WEBVTT

1
00:00:02.970 --> 00:00:08.940
Lisa Kaufman: And just a reminder that if you're going close to the time I'll, I'll interrupt just to tell you, and you have five minutes left.

2
00:00:09.690 --> 00:00:10.710
Lisa Kaufman: Sounds good.

3
00:00:13.380 --> 00:00:26.460
Lindley Winslow: Okay. Well, thank you everybody for being here on this Friday morning, afternoon or wherever your timezone happens to be. I'll be telling you about new fuel is still a beta decay today.

4
00:00:29.580 --> 00:00:33.180
Lindley Winslow: Why is that not advancing one second. I'm going to stop sharing

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00:00:48.060 --> 00:00:51.600
Lindley Winslow: It always stops working just as soon as you have to do it for real.

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00:00:53.820 --> 00:01:07.020
Lindley Winslow: There we go. So back to where we were. So what I'm going to talk about today. First, I'd like to give you the big picture of mutual still decay. Why is this physics. Interesting. Then some details about

7
00:01:08.160 --> 00:01:15.990
Lindley Winslow: The particulars of the double beta decay process, especially I was going to take a little second to talk about nuclear matrix elements which is

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00:01:17.610 --> 00:01:25.500
Lindley Winslow: A place where there's been quite a bit of theoretical advancement. And then finally, I wanted to give you two experimental examples. I understand that. Roxanne Wynette

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00:01:26.100 --> 00:01:33.600
Lindley Winslow: Talk to you a little bit about a TPC earlier in the week and that of course is another experimental technique that's used for you to live elevated. Okay.

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00:01:34.470 --> 00:01:43.050

Lindley Winslow: So let's get going with the big picture. So the big question we're trying to answer is why is there more matter than anti-matter in the universe.

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00:01:44.160 --> 00:01:59.640
Lindley Winslow: And our sort of framework for trying to understand this is the standard model of particle physics and I like to give it the tagline of not complete, but never wrong. And so we're constantly trying to look for something, the standard model doesn't predict correctly.

12
00:02:01.080 --> 00:02:03.120
Lindley Winslow: But, but we just haven't found it yet.

13
00:02:04.170 --> 00:02:14.250
Lindley Winslow: So we know it's has huge holes like generating the Matter, Antimatter asymmetry, but we just haven't quite found the answer to what comes after the standard model.

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00:02:14.790 --> 00:02:24.510
Lindley Winslow: So what's a good place to look. And so one of the energy scales is a particular interest is this so called grand unification scale the guts scale.

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00:02:24.840 --> 00:02:31.800
Lindley Winslow: Where you should have all of the forces that are described by the Standard Model unified it's somewhere around 10 to the 16 GB

16
00:02:32.280 --> 00:02:43.080
Lindley Winslow: So we're not exactly going to start probing it with the ELYSEE, anytime soon. So what we're going to look for is ways to go after physics at this scale that don't require us to actually get particles that these energies.

17
00:02:44.280 --> 00:02:50.040
Lindley Winslow: So where's another good place to sort of poke at the standard model. And the answer is the neutrinos.

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00:02:50.790 --> 00:03:04.680
Lindley Winslow: So you'll notice our neutrinos down here at this corner and you'll notice all the other particles are connected up to this Higgs field and the neutrinos or not. And that's actually a very accurate part of this diagram that it's coming from, from the lab.

19
00:03:05.970 --> 00:03:12.270

Lindley Winslow: And it's going to the fundamental question is, we don't know how the neutrinos get their mass. And that's going to come back again.

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00:03:12.840 --> 00:03:23.880
Lindley Winslow: So what do we know about neutrinos well neutrinos, or for me on they have spin one half, just like their friends. The charge leptons in the corks, they come in three flavors electron you on Intel

21
00:03:24.600 --> 00:03:34.530
Lindley Winslow: They carry no electric charge they carry no strong charge I eat. They don't interact with the electromagnetic or strong interaction. The only interact with the week interaction.

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00:03:34.920 --> 00:03:43.410
Lindley Winslow: And to first order neutrinos or left handed anti-neutrinos or right handed and they have very small masses. And actually, these two things are are related.

23
00:03:44.430 --> 00:03:54.090
Lindley Winslow: And so how small are there masses. Well, if you sort of do a cartoonish plot of the masses of the charge leptons and the corks, you'll notice that you have about six

24
00:03:55.290 --> 00:04:12.720
Lindley Winslow: Orders of magnitude between sorry more than that nine orders of magnitude between the leptons. The charge leptons and the neutrinos. And so the question is why are they so much lighter than the other particles we know the standard model and that that might give us a clue to

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00:04:13.830 --> 00:04:14.820
Lindley Winslow: What's going on.

26
00:04:15.900 --> 00:04:16.230
Okay.

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00:04:17.310 --> 00:04:25.170
Lindley Winslow: So what do we know about neutrino mass. Well, everything we've learned about neutrino mass comes from neutrino oscillation experiments and in these experiments.

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00:04:25.620 --> 00:04:36.810

Lindley Winslow: Since you're looking for this oscillation pattern that goes is delta m squared. All you've extracted is that there are mass differences squared between the mass like and states.

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00:04:38.250 --> 00:04:48.180
Lindley Winslow: For neutrinos. And what you see here is a nice cartoon indicating the flavor composition of each of the mass, I can states 123 that corresponds to the three flavor states.

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00:04:48.690 --> 00:04:59.820
Lindley Winslow: And what you'll see is that you have two options for how to order your mass states, you have the so called normal hierarchy where what we've called an electron neutrino is the

31
00:05:00.540 --> 00:05:07.380
Lindley Winslow: Or sorry, the first mass, I can state or this the smaller delta m squared is mostly sorted with the electron neutrino.

32
00:05:08.490 --> 00:05:15.420
Lindley Winslow: Or you could have the inverted hierarchy where the lighter. The smaller mass different squared is mostly

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00:05:16.380 --> 00:05:28.680
Lindley Winslow: That's associated with the electron neutrinos actually heavier and that's called the normal and the inverted hierarchy, because normal looks like the cork sector with two later once in a heavy one. And the inverted doesn't look like the cork sector.

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00:05:29.310 --> 00:05:33.420
Lindley Winslow: But the neutrinos. Probably don't care about our preferences for what's normal and what's inverted.

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00:05:35.250 --> 00:05:43.890
Lindley Winslow: And so then what you will notice right away is that if we just had delta m squared. We don't know the absolute massive that neutrino and that is a topic for another day.

36
00:05:44.430 --> 00:05:50.640
Lindley Winslow: But that is an active area of research with the catcher and experiment and using new techniques such as project eight actually look at

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00:05:51.390 --> 00:06:02.280

Lindley Winslow: The electromagnetic radiation given off by electrons and tritium decay. So, going on to the topic of this conversation this talk today.

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00:06:03.030 --> 00:06:11.130
Lindley Winslow: There's actually an even more fundamental problem with neutrino mass and that we actually don't know how to put it into the standard model we have two options.

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00:06:11.580 --> 00:06:21.780
Lindley Winslow: Between those could be direct particles like the electron or any of the corks where you have a definitive neutrino and anti-neutrinos they are different particles.

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00:06:22.290 --> 00:06:29.790
Lindley Winslow: Or the neutrino could be a Meijer on a particle where your neutrino and anti-neutrinos are just different felicity states of the same particle

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00:06:30.570 --> 00:06:39.540
Lindley Winslow: And this has an interesting consequences. So those consequences are very nice. We really like my Ronnie neutrinos. And why is that

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00:06:40.050 --> 00:06:44.100
Lindley Winslow: And so that's because there's this whole class of models, called the seesaw mechanism.

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00:06:44.940 --> 00:06:53.820
Lindley Winslow: Where, what happens is a big Myron a mass splits the direct neutrino into two neutrinos. The light neutrino knew that we know and love.

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00:06:54.150 --> 00:07:03.660
Lindley Winslow: And a heavier sister neutrino the capital ends which would have been made in abundance in the early universe and haven't done much since

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00:07:04.260 --> 00:07:24.660
Lindley Winslow: So what is the seesaw mechanism. So let's actually do a little bit of math. The obvious thing to do in the center model is to add a direct mass term were empty is given as you see here, and you end up with your right hand and neutrinos coupling to your left handed anti-neutrinos

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00:07:27.480 --> 00:07:41.460
Lindley Winslow: And so then if you keep going. But because the neutrinos have no charge. There's no reason you can't have a Meijer on a mass term as you see here. And what's interesting about this term is that it no longer conserves leptons number

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00:07:42.660 --> 00:07:50.640
Lindley Winslow: And so, dot, dot, dot, interesting, and I should notice that that this series of slides is coming, based on those of Horus Kaiser from the lab.

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00:07:51.630 --> 00:07:59.460
Lindley Winslow: So if you add both the Marana interact masses to the standard model the grungy, and then you end up

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00:08:00.090 --> 00:08:11.490
Lindley Winslow: With the Lagrangian as you see here, and you can rewrite it in terms of a mass matrix. This is the neutrino mass matrix. Don't get it confused with the flavor matrix that you might have heard about earlier.

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00:08:12.840 --> 00:08:21.450
Lindley Winslow: And so then the next step is to diagonal eyes. This matrix into the neutrinos that we are the physical neutrinos.

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00:08:21.870 --> 00:08:30.270
Lindley Winslow: And then after you do that you end up with the standard model the garage and as you see here where you have your right Panda neutrinos with a

52
00:08:30.930 --> 00:08:40.440
Lindley Winslow: With their own heavy mass, but the light handed the, sorry, the light neutrinos go into the grungy and with their direct masses divided by this heavy mass

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00:08:40.710 --> 00:08:47.310
Lindley Winslow: And so this is the seesaw where the heavy neutrino throws those light neutrinos to light methods.

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00:08:48.000 --> 00:09:01.830
Lindley Winslow: With empty squared over Mr. And so if you set this mass up at the gut scale, you end up with light neutrinos bright about where we find them. And so that is really tantalizing both as it helps us explain the lightness of the neutrino masses.

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00:09:02.400 --> 00:09:10.830
Lindley Winslow: And it gives us a new physics up at that gut scale. So once again, this is the seesaw. The have the

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00:09:12.360 --> 00:09:18.390
Lindley Winslow: The heavy neutrinos and then the light neutrinos getting thrown getting divided by that mass

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00:09:20.220 --> 00:09:27.990
Lindley Winslow: So how does this then get you to the Matter, Antimatter asymmetry, because I told you. Isn't that interesting that the Marana neutrino does not

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00:09:30.150 --> 00:09:35.820
Lindley Winslow: That this mass term does not preserve laptop number. Well, you have the neutrinos that we can

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00:09:37.980 --> 00:09:41.280
Lindley Winslow: That we know about and we can make. And we detected. We do Neutrino Physics with

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00:09:41.880 --> 00:09:51.150
Lindley Winslow: These heavy guys are very heavy, we wouldn't have been able to make them yet at the LLC or anywhere like that, but they will be made in abundance in the Big Bang. And it's the CP violation.

61
00:09:51.780 --> 00:09:58.560
Lindley Winslow: And electron number violation from there to case in the early universe that can be turned into the Matter, Antimatter asymmetry.

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00:09:59.490 --> 00:10:10.290
Lindley Winslow: And then you heard a little bit about something called a sailor on process and through that you can generate the biryani symmetry which is what we actually have right now in the universe. Now,

63
00:10:11.220 --> 00:10:25.110
Lindley Winslow: If we go ahead and detect CP violation and leptons number violation and the light neutrinos, then it would be difficult to construct a theory where the ends, which are the capital ends which are made in the early universe are not also violating

64
00:10:26.100 --> 00:10:38.580
Lindley Winslow: Laptop number and CP. And so that's why we would really like to measure laptop number violation in these light neutrinos and you probably already heard this week about CP violation searches.

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00:10:39.750 --> 00:10:47.460
Lindley Winslow: And so, first with the laptop number violation. You need to generate the laptop asymmetry and then to keep it you need that CP violation.

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00:10:49.620 --> 00:10:59.280
Lindley Winslow: So that is your setup and I hope I convinced you that it'd be really nice to have my Iran neutrinos. So how do we actually find out if neutrinos are Marana

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00:11:00.540 --> 00:11:12.480
Lindley Winslow: And so that is by looking for a process called neutrino list double bass. Okay. And so in this process a nucleus to case the neutrino. If it's a marijuana particle

68
00:11:13.320 --> 00:11:20.760
Lindley Winslow: can effectively be exchanged within the diagram and you have two electrons coming out. You will notice that you have two electrons.

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00:11:21.750 --> 00:11:32.460
Lindley Winslow: Know anti-neutrinos and therefore you have violated laptop number. And so, that in itself will be very exciting. Regardless of the particle physics or the nuclear physics that's going on in this decay.

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00:11:33.990 --> 00:11:44.550
Lindley Winslow: So this is a process that you might be more familiar with, which is playing beta decay, where a neutron turns into a proton rejecting the electronic anti-neutrinos

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00:11:45.570 --> 00:11:51.240
Lindley Winslow: Um, it usually takes place in a much larger nucleus. And so you have the complication of large nuclei.

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00:11:52.320 --> 00:11:58.830
Lindley Winslow: Where you have the number of protons going to see plus one protons ejecting electron and anti neutrino.

73
00:11:59.610 --> 00:12:08.670
Lindley Winslow: So double beta decay is exactly what it sounds like. There are some nuclei, where they can split out to electrons and to me it is at the same number at the same time.

74
00:12:09.660 --> 00:12:20.850
Lindley Winslow: This process is a completely allowed Standard Model process and the change in the electron number is zero. In this case, if the two electrons come out so you can call this neutrino foldable be the case, you would like

75
00:12:21.450 --> 00:12:28.140
Lindley Winslow: Now the process we're interested in is this neutrino less that will beta decay or that light neutrino is exchanged in the diagram.

76
00:12:28.560 --> 00:12:46.890
Lindley Winslow: And known neutrinos come out. So in this case, if you see a decay with these two electrons coming out and no neutrinos than the change in the number of leptons is to you have violated leptons number you have made more matter than anti-matter which is of course very exciting on itself.

77
00:12:48.570 --> 00:12:56.640
Lindley Winslow: So that is what we're up to. That's what we are looking for. And I'd like to stress, just one more time. If you get nothing out of this talk, but this is that

78
00:12:57.060 --> 00:13:06.330
Lindley Winslow: If we see these two electrons come out and know neutrinos. It doesn't really matter what the particle physics is or what the nuclear physics is we have seen something very, very exciting.

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00:13:06.630 --> 00:13:17.430
Lindley Winslow: And the job will be once we see it to actually figure out the details of the nuclear physics and the particle physics that's going on here. But the standard in the field is to talk about this light, light running neutrino exchange.

80
00:13:19.350 --> 00:13:23.220
Lindley Winslow: So going on. So let's take a step back.

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00:13:24.300 --> 00:13:32.190
Lindley Winslow: And talk a little bit about the the sort of the more nuclear physics and some more of the details just obey to care.

82
00:13:32.820 --> 00:13:47.640
Lindley Winslow: So do the energy conservation, you can look through the table of isotopes and find nuclei that can't dictate to their daughter

nucleus in order to decay. They have to skip over their daughter and go to their granddaughter nucleus objecting to electrons at the same

83
00:13:49.140 --> 00:13:55.440
Lindley Winslow: At the at that at that time and you can list it out. There's a handful of isotopes that can do this.

84
00:13:56.940 --> 00:14:06.990
Lindley Winslow: The to Chino process has been known about for a very long time. In fact, the first calculations of it were done by Maria Gilbert mayor in the 30s, with the first versions of

85
00:14:08.010 --> 00:14:13.410
Lindley Winslow: Of her shell model. And sorry, of the Fermi beta decay model.

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00:14:14.460 --> 00:14:18.240
Lindley Winslow: She won her Nobel Prize for the shell model in the early 60s.

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00:14:20.010 --> 00:14:24.810
Lindley Winslow: So then what does this actually look like when you are trying to detect it in your detector.

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00:14:25.200 --> 00:14:32.520
Lindley Winslow: So if you have to neutrino debated K, you end up with a spectrum that looks like a standard don't beta decay spectrum, if you sum up the

89
00:14:32.790 --> 00:14:43.290
Lindley Winslow: Energy of those electrons. And that's because you're losing some energy to the neutrinos in the decay. Now, if you have neutrino less double beta decay.

90
00:14:43.800 --> 00:14:59.550
Lindley Winslow: Which looks like that. You don't have any neutrinos coming out. So the sum of the electron energy has to equal the energy available to the decay, the Q value and this cartoon is a cartoon. This is exaggerated for demonstration purposes.

91
00:15:01.080 --> 00:15:13.680
Lindley Winslow: Now how do we actually go about measuring this so you need to measure an energy. And so you're going to be really looking at sort of if you're coming from sort of more classical collider physics, you're going to look for Cal perimeters

92
00:15:14.820 --> 00:15:23.010
Lindley Winslow: These don't end up looking like how it renders that you're used to. So what's going in to this decay. Well, you're measuring a decay. So you're measuring a half life.

93
00:15:23.670 --> 00:15:32.490
Lindley Winslow: The half life depends on three factors. The first factor is bass, bass factor that's how much energy is basically billable to the electrons as they come out.

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00:15:33.030 --> 00:15:39.870
Lindley Winslow: And you'll notice that a higher endpoint means a faster rate of decay. So we're going to look for the highest energy nuclei that can do double beta

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00:15:42.060 --> 00:15:49.590
Lindley Winslow: The second component will be the nuclear matrix element which will tell you how the nuclear way functions interact in this decay.

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00:15:49.800 --> 00:15:57.030
Lindley Winslow: And this is a difficult calculation and I wanted to take a second to talk about it because there's been quite a bit of progress and understanding, be clear matrix elements recently.

97
00:15:57.990 --> 00:16:11.160
Lindley Winslow: And then finally, the last component of this is the effective my around a mass of the neutrino. And so this is the fact that you are exchanging neutrinos, you get a factor of the mass of the neutrino squared in the back half left

98
00:16:12.660 --> 00:16:27.990
Lindley Winslow: So of course nuclear neutrino mass is complicated. You got that way back at the beginning of the talk. So what is the effective Marana master the neutrino. And so that's what you're seeing up here. This is this m beta beta. And it's equal to the some of the

99
00:16:29.040 --> 00:16:38.250
Lindley Winslow: Mass, I can states weighted by the mixing angles. There is to details a my Iran and neutrino in its phenomenology picks up two phases.

100
00:16:39.780 --> 00:16:50.460

Lindley Winslow: And so the mass is a little bit more complicated than, say, the electron neutrino mass which is just a straight superposition of the mass states and the weighted by the mixing ankles.

101
00:16:51.330 --> 00:16:58.650
Lindley Winslow: And so the classic plot to show for in beta, beta is a plot of the lightest mass, I can state versus and beta beta

102
00:16:59.130 --> 00:17:06.330
Lindley Winslow: This is called the lobster plot because at some point someone plotted the inverted sorry the normal hierarchy and read and it kind of looks like a lobster call

103
00:17:06.810 --> 00:17:12.780
Lindley Winslow: So really, what are these regions. So this top region and green corresponds to the inverted hierarchy.

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00:17:13.440 --> 00:17:21.060
Lindley Winslow: And so once again I told you in the inverted hierarchy. What we've called an electron neutrino is associated with a heavier neutrino.

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00:17:21.660 --> 00:17:29.010
Lindley Winslow: And so if you look on this plot, you'll see that the inverted hierarchy corresponds to this green region that corresponding to a larger and beta beta

106
00:17:29.970 --> 00:17:37.800
Lindley Winslow: Now, if you're in the normal hierarchy, what we call them electronic Chino is associated with the lighter mass lightened states. And so you're down here in this Fred region.

107
00:17:38.370 --> 00:17:49.980
Lindley Winslow: And I had pointed out earlier that a my run a neutrino gains two phases and to the problem is that you're measuring one quantity but you have two parameters. And so there's some real interaction of these phases.

108
00:17:50.310 --> 00:18:03.630
Lindley Winslow: And if the universe is unfair to you. You could get a cancellation of these phases where you end up with very, very small and beta beta, but there's some arguments of probabilistic Lee, that is, it's hard for that cancellation to happen, but not impossible.

109
00:18:05.010 --> 00:18:08.760

Lindley Winslow: And so those are your two reasons normal hierarchy inverted hierarchy.

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00:18:11.760 --> 00:18:17.730
Lindley Winslow: So then there's a little note is if you're beginning to look at more recent reviews and I'll point you to this very nice.

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00:18:18.510 --> 00:18:28.290
Lindley Winslow: Review of Nietzsche list elevated. Okay, there is a movement to start plotting and beta beta versus more physical variables than the lightest nutrient of ass.

112
00:18:28.590 --> 00:18:39.000
Lindley Winslow: And so that's what you see in these two plots and so you can plot it versus the electron neutrino mass and beta which will be measured and experiments like Catrin the very large spectrometer or project eight

113
00:18:39.930 --> 00:18:52.680
Lindley Winslow: Or you can plot it versus the some of the neutrino masses which will be coming out a CSV. I meant to take out BBN there is some interaction in the cosmology, but that's really coming from the C and B as you might have heard about in the previous talk

114
00:18:54.420 --> 00:18:59.550
Lindley Winslow: And so once again though you have the two regions, corresponding to the inverted and normal hierarchy.

115
00:19:00.690 --> 00:19:05.730
Lindley Winslow: And in the infrared hierarchy, what we called an electron neutrino is heavier, and you're in this red region.

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00:19:06.900 --> 00:19:17.580
Lindley Winslow: And if you're in the normal hierarchy, you're in the blue region and in this sort of plotting it's becomes more obvious that there's quite a bit of parameter space overlapping between the normal and the inverted hierarchy.

117
00:19:20.160 --> 00:19:23.550
Lindley Winslow: Yes, I feel like it looks a little bit nicer when you plot it this way.

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00:19:25.440 --> 00:19:27.390
Lindley Winslow: So that is

119
00:19:29.400 --> 00:19:33.420
Lindley Winslow: The phenomenology of the affected my around a mass neutrino.

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00:19:34.560 --> 00:19:40.260
Lindley Winslow: Versus both the lightest neutrino mass and some more physical barriers variables.

121
00:19:40.830 --> 00:19:49.440
Lindley Winslow: So then I just want you to talk a little bit more about the nuclear physics that's going on here because I have a feeling this is one of the few talks where you're going to have quite a bit of nuclear physics of it.

122
00:19:50.130 --> 00:19:55.530
Lindley Winslow: And so it's all going to come in in this nuclear matrix element and here and going to borrow some slides from john angle.

123
00:19:55.980 --> 00:20:06.840
Lindley Winslow: And I will point you to the fact that last week or the week before I get lost in time, there was a nice series of talks really outlining the state of nuclear theory on the matrix elements.

124
00:20:08.010 --> 00:20:10.770
Lindley Winslow: And I'll point you there those talks are still available online.

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00:20:12.210 --> 00:20:18.000
Lindley Winslow: And what I would like to just go through here to give you an idea of sort of where where they are on doing these

126
00:20:18.510 --> 00:20:24.990
Lindley Winslow: nuclear matrix calculations and just for a little cheat sheet if you don't think about these nuclear transmit transitions, all the time.

127
00:20:25.650 --> 00:20:31.950
Lindley Winslow: GT stands for gamma. I'll tell her transition. It means a transition where the total angular momentum change is one

128
00:20:32.310 --> 00:20:38.520
Lindley Winslow: And for me, transition is the total angular momentum change of zero and higher order transitions become more forbidden.

129
00:20:39.390 --> 00:20:53.670
Lindley Winslow: As as the change in England that gets larger and if you would like to, as usual, Wikipedia actually has a very nice article on beta decay transitions. So once again, what we're measuring in double beta decay is the half life. It has the three

130
00:20:54.870 --> 00:20:59.400
Lindley Winslow: Components, the base pay factor the nuclear matrix element and beta beta

131
00:21:00.630 --> 00:21:06.840
Lindley Winslow: The nuclear matrix element has different you can factor it into its different components. The gamma Teller component, the Fermi component

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00:21:07.830 --> 00:21:17.400
Lindley Winslow: And higher order effects and these higher order effects will be from higher order angular momentum transitions and then other various effects from many bottom body body physics.

133
00:21:19.290 --> 00:21:19.890
Lindley Winslow: And beyond

134
00:21:21.540 --> 00:21:31.080
Lindley Winslow: And so then you have different models in which to calculate these nuclear matrix elements and some of the most popular ones are Q our PA and the show model or the IBM

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00:21:31.440 --> 00:21:40.920
Lindley Winslow: Model and you see that you get a range of values depending for all of the isotopes. Some of the isotopes they agree more. Someday agree less

136
00:21:42.090 --> 00:22:00.540
Lindley Winslow: And this is a real theoretical uncertainty, but it's an uncertainty. That's very hard to quantify, because these are very complicated calculations and so from an experiment as an experimental is we kind of take the high end and take the low one and call that the end of the day.

137
00:22:02.070 --> 00:22:18.960
Lindley Winslow: But it would be nice to do more with it. So how do these calculations work. So this is the diagram that we're trying to calculate. If you're talking about nuclear physics theory, you're talking about an

effective field theory where the pion level operators are what's important.

138
00:22:20.940 --> 00:22:30.060
Lindley Winslow: And what is about which what is new is that now we're beginning to use lattice key CD to try to calculate some of the

139
00:22:31.770 --> 00:22:42.840
Lindley Winslow: The more complicated aspects of these calculations and try to understand it that way. So what are we, where do we start from. Well, the starting point is always a mean field approximation.

140
00:22:45.270 --> 00:22:51.870
Lindley Winslow: And then you can expand it with different effects of sort of the squishing of the nucleus, etc. And this is me being very hand wavy here.

141
00:22:52.680 --> 00:23:07.980
Lindley Winslow: And then other methods build on a single independent particle states where you just add them up. So, the ones that are really sort of adding up the single independent particle SKATES ARE QR PA where you're talking about correlation deck cetaceans, as shown in this

142
00:23:09.360 --> 00:23:20.610
Lindley Winslow: Diagram. The other model the shell model once again going all the way back, based on real goober Myers work in the in the in the early part of the last century.

143
00:23:21.660 --> 00:23:28.890
Lindley Winslow: Is quite literally looking at the shelf at the nucleus. And so here you're really using single particle states to model the nucleus.

144
00:23:30.360 --> 00:23:41.400
Lindley Winslow: And so as you could tell these models are very phenomenal logical and will have different parameters, depending on the model that are that are hard to compare from QR PA to say the shell model.

145
00:23:42.420 --> 00:23:49.140
Lindley Winslow: And so what's been really exciting lately in the field is the so called ab initio nuclear calculations.

146
00:23:50.190 --> 00:24:01.410

Lindley Winslow: And once again, also be able to take advantage of lattice QC within these ab initio calculations, where you actually divide up the diagrams until leading order next deleting order you guys get the idea.

147
00:24:02.970 --> 00:24:10.080
Lindley Winslow: And so one of the recent realizations was when you're discussing the usual light neutrino exchange.

148
00:24:10.920 --> 00:24:19.290
Lindley Winslow: Then chanteuse for the three Galliano and his collaborators found that you actually already need to start, including this content point contact interaction.

149
00:24:19.740 --> 00:24:25.980
Lindley Winslow: And so a lot of work is being done. Tap to understand how to put together these avenues of calculations.

150
00:24:26.700 --> 00:24:32.370
Lindley Winslow: And they're really beginning to make some really good progress. And so this is what was reported like last week.

151
00:24:33.330 --> 00:24:43.860
Lindley Winslow: And it's been coming out in the last few years is that these ab initio calculations are really beginning to catch up with some of the more established calculations in the field. And so right now they're able to get up to calcium 48

152
00:24:44.160 --> 00:24:52.740
Lindley Winslow: That is the lightest of the isotopes that we consider usually and they're beginning to work on some of the heavier isotopes. So 132 laurium

153
00:24:53.250 --> 00:25:08.580
Lindley Winslow: xenon 136 etc. And so I hope that gives you an idea of what goes into these nuclear physics calculations. Some of the differences between them. And this of course is a very hand wavy explanation coming from an experimental nuclear physicist.

154
00:25:10.350 --> 00:25:23.070
Lindley Winslow: So I think you should take away that theoretical progress is being made now that that will be the case. Such a important measurement to experimentally. So speaking of that back to experiment.

155
00:25:24.630 --> 00:25:30.480

Lindley Winslow: So how do we go about comparing different experiments sensitivity. So once again, we're measuring a half life.

156
00:25:31.260 --> 00:25:35.640
Lindley Winslow: We have to measure it to some sort of precision and it has a different a couple of different components.

157
00:25:36.120 --> 00:25:44.310
Lindley Winslow: Well, you're going to want something with a high isotopic abundance, because if you have to instrument, a lot of material for not much isotope that's going to get expensive.

158
00:25:44.820 --> 00:25:52.260
Lindley Winslow: So you can list off the isotopes with an endpoint that is high enough that you have a significant rate, you would have a significant rate.

159
00:25:52.590 --> 00:26:07.350
Lindley Winslow: And start seeing what are your abundances. And so you might get really excited about about calcium 48 endpoints at 4.2 and Ed, but then realize that the natural abundance is about point 2% that is not a lot of calcium 48

160
00:26:08.400 --> 00:26:18.780
Lindley Winslow: And then you'll go down this list, and you'll be like, ooh, to learn them 130 at 2.5 and maybe or so and an abundance of 34 and a half percent. That sounds really great

161
00:26:19.560 --> 00:26:37.320
Lindley Winslow: And and you might notice that I actually will tell you about the experiment I work on that uses to Lori a month 30 all of the rest kind of follow in this sort of you know 910 percent range. If you're a particle physicist and they will require enrichment to get to significant masses.

162
00:26:38.550 --> 00:26:40.860
Lindley Winslow: But they all then become about equally.

163
00:26:42.630 --> 00:26:53.310
Lindley Winslow: equally difficult or what have you to make into an experiment. Cool. So then once again isotopic Richmond, the ability to get a large mass

164
00:26:54.330 --> 00:26:57.150
Lindley Winslow: A low background rate so that you're not confusing.

165
00:26:58.590 --> 00:27:07.560
Lindley Winslow: Background events with double beta decay and good energy resolution and the key about this is both to resolve, you know, external backgrounds.

166
00:27:07.890 --> 00:27:23.190
Lindley Winslow: But also you will notice that we're looking for a peek at the end of the two neutrino spectrum. And so you will have an internal background to your experiment naturally from the to neutrino and what you'll hear about a lot of these experiments is they're going from zero background.

167
00:27:25.260 --> 00:27:27.150
Lindley Winslow: In order to get to very long half lives.

168
00:27:28.560 --> 00:27:42.330
Lindley Winslow: So what I'm going to argue for you guys today is that fundamentally, there is a conflict when you're designing these experiments between things that are easy to build very, very large and there forget a lot of math and a lot of opportunity to see the decay.

169
00:27:42.720 --> 00:27:51.750
Lindley Winslow: And things that have very, very good energy resolution so that you're not confused by background external to your detector or even the two neutrino. Great.

170
00:27:53.340 --> 00:28:04.230
Lindley Winslow: And so what's been happening lately in the field. Well, the last decade or more has been spent, focusing on experiments to drip address this claim that was in germanium 76

171
00:28:05.370 --> 00:28:10.590
Lindley Winslow: I think we have addressed that claim and we are now setting limits around 10 to the 26 years

172
00:28:11.250 --> 00:28:28.620
Lindley Winslow: To give you a rough idea to understand the difficulty of the experiments. What is 10 to the 26 years. Well, we talked about things like carbon 14 dating or more elaborate dating techniques like to thorium to 32 dating and you're talking for carbon 14 10,000 years

173
00:28:30.450 --> 00:28:31.800
Lindley Winslow: 10 billion years for

174
00:28:33.840 --> 00:28:39.750
Lindley Winslow: The age of the universe 10 BILLION YEARS TO neutrino debated. Okay, there's a couple different rates, but you're talking about

175
00:28:40.380 --> 00:28:48.480
Lindley Winslow: 10 to the 20 years and the current limits for neutrinos double beta decay around 10 to the 26 years. The only thing that we have measured

176
00:28:49.440 --> 00:28:58.320
Lindley Winslow: Or set limits on that is more rare is proton to K and those limits are up above 10 to the 30 years from the large water shrink detectors.

177
00:28:58.620 --> 00:29:10.020
Lindley Winslow: So you're really talking about very long half life. At this point, many times he age of the universe. And so I tend to the 26 years you're talking about five decays per year per ton of isotope

178
00:29:11.160 --> 00:29:19.080
Lindley Winslow: And so you, you really have an experimental challenge on your hands to build an experiment that cleanliness and have that performance.

179
00:29:20.520 --> 00:29:33.510
Lindley Winslow: So we as a field have really been trying to figure out what is needed for a definitive search over the parameter space corresponding to the inverted hierarchy for neutrino mass and these are the experiments that are are going to be getting started in the next decade.

180
00:29:35.100 --> 00:29:45.330
Lindley Winslow: And we have had unexplored many, many ideas and they range from reusing the large scale liquid simulator and water shrink off detectors to

181
00:29:46.050 --> 00:29:57.270
Lindley Winslow: germanium detectors with my Iran and Garda kilometers with core a some fun wants. This is a candles with this, which is calcium crystals and then some things that look like a very

182
00:29:58.380 --> 00:30:11.640
Lindley Winslow: Specialized but more traditional particle detectors OF THE NEXT OH time sorry XO time production chamber super an email and the next gashes time production chamber.

183
00:30:13.440 --> 00:30:16.140
Lindley Winslow: And you want to again see that you have this

184
00:30:17.610 --> 00:30:24.960
Lindley Winslow: Decision between things that are very, very large. You'll notice for camera and that's a little person sitting there and things that are cold and very precise.

185
00:30:26.880 --> 00:30:35.130
Lindley Winslow: And now we have tried all of them and you then may ask, what did I choose to do since I am and he must obey to a researcher.

186
00:30:35.850 --> 00:30:43.050
Lindley Winslow: And the answer is, I didn't choose because it's still not obvious to me, which you will want to go for and

187
00:30:43.560 --> 00:30:52.170
Lindley Winslow: Is you are looking at the nuclear physics involved, you're going to need to instrument multiple isotopes, and therefore you're actually going to want to have multiple

188
00:30:53.010 --> 00:31:11.400
Lindley Winslow: Technologies that allow you teach men multiple isotopes. And so what you have in my research group and you could do it with a couple of the other technique of technologies is you. I have chosen to do below amateurs, which have very good energy resolution and are rather complicated

189
00:31:12.660 --> 00:31:22.170
Lindley Winslow: Or the very, very simple large scale liquid simulator experiments which are very, very simple, but have very poor energy resolution. And just to give you an idea of the difference between these two.

190
00:31:22.800 --> 00:31:30.570
Lindley Winslow: Campaigns and we measured the energy resolution in percent and for the kilometers. We measure the energy resolution in KD

191
00:31:31.680 --> 00:31:33.570
Lindley Winslow: And that gives you a good idea of what's going on.

192
00:31:34.980 --> 00:31:42.540

Lindley Winslow: So at this point I wanted to sort of dive in to the particulars of this experiment. And so this is Corey.

193
00:31:44.160 --> 00:31:55.890
Lindley Winslow: And its tagline is that it's super cool. And so this is one of the precision experiments, it will give you an idea for what the data looks like coming out of a precision double Vedic experiment.

194
00:31:57.330 --> 00:32:08.490
Lindley Winslow: So it is a kilometer and you're supposed to giggle and in real time in like in the olden days, if you were actually in the room with me, I would have tried to make you laugh about calling Cory super cool.

195
00:32:09.180 --> 00:32:20.400
Lindley Winslow: Because what you do with a kilometer is you take a crystal. You call it down in this case attend to the Kelvin and what you're actually looking for is the heat rise in the crystal due to the deposition of energy from a decay.

196
00:32:21.000 --> 00:32:26.700
Lindley Winslow: And so what you see here in the bottom right corner is an example pulse coming out of Korea and the

197
00:32:27.900 --> 00:32:43.290
Lindley Winslow: Fall time on the crystal is on the order of one second. So these are not fast detectors by any stretch of the imagination, but they are very precise detectors and they get energy resolutions on the order of five K, Ed, which is only equaled by germanium detectors.

198
00:32:45.030 --> 00:33:00.870
Lindley Winslow: For core a we have instrumented to learn them dioxide crystals going back you'll remember that the natural abundance of jewelry on is up a brown 30% so it's very easy to instrument quite a bit of jewelry on 130 by just using natural crystals.

199
00:33:02.760 --> 00:33:10.140
Lindley Winslow: So this is what Cory looks like what you see here on the left is a dilution refrigerator. The heart of the dilution.

200
00:33:10.800 --> 00:33:29.040
Lindley Winslow: The heart of the detector is this one cubic meter of to learn dioxide crystals. It is 988 crystals operated as kilometers and it actually as far as we know, is the coldest cubic meter in the known universe. And there's actually a paper to argue about the title of the coldest cubic meter.

201
00:33:30.390 --> 00:33:31.920
Lindley Winslow: And he will notice that

202
00:33:33.060 --> 00:33:39.210
Lindley Winslow: That getting something down to 10 below Kelvin is quite complicated. You'll also notice that this

203
00:33:39.990 --> 00:33:54.930
Lindley Winslow: This technology of a dilution refrigerator looks a lot like what you will see for superconducting cubits, and that is because it is the same technology. So if someone was going to make a cubic meter of superconducting cubits, they would need the quarry dilution refrigerator.

204
00:33:56.430 --> 00:34:07.020
Lindley Winslow: So here's a picture to give you an idea for scale of the size of the quarry delusion refrigerator and so that is Dr. The chia canonical a commissioning the quarry Christ.

205
00:34:08.670 --> 00:34:13.080
Lindley Winslow: So where are we now, well, we've been taking data since January of 2017

206
00:34:14.490 --> 00:34:18.090
Lindley Winslow: We had a first result back in 20 early 2018

207
00:34:19.200 --> 00:34:27.030
Lindley Winslow: And then it took a little bit to actually make the Christ stack stable for long term running because you were

208
00:34:27.510 --> 00:34:33.690
Lindley Winslow: Measuring such a rare decay. The idea is just to basically park it in the mind and needed there and leave it alone and not touch it.

209
00:34:34.470 --> 00:34:44.460
Lindley Winslow: But you're also dealing with very complex cryogenic to cool down 10 mil Kelvin. So there was quite a bit of work to increase the reliability of the Christ step. And so since about December.

210
00:34:45.630 --> 00:34:53.520
Lindley Winslow: As or December march of 2018 it's been operating very reliably and we've just been steadily taking data.

211
00:34:53.940 --> 00:35:11.490
Lindley Winslow: And so the most recent published data set corresponds to about 370 kilogram years of exposure. You'll notice that we are really getting close to that exciting. A one ton year of exposure and so keep keep an eye out for the next analysis and the near future.

212
00:35:12.960 --> 00:35:24.240
Lindley Winslow: So how does the analysis actually work. So we have these crystals. And so if you have a double Bay decay event, it should stay in one crystal those electrons can't get out of the to learn dioxide

213
00:35:24.690 --> 00:35:32.340
Lindley Winslow: But if you have the background event like say a gamma ray created in uranium authority and the crisis that is going to scatter around from Crystal crystal.

214
00:35:32.610 --> 00:35:41.280
Lindley Winslow: And so it'll happen in multiple crystals. And so it's very easy to quickly get rid of a lot of backgrounds by requiring that the event happening just one crystal.

215
00:35:41.850 --> 00:35:50.670
Lindley Winslow: And then after that you can also look at various qualities of the pulse does it actually look like how we expect an energy deposition to look like in the detector.

216
00:35:51.750 --> 00:35:58.980
Lindley Winslow: And so after you've done that you end up with a spectrum that looks like this. And so this is the full energy range of events that are measured and Cory

217
00:35:59.460 --> 00:36:03.090
Lindley Winslow: I'm just for those that are not used to looking at this sort of data.

218
00:36:03.600 --> 00:36:18.270
Lindley Winslow: The highest naturally occurring gamma ray is it 2.6 me be from tell you to wait and that's that sitting right about there. The spectrum in Korea is dominated by gamma's a below 2.6 MTV and dominated by alphas above 2.6 me TV.

219
00:36:19.080 --> 00:36:27.600
Lindley Winslow: Now what we're going to do is we're going to zoom in here at about 2.52 MIDI the endpoint for to learn 130 and analyze our data.

220
00:36:28.080 --> 00:36:35.430
Lindley Winslow: And so this is the zooming in the region that we actually analyze and you'll notice that with that precision energy resolution, we can really zoom in.

221
00:36:35.970 --> 00:36:44.520
Lindley Winslow: The average energy resolution once again is around seven K TV. And what we do is we do a very simple fit. It's almost a cut and count experiment.

222
00:36:45.510 --> 00:37:02.400
Lindley Winslow: Where we fit the background component and the double beta decay signals and we set a limit. So the average background rate in this region is about zero sorry about one times 10 to the minus two counts per kb per kilogram year

223
00:37:03.630 --> 00:37:10.830
Lindley Winslow: Most of this background is corresponding to those alphas, which had been degraded due to probably be on the surface of the crystals.

224
00:37:12.330 --> 00:37:13.050
Lindley Winslow: And

225
00:37:14.160 --> 00:37:19.680
Lindley Winslow: At the moment, the signal is consistent was just background only we are not measuring access the events there.

226
00:37:20.430 --> 00:37:31.650
Lindley Winslow: At that endpoint. And from that we can set a limit on the neutrino List of beta decay and support currently set a limit of greater than three times 10 to the 25 years for the decay have to learn to

227
00:37:32.010 --> 00:37:39.480
Lindley Winslow: 30 now if we go back and put this on the so called lobster plot of the lightest neutrino mass versus and beta beta

228
00:37:39.840 --> 00:37:48.510
Lindley Winslow: The current quarter, a half life limit corresponds to an end beta beta of 75 to 350 million electron volts. So this TN region here.

229

00:37:49.200 --> 00:37:58.680
Lindley Winslow: And if you'll remember back. I was telling you about those nuclear matrix elements. So the width of this band here corresponds to our uncertainty in the nuclear matrix elements.

230
00:37:58.980 --> 00:38:06.000
Lindley Winslow: So, you know, it's 75 mil electron volts. That's our favorite nuclear matrix element that gives us the best limit on and beta beta

231
00:38:07.050 --> 00:38:08.970
Lindley Winslow: And of course there's ones that are not quite as

232
00:38:10.110 --> 00:38:11.580
Lindley Winslow: favorable for us.

233
00:38:12.600 --> 00:38:16.470
Lindley Winslow: There are of course different experiments using different isotopes. And what you see here.

234
00:38:16.680 --> 00:38:27.810
Lindley Winslow: Is a scattering of the other isotopes that are being used for double beta k research and how we compare and you'll notice that they have a little width to them, too, because once again that nuclear V2 salads.

235
00:38:28.170 --> 00:38:40.530
Lindley Winslow: And we are all sort of beginning to hopefully start touching the top of the inverted hierarchy and so core. I will stop just a little tiny bit into the inverted hierarchy depending of course on your nuclear matrix. I'll

236
00:38:42.510 --> 00:38:49.560
Lindley Winslow: Say that is a precision experiment as far as the electron, the energy business. She goes,

237
00:38:50.730 --> 00:39:00.330
Lindley Winslow: So what is next for Corey. Well, we really would like to get rid of those degraded alphas. And so this is our model of our backgrounds and the detector.

238
00:39:00.630 --> 00:39:15.690
Lindley Winslow: And so you'll see here in blue as a function of energy that we have you want background that becomes a background that's

dominated by gamma rays and beta decays to neutrino and one appeared to kill the crystal.

239
00:39:18.090 --> 00:39:28.980
Lindley Winslow: Then most of the decays of the region of interest are coming from these so called degraded alphas. Now, if you had a way to separate the alphas from the beta, that would be very powerful and reducing your background.

240
00:39:29.400 --> 00:39:39.060
Lindley Winslow: And there's a way to do that if you add a leak detector to your, to your kilometer like detectors are just a secondary builder is made from Romania wafer.

241
00:39:39.870 --> 00:39:45.600
Lindley Winslow: You can measure the light output from a scintillating crystal or the shrink off light in a non scintillating crystal.

242
00:39:45.900 --> 00:39:54.210
Lindley Winslow: And compare that to the thermal measurement of the heat and that's exactly what's in this plot, you have the heat on this axis and the light signal and this axis.

243
00:39:54.600 --> 00:39:58.680
Lindley Winslow: And the beta events and the alpha events are very easily separated

244
00:39:59.190 --> 00:40:06.150
Lindley Winslow: On this experiment that you seen data friend here is so called the Cupid molybdenum demonstrator, and that's because it's using

245
00:40:06.480 --> 00:40:17.670
Lindley Winslow: Lithium eliminate crystals molybdenum 100 is a very interesting isotope for double beta decay and the demonstrators currently running and the same cryostat as the Edelweiss dark matter experiment in the Medan

246
00:40:18.870 --> 00:40:19.320
Lindley Winslow: Lap.

247
00:40:20.760 --> 00:40:35.430
Lindley Winslow: And the data is looking very beautiful. You can see from our spectrum, this blue was actually dominated by the two neutrino decay. The red is the alpha you do your separation and you get rid of all your alpha that's

248
00:40:35.910 --> 00:40:43.800
Lindley Winslow: The other nice thing about molybdenum is that the endpoint is at three, I'm Ed. So you are, above all, of the gamma ray background. And so at the moment.

249
00:40:45.000 --> 00:40:51.960
Lindley Winslow: The data coming from the Cuban mo demonstrator is beautiful and setting some of the best limits for validity of 100 in the world.

250
00:40:53.640 --> 00:41:05.670
Lindley Winslow: And so that is what we're doing. Next we are going to upgrade core a with the molybdenum crystals and like detectors, you know, hopefully that will be starting within the next five years or so.

251
00:41:07.140 --> 00:41:15.570
Lindley Winslow: So now going on the other side, from the very complex detectors to the simplest detector. You could possibly build the liquid simulator I present to you can land.

252
00:41:16.410 --> 00:41:32.640
Lindley Winslow: So Kim Liam. You might know from its days is a reactor neutrino experiment it measured the reactor neutrinos from all the nuclear reactors in Japan, when they were on and prove that neutrinos oscillate by measuring the energy defamation of the neutrino oscillation spectrum.

253
00:41:33.660 --> 00:41:43.080
Lindley Winslow: That detector has now been retrofitted the one kill a ton of liquid simulator now has a smaller balloon. The so called mini balloon suspended from the middle

254
00:41:43.470 --> 00:41:57.360
Lindley Winslow: In the current phase can lens and 800 there's currently 742 kilograms at 90% and bridging on 136 living in this balloon. There were previous phases that instrumented about 400 kilograms.

255
00:41:59.490 --> 00:42:07.410
Lindley Winslow: If you don't know these large liquid simulator detectors, or any simulator detector works by the fact that an electron passes through

256
00:42:07.950 --> 00:42:19.260

Lindley Winslow: And causes vibrations, either in the crystal lattice, or in this case the molecules of the liquid simulator. The D excitation of those particles gives light and you detect that light with photo multiplier today.

257
00:42:20.730 --> 00:42:22.380
Lindley Winslow: It is a very simple mechanism.

258
00:42:23.700 --> 00:42:33.360
Lindley Winslow: And allows you to instrument quite a large volume of liquid with just the surface area of the MTS so it's very economical for a large scale detector.

259
00:42:34.290 --> 00:42:43.380
Lindley Winslow: And so the nice thing about it too is that you can actually reconstruct the position of your events in the detector. And so what you see here is the radial position.

260
00:42:44.190 --> 00:42:52.770
Lindley Winslow: And the Z position in cylindrical coordinates of events and detector. And what you can see here, very nicely is the

261
00:42:53.760 --> 00:43:01.680
Lindley Winslow: The centering a background on that mini balloon because the electric statics of the plastic attracts the daughters of the uranium, thorium shade.

262
00:43:02.220 --> 00:43:09.240
Lindley Winslow: And so since you have the position information, you can look just at a cleaner region in the center of the balloon, which is

263
00:43:10.050 --> 00:43:21.840
Lindley Winslow: Nicely shielded just due to the volume of the detector what's actually done is a much more complicated analysis, which allows you to use all the information which is using 40

264
00:43:22.680 --> 00:43:29.400
Lindley Winslow: Bins in position and simultaneously analyzing the spectra of those to actually get your limit. So it's a little

265
00:43:30.090 --> 00:43:41.190
Lindley Winslow: Not a little it's much more complicated than the core analysis and because of the poor energy resolution. You also need to understand more of your backgrounds and so this fit on the right is

266
00:43:42.120 --> 00:43:54.690
Lindley Winslow: A sampling of what the data looks like here in red, pink is the two neutrino xenon 136 at the end point you would see a

267
00:43:55.800 --> 00:43:56.850
Lindley Winslow: double beta decay.

268
00:43:58.050 --> 00:44:06.660
Lindley Winslow: Signal if it was there. And then you have backgrounds, from things like nuance violation and the daughters of the writing of thorium chain on the mini balloon.

269
00:44:07.680 --> 00:44:16.890
Lindley Winslow: One of the largest backgrounds is the carbon 10 which is made when you knock two electrons off of carbon in a new installation event.

270
00:44:17.370 --> 00:44:27.240
Lindley Winslow: In carbon 10 as a as a rather long half life. It's not easily cut the data that you see there corresponds to cam lens and 400

271
00:44:27.930 --> 00:44:40.980
Lindley Winslow: So that was the previous run of catlin's in and it was able to set a limit of one times 10 to 26 years and so that is as far as half light goes the most stringent limit on double beta decay, regardless of isotope

272
00:44:41.730 --> 00:44:52.170
Lindley Winslow: In the meantime, we were preparing for cam lens and 800 which acquired a bigger balloon. And so I thought, this is thought because it gives you an idea of what it takes to build one of these millennial many balloons.

273
00:44:52.440 --> 00:45:00.180
Lindley Winslow: And the answer is a lot of time watching film and a lot of time welding together that there is pieces to get this spherical shape.

274
00:45:01.980 --> 00:45:06.990
Lindley Winslow: And those are some MIT undergraduates having fun washing plastic for the summer.

275
00:45:08.520 --> 00:45:14.220

Lindley Winslow: We've also in the meantime upgraded the outer water detector, once again, to try to have a better understanding of you on

276
00:45:15.840 --> 00:45:25.110
Lindley Winslow: The ability to be to be one's better. And so what you see here is the outer water shake up detector and what's Kirby down below is a stainless steel sphere where the PMT is our mountain

277
00:45:26.460 --> 00:45:34.590
Lindley Winslow: So what you see now on the left is the camera lens and 400 plot that you saw earlier to now in a rainbow color scheme.

278
00:45:35.040 --> 00:45:49.680
Lindley Winslow: You see the large backgrounds on the balloon and you see the slightly smaller balloon on the right is catlin's and 800 do to better handling of the balloon better monitoring of the environment that the moon was made in you see that there's almost no backgrounds on the balloon.

279
00:45:51.300 --> 00:45:58.590
Lindley Winslow: And except for like a small hotspot down here and we have reduced the backgrounds in the detector by a factor of 10

280
00:45:59.940 --> 00:46:14.010
Lindley Winslow: And what's so cool for me as an experimental list. Is that what dominates in this region now is to neutrino debated. Okay, so something with a half life over 10 to the 20 years is the number one process and center of Camden

281
00:46:17.010 --> 00:46:26.550
Lindley Winslow: So we are in the process of understanding this detector now with the larger volume of xenon, the current run

282
00:46:27.900 --> 00:46:38.280
Lindley Winslow: Has a limit of about four times 10 to the 25 years and we are working to increase the exposure and improve the background rejection to get us up to

283
00:46:40.800 --> 00:46:46.920
Lindley Winslow: Up to a final sensitivity of around five times 10 to the 26 years for this. I'd like to point out some works of

284
00:46:47.940 --> 00:46:50.850
Lindley Winslow: My graduate student Jen gal foo and oboe.

285
00:46:51.960 --> 00:47:02.790
Lindley Winslow: oboe leaf from bu who will be graduating this year that we're also working on a Bayesian analysis of this 40 volume 40 energy spectral fit.

286
00:47:03.600 --> 00:47:11.250
Lindley Winslow: To complement the frequency based approach. And the idea here is to use the Bayesian analysis where it sort of naturally incorporates things like deep learning

287
00:47:11.730 --> 00:47:19.800
Lindley Winslow: And so what's neat about these very large scale liquid simulator experiments is they're basically taking a photo a time lapse photos of the event.

288
00:47:20.250 --> 00:47:25.590
Lindley Winslow: And so what you see here is these time lapse photos of the event. And so for zero new

289
00:47:26.010 --> 00:47:34.920
Lindley Winslow: If you had a perfect detector. You could actually pick out to shrink offerings early in the event before it swamped by the simulation light.

290
00:47:35.340 --> 00:47:46.140
Lindley Winslow: And you actually see a slight difference between the decay type of simulation light from the two electrodes of double beta k and the decay of the simulation light due to the

291
00:47:46.740 --> 00:47:56.610
Lindley Winslow: Decay of carbon 10 which is the mixture of a beta plus plus some gamma's and that gathering at the gamma is around actually leads to a difference. And so these

292
00:47:57.540 --> 00:48:14.370
Lindley Winslow: The machine learning algorithms are actually very powerful to take sort of what we see by AI and to convert it into something that you could include as a prior or, you know, non slightly less fancy way as a cut into the analysis and we're having a lot of fun doing that.

293
00:48:16.200 --> 00:48:32.940
Lindley Winslow: So that was an incredibly quick tour of neutrino list. I will beta k and I was going to stop there and open it up for questions and I see that you guys with some ideas of questions from more

experiments and how they work to how do we move beyond the inverted hierarchy.

294
00:48:34.200 --> 00:48:44.610
Lindley Winslow: And connections to other topics that you have heard about. And you can ask me about the things that are on the first slide so that I will, thank you all and leave it open.

295
00:48:46.890 --> 00:48:53.970
Lisa Kaufman: Excellent. Lisa very nice talk to john will be handling questions and you finished actually few minutes early so plenty of time.

296
00:48:55.410 --> 00:48:57.720
Lindley Winslow: Yes, the problem of being at home and not happy o'clock.

297
00:49:01.110 --> 00:49:05.250
dong su: Thanks very much. So that, yeah, we do have a bunch of questions. So

298
00:49:05.400 --> 00:49:10.950
dong su: Maybe let's get going with that. So on page 13 I'm

299
00:49:12.570 --> 00:49:15.540
dong su: Builders this discussion of

300
00:49:15.900 --> 00:49:16.410
Heavy

301
00:49:20.760 --> 00:49:37.170
dong su: Yes, the, the heavy Cecil neutrino. So the question is, is there just one or why not six or the people considering pairing them up or just why does not pairing up with any one of them.

302
00:49:38.790 --> 00:49:48.180
Lindley Winslow: Yes, so this is being done in mass state which is different than flavor states. So I think there would be there could be a flavor component there too.

303
00:49:48.930 --> 00:50:02.250
Lindley Winslow: If you're asking a more detailed question of whether they're So currently we know have three flavors and I'll go back to our standard model diagram three flavors of light neutrino.

304

00:50:02.310 --> 00:50:03.450
Lindley Winslow: He knew and tell

305
00:50:03.630 --> 00:50:04.770
Whether there's not

306
00:50:05.940 --> 00:50:12.690
Lindley Winslow: He knew Tao alpha, beta, gamma, you know, arbitrarily number of even lightened chinos, the so called sterile neutrinos.

307
00:50:13.380 --> 00:50:24.780
Lindley Winslow: That is a possibility to it adds complexity to the seesaw models, but it's also an interesting question for debate decay. What happens if they are sterile neutrinos. And the answer is, if you add scale neutrinos.

308
00:50:26.100 --> 00:50:26.730
Lindley Winslow: Our

309
00:50:27.930 --> 00:50:37.140
Lindley Winslow: Are, you know, very nice regions of inverted hierarchy and normal hierarchy parameter space become even more diffuse because we're measuring one thing with a lot more

310
00:50:37.140 --> 00:50:47.070
Lindley Winslow: Variables and so we could make a discovery anytime. Now, in any part of that plot which could be very exciting. And in fact, let me get to that plot.

311
00:50:47.580 --> 00:50:49.770
Lindley Winslow: My hope is that we like fine.

312
00:50:49.920 --> 00:51:01.260
Lindley Winslow: A neutrino like right there and then we really get to start talking about more neutrinos and different mechanisms. So that was that probably took to my favorite topic which is alternative mechanisms were elevated again.

313
00:51:02.520 --> 00:51:06.000
dong su: Right. Okay. Thanks. Yes. I think the original question was the

314
00:51:06.330 --> 00:51:11.040
dong su: Why not the re pairing, but with the model car model is just

315
00:51:11.280 --> 00:51:14.550
Lindley Winslow: Using one for the moment. But there are other possibilities.

316
00:51:15.030 --> 00:51:15.420
dong su: So,

317
00:51:16.380 --> 00:51:20.130
dong su: On page 17 again is related to the Cecil model.

318
00:51:22.080 --> 00:51:24.420
dong su: So what is the the mass scale, the energy

319
00:51:24.420 --> 00:51:25.200
dong su: Skill he

320
00:51:25.620 --> 00:51:27.600
dong su: Sees all that heavy

321
00:51:30.060 --> 00:51:33.240
Lindley Winslow: Um, so, since, of course, we've never

322
00:51:34.260 --> 00:51:39.990
Lindley Winslow: Measured or run into one of these capital and neutrinos. You could set this

323
00:51:40.080 --> 00:51:42.390
Lindley Winslow: To any location.

324
00:51:43.410 --> 00:51:47.280
Lindley Winslow: But just sort of naturally set into racket say

325
00:51:47.340 --> 00:51:48.930
Lindley Winslow: You know the mass, the electron

326
00:51:49.200 --> 00:51:53.730
Lindley Winslow: You naturally then put em are at the gut scale at around 10 to the 16

327
00:51:53.730 --> 00:51:59.340

Lindley Winslow: GB. There's a course you know orders of magnitude kind of an either direction because you have a

328
00:52:00.480 --> 00:52:00.900
Lindley Winslow: You know,

329
00:52:01.410 --> 00:52:03.660
Lindley Winslow: You can both set empty and Mr.

330
00:52:04.050 --> 00:52:07.710
Lindley Winslow: But kind of in that range. It's definitely sort of natural at the gut scale.

331
00:52:09.300 --> 00:52:13.620
dong su: Right. So yeah, actually, there's another question related to this is

332
00:52:14.730 --> 00:52:16.140
dong su: Is that whether we

333
00:52:16.380 --> 00:52:17.730
dong su: Tend to think about the

334
00:52:17.820 --> 00:52:24.240
dong su: things we're doing is actually saying whether these neutrinos are Marianna but but you look at the

335
00:52:24.690 --> 00:52:41.370
dong su: Groundlings actually is only the regular ones are actually derived. In this case, it's only the Cecil one is after Marianna. So in that case, are we still talking about the regular routine opium Ariana or, oh, this is actually only the Cecil one in this case.

336
00:52:43.380 --> 00:52:44.760
Lindley Winslow: Um, so

337
00:52:44.790 --> 00:52:54.510
Lindley Winslow: I should say that a my Iran and neutrino can have a mile run the master, but am I run into Fino will have both a direct Anna Myron a master.

338
00:52:55.800 --> 00:53:07.110

Lindley Winslow: And so, so that's my first point. And so then it in order to observe nutrients elevated. Okay, you need to have a Maya Rhonda industry now.

339
00:53:08.610 --> 00:53:14.460
Lindley Winslow: If especially if you're looking at something like lite my Iran and neutrino exchange that that requires my Iran neutrino.

340
00:53:16.140 --> 00:53:17.310
Lindley Winslow: I think, does that answer it.

341
00:53:18.870 --> 00:53:21.810
dong su: Yeah, I think that I think we've done it.

342
00:53:21.870 --> 00:53:28.530
dong su: So maybe let's move on to the next one, which is page 30 open to where we

343
00:53:30.120 --> 00:53:30.450
dong su: Show.

344
00:53:30.510 --> 00:53:31.650
Lindley Winslow: The beta spectrum. I

345
00:53:31.650 --> 00:53:45.000
dong su: Think there's a question maybe explain a little bit of the feature of the spectrum where the peak is and where the endpoint and where are they come from what what determines the shape. Okay.

346
00:53:46.800 --> 00:53:52.530
Lindley Winslow: Okay, so let's just back up one slide, which is the diagram of tutoring and elevate okay

347
00:53:53.070 --> 00:54:05.790
Lindley Winslow: Um, so when you have to tune debate. Okay. The two electrons come out and to neutrinos come out and so all four of those particles are sharing the energy of the decay. So if you are plotting the summed energy

348
00:54:05.910 --> 00:54:09.300
Lindley Winslow: Of the two electrons. Then they have

349
00:54:09.480 --> 00:54:11.040

Lindley Winslow: All the energy, the electrons.

350
00:54:11.250 --> 00:54:13.500
Lindley Winslow: And then there's some energy of the neutrinos.

351
00:54:14.130 --> 00:54:19.500
Lindley Winslow: So if the electrons have taken all of the energy they will be up here at one

352
00:54:19.620 --> 00:54:26.400
Lindley Winslow: They have taken all of the energy all of the key beta beta of the decay. If the neutrinos take all the energy then

353
00:54:26.910 --> 00:54:34.560
Lindley Winslow: He will be down here at zero and everywhere in between is some sharing of the neutrino energy and the electron neutrino.

354
00:54:35.130 --> 00:54:43.440
Lindley Winslow: I should add to this plot sometime the individual energy of the electrons. It's just not as clean and most detectors are not sensitive to the individual energies of the

355
00:54:43.440 --> 00:54:53.940
Lindley Winslow: Electrons. Now in the case where you have neutrino less that will be okay the neutrinos don't come out there they stay within the diagram.

356
00:54:54.180 --> 00:54:56.250
Lindley Winslow: And you just have the two electrons coming out.

357
00:54:56.460 --> 00:55:03.930
Lindley Winslow: So if you are plotting the spectrum, you have the two neutrinos spectrum here.

358
00:55:04.380 --> 00:55:14.580
Lindley Winslow: The total energy of the k is here at one. And so you would just end up with a peak of events where the sun's energy of those two electrons comes out to the total energy of the decay.

359
00:55:15.060 --> 00:55:23.310
Lindley Winslow: So you have to look for that excess of events right there at the total energy of the decay. So nature is kind, and that it told us exactly where to look.

360
00:55:23.670 --> 00:55:29.520
Lindley Winslow: And that's some of the argument for these precision electron measurements is that you can like zoom in right where you expect it to be.

361
00:55:31.320 --> 00:55:34.530
Lindley Winslow: But as I said, there's arguments for the not precise energy measurements do

362
00:55:37.620 --> 00:55:41.880
dong su: Okay, let's move on to the next one is on Cory

363
00:55:43.170 --> 00:55:43.530
dong su: The

364
00:55:45.900 --> 00:55:49.230
dong su: What is the the factors that are influencing the price on the

365
00:55:51.000 --> 00:55:52.380
Lindley Winslow: Crystal size and shape.

366
00:56:01.740 --> 00:56:10.560
Lindley Winslow: That comes down to some details a growing crystals. It is actually pretty. These are very large crystals on the scale of growing crystals.

367
00:56:10.860 --> 00:56:21.030
Lindley Winslow: The only crystals that I have come across that are larger are the crystals that they grew for NIF and that was using NIF is the National Ignition Facility.

368
00:56:21.450 --> 00:56:41.220
Lindley Winslow: That gigantic lasers at Livermore National Lab where they grew crystals that were like a foot across most crystals, you are growing by doing a pulling method you have sort of a bat on the order of you know about a foot wide and a you just pull the crystal out and

369
00:56:41.220 --> 00:56:43.170
Lindley Winslow: So in order to have

370
00:56:44.190 --> 00:56:48.600
Lindley Winslow: That furnace that keeps the crystal material liquid that sort of setting the size of

371
00:56:48.600 --> 00:56:55.620
Lindley Winslow: Things and then you need to pull it slowly so that you don't that you get a pretty crystal, you don't end up with lots of, like, little tiny crystals.

372
00:56:56.970 --> 00:57:07.590
Lindley Winslow: mixed into your bigger crystal because you want that pure you know deform free crystal. And so it's really the size is sort of the largest you can economically grow.

373
00:57:09.750 --> 00:57:18.000
Lindley Winslow: A follow up question, but you didn't ask is what sets the size of them a little lithium elliptic crystals. It turns out, lithium live date is easier to grow.

374
00:57:18.930 --> 00:57:31.980
Lindley Winslow: But the two neutrino rate of molybdenum is much higher. So we're actually having to set the size of those crystals by our, our willingness to have actual pile up of the molybdenum rate.

375
00:57:33.240 --> 00:57:38.700
Lindley Winslow: And that leads to another follow up question on new sensors that would be faster, but we'll, we'll wait for that for another day.

376
00:57:40.350 --> 00:57:40.650
Lindley Winslow: Right.

377
00:57:41.010 --> 00:57:44.910
dong su: Okay, so another question on on Korea's

378
00:57:44.970 --> 00:57:45.480
dong su: Actually

379
00:57:45.750 --> 00:57:48.840
dong su: You mentioned power. You want to know what what do you mean by Pilar.

380
00:57:50.160 --> 00:58:03.630
Lindley Winslow: Oh, I'm so you will notice that these pulses are slow for one about one second. So there is some possibility that you will have two events occurring within that one second. And that's called pile up

381
00:58:05.130 --> 00:58:09.240
Lindley Winslow: in term of course it's also use when you're talking about accelerators piling up

382
00:58:10.080 --> 00:58:18.870
Lindley Winslow: But normally in these little background experiments you don't worry about it but kilometers are so slow that it's an issue. And so then, once again, when you're talking about the molybdenum experiment.

383
00:58:19.590 --> 00:58:27.270
Lindley Winslow: The pile up of the two neutrino rate it to new events, adding up to an event that looks like it's in the region of interest.

384
00:58:28.290 --> 00:58:30.390
Lindley Winslow: Is an issue. And it's a background.

385
00:58:32.070 --> 00:58:32.250
Yeah.

386
00:58:33.570 --> 00:58:34.080
dong su: Okay.

387
00:58:35.250 --> 00:58:43.770
dong su: The next one is also about the query tapes where if the event happened near the edge of the personal

388
00:58:44.070 --> 00:58:45.420
Lindley Winslow: Then what happens is the

389
00:58:45.450 --> 00:58:52.320
dong su: Whole machine doesn't matter. And the whole much of the kinds of the address still usable or a small fraction

390
00:58:54.210 --> 00:58:54.570
dong su: Of that

391
00:58:55.710 --> 00:59:04.950
Lindley Winslow: So, um, so when your instrument to these crystals. There is a dead layer, but you're talking about sort of microns of a dead layer.

392
00:59:05.460 --> 00:59:09.360

Lindley Winslow: Everything else, as far as we can tell, reconstructs the same

393
00:59:10.200 --> 00:59:19.800
Lindley Winslow: So if the alphas are at that surface where the energy doesn't get into the the main part of the crystal, you do see a degradation of their energy

394
00:59:20.190 --> 00:59:30.420
Lindley Winslow: And so that is what's happening. Let me find the spectrum. So these are alpha peaks here. And that is what's happening is that their energy gets degraded into a flat background down here.

395
00:59:32.160 --> 00:59:42.150
Lindley Winslow: So you can see that, but that's happening in the very, very like skin of the crystal. So everything else appears to first order to have the same energy response, but people

396
00:59:42.150 --> 00:59:46.470
Lindley Winslow: Are sort of constantly seeing if we can see some sort of pulse shape discrimination.

397
00:59:46.680 --> 00:59:53.100
Lindley Winslow: From something that came from the middle versus the edge of the crystal, but we haven't been able to see that in these crystals.

398
00:59:55.800 --> 01:00:01.740
dong su: Right. Okay. Thanks. So actually, there are a couple question related to all the

399
01:00:02.940 --> 01:00:10.830
dong su: double beta decay, the Packers us with our manager searches English have some lectures. Next week on that. But there is a one.

400
01:00:12.000 --> 01:00:22.560
dong su: Is interesting thing for both type of experiment is Wayne designed the same detector. How does the, the resolution consideration in the detector designing can be

401
01:00:23.010 --> 01:00:32.400
dong su: You consider both ways for both internal double Bailey K and also consider for dark matter of searches that how much people think of that in terms of defining

402

01:00:34.200 --> 01:00:40.710
Lindley Winslow: So this has been a question in the field for a very long time. And I think you probably would have run into it.

403
01:00:42.180 --> 01:00:43.860
Lindley Winslow: Earlier this week, when you're talking about the

404
01:00:44.160 --> 01:00:45.060
Lindley Winslow: Liquid noble

405
01:00:45.330 --> 01:00:51.510
Lindley Winslow: Detectors with Roxanne gwynedd's talks, since the technology there is

406
01:00:51.540 --> 01:00:52.050
Very

407
01:00:54.360 --> 01:00:56.310
Lindley Winslow: Obviously, LLC and

408
01:01:00.180 --> 01:01:04.530
Lindley Winslow: Sorry, where you have a lot of different physics being done with the liquid

409
01:01:04.530 --> 01:01:05.430
dong su: Novelty PCs.

410
01:01:06.450 --> 01:01:24.450
Lindley Winslow: Inquiry. We are sensitive to dark matter. If we can push our threshold low enough and so dark matter will show up at ke VI like one kV where our neutrino several beta decay is showing up at 2500 kV. And so if you're asking, you know,

411
01:01:24.480 --> 01:01:25.740
What are the trade offs.

412
01:01:26.820 --> 01:01:35.610
Lindley Winslow: Here, you need to optimize everything about the readout chain to give you good energy resolution at 220 500 kV

413
01:01:36.690 --> 01:01:37.590
Lindley Winslow: Versus

414
01:01:39.390 --> 01:01:46.530
Lindley Winslow: When you're talking about one kV you're talking about a different way of triggering the detector.

415
01:01:47.850 --> 01:01:51.570
Lindley Winslow: And, you know, different worries as far as backgrounds go

416
01:01:52.650 --> 01:02:00.180
Lindley Winslow: And so it's an irony at one ke VI, you're actually a little less sensitive to backgrounds and you are at 2500 K

417
01:02:00.180 --> 01:02:07.920
Lindley Winslow: Ed. And so there's all these sort of optimizations that happen as far as the readout chain and the cleanliness and what backgrounds you worry about

418
01:02:09.180 --> 01:02:16.680
Lindley Winslow: That differ between these two. Now, I think, as these experiments get bigger, especially when you're talking about Darwin these

419
01:02:17.700 --> 01:02:20.460
Lindley Winslow: You know, beyond and ton experiments.

420
01:02:22.290 --> 01:02:28.170
Lindley Winslow: The question is really being asked if whether, you know, at that point, the massive z.

421
01:02:29.190 --> 01:02:34.920
Lindley Winslow: xenon is so large that should they be one and there's a lot of work to try to understand

422
01:02:36.060 --> 01:02:36.600
Lindley Winslow: You know,

423
01:02:36.960 --> 01:02:39.450
Lindley Winslow: What it would take to do that.

424
01:02:41.550 --> 01:02:41.940
Okay.

425
01:02:43.020 --> 01:02:52.350

dong su: Right, so the bunch of other question I think it's probably a better deal with them offline. Maybe I'll just do one last one which is kind of interesting.

426
01:02:53.550 --> 01:02:56.880
dong su: Maybe page 27 actually shows that

427
01:02:58.320 --> 01:02:59.400
dong su: So when you say

428
01:03:01.530 --> 01:03:11.970
dong su: What laptop number of violated, I think like site people thinking on your lap on number of violation. But then there is a the immediate question on that is that

429
01:03:13.170 --> 01:03:25.560
dong su: Then how do you assign the laptop. Number four for the neutron which. So which one is the laptop. Number one, which is an apple minus one, given that is Marianna so the

430
01:03:27.030 --> 01:03:28.680
dong su: Laptop numbers in this case.

431
01:03:29.490 --> 01:03:39.930
Lindley Winslow: Right. So it turns out that as soon as you start discussing Myron and neutrinos then leptons number you can no longer

432
01:03:41.340 --> 01:03:43.170
Lindley Winslow: You no longer accounting leptons.

433
01:03:45.600 --> 01:03:46.080
Lindley Winslow: So,

434
01:03:46.110 --> 01:03:50.400
Lindley Winslow: One of the sort of fun asides, is that there are not finding roles.

435
01:03:50.550 --> 01:04:00.690
Lindley Winslow: For my Ron and neutrinos. So think about the five and rules for examining the case, you know, antiparticles going this way particles going that way with the arrows.

436
01:04:01.590 --> 01:04:11.790

Lindley Winslow: So as soon as you do that, then, then things become just much more complicated. And so if leptons numbers violated, it's violated and we have to stop counting leptons. Now, of course, like a lot of quantum

437
01:04:12.600 --> 01:04:14.550
Lindley Winslow: A lot of numbers, a quantum numbers.

438
01:04:15.180 --> 01:04:28.110
Lindley Winslow: They are it is a pretty good symmetry, when you're walking around the universe as a whole, it's just in these very specific places where where you're going to have to throw out counting your leptons any events.

439
01:04:30.990 --> 01:04:31.230
dong su: Yeah.

440
01:04:31.470 --> 01:04:38.400
dong su: Okay, maybe let's the end there. And thanks very much for answering the questions are a few others. I think we will do it. Maybe do the offline version.

441
01:04:39.600 --> 01:04:43.080
Lindley Winslow: Packs. They are okay thank you everybody.

442
01:04:44.280 --> 01:04:54.870
Lisa Kaufman: excellently. Okay. And we've had been or will start our next talk at 11:40am Pacific time. So that's in 15 minutes

443
01:04:56.370 --> 01:04:57.570
Lisa Kaufman: And I'll stop the recording.