# ATLAS, CMS Higgs Boson Data May Already Contain Clues for Solving Decay Rate Puzzle

Lamont Williams

lamontwilliams003@gmail.com

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ATLAS and CMS, the two principal laboratories operating at the Large Hadron Collider (LHC) at CERN, have made great strides in clarifying the properties of the newly discovered Higgs boson.[1,2] In particular, they have tested how the particle decays to other particles, namely photons, Z bosons, W bosons, tau particles, and bottom quarks. Although the decay rates of these particles have been compatible with those determined through the Standard Model, they have not been an exact match. This report shows how data from ATLAS and CMS may already be solving the puzzle of the incongruent decay rate values, while also revealing a potential, and currently unrecognized, proportional relationship at work in the decay mechanisms of the Higgs particle.

The signal strength is the ratio of the observed number of events in a given decay channel over the number expected by way of the Standard Model. A value of 0 would mean no events were observed in that decay channel. A value of 1, the ideal value, would mean that the number of observed events matched the number expected from the Standard Model. If the boson discovered at the LHC is the Standard Model Higgs boson, the signal strength in each decay channel would be 1.

To date, neither ATLAS nor CMS has been able to achieve a value of 1 in all channels simultaneously. Some values have been higher than 1, while some have been lower than 1 (Table 1).[3,4]

| **Table 1. ATLAS and CMS Signal Strength Data [3,4]** | | |
|---|---|---|
| **Decay Channel** | **ATLAS** | **CMS** |
| Photons* | 1.57 | 1.13 |
| Z bosons* (4l) | 1.44 | 1.00 |
| W bosons* (lvlv) | 1.00 | 0.83 |
| Tau particles | 1.40 | 0.91 |
| Bottom quarks | 0.20 | 0.93 |

*Dibosons

The values shown in Table 1 are considered to be in fairly good agreement with the value of 1 predicted by the Standard Model. However, for the most part, they are not 1 except perhaps within uncertainty ranges, some of which are unfortunately large.

Interestingly, despite their widely disparate individual channel results, ATLAS and CMS actually have overlapping results regarding some aspects of their signal strength data. Equations (1) and (2) show how they have a near-identical value for the ratio of the combined fermion signal strength value to the combined signal strength value for all channels[3,4,5]:

$$(1) \qquad \frac{\text{ATLAS' combined fermion signal strength value}}{\text{ATLAS' combined signal strength value for all channels}} = \frac{1.09}{1.30} = 0.84$$

$$(2) \qquad \frac{\text{CMS' combined fermion signal strength value}}{\text{CMS' combined signal strength value for all channels}} = \frac{0.83}{1.00} = 0.83$$

CMS has not released combined diboson signal strength data, but it may be the case that it and ATLAS additionally have the same value for the ratio of the combined diboson signal strength to the combined signal strength for all channels. For ATLAS, it is as follows:

$$(3) \qquad \frac{\text{ATLAS' combined diboson signal strength value [ref. 3]}}{\text{ATLAS' combined signal strength value for all channels}} = \frac{1.35}{1.30} = 1.04$$

In an earlier published analysis, ATLAS found a combined diboson number of 1.33, producing a ratio closer to a value of 1[6]:

$$(4) \qquad \frac{\text{ATLAS' combined diboson signal strength value [ref. 6]}}{\text{ATLAS' combined signal strength value for all channels}} = \frac{1.33}{1.30} = 1.02$$

As noted earlier, if the LHC's boson is the Standard Model Higgs boson, all signal strength values for the decay channels should equal 1, which also means that the combined values for the fermions and dibosons should also be 1 each, as well as the combined signal strength values for all channels.

Although ATLAS' signal strength numbers generally run high, the above ratios of the combined diboson value to the all-channel value, at 1.02 and 1.04, are where they should be in relation to the Standard Model (i.e., near a value of 1). In time, it may be found that a ratio of CMS' combined diboson value to its all-channel value also is about 1.

The ratio of the combined fermion value to the all-channel value in both ATLAS and CMS (ATLAS, 0.84; CMS, 0.83), however, differs from a value of 1 by quite a bit. Interestingly, these values could be revealing something important when considered in combination with the data on invisible decays stemming from the Higgs boson.

If one sets aside the calculated invisible decay results that a Higgs particle of a certain mass *might* be expected to yield naturally and looks purely at the invisible decay events that are observed versus what would be expected from the background, one finds a slight excess in invisible decay events, with the ATLAS value being about 1.10 and the CMS value being about 1.17.[7,8]

This means that about 10 to 17 percent of the Higgs energy is removed through invisible decay events outside of what would be expected from the Standard Model, again with the stated caveat. More specifically, this means that, in this scenario, about 10 to 17 percent of the energy is involved in invisible events during fermion and/or diboson decays.

Interestingly, if one adds the presumed 0.10 (ATLAS) and 0.17 (CMS) excess values from the invisible decay experiments to the quotients of equations (1) and (2), respectively, one obtains a value near 1 or exactly matching it:

$$\frac{\text{ATLAS' combined fermion signal strength value}}{\text{ATLAS' combined signal strength value for all channels}} = \frac{1.09}{1.30} = 0.84 + 0.10 = 0.94 \quad (5)$$

$$(6) \qquad \frac{\text{CMS' combined fermion signal strength value}}{\text{CMS' combined signal strength value for all channels}} = \frac{0.83}{1.00} = 0.83 + 0.17 = 1.00$$

As ATLAS' combined diboson to all-channel signal strength ratio is already about 1 — where it should be from the standpoint of the Standard Model — but its combined fermion to all-channel ratio is about 0.84, it seems reasonable that if there is indeed missing energy, it is likely associated with the fermions rather than the dibosons.

It may not merely be a coincidence that, despite the laboratories' widely disparate individual channel results, the ratio of the combined fermion signal strength value to the all-channel value for ATLAS is nearly identical to that of CMS, at 0.84 (ATLAS) and 0.83 (CMS), *and* that the amount by which these values fall short of 1 nearly or exactly matches the amount by which the presumed invisible decay results exceed 1, at 0.10 (ATLAS) and 0.17 (CMS).

Admittedly, it is no small matter to remove from consideration the currently accepted assumptions about the number of invisible decay events a Higgs particle of a certain mass might be expected to yield naturally. In their studies, ATLAS and CMS maintain these assumptions and, based on their data and calculations, conclude that the Higgs boson does not undergo invisible decays outside of what would be expected by the Standard Model.

Nonetheless, this leaves a potential proportional relationship — of the type y = kx — between the combined fermion signal strength value and the combined value for all channels. In the equation, y would be the combined fermion number; x would be the all-channel value. The value k is a proportionality constant with the value 5/6 or 0.83 — taken as the rounded average value between that of ATLAS and CMS — resulting in the following:

$$y = 5/6\,(x) \tag{7}$$

or

$$x = 6/5\,(y) \tag{8}$$

Using ATLAS' combined fermion value of 1.09 (the y value), the x value equals 1.31, close to the experimentally established value 1.3. And of course, with CMS' combined fermion value being 0.83, the all-channel value comes close to 1 using the equation, again which has been experimentally found.

Of course, the true proportional relationship might exist between the combined fermion value and the combined diboson value:

$$\frac{\text{ATLAS' combined fermion signal strength value}}{\text{ATLAS' combined diboson signal strength value}} = \frac{1.09}{1.35 \text{ (or } 1.33)} = 0.81 \text{ (or } 0.82) \tag{9}$$

Additional data and analyses will help clarify (1) whether the proportional relationship is real, and (2) if it is, whether it is between the fermions and dibosons, or between the fermions and all channels.

The closeness of the potential proportionality constant to 1, at about 0.83, is consistent with the fact that many of the decay rate results (particularly the individual decay channel results) to date have come "close to" what would be expected from the Standard Model, but do not exactly match.

If the proportional relationship remains as more data are generated at the LHC and if it is between the fermions and dibosons (as opposed to the fermions and all channels), it would seem that the best individual signal strength values achievable in relation to Standard Model expectations would be as outlined in Table 2.

| **Table 2. Potential Final Signal Strength Values for Higgs Decay Channels** | |
|---|---|
| Photons | 1.0 |
| Z bosons | 1.0 |
| W bosons | 1.0 |
| Tau particles | 0.83 |
| Bottom quarks | 0.83 |

If the fermions are indeed involved in a proportional relationship with the combined dibosons or all the channels collectively, it would strongly suggest that there are indeed invisible (non-Standard Model) decays occurring in relation to the fermion decays, carrying away perhaps up to 20 percent of the Higgs boson's energy in undetected events in each fermion channel. Considering this and accounting for it during calculations may help yield clearer and more consistent results during decay rate analyses. However, time will tell if the numbers presented here, particularly the proportional values, remain consistent.

**References:**


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