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00:06 Sarah Crespi: Welcome to the Science Podcast for May 24th, 2019. I'm Sarah Crespi. On this week's show, we've got staff writer Adrian Cho. He's gonna talk to me about potential new targets for the Large Hadron Collider. Could long live particles be alluding the detectors on the LHC? And I also talked with Tian Li about using modified wood to passively cool buildings. The idea is to make a cheap scalable material that substantially reduces the energy footprint of buildings by sending heat into space.

00:43 SC: I've got staff writer Adrian Cho here to talk with us about a hunt for odd ball particles at the Large Hadron Collider. Hi, Adrian.

00:51 Adrian Cho: Hi, Sarah. How are you?

00:52 SC: I'm good. I just wanted to say that we are both gonna say Hadron but other people say Hadron, so that's okay. Large Hadron Collider is also known as the LHC. Can you remind us what it does?

01:04 AC: The LHC is the world's biggest atom smasher. It's this accelerator that's underground on the French-Swiss border, and it's 27 kilometers long, and it basically accelerates protons in opposite directions, and then smashes them together in the middle of these gigantic particle detectors, and the idea is to smash particles together with enough energy to produce new fleeting subatomic particles and to study them.

01:33 SC: And most people think of this in connection with the Higgs boson, right? That was the big find for the LHC, it was one of the main reasons it was built.

01:41 AC: That's completely correct. Its mission number one was to find the Higgs boson, which was this particle that was predicted by the theory known as the standard model. It was the last particle in the theory that hadn't been observed, and so finding it was a huge triumph for particle physicists. This was in 2012 that they announced it.

02:01 SC: And what have you done for me, lately, LHC? That's the question here, right?

02:05 AC: That's exactly correct. Besides the Higgs boson, particle physicists working with these atom smashers haven't found anything not predicted by the standard model for decades. They have lots of big unanswered questions, but in terms of what they can actually see in an atom smasher, so far, the standard model explains everything they've seen, so they're desperate, more or less, to find something new that will open up the field and maybe connect to these much bigger questions.

02:33 SC: When you described how the LHC works, that it smashes these two protons together in the middle, that's the key here. Some people are talking about changing the viewport, looking at different time points or different parts of the area where these particles come together. Can you talk about how that change would work? How much different would this viewport be than the one that is currently being used?

02:56 AC: The assumption is that these particles decay very, very quickly and always in the center of these gigantic detectors. And what people have begun thinking about, and some people have thought about this for a long time, but it's picking up momentum, is the possibility that that new particle that's produced doesn't decay quite so quickly. The Higgs boson decays in less than a trillionth of a nano second. And the idea here is that maybe these particles live a little or even a lot longer, and so instead of decaying right in the middle where everything is focused, maybe they move a few millimeters, a few centimeters, maybe even meters, maybe even long enough to make it out of the detector. And so the question is, "Could you be making these long-lived particles already that you're simply not seeing because everything is built on... "

03:45 SC: Pointing at a different location, what about moving the viewport so that we're seeing a wider view with the sensors or re-calibrating the actual machine?

03:56 AC: There are something like a half dozen proposals for small... Actually some not so small, purpose-built detectors that would look exclusively for these long-lived particles, particularly ones that live so long that they'd actually make it all the way out of the existing detectors before they decayed and could be detected meters away.

04:19 SC: Is that expensive? How long would it take? How likely is it to happen?

04:25 AC: These are mostly in the proposal stage, but there's one, an experiment called FASER which is already funded, it has $2,000,000 of private foundation money and it will be positioned along the beam line in about 500 meters in front of the ATLAS detector. And the idea is that ATLAS may be producing lots and lots of light long-lived particles, in particular, things known as dark photons that would just be streaming out of the detector, but there's nothing there to see them, especially 'cause they're going along the beam line where the big detectors are mostly lying. And basically, what FASER would be looking for is evidence of light particles coming through a whole bunch of rock, and then turning into electron-positron pairs. And if you saw that, you would know, "Oh my gosh, something that we've never seen before is coming out of ATLAS." And that would be pretty cool.

05:22 SC: Well, let's assume that somehow this gets done. What kinds of things would they see? Well, you said long-lived, what would that be?

05:28 AC: There's an upper limit on how long long-lived can be. You can't have new particles like this that last much more than a second, so it's from picoseconds to about a second. Things that move from a few millimeters to, say, meters, and even beyond. And the reason you might think that you'd miss them is because the events that the LHC makes are incredibly messy, there's...

05:53 SC: Right, it's like little explosions.

05:55 AC: Right. And there's like 30 of them in each proton bunch crossing, so they're really messy things, but since everything is focused at the middle, a lot of the software, even the hardware, is designed to discount things that come at weird places.

06:11 SC: They're gonna filter it out, saying, "That's noise. We only want signal."

06:15 AC: That's exactly right. They'll say it's not a good event because we make billions of collisions every second, we'll just toss that one out.

06:22 SC: Now, is it all really gone or is it, can we go back and find those data and just put them through a different analysis?

06:31 AC: The detectors use these sophisticated trigger systems to make sure that they don't get overwhelmed with all these collisions and so, they actually throw out... Out of every roughly 2000 collisions, they threw out 1999.

06:46 SC: I do wanna circle back to the, how likely is this to happen and when will it happen. When might additional sensors or changing some of these settings happen so that these long-lived particles get a fair shake?

07:00 AC: The LHC is currently idle for upgrades and then it's gonna come on and run from 2021 to 2023. A lot of physicists think that this is the ideal window to look for these long-lived particles and the reason is that after that, the LHC is going to undergo another upgrade and it's gonna get a big boost in beam intensity. That's aimed to allow it to do things like really precise measurements of the Higgs boson to see if the Higgs really behaves the way the standard model says it does, or maybe it's slightly different, but it's not so good for these long-lived particle searches because every time the LHC now collides bunches of protons, it has somewhere between 20 and 40 individual proton pairs colliding.

07:46 AC: After the upgrade it's gonna be up to like 200 and these events are gonna get very messy. To even be able to make sense of them, they're gonna have to tighten up the triggers that folks want to loosen up, to look for these long-lived particles. And so, physicists are thinking that in terms of long-lived particle searches, most of them are gonna get harder once they go to these much more intense beams. They're really thinking that right now, this upcoming run, that's gonna be the opportune moment to look for these things. The folks who were building these additional detectors, they could run later. In fact, they're mostly in the development stages, and they're hoping to get test detectors in line for the next run. But since they won't be tied to these trigger issues with the usual detectors, they can run independently.

08:35 AC: Some of these efforts are pretty ambitious and are probably gonna take some time. There's one called MATHUSLA, essentially this is a really cool idea. A gigantic empty building 100 meters long, 200 meters wide, that's gonna sit above the CMS detector and look for long-lived particles coming up through the ground 70 meters of rock. And what they would do is that they would come up and some of them would decay in the empty air in this building, and produce upward going showers of particles that would be detected by tracking layers under the roof. One of the developers described it as two IKEA's worth of empty space with a few tracking chambers in the top to look for these long-lived particles. The developers think they can build this for less than 100 million euros they don't have approval yet. That's obviously one that they're not gonna have ready in 2021. It's gonna take some time.

09:28 SC: I'm imagining that the LHC is just... Is gonna end up being the seed and the center of bigger and bigger detectors surrounding it [chuckle] from every angle, trying to find stuff that escapes and does interesting things outside of its actual main space.

09:44 AC: I think that that's a key point to this. The LHC hasn't produced new particles yet. And I think that some physicists really feel that they have a duty to make sure that they haven't overlooked anything, that the big failure would be that something is there and for whatever reason, you just weren't clever enough to find it. And I think that this is part of what's going on here and I completely agree with you. I mean it has this feel like they'll just keep adding detectors on the outside till...

10:14 SC: Why not?

10:16 AC: It's the only accelerator like this that exists. If you can get it funded and if you can afford it, why not?

10:22 SC: Alright. Okay, Adrian, thank you so much for talking with me.

10:25 AC: My pleasure, Sarah.

10:26 SC: Adrian Cho is a staff writer for Science. You can find a link to his story at sciencemag.org/podcast. Stay tuned for an interview with Tian Li about using modified wood to passively cool buildings.

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10:46 SC: Buildings use a lot of energy. They're energy intensive to build, to light, to heat and to keep cool. Tian Li is here to talk about a new kind of structural element a special wood that might lighten some of this energy burden inherent in buildings. Hi, Tian.

11:03 Tian Li: Hi Sarah, thank you so much for having me here.

11:06 SC: Oh sure, so let's talk about this special wood. What's so special about it?

11:11 TL: Well, you were absolutely right, Sarah. The buildings, it consumes a lot of energy. A building consumes about 40% of all the energy and 70% of all the electricity generated by all kinds of infrastructure. It's definitely the largest energy slice. And what we did here for this work is to process natural wood so that it can cool itself so when you use it as building materials, it helps you to get cooler temperature. This is rather important, since that, well, we use air-conditioning a lot, especially during summer, and air conditioning consumes a lot of energy. By doing that, you are reducing substantially, the energy required to power our buildings.

12:00 SC: How would wood fit into cooling or changing the energy demands of a building?

12:05 TL: The short answer is that the wood we process, it efficiently back scattering the solar radiation, meaning that it does not heat up under the sun. And in the meantime, it efficiently emit thermal energy into universe while the atmospheric transparency window.

12:24 SC: Let me just rephrase that. That means that all the sunlight that's hitting it is bouncing off anything in the visible spectrum, but in the infrared spectrum or the near-infrared spectrum, just escapes into space. The heat is bouncing directly through the atmosphere, and out into space.

12:41 TL: That's actually absolutely right. This material is white in visible range, but black in the IR range, meaning that it does not absorb energy from the sunlight, which is mainly in the visible range. But is efficiently emitting thermal energy within the IR range. And if you look at the transmission spectrum of our atmosphere, you would immediately notice that there's a transparency window or wavelengths that falls within 8-30 microns. This part, it can efficiently radiate out to the universe.

13:21 SC: So that means that if you manage your energy into this particular wavelength, it no longer interacts with particles, gas, anything, it just escapes. And I wanna point out, though, that... We said, "It's white to visible light and it's black in the infrared." What that means is it... It is not just bouncing, it's also drawing energy out of the building and then sending it into space. It's passively cooling just by being a structural element.

13:50 TL: Yes, when you have immediate energy greater than absorbed energy from sunlight, you can reach a sub-ambient temperature.

14:01 SC: What did you do to the material to make it have these special properties?

14:06 TL: Well, natural wood have this brownish color. That is because of this pigment called lignin. As you know, if it have this color, it is absorbing the sunlight. In the first step, we would remove all this pigment, so that it won't heat up just like natural wood would do. After remove the pigments, the wood would become white. All the light is very efficiently scattered backwards, it does not absorb. In the second step, because we want to use it for structural materials, we densified it, basically to maximize the interaction area between all these nano fibers of cellulose. These are all of hydrogen bonds and then they bond very strongly together, when you have this maximized interaction area. The resulting structure is very strong, it's even eight times stronger than natural wood and 10 times tougher than the natural wood.

15:04 SC: First, you took out the pigment, then you densified it. How exactly did you make it more dense?

15:09 TL: It's by hot pressing. You have this machine, you press it while you heat it up a little bit, so that it can be further densified.

15:17 SC: So it's now, it's strong, it's dense, and it's cooling. Where does it go? Does it have to be on the outside of the building in order to use all these functions?

15:28 TL: Yeah, because for this radiative cooling to work, it has to face to a object that is cooler. Our universe, it has a temperature of only three Kelvin. Earth have a temperature of 300 Kelvin.

15:42 SC: What did you do to test the efficiency of this material? Did you build something out of it?

15:49 TL: We took the samples to Arizona, where there's a clear sky, in a very hot middle of desert. And so, we're actually are testing the sub-ambient temperature of the samples and also there's a thermal box that's testing its cooling power. Basically there's a heater beneath it. The heater is heating up the wood and there's a close loop connection to maintain the temperature of wood to be the same as ambient temperature, so that this way the power of the heater is the cooling power of the wood.

16:23 SC: How much of a temperature difference did you see, say, between the inside of one of these boxes, that has this wood on it and the outside air?

16:31 TL: During mid of the day, when the sun is the strongest, we're observing a 3-5 degrees Celsius temperature drop. During the night when there's no sun, it is typically more than 12 degrees Celsius. For the cooling power-wise, it's about an averaging 50 watt per meter square, averaging through 24 hours.

16:57 SC: Is that considerable energy savings?

17:00 TL: If you think about it, it's 50 watt per meter square. For a solar cell, we know solar cell are very efficient and for 10% efficiency solar cell, it gives you about 100 watt per meter square. If you think it this way, the cooling power is in the same order of magnitude of a solar cell.

17:21 SC: Would this work in a place that had a lot more variable weather? Would people want to use something like this, say, if they're in the Pacific Northwest, where it rains a lot of the year, and it's cold in the winter, would you want this in your house?

17:34 TL: The weather plays a very important role in how efficient the rate of cooling is. If it's rainy, you will have a lot of cloud in the sky, and you know the temperature of the cloud is not that low, not as low as the universe is. If the cooling wood is facing to the cloud, which has a much higher temperature, the efficiency of this cooling will reduce, that's for sure.

18:00 SC: Some places would work... This would work better than others, it sounds like.

18:04 AC: Yeah, in dry and hot climate.

18:07 SC: Another practical question here. This is wood, which, while it is something that you can grow and it doesn't necessarily have a lot of energy density when it comes to construction, it's not very durable. People don't make roofs out of wood. We have things that last a lot longer, like metal or shingles. Are people going to want to put wood on top of their houses?

18:34 TL: I think the people should for multiple reasons. After densification, this wood have a very high specific strengths, even higher than the best alloy. It's definitely strong enough to support the buildings, even the high-rise buildings. Another reason is more towards the environmental effects. There's energy called embodied energy. Meaning, the energy takes to make the material. Giving the large quantity of constructional material, it is very important that we consider this energy. The energy it takes to make this material. See, for steel, concrete, alloys, it takes a lot of energy. Those are the materials that typically have a high embodied energy, but the wood is different. It's naturally there. You do some modification, some functionalization, it is still considered a low-embodied energy material. And the third one is that it's actually... It's counterintuitive, but the more you use wood, the more you promote this high added value wood-based technology. You are promoting a healthy cycle of wood regrowth. You see? When the small trees, they grow into larger trees, they are capturing carbon dioxide from atmosphere, and they convert it into the biomass, which is cellulose, which is to saying that we're using for radiative cooling.

20:06 SC: People have come up with paints or films that you can apply to, say, a different kind of roof or a window. Why would wood be preferred over those kinds of things?

20:16 TL: It is very important to consider that it has to be applied at a massive scale. It is good to bear in your mind, the cost and the scalability from day one. There was this development using dielectric materials, metamaterials, photonic structures to realize the radiative cooling. If you are departed in layer by layer, it's limited by the cost and the scalability. The nice thing that we think about wood is that it's there. And see, the process that we did to wood to convert it from a natural wood board to a cooling wood is very simple. First step, you remove lignin. You basically are putting a block of wood into a chemical bath. In the second step, you basically are pressing it. Those are the process that are compatible with industry developed techniques. Because timber industry, and the paper, and the wood industry, they have very, very good technology that are already there.

21:21 SC: Do you see this as part of a suite of passive cooling technologies: Paints, films, wood, all working together to lower the energy footprint of buildings and the process of building buildings?

21:34 TL: Yeah, definitely. If you want a really deep freezing, like deep freezing, just freeze it even below zero degrees Celsius, maybe to make ice cream or something, you want something that have the precisely tuned spectrum, like in the visible range and at the IR range. You do wanna go with those carefully departed dielectric materials. And if you want to use this in a massive scale, wood would be a good choice there.

22:07 SC: Okay. Tian Li, thank you so much for talking with me.

22:10 TL: Thank you so much, Sarah, for having me here. It's a pleasure.

22:14 SC: Tian Li is a post-doctoral researcher in the Department of Material Science and Engineering at the University of Maryland, College Park. You can find a link to this paper at sciencemag.org/podcast.

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22:28 SC: And that concludes this edition of the Science Podcast. If you have any comments or suggestions for the show, write to us at sciencepodcast@aaas.org. You can subscribe to the show on iTunes, Stitcher, many other places, or you can listen to us on the Science website. That's sciencemag.org/podcast. There you'll find links to the research and news discussed in the episode. To place an ad on the podcast, contact midroll.com. The show was produced by Sarah Crespi and edited by Podigy. Jeffrey Cook composed the music. On behalf of Science magazine and its publisher, AAAS, thanks for joining us.