

Article

Expected LHC Higgs Significance at 5/fb+5/fb and Where Does Higgs Fit Best?

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Abstract

While we are waiting for that we can look forward to next year when results for 5/fb will be revealed, probably in March. When the results are combined we will see 10/fb and here we discuss the expected significance at that level. Further, it may be a little late now to try to analyse the latest public data from the LHC given that the collaborations themselves are now looking at 3 times the amount of integrated luminosity. So, I also discuss how can we see what really fits best? To answer this we first have to think about what the familiar brazil band plots mean such as the one showing the recent Higgs combination for the summer data from the LHC.

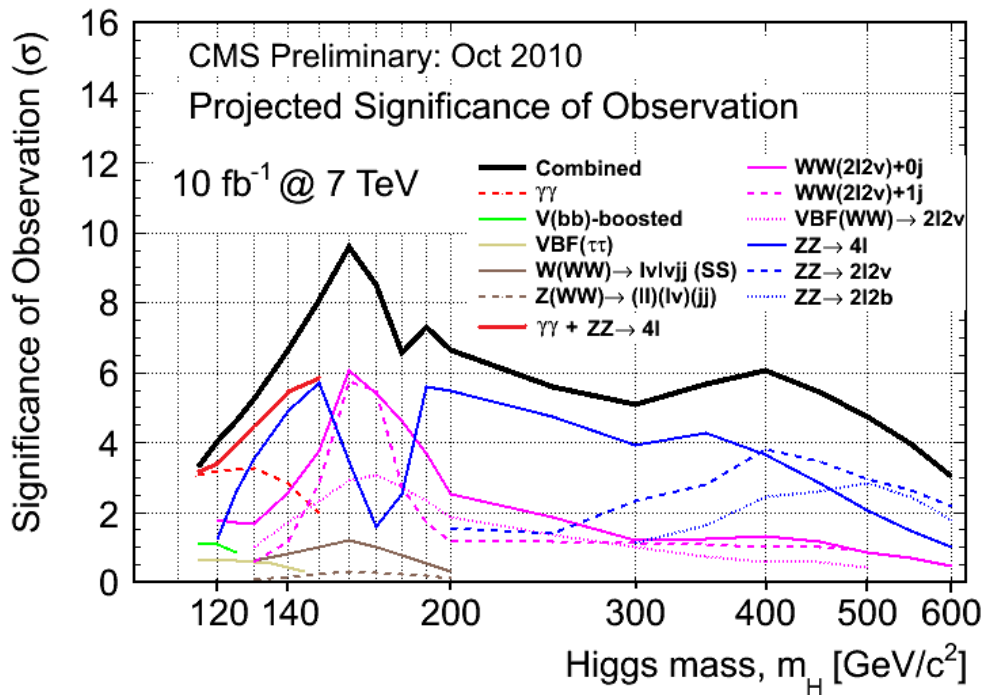
Key Words: LCH, Higgs fit, Higgs combination, CERN.

November 14, 2011: [Expected LHC Higgs Significance at 5/fb+5/fb](#)

The Hadron Collider Physics conference starts today in Paris and we eagerly await updates for various searches including the Higgs. 5/fb of luminosity have been collected in each experiment but it is too soon for the analysis of the full data to be out and this week we are only expecting results at 2/fb to be shown (but surprises are always possible) Indeed ATLAS have recently revealed updates for three of the diboson Higgs channels at 2/fb in conference notes and other conferences. These do not make much difference but an update to the diphoton search would be worth seeing. It has so far only been shown by ATLAS at 1/fb. CMS have only released results at 1.6/fb for the main Higgs decay modes so they are even more overdue for updates.

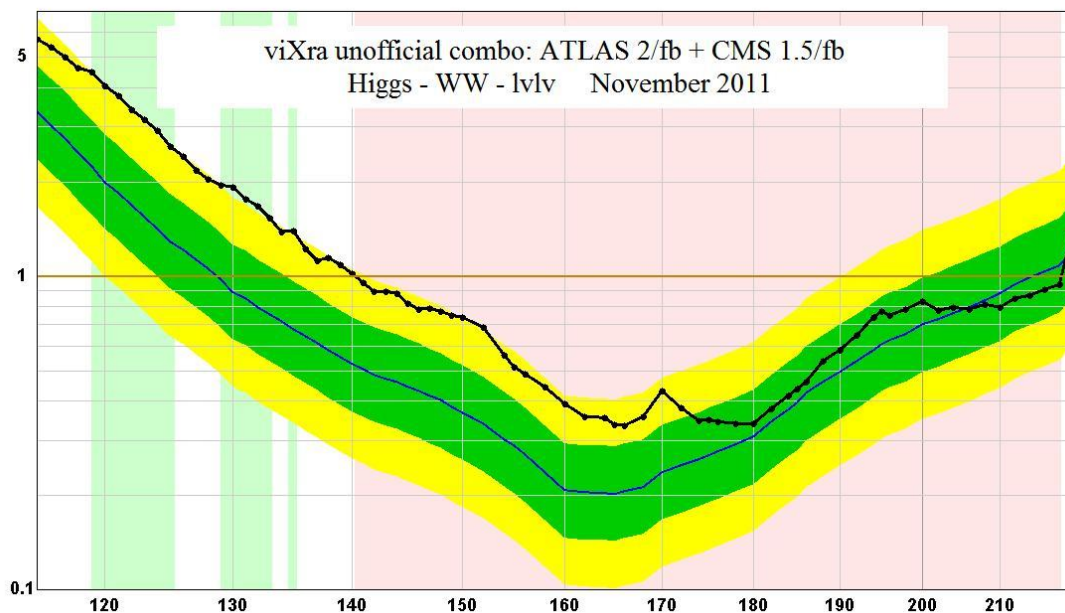
While we are waiting for that we can look forward to next year when results for 5/fb will be revealed, probably in March. When the results are combined we will see 10/fb and here is a plot showing the expected significance at that level. This is for 10/fb at CMS which can be taken as a good approximation for the ATLAS+CMS combination at 5/fb for each.

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From this you can see that they expect at least 4 sigma significance all the way from 120 GeV to 550 GeV, which suggests that a good clear signal for the Higgs is almost certain if it exists, but not so fast. There are a couple of caveats that should be added.

Firstly the WW decay channels have been very good for excluding the Higgs over a wide mass range. Here is the viXra combined plot using 2/fb of ATLAS data and 1.5/fb from CMS.

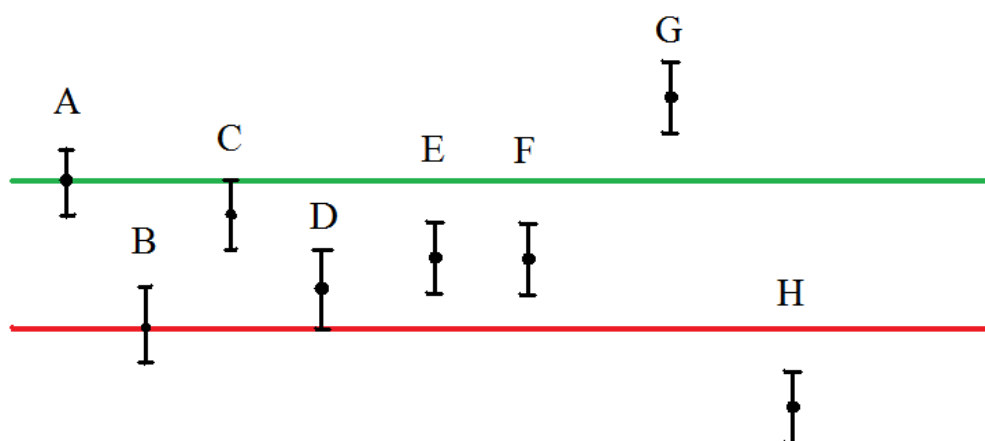


This is only a rough approximation to what would be produced if they did an official version because it assumes a flat normal distribution uses a linear interpolation for CMS points and ignores any correlations.

Within those limitations we get an exclusion from 140 GeV to 218 GeV with a broad excess around 2 sigma extending all the way from 120 GeV to 160 GeV. A Standard Model Higgs in this region would only have a width of a few GeV and no bump of the sort is seen, so what does it mean? ATLAS and CMS will probably need to consider this question for a long time before agreeing to approve results like this with more data along with a suitable explanation. For now you should just bear in mind that this plot suffers from large backgrounds and poor energy resolution due to the use of missing energy to identify the two neutrinos. These effects have been worsened by high pile-up this year. I suspect that this channel will have to be used only where it provides a 5 sigma exclusion and should be left out when looking for a positive signal.

For this reason I have added a red line to the projected significance plot above showing the expected significance for just the diphoton plus ZZ to 4 lepton channels. These decay modes have very good energy resolution because the photons and high energy leptons (electrons and muons) are detected directly with good clarity and are not effected by pile-up. I think that the best early signal for the Higgs boson will be seen in a combination of these channels alone. The projected significance plot shows that with the data delivered in 2011 we can expect a signal or exclusion at a level of significance ranging from about 3 sigma to 6 sigma in the mass range of 115 GeV to 150 GeV where the Higgs boson is now most likely to be found.

Does this mean that we will get at least a 3 sigma “observation” for the Higgs by March? No, not quite. There is one other obvious caveat that is often forgotten when showing these projected significance plots. These are only expected levels of significance and like everything else they are subject to fluctuations. Indeed, given twenty uncorrelated mass points we should expect fluctuations of up to 2 sigma over the range. How could this affect the result? The next plot illustrates what this could mean assuming an expected significance of 4 sigma



In this plot the green line represents the expected level for a positive signal of a standard model Higgs, while the red line represents the level where there is no Higgs. The data points have error bars at the size you will get when you expect a 4-sigma level of significance. So point A shows where the bars are expected to sit if the SM Higgs exists at a given mass value and point B shows where the bars are expected if there is no Higgs. If they get observed data in these locations they will be able to claim a 4-sigma observation or exclusion, but remember that fluctuations are also expected. Point C shows what happens when the Higgs is there but an unlucky one sigma fluctuation reduces the number of observed events. The result is a reduced significance of three sigmas. Likewise point D shows an unlucky one sigma fluctuation when there is no Higgs which still gives a healthy three sigma exclusion. But remember that we expect fluctuations of up to two sigma somewhere in the range. Point E shows what happens when a Higgs is there but an unlucky two sigma fluctuation hits that mass point, and point F shows what happens when there is no Higgs with an unlucky two sigma fluctuation. The points are the same, corresponding to either a two sigma signal or a two sigma exclusion. We have already seen some points that look just like this at the summer conferences. This is why the CERN DG has cautiously promised to identify or exclude the Higgs only by the end of 2012 and not by the end of 2011. More optimistically we can also hope for some lucky fluctuations. If they fall at the mass where the Higgs actually lives we will get a 6 sigma discovery level signal like point G instead of merely a 4-sigma observation.

It's a simple point and my explanation is a little too long-winded, but I think this had to be said clearly before the next results come out in case people do not see what they thought they should have expected to see. With another year of data 10/fb becomes (perhaps) 40/fb and 4 sigma becomes 8 sigma. Even with unlucky 2 sigma fluctuations they will be left with 6 sigma signals. The results will probably be good enough to claim discoveries even for the individual experiments and some individual decay channels, but for this year's data there could still be a lot of ambiguity to mull over.

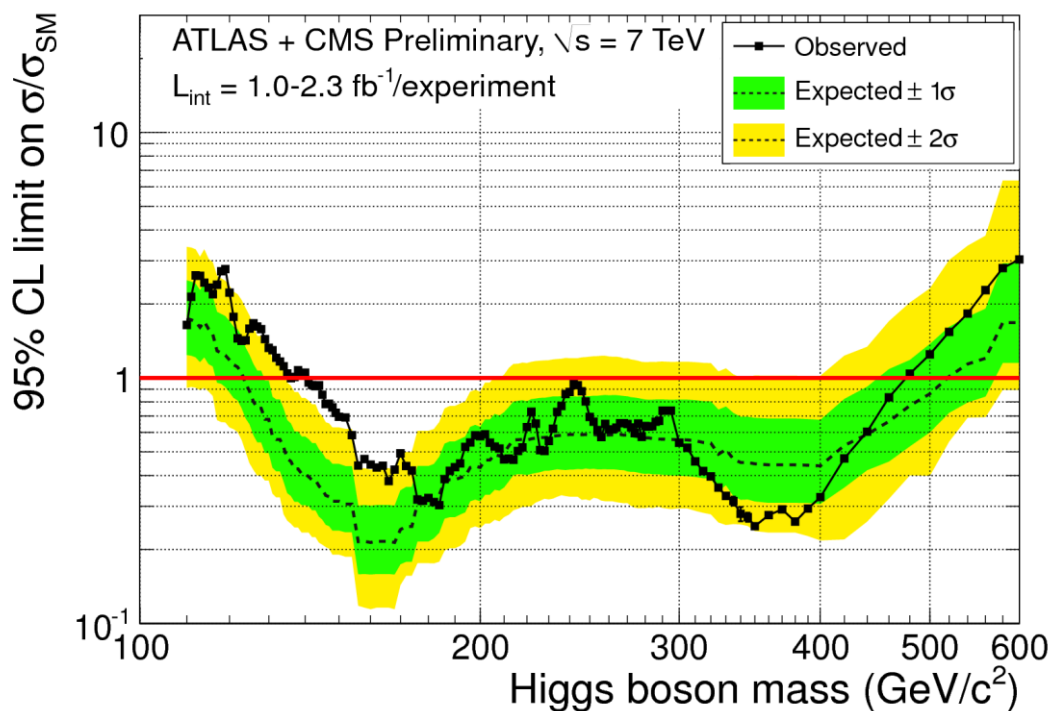
November 21, 2011: [Where does Higgs fit best?](#)

When I looked at this picture of Easter Island and matched it to a recent picture of Peter Higgs the best fit was the first statue, but where does the Higgs Boson fit best on the search plots from the LHC?



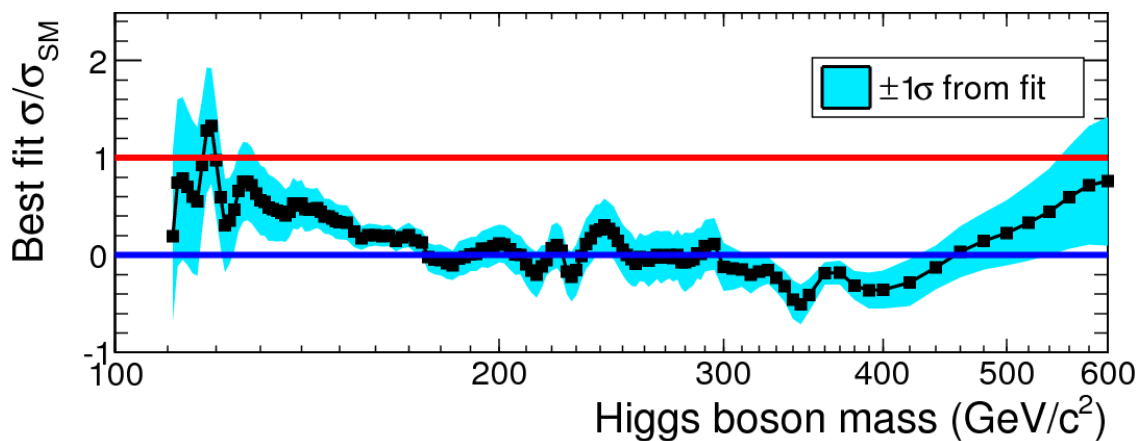
It may be a little late now to try to analyse the latest public data from the LHC given that the collaborations themselves are now looking at 3 times the amount of integrated luminosity, but [Tommaso Dorigo](#) is claiming that the summer data best fits a Higgs boson at 119 GeV and [Peter Woit](#) is pressing the case for no Higgs at all. I have my doubts about either claim, so how can we see what really fits best?

To answer this we first have to think about what the familiar brazil band plots mean such as this one showing the recent Higgs combination for the summer data from the LHC.



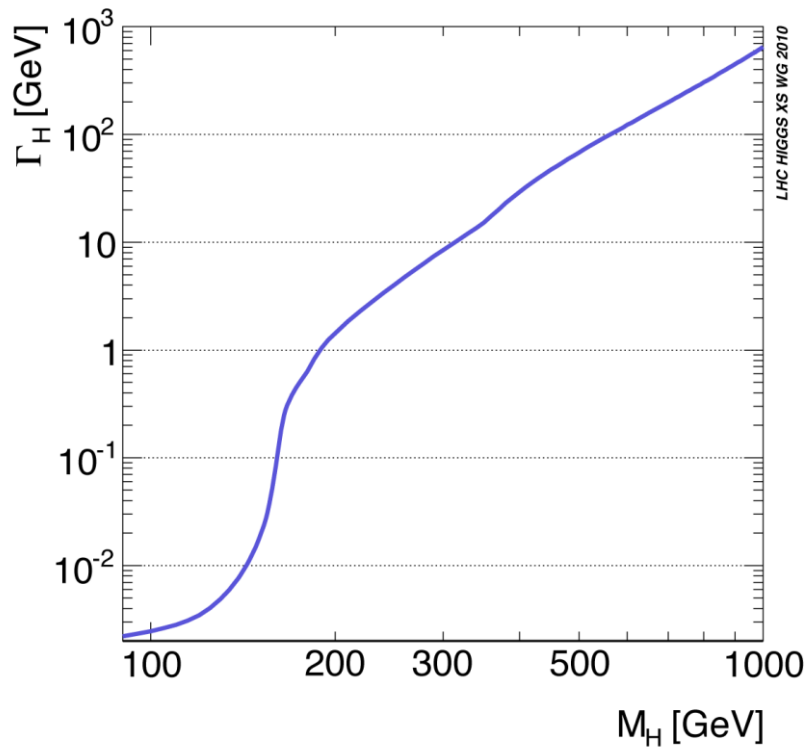
If you look at the 140GeV point you will see that the observed CLs line is crossing the red line. The naive interpretation is that the probability for no Higgs boson at this mass is 0.95 so it is ruled out at the 95% confidence level. However, this is wrong. Such a probability can only be calculated when we plug in our prior probabilistic beliefs for the existence or not of a Higgs boson at that mass. The correct interpretation of the plot is that if there were a Standard Model Higgs boson at 140 GeV then the probability of getting a stronger signal than the one seen would be 0.95. This is a very different statement.

Looking at the plot again we see that there is also a nearly three sigma excess at the 140 GeV point. We tend to discount it because of the exclusion, but again this is the wrong thing to do. The excess tells us that if there were NOT a Higgs boson (SM or otherwise) at this point then the probability of getting a weaker signal than the one seen would be about 99% (roughly). So actually the signal indicating a Higgs boson at 140GeV is five times stronger than the one tending to exclude it. The symmetry between the signal and no signal possibility is best seen on this signal plot that uses the same information differently.

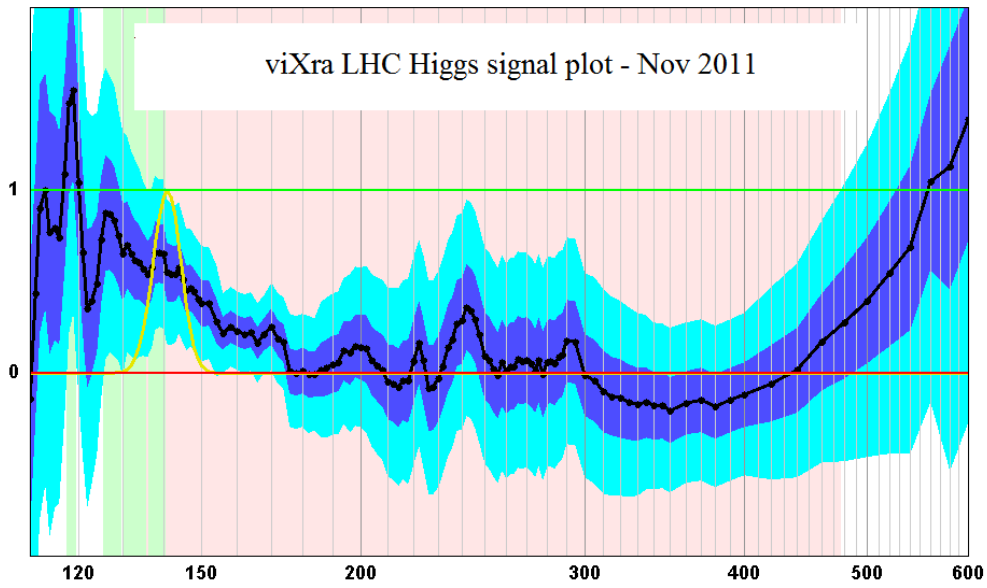


If we were being Bayesian, our prior probability for no Higgs at this point would probably be higher than the probability that one exists because there should be more places where it isn't than where it is. If we favoured a light Higgs mass for theoretical reasons and discounted non-standard models we might assign a probability of 0.8 to no Higgs boson at around 140 GeV and 0.2 to a SM Higgs at 140GeV. In this case we would look at the 140GeV point on the plot and come down slightly in favour of the Higgs boson at that mass.

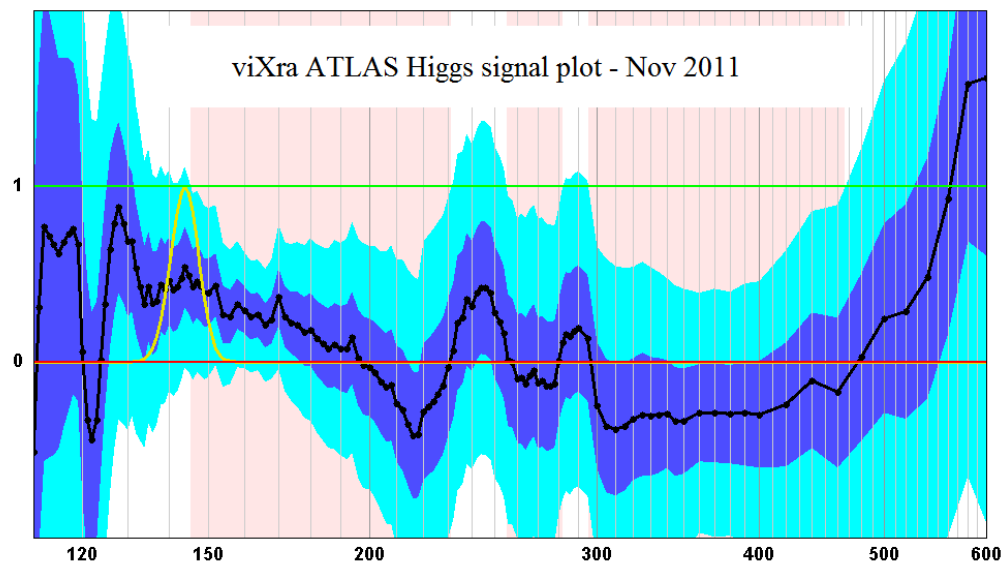
However, the plot contains much more information because it covers the whole mass range where a Standard Model Higgs might be. We can compare the probabilities for a Higgs boson at any mass in the range and see which one is favoured. For this we need to use our prior beliefs for where the Higgs might be over the whole range. For simplicity lets just assume that we believe in a single standard model Higgs boson and we favour equally each of the mass points where they plot a square on the graph. To apply this we need to know the width of the signal that a Higgs boson at a given mass would produce on the signal plot. The underlying decay width for a Higgs boson is predicted by the standard model as shown in this plot.

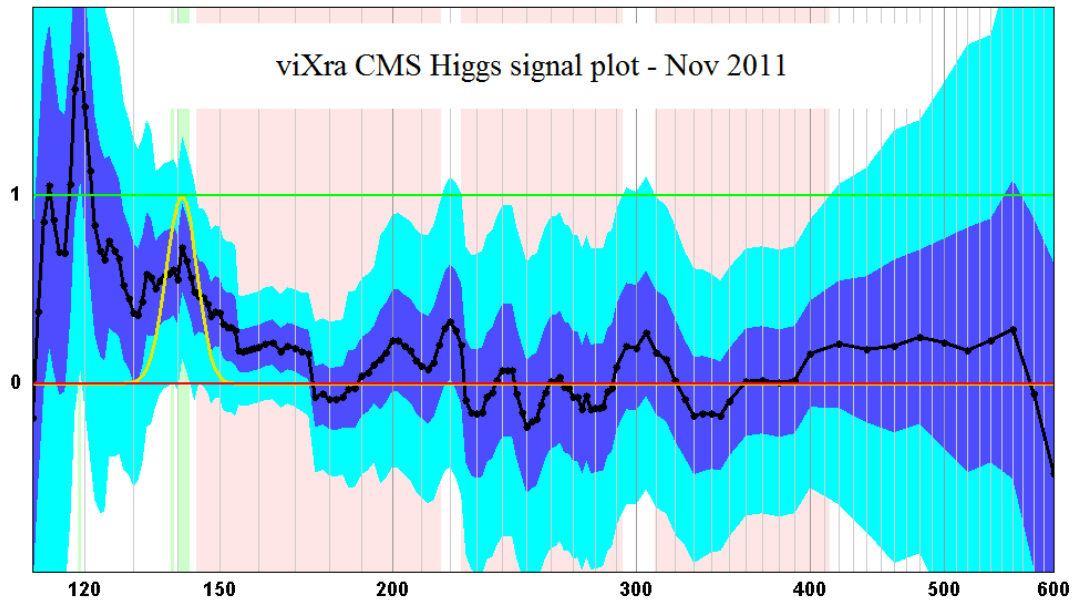


Below twice the mass of the W the width is very narrow and it is the resolution of the detectors that counts. This varies depending on the channel and the mass but I am going to assume that it is ± 5 GeV at worst and fit to a bell curve on that assumption. If you think differently you may get a different result from me. The method is to overlay the bell curve on the signal plot with a peak at 1.0 where we think the mass of the Higgs may be and tending to zero either side. At each mass point we read the signal strength and use the observed data to tell us the conditional probability for that signal strength (assuming a flat normal PDF). These probabilities are all multiplied together to give the conditional probability for the fit. We can then try all the curves for different Higgs masses we believe in and see which one has the best fit. Here is the result.

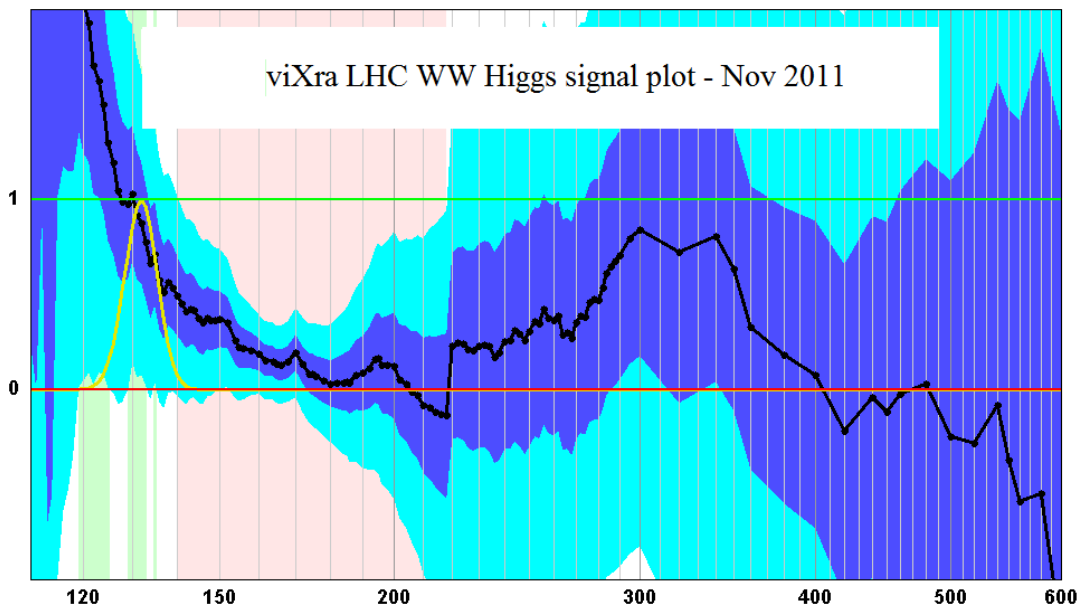


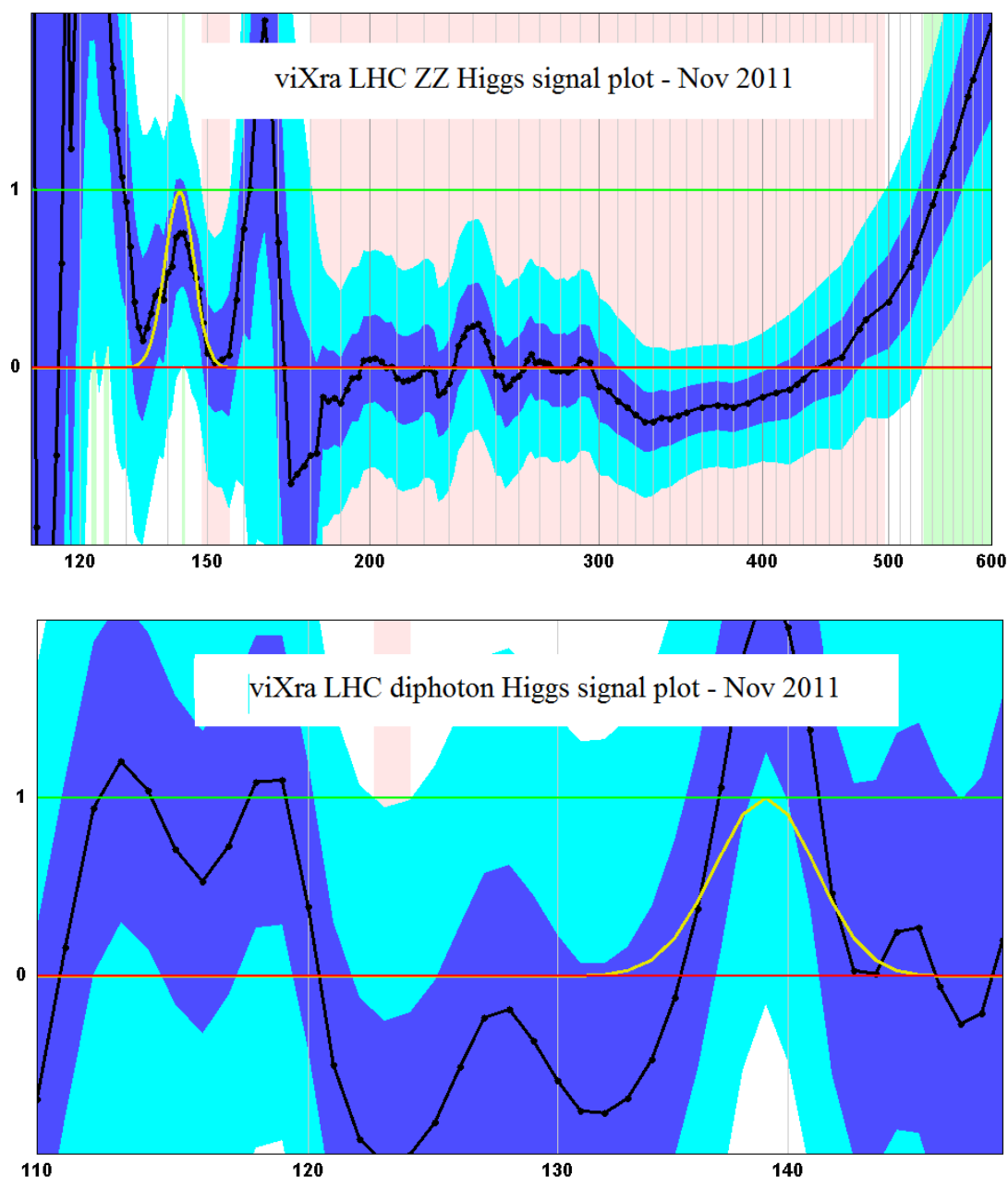
As you can see the best fit is actually at 141 GeV. Perhaps we should see how it works for the separate plots from ATLAS and CMS





ATLAS sees the Higgs at 144 GeV and CMS sees it at 141 GeV. That is pretty consistent given the resolution of the detectors. What about using different channel combinations. I will limit this to the three with the most data.





The best fits are 132 for WW (which has poor resolution), 143 GeV for ZZ and 139 GeV for diphoton. So it is a pretty consistent result.

I don't think it is safe to conclude that the Higgs boson has mass around 140 GeV. All we can say is that the limited data published so far supports that as best fit. The summer data has not probed the 120 GeV region well enough so there could be something there with a stronger signal when we look at the 5/fb data for this winter. Rumours are that there is not much of a signal anywhere with 120 GeV being the best chance, but I am waiting until I have seen the data myself and repeated this objective analysis.

References

1. <http://blog.vixra.org/2011/11/14/expected-lhc-higgs-significance-at-5fb5fb/>
2. <http://blog.vixra.org/2011/11/18/new-higgs-combinations-released/>