

Higgs fiducial and differential measurements at ATLAS and CMS

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Recent differential cross section measurements in the Higgs sector published by the ATLAS and CMS collaborations are presented, exploiting the full data set from Run 2 of the LHC. Results cover an extensive set of observables, production modes and final states. In particular, the measurements that are presented include Higgs boson decays to a pair of W or Z bosons, a pair of photons, a pair of τ leptons and a pair of b quarks. All results are found to be in good agreement with the Standard Model of particle physics.

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1. Introduction

Since the discovery of a new scalar resonance, compatible with the Higgs boson predicted by the Standard Model (SM) of particle physics [1–3], by the ATLAS [4] and CMS [5] collaborations, its properties have been measured with ever increasing precision. One particularly important class of measurements is that of differential and fiducial production cross sections: these allow to extract information on the coupling structure of the Higgs sector of the SM in a way that relies on relatively few a priori assumptions; moreover all measurements discussed in this report are unfolded to particle level by correcting the observable distributions for distortions caused by the finite resolution of the detectors. These two factors combined make such results directly comparable with predictions from theory, and thus serve both as a benchmark for the SM itself as well as a test for possible Beyond the SM (BSM) theories. This overview covers differential and fiducial Higgs boson production cross section measurements in the $H \rightarrow ZZ$ [6, 7], $H \rightarrow \gamma\gamma$ [8, 9], $H \rightarrow WW$ [10], $H \rightarrow b\bar{b}$ [11, 12] and $H \rightarrow \tau\tau$ [13] decay channels. All results discussed exploit the entire data set gathered by the detectors during Run 2 of the LHC, corresponding to an integrated luminosity of 139 fb^{-1} and 137 fb^{-1} for the ATLAS and CMS experiments respectively, with the exception of the CMS $H \rightarrow \gamma\gamma$ result which makes use of data gathered in 2016 for an integrated luminosity of 36 fb^{-1} .

2. Observables

An extensive set of observables is covered, providing information on different physics aspects: the transverse momentum (p_T^H) and pseudorapidity (η_H) of the Higgs boson, as well as the number of hadronic jets produced in association (N_{jets}) and the invariant mass (m_{jj}), pseudorapidity ($\Delta\eta_{jj}$) and azimuthal angle ($\Delta\phi_{jj}$) separation of the leading dijet pair probe perturbative QCD calculations, radiative corrections, coupling of the Higgs boson to light quarks and the CP structure of the Higgs sector; observables related to associated hadronic jets, such as their transverse momenta (p_T^j), probe radiative QCD emission patterns and resummation effects; finally, decay related observables such as the invariant mass of the dilepton pairs in $H \rightarrow ZZ \rightarrow 4\ell$ decays probe electroweak corrections.

The extent of the data set gathered by the ATLAS and CMS detectors during Run 2 of the LHC has also opened the possibility to perform multi-differential cross section measurements. While still statistically constrained as of now, such measurements will become increasingly relevant once data from Run 3 and High Luminosity LHC will be available.

3. Bosonic channels

Analyses targeting events in which the Higgs boson decays to either a pair of W or Z bosons or a pair of photons benefit from relatively clean and well reconstructed final states. This is reflected in a good sensitivity across the accessible phase space. Results from both ATLAS and CMS in the ZZ final state include cross sections as a function of p_T^H , $|y_H|$, N_{jets} and the transverse momentum of the leading jet produced in association with the Higgs boson $p_T^{j_1}$. The ATLAS results expand on this set with a number of other observables, including the invariant masses of the two dilepton pairs in the final state, the invariant mass (m_{jj}) pseudorapidity ($\Delta\eta_{jj}$) and azimuthal angle separation ($\Delta\phi_{jj}$) of the leading dijet system and a number of angular variables characterizing the decay of

the Higgs boson. Uncertainties on the differential cross sections range from 10% to around 75% in the least sensitive bins, with the statistical component being the dominant contribution. Results also include a set of double-differential cross sections measured by the ATLAS collaboration as a function of two-dimensional observables such as $(p_T^H, |\gamma_H|)$ and (p_T^H, N_{jets}) . Results from the ATLAS collaboration are compared to predictions from MadGraph5_aMC@NLO [14] with the FFXF merging scheme, NNLOPS [15], RADISH [16] and NNLOJET [17]; results from CMS are compared to predictions from POWHEG 2.0 [18] and NNLOPS. The agreement with the SM is found to be good in all distributions.

Similarly good overall sensitivity is achieved in the diphoton final state. Both collaborations present measurements of $p_T^H, |\gamma_H|, N_{jets}, p_T^j, m_{jj}$ and $\Delta\phi_{jj}$, with the CMS results also including transverse momenta and rapidity of the two leading jets, the pseudorapidity gap between the leading jets as well as the rapidity and azimuthal angle separation between the diphoton system and the leading jet. Results from the ATLAS collaboration are compared to POWHEG NNLOPS normalized to N³LO(QCD)+NLO(EW), while results from the CMS collaboration are compared to MadGraph5_aMC@NLO reweighted to match the NNLOPS prediction. In all cases the agreement with the SM is found to be good, with uncertainties ranging from ~10% in the most sensitive bins to ~50% in the least sensitive ones in the ATLAS results, and between ~35% and ~200% in the CMS results. In all cases the dominant contribution to the overall uncertainty is of statistical nature, especially in the CMS results which rely on data gathered in 2016 for and integrated luminosity of 36 fb⁻¹.

Finally, the CMS collaboration has performed a differential cross section measurement in p_T^H and N_{jets} targeting events in which the Higgs boson decays to a pair of W bosons. Compared to the other bosonic channels described above, the WW channel benefits from a larger branching fraction, but suffers from the presence of neutrinos in the final state (due to the decay of the W bosons) reducing experimental sensitivity especially at lower values of p_T^H . This combination makes this channel the only bosonic one in which systematic uncertainties play a role comparable to the statistical contribution. For the same reason, given the larger detector resolution effects at low p_T^H in this channel, a regularisation constraint is applied within the unfolding procedure in the p_T^H measurement. Overall uncertainties on the differential cross sections range from ~15% to ~100%. Results are compared to MadGraph5_aMC@NLO and found to be in good agreement with the SM.

4. Fermionic channels

In the space of differential measurements of the Higgs boson's production cross section fermionic channels play a complementary role to bosonic ones, in that where the latter provide good sensitivity on a wide range of different observables, the former contribute significantly in specific regions of phase space. Such is the case for the $b\bar{b}$ final state especially: while at low p_T^H this channel suffers from an overwhelming QCD induced background, its 58% branching fraction makes it crucial in the very high (i.e. above ~500 GeV) p_T^H regime, where the overall production cross section naturally decreases. At these energies the two b-quark induced jets (b-jets) coalesce into a single, large radius jet with a substructure compatible with two sub-jets. This is commonly referred to as the boosted topology, and its peculiar kinematic features can be exploited to separate the $H \rightarrow b\bar{b}$ signal from the background. The two experiments report measurements of the p_T^H

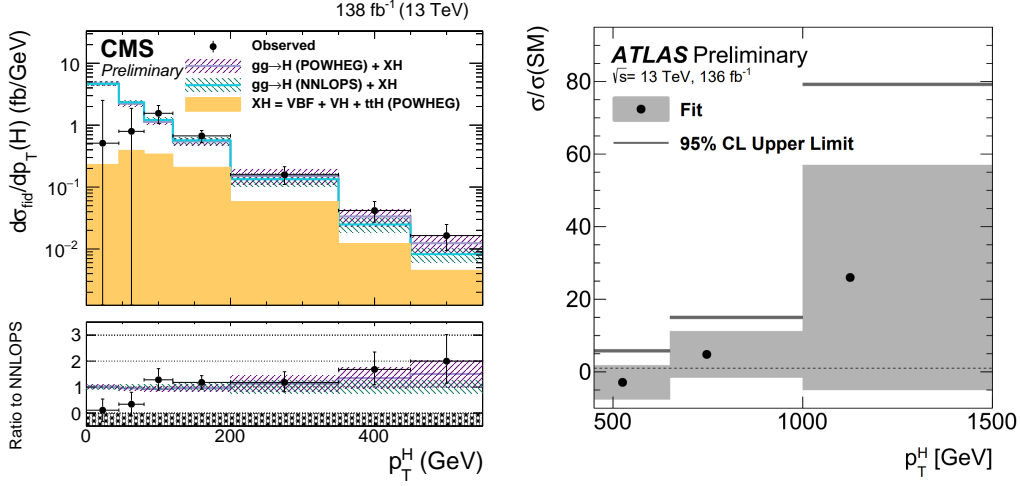


Figure 1: The p_T^H spectrum as measured by CMS in the $H \rightarrow \tau\tau$ channel [13] (left), and by ATLAS in the $H \rightarrow b\bar{b}$ channel [11] (right).

spectrum, starting from 300 GeV and 450 GeV for the CMS and ATLAS results respectively, with the unique feature of having sensitivity for transverse momenta of the order of 1 TeV. Uncertainties are statistically dominated, and results are found to be compatible with predictions from the SM.

Finally, the CMS collaboration reported on the first Higgs boson differential cross section measurement in the $\tau\tau$ final state. Similarly to the $b\bar{b}$ channel, this analysis benefits from a large branching fraction of 6%, making it competitive with bosonic channels especially at high p_T^H and larger jet multiplicities. All decay combinations of the pair of τ leptons are taken into consideration, excluding purely leptonic ones where the final state leptons are of the same flavor. Results include p_T^H , N_{jets} and p_T^j spectra. Similarly to the previously discussed $H \rightarrow WW$ analysis, a regularisation term is added to the unfolding procedure to prevent large fluctuations due to detector effects. Uncertainties range from order 20% to order 100%.

5. Conclusions

The extensive data set gathered by the ATLAS and CMS detectors during Run 2 of the LHC has enabled a wide range of detailed measurements of the properties of the Higgs boson, two examples of which are shown in Fig. 1. The available fiducial and differential results cover a wide range of observables in different decay channels of the Higgs boson, serving both as precision benchmarks for the SM as well as probes for possible deviations from it, with many BSM theories predicting discrepancies in the tails of differential cross sections. The combination of bosonic and fermionic decays allows to cover a large portion of phase space, with reach up to the TeV scale. The uncertainties in most analyses are currently constrained by the statistical power of the Run 2 data set, and will greatly benefit from Run 3 and the High Luminosity phase of the LHC. The increased amount of available data will enhance the reach of all channels and enable finer measurements (e.g. narrower bins in the observables, more and more precise multi-dimensional differential cross sections), further boosting the sensitivity to new physics. Finally, all results discussed are unfolded to particle level, enabling direct comparison with theory.

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