charlie young: Please go ahead.

Alright.

Jodi Cooley: Um. Let me confirm you can hear me.

Yes. We hear you.

Okay, fantastic.

So it's a real pleasure to be here. Virtually with you all.

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.

Jodi Cooley: Of what I plan to talk about today. And then what I will talk about tomorrow.

You can see this outline on the slide. Give me a second here.

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

Rate calculations the sorts of things that go into those rate calculations for a simplified model.
Jodi Cooley: I'll spend a great deal of time talking about background considerations that we take into account 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

Jodi Cooley: Some of the unique signatures that we might be what we would expect from direct detection of dark matter.

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

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

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

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.

Jodi Cooley: And then I'll talk about detecting scattering from the nucleus using existing experiments and then talking about how we can reach

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.

Jodi Cooley: That people have now to extend the sensitivity of dark matter experiment into the sub EV range.
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.

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.

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 in the books and special editions that I have on one being the dark universe. The very first volume of it.

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.

Jodi Cooley: So I think last week when you had your lecture on cosmology. And and and such.

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.

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.
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.

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.

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.

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

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

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.

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.

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.

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.

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.

And then, as you've been hearing from Tim to over the last three days.

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.

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.

We're recently we've been looking at dark matter electron recoil scattering in a number of experiments and then you also could have electron recoil absorption is another way that you could or another channel through which you could directly detect dark matter.

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

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.

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.
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.

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.

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

So what are the elements that would go into your calculation.

So this is the equation for the differential evaporate.

In your detector from direct detection. It depends on the local wins density row, not

It depends on the mass of your nucleus. It depends on the mass of your dark matter candidate.

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.

You integrate this over the minimum with velocity that can cause a recoil of energy, er, in your nucleus to infinity.

So what you can see is that you need input from astrophysics particle physics and nuclear physics in order to do this calculation.
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

\[ E = \text{new n square} \times \text{velocity squared} \times (1 - \cos \theta) \div \text{mass of your nucleus}. \]

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.

Alright, so right now we're going to integrate this over the threshold energy and examine the d sigma Dr component.

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

I realized here that a copy of the same same words twice the spin dependent arise from vector and axial vector.

Okay. So to calculate you add coherently the spin and scale or component. And so when you do this.

What you end up with is the mass of the nucleus divided by two times for Christmas squared plus b squared.

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.
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.

Jodi Cooley: Alright so breaking this down even further.

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.

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

Jodi Cooley: The skin.

Jodi Cooley: Or the skin thickness of the nucleus, which generally is about a centimeter and an effective nucleus radio

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.

Jodi Cooley: So the recoil dependent form factor. You can see depends on these

Jodi Cooley: Ay, ay, ay sub JS. These are iso sailor and ISO vector coupling.

Jodi Cooley: And those coupling.

Jodi Cooley: Are different for protons and neutrons.
Jodi Cooley: Alright, so let's take a look. That's the nucleus interaction and sorts of things that are involved in this.

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.

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.

Cross section as coherently with a square.

Which is your atomic number of your target.

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.

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.

And in the spin dependent case there is no coherent effect. And so you don't really gain.

From that a square factor.
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 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.

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.

Jodi Cooley: And in the most simple model that you can take the dark matter would be distributed in an ISO thermal spherical Halo.

Jodi Cooley: With a Gaussian velocity distribution. This is often known as a Maxwell Maxwell Boltzmann distribution, it looks like this.

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.

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.

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.

Jodi Cooley: But there is a good reason for it. And that's because
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.

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.

Jodi Cooley: This is a picture of my local group at SMU.

Jodi Cooley: We even had somebody on zoom from remote.

Jodi Cooley: That day so remembering that our local density is point three GB per cubic centimeter.

Jodi Cooley: What you need to do is essentially 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.

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.

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.

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.

Jodi Cooley: Either way, enough particles to give you a flux to build a detector to try to see dark matter.

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.

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.

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.

Jodi Cooley: And you can combine these operators in such a way that the Wimp nuclear cross section would depend on six independent

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

Jodi Cooley: When you have two pairs interfering. You can get a result that is essentially eight independent parameters that you can produce

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.

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.
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.

Jodi Cooley: Some affected field theory operation have a momentum dependence and the operators can interfere.

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 your results have different rate between the targets. They also have different spectral shapes.

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.

Jodi Cooley: So now, going back to our simple into us been independent case.

Jodi Cooley: What we can see here is this is the total rate.

Jodi Cooley: Per 10 kilograms per year versus your detector threshold for a variety of targets. So this assumes that the mass 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.
Jodi Cooley: The spectrum itself is featureless. There's no need. There's no bumps. There's no brakes.

And furthermore, the event rate is very low. This year line is one event per 10 kilograms per year.

So the radioactive background of most materials is much higher than the event rate that we're looking for.

So that means that you need large exposure times and you also need very low backgrounds.

Jodi Cooley: 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

So the challenge. Again, this recoiling energy that you also have the current constraint that a wimp needs to have a minimum of velocity in order to produce a recoil.

And so here plotted here is the integrated event rate per kilogram per year versus experimental threshold in KGB.

This is for germanium, assuming when scattered went up on cross section of scattering cross section of one times 10 to the minus

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.

In addition to that,
Jodi Cooley: The total rate for different thresholds is also different. So in this plot here again it events per kilogram per year.

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.

Jodi Cooley: So these are the types of considerations that you would take into account when selecting the target for your detector material.

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.

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.

Jodi Cooley: Of potassium 40 who decay at about 4400 disintegration per second.

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

Jodi Cooley: The, the rate for energy and kilograms per kV per day.

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.

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,
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 measure this.

Jodi Cooley: So backgrounds are important with the moral of that story.

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

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

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

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.

Jodi Cooley: We worry about radiogenic neutrons that have energies below 10 MTV and this includes neutron term alpha and envision reactions.

Jodi Cooley: We have to worry about cosmic rays and their secondary

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
Jodi Cooley: Backgrounds in your detector materials themselves by just having them on the surface of the Earth.

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.

Jodi Cooley: So,

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.

Jodi Cooley: And so the hydroponic component of the cosmic ray flux is negligible.

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.

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.

Jodi Cooley: The overburden so different sites have a different overburden different types of rocks or compositions of material that are above them.

Jodi Cooley: It becomes very difficult to compare side. And so what we do is we take the overburden of the site.
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.
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.

Jodi Cooley: That are related to both cars mechanic and radiogenic neutrons.

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.

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.

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.

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.

Jodi Cooley: And so a lot of times

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.

Jodi Cooley: So the most prevalent background that you actually see in your detector is a gamma ray or a beta particle

Jodi Cooley:
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.

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

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

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

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

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.

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

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

00:34:02.800 --> 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.

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.
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

Jodi Cooley: And so here's

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.

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.

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

Jodi Cooley: This is another crystal calcium tongue.

Jodi Cooley: Then

Jodi Cooley: It.

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.

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.
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.

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

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.

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

Jodi Cooley: So these are some clever ways that experimentalists have come up with in order to help reduce their backgrounds.

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

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.

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

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.

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.
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.

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.

Jodi Cooley: So,

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.

Jodi Cooley: And so

Jodi Cooley: It's really important that we screen all of the materials we use to build our detectors.

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.

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
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

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

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

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

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.

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.

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

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

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

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.

00:43:05.010 --> 00:43:11.760
Jodi Cooley: So using some ultrapure p&l copper that was electro formed, especially for this.
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 of what the ultimate background of this particular instrument is.

Jodi Cooley: Another way that we can get a handle on surface events now 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.

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.

Jodi Cooley: And point one alphas per meter squared per day.

Jodi Cooley: And so again,

Jodi Cooley: That this this instrument ultimately would have really great sensitivity is essentially a wire chamber.

Jodi Cooley: And there are many other options for doing the screening. I just highlighted these three instruments, because

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

Jodi Cooley: Accelerator mass spectrometer spectroscopy and neutron activation analysis. So there are a lot of options for characterizing materials.
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.

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 spectra of these neutrons on that are produced by alpha and interactions. They are sources.

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.

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.

Jodi Cooley: Both are good, but neither of them can calculate all the resonant behavior that's experimentally observed from these alpha and interactions.

Jodi Cooley: And basically, you would use these tools to generate a spectra that you would then feed into a summit simulation.

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.

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.

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.
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.

Jodi Cooley: But

Jodi Cooley: Both of them do have some errors in cross sections.

Jodi Cooley: And and these errors may require a human eye in order to check

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.

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.

Jodi Cooley: So once you have your neutron spectra you competed interesting relation tool and jam for

Jodi Cooley: Is is the most prevalent Lee used tool it simulates backgrounds, based on essay information that you would give to it.

Jodi Cooley: And so here I just have a picture of a super CMS geometry in jail for

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

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.

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

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

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.

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.

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

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

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.

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

Jodi Cooley: Of buildings.

Jodi Cooley: One is a copper. Copper can really vary and it's uranium authority and content and some experiments and

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

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.

Jodi Cooley: Another example would be gas purification. So this is something that both xenon and LD worry about

Jodi Cooley: So you purify the clap gap you distill

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.

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
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.

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.

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.

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.

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.

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.

00:52:39.400 --> 00:52:40.680
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.

00:52:40.680 --> 00:52:53.070
Jodi Cooley: The other thing you could have is a neutrino induced nuclear 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.

00:52:54.240 --> 00:53:07.380
Jodi Cooley: Here, you would expect about 10 to the three events per ton year for heavy targets.

00:53:09.180 --> 00:53:14.430
Jodi Cooley: In addition to that, the other neutrino and just nuclear 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 nuclear 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.
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.

Jodi Cooley: That sort of show up in this energy regime.

Jodi Cooley: You could go to pee and SSM models.

Jodi Cooley: Models.

Jodi Cooley: You could go to an MSM models and get slightly lighter dark matter.

Jodi Cooley: And then

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.

Jodi Cooley: And we certainly have even more parameter space to explore

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.

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.
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.

Charlie Young: This is wonderful. Thank you for tonight's lecture.

Charlie Young: So let's go to Q & A. A quick.

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's an excellent.

Jodi Cooley: Excellent yes module is an acronym. I, I saw holiday so massive.

Jodi Cooley: I forget what it is. Oh, me as her massive compact halo August. So these would be things like Bronk works.

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.

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.

Jodi Cooley: That's a great question. Sorry for for using an acronym.

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.

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.
Jodi Cooley: absorption. So think about your particle physics right different ways that particles can interact. So, this is this is essentially

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.

Jodi Cooley: You know in the in the in the materials that we upload

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.

grzegorz madejski: Okay on slides 11 to 12 there's a question. How were those four formula is derived generally

Jodi Cooley: Yeah, let me see here.

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: 11

Jodi Cooley: So these form factors.

Jodi Cooley: I'm assuming

Jodi Cooley: That this is referring to
grzegorz madejski: I suspect probably providing reference would be good because I think it might take a

Jodi Cooley: Little okay

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.

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

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.

Jodi Cooley: To get those these papers here also walk through those calculations.

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

grzegorz madejski: All right. On slide 14 there is a question. How is the local dark matter density measured

Jodi Cooley: You know, I forgot how they do that, to be honest.

Jodi Cooley: I suspect I think you you guys must know
grzegorz madejski: A little bit. I think that the way it's usually done is basically by looking the

grzegorz madejski: The velocities of stars and assuming that you know since the total mass of our galaxy is dominated by dark matter.

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.

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.

Jodi Cooley: And I know that I have a reference for this as well. So I can put that in the notes to

grzegorz madejski: That that's probably not and

Jodi Cooley: There's a standard. There's a sample reference that we use for this all the time.

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.

Jodi Cooley: Yeah, this is the part of the talk that I, I have to say I am really not prepared to give

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
Jodi Cooley: I think the papers that I have listed here on

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.

Jodi Cooley: But essentially what it is is that

Jodi Cooley: You know, similar to how I have done this calculation out for the spin independent and the spin depending cases.

Jodi Cooley: You can get different item vectors that you would use like you would have spent days.

Jodi Cooley: To do your calculation. So the idea would be is that perhaps you would

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.

Jodi Cooley: Where guns are pointing at my screen and you can't seem to the point

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.

grzegorz madejski: Yeah, I think that the next, next question is actually closely related. It says again related to slide 17 and the

grzegorz madejski: Yeah, I think that the next, next question is actually closely related. It says again related to slide 17 and the
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.

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.

Jodi Cooley: The point I think that people were were thinking about when they were coming up with these effective field theories is that

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.

Jodi Cooley: And using just spin dependent and spin independent sort of interpretations, you know, could be right. And if you were to use

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

Jodi Cooley: Some dark matter. We can't constrain the vast parameter space. So in the same way.

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

Jodi Cooley: At sort of the, the quantum mechanics level of the nucleus, you have the same types of things going on.

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.
Jodi Cooley: That depending on what type of target we have in which of these responses these nuclear responses was most important 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 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.

Jodi Cooley: We can start to understand which of these nuclear form factors would be most important for those interactions.

Jodi Cooley: That's why I wanted to introduce the idea at all.

grzegorz madejski: Okay. 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.

Jodi Cooley: Yeah, so I would say 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.
grzegorz madejski: Wait, cannot be completely stationary, because then everything would collapse into galactic

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

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

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

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

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

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

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

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.

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

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

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

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

01:06:52.650 --> 01:06:54.030
Jodi Cooley: So as information is so let's say that I have a material of videos. My copper like

Jodi Cooley: And I want to use that in my experience, or I'm trying to get this like 43. Okay. Oh well.

Jodi Cooley: The essay information. Maybe it's here.

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

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

Jodi Cooley: Essays also can refer to

Jodi Cooley: Surface events. So when I was talking about.

Jodi Cooley: The exhale alpha counter in the beta cage.

Jodi Cooley: These instruments are designed to ask a

Jodi Cooley: particles that are coming off the surfaces of materials.
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.

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

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

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.

thomas rizzo: This is an artist. This is an artifact of how they slide
was made is no gap.

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.

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.

charlie young: And so that wraps wraps it up for today and we'll see you
all tomorrow.
grzegorz madejski: All right, bye. You're going to stop recording