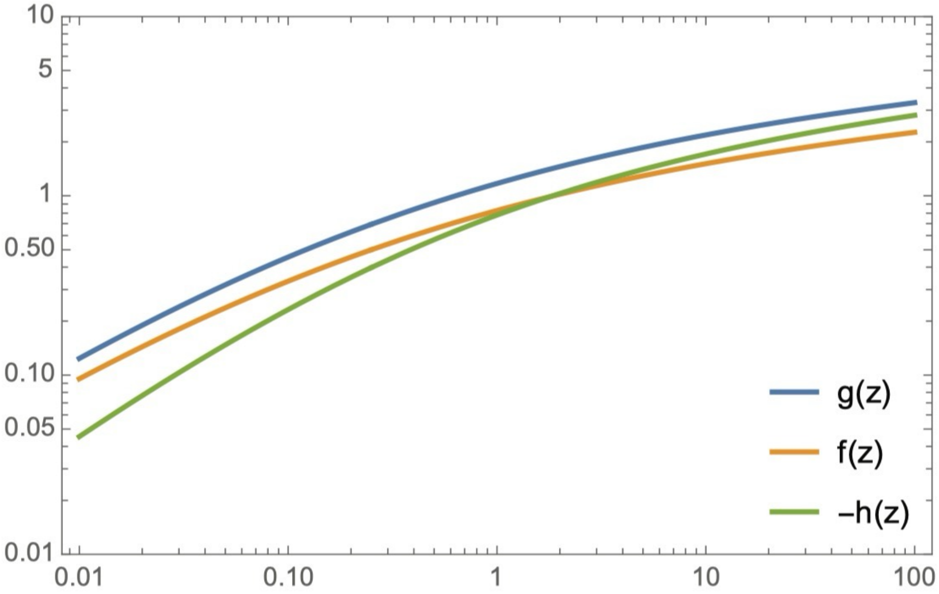


Figure 1: Plots of $g(z)$ given by eq. (62), $f(z)$ given by eq. (60), and $h(z)$ given by eq. (61) as a function of the variable z for $0.01\leq z\leq 100$. These plots were produced using Version 14.0 of Mathematica.

Ongoing and Future Activities

- Higgs alignment at one loop (with Eric Shahly).
- Basis independent treatment of Cheng-Sher ansatz for flavor violation in the Higgs sector (with Joseph Connell).
- Basis-invariant treatment of the 3HDM (with V. Keus).
- Beyond the S, T, and U oblique parameters in extended electroweak models containing a dark Z boson.
- Higgs alignment in 2HDM effective field theory.
- The anapole moment of fundamental particles.

Various projects are waiting for the right Ph.D. student…