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SPEAKERS

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ALTA: A

M: Welcome to the plenary session. It will be chaired by Caterina Doglioni and myself. Each talk will last 24 minutes and there will be six minutes for questions and discussions. Let me briefly remind you of the set-up of this session. So, first of all, I would like to ask the speakers to mute themselves unless they are speaking. All the other attendees will be muted by default. At the end of each talk you can ask questions by using the raising hands button and I will then or Caterina will unmute you. You can also post questions in the chat box, but we would like you to use this option only if you can't use raising hands. Please think when you ask your question to say your name. Once you have finished lower your hand again. The fix time will be about new ideas in dark sectors and how they can be probed by Simon Knapen.

S: Thanks, everyone, for dialling in on your Saturday. I hope everyone is doing as well as possible given the challenging circumstances and so on. I was asked to tell you a bit about some recent and less recent theory developments in dark sectors and that is what we will be doing. You can start by asking a question: what is a dark sector? If you are doing the first thing, to Google, you will find an unhelpful in the answer that it is a collection of yet-unobserved quantum fields and their corresponding hypothetical particles. I'm going to operate on the following definition where a dark sector here means an extension of the model which does not carry the model numbers. In this diagram you see the space where the gluino and EWino and so on are visible in the standard model, so this is not in the dark sector and everything else counts as a dark sector. The dark sector may or may not include a dark matter candidate, and that is not mandatory. I will talk only about accelerator applications about these models. There are a lot of things that I won't be addressing today. With these caveats, it is a huge chunk of literature and I will be neglecting large amounts of it and apologies for that.

First I thought it would be useful to elaborate a little bit on what are the two schools of thoughts in my mind that are present in the community when we think about these things. The first series of theory priors you can adopt ask that minimalism, in the sense that they take the standard model and try to set it with a smaller set of particles, one or two, and a small set of couplings. We talked about simplified models or portals and this is the thing you talk about. The other school of thought is a realism, which is where you're trying to address a particular problem in the model like the dark matter or what not, and these models are elaborate and intricate and they tell a story rather than a set of particles. At the risk of beating that horse, I thought it would be useful to briefly remind you of the pros and cons of each of these approaches. In the minimalist scenario, you have a fairly limited set of options that you could be pursuing. There are only certain ways that you can extend the models with the particles. They're simple, low parameter space and make them great for benchmarking and for comparing one experiment against another.

That is, of course, a gloss, but it is in the negative column in the sense that it is very easy to get carried away a little bit with this if one is not careful because of the convenience of projecting everything onto the parameter spaces. This is something that we have to be mindful of when we do these things. It then there is the obvious down side that there is no priori demotivation as to why these things have to be there. The realist theory, the theory motivation is there. There is a specific problem you're trying solve. These models have much more predictive power than the minimalist power. That gives you a prediction on the parameter space. The down sides are that there is a huge number of these things, over hundreds of these each year being published and it is unmanageable in that sense. Often in these models the parameter space is relatively high dimensional and it means that it can be difficult to rigorously falsify them. A model independent approach to the dark sector is probably not possible and if it is, it is very difficult. In that light I think it is important that we balance niece two schools of thought and relying too strongly on one of them could be dangerous and we could be missing things.

Here is a cartoon of what a journey through the dark sector could look like for us. We live on the model here, the standard model, the continent on the bottom left. It is nice. All the stuff is there. We're having a good time and lots of interesting things to explore, but we want to see what is beyond and so if you're interested in minimalist models, the analogy is that these things live around the shallow water along the island. Here are a few examples of a model that you see showing up in literature very often. The realist model will be islands in the distance with a boat required to go there to explore and more rich structure on these things, but they're off in the distance. I will be discussing a little bit about these. We will start with the minimalist models. In the upper right corner you always see the depiction of what I am talking about, so you can see which model I'm currently discussing. Usually a typical minimalist model is one single new particle that you connect to the standard model. There is a production moat and decay moat. The couplings of these are very small. That means because they are your production modes that are most promising on either exotic delays of standard particles or situations of high parton, luminosity function.

The decay is also intricate and interesting in the sense here you see a simple high formula of what the decay with a particular particle might look like or achieve a constant and M is heavy scale and the n is an integer that depends on the particular model in question. From this structure, all these will look like this. You see that if this M here is fairly heavy because we haven't observed the new particles yet, that means that if this light particle, the thing you're looking for is in the GV range, you can generically expect that this is very small and you have a long particle in the context. That really informs the way we look for these models, at least in the low range. Because we are in the minimalist mindset, you get bonus points if your particular model predicted to K and production project if it's the same. If it is the same vertex it is considered better. Let's first show you one example of where you have very high luminosity. This is a light by light scattering. Here the photon is with high charges here. You can fuse them into particles. Here are some limits produced by ATLAS and CMS on the particle and this is the coupling constant. You have pretty small ones.

The world's best limits here are coming from heavy ion coaches which is kind of interesting. This is where you're producing one of the light stages through the decay of a standard particle which is low. This example, which came out a few weeks ago, we are looking for a heavy neutral lepton. This is a standard model here and so it is below the K that you can produce it in this particular decay over here. What they're taking advantage of here is that the K on itself asks an extremely narrow particle in the standard model, even a coupling here, you can still have an appreciable rate for this. Of course, if your ATLAS and CMS, the last thing is you want to pick a fight with the NA62. You have heavier particles at your disposal which are narrow which is the standard here. I would say little about Higgs because that will be in one of the next sessions, so I will be largely silent about this. Just to give you some motivation as to why we care, here you see the number of particles produced in the high luminosity LHC plus the ILC in some optimistic scenario or Bell II. You see the high by far is the largest production rate.

Because they're so narrow, they're excellent targets for us to look for hidden sector particles. The challenge is under what conditions can we overcome the trigger and background challenges to the effect that we can increase the production rate over some of the experiments like lepton collider or the Bell II. So that is the challenge we have to think about. One great advance in this direction is the data scouting. What you see here is the sort of famous curve here that every experiment in history has made, in some way or the other, but really what is special about this CMS over here was it was done with a data scouting dataset. The threshold was 3 GeV. This is as low as you can go. I think this type of analysis has a lot of potential to look for hidden sector particles. On the same note, there is the whole data parking concept where you save some of the data for later construction and in particular CMS is already unbiased on tape and so that is something that we should be looking into. From both of these cases, it is very important that some plan was in place before the data has been taken, of course, and I think this is where the community should engage more with the experimental colleagues to try to understand what is possible in the experimental side and what is the theories we are looking for in this trigger level analyses or dataset.

When I'm talking about online event reconstruction it would be outrageous if I didn't mention LHCb, specifically their new line online event reconstruction and reducing the trigger. They show in this the context, they will be able to cover very large chunks of the parameter space. This is thanks to innovation where they can do things on the software trigger. They can cover the triangle of doom in the sense that these upper grey areas are excluded by factors, whilst this is the triangle over here. The grey area is from experiments. This is a difficult part of parameter space because for a B factory, the production rate is not high enough, while the lifetime is too short. It's going to clean up this parameter space. Putting those in a broader context, if you extend this plot all the way to lower couplings, you see that once we have the LHCb result, we will know fairly robustly that there are no dark photons below, because these constraints are coming in. Another thing just focusing on a slightly different model and focusing on CMS that you can try doing is you can with the new CMS level 1 track trigger that with we triggered, it might be able to look for dark Higgs scenarios or you have a light scalar field here, and it picks up a coupling here.

You produce it in these down to this case. There was a study last year which was trying to estimate what the signal will be for this model. You can see that it is roughly in the same ballpark. This year with Gerard Evans I have been looking into what is the off line implications for this and you can see that he can potentially improve this by quite a lot and CMS is able to do it. This is all I wanted to say about the minimal model scenario. There is a really nice review that we worked out last year led by these two. It is a comprehensive view of minimal models in the context of experiment and theory where a lot of things were compared. This is a fastly-moving field, so many were already updated when this came out. I want to advertise a workshop in a few weeks where these things will be addressed. I encourage you to sign up for the workshop. I will talk about the more complete models which are attempting to address one of the usual big questions that are plaguing us. I think you're all familiar with what it is said on these. Starting on these three examples.

Let's talk about asymmetric areas. This question was answered in the 60s. If you want to get a baryogenesis, it nits CP violation and dynamics and number violation. The model offers all these CKM face, electroweak phase transition, electroweak sphaleron processes. It has all the right ingredients but in the details it doesn't work. This means when you think about hidden sectors, you put your hopes and dreams there. It means that you can realise all the things that the standard model had the potential for but didn't actually achieve. So here to understand how it works, we need to take a look at the history of the universe as a function of timing temperature, so we always start very hot as usual. As the universe cool, you go to an EW face transition, then around 1 GeV you start condensing and around BBN, 1 MeV. On the dark sector, something happens if you want to realise the scenario. You have a dark phase transition which happens when the temperature is higher than the transition, and you want it to be a strong one so you can generate lots of large enough numbers in the dark sector.

The next thing that happens is it must be transferred to the standard model. You are left with the symmetric sector, so they have to go away from the standard model. These last two steps are very interesting for us because it means that there is some mandatory coupling between the dark sector and the standard model for it to work, for this cosmology to work. These are the couplings that we will try to use to discover these things in the experiment. Here is a recent example from the group at UC Berkeley. You have a dark neutron. They end up with a lot of these. You have to get rid of them before the N starts because otherwise you will mess up the synthesis. The model is the dark photons which you can see in the parameter space here. This is what I showed before. That is the standard model which is the triangle of doom that I talked about earlier, and in their model they don't have a specific prediction of where you should live in this parameter space, but it tells you that you have to live to the left of the blue line and above the red line. The model is discoverable, but it is not falsifiable.

This is a generic feature of the more complicated models. That tends to be some way out. The other problem that is interesting is the action quality problem. If you're interested in the strong CP problem, this works really well if there's no - there's a global symmetry, and broken this it has the potential by contributions of PCD and you want to sit here. Even very small deviations from gravity will mess this up and you're slightly off the centre of the potential which ruins the set-up. You're seeing the mass of the axion versus the coupling constant. This is the axion line. Above there is a quality problem and below you end up with a bit of equality problem so solve. There's additional model building needed. Can you make the axion heavier so you live in this space? You can see that colliders, but you don't have this quality problem. So this is where the dark sector comes in. If you have an extra dark sector and it is second with the axion in this way, it derives from the standard model and from the dark sector and it is lighter than the standard model. However, if you now mark the dark sector heavier, you can pull up the action and continue on its way and solve the quality problem.

Of course, as always, there is some collaboration needed. There is a set of papers here which do exactly this. Experimentally, consequences were studied recently in these two papers over here. This is the parameter space. The Axion versing the coupling. There are many different interesting channels. If you want to solve the strong CP problem you must have a coupling to gluons. You're also very likely to copy the photons. The final thing I wanted to talk about was the hierarchy problem and specifically the class of twin Higgs models. It is a little bit bleak these days in the sense that your stop is ex-can included down below roughly at 13500 GeV or so where you want it to live around 500 GeV. Can you still have top partners living in the more parameter space. This is an additional sector from the standard model, can which is a copy of the standard model. It has a top part in it and really what is happening is that the top part in the twin sector serves to partially cancel the divergence of the standard model and this reduces the problem to some degree. This was achieved in this paper and follow-up papers since.

The history of this particular paper is actually interesting because it is a very nice metaphor for the psychology of physics in the last decade or so. Once the paper came out, people were quite competent that this is a nice model and so on, so we will give you citations, but SUSY will show up at the LEC. These are the reality was starting to set in and these sort of more exotic possibilities became much more attractive for us to study. Jokes aside, in terms of the pragmatic point of view, what are the implications of these types of models.

M: Your time is almost up.

S: This is my second to last slide. This model is an example of a hidden valley, which means there is some confining dynamics there and complicated things can happen. You can have these in the dark sector so you can have some dark shower, large multiplicity, and then to the standard model. You have got this very goofy signature over here. The general question here is how do we build a set of maximally searchers that can catch these with a minimal amount-searches on the experimental side. This is a very complicated problem. A lot of theory work is needed and is in progress for this, but the current status has been summarised and the parcel White Paper came out last year and it is a nice subject in the sense that it combines things that you do along with particle searches. So this is where we will conclude. One of the points I wanted to make is that the dark sector is like the jack of all trades. It just shows up everywhere because it is such an incredibly broad framework. There is a lot of flexibility in terms of doing things, which makes it difficult to really pin it down. There is a lot of great work going on in all different frontiers.

We didn't mention much about the intensity frontier, but there is a lot in this field. On the theory side we talked about model building. We didn't touch this. What is there to do for experimental, is I think the challenges are really how do we maximise our sensitivity to exotic Higgs and Beta Ks to make sure that we will squeeze the most out of this. More long-term perspective is how do we preserve our data for future generations because given the complexity of these models, it is quite plausible that in a few decades from now someone will come up with a plausible new model and we really need to find a way of making sure it doesn't get lost at this point. On the theory side I would say that we need to engage our experimental friends more but triggers and scouting techniques, to maximise the efficacy of these cool methods. There is a question about whether comprehensive coverage is possible and if so, what does that even mean, how do we define this as a debate we can have and then maybe object to a philosophical level, what do we mean when we are making predictions.

Do we focus on discoverability, falsifiability. These are open questions. I will finish. I thank you all for listening. I hope everyone stays healthy and well in these difficult times. If anyone wants to discuss more at the end of the session, I will be present after the last talk in the session.

M: Thank you very much, Simon, for the nice overview talk. We have 92 participants. I'm sure there will be questions. At the moment I don't see any. So let me ask you about precision in this area. What is the status here? I mean, are you at one loop level, two loop level?

S: It depends on the scenario. For example, I can show maybe these are two results on the theory side that I wanted to highlight but I didn't have time for. If you have a dark Higgs, as on the left-hand side, you're trying to calculate the decay width, it is very challenging to do the calculation. You need to use other methods. This was very nice. The regime is fairly large. It is still order 1. It will remain like that in the foreseeable future. The events are fairly small. Then on the right-hand side there is the same. It's very challenging.

M: Thank you very much. I have now one question. So you can talk now, Alta.

A: A very nice talk, thank you very much. I have, perhaps, a little bit of a weird question. We had just recently had a nice seminar requesting how do we have a test [indistinct] is the right theory. If I understood all your models correctly, they rely on this very, very fundamental assumption that we are working [indistinct]; is that right?

S: Correct, yeah.

A: I found it an intriguing question, tremendous date and position, you were mentioning [indistinct] as an example, would you see any way forward in respect to possibility [indistinct].

S: This is a very challenging question. I spent time thinking about this. I had useful discussions with people thinking about this. One thing that if you are measuring a distribution [indistinct] for some reason your [indistinct] one robust prediction that you should see very well continue, if you would see this continuity, delta functions or things falling off cliffs, that would be strong evidence that something very major is wrong. Having said that, we don't know how to calculate anything in that scenario. You might be able to do a tree level calculation, but then at one loop, if you're violating things like locality and so on, it becomes difficult to really understand what it is you're doing when trying to calculate the particulars. If you would see strange things in the data like this continuity, it would be my first guess.

A: Thank you. This may represent what you need from the theories, just look to this [indistinct]. Thank you.

M: Thanks. We are running out of time but maybe you can answer this question from the chat: what is your point of view about the 817 as you mentioned the current exclusion limit ...

S: Can you repeat the question?

M: What is your point of view about the X17.

S: Are you referring to the axes in the Hungarian experiment?

M: The new resonance, yes.

S: I want to be careful about this. The theory model that models you have to build to accommodate this access exist, but they're very complicated and quite contrived. They don't give you a lot of confidence in my opinion that this is real, at least from a theory prior point of view, and then this is not my opinion necessarily, but I hear from colleagues on the observation itself is tricky and it might be questionable. I am not qualified to weigh in on that very accurately.

M: Thank you. We're running out of time. People can join you in the zoom room afterwards. Thank you for giving your teaching. I hand over now to Caterina.

C: I move on to the experimental part of the session. The first talk is by Kay Pahal.

K: Firstly, I wanted to say thank you for the organisers who have done a lot of work to put together an online conference. Thank you to those joining us too. I'm here to give the experimental overview of dark matter searches at ATLAS and CMS. I'm studying at the baseline. Simon has set the stage for this better. Here is what you will have seen million times about dark matter searches. If we assume we have some particle, which we will just say there is only one for now, nothing else, and that there is some form of interaction which connects it to the standard model, then there are three ways that we look for this. The first way would be to look for dark matter particles. Next you have dark matter and standard model parcels scattering. There is, of course, one more dimension which would be standard model particles interacting in some way to produce dark matter particles and this is what we have here. What you can see is that colliders do make up a key part of the session. All can access different models, and so we do need all three components to build up a full search picture. Today I'm just going to be talking about this one here which is dark matter searches at ATLAS and CMS.

A tonne of different things can constitute dark matter searches. I'm only speaking about a few of those. Let's start by thinking about what dark matter could actually look like. Essentially, this blob from the previous slide, what is that? This depends a tonne on our assumptions. We've had an entire talk about this, but to take it down to how we've been addressing this in the experiments, at very low energies you don't need a clearer picture than that. You can have an effective field theory treating this as a four-appointed direction and you're pretty much done. This is valid with momentum transfer being small. For direct and indirect experiments that is valid. Most of the time there is one exception, and high energies mean we need a complete picture. Then we have to ask ourselves what should that about be? There's models available with different levels of completeness and each of them has different dominant signatures which is where this is becoming an important question for us. In this talk I'm going to discuss dark matter by a few simplified models, fitting into the minimalist version of Simon's landscape, and highlighting the analyses that constrain this.

This is a picture that is very useful. They're clustered into regions. This over here is basically the EFTs at not what we do at the LHC. In the middle we have simplified these, one dark matter particle. This is where we're at today. I will be using a couple of these models to frame the discussion we will have in a minute. They're electric all of these complete models as well. These were mentioned by Simon. They're beyond today's scope. One of the ones that we have a lot of experimental limits in terms of super symmetric models. I want to talk about mono-X signatures. This is a really key final state in all of our dark matter searches. You have missing energy plus a visible object. We have something, usually a jet, and this gives us both something we can trigger on, and the momentum that we can measure, which is important because then we can also have missing energy by an unobserved system of particles on the other side of our event. If we look at the momentum balance and it isn't there. It doesn't matter where the blob is. No matter what your interaction is between the dark matter and the standard model, you can still get the signature.

What is interesting is that once you assume the model a lot of other signatures become powerful as well. Today we're actually going to go beyond the signature. We won't talk about mono jet. Let's start out by talking about the S-channel Z model and the mediator searches you get from that. Stretch out the blob and one single interacting media X. This could be all kinds of things. It could be a vector, scalar, whatever you like, but we're going to have one mediator, particle and two pseudos. When you think about this model you can see that there are two key signatures. The first one is the mono-X that we talked about, where you have a decay to the dark matter particles and then you have a radiated something that you can trigger on and look at in the signature. You additionally have this one down here where you could have some coupling and you just have a pair of these in the final stage. This is a visible channel. We don't have to worry about the missing energy. It means that we have a resonance that we can reconstruct by looking at these two that come out. I also wanted to highlight because we're using this model a lot throughout this talk, there are only two new cuppings on it.

In this case it could be here between your Z prime and there's the coupling of the Z prime to dark matter. It means that the values that we choose for the couplings affect the limits we present. We can have a large or small amount of exclusion in this model by finding these parameters. It is something to bear in mind. To the first experimental result. We will talk about Dijet resonances. It is the absolute simplest of the mediated searches. You can have Z prime back to QQ as your channel. All you need to do is particular tower two jets and look in it for some sort of new resonance. If you have a background made entirely of the jets then you expect it will be smoothly falling as you can see this line of black dots in the right-hand side where signals will appear as peaks where um pick up on the background. Traditionally we have used an approach to the background estimation where fit a functional form, smoothly falling to the background. They have actually used the data which has jets going forward in the detector to predict the shape of the spectrum in the centre.

You can see in the bottom here that there is good agreement between the two methods, which are the red and the green leftovers, but the fact that they're using this method instead means that you can have much wider signals and still constrain them compared to what was possible on the fit on the search. This allows us to set limits up to higher couplings than we have in the past. This means that the CNS result was actually able to extend limits on this model all the way up to cases where you have the mass ratio up to 50%. You can see that here. The next thing is if you have a leptophilic Z prime. This is a very clean powerful channel and can be a very important sort of mediator search. You can see this new ATLAS result here. We have an electron pair channel on the left-hand side and on the right-hand side. One thing you will notice, they have low thresholds and we're able to access them. The axes go down a lot. The resolution is better in the TeV channel and we have these peaks which are a big improvement. In the situation where you might have these, this is a really great signature to look at. You can also, of course, assume that you have heavy tracks.

This is a new ATLAS program that came out recently. In this case you would want to identify the decaying tops which turn into large radius jets and have various substructures. We would tag two top-like jets and look at their invariant mass. In order to sort of assist with this, the analysis was looking at the tracks that are contained within these high radius or large radius jets to identify when there was a B jet inside of them. You would expect there would be one within your top candidates. There is also a situation that we failed to tag one adequately. There are two signal regions for this analysis. You can see the results there. Taking the two in combination gives a stronger limit and so you can see that nice limit obtained from the statistical combinations right here. I want to highlight that these three curves here are different. That is the mass limit being set here. You can see here the difference between the blue dotted line and the red dotted line is the difference in the width. That can change the result. I mentioned that low-mass is one of the advantages of the analysis. If we wanted to go lower in any object that we have than the simple searches we've seen before.

It's challenging to search for low-mass mediators because of our triggers. This is something that Simon mentioned a moment ago. The products have to have the highest momentum. Then in ATLAS and CMS we have two main records to work around this. One is to trigger on associated objects which are produced with the resonance that you're looking for and the other is to form the analysis at the trigger level. I will talk about triggering on initial state radius. This will decay. They're going to be too soft to pass the trigger. If we have a hard radiation these will be boosted. This is the CMS results that I want to talk about. In this case the decay products are so close together that they are a single large radius jet. You can look at the distribution of energy within the large jet in the same way as we tag to select for topology to see the clusters and we can use it to eject and identify the signal. This gives you something where you can estimate the background. You can see the nice estimate here. This is then used to push a resonance search down to 50 GeV, which is fantastic. ATLAS put out an additional result which is looking for the same kind of Z prime radiator.

This is looking for the results. You can see that it is possible to push this out down to around 250 GeV which for a search is low. Once again, fit the smooth distribution that goes all the way up to around 730 GeV and searching for it as with the other things that we have been showing here you can see there aren't any, but it is neat to have a look. You can see here on the bottom right-hand side, you will note that the intersection is quite a bit of a lower mass than for the previous limits we have seen in this model. That is because of the lower probability when you expect certain things in the initial state. Coming back to the trigger level, we have two cool results to highlight here. I switched up my links by mistake. This is a CMS result and ATLAS is up there. Both have done trigger level jet analyses, but I highlight an interesting combination of the radiation level approaches. This is using three jets to have enough combined momentum to pass a trigger, and then saving only the information and nothing else so that by saving a small amount you could save the reduction. They take the two hardest jets to make the mass.

When doing this, you can see that there is a really high statistic distribution. That can get around to 300 GeV and used to search for excesses. There are also some new results which are interesting which are using the same trigger level strategy, saving a lot of data, receiving a small amount of data for a large number of events, but doing this for the first time and doing a mass search similar to the one that we did before. You can see right here the distribution of the invariant mass of them. You can see a nice Z here and going downwards, around 50 GeV the red line here which is from the standard triggers drops off, whereas the green line here represents what is gained by doing the scouting or trigger level analysis. You can see that at the lowest end here is a gain. This region is able to be searched for new accesses in a much more sensitive way than we have before. The last thing I want to talk about in the search section is di-boson references. This is different to what we have been talking about so far. You can allow a Z prime to allow it. You have various available production notes for that. It really depends.

This is a recent ATLAS search which has a huge number of signal agents. We have picked out one to highlight, but they're looking at 01 and 2 lepton final states. Assuming one of them goes to QQ and you get another one of these large radius jets. Then look at the invariant mass distribution. You can see the distribution up here. This is the WW with one lepton invariant mass distribution. Assuming fusion and electing for that. This is down here in the bottom plot. This brings me to the next section of this talk. We will move away from the S channel Z prime model and have a brief inter lewd to talk about the Higgs. This is another form of simplified model connection between the standard model and dark matter which is a powerful benchmark to be checked out. In this case we're going to assume that we have one new dark matter particle. If we assume that we understand the total Higgs production cross-section, it is natural to ask how much room is there within that. All of the numbers that you see here have been taken from the implementation which is linked into the next slide.

The combination of the observed one now sets an upper limit on the remaining possible Higgs to invisible and around 30%. This is a larger number than I expected. My understanding is that this is because there is quite a bit of writing room in the theoretical cross-section. This leaves us some wriggle room. These are challenging searches. The goal is to set an upper limit on the ratio. Here is the nice new result that has come out of ATLAS. This is looking for production of Higgs to decay to dark matter or other invisible particles. You have very forward jets. This helps you to reject the jets. The approach for this analysis is the trigger on the missing energy. Look for GCD. There are multiple corollary jobs defined which allow the constraints of the backgrounds. You can see these along the sign here. What you can see here is that this red line represents the maximum amount of Higgs to invisible decay that we could be having without observing it in the data. This is 13% both observed and expected. This is a nice comparison to the direct detection limits. This is valid essentially because the relevant mass here is the Higgs which is lighter than additional processes that would be happening in this model.

You can see there're two different lines that are being set as limits which correspond to the differences in the relationship between Higgs invisible branch infraction. You can see that the limits end here as we would expect. The last thing I want to talk about is the 2 HDMa model and the dominant signatures that come with that. If we move to the two-Higgs doublet model, then like the Z prime model you can search with the typical signature over here or you can look for the mediator, something like this, but you will note all of these situations here prioritise third generation couplings and signatures which have vector bosons. Over here are the signatures which have a special role. The first thing I want to talk about here is the heavy flavour and MET. This is the diagram here where you have a TT bar and invisible decay. The thing to do here is to search for dark matter looking for two tops. In this case this is from ATLAS, select one lepton decay to balance high stats and it requires two B tags to get the events. The signal region has defined here optimised towards dark matter in this distribution which is the angular difference.

You can see this is dominated and that is in this case constrained with a corollary John. You can see the plot coming up here. This is a very new and cool analysis.

We have now mono-V or Higgs which has a sensitive ability. This is added in WW and ZZ channels for this. This plot is for the Higgs WW where they train the BDT on momenta, et cetera. For the ZZ it was a simple contribution. The combination of the two has gone to this nice thing. You can see the dominant channel across here. It has pushed down there. You can also, of course, look for visible decay. You can detect this. This relies heavily on an estimation of this. The first step was to train on a single small radius jet in signal to look for the two pronged substructure and learn from that. A second step took that learned mass and the substructure and trained. For events, you take your ZLL candidate and this single small radius jet. If you have a new resonance, it amounts to the mass of the heads. This brings me to the end of the specific analyses that I wanted to show you today. This is just a reminder that supersymmetry can also be a dark matter model.

When we look for our parity concerning SUSY, what this means is that we require that there is an even number of SUSY particles in this interaction. That means that the light has to be stable and this makes it a good dark matter candidate, depending on other parameters. The quality will depend on the assumptions because various parameter choices can give you too high a level, but this is one of the powerful more complicated models that we should be thinking of as part of our dark matter research program. I have a link to one of the other talks there so go and check it out. It is really hard to keep track of the scattered analyses if we don't have the model to put them all in one plot and see how they interrelate. This is the first plot I want to show for this. This is taking all our searches and putting them on where we have. Everything above the solid line is something that we've excluded. This has been updated. You can see the new limits here and how they are really strongly constraining us down here. The other thing is to put this more clearly into the rest of the dark matter picture.

These are some plots you will see a lot where we have in this case dark matter mass on the Y axis, and we have to specify the couplings. What you can see there is the limit is in this corner and you have independence when you look at the resonant searches. I highlight the couplings here because I want to point out that if you change them you will get a completely different picture. This is reminding you all that we should be paying close attention to the non-collider world. It is important that we keep track of how our results inter play. You can see this is the dependent limit. On this side, a spin independent. Dark matter interaction, cross-section limit. You can see how different they are. We have power and where we don't. Continuing to try and introduce these is making sure we can be as active as possible. This brings me to my conclusions. We explored the wide range here today which can constraint dark matter and try to highlight them. They're all key contributors to the dark matter program. There are more results in progress now. Stay tuned for exciting updates. It should be fun T as a final reminder, our dark matter possibilities are centre diverse.

There's a lot of dark matter searches, along with particle searches. I put down here a collection of talks around this week that you can look at. There's still more, but it's a place to start. Thanks a lot.

C: **Thank you very much. Do we have any questions? At the moment it doesn't look like there's any. Maybe I will ask one. When would you see the most exciting round 3 developments that could be coming up in kind of analysis?**

K: That would be coming up?

C: **It is just a personal question. It's not a right or wrong answer anywhere else. What would you aim for in round 3?**

K: I'd be interested to see us extending what we're doing in triple level analysis. I really do think we have only begun to scratch the surface of what we can do. At the moment we're being limited by the number of objects using. We could be thinking about if we are able to, what other analyses like this could benefit. The other thing I think we need to do is think more about the simplified models that we're interested in using. It is too easy to make a plot and see no holes and say we're done. So I think we need to be pushing ourselves to examine more thoroughly more realistic scenarios where we're making progress on the limitations.

C: **Thank you. Any other questions about this talk? To the next speaker, Bhawna Gomber will give a talk on searches for unconventional signatures and long-lived particles.**

B: Let us try to understand what is a long-lived particle and what are its properties. From the experimental point of view, you can see the picture here, it is showing the nature based on whether it is neutral, charged or any charge. It is a neutral particle. It can be a particle which will have other characteristics. Long-lived particles have unconventional signatures. They need a signature to think on the lifetime of the particle. Then these LLPs are different from the experimental point of view. First and foremost is the nonstandard reconstruction for the displacement and timing. Secondly we have dedicated triggers for these. The third challenge is the nonstandard background which arises from data noise and rays, et cetera. These should be estimated from the data. Then are many long-lived searches. I'm showing some results which I present here. Let's get started. This is the first time we will talk about a new result for ATLAS. It is about the large-impact. It is a new result. This particular search targets a production of long-lived top spots, they have a small out link and beyond.

The models where we have this sufficiently small line, this operation is basically causing it to operate on a discernible distance. We have such a signature, we need dedicated drafting and that is what we have. A reconstruction is performed. This long lived is impacted which basically has an impact on people outside this. Then we have the reconstruction to reconstruct. In this particular case none should be more important. In this particular search we have different backgrounds. Then how do we select these kinds of things? We have exclusive trigger base selection. The first one is based here on the synergy and based on in one. In the bottom I'm showing you about the observed in the corollary John, development region and signal region. In the left it is the selection and on the right is for the non-selection. You can see we observe this. Beyond the selection there. We have the expectation that we see from the back. This comes here in the region for the selection which we have. Everything agrees nicely. So we move on as a function of the lifetime. This graph shows a lifetime which is below roughly top mass.

If you see this, comprehend this particular one with the bigger picture when you're comparing it with other analyses, you can see that doubling there, which was not by the other. This was done after. It came up. Then we move on to the analysis which is performed by CMS. This is also an analysis. This particular ATLAS has a particular topology. There are a pair of jets. There are many different signal models that have been studied. I will explain the two models. One is the simplified model and the other is the exotic. We have a long particle which is being produced there. Each particle will again hire and end here. Then the two will be having a displacement. Then the other interesting model which has the 17 and 18 search, we can see the particles arising from the exotic bits. You can see that the heat was on, and then this will be in the work part. Then there are other models which have been studied also, and the limits there. When this is displaced, we need a figure for this. Then we have our reconstruction also there. So the background is there, you can see the process. Then there is the selection and we get this. Let's try to understand these variables a little bit.

We have a vortex. Looking at the picture here, trying to understand, each displaced track is expected. It is defined by finding the frozen point in the track. This is what we had there in the picture. This is the transfer distance. This is how we have this. Then entrusting another variable which we have is okay. This is basically the sum of the significance of the impact. You can see a picture here. This is where the signal is basically having a large value. It is a discrimination with the signal. We have the particular ones here. Then after doing that, there is the plot which shows the data similar, and this is more interesting. You can see here for the score we have the different things here and the last thing, which is the GeV fine line. This is the signal region for us. This is where we have the moment which is a predicted expectation as you can see there. Then what we do is basically go ahead and look there for the particular search, so we have the defined search. On the left here, you will see the cross-section on the neutral. This is the jet to jet model, the simplified model. In the middle, this is this one, and it is a result from CMS. It is up to 1.64 TeV.

One can see that for the ATLAS excludes top skwark masses up to 1.4 TeV. This has more restrictive limits here. Then in the search, we added enthusiasm to the new model. There one can see the inflection. Something happened with the internet. Sorry about that. Do you see it now? Sorry about that. I will start with this now, where I was. I was talking about the exotic Higgs model. In this case I was saying that the branching fractions larger than 1% is excluded for mean proper decay. That brings me to the next search, which is this analysis. The particular feature for this is that we have particles which are decaying. These two have to be here, and these jets will have a high issue here. Another opportunity, and then at the end these were directed. If you look here, I'm showing the upper limit. It is a function here. This line is the line from this particular analysis, which is for the CR, and this is a search that was done. We also did the combination of this, so you can see the combined limit. So at the large end we can see that the one here looks better, but the lower one you can see the combination.

Then the same analysis was done, but we had done these, with the same model. In this particular case we did acquire that one long particle will be here and then another at another point. So this analysis is sensitive to the life term here. Basically, I'm answering the comparison. The scalar plot here, we can see the sensitive below here. As you see in this particular plot on the left, but this is related to the combined analysis. Once we combine this, the high scalar that is not the case. Now I will go ahead and talk about the reinterpretation of the displaced hadronic jets with recast framework. If you look at this, the original model can offer good analysis as well. Even the selection that is made, and the solution do not change. What will be required is the signal distribution, a new signal model. This is the basic interpretation which is basically which is designed to facilitate. This particular recasting is designed. With this particular analysis ATLAS has tried to have the model, exportal. In this particular slide I'm talking about the model and the invitation from this end. In the other cases, it will in turn give you some dark.

In this particular case, we will get four. Then what we did was look at the limits of the Higgs. The dark photon and the bottom one is the 800 GeV. These are the set by the ATLAS in this particular model. For the 800 GB we had some that have been published. This was the analysis. So this is telling how it happened. We can just put down the new single modelling with the constraints, which is really nice. Now I will talk about another interesting search from the CMS. This particular search basically targets which will have it here. This one is unprotected so what will have. The signature is isolated. It will extend from the interaction vision, but after the point of disappearance, it will leave the muon, and then it will have a lot there. So that will be the nature. The benchmarks in the model which is considered here is this model. You can reach it here. It will interact with it and it will be very soft to be constructed. What we found is the result here. So in this particular case I'm showing the mass and the function of the lifetime. So this dotted line here is the result. In this new line here is the result using the tag.

There is a significant game in excluding the value of the masses. We have ten here. Up to around 500 GeV. Then 240 for the one above, 1 millimetre. What this is also competitive with the reconstruction, that was a good idea. What happened in this region, which was less than 1 millimetre, we see it was degrading because of the limited situation. This particular search is able to have the model. If we could do better there with this. That brings me to the overview of all the long-lived searches. We have different models here. I'm highlighting here the two analyses, and you can see the full dataset, and similarly here are the active site and this is expressed on the vortex search and you can see them here. So that brings me to the summary. So I have several searches on the dataset. This made use of this upgrade. In this particular case there is an idea here of the interpretation. It is just a simple one here. It is an exotic detail. That will be there. It is really nice. We can just use this paper which is really a nice thing. It is out of the box, thinking like we have the new search, which can be accomplished.

This is what we have at present. There are more details coming out of these, and as for us moving ahead for the longer particle searches, I would say we have new ideas for trigger reconstruction techniques. All this is going on. We can expand it. There was also here. We are looking for these and thanks for listening for me and sorry for the trouble in between. Thank you.

C: Thank you very much for your talk. I will ask if there's any questions. Not yet. I'm intrigued, of course, about the new items for triggers and construction techniques.

B: Yes. We have not gone below 10 TeV. There are 4 and 5, so we have to have triggers designed for these searches. Salary, the reconstruction techniques. There are a few models where it will be in case of the jet searches where you have the particular jet, which is narrow and basically some techniques. We're targeting a particular model. All these new ideas are coming up for the trigger, and that is what we're trying to improve the searches. We go to a lower PT. That is where I think it is really helpful.

C: Thank you very much. Last chance to ask any questions here for this session. There is a question and I'm not sure, I don't have the option to talk. Good, someone did it for me. Please unmute yourself and you can ask a question.

A: I just wanted to follow-up on the idea of have you considered data parking looking for long-lived particles, especially since you would benefit from low PT muons or jets. You could reconstruct the data later. Has this been considered at all for long-lived particle searches?

B: Yes, this has been considered in CMS. We have been really looking into the feature and there has been parking. We are taking on as a feature on the CMS side. I don't know about the ATLAS side.

A: Thank you. That's really interesting. It will be interesting to see the results of that.

K: I think this concludes our session and thanks to all the speakers again, virtual clapping hands. I don't know if we have that in the option.

R: The next session starts in nine minutes in another webinar, so go there.

END OF TRANSCRIPT