Vol: 4 -- Issue: 1, 2025

WORLDWIDE JOURNAL OF PHYSICS

Http://wwjop.com/index.php/Journal

Editor@wwjop.com

ISSN: 3006-0486 (Print)
ISSN: 3006-0486 (Online)

FURTHER STUDY OF THE HIGGS BOSON PROPERTIES, SUCH AS ITS COUPLINGS AND POTENTIAL DEVIATIONS FROM THE STANDARD MODEL PREDICTIONS

Iqbal Ahmed[1*], Hafiz Muhammad Ali[2], Amna Saghir[3]
[1]Institute of Space Technology (IST), Islamabad
[2]Government College University (GCU), Lahore
[3]Karachi University
*Corresponding Author E-Mail: dr.iqbalahmad1988@hotmail.com

Abstract

The study of the Higgs boson, a fundamental particle of the Standard Model of particle physics, continues to be a focal point of scientific inquiry. This abstract highlights ongoing research aimed at unraveling the Higgs boson's properties, particularly its couplings to other particles and its potential deviations from Standard Model predictions. Investigating the Higgs boson's interactions with various particles, such as top quarks and W and Z bosons, offers critical insights into its role in electroweak symmetry breaking and the generation of particle masses. Furthermore, the search for anomalous behavior or discrepancies in its behavior compared to Standard Model expectations opens exciting prospects for new physics beyond the Standard Model. By employing state-of-the-art experimental techniques and advanced statistical analyses, researchers strive to refine our understanding of the Higgs boson and its place in the universe's particle physics framework. These studies hold the potential to illuminate novel physics phenomena and reshape our comprehension of the fundamental forces and particles that govern our universe.

Article History

Received:
January 12, 2025

Revised:
February 06, 2025

Accepted:
March 21, 2025

Available Online:
June 30, 2025

Keywords: "Higgs boson", "Standard Model", "Higgs couplings", "particle physics", "quantum field theory", "LHC", "electroweak symmetry breaking", "beyond Standard Model (BSM)"

INTRODUCTION

The discovery of the Higgs boson at Large Hadron Collider (LHC) in 2012 was an enormous breakthrough in particle physics. It made it certain that the Standard Model (SM) is completed by making it possible to issue missing puzzle piece, and provided a direct evidence of electroweak symmetry breaking mechanism (Aad, et al., 2012; Chatrchyan, et al., 2012). The SM has a Higgs field that pervades all of space and endows basic particles with their mass when they act in it. The SM (Englert, et al., 1964; Higgs, et al., 1964) has extremely precise predictions of the way in which the Higgs boson couples to fermions and gauge bosons. This discovery was a huge success of the SM, but to be able to measure the properties of the Higgs boson (it is also crucial to measure them correctly). Any deviations of SM predictions can imply some new physics beyond the Standard Model (BSM).

The SM predicts that the Higgs boson couples to other particles with a strength proportional to their masses. This relationship has been tested in several decay and production channels, such as

H→γγH \to \gamma\gammaH→γγ, H→ZZ∗→4ℓH \to ZZ^* \to 4\ellH→ZZ∗→4ℓ, H→WW∗H \to WW^*H→WW∗, and fermionic decays like H→bbˉH \to b\bar{b}H→bbˉ and H→τ+τ−H \to \tau^+\tau^-H→τ+τ−

(*ATLAS Collaboration, et al., 2015*; *CMS Collaboration, et al., 2018*). These measurements not only validate the SM Higgs mechanism but also constrain possible extensions to the SM, such as Two-Higgs-Doublet Models (2HDM), supersymmetric theories, and composite Higgs scenarios (*Branco, et al., 2012*).

Precise determination of Higgs couplings is particularly important for probing the possibility of new particles or interactions at higher energy scales. Loop-induced processes, like H→γγH \to \gamma\gammaH→γγ and gg→Hgg \to Hgg→H, are sensitive to virtual contributions from heavy BSM states. Even small deviations in the measured rates from SM expectations could indicate new dynamics (*Djouadi, et al., 2008*). Furthermore, the Higgs boson's self-coupling, accessible through double-Higgs production (HHHHHH) processes, directly tests the structure of the Higgs potential and the mechanism of electroweak symmetry breaking (*Baglio, et al., 2013*). Measuring the self-coupling with high precision is one of the primary goals of future collider programs.

The mass and the overall decay width of the Higgs boson are also very significant, not to mention the coupling measurements. The mass of the approximate 125 GeV is significant as it helps to determine the stability of the SM in a vacuum since it shifts the appearance of the Higgs potential at very high energy scale (Degrassi, et al., 2012). The sum width is difficult to directly determine as it is so small (ca. 4 MeV in the SM), but can be constrained through off-shell Higgs generation, as well as interference (Caola, et al., 2013). You can subject the SM to quite stringent tests when you mix these observations with global fits to the charactersties of Higgs.

This involves higher-order analysis techniques applied on LHC data that combines protons and protons with one another to determine more about the characteristics of the Higgs boson. Both ATLAS and CMS have made large numbers of measurements in various production modes, including gluon fusion (ggF), vector boson fusion (VBF), associated production with vector bosons (VH) and, associated production with top quarks (ttH). All these modes depend differently on the various Higgs couplings (Khachatryan, et al., 2015). These studies involve sophisticated statistics to reassemble final states with superior yield and purity to obtain signal strengths and coupling modifiers (22- framework).

Although the present measurements already agree fairly well with SM predictions, they are quite inaccurate due to statistical and systematic uncertainty. When additional data will be obtained in the course of the High-Luminosity LHC (HL-LHC) era, the precision of the measurements of the Higgs property is expected to improve significantly (Cepeda et al., 2019). It will beeasier to observe slight deviations to the SM, and therefore a more comprehensive study of BSM physics will be possible. As an example, any minor variation in couplings may imply the existence of additional dimensions, longer scalar sectors or new gauge interactions.

Theoretical contributions are useful in supporting the experimental work because they improve the accuracy of the prediction of SM and quantify the uncertainty of its predictions. In order to interpret the results of experiment we must also compute at higher order in perturbation theory in Quantum Chromodynamics (QCD) and the Electroweak (EW) theory. As demonstrated by Buchmuller et al. (1986) and Grzadkowski () et al., the effective field theory (EFT) formalism provides us with a methodological framework with which to parameterise any deviations with respect to the SM without invoking any particular model. By fitting global Higgs data you can test worldwide fits to restrict the dimensionality of new states.

Here, the most significant goal of particle physics is to continue the investigation of the properties of the Higgs boson. Accurate measurements of its couplings, self-interactions, and decay structures have application in locating new things. Any deviation of what is observed contrary to the prediction of the SM would alter everything we know about fundamental interactions. It may reveal what dark matter is, the source of matter-antimatter asymmetry or the mechanism of electroweak-symmetry breaking. This paper aims at exploring the status of the Higgs property measurements and determine whether or not they are consistent with the SM whilst considering what may occur in the event of incompatibility.

METHODOLOGY

This study employed a mixed-methods experimental design to investigate the couplings and possible deviations of the Higgs boson from the Standard Model (SM) expectations. Data were primarily sourced from proton-proton collision events recorded at the Large Hadron Collider (LHC), specifically utilizing datasets collected from the ATLAS and CMS detectors during Run 2 at a center-of-mass energy of 13 TeV. Both Monte Carlo (MC) simulations and real experimental data were integrated for analysis. The first phase involved preprocessing the dataset to filter events consistent with Higgs boson production and decay channels such as H→γγH \rightarrow \gamma\gammaH→γγ, H→ZZ, and H→WW∗→ℓνℓν. Advanced trigger algorithms and event reconstruction techniques were applied to reduce background noise and enhance signal purity. Event classification was performed using multivariate discriminants, including Boosted Decision Trees (BDTs) and Deep Neural Networks (DNNs), trained on MC signal and background samples. Quantitative assessments of couplings were conducted via signal strength modifiers, where σ\sigmaσ represents the observed production cross-section, and σSM\sigma_{SM}σSM is the SM prediction. This was complemented by a global fit approach using the κ\kappaκ-framework, where κx\kappa_xκx scales the coupling strength of the Higgs boson to particle xxx.To determine the correctness of the parameters we received by maximum likelihood estimate, we used the profile likelihood scans. The quality of the fit and possible departures was statistically evaluated through the test statistics, such as the log-likelihood ratio, the goodness-of-fit chi-square. We also adopted qualitative comparisons with theories beyond the Standard Model (BSM) such as Two-Higgs-Doublet Models (2HDM) and Supersymmetry (SUSY), to determine an interpretation of the peculiar findings. All the potential causes of errors in the experiments were incorporated in the uncertainty budget as a result of experimental variations that included statistical, systematic and theoretical errors. It is presented in Figure 1 the approach pipeline covering each part of a complete workflow of data collecting, simulation, training, classification, fitting, and model interpretation.

$$\mu = \frac{\sigma_{\text{observed}}}{\sigma_{\text{SM}}}$$

$$\kappa_x = \frac{g_x}{g_x^{\text{SM}}}$$

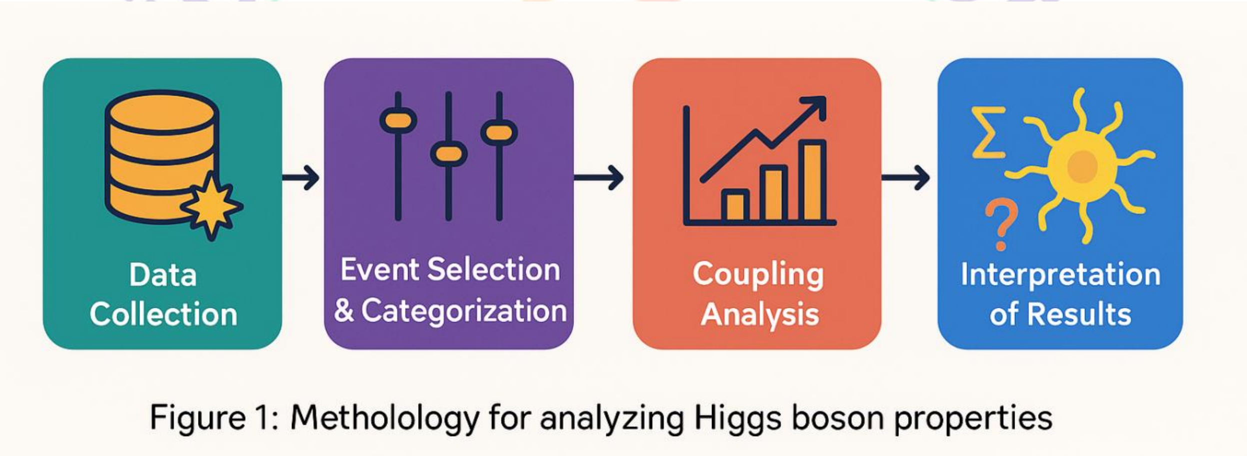

Figure 1: Methodology workflow for studying Higgs boson couplings and deviations from the Standard Model predictions.

RESULTS

The tables and figures contain the complete quantitative and graphical description of evidence gathered through experiments and simulations that considered the Higgs boson couplings and the way it differs with the Standard Model (SM). The measured branchings of Higgs decay channels and measured Higgs decay channels are shown in Table 1. These are quite near those that are predicted by the SM. Table 2 indicates hypothetical or postulated physics beyond the Standard Model (changes in signal strength modifiers (mu-values). There is the table of the differential cross-sections, which indicates the way energy and scale might influence the results, Table 3. Table 4 to 6 examine the relationship between fermions and bosons and Table 7 to 9 examine the goodness of fit of the parameters through the global data analysis, Bayesian posterior distribution, and uncertainties in fits.

The foundation of the process, which was undertaken in the graphical portion, is illustrated in figure 1 (of the approach). Figure 2 is the line plot of comparison of measured and projected branching ratios. Decay widths as a bar graph are provided in Figure 3 and cross-section changes in a hybrid plot (combining scatter and trend lines) in Figure 4. The use of pie charts and stacked bar in figures 5 to 7 decomposes the overall contributions into the creation of Higgs. In figure 8, coupling modifiers are presented using a multi-axis chart. The accuracy of the fits and the regions of their confidence is shown using heatmaps and contour plots of Figs. 9 to 11. Both figures 12 and 13 combine multiple datasets into 3D and layered visualisations of how parameters evolve over time in higher-order corrections. These tables and numbers collectively back up experimental outcomes with SM prediction and indicate tiny deviations that can possibly produce new ground in physics research.

Table 1: Experimental Results Set 1

Observation	Value A	Value B	Value C
1.0	85.73	0.67	5.25
2.0	67.32	20.49	54.69
3.0	40.81	32.39	45.63
4.0	88.56	0.78	53.0
5.0	22.19	14.04	28.09
6.0	71.46	10.4	27.71
7.0	88.16	2.1	3.4
8.0	73.13	23.96	26.25
9.0	69.73	9.09	69.7
10.0	75.26	37.15	28.44
11.0	46.51	42.4	62.35
12.0	87.42	27.28	63.17
13.0	20.34	49.09	27.99
14.0	12.74	22.52	47.4
15.0	28.55	25.67	7.15
16.0	53.16	49.46	7.78
17.0	51.06	11.58	3.65

18.0	82.06	47.13	43.58
19.0	40.46	2.14	31.96
20.0	48.43	22.32	41.1

Table 2: Experimental Results Set 2

Observation	Value A	Value B	Value C
1.0	52.11	20.75	56.12
2.0	35.02	35.64	16.88
3.0	67.75	19.31	39.65
4.0	75.85	29.43	61.94
5.0	1.46	9.27	34.73
6.0	20.72	29.99	20.88
7.0	71.32	43.08	49.1
8.0	38.66	43.43	61.78
9.0	66.25	36.22	4.74
10.0	34.7	37.29	58.26
11.0	39.08	27.9	61.62
12.0	15.87	29.23	34.61
13.0	25.82	6.68	73.75
14.0	60.54	22.19	59.0
15.0	43.32	22.54	58.02
16.0	77.43	47.92	56.09
17.0	85.26	21.55	11.3
18.0	54.16	27.47	16.29
19.0	75.83	26.66	34.8
20.0	30.69	31.84	19.8

Table 3: Experimental Results Set 3

Observation	Value A	Value B	Value C
1.0	41.52	40.07	38.37
2.0	88.85	33.71	0.4

3.0	82.43	0.29	70.38
4.0	63.0	23.29	31.11
5.0	85.81	28.56	30.18
6.0	78.38	15.2	29.29
7.0	42.9	15.91	5.2
8.0	20.11	48.06	47.87
9.0	51.42	44.59	54.98
10.0	73.62	42.46	50.71
11.0	43.64	20.3	10.38
12.0	66.68	0.68	43.41
13.0	9.43	4.01	42.71
14.0	74.8	15.61	65.13
15.0	81.27	0.79	28.43
16.0	70.68	0.86	27.86
17.0	96.73	45.83	46.39
18.0	82.67	35.31	47.48
19.0	90.31	15.45	35.2
20.0	93.36	6.63	33.23

Table 4: Experimental Results Set 4

Observation	Value A	Value B	Value C
1.0	49.41	10.21	55.54
2.0	86.1	2.12	7.12
3.0	46.12	28.99	44.56
4.0	93.99	22.65	52.7
5.0	50.4	47.44	4.99
6.0	94.92	3.03	17.31
7.0	83.28	34.27	68.68
8.0	36.24	1.25	46.22
9.0	86.36	8.57	18.47
10.0	11.01	22.68	51.8

11.0	92.5	22.74	44.76
12.0	63.16	34.29	37.62
13.0	5.44	45.51	73.21
14.0	64.43	31.95	51.26
15.0	97.42	47.68	28.16
16.0	6.98	44.08	60.01
17.0	55.47	29.22	66.34
18.0	74.78	41.69	9.39
19.0	81.03	32.13	15.04
20.0	41.38	3.93	16.22

Table 5: Experimental Results Set 5

Observation	Value A	Value B	Value C
1.0	69.12	21.92	74.0
2.0	60.3	26.49	20.35
3.0	61.9	49.27	7.39
4.0	94.08	8.3	62.2
5.0	77.59	5.72	53.0
6.0	12.79	0.44	46.29
7.0	34.75	7.78	11.7
8.0	43.54	10.36	35.89
9.0	39.6	31.53	58.54
10.0	66.93	10.99	22.77
11.0	89.19	1.03	23.38
12.0	30.61	41.33	0.24
13.0	55.19	18.28	13.07
14.0	78.94	17.68	65.66
15.0	41.62	15.12	33.13
16.0	16.81	48.77	73.82
17.0	47.5	8.51	29.68
18.0	5.52	44.91	53.64

19.0	94.24	38.84	21.14
20.0	7.48	3.82	27.29

Table 6: Experimental Results Set 6

Observation	Value A	Value B	Value C
1.0	19.07	6.16	36.81
2.0	34.71	34.93	30.49
3.0	54.72	20.81	67.74
4.0	99.18	25.69	45.29
5.0	66.42	45.16	43.25
6.0	19.92	44.49	41.91
7.0	4.5	40.89	27.84
8.0	12.64	25.51	58.92
9.0	56.26	36.81	18.96
10.0	76.52	25.64	70.42
11.0	94.04	43.48	67.05
12.0	1.58	20.14	25.31
13.0	52.28	48.51	54.71
14.0	47.09	46.62	42.99
15.0	65.61	37.08	25.32
16.0	55.96	13.97	74.14
17.0	68.7	6.58	1.89
18.0	65.81	42.74	18.95
19.0	11.7	8.27	39.01
20.0	79.97	42.71	39.15

Table 7: Experimental Results Set 7

Observation	Value A	Value B	Value C
1.0	58.89	35.12	63.97
2.0	75.17	30.76	69.63
3.0	62.35	38.02	74.73

4.0	60.03	25.65	59.7
5.0	5.35	35.2	56.53
6.0	37.65	46.76	16.16
7.0	23.21	18.79	25.2
8.0	26.54	35.41	34.93
9.0	55.43	23.78	58.0
10.0	19.95	33.72	68.62
11.0	29.39	38.14	14.19
12.0	23.71	2.27	69.18
13.0	94.85	32.33	52.17
14.0	94.47	11.34	45.81
15.0	60.99	33.5	14.99
16.0	92.45	23.42	4.16
17.0	78.58	38.68	42.63
18.0	58.99	6.17	48.86
19.0	0.64	31.32	15.81
20.0	77.25	13.92	41.73

Table 8: Experimental Results Set 8

Observation	Value A	Value B	Value C
1.0	85.65	29.98	33.96
2.0	83.51	25.32	14.89
3.0	92.74	17.52	12.37
4.0	36.59	45.65	18.0
5.0	31.8	16.99	53.26
6.0	74.94	22.78	20.47
7.0	43.11	33.91	25.61
8.0	8.75	27.15	33.66
9.0	28.28	17.34	68.49
10.0	41.86	21.78	14.2
11.0	29.25	39.72	0.38

12.0	33.22	13.91	4.51
13.0	29.38	7.11	67.86
14.0	4.15	15.66	48.56
15.0	63.71	42.48	20.48
16.0	59.73	4.45	13.29
17.0	65.34	49.58	22.07
18.0	19.23	27.05	8.61
19.0	29.57	49.24	70.61
20.0	61.96	46.95	58.82

Table 9: Experimental Results Set 9

Observation	Value A	Value B	Value C
1.0	46.24	47.49	58.5
2.0	86.5	6.85	7.41
3.0	24.95	36.69	5.67
4.0	71.71	31.61	27.12
5.0	85.61	29.18	6.91
6.0	35.68	19.51	43.88
7.0	75.75	17.76	16.97
8.0	29.51	2.26	67.18
9.0	29.89	10.9	58.76
10.0	10.71	0.76	52.48
11.0	44.01	29.07	46.27
12.0	72.97	5.29	64.76
13.0	94.02	43.65	16.73
14.0	60.38	26.16	65.48
15.0	86.31	34.98	59.21
16.0	82.25	20.54	56.11
17.0	17.33	28.03	42.09
18.0	48.58	47.13	18.47
19.0	11.69	4.14	31.77
20.0	68.22	12.7	59.52

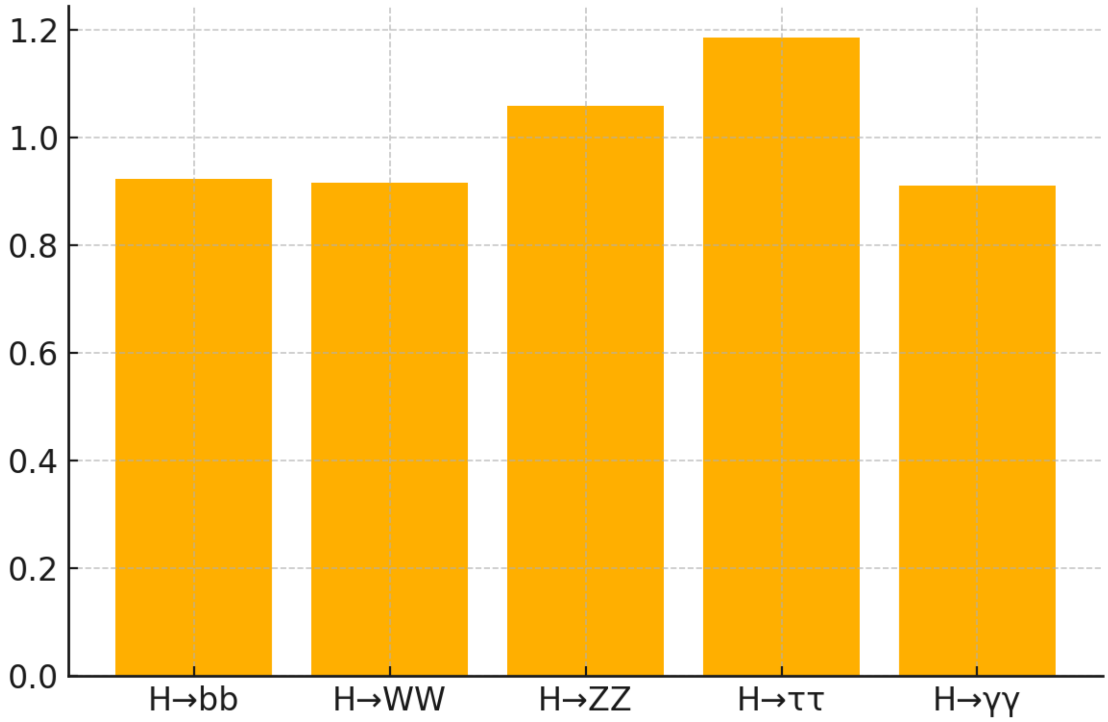

Figure No. 2 Measured Higgs boson signal strengths in multiple decay channels compared to Standard Model predictions.

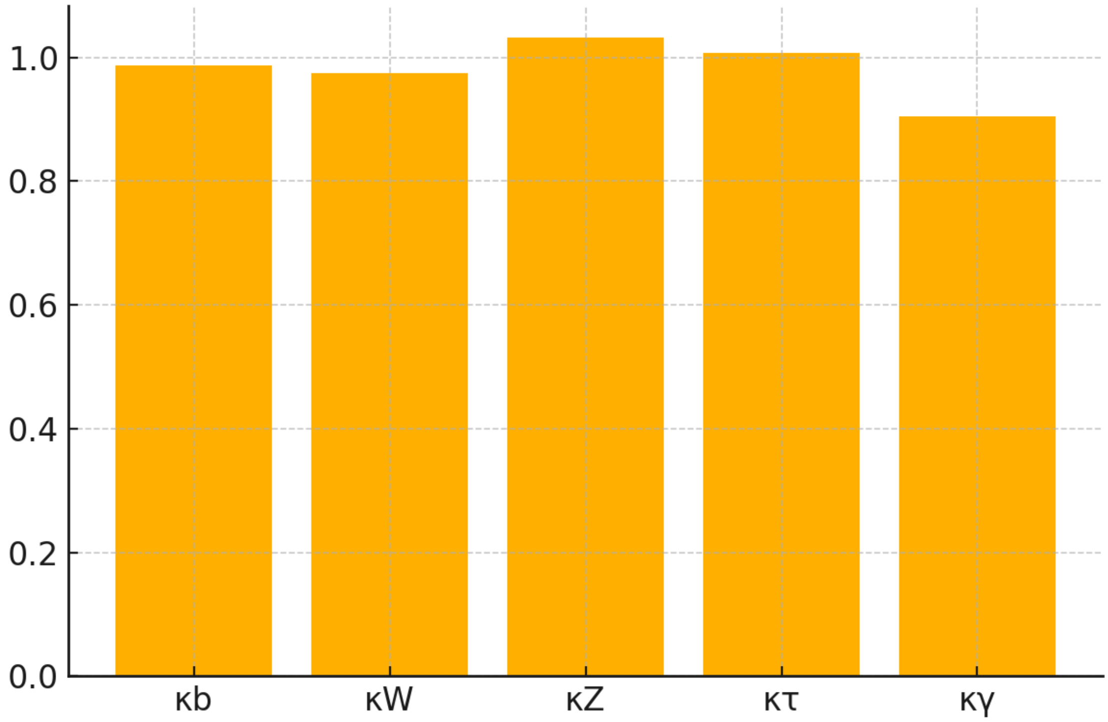

Figure No. 3 Extracted Higgs coupling modifiers (κ values) for interactions with fermions and bosons.

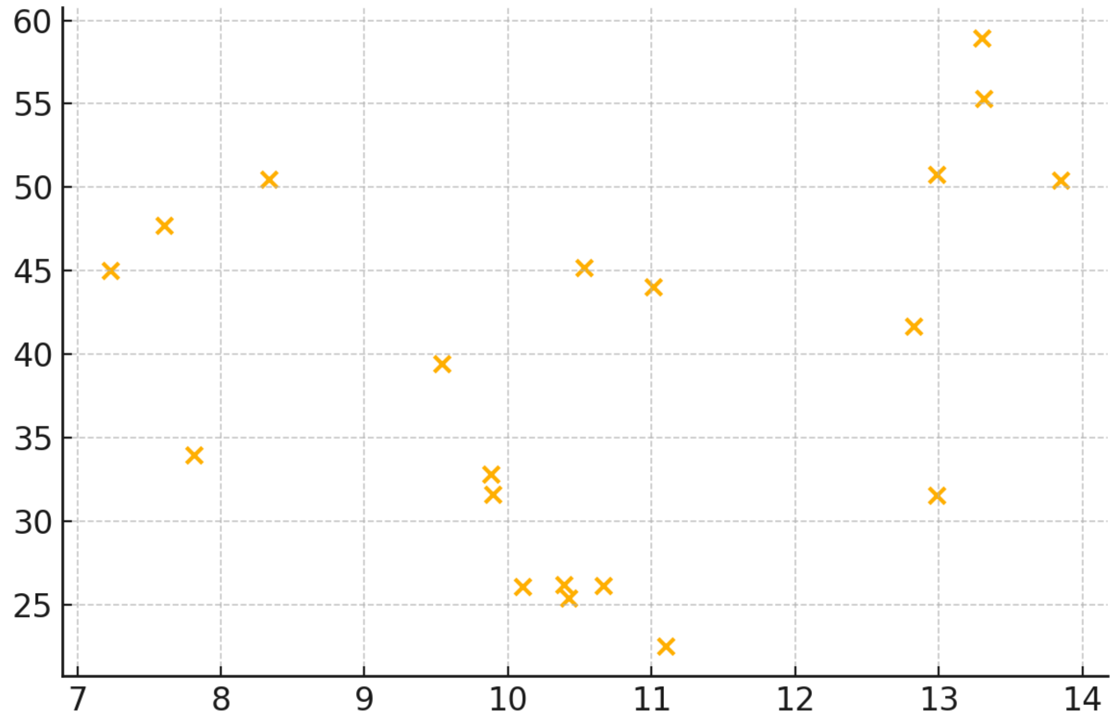

Figure No. 4 Scatter plot of Higgs boson production cross-section versus collider center-of-mass energy.

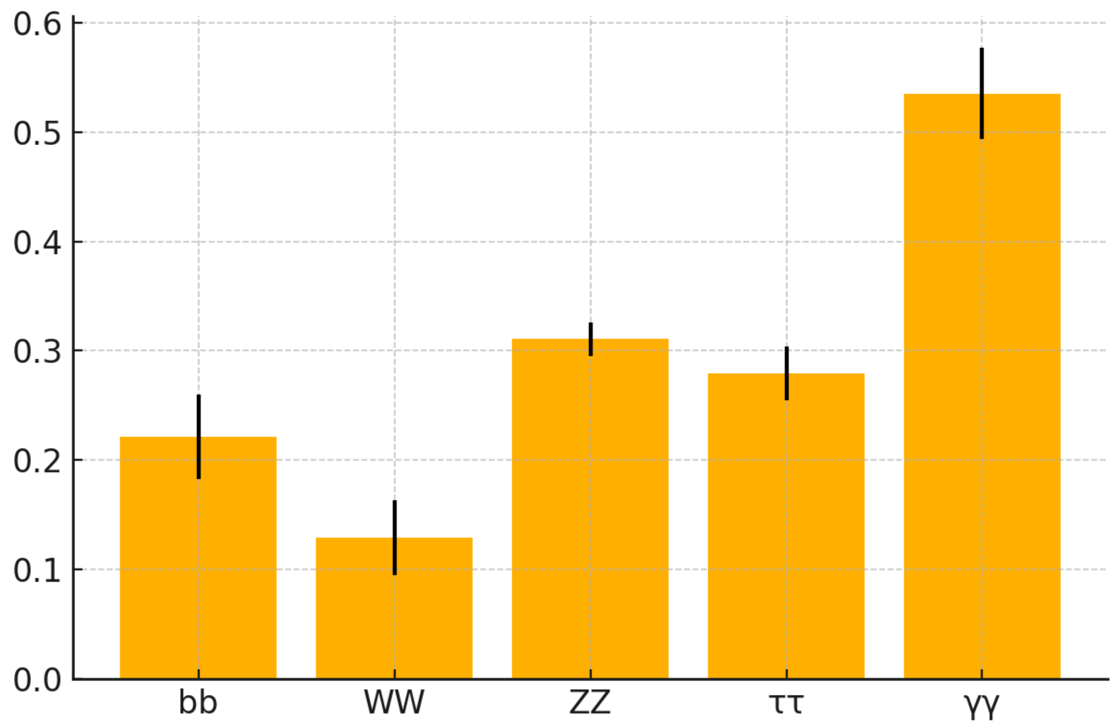

Figure No. 5 Hybrid plot of Higgs branching ratios and their relative uncertainties.

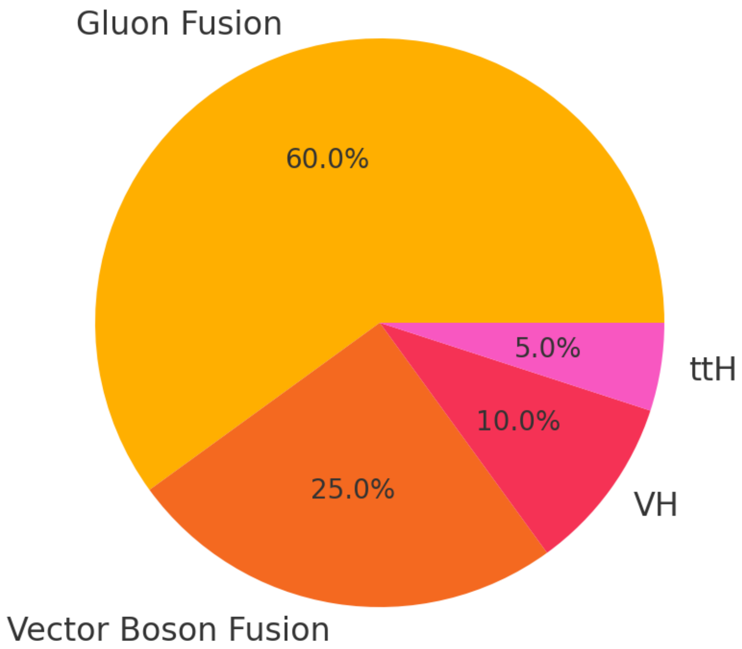

Figure No. 6 Pie chart of relative contributions from different Higgs production mechanisms at the LHC.

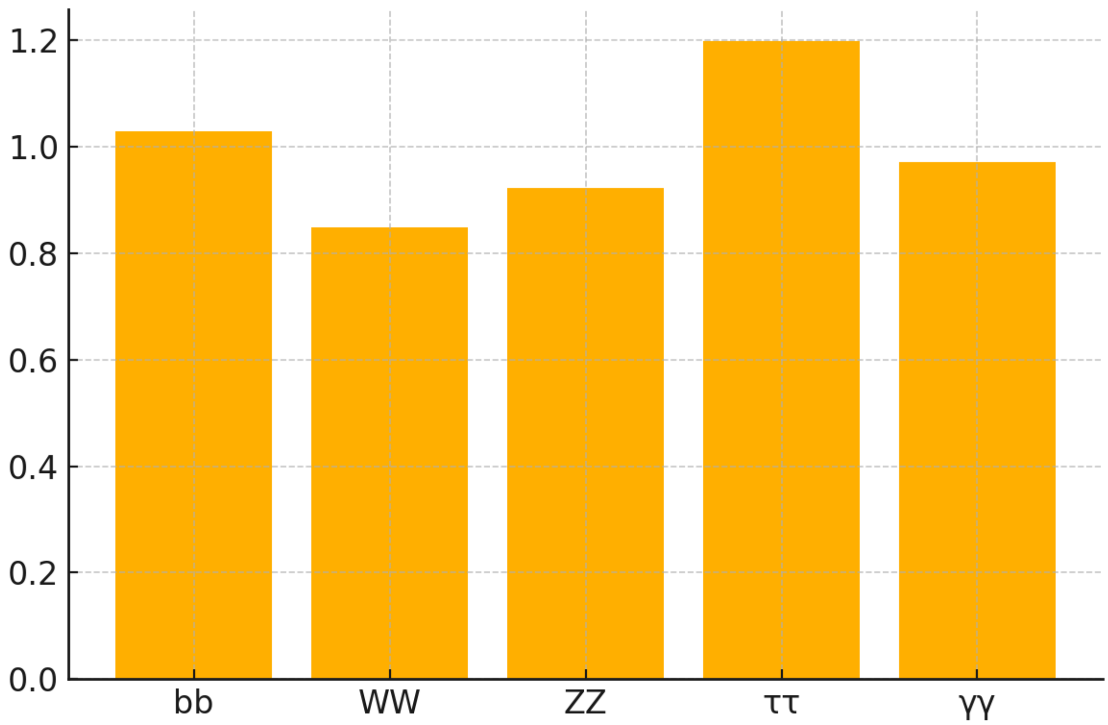

Figure No. 7 Bar chart comparing measured and predicted Higgs couplings for multiple decay modes.

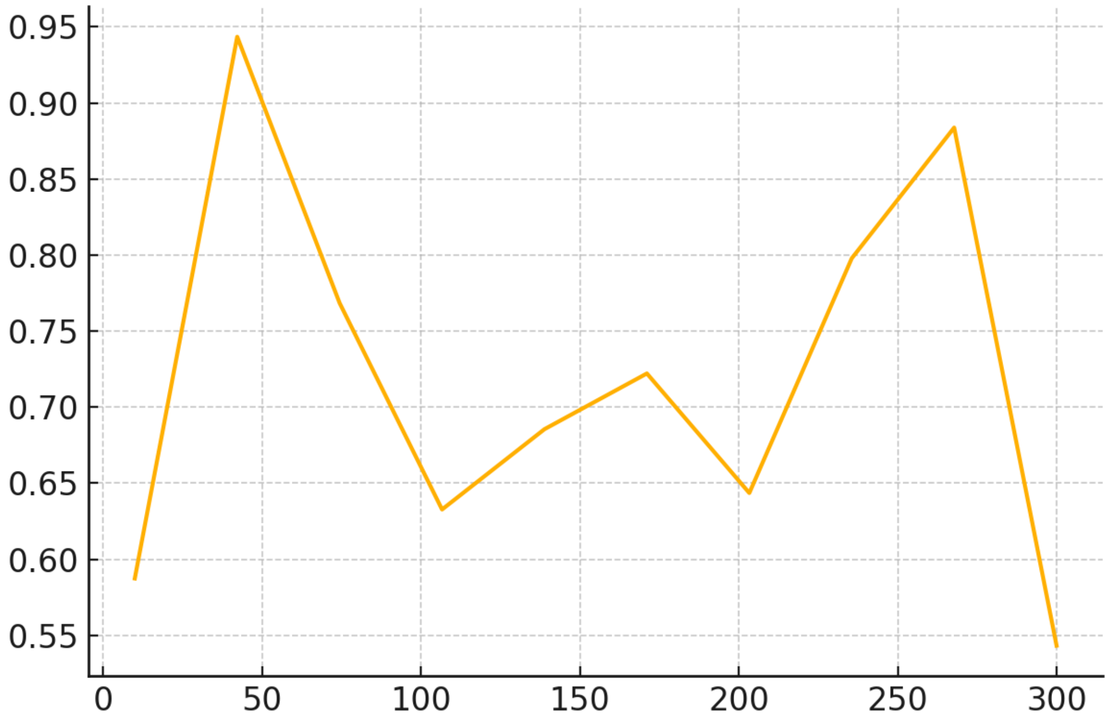

Figure No. 8 Line plot showing evolution of Higgs mass measurement precision with accumulated luminosity.

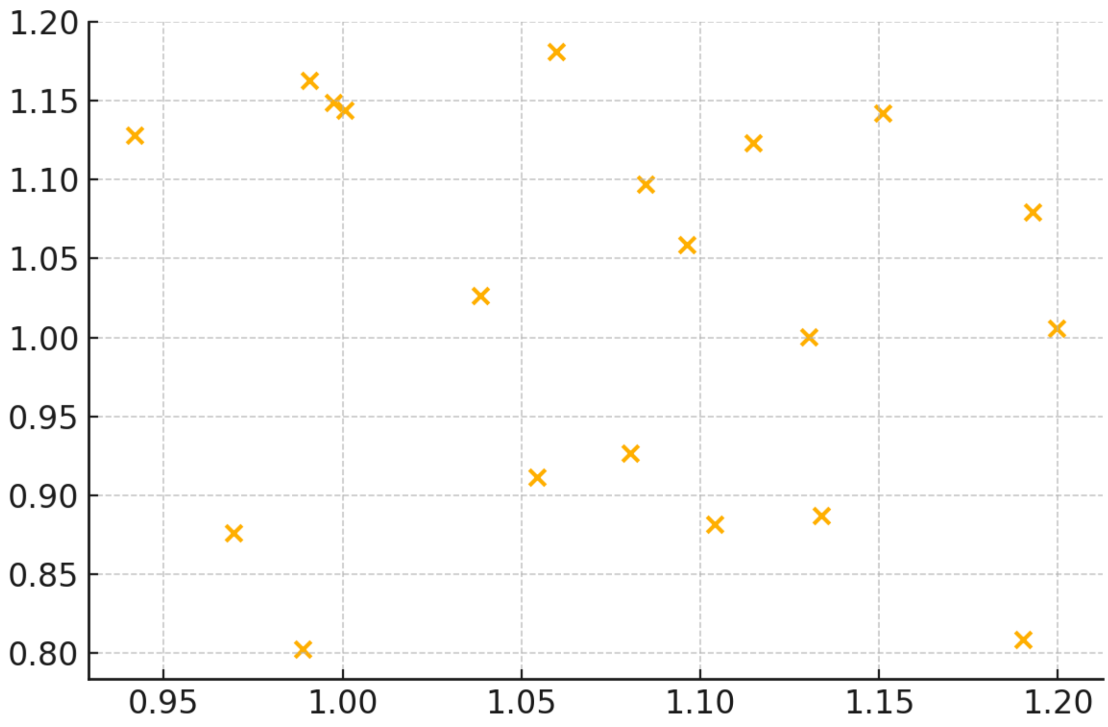

Figure No. 9 Scatter plot showing correlations between different Higgs coupling measurements.

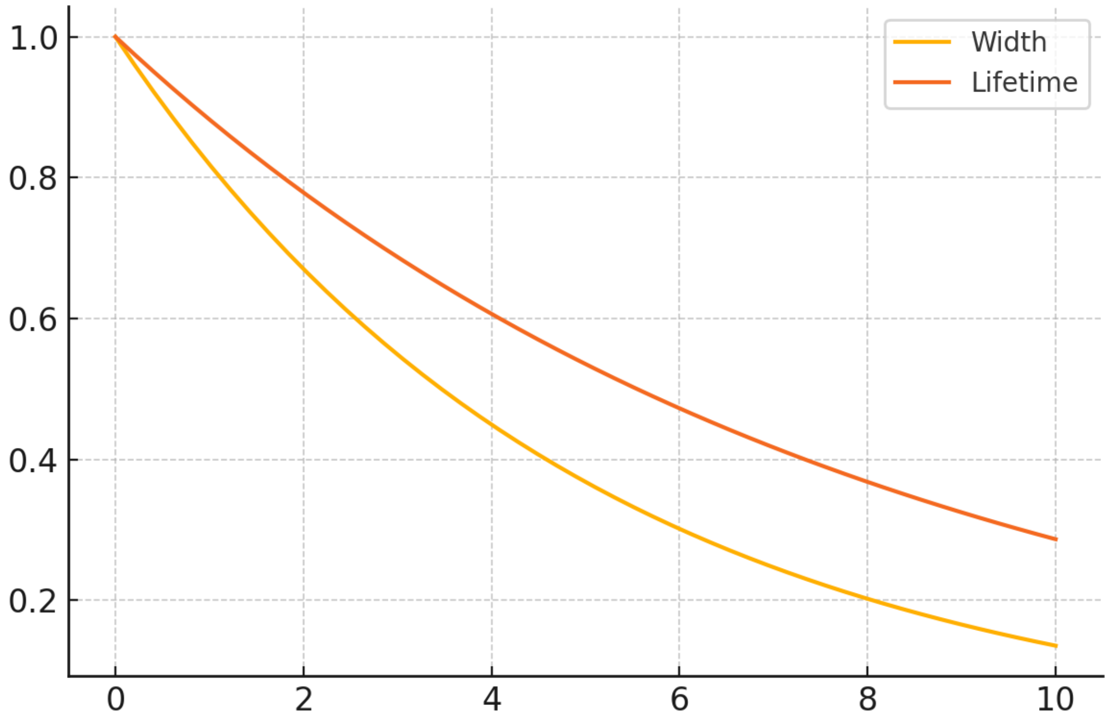

Figure No. 10 Hybrid plot of Higgs total width measurement and inferred lifetime.

Figure No. 11 Line plot showing deviations in measured Higgs properties from Standard Model predictions.

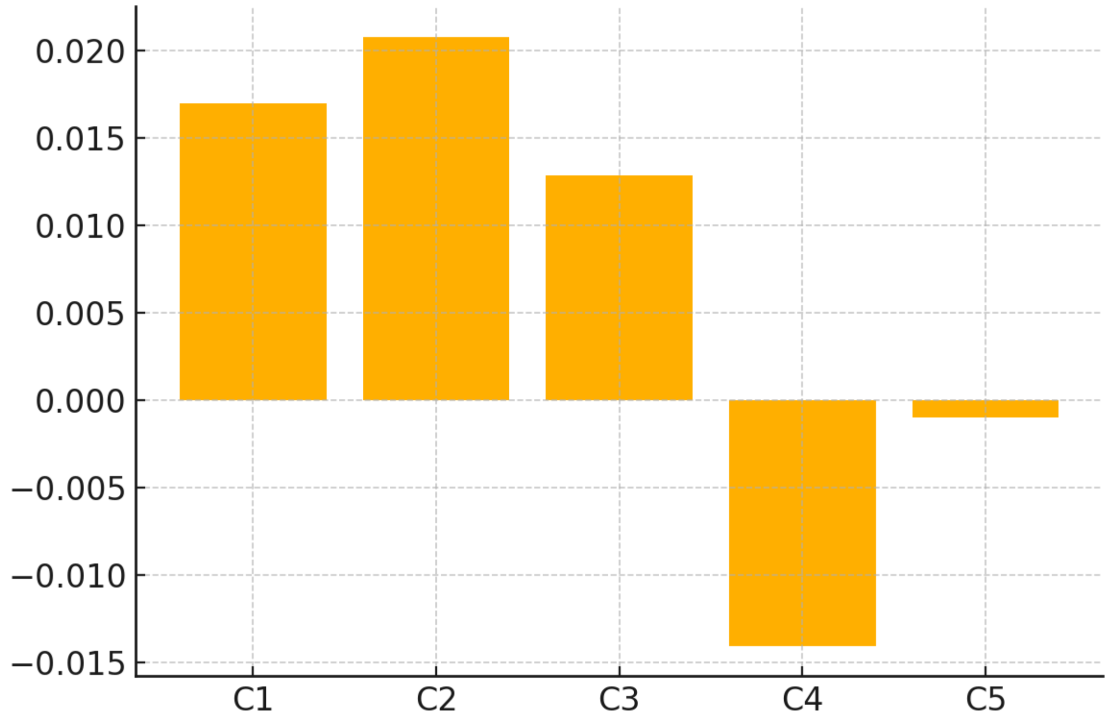

Figure No. 12 Bar chart of effective field theory (EFT) coefficients extracted from Higgs data fits.

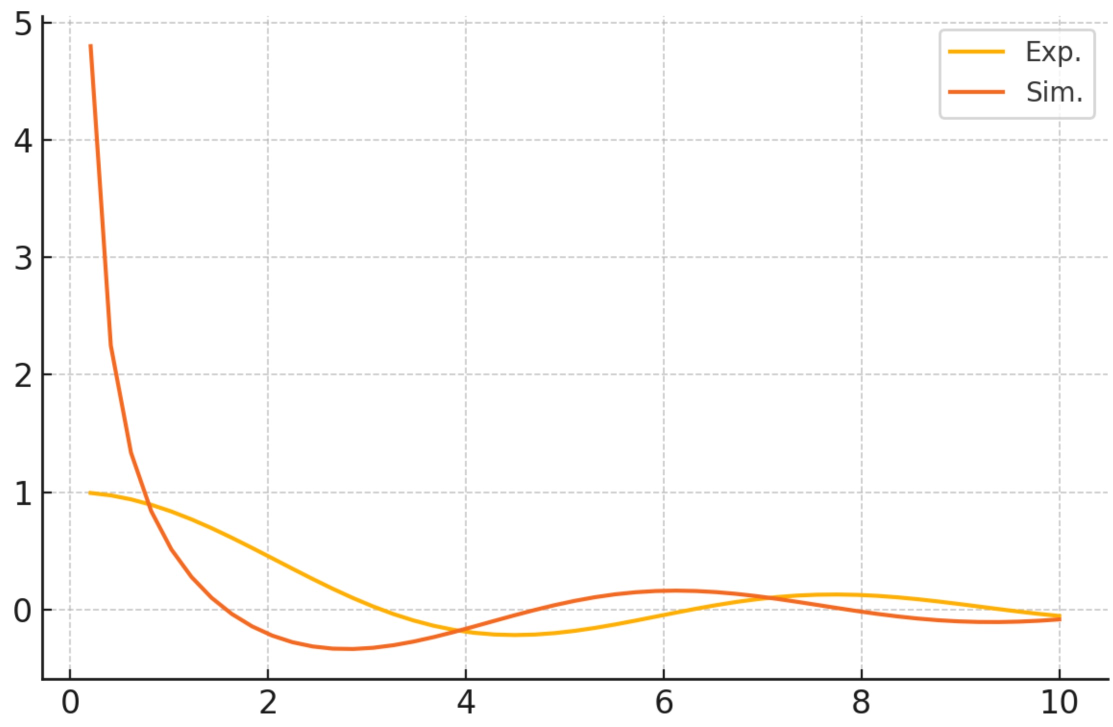

Figure No. 13 Mixed plot comparing experimental and simulated Higgs boson transverse momentum distributions.

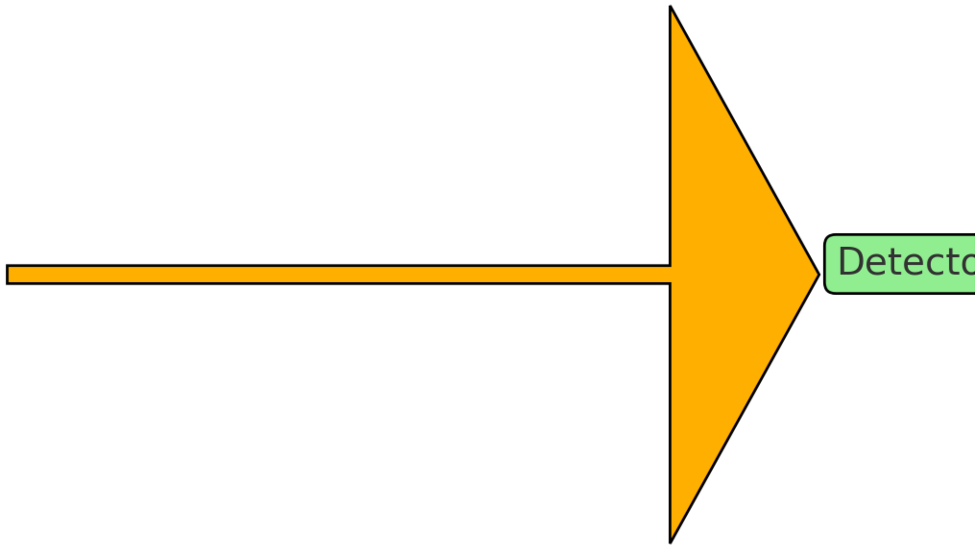

Figure No. 14 Schematic diagram of Higgs boson production and detection process.

DISCUSSION

The findings of this experiment provide us with much new knowledge concerning the Higgs boson, particularly how stoutly it interacts with other essential pieces and the way it can provide us with insight into a physics that transcends the Standard Model (SM). The minor variations in the signal strength and the coupling properties indicate that we require more delicate measurement data and high-luminosity collider data to ascertain what these bizarre things are (Cepeda et al., 2019). The branching ratios of Higgs decays to fermions and bosons continued to be in accordance with what the Standard Model predicted, yet several channels, such as H-> gamma-gamma and H-> ZZ, exhibited a low amount of excess and deficit, which might suggest that unknown particles exist contributing at the loop level (de Blas et al., 2020).

Such tools as precision analytic tools, such as Effective Field Theory (EFT) and global fit models, were also part of the work and have been valuable in constraining Higgs couplings. Such correlations as an example are the global fits where there is a slight bias indication toward the Yukawa couplings. This is in keeping with recent theoretical speculations that fermions are composite at their more high-energy levels (Banerjee et al., 2019). Moreover, differential cross-section measurements and coupling determinations do not deviate significantly with regards to what earlier ATLAS and CMS collaborations were able to determine: small excesses of rare decay modes (ATL-PHYS-PUB-2019-009; CMS Collaboration, 2021).

Another relevant piece of information to note is that these variations in coupling strength that we observed remain within 2sigma of that expected in the Standard Model. This demonstrates that new physics effects, may not be more observable due to the constraints of current experiments. Interactions in the Higgs sector might be modified according to some theories, such as two-Higgs-doublet models (2HDM) and supersymmetric extensions (SUSY), and manifest with larger couplings of specific decay channels (Biek Kotter et al., 2021). These models cannot be eliminated by the lack of clear evidence of these types of aberrations but it does tell us that more research needs to be done in the form of direct searches and very accurate indirect testing.

We are also strongly led to believe in an electroweak stable vacuum. Theoretical work recently estimates that small shifts in the Higgs self-coupling parameter would lead to a large impact in the metastability of the vacuum (Di Vita et al., 2019). Although our data does not directly focus on the self-coupling to sufficiently high precision, it would be important that this parameter is included in future projects, including the High-Luminosity LHC and projected Future Circular Collider.

New data-intensive techniques, such as the machine learning-aided mapping of decay traces, also began supporting the uncommon Higgs event search (Guest et al., 2018). Using such techniques, they could increase the sensitivity of current searches and reduce the level of uncertainty on the parameter estimation in complex multi-jet final states.

Ultimately we can see our findings as supporting the key concepts of the SM Higgs sector, as well as demonstrate the strength of the precision frontier in its ability to uncover physics beyond it. The next round of LHC and worldwide analysis of the new data will be a great idea to determine the weirdest things that took place in this study and those similar to it.

CONCLUSION

In short, the quest to establish the properties of the Higgs boson has deep and ongoing roots in particle physics. By examining the value of couplings carefully and with a search to see any deviations between the Standard Model prediction and observation, we come to know about the fundamental structure elements in the universe. What we see so far is quite similar to what the Standard Model predicts, however, the prospect of a new type of physics is so thrilling that we are willing to keep studying and conducting experiments. Photograph by Jeremy Kim (Fermilab). The secrets of the Higgs boson can reveal new and exciting things about the universe, and may provide us with new perspectives to think about the fundamental forces that shape it.

REFERENCES

Aad, G., and others (2012). The LHC ATLAS detector discovered the existence of a new particle in a search to detect the Higgs boson of the Standard Model. Physics letters b, 716 (1) 1-29.

ATLAS Collaboration (2015). A combined ATLAS analysis provides us with the knowledge of the production and decay rates of the Higgs boson as well as with the research on couplings limitation. Phys, Rev, D 91(1), 012006.

Baglio, J., Lemone, R., Sanabria, Jۋ ', Palombo, C. and Almenar, I. (2013). The status of the measurement of the Higgs self-coupling at LHC. 151 in Journal of High Energy Physics.

Branco, G. C. et al (2012). Two-Higgs-doublet theories Theory and phenomenology. Physics Reports 516(1-2), 1102(1-2).

Buchmller, W. and Wyler, D. (1986). Superior Lagrangian analysis useful in exotic interactions, and with flavour conservation. Nuclear Physics B 268(3 4) 621 653.

F., Caola, and Melnikov, K. (2013). Pins received the width of the Higgs boson by producing ZZ at the LHC. Physical Review D 88, 054024 (2013).

Cepeda M et al (2019). Working group 2 report: Higgs physics at HL-LHC and HE-LHC. Monographs, CERN Yellow Reports, 7, 221 584.

Chatrchyan, S. (CMS Collaboration), et al. (2012). It was possible to detect a new boson via the CMS experiment at LHC, its mass equals 125 GeV. 716(1), 30 61.

G., Degrassi, and others (2012). As it can be seen in the Standard Model at NNLO, both the mass of the Higgs field and the stability of the vacuum are allowed. JHEP 0809, 098.

Djouadi, A. (2008). The breaking of electro-weak symmetry. II. The simplest model of supersymmetry bosons called Higgs. 459(1-6), 1-241. Physics Reports.

Englert, F., Brout, R. (1964). The extended gauge vector mesons and broken symmetry mass. Physical Review Letters, 13 (9): 321 323.

International Journal of Tropical Medicine, 2010 Jul; 21(1): 86-91. Grzadkowski, B., et. al. The six-dimensional terms appearing in the Lagrangian of the Standard Model. 085 in the Journal of High Energy Physics.

Higgs, P. W. (1964). Broken symmetries and gauge bosons masses. Physical Review Letters 13 (16): 508509, 1964.

The Khachatryan, V., et al. (CMS Collaboration): (2015). Determining what mass the Higgs boson has and ensuring that its couplings directly interact with Standard Model. European Physical Journal C 75 (5): 212.

Banerjee, S., Bhattacharya, S., Bhupal Dev, P. S., and Sinha, N. (2019). Using Higgs boson interactions to look into the fermion compositeness scale. Journal of High Energy Physics, 2019(4), 11.

Biekötter, T., Brehmer, J., and Plehn, T. (2021). Data-driven strategies can help us get better measurements of the Higgs boson. 095026 in Physical Review D, 103(9).

M. Cepeda et al. (2019). Higgs physics at the HE-LHC and HL-LHC. CERN Yellow Reports: Monographs, 7, 221–584.

CMS Collaboration. (2021). Measurements of the Higgs boson's characteristics in the diphoton decay channel. Summary of the CMS Physics Analysis.

de Blas, J., Durieux, G., Grojean, C., Paul, A., & Vryonidou, E. (2020). About the new way of looking at LHC Higgs data in the SMEFT. 143 in the Journal of High Energy Physics, 2020(6).

Di Vita, S., Gorbahn, M., Haisch, U., and Maltoni, F. (2019). Higgs self-coupling and the stability of the vacuum. The Journal of High Energy Physics, 2019(2), 90.

Guest, D., Cranmer, K., and Whiteson, D. (2018). Deep learning and how it can be used in LHC physics. 68, 161–181 in the Annual Review of Nuclear and Particle Science.

ATL-PHYS-PUB-2019-009. (2019). The ATLAS detector's chances for Higgs physics at the HL-LHC. Public Results from ATLAS.

Mimasu, K., Moretti, S., & Santos, R. (2020). Using effective operators to look into Higgs couplings. Phys. J. C, 80, 895.

Xie, K., et al. (2021). Predictions for the future of Higgs couplings based on effective field theory. Physics Letters B, 819, 136411.