Episode 21: Things Fall Apart
Physicists: Ken Clark, Tia Miceli

Transcribed by Denny Henke

Ben: Over the course of my studies in theoretical physics I've traveled across the continent and around the world sampling new ideas and tasting different answers to the questions of how and why. And still I find there remains a deep hunger which lives within me, a burning desire to share these great ideas with the people around me. And so, I have assembled a team of some of the greatest, most lucid, most creative minds, I have encountered in my travels and I call them my Titanium Physicists. You're listening to the Titanium Physicists Podcast and I'm Ben Tippett. And now allez physique!

[1:49]

Sometimes things fall apart. Decay into other things. In the regular world we might say they decay into their component parts. For instance, when my pen falls apart it stops being a pen and starts being a collection of pen components: the cap, the body, the spring, the tube of ink, the clicking mechanism, and the tip. Or if my car were to fall apart it would become a collection of tires and engine parts and transmission parts and some doors and a frame and stuff. Okay, let's talk particle physics, specifically elementary particles like electrons and photons, quarks and stuff. They are not made of anything else. When we say elementary particle, we mean that there aren't two or three things composing them, they've got a unique character and they are indivisible. But, elementary particles can be unstable. They can undergo a process we call decay, that is to say that if you take a tau lepton, tau leptons look just like electrons but they're really heavy, if you take a tau lepton and you put it on the table and you wait long enough it will turn into a collection of other things just like your janky old car. But here is the thing, unlike your janky old car, the tau lepton particle isn't really built out of other particles. It is, after all, elementary and indivisible and unlike your janky old car which can only turn into a pile of four tires, the steering wheel, a carburetor, and a donkey when it falls apart, the tau lepton will decay into different piles of other elementary particles. Sometimes it will turn into a pile composed of an electron and some neutrinos, sometimes a muon and some neutrinos and sometimes a kaon and some neutrinos. So, while elementary particles aren't composed of other particles, they can turn into a collection of other elementary particles and this might seem like a contradiction but it's actually the fundamental truth to all matter in the universe. So today we are going to talk about particle decays. So in life some things don't decay like friendship. To help us talk about particle decays I have invited my old friend Dan Jankwoski. So, Dan and I met at University and he has led a fantastic life since we graduated. He has worked as a social worker and has traveled all around the world as an English teacher and a gentleman and he currently goes to the beach professionally and he is also the tallest man I know. Hi Dan!

Dan: Hey Ben how's it going?

Ben: Thanks for coming on the show, I really appreciate it.

Dan: My pleasure.

Ben: For you today I have assembled two fantastic titanium physicists. Arise Dr. Ken Clark. Wow, it's a bird, it's a plane, no wait it's Dr. Ken. So Dr. Ken did his undergraduate at the University of Toronto in his masters and PhD at Queens University and is now at Penn State working on ice cube. Now arise Tia Miceli. Alright, Tia is a graduate student at the University California at Davis where she studies high-energy experimental particle physics and she is writing her thesis on Zed decays. She is currently a contestant in the two-minute thesis contest at PhD comics. So, if you like what you hear go vote for her. So, let's start talking about particle decays. So let's talk about how these things fit into the natural world. So I want you to imagine, like an atom, imagine an atom in your head, on the outside there is an electrons and on the inside there's a nucleus right?

Dan: Okay, sure.

Ben: An electron as a particle is part of the family of the other particles. So, there are other elementary particles that are similar to it, they're all called leptons. So there is the electron, there is one called a muon on which is slightly heavier, and then a tauon which is even heavier than that. So they're three brother leptons and they all have negative charge the same charge as an electron does but they have different masses, ok?

Dan: Okay.

Ben: And the thing about this is, in regular life you never see tauons or muons, you only see electrons and that's because tauons and muons decay. They fall apart. Well, they don't fall apart, they turn into other things, you know fairly quickly and so all you end up seeing in the end is electrons because electrons are stable. They don't randomly decay into other things. Now inside the nucleus of the atom, nucleus' are made of protons and neutrons, right.

Dan: Yes.

Ben: Protons and neutrons are not elementary particles, they are made out of smaller particles called quarks. So, the deal is that there are three quarks inside of each proton and each neutron and each quark is elementary. And you, just, like, in the electron, where there's an electron, a muon, and a tauon, there's different types of quarks, okay. So there are up and down quarks, those are the usual ones that we see. But there are also weirder ones. There's one called the charm quark, there is one called the strange quark, there is one called the truth quark, and there's one called a beauty quark, sometimes they're called top and bottom quarks, those last two, they're just represented by T and B when people do math, don't worry about it. The moral of the story is, in regular life the only quarks that we ever interact with are up and down quarks. Because all of the other types of quarks are also unstable so they decay eventually into up and down quarks. So in regular life we only see electrons, we only see up-and-down quarks, but you know if you take high energy physics, if you take particles and smash them together at high enough energy this gives the system enough energy to generate these unstable particles.

[7:10]

Dan: Okay, and do they eventually collapse down into just basic, up and down?

Tia: Yeah, eventually they just all go to the stable particles that we see like up, down, electron, and neutrinos and then, also, photons.

Ben: The moral of the story though is that there are lots of different particles that are possible some of the particles decay into other particles and others don't really naturally decay into anything.

Ken: In your intro you said, you know you have these, let's just take, for example, electrons. You have these electrons and you said there also exist muons and taus which are heavier particles. And they, both the muons and the taus, eventually will decay and they will decay into the electron and the reason for that is is that the electron has the lowest rest mass of the particles, essentially. So when you are decaying you can't create mass, you can't go heavier and in fact you can't even stay the same, you can't break even unless you produce something at rest. Okay you can break even but it's rare that you break even. Essentially you lose energy so because you can only do it that way that's why everything decays to the lightest particle. In each decay you have to go lighter you cannot go heavier essentially.

Tia: So I mean when you say that you lose energy, I mean it's not completely lost right.

Ken: Yeah you are right. I mean you lose, I'm doing air quotes, you lose on rest mass, your rest mass has to be less.

Tia: Yeah the rest of that energy goes into kinetic energy making that end particle move fast.

Dan: I'm sorry to interrupt but what's a rest mass.

Ken: You can think of it as the mass of the particle. So the electron is the lightest, the muon is heavier and the tau is heavier still. And we call it rest mass because in all of this physics stuff the energy and mass become interchangeable and the actual energy of the particle is composed of its rest mass plus whatever other energy it has and usually we talk about kinetic energy as being the other component.

Ben: So, you know like Einstein's $E=MC^2$ relation. So kinetic energy is a type of energy right. If you take an electron sitting still it will have a specific mass, all electrons will have the same mass. But then if you accelerate it, if you whip it up so that it's going really fast, sometimes that kinetic energy that you give it is so high that it changes the affective mass of the moving electrons. So the kinetic energy counts as a contribution to the overall mass so the faster you make the electron go, the heavier it seems to get.

Dan: Interesting.

Ben: So that's why we say rest of mass because we are like, you know, an electron is going to seem like it's heavier if it's moving faster. So you have to talk about you know, if you were sitting still, all electrons will have this one specific mass.

Ken: Right if you could put an electron on a scale and it just sat there on the scale that would give you its rest mass.

Dan: Okay, sure, that makes sense actually.

Ken: What we were saying was that all particles decay to particles with lower rest mass, essentially. And as Tia was saying, the energy difference between them can go to a number of things but one of the things is kinetic energy. For example a muon, if you take the rest of mass of the muon and the difference between the rest mass of the electron, if those were the only two things that just changed immediately, all of that energy can go into the electron moving very quickly.

Ben: Do you want a metaphor for that? I've got one.

Dan: I want a metaphor.

Ben: Alright. So it's like the conservation in value. Imagine you've got a crisp $20 bill in your pocket. Buy $10 dollars worth of gas and you get back a new particle, the $10 bill, and you can use that gas to, you know, accelerate your car. So you started with $20 dollars worth of value, you changed that into a $10 bill and then $10 worth of velocity in your car. So the conservation of energy makes it so that these particles are always decaying into lighter particles but these processes are reversible. If you take one of these electrons say, and you set up the appropriate conditions you can give it enough energy so that it turns into a muon. So it's only kind of the inescapable flow of time that means that overall you end up with fewer muons as time goes on. Because the system starts out with the muon having a certain amount of energy it can turn into an electron that has a whole bunch of kinetic energy and then as that electron bounces around and hits other things it loses some of that kinetic energy and then it doesn't have enough energy to turn back into the muon.

Dan: So kind of like if I was playing the guitar and I hit a guitar string the sound waves will bounce off walls and eventually dissipate.

Ben: In essence that's kind of what's going on. The energy is kind of dissipating into the system so that the electron won't be able to turn back into the muon.

Dan: Okay.

Ben: And so instead of having an even balance of muons and electrons, all of the muons turn into electrons, that energy kind of dissipates into the system and then the electrons themselves will no longer have enough energy to turn back into the muons.

Dan: Okay, but what about all of this energy that's disappearing into the system? What happens to all of that, does it collectively turn into something else or does it just go away?

[12:01]

Ben: So, you know, in the universe there is a lot of empty space, if some of this energy turns into a photon a particle light, that particle of light can go off into space and we will never see it again. So in essence, the universe as it currently is, because it's expanding, it's not really a closed system. So in a star or on earth, we can lose energy to space and not be able to get it back.

Dan: I lose energy to space all the time. That makes sense, thank you.

Ken: Is it maybe the next step that, my analogy was far too simple, it was just one particle going to one particle and that's not really what occurs most of the time.

Ben: Yeah why don't we start talking about that, conservation laws.

Tia: When we have the muon decay, there's a couple things going on. There're things that need to be conserved when it decays. So, first of all a muon has an electrical charge, it's negatively charged so when it decays, it decays into an electron plus some neutrinos which are neutrally charged so the charge needs to be conserved if it's -1 in the beginning then it's -1 at the end, so the electron and the muon have the same charge. And then muon decay also needs to conserve lepton number and so muon has a lepton muon number of 1 so at the end of the decay, the decay particles also need to sum up to a lepton muon number of 1. So let's look at the decay particles which is an electron antineutrino of the electron type and a muon neutrino. So before and after we have this muon lepton number. The muon has a 1 lepton muon charge and the end product neutrino muon has a 1 muon lepton charge. And then the electron and anti-electron neutrino their charge adds up to 0 because the electron carries plus electron lepton number charge and the antineutrino has minus electron lepton charge so that sums 0. So the beginning product and end product have the same lepton flavor numbers.

Dan: Okay, so I understand the conservation of mass so that everything that comes, has to, at the end, equal the same thing but the flavor of the lepton. I'm a little bit shaky on what an actual lepton is. Is it a term in terms of measuring how these electrons turn into each other or is it something else special.

Tia: So it's just a name, a lepton is just a particle that's either an electron, muon or tau. And they also have neutrinos associated with them that we kind of skipped over before.

Ken: Okay, so there are a group of particles called leptons and they have three, what could be called flavors: electron, muon and tau. Okay, so, an electron has an associated neutrino, so it's an electron type neutrino and there is the same for the muon and the tau. There is muon neutrinos and tau neutrinos. So when you want to talk about flavor conservation, essentially, electrons and electron neutrinos, get a 1 in their, let's just call it an electron number. So electrons and electron neutrinos get a 1 and then their inverse particles, we'll call them anti-electrons and anti-electron neutrinos, get a -1. Does that make sense?

Dan: Yes

Ken: So if you were trying to balance your equation, if you started with, for example a 0, you could end with a 0 by creating both an electron and an anti-electron or an electron and an anti-electron neutrino, those would both give you a zero at the other end.

Dan: Okay, sure.

Ken: This is what we were referring to earlier, is that when you want to go through a decay, if you start for example with a muon which is where we were starting, you have to end up with a 1 in the muon column. So you have to end up with either a muon or a muon neutrino at the end because you need that 1. But in addition to that 1 you can create other things such as an electron and an anti-electron neutrino because those will sum to 0 in their electron number and you are left with a 1 in your muon number.

Dan: That totally makes sense.

Ken: That’s roughly how it goes.

Ben: Let’s say that you have ice cream, there are three flavors of ice cream. There is vanilla, that's like the electron ice cream, chocolate, that's like the tauon ice cream, and then strawberry which is kind of a middle flavor, and it's the muon ice cream. So you can change the strawberry ice cream into vanilla ice cream but in order to do so you need to extract the flavoring. So, let's imagine that there are little bottles of artificial flavoring, okay? So, the little bottles of artificial flavoring, if they're full up of artificial flavor that's called a neutrino. It's got a specific flavor and the idea here is that as we extract and add a flavor to our ice cream to change the type of ice cream it is we need to conserve the flavor we need to extract flavor and put it in a bottle or empty out a bottle. So, you take the strawberry ice cream, you extract the strawberry flavoring, then you end up with a little bottle of strawberry flavoring and then you add vanilla flavoring but in order to add vanilla flavoring you end up with a little empty bottle of vanilla flavoring. You start off with strawberry, in the end you end up vanilla but you also end up with one full bottle of strawberry flavoring, that's your muon neutrino and then you end up with a little empty bottle a vanilla flavoring and that your anti-electron neutrino.

[17:45]

Dan: That’s actually pretty cool. So, neutrinos are delicious.

Tia: Can I have a coconut flavor?

Laughter

Ben: I think that's beyond the standard model of ice cream.

Ken: That's a sterile neutrino, they taste like coconut.

Tia: Tasty.

Ben: So the deal here is that before I used a metaphor for changing money right you started out with a crisp $20 bill and you ended up with a $10 dollar bill and some gas that turned into velocity. The deal here is that it's not quite that simple you can't change particles into other particles willy-nilly because it turns out that there are these conservation laws that constrain what you can change some particles into.

Dan: Okay.

Ben: Lepton charge is a really good one, it's really straightforward to understand but there're also ones governing say, before I mentioned that there're quarks on the inside of these protons and neutrons, and how charmed and strange and truth and beauty quarks turned into up and down quarks, there are similar conservation laws governing how these flavors can change around so your system is constrained, you can't just change one type of particle into any other particle that has less mass. When it decays it always undergoes a decay that's constrained by these particular conservation laws.

Dan: Okay that makes sense because there's laws for everything in the physics world, right?

Ben: Yeah.

Dan: Can I ask a question?

Ben: Yes

Dan: I just always have to do it politely I got yelled at too many times in school. So, we are talking about you know electrons decaying and turning into other electrons or muons or tau things, neutrinos flying off, what's the real significance of all this particle decay, what's the endgame here. Like is this where the universe comes from, is this what creates the beaches around and causes helium and things to explode and create universes?

Ben: Actually, yeah. In the early universe around the time of the Big Bang, really, really, really early universe the energy density was so high that lots of different types of particles were allowed and wandered around so there were tauons aplenty and stuff like that. I mentioned before that the reason we don't have tauons, we have electrons in this day and age, is essentially because the energy dissipates. But the energy density back then was so high that almost anything could have been excited. And then, as the universe expanded and cooled off one effect that this expansion had was that it lowered the energy density, it lowered the temperature of the universe in doing so means that suddenly there wasn't enough energy for a tauon to wander around free because there wasn't enough energy for electrons and muons to get excited and to change into tauons. And so the tauon would change into a muon or an electron and that energy would dissipate. And the muons would turn into electrons in that energy would dissipate.

Dan: As the universe expanded.

Ben: As the universe expanded. So the story of particle decays is really, as you alluded to, it's entirely related to the story of why the universe is composed of the particular types of matter that it has in it.

Dan: Okay.

Ben: So, it turns out that each of these fundamental elementary particles at rest they'll all have a kind of unique decay rate regardless of what time of day it is, regardless of what kind of music is playing in the background, a tauon we'll always decay into a muon and an electron at certain rates. And this process, it's an exponential decay, which means that, you know, in the first quarter of a second half of these muons will turn into electrons. And then you'll have, you know, a population of muons on the table will have halved. And then in the next quarter second half of those remaining muons will turn into electrons and in the next quarter second half of those remaining ones…

Ken: The number of particles you have left essentially halves every time you go through one half life. So yeah it goes from, you know, 16 to 8 after one half life to 4 after two half lives to 2, it gets a bit fuzzy after 1 but essentially that's it, you just keep halving the number of particles in your sample.

Ben: And then the half-life is characteristic, it hasn't changed since the start of the universe. It's fundamental in nature, to the muon for the tauon for the strange quark.

Dan: Okay, and in this similar to what like archaeologists used to gauge how old an artifact is?

Ben: Yeah. That's how they do it.

Ken: Exactly.

Ben: The half life of well it depends.

Ken: Carbon-14.

Ben: Yeah often carbon-14. What happens with the carbon-14 is in the upper atmosphere cosmic rays come in and hit the particles in the upper atmosphere the carbon atoms and they make a new isotope of carbon which is radioactive carbon-14. And so as long as the earth has been around the ratio of regular carbon in the atmosphere to carbon-14 is always fixed so if you're an animal, you're breathing in carbon, you know you eat food that's made of carbon and you exhale carbon dioxide you're always interacting with the atmosphere. And so the ratio of regular carbon to carbon-14 in your body is always fixed to the same as the atmosphere but when you die and stop breathing, you stop replenishing the carbon in your body and so suddenly there's a fixed population of carbon-14 in all of your bones and that carbon-14 is radio active and it decays. The number of particles of carbon-14 in your body will half every half-life of carbon-14 over and over and over. And so you can look at a dead animal or dead plant and judging by the ratio of carbon-14 to regular carbon you can tell how old it is, when it died.

[23:39]

Dan: Okay, and so that's the same thing with particle physics except that you're not going to be using carbon as your main indicator, right?

Ben: Ah, so in particle physics, when we are dealing with these, these particles that decay usually they have to be created because they usually don't stick around for very long. And so they will be either created through radioactive processes or they have been created by cosmic rays or they've been created by a particle accelerator. And then so the issue here is kind of people wanting to know the nature of all these new types of particles that are generated when you fire two protons at one another or you shoot electrons at each other. So each of these particles and then more complicated particles like carbon-14 will have a decay rate which is fixed which won't change for that particular type of particle. You know a carbon-14 atom will have the same half-life now as it did 3000 years ago. So, the kicker is that physicists in the middle of the 20th Century figured out ways to calculate and predict these half lives so it's not just a matter of stamp collecting, we don't just, you know collect a whole bunch of carbon-14 and see how long it takes for the particles to the decay. We have a theoretical model for this decay process.

Tia: Well we do both.

Ben: Yeah, well right.

Tia: So, remember the muon decay, it was the strawberry ice cream and it decays into vanilla ice cream plus some flavor bottles which were the neutrinos and the electron was the vanilla ice cream.

Dan: Yes.

Tia: Well, let's start with what happens when you strawberry ice cream.

Laughter.

Tia: Okay, so imagine a little diagram of yourself a little stick figure of yourself. So you have these two arms sticking out and these two legs on the bottom and then you have your torso in the middle where deliciousness happens. So you eat your strawberry ice cream with one of your hands and after you eat it and it goes into your body and it gets circulated from the other arm of your body as you digest the strawberry ice cream you create waste products so one of those waste products is sweat of course so that comes out of the other side of your arm and then on the bottom the feet of your diagram you have to other kinds of body excrement and…

Laughter.

Tia: One of these could be the electron and the other one the electron neutrino. So it's just to help you visualize what these Feynman diagrams look like. So you can imagine the stick figure and along the arms and legs is where these particles are traveling and then the torso of your body is something called the W boson, that's your digestive system.

Ken: That was well-done.

Ben: Did you understand.

Dan: Yeah, I drew a picture and it makes total sense.

Ben: Haha, he drew a picture.

Laughter

Ben: So right, there is this calculation tool called the Feynman diagram and I'm sure you've seen them before. You've seen them on like physics textbooks and like in the background of big fancy physics lectures that happened in movies they're pretty ubiquitous. And essentially they're just these stick line drawings that show two sticks coming together and then another stick coming out of that and then two sticks coming out of a second vertex, right. They're just the arms and legs and torso of the stickman and then variations on that. So these were invented by Richard Feynman as a way to kind of keep track of all of the different processes that could happen inside of a particle. It's kind of like, you know, you'd have a muon and you put it in a box and you close the box and you open the box and there's a neutrino and an anti-neutrino and an electron then suddenly right. We can't imagine what the process is from one going to another. So what Feynman came up with was a way of charting out the different processes because what he then came up with was not just these stick drawings that diagramed the evolution of the system from one arm of ice cream into one arm and two legs. He also established a way to assign numbers to that. So each of those represent a calculation that can be done for a specific process and then what you can do is you can chain them together so one tauon becomes an electron and some neutrinos or one tauon becomes a muon and some neutrinos or one tauon becomes a muon which then becomes an electron including all these neutrinos. It's a really visual way to kind of sort out all of the different possibilities.

[28:46]

Tia: Yeah, it’s really cool because each little piece of that diagram stands for a piece of a mathematical formula that will give you your final answer of what the probability of that interaction or decay happening. Each leg or arm of your Stickmen has a particular mathematical form, and then the body does which is called the propagator and then each of the vertex, you know where your arms meet, so you multiply each of those pieces of the body together and you can get the probability of what will happen when you eat your strawberry ice cream.

Laughter

Ben: It Will let you calculate the probability of eating chocolate ice cream and getting strawberry ice cream versus the probability of eating chocolate ice cream and getting vanilla ice cream.

Tia: Yeah, there ya go.

Ben: And it's a perturbative system so there's a whole zoo of these diagrams that you can do but in essence the simplest diagrams are the ones most likely to happen and the really, really complicated ones get less and less likely. But what you can do is you can correct your prediction to higher and higher order by making your diagrams more and more complicated because there will end up being more than one route to start from chocolate ice cream and end up with vanilla ice cream. And so you can use this method to chart out all of the different possible routes. So for instant you can imagine starting with chocolate and getting vanilla and anti-vanilla and strawberry and then the two anti-vanillas cancel out and become flavor bottle neutrinos and then the strawberry becomes you know, you can have all sorts of fairly complicated interactions that are less and less probable but we can revise our estimates of what the probability is to higher and higher order by drawing more complicated diagrams.

Tia: So some radioactive atoms decay into other atoms and the way that happens is that a neutron in the nucleus will decay into a proton and electron and an anti-electron neutrino. So this is the main process for radioactive decay. So the neutron decaying follows energy conservation rules and also these other conservation rules that we were talking about such as electrical charge because you know the neutron is neutral and then the final products, the sum of those is also neutral. Because the proton has a +1 charge and the electron is a -1 the neutrino is also neutral so we have the final state has zero net electrical charge. And then our electron number is also conserved because in the end products we have an electron but also the anti-electron. So we have, what is that vanilla ice cream and then an empty vanilla flavoring bottle, the cool thing is if you take that neutron out and just have a neutron decay by itself not near the rest of the atom that process takes 15 minutes which is really long. Because the other decays that we were talking about happened so fast, like much less than a nano second.

Ken: Muons are what, 10^{-6} and Taus are 10^{-13} or something?

Dan: Seconds

Tia: Yeah

Ken: Something like that.

Ben: Great. So, Higgs, Heard of the Higgs boson thing.

Dan: Yes, it's in the news.

Ben: Right. So the Higgs boson is just a particle okay but it's a really heavy a really unstable particle. This is why the CERN facility needed such high energies just that they were smashing protons together at really high energies to be able to see it. So these protons are smashed together, these would excite a Higgs boson which would then decay and then, it could decay into a number of things but it's not the Higgs itself that we detect. We don't have a stick that kind of gets wiggled every time a Higgs bumps into it. Instead what we detect are the different things that it can turn into.

Tia: Ok, so the Higgs decays into particles that we can see, fortunately, or else we would never know it exists. The Golden decay that physicists love to measure is Higgs decaying into photons and it can also decay into bottom quarks and anti-bottom quarks and W bosons and those W bosons go off into leptons and neutrinos.

Dan: Okay, sure. Tia, why is it called the Golden decay?

Tia: Because it's really easy to find. It's not very messy. The number of backgrounds for it is low, so the number of ways that other decays background events could appear like this one those are few so it's called the Golden decay.

Dan: Okay, sure.

Ben: But yeah, so in essence these Higgs bosons are invisible to us but they decay into things and we can theoretically predict the energies of the things they are going to decay into, right?

Tia: We also empirically get them.

Ben: That’s what we measured right?

Tia: Yeah.

Ben: Yeah. So that was the big announcement, we had seen these energies that say this is the byproduct of a Higgs boson decaying.

Tia: That’s right.

Ben: Well, that was fun. So thanks Ken, thanks Tia. You have please me, your efforts have born fruit and that fruit is sweet, here is some fruit. So Ken. you get a nectarine.

Ken: mmmmm, delicious!

Ben: And Tia get a peach.

Tia: Nom, nom, nom, nom, nom, nom.

Ben: You'll note to that both of those fruit decay very quickly. Alright so I would like to thank my guest, it's Dan. Thank you Dan for coming on.

Dan: My pleasure. Where is my fruit.

Ben: Um, you get a kumquat that was sitting under the table here, wash it off before you eat it.

Dan: Alright, thank you I'll do that later.

Ben: Thanks buddy.

Ben: Alright, so, let's suppose you, the listener, want to interact with the titanium physicists a little bit more. If you would like to keep track of us why not follow us on Twitter at @titaniumphysics or join our Facebook group. If you would like to hang out with us, if you would like to hangout with us and socialize a little bit, why not join our online forum. Now, if you would like to send me an email directly or to ask a question or propose a topic you can email me at barn@titaniumphysics.com. Now let's suppose you want to listen to us more conveniently. If you've got and iPod or an iPad you can try subscribing to our show using the iTunes store. While you're there write us a review. Your reviews determine our ranking in the iTunes Store which in turn determines how many new listeners discover our show. If you have a Zune or a BlackBerry you can subscribe to our show on those doodads as well or you can download the Stitcher radio app which will lets you subscribe to listen to all of your favorite podcasts. You can download the Stitcher app for free onto your iPhone and your Kindle fire or other devices. Stitcher is convenient because it lets you subscribe to your favorite podcast and listen to them automatically. For all of this and more information visit hour website at www.titaniumphysics.com. The Titanium Physicist podcasts is a member of the BrachioMedia. If you enjoyed our show you might also enjoy Science Sort Of or the Weekly Weinersmith, so check them out! The intro music is by Ted Leo and the Pharmacists and the end music is by John Vanderslice. Good day my friends and remember to keep science in your hearts.

[37:27]

Ben: … Like things Tia said, right. So.

Ken: Are you referring to the CMS detector as a stick?

Ben: No! I'm saying that there is no stick, there is no stick for the Higgs.

Ken: It sounded like that was the comparison you were making, use the right stick.

Tia: Were you, were you talking crap about my experiment.

Ben: There's nothing sticky about the CMS detector.

Tia: That’s right it's smooth.

Laughter

[38:12]

Ben: Um, anyway, Feynman diagrams, I am sure you've seen them. There is a story about Richard Feynman, there's a couple stories…

Tia: There’s many stories about Richard Feynman.

Laughter

Ben: Have you ever heard of this guy Dan?

Dan: No

Ben: Oh, he is a physicist from like California. Well he wasn't from California but he ended up working in California for a while. He worked on the atom bomb and stuff. But he was really, really, really eccentric and so, oh he was also really social which is fairly rare for physicist of his caliber. He invented these stick drawings, these Feynman diagrams and then he bought a van and he covered his van with these drawings. And then he would drive around town with his window unraveled like cat calling women and asking them out on dates. And then when he would finally get a date he would take them out in the van and spend dinner explaining these diagrams to them.

Laughter.

Tia: Sounds like a good date to me.

Laughter.

Ben: And then there is another famous story we're he went to…

Ken: How many dates did he get that way?

Ben: Probably lots, he was fairly handsome.

Ken: It’s true I guess.

Ben: And then there's another story where he went into like a, it was like a McDonald's or some kind of restaurant on the side of the road and he came out and there was a guy standing in front of his van staring, it was a young guy in his 20s and he said, hey why are you looking at my van? And the kid went, why is your van covered in Feynman diagrams. And Richard Feynman said well it's because I'm Richard Feynman and the kid went oh okay.

Laughter.

Dan: Okay, so just to rehash something that you guys were saying. I understand that you have basic little stick figures that you can build them up into complex reactions of probability of what could happen with decay or what the end products would be. And so, is the end game here, so what's the reason behind knowing all of this, what was Feynman trying to achieve by understanding what would come out the other end?

Tia: Well, I mean we are physicists we want to be masters of the universe right.

Laughter.

Tia: We want to be clairvoyant and know everything that can happen.

Dan: Okay, fair enough.

Ben: it's a little bit, okay, so in truth…

Ken: No, I think that's just about right.

Ben: I Think it's right too. At its heart I think it's right. So, in essence you know you've heard of the like electromagnetic field, right?

Dan: Yes. I've heard of such a thing.

Ben: Right. And you know about quantum mechanics this wave particle duality.

Dan: Slightly, yes.

Ben: Okay, so in quantum mechanics, everything that's a wave is also a particle and everything that's a particle is actually a wave. So early, early quantum mechanics, in the 20s and 30s right, they were doing things using atoms, they were like, shooting atoms at each other. Atoms are particles and they were kind of coming up with a description for the wave character of these particles. So they look at how these particles interfere like waves and have general behaviors like waves even though we kind of a imagined them to be like little billiard balls. So, when Feynman came along, the question was we have something like the electromagnetic field, it is a field that has waves in it. So the question is how do we treat those waves like particles and so the math of doing that is really complicated really, really complicated. Well it's not that complicated but it's pretty complicated though. And it's a big pain in the ass and I refuse to do it. But it is so complicated that people kind of had trouble trying to get their heads around how to do these calculations. But the useful thing was that it could be used to describe how say one atom, would shoot off say an electromagnetic wave that would hit another atom, it could be used to describe how two different systems interacting through one of these fields could interact because this field is quantized. So it will was, necessary it's a necessary theoretical step to be able to describe how you know particles interact, elementary particles interact with each other. So what Feynman did was he essentially came up with this drawing diagram technique and that made doing these calculations really, really simple. So suddenly everybody could do it and they're super popular and that's why there're so many particle physicist now, is Feynman diagrams are super straightforward. But, in essence, if you want to do more then talk about how individual particles kind of bounce around in the, in a system, right, so if you want to talk about more than the trajectory of one particle and you want to talk about how different particles are interacting. They interact through one of these fields like the electromagnetic field and so you need a way to use quantum mechanics to describe that field in order to talk about how particles, you know, interact on a fundamental level or how they decay for instance this is one of the big things that I was going on about. So this whole description of decaying particles is useful because it gives that's a nice way to sharpen our teeth for describing other quantum mechanical systems. It gives us a window into the larger quantum mechanical world.

Ken: Okay, that makes total sense for sure.

Ben: And why do we care about the quantum mechanical world. The answer to that is that physicists want to know everything.

Laughter.

Ken: That’s awesome.