Maria Cepeda – Lecture 1 Questions

Questions marked in green were answered during the Q&A session. Original questions listed without correction for grammar/spelling. Where a slide number was given it is shown.

Q1 (slide 15) Is either CMS or ATLAS capable of / planning to record data for every bunch crossing? Or at least rely only on software based triggers which can be more sophisticated?

CMS and ATLAS do need a L1 (hardware) & HLT (software) trigger to be able to cope with the rate we will have at 140/200PU. However, there is a lot of work in progress to make the hardware trigger as close as possible to the offline techniques, including the use of sophisticated techniques exploiting FPGAs.

Q2 (slide 4) Agustin Romero: Hi great lecture! In the introduction, you said the full Run 2 dataset phase space is large to explore. Could you explain what phase space means in this context?

It was just meant to imply all the different topologies, signatures, measurements that we can accomplish with close to 150 fb-1 at 13TeV: there is a really rich program ongoing.

Q3 (slide 25) While individual systematic uncertainties are improved, how confident are we about their possible correlations? Based on current understanding, which ones are positively correlated and which ones are negatively correlated?
The couplings projections are based on the current analysis, for which the correlations of the different uncertainties are scrutinized in a lot of detail and taken into account in the measurements (including which ones are positively correlated or negatively correlated). The projections for each experiment therefore also account for correlations correctly. Plots like this one show the impact of each uncertainty on the measurement, already taking correlations into account.

A related question is how to deal with correlations when combining CMS and ATLAS: theoretical uncertainties were considered correlated and experimental uncorrelated. And finally, in order to do a combined fit, the correlation matrix of the projected signal strength / kappa sensitivity needs to be taken into account. Check for instance this plot , showing the correlation for the signal strength parameters for CMS.

Q4 (slide 27) What does "postfix" [Q&A chair: “postfit”] mean?

Simply that the effect of the systemartic uncertainty on the measurement is shown after a fit to the data (on in this case, a fit to the expectation as given by an assimov dataset)

Q5 (slide 28) I don't understand projecting. Can you explain in details and simple example?

Projecting simply means estimating the future performance of a particular (existing) analysis.

Imagine you have a measurement done for a specific dataset (eg: 150 fb-1), for example the measurement of a particular cross section, σ, with a precision $\Delta\sigma_T$ that you can split in $\Delta\sigma_{stat}$ and $\Delta\sigma_{syst}$ (added in quadrature). You might want to know how this same measurement will perform in the future, or in different conditions. In the LHC/HL-LHC, we know that we will accumulate more data in the future Runs, which will reduce that statistical uncertainty. We can also estimate or model how our systematic uncertainties evolve, considering what we know of the detector: will it be the same? Improve? Worsen? With both the change in statistical uncertainty (given by the increase in integrated luminosity of the future dataset) and the change in systematic uncertainty (that you need to think about) you can obtain the future 'projected' sensitivity, $\Delta\sigma_{Projected}$.

Q6 (slide 29) Agustin Romero: For B-mu-mu and B-Z-gamma, why is their expected relative uncertainty much higher than the others? Thanks!

They are rare decays, with uncertainties still dominated by statistics even at the HL-LHC

Q7 (slide 29) ATLAS seems to have systematically larger uncertainties in branching ratios than CMS. But cross section uncertainties are very similar between the two experiments. What is the reason for this?

It is important to remember that these are projections of performance - not measurements on data. We synchronized as much as possible the assumptions (for example, the basic experimental systematic uncertainties), but the setups to do the combinations and extrapolations are different by definition, and the starting analyses are also different. Details like how particular backgrounds are modelled (MC or data driven? How well do they scale?) and therefore extrapolated start playing a role, for instance, if you want to do a very very fine comparison. At the same time, it would not be realistic to have obtained exactly the same: the fact is that the results are really very compatible if you take into account the 'uncertainty' associated with projecting to a future measurement, and the spread you observe (or the fact that one experiment is slightly more optimistic than the other) is normal.

Regarding the difference in cross section vs Br results, this is a red herring: it is better if you look at the individual channels (Br x Xsec) for this: either the CMS and ATLAS projection papers, or the comparison plots in the YR that focus on individual results. Looking channel by channel the trend you mention in Br vs Cross Section is less evident.

Take for example B(HMuMu) where the CMS result is better: the measurement of the muon momentum&resolution in CMS slightly outperforms ATLAS, and moreover we folded the upgrade tracker performance into the CMS result. It was expected to get a slightly better result in the CMS projection.

Taking another example: the VH cross-section better in ATLAS in the plot - going to the fine print, there is a difference in the analysis that is projected in each case: the original CMS Run2 paper used to base the projections starts with strictly 36 fb-1 (2016 datacards). The ATLAS one uses 79.8 (2016+2017 datacards) for several channels, including Hbb. Projecting a more advanced analysis has an impact in the results.

In all, we scrutinized the results in ATLAS and CMS before releasing the projections, making sure there were no evident problems that could cause a fixable bias. The CMS S2 'ultimate' numbers are overall a little bit more optimistic than the ATLAS ones, but the results are well within the uncertainty envelope that unavoidably comes with the concept of projecting. The power of combining the two experiments is not only exploiting the larger statistics and thinking of the LHC as a whole, but that this enables us to even out such differences and have a more robust LHC-wide result.

Q8 (slide 45) Agustin Romero: Can you describe how the higgs mass uncertainty propagates to uncertainty in the ZZ/WW couplings?

The branching ratios of the Higgs boson in the SM depend on its mass (to see how much with a numerical example, see for instance the LHC Higgs WG tables, https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR). The table I showed in slide 45 shows the uncertainty on the Higgs mass as measured now by the LHC (160 MeV) compared to future predictions (for example, 10-20 MeV for the HL-LHC), and the corresponding uncertainty on the ZZ width for those same mass measurements (for the same LHC/HL-LHC comparison: 1.9% and 0.12%-0.24% respectively). At the LHC we cannot achieve enough precision in H->ZZ or H->WW mesurements for this to be an issue. However, future lepton colliders will be able to measure HZZ so precisely, below the % level, that in order to avoid limitations in the couplings measurement we do need to know the mass well. Check https://arxiv.org/pdf/1905.03764.pdf section 7 for more details.

Q9 (slide 46) Does measuring Higgs width off shell require additional assumption? If so, how important are these assumptions?

Very good question: yes, using the offshell/onshell method is model dependent, and a more model independent (and much more precise) measurement can be obtained in a lepton collider in the future. You can see the details of the measurement in this CMS result and its projection . And https://arxiv.org/pdf/1905.03764.pdf section 7, and the Future lepton colliders lecture of P. Azzi,, for the comparison with what a lepton collider can do.

Q10 What is the difference between "statistical" and "experimental" uncertainties? [Q&A chair: probably referring to slide 29,31]

'Experimental' uncertainties refer to the ones that come from the detector. Examples: the efficiencies for triggering, reconstructing, and identifying the different objects involved in the analysis, the momentum scale of the leptons and photons, the energy scale of the jets, the identification of jets with b-quarks ('b-tagging'),... There is a list of some of the most relevant sources of experimental uncertainty in slide 25, and the reference values for the 'ultimate' floor value associated with them in these projections.
'Statistical' uncertainty corresponds to the statistics of the data (how much integrated

luminosity you are considering for each projection, in this context).