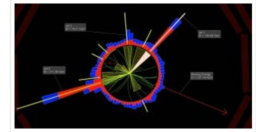
Out There

« The Real Stories and Real Science Behind "Gravity" Crowdsourcing Astronomy: DISCOVER Readers Fight Asteroid Threat »

After the Higgs Boson: A Preview of Tomorrow's Radical Physics

By Corey S. Powell | October 11, 2013 10:51 am

I don't mean any disrespect when I say that the Higgs Boson is yesterday's news. In some ways, that is the very definition of what qualifies something for a Nobel Prize: a discovery that has already established its lasting importance and shown the way toward deeper insights. The foundational papers by Peter Higgs and Francois Englert, his Nobel-co winner, were published in 1964–nearly a half century ago. (Several other researchers also contributed to the work around this time, but are not recognized as part of this year's Nobel prize.)



Simulated particle event at the Large Hadron Collider shows a "supersymmetry event"–a long-sought indicator of fundamental physics unity. (Image courtesy of Matevz Tadel, UC San Diego/CMS)

By the time researchers found strong evidence of the Higgs boson in 2012 at the Large Hadron Collider, or LHC, almost all physicists expected that it would be there; the shock would have been not finding it. The Higgs boson was the last missing piece of the standard model of particle physics, a model so well accepted that it is formally known–seriously–as the Standard Model. As with groundbreaking discoveries in general, the most interesting thing now is where it will lead next. So I conferred with one of the most thoughtful and articulate particle physicists I know, Joseph Lykken of Fermilab.

Lykken is looking forward to two big, interlinked post-Higgs discoveries: supersymmetry and dark matter. Supersymmetry is a model that links the two distinctly different types of particles in the Standard Model (known as fermions and bosons) and aims to expose an underlying unity between the two. One happy byproduct of the theory is that it also predicts the existence of a whole class of undiscovered particles, called supersymmetric particles, some of which have predicted properties that nicely fit what (little) we know about dark matter.

So that's the next goal for the LHC, currently shut down for an upgrade, when it restarts in 2015: Make all of physics look neat and balanced, and discover the missing majority of the universe. Not too shabby. Excerpts from my conversation with Lykken run below. [Follow me on Twitter here: @coreyspowell]

How do you look for supersymmetric particles–things that you can't even detect directly?

Lykken: Fortunately for us, there's already a particle that we make lots of at the LHC that we can't see, the neutrino. So we have a way of checking how well we can find invisible things. The only difference really is that the neutrinos were light and we were expecting that the dark matter particles are fairly heavy although we don't actually know that. But we, for example, we have already produced many millions of these heavy particles called W bosons, which a lot of the time decay into an electron or a muon [a heavier cousin of the electron] that we can see, and a neutrino that we can't see.

We can look at those events and say, how well can we actually do to pick out these what we call missing energy signatures? And the answer is we can already do it with great precision. So we can already say–and this is the basis for supersymmetry researchers saying they have come up with nothing so far–that even pretty small missing energy signals, much smaller than the Higgs signal, would have been seen already in these experiments.

And now that you've found the Higgs, you are just looking harder?

We try to look at as many kinds of things that we can look at. We're probably looking now at between 20 and 50, depending on how you want to count, different kinds of events just looking for imbalance and not asking any other question than do you see more imbalance than you would expect from things that involved neutrinos.

There are always some energy excesses somewhere. That shows that you're doing an honest job, because these are statistical events. When I collide these protons at the LHC, quantum mechanics is in charge, and quantum mechanics does things in a probabilistic way. You should have always some excesses if you're looking at different kinds of events. If you don't, that means you cheated. But so far all we've seen are those small fluctuations.

Many physicists expected—or at least hoped—that the LHC would have seen signs of supersymmetry by now. Are you concerned it hasn't happened?

Joseph Lykken plays Scrabble with the universe. (Credit: Reidar Hahn, Fermilab)

You know, people said the same thing about the Higgs boson. "You're going to turn on the LHC and you're not going to see anything. You guys are all wrong." And they turned on the LHC and there it was.

That said, we're sort of in that nervous in-between phase, especially now that the LHC is turned off for a couple of years. Roughly speaking we've looked at about half of the theory parameter space where supersymmetry would live. So yes, I think it was reasonable to hope that you might've seen it in the first half of things that you looked at, but things happen sometimes. You don't always find things on the first look. Sometimes you find them on the last look. We didn't really have a theory that said supersymmetry had to look exactly like this, we had a range of millions of different models to look at. So I don't want to be too discouraged.

OK, but what if you keep going and still don't see anything?

When you're a theorist, part of your job is to jump ahead of what the experiments are doing. So there is a lot of activity in the theory community, myself included, in thinking about what would it mean if the LHC conclusively ruled any superpartner particles below its full energy range. What would we do then?

My personal feeling is that I would say then that our basic idea about supersymmetry and its role with the Higgs boson and electroweak symmetry breaking [which splits particles into two families] is wrong. Maybe that means we made a fundamental mistake in the way that we've thought about this whole problem, even though we've all agreed that for the last 30 years that this was the most obvious thing for nature to do.

I was at a meeting of LHC theorists and I brought up exactly this question. I said, can we all agree that if the LHC runs for its full run and doesn't see any superpartners that we give up on supersymmetry in the conventional sense? And there was no agreement. There are people that say, oh no, supersymmetry must still be there and it's just out of reach; it's such a good idea that we can't give it up, even if the LHC doesn't find it. I don't agree with that, but this is a matter of taste because of course nature is doing whatever nature is doing and it doesn't matter what I think.

And what about the search for dark matter? How does that fit in with this next stage of research at the LHC?

One thing that could happen is that you could detect dark matter directly [using an experiment like LUX] and find that doesn't look like the kind that the supersymmetry models predict. There are already some preliminary signals for fairly lightweight dark matter particles, which what you expect from supersymmetry models. If confirmed, that would be evidence that the supersymmetry picture is wrong or at least needs radical revamping

If those low-mass dark matter particles really exist, we should produce a large amount of them at the LHC.We already are gearing up to do experimental searches designed to look for this kind of dark matter, as well as the heavier things predicted by supersymmetry models. So if that's what's going on: Low-mass dark matter can run but it can't hide forever because it's light enough that we make lots of it.

Or could dark matter be something even more exotic that you've missed entirely?

Right. For example, the real answer could involve some extra dimension. It could be that dark matter lives in a different slice in the extra dimension or something like that. That remains to be seen. The question of why we don't see dark matter, as [Harvard physicist] Lisa Randall always reminds us, it's not that it's dark, it's that it's transparent. You can go down many roads to explain why something is there but you don't see it. Maybe it's a much more sophisticated story. I'm open to that.

Some theorists, including Lisa Randall, suggest that dark matter might have its own interactions, leading to a whole complicated dark universe. Will your supersymmetry studies be able to provide any answers?

The idea that dark matter has self-interactions is very compatible with this idea that it comes from supersymmetry. The idea is that the dark matter is a superpartner of a Standard Model particle [such as a partner to the neutrino, called the neutralino] and then there's lots of other superpartners and they interact in lots of complicated ways. If you think there might be lots of different kinds of dark matter having different masses and different kinds of interactions, then the kinds of searches we're doing now are exactly the right searches: ones where we look for not just imbalances but imbalances in lots of different ways.

What is the prospect for finding such exotic physics with the LHC, given that people already worked so hard to find the Higgs boson?

In 2015 the LHC is supposed to start again at higher energy. So we could have something turn up just because we're running with significantly more energy. When it restarts, that actually will be the Large Hadron Collider that was originally advertised. The one that we just did for two years was the backup plan after we had the accident [a major spill of liquid helium that closed down the LHC before it even started up]. The real LHC, the one everybody was planning on, hasn't happened yet. That's the one that's starting in 2015.

When people say they are disappointed we didn't find supersymmetry at the LHC, I say: the real LHC, the one we always advertised hasn't actually happened yet. So it's not fair to be too disappointed.

What about after the LHC—are there plans for an even greater particle accelerator?

There's a lot of excitement about the proposed International Linear Collider. The ILC won't be able to produce the heaviest particles that you make at the LHC, but it will be able to produce particles with masses up to something like 500 GeV which is pretty heavy [about 500 times the mass of a proton]. There's a good chance that the ILC might be able to produce dark matter particles. If there are several kinds of dark matter particles, as we were saying, there's an even better chance that it will be able to produce one of them.

That would be absolutely amazing because the ILC is a whole different kind of machine than the LHC. It collides electrons with positrons [their antimatter twins], which produces very clean collisions. You can do precision measurements of the kind you can't even think about at the LHC. So if you can produce dark matter at the ILC, then it will become the dark matter factory for the next 30 years. That's the way we're going to figure out what the dark universe is all about.

It's not guaranteed that the ILC can produce dark matter, but it's a pretty good bet. It is guaranteed that the ILC can make the Higgs boson, and the Higgs boson also has a connection to dark matter.

Wait: The Higgs boson is linked with dark matter? That's something I haven't heard about before.

One of the things we're very interested in is whether the Higgs boson itself has invisible decays and if it does – and this is something we're going to look for at the LHC – those decays might be dark matter particles. There might be a direct connection.

In this scenario, the Higgs is decaying invisibly, so you have to look at an event where you have a good idea how often Higgs bosons are produced. That requires going from where we are now, where we're lucky to see any Higgs bosons at all, to being able to say, oh yeah, out of these million particle events, 50,000 of them should have produced Higgs bosons, but instead I saw 50,000 events where nothing was there—and that's my invisible Higgs boson. We're not at the level yet of being able to do that, but that's the kind of thing we're thinking about for the end of the LHC run once we have much, much more data than we have now.

At that point the Higgs boson will become the boring raw material for finding the more interesting, exotic dark matter? Is that what you're saying? What a wild idea.

Exactly. Just as the top quark is now considered a boring background particle, the Higgs boson, at some point will be so well known that we'll be able to do these kinds of dark matter measurements.

Does it amaze you that we are able even to ask these kinds of questions, and to learn as much as we have?

To me as a theorist it's especially amazing because nature certainly doesn't care what our science budget is. It could just have easily as been that dark matter direct detection was possible, but only if you spent $100 billion on it. The fact that it's possible with things we can actually do now, using technology that we have now, is an amazing coincidence because nature did not care about that.

Carl Sagan used to say that we are the way for the cosmos to know itself. It almost seems like nature is saying: I want you guys to figure this out so I'm going to lay everything down where you can get it.

CATEGORIZED UNDER: ASTRONOMY, COSMOLOGY, DARK ENERGY, DARK MATTER, SELECT, TOP-POSTS, UNCATEGORIZED

MORE ABOUT: HIGGS BOSON, ILC, JOSEPH LYKKEN, LHC, NOBEL PRIZE, SUPERSYMMETRY

- **Mohammad Shafiq Khan**

  Sooner or later world would realize the seriousness of the following message which I sent to Nobel Organisation on the eve of awarding Nobel Prize in Physics in 2013

  Nobel Committee A Big Joke
  â€œI fail to understand how the Nobel Prize in physics 2013 was announced on the basis of the paradigm which is under standing open challenge. It is painful to see that Nobel Committee upholds the paradigm of physics which has been mathematically, theoretically & experimentally shown to be fundamentally incorrect. Standing open challenge could be seen at World Science Database & General Science Journal in my profile at http://www.worldsci.org/php/in... and http://gsjournal.net/Science-J..."

  I agree with Mohammad Khan that the award of the Nobel Prize for the theory of the Higgs boson is unjustified. The Higgs apparition is alleged to be composite, made up of 'higgsinos'. This is all nonsense. (Steve Crothers)

- **Vladimir Tamari**

  The discovery of the Higgs boson, wonderful as it is, has confirmed expectations about the Standard Model. Unfortunately that and supersymmetry, even an explanation of dark energy and matter is not enough. A simple realistic theory of everything free from gobbledygook is still missing - particularly one that unifies gravity with Quantum Mechanics.

  Here is my short paper along these lines:
  "Fix Physics! â€“ Reverse Engineer Relativity, Quantum Mechanics and the Standard Model, Get Rid of Outdated Assumptions, Consolidate, and Reconstruct on New First Principles"
  http://www.ne.jp/asahi/tamari/...

- **stevlich**

  This is all theoretical gobbledygook. It will never in a gazillion years have any practical application. And 90% of the universe is still missing.

- **coreyspowell**

  A century ago, you might have said the same about relativity or quantum physics. The practical applications took a great deal less than a gazillion years (unless gazillion is defined to mean "about 30").

  It is quite possible that we will learn within the next five years what that missing 85% of the universe is made of. But there's no need to wait to be amazed. It is astonishing that we have learned as much as we have already, and that by using that knowledge humans have achieved such mastery over the natural world. Look around your home. Everything you see was touched by a human mind. That is cause for celebration, every day.

- **Michael Geil**

  How many theories have been completely wrong or have not been useful in other aspects of science? I would hope that it would be useful in a gazillion years because