Episode 56, Tron
Dramatis personae:
- Ben Tippett
- Dave Shumka
- Ken Clark
- Tia Miceli

The Titanium Physicists Podcast
www.titaniumphysics.com

Ben: Oh! Hello, old friend. It's good to see you. Let's talk about his word, fascination. It describes an unquenchable urge, which compels our hearts to quest and be captivated. As long as there are elegant explanations to complicated phenomena, science will never lose its romance. Over the years I've traveled the world, indulging in my fascination in physics. And now, I find that a new hunger has woken within me: A fiery need 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 are listening to the Titanium Physicist Podcast, and I'm Ben Tippett. And now... allez physique!

01:11

[Intro song; Tell Balgeary, Balgury Is Dead by Ted Leo and the Pharmacists]

01:48

Last night I was trying to rack my brains to figure out what to write in the intro today. Physics is full of fun anecdotes which can be used to bring people out of their daily lives, and into the fun world of explanations and adventures but I couldn't think of anything. I got so desperate that I tweeted his honor the Elder Plops himself, John Hodgman, asking for a lead. Now, the master of arcane trivia and anecdotes merely replied that the answer was staring right at me. He was of course correct: Was I not interacting with His Honor over the internet? Specifically over the World Wide Web? And who invented the World Wide Web? Why do all the internet addresses start with "www"? The answer is – no, no shut up. It's not Al Gore. That was a stupid thing to say. You should pinch yourself! I'll wait while you do it… Okay. The World Wide Web was first proposed by a British scientist name Tim Berners-Lee in 1989. It was a way for people over an extended computer network to share information, mostly academic information, because Tim Berners-Lee worked for CERN. So, the internet was invented not for us to share videos of adorable pugs but rather for particle physicists to coordinate an international collaboration as they ran one of the world's biggest particle accelerators. Brilliant work Tim Berners-Lee! Judge John Hodgman! Al Gore! I couldn't have done it without you. Today's topic is Particle Accelerators. Now, speaking of videos of adorable pugs, today's guest has many reasons to claim that sweet, rich prize of internet fame. For one, his dog is famous. For another, he almost got shot a few months ago at a wrestling comedy show but he dodged that bullet! And finally, he's one of the co-hosts of one of my favorite podcasts, winner of two Canadian Comedy Awards, "Stop Podcasting Yourself". Hey, welcome to the show Dave Shumka!

03:34

Dave: Hello!

Ben: Hi! Oh my gosh Dave, for you today …

Dave: Yeah?

Ben: I have assembled two fantastic Titanium Physicists. Arise Dr. Ken Clark!

Ken: Whoosh!

Ben: It's a bird! It's a plane! No, wait – it's Dr. Ken! Dr. Ken did his undergraduate at the university of Toronto, and his masters and PhD at Queen's University, and he's now faculty at the university of Toronto where he studies dark matter and neutrinos. Now arise Dr. Tia Miceli!

Tia: Boing boing boing.

04:01

Ben: Dr. Tia got her PhD, congratulations Tia, from the University of California Davis. And she's now a post-doc for New Mexico State University working on MicroBooNE at Fermilab! Alright everybody let's start talking about particle accelerators. Okay, Ken, let's start talking about television sets.

Ken: Right. Because this is the way that most people would have interacted with a particle accelerator. So big old TVs, you know the ones that actually had some thickness and stuff to them, actually use particle accelerators to generate the picture. I don’t know if people know that, but it's pretty cool, and it's neat how it actually happens. You know, if you were sitting around watching your black and white TVs or playing text-based games of some kind, the screen that all of your stuff is displayed on essentially is made up of this material that glows when it's hit by electrons. And the way that the images are actually made is that there's an accelerator in the back of the TV that fires electrons at that screen to make it glow in certain places. So, essentially what happens is you have at the very back, you have something that generates electrons. In this case it just heats up a material and frees them. And then it has another piece that essentially accelerates them with an electric field, and then you aim them with a magnetic field and they hit the front of your TV, making your picture, and you can see I don't know, The Little Rascals or whatever you happen to be watching in 1972 when this would have been, you know, a relevant and very exciting technology.

Ben: So Dave, you know when you were a kid, did you every like go up really close to your TV and press your eye right up against it?

Dave: And see all of the like, the, there's like a red, a green, and a blue?

Ben: Yeah, those little pixels.

Ken: Exactly! Yeah.

05:43

Ben: So those little pixels are little pigments that would glow whenever an electron hit them. Ad you know how if your television was running for a long time and you go up and you'd put your hands on the TV and they'd feel like prickly, like static electricity?

Ken: Yeah.

Ben: Okay so that's literally static electricity, because the back of the television tube is called a cathode ray tube. But essentially it's like a big light bulb. It's a big vacuum tube made of glass. And electrons are being shot out of the back of them, so in the back there's a little electron gun it's called. So it shoots these electrons forward, and then there's a little focusing apparatus that focuses where it goes, and then that electron goes and it shoots and it lights up one of the pixels. And so the way television broadcasts work is essentially that information coming in through the airwaves or through the cable to your TV telling you what to show, tells the thing which pixels to light up, and when. So when this electron gun shoots electrons and they get focused and then that makes the picture you see. Okay, so here's the crazy thing: how electrons get made is essentially there's a little tungsten filament like inside an old fashioned light bulb. And if you heat up the metal hot enough, it will start to spit off electrons, like popcorn or something. So there's this thing, it spits off electrons – pop pop pop – and then there are just kind of electrons hanging out nearby it.

DAVE: And would I recognize the electrons if I saw them just hanging around?

07:00

Ben: If you could see into my mind you would because they look like little billiard balls.

Dave. Ah, okay…

Ben: But if you opened up the back of the TV it would look invisible. I mean electrons are very small and they don't do anything.

Dave: Right, okay. Lazy.

Ben: So for you to see anything, they have to smash into something, and then whatever they smash into will light up.

Ken: As a side note, isn't it pretty crazy, like, how dangerous these things were? Like, you had a huge vacuum tube, which if you like jostle it around will explode.   You have this incredibly hot…

Tia: Implode!

Ken: It will implode and then explode. Then you have this incredibly hot electron gun, it's crazy!

Ben: Yeah, and it's shooting electrons pretty much right at the person sitting in front of it. You know how your parents told you not to sit too close to the TV?

Tia: [laugh]

Dave: Well that's because it was gonna implode and suck me in.

Ben: Well yeah!

Ken: [laugh]

07:46

Ben: So TVs are a fun example because it has all of the kind of simpler components that go into larger scale particle accelerators. So there's two parts to it. So an electron gets spit off this filament, and it's just kind of floating near the filament. There are two things that you've heard of I'm sure of, electric fields and magnetic fields.

Dave: I've heard the names, yeah, yeah, we run in the same circles…

Ben: [laugh] Yeah, right. So electric fields are the fields – you know how you take a balloon and you rub it on your head and you give it an electric charge and then you kinda put it over a table or something and it kinda floats in the air, it levitates?

Dave: Uh-huh.

Ben: That's the effect of the electric field. So electric fields kind of push and pull on things with charges on them, so electrons and protons.

Dave: Okay.

Ben: Magnetic fields, like from magnets - if you take two magnets they'll suck each other together, right? But if you just take a magnet and you take a charged particle near the magnet, the magnet won't pull or push the electron towards it; magnets can only, kind of, deflect the path of an electron. So if an electron is moving through a magnetic field it will keep the same speed but it will end up moving in a slightly different direction and it will curve off into a different direction.

Dave: Okay.

08:52

Ben: So at the back of your TV this filament would spit off an electron, and then there'd be these two charged electric plates. So there'd be a plate behind the filament, and it would be negatively charged, and the there would be a big plate in front of the filament and it would be positively charged. And electrons are negatively charged, opposites attract, right? So the electron would feel a push from the back plate and the plate in front of it, it would feel a pull towards it. And so it would accelerate down towards that plate. And in the middle of the plate there's a hole. So it would accelerate toward the plate, and then instead of running into the plate it would go through the hole. And the net result is you end up with kind of a stream of electrons moving through this hole, that are coming out of the hole moving pretty fast.

Dave: Okay.

09:30

Ben: And then so you had this stream of electrons and then the TV would have these two magnetic fields: there would be a vertical magnetic field that could re-orient the beam of electrons in one direction, and then there's a horizontal magnet field that can re-orient them up and down. And the moral of the story is, that these two magnetic fields, you can use them to kind of steer where the beam is going. Kinda like if you got a big hose of water, you can use the nozzle to direct where the stream of water is going. These two magnetic fields, they take these fast moving electrons and they guide them to be pointing into the pixels that the TV wants to light up.

Dave: Right.

Ben: So in essence that's how televisions work and that's why they're terrifying. Um…

Dave: [laugh]

Ben: And the deal is, that similar stories take place in much larger scales and with much more finesse in a larger particle accelerator.

Tia: So thanks, Ben. If we extend your television, and we make the electron beam go through another set of plates, and then another set of plates, and then another set of plates, we can form a linear accelerator. And these things have many uses. Some of them in particle physics, some of them for radiation therapy.

Dave: Maybe like a really big TV? [laugh]

Ben: [laugh] Yeah, like the ones in Tokyo.

Dave: Yeah.

Tia: So then these linear accelerators I mean, they have these many uses. But they basically work: you have different segments of tube held at positive or negative voltage and as an electron passes through it's attracted to the positive and then after its done passing through that piece of the tube, the next tube is switched to be positive while the tube it just spun through switches to negative. So the tube behind it will push it, and the tube in front of it will always be pulling in. And then that way you can accelerate the electron to pretty close to the speed of light, like around seventy percent or more of the speed of light.

11:35

Dave: So is that the same model as the TV with just the two plates or are these, you know, more plates doubled on each other?

Tia: Yeah so instead of having these plates, the shape of the piece of metal is now a tube. And the particles are allowed to travel through the center of the tube.

Dave: Is it just the two tubes or are there more?

11:57

Tia: Yeah there's a whole bunch of tubes in a row. And as you go farther and farther along to the later tubes, the particle will have more energy, it'll be going faster, because it keeps getting pushed and pulled through each successive set of tubes. It's kind of like if you're pushing a kid on a swing, and each time you push the swing the kid will go a little bit higher and a little bit higher. The electric fields are timed such that you keep on giving this kick to the particle to make it go faster.

Dave: So how fast is too fast?

Tia: I think pretty much as long as we stay below the speed of light we're okay. [laugh]

Ben: [laugh] Okay so these linear accelerators, there's one in um, where, not, not…

Tia: Stanford.

Ben: Stanford!

Tia: Stanford. Okay, so Stanford has SLAC, wait, SLC: Stanford Linear Accelerator Collider. [note: Stanford Linear Accelerator Center: SLAC National Accelerator Laboratory]

Ken: Complex? Isn't it? Isn't that the C?

Tia: I don't know. They study biology there now.

Ben: [laugh]

Dave: Oh, nerds.

Ken: [laugh] Nerds indeed!

13:00

Tia: There's also major linear colliders at Fermilab in Chicago, and in Japan.

Dave: So at this one in Stanford, where they're now doing biology, are they like putting an eyeball in there and then seeing how fast they can get it to go?

Ben, Ken: [laugh]

Tia: Well they shoot these particles at eyeballs and various other biological pieces of humans.

Ben, Dave, Ken: [laugh]

13:28

Ben: Okay, so you're missing one fundamental element that I keep trying to bring up. The one at Stanford is two miles long. These things are - I mean it's just like Tia said - it's just plate after plate after plate. And the deal is that you know if you're going to build one like this, it's, I'm not going to say that it's very straightforward, I guess it's literally straightforward.

Dave: [laugh]

Ben: But the problem is, you build one that's two miles long or four miles long, but the length of the track, it kind of limits how fast you can get the things going, right? Because eventually the particle will reach the end of the track and you can't accelerate it anymore.

Dave: Right.

14:06

Tia: You better stick your experiment there.

Ben: [laugh] Yeah.

Ken: [laugh] Yeah!

Tia: So eventually with these linear accelerators you run out of resources to build very long buildings to accelerate these particles very fast.

Dave: Run out of bricks? [laugh]

Tia: Yeah. So they came up with a variation on it. They're like okay, well we know magnets bend charged particles so you can control the direction of a charged particle by putting it near a magnet. So they're like okay, let's make a series of these linear accelerators and put them in a circle and then just connect all of the joints with these magnets. So you can get the particles going around in a circle and that's basically how you make a synchrotron.

Dave: Oh, easy enough! Sounds like a weekend's work.

Ben: [laugh]

15:00

Tia: Yeah, it's not so bad. So, these are even cooler than linear accelerators because you can collide particles at much higher energy because you can have particles going in both directions around the ring. You have two separate beams of particles going around and you can collide those head on with each other at very high energy because both of the particles are traveling towards each other. But with the linear accelerator you have a fixed target, something that's not moving, and then your particle crashing into it. So it's the difference between the energy in a head-on car collision versus driving your car into a wall. So there's lots of applications for these synchrotrons. One is obviously particle physics, and there's a few labs that have these around the world. So there's Fermilab near Chicago, the Tevatron which was recently shut down two years ago.

15:59

Dave: Is that the one Lex Luthor has?

Tia: [laugh] Wait is it?

Dave: No, I didn't think [laugh], I think he's fictional.

Tia: And there's also the Large Hadron Collider [LHC] at CERN which found the Higgs particle recently. So at the Tevatron they have protons and antiprotons travelling around and would collide with each other.

Dave: What is an antiproton?

Tia: So that's a great question.

Dave: Thanks.

Tia: A proton has positive charge and an antiproton has negative charge.

Ben: It's antimatter, guy!

Tia: It's exactly the opposite.

Dave: Oh…So if it's antimatter, can it go past the speed of light?

Tia: It's still has mass.

Dave: Oh great.

16:45

Tia: So these antiprotons - how do you make antimatter? How to you make antiprotons? I mean, what they do is they take protons, they smash it into a target of copper and a whole bunch of particles come flying out of that: protons, antiprotons, kaons, pions, all kinds of particles.

Dave: What a mess.

Tia: Yes. And so they filter out many of the particles by using magnets because different momentum particles will bend different amounts when they're close to magnets. So they filter them all out and they collect the antiprotons and then there's a ring called the storage ring and they do a bunch of tricks to get the antiprotons closely packed together in this storage ring. And after they collect enough of them then they can inject them into the big collider ring and they'll travel opposite of the proton beam and they collided them at the CDF and DØ experiments [note: sometimes written D0 experiment, or DZero experiment].

Dave: And what happened?

17:50

Tia: They were able to find, let's see, the top quark in 1995, and they nearly saw the Higgs, but…not.

Dave: Awwww…

Ben: [laugh] Okay. So what Tia has just told you is absolutely fantastic. There's a fundamental thing in particle physics which is that particles can turn into other particles if you give them enough energy, kind of. Rule of thumb, right?

Dave: It's the American Dream.

Ben: Yeah, that's right. So you take these protons and they're going really really fast and you ram them into, well, anything. The deal with particle physics is you often want to smash streams of particles together because if they hit each other with enough speed then they can turn into any type of particle. So you get all sorts of weird crazy particles that are theoretically very rare and they'll only exist for a very short amount of time generated in these, in these collisions. That's the particle physics reason why we have all these accelerators. You accelerate them to huge energy, and when they smash together if they have enough energy they can turn into other weird things that we can study.

Dave: Okay.

18:52

Ben: So one of the weird things that things can occasionally turn into if you give them enough energy is antimatter. You make matter/antimatter pairs. So an electron and a positron – a positive antimatter electron – will get made.

Dave: Is there antimatter? I asked this about electrons earlier:

would you know them to see them? Like is antimatter all around us?

Ben: No, it's not. So when antimatter touches regular matter ah, it explodes. So if you take a positron with your little magnetic tweezers or something so you're not touching it, and you touch an electron to it then all of the energy that it took to make the electron and all of the energy that it took to make the positron will just turn into light. It'll flash, it'll turn into gamma rays. They're kind of like bubbles popping, so they touch each other and then they pop, and then all the energy goes somewhere else. So the deal is, you're making a whole bunch of weird exotic bubbly things. Ah, and one of the things you can make is antimatter. So if you make protons go fast enough and you ram them into a nice target like – ah, what is it, copper? – one of the things that get made is a whole bunch of antiprotons. So it's essentially nucleuses. You know how atoms have electrons and…

Ken: Nuclei!

Dave: I know, I know vaguely.

Ben: Right. So the parts of the nucleus come out, only they're antimatter ones. So they're in the mix with the other weird things that get generated in these high energy collisions and then the good people in Chicago use magnetic fields and electric fields and stuff to sort through it until they've got all of the antiprotons in one big batch and then they take them off to the side so they're already moving in one direction and they kinda rally them off. It's kind of like if you're in a car on the freeway and you turn right and then suddenly you're going in a big circle and you're stuck in a circle.

Dave: Yeah.

20:28

Ben: They essentially put all the antimatter in a big loop and it goes around in a loop until they're ready to use it. And then when they've got it all, they're ready for their experiment, they let it into the big accelerator ring and it gets accelerated anticlockwise around the ring and then regular matter, nucleons, get accelerated clockwise around the rings. So there are two different streams of matter. One's antimatter, one's regular matter, both going around this ring. One's clockwise, one's anticlockwise, and they're very careful not to let them touch until they've got the camera rolling…

Tia: [laugh]

Ben: …and when the cameras are rolling they let these big streams of antimatter and matter smash together. And then, you know, it's so much energy when that happens, that all sorts of weird crazy stuff can get made. And then…

Tia: But the cool thing about the Tevatron is that they only have one beam pipe. So they have the protons and the antiproton travelling around the circle, not interacting, until they choose with the magnets at the collision points, to have them collide. I mean, it's pretty clever they way they were able to design it because they turn into light when they touch each other so you have to be really careful so that they don't touch.

Dave: So are particle physicists just really violent and they just want to smash stuff together all the time?

Ken: [laugh]

Dave: Is that what I'm learning?

Ken: Yeah.

Tia: Yeah.

Ken: Pretty much.

21:44

Dave: Okay, cool. When they're creating these antiprotons, I assume they collect them in like a bucket. Have they ever gone missing, like has the cleaning lady throwing them out by accident?

Ben: [laugh]

Ken: They keep a pretty close watch on them.

Dave: Okay. I think it'd be pretty clear if the cleaning lady had them.

Tia: [laugh]

Ben: How come the cleaning lady exploded and now has cancer?

Ken: [laugh]

Tia: [laugh] Awwww, no!

Dave: Doesn't need to happen in that order.

Ken: [laugh]

Ben: Speaking of cancer, there are other uses besides just letting particle physicists smash things together for these streams of essentially high speed protons and electrons, and it's worth mentioning some of them. So one of them is there's a cancer treatment that you can do where essentially they take the part of you that has cancer and they put it in front of a stream of high speed protons or electrons. Essentially in their medical laboratories they've got particle accelerators.

Dave: Mm hmmm…

22:39

Ben: So the deal with electrons is they don't penetrate very deep into humans. But part of the nice thing is if you've got something on the surface of your skin, you can shoot it with electrons instead of cutting it off or something.

Dave: Right.

Ben: So what you do is you essentially kind of cook and you mess up all of the DNA of all the cancer cells under the very precisely aimed beam of electrons. And then if you've got caner inside you in a place that maybe you can't do surgery on: brain cancer…

Tia: Eye cancer.

Ben: Eye cancer. What you do is you can take protons.

Ken: So as Ben said, if you've got cancer that you can't actually get to, to operate, you essentially want to have something that will go through, that will penetrate the cells that you don’t want to damage, and then will deposit all of its energy into the cells that you do want to damage. And so what you can do with that is use beams of protons. And protons are pretty interesting since they're a charged particle the way that they deposit their energy as they go through, they don’t deposit energy all they way as they go through, so as they start to go through your cells they'll deposit a little bit of energy and then a little bit more energy and as they slow down, they'll deposit more and more energy with each deposit. So you can tune that so it will go through you know, depositing very little energy in say the first couple of centimeters and then when you want it to hit it, it will deposit all of its energy there and essentially just blast the cancer into pieces by using these protons. Which is a pretty cool effect called the, it creates a peak called the Bragg peak, which you can look up. But that's essentially it – it's not damaging healthy tissue, and blasting apart your cancer tissue.

Dave: Cool.

Ken: Yeah! Which is pretty clever and I think it's a good use. And as Tia said, one of the really neat uses is using it on eyeballs. So it can actually save your sight by using this stuff.

24:25

Dave: So what is this process called?

Ken: So it's called radiotherapy I think is the name that they use and they actually have these radiotherapy labs where they have accelerators and they'll accelerate this beam of protons and tune them so that they can deposit the energy exactly where the bad tumors are.

Dave: And it's the same sort of idea as the giant particle accelerators but it's just a smaller scale?

Ken: Yeah, very, exactly the same idea. You just want to get protons in this case, you want to sped them up to a chosen energy and then fire them at the person. Hopefully in the right place.

Tia: Yeah, and even at the big physics labs, they have medical facilities also. Um, I know Fermilab for sure has medical facilities. So, I think lots of people are interested in this technology for treating cancer using particle accelerators and I mean there's a lot of people across the world that I mean need this and in the United States they were looking at building more particle accelerators in order to treat cancer but also to build something called an accelerator driven nuclear reactor. Um, which is a safe version of a nuclear reactor. So these accelerators would serve two purposes: a medical purpose and then an energy production purpose with a safe version of nuclear reactors. So you're able to take the uranium and other nuclear material that they use in regular reactors and even other less efficient forms of radioactive elements and you shoot a particle accelerator at it, and those high energy particles kick enough energy at those heavy atoms to make them fission. They split apart.

Ben: Oh, so you don't need to go to critical mass.

Tia: Yeah.

26:28

Ben: I see. Okay, that's neat. Okay, there's one more medical application hat we didn't mention and it's medical isotopes.

Dave: Okay.

Ben: There's like a medical isotope crisis a few years ago. Do you remember when that happened?

Dave: I think I remember.

Ben: Okay.

Dave: The words.

26:42

Ben: Yeah, right, so there are various uses for radioactive elements. Especially elements that will decay in a very specific way. Um, and so there are various ways to make certain really specific elements, and one of them gets used in a PET scan. I'm going to say it's fluorine, and the idea here is you take oxygen and you shoot it with a beam of particles until it changes into a different element: fluorine. And this element is pretty heavily radioactive, so it decays and emits protons. And then what you do is you take this vat of fluorine, this chemical, and you make pharmaceuticals with it. And there are pharmaceuticals that attach themselves to the various parts of you body that you want to image medically. And then so what you do is you take this medicine and then the molecules bind to the organs that have cancer or whatever, and then they start glowing: they start emitting positrons which you can then detect with a particle detector and it's a medical imaging system called a positron emission tomography scan, a PET scan.

27:44

Dave: Right.

Ben: So actually there's a particle detector I'm going to tell you about in a second: TRIUMF. It's in Vancouver.

Dave: Yeah, TRIUMF with an "F", right?

Ben: Yeah, I'll spell it in a second. It's particle accelerator that has tubes, pipes going straight from the detector all the way to the university hospital so they can use the isotopes right away before they start decaying, in medical practices. Alright. So TRIUMF with an "F", let's talk about it. Have you gone on a tour of TRUIMF with an "F" before?

28:13

Dave: No, I have not.

Ben: Okay, they offer free tours and they're pretty cool?

Dave: Is that what the "F" stands for – "Free"?

Ben, Ken, Tia: [laugh]

Ben: TRIUMF, it's T-R-I-U-M-F: TRi University Meson Facility, right Ken?

Ken: That's it.

Ben: Okay! It's a different type of particle accelerator than the ones we've been talking about. The structure of it is different fundamentally. So the thing about synchrotron rings, you know like at CERN, the ones Tia was telling us about, is you have to kinda make your accelerated particles in batches because you take some and then you accelerate them and as they go around the ring you make them go faster, faster, and faster. But the timing that you use depends on how fast they are going. And so you really need to tune the time of accelerating them to how fast they are going around the ring and so you can only make batches of them going quickly at one time. And some times it's helpful to have a nice stream of fast moving particles and TRIUMF is one of these accelerators that does it, and they do it in a completely different way. Oh it's so great I love it! Okay.

Dave: Mm-hmm.

29:11

Ben: The TRIUMF facility's accelerator is kind of shaped like a big hockey puck, okay? So what it is, is: imagine a great big hockey puck. It's huge! It's like the size of, it would take up a sizeable portion of a hockey rink. It's a really big thing. There are photographs of all the old physicists sitting over it as they built it. It's a big, kind of cylindrical area and there's a great big magnet above and below it. So there's a great big magnetic field going right down vertically through it, okay?

Dave: Okay.

29:38

Ben: Now, a charged particle can't go in a straight line in one of these fields. It will be kind of stuck in a circle, depending on it's speed. And the faster the speed it has, the larger a circle it'll be able to make. So if it's moving very slowly it will make a small circle. If it's moving fairly quickly it'll make a really big circle. So at the very center of it they let out an electron – BOOP! – Now, here's where the clever part comes in. So there are great big, they're called "D"s because they're capital D shaped, they're shaped like you know you take a hockey puck and you cut it in half and then you hollow it out so it's kind of like, imagine if you had a Boston cream donut and you cut in half and sucked out all the cream. It's shaped like that.

Dave: Okay

30:15

Ben: And, the deal is that they charge these two D's with electric charge back and forth. Um, so they'll let out an electron in the middle and then they'll make on of the D's positive and the other negative. And the electron will go, "Oh, I wanna go to the positive one" and so it's accelerated a little bit towards the positive one and it ends up making kind of a small circle. And then they'll switch it: as the particle rounds the circle and it starts moving towards the other D, it'll switch the polarity so the other D is slightly positive. And then the electron will go, "Oh, I wanna go towards the other one". And so it'll accelerate a little bit more. And they switch back and forth, and back and forth, and back and forth periodically and the nice thing about it is you only need to, you don't need to time it too carefully. You switch it back periodically with a regular period and the particle will go back and forth and as it swings in circles it'll get accelerated back and forth, and back and forth, and back and forth, and back and forth, and end up tracing larger and larger circles. It'll spiral out from the middle in other words as it gets accelerated. The longer it's on the spiral the faster it ends up going, until at the very edge when it's at the circle's widest part, it'll be going, like, the fastest. And at that point in time you can grab the electron stream straight out of it. And the nice thing about this is you can just let out a constant stream of electron in the middle of it and you'll get a constant stream of really fast moving electrons out the other side of it. And this thing is called a cyclotron.

Dave: Sweet.

Ben: Yes.

31:41

Dave: I mean the names are all really cool. Even if you don't get what's going on, it's impressive.

Ben: Right! Okay, do you want me to use an analogy to describe what's going on here?

Dave: I would like you to use cyclotron in a sentence.

Ken, Tia: [laugh]

Ben: Okay. Last night my bike got hit by lightning and now it's a sentient robot. It's name is cyclotron.

Dave: Pretty good.

32:00

Ken: Not bad.

Ben: Okay so I like dogs a lot because they're really excitable. So let's suppose you have essentially a dog and you put him in the middle of a bowl. A great big bowl, a bowl the size of like a corral. So you and your partner stand on opposite sides of the fence. So I'm on the north side of the fence, on the top north side of the corral, and then Tia's on the bottom side. And what we're going to do is we're going to periodically going to either shout at the dog o, ah, you know hold up some sausages. And dogs love sausages and they hate being shouted at right?

Dave: Mm-hmmm.

Ben: So the dog will take off towards me when I'm holding up the sausage. But then as he gets closer to me he'll end up swinging out in a circle because of this weird magnetic field and be kind of going in the opposite direction, and as soon as he's moving in the opposite direction, instead of holding up sausage, I'll start shouting at him. So he'll want to run away from me. And Tia will hold up some sausages and go, "Hey nice sausages!" And the dog will speed up running toward Tia and end up looping in a great big circle. And then as soon a he's not facing Tia any more and facing me, Tia will start shouting at the dog, and I'll hold up sausages and we'll go back and forth and the dog will accelerate as we periodically temp it with sausages and beatings.

Dave: [laugh] Right.

33:13

Tia: You're gonna get PETA called on us.

Ben: [laugh]

Dave: And so this is the cyclotron?

Ben: This is the cyclotron. So yeah, you live in Vancouver – if you go to the cyclotron in Vancouver you can get a tour of it. It's one of the premier facilities in the world.

Dave: I'm really busy…

Ken, Tia, Ben: [laugh]

33:31

Tia: Do they give free cookies?

Dave: Do they have sausages or will they yell at me?

Ben, Ken [laugh]

Ben: First one, and then the other. Alright, well that was fun. Thank you Ken, thank you Tia. You've pleased me. Your efforts have born fruit and that fruit is sweet! Here's some fruit: Ken, you get a lemon.

Ken: Oh, yum.

33:46

Ben: Oh, incidentally did I tell you ah, if you, some of you wrote a paper, if you taste one of these particles beams they taste acidic, like lemons and limes.

Ken: Okay.

Ben: Yeah, ah… Tia you get a lime!

Tia: Mmmmmm.

Ben: And you also get a Jammie Dodger cookie for suggesting the topic.

Tia: Woo-hoo! Nom, nom, nom.

34:05

Ben: Good. Alright. I'd like to thank guest Dave Shumka. Thanks Dave!

Dave: Thank you.

Ben: Okay everybody remember to listen to the Stop Podcasting Yourself Podcast, it's really really good. Okay, so hey Ti-Phi-ters, listen. Some of you might want to support our show financially. This is understandable. We don't just have hosting costs to take care of now, we've also got dues to pay to the Brachiolope Media Network and we can use your money to improve our hardware and send physicists to podcasting conferences. So let's suppose you want to support us. You can do so in a variety of ways. Firstly, donations! There is now a donation button on the website where you can go and set up one time or recurring donations. Thank you in advance if you do it! Okay secondly, there is a podcast app called Podiversity and it's on the Android phone. So for all of you people not using Apple phones great, finally a podcasting ap. The nice thing about the Podiversity app is it's a subscription-for-content based app. So it's kind of like Netflix for podcasts. You pay them a little bit of money, I think the first month is free, and then they pay us cash money for all the episodes that you download. So if you get the app and then listen to our show a whole bunch of times, cha-ching!

35:12

Ben: Thirdly, T-shirts! So, go to our store off the Ti-Phi website and buy yourself a sweet shirt. Some of them were designed by brilliant designer Chelsea Anderson. They're lovely shirts, oh I love them! And are the shirts expensive? Yes, they are a little bit expensive, but they are very high quality! And Ti-Phi gets a cut of each shirt sold. Bethany bought one a couple of years ago and she's worn it pretty much every other day for the last two years and it still hasn't worn out! It's lovely. So the t-shirts are very nice, go and take a look at them. Okay, that's it for the main part of today's show. Remember, that if you like listening to scientists talk about science in their own words, you might also like to listen to other shows in the Brachiolope Media Network. There is a brand new show on the network I'd like you to know about: it's call Astrarium. My good pal and Titanium Physicist James Sylvester has a show where he and his buddy David talk about astronomy. It's so good, you'll want to go outside and lie down and listen to it and watch the stars come out.

36:03

Ben: The intro song to our show is by Ted Leo and the Pharmacists and the end song is by John Vanderslice. Okay, until next time friends, remember to keep science in your hearts.

[Outro song; Angela by John Vanderslice]

36:57

37:03

Ben: Well Ken, do you want to talk about this, or do you want me to keep ranting?

Ken: Ah, I dunno. Do you want to keep ranting?

Ben: Well correct me and interrupt me when I start being wrong and weird, okay?

Ken: [laugh] Okay, we'll stick with wrong for now.

Ben: [laugh]

Tia: I think Ken should do this.

37:20

Dave: I mean, can we go past the speed of light?

Tia: We haven't yet.

Ben: No! You can't go past – Tia, c'mon!

Tia, Ken: [laugh]

Ken: It's some serious argument there.

Ben: [laugh] Tia's a particle physicist and I'm a general relativist. So I study Einstein's theory of general relativity and we only have one rule, and that's that nothing can go faster than the speed of light.

Tia: See, I'm an experimentalist and so I don't believe I see it.

Ben: Right.

Dave: Well when I was, this is my high school memory of it is matter couldn't go faster than the speed of light. Is an electron matter?

Ben: Yeah.

Ken: Yeah.

Tia: Yeah, it has a mass, so – a very small mass.

38:06

Dave: Have they every put anything fun in a particle accelerator?

Ben: [laugh]

Dave: Like coins?

Ben: There was a guy who accidentally put his head in one. Did you hear about that?

Tia: Wait, I don't think that's funny, Ben.

Ken: No, no, that's not so much fun as sad.

Ben: He lived though! [laugh] He lived. He got a PhD after that. As far as I'm concerned he's doing fine.

Ken, Tia: [laugh]

Ben: I guess it's sad.

Dave: If you say so.

Ben, Ken: [laugh]

Ken: We're certainly not presenting it like it's very sad.

Ben: [laugh]

Tia: I don't know of any other stories besides that one.

Ken: What was the story with the beer bottles in one of the accelerator tubes? That they actually found them because they were distorting the beam line?

Ben: What?

Tia: Oh.

Ken: That's totally a story. The story is that at one of these accelerators, I can't remember which one, somebody had actually left some beer bottles in the, in the tube, in the beam line. And they found that they were there because they were distorting the field so much. So, yeah, apparently it was reported on in '96 in the New Scientist. So I'm not completely making this up.

Tia: [laugh] Wow.

Dave: Sounds like my kind of party.

Ken: [laugh] Yeah. I don't know who was down there drinking that kind of thing but I kind of wish it was me.

39:26

Dave: Frat boys.

Ken: [laugh]

Ben: I bet if you opened up a beer, you know how like beer, when you just opened it up, all those bubbles form? I bet they would like form along the tracks the electrons passed and it would work like a crappy bubble chamber.

Tia: [laugh]

Dave: So what, with a linear one, we're gonna run out of room, so we're gonna need to come up with a different shape, or maybe do one that goes back in time?

Ken: Back in time would be preferable.

Dave: Okay. Cool.

Ben: Like the guy trying to keep CERN from turning on.

Ken: Oh yeah – that guy was crazy!

Tia: I was there when he was there. That was weird.

Ben: Dave, have you heard this particular story?

40:02

Dave: You lost me at CERN.

Ben, Ken: [laugh]

Tia: So CERN is the European Center for Nuclear Research, only the acronym doesn't really work anymore.

Dave: It's in French.

Tia: Yeah, it's just called CERN now.

Dave: Okay.

Tia: I don’t know – it's like KFC.

Dave: Sure.

Ken: [laugh]

Tia: Anyway so CERN is CERN. And it's on the border of France and Switzerland. And right outside the gates where the busses were there was some bum, like ranting and raving. I don't, I, what was he saying?

Ben: Well the newspapers talked to him, right? He was saying that he was from the future and that CERN destroyed the world or something, and then they sent him back in time to keep from switching it on…

Ken: Wait, wait…

Dave: But they sent him as a crazy homeless guy that no one would believe?

Ken, Ben, Tia: [laugh]

Ben: Time-travelling is hard man! It's hard on a body.

Dave: Yeah, you gotta go naked.

40:57

Tia: Have you ever seen 12 Monkeys?

Ken: There seem to be some causality problems in the is story. Like if the world is destroyed, how did they send him back?

Ben: It was like in Terminator, where he was the last person they could send back.

Ken: Oh, maybe.

Ben: You know, "You're our last hope, go keep them from turning it on and finding the God particle. That's his particle. He'll get mad if we find it – he'll destroy the world."

Ken: Well he failed.

Ben: [laugh] He did fail! And then there was somebody else who wrote a paper. So there were lots of, when they were turning CERN on, um, this Large Hadron Collider, the latest and biggest particle accelerator in the world.

Dave: How long has this guy been around?

41:33

Ben: The Large Hadron Collide?

Dave: CERN, yeah.

Ben: Okay, CERN has been around for how many years? Years and years and years, right?

Tia: Since the sixties?

Ben: Yeah, but every couple decades they build a new accelerator, kind of surrounding the old one. So the first ring was relatively small. And then they make a bigger ring surrounding that. And then a bigger ring. And the current one is 27 kilometers in circumference. So it's this…

Dave: Oh, my.

Ben: So it's this massive ring.

Dave: To rule them all.

Ben: Yeah, that's right. So they… [laugh]

Ken, Tia: [laugh]

42:07

Ben: So there's some more ridiculous stories out there but, so there were lots of, oh and when they were trying to set it up and turn it on there were lots of technical failures. Like the magnets would blow up, or the cooling would fail and then the magnets would blow up and, at one point, uh, a seagull dropped a baguette into a transformer station and that [laugh] blew it up and then the magnets blew up.

Dave: How very French.

Ben: It's just one thing [laugh] after another.

Ken: [laugh]

42:32

Ben: And so somebody wrote, somebody actually…

Tia: Wait, the magnets didn't blow up for that one.

Ben: [laugh] Okay.

Tia: They shut down safely.

Ben: [laugh]

Tia: We just had to get power back after someone ate the baguette.

Dave, Ben: [laugh]

42:45

Ben: So..

Dave: A mime rode a bicycle…

Ben: [laugh]

Dave: …into the accelerator, I get it.

Ben: So, so many things kept happening wrong that a very well respected physicist wrote a paper saying, maybe humanity's not supposed to find the God Particle, quote un-quote, because God is preventing us from finding it by fucking with our shit every time we try to turn this thing on [laugh]. It was like oh, yeah, we'll never get it on, we'll ever be able to detect this particle because you know circumstances will always prevail, and there will always be another bird with a baguette.

Ken: And a beret.

Dave: Yeah, it's like the lost island.

Ben: [laugh]

Tia: But we got it, but we got it, so –

Ben: It's true.

Dave: We got the God particle?

Ben: Yep.

Tia: We got it.

Dave: Oh, cool!

Ken: Hooray!

43:30

Dave: What's it like?

Ben: [laugh] It's got a beard…

Tia: [laugh]

Ken: Smells good.

Ben: Smells like cinnamon.

Tia: [laugh]

43:40

Dave: Is there just one are there many? Is it multi-theistic? Is that the right term?

Tia: Wow, that's a good question.

Dave: Thank you.

Tia: I think I would say it is multi…wow.

Ben: Well okay, so there's only, there's, there's, you see it in multiple places but all of the God Particles are indistinguishable from one another.

Tia: Yeah.

43:02

Ben: So you can tell me if [laugh]. So apparently, so you've heard of the God Particle, obviously – we've mentioned it thirty-five times.

Dave: Yeah, I don't know what it is.

Ben: Right. Okay, it's this thing called the Higgs boson. I don’t want to talk too much about it. It's called the Higgs boson. It's named after a guy named Peter Higgs.

Dave: Okay, I've heard of that.

Ben: Um, but, ah, I forget who, somebody wrote a book about it trying to popularize what CERN was trying to do in detecting this weird particle.

Tia: Lederman. [note: The God Particle: If the Universe Is the Answer, What Is the Question? by Leon Lederman]

Ben: And ah, and he wanted to call it the Goddamn Particle, because it was so infuriating to detect. But then the editors were like, "We can't call it that", so they shortened it to the God Particle. [laugh] And they put it on the cover. And so ever since then everyone's been calling it the God Particle like it's really important and impressive.

Dave: Oh I see.

Ben: Even though it's just a goddamn particle.

Dave: Classic editors.

Ben: Yeah [laugh].

44:57

Dave: Well, I have a question.

Ben: Yes.

Dave: So there are all these positive applications.

Ben: Mm–hmmm.

Dave: Is there, like, a big negative threat? Like will this, any of these create a black hole, or kill god, or anything.

Ken: [laugh]

Ben: Did you hear about the stories where people, people would go up to physicists and they'd say, is CERN, – CERN is the strongest, the most powerful particle accelerator on earth, right –

Dave: Yeah.

Ben: And so as they were bringing this online they'd say, is CERN going to make a black hole? And the physicists said, "Maybe".

Dave: Yeah.

Ben: Do you remember that?

Dave: Yeah.

Ben: Okay. So the story is, there are lots of very complicated theories that are very speculative for how the universe forms. And some of them involve five of six dimensions. Now how many dimensions do we have? We've probably got three special dimensions, but, you know, some physicist re like, what if we had six spacial dimensions? I dunno. So what these physicists found is: if there were extra dimensions, it might be easier than it should be to make a black hole. And when they did calculations, they said oh look, if there are six dimensions, maybe CERN has enough energy to make a black hole. And so, you know, how probably is it that there are extra special dimensions? Not all that probable, but it's possible right?

Dave: And if there is a black hole created, it's not a problem right?

Ben: No.

Dave: We're cool with that, right?

46:26

Ben: It's really not a problem. Part of it, black holes do this thing called, they, they emit radiation. The smaller they are, the more intensely they emit radiation. It's called black hole evaporation. Stephen Hawking discovered it actually – clever man.

Dave: Mm–hmmm.

Ben: So the deal is that ah…

Dave: I presume. People tell me he's smart.

Ben: Oh he's very smart.

Dave: I'm sure.

Ben: Yeah, ah…

Ken: There's another person telling me he's smart.

Dave: Yeah, yeah. I'll write you down. You're pro Steven Hawking? Okay.

Ben, Ken: [laugh]

46:57

Ben: So alright. If we did manage to make a black hole, what it would do is it would immediately start radiating particles. It would shoot off all sorts of weird particles and then disappear. And it wouldn't have enough time to fall into the center of the earth and eat the earth and turn us all into black holes or whatever. It would, according to the various physical theories that predict it forming, it would probably just turn into a whole bunch of stuff. So they were actually looking for black holes in the CERN detectors. One of the things that they were looking for wasn't a black hole coming through and eating everything, it was nothing, because a black hole wouldn't show up on their instruments and then suddenly the black hole would turn into a whole bunch of particles, so you would see a track with nothing on it and then a whole bunch of weird particles. And they didn't see that, so it didn't make a black hole.

47:42

Dave: So is the CERN, like, the most evil of these particle accelerators? I mean it's got the scary time-travelling guy, the black hole theorists. Do the other particle accelerators have this much controversy?

Ben: There was going to be one called the Superconducting Super Collider. Have you heard of this one? It's kind of a legend. It um, they were going to make it in the 80s and 90s. And it was going to be 87 kilometers around.

Dave: Wow.

Ben: A great big ring one. So they dug the hole, and then congress cut their funding. [laugh].

Ken: They dug the hole at a cost of two billion dollars.

Ben: [laugh]

Ken: And THEN congress cut their funding.

48:28

Ben: So there's a big hole out in the middle of the desert somewhere.

Dave: Do you think it was maybe the mole people?

Ben, Tia: [laugh]

Ben: Maybe. Maybe they dug a hole in the wrong place?

Ken: The C.H.U.D.s?

Ben: Yeah the C.H.U.D.s! [laugh]

Dave: [laugh] Probably the C.H.U.D.s.

Ben: Congress knew about the C.H.U.D. threat and it was like, "We gotta put a lid on this! People are gonna find out!"

Ken, Dave: [laugh]

Dave: Yeah, congress has always been in the pocket of Big C.H.U.D.

Ken, Ben: [laugh]

48:55

Tia: But now they're looking at building another particle accelerator that, called the ILC, the International Linear Collider.

Ben: Is it gonna be a linear accelerator?

Tia: Mm-hmmm. And the latest news is that Japan will host it and ask for collaborators from around the world to help build and finance it.

Dave: Could you in theory build a linear one around the equator? And then I guess it's not linear anymore, and it just goes all around the world. Did I just blow your minds, guys?

Tia: That would be awesome.

Dave: I think we all agree.

Ken: Oh, yeah absolutely.

Tia: That would be awesome. But I mean I think we might run out of bricks.

Dave: Yeah…

Tia: [laugh]

Ben: If we did that, what we could do is incrementally slow down the rotation of the earth.

Ken: Like superman did, to turn back time?

Ben: Like superman did, to turn back time.

Dave: Ahhh! Did we just invent a time machine?

Ben, Ken: [laugh]

Ken: I believe we did!

Tia: Wait a second, aren't the currents in the ocean already slowing down Earth?

Ben: Yeah, I think they have an effect. So do it like that, but with protons going really really fast.

50:11

Dave: Oh man. I'm so baked.

Ben, Tia: [laugh]

Ben: Ahhh. Okay, we've been recording for about an hour, so we probably have enough material. Do you have any other questions?

Dave: I think that was my ah, my big one was about the evil CERN.

Ben: Yeah, that was a good one.

Dave: I guess I mean, seriously, consider my earlier question.

Ben: Yeah.

Dave: Is this the kind of thing a super villain wants to get a hold of? In this day and age, what else would a super villain want, a giant laser, or a particle accelerator?

Ken: Lasers are pretty played out, I agree.

Ben: No, but you can blow stuff up with lasers. With particle accelerators, you're just gonna give things cancer. Well I guess there was that guy who got zapped by one and then that wasn't good.

Dave: Well, he got a PhD.

Ben, Ken, Tia: [laugh]

Ken: It's a lot of PhD's you gotta give out, you start zapping people.

Tia: [laugh]

51:05

Ben: Do you think they gave him a PhD just out of sympathy? No – I think, I think he earned the PhD. I guess he has trouble, but…

Tia: I mean if you wanna hurt someone with it, I mean, you have to somehow bring them down into the pit to… Yeah I think drones are much more dangerous.

Ben: [laugh]

Dave: Well I guess we'll agree to disagree.

Ben: [laugh] I guess, you know, if earth ever got attacked by an alien spaceship that was passing over Europe you could probably re-aim some of the particle beams so they were giving the spaceship cancer.

Dave: So what you are telling me is these things are basically a dud.

Ben, Ken: [laugh]

51:47

Ben: Yeah, super villains can't do much with them. I guess they would spend all their money on them. Yeah.

Dave: Yeah.

Ben: So maybe super villains are just really bad with their money, and they want to waste their money. In that case yeah, sure. Yeah, I don't know what you could do with them, villainously.

Dave: I'm satisfied.

Ben: You kinda need one spot, and you need it to be kinda seismically, you know, neutral so that things aren't messing up everything with earthquakes all the time. It takes a lot of care. I don't know if you're gonna take on superman if you're worried so much about your magnets exploding all the time.

Dave: Yeah. Alright, alright, I'm satisfied.

Ben: [laugh]

52:29

Ken: So are you planning for your future super-villain-ry? Or what?

Dave: Yeah, I guess I'm gonna cross that off my list of things to you know, use to hold the world hostage.

Ben: You should make… lasers can do anything.

52:42

Dave: Oh man, that would be a good episode.

Ben, Ken: [laugh]

Ben: Called "Lasers Can Do Anything"? Well they, one of the, somebody made a particle accelerator with a laser recently. I don't know much about it.

Dave: What?!

Ben: They just shoot a really, I guess, a big really really strong laser at some particles and it speeds them up really fast. I guess that makes sense. Not much of a story.

Ken, Ben: [laugh]

Tia: Yeah, but I mean there's like, photon colliders.

Ben: Mmmmm… yeah lasers. Anyway…

Tia: At Berkeley Labs, yeah. [note: Lawrence Berkeley National Laboratory]

Dave: I guess this episode just really needed a big finish. Mmm, like we had the beginning, we had the middle, but it's like….

Ben, Tia: [laugh]

Dave What's gonna be the big conflict at the end?

Ken: Oh yeah that's tough. We need a good third act.

53:38

Tia: Isn't that ironic that I mean, these things both cause and cure cancer?

Ken: In the Alanis Morisette sense?

Ben: [laugh]

Tia: Yeah. [laugh]

Dave: I mean it's true of cigarettes, too.

[Silence]

Ken: Ummm…

Tia: Wait, wait, no, I don't think that one's true.

Ben, Ken, Tia: [laugh]