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Overview of physics at the Large Hadron Collider

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Summary. — The Large Hadron Collider has produced during the run from 2010 to 2012, proton-proton collision to a center-of-mass energy up to 8 TeV. The data delivered to the experiments placed along the ring allowed studies of the hadron collision physics at this unprecedent energy scale, and accurate checks of the Standard Model have been performed. An overview of the most representative physics results achieved are briefly presented and discussed, with emphasis to the most recent studies made. In particular, an update on the first measurements of the new resonance with mass around 125 GeV is reported.

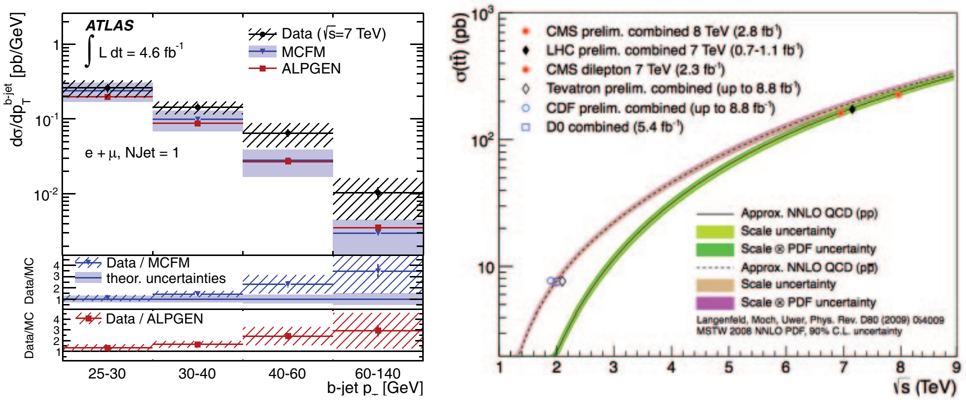
PACS 14.70.Fm – W bosons.
PACS 12.60.Cn – Extensions of electroweak gauge sector.
PACS 13.85.Fb – Inelastic scattering: two-particle final states.
PACS 13.38.Be – Decays of W bosons.

1. – Introduction

The Large Hadron Collider (LHC) started operations at the end of 2009. In 2011 LHC collided protons at centre-mass-energy $\sqrt{s} = 7\,\text{TeV}$, delivering more than $5\,\text{fb}^{-1}$ of data per each of the two general-purpose experiments, ATLAS and CMS. In 2012, more than $20\,\text{fb}^{-1}$ of $\sqrt{s} = 8\,\text{TeV}$ data were delivered. ATLAS [1] and CMS [2] recorded a high fraction of the delivered data, about 95%. Both runs, and in particular the one of 2012, were caracterized by a large average number, $\langle\mu\rangle = 20.7$, of proton-proton collisions per bunch crossing. Nevertheless, both experiments were able to reconstruct physics objects with high efficiency even in this severe experimental condition.

In this paper, the most representative physics results that have been published by ATLAS, CMS and LHCb [3] based on the data collected during the first run of LHC are described, with particular attention to the most recent measurements and findings. Emphasis is given to the new particle with mass of about 125 GeV, recently discovered by ATLAS and CMS compatible with the Standard Model Higgs boson.

Measurements from data of heavy-ion collisions by ALICE [4], ATLAS and CMS are presented and discussed elsewhere in these proceedings.



(a) (b)

Fig. 1. – (a) Measured differential W+b-jets cross sections with the statistical plus systematic uncertainties as a function of b-jet transverse momentum in the 1-jet and 2-jet fiducial regions, obtained by combining the muon and electron channel results. The measurements are compared to the MCFM predictions and to the ALPGEN predictions interfaced to HERWIG and JIMMY and scaled by the NNLO inclusive W normalization factor. The ratios between measured and predicted cross sections are also shown. (b) Top pair inclusive production cross section as function of centre-of-mass energy measured at the Large Hadron Collider, compared to results from Tevatron and to QCD NNLO predictions.

2. – Standar Model physics

ATLAS and CMS perfomed a wide measurement campaign of Standard Model (SM) processes. A few examples of the most representative analyses made are here reported.

2˙1. *W, Z and diboson physics*. – The vector boson production is an important benchmark channel for QCD and electroweak studies. Deviations of the inclusive or differential production cross section of $W^{\pm}$ Z, or the associate production of vector bosons with one or more jets, would indicate new phsyics at the energy scale of LHC. Measurement of pair production Vγ (V = W or Z), WZ, WW, ZZ is a crucial test of SM with next-to-leading order (NLO) predictions in processes relevant for electroweak symmetry breaking (EWSB).

Data at $\sqrt{s} = 7\,\text{TeV}$ allowed a measurement accuracy of inclusive vector boson cross section production of 1%, especially for ratio-observables. New results are available on $\sqrt{s} = 8\,\text{TeV}$ from dedicated low event pile-up run, early in 2012. The total uncertainty achived by CMS is in the range between 2% and 5%, dominated by the integrated luminosity measurement. A good agreement has been found with respect to next-to-next-to-the-leading order (NNLO) prediction from QCD, both at 7 and 8 TeV, within experimental and theory uncertainties. Measurements of differential production cross section of vector bosons in association with jets, heavy flavour quarks, as well as W polarization studies, have been made: an example is given in ref. [5]. W boson charge asymmetry production is important to constraint proton parton distribution functions (PDFs); an example is reported in ref. [6]. Figure 1(a) shows the differental W+b-jets cross section as a function of the b-jet p_{T} as measured by ATLAS.

Diboson production represents the irreducible background for many Higgs boson searches. Measurements have been made of the ZZ pair production cross section also at $\sqrt{s} = 8\,\text{TeV}$ using the full statistics available. ATLAS has measured $\sigma^{tot}_{ZZ} = 7.1^{+0.5}_{-0.4}(\text{stat}) \pm 0.3(\text{sys}) \pm 0.2(\text{lumi})\,\text{pb}$ [7]. Using $3.5\,\text{fb}^{-1}$ of $\sqrt{s} = 8\,\text{TeV}$ data, CMS has measured the WW pair production cross section to be $\sigma^{tot}_{WW} = 69.9 \pm 2.8(\text{stat}) \pm 5.6(\text{sys}) \pm 3.1(\text{lumi})\,\text{pb}$ [8]. Both measurements are compatible with SM predictions within uncertainties. The ZZZ and ZZγ neutral triple gauge couplings (nTGCs), absent in the SM at leading order (LO), have been also studied. At one-loop level, nTGGs have a magnitude of the order of 10^{-4}. Many models of physics beyond SM (BSM) predict values between 10^{-4} and 10^{-3}. No significant deviations from SM predictions have been observed, and limits have been set. Neutral triple gauge couplings are excluded at 95% confidence level (CL) for absolute values 1.3×10^{-2}–2.3×10^{-2} or larger [9].

A 3-sigma evidence on Z electroweak production has been also found [10]. The measurement, combining the muon and electron channels, gives the cross section $\sigma_{meas} = 154 \pm 24(\text{stat}) \pm 46(\text{exp.}) \pm 27(\text{theory}) \pm 3(\text{lumi})\,\text{fb}$ in an agreement with the theoretical cross section of 166 fb, calculated with NLO QCD corrections.

More details on electroweak studies at LHC are reported in these proceedings [11].

2˙2. *QCD studies*. – A myriad of QCD measurements has been performed by the collaborations ATLAS, CMS, LHCb and ALICE. It would be impossible to report all of them in this paper. Among these, studies of the differential inclusive production cross section of jets [12] and direct photons [13] are worth mentioning. Most recent measurements (mostly at $\sqrt{s} = 7\,\text{TeV}$) reported excellent progress: jet energy scale uncertainties, that represent the most important experimental systematic effect, have been reduced to a few % level. Measurements relative to central rapidities have show similar experimental and theoretical uncertainties, in the 5%–10% range. NLO QCD describes ATLAS and CMS data over nine orders of magnitude. The available data are becoming important for constraining the PDFs at the LHC.

2˙3. *Top quark physics*. – The analysis of the top quark production (in single mode or in $t\bar{t}$ pairs), and of its physics properties, is of paramount importance for the study of SM. As heaviest quark, top may play an important role in the electroweak symmetry breaking mechanism. Single-top and $t\bar{t}$ production represent a crucial test of QCD, and are also among the most severe background sources to Higgs boson and New Physics searches. Hence, an accurate understading of these processes is crucial. The study of top production has been made at the LHC using complementary analysis techninques by probing different final states and single lepton final states, dileptons, fully hadronic final states [14-16]. These event configurations have been crucial also for trigger selection. Both ATLAS and CMS have measured $t\bar{t}$ production cross section at $\sqrt{s} = 7$ and $8\,\text{TeV}$ with an experimental uncertainty smaller than 7%, in very good agreement with Standard Model predictions.

ATLAS and CMS have performed measurements also of $t\bar{t}$ production in association with jets, as a function of the jet transverse momentum. This is useful to constrain models of initial and final state radiation (ISR/FSR) at the energy scale of the top quark mass [17], see fig. 1(b). Normalised differential top-antitop pair production cross section as a function of the p_{T} of the $t\bar{t}$ system has been also made [18].

Single top-quark production [19,20,22,21] provides a direct probe of the Wtb coupling, and is sensitive to many models on new physics. The measurement of the production cross section constrains the absolute value of the quark-mixing matrix element without assumptions on the number of quark generations. The CKM Vtb parameter has been measured to be $1.020 \pm 0.046(\text{exp}) \pm 0.017(\text{theory})$. Evidence of Wt production has been provided also by CMS, measuring a cross section of 16^{+5}_{-4} pb, with a 4-sigma significance.

The top-quark mass is an important parameter of the Standard Model, as it affects predictions via radiative corrections. Precise measurement of the top-quark mass is a critical input to global electroweak fits which provide constraints to the properties of the SM Higgs boson. CMS has measured the top quark mass to be $m_{top} = 173.4 \pm 0.4(\text{stat}) \pm 0.9(\text{syst})$ GeV [23, 24]; similar values have been found by ATLAS [25, 26]. First studies on the top-antitop quark mass difference are also available. In SM, CPT invariance imposes these two masess to be equal. Deviations from zero would indicate an important violation of SM, in favour of BSM models where CPT invariance is not kept. Available measurements have a sensitivity of about 200 MeV, and no deviation from zero is observed [27]; this is the best measurement of this difference to date.

More details on top quark physics at the LHC are discussed in the proceedings of this conference [28].

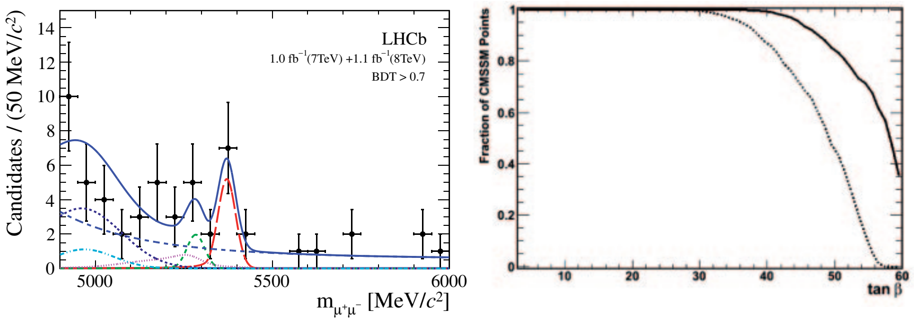
2˙4. *B-physics*. – The LHC physics programme is chacterized by a very rich Heavy Flavour (HF) investigation workplan, for which the LHCb experiment has a prominent role. However, the important complementarity in this field with the general purpose experiments ATLAS and CMS should be emphasized.

HF analyses are crucial to the Standard Model predictions. Rare decays such as $B^0_{(s)}\mu^+\mu^-$ are highly suppressed. Precise branching ratio (BR) predictions make these channels powerful probes in seraching for deviations from SM, expecially in models without a non-standard Higgs sector. As an example, the decay $B^0_s \to \mu^+\mu^-$ is predicted to have a BR of $(3.32 \pm 0.27) \times 10^{-9}$.

LHCb searches have been based on multivariate classifier (BDT, Boosted Decision Tree) and on dimuon invariant mass analyses of a data sample equivalent to an integrated luminosity of $1.0\,\text{fb}^{-1}$ taken at $\sqrt{s} = 7$ TeV, and $1.1\,\text{fb}^{-1}$ taken at $\sqrt{s} = 8$ TeV [29].

In fig. 2(a) the $\mu^+\mu^-$ invariant mass is plotted for a data sample enriched by signal events through the selection based on the BDT output. The mass sidebands are studied to perform a background estimated expected in the signal region. The signal mass central value is determined from the analysis of $B^0 \to K^+\pi^-$, $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ processes (and charge conjugated); the background shape is based on data. An excess is visible in the mass interval 5.2–5.5 GeV, where a possible signal from $B^0_{(s)} \to \mu^+\mu^-$ decays is expected. As a result, the BR of $B^0_s \to \mu^+\mu^-$ has been measured to be $\text{BR}(B^0_s \to \mu^+\mu^-) = 3.2^{+1.4}_{-1.2}(\text{stat})^{+0.5}_{-0.3}(\text{syst}) \times 10^{-9}$, and the upper limit $\text{BR}(B^0 \to \mu^+\mu^-) < 0.94 \times 10^{-10}$ at 95% CL has been set.

The purely leptonic decay $B^0_s \to \mu^+\mu^-$ is very sensitive to supersymmetric contributions which are free from the helicity suppression of the Standard Model diagrams. This observation from LHCb has motivated a review of their impact on the viable parameter space of supersymmetry (SUSY) [30]. The measured $B^0_s \to \mu^+\mu^-$ BR strongly constraints cMSSM and MSUGRA SUSY implementations. The improved accuracy of the branching fraction measurement expected from the 14 TeV run together with the expected improvements in the theory uncertainties, will boost the sensitivity, in particular for the region $\tan\beta > 50$ which could be almost fully constrained, see fig. 2(b). This represents a strong example of complementarity between direct and indirect SUSY signal searches.



(a) (b)

Fig. 2. – (a) Invariant mass distribution of the selected $B_s^0 \to \mu^+\mu^-$ candidates (black dots) with BDT > 0.7 in the combined 2011+2012 dataset. The result of the fit is overlaid (blue solid line) and the different components detailed: $B_s^0 \to \mu^+\mu^-$ (red long dashed), $B^0 \to \mu^+\mu^-$ (green medium dashed), $B^0_{(s)} \to h^+h'^-$ (pink dotted), $B^0 \to \pi^-\mu^+\nu_\mu$ (black short dashed) and $B^{0(+)} \to \pi^{0(+)}\mu^+\mu^-$ (light blue dot dashed), and the combinatorial background (blue medium dashed). (b) Fraction of CMSSM points obtained through a 4-parameter flat scan passing the LHC SUSY constraints and in agreement with the present BR($B_s^0 \to \mu^+\mu^-$) measurement (continuos line), and assuming an ultimate accuracy of about 10% (experimental and theoretical uncertainties combined) on this BR (dotted line) [30].

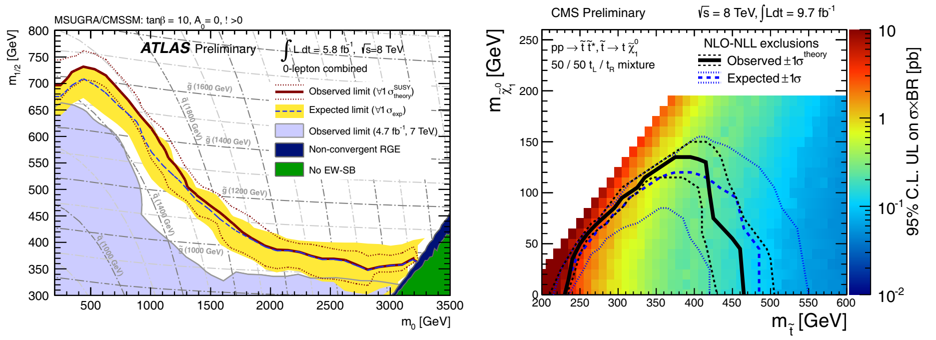
Also ATLAS and CMS have a rich B-physics programme. Important contributions have already been given in searches for $B_s^0 \to \mu^+\mu^-$ decays; observation of a new χ_b state in radiative transitions to $\Upsilon(1s)$ and $\Upsilon(2s)$ (interprted as χ_{3P}); measurements of production cross section of pp $\to B^\pm$+X, pp $\to B^0_{(s)}$+X, pp $\to B_s^0 \to J/\psi\phi$; measurement of the X(3872) production cross section; measurement of the Λ_b lifetime; measurement of the $\Upsilon(1s)$, $\Upsilon(2s)$ and $\Upsilon(3s)$ production cross section and polarization; observation of $B_c^+ \to J/\psi\pi^+$ and $B_c^0 \to J\psi\pi^+\pi^-$; etc. Details of these studies are given in several papers in these proceedings [31].

3. – Beyond Standard Model physics searches

Many studies have been made on the LHC data at 7 and 8 TeV taken in 2011 and 2012 to search for new physics beyond SM.

Neither excess of events nor other anomalies with respect to what predicted by Standard Model has been observed. Hence 95% CL exclusion limits have been set on the most important parameters describing the several models that have been studied to interpret the available data.

The most characterinzing SUSY analyses have been based on searches for strong production of 1st and 2nd generation squarks and gluinos. The classic final state signatures considered are events with large missing transverse energy (MET) and large high-p_T jet multiplicity (from 2 to 6). The background composition depends very much on the number of the required jets in the event, but it can be said that $t\bar{t}$, single top, W, Z+jets and diboson production represent the most severe background to these searches. Gluino with masses below 1100 GeV, and squark with masses below 630 GeV are excluded in simplified models containing only squarks of the first two generations, a gluino octet and a massless neutralino. In mSUGRA/CMSSM models with $\tan\beta = 10$ and $A_0 = 0$ and $\mu > 0$, squark and gluinos of equal mass are excluded below 1500 GeV [32]. At the



(a) (b)

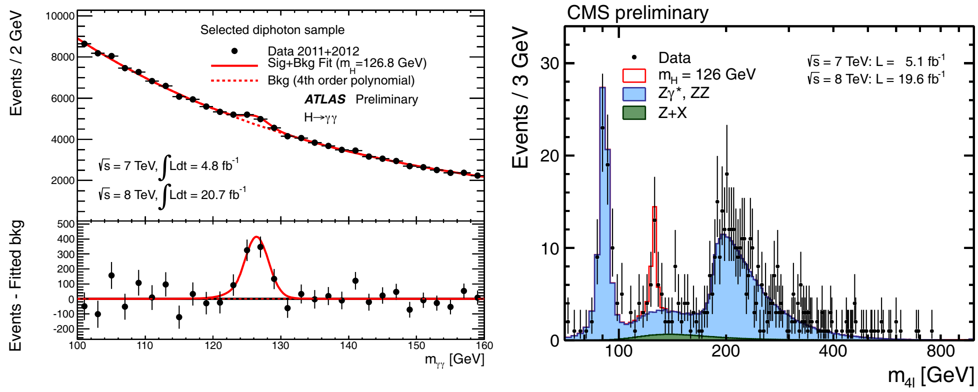
Fig. 3. – (a) 95% CL exclusion limits for MSUGRA/CMSSM models with $\tan\beta = 10$, $A_0 = 0$ and $\mu > 0$ presented (left) in the m_0-$m_{1/2}$ plane and (right) in the m_{gluino}-m_{squark} plane. Exclusion limits are obtained by using the signal region with the best expected sensitivity at each point. The blue dashed lines show the expected limits at 95% CL, with the light (yellow) bands indicating the 1σ excursions due to experimental uncertainties. Observed limits are indicated by medium (maroon) curves, where the solid contour represents the nominal limit, and the dotted lines are obtained by varying the cross section by the theoretical scale and PDF uncertainties. Previous results from ATLAS are represented by the shaded (light blue) area. Green and blue colors describe the theoretically excluded regions [32]. (b) Interpretation in the top squark pair production with $\tilde{t} \to t\tilde{\chi}_1^0 \to bW\tilde{\chi}_1^0$, in the plane of $m_{\tilde{\chi}_1^0}$ *vs.* $m_{\tilde{t}}$. The shading indicates the upper limit on the signal cross section. The observed, median expected, and $\pm 1\sigma$ exclusion contours are indicated assuming next-to-leading order and next-to-leading log cross sections, as well as the observed contours when the theory cross section is varied by $\pm 1\sigma$ (the region below the contours is excluded) [34].

time of writing this paper new results have been made public by ATLAS and CMS. For example, ref. [33] reports on new squark and gluinos of equal mass limits based on the full 2012 (and 2011) dataset, now excluded below 1800 GeV; see also fig. 3(a).

Naturalness arguments require the light top squark mass eigenstate to be significantly below 1 TeV, which now appears to be significantly lighter than the first two generation squarks. Most recent stop and sbottom searches at the LHC have focused to scenarii where third generation squarks are indirectly and directly produced in pp collsions. The analysis is based on generic SUSY particle searches, adding the requirements of jets b-tagged, or adapting studies optimized for searches in $t\bar{t}$ + MET final states. Recent analyses published by CMS have been based on two decay modes of the top squark $\tilde{t} \to t\tilde{\chi}_1^0 \to bW\tilde{\chi}_1^0$ and $\tilde{t} \to b\tilde{\chi}_1^+ \to bW\tilde{\chi}_1^0$, which are expected to have large branching fractions if kinematically allowed. Good agreement has been observed between the observed yield and the predicted backgrounds in several regions, defined by requirements of large MET and M_T [34]. The results have been interpreted in the context of simplified models of top squark production, and probe the top squarks with masses in the range 160-430 GeV, see fig. 3(b) [34].

A more extensive discussion of latest SUSY results is available in these proceedings [35].

A large variety of non-SUSY beyond Standard Model direct searches has been performed by ATLAS and CMS. These include searches for heavy resonance decays to leptons, photons, dijets, $t\bar{t}$ SM vector boson final states; long lived particles, leptoquarks, 4th generation, contact interactions, extra-dimensions and black holes. No evidence of



(a) (b)

Fig. 4. – (a) Invariant mass distribution of diphoton candidates for the combined $\sqrt{s} = 7$ and $\sqrt{s} = 8\,\text{TeV}$ data samples by the ATLAS experiment. The results of a fit to the data of the sum of a signal component fixed to $m_H = 126.8\,\text{GeV}$ and a background component described by a fourth-order Bernestein polynomial is superimposed. The bottom insert displays the residuals of the data with respect to the fitted background. The largest local significance is found to be 7.4σ at $m_H = 126.5\,\text{GeV}$, where the expected significance is 4.1σ. (b) Distribution of the four-lepton reconstructed mass in the full mass range for the sum of the 4e, 4μ and $2e2\mu$ channels using the $\sqrt{s} = 7$ and $\sqrt{s} = 8\,\text{TeV}$ data samples by the CMS experiment. Points represent the data, shaded histograms represent the background and the unshaded histogram the signal expectation. The maximum local observed significance is reached around $m_H = 125.8\,\text{GeV}$, and it is found to be 6.7σ (expected 7.2σ).

signals from new physics has been found, and exclusion limits on parameters from several BSM models have been set. As an example, at the moment of writing this paper, ATLAS and CMS exclude new heavy vector bosons W′ (Z′) decaying to leptons, with mass ligther than 3.35 TeV (2.86 TeV) at 95% CL. Limits up to 4.49 TeV at 95% CL have been set on the model parameter M_s of the Large Extra Dimension theory, depending on the number of extra dimensions and the validity range of this model. More details on non-SUSY BSM data interpretation are available in these proceedings [36].

4. – Higgs boson discovery and properties measurement

On July 4th, 2012, ATLAS and CMS announced the discovery of a new resonance with mass about 125 GeV, with analyses dedicated to the search for the SM Higgs boson in the $H \to \gamma\gamma$, $H \to ZZ^{(*)} \to llll$ and $H \to WW^{(*)} \to l\nu l\nu$ final states [37,38]. The datasets used by ATLAS (CMS) corresponded to integrated luminosities of approximately 4.8 (up to 5.1) fb^{-1} collected at $\sqrt{s} = 7\,\text{TeV}$ in 2011 and 5.8 (up to 5.3) fb^{-1} at $\sqrt{s} = 8\,\text{TeV}$ in 2012. The results for the three Higgs boson decay modes mentioned above (plus also $H \to \tau\tau$ and $H \to b\bar{b}$ in the case of CMS) showed a local significance of 5.9 (5.0 in CMS) standard deviations, corresponding to a probability that the background produces a fluctuation greater than or equal to the excess observed in data of 1.7×10^{-9} (ATLAS). This is compatible, within their uncertainties, with the Standard Model Higgs boson expectations.

More data collected in 2012 have been analysed by ATLAS and CMS for many Higgs boson final states, and in particular for the final decay modes $H \to \gamma\gamma$, $H \to ZZ^{(*)} \to llll$

TABLE I. – *The most important Higgs boson decay channels in the low mass region (*$100\,\text{GeV} \leq m_H < 2m_Z$*) studied by ATLAS and CMS. The "S/B" column reports the ratio between the signal yield expected for a Standard Model Higgs boson and the observed background after full event selection. The column "mass res." reports the expected mass resolution of the system made by the observed physics objects belonging to the Higgs boson decay.*

Decay channel	Experimental signature	S/B	Mass res., %	ATLAS dataset, fb^{-1} (2011+2012)	CMS dataset, fb^{-1} (2011+2012)
$H \to \gamma\gamma$	Two high-p_T photons; peak in inv. mass	few 10^{-2}	1–2	5+20	5+20
$H \to ZZ^* \to llll$	Four high-p_T leptons; peak in inv. mass	$\gtrsim 1$	1–2	5+20	5+20
$H \to WW^* \to l\nu l\nu$	Two high-p_T leptons; large missing E_T	few 10^{-1}	–	5+20	5+20
$H \to \tau\tau$	Two high-p_T leptons; hadronic τ's and large missing E_T	few 10^{-2}	~ 20	5+13	5+20
$H \to b\bar{b}$	Two high-p_T b-jets in association with W and Z bosons	few 10^{-2}	10–16	5+13	5+12

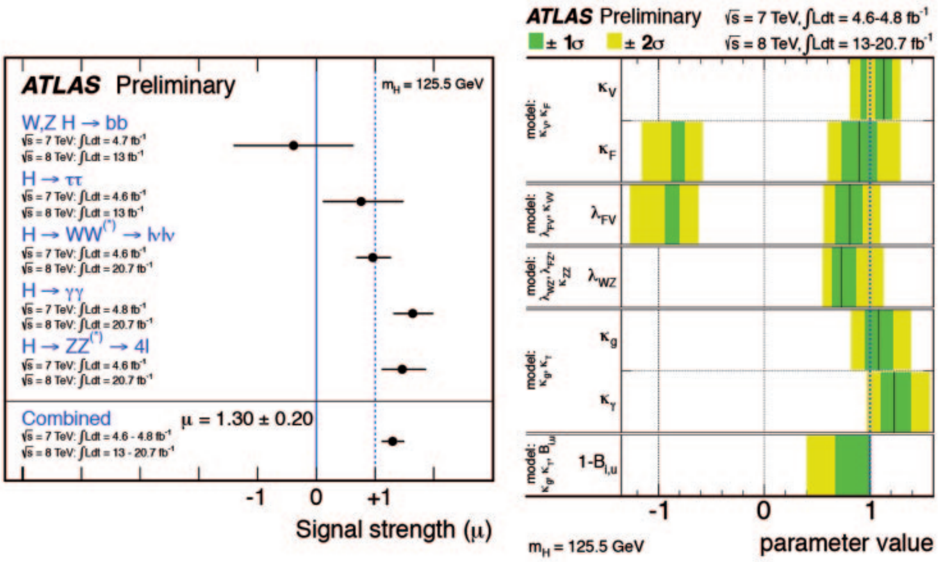
and $H \to WW^{(*)} \to l\nu l\nu$ the full available data sample has been analysed. The excess observed in 2012 has been confirmed, with a significance close to seven standard deviations, see figs. 4(a) and (b). Table I is a summary of the main channels investigated by ATLAS and CMS on searches for the Standard Model Higgs boson. In this table, representative figures for the mass resolution, signal purity and analysed integrated luminosity is given. ATLAS and CMS have shown preliminary results on the full 2011 and 2012 datasets for $H \to \gamma\gamma$, $H \to ZZ^{(*)} \to llll$ and $H \to WW^{(*)} \to l\nu l\nu$, while for $H \to \tau\tau$ and $H \to b\bar{b}$ up to $13\,\text{fb}^{-1}$ of data have been analysed from the 2012 sample by ATLAS, while CMS has analysed the full 2012 dataset also for $H \to \tau\tau$ and $12\,\text{fb}^{-1}$ for $H \to b\bar{b}$.

In the analysis of the event yield, for each Higgs boson final state a signal strength factor $\mu_i = \sigma_i/\sigma_{i,SM}$ is introduced. In the hypthesis of no signal from the Higgs boson, we would have $\mu_i = 0$, while for a Standard Model Higgs boson $\mu_i = 1$.

The mass measurement is based on the findings from the channels $H \to \gamma\gamma$ and $H \to ZZ^{(*)} \to llll$, and it has been mesaured by ATLAS(CMS) to be $m_H = 125.5 \pm 0.2(\text{stat}) \pm^{+0.5}_{-0.6}\,(\text{syst})\,\text{GeV}$ ($m_H = 125.8 \pm 0.4(\text{stat}) \pm 0.4(\text{syst})\,\text{GeV}$).

Figure 5(a) shows the measurement by ATLAS of the signal strength μ for $m_H = 125\,\text{GeV}$ for the individual channels analysed in [39-43] an their combination [44]. The overall signal strength μ is found to be $\mu = 1.30 \pm 0.20$, assuming $m_H = 125\,\text{GeV}$. CMS has found similar results [45-49]. The signal strength evaluated by CMS is found to be $\mu = 0.88 \pm 0.21$, assuming $m_H = 125\,\text{GeV}$.

The observed signal strengths can be expressed as a function of the Higgs boson couplings c_i to the elementary particle i (with i = quarks and leptons). These couplings can be normalized to Standard Model couplings through the relation $c_i = k_i \times c_{i,SM}$. Hence, in SM $k_i = 1$ for all i's. Several type of models can be adopted to interpret



(a) (b)

Fig. 5. – (a) Measurements of the signal strength parameter μ for $m_H = 125\,\text{GeV}$ for the individual channels and their combination. (b) Summary of the couplings scale factor measurements for $m_H = 125\,\text{GeV}$. The best-fit values are representd by the solid black vertical lines. The measurements in the different coupling benchmark models are strongly correlated, as they are obtained from fits to the same experimental data. Hence they should not be considered as independent measurements [44].

the observed data. For example, it can be assumed that all fermion couplings scale with a common factor k_F, and W, Z bosons with k_V, assuming that only SM particles contribute to the gluon-gluon fusion production processes, and that only SM processes contribute to the total width. In another model the ratios $\lambda_{WZ} = k_W/k_Z$, $\lambda_{FZ} = k_F/k_Z$ and $k_{ZZ} = k_Z \times k_Z/k_H$ (where k_H is the scaling factor to the SM Higgs boson width) have been studied (here no assumption on the Higgs boson total width is made). Also the "effective" couplings to gluons and fotons (= 0 in Standard Model at LO) have been studied. By constraining some of the k factors to their SM values, it is possible to probe for new non-SM decay modes, either invisible or undetected. More details on these analyses are given here [50].

Figure 5(b) reports the summary of the couplings scale factors measurements by ATLAS for $m_H = 125.5\,\text{GeV}$. A good agreement with of these measurements has been found with SM predictions within experimental and theoretical uncertainties. However, with current data is not possible to rule out other possibilities. A Higgs boson mass around 125 GeV excludes large regions of the MSSM SUSY parameter space. Electroweak-scale SUSY is still possible with—for example—large mixing parameter in the stop sector, or extra matter of gauge fields (extra gauge bosons, . . .). Figure 6 shows the coupling of the Higgs boson to elementary fermions and bosons as a function of the particle mass, using measurements by the CMS experiment.

Two paths to discovery of New Phsyics are possible: precise measurements of the Higgs boson physics properties and direct observation of new particle and phenomena.

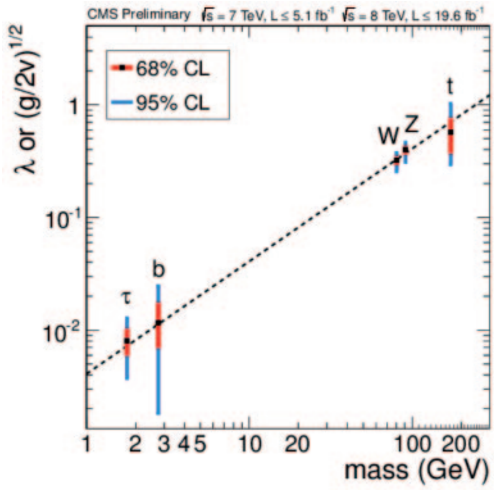


Fig. 6. – The relation between the Higgs boson coupling to elementary fermions and bosons as a function of the particle mass. Couplings to W and Z vector bosons are normalised to 2 vev (vev is the Higgs field vacuum expectation value) and the square root is reported. The dashed line shows the expectation of the Standard Model, while dots represent the current CMS measurements with associated 1σ and 2σ total uncertainty.

5. – Future plans

According to current schedule of the LHC accelerator, the next physics run will start in 2015, after the first upgrade of the machine (which is still on-going at the moment of writing this paper). The LHC will reach the collision energy of $\sim 14\,\text{TeV}$, and the luminosity $L = 1\times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ with a bunch spacing of 25 ns. The expected integrated luminosity in this second run for ATLAS and CMS is 75–100 fb^{-1}. The physics run will be followed by another shutdown, in which the machine and detectors will undergo to another upgrade process. The LHC instantaneous luminosity should reach the $L = 2\times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ level, and up to 300–350 fb^{-1} integrated luminosity should be collected by each of the two general-purpose experiments. With these data, ATLAS and CMS will be able to measure Higgs boson couplings with an accuracy $\lesssim 10\%$. The increase of the pp collision energy will allow another round of comprehensive searchs for SUSY and other "new physics" beyond Standard Model.

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