WEBVTT

1
00:00:03.659 --> 00:00:15.630
mark convery: And we're very pleased to have our second lecture today, Andre to goopy. A from Northwestern University will be presenting the second lecture in the series on Neutrino theory. So I see Andrea sharing. So please take it away.

2
00:00:16.049 --> 00:00:17.970
Andre de Gouvea: Okay, so can you see my slides.

3
00:00:19.260 --> 00:00:19.560
mark convery: Yeah.

4
00:00:19.980 --> 00:00:21.090
Andre de Gouvea: Okay, good. So

5
00:00:22.560 --> 00:00:30.420
Andre de Gouvea: So thanks everybody for all the great questions. I try to answer some of them in writing. I don't know how you're getting them, but I, I assume you're getting them.

6
00:00:31.470 --> 00:00:47.010
Andre de Gouvea: One thing I wanted to do before I start talking about what I want to start to, you know what, before I start talking on the new stuff. I want to go back a couple of steps because I I talked to very very quickly towards the end of last lecture.

7
00:00:48.030 --> 00:00:55.140
Andre de Gouvea: And there are a couple of things which are important, which I didn't get to say very well. So let me try that again.

8
00:00:56.010 --> 00:01:08.730
Andre de Gouvea: I'll go through this briefly. This came up in some of the questions that people asked. So what we talked about the last time, for the most part was about neutrino oscillations and I talked about neutrino oscillations in the context of a two flavors.

9
00:01:10.170 --> 00:01:20.400
Andre de Gouvea: And I try to argue very quickly that if you look at the neutrino data, the neutrino data can be explained by the SA to flavor models of oscillations.

10
00:01:21.120 --> 00:01:27.150

Andre de Gouvea: And there's nothing wrong with that. It's just a fact. And basically what they tell us is that there's one

11
00:01:28.110 --> 00:01:35.910
Andre de Gouvea: Mass square difference which governs the size of an oscillation lane, which is a hoarder tentative minus four electron volts squared.

12
00:01:36.540 --> 00:01:54.480
Andre de Gouvea: And then there's another delta x squared, which is actually much bigger. It's a harder time than a minus three electron volts square that governs another subset of these in Reno oscillation experiments. And again, all of these analyses were done in the context of the two flavors scenario.

13
00:01:55.500 --> 00:02:06.900
Andre de Gouvea: You are allowed to ask and you should be asking whether everything falls apart. If you go into three flavor oscillation. And the answer is no, because I've already told you that the answer's no.

14
00:02:08.040 --> 00:02:10.620
Andre de Gouvea: And. And the question is, how come that happens.

15
00:02:11.940 --> 00:02:28.980
Andre de Gouvea: And this happens for two different reasons. One reason which is the easiest one to understand is that when you have three flavors you have two independent oscillation links and our data. Want to different oscillation lanes, so that's good. That means we can fit.

16
00:02:30.480 --> 00:02:38.970
Andre de Gouvea: At least that character of the data with three flavors, because we have three different three masses, we can define two differences of masses.

17
00:02:39.630 --> 00:02:46.470
Andre de Gouvea: And what the data also want is that they want one Bell Pam square to be much bigger than the other and magnitude

18
00:02:47.190 --> 00:02:55.710
Andre de Gouvea: What this means is that there will be many experiments that you're going to do. And again remember the oscillation length is inversely proportional to the delta square

19
00:02:56.580 --> 00:03:07.470

Andre de Gouvea: That means that if you set up an experiment that is very sensitive to the small oscillation Lee, chances are that in that experiment, you don't get to see the very long oscillation link.

20
00:03:08.250 --> 00:03:18.960
Andre de Gouvea: So for all of those types of experiments da the to flavor approximation is very natural, because even though you normally have to oscillation frequencies.

21
00:03:19.320 --> 00:03:30.270
Andre de Gouvea: If you're doing a an experiment with a relatively short baseline. You only get to see one of these delta him squares. So that's one of the reasons why the two flavor approximations work very well.

22
00:03:30.900 --> 00:03:40.590
Andre de Gouvea: The other one also is a parametric reason, you know, again, the reason the statement is true is because one delta x squared is way bigger than the other.

23
00:03:41.880 --> 00:03:50.070
Andre de Gouvea: The or the other reason turns out to be that there is one mixing angle that happens to be small. That means that when you do experiments.

24
00:03:50.610 --> 00:03:58.920
Andre de Gouvea: Involving electrons. That's the consequence of that, it turns out that for experiments involving electrons, for the most part.

25
00:03:59.310 --> 00:04:11.430
Andre de Gouvea: The electrons only participate in a subset of the oscillations. It says if the electron doesn't know about one of the mass states because the associated mixing angle happens to be small.

26
00:04:12.480 --> 00:04:21.600
Andre de Gouvea: And this is a easy to see in this picture here, and I'm going to talk about this picture in just a second. Again, but basically if you concentrate, for example, on the

27
00:04:21.990 --> 00:04:26.640
Andre de Gouvea: On the pattern on the left hand side and you also concentrate in the colors.

28
00:04:27.420 --> 00:04:36.270

Andre de Gouvea: It basically means that if you only care about electron neutrinos, the electronic Reno, for the most part only cares about mass state number one into

29
00:04:36.900 --> 00:04:45.780
Andre de Gouvea: The fraction of electronic Trina and state number three is very small. So if you're doing a gross measurement you know that that doesn't have a lot of precision and

30
00:04:46.140 --> 00:04:53.730
Andre de Gouvea: It turns out that you only get to see in many quotes the one in two states. So it looks like a to flavor approximation works very well.

31
00:04:54.630 --> 00:05:01.110
Andre de Gouvea: If it had turned out that this other mixing angle. It's called data when three at also be enlarge

32
00:05:01.680 --> 00:05:10.440
Andre de Gouvea: Then three flavor effects would have impacted. For example, the to flavor approximation to the solo neutrino puzzle.

33
00:05:11.220 --> 00:05:17.460
Andre de Gouvea: In a much more interesting and non trivial way but because this data when three mixing NGO happens to be small.

34
00:05:18.210 --> 00:05:24.060
Andre de Gouvea: Everything that we learned from the to flavor approximation carries very well into three flavor approximation.

35
00:05:25.020 --> 00:05:32.130
Andre de Gouvea: Okay. So this slide is where we stopped the last time I described what is some of the stuff that we haven't measured yet.

36
00:05:32.580 --> 00:05:39.150
Andre de Gouvea: And one thing which I also forgot to measure is that there's a comment at the very bottom of the slide. And it's sort of a reminder

37
00:05:39.540 --> 00:05:46.590
Andre de Gouvea: That this sign Makino oscillation picture again in particle physics time units is pretty recent and

38
00:05:47.250 --> 00:05:58.980

Andre de Gouvea: Even though we have been accumulating data and the data seem to agree with this picture that I'm trying to sell to you. It's not clear to us at the picture is actually correct or not.

39
00:05:59.580 --> 00:06:10.110
Andre de Gouvea: So one of the main reasons for doing isolation experiments is not just to measure a whole book bunch of neutrino oscillation parameters that we haven't gotten to yet.

40
00:06:10.710 --> 00:06:20.340
Andre de Gouvea: But most importantly, one thing we're trying to do is to see if we can get enough measurements to to perform. If you want a stress tests on the model.

41
00:06:20.850 --> 00:06:27.030
Andre de Gouvea: So we have a nice model you know neutrinos have weakened through actions McQueen's have masses neutrinos mix.

42
00:06:27.570 --> 00:06:36.150
Andre de Gouvea: But the question you're supposed to be asking yourself is, is that actually the right answer is there are some ingredient that's missing that we haven't taken into account, yet.

43
00:06:36.660 --> 00:06:46.500
Andre de Gouvea: And I think it's always important to pause and and ask, you know, how much data do we really have and how many non trivial assumptions have we tested.

44
00:06:47.010 --> 00:06:53.520
Andre de Gouvea: Before we jump in and say that we totally understand what's going on in the reno sector. So, so basically the

45
00:06:53.970 --> 00:07:03.660
Andre de Gouvea: The opportunity that we're buying ourselves with next generation Aquino experiments. It's not just to measure a bunch of parameters, but also to ask if the picture that we've drawn is the correct picture.

46
00:07:04.920 --> 00:07:10.500
Andre de Gouvea: So let me talk briefly about how do we plan to measure some of the stuff that we haven't mentioned yet.

47
00:07:11.070 --> 00:07:24.000
Andre de Gouvea: And one thing which I said is we don't know the neutrino mass hierarchy or the neutrino mass ordering. It's a simple question. You

know, the neutrino masses are either ordered as in the left hand side, or they're ordered as in the right hand side.

48
00:07:25.140 --> 00:07:33.420
Andre de Gouvea: Clearly, only one of those two pictures is correct. I like to emphasize this. Sometimes we get so accustomed to looking at this picture.

49
00:07:33.870 --> 00:07:44.490
Andre de Gouvea: But, but this is an old picture. It's either one or the other. And I want to emphasize, of course, that these pictures are very, very different and I already said this.

50
00:07:45.360 --> 00:07:55.080
Andre de Gouvea: On the picture on the left hand side. If the lightest mass is very small then the masses can be hierarchical as in one is much less than the other.

51
00:07:55.410 --> 00:08:05.820
Andre de Gouvea: Which is much less than the other one. But in the so called inverted hierarchy, it is guaranteed for us that at least to have been a prenup masses are almost exactly the same.

52
00:08:06.390 --> 00:08:19.440
Andre de Gouvea: So even in the inverted mass ordering, even if M three is equal to zero. The difference between one and two is really small relative to the size of the mass itself. It's at the percent level.

53
00:08:20.790 --> 00:08:25.830
Andre de Gouvea: So we want to know what the right picture is and I will very briefly, try to

54
00:08:27.930 --> 00:08:36.030
Andre de Gouvea: convince you, how come we don't know what the right picture is yet. And the reason is related to what I started talking about today, which is the fact that

55
00:08:36.360 --> 00:08:46.020
Andre de Gouvea: For all practical purposes, almost all experiments we've ever done only get to see one oscillation. The either see the the short

56
00:08:46.740 --> 00:08:59.430
Andre de Gouvea: Wavelength oscillation, because the baseline is not long enough, or they only get to see the small delta x squared, because the experiment only cares about electrons. So for example, if we look at

57
00:08:59.880 --> 00:09:16.050
Andre de Gouvea: You know this delta x squared one three parameter. And one of the mixing angles called data, two, three, we learn about that one from new mute disappearance and new disappearance experiments what they've roughly measure is an oscillation probability that you can write like this.

58
00:09:17.070 --> 00:09:22.860
Andre de Gouvea: It's a new mule going to new new oscillation and it has a dominant term.

59
00:09:24.000 --> 00:09:25.560
Andre de Gouvea: Which has a very big amplitude

60
00:09:27.090 --> 00:09:35.040
Andre de Gouvea: And if you're doing an experiment again where the baseline is such that this awesome authority phase here is a harder one.

61
00:09:35.430 --> 00:09:42.990
Andre de Gouvea: Then you have a bunch of other terms which are really sub leading. They're very, very tiny. And you'll notice that if you stare at this picture.

62
00:09:43.470 --> 00:09:49.200
Andre de Gouvea: Oh, and one thing. And let me remind you that in the language that I introduced the last time.

63
00:09:49.950 --> 00:09:56.700
Andre de Gouvea: The Thurman in the neutrino mass ordering is the same as the third, meaning the sign of delta x squared, one, three,

64
00:09:57.240 --> 00:10:04.950
Andre de Gouvea: And the sign here means plus or minus, you know, is dealt them squared, one, three, a positive number, or as delta x squared, one, three and negative number.

65
00:10:05.400 --> 00:10:12.630
Andre de Gouvea: And the normal ordering em three squared minus one squared is a positive number in the inverted ordering

66
00:10:13.020 --> 00:10:19.710

Andre de Gouvea: You know em one squared minus three squared is a positive number. So, M three squared minus one squared is negative number.

67
00:10:20.610 --> 00:10:28.080
Andre de Gouvea: So the, the physics observable is is this belt M squared, three, one, a positive number or a negative number.

68
00:10:28.770 --> 00:10:39.090
Andre de Gouvea: If you stare at this oscillation expression here, it's very clear that regardless of whether this is a positive number or a negative number. You always get the same answer in order to be able to

69
00:10:39.660 --> 00:10:51.300
Andre de Gouvea: Disentangle whether this numbers, positive or negative, you really would have to rely on these sub leading terms. There's one exception to that which is what happens if you have matter effects.

70
00:10:52.290 --> 00:10:58.320
Andre de Gouvea: Let's say you have matter effects and then you calculate the new move to New we oscillation probably

71
00:10:58.890 --> 00:11:05.970
Andre de Gouvea: Actually let me back up one, let's say that we're doing this experiment in vacuum. If I'm calculating new mutiny. We oscillations.

72
00:11:06.450 --> 00:11:19.140
Andre de Gouvea: To leading order and here the leading order is not so leading anymore. But let's forget about that the leading order, you have an expression that looks like this. And of course, you notice that if I change the sign of delta m squared, one, three,

73
00:11:20.250 --> 00:11:34.620
Andre de Gouvea: The probability is also invariant. That means if I don't you move to New V isolation measurements. I can't tell the mass ordering either again here's one place where the sub leading terms are not so small, but let's not get into that.

74
00:11:35.970 --> 00:11:45.870
Andre de Gouvea: If I include. Matter of fact, however, and if I neglect delta m squared one two effects, which is often a good approximation certainly to understand the physics.

75
00:11:46.260 --> 00:11:52.410

Andre de Gouvea: Then my oscillation probability has a different character. It looks like this expression here on top.

76
00:11:53.220 --> 00:12:03.840
Andre de Gouvea: And this resembles the expression that we get for doing oscillations in constant matter in the two flavor approximation that I talked about before. So here it looks the same.

77
00:12:04.560 --> 00:12:13.380
Andre de Gouvea: And the key point here is, again, you have a matter modified oscillation frequency and you have a model matter modified oscillation amplitude

78
00:12:14.070 --> 00:12:30.990
Andre de Gouvea: And again, the key point is that the way in which the matter potential a modifies the isolation probability is proportional to this combination here which goes like delta x squared one three cosine to data on three divided by two, he minus this matter potential

79
00:12:32.280 --> 00:12:39.540
Andre de Gouvea: We know that this data on three is a very small number. So let's forget about this co sign up to theta when three. That's about that's close to one.

80
00:12:40.080 --> 00:12:57.240
Andre de Gouvea: And you notice that this frequency here, the fans on whether delta m squared one, three and a half the same plus or minus sign or whether they have opposite plus or minus signs, which is great because we know the sign of a

81
00:12:58.440 --> 00:13:04.920
Andre de Gouvea: And if we want to determine the sign of delta m squared, one, three, we just have to check whether

82
00:13:06.870 --> 00:13:14.550
Andre de Gouvea: Whether the frequency gets shorter or longer for neutrinos any empty neutrinos. So again, I showed you this picture before

83
00:13:15.150 --> 00:13:23.430
Andre de Gouvea: The idea is that, you know, here you know the the blue curve, for example, would correspond to delta m squared one three positive sign

84
00:13:23.940 --> 00:13:29.880

Andre de Gouvea: And the dotted black curve would correspond to a belt M squared, one, three, having a negative sign.

85
00:13:30.630 --> 00:13:36.420
Andre de Gouvea: Again, we can do even better than that because we can do an experiment with neutrinos and anti neutrinos.

86
00:13:36.810 --> 00:13:48.750
Andre de Gouvea: And the key point is that the matter effects will make the maximum amplitude for one be bigger than the maximum amplitude for the other or vice versa. And that's how we believe we can see

87
00:13:49.830 --> 00:13:53.670
Andre de Gouvea: The mass ordering by using matter effects now.

88
00:13:54.930 --> 00:14:02.820
Andre de Gouvea: It's fun to ask whether this measurement is doable and what conditions, you need to satisfy, you know, in order for this measurement to be doable.

89
00:14:03.330 --> 00:14:11.280
Andre de Gouvea: And there's a bunch of things you need one is that you need to have three to not be zero. You don't want your matter potential to be gigantic

90
00:14:11.730 --> 00:14:19.710
Andre de Gouvea: Because if the matter, but the intro is gigantic can actually have some funny effects to make the mixing angle, very small. And you also need a baseline that's long enough.

91
00:14:20.460 --> 00:14:27.270
Andre de Gouvea: There's a fun feature of this blocks which you can figure out by staring at this expression that at at small l

92
00:14:27.810 --> 00:14:36.480
Andre de Gouvea: On the matter of fact don't don't matter. They kind of cancel out and it's fun to ask why. But that's one way that we think we're going to see the matter of facts.

93
00:14:36.960 --> 00:14:45.720
Andre de Gouvea: Life is a little bit harder because of CP violation CP violation gets in the way. Because, effectively what you're doing is you're asking whether

94

00:14:46.650 --> 00:14:57.210
Andre de Gouvea: neutrino oscillations get enhanced relative to ante up new oscillations and depending on which one is enhanced by the matter of fact, the mass ordering is one way or the other.

95
00:14:59.040 --> 00:15:09.750
Andre de Gouvea: Unfortunately CP violation does something similar. It also makes neutrino oscillations have a larger amplitude and anti lucchino oscillations. So you need enough data to disentangle all of now.

96
00:15:10.980 --> 00:15:20.910
Andre de Gouvea: The last thing, which I'll say about this is a, you can ask what do the matter effects do that allow you to tell one mass hierarchy from the other

97
00:15:21.240 --> 00:15:30.510
Andre de Gouvea: And and in hand wavy terms with the matter effects do is that they really like the electronic neutrino. They can tell the electron flavor from the other flavors.

98
00:15:31.020 --> 00:15:42.570
Andre de Gouvea: And basically they care about whether the electron flavor in quotes is mostly heavier mostly light. And if you look at this picture here for the normal ordering

99
00:15:43.770 --> 00:15:55.170
Andre de Gouvea: The electronic flavors mostly on the lighter states and for the inverted ordering the electronic flavors mostly on the heavy states. And that's what the matter effects know how to do.

100
00:15:56.340 --> 00:15:58.170
Andre de Gouvea: Okay, so enough about that.

101
00:15:59.760 --> 00:16:07.470
Andre de Gouvea: I want to say a few words about CP violation. I don't want to spend too much time on explaining why CP violation is sort of a big deal.

102
00:16:08.190 --> 00:16:21.600
Andre de Gouvea: But it is, it's a funny phenomenon. It's something that we took a long time to figure out was even possible. And it's one of the features of the standard model with three generations that CP violation is possible.

103
00:16:22.620 --> 00:16:31.170

Andre de Gouvea: And of course you know CPU violation in the corporate sector is an old subject, we've been measuring it for a long time and all of it is explained by a phase in the

104
00:16:31.650 --> 00:16:38.940
Andre de Gouvea: Matrix, which is the equivalent of the neutrino mixing matrix, but in the corporate sector. Now that neutrinos have mass

105
00:16:39.570 --> 00:16:48.660
Andre de Gouvea: And because there was also three of them at least we know that there are also CP highlighting parameters in this neutrino mass matrix.

106
00:16:49.290 --> 00:16:59.610
Andre de Gouvea: So it's a new opportunity we have to see a new manifestation of CP violation in a way that we are completely sure has nothing to do with the CK matrix.

107
00:17:00.030 --> 00:17:05.520
Andre de Gouvea: Or if you turn the picture around if you found out that the amount of CP violation and the cork sector.

108
00:17:05.970 --> 00:17:18.150
Andre de Gouvea: And the amount of CPU violation and the leptons sector, whatever that means, if you found out that those parameters are the same, that would kind of be a miracle. And that would probably require some very interesting explanation.

109
00:17:19.260 --> 00:17:25.410
Andre de Gouvea: So I'm going to skip this. I want to give you a flavor of how CP violation works in between oscillations.

110
00:17:26.070 --> 00:17:32.430
Andre de Gouvea: If you wanted a calculates a new mutiny. We oscillations following the recipe that I talked about yesterday.

111
00:17:33.420 --> 00:17:46.650
Andre de Gouvea: You would get an amplitude that has a form that looks like this, the amplitude is the thing that you need to square to calculate the probability. And if you're calculating say new new to new we you would get an expression that looks like this.

112
00:17:47.970 --> 00:17:56.700

Andre de Gouvea: If you do the same thing for new Mubarak to new rebar. The only thing that changes is that the elements of the mixing matrix or the couplings.

113
00:17:57.330 --> 00:18:07.680
Andre de Gouvea: They get complex conjugated. So we have this amplitude for neutrino oscillations. We have this other amplitude for anti neutrino oscillations. So it's fair to ask

114
00:18:08.880 --> 00:18:16.770
Andre de Gouvea: Can those amplitude square be different numbers. And if the answer is yes, then you've measured CP violation in the sense that

115
00:18:17.250 --> 00:18:24.990
Andre de Gouvea: Neutrinos and anti neutrinos. We're doing different things and but it is possible that those amplitude squares, even though they look different.

116
00:18:25.830 --> 00:18:39.510
Andre de Gouvea: It is possible that those numbers end up being exactly the same. And if you stare at this you can identify circumstances where those too complex numbers square give you exactly the same answer.

117
00:18:40.590 --> 00:18:48.030
Andre de Gouvea: The most dangerous circumstance, as far as, you know, there's two things we care about. One is, notice that if one of the you elements were zero

118
00:18:48.600 --> 00:19:05.520
Andre de Gouvea: Then your amplitude would not be the sum of two terms, it would only have one term, let's say it only had this one and then this one would only have that term. And you can convince yourself that those two amplitude squared have exactly the same magnitude. They are exactly the same number.

119
00:19:06.780 --> 00:19:15.240
Andre de Gouvea: So you need to have those two different contributions to the amplitude. This is not a surprise you know CP violation is often

120
00:19:15.690 --> 00:19:26.190
Andre de Gouvea: Associated with different contributions to the amplitude of a process and the fact that you need to have them interfered with one another in the complex number sense

121
00:19:26.790 --> 00:19:38.370

Andre de Gouvea: And the other thing which is very important here is that this side, either the Delta terms. This is the kinematics per therm. This is a term that will give you this assigned squares of delta x squared L. O. V.

122
00:19:39.690 --> 00:19:49.200
Andre de Gouvea: And the key point is that if this term here is also zero. Then again, you only have one amplitude contributing that also makes

123
00:19:50.190 --> 00:19:59.970
Andre de Gouvea: The CP violation equals zero. So it's not observable either. The reason this is important for us is that remember I've been telling you that there's one belt AMP square that small

124
00:20:00.930 --> 00:20:07.800
Andre de Gouvea: And then there's the other delta m squared. That's big. And if you don't see the Dell Time Square that small

125
00:20:08.340 --> 00:20:17.820
Andre de Gouvea: You don't get the CCP violation, either because that would mean that, for example, this either the i delta want to, if this is approximately equal to one.

126
00:20:18.390 --> 00:20:36.900
Andre de Gouvea: Then this contribution to the amplitude vanishes and you don't get the CCP violation. This tells you that when you're doing these CP violation experiments, you need a baseline that is long enough so that you see some remnant effect of the small belt M squared effects.

127
00:20:38.280 --> 00:20:43.860
Andre de Gouvea: There's a whole bunch of other stuff that needs to happen. The only other one that's important, of course, is that

128
00:20:44.460 --> 00:20:52.410
Andre de Gouvea: It better be the case that these use this. I use star you products that show up here. These better be relatively complex numbers.

129
00:20:52.950 --> 00:21:09.480
Andre de Gouvea: Because if these numbers were real numbers, there would be no CP violation period so what what governs or what parameters the CP violation in the couplings is whether or not these you elements are complex numbers or not. And that's the thing that we're fighting

130

00:21:10.500 --> 00:21:18.600
Andre de Gouvea: And that's captured by this parameter delta and I showed you that this parameter delta is not something that we can see very well.

131
00:21:19.650 --> 00:21:32.340
Andre de Gouvea: That's all I'm going to say about CPU validation. What I want to do now is to go over very briefly. What's the other stuff that we don't know about neutrinos and then I'll spend some time talking about my Ryan and opinions and then I'll see how much time I have

132
00:21:34.050 --> 00:21:43.470
Andre de Gouvea: But what is it about neutrino masters, that we don't know yet something very simple. We don't know is when we do these oscillation experiments, we only measure the mask were differences.

133
00:21:43.980 --> 00:21:49.500
Andre de Gouvea: So we don't actually get to measure the masses themselves. We measure the differences of the masses.

134
00:21:49.950 --> 00:21:58.800
Andre de Gouvea: So if you ask somebody, or if you ask a neutrino physicist. So what's the mass of the neutrinos. The answer is we don't know because we only know the differences of the masses.

135
00:21:59.460 --> 00:22:06.390
Andre de Gouvea: And oscillations can't answer what what the masses are supposed to be. And you need experiments outside of oscillations.

136
00:22:06.840 --> 00:22:14.190
Andre de Gouvea: We're going to you guys are going to have lectures on how neutrino masters show up in cosmology, you heard a little bit about this.

137
00:22:14.730 --> 00:22:22.020
Andre de Gouvea: Earlier today I think Scott is giving a lecture on this and it will be an amazing lecture. So you're going to learn all about that from this

138
00:22:22.800 --> 00:22:29.880
Andre de Gouvea: You'll also get lectures on emptiness double beta decay. That's another place where you can see neutrino masses. So I just want to mention

139
00:22:30.600 --> 00:22:42.810

Andre de Gouvea: The nicest way to see nonzero neutrino masses, which is just to use kinematics and I'm not going to say too much about this because I think hawks and we'll talk about this a little bit, which was a beta decay experiments.

140
00:22:44.220 --> 00:22:51.990
Andre de Gouvea: So this is a very old idea it was actually Fermi's idea. So once they figured out that neutrinos existed.

141
00:22:52.470 --> 00:23:00.210
Andre de Gouvea: They said, okay, so how do we measure the mass of these. So here's a simple way you look at some data DK let's say like tritium beta decay.

142
00:23:00.750 --> 00:23:15.720
Andre de Gouvea: We don't get to measure the neutrino but we get to measure the electron very well. And then you can ask yourself. So what's the largest energy that this electron can have. And the answer is, it depends on the neutrino mass. So by doing a precision measurement of the

143
00:23:17.010 --> 00:23:26.040
Andre de Gouvea: energy of the electron that comes out from beta decay. You can get information on the neutrino mass. Now you can ask yourself what neutrino mass is it

144
00:23:26.580 --> 00:23:34.410
Andre de Gouvea: And the answer is it's some combination of neutrino number one mass and the neutrino. Number two, mass and the neutrino number three mass

145
00:23:34.950 --> 00:23:47.010
Andre de Gouvea: Because the neutrino masses are very small, you can convince yourself that the thing that you actually are sensitive to is a linear combination of the neutrino massive squared, which is this linear combination here.

146
00:23:47.940 --> 00:24:01.440
Andre de Gouvea: This is given the very unfortunate name electron neutrino mass. And the reason it's unfortunate is because the electronic reno doesn't have a mass. It's not even a particle. It's a linear superposition of mass second states.

147
00:24:02.610 --> 00:24:11.040
Andre de Gouvea: But we call this linear combination of the neutrino masses. The electronic Trina mass. And that's the thing that people are sensitive to

148
00:24:11.940 --> 00:24:24.960
Andre de Gouvea: Here's a picture of how this works. If the neutrino Massa zero the end point of the beta spectrum has this read shape. If the neutrino mass is not zero, the shape of the endpoint is different.

149
00:24:25.410 --> 00:24:33.960
Andre de Gouvea: And what people are out there trying to do is to measure the shape of the endpoint of the beta spectrum as precisely as they can.

150
00:24:34.740 --> 00:24:45.390
Andre de Gouvea: And I really I think Coxon will say something about this. These are amazing experiments they are incredibly hard and and I will just show you this fun picture, and I'm not gonna say anything about

151
00:24:46.770 --> 00:24:47.190
Andre de Gouvea: So,

152
00:24:48.510 --> 00:24:54.060
Andre de Gouvea: The other thing we don't know about neutrinos is a question that I want to spend a few minutes on

153
00:24:54.990 --> 00:25:02.700
Andre de Gouvea: You know Lindley will give you some lectures on Neutrino less double beta decay. And I'm sure she will also talk about this, but it's a question that people ask

154
00:25:03.210 --> 00:25:13.530
Andre de Gouvea: And it is a source of confusion. So I will try to introduce it in a way that perhaps SHIFTS, YOUR confusion into a different state. And maybe that's a useful thing to do.

155
00:25:14.490 --> 00:25:26.100
Andre de Gouvea: So I want to talk about a firm aeons and in order to talk about neutrinos as either they're accurate my run a firm yawns I always find it useful to think about

156
00:25:26.850 --> 00:25:35.490
Andre de Gouvea: Electrons. We all are big fans of electrons we know about electrons we found out about electrons, probably in middle school.

157
00:25:35.880 --> 00:25:43.860

Andre de Gouvea: And they've been around. They are the first fundamental particle we ever got to discover, except maybe photons. But let's not talk about that.

158
00:25:44.760 --> 00:25:53.910
Andre de Gouvea: And anyway, so let's talk about electrons. And let's do I get Duncan, a particle physics experiment which is let's pretend that we didn't know electrons existed.

159
00:25:54.840 --> 00:26:00.090
Andre de Gouvea: But we're out there doing experiments and then all of a sudden we find this charged firm eon

160
00:26:00.840 --> 00:26:06.420
Andre de Gouvea: And we're very excited. We've just discovered a new particle, we call it the electron because it makes sense.

161
00:26:06.840 --> 00:26:13.770
Andre de Gouvea: And we start measuring properties of this electron. And let's say we do this experiment where the electron was moving

162
00:26:14.340 --> 00:26:31.470
Andre de Gouvea: And we furthermore got to measure that the electron was a left felicity particle. So, even got to measure a polarized electron that was we got very lucky. So we've done our experiment we discovered a negatively charged particle that is left handed.

163
00:26:32.850 --> 00:26:42.810
Andre de Gouvea: So now we go back and we say, Okay, let's try to describe this particle and last ask, what else do we know about the system, which is the electron

164
00:26:43.200 --> 00:27:00.990
Andre de Gouvea: And one thing we can conclude right away is if we ever find out that left handed electrons exist, we can use the CPT theorem to tell us for free, that there's another particle that also exists, which is a positron. And that positron is actually right handed.

165
00:27:02.100 --> 00:27:13.020
Andre de Gouvea: So that means that if you, if somebody ever told you that left handed or electrons exist. You could conclude right away that right handed electrons also like a right handed positrons also exist.

166
00:27:14.040 --> 00:27:24.810

Andre de Gouvea: If you continue doing experiments with your electron one other thing that you would find out is that the electron has mass. And what this tells you is that you can now.

167
00:27:25.710 --> 00:27:42.330
Andre de Gouvea: Go to the electrons rest frame and you can ask questions about the electron for an electron at rest. So let's talk about that. And if the electron has a rest frame that means that you can polarize the electron. And you can see the electron, having seen, for example, spin up

168
00:27:43.560 --> 00:27:52.980
Andre de Gouvea: And of course, if you ever see an electron would spin up you can instantaneously conclude that there must also be an electron with a spin down

169
00:27:53.760 --> 00:28:11.100
Andre de Gouvea: It is not possible to live in a world where all of the electrons have spin up. And the reason is a lawrenson variance or rotational invariance, because if you see an electron would spin up, you can just turn upside down and then you would see an electron, who to spin down

170
00:28:12.180 --> 00:28:20.850
Andre de Gouvea: So, to make a long story short, once you've discovered a left handed electron and somebody told you that the electron has mass

171
00:28:21.270 --> 00:28:37.410
Andre de Gouvea: You would conclude that this electron particle actually comes in two different states, one which is left handed. The other one which is right handed, so that means that a massive left handed felicity electron tells you that there is also such a thing.

172
00:28:38.430 --> 00:28:59.850
Andre de Gouvea: As a massive right handed felicity electron as well. And of course, if the right handed electron exists the CPT theorem tells you that left handed positrons also exist. So after this very long story that our conclusion is that in order to describe an electron or or

173
00:29:01.050 --> 00:29:06.450
Andre de Gouvea: The description of the electron actually describes for you for the degrees of freedom.

174
00:29:07.170 --> 00:29:19.800
Andre de Gouvea: You know the spin up and spin down electron and the spin up and spin down positrons, if you don't like spin up and down. People

like to talk about felicity. So there's a left handed electron. And then there's a right handed electron

175
00:29:20.880 --> 00:29:24.900
Andre de Gouvea: So that's the end of this very long story. Now let's talk about neutrinos.

176
00:29:25.920 --> 00:29:26.340
Andre de Gouvea: Now,

177
00:29:27.540 --> 00:29:35.760
Andre de Gouvea: We discovered, historically, it's the other way around. But it doesn't matter. We know that there's such a thing as a left handed neutrino.

178
00:29:36.810 --> 00:29:49.200
Andre de Gouvea: So the CPT theorem tells us for free that because the left handed neutrino degree of freedom exists there must be a right handed degree of freedom, which we normally call the anti neutrino.

179
00:29:50.040 --> 00:30:02.190
Andre de Gouvea: Those two states must exist because of the CPT theory, incidentally, when we do a laboratory experiments. These are the states that we've actually observed in nature in all of our experiments.

180
00:30:02.820 --> 00:30:13.080
Andre de Gouvea: And the thing that's crucial about this, which is a source of a lot of confusion is that if the neutrino mass were zero. These are all the states that exists.

181
00:30:14.130 --> 00:30:25.080
Andre de Gouvea: That means that you know if the neutrino master zero, there is only a left handed neutrino and a right handed anti neutrino. There is no other state.

182
00:30:25.830 --> 00:30:33.720
Andre de Gouvea: And there's nothing wrong with that. And the reason is if you do all the Rams transformation and a Masters particle, the historicity is invariant

183
00:30:34.920 --> 00:30:38.160
Andre de Gouvea: Okay. That means that in the mass list neutrino world.

184
00:30:39.840 --> 00:30:47.610

Andre de Gouvea: The neutrino only requires two degrees of freedom to be described it doesn't, it's not like the electron which has four degrees of freedom.

185
00:30:48.840 --> 00:30:54.930
Andre de Gouvea: So, but that's not the world that we live in the world that we live in is one where the neutrinos do have mass

186
00:30:55.890 --> 00:31:04.470
Andre de Gouvea: So now if the neutrino has a mass, I can think about talking about an neutrino at rest. So let's say I have an arena would spin up

187
00:31:05.220 --> 00:31:13.320
Andre de Gouvea: So surely if there was a neutrino would spin up there must also be a neutrino with a spin down in the city language, it means that

188
00:31:13.890 --> 00:31:22.680
Andre de Gouvea: If you ever see a left handed and primo and you tell and you and you learn that then pre Namaste is not zero, there must be a right hand and

189
00:31:23.130 --> 00:31:39.270
Andre de Gouvea: Other degree of freedom, which is paired up with the neutrino because the neutrino has a mass. So this is the equivalent of the the left hand that electron and the right hand that electron both existing as physical states because the electron has a mass

190
00:31:40.500 --> 00:31:42.750
Andre de Gouvea: Now here's where the neutrinos special

191
00:31:43.770 --> 00:31:52.980
Andre de Gouvea: The neutrino special because the new Pino doesn't have any charge. So when you learn that the neutrino has a mass, which tells you that

192
00:31:53.340 --> 00:32:10.680
Andre de Gouvea: For every left handed degree of freedom, there must be a right handed degree of freedom. It turns out that you have a choice. One choice that you can make is that maybe the cell aranesp partner of the left hand the neutrino is a new degree of freedom that we call the right hand and neutrino.

193
00:32:11.910 --> 00:32:21.390

Andre de Gouvea: If that's the case, in order to describe a neutrino you need as many degrees of freedom as you need in order to describe the electron, it would be for

194
00:32:22.740 --> 00:32:33.390
Andre de Gouvea: You. And again, what makes the neutrino special is that you have a choice, which is we already have a right handed degree of freedom in the neutrino system is the thing that we normally call the anti neutrino.

195
00:32:34.530 --> 00:32:42.840
Andre de Gouvea: So why do you have the right handed anti neutrino where the LA Rams partner of the left handed neutrino. Also, and that's the sun.

196
00:32:43.710 --> 00:32:51.300
Andre de Gouvea: You know, very poorly drawn cartoon, and the very bottom here and and it basically says that it is possible

197
00:32:51.900 --> 00:33:05.700
Andre de Gouvea: That you know if you could go to the restroom, or the neutrino is at rest and I'll say this in many quotes. It is possible that the the neutrino will spin up and then Akina with a spin down or actually the thing that we normally call the neutrino in the anti nuclear

198
00:33:06.990 --> 00:33:11.250
Andre de Gouvea: So if that was confusing, you know, ignore that last statement. But the point is,

199
00:33:12.510 --> 00:33:20.100
Andre de Gouvea: We can ask whether the right handed neutrino is actually the same particles, the right hand that anti neutrino.

200
00:33:20.640 --> 00:33:28.410
Andre de Gouvea: In such a way that at the end of the day, the number of degrees of freedom that that it takes to describe neutrinos to and not for

201
00:33:29.400 --> 00:33:43.080
Andre de Gouvea: So this, this concept if that happens with the neutrino. We call it a Mirena for me on and it's actually more economical from you and then the electron because the electron has four degrees of freedom. Am I right, and rufino only has two

202
00:33:44.160 --> 00:33:50.070

Andre de Gouvea: Now you can ask, why didn't we play this game with the electron and the reason is very simple.

203
00:33:50.820 --> 00:33:59.400
Andre de Gouvea: In order for the electron to be. Am I run a firm young, we would have to equate the right handed positron with the right hand that electron

204
00:33:59.910 --> 00:34:11.040
Andre de Gouvea: And they would have to be the same particle, we know that's clearly nonsense because the right hand positron has charged plus and the right handed electron has charged minus

205
00:34:11.730 --> 00:34:17.100
Andre de Gouvea: So here's why the neutrino special because the neutrino has no charge. So you can talk about

206
00:34:18.060 --> 00:34:25.350
Andre de Gouvea: You know, there's no distinguishing feature between the thing that we call the neutrino and the thing that we call the anti neutrino.

207
00:34:25.860 --> 00:34:36.870
Andre de Gouvea: With one exception, which is left on number which I talked about at the very beginning of the first lecture, the only thing that tells neutrinos and anti neutrinos apart is left on number

208
00:34:37.950 --> 00:34:44.400
Andre de Gouvea: Which seems to be a quantum number where the neutrino has one quantum number and the anti neutrino has the opposite quantum number.

209
00:34:44.910 --> 00:34:52.890
Andre de Gouvea: So, it better be that if the neutrinos. Am I run a firm you on that this select on number is not a perfect symmetry, it has to be broken.

210
00:34:53.400 --> 00:35:00.570
Andre de Gouvea: And that's the way in which we try to ask whether the neutrinos and Mirena from you. So, again, to summarize this very long story.

211
00:35:01.050 --> 00:35:16.080
Andre de Gouvea: If the neutrinos at the back from you on you need four degrees of freedom to describe it. If the neutrino is a Mirena from you

on. You only need two degrees of freedom to describe it. So that's the question that we're asking. And that's the question. We don't know the answer to.

212
00:35:17.640 --> 00:35:25.860
Andre de Gouvea: Now I like to say that, you know, for him to are totally different numbers. So you're allowed to ask, How come we don't know that for is not equal to two.

213
00:35:27.210 --> 00:35:34.110
Andre de Gouvea: And the reason for this as neutrino masses and the key point is the following. And I said this and I'll try to say this again.

214
00:35:34.650 --> 00:35:48.210
Andre de Gouvea: If the neutrino mass war exactly zero, you would not be able to ask if the mass list neutrinos of the rack firm you and or am I run a from you in some sense it's a weird non question so you can't really ask that question.

215
00:35:49.320 --> 00:35:56.880
Andre de Gouvea: This is very important because, again, if the neutrino mass had been zero, I wouldn't be able to ask if the neutrinos drakkar Myron

216
00:35:58.260 --> 00:36:01.260
Andre de Gouvea: Of course, if you know mass is not zero, so I can ask the question.

217
00:36:01.710 --> 00:36:08.580
Andre de Gouvea: And then I can come up with some observable that can distinguish the neutrinos from the team that can distinguish my runner from direct neutrinos.

218
00:36:09.000 --> 00:36:18.300
Andre de Gouvea: But of course up whatever answer I get from this observable THE ANSWER BETTER BE zero in the limit where the neutrino mass goes to zero.

219
00:36:18.960 --> 00:36:28.080
Andre de Gouvea: And again, the rationale for this is very simple. I'm telling you that if the neutrino mass word zero, you wouldn't be able to ask if the neutrinos Dirac Ramayana

220
00:36:28.740 --> 00:36:39.270

Andre de Gouvea: That means that if there's some observable that can tell you whether the neutrinos director Marana that observable better not be able to give you an answer. If the neutrino master zero because you can't ask the question.

221
00:36:40.290 --> 00:36:51.870
Andre de Gouvea: In practice, what that what that means is that the amplitude for observable that can distinguish the rack from my run and Aquino's those observable vanish. When the neutrino massive zero

222
00:36:52.320 --> 00:37:04.230
Andre de Gouvea: That means that their attitudes are proportional to the neutrino mass in units of whatever energy you are in are involved in the experiment that you're doing and see where life gets very, very hard.

223
00:37:04.680 --> 00:37:14.670
Andre de Gouvea: Because the neutrino mass is always a lot smaller than the typical energies of neutrinos that you have in the experiments that could tell you whether the neutrinos Myron or the rack.

224
00:37:16.260 --> 00:37:19.440
Andre de Gouvea: Let me give you an example of how this works, and

225
00:37:21.510 --> 00:37:28.350
Andre de Gouvea: Let's remember. And again, the key feature. And all of this is the, the fact that the week interactions are purely left Cairo.

226
00:37:29.490 --> 00:37:36.270
Andre de Gouvea: So let's do a good Duncan experiment which is let's say that I have an electron, it hits something and it produces a neutrino.

227
00:37:37.380 --> 00:37:47.010
Andre de Gouvea: But then Makino has mass and let's say that I'm living in the laboratory where the energy is much bigger than the neutrino mass. So if I ask, what's the

228
00:37:47.430 --> 00:37:57.810
Andre de Gouvea: polarization state of this neutrino that I've just produced, it's going to be mostly a left felicity state with a tiny contamination of a right. Hello, city, state.

229
00:37:59.400 --> 00:38:16.530
Andre de Gouvea: So this is a this is what this neutrino looks like. Now the key point is the following. If the neutrino is a direct from you on

the left. Felicity state has a huge projection along the left chi reality state. And that's the thing that knows how to interact

230
00:38:17.670 --> 00:38:34.650
Andre de Gouvea: The right felicity state has a really, really tiny overlap with the left curiosity state. So that means that, for all practical purposes, you know, these are right, these right handed neutrinos virtually don't interact

231
00:38:35.760 --> 00:38:42.960
Andre de Gouvea: If the neutrinos on my run a firm eon life is completely different. Again, the first statement that I made is the same, is that the

232
00:38:43.380 --> 00:38:53.430
Andre de Gouvea: The left handed state has a large component with the left reality state. That's the one that we care about. And that behaves like what we call the electronic Reno.

233
00:38:54.210 --> 00:39:02.970
Andre de Gouvea: But this right felicity state is actually the thing that we normally call the anti neutrino in disguise. What this means is that this

234
00:39:03.600 --> 00:39:12.510
Andre de Gouvea: If the neutrinos on my run from you on the right. Felicity state is far from sterile, but it really likes to behave like the thing that we call the anti neutrino.

235
00:39:13.530 --> 00:39:20.790
Andre de Gouvea: So here's my experiment I produce my electron neutrino I let the electronic neutrino hit something, and

236
00:39:21.450 --> 00:39:30.720
Andre de Gouvea: If we're lucky enough to have it behave like the right felicity state which is up here, the right felicity state really likes to produce positrons

237
00:39:31.500 --> 00:39:37.320
Andre de Gouvea: So that means I can do an experiment where an electron comes in and a positron comes out at the other end.

238
00:39:38.310 --> 00:39:46.320

Andre de Gouvea: And if I observe that notice that are violated left on number by two units. And this only happens because the neutrinos a Mirena from you.

239
00:39:47.250 --> 00:39:56.610
Andre de Gouvea: Now that's the good news. The bad news is that the probability for this to happen is proportional to this mo very coefficient squared.

240
00:39:57.300 --> 00:40:13.680
Andre de Gouvea: And I told you that this mo re is actually a really tiny number. So if you plug in your favorite units for your favorite and particle physics experiment, you know, the probability that this will happen is of order 10 and a minus 1516 1718 some ridiculous really small number.

241
00:40:15.090 --> 00:40:26.040
Andre de Gouvea: So the way that we do this in practice is to look for neutrino less double beta decay and again Lindley is giving you a very nice lecture on this later this week, so I won't say anything about that.

242
00:40:28.440 --> 00:40:36.090
Andre de Gouvea: I do want to say something else, very quickly about my Rhino neutrinos and that has to do with the mixing matrix and

243
00:40:37.710 --> 00:40:46.440
Andre de Gouvea: I want to remind you in in a little bit of detail of how do we do parameter counting of our mixing matrix.

244
00:40:47.040 --> 00:40:57.600
Andre de Gouvea: And this is going to happen in this slide, which is a very confusing slide and it will be more confusing to do it remotely. So you have to follow. Hopefully this little hand that you can see here

245
00:40:59.100 --> 00:41:11.370
Andre de Gouvea: Let's talk about the rack neutrinos. First, and that's the blue text in the bottom here, and if I take a basis where the charge left on masses, or diagonal

246
00:41:12.240 --> 00:41:26.640
Andre de Gouvea: And the neutrino masses, or that hacking. Oh, so this am new here is a diagonal matrix. This me here is a diagonal matrix, then my week current is off diagonal and its parameters by some unitary matrix IE, you

247

00:41:27.300 --> 00:41:41.700
Andre de Gouvea: That's the same thing that we do with quarks, for example, and in this language. The W couplings are off diagonal and flavor space. Now you as a unitary matrix, you know, it's a three by three matrix a three by three unitary matrix has nine parameters in it.

248
00:41:42.720 --> 00:41:58.950
Andre de Gouvea: Now what I want to do is I want to write this unitary matrix in the following sense. I want to write it as a diagonal phase matrix on the left hand side. Another diagonal phase matrix on the right hand side and everything that's left over is another matrix in the middle.

249
00:42:00.540 --> 00:42:10.800
Andre de Gouvea: The reason I WANT TO DO THIS IS NOW THIS YOU LOOKS LIKE A diagonal phase matrix multiplied by another non generic matrix multiply by another diagonal face matrix.

250
00:42:11.340 --> 00:42:25.020
Andre de Gouvea: Now I can redefine my fields so I can redefine my left handed electron field to absorb these phases and then I can redefine the left hand the neutrino fields to also absorb those phases.

251
00:42:25.860 --> 00:42:38.640
Andre de Gouvea: When I do that, my leg rancher looks like this thing here in the bottom and blue. And you notice that I acquired a diagonal phase matrix that shows up in the electron mass

252
00:42:39.210 --> 00:42:50.460
Andre de Gouvea: And another diagonal phase matrix that shows up in the neutrino mass and you say okay I didn't do anything. But the thing that's interesting is I can now redefine my right hand that neutrino fields.

253
00:42:51.120 --> 00:42:58.710
Andre de Gouvea: And my right hand that electron fields to absorb these phases. And if I do that these phases completely disappear.

254
00:42:59.880 --> 00:43:12.240
Andre de Gouvea: In that process. I can eat five parameters out of the matrix. And then I'm just left with the four that we're familiar with this is what happens with the quarks. This is what happens if the neutrinos, or the rack for me.

255
00:43:13.560 --> 00:43:23.160

Andre de Gouvea: However, if the neutrinos Mirena from yawns, the story is the same, except it now the neutrino master, which I didn't talk about, but you just have to believe me.

256
00:43:23.640 --> 00:43:29.940
Andre de Gouvea: It doesn't have right handed neutrinos anymore. It includes only neutrinos. And that means that this

257
00:43:30.690 --> 00:43:39.030
Andre de Gouvea: Diagonal phase matrix here this either the i alpha one, alpha two, alpha three, you can't absorb that. That is still a physical parameter

258
00:43:39.570 --> 00:43:49.410
Andre de Gouvea: That means that you're mixing matrix has more parameters in it. These are called marijuana phases. So I can still absorb these phases. Again, this is the same story back again.

259
00:43:49.860 --> 00:43:58.320
Andre de Gouvea: But I can't absorb these phases here because I don't have right handed rufino fields. So that means I'm left with some phases.

260
00:43:58.800 --> 00:44:09.360
Andre de Gouvea: And those phases are actually two, not three because the, the, the global phase is not a physical thing. So we don't care about that one, but there are two phases which we do care about

261
00:44:09.810 --> 00:44:20.670
Andre de Gouvea: And we normally do that by writing our mixing matrix, including some phases over here. And even though I wrote three phases here only two of them are physical.

262
00:44:21.600 --> 00:44:31.470
Andre de Gouvea: These are called marijuana phases and we have no idea how to measure them in some sense, they will impact the rate for new meaningless double beta decay, but sadly

263
00:44:32.310 --> 00:44:44.670
Andre de Gouvea: They impacted in a way that's very, very difficult to to extract experimentally and I'm not going to talk about this at all, but it is a new parameter that we have to contend with that lives in the neutrino sector.

264
00:44:46.350 --> 00:44:51.270

Andre de Gouvea: Okay, so I think I have about 10 minutes left. Unless my calculation is way off.

265
00:44:52.980 --> 00:45:02.010
Andre de Gouvea: under that assumption. What I want to do for these last 10 minutes is to try to talk a little bit about neutrino masses and why neutrino masses are a very big deal.

266
00:45:02.490 --> 00:45:10.950
Andre de Gouvea: And I think this is all I'm going to have time for. But I think that's fine. Okay, so this is what we've discovered we've discovered that neutrino masses are not zero.

267
00:45:12.270 --> 00:45:26.520
Andre de Gouvea: And the one point which I hope comes across. If you ever look at rufino masses, is that that's what shows up here on this plot on the left hand side is that even though that are Trina masses are not zero. They are ridiculously small

268
00:45:27.810 --> 00:45:41.580
Andre de Gouvea: Okay, now again every time you say that something is big or small, it better be big or small relative to something. And the point is that neutrino masters or small relative to all the other fundamental particle masters that we know about.

269
00:45:43.230 --> 00:45:45.390
Andre de Gouvea: The example that I like to give is

270
00:45:46.620 --> 00:45:54.000
Andre de Gouvea: If you look at this picture, I hope you notice that it's in and log scale. And these are all the masses of the charge from yawns

271
00:45:54.900 --> 00:45:59.460
Andre de Gouvea: They live up here, you know, here's the electron up cork down cork, all the way to the top cork.

272
00:46:00.300 --> 00:46:13.140
Andre de Gouvea: And if you stare at this picture, you will notice a fact that people worry about a lot, which is the fact that the electron mass is five orders of magnitude smaller than the top quark man's

273
00:46:14.130 --> 00:46:20.400
Andre de Gouvea: And then all the other charge firm your masters sit somewhere in between the electron mass and the top workmates

274
00:46:21.870 --> 00:46:36.510
Andre de Gouvea: The neutrino masses, or the largest possible value that Makino mass could have. And again, I said at one electron volts here because that's the tritium beta decay bound. But if you look at the cosmology bound. That's an order of magnitude smaller

275
00:46:37.560 --> 00:46:51.150
Andre de Gouvea: That the gap between the largest possible neutrino mass and the electron mass is actually at least an order of magnitude bigger than the distance between the electron mass and mass. So Trina masses are super small

276
00:46:52.230 --> 00:47:02.700
Andre de Gouvea: And we don't know what that means. Okay, so that's one of the attractiveness of neutrinos. And I do want to say that this is not something that should have happened.

277
00:47:03.390 --> 00:47:13.620
Andre de Gouvea: So people like to say, and you're going to hear about all of this and the school is that Makino masses were expected to be exactly zero in the standard model.

278
00:47:14.220 --> 00:47:23.010
Andre de Gouvea: Which means that if you want to understand why neutrino masses are not zero, you need to do something that goes beyond the standard model or it's one of the

279
00:47:23.460 --> 00:47:33.510
Andre de Gouvea: It's one of the failed predictions of the simple standard model that we like to talk about so much. And this is a big deal because the standard model is ridiculously successful

280
00:47:34.500 --> 00:47:42.150
Andre de Gouvea: There are very, very few things that the standard model doesn't explain and you're going to be hearing about all of those in this sign in these next two weeks.

281
00:47:43.050 --> 00:47:51.630
Andre de Gouvea: So what are the other things we don't understand the dark matter puzzle. We know it's not a there's no standard model solution to the dark matter puzzle.

282
00:47:52.680 --> 00:48:00.150

Andre de Gouvea: The other question that we like to talk about is this thing called barrier Genesis barrier Genesis is a question in particle physics.

283
00:48:00.660 --> 00:48:10.980
Andre de Gouvea: And there is no solution to lie. The universe is made out of matter that lives within our understanding of particle physics. And the last thing which we heard about saying the last lecture, is that

284
00:48:12.030 --> 00:48:22.560
Andre de Gouvea: The expansion rate of the universe seems to accelerate every once in a while, it seemed to happen during inflation, it seems to be happening now because of dark energy.

285
00:48:23.070 --> 00:48:33.840
Andre de Gouvea: We have no idea why that happens. We don't know if that's a particle physics question, but we're pretty sure that the standard model has nothing to say about why the expansion rate of the universe accelerates

286
00:48:34.830 --> 00:48:41.070
Andre de Gouvea: So along with these questions, there is the question of how can we create a Masters or not zero.

287
00:48:43.350 --> 00:48:50.910
Andre de Gouvea: And I want to remind you, very quickly, of why do I mean by neutrino masses are zero and the standard model. It's actually very simple.

288
00:48:51.450 --> 00:49:02.010
Andre de Gouvea: If you take the Standard Model gauge group. If you take the particle content that we know about for the standard model and we write down the most general generalizable, the growth engine that we can think of.

289
00:49:02.700 --> 00:49:13.590
Andre de Gouvea: And we don't need to know any particle physics for this. We just have to know quantum field theory. And if we follow all of these steps we make a prediction and the prediction is neutrino masses are exactly zero

290
00:49:14.670 --> 00:49:25.320
Andre de Gouvea: And that's not true because the neutrino masses are not zero. What this means is that there's something in the story of this slide that I hope you have time to read that is wrong.

291
00:49:26.070 --> 00:49:37.260
Andre de Gouvea: So there's some there's a failure point here somewhere. And, and the other way of saying the same thing is that non zero neutrino masses require new degrees of freedom.

292
00:49:38.340 --> 00:49:42.420
Andre de Gouvea: So something has to be something has to violate

293
00:49:43.740 --> 00:49:54.930
Andre de Gouvea: What we what we call the standard model in order for you to even start thinking about writing down in Reno mass. So that's what I mean by neutrino masses are physics beyond the standard model.

294
00:49:56.310 --> 00:50:04.800
Andre de Gouvea: What makes Neutrino Physics fun is that we don't know what these new degrees of freedom are supposed to be. And I like to say that

295
00:50:05.310 --> 00:50:14.760
Andre de Gouvea: It's not that we're not smart enough to figure out how the trina's could get enhance it is kind of the other way around that we're actually too smart because we can figure out

296
00:50:15.180 --> 00:50:26.490
Andre de Gouvea: 20 different ways in which the trina's can get a mass and it would be nice to know which one of these 20 different ways is correct. If and and in order for us to make progress. We're going to need more experimental data.

297
00:50:28.500 --> 00:50:46.620
Andre de Gouvea: So there's an important point which I want to drive across that. That explains why there are all these different choices and has to do with Masters in the standard model in general. One thing that you all know about his masters are hard to come by in the standard model.

298
00:50:47.700 --> 00:51:04.380
Andre de Gouvea: If you look at the Standard Model very naively, you will notice that except for the Higgs boson. No other particles have masses in the Lagrangian. So all the other particles are mass lists and of course the reason for that is that they get their masters from the Higgs mechanism.

299
00:51:05.850 --> 00:51:12.480
Andre de Gouvea: Now neutrinos are not special. In this way they also get masses after electric cemetery breaking

300
00:51:13.470 --> 00:51:25.950
Andre de Gouvea: And the neutrinos are special because they can get masses in different ways. And the main reason for that is that the quote de Marana from yawns so here's a list of different possibilities. One is that

301
00:51:27.570 --> 00:51:34.500
Andre de Gouvea: You add to the standard model. And your degree of freedom or right handed and keno and then the neutrinos. Get a mess like everybody else.

302
00:51:35.130 --> 00:51:44.430
Andre de Gouvea: And that means that they thought that a Higgs boson. They have to talk to the Higgs boson very weakly. And then they would get a mass like everybody else. They would end up being direct neutrinos.

303
00:51:45.000 --> 00:51:52.770
Andre de Gouvea: There is an intermediate possibility, which is that maybe there's a new Higgs Boson. It's a Higgs boson that would violate left on number in some way.

304
00:51:53.430 --> 00:52:01.890
Andre de Gouvea: And that could coupled to the neutrinos and give the neutrinos on my run a mass. And then there's a third choice which I won't have time to talk about, but that's

305
00:52:02.280 --> 00:52:08.640
Andre de Gouvea: The choice that people like to discuss the most, which is that maybe the neutrino masses are the consequence of

306
00:52:09.570 --> 00:52:13.530
Andre de Gouvea: On the one hand, the Higgs boson that gives a message to everybody.

307
00:52:13.980 --> 00:52:27.930
Andre de Gouvea: But another source of mass, which has nothing to do with the Higgs boson might also exist in the standard in the in the grind and for nature and then Fino masses are a mixture of that. And in that scenario, the neutrinos are also my from you.

308
00:52:30.870 --> 00:52:41.610
Andre de Gouvea: So I have two minutes. So let me not talk about this. I think it's better to say fewer things but to say it better and you can read all of that in your leisure and hopefully it makes sense.

309
00:52:43.110 --> 00:52:44.160
Andre de Gouvea: And let me just

310
00:52:46.380 --> 00:52:52.170
Andre de Gouvea: Show the last step, the last slide. And then my conclusions, so

311
00:52:54.780 --> 00:53:04.830
Andre de Gouvea: So, so, to make a long story short, the reason we care about neutrino masses, is that there's a lot of choices and those choices have to be informed by experiment.

312
00:53:05.790 --> 00:53:15.270
Andre de Gouvea: And the question is, what kind of experiment. Do we care about. And the answer is we care about all kinds of experiments. So here's a list of different

313
00:53:15.870 --> 00:53:26.400
Andre de Gouvea: Pieces of particle physics that might inform the neutrino mass puzzle, a really big deal is to ask if left on numbers, a fundamental symmetry of nature and not

314
00:53:26.880 --> 00:53:29.040
Andre de Gouvea: So in your opinion, is to have a beta, the case that they do.

315
00:53:29.880 --> 00:53:36.300
Andre de Gouvea: Another big do is to understand neutrino oscillations, as well as we can because the neutrino oscillation phenomenon.

316
00:53:36.660 --> 00:53:47.610
Andre de Gouvea: Today is the only one that tells us that neutrino masses are not zero. So there could be a lot of surprises lurking in neutrino oscillations that might inform how neutrinos. Get a mass

317
00:53:48.720 --> 00:53:55.770
Andre de Gouvea: We do other experiments with neutrinos. They might help reveal new interactions new states, stuff like that.

318
00:53:56.580 --> 00:54:05.730
Andre de Gouvea: We also care about experiments with charged leptons. So neutrinos and charged leptons are friends, they are actually cousins or brothers and sisters. If you want to think about them.

319
00:54:06.090 --> 00:54:22.980
Andre de Gouvea: So it is possible that the physics that gives you a nonzero neutrino mass will show up in properties of charge leptons, or on searches for rare processes that involve Charles leptons, including me to be gamma the case mutually conversion and nuclei, things like that.

320
00:54:24.060 --> 00:54:36.870
Andre de Gouvea: Another possibilities that neutrino masses require new particles new degrees of freedom and the challenges we don't know if these new particles are very light if they're very heavy if they couple a lot if they couple very little.

321
00:54:37.620 --> 00:54:47.370
Andre de Gouvea: And we know about this thing called the ELYSEE, which is a good place to look for new particles. So, it is possible that whatever is getting the neutrinos amass will show up.

322
00:54:47.910 --> 00:55:04.320
Andre de Gouvea: At the Large Hadron Collider or maybe other collider experiments and. And again, we don't know. So we pay attention to what's going on there. What you're going to hear a lot about is neutrinos are one of the big players in the history of the universe. So we're going to learn a lot about

323
00:55:05.790 --> 00:55:18.900
Andre de Gouvea: neutrino properties from cosmology, but the price that we pay for that is that the information is mixed up with a lot of other information as well. So there's a lot of give and take between premium experiments and cosmic surveys

324
00:55:19.830 --> 00:55:38.610
Andre de Gouvea: And then another last example is in many models baryons and leptons are friends. So it's also possible that searches for like proton DK or in particular. People like to talk about a neutron anti new translations that might help inform entrepreneurs get a non zero max.

325
00:55:39.660 --> 00:55:48.390
Andre de Gouvea: So let me very quickly conclude Neutrino Physics is a very exciting topic. It is one place in the standard model when something went wrong.

326
00:55:48.930 --> 00:55:54.900
Andre de Gouvea: And it went wrong in a way that we can quantify what that it went wrong. And that's neutrino non zero mass

327
00:55:55.710 --> 00:56:01.830
Andre de Gouvea: We have made a lot of progress understanding and parameter rising this discovery of neutrino oscillations.

328
00:56:02.250 --> 00:56:11.220
Andre de Gouvea: And we even know what types of experiments, we want to do next. So there's a whole bunch of questions that we know we can get an answer to, and we know how to do experiments.

329
00:56:12.000 --> 00:56:20.070
Andre de Gouvea: from a theoretical point of view, there's a couple of big deal questions. One is that and premium acids are very small. We think that that means something.

330
00:56:20.640 --> 00:56:29.430
Andre de Gouvea: The other one which I didn't talk about is that we also know that left on mixing and mixing are very different. And a lot of people think that that also is nature's way of telling us something.

331
00:56:31.530 --> 00:56:49.530
Andre de Gouvea: And Neutrino Physics is a very, very data driven field that is we have a bunch of questions and all of those questions require experimental input. So if you if you're a terrorist and you only talk to theorists, you will make no progress in understanding how to feed the masses or not.

332
00:56:51.660 --> 00:56:57.300
Andre de Gouvea: And I think this is all I want to say, so I think I'm two minutes overtime. So I will stop here. Thank you.

333
00:56:58.200 --> 00:57:00.960
mark convery: Hey, thank you very much. Andre very compelling pocket. Thank you.

334
00:57:01.980 --> 00:57:04.770
mark convery: And I'm sure their questions. So I'll pass it over to Tom

335
00:57:05.700 --> 00:57:07.230
thomas rizzo: Oh yeah, we have plenty of questions.

336
00:57:08.400 --> 00:57:09.540
thomas rizzo: Let's begin with this one.

337

00:57:10.620 --> 00:57:17.310
thomas rizzo: Why does si P violation. Make the oscillation amplitude larger from neutrinos than anti-neutrinos

338
00:57:18.990 --> 00:57:35.490
Andre de Gouvea: That's a good question. So let me rephrase the question. And what CP violation does is that it, it allows for the possibility that the amplitude for neutrino oscillation is different for the amplitude for anti and premium isolation.

339
00:57:37.050 --> 00:57:55.770
Andre de Gouvea: That's the correct statement, and that makes the probabilities different now which one gets bigger is a is a quantitative question and both possibilities are allowed. It is possible that the probably the oscillation probability for new mutiny. He is bigger than the oscillation

340
00:57:55.770 --> 00:57:58.050
Andre de Gouvea: Probability for new Mubarak to new a bar.

341
00:57:58.380 --> 00:58:06.540
Andre de Gouvea: Or the other way around. And that's an experimental question and both possibilities are allowed. So it's not the case that

342
00:58:07.050 --> 00:58:18.360
Andre de Gouvea: The neutrinos always get enhanced relative to the anti neutrinos. There's a good way to understand that that has to be true because I noticed that when I did this calculation I talked about

343
00:58:19.500 --> 00:58:25.680
Andre de Gouvea: The probability that a new meal will behave like a new fee or the new bar behaves like a new bar.

344
00:58:26.190 --> 00:58:34.500
Andre de Gouvea: If you ask the question, what's the probability that a new new will continue to behave like a new new compared with the probability that a new bar.

345
00:58:34.830 --> 00:58:45.570
Andre de Gouvea: Will continue to behave like a new bar. These are the these are the disappearance probabilities, those two probabilities in vacuum. They have to be exactly the same, because of the CPT theorem.

346
00:58:46.830 --> 00:58:55.590

Andre de Gouvea: That means that if I make new mutiny. We bigger than new Mubarak to new a bar. That means that new new to new Tao has to be smaller than

347
00:58:55.950 --> 00:59:12.810
Andre de Gouvea: New Mubarak to New Tab bar because the disappearance probabilities have to be exactly the same in vacuum because of the CPT theory. If you want to keep in a great way of testing the CPT theorem to ask if the new meal. This appears at the same rate as the new new bar.

348
00:59:14.970 --> 00:59:26.280
thomas rizzo: Quick question, Andre that somebody asked, but it's right on this slide it when you go to the CP conjugate. In the second expression below. Why didn't the deltas and the exponents change sign that's

349
00:59:26.310 --> 00:59:40.380
Andre de Gouvea: A very good question. And the reason is the origin for that term is the kinematics part or it's the solution to the shortened to the truth and great question and the Schrodinger equations are the same for the article on the anti particle

350
00:59:41.760 --> 00:59:55.860
Andre de Gouvea: So it's the, it's the time evolution, you know the the time evolution of a particle and the time evolution of an empty particle is the same. Actually, if you want, if you remember this from us infinitely long time ago. That's how we invented anti particles to begin

351
00:59:55.860 --> 00:59:56.100
Andre de Gouvea: With

352
00:59:56.580 --> 01:00:02.280
Andre de Gouvea: It's because we had these solutions to the time evolution that we're going backwards in time. We didn't like that.

353
01:00:02.730 --> 01:00:07.980
Andre de Gouvea: So we flipped the sign of that. And then we call that the anti particle, so that if you want. This is the

354
01:00:08.400 --> 01:00:19.770
Andre de Gouvea: This kinematics phase doesn't change sign the couplings do so when you when you flip from the process to the anti process all of the couplings get complex conjugated.

355
01:00:20.160 --> 01:00:26.850

Andre de Gouvea: But, but that piece doesn't change. If you like quantum field theory better this piece here is related to the propagator

356
01:00:27.840 --> 01:00:37.650
Andre de Gouvea: And the proper gators are the same. And again, you know that they're not exactly the same. There's some so but that part is the same. And that's another way of saying the same thing.

357
01:00:38.070 --> 01:00:45.480
Andre de Gouvea: And finally, the last random comment I can make is that if you're a quark fanatic, and you're like CP violation in the corporate sector.

358
01:00:45.960 --> 01:01:05.730
Andre de Gouvea: The, the, the physics analog of this is what color is what's called a CP violation in the decay and they use, they play the part of what's called a week phases and believe it or not that either the Delta plays a part of what's called a strong things and the strong phases are things which

359
01:01:06.930 --> 01:01:14.220
Andre de Gouvea: Are the same for the particle for the process and the CP conjugate process and the week phases are the things that change.

360
01:01:14.610 --> 01:01:28.860
Andre de Gouvea: By the way, if, if there was a phase shift between the Delta terms, then you would never be able to finally CP because then one one amplitude would be the complex conjugated. The other and then the magnitudes would be exactly the same.

361
01:01:31.500 --> 01:01:45.810
thomas rizzo: Okay, here's another question. If we observe new treatments double beta decay, we can safely eliminate the possibility of the direct nature of neutrinos. Similarly, is there any experiment where we can eliminate the Marana nature of neutrinos directly

362
01:01:46.560 --> 01:01:49.440
Andre de Gouvea: That's a very good question and the answer is

363
01:01:55.470 --> 01:02:04.920
Andre de Gouvea: So, in principle, yes. So so the so the reason you can't do that with between or less double beta decay is because you can't prove a negative,

364
01:02:05.700 --> 01:02:14.310

Andre de Gouvea: I mean, you can't prove that neutrino less double beta key doesn't happen. You can only prove that it doesn't happen with a certain rate.

365
01:02:14.970 --> 01:02:34.530
Andre de Gouvea: And that's the challenge for this proving de de de Marana hypothesis by looking for nutrients double beta decay. So you have to ask a question. Is there something that my Ryan and Reno's don't know how to do and you can cook up some observable. If you are a

366
01:02:35.640 --> 01:02:52.320
Andre de Gouvea: So here's one random thing that I happen to know because I've worked on it, which is a Imagine, for the sake of argument that the neutrino the case and it decays into a very light neutrino and some scale or particle. Let's say that that statement is correct.

367
01:02:53.550 --> 01:02:54.900
Andre de Gouvea: If that happens,

368
01:02:55.980 --> 01:03:05.400
Andre de Gouvea: We can measure the decay of the neutrino and the neutrino rest frame and we can measure the angular distribution of the neutrino that comes out.

369
01:03:06.060 --> 01:03:22.500
Andre de Gouvea: If the parent particles polarized. That's an experiment, you can do. And of course, in general, you expect that the decay distribution of the daughter particle can depend on the, the angle that the neutrino forms with spin of the parent neutrino.

370
01:03:23.550 --> 01:03:26.610
Andre de Gouvea: Okay, let's say that you that that was something you could measure

371
01:03:27.630 --> 01:03:35.940
Andre de Gouvea: It turns out that if the neutrinos at the rack from you on that angle distribution can be non trivial. That means that you can be something between

372
01:03:37.020 --> 01:03:50.340
Andre de Gouvea: One plus cosine data and one minus cosine theta. That's it can be a symmetric in that way. So that means that the daughter neutrino can either be emitted preferentially forward or preferentially backwards.

373

01:03:51.000 --> 01:03:58.650
Andre de Gouvea: And that happens for the direct and freedom for them. I run a neutrino. It turns out that the distribution has to be isotopic

374
01:03:59.790 --> 01:04:07.260
Andre de Gouvea: So that means that if you if the neutrino did decay in this way that I described and the distribution of the decay was not isotopic

375
01:04:07.680 --> 01:04:17.190
Andre de Gouvea: You could rule out the possibility that the neutrinos a minor from you. Now, there's a lot of ifs and buts in that statement but but that's kind of the game that you have to play.

376
01:04:17.910 --> 01:04:23.250
Andre de Gouvea: And there are a couple of other observable that act like that. So you basically need an observable.

377
01:04:23.610 --> 01:04:40.470
Andre de Gouvea: Where the my Rhino neutrino is incapable of doing something, but the direct neutrino is allowed to do something else and then by observing a direct like behavior. You could rule out the possibility that the neutrinos from that was a very long answer. Sorry about that.

378
01:04:41.490 --> 01:04:42.300
thomas rizzo: Important one

379
01:04:43.860 --> 01:04:45.360
thomas rizzo: Maybe we have time for one more question.

380
01:04:46.740 --> 01:04:47.280
thomas rizzo: Could see

381
01:04:48.300 --> 01:05:03.990
thomas rizzo: I like this one. Could it be that one or two of the mass, I can state some neutrinos of ironic and the other one or other ones are direct and if that were true, how would they mix into the from the flood name for the mass, I can states of the flavor. I can states.

382
01:05:04.800 --> 01:05:12.030
Andre de Gouvea: Yeah, that's how that's a very confusing question. I think because of everything that we know about mixing

383

01:05:14.070 --> 01:05:31.500
Andre de Gouvea: And I'll say this very slowly. I don't think it's possible for some of the neutrinos to be Mirena from yawns and some of the neutrinos to be direct from yawns, I think you have to be it's an either or either everybody's interact from you on or everybody's in my arena from you on

384
01:05:32.700 --> 01:05:33.840
Andre de Gouvea: There are some

385
01:05:36.060 --> 01:05:39.480
Andre de Gouvea: provisos you can you can add you need to add one is

386
01:05:41.790 --> 01:05:43.950
Andre de Gouvea: You can imagine a scenario where

387
01:05:44.970 --> 01:05:48.810
Andre de Gouvea: Where the neutrino is almost a direct from Yun but not really.

388
01:05:50.070 --> 01:05:51.360
Andre de Gouvea: And then you can have a

389
01:05:53.580 --> 01:05:56.010
Andre de Gouvea: So, in a world where the neutrinos are almost

390
01:05:56.010 --> 01:05:59.310
Andre de Gouvea: Direct from humans. One could have some weird stuff going on.

391
01:05:59.910 --> 01:06:10.110
Andre de Gouvea: In anything I say in in one minute will be incredibly confusing, so, so, so I think that the rule of thumb, beans, either. Everybody's had their act from you on or everybody's on my own firm jaan

392
01:06:10.560 --> 01:06:22.980
Andre de Gouvea: And the main reason for that is because of the mixing the mixing is the thing that would be very confusing if if you had some, some of the neutrinos be my run it from you and some of the neutrinos be the rack from you.

393
01:06:25.110 --> 01:06:34.980

Andre de Gouvea: And again, it's a great question and it's a very confusing question and I'm pretty sure what I've just said is, for all practical purposes. Correct.

394
01:06:36.780 --> 01:06:38.850
Andre de Gouvea: But you know how theorists are okay.

395
01:06:39.480 --> 01:06:40.170
thomas rizzo: Yes, I did.

396
01:06:41.340 --> 01:06:49.920
thomas rizzo: Okay, can we get constraints on CP violation and neutrino oscillations from the limits on CP violation and the charge left on sector.

397
01:06:55.980 --> 01:07:06.030
Andre de Gouvea: That's a complicated question. The answer is, again, in principle, yes, in practice, no and. And the reason is the following.

398
01:07:07.920 --> 01:07:12.210
Andre de Gouvea: We know exactly what we're measuring when it comes to CP violation and the neutrino sector.

399
01:07:13.260 --> 01:07:27.900
Andre de Gouvea: So the more practical question is how does that CP violations show up in observable that have to do with CP violation and the charge left on sector. One good example would be an electron EDM, for example.

400
01:07:28.770 --> 01:07:37.140
Andre de Gouvea: And the answer is this EP violation that lives in the neutrinos actor who would show up in the electron EDM, but sadly

401
01:07:37.860 --> 01:07:54.180
Andre de Gouvea: It also shows up in a way that kind of looks like an oscillation, but it's an oscillation at the quantum level which is allowed. I mean, we know that you know in quantum mechanics, you can have particles propagating and these are even virtual particles. So, they are allowed to oscillate.

402
01:07:55.170 --> 01:07:57.630
Andre de Gouvea: Now sadly neutrino oscillations requires a

403
01:07:58.020 --> 01:08:07.920

Andre de Gouvea: Macroscopic distance to turn on and these quantum effects are incredibly microscopic so the neutrinos never have enough time to develop a phase.

404
01:08:08.370 --> 01:08:16.380
Andre de Gouvea: So that this CP violation shows up. So that's the. So the short answer is, in principle, the same CP phase shows up.

405
01:08:16.830 --> 01:08:24.210
Andre de Gouvea: In charge left hand processes, but the way it manifests itself is incredibly suppressed. Another way of seeing this is the following.

406
01:08:24.780 --> 01:08:35.550
Andre de Gouvea: These are CP violation questions. This by the way is also true in the corporate sector but CP violation questions rely on the fact that all of the mixing angles are not zero.

407
01:08:36.060 --> 01:08:42.210
Andre de Gouvea: And all of the particle masses are different. That means that if you want the CP violation to show up.

408
01:08:42.720 --> 01:08:50.430
Andre de Gouvea: Your amplitude has to know about all of the mixing NGOs, be not zero, and all of the particle mass has been not zero.

409
01:08:51.360 --> 01:09:00.030
Andre de Gouvea: And the neutrino masses are super small, that means that the impact of the CP violation that knows about the fact that the neutrinos have mass

410
01:09:00.330 --> 01:09:13.770
Andre de Gouvea: Is always absurdly suppressed, just because the neutrino masses are so small. Again, if this sounds confusing. Just think about how CP violation happens in the quark sector and again the CP violation is really

411
01:09:14.850 --> 01:09:29.910
Andre de Gouvea: It hasn't no mercy. It really needs to know that all the particles mix in all the particles have non zero masses. Actually, that's not true. But all the, you know, the barcode masses are not not not exactly the same. So that's the, that's the challenge there.

412
01:09:33.660 --> 01:09:34.680
mark convery: OK, now I think that we

413
01:09:35.160 --> 01:09:38.250
mark convery: Must there's one more really compelling one. Maybe we should wrap it up there.

414
01:09:38.580 --> 01:09:40.050
thomas rizzo: At a time. It's fine.

415
01:09:40.830 --> 01:09:48.030
mark convery: Okay. All right. Well, thank you very much. Andre for various the lecture and the great questions from the, from the attendees.

416
01:09:49.290 --> 01:09:55.620
mark convery: I guess we will end this one here and we will resume in 10 minutes with rock fans for sock under the Northeast experiments.

417
01:10:00.000 --> 01:10:00.960
mark convery: And I will stop the recording.