Royal Society Summer Science Exhibition July 2013 - "Understanding the Higgs boson"

Guide to Activities & Demos

Description of the RHUL activities & demos

These descriptions are intended to be used to brief the shifters who will be explaining the activities to the public. Most of what is pointed out below is obvious to us, the shifters; in fact, it might be so obvious that we forget that it might not be obvious at all to members of the public. The emphasis here is therefore to try to make the shifter more aware of the likely questions or misconceptions that members of the public might have, and how to deal with those. Jargon words that we are likely to use are highlighted in red, with some alternative explanations provided.

The statistics of finding the Higgs and the mass plot

One misconception the public might understandably have, is that searching for the Higgs is not unlike searching for a new animal species, eg pink elephants, that would be clearly different from other animals around. If biologists observed a pink elephant once, that would be the end of the search: once you have seen one, you do not need more data to confirm that they exist.

The search for the Higgs does not work like this. Seeing an event with a di-photon invariant mass of 125 GeV does not mean you have found the Higgs. In fact, the vast majority of the di-photon events (the outcome of pp collisions) we have with that mass are background (i.e. they arose from processes that do not involve the Higgs particle at all) rather than Higgs events. However carefully one examines individual collisions with a di-photon invariant mass around 125 GeV, it is not possible to tell which specific events are Higgs events, and which are not. [Note to shifters: it is, in principle, possible to have a search for a signal which is completely free of background; in that case it would be possible to tell that the events observed were signal. The "golden" Higgs search, for four-lepton events, is close to being almost background-free.]

The search for the Higgs is a search for an **excess** of the no. of such events collected, compared to the numbers of events you would expect to collect if the Higgs didn't exist. In this sense it is very much like trying to establish whether a die is loaded (the Higgs exists) or not (the Higgs does not exist). The way to establish whether the die is loaded or not is to roll the die **many times** and record the outcomes. Namely, count how often the outcome is 1, 2, 3, 4, 5 or 6. If, after many rolls of the die, all outcomes have roughly the same probability the die is likely fair. If, on the other hand, a particular outcome (eg rolling a six) occurs more frequently than the others, the evidence would be towards the die being loaded.

This demo uses a set of 10 dice that are biased [note to shifters: the probability of rolling a "4" is higher than that of rolling any of the other numbers: 1,2,3,5 or 6]. The analogy is between a pp event and the outcome of rolling one die. To get an excess to build up quickly, we will roll 10 dice at a time (using the dice-shaker box; or a dice cup and dice tray). The outcomes of the dice-rolls are then recorded every time on a "wooden histogram" with six bins (see Figure 1). The histogram has six vertical rods, and the white wooden discs provided slide down the rods and are used to count how many times a given number has come up in the rolling of the dice. A visible excess should build up quickly on the "4" bin. This should help to explain the mass plot (which will be on display on the stand elsewhere): namely that the excess of events that builds up after many collisions have been analysed shows that the Higgs exists (or that the dice are loaded). It also tells us additional information: the location of the excess, or "peak", tells us about the actual mass of the Higgs (or, in the case of the dice we used, that the bias is on the "4").

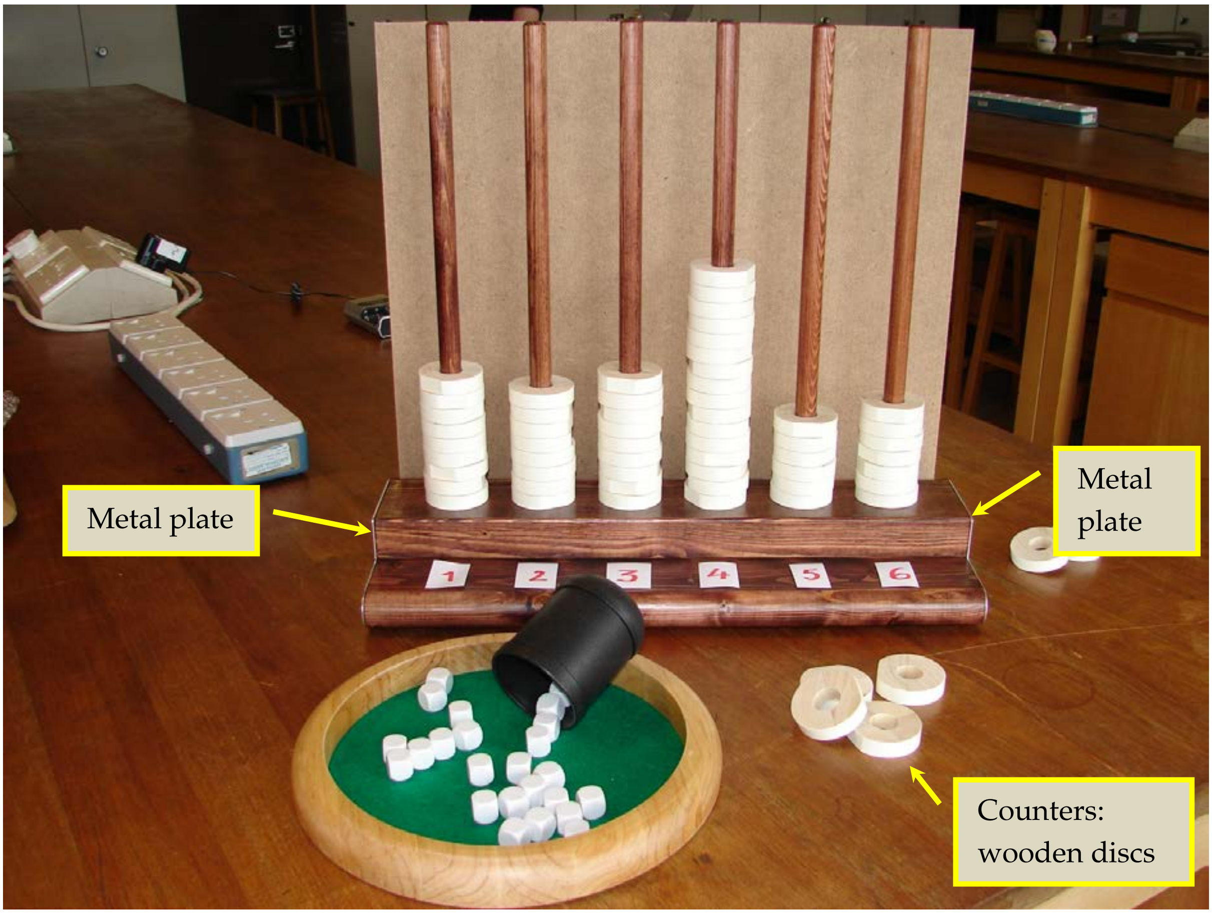

Figure 1: The wooden histogram has six numbered vertical rods to count the outcomes of the rolls of the dice, using the white wooden discs provided. ***SAFETY:*** *if you need to move or lift the "histogram", hold it with both hands, one on each side of the base, where the metal plates are.* ***Do NOT hold or lift the histogram by holding the rods****, as they will detach from the base!*

(*Suggested additional reading*: see also "Long odds: Statistics and the search for the Higgs" by Glen Cowan, in particular the caption of Figure 4. Available at http://www.pp.rhul.ac.uk/~cowan/atlas/booklet/higgscombo_for_booklet.pdf)

Something for the younger ones: Higgs hunt ("Wanted" poster)

This activity is aimed at younger children (4-9 year olds?). They will be given an A4-sized card (we call it the "Wanted" poster; see Figures 3 & 4) and a coloured pencil. The main activity for them is to go on a **"Higgs Hunt"** and also solve a **"Mystery Word"**. We have "hidden" 4 Higgs plush toys (see Figure 2) around the room for them to find.

Figure 2: The Higgs Boson plush toy (from the Particle Zoo: http://www.particlezoo.net).

Each "Higgs particle" that they find will have attached a stamp with one of the 4 different letters in "H-I-GG-S": they should stamp the letter on the card (the stamps and the card are colour-coded, to help them stamp in the correct place). They will also find a "clue card" providing a clue to each of the letters in the mystery word. The clue cards are shown in Figures 5 & 6 (we have filled in all the answers, for information – the mystery word is "ATOM"). Having found all the "Higgs particles" the children then return to the stand, show us their card with the stamps "H-I-G-G-S" and we give them a badge ("I found the Higgs!").

The "Higgs Hunt" part of the activity should be accessible to most young children, even if they cannot yet read (knowing the numbers up to 4 might help, but shouldn't be necessary). The "Mystery Word" requires reading the clue cards: children that can't read can skip this, or they can ask their parents. Feel free to encourage the parents to help the children.

Figure 3: "Wanted" poster (front).

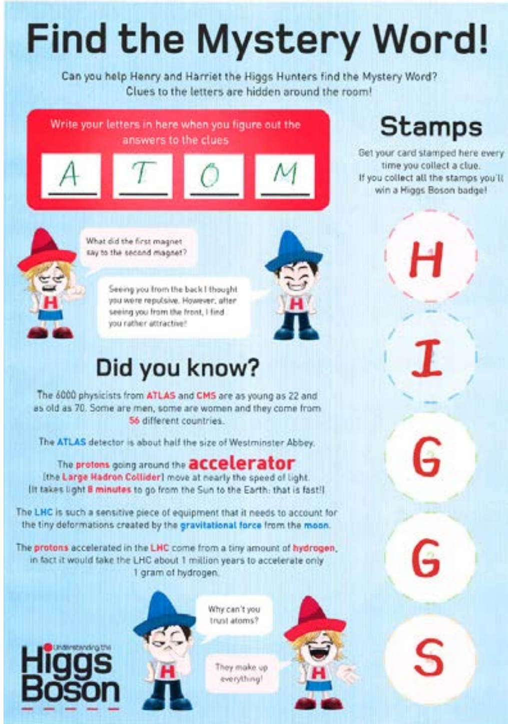

Figure 4: "Wanted" poster (back). The mystery word has been filled in (ATOM), and the H-I-G-G-S letters have been stamped.

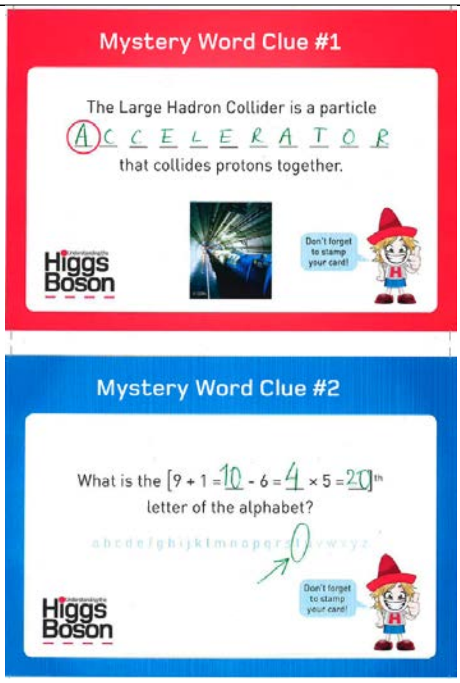

Figure 5: Clue cards 1 & 2 – the cards have clues to the letters in the mystery word. For information, the answers have been filled in.

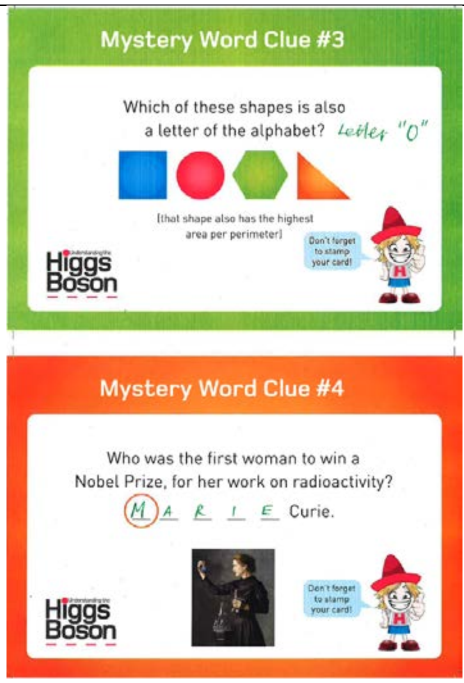

Figure 6: Clue cards 3 & 4 - the cards have clues to the letters in the mystery word. For information, the answers have been filled in.

Higgs decay dice

This activity, using 12-sided dice, is simply to put across the fact that the Higgs decays are a random process.

First, it needs to be explained that the Higgs is really a very short-lived particle, and it decays (it transforms into other particles) almost as soon as it is produced at the centre of our detectors. We never really record Higgs particles directly in our detector: only the particles that he Higgs decays **to** are observed. As an example, one of the possible decays of the Higgs is to two photons: the Higgs disappears and, in its place, two photons appear. (Not all decays are possible; certain physical quantities have to be conserved - such as the total energy or the total electric charge, before and after the transformation.)

The Higgs can just as well decay to other pairs of particles instead: it is a random process. For instance, two b-quarks, two W particles or two Z particles to name just a few other possible decay modes. All we know is that when the Higgs decays there is a certain **probability** of getting a certain outcome, such as two photons. This is just like rolling dice: you can't predict with certainty that you will roll, say, a "6"; but you can calculate the **probability** of rolling a "6".

Figure 7: Higgs decay dice: The Higgs die is yellow (decays included are $\gamma\gamma$, bb, WW and ZZ). The two W dice are red ($e\nu$, $\mu\nu$, $\tau\nu$, qq) and the two Z dice are blue (ee, $\mu\mu$, $\tau\tau$, $\nu\nu$ and qq).

This intrinsic randomness at the heart of nature is not unique to the Higgs particle: other elementary particles exist (such as the W and Z particles) that are also unstable and will decay into other particles. Many great minds have grappled with this issue. Einstein famously said that "God doesn't play dice"; on this particular count, it is actually believed he was not right...!

The yellow die represents the Higgs: roll it to find out what the Higgs decays to ($\gamma\gamma$, bb, WW, ZZ; other possible decays are not included). The W and the Z particles are however, also unstable. Therefore, if the Higgs decayed to two Ws or two Zs, then you need to roll the two red or the two blue dice, respectively, to determine which final state you will be seeing in the detector.