March 29, 2022

Plenaries 11am to 12pm

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>> Okay. We can see Sally, right?

>> Yes. And you're going to change the slides.

>> Yes, I will change the slides. Okay. Since I'm in the

room, we are charged are hosting a discussion, challenges and

opportunities for Higgs physics.

So Sally and I are cohosting this and so we tried to come up

with a few questions to kind of make it a little provocative to

get people thinking and discussing and hopefully we can have a

fruitful discussion today.

Sally is going to start with a few more questions from the

more theoretical point of view and I have a few questions from

the experimental point of view. I think it's okay with both of

us if we go off onto a different tract as well.

We have a few panelists that we asked to take a look and

participate. But everyone is welcome to participate today.

Sally, is that a good introduction?

>> Perfect. Done. As Isabel said, the point is to get your

blood pressure up high. We really, really want people to

participate and think about why somebody should give us N where N

is a big number, N billion dollar to build and explore the Higgs.

We have to have a simple and punchy answer for why exploring the

Higgs is important.

I put the archive number here. This is a Snowmass white

paper from an E plus E minus centric point of view talking about

some of the possible answers why you need to explore the Higgs

sector. Is it enough to say the Higgs is a fundamental part of

the standard model and we need to explore it or do we need to

have more.

In the standard model, we know most everything and I qualify

myself here because I didn't want to get into details. But we

know most everything except the Higgs mass. So we can make these

precise comparisons between the standard model predictions and

the data.

So before we start, that leads us into the question of are

the theory calculations sufficient for the comparisons?

And I've highlighted on the right-hand bottom side of the

page another white paper from the people that do the higher order

perturbative calculations where they discussed in this white

paper the challenges for getting to N cubed LO in the hadron

sector.

And the places where the uncertainties go. And this plot

here is an old plot showing where the uncertainties come from

when you're calculating Higgs production in a Hadron Collider,

but I think for our report, we need a nice graphic showing where

the uncertainties come from when we compare with our data.

So this is a challenge for our group is to make something

punchy illustrating the challenge of getting theory calculations

to agree or to sufficient precision. Again, for E plus E minus

we need something punchy showing the status of the theory and the

experiment. Not complicated but just showing how accurately we

need to measure.

Okay. Next slide.

So the real question, and the question I think that is going

to set the tone of the report is what do we learn from all these

precision measurements of the Higgs properties? I hope a lot of

you will have opinions on this subject. We've heard from

Caterina yesterday all the beautiful studies of measuring this,

that, and the other thing, hadron machines and electron machines

but what do we learn from it? Why should I care about this? I

think the plot on the left is my answer. The precision is high

scale. This is my cartoon but you get in trouble when you try to

make it more detailed. It's a challenge to this group to finesse

this simple graphic on the left into something with more content.

You can say in the SMEFT framework, it's one over Higgs M

squared. You can say, as Patrick is going to say when he

critiques me, it only makes sense in the context of specific

models to look at this.

You can make unitarity criteria. This is another Snowmass

paper in the bottom, but it looks like the plot on the left,

precision versus scale.

We want to make a nice graphic that shows the connection of

precision measurements to understanding new V physics.

Next one.

So it's a window. How are we going to search for the new

physics? I think our report needs to have a couple examples.

And these examples need to show the complementarity of looking

for heavy Higgs which is the regime of the high energy hadron

machines and the precise measures of the Higgs factories.

This plot is from another nice white paper and it's a type

2HDM that has the limits, the black and yellow lines are the LHC

and the high Lumi LHC and the lines on the right are the plus and

minus machines.

There is one nose for the high lumi LHC and another for the

E plus E minus machines and you want to put on this the direct

searches.

Here is another challenge to somebody in the audience, to

try to make a simple graphic. Since we just heard about

naturalness from Brian, we need to construct some examples. Not

a lot but some with a strongly interacting scenario motivated by

naturalness.

Next one.

So again, we need to highlight precision not versus direct

searches but how they go together is a better way to say it and

how their complementary and how do we quantify this. This

particular plot is from the European strategy report and the

modifications of the Higgs couplings we can and will update with

all the new numbers that Caterina showed but maybe somebody can

think of another way to show probing searches for heavy particles

with these precision measurements in a nice way and in a

particular model.

There is another challenge.

These are all sort of models where the new physics is in

high scale but there are other ways.

Next one.

So this is another of our white papers where they pointed

out Higgs is sensitive to looking for new decays. You can have

light scalars which in this plot is S and in this particular plot

the light scalars are tens of GeVs. You can make a connection

between looking for the light scalars and the electroweak phase

transition.

So the shaded region, you're sensitive to the electroweak

phase transition and there is some limits from the high lumi LHC

and E plus E minus collider. I should thank the authors of this

white paper, because I was looking at this and thinking about it

and thinking there are way too many lines here and they took off

most of the lines to try to simplify it.

I think this is what we need for our report. Take this

content that we have and boil it down to the message. What are

we learning here? Why is this important?

Next slide.

Finally, we've heard a lot about measuring the triple Higgs

coupling as a window into understanding electroweak symmetry

breaking. But I think we need a way for our report to explain

this very, very simply and tell us what it means.

I'm going to stop here, and I hope that people in the

discussion will point out what we learned from measuring the

Higgs in a very, very general sense that we can communicate to

the neutrino physicists, to the funding agencies. Not all of the

details that will be in the white papers but really why it's so

very, very important?

>> Isabella is going to come from a different angle and

provocative questions about the Higgs.

>> I took a few examples from instrumentation R and D. I

was trying to think about a few of the instrumentation research

and development projects that could really have a huge impact on

future Higgs measurements and searches.

So I came up with a bit of a list. Probably there's things

missing and that's one of the things we want to hear about. Or

probably we should be talking about them in a different light.

One of the important, well, in my mind important features

which I think is quite interesting R and D project is precision

timing and how it's being advanced and incorporated into the use

currently in the HL-LHC is an example how we can use it in the

future colliders and experiments.

People have been looking at various studies recently and

have seen that having precision timing for instance at a muon

collider can really greatly reduce the BIB background. Or you

can see this plot on the right where they directly reduce the

effective pileup in the FCC-hh tracker by indicating different

levels of precision timing.

This is from a beam induced background and you can see with

the different levels of timing, 10 pico second, and 20 pico

second and 50 pico second, you can compare the background

efficiency to the collision product efficiency. Here is an

effective pileup versus eta for various timing windows as well.

5 pico second and 25 pico second.

So thing is quite compelling.

Another area where it's interesting and something that

theorists like to beat up on the experimentalist is doing flavor

measurements. These are programs that can really help with the

separation of particles or identification of particles at various

detectors.

And so on the left, you can see for instance, SS, BB, CC and

the various fractions of the particles in an individual jet. And

so if we can improve our identification of the particles that are

within a jet, perhaps we can actually improve our flavor at the

future collider.

Multilayer tracking, et cetera, there is a link here. It's

been shown that precision timing can help to improve particle ID

at a future E plus E minus collider. These are interesting and

compelling projects and maybe we haven't thought of all the ways

that we can probably include or improve flavor measurements in

the future.

I have one more example because it's near and dear to my

heart, trigger detectors and fast ML and reconstruction. If we

save everything at the current LHC, it would change the way to do

various measurements.

You can think instead of things like triggerless detectors

and improve our data readout and do realtime reconstruction and

only save a subset of the information and therefore reduce the

amount of data that you save.

Or you can think about ways to do machine learning online

and prove your identification of various processes online.

This would also mix with different detectors and different

scenarios. So the data rates a zoonotic you know will very

greatly. And the definition of interesting physics is also

equally diverse.

We need to think about how we define equally, interesting

physics, what sort of data rates we're going to come up against,

what is the -- of the detectors and all of these are interesting

and compelling research topics that can potentially improve how

well remeasure, for instance, rare Higgs processes in the future.

And I put this other slide because personally I'm going

through a instrumentation submitted white papers. What other R

and D projects should be tied directly to future Higgs searches?

This is all I have for today.

Perhaps we can go back to the beginning and try to field

questions in order. Sally, what do you think?

>> Good. That is great. Let's see.

>> Do we have any --

>> Brian agreed to say something. Brian, let me pick on

you.

No?

>> Hi, Sally.

>> Yes?

>> Okay. I may have misinterpreted the charge. I was

thinking you wanted some general cheer leading.

>> Your talk was a perfect introduction, why should I care

about naturalness? How -- for measuring the Higgs?

>> Let me just focus on one example that you brought up. It

was slide, you had a comment about needing something with a

strongly interacting or composite Higgs.

>> Exactly.

>> I think there must be some nice plots already in the

literature. But I don't know, showing the reach of different

facilities as a function of the scale F, the scale F is, it's

concrete parameter in these composite Higgs models. And Higgs

couplings generically are, have deviations of order V squared

over F squared. That would be an interesting, fairly simple plot

to interpret.

>> So you could almost put that onto my cartoon on my second

slide where I had scale versus precision.

>> Yes. It might --

>> This one.

>> -- in my talk I showed one plot from Veronica Sans who

put bounds from the LHC Run2 showing that, under various

different model assumptions on how fermion couplings are gauge

boson couplings of the Higgs vary in different models, you can

exclude at some level.

So the lowest bound is F equals 600 GeV. So that's really

nice, simple plot that gets the message across.

Maybe another comment is on the triple Higgs coupling. I

think that is maybe a little later.

The last slide that Sally had?

>> The last slide where I said we have to explain why we

should care so much.

>> You can do this from different points of view. You can

have an effective field theory operators. I forget what it's

called, C6 or something. That tells you a scale. And then you

can have it in various model interpretations. So for example,

you can have some new light physics which runs in the loop and

modifies Higgs pair production.

Light stops can do that, for example.

Or you can have some new heavy state that decays into two

Higgs, like a diHiggs resonance. And I think those are fairly

simple models that one could, I don't know, conceivably come up

with plots that get the message across?

>> I think the challenge would be to put them all on one

plot somehow.

>> Uh-huh.

>> Great. Thanks. Are you done, Brian? So I can pick on

somebody else?

>> Yes. Please go ahead.

>> I was going to pick on Patrick now.

>> There's lots of hands up, Sally, I can always add more.

Maybe you should go through the hands.

>> Okay. Whose hands are up.

>> Mike was first.

>> I have a comment and question. About the possible light

Higgs, 10, 20 GeV something like that which would naturally be

long-lived and can travel a hundred meters and decay to CC bar.

We have a project called facet that is going to look for

such things.

My question is can such a state be produced by mixing with

the standard model Higgs or decay of the standard model Higgs to

these Ss? How do they compare? The two mechanisms?

>> In most models you find it through the decay. But I'm

not an expert in the mixing models but I think it's mostly in the

decay.

>> Mixing is another way. But probably if this one is very

light, it would be very small effect, I guess, is that correct.

>> I think it depends on the scenario.

>> Okay. All right.

>> But it's certainly important for us to look for these new

signatures in the different ways. I think that's what you're

making the point. We can't just, like, go linearly here.

>> Yes. I'll send you a link about this facet project.

>> I know about Passet (ph.) it's great.

>> Maybe I can ask something.

>> Yes, somebody in the room.

>> On the first slide you had about the theory

uncertainties.

I think for the discussion, it's interesting to look back at

the extrapolation that we did for the Euro report in 2018 and the

extrapolation that we're currently doing for Snowmass and compare

how the extrapolation has changed. And I think you can realize

there, on the experimental side, we have very much in line with

what is considered an aggressive scenario back then. We have

improved quite a lot. We have four times for data.

So we can also design better signal regions where the -- is

more favorable.

If you do compare those extrapolations carefully, you

realize on the theory side, things haven't changed much. Most of

our constraint on the couplings are the same level of

uncertainties.

And there was a rather long discussion at this at the 2021

conference a few months ago and what was stressed there is a lot

does not come from the calculation on the Higgs itself but from

parton shower or matching uncertainties, which I think should be

stressed because it's not just the Higgs problem but more

generically a problem at the LHC. And if we want to highlight

this nicely, I think it would be very [inaudible]

>> That's a good point and we'll have to remember to include

that. Yes, absolutely.

>> Did you want to say something?

>> Yes.

>> So just following up with what you just said, I think

that since we are on this slide, the question how accurate do we

need to measure, I think the first approximation I would say from

high luminosity LHC studies, one of the big limitations for high

luminosity LHC is the theory.

If we want to reach the numbers quoted, and reduce the

errors to have meaningful numbers. We need to work towards that

goal. That is our level zero goal. If you want really to

explore the physics of high luminosity LHC.

And the previous bullet points, are the existing

calculations sufficient for the comparison? This is a multilayer

problem. It's a process-dependent problem.

So the plot that you're looking at here is gluon/gluon

fusion. But if you look at more exclusion signatures there are

many more different layers of what does it mean to have an error

and to reach precision that sometimes are due to calculations and

simulations and sometimes are due to understanding different

levels of QCD and electroweak effects that are not just unique.

So you have a difficult way to quantify like in one plot like

that one. But maybe more different aspects?

>> Like if we have a plot with blocks showing, sort of the

generic sources of errors?

>> Yes. Probably.

>> Like parton showering, and modeling or whatever.

>> That is sometimes process dependent.

>> We need something simple for the high-level summaries to

make sure we have this and that's the challenge.

>> At first, if I can interject my own personal feelings on

that, I think we can't under emphasize that. Because we need to

really emphasize to external P5 and funding agencies how

important it is to have these theory calculations available to us

and how important the research budgets are to be honest.

>> Next online question is from Kevin.

>> Thank you. Thank you for the nice summary and

discussion. I don't have really any deep philosophical things to

adhere. I want to emphasize that I strongly believe the slide

that you were showing before, you know the one with the mass

scale probe versus the precision of the Higgs coupling.

We should try to make this argument as strong and precise as

we can. I know it's not as easy as some cases in the distant

path. But it goes a long way in making the argument as precise

and easy to understand, especially for not only our own community

but for people outside. I've had discussions with people in my

department and they kind of think you want to spend $20 billion

to improve the precision by a factor of 2 but what does that

mean. Making it as clear as we can as to why this is important

and as specific as we can. I think that is a really important

thing to basically get general support for this program.

>> Right. Thank you. I 100 percent agree.

>> Then we have another comment in the room.

>> I have a more specific thing that I wanted to also say

something more broader. I think a specific thing is about, you

asked about what's the best plot for composite Higgs models. And

you know that our Italian colleague has a long tradition of

making a plot and there's a G star, there is a composite Higgs

model that can be broadly characterized by two parameters. One

is the coupling and the other one is composite to resonance mass.

In that plot, the V squared over F squared. The generic

deviation from the Higgs coupling shows up as a diagonal line.

I think it does show improvement. If you look at those

plots, it shows the improvement very clearly how well you can do

by improved Higgs mass measurement. But my guess is you're

asking for something new. You have something unhappy about those

representations?

>> I'm trying to figure out what the right plot is. We're

not going to have 20. We will have one or two.

>> The composite Higgs model is a nice way of talking about

this. You can put the collider reach on the same figure, you

can see that they're quite complementary. The Higgs measurement

and the direct search.

I also have a more general, I think you're asking for

something new. And we have been talking about the meaning of

Higgs physics for the last ten years including the European

strategy update several years ago. We have this forest of EFT

bars. How well you can do and so on. And we have, for all the

questions there is an answer. I'm not saying they are perfect

answer but for all the questions that you raised. How do we talk

about naturalness and phase transition and why -- coupling is

important.

I think, I'm currently now seeing that the new physics point

just in terms of physics content, we can add to that kind of

discussion. You're asking for a different representation of the

same thing?

>> I'm just thinking that we need to write it very, very

clearly and make this physics case. There are many ways to say

the same thing, right. You're probing --

>> I guess you're asking for better representation?

>> I don't think better is the right word but that we'll put

our own take on it and make it really clear and punchy. More

that we have this job to do to the best we can to make it very

clear and salable, quite honestly.

>> My question is wondering if you have any specific that

you're unhappy about, about the way this used to be presented? I

think that way has existed for some years now.

>> I mean, yes, if I can also interject and be provocative,

that is true. But we have more data and more measurements in the

past couple of years as well. Maybe we can use that.

>> It's qualitatively different, right. We're talking about

the future colliders, what the Higgs factory can do, what the

Higgs measurement can do and so on. Right. I'm not sure what --

>> You have Higgs as well and not just the standard model.

>> Maybe BSM physics is something new. I'm saying there's a

standard Higgs measurement, I'm, you know.

>> One thing that is new is the idea that we can actually

measure some of the light Higgs -- couplings and that's a window

into a new type of physics and perhaps that is something we

should emphasize.

>> Okay.

>> Another question online from Marcus.

>> I have more a comment than a question. First of all, I

hope very much that Snowmass can support the general notion that

we need a Higgs factory. The Higgs with much more precision.

When you make the argument, a question like how well do we have

to measure should include -- the added value of that machine in

terms of physics reach. And for the Higgs, this is not difficult

to answer. This is absolute coupling measurements and increased

precision and a few other things, of course.

There and I will repeat the comment I made yesterday, we

have to be more precise in what the high lumi Lhc can do. And if

you just do a comparison of the kind of performance that we had

using the 2016 data compared to the full Run2 data and take out

the statistical increase of the dataset, you see that because of

improved techniques and in some cases improved detectors, the

reach, and some theory improvements, the level of performance is

increased quite a bit. In fact, there are two in the diHiggs

measurement. There is no guarantee that we can continue this but

there is a few upgrades planned for ATLAS and CMS specifically on

the trigger that will lead to further improvements for sure.

This is to be taken into accounts.

Just an example, when you look at the current projection for

the Higgs, you get 50 percent on the Higgs -- coupling. That

compares to the lepton colliders of 20 percent. That is a bit

more than a factor of 2 and it's not out of reach for the high

Lumi LHC.

But the wide Quarks, for example, we are able to probe them

with the LHC. Those turn into precision measurements and that's

a story one can easily tell for those specific points and then

the plot that is shown here is fantastic.

But again, points to a -- specific points.

The uncertainty on the coupling parameters are on the order

of a couple of percent, some of them. That gives to you a

specific physics reach which is similar to the direct search

reach at the same machine. The high Lumi LHC.

To learn more you have to be significantly above or below

the 2 percent. That is point you want to learn. If you want to

learn something new, you need improvement of a factor of three or

higher than that to really learn something. If not, you end up

in a situation where you find small deviations and you're not

able to unfold them with the next machine. That would be a

disaster, to me at least.

And then I have a couple of specific points on the

instrumentation, those are very good points, Isabel. But the

connection to the extra physics region needs to be made and it

can be made with a few examples. Starting with the trigger, the

reach of physics. If you want to stay at high Lumi LHCs you have

a couple of examples.

This is an important connection. Improve instrumentation

leads to better results but how much is the question.

And I have a very specific point on this, I think on the

next or next to next slide.

The one which was the light scalar?

>> That one?

>> This one?

>> No. This one, here. The line Higgs factory statistical

limits on it.

>> It's the slide before, Isabel.

>> This one?

>> Yes. That one.

>> Okay.

>> Yes. 10 to the 6 Higgs bosons. But if you look for

light scalars and you're using a circular machine, you have

potentially a Z dataset that is much larger and can be used to

look for the very same thing. And those are not decays

necessarily Higgs to SS decays but through the coupling to the Z

boson and then the reach goes much much lower than this.

Orders of magnitude lower.

That's a specific comment on this plot. But this is model

dependent?

>> Right. This is a specific model these folks have looked

at.

>> Okay. That's all I wanted to say.

>> Okay, thank you Marcus. We have a hand raised from

Michael Peskin.

>> Yes. I wanted to share this slide. Sally, I think this

is something that is missing from your talk. But it's very

important. So these are six models you can figure out what they

are, chosen from the literature. They are models that give

relatively large deviations in the Higgs couplings in various

channels, bbBar, CC bar, you can read from left to right.

They're very different. All these models now are in the

noise of the current LHC Higgs couplings. We don't have the

sensitivity today to rule out any of these models.

The models also have the property that at the end of HLLHC,

some of these deviations will be observed as hints but not 5

sigma. And people will argue forever whether they're real or not

unless we have the next machine.

What is shown here is the accuracy on these couplings that

we predict for the I LC and I should emphasize it's the same

story for any of the proposed Higgs factories.

There is a clear distinction among these models and that

distinction is coupled to the mechanism of electroweak symmetry

breaking. By measuring one of these patterns and distinguishing

from the others, we're going to learn a lot about physics beyond

the standard model.

And this is really why we're doing the experiment. And so

somehow we need to convert this figure which is meant for a

physics specialist audience into something that can be in your

elevator pitch. And this is a very important part of the story.

I would like to make a comment to Marcus, you're wearing two

hats and they're fighting each other. You need to decide which

side you're on. The comment that I gave that these models will

be only hints at the HLLHC and we'll argue about them forever

without the next machine is an important one when you discuss the

capabilities of the LHC is. We quote these on the basis of full

simulation with what we understand today to be the systemic

limitations.

We're not taking into account that people are going to be

smarter in the future. In the future, we'll do even better. But

that's as true for E plus E minus machines as for hadron machines

and when you compare the two, you have to take that into account.

And so please take that into account when you talk about

this in the future. Okay.

>> Can I respond to that? I think we're saying very much

the same thing. My point is we need to build a new machine that

can exactly do what you propose here, namely, give us some light

or shine on an unsolved potential differences between our

expectation from the standard model and the real physics. So

that means that the next machine needs to have a precision

capable of doing so.

>> Thanks, Michael. You make the important point that of

course the patterns of these coupling deviations is telling us

about the new physics. And yes, we should make sure to emphasize

this and think of a way to visualize this in a simpler fashion.

>> Next person in line is Patrick.

(Captioning stopping at scheduled time.)