WEBVTT

1
00:00:06.270 --> 00:00:06.930
Jonathan Feng: Hi everyone.

2
00:00:08.670 --> 00:00:09.660
Jonathan Feng: Set up here.

3
00:00:16.890 --> 00:00:17.400
Jonathan Feng: Okay.

4
00:00:18.960 --> 00:00:25.080
Jonathan Feng: All right, so this is the second and last talk in this series on accelerator searches the banking sector.

5
00:00:26.640 --> 00:00:44.520
Jonathan Feng: So let me just remind you, the outline of these talks, there's two vectors between parks, you actually finished the first two, which was about particle physics and irrelevant to the and then also a discussion of heavy bag sectors, namely week scaled up sectors had accelerators and colliders

6
00:00:45.900 --> 00:01:00.420
Jonathan Feng: So what we're going to do this time is talk about light back sectors and accelerators. We actually started that last time talking about portals and various models of light pack sectors.

7
00:01:02.640 --> 00:01:16.290
Jonathan Feng: One thing I asked you to do last time was to little homework problem. If you're interested in having done it before, to look a little bit more declared the dark photon the grind. So this is the solution to the homework.

8
00:01:17.730 --> 00:01:28.770
Jonathan Feng: But basically, the idea was you start with a Lagrangian which had a you engage goes on in the visible sector and that you engage Roseanne and the dark sector.

9
00:01:29.640 --> 00:01:43.560
Jonathan Feng: Which had a mass. And then we noted that there was usually a mixing that's generated between the visible sector and the back sector. So these F new news from the visible sector and the private sector have a coupling.

10

00:01:45.000 --> 00:01:55.320
Jonathan Feng: And I asked you to try to figure out what the physical basis Lagrangian look like because that would help in terms of understanding what the actual phenomenal logical consequences are.

11
00:01:56.250 --> 00:02:05.040
Jonathan Feng: And so here's the answer. If you make this definition define this the in terms of PNC in terms of DNA.

12
00:02:06.120 --> 00:02:13.680
Jonathan Feng: The resulting in the garage in is this and you find that you've eliminated the cross term. So there's no mixing and these are actual physical states.

13
00:02:14.460 --> 00:02:24.120
Jonathan Feng: And this A, then, is the standard model normal photon. Good old normal full time and there's be is this new field, which turned out to be the dark, long time.

14
00:02:24.900 --> 00:02:36.870
Jonathan Feng: And with this exercise, you got actually suck a lot of interesting physics out of it because you find, for example, that sure enough the Standard Model photon is nationalists as required. And it doesn't couple of to the darker.

15
00:02:38.700 --> 00:02:49.260
Jonathan Feng: Which is maybe a surprise, but the dark proton does coupled to the standard model. And that gives us a way to actually figure out if it's that they are not and whether this is actually

16
00:02:50.340 --> 00:03:00.810
Jonathan Feng: portal to the drug sector. Okay, so you can take a look at that and on the previous slide when I introduce this problem. I gave you a reference which can help you understand where you come up with this transformation. If

17
00:03:01.320 --> 00:03:10.290
Jonathan Feng: If that's a bit mysterious. But anyway, that's a nice little exercise which is really kind of fun to do because doc photons are just all over this field.

18
00:03:12.660 --> 00:03:16.530
Jonathan Feng: Okay, so then moving on to the actual lecture so

19
00:03:17.970 --> 00:03:24.300

Jonathan Feng: One slide just to remind you where we are. So what we did is we talked about the idea that the dark sector might actually

20
00:03:24.900 --> 00:03:31.170
Jonathan Feng: Be quite full and rich just dark matter, but actually it might have more matter in it and forces.

21
00:03:31.860 --> 00:03:40.200
Jonathan Feng: And then we were confronted with this seemingly Pandora's box where you have infinite number of ways you could have the dark sector interact with us.

22
00:03:40.770 --> 00:03:44.940
Jonathan Feng: And what do you do, and we found that there is a very nice organizing principle.

23
00:03:45.480 --> 00:03:51.150
Jonathan Feng: Which is to use the normal is about interactions, because those are likely the dominant ways that the interactions will take place.

24
00:03:51.720 --> 00:04:05.250
Jonathan Feng: And there are very few of them. In fact, there are three commonly defined in these lead to the dark photons that kicks bowls and in dark firm Ian's got for me and is also a very well known.

25
00:04:06.270 --> 00:04:15.780
Jonathan Feng: Case, which is other names stale neutrinos in every new guns, but the dark for me on name is nice because then we see that we basically completely

26
00:04:17.070 --> 00:04:29.790
Jonathan Feng: You know comprehensively sort of this out. These are the skin, the one that photons. These are the spin zero gatekeepers and sees that there's been one half Crimea and that's basically a complete enumerating of all these portals.

27
00:04:32.130 --> 00:04:39.060
Jonathan Feng: Now each of these models is very simply characterized by only two parameters, the mass of the new particle

28
00:04:39.480 --> 00:04:54.090
Jonathan Feng: And some coupling that tells you how much the bag sectors, talking to us, typically denoted epsilon are some cases mixing angled same data but in either case, these are small numbers and that tells you basically the new particles coupling and interaction spec.

29
00:04:55.140 --> 00:05:12.300
Jonathan Feng: And so in some ways it's a totally wonderful field because you've got, you know, just a few models and each model can be very simply displayed in a nice parameter space which is even two dimensional which you can put on a plane and you can ask how the different experiments produce things

30
00:05:13.710 --> 00:05:16.260
Jonathan Feng: And that has basically led to a

31
00:05:17.340 --> 00:05:29.100
Jonathan Feng: Was gonna say minor industry. But actually, at this point is almost a major industry and trying to understand what are interesting accelerator experiments we can do to pro this new parameter space.

32
00:05:30.240 --> 00:05:39.360
Jonathan Feng: So I will try to do that. It's actually a huge and diffuse topic, so it's hard to do a comparatively, but I'll give some feel for that.

33
00:05:39.960 --> 00:05:50.010
Jonathan Feng: But before we do that, that's just going in ourselves in this parameter space a little so we know kind of what an interesting regions to want to probe before we figure out what we would do to probe.

34
00:05:51.840 --> 00:05:58.650
Jonathan Feng: And I'm going to focus just on one model these dark photon models, just, you know, in the interest of trying to keep this lectures.

35
00:05:59.790 --> 00:06:01.080
Jonathan Feng: Not five hours long.

36
00:06:02.190 --> 00:06:07.620
Jonathan Feng: And then just talk about several of these well known targets that people have discussed in the literature.

37
00:06:08.790 --> 00:06:20.340
Jonathan Feng: There's a meal on D minus two anomaly. There's these nuclear physics anomalies called sometimes the atomic key anomalies their self interacting dark matter. Then of course there's sort of a map really

38
00:06:21.900 --> 00:06:27.960

Jonathan Feng: An anomaly, but a target, which is thermal relevancy like to have a model where you naturally get currency.

39
00:06:31.140 --> 00:06:42.210
Jonathan Feng: So just so you know, these are not picked out of nowhere. This was the cosmic visions report summary of basically all of dark matter searches that could be considered in the next couple years.

40
00:06:42.870 --> 00:06:53.970
Jonathan Feng: And you see there's this enormous giant mass parameter space going the from the zip though EV down here all the way to TV and then even solar mass sort of black hole.

41
00:06:54.690 --> 00:07:05.850
Jonathan Feng: Dark Matter candidates and there were then a bunch of candidates and blue and then some interesting anomalies, you might want to investigate and read and the various techniques to look at them in green.

42
00:07:07.140 --> 00:07:16.770
Jonathan Feng: And what we're talking about then is basically the ones in here. So we're talking about things that are these hidden thermal relics.

43
00:07:17.790 --> 00:07:21.510
Jonathan Feng: Which can be investigated by accelerators right that's the topic of the selectors.

44
00:07:22.110 --> 00:07:32.040
Jonathan Feng: And you see in this agent there happened to be some very interesting anomalies here and the fact that quite clustered together, at least on these giant huge mass scale.

45
00:07:32.700 --> 00:07:38.010
Jonathan Feng: And so they're going to just mention a few of these. So you kind of know what they are. If you haven't heard a lot about them already.

46
00:07:39.900 --> 00:08:02.100
Jonathan Feng: Okay, so starting with the meal and d minus two. This is probably the most long standing anomaly, having to do with particle physics. It started in about 2001 20 years now. It's at the present time. A 3.7 sigma discrepancy between the standard model and experimental value.

47
00:08:03.630 --> 00:08:22.800

Jonathan Feng: And this is something that's very well known, it can be resolved by week scale things like supersymmetry. But what was realized in about 2003 2008 is that they can also be resolved by very light particles which are very weakly interacting

48
00:08:23.850 --> 00:08:35.220
Jonathan Feng: And so here's a diagram of the D minus two in fireman diagrams. So you have a new one and photon comes off and they have various corrections.

49
00:08:35.760 --> 00:08:43.470
Jonathan Feng: And so of course there's the Standard Model correction where there's where there's a photon here in this propagator and that's sort of the one loop.

50
00:08:45.120 --> 00:08:51.570
Jonathan Feng: Standard my contribution and then there's two and three and four and five. And these are the calculated and what extraordinary precision.

51
00:08:52.590 --> 00:09:04.620
Jonathan Feng: But it's also true that if you have a dark photon, you can stick one others around here there's a prime and asked, What kind of properties as a proton have to have to resolve this anomaly.

52
00:09:06.060 --> 00:09:08.430
Jonathan Feng: And the answer is given here in this plot.

53
00:09:09.990 --> 00:09:16.650
Jonathan Feng: Here is the mass of the dark time and you see a kind of ranges from a few and maybe half a GV

54
00:09:17.760 --> 00:09:25.350
Jonathan Feng: So between the electron and the proton mass rain, and then there's a coupling here this kappa is the epsilon i had previously.

55
00:09:26.430 --> 00:09:40.080
Jonathan Feng: Kappa squared is sort of between tell my story and telematics here and you'll see that in this region, there's light gray region, the new amp D minus two can be corrected from the standard model prediction to give you

56
00:09:41.550 --> 00:09:42.480
Jonathan Feng: The experimental value.

57
00:09:44.160 --> 00:09:57.270
Jonathan Feng: And so, you know, this is kind of interesting. This is sort of this region from MTV, the DB, we were interested in and we're talking about couplings of order 10 minus three which is kind of loop level couplings, which is what we were expecting actually also

58
00:09:58.680 --> 00:10:07.350
Jonathan Feng: Turns out, now that a couple years later, this region has now been probed by experiments and it's been excluded for the time

59
00:10:07.950 --> 00:10:24.840
Jonathan Feng: So, strictly speaking, this is not a viable solution anymore, but other particles with similar masses and couplings are ok similar me to be the GV and Tennessee couplings are viable solutions to resolve the GMC my state. So it does still remain interested in Carnegie

60
00:10:33.720 --> 00:10:37.980
Jonathan Feng: What I consider the most tantalizing anomaly in the books at the moment.

61
00:10:39.000 --> 00:10:41.370
Jonathan Feng: Which is the atomic key anomalies.

62
00:10:43.200 --> 00:10:56.190
Jonathan Feng: This is from the field of nuclear physics, a quite a bit different from where we would normally have expected a particle physics now may come from maybe, but the basics are here is that in 2015

63
00:10:57.210 --> 00:11:07.020
Jonathan Feng: The attempt a nuclear physics group look for the case and excited brilliant eight nucleus. So they smash a proton into brilliant maker.

64
00:11:08.130 --> 00:11:21.210
Jonathan Feng: Lithium make an excited brilliant nucleus here and then watch it again, and it turns out that is the case, sometimes to the ground state brilliant and also he plus c minus

65
00:11:22.170 --> 00:11:35.670
Jonathan Feng: And you expect that the opening angle of the plus and minus pair should be very easily, very small. And then as you increase the opening angle to Dropbox. Here's any procured is the opening angle which

66

00:11:36.270 --> 00:11:44.370
Jonathan Feng: Goes from 40 260 degrees and the number of events, a lot of scale should be very much peaked at low angles and then crops and drops and drops

67
00:11:45.210 --> 00:12:04.230
Jonathan Feng: And that's what you'd expect in the standard model. But what they found instead was when they were probing particular excited states that you have this drop that then arise and this right here, this little bump here is statistically extremely significant effort seven signal level.

68
00:12:05.580 --> 00:12:15.660
Jonathan Feng: And it's they've done a lot of prospects to make sure it's not some other spurious thing and they can't find anything wrong with it and no neither can anyone else.

69
00:12:16.890 --> 00:12:29.130
Jonathan Feng: Even more tantalizing just about a year ago they investigated not beryllium nuclei, but helium nuclei and found the same thing. They found a bump in that spectrum to

70
00:12:30.000 --> 00:12:35.220
Jonathan Feng: The bumps are at different angles. This one's at 140 degrees. The other one was at like 110 degrees.

71
00:12:35.730 --> 00:12:42.420
Jonathan Feng: But if you were to explain it in terms of the production of any particle may make some x equals I'm instead of just a normal full time.

72
00:12:42.990 --> 00:12:55.830
Jonathan Feng: It turns out both of those anomalies can be explained by an identical particle with a 17 MTV mass. So this is a plot from paper I wrote with Tim paid and crystal horn.

73
00:12:56.610 --> 00:13:08.610
Jonathan Feng: And the these blue things are the experimental anomalies and feta opening angle and the mass of the excited state the gay surpassed splitting.

74
00:13:09.420 --> 00:13:27.870
Jonathan Feng: And you'll see that in the early in case there was an opening angle hundred 20 degrees in the Caribbean case was opening ankle 110 degrees. But if you were to explain it in terms of the actual master

list of a particle, they both lie along the exact same curve of a 17 MEP particle

75
00:13:29.070 --> 00:13:33.480
Jonathan Feng: So this is providing some evidence for a 17 and maybe state.

76
00:13:34.500 --> 00:13:42.750
Jonathan Feng: With couplings turns out to be in the 10 to the minus or kind of the minus three range which is allowed, but so right in the thick of things as we're going to see

77
00:13:47.610 --> 00:13:53.460
Jonathan Feng: Another anomaly. Now, you know, we had sort of a particle physics anomaly than a nuclear physics anomaly. And then there's this

78
00:13:54.120 --> 00:14:04.380
Jonathan Feng: Good call an anomaly which is from astrophysics yourself interacting dark matter. There are indications from small scale structure that dark matter may be strongly soft interacting

79
00:14:06.390 --> 00:14:14.070
Jonathan Feng: So what I mean by small scale structure. I mean by that variety of observations, but in particular.

80
00:14:15.390 --> 00:14:26.970
Jonathan Feng: Be Halo profiles galaxies had been observed and some of them do not appear to be as custody as projected by standard called the matter predicted by standard called dark matter.

81
00:14:27.840 --> 00:14:44.010
Jonathan Feng: There's a plot is a very nice review of this entire subject by shine through and and Michael you from a couple years ago, but it was just one plot where you have, you know, as a function of the radius from the center of the galaxy out the density

82
00:14:45.090 --> 00:14:57.090
Jonathan Feng: And the black curve is what's predicted by lambda CPM that is standard collision lists called dark matter. And it's, you know, quite

83
00:14:57.870 --> 00:15:15.450
Jonathan Feng: Goes up quite steeply as you get toward the center of the galaxy. And that's what we would call sort of Caspi behavior. But let's observed in some galaxies is it doesn't do that. It actually flattens out

some ways out and it's what we call a chord profile. So I'm not supposed to be.

84
00:15:17.190 --> 00:15:23.040
Jonathan Feng: And, you know, this is basically not ever predicted by called dark matter.

85
00:15:24.630 --> 00:15:37.380
Jonathan Feng: And so if the observations and the simulations are correct. We have a serious discrepancy here. And one thing you can do to resolve discrepancy is to require some self interacting dark matter.

86
00:15:38.370 --> 00:15:55.530
Jonathan Feng: So what's also shown here is that if you got my that self interacts at a very large cross section so sort of cross section of interaction over to the mass of the document or particle of one centimeter square program, you can actually get a prediction that matches this cord from file.

87
00:15:57.600 --> 00:16:04.290
Jonathan Feng: Okay, so what does that mean. So, sigma over am of centimeters squared over Graham can resolve this discrepancy

88
00:16:05.490 --> 00:16:10.050
Jonathan Feng: That's a nice astrophysics units barn per GB is more particularly

89
00:16:11.640 --> 00:16:20.310
Jonathan Feng: The cross sections over mass. And if you convert that whole thing to a mass scale that's 100 MTV to the minus three power.

90
00:16:22.680 --> 00:16:30.240
Jonathan Feng: So they start portal sort of story very simply can give you this. In fact, you can't really get rid of

91
00:16:31.440 --> 00:16:41.010
Jonathan Feng: A documentary matter self interaction. If you've got other stuff in the tech sector. So, for example, a quote on case dark matter, dark matter can scatter in this way with this diagram.

92
00:16:41.670 --> 00:16:47.910
Jonathan Feng: So there's a completely dark sector process. It has no standard model parts to it at all.

93

00:16:48.780 --> 00:17:07.470
Jonathan Feng: But from this we can find that, you know, let's say these couplings. Here are our border one and the dark matter and a prime are all of order the same mass. Well, the way you get this to be signaling over am of sigma squared over Graham is to make the mass scale 100 and maybe

94
00:17:09.240 --> 00:17:23.430
Jonathan Feng: And so this then provide some motivation for a characteristic dark sector mass scale or say 10 or hundred and maybe it depends of course on exactly what this coupling us here. So there's some fudging here, but it's some light.

95
00:17:24.510 --> 00:17:37.410
Jonathan Feng: Light sort of scale and this is not a surprise people talk about how in if you had dark neutrons, effectively, this would give you the right price action. So, this is this QC the scale coming out here.

96
00:17:40.950 --> 00:17:53.100
Jonathan Feng: Okay, last as a sort of target of, you know, wearing parameter Stacy might be interested to simply the thermal relic density, which I've been discussing the last lecture. And just to remind you, this is this plane.

97
00:17:54.690 --> 00:18:03.660
Jonathan Feng: Sort of the interaction strengthen mass when the particle and I gave you this sort of almost cartoonish fact that we like to be on this diagonal

98
00:18:04.530 --> 00:18:19.650
Jonathan Feng: Now with an actual portal model in mind. You can do this in more detail. And so, you know, what are we talking about, we're talking about, say, dark matter, dark matter and dark sector annihilating through a dark coat can say to a plus a minus in the standard model sector.

99
00:18:20.700 --> 00:18:21.270
Jonathan Feng: And

100
00:18:22.380 --> 00:18:35.220
Jonathan Feng: This then has its epsilon coupling here at the dark kotani pissy minus works and you can calculus it let's cross section and you know it's going to go as epsilon squared over the sort of characteristic and mass scale square

101
00:18:36.300 --> 00:18:50.400

Jonathan Feng: And so, in fact, in this case, this line is more accurate than we had any right to expect because it does in fact go with the slope of one in the log log plane because it's epsilon over me crying.

102
00:18:53.400 --> 00:19:04.560
Jonathan Feng: Okay, so these are you know some considerations and then we can actually look at them on a particular plot. So let's just ask where this all fits in this parameter space.

103
00:19:05.280 --> 00:19:13.050
Jonathan Feng: So this is for duck photons. This is the dark photon mass from MTV to GV down here. Here's this coupling.

104
00:19:13.530 --> 00:19:27.630
Jonathan Feng: And it's actually coupling squared. So you gotta be careful. People have different conventions which confused. Everything unnecessarily. But this company squared. And so, you know, coupling of 10 minus three is here and then the minus six recoupling square. Set your

105
00:19:28.920 --> 00:19:30.300
Jonathan Feng: Your price.

106
00:19:31.500 --> 00:19:41.670
Jonathan Feng: And so this is a nice plot from Kim Nelson where he's actually shown where the thermal target is for certain models. So there's a bit of a range.

107
00:19:43.080 --> 00:19:51.690
Jonathan Feng: In some assumptions about parameters, but basically it's doing exactly what I said it's part of going at the slope of one in the logline plane.

108
00:19:52.410 --> 00:20:04.200
Jonathan Feng: And it's, you know, in this region where some of it is ruled out. So I'll be stated regions are excluded already and but some of it is not. And so this is sort of a nice, interesting target range.

109
00:20:05.610 --> 00:20:06.990
Jonathan Feng: If we put some more of these.

110
00:20:08.670 --> 00:20:09.810
Jonathan Feng: Considerations on here.

111
00:20:10.860 --> 00:20:25.410

Jonathan Feng: Here I've highlighted the new on t minus two anomaly, which was already here. So this is his favorite region I mentioned previously, which, as you see in that quote on case is already excluded by a whole variety of experiments, but there it is.

112
00:20:27.840 --> 00:20:37.440
Jonathan Feng: This soft interacting dark matter has no bearing on the coupling to the standard model, as I said, it's a completely dark sector side of phenomenology.

113
00:20:38.190 --> 00:20:48.900
Jonathan Feng: But it does impact the mass. The mass. I say it was roughly 10 maybe 200 and maybe. So this is in some way, nice, simple region to solve itself interacting matter problem.

114
00:20:50.220 --> 00:21:06.060
Jonathan Feng: And then the last one I mentioned was these attempting nuclear anomalies, which is very, very specific in terms of the mass. It's going to be a 17 and maybe particles. There's that line and then it's got a range couplings that are allowed in terms of

115
00:21:07.680 --> 00:21:10.320
Jonathan Feng: Be electronic coupling, which is actually what's written here.

116
00:21:11.460 --> 00:21:23.910
Jonathan Feng: And I should be clear, this is actually not a dark photon. It's something called the protocol a bit cage goes on but you can sort of put its parameters stays in the dark proton plot you assume that we're just talking about

117
00:21:25.770 --> 00:21:31.830
Jonathan Feng: Anyway. So bottom line is, you know, a whole variety of interesting constraints and anomalies that you might want to

118
00:21:33.240 --> 00:21:44.730
Jonathan Feng: Resolve and clearly, you can't do them all at the same time. Right, but there are more relevant doesn't have that he might still would roll anyway. But this is giving idea that this is a particularly interesting regional premise, please.

119
00:21:48.780 --> 00:22:04.860
Jonathan Feng: Okay, so then now let's ask, well, what can experiments to accelerate is due to probe this parameter space. So we need to know what the properties are of the particle. We're looking for and, in particular, how does it decay. And then later. How is it produced

120
00:22:06.210 --> 00:22:10.080
Jonathan Feng: So let's first look at the dark photon decay.

121
00:22:11.820 --> 00:22:21.240
Jonathan Feng: So well, even before that we might ask, you know, how does this thing interact as it goes through matter. So you got this photon like thing, you know, photons get stopped in

122
00:22:22.500 --> 00:22:28.020
Jonathan Feng: Detectors. What about the dark proton. Well, you can very quickly realize that it doesn't interact

123
00:22:28.830 --> 00:22:43.170
Jonathan Feng: Effectively, it passes through matter without interacting the radiation length is sort of the 10 centimeters. You know, you're like, I don't know what TV quote on 10 centimeters, but then modified by this epsilon and so epsilon is 10 to the minus four.

124
00:22:44.610 --> 00:22:53.790
Jonathan Feng: Then, you know, all of a sudden that radiation land for this doc photon is 10 to nine meters distance of the moon. So in terms of any human scale.

125
00:22:55.320 --> 00:22:57.480
Jonathan Feng: Detector. It simply doesn't interact

126
00:22:59.670 --> 00:23:10.080
Jonathan Feng: Can I be detected them. Well, luckily, yes, because it decades. So this is not only not like a photon in that it's much more weekly interacting, but it's also not like it because it's massive.

127
00:23:10.680 --> 00:23:17.850
Jonathan Feng: Instead of mass Lex. And so it can be k two things. So if it's above an MTV indicate, give me a C minus with some coupling there.

128
00:23:19.230 --> 00:23:27.960
Jonathan Feng: And so then, let's ask, Okay, well, how far does it go before the case. So what is the lamp, the lamp is you know the velocity times the

129
00:23:29.520 --> 00:23:31.860
Jonathan Feng: Tao time again factor. How's the

130
00:23:33.750 --> 00:23:34.560
Jonathan Feng: Rest lifetime.

131
00:23:35.670 --> 00:23:53.130
Jonathan Feng: And you can plug in these numbers were a you know relativistic quote time where v is about one this lifetime those as one over epsilon squared times the mass heavier things that a faster, stronger, only a couple things to keep faster.

132
00:23:54.360 --> 00:24:02.160
Jonathan Feng: And then the lifetime is further enhanced by time Belize. And of course, if it's like a TV particle and it's only 100 MTV, well then you kind of live camera.

133
00:24:03.870 --> 00:24:18.960
Jonathan Feng: So put these things in here if you normalize to epsilon attended minus five and mass hundred or maybe we'll just sort of event target range we identified earlier and talk about a TV particle this dark photon those 100 meters before the case.

134
00:24:20.040 --> 00:24:39.660
Jonathan Feng: Which is a very and particularly the cabling right we're used to things like 10 to the minus 15 meters. So this is a macroscopic land and leads to the idea that these particles are long live particles, I go a long way in actual sort of, you know, human lengthy units meters and things

135
00:24:40.980 --> 00:24:51.360
Jonathan Feng: And it's double equals one over epsilon squared one over at Mass square. So it's actually quite dependent on these these masses and couplings.

136
00:24:53.790 --> 00:25:11.670
Jonathan Feng: Okay, so then just to sort of orient us again here's this new political landscape. And the point here is that the lamp goes is one over epsilon squared m squared. So we know that up here, you know, things last go for like a fair me or something. But if you start moving down this diagonal

137
00:25:12.870 --> 00:25:23.580
Jonathan Feng: You basically got four powers here. So if you go from here down here, which is six order of magnitude and either interaction strengthen mass that's 10 to the 24

138
00:25:24.240 --> 00:25:36.630

Jonathan Feng: And so that family left becomes enormous very quickly. And so this least Long live particles were lifetime can vary quite a bit how long this diagonal

139
00:25:40.560 --> 00:25:49.050
Jonathan Feng: Okay, so that's interesting. We're talking about long the particles. Now that power they produced. Well, let's again, we're always focused on the dark photon here.

140
00:25:49.590 --> 00:26:02.610
Jonathan Feng: How can you produce this or very quickly realized that you can think of any standard model process, you've ever heard of which has a standard model photon in it and replace the Standard Model photon or the dark for time.

141
00:26:03.750 --> 00:26:18.930
Jonathan Feng: Okay, so you know you know pions. The key to photons. Now you can replace one of the photons with a dark proton, you know, the photons get Prem baffled things and so you can replace been struggling with that premise, Robin. Are you radiate after dark.

142
00:26:20.250 --> 00:26:25.680
Jonathan Feng: You know, you can have a hard scattering where cork and I glue on smashed together and make

143
00:26:26.850 --> 00:26:38.460
Jonathan Feng: A photon one. Now you can make a doctor baba scattering molar scattering. Anything you can think of that has a photon in it can now happen again with the dark for nothing.

144
00:26:39.660 --> 00:26:46.800
Jonathan Feng: So, you know, once this sinks in. You realize that you have now opened up the floodgates to experimental probes.

145
00:26:48.270 --> 00:26:58.800
Jonathan Feng: At both the energy and intensity frontiers, there's so many different processes that one can imagine the probe a quote on because photons are so ubiquitous throughout particle physics phenomenology.

146
00:27:00.420 --> 00:27:14.190
Jonathan Feng: So here I will try to just give a small sampling of ways that this has been done to give an impression of the diversity of existing and plant experiments and also hopefully to convey a bit of excitement because it's really become a growth industry sort of

147
00:27:15.300 --> 00:27:17.670
Jonathan Feng: still growing, I think, very rapidly.

148
00:27:20.280 --> 00:27:34.950
Jonathan Feng: Okay, so let's look at existing constraints of dark photons before we move on to feature and proposal constraints. So here again is that photon parameter space. And this is the mass. This is the coupling.

149
00:27:36.420 --> 00:27:49.980
Jonathan Feng: And again, in a nice plan from Kim Nelson. You see this thermal target region here, but also you see the lifetime, at least the rest lifetime of the photon in these countries here.

150
00:27:50.670 --> 00:27:58.890
Jonathan Feng: And exactly what I said to you before that it increases rapidly as you go down this diagonal. So here's 10 microns. But, you know, here it's already

151
00:27:59.790 --> 00:28:13.560
Jonathan Feng: Centimeter and what is it yeah 10 millimeter and that's of course rest lifetime. If these things are produced boosted which we usually are concerned, like, you know, we could easily have meters or kilometers around here.

152
00:28:14.640 --> 00:28:25.260
Jonathan Feng: So that gives you a feel for the kind of thing we're talking about. And then there's this enormous number of existing constraints in these various colors.

153
00:28:27.240 --> 00:28:38.010
Jonathan Feng: So as I mentioned last time, I can't possibly describe all these and you wouldn't want me to anyway. But just to give sort of a feel for kind of how this works.

154
00:28:39.360 --> 00:28:55.260
Jonathan Feng: Roughly speaking, there's two kinds of constraints on here. There's a top there's a bunch of constraints that are pushing down from, you know, high epsilon. Okay. And these are what you could call bump hunts. So you make

155
00:28:56.580 --> 00:29:13.260
Jonathan Feng: You know, a dark photon in some way and it decays fairly quickly to say equals a minus. And you look for the policy minus

signature with whatever else in the event and better yet look for the policy minus having an invariant mass of a certain

156
00:29:14.670 --> 00:29:17.940
Jonathan Feng: You know, constant, which would be the proton mass

157
00:29:19.440 --> 00:29:29.580
Jonathan Feng: And so, you know, this can happen in all sorts of ways. One of the leading ways is from a bar and now Bell, where you have A plus A minus

158
00:29:30.030 --> 00:29:43.980
Jonathan Feng: Which can of course go to two photons. But now you think of a going to twofold one photon and wonderful and the dashboard and the case in this way so you have equal to minus two equals A minus photon and you look for these sort of unusual.

159
00:29:45.420 --> 00:29:46.710
Jonathan Feng: Kinematic distributions.

160
00:29:48.390 --> 00:30:03.000
Jonathan Feng: And when you do that you get, you know, because you're looking at these little bumps here these very spiky sort of constraints here but basically you start eliminating everything with epsilon up the down to 10 minus three.

161
00:30:04.350 --> 00:30:15.450
Jonathan Feng: And this is simply understood, because when epsilon gets a little less than that. You just don't make very many of these protons because your original production depends on epsilon

162
00:30:15.930 --> 00:30:25.980
Jonathan Feng: So that's nice too small. The event rate goes down and you can't put any bounds on it. So, you know, okay, this rules out but parameter space with epsilon bigger than 10 minus three.

163
00:30:26.670 --> 00:30:41.610
Jonathan Feng: But in some ways, we didn't expect that plan to be that high. Anyway, we thought it was leaked generated. So it should have been kind of minus three or less. And so, you know, this is certainly great progress, but it's not dimming anyone's hopes that there's that photon in the world.

164
00:30:44.130 --> 00:30:48.450

Jonathan Feng: Now the other side though is coming up from the bottom in the sort of that Norway.

165
00:30:49.110 --> 00:31:00.690
Jonathan Feng: And what are these, these are constraints from being done experiments from a variety of them. Many of them very old say even from the 80s summit slack some certain places.

166
00:31:01.530 --> 00:31:09.660
Jonathan Feng: And the story here is the following. You have some being the electrons and protons, which smashes into a target. That's the being dumped

167
00:31:10.590 --> 00:31:21.990
Jonathan Feng: Then you have some shielding. In this case it's pictured as a mountain, but it could be anything like a lead or something and then on the other side you have your detector.

168
00:31:23.160 --> 00:31:30.090
Jonathan Feng: So what you do here is you are looking for the stock photon, you take advantage of the fact that it doesn't interact in matter.

169
00:31:30.630 --> 00:31:47.250
Jonathan Feng: And it decays after a long time. And so it can easily get through this. She'll but you know make visible he plus A minus pairs or me plus or minus whatever but most other stuff doesn't. So the shielding this hill in this case.

170
00:31:48.480 --> 00:31:55.410
Jonathan Feng: filters out all the background from the junk that would, you know, normally apparent when you have a high energy be hitting a target.

171
00:31:56.550 --> 00:31:58.050
Jonathan Feng: And so there's a fixed time to get

172
00:31:59.430 --> 00:32:08.220
Jonathan Feng: Experiment and you're looking for this very unusual signal of high energy stuff coming out of a hill or something.

173
00:32:10.140 --> 00:32:20.550
Jonathan Feng: And so these then put constraints coming from down here. And the reason they don't go up to here is that when you start moving in this direction.

174
00:32:20.970 --> 00:32:27.120
Jonathan Feng: All of a sudden your dark photon decays in the hill in the shielding and so you don't get any signal.

175
00:32:27.750 --> 00:32:42.510
Jonathan Feng: So these very rapidly cut off if you move up in this direction, because you have this exponential decay and very rapidly. If the decay is only a centimeter. Nothing is going to get through a meter of rock.

176
00:32:44.220 --> 00:32:55.290
Jonathan Feng: This isn't shown here, but these also cut off down here. They sort of exclude regions like this. But if people are very low epsilon, they don't work either, because you just don't make remade back photons in the first place.

177
00:32:57.450 --> 00:33:09.510
Jonathan Feng: Okay, so that's my attempt to sort of orient you to this parameter space. There's some interesting region in here and there's two kinds of existing constraints being dumped and bump heads.

178
00:33:12.600 --> 00:33:24.540
Jonathan Feng: And what about the future well for the future. Everything that I just talked about will be improved. So for example, the bump heads. We go from that bar and belt, the belt to

179
00:33:25.020 --> 00:33:34.500
Jonathan Feng: And so that will push down from the top into this region, especially with the phenomenal expect the luminosity and say 50% of Barnes, about two

180
00:33:35.820 --> 00:33:45.930
Jonathan Feng: And then similarly would come up. We're going to improve sensitivity in the been done type experiments. So there are balanced on here from like a 62

181
00:33:47.130 --> 00:33:48.720
Jonathan Feng: Dark quest ship.

182
00:33:51.360 --> 00:33:51.960
Jonathan Feng: So,

183
00:33:54.840 --> 00:33:55.260

This

184
00:34:00.150 --> 00:34:01.320
Jonathan Feng: Okay, so

185
00:34:02.670 --> 00:34:10.140
Jonathan Feng: That is all good, but qualitatively. There's nothing different questions. Huge amounts of approvals required to do any of these things.

186
00:34:11.130 --> 00:34:18.720
Jonathan Feng: Also want to hear that. Let me just applies there some kind of new things. So there's this red top experiment which is a proposed experiment.

187
00:34:19.350 --> 00:34:30.570
Jonathan Feng: Which is looking for at the case. So I mentioned before that mess on the case can be a powerful prob about Qualcomm's red top is really interesting. It's proposed.

188
00:34:31.740 --> 00:34:48.210
Jonathan Feng: I guess it could be Cerner formula, but at CERN. It's at the PS, which is one of the sort of progenitor accelerators that feeds into the ELYSEE, eventually, but you don't need much energy to make an ADA so right. A prime. And so you just need a huge numbers of these

189
00:34:49.530 --> 00:35:03.690
Jonathan Feng: Haters this and you can look for their rededicated tokens. So that's the sort of for that purpose, sort of region coming in from the top to be quite interesting, especially if it gets down to here because I will cover the whole brilliant rain.

190
00:35:05.520 --> 00:35:20.640
Jonathan Feng: Another one here is Fazer which you see does shower into this interesting region also and there are a variety of bounds here. One is from run three and one is from behind the monastic era which will cover more space.

191
00:35:21.840 --> 00:35:28.650
Jonathan Feng: This is different from the previous ones and that it's actually operating at the energy friend here at the LLC.

192
00:35:30.150 --> 00:35:43.020
Jonathan Feng: So let me just give you a little bit of a flavor for Fazer is the phasers hands for forward search experiment. And it's basically

using this being time idea but Adam itself had a collider said, I'm excited.

193
00:35:44.220 --> 00:35:54.540
Jonathan Feng: And so here's say Atlas and the Atlas proton beam goes the ELYSEE partner and being goes like this, but a Forbes eventually curves. So, can make a big circle.

194
00:35:57.420 --> 00:36:09.900
Jonathan Feng: Immediate phasers, to put it here, Claire a dark photon would just travel straight and leave the LSC being pipe and tunnel and keep going straight into

195
00:36:10.470 --> 00:36:23.490
Jonathan Feng: Where phasers located and turns out there's a little tunnel here and put Fazer there without being too much. And this is now currently under construction. In fact, it's going to be installed barely see in a few months.

196
00:36:23.970 --> 00:36:33.480
Jonathan Feng: And it has the same idea. There's this, you know, large collision here with us and all sorts of stuff including lots of photons possibly

197
00:36:33.960 --> 00:36:48.000
Jonathan Feng: Than 100 meters a rock which fields off everything else, leaving you this very quiet place here where you can look for some crazy signal basically 100 GB or TV electrons coming out of the wall.

198
00:36:49.470 --> 00:37:06.690
Jonathan Feng: And so this is a picture of this thing. What I want to emphasize here is that this entire detector is about five meters long. So it like many of the other detectors in this story is small and can be put together pretty quickly and inexpensively.

199
00:37:07.740 --> 00:37:15.750
Jonathan Feng: And this is the sort of future and Fazer we would just want to overstep the barn roughly about a week of running on the ELYSEE turns back on.

200
00:37:16.140 --> 00:37:27.090
Jonathan Feng: You will prob this parameter space, which includes some new parameter space. And also, interestingly, the brilliant mate area. And then, of course, because more and more sensitive to gather more data.

201

00:37:31.230 --> 00:37:39.660
Jonathan Feng: Okay, so everything I talked about there was for charged, click on the case, the case to eat plus c minus plus minus, things like that.

202
00:37:41.070 --> 00:37:48.090
Jonathan Feng: It's also possible, though, that the photon indicate invisibly so if your dark photon mass along with particle

203
00:37:49.110 --> 00:37:53.730
Jonathan Feng: Is bigger than two times the dark matter mass which is presumably also sitting in the backseat.

204
00:37:54.870 --> 00:38:01.680
Jonathan Feng: Then since that the case and suppressed by any of these excellence, having to talk to the visible sector.

205
00:38:02.760 --> 00:38:09.750
Jonathan Feng: This will typically dominate and so hundred percent of the branch and fraction of regret full time working on the dark matter, leading the invisible the case.

206
00:38:11.280 --> 00:38:22.290
Jonathan Feng: So then nothing I talked about previously works because those are all looking for classy minus and things. But what can you do. Well, it turns out there's a lot of interesting work in this direction.

207
00:38:23.760 --> 00:38:34.530
Jonathan Feng: One idea is, OK, you make the dark matter. So the dark photon, you know, the case, but it was too dark matter. And then you can look for the dark matter to scatter off of something

208
00:38:35.400 --> 00:38:49.080
Jonathan Feng: And in fact this is extremely similar to and neutrino detector. So here's the kind of picture. This is, I think, from attacked by Brian bell to tell. So stay at Fermilab you have a proton beam. It's a brilliant target.

209
00:38:51.090 --> 00:38:59.730
Jonathan Feng: Makes a whole bunch of stuff being done. And typically, you might think it might make some neutrinos coming up with charge pion decay.

210
00:39:00.150 --> 00:39:17.340

Jonathan Feng: neutrino comes in and then scatters off of some detector my community boom in this case. Well, the same process will kind of work for the dark matter, you now have mutual clients, which the K to say dark photons and the dark photons turn into dark matter this chi.

211
00:39:18.810 --> 00:39:30.450
Jonathan Feng: But then that background, I can come in and scatter off with something here in the detector. So this is the entire process here. Dark matter production through pion decay and then documentary scattering to

212
00:39:32.130 --> 00:39:33.390
Jonathan Feng: Quote on exchange.

213
00:39:34.650 --> 00:39:43.830
Jonathan Feng: And so even if the dark float on the case and visibly you can look for it this way. And so this is a parameter space which is roughly the same mass here some coupling here.

214
00:39:44.400 --> 00:39:57.810
Jonathan Feng: And, you know, like this many boom thing will be able to push down a little bit here and there's a variety of other interesting already interesting approach here and this is the relevancy target that you want to read

215
00:40:00.810 --> 00:40:09.270
Jonathan Feng: Another idea is to look for invisibly decaying got photons for you don't even need that truck manager scatter so

216
00:40:10.290 --> 00:40:14.940
Jonathan Feng: This is basically looking for missing energy harnessing momentum.

217
00:40:16.560 --> 00:40:27.840
Jonathan Feng: And this is in even more powerful technique if you can get work. So this is taken from Kim Nelson describing big L DMX experiment proposed for slack.

218
00:40:28.740 --> 00:40:38.550
Jonathan Feng: So here's the same sort of thing at the beginning, you have some electron come in scatter and you'll make a duck float on which the case to dark matter invisibly okay

219
00:40:39.360 --> 00:40:48.660

Jonathan Feng: But instead of trying to then look for the dark matter to scatter later on, which costs you some rate because of course that's a real process.

220
00:40:49.350 --> 00:41:05.610
Jonathan Feng: You just simply note that the incoming energy electron and this electron that comes out here don't have the same energy. And of course the momentum can be there for the the missing momentum because something was taken off by the token, which you don't see

221
00:41:06.960 --> 00:41:25.680
Jonathan Feng: So this can be a very powerful technique to look for the production of something invisible. And if you look here, the same parameter space LDL max in various phases can probe this parameter space and notably go well past the target to a relic density

222
00:41:26.940 --> 00:41:33.660
Jonathan Feng: Region. So that's quite an improvement say maybe for there's a magnitude which is really remarkable in this field.

223
00:41:37.650 --> 00:41:39.810
Jonathan Feng: Okay, everything I talked about there was

224
00:41:41.550 --> 00:41:49.260
Jonathan Feng: No dark photons. Of course there's other part portal particles and they can have quite different behavior. So just to be feel for this.

225
00:41:50.040 --> 00:41:58.140
Jonathan Feng: Dark Higgs bosons are also like an extremely weekly coupled, but they're different in that they are crippling proportional the color complaints.

226
00:41:58.650 --> 00:42:03.960
Jonathan Feng: So instead of for the being democratic coupling that all charged particles like that protons do okay expose on

227
00:42:04.470 --> 00:42:14.220
Jonathan Feng: As soon as you get to a place or you can cinematically decay to have your protocol, they will do that. So as soon as the new threshold turn on as you move up and up in mass you start getting

228
00:42:15.540 --> 00:42:17.670
Jonathan Feng: The case to the heaviest possible particle

229
00:42:19.710 --> 00:42:24.240
Jonathan Feng: The best probes are then things that talk to heavy things like the beans on

230
00:42:25.800 --> 00:42:33.930
Jonathan Feng: Because, you know, the beam is on. So here's the cubby cork, which can decay to a dark expose on strange cork.

231
00:42:34.620 --> 00:42:41.010
Jonathan Feng: And you benefit a lot and the fact that this is coupling to a top cork in the loop. So, you know, you call a coupling suppression.

232
00:42:41.580 --> 00:42:57.390
Jonathan Feng: But as soon as you start talking about kayonza pions doing this, you start paying large prices in the accompanying here. And so being as on the bank transaction is much bigger than the K on one the Higgs boson of is much bigger than the pie, and it gets closer

233
00:42:59.070 --> 00:43:01.920
Jonathan Feng: So in this case, you really want to make Venus ons.

234
00:43:02.610 --> 00:43:12.210
Jonathan Feng: And then you confronted with the fact that these beans and they're heavy, so I'll fix type of experiment is not so great typically for making lots of being as honest because it just don't have enough energy

235
00:43:12.780 --> 00:43:30.840
Jonathan Feng: With a single exonerated being you want colliding beans. And so here's a plot from the physics bound colliders summary, this is the dark Higgs case which is standing, you know, several orders of magnitude in the caves mass and this coupling parameter science data here.

236
00:43:31.860 --> 00:43:41.220
Jonathan Feng: And all these bounds our existing ones. This is an interesting. These are from astrophysics. So say from supernovae and BBN

237
00:43:42.000 --> 00:43:49.950
Jonathan Feng: And appear. Some of those particle physics ones. But if you really look at the future you find all these experiments care and

238
00:43:50.730 --> 00:44:00.900

Jonathan Feng: The thing. Most of these have in common is that they are actually happy Energy Frontier, where you have lots of energy, you know that the hell he makes lots of the Amazons

239
00:44:01.500 --> 00:44:10.350
Jonathan Feng: And so you can look for these so Fazer already mentioned, but let me talk a bit about Methuselah and Codex, be a really interesting experiment.

240
00:44:11.460 --> 00:44:25.860
Jonathan Feng: So Methuselah is a large detector proposed for the surface on your CMS at the LA FC. And this is a slide from Henry in the body. And one of the leaders of them obviously collaboration.

241
00:44:27.090 --> 00:44:46.200
Jonathan Feng: And he shows here but basically what the idea is. So here's CMS. Here's the LSC smashing together protons of high energy and then pop on the surface, a very near the surface, you have this huge array of simulators basically a tracking detector.

242
00:44:47.250 --> 00:44:54.210
Jonathan Feng: And how, what I mean by huge and if you can see it, but these dimensions are like 100 meters by hundred meters.

243
00:44:54.840 --> 00:45:12.780
Jonathan Feng: So, you know, square football field like size and then the hype here is about 30 meters so very tall, and I think the latest is that they hope to sink this into the ground. So it's not sticking out 30 meters high in the air, but still it's 30 meters in terms of the sort of

244
00:45:13.920 --> 00:45:14.760
Jonathan Feng: The key volume.

245
00:45:16.290 --> 00:45:29.850
Jonathan Feng: And so the idea is that you can make fade in this case, you know, quote, cons that then come out our dark Higgs Boson zipping come out and then decay two tracks tracks tracks and you see them.

246
00:45:30.960 --> 00:45:35.550
Jonathan Feng: Through these layers of tracker simulator layers.

247
00:45:36.600 --> 00:45:43.800
Jonathan Feng: And so this is a really interesting idea, which is been proposed for for Sir clearly see

248
00:45:45.660 --> 00:45:51.480
Jonathan Feng: And then there's also codec is B, which is in some ways sort of a slightly smaller version of what these

249
00:45:52.110 --> 00:46:11.400
Jonathan Feng: Little closer. This is again near CMS and the idea is to basically instrument similar sort of way to like this, with this little box, which I believe was sort of a centimeter cube box and put this in this hole here which is

250
00:46:12.720 --> 00:46:21.990
Jonathan Feng: Also sort of at an angle. When I PT relative to the beam direction, but there's some shielding here to kill our backgrounds and then

251
00:46:23.070 --> 00:46:26.640
Jonathan Feng: The dark Higgs Boson Decatur. There's a lot of stuff here and codecs be

252
00:46:30.600 --> 00:46:44.040
Jonathan Feng: Okay, so I'm near the end of my time. And so let me just end with the following. So I talked about a whole bunch of speculative ideas and I think they're quite exciting. But I thought I'd maybe end with something which is

253
00:46:45.570 --> 00:46:50.520
Jonathan Feng: I think exciting because it's an detection of an almost invisible.

254
00:46:51.630 --> 00:46:55.800
Jonathan Feng: Which is going on right now at at the LA see

255
00:46:57.030 --> 00:47:07.200
Jonathan Feng: So this is the detection of an anonymous of Islam, which you know is just any trainer and of course neutrinos admin detected in many, many ways always feeling pretty interesting insights

256
00:47:08.130 --> 00:47:18.930
Jonathan Feng: But one fact that his little advertise. Is that not a single collider neutrino has ever been detected. So accelerators. Sure. Fix target, sure, but not colliding beans.

257
00:47:20.550 --> 00:47:29.190

Jonathan Feng: 1984 the Ruhollah and recall said, you know, if you wanted the technical either neutrino. You should look in the forward direction at

258
00:47:30.660 --> 00:47:42.030
Jonathan Feng: Just down the beam pipe. Basically, because the highest energy neutrinos are there. And as we all know, neutrinos don't like to interact, but they do it back a little bit better after that high energy get higher cross sections there.

259
00:47:43.560 --> 00:47:57.300
Jonathan Feng: So this idea sat around for 14 years at 2134 years and nothing happened. Except in 2018 that laser collaboration actually stuck at 30 kilograms and most of detector in

260
00:47:57.750 --> 00:48:13.740
Jonathan Feng: Before direction hammock being collision axis. So this is a picture of it. This was the sort of prototype of the prototype. This is the pilot detector stuff and sat there just for 12 and a half in redemptive barn six weeks of data.

261
00:48:15.210 --> 00:48:27.090
Jonathan Feng: And the amazing thing is that this detector is expected to have found 10 treatment interactions, just because of where it's located this detector, despite its small size, and it's

262
00:48:28.290 --> 00:48:36.360
Jonathan Feng: Been only there for six weeks collects 10 neutrinos, whereas all collider detectors ever placed in a collider so far, zero.

263
00:48:37.680 --> 00:48:39.870
Jonathan Feng: And so this is now underway.

264
00:48:40.980 --> 00:48:56.970
Jonathan Feng: We in the phase of collaboration have now started analyzing this data. And this is sort of hot off the press or soon to be hot off the press. These are actual neutrino events, very likely that were detected interacting in this little 30 kilograms protector.

265
00:48:58.710 --> 00:49:02.970
Jonathan Feng: And so this is just the beginning of probably quite interesting story.

266
00:49:04.350 --> 00:49:09.570

Jonathan Feng: This Fazer neutrino detector will detect neutrinos for the hologram three

267
00:49:11.220 --> 00:49:21.720
Jonathan Feng: Here are three flavors and neutrinos new a new new town and you know that there's a lot of low energy data, but basically it's very hard to find TV neutrinos.

268
00:49:22.290 --> 00:49:43.200
Jonathan Feng: And so there's this, you know, no TV any trainer has never been seen to interact and then your ears and our new town and your meal. Same thing, although there are ice cube in us up here and so phase and it will detect thousands of these things in this highest energy ever sort of regime.

269
00:49:44.610 --> 00:49:51.930
Jonathan Feng: And then going forward to the high luminosity here. There's some talk of forward physics facility that will allow us to put a even bigger detector here.

270
00:49:52.710 --> 00:50:01.110
Jonathan Feng: Potentially even detect the million million neutrinos at a TV energy, which will lead to all sorts of possible advances which is right here.

271
00:50:02.370 --> 00:50:15.570
Jonathan Feng: So anyway, this is now it's not quite dark sector because it's a neutrino. But it is an almost invisible and I think it's a very interesting sign of things to come, where we can actually just get some of these detectors built

272
00:50:17.940 --> 00:50:22.800
Jonathan Feng: So let me summarize. So in this last part.

273
00:50:24.270 --> 00:50:29.430
Jonathan Feng: I tried to point out that duck sectors, open up many new opportunities for putting the physics static songwriters

274
00:50:31.350 --> 00:50:44.130
Jonathan Feng: There are many, many, many different ways this could happen but and useful organizing principle in the field has been through these portal particles. And so there's dark photon and start kings bows on stay on the train else trainers.

275
00:50:45.870 --> 00:51:03.150

Jonathan Feng: But of course this isn't everything. There are many others. So like axiom like particles like gauge goes on b minus all gauge bills on other kinds of dark matter and elastic dark matter, the whole variety merely charged particles of things that I didn't talk about but

276
00:51:04.860 --> 00:51:07.740
Jonathan Feng: They're easy to find some reference the second

277
00:51:09.330 --> 00:51:14.280
Jonathan Feng: And the basic point is in all these models. They're enormous untouched regions, a parameter space.

278
00:51:15.720 --> 00:51:20.850
Jonathan Feng: are characterized by light very weakly interacting particles long lifetimes, so it's

279
00:51:22.260 --> 00:51:25.530
Jonathan Feng: You know growth industry and looking for LLP long the particles.

280
00:51:27.780 --> 00:51:40.290
Jonathan Feng: And it's just a question, though, sort of, you know, getting organizing sorry are starting to tap into some of these regions because we might find something very enlightening, not only for particle physics but also for cosmology.

281
00:51:41.970 --> 00:51:48.060
Jonathan Feng: So there are many other candidates. I didn't get a chance to discuss many new experimental applications. I bought it has the energy frontiers.

282
00:51:49.170 --> 00:51:57.450
Jonathan Feng: But luckily, this has become a huge field now. So there are nice reviews of it. So if you're interested, I listed three resources that could be helpful.

283
00:51:58.080 --> 00:52:08.190
Jonathan Feng: One is from 2017 in this field that's actually a little bit out of date because there's been a lot of progress in three years. But anyway, that's a good one.

284
00:52:08.550 --> 00:52:20.040
Jonathan Feng: Because it was sort of a summary of the US cosmic revisions exercised. So in terms of an American North American perspective, it gives a pretty good feel for what's going on then.

285
00:52:22.710 --> 00:52:29.700
Jonathan Feng: The year and a half ago, a sort of European version came out was gone colliders at CERN put out a report which

286
00:52:30.420 --> 00:52:40.110
Jonathan Feng: Summarize things with a sort of more European certain centric perspective, but also tried to collect a lot of the information on various portals and things

287
00:52:40.980 --> 00:52:56.190
Jonathan Feng: And then finally, if you want to really up to date version which is not completely process, but it's you know happened the last week or so snowmass process is underway and there are a variety of interesting meetings the rare process six group had a kickoff.

288
00:52:59.880 --> 00:53:12.090
Jonathan Feng: And this is the indigo paint. So if you want to find the latest, greatest summary of many of these experiments and the proposed experiments. You can go there. So I think that's it. Let me stop now.

289
00:53:13.770 --> 00:53:16.830
Lisa Kaufman: Thanks, Jonathan, I don't know what caused the reporting to stop but

290
00:53:18.900 --> 00:53:19.380
Jonathan Feng: Yeah.

291
00:53:19.590 --> 00:53:28.860
Lisa Kaufman: You started back up again. And thanks for ending on time. Also, and so we have plenty of time for questions, so I'll hand it over to rich so that we can get this going.

292
00:53:30.180 --> 00:53:33.240
Richard Partridge: Right, good. Thank you, Lisa. Great talk.

293
00:53:35.670 --> 00:53:36.150
Richard Partridge: Thanks.

294
00:53:37.500 --> 00:53:43.980
Richard Partridge: So the first question is on slide number 32

295
00:53:47.520 --> 00:53:47.820

Jonathan Feng: Okay.

296
00:53:48.000 --> 00:53:55.320
Richard Partridge: So the question is there a difference between stern trios, and having neutral lap times

297
00:53:56.820 --> 00:54:04.020
Jonathan Feng: So not really from a, you know, for my point of view, they're very much the same. They're complete gauge single it

298
00:54:05.280 --> 00:54:13.110
Jonathan Feng: Particle is a couple through this Higgs doublet lap time and then this particle coupling.

299
00:54:14.670 --> 00:54:29.220
Jonathan Feng: In terms of how people use it. I guess most people would think of stay on neutrinos as these things are sorted the Eb range that are you know like the LSD anomaly and other families mostly soundbites Johnny trainers, even the three and a half kV

300
00:54:30.390 --> 00:54:40.650
Jonathan Feng: Anomaly as far as telling Trina whereas having it for leptons refers to things that are more more heavy. So in the sort of GV hundred MTV range.

301
00:54:41.070 --> 00:54:52.350
Jonathan Feng: And so there's sort of that distinction. But in terms of exactly where that border is it's it's a little bit messy and the dog for me I name is also sort of overlapping with all these things as well.

302
00:54:54.870 --> 00:54:55.470
Richard Partridge: Okay.

303
00:54:57.120 --> 00:55:17.550
Richard Partridge: The next question is, is dark photo, the only game in various ways, which we can have what we call usually the vector portal models in simplified dark matter model literature. So you can gauge in various issue the simplified models is not emphasized in the literature.

304
00:55:19.470 --> 00:55:26.760
Jonathan Feng: So yeah, that's a good point. That is true. It's the only gauge invariant point I think last lecture.

305
00:55:27.120 --> 00:55:38.100

Jonathan Feng: Is a bit related to the question that came up in the last lecture, which is why don't you put like a su to gauge will sign or something like that. And no, it has to be you engage both sides on both sides.

306
00:55:40.740 --> 00:56:00.510
Jonathan Feng: One thing that's important, though, is that this gauge bows on mixing can further and mix with other things. So you can take a dark photon and then mess around with this couplings little bit by mixing it with, say, a, b minus engage those on LM you minor cell tower gauge

307
00:56:01.620 --> 00:56:07.080
Jonathan Feng: And so in that way you can sort of change the complaints. But in terms of the portal interaction itself.

308
00:56:08.460 --> 00:56:14.430
Jonathan Feng: The only gauging variant one you can write down is that one that I wrote down which yields a sort of standard vanilla.

309
00:56:19.050 --> 00:56:19.830
Richard Partridge: Thank you.

310
00:56:21.150 --> 00:56:25.980
Richard Partridge: Christian. Yes. On slide 36

311
00:56:27.000 --> 00:56:32.430
Richard Partridge: Why would we only get this 17 maybe protocol a particular opening

312
00:56:34.680 --> 00:56:36.630
Jonathan Feng: Okay, so I might have

313
00:56:38.550 --> 00:56:39.810
Jonathan Feng: Changed the

314
00:56:41.160 --> 00:56:44.490
Jonathan Feng: Ordering of the slides. So I think this is the slide we're talking about here.

315
00:56:45.540 --> 00:56:46.050
Jonathan Feng: So,

316
00:56:48.870 --> 00:57:03.240

Jonathan Feng: What happens is that okay so if you're in the expos on restroom, then of course the positron and the electron come out back to back, because, you know, that's all they can do.

317
00:57:04.140 --> 00:57:25.500
Jonathan Feng: And the reason the state is not 180 degrees is because the X is actually moving. And so that sort of bands. The plus a minus in the direction of the x and so that opening angles 180 degrees 240 or something. So it's absolutely true that the opening angled is not 100% fixed. It's

318
00:57:26.760 --> 00:57:35.130
Jonathan Feng: Got a range, but it turns out and actually this was something that we discussed in depth in this last paper with the Tate and behind

319
00:57:36.060 --> 00:57:53.490
Jonathan Feng: That it turns out that the minimal angle is the one where spray strongly peak so so brilliant case the opening angle can be say 140 degrees in Hyder but it's extremely pick that 140 the minimum one. And so that's presumably what they're seeing in this experiment.

320
00:57:54.840 --> 00:58:12.570
Jonathan Feng: Although it's also spread out by experimental energy resolution and things, but so it's a very good question. Formally, at the end of your perfect detectors, you will see a distribution will open the ankles. But in practice, what you see is almost, almost Mano a

321
00:58:13.650 --> 00:58:19.140
Jonathan Feng: Mano ankle distribution and it spread out just by experimental effects.

322
00:58:22.470 --> 00:58:22.830
Richard Partridge: Great.

323
00:58:24.090 --> 00:58:24.930
Richard Partridge: Slide through

324
00:58:27.240 --> 00:58:39.240
Richard Partridge: This code slide 36 or their arguments against so interacting dark matter and in favor of cold dark matter. Why is the leader. The one people usually talk about

325
00:58:41.580 --> 00:58:43.890
Jonathan Feng: That's a very interesting question.

326
00:58:46.980 --> 00:58:51.390
Jonathan Feng: I don't think there are solid arguments against

327
00:58:54.540 --> 00:58:57.960
Jonathan Feng: You know collision list dark matter terms of data.

328
00:58:58.980 --> 00:59:16.500
Jonathan Feng: I think it's mainly a bias, which is, you know, look, we have some dark matter, it can have some self interaction. Okay. But if it's, you know, from some value x to zero, a huge range, then it all looks like lambda CDN.

329
00:59:17.850 --> 00:59:24.330
Jonathan Feng: And it has to be in this one particular range right to have this one interesting effect. I can sell a sort of a

330
00:59:26.130 --> 00:59:34.470
Jonathan Feng: Argument from, you know, kind of like most of the parameters space, things are effectively collision list and so collision. This is probably right.

331
00:59:35.310 --> 00:59:47.190
Jonathan Feng: But you know this small scale structure problem has been around, and many guises for a long time and I don't think it's diminished in any way. In fact, it's probably got stronger.

332
00:59:48.750 --> 00:59:56.370
Jonathan Feng: The interesting thing here is that now with the dark sector developments, you know, the dark sector is very

333
00:59:58.320 --> 01:00:04.260
Jonathan Feng: adept at explaining this problem. In fact, you know, you have to work a little bit to get rid of.

334
01:00:04.740 --> 01:00:13.830
Jonathan Feng: The darker background yourself interactions. If you've got some for some here. And as you said this 10 and maybe 200 and maybe region is sort of favorite by a number of different

335
01:00:14.460 --> 01:00:26.070
Jonathan Feng: Arguments so sort of works all together. So, you know, maybe if someone had come up with dark sectors back in 1970s when people are discovering dark matter, we wouldn't have been so biased against it.

336
01:00:26.760 --> 01:00:39.030
Jonathan Feng: Stop and recognize it better. But if you just look at the data right now. This is certainly something one should consider because it actually physically motivated and now particle physics, maybe

337
01:00:40.710 --> 01:00:41.070
Richard Partridge: Okay.

338
01:00:42.720 --> 01:00:44.130
Richard Partridge: Also on this side.

339
01:00:45.600 --> 01:00:47.520
Richard Partridge: How does well.

340
01:00:52.650 --> 01:00:56.940
Richard Partridge: How does self direction. Dark matter causes us to disappear.

341
01:00:58.200 --> 01:01:02.490
Jonathan Feng: Ah, yeah. Okay, so basically what happens is if you had

342
01:01:03.870 --> 01:01:11.490
Jonathan Feng: A huge buildup of dark matter epicenter, as he would kind of be moving toward in collision less dark matter.

343
01:01:12.300 --> 01:01:18.030
Jonathan Feng: If you turn on the collisions and some sense that the high density regions kind of base are bumping the dark matter out

344
01:01:18.510 --> 01:01:29.850
Jonathan Feng: You start having collisions that knock the dark matter out of the central region and they basically smooth out that singularity or so, without that cuts. And so that leads to this more smooth profile here.

345
01:01:31.050 --> 01:01:40.740
Jonathan Feng: But so this has been that's the heuristic way, at least I look at it, but this has been done with actual simulations and this is how you actually really come up with

346
01:01:41.820 --> 01:01:47.940

Jonathan Feng: You know exactly what the effect is and how big the collision has the cross section has to be to get the desired effect.

347
01:01:50.400 --> 01:01:52.440
Richard Partridge: The next question is on slide 38

348
01:01:57.120 --> 01:02:05.310
Richard Partridge: Does this mean that we have to find another dark sector explanation from you on GMOs to that doesn't involve dark photon.

349
01:02:06.540 --> 01:02:15.840
Jonathan Feng: Ah, so yes, it does. So this is the image you would show to show the dark photons can explain d minus two and

350
01:02:17.040 --> 01:02:27.330
Jonathan Feng: That's a fact. Now, but perspective links in beautifully with the question previously about exactly, you know what, to the light gate goes on allowed

351
01:02:28.830 --> 01:02:33.540
Jonathan Feng: There are other known examples that do solve it. So, for example,

352
01:02:35.730 --> 01:02:36.750
Jonathan Feng: Let's see, where was I

353
01:02:39.510 --> 01:02:40.770
Jonathan Feng: Okay, so here

354
01:02:43.230 --> 01:02:49.500
Jonathan Feng: Right here, if you look at this, this is the overlay of the Tempe anomalies with the dark

355
01:02:50.760 --> 01:02:55.200
Jonathan Feng: In the dark photon plane and it actually goes up into this d minus three region.

356
01:02:55.890 --> 01:03:02.580
Jonathan Feng: And it turns out that's actually allowed because this solution is not actually about photon. It's this little bit gauge Rosen.

357
01:03:03.120 --> 01:03:14.400

Jonathan Feng: And in that case, some of these limits don't apply. And so it turns out that the brilliant helium anomalies resolution can also actually resolve the d minus to you on one

358
01:03:15.210 --> 01:03:32.070
Jonathan Feng: So that's one pretty interesting coincidence of resolutions. Another one is, I think, minus towel gauge both hands can resolve a d minus two anomaly without running into trouble with these other things. So there are various other solutions.

359
01:03:33.360 --> 01:03:33.840
Jonathan Feng: And

360
01:03:34.920 --> 01:03:39.090
Jonathan Feng: It just all sorts of variations of the doctor can slightly cufflinks.

361
01:03:41.040 --> 01:03:46.170
Richard Partridge: This question may be somewhat related but section is a little bit different, or the

362
01:03:49.470 --> 01:03:56.760
Richard Partridge: Anomalies they're not able to be playing a dark photon since the part of the parameter space with Iraq.

363
01:03:59.460 --> 01:04:02.610
Jonathan Feng: Yeah, so that's, that's exactly right. That

364
01:04:03.630 --> 01:04:06.720
Jonathan Feng: Bulky Wait let me, let me try. Understand the core so

365
01:04:07.890 --> 01:04:10.530
Jonathan Feng: The top the anomaly can be explained.

366
01:04:12.630 --> 01:04:22.770
Jonathan Feng: By the 17th and maybe particle, if you look at this very closely, you'd say most of this premise laces rolled out by 60 constraints, but that's because

367
01:04:23.820 --> 01:04:32.040
Jonathan Feng: Of this problem that this is a product level thing. And I'm trying to throw it onto the stock photo. So turns out there's parameter space that's totally fine appear

368
01:04:33.960 --> 01:04:41.880
Jonathan Feng: Down here, it is kind of excluded. But it turns out that some of these balance have some wiggle room, depending on things and so

369
01:04:43.290 --> 01:04:53.520
Jonathan Feng: I would not rule out this rest of this region here. If you start getting into this region. This probably really use the plastic rolled out but they said arrange here where this solution is still works pretty well.

370
01:04:56.160 --> 01:04:57.180
Richard Partridge: OK. OK.

371
01:04:58.230 --> 01:04:58.770
Richard Partridge: Aside

372
01:05:00.480 --> 01:05:01.110
Richard Partridge: 50

373
01:05:06.990 --> 01:05:11.940
Richard Partridge: Why or higher energy neutrinos preferentially produced in the forward direction.

374
01:05:12.900 --> 01:05:15.300
Jonathan Feng: Ah, so that's very interesting.

375
01:05:18.060 --> 01:05:29.340
Jonathan Feng: Basically, okay. So where did these neutrinos come from. They come from pion the case say and what are the pioneers pions typically go, Well, turns out if you look at the pie on

376
01:05:30.660 --> 01:05:40.230
Jonathan Feng: Production cross section. They're basically all at low key T. Okay. Typically there's the ions are produced that low PT

377
01:05:40.800 --> 01:05:49.230
Jonathan Feng: But sort of uniformly in longitudinal PT in some sense. So, to be precise, his uniform and in and sort of repeated.

378
01:05:50.220 --> 01:05:55.380
Jonathan Feng: And so it turns out that means that they're very, very highly peaked in the forward direction.

379
01:05:56.370 --> 01:06:03.990
Jonathan Feng: And so, you know, because like between rapidity, eight, nine. You talking about angles between, you know, I don't know.

380
01:06:04.500 --> 01:06:14.880
Jonathan Feng: A couple mil radiance, whereas between a dot zero. And when you're spending 45 degrees or something so that that's one way to say it. The other way to say it may be more intuitive is you know that

381
01:06:15.930 --> 01:06:23.040
Jonathan Feng: You know making high energy, high PT things is hard, like if you want to make a Higgs boson, you know, cross sections I femto bar.

382
01:06:23.490 --> 01:06:30.810
Jonathan Feng: But the total interaction cross section of protons pp collisions is like a Milburn are actually hundred member Barnes.

383
01:06:31.260 --> 01:06:37.290
Jonathan Feng: And where does all that kind of Section go well the answer is, it all goes down the been pipe and, you know,

384
01:06:38.040 --> 01:06:47.010
Jonathan Feng: 515 orders of magnitude higher cross sections going down the bean pie, and it's going to make your precious you know score up for me, you know,

385
01:06:47.790 --> 01:07:06.360
Jonathan Feng: And so they're just huge amount of cross section and events that go down the beam pipe in the forward direction. And a lot of those make neutrinos. And so it turns out that, like, you know, this is the, the source of this this result that's coming out this little box here, there are probably

386
01:07:08.580 --> 01:07:23.970
Jonathan Feng: 10 to 15 neutrinos that went through it. Many of them with very high energies TV energies. And so that's leading to the ability to detect these things. And there's a little box on you couldn't detect a single line and say all of the Atlas of CMS.

387
01:07:26.700 --> 01:07:31.980
Richard Partridge: Great Sun sign 51

388
01:07:34.140 --> 01:07:41.430

Richard Partridge: Can Fazer also helped look for your standard model you treat others like stone Katrina's

389
01:07:42.870 --> 01:07:54.720
Jonathan Feng: So it can, but in a slightly strange reason, a premier space. So we can look for things oscillating to scale neutrinos, just like as you would in many other experiments, the

390
01:07:55.560 --> 01:08:00.450
Jonathan Feng: Benefits of these oscillations are, of course, the function of again over energy

391
01:08:01.200 --> 01:08:11.880
Jonathan Feng: And so it turns out that the energies that you would see on TV and the lamp is a half a kilometer. Turns out that you could look for sale neutrinos with a massive like 40

392
01:08:12.330 --> 01:08:21.270
Jonathan Feng: Ed, I think that was sort of the heart of the parameter space. So you can look for them. Maybe they're there, but they certainly aren't in the canonical regions of

393
01:08:21.690 --> 01:08:37.200
Jonathan Feng: You know anyone has in mind, either kV for standard to dark matter RV for solving race anomalies, sort of in this no man's land you know 50 to 100 me TV but but you could look at them and certainly we will

394
01:08:39.780 --> 01:08:40.500
Richard Partridge: Okay.

395
01:08:41.610 --> 01:08:43.110
Richard Partridge: Lisa. How we doing on time.

396
01:08:46.200 --> 01:08:47.580
Lisa Kaufman: We have about one minute.

397
01:08:48.900 --> 01:08:51.480
Richard Partridge: Okay, so

398
01:08:53.010 --> 01:08:54.990
Richard Partridge: Can we go back to slide 47

399

01:08:56.130 --> 01:08:56.550
Mm hmm.

400
01:08:58.770 --> 01:09:05.250
Richard Partridge: Why do so many of the propose experiments have a custom sensitivity around one g

401
01:09:07.290 --> 01:09:15.720
Jonathan Feng: Oh, this is because there you get some mixing with the Standard Model particles. So it's probably

402
01:09:16.770 --> 01:09:17.580
Jonathan Feng: Visitor

403
01:09:19.140 --> 01:09:29.610
Jonathan Feng: Row or something in here and basically what that does is it leads to the lifetime, all of a sudden getting too.

404
01:09:30.720 --> 01:09:31.710
Jonathan Feng: Short

405
01:09:33.240 --> 01:09:48.330
Jonathan Feng: So that basically means that the lifetime is actually too short to compensate for that you need to cut down this coupling so that you keep the lifetime long enough that the particle goes far enough that you can see it so

406
01:09:49.680 --> 01:09:51.720
Jonathan Feng: Bottom line, it's basically there's some mixing

407
01:09:54.330 --> 01:10:04.050
Jonathan Feng: So this is the mixing it. Okay, so what is this. This is what the fire, I guess, or something. This is the mixing of the scale of particle. In this case, which is a

408
01:10:05.250 --> 01:10:06.150
Jonathan Feng: bigger scale and mixing

409
01:10:07.980 --> 01:10:13.410
Jonathan Feng: Yeah, that's why everybody goes down there is, it's, it's nothing, having to do with experiments. It just happened to do it.

410
01:10:14.790 --> 01:10:16.350

Jonathan Feng: Makes it look Standard Model particles.

411
01:10:20.040 --> 01:10:23.040
Lisa Kaufman: Okay, thanks a lot. JOHN was really nice talk.

412
01:10:23.310 --> 01:10:24.720
Jonathan Feng: And thanks for tonight. Thank you, everyone.

413
01:10:24.720 --> 01:10:25.200
Question.

414
01:10:26.460 --> 01:10:27.870
Jonathan Feng: Yeah, thanks for the excellent questions.

415
01:10:28.650 --> 01:10:30.180
Lisa Kaufman: All right, I'll stop the recording now.