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SPEAKERS

GIOVANNI – G

GAUTIER HAMEL DE MONCHENAULT – **GM**

LUCIA DI CIACCIO – **L**

ALLESANDRO Viccini – A

CHRISTIAN: C

G: So maybe we start. So before handing the mic to the convenors of this session on electroweak physics session, we just wanted to say a few words from the organising committee about the process sessions. So the process sessions will take place today at 6.45pm central time and tomorrow Friday at 11.15. The duration of each session is one hour. And be careful, because due to the time differences between the various time zones not all the presenters could be available in both sessions, so you're invited to first try to connect in the first session. And if the speaker is not there, try again tomorrow morning. Each poster had its own meeting room. You can find the link on the conference agenda. The passwords were sent by email to connect to the room. And on the agenda you will also find a poster PDF and the three minutes video recording, which will be an explanation of the poster, can you also consult offline. The four best posters will be awarded the prizes sponsored by EPJ and CERN and the awards ceremony will take place on Saturday in the closing plenary session. So that's it. And now we hand over the mic to the session conveners for the electroweak physics session.

GM: Thank you, Giovanni. So welcome to the electroweak physics session of the LFCT conference online 2020. So it's a great pleasure from myself, I'm Gautier Hamel de Monchenault and I am co-sharing this session with Lucia di Ciaccio with IT FRI and today we have four talks, one theory talk and three experimental talks so we will start right away. Please at the end of the talk, you will be asked to ask questions, so if you want to ask questions, raise your hand and we'll give you the floor. So the first talk is by Alessandro Viccini from the University of Milano. So, Alessandro, whenever you are ready you can start.

A: Okay. Let me try.

GM: If you can share your slide.

A: Okay, can you see the slides.

GM: Yes, perfect.

A: Okay. So let's start. Thank you very much. First of all, of course, for the invitation and to have this opportunity to review the recent progresses in electroweak theory and I decided to head this multi-lepton production in hedron-hedron collisions just to emphasise one aspect that would be the central topic of my talk. Mainly the fact that the distinction between electroweak processes taking place in our hydronic environment is factorised we would say it's not sufficient anymore. We're entering in a phase where both interactions [unclear 00:05:01] interactions are really entangled and mixed together so that we need a comprehensive picture, a full picture in order to achieve the level of precision that we need for precision measurements. In particular the topics that we want to discuss, that we want to touch, with electroweak theory are of the fact that we want to perform precision test of this sector and the symmetry breaking sectors of this type of model. The logic is very simple. We want to compare standard model predictions against the measured value of the same quantity in order to test the validity of the model.

I should say that it's very important the progress in the last 20 months, let's say, into different directions, for the predictions, but also for the simulation tools. Predictions are in item one are hadron of the model calculations of different quantities, including all the available higher order interactions. But, of course, we want to measure also the corresponding quantity, the corresponding parameters and to do the measurement we need simulation tools. The simulation tools are to prepare templates, to fit the kinematical distributions and eventually we get the number per metre. So the reduction of the critical systematic error component for the experimental value of the quantity of interest is also an important item to be discussed. It will be the main item that I will discuss today. Of course, then comparison between one and two, kinematical prediction and experimental value is compared looking for discrepancies and then in this logic we can also try to think or rethink about what is the test of the extension of the standard model. Now the progress that I want to report about is so the predictions of hadron collider processes mostly.

I will just make one sentence about plus or minus collider, you will see in a moment. As I said, we are moving beyond the "electric processes in a hadronic environment factorisation". There are several results where mixed corrections are becoming available and this is for single boson production and also for multiple boson production. Now, productivity of the standard model is renormalizable theory. We have a fixed finite number of input parameters and this is a statement that [unclear 00:07:23]. We can make predictions for new quantities. This is typical slide where you say that in terms of alpha, GU and Z from the amplitude we can compute the mass. As you see sketched in the lower part of the slide, there is a formula which has the general structure and then relative corrections and data R parameter. Everything on the right-hand side is expressed in terms of alpha, GU and Z. So three parameters for each sector of course. Then we can compute including the higher orders in getting better and better predictions [unclear 00:08:02]. There has been a long story and the current status is still based on [unclear 00:08:10] results, supplemented by higher-order QCD corrections and resumation of reducible terms.

Altogether this can be represented in a very simple way, with this single line where this different coefficient express the value of the different logs or powers of the parameters [unclear 00:08:34. Entered in the prediction. If their value changes a bit we can adjust the standard model prediction accordingly. This summarises the best of our knowledge and light five, something similar can be said for affect being the other typical quantities used in precision test of the standard MoD elf. The Gluinos results become available. There's been an important date by collaborators last June, where essentially they made available all firm factors and observables needed to perform physics of this address and answer including the two loop complete corrections for all the quantities. Then best predictions include those in this case, three and four loop correction was some convenient parameterisation again to express the residual paramettic dependency. The single line summarises this huge amount of theoretical work. All this work is very interesting. Because it leads us to make estimates about the theoretical uncertainties that are limiting these predictions.

In the upper tables, for the limiting factors in the predictions, I took it from the studies done for FCC, which is probably represents the ultimate precision that we can imagine to reach ever, let's say. And you see that it's the projected numbers on the FCC measurement that are absolutely incredible and very, very challenging. The intrinsic error based on previous results that were mentioned and the estimate of missing higher order corrections, well the error as estimated today is quite large, at least in these ultimate perspective. As you see, the loop is not sufficient to receive such a high level of precision, essentially the message from these upper tables is that we need to start thinking about full three loop calculations in order to cope with this level of precision. Of course, we are discussing on the left, the missing higher orders. It's interesting to see that in the right table, the fact that also the input parameters are possible source of further uncertainty and further Hadronic turns out to be one of the main actors as for other observables it's alpha strong. These are the predictions, then we have the error that enters into the experimental analysis via the simulation tools.

So this is what I will discuss in the following, so I just want to distinguish the two main points that are given by missing higher orders and uncertainties and modelling. I will not touch in the presentation on the second item which require the discussion. For the last, you have perspectives ever LEC, where we see for instance we can expect a cycle two a final reduction of the final error which is quite an important challenging number. This is a sketch of the vector Boson production, we have the convolution of certain densities with the cross-section. We want to achieve the best description in both sectors, including the available knowledge. The QCD plays a role. There are certainties entered. There are also important electroweak effects important to see the observables. These effects are underlined. It's a complex framework that we're discussing here. Each observable requires it's own set of higher order corrections. So in slide 8, I'm showing the typical standard predictions that you can get, the standard tool based on QCD. Convoluted with the final state. You see that QCD is important to predict the distribution because it broadens very incredible way the order distribution but QDFSR reduces the distribution by several per cent.

If you look at the right plot in the slide, the comparison between the blue dots which express the pure effect and after, the dots represent the effect after convolution with QCD tells you an important message that the difference between blue and red can be interpreted as alpha strong mixed QCD-QED effect. This effect is several per cent. So absolutely very important. They are included in the analysis for more than 15 years. There is no worry about their absence. They are present in all the analysis. But of course, this description could be poor for high precision analysis. We need to improve in this description. This has been achieved by moving to a NLO-QCD, including the low factors, given by the factors of QCD or weak logs or the product of K factors, improving the description of resonances. Including the description of the QDC having medium improvement but there are limitations. This is one possible result. This is still affecting the ultimate precision of the code. In the right plot you see for development distribution, lance cancellations between QCD and electric productions, so the final combination could be still uncertain.

This motivates the theoretical effort towards analogue calculations. You might ask, why is it so difficult to make this calculation with modern techniques? And essentially, the progress that is limited by the availability of experiments and by the existence of PDFs and the confirming a consistent matching possibly fix and all order results. Come back to the first point, which was probably the biggest obstacle, you see that the sedge of the kind of corrections that we face when we make an exact NLO-QCD electric calculation, where we final double corrections, real virtual corrections and double virtual. For instance, in the double virtual correction there's are boxes with internal massive lines, so that represents the frontier in this sector of mathematics, in this sector of quantum theory for these relative corrections. Now the strong boost in the last 12 months, activities have been really impressive. We have mathematical for master integrals with internal masses. In the last year, we had more results. The subtraction initial state circulates required splitting function of this order and then, there is a list of results on production that will give a dedicated talk tomorrow.

Starting from all the results, now we have recently have the prediction of the total cross-section, theoretical cross-section, more interesting we have distribution including resummation of QD and the last four items, the production, the effort to availability to the full differential codes, shells of production, including QCD QD and electric corrections. We have the total cross-section of form including the full analytical form and analogue QCD corrections. Last but I want to mention the appearance of results for photon production, which is the ultimate precision benchmarker. There is a complete Drell-Yan. Between a nutrino pair in the first step to the complexity of the full process. I don't have much time. So this is just a slide mentioning the evolution in the evaluation of master integrals. More mathematical, to more inclusive representations with polylogarithms that depends on complex arguments. So the presence of the internal masses represents one of the frontiers and also affected by additional problems related to the appearance of elypic. This is a difficult progress that the sector is facing a strong evolution.

These are probably among the most interesting, exciting results in the last month or even weeks. Let's say for the PTZ spectrum we can see that the analytical summation leads now to a better theoretical understanding of the predictions, though the agreement with POWHEG is still true. So that we can say that terminology that is speaking, this was already quite well under control. Now we understand better uncertainties. In the lower box, the very recent results for production, including QCD and weak effects. I want to make one comment in the time I have for the fact that QCD-QED effects are possibly small, and the right plot in the lower sector, you see that the green line effects are small and instead, the blue line, the QCD weak effects are quite large, of the same mag any night of the productions. These effects are not small, negligible in view of precision physics. Of course, all this discussion requires the introduction of proton in the initial stage. We need photon in the initial stage. We want to include the electroweak corrections. If we want to have precision, these corrections we need to have the protons with QED evolution. It's not an option.

It's mandatory to have protone PDFs with QED evolution. It's not possible to do it without. Of course, this has an implication because we have the redistribution of the momentum fraction. We have more Photonic channels. There are difficulties to combine all these different protonic channels have them under control at the level of precision we want to discuss. I make reference for the role of photon induced processes, activities of the working group, where they're all photon processes for the angle are actively discussed and showed to be quite a non-trivial topic. In any case, we move to the second part of my talk, I want to make one theoretical comment about parameter determinations. The input parameters are the only parameters that can be featured against the data. If you introduce the scheme with NW among the parameters because we wanted to feed MW. It would have not been possible, been possible to feed MW without MZ in the scheme. This raised the question about the hadron colliders. There has been progress in the development of new schemes that allow to prepare templates adding in input.

This kind of discussion is important because in this case, we have direct dependence on the fit parameter. They control the theoretical and experimental systematics, and the finish of parameters so that the combination, consistent combinations are possible. This leads us to the develop the possibility of making a robust consistency check of the standard model. This definition, in this specific example, allows to reasorb larger correction in the parameter we want to fit. This was advocated at that time. There is a bunch of papers that were discussing the possibility of using such a scheme with effect in the input to search for new physics. The logic is simple. You want to rep solve and code in the cupings. The largest fraction of information comes from the available data. The data that is addressed on us. If you do so, if you make the reabsorption the best you can, any discrepancy will further emerge will not be in the parameterisation and will be sensible new physics signal. I want to leave this comment open, whether the same choice could be adopted in the standard model. When we have the presentation of coefficients. This is an investigation so that the discussion between the literary community and FT community is welcome. We move to the last part of my take about Boson production. Yes?

GM: Five minutes left.

A: That's fine. For the Boson production, it's very important because it allows us to test the electric symmetry sector of the standard model. In particular we can test the structure of the introduction and possibly to appreciate the presentation of higher dimension in the language of effective theories. The complexity of the calculations for the Boson production compared to single Boson production has led to the production of large diagrams interplay of QCD in the interactions. So that this next order correction cannot be labelled by QCD or electrocorrections only the total makes sense. There is the presence of different mechanisms announcement of different times QCD origin. Then you see radiation. Virtual corrections and all these are not in competition . There is the need for precision physics including multiple par tons. There's impressive progress again in this sector with availability of analogue QCD and results combined in some cases. I want to make the general comment that all this progress has been possible thanks to different kinds of automation for the one loop integrals, for the generation and reduction and also in more general for the mull pull processes handling, because we have to deal with large number of par tonic processes.

Let me make my first example for the Boson production of fixed order with analogue QCD and electroweak corrections. Here in order to achieve 1% precision we need a consistent combination of these corrections. These have been studied in open loops framework. They also studied different combinations of separate ingredients, QCD and and observing that these processes receive so-called giant K factors. And the role of these processes in the generation of these factors is very important. Also, different, another combination of other recipes that separates the channels has been attempted. Now I have taken just for demonstration the worst case observable to stress all potential issues. You can see from the insets from the lowest insets the fact that the different recipes lead to other different predictions, with the uncertainty not always overlap. Furthermore the different freak Wednesday of the photon processes can lead to -- photon processes can lead to differents. There are several observables in several regions which behave properly. But the potential issues present in such complex environment can be appreciated I think.

Thanks to these plots and the fact that the combination of different effects is not a trivial point. Second example that I want to make has to do with the availability now of new codes that merge with the results, which are standard of course, together with QCD and QED pattern. We know the importance of these separate ingredients. But the possibility of merging together the showers is not trivial at all. Because the meshing of these try to choose the hardest part and in combination with QCD and QED, QCD tends to win. So indeed we only apply the matching for QCD interaction. This is not acceptable. And the treatment of resonances as a systems that excited the process receive mostly QCD corrections in the production phase, stage or mostly QED corrections in the K stage. This is a treatment of resonances of identification of resonances inside our process allow this technical progress. Now we have code, like in the formulation that allows the combined matching. You can appreciate from the plots on the different curves on the right that having only mixing order weak, or mixing with parton shower makes a difference at the few per cent level which is not negligible.

Last examples came from same sign. This is again, an example where we can appreciate the importance of all these higher order corrections because it's important for the study. There are six particles in the final state. They turn out to be large, as is the case several examples, for several observables because of the usual electric corrections. Adding on top of this very complex calculations the QED pattern shower is the level of complication, the results you can see in the lower part of the plot, where the difference between pure analogue and marched with pattern shower is shown. The interplay of K factor and the QED parton shower, combining two large effects are still additional very large deviation from the, in the change of the predictions, so again, having these tools available represents for sure, a very important progress for these studies. I can come to my conclusions. Since we want to have control of the level at 1% level for the Boson as a final challenge, let's say. We have to deal with many different ingredients whose combination is not trivial at all.

In particular, entangle between Costa Rica and electric elements. There has been an impressive theoretical progress in the last month. And many results are now -- now NLO results are now routine. If there isn't automation, none of this process is trivial. It's not routine. But they are becoming available. And also the match with multiple par ton, with the description of submissions is now possible and demonstrated in practice. For reference processes. Furthermore, the next order are becoming available. And wishes to have such level of precision also for Boson. In effect, I have shown you in the Higgs Boson case there are regions or observables that are not completely understood which large cancellations and additional progress is needed to stabilise the predictions. My further comment is that ultimate precision of the predictions depends on the observable understudy. I cannot make one statement for all observables. It depends on their definition, their pace. The decision depends on the development of pdfs with the results. And which I didn't discuss, the development of procedures to reduce the dependence on the QCD modelling, which is the underlying ghost, let's say.

Because we need to describe data and describe data that receives contributions also from physics. This entangling theoretical physics from the hard is vital. That's what I could say. Thank you for your attention.

GM: Thank you. We are a little bit of a time. So we have time for one or two questions. Please raise your hand if you want to ask a question. You can speak.

?: Thank you, for this excellent talk . It was very inspiring. And I have an awful lot of questions. But just one, because you mentioned quite right that we have now this really big family assess to go to standard model theories. You mentioned very interesting the scheme, would you advise now that we should change even if we have order leading orders, if we should try to explore the scheme?

A: I would say yes. Well, we have discussions in the working group. I would say that considering the scheme is interesting for let's say two reasons. We want to make, direct determination, so this is the first a very good reason. We want to have free control over theoretical and experimental system attics. What we noticed is that it's defined at the Z scale. It reabsolves large corrections. It's well understood and well-motivated. It's robust choice for input parameters to describe this. Then after your question, I don't have an answer yet. Because the global feat involves different data set, there is not only resonance, but states. Which the parameter myisation of this is good, eexcellent or poor is something that one should check with an explicit study and if, the description of it is good, you would have the advantage of describing an efficient way both the rationals and the states. Otherwise the decision on the relative importance of the two data set must be made.

?: Thank you.

GM: I don't see any other raised hands. So let's thank Alessandro for this difficult talk.

A: Thank you, I will stop sharing.

GM: Yes, please. Now we have a talk by Lucia. And she will talk with us. Please share your slides. (inaudible) please unmute, maybe.

L: Okay, can you hear me?

GM: Yes, perfect.

L: Cool. Yes, so today I'm going to review the electroweak precision measurements, so I will describe results from the collaboration. I will start directly on why electroweak precision measurements are important. The test of consistency of the electroweak sector in standard model through precision measurements is one of the fundamental goal of the physics programme. As can you see from the formula shown here in the slide, and also as was well mentioned, it's one nice feature of standard model is that it's possible to derive and predict fundamental parameter through other fundamental parameter for the electroweak sector. From this plot, you can see how the mass of the W and the mixing angle with strictly connected. We can measure it and verify the validied of the standard model. It's clear to see that the direct administration of mixingagesome more precise than experimental measurements. This has called for more precise measurements. In absence of the direct sign of new physics, discrepancy in this kind of precision measurements can refine the sign of new physics.

Of course, this is bring us a lot of challenge from both the experimental side and the theory side to exceed this position. The reason measurements were published by several experiments. Today I'm going to show you some results about the mixing angle, atlas and measurements published a few years ago. I will remind you the very nice measurements of atlas for W mass and I with ill talk for the first time about very nice an sillery measurements. Let's start with the measurements of the weak mixing angle. CMS is with the weak mixing angle with a standard distraction using the simultaneous measurements of forward back ward asymmetry in Collins Soper frame. In this plot you can see the measurements and in this plot in the centre of the slide you have the AFB shown in different rapidity. You can see the asymmetry goes larger and larger. And to improve the study, reduce the impact on efficiency. This measurements used the weak events. The distraction is done from a template fit to AFB using the prediction of Powheg. Atlas, the next slide, I will show you quickly, atlas extraction uses a bit more new approach. Distracting the weak mixing angle directly on the full composition of the relevant cross-section.

In these slides I show you the full formula and in the boxes you have the A3 and A4 coefficients which depends on the weak mixing angle as shown in the plot on the left. This kind of distraction is a bit technically more challenging than the stand order for the asymmetry, but for some advantage, for example the measurements is done in the full space analytics extrapolation of this and this reduced the theory uncertainty and constrained some experimental systematics and then another very interesting feature of this analysis is that it's interesting to mention is that atlas here uniquely, so different from CMS is exploiting the central forward channel, where forward electron with a rapidity greater than 2.5 is used and this is highly enhanced the sensitivity and weak extraction. So the final results here you can see that the measurements, though are done with the ATV that effects, are not limited but the main statistical uncertainties here in pink and purple. If you compare the break down of the uncertainty between atlas and CMS you can see that the final results where you combine the full channel in atlas greatly profit from the inclusion of the central forward, and this is drastically reduced the uncertainty.

Of atlas measurements, because this channel reduces the pdf uncertainty . This brings me to this slide where I would quickly talk about the weak mixing angle. On the left side you can see the asymmetry are strongly dependent on PDF uncertainty, the dominant system attic of these measurements. The dilution of the asymmetry and the dependence of the four versus ML. The strong power of the analysis is that the PDF uncertainty constraining with the data itself, resulting in this PDF uncertainty. The profile is likely done different between atlas and CMS. The difference between the PDFs are similar to the uncertainty that at the end is supporting and therefore this analysis so, both analysis use the same need to reduce one of the biggest uncertainty. I will just flash the summary of the mixing angle. Can you see from the summary plots that the atlas and CMS uncertainty, in blue, are very approaching the precision of teratron in orange, thanks to the new analysis techniques which including the PDF filing and the categorisation and the analysis. This is measurements that was experiments did. A few words about the prospect studies.

Electroweak experiments officially enter into electroweak raise I showed. And they're limited by the PDFs. On the top right you can see the evolution of the statistical uncertainty while including the luminosity. Can you see while statistical uncertainty goes down, the PDF uncertainties stay on the top in blue. The only way to reduce the uncertainties is to look at the PDFs and not treat it as any more as a black box, but really try to understand it, the uncertainty position and correlation as an experimental uncertainty. In the bottom plot this is the same prediction, projection for atlas, where you can see that including the projection of PDF for LHEC you can drastically reduce uncertainty and five ten to the minus 15, so really, being the same as the average. If you use the new this experiments you would get this factor of five improvement in PDF so exceed the precision. More in prospect studies and in particular enlarging the measurement acceptance and using LHCb data we can expect that for LHCb with the full run too, we expect statistical uncertainty of 31 plus or minus five. This is intrinsically due of the big reduction in PDF uncertainty, which is due to the fact that the forward region, the low dilution in the forward region means small PDF uncertainty.

The profiling is less advantage including the offer asks awe crucial handing by scamming the precision in region where the PDF is intrinsically small. It was mentioned the working group and PDF is looking to investigate this interplay between electroweak correction, and also, all these PDFs are in correlation as I mention. Now I'm moving to the measurements of the W mass. And in particular I will flash the challenge of the W mass Boson mass at LHC, in particular, the topology of W mass is challenging because due to the missing nutrino energy. And then you have to consider the underlying events, the hard and soft recoil and the pile up. You need really an excellent understanding of detector and simulation, to get robust measurements from an experimental point of view and without forgetting the physics modelling that you need to reach a very nice precision currently we have atlas measurements which were published a few years ago. Extracted the W mass atlas and the mass peak. This distribution and the method is using distribution with a template fit.

The two separate templates I use because both MT and PT are sensitive to different problems, if you want, and challenge, and these measurements, what atlas measurements teach us is that in order to reach 20 uncertainty you need to have physics modelling, so QCD effect and detector response controlled up to 11. Here you have the very summary of the very beautiful W mass measurements in atlas where you see that there is a note challenge, measurements that nicely align to the final results which was measurement 80.370mev, plus or minus 19mev and in the table in the bottom you will see the break down of the uncertainty and it's obvious here that the statistic answer is not a dominant uncertainty here, even though the experimental system attic which is subdominant with respect to the modelling system attic. If you're worrying about the physics model in atlas, say it's hybrid, which use par ton shower model analystic in QCD. And the main uncertainty come from the PDF variation. In particular the next to next living order calculation and accounts about 13 and 15meV.

The large anti-correlated between W plus and W minus, we saw in congregation of those. The second higher uncertainties coming from the QCD uncertainty, which are evaluated from par ton shower and in particular from the modelling of W. And the higher order electroweak correction are relatively small with respect to the other two dimension. In this outlook page, you will see how the atlas measurements looks like with respect to the other measurements that we have currently. 19mev of atlas results is far from the target, set from the electroweak fit. So the question is how we can improve. From my side here, first of all, I think that measurements able to resolve the wpt means a 5gv with 5% uncertainty would provide for sure the open issue QCD which represents the ratio. You can see from the plot in the last, top left side, is still an open in Costa Rica, you can see that the prediction of this ratio, is very, very different to whatever is predict by next to living, next living order prediction. This is a very important experimental input to solve this issue. And for sure, this is the low u run that we had during run two will be the fantastic opportunity to have more W present physics in already to solve this issue and reduce the big problem of the modelling of the W mass.

Then another thing that I would like to mention is about the small inconsistency that we are now seeing and also shown by Alessandro between the fixing the lepton distribution, which is actually makes some difficulties when we are using acceptance when we count on this parable. This is actually a full problem when we are trying to interpret cross-section measurements that are done in stage for PDFs constrained, for example for W mass. And in the plot on the bottom, from atlas notes, you can see the missing resummation correction match somehow the half per cent experimental precision of the measurement. This is something interesting that we might want to have a look at. I will go through this very new ancillary measurements done by CMS which is a very important hint for future CMS W mass measurements. So this is as I said a new CMS measurement done at 13TeV with the data set. This is actually quite accessible, because we have millions of W plus and W minus in this data set for electron challenge. There is a set of measurements in W Boson rapidity, plus all the differentials measurements.

So going through the concept of these measurements, as you know, W production can be expressed in term of a fraction. This is an absolute, it's given the nature of the capping of the W leptons. The LHC could be mapped on the plane. Thanks to this mapping, we can indeed extract the he -- helicity fractions. This is what is done in CMS. Of course, this is measurements got a huge amount of experimental challenges. In particular, because this measurements is done in several bins. It's essential to control the experimental system attics in this fine granularising plane. Also the full set of system attics is profiled in a single likelihood fit. This analysis for the first time using tensor flow base. So the main system attic uncertainty for these measurements are coming from experimentally from the lepton efficiency and the main theoretical uncertainty is coming from pdfs and alpha. Strong uncertainty and also missing higher order uncertainty and in particular on the modelling uncertainty of the pkw, as I said at the beginning, in atlas, the measurement was one of the big headaches of this measurements. In this case CMS is doing similar. It's weighting the spectrum to CMS has done.

The main modelling uncertainty is coming from this reweighting and the correlation between the scale variation. So here in the plot in the slide you will see the relative uncertainty for the W plus measurements that is done and as you can see the uncertainties are around, dominated by luminosity, these are absolute measurements. Now I'm going really flashing the results. In this note we have double differential cross-section of the section and I compare with the plus the PDFs 3 sets as you can see here. We have more standard 1D projection plots. This is more similar to the W measurements, like the asymmetry, as a function of vita. Of course, we also have some new measurements in particular the W plus or minus cross-section and charge asymmetry. And also the unpolarized W plus minus cross-section shown in the bottom plot as an example. As you know the polarization of the W Boson is an important source of uncertainty for the distraction of W mass for the spectrum because this is directly related to PDF uncertainty which direct affect the spectrum.

One of the main goal of this analysis was to test the constraining power of the pdf uncertainty in view of the W mass measurements through this fuller machinery to distract the cross-section. And from this, as you can see, we show actually the both of the pdf parameter after, can you see there is a significant power constraint up to 90% on average for the parameter. Down to 70% of summation. And in the bottom plot, even though it's not a full pdf analysis, can you see how you expect to constrain the u-valence pdf. At the scale of the, where this measurement is done. We expect from this measurement ...

GM: **You have five minutes.**

L: Yes, this is for sure a very interesting input for W mass measurements and we are looking forward though to new measurements. So now, going a bit more further in prospect of MW measurements, again enlarging the acceptance and including HHCb measurements, as I said for this valid is for the measurements of the weak mixing angle, acceptance is entirely complimentary into other CMS.

And moreover the production has a different flavour to the composition with respect to atlas and CMS. Which is nice for possible future combination. The pdf uncertainty is largely uncorrelated. So this is of course, everything is that nicely entering in the future combination possible within LHC experiment. So the HHCb analysis plans is to exploit the distribution to both W mass and PTW modelling uncertainty. So the goal is to have a simultaneousy to get the final instruction of both things. Can you see in the plot in the centre of the slides you can see when the fit range is large enough on PT lepton is large enough it's possible to determine all the parameters which are fundamental for the modelling of the PTW without a big loss in the precision of the W mass.

So this is very important measurement that we are looking forwards. More further in the future, mentioning some prospect of future W mass measurements, so this studies were done by atlas, with the prospect of atlas high luminosity LHC detector. So we have, we expect two major reduction of uncertainty, which come from the extended coverage with the new tracking detector, which we alied to the tracking up to and this will benefit from a reduction on pdf uncertainty as we saw for other analysis. Of course, some reduction of uncertainty from the instruction of missing transverse momentum of the W. We have hope to have 11mev. So in this prospect we have a projection of 11mev with 200pb plus two. In this analysis the inclusion of prospect pdf can help us reduce the pdf uncertainty by a factor of two. And also, here including a DIS experiment a kind of pdf constraint will help to reduce the pdf uncertainty gained by the factor of five-six, reaching at the end the ten mev goal. So this bring to my conclusion, LHC experiments, I hope that I managed to convince you that LHC experiments are reaching unprecedented precision.

And experiments have now reached similar precision of combined electroweak measurements which was never expected a few years ago. This is coming mostly from two main points, first of all they create knowledge of the detector response that we now reaching at LHC. It's incredible. And so this is of course the first essential point. The second one is that we are more and more adding advanced techniques to have have complex multidifferential measurements with extremely challenging experimental scenarios. Of course, the outlook to reaching the ultimate precision of the weak mixing angle and the mw of five mev relies on improvements in both physics modelling and pdfs knowledge and but of course, I tried to show you that extended acceptance using the data and high luminosity detector with more ancillary measurements are essential steps to reach the final goal. And that's it. Thank you.

GM: **Thank you for keeping your time. It was perfect. We have time for questions. So please, raise your hand. I don't see any hands. Maybe I have a question on slide 17, I think. So you said that the target is there for the precision of the W mass and you gave a few hints to improve this certainty from what it is now to such a low uncertainty. So do you still think that this target is feasible for the foreseeable future without any new ways to improve the pdf?**

L: What we have right now as a projection is indeed with the current machine, with LHC, is indeed something like 11mev. Of course, we need as I said, at the bottleneck for all these precision measurements is really understanding the pdfs. So for sure we need to work on this, on the experimental side. We really need to now don't consider the pdfs as a black box, but trying to understand the correlation, trying to improve the measurements, adding more stringent tests like for example, as you can see this ancillary measurements for C MS has proved that we kin deed constrain very much the pdfs using more complex measurements. So this is for sure can be possible. Of course, to drastically reduce the pdfs uncertainty you need to probably to use more, other experiments. For example, something like this experiment like for example HEC could bring this factor five reduction of pdfs that for sure you will not reach at LHC itself.

GM: Thank you. Is there any questions? So I don't see any. So thanks a lot again to have a very nice time. -- nice talk. Lucia I give you the floor for the next talk.

L: Thanks, it's the pleasure for me to introduce the last two talk of this plenary session. So the first of the two will be from on the multiBoson measurement with CMS and atlas. So please could you please share your slides. You can go on. I will sell you when five minutes before the end. Sepe OK, hopefully you can see my slides. OK, I'm at north-western and I'm going to talk about multiBoson measurements in CMS and atlas. I would like to thank the organisers for inviting me and for keeping this format of the conference so that I still got this opportunity to give this talk. All right, so mull pulls on measurements span six to seven orders of magnitude. This is physics spanning many orders of magnitude. And it's also difficult to unearth these signals because they are rare. So if one compares the rate of Higgs production to say Boson production, the production cross-section is by a factor of two. Then one looks at processes like www or wwz, the production cross-sections are lowerror lowered by a factor of 100. This is just to set things in context and see how rare these processes are. And that's why I wanted to use the Higgs. That is our newly discovered particle.

So tease are rarer, much rarer than the Higgs. And so, the challenge here is to isolate these processes from backgrounds and in some cases, this is extremely challenging not just because of the lower cross-section, but in some cases we don't have variables like we have for vbs type analysis. I don't focus on vbs topologies, that's the subject of the next talk. I'm going to focus on tri and di Bosons. I want to talk about the recent discovery of triBosons and I pick a couple of precision analyses and the C gamma analysis. I picked these because they were the newest results from atlas and CMS collaborations. But really there are a slew of results produced by both of these clap racings over many years. So I link to all of the results in my final conclusion slide. But just to say why I chose these particular analyses. I tried to focus on analyses that use the full run two data set. As I said I'm going it talk about the discovery of triBosons. This was a major milestone in standard model physics. The CMS collaboration put forth this physics briefing that I think was released some time in April. This is very, very new.

I link to our documentation here and since it's a prl type paper I link to the auxillary material in case you're interested this those kinds of information. At the risk of giving away my punch line, but I suppose I should begin with, that the combined observed significance for triBoson introduction is at 5.7sigma. This constitutes a discovery and the observed significance for just www and wwz processes alone are at more than three sigma. Why look at triBoson. It's because the production is through various modes and gives evidence of the couplings. I have the diagrams here on the right. Can you see and I have tried to emphasise the vertices by these circles here. You can see that triBoson production can occur through trilinear modes, the Higgs mediated modes, and it's three Bosons being radiated. And just to give you a brief background or the context of this analysis, last year, the atlas collaboration announced in evidence for www and wwz production where w an observed significance of four sigma. Before that, the CMS collaboration looked at the triple W production with the 13 data and a third of the data sets.

So this was the 2016 data set. So about 35.9. In that analysis we looked at effective theory interpretations and full model interpretations. In this particular case, this is new results from CMS. They are geared completely to the standard model production. We look at trilepton final states and this is geared towards triple w. Four leptons and this is geared to wwz and for wzz and zzz we look at five and six lepton final states. These are, this lepton, the final states are with the number of leptons and mutually exclusive categories. Just to give you an idea of what the cross-section branching faction scenario looks like. So you can see that production cross-section for www is 0.5 and the cross-section decreases as the number of Zs increase. We go all the way to 0.04 for zzz. I mention that we look at leptonic final states. To give us a final idea of what the expectations of event yields are. For www we have 70 events. For zzz it's just seven events. This is just production cross-section times branching faction times luminosity. This does not take into account acceptances and so on. You know that we will be taking a hit from those efficiencies. But this is just to give you an idea of what are our expectations are.

It tells you that processes like wzz and zzz are extremely rare and therefore they have not been explored before. And the main idea of this analysis as I mentioned that we are looking at leptonic final states. We reduce the background with the base add poach. We have a complimentary cut base approach. I focussed on the results of the BDT based analysis. The idea is to reduce the background to cross-section that's are comparable to the signal so we have some hope of unearthing our signal. That's the main idea behind this analysis. Just to go over some of the the main building blocks of the analysis. So for, as I mentioned for www we have the two same sign categories and the three lepton category. Here we do further subdivide into category based on the mass of the two jets and how close it is to the w mass. So we do consider it to be less than 15. This picked up on the shell components. We look at the side band to pick up off shell components that may arise out of the Higgs. This is the motivation for further cat goreisation. We have a two same sign lepton and one jet category. This one jet category is there to pick up any jet that we may have lost due to the minimum threshold.

So something arising from the Higgs that could be soft. For the trileptons we further categorised based on the number of opposite sides same flavour leptons and this is behavioural the number of Z candidates in an event. Not surprising the 0z candidate channel is one of our most sensitive channels. We do use, we do train 2BDTs to mitigate prompt and non-prompt backgrounds. The prompt arise from irreducible processes like the w, same sign ww production and non-prompt would be something like a bdt background. The major backgrounds are wz, tt bar, and then we have some backgrounds from charge reassignment or the photon going to lepton. We do train these bdts with leptons, this is a bunch of kinematic information that goes into training. Here we actually this constitutes nine different categories, sorry 12 different categories because this will all, I bring all this together in my results slide. So I just wanted to say that. The www inspiration in these two same signed entries lepton and the three lepton category accounts for 12 subcategories. And this is a nice event display I have here which shows a same sign muon and two jets with a w and missing energy arising from the neutronees. For the wwz we look at the 4 lepton channel.

In this case we have a one z category. There's a z in the event. The rest of the event classification is based on the flavours of the Ws. So we could have Emu or ee/uu. This is a major discriminant in this channel. That's because in the channel, we have backgrounds that, the zz background essentially arises from the component and so the zz background is restricted to likes it lower, while the signal until no such constraint and it's spread over all of the bins. So this shape differentiation allows us provides us with discrimination power to remove the background and in favour of the signal. As I said, zz is a dominant background. There is background from ttz. Even though we mitigated. So we have these two dimensional scores that we plot. Then we have signal regions based on these, on the 2D plane of BDT scores. This accounts for seven different signal regions. Fiver from the emu channel and two from the same sign channel. In the same sign channel we get discrimination from the missing ET spectrum and that's because ZZ background is going to be fully balanced while that's not the case for the signal where there are, there is missing energy arising from the neutronees.

This is a very nice four lepton event here. You can see that there are plus or minus that arises from the Z and a electron and muon consistent to arise from the two Ws and then there's missing energy. This is a nice, clean event that we have observed that shows wwz production. First the wzz and the zzz, we explored this in five and six lepton final states. These are characterised by low event yields. These are extreme lepton ton multiplicity environments. We can mitigation the background by requiring two Zs. And then requiring that the transverse mass computed with the fiveth lepton be created in 50gb. We do this with a flavoured pen and cut. Because the backgrounds are from zz where one of the electrons or jets is misidentified as an electron. It helps to have flavour separation. Background rejection requirement here. In the six lepton channel we required to the sum bt of all the leptons is the scalier sum of the bt be greater than 250gev. At this point, the backgrounds are at a per cent level. It is to be noted that the signal expectation are also low. But the backgrounds are lower by an order of magnitude in comparison to the signals.

These are very clean channels. I have an event here showing the 5 lepton event, it's five electron event much it's quite spectacular. The two pairs of electrons are consistent arising from the z, and the fifth electron is associated with the w and is missing energy. We observe a five lepton event. We observe three events in the five lepton category. So now bringing everything together, so I mention that we have several different subcategories. So for the same sign three lepton we have 12 subcategories for the four lepton, we have seven subcategories and for the five and six leptons since they are, statistics are limited, we have one bin each. This leads to 21 bin analysis. I have marked the sensitive bins here with these little stars here. In the most sensitive signal untils the not vah dominates with 56% probability. While the vh is 33% contribution there. When we were doing statistical interpretation we were careful to make sure that we take into account cross-channel contamination. So for example a wwz event is going to contribute mostly in the four lepton channel F there are contributions in the three lepton channel, that is taken into account carefully.

And so, going to the results, I'm showing you the final significances here. You can see as I mentioned before, just for the www and the wwz production we see significance higher than three sigma and our combined significance is at 5.7 sigma, where expectation was 5.9. This is very exciting. It is the observation of production for the first time. And we have, and I have the plot of the signal strength on the right and for the www and wwz signal strengths are close to one, while wzz has this large area associated with it. For zzz since we do not observe data events we set an upper bound on the signal strength. So now I want to change gears a little bit. I spoke about discovery analysis or discovery physics with multiBosons. I want to shift gears and talk about precision physics and I'm going to start with the w plus, w minus analysis which has been performed by CMS and atlas. I have this picture here just to tell you that we are doing precision measurement in the back drop of an LHC events. This is it in all its resplendent glory. We can do precision analyses with this. The di Boson production occurs with the mode. Emarked the vertices that can produce from higher operators.

There are six operators in this case. There are the T channel diagram and contributions from the diagrams or the box diagrams. These kind of processes allow us to study the standard model precisely. And they're also important in many new fibbingics -- physics searches. It is important to understand these processes. And now to do them at unprecedented precision, this leads us to various other explorations and also hints at other theoretical improvements that can be made in terms of cross-section and go on. I go over that in my talk. In atlas this analysis was studied in 0 jet bins category. And this is because the actual signal until no jets. So this makes sense. It also helps to reduce a lot of the backgrounds, for example from tt bar or drell-yan. And in CMS we look at two different complimentary search strategies, so the sequential cut based analysis is pursued in 0 and 1 jet bins. We use a random forest class fire. This is trained on simulated events. This includes 0 and one jet and greater than two. This is interesting because this process has not been explored in these jet multiplicity bins.

So the random forth class fire with the no jet requirement, I should say, no requirement of the jet multiplicity allows us to explore the cross-section as a function of the jet wins. I should say that the CMS analysis takes the Higgs ww process as a background. This is the process contributes at about 10% of the total cross-section, while for the atlas analysis this is considered signal until. So in the, now I want to talk about the random forest discriminator. The background contributions for in this case was reduced by this novel method called the random forest method. It's basically in the collection of binary decision trees. And the score is defined as a combination of the decisions of each tree. And there are a number of features that were actually given as input for the Drell-yen process, ten features and for tt bar eight. For tt bar features like hd or any kind of hadronic feature would rank higher. And this I have this sort of plot here on the left to show you how the random forest picks up the ww signal. So on the top panel, can you see the random forest score, with just the preselection requirements including the bv2 and basic requirements. When there's a cut placed on the score you can pick the signal here.

You can see that the last is really then dominated by the signal. It's a nice way to unearth the signal. This kind of analysis as I said before, let's us produce the fiducial cross-section of the jets. This hasn't been done before. This illustrates the power of this method. You can cannot talk about precision analysis and not talk about system attic uncertainties. The tier receiptical systematic, we are sensitive because the cut based analysis is done in a jet bin category. These system attic uncertainties were ascertainsascertained by normalisation and factorisation skills and uncertainties arise from alpha s pdf variations. The uncertainty is at 1.2%. While the total is at 4.6%. This is a system attic dominated. The total production cross-section is 117.6picobarn with other components there. If you compared with the N squared prediction the cross-sections are quite comparable. I want to touch on the analysis performed in atlas using the data, the atlas detector. And the different flavour final state was chosen to atlases and that makes sense. This then helps reduce the very large Drell-yen background.

There's a jet veto and bin veto. And the cross-section, which are the cuts that replied when these plots were produced are in one of my other slides. If you're interested in seeing what exact requirements were. I have the plot of the distribution and this is because these kinds of variables can pick up contributions from higher operators in the tails . It makes sense to look at this variable. There's an interesting star variable sensitive to the spin truckure of the pairs. And an interesting variable to look at. In the atlas analysis the system attic uncertainties were about 6.7%. While statistic uncertainty is about 1.3%. And so like the CMS analysis, this was systematics dominated as well. There are comparisons with different, under different assumptions with computations arising from matrix. There are other comparisons with Sherpa and so on. It is in the paper. They are consistent with what is measured in data, which is at 379. Bear in mind this is the fiducial cross-section. -- we can look at differential cross-sections and they were performed by CMS and atlas collaborations and the fiducial requirements I have included here. And they are different between the two analyses.

I have the emu plot which is the variable I looked at before in the 0 jet category. The reason for looking at this is because the higher bins are high values and emu could pick up contributions from higher order operators. There are several comparisons here with theoretical predictions including matrix. And in the CMS analysis this includes both jet bins so both jet categories, and it is the different flavour final state. So this is really even though it says mlm it's an emu, it's the same kind of fiducial cross-section of mlm. If there are higher operators this is where they would start showing up. So now, let me talk with the EFT interpretation. So we then go ahead and look at using ...

GM: You have five minutes.

L: Okay, that's perfect. So then we go ahead and look at the EFT formulation. This is a very convenient and nice way to characterise new physics or indirectly probe new physics. And as I said multiple times at high mll is an interesting place where new physics can show up. I have the plot here and have highlighted that region to show that really in these bins the new physics contributions starts dominating. Over the standard model expectations. The operators that were chosen by both CMS and atlas are the cp conserving operators. In the analysis non-conserving operators were also looked at. I don't include those specifically here. But they are in the paper. So this allows for a direct comparison of the limits. - let's see if the CMS collaboration we also looked at the 2D contour plots of these coefficients associated with the operators above. So I only include two here. We looked at the third possible combination to look at any possible correlations between the Boson coefficients. With this I want to manufacture on to the next precision physics analysis. This is the zgamma analysis. This was performed by the atlas collaboration.

Of course zgamma allows the electroweak of the standard model. It's one of the very interesting Higgs discovery channels. It really helps to understand this background well. In the past, in previous explorations of this final state the photon PT was set to high values. And so you can see the value, the range is here. They were within 150gev or so. They were designed to be sensitive to high dimensional operators. But this particular analysis really probes a full range of photon ET from 30-1200GeV, it's impressive the full range that has been probed in this analysis. And as you can tell that the signal until is the one, the final diagram I have on top. We need to suppress the fsr photon, which is seen in the diagram on the bottom here. This can be done by placing a cut on the 2 dimensional plane of the lepton and the three body invariant mass. That was done in this analysis. And this allows for a highly precise measurement of the fiducial cross-section. In this analysis one of the major backgrounds is the Z plus jets where the jet is beside a photon . This is estimated from side pans, where the jet is then required to pass the photon IDification and isolation requirements.

There were three controls. This was carefully computed. There is a small but non-negligible background . This arises when the selected photon and lepton pair are from different collisions in the LHC bunch crossing. I quote this because for this analysis a novel method was used to determine the background that's correlating the z cord negotiates of the z and the photonment and this background was studied very carefully using two different methods. And it's an interesting background. As I said this particular method was invented for this analysis. Other backgrounds are determined from simulations like the God background and so on. If the bottom I have the plots of the photon ET and mll gamma. You can see the full range in which the data and the simulations agree. As I said before, that's really impressive. And the mll gamma spectrum has the same feature. It's interesting to note that because it's in linear scale you can see the sample purity. It is a very pure sample in Z gamma. We can also then go ahead and look at differential cross-sections. As I said this is a highly precise measurement with the relative cross-section uncertainty of 2.9%.

This is really unprecedented. The fiducial cross-section is computed by requirements on the mll mass and the sum of the mll and the three body invariant mass.

GM: Are you out of time.

L: Okay, I'm almost done. They were then computed in several bins of the several physics variables. Each of these are interesting in their own right. And just to give you a sense of the system attic uncertainties they are about a per cent level for the major contributors. The statistic uncertainty was lowered by a factor of six. The fiducial cross-section is computed with an uncertainty of 2.9%. So as I promise, just to wrap up, I have presented three different analyses that highlight several possibilities of exploration in multiBoson final states. There is discovery physics like the vvv analysis and precision analysis. So I just picked a few as I said before, but then the full slew of analyses can be found by clicking on the links. I will be in the Zoom room after talk or after the session, should you have any questions. Thank you.

GM: Thanks to you. Now it's time for questions. But we have not much time. We are out of time. But there is already a question. Perhaps only one we will take. Please I have already allowed my caller.

?: Yes hello. Thank you very much for your talk . It was really very interesting. My question is about the prospects of the triBoson measurements? Are there any studies on what's going to be the possible results, of such a measurement on the HLO conditions, you mention that the statistical error does not dominate in your measurements. So would that be, help a lot? Do you expect new results from the HLLAC conditions and measurements?

L: Thank you for the questions. For the vvv analysis we are statistics dominated. That I think with 300fentobarn we will be more precise. To say that the vvv analysis is very much statistics dominated at this point. For the di Bosons yes, I think especially with the at least a very quick answer to that would be that our luminosity uncertainties are expected to go down from 2.5% that we assume now to 1%. This is going to be more precise. I think, I don't think there are exact projection analyses for these two channels. But definitely, at this point, we would benefit from some theoretical computed more precise theoretical computations in. Bin channels we are dominated by theoretical uncertainties. Certainly amount of increasing uncertainty there would be helpful. The lumi uncertainty is going to go down to (inaudible) per cent and that will make it more precise. There are several avenues for improvement of this analysis. This is for the two precision analyses I spoke about the vvv is very much statistics dominated.

?: Thank you.

GM: **Thanks. Thanks for the very interesting talk. For the questions. We will now move on. We will move to vector Boson scattering from University college London. Christian, you can start.**

C: Hi. Can you hear me okay?

GM: **Yes.**

C: Brilliant. Okay. I hope you can see my screen now. Is that projecting all right?

GM: **Yes, you are projecting.**

C: Excellent. Thank you very much, I will get started then. I'm the last talk of the session on VBF and VBS measurements. I have to start with the caveat that actually there is no such thing. The reason will become clear on the next slide. If I go to slide two. So VBF and VBS fusion and scattering is the diagrams that I've illustrated here on the left hand column. The scattering at the top and the infusion at the bottom. These cannot be measured by itself. It includes the diagrams on the right, they're more like weak Boson. These interfere strongly with each other and they interfere negatively with each other. The only thing that we can actively measure is vvjj production. This is what we mean, the complete set. This is quite interesting. The dominant background is typically the QCDv two plus jet production variables. Where you have two additional particle emissions from a strong interaction. This is in the vjj case, this is the dominant background. Like Drell-yen with two additional part emissions. In that sense the component is part of the NLO electroweak correction. So measure it precisely and test the high precision calculations and testing really properly.

It's also a mixed QCD-electroweak contribution interference. Most of the measurements haven't been sensitive to that. But this will become a significant component. OK. So why is this interesting? So the thing that I've mentioned is that these interfere strongly and negatively but also, this interference is really delicate. So if you look at the integrated cross-section as a function of the centre of mass energy and this is illustrated here, this is for same sign ww production and in particular looking out at longitudinal component and what you see is that if you were to fiddle with the couplings this is supersensitive to that. This is the standard model in black here. There's a delicate cancellation between the terms. If you were to remove the Higgs component contributing to that process, the whole thing is just completely blows up and diverges as a centre of mass energy. The only reason that the unitary is restored is through this delicate cancellation contributing to this process. It's not just true for variations in the Higgs coupling, it's also sensitivity when you play around the triple gauge couplings as indicated in the two bottom plots.

Measuring this precisely is really absolutely crucial in order to fundamentally test the electroweak sector and gauge symmetry of the stand ad model. OK, slide four.

GM: **Sorry, it seems to me that it's not full screen. Could you try to put full screen? Let me try. Is that full screen now?** Okay, if not, don't worry. It's clear enough. If it's not possible, let's go on.

C: OK, sorry about that. OK so slide four now. What does this look like? So typically, if you think about the process again, you two incoming quarks, and then these two views are scattered. Other than that the two quarks continue into the detector you end up with two forward jets with large rapidity. You see it here, this it s in the case of zjj. You can see for the blue signal, the rapidity span between the two jets tends to be much larger. Because you have a T channel exchange singular between the two quarks, the additional radiation in the gap between the two jets is also heavily suppressed. So you would expect no additional jets. So it's just the member of jets in the gap and most of them sit in the zero jet. With the QCD background we have additional radiation. Of that topology is such that you have two forward jets in the central Boson or two Bosons you have a hard mass. That's shown at the top right. It's much harder in case of the electroweak component compared to the QCD background. On the bottom I have also put an event display from a zzjj recent paper. Can you see this here, the two forward jets along the axis and then the two electrons in green and blue.

So the rest of the talk is essentially going through the most recent of the measurements. You'll understand the model production cross-section overview. You can see the electroweak vvjj measurement here. This is quite anstonnishing plot. It's 14 orders of magnitude. It's essentially like comparing the weight of a super jumbo airBus here at the top and still sort of able to pin down individual grains of salt from the last holiday pre-corona, if you remember that! This is the grains of salt measurements that we're looking at. OK? I will now start with reBoson fusion. This is enlargement of the cross-section. This is a fresh result from atlas on slide seven. The first thing are the patterns that are relatively common between the different measurements is the background modelling for zjj the most important variable in this analysis is the mass spectrum. If you look at how do the various generators model the spectrum, this is illustrated in the plot at the top for the control region. This is all over the place. Different generators shown in blue. You can see this known to overshoot massively. This is the point that's the mismodelling between the different generators is much larger and the size of the electroweak component.

If you do the analysis typically what is done you will control region, and different control regions and validation regions and probe the modelling in all of these. This is illustrated in the plot in the middle. Looking at the mjj distribution in different control regions, also in the signal until. In this case this is looking at Sherpa. What you can see is a massive, data prediction discrepancy. So the modelling is crap. But the modelling is similarly crap in all the control regions, which is consistent. That is quite important because then you can correlate between the different control regions and constrain the modelling and transfer that constraint using the data into the signal region in order to constrain the background modelling there. If you do that in the fit, then the one at the bottom is what you end up with, where you really constrain the modelling and the mjj looks fine afterwards. More details on that in Heather's talk. I can't go into too many details yet. Just to say, that because you're playing around with this, one of the crucial things that you have to keep in mind is in addition to destruct the component it's crucial to measure the inclusive jet production in one go.

In addition to extracting the component. Slide eight, this is what's been done. I start off with the inclusive measurements. Here I'm presenting inclusives cross-section measurements from this analysis. They show differential cross-sections as a function of mjj, the Delta rapidy between the two leading jets. The mass spectrum and the sign as a different between the two jets. And a measure that in the signal until control region in order to be able to later constrain the modelling, improve the modelling of the Monte Carlos. In these plots, the data is compared to multileg predictions and leading order from both using sherpa but also fx from mad graphs. In the control region on the right and signal region on the middle and the signal on the left. Once you have done that you can subtract the background and also measure differential cross-sections for the electroweak component. This is on the next slide. Once the background is subtracted this is the different cross-section of as function of zjj. An the signal region and the electroweak component. Any other data compared to redictions an approximation.

You can see this is actually known for one, the sherpa2.2 series have a condistribution in the colour flow. The par ton showed radiance way too much into the gap between the two jets and because it has too much radiation, the events tend to fail some sort of central jet like veto cut that the analysis typically apply. And that defeats the cross-sect and concedes the factor of two everywhere. On the other hand, yeah that's the source of integrated cross-sections. This is an excellent agreement with the standard model prediction. Slide ten. Now once you've got the cross-section measurements and more predictions the question is what else can you do with that? The answer is you can place EFT constraints on this. You take the standard model prediction and supplement is with dimension six operators. So there's four, it turns out that are relevant for the couplings and zjj to open. What the analysis has done here is taking the SM prediction and supplemented with the interference of SM and dimension six eft operators but also the pure dimension six contribution estimate both with this maximum package but also mad graph order.

They set limits on these four operators. Both with the pure dimension six term included and excluded. The difference typically not that great. It's very similar. Can you see this on the plots here for the different bins measured. As a function of the, in the single region. Can you see in the purple and red the difference between having the pure damage included or not is small. You can see that is important to measure the difference between the two jets as a signed one. Because the cpo terms, they have such a form that if you had put an absolute value around it, the difference would have been completely washed out so that you're gaining additional sensitivity by defining in this form. OK the elements are presented here. One feature you can see for one of them the SM is outside the 95% confidence interval. If you take into account the atlas effect you find that it's more or less expected. So it's 6.2% chance to happen when you convain these four operators. This was Boson infusion. Moving onto scattering. A lot of final states. Brace yourselves. I start with the same sign wwjj production and wzjj production.

This is a result from CMS now. It's a similar topology thing again where you have a large rapid ti interval between the two jets going hard on the mass distribution, there's a, some sort of central jet applied, or lepton centrality. It's for contributions from top processes. The QCD and electroweak same processes calculated in this case, leading order using mad graph pythia. And at the bottom you can see wz. In the left, top, you can see mjj distribution and on the right you see the di lepton distribution. At the bottom we see a score of the Boson decision tree that was trained in order to suppress the background and exact the reactry component. This was fit to the bin that was used to extract the component. You can see the cross-section measurements here. The systematic uncertainties come from the energy scale and theory uncertainties, dominated by the QCD scales. Then in addition, the inclusive since of wwjj cross-sections QCD and electroweak combined as well as inclusive wwz jj cross-section. Compare that to the next leading order predictions. The predictions are with and without corrections for alpha res. You can see the effect starting to set.

Moving on to zzjj. So this is going down quite a bit in cross-section now. This is a fairly recent result. They've done this in both the 4 lepton jj channel and the two charge lepton channel. Here the background is simulated at sherpa2.2. The control region similar to zjj used to constrain the modelling. They used a multivariant discriminant to extract the component and used and posted decision tree here. The impact of the interference, the impact of the interference as a sign as system attic on the electrics signaluntil This happens in atlas quite often. Systematics largest impact from system attic theoretical from the QCD component. The results on slide 16. The extraction of the component on the top, if you combine them as well, this is a five signal result. After combinations so the next, the first observation really ran the process. And the distribution for this is shown on the right and the two charge lepton nutrino case on the top and the four charge channel at the bottom. There are inclusive cross-sections not just the extraction of the component and the inclusive cross-sections are in good SM predictions.

So zzjj result from CMS. This is brand new. Here this is using a calculation that actually isn't using vbf approximation but includes the triBoson component, the electroweak calculation. In the back actually the leading order. Using various K factors, differential K factors to correct the predictions for NLO QCD effects for electric.

GM: Sorry, Christian, you have five minutes left.

C: OK. They use a metrics element discriminant in order to extract the background. The results are shown on slide 18. Measured inclusive cross-section in addition to extracting the electric signal and all of those in good agreement with the SM. Can you see the distribution is here and the typical effect of the electroweak component to the and these are the most effective ones in discriminating between signal which goes into this matrix element and class fire. OK I'm starting to move on. From CMS, this is also not too recent. Fairly recent I would say. Similar story here. Mad graph used for the electric signal and NLO for the QCD. The results are here. This is split up across different jj bins and mjj bins. And in a simultaneous fit in the control regions they measure the signal trends and extract the fiducial cross-section for the inclusive set and the electroweak corrections rjj. The atlas results from the end of last year, similar thing here. They measured again the electroweak component and the inclusive cross-section as well in good agreement with the SM. And then the final result that I want to talk about, so I have to speed up is brand new from CMS.

This is also using a control region to constrain the modelling. They're looking at the low part of mjj and similar to the z gamma jj. They split it into the channels. But also in the part and looking at looking at different gamma bins as well and in the simultaneous bit in different regions they extract this and it amounts to 4.9 signal observed. 4.6 if not expected with the 2016 data set alone. If you combine that with the previous atv result you had the five signal mark. This makes it the first observation of this. Fiducial cross-section measurements for the w gamma jj as well. This is also then used to set limits on gauge couplings showing you the full list here. I don't have much time to go into the details here. You can see all the details tomorrow in Maria's talk. What I will do is leave you with my summary slide. Measurements of vjj and vvjj final states are vital probe of the electroweak sector. This is interesting as the unitary bound achieved through delicate consolation of terms developing to these processes. So it's important to do this.

Also measurements of inclusive productions really a stress test of QCD when you look at the VBF and VBS topologies, so it's important not to focus on the electroweak distraction but look at the inclusive measurements and crucially to make the data then available and have data provide a rivet rue tone to really understand that modelling and can be better in the future. I encourage you to look at the talk tomorrow and leave you with that. Thank you.

GM: Thanks for this interesting talk. There is a question now. I have allowed him to speak. Please could you please.

?: Hi Christian. Thanks for this excellent talk. So I have a question, actually a few questions. So number one is in your vvf analysis, so you produce z plus jet, so I want to ask a few questions here. Z plus jets do you consider like z plus single jet and z like an emerge sample when you are generating everything together? I'll ask the other questions together, so that you can answer everything. Isn't Higgs plus jets also a background here? And if so, like Higgs going to is one of the like biggest backgrounds in that sense. So in that case, do you use or do you plan to use something like a co-linear mass variable to differentiate between the Higgs plus jets and the z plus jets. These are my two essential questions. Thanks.

C: Can I just, are you talking about the zjj results?

?: Exactly.

C: Let me go back. The Higgs is really a background. In the selection for zjj you can actually or you want to actually type fairly tightly on the z mass so the x doesn't play a role any more for the backgrounds. The other question was on the accuracy of the background component.

?: It was mostly the modelling of z plus jets, do you also from your final diagrams I see you generate z plus jets which is the quark fusion. Do you include z plus single jet or just z production and include a merge sample while modelling the sample?

C: No, these atlas at least always are done with merged samples. The zjj is ex-linear accurate. The set plus steer row one or two jets ex-leading order even the fourth jets at leading order.

?: Thank you so much.

GM: So there are additional questions if not, since we are still have two minutes, I have one slide, the 17, in which you say that the largest impact comes from QCD scale up to 11%. I wonder in comparison with the atlas measurement is there is no uncertainty related to shape. Because atlas quotes I think for the same measurement something 30% theoretical uncertainty if I remember correctly.

C: That is a good question. Let me see if I have the break down. No I don't. I'm not sure. I would have to refer you to the analysis team actually.

GM: OK. Are there additional questions? So if not, thanks to the speakers for the very interesting talks. And two people asked questions. Thanks. So the session is over. And there is now a coffee break. Bye. See you soon.

END OF TRANSCRIPT