When Photons Collide

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Jorge: [00:00:00] Hey, Daniel. I have a question for you. Very important. All right. What is it? How close are we to having real lifesavers? You're

Daniel: asking a physicist. That question. I would ask the same question to my favorite engineer.

Jorge: Wait, do you think it's an engineering solution? Don't we need like, uh, some kind of breakthrough in theoretical

Daniel: physics.

Not, I mean, the science fiction authors have done their job already and they passed it on to the

Jorge: physicists. Oh yeah. And the physicists have

Daniel: figured out how to do it. Well, you know, we've been smashing photons together to see what happens. And how does that

Jorge: give us a light saver?

Daniel: well, so far it makes a really awesome sound like, Ooh

Jorge: but can it cut through swords and deflect my

Daniel: guns?

That's the engineering problem.[00:01:00]

Jorge: Hi, I'm Jorge cartoon and the creator of PhD comics.

Daniel: Hi, I'm Daniel. I'm a particle physicist and a professor at UC Irvine. And until a moment ago, I had never made a light saber sound with my mouth.

Jorge: Yeah, we could tell that was terrible.

Daniel: Daniel all right. Let's hear your light Saer sound.

Jorge: right. That sounds a lot

Daniel: more accurate. Well, we'll let the listeners vote. I think the coolest sound though is when they clash, you know? Cause they're like, and then it's or something

Jorge: when they hit it. Oh boy. That's even worse. Daniel. Everyone knows it's

Daniel: oh, that was much better. All right. You're right.

That's definitely better. Those movies

Jorge: are ingrained. are burning into my brain for better

Daniel: or for worse. Like somebody inscribed them with a

Jorge: light Saer like somebody weighed their hand and said, I would only remember these movies for the rest of my

Daniel: life. . It'd be pretty awesome. If the movies themselves were a Jedi mind trick, what

Jorge: I think they were

They certainly got a lot of my money out of my pocket. These are the

Daniel: movies

Jorge: you want to [00:02:00] pay for. But anyways, welcome to our podcast. Daniel and Jorge explained the universe, a production of iHeart radio in which

Daniel: we pull off the physics mind trick of attempting to understand the universe. We convince ourselves and hopefully convince you that the crazy cosmic mysteries, the grandest questions of the existence of humanity, the things that philosophers have been wondering about for thousands of years, the very nature of our reality and its meaning can be understood by tiny little squishy brains, living on a little rock, orbiting, a very normal star.

We talk about all of these questions and we explain all of the answers. To you.

Jorge: That's right. We used the force to understand the forces of the universe and to look out to galaxy far, far away, and actually also a long, long time ago to understand how it's all put together and why it's all hanging there.

The way it is because

Daniel: everything around us presents mysteries. How do these things work? What happens when they bump into each other and as a particle physicist, my favorite way to understand how things work is to do exactly. [00:03:00] Smash them into each other or collide them into each other or blow them up, whatever you prefer.

Jorge: Yeah, because the universe has a dark side and also a light side and it seems to be in constant struggle with itself, bumping into each other colliding fields, interacting with each other. To create this amazing spectacle that we can see just by looking out into the night

Daniel: sky. And we've made remarkable progress in understanding the very nature of the universe by describing space itself and everything out there in terms of oscillating, quantum fields, these things which fill the whole universe with their energy and slide and smush against each other to come together to describe the reality that you and I experience.

Jorge: Wait, Daniel, you mean it's not all made out of Melor little tiny beings that, you know, bind everything together.

I,

Daniel: the Melor were biological, not quantum

Jorge: mechanical. They never described it in Starwars. Maybe they are quantum mechanical.

Daniel: Ooh. Maybe they are quantum

Jorge: biology. yeah, maybe right. Well, in a [00:04:00] way it seems almost, uh, the same.

I mean, you're saying that the, the universe made. Fields that are bound together with these little tiny things that bump around each other and somehow direct the cosmos. That's kind of what George Lucas was saying.

Daniel: That's kind of what everybody was saying. If you're gonna say kind of, and be really generous about it, you know, yeah.

Kind of, but I love this picture of the universe as all these different quantum fields. You have like a field for the photon. You have a field for the electro and you have a field for the. You know those fields we can think about as having particles in them, which slide around to keep a little discreet blob of energy.

And we've talked on the podcast about how particles are these little ripples in the quantum fields. But one of the most interesting things that these fields can do is talk to each other, the photon field and the electron field. Don't just fill the space of the universe and ignore each other. They interact, they touch, they bind together.

They transfer energy back and. Yeah.

Jorge: And thankfully, I guess, right, because if the, all the fields ignored each other, like nothing would ever happen, we wouldn't be here. We're here because of those [00:05:00] interactions

Daniel: in a way, every interaction between two different kinds of particles, the way the electron is bound to the nucleus of the atom, the way chemical bonds form, the reason you don't fall through your chair is all because those quantum fields don't ignore each other.

It's because they interact with each other because they pass energy back and. In some sense, it's a bit of an artificial distinction to say we have two different fields. You might want to think of them holistically as one bundle of

Jorge: fields. Mm. One force with the dark side and the light side. Right. I think you're kind of saying the same thing.

Mm. One

Daniel: force to rule them all. Now I'm mixing our mythologies. we, we need to have like a Lord of the ring star wars crossover event who would win. Oh

Jorge: my goodness. Fan fiction writers get on it.

Daniel: are those owned by like different corporate conglomerates, in which case it'll never happen. Not

Jorge: on the internet.

Anything can happen on the internet.

Daniel: that's true until Disney's lawyers come after you. No. If Disney buys Lord of the rings, then we might get like a Marvel star wars, Lord of the rings [00:06:00] photo crossover. Right?

Jorge: Oh, my goodness with throw Ironman in there. And I'm, I'm all in

Daniel: Gandolph versus Ironman. Wow.

Jorge: who would win Dr.

Strange or Gandolph the war of the wizards?

Daniel: I don't know. Who's got a better grasp on the quantum fields.

Jorge: But it is interesting in things like star wars, they use lasers, right? Laser guns to shoot at each other, and also light savers to cut through appendages and also doors and walls. And it's interesting to think that light can interact with matter.

Like if you shoot a laser, it's gonna burn a hole through your wall. Right. And you can even use light to push a solar, sail to purchase spaceship off of. Solar system. Exactly.

Daniel: Light is really weird. It has energy. It has a momentum, but it doesn't have any mass. And yet of course it can influence our world because of that energy.

In that momentum, a laser will deposit a lot of energy in a very small spot and burn right through it. And that exactly happens because those photons can interact. With charged particles, the quantum field, the photon, and the quantum field [00:07:00] of those electrons or muons or quirks can interact and pass energy back and forth.

I always wondered when I watched those lightsaber battles, I thought, how does that work? How do two lightsabers, two beams of light hit each other?

Jorge: Mm, well, this is getting a little philosophical. Daniel are lightsabers beams of light, actual like light that just stands there and sits there. Or are they like some kind of material?

Like, you know, like a plasma beam?

Daniel: Mm, well, wouldn't they be called plasma SAS then? I mean, they are called light savers. And I imagine George Lucas knows his quantum

Jorge: mechanics. Yeah. But maybe they're called light savers cuz they give off light. Mm. I

Daniel: guess that's a good point. You know, light bulbs are not made of light.

Jorge: Yeah. We're getting deep here. this is very stimulating, uh, illuminating conversation here.

Daniel: well, two bright minds, you know, Let's see what we can do.

Jorge: I guess we were talking about interacting things, interacting, and, you know, it's kind of interesting that electrons can definitely interact with other electrons, right?

Like an electron will repel another electron and [00:08:00] like a proton will repel another proton. Like things seem to be able to interact with it

Daniel: themselves, but not directly, actually electrons do not interact directly with other electrons, electrons interact with photons and photons interact with El. Sort of like having an interpreter, right.

You can talk to the photo, Don and the photon can talk to the other electron, but electrons don't interact with each other directly.

Jorge: Mm. I see. You gotta go through their agents. Like, uh, talk to my people.

Daniel: Exactly. It's like electrons are celebrities that don't just email you. They're people email your people.

But

Jorge: I guess this brings up the, an interesting question, which is what do Fullton interact with

Daniel: specifically? Yeah, exactly. When those two light SAS are about to cross and to make that sound that I can't make. What exactly is going on at the microscopic level in George Lucas's

Jorge: mind? Yes. It's the, on the podcast, we'll be asking the question.

Do photons bump into each other? Daniel, this seems a little risque. [00:09:00] Like what do you mean bumping to each other? like they, they bump and grind or they like casually like, oops, sorry. Bumping to each other. Yeah.

Daniel: Well, you know, photons can do all sorts of things. They can be circularly polarized. So I guess they can do like spins on the dance floor.

And you know, I'm not one to tell you what's appropriate and what's not appropriate. Talk to your parents about that. But this is more of a physics question. You know, what happens when two beams of light cross each other, do the photons ignore each other? Do they hit each. Do two photons push against each other.

You know what happens when you cross the streams? Oh man. Now we're

Jorge: getting to another mythology. Ghostbusters do not cross the

Daniel: streams. Exactly. I wanna see Venkman versus Gandolph versus a Jedi now.

Jorge: Oh, obviously Ackerman would win. I mean the smart engineer always wins. I don't know.

Daniel: Venkman's quite the smart professor.

Jorge: Yeah, because I think this is something that I wondered about as a kid. Like if you take a flashlight. And you take another flashlight and you point them, not even at each other, but just like pointing 'em in the same direction or cross their beams, like what's happening there. Like what's happening to the [00:10:00] light.

Do the light beams ignore each other or do they kind of, uh, interfere or somehow scatter each other? So

Daniel: you're saying you wanted to understand light and so you make light collisions.

Jorge: Well, I don't know. Is it possible for light to collide? .

Daniel: That's the question of today's episode you can

Jorge: create a collide, a photon Collider.

So that's the big question we're asking today is can light bump into each other, does light interact

Daniel: with itself because not every particle interact with other particles neutrinos, for example, ignore most of the matter in the universe sliding right by as if it wasn't even there. Each particle each ripple in the quantum field can either see other fields or ignore the other fields.

And it's not like an option. It's not like it depends on its mood. Some of these fields, couple with each other and other fields, just don't couple with each other at

Jorge: all. Well, it's kind of, uh, interesting, cuz I know we've talked about this a lot before, how there are two kinds of particles. There are matter particles, like the stuff that we think of as stuff, and then there are force particles and so a photon is a force particle.

And so the question, I guess maybe a larger [00:11:00] question is. Force particles interact with themselves.

Daniel: It is a really interesting and deep question. Some of the force particles can actually interact directly with themselves and others interact indirectly with themselves. But as we'll learn today, there's several layers of nuance to the answer.

All right,

Jorge: well, we'll get right on it. But as usual, we were wondering how many people had thought about this. Light question. This question of whether light can interact with itself. And so as usual, Daniel went out there into the internet Daniel or to your campus. these

Daniel: are questions from our cadre of internet volunteers.

So thanks very much for everybody who continues to participate and fill my inbox with these really fun answers. I greatly appreciate it. And if you'd like to hear your voice on the podcast, please don't be shy. Write to us two questions@danielandjorge.com.

Jorge: Yeah. So we ask folks, do you think that photo bounce off of each other?

Here's what people had to say since photo

Daniel: do not have electric charge and Maas. I think they do not bounce off each other. I think that photon [00:12:00] should bounce off each other because in physics we learned that photons are particles that act as waves because they have a particle wave kind of duality to them.

So if they're particles, they should be able to bounce off each other. But also at the same time, they're very small. So the rate that they do bounce off each other is so small because it. Very hard to hit two very small particles together. I would think not. I think they'd pass

Jorge: right on by each other. Yes,

Daniel: yes, yes, yes.

Why or how

Jorge: wait,

Daniel: because, oh, maybe they don't. Wait proton, maybe they need

Jorge: neutrons. Do you know what a photon is? Wait a photon. What's

Daniel: a photon. Wait, a photon will need to stick to a

Jorge: proton. What is a photon? Wait, is it two protons?

Daniel: I would say [00:13:00] the photons can bounce off each other because I know my understanding is the photons don't have mass.

but I know the idea of a light sale requires bouncing photons off of them. So it's something about the momentum or energy of a photon can actually impart some momentum into an object. So I would say because of that, photons probably can bounce off each other. shot at each other

Jorge: just right. If I remember

Daniel: rightly you've said on some prior episode, that photons do not bounce off each other,

Jorge: but just pass right through

Daniel: one might think they would bounce off because of their particle nature, but they also

Jorge: have wave nature.

And I guess that's what lets them. Pass right

Daniel: through each other. I don't believe photons can directly interact with each other, uh, being waves as

well

Jorge: as particles. They

Daniel: just [00:14:00] pass

Jorge: through, uh, interfering or not on their way

Daniel: through. Uh, but then continuing

Jorge: on their happy ways. I really

Daniel: don't know. I suppose they could.

I know if they hit hard enough, they'll break

Jorge: into other things. All right. I like that kid's answer. That was pretty funny. yes. Yes, of course. Wait,

Daniel: what? I love hearing people think about it on the fly. They have their initial reaction and then their physics brain engages. And they're like, hold on a second.

Is that really the way this works? Really? They have two brains. I have lots of small brains all wrapped up together into

Jorge: my . Oh boy, that's a weird picture. Like if we open your skull, we wouldn't find a brain. We just find a whole

Daniel: bunch of little brains. Yeah. I'm like 19 little brains in a trench coat. Not actually a full person.

Jorge: Boy, that's a bit disturbing, I guess, you know, you

Daniel: got different parts of your life and so you gotta engage like, oh, I need dad brain or oops, I need husband brain or it's physics brain time.

Jorge: I find that having split personalities [00:15:00] is a bit of a problem. I see.

Daniel: So everybody's always just getting the same cartoon is brain all the time.

Yeah. Everyone's just

Jorge: getting the Hoy brain. There's no menu option. you get what you get. You don't get upset. But yeah, pretty interesting answers here from people. Uh, some people think they, yes, definitely they do. And some people think they definitely don't. And here's an interesting answer because they're waves like can two waves interact with each other.

Yes.

Daniel: Right? No reason. Why not? Like two waves definitely can interact with each other. If you've seen waves in the ocean, you know, they can add up together. They can even cancel each other. So waves can definitely interact with each other. And photons can do that as well. You know, we've seen like the double slit experiment is interference between photons and so waves can definitely interact with each other.

That's not an issue, but I

Jorge: guess in, in water, in the ocean, if you get like a one wave going one way and another wave going the other way, they do sort of mix in the middle, but afterwards they just keep going as if they hadn't interacted. Right? Yeah. The

Daniel: effect that you see is a super position of the two waves.

[00:16:00] So there isn't necessarily direct coupling between the waves, but what you see is the addition of the two waves in that sense, you experience the combination of them, but the individual waves can still be thought of as individual waves.

Jorge: Yeah. But then they keep going as if they hadn't interacted. Right.

Daniel: Mm-hmm yeah, no, that's a good point. They don't interact with each other the way they would interact with, for example, a boundary or a wall where they really would reflect.

Jorge: Yeah. They just sort of ignore each other. I mean, in the moment, if you're standing in the middle, you would experience both waves. And they would add or subtract, but they eventually the ways just keep going.

Right? Yeah. That's true. And so the question is, does it same happen two

Daniel: photons? That is indeed the question of the episode. And what happens when two photons get near each other? Do they ignore each other or do they bounce off each other or do they do something else?

Jorge: Right. Well, let's dig into it, Daniel, I guess.

First of all, what is, um, bouncing off? Actually mean, like what does it mean for one particle to bump into another particle? Do they actually bump?

Daniel: Yeah. So the microscopic view of bumping into things on the dance floor or sitting in your chair or whatever is [00:17:00] not sort of the conceptual view that you might have.

You know, you probably imagined that the reason that you don't pass through a wall is that like the surface of your body is touching the surface of the wall and it's pushing back. Right. But what do we really mean by touching like microscopically zoom in what's happening? Well, you know, the surface of your body is a bunch of atoms and those have electrons around them.

So really the tip of your finger, for example, Is a bunch of electrons and the edge of the wall, the surface of the wall is also a bunch of electrons. And what happens when you push one against the other, the electrons themselves don't have to touch, right? They can repel each other without actually touching.

So this microscopic view of the world from a physics point of view, and there's no actual contact between these particles, it all happens via the fields between them or equivalently, the particles that they're passing between each other. So when your finger pushes against the wall, it's ripples in the electromagnetic field or equivalently photons that are transmitting that information that are pushing [00:18:00] back on you.

Yeah, but

Jorge: I, you know, I think we have, uh, everyone has this intuitive feeling that things touch each other because like my finger has a volume and the table has a volume and that two objects can sort of occupy the same space at the same time. And so if I press my finger against the table, like somehow the universe is resisting my finger being in the same place as the table,

Daniel: but two things can occupy the same place at the same time.

Your body is full of Neu Trinos right now as well. And they're passing right through you and ignoring you. They are taking up your volume. The only reason you perceive a volume, the reason you think there's a boundary between your particles and the other. Is when there's a force between them neutrinos don't feel a force.

So they just TRAs right through the edge of Jorge and then out the other side, no big deal. The reason the table in the chair doesn't is because there's a force that prevents. It's really all about the force. You can imagine things is sort of like with virtual Springs, between them preventing them from getting too [00:19:00] close, but there's no actual contact contact doesn't really mean anything.

All there is, is force between particles,

Jorge: right? I think that's what you were saying is that this idea that my finger can't occupy the same space as the table is really just kind of an illusion, right? Cuz they could, I guess, but something is somehow preventing my cluster of atoms in my finger from somehow.

Being, or, you know, penetrating or infringing upon the volume of the atoms cluster together on the

Daniel: table. Yeah. And I wouldn't say the volume is an illusion. You know, people talk about like atoms being mostly empty space. And I think that's cool to give you the sense that like it's made of tiny particles, but it's also a little bit misleading that space isn't empty.

It's filled with fields or with virtual photons that are zooming around and keeping everything in its position. You can define what your volume is, but that volume, the edge of it is not defined by like the stuff that you're made out of, but the fields from that stuff, the forces of that stuff. And the volume also depends on what [00:20:00] you're touching.

Right? You want to touch a blob of neutrinos, then your volume is different. Then you want to touch something like a table or a chair. Right? So, because the volume depends on the fields and not everything fields, those fields, then the volume is a little bit dependent on what you're touching.

Jorge: Right. I think you're saying that, you know, instead of thinking of our fingers or at the table as collections of stuffy particles, maybe it's better to think of them as like clusters of ripples in the fields of the.

Like my finger is not really a finger. It's just a whole bunch of ripples, kind of tightly clustered together. And so this whole bunch of ripples doesn't wanna just, um, go through the bunch of ripples of the table. There are forces that push my group of ripples against the.

Daniel: Tables group of ripples. That's right.

And I like the sound of the word ripples and yeah, you are made of little matter ripples, right? Your particles you can think of as like little ripples in quantum fields of matter and the way those things stay apart. Again, it's not that they are physically touching [00:21:00] each other, but that they exchange other kinds of ripples.

These force ripples between them. So you can think of yourself. A cloud of these little matter ripples that are maintaining their distance from each other, by passing back and forth, these other little ripples and also maintaining their distance from other things. But there's no microscopic equivalent of touching the surfaces are not like actually coming into contact.

Jorge: Right. But in a way, sort of like my ripples. Like my wave functions of my ripples are touching the wave functions of the other ripples. And so it's, that's kind of like touching, right? They're getting into each

Daniel: other's business. Another way to say it, instead of saying there is no touching is to say, that's exactly what touching is.

That's how touching works. Your experience of touching means these particles are communicating with the other particles, but they don't have to be on top of each other. And this is something that physicists struggle to understand for a long time. They. Spooky action at a distance, cuz we like to think of physics as local, that you only affect things that are right next to you.

You can't like do something here and instantly affects things in aro. So [00:22:00] we like to think of physics is only happening in like a very close vicinity to an object. And so this idea that like an electron could push another electron without actually touching. It was a little bit weird for physicists for a while.

And then they invented this concept of a field that the El. Creates this field around it, which then pushes on other electrons. Right.

Jorge: And like you said, it sort of all depends on which fields you're talking about. Like some fields do interact with each other and some don't like there could be a whole house made out in Tris following on top of me right now, but it'll just keep going.

It won't. Touch or interact with any of my ripples. Exactly.

Daniel: And each particle that's out there has a different set of ways to interact. Like the electronic can interact via photons. It could also interact with the weak force, so it can interact using Ws and interact using Zs, for example. So it's got like two ways to talk to other particles.

It can like speak two different languages. Whereas the quirks, they can speak a third language, right. They can interact via gluons because they feel the strong force. The neutrino only speaks one language, just the weak force. [00:23:00] So depending on which kind of particle you are, you see the universe very differently, right?

Either it's filled with stuff that wants to talk to you, or it's filled with people speaking gobbly book that you can't understand and mostly just

Jorge: ignore. Mm. All right. Well, let's touch on this a little bit more and we'll speak to what some of these forces are up to. But first let's take a quick break.

All right. We're talking about the question of, uh, what's going on in star wars. When, uh, a lightsaber hits another lightsaber. Daniel is the light actually touching itself? Is, is it colliding or, uh, is that actually something that's impossible in the. George Lucas make all that stuff up, then ,

Daniel: you know, he has a huge budget, so I'm sure he did all the R and D necessary to make sure that star wars is realistic, but actually didn't star wars happen a long time ago.

So in principle, all this stuff has already [00:24:00] been developed.

Jorge: Yeah. Well it depends on who the movie's for. You know, like the, the movie could be for aliens who are really far away in which case it will have happened a long time. For

Daniel: them. I see. Wow. I wonder if he wrote that into his contracts, you know, future kinds of revenue from alien galaxies, he was pretty savvy.

I heard I'm

Jorge: sure those contracts say, uh, everywhere in the known universe

Daniel: and some lawyer out there is like, Ooh, what if we discover a new universe? Does this contract extend to merchandise sold and then multiverse

Jorge: yeah, although actually, uh, GICA sold everything. Star wars to Disney. Yeah.

Daniel: That's right. So Disney owns the universe.

That's

Jorge: right. Well, we're talking about whether photons interact with photons, whether light can hit light, I guess, uh, or interact with itself. And so we talked about what it actually means for particles to interact with each other. And it sort of all depends on what fields they're in and how they interact with each other.

One thing I think that's interesting that you said is that sometimes particles don't actually interact with each other, but they have sort of intermediary. Feels [00:25:00] that they talk through like an electron doesn't actually interact with another electron. Exactly.

Daniel: Electrons can interact with a very small number of particles directly.

They can interact with photons, Ws, and Zs, and that's it. Like electrons can only interact with force particles. They can't interact with other matter particles, not directly. Like if you look at the equations of the standard model, we have all of these fields and we say very specifically, which fields can talk to the other fields.

And the electron can only talk to the photon field, the w field, the Z field, and actually also the Higgs field. Wait,

Jorge: are you saying that like an electron can actually be on top of another electron isn't there some sort of. Universe rule that says no to electrons can be in

Daniel: the same place. There certainly is that rule.

And so quantum mechanics prevents that from happening, but that would never happen anyway, because electrons though they can't talk to each other directly, they can talk to each other via the photon. And so the way we build up our description of the universe is we have these little basic building blocks, like what are the simplest things that can [00:26:00] happen?

And then from that, you can build up more complex things. You can say, well, an electron can only talk to a photon, but that means a photon conduct an El. So then you put together this two step process when an electron talks to photon, which passes the information to another electron. So like when the parents are arguing and they interact via the kids, you know, tell your mother that dinner will be ready at 6:00

Jorge: PM.

I don't know what you're talking about. Daniel what, what sort of house are you running

Daniel: there? I mean, I've just seen that in the movies. I've never had an argument with myself. Well,

Jorge: well, tell our agent that, uh, I don't agree with that.

Daniel: all right. And remember that this is like our description of the universe.

We try to boil it down to the simplest set of interactions. And then we can use those to try to describe all the complex phenomena that we see out there. Some of which can be described with just the basic pieces and some of which requires us to put two or three of these pieces together to describe everything

Jorge: that happens.

But it's kind of weird to think that if there wasn't a photon field, then you could have electrons kind of running into each other, kind of right. Occupying the same field in the same [00:27:00] spot. It's pretty

Daniel: hard to think about a universe without a photon field, cuz it would break a lot of our laws. Remember we had this episode about gauge and variance.

You actually need photons around. For electrons to behave properly, to like conserve electric charge and all that stuff. Remember forces aren't everything in physics. They're also just rules of quantum mechanics. Electrons. Can't be in the same state as another electron. And that's not like due to a force.

It's just something electrons don't do.

Jorge: All right. So then all electrons have to go through the photon field to talk to each other. Um, what about things like cos so

Daniel: corks can do the same thing, cos interact with all the same particles that electrons do plus gluons. So if two Coks are approaching each other, they have a lot of different ways to talk to each other.

They can exchange Ws, they can exchange Zs, they can exchange photons or they can exchange those crazy particles, the glue ons. And so again, quirks, don't talk to each other directly, right matter particles never interact directly with matter particles. What they do is they [00:28:00] interact via the fields. They.

Which is equivalent to saying that they interact via these force particle. Again, just to be totally clear, you can imagine like the electromagnetic field that a core generates cause a cork has electric charge, like two thirds or minus one third, and another cork is flying through that field and feels a force.

That's what the field is. Right. Another equivalent way of thinking about it is thinking of that field is a bunch of virtual particles being created by the first cork. Those are two equivalent ways of thinking about particles interacting either via fields or via virtual.

Jorge: Mm, but I guess maybe like a philosophical question is could you have a universe without a photon field or a glue on field and still like, make sense mathematically?

Like, is it just coincidence that somehow horse can talk to each other via the glue on field? Or is it not even possible for. Quirks exist

Daniel: without gluons. I mean, philosophically you can put together all different kinds of universes. You can put together universes with [00:29:00] just quirks in them or with just electrons in them.

Of course you wouldn't get any interesting complex structure. Like everything that we know and love about the universe comes from the fact that these particles do interact and make protons and neutrons and atoms and chemistry and ice cream and all that good stuff. So you wouldn't get anything interesting.

And if you had these fields and they couldn't talk to each other, You couldn't form really any kind of complex structure. Also without these forces, remember these forces exist to preserve symmetries that we observe in nature between these particles. So there are symmetries among the quirks and symmetries among the electron and the other particles that are preserved by these forces.

Check on our episode on gauge symmetry to explain a little bit more, what, I mean, you have to have these forces. If the universe has these symmetries though, we don't know why the universe has these C. So you could in theory, create other universes without these symmetries and without the forces, but they would be pretty boring.

Jorge: yeah, there wouldn't be, there would be any sequels probably. Well, I guess it's sort of a, it's sort of an interesting, philosophical thing to think about. Like, you know, there are [00:30:00] matter particles and those matter, because that's what they make stuff out of. But the force particles, you know, they seem to only be there so that the matter particles can talk to each other.

And so like, are they there just to make the other ones interact or are they there because they have to be there or are they there by

Daniel: coincidence? It is an interesting philosophical question. You know, we observe these things in the universe that doesn't answer the question of why they are there. What we can do is think about like, what other possible universe could you put together?

And then think about why we have this one. And we do see these amazing mathematical symmetries that tell us that the force particles really do compliment the matter particles in this way that they preserve these internal mathematical symmetries. But, you know, you could also have other kinds of universes.

We can imagine other kinds of universes that do follow their own self consistent laws, you know, like universes with just photons in them. Or universes with just glue ons in them. Right? You can imagine those universes, they could exist. You can write down the equations for [00:31:00] them on paper. You can think about them in your mind.

You can do computer simulations that doesn't tell you why we have quirks. So much of what we do in particle physics is just observation. We see this out here in the universe, we try to describe it mathematically. We don't know why it's this universe and not another universe. We just don't know. You're just describing what you see.

We are, we're describing what we see. We're trying to boil it down to as few rules as possible to describe all of the complexity. And then we're trying to look at those rules and say, Hey, does this make sense? Could it have been different? Why is it this way? Not another way. Mostly, we're still pretty clueless about the answers to those questions.

So many things about the. That just don't make any sense and don't seem to have any reason at all. You know, why are there three kinds of electrons? We have no idea. All sorts of interesting questions. All right. Well,

Jorge: the, what seems to be observed is that matter particles don't interact with each other.

They do it through force particles. And so the question is what do force particles interact with? Can they interact with themselves? Like the photon, can the photon interact with itself?

Daniel: So again, not directly, right. A photon [00:32:00] only interact. With particles that have electric charge. So the photon can interact with the electron or the muon or any of the quirks.

It can also interact with the w Bozone, which is not a matter particle. The rule for the photon is that it only interacts directly with particles that have electric charge. Particles like the Z and the Neu Trino. It cannot see, it cannot interact with them. And interestingly, the photon itself doesn't have electric charge.

It's neutral. So the photon cannot directly bump into another

Jorge: photon. Well, okay. So you're saying that a photon can't interact with it itself. Can any particle, can any force particle interact with itself or get any particle in general interact with itself?

Daniel: Actually, yes. Some of them. Like a gluon interacts only with particles that have strong charge color, right?

Like the quirks, for example, and not the electrons, but the glue ons themselves have color. So glue ons can interact with themselves. Do gluons who find each other in the universe can bounce directly off each other without using some other [00:33:00] intermediate particle

Jorge: wait, they can like, they can bounce off, but they don't use an intermediary to bounce off.

They can just

Daniel: bounce off. Luan can talk directly to each other. And that's one of the reasons why the strong force is so strong and so weird, and so much of a pain in the butt to do any calculations with, cuz gluons just, can't stop talking to each other, you know, cos are constantly generating gluons and those gluons talk to each other and the other corks and it's a huge tangled mess.

Photons are much easier cuz once you make them, they don't talk to each other. They can like fly along inside each other and hardly interfere with each other. So gluons are very chatty and that's kind of

Jorge: a pain. Are you saying they're very sticky. That's the problem? they

Daniel: are indeed very sticky.

Absolutely.

Jorge: Are you sure that there's no like hidden particle that they're using to react with it themselves? Like, isn't that weird that like electrons can interact with electrons, but gluons can interact with gluons. It is

Daniel: weird. And the mathematics you need to describe gluons becomes very different from the mathematics.

You need to describe photons and W's disease. And [00:34:00] that's what, another thing that makes a strong force. So weird and so powerful. It's very different kind of particle. Another example is the Higgs boon. The Higgs boon can also interact directly with itself like Higgs boon flying through space can bounce into another Higgs Bo.

Or it can radiate a Higgs boon. It can like pop off one of itself. Whoa.

Jorge: But then, so what's the difference between the Higgs boon and let's say the electron or the photon that ignores itself? Well, the

Daniel: rule is the photon can only interact with particles that have electric charge because that's a photon's job is to preserve electric charge in the universe.

Higgs boon interacts with anything that feels the weak force. And that includes the Higgs boon. The Higgs boon has this weird ability to talk to itself. And then again, this is not something where we understand why it is this way, but if it wasn't this way, the Higgs boon couldn't do its job. We talked on the podcast about the Higgs boon and its relationship to Mexican hats, how it has this weird vacuum energy that gives it the power to apply mass to [00:35:00] particles.

And that comes partially from its interaction with itself. That's what makes the Higgs bows on weird and just the right. Then it can give mass to these particles. So it's, again, not something we totally understand. So

Jorge: I guess you're saying as far as we know the photon can't interact with itself at least directly.

And so that kind of answers the question of the episode, right? Like can't interact with itself

Daniel: directly. Yeah. Directly. Although, you know how we organize these things in our minds doesn't necessarily determine what happens out there in the universe. We have this strategy. Let's make the simplest possible basic ideas and then build everything out of it.

Like the way you might describe the universe in terms of Legos and say, I only need these Lego pieces to describe anything I can build out of Legos that doesn't necessarily limit what you can make out of Legos. And it'll be like artificial to say, what can I make out of only these pieces? Nobody really cares.

Right? What's out there in the universe is all sorts of crazy combinations of those pieces. So while it's true, In our model, two photons can't mump against each other directly. There are [00:36:00] definitely ways for photons to interact indirectly. And we see that in the universe. But

Jorge: I guess just to be clear, like if I take a flashlight and I cross the beam with another flashlight beam, like nothing happens

Daniel: zero, well, two photons don't touch each other directly, but they do have ways.

Passing information against each other. So effectively photons can interact again, not directly. They have to like use an intermediary, like other electrons or other particles, but in the same way that my electrons can't interact with your electrons directly, they do it via photons. My photons can't interact with your photons directly.

They have to do it via

Jorge: electrons. But does that mean that I can just, um, pile photon on top of each other? Photons just be like in the two photons, can they be in the same place at the same

Daniel: time? Photons actually can because they don't follow the same rules as electrons. They have different spin they're integer spin, which means they are boons.

And quantum mechanics says that matter particles Perons cannot be in the same state at the same time, but no rule for like that [00:37:00] exist for boons. So you can pile as many boons as you want on top of each other. And that's why, for example, we've been able to do things like make Boes, Einstein, condensate.

Which is a bunch of boons on top of each other, have the same wave function, macroscopically act like a quantum object. You can do the same thing with photon. You can have as many photons as you want in the same state. That's why I like lasers work. For

Jorge: example. Mm. Yeah. I heard you can stick a bunch of bozos too, in a small cart.

they do that? they do that in some, uh, particle Collider circuses,

Daniel: particle Collider does feel like a circus

Jorge: sometimes. Yeah. it is a ring, right? It's a ring. It's a three ring circus out there in Geneva.

Daniel: We do our best to keep the energy

Jorge: high. So you're saying that futons cannot interact with themselves directly.

What does that mean? Does that mean they can interact in.

Daniel: Yes, they can interact indirectly that the process is a little bit different than electrons interacting. Like when electrons come by, one of them can just radiate a photon, which is absorbed by the other electron and go on its [00:38:00] business. Right.

Doesn't cost anything but energy to radiate a photon. Now imagine the case with photons, two photons are approaching each other. Can. One of them just radiate an electron, which is then absorbed by the other one. Can't actually do that. Because that would violate conservation of electric charge a photon.

Can't just create an electron out of nothing in order to interact with that other electron, it has to do something slightly different. It has to die.

Jorge: yeah. Wait, the light has to die. Yeah.

Daniel: The light has to die in order for it to interact with the other photon. It has to convert into an electron and a Poron.

So the photon doesn't just like emit an electron, which is then absorbed by the other photon. It converts into a new pair of particles, an electron and APO. And then those guys can interact with the second

Jorge: photon. Can they, or does the other photon also have to turn into an, a pair of electron and an anti

Daniel: electron?

No, that electron PostIt pair, they can interact directly with the photon cuz photons can interact with charged particles. And so if you have a photon coming in, it could convert into this [00:39:00] pair, one of which, or both of which can interact then with that photon. And so you can deflect that other photon.

With the first photon, but the first photon doesn't just like emit something, go on its way. It has to kill itself as to transform into an E plus E minus pair. Oh,

Jorge: okay. So let me see if I'm understanding the picture. You have two photons heading towards each other, right? A dart Vader is swinging his lights saver.

Luke Skywalker is, you know, moving to Perry and the one of the photons turns into an electron anti electron pair. And then those. Somehow deflect the other photon that's still alive. Is that what you're saying? Like it can actually bump it. That's

Daniel: exactly what happens because the electronic Tron can interact with the photon when they can absorb the photon or they can deflect the photon.

All sorts of things

Jorge: can happen there. Now this dependent on the first photon doing that split, splitting off into a pair of electron anti electron particles, or is this like a quantum mechanical thing where. [00:40:00] Fullton is always kind of splitting into an, uh, pair of these particles all the time. But with a.

You know,

Daniel: probability. Yes, exactly. A photon. Isn't just a little packet of energy in the photon field, flying through space. It's constantly creating E plus E minus pairs and then going back to being a photon. And sometimes it creates E plus E minus pairs and those things really their own photons, which create more E plus minus pairs.

Which then collapse back. So it's just like buzzing swarm of particles all the time. So what happens when two photons come near each other is that sometimes they pass right through each other and ignore each other. Sometimes one of the photons will interact with one of these E plus E minus pairs that briefly exists.

So it's sort of probabilistic. What happens when two photons come near each other, but the way that they can interact is through the creation of this matter, anti matter pair momentarily. Wait,

Jorge: what? Like sometimes that photon will bump into another photon and sometimes not, or does it always happen, but just a little bit, like, is it quantum in that way or.

[00:41:00] Like does one photon feel a little bit of force or does it only sometimes feel a

Daniel: force? Well, it is an infinite number of possibilities because it's an infinite number of ways that a photon can split into these pairs, which can then split into the pairs. And so technically what happens when a photon passes through another photon is it has an infinite number of possibilities.

So then if you measure that photon, then you're gonna get one of those possibilities. And in principle, one of those possibilities is zero deflection though in practice actually measuring zero deflection is probably impossible because you're measuring things with physical systems. And so you're never gonna get the photon at exactly the angle that it came in at.

Mm,

Jorge: I see you're saying there's always some sort of interaction, but it's quantum mechanical. So there's sort of a probability range of things that can happen. Like if I shoot a photon at another photon, it is gonna bump into each other. Through these split of the particle antiparticle pair. Um, but what actually happens is sort of probabilistic.

Like it can be [00:42:00] deflected a little bit or a lot, or maybe not

Daniel: at all. Exactly. And sometimes crazy things happen. Like sometimes the two photo come together, they both create the E plus E minus pair, two, those that annihilate and like destroy each other. And you end up with just an E plus E minus pair, which comes out.

So it's like two photons come together and then an electron and Tron come. So it's like light gets converted into matter.

Jorge: Wait what? So if I collide two photons, I'm gonna get some bits of matter out of it sometimes. Yeah. Don't those two things annihilate each other also. Instantaneously. Well,

Daniel: you know, there's possibilities for lots of different things to happen, but if they've come in opposing each other and then the electron trying fly out the other direction, then they're not likely to then annihilate each other.

But yeah, that's also a possibility. Whoa.

Jorge: So like if I point my flashlight at another flashlight, stuff is happening, like stuff can happen. The light is gonna bump into the other light. And also I could be creating matter out of my flashlights.

Daniel: Yeah. You are creating matter and anti-matter if you cross the stream, so be careful out there [00:43:00] folks

Jorge: yeah, it sounds kind of dangerous.

little did I know I could have ended the universe as a kid crossing, uh, some

Daniel: flashlights together. The other thing to understand. Is that, you know, we build up this picture of how particles interact using these basic, like tinker toys. You know, this one can talk to this one and then you can chain those things together to make more complex interaction.

The more pieces of the chain you need to use, the less likely it is for things to happen. Because it's like two quantum mechanical things have to happen. Both of which are not that likely. So particles interacting directly is more likely than particles interacting indirectly. If you have to have multiple steps in your chain, it's less and less likely.

So light by light scattering, for example, is less likely. Then light scattering off of electrons, cuz that's more direct.

Jorge: All right. So, uh, it sounds like the answer is actually a little bit complicated.

Daniel: like everything in particle

Jorge: physics. Yeah. And so let's get into how we have actually observed this in experiments and seen light bump into other kinds of light.

[00:44:00] So let's get into that. But first let's take another quick break.

All right. We're talking about, uh, the question of whether photons can bump into each other. Like if I point a flashlight and I crossed its beam with another Flashline what's gonna happen, is it just gonna keep going or is it gonna bump into each other? And it sounds like, like the answer is they're gonna bump into each other, like not directly.

Like the photons can interact with the other photons, but they kind of do through these other quantum mechanical possibilities.

Daniel: Exactly. Everything in your body is a constant swarm of particles turning into other particles. And so if you want to interact with something else, you got sort of lots of options being presented simultaneously.

So the fact that photons don't interact directly with other photons is not really a limitation because they can talk to each other via electrons or via other charged particle.

Jorge: Yeah. I'm not feeling [00:45:00] quite myself today. Is it because of my quantum mechanical nature or me? Just the fact I didn't sleep enough

Daniel: last night.

Well, I thought you said everybody always gets the

Jorge: same Jorge. Yeah. And sometimes that Jorge's sleepy and sometimes less sleepy, but it's still the same Jorge. Maybe

Daniel: we need to put you in the particle beam and charge you up a little bit. Yeah. Yeah. It's my answer to

Jorge: everything. That's what I need a sun tan bed.

I feel like you're telling me that if I take a flashlight and I cross its beam with another flashlight, they're gonna interact with each other. Like the light beam is gonna hit the other light beam and matter can come out or light's gonna get scattered, but that's kind of not my experience. You know, I feel like if you 0.2 flash sticks at each other, like the beam, just go through each other.

Yeah. Mostly

Daniel: that's not your experience because it's pretty rare because it has to have two steps to happen. It's less likely than particles interacting directly. It's also very strongly a function of the energy, the higher energy, the photons, the more likely this is to happen. So photons in the visible spectrum don't actually have that much energy.

And so it's harder for them to [00:46:00] create these E plus E minus pairs because electrons have mass. And so it costs more of their energy to make the E plus E minus pair. So it's less likely for them to happen. So if you wanna see this happen, you need really high energy photons. That's where it's more likely for photons to bounce off each other.

Jorge: Oh, I see. So you're saying when I cross my flashlight beams, they are mostly going through each other, mostly ignoring each other, but they are maybe in a very low scale, like very improbable. There are little photons here and there that are scaring with each other or creating. Matter and anti matter,

Daniel: almost certainly because they're a huge number with a photon.

So even if the probabilities are tiny, one or two photons are probably doing something crazy in those beams, you won't notice it because it's such a tiny fraction and it's impossible and they're drowned out by the other photons, but almost certainly some of those photons are dancing together. Wow.

Jorge: That's pretty cool. It means I can make matter. And anti-matter like in my house, I just take two flashlights and cross the.

Daniel: Yeah, and you're making positrons

Jorge: momentarily. And you're saying like, if they higher the energy, so if I [00:47:00] take x-ray flashlights, then that would, they would interact more.

Daniel: Yeah. X-rays would interact more.

And this is something we've actually done. We've studied this. We have created matter just from colliding light. Though, in order to do it, we need higher energy beams of light than even x-rays can provide. Yeah.

Jorge: These are like real experiments you've done in colliders. So tell us about this. So first of all, how do you make two light beams into matter?

Daniel: So your first thought might be like, let's take two lasers and shoot them at each other and see what happens, right. Or cross them at

Jorge: least. Yeah. Or to light savers, light savers. That would be even cooler. Yeah. That's the

Daniel: closest thing we can do to light savers. Right? The issue is that while lasers are really good at making.

Coherent sources of monochromatic light, you know, photons all with the same phase and all with the same wavelength. They're not actually great at making very high energy photo. Like you can have an intense beam where you got lots of photons per second from lasers, but you can't make photons with a lot of energy per photon, cuz his limitations on the cavity and how you can actually [00:48:00] make lazing happen, which requires, you know, reflections and resonances.

Even x-ray lasers are hard to do. We need things like, well above x-rays. Well above gamma rays like super high energy photons. So the way we do that is not by creating light sources at all, but by going to our colliders and using the photons radiated from the other particles that we're smashing together.

Jorge: So in, uh, to make high energy light, you use colliders, but isn't, it doesn't get scattered all over the place. Like, isn't it hard to like harness that or aim those photons at another source of photo. It is

Daniel: tricky and we don't actually create photons in our colliders, you know, at the LHC, for example, we're colliding protons, right.

But protons have electric charge, which means that they're constantly radiating photons, especially when they're flying really fast and bending. So protons, when the LHC, for example, is surrounded by a swarm of photons, which have really high energy and to get even higher energy, what you need is not a proton, which just.

One [00:49:00] electric charge. You need something with even more electric charge because it'll generate higher energy and higher number of photons. So for that, we don't collide protons. We collide gold or lead nuclei. Like you take gold, you strip off all of the electrons. So now you have something with like a very, very strong, positive charge, and you put that in the Collider instead of protons and you swing those around and they generate huge numbers of photons, which can then smash into each

Jorge: other, meaning they glow like the, the ring glows.

But then how do you, like, how do, how do you focus these so that they, you know, collide with another set of photons? Yeah.

So

Daniel: you can't focus them at all. We do this anyway because we're interested in collisions of heavy nuclei for other things. Cork glue on plasma. And we're gonna do an episode about that soon.

So we already have this program to put gold in the Collider, accelerate it and smash it into other gold particles because that's really cool and fun to do, but sometimes the gold particles, miss each other. So say for [00:50:00] example, you have the gold particle swinging around the Collider and they don't actually smash into each other.

They miss, they call this an ultra peripheral Interac. As they pass by each other, because both of them are surrounded by these glowing swarms of photons. Then those photons smash into each other. So like two gold atoms do a near miss. Then their photon swarms will bang into each other. And that's how you study photon, photon collisions at very high energy.

Mm.

Jorge: You actually like miss the gold particles. And you're hoping that their, their glow, their re respective glow then

Daniel: collides. Yeah, exactly. It's like you have two celebrities moving to a party and their entourages smash into each other, get into

Jorge: a fight. Yeah. That that's what always seems to happen.

Daniel: Right. Exactly. That makes the most exciting videos the next day. Anyway. And so remember, we can't like aim these gold particles. Very precisely. It's just that sometimes we. And then we don't get a gold, gold collision, but Hey, we can look at that and see if we saw a photon photon collision instead. So it's like the [00:51:00] accidents, the mess up from the gold gold physics gives us interesting photon photon physics.

And

Jorge: you can tell that it was two photons crashing into each

Daniel: other. It's a big mess and it's really hard to analyze, but sometimes they do. And in fact, they've seen electrons fly out. Like they've seen these gold atoms, miss each other, and then pairs of electrons and positrons fly out and they've analyzed it.

And they're convinced that this is due to the photons, smashing into each other and creating matter. Wow.

Jorge: Cool. Yeah. Cuz that's the only thing that could explain where these electron pair

Daniel: came from. Exactly. It also has to do with the angles. Like sometimes you get electrons just flying out randomly. And so you could really convince yourself that this is due to the process that you think it is.

Like you understand the quantum mechanics of it. You calculate and say where the probabilities for the electrons to fly out at this angle or that angle. And then you measure a bunch of them and you see them at the angles you expect, and then you can convince. That you haven't been fooled. So this is an experiment.

This is something we've just done last year in 2021, [00:52:00] the star collaboration did this, not the large Hadron Collider, but at Rick and Brookhaven, Rick is R H I C. It stands for the relativistic heavy ion Collider and they specialize in gold collisions and all sorts of other crazy

Jorge: stuff. Now, I guess the question is, do they actually have to use gold or is this just how they roll?

Daniel: You don't have to use gold. It's just sort of awesome. It's funny though, at the LHC on the European side, they tend to use lead. So it's gold on the American side and lead on the European side. And you know, sometimes you smash lead together and gold comes out. You can make gold from lead at the Collider though.

It's not

Jorge: economical. That sounds very American. Like , you know, the Germans are literally like, no let's use lead. Of course that's more practical and the Americans are like, whatever let's use gold.

Daniel: Yeah. You know, I think Rick is on long island and, you know, Maybe they like their glam, you know, they got like their bling out there.

Jorge: What are you saying about long island? There's

Daniel: damn. I think I just said it, you know, they like things shiny and Hey, who doesn't, I'm all into shiny stuff. I think you're saying that's

Jorge: [00:53:00] how Rick rolls

Daniel: I think we all just got Rick rolled. . I'm never gonna let you down. But anyway, at the LHC they do the same kinds of studies where instead they use lead ions and they see interesting things.

They've seen light by light collisions where you get two photons coming out at weird angles. So at Rick they've seen two photons turn into two electrons. And at Atlas, the experiment I work on at the LHC, they've seen photons bounce off each other, deflect each other and go out at weird angles. Whoa.

Jorge: Yeah.

Cuz I guess, so you had these lead particles, miss each other and you saw light coming off with weird, like strange angles. Yeah, I guess. Right. And, but they didn't actually bump with each other. They turned into an electron anti electron pair and then those maybe bumped into each other and then created photons that.

Sped off in weird directions.

Daniel: Exactly. And we can only explain those weird directions using that description you just gave, which is photons interacting with each [00:54:00] other via this weird box of electrons. And positrons so that's pretty cool, cuz it's a rare process. It's hard to reproduce. It's a really good test of like, do we actually understand the quantum mechanics and it's something that was predicted, you know, decades and decades.

Physicists, like in the thirties were thinking about this. They're like, huh, is this possible? I think it might be possible. It would be really hard to do. And it's one of these like open questions that stood for decades. Is this really happening out there in nature? The amazing thing about the standard model is that it seems like an ugly clue sometimes.

Like there's so many things we don't understand and yet it works so well. Every time we go to check it on the details, it's exactly right. It really nails it down to the decimal.

Jorge: Mm. Cool. All right. So that means that you've done that experiment. You've shown two light beams at each other, and you see that light does collide with itself,

Daniel: right?

Mm-hmm although we missed amazing opportunity, we don't have microphones in the Collider, so we can't tell what sound it made when those two photons smashed into each other was like a Z or like a, [00:55:00] or like what sound do light SAS really make

Jorge: can I can't though you're joking or not? Would light actually make sound.

Daniel: No, it all happens in a vacuum, so it wouldn't make sound, but that would

Jorge: be awesome. Oh, geez. Daniel that's the Cardinal sin of star wars is the sound of explosions in space. Now you're trying to tell people that, uh, sounds happen at the large Hadron Collider. Hmm.

Daniel: Statistics. Yeah. Science disinformation right here on the podcast.

But you know, there could have been surprises. It could be that we didn't see it or that the photons came out at even weirder angles, which would mean that maybe the photons interact in different ways from the way we expect, you know, maybe there's some other particle that appears that let's photons talk to each other, like the Axion.

Or something else weird and new that we don't know if it's out there. That's one of these reasons that we do these really high precision cross checks of these little details of particle physics, because it could be in one of those details, we find something weird in that unraveling, that thread is exactly how we [00:56:00] create a whole new understanding of the universe.

You know, that's how we discovered quantum mechanics. Understanding why the photo electric effect wasn't exactly as we expected it to. So we never know which little crosscheck is gonna reveal the right thread to pull

Jorge: on. Cool. Or the right lightsaber to turn on.

Daniel: that makes just the right sound. I

Jorge: guess it's kind of interesting to think now that photons can interact with each other, uh, although not directly does that mean though, though, I have a question of whether all particles end does that mean that all particles can interact with themselves just indirectly.

Like it's, everything's a fair game in the.

Daniel: Yes, everything is fair game in the universe. Photons can interact with themselves indirectly, right? They can generate E plus E minus pairs, which can then interact back

Jorge: with them. Could Narinos like Narinos interact with regular electromagnetic things through these quantum transformations.

Daniel: Absolutely. And neutrino feels the weak force and it can generate a w particle. Right. And that w particle can interact with El. And that's exactly how the neutrino feels the [00:57:00] rest of the universe and a neutrino could indirectly interact with quirks in the same way or other stuff. Um, the only thing we don't know about is dark matter is dark matter, a particle, which forces does it feel?

Does it feel any forces at all, other than gravity dark matter might be out there totally inert, unable to interact with anything except for gravity. As

Jorge: far as we know, we don't know if it's fair game or not, but it could. It could be just be super rare. Maybe it could just

Daniel: be super rare. There could be some other kind of force that dark matter can use to interact with itself.

Like the whole universe could be split into different sectors, this whole group of particles that can talk to each other with forces, the ones we know and love and another separate sector that can only talk to each other and can't interact with us except through gravity. That's possible.

Jorge: What about Milo?

Can they interact with themselves only

Daniel: if they make sound right? Do they scream in space? maybe

Jorge: that's, maybe that's a sound that like savers actually make when they crashing each other. It's it's a billion LOR screaming at the same

Daniel: time. Oh, wow. Now that I understand the true cost of using the [00:58:00] force, I will be more careful about it.

yeah.

Jorge: It's, it's pretty tragic actually. Boy that puts a whole different spin on stars.

Daniel: Isn't it? It really does. Yeah. I wonder is any of this can, do you think, yeah. Cuz you're a physicist, right? Right. Absolutely. Yeah. This is all official now folks.

Jorge: Yeah. Yeah. But the question is can LOR feel, not just forces but

Daniel: feelings?

Well, we'll have to have one on the podcast as a guest and ask it.

Jorge: Yeah. Or, or George Lucas, whichever one will come first. All

Daniel: right, George, give us a call.

Jorge: All right. Well, uh, again, an interesting look into how the universe surprises you, you know, sometimes you think that two things can interact with each other, but through quantum mechanical magic, they sort of do.

and it's almost the same thing as if they were interacting with

Daniel: each other. Yeah. And the universe out there is a crazy swarming quantum mechanical nightmare complexity, but somehow we can pull together these beautiful, simple stories about particles, interacting with each other and use those as Lego bricks to describe all of the amazing [00:59:00] complexity out there, even gold, gold near misses at very high energies.

It's incredible. What physics has been able to do.

Jorge: Yep. So I think this is the part where we thank people for joining us. And this is the part where we join off our lights, savers. thanks for joining us. See you next time.

Daniel: Thanks for listening. And remember that Daniel and Jorge explain the universe is a production of iHeart radio. For more podcast for iHeartRadio visit the iHeartRadio app, apple podcasts, or wherever you listen to your favorite.