

The Higgs Boson?

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The summer of 2012 was an exciting time for particle physicists: the elusive Higgs boson had been discovered by two experiments at CERN, the European Organization for Nuclear Research. Champagne bottles were a-popping! The Higgs boson, a type of subatomic particle, had been proposed by physicist Peter Higgs in 1964 to explain the mass of fundamental particles, and its existence had finally been confirmed. Or so we think. Only a few properties of the proposed Higgs boson have been experimentally verified thus far. In order to determine if the newly discovered particle is truly the Higgs boson, physicists still need to experimentally verify the boson's various other theoretical properties.

One of these properties is how strongly the Higgs boson couples with top quarks. The Ohio State University CMS group is actively attempting to measure this property.¹ Finding out the rate at which top quark pairs are produced in association with this new particle from the proton-proton collisions at CERN will pin down this property and help determine if the particle discovered was truly the Higgs boson.

The CMS detector records information about the various final state products produced in proton-proton collisions. With this data, we can try to identify what process has occurred in a collision. When top quarks are produced in association with a Higgs boson ($t\bar{t}H$), various decay structures are predicted to exist. If we

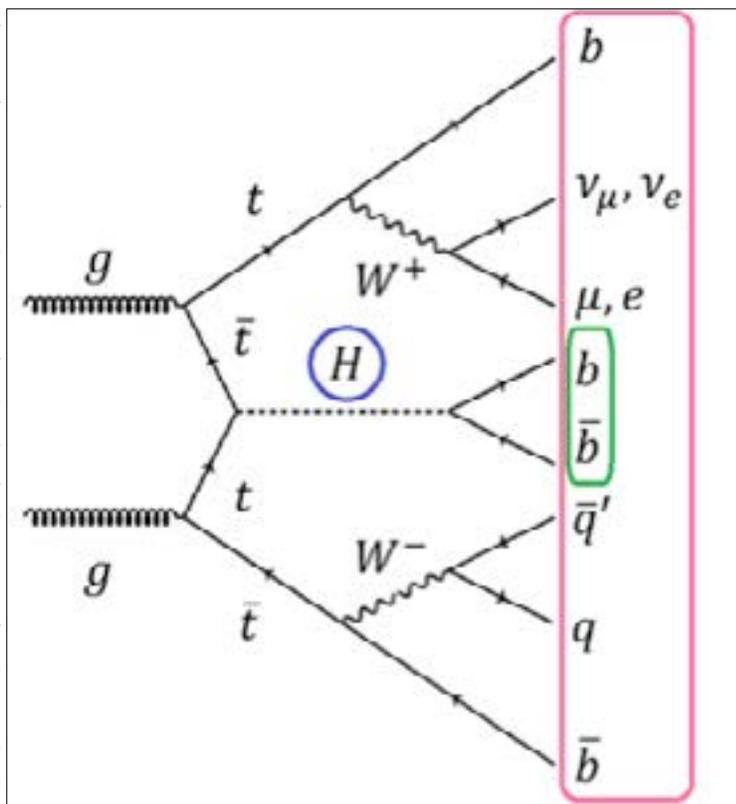


Figure 1: $t\bar{t}H$ Feynman diagram

can uniquely match the collection of final state product properties that we see in the detector with the predicted decay structure of $t\bar{t}H$, we can presume that the collision event producing those final state products was a $t\bar{t}H$ event. If no other processes produced final state product collections similar to $t\bar{t}H$, then measuring $t\bar{t}H$ would be a piece of cake. Unfortunately, there are processes that mimic the nature of $t\bar{t}H$ events and give similar final state products. These processes are called backgrounds. Moreover, extremely problematic “irreducible” background processes result in virtually identical collections of final state products to those of $t\bar{t}H$. One such process is $t\bar{t}b\bar{b}$. To discriminate between $t\bar{t}H$ and $t\bar{t}b\bar{b}$, we have to get clever.

1. CMS, Compact Muon Solenoid, is one of the Higgs discovering experiments at CERN. I am an undergraduate member of The Ohio State University CMS group.



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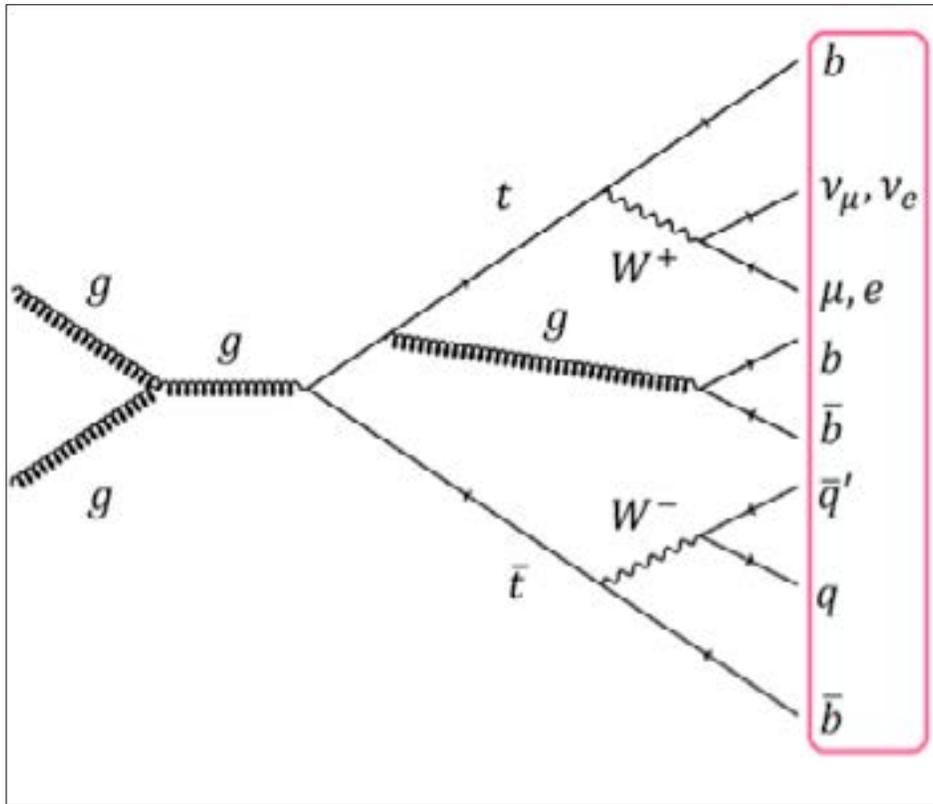


Figure 2: $t\bar{t}b\bar{b}$ Feynman diagram

To begin, we place certain requirements on the number of particular final state products detected; this greatly reduces the relative amount of $t\bar{t}H$ backgrounds right off the bat. A typical $t\bar{t}H$ process is represented by the Feynman diagram in Figure 1. The Feynman diagram for the background $t\bar{t}b\bar{b}$ process is shown as Figure 2. Through complex interactions in the proton-proton collision, the particles on the leftmost of each diagram end up decaying to the vertical column of final state particles on the rightmost of each diagram, with the final states enclosed in pink boxes. Notice that the final states are the same for each process. This is what the CMS detector “sees,” and this is why it is hard to tell $t\bar{t}H$ events and $t\bar{t}b\bar{b}$ events apart.

So how can we proceed? One idea is to pick out a blatant difference between $t\bar{t}H$ and backgrounds like $t\bar{t}b\bar{b}$, namely that $t\bar{t}H$ has a Higgs boson, circled in blue, in its decay structure. If we can devise a way of identifying the final state products, enclosed in green, that came from the Higgs boson, we can literally add them up in a relativistic 4-vector sum, compute a quantity called the invariant mass, and expect to get the Higgs boson mass.

In order to identify the Higgs boson decay products, it is essential to make use of additional information.

The masses of the other parent particles in the decay structure of $t\bar{t}H$ are known. This prompted the development of a selection technique that tries to identify all final state products that did not come from the Higgs boson. This technique calculates a “how-well-do-they-match” value, mathematically known as a chi-squared (χ^2), with lower values representing better matches. The technique works as follows. First, take a guess at where the various final state products we see in the detector could be arranged at the end of the decay structure. Second, reconstruct the parent particles (t, \bar{t}, W^+, W^-) in the decay structure with this arrangement. Third, compare the reconstructed masses of the parent particles to the known masses of the parent particles: compute a χ^2 value by adding differences in mass for each parent particle in

quadrature taking into account the experimental uncertainty of measurements. Fourth, if this arrangement gave a very low χ^2 , then this arrangement of final state products is likely to be the correct arrangement. In order to find the best arrangement, we perform this technique on every possible final state product arrangement and see which gives the lowest χ^2 value.

After this technique is performed, we can eliminate all but two final state products as possible decay products from the Higgs boson; therefore, we have effectively identified the decay products of the Higgs boson! Maybe in a perfect world this would be true, but the minimum chi-squared technique identifies the correct Higgs boson decay products only about 27% of the time. However, this is far better than what we started with: a random guess at the Higgs boson decay products is correct about 6% of the time.

We can test this technique on computer simulated Monte Carlo samples to see how it helps discriminate between $t\bar{t}H$ and backgrounds such as $t\bar{t}b\bar{b}$. The “Best Higgs Mass,” the resulting mass from the summation of the identified Higgs boson decay products, is shown for $t\bar{t}H$ in pink in Figure 3. We see a peak in the simulated distribution at $120 \text{ GeV}/c^2$, the mass of the Higgs boson in this sample. When performing this same technique on $t\bar{t}b\bar{b}$, shown in black, a broader mass distribution is created since there is no Higgs boson in this sample. The difference between these distributions is helpful

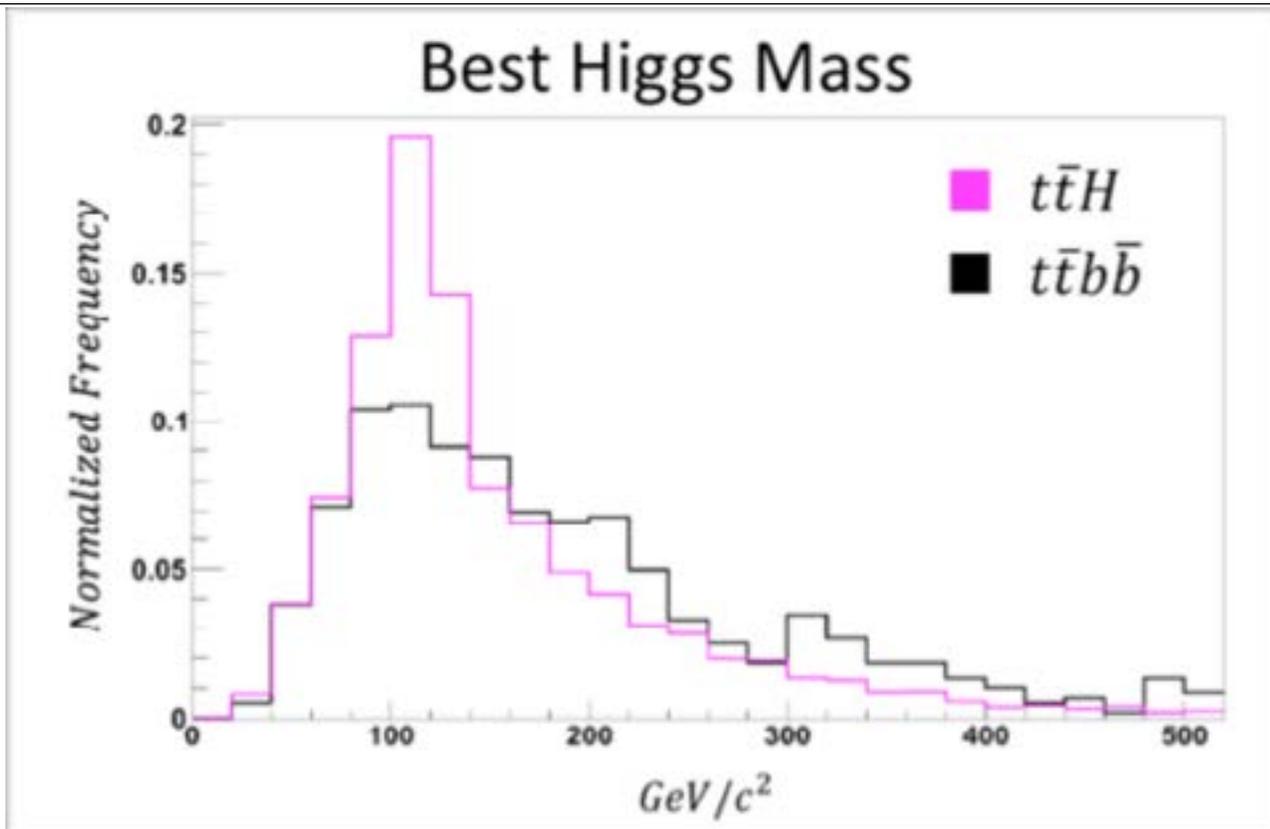


Figure 3: “Best Higgs Mass” $t\bar{t}H$ vs. $t\bar{t}b\bar{b}$

in separating $t\bar{t}H$ events from pesky backgrounds like $t\bar{t}b\bar{b}$.

This variable, the “Best Higgs Mass,” is expected to have a significant impact on the sensitivity of the current $t\bar{t}H$ search at CMS and will be included in the analysis of this endeavor, whose results are projected to be available in early 2013. Ultimately, studies of this sort will help determine if the Higgs boson from theoretical predictions was really discovered and take us one step forward to a more fundamental understanding of the universe.

To cite this article, please visit go.osu.edu/citations2012

Editor’s note: Instances of $t\bar{t}H$ should be read as $t\bar{t}H$ and instances of $t\bar{t}b\bar{b}$ should be read as $t\bar{t}b\bar{b}$. Also, an incorrect revision of this feature article was published in the 2012 Oculus Award Edition (print). The above feature article is the appropriate, final revision.