WEBVTT

1
00:00:03.870 --> 00:00:04.560
charlie young: Please go ahead.

2
00:00:05.400 --> 00:00:05.819
charlie young: Alright.

3
00:00:06.120 --> 00:00:07.680
Jodi Cooley: Um. Let me confirm you can hear me.

4
00:00:10.380 --> 00:00:11.219
charlie young: Yes. We hear you.

5
00:00:11.550 --> 00:00:12.780
Jodi Cooley: Okay, fantastic.

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00:00:13.200 --> 00:00:16.350
Jodi Cooley: So it's a real pleasure to be here. Virtually with you all.

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00:00:16.740 --> 00:00:30.600
Jodi Cooley: To talk a little bit about director matter searches and the sorts of considerations that we have when we're thinking about building detectors. So just to give you an outline of what I do. I'm sorry.

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00:00:31.920 --> 00:00:35.850
Jodi Cooley: Of what I plan to talk about today. And then what I will talk about tomorrow.

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00:00:37.080 --> 00:00:39.540
Jodi Cooley: You can see this outline on the slide. Give me a second here.

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00:00:42.000 --> 00:00:57.750
Jodi Cooley: Okay, so today what I'm going to do is I plan to talk about the sorts of considerations that we would take into account when trying to design a detector for the direct search of dark matter. And so this means I'll be reviewing some

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00:00:59.790 --> 00:01:05.670
Jodi Cooley: Rate calculations the sorts of things that go into those rate calculations for a simplified model.

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00:01:06.870 --> 00:01:20.640
Jodi Cooley: I'll spend a great deal of time talking about background considerations that we take into account and and how it is, and the types of tools we use to think about backgrounds and then I'll wrap up today by talking about

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00:01:21.960 --> 00:01:27.540
Jodi Cooley: Some of the unique signatures that we might be what we would expect from direct detection of dark matter.

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00:01:29.640 --> 00:01:39.990
Jodi Cooley: And in the lecture. Tomorrow I will go into details about how it is that we have experiments running right now what those experiments are

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00:01:40.410 --> 00:01:46.200
Jodi Cooley: That are searching for dark matter and talk a little bit about some of their features, some of the things that make

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00:01:46.830 --> 00:01:53.010
Jodi Cooley: Some of the experiment experiments, different from others and why it is that we really want a broad range of experiments.

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00:01:53.730 --> 00:02:07.620
Jodi Cooley: And so tomorrow I'll start by talking a little bit about the domino Libra signal claim and try to make you think a little bit about whether or not we actually have already seen a dark matter signal from that experiment.

18
00:02:09.300 --> 00:02:17.430
Jodi Cooley: And then I'll talk about detecting scattering from the nucleus using existing experiments and then talking about how we can reach

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00:02:17.760 --> 00:02:33.540
Jodi Cooley: An access lower mass dark matter, matter candidates by detecting electron scattering using existing experiments and then unfortunately, it would be great if there was a third lecture because I think we could spend a whole nother lecture talking about ideas.

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00:02:34.590 --> 00:02:41.250
Jodi Cooley: That people have now to extend the sensitivity of dark matter experiment into the sub EV range.

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00:02:42.300 --> 00:02:49.830
Jodi Cooley: But I will, I will touch on that and I will leave you with some resources in case it is that you want to go out and watch some lectures on that specific topic.

22
00:02:51.810 --> 00:03:05.340
Jodi Cooley: And then also my notes which you can download online. I put a few references that I think are pretty helpful when it comes to doing some of these classic calculations. And so the first three here are just sort of classic papers.

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00:03:06.810 --> 00:03:13.110
Jodi Cooley: Some of the information that might be a little bit dated, but the basics of the calculations are still the same, and you will see

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00:03:14.040 --> 00:03:19.290
Jodi Cooley: In the books and special editions that I have on one being the dark universe. The very first volume of it.

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00:03:19.860 --> 00:03:30.990
Jodi Cooley: Is is dedicated to dark matter searches and it's free and online. But if you were to look at this you and go back to these classic papers will see that we basically are always starting with the same physics.

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00:03:34.680 --> 00:03:39.270
Jodi Cooley: So I think last week when you had your lecture on cosmology.

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00:03:40.440 --> 00:03:41.670
Jodi Cooley: And and and such.

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00:03:42.690 --> 00:03:53.370
Jodi Cooley: You probably reviewed the abundance of evidence for particle dark matter. And so I just wanted to very quickly review this again just to set the stage for what why it is we're doing these calculations.

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00:03:54.000 --> 00:04:11.610
Jodi Cooley: So we know that there is a missing mass problem. And this comes to us from studying the dynamics of stars and galaxies and clusters of galaxies. So thinking back to Fritz wiki and his initial studies, it comes to us from studying rotational curves.

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00:04:12.630 --> 00:04:25.380

Jodi Cooley: Like your ribbon had done back in the early 1970s and gravitational lensing. And it also comes to us from simulations of the large scale structure formation in the early universe.

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00:04:27.060 --> 00:04:33.540
Jodi Cooley: And we have a wealth of evidence that there's a particle solution to this dark matter or missing mass problem.

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00:04:34.980 --> 00:04:45.090
Jodi Cooley: We know that microlensing has mostly Rolo MACHOs and we know that modified theories of gravity have trouble explaining

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00:04:45.660 --> 00:05:00.810
Jodi Cooley: Things like the Bullet Cluster, even though I will, I will take it that yes, indeed, you could come up with some way to work around because there's a very cover, but trying to find a unified theory that can explain everything from Big Bang cosmology up to

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00:05:01.950 --> 00:05:07.500
Jodi Cooley: You know gravitational dynamics on the galaxy scale has been very challenging.

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00:05:09.060 --> 00:05:20.790
Jodi Cooley: We also know from the height of the acoustic peaks in the CSV and power spectrum density fluctuations that this dark matter is probably not baryonic

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00:05:22.860 --> 00:05:40.680
Jodi Cooley: And then the other clue that we have about the dark matter and the nature of it that is still here. So, whatever it is. It was required to be present at the very earliest times of the universe, and that the still here and needs to be somehow a stable neutral non relativistic

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00:05:41.850 --> 00:05:55.020
Jodi Cooley: Particle we do that interact via gravity all the evidence that we have so far for dark matters existence comes to us from observing the effects of gravity on matter.

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00:05:56.790 --> 00:06:02.790
Jodi Cooley: And there is some reason to believe that potentially it could interact through the weak force.

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00:06:05.280 --> 00:06:21.900

Jodi Cooley: So if you take all of these pieces of evidence and you put it together. What you find is actually a pretty remarkable picture, and that is that dark matter makes up almost 27% of the stuff in the universe. So it makes it a very compelling problem.

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00:06:24.270 --> 00:06:27.840
Jodi Cooley: And then, as you've been hearing from Tim to over the last three days.

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00:06:28.860 --> 00:06:46.020
Jodi Cooley: There are enormous number of candidates for dark matter and those candidates range over a massive energy scale anywhere from the TV and above scale down to the EV, and even smaller scale.

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00:06:47.700 --> 00:07:01.590
Jodi Cooley: And we can probe. A lot of these energy ranges with direct detection by looking at sort of three different interactions, one would be the dark matter nucleus scattering, which is the classic way that we have been searching for a very long time.

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00:07:02.550 --> 00:07:11.820
Jodi Cooley: We're recently we've been looking at dark matter electron recoil scattering in a number of experiments and then you also could have

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00:07:12.840 --> 00:07:20.220
Jodi Cooley: Electron recoil absorption is another way that you could or another channel through which you could directly detect dark matter.

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00:07:22.890 --> 00:07:32.820
Jodi Cooley: So what I want to do today is just start with sort of the classic easiest thing to calculate and that is dark matter via nucular scattering

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00:07:34.920 --> 00:07:48.120
Jodi Cooley: So the idea is, is that you would have a wimp in the Galactic animal or your dark matter candidate, it would interact with a target nucleus, which is the target that is your experiment.

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00:07:48.690 --> 00:08:00.600
Jodi Cooley: In the laboratory here on earth and through elastic collision. The Wimp would go off in one direction and you would have electronic recoil by depositing small amounts of energy in the detector.

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00:08:02.370 --> 00:08:12.600

Jodi Cooley: This can occur this process there either as independent or spin independent channel. And it turns out, those are actually the two simplest cases, there are many other channels through which this could happen.

49
00:08:12.990 --> 00:08:20.670
Jodi Cooley: As well. And we'll touch on effective field theory, a little bit today. And so the idea is that you need to distinguish this event.

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00:08:21.060 --> 00:08:29.850
Jodi Cooley: From the overwhelming number of backgrounds that you might see. So different events that could happen in the detector that are not the went scattering on the Nicholas

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00:08:32.010 --> 00:08:35.220
Jodi Cooley: So what are the elements that would go into your calculation.

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00:08:36.600 --> 00:08:41.790
Jodi Cooley: So this is the equation for the differential evaporate.

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00:08:42.840 --> 00:08:48.960
Jodi Cooley: In your detector from direct detection. It depends on the local wins density row, not

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00:08:50.310 --> 00:08:56.190
Jodi Cooley: It depends on the mass of your nucleus. It depends on the mass of your dark matter candidate.

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00:08:57.360 --> 00:09:07.800
Jodi Cooley: It depends on the Wimp Nick Leon scattering cross section and it depends on the dark matter or wind speed distribution in the detector frame.

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00:09:09.960 --> 00:09:20.730
Jodi Cooley: You integrate this over the minimum with velocity that can cause a recoil of energy, er, in your nucleus to infinity.

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00:09:22.170 --> 00:09:29.880
Jodi Cooley: So what you can see is that you need input from astrophysics particle physics and nuclear physics in order to do this calculation.

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00:09:31.740 --> 00:09:45.780

Jodi Cooley: The elastic scattering in this process happens in the extreme non relativistic case in the lab. Right. So that means that your report energy is equal to new n square where music is your reduce mass

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00:09:46.800 --> 00:09:54.630
Jodi Cooley: Times velocity squared times one minus cosine of the recoil angle divided by the math of your nucleus.

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00:09:57.330 --> 00:10:05.880
Jodi Cooley: Alright, so let's take a look at this formula and break it down, piece by piece, because each of these pieces has considerations that you need to take into effect.

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00:10:06.960 --> 00:10:16.170
Jodi Cooley: Alright, so right now we're going to integrate this over the threshold energy and examine the d sigma Dr component

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00:10:17.220 --> 00:10:35.850
Jodi Cooley: So this component and purple here is your nucleus cross section and it can be separated into a spin dependent and a spin independent component, the spin independent component arises from scale or vector couplings to corks and

63
00:10:37.770 --> 00:10:45.360
Jodi Cooley: I realized here that a copy of the same same words twice the spin dependent arise from vector and axial vector

64
00:10:47.550 --> 00:10:48.270
Jodi Cooley: couplings.

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00:10:49.830 --> 00:10:58.320
Jodi Cooley: Okay. So to calculate you add coherently the spin and scale or component. And so when you do this.

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00:10:58.860 --> 00:11:04.290
Jodi Cooley: What you end up with is the mass of the nucleus divided by two times for Christmas squared plus b squared.

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00:11:04.740 --> 00:11:16.170
Jodi Cooley: And you'll notice that you have a spin independent cross section and spend on a cross section and then you also have a spin independent for faculty factor and you have a spin dependent

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00:11:16.950 --> 00:11:28.110

Jodi Cooley: form factor the form factor depends on energy of the recoil and essentially encodes the dependence on the momentum transfer in the reaction.

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00:11:30.000 --> 00:11:32.700
Jodi Cooley: Alright so breaking this down even further.

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00:11:34.140 --> 00:11:50.790
Jodi Cooley: Let's take a look at these form factors. These form factors, like I said encode the quantum mechanics with the interaction in the nucleus. So starting with the skin independent form factor this essentially takes the woods Saxons form factor.

71
00:11:52.020 --> 00:12:01.560
Jodi Cooley: And if you break this down, you end up with this equation here so you can see that it depends on the spherical vessel function. The momentum transfer

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00:12:04.050 --> 00:12:05.190
Jodi Cooley: The skin.

73
00:12:06.420 --> 00:12:15.570
Jodi Cooley: Or the Nick the skin thickness of the nucleus, which generally is about a centimeter and an effective nucleus radio

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00:12:17.940 --> 00:12:30.060
Jodi Cooley: For spin dependent interactions, your form factor is a bit more complicated. If this x over x. This ISIS scale or ISO vector interference form factors.

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00:12:31.620 --> 00:12:36.990
Jodi Cooley: So the recoil dependent form factor. You can see depends on these

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00:12:38.040 --> 00:12:43.620
Jodi Cooley: Ay, ay, ay sub JS. These are iso sailor and ISO vector coupling.

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00:12:46.080 --> 00:12:47.400
Jodi Cooley: And those coupling.

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00:12:48.630 --> 00:12:50.880
Jodi Cooley: Are different for protons and neutrons.

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00:12:54.690 --> 00:13:00.240
Jodi Cooley: Alright, so let's take a look. That's the nucleus interaction and sorts of things that are involved in this.

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00:13:01.710 --> 00:13:13.350
Jodi Cooley: So in the spin independent case this is equal to four times the reduced mass squared divided by pie. You can see that it depends on the coupling to the proton and the coupling to the neutron

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00:13:14.460 --> 00:13:34.770
Jodi Cooley: If we assume a low momentum transfer, which is which is was going on in these extreme non relativistic cases most models will give you that fn the coupling to the neutron is approximately equal to the coupling to the proton. And so what that means is that your spin independent

82
00:13:37.710 --> 00:13:41.940
Jodi Cooley: Cross section as coherently with a square

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00:13:42.990 --> 00:13:45.450
Jodi Cooley: Which is your atomic number of your target.

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00:13:48.000 --> 00:13:55.770
Jodi Cooley: In the spin depending case. So this term over here you have a little bit more complicated looking equation.

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00:13:56.280 --> 00:14:16.380
Jodi Cooley: Here you can see it depends on the Fermi constant. The reduced math. Again, the nuclear Angular nuclear angular momentum factor. And then you have the coupling constant to the proton, neutron and these expectation values for the proton, neutron spin

86
00:14:18.630 --> 00:14:36.570
Jodi Cooley: So in the spin depending case the scaling occurs with the spin of the nucleus. So if you have extra protons, you'd be more sensitive to proton dependent spin interactions. And if you had extra neutrons, you would have be more sensitive to that interaction.

87
00:14:38.160 --> 00:14:44.520
Jodi Cooley: And in the spin dependent case there is no coherent effect. And so you don't really gain

88
00:14:45.570 --> 00:14:47.670
Jodi Cooley: From that a square factor.

89
00:14:49.950 --> 00:14:59.280
Jodi Cooley: Alright, so taking this into account. If you're going to build your detector, you're going to want to pick a target that's going to make you most sensitive

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00:15:00.390 --> 00:15:22.680
Jodi Cooley: To the interactions. And so in the spin dependent case, you're going to want to choose a target that has some high number of spin expectation and so you know targets like floor fluorine iodine or xenon 129 could be good targets for spend dependent interactions.

91
00:15:25.710 --> 00:15:44.970
Jodi Cooley: So there's also astrophysics involved. And so, generally speaking, you want to have some kind of model of your Halo. So the earth, you know, goes around the sun, and the sun travels around the the solar system in the direction of the star Cygnus

92
00:15:46.710 --> 00:15:55.110
Jodi Cooley: And in the most simple model that you can take the dark matter would be distributed in an ISO thermal spherical Halo.

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00:15:56.220 --> 00:16:05.430
Jodi Cooley: With a Gaussian velocity distribution. This is often known as a Maxwell Maxwell Boltzmann distribution, it looks like this.

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00:16:06.540 --> 00:16:27.210
Jodi Cooley: And the speed dispersion is related to the local circular speed through this factor the sigma factor which is equal to the square root of three half times the circular speed and in most models, the circular speed in the most generic span sense is taken to be 220 kilometers per second.

95
00:16:29.550 --> 00:16:43.710
Jodi Cooley: The density profile of the spear goes as one over our square and locally, where we are located in our galaxy our local density has been measured to be approximately 0.3 GB per square

96
00:16:46.680 --> 00:17:01.410
Jodi Cooley: So particles of speed that are greater than the speed, speed aren't gravitationally bound. And so the speed distribution has to be truncated and that's done somewhat part of artificially

97
00:17:02.790 --> 00:17:05.040
Jodi Cooley: But there is a good reason for it. And that's because

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00:17:06.210 --> 00:17:15.900
Jodi Cooley: Particles do have an escape speed and escape speed that we use most of the time when we're interpreting our data is a velocity of 650 kilometers per second.

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00:17:18.300 --> 00:17:26.340
Jodi Cooley: Alright, so let's just get a sense for what that means. Let's think about the density of WIMPs that you might have in your work area.

100
00:17:27.960 --> 00:17:30.690
Jodi Cooley: This is a picture of my local group at SMU

101
00:17:31.770 --> 00:17:33.810
Jodi Cooley: We even had somebody on zoom from remote

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00:17:35.070 --> 00:17:41.730
Jodi Cooley: That day so remembering that our local density is point three GB per cubic centimeter

103
00:17:42.930 --> 00:17:45.600
Jodi Cooley: What you need to do is essentially pick

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00:17:47.220 --> 00:17:55.710
Jodi Cooley: What Massey wonky. So, pick your favorite dark matter particle and you can all do this. So I actually different two methods, a different five GB and for 60 TV.

105
00:17:57.120 --> 00:18:13.290
Jodi Cooley: And then from here just calculate out what your number density. Yes. So essentially, that means that if you have a five God Particle you'll need 60,000 particles per cubic meter. But if you had a 60 GB particle that would reduce to about 5000 particles per meter to you.

106
00:18:14.640 --> 00:18:22.860
Jodi Cooley: Alright, so, since all of us right now are in different rooms that are different sizes. I decided let's run this calculation for two liter bottle instead

107
00:18:24.300 --> 00:18:44.820
Jodi Cooley: Recalling that a leader is equal to basically point 001 meters cube, you would find if the width had a massive five GB there

would be about 120 particles in that two liter bottle. And if you're when we're 60 DB there would be about 10 particles.

108
00:18:45.840 --> 00:18:51.600
Jodi Cooley: Either way, enough particles to give you a flux to build a detector to try to see dark matter.

109
00:18:53.550 --> 00:19:11.040
Jodi Cooley: Okay, so this is a really nice, simple explanation and model that I gave up you know your dark matter interacts with the nucleus interacts either through a spin independent or spin dependent model, but maybe it's not really that simple.

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00:19:12.660 --> 00:19:30.570
Jodi Cooley: Effective field theories were calculated in some papers. A number of years ago. And what they did is they started considering leading order next deleting order operators that can occur in the effect of a lot Lagrangian that describes the limp implant interactions.

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00:19:31.860 --> 00:19:41.970
Jodi Cooley: And so essentially what you have is you have 14 operators that rely on our range nuclear properties. In addition to the spin independent and spin dependent cases.

112
00:19:42.690 --> 00:19:50.970
Jodi Cooley: And you can combine these operators in such a way that the Wimp nuclear cross section would depend on six independent

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00:19:51.570 --> 00:20:02.790
Jodi Cooley: nucular response functions. One of those response functions is a spin is a classic independent case. Two of them have been dependence and three of them have velocity dependent

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00:20:05.370 --> 00:20:15.180
Jodi Cooley: When you have two pairs interfering. You can get a result that is essentially eight independent parameters that you can produce

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00:20:16.350 --> 00:20:21.870
Jodi Cooley: And so I'm not gonna spend a lot of time talking about effective field Terry's I'm not an expert in them.

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00:20:22.830 --> 00:20:32.250
Jodi Cooley: But if you would like to know more about effective field theories and how these are calculated. I look for papers here in the notes so that you can download and read them on your own.

117
00:20:34.230 --> 00:20:45.810
Jodi Cooley: Okay, so if we were to take this effective field theory and look at the nuclear responses for different target elements, what we would see is that that response series.

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00:20:46.980 --> 00:20:54.450
Jodi Cooley: Some affected field theory operation have a momentum dependence and the operators can interfere

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00:20:55.830 --> 00:21:16.770
Jodi Cooley: So the example that I have here on the left hand side shows differences if you're using the flooring Eigen factor or if you use a germanium Ivan factor for selecting target ranges and what you'll notice is that not only do

120
00:21:17.910 --> 00:21:24.270
Jodi Cooley: Your results have different rate between the targets. They also have different spectral shapes.

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00:21:26.160 --> 00:21:43.110
Jodi Cooley: So a robust dark matter direct detection program that has different target materials would be absolutely critical. If you wanted to nail down which operators are actually contributing to any signal that we might observe in the future.

122
00:21:48.000 --> 00:21:53.340
Jodi Cooley: So now, going back to our simple into us been independent case.

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00:21:55.110 --> 00:21:58.230
Jodi Cooley: What we can see here is this is the total rate.

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00:21:59.580 --> 00:22:08.130
Jodi Cooley: Per 10 kilograms per year versus your detector threshold for a variety of targets. So this assumes that the mass

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00:22:08.520 --> 00:22:26.730
Jodi Cooley: Of your dark matter candidate in this case of 100 GB and that the cross section that interacts the dark matter and accept the nucleus is 10 to the minus 45 centimeters. And so what you can see is that the elastic scattering deposit only a small amount of energy into a nucleus.

126

00:22:28.350 --> 00:22:33.150
Jodi Cooley: The spectrum itself is featureless. There's no need. There's no bumps. There's no brakes.

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00:22:34.980 --> 00:22:42.540
Jodi Cooley: And furthermore, the event rate is very low. This year line is one event per 10 kilograms per year.

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00:22:44.640 --> 00:22:50.850
Jodi Cooley: So the radioactive background of most materials is much higher than the event rate that we're looking for.

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00:22:51.870 --> 00:22:58.200
Jodi Cooley: So that means that you need large exposure times and you also need very low backgrounds.

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00:23:01.380 --> 00:23:14.490
Jodi Cooley: So the challenge. Again, this recoiling energy that you could calculate out using sort of a generic one for 100 K GV gives you a recoil nucleus, on the order of three kV

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00:23:16.680 --> 00:23:25.380
Jodi Cooley: In addition to that, you also have the current constraint that a wimp needs to have a minimum of velocity in order to produce a recoil.

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00:23:25.950 --> 00:23:38.580
Jodi Cooley: So that says that you need to have a really low threshold. And so here plotted here is the integrated event rate per kilogram per year versus experimental threshold in KGB.

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00:23:39.780 --> 00:23:48.330
Jodi Cooley: This is for germanium, assuming when scattered went up on cross section of scattering cross section of one times 10 to the minus

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00:23:49.020 --> 00:24:05.610
Jodi Cooley: 40 to 70 or squares. And so you can see if I change the maximum I went from 10 to nine to eight to seven down to three GB my threshold really matters a lot. So having the ability to detect a very low threshold trigger is important.

135
00:24:07.290 --> 00:24:08.700
Jodi Cooley: In addition to that,

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00:24:09.750 --> 00:24:17.130
Jodi Cooley: The total rate for different thresholds is also different. So in this plot here again it events per kilogram per year.

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00:24:17.550 --> 00:24:36.900
Jodi Cooley: Versus the experimental threshold and kV and looking at a width that has a massive five GB. And again, the same cross section of 10 to the minus 42 centimeter square. You can see the different rates that you would expect for oxygen, silicon calcium germanium xenon and tungsten

138
00:24:38.850 --> 00:24:46.410
Jodi Cooley: So these are the types of considerations that you would take into account when selecting the target for your detector material.

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00:24:48.300 --> 00:24:56.670
Jodi Cooley: So the point I want to now move on to is thinking a little bit about that guns. So the background rates are extremely low.

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00:24:58.770 --> 00:25:22.200
Jodi Cooley: Potassium 40 is, for example, the largest source of natural radioactivity in animals and humans. So if you're a 70 kilogram human you contain about 160 grams of potassium. So that would calculate out to being about point 0187 grams.

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00:25:24.060 --> 00:25:30.870
Jodi Cooley: Of potassium 40 who decay at about 4400 disintegration per second.

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00:25:32.160 --> 00:25:40.770
Jodi Cooley: So that that can be quite a lot. And so over here we're looking at the whim spectrum. So the rate per, per

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00:25:42.330 --> 00:25:46.200
Jodi Cooley: The, the rate for energy and kilograms per kV per day.

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00:25:47.610 --> 00:25:58.890
Jodi Cooley: And what you end up with is, you end up with about one event per kilogram per year in your material with the assumption of a 20 GB with that interacts

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00:25:59.610 --> 00:26:13.080
Jodi Cooley: At a cross section of 10 to the minus 45% of your squares over here, this this measurement actually comes from an undergraduate journal where they measured the spectrum of a banana bananas are high in potassium, as you know,

146
00:26:14.820 --> 00:26:28.140
Jodi Cooley: Here you get about 100 events per kilogram per year and electron recoil. So this was measured. I think it was, if I recall correctly, it was a high purity germanium detector that they use to to measure this.

147
00:26:31.050 --> 00:26:34.410
Jodi Cooley: So backgrounds are important with the moral of that story.

148
00:26:35.940 --> 00:26:37.170
Jodi Cooley: So I want to take

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00:26:38.220 --> 00:26:44.730
Jodi Cooley: The next 10 or 15 minutes to talk a little bit about background sources and mitigation techniques for for those backgrounds.

150
00:26:45.690 --> 00:26:55.350
Jodi Cooley: So one source of background is environmental radioactivity. This includes both airborne radon that everywhere and it's daughters and, as some of you know

151
00:26:55.950 --> 00:27:10.410
Jodi Cooley: These experiments that we do with dark matter are underground in order to another background from consideration and underground, the concentrations of radon, or even higher rate on is just everywhere and underground is extremely concentrated

152
00:27:12.180 --> 00:27:22.410
Jodi Cooley: We also have to worry about radio impurities and the materials that are used in the direct detector construction and the construction of any shielding material around the detector.

153
00:27:23.790 --> 00:27:32.430
Jodi Cooley: We worry about radiogenic neutrons that have energies below 10 MTV and this includes neutron term alpha and envision reactions.

154
00:27:34.110 --> 00:27:37.350
Jodi Cooley: We have to worry about cosmic rays and their secondary

155
00:27:39.030 --> 00:27:47.610
Jodi Cooley: We have to worry about activation of the detectors materials when the detector is near the surface of the Earth. So you can actually induce

156
00:27:48.780 --> 00:27:53.760
Jodi Cooley: Backgrounds in your detector materials themselves by just having them on the surface of the Earth.

157
00:27:55.290 --> 00:28:04.560
Jodi Cooley: And then of course there are those other background sources that we haven't yet identified, but certainly in the search for dark matter will probably encounter.

158
00:28:06.420 --> 00:28:06.930
Jodi Cooley: So,

159
00:28:09.000 --> 00:28:20.610
Jodi Cooley: We like to place these experiments underground in order to reduce backgrounds, from cosmic rays and worldwide, I believe. Currently there are 17 underground sites for physics research.

160
00:28:22.260 --> 00:28:27.630
Jodi Cooley: And so the hydroponic component of the cosmic ray flux is negligible.

161
00:28:28.860 --> 00:28:42.660
Jodi Cooley: Once you have about 10 meters water equivalent overburden, so let me just pause for a minute to talk about this funny unit meters water equivalent. So generally speaking as an experimental is if you're trying to pick a site.

162
00:28:43.710 --> 00:28:53.070
Jodi Cooley: You want to have a way an underground. You want to have a way to compare one site to another. And if we just measured alone without taking into account.

163
00:28:53.430 --> 00:29:01.230
Jodi Cooley: The overburden so different sites have a different overburden different types of rocks or compositions of material that are above them.

164
00:29:02.040 --> 00:29:07.560
Jodi Cooley: It becomes very difficult to compare side. And so what we do is we take the overburden of the site.

165
00:29:08.100 --> 00:29:20.850

Jodi Cooley: And convert it to a meter of water. So meter water equivalent is just what it sounds like. It is the number of meters of water. That would be overhead. If you took the overburden and converted to water.

166
00:29:22.830 --> 00:29:31.230
Jodi Cooley: So nuance that penetrate deep and produce high energy neutron these facts neutrons, they can produce Katie recoils and our detectors.

167
00:29:33.000 --> 00:29:40.800
Jodi Cooley: And and those neutrons are attenuated by rocks and shield that we put around the detector. So those are, that's something that we have to worry about.

168
00:29:42.660 --> 00:30:04.500
Jodi Cooley: So the processes to produce fast neutrons include negative new on capture photo nuclear reactions that could come from any associated electromagnetic shower from a primary deep inelastic new on nucleus nucleus scattering and hydroponic interactions of nucleotides pions or chaos.

169
00:30:05.670 --> 00:30:08.520
Jodi Cooley: And so all of these things that are things that we worry about

170
00:30:09.750 --> 00:30:27.030
Jodi Cooley: So to further reduce these neutron backgrounds. We use a combination of highs and lows. The material to diminish the neutron and also the Gamma Ray Ray flexes and so kind of materials that we use include lead polyethylene and copper

171
00:30:28.740 --> 00:30:38.010
Jodi Cooley: Often a nitrogen purge of the shield structures is used to reduce the background that would come from airborne radon to case.

172
00:30:39.660 --> 00:30:52.200
Jodi Cooley: And then another tool in our tool kit are large water shield. They can passively reduce environmental radioactivity am you and just neutrons and

173
00:30:53.340 --> 00:31:02.280
Jodi Cooley: You can reduce the underground flux of gamma every do genetics by a factor of approximately 10 to the six. If you employed a 123 meter watersheds.

174
00:31:04.890 --> 00:31:22.170
Jodi Cooley: And then a final tool that some of the experiments on employee is an active new on Vito. So essentially what you do is you take simulator and you don't fit with something like boron or gadolinium and once you have an active new on Vito you can identify events.

175
00:31:23.310 --> 00:31:26.910
Jodi Cooley: That are related to both cars mechanic and radiogenic neutrons.

176
00:31:30.060 --> 00:31:39.840
Jodi Cooley: Another tool that can work for some detectors. For example, the large liquid noble detectors. This example here comes from the LV experiment.

177
00:31:40.620 --> 00:31:53.220
Jodi Cooley: Is the shelf shelf shielding properties. So what you can see here is that if you have a material like Xena, where the gamma rays would naturally attenuate in the material.

178
00:31:53.640 --> 00:32:05.220
Jodi Cooley: You can just make additional volume cut and only take a portion that's closest to the center of the detector where it's essentially background free and that's your search area.

179
00:32:11.460 --> 00:32:26.460
Jodi Cooley: So the most problematic BACKGROUNDS COME FROM neutrons that result in up and efficient reactions from uranium authority of became in detector components and close vicinity of the target materials.

180
00:32:28.140 --> 00:32:29.640
Jodi Cooley: And so a lot of times

181
00:32:30.810 --> 00:32:43.140
Jodi Cooley: One of the best ways to reduce your background, after you've done the shielding and everything you can possibly do is to have an event signature yet that can distinguish your backgrounds, from your signal.

182
00:32:44.190 --> 00:32:51.330
Jodi Cooley: So the most prevalent background that you actually see in your detector is a gamma ray or a beta particle

183
00:32:52.770 --> 00:33:06.630

Jodi Cooley: Gamma rays can be in the bulk of the detector, the beta is tend to be on the surfaces of the chapters. And so essentially if you can distinguish between an electron recoil or nucular recoil and your detector.

184
00:33:07.200 --> 00:33:13.140
Jodi Cooley: You can get rid of the majority of your backgrounds neutrons aren't distinguishable from a whim, but

185
00:33:14.220 --> 00:33:29.760
Jodi Cooley: Alpha particles are almost always a surface event. And so the other background that you might have has nucular recoil is recoiling parent nucleus. And again, this is a surface event. So you could have say polonium 210 on the surface area detector decaying

186
00:33:30.780 --> 00:33:32.730
Jodi Cooley: Thing in as it decays.

187
00:33:33.990 --> 00:33:40.380
Jodi Cooley: The lead 206 at so A alpha particle would go in one direction and your

188
00:33:41.520 --> 00:33:52.470
Jodi Cooley: Lead to a six recoiling nucleus would go in the opposite direction. And if it happened in such a way that the reclaiming nucleus presents your detector on that to can sometimes be a background.

189
00:33:55.260 --> 00:33:59.520
Jodi Cooley: So your detector response to these types of events can be really important

190
00:34:00.660 --> 00:34:00.990
Jodi Cooley: And

191
00:34:02.280 --> 00:34:09.780
Jodi Cooley: In the the dark matter community, the direct detection community we employ a variety of ways that you could measure that Hector response.

192
00:34:11.070 --> 00:34:21.450
Jodi Cooley: There are superheated detectors. So Paso and COO, and now people they form together to form a corporation called Pico use that sort of technique.

193

00:34:22.140 --> 00:34:41.190
Jodi Cooley: But the majority of experiments are either measuring one or more of simulation phone on or ionization signals in the detector and by comparing any two of these signals you can distinguish usually requires from electron very close

194
00:34:42.570 --> 00:34:43.740
Jodi Cooley: And so here's

195
00:34:45.390 --> 00:34:56.760
Jodi Cooley: Sort of a schematic of the particle dependent response. So in the non essentially you would have your xenon, and you would have photo tools to measure.

196
00:34:58.380 --> 00:35:08.070
Jodi Cooley: The photons that are coming out in the charge. And you can kind of see in this picture here that you get a separation between electron recoil and nuclear recoil.

197
00:35:08.910 --> 00:35:23.460
Jodi Cooley: Similarly crystals like germanium are measuring charge and finance and again if I take the ratio of this you can see electron recalls line up in in one band and the nuclear recoils line up in another

198
00:35:24.510 --> 00:35:26.370
Jodi Cooley: This is another crystal calcium tongue.

199
00:35:27.480 --> 00:35:28.140
Jodi Cooley: Then

200
00:35:30.390 --> 00:35:30.720
Jodi Cooley: It.

201
00:35:31.950 --> 00:35:49.860
Jodi Cooley: And it actually matters, both centralization white and photons. So vibrational energy and again you can see electron recoils up here nucular recoils down here and these pots that I'm showing you here are clearly from calibration sources.

202
00:35:51.450 --> 00:36:04.410
Jodi Cooley: A bubble chamber is a little bit different. So if you take an energy like the energy per unit length versus energy, you can essentially tuna bubble chamber to reject your backgrounds.

203

00:36:05.430 --> 00:36:12.060
Jodi Cooley: And we'll talk a little bit more exactly about how bubble chambers work in the next lecture. But just to give you a flavor.

204
00:36:12.510 --> 00:36:23.940
Jodi Cooley: A bubble chamber is filled with a superheated fluid and it's kept in a meta stable state. And so a particle in our action that the positive energy greater than

205
00:36:24.600 --> 00:36:35.790
Jodi Cooley: Some threshold energy within a certain critical radius results in a bubble that expands and like I said, we'll go through the calculations on how this works in the next lecture.

206
00:36:36.720 --> 00:36:50.130
Jodi Cooley: A smaller diffuse energy deposition results in a bowl that immediately collapses. So you can essentially tune the chamber to make bubbles for nuclear recoil and not make bubbles or electron recoils

207
00:36:51.180 --> 00:36:57.420
Jodi Cooley: So these are some clever ways that experimentalists have come up with in order to help reduce their backgrounds.

208
00:37:00.990 --> 00:37:11.430
Jodi Cooley: I should point out that in this clock here I showed a very simple cut and cut out cut and count analysis. And it turns out that

209
00:37:12.990 --> 00:37:25.530
Jodi Cooley: These simple Putnam County analyses, although are very robust are not the types of analyses that give us the greatest sensitivities and our detectors and so nowadays.

210
00:37:25.920 --> 00:37:32.520
Jodi Cooley: We're starting to understand our backgrounds so well need experiment that we're actually able to use profile likelihood and other multi

211
00:37:33.360 --> 00:37:45.090
Jodi Cooley: Variant analysis techniques in order to do these analyses. But again, if you're using this type of technique you need to really understand and be able to characterize your background.

212
00:37:47.970 --> 00:38:04.920
Jodi Cooley: Another way that you would get rid of background is to look for a signal modulation and there's essentially two types of modulation,

you could look for one is a time dependence of an annual modulation. And so as the

213
00:38:06.060 --> 00:38:12.060
Jodi Cooley: As the earth is going around the sun. The sun is moving around our solar system.

214
00:38:13.020 --> 00:38:24.300
Jodi Cooley: And so that means, in a sense, sometimes we on Earth are going with the liquid and sometimes we're going against the liquid. And so what this means is that

215
00:38:25.020 --> 00:38:33.990
Jodi Cooley: Your flux of wins would essentially through your detector change over the course of the year and at modulation and assigning affordable fashion.

216
00:38:37.260 --> 00:38:44.100
Jodi Cooley: So that modulation is described by this equation here where essentially

217
00:38:45.270 --> 00:38:55.230
Jodi Cooley: Because the earth horrible speed is so much smaller than the Sun circular speed. You can use a tailor expansion to simplify the period or the

218
00:38:56.100 --> 00:39:12.810
Jodi Cooley: Simplified the equation in typically your period then would be one year and T not would be 150 days. So the differential rate peaks in December for small energy recoils and in the summer for large enterprise energy required

219
00:39:14.820 --> 00:39:20.490
Jodi Cooley: Now the second signal modulation that you could potentially seeing a detector comes from

220
00:39:21.600 --> 00:39:26.760
Jodi Cooley: It's called a directional signal. And essentially, it comes from the fact

221
00:39:27.900 --> 00:39:45.240
Jodi Cooley: That the earth is spinning on its axis that it goes around and so the easiest way to see this is in this picture here. So as the, the earth is moving and spinning. As you can imagine, because we're sort of tilted your this tilted.

222
00:39:46.380 --> 00:40:07.650
Jodi Cooley: Compared to the circular speed. What this means is that over the course of the day if the wind wind is coming in in a direction that is in the same direction that VC then over the course of the day you could track what direction your Wimp should make a trail in your detector.

223
00:40:08.700 --> 00:40:23.310
Jodi Cooley: So essentially what you're doing here is you're measuring the direction of the wind interacting in your detector and you remove all events that don't come in that don't come from the direction of the wind.

224
00:40:27.150 --> 00:40:27.720
Jodi Cooley: So,

225
00:40:28.860 --> 00:40:43.050
Jodi Cooley: I think that this demonstrates hopefully for you that the best thing you can do is to get rid of your backgrounds and when you can't get rid of the background. You want to characterize them as best you can, so that you can do a multivariate sort of analysis.

226
00:40:44.100 --> 00:40:44.760
Jodi Cooley: And so

227
00:40:45.870 --> 00:40:53.610
Jodi Cooley: It's really important that we screen all of the materials we use to build our detectors.

228
00:40:55.350 --> 00:41:13.620
Jodi Cooley: Here I've just shown a few pictures of some of the types of tools we use alpha screening beta screening high purity germanium screening is the workhorse of most of these experiments ICP MS radon emanation in most cases, we're looking for levels that are less than a part pavilion.

229
00:41:15.900 --> 00:41:28.140
Jodi Cooley: And so the question is, how can we do as I mentioned, high purity germanium cocking is sort of a workhorse for screening materials. And so I've made a table here of the isotope chain that you would be interested in

230
00:41:29.430 --> 00:41:39.120

Jodi Cooley: Sort of the standard size for a standard sized piece and for a larger size piece or a longer counting period in the instrument what sensitivity to get to

231
00:41:40.020 --> 00:41:53.790
Jodi Cooley: So if you had an augmented commercial system oftentimes people will buy commercial system and the augmented by design, either custom lead shield using low background lead copper or

232
00:41:54.900 --> 00:41:56.880
Jodi Cooley: Modulating neutrons and somewhere.

233
00:41:58.080 --> 00:42:00.900
Jodi Cooley: And putting them underground. We can do pretty good.

234
00:42:03.270 --> 00:42:12.600
Jodi Cooley: If you have lots of money or wanted to buy a really sensitive instrument, you will get a custom shield a custom cross tab design.

235
00:42:14.040 --> 00:42:32.130
Jodi Cooley: You make careful attention to where it is that you will place the electronics to minimize background sources of uranium sodium and potassium that we get into her computer. And when you do that, you can see that you can get much, much more sensitive measurements.

236
00:42:34.560 --> 00:42:39.150
Jodi Cooley: I mentioned alpha screening. So the x i alpha counter

237
00:42:40.260 --> 00:42:42.270
Jodi Cooley: Essentially is a chamber.

238
00:42:43.980 --> 00:42:45.060
Jodi Cooley: It's filled with gas.

239
00:42:46.290 --> 00:43:03.900
Jodi Cooley: And essentially, it does a Paul shape analysis in order to understand if the alpha event a spectrometer. And so whether that event came from the surface of your sample or whether it would have come from some other place in the in the instrument.

240
00:43:05.010 --> 00:43:11.760
Jodi Cooley: So using some ultrapure p&l copper that was electro formed, especially for this.

241
00:43:12.960 --> 00:43:30.540
Jodi Cooley: We were able to make a measurement as low as 25 nano girl per centimeter square in the sort of to 10 polonium region of interest and this we think is quite indicative indicative of what the ultimate background of this particular instrument is

242
00:43:32.340 --> 00:43:46.350
Jodi Cooley: Another way that we can get a handle on surface events now is is using an instrument called the beta cage that's been under development at South Dakota School of Mines in technology Caltech in and out and the University of it.

243
00:43:47.940 --> 00:43:49.650
Jodi Cooley: You know, Alberta, Canada.

244
00:43:51.660 --> 00:44:01.380
Jodi Cooley: They can measurable beta particles and alpha particles in here. And essentially, they can see point one beta kV per meter squared per day.

245
00:44:02.430 --> 00:44:05.340
Jodi Cooley: And point one alphas per meter squared per day.

246
00:44:07.980 --> 00:44:09.480
Jodi Cooley: And so again,

247
00:44:10.680 --> 00:44:16.470
Jodi Cooley: That this this instrument ultimately would have really great sensitivity is essentially a wire chamber.

248
00:44:19.260 --> 00:44:23.880
Jodi Cooley: And there are many other options for doing the screening. I just highlighted these three instruments, because

249
00:44:25.800 --> 00:44:36.810
Jodi Cooley: You know they're they're very well used in our community. But there's also read on emanation emotional body counters ICP MS Sims GD a math.

250
00:44:37.890 --> 00:44:49.080
Jodi Cooley: Accelerator mass spectrometer spectroscopy and neutron activation analysis. So there are a lot of options for characterizing materials.

251
00:44:51.480 --> 00:45:04.920
Jodi Cooley: Okay. So on the next the next sort of tool and thing to use for thinking about backgrounds is software. So remember these neutrons are a little bit concerning

252
00:45:05.760 --> 00:45:19.710
Jodi Cooley: So that's, that's one thing that that we look at. And there are three software frameworks that exists that we can use to calculate the specter of these neutrons on that are produced by alpha and interactions. They are sources.

253
00:45:21.780 --> 00:45:33.390
Jodi Cooley: The University of South Dakota has a web tool that you can use and then new see bot is something that was developed by the deep collaboration to calculate these types of interactions as well.

254
00:45:35.010 --> 00:45:49.620
Jodi Cooley: $10 you'll notice that one of these uses a ton of libraries. It's a validated library and this empire library is elaborated recommended by the International Atomic Energy Agency.

255
00:45:50.880 --> 00:46:02.490
Jodi Cooley: Both are good, but neither of them can calculate all the resonant behavior that's experimentally observed from these alpha and interactions.

256
00:46:04.110 --> 00:46:10.560
Jodi Cooley: And basically, you would use these tools to generate a spectra that you would then feed into a summit simulation.

257
00:46:11.160 --> 00:46:25.650
Jodi Cooley: To predict the number of background events from neutrons that you would see in your experiment. So before I go on to that next step. Let me just show you that there has been a bit of work done. Comparing these three different

258
00:46:26.700 --> 00:46:36.420
Jodi Cooley: Tools to each other. And so again, I put up references to papers in case people want further information, but this is a sample.

259
00:46:37.440 --> 00:46:47.850
Jodi Cooley: From a paper that compared to USD web tool and sources for see. And so what you can see here, over here are the spectra for uranium and thorium.

260
00:46:48.510 --> 00:47:04.260
Jodi Cooley: For for for a silicate last, which is something that's using PMT for many of the experiments and for copper, which is is used in a lot of experiments as well. And what you can see is that the spectra have no major systematic differences.

261
00:47:06.690 --> 00:47:07.260
Jodi Cooley: But

262
00:47:09.420 --> 00:47:12.540
Jodi Cooley: Both of them do have some errors in cross sections.

263
00:47:14.010 --> 00:47:18.810
Jodi Cooley: And and these errors may require a human eye in order to check

264
00:47:21.840 --> 00:47:31.740
Jodi Cooley: There's also another paper here that compared to new see box and sources. And again, you can see the yield comparison looks quite good.

265
00:47:33.150 --> 00:47:56.460
Jodi Cooley: The spectra also look quite well. And again, this was used by the deep collaboration to predict their neutron and essentially looking at the PMT glass you see 13 new transfer your from UC bought verses 15 verses 13 from sources for seeds. These numbers are all quite comparable.

266
00:47:59.520 --> 00:48:06.300
Jodi Cooley: So once you have your neutron spectra you competed interesting relation tool and jam for

267
00:48:07.410 --> 00:48:15.990
Jodi Cooley: Is is the most prevalent Lee used tool it simulates backgrounds, based on essay information that you would give to it.

268
00:48:17.040 --> 00:48:21.300
Jodi Cooley: And so here I just have a picture of a super CMS geometry in jail for

269
00:48:22.590 --> 00:48:36.240
Jodi Cooley: And so then jail for can produce for You anticipated backgrounds backdrop. And so here you can see anticipated spectra from

the extreme and our concert proceeding math for one of our germanium eyes of

270
00:48:38.040 --> 00:48:50.820
Jodi Cooley: And so this is the spectra that you would see from a different types of backgrounds and then you can take the spectra and you can do a mini analysis on it so develop selection criteria.

271
00:48:51.420 --> 00:49:03.210
Jodi Cooley: To see exactly what it is you would have after you perform some analysis on your experiment. So this can give you a good idea. And it's a tool that would be appropriate for making

272
00:49:04.530 --> 00:49:07.110
Jodi Cooley: Estimates of the sensitivity of your proposed detector.

273
00:49:09.810 --> 00:49:16.410
Jodi Cooley: And the other thing. So notice I said that their measurements that also go into the DNA for. And then as you construct your experiment.

274
00:49:17.520 --> 00:49:33.450
Jodi Cooley: What you want to do is you want to keep a background inventory and so I am showing here to inventory. So this is a snapshot of the super CMS background inventory and this is a snapshot of the LC background inventory. And so essentially what you have here.

275
00:49:34.470 --> 00:49:46.350
Jodi Cooley: Are keeping track of measurements or desire rates that you would like to have from the different materials that you construct your whole experiment auto and

276
00:49:47.070 --> 00:49:57.270
Jodi Cooley: These are really important for making trade offs, as you're trying to select your materials to make your detector. Like if one of your materials. You can't get to be as radio purity of it helped

277
00:49:57.840 --> 00:50:09.450
Jodi Cooley: Can you make a trade off of another material and it also is a tool that can be really important for vendor selection for helping you to figure out what vendors can provide you materials that that meet your needs.

278
00:50:11.610 --> 00:50:13.020
Jodi Cooley: So of course,

279
00:50:15.240 --> 00:50:25.980
Jodi Cooley: It's not that we can get a vendor for every material that we want to put into some of these detectors, sometimes we can't find it. So we just have to make it ourselves. And so I still have three examples here.

280
00:50:27.030 --> 00:50:28.080
Jodi Cooley: Of buildings.

281
00:50:29.130 --> 00:50:36.150
Jodi Cooley: One is a copper. Copper can really vary and it's uranium authority and content and some experiments and

282
00:50:36.540 --> 00:50:45.150
Jodi Cooley: In some locations really need to have their copper BL ultrapure. And so essentially what you can do is you can make ultrapure copper by Electra for me it

283
00:50:45.630 --> 00:50:58.710
Jodi Cooley: Piano was pretty good at this. And if you really have to be careful with it. You could even elect performant underground. If you really wanted to have something. Now, this stuff is really expensive. But if you need it. You can make it.

284
00:50:59.880 --> 00:51:06.060
Jodi Cooley: Another example would be gas purification. So this is something that both xenon and LD worry about

285
00:51:07.560 --> 00:51:11.400
Jodi Cooley: So you purify the clap gap you distill

286
00:51:12.690 --> 00:51:26.160
Jodi Cooley: Your xenon in order to remove Krypton. So in the case of the zenith collaboration commercial the non has about one part per million to 10 parts per billion of Krypton.

287
00:51:26.940 --> 00:51:37.260
Jodi Cooley: But the xenon one time sensitivity demand that it has point two parts per trillion of crypto and so they have built a distillation column in order to get that

288
00:51:39.330 --> 00:51:50.250

Jodi Cooley: Another example of getting material that you need is are gone. So you need to purify are gone. Argon has a naturally occurring background isotope our boundary nine

289
00:51:50.730 --> 00:51:59.250
Jodi Cooley: And so again, you might distill that and purify that and that is something that certainly the dark side collaboration has become experts in doing

290
00:52:02.520 --> 00:52:11.340
Jodi Cooley: Okay. So finally, after you get past all those backgrounds, you can control. There's one more that's going to get you.

291
00:52:11.880 --> 00:52:18.510
Jodi Cooley: Perhaps in the end where you're going to have to come up with a clever way to work around it. And those are neutrino backgrounds, from the sun.

292
00:52:19.410 --> 00:52:27.900
Jodi Cooley: So you have solar pp neutrinos, which could also be considered a signal, I suppose, if you're if you're doing different types of physics, it's not

293
00:52:28.530 --> 00:52:39.300
Jodi Cooley: Looking for dark matter, but the solar PV neutrinos there at low energies we have high fluxes. So they contribute to your electronic records background via nutrient

294
00:52:40.680 --> 00:52:53.070
Jodi Cooley: neutrino electron scattering and this will happen at about a level of 10 to 25 events per tonne year and again in the low energy, low as energy regimes.

295
00:52:54.240 --> 00:53:07.380
Jodi Cooley: The other thing you could have is a neutrino induced nucular recoil and that can't be distinguished from old signal. And so the board on eight solar neutrinos would be a great example of this.

296
00:53:09.180 --> 00:53:14.430
Jodi Cooley: Here, you would expect about 10 to the three events per ton year for heavy targets.

297
00:53:15.780 --> 00:53:30.420
Jodi Cooley: In addition to that, the other neutrino and just nucular recoil that you could get our atmospheric neutrinos and diffuse supernova

neutrinos. And then again, depending on your estimates that something like one to five events per hundred 10 years

298
00:53:33.600 --> 00:53:35.850
Jodi Cooley: Alright so let me summarize

299
00:53:37.380 --> 00:53:42.840
Jodi Cooley: So direct detection needs the ability to see low energy weapon nucular recoils

300
00:53:44.880 --> 00:53:51.990
Jodi Cooley: So you need radio genetically pure materials and you need a detector that can have a very low threshold.

301
00:53:54.240 --> 00:54:13.860
Jodi Cooley: The ability to distinguish nuclear recoil can be really critical when it is that you actually see a signal. So being able to distinguish between electric electronic or electronic files and nuclear recoils and being able to see the difference between alpha events and you feel recoils

302
00:54:16.590 --> 00:54:24.930
Jodi Cooley: You need to have a plan for radio Genet and cosmic genetic background mitigation. This could be passive and or active shielding.

303
00:54:26.310 --> 00:54:35.640
Jodi Cooley: Position reconstruction and financial ization can help with this and characterization of these backgrounds through an essay and simulation.

304
00:54:37.200 --> 00:54:55.050
Jodi Cooley: Finally, you need to have long exposures and those exposures need to be stable. And this is especially important that stability is especially important if it is that you want to use annual or diurnal modulation.

305
00:54:56.190 --> 00:54:57.390
Jodi Cooley: In searching for dark matter.

306
00:54:59.340 --> 00:55:02.640
Jodi Cooley: All right, so let's take a brief look here.

307
00:55:04.710 --> 00:55:05.760
Jodi Cooley: At our search space.

308
00:55:06.960 --> 00:55:18.750
Jodi Cooley: Alright so Tim would have gone over these in the last several days. But just to give you an idea, there are lots of models are here. These are some constraints minimal supersymmetry models.

309
00:55:20.310 --> 00:55:22.560
Jodi Cooley: That sort of show up in this energy regime.

310
00:55:24.030 --> 00:55:27.270
Jodi Cooley: You could go to pee and SSM

311
00:55:28.650 --> 00:55:29.220
Jodi Cooley: Models.

312
00:55:30.660 --> 00:55:36.330
Jodi Cooley: You could go to an MSM models and get slightly lighter dark matter.

313
00:55:37.650 --> 00:55:38.220
Jodi Cooley: And then

314
00:55:39.390 --> 00:55:55.860
Jodi Cooley: You could also look at sort of newer ideas and dark matter, some that have become popular like a symmetric dark matter to cover the low range, so we can probably find a model pretty much anywhere you want to go. And so the winds, not, not quite dead yet.

315
00:55:56.880 --> 00:55:59.940
Jodi Cooley: And we certainly have even more parameter space to explore

316
00:56:01.260 --> 00:56:19.620
Jodi Cooley: So where do we stand now. Um, so here I have basically plotted some of the leading results that are out there and the gray area now that shade of gray here is excluded region. So, this is what we've excluded. So you can see that that we still have a ways to go.

317
00:56:21.360 --> 00:56:39.660
Jodi Cooley: So finally, what it is that we're going to want to do is not only do we want to push down. We want to push to lower masses. The lower cross section and lower masses, but at some point we will run into that nutrient background which I had pointed out.

318

00:56:41.010 --> 00:56:47.580
Jodi Cooley: And so that is what I had for today. I think that I ended three minutes early, and maybe I should have more

319
00:56:50.610 --> 00:56:53.130
charlie young: This is wonderful. Thank you for for tonight's lecture.

320
00:56:54.150 --> 00:56:56.970
charlie young: So let's go to Q AMP. A quick

321
00:56:57.630 --> 00:57:09.570
grzegorz madejski: Sure. Thank you God for a great lecture. I look forward to them tomorrow as well. So let's get going with the questions that aren't that many. But the first one is what our modules. I think that that's an excellent

322
00:57:10.410 --> 00:57:15.660
Jodi Cooley: Excellent yes module is an acronym. I, I saw holiday so massive

323
00:57:17.010 --> 00:57:25.620
Jodi Cooley: I forget what it is. Oh, me as her massive compact halo August. So these would be things like Bronk works.

324
00:57:26.520 --> 00:57:37.770
Jodi Cooley: There was a huge inventory of these sort of massive compact halo objects done back in the late 80s and 90s and an inventory was done at them. So these would be things that when it shine.

325
00:57:39.210 --> 00:57:45.960
Jodi Cooley: And and and could be hard to detect. But there just aren't enough of these objects in order to account for all the dark matter.

326
00:57:47.610 --> 00:57:50.310
Jodi Cooley: That's a great question. Sorry for for using an acronym.

327
00:57:51.300 --> 00:58:02.250
grzegorz madejski: Right on slide six. There's a question from one of the attendees saying that's absorption mean that the electron absorbs the dark matter. I suspect the answer is no.

328
00:58:03.750 --> 00:58:12.660
Jodi Cooley: Yeah, no, no. So, um, oh, this is what I wished him with online for to be able to explain better. Um, but no, it's not.

329
00:58:13.890 --> 00:58:22.680
Jodi Cooley: absorption. So think about your particle physics right different ways that particles can interact. So, this is this is essentially

330
00:58:23.760 --> 00:58:35.700
Jodi Cooley: Interacting through your just your standard absorption mechanism. I don't have a very good slide on it, but perhaps I can respond to that with a with a better graphic.

331
00:58:38.100 --> 00:58:40.950
Jodi Cooley: You know in the in the in the materials that we upload

332
00:58:41.760 --> 00:58:53.880
Jodi Cooley: Okay, but essentially it's just the standard of search and process that you would have seen in particle physics. And so I can, I can probably provide like a Venn diagram and some explanation later that would be better.

333
00:58:54.870 --> 00:59:01.290
grzegorz madejski: Okay on slides 11 to 12 there's a question. How were those four formula is derived generally

334
00:59:01.920 --> 00:59:02.820
Jodi Cooley: Yeah, let me see here.

335
00:59:03.840 --> 00:59:04.380
Jodi Cooley: 11

336
00:59:04.920 --> 00:59:05.400
grzegorz madejski: And 12

337
00:59:06.960 --> 00:59:08.340
Jodi Cooley: So these form factors.

338
00:59:09.570 --> 00:59:10.500
Jodi Cooley: I'm assuming

339
00:59:12.330 --> 00:59:13.860
Jodi Cooley: That this is referring to

340

00:59:22.710 --> 00:59:26.010
grzegorz madejski: I suspect probably providing reference would be good because I think it might take a

341
00:59:26.010 --> 00:59:26.610
Jodi Cooley: Little okay

342
00:59:26.820 --> 00:59:33.570
Jodi Cooley: So yeah, let me let me provide a reference to this is really a really great reference to that. Actually, I have it right here.

343
00:59:36.000 --> 00:59:46.980
Jodi Cooley: I would take a look, look. Sorry, this one here, we'll take a look at this. I'm the physics of the dark universe. There is an article in it by Laura about us that steps through

344
00:59:47.670 --> 01:00:03.000
Jodi Cooley: The derivation. And in this book by her town. So if your library habit. Perhaps you can get it also has a chapter that is by and green and David CD or no, and they walked through the calculations step by step. So these would be great places.

345
01:00:04.620 --> 01:00:10.320
Jodi Cooley: To get those these papers here also walk through those calculations.

346
01:00:12.750 --> 01:00:27.660
Jodi Cooley: I think here. It's in chapter seven and I forget where I forget what's in this paper and Lieutenant Smith has a lot does go through some of the nuclear physics and dependent and independent calculations. So those are great. References

347
01:00:29.010 --> 01:00:35.280
grzegorz madejski: All right. On slide 14 there is a question. How is the local dark matter density measured

348
01:00:42.960 --> 01:00:45.150
Jodi Cooley: You know, I forgot how they do that, to be honest.

349
01:00:45.870 --> 01:00:46.140
Jodi Cooley: I

350
01:00:46.770 --> 01:00:50.040
Jodi Cooley: I suspect I think you you you guys must know

351
01:00:50.370 --> 01:00:54.510
grzegorz madejski: A little bit. I think that the way it's usually done is basically by looking the

352
01:00:55.320 --> 01:01:02.010
grzegorz madejski: The velocities of stars and assuming that you know since the total mass of our galaxy is dominated by dark matter.

353
01:01:02.310 --> 01:01:10.740
grzegorz madejski: You could actually try to figure out what is the total density in the interior and looking at the distribution of velocity as a function of radius away from the galactic center.

354
01:01:11.070 --> 01:01:18.780
grzegorz madejski: You can actually determine how much, what is the local data density to to basically to account for the gravitation that starts encounter.

355
01:01:19.470 --> 01:01:23.460
Jodi Cooley: And I know that I have a reference for this as well. So I can put that in the notes to

356
01:01:23.910 --> 01:01:25.590
grzegorz madejski: That that's probably not and

357
01:01:25.740 --> 01:01:28.680
Jodi Cooley: There's a standard. There's a sample reference that we use for this all the time.

358
01:01:28.920 --> 01:01:40.320
grzegorz madejski: Right. The next one, next three or four the seven for slide 17. The first one is, what does it mean to use a chlorine or fluoride in eigenvector.

359
01:01:41.880 --> 01:01:48.090
Jodi Cooley: Yeah, this is the part of the talk that I, I have to say I am really not prepared to give

360
01:01:49.290 --> 01:01:58.410
Jodi Cooley: You know, a lot of in depth explanation of I am like, I'm not an expert on these theories. I will try to do the best I can and

361

01:01:59.610 --> 01:02:02.610
Jodi Cooley: I think the papers that I have listed here on

362
01:02:04.080 --> 01:02:13.290
Jodi Cooley: Those are sort of the fundamental foundation papers that can give you some more details like with the law grungy ends and everything worked out. If you want to study them in detail.

363
01:02:14.370 --> 01:02:16.110
Jodi Cooley: But essentially what it is is that

364
01:02:17.790 --> 01:02:25.620
Jodi Cooley: You know, similar to how I have done this calculation out for the spin independent and the spin depending cases.

365
01:02:26.760 --> 01:02:32.460
Jodi Cooley: You can get different item vectors that you would use like you would have spent days.

366
01:02:33.510 --> 01:02:37.770
Jodi Cooley: To do your calculation. So the idea would be is that perhaps you would

367
01:02:39.060 --> 01:02:48.750
Jodi Cooley: Find for some reason that the axial vector is what you want to use to make the measurement and you go back to here.

368
01:02:50.490 --> 01:02:53.970
Jodi Cooley: Where guns are pointing at my screen and you can't seem to the point

369
01:02:56.250 --> 01:03:14.610
Jodi Cooley: Where you have these response functions. And so essentially we can take combinations of these response functions and mathematically combine them using like I vectors and you can pick out what it is that you might want to use to do your calculation.

370
01:03:16.440 --> 01:03:23.940
grzegorz madejski: Yeah, I think that the next, next question is actually closely related. It says again related to slide 17 and the

371
01:03:24.600 --> 01:03:35.400

grzegorz madejski: Question goes as follows. This would be also the case, even if we don't use effective field theory, right, the cross section depends on the form factors. Every nucleus has its own form factors.

372
01:03:35.730 --> 01:03:45.720
Jodi Cooley: Right. And for this is, I mean, this is sort of sort of the point. The point of developing these effective field theories. I think that at least this is where I think the question is, is coming from.

373
01:03:46.200 --> 01:03:51.900
Jodi Cooley: The point I think that people were were thinking about when they were coming up with these effective field theories is that

374
01:03:52.440 --> 01:04:01.470
Jodi Cooley: For the longest time, we know that the interaction, like if we see a signal the interaction that we would see certainly depends on the nuclear physics is going on at that scale.

375
01:04:01.920 --> 01:04:12.030
Jodi Cooley: And using just spin dependent and spin independent sort of interpretations, you know, could be night. And if you were to use

376
01:04:13.050 --> 01:04:18.840
Jodi Cooley: You know, because the truth is if we just don't know for sure what it is. And so until it is that we start seeing

377
01:04:19.440 --> 01:04:24.930
Jodi Cooley: Some dark matter. We can't constrain the vast parameter space. So in the same way.

378
01:04:25.560 --> 01:04:39.240
Jodi Cooley: When I showed the plot of the mass versus the cross section. And I said, people have all these ideas they have you know PSM they have CSS on me an asymmetric dark but you have all these things and they give you a variety. The some similarly

379
01:04:40.410 --> 01:04:45.810
Jodi Cooley: At sort of the, the quantum mechanics level of the nucleus, you have the same types of things going on.

380
01:04:46.500 --> 01:04:56.490
Jodi Cooley: There there's physics there that we don't understand and have nailed down and this paper or the sets of papers were essentially showing us how it is.

381
01:04:56.910 --> 01:05:05.220
Jodi Cooley: That depending on what type of target we have in which of these responses these nuclear responses was most important

382
01:05:05.850 --> 01:05:16.710
Jodi Cooley: Would depend on is something you would want to take into account, depending on what you're testing when you're choosing your target material. And I think probably the most important lesson from it is that

383
01:05:17.760 --> 01:05:28.380
Jodi Cooley: It shows you how important it is to have multiple targets, because if we do start seeing signals and can see it in multiple detectors that have different targets.

384
01:05:29.430 --> 01:05:36.600
Jodi Cooley: We can start to understand which of these nuclear form factors would be most important for those interactions.

385
01:05:37.950 --> 01:05:38.310
grzegorz madejski: Okay.

386
01:05:39.750 --> 01:05:42.030
Jodi Cooley: That's why I wanted to introduce the idea at all.

387
01:05:42.990 --> 01:05:55.200
grzegorz madejski: Okay, thanks. The next one is can we assume that the dark matter Halo is static, with respect to the galactic center. And how do we know that there is no steering movement of dark matter particles.

388
01:05:56.490 --> 01:05:57.390
grzegorz madejski: within you.

389
01:05:57.600 --> 01:06:00.300
Jodi Cooley: Yeah, so I would say that

390
01:06:02.730 --> 01:06:14.010
Jodi Cooley: That it is a reasonable assumption that I think it's static based on tourism. It's like if it was moving right then, like, you have to have a mechanism that starts that motion.

391
01:06:17.640 --> 01:06:21.510

grzegorz madejski: Wait, cannot be completely stationary, because then everything would collapse into galactic

392
01:06:21.510 --> 01:06:22.500
Jodi Cooley: Center. Yeah.

393
01:06:22.830 --> 01:06:23.160
Because

394
01:06:24.600 --> 01:06:24.930
grzegorz madejski: There's

395
01:06:25.260 --> 01:06:27.060
grzegorz madejski: Roughly the same as speeds of stars. Right.

396
01:06:27.480 --> 01:06:30.150
Jodi Cooley: Right. But yeah.

397
01:06:31.320 --> 01:06:33.750
Jodi Cooley: So I think that's why we use laboratory frame right

398
01:06:34.140 --> 01:06:34.440
grzegorz madejski: Right.

399
01:06:35.100 --> 01:06:40.830
Jodi Cooley: I mean, it's not that we're saying it's static but it static depending on what frame of reference, you put it in.

400
01:06:43.290 --> 01:06:43.560
Jodi Cooley: Well,

401
01:06:44.850 --> 01:06:45.660
Jodi Cooley: Okay, maybe

402
01:06:46.650 --> 01:06:49.710
grzegorz madejski: The next one is what's sad information.

403
01:06:51.120 --> 01:06:52.200
Jodi Cooley: As a, ah,

404
01:06:52.650 --> 01:06:54.030

grzegorz madejski: Slide 43. Yep.

405
01:06:54.390 --> 01:07:00.330
Jodi Cooley: So as a information is so let's say that I have a material of videos. My copper like

406
01:07:03.690 --> 01:07:11.040
Jodi Cooley: And I want to use that in my experience, or I'm trying to get this like 43. Okay. Oh well.

407
01:07:12.210 --> 01:07:14.100
Jodi Cooley: The essay information. Maybe it's here.

408
01:07:15.240 --> 01:07:31.680
Jodi Cooley: So essentially the idea is that if I have material in as a candidate material that I'm going to build the detector auto, I would like to know how much uranium, thorium potassium primarily those three candidates are inside

409
01:07:32.760 --> 01:07:48.120
Jodi Cooley: That material because all materials can contain some kind of trace amounts of the of these sorts of elements. And so an essay is the results you get from putting it in an instrument that can measure those contaminants

410
01:07:49.230 --> 01:07:51.240
Jodi Cooley: Essays also can refer to

411
01:07:52.320 --> 01:07:54.480
Jodi Cooley: Surface events. So when I was talking about.

412
01:07:55.980 --> 01:08:00.030
Jodi Cooley: The exhale alpha counter in the beta cage.

413
01:08:01.080 --> 01:08:03.510
Jodi Cooley: These instruments are designed to ask a

414
01:08:05.100 --> 01:08:08.070
Jodi Cooley: particles that are coming off the surfaces of materials.

415
01:08:09.540 --> 01:08:10.080
Jodi Cooley: The

416
01:08:11.850 --> 01:08:32.220
Jodi Cooley: high purity germanium counters as they like uranium authority and potassium content inside the bulk of materials and these are important. Like I said, because when they decay. You know, they give off gamma they give off you know particles that can be electron recall backgrounds, two years.

417
01:08:35.220 --> 01:08:45.450
grzegorz madejski: All right. And there's one last question really that relevant two slides 49 or 50. And the question goes, Why is there a gap in the mass around three GV

418
01:08:52.950 --> 01:09:01.800
Jodi Cooley: I honestly don't know. I'm certain that if we found a dark matter candidate at three GV we could find a dark matter particle that

419
01:09:03.480 --> 01:09:11.160
Jodi Cooley: That talks to you, but I am not familiar enough with supersymmetry theories to know why there appears to be a gap there.

420
01:09:11.580 --> 01:09:16.710
grzegorz madejski: There is a possibility to tell might be able to answer the question, because I think it's one of the originators of those plots.

421
01:09:16.920 --> 01:09:21.720
thomas rizzo: This is an artist. This is an artifact of how they slide was made is no gap.

422
01:09:25.050 --> 01:09:33.600
grzegorz madejski: Okay, this is pretty much all the questions that we have God, thank you very much for a great lecture. We look forward to another one tomorrow. So back to you, Charlie.

423
01:09:34.320 --> 01:09:34.800
Thank you.

424
01:09:36.000 --> 01:09:45.150
charlie young: I will also like to express my thanks to all of today's speakers Tim June Paolo and now God and to all the participants for joining us.

425
01:09:45.690 --> 01:09:49.890
charlie young: And so that wraps wraps it up for today and we'll see you all tomorrow.

426
01:09:50.970 --> 01:09:52.920
grzegorz madejski: All right, bye. You're going to stop recording