Article

Better Higgs Combo, New Unofficial Higgs Combo & Higgs Signal Plots

Philip E. Gibbs*

Abstract

It is traditional to present the results of searches such as Higgs hunting as Brazil plots that show us where a signal can be excluded at 95% confidence, but when the data starts to show a positive signal it is better to show signal plots like Higgs Signal Plot shown herein. This is just the observed confidence level limit minus the expected with the error bands for one and two sigma statistical variation shown around the signal level line. From about 135 GeV to 150 GeV it disfavors both a signal and no signal of a standard model Higgs. It is tempting to say that this rules out standard model physics in this region but I think it is too soon to draw such a conclusion. It may be that there is a SM Higgs boson at say 140 GeV but the resolution is not sufficiently good to get a clean signal there, or more data may see the line fluctuate down to the no signal level. It is important to remember that we are still at the stage where just a few signal events have a big effect on the curve. More detail will emerge with more data. Furthermore, the plot above is only an approximation that does not properly take into account all uncertainties and correlations.

Key Words: Higgs combos, Higgs signal plot, LHC, ATLAS, CMS, Lepton-Photon 2011.

Better Higgs Combinations

During the recent EPS conference when some new Higgs Exclusion plots were unveiled I has a stab at putting together some combinations of the plots using some basic formulas. Despite the broad caveats I gave them the plots got a surprising amount of attention. At a plenary session during EPS Bill Murray referred to my plots as “nonsense based on absolutely nothing” (which is not too far from the truth). Then at the Higgs Hunting workshop that followed EPS, John Ellis showed my “bloggers conbinations” saying that they were garbage but in the absence of anything better he would use them anyway. I hope this all added to everyone’s amusement and excitement as all the great new results were shown and discussed.

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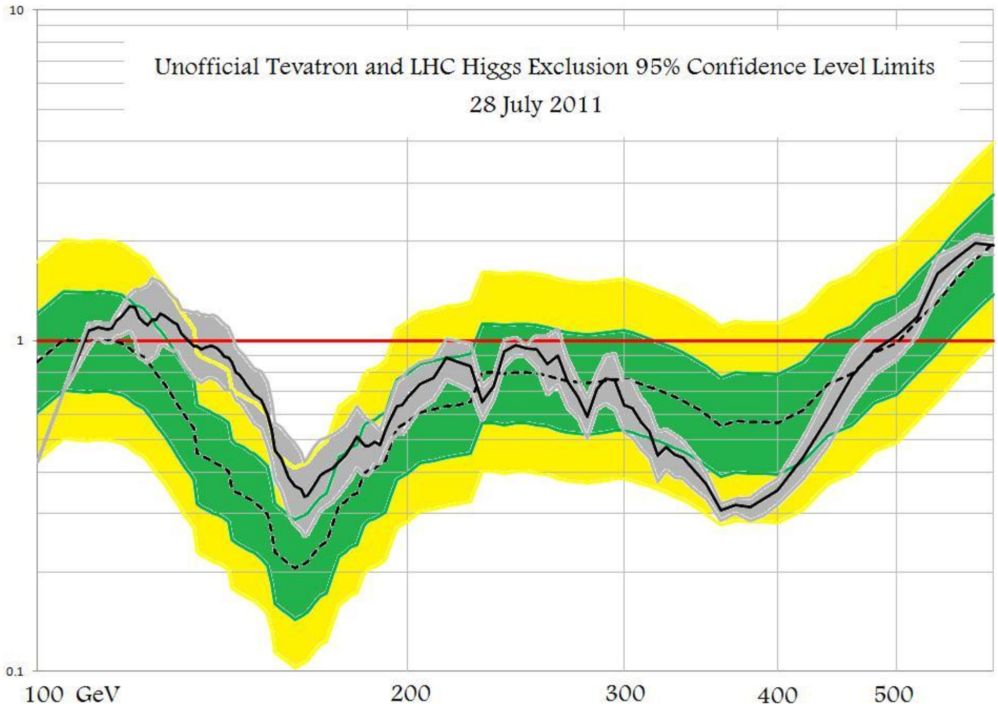


The formulas I used in those combinations were just quick guesses but they worked quite well for the Tevatron combination of CDF and Dzero Higgs results. In two or three weeks the LHC will reveal their combination for ATLAS and CMS at the Lepton-Photon conference in Mumbai so we will see how well my combination for that worked too.

Now that there has been a little more time to think about it I have looked at the basic statistic theory behind the plots to see why my formulas worked (so far). As a result I have come up with some improvements so I want to show some new plots that I think will be more accurate. There will be many more plots to combine in the near future as the LHC and Tevatron continue to churn out more data, so if they do work even approximately they may have some real use.

First some theory. Imagine you are looking for a signal of new physics in some decay channel. The standard model (without Higgs) will predict a certain background cross-section $b$in a given mass bin. The new process (such as a Higgs decay) will add a signal cross section $s$to give a total cross-section $b+s$. After gathering lots of integrated luminosity Lyou may see Nevents with the required signal so you calculate the observed cross-section $x=\frac{N}{L}$. Now you are interested in whether x corresponds to the background b or the background plus signal $b+s$. In practice you can't be sure so you have to look at the uncertainty.

To make things even simpler I am going to assume that the signal is smaller than the background but there are plenty of events N. For a Higgs search this is a better approximation for low mass than for bigger mass but there are lots of other things we are going to ignore so why not start here?

Our estimate of the cross section $x$has an uncertainty which we can write as $\sigma=\pm\frac{x}{\sqrt{N}}$. One thing we can say is that with 95% confidence the cross section is less than a limit $x+2\sigma$. We calculate the limit minus the background over the expected signal

$$CL_s = \frac{x-b+2\sigma}{s}$$

If this is less than one it means that the cross-section is less than the signal required for the Higgs boson with 95% confidence. This is roughly what the experiments plot against the Higgs mass. They also look at background uncertainty, trial error and combine different channels in a non-trivial way, but let's ignore those things and see what happens. The expected value if there is no signal is just what we would get for CL_sif $x = b$. This is also added to the plot as a function of mass with the familiar green and yellow uncertainty bands.

Now imagine that there are two experiments measuring the same quantity. They have different amounts of luminosity recorded and may be working at different energies and they will surely see different number of events. For now let's pretend the background and signal are the same for each. This would be roughly true for two experiments at the same collider, but since the actual values of these numbers will not enter into the final formula we can try and use it even for different colliders.

For experiment 1 the observed value of $CL_s$is

$$c_1 = \frac{x_1(1+\frac{2}{\sqrt{N_1}})-b}{s}$$

and for the expected value it is

$$e_1 = \frac{2b}{s\sqrt{bL_1}}$$

Similarly for experiment 2 with observed and expected CL_s, $c_2$and e_2. If we combine the two sets of events we will have $N = N_1 + N_2$events in total, and total Luminosity $L = L_1 + L_2$. This combination of luminosities can be substituted into the formula for excpected $CL_s$to derive the following combination law

$$e = \frac{1}{\sqrt{\frac{1}{e_1^2} + \frac{1}{e_2^2}}}$$

This is exactly the formula I used before, so far so good. However I used the same formula to combine the observed $CL_s $, this was not quite correct. The excess $\Delta = c - e$is given by

$$s\Delta = (x-b)(1 + \frac{2}{\sqrt{N}})$$

Using the large Napproximation this reduces $s\Delta = x - b$. If you dont like this approximation and you know the signal to background ratio you can improve it. I found that this does not make much difference in practice.

The observed cross-sections combine with weights given by the luminosities

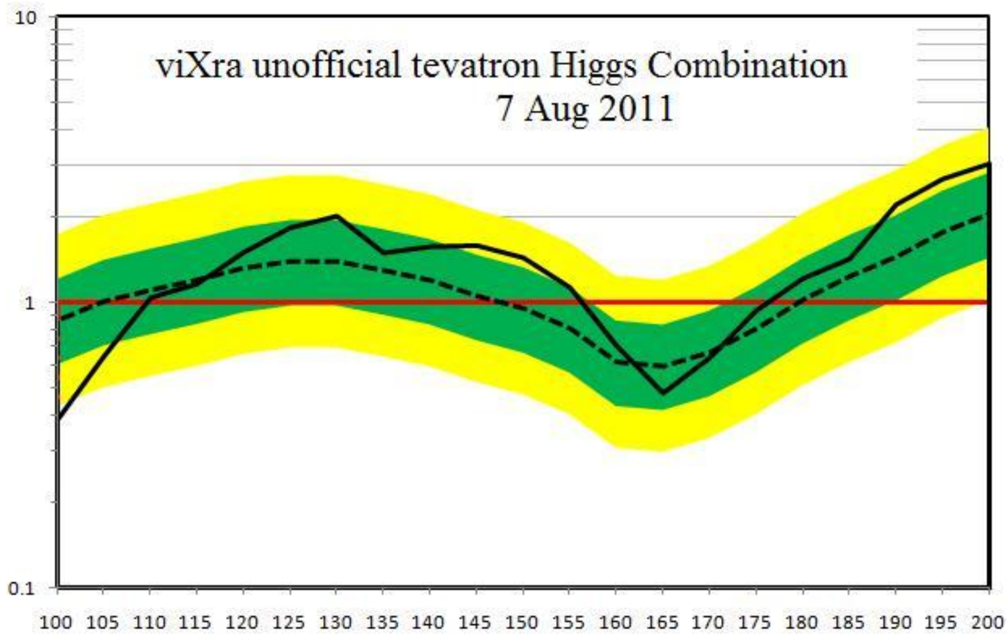
$$xL = x_1L_1 + x_2L_2$$

Which implies a similar combination law for Δ. Using the relationship between the expected CL_s and the luminosity this reduces to

$$\frac{\Delta}{e^2} = \frac{\Delta_1}{e_1^2} + \frac{\Delta_2}{e_2^2}$$

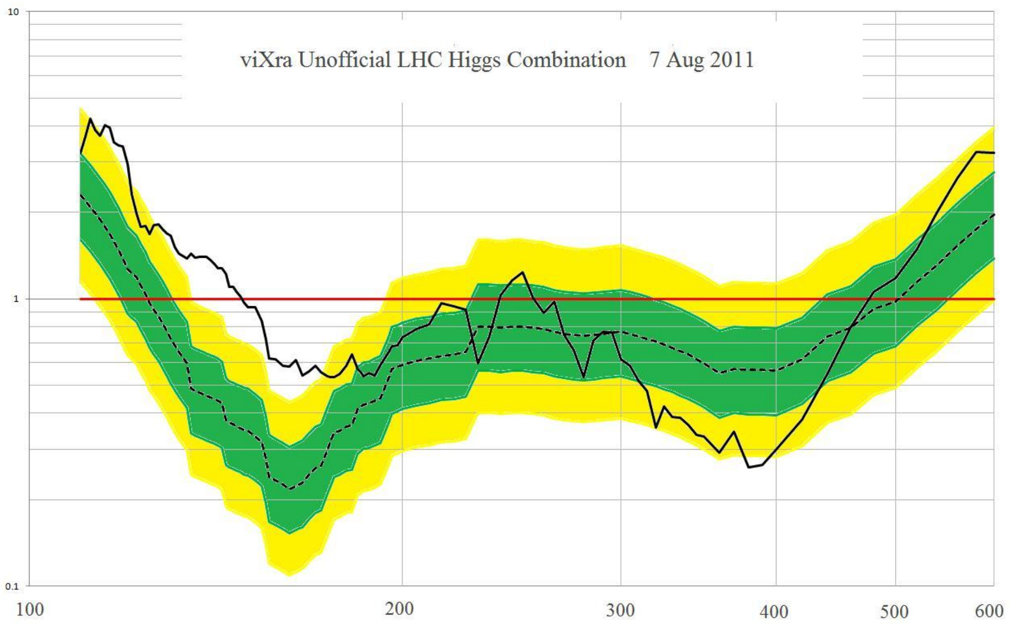
This allows us to combine the observed and expected CL_s without knowing the background cross-sections.

Here is what it does for the combination of CDF and Dzero. This is slightly better than my previous attempt when compared with the official combination shown at EPS.

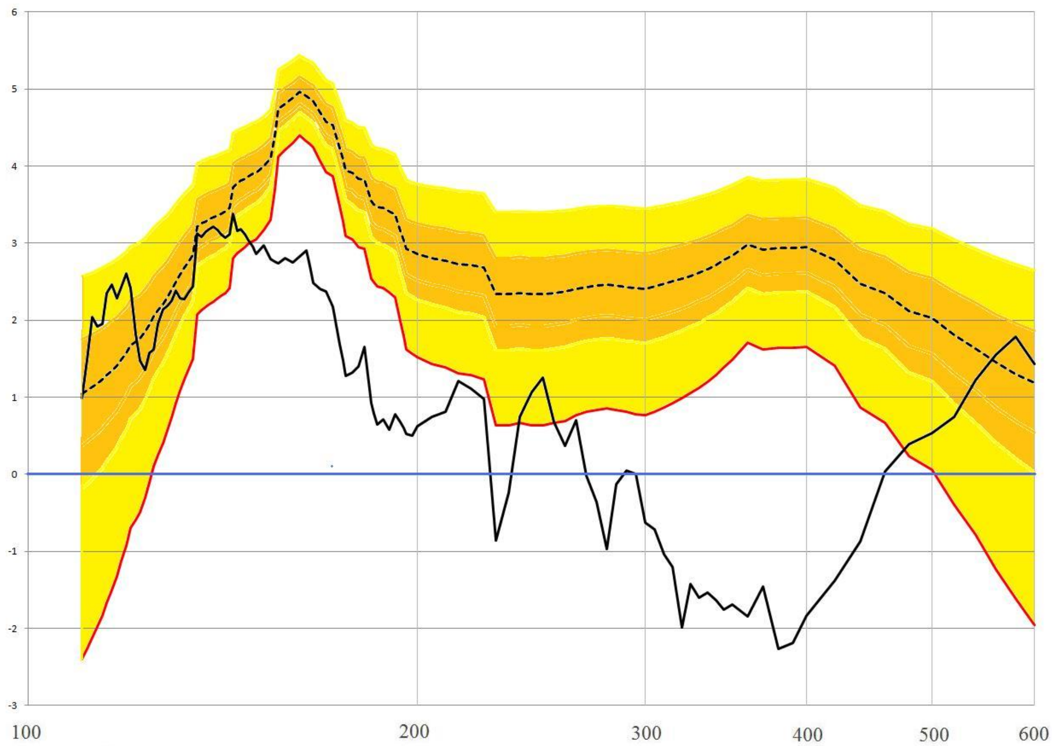


Next here is the new result for the LHC combination that has not yet been shown officially.

As you can see this gives much more significant excesses than my earlier combination. It is even a little above the upper limit of the grey uncertainty area I drew before. The broad excess around 140 GeV is well over three sigma so it can be claimed as an “observation” of a candidate Higgs if this is how the official plot looks. The excess at 120 GeV is also hard to ignore at over 2 sigma and even the limit at the high end near 600 GeV cannot be ruled out. I hope that CERN will decide to extend the plot to higher masses so that we can see this a little better if it appears on their plot.

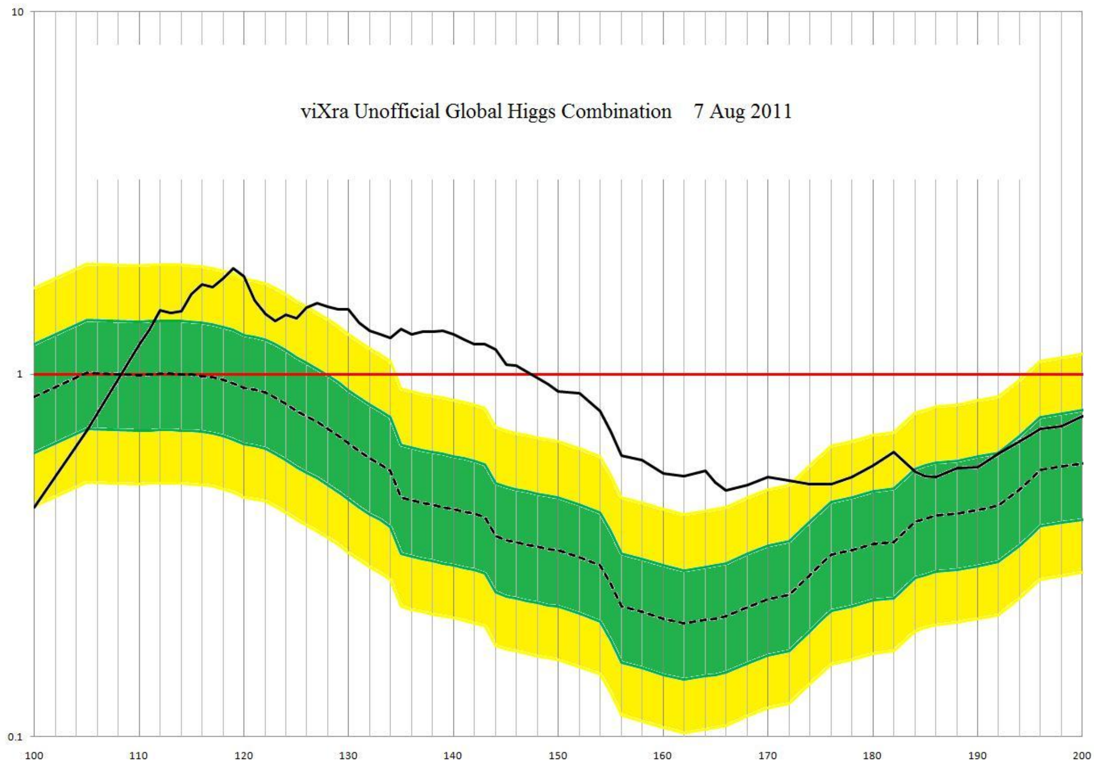


To look at this in another way we can plot just the size of the excess as seen on the logarithmic graph. In doing so it would be useful to know the expected size of the excess when there *is* a Higgs boson rather than when there *is not* as shown on the plot above. I can approximate this by adding 1 to the expected CL_s and showing it with the excess. I also hope CERN will decide to do an accurate version of this or something like it. It is fine to show expected values for no Higgs boson when you are just excluding, but as soon as a signal appears you need to know what a signal is expected to look like with the boson.



This plot is less familiar so let me explain what it is telling us. The black line shows the observed excess in numbers of sigma. There is a broad region of excess above two sigma for masses from 112 GeV to 172 GeV, but this is below the red exclusion line above 149 GeV. It lies within the bands for an expected Higgs boson signal between 110 GeV and 144 GeV. 144 GeV is also where we see the maximum excess at 3.4 sigma, but there is also a minor peak at 119 GeV where the signal reaches 2.6 sigma. Finally there is also a less significant peak at 580 GeV of 1.7 sigma. Although the plot does not exclude a signal for a small window around 250 GeV this is lower than the excess expected for a Higgs boson.

That is not the end of the story because we also have the full Tevatron combination and we can add that in as well to produce a global Higgs combination plot. Nothing changes above 200 GeV so here is a closeup of the low mass window



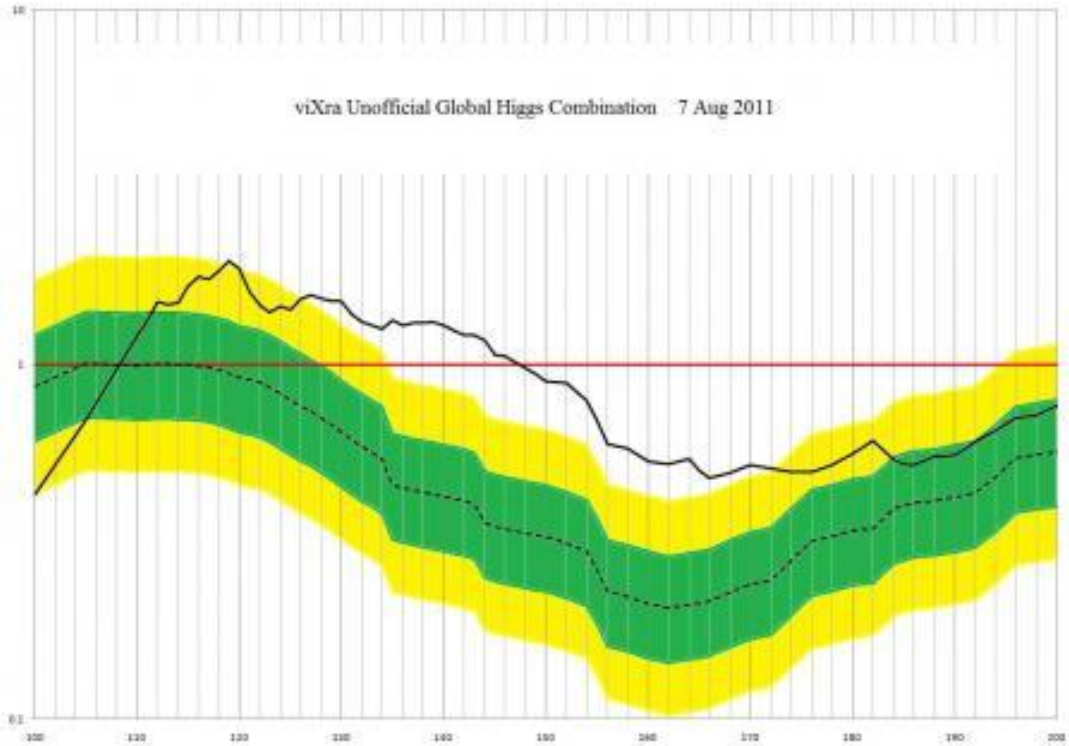
The excess at 120 GeV is a little reduced, but otherwise the message is similar.

With twice as much data now recorded by ATLAS and CMS we can expect some clarification on what this is telling us quite soon. Until then the conclusions are uncertain and you are free to speculate.

Has the LHC seen a Higgs Boson at 135±10 GeV?

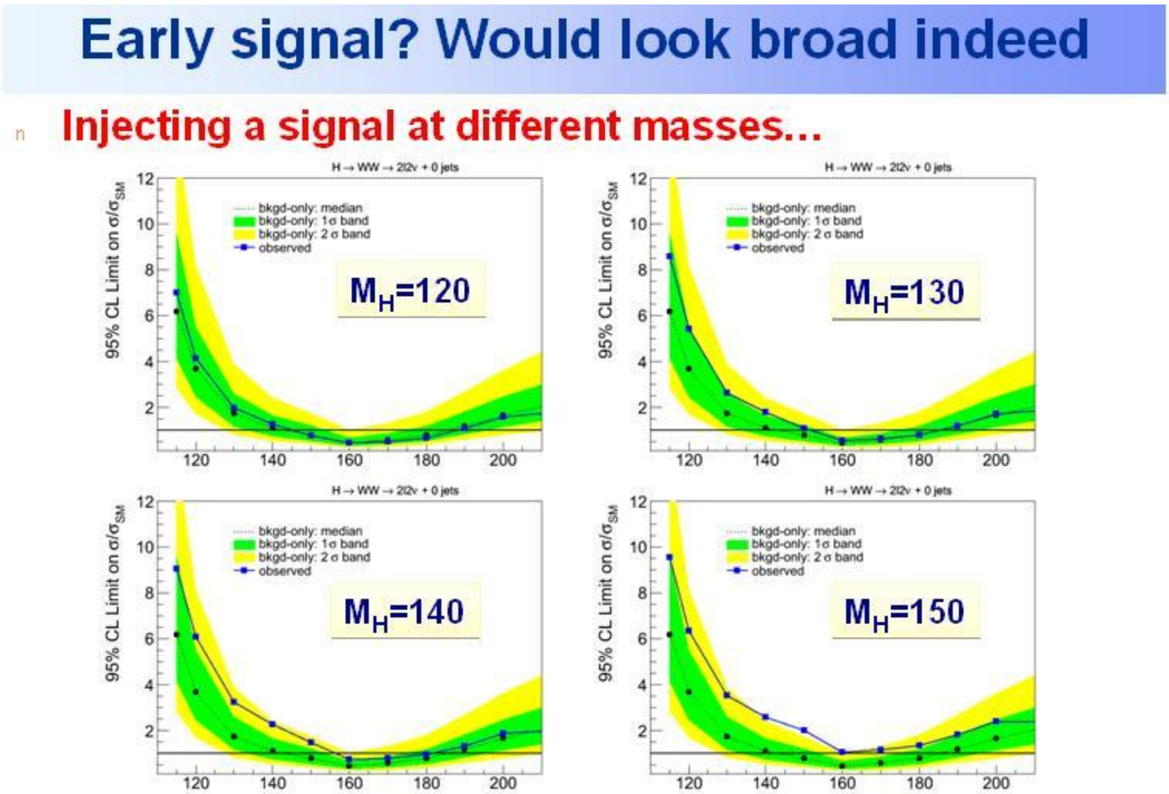
Once again rumours are circulating that the Higgs Boson has been seen and now they are more stronger than ever. At the EPS conference it was seen that both ATLAS and CMS have an excess of events peaking at around 144 GeV. Fermilab had a signal in the same place but much weaker. At the Lepton-Photon conference starting 22nd August ATLAS and CMS will unveil their combined plot. The question is, will the combined signal at 144 GeV be enough to announce an observation over 3-sigma significance?

Needless to say some early versions of the combined plot have already been leaked but rather than show results that may change I am just going to discuss my own unofficial combinations that are not very different. So here again is my combined plot for CMS, ATLAS and the Tevatron.



This shows a brought excess peaking at 144 GeV where it is well over 3-sigma significance. It extends from 120 GeV to 170 GeV above 2-sigma most of the way but it shows an exclusion above 147 GeV at 95% confidence. The signal is the expected size for a standard model Higgs boson from 110 GeV up to 145 GeV but is excluded by LEP below 115 GeV. What could it be, a Higgs boson, two Higgs bosons or something else?

The width of the Higgs boson is determined by its lifetime and at this mass it should be no more than 10 GeV. However there is a lot of uncertainty in the measured energy in some of the dominant channels. Some useful plots shown at Higgs Hunting 2011 by Paris Sphicas show what a simulated signal looks like in the WW channels and it is clear from these that a Higgs boson at 130 GeV or 140 GeV is perfectly consistent with the broad signal now observed.

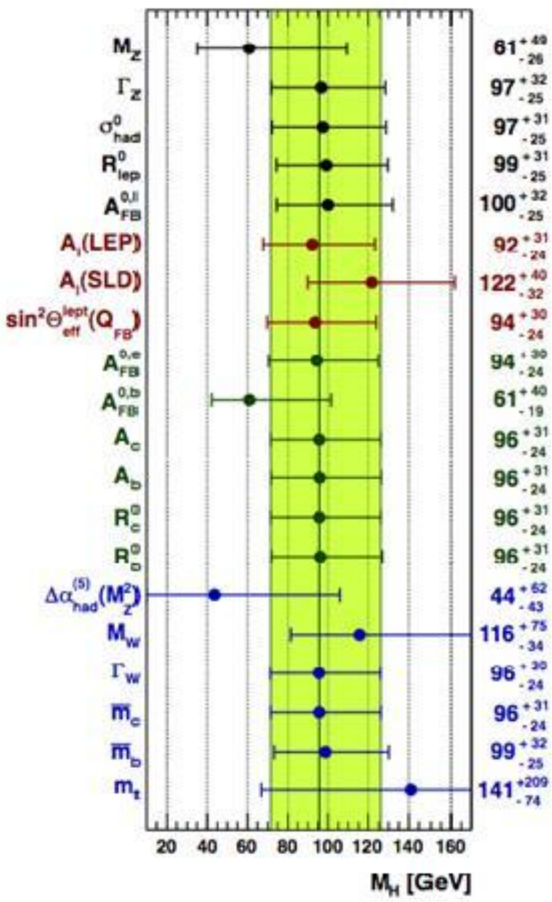


There is also a hint of a signal around 120 GeV but it is not strong enough for a claim. I would say that overall this plot is consistent with a single Higgs boson with mass between about 125 GeV and 145 GeV or more than one Higgs boson in the range 115 GeV to 150 GeV. Whatever it is, the significance is enough to claim that a Higgsless model is now unlikely to be right unless some other particle is mimicking the Higgs boson in this plot and it is probably a scalar. Afterall, we can't really say that the signal is definitely a Higgs boson until we can confirm that it has the right cross-section in some of the individual channels.

What does this say for SUSY and other models? The MSSM requires a Higgs boson below 140 GeV. In detail the signature would be different from the standard model Higgs boson. If there were a Higgs below about 130 GeV the vacuum would be unstable (but perhaps metastable) I think something as light as 120 GeV would be hard to accept as a standalone Higgs boson and would have to be stabilised with something that looks like either a SUSY stop or a Higgsino. On the other hand a 140 GeV Higgs can easily exist on its own and requires no new physics even at much higher energy scales. At this point we cannot rule out either MSSM or a lone Higgs boson.

Earlier I said that the electroweak fits could kill the standard model and that is still the case. At Higgs Hunting 2011 Matthias Schott from the gfitter group told us that a Higgs at 140 GeV has just a p-value of 23% in the fit which includes the Tevatron data. This is far short of what is required to rule it out but it tends to suggest that there may be something more to be found if the gfitter data is good (count the caveats in that sentence.) So just how good is the gfitter data?

This plot shows the effect on the electroweak fit of leaving out any one of the measurements used.



The green bar shows the overall preferred fit for the Higgs boson mass giving it a mass of 71 GeV to 122 GeV. But anything below 114 GeV is excluded by LEP. Anything below 122 GeV would certainly favour SUSY which is why this plot has been encouraging for theorists who prefer the BSM models. Indeed it is possible to get a much better fit to the data with just about anything other than the standard model.

How seriously should we take this? To get back some sanity have a look at the effect of the A_l measurement. The fit includes two separate measurements of this parameter, one from LEP and one from SLD (SLAC Large Detector). The reason for using the two is that they disagree with each other at about 2-sigma significance. This could just be statistical error in which case we should use the combination of them both, but suppose it is a systematic error in one or other of the experiments, such as a mismodelled background? Removing the SLD measurement would push the preferred Higgs mass up and widen the error bars so that anything up to 160 GeV becomes a reasonable fit. This is just one example of how a measurement could compromise the fit. That being the case I think we should not take the fit too seriously if we have good direct evidence for something different, and now we do.

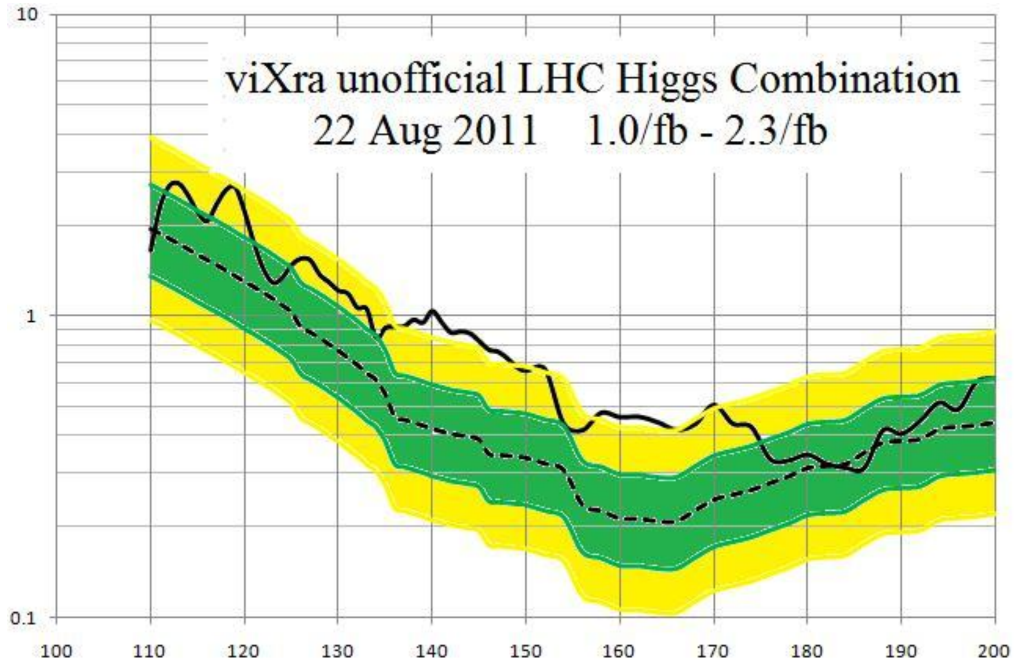
In Conclusion: From reliable sources I am expecting CERN to issue a press release about the status of the search for the Higgs Boson next week in advance of the LP2011 conference. If the official Higgs combination is similar to my version (the leak shows that it is) then they have the right to claim an observation (but not a discovery) of a strong signal consistent with a Higgs boson at 144 GeV (or soewhere else nearby). They cannot excluded other

BSM signals including MSSM. I don't know exactly how they will spin it but they will want the media to take notice.

For more details we will need to await the next analysis. Given present results and the extra data already recorded I am sure we will not have to wait too long.

New Unofficial Higgs Combo

Sadly CERN decided not to show any full LHC Higgs combinations today but we can always do an unofficial version again using the new ATLAS and CMS plots with more data. From 200 GeV to about 500 GeV everything is excluded and above that there is not enough data to say much so we just look below 200 GeV now. This is what we get

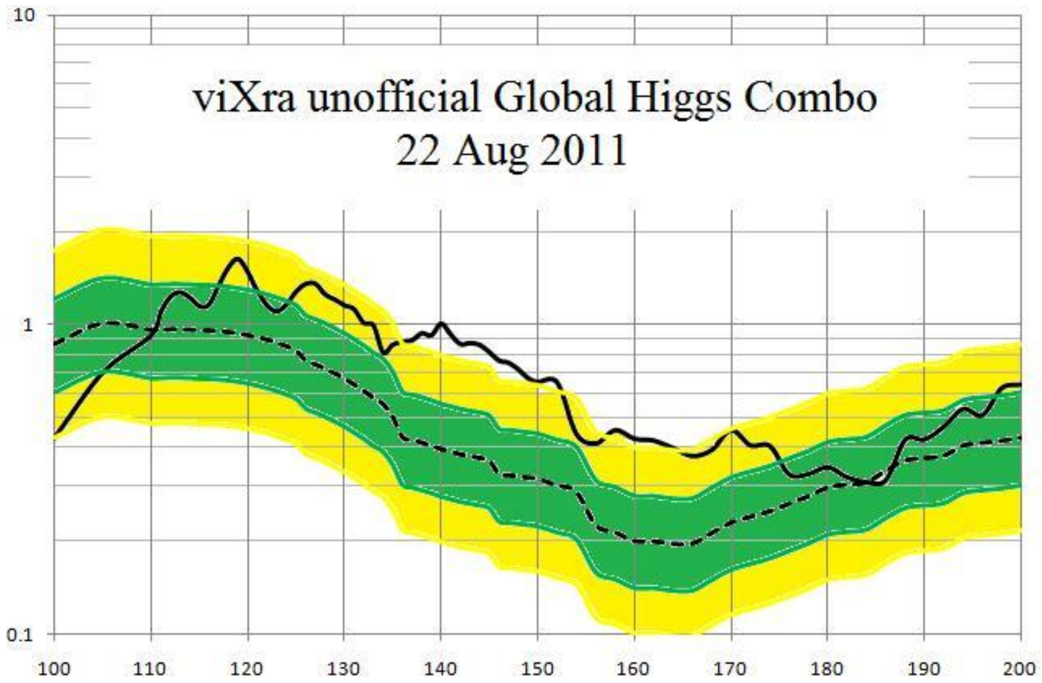


The previous Combo after EPS was consistent with a standard model Higgs somewhere between 125 GeV and 145 GeV, or a more complex mixture of bosons over a wider range. The conclusion has now swung back away from the standard model with masses above 135 GeV all but eliminated. There is still a signal for something but it is much less strong than before. The 3-sigma "observation" that CERN could have claimed has gone.

Technically there is still a chance for a boson at around 140 GeV, and a standard model Higgs boson is not excluded around 130 GeV but in that case the vacuum would be unstable or metastable unless there is something else such as superpartners. The Higgsless models have also been resurrected with an outside chance that the excess could fade away completely.

The case for a lighter Higgs at around 120 GeV is still wide open.

If you are wondering what it looks like with the Tevatron data added, the only difference is at the low mass end. Conclusions don't change.

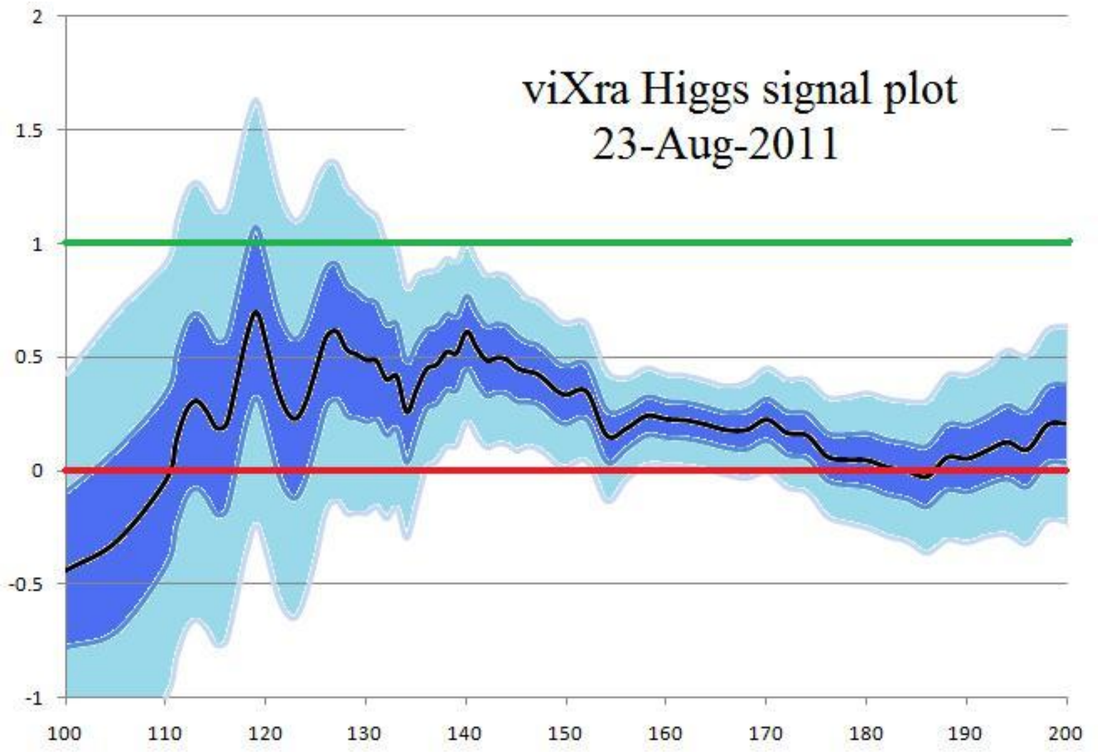


Higgs Signal Plots

It is traditional to present the results of searches such as Higgs hunting as [Brazil plots] that show us where a signal can be excluded at 95% confidence, but when the data starts to show a positive signal it is better to show signal plots like the one below. This is just the observed confidence level limit minus the expected with the error bands for one and two sigma statistical variation shown around the signal level line.

In this plot an absence of a Higgs boson is indicated by the black line being at the red zero line, but the presence of a standard model Higgs is indicated by meeting the green line at one.

Here I am using the latest CMS and ATLAS data shown at Lepton-Photon 2011 as well as the Tevatron combination shown at EPS 2011



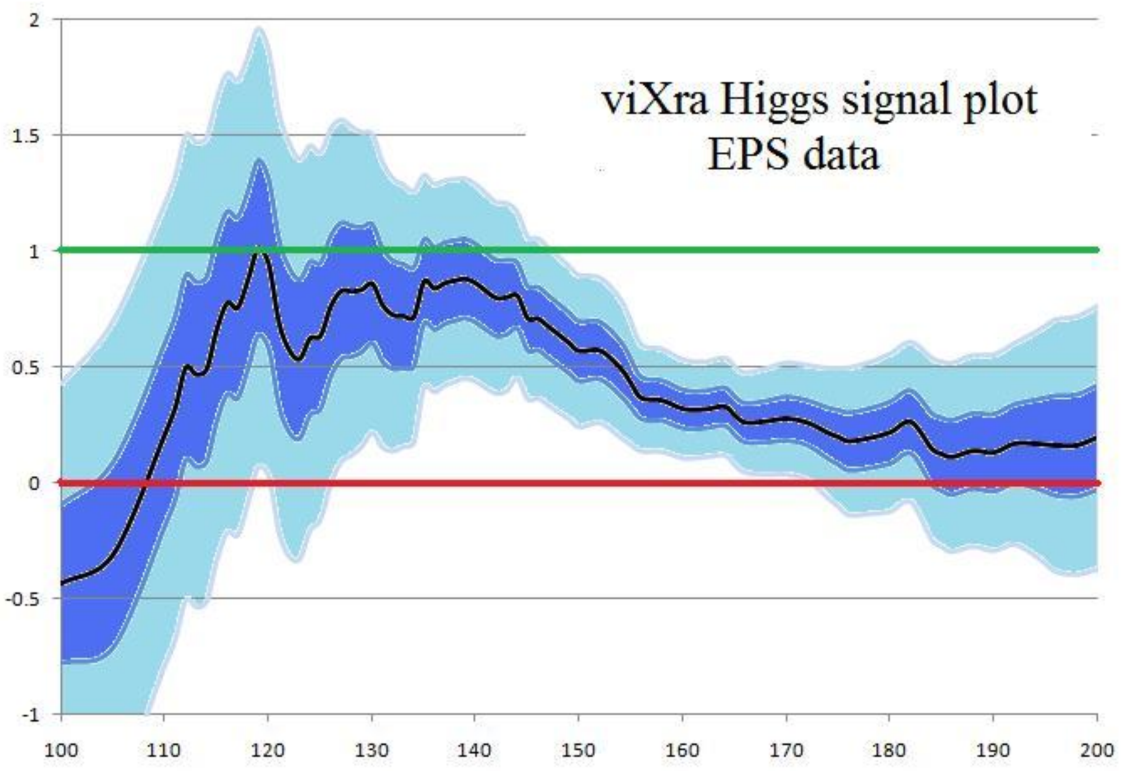
This gives a much clearer picture of what is going on. Above 155 GeV the signal is nicely consistent with no Higgs. Below 135 GeV the signal is right in the middle but the error bands are large and easily allow for either a Higgs or no Higgs.

The middle region is more interesting. From about 135 GeV to 150 GeV it disfavours both a signal and no signal of a standard model Higgs. It is tempting to say that this rules out standard model physics in this region but I think it is too soon to draw such a conclusion. It may be that there is a SM Higgs boson at say 140 GeV but the resolution is not sufficiently good to get a clean signal there, or more data may see the line fluctuate down to the no signal level.

It is important to remember that we are still at the stage where just a few signal events have a big effect on the curve. More detail will emerge with more data. Furthermore, the plot above is only an approximation that does not properly take into account all uncertainties and correlations.

The LHC is now entering a Machine Development and Technical Stop phase for the next two weeks with 2.5/fb recorded in each of ATLAS and CMS. There are no big conferences on the horizon but both experiments have CERN seminars scheduled for the middle of September. With luck they might update all the channels and give us another update soon. Hopefully they will also do some official combos for both exclusion and signal plots.

In case you were wondering what it would have looked like with the EPS data, here it is.



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